The Condition of Wisconsin's Wadeable Streams: Natural Community Stratified Random Monitoring Program 2010-2013

WISCONSIN
DEPT. OF NATURAL RESOURCES

August, 2015

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Acknowledgements:
The data collection effort for this study was contributed by dozens of dedicated Water Quality staff across Wisconsin and we thank them for their efforts.

Cover Photo:
Jim Klosiewski – McNaughton Creek, Oneida County, WI

Suggested Citation:
WDNR. 2015. The Condition of Wisconsin's Wadeable Streams: Natural Community Stratified Random Monitoring Program 2010-2013. Wisconsin Department of Natural Resources, Madison, WI. PUB-WY-076-2015.

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Introduction

Since the passage of the Clean Water Act (CWA) in 1972, the U.S. Congress, American public, and other interested parties have asked the U.S. Environmental Protection Agency (USEPA) to describe the water quality condition of U.S. waterbodies. These requests have included seemingly simple questions:

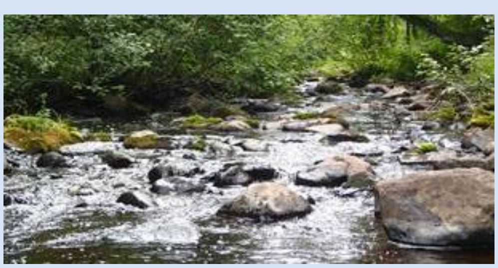
- *Is there a water quality problem?*
- *How widespread are environmental stressors?*
- *Which environmental stressors are most detrimental?*

To answer these questions, USEPA, other federal agencies, states, and tribes have independently or collaboratively used probabilistic surveys as the primary tool in a project to answer these questions. (see http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm).

Designing a State-wide Assessment

In 2003, 2008 and 2013 the Wisconsin Department of Natural Resources (WDNR) took part in three statistically valid surveys of the Nation's rivers and streams led by the USEPA: the 2003 Wadeable Stream Assessment (USEPA 2006) and the 2008 and 2013 National Rivers and Streams Assessments (USEPA 2013). The sampling designs for the National surveys were a probability based network that provided statistically valid estimates of conditions for the population of rivers and streams across the United States with a known confidence.

In 2010-2013 the WDNR began a similar monitoring program to conduct a detailed assessment of the condition of wadeable streams across the State using a probabilistic design called the Natural Community Stratified Random (NCSR) monitoring program. The Wisconsin project design included monitoring at 548 sites over four years that was spatially stratified to cover the entire stream, geographic and land use types found throughout the State (Fig. 1). By using a probabilistic design the WDNR was able to use the results to determine the condition of Wisconsin's wadeable streams in a statistically valid manor. The results of this analysis provide a clear assessment of the physical, chemical and biological quality of wadeable, perennial streams across the State.



Did you know?

Approximately 90% of stream and river miles in the United States are small, wadeable streams. Wisconsin alone has ~45,000 miles of perennial wadeable streams.

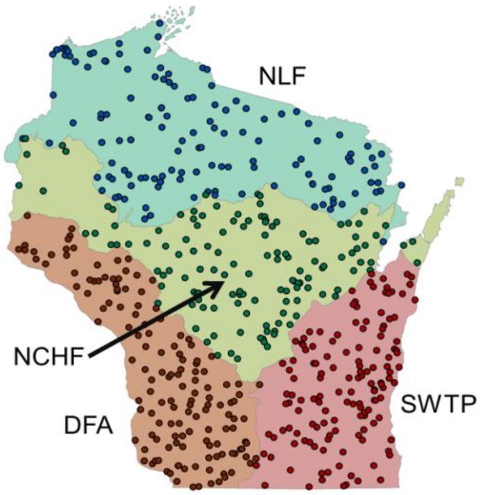


Figure 1. Locations of 548 monitoring sites for the NCSR monitoring program from 2010-2013. Colors represent Modified Omernik Level III Ecoregions including Northern Lakes and Forests (NLF), North Central Hardwood Forests (NCHF), Driftless Area (DFA), Southeastern Wisconsin Till Plains (SWTP).

Why Wadeable Streams

Wadeable streams provide valuable benefits to Wisconsin residents including fishing, swimming and aesthetics; as well as vital habitat to aquatic and semi-aquatic wildlife (such as amphibians and waterfowl). In Wisconsin there are nearly 45,000 miles of perennial wadeable streams, a number that could potentially double if including intermittent and ephemeral streams. Most of the State's (and Nation's) waterways are smaller wadeable stream and river systems that form an intimate linkage between the land and water. Thus, activities performed on land are reflected as local water quality of wadeable streams. That water is carried to all parts of the State through the dense networks of streams to rivers, lakes and other downstream waterbodies.

How Were Sampling Sites Chosen

NCSR sampling locations were selected using a probabilistic survey design. Probabilistic survey designs are used in a number of disciplines (e.g. election polls) when a population of interest is too large or too cost expensive to sample all components (such as Wisconsin's 45,000 stream miles). To select sites for the survey, all of Wisconsin's wadeable streams were included in a sample population and stratified based on geographic location and stream type. Geographic location was defined as modified Level III Omernik Ecoregions that generally divide the State into four equal areas (Fig. 1). Stream types were defined as Wisconsin's Natural Community classification system which classifies streams based on size (flow) and temperature (dnr.wi.gov/topic/rivers/naturalcommunities.html). Sites were selected using a spatially balanced stratified random sampling technique where each site was assigned a probability of being selected based on the population size of the respective strata (Stevens and Olsen 2004). This ensures that the full range of stream attributes have a chance of being selected. For example, sites were not biased towards one region of the State or towards really small streams which are more numerous than bigger rivers. This unbiased site selection with known probabilities allows for extrapolation of results to the entire population by using the known sample size and the inverse of the probabilities as a weighting factor in subsequent analyses. This ensures that assessment results represent the unbiased condition of streams throughout the State.

Field Sampling

Selected sites were sampled for water chemistry, physical habitat, macroinvertebrate and fish assemblages by field crews from 2010 to 2013 using WDNR standard operating procedures (http://dnr.wi.gov/topic/surfacewater/WaterResearch.html). Water quality samples were taken once per year during summer at or near baseflow conditions. Specific conductivity, dissolved oxygen and pH were sampled instantaneously using a water quality sonde. Total suspended solids, nitrogen-series and total phosphorus grab samples were collected and analyzed at the Wisconsin State Laboratory of Hygiene. Qualitative physical habitat and fish assemblage surveys were conducted once during the summer index period over an area of stream equal to 35 times the mean stream width (minimum 100 meters to maximum 400 meters). Fish assemblages were collected by electroshocking, targeting all species while enumerating and identifying individuals to species in the field. Macroinvertebrate assemblage samples were collected once during the fall index period using a 600 micron D-frame kick net targeting riffles or other coarse habitats. Macroinvertebrate samples were subsampled and sorted to reach target of 125 individuals per sample. All individuals were identified to species when possible at the UW Stevens Point Aquatic Biomonitoring Laboratory.

Waterbody Condition vs Water Quality Assessments

This report focuses on waterbody condition, which is different than water quality assessments as defined by Wisconsin's water quality standards (WQS). For the NCSR analysis classification of waterbody condition was determined specifically for this report using categorical rating system. Thresholds to determine if a stressor or biologic assemblage was in "Good" or "Poor" condition was assessed by one of three methods in descending order of priority 1) applying the numeric criteria found in Wisconsin's WQS 2) applying the categorical rating developed as guidelines for biologic and habitat indices as found in WisCALM (WDNR 2013), or 3) applying the 90^{th} percentile of reference site conditions (see Table 1).

Water quality assessments determine if a water body is impaired according to Wisconsin's WQS. An impaired water quality assessment identifies that a specific stressor is exceeding acceptable levels that are set to be protective of stream uses (http://dnr.wi.gov/topic/SurfaceWater/assessments.html). WDNR applies stressor-specific data requirements and assessment methods to determine if a water quality stressor is exceeding acceptable levels. For most constituents this requires more than one summer sample as was collected for the NCSR monitoring program. While this method results in fewer statewide water quality assessments due to the rigorous data requirements, it ensures that water quality assessments are made with a high degree of certainty. Therefore, results presented in the NCSR analysis as in "Poor" condition does not specifically equate to an impaired water because minimum data requirements necessary for water quality assessments were not met. Any site with a water quality sample indicating a possible impairment is prioritized by the WDNR for follow up monitoring in subsequent years in order to meet minimum data requirements for water quality assessment decisions. Those analyses were not part of the NCSR program and are not reflected in this report.

Is There a Water Quality Problem?

Indicators of Biologic Stress

A seemingly simple question such as - is there a water quality problem? – can be difficult to answer. Stressors can be variable in space and time in stream ecosystems. Furthermore, the combined impact of multiple stressors at low levels can be difficult to unravel. In order to understand the health of a stream ecosystem water resource managers often evaluate the health of biologic assemblages that reside in the streams. Measuring biologic assemblages, such as macroinvertebrates and fish, has the advantage in that it integrates the cumulative effects of multiple stressors over long periods of time (weeks to years) on a waterbody. This allows a direct examination of how stressors are affecting the condition of a stream ecosystem by examining how the biologic communities are responding. The WDNR currently assesses biologic stream health using both macroinvertebrate and fish assemblages by using an Index of Biotic Integrity (IBI) that provides an overall score for stream health.

We used two measures of macroinvertebrate community health in this study to evaluate the biologic condition of wadeable streams. The macroinvertebrate IBI (mIBI) is comprised of multiple metrics of assemblage composition (taxonomic and functional) that are statistically related to environmental stress. Macroinvertebrate metrics in the mIBI include measures of pollution tolerance, sediment deposition tolerance, taxonomic composition, species richness and functional feeding groups. Each of the individual metrics are weighted and summed to create the mIBI (Weigel 2003). The mIBI is applied at wadeable streams across all geographic and physical (flow and temp) conditions (see WDNR 2013).

The macroinvertebrate Observed/Expected Taxa Loss model (O/E) is a measure of biologic health that quantifies taxa lost at a specific stream (WDNR 2016). The first part of the O/E model is the development of the Expected (E) taxa that occur at a site from a model derived from least disturbed sites. The Expected taxa are then compared to the number of Expected taxa that are actually Observed (O) in a sample to calculate an O/E score (Hawkins et al. 2000). Models of expected taxa richness are developed on the stream reach scale from natural landscape level variables so that all taxonomic expectation are on a site-specific scale. An O/E score of 1.0 is considered representative of a least disturbed condition while a score <<1.0 imply the site has had localized taxa extirpation due to environmental stress. Macroinvertebrate O/E ratios are not currently used by WDNR for biologic assessment decisions but are presented here as information only.

Why sample bugs and fish?

As aquatic macroinvertebrates and fish spend the majority of their life in aquatic environments, they are capable of integrating the combined effects of multiple stressors over time, providing a measure of the past and present conditions (Karr and Dudley, 1981).

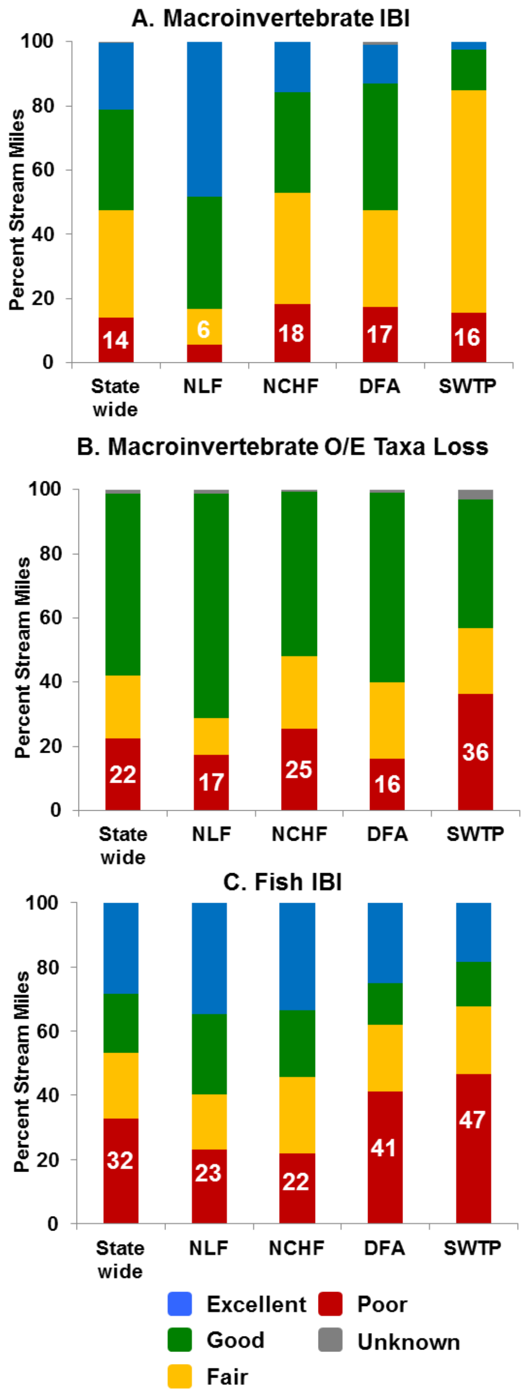


Figure 2. Stacked bar charts showing percent of stream miles in each condition class for A) macroinvertebrate IBI, B) macroinvertebrate O/E taxa loss and C) fish IBI. Numbers in white indicate the percent of stream miles in "Poor" condition. Statewide and Ecoregion specific estimates are shown, see Figure 1 for explanation and location of Ecoregion codes.

The fish IBI is comprised of multiple metrics of fish assemblage composition in a similar fashion to the macroinvertebrate IBI. Fish assemblage metrics that are used in the fish IBI include: thermal preferences, taxonomic composition, pollution tolerance, functional feeding groups, spawning traits, number of native species and deformities. Unlike the mIBI, there are multiple versions of the fish IBI that are applied depending on geographic location and stream type using all or a subset of the above metrics for the calculation of the IBI (Lyons, 1992, Lyons et al. 2006 and Lyons 2006). Stream types are determined by flow and temperature estimates, and there are generally five individual fish IBIs with some additional corrections for geographic locations (north vs south or distance from lake corrections).

Condition of Biologic Assemblages

Biologic assemblages (macroinvertebrates and fish) were assessed comparing the percentage of stream miles that were in "Poor" overall condition. Although different IBIs may be applied based on the stream type the numeric score is always translated into a categorical rating that can be compared among all IBIs. Categorical ratings for macroinvertebrate and fish IBIs were applied following WisCALM guidance. O/E numeric scores were translated into categorical ratings where Poor condition was set at the lower 95% confidence interval (CI) of least disturbed site scores. Fair condition was applied to scores that were between the 68% and 95% CI of reference site scores. An Excellent rating was not applied to the O/E scores as they are in the macroinvertebrate and fish IBIs. By using a probabilistic survey approach we are able to use the percentage of sampled sites that are in Poor condition plus the site specific weighting factor to estimate condition across the State as total stream length.

For the macroinvertebrate IBI we found that 14% of streams, by length, are in Poor condition State wide. Comparing the spatial distribution we found that percent Poor was lowest in the NLF Ecoregion (6%) and was higher in the other Ecoregions. The NLF is the northern most Ecoregion in Wisconsin and is generally the least populated and most "pristine" so the spatial differences agree with expectations (Figure 2A). All other Ecoregions were fairly similar with a percentage of Poor sites between 16%-18%. The macroinvertebrate O/E model generally agreed with the mIBI but estimated more Poor sites as 22% of streams were in Poor condition (Fig. 2B). The NLF and DFA Ecoregions had the lowest percentage of impaired sites (17% and 16%, respectively) while the NCHF and SWTP where the highest (25% and 36%, respectively).

Fish assemblage condition is estimated to be in Poor condition at 32% of streams Statewide (Fig. 2C). Again, there is a spatial difference where the northern most Ecoregions, NLF and NCHF have a lower percentage of Poor streams (22-23%) than the southern DFA and SWTP Ecoregions (41-47%). In general, the estimate for %Poor condition was much higher for fish than macroinvertebrates. In most cases, the Statewide and Ecoregion level extent estimates for %Poor were two-fold higher for fish IBI than mIBI.

How Widespread Are Environmental Stressors?

Chemical and Physical Stressors

Environmental stressors are chemical or physical conditions in the ecosystem that are detrimental to biota. Stressors are either introduced to an ecosystem or are naturally occurring but increased in frequency and/or intensity by human activities. The NCSR monitoring program selected a set of chemical and physical stressors that are commonly found to be important in stream ecosystems.

Table 1. Sources for thresholds to determine "Poor" condition for each of the stressors and biologic indices analyzed in this study. WQS = Wisconsin's Water Quality Standards and WisCALM =Wisconsin's Consolidated Listing Methodology.

Parameter	Condition Threshold Source
Total Phosphorus	Wisconsin WQS
pH	
Conductivity	Reference Site 90th Percentile
Dissolved oxygen	
Nitrogen	
TSS	
Qualitative Habitat	WisCALM Categorical Rating
Macroinvertebrate IBI	
Fish IBI	
O/E Taxa Loss	Reference Site 95% Confidence Interval

A) Phosphorus and Nitrogen

Phosphorus and nitrogen, commonly referred to as "nutrients", are naturally occurring elements that are necessary for all life. The concentrations of nutrients in aquatic ecosystems have been increased over time by a variety of human land uses and sources that lead to a condition called "eutrophication". This is a state where excess nutrients lead to increased productivity that is often reflected by increased algal blooms and low dissolved oxygen concentrations that are harmful to sensitive aquatic life and impair recreational opportunities. Wisconsin has a WQS for total phosphorus in wadeable streams with a numeric threshold at 0.075 mg/L. There is currently no numeric WQS for nitrogen.

B) Total Suspended Solids

Total Suspended Solids (TSS) is a measure of the weight of solids that are suspended in water. High concentrations of TSS can lead to high rates of sedimentation in streams and alter benthic habitat, as well as indicate general pollution. Sources of TSS pollution usually come from erosive forces on the landscape, such as rain events on bare agricultural soil or storm water discharges. Native geology, soils, and stream geomorphology can all contribute to natural ranges of background TSS concentrations in streams.

C) Conductivity

Conductivity is the ability of water to pass an electrical current and is used as a surrogate for the concentration of inorganic dissolved ions in the water, such as chloride, sulfate, and sodium, among others. Natural background conductivity in streams ranges geographically based on the geology, soils and weathering rates of the bedrock in the surrounding watershed. Conductivity can be increased through urban and agricultural land use practices, especially from road salt runoff in the winter. High concentrations of dissolved ions, measured as conductivity, can impair the osmoregulation of organisms with gills and other semipermeable membranes.

D) Dissolved Oxygen

Dissolved oxygen (DO) is the amount of gaseous oxygen that is dissolved in water and available to aquatic organisms. DO varies within streams based on time of day (production and respiration cycles), water temperature and physical gas exchange with the atmosphere. Eutrophication can cause DO to have larger diurnal swings with low nighttime DO which can be detrimental, or even lethal to aquatic organisms. WDNR has a DO WQS for minimum concentrations. However, daytime grab sampling is not a collection procedure adequate to assess against this WQS.

E) pH

pH is the measure of hydrogen ions present in stream water. pH can control the biologic availability, solubility and speciation of chemicals in water. Even moderately acidic water may irritate the gills of aquatic fish and insects or reduce the hatching success of fish eggs. pH can be affected in streams by direct discharges, algal productivity (increased through eutrophication) or naturally from wetland drainage.

F) Qualitative Habitat

Qualitative habitat is an index that aggregates several factors of stream physical characteristics and developed as a numeric and categorical rating (Simonson et al. 1994). In general, the habitat rating indicates the amount of good habitat, such as hiding, resting and foraging areas for stream fishes, as well as the general condition of the riparian corridor.

Ranking Stressors – Extent

One way to compare stressors is to rank them based on how prevalent they are in the environment. Stressors that are widespread in the environment, meaning they commonly exceed the Poor threshold, have a greater extent. Among all streams in Wisconsin total phosphorus (TP) is the most prevalent stressor of those considered in this study (Fig 3). 56% percent of all streams in the State, by length, are in Poor condition for TP concentration ("Poor" threshold sources are defined Table 1). Total nitrogen (TN), dissolved inorganic nitrogen (DIN) and total suspended solids (TSS) are the next most prevalent stressors ranking at 38%, 33% and 29% of streams in Poor condition, respectively. In order of decreasing extent, dissolved oxygen (DO), conductivity, physical habitat and pH are the least prevalent stressors in Wisconsin's streams.

The spatial distribution of stressors was compared by making individual extent estimates for each Ecoregion for the most prevalent chemical stressor, TP, and physical habitat (Fig. 4). TP %Poor was greatest in the Driftless Area (DFA) and Southeastern Wisconsin Till Plains (SWTP) Ecoregions and lowest in the Northern Lakes and Forests (NLF) and North Central Hardwood Forests (NCHF) Ecoregions. TP %Poor extent generally followed population and land use trends throughout the State increasing generally along a north to south gradient. Physical habitat showed a similar gradient, however they were very few Poor scores except for in the southern most Ecoregions, the DFA and SWTP (see Fig. 1 for geographic locations of Ecoregions).

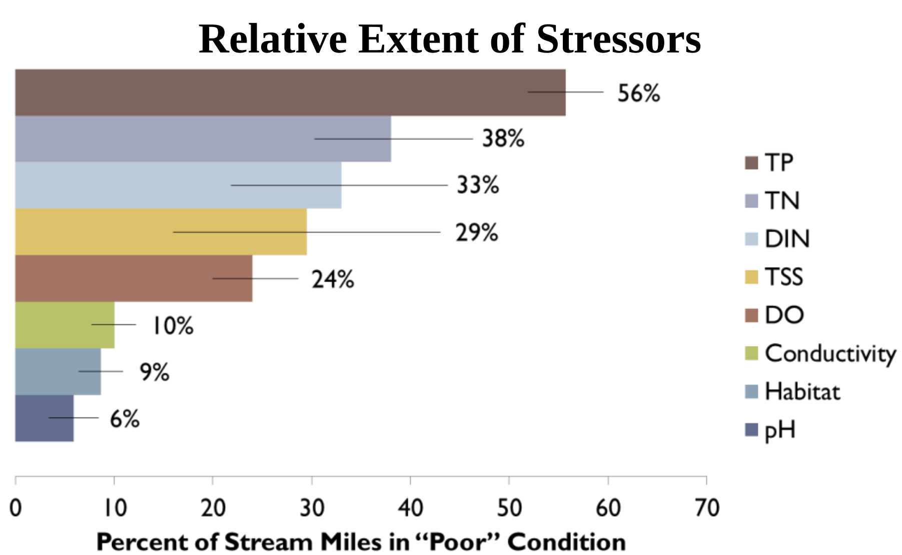


Figure 3. Relative extent (prevalence) of stressors analyzed in this study. Error bars indicate 95% confidence intervals and numeric values represent the percent of stream miles Statewide that are in "Poor" condition.

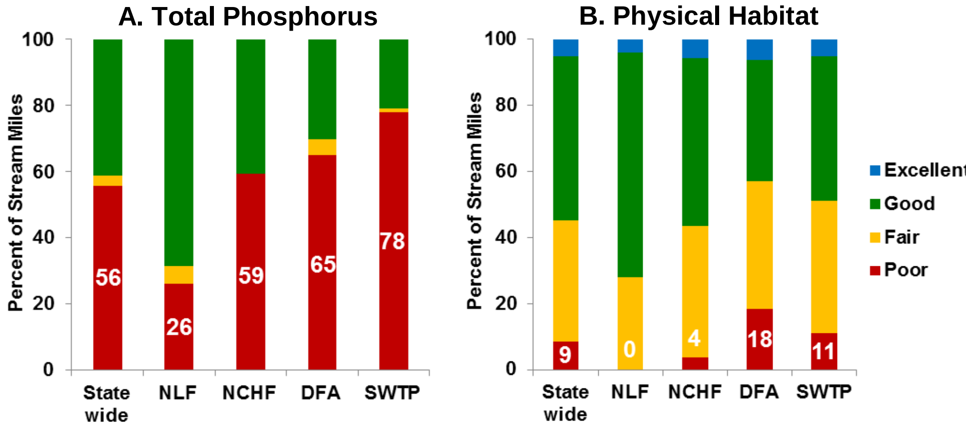


Figure 4. Stacked bar charts showing selected stressors and percent of stream miles in each condition class for A) total phosphorus and B) physical habitat. Numbers in white indicate the percent of stream miles in "Poor" condition. Statewide and Ecoregion specific estimates are shown, see Figure 2 for explanation and location of Ecoregion codes.

Extent of Stressors and Biologic Condition by Stream Type

Biologic condition and stressor extent by stream type was also compared. Stream type was determined by Natural Community type, which classifies streams by inherent flow and thermal regimes. For the NCSR analysis streams were combined into four categories based on flow and temperature combinations in order to achieve adequate sample sizes for analysis within each temperature-size class combination. Cold headwaters and cold-cool transitional headwaters (hereafter referred to as CCH), cold mainstems and cold-cool transitional mainstems (CCM), warm and warm-cool transitional headwaters (WCH) and warm mainstems and warm-cool transitional mainstems (WCM) were combined into the four groups for the NCSR analysis. Headwater streams are defined as those streams where modeled streamflow is <3.0 cfs during baseflow while cold and cool-cold transitional streams have a modeled maximum daily mean water temperature of 72.5 ^{o}F or less.

Two clear patterns emerged when comparing biologic condition and stressor extent among stream types. Biologic condition among all three indices was much better for mainstem stream types, regardless of temperature class (Figs. 5A, B & C). As for stressors, we examined TP and physical habitat and found very little variation in %Poor scores among stream types (Figs. 5D & E). It does appear that mainstems have slightly fewer estimated stream miles in Poor condition than mainstems, but the difference is much less pronounced than for biologic condition.

From our analyses mainstem streams are in better biologic condition than headwaters even though the extent stressors to those streams are relatively similar. This may indicate that larger wadeable streams have a greater ability to buffer biota from environmental stress than smaller headwater streams. If this is the case, biota in headwaters streams require further protection from environmental stressors to preserve a healthy biologic community. The Statewide estimates for Poor condition closely track that of headwater systems as headwater streams compromise the majority of Wisconsin's wadeable streams, as measured by length (~78%).

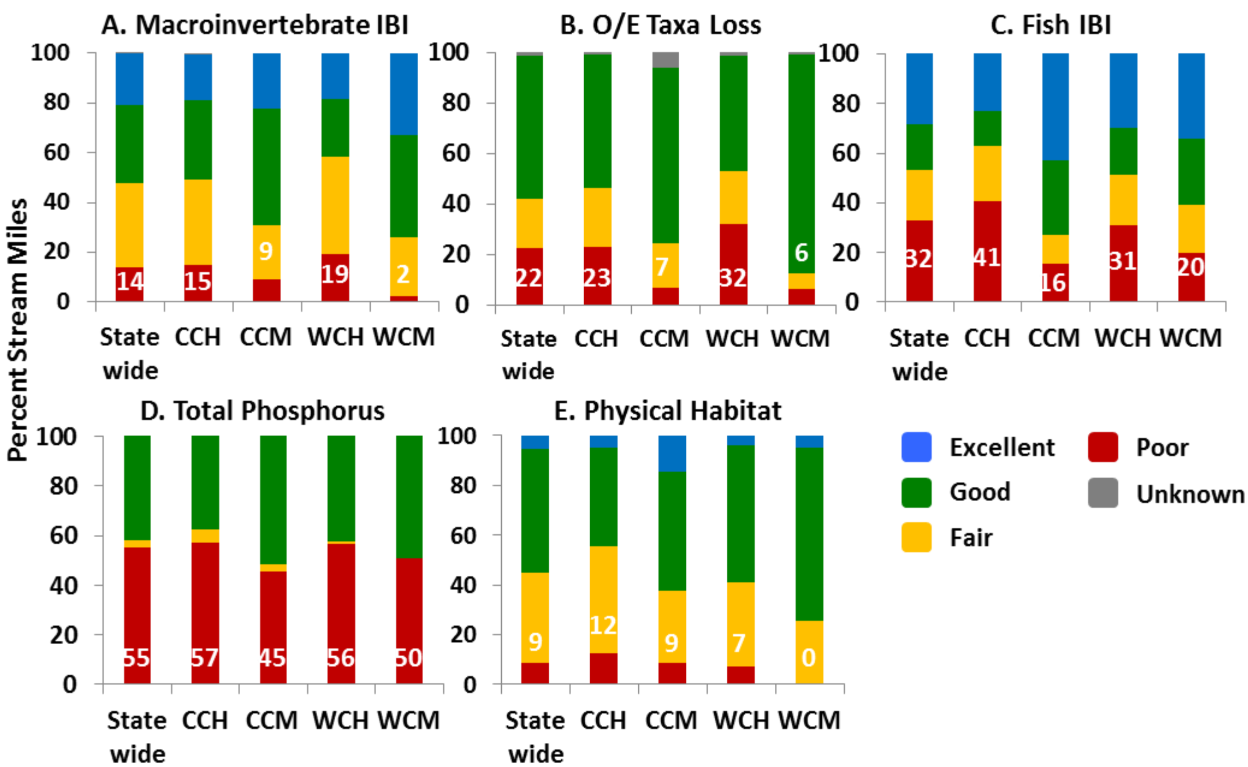


Figure 5. Stacked bar charts showing percent of stream miles in each condition class for A) macroinvertebrate IBI, B) macroinvertebrate O/E taxa loss and C) Fish IBI D) total phosphorus and E) physical habitat. CCH – cold and cool-cold transitional headwaters, CCM = cold and cool-cold transitional mainstems, CWH = warm and cool-warm transition headwaters, WCM = warm and cool-warm transitional mainstems. Numbers in white indicate the percent of stream miles in "Poor" condition.

Which Environmental Stressors Are Most Detrimental?

Ranking Stressors - Severity

Stressors can be ranked on their prevalence, or how widespread they are but that doesn't capture the severity of a stressor. In other words, a stressor may not be very common but where it is found it may be very detrimental to biologic communities. In this report stressor severity is assessed using a measure called Relative Risk (RR, Van Sickle and Paulsen 2008). RR measures the increased probability that a biologic assemblage will be in Poor condition if the stressor is also in Poor condition (see Table 1 for definitions of Poor stressor condition). This risk assessment method is commonly used in the medical community and produces and easy to interpret result. A RR of three (3) to the fish IBI condition would be interpreted as: if stressor A is in Poor condition at a particular stream than the fish assemblage would have a 3x greater probability of also being in Poor condition.

The most severe stressor to macroinvertebrate IBI is total phosphorus (TP) with a 9.4x greater chance of macroinvertebrates being in Poor condition when TP exceeds the Poor threshold (Fig. 6A). The next most severe stressors were total suspended solids (TSS), dissolved oxygen (DO) dissolved inorganic nitrogen (DIN), physical habitat and conductivity (Cond) with a RR of 3.6, 3.6, 2.5, 2.5 and 2.1, respectively. Although TSS and DIN had large RR scores it was not considered statistically significant in this study. TSS and nitrogen samples were only taken at a subset of sites and the low sample sizes likely led to higher error estimates and a lower confidence interval that overlapped with 1.0, indicating the estimate was not statistically significant. Macroinvertebrate O/E condition revealed similar stressors as the mIBI with TP (6.1), conductivity (2.8), DO (2.6) and physical habitat (2.5) having the highest RR scores (Fig. 6B). The RR estimate for each of these four stressors to macroinvertebrate O/E condition was considered significant.

The most severe stressors to fish IBI condition was found to be dissolved inorganic nitrogen (DIN) and total nitrogen (TN) with a 2.8 and 2.2 greater chance of fish assemblages being in Poor condition, respectively. From this analysis, relative to the current threshold for Poor stressors, nitrogen appeared to be more detrimental to fish assemblages than macroinvertebrate assemblages. The next most severe stressors were physical habitat, TSS and DO with a RR of 2.1, 1.9 and 1.7, respectively. Again, although TSS and nitrogen had higher RR scores it was not considered statistically significant in this study likely because of low sample size (Fig. 6C).

Relative Risk estimates of environmental stressors revealed interesting results among the three measures of biologic condition. Patterns of RR were similar among the mIBI and macroinvertebrate O/E model. While the mIBI and O/E model scores are only moderately correlated (Spearman r=0.43) the RR estimates both responded significantly to the same four stressors (TP, DO, habitat and conductivity). However, the mIBI appears to be slightly more sensitive with higher RR values for TP and DO, identical value for habitat and a lower value for conductivity. Although the mIBI and O/E model measure responses for the same biologic assemblage, they estimate different responses to stress – trait based assemblage shifts versus taxa loss. Therefore, we would expect differences in condition results on a site specific basis. The correspondence of these two condition estimates strongly relating to environmental stress indicates they both have use as an indicator of ecosystem health.

The RR estimates for fish IBI, in general, were much weaker than those for the macroinvertebrate indices. Most notably, fish IBI condition showed no response to TP condition (RR=0.9). There could be two possibly explanations for this result. First, the fish IBI may respond to TP values that are higher or lower than the threshold identified for this analysis (0.075 mg/L). As RR is a statistical measure using a binary stressor and response categorical variable, the location of the threshold delineating a Poor response has large effects on the results. It is possible that fish assemblages do respond predictably to TP, but at a concentration that is higher or lower than the current WQS. Secondly, the fish IBI may not respond strongly to TP concentrations at all. As TP impacts start at lower trophic levels and cascade up the food chain it is reasonable to expect fish to be less sensitive to TP than macroinvertebrates.

RR estimates for nitrogen (DIN and TN), another nutrient, and DO, a common eutrophication response, were significant risks for fish IBI condition. From these results it appears there may be some fish response to eutrophication. Examining the correlation among macroinvertebrate IBI, macroinvertebrate O/E, fish IBI versus TN reveal similar strength of association (Spearman r=0.33-0.38). This indicates it may be the stressor threshold location that is driving the major difference in RR estimates among macroinvertebrate IBI, O/E and fish IBI and TN. Nitrogen thresholds were determined by a reference site analysis and it appears it may have been set at a more appropriate level to capture major changes in fish IBI condition than they were for macroinvertebrate condition. Physical habitat and dissolved oxygen concentrations had significant RR estimates, similar to both macroinvertebrate indices.

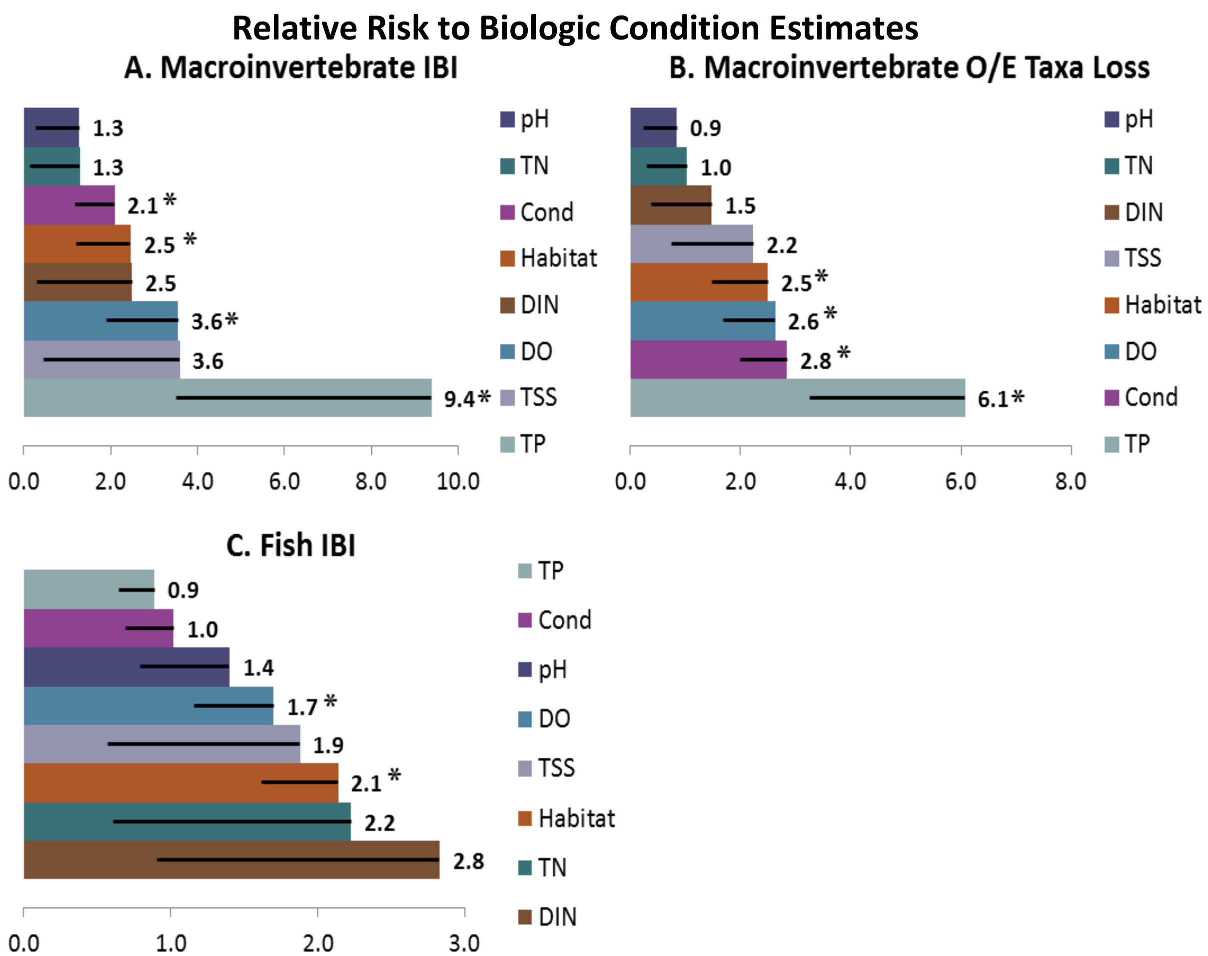


Figure 6. Bar charts indicating relative risk (RR) of stressors on A) macroinvertebrate IBI, B) macroinvertebrate OE taxa loss and C) fish IBI. Numeric values indicate RR score and an asterisk indicate a significant result. Lower 95% confidence intervals are shown as black lines. Results are not considered significant if the lower confidence interval overlaps with 1.0.

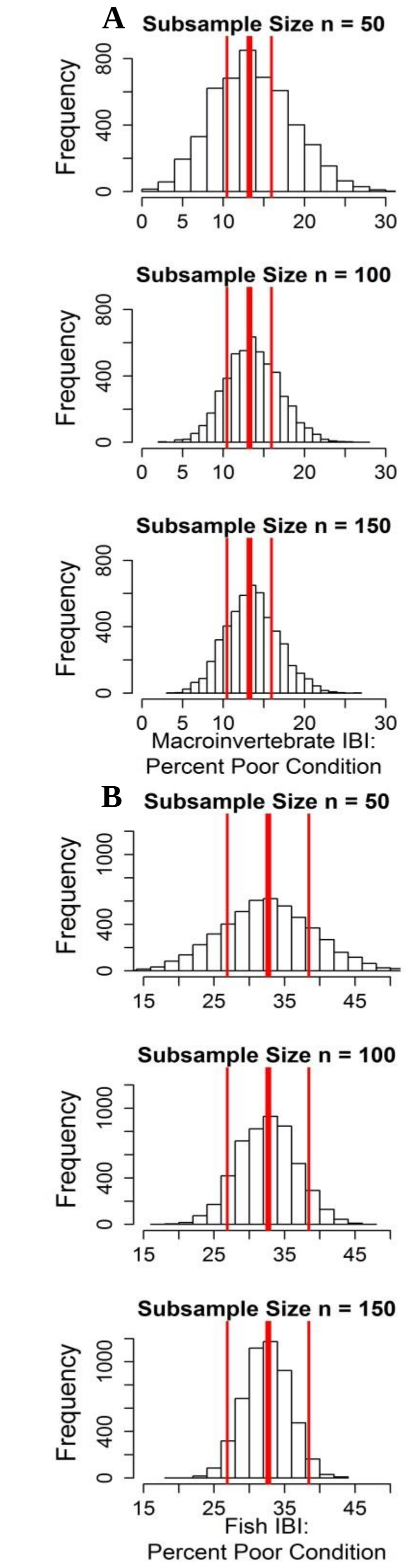


Figure 7. Histogram of a 5000 sample random subsetting of mIBI (A) and fIBI (B) percent Poor scores for different sample sizes. Red vertical lines indicate %Poor estimates (± 95% CI) from original 548 site dataset.

Analysis of Future Sample Sizes

WDNR targeted 548 sites to be sampled over a four year period for the first iteration of the NCSR monitoring program. The large datset has the advantage of assessing stressors and condition by Ecoregion and stream type. However, the study design was developed knowing that this was likely more sites than were needed to assess Statewide conditions, and likely too intense a data collection effort to continue monitoring indefinately. As the purpose of probabilistic monitoring is to estimate the condition of a large resource with as few samples we needed to evaluate the minimum number of sites neccessary for future monitoring.

We attempted to determine the necessary sample size by replicating the original extent estimates with a random subset of the original dataset. The objective was to quntify the increase in uncertaintly in our estimates if we had the same data but fewer sites for analyses. We randomly selected a subset of the original data and estimated %Poor condition for 50, 100 and 150 count sample sizes. Random subsetting was done 5000 times for each of the four major variables; mIBI (Fig. 7A), fish IBI (Figs 7B), macroinverebrate O/E and total phosphorus (data not shown). Spatial and waterbody type balance was maintained by selecting sites from each of the four Ecoregions and headwater versus mainstem streams according to the relative abundance of streams in each Ecoregion-stream size combination. Weights were adjusted based on the probablility of selection for each of the subsetted sample sizes. Basically, the fewer sites we have in the datset the larger the weight each site has in the analysis.

We visually examined the central tendancy and spred of histogram from the 5000 randomly selected subset sample population %Poor extent analysis. We found that the central tendency of the subsetted dataset always aligned with the original %Poor erorr estimate (center red line Figs 7A & B) independent of the subsample size. However, looking at the spread of the histogram, we found that there were major differences in the number of subsetted samples that were outside of the 95% CI error estimate for the original analysis (thinner outside red lines, Figs 7A & B).

We found that with 100 samples we could be relatively confident that our % Poor condition estimates would be near the original estimate and within the error estimates for the original analysis. Among all four parameters analyzed, ~75-85% of the %Poor condition estimates for 100 site subset were within the 95% CI of the original %Poor condition estimates. We decided that 100 sites was a proper tradeoff among the highly variable, but easy data collection effort of 50 sites, and the slightly more precise, but more difficult data collection effort of 150 sites.

Summary

Overall we found that in the majority of Wisconsin's wadeable streams there was not a water quality problem as assessed by biologic condition, although results varied regionally. These results indicate that the condition of fish assemblages in wadeable streams is slightly worse than the condition of macroinvertebrate assemblages - 32% compared to 14% to 22% in Poor condition. There were strong spatial differences where the northern most Ecoregion in the State, the NLF, consistently had fewer Poor biologic condition scores and environmental stressor scores than the rest of the State. The major difference in this part of the State can probably be attributed to land use intensity. The land use in the NLF is comprised of ~7% agriculture and ~4% urban while the rest of the State is ~48% agriculture and ~7% urban. The large north to south disparity in agricultural land use intensity is likely the driving force in regional patterns of stream quality across Wisconsin.

The pattern of water quality degradation in Ecoregions with high anthropogenic land use was also found in a probabilistic survey of Minnesota's wadeable streams (Lueck and Niemela 2014). Data from Minnesota should be comparable to Wisconsin as the two states share many geophysical and land use characteristics. In addition, three of Wisconsin's Omernik Level III Ecoregions are shared with Minnesota (http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm). There is also a strong north to south gradient in land use intensity, especially agriculture, in both States. Minnesota found that nearly twice as many stream miles were found in Poor biologic condition for macroinvertebrate and fish assemblages in the heavily agricultural southern Temperature Prairies Ecoregion than the northern, heavily forested, Mixed Wood Shield Ecoregion (30-52% and 37-66%, respectively). Minnesota attributed the reduced biologic condition to a combination of direct impacts such as drainage practices (i.e. channelization, modified habitat) and indirect processes, such as increased runoff leading to increased nutrient and sediment loading. Considering the high RR scores in our study for total phosphorus, nitrogen, TSS and physical habitat these are likely the prevailing mechanisms connecting land use practices to Poor environmental stressors and Poor biologic condition estimates in Wisconsin streams.

Results across States are not always comparable as States generally use different methods for data collection, analysis and interpretation. In order to get a Nationwide assessment the USEPA conducted the National Rivers and Streams Assessment (NRSA), a probabilistic survey using consistent methods across the contiguous United States. The data collection and analytical methods used in the NCSR study are different than those used in the USEPA's NRSA. However, interpretation of the data was similar so we can make generalizations about the condition of Wisconsin's streams from this study to the Nationwide estimates in the USEPA's NRSA.

Compared to the Nationwide estimates for stream condition from the USEPA's NRSA Wisconsin's stream condition is similar or slightly better condition to the rest of the Nation. Macroinvertebrates were found in Poor condition for 55% (IBI) and 17% (O/E) for the Nationwide estimate (USEPA 2013). Wisconsin's estimates were better with 14% (mIBI) and 22% (O/E) in Poor condition Statewide. Fish condition was also slightly better for the Wisconsin estimate than the Nationwide estimate at 32% to 36%, respectively. Examining environmental stressors we found those that impact Wisconsin are also some of the most prevalent across the nation. Total phosphorus and total nitrogen were two most prevalent stressors in the Nationwide estimates followed by several measures of physical habitat. The EPA's NRSA further divided the nation into three climatic regions generally based on Ecoregions. In terms of biologic condition the eastern and midwestern U.S. generally scored in worse condition than the western U.S. These results likely follow broad nationwide patterns of population and land use that were observed at a smaller scale within Wisconsin.

What is Wisconsin Doing to Protect Water Quality?

The State of Wisconsin has a long history in conservation and remediation from environmental stressors, both aquatic and terrestrial. In fact, in the 1930's the Coon Creek Watershed in southwestern Wisconsin was the nation's first watershed erosion control project to protect land and water using better land management practices (Anderson 2002). With this history of environmental protection, it has long been understood that total phosphorus is a cause of eutrophication and a major stressor of aquatic ecosystems in Wisconsin. The NCSR study further confirms this showing that it continues to be the most prevalent and most severe stressor to biologic condition. In order to combat phosphorus pollution, in 2010 the WDNR adopted numeric total phosphorus criteria for wadeable streams to be protective of aquatic life (see s. NR 102.06 Wis. Adm. Code, Robertson et al. 2006). To meet WQS for phosphorus Wisconsin is taking steps to curb pollution from point and nonpoint sources alike.

In 2002 Wisconsin adopted Chapter NR 151, Wis. Adm. Code, which set statewide agricultural and non-agricultural performance standards to address nutrient, sediment, and bacteria loading to streams and lakes from nonpoint source (NPS) pollution. These performance standards are minimum expectations that apply to phosphorus delivery, cropland erosion, livestock and manure storage management, nutrient management, livestock process wastewater, construction erosion, post-construction storm water management, developed urban areas and transportation facilities. The performance standards can be met through the implementation of best management practices (BMP) applied to the landscape. Cost-sharing funds are available from state and federal grant programs to implement BMPs to meet the performance standards. WDNR and the Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) provide ~$20 million per year to rural and urban communities for BMPs and local staff to reduce NPS pollution to aquatic ecosystems (e.g. phosphorus, nitrogen and TSS, among others). WDNR, along with local, state and federal partners, have made many improvements in controlling NPS pollution to aquatic ecosystems with such examples as the West Branch of the Sugar River, German Valley Branch, Joos Valley Creek and Pleasant Valley Branch. More information on these projects can be found at the USEPA's NPS success stories website (http://water.epa.gov/polwaste/nps/success319/) and from the Wisconsin Buffer Initiative Project (https://www.aae.wisc.edu/news/PDF/Pecatonica_project.pdf).

In order to reduce phosphorus entering streams and lakes from point sources (PS), such as municipal and industrial wastewater, Wisconsin set procedures to implement the phosphorus WQS in Chapter NR 217 Subchapter III, Wis. Adm. Code. These requirements are in addition to technology-based phosphorus limitations that have been in place since the early 1990's (see NR 217 Subchapter II, Wis. Adm. Code). More restrictive phosphorus water quality-based effluent limitations may be included in Wisconsin's Pollutant Discharge Elimination System (WPDES) permits upon permit reissuance. Guidance has been developed to help clarify when more restrictive limits may be needed, the timeline for complying with these limits, and provide explanation of innovative compliance options like water quality trading and adaptive management (see http://dnr.wi.gov/topic/surfacewater/phosphorus.html). The time for point sources to comply with more restrictive phosphorus limits can be given through a compliance schedule, which is as short as reasonably practicable, extending no more than 7-9 years. During this time it is the responsibility of the point source to evaluate their compliance options, select the most cost effective method to comply with the limits in question, and implement their preferred compliance strategy.

In some cases, the most cost effective way to remove phosphorus from an aquatic system is to control pollution from NPS in the same watershed. Wisconsin has two innovative phosphorus compliance options, referred to as adaptive management and water quality trading, which allows PS to work with NPS in the watershed to reduce the amount of phosphorus or TSS loading to a waterbody. The PS work with landowners in the watersheds to install NPS BMPs that may be a more cost effective measure for reducing phosphorus pollution. This effort brings the knowledge watershed level management, which was so successful in the Coon Creek Watershed project nearly 100 years ago, into regulatory PS compliance through working with partners in the watershed.

Next Steps

- The NCSR monitoring program will continue with monitoring 50 sites per year stratified by Level III Ecoregion and Natural Community. The results will be analyzed and reported every two years (100 total sites).
- Total nitrogen, dissolved inorganic nitrogen and total suspended solids (TSS) will be collected at every NCSR monitoring location in order to increase sample size and confidence in analyses for future iterations.
- As the NCSR program continues increasing emphasis will be placed on water quality trends analysis as the dataset covers sufficient time period.
- Correlations among stressors will be examined to further refine severity to biologic assemblage analysis.

For more information of WDNR Water Quality monitoring program please visit our webpage at: http://dnr.wi.gov/topic/surfacewater/monitoring.html.

If you would like to get involved in citizen science and learn about and improve the quality of Wisconsin's streams and rivers please visit: http://watermonitoring.uwex.edu/wav/

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WDNR Water Quality monitoring webpage: http://dnr.wi.gov/topic/surfacewater/monitoring.html

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WDNR PUB-WY-076-2015
EGAD# 3200-2014-04