Sequential Diagnostic Monitoring Plus Protocol

Developed for the *Lower St. Croix*

One Watershed One Plan

by the

Comfort Lake–Forest Lake Watershed District

Contents

Foreword

The Comfort Lake – Forest Lake Watershed District (CLFLWD) has been conducting Sequential Diagnostic Monitoring Plus (SDM+) for over a decade. SDM+ methods have allowed the CLFLWD to achieve 91% of our watershed wide phosphorus reduction goals within a 10-year period. In 2021, the CLFLWD was approached by the Lower St Croix One Watershed One Plan (LSC) regarding the CLFLWD's Sequential Diagnostic Monitoring program. Though we did not have an officially written out protocol, we agreed to document our methods for the LSC. We offer this protocol as a way to help our partners in the LSC, greater MN, and across the Midwest to rapidly achieve their pollution reduction goals. We feel that the CLFLWD SDM+ is a novel approach that utilizes robust datasets to target and select projects, resulting in the best Return on Investment (ROI) for grant and taxpayer dollars. This approach uses fundamentals of standard monitoring but applies these fundamentals and interprets the data from the monitoring in an innovative manner.

As such, the protocol presented herein may not align with other targeting protocols, and in part, this is the point. Continuing down the current "standard" project identification and targeting path will only continue to result in the limited successes in reducing pollutant loading in the region that we have historically seen. We, as a water resource community, need to evolve and innovate, find new paths to achieving our water quality goals and objectives. We offer the CLFLWD's SDM+ method as this new way.

Introduction

Sequential Diagnostic Monitoring Plus (SDM+) is a combination of traditional sequential diagnostic monitoring efforts combined with historical reviews of past (legacy) land use activities, interviews with long standing landowners, and the use of the economic principal known as the Pareto Principle. This highly effective method of using actual data to focus on a small number of activities and/or projects that possess the greatest loads can reduce both the cost and time needed to achieve water quality goals. Internal cost and time estimates of several approaches (SDM+ and SWA) suggest that the SDM+ approach can reduce the time needed to achieve water quality goals by up to $1/7^{th}$ that of most current efforts.

SDM+ has been shown to be a critical tool in positively identifying sources of external nutrient loading to a waterbody. Through the collection and review of collected water quality samples, SDM+ can identify excessively high loads that may not be visible by mere field observations or modeling of the land management within the watershed of interest. The data analysis and calculations needed to identify high return on investment sites is more than just a review of sampling data often used to estimate baseline water quality data in lakes. The CLFLWD has found that using District staff to coordinate and perform the sampling combined with the expertise of outside professionals to provide recommendations has produced the most efficient results. These results have been further verified by post-construction "effectiveness monitoring" to ensure that both the analysis and use of public funding achieve maximum efficacy.

This SDM+ technique can be applied to a variety of waterbodies and enables targeting of load sources for mitigation and/or restoration. Proper identification of the source of the nutrient and its impact on the target waterbody allows direct, targeted treatment of the cause of the nutrient source. As such, Sequential Diagnostic Monitoring Plus enables both timely reduction of pollution loading sources as well as documented data to verify the high return on investment of public and/or private funding.

Focusing restoration efforts on projects that have the largest, most cost-effective load reduction to the target waterbody of concern, as opposed to edge-of-field calculated projects, is key. Some projects may seem to have a large nutrient reduction (at the edge-of-project) but due to drainage patterns in the watershed and intermediary treatment systems, these reductions may not be fully realized at the target waterbody. Even more importantly, desktop modeling has no ability to include 'legacy' nutrient loads that exist throughout the landscape. By contrast, legacy loads can be identified through SDM+. Legacy loads may account for as much as 1/3 of all external loading to state waterbodies but current restoration efforts have no means to take them into account, let alone identify them. As such, SDM+ can eliminate the potential of missing sizable nutrient loads within a watershed, and thus lead to better project identification and subsequent load reductions at the target waterbody.

A key element of the way the CLFLWD employs SDM+ is focused on the Pareto Principle, or more commonly known as the 80-20 rule. This principle asserts that 80% of outcomes (or outputs) result from 20% of all causes (or inputs) for any given event. A goal of the 80-20 rule (restated in water resources/restoration terms) is to identify inputs (nutrient sources) that are potentially the most productive (contributing the highest watershed loads) and make them the priority (for restoration/mitigation). For instance, once (water resource) managers identify factors that are critical to their company's (target waterbody's) success, they should give those factors the most focus. Thus, maximizing the return on investment (ROI).

Sequential Diagnostic Monitoring Plus is the tool that can enable the identification of the "input" factors and thus determine the "20%" of sources accounting for "80%" of the total nutrient load. It should be noted that SDM+ *does* require an initial investment of both staff time and funds. However, this initial investment will pay for itself more than several times over in the end through more timely and efficient reductions in watershed load and subsequent water quality improvements in the target waterbody. Furthermore, in some cases, watershed load reductions cannot be achieved without SDM+ efforts since the load can be from a historical 'legacy' activity that discharged to a wetland and still continues to discharge nutrients decades after the activity has ceased. To address the upfront investment hurdle of SDM+ costs, this CLFLWD protocol offers two diagnostic monitoring overviews. Traditional diagnostic monitoring utilizing staff and external consultants, and commercial laboratory analysis; and a low-cost alternative using staff and readily available technology. The latter hereby referred to as do-it-yourself (DIY) diagnostic monitoring. Both utilize the same monitoring techniques but differ in technology and cost.

Methodology Overview

In its most basic form, sequential diagnostic monitoring entails sampling all significant water inputs into a waterbody for a contaminant or a nutrient of concern. Sampling efforts should take place throughout the entire year (if possible) or over several years to capture a statistically valid range of environmental conditions and precipitation events to achieve the highest level of confidence in the dataset. However, even a partial season's worth of data is sufficient to provide enough information to suggest focusing additional sampling in a particular tributary or area. Monitoring should be timed to correspond with precipitation events and ideally water samples are collected during or immediately after such an event to determine the nutrient load being transported in the storm runoff. This approach will provide a general idea of the source of the target nutrient in the watershed. It does not, however, inform on the volume of the nutrient load. To determine a true "hot spot" or source of an excess nutrient, both the nutrient concentration and the stream flow to deliver the nutrients downstream to the target waterbody are needed.

Nutrient load can be determined by incorporating stream discharge monitoring into the monitoring methodology. With both nutrient concentration and stream discharge, a flow-weighted mean load can be calculated and thus the 80-20 rule can be applied to determine which subwatershed(s) should be prioritized for restoration/mitigation. In most cases, further refinement of the nutrient source is needed within the subwatershed. This is accomplished by applying the same SDM+ methodology again at the subwatershed scale to refine the specific source of the excess nutrient loading (e.g., an abandoned manure storage lagoon, highly erodible agriculture field, ditched wetland complex, etc.).

This protocol provides two strategies of SDM+ – traditional and do-it-yourself diagnostic. Each method has strengths and weaknesses, but both share the general methodology described above and in greater detail below in this document. Traditional monitoring can be rather expensive as it is often conducted by a third party (consultant) and water grab samples are analyzed by a commercial laboratory. As such, it does offer a higher degree of certainty in monitoring results and could be considered more robust as it is conducted by specialists in the field. DIY monitoring, as indicated by name, is conducted by in-house staff using readily available and inexpensive equipment. As such, DIY is less expensive but still requires a great deal of staff time, and results from the effort are not considered as accurate as those from a commercial laboratory. In addition, most DIY technology is limited in its scope, and can generally only monitor one nutrient per device, and in the case of phosphorus, only the ortho-phosphate form of this nutrient can be quantified at this time. Traditional monitoring is only limited by the laboratory used for the analysis. Most laboratories can analyze all forms of a nutrient, or multiple nutrients present in the water sample – thus providing an elevated level of analysis. The DIY diagnostic technique is a useful screening tool to narrow down nutrient sources, but traditional diagnostic monitoring may still be needed to fully verify results and accurately identify the nutrient source.

Application to the Lower St Croix Basin

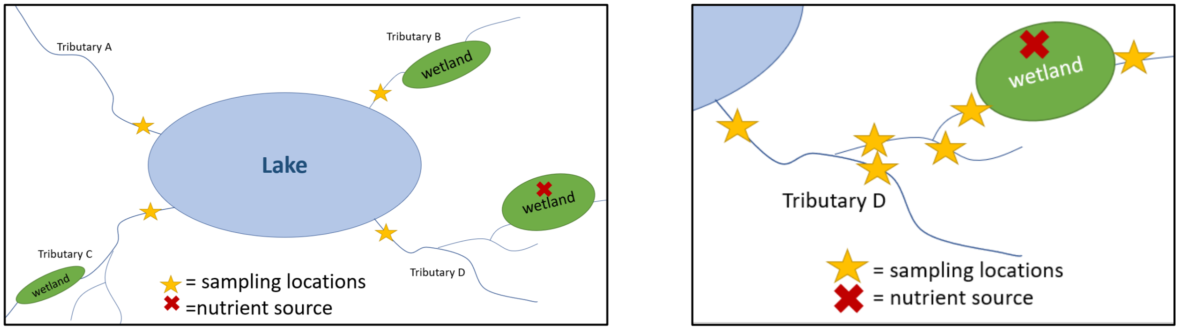
The Lower St. Croix (LSC) is a large watershed and has an estimated phosphorus load reduction target of 64,395 lbs./year needed to achieve state standards for all priority waterbodies in the basin (LSC CWMP Tables 5-2 and 5-3). Sequential diagnostic monitoring and application of the Pareto Principle may be the most efficient and cost-effective way to meet the load reductions goals for the Lower St. Croix. Application of the SDM+ methodology on this large of a watershed could leverage the already acquired data obtained through WRAPS and other such efforts. A limited amount of additional DIY screening to inform the need for any focused monitoring effort could also be employed.

Naturally, efforts should be focused on the most known impaired waterbodies (lakes or streams with poorest water quality) and the contributing inputs to these waterbodies. Through sequential diagnostic monitoring, combined with historic aerial photography investigations (discussed below), the potential 20% of subwatersheds contributing 80% of the total load should become readily apparent. Through additional subwatershed SDM+ efforts, these nutrient sources can be pinpointed, and restoration or mitigation actions taken to reduce or eliminate them. Though the initial SDM+ effort may take several years to complete across the full scale of the already known priority areas of the LSC, and require a local investment of funding, the cost savings from implementation of only ~20% or less of the potential projects would provide a great ROI for this initial investment *and* greatly compress the timeframe for achieving the potential phosphorus load reduction of over 50,000 lbs. in the LSC basin.

Sequential Diagnostic Monitoring Methodology

The following is a general methodology for conducting sequential diagnostic monitoring. It is presented in two phases (Figures 1 and 2). Phase 1 encompasses the entire watershed and includes desktop analysis and planning, field verification, pollutant monitoring, flow monitoring, and data analysis. The goal of phase 1 is to identify the subwatershed(s) that contain the sources of excess nutrient. The second phase is a focused reiteration of these steps on the subwatershed scale with the goal of refining the location of the source of the excess nutrient identified in phase 1. This document is intended to provide a general outline of how to approach diagnostic monitoring with links to established protocols for each monitoring element, and helpful tips and resources along the way.

This document should be used as a guide with the understanding that each monitoring program should be tailored to the specific goals of the waterbody and the available staff/resources. It is highly recommended that the professionals that will ultimately use the results of the monitoring data be consulted before embarking on SDM+ to ensure that the appropriate amount and type of data is collected.



Figures 1 and 2. Schematic drawing of Phase 1 - whole watershed sequential diagnostic monitoring (left panel) and Phase 2 – focused subwatershed sequential diagnostic monitoring (right panel).

Desktop Analysis

Using all available data, identify all flow paths/drainages into the target waterbody. GIS and other mapping sources are particularly useful in this effort. Other useful data tools include: wetland inventories, stream layers, LiDAR elevations, watershed delineation layers, hydrologic & hydraulic modeling, drain tile location and data, direct drainage information, municipal stormwater infrastructure, road ditch networks, culvert inventories, septic field location data, road networks (access for monitoring), known feedlot information, Total Maximum Daily Load studies (TMDL), Subwatershed Assessment (SWA) reports, and any other pertinent information - such as local knowledge. Much of this information can be obtained from local government partners or the state GIS Geospatial Commons database (https://gisdata.mn.gov/). It may also be beneficial to solicit public input (e.g., lake associations or local residents) regarding known outfalls or ditches that may not be indicated on map layers or in watershed studies. These data are easily compiled and accessed using GIS software.

From this effort, a list and map can be generated of all known potential inputs into the waterbody. These inputs should be temporarily numbered or identified to aid in the next steps of the process – field verification. However, prior to field verification, additional effort should be made to refine the list of potential nutrient sources.

Landlocked basins, or those which would only contribute to the watershed during an extreme precipitation event can be eliminated as potential source locations. Use professional judgement as to what precipitation event return internal is considered extreme (50 or 100-year event may be an appropriate starting point). Remember, to be considered a true source of excess nutrient, both high levels of nutrient concentration and the flow volume to deliver these excess nutrients downstream to the target waterbody are needed. Also take into consideration intermediary treatment (e.g., wetlands, ponds, etc.) that could act as natural treatment to a nutrient source. These areas should still be included in the monitoring effort but should be weighted accordingly in the final analysis. To achieve the greatest results at the target waterbody, you will need to address the highest loading sources which aren't being naturally treated.

Field Verification

The information developed by the desktop analysis should be evaluated in the field prior to designing the monitoring plan. All potential water inputs should be evaluated to ensure that they are in fact flow paths to the target waterbody, that they do in fact contain flow or show evidence of recent/active flow and can be routinely accessed/monitored. In many cases, the flow path indicated in a GIS may be a dry road ditch or other drainage networks that cannot be readily monitored. Field verification can be difficult during dry periods of the year or in dry years. Look for signs of active flow such as recent erosion, sediment deposits, water marks, stained or bent vegetation, and/or hydrophytic plant species.

One of the key elements of field verification is identifying potential monitoring locations along the verified inputs/flow paths. The simplest approach is to focus on access to the input from public property – the most common being public road crossings. Most road rights-of-way are wide enough to allow sufficient access for monitoring of the input water resource. In remote areas, private access may be needed, and the outreach process for this type of access can be both difficult and time consumptive. As such, try to target public road access whenever possible. It may also be useful to reach out to local governments and road authorities to both verify the status of road ownership (public vs private) and give notice of the monitoring effort as to avoid conflicts or issues with disturbed equipment during the monitoring effort.

Monitoring Planning

Based on the information gathered during the field verification step, a monitoring plan can be developed that should effectively cover the entire watershed, while focusing on inputs that can be readily accessed for monitoring. This is often accomplished by sampling inputs low in the basin, close to the target waterbody (e.g., the outflows from the subwatersheds). Remember that this is the first step in the process and as such, the watershed should be viewed from the "10,000-foot" level. During this first phase of SDM+, it is important to assess the entire watershed and identify subwatersheds that may be contributing excess nutrients. Refinement of the actual location of the nutrient source will come in later phases of the monitoring effort that occur on the subwatershed scale.

To ensure coverage of the entire watershed, start with primary tributaries (highest stream order) closest to (or lowest in the watershed) the target waterbody. Monitoring sites will be dependent on access, so some flexibility may be needed. Also note that the details of the monitoring plan are contingent on the size of the waterbody. Some lakes may only have one or two tributaries (in that case monitor all tributaries), while others could have dozens and it may not be practical to monitor them all. In the latter case, it may be necessary to break the watershed in to sections and monitor over multiple years rotating between areas of the watershed to get full coverage of all major inputs into the target waterbody or focus your monitoring effort based on current and historic land use (see the historic aerial photography review section below).

The monitoring plan should incorporate a well thought out monitoring site naming convention. A simple and logical system should be developed that allows some adjustment in future phases yet avoids confusion during this phase. A numbering system to consider is "numbering clockwise by 5's" (e.g., monitoring locations 5, 10, 15, 20 for a 5's numbering system, Figure 3). This will allow for infilling if additional monitoring locations are identified during the monitoring effort (e.g., previously unknown drain tiles or ditches).

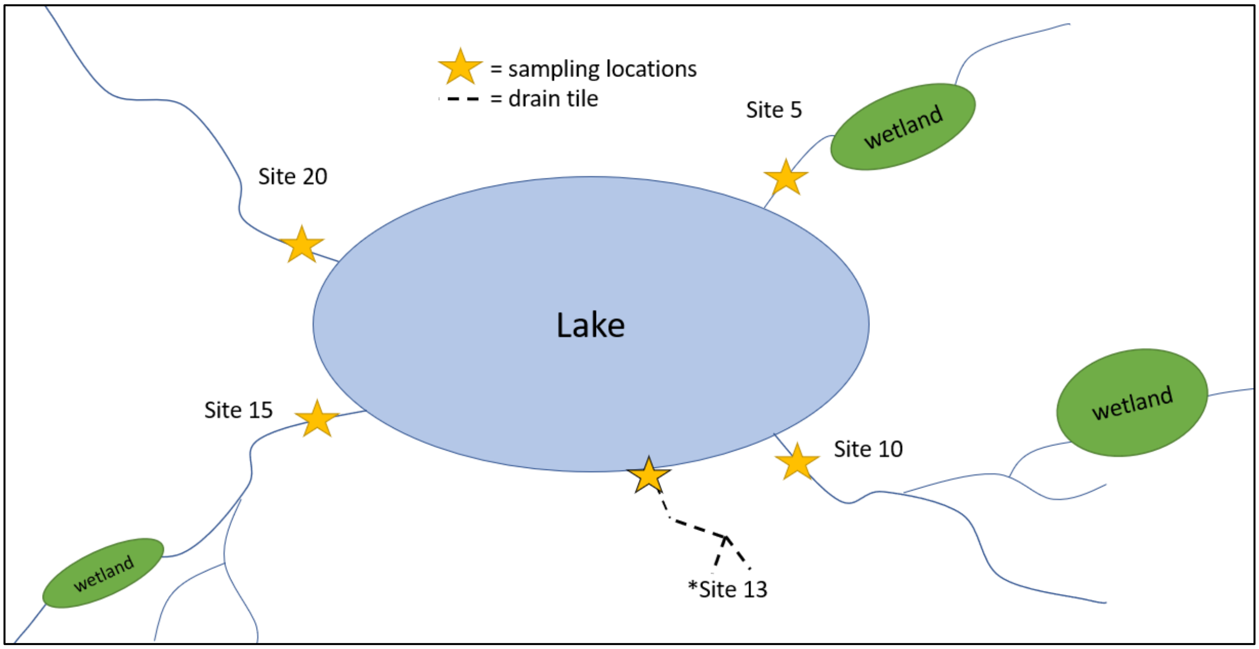


Figure 3. Schematic drawing of a typical sampling site numbering system – clockwise by 5's. This type of system can accommodate additional future sampling locations such as the drain tile (Site 13) depicted in the schematic. Note that the monitoring locations are low in the subwatershed (close to the target waterbody) to be sure to sample water from the entire subwatershed of each input.

It is also important during this planning phase to identify the commercial laboratory or technology that will be used for analyzing the water quality grab sample collected during the monitoring effort. It is recommended to investigate and obtain quotes from several laboratories prior to selecting a facility to analyze your water samples.

> DIY Consideration: If using the DIY approach, it is important to select the best technology for the nutrient of concern in your waterbody. In most instances, the DIY colorimeter technology that is readily available will only analyze for one parameter, so multiple pieces of equipment may be needed if focusing on several nutrients. It is very important to fully understand the technology that will be used and make sure that staff are properly trained on the technology as it may involve the use of potentially hazardous chemicals. Each piece of equipment should come with detailed instructions on proper operation and processing of water samples. Additional training resources are also generally available from the manufacturer or can be viewed on websites like Youtube.com.

The planning phase is also a good time to procure all sampling equipment and supplies. The type of monitoring (traditional vs DIY) will determine the supplies needed. Both monitoring strategies will require similar equipment with the exception that DIY diagnostic will require syringes and filters (0.45 µm), a nutrient colorimeter(s) and associated reagent(s). If including flow monitoring in the SDM+ or DIY effort, a set of discharge monitoring equipment will also be needed. A complete equipment list, with product links, can be found at the end of this document.

Phase 1 – Sequential Diagnostic Monitoring (The Early Years)

Flow monitoring and stream stage monitoring are key elements to the SDM+ effort in that they allow for the calculation of total discharge over a period of time, which in turn, allows for the total nutrient load to be determined. Discharge can be determined in multiple ways including area-velocity dataloggers for culverts and pipes, v-notch weirs, and flow meters and ratings curves for natural channels. For natural channel, these calculations require the development of a discharge ratings curve based on multiple measurements of discharge (over a wide range of flow regimes) as plotted against observed stream stage. Continuous level data, as collected by level logger, can then be applied to the developed ratings curve to determine the discharge for any given time (when the level logger was active). With these data, the total discharge, total nutrient load, and a flow-weighted load can be determined. This information allows for comparison of subwatersheds and the identification of the subwatershed containing the source of excess nutrient.

The main pieces of equipment needed for the SDM+ effort include: a flow meter or area-velocity data logger to measure discharge, staff gages to monitoring stream level or stage at each monitoring location, sample bottles to collect the water quality samples, and level loggers to measure a continuous stream stage. DIY SDM+ will also require the colorimeter or other equipment appropriate for monitoring the nutrient of concern.

Install Monitoring Equipment

As early as possible (ideally during spring melt) all monitoring equipment should be deployed at each sampling location, and sampling should begin. It is important to capture early spring runoff events as they often carry a large pulse of nutrient. If spring thaw occurs early, water grab samples and flow measurements can be taken before all monitoring equipment has been installed, provided the monitoring occurs at the location where the level loggers will eventually be installed. If monitoring before level logger and staff gage equipment is installed, be sure to capture the stream stage – this can be accomplished by measuring the vertical distance from a local benchmark (or set structure) to the water surface for a stage reference (typically the top or crown of a road culvert). If this benchmark is not already established, it can be set later on in the field season and the stage can then be back calculated.

<u>Level Loggers and Staff Gages -</u> Level loggers (either vented or non-vented) should be installed at the lowest point in the flow channel at each monitoring location to ensure they remain wet during the entire monitoring period. Reference the manufacturers recommendations for logger set up, installation, and maintenance. They should be installed in a stilling well and preferably be located near a culvert crossing where a local elevation benchmark or staff gage (Figure 4) can be established using survey grade GPS. If staff gages are not available, the top of the culvert often makes a good permanent benchmark. The benchmark/staff gage level should be recorded during each sampling event and during all discharge measurements as these readings must be applied to the level logger data to calibrate or verify the actual

recorded water surface elevations. To record stage from a benchmark, measure the vertical distance from the benchmark to the water surface and subtract this number from the known benchmark elevation – this value is the stage (as would be read from a staff gage). The stage data, combined with the discharge data is used later to calculate a discharge rating curve used to determine total flow over the monitoring season.

Non vented level loggers require the use of a secondary “open air” barometric pressure logger to compensate for the effects of atmospheric pressure. This secondary logger needs to be installed above the highest expected flow stage (in open air) at a given site. Generally, one barometric pressure logger can supply data for several non-vented level loggers installed within a ~5-mile radius. The data from this “open air” barometric logger will be used to correct the data from the “wet” level loggers. Vented level loggers do not require this data correction.

Figures 4 and 5. Stilling wells, staff gages (left panel), and level loggers (right panel) are essential tools in sequential diagnostic monitoring.

Stilling Wells - Level loggers should be installed in a stilling well (Figure 5, BWSR Hydrologic Monitoring of Wetlands) to secure and protect the logger. A stilling well is essentially a protective enclosure (usually made of PVC) for the level logger that holds the logger in the same position throughout the monitoring season as well as provides greater water surface stability and reduces the effects of wave action. Stilling wells can be purchased online from several scientific equipment dealers or constructed by drilling vent or flow holes into an appropriately sized PVC pipe. Hole size and pattern are subjective, but some recommendations can be found by searching online.

Data Collection

Flow Monitoring - Flow or discharge monitoring should be conducted at each monitoring location throughout the monitoring year over a range of stages such as low flow, base flow, small precipitation events, and large precipitation events (USGS Guidance). Flow monitoring involves taking a series of flow measurements (with a flow meter) and water depths across a cross section of a stream or culvert. This allows the calculation of discharge at each location (cell) along the cross section. When the values are added, flow or discharge for that cross section is determined with great accuracy (EPA Guidance).

Discharge and stream depth for each cross-section cell should be recorded on a data sheet or a field notebook and entered into simple spreadsheets back at the office to calculate discharge. A template discharge spreadsheet can be downloaded from the internet (link) or be obtained from a government agency such as the USGS or DNR. Modern flow meters have the capacity to calculate the discharge for the cross-section instantaneously during the monitoring event. This can save time and reduce the likeliness of data transfer error, but these meters are often costly.

The flow data will be used along with staff gage data to develop a rating curve for stream discharge and will ultimately be paired with the water quality grab sample results to determine "flow-weighted loads" or the amount of load being exported by the tributary over a given time (discussed in later sections).

Stream Stage and Level Loggers – Stream stage should be recorded during each water quality grab sample event and during discharge monitoring (to help develop a discharge ratings curve). Typically, stage is measured by noting the staff gage reading (if installed) or measuring down from the established benchmark to determine the water surface elevation or stream stage (benchmark elevation minus the vertical distance to water surface equals the actual water surface elevation).

Level loggers should be retrieved, downloaded, and redeployed periodically throughout the monitoring season, typically every 2 to 3 weeks to ensure the logger data is being recorded properly, and to determine if logger malfunctions have occurred - this will require close inspection of the data after download to assess quality and/or identify abnormalities in the data set. See the manufacturer's recommendations for downloading and data QA/QC.

Data downloads are usually planned during flow monitoring efforts to reduce field and travel time. A rugged weather resistant laptop or tablet with the logger software installed can be used for such field work. After download, be sure to reinstall the logger at the same elevation as before to maintain a consistent data set– a stilling well can help to ensure this. Also, remember to remove all level loggers at the end of the monitoring season before frost as ice can rupture the logger sensor diaphragm and may damage the internal components of the logger. Note: If using a non-vented level logger, barometric pressure must be accounted for, and logger data must be corrected accordingly (see the level logger manufacturer's guidance for this procedure).

Water Quality Grab Samples – Water quality (WQ) grab samples should be collected during or immediately after a precipitation event of a given value that is dependent on watershed size and land use. Professional judgement should be used to determine what amount of precipitation yields flow in the target subwatershed. In the Comfort Lake – Forest Lake Watershed District, rain events greater than 0.75 inches result in increased flow in a natural flow channel. Flashier or urban systems may warrant monitoring of smaller events.. Remember, runoff is dependent on rainfall frequency and intensity, the dominant land use of the subwatershed (i.e., urban, agricultural, mixed land use, forested), and slope of the drainage area. Consider these factors when determining the minimum precipitation event for monitoring. Other considerations regarding WQ sampling frequency are staffing and the need to monitor a representative number of precipitation events over the entire open water season. In this regard, adaptive management may come into play if there are wet or dry periods with a monitoring season. Websites like weatherunderground.com, noaa.gov or cocorahs.org are good resources for precipitation estimates and totals.

Collecting WQ grab samples is quick and fairly straightforward – simply collect a small volume of water from the thalweg of the flow channel during or immediately after a storm event. Care should be taken to avoid disturbance of the stream bed and to ensure the collection bottle has been properly cleaned to prevent cross contamination (see the Sample Collection Procedures and Notes section at the end of this document for additional detail and recommendations). Commercial laboratory water grab sample analysis may require that a fixative chemical is added to the sample for preservation – laboratories usually provide the bottles and fixative. WQ samples should be kept on ice and delivered to the lab or analyzed (DIY) in a timely manner after collection, usually within 24 hours for lab processing or within a few hours for DIY analysis (see the DIY colorimeter manufacturer's recommendations.)

An important aspect of WQ grab sampling is documentation. All samples should be labeled with the date, time, monitoring location, and staff who collected the sample. Similarly, a monitoring data sheet (See example in the Additional Resources section below) with this same information and any additional notes should be recorded and kept for each monitoring event. The data sheet should also contain additional information such as the stage or gage reading at the time of the sample and the precipitation total for the monitoring event (if known). This information should be entered into a database upon return from the field.

As many of the samples will be collected from road rights-of-way, safety should be considered during all monitoring events. Park vehicles as far off the roadway as is possible, wear brightly colored clothes or hi-visibility vests and collect the data in a timely manner. Consider installing flashing safety lights on vehicles or use the vehicle's emergency lights during monitoring and be sure to use extra caution when merging back into traffic form the road shoulder. Some roadways may be too dangerous, thus parking a distance away and walking to the site may be the safer option.

> DIY Considerations: DIY WQ grab sampling follows the same steps as presented above, except that no fixative chemicals are needed to preserve the grab samples and the data sheets/database should include a section for results as all WQ grab samples should be analyzed within a few hours of collection. Analyzing the samples should follow the protocols included with the colorimeter or other technology chosen for the DIY monitoring effort. Generally, the processing and analysis steps include filtering the water sample through a 0.45-micron filter, adding a chemical reagent, waiting for several minutes for a color change and then running the sample through the colorimeter (Figure 6). Total time per sample is usually less than 3-5 minutes. Alternatively, WQ samples can be filtered and frozen for later analysis. Care should be taken to ensure no cross contamination of samples (proper rinsing/cleaning between samples) and proper PPE should employed as the chemical reagents needed may be caustic or otherwise hazardous. Sample readings/results should be immediately recorded on the monitoring data sheet and entered into

a database upon completion of the sampling event. All data sheets should be kept for future reference as they are useful during the data analysis phase.

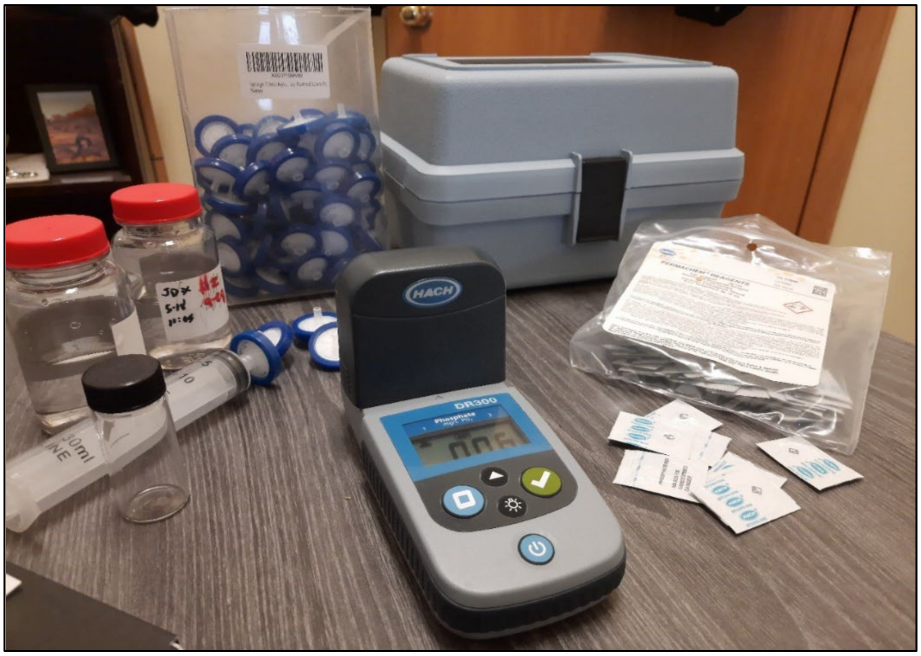


Figure 6. HACH Colorimeter and accessories used by the Comfort Lake–Forest Later Watershed District for their DIY sequential diagnostic monitoring orthophosphate monitoring effort. Total cost for all equipment and supplies pictured was less than $700. After the initial investment in equipment, it costs less than $50 to analyze 100 water samples, or ~$0.50 per sample (not including staff time).

Data Entry/Database – Data tracking and organization is key to any SDM+ program. Information collected during a sampling event, however minor, may prove invaluable when interpreting the data. All observations and notes should be recorded on field data sheets and kept until completion of the diagnostic investigation – if not longer. All data should be entered into a database immediately after the monitoring event to decrease the likelihood of entry error or general loss of data. Databases can be as simple as an Excel or Access spreadsheet (see example below in the Additional Resources section), or a more robust form for large complicated diagnostic efforts. At a minimum, the database should be set up to allow future analysis with minimal data reformatting.

Data Analysis

Upon completion of the first year of diagnostic monitoring, all data should be analyzed to determine if any nutrient load trends can be identified. Depending on the amount of precipitation (or lack thereof) during the monitoring season, or the complexity of the watershed, one year of data collection may not be sufficient to properly identify sources of nutrient load within a watershed or subwatershed. Furthermore, one monitoring season may not properly account for any year-to-year variability of nutrient loading. During drought and/or wet years, data can be skewed, and this may lead to misinterpretation of the results. Therefore, it is recommended that the first phase of diagnostic monitoring occurs over several years and includes at least one precipitation year with "near-normal" precipitation.

Flow Data – Discharge and stage data can be used to develop a discharge ratings curve that, when combined with level logger stage data, will allow for the determination of the discharge at any given point in time (based off stage height). These values then allow for the calculation of total discharge for a period of time (e.g., during the monitoring season). This information, when combined with the water quality data, enables the calculation of flow-weighted mean load concentrations. These flow-weighted mean load values are of particular importance as they consider the effect of discharge on nutrient load transport and thus allow for direct comparison between subwatersheds as potential sources of nutrient loading to the water resource of concern.

The discharge rating curve can be developed based on data from the discharge monitoring (flow gauging) and stage measurement readings collected during flow monitoring. A rating curve correlates the actual measured discharge to the measured stage or staff gage reading and thus determines discharge for a given stage point (USGS Guidance). The ratings curve can then be used to determine a "discrete" discharge value by referencing the continuous stage measurements from the level logger to the ratings curve. In this manner, discharge can be determined for any point in time, thus informing the discharge when a water quality grab sample was taken. These data can also then be used for calculating the total discharge (for a period of time) needed to determine both total load and flow-weighted mean load concentrations (see section below).

> DIY Considerations: A DIY alternative to the use of level loggers and the development of a ratings curve is to take a discharge measurement during every sampling event at each monitoring location for a "real time" discharge. This would allow for the calculation of load during a precipitation event but would not allow for the calculation total load for the monitoring season nor allow for calculation of the flow-weighted mean load concentrations (as there is no record of continuous flow). As such, this approach is only practical for a very small-scale or a preliminary "screening" DIY diagnostic monitoring effort as it will only provide a portion of the data needed to fully understand nutrient loading in the watershed.

An advantage of the ratings curve and level logger methodology is that discharge monitoring and WQ sampling can be independent of each other, thus allowing field time to be spread over the work week as opposed to during a storm event. Some of the flow measurements can be (and should be) taken during non-monitored WQ events or at base flow to improve the accuracy of the ratings curve.

Water Quality Grab Samples – At the end of the monitoring season, look for values in your water quality dataset that are higher than what are considered normal background levels for a particular nutrient. Normal nutrient background levels will differ regionally based on land use, soils, and parent geology. For example, phosphorus background levels in the Comfort Lake–Forest Lake Watershed District are generally under 0.15 mg/l, and readings above this value are considered elevated. This background value was determined through the SDM+ process by collecting numerous samples across the watershed over several years of diagnostic monitoring. As such, it may take several years of monitoring and data to get a sense of both normal background and elevated nutrient levels for your area. Other resources include state (MPCA) and federal nutrient standards and values from scientific literature.

When looking for true hot spots or sources of nutrient, values that are double or triple the normal background level should be flagged as opposed to values at or just above background readings. These highly abnormal readings are a strong indication of a potential nutrient hot spot. However, do not fully discount readings that are slightly elevated. If no “hot spots” are identified, and if there is steady stream flow, a subwatershed with moderately elevated nutrient levels may be a “chronic” contributor of a nutrient to the target waterbody (e.g., a steady flow of moderately elevated nutrient loads.) Thus, it is important to consider the effect of flow on nutrient load delivery.

Flow-Weighted Mean Load – Once potential areas with elevated nutrient levels have been identified, these subwatersheds should be viewed in the context of how discharge impacts nutrient loading. Remember, to be considered a true source of excess nutrient, both high levels of nutrient and the flow to deliver these excess nutrients downstream to the target waterbody are needed. As such, water quality data and flow data should be used to calculate an average flow-weighted mean load for each tributary or flow path monitored during Phase 1. This will allow for direct comparison of subwatersheds and properly identify the sources of excess nutrient loading.

Flow-weighted mean load concentrations can be calculated by dividing the total load over the estimation time period by the total streamflow. The time-weighted mean concentration is calculated as the average of the daily concentrations for the same time period (EPA Guidance). When viewed in this context, data can be properly compared and subwatersheds that are potentially contributing excess nutrient to the target waterbody can be identified. This is, however, only the culmination of the first phase of the systematic diagnostic monitoring effort. Further refinement of the actual nutrient source within a watershed or subwatershed is needed to maximize the mitigation of these excess nutrients in a timely and cost-effective manner.

> DIY Considerations: Flow monitoring may not be practical for some DIY diagnostic monitoring efforts as it requires specialized equipment, software, and is time consuming. As such, a qualitative approach can be employed to get a sense of the impact of discharge on nutrient loading. Monitoring staff should take note of flow (visual estimation) during grab sampling and this information can be used to provide some context when comparing grab sample data. For example, staff may indicate flow is stagnant or no flow (standing water), low flow (just a trickle), steady flow (noticeable flow within the bankfull prism of the tributary), or high flow (swift flow at or above the bankfull stream stage). Though no numbers can be applied to determine a flow weighting for this data, potential sources can be eliminated based on a lack of flow to transport the load downstream to the target water body. Thus, by a process of elimination the nutrient source can be refined. This approach can be used as a good screening tool before embarking on a more targeted traditional SDM+ effort.

Phase 2 - Subwatershed Monitoring (Refinement / Targeting)

During the first phase of Sequential Diagnostic Monitoring, all the main inputs into the target waterbody should have been monitored (Figure 1). This process hopefully identified the key subwatersheds responsible for the majority of load exported to the target waterbody (remember the Pareto Principle). In Phase 2, focus should now switch to the subwatershed scale (Figure 2), to identify the main source or location within the subwatersheds (identified in Phase 1) that are exporting the excess nutrient. Identification of the nutrient sources allows for targeted mitigation/restoration to remove or reduce these sources. This targeting enables rapid and cost-effective reduction of the nutrient load to the waterbody.

Subwatershed diagnostic monitoring is conducted in a similar manner as described above, only on the subwatershed scale. Similar to full watershed SDM+, desktop, field verification, and planning steps are needed to identify all inputs into the subwatershed and identify appropriate monitoring locations. Both WQ grab sampling and flow monitoring would be conducted in accordance with the protocol outlined in phase 1. In some cases, the subwatershed requires a more thorough and detailed monitoring plan as there may be a large number of potential inputs (tributaries, wetlands, or other water resources) or nutrient sources. If funds are limited, it may be necessary to focus on a single sub-shed or catchment within the subwatershed and rotate through the subwatershed in subsequent years or have a multi-year sequential approach looking at the major inputs in the subwatershed in year 1 and then narrowing in on the sources in subsequent years.

An additional resource or tool that can be used to focus the subwatershed monitoring efforts is historic aerial photography. The University of Minnesota has an online repository of historic aerial photos dating back to the 1930's (https://apps.lib.umn.edu/mhapo/). Investigation of historic aerial photos may point to historic land management practices that may no longer be visible 50 to 100 years later but may have a lasting impact on current water quality. A historic photo review may identify historic cattle, dairy, or livestock operations and associated manure storage areas [traditionally in an adjacent low (wetland) area], wetland ditching, stream straightening/manipulations, or other land clearing/alterations. These areas may be a good starting point for the subwatershed diagnostic monitoring effort or at least should be included in the effort.

Remote areas or areas with contiguous wetland complexes present a monitoring challenge. If there is no access to a contributing tributary/wetland, attempt to sample the main flow path (if accessible) both directly upstream and downstream of the confluence (Figure 7) with the isolated (non-accessible) area. The results from these upstream and downstream monitoring locations can then be compared to determine if the load originates from the isolated area – a noticeable increase in nutrient levels in the downstream location, as compared to the upstream location would be seen. When monitoring large contiguous wetland complexes or areas with no direct drainages, consider taking grab samples along the main channel or "road pinch points" at accessible locations along its flow path (Figure 8). This approach can help identify where the load begins to increase on the main flow path/channel by comparison of upstream to downstream results – thus identifying where within the wetland complex the load may originate. If the nutrient load steadily increases longitudinally from upstream to downstream, the entire wetland complex may be degraded to such an extent that the entire complex may be exporting nutrient. In this case, consider mitigation at the most downstream location of the wetland complex or restoration of the hydrology of the entire complex.

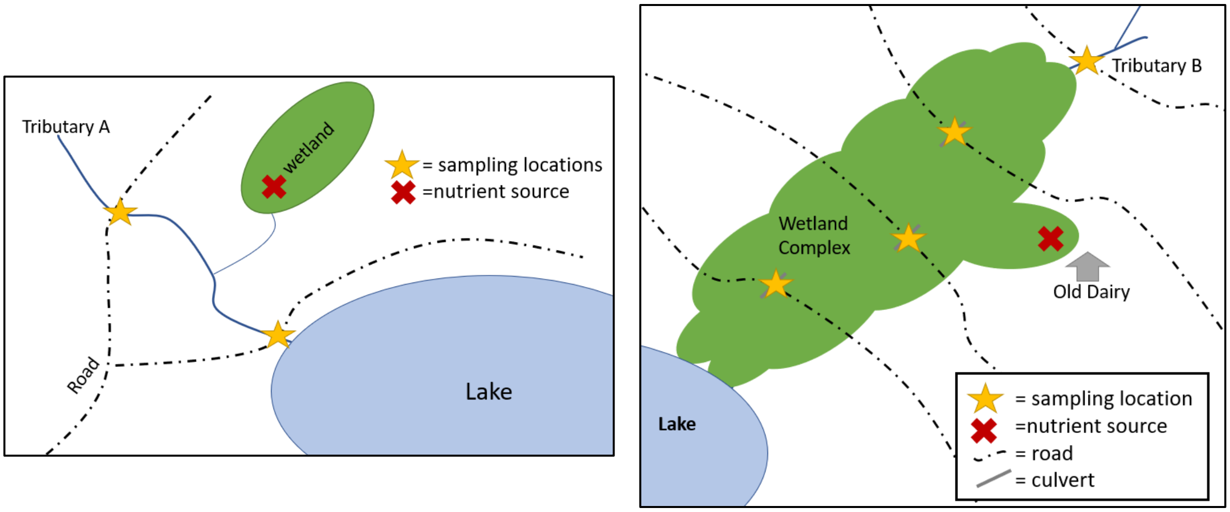


Figure 7 and 8. Schematic drawing of sampling locations for remote or inaccessible sites (left panel) or for large wetland complexes (right panel).

Additional Refinement Techniques

The following are a few additional refinement techniques or tools that could be used in conjunction with the SDM+ effort to identify or refine the location of a nutrient load. The techniques are not implicit to a SDM+ effort but can be useful to further locate a nutrient source after the SDM+ effort has been completed or can be useful during the SDM+ planning process.

Historic Photography

As mentioned earlier, in the Phase 2 SDM+ section above, historic aerial photography can be a useful tool in identifying past land practices that may have been visually erased due to recent changes in land uses, yet still physically remain on the landscape (https://apps.lib.umn.edu/mhapo/). One hundred years ago there were an estimated 178,500 farms throughout Minnesota, many of which were adjacent to, and dependent upon open water. As we know, many of the land management practices during this period were not focused on the long-term sustainability of the landscape nor the protection of the adjacent water resource – as is evident in the common practice of routing manure and wastewater directly into wetlands, streams, and lakes. These historic legacy loads, or "land management baggage", left on the landscape may represent a significant source of hidden nutrient load for much of the state of MN, presently and into the future, if not addressed.

Since the turn of the century, the number of active farms throughout the state has steadily declined to a number today that is approximately 38% of what it was (~68,500 farms in total, but just a 15.6% reduction in farm acres, https://www.nass.usda.gov/Statistics_by_State/Minnesota/index.php). The abandoned farmsteads have been developed, build over, and sprawled upon to the extent that most people would not know that they were once agriculture fields or cattle barnyards. As such, there may be remnant or legacy sources of nutrients "hidden" in plain sight.

Historic aerial photography allows a glimpse, however fleeting, into our past and provides some indication of past land management. Aerial photography may allow for the identification of past livestock yards, areas of erosion, shoreline recession, loss of riparian vegetation, and wetland alteration. Further investigation into these areas may reveal a legacy load of nutrient, often in an adjacent wetland or other water resource. Figures 9 and 10 indicate just such a situation near Bone Lake in Washington County, where a wetland adjacent to a past dairy farm was found to have highly elevated phosphorus levels in its soils. The contaminated wetland soils were eventually excavated to remove this chronic source of nutrient from flowing into Bone Lake.

Figures 9 and 10. 1964 aerial photography indicating an active dairy farm near Bone Lake in Washington County (left panel) and a 2019 Google Earth image of the same area. No evidence of the farm remains in 2019. The 1964 image indicates cows in the barnyard right down to the wetland boundary. Soil samples taken from the wetland found phosphorus levels three to ten times normal background levels – likely from manure laden runoff entering into the wetland over several decades given the natural swale that drained from where the barnyard was located toward the wetland.

Local Knowledge

The Bone Lake dairy mentioned above was not initially identified via a historic aerial photography review. It was identified by another useful source of information – a local historian who grew up near the dairy farm and was one of the few people to remember its existence. In instances where the source of nutrient is unclear or difficult to determine through the SDM+ effort, it may prove useful to seek out a longtime resident to discuss the water resource of concern and ask them about landscape level change, past land management, and changes in water quality. Their historical knowledge may point to or direct the SDM+ effort toward an area of the subwatershed or help to narrow the scope of a historic aerial photography review – as was the case for the Bone Lake dairy farm. Additional data will, of course, be needed to verify this location as a nutrient source. This can be accomplished through a localized diagnostic monitoring effort, or by collecting and analyzing soil samples directly from the area of interest – ideally through both efforts.

Soil Samples

Soil samples can be collected by hand from an area of interest, whether it be a floodplain, riparian area, wetland, or lake to identify the presence of remnant legacy nutrients. For the Bone Lake dairy mentioned above, this involved taking a series of soil samples from the wetland adjacent to the past farm operation. Samples focused on the area nearest the historic dairy yard, but also covered the entirety of the wetland to determine the extent of the contamination (Figure 11).

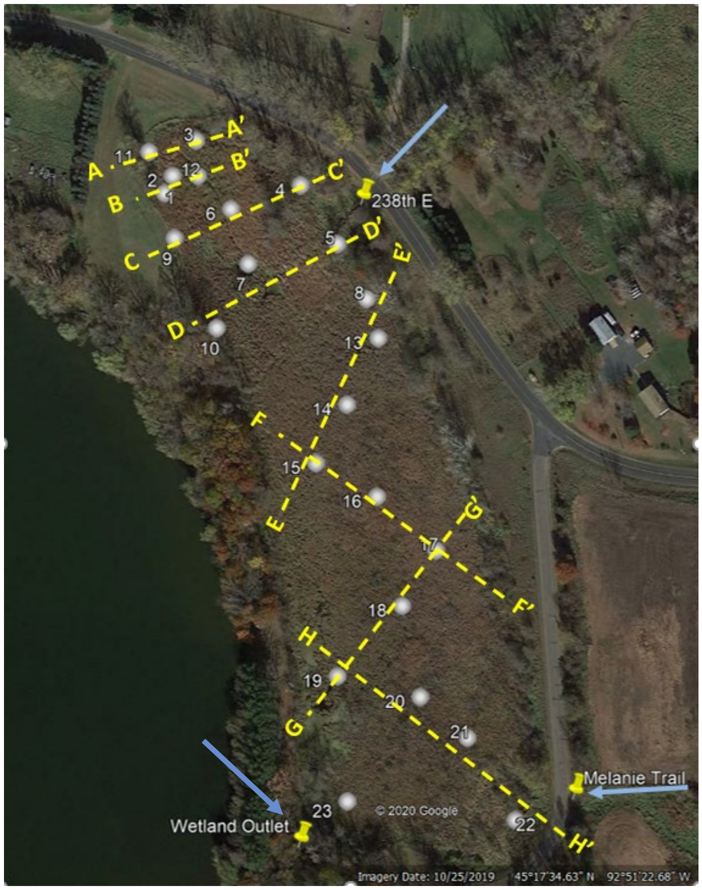


Figure 11. Plan view of the Bone Lake dairy wetland soil boring locations (grey dots) and transects (yellow dashed lines). The blue arrows and yellow pins indicate sampling locations for the localized diagnostic effort that was also employed to further evaluate this wetland as a source of excess nutrients for Bone Lake.

Soil samples were taken using a hand auger (Figure 12) to a depth of approximately four feet or down to the confining layer (clay) or native wetland soils (peat). Each soil layer within the boring was identified by soil type and color (Munsell), and an approximately 50 to 100-gram soil sample was collected for later laboratory analysis. Soil samples should be clearly labeled with the sample location and soil sample depth or layer indicated on the sample bag and all information collected should also be entered onto a field data sheet. Data sheets should be retained for later use in submitting samples to the laboratory and for reference during data interpretation. For the Bone Lake dairy wetland, the top 14 to 24 inches of mucky soils contained the highest concentrations of phosphorus – generally at levels of three to ten times the natural background levels for this type of wetland (Table 1, Figure 13). Soil samples collected through this effort should be kept on ice or frozen prior to delivery to the laboratory for analysis. To reduce costs, a subsample of these soil samples could be submitted for analysis, and based on results, additional samples could be submitted to fill in the data set. For example, from the initial laboratory results, it may be apparent that a legacy load does not exist, or that the nutrients are not elevated in a certain soil type, thus reducing the need for analysis in this soil type or in certain locations.

Figure 12. Soil borings being collected using a hand auger in the Bone Lake dairy wetland (left panel) and a representation of the soil samples collected (right panel).

Table 1. An excerpt of the results from the Bone Lake dairy Wetland soil borings for transect B (northern end of the wetland near the historic dairy yard). The upper table represents phosphorus concentration in mg/l and the lower table indicates soil type. Normal wetland background levels for this type of wetland are less than 550 mg/l for phosphorus. In the table below, cells in green are within normal ranges and those in red or dark red are considered elevated.

Transect B-B'

TP Concentrations:

Soil Boring	1-6"	7-12"	13-18"	19-24"	25-30"	31-36"	37-42"	43-48"
1	3,100		5,210					802
2	260				678		880	309
12	2,800		910					

Soil Type:

Soil Boring	1-6"	7-12"	13-18"	19-24"	25-30"	31-36"	37-42"	43-48"
1	P/M-P	M-P	M	M	M	M	M	M
2	M-S	M	M	M	M	M	M-P	P-M/ P
12	M-P	M-P	M-P/P	P	P	P	P	P

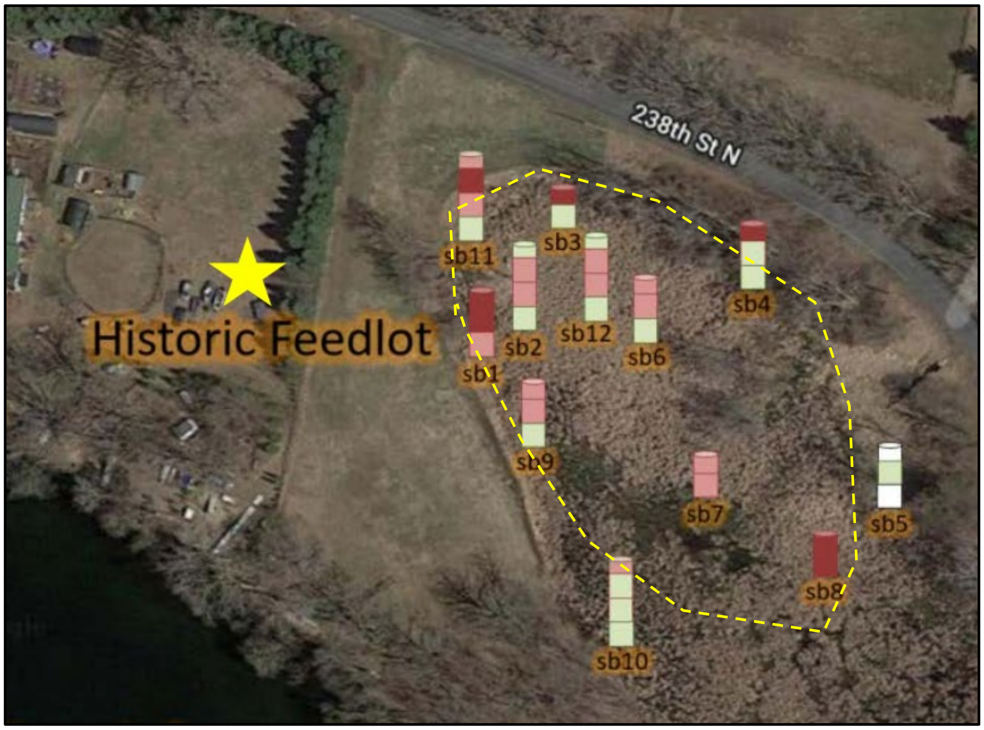


Figure 13. Plan view of the Bone Lake dairy wetland soil boring locations nearest to the past dairy feedlot with the soil boring phosphorus concentration results overlayed. The green colors indicate phosphorus levels in the normal ranges and the red or dark red colors indicate elevated levels. The yellow dashed line indicates the approximate area of the wetland that was excavated to remove the nutrient laden soils.

Equipment/Tools

The following is a brief list of some of the available equipment, tools, and guidance documents that can be used for sequential diagnostic monitoring. It is by no mean an all-inclusive list. It represents equipment and tools that are familiar to the authors of this protocol, and as such, should be only used as a starting point when researching or purchasing monitoring equipment or searching for guidance documents.

General Monitoring Protocols and Guidance

MN Pollution Control Agency – Basic Water Quality Monitoring Techniques
https://www.pca.state.mn.us/sites/default/files/wq-iw3-50-8.pdf

MN BWSR – Hydrologic Monitoring of Wetlands 2013 -
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjB2KHP2uH0AhV3AZ0JHTGYDGkQFnoECAwQAQ&url=https%3A%2F%2Fbwsr.state.mn.us%2Fsites%2Fdefault%2Ffiles%2F201812%2FWETLANDS_delin_Hydrologic_Monitoring_of_Wetlands_Guidance_BWSR.pdf&usg=AOvVaw0bRVLFCMi2Ble0n0w5csiP

EPA Load Estimate guidance
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjG8IWk8-

P0AhXQWM0KHUOABRgQFnoECAIQAQ&url=https%3A%2F%2Fwww.epa.gov%2Fsites%2Fdefault%2Ffiles%2F201605%2Fdocuments%2Ftech_notes_8_dec_2013_load.pdf&usg=AOvVaw2C0RXZ8nxmG1DCMypaW55D

USGS Discharge Monitoring Guidance - https://www.usgs.gov/special-topics/water-science-school/science/how-streamflow-measured?qt-science_center_objects=0#qt-science_center_objects)

UMN Historic Aerial Photography - https://apps.lib.umn.edu/mhapo/

GIS and Appropriate Data Layers

ArcGIS – Esri product, subscription needed. https://www.esri.com/en-us/home

QGIS – free GIS. https://qgis.org/en/site/

Minnesota Geospatial Commons. https://gisdata.mn.gov/

Level Loggers and Associated Software

Vented level loggers: when purchasing **any** level logger, choose the lowest PSI/level range expected at the site; usually loggers that can measure water level between 0-15 feet will be the most accurate.

1. In-Situ LevelTROLL 500: https://in-situ.com/us/level-troll-500-data-logger
2. Solinst LevelVent 5: https://www.solinst.com/products/dataloggers-and-telemetry/3250-levelvent/levelvent.php
3. Global Water Logger: https://www.forestry-suppliers.com/product_pages/products.php?mi=40911&itemnum=90714&redir=Y

Non-vented level loggers - will also need to purchase and install a barometric pressure logger

1. Solinst Levelogger 5: https://www.solinst.com/products/dataloggers-and-telemetry/3001-levelogger-series/levelogger/
2. In-Situ LevelTROLL 400: https://in-situ.com/us/level-troll-400-data-logger
3. Onset Hobo logger: https://www.onsetcomp.com/products/data-loggers/u20-001-04/

Barometric pressure logger - only needed if using non-vented level loggers

1. Solinst Barrologger 5: https://www.solinst.com/products/dataloggers-and-telemetry/3001-levelogger-series/levelogger/datasheet/barometric-compensation.php
2. In-Situ BarroTROLL: https://in-situ.com/us/rugged-barotroll-data-logger

Stilling wells - slotted PVC pipe with screen to house the loggers

https://www.shop-esp.com/2-x-48-PVC-Water-Well-Screen-020brPlain-Ends-Sch40-P3592.aspx?gclid=EAIaIQobChMIg6e8hLbD9AIVp2xvBB34-QJmEAQYBCABEgKuB_D_BwE

associated mounting post (i.e., T-post, fence post, etc.)

PVC caps (to be installed at the bottom of the well- drill a few ¼" holes through well cap to allow water drainage through the bottom of the well & cap)

Discharge Monitoring

Flow meter

1. Hach FH950: https://www.hach.com/fh950-portable-flow-meter-velocity-depth-system-with-20-cable/product?id=12287984105&source=googleshopping&locale=en-US
2. Sontek FlowTracker2: https://www.sontek.com/flowtracker2

Associated Accessories – 50 ft tape measure, wading rod, field book or data sheet

Universal Top-set Wading Rod: https://prph2o.com/wading-rods/ (formerly Rickly.com)

Water Quality Grab Samples

Water sample collection bottles (100 -500 ml) with stabilizing reagents (i.e., H2SO4 for TP)

May be available from the laboratory contracted to analyze the grab samples

DIY Specific Equipment

Colorimeter or alternative meter

Hach DR300 Colorimeter: https://www.hach.com/colorimeters/dr300-pocket-colorimeter

Nutrient Specific Reagents

https://www.hach.com

Grab Sample Bottles: (100 - 200 ml)-no stabilizing chemicals needed

Syringe and 0.45-micron filters (with Luer locks)

1. 100ml Syringe with Luer lock: available at Amazon.com
2. 0.45 micron filters with Luer lock: https://www.amazon.com/Simsii-Syringe-Filter-NylonDiameter/dp/B01BNA0280/ref=sr_1_5?keywords=0.45+micron+filters+with+lure+locks&qid=1637354477&sr=8-5

Additional Equipment Considerations

First aid kit

reflective vest or safety outerwear

wader, hip boots or knee-high (muck) boots

life jacket

Additional Resources

Citizen Assisted DIY Monitoring

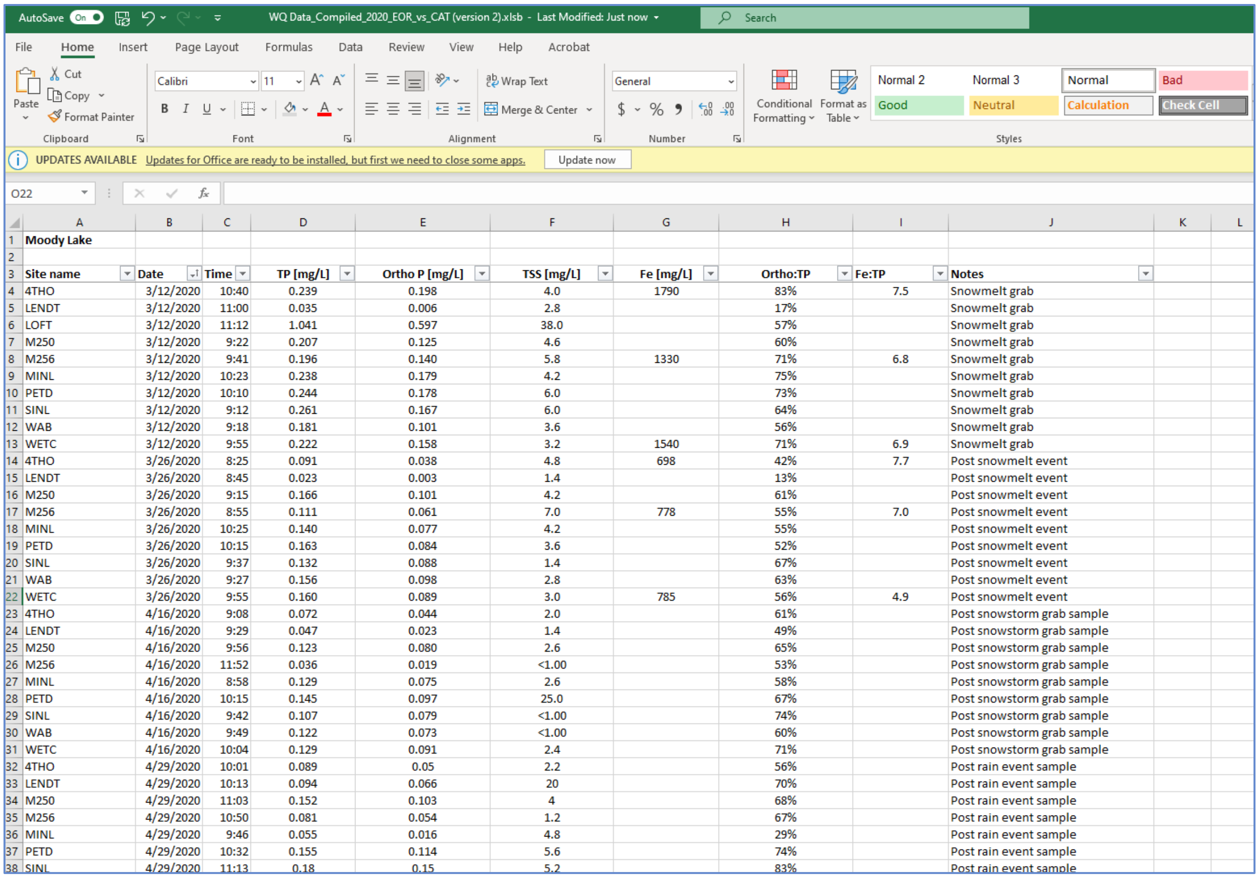
Natural Resource agencies often lament that they don't have the funding or "cannot afford to do monitoring." While the balance between implementation and monitoring can be appreciated, this protocol strives to offer a cost-effective alternative to the standard SDM+ effort – the DIY diagnostic monitoring strategy. Though not as precise as a traditional SDM+ effort, it is a useful tool and can go a long way in narrowing in upon a nutrient load.

To further reduce the expenses associated with a DIY monitoring diagnostic effort, citizen scientists can be utilized for water quality grab sample collection. Local residents can be organized and trained to collect grab samples during or immediately after a precipitation event near their residences. This has the advantage of both reducing staff time and allowing for sample collection after normal work hours or on the weekend - when precipitation events often occur. Samples can be kept chilled and delivered to the agency for analysis the next workday or filtered by the citizen scientist and frozen for later drop off and analysis. Drawbacks of this strategy include the amount of staff time dedicated to volunteer outreach, coordination, and training, and the availability of volunteers to collect samples during a precipitation event - as they may be reluctant to change their schedules to accommodate water quality grab sampling (e.g., prioritize the monitoring event). As such, Citizen Assisted DIY monitoring can provide some inexpensive data, but may not provide a data set as robust as is needed for a full diagnostic effort. Staff may need to follow up and collect grab samples missed by the citizen scientists or evaluate the data set with the proper context in mind.

Example Forms

	DIY Monitoring Event			Date: Staff: Drainage: known Precip: _______inches	
sample	Site	time	staff gage / stream stage	notes	Reading mg/l Ortho P
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Example of a basic DIY field data sheet



Moody Lake

Site name	Date	Time	TP [mg/L]	Ortho P [mg/L]	TSS [mg/L]	Fe [mg/L]	Ortho:TP	Fe:TP	Notes
4THO	3/12/2020	10:40	0.239	0.198	4.0	1790	83%	7.5	Snowmelt grab
LENDT	3/12/2020	11:00	0.035	0.006	2.8		17%		Snowmelt grab
LOFT	3/12/2020	11:12	1.041	0.597	38.0		57%		Snowmelt grab
M250	3/12/2020	9:22	0.207	0.125	4.6		60%		Snowmelt grab
M256	3/12/2020	9:41	0.196	0.140	5.8	1330	71%	6.8	Snowmelt grab
MINL	3/12/2020	10:23	0.238	0.179	4.2		75%		Snowmelt grab
PETD	3/12/2020	10:10	0.244	0.178	6.0		73%		Snowmelt grab
SINL	3/12/2020	9:12	0.261	0.167	6.0		64%		Snowmelt grab
WAB	3/12/2020	9:18	0.181	0.101	3.6		56%		Snowmelt grab
WETC	3/12/2020	9:55	0.222	0.158	3.2	1540	71%	6.9	Snowmelt grab
4THO	3/26/2020	8:25	0.091	0.038	4.8	698	42%	7.7	Post snowmelt event
LENDT	3/26/2020	8:45	0.023	0.003	1.4		13%		Post snowmelt event
M250	3/26/2020	9:15	0.166	0.101	4.2		61%		Post snowmelt event
M256	3/26/2020	8:55	0.111	0.061	7.0	778	55%	7.0	Post snowmelt event
MINL	3/26/2020	10:25	0.140	0.077	4.2		55%		Post snowmelt event
PETD	3/26/2020	10:15	0.163	0.084	3.6		52%		Post snowmelt event
SINL	3/26/2020	9:37	0.132	0.088	1.4		67%		Post snowmelt event
WAB	3/26/2020	9:27	0.156	0.098	2.8		63%		Post snowmelt event
WETC	3/26/2020	9:55	0.160	0.089	3.0	785	56%	4.9	Post snowmelt event
4THO	4/16/2020	9:08	0.072	0.044	2.0		61%		Post snowstorm grab sample
LENDT	4/16/2020	9:29	0.047	0.023	1.4		49%		Post snowstorm grab sample
M250	4/16/2020	9:56	0.123	0.080	2.6		65%		Post snowstorm grab sample
M256	4/16/2020	11:52	0.036	0.019	<1.00		53%		Post snowstorm grab sample
MINL	4/16/2020	8:58	0.129	0.075	2.6		58%		Post snowstorm grab sample
PETD	4/16/2020	10:15	0.145	0.097	25.0		67%		Post snowstorm grab sample
SINL	4/16/2020	9:42	0.107	0.079	<1.00		74%		Post snowstorm grab sample
WAB	4/16/2020	9:49	0.122	0.073	<1.00		60%		Post snowstorm grab sample
WETC	4/16/2020	10:04	0.129	0.091	2.4		71%		Post snowstorm grab sample
4THO	4/29/2020	10:01	0.089	0.05	2.2		56%		Post rain event sample
LENDT	4/29/2020	10:13	0.094	0.066	20		70%		Post rain event sample
M250	4/29/2020	11:03	0.152	0.103	4		68%		Post rain event sample
M256	4/29/2020	10:50	0.081	0.054	1.2		67%		Post rain event sample
MINL	4/29/2020	9:46	0.055	0.016	4.8		29%		Post rain event sample
PETD	4/29/2020	10:32	0.155	0.114	5.6		74%		Post rain event sample
SINL	4/29/2020	11:13	0.18	0.15	5.2		83%		Post rain event sample

Example of a basic monitoring Excel database

Emmons & Olivier Resources, Inc. 7030 6th Street North Oakdale, MN 55128 water | ecology | community					Project:	South Moody Wetland (SMW)
					Location:	
					Date:	11/2/2020
					Boring Number:	16
(651) 770-8448					Personnel:	JM/BE
Soil Boring Log - Bucket Auger						
Depth [in]	Soil Type	Color	# Mottles/Color	Moisture Content	Notes	
0-10	loamy peat	10YR 2/2		saturated	4" surface water	
10-14	muck	10YR 2/1		not saturated		
14-35	sand	10YR 3/2		saturated	sloppy, unconsolidated sand - difficult to collect	
35-40	sandy clay	10YR 3/2		saturated		

Example of a Soil Boring Data Sheet from a wetland near Moody Lake, Chisago County.

Sample Collection Procedures and Notes

Sample Collection/ Safety

Access from the Stream Bank

Wherever practical, samples should be collected at mid-stream rather than near the shore. Samples collected from mid–stream reduce the possibilities of contamination from shore effects such as back eddies, seepage from near–shore soils, and atmospheric components such as pollen concentrated in slow moving water. Samples should not be taken in back eddies or brackish waters unless required by the monitoring program objectives. The most important issue to consider when deciding where the sample should be collected from is SAFETY. If the flow is sufficiently slow that the collector can wade into the stream without risk, then the sample may be collected at a depth that does not pose a safety threat to the sampler. Never wade into water that appears deep or is fast flowing. When conditions dictate that the sample be taken from the stream bank, deviations from the standard protocol should be accurately documented on the field data sheet or in a logbook and transferred to the database as soon as possible. Samplers must be wary of a non–visible bottom under turbid conditions.

Sampling While Wading Protocol

1. Obtain labeled bottles and wade into the river downstream from the point at which you will collect the samples, and then wade upstream to the sample site. This ensures that you will not disturb sediments upstream of the sample point. Attach safety line if conditions have any significant risk
2. Stand perpendicular to the flow and face upstream
3. Remove the lid and hold it aside without touching the inner surface. If rinsing is required for the type of bottle, fill and rinse three times (Note: No need to rinse lab bottles, they are clean and some bottles contain a preservative)
4. With your other hand, grasp the bottle well below the neck. Plunge it beneath the surface in front of you with the opening facing directly down, then immediately orient the bottle into the current. Avoid collecting surface scum and film
5. Once the bottle is full, remove it from the water by forcing it forward (into the current) and upwards
6. Replace the cap immediately
7. Note: If the lab bottle contains a preservative (TP or total iron bottles) do not invert the bottles or the preservative will be lost! Fill these bottles using another clean non-preservative bottle. One option is to fill the TSS/Ortho P bottle and transfer the contents into the preservative bottle so as to not spill the preservative. Once the preservative bottles are full, the TP/TSS bottle can be filled. Another option is to fill a clean bucket with sample water and transfer the contents to all the lab bottles.

Sampling from the Stream Bank Protocol

This method is to be used when the current is too strong, the water too deep, or the ice too thin.

1. Secure yourself to a solid object on shore (with a safety harness and line, if necessary). As a safety precaution, the second person must remain nearby while the first is collecting the samples
2. Remove the cap from a labeled bottle
3. Hold the bottle well below the neck or secure it to a pole sampler

4. Reach out (arm length only) and plunge the bottle beneath the water surface with the opening facing directly down, then immediately orient it upstream into the current
5. When the bottle is full, pull it up through the water while forcing it into the current
6. Immediately recap the bottle
7. See note above about filling preservative bottles

The TP bottle contains sulfuric acid (H2SO4) and the total iron bottle contains nitric acid (HNO3). The TSS/ Ortho P bottles are unpreserved. The lab usually pre-fills each bottle with the appropriate amount of preservative. Caution should be exercised with working with any acid preservation chemicals. Utilize all pertinent personal protection equipment and follow all chemical handling recommendations for each preservative or chemical.

Make sure to completely fill out each lab bottle label with the site name/number, date/time, and sampler initials.

All water quality samples should be immediately be cooled or refrigerated and then shipped or delivered to the lab in a cooler with enough ice to cover and sufficiently cool the sample bottles.

Field Notes

Always record the site name/number, date, and time in a field book or on the data sheet when each sample is collected, along with weather conditions and air temp. If no staff gage is present at the sampling location, use a ruler or wooden tape to measure the distance from the top of the monitoring fence post or culvert to the water surface. This measurement is used to calibrate the logger stage data. The monitoring fence posts are usually obvious and are typically located within the stream channel at the downstream ends of the culverts.

Holding Times:

Holding times for several common parameters are given below, the shortest being 48 hours for Ortho Phosphorus. As such, water samples should be submitted to the laboratory as soon as is possible, ideally the day of collection.

Ortho Phosphate is 48 hours

TSS is 7 days

TP is 28 days

Total Iron is 6 months