Optimizing a Monitoring Design in Targeted Watersheds:

The Targeted Watershed Site Selection Tool

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Optimizing a Monitoring Design in Targeted Watersheds: The Targeted Watershed Site Selection Tool

Project Report

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The TWSST tool can be accessed via the Water Condition Viewer with the following URL:

http://dnrmaps.wi.gov/sl/?Viewer=water condition viewer

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Section 1

Introduction

Wisconsin Department of Natural Resources (WDNR) staff collect field data for a number of physical, chemical, and biological parameters in wadeable streams across Wisconsin. These data are used to assess stream health, manage waters for a number of designated uses, and prioritize restoration or protection efforts. Strategies and methods are needed to optimize the use of time and resources for monitoring among the more than ~72,000 km of rivers and wadeable streams in Wisconsin.

Targeted Watershed Assessments (TWA) is a study design proposed for Wisconsin's cross-program water resources monitoring work. The TWA monitoring framework utilizes a flexible watershed selection process and site specific assessment and planning tools to target high priority resources for key implementation work. In targeted watersheds WDNR staff intensively monitor physical, chemical, and biological condition at multiple sites in small, high priority catchments (usually HUC 12s, average ~80 km^2). High priority catchments are identified by programmatic needs such as nutrient reduction strategies, best management practices (BMP) effectiveness monitoring and protection areas identified through the Healthy Watersheds Assessment. TWA monitoring in these catchments is designed to meet multiple programmatic needs, including Wisconsin Point Source Discharge Elimination System permits, Runoff Management, Nine Key Element plans, stream flow determination, among others.

Stream physical, chemical, and biological conditions are influenced by both natural and anthropogenic factors (see Allan and Castillo 2007, Wang et al. 2006). The locations and density of monitoring stations in TWAs should be able to effectively represent the relevant natural and anthropogenic factors influencing water quality throughout the catchment. This requires an understanding of the geographic distribution of these factors at the catchment scale. Some major landscape changes are relatively easy to detect, such as a longitudinal transition from agricultural to urban land use. Others are much more difficult to visualize or interpret, such as changes in soil structure, watershed slope or diffuse, cumulative changes in the watershed.

Visualizing and interpreting multiple spatial factors at once presents challenges in trying to differentiate or group similar stream systems. This has resulted in a variety of landscape and stream classification techniques designed to integrate and generalize multiple natural and/or anthropogenic variables into a simpler, categorical representation. Ecoregions (Omernik 1987) are a well-known landscape classification, developed at national (level III) and regional (level IV) scales. Assessment Units (AUs) are a classification system that groups stream reaches for impaired water assessments and regulatory reporting purposes. WDNR's Natural Community model is a stream classification used to group stream and river reaches by stream flow volume and water temperature in order to develop expectations for fish assemblages likely to occur (http://dnr.wi.gov/topic/rivers/naturalcommunities.html). However, these classification systems are usually not at the appropriate scale (Ecoregions) for a TWA monitoring plan, are often based on best professional judgment or political boundaries (AUs), or do not incorporate anthropogenic factors that influence water quality (Natural Communities).

A practical watershed scale stream classification system would increase the WDNR's capacity to develop an optimal monitoring design in TWAs by ensuring that monitoring station locations are representative of key natural and anthropogenic factors in the watershed. Furthermore, stream network heterogeneity can be estimated before field sampling and the appropriate density of sampling sites can be planned. This will help eliminate redundant sampling locations or sparse data collection of complex systems hindering assessment of environmental condition. The Targeted Watershed Site Selection Tool was developed for this purpose.

The Targeted Watershed Site Selection Tool

The Targeted Watershed Site Selection Tool (TWSST) is a watershed scale classification system that groups stream reaches according to a variety of stream channel and landscape-level physical characteristics. The TWSST model can be used *a priori* to set up an efficient monitoring design in a watershed where very little known information exists on waterbody condition. The model can also be used *a posteriori* on previously collected data to determine the spatial extent on a stream network that a particular monitoring location represents (e.g. refining AUs).

In order to be useful for a TWA monitoring design, the TWSST model was designed to classify streams at a relatively small scale such as a HUC 12 sized watershed. The physical characteristics in the classification system were selected to incorporate both natural and anthropogenic factors with demonstrated relationships to water quality and aquatic biota. Because these relationships may vary at different spatial scales (Allan 2004), we investigated physical characteristics measured at multiple spatial scales, from the stream channel to riparian zones to upstream drainage area. This is of particular importance in smaller scale watersheds where local watershed dynamics may outweigh broad, landscape level dynamics.

For ease of use and interpretation the TWSST model was built to be compatible with the Wisconsin Hydrography Dataset (WHD). WHD is the WDNR 1:24k hydrography layer that maps the geographic and network locations of all the stream reaches in the State. Stream reach features in WHD are spatially referenced and constitute the hydrography layers in WDNR desktop and web-based mapping applications. Consequently, we were able to integrate the TWSST model with WDNR's existing spatial data infrastructure. Specifically, TWSST output has been incorporated as map layers in WDNR's Water Condition Viewer, a web-based mapping application (http://dnr.wi.gov/topic/surfacewater/monitoring/twsst.html). This provides staff and biologists a readily accessible way to visualize landscape changes in targeted watersheds alongside a variety of other data layers relevant to the monitoring site selection process. Existing layers in the Viewer contain spatially referenced information on dams, surface water outfalls, grants, and many other features not explicitly incorporated in the TWSST model. By combining the TWWST tool, existing monitoring locations and other spatially referenced information in the Water Condition Viewer staff have the ability to integrate large amounts of information in order to develop a comprehensive monitoring plan.

The remaining sections in this document describe TWSST model development, interpretation, outputs, and a user guide. Section 2 describes the monitoring data used in this study and provides more detail on the stream channel and landscape-level physical characteristics in WHD. Section 3 presents the statistical analyses used to assess relationships between monitoring parameters and WHD physical characteristics at multiple spatial scales and to identify a parsimonious set of WHD variables to use in the stream classification. Section 4 discusses the development and validation of the stream classification in test watersheds of different sizes and in different geographic locations. The statewide implementation of the stream classification is described in Section 5.

Output from the Targeted Watershed Site Selection Tool includes maps of the stream groups, narrative interpretations of each stream group, and summary statistics of stream characteristics within groups. These results are available as summary reports for each watershed and as interactive map layers in the Water Condition Viewer. Section 6 describes this output and provides guidance on how to incorporate it into the monitoring site selection process.

Section 2

Data Sources

Water chemistry and biology data

All water chemistry and biology data were collected in previous studies by WDNR and are stored in publicly available databases. Water chemistry parameters and data from benthic macroinvertebrate surveys were obtained from WDNR's Surface Water Integrated Monitoring System (SWIMS) database. Fish survey data were obtained from WDNR's Fisheries Management database.

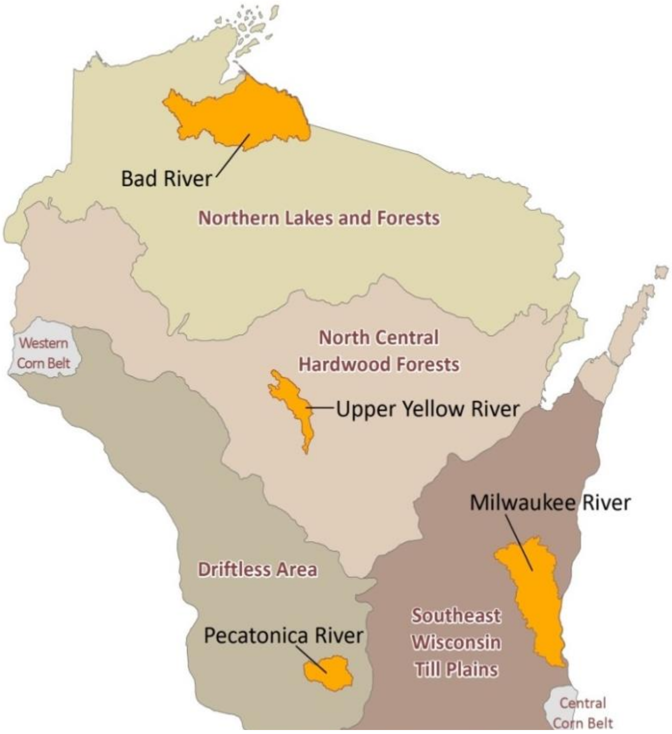


Figure 1. Pilot watersheds (Pecatonica and Upper Yellow Rivers) used in the WHD variable selection process and testing of the classification system. HUC 8 watersheds (Bad and Milwaukee Rivers) used to validate the classification system in different regions and at different scales. Omernik level III ecoregions are shown and labeled.

The TWSST model was initially developed from two watershed monitoring pilot projects conducted in Wisconsin during 2010-2011 (WDNR 2012, WDNR 2013). These pilot projects collected data from a dense network of monitoring stations for multiple water quality constituents, each within a single field season. These watershed monitoring projects provided an ideal dataset to develop the TWSST model. A total of 68 sites in the Pecatonica River watershed (572 km^2) and 60 sites in the Upper Yellow River watershed (580 km^2) were sampled for habitat, macroinvertebrates, fish, water chemistry, and streambed sediment (Figure 1). This dense spatial sampling provided a robust dataset for examining catchment scale relationships between physical characteristics and monitoring parameters. Additionally, we used this dataset to validate the usefulness of the stream classification, again at a scale comparable to a Targeted Watershed.

In order to validate the model across the State a second dataset was compiled containing monitoring data from over 4,000 stations throughout Wisconsin sampled by WDNR between 2003 and 2013. This dataset provided the opportunity to examine relationships between stream channel or landscape physical characteristics and monitoring parameters at the statewide scale to ensure results from the pilot watersheds were transferable to other watersheds. From the statewide dataset, we used data from the Bad River and Milwaukee River watersheds (HUC 8 catchments; Figure 1) to test the efficacy of the classification system in different geographic regions containing different land use regimes, and at a larger spatial scale to determine if the final classification scheme would still be useful at the TWA monitoring scale (typically HUC 12). Additionally, we used the statewide dataset to summarize existing monitoring data for each group in the stream classification in order to provide context to the different stream groups. This information is provided in the TWSST output and discussed in greater detail in Section 6.

Table 1 provides summary statistics of the commonly collected water quality and biologic monitoring parameters included in the statewide dataset, as well as abbreviations used throughout this report. Monitoring parameters in the pilot study datasets include all those listed in Table 1 plus the following, less commonly collected parameters: chloride (Cl), sulfate (SO4), pH, Chlorophyll a (Chl a), biological oxygen demand (BOD), and E. Coli.

Table 1. Summary statistics for water quality and biology parameters included in the statewide dataset.

Monitoring parameter	Abbreviation	Units	n	Median	Mean	Std Dev
Total Phosphorus	TP	µg/L	2223	88	125	121
Total Nitrogen	TN	mg/L	1313	1530	2215	1924
Dissolved Inorganic Nitrogen	DIN	mg/L	1432	686	1467	1875
Transparency	Trans	cm	1802	101	88	35
Total Suspended Solids	TSS	mg/L	1098	7.0	13.9	19.5
Conductivity	Cond	µS/cm	1724	415	455	309
Hilsenhoff Biotic Index	HBI	--	3273	4.7	4.8	1.5
Macroinvertebrate IBI	mIBI	--	3273	5.3	5.4	2.3
Percent EPT	EPT	--	3273	33.0	34.2	23.6
Fish IBI	FIBI	--	1004	80.0	71.4	24.9

Quality control was applied to all data used in the statewide dataset beyond minimum data quality elements required for all data stored in WDNR databases. To reduce seasonal variability in the data, we only used water chemistry samples collected between May and October (the growing season) and macroinvertebrate surveys conucted during the spring or fall, the standard WDNR macroinvertebrate index period. All lab analyzed water chemistry data flagged by the laboratory for not meeting quality assurance standards were excluded. Water chemistry samples where analyte measures were below the laboratory's reporting limits (non-detects) were set to half the laboratory's detection limit. Total nitrogen (TN) was derived as the sum of total Kjeldahl nitrogen and nitrates+nitrites. Dissolved inorganic nitrogen (DIN) was derived as the sum of ammonia and nitrates+nitrites. We screened out fish surveys from projects targeting specific species or related to fish kills, fish passage, or stocking evaluations. Also, we only included fish surveys where fish assemblage data collected at a site supported the predicted Natural Community class for that stream segment. The Natural Community model must be verified in order to apply the correct fish IBI to assess the fish community. Currently, this is not an automated process; therefore we only used fish data that supported the modeled Natural Community. This resulted in much fewer fish IBIs used in the report than there are results in the database. However, this ensured that the fish IBI data represented here is accurate of the community and not an artifact of using the wrong tool for assessments.

We combined data collected from the same station over time (2003-2013) or any two stations located on the same stream reach (defined by WHD HydroID). Where multiple data collections existed we calculated median values for water quality parameters and mean values for biology parameters.

Wisconsin Hydrography Dataset Plus (WHDPlus)

For our stream classification we desired a range of stream channel and landscape-level physical characteristics with demonstrated relationships to water quality and aquatic biota. We obtained stream channel and landscape-level characteristics from the Wisconsin Hydrography Dataset Plus (WHDPlus). WHDPlus was developed by WDNR staff in a GIS environment and provides hundreds of physical attributes for each of the ~160,000 WHD stream reaches and lake features throughout the state (Menuz et al. 2013, Ruesch et al. 2013). Stream reaches in WHD are inter-confluence segments from WDNR's 1:24k hydrography layers, which were digitized from USGS 1:24k topographic maps. The hydrography features and their attributes are stored in a geodatabase following the National Hydrography Dataset data model. Contributing watershed areas for each stream reach were delineated using the 10 meter resolution National Elevation Dataset (NED, http://ned.usgs.gov/). WHD stream reaches and their contributing drainage areas are typically small, with a mean length of 0.8 km and a mean drainage area of 0.9 km^2. WHD hydrography layers and WHDPlus attributes are available for download and public use at: ftp://dnrftp01.wi.gov/geodata/hydro_va_24k/.

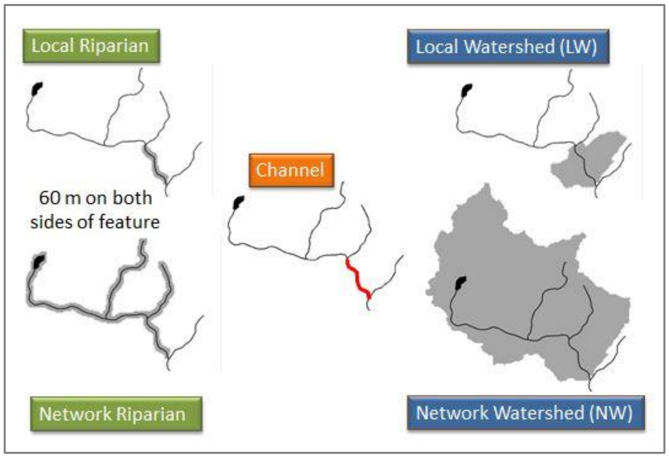


Figure 2. Illustration of the stream channel and four landscape-level spatial scales available in the WHDPlus dataset.

Stream reach attributes in WHDPlus include those related to the stream channel (e.g. stream flow and gradient) and those related to the surrounding landscape (e.g. soils and land slope). Landscape-level attributes are computed for network (total upstream area) and local (immediate drainage area) spatial scales, and for 60 meter riparian buffers and watershed scales (Fig 2). Analysis of relationships between monitoring parameters and physical characteristics at these multiple spatial scales played a key role in the selection of physical characteristics to use for the TWSST stream classification.

We tested a number of stream channel and landscape-level characteristics along with their spatial scales of measurement available in the WHDPlus dataset. The general categories and scales of variables are listed in Table 2. Candidate variables are those from WHDPlus that are commonly examined in scientific literature, or those we hypothesized would influence water quality and aquatic biota. Since the statistical method we selected for the stream classification (k-means clustering, discussed in Section 4) is designed for continuous variables, no discrete or categorical characteristics (e.g. stream order, dam presence/absence, Natural Community classes) were considered as candidate variables. Physical characteristics that would clearly not be useful for a catchment scale stream classification (e.g. air temperature, precipitation, and Omernik ecoregion) were also omitted from the list of candidate variables.

Table 2. General types of candidate stream channel and landscape-level characteristics in the WHDPlus dataset with corresponding spatial scales of attribution.

Candidate physical characteristic	Spatial scale of attribution
Stream flow and water temperature	Channel
Stream channel gradient and sinuosity	Channel
Land cover	All 4 landscape-level
Soil permeability	All 4 landscape-level
Other soils properties	Network watershed
Land slope	All 4 landscape-level
Topographic sinks	Network watershed
Surficial geology	All 4 landscape-level
Bedrock geology	All 4 landscape-level

WHDPlus contains stream flow volume for multiple probabilities of exceedance and at seasonal and annual time steps. Stream flow values were derived from regression models of watershed attributes at continuously gauged stream segments then applied to all catchments throughout the state (Diebel et al. 2014). We selected annual E10, E50, and E90 for initial model development to characterize high, median, and low flow regimes, respectively. We also calculated flow yield for each metric by dividing flow volume by drainage area. Stream water temperatures were estimated from an artificial neural network model of measured daily water temperatures for the summers of 1990-2008 linked with geology, topography, climate, and land cover variables (Stewart et al. 2015). Water temperature predictions are summarized into three metrics: June–August mean, July mean, and maximum daily temperature.

Stream gradient and channel sinuosity were included as candidate variables for model development. Stream gradient was derived from the 10-meter NED. Along with channel sinuosity, stream gradient was calculated using spatial analysis tools in ArcGIS software for each HydroID.

Land cover data are from the 2006 National Land Cover Dataset (NLCD) and are attributed at all four landscape-level scales. In addition to considering specific land cover classes, we aggregated NLCD classes into four general classes—agriculture, developed, forest, and wetlands/open water. These aggregations are summarized in Table 3. The remaining two NLCD categories found in Wisconsin—barren land and grasslands—were considered individually.

Table 3. Summary of generalizing specific NLCD land cover classes into aggregated land cover classes. NLCD class numbers are given in parentheses.

Aggregated class	**Developed**	**Forest**
Specific NLCD classes	Open developed (21)	Deciduous forest (41)
	Low intensity developed (22)	Evergreen forest (42)
	Moderate intensity developed (23)	Mixed forest (43)
	High intensity developed (24)	Woody wetlands (90)

Aggregated class	**Agriculture**	**Wetlands and lakes**
Specific NLCD classes	Pasture/hay (81)	Open water (11)
	Row crops (82)	Emergent and herbaceous wetlands (95)

Soils data were used in model development and were sourced from the Natural Resources Conservation Service soil surveys. Soils variables include percent sand, silt, and clay, available water capacity, bulk density, cation exchange capacity, organic matter content, permeability, hydraulic conductivity, soil thickness, depth to water table, and erodibility factor. Permeability is derived from STATSGO datasets and is attributed at all four landscape-level scales. However, given the relatively coarse resolution of STATSGO (1 km), we only considered the network watershed scale for this project. All other soils variables are derived from gridded SSURGO (gSSURGO, 10-meter resolution) datasets and are currently attributed at just the network watershed scale.

Topography variables include land slope and percent internally draining topographic depressions (sinks), both derived from the 10-meter NED using ArcGIS software. Land slope is attributed at all four landscape-level scales; topographic sinks are attributed only at the network watershed scale.

Surficial and bedrock geology characteristics are from multiple US Geological Survey data sources and are attributed at all four landscape-level scales. Surficial geology data in WHDPlus are given as percent by area of 25 unique classes of glacial deposits and other Quaternary depositional features (e.g. coarse end moraine deposits, fine lacustrine clays and silts, alluvium). As with land cover, we aggregated specific surficial geology classes into four general classes—coarse, medium, and fine glacial deposits, and a class combining colluvium and alluvium deposits.

Screening of candidate characteristics

We screened the list of candidate stream channel and landscape-level physical characteristics (Table 2) for those that were meaningful throughout most of Wisconsin and regularly exhibited spatial variability at the TWA scale. The first criterion reflects a desire for stream classifications in all watersheds to use the same set of physical characteristics. The second criterion reflects a desire for the classification to differentiate streams as much as possible at the catchment scale.

Candidate characteristics were mapped in ArcGIS to visualize statewide geographic distributions and catchment scale variability. For example, stream flow and water temperature exhibit variability at the watershed scale and are relevant statewide, and were retained for further analysis. Maps of stream flow volume and mean annual water temperature are provided in Appendix B.

Variables that were too sparse on the landscape were combined with similar measurements to create more meaningful metrics. For example, the geographic distributions of pasture/hay land cover (NLCD class 81) and medium and high intensity developed land cover (NLCD classes 23 and 24) are mapped in Figure 3a. These characteristics exhibit catchment scale variability where present, but are not present in significant amounts throughout most of the state. The geographic distributions of aggregated agriculture and developed land cover classes are mapped in Figure 3b. These aggregated classes exhibit catchment scale variability and are meaningful throughout most of the state. Consequently, we retained only the general, aggregate land cover classes for further analysis.

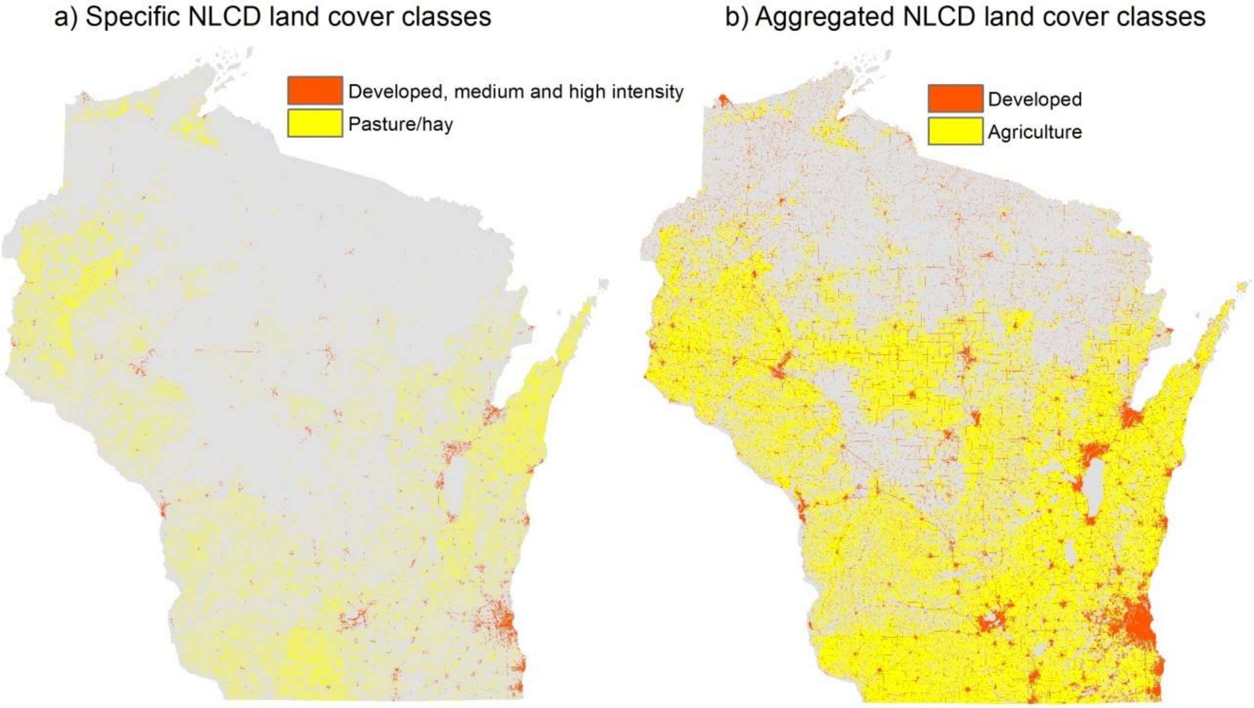


Figure 3. Geographic distribution of a) specific NLCD land cover classes and b) aggregated land cover classes. Only classes related to developed and agricultural land cover are shown.

Similar to some land cover metrics, the 25 individual surficial geology characteristics are not present in significant amounts throughout most of the state. The geographic distribution of aggregated surficial geology classes and bedrock geology classes are mapped in Figure 4. Areas shaded red indicate some degree of heterogeneity in the underlying geology, whereas all other colors indicate the underlying geology is homogeneous (e.g. 100% coarse glacial deposits or 100% carbonate bedrock). Although both general surficial geology and bedrock geology are relevant landscape-level physical characteristics throughout the state, they both lack variability at the within-TWA scale and were dropped from the list of candidate characteristics.

Our screening process retained stream flow, water temperature, channel gradient and sinuosity, aggregated land cover classes, soils properties, and land slope as candidate physical characteristics in the stream classification. Relationships between these characteristics and a suite of water quality and biology monitoring parameters are analyzed in Section 3.

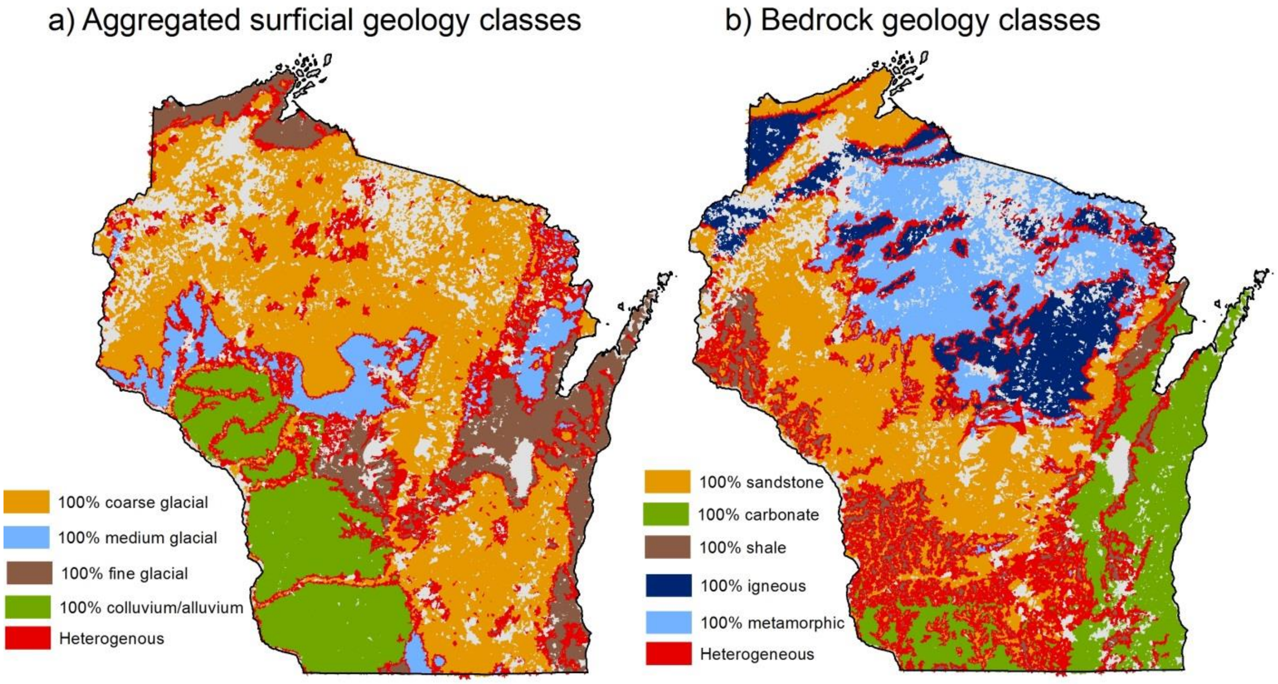


Figure 4. Geographic distribution of a) surficial and b) bedrock geology in Wisconsin. Variability in geology is limited to areas shaded red.

Section 3

Selection of WHDPlus physical characteristics for stream classification

In this section, we derive a small subset of variables for the stream classification from those stream channel and landscape-level physical characteristics retained from the screening in Section 2. We initially sought between 6 and 12 physical characteristics for ease of interpretation and ended up selecting ten variables representing four general types of physical characteristics—stream channel, land cover, soils properties, and topography.

We used Spearman rank correlations and Canonical Correlation Analysis (CCA) to identify physical characteristics with demonstrated relationships to water quality and aquatic biota and to identify variables providing similar information. Both Spearman correlation coefficients and CCA are statistical methods for analyzing the magnitude and direction of relationships among variables. Correlation coefficients are useful for quantifying pairwise relationships and their statistical significance. CCA is a constrained ordination technique useful for analyzing and visualizing gradients among and multiple relationships between response variables (in this case, monitoring parameters) and predictor variables (in this case, candidate stream channel and landscape-level physical characteristics). Both analyses allowed us to examine the strength of association between and among predictor and response variables as well as identify potentially redundant variables. In cases where physical characteristics appeared to be providing similar information, we preferentially selected those with more straightforward interpretation.

We selected Spearman rank (rather than Pearson) correlation coefficients since this non-parametric method makes no assumptions about the underlying distributions of variables, many of which are highly skewed. We calculated Spearman rank coefficients using the `rcorr` function from the `Hmisc` package in R statistical software. Coefficients are interpreted where a value of 1 indicates perfect positive correlation between two variables, a value of -1 indicates perfect negative correlation, and values near zero indicate no correlation. For physical characteristics attributed at multiple spatial scales (e.g. local versus network, riparian versus watershed, Figure 2), we compared Spearman coefficients to assess how relationships to water quality and aquatic biota varied across these scales.

We developed canonical correlations and CCA plots using functions from the `CCA` package in R. We examined all statistically signification canonical dimensions, though typically only the first two were readily interpretable. Plots of the first two canonical dimensions were created to visualize gradients among and relationships between response and predictor variables. Predictor variables that are near each other in xy-space, or are separated by a 180° line through the center, are highly correlated and conveying similar information. Predictor variables that are orthogonal (at 90° angles through the center) in xy-space are unrelated and convey unique information. In the context of this study, predictor and response variables farthest from the center of the plot have the strongest ability to differentiate stream reaches. Ideal predictor variables (i.e. physical characteristics) are those that are orthogonal (unrelated) to other predictors, close to (highly correlated with) response variables, and farthest away from the center.

Our main goal was to identify relationships between physical characteristics and monitoring parameters at the catchment scale. However, we wanted to verify that observed relationships at the catchment scale remained relevant statewide (e.g. not a result of chance occurrence in the pilot watersheds). Consequently, Spearman correlation analysis and CCA were conducted at the watershed scale using the Upper Yellow River and Pecatonica River pilot project datasets and at the statewide scale using the statewide dataset (see Section 2).

We have grouped analyses, results, and conclusions from Spearman rank correlation and CCA analyses by the following general types of physical characteristics—stream channel, land cover, soils, and topography. Given the large number of candidate physical and monitoring parameters, Spearman correlation results are summarized as the number of water quality parameters (out of 12) or measures of biotic response (out of 4) that were significantly correlated ($p < 0.05$) with individual physical characteristics (parameters are those listed in Table 1). The magnitudes and directions of all correlations are provided in Appendix A. Specific values of Spearman correlation coefficients (ρ) are stated in the text where informative.

Stream channel

We compared the number of significant Spearman correlation coefficients between stream channel characteristics and monitoring parameters in the Upper Yellow River and Pecatonica River study areas (Table 4). In the Upper Yellow River watershed, all stream flow estimates were significantly correlated with all 4 biology parameters and 3 of 12 water quality parameters. In the Pecatonica River watershed, stream flow demonstrated few relationships with biology but was significantly correlated with up to 6 water quality parameters. Water temperature was significantly correlated with multiple biology and water quality parameters in both watersheds. In particular, 8 of 12 water quality parameters were significantly correlated with water temperature in the Pecatonica watershed. Sinuosity and channel gradient were significantly correlated with very few water chemistry and biology parameters in the Pecatonica and Upper Yellow watersheds.

Table 4. Spearman correlations in the Upper Yellow River and Pecatonica River study areas, summarized as the number of water quality (out of 12) or biology (out of 4) parameters that were significantly correlated ($p < 0.05$) with the stream channel characteristic. Abbreviations used in the CCA plots in Figure 5 are also provided.

Abbreviation used in CCA plots	Stream channel physical characteristic	Upper Yellow		Pecatonica	
		Bio	WQ	Bio	WQ
E10	Annual stream flow (E10)	4	3	1	3
E50	Annual stream flow (E50)	4	3	1	5
E90	Annual stream flow (E90)	4	3	1	6
E10Norm	Area normalized E10	1	3	0	2
E50Norm	Area normalized E50	3	4	0	4
E90Norm	Area normalized E90	3	4	1	5
MaxTemp	Maximum daily mean water temperature	2	1	2	8
SumTemp	June-August mean water temperature	1	4	1	8
JulyTemp	July mean water temperature	1	4	1	8
Sinuosity	Sinuosity	2	1	1	0
Gradient	Gradient	0	2	1	2

Each of the flow duration and temporal scales of stream flow and water temperature were usually highly correlated. For example, the E90, E50, and E10 stream flow measures were highly correlated ($\rho > 0.87$ for all combinations in the Upper Yellow watershed and $\rho > 0.99$ for all combinations in the Pecatonica). Area normalized flow yields were highly correlated in the Pecatonica ($\rho > 0.78$ for all combinations). However, in the Upper Yellow only area normalized E50 and E90 were highly correlated ($\rho = 0.83$) while area normalized E10 was weakly correlated with area normalized E50 ($\rho = 0.03$) and E90 ($\rho = -0.20$). All three water temperature measures were perfectly correlated with each other ($\rho = 1.0$) for all combinations in the Pecatonica. In the Upper Yellow watershed, July and summer mean water temperatures were perfectly correlated ($\rho = 1.0$) but both seasonal measures were weakly correlated ($\rho = 0.25$) with maximum annual mean water temperature. The high degree of correlation indicates the need for only one stream flow and one stream temperature measurement in the final classification system.

Relationships between predictor variables and response variables, and relationships among predictor variables, were further evaluated with CCA. Figure 5 shows the first two canonical dimensions from CCA between response variables (i.e. monitoring parameters, red text) and predictor variables (i.e. stream channel characteristics, blue text) for a) the Pecatonica River watershed, b) the Upper Yellow River watershed, and c) the statewide dataset. These plots facilitate visualization of multiple correlations among and between response and predictor variables.

The water temperature and stream flow variables in the CCA plots demonstrate the relationships among variables found in Spearman correlations. In the Pecatonica, all water temperature variables were perfectly correlated ($\rho = 1.0$) and occupy the same CCA space in Figure 5a. In the Upper Yellow, summer and July water temperatures provide equivalent information but are not highly related to annual mean water temperatures. In the Pecatonica watershed, the first dimension (x-axis) indicates a gradient from colder to warmer water temperatures. The second dimension (y-axis) suggests a gradient in stream flow. Both stream flow volume and area normalized flow are largely providing similar information (close together), though normalized flows are less related (orthogonal) to water temperature.

In the Upper Yellow watershed, stream flow volume and area normalized high flow (E10) are largely unrelated (orthogonal) to area normalized median (E50) and low flow (E90). Moreover, key measures of biologic condition—FIBI, mIBI, and %EPT—appear more related (closer in xy-space) to flow volume and E10Norm than to E50Norm and E90Norm. The opposite relationship was observed in the Pecatonica, where FIBI, mIBI, and %EPT were more related to E50Norm and E90Norm than to flow volume.

In all three CCA plots TP, TN, and conductivity are related (same quadrant). In Figure 5a, the first quadrant (upper right) of the plot demonstrates that water chemistry parameters are highly correlated in the Pecatonica. In addition, poorer mIBI and HBI scores are associated with higher levels of nutrients and conductivity in both pilot watersheds and statewide. The mIBI and HBI scores indicate quality in opposite directions, where high mIBI scores indicate good quality while low HBI scores indicate good quality. This is why the HBI is near (in xy-space) water chemistry variables and the mIBI is located nearly 180^{o} across the plot, indicating negative correlation.

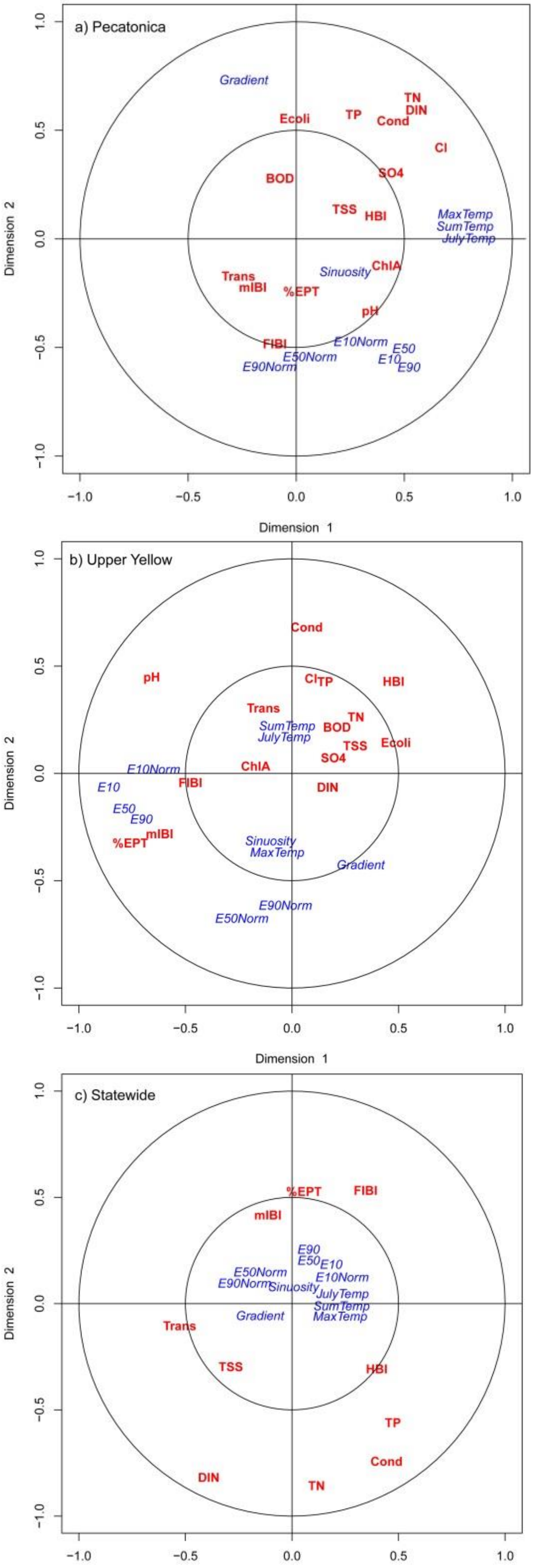


Figure 5. First two canonical dimensions for response variables (red text) and stream channel predictor variables (blue text) for a) the Pecatonica River watershed, b) the Upper Yellow River watershed, and c) the statewide dataset.

The CCA plot for the statewide dataset indicates that although water quality and biology parameters are well differentiated (far from center) at this scale, associations with stream channel physical characteristics are less pronounced than those at the watershed scale, although both are statistically significant. It appears that comparing responses and predictors at the watershed scale may be more meaningful than the statewide scale. At the watershed scale there should be a number of spatially auto-correlated physical characteristics (e.g. land cover, soils properties). In essence, those auto-correlated characteristics are corrected for by comparing smaller catchments and the differences among variables that truly vary at the watershed scale (e.g. stream flow) are easier to detect. Although we expect a set of predictors to be important and used to classify all watersheds statewide, there will be a unique subset of predictors in each watershed that truly differentiates stream reaches.

Both stream flow and water temperature were considered priority candidate variables for the stream classification system so that TWSST could be interpreted alongside WDNR's Natural Community classification system. Results from Spearman correlations and CCA provided substantial evidence that these variables were related to multiple monitoring parameters at the watershed scale, and that a single measure for each was sufficient for characterizing flow and temperature regimes.

We selected stream flow volume over area normalized stream flow because stream flow volumes were significantly correlated with as many or more total parameters compared to their area normalized counterparts and it has a more straightforward interpretation. The low flow measure (E90, the flow volume with a 90% probability of exceedance) was retained for the final classification since 1) stream flow modeled as 90 percent probability of exceedance was significantly correlated with as many or more total parameters compared to 10 and 50 percent probabilities of exceedance, 2) stream monitoring is typically conducted during low flow rather than high flow conditions, and 3) this measure is the one used for differentiating Headwaters from Mainstems in the Natural Community model.

We selected maximum daily mean water temperature for the classification since 1) with the exception of water quality parameters in the Upper Yellow, the annual measure was significantly correlated with as many or more total parameters compared to the summer or monthly measures and 2) this measure is the one used for differentiating thermal classes in the Natural Community model.

Neither sinuosity nor channel gradient exhibited compelling associations with water quality or biota. This result was unexpected, given established ecological relationships between channel morphology and in-stream habitat, streambed composition, and rates of nutrient or sediment transport (Hynes 1970, Allan and Castillo 2007). We suspect the lack of significant correlations is due to sinuosity and gradient being computed for typically very short stream reach segments (~0.8 km) that may not reflect the pattern of the entire upstream channel. We recommend these stream channel characteristics remain a part of the overall site selection process as part of best professional judgment. However, neither gradient nor sinuosity was selected for use in the TWSST stream classification.

Stream channel physical characteristics selected

- E90 stream flow volume (90% probability of exceedance)
- Maximum annual mean water temperature

Land cover

The first step in identifying appropriate land cover variables for the stream classification was to determine the strength of association of each of the predictor variables. Again, we computed and compared Spearman correlation coefficients to determine the relationship of predictors and water quality. Secondly, as land cover characteristics are attributed at four spatial scales in WHD, we also had to determine which scale was best suited for the classification system. We created bar charts to visually compare how relationships with monitoring parameters varied by scale of measurement. Figures 6 and 7 present representative results from this analysis. A complete set of bar charts (each aggregated land cover variable at both pilot watershed and statewide scales) is given in Appendix B.

The direction and magnitude of Spearman correlations between percent agriculture and a suite of monitoring parameters in the Upper Yellow River watershed were visually examined by creating bar charts (Fig 6). Percent agriculture land cover and water chemistry (e.g. total phosphorus, chloride, conductivity, and total nitrogen) tend to increase moving from riparian to watershed and local to network spatial scales. This result likely reflects the cumulative effects of agricultural land use practices moving from smaller to larger scales of measurement. On the other hand, benthic macroinvertebrate indices (e.g. HBI and mIBI) exhibited a similar response to agriculture at all scales, suggesting that local land cover is relatively more important for these biological measures than for water chemistry measures. E. coli was the only parameter that clearly exhibited stronger relationships with percent agriculture at the local scales, both riparian and watershed.

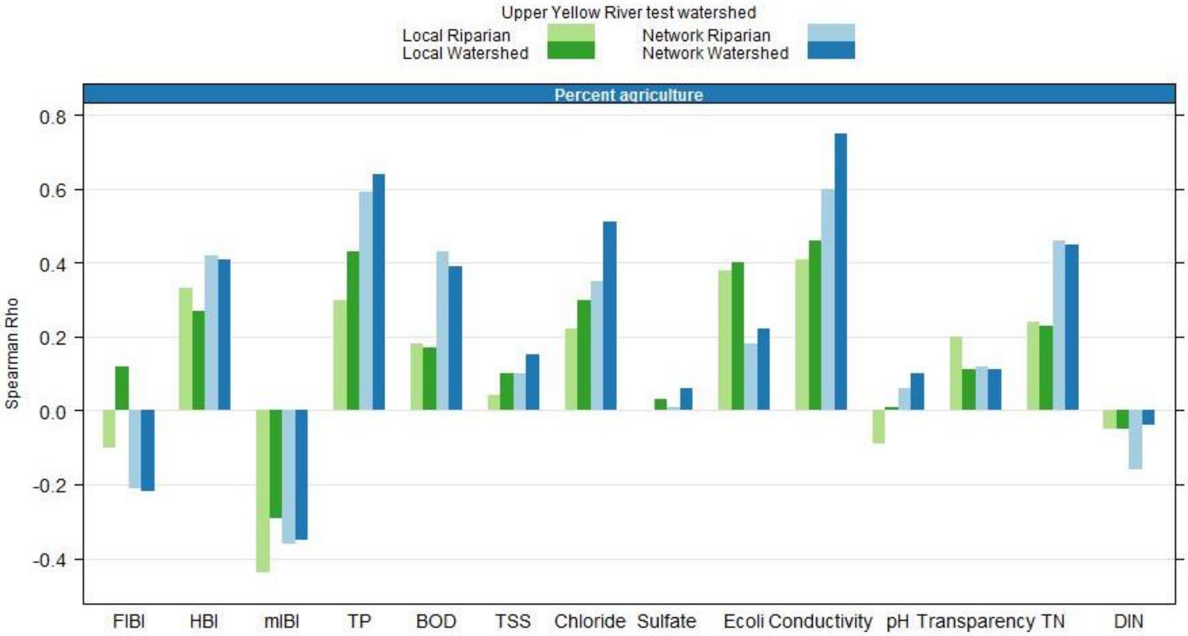


Figure 6. Spearman rank correlations between percent agriculture land cover and water quality and biology parameters in the Upper Yellow River watershed. Correlations are calculated at four spatial scales: watershed (blue) versus riparian (green), and local (light shading) versus upstream network (dark shading).

We also compared statewide differences in the relationships between land cover and monitoring parameters. An example plot for percent developed land cover is shown in Figure 7. There are fewer parameters in the statewide dataset than the pilot studies dataset although similar relationships were observed among comparable water quality variables. With the exception of fish IBI, total upstream network developed land cover exhibits higher correlations with water chemistry and biology compared to local amounts of developed land cover. These results suggest that cumulative impacts factor into water quality, and not just point source impacts from urban water conveyance (e.g. effluents or storm drains). These results provide a strong case for characterizing developed land cover at the network (total upstream area) scale for the stream classification system.

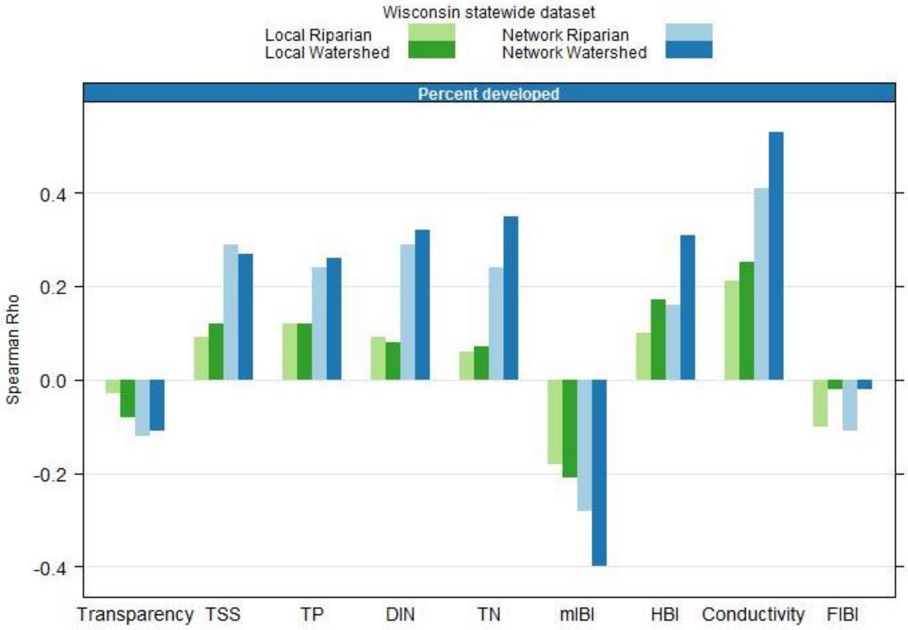


Figure 7. Statewide correlations between percent developed land cover water quality and biology parameters.

Although there are indications that a few response parameters, particularly biological measures, were more sensitive to land cover at local or riparian scales, the network watershed scale overall exhibited the strongest relationships with the most water chemistry and biology parameters. Consequently, we selected the network watershed scale for characterizing land cover. Table 5 contains a summary of statistically significant Spearman correlations between land cover characteristics at the network watershed scale and monitoring parameters in the Upper Yellow River and Pecatonica River study areas.

Table 5. Spearman correlations in the Upper Yellow River and Pecatonica River study areas, summarized as the number of water quality (out of 12) or biology (out of 4) parameters that were significantly correlated (*p* < 0.05) with the land cover characteristic.

Aggregated land cover class	Upper Yellow		Pecatonica	
	Bio	WQ	Bio	WQ
Agriculture	3	5	0	2
Developed	0	3	2	8
Forest	3	6	2	6
Wetlands and lakes	1	2	0	7

As with stream flow and water temperature, land cover relationships differed between biology and water quality parameters and between the two watersheds. For example, percent agriculture land cover was significantly correlated with water quality and biology parameters in the Upper Yellow, but not significantly correlated with any biology parameters and only significantly correlated with TN and DIN in the Pecatonica. Interestingly, percent forest land cover in the Pecatonica demonstrated many unique significant correlations with monitoring parameters, despite the fact that agriculture and forest are themselves highly negatively correlated (ρ = -0.71). Percent wetlands and lakes appeared more correlated to water quality parameters in the Pecatonica than the Upper Yellow, though this land cover type is far more prevalent in the Upper Yellow. These results reflect complex interactions among response and predictor variables at the watershed scale and the need for CCA to view multiple gradients and relationships together.

Figure 8 shows the first two canonical dimensions for response variables (red text) and land cover predictor variables (blue text) for a) the Pecatonica River watershed, b) the Upper Yellow River watershed, and c) the statewide dataset. In all three plots, the first dimension (x-axis) indicates a gradient from land cover altered by humans (agriculture and developed) to natural land cover (forests and wetlands). Compared to the statewide plot, this gradient is more pronounced at the watershed scale, with variables being further away from the center of the plot, and therefore better differentiating stream reaches.

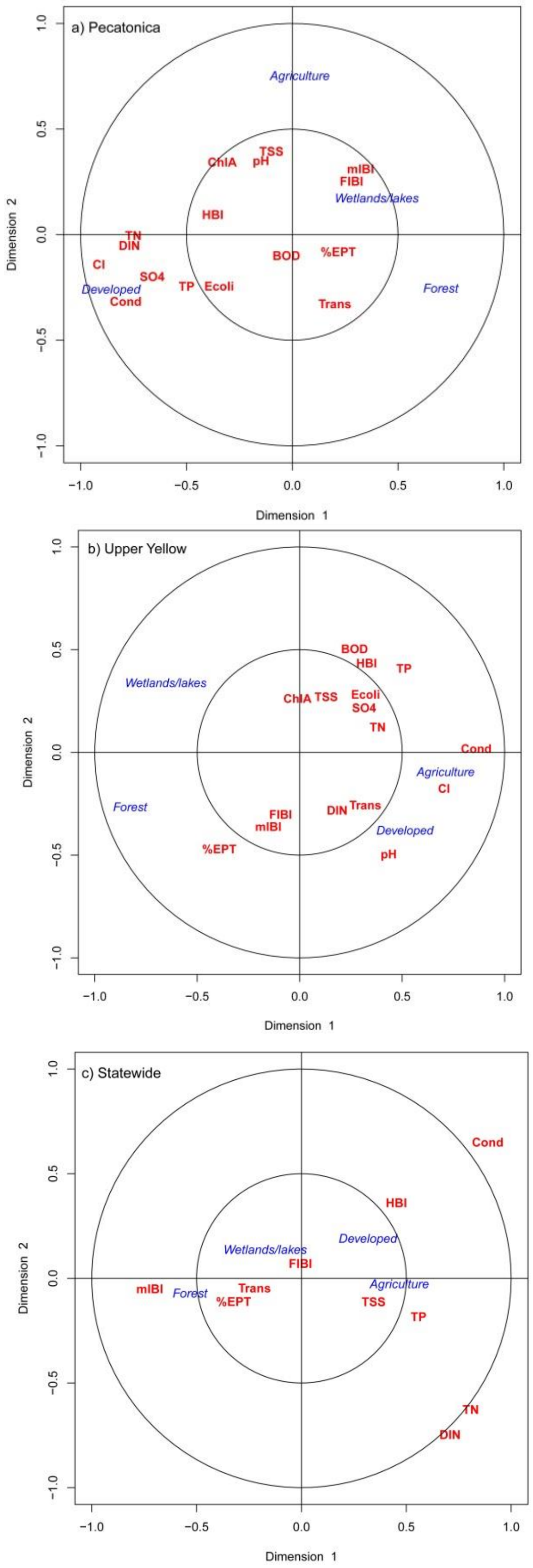


Figure 8. First two canonical dimensions for response variables (red text) and land cover predictor variables (blue text) for a) the Pecatonica River watershed, b) the Upper Yellow River watershed, and c) the statewide dataset.

The CCA plot in Figure 8a identifies developed land cover as an ideal predictor variable in the Pecatonica watershed since it is largely unrelated to other predictors, close to multiple response variables (nutrients and dissolved solids), and far from the center of the plot.

Further, there is evidence that the agriculture, developed, forested, and wetlands/lakes characteristics each contribute unique information towards explaining the variability in water chemistry and biology to the extent that each category largely occupies its own quadrant in the plots. Percent wetlands/lakes is largely 180^{o} from percent developed land, indicating an inverse relationship in both watersheds. However, this is not true in the statewide plot.

It appears that all four land cover categories provide important and unique information. As with stream channel characteristics, land cover characteristics exhibited greater correlations with response variables at the watershed scale than at the statewide scale. Although percent forest and agriculture may be inversely related at the statewide scale, within catchments this pattern is not ubiquitous. Therefore, all four land use categories should be retained for the final classification.

Land cover physical characteristics selected

- Agriculture
- Developed
- Forest
- Wetlands and lakes

} All at network watershed spatial scale

Soils

All candidate soils variables were attributed only at the network watershed scale. Table 6 contains a summary of Pearson correlations between soils characteristics and monitoring parameters in the Upper Yellow River and Pecatonica River study areas. Soils variables were significantly correlated with many water quality and biology parameters in both watersheds, though notably more so in the Pecatonica. In particular, soil texture (percent sand, silt, and clay) were significantly correlated with most water quality parameters in the Pecatonica. As with land cover, we used CCA plots to view these multiple relationships together.

Table 6. Spearman correlations in the Upper Yellow River and Pecatonica River study areas, summarized as the number of water quality (out of 12) or biology (out of 4) parameters that were significantly correlated ($p < 0.05$) with the soil property. Abbreviations used in the CCA plots in Figure 9 are also provided.

Abbreviation used in CCA plots	Soils physical characteristic	Upper Yellow		Pecatonica	
		Bio	WQ	Bio	WQ
Sand	Percent sand	3	1	1	8
Silt	Percent silt	1	2	3	10
Clay	Percent clay	0	3	2	8
ksat	Hydraulic conductivity	2	4	4	8
Perm	Permeability	0	3	0	6
RockDep	Depth to bedrock	1	2	2	7
WTdep	Depth to water table	2	2	0	3
Kfact	Soil erodibility (K) factor	1	2	1	6
AWC	Available water capacity	0	4	0	5
BDL	Bulk density	1	2	0	6
OML	Organic matter content	2	3	0	6
CEC	Cation exchange capacity	0	3	1	3

Figure 9 shows the first two canonical dimensions for response variables (red text) and soils predictor variables (blue text) for a) the Pecatonica River watershed, b) the Upper Yellow River watershed, and c) the statewide dataset. In all plots, there is a clear differentiation related to soil texture from fine silts and clays to coarse sands, though this gradient is more pronounced at the watershed scale. In all cases, this gradient is on a diagonal in the plot and appears to be associated with both canonical dimensions, though more so with the first dimension.

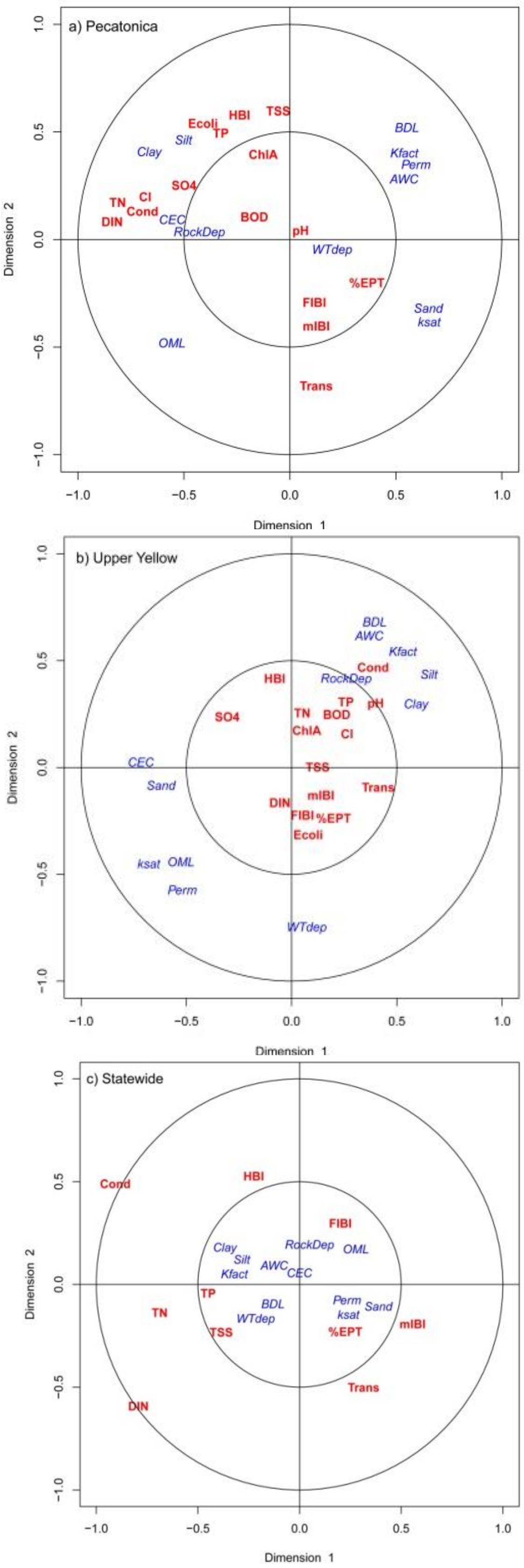


Figure 9. First two canonical dimensions for response variables (red text) and soils predictor variables (blue text) for a) the Pecatonica River watershed, b) the Upper Yellow River watershed, and c) the statewide dataset.

Many soils attributes characterize how surface water runs off, percolates into the soil, and contributes to base flow and water filtration. The second dimension (y-axis) in Figure 9a suggests a gradient from clearer to more turbid streams, with biological measures favoring the clearer streams. As in the Spearman correlation analysis this relationship is particularly strong in the Pecatonica watershed. The CCA plots demonstrate that many of these measures are also highly correlated (close together in the plots) and therefore provide similar information. For example, soil bulk density, available water capacity, and soil erodibility factor are all highly correlated in both watersheds and statewide.

Although the soil texture gradient is common to all plots, other soils properties exhibit different relationships by watershed. For example, in the Pecatonica organic matter content and permeability are opposite one another in the plot and exhibit a gradient orthogonal (unrelated) to the soil texture gradient. However, organic matter and permeability are correlated in the Upper Yellow and are more closely aligned with the soil texture gradient. At the statewide scale, organic matter content is again unrelated (orthogonal) to the soil texture gradient, while permeability is strongly related to soil sand content.

For our classification system we desired soil characteristics that were integrators of multiple properties yet fairly straightforward to interpret. For instance, percent sandy soils and permeability describe similar soil properties but we chose to use permeability because it not only describes soil texture but also compaction, sorting, and layering, among others. Permeability is also a more interpretable measurement especially considering the relationship of soil properties and watershed dynamics.

Similarly, percent sand, silt, and clay were each identified as a key predictor in both watersheds. All three are highly correlated among themselves (and by definition, adding up to 100%). We chose soil clay content because it not only describes soil texture but also because of the well-known phenomenon of phosphorus binding to clay particles, constituting a primary pathway for the nutrient to run off land and enter waterbodies.

In the Pecatonica watershed and at the statewide scale, soil organic matter content appeared unrelated to other soils variables, in particular the soil texture gradient. Further, in both the Pecatonica and the statewide datasets, there is a general gradient between soil organic matter and transparency versus instream TSS and TP, with biological condition favoring the former. The proposed mechanism would be water absorption and retention of nutrients by organic matter, reducing loads of nutrients and sediment to the stream (Gosz et al. 1976, Doran and Zeiss 2000). Consequently, we included soil organic matter content in the stream classification to account for processes near the soil-water interface.

Soils physical characteristics selected

- Permeability
- Clay content
- Organic matter content

} All at network watershed spatial scale

Topography

Land slope was the only topography characteristic retained from the screening process in Section 2. Given that stream channel gradient and sinuosity were screened out for lack of demonstrated correlations at the catchment scale, we considered land slope a priority characteristic for the stream classification in order to account for factors related to fluvial geomorphology, such as sediment transport, substrate composition, and instream habitat (Hynes 1970).

Land slope is attributed at all four landscape-level spatial scales. As with land cover, we created bar charts of Spearman correlation coefficients to visually compare how relationships with water quality and biology varied by scale of measurement. The bar chart in Figure 10 shows the direction and magnitude of Spearman correlations between land slope and a suite of monitoring parameters in the Pecatonica River watershed, where hills and valleys are prominent landscape features. Bar charts for the Upper Yellow River watershed and statewide dataset are given in Appendix B.

For all parameters except fish IBI, magnitudes of correlation coefficients at the network scale are greater, in many cases much greater, than those at the local scale. Land slope at the local riparian scale is positively correlated with TP, chloride, E. coli, TN, and DIN, but negatively correlated with the same responses at network riparian and watershed scales. The same is true for mIBI, but with opposite directions of correlation. One interpretation of these results is higher slopes in the immediate vicinity of the stream delivering pollutants via surface pathways, while higher slopes throughout the watershed result in higher baseflow potential (and therefore dilution). We chose the network watershed scale for exhibiting overall greater correlations.

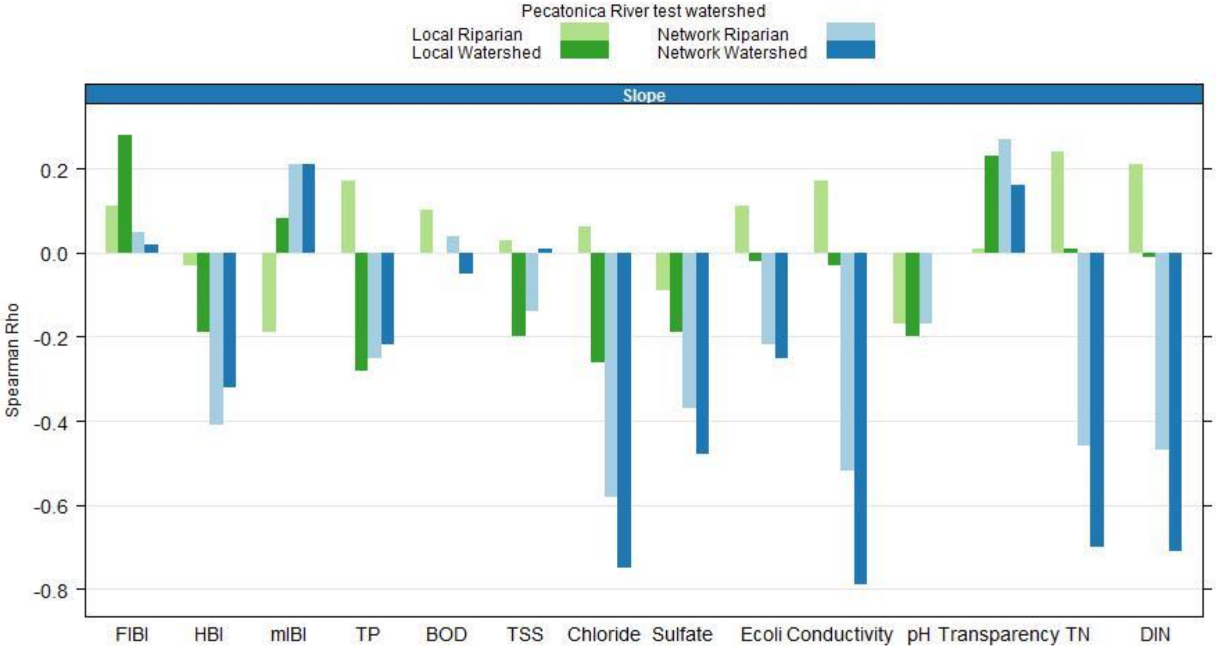


Figure 10. Spearman correlations between land slope and water quality and biology parameters in the Pecatonica River watershed.

Correlation coefficients showing strength of association between (network watershed) land slope and monitoring parameters in the Upper Yellow River and Pecatonica River study areas are shown in Table 7. Since this was the only topography variable, we provide actual correlation coefficients instead of a CCA plot. Fish IBI, TP, BOD, TSS, and Chlorophyll a were not significantly correlated with land slope in either watershed and are omitted from the table.

Table 7. Spearman correlation coefficients between land slope and monitoring parameters in the Upper Yellow River and Pecatonica River watersheds. Bold face type indicates statistical significance at $p < 0.05$.

Parameter	Upper Yellow	Pecatonica
HBI	**-0.30**	**-0.32**
mIBI	**0.40**	0.21
% EPT	0.15	**0.28**
TN	0.01	**-0.70**
DIN	**0.48**	**-0.71**
Conductivity	0.18	**-0.79**
Chloride	**0.41**	**-0.75**
Sulfate	-0.08	**-0.48**
E. coli	**0.31**	**-0.25**
pH	**0.46**	0.00
Transparency	**0.29**	0.16

The different responses across multiple scales and in different watersheds suggest complex relationships between land slope and monitoring parameters. Land slope may have direct and indirect influence on stream ecosystems. For example, slope can directly influence the physical process in stream ecosystems or watershed slope can be related to the location and intensity of anthropogenic land uses that influence water quality. Land slope was significantly correlated with multiple water quality and biology parameters in both watersheds. For biology measures (HBI, mIBI, %EPT), correlations are in the same direction. However, the influence of slope on water quality parameters is clearly different in the two watersheds. The Yellow River watershed had much lower land slopes with little variation across the watershed. With less overall variation in watershed slope there may be a smaller influence of this variable on stream chemistry and biology which may lead to opposing influence of watershed slope among the watersheds. Although responses across watersheds may be different, slope appears an important predictor of water quality and biology at the catchment scale and was selected for inclusion in the stream classification.

Topography physical characteristics selected

- Land slope (network watershed scale)

Summary of physical characteristics selected for the stream classification

A total of ten physical characteristics from the WHD dataset were selected for the TWSST stream classification. Summary statistics for these ten variables are given in Table 8. Values in Table 8 reflect data from all WHD stream reaches in Wisconsin. Maps illustrating the statewide distributions of each characteristics and brief narratives describing the significance of each variable with respect to water quality and biology are provided in Appendix B.

Table 8. Summary statistics for the ten WHD physical characteristics selected for the stream classification.

WHD physical characteristic	Units	Min	Max	Median	Mean	Std dev
Stream flow volume (E90)	cfs	0.01	6010	0.15	20	208
Water temperature	°C	12.0	32.5	21.8	21.7	2.4
Land slope	degrees	0.0	19.3	2.6	4.0	3.6
Agriculture land cover	Percent	0	100	45	43	31
Developed land cover	Percent	0	100	4	6	9
Forested land cover	Percent	0	100	42	45	31
Wetlands/lakes land cover	Percent	0	100	1	4	8
Soil clay content	Percent	0	59	13	15	8
Soil organic matter content	Percent	0	47	2	4	5
Soil permeability	in/hr	0.52	1.28	2.41	3.55	2.88

Section 4

Development and validation of the stream classification in pilot watersheds

The next step in the TWSST model process was to identify similar stream reaches and group them together. We used k-means clustering to group similar stream reaches based on the ten WHD physical characteristics identified in Section 3. K-means is a commonly used unsupervised learning technique designed to partition data into a predetermined number of groups by minimizing within-group sum of squared differences between observed values and group means. We used the `kmeans` function from the `stats` package in R statistical software for the stream classification. Prior to developing stream groups with k-means, all left skewed variables were natural log transformed and all right skewed variables square root transformed in order to better approximate normal distributions. All variables were normalized (scaled to z-scores) in order to have comparable numerical ranges and therefore contribute equally to the classification.

We tested the k-means method in the Pecatonica and Upper Yellow River pilot watersheds, classifying stream reaches into four, five, six, and seven discrete groups. Preliminary analyses in these watersheds and others indicated that three groups provided limited stream differentiation while eight or more groups became difficult to interpret and explained minimal additional variation among and within groups. Also, having fewer groups than there are predictor variables meant that the variables that best differentiated streams in that watershed would be used in the classification system. Therefore, a variable whose values had limited range throughout a particular watershed could remain in the classification scheme since it would have very little influence on the classification of stream groups. This allowed the TWSST model to use the same set of predictor variables to classify all watersheds across the State.

For each test watershed, we mapped the different classification scenarios (4 through 7 groups) in ArcGIS to visualize how stream reaches were grouped together, overlaying HUC 12 boundaries, aerial photography, and other relevant map layers for reference. We examined boxplots of WHD physical characteristics to interpret the watershed scale differences driving the classification. We also examined boxplots of multiple monitoring parameters to determine if stream differentiation by physical characteristics resulted in observable and statistical differentiation in water quality or aquatic biota.

The following detailed explanation for the Pecatonica watershed describes how we used the maps and boxplots to assess the proposed stream classification in test and validation watersheds. This detailed explanation is also provided because it represents the same overall process used to identify the optimal number of stream groups during the final model development stage for all TWSST watersheds.

Figures 11-13 contain results from the four group classification in the Pecatonica River watershed. A consistent color scheme was used for these and all subsequent results. That is, for both maps and boxplots, Group 1 is always dark blue; Group 2 is always light blue, etc. The group numbers themselves are only meaningful as labels for the groups.

Group 1 (dark blue) in the classification is differentiated by stream flow volume, inferred from the drainage pattern in Figure 11 and clearly shown in the stream flow boxplot in Figure 12, where the majority of flow values are orders of magnitude greater than other groups. Most of these reaches are classified as Mainstems in the Natural Community system. Groups 2, 3, and 4 contain lower order streams, most of which are classified as Headwaters in the Natural Community system.

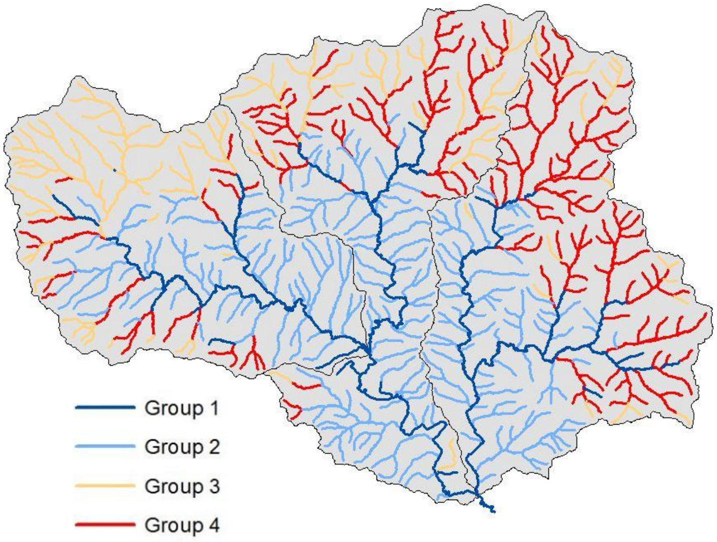


Figure 11. Four group classification in the Pecatonica River watershed.

Group 2 (light blue) contains streams in the central and south part of the watershed that drain directly into the Mainstems in Group 1. Groups 3 and 4 contain streams higher in the watershed, with Group 3 (orange) predominantly in the north and west and Group 4 (red) predominantly in the north and east.

While the differences in groups can be viewed spatially the underlying drivers of the classification are the WHD variables used in the k-means cluster analysis. The boxplots in Figure 12 are useful for understanding the differences in physical characteristics that account for differentiation among stream groups. For example, Group 2 is differentiated by predominantly cold water temperatures and includes the highest slopes in the watershed. Group 3 contains predominantly cool water temperatures, with the lowest slopes and highest amounts of agriculture and developed land cover in the watershed. No individual characteristics clearly differentiate Group 4 from all other groups, although water temperature, slope, and land cover do differentiate these streams from Group 3 and therefore Headwater streams higher in the watershed. Boxplots of physical characteristics also provide information on the degree of variability within a group. For example, soil clay content exhibits much more variability in Group 2 than in Group 3.

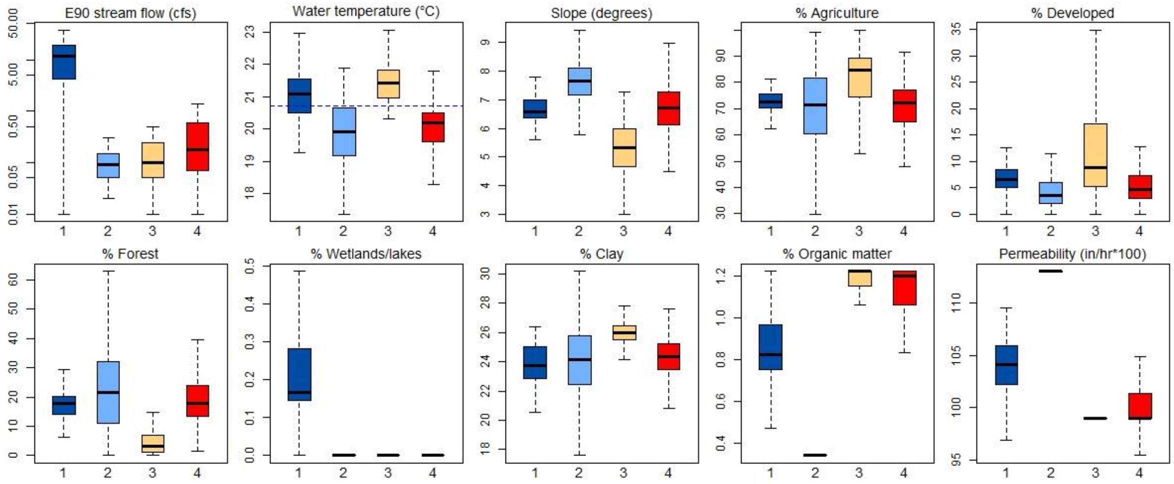


Figure 12. Boxplots of physical characteristics (four groups, Pecatonica).

Boxplots were created to test if stream differentiation based on physical characteristics translated into differentiation in water quality and biology parameters (Fig 13). Group 3 is clearly differentiated in terms of TP, TN, and chloride. Boxplots of monitoring parameters also provide information on the degree of variability within a group. For example, Fish IBI scores cover the full range of possible values in Groups 2 and 3, but are consistently greater than 60 in Group 4. Overall, Group 4 streams appear to be in the best condition and Group 3 the poorest. However, caution should be used when making inferences about the water quality among groups as the data collection efforts were not specifically designed to test this classification system.

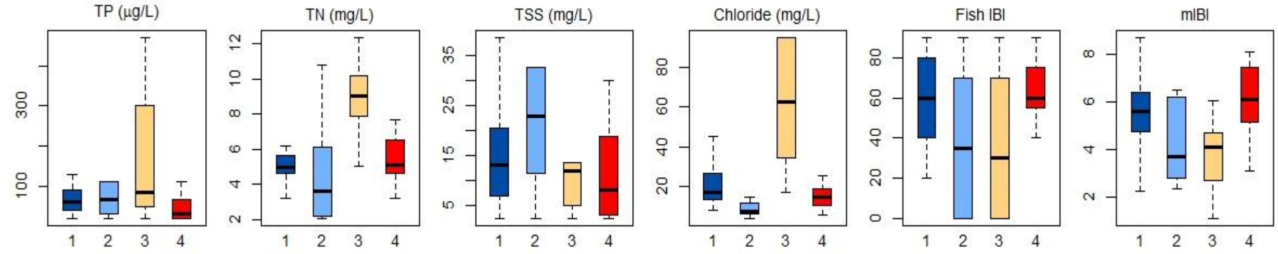


Figure 13. Boxplots of monitoring parameters (four groups, Pecatonica).

Results from the five group classification in the Pecatonica River watershed show good spatial differentiation (Fig 14). The main change observed in Figure 14 is that Group 2 from the four group classification has been differentiated into two new groups, Groups 2 and 5. The other three groups of streams remained largely the same, though a few reaches were classified differently.

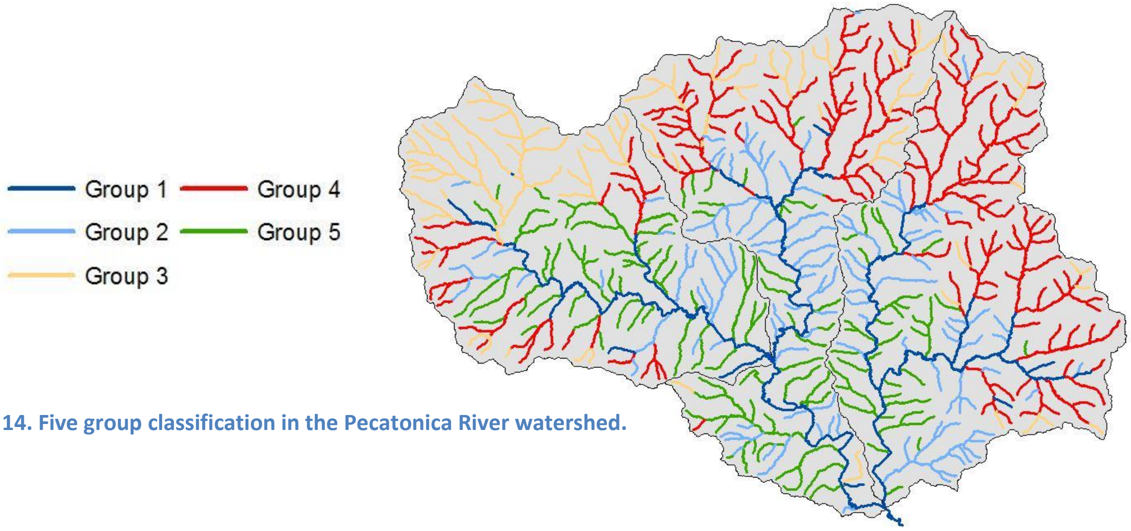


Figure 14. Five group classification in the Pecatonica River watershed.

Referring to the boxplots in Figure 15, this differentiation is based on water temperature and levels of forest and agricultural land cover. While Group 2 in the four group classification had moderately variable water temperatures and highly variable forest and agriculture land cover, the five group classification has clearly reduced this variability in the central and south part of the watershed. Now, Group 2 is entirely comprised of coldwater streams and contains lower amounts of agriculture and higher amounts of forested land cover compared to Group 5. From classification accuracy perspective, this represents a major improvement over the four group model. The differentiation in physical characteristics between Groups 2 and 5 translated into differences in observed water quality and biology (Figure 16), particularly for TN and fish IBI, which were highly variable in the four group classification.

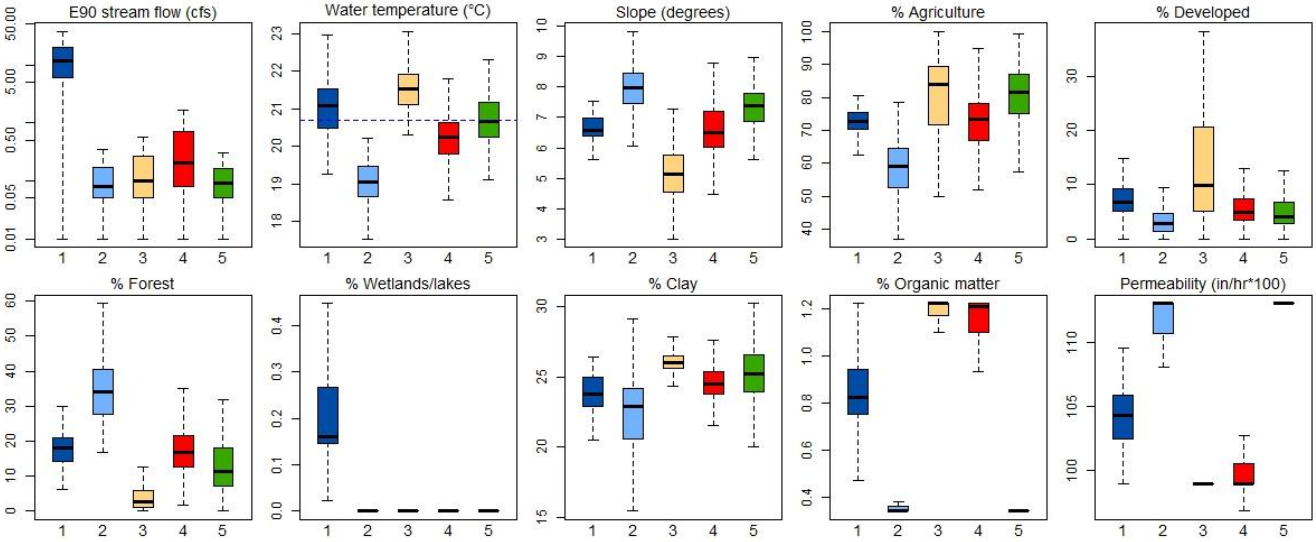


Figure 15. Boxplots of physical characteristics (five groups, Pecatonica).

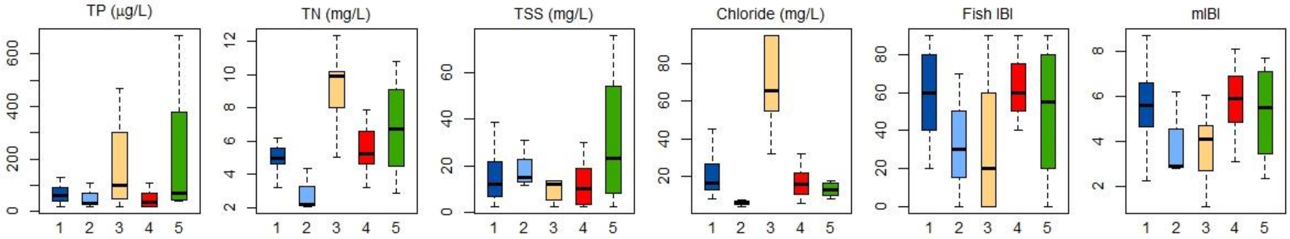


Figure 16. Boxplots of monitoring parameters (five groups, Pecatonica).

Figure 17 contains results from the six and seven group classifications of stream reaches in the Pecatonica River watershed. Note that while the association between colors and group numbers is always the same, a group of streams sometimes ends up with a different label (number) in this process as the group assignments are mainly arbitrary in the clustering process. This introduces some confusion when comparing the above figures but supports a consistent color scheme for the boxplots and consistent symbology in the final product.

In contrast to the four and five group classifications, the six and seven group classifications each identify a very specific group of streams containing very few reaches. The six group classification differentiates a small number of reaches (Group 4, red), most of which are within the city of Dodgeville in the northwest part of the watershed. The seven group classification additionally differentiates a small number of reaches scattered throughout the watershed (Group 5, dark green).

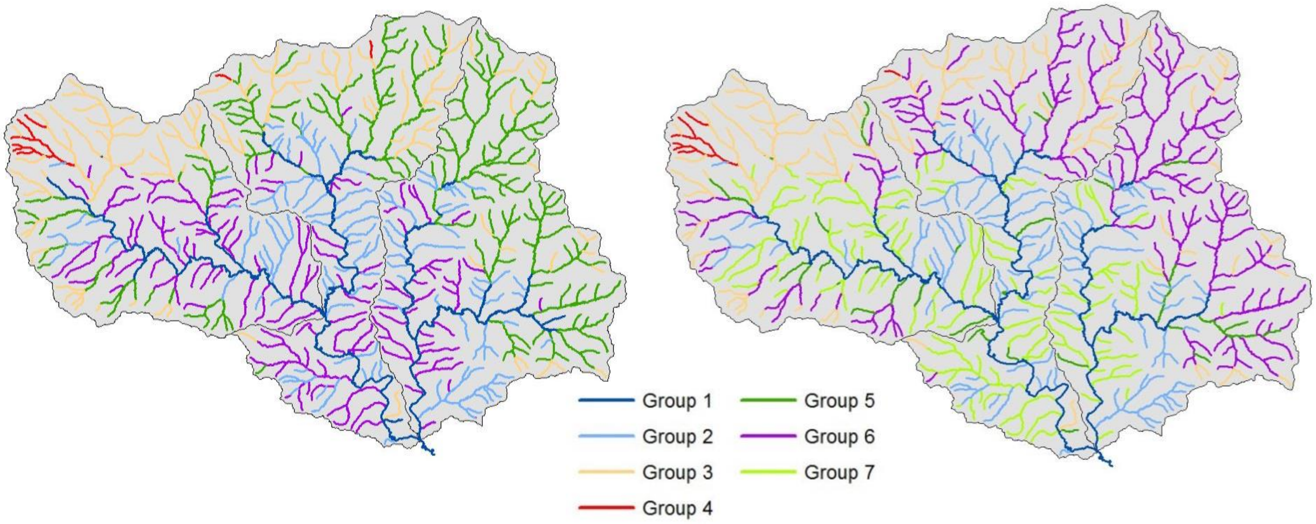


Figure 17. Maps for the six group classification (left) and the seven group classification (right) in the Pecatonica River watershed.

Boxplots of physical and land use variables were visually examined to help determine the effectiveness of these group size classifications (Fig 18). Boxplots from the six group classification are omitted since they are practically the same as the seven group plots, as the two new groups have so few members. Both figures are useful for assessing how much information these two small groups of streams add to the classification at the expense of increased complexity.

Group 4 (red) reaches are clearly differentiated by the warmest water temperatures, lowest slopes, and highest levels of developed land cover in the watershed (Figure 18). The differentiation of Group 4 from surrounding reaches in Group 3 (orange) results in differentiation of monitoring parameters as well, particularly for chloride, fish IBI, and mIBI where Group 4 is in notably poorer condition compared to Group 3 (Figure 19). Consequently, the differentiation of Groups 3 and 4 contributes important information to the classification.

The geographically scattered reaches in Group 5 (dark green) appear to comprise a distinct group differentiated by the presence of wetlands/lakes (Figure 18). However, wetlands/lakes only range from 0 to 1 percent of total watershed area. While this group does contain some of the highest fish and macroinvertebrate IBI scores, it is difficult to relate this differentiation in biology to differences in physical characteristics.

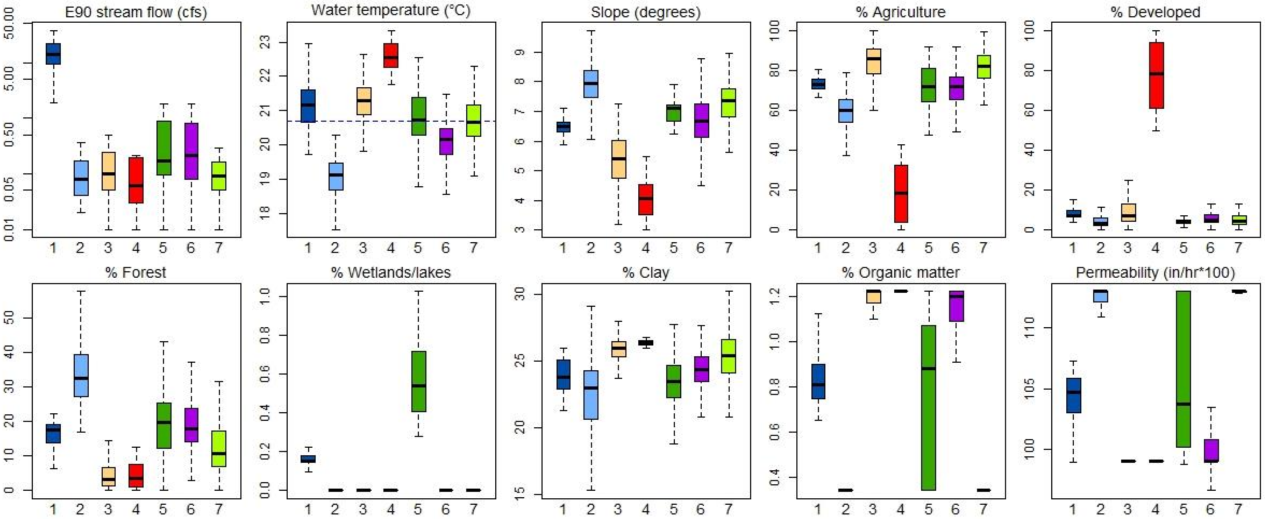


Figure 18. Boxplots of physical characteristics (seven groups, Pecatonica).

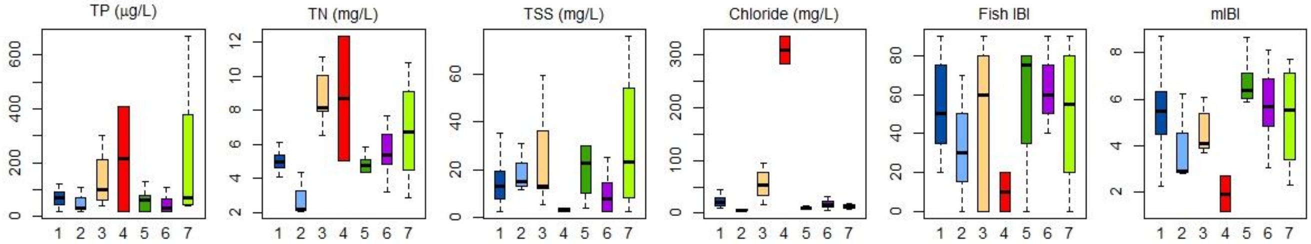


Figure 19. Boxplots of monitoring parameters (seven groups, Pecatonica).

To summarize results from the Pecatonica River watershed, the k-means classifications resulted in observable and explainable differences in both physical characteristics and monitoring parameters. For the purposes of aiding the selection of monitoring locations, four groups appeared too general while five groups appeared sufficient. Six or seven groups provided additional differentiation of very specific groups with few constituent reaches. For this test watershed, we determined that five groups would provide the best balance between stream differentiation and model interpretability.

We conducted the same analysis in the Upper Yellow River watershed. Maps of the four, five, six, and seven group classifications are shown from left to right in Figure 20. Figures 21 and 22 contain boxplots from the six group classification in the Upper Yellow River watershed for physical characteristics and monitoring parameters, respectively.

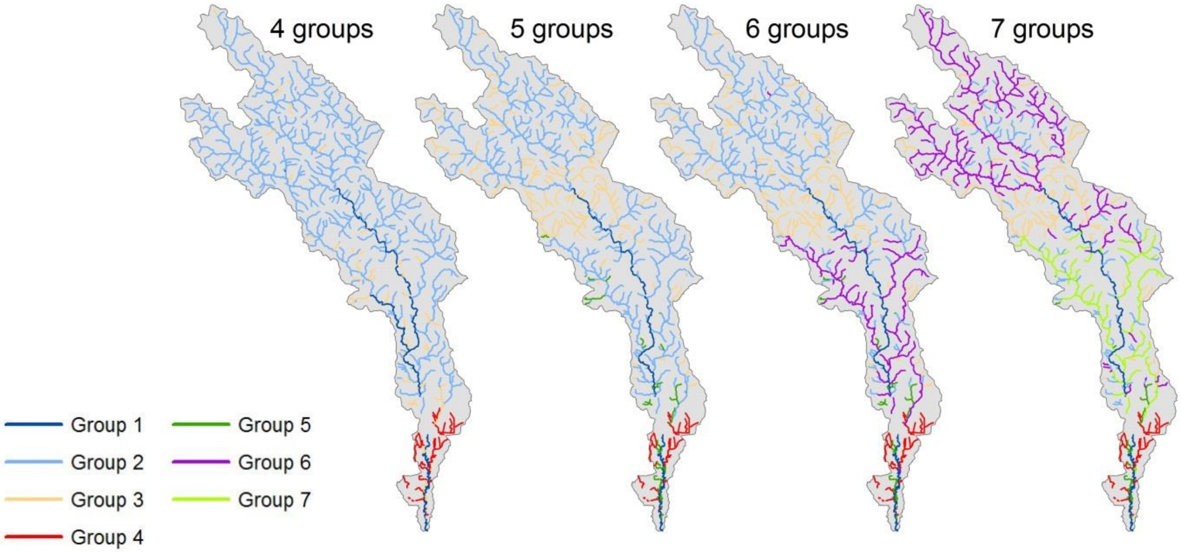


Figure 20. Stream groups obtained from classifications in the Upper Yellow River watershed.

As in the Pecatonica, the highest flow streams (Group 1, dark blue) group together in the Upper Yellow River watershed. This group contains the same stream reaches regardless of the number of groups used in the classification. Unlike the Pecatonica, very specific stream groups with few members were obtained right away with only four or five groups, while in the Pecatonica six or seven groups were needed to isolate very specific groups. For example, in the Upper Yellow, Group 4 in the southern part of the watershed is differentiated by the lowest amounts of agricultural land cover, lowest soil clay content and highest soil organic matter and permeability in the watershed. These stream reaches are so different from the others that they group together regardless of the number of groups in the classification (Figure 20).

The primary differences between the four, five, and six group classifications occur in the central and northern part of the watershed. The boxplots can be used to determine if the statistical differentiation of these streams corresponds to observable differences in physical characteristics and explainable differences in water quality and biology. Figure 21 shows that Groups 2, 3, and 6 are differentiated by the combination of water temperature, land slope, and agriculture and forest land cover. These three groups all have very similar soils properties, which likely explain why they were grouped together in the four group classification. Additionally, Groups 2, 3, and 6 exhibit differences in water quality that can be explained by differences in physical characteristics. For example, Group 3 streams have by far the highest levels of TP, including some extremely high levels, and some of the poorest macroinvertebrate IBI scores (Figure 22). This is likely related to the very high percentages of agricultural land cover combined with the highest slopes in the watershed contributing to runoff related impacts.

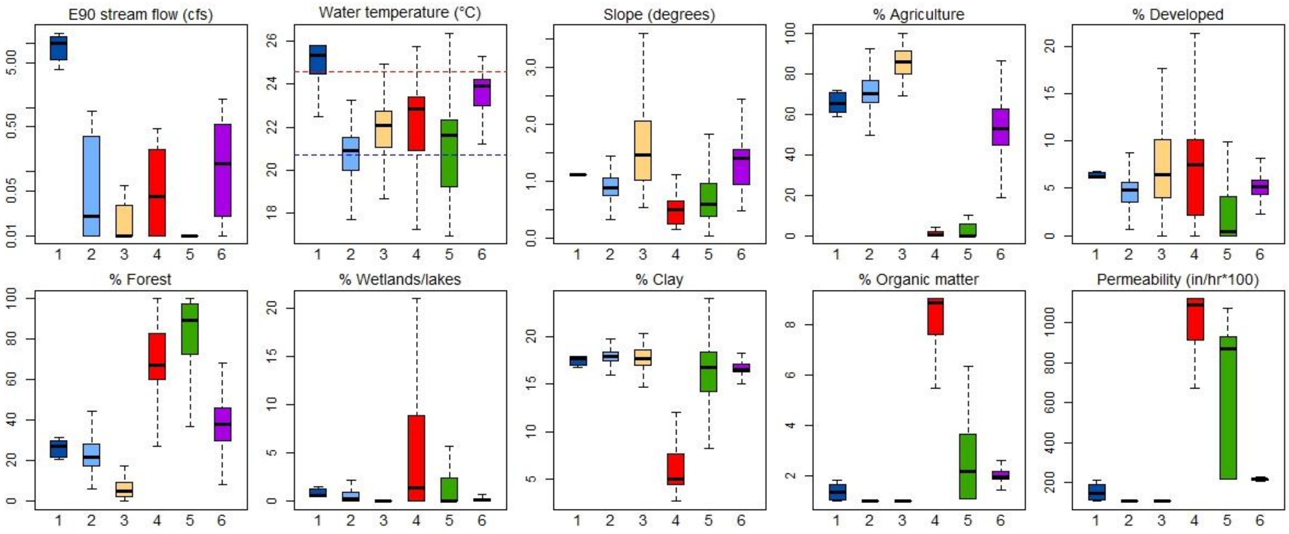


Figure 21. Boxplots of physical characteristics (six groups, Upper Yellow).

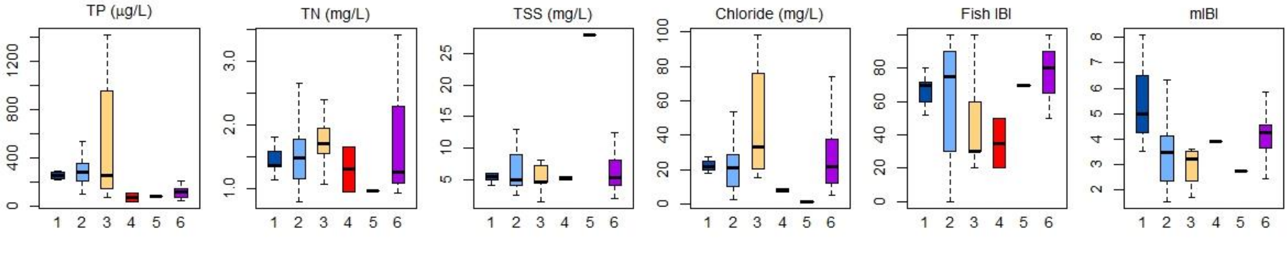


Figure 22. Boxplots of monitoring parameters (six groups, Upper Yellow).

To summarize results from the Upper Yellow River watershed, the k-means classifications resulted in observable and explainable differences in the grouping variables, physical characteristics, and monitoring parameters. This conforms that the physical characteristics selected for grouping are actually related to in-stream water quality. Although, caution is urged when interpreting water quality parameters within groups as study design and purpose of the original data collection were not accounted for when aggregating monitoring results by stream group.

In the Upper Yellow River watershed four and five groups were insufficient for differentiating streams in the central and northern parts of the watershed. These streams were differentiated starting with six groups. Adding a seventh groups did not appear to provide enough additional differentiation at the expense of increased complexity. Consequently, for this test watershed, we determined that six groups would provide the best balance between stream differentiation and model interpretability.

Results from the Pecatonica River and Upper Yellow River test watersheds indicated that the proposed stream classification was able to differentiate stream reaches at the TWA scale. Further, the classification resulted in observable and explainable differences in water quality or biology among groups. Consequently, we accepted the proposed stream classification approach and proceeded to validate its potential for all watersheds throughout the state.

Section 5

Extension of stream classification system statewide

After promising results in test watersheds, we looked to apply the stream classifications statewide. We proposed HUC 8 watersheds (n=50) as the spatial unit for applying the classification. This spatial scale was a compromise between capturing variability at the Targeted Watershed scale and interpretation of the classification results. For example, we attempted the classification at statewide and regional scales, but these resulted in broad longitudinal gradients and insufficient variability at the Targeted Watershed scale. On the other hand, applying the classification to every HUC 10 would have resulted in 368 spatial units requiring an overwhelming amount of interpretation and description.

We applied the k-means clustering method (described in Section 4) to the Bad River and Milwaukee River watersheds (each comprises a HUC 8, see Figure 1 for locations) to test the classification at this larger scale. This also tested how well the classification worked in watersheds in different geographic settings with different land cover regimes (minimally developed in the Bad and highly developed in the Milwaukee).

Taking the same steps as in the pilot watersheds, we developed multiple classification sizes and visually examined the resulting patterns. In the maps in Figures 23 and 24, HUC 12 catchments are shaded to visualize how well the HUC 8 classification would differentiate streams at the TWA scale. Our goal was that most HUC 12s (e.g. potential TWA catchments) would contain at least two and ideally three or four different stream groups. The insets in each map show a single HUC 12. In the Figure 23 inset for the Bad River, a Mainstem is present, plus three Headwater groups. A transition from Group 2 to Group 5 is evident in the eastern portion of the catchment, while potentially unique streams (Group 3) are located in the southwest. In the Figure 24 inset for the Milwaukee River, two primary stream groups are present (Groups 3 and 4) with a few potentially unique streams in the western part of the catchment (Group 2).

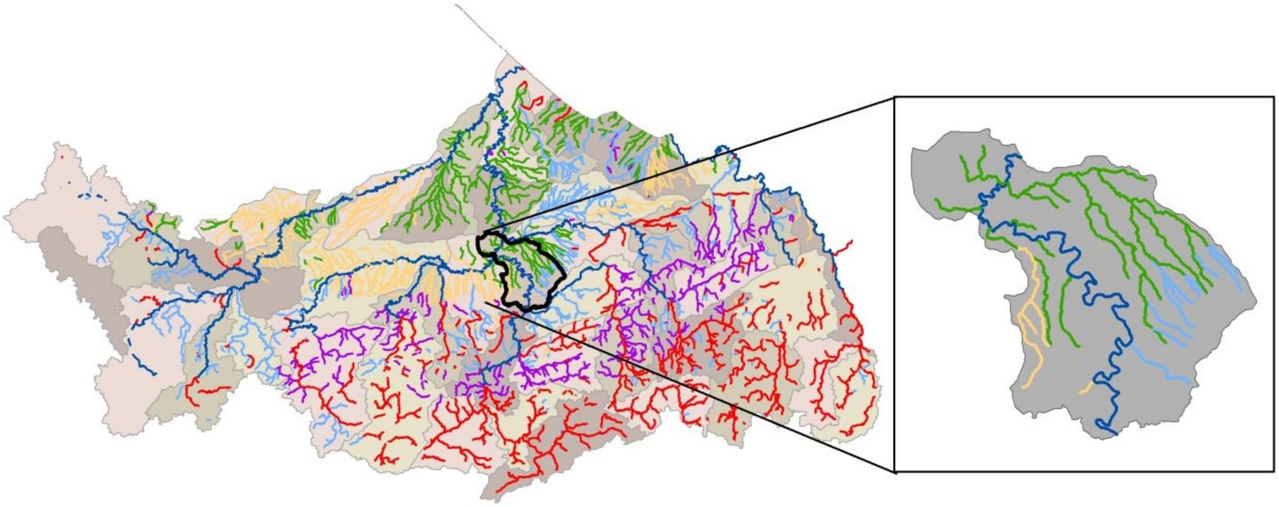


Figure 23. Stream classification in the Bad River watershed.

In both watersheds, most HUC 12s contained at least two groups, and many had three or four. However, it was not possible to get multiple groups in every HUC 12 without an extremely complicated classification. We also reasoned that if a TWA only contained one group, the TWSST classification could identify the watershed as homogenous relative to its larger watershed. For example, the southern part of the Milwaukee River watershed (Figure 24) is within the metro Milwaukee area, an unlikely TWA location but one where monitoring sites would be determined by factors other than landscape characteristics (such as point source outfalls, political boundaries or channel characteristics).

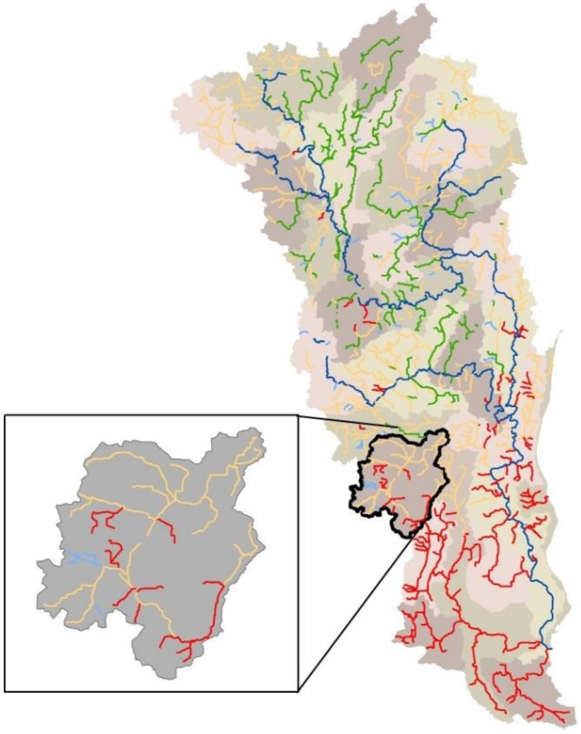


Figure 24. Stream classification in the Milwaukee River watershed.

At the HUC 8 scale, the stream classifications were still informative at the TWA monitoring scale (HUC 12) for most of our test watersheds. Consequently, we accepted the proposed HUC 8 spatial scale for extending the stream classification throughout the state.

TWSST Watershed Delineation

A total of 50 HUC 8 watersheds are partially or wholly within Wisconsin, ranging in size from 36 to 9,645 km^2. Very small HUC 8 units were merged with adjacent HUC 8s, maintaining common drainage whenever possible. These small HUC 8 units are shaded green in Figure 25, with arrows indicating which HUC 8 the unit was merged with. Although large, the Lake Winnebago HUC 8 is mainly comprised of Lake Winnebago with few stream segments and was merged with the Upper Fox River HUC 8. Initial classifications with many of the largest HUC 8 watersheds resulted in broad longitudinal gradients and insufficient variability at the Targeted Watershed scale. These watersheds were split into smaller units. For example, in Figure 25, the Wolf River HUC 8 was split into its upper, central, and lower drainage areas, while the Castle Rock HUC 8 was split according to the main river systems within the watershed (Wisconsin River in the East, Yellow River in the West, and Lemonweir River in the South). All HUC 8s that required splitting are noted in the map legend.

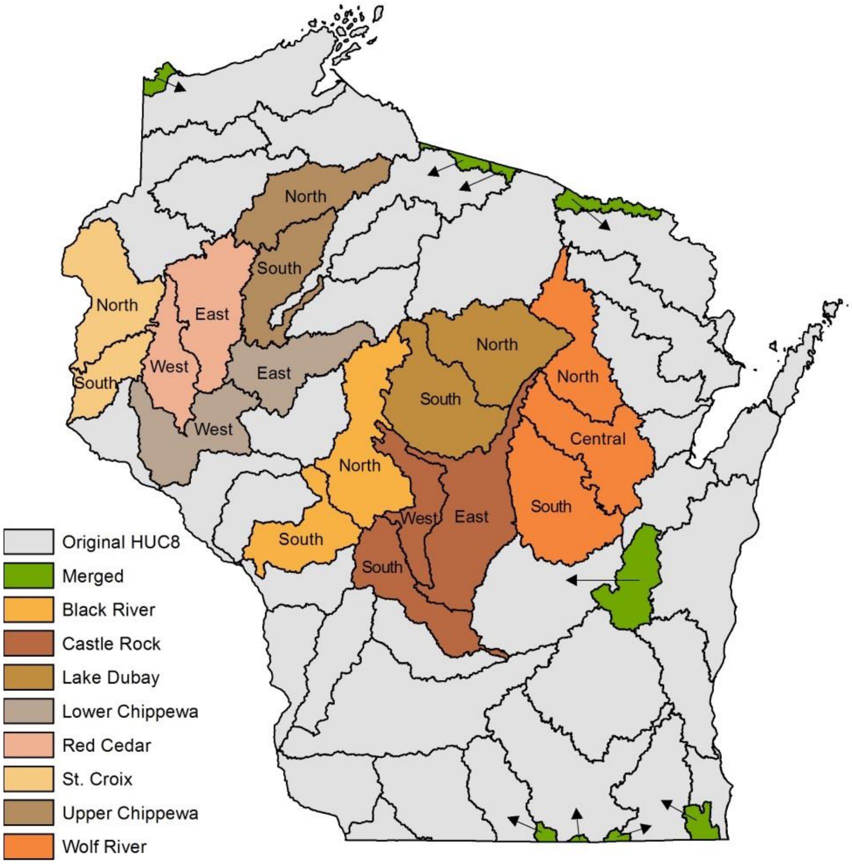


Figure 25. Spatial units for the TWSST stream classification. HUC 8 boundaries are outlined in black. Areas shaded grey indicate the original HUC 8 was used for the classification. Areas shaded green are portions of HUC 8s that were merged with adjacent HUC 8s. Other colored areas are HUC 8s that were split into two or three smaller units.

After merging small HUC 8s and splitting up larger HUC 8s, there were 52 watershed units to classify, ranging in size from 601 to 6,112 km^2 (mean of 2,792 km^2). These spatial units are referred to as "TWSST watersheds" in this report since they are not strictly HUC 8s in all cases (Figure 25). The k-means clustering function was applied to each of the 52 TWSST watersheds. Stream reaches with modeled E90 stream flow volume less than 0.01 cfs were removed from the analysis in order to filter out intermittent streams with extremely low flow. Such streams are not likely to be included in a TWA monitoring sampling design, but are numerous and could add unwanted bias to the classification.

We did not require all TWSST watershed classifications to use the same number of groups. In each TWSST watershed, we classified stream reaches into four, five, six, and seven groups. Analyses in test watersheds suggested that for smaller TWSST watersheds and those with limited landscape heterogeneity, four groups might be sufficient, while larger watersheds and those with greater landscape heterogeneity might require seven groups to sufficiently differentiate streams.

Statistical and geographical methods were used to determine the optimal number of groups for a given TWSST watershed. We began by creating scree plots and cluster plots as statistical methods for evaluating the optimal number of groups. Sample plots are given in Figure 26 for the Kewaunee River TWSST watershed.

In order to determine the effectiveness of the number of cluster groups two graphical analysis were used. The scree plot (Figure 26a) displays how the within cluster sum of squares (y-axis) decreases with increasing number of clusters (x-axis). The sum of squares quantity is a measure of within group variability, where lower numbers indicate greater within group homogeneity. This quantity will usually decrease as more groups are created, though at a decreasing rate of improvement. With more groups the classification becomes increasingly difficult to interpret and describe so we attempted to select only as many groups as needed. The scree plot suggests five as the optimal number of groups, since adding more groups beyond this adds complexity without substantial decrease in the sum of squares.

The cluster plot (Figure 26b) displays degrees of similarity and difference among clusters by plotting the first two principal components of the underlying data and drawing ellipses around points that are in the same group (points not shown). Overlap among ellipses indicates similarity in physical characteristics. For example, Group 1 (the highest flow group) is partially similar to (overlaps) Groups 2, 3, and 4, but not Group 5. Similarly, Group 2 is the most distinct, with most of its ellipse area not overlapping with other groups.

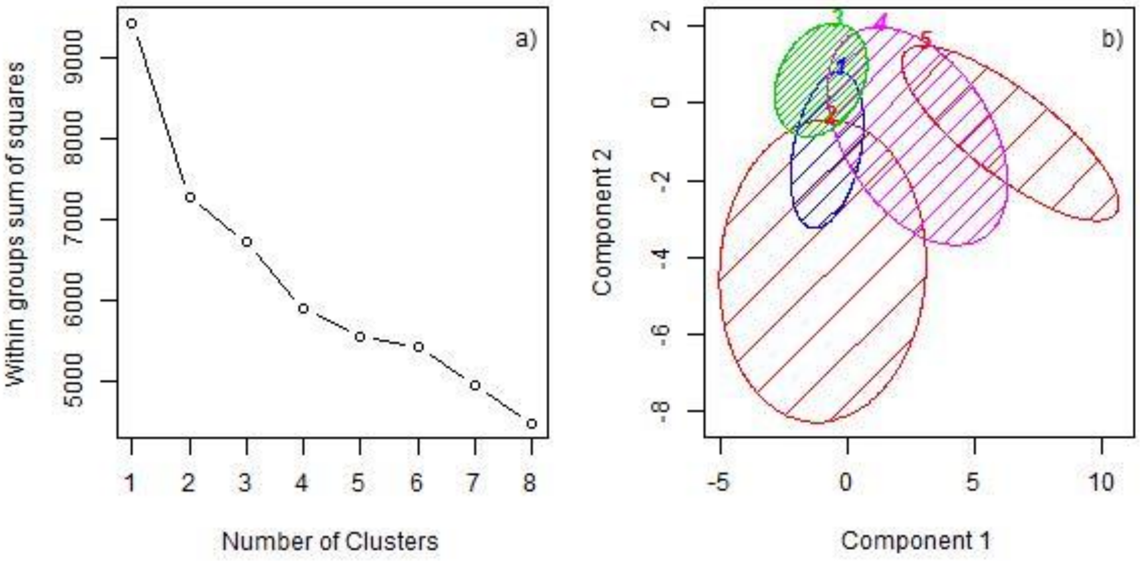


Figure 26. Statistical methods for determining the optimal number of groups for the stream classification as a) scree plots and b) cluster plots, both for the Kewaunee River TWSST watershed.

While the scree and cluster plots provided a starting point, we found that mapping the stream groups helped in selecting the optimal number of groups, given our goal of having at least two and ideally three or four stream groups in each HUC 12. We followed the process described earlier for the Pecatonica test watershed, mapping the different classification scenarios (4 through 7 groups) in ArcGIS and overlaying HUC 12 boundaries, aerial photography, and other relevant map layers for reference. We also examined the boxplots of physical characteristics and water quality and biology parameters for the different grouping scenarios.

Our final decision on how many groups to use for a given TWSST watershed was based on weight of evidence from the various statistical and geographical analyses. Five or six groups seemed to best characterize nearly all of the 52 TWSST watersheds. Only one watershed was best characterized by four groups. Five watersheds required a full seven groups to provide sufficient differentiation among reaches.

Section 6 discusses how to access and interpret TWSST output and how to incorporate TWSST into the monitoring site selection process.

Section 6

How to use the Targeted Watershed Site Selection Tool

We developed the Targeted Watershed Site Selection Tool (TWSST) to assist in the development of a monitoring design in Targeted Watershed Assessments (TWA). We designed TWSST to be flexible to TWA objectives by classifying stream reaches according to physical characteristics that were both easily interpretable and shown to influence a range of water quality and biology monitoring parameters. The TWSST tool can be used to visually estimate the location and number of sites needed to capture the variability of stream systems in a TWA watershed. However, specific monitoring site locations will also be needed expressly for study purpose, such as capturing wastewater treatment plant surface outfalls or evaluating the success of projects involving best management practices to reduce non-point source pollution.

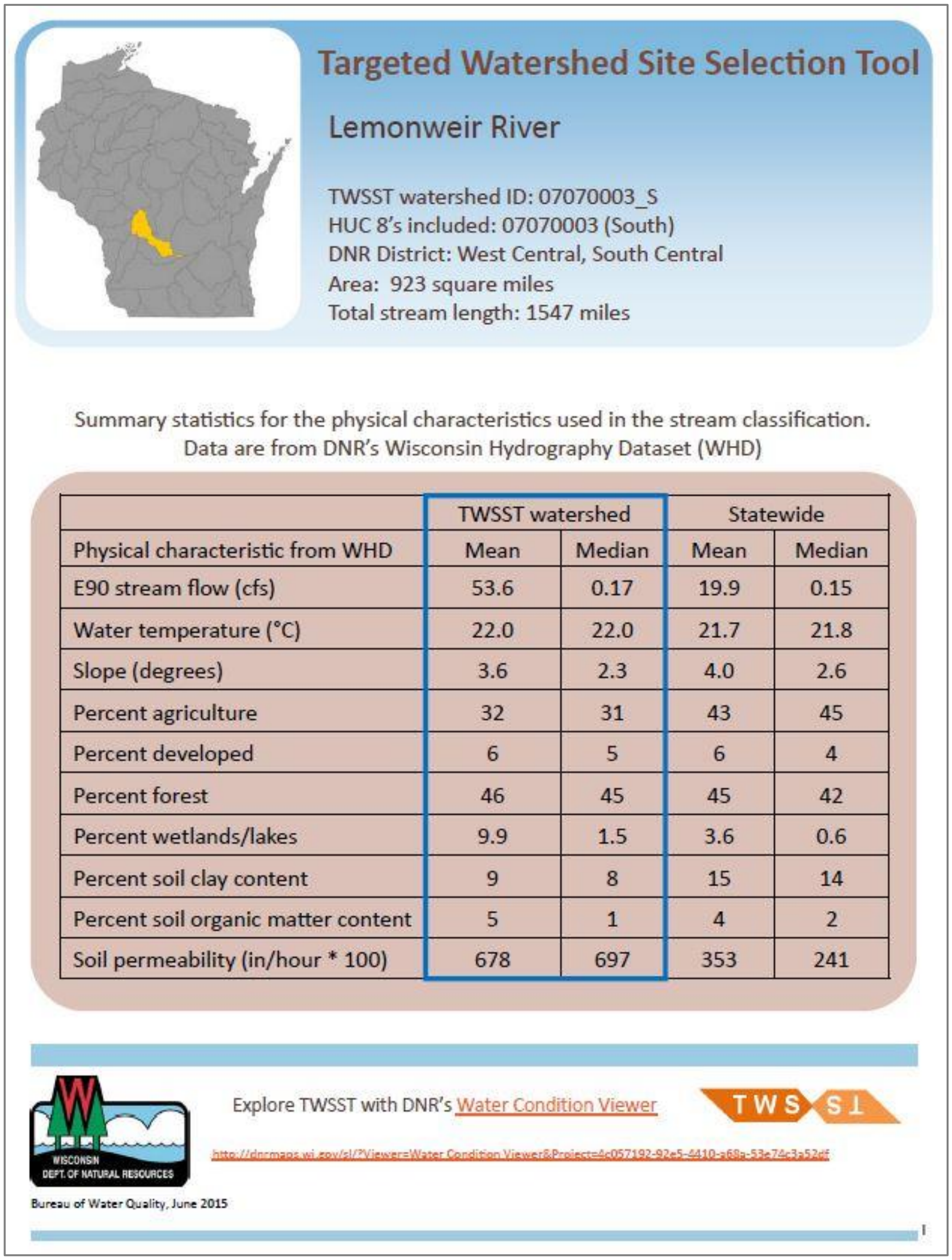
TWSST products are both spatial (e.g. maps) and statistical (e.g. boxplots). The primary products for each TWSST watershed are the same as those presented for test watersheds: 1) a color-coded map of the stream classification, 2) boxplots of the ten physical characteristics by stream group, and 3) boxplots of representative monitoring parameters by stream group. TWSST products can be used to analyze catchment scale variability in stream channel and landscape-level physical characteristics. TWSST products can also be used to estimate the spatial applicability of previous monitoring efforts in the catchment.

TWSST products are available as a four page summary report for each watershed and as map layers in WDNR's web-based Water Condition Viewer. A step by step user guide to viewing the TWSST model in the Water Condition Viewer is provided in Appendix C. The user guide describes how to access TWSST products and integrate them with TWA objectives and ancillary information (e.g. base maps and other spatial data). This section describes the TWSST watershed summary reports and how information contained in them can aid in the development of an effective and efficient monitoring design. Links to each summary report are provided in the Water Condition Viewer. We recommend the summary reports as an introduction to the TWSST classification for a given watershed and as a general reference document.

How can the TWSST tool inform a watershed monitoring design? (See Appendix D for examples)

1) An ideal monitoring design would collect data from each of the TWSST stream types in the watershed to capture within-watershed variability.
2) For stream monitoring locations that are selected for any purpose, estimate how far upstream that monitoring location likely represents by number and location of TWSST groups upstream.
3) From previously collected stream monitoring data, determine if those data are representative of the entire upstream area. If not, locate monitoring locations upstream on unique TWSST stream groups to capture spatial variability.
4) Determine vulnerable tributaries contributing to poor water quality downstream and most likely pollutants, for example, TWSST groups with high agriculture or developed land cover or high soil clay content.

The summary report for the Lemonweir River watershed is provided in Figures 27-30 as an example of the TWSST output. Page 1 of the report (Figure 27) contains an overview map showing the location of the watershed, general information about the watershed, and summary statistics for the ten physical characteristics used in the stream classification. Summary statistics are provided for the TWSST watershed and the entire state to enable comparisons. For example, soil clay content is very low in the Lemonweir River watershed and lower than the statewide average. Presence of wetlands/lakes is notably higher here compared to the whole state, while developed and forested land cover are typical for the state.



Targeted Watershed Site Selection Tool

Lemonweir River

TWSST watershed ID: 07070003_S
HUC 8's included: 07070003 (South)
DNR District: West Central, South Central
Area: 923 square miles
Total stream length: 1547 miles

Summary statistics for the physical characteristics used in the stream classification.
Data are from DNR's Wisconsin Hydrography Dataset (WHD)

	TWSST watershed		Statewide	
Physical characteristic from WHD	Mean	Median	Mean	Median
E90 stream flow (cfs)	53.6	0.17	19.9	0.15
Water temperature (°C)	22.0	22.0	21.7	21.8
Slope (degrees)	3.6	2.3	4.0	2.6
Percent agriculture	32	31	43	45
Percent developed	6	5	6	4
Percent forest	46	45	45	42
Percent wetlands/lakes	9.9	1.5	3.6	0.6
Percent soil clay content	9	8	15	14
Percent soil organic matter content	5	1	4	2
Soil permeability (in/hour * 100)	678	697	353	241

WISCONSIN DEPT. OF NATURAL RESOURCES

Explore TWSST with DNR's Water Condition Viewer

TWSST

http://dnrmaps.wi.gov/sl/?Viewer=Water Condition Viewer&Project=4c057192-92e5-4410-a68a-53e74c3a52df

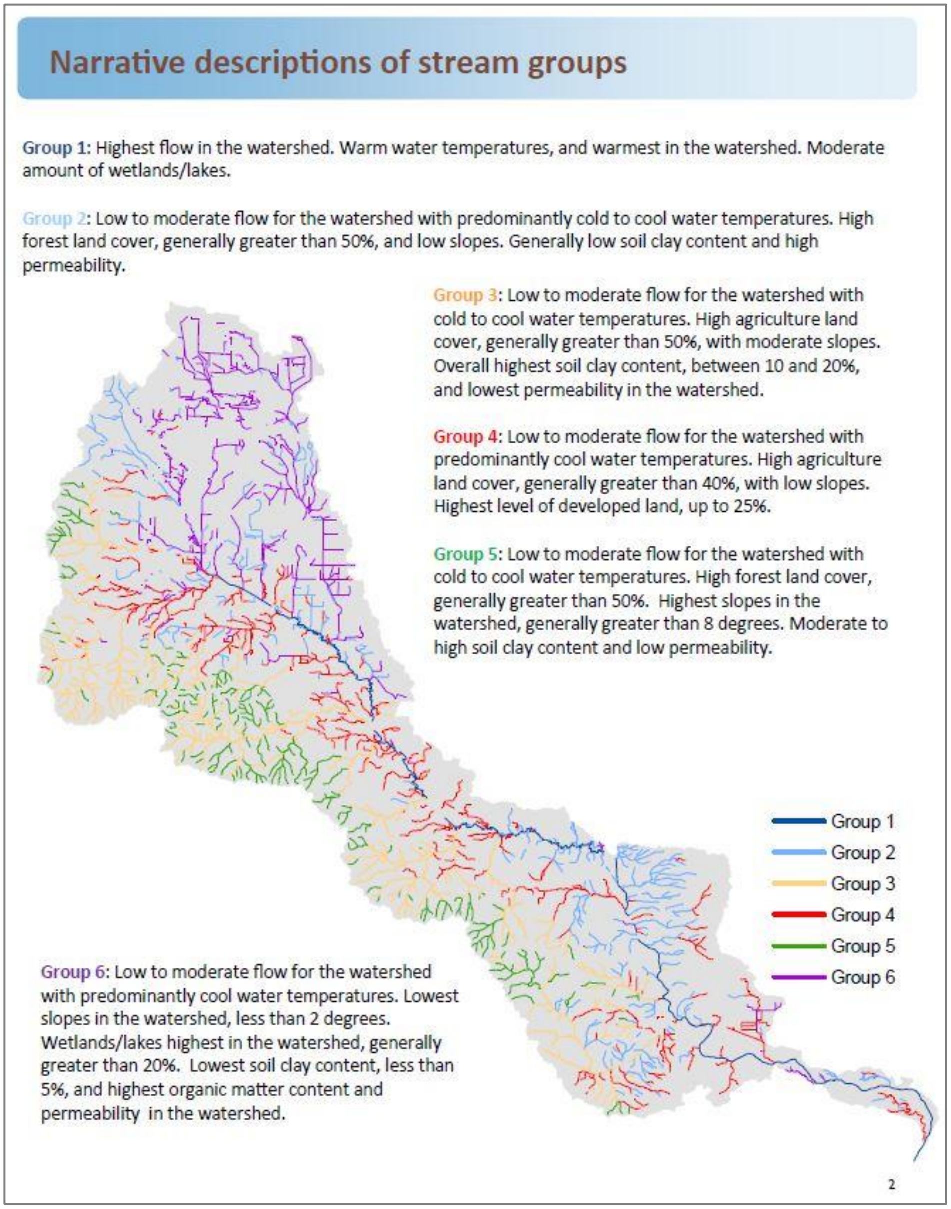
Bureau of Water Quality, June 2015

1

Figure 27. Page 1 of the summary report for the Lemonweir River TWSST watershed.

Page 2 of the report (Figure 28) contains a map illustrating the stream classification in the watershed. Narrative descriptions highlight the physical characteristics differentiating each group in the classification. Narrative descriptions are based on boxplots of the ten WHD physical characteristics used in the classification and inspection of various GIS map layers (e.g. aerial photography and base maps).

In most cases stream group numbers are assigned arbitrarily although there are some exceptions. We followed the convention of Group 1 always designating the group with the highest (median) stream flow and Group 2 always designating the group with the coldest median water temperature. All other group numbers can be considered arbitrary. Consequently, stream groups and their narrative descriptions are not comparable to groups in other TWSST watersheds. In other words, the classification and narratives in Figure 28 are unique to the Lemonweir River watershed.



Narrative descriptions of stream groups

Group 1: Highest flow in the watershed. Warm water temperatures, and warmest in the watershed. Moderate amount of wetlands/lakes.

Group 2: Low to moderate flow for the watershed with predominantly cold to cool water temperatures. High forest land cover, generally greater than 50%, and low slopes. Generally low soil clay content and high permeability.

Group 3: Low to moderate flow for the watershed with cold to cool water temperatures. High agriculture land cover, generally greater than 50%, with moderate slopes. Overall highest soil clay content, between 10 and 20%, and lowest permeability in the watershed.

Group 4: Low to moderate flow for the watershed with predominantly cool water temperatures. High agriculture land cover, generally greater than 40%, with low slopes. Highest level of developed land, up to 25%.

Group 5: Low to moderate flow for the watershed with cold to cool water temperatures. High forest land cover, generally greater than 50%. Highest slopes in the watershed, generally greater than 8 degrees. Moderate to high soil clay content and low permeability.

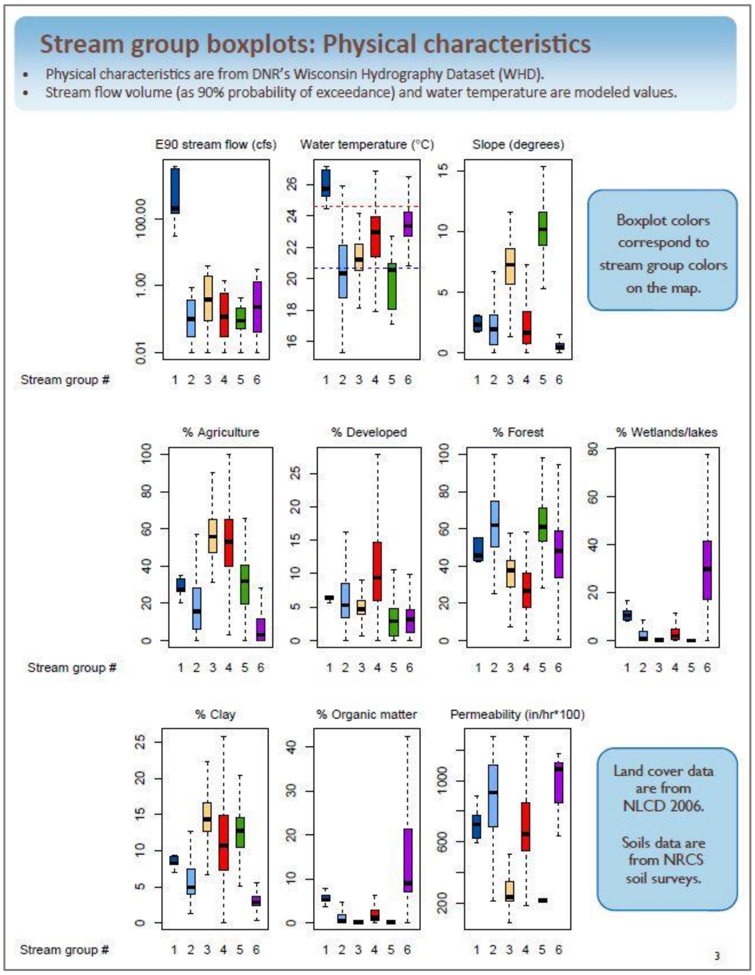
Group 6: Low to moderate flow for the watershed with predominantly cool water temperatures. Lowest slopes in the watershed, less than 2 degrees. Wetlands/lakes highest in the watershed, generally greater than 20%. Lowest soil clay content, less than 5%, and highest organic matter content and permeability in the watershed.

Figure 28. Page 2 of the summary report for the Lemonweir River TWSST watershed.

Page 3 of the summary report (Figure 29) contains boxplots by stream group of the ten physical characteristics used in the classification. The color scheme used for all boxplots is the same as that used for all maps (e.g. Figure 28). For all boxplots, the boxes are defined by the 25th and 75th percentiles, and the whiskers define the 5th and 95th percentiles. All stream flow boxplots are plotted on a logarithmic scale. Horizontal dotted blue lines in water temperature boxplots correspond to the threshold between cold and cool temperatures in the Natural Community system. Horizontal dotted red lines in water temperature boxplots corresponds to the threshold between cool and warm temperatures in the Natural Community system.

Like the groups narratives, the boxplots can be used to identify the physical characteristics differentiating each group in the classification. For example, Group 1 in the Lemonweir River watershed is primarily differentiated by stream flow volume, Group 5 by high slopes, and Group 6 by presence of wetlands/lakes. In cases where no single physical characteristic clearly differentiates a group (e.g. Group 4), pairwise comparisons are more informative. For example, compared to Group 5, Group 4 contains warmer streams with lower slopes and more developed land cover. In addition to illustrating how groups are differentiated, the boxplots can also be used to assess within group variability. For example, soil clay content is highly variable in Group 4 but very homogeneous in Groups 1 and 6.

One particularly useful application of this information relates to Group 1, which in almost all watersheds contains streams primarily differentiated by high flow volume. The boxplots for all the other physical characteristics for Group 1 can be used to determine monitoring needs along these Mainstems. Higher variability suggests more monitoring locations may be needed. In the case of the Lemonweir River watershed (Figure 29), there is minimal variability in all the other physical characteristics, suggesting that fewer monitoring locations may be needed along these Mainstems.



Stream group boxplots: Physical characteristics

- Physical characteristics are from DNR's Wisconsin Hydrography Dataset (WHD).
- Stream flow volume (as 90% probability of exceedance) and water temperature are modeled values.

Boxplot colors correspond to stream group colors on the map.

Land cover data are from NLCD 2006.

Soils data are from NRCS soil surveys.

3

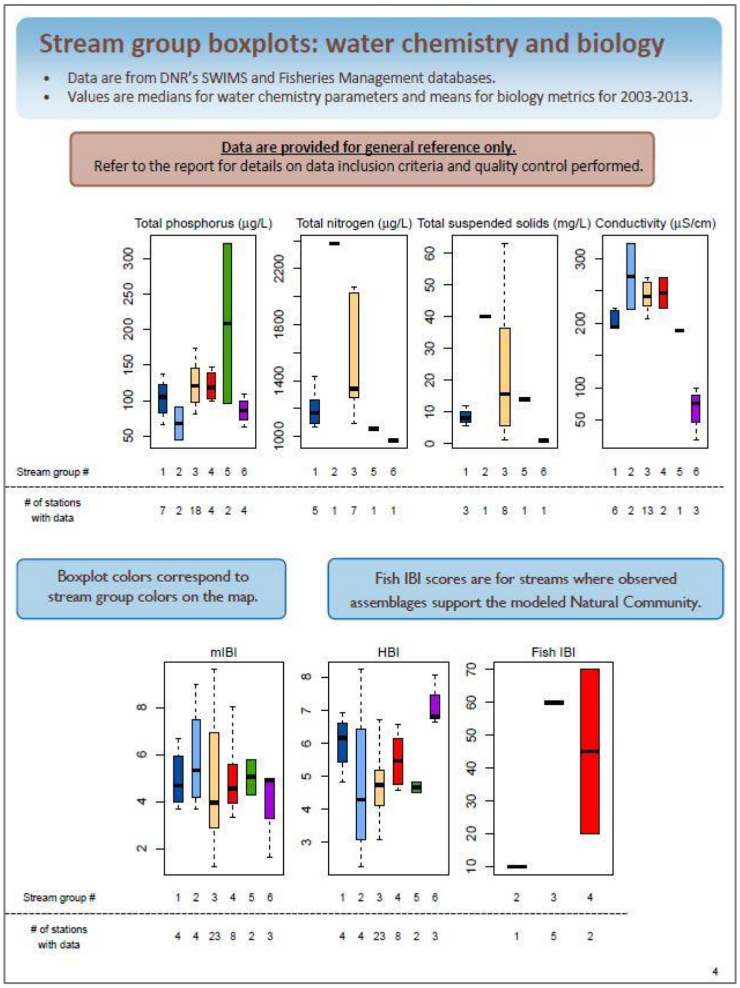
Figure 29. Page 3 of the summary report for the Lemonweir River TWSST watershed.

Page 4 of the summary report (Figure 30) contains boxplots of commonly monitored chemistry and biology parameters for each group in the classification. Reported values represent a subset of all monitoring data collected by WDNR and are provided for general reference only. Reported values are medians for water chemistry and means for biology metrics for the period 2003-2013. Reported fish IBIs are only for stream reaches where observed assemblages confirmed the modeled Natural Community. Refer to Section 2 for detailed information on quality control for monitoring parameters reported in TWSST products.

The boxplots can be used to identify stream groups with unique water chemistry and biology characteristics. For example, Group 6 has low TP and TN and extremely low TSS and conductivity compared to the other groups. Referring to the group narratives and boxplots of physical characteristics, this group is differentiated primarily by the presence of wetlands lakes and high soil organic matter content. Groups with high variability in water chemistry or biologic assessments (e.g. Group 3) may require more monitoring locations to adequately characterize conditions in the watershed.

Included below the boxplots is the number of stations in each group for which data is being reported. This information may be used to assess how extensively types of streams were monitored from 2003-2013. The number of stations is also important for interpreting the boxplots. For example, in Group 5, there are only two stations with TP data and values are very different, while Group 3 has 18 different stations with TP data and values are typically between 100-150 µg/L.

A user guide with step by step directions on how to use the TWSST model in the Water Condition Viewer is provided in Appendix C.


Stream group boxplots: water chemistry and biology

- Data are from DNR's SWIMS and Fisheries Management databases.
- Values are medians for water chemistry parameters and means for biology metrics for 2003-2013.

Data are provided for general reference only.
Refer to the report for details on data inclusion criteria and quality control performed.

Boxplot colors correspond to stream group colors on the map.

Fish IBI scores are for streams where observed assemblages support the modeled Natural Community.

Figure 30. Page 4 of the summary report for the Lemonweir River TWSST watershed.

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Appendix A

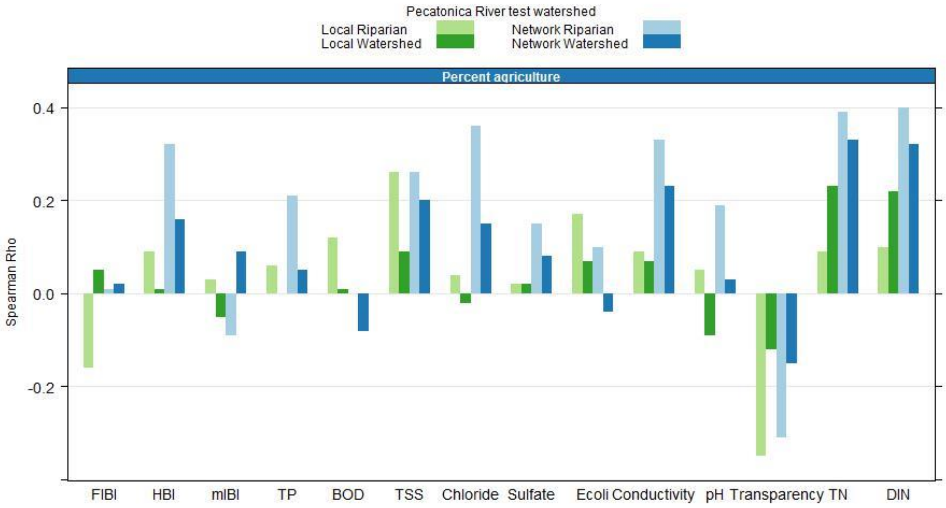
Spearman rank correlation coefficients

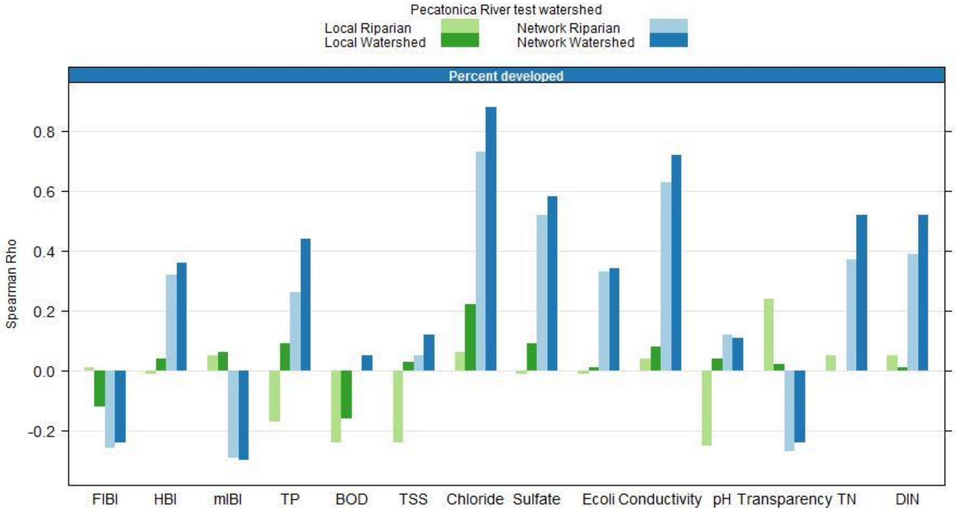
Complete results from the Spearman rank correlation analysis are provided here for the Pecatonica River and Upper Yellow River test watershed datasets, and for the statewide dataset. Correlations are between WHD physical characteristics and a suite of monitoring parameters characterizing water quality and biology. Correlations for WHD physical characteristics measured at only one spatial scale are provided as tables. Correlations for WHD physical characteristics measured at multiple spatial scales are provided as bar charts. Note that the test watersheds contain monitoring parameters not commonly collected statewide.

Pecatonica River watershed

Stream channel characteristic	**TP**	**TN**	**DIN**	**Trans**	**TSS**	**Cond**	**Chloride**	**Sulfate**	**pH**	**Chl a**	**BOD**	**Ecoli**	**HBI**	**mIBI**	**%EPT**	**FIBI**
Annual streamflow (E10)	0.02	-0.23	-0.21	-0.01	0.01	-0.15	0.20	0.08	**0.39**	**0.29**	-0.24	**-0.30**	0.01	-0.02	**0.34**	0.08
Annual streamflow (E50)	0.01	**-0.26**	-0.23	0.00	0.02	-0.19	0.15	0.06	**0.38**	**0.29**	**-0.24**	**-0.32**	0.01	-0.01	**0.33**	0.08
Annual streamflow (E90)	-0.01	**-0.28**	**-0.26**	0.00	0.01	-0.22	0.12	0.05	**0.39**	**0.26**	**-0.24**	**-0.32**	-0.01	0.00	**0.35**	0.07
Area normalized annual streamflow (E10)	0.11	**-0.27**	**-0.26**	0.08	-0.02	-0.23	0.08	0.12	0.21	0.18	-0.17	-0.24	0.04	-0.07	0.22	0.02
Area normalized annual streamflow (E50)	0.05	**-0.36**	**-0.36**	0.07	0.04	**-0.42**	-0.20	-0.07	0.17	0.16	-0.14	**-0.28**	-0.03	0.03	0.13	0.05
Area normalized annual streamflow (E90)	-0.04	**-0.53**	**-0.53**	0.13	0.02	**-0.58**	**-0.36**	-0.18	0.13	0.06	-0.13	**-0.34**	-0.13	0.12	**0.25**	0.03
Maximum daily mean water temperature	**0.39**	**0.46**	**0.47**	**-0.30**	0.22	**0.56**	**0.71**	**0.50**	0.20	**0.42**	0.03	0.20	**0.35**	-0.21	0.02	**-0.26**
June-August mean water temperature	**0.38**	**0.45**	**0.46**	**-0.30**	0.22	**0.55**	**0.71**	**0.50**	0.21	**0.42**	0.05	0.19	**0.33**	-0.20	0.03	-0.25
July mean water temperature	**0.38**	**0.45**	**0.46**	**-0.30**	0.22	**0.55**	**0.71**	**0.50**	0.21	**0.42**	0.05	0.19	**0.33**	-0.20	0.03	-0.25
Sinuosity	-0.15	0.04	0.07	-0.03	0.00	0.14	0.08	0.15	0.13	-0.06	0.06	-0.13	-0.22	**0.30**	0.24	0.09
Gradient	-0.01	0.24	0.22	0.01	-0.04	0.19	-0.06	-0.02	**-0.41**	**-0.32**	0.16	0.24	0.05	-0.06	**-0.35**	-0.14

Landscape-level characteristic	**TP**	**TN**	**DIN**	**Trans**	**TSS**	**Cond**	**Chloride**	**Sulfate**	**pH**	**Chl a**	**BOD**	**Ecoli**	**HBI**	**mIBI**	**%EPT**	**FIBI**
Slope	-0.22	**-0.70**	**-0.71**	0.16	0.01	**-0.79**	**-0.75**	**-0.48**	0.00	-0.16	-0.05	**-0.25**	**-0.32**	0.21	**0.28**	0.02
Agriculture	0.05	**0.33**	**0.32**	-0.15	0.20	0.23	0.15	0.08	0.03	0.14	-0.08	-0.04	0.16	0.09	-0.08	0.02
Developed	**0.44**	**0.52**	**0.52**	-0.24	0.12	**0.72**	**0.88**	**0.58**	0.11	**0.35**	0.05	**0.34**	**0.36**	**-0.30**	-0.18	-0.24
Forest	**-0.30**	**-0.59**	**-0.60**	0.16	-0.08	**-0.55**	**-0.55**	**-0.33**	0.01	-0.18	0.01	-0.16	**-0.41**	0.19	**0.26**	0.13
Wetlands/open water	**-0.25**	**-0.38**	**-0.37**	-0.01	0.00	**-0.40**	**-0.28**	0.03	**0.24**	0.09	-0.21	**-0.26**	-0.17	0.16	0.23	0.17
Soil percent sand	**-0.34**	**-0.72**	**-0.71**	**0.31**	-0.23	**-0.80**	**-0.61**	**-0.50**	0.03	-0.21	-0.15	**-0.47**	**-0.31**	0.19	0.22	0.12
Soil percent silt	**0.37**	**0.44**	**0.43**	**-0.51**	**0.36**	**0.62**	**0.60**	**0.49**	0.07	**0.44**	0.07	**0.48**	**0.41**	**-0.33**	-0.17	**-0.32**
Soil percent clay	**0.29**	**0.70**	**0.69**	**-0.28**	0.18	**0.72**	**0.51**	**0.41**	-0.12	0.15	0.19	**0.41**	**0.38**	-0.20	**-0.32**	-0.18
Hydraulic conductivity	**-0.40**	**-0.68**	**-0.66**	**0.34**	-0.24	**-0.75**	**-0.60**	**-0.41**	0.09	-0.24	-0.23	**-0.47**	**-0.41**	**0.31**	**0.29**	**0.30**
Permeability	0.08	**-0.39**	**-0.42**	-0.23	**0.32**	**-0.38**	**-0.30**	-0.19	0.03	**0.26**	-0.01	0.00	0.03	0.01	0.21	-0.23
Depth to bedrock	**0.27**	**0.39**	**0.40**	-0.14	0.01	**0.54**	**0.73**	**0.51**	0.11	**0.26**	-0.09	0.11	**0.27**	**-0.26**	-0.12	-0.04
Depth to water table	-0.20	0.00	-0.01	0.23	-0.14	-0.10	**-0.34**	-0.06	**-0.27**	**-0.29**	0.04	-0.09	-0.07	0.24	-0.15	0.00
Soil erodibility factor	0.12	**-0.33**	**-0.36**	**-0.28**	**0.28**	**-0.29**	-0.16	-0.15	0.13	**0.31**	0.00	0.05	0.04	-0.03	**0.25**	-0.22
Soil available water capacity	0.09	**-0.39**	**-0.40**	**-0.24**	0.20	**-0.34**	-0.22	-0.21	0.13	**0.27**	0.05	0.06	0.03	0.02	0.20	-0.20
Soil bulk density	0.18	**-0.32**	**-0.34**	**-0.37**	**0.39**	**-0.25**	-0.16	-0.10	0.17	**0.36**	0.04	0.12	0.15	-0.15	0.15	-0.25
Soil organic matter content	-0.16	**0.33**	**0.36**	**0.37**	**-0.40**	**0.29**	0.18	0.12	-0.20	**-0.38**	-0.03	-0.11	-0.09	0.09	-0.20	0.16
Soil cation exchange capacity	-0.02	**0.47**	**0.48**	0.06	-0.14	**0.36**	0.13	0.19	-0.11	-0.17	-0.02	0.06	0.15	-0.01	**-0.26**	0.23


Pecatonica River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent agriculture
Spearman Rho
0.4
0.2
0.0
-0.2
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN


Pecatonica River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent developed
Spearman Rho
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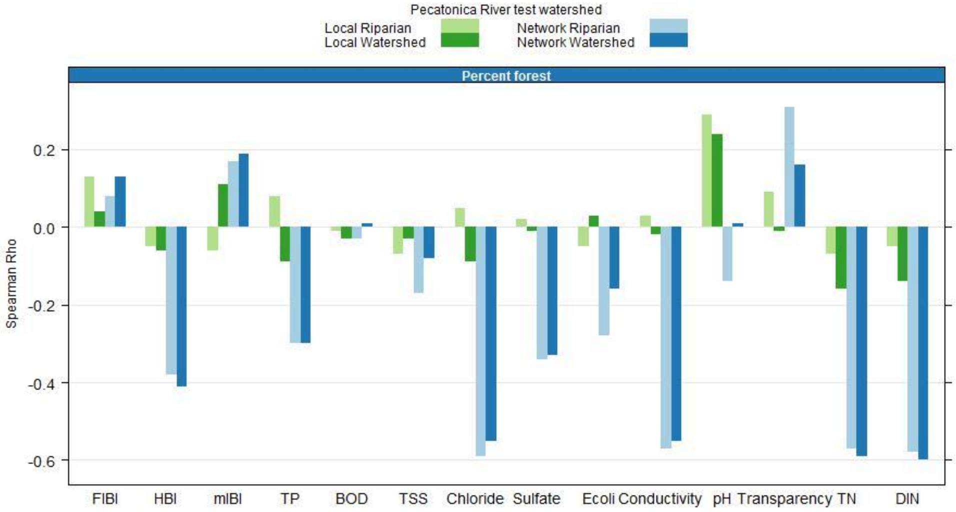
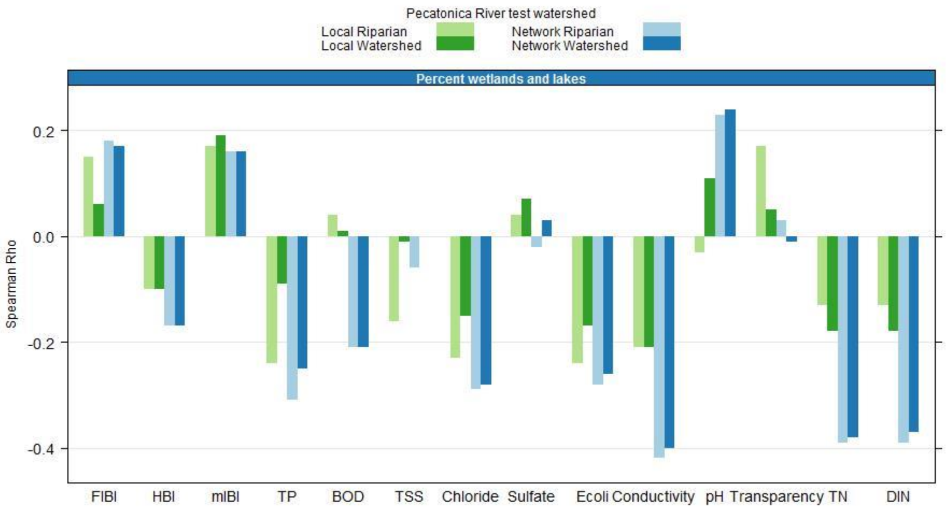
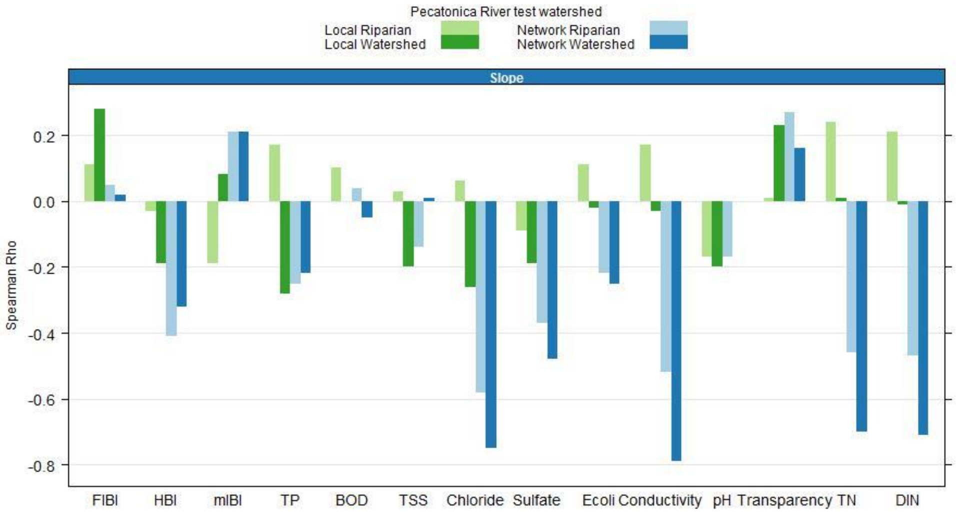
0.6
0.4
0.2
0.0
-0.2
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN


Pecatonica River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent forest
Spearman Rho
0.2
0.0
-0.2
-0.4
-0.6
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN


Pecatonica River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent wetlands and lakes
Spearman Rho
0.2
0.0
-0.2
-0.4
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN


Pecatonica River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Slope
Spearman Rho
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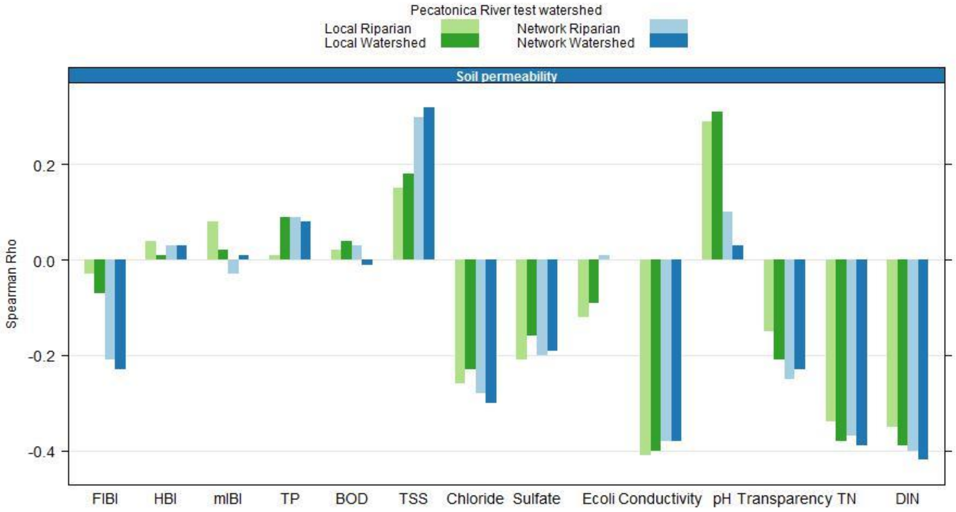
0.0
-0.2
-0.4
-0.6
-0.8
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN


Pecatonica River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Soil permeability
Spearman Rho
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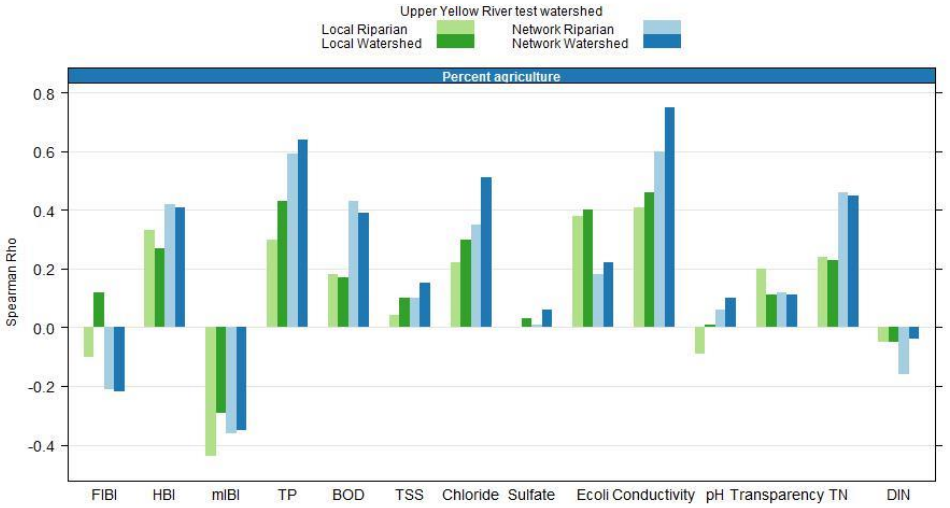
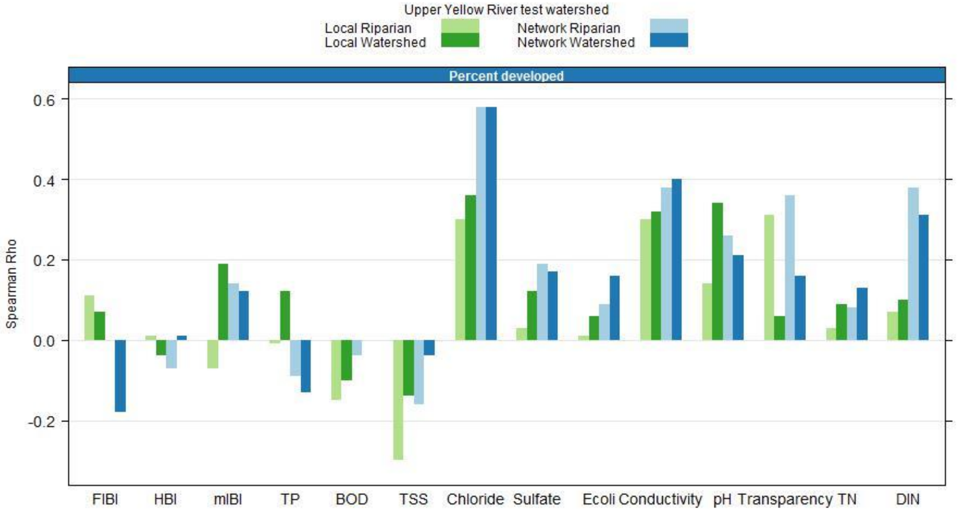
0.0
-0.2
-0.4
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN

Upper Yellow River watershed

Stream channel characteristic	**TP**	**TN**	**DIN**	**Trans**	**TSS**	**Cond**	**Chloride**	**Sulfate**	**pH**	**Chl a**	**BOD**	**Ecoli**	**HBI**	**mIBI**	**%EPT**	**FIBI**
Annual streamflow (E10)	0.15	-0.11	-0.11	-0.01	-0.19	-0.03	-0.10	0.01	**0.54**	**0.27**	-0.11	**-0.44**	**-0.43**	**0.56**	**0.64**	**0.35**
Annual streamflow (E50)	-0.02	-0.22	-0.02	0.04	-0.22	-0.13	-0.11	-0.02	**0.57**	**0.27**	-0.15	**-0.37**	**-0.54**	**0.69**	**0.72**	**0.39**
Annual streamflow (E90)	-0.11	-0.23	0.03	0.05	-0.20	-0.17	-0.09	-0.03	**0.56**	**0.28**	-0.13	**-0.32**	**-0.59**	**0.73**	**0.73**	**0.35**
Area normalized annual streamflow (E10)	**0.28**	-0.06	**-0.31**	-0.14	-0.16	-0.09	-0.25	0.08	0.23	0.12	-0.03	**-0.49**	-0.19	0.23	0.41	0.20
Area normalized annual streamflow (E50)	**-0.39**	**-0.32**	0.20	-0.04	-0.03	**-0.41**	-0.16	-0.03	**0.32**	0.18	-0.14	-0.15	**-0.57**	**0.70**	**0.54**	0.20
Area normalized annual streamflow (E90)	**-0.42**	-0.17	**0.37**	0.10	-0.10	**-0.26**	0.06	0.02	**0.32**	0.15	-0.12	0.09	**-0.51**	**0.64**	**0.43**	0.12
Maximum daily mean water temperature	**-0.38**	0.03	0.22	-0.06	-0.01	-0.10	0.15	0.12	0.10	0.15	0.05	0.06	**-0.38**	**0.43**	0.16	-0.11
June-August mean water temperature	**0.32**	0.15	**-0.31**	0.01	0.05	0.23	0.18	0.08	0.16	**0.33**	**0.44**	-0.05	0.05	0.00	-0.07	**-0.27**
July mean water temperature	**0.32**	0.16	**-0.32**	0.00	0.05	0.23	0.18	0.08	0.15	**0.33**	**0.45**	-0.04	0.06	0.00	-0.07	**-0.28**
Sinuosity	-0.13	-0.16	0.10	0.02	0.04	**-0.26**	-0.08	0.05	0.10	0.00	-0.12	0.03	**-0.33**	**0.37**	0.20	0.16
Gradient	**-0.28**	-0.04	0.20	-0.03	-0.02	-0.09	0.15	0.12	-0.18	-0.18	0.03	**0.42**	-0.04	-0.07	-0.21	0.07

Landscale-level characteristic	**TP**	**TN**	**DIN**	**Trans**	**TSS**	**Cond**	**Chloride**	**Sulfate**	**pH**	**Chl a**	**BOD**	**Ecoli**	**HBI**	**mIBI**	**%EPT**	**FIBI**
Slope	-0.22	0.01	**0.48**	**0.29**	-0.08	0.18	**0.41**	-0.08	**0.46**	0.03	-0.12	**0.31**	**-0.30**	**0.40**	0.15	0.14
Agriculture	**0.64**	**0.45**	-0.04	0.11	0.15	**0.75**	**0.51**	0.06	0.10	0.12	**0.39**	0.22	**0.41**	**-0.35**	**-0.31**	-0.22
Developed	-0.13	0.13	**0.31**	0.16	-0.04	**0.40**	**0.58**	0.17	0.21	0.08	0.00	0.16	0.01	0.12	-0.08	-0.18
Forest	**-0.54**	**-0.46**	0.00	-0.13	-0.12	**-0.81**	**-0.61**	-0.11	-0.11	-0.11	**-0.40**	**-0.27**	**-0.41**	**0.33**	**0.36**	0.20
Wetlands/open water	0.01	-0.19	-0.22	-0.17	-0.05	**-0.41**	**-0.38**	0.16	-0.10	0.17	0.00	-0.19	-0.18	0.20	**0.34**	0.10
Soil percent sand	-0.19	**0.26**	0.05	-0.10	0.06	0.11	-0.01	0.10	-0.23	0.00	0.19	-0.08	**0.35**	-0.20	**-0.32**	**-0.32**
Soil percent silt	**0.58**	0.15	-0.23	0.19	-0.02	**0.50**	0.19	-0.17	0.25	0.01	0.20	-0.03	**0.30**	-0.23	-0.03	-0.14
Soil percent clay	0.22	0.07	0.16	0.12	0.04	**0.43**	**0.50**	0.08	**0.38**	-0.08	-0.04	0.13	0.01	-0.06	-0.01	0.08
Hydraulic conductivity	**-0.51**	-0.19	0.21	-0.18	0.02	**-0.61**	**-0.31**	0.18	-0.19	-0.03	**-0.26**	0.01	**-0.34**	**0.27**	0.14	0.16
Permeability	**-0.60**	-0.18	**0.30**	-0.14	0.10	**-0.40**	-0.04	0.11	-0.18	-0.01	-0.09	0.09	-0.24	0.24	0.02	0.03
Depth to bedrock	**0.38**	-0.01	**-0.25**	0.02	0.01	0.10	-0.18	-0.08	0.02	-0.06	0.03	-0.17	0.24	**-0.32**	-0.06	-0.11
Depth to water table	**-0.45**	-0.14	**0.26**	0.06	0.03	-0.15	0.16	-0.04	0.00	0.02	-0.02	0.12	**-0.32**	**0.32**	0.13	0.13
Soil erodibility factor	**0.58**	0.19	-0.24	0.14	-0.10	**0.37**	0.06	-0.04	0.20	0.01	0.10	-0.10	0.26	**-0.26**	-0.03	-0.06
Soil available water capacity	**0.52**	**0.34**	-0.15	0.21	-0.08	**0.57**	0.21	-0.04	**0.30**	0.02	0.22	-0.10	0.25	-0.16	-0.13	-0.12
Soil bulk density	**0.59**	0.21	-0.24	0.11	-0.09	**0.39**	0.07	0.00	0.21	0.03	0.09	-0.13	**0.27**	-0.25	-0.04	-0.07
Soil organic matter content	**-0.57**	-0.13	**0.28**	-0.08	0.03	**-0.31**	-0.03	0.08	-0.12	0.01	-0.11	0.06	**-0.28**	**0.30**	0.06	0.07
Soil cation exchange capacity	**-0.41**	-0.08	**0.28**	-0.09	-0.25	-0.15	0.01	**0.36**	0.12	-0.19	-0.24	0.10	-0.08	0.00	-0.04	0.00


Upper Yellow River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent agriculture
Spearman Rho
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN


Upper Yellow River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent developed
Spearman Rho
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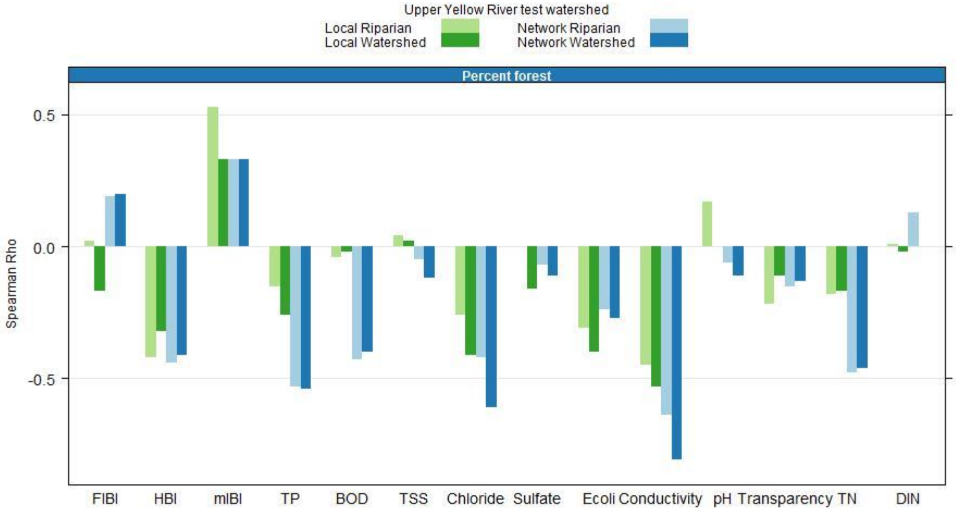
0.4
0.2
0.0
-0.2
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN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Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent forest
Spearman Rho
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-0.5
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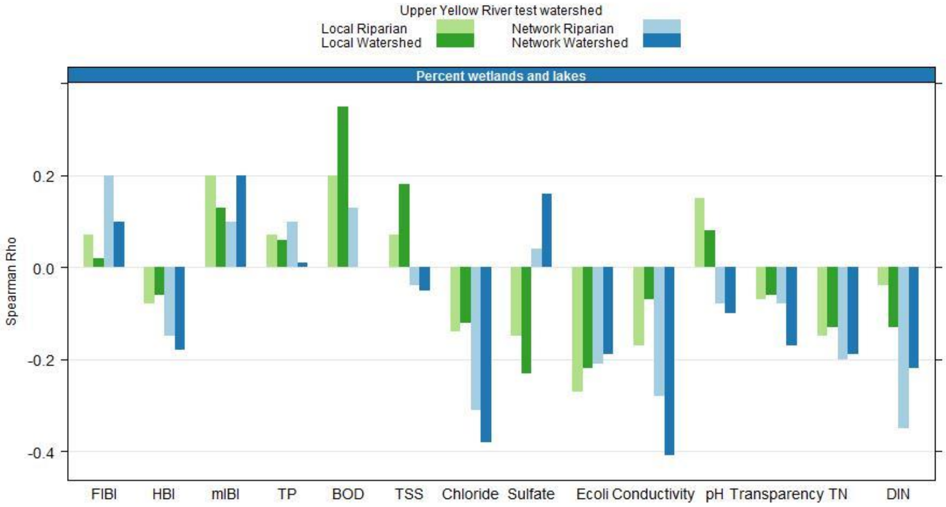
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN


Upper Yellow River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent wetlands and lakes
Spearman Rho
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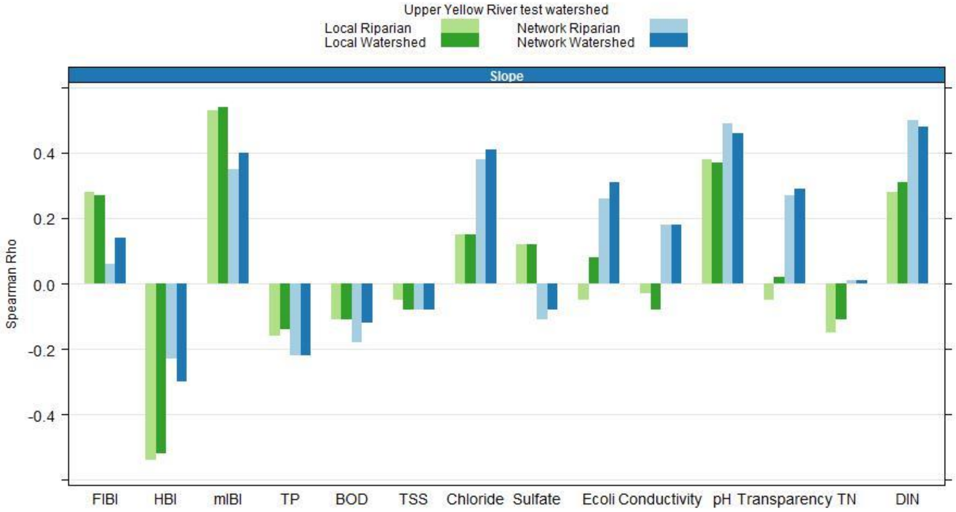
0.0
-0.2
-0.4
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN


Upper Yellow River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Slope
Spearman Rho
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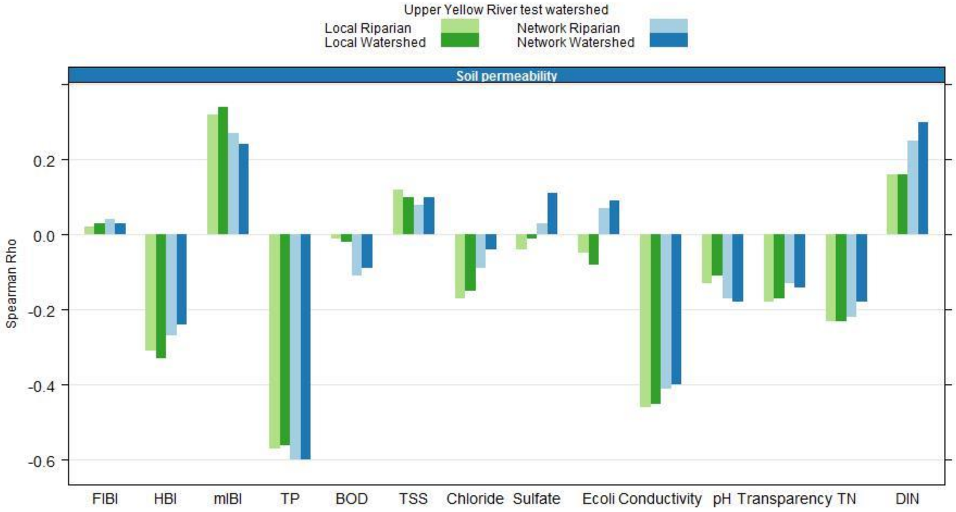
-0.4
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN


Upper Yellow River test watershed
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Soil permeability
Spearman Rho
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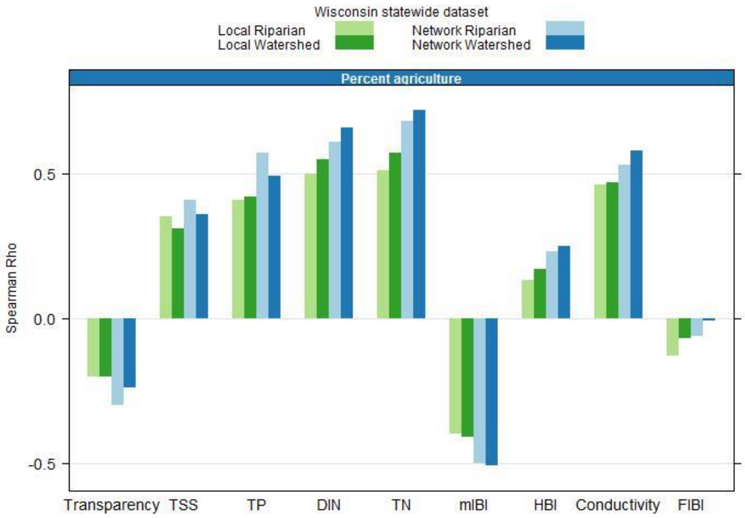
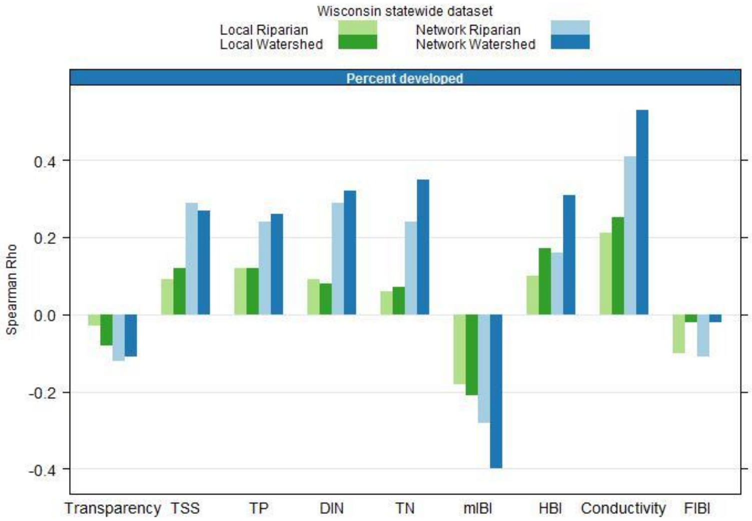
-0.4
-0.6
FIBI
HBI
mIBI
TP
BOD
TSS
Chloride
Sulfate
Ecoli
Conductivity
pH
Transparency
TN
DIN

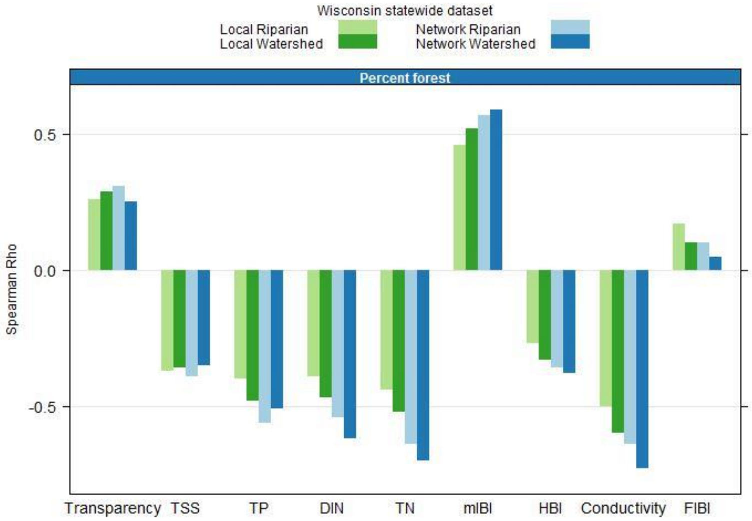
Statewide

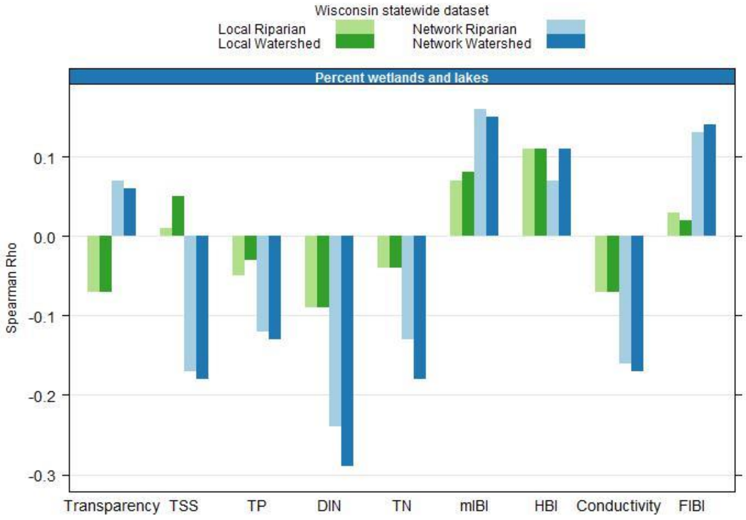
Stream channel characteristic	TP	TN	DIN	Trans	TSS	Cond	HBI	mIBI	%EPT	FIBI
Annual streamflow (E10)	-0.02	**-0.12**	**-0.16**	**-0.13**	-0.03	**-0.08**	**0.04**	**0.09**	**0.27**	**0.32**
Annual streamflow (E50)	**-0.11**	**-0.11**	**-0.09**	**-0.08**	0.00	**-0.10**	**-0.11**	**0.16**	**0.34**	**0.30**
Annual streamflow (E90)	**-0.15**	**-0.11**	**-0.06**	**-0.05**	0.01	**-0.13**	**-0.21**	**0.21**	**0.36**	**0.25**
Area normalized annual streamflow (E10)	**0.06**	**-0.20**	**-0.37**	**-0.11**	**-0.10**	**-0.05**	**0.24**	**0.04**	**0.04**	**0.18**
Area normalized annual streamflow (E50)	**-0.29**	**-0.13**	0.02	**0.06**	0.05	**-0.13**	**-0.30**	**0.25**	**0.24**	**0.04**
Area normalized annual streamflow (E90)	**-0.28**	**-0.11**	**0.09**	**0.10**	**0.08**	**-0.17**	**-0.40**	**0.26**	**0.22**	**-0.04**
Maximum daily mean water temperature	**0.07**	-0.03	**-0.16**	**-0.14**	-0.02	**0.06**	**0.28**	**-0.05**	0.02	**0.22**
June-August mean water temperature	**0.05**	0.04	**-0.11**	**-0.10**	-0.05	**0.18**	**0.32**	**-0.10**	-0.03	**0.21**
July mean water temperature	**0.04**	0.03	**-0.11**	**-0.10**	-0.05	**0.18**	**0.32**	**-0.09**	-0.02	**0.21**
Sinuosity	**-0.11**	0.03	**0.06**	**0.06**	**-0.07**	-0.04	**-0.06**	**0.09**	**0.10**	**0.16**
Gradient	**-0.07**	-0.02	**0.05**	**0.19**	**-0.06**	**-0.05**	**-0.24**	**0.06**	**-0.04**	**-0.19**

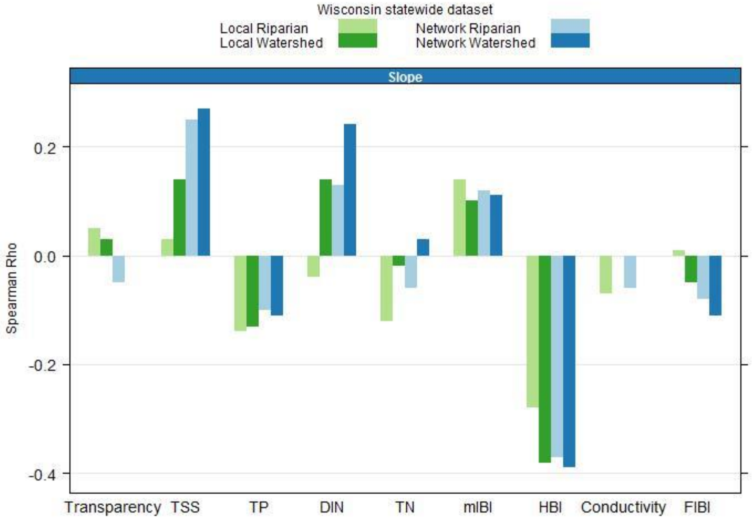
Landscape-level physical characteristic	TP	TN	DIN	Trans	TSS	Cond	HBI	mIBI	%EPT	FIBI
Slope	**-0.05**	**0.05**	**0.26**	0.01	**0.23**	0.00	**-0.38**	**0.11**	**0.12**	**-0.13**
Agriculture	**0.46**	**0.72**	**0.67**	**-0.24**	**0.30**	**0.57**	**0.27**	**-0.51**	**-0.26**	0.00
Developed	**0.24**	**0.33**	**0.28**	**-0.13**	**0.25**	**0.54**	**0.32**	**-0.40**	**-0.17**	-0.01
Forest	**-0.47**	**-0.70**	**-0.62**	**0.27**	**-0.32**	**-0.74**	**-0.39**	**0.59**	**0.31**	**0.03**
Wetlands/open water	**-0.12**	**-0.20**	**-0.34**	0.04	**-0.18**	**-0.18**	**0.10**	**0.15**	**0.10**	**0.15**
Soil percent sand	**-0.38**	**-0.44**	**-0.38**	**0.35**	**-0.41**	**-0.52**	**-0.19**	**0.38**	**0.19**	**0.07**
Soil percent silt	**0.40**	**0.45**	**0.40**	**-0.23**	**0.30**	**0.45**	**0.18**	**-0.36**	**-0.17**	0.01
Soil percent clay	**0.41**	**0.50**	**0.45**	**-0.37**	**0.40**	**0.62**	**0.27**	**-0.46**	**-0.24**	**-0.08**
Hydraulic conductivity	**-0.41**	**-0.33**	**-0.24**	**0.28**	**-0.28**	**-0.39**	**-0.27**	**0.35**	**0.21**	0.03
Permeability	**-0.34**	**-0.28**	**-0.20**	**0.24**	**-0.24**	**-0.33**	**-0.20**	**0.29**	**0.18**	**0.04**
Depth to bedrock	**-0.21**	**-0.13**	**-0.20**	**0.18**	**-0.26**	**0.07**	**0.16**	**0.07**	-0.02	**0.13**
Depth to water table	0.03	**0.35**	**0.53**	-0.02	**0.29**	**0.27**	**-0.24**	**-0.06**	0.00	**-0.11**
Soil erodibility factor	**0.44**	**0.45**	**0.40**	**-0.28**	**0.33**	**0.51**	**0.22**	**-0.42**	**-0.20**	**-0.05**
Soil available water capacity	**0.23**	**0.28**	**0.18**	**-0.30**	**0.28**	**0.25**	**0.09**	**-0.19**	**-0.11**	-0.02
Soil bulk density	**0.32**	**0.13**	**0.17**	**0.04**	0.00	**0.09**	**0.12**	**-0.20**	**-0.09**	**-0.04**
Soil organic matter content	**-0.30**	**-0.30**	**-0.40**	**0.14**	**-0.28**	**-0.14**	**0.12**	**0.16**	**0.05**	**0.11**
Soil cation exchange capacity	**-0.08**	**0.14**	**0.06**	**-0.08**	-0.01	**0.19**	**0.09**	0.01	-0.03	**0.04**

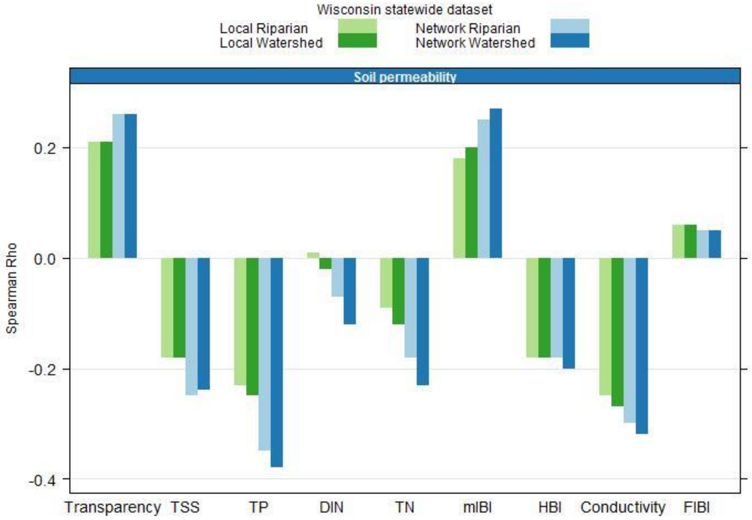

Wisconsin statewide dataset
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent agriculture
Spearman Rho
0.5
0.0
-0.5
Transparency
TSS
TP
DIN
TN
mIBI
HBI
Conductivity
FIBI


Wisconsin statewide dataset
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent developed
Spearman Rho
0.4
0.2
0.0
-0.2
-0.4
Transparency
TSS
TP
DIN
TN
mIBI
HBI
Conductivity
FIBI


Wisconsin statewide dataset
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent forest
Spearman Rho
0.5
0.0
-0.5
Transparency
TSS
TP
DIN
TN
mIBI
HBI
Conductivity
FIBI


Wisconsin statewide dataset
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Percent wetlands and lakes
Spearman Rho
0.1
0.0
-0.1
-0.2
-0.3
Transparency
TSS
TP
DIN
TN
mIBI
HBI
Conductivity
FIBI


Wisconsin statewide dataset
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Slope
Spearman Rho
0.2
0.0
-0.2
-0.4
Transparency
TSS
TP
DIN
TN
mIBI
HBI
Conductivity
FIBI


Wisconsin statewide dataset
Local Riparian
Local Watershed
Network Riparian
Network Watershed
Soil permeability
Spearman Rho
0.2
0.0
-0.2
-0.4
Transparency
TSS
TP
DIN
TN
mIBI
HBI
Conductivity
FIBI

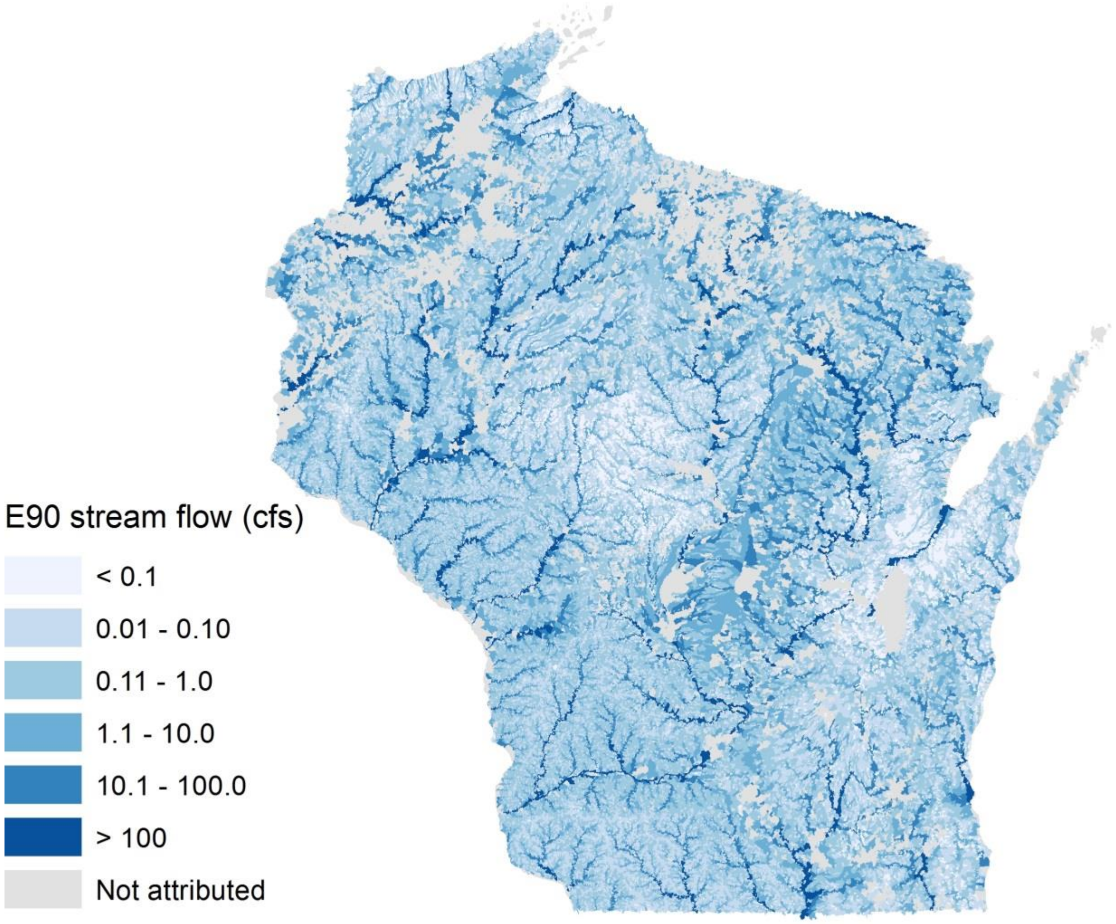
Appendix B

Maps of WHD variables used in the TWSST stream classification

This appendix contains maps of the ten physical characteristics from WHD used in the TWSST stream classification.

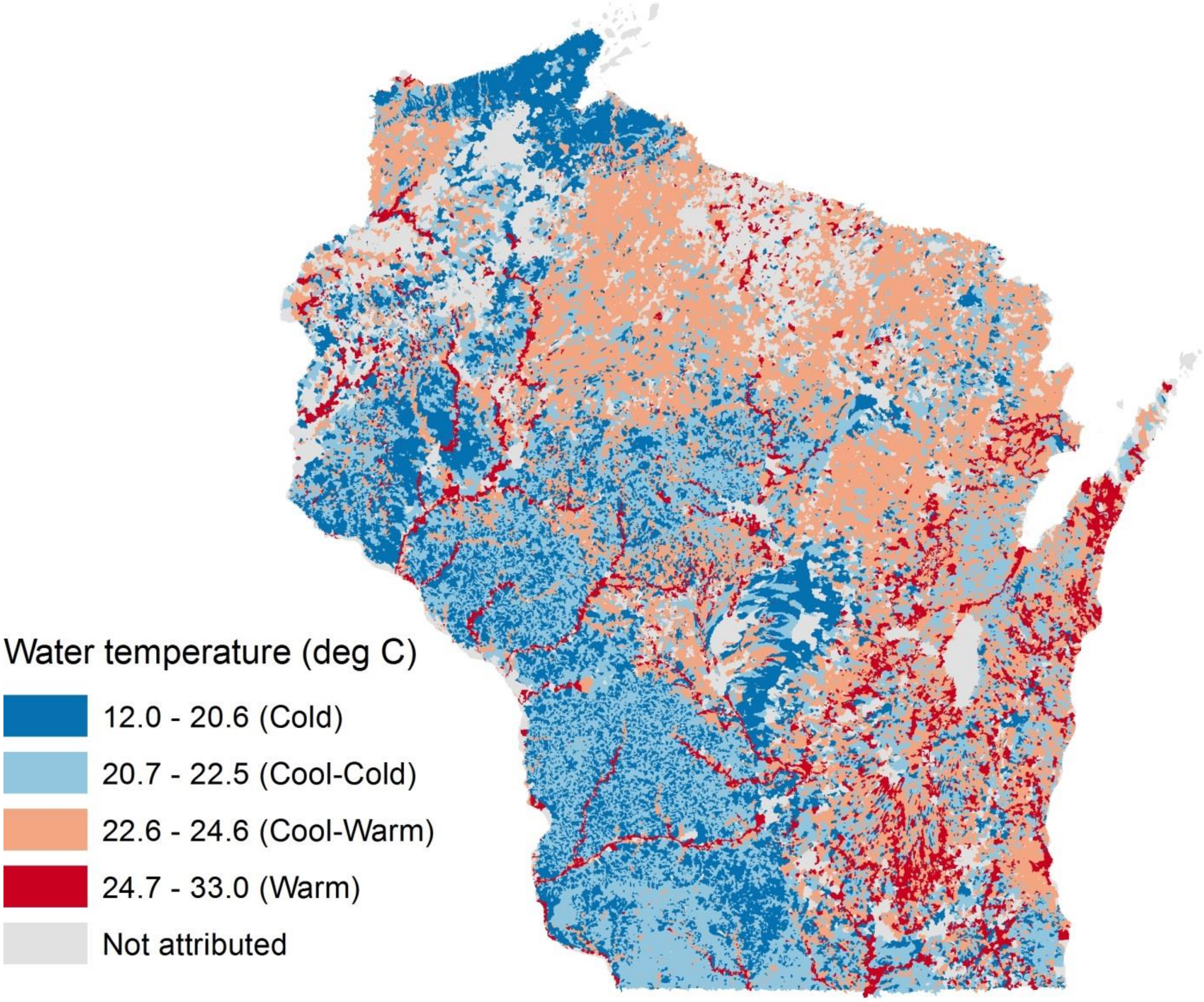
Modeled stream flow volume

Modeled stream flow volume is based on the Natural Community annual 90 percent probability of exceedance in cfs and is considered a baseflow measurement. Stream groups in the TWSST model are not classified using the same breakpoints as the Natural Community model but use the same data to develop the groups. Stream baseflow strongly influences fish community structure but has a lesser effect on macroinvertebrate communities. This model does not measure stream flow variability (or flashiness) which can have large effects on structuring aquatic communities and the relative impacts sediment and nutrient loading have on streams.



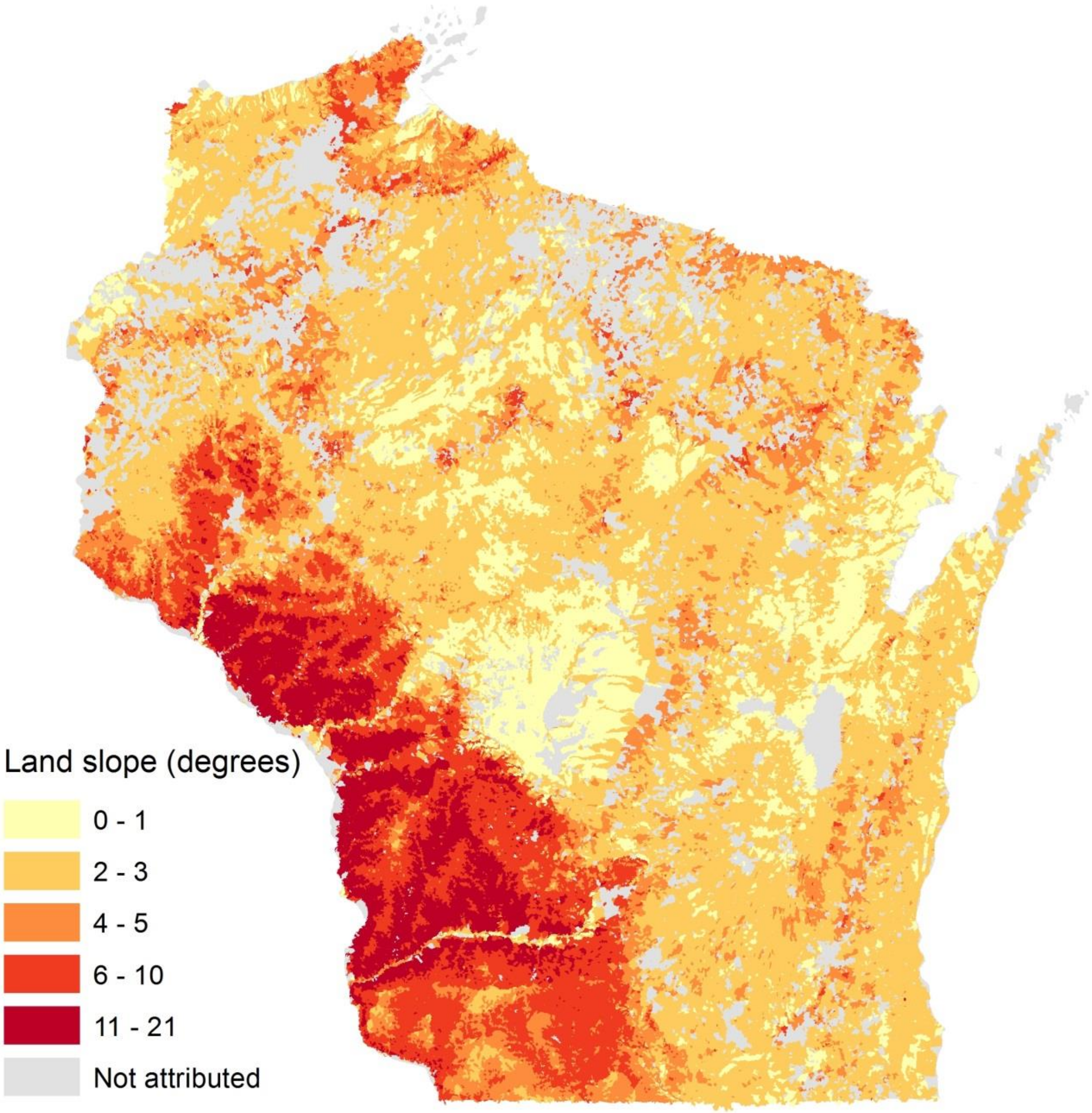
Modeled water temperature

Modeled water temperature is based on the Natural Community maximum daily mean water temperature (^{o}C). Stream groups in the TWSST model are not classified using the same breakpoints as the Natural Community model but use the same data to develop the groups. Water temperature strongly influences the structure of fish communities. Temperature has a lesser effect on macroinvertebrate communities, except that warm water systems are able to hold less dissolved oxygen which may prevent some very sensitive taxa from colonizing those streams. In Wisconsin, coldwater streams are associated with more groundwater inputs and warmwater streams with more overland flow.



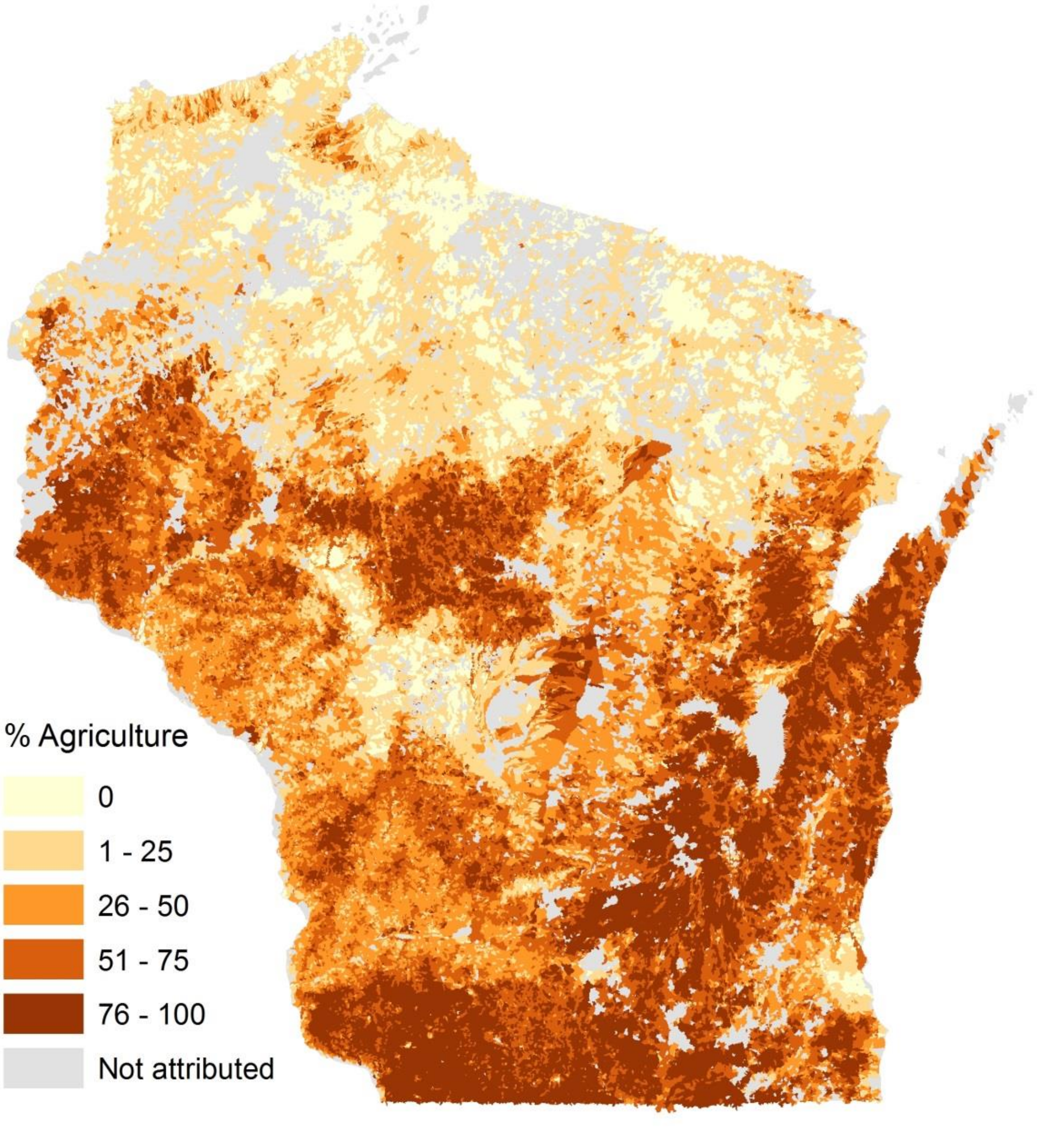
Land slope

This variable is measured as the average slope (in degrees) of the entire upstream watershed for a particular stream reach. In watersheds with steeper slopes rainwater will typically run off faster into the valley bottoms and into the streams, although this depends on the permeability of the soils or bedrock material. Areas of high slopes and anthropogenic land uses have high potential for soil erosion and corresponding impacts on stream systems. Streams with steep gradients (measured as the channel slope) may have the ability to mitigate this phenomenon because of increased stream velocity flushing sediments and depositing them at a lower gradient section downstream.



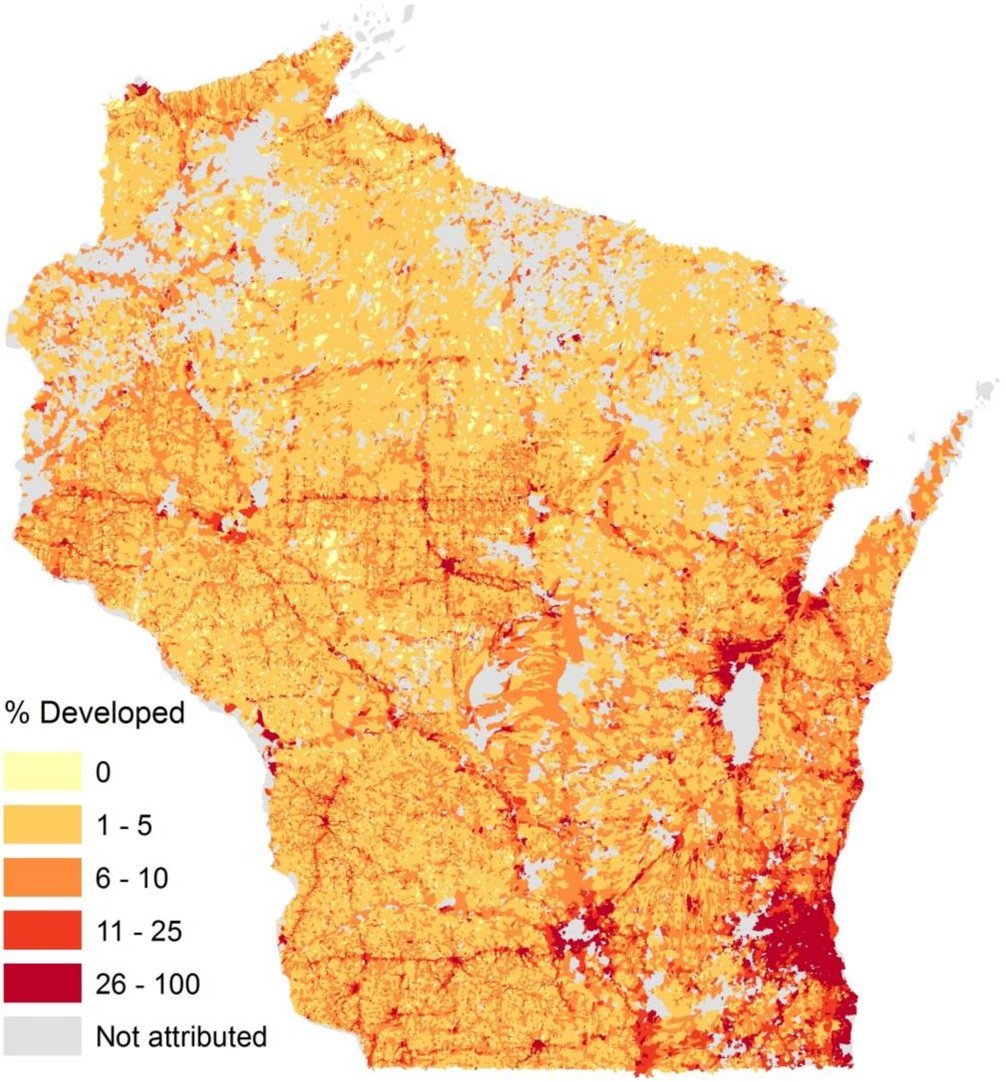
Agricultural land cover

Percent agricultural land cover was calculated as the sum of the row crop and pasture land classes from the 2006 National Land Cover Dataset (NLCD). Agricultural land use can affect water quality through stream modifications such as removal of riparian vegetation and channel/habitat modifications. Agricultural land use can also lead to changes in water quality through a variety of land use practices that alter pathways and rates of sediment and nutrient loading.



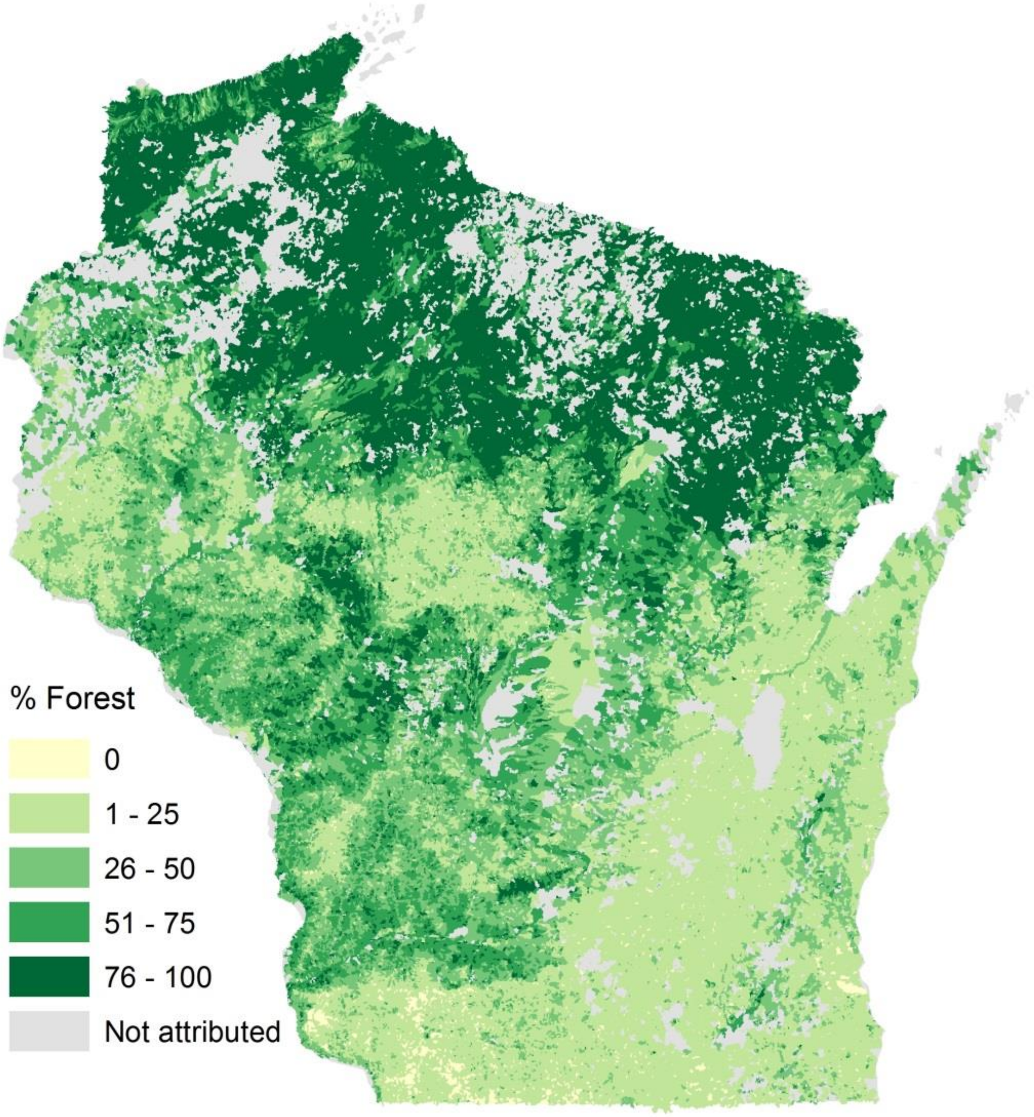
Developed land cover

Percent developed land cover was calculated as the sum of the open, low, medium, and high developed classes from the 2006 National Land Cover Dataset (NLCD). Developed land cover is generally associated with impervious surfaces where rainwater runs off quickly, carrying pollutants to streams and often resulting in flashy systems. Unique pollutants such as metals, pesticides, and volatile organics may also be present. Percent developed land cover does not take into account the location of point source discharges.



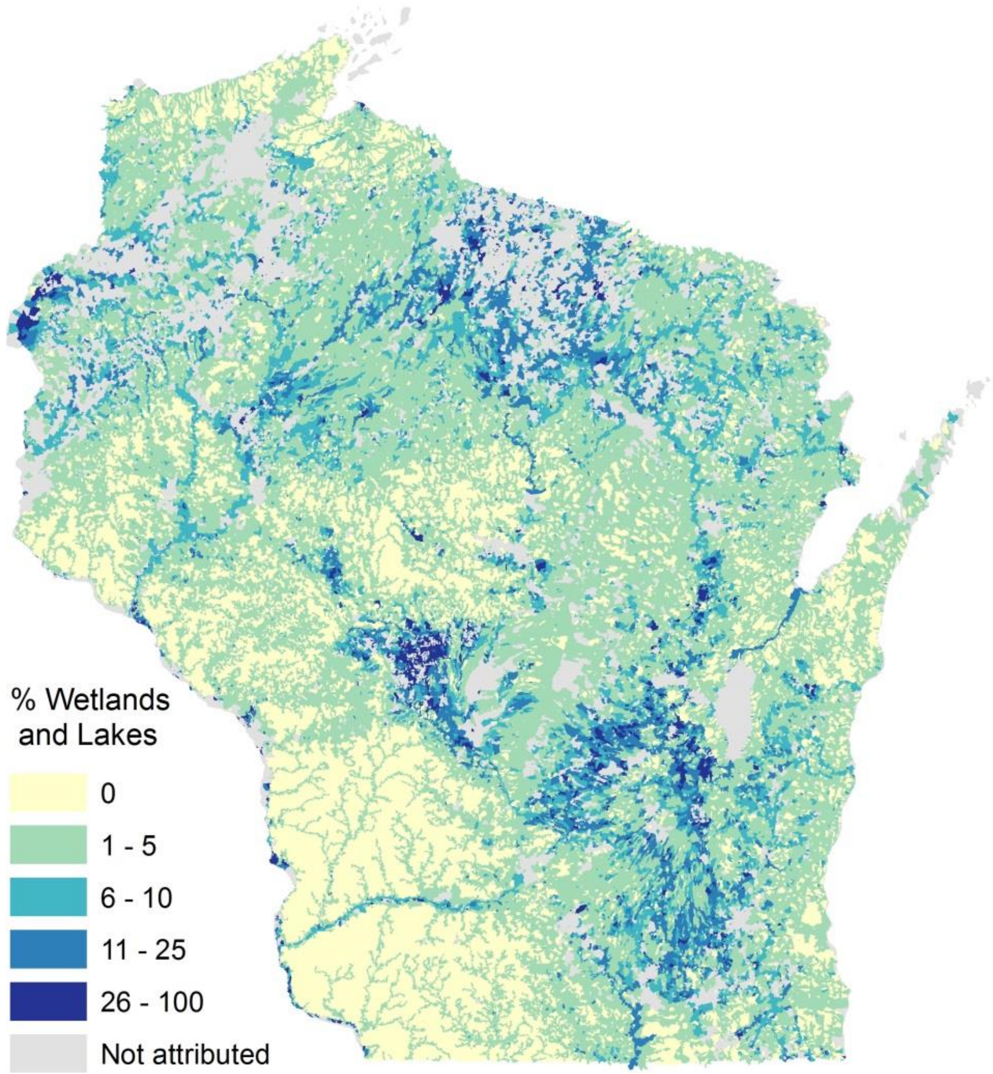
Forested land cover

Percent forested land cover was calculated as the sum of deciduous, evergreen, mixed forest, and forested wetland classes from the 2006 National Land Cover Dataset (NLCD). More forested land cover in a watershed generally relates to better water quality. For example, tree roots may extend into shallow aquifers to intercept nutrients before they enter the stream system. Surface runoff and soil erosion is limited by rainfall interception in the canopy, the protective cover of leaf litter on the forest floor, and soil stability provided by established vegetation. Percent forested land cover does not account for management practices such as logging which may contribute to intermittent water quality problems.



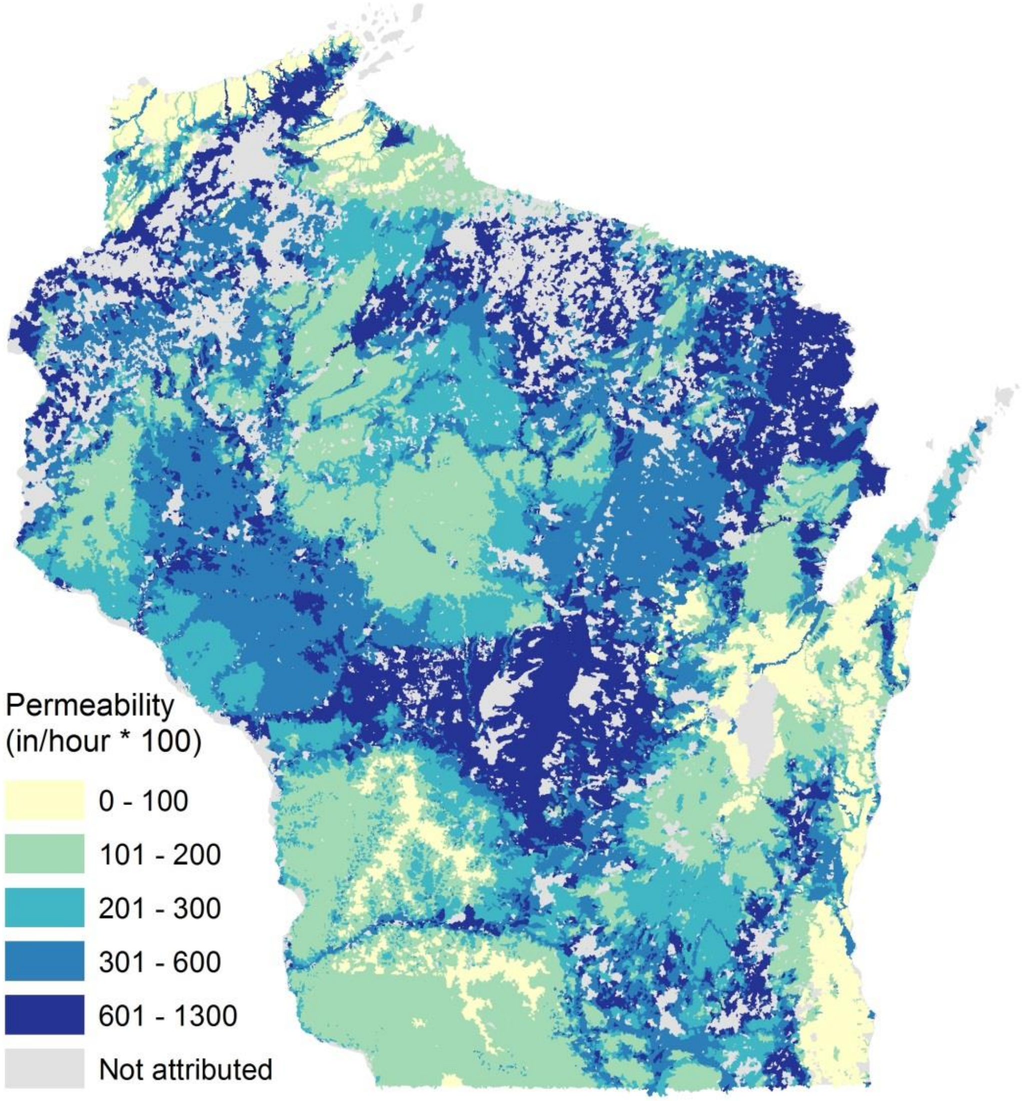
Wetlands and lakes

Percent wetlands and lakes was calculated as the sum of the emergent wetlands and open water classes from the 2006 National Land Cover Dataset (NLCD). The presence of wetlands and lakes in watersheds can result in a variety of impacts on stream systems. Wetlands and lakes trap and hold rainfall or water from upstream tributaries, allow a number of biogeochemical processes on chemical constituents to occur. Upstream wetlands and lakes usually mediate surface runoff by trapping sediments and stabilizing stream flow, but chemical composition of the water leaving these systems may vary depending on the type of wetland or lake and seasonal patterns. Streams in watersheds dominated by wetlands may have naturally reduced dissolved oxygen, low pH, and limited aquatic life potential.



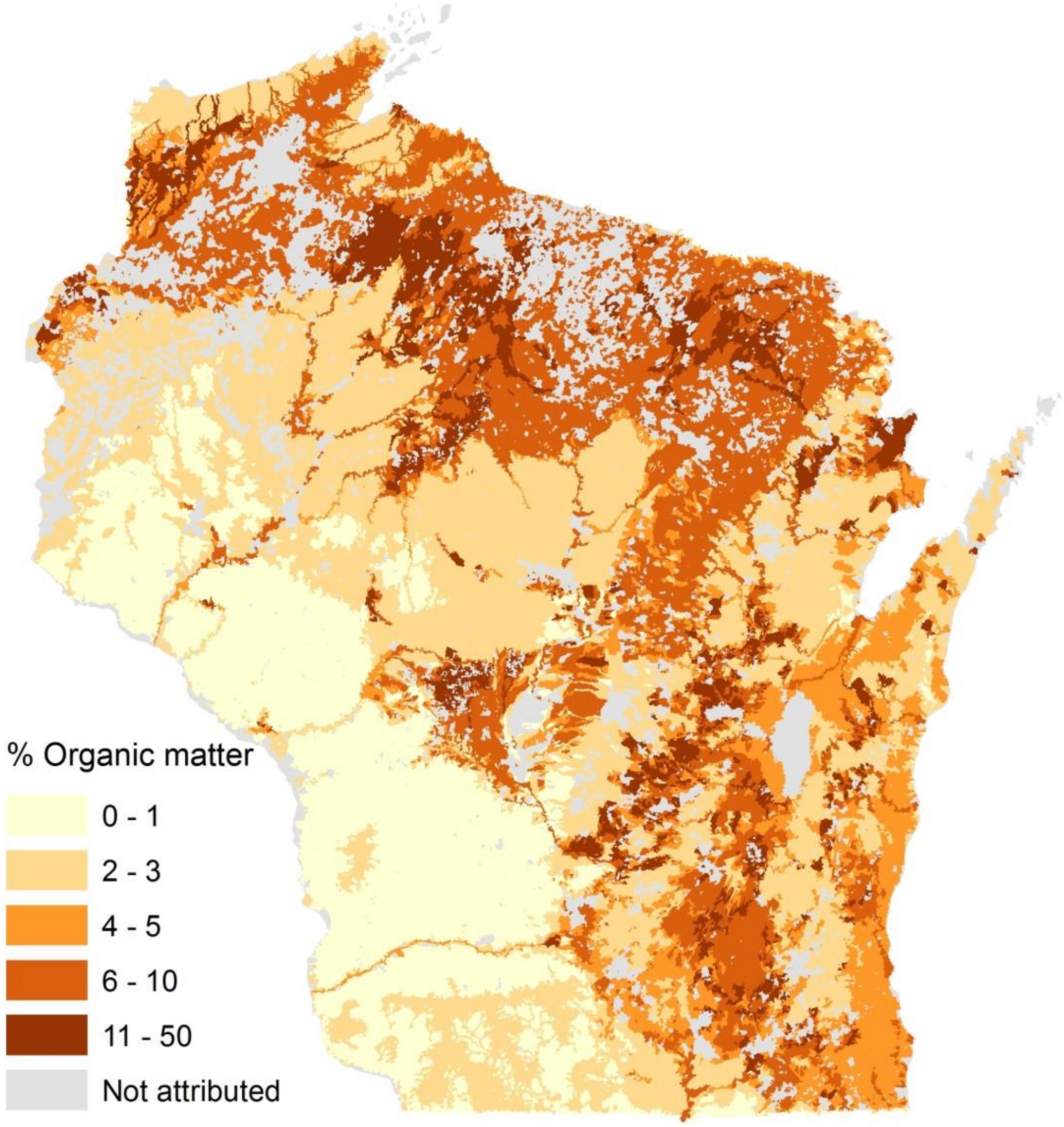
Soil permeability

Soil permeability is a measure of the rate (inches per hour) at which water is transmitted through soil pore spaces. Highly permeable soils, such as sandy soils, will absorb and filter water quickly, generally leading to better water quality. Such soils tend to retain very little water. Low soil permeability associated with compaction or certain soil structures will lead to more surface runoff and potential for more sediment, nutrients, and pollutants to enter the stream. Low soil permeability may also lead to flashier stream systems where water levels rise and fall quickly before and after storm events.



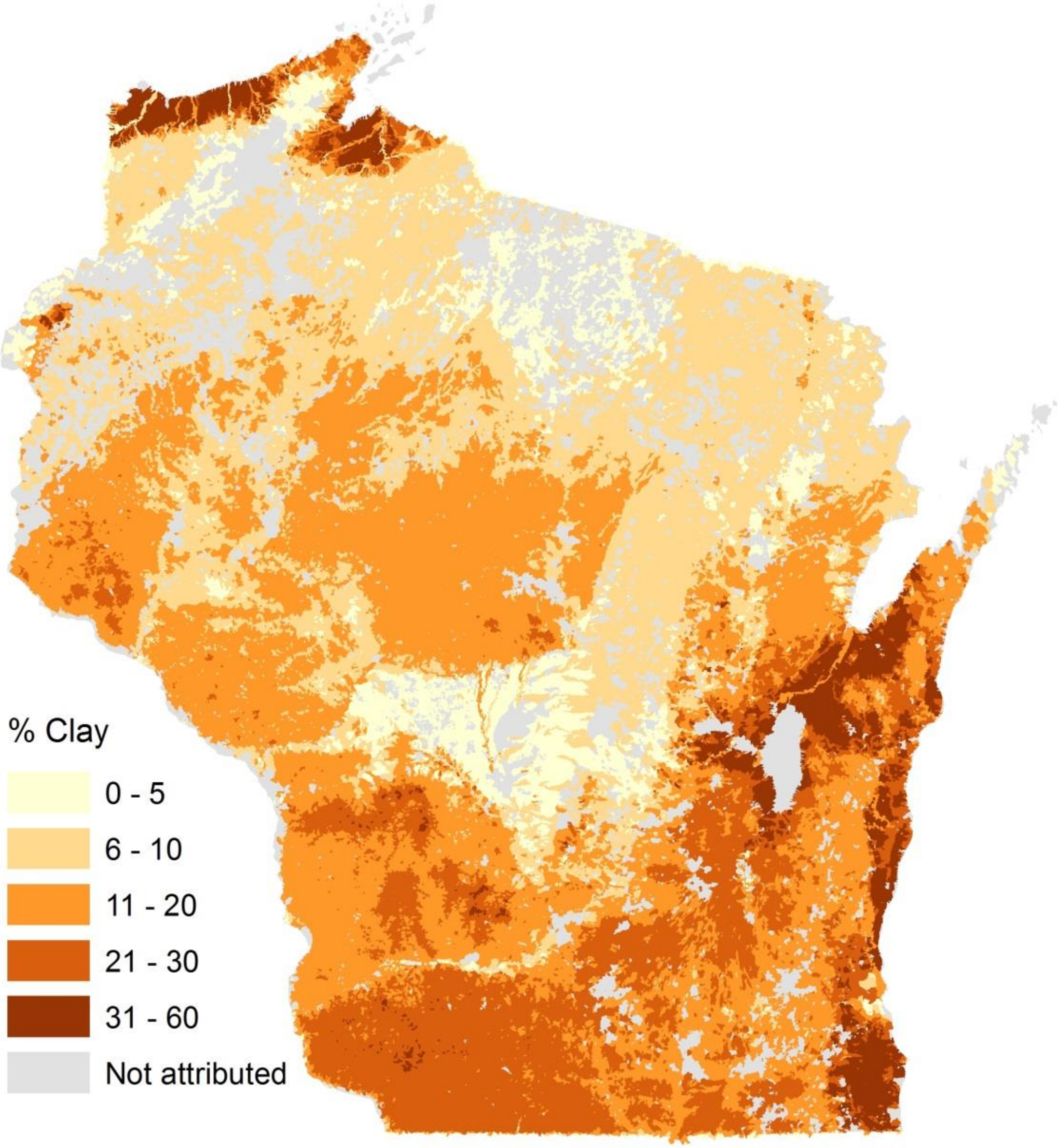
Soil organic matter content

Soil organic matter is a measure of the amount of organic carbon stored in terrestrial soils. Higher soil organic matter improves water and nutrient retention. This reduces erosion and subsequently mediates sediment and nutrient loading to stream systems. Higher levels of soil organic matter also leads to more biological activity, increases filtration capacity and thereby benefiting water quality.



Soil clay content

Soil clay content is measured as the percent of soil particles <0.002 millimeters in diameter. Soils with high clay content have limited capacity for infiltration resulting in increased surface runoff and erosion and associated impacts on water quality. Clay particles have a weak negative charge which means that they can hold onto nutrients that have a weak positive charge (cations) such as potassium and magnesium. Clay particles are also able to bind high amounts of phosphate because of their high surface area compared to other soil types. These bound nutrients can be easily transmitted through erosion to stream systems during runoff events.



Appendix C

How to navigate TWSST output in the Water Condition Viewer

The following tutorial provides a brief introduction to locating and using the Targeted Watershed Site Selection Tool in the Water Condition Viewer. While this tutorial will be updated periodically, information in this document may not reflect recent additions or modifications to the Water Condition Viewer. If this tutorial appears out of date with the look and format of the Viewer the most recent version can be found online at http://dnr.wi.gov/topic/surfacewater/monitoring/twsst.html or by visiting http://dnr.wi.gov/ and searching for “TWSST”.

The Targeted Watershed Site Selection Tool (TWSST) has been integrated with WDNR’s 1:24k hydrography layers and can be accessed via WDNR’s Water Condition Viewer (WC Viewer), a web-based mapping application. All TWSST products contained in the summary reports are also available in the WC Viewer. Advantages of using TWSST in the WC Viewer include access to base maps, aerial photography, existing monitoring locations, and numerous ancillary map layers.

The WC Viewer looks and functions essentially the same as the Surface Water Data Viewer. The large and increasing number of map layers in the Surface Water Data Viewer and related performance issues motivated the addition of a second Viewer to house spatial data for WDNR’s Water Resources program. The main difference between the two Viewers is the list of available map layers. While some critical map layers are common between the Viewers (e.g. monitoring stations and Natural Communities), many others are unique to the WC Viewer, such as calculated results and related ratings from streams and lakes assessments, as well as output from the TWSST model.

The following brief tutorial describes how to access TWSST map layers and products in the Water Condition Viewer. It also provides a variety of examples of how to incorporate additional map layers with the TWSST stream classification to assist in the monitoring site selection process. The tutorial assumes some familiarity with the Surface Water Data Viewer. More information on WDNR’s numerous interactive web-based mapping applications can be found at http://dnr.wi.gov/maps/gis/applist.html.

Open the Water Condition Viewer

The Water Condition Viewer can be accessed via the Internet with the following URL:

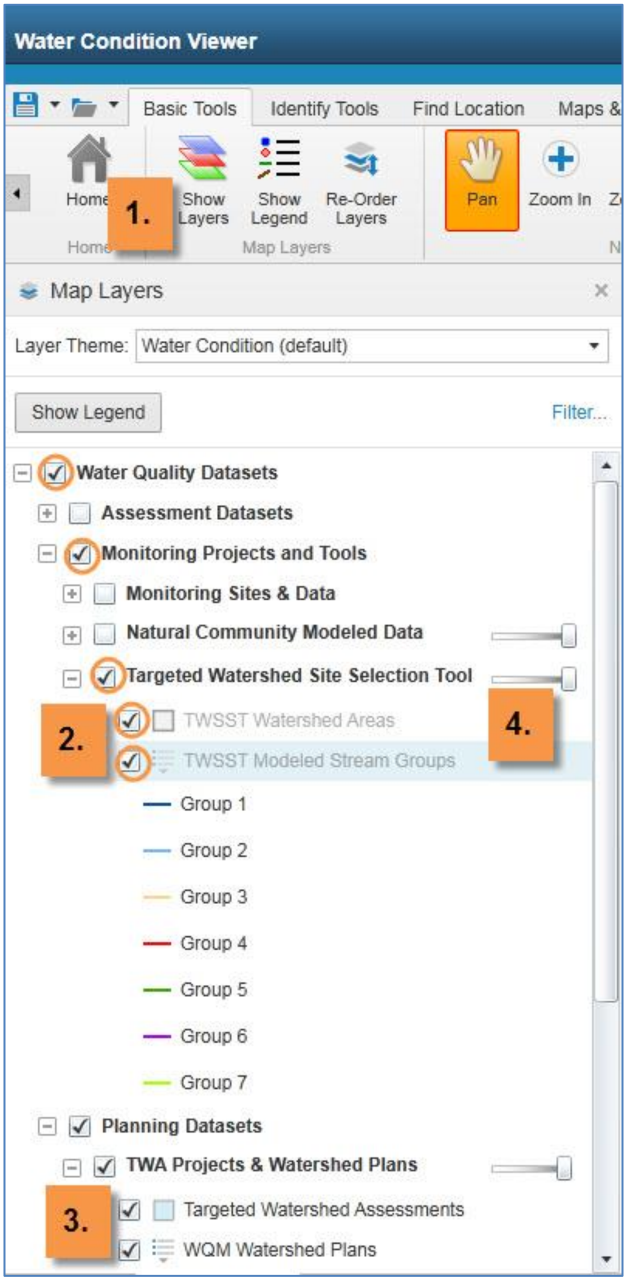
http://dnrmaps.wi.gov/sl/?Viewer=water condition viewer

Turn On TWSST Map Layers

1. Click the Show Layers button.

Like the Surface Water Data Viewer, map layers in the WC Viewer are organized into groups of similar layers. Both layer groups and individual layers can be turned on and off. Several layers are automatically turned on when opening the WC Viewer; this can be adjusted for your personal preferences.

2. Locate and expand the “Monitoring Study Tools” group and then the “Targeted Watershed Site Selection Tool” group. To view the two TWSST map layers, turn on all groups and layers circled in the screen shot below.



The “TWSST Watershed Areas” map layer contains the 52 TWSST watersheds and most of the information in the summary report—summary statistics, narrative descriptions of stream groups, and boxplots of physical characteristics and monitoring parameters. The “TWSST Modeled Stream Groups” map layer contains stream reaches color-coded by group and is the primary visual component for interpreting the stream classification.

3. Optional – If your TWA watersheds are already in the WC Viewer you can locate and expand the “TWA Projects & Watershed Plans” group. Turn on the map layers in this group to view locations and information on past and current Targeted Watershed Assessments.

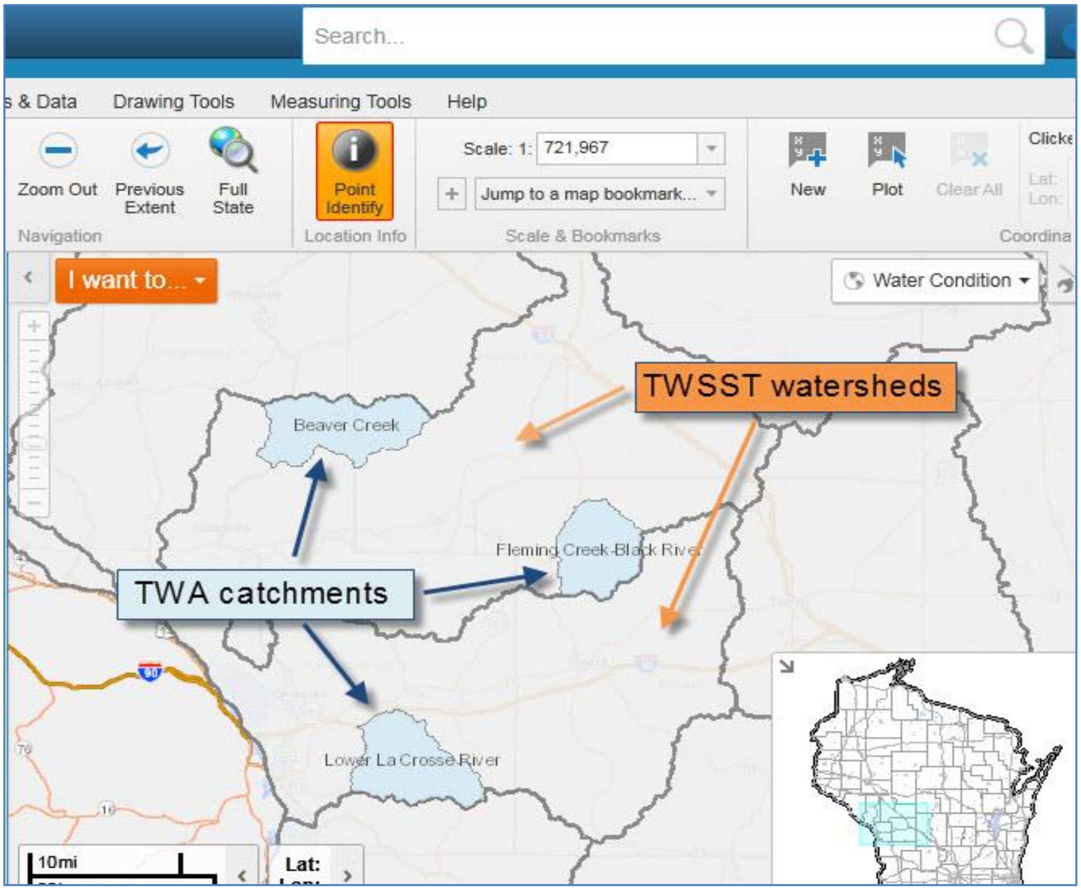
4. Adjust a group’s transparency to allow more or less visibility of your watershed area.

Map layer groups can be made partially or entirely transparent, enabling visualization of any layers behind it. However, the transparency of individual map layers cannot be adjusted independently of the group.

Locate TWA and TWSST Watersheds

1. Zoom in to the TWSST watershed that contains the TWA of interest.

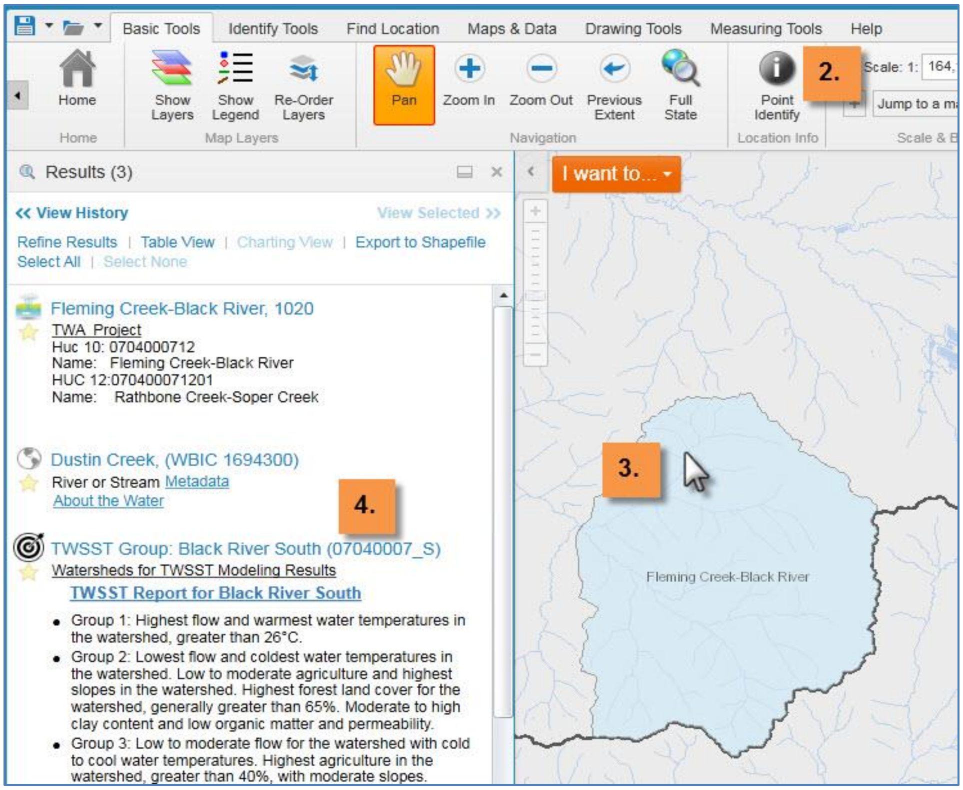
The TWSST watersheds (typically HUC 8s) are the spatial unit for the stream classification, while TWAs are typically conducted at the HUC 12 scale. In the screen shot below, TWSST watersheds are shaded light grey and have thick grey borders. TWA catchments are shaded blue and have thin grey borders. To aid identification of TWA and TWSST boundaries, the "TWSST Modeled Stream Groups" map layer has been turned off and partial transparency has been applied to both of the active (turned on) map layer groups. Recall that the TWSST stream classifications only apply within a TWSST watershed (typically a HUC 8) and comparisons cannot be made across TWWST watersheds.



Access TWSST Products

1. Zoom in to a TWA or watershed of interest.
2. Click the Point Identify button.
3. Click anywhere within the TWA.

The Point Identify function returns a list of features located at the point clicked. Results are limited to features from map layers that are active (turned on). In the example below, results include the TWA feature, a stream feature, and the TWSST watershed.



Fleming Creek-Black River, 1020
TWA_Project
Huc 10: 0704000712
Name: Fleming Creek-Black River
HUC 12:070400071201
Name: Rathbone Creek-Soper Creek

Dustin Creek, (WBIC 1694300)
River or Stream Metadata
About the Water

TWSST Group: Black River South (07040007_S)
Watersheds for TWSST Modeling Results
TWSST Report for Black River South

- Group 1: Highest flow and warmest water temperatures in the watershed, greater than 26°C.
- Group 2: Lowest flow and coldest water temperatures in the watershed. Low to moderate agriculture and highest slopes in the watershed. Highest forest land cover for the watershed, generally greater than 65%. Moderate to high clay content and low organic matter and permeability.
- Group 3: Low to moderate flow for the watershed with cold to cool water temperatures. Highest agriculture in the watershed, greater than 40%, with moderate slopes.

4. Hover over the name of any feature in the Results list and that feature is highlighted on the map.
5. Click the name of the TWSST watershed in the Results list.

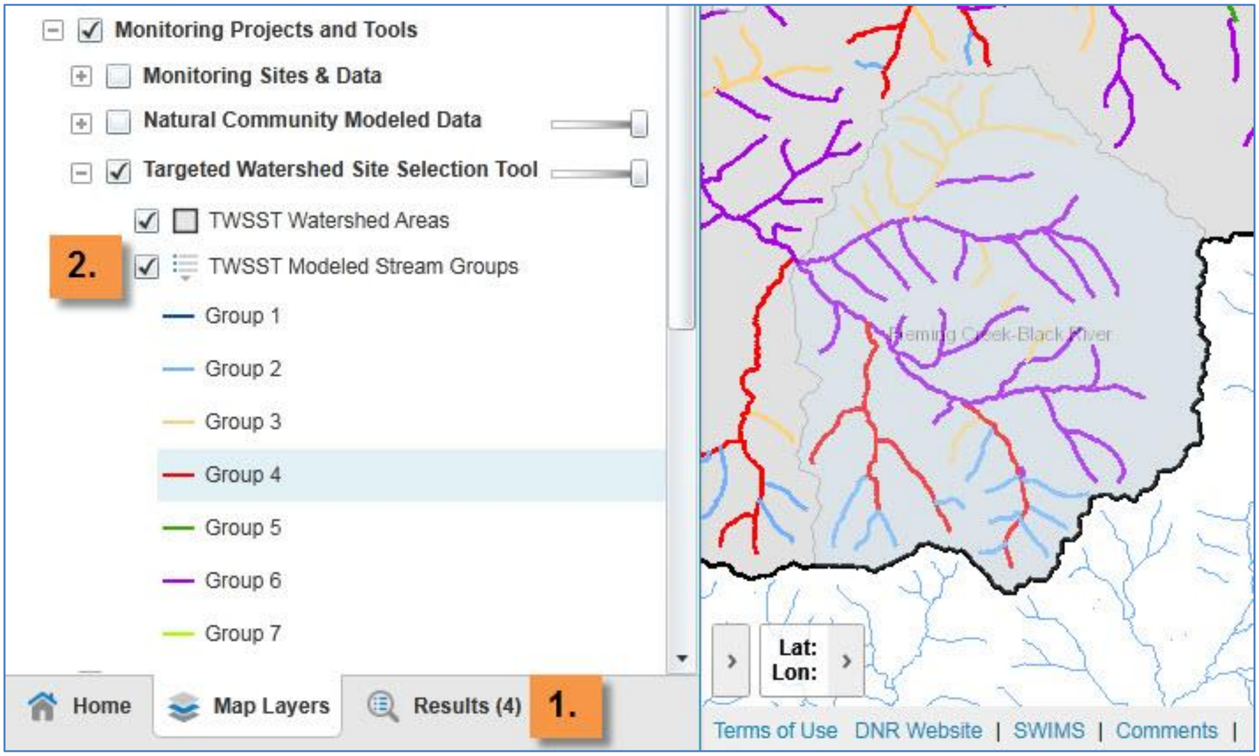
A pop up window appears containing two tabs, Details and Attributes. Click on the Attributes tab to display a table of all attributes associated with the TWSST watershed. Most of these will be familiar from the summary reports. Click on the Details to access narratives of stream groups and links to the TWSST watershed summary report and boxplots of physical characteristics and monitoring parameters. It may be helpful to print the TWSST watershed reports and have a hard copy on hand to refer to instead of switching between tabs on your computer screen,

<u>View The Stream Classification</u>

1. Switch from the Results tab back to the Map Layers tab.

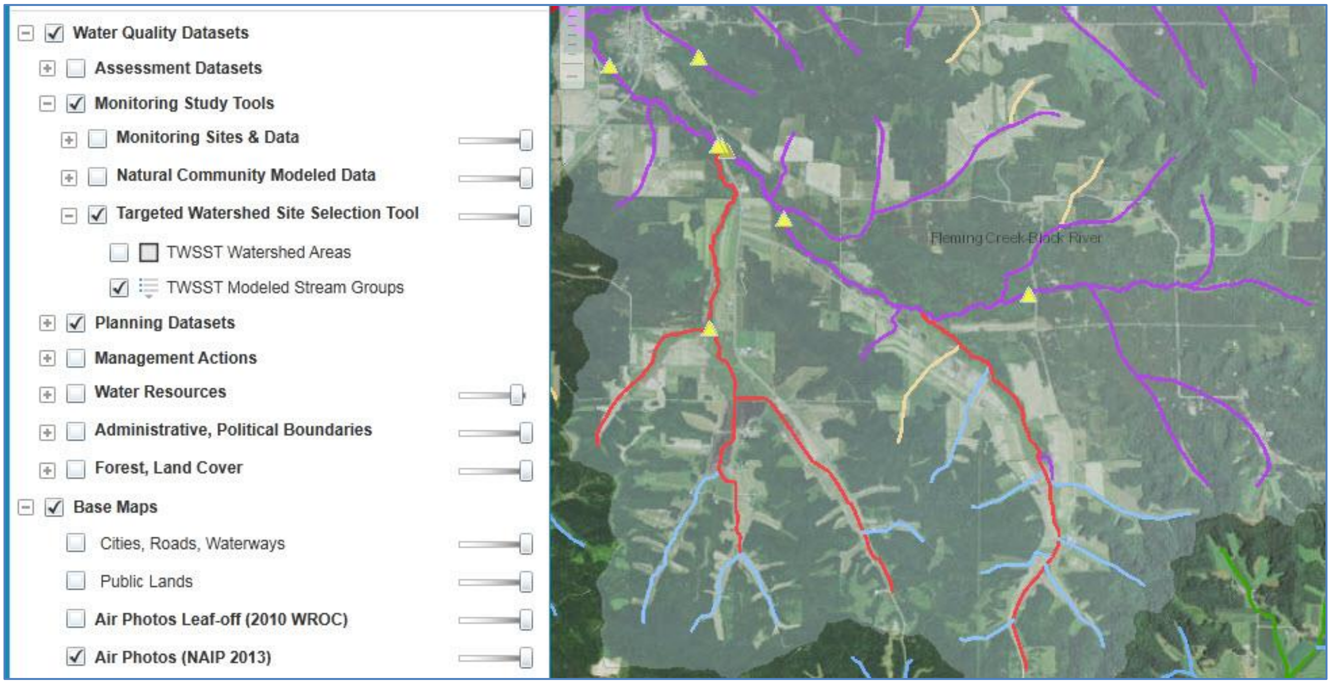
2. Turn the "TWSST Modeled Stream Groups" map layer on if needed.

There are six groups in this TWSST watershed, four of which are found in this TWA. At this point, it is useful to review the group narratives and boxplots with the objective of relating the spatial patterns on the map to both differences and variability in physical characteristics and monitoring parameters. If you are unable to open the maps, group descriptions and boxplots at once on your monitor it can be useful to print out the relevant summary report to help interpret differences in stream groups.



Incorporate Base Maps

Multiple base maps are currently available in the WC Viewer. In the screen shot below, leaf-on air photos provide context for the stream groups. The darker air photo base maps may also provide contrast to the color-coded streams making them easier to visualize.



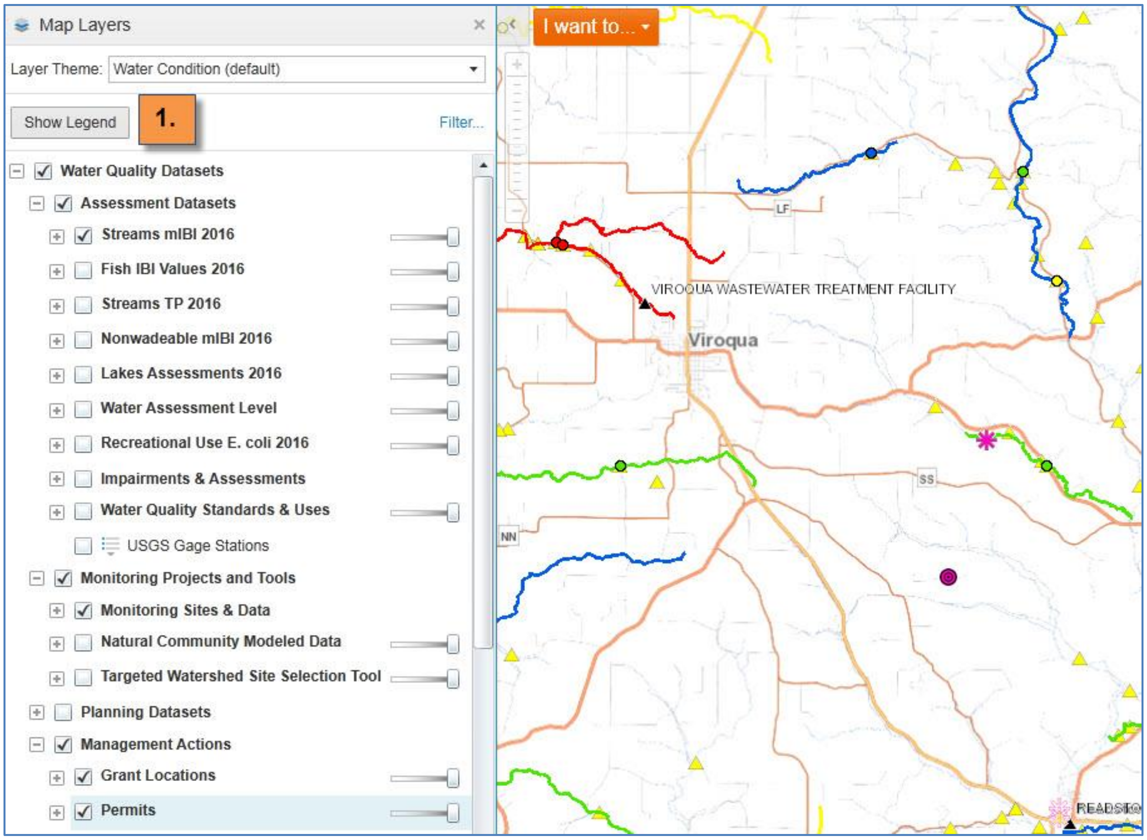
- ☑ Water Quality Datasets
  - ☐ Assessment Datasets
  - ☑ Monitoring Study Tools
    - ☐ Monitoring Sites & Data
    - ☐ Natural Community Modeled Data
    - ☑ Targeted Watershed Site Selection Tool
      - ☐ TWSST Watershed Areas
      - ☑ TWSST Modeled Stream Groups
  - ☑ Planning Datasets
  - ☐ Management Actions
  - ☐ Water Resources
  - ☐ Administrative, Political Boundaries
  - ☐ Forest, Land Cover
- ☑ Base Maps
  - ☐ Cities, Roads, Waterways
  - ☐ Public Lands
  - ☐ Air Photos Leaf-off (2010 WROC)
  - ☑ Air Photos (NAIP 2013)

Incorporate Additional Map Layers

The WC Viewer contains numerous map layers than can be turned on for viewing alongside the TWSST stream classification. Some of these map layers are also contained in the Surface Water Data Viewer (e.g. SWIMS monitoring stations locations) and you may be familiar with them. Other layers are only contained in the WC Viewer (e.g. mIBI ratings for stations and assessment units).

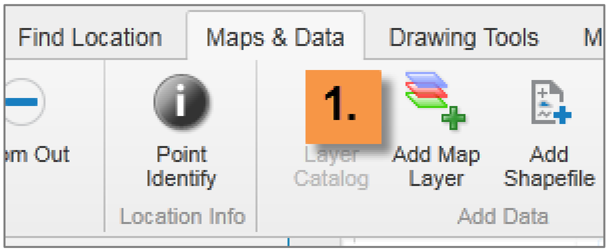
In the screen shot below, the following map layers have been turned on: SWIMS point stations, mIBI assessments, and grant and permit locations.

1. Click the Show Legend button to view the symbology for features in all map layers that are turned on.

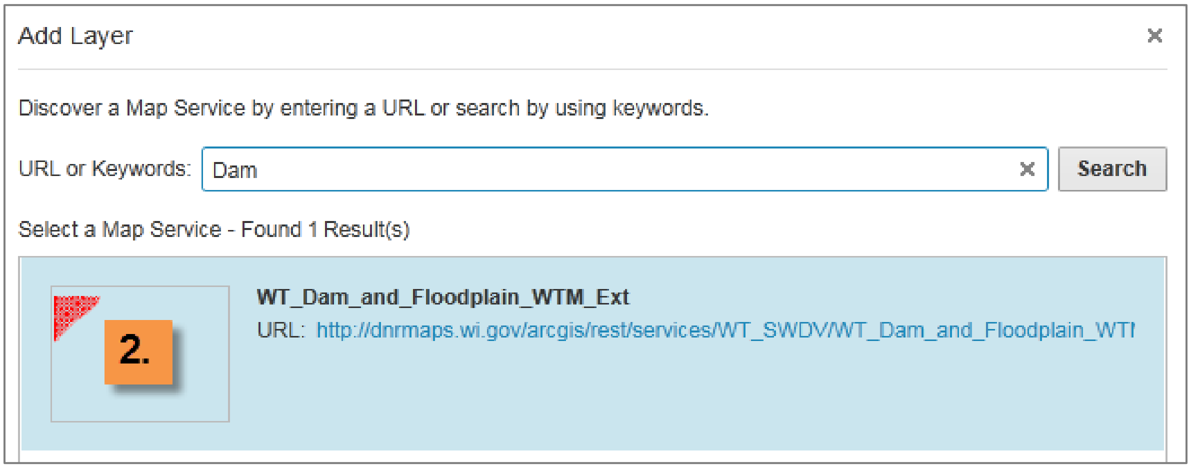


Any map layer that has been published as a map service can be added to the WC Viewer. For example, the Dams & Floodplains map layers found in the Surface Water Data Viewer are not automatically loaded in the Water Condition Viewer but can be added.

1. Click the Maps & Data tab, and then click the Add Map Layer button.



2. Scroll through the list of available map services or search for one by keyword. A search by the keyword “dam” results in one map service. Click on the thumbnail (not the URL hyperlink) for the map service to select it, and then click Next.



Discover a Map Service by entering a URL or search by using keywords.

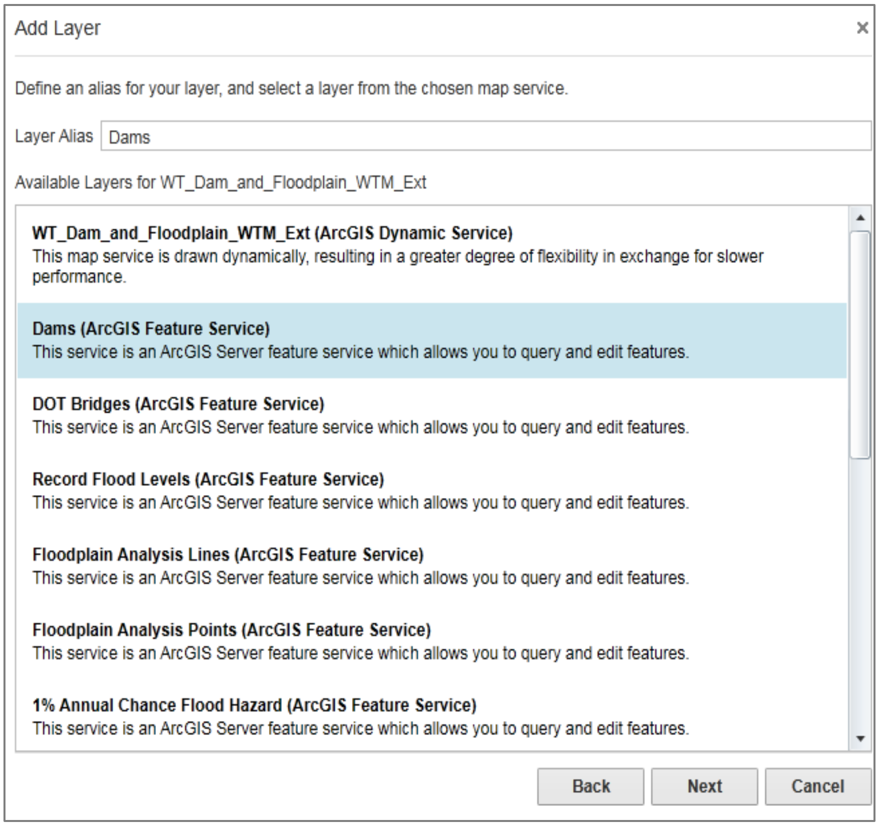
URL or Keywords: Dam

Select a Map Service - Found 1 Result(s)

WT_Dam_and_Floodplain_WTM_Ext

URL: http://dnrmaps.wi.gov/arcgis/rest/services/WT_SWDV/WT_Dam_and_Floodplain_WT

Select the parent project (top result) to add all layers contained in the Dams and Floodplains group. You can also select an individual map layer from the group, for example only the dams layer, and exclude the other layers that are grouped under that parent project. Click Next, and then Finish and the map layer will be added to the table of contents in the WC Viewer (the Map Layers pane).



Define an alias for your layer, and select a layer from the chosen map service.

Layer Alias: Dams

Available Layers for WT_Dam_and_Floodplain_WTM_Ext

WT_Dam_and_Floodplain_WTM_Ext (ArcGIS Dynamic Service)
This map service is drawn dynamically, resulting in a greater degree of flexibility in exchange for slower performance.

Dams (ArcGIS Feature Service)
This service is an ArcGIS Server feature service which allows you to query and edit features.

DOT Bridges (ArcGIS Feature Service)
This service is an ArcGIS Server feature service which allows you to query and edit features.

Record Flood Levels (ArcGIS Feature Service)
This service is an ArcGIS Server feature service which allows you to query and edit features.

Floodplain Analysis Lines (ArcGIS Feature Service)
This service is an ArcGIS Server feature service which allows you to query and edit features.

Floodplain Analysis Points (ArcGIS Feature Service)
This service is an ArcGIS Server feature service which allows you to query and edit features.

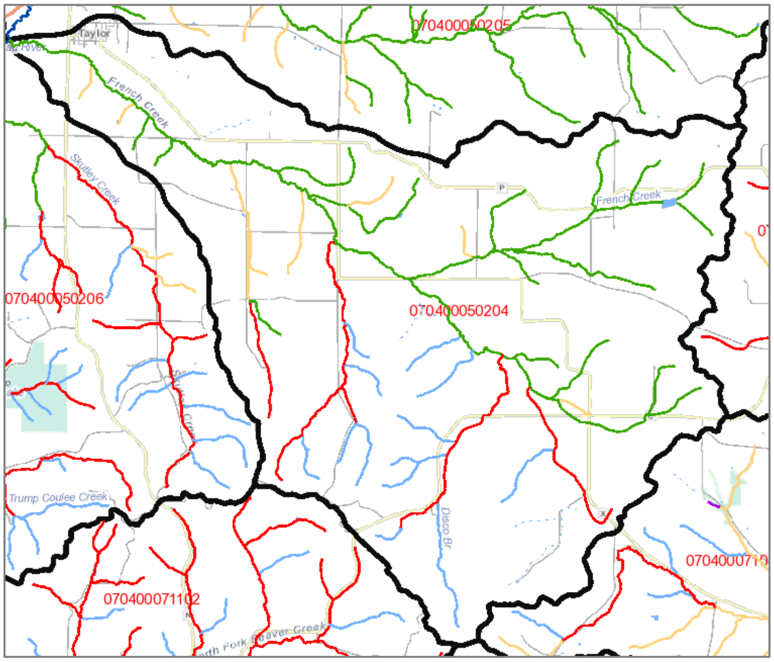
1% Annual Chance Flood Hazard (ArcGIS Feature Service)
This service is an ArcGIS Server feature service which allows you to query and edit features.

After adding additional layers such as point sources, base maps, and road layers, begin site selection by locating SWIMS stations as needed for the specific design and intent of the TWA.

Appendix D

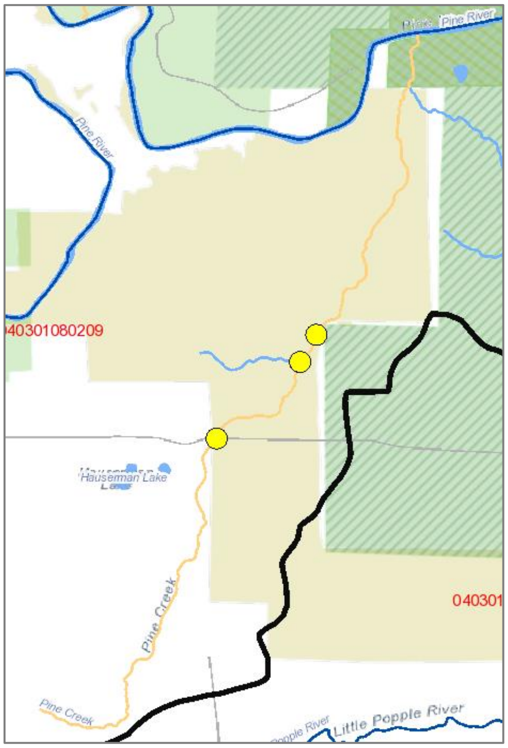
Examples of how TWSST can be used to determine a watershed monitoring design – From suggestions in Section 6.

1) An ideal monitoring design would collect data from each of the TWSST stream types in the watershed to capture within-watershed variability.



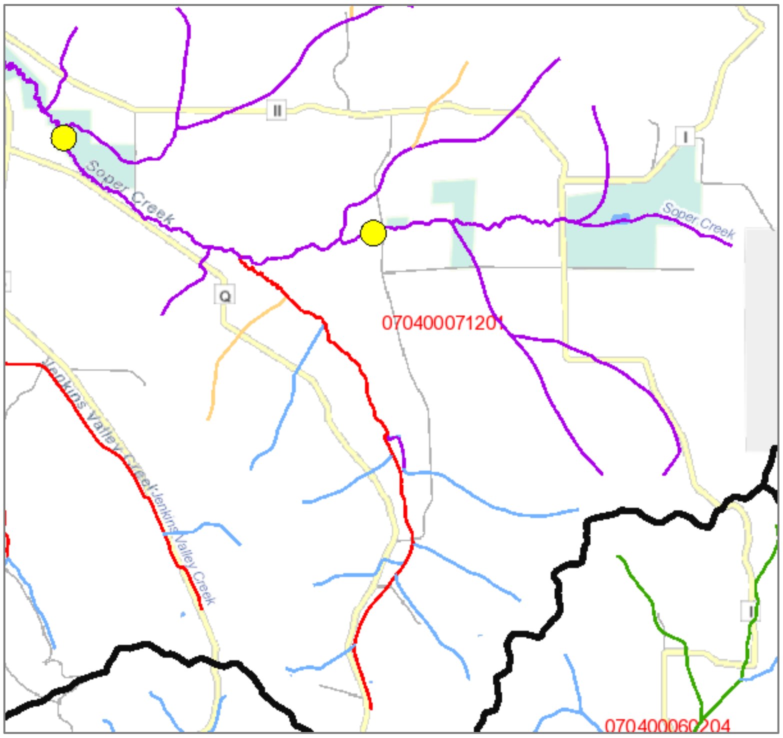
The TWSST tool can be used to make sure all stream types are accounted for in a monitoring design and redundancy in monitoring avoided. Notice in this watershed (HUC 12, black lines) that some tributaries are similar to the mainstem (green lines). The TWSST tool would suggest more intensive monitoring in the red and blue tributaries and fewer in the green.

2) For stream monitoring locations that are selected for any purpose, estimate how far upstream that monitoring location likely represents by number and location of TWSST groups upstream.



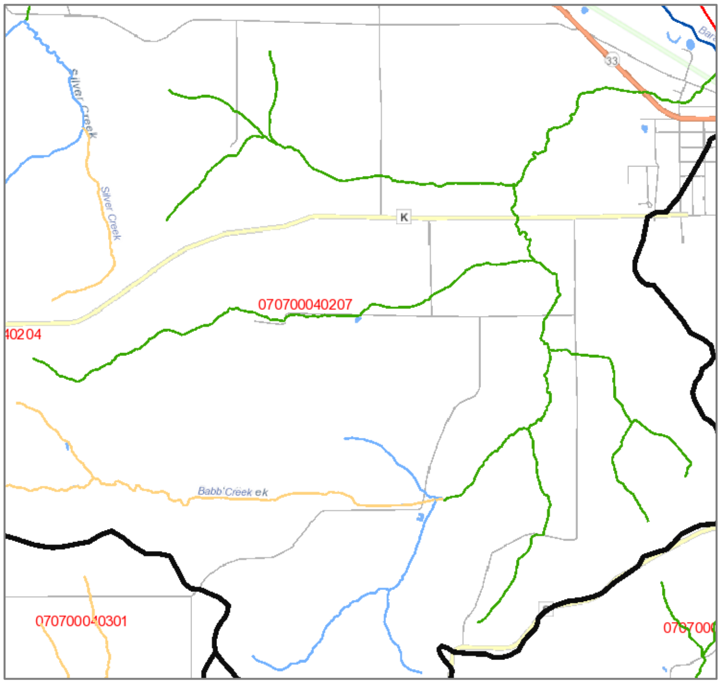
For example, there are three monitoring sites (yellow circles) on Pine Creek (orange line), a tributary to the Pine River (blue line, top of picture). The TWSST model suggests that these three monitoring stations apply to the entire stretch of Pine Creek, from headwaters to confluence. Unless there was local knowledge of why these reaches should be treated differently, staff could apply the data from these sites to the entire waterbody.

3) From previously collected stream monitoring data, determine if those data are representative of the entire upstream area. If not, locate monitoring locations upstream on unique TWSST stream groups to capture spatial variability.



There are two previous monitoring locations along Soper Creek (purple). The monitoring location on the northern tributary (top, center) appears as if it is representative of the entire upstream reach. The downstream station (top left) appears that it would not apply to the southern tributary, which is a different stream type and more variable (red, blue and orange streams) than where the downstream monitoring station is located.

4) Determine vulnerable tributaries contributing to poor water quality downstream and most likely pollutants, for example, TWSST groups with high agriculture or developed land cover or high soil clay content.



In this example, Babb Creek (orange line, lower left) meets multiple tributaries as it flows towards the upper right. From the TWSST stream group descriptions the orange reaches have the highest % agriculture and highest % clay soils in this watershed. The blue and green streams have more forest and lower soil clay content. If there were issues with sedimentation or total phosphorus downstream, the orange sections of Babb Creek would be likely contributors to these problems. While this is very much influenced by local land management practices the TWSST tool indicates a good spot to begin investigating.

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