THE WOLF RIVER AND ROCK RIVER WATERSHEDS: DEVELOPING A REGIONAL CURVE FOR BANKFULL STAGE

By

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ABSTRACT

Regional hydraulic geometry curves are graphical plots of discharge and channel geometry that can be used to calculate bankfull discharge and the bankfull channel geometries (bankfull), the channel-forming flood. Specifically, a regional curve provides information to estimate bankfull discharge, mean depth, width, and cross-sectional area at ungauged sites within given watersheds, (Mistak and Stille, 2007). Bankfull forms the average or natural stream channel and can be used to guide stream restoration. Bankfull is frequently assumed to be associated with the $Q_{1.5}$ year flood, but varies between the 1.0 and 2.5-year flood (Copeland et al., 2000). Land use practices within a watershed have been found to affect bankfull discharge (Reidel et al., 2005). Areas that are primarily forest cover tend to produce less runoff and consequently less mass wasting, while areas that are primarily agricultural tend to produce more runoff and consequently more mass wasting (Reidel et al., 2005). Stream type affects the geometry and morphology of a stream and consequently the stream discharge. The purpose of this study is to develop a regional curve for bankfull stage by determining bankfull discharge using field techniques and historical gauging station data. For the purpose of this study, the 1.5-year recurrence 1.0-year recurrence intervals are used as surrogates for bankfull stage. This study also examines landcover and stream type to determine if these variables affect the relationship between hydraulic geometries and watershed area.

This study conducts hydraulic geometry surveys in the Wolf River Watershed in Northeastern Wisconsin and the Rock River Watershed in Southeastern Wisconsin. These sites are chosen due to similarities in topography and an abundance of USGS gauging

stations, which are used for historical data. Seven sites within the Wolf River and four sites within the Rock River are examined and compared to each other.

This study finds a strong correlation between surveyed data and historical data within the Wolf River Watershed, and a strong relationship between the 1.5-year recurrence interval and watershed area. A strong relationship is also found between surveyed data and historical data within the Rock River Watershed, where a strong relationship exists between the 1.0-year recurrence interval and watershed area. This study did not find a consistent, significant relationship between landcover and discharge, which may be due to many factors, including relatively homogenous percentages of landcover, and heterogeneous watershed areas. Stream types are found to be relatively homogeneous across both watershed regions.

Published regional curves are not available for the state of Wisconsin. This study uses survey data and historical data to develop a regional curve for the Wolf River Watershed and Rock River Watershed. A regional curve that is suitable for stream restoration was not developed for the Rock River due to challenges associated with historical data and survey calculations; however, these challenges provide many insights into the development of a regional curve and could aid in stream restoration efforts in the future.

Acknowledgements

This project, which has taken more than the two years of collegiate hours to build up to and produce, would not have been possible without the assistance of many people. First and foremost I would like to thank my graduate committee: Katherine Clancy, David Ozsvath and Paul McGinley. I would also like to thank the additional wonderful faculty and staff who supported this research in one way or another: John Houghton, Hans and Jill Schabel, Patti and Robert Tomlinson, Paul Doruska, Gary and Michelle Shulfer, Lucinda Thayer, Jessica Dunnavant, Betsie Graham, Michael Estanich, and Paul and Ann Doebler. I'd like to especially thank the Geography and Geology Department faculty for all of their years of help: Diane Stelzer, Keith Rice, Karen Lemke, Eric Larsen, Kevin Hefferan, Michael Ritter, Neil Heywood, Jia Lu, and again David Ozsvath.

I would like to thank my family and friends for their love and encouragement throughout this endeavor. Thank you to my family and fellow field crew: Mom and Dad, for their extraordinary support, Murphy and Charlie the Brown Mutts for their unconditional love, and especially my sister Julie, for doing more fieldwork than she would ever like to remember, and for being a great supplier of oreo cookies, doritos, and helpful metaphors for life. Thank you also to Grandma Frances Hess, Adrian and Anna Ackley, Claudia Bodway, Marion and Norm Brown, Mary Peterson and Vicki Fiebig, Beth and Jim Franson, Kathleen Urban, Bonnie and Robert Wolff, and many wonderful cousins and aunts and uncles and family: Steph, John, Maddy and MacKenna Belter, Nate and Mary Calkins, Lynn and Ron Ackley, Beth and Kirk Calkins, Bill Shimek, Bill Sharpee, Debbie and Jeff Hess, Becky and Richard Hess, Judy and John Hess, and Jim and Julie Hess. Thank you to my friends who were there for the college support when I

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INTRODUCTION

The main objective of this study was to collect bankfull discharge and the associated bankfull geometries (bankfull) survey and historical data from selected sites within the Wolf River Watershed and Rock River Watershed in order to determine bankfull discharge and develop a regional curve. Published regional curves are not available for the state of Wisconsin. The Wolf River Watershed within the Great Lakes Basin and the Rock River Watershed within the Mississippi River Basin were chosen for this study due to the high density of United States Geological Survey (USGS) gauging stations within each watershed. The Wolf River Watershed is located in Northwestern Wisconsin and covers over 3,700 square miles in area. The Rock River Watershed, located in Southeastern Wisconsin, is formed of the Upper Rock River and Lower Rock River sub-basins, which together cover over 3,800 square miles in area.

Regional curves are used for stream design in restoration projects (Mistak and Stille, 2007). Also called bankfull hydraulic geometry relationships, these curves relate bankfull stream channel dimensions and discharge to watershed drainage area (Harman et al., 2007). Only gauged streams provide the data required to calculate bankfull discharge, but can be used to estimate bankfull on streams that do not have gauges. The method of regional curve development that was used incorporated stream survey data (velocity, cross section area, slope, etc) and historical data recorded and maintained by the USGS. These data were used to calculate the 1.5-year and 1.0-year recurrence interval, which was used as proxies for bankfull stage.

The best approach to developing a regional curve is to combine both methods by comparing survey data to historical data, in order to determine how representative a recurrence interval flow is for a region.

In addition, landuse (e.g. imperviousness) has been found to influence bankfull discharge. Stream type is an additional factor that should be considered. Stream type may affect the regional curve by displacing different stream types from the linear relationship between discharge and watershed area. For example, channelized streams in urban areas will create miscalculations regarding the natural flow of rivers in a region. Due to these factors, landuse and stream type were examined in order to find relationships between these and discharge.

The bankfull flood stage, used for natural stream design in restoration projects, is also used to establish watershed research and restoration/research funding by many federal and state sources. This project provides a basis for stream restoration projects in Wisconsin, an area where both land development and stream restoration are common.

OBJECTIVES

The overall goal of this study was to collect bankfull data from selected sites within the Wolf River Watershed and Rock River Watershed in order to determine bankfull discharge and develop a regional curve. Eleven sites were selected in Northeastern and Southeastern Wisconsin: seven sites located on the Wolf River and four sites located on the Rock River.

Objectives for this study are as follows:

1) Determine bankfull and hydraulic variables for river reaches;

2) Compare bankfull calculations to historical data;

3) Determine landcover at each site; and

4) Develop a regional curve for bankfull discharge.

This study hypothesizes that bankfull discharge will best correlate with the 1.5-year recurrence interval and increase linearly with drainage area and that landcover and stream type (based on Rosgen's Classification) will affect this linear relationship.

LITERATURE REVIEW

Regional Curves

Regional hydraulic geometry curves, or regional curves, are a comparison of stream discharge and channel dimensions to watershed area. Regional curves (Figure 1) provide information to estimate discharge, mean depth, width, and cross-sectional area at ungauged sites within a given watershed area (Mistak and Stille, 2007). In other words, regional curves can be used for the initial estimation of bankfull dimensions in the absence of stream flow data, providing that they adequately represent the watershed region (Rosgen, 1996). Flood-frequency characteristics from different catchments within a basin can then be used to estimate the floods in ungauged catchments (Dunne and Leopold, 1978). The bankfull flood, or Q_{bf}, is considered the channel-forming flood, generally performing the work that results in the average morphological characteristics of a channel (Dunne and Leopold, 1978). This channel-forming flood occurs within a range of years; however, the 1.5-year discharge is considered as a general proxy for bankfull. Because bankfull is considered the channel-forming flood, using a regional curve to estimate bankfull for ungauged streams is a useful component in natural channel design.

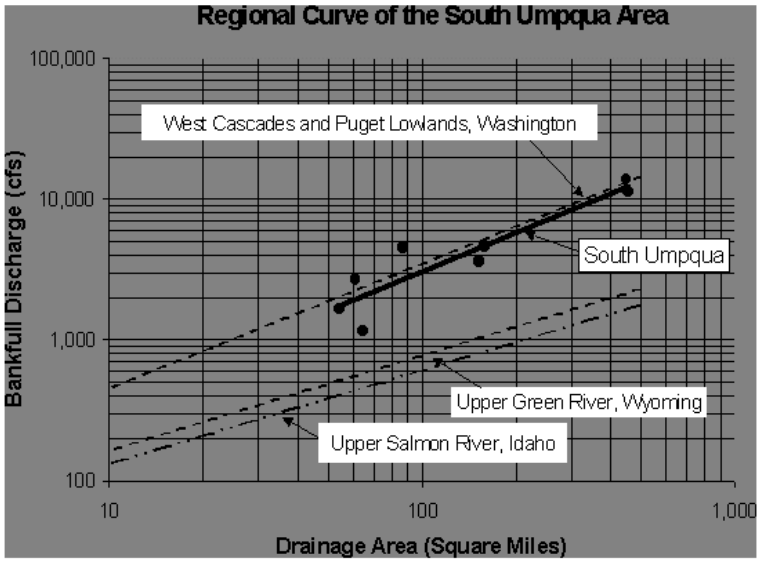


Figure 1: Regional hydraulic geometry curve for the South Umpqua Area of the continental U.S.

Regional curves are commonly produced using data grouped within hydrologic regions, due to the assumed similarity in hydrology (Wilkerson, 2008). These hydrology studies are typically conducted by first selecting sites, followed by data collection and analysis (Wilkerson, 2008). Regional curves can be developed in two ways: 1) Using gauging stations within a watershed and comparing their 1.5 year flood discharge to watershed area, and 2) Using survey data within a watershed and comparing the surveyed/calculated discharge to watershed area (Dutnell, 2000). One way to reduce the amount of variability due to sampling errors is to combine and compare the records from many stations in an area (Dunne and Leopold, 1978). Variability can also be reduced by comparing survey data to historical data which would minimize errors and create a more accurate regional curve.

Bankfull

Regional curves that are used for stream restoration frequently refer to the bankfull flood (Figure 2) because bankfull characteristics, including bankfull cross-sectional area, width, and mean depth are strongly correlated with watershed drainage area (Dunne and Leopold, 1978). The bankfull stage corresponds to the discharge of most effective channel maintenance, at which discharge is moving the sediments and doing the work that results in the average morphological characteristics of a channel (Dunne and Leopold, 1978). This flood is not necessarily consistent (does not always occur every 1.5-years) and it is best to assume bankfull as a range of values, rather than a discrete one (Copeland et al., 2000). The bankfull flood can occur approximately every one to two years, although a wide range of values have been calculated (Leopold et al., 1964).

Figure 2: A visual guide to determining bankfull.

Three channel-forming flood levels are commonly chosen for channel analysis: bankfull discharge, the effective discharge, and a discharge of a chosen recurrence interval (Doyle et al., 2007). These floods are used because they are theoretically similar in stable channels (Doyle et al., 2007). Effective discharge is discharge which transports the greatest amount of sediments, while the discharge of a chosen recurrence interval

refers to a flood chosen within the target range of one to two years (Doyle et al., 2007). The bankfull discharge is often defined as discharge that barely overflows the top of a channel (Doyle et al., 2007). The bankfull flood level was chosen for this study because of its importance to the formation of channel geometries. Bankfull is considered a surrogate for the hydraulic variables that drive a stream; therefore, bankfull discharge can serve as an indicator of formation, maintenance, and dimensions of a channel (U.S. EPA, 2007).

Determining Bankfull and Bankfull Discharge

Many methods are used to determine the bankfull level in a stream channel. The most accurate method is to determine the elevation of bankfull at a specific site while in the field. An additional method is to examine USGS gauging station data concerning mean annual discharge (Schumm, 1967). USGS data is then used to calculate the bankfull flood recurrence interval. There are also several methods for surveying the stream channel and associated bankfull level.

Leopold (1984) provides detailed instructions for a channel geometry survey; including: determining bankfull indicators, determining bankfull elevations in relation to the channel bed, stretching a line across the river with the zero end on left bank, surveying the cross section area and bankfull level, taking pebble counts, and recording details of the bank and its stratigraphy.

Rosgen (1996) provides a morphological description for the determination of the flood-prone area that includes obtaining elevation readings from the maximum-depth stage located outside the bankfull stage and elevation readings from the bankfull stage.

Elevation readings are then used to determine morphology of the stream, for the determination of a stream channel cross-section and width-depth ratios. Rosgen (1996) suggests a measuring tape to be strung across the floodplain, while elevation measurements are taken at bankfull stage.

When the bankfull level is determined, bankfull discharge must be calculated. General practice for the calculation of field discharge involves using cross-sectional area and velocity measurements (McCuen, 2005). Researchers determine bankfull discharge by first calculating bankfull stage and then determining the discharge associated with that stage (Copeland et al., 2000). Additional methods include examining USGS gauging station data and calculating the 1.5-year recurrence interval, which is considered a proxy for bankfull discharge.

Manning's equation is often used in the calculation of bankfull discharge, incorporating velocity (V), hydraulic radius (R_h), slope of the water surface (S), and the roughness coefficient or resistance coefficient (*n*) (Rosgen, 1996 and Dunne and Leopold, 1978). Variations on Manning's equation include using bankfull geometries, instead of channel geometries to determine *n*, the use of gravity instead of channel velocity to calculate bankfull velocity, and the use of pebble size to determine friction. Pebble size is determined using Wolman's methods which requires field determination of the particle size distribution of channel materials and involves a systematic method of sampling materials along various bed features at a site (Rosgen, 1996).

It is recommended that methods be checked against each other to reduce error in estimations of channel-forming discharge (Copeland et al., 2000). This study will compare multiple methods to minimize error and validate bankfull levels.

Determining Roughness Coefficient

Manning's *n*, or the roughness coefficient, is routinely used to predict mean velocity (Chow, 1964). The roughness coefficient evaluates the overall shape of the channel bed, including the channel roughness (McCuen, 2005). The roughness coefficient value is then used to calculate bankfull velocity. The lack of consistent criteria for selection of *n* values subsequently leads to great variation in the estimates of flow velocity (Rosgen, 1996). Many different methods are used to calculate *n*, including Manning's roughness coefficient equation. Manning's equation incorporates velocity (V), hydraulic radius (R_h), slope of the water surface (S), and the roughness coefficient or resistance coefficient (*n*) (Rosgen, 1996).

Other methods of determining *n* involve visually evaluating a stream channel and estimating *n* based on stream variables, such as: stream type, channel sinuosity, in-stream vegetation, sediment size, and stream channel irregularity. An estimation chart for Manning's *n* was designed at bankfull stage for selected Rosgen's stream types (Rosgen, 1996). Chow (1959) breaks down Manning's *n* values by minimum, normal, and maximum *n* values according to channel type and description. Cowan (1956) provides a chart for estimating a recommended value for possible variables within a stream channel that could affect Manning's roughness coefficient, such as stream irregularity and in-stream vegetation. Use of each of these methods can provide a means for comparing and best estimating roughness coefficient values, decreasing variability in estimates of flow velocity.

Challenges Associated with the Development of a Regional Curve

Keaton et al. (2005) states that stream geometry characteristics such as width, depth, discharge, and bankfull vary between small streams. In other words, there is a great deal of geometry variation between small streams. These characteristics affect bankfull levels and are dependent upon many watershed characteristics, including size, length, width, shape, slope, topography, landcover, soil type and geology. Stream channel morphology, described as the width/depth ratios in relation to the bankfull stage cross-section, varies with the geometries of the channel cross-section for the slope at that site, the boundary roughness as a function of the stream flow and sediment, the bank erodability, entrenchment ratio, and boundary stress of the stream channel (Rosgen, 1996).

Due to the complexity of stream channels and watershed areas, developing a regional curve suitable for stream restoration includes selecting appropriate sites within a region (sites that have a natural stream channel) and determination of bankfull discharges at each site (accurately measuring the bankfull width, depth, and discharge). Subwatersheds within a hydrologic region will have similarities in discharge and stream geometry but will differ from other hydrologic regions. Care should be taken when comparing streams from different hydrologic regions. Consequently, there are challenges associated with developing a regional curve that represents an entire watershed. It is essential, then, that regional curves are established specifically for streams within an area (Dutnell, 2000). Developing a regional curve that is suitable for stream restoration is entirely possible when comparing streams within a single hydrologic region, but is also possible when carefully comparing streams between hydrologic regions.

Landcover

Channels adjust as a result of altered discharge and sediment load including changes in width, depth, velocity, slope, sediment size, and roughness, reflecting the environmental factors that determine erosion, transportation and fluvial deposition (Dade and Friend, 1998). Land uses such as urbanization, agriculture, forestry practices and dam construction alter channel processes that affect fluvial systems (Montgomery et al., 1993). Therefore, landcover greatly influences the flow of a stream and subsequently the bankfull level of a stream. For example, the hydrologic regime of a watershed is affected by the conversion of forest to a type of non-forest land-cover (Reidel et al., 2005).

Reforestation of abandoned farmlands increases interception and evapotranspiration and vice versa, while clearing large areas of land usually increase mass wasting and erosional processes (Dunne and Leopold, 1978). Watershed urbanization increases peak discharges due to an increase of impervious area, which increases runoff surface area (Montgomery and Buffington, 1998). These changes generally cause the channel to increase in either channel width or depth (Montgomery and Buffington, 1998).

Early settlement of the upper Midwest and the associated urbanization and depletion of forest cover to agricultural lands increased flood magnitudes within watersheds (Woltemade, 1994). These changes altered sediment loads and consequently stream geometries and flood magnitudes (Woltemade, 1994). These early alterations in stream geometry, resulting from agricultural practices, continue to affect the landscape in the form of overly incised stream channels and increased peak-flood discharges

(Woltemade, 1994). Due to these alterations, natural stream geometries within Wisconsin must be carefully considered before being applied to stream restoration design, and streams in areas that are predominantly agricultural and residential should not be considered to be in their natural state.

Stream Type

In order to account for some of the variation found between streams within a watershed and to more accurately transfer known bankfull geometry between basins, stream type should be considered. Stream width, depth and other geometries that are influenced by watershed landcover, geology, soils, climate and topography can be summarized by stream type. Classifying streams on the basis of channel morphology (cross section, slope, and river shape) provides site-specific information that can be transferred to similar river reaches and aid in the selection of sites more representative of the watershed. One method of determining stream types is using the Rosgen Stream Classification System (Figure 3).

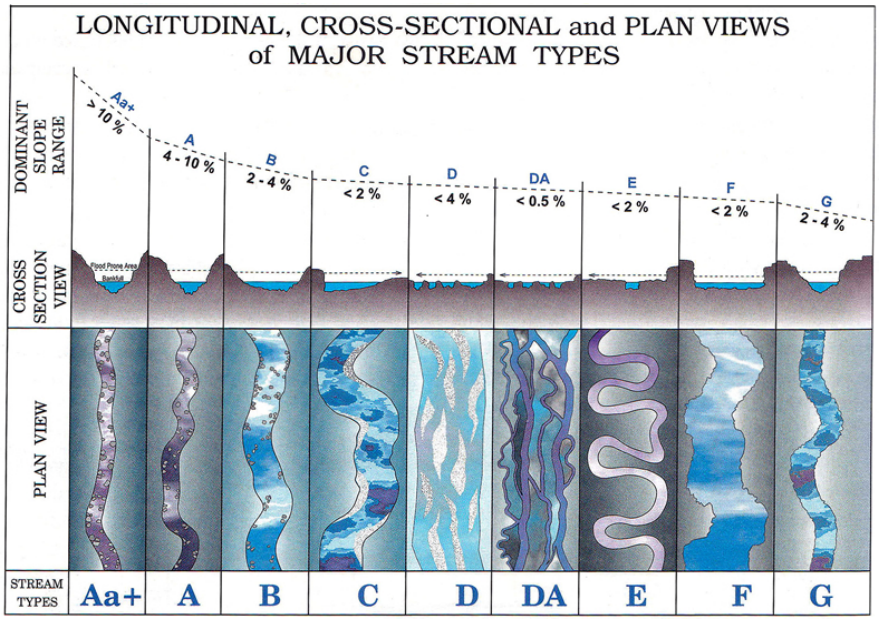


Figure 3: Rosgen's stream classification system (Rosgen, 1996)

The Rosgen Stream Classification System is used to categorize a stream according to cross section, slope and river shape (Malakoff, 2004). The system aims to predict a river's behavior based upon appearance, to develop specific hydraulic and sediment relationships for a specific site, to provide a tool for extrapolating site-specific data to areas with similar characteristics, and to provide a consistent system of reference for stream morphology among a variety of disciplines (Rosgen, 1994). Recently there has been an increase in the use of Rosgen's methods for restoration; methods which include examining the streams characteristics as well as those of the watershed. These methods are used by state and federal agencies and are mandatory in some state-funded restoration activities. However, as Rosgen states, the stream classification system is a guideline to stream restoration that is subject to variation between streams (Malakoff, 2004). This research does not seek to evaluate the Rosgen system, but uses stream classification in

the analysis as an aid to workers who may use this regional curve as a reference in stream restoration.

Stream Restoration

Stream restoration is a multi-million dollar industry that affects not only specific sites but the entire associated watershed and biogeographical area. However, the channel design based on bankfull dimensions used in stream restoration is site specific and requires specific parameters concerning bankfull discharge, width, and depth (Brown et al., 2007). Various differences between stream reaches must be taken into consideration when extrapolating known hydraulic geometries from one stream to a site with unknown geometries. Successful natural channel design, therefore, must include every aspect of dynamic equilibrium, such as channel pattern (plan view), dimension (size and shape), and profile (longitudinal characteristics) (Brown et al., 2007). In addition, by measuring flows, sediment transport, and debris movement, the natural conditions and anthropogenic impacts of the watershed's stream can be determined (Brown et al., 2007). Because of these outside complexities that contribute to stream geometry, only reaches of similar hydrologic regions are appropriate reference sites when comparing data in a regional curve.

The Rosgen classification system is most effective when all levels of analyses are referenced. Rosgen himself concedes that stream classification can be problematic on some river types, especially urban waterways that have been adjusted by disturbances (Malakoff, 2004). A particularly difficult variable to calculate is bankfull discharge

(Malakoff, 2004). Consequently, all bankfull geometries, such as width, depth, and velocity, should be taken into consideration.

Stream restoration efforts are executed using any of several methods: 1) similar or nearby streams reaches are referenced for stream characteristics such as width, depth, velocity and bankfull, 2) stream classification systems such as the Rosgen's system are prescribed to a specific site, and 3) stream restoration design is executed by developing a regional curve. Because stream restoration is site specific and the bankfull discharge forms the natural stream channel, a regional curve that takes into account all of the above is most likely the most accurate method for calculating stream restoration channel design.

Summary

Regional curves are used for stream design in restoration projects by providing information to estimate bankfull discharge, mean depth, width, and cross-sectional area at ungauged sites within given watersheds. (Mistak and Stille, 2007). Bankfull discharge, or the channel-forming flood, is defined as a flow that just fills the top of its bank, assumed to be equal to the 1.5-year flood ($Q_{1.5}$), but varying between the 1.0 and 2.5-year flood (Copeland et al., 2000). Bankfull is used as a surrogate for the hydraulic variables that form a natural channel, and can be determined by collecting field data, collecting gauging station data, and by developing a regional curve.

Problems associated with developing an accurate regional curve include selecting appropriate sites that accurately represent the surrounding watershed and are hydrologically similar and determining the correct bankfull level for a specific site.

Landcover and stream type are expected to affect the relationship between discharge and watershed area, due to the variations in discharge as a result of watershed drainage.

Land use practices within a watershed are known to effect bankfull discharge: areas that are primarily forest cover tend to produce less runoff and consequently less mass wasting, while areas that are primarily agricultural tend to produce more runoff and consequently more mass wasting (Reidel et al., 2005).

Classifying streams on the basis of channel morphology (cross section, slope, and river shape) can provide site-specific information that can be transferred to similar river reaches and aid in the selection of sites more representative of the watershed. Due to these variations in a hydrologic region, regional curves must represent the dominant landcover and stream type within a watershed in addition to the most prominent bankfull stage (such as the 1.5-year or 1.0-year recurrence interval).

SITE DESCRIPTIONS

The Wolf River Watershed and the Rock River Watershed were chosen for this study due to a high density of USGS gauging stations, and similarities in topography (Figure 4). Seven rivers from within six subwatersheds in the Wolf River Watershed and four rivers within the Rock River Watershed were selected according to period of activity and watershed area. These were used to develop regional curves, which compare hydraulic geometries to watershed area.

Hydrology, digital elevation models, geology, soils, and landuse from both county landcover and national landcover databases were delineated for both the Wolf River Watershed (Figures 5,Figure 6,Figure 7,Figure 8,Figure 9,Figure 10) and Rock River Watershed (Figure 11,Figure 12,Figure 13,Figure 14,Figure 16) to provide a better understanding of the physiography of the site. For physiography per subwatershed, see Appendix C, D, E, F, G, H, I, J.

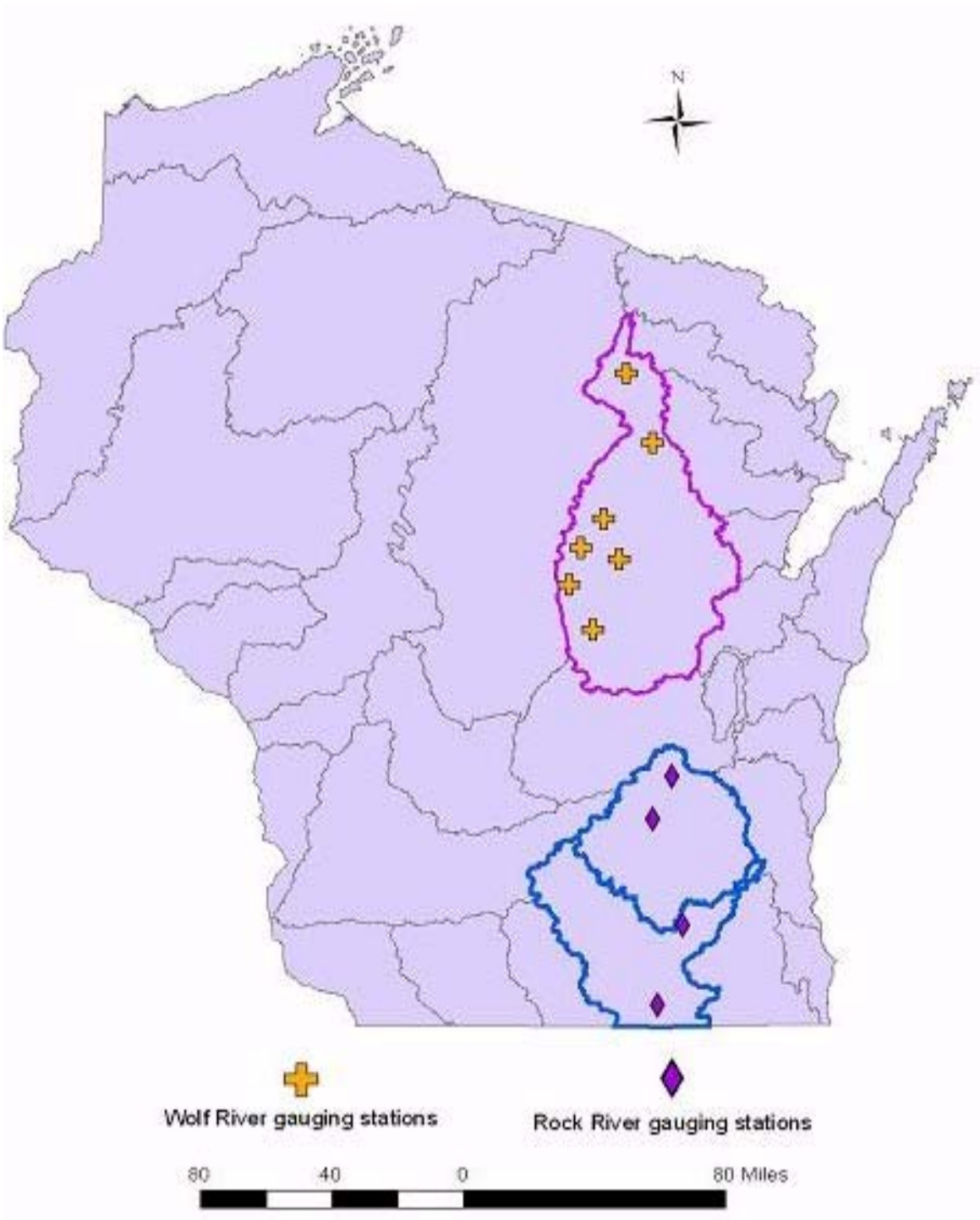
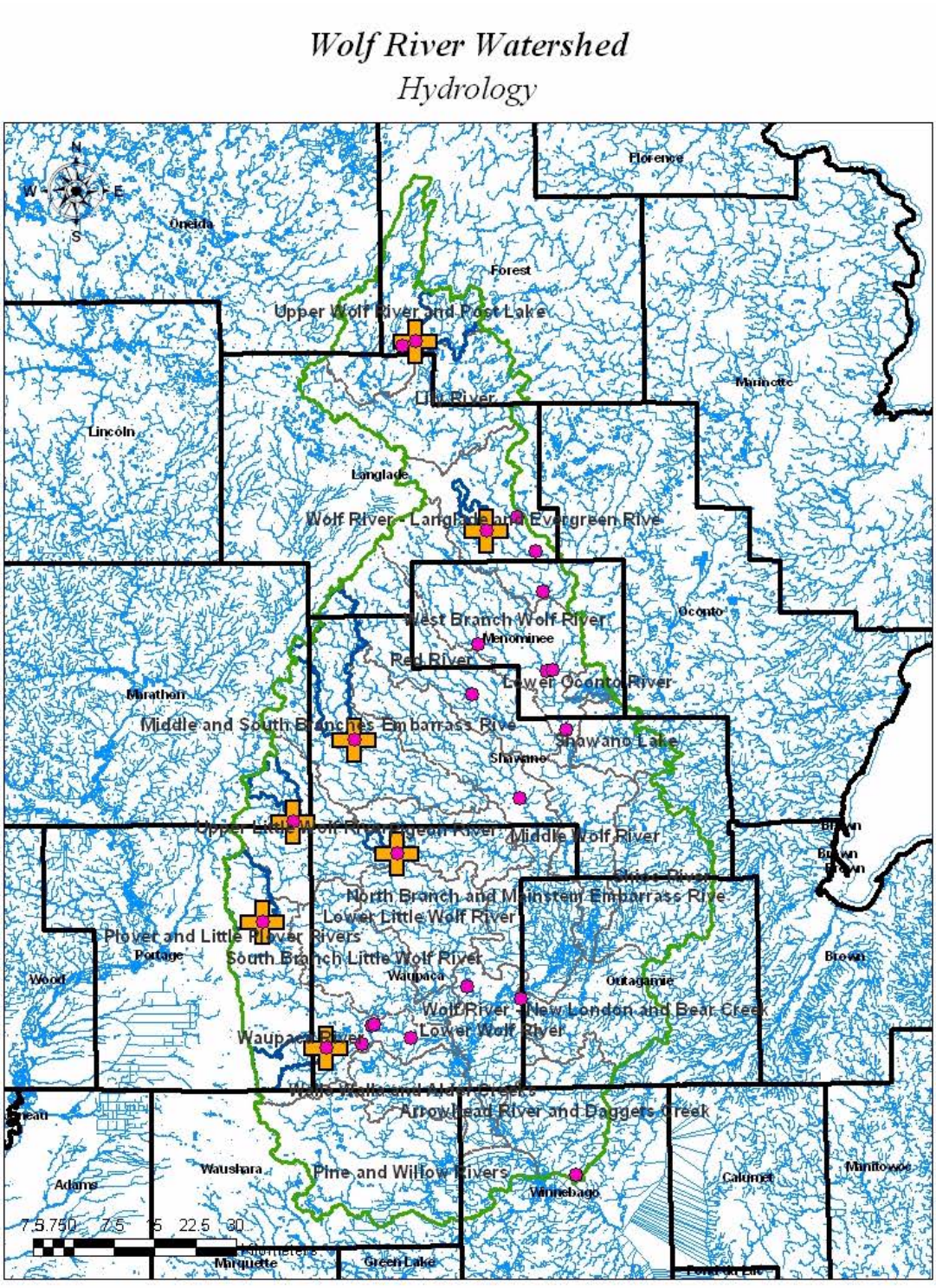


Figure 4: The Wolf River Watershed and Rock River Watersheds.



Figures 5: USGS Gauging Stations in the Wolf River Watershed in Northeastern Wisconsin.

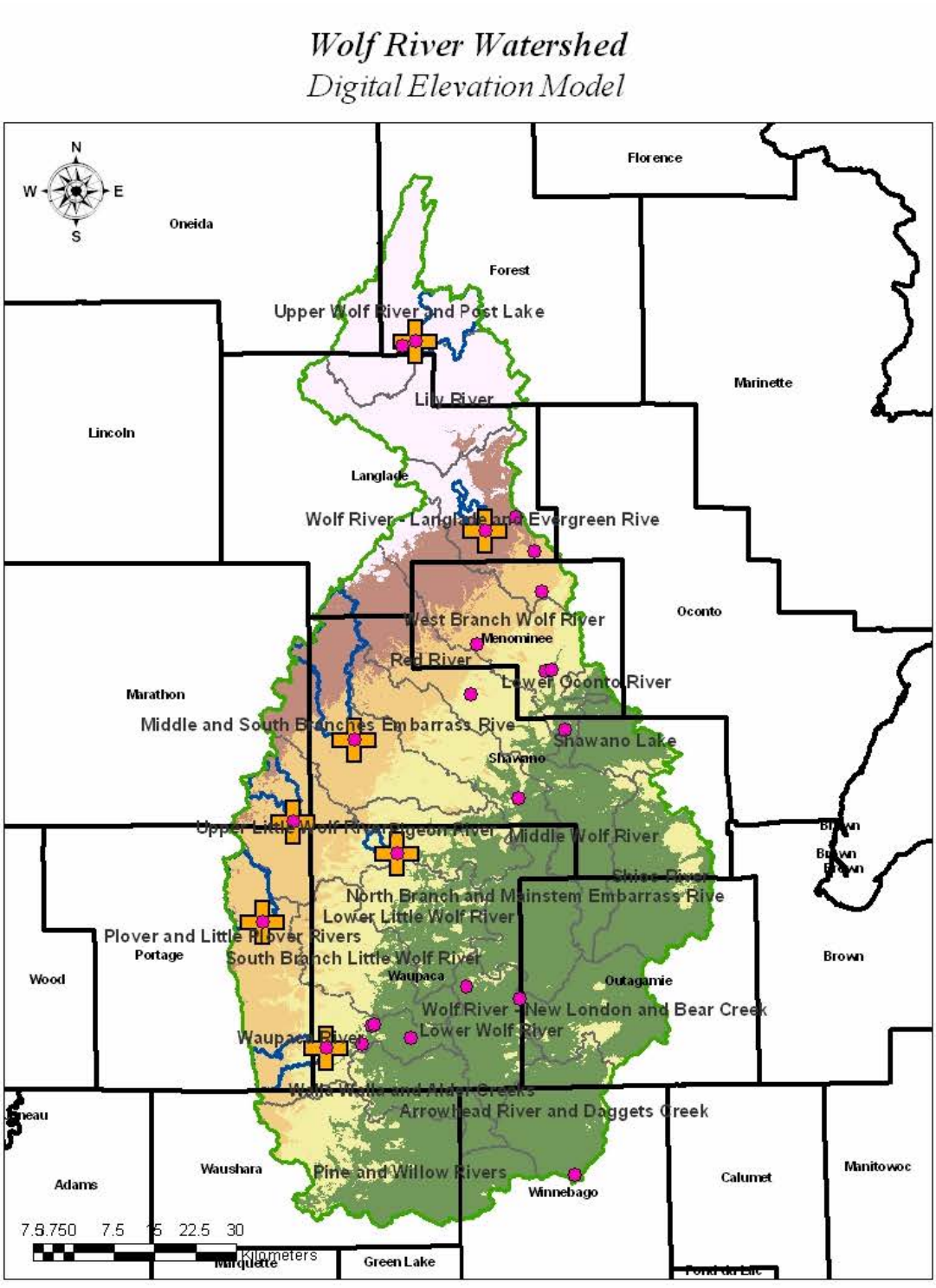


Figure 6: Digital Elevation Model for the Wolf River Watershed.

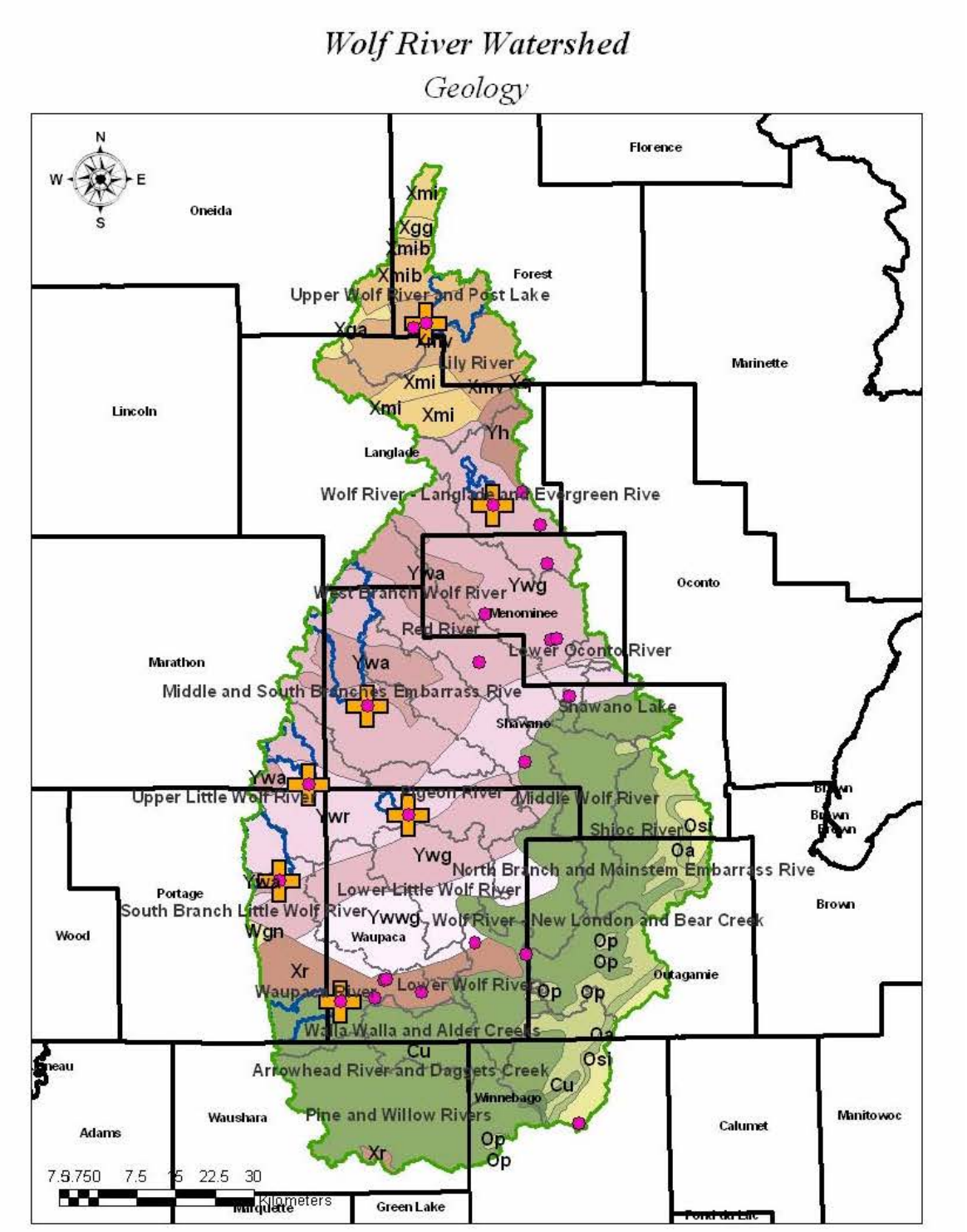


Figure 7: Geology of the Wolf River Watershed.

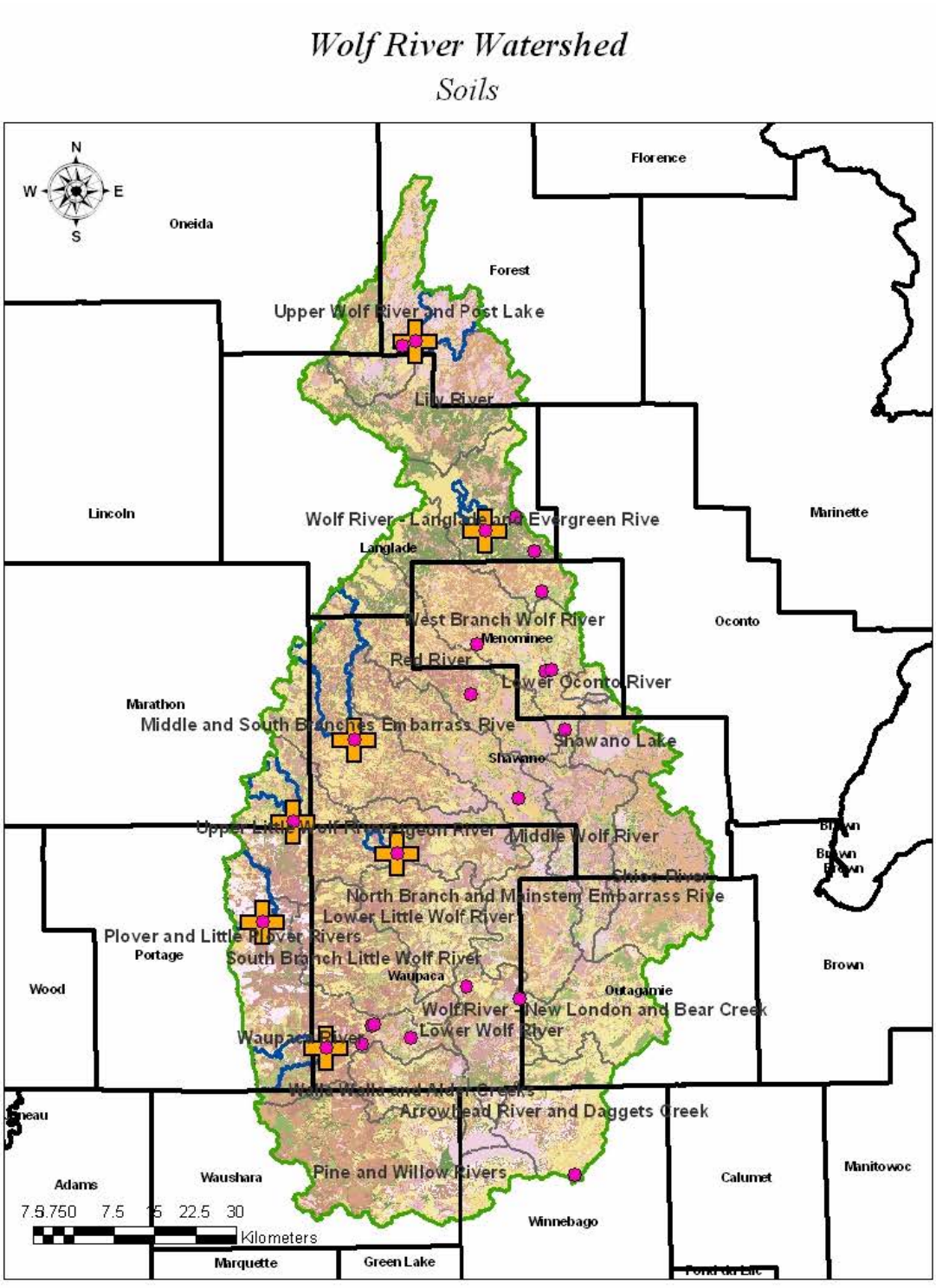


Figure 8: Soils of the Wolf River Watershed.

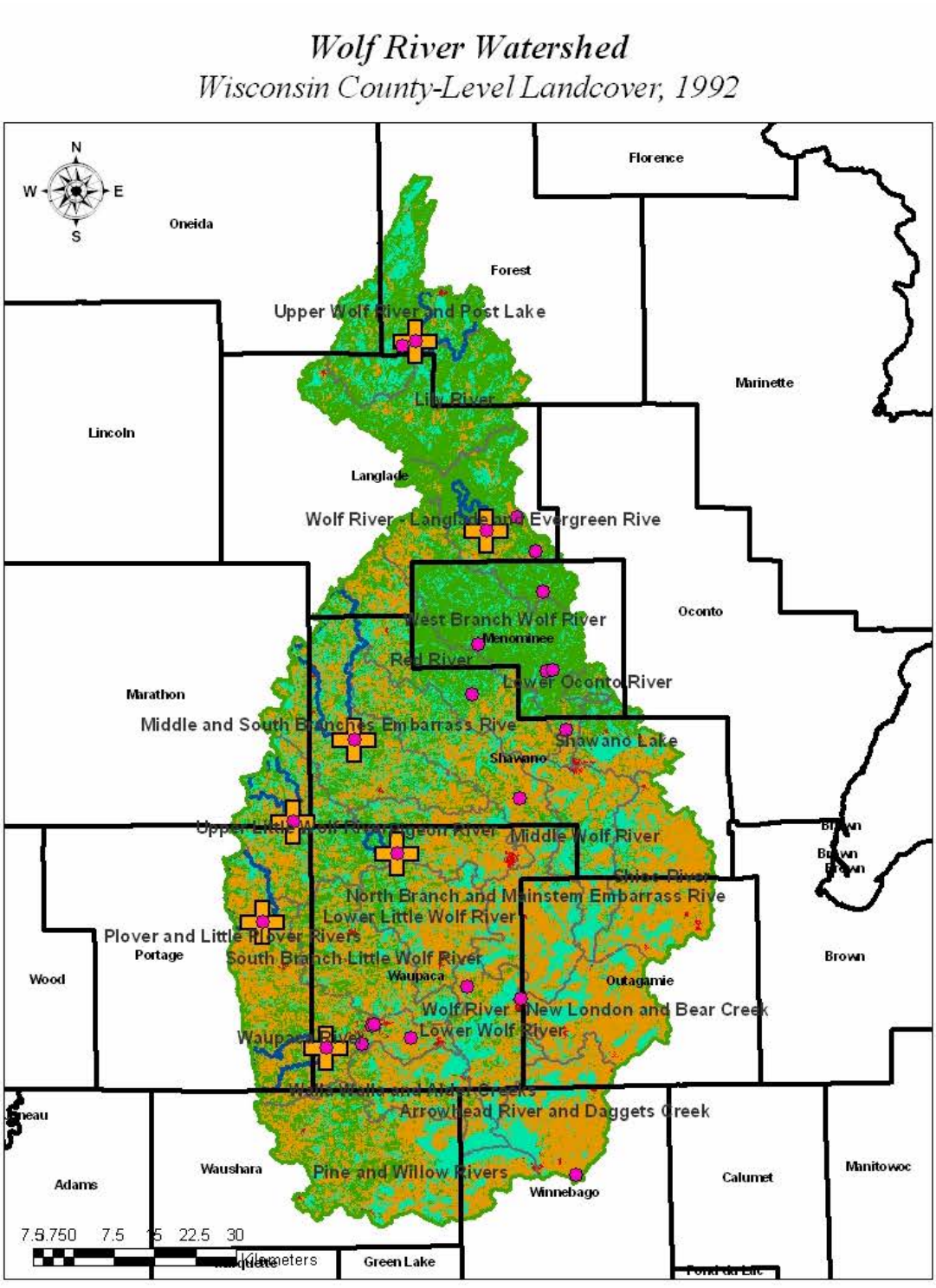


Figure 9: Wisconsin County-level Landcover from 1992 for the Wolf River Watershed.

Landcover has been grouped into 4 categories: ag/grasslands (orange), residential/industrial (red), water/wetlands (blue), and forest (green).

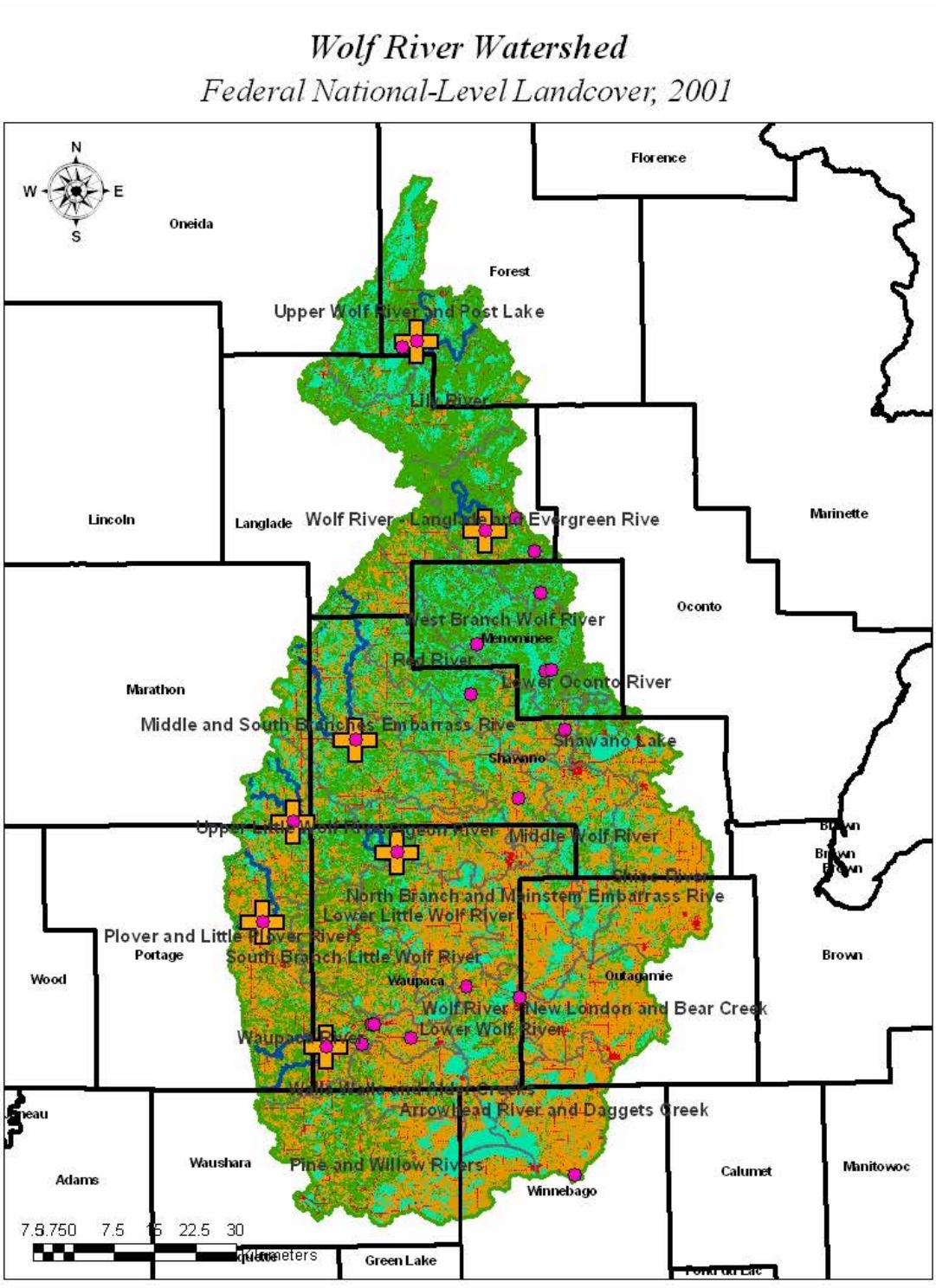


Figure 10: National landcover from 2001 for the Wolf River Watershed.

Landcover has been grouped into 4 categories: ag/grasslands (orange), residential/industrial (red), water/wetlands (blue), and forest (green).

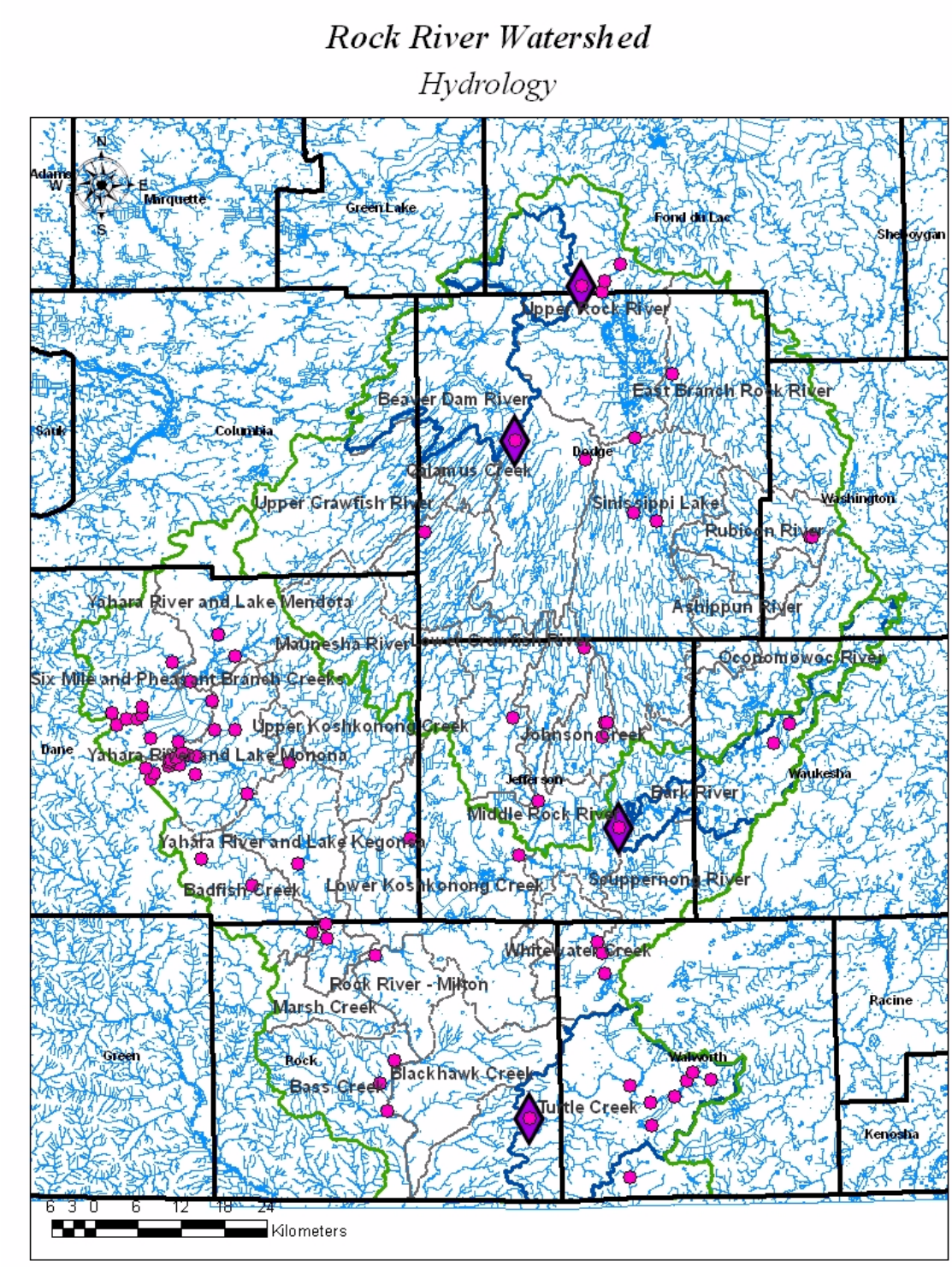


Figure 11: USGS Gauging Stations in the Upper and Lower Rock River Watershed in Southeastern Wisconsin.

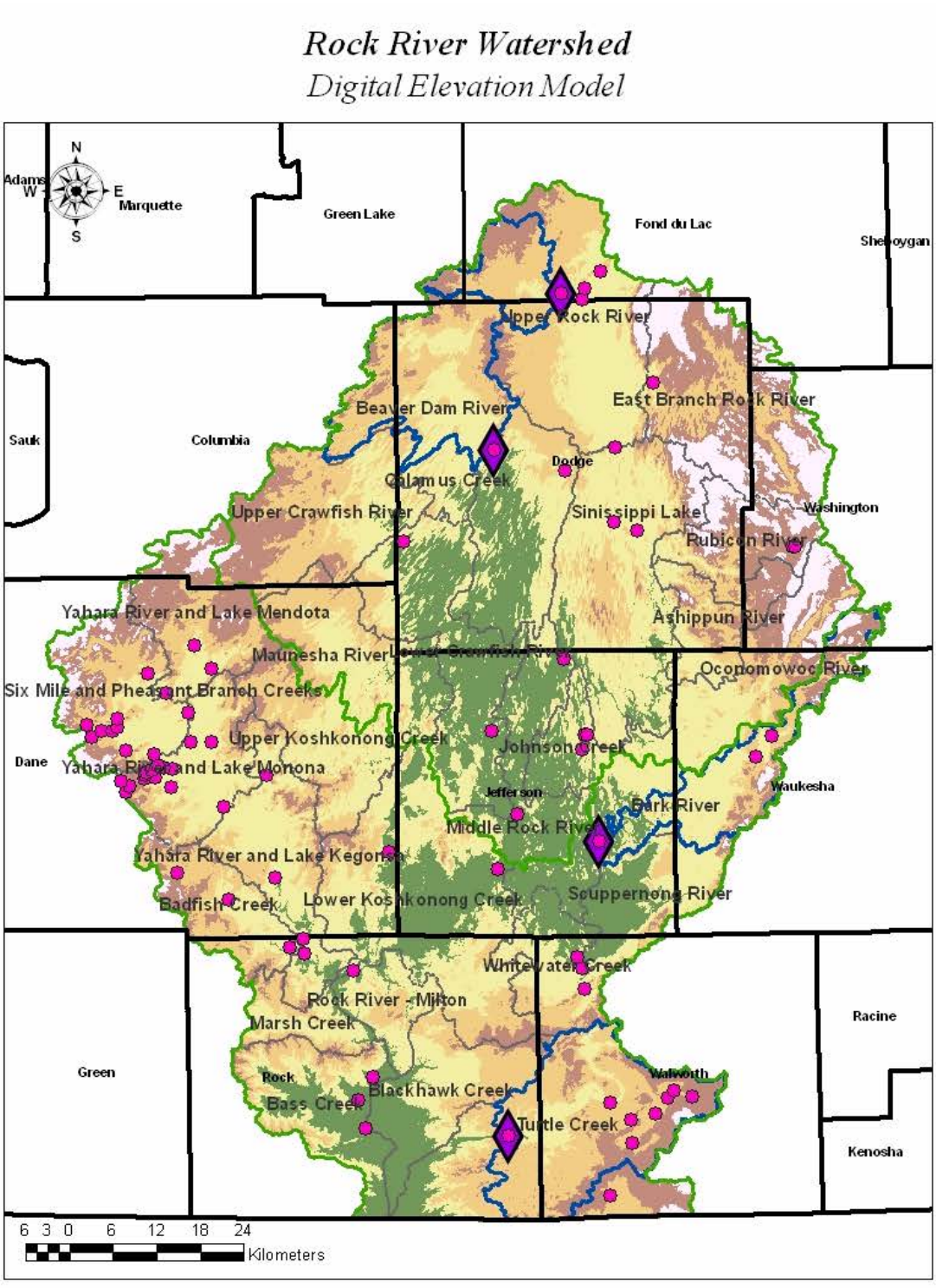


Figure 12: Digital Elevation Model for the Rock River Watershed.

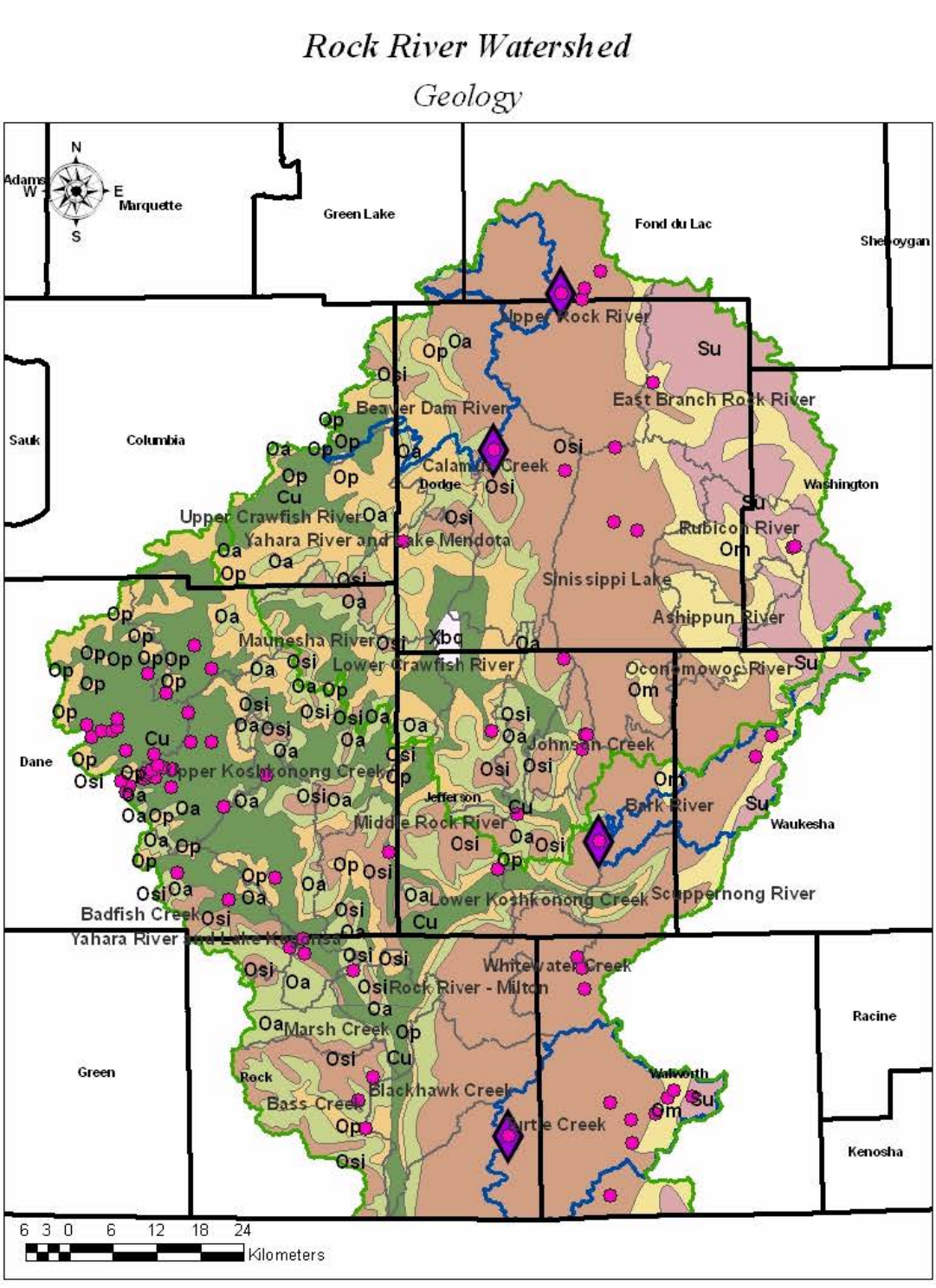


Figure 13: Geology of the Rock River Watershed.

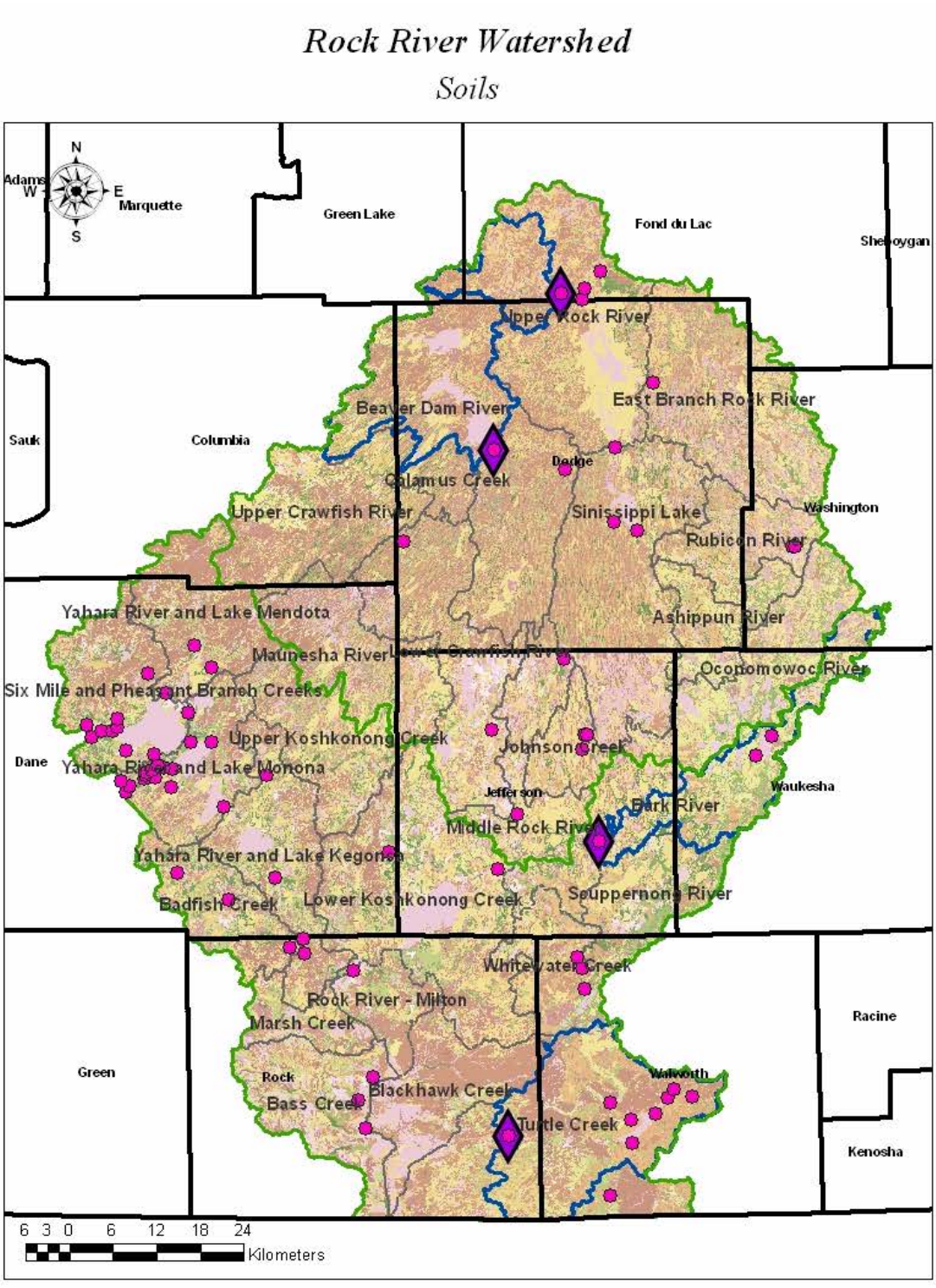


Figure 14: Soils of the Rock River Watershed.

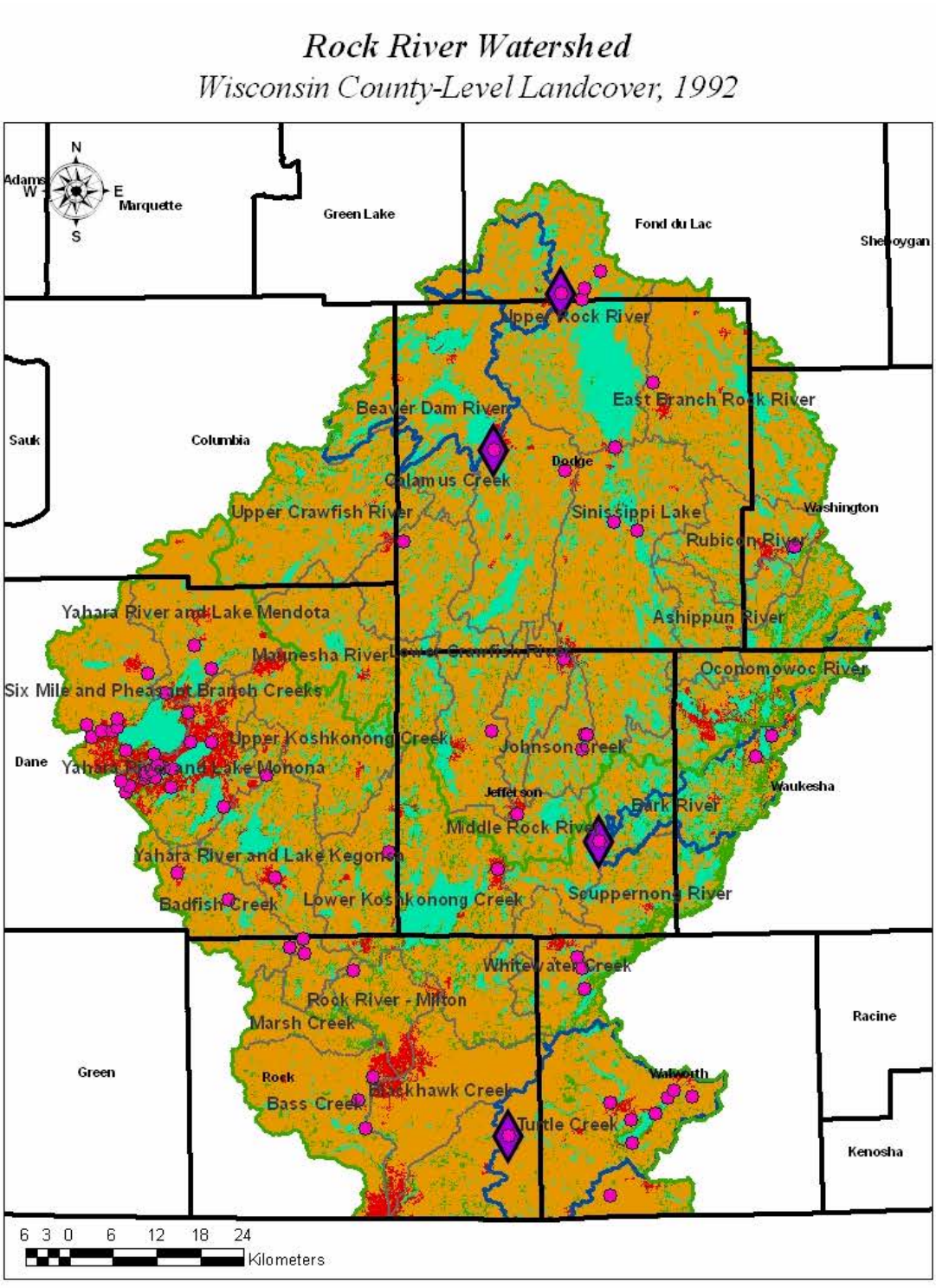


Figure 15: Wisconsin County-level Landcover from 1992 for the RockRiver Watershed.

Landcover has been grouped into 4 categories: ag/grasslands (orange), residential/industrial (red), water/wetlands (blue), and forest (green).

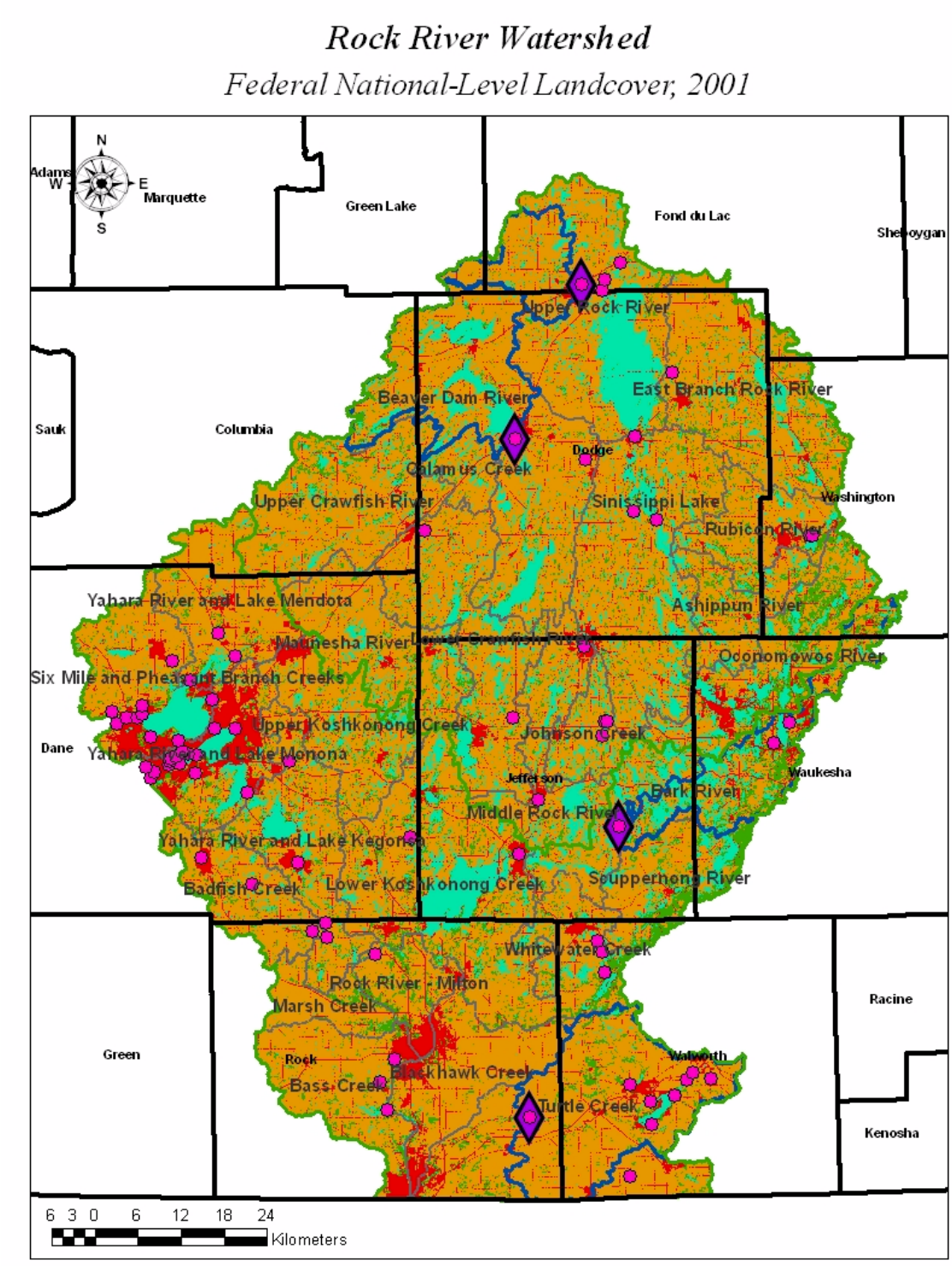


Figure 16: National landcover from 2001 for the Rock River Watershed.

Landcover has been grouped into 4 categories: ag/grasslands (orange), residential/industrial (red), water/wetlands (blue), and forest (green). Note that the majority of the watershed is agriculture/grasslands.

METHODOLOGY

This method of regional curve development incorporates stream survey data (velocity, cross section area, slope, etc) and historical discharge data recorded by the USGS. These data were used to calculate bankfull discharge, which was expected to increase linearly with watershed area. Landcover and stream classification were used to examine influential habitat and assess patterns within and deviations from between bankfull discharge and watershed area.

Field Data

Site Selection

Seven rivers from the Wolf River Watershed and four rivers from the Rock River Watershed were selected considering the following criteria: 1) Gauging stations at the site should be active within the last ten years; 2) Gauging stations at the site should be associated with at least five years of available USGS historical data; 3) watershed area must be less than 200 square miles; 4) stream width must be less than or equal to 100 feet in width; and 5) stream depth must be less than or equal to 3 feet at time of survey (for surveying purposes). As a result, the majority of the rivers chosen have a small watershed area and discharge (Table 1) (See Appendix B, K, and N). Data were collected during the late spring and early summer seasons, when many were nearly at bankfull condition. At all sites three transects were setup near the selected USGS gauging stations. Transects were preferably upstream from the gauging station due to gauging stations generally being positioned at dams, bridges, culverts, or other structures that affect the downstream

channel. Data collected included: width, depth, slope, velocity, and bankfull measurements.

These hydraulic variables were used to calculate the wetted perimeter, hydraulic radius, cross sectional area, and eventually bankfull discharge and Manning's *n* (Table 6). Transects results were then averaged for each site.

Table 1: USGS gauging station sites.

Sites	Abbrev.	Watershed Area (km^2)
WOLF RIVER		
Emmons Creek at Rural	ECR	65.01
Evergreen River at Langlade	ERL	20.95
Little Wolf River near Galloway	LWG	58.53
Middle Branch Embarrass at Wittenberg	MBEW	197.62
Spaulding Creek near Big Falls	SCBF	14.43
Swamp Creek above Mole Lake	SCML	119.92
Tomorrow River at Nelsonville	TRN	113.96
ROCK RIVER		
Bark River at Rome	BRR	315.98
Beaver Dam River at Beaver Dam	BDBD	406.63
South Branch Rock River at Waupun	SBRW	164.72
Turtle Creek at Carvers Rock	TCCR	515.41

Measuring Hydraulic Variables

Data collected at each site included: pebble counts and survey data such as bank and bankfull elevations, slope, and velocity measurements. At all sites three transects were setup near the selected USGS gauging stations. Each transect began at left bank, looking upstream, and generally reached a distance of 100 feet downstream. Transects

were stretched across the floodplain for the determination of width/depth ratios, and the construction of cross-sectional areas (Rosgen, 1996).

Slope

The bed and water slope were surveyed using a total station. Slope is generally determined by measuring the vertical drop in elevation along the streambank (DeBarry, 2004). Slope was measured longitudinally down the thalwag of the channel. The surveyor's rod was positioned alternately on the streambed and the water surface. In this way both the streambed elevation and water surface elevation were recorded by the total station. Slope was then determined by graphing the elevation points and finding the slope of the regression line between the elevations (Figure 17).

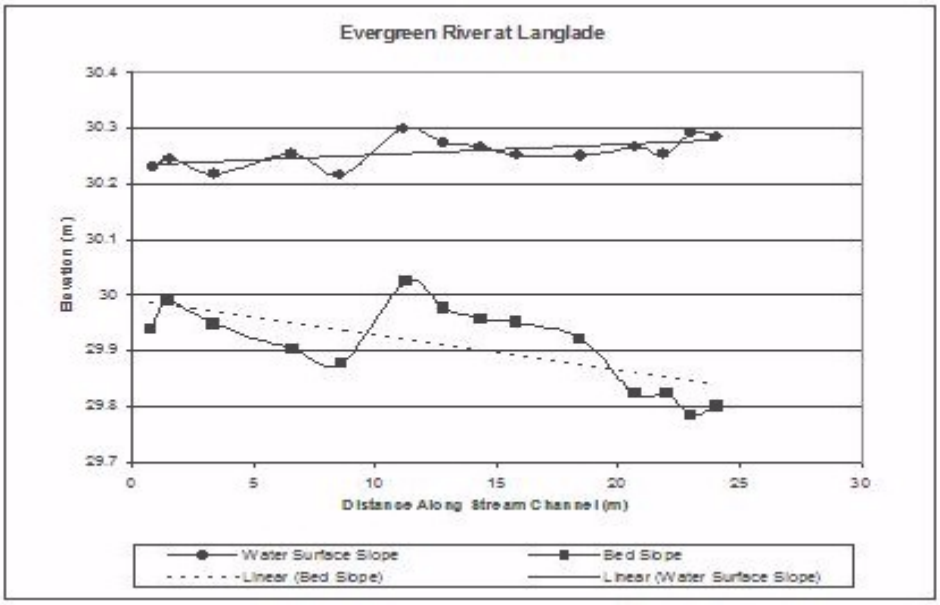


Figure 17: Water surface and bed slope elevations.

Cross Section and Bankfull Elevation

Cross-section measurements were determined using elevation and distance measurements. Elevations were calculated using a total station and measurements were taken at bankfull, bank edge, water bed and associated water surface moving across the transect (Figure 18). Elevation points were used to calculate distance across the transect and depth between water surface and streambed (Figure 19).

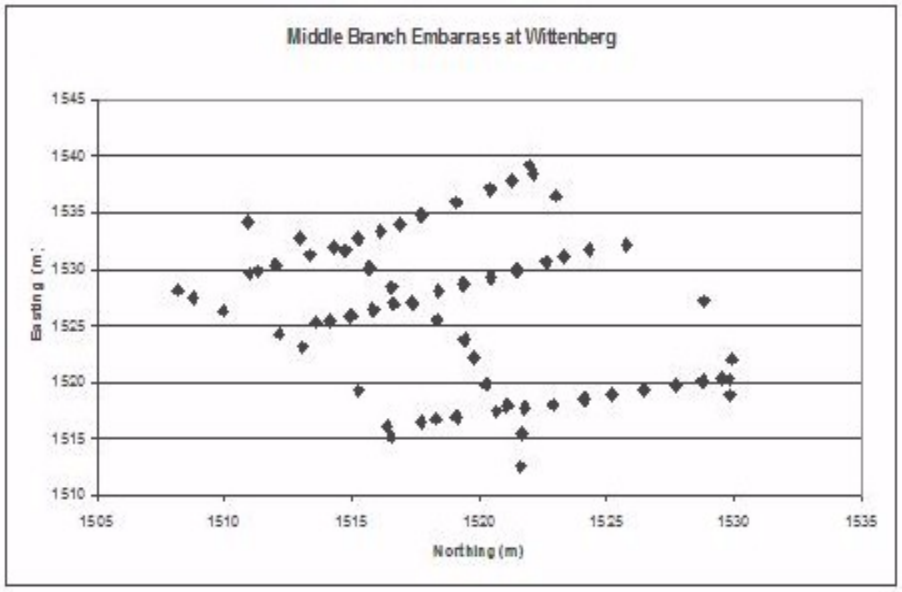


Figure 18: Birds-view diagram of survey data from the total station.

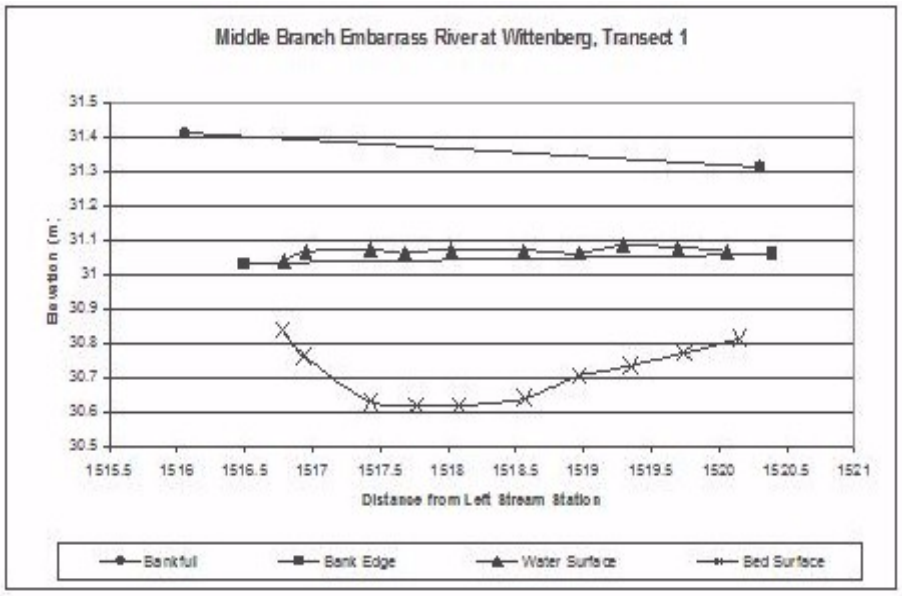


Figure 19: Cross section diagram of a site.

Bankfull elevation was determined by visually assessing the streambank and identifying the edge of the floodplain adjacent to the stream bank. The edge of the floodplain is the position near the horizontal plane adjacent to the stream channel before inclining into the channel. This can be evaluated from an elevated point above the floodplain or from a point in the channel looking upwards towards the floodplain. Bankfull was calculated by positioning the surveyors' rod at several bankfull points on both left and right bank. At least one bankfull elevation was taken in-between transects and at each transect point. Bankfull elevations were used to calculate distance between points and distance from bank edge (Figure 20). When bankfull was uneven the more undisturbed level was considered to be the true bankfull.

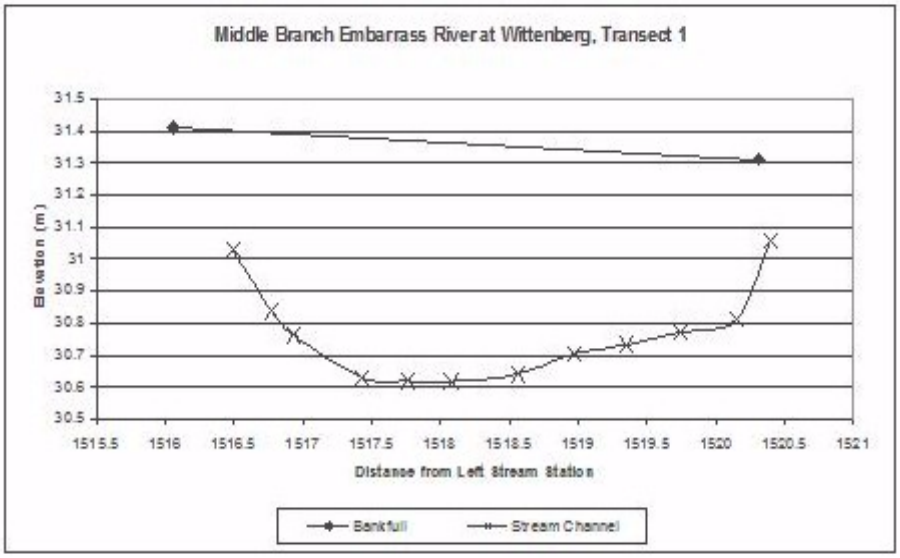


Figure 20: Cross section diagram of a site.

Velocity

Velocity measurements were collected at regular intervals at each transect, when the width between two velocity measurements were no more than 10% of the entire bank width. These hydraulics were taken using a velocity meter.

Data collected during these river surveys were used to calculate the average velocity of each transect and the river profile, longitudinal slope, bank and bankfull distance and elevations, both water bed and water surface elevation, Manning's *n*, and Manning's velocity.

Sediment Counts

Sediment counts were conducted using a simplified version of Woman's methods. Woman's methods involve a systematic method of sampling materials along various bed features at a site (Rosgen 1996). 100 sediment samples were collected from along the

length of each transect. Diameters were recorded by hand and the 84th percentile was calculated from each transect.

Roughness Coefficient

Channel discharge was calculated by multiplying the velocity measurements from each transect against the pre-calculated cross sectional area of each transect. The hydraulic variables determined from the cross sectional area, including hydraulic radius, wetted perimeter, and area, were used to determine bankfull discharge. Bankfull discharge was calculated using Manning's equation.

Four different methods were used to calculate *n*: *n* from survey calculations (n_s), *n* from Rosgen's stream type (n_r), *n* from visual estimations using Manning's estimation chart (n_m), and *n* from visual estimations using Cowen's method (n_c) (Table 2).

Table 2: Descriptions of *n* for this study.

Variable	Description	Obtained
n_s	Survey data calculated *n*	$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$
n_r	Rosgen's stream type determined *n*	Determine Rosgen's stream type, use chart to find *n*
n_m	Manning's estimation chart determined *n*	Follow Manning's estimation chart to find *n*
n_c	Cowan's estimation chart determined *n*	Follow Cowan's variable estimation chart to find *n*

The roughness coefficient from survey data (n_s) was calculated utilizing Manning's equation and the channel hydraulic radius, the water slope, and the channel average velocity (Equation 1).

$$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$$

Equation 1: Manning's equation.

The roughness coefficient from Rosgen's stream type (n_r) was calculated using a charted comparison of Manning's roughness coefficient and Rosgen stream types. Manning's *n* for a specific location was determined by following the relationship between *n* and the Rosgen classified stream type (Figure 21). This relationship differs for medium to large sized rivers, smaller rivers with controlling vegetative influence, and smaller rivers without controlling vegetative influence. The relationship for smaller rivers with controlling vegetative influence was used to determine *n* for each of the transects.

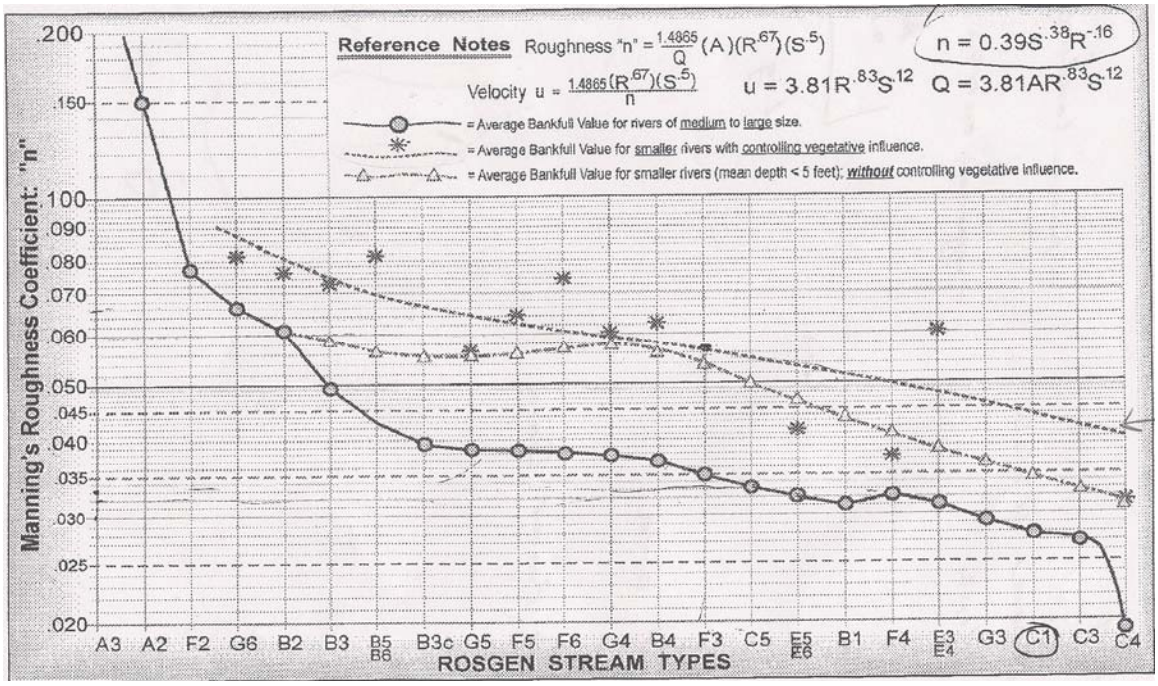


Figure 21: A reference chart for determining Manning's *n* based on Rosgen stream type (Rosgen, 1996).

The roughness coefficient from visual estimations using Manning's estimation chart (n_m) was determined using Manning's *n* values for channels (Chow 1959). Manning's *n* for a specific location was determined by selecting the channel description that best describes the location and the associated *n* value for that location (Figure 22). According to Manning's chart, roughness coefficient values are divided according to minimum, normal, and maximum *n* values. Normal values were used to determine *n* for each of the transects.

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Figure 22: Manning's method for estimating the roughness coefficient *n* (Chow, 1959).

The *n* from visual estimations using Cowen's method (n_c) was determining using Manning's *n* values for channels according to the variables and the recommended value for each variable (Cowen, 1956). According to Cowen's chart, variables such as stream irregularity and vegetation are given a visual description and a recommended value.

These values are then added up for the total roughness coefficient value of that location (Figure 23). These total values were used to determine *n* for each of the transects.

TABLE 3–11 Computation Sheet for Manning's Roughness Coefficient

Variable	Description Alternatives	Recommended Value	Actual Value
Basic, n_1	Earth	0.020	n_1 = _____
	Rock	0.025	
	Fine gravel	0.024	
	Coarse gravel	0.028	
Irregularity, n_2	Smooth	0.000	n_2 = _____
	Minor	0.005	
	Moderate	0.010	
	Severe	0.020	
Cross section, n_3	Gradual	0.000	n_3 = _____
	Occasional	0.005	
	Alternating	0.010–0.015	
Obstructions, n_4	Negligible	0.000	n_4 = _____
	Minor	0.010–0.015	
	Appreciable	0.020–0.030	
	Severe	0.040–0.060	
Vegetation, n_5	Low	0.005–0.010	n_5 = _____
	Medium	0.010–0.020	
	High	0.025–0.050	
	Very high	0.050–0.100	
			Subtotal n_s = _____
Meandering, n_6	Minor	0.000	n_6 = _____
	Appreciable	$0.15n_s$	
	Severe	$0.30n_s$	
			Total = Reach n = _____

Figure 23: Cowan's method for estimating the roughness coefficient *n* (Cowan, 1956).

Analytical Methods

Field data collected at these sites and USGS data were used to calculate and compare bankfull values. Bankfull values were then compared to watershed area with the construction of a regional curve. The resulting regressions were then compared between the two watersheds.

Manning's Equation

Hydraulic variables calculated using field measurements were primarily used to calculate Manning's Equation (in metric units) (Equation 1). Manning's equation incorporates velocity (V), hydraulic radius (R_h), slope of the water surface (S), and the roughness coefficient, or resistance coefficient (*n*).

Manning's equation is a velocity measurement for the stream channel that is an empirical formula for open channel flow (McCuen, 2005). The equation is chiefly used to calculate Manning's *n*, which is a roughness coefficient of the streambed. The roughness coefficient evaluates the overall shape of the channel bed, including channel roughness and stream sinuosity (McCuen, 2005). Several methods can be used to determine Manning's *n*, including calculating the coefficient, and utilizing visual methods to assess the roughness of the stream and estimate the coefficient. In order to statistically calculate the roughness coefficient, the average velocity of the stream (the average of three transects at a stream site) must be substituted for Manning's velocity. The equation is then solved for *n*, and then transposed and solved for Manning's velocity, and subsequently the bankfull discharge. Manning's *n* can be visually determined by examining the pebble size and quantity within the stream, the size and expanse of vegetation, and the overall channel size and shape.

Four different methods of calculating discharge were used in this study (Table 3): Q bankfull from survey calculations (Q_s), Q resistance (Q_r), Q bankfull from the historical 1.5-year recurrence interval ($Q_{h1.5}$), and Q bankfull from the historical 1.0-year recurrence interval ($Q_{h1.0}$). General practice for the calculation of field discharge involves using area and velocity measurements (McCuen, 2005).

Table 3: Descriptions of discharge for this study.

Variable	Description	Obtained
Q_s	Survey data calculated discharge	$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$
Q_r	Resistance Discharge	$Q_r = \left[\left(2.83 + 5.66 Log \frac{R}{D^{84}} \right) * u * \right] * A$
$Q_{h1.5}$	Historical 1.5-year recurrence interval discharge	1.5-year recurrence interval
$Q_{h1.0}$	Historical 1.0-year recurrence interval discharge	1.0-year recurrence interval

Discharge calculated by Q discharge from survey data (Q_s) was calculated by multiplying the average bankfull velocity and the bankfull area. The bankfull velocity was calculated using Manning's equation (bankfull hydraulic radius from survey data, water slope, and *n* from survey data calculations), while the bankfull area was calculated using elevation data collected during field surveys.

Discharge calculated by the Q resistance equation (Q_r) was calculated by using the Q resistance equation where: u is the bankfull velocity, u* is the shear velocity, 2.83 and 5.66 are constants, R is the bankfull hydraulic radius, D^{84} is the 84^{th} sediment percentile, and A is the bankfull area (Equation 2).

$$Q_r = \left[\left(2.83 + 5.66 Log \frac{R}{D^{84}} \right) * u * \right] * A$$

Equation 2: Q resistance equation.

Discharges calculated from the historical 1.5-year recurrence interval ($Q_{h1.5}$) and the historical 1.0-year recurrence interval ($Q_{h1.0}$) were determined by calculating the recurrence intervals from the peak discharge data associated with each year a gauging station was active (Table 4). Peak discharge data were ranked in descending order, and each rank (with the highest discharge ranked as 1) was divided by the total number of years available, plus one. The discharge associated with the 1.5-year or 1.0-year recurrence intervals as used to determine the historical bankfull discharge for each site.

USGS Gauging Station Data

For the purpose of this study, the 1.5-year and 1.0-year recurrence intervals represent bankfull and were used as a guideline when assessing field discharge measurements. Peak discharge data for each year ranging between the first to the last year of gauging station activity was used to calculate the recurrence interval (Table 4). The data was found using the public USGS website data which includes real-time data, site-information data, surface water, groundwater, and water quality information. The recurrence interval derived from these data represents the average time span between similar flows.

In the case of the Tomorrow River at Nelsonville site, peak discharge data was not available. Instead, the peak discharge was calculated from daily data for each year the site was active. These calculated peak discharges were then used to calculate the recurrence interval.

Table 4: Recurrence interval example.

Peak Discharge	Rank	RI
1140	1	21
758	2	10.5
754	3	7
707	4	5.25
639	5	4.2
616	6	3.5
567	7	3
540	8	2.625
535	9	2.333333
507	10	2.1
475	11	1.909091
450	12	1.75
427	13	1.615385
427	14	1.5
401	15	1.4
394	16	1.3125
367	17	1.235294
360	18	1.166667
313	19	1.105263
296	20	1.05

Recurrence Interval

In order to find the recurrence intervals the data collected from the USGS were given a numerical rank according to the peak discharge for each year in descending order (Table 4). The years of data plus one (n+1) is then divided by the numerical rank. (DeBarry, 2004). The resulting value was identified as the recurrence interval, which gives the estimated amount of time for a specific discharge value to occur. The 1.5, 10, and 50-year recurrence intervals represent the 1.5, 10, and 50-year floods. In this study

the USGS 1.5 year flood ($Q_{1.5}$ discharge) was then compared to the bankfull discharge calculations calculated by the data gathered from the research sites.

ArcMap Land use Mapping

ArcMap 9.2 and ArcHydro were used to determine the land use percentages for each river reach as well as the entire Wolf River Watershed and Rock River Watershed region. ArcHydro was used to delineate the watershed region upstream of the site-specific USGS gauging stations. Landcover shapefiles and grids derived from county (2002) and federal (1997) landcover maps were used to assess landuse. Landuse was assessed for each set of data and compared. Landcover was generalized to create a new land use classification for calculating land use percentages, including: forest/shrubland, agricultural/grasslands, commercial/residential, and water/wetlands. This landcover was compared to overall percentage of landcover within Department of Natural Resources subwatershed management units. These land use percentages were then used to analyze patterns within and diversions from the linear regression within the regional curves developed for both the Wolf River and Rock River watersheds. Relationships between landcover and discharge were analyzed using linear regressions between specific landcovers and stream reaches (See Appendix A).

Rosgen Stream Classification

Stream classification was used for further analysis of patterns within and deviation from the regression within the regional curves. To do this, the Rosgen Stream Classification system was considered. The Rosgen Stream Classification system (Figure

24) is a composed of four basic elements: Levels I through IV (Rosgen, 1994). The classification then breaks down into nine different stream types arranged in descending slope: Aa+, A, B, C, D, DA, E, F, and G (Rosgen, 1994). These stream types are classified according to letter by entrenchment ratio, width/depth ratio, sinuosity, and slope, and by according to number (1-6) according to decreasing dominant bed material size: bedrock, boulder, cobbler, gravel, sand, silt/clay (Rosgen, 1994). Relationships between stream type and discharge were analyzed by examining the stream classification of specific stream reaches along a linear regression between discharge and watershed area.

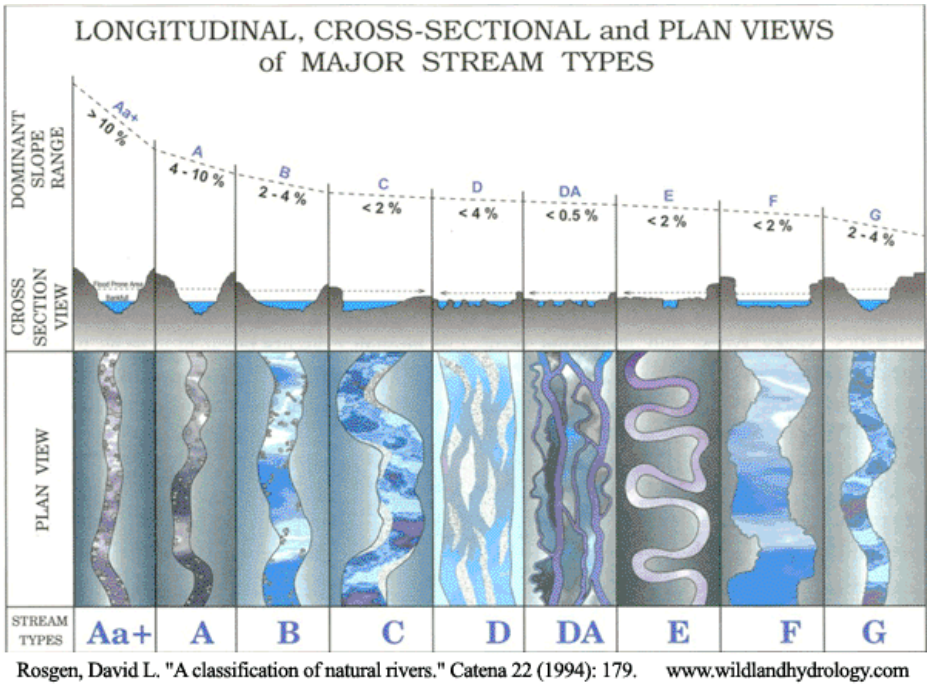


Figure 24: Rosgen Stream Classification system (Rosgen, 1994).

Regional Curve

A regional curve was developed for both major watersheds by comparing watershed area (mi^2) to bankfull discharge, as well as width to discharge, and average depth to discharge. This involved graphing a series of known discharge, width, and depth values and their corresponding watershed sizes, and analyzing the regression between the variables.

The chosen sites were used to create the regional curves that are the purpose of this project. The regional curves were designed to represent the natural bankfull of the watershed region for natural channel design to be used in restoration projects. However, the Rock River Watershed provided many challenges, including factors which may have affected the natural stream channel and ultimately the relationship between the surveyed channel and the historical channel data.

RESULTS

Objectives for this project included calculating hydraulic variables, such as velocity and discharge, for each river reach; determining landcover and stream type for each river reach; comparing survey data to historical data; and developing a regional curve for both the Wolf River and Rock River Watersheds.

Field Data

Site Selection

Regional curves must be developed with a well-distributed set of sites in order to compare watershed size to bankfull discharge, bankfull area, and bankfull width. The seven Wolf River sites were chosen from six subwatersheds, while the four Rock River sites were chosen from four subwatersheds (Figure 4) (See Appendix B, C, D, K and N). There was considerable variation in watershed size, ranging from 14.4 km^2 to 197.6 km^2 in the Wolf watershed to 164.7 km^2 to 515.4 km^2 in the Rock watershed (Table 5). The Rock River Watershed sites were considerably larger than those in the Wolf River, although sites in both watersheds were chosen using the same criteria. Width and depth of the sites differed (Table 6). Most sites chosen within the Rock watershed were wider, deeper, and had a larger area (Figure 25,Figure 26,Figure 27). The Wolf subwatersheds are more natural and less subjected to urban channelization.

One site within the Rock River Watershed, the Beaver Dam River at Beaver Dam, was removed from the development of a regional curve. The historical discharges associated with this data, as well as the survey calculations, were affected by dam

releases upstream of the gauging station and were therefore inconsistent with the rest of the sites within the Rock River study.

Table 5: Research sites at USGS gauging stations.

Sites	Abbrev	Range of Years	Years of Data	Survey Q1.5 (cms)	Historical Q1.0 (cms)	Historical Q1.5 (cms)	Watershed Area (km^2)
WOLF RIVER							
Emmons Creek at Rural	ECR	6	6	2.4	1.4	1.5	65.0
Evergreen River at Langlade	ERL	48	48	1.0	0.7	1.0	21.0
Little Wolf near Galloway	LWG	4	4	5.5	1.7	3.9	58.5
Middle Branch Embarrass at Wittenberg	MBEW	16	16	3.9	7.3	10.3	197.6
Spaulding Creek near Big Falls	SCBF	48	48	1.3	0.5	1.3	14.4
Swamp Creek above Mole Lake	SWML	11	11	12.8	2.9	3.3	119.9
Tomorrow River at Nelsonville	TRN	3	3	4.7	2.7	2.7	114.0
ROCK RIVER							
Bark River at Rome	BRR	22	22	6.6	4.4	7.2	316.0
Beaver Dam at Beaver Dam	BDBD	20	20	1.0	8.4	12.1	406.6
South Branch Rock River at Waupun	SBRW	37	37	1.6	1.4	9.9	164.7
Turtle Creek at Carvers Rock	TCCR	66	66	7.2	7.6	33.4	515.4

Measuring Hydraulic Variables: Width, Depth, Slope Determination, Velocity and Bankfull

Data for transects at a site were averaged and compared (Table 6) (See Appendix L and M). Comparisons display weak linear relationships between bankfull width, depth, and area for both watersheds, and a linear increase in bankfull width, depth, and area between the Wolf watershed and the Rock watershed. A strong relationship is considered an $R^2 > 0.5$, while a weak relationship is considered $R^2 < 0.5$.

Table 6: Channel and Bankfull hydraulic variables.

Sites	Abbrev.	Watershed Area (km^2)	Area (m^2) Channel	Area (m^2) Bankfull	Width (m) Channel	Width (m) Bankfull	Ave. Depth (m) Channel	Ave. Depth (m) Bankfull	Max Depth (m) Bankfull	Wetted Perimeter (WP) Channel	Wetted Perimeter (WP) Bankfull	Rh (m) Channel	Rh (m) Bankfull	Ave Velocity (*m/s*) Channel	Ave Velocity (*m/s*) Bankfull
WOLF RIVER															
Emmons Creek at Rural	ECR	65.01	1.97	3.57	4.17	6.70	0.29	0.55	1.02	4.79	7.58	0.42	0.48	0.63	0.70
Evergreen River at Langlade	ERL	20.95	1.41	2.62	5.63	7.08	0.15	0.38	0.36	5.98	7.57	0.25	0.35	0.30	0.38
Little Wolf River near Galloway	LWG	58.53	0.96	4.07	7.00	13.47	0.10	0.31	0.52	7.06	13.68	0.14	0.30	0.78	1.34
Middle Branch Embarrass at Wittenberg	MBEW	197.62	4.78	8.18	11.95	15.67	0.14	0.52	0.71	12.81	15.91	0.37	0.52	0.38	0.47
Spaulding Creek near Big Falls	SCBF	14.43	1.28	2.22	4.30	4.98	0.22	0.47	0.66	4.71	5.69	0.28	0.40	0.44	0.56
Swamp Creek above Mole Lake	SCML	119.92	5.98	21.47	20.34	27.97	0.17	0.77	1.11	18.88	28.22	0.33	0.76	0.33	0.59
Tomorrow River at Nelsonville	TRN	113.96	2.28	5.85	8.96	6.45	0.29	0.92	0.88	9.56	11.51	0.24	0.51	0.50	0.82
ROCK RIVER															
Bark River at Rome	BRR	315.98	4.75	13.26	19.40	20.78	0.14	0.64	0.77	19.50	21.21	0.24	0.63	0.27	0.50
Beaver Dam River at Beaver Dam	BDBD	406.63	4.50	10.46	10.43	10.72	0.31	1.04	1.25	9.77	12.52	0.44	0.82	0.07	0.11
South Branch Rock River at Waupun	SBRW	164.72	3.09	10.84	11.61	13.60	0.11	0.79	0.94	9.98	14.22	0.31	0.75	0.08	0.14
Turtle Creek at Carvers Rock	TCCR	515.41	8.63	23.91	19.12	21.12	0.35	1.13	1.37	19.27	22.45	0.45	1.06	0.19	0.33

The surveyed bankfull width was averaged for all three transects at each site and compared to watershed area (Figure 25). Bankfull width in the Wolf River Watershed averages 11.76 m, while the Rock River Watershed averages 18.55 m. Bankfull width showed a weak relationship with watershed area in the Wolf River Watershed and a strong relationship with watershed area in the Rock River Watershed: Wolf River R^2 = 0.42, while Rock River R^2 = 0.84 (Figure 25). Outliers above the trendline (Figure 25) in the Wolf River Watershed include the Swamp Creek above Mole Lake site and the Little Wolf near Galloway site. The Swamp Creek site bankfull width averages 27.97 m with a watershed area of 119.9 km^2, while the Little Wolf site bankfull width averages 13.47 m with a watershed area of 58.5 km^2. Outliers below the trendline (Figure 25) include the Emmons Creek at Rural site, and the Tomorrow River at Nelsonville site. The Emmons Creek site bankfull width averages 6.70 m, with a watershed area of 65.0 km^2, while the Tomorrow River site bankfull width averages 6.45 m, with a watershed area of 114.0 km^2. There are no significant outliers in the Rock River Watershed.

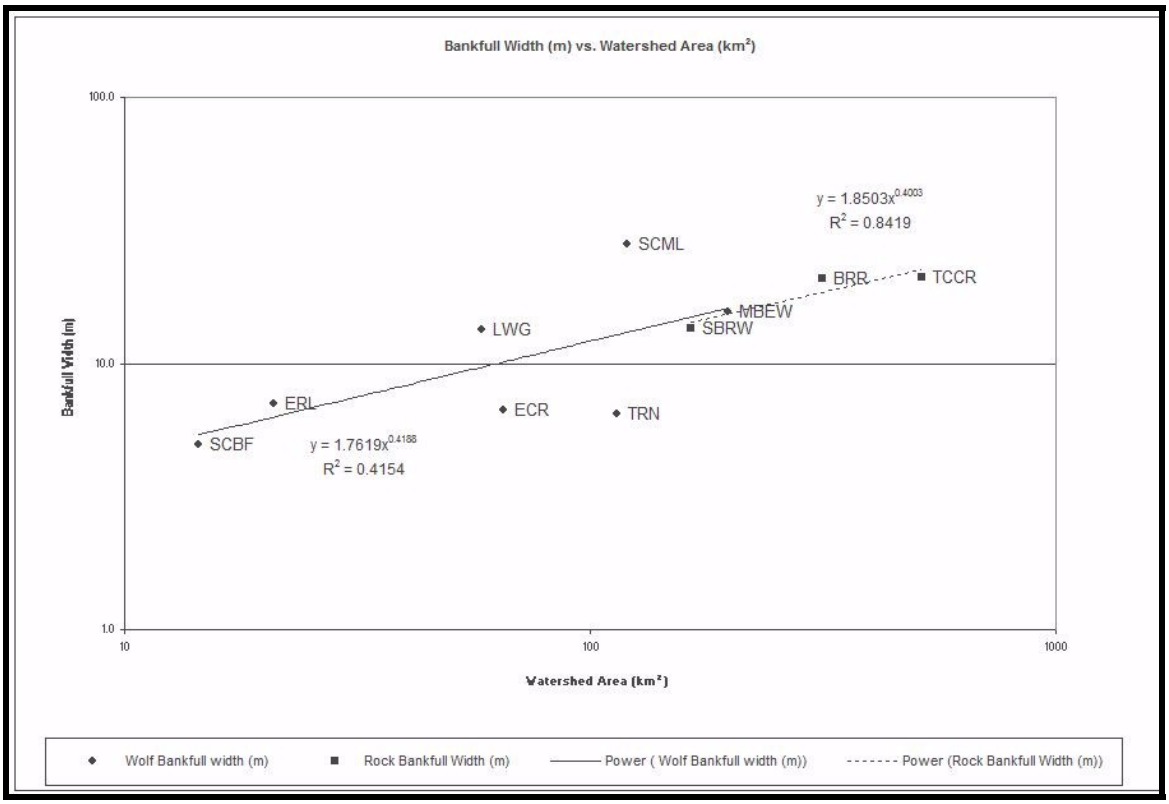


Figure 25: Regional curve of surveyed bankfull width to watershed area.

The surveyed bankfull depth was averaged for all three transects at each site and compared to watershed area (Figure 26). Bankfull depth in the Wolf River Watershed averages 0.56 m, while the Rock River Watershed averages 0.85 m, excluding the Beaver Dam site. Bankfull depth showed a weak linear relationship with watershed area in both watersheds: Wolf River $R^2 = 0.28$, while Rock River $R^2 = 0.31$. Outliers above the trendline (Figure 26) in the Wolf River Watershed include the Tomorrow River at Nelsonville site. The Tomorrow River site bankfull depth averages 0.92 m, with a watershed area of 114.0 km^2. Outliers below the trendline (Figure 26) in the Wolf River Watershed include the Little Wolf River near Galloway site. The Little Wolf site bankfull

depth averages 0.31 m, with a watershed area of 58.5 km^2. There are no significant outliers in the Rock River Watershed.

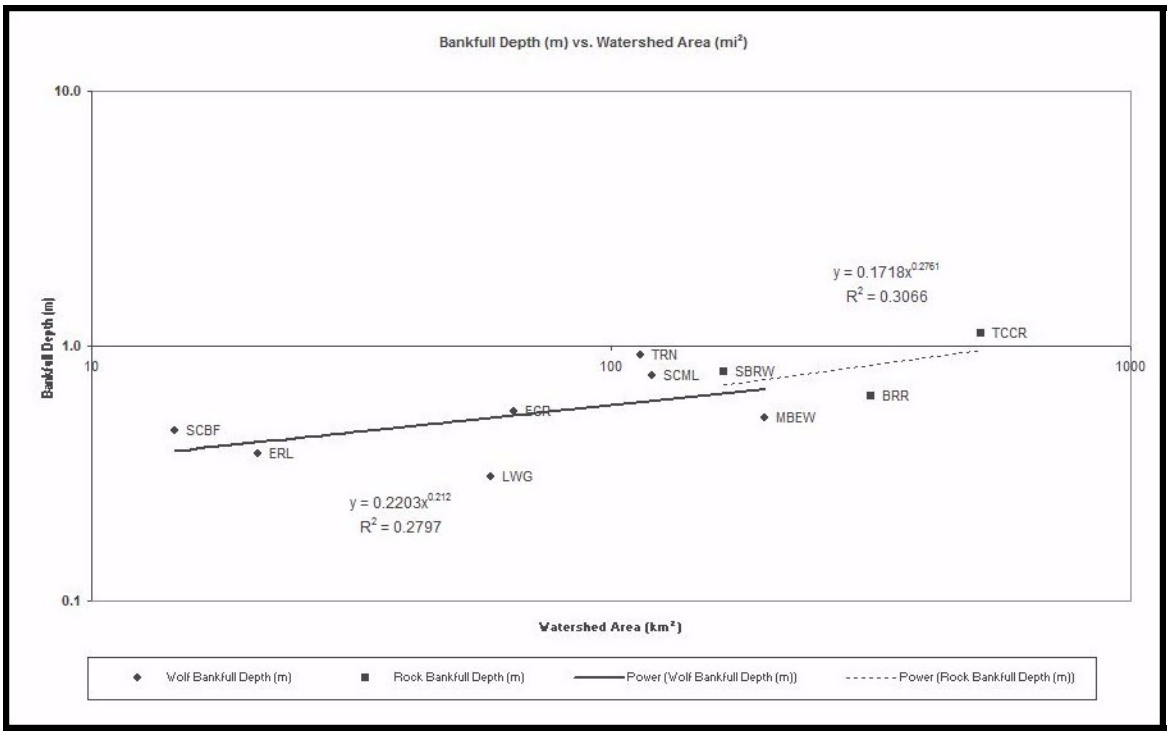


Figure 26: Regional curve of surveyed bankfull depth to watershed area.

The surveyed bankfull area was averaged for all three transects at each site and compared to watershed area (Figure 27). Bankfull area in the Wolf River Watershed averages 6.86 m^2, while the Rock River Watershed averages 16.00 m^2 , excluding the Beaver Dam site. Bankfull area showed a strong linear relationship with watershed area in the Wolf River at $R^2 = 0.62$, and a strong relationship with the Rock River at $R^2 = 0.88$. Outliers above the trendline (Figure 27) in the Wolf River Watershed include the Swamp Creek above Mole Lake site. The Swamp Creek sites bankfull area averages 0.6221.47 m^2, with a watershed area of 119.9 km^2. Outliers below the trendline (Figure

27) in the Wolf River Watershed include the Emmons Creek at Rural site. The Emmons Creek site bankfull area averages 3.57 m^2, with a watershed area of 65.0 km^2. There are no significant outliers in the Rock River Watershed.

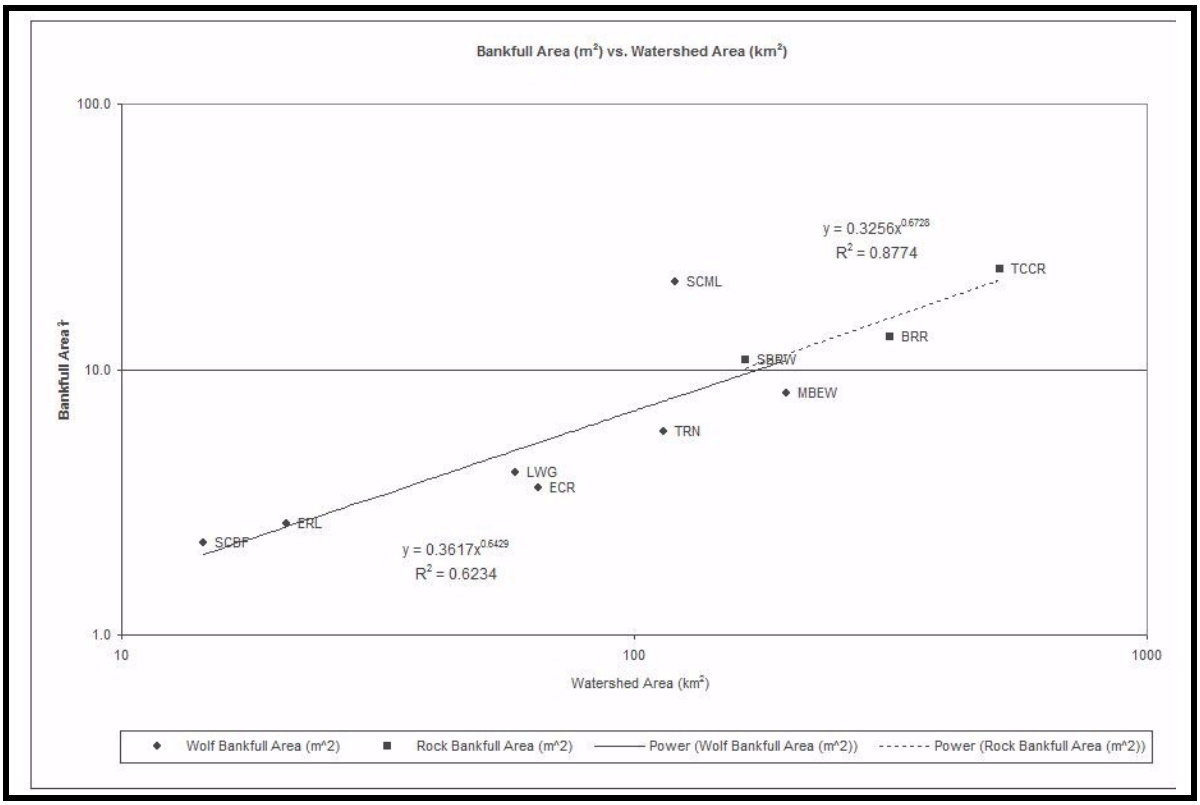


Figure 27: Regional curve of surveyed bankfull area to watershed area.

Analytical Results

Manning's Equation and Bankfull Discharge

Field data and historical data from the USGS gauging stations at these sites were used to calculate Manning's n for each river reach. Manning's *n* is calculated and estimated four ways (Table 2, Table 7).

Table 7: Manning's *n* (roughness coefficient) calculations.

Manning's n Calculations				
Sites	n (survey calculations)	n (from stream type)	n visual (from Manning's estimation chart)	n visual (from Cowan estimation chart)
WOLF RIVER				
Emmons Creek at Rural	0.023	0.064	0.040	0.044
Evergreen River at Langlade	0.057	0.062	0.043	0.069
Little Wolf River near Galloway	0.017	0.050	0.035	0.034
Middle Branch Embarrass at Wittenberg	0.024	0.062	0.048	0.059
Spaulding Creek near Big Falls	0.077	0.062	0.045	0.083
Swamp Creek above Mole Lake	0.014	0.062	0.048	0.044
Tomorrow River at Nelsonville	0.025	0.060	0.040	0.050
ROCK RIVER				
Bark River at Rome	0.096	0.050	0.045	0.103
Beaver Dam River at Beaver Dam	0.144	0.057	0.050	0.075
South Branch Rock River at Waupun	0.228	0.050	0.048	0.039
Turtle Creek at Carvers Rock	0.099	0.062	0.048	0.049

Wolf River Manning's n

Manning's *n* calculated from survey data (n_s) are mostly smaller than would be expected (Figure 22) when compared to the visual stream assessments, with the exception of the Spaulding Creek site. Manning's *n* estimated using Rosgen's stream type (n_r) is higher than other calculations and estimations, with the exception of the Spaulding Creek site.

Manning's n_s (n calculated using survey data)

Manning's n_s averages 0.034 throughout the Wolf River Watershed (Table 7). Manning's n_s values are lower than all other calculations, per site, with the exception of high values calculated at the Evergreen River at Langlade site (0.057) and Spaulding

Creek at Big Falls site (0.077). With these exceptions, Manning's n_s values consistently calculate a low n value, indicating a high velocity and low channel roughness at each site.

The Evergreen River site averages 0.057, compared to n_r average 0.062, n_m average 0.043, and n_c average 0.069. The Spaulding Creek site averages 0.077, compares to n_r average 0.062, n_m average 0.045, and n_c average 0.083. Very low values are calculated at the Little Wolf River site and the Swamp Creek site. The Little Wolf River n_s averages 0.017, n_r averages 0.050, n_m averages 0.035, and n_c averages 0.034. The Swamp Creek n_s averages 0.014, n_r averages 0.062, n_m averages 0.048, and n_c averages 0.044. Manning's n_s average the smallest of all values.

Manning's n_r (n calculated using Rosgen's stream type)

Manning's n_r averages 0.060 throughout the Wolf River Watershed (Table 7). Manning's n_r values are higher than all other calculations, with the exception of the Spaulding Creek at Big Falls site (0.062).

A very high value is calculated at the Spaulding Creek site n_r , with an average 0.062, while n_s averages 0.077, n_m average 0.045, and n_c average 0.083. A low value is calculated at the Little Wolf River site. The Little Wolf River site n_r averages 0.050, n_s averages 0.017, n_m averages 0.035, and n_c averages 0.034.

Manning's n_m (n estimated using Manning's estimation variables)

Manning's n_m averages 0.043 throughout the Wolf River Watershed (Table 7). Manning's n_m values are close in range to Manning's n_c values calculated using Cowan's estimation chart.

A high value is calculated at the Middle Branch Embarrass site and the Swamp Creek above Mole Lake site. The Middle Branch Embarrass n_m averages 0.048, n_s averages 0.024, n_r averages 0.062, and n_c averages 0.059. The Swamp Creek above Mole Lake site n_m averages 0.048, n_s averages 0.014, n_r averages 0.062, and n_c averages 0.044. A low value is calculated at the Little Wolf River site. The Little Wolf River site n_r averages 0.050, n_s averages 0.017, n_m averages 0.035, and n_c averages 0.034.

Manning's n_c (n estimated using Cowan's estimation variables)

Manning's n_c averages 0.055 throughout the Wolf River Watershed (Table 7). Manning's n_c values are close in range to Manning's n_m values calculated using Manning's estimation chart.

A high value is calculated at the Evergreen River at Langlade site, and the Spaulding Creek at Big Falls site. The Evergreen River at Langlade site n_c averages 0.069, n_s averages 0.057, n_r averages 0.062, and n_m averages 0.043. The Spaulding Creek at Big Falls site n_c averages 0.083, n_s averages 0.077, n_r averages 0.62, and n_m averages 0.045. A low value is calculated at the Little Wolf River site. The Little Wolf River site n_c averages 0.034, n_s averages 0.017, n_r averages 0.050, and n_m averages 0.035.

Rock River Manning's n

Manning's *n* calculations within the Rock River are overall higher than estimated (Table 7). These results are considerably larger than was estimated.

Manning's n_s (n calculated using survey data)

Manning's n_s averages 0.141 throughout the Rock River Watershed (Table 7). Manning's n_s values are higher than all other calculations, per site, with the exception of the Bark River at Rome site (0.096). With this exception, Manning's n_s consistently calculates a high n value, indicating a low velocity and high channel roughness at each site.

The Bark River at Rome site n_s averages 0.096, n_r averages 0.050, n_m averages 0.045, and n_c averages 0.103. The lowest value is calculated at the Bark River at Rome site. This value is still much higher than would be estimated in the area. The South Branch Rock River site calculates a value of 0.228, which is exceptionally higher than would be estimated in the area.

Manning's n_r (n calculated using Rosgen's stream type)

Manning's n_r averages 0.054 throughout the Rock River Watershed (Table 7). Manning's n_r values are close in range to Manning's nm values calculated using Manning's estimation chart.

A high value is calculated at the Turtle Creek at Carvers Rock site. The Turtle Creek site n_r averages 0.062, n_s averages 0.099, n_m averages 0.048, and n_c averages 0.049. This value is not abnormally high, but is higher than estimated in the area. The lowest values are calculated at the Bark River site and the South Branch Rock River site. These values are what would be expected from this area.

Manning's n_m (n estimated using Manning's estimation variables)

Manning's n_m averages 0.048 throughout the Rock River Watershed (Table 7). Manning's n_m values are close in range to Manning's n_r values calculated Rosgen's stream type. The values calculated at this site are what would be expected from this area.

Manning's n_c (n estimated using Cowan's estimation variables)

Manning's n_c averages 0.064 throughout the Wolf River Watershed (Table 7). Manning's n_c values are close in range to Manning's n_m values calculated using Manning's estimation chart.

A high value is calculated at the Bark River site. The Bark River site n_c averages 0.103, n_s averages 0.096, n_r averages 0.050, and n_m averages 0.045. A low value is calculated at the South Branch Rock River site. The South Branch Rock River site n_c averages 0.039, n_s averages 0.228, n_r averages 0.050, and n_m averages 0.048.

Bankfull Discharge

Bankfull discharge was calculated for each transect and averaged for each river site. Bankfull was calculated four ways using both survey data and historical USGS gauging station data and compared to the 1.5-year and 1.0-year recurrence interval estimates (Table 8).

Table 8: Bankfull discharge calculations.

Discharge Calculations				
Sites	Q Bankfull (from survey calculations)	Q resistance cms	Q1.5 Bankfull (from R.I.)	Q1.0 Bankfull (from R.I.)
WOLF RIVER				
Emmons Creek at Rural	2.37	3.89	1.47	1.4
Evergreen River at Langlade	0.98	3.90	0.99	0.7
Little Wolf River near Galloway	5.46	4.34	3.91	1.7
Middle Branch Embarrass at Wittenberg	3.87	5.78	10.31	7.3
Spaulding Creek near Big Falls	1.34	6.15	1.27	0.5
Swamp Creek above Mole Lake	12.82	10.96	3.26	2.9
Tomorrow River at Nelsonville	4.73	5.82	2.7	2.7
ROCK RIVER				
Bark River at Rome	6.58	31.01	7.17	4.40
Beaver Dam River at Beaver Dam	0.96	4.18	12.09	8.40
South Branch Rock River at Waupun	1.56	24.80	9.88	1.40
Turtle Creek at Carvers Rock	7.24	37.12	33.42	7.60

Wolf River Bankfull Discharge

Bankfull discharge derived from survey data (Q_s) within the Wolf River were close in relation to discharge calculated from the Q resistance (Q_r), with the exception of the Evergreen River at Langlade and Spaulding Creek near Big Falls. The 1.5-year recurrence interval ($Q_{h1.5}$) coincides well with the Wolf River bankfull discharge, with the exception of the Middle Branch Embarrass River at Wittenberg, and Swamp Creek above Mole Lake. This may be due to the assumption that the 1.5-year recurrence interval is the bankfull flood in that region.

Discharge Q_s (Discharge calculated using survey data)

Discharge Q_s averages 4.28 cms throughout the Wolf River Watershed (Table 8). Discharge Q_s correlates positively with $Q_{h1.5}$, with an $R^2 = 0.42$. Values fall within the range of other discharge calculations with the exception of the Little Wolf at Galloway site, the Middle Branch Embarrass site, and the Swamp Creek above Mole Lake site.

The Little Wolf site discharge Q_s is higher than all other values, and averages 5.46 cms, while Q_r averages 4.34 cms, averages 3.91 cms, and $Q_{h1.0}$ averages 1.7 cms. The Middle Branch site discharge Q_s is lower than all other values, and averages 3.87 cms, while Q_r averages 5.78 cms, $Q_{h1.5}$ averages 10.31, and $Q_{h1.0}$ averages 7.3. The Swamp Creek site discharge Q_s is higher than all other values, and averages 12.82 cms, while Q_r averages 10.96 cms, $Q_{h1.5}$ averages 3.26 cms, and $Q_{h1.0}$ averages 2.90 cms. The highest discharge value calculated in the Wolf River Watershed is the Swamp Creek Q_s, with a discharge of 12.82 cms. This value is much higher than calculated using other methods. The lowest Q_s value is calculated at the Evergreen River site, with a discharge of 0.98 cms.

Discharge Q_r (Discharge calculated using resistance equation)

Discharge Q_r averages 5.67 cms throughout the Wolf River Watershed (Table 8). Discharge Q_r values are higher than all other discharge calculations with the exception of the Little Wolf at Galloway site, the Middle Branch Embarrass site, and the Swamp Creek above Mole Lake site.

The Little Wolf site discharge Q_r averages 4.34 cms, while Q_s averages 5.46 cms, $Q_{h1.5}$ averages 3.91 cms, and historical Q1.0 averages 1.7 cms. The Middle Branch site

discharge Q_r averages 5.78 cms, while Q_s averages 3.87 cms, $Q_{h1.5}$ averages 10.31, and $Q_{h1.0}$ averages 7.3. The Swamp Creek site discharge Q_r averages 10.96 cms, while Q_s averages 12.82 cms, $Q_{h1.5}$ averages 3.26 cms, and $Q_{h1.0}$ averages 2.9 cms. The highest Q_r discharge value calculated in the Wolf River Watershed is the Swamp Creek $Q_{s,}$ with a discharge of 9.29 cms. The lowest Q_s value is calculated at the Emmons Creek site, with a discharge of 3.89 cms.

Discharge $Q_{h1.5}$ (Discharge calculated using 1.5-year recurrence interval)

Discharge $Q_{h1.5}$ averages 3.41 cms throughout the Wolf River Watershed (Table 8). Discharge values $Q_{h1.5}$ correlates positively with discharge calculated using survey data (Q_s), with an $R^2 = 0.42$ (See Discussion, Figure 5), with the exception of the Middle Branch Embarrass site, and the Swamp Creek above Mole Lake site.

The Middle Branch site discharge $Q_{h1.5}$ averages 10.31, while Q_s averages 3.87 cms, Q_r averages 5.78 cms, and $Q_{h1.0}$ averages 7.3. The Swamp Creek site discharge $Q_{h1.5}$ averages 3.26 cms, while Q_s averages 12.82 cms, Q_r averages 10.96 cms, and $Q_{h1.0}$ averages 2.9 cms. The highest $Q_{h1.5}$ discharge value calculated in the Wolf River Watershed is the Middle Branch $Q_{s,}$ with a discharge of 10.31 cms. The lowest Q_s value is calculated at the Evergreen River site, with a discharge of 0.99 cms.

Discharge $Q_{h1.0}$ (Discharge calculated using 1.0-year recurrence interval)

Discharge $Q_{h1.0}$ averages 2.46 cms throughout the Wolf River Watershed (Table 8). Discharge $Q_{h1.0}$ values are the smallest discharges calculated in the Wolf River Watershed with the exception of the Middle Branch Embarrass site.

The Middle Branch site discharge $Q_{h1.0}$ averages 7.3, while Q_s averages 3.87 cms, Q_r averages 5.78 cms, $Q_{h1.5}$ averages 10.31. The highest $Q_{h1.5}$ discharge value calculated in the Wolf River Watershed is the Middle Branch $Q_{s,}$ with a discharge of 7.30 cms. The lowest Q_s value is calculated at the Spaulding Creek at Big Fall site, with a discharge of 0.50 cms.

Rock River Bankfull Discharge

Bankfull discharged derived from survey data within the Rock River does not coincide well with any other discharge calculations with the exception of the Bark River at Rome coinciding with the 1.5-year recurrence interval (Table 8). Discharge Q_s coincide better with the historical $Q_{h1.0}$ values than with the $Q_{h1.5}$.

Discharge Q_s (Discharge calculated using survey data)

Discharge Q_s averages 5.13 cms throughout the Rock River Watershed (Table 80. Discharge Q_s correlates well with $Q_{h1.0}$, with an R2 = 0.9306. Values fall within the range of other discharge calculations with the exception of the Turtle Creek at Carvers Rock site.

The Turtle Creek site discharge Q_s averages 7.24 cms, while Q_r averages 37.12 cms, $Q_{h1.5}$ averages 33.42, and $Q_{h1.0}$ averages 7.60 cms. The highest discharge value calculated in the Rock River Watershed is the Turtle Creek $Q_{s,}$ with a discharge of 7.24 cms. This value does not coincide with the Q_r or $Q_{h1.5}$ values, but coincides well with $Q_{h1.0}$.

Discharge Q_r (Discharge calculated using resistance equation)

Discharge Q_r averages 30.97 cms throughout the Rock River Watershed (Table 8). Discharge Q_r values are higher than all other discharge calculations.

The highest Q_r discharge value calculated in the Rock River Watershed is the Turtle Creek Q_s, with a discharge of 37.12 cms. This value is significantly higher than any other discharge value calculated in the watershed.

Discharge $Q_{h1.5}$ (Discharge calculated using 1.5-year recurrence interval)

Discharge $Q_{h1.5}$ averages 16.82 cms throughout the Rock River Watershed (Table 8). Discharge $Q_{h1.5}$ values are not close to discharge calculated using survey data (Q_s), with the exception of the Bark River at Rome site.

The Bark River site discharge $Q_{h1.5}$ averages 7.17 cms, while Q_s averages 6.58 cms, Q_r averages 31.01 cms, and $Q_{h1.0}$ averages 4.40 cms. The highest $Q_{h1.5}$ discharge value calculated in the Rock River Watershed is the Turtle Creek Q_s, with a discharge of 33.42 cms. This is the second highest discharge calculated throughout the entire watershed. The lowest Q_s value is calculated at the Bark River site with a discharge of 7.17 cms. This value matches well with the discharge value calculated using survey data (Q_s).

Discharge $Q_{h1.0}$ (Discharge calculated using 1.0-year recurrence interval)

Discharge $Q_{h1.0}$ averages 4.47 cms throughout the Rock River Watershed (Table 8) Discharge $Q_{h1.0}$ values and are close to the survey data discharge (Q_s), with an R^2 =

0.9306. The $Q_{h1.0}$ values are the smallest discharges calculated in the Rock River Watershed with the exception of the Turtle Creek at Carvers Rock site.

The Turtle Creek site discharge $Q_{h1.0}$ averages 7.60 cms, while Q_s averages 7.24 cms, Q_r averages 37.12 cms, and $Q_{h1.5}$ averages 33.42. The lowest Q_s value is calculated at the South Branch Rock River site, with a discharge of 1.40 cms.

Sediment Analysis

Average sediment sizes ranged between coarse sand to small gravel (Table 9). The largest sediment sizes were found in transect 1 of the Tomorrow River, due to wingdams present at the transect from stream restoration (Table 9).

Table 9: Average sediment size, in millimeters, per transect.

Sediment Sizes			
Sites	**Transect 1**	**Transect 2**	**Transect 3**
Wolf River			
Emmons Creek at Rural	0.5	0.5	0.5
Evergreen River at Langlade	0.5	0.5	0.5
Little Wolf near Galloway	5.0	5.0	5.0
Middle Branch Embarrass at Wittenberg	1.0	0.5	1.0
Spaulding Creek near Big Falls	1.0	1.0	1.0
Swamp Creek above Mole Lake	1.0	1.0	1.0
Tomorrow River at Nelsonville	100.0	1.0	0.5
ROCK RIVER			
Bark River at Rome	5.0	5.0	5.0
Beaver Dam at Beaver Dam	0.0625	200.0	150.0
South Branch Rock River at Waupun	1.0	1.0	1.0
Turtle Creek at Carvers Rock	1.0	1.0	1.0

Landcover

ArcMap 9.2 and ArcHydro were used to determine the land use percentages for each river reach as well as the entire Wolf River Watershed (Figure 28, Figure 29) and Rock River Watershed (Figure 30, Figure 31) regions (See Appendix F and G). ArcHydro was used to delineate the watershed region upstream of the site-specific USGS gauging stations while landcover maps from both county landuse (1992) and federal landuse (2001) were used to assess landcover. Landcover was generalized to create a new land use classification for calculating land use percentages, including: forest/shrubland, agricultural/grasslands, commercial/residential, and water/wetlands.

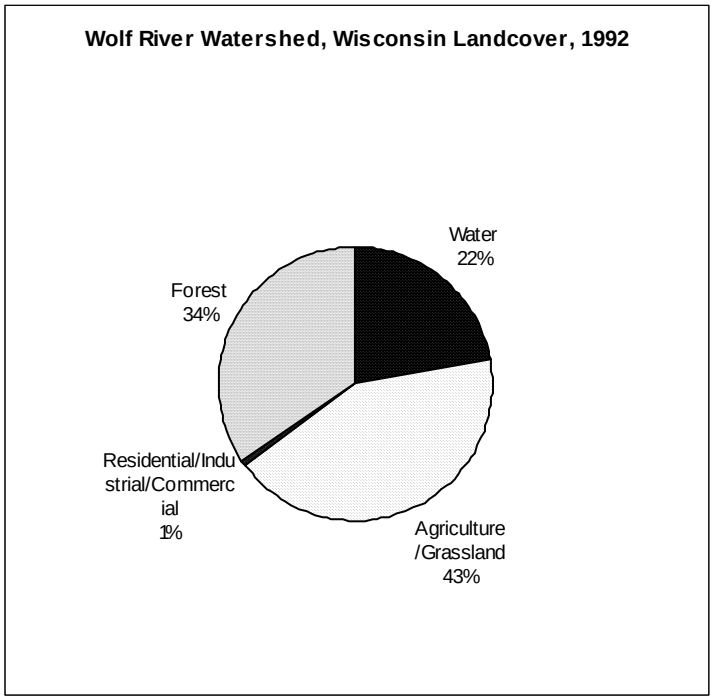


Figure 28: County level landcover for the Wolf River Watershed.

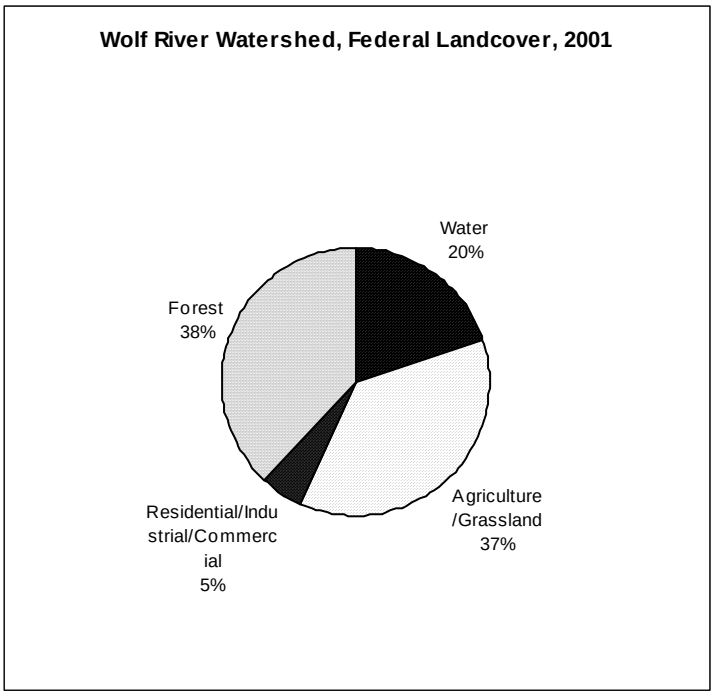


Figure 29: Federal level landcover for the Wolf River Watersheds

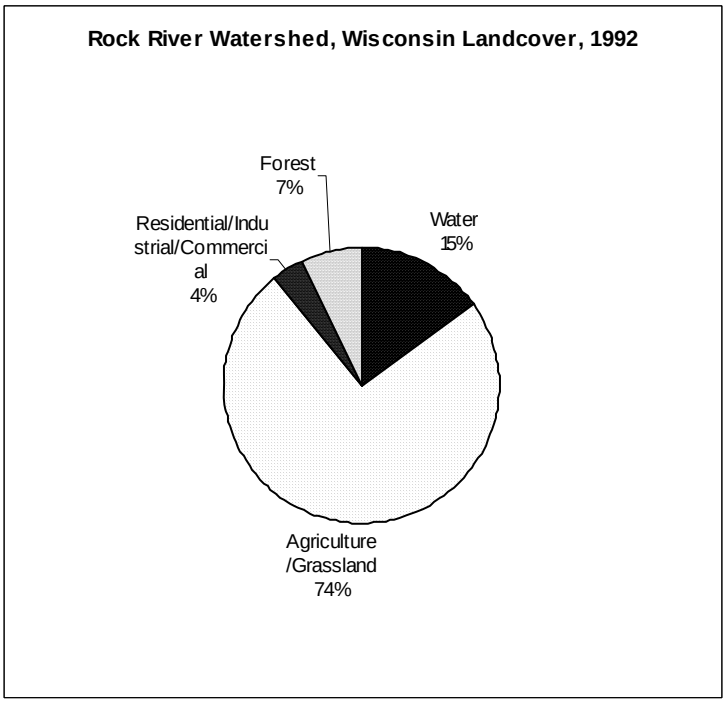


Figure 30: County level landcover for the Rock River Watershed.

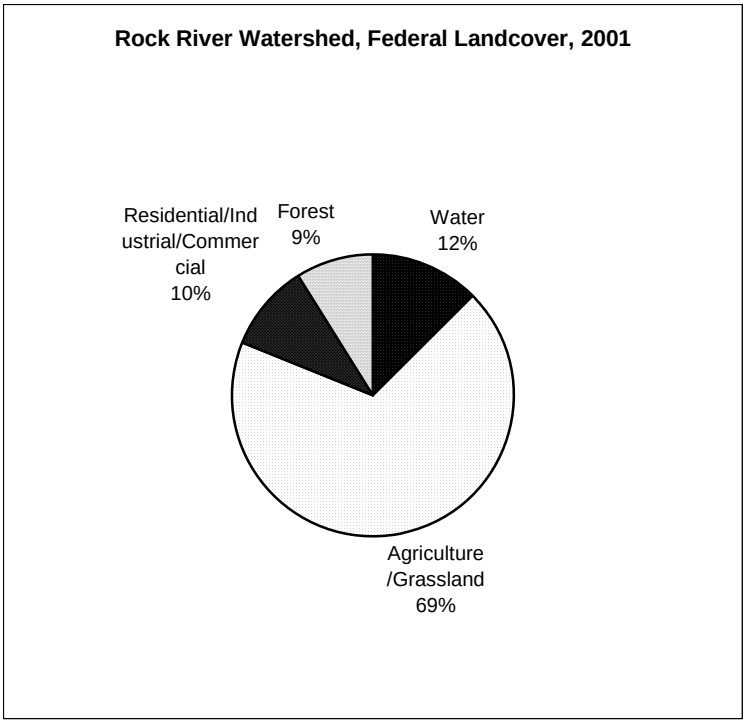


Figure 31: Federal level landcover for the Rock River Watersheds.

Overall both the Wolf River and Rock River showed higher percentages of agriculture/grasslands; however, the Wolf River showed a much higher percentage of forest cover and smaller percentage of residential/industrial/commercial areas with both the county and federal landcover.

Landcover, between 1992 and 2001, within the Wolf River Watershed (Table 10) decreased by 10% in water/wetlands and by 15% in agriculture/grasslands, while increasing by 821% in residential/industrial/commercial areas and by 11% in forest between the county landcover and the federal landcover. Landcover, between 1992 and 2001, within the Rock River Watershed decreased by 17% in water/wetlands and by 8% in agriculture/grasslands, while increasing by 178% in residential/industrial/commercial and by 25% in forest between county landcover and the federal landcover.

Landcover was analyzed to determine whether a relationship existed between landcover and bankfull discharge. Linear regressions between specific landcover types and bankfull discharge were examined (Figure 32,Figure 33,Figure 34,Figure 35) (See Appendix A). No significant relationship was found between landcover type and bankfull discharge within either major watershed with the exception of the Wolf River Watershed residential/commercial landcover vs. discharge, which showed a significant $R^2 = 0.83$ in 1992 and $R^2 = 0.45$ in 2001, and the Rock River Watershed forest landcover vs. discharge, which showed a significant $R^2 = 0.55$ in 1992 and $R^2 = 0.47$ in 2001.

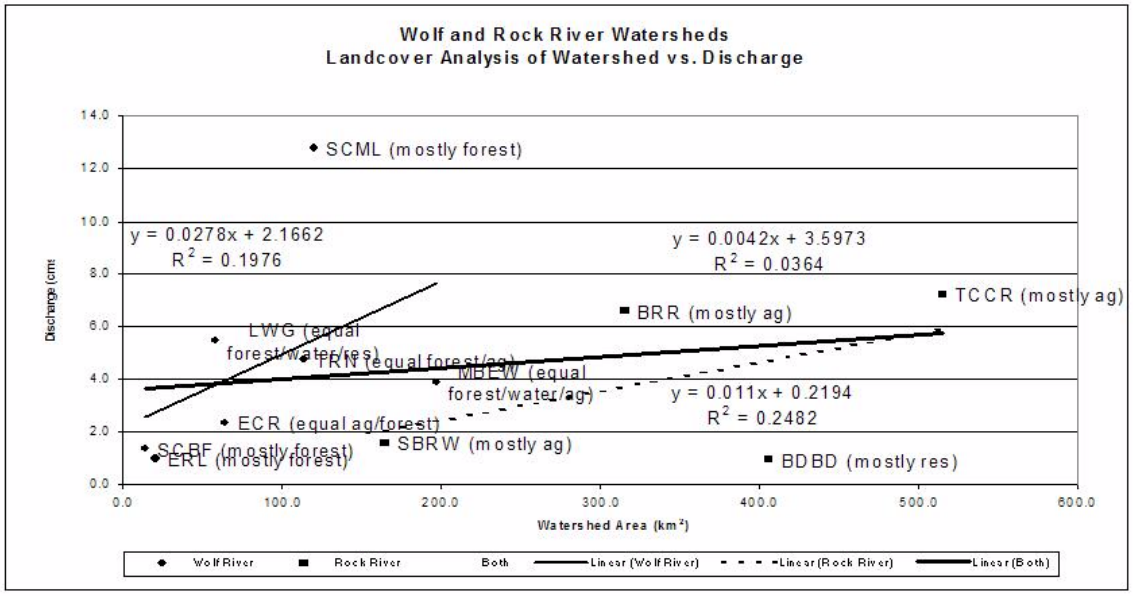


Figure 32: Analysis of Landcover in the Wolf and Rock Watersheds.

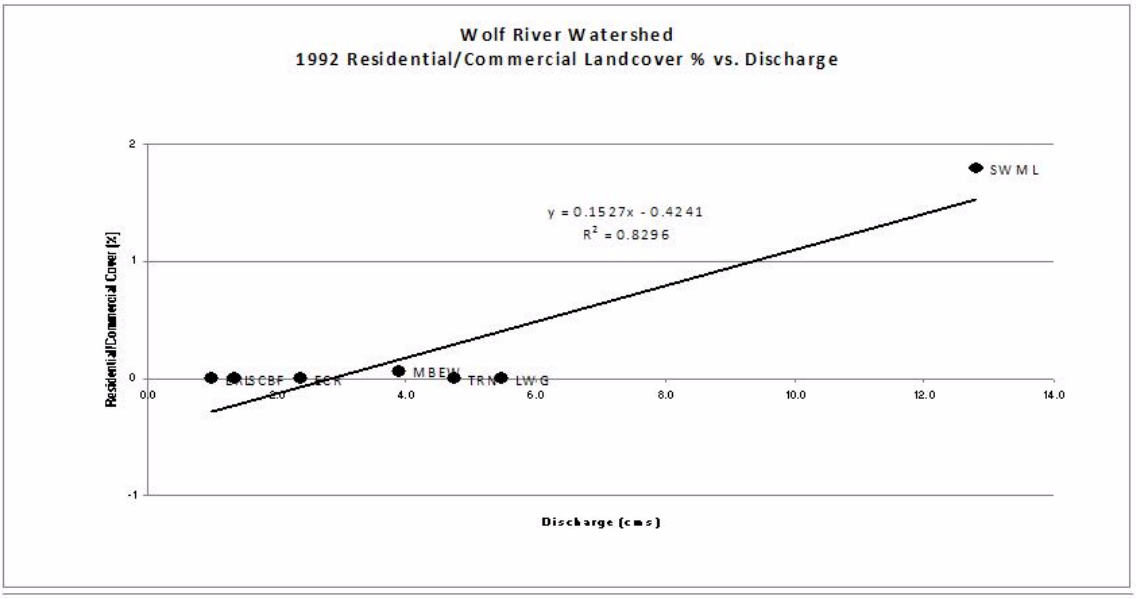


Figure 33: 1992 Wolf Watershed Res/Comm Landcover vs. Discharge

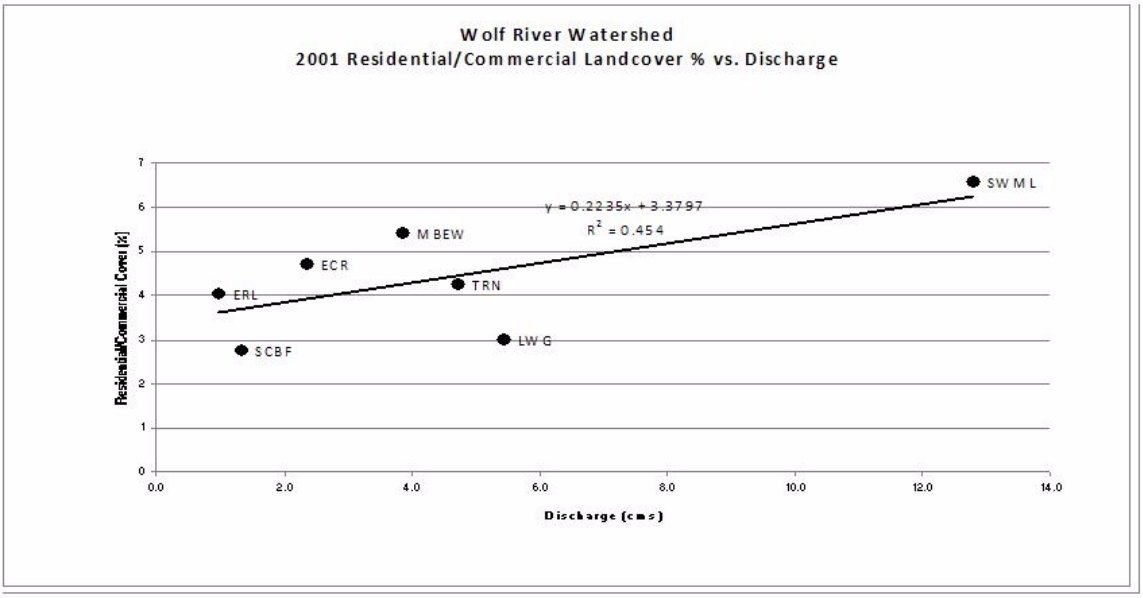


Figure 34: 2001 Wolf Watershed Res/Comm Landcover vs. Discharge

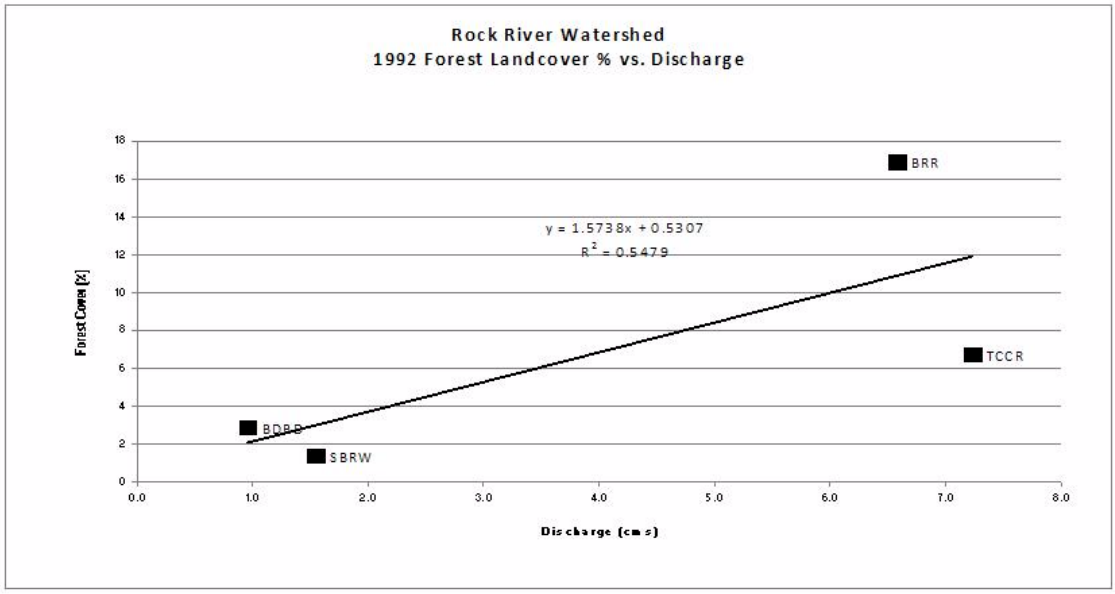


Figure 35: 1992 Rock Watershed Forest Landcover vs. Discharge

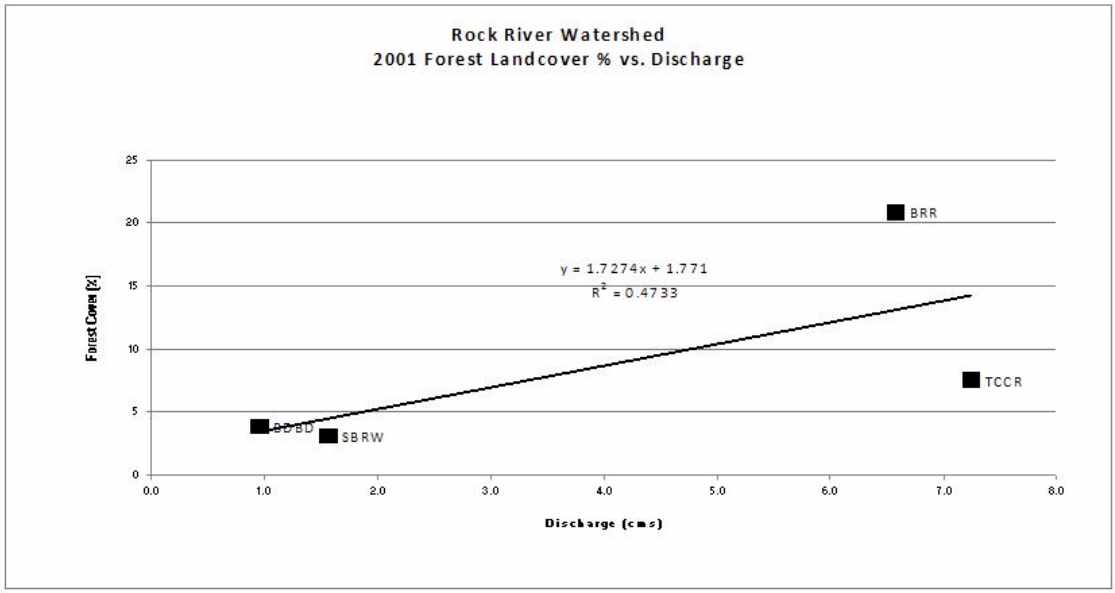


Figure 36: 2001 Rock Watershed Forest Landcover vs. Discharge

Table 10: Wisconsin County Landcover (1992) and National Landcover (2001).

Landcover Calculations		Watershed Calculations					WISCONSIN LANDCOVER - 1992				NATIONAL LANDCOVER - 2001			
Sites	Abbrev	Years of Data	Survey Q1.5 (cms)	Historical Q1.0 (cms)	Historical Q1.5 (cms)	Watershed Area (km^2)	Water	Agriculture /Grassland	Residential/ Industrial/ Commercial	Forest	Water	Agriculture /Grassland	Residential/ Industrial/ Commercial	Forest
WOLF RIVER							**22**	**43**	**1**	**34**	**20**	**37**	**5**	**38**
Emmons Creek at Rural	ECR	6	2.4	1.4	1.5	65.0	3	57	0	40	1	44	5	50
Evergreen River at Langlade	ERL	48	1.0	0.7	1.0	21.0	7	3	0	90	7	1	4	88
Little Wolf near Galloway	LWG	4	5.5	1.7	3.9	58.5	29	36	0	35	24	28	3	45
Middle Branch Embarrass at Wittenberg	MBEW	16	3.9	7.3	10.3	197.6	29	41	0	31	28	31	5	35
Spaulding Creek near Big Falls	SCBF	48	1.3	0.5	1.3	14.4	60	12	0	58	30	7	3	60
Swamp Creek above Mole Lake	SWML	11	12.8	2.9	3.3	119.9	24	9	2	65	26	5	7	62
Tomorrow River at Nelsonville	TRN	3	4.7	2.7	2.7	114.0	15	56	0	29	9	46	4	41
ROCK RIVER	**TOTAL**						**15**	**74**	**4**	**7**	**12**	**69**	**10**	**9**
Bark River at Rome	BRR	22	6.6	4.4	7.2	316.0	23	56	4	17	21	45	13	21
Beaver Dam at Beaver Dam	BDBD	20	1.0	8.4	12.1	406.6	25	70	2	3	18	71	7	4
South Branch Rock River at Waupun	SBRW	37	1.6	1.4	9.9	164.7	12	83	3	1	6	83	8	3
Turtle Creek at Carvers Rock	TCCR	66	7.2	7.6	33.4	515.4	6	84	2	7	3	80	10	8

Rosgen Stream Classification

Stream classification was completed for bio assessment and habitat discussion. The Rosgen Stream Classification system was used to determine stream type (Table 11). Examination of each site on the regional curve did not find a relationship between stream type and discharge.

Table 11: Rosgen Stream Classification per transect.

Stream Type			
Sites	Transect 1	Transect 2	Transect 3
WOLF RIVER			
Emmons Creek at Rural	G5	G5	G5
Evergreen River at Langlade	F5	F5	F5
Little Wolf River near Galloway	F4	F4	F4
Middle Branch Embarrass at Wittenberg	F5	F5	F5
Spaulding Creek near Big Falls	F5	F5	F5
Swamp Creek above Mole Lake	F5	F5	F5
Tomorrow River at Nelsonville	F3	F5	F5
ROCK RIVER			
Bark River at Rome	F4	F4	F4
Beaver Dam River at Beaver Dam	F6	F3	F3
South Branch Rock River at Waupun	F4	F4	F4
Turtle Creek at Carvers Rock	F5	F5	F5

Regional Curve

A regional curve was developed for both major watersheds by comparing watershed area (km^2) to bankfull discharge, as well as width to discharge, and average depth to discharge (Figure 25,Figure 26,Figure 27) Regional Curves were developed using both survey data, and the historical 1.5-year recurrence interval (Figure 37,Figure

38,Figure 39,Figure 40). A second regional curve developed using the historical 1.0-year recurrence interval as a proxy for bankfull, due to the lack of relationship between survey data and the historical 1.5-year recurrence interval in the watershed. The final product of this research was a regional curve for each watershed comparing survey to historical data.

Wolf River Regional Curve

The Rock River Watershed survey data was compared using both the historical Q1.5 and Q1.0-year recurrence interval (Figure 37,Figure 38). Overall, the relationship between Wolf River survey data and Q1.5-year recurrence interval was much closer than that of the Q1.0-year recurrence interval.

The Wolf River Watershed regional curve (Figure 37, Figure 38) correlates well for both survey and historical Q1.5-year recurrence interval bankfull discharge to watershed area. The Wolf River data finds an $R^2 = 0.62$ for survey data to watershed area. It also finds $R^2 = 0.68$ for historical Q1.5 data to watershed area and $R^2 = 0.94$ for historical Q1.0 data to watershed area. Survey discharge to historical Q1.5 discharge finds and $R^2 = 0.42$ (Figure 41).

Rock River Regional Curve

The Rock River Watershed survey data were compared using both the historical Q1.5 and Q1.0-year recurrence interval (Figure 39,Figure 40). Overall the relationship between Rock River survey data and Q1.0-year recurrence interval was much closer to the survey discharge than that of the Q1.5-year recurrence interval.

The Rock River regional curve correlates well using the Q1.5-year recurrence interval and using the Q1.0-year recurrence interval; however, the survey data coincides better with the Q1.5-year recurrence interval.

The Rock River data (Figure 39, Figure 40) finds an $R^2 = 0.86$ for survey data to watershed area. It also finds $R^2 = 0.48$ for historical Q1.5 data to watershed area and $R^2 = 0.99$ for historical Q1.0 data to watershed area. Survey discharge to historical Q1.5 discharge finds and $R^2 = 0.93$ (Figure 41).

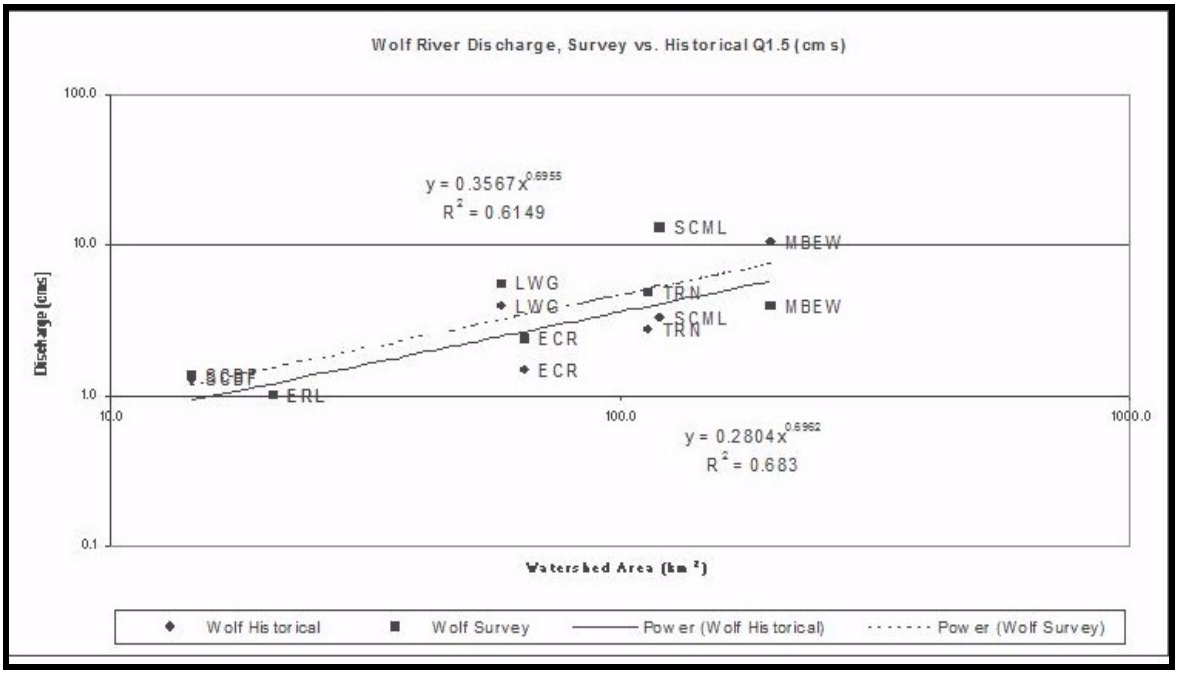


Figure 37: Regional curve comparing Wolf River survey and historical Q1.5 discharge.

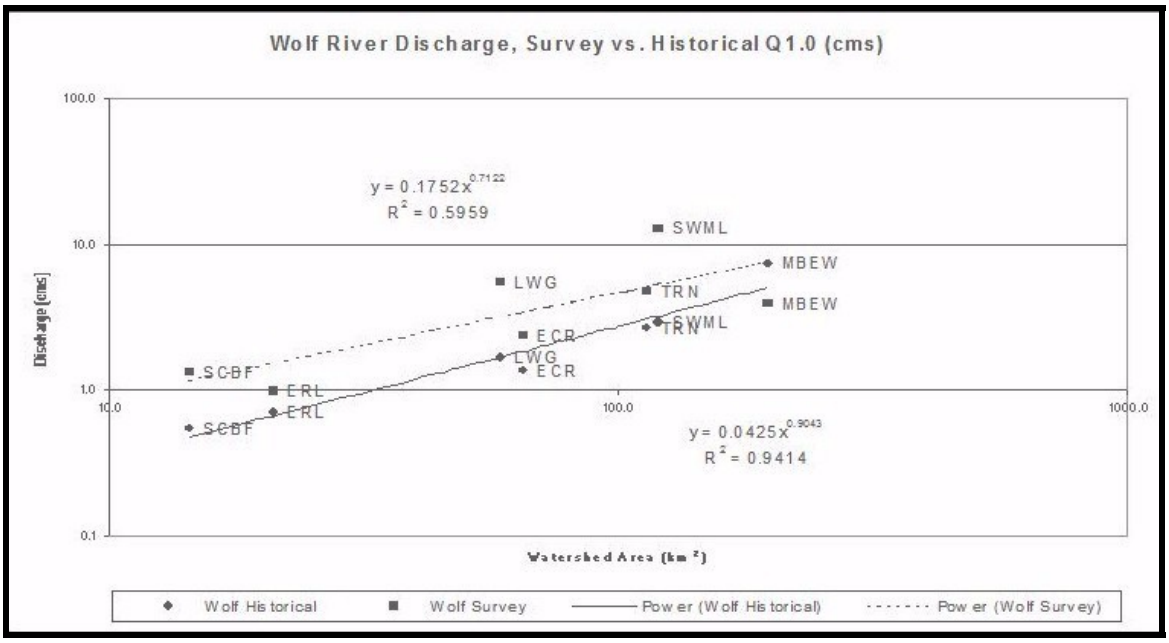


Figure 38: Regional curve comparing Wolf River survey and historical Q1.0 discharge.

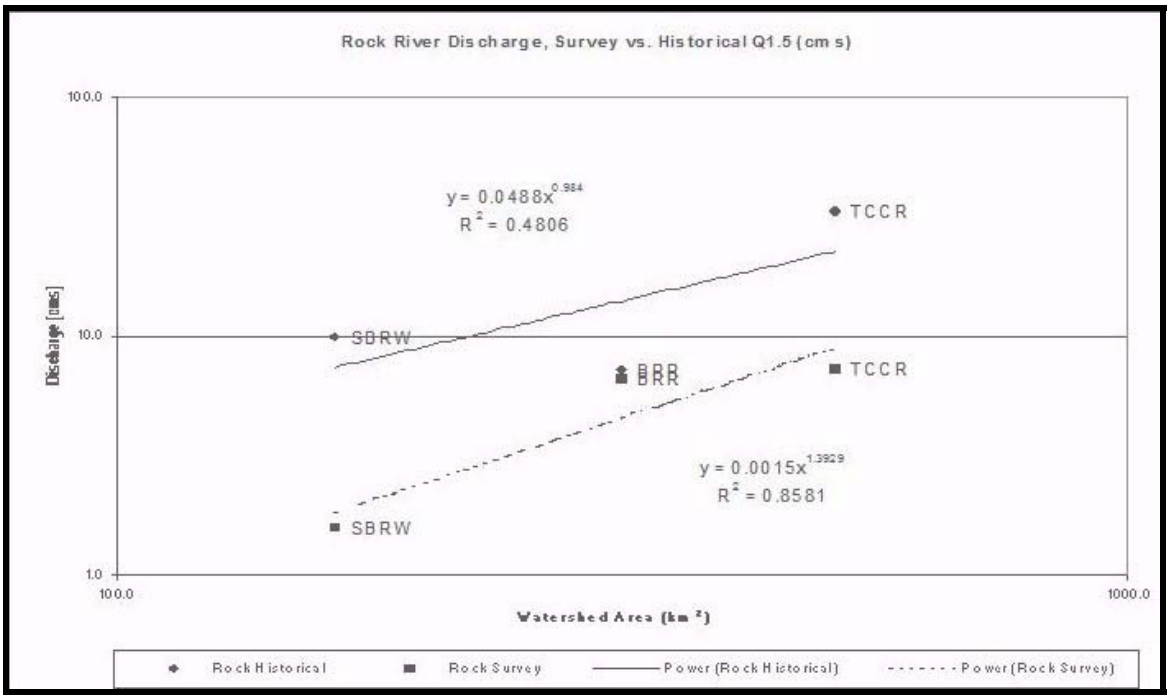


Figure 39: Regional curve comparing Rock River survey and historical Q1.5 discharge.

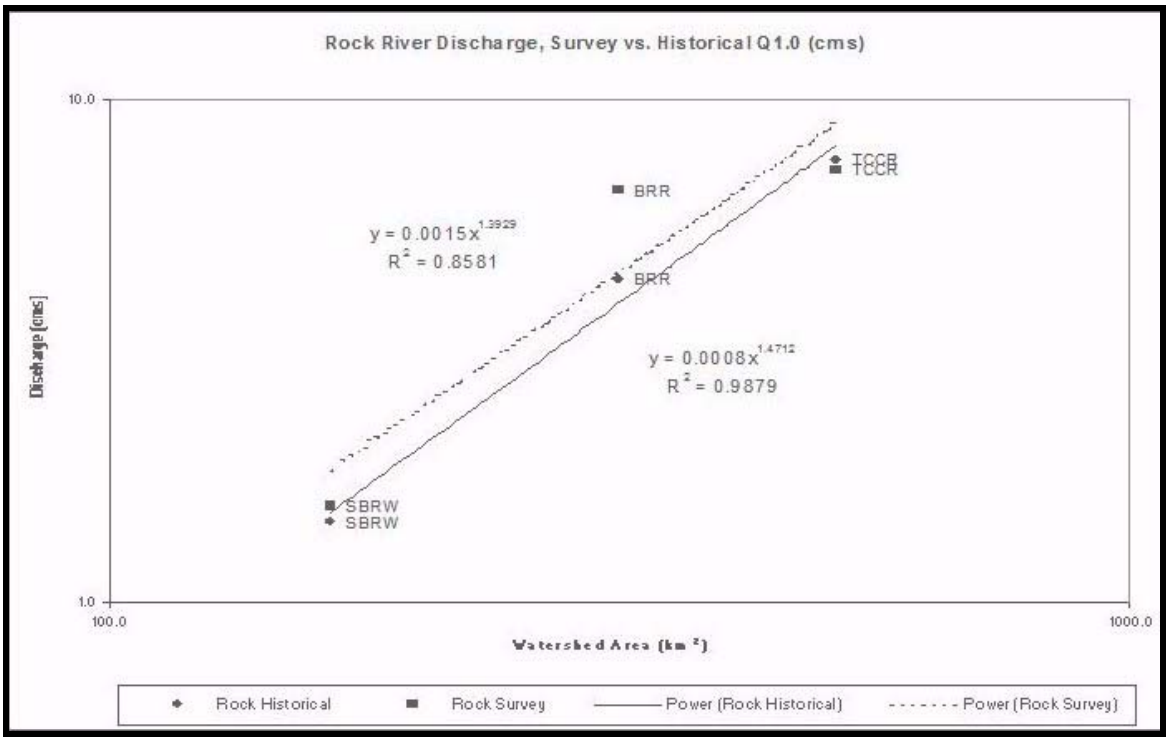


Figure 40: Regional curve comparing Rock River survey and historical Q1.0 discharge.

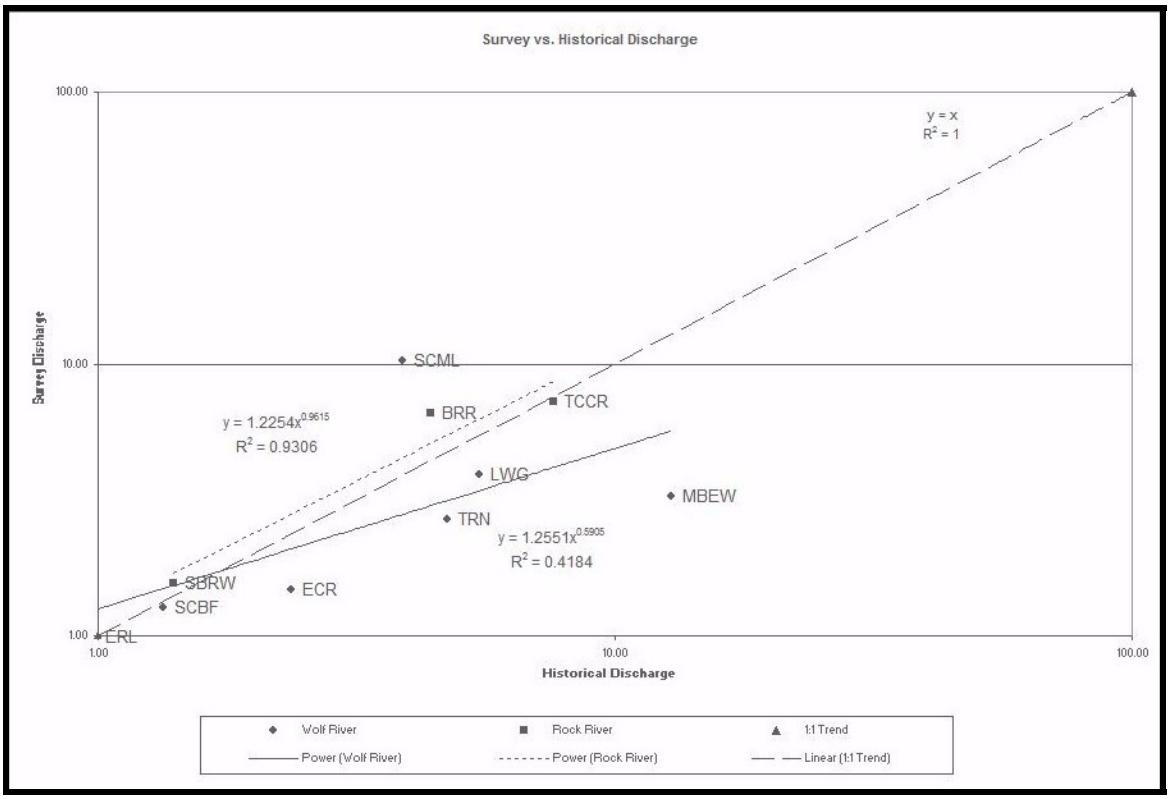


Figure 41: Comparison of survey discharge to historical discharge.

DISCUSSION

The Wolf River Watershed and the Rock River Watershed were chosen due to the high density of USGS gauging stations. Study of the Rock River was discontinued due to flooding within the region during the late summer of 2008 and the summer of 2009. The Wolf River Watershed sites are more suited for stream restoration recommendations than those in the Rock River Watershed, due to the more natural condition of the streams.

Regional Curves

The regional curve developed for the Wolf River Watershed shows good agreement with the $Q_{1.5}$ -year interval (Figure 37,Figure 38,Figure 41), while the Rock River Watershed shows good agreement with the $Q_{1.0}$-year interval (Figure 39,Figure 40,Figure 41). As stated earlier, it is best to assume bankfull as a range of values, rather than a discrete one, between the 1.0 and 2.5-year flood (Copeland et al., 2000). For this reason, field surveys are compared to the USGS historical data to estimate a more precise approximation of the recurrence of the bankfull flood.

There are several possible reasons for the Rock River Watershed's agreement with the $Q_{1.0}$-year interval. This agreement implies that floods occur more frequently within the Rock River Watershed, which is a highly agricultural area. It is possible that, due to the increased overland flow in agricultural and urban areas, flooding is more frequent and therefore the bankfull flood is more frequent. In addition, only three sites in the Rock River Watershed were used to compare survey data to historical data, and more sites are needed to develop a confident relationship.

Additional challenges associated with developing these regional curves include analyzing differences in bankfull width, depth, area, and discharge between sites, an differences between survey data and additional discharge calculations. Details of this are explained below.

Regional Curve Comparison to Michigan Study

Regional curves in comparable areas should show similar trends. The results from this study are compared to a study done by Mistak and Stille (2007) to analyze the strength of the methods used in this study.

The study "Upper Menominee River Regional Curve" by Mistak and Stille (2007) examines five river reaches in Michigan for the Upper Menominee River Watershed, based on bankfull characteristics of the Sturgeon River, Iron River, Brule River, Pine Creek, and Peshekee River (Mistak and Stille, 2007). Data collection methods used in the Michigan study are very similar to those used in this study.

Comparisons of bankfull discharge to watershed area (Figure 42) finds Michigan at $R^2 = 0.84$ and Wolf at $R^2 = 0.60$.

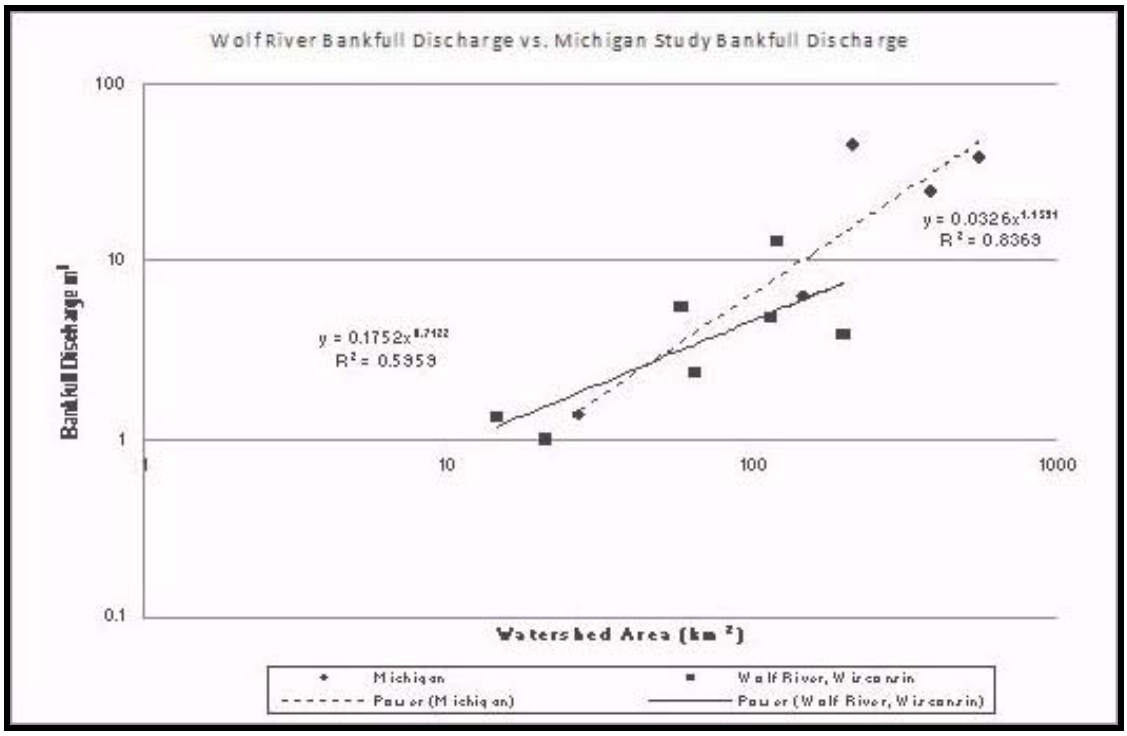


Figure 42: Comparison of bankfull discharge to watershed area between Mistak study and the Wolf River Watershed.

Comparisons of bankfull width to watershed area (Figure 43) finds Michigan at $R^2 = 0.59$ and Wolf at $R^2 = 0.42$.

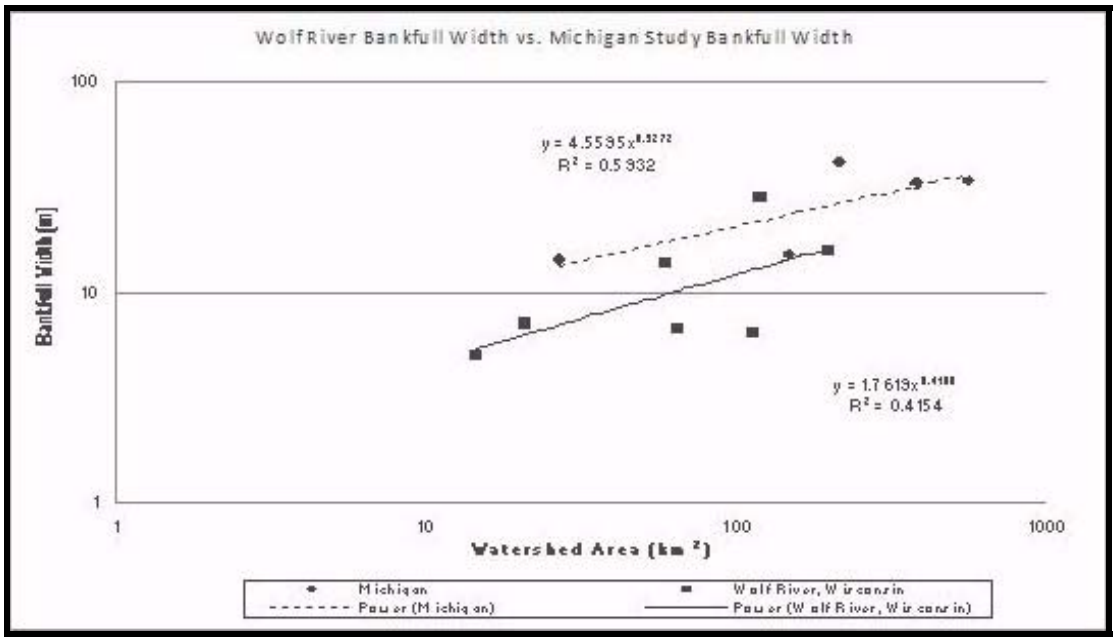


Figure 43: Comparison of bankfull width to watershed area between Mistak study and the Wolf River Watershed.

Comparisons of bankfull depth to watershed area (Figure 44) finds Michigan at $R^2 = 0.45$, and Wolf at $R^2 = 0.28$. This indicates a weak relationship between bankfull depth and watershed area within each watershed. The weak relationship between bankfull depth and watershed area within each watershed indicates a high level of variance in the bankfull depth between river reaches and their associated watershed area.

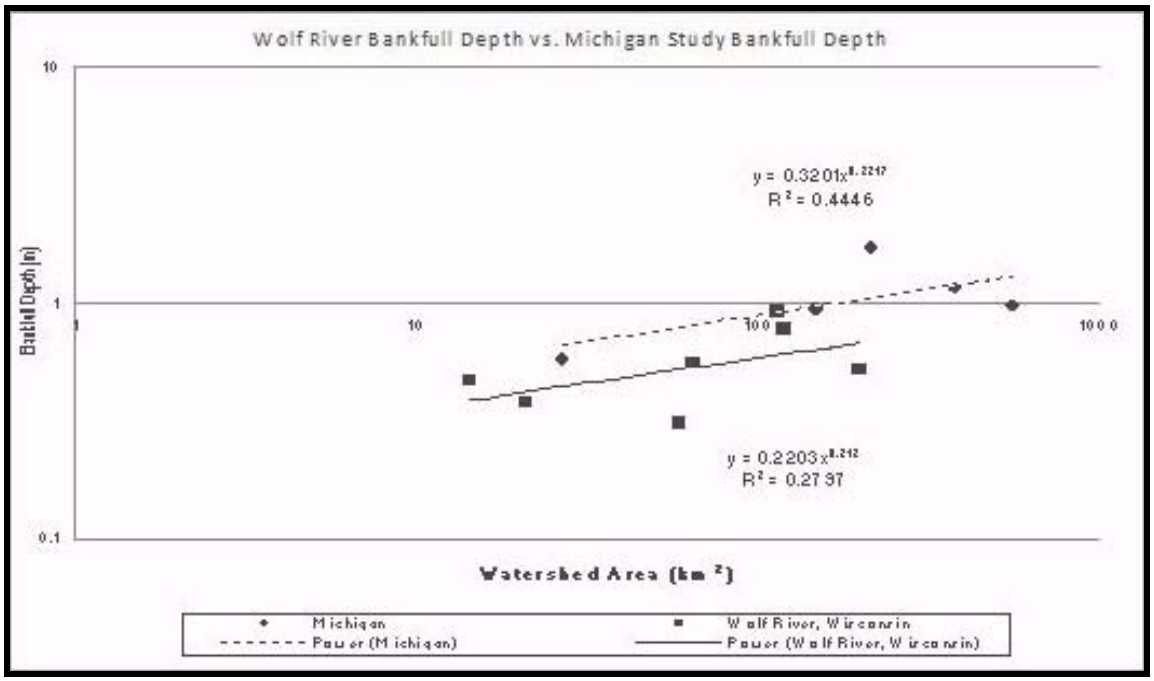


Figure 44: Comparison of bankfull depth to watershed area between Mistake study and the Wolf River Watershed.

Comparisons of bankfull area to watershed area (Figure 45) finds Michigan at R^2 = 0.58 and Wolf at R^2 = 0.62. This indicates a strong relationship between bankfull area and watershed area within each watershed. The strong relationship between bankfull area and watershed area within each watershed indicates a high level of homogeneity in the bankfull area between river reaches and their associated watershed area.

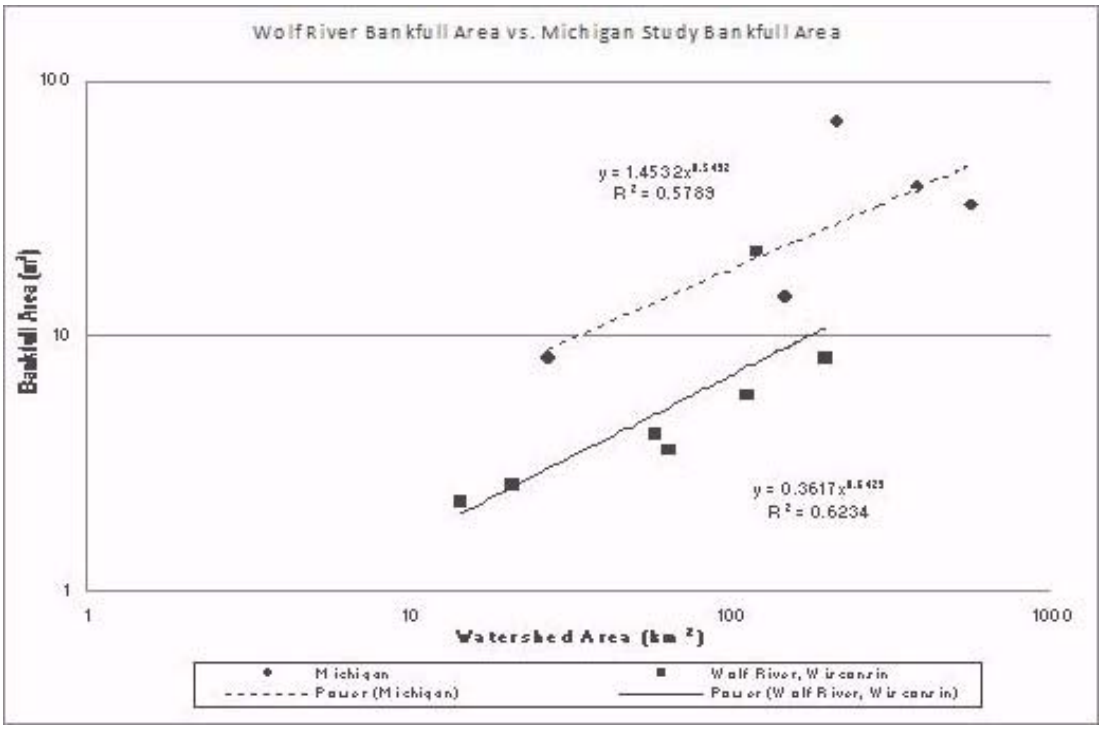


Figure 45: Comparison of bankfull area to watershed area between Mistak study and the Wolf River Watershed.

Site Selection, Site Discussion, and USGS gauging station activity

Specific criteria were used to select sites in order to collect relatively homogeneous data within the major watersheds. These guidelines may have been too stringent for this study, and were at times loosely regarded in order to find a suitable amount of sites for the study. However, regardless of whether or not the criteria were too strict, wadable gauged streams were generally lacking throughout the watersheds.

There was also a lack of active USGS gauging stations throughout the watersheds. Many stations have been shutdown in the last 10-20 years or have been repeatedly turned on and off, most likely due to funding cuts. Stations that have been consistently active tend to be mainstream channels that are much too large for survey purposes. For these reasons, finding active gauging stations at wadable streams quickly narrowed down the

possible channel sites. In one case a site, referred to as the Little Wolf River at Royalton site, was less than 3 feet in depth and wadable, but was more than 300 feet in width. This site was left out of the study. In future cases researchers may wish to conduct surveys on any stream that is wadable, regardless of watershed size or stream width, although greater widths may require adjustments in survey methods.

Only seven sites within the Wolf River Watershed and four sites within the Rock River Watershed (Table 1) (See Appendix C, D, K, and N) were suitable for the field requirements of this study. A variety of physiology at each site provided a variety of stream shapes and sizes (See Appendix C, D, E, F, G, H, I, J). In some cases geology and soil type may have affected the discharge levels, such as the Swamp Creek at Mole Lake site. A variety of depths, widths, and bankfull areas provided comparisons for bankfull discharge and Manning's *n* at each site.

Wolf River Sites

Sites within the Wolf River Watershed have more natural, less developed stream channels and are less prone to the agricultural/urban channelization (Table 10). These sites were proportionally smaller in width, depth, and area than those in the Rock River (Table 6), were less channelized, mostly located within forested areas, and had more in-stream vegetation, with the exception of the Bark River at Rome site in the Rock River Watershed.

The Emmons Creek at Rural site, located in Waupaca County, is a deeply entrenched, meandering, restored trout stream located in a woods and surrounded by approximately 14.0% agricultural land and 50% forest. The watershed area is 65.0 km^2

and is associated with six years of active gauging station data from 1969 to 1974. Any notable deviations between the survey discharge and historical discharge were most likely due to the age of the historical data. This site could be considered pristine and would serve as a good reference for stream restoration.

The Evergreen River at Langlade site, in Langlade County, is a shallow, meandering stream set in a highly forested area (approximately 88% of total subwatershed landcover). The watershed area is 21.0 km^2 and is associated with 48 years of active gauging station data from 1959 to 2007. This site would serve as a good reference for stream restoration due to its natural condition.

The Little Wolf River near Galloway site, in Marathon County, is a shallow, wide stream located in a wooded area with a subwatershed landcover distribution of approximately 24% water/marshland, 28% ag/grasslands, and 45% forest. The watershed is 58.5 km^2 and is associated with four years of active gauging station data during 1974, 1977, 1978 and 1979. Differences between the survey discharge and historical discharge are most likely due to the inconsistent and historical gauging station data. However, survey calculations correlated well with historical bankfull calculations and the site served as a reference to other rivers. This site would serve as a good reference for stream restoration due to its natural condition.

The Middle Branch Embarrass at Wittenberg site, located in Shawano County, is a wide, mucky, stream channel downstream from a golf course and upstream from a highly reinforced ravine and bridge structure, in a subwatershed of approximately 31% agricultural area, 28% water/marshland, and 35% forest landcover. The watershed is 197.6 km^2 and is associated with 16 years of active gauging station data between 1990

and 2006. Differences between the survey discharge and historical discharge are most likely due to upstream runoff influences from the golf course.

The Spaulding Creek near Big Falls site, in Waupaca County, is a tiny, rocky-bottomed stream channel with deep pools and riffles. The site lies upstream of a culvert and is located in a heavily forested subwatershed (approximately 60% of total landcover) with some marshlands (approximately 30% landcover). The watershed is 14.4 km^2 and is associated with 48 years of active gauging station data from 1959 to 2007. Differences between survey discharge and historical discharge are most likely due to the flashy hydrology of the small watershed. However, this site would serve as a good reference for stream restoration due to its natural condition.

The Swamp Creek at Mole Lake above Mole Lake site, in Forest County, is a wide, deep, sandy channel with wide, mucky stream channel edges, and highly forested banks. The site is located in a mostly forested subwatershed (approximately 62% of total landcover) with some water/marshland (approximately 26% of total landcover). The watershed is 119.9 km^2 and is associated with 11 years of active gauging station data between 1978 and 2004. Differences between the survey discharge and historical discharge are most likely due to the wide, mucky stream edges, which retain water flow and slow velocity measurements. Differences may also be due to the geology in the area (See Appendix I). The imperviousness of the type Xmv and type Xmiv rocks in that area may encourage runoff and therefore increase discharge. This type of rock was only found at this site.

The Tomorrow River at Nelsonville site, in Portage County, is a shallow, sandy-bottomed trout stream that has experienced some trout restoration activities that have

created wingdams. These wingdams and the associated pool were included in the transects due to the inability to survey in another location. This site is located in a subwatershed comprised of approximately 46% ag/grassland and 41% forest landcover. The watershed is 114.0 km^2 and is associated with 3 years of historical data taken from daily data measurements between 1993 and 1995. The peak flood was selected from the associated historical daily discharge data and was treated as peak discharge data in the calculation of the 1.5-year recurrence interval. Differences between survey discharge and historical discharge are most likely due to the lack of historical data at the site. However, this site would serve as a good reference for stream restoration considering the successful restoration already conducted at the site.

Removal of the Nelsonville site from the study was considered due to the small amount of historical data. However, removal of this site did not have a significant effect on the relationship between discharge and watershed area within the Wolf River Watershed and was included in the study as a comparison to the other rivers.

Rock River Sites

The Rock River sites provided many challenges for developing a regional curve. These sites were proportionally greater in width, depth, and area than those in the Wolf River (Table 6), were more channelized, mostly located within agricultural and urban areas (Table 10), and had less in-stream vegetation. These differences had an obvious effect on discharge and contributed to the difficulty in developing a regional curve for the Rock River Watershed. Overall a strong correlation between survey data and the historical Q1.0 year recurrence interval (a more frequently occurring flood level). Due to

the stream morphology differences, the channelization and subsequent changes to width, depth, velocity, and discharge within the Rock River affected the bankfull flood and the historic flood level.

As stated earlier, the Beaver Dam at Beaver Dam site within the Rock River watershed was removed from the development of a regional curve entirely (See Appendix O). This was due to upstream influence from a dam structure located in the city of Beaver Dam.

The Bark River at Rome site, in Jefferson County, is a wide, rocky, highly vegetated shallow channel. The site is located downstream from an old dam and bridge, in a subwatershed with approximately 45% agricultural and 13% residential landcover. The watershed is 316.0 km^2 and is associated with 22 years of historical data taken from daily data measurements between 1984 and 2005. Differences between survey discharge and historical discharge are most likely due to the downstream influences of the dam and bridge structures and the surrounding ag/residential landcover. However, the site is a healthy river containing a high percentage of biota and could serve as a reference for stream restoration within the Rock River Watershed.

The South Branch Rock River at Waupun site, in Fond du Lac County, is a murky, slow flowing stream channel with mowed banks. It is located within the city boundaries of Waupun located adjacent to a large, mowed park. The subwatershed is approximately 83% ag/grassland area and 8% residential landcover. The watershed is 164.7 km^2 and is associated with 37 years of historical data from 1949 to 2004, with data missing from 1969 to 1988. Differences between survey discharge and historical discharge are due to the influences from the residential and agricultural induced runoff in

the area. This site would not serve well as a reference for stream restoration due to its unnatural conditions.

The Turtle Creek at Carvers Rock site, in Rock County, is a wide, deep, sandy-bottomed channel with highly forested banks located downstream from a bridge. This subwatershed is approximately 80% ag/grassland area, 8% residential/commercial and 3% forest landcover. The watershed is 515.4 km^2 and is associated with 66 years of historical data from 1940 to 2005. Differences between survey discharge and historical discharge are most likely due to the downstream influences from the bridge structure. This site would not serve well as a reference for stream restoration due to its unnatural conditions.

Hydraulic variables, Manning's n, and Bankfull Discharge

At all sites three transects were setup across the stream channel, preferably upstream from dams, bridges, culverts, or other structures. These structures are known to affect stream morphology (sediment and vegetation) and geometry (width, depth, and velocity). It was not always possible to setup transects upstream of a gauging station due to stream width and depth. All transects within the Rock River watershed were setup downstream of influential dams, bridges, and other structures.

Hydraulic Variables

Bankfull width, depth, and area measurements from within the Rock River were considerably larger than most within the Wolf River Watershed sites (Table 6) (See Appendix L and M). This could be due to data collection downstream from highly

influential structures such as dams, bridges, and culverts or the increase in subwatershed size between the Wolf River and Rock River watersheds.

Width

Of the hydraulic variables, bankfull width varied the most between the Wolf River and Rock River watersheds. Bankfull width showed a weak relationship with watershed area (Figure 25) in the Wolf River Watershed (Wolf River $R^2 = 0.41$) and a strong relationship in the Rock River Watershed ($R^2 = 0.84$).

Several sites within the Wolf River Watershed deviate from the relationship between bankfull width (Figure 25). Two of the largest deviations were the Swamp Creek at Mole Lake site and the Tomorrow River at Nelsonville site. The Swamp Creek deviation is due to marshy areas buffering two of the three transects, which widened the bank width and consequently the bankfull width in relation to the watershed area. The wide stream channel may also be due to the impervious geology in the area which would increase runoff and therefore discharge in the watershed (See Appendix I).

The Tomorrow River's deviation is primarily due to the width of the stream transects but may also be influenced by some stream restoration at the site. Several wingdams and increases in depth upstream of transects were noted. These remnants of stream restoration efforts would adversely affect velocity downstream. This wingdam structure could not be avoided due to a meander in the river downstream that prevented the use of the total station meter that was required for all elevation and distance measurements.

Additional, but less severe, deviations in the Wolf River Watershed included the Little Wolf near Galloway site and Emmons Creek at Rural. The Little Wolf River's deviation is due to the shallow, wide nature of the stream channel in relation to watershed size. The Emmons Creek deviation is due to the deeply incised channel and short bankfull width in relation to watershed size. There are no significant deviations in the Rock River Watershed mainly due to the small sample size.

Depth

Bankfull depth varied between the Wolf and Rock River watersheds (Table 6). Comparisons between bankfull depth and watershed area (Figure 25) calculate the Wolf River at $R^2 = 0.28$, and the Rock River at $R^2 = 0.31$.

Several sites within the Wolf River Watershed deviate from the relationship between bankfull depth and discharge, including the Tomorrow River at Nelsonville site and the Little Wolf River near Galloway site. The Tomorrow River deviation is due to large bankfull depth at one of the stream transects as a result of stream restoration. Several wingdams were noted at the site that increased the depth upstream of the first transect. The depth of this transect was considerably larger than the remaining transects at the study site. This wingdam structure could not be avoided due to a meander in the river downstream that prevented the use of the total station meter that was required for all elevation and distance measurements. The Little Wolf near Galloway deviation is due to the bankfull width and shallow bankfull depth of the site in relation to watershed size.

Cross-sectional Area

Bankfull cross-sectional area vs. watershed area (Figure 27) found the strongest correlations between a hydraulic variable and discharge in both the Wolf River (R^2 = 0.64) and Rock River (R^2 = 0.88) Watersheds. This indicates a strong relationship between bankfull cross-sectional area and watershed area.

Several sites within the Wolf River Watershed deviate from the relationship between bankfull area and discharge; Swamp Creek above Mole Lake and Emmons Creek at Rural. The Swamp Creek deviation is due to wide bankfull banks at the site which influenced the calculation of area in relation to watershed size, and may also be due to the impervious geology in the area that may increase runoff and therefore discharge (See Appendix I). The Emmons Creek deviation is due to deeply incised banks at the site which in turn influenced the calculation of area in relation to watershed size. These incised banks may be due to stream restoration at the site which deepened the channel for trout habitat.

Manning's n

Stream morphological (sediment and vegetation) and geometrical (width, depth, and velocity) influences from upstream structures would affect Manning's *n*, or the roughness coefficient, which is the most sensitive variable within Manning's equation. Manning's *n* strongly influences the calculation of bankfull discharge, which consequently affects all calculations, especially within the Rock River Watershed. Sites within the Wolf watershed were considered more natural than sites within the Rock

watershed. Visual estimations of Manning's *n* in the Wolf River Watershed corresponded well with calculations at most sites.

Manning's *n* was calculated four different ways (Table 2), including visual estimations for each transect within each site that were then averaged for each site. These calculations include using Manning's equation calculated with stream data, determining *n* by determining Rosgen's stream type, using Manning's estimation chart for *n*, and using Cowan's estimation chart for *n*.

Wolf River Manning's n

Manning's *n* calculations within the Wolf River Watershed were close to estimations from visual stream assessments (Table 7). Overall Manning's n_s are lower than other calculations, with some deviations. This is due to the use of surveyed velocity and channel geometries in the calculation of Manning's *n*, instead of the use of gravity and bankfull geometries in initial calculations. Manning's n_r is higher than other calculations, with some deviations. This is due to the variability in small stream types as a result of sediment and vegetation differences, subsequently affecting roughness coefficient estimations.

Manning's n_s (n calculated using survey data)

Manning's n_s values are lower than all other calculations, per site, with the exception of high values calculated at the Evergreen River at Langlade site and Spaulding Creek at Big Falls site (Table 7). Low values n_s indicate a high velocity and low channel roughness at each site. Manning's n_s values are generally low due to the use of surveyed

velocity and channel geometries in the calculation of Manning's *n*, instead of the use of gravity as and bankfull geometries in initial calculations.

The Evergreen River n_s calculation is close to all other n_s calculations at the site and is not considered a deviation; however, the higher than average n_s calculated at the site may be due to slow velocity measured at the site. The Spaulding Creek deviation is due to low velocity and a high wetted perimeter at the site, which would increase the roughness coefficient.

A very low n_s value is calculated at the Little Wolf River and the Swamp Creek River. The Little Wolf deviation is due to high velocity and a small hydraulic radius at the site, which would decrease the roughness coefficient. The Swamp Creek deviation is due to relatively high velocity at the site and a small hydraulic radius, which would decrease the roughness coefficient.

Manning's n_r (n calculated using Rosgen's stream type)

Manning's n_r values are higher than all other *n* calculations, with the exception of a high value calculated at the Spaulding Creek at Big Falls site (Table 7). The consistently high value of Manning's n_r is due to the variability in small stream types as a result of sediment and vegetation differences, subsequently affecting roughness coefficient estimations.

The Spaulding Creek value is close to all other n_r values but is not the highest value at that site. This is due to high n_s values at the site as a result of low velocity and high wetted perimeter, which would increase the roughness coefficient.

Manning's n_m (n estimated using Manning's estimation variables)

Manning's n_m values and Manning's n_c values have a similar range (Table 7). This is due to the similar estimation values used by both Manning's and Cowan's estimation chart. Manning's estimation methods include evaluating the stream characteristics according to shape, approximate in-stream vegetation and sediment, while Cowan's estimation methods include calculating a value for each stream variable and then summing the total to find *n*.

A high Manning's n_m value is calculated at the Middle Branch Embarrass site and the Swamp Creek above Mole Lake site. The Middle Branch site and Swamp Creek site deviations are due to Manning's evaluation of lower stage rivers, which was not as prominent at other sites.

Manning's n_c (n estimated using Cowan's estimation variables)

Manning's n_c values and Manning's n_m values have a similar range (Table 7). As stated earlier, this is due to the similar estimation values used by both Manning's and Cowan's estimation chart.

A high n_c value is calculated at the Evergreen River at Langlade site and the Spaulding Creek at Big Falls site. These deviations are due to Cowan's evaluation of stream irregularity, cross sectional differences, obstructions and in-stream vegetation, which were not as prominent at other sites.

Rock River Manning's n

Calculated Manning's *n* values were considerably higher than visually estimated *n* values in the Rock River Watershed (Table 7). Large deviations occur within all calculations and values are relatively dissimilar. Despite this, the bankfull discharge from survey data values coincided well with the historical Q1.0 discharge values. The lack of consistency between the *n* values within the Rock River are most likely due to the transect locations downstream from the gauging stations, which were all located at bridges, dams, and culverts that are known to affect the morphology of streambeds and consequently the roughness coefficient. Deviations may be due to the erratic discharges at each site at the time of survey and complications associated with the surrounding landuse.

The n_s values within the Rock River watershed deviated far from the visual estimations. Because the bankfull width, depth, and area correlate well with watershed area and the velocity measurements from these sites are approximately the same as those within the smaller sites of the Wolf River, *n* calculations indicate that the roughness of the stream, such as sediment and vegetation, is considerably greater than was estimated. More than likely, the velocity measurements taken at the time of survey may not have been representative of the normal flow within the stream. Precipitation was lower than normal during the survey session and it can be assumed that velocity measurements were slower than what would normally have been measured, consequently affecting the calculation of Manning's *n* and falsely indicating a higher roughness coefficient than is actually present.

Manning's n_s (n calculated using survey data)

Manning's n_s values are higher than all other *n* calculations per site, with the exception of the Bark River at Rome site (Table 7). Manning's n_s values should generally be low due to the use of surveyed velocity and channel geometries in the calculation of Manning's *n*, instead of the use of gravity and bankfull geometries in initial calculations. However, in the Rock River values were exceptionally high, which may be due to the extremely low velocity levels recorded at the sites, caused by several factors, including obstructions in the water.

The South Branch Rock River site has a n_s value of 0.228, which is much higher than would be estimated in the area. This is due to the extremely slow velocities at the site, mainly influenced by the low slope passing through the urban area of Waupun.

Manning's n_r (n calculated using Rosgen's stream type)

Manning's n_r values had a similar range to Manning's n_m values calculated using Manning's estimation chart (Table 7). Manning's n_r values tend to deviate a great deal due to the variability in small stream types as a result of sediment and vegetation differences, subsequently affecting roughness coefficient estimations. The similarities between Manning's n_r and Manning's n_m values may be due to the lack of complexity in the unnatural, channelized stream channels of the Rock River Watershed which result in more standard estimations of *n* based on stream type, as opposed to the variability in stream type normally found when calculating Manning's n_r.

A high n_r value is calculated at the Turtle Creek at Carvers Rock site. This is due to the evaluated stream type, correlating with a higher n value when using Rosgen's stream type estimation chart.

Manning's n_m (n estimated using Manning's estimation variables)

Manning's n_m values are smaller than, but close in range, to Manning's n_r values calculated using Rosgen's stream type classification (Table 7). As stated earlier, this may be due to the simpler, channelized stream channels in the Rock River Watershed resulting in more standard estimations of *n* based on stream type as opposed to the variability in stream type normally found when using stream type as an estimation of *n*. The values calculated at this site are what would be expected from this area.

Manning's n_c (n estimated using Cowan's estimation variables)

Manning's n_c values are smaller than, but close in range to Manning's n_m values calculated using Manning's estimation chart (Table 7). As stated earlier this is due to the similar estimation values used by both Manning's and Cowan's estimation chart including the evaluation of stream characteristics to find *n*.

A high n_c value is calculated at the Bark River site. This high value is due to Cowan's evaluation of obstructions and in-stream vegetation within the stream. In-stream vegetation was denser at this site than at other sites.

Bankfull Discharge

Bankfull discharge is calculated using four different calculations (Table 3) for each transect at each site within both watersheds and then averaged for each site. These calculations include using Manning's equation calculated with survey data, calculating the Q resistance equation using shear velocity, and determining a specific recurrence interval for the site (in this case, the 1.5 and 1.0-year intervals).

Overall, the survey calculations fell within the values of the other four calculations (Table 8). The $Q_{h1.0}$ discharge was the smallest discharge with the exception of the Beaver Dam at Beaver Dam site, which is due to the historical data from the Beaver Dam site being influenced by dam releases upstream of the gauging station.

The greatest deviations in both watersheds were found using the Q_r equation, which found much higher bankfull discharge values than the other equations. The higher values are most likely due to the method of calculation, which used bankfull geometry instead of channel geometry and gravity instead of channel velocity for the initial calculations of bankfull velocity. These differences would affect the bankfull discharge.

Wolf River Bankfull Discharge

The relationship between the $Q_{h1.5}$ and the Q_s discharge was strong throughout the Wolf River Watershed (Table 8), indicating a strong relationship between the 1.5-year recurrence interval and the survey-calculated discharge for bankfull stage. The greatest deviation from the survey bankfull discharge calculations were from using the Q resistance equation. These deviations are due to the equation's use of pebble size in the equation and the use of gravity and not channel velocity in the calculation of bankfull

velocity. The deviations account for differences between discharges at each site within the Wolf River Watershed with the exception of the Little Wolf River, Middle Branch Embarrass, and Swamp Creek sites.

Bankfull discharge derived from survey data (Q_s) within the Wolf River is similar to the Q resistance (Q_r), with the exception of the Evergreen River at Langlade and Spaulding Creek near Big Falls. This may be due to the hydraulic variables used within the equations (Table 6). The 1.5-year recurrence interval ($Q_{h1.5}$) coincides well with the Wolf River bankfull discharge with the exception of the Middle Branch Embarrass River at Wittenberg and Swamp Creek above Mole Lake. This may be due to the assumption that the 1.5-year recurrence interval is the bankfull flood at these sites.

Discharge Qs (Discharge calculated using survey data)

Discharge Q_s values fall within the range of other discharge calculations with the exception of the Little Wolf at Galloway site, the Middle Branch Embarrass site, and the Swamp Creek above Mole Lake site (Table 8).

The Little Wolf deviation is due to the small *n* calculated using survey data (Table 5), resulting from the high velocity recorded at the site. The Middle Branch Embarrass deviation is due to the small *n* value calculated at the site, as a result of relatively high velocity recorded at the site in relation to channel size.

The highest discharge value calculated in the Wolf River Watershed is the Swamp Creek $Q_{s,}$ with a discharge of 12.82 cms. This is not close to other calculations and is due to the low *n* calculated as a result of high velocity and a small hydraulic radius.

Discharge Q_r (Discharge calculated using resistance equation)

Discharge Q_r values are higher than all other discharge calculations with the exception of the Little Wolf at Galloway site, the Middle Branch Embarrass site, and the Swamp Creek above Mole Lake site (Table 8). The Q_r discharge calculates a higher than normal value due to the equation's use of pebble size in the equation and the use of gravity instead of channel velocity in the calculation of bankfull velocity.

The Little Wolf deviation is due to the high Q_s calculated at the site as a result of a low n_s calculation. The Middle Branch deviation is due to an extreme $Q_{h1.5}$ calculated using the 1.5-year recurrence interval. The deviation between the other discharges and Middle Branch $Q_{h1.5}$ may be due to the relatively small amount of historical data used in the calculation of the recurrence interval.

The highest Q_r discharge value calculated in the Wolf River Watershed is the Creek Q_r. This is due to the increased stream bankfull area at that site, which may be a result of the impervious geology in the area which may increase runoff and therefore discharge (enlarging the channel) (See Appendix I). The Q_r value is close to the Q_s value but not to other discharge values.

The lowest Q_r value is calculated at the Emmons Creek site, with a discharge of 3.89 cms. This is due to the small bankfull area at the site. The Q_r value is close in range to Q_s but not with other discharge values.

Discharge $Q_{h1.5}$ (Discharge calculated using 1.5-year recurrence interval)

Discharge $Q_{h1.5}$ values are closely related to discharge calculated using survey data (Q_s), with the exception of the Middle Branch Embarrass site and the Swamp Creek

above Mole Lake site (Table 8). The Q_s and $Q_{h1.5}$ discharges are closely related due to the assumption that a specific historical recurrence interval, in this case the 1.5-year recurrence interval, is representative of the bankfull flood.

The Middle Branch deviation may be due to the small amount of historical data (16 years) and to the low *n* calculated at the site using survey data. The Middle Branch value is also the highest $Q_{h1.5}$ calculated in the Wolf River Watershed, which may be due to the increased bankfull area at the site or due to the urban areas surrounding the site, including a golf course upstream, which would increase runoff as a result of impervious areas. The Swamp Creek deviation is due to the small amount of historical data (11 years) at the site and because of the increased bankfull area calculated due to a natural pool formed by a tree fall located at one transect on the site.

Discharge $Q_{h1.0}$ (Discharge calculated using 1.0-year recurrence interval)

Discharge $Q_{h1.0}$ values are the smallest discharges calculated in the Wolf River Watershed with the exception of the Middle Branch Embarrass site (Table 8). That $Q_{h1.0}$ is smaller than and does not correlate well with Q_s. This further validates that the 1.5-year interval is more representative of the bankfull flood in the Wolf River Watershed.

The Middle Branch Embarrass deviation may be due to the assumption that the 1.5-year recurrence interval is representative of the bankfull flood. It is possible that, at this site, the 1.0-year recurrence interval is more representative of the bankfull flood. In addition, this discharge value is the highest $Q_{h1.0}$ calculated in the watershed. This is most likely due to the large bankfull area of the river.

Rock River Bankfull Discharge

There was a general lack of consistency between discharge calculations in the Rock River Watershed. However, the relationship between $Q_{h1.0}$ and Q_s values are much stronger than the relationship between $Q_{h1.5}$ and Q_s bankfull discharge (Table 8). This indicates a more frequent bankfull flood within the Rock River watershed, occurring approximately every 1.0-year instead of every 1.5-years. This could be due to increased runoff from a higher percentage of agricultural/urban areas within the watershed, although this research did not find a relationship based upon these sites. However, the more frequent bankfull flood implies a difference between the landuse governing the Wolf River and Rock River watersheds.

The greatest deviations from the survey bankfull discharge calculations were calculated using the Q resistance equation. This is due to the equation's use of gravity and not channel velocity to calculate bankfull velocity, the use of pebble size in the calculation of discharge, and the use of bankfull geometry in the place of channel geometry. The deviations account for the majority of differences between discharges at each site within the Rock River Watershed.

Discharge Q_s (Discharge calculated using survey data)

Discharge Q_s values fall within the range of all within the range of other discharge calculations with the exception of the Turtle Creek at Carvers Rock site (Table 8), which almost exactly coincides with $Q_{h1.0}$. This is to be expected, due to Q_r generally calculating a larger discharge and $Q_{h1.0}$ calculating a flood that is generally regarded as smaller than

the bankfull flood. The highest discharge value calculated in the Rock River Watershed was the Turtle Creek Q_s with a discharge of 7.24 cms which coincides well with $Q_{h1.0}$.

Discharge Q_r (Discharge calculated using resistance equation)

Discharge Q_r values are higher than all other discharge calculations (Table 8). This is due to the equation's use of pebble size in the equation, the use of gravity instead of channel velocity, and the use of bankfull geometry instead of channel geometry in the calculation of bankfull velocity. The highest Q_r discharge value calculated in the Rock River Watershed is the Turtle Creek Q_s with a discharge of 37.12 cms. This value is significantly higher than any other discharge value calculated in the watershed and is due, in addition to the equation's use of bankfull geometry, particle size, and gravity in calculations, to the large bankfull area and wide bankfull width calculated at the site.

Discharge $Q_{h1.5}$ (Discharge calculated using 1.5-year recurrence interval)

Discharge $Q_{h1.5}$ values are not close to discharge calculated using survey data (Q_s), with the exception of the Bark River at Rome site (Table 8). This may be due to the historical 1.0-year recurrence interval better representing the Rock River Watershed floods than the historical 1.5-year recurrence interval. The stronger correlation between the 1.0-year recurrence interval $Q_{h1.0}$ and Q_s supports the supposition that the bankfull flood occurs more frequently in streams that are more channelized and in areas that are likely influenced by impervious areas, e.g. urban and agricultural areas. Although no relationship was found between landcover and discharge in either the Wolf or Rock River Watersheds, the indication of a more frequent bankfull flood supports the assumption that landcover may influence flooding in the region.

The Bark River site discharge $Q_{h1.5}$ averages 7.17 cms while the Q_s averages 6.58 cms and $Q_{h1.0}$ averages 4.40 cms. The $Q_{h1.5}$ value and Q_s value are close to each other, most likely due to the natural stream characteristics of the channel and lack of channelization that has occurred at this site. This site is more natural than any other sites referenced in the Rock River Watershed and would flood less frequently than other site that are more channelized. This site would likely have more in common with sites referenced in the Wolf River Watershed, which correlate well with the historical 1.5-year recurrence interval.

Discharge $Q_{h1.0}$ (Discharge calculated using 1.0-year recurrence interval)

Discharge $Q_{h1.0}$ values are close to the survey data discharge (Q_s). The $Q_{h1.0}$ values are the smallest discharges calculated in the Rock River Watershed with the exception of the Turtle Creek at Carvers Rock site (Table 8). The small values $Q_{h1.0}$ are due to the historical 1.0-year flood representing a more frequent and smaller flood than the historical 1.5-year flood. The $Q_{h1.0}$ values most likely correlate with the Q_s values in this watershed because of the channelized streams that were referenced in the Rock River Watershed, with the exception of the Bark River at Rome site. This site is more natural and Q_s values correlate better with $Q_{h1.5}$ values. However, this site is located downstream from a dam structure.

The historical 1.0-year recurrence interval better representing the Rock River Watershed floods than the historical 1.5-year recurrence interval. A stated earlier, the correlation between the 1.0-year recurrence interval ($Q_{rh1.0}$) and Q_s supports the assumption that the bankfull flood occurs more frequently in streams that are more channelized and more influenced by impervious areas, e.g. urban and agricultural areas.

Sediment Analysis

Average sediment sizes ranged between coarse sand to small gravel, with the majority of the 84th percentile of sediment size measuring 1.0 mm (Table 9). The largest sediment sizes were found in transect 1 of the Tomorrow River due to the wingdams from stream restoration. The transect could not be moved due to a bend in the river that compromised the use of the total station meter used for elevation measurements. The large sediment sizes present at the transect affected the velocity at the transect, in addition to the width and depth of the channel at that transect.

Landcover

This study did not find a consistent significant relationships between landcover and discharge; although, landuse practices have been found to affect bankfull discharge in other watersheds (Reidel, et al., 2005) (See Appendix A, F, and G). Landcover was delineated in the watersheds upstream of the USGS gauging stations at each site. Both county landuse (1992) and federal landuse (2001) were used to assess a generalized landcover system (Table 10).

Two significant relationships between landcover and discharge were found (Figure 32,Figure 33,Figure 34,Figure 35) (See Appendix A). The Wolf River Watershed residential/commecial landcover vs. discharge showed a significant $R^2 = 0.83$ in 1992 and $R^2 = 0.45$ in 2001. The Rock River Watershed forest landcover vs. discharge showed a significant $R^2 = 0.55$ in 1992 and $R^2 = 0.47$ in 2001.

The expected trends would an increase of discharge in areas with increased runoff, such as residential and agricultural areas, and a decrease in discharge in areas with increased interception, such as forest areas. This pattern was not consistent throughout the watersheds with the exception of residential/commercial areas which increased in both watershed regions.

Comparisons between landcover and discharge may have been affected by the heterogeneous watershed areas. Site areas ranged from 14.4 km^2 to 197.6 km^2 in the Wolf River and 164.7 km^2 to 515.4 km^2 in the Rock River. When comparing landcover, a homogeneous set of watershed sizes would reduce variables and provide for a more accurate comparison. In addition, comparisons may have been affected by relatively homogeneous percentages of landcover across the major watersheds: the Wolf River displays a high percentage of forested area throughout the watershed, while the Rock River displays a high percentage of agricultural area throughout the watershed.

Comparisons within the Wolf River Watershed may have been affected by the high percentage of wetlands, which retain water, and the high percentage of forest cover within each subwatershed. High percentages of the same landcover between subwatersheds would negate comparisons between the subwatersheds.

This comparison cannot be accurately assessed within the Rock River Watershed due to survey calculations affected by upstream structures such as dams and bridges, and historical data affected by upstream structures and possibly an incorrect recurrence interval representing bankfull discharge.

CONCLUSION

The main objective of this study was to collect bankfull survey and historical data from selected sites within the Wolf River Watershed and Rock River Watershed in order to determine bankfull discharge and develop a regional curve. Published regional curves, which are used as a first step in stream restoration, are not available for the State of Wisconsin. A published regional curve would greatly benefit this activity, as Wisconsin, a leading state in stream restoration and dam removal, invests millions of dollars in stream restoration every year.

A regional curve that could be used in stream restoration was successfully developed for the Wolf River Watershed. A regional curve was successfully developed for the Rock River Watershed, but it would not be suitable for stream restoration design. The regional curve developed for the Wolf River correlated well between survey data and the 1.5-year historical recurrence interval. The regional curve developed for the Rock River correlated well between survey data and the 1.0-year recurrence interval. This indicates that the Wolf River Watershed bankfull flood is more closely related to the historical 1.5-year flood, while the Rock River Watershed bankfull flood may be more closely related to the historical 1.0-year flood.

This study did not find a consistent significant relationship between landcover and discharge, but landcover has been found to affect bankfull discharge in other studies (Reidel, et al., 2005). Changes in landuse were found between the county (1992) and federal (2001) landuse systems, generally showing an increase in developed areas and a decrease in undeveloped areas.

The results found through this data were comparable to those found by another study. This research was compared to a study conducted by Mistak and Stille (2007) in the State of Michigan. Comparisons between watershed area and bankfull width, depth, area, and discharge have similar R^2 values regarding bankfull width vs. watershed area, bankfull depth vs. watershed area, bankfull area vs. watershed area, and bankfull discharge vs. watershed area.

RECOMMENDATIONS

This study faced many challenges and the associated recommendations would greatly benefit future studies. The recommendations I outline include: sample size, historical and background data, field data collection, and field research organization and planning.

The first recommendation for this study is the collection of data from a larger sampling size. Only seven sites were used in the Wolf River Watershed and only four sites in the Rock River Watershed. There were several reasons for this, including the general lack of historical data associated with small, wadable streams, and the difficulty in finding streams that are natural and unchannelized. Most streams in Wisconsin have a low gradient and have, throughout Wisconsin history, been logged or dammed making this type of work very challenging.

The second recommendation for this study is the need for more historical data associated with each study site. As stated earlier, there was a general lack of historical data associated with small, wadable streams. However, with better planning and equipment (such as equipment that would allow surveying in deeper water), a wider range of sites could be researched, greatly improving the development of a regional curve.

The third recommendation regards the collection of background information. Background information such as topography, landcover, soils, geology and surrounding hydrology should be researched and taken into consideration for each site. Careful consideration of these variables would lead to more conclusive explanations of differences between sites, and anamolies at individual sites.

The fourth recommendation regards field data collection and should already be addressed in most studies. A field-team of at least three trained individuals with consistent jobs throughout the field season should be arranged. Data documentation should include weather conditions (such as precipitation events upstream) and observations of the surrounding area and stream channel. It would also be beneficial to take velocity measurements at the site before and after the field day. This would be difficult but would indicate any influential precipitation events upstream of the site.

The fifth recommendation provides several improvements for the organization of a field season and should already be addressed in most studies. Thorough background information should be collected on each site, within each watershed, from several sources before considering a site for research. Sites should always be visited before a field day so that they can be evaluated for quality and so that transects can be selected in advance.

The sixth recommendation includes scheduling a field season in advance, with the flexibility to move schedules to accommodate unusual seasonal weather conditions. For example, in the first season this data was collected a large flood occurred in the Rock River Watershed making data collection impossible. Data collection was moved to the Wolf River Watershed the following field season where a drought occurred. Given enough time and resources, the field season should have been moved to a year in which normal weather conditions, and subsequently normal water levels, applied. This is often difficult to fix.

With these recommendations in mind, future studies could make better use of time and resources and potentially provide research that is accurate, precise, and beneficial to the scientific community.

REFERENCES

Brown, Clint M., Garrett T. Decker, Ronald W. Pierce, and Troy M. Brandt. Applying Natural Channel Design Philosophy to the Restoration of Inland Native Fish Habitat. Practical Approaches for Conserving Native Inland Fishes of the West. Montana Chapter of American Fisheries Society. U.S. Fish and Wildlife Service. <http://www.fws.gov/mountain-prairie/pfw/r6pfw2h16.htm> Accessed on September 27, 2007.

Chow, V.T., 1959. Open-channel hydraulics. New York, McGraw- Hill Book Co. 680 pages.

Copeland, R.R., D. S. Biedenharn, and J. C. Fischenich, December 2000. Channel-Forming Discharge. *U.S. Army Corps of Engineers*, Vol.VIII-5. Pages 1-10.

Cowan, W.L., 1956. Estimating Hydraulic Roughness Coefficient. *Agricultural Engineering*, Vol. 37, No. 7. Pages 473-475.

Dade, W. Brian and Peter F. Friend. 1998. Grain-Size, Sediment-Transport Regime, and Channel Slope in Alluvial Rivers. *The Journal of Geology*, Vol. 106. Pages 661-675.

DeBarry, Paul A. 2004, Watersheds: Processes, Assessment and Management. John Wiley and Sons, Inc. Chapters: 3,4,5,6,8,9,11,12,14,17.

Doyle, Martin W. and Doug Shields, Karin F. Boyd, Peter B. Skidmore, and DeWitt Dominick, July, 2007. Channel-Forming Discharge Selection in River Restoration Design. *Journal of Hydraulic Engineering*, Vol. 133, No. 7, Pages 831-837.

Dunne, Thomas and Luna B. Leopold, 1978. Water Use by Vegetation. Water in Environmental Planning. New York: Freeman and Co, Pages 126-162.

Dutnell, Russell, 2000. Development of Bankfull Discharge and Channel Geometry Relationships for Natural Channel Design in Oklahoma Using a Fluvial Geomorphic Approach. M.S. Dissertation, University of Oklahoma, Norman, Oklahoma.

Harman, W.A., D.E. Wise, M.A. Walker, R. Morris, M. A. Cantrell, M. Clemmons, G.D. Jennings[1], D. Clinton[1], and J. Patterson. Accessed 2007. Bankfull Regional Curves for North Carolina Mountain Streams. North Carolina State University Stream Restoration Program. <http://www.bae.ncsu.edu/training_and_credit/search_results.php?cref=http%3A%2F%2Fwww.bae.ncsu.edu%2Fassets%2Fincludes%2Fgoogle%2Fbae_cse.xml&cof=FORID%3A9&q=bankfull+regional+curves+for+north+carolina+mountain+streams&sa=Go!#1042>

Keaton, Jefferson *N*., Terence Messinger, and Edward J. Doheny, 2005. Development and Analysis of Regional Curves for Streams in the Non-Urban Valley and Ridge Physiographic Province, Maryland, Virginia, and West Virginia. U.S. Department of the Interior U.S. Geological Survey Scientific Investigations Report 2005-5076, 116 p. <http://pubs.usgs.gov/sir/2005/5076/sir05_5076.pdf>

Leopold, L.B., Wolman, M.G., and J.P. Miller, 1964. Fluvial Processes in Geomorphology. W.H. Freeman, San Francisco, California.

Leopold, Luna B., 1994. A View of the River. First Harvard University Press.

Malakoff, David, August 13, 2004. The River Doctor Profile: Dave Rosgen. *Science*, Vol. 305, Pages 937-939.

McCuen, Richard H., 2005. Hydrologic Analysis and Design. Pearson Prentice Hall. Upper Saddle River, New Jersey. Chapters: 1,2,3,5,7,9.

Mistak, Jessica L. and Deborah A Stille, January, 2007. Upper Menominee River Regional Curve. Michigan Department of Natural Resources and Department of Recreation Studies and Exercise Science.

Montgomery, David R. and John M. Buffington, 1993. Channel Classification, Prediction of Channel Response, and Assessment of Channel Condition. Timber Fish and Wildlife. Department of Geological Studies and Quaternary Research Center.

Riedel, Mark S., Verry, Elon S., and Kenneth *N*. Brooks, 2005. Impacts of land use conversion on bankfull discharge and mass wasting. *Journal of Environmental Management*, Vol. 76, Pages 326-337.

Rosgen, David L., 1994. Catena, A Classification of Natural Rivers. Vol. 22, Pages 166-199.

Rosgen, David L., 1996. Applied River Morphology. Wildland Hydrology.

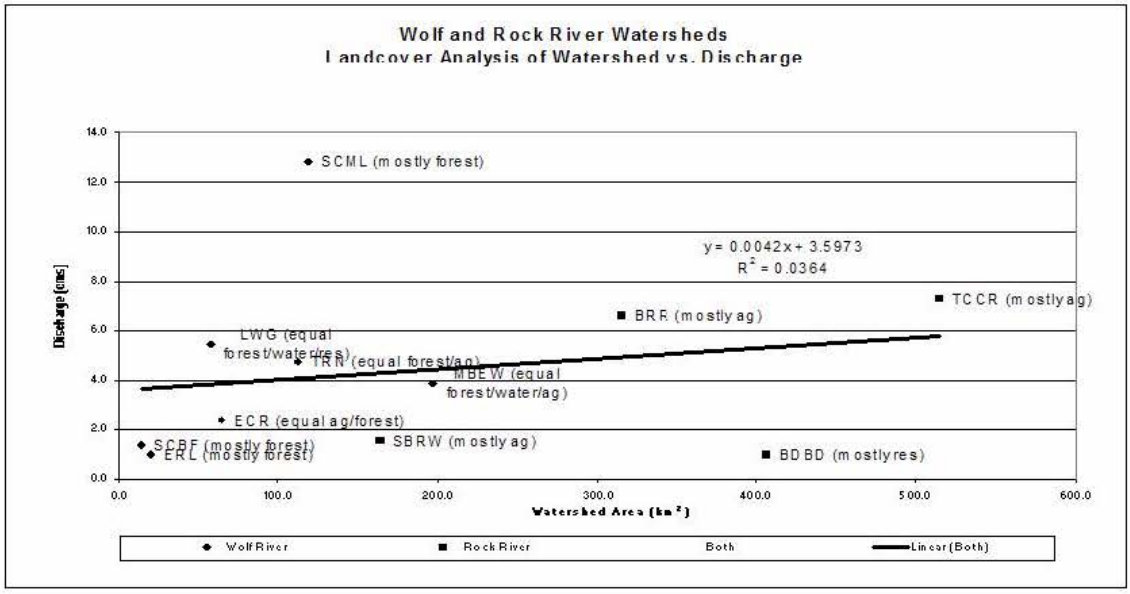
U.S. Environmental Protection Agency, January 2007. Online Training Watershed Management: Fundamentals of the Rosgen Stream Classification System. <http://www.epa.gov/watertrain/stream_class/> Last updated on Thursday, January 25, 2007.

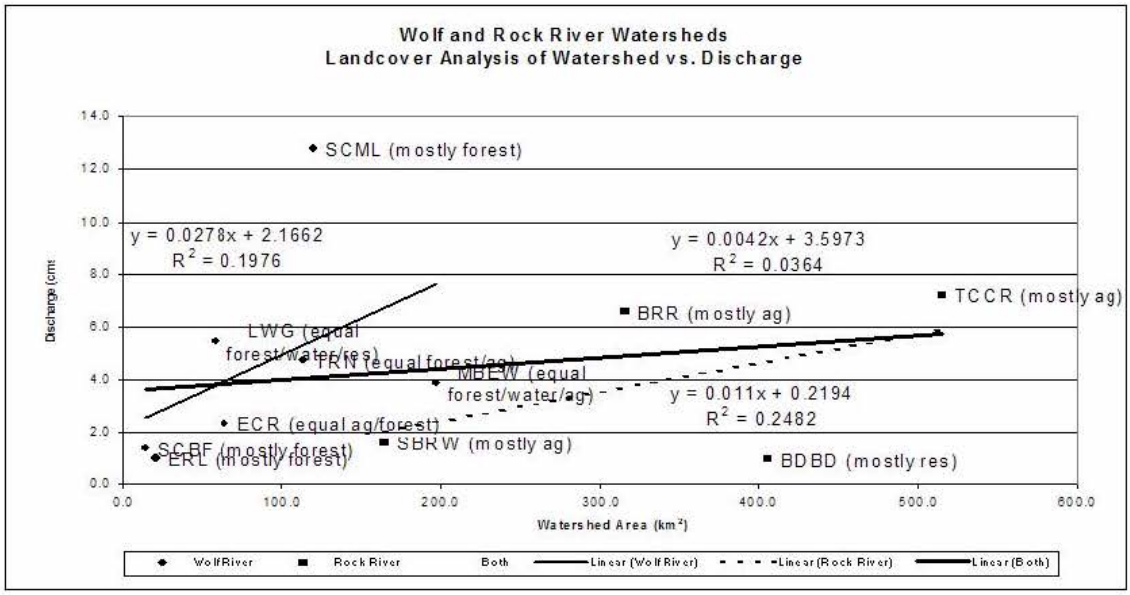
Wilkerson, Gregory V. February, 2008. Improved Bankfull Discharge Prediction Using 2-Year Recurrence-Period Discharge. *Journal of the American Water Resources Association* (JAWRA), Vol. 44, No.1, Pages 243-258.

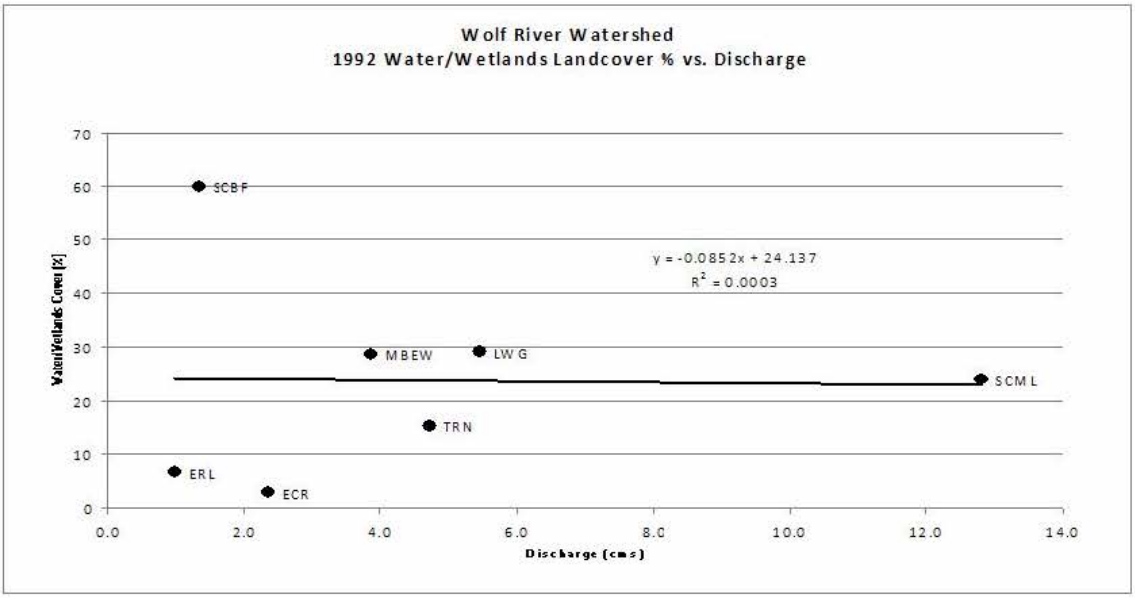
Woltemade, Christopher J., 1994. Form And Process: Fluvial Geomorphology and Flood-Flow Interaction, Grant River, Wisconsin, *Annals of the Association of American Geographers*, Vol. 84 (3), Pages 462-479.

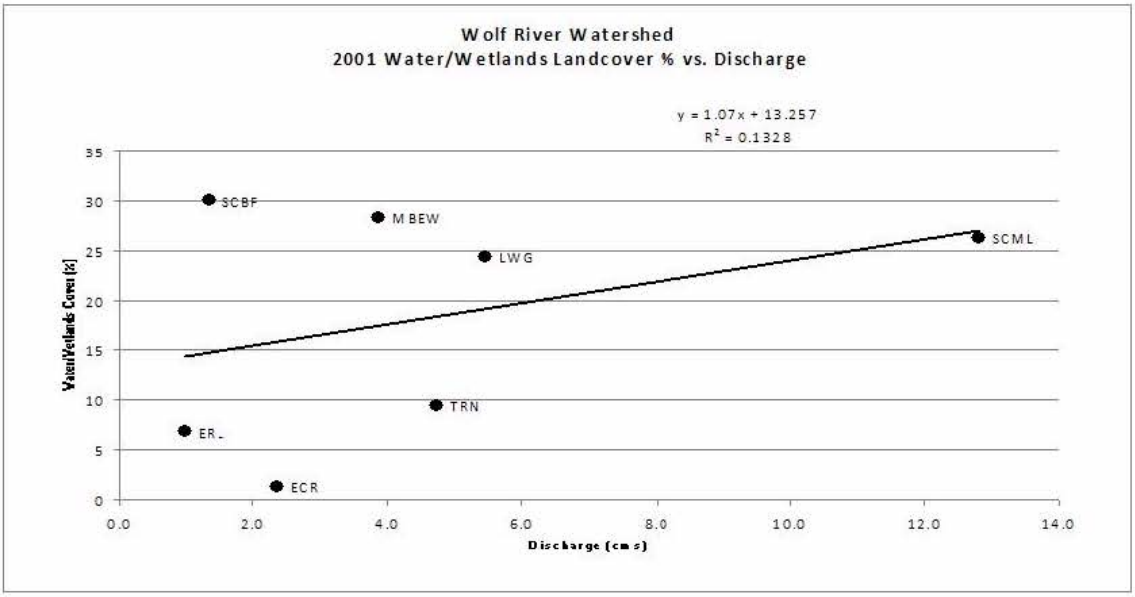
APPENDICES

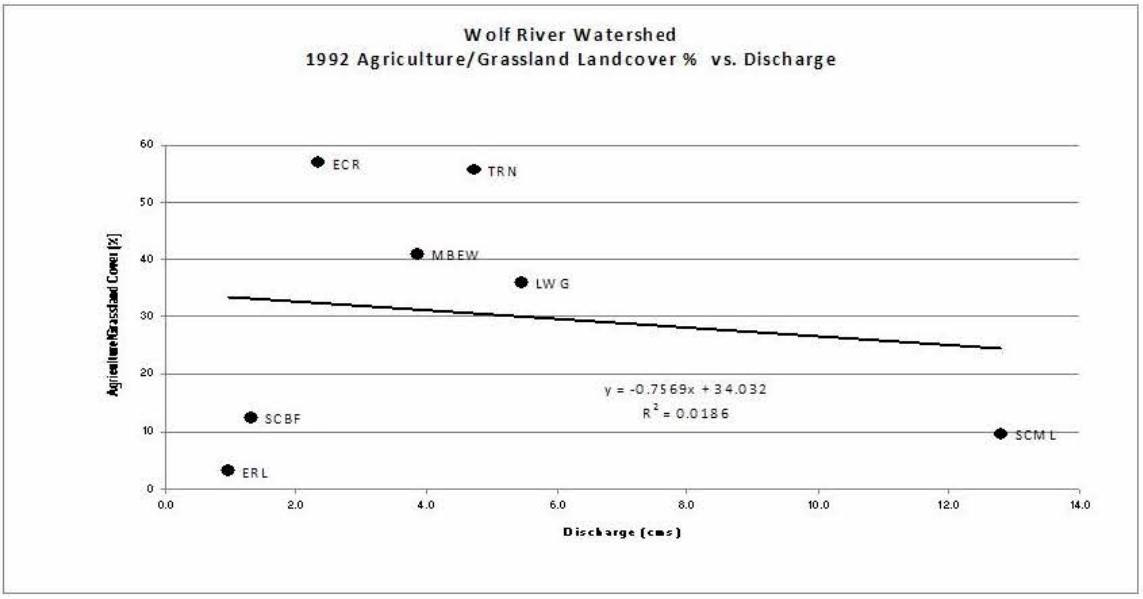
Appendix A: Landcover vs. Discharge

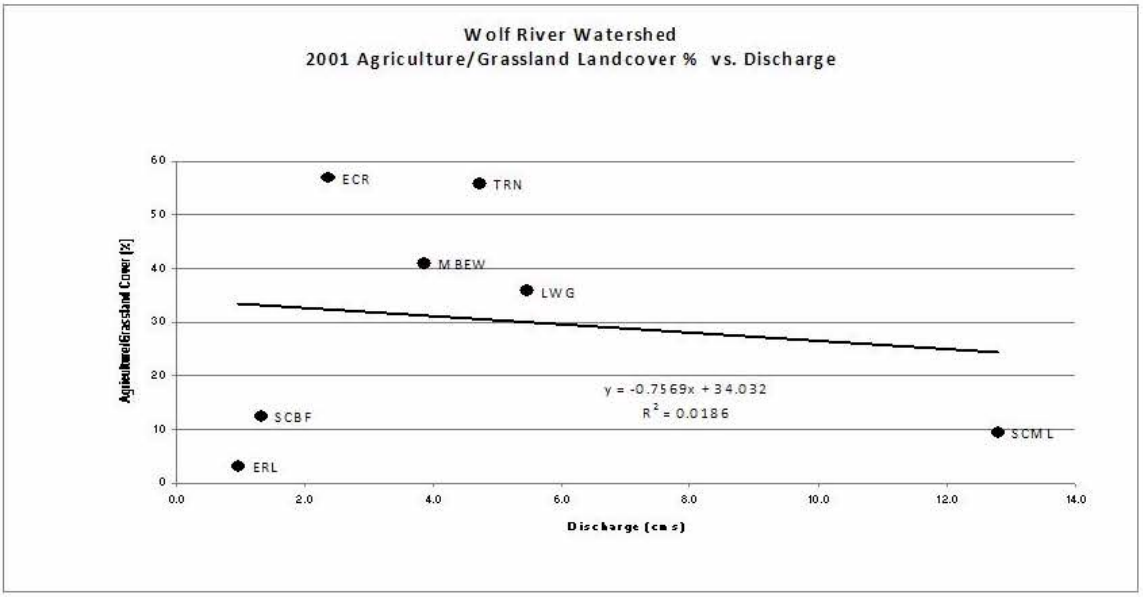

Wolf and Rock River Watersheds
Landcover Analysis of Watershed vs. Discharge
SCML (mostly forest)
y = 0.0042x + 3.5973
R² = 0.0364
TCCR (mostly ag)
BRR (mostly ag)
LWG (equal forest/water/res)
TRN (equal forest/ag)
MBEW (equal forest/water/ag)
ECR (equal ag/forest)
SCBF (mostly forest)
ERL (mostly forest)
SBRW (mostly ag)
BDBD (mostly res)
Watershed Area (km²)
Wolf River
Rock River
Both
Linear (Both)

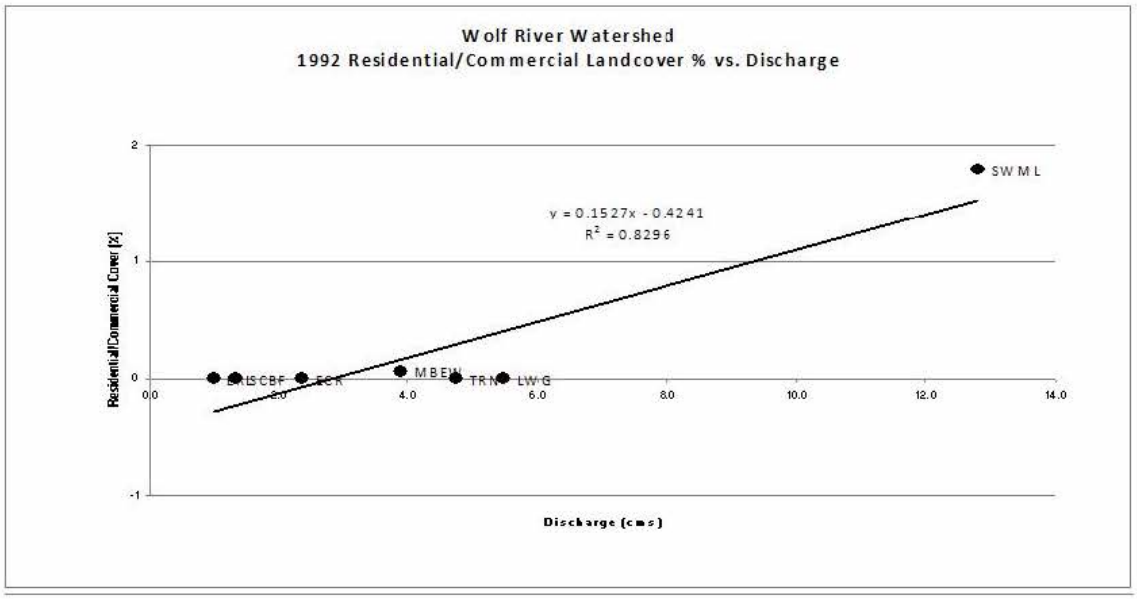

Wolf and Rock River Watersheds
Landcover Analysis of Watershed vs. Discharge
SCML (mostly forest)
y = 0.0278x + 2.1662
R² = 0.1976
y = 0.0042x + 3.5973
R² = 0.0364
TCCR (mostly ag)
BRR (mostly ag)
LWG (equal forest/water/res)
TRN (equal forest/ag)
MBEW (equal forest/water/ag)
y = 0.011x + 0.2194
R² = 0.2482
ECR (equal ag/forest)
SCBF (mostly forest)
ERL (mostly forest)
SBRW (mostly ag)
BDBD (mostly res)
Watershed Area (km²)
Wolf River
Rock River
Both
Linear (Wolf River)
Linear (Rock River)
Linear (Both)

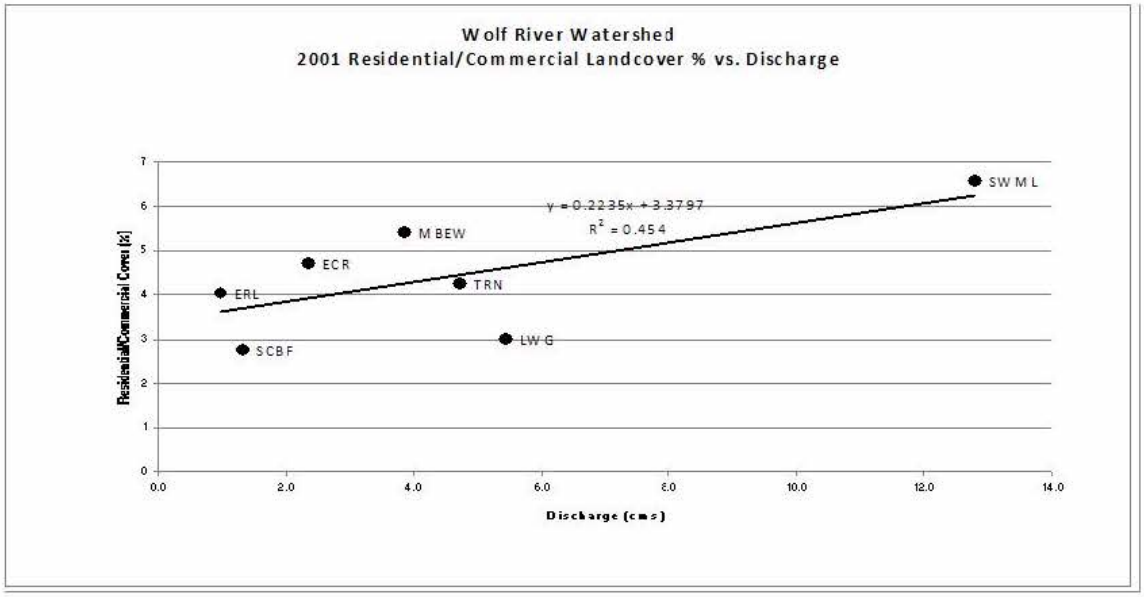

Wolf River Watershed
1992 Water/Wetlands Landcover % vs. Discharge
y = -0.0852x + 24.137
R² = 0.0003
SCBF
MBEW
LWG
SCML
TRN
ERL
ECR
Water/Wetlands Cover [%]
Discharge (cms)
0
10
20
30
40
50
60
70
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0

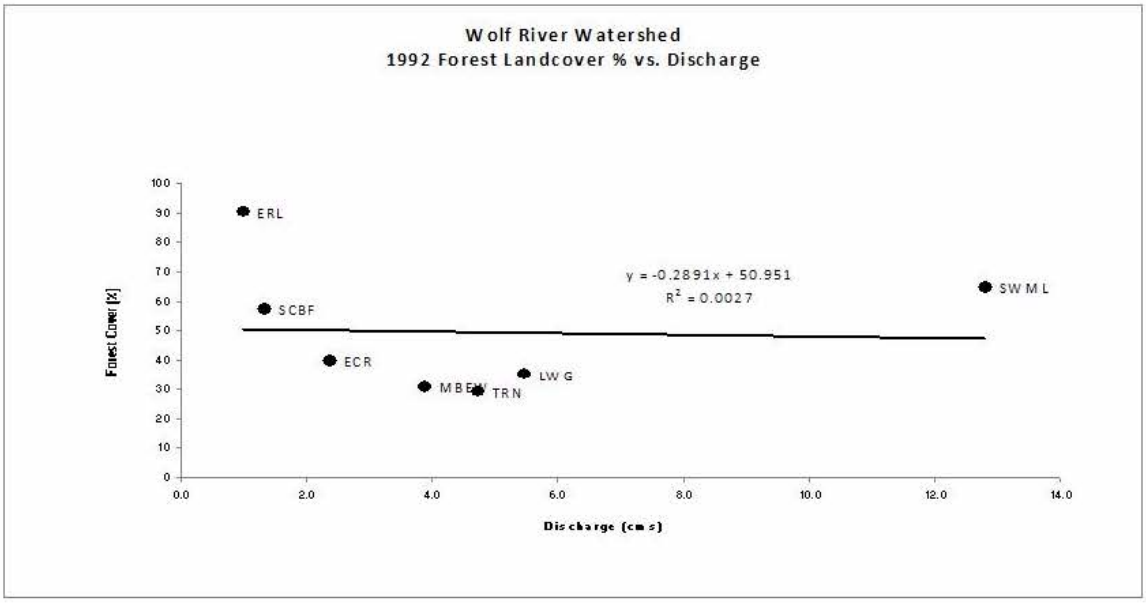

Wolf River Watershed
2001 Water/Wetlands Landcover % vs. Discharge
y = 1.07x + 13.257
R² = 0.1328
SCBF
MBEW
LWG
SCML
TRN
ECR
Water/Wetlands Cover [%]
Discharge (cms)
0
5
10
15
20
25
30
35
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0

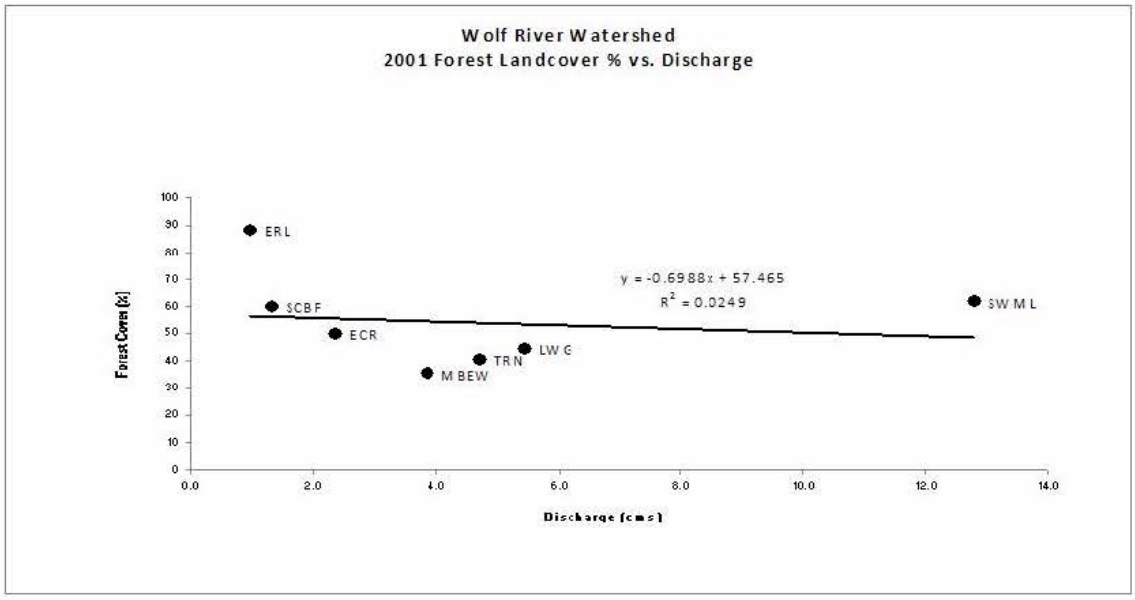

Wolf River Watershed
1992 Agriculture/Grassland Landcover % vs. Discharge
Agriculture/Grassland Cover [%]
Discharge (cms)
ECR
TRN
MBEW
LWG
SCBF
SCML
ERL
y = -0.7569x + 34.032
R² = 0.0186
0
10
20
30
40
50
60
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0

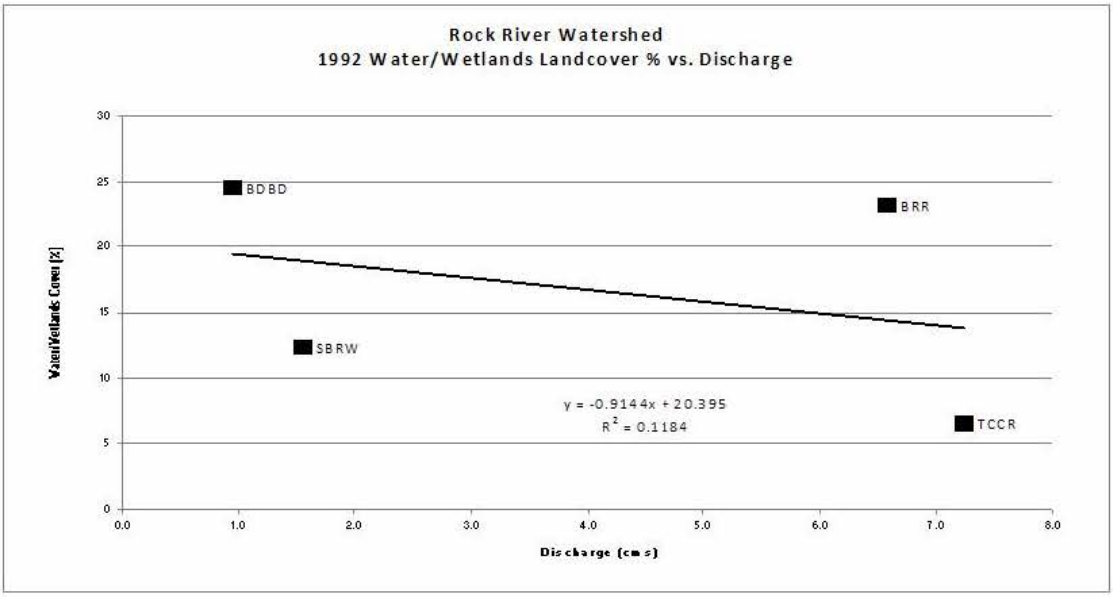

Wolf River Watershed
2001 Agriculture/Grassland Landcover % vs. Discharge
Agriculture/Grassland Cover [%]
Discharge (cms)
ECR
TRN
MBEW
LWG
SCBF
SCML
ERL
y = -0.7569x + 34.032
R² = 0.0186
0
10
20
30
40
50
60
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0

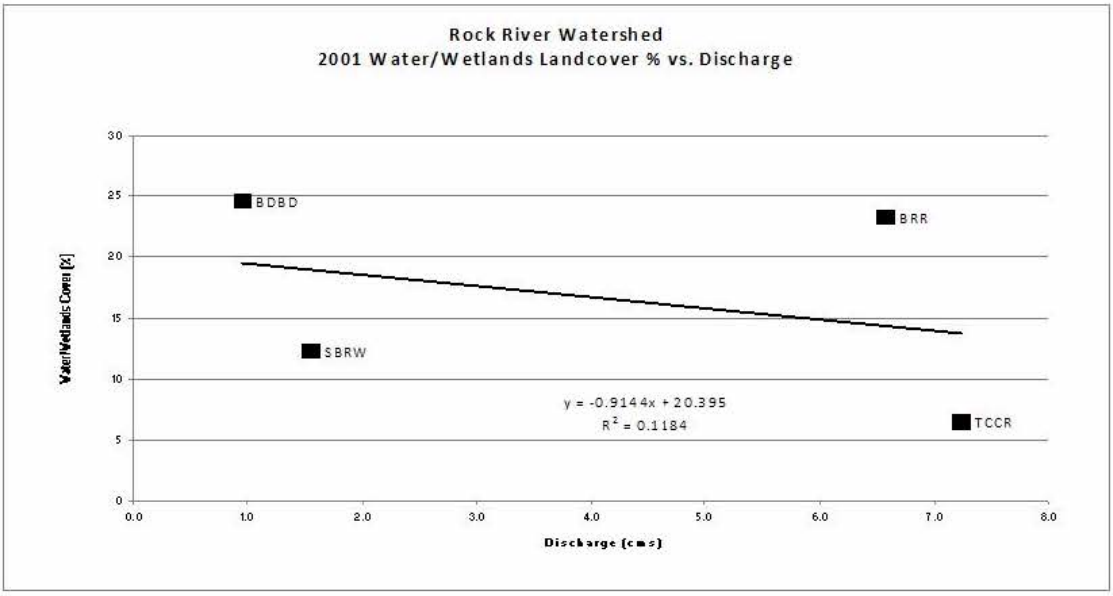

Wolf River Watershed
1992 Residential/Commercial Landcover % vs. Discharge
y = 0.1527x - 0.4241
R² = 0.8296
SWML
MBEW
TRN
LWG
ECR
ERL
SCBF
Residential/Commercial Cover [%]
Discharge (cms)
2
1
0
-1
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0

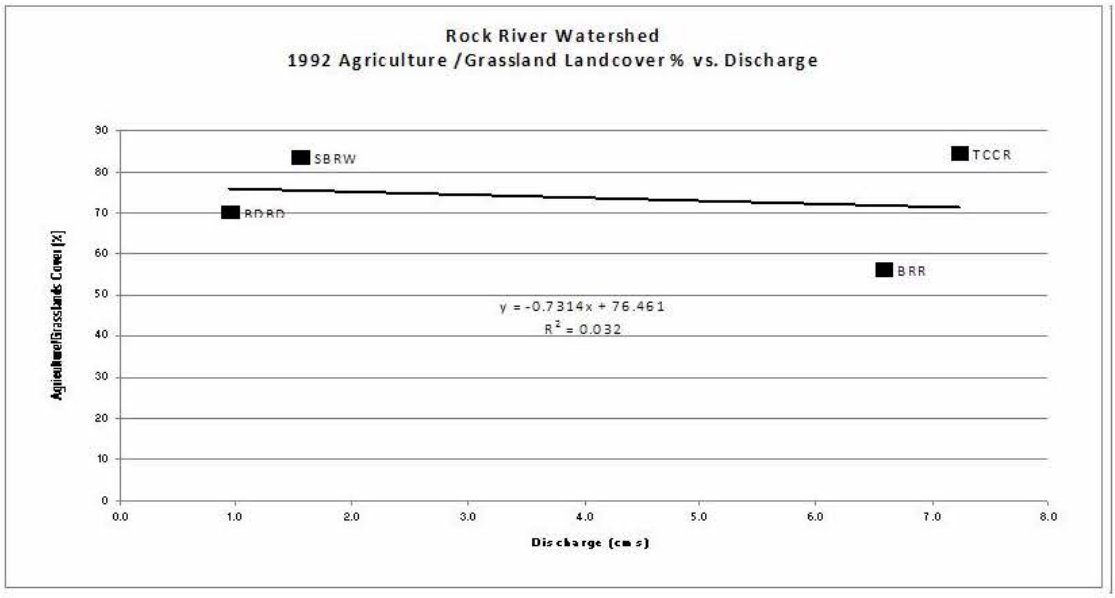

Wolf River Watershed
2001 Residential/Commercial Landcover % vs. Discharge
y = 0.2235x + 3.3797
R² = 0.454
SWML
MBEW
ECR
ERL
TRN
LWG
SCBF
Residential/Commercial Cover [%]
Discharge (cms)
7
6
5
4
3
2
1
0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0

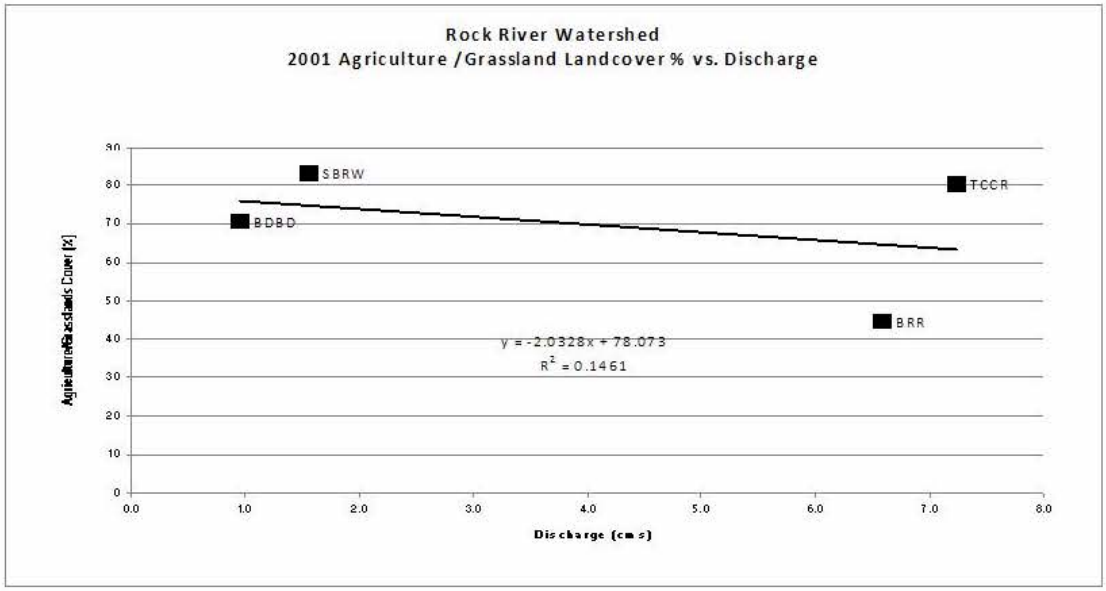

Wolf River Watershed
1992 Forest Landcover % vs. Discharge
Forest Cover (%)
Discharge (cms)
y = -0.2891x + 50.951
R² = 0.0027
ERL
SCBF
ECR
MBEW
TRN
LWG
SWML
0
10
20
30
40
50
60
70
80
90
100
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0

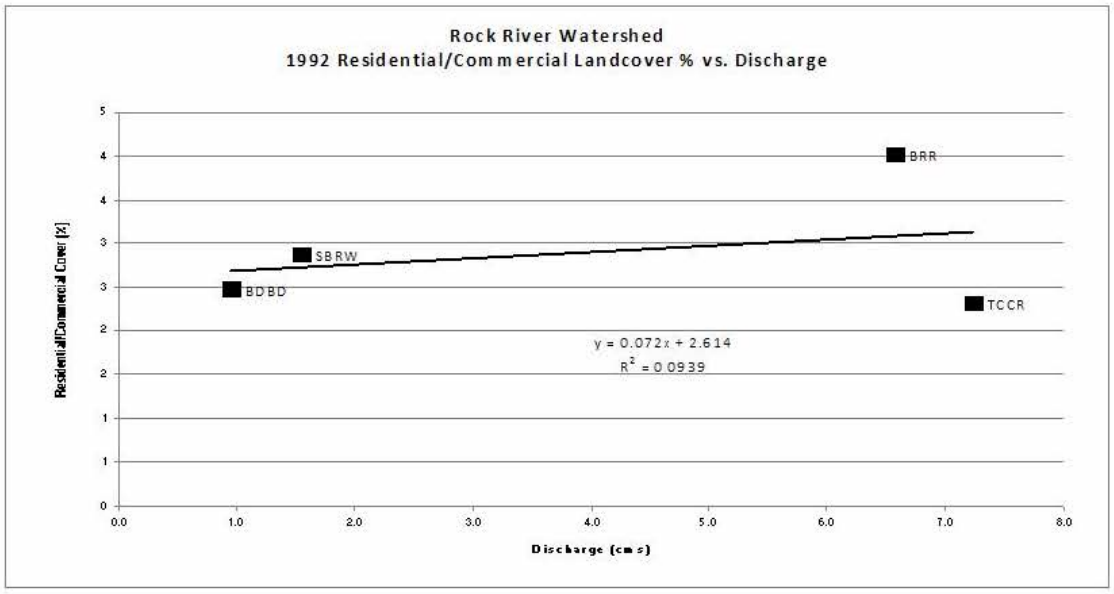

Wolf River Watershed
2001 Forest Landcover % vs. Discharge
Forest Cover (%)
Discharge (cms)
y = -0.6988x + 57.465
R² = 0.0249
ERL
SCBF
ECR
TRN
LWG
MBEW
SWML
0
10
20
30
40
50
60
70
80
90
100
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0

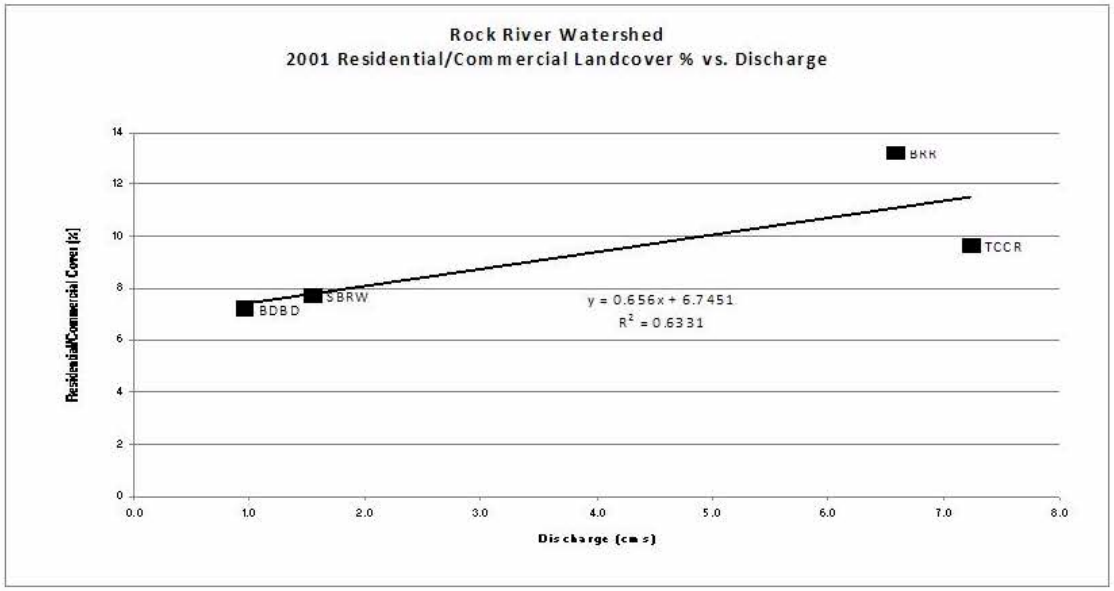

Rock River Watershed
1992 Water/Wetlands Landcover % vs. Discharge
Water/Wetlands Cover (%)
Discharge (cms)
BDBD
BRR
SBRW
TCCR
y = -0.9144x + 20.395
R2 = 0.1184
0
5
10
15
20
25
30
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0

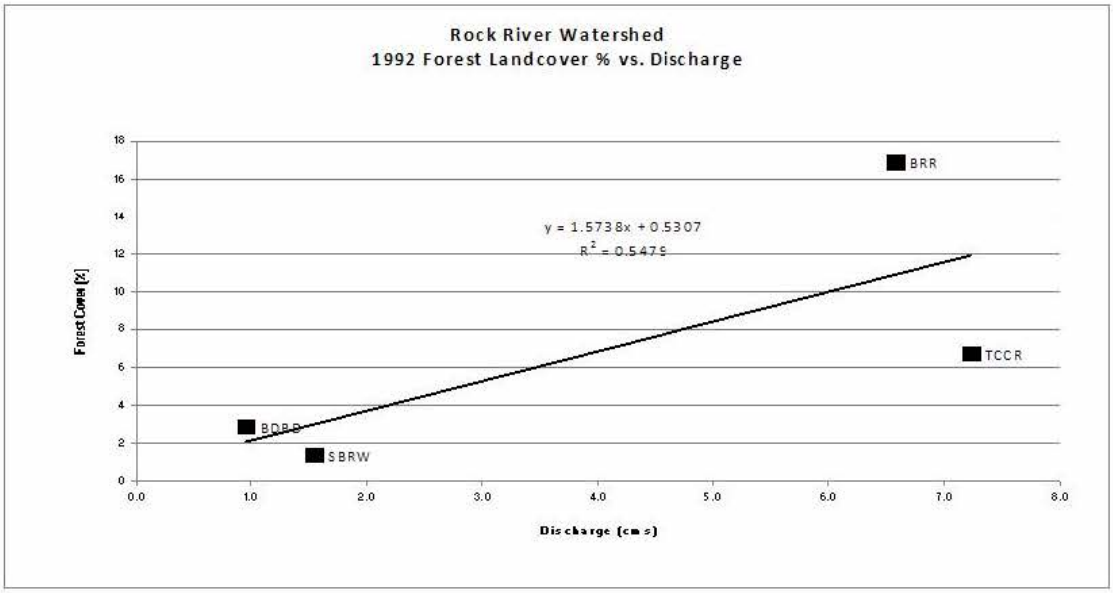

Rock River Watershed
2001 Water/Wetlands Landcover % vs. Discharge
Water/Wetlands Cover (%)
Discharge (cms)
BDBD
BRR
SBRW
TCCR
y = -0.9144x + 20.395
R2 = 0.1184
0
5
10
15
20
25
30
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0

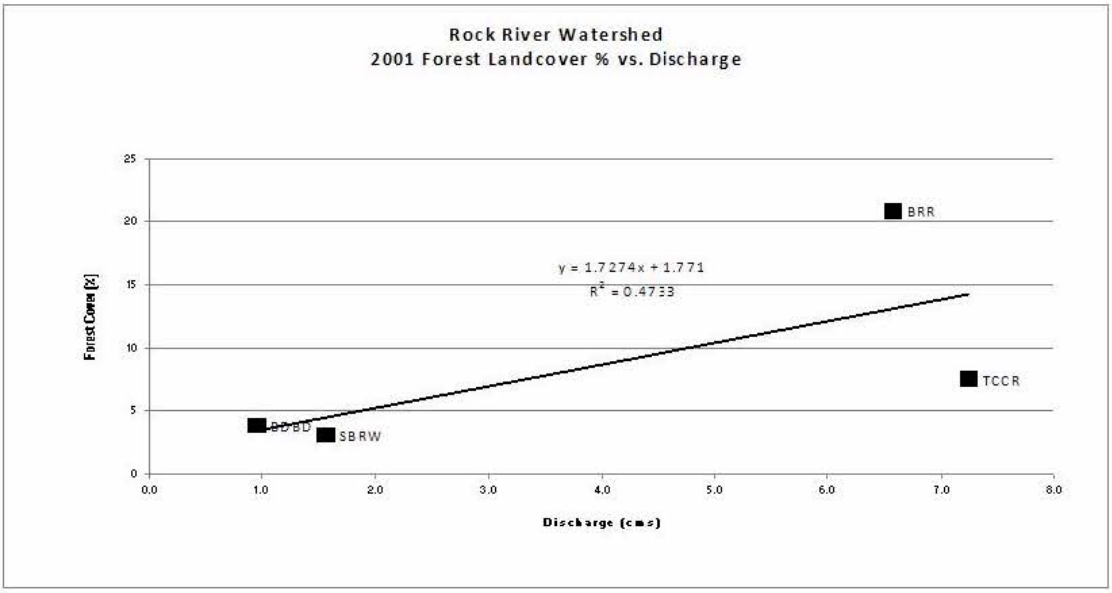

Rock River Watershed
1992 Agriculture /Grassland Landcover % vs. Discharge
SBRW
TCCR
BDBD
BRR
y = -0.7314x + 76.461
R² = 0.032
Discharge (cms)


Rock River Watershed
2001 Agriculture /Grassland Landcover % vs. Discharge
SBRW
TCCR
BDBD
BRR
y = -2.0328x + 78.073
R² = 0.1461
Discharge (cms)


Rock River Watershed
1992 Residential/Commercial Landcover % vs. Discharge
Residential/Commercial Cover [%]
Discharge (cms)
BRR
SBRW
BDBD
TCCR
y = 0.072x + 2.614
R² = 0.0939


Rock River Watershed
2001 Residential/Commercial Landcover % vs. Discharge
Residential/Commercial Cover [%]
Discharge (cms)
BRR
TCCR
SBRW
BDBD
y = 0.656x + 6.7451
R² = 0.6331


Rock River Watershed
1992 Forest Landcover % vs. Discharge
Forest Cover [%]
Discharge (cms)
y = 1.5738x + 0.5307
R² = 0.5479
BRR
TCCR
BDBD
SBRW


Rock River Watershed
2001 Forest Landcover % vs. Discharge
Forest Cover [%]
Discharge (cms)
y = 1.7274x + 1.771
R² = 0.4733
BRR
TCCR
BDBD
SBRW

Appendix B: USGS Available Data, per site

Emmons Creek near Rural

USGS 04080950 EMMONS CREEK NEAR RURAL, WI			
DESCRIPTION:			
Latitude 44°18'55", Longitude 89°11'34" NAD27			
Waupaca County, Wisconsin, Hydrologic Unit 04030202			
Drainage area: 25.10 square miles			
Datum of gage: 890 feet above sea level NGVD29.			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Daily Data			
Discharge, cubic feet per second	1968-05-15	1974-09-30	2330
Daily Statistics			
Discharge, cubic feet per second	1968-05-15	1974-09-30	2330
Monthly Statistics			
Discharge, cubic feet per second	1968-05	1974-09	
Annual Statistics			
Discharge, cubic feet per second	1968	1974	
Peak streamflow	1969-06-26	1974-06-09	6
Field measurements	1968-05-15	1974-09-23	69

Evergreen Creek near Langlade

USGS 04075200 EVERGREEN CREEK NEAR LANGLADE, WI			
DESCRIPTION:			
Latitude 45°10'11", Longitude 88°48'12" NAD27			
Langlade County, Wisconsin, Hydrologic Unit 04030202			
Drainage area: 8.09 square miles			
Contributing drainage area: 6.09 square miles,			
Datum of gage: 1,320.00 feet above sea level NGVD29.			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Daily Data			
Precipitation, total, inches	1966-10-01	1978-10-31	2898
Discharge, cubic feet per second	1964-06-01	1973-09-30	3049
Daily Statistics			
Discharge, cubic feet per second	1964-06-02	1973-09-30	3048
Monthly Statistics			
Discharge, cubic feet per second	1964-06	1973-09	
Annual Statistics			
Discharge, cubic feet per second	1964	1973	
Peak streamflow	1959-09-27	2007-10-18	45
Field measurements	1961-08-01	2006-04-03	116
Field/Lab water-quality samples	1967-05-23	1983-05-05	2
Additional Data Sources			
*Annual Water-Data Report (pdf) **offsite***	2006	2008	3

Little Wolf River near Galloway

USGS 04079602 LITTLE WOLF RIVER NEAR GALLOWAY, WI

DESCRIPTION:

Latitude 44°41'27", Longitude 89°15'51" NAD27
Marathon County, Wisconsin, Hydrologic Unit 04030202
Drainage area: 22.60 square miles
Datum of gage: 1,140 feet above sea level NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Daily Data			
Discharge, cubic feet per second	1973-02-09	1979-09-30	2199
Daily Statistics			
Discharge, cubic feet per second	1973-02-09	1979-09-30	2199
Monthly Statistics			
Discharge, cubic feet per second	1973-02	1979-09	
Annual Statistics			
Discharge, cubic feet per second	1973	1979	
Peak streamflow	1974-04-13	1979-05-03	4
Field measurements	1974-09-11	1979-10-01	53
Field/Lab water-quality samples	1973-11-20	1979-10-01	32

Middle Branch Embarrass River near Wittenberg

USGS 0407809265 MIDDLE BRANCH EMBARRASS RIVER NEAR WITTENBERG, WI			
DESCRIPTION:			
Latitude 44°49'31", Longitude 89°07'05" NAD27			
Shawano County, Wisconsin, Hydrologic Unit 04030202			
Drainage area: 76.3 square miles			
Datum of gage: 1,118.24 feet above sea level NGVD29.			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Daily Data			
Temperature, water, degrees Celsius	1989-12-01	2006-10-05	17760
Precipitation, total, inches	1998-12-16	2006-10-06	2849
Discharge, cubic feet per second	1989-10-01	2006-10-05	6214
Daily Statistics			
Temperature, water, degrees Celsius	1989-12-01	2006-09-30	5917
Discharge, cubic feet per second	1989-10-01	2006-09-30	6209
Monthly Statistics			
Temperature, water, degrees Celsius	1989-12	2006-09	
Discharge, cubic feet per second	1989-10	2006-09	
Annual Statistics			
Temperature, water, degrees Celsius	1990	2006	
Discharge, cubic feet per second	1990	2006	
Peak streamflow	1990-03-14	2006-08-04	16
Field measurements	1989-07-19	2006-10-06	133
Field/Lab water-quality samples	1989-10-24	2007-09-11	58
Additional Data Sources			
*Instantaneous-Data Archive **offsite***	1989-10-01	2006-09-30	406952
*Annual Water-Data Report (pdf) **offsite***	2006	2007	2

Spaulding Creek near Big Falls

USGS 04079700 SPAULDING CREEK NEAR BIG FALLS, WI			
DESCRIPTION:			
Latitude 44°38'13", Longitude 89°01'20" NAD27			
Waupaca County, Wisconsin, Hydrologic Unit 04030202			
Drainage area: 5.57 square miles			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Daily Data			
Precipitation, total, inches	1966-10-01	1978-10-31	2959
Discharge, cubic feet per second	1964-06-01	1966-09-30	852
Daily Statistics			
Discharge, cubic feet per second	1964-06-02	1966-09-30	851
Monthly Statistics			
Discharge, cubic feet per second	1964-06	1966-09	
Annual Statistics			
Discharge, cubic feet per second	1964	1966	
Peak streamflow	1959-04-03	2008-04-12	50
Field measurements	1972-04-21	2009-03-25	10
Field/Lab water-quality samples	1967-05-23	1967-05-23	1
Additional Data Sources			
*Annual Water-Data Report (pdf) **offsite** *	2006	2008	3

Swamp Creek above Rice Lake at Mole Lake

USGS 04074538 SWAMP CREEK ABOVE RICE LAKE AT MOLE LAKE, WI			
DESCRIPTION:			
Latitude 45°29'18", Longitude 88°57'49" NAD27			
Forest County, Wisconsin, Hydrologic Unit 04030202			
Drainage area: 46.3 square miles			
Datum of gage: 1,532.28 feet above sea level NGVD29.			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Real-time	Previous 60 days		
Daily Data			
Discharge, cubic feet per second	1977-05-26	2009-05-04	5935
Daily Statistics			
Discharge, cubic feet per second	1977-05-26	2008-09-30	5719
Monthly Statistics			
Discharge, cubic feet per second	1977-05	2008-09	
Annual Statistics			
Discharge, cubic feet per second	1977	2008	
Peak streamflow	1978-07-23	2008-04-19	15
Field measurements	1986-09-16	2009-04-27	66
Field/Lab water-quality samples	1977-07-06	1986-09-16	120
Additional Data Sources			
*Instantaneous-Data Archive **offsite** *	2001-07-01	2007-09-30	162814
*Annual Water-Data Report (pdf) **offsite** *	2006	2008	3

Tomorrow River near Nelsonville

USGS 04080798 TOMORROW RIVER NEAR NELSONVILLE, WI			
DESCRIPTION:			
Latitude 44°31'28", Longitude 89°20'16" NAD27			
Portage County, Wisconsin, Hydrologic Unit 04030202			
Drainage area: 44 square miles			
Datum of gage: 960 feet above sea level NGVD29.			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Daily Data			
Discharge, cubic feet per second	1993-04-09	1995-09-30	905
Daily Statistics			
Discharge, cubic feet per second	1993-04-09	1995-09-30	905
Monthly Statistics			
Discharge, cubic feet per second	1993-04	1995-09	
Annual Statistics			
Discharge, cubic feet per second	1993	1995	
Field measurements	1993-03-23	2002-10-17	30
Field/Lab water-quality samples	1992-08-24	2002-10-17	49
Additional Data Sources			
*Instantaneous-Data Archive **offsite**	1993-06-24	1995-09-25	58829

Bark River near Rome

USGS 05426250 BARK RIVER NEAR ROME, WI			
DESCRIPTION:			
Latitude 42°57'37", Longitude 88°40'14" NAD27			
Jefferson County, Wisconsin, Hydrologic Unit 07090001			
Drainage area: 122 square miles			
Datum of gage: 810 feet above sea level NAVD88.			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Real-time	Previous 60 days		
Daily Data			
Discharge, cubic feet per second	1979-10-18	2009-05-04	10641
Daily Statistics			
Discharge, cubic feet per second	1979-10-18	2008-09-30	10425
Monthly Statistics			
Discharge, cubic feet per second	1979-10	2008-09	
Annual Statistics			
Discharge, cubic feet per second	1980	2008	
Peak streamflow	1984-05-29	2008-06-09	25
Field measurements	1987-09-24	2009-04-27	245
Field/Lab water-quality samples	1979-10-18	1994-09-16	115
Additional Data Sources			
*Instantaneous-Data Archive **offsite***	1986-10-01	2007-09-30	619687
*Annual Water-Data Report (pdf) **offsite***	2006	2008	3

Beaver Dam River at Beaver Dam

USGS 05425912 BEAVER DAM RIVER AT BEAVER DAM, WI			
DESCRIPTION:			
Latitude 43°26'40", Longitude 88°50'42" NAD27			
Dodge County, Wisconsin, Hydrologic Unit 07090002			
Drainage area: 157 square miles			
Datum of gage: 839.42 feet above sea level NGVD29.			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Real-time	Previous 60 days		
Daily Data			
Discharge, cubic feet per second	1985-03-01	2009-05-04	8831
Discharge, cubic feet per second -- NEW SITE	2006-12-19	2007-06-03	165
Phosphorus, water, unfiltered, pounds per day	1998-09-01	2000-09-30	761
Suspended solids, dried at 105 degrees Celsiu	1998-09-01	2000-09-30	761
Orthophosphate, water, dissolved, pounds per	1998-09-01	2000-09-30	761
Daily Statistics			
Discharge, cubic feet per second	1985-03-01	2008-09-30	8615
Phosphorus, water, unfiltered, pounds per day	1998-09-01	2000-09-30	761
Suspended solids, dried at 105 degrees Celsiu	1998-09-02	2000-09-30	760
Orthophosphate, water, dissolved, pounds per	1998-09-02	2000-09-30	760
Monthly Statistics			
Discharge, cubic feet per second	1985-03	2008-09	
Phosphorus, water, unfiltered, pounds per day	1998-09	2000-09	
Suspended solids, dried at 105 degrees Celsiu	1998-09	2000-09	
Orthophosphate, water, dissolved, pounds per	1998-09	2000-09	
Annual Statistics			
Discharge, cubic feet per second	1985	2008	
Phosphorus, water, unfiltered, pounds per day	1998	2000	
Suspended solids, dried at 105 degrees Celsiu	1998	2000	
Orthophosphate, water, dissolved, pounds per	1998	2000	
Peak streamflow	1986-09-26	2008-06-16	23
Field measurements	1987-07-30	2009-03-20	237
Field/Lab water-quality samples	1986-02-27	2000-09-12	141
Additional Data Sources			
*Instantaneous-Data Archive **offsite***	1986-10-01	2007-09-30	734033
*Annual Water-Data Report (pdf) **offsite***	2006	2008	3

South Branch Rock River at Waupun

USGS 05423500 SOUTH BRANCH ROCK RIVER AT WAUPUN, WI			
DESCRIPTION:			
Latitude 43°38'30", Longitude 88°43'14" NAD27			
Fond Du Lac County, Wisconsin, Hydrologic Unit 07090001			
Drainage area: 63.6 square miles			
Datum of gage: 863.46 feet above sea level NGVD29.			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Real-time	Previous 60 days		
Daily Data			
Precipitation, total, inches	1995-06-01	2009-05-05	4050
Discharge, cubic feet per second	1948-10-01	2009-05-04	15765
Daily Statistics			
Discharge, cubic feet per second	1948-10-01	2008-09-30	15555
Monthly Statistics			
Discharge, cubic feet per second	1948-10	2008-09	
Annual Statistics			
Discharge, cubic feet per second	1949	2008	
Peak streamflow	1949-03-27	2008-06-13	42
Field measurements	1987-02-20	2009-03-25	81
Field/Lab water-quality samples	1968-02-13	1994-09-02	75
Additional Data Sources			
*Instantaneous-Data Archive **offsite***	1987-03-01	2007-09-30	664669
*Annual Water-Data Report (pdf) **offsite***	2006	2008	3

Turtle Creek at Carvers Rock Road Clinton

USGS 05431486 TURTLE CREEK AT CARVERS ROCK ROAD NEAR CLINTON, WI			
DESCRIPTION:			
Latitude 42°35'50", Longitude 88°49'45" NAD27			
Rock County, Wisconsin, Hydrologic Unit 07090001			
Drainage area: 199 square miles			
Contributing drainage area: 196.67 square miles,			
Datum of gage: 823 feet above sea level NAVD88.			
AVAILABLE DATA:			
Data Type	**Begin Date**	**End Date**	**Count**
Real-time	Previous 60 days		
Daily Data			
Precipitation, total, inches	1994-07-12	2009-05-05	5412
Discharge, cubic feet per second	1939-09-25	2009-05-04	25425
Suspended sediment concentration, milligrams per liter	1980-01-01	1982-09-30	1004
Suspended sediment discharge, tons per day	1980-01-01	1982-09-30	1004
Phosphorus, water, unfiltered, pounds per day	1998-09-01	2000-09-30	761
Suspended solids, dried at 105 degrees Celsius, water, unfilt	1998-09-01	2000-09-30	761
Orthophosphate, water, dissolved, pounds per day	1998-09-01	2000-09-30	761
Daily Statistics			
Discharge, cubic feet per second	1939-09-25	2008-09-30	25209
Suspended sediment concentration, milligrams per liter	1980-01-01	1982-09-30	1004
Suspended sediment discharge, tons per day	1980-01-02	1982-09-30	1003
Phosphorus, water, unfiltered, pounds per day	1998-09-01	2000-09-30	761
Suspended solids, dried at 105 degrees Celsius, water, unfilt	1998-09-02	2000-09-30	760
Orthophosphate, water, dissolved, pounds per day	1998-09-02	2000-09-30	760
Monthly Statistics			
Discharge, cubic feet per second	1939-09	2008-09	
Suspended sediment concentration, milligrams per liter	1980-01	1982-09	
Suspended sediment discharge, tons per day	1980-01	1982-09	
Phosphorus, water, unfiltered, pounds per day	1998-09	2000-09	
Suspended solids, dried at 105 degrees Celsius, water, unfilt	1998-09	2000-09	
Orthophosphate, water, dissolved, pounds per day	1998-09	2000-09	
Annual Statistics			
Discharge, cubic feet per second	1939	2008	
Suspended sediment concentration, milligrams per liter	1980	1982	
Suspended sediment discharge, tons per day	1980	1982	
Phosphorus, water, unfiltered, pounds per day	1998	2000	
Suspended solids, dried at 105 degrees Celsius, water, unfilt	1998	2000	
Orthophosphate, water, dissolved, pounds per day	1998	2000	
Peak streamflow	1938-02-00	2008-07-12	70
Field measurements	1987-08-17	2009-04-01	189
Field/Lab water-quality samples	1980-06-07	2002-10-17	188
Additional Data Sources			
*Instantaneous-Data Archive **offsite***	1986-10-01	2007-09-30	603202
*Annual Water-Data Report (pdf) **offsite***	2006	2008	3

Appendix C: Map Legends

Legend

Gauging Stations and Boundaries

- USGS gauging stations
- Wolf River Research Sites
- Rock River Research Sites
- Wisconsin County Boundaries
- Major Watershed Boundaries
- Hydrology

Wolf River Elevation

- 221 - 267
- 267.1 - 317
- 317.1 - 375
- 375.1 - 446
- 446.1 - 588

Rock River Elevation

- 224 - 255
- 255.1 - 274
- 274.1 - 294
- 294.1 - 317
- 317.1 - 404

Landcover Type

- Residential/Commercial/Industrial
- Agriculture/Grasslands
- Water/Wetlands
- Forest/Shrubland

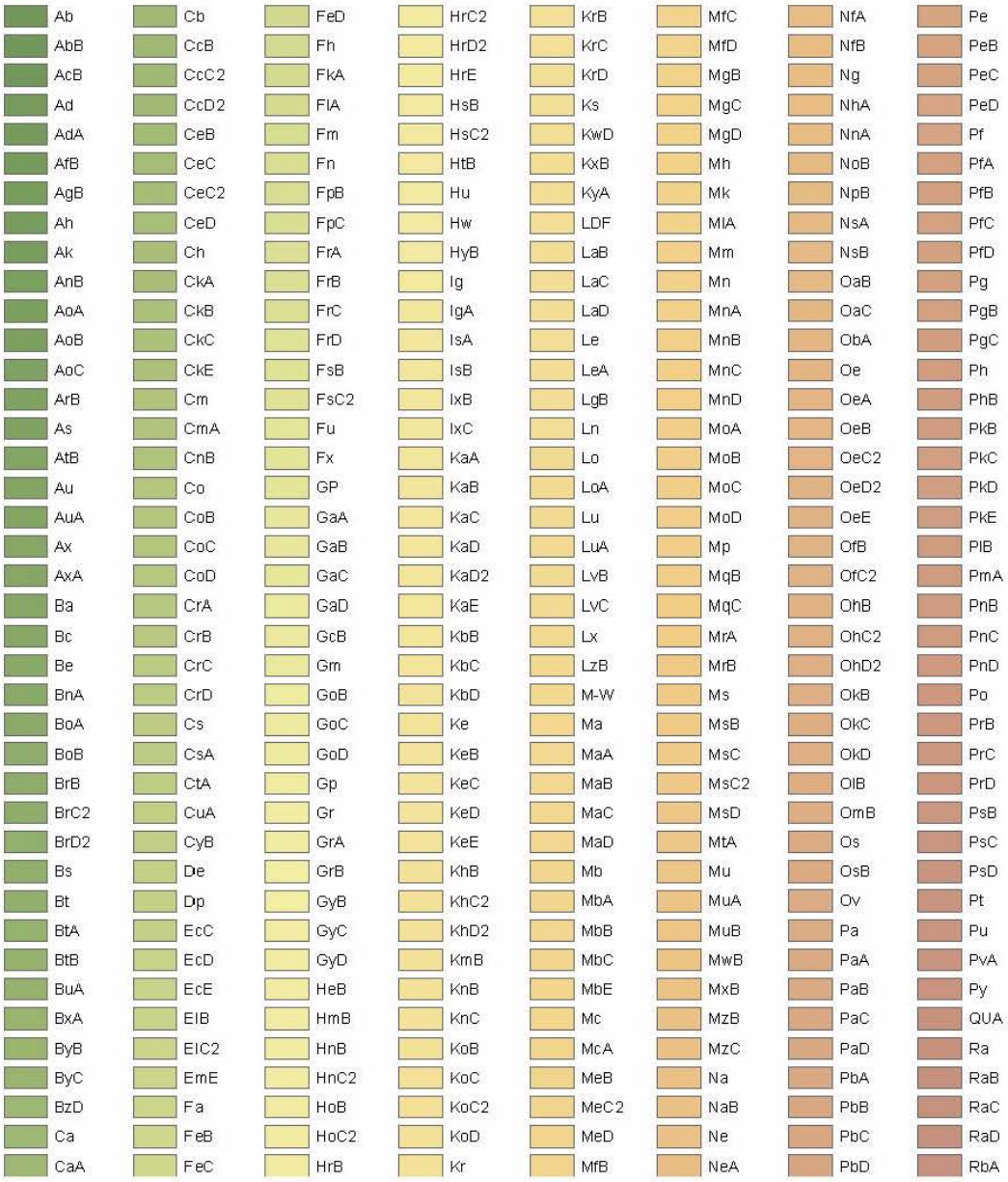
Wolf River Geology

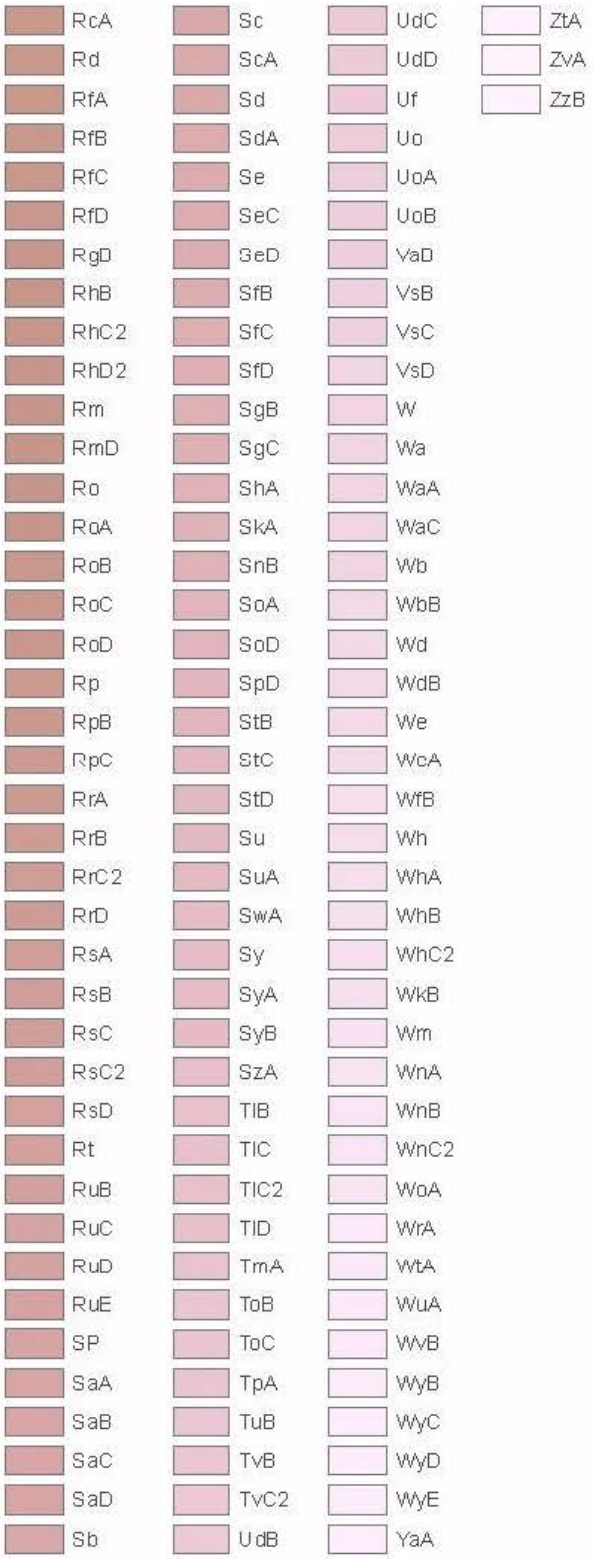
- Cu
- Oa
- Op
- Osi
- Wgn
- Xga
- Xgg
- Xmi
- Xmib
- Xmv
- Xq
- Xr
- Yh
- Ywa
- Ywg
- Ywr
- Ywwg

Rock River Geology

- Cu
- Oa
- Om
- Op
- Osi
- Su
- Xbq

Wolf River Soils

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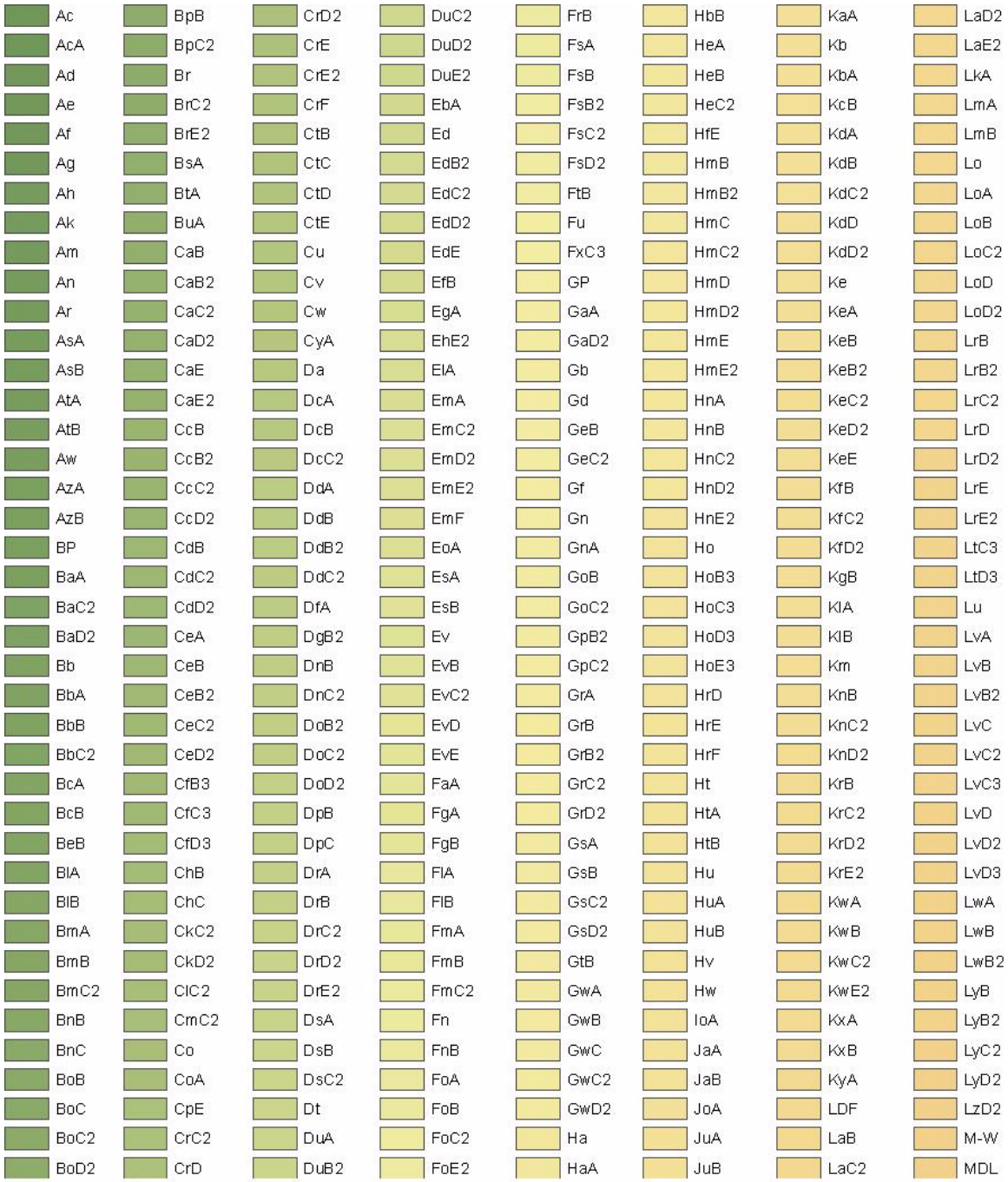
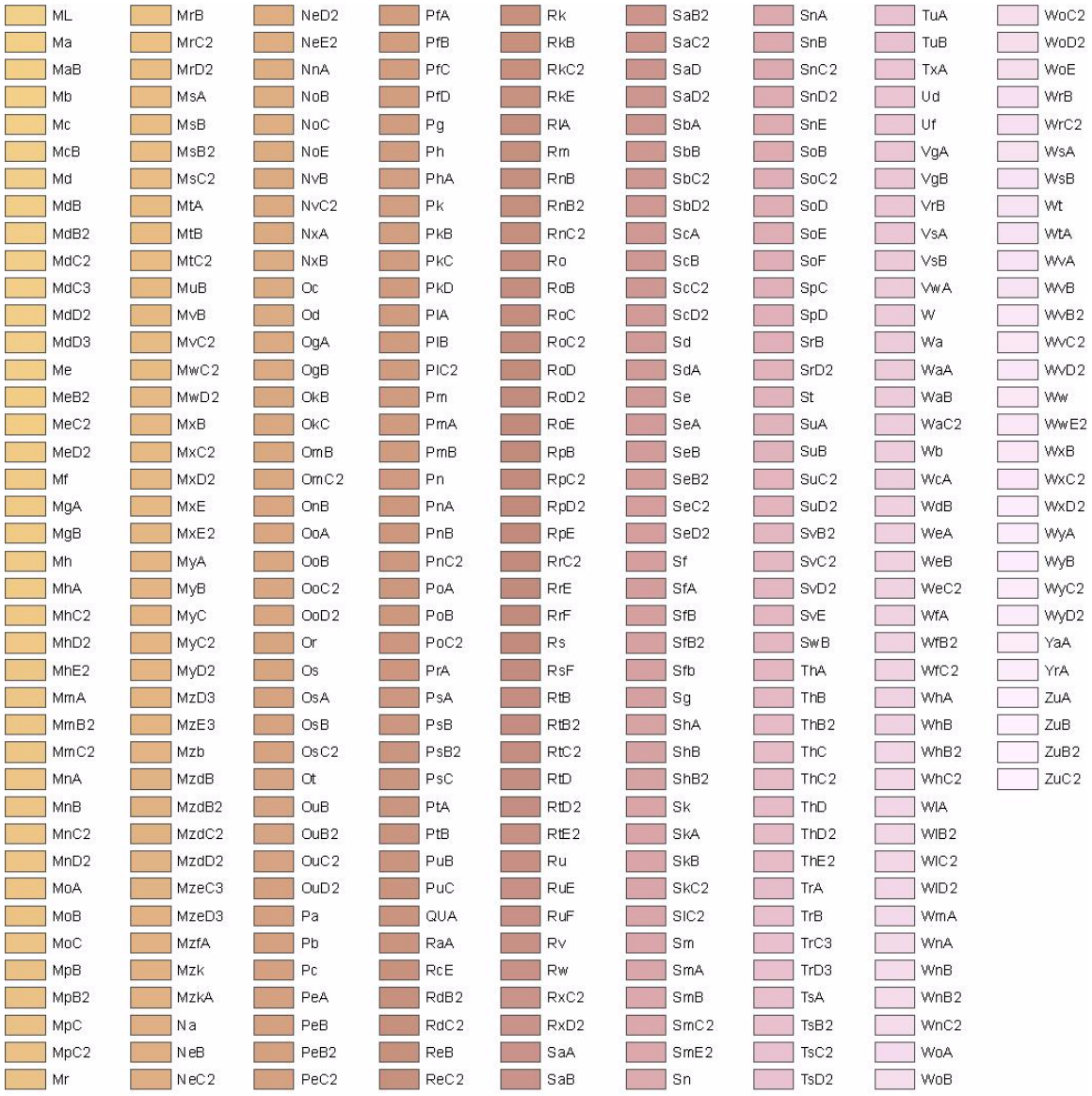
RfA
RfB
RfC
RfD
RgD
RhB
RhC2
RhD2
Rm
RmD
Ro
RoA
RoB
RoC
RoD
Rp
RpB
RpC
RrA
RrB
RrC2
RrD
RsA
RsB
RsC
RsC2
RsD
Rt
RuB
RuC
RuD
RuE
SP
SaA
SaB
SaC
SaD
Sb
Sc
ScA
Sd
SdA
Se
SeC
SeD
SfB
SfC
SfD
SgB
SgC
ShA
SkA
SnB
SoA
SoD
SpD
StB
StC
StD
Su
SuA
SwA
Sy
SyA
SyB
SzA
TlB
TlC
TlC2
TlD
TmA
ToB
ToC
TpA
TuB
TvB
TvC2
UdB
UdC
UdD
Uf
Uo
UoA
UoB
VaD
VsB
VsC
VsD
W
Wa
WaA
WaC
Wb
WbB
Wd
WdB
We
WcA
WfB
Wh
WhA
WhB
WhC2
WkB
Wm
WnA
WnB
WnC2
WoA
WrA
WtA
WuA
WvB
WyB
WyC
WyD
WyE
YaA
ZtA
ZvA
ZzB

Rock River Soils

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MaB
Mb
Mc
McB
Md
MdB
MdB2
MdC2
MdC3
MdD2
MdD3
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MeC2
MeD2
Mf
MgA
MgB
Mh
MhA
MhC2
MhD2
MhE2
MmA
MmB2
MmC2
MnA
MnB
MnC2
MnD2
MoA
MoB
MoC
MpB
MpB2
MpC
MpC2
Mr
MrB
MrC2
MrD2
MsA
MsB
MsB2
MsC2
MtA
MtB
MtC2
MuB
MvB
MvC2
MwC2
MwD2
MxB
MxC2
MxD2
MxE
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MyC
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MyD2
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MzdB
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MzdD2
MzeC3
MzeD3
MzfA
Mzk
MzkA
Na
NeB
NeC2
NeD2
NeE2
NnA
NoB
NoC
NoE
NvB
NvC2
NxA
NxB
Oc
Od
OgA
OgB
OkB
OkC
OmB
OmC2
OnB
OoA
OoB
OoC2
OoD2
Or
Os
OsA
OsB
OsC2
Ot
OuB
OuB2
OuC2
OuD2
Pa
Pb
Pc
PeA
PeB
PeB2
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PhA
Pk
PkB
PkC
PkD
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PlB
PlC2
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PmA
PmB
Pn
PnA
PnB
PnC2
PoA
PoB
PoC2
PrA
PsA
PsB
PsB2
PsC
PtA
PtB
PuB
PuC
QUA
RaA
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RdB2
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RkB
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RkE
RlA
Rm
RnB
RnB2
RnC2
Ro
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RoC
RoC2
RoD
RoD2
RoE
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RrC2
RrE
RrF
Rs
RsF
RtB
RtB2
RtC2
RtD
RtD2
RtE2
Ru
RuE
RuF
Rv
Rw
RxC2
RxD2
SaA
SaB
SaB2
SaC2
SaD
SaD2
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SbB
SbC2
SbD2
ScA
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Sg
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SkC2
SlC2
Sm
SmA
SmB
SmC2
SmE2
Sn
SnA
SnB
SnC2
SnD2
SnE
SoB
SoC2
SoD
SoE
SoF
SpC
SpD
SrB
SrD2
St
SuA
SuB
SuC2
SuD2
SvB2
SvC2
SvD2
SvE
SwB
ThA
ThB
ThB2
ThC
ThC2
ThD
ThD2
ThE2
TrA
TrB
TrC3
TrD3
TsA
TsB2
TsC2
TsD2
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TxA
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Uf
VgA
VgB
VrB
VsA
VsB
VwA
W
Wa
WaA
WaB
WaC2
Wb
WcA
WdB
WeA
WeB
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WfA
WfB2
WfC2
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WhB
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WlB2
WlC2
WlD2
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WwE2
WxB
WxC2
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WyA
WyB
WyC2
WyD2
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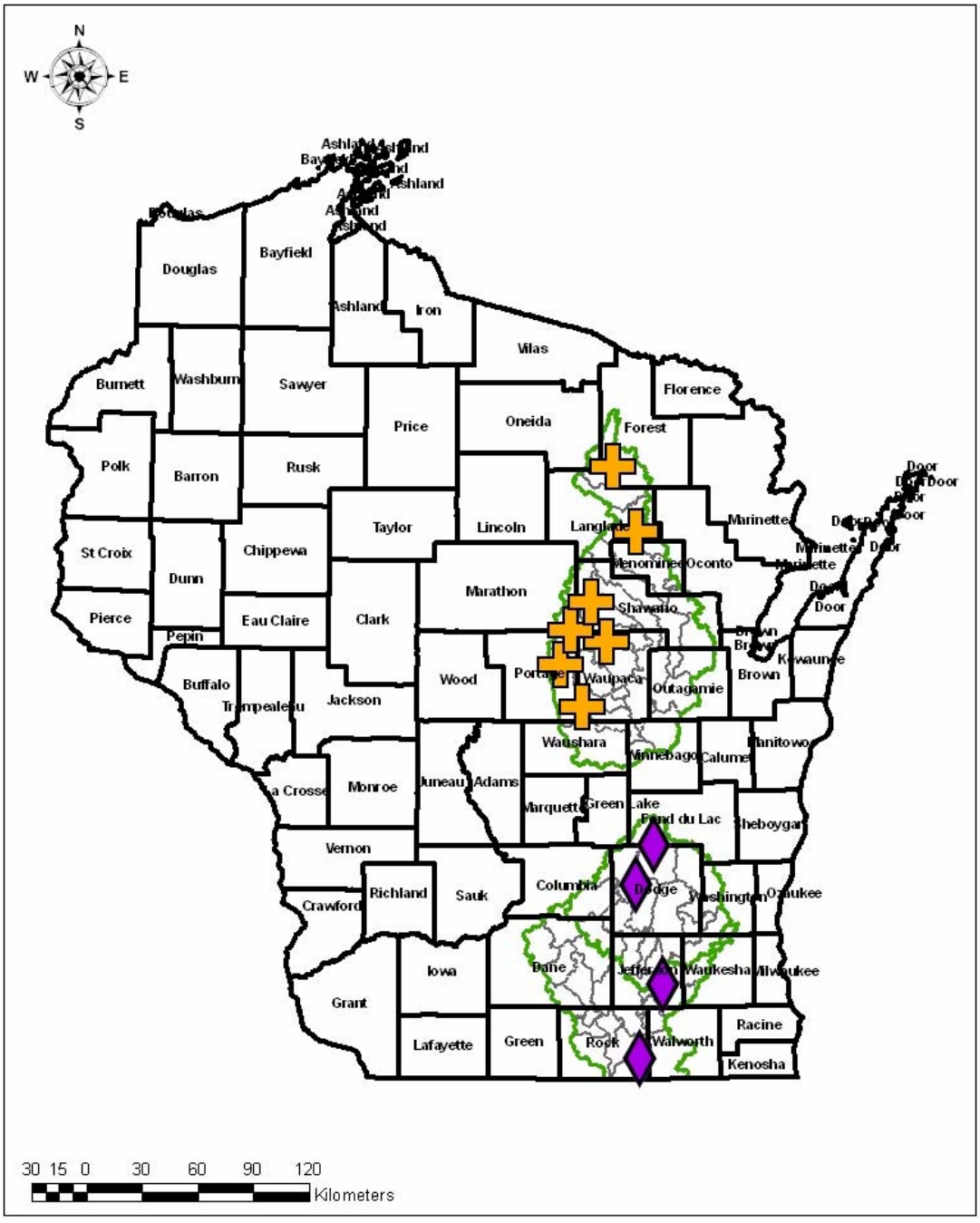
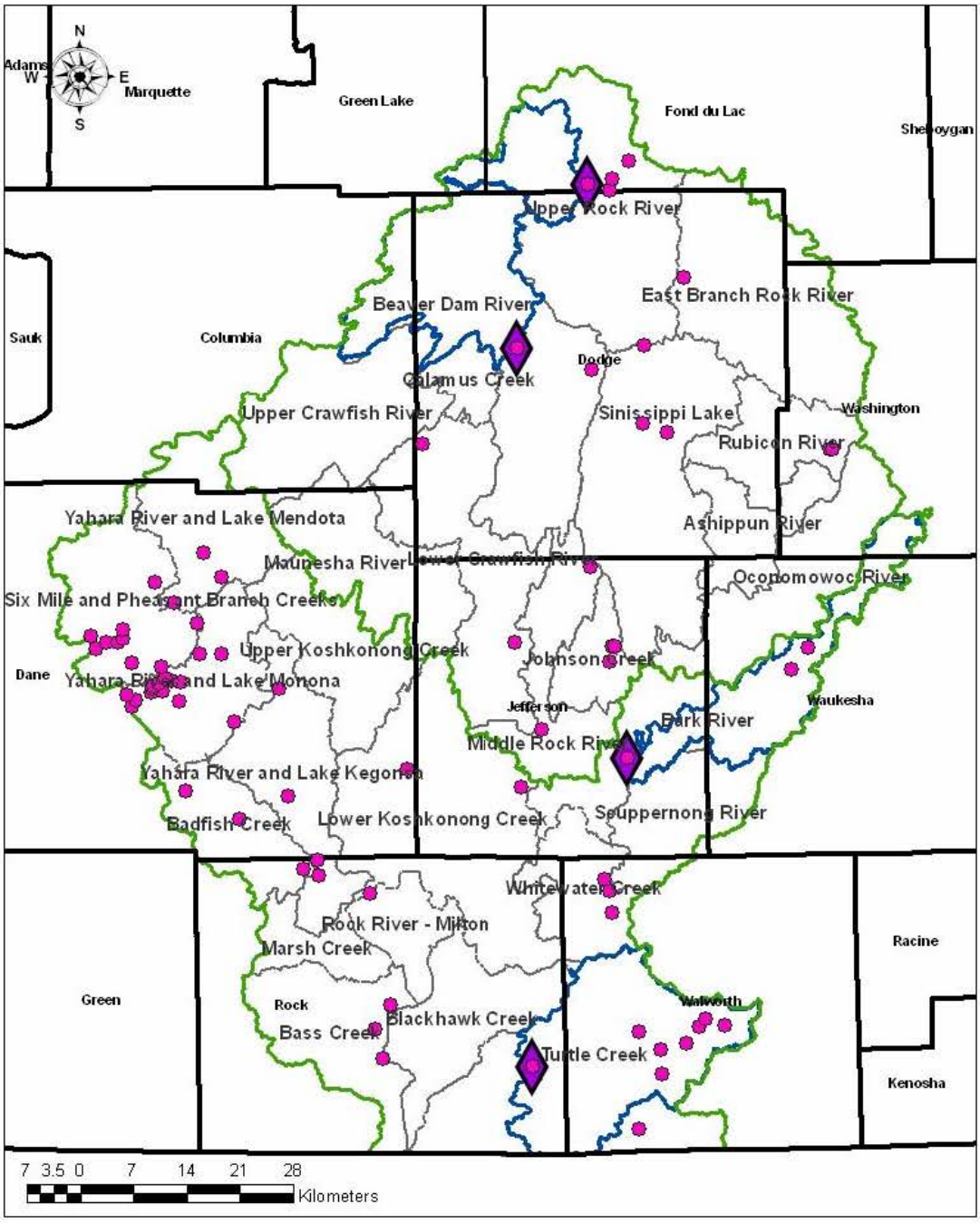
YrA
ZuA
ZuB
ZuB2
ZuC2

Appendix D: Watershed Delineation Maps

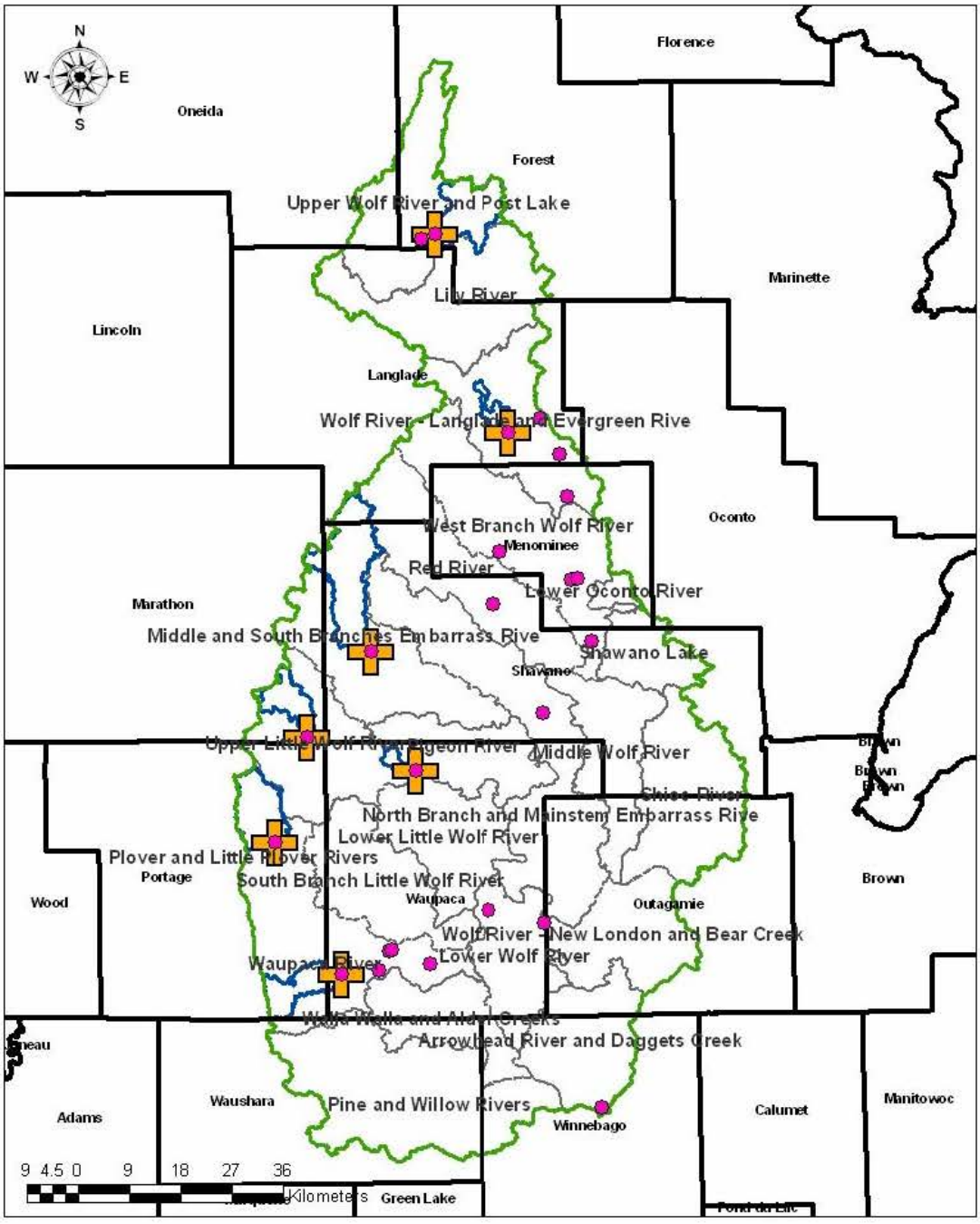
Wolf and Rock River Watersheds



Rock River Watershed



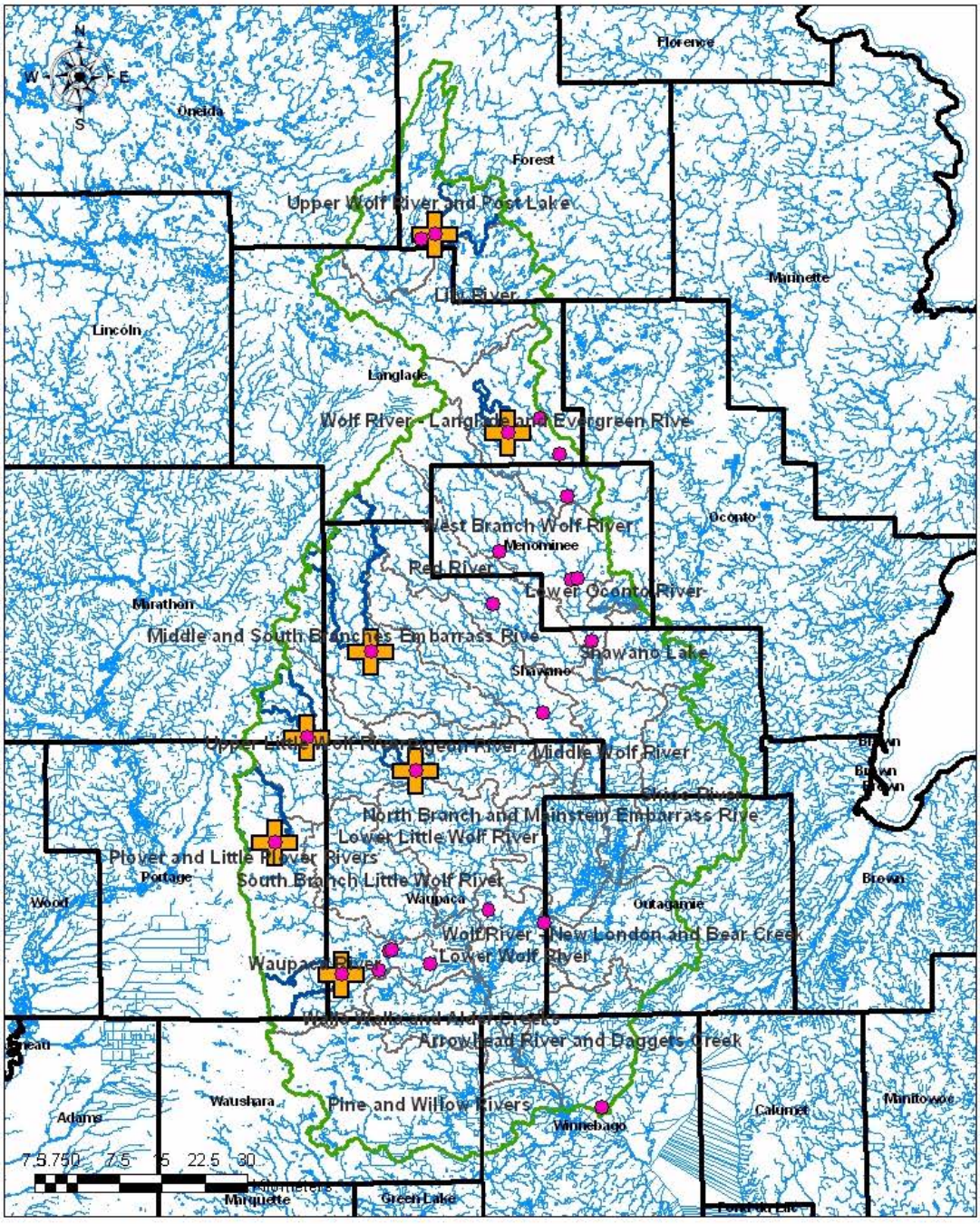
Wolf River Watershed



Appendix E: Hydrology Delineation Maps, by site

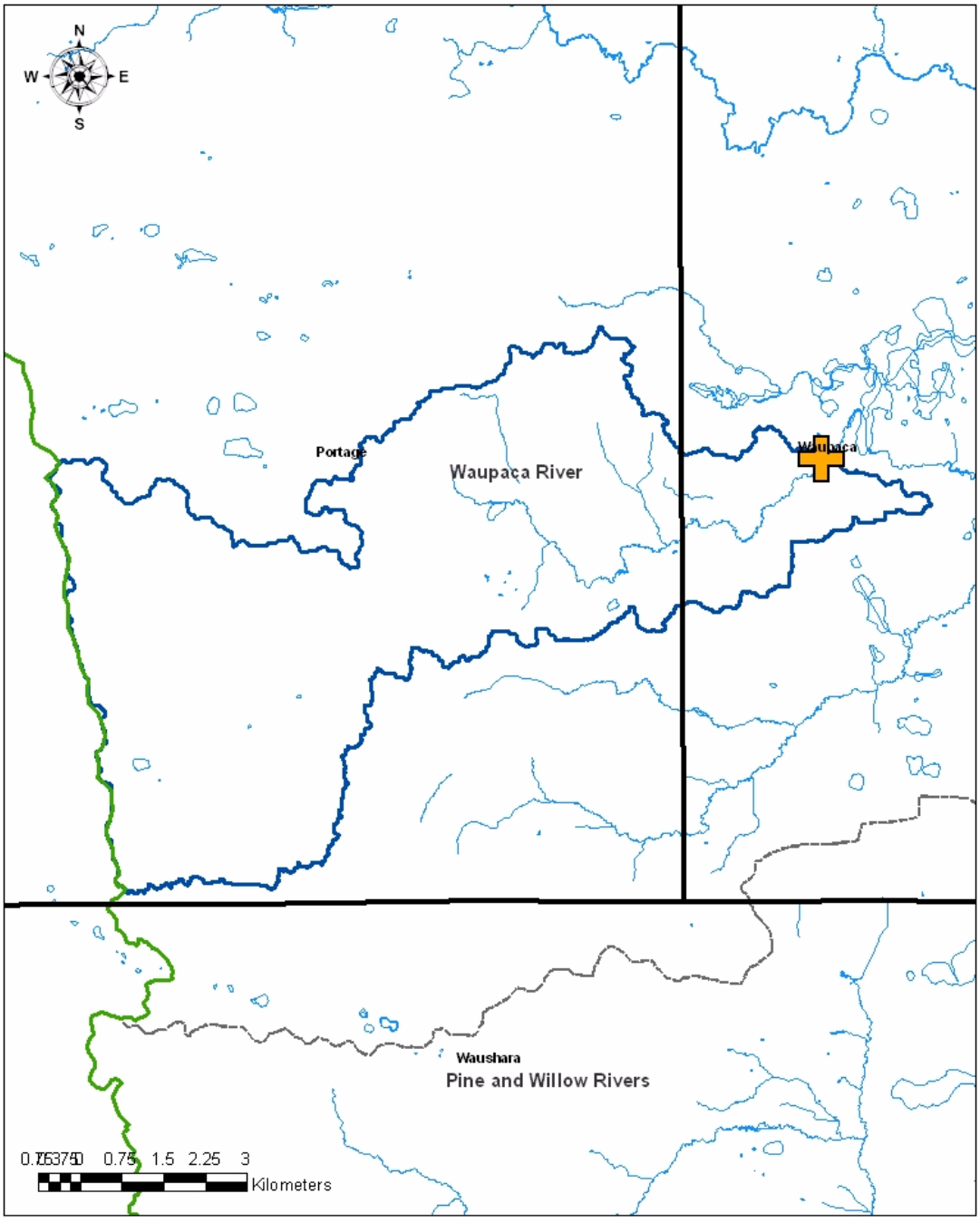
Wolf River Watershed

Hydrology



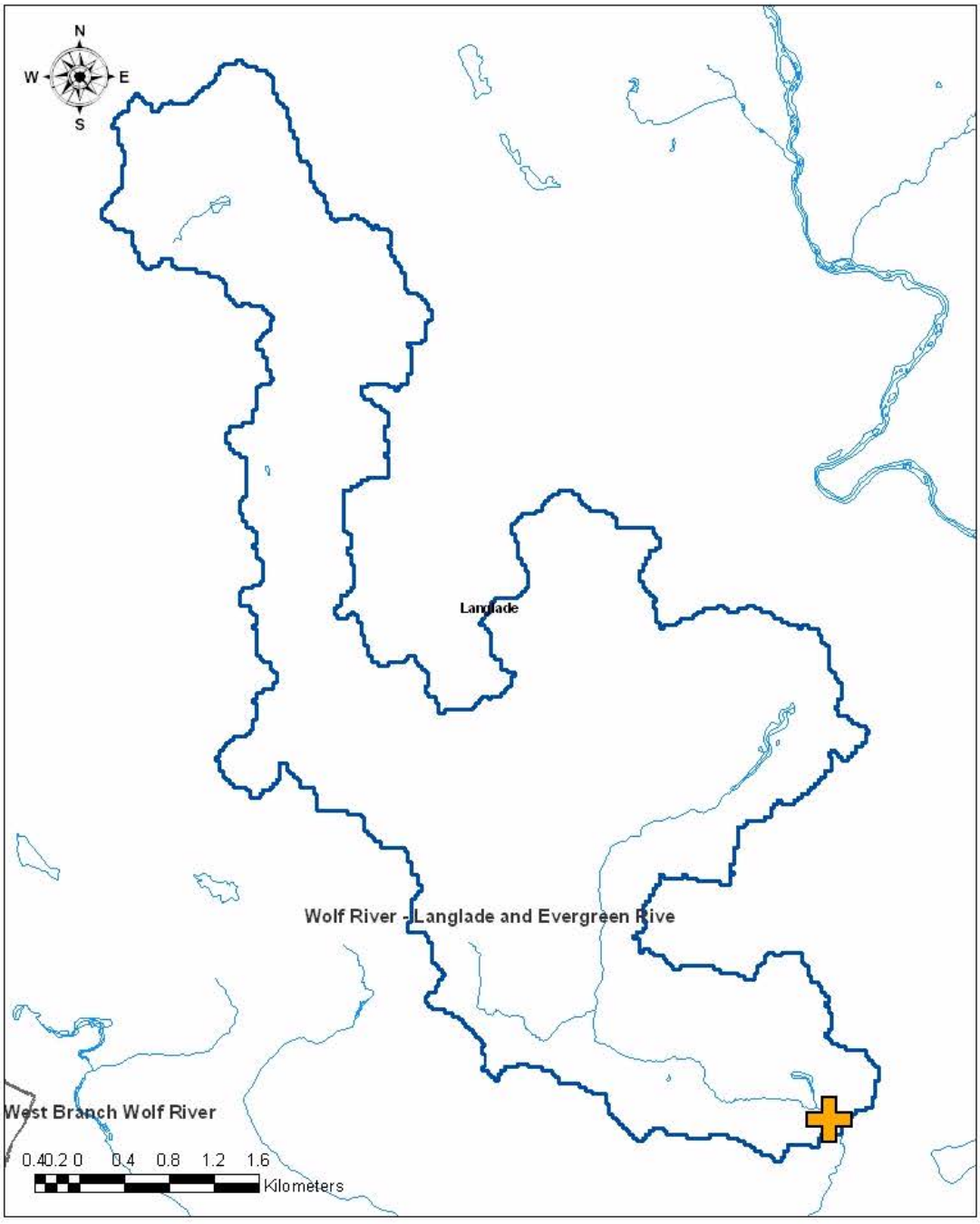
Emmons Creek at Rural, Wolf River Watershed

Hydrology



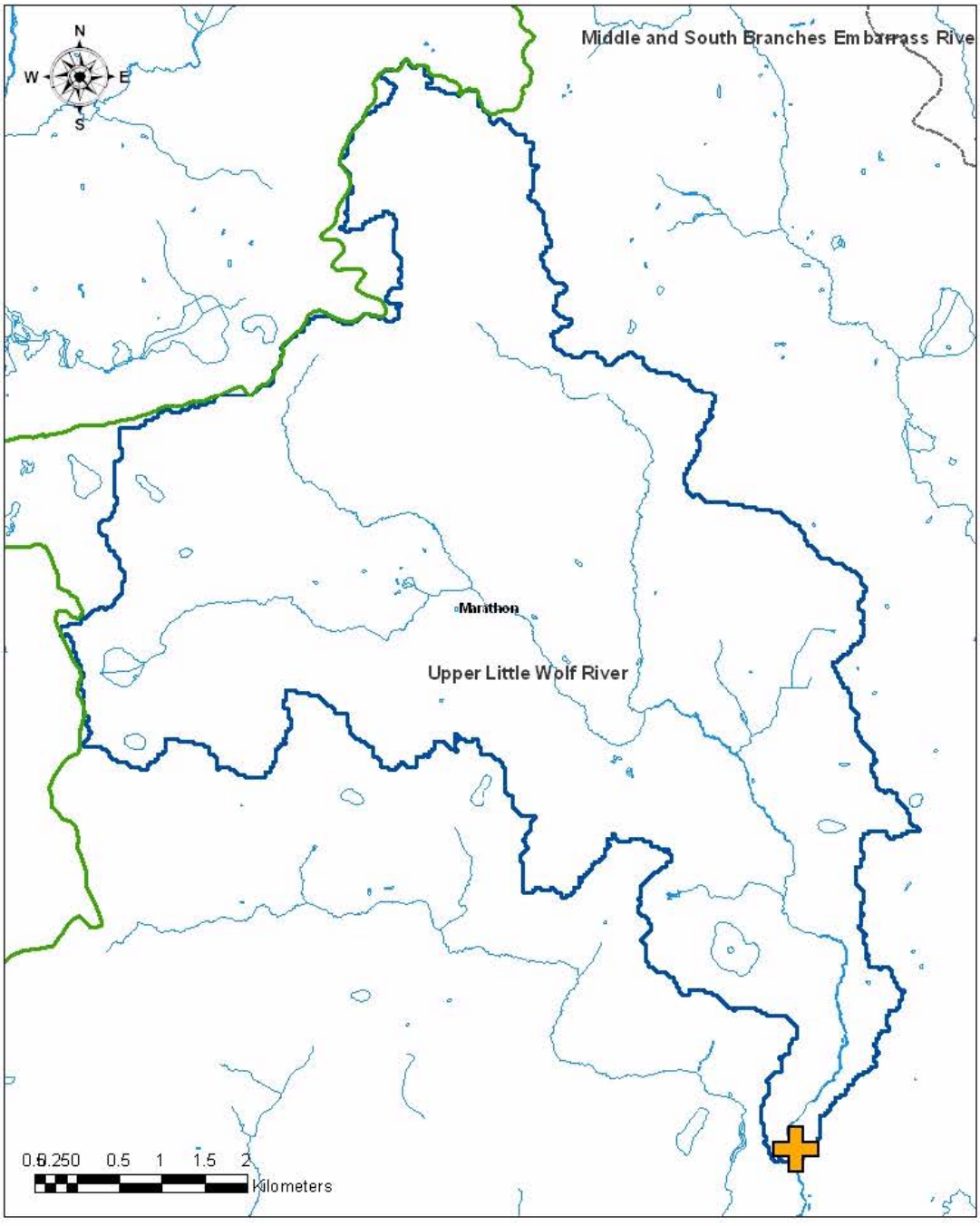
Evergreen River near Langlade, Wolf River Watershed

Hydrology



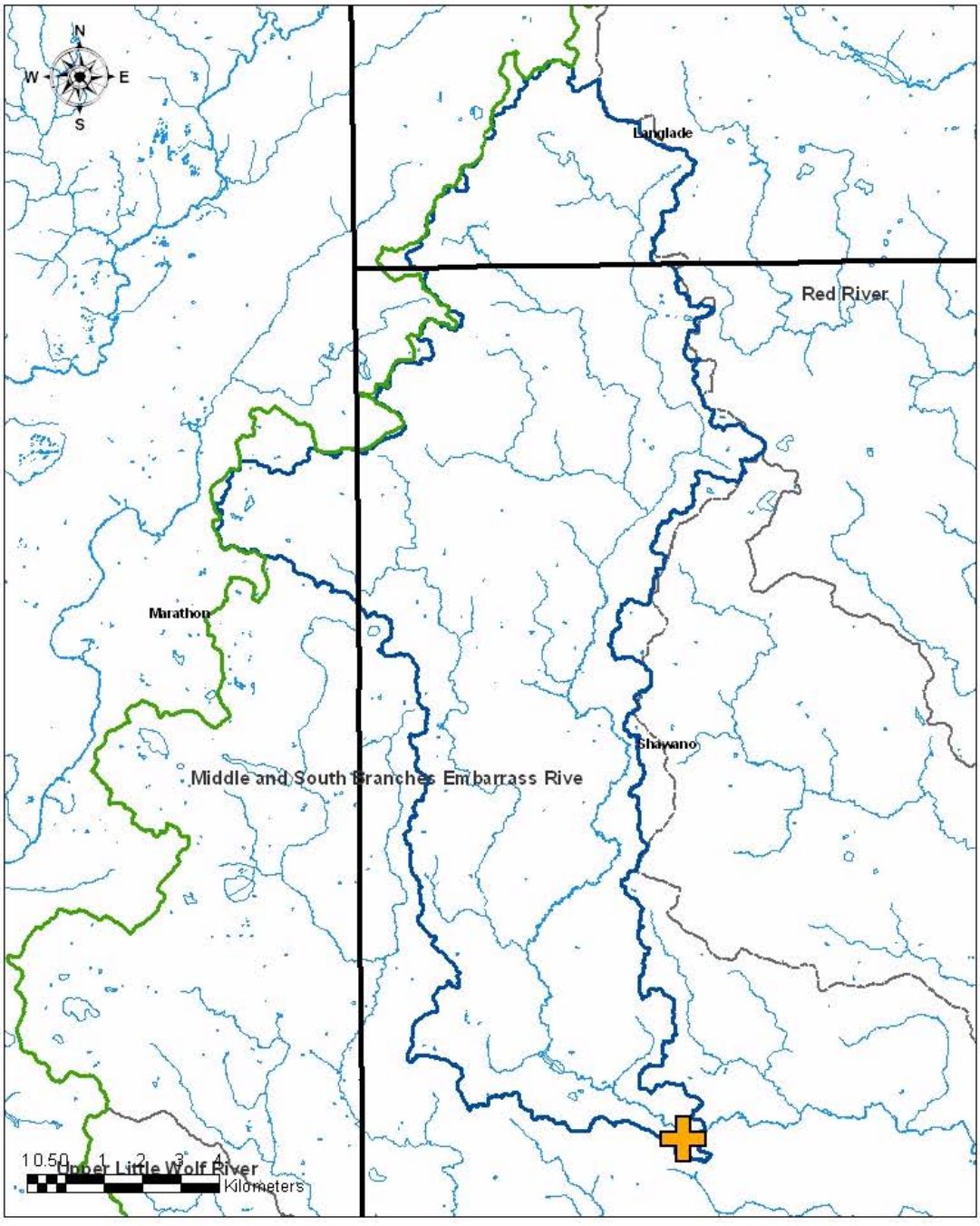
Little Wolf River near Galloway, Wolf River Watershed

Hydrology



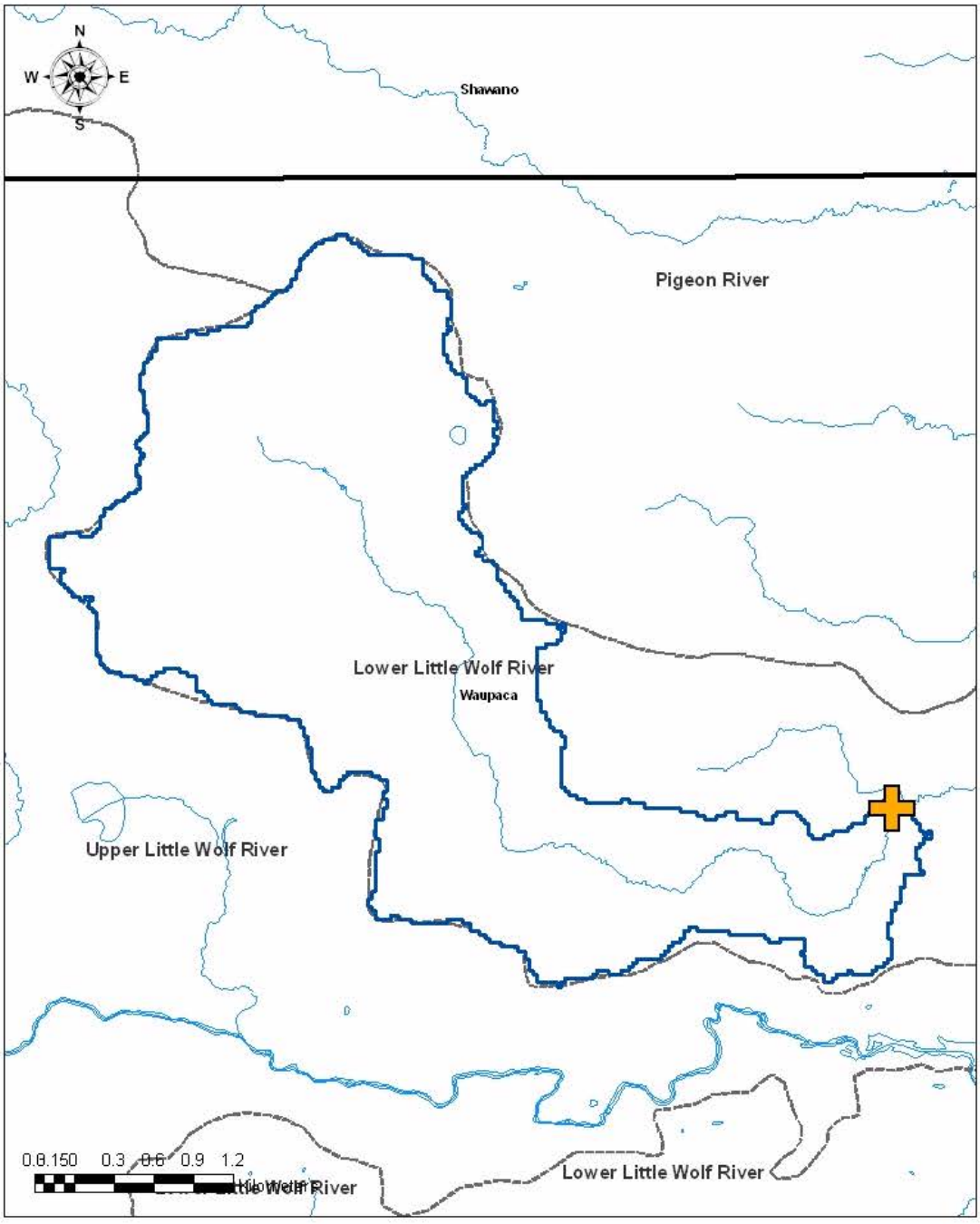
Middle Branch Embarrass River, Wolf River Watershed

Hydrology



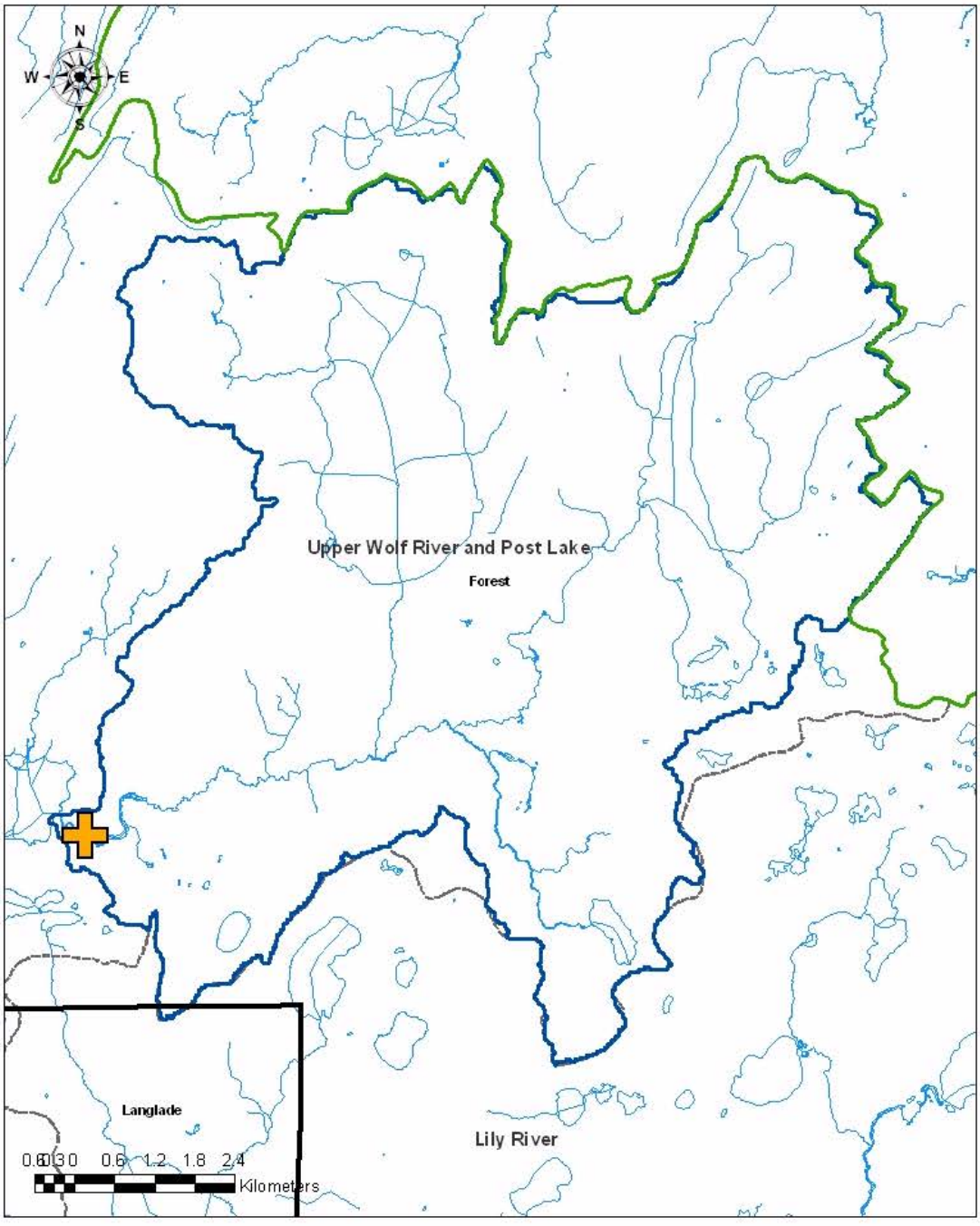
Spaulding Creek near Big Falls, Wolf River Watershed

Hydrology



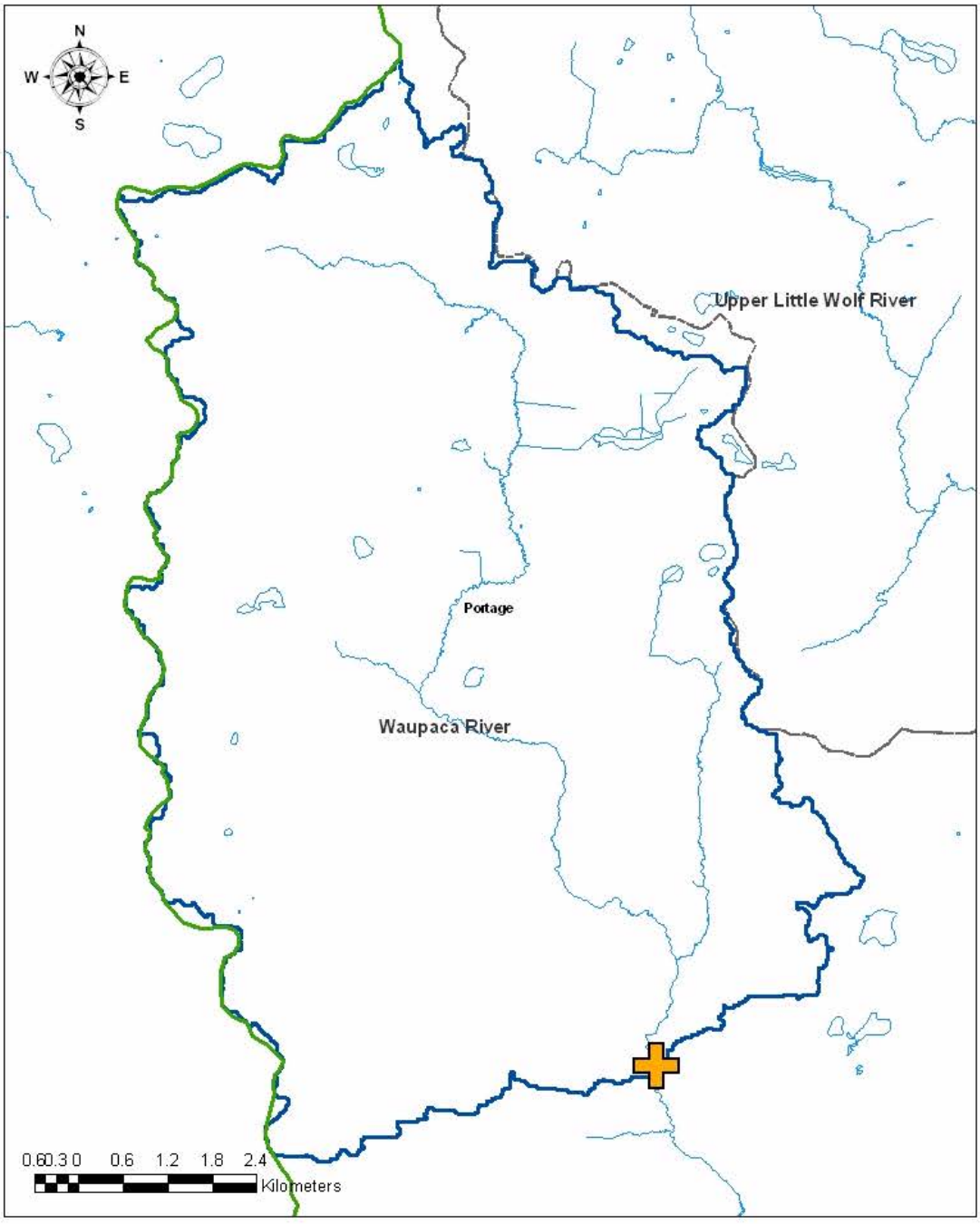
Swamp Creek above Mole Lake, Wolf River Watershed

Hydrology



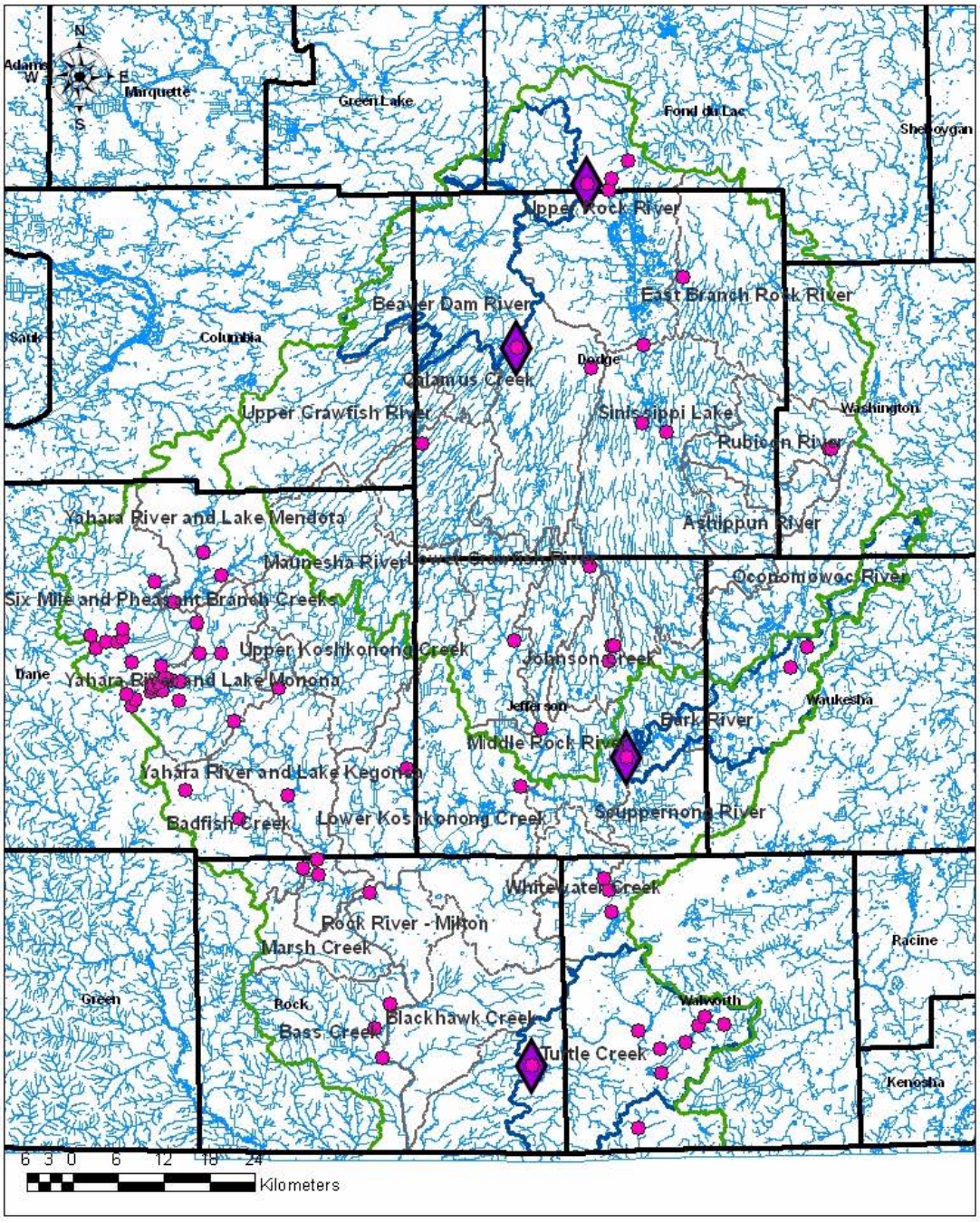
Tomorrow River near Nelsonville, Wolf River Watershed

Hydrology



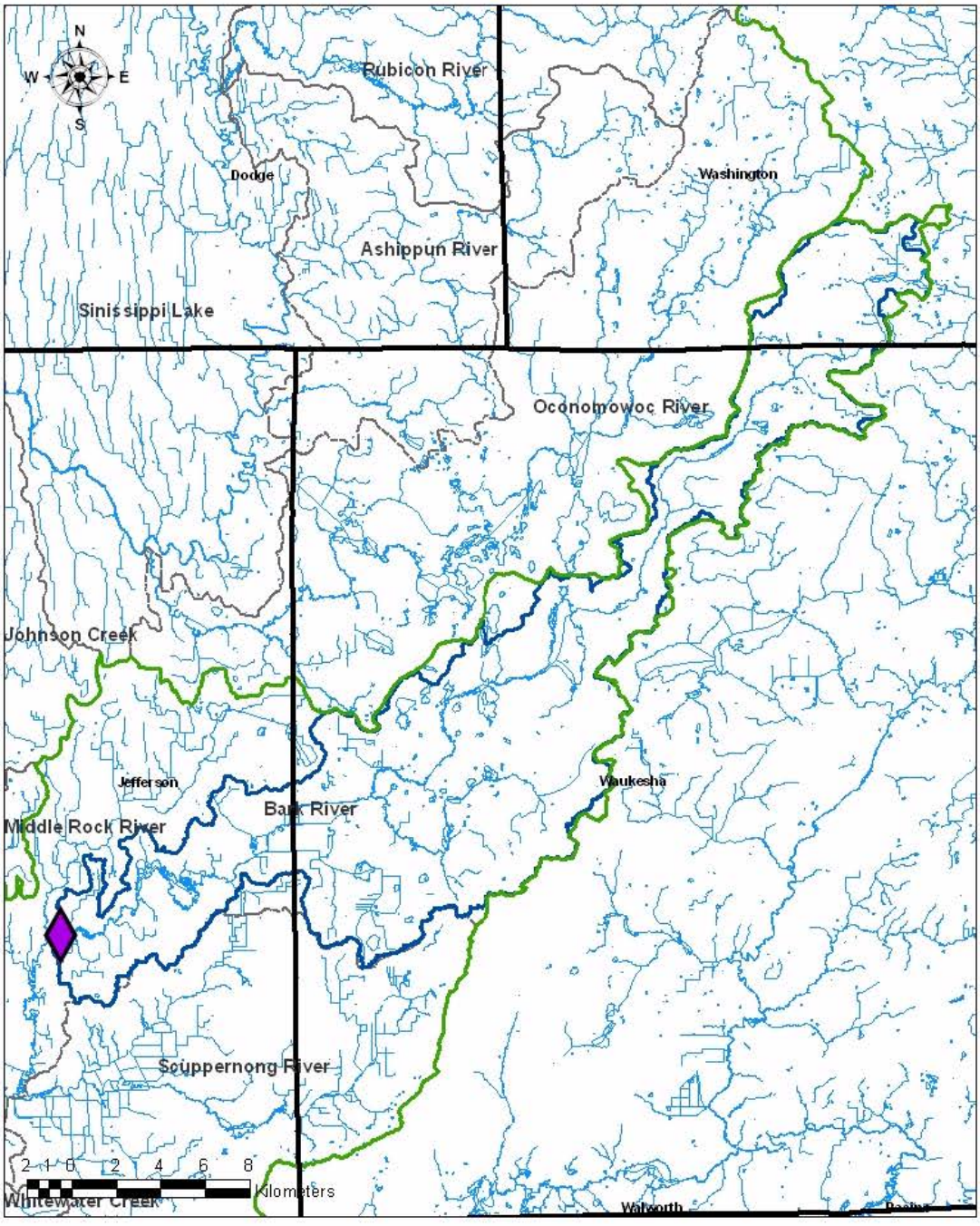
Rock River Watershed

Hydrology



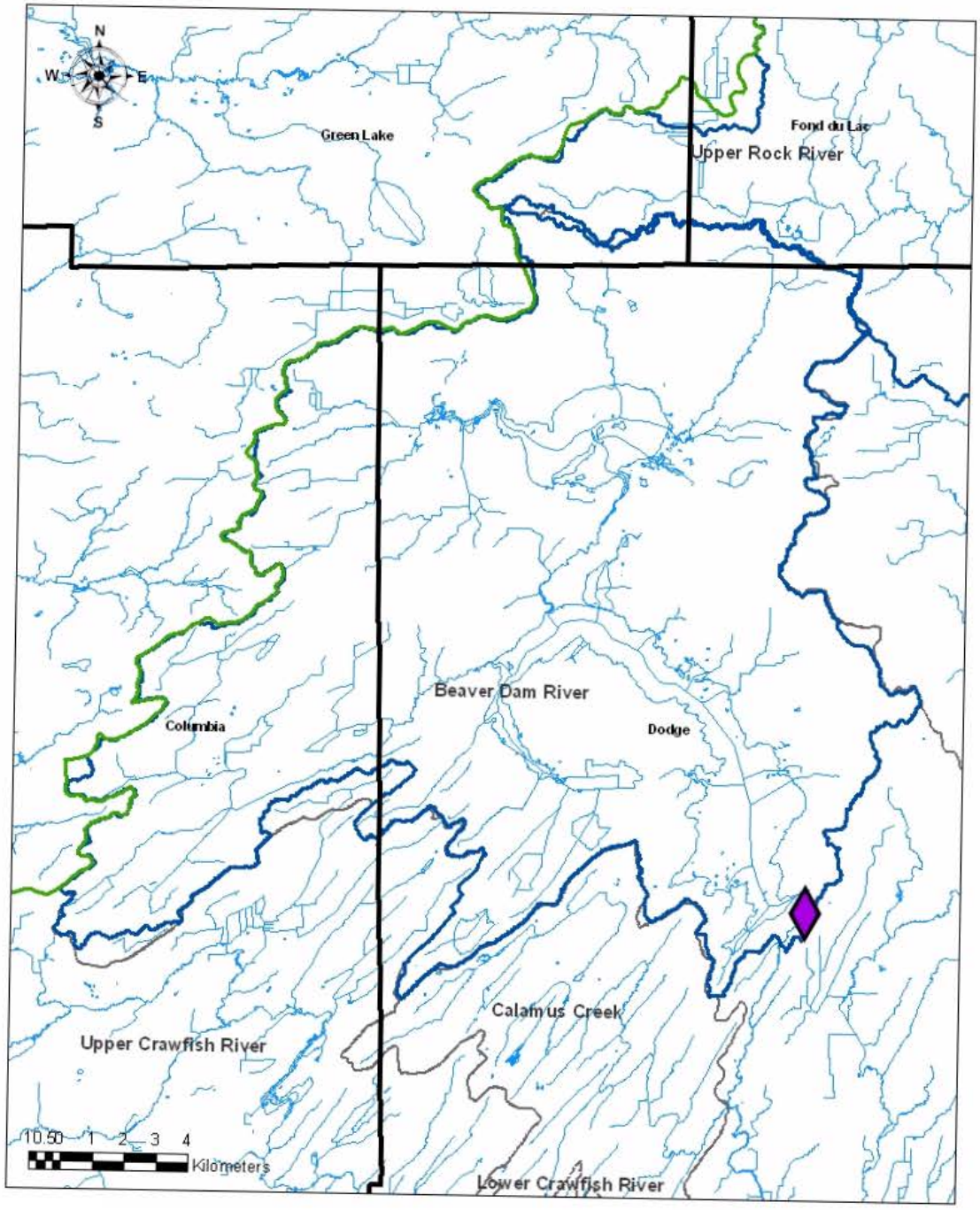
Bark River near Rome, Rock River Watershed

Hydrology

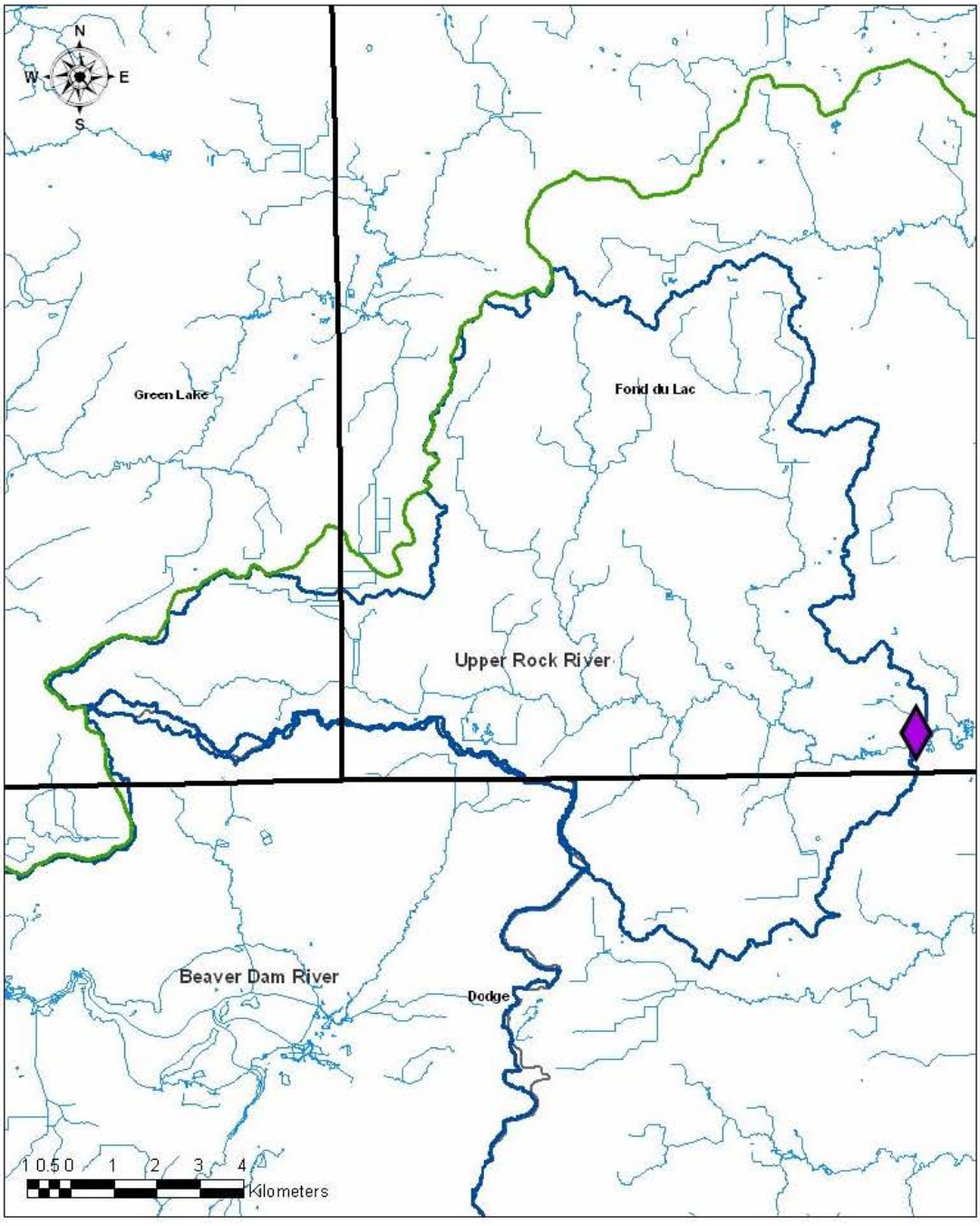


Beaver Dam at Beaver Dam, Rock River Watershed

Hydrology

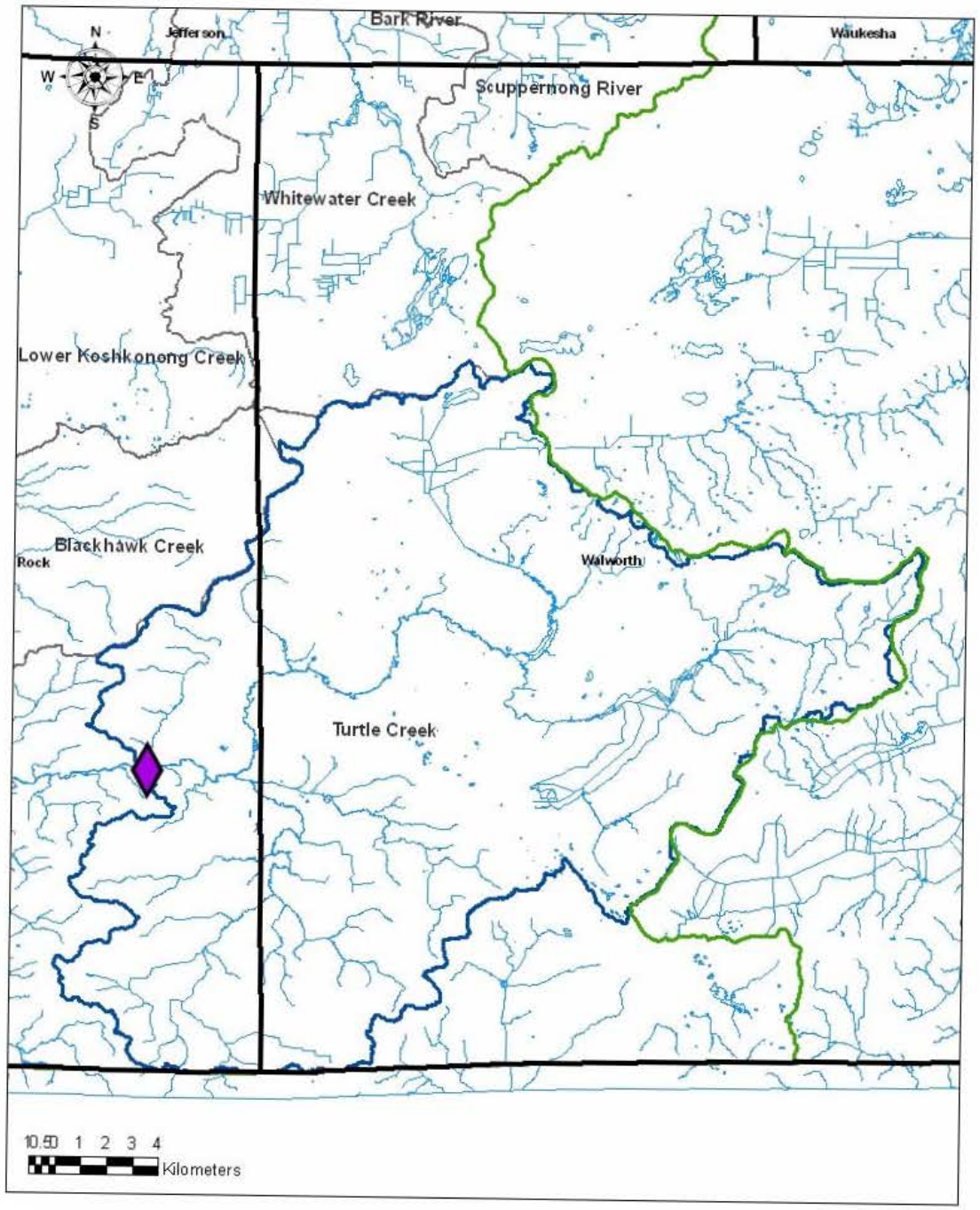


South Branch Rock River at Waupun, Rock River Watershed
Hydrology



Turtle Creek at Carvers Rock, Rock River Watershed

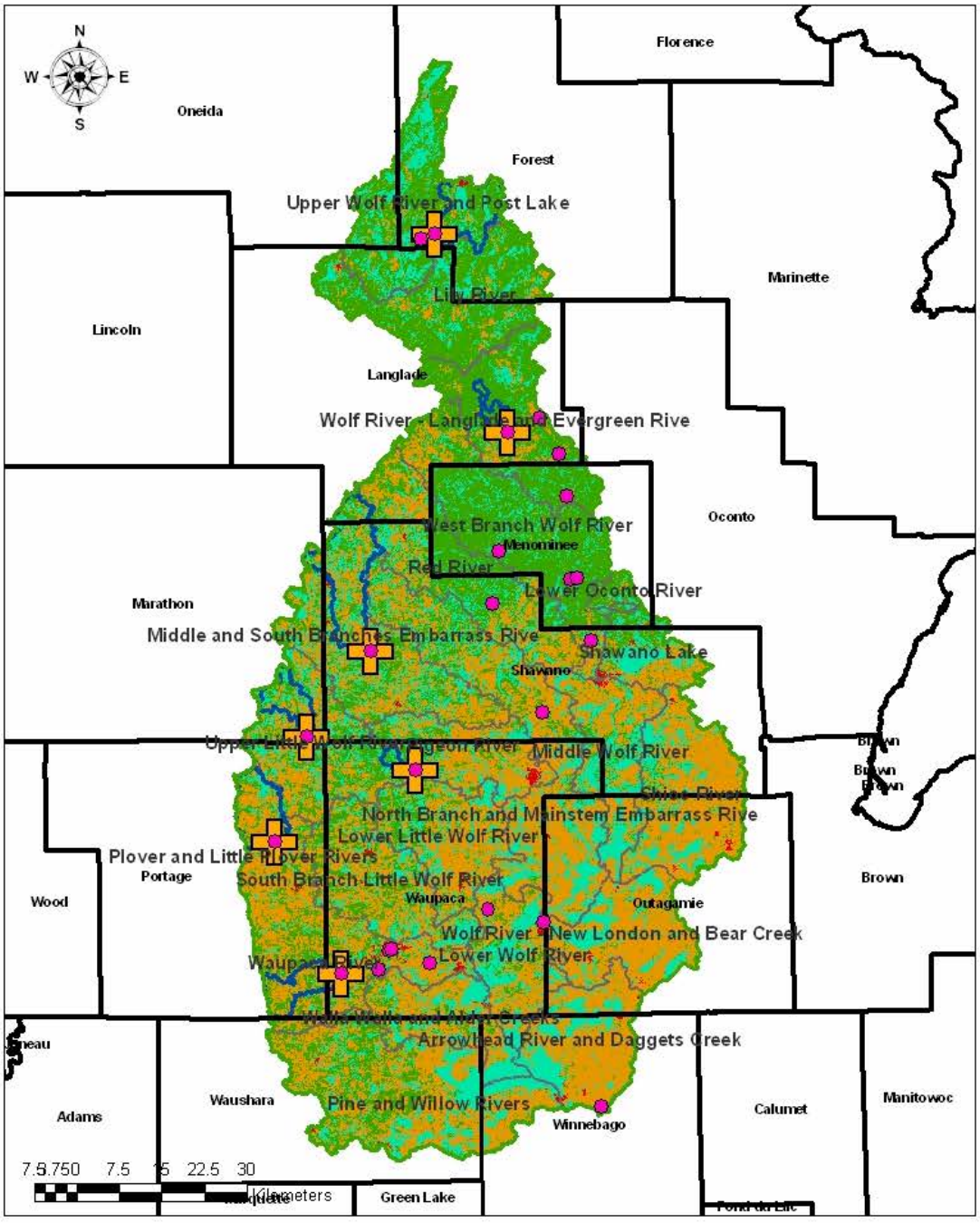
Hydrology



Appendix F: Landuse Delineation (State), by site

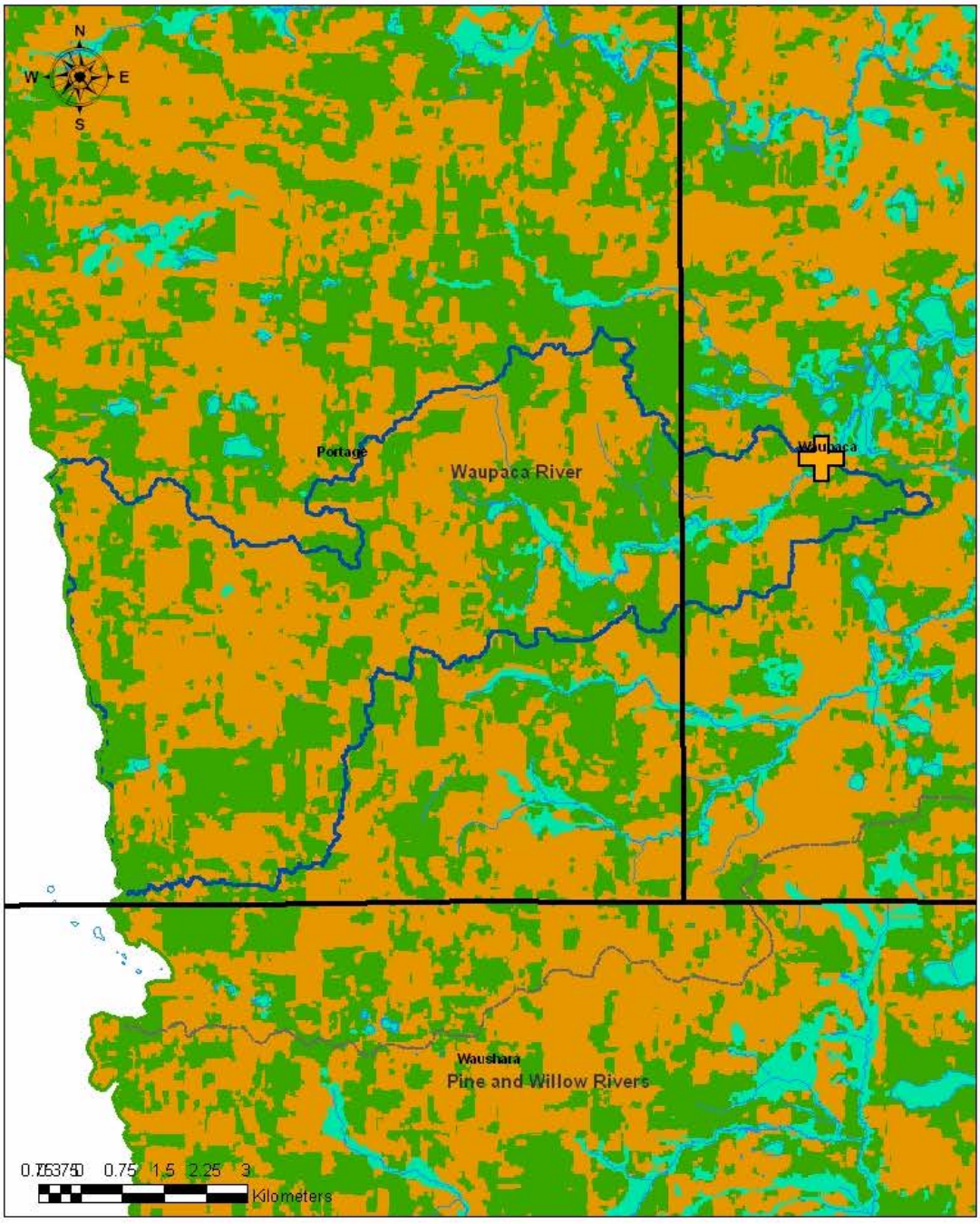
Wolf River Watershed

Wisconsin County-Level Landcover, 1992



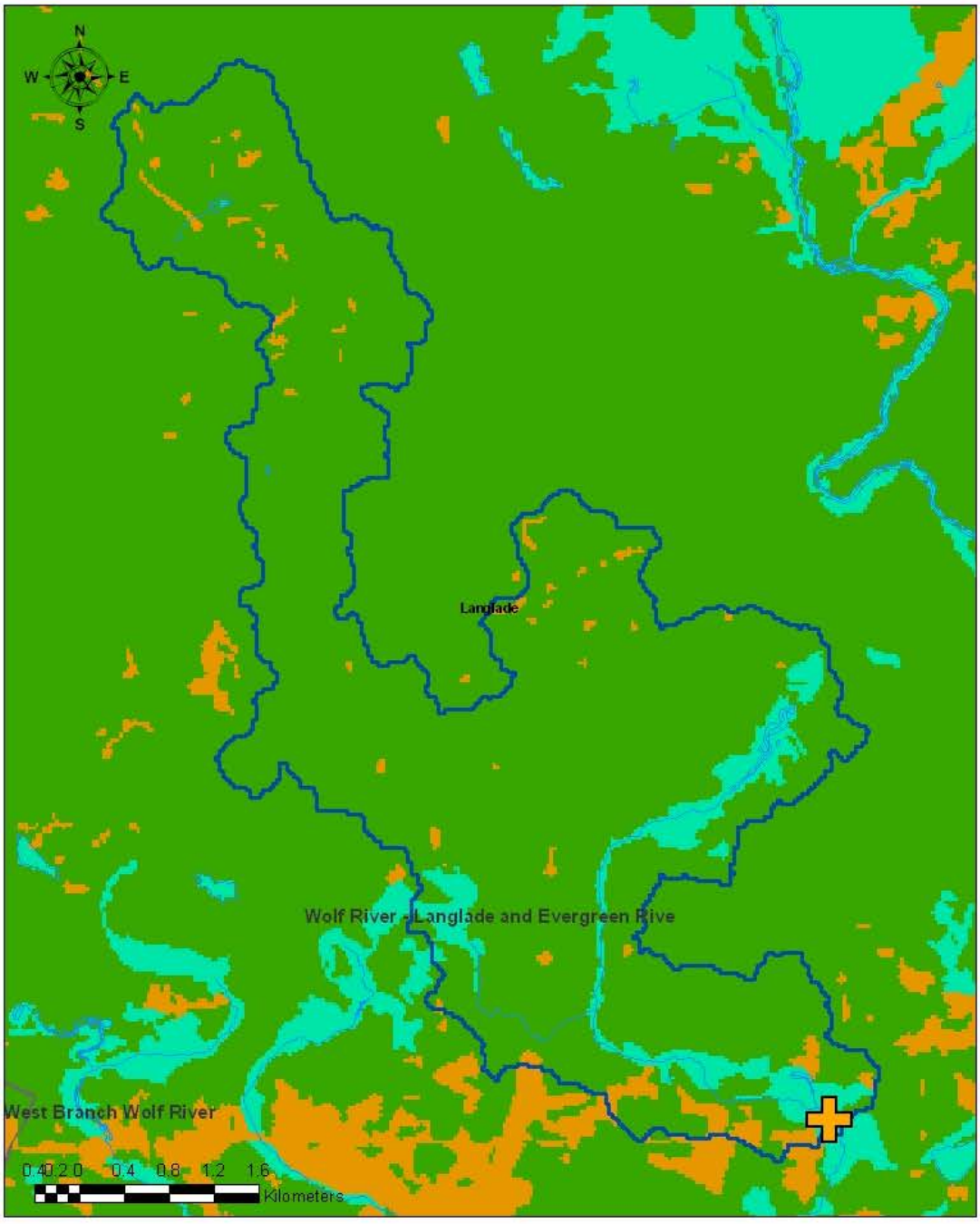
Emmons Creek at Rural, Wolf River Watershed

Wisconsin County-Level Landcover, 1992



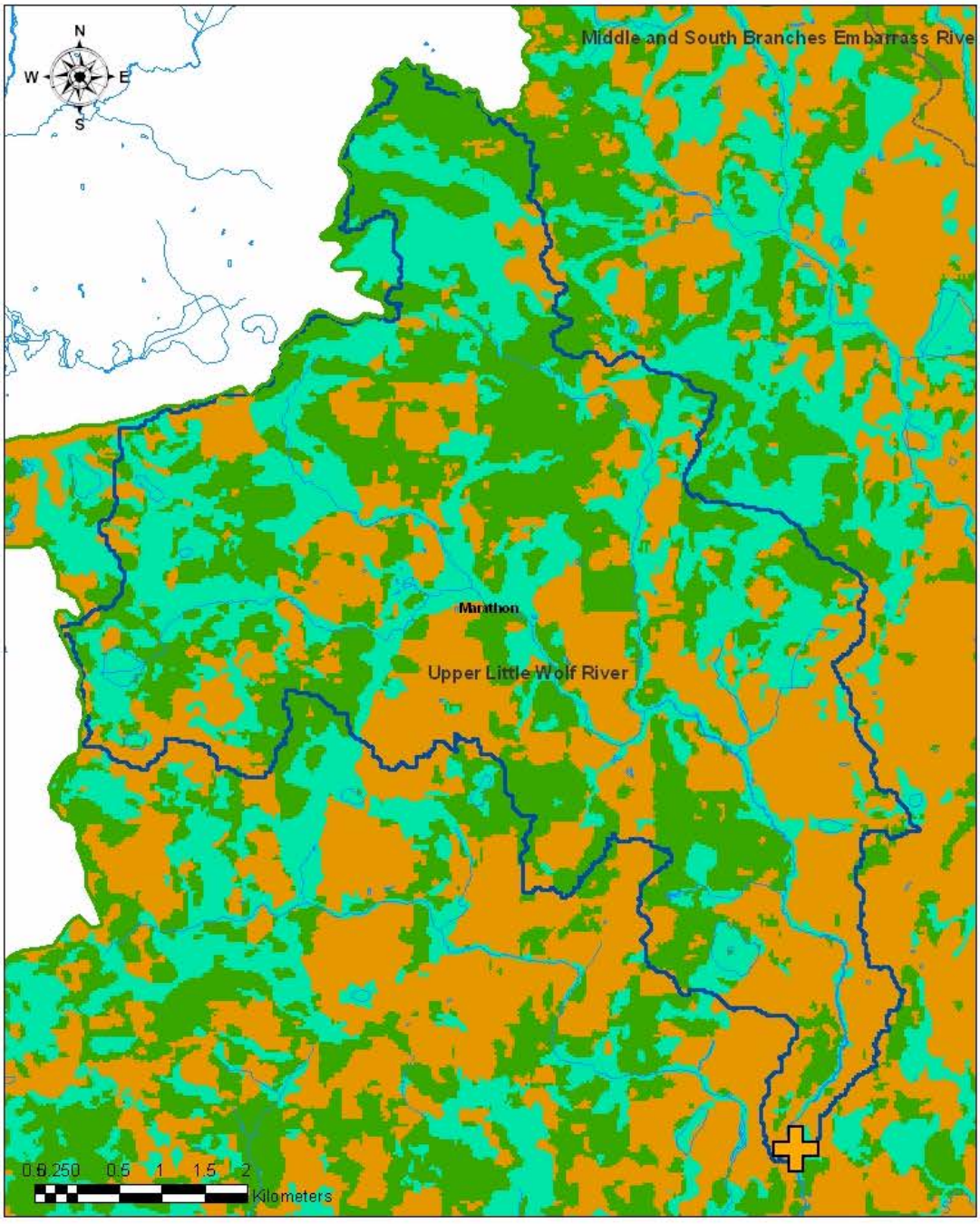
Evergreen River near Langlade, Wolf River Watershed

Wisconsin County-Level Landcover, 1992



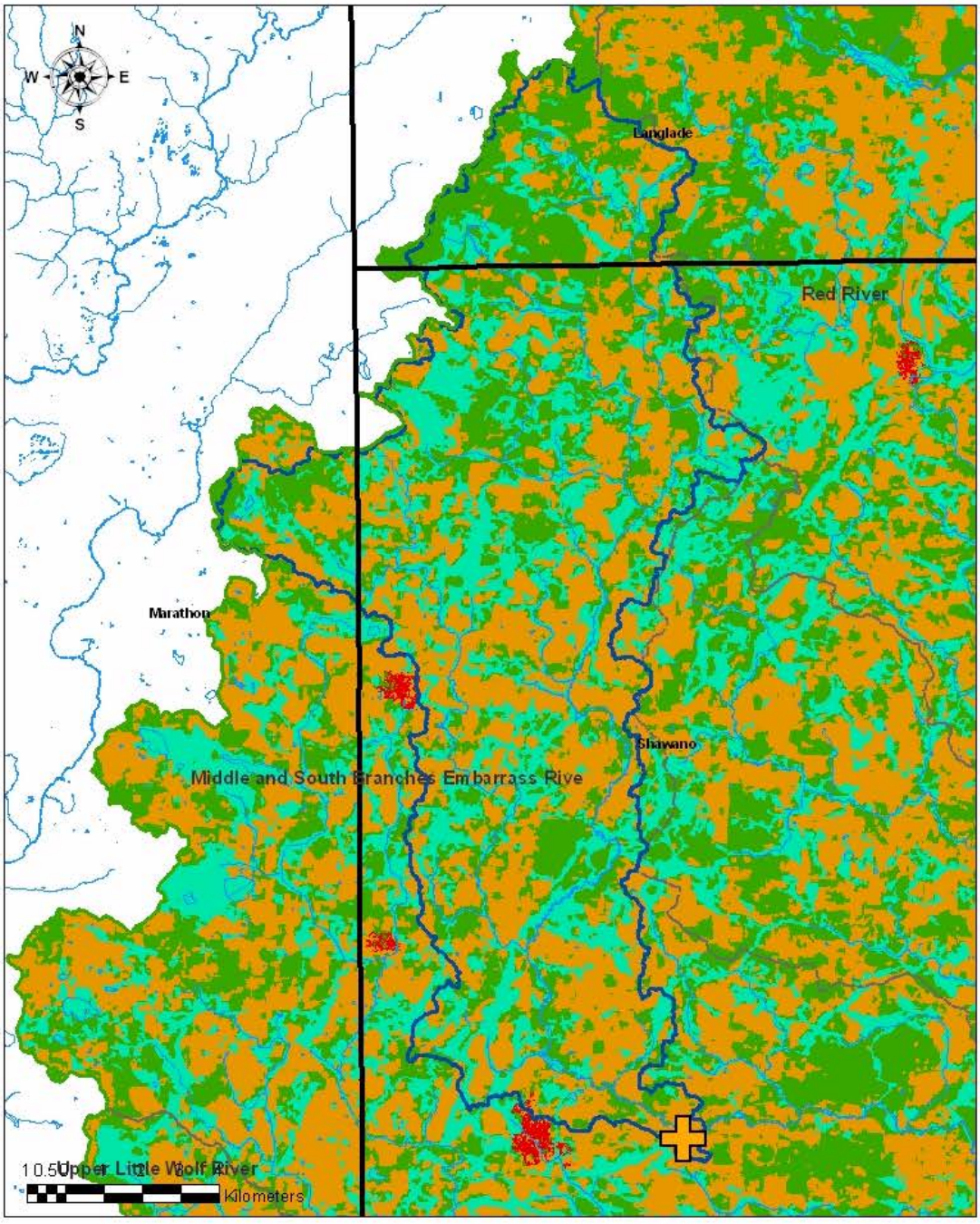
Little Wolf River near Galloway, Wolf River Watershed

Wisconsin County-Level Landcover, 1992



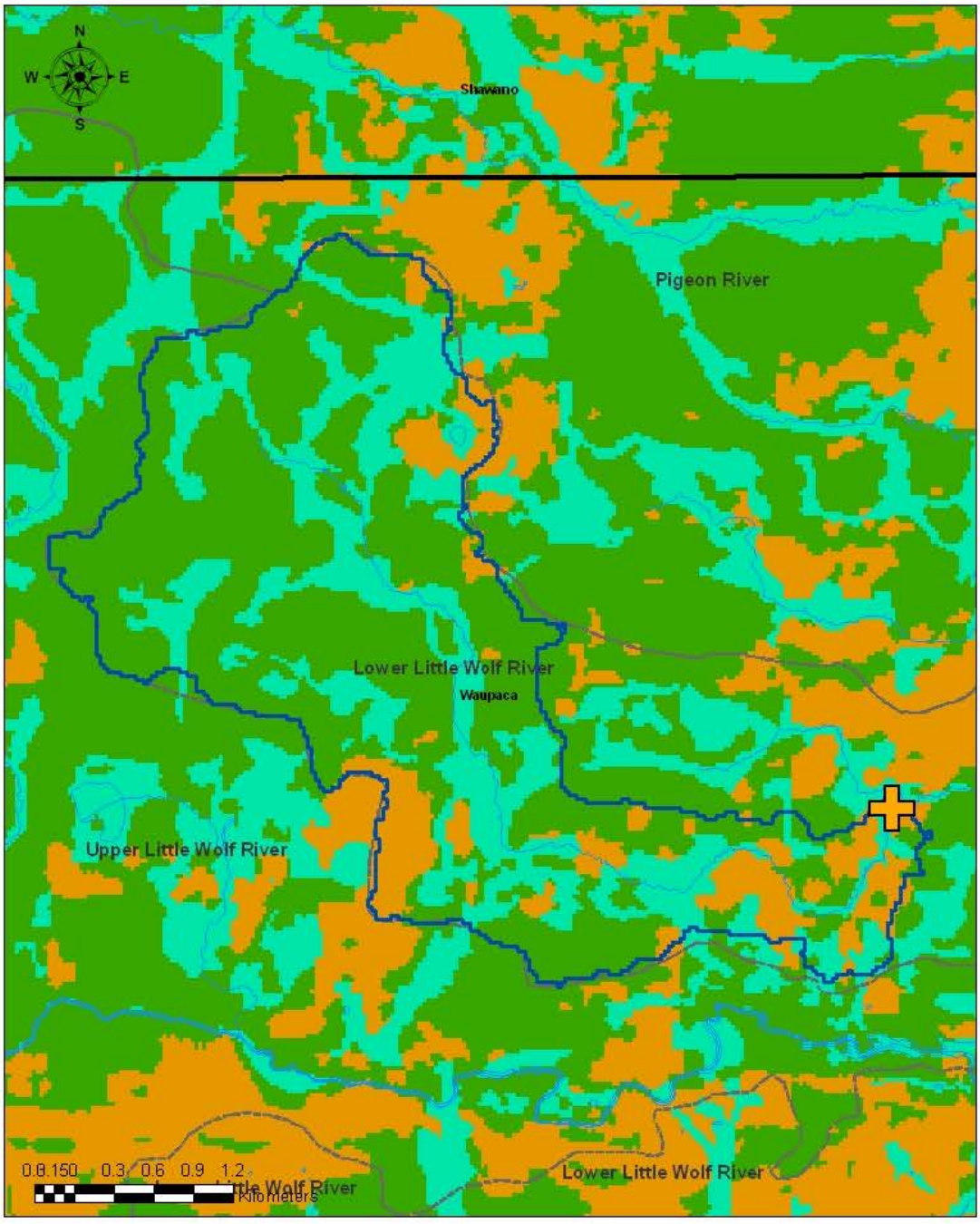
Middle Branch Embarrass River, Wolf River Watershed

Wisconsin County-Level Landcover, 1992



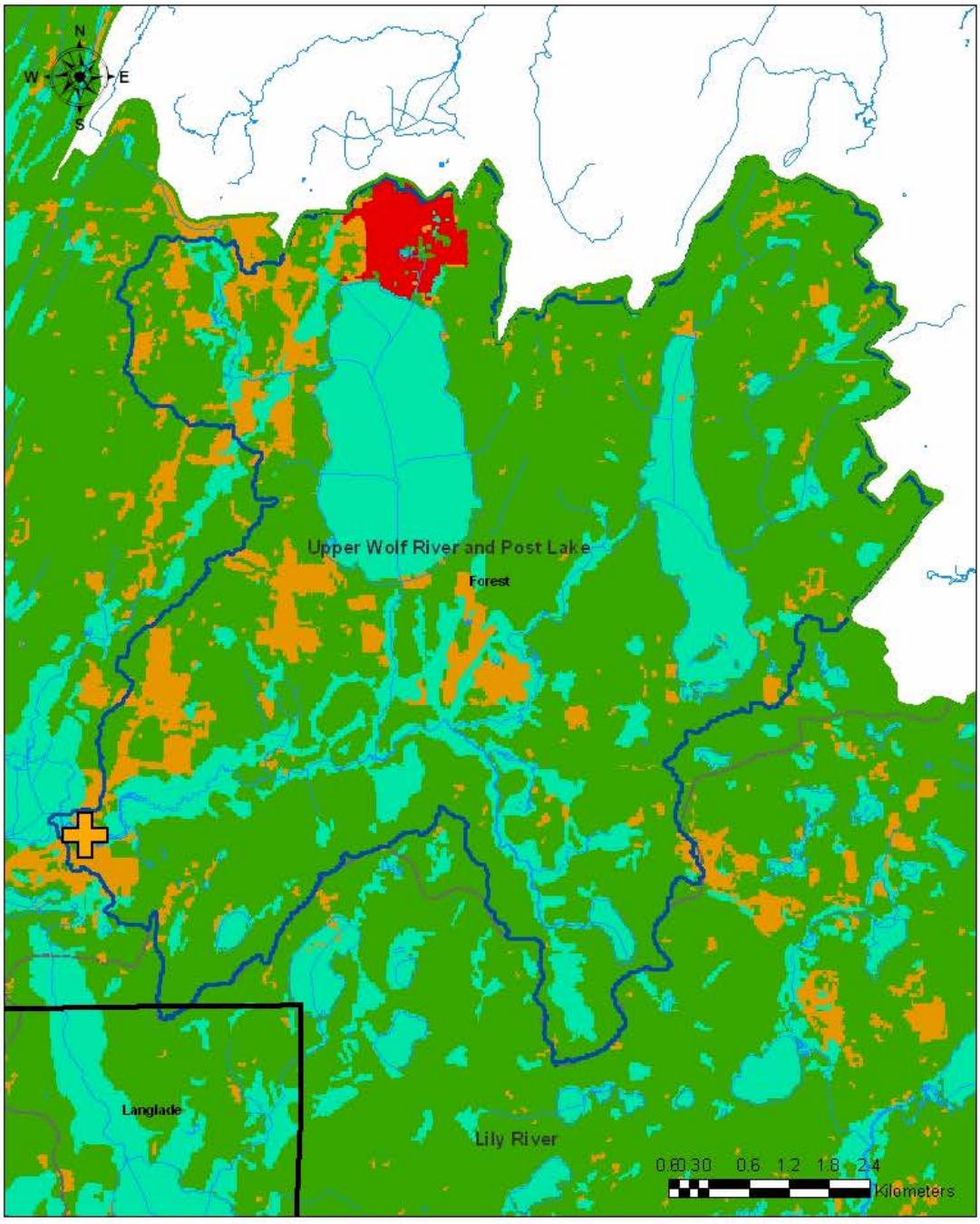
Spaulding Creek near Big Falls, Wolf River Watershed

Wisconsin County-Level Landcover, 1992



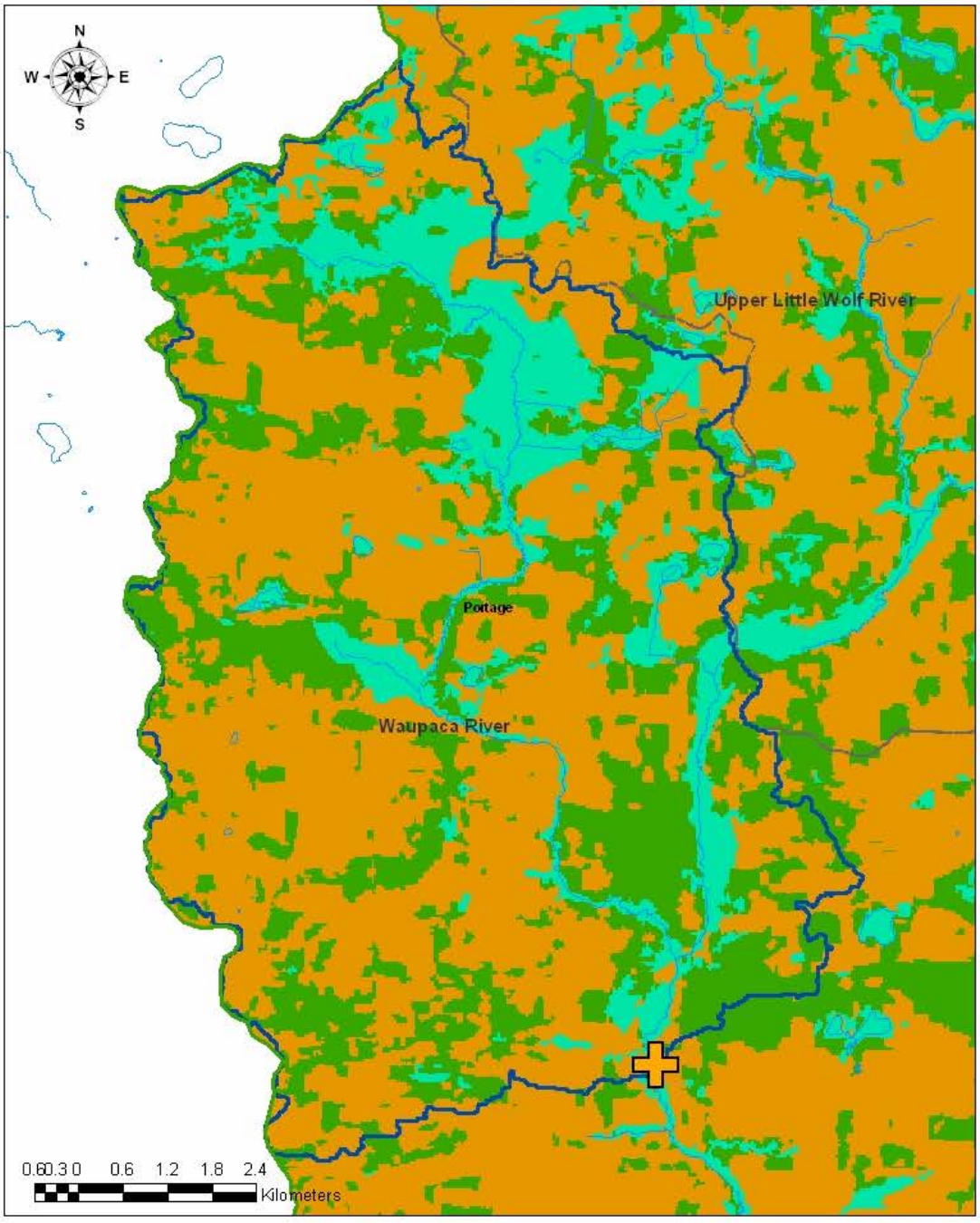
Swamp Creek above Mole Lake, Wolf River Watershed

Wisconsin County-Level Landcover, 1992



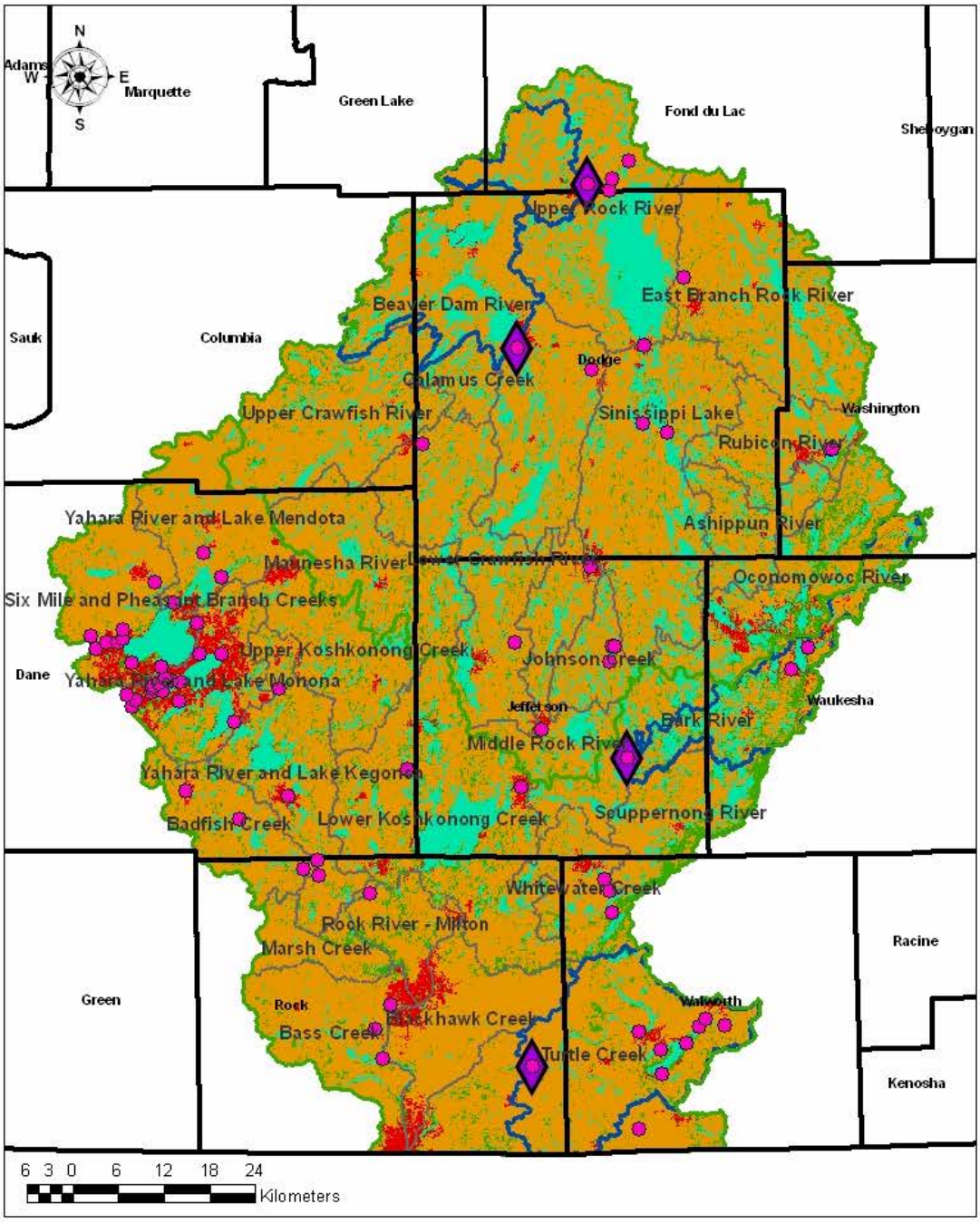
Tomorrow River near Nelsonville, Wolf River Watershed

Wisconsin County-Level Landcover, 1992



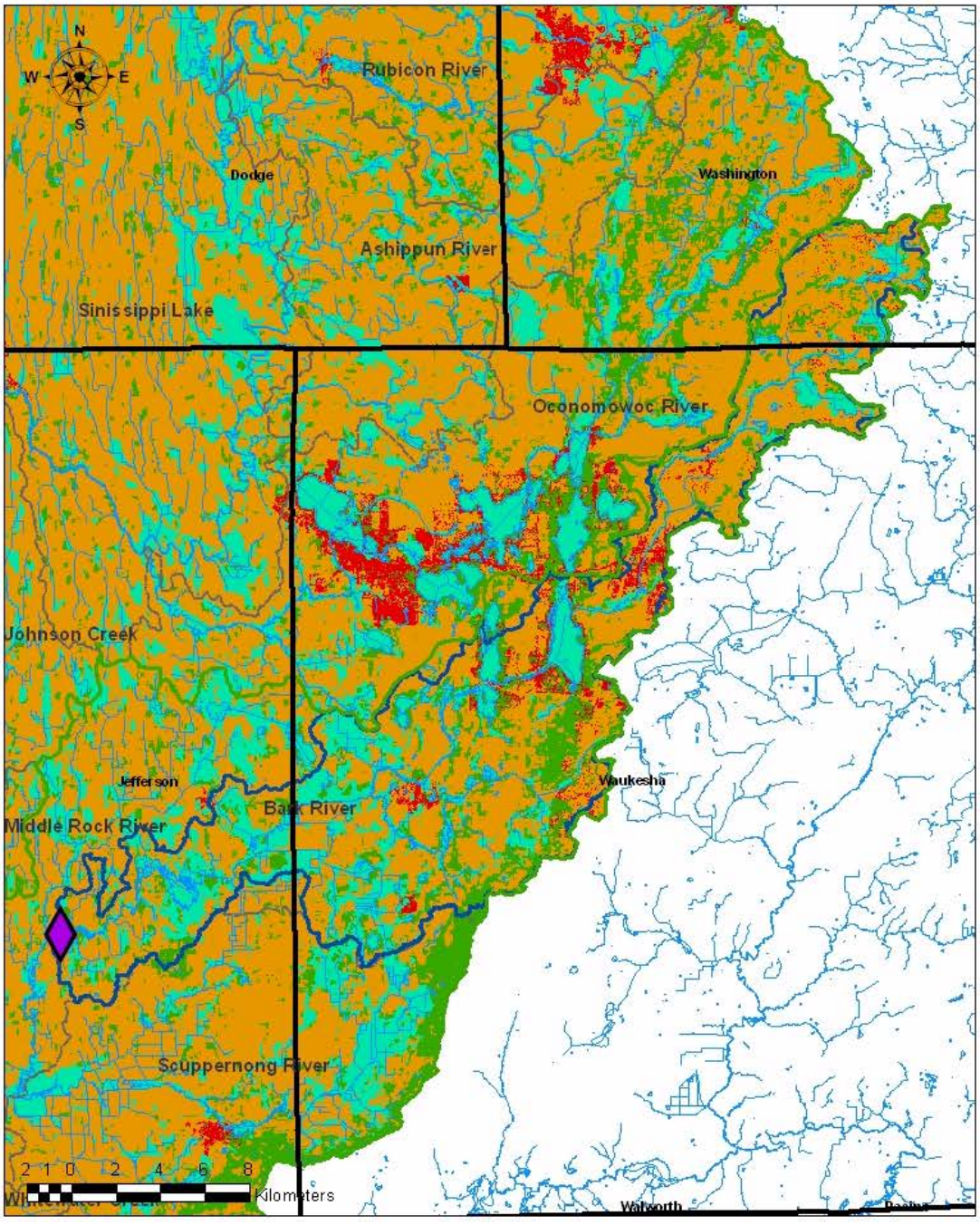
Rock River Watershed

Wisconsin County-Level Landcover, 1992



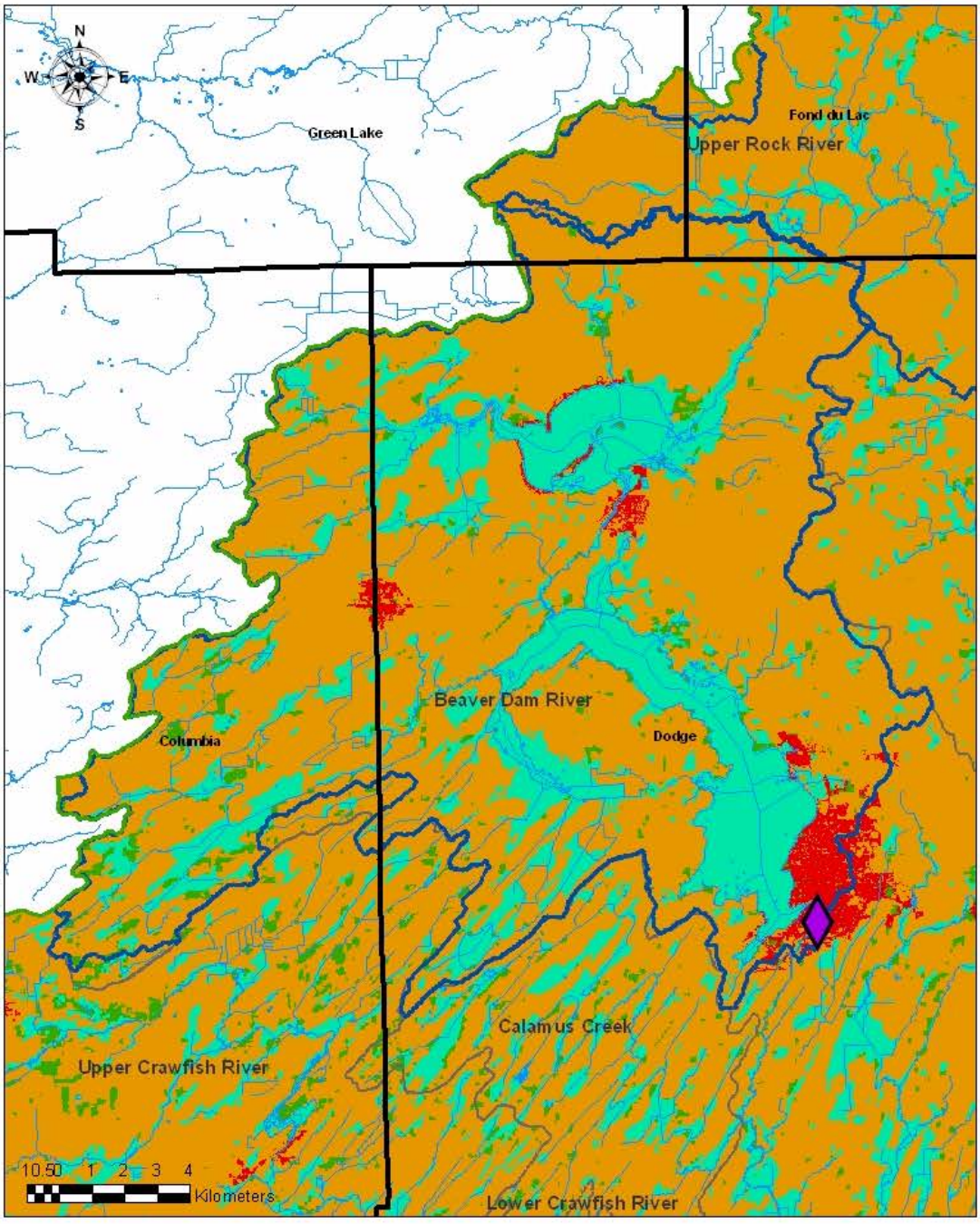
Bark River near Rome, Rock River Watershed

Wisconsin County-Level Landcover, 1992



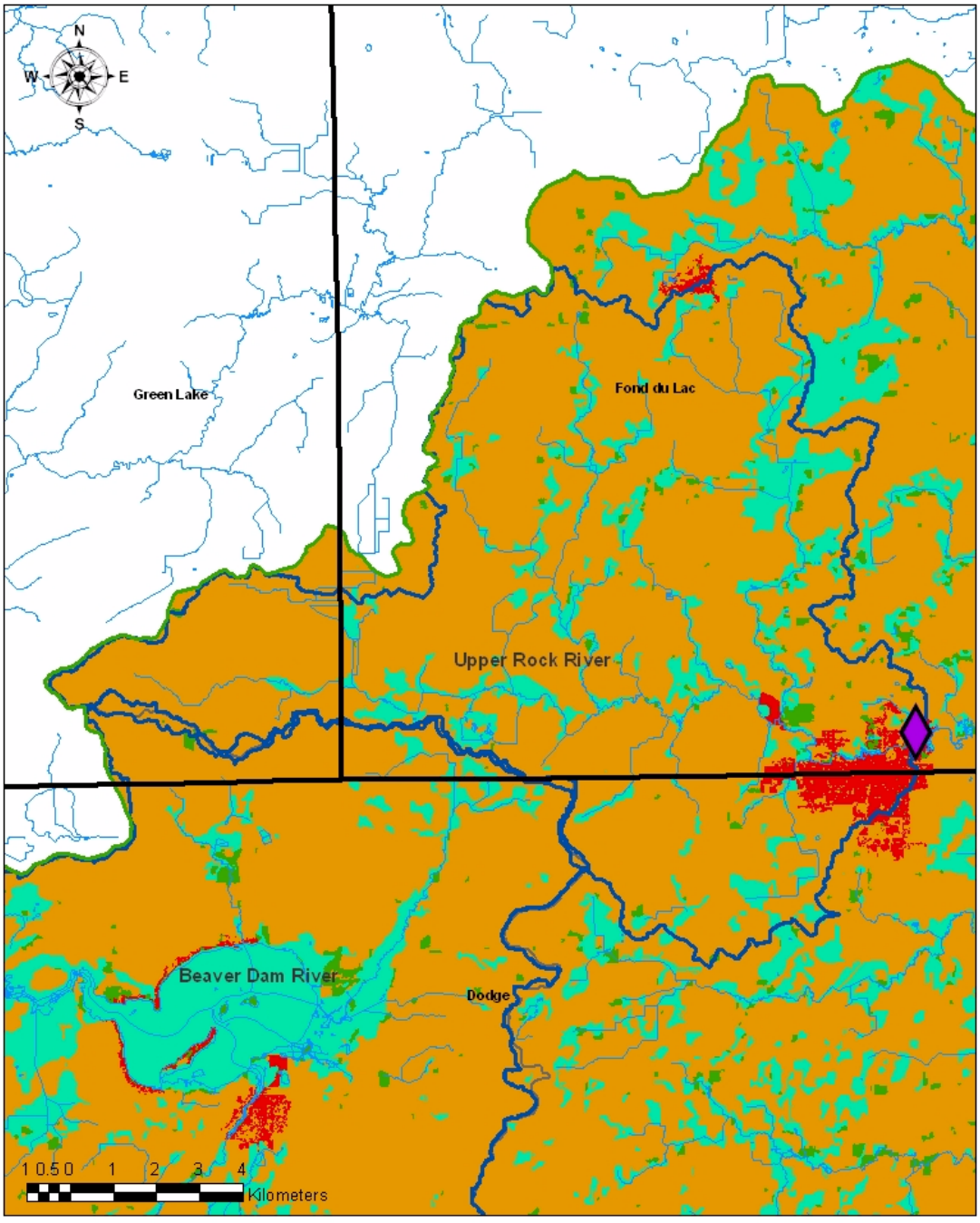
Beaver Dam at Beaver Dam, Rock River Watershed

Wisconsin County-Level Landcover, 1992



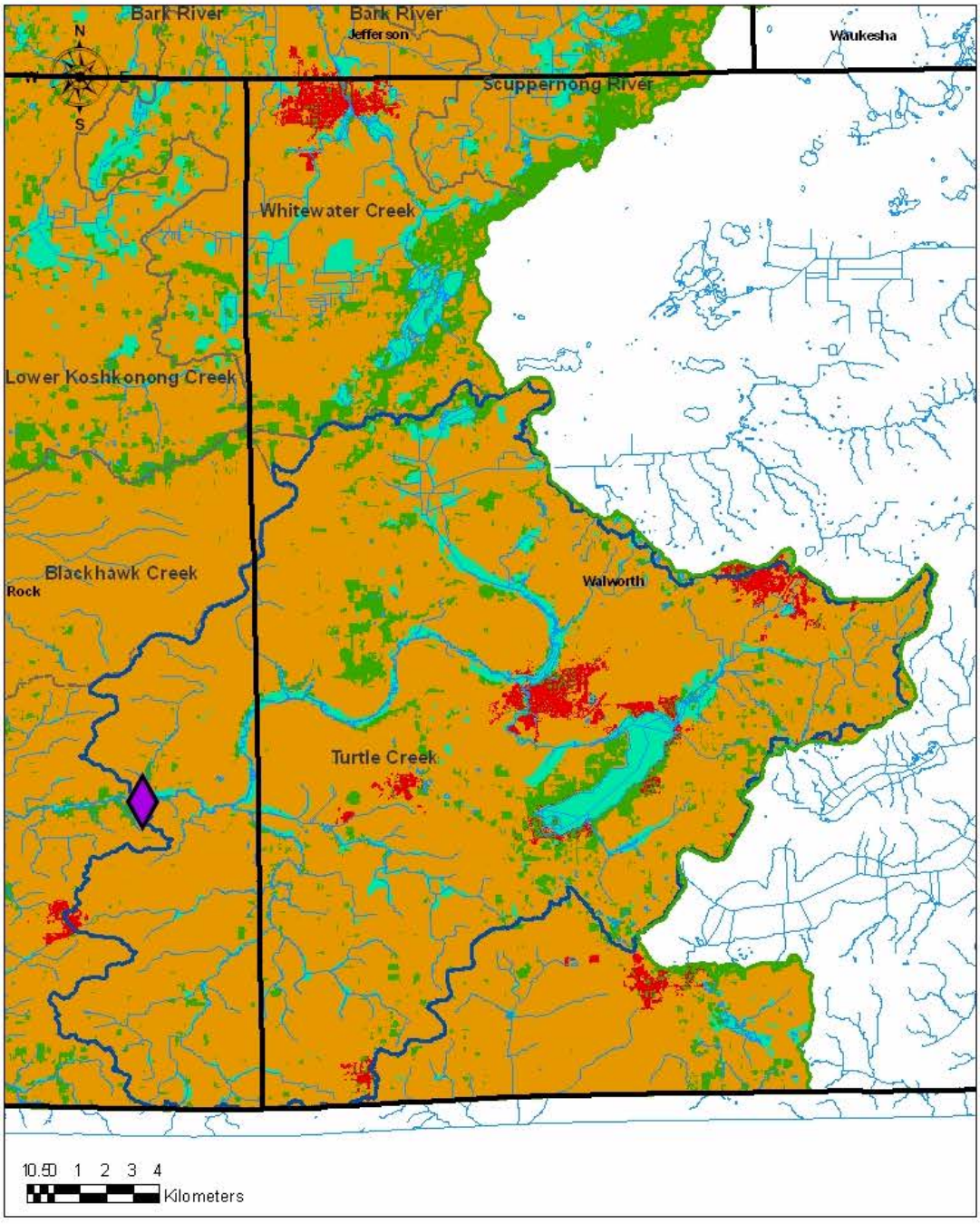
South Branch Rock River at Waupun, Rock River Watershed

Wisconsin County-Level Landcover, 1992



Turtle Creek at Carvers Rock, Rock River Watershed

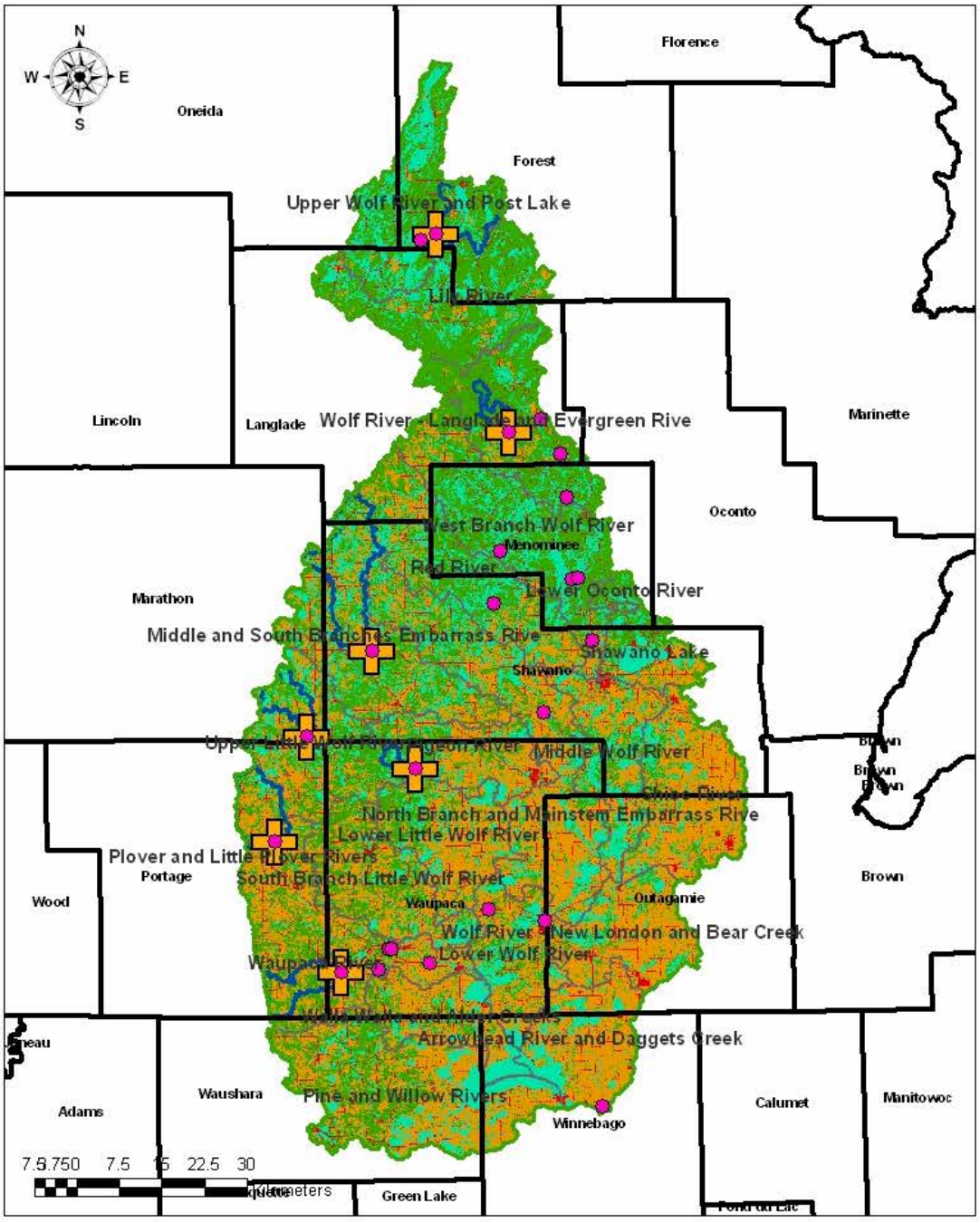
Wisconsin County-Level Landcover, 1992



Appendix G: Landuse Delineation (Federal), by site

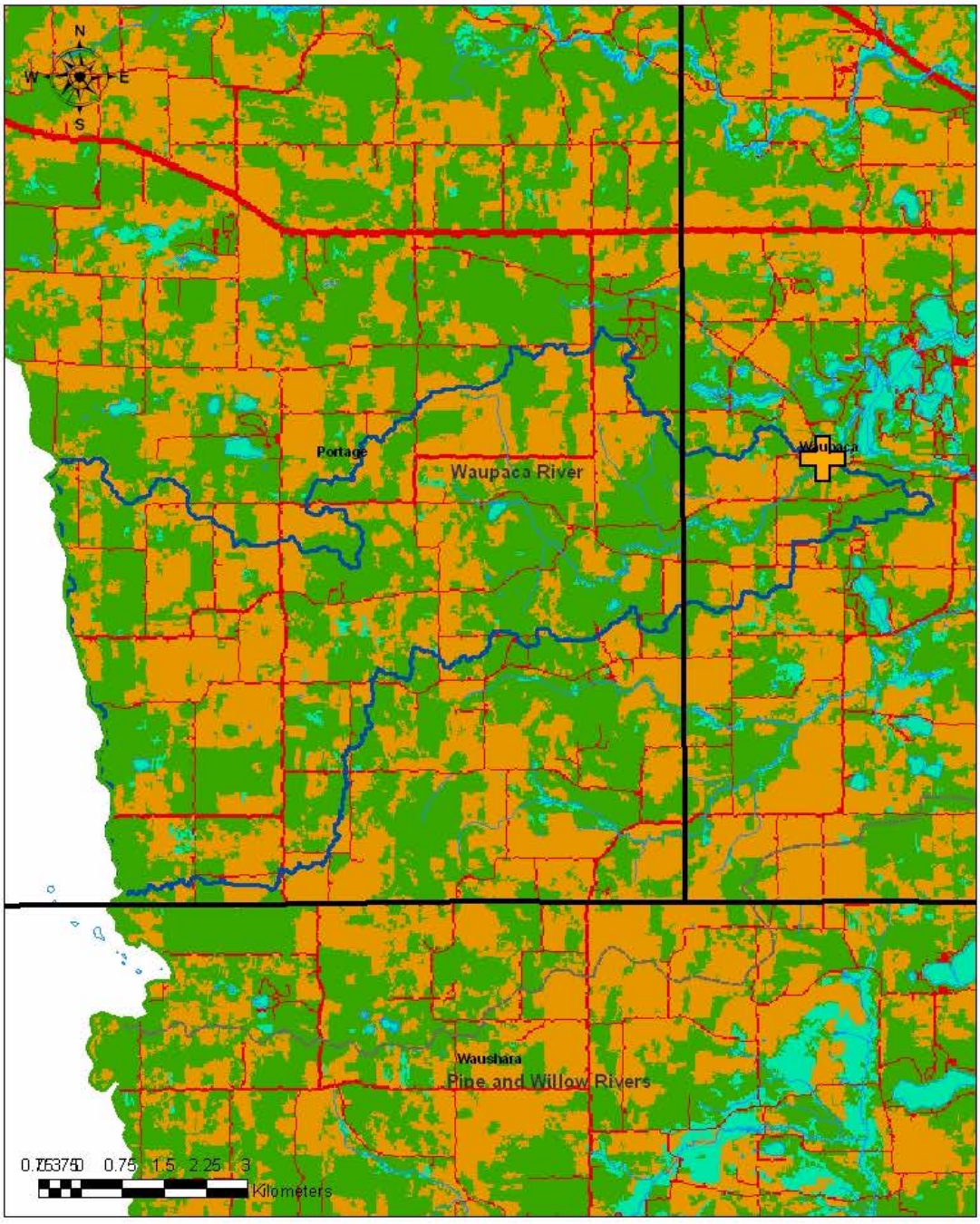
Wolf River Watershed

Federal National-Level Landcover, 2001



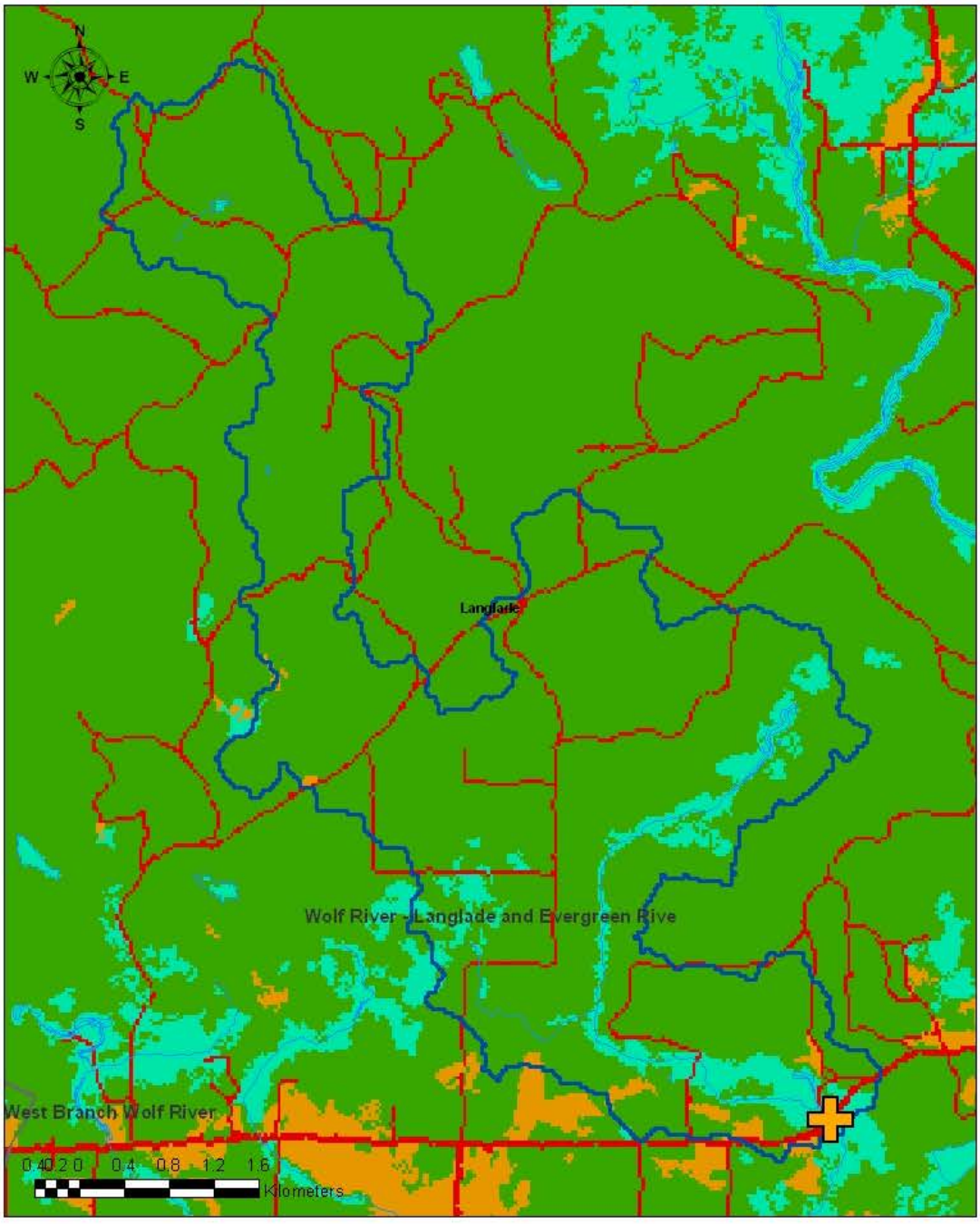
Emmons Creek at Rural, Wolf River Watershed

Federal National-Level Landcover, 2001



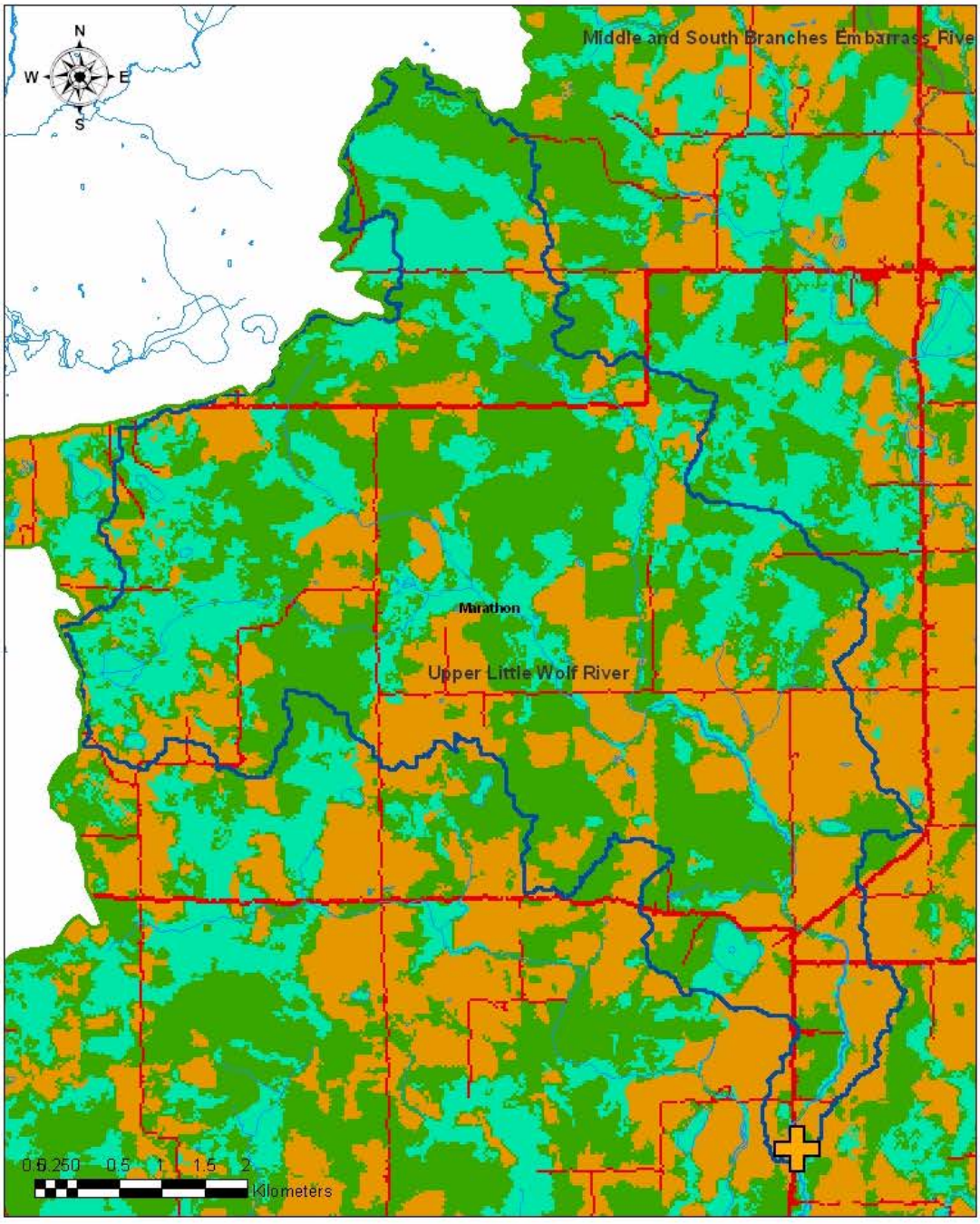
Evergreen River near Langlade, Wolf River Watershed

Federal National-Level Landcover, 2001



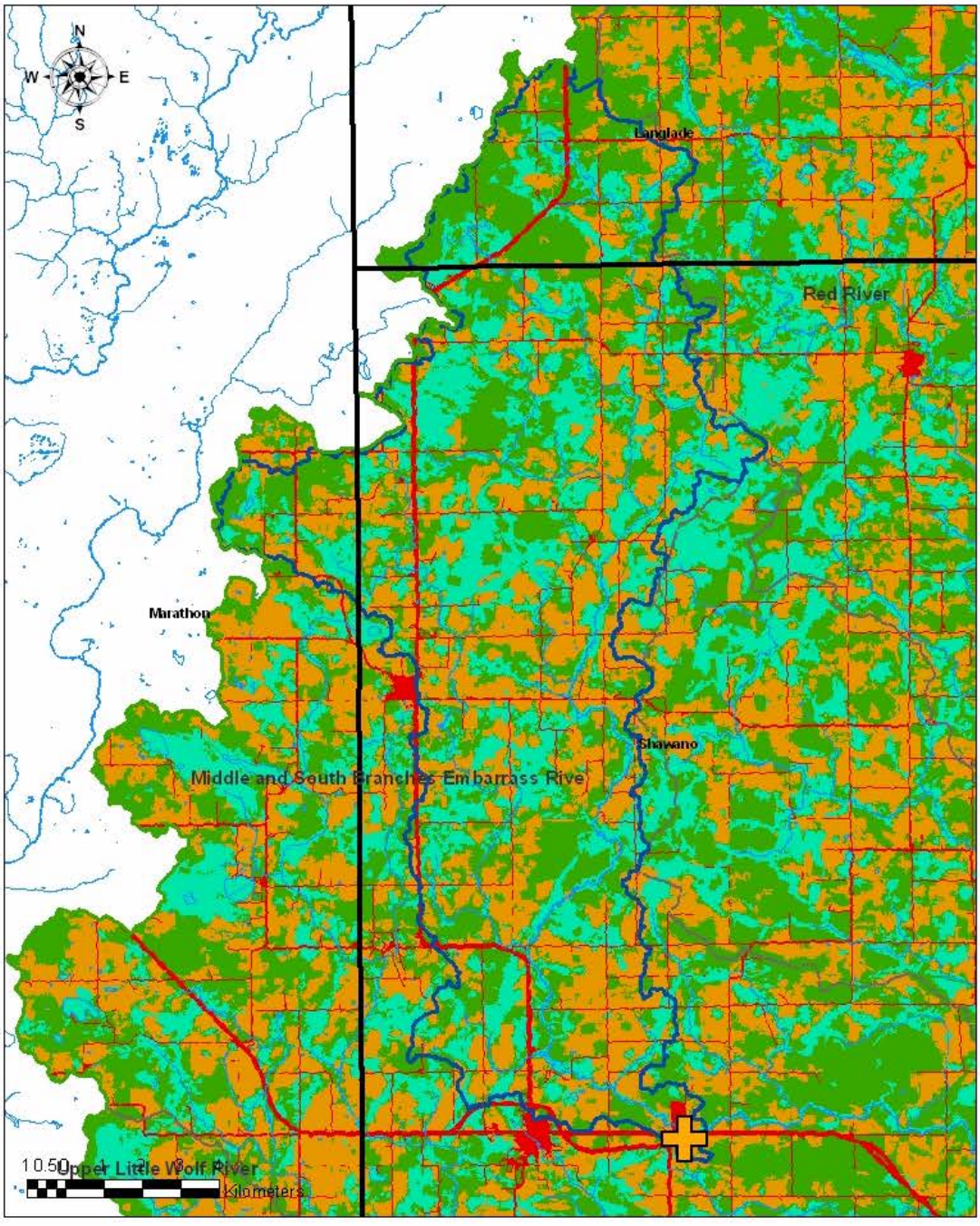
Little Wolf River near Galloway, Wolf River Watershed

Federal National-Level Landcover, 2001



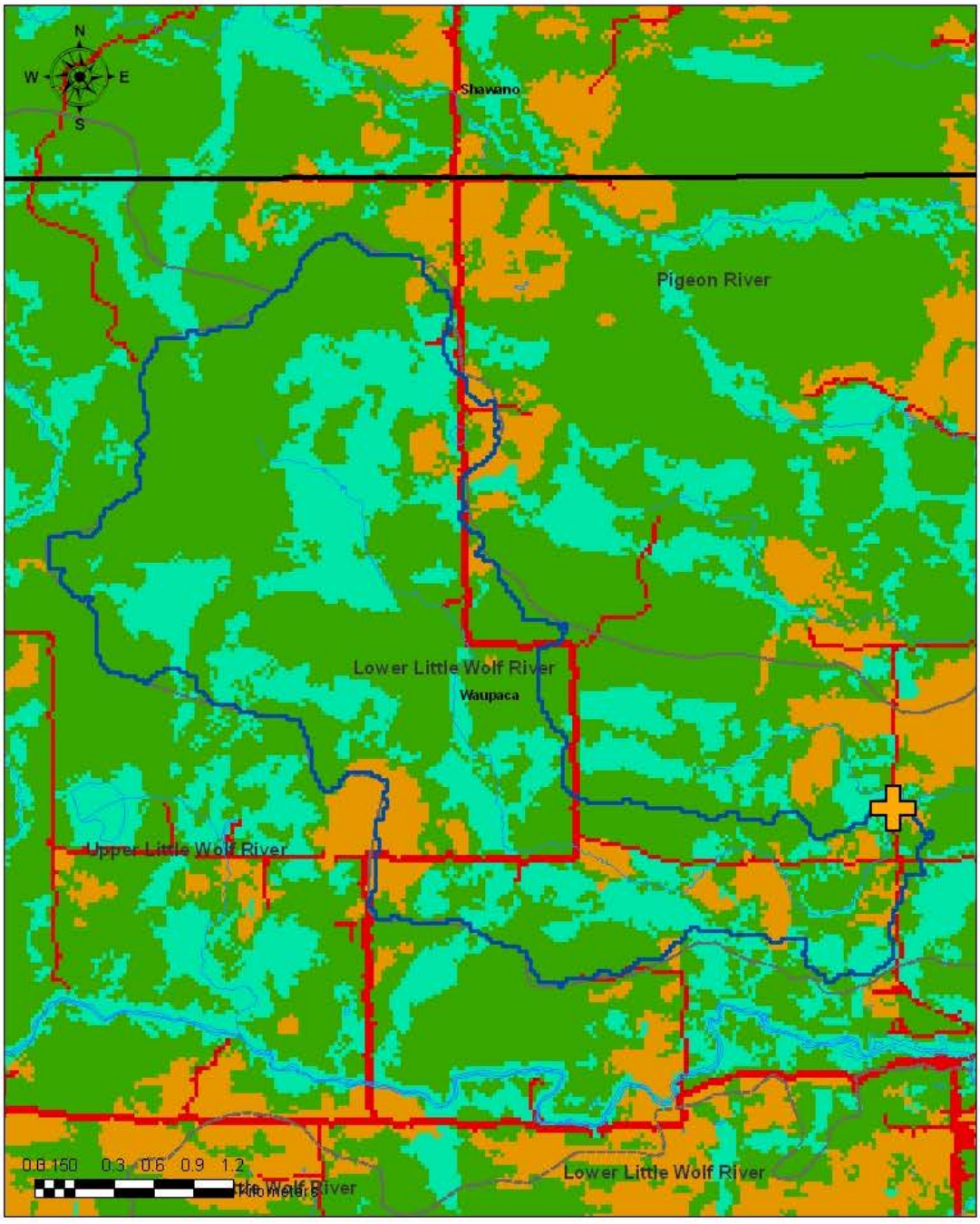
Middle Branch Embarrass River, Wolf River Watershed

Federal National-Level Landcover, 2001



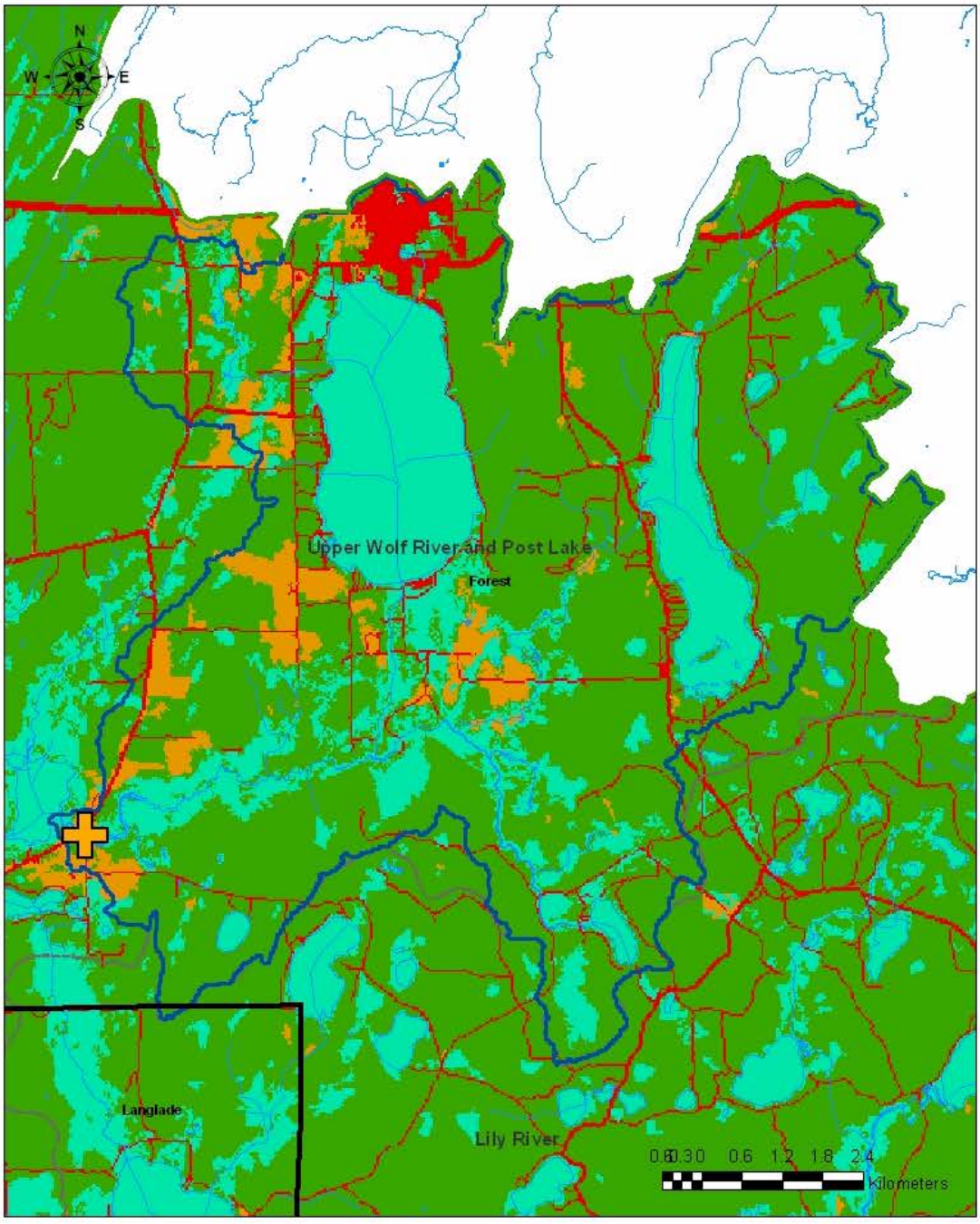
Spaulding Creek near Big Falls, Wolf River Watershed

Federal National-Level Landcover, 2001



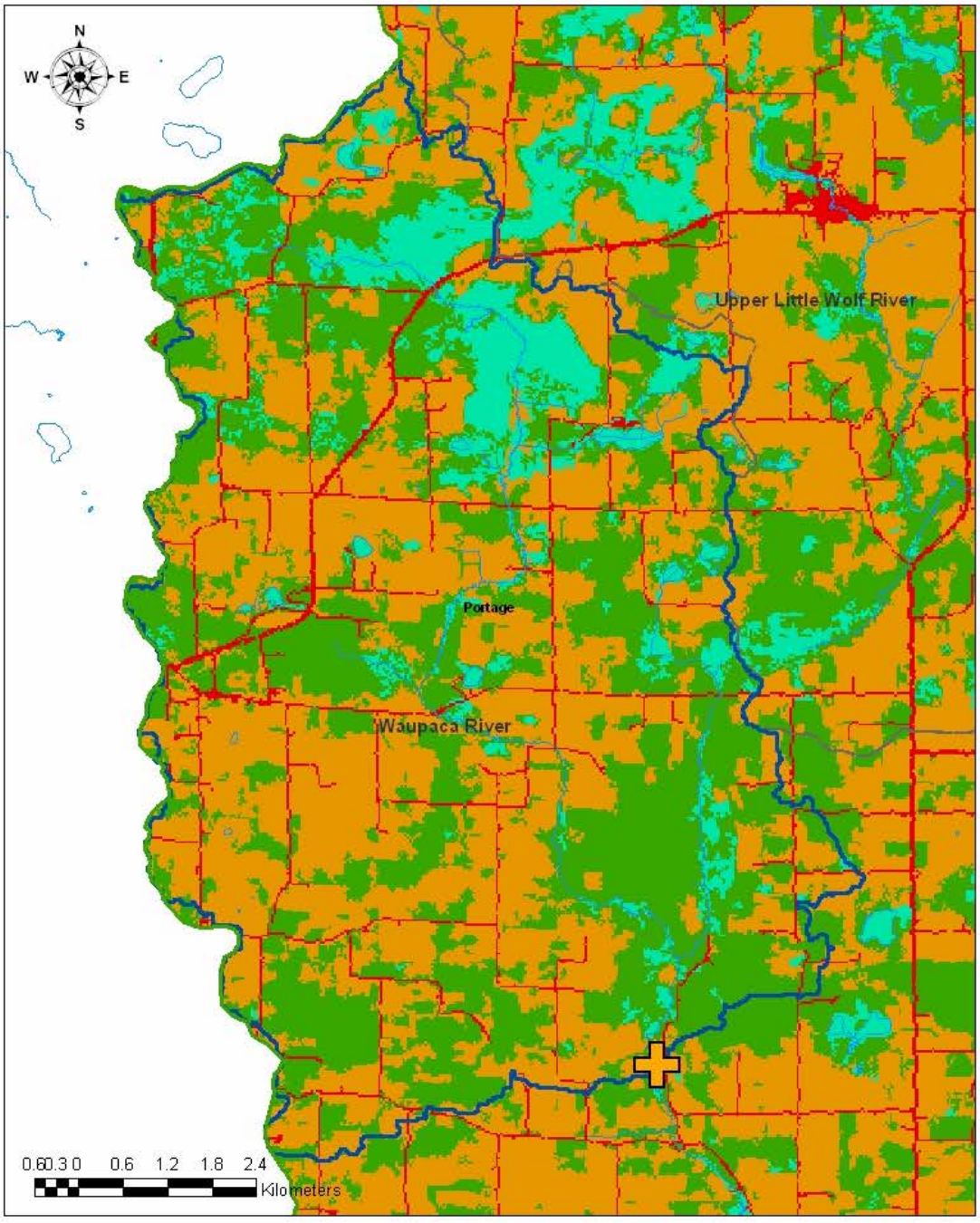
Swamp Creek above Mole Lake, Wolf River Watershed

Federal National-Level Landcover, 2001



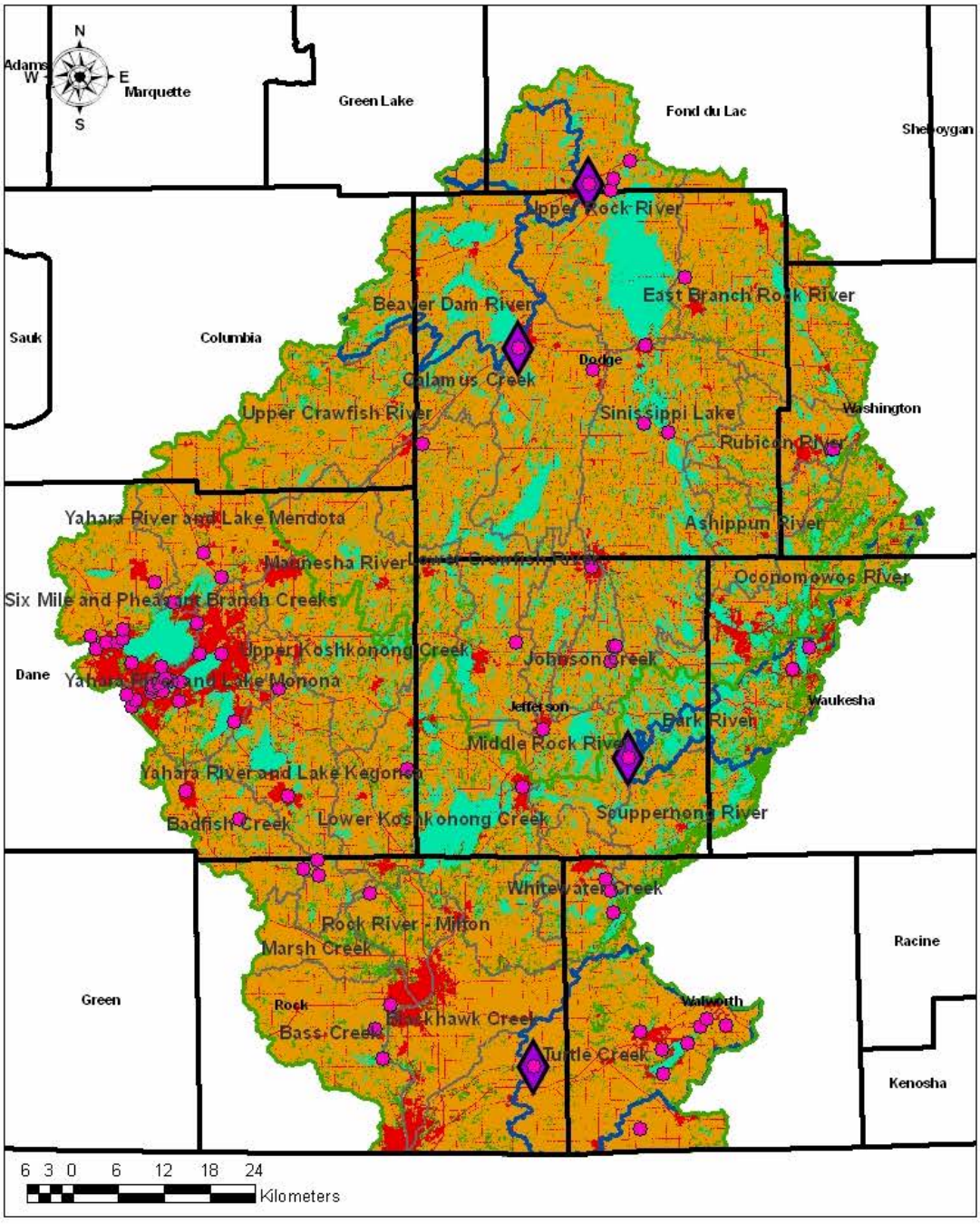
Tomorrow River near Nelsonville, Wolf River Watershed

Federal National-Level Landcover, 2001



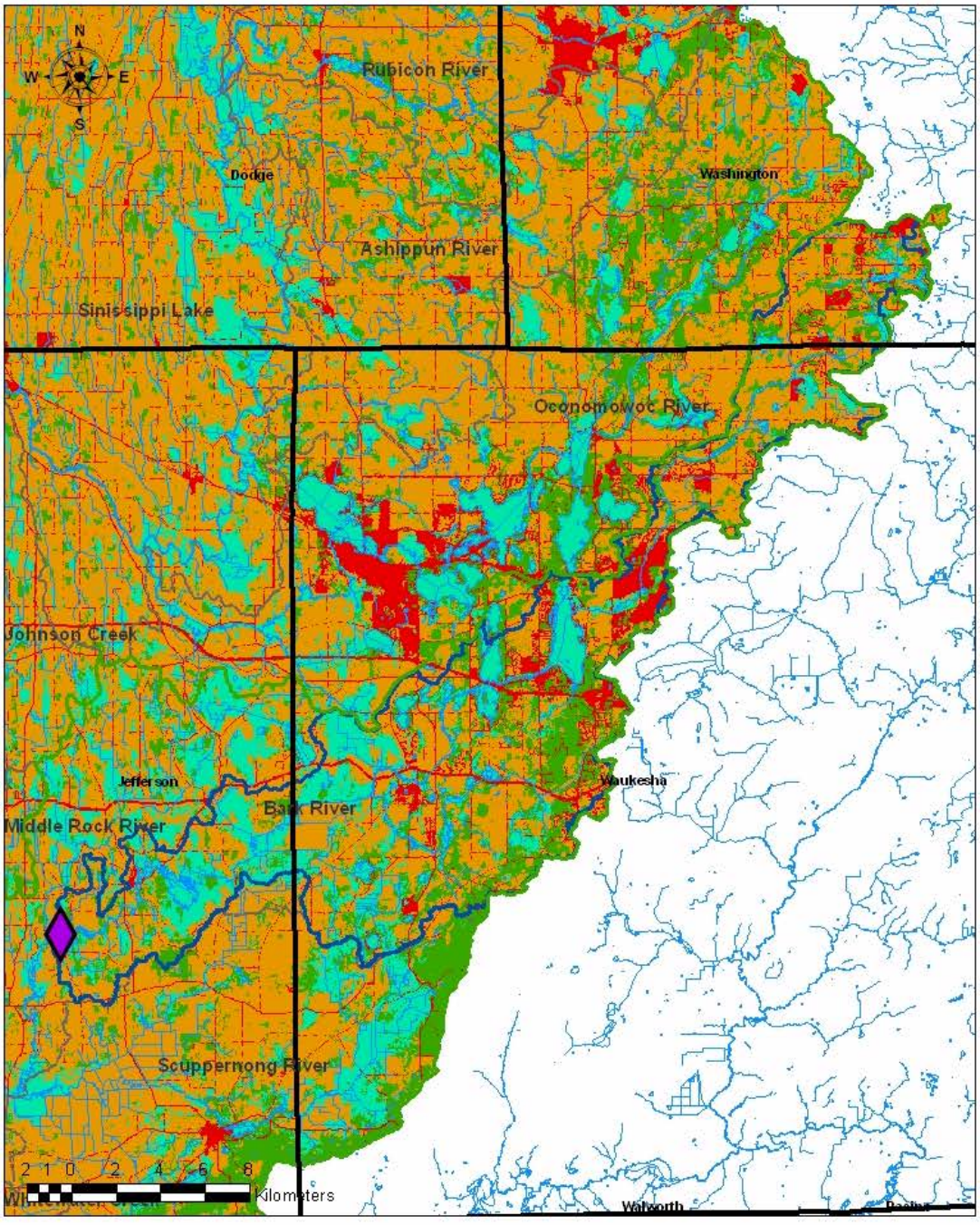
Rock River Watershed

Federal National-Level Landcover, 2001



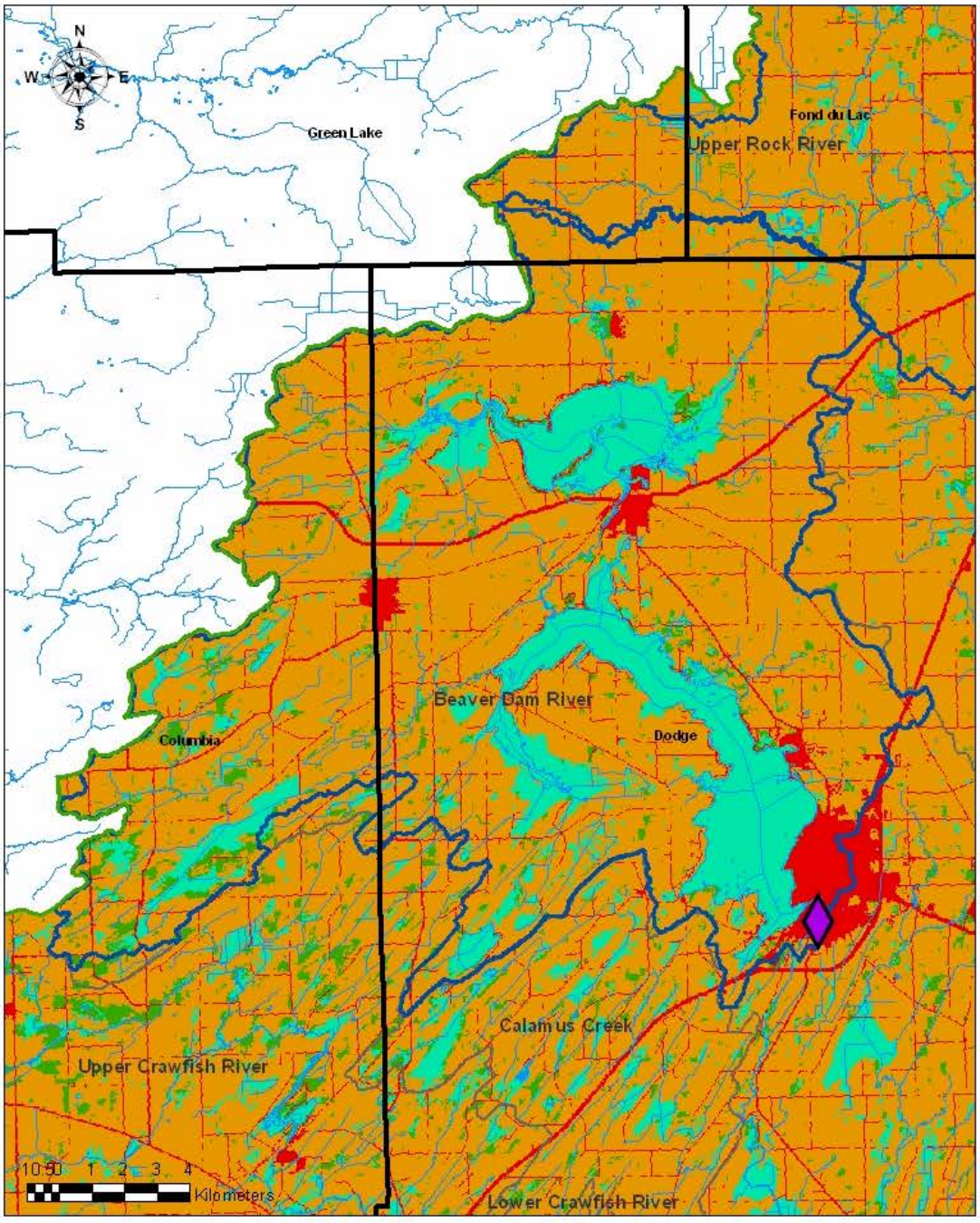
Bark River near Rome, Rock River Watershed

Federal National-Level Landcover, 2001



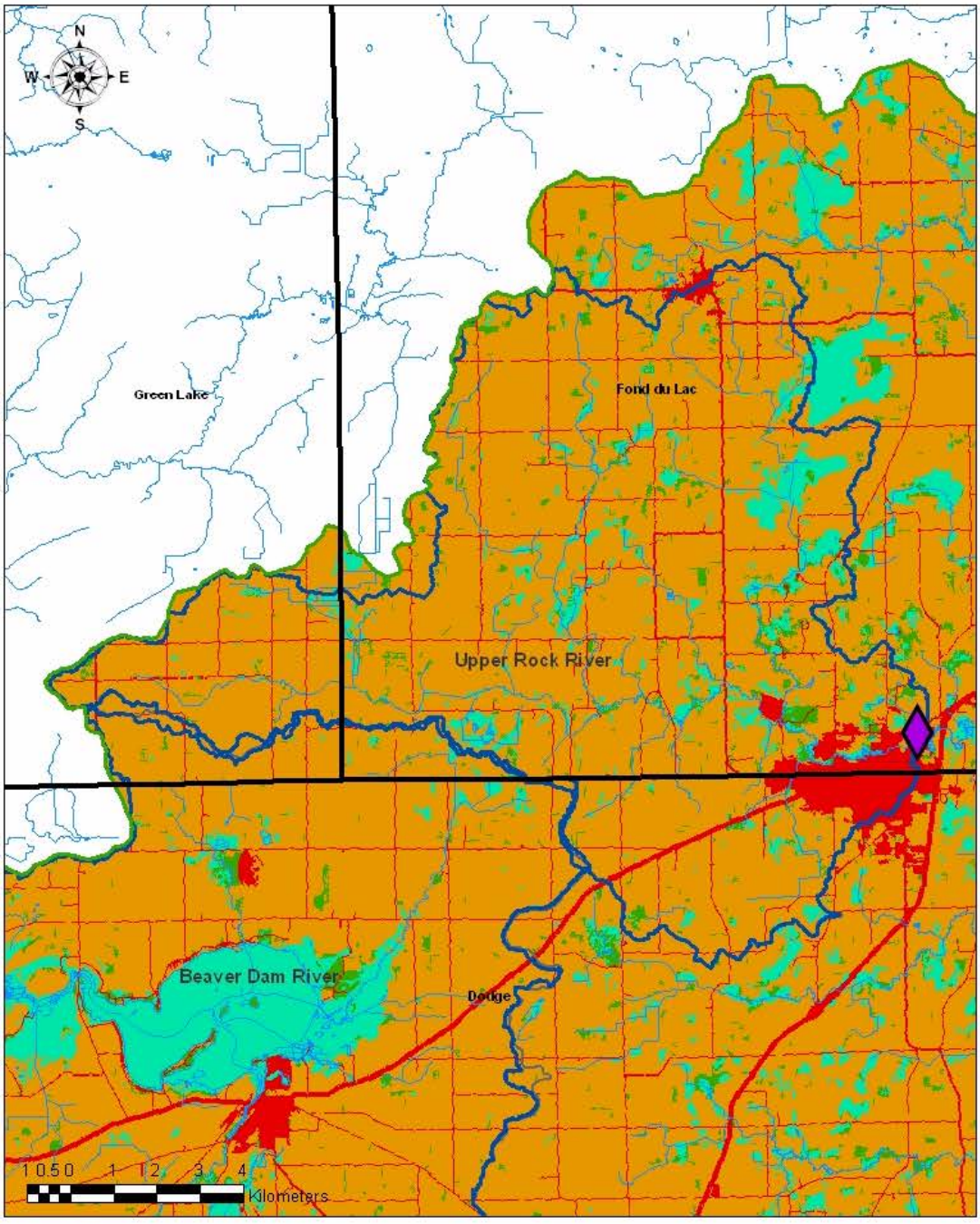
Beaver Dam at Beaver Dam, Rock River Watershed

Federal National-Level Landcover, 2001



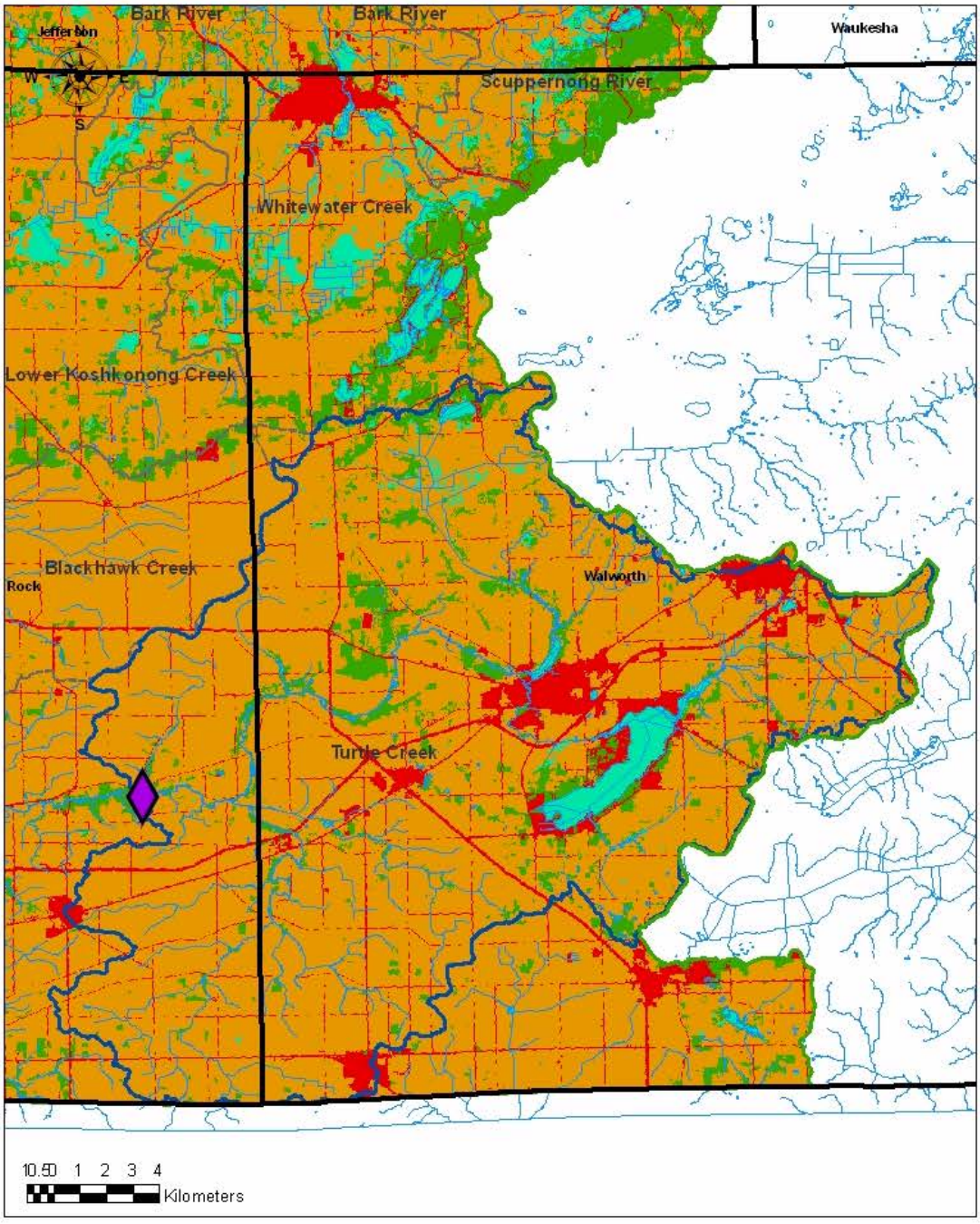
South Branch Rock River at Waupun, Rock River Watershed

Federal National-Level Landcover, 2001



Turtle Creek at Carvers Rock, Rock River Watershed

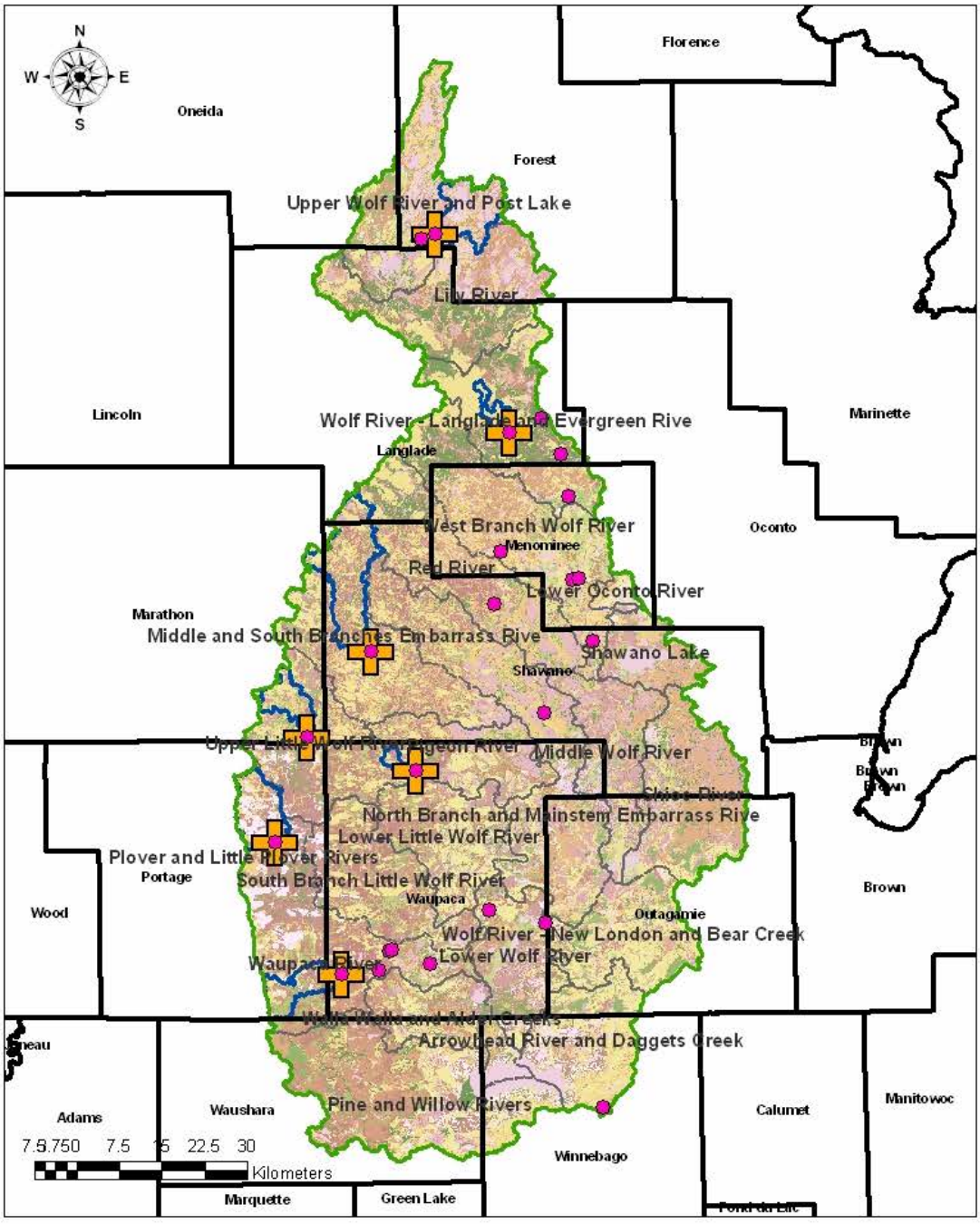
Federal National-Level Landcover, 2001



Appendix H: Soil Delineation, by site

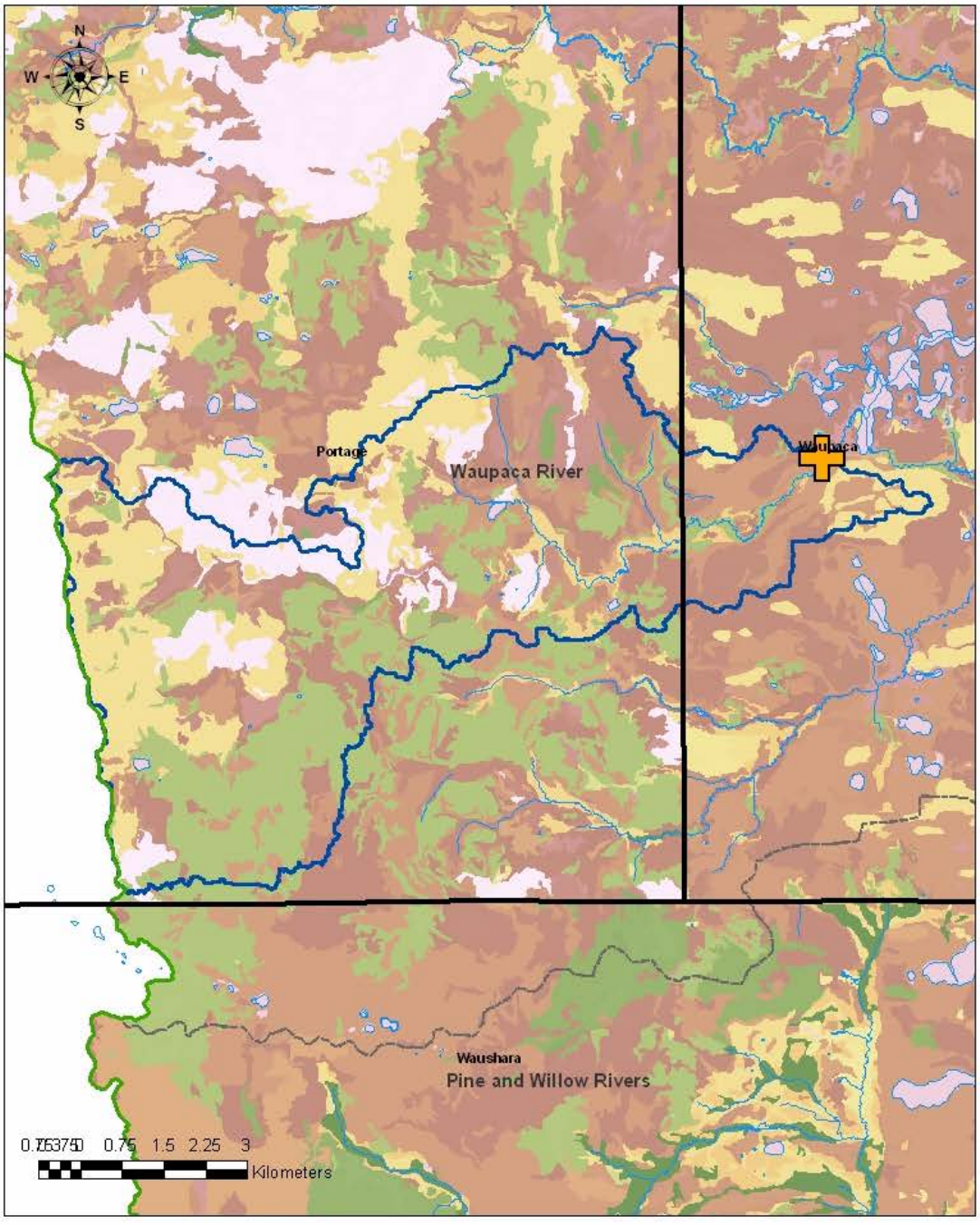
Wolf River Watershed

Soils



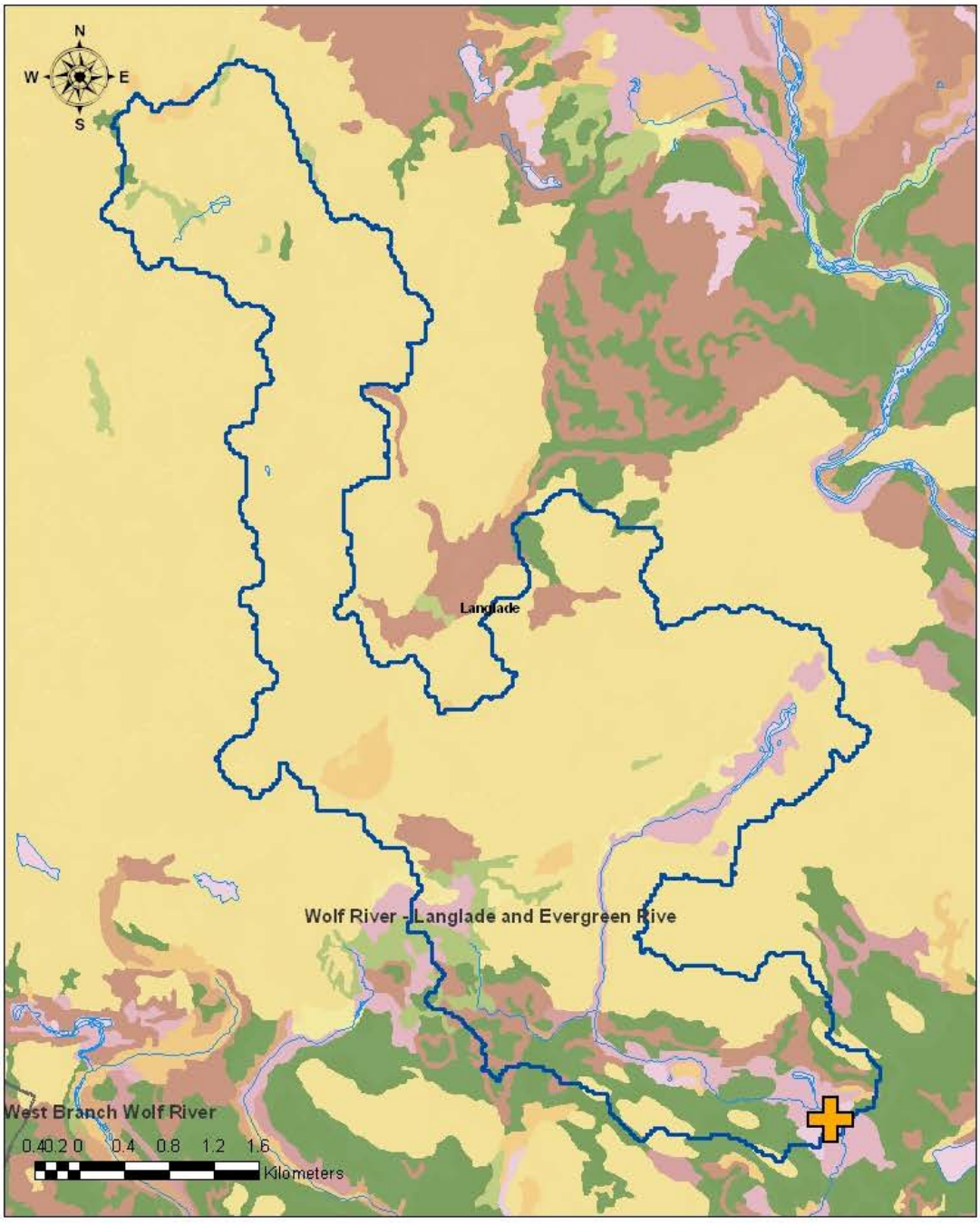
Emmons Creek at Rural, Wolf River Watershed

Soils



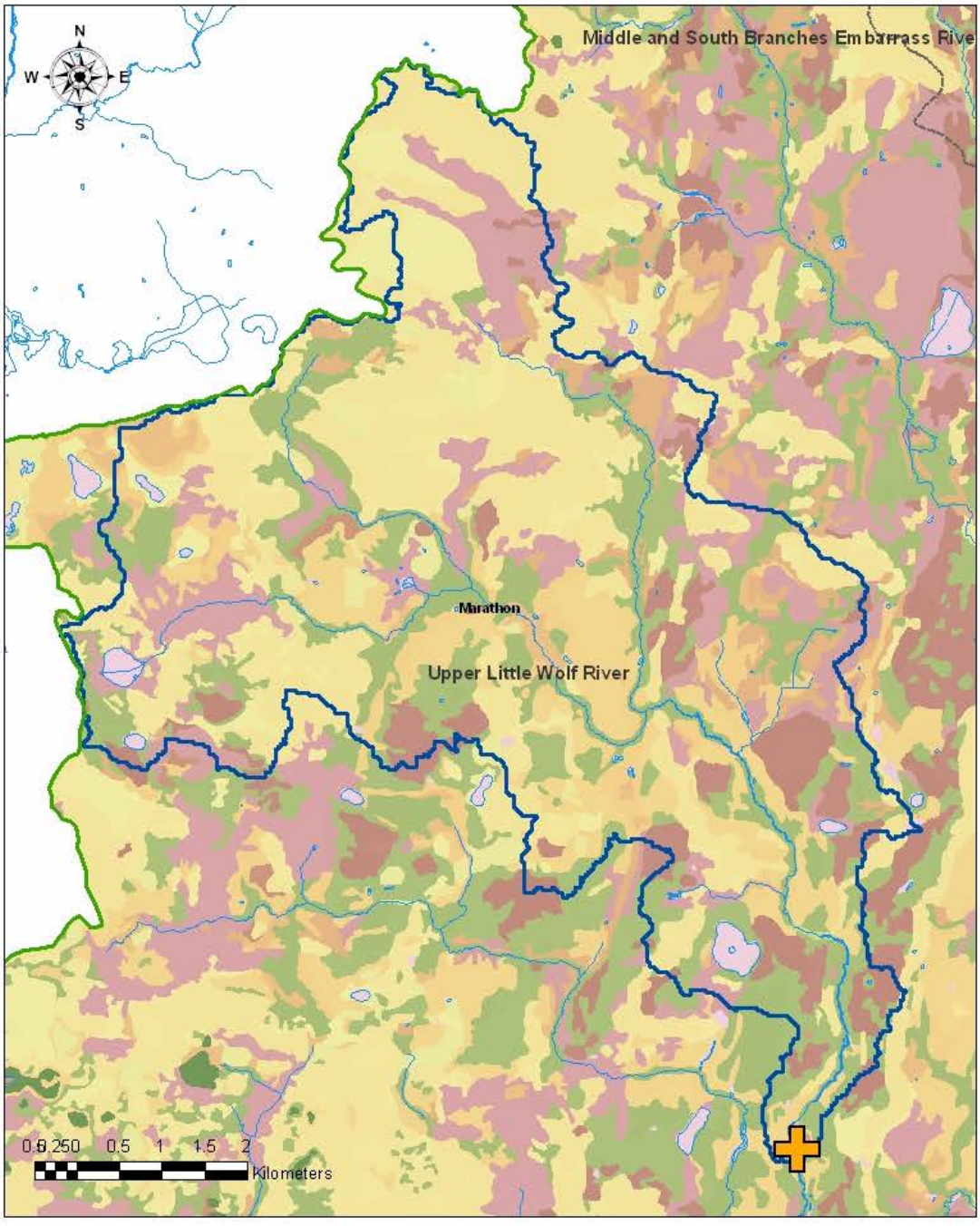
Evergreen River near Langlade, Wolf River Watershed

Soils



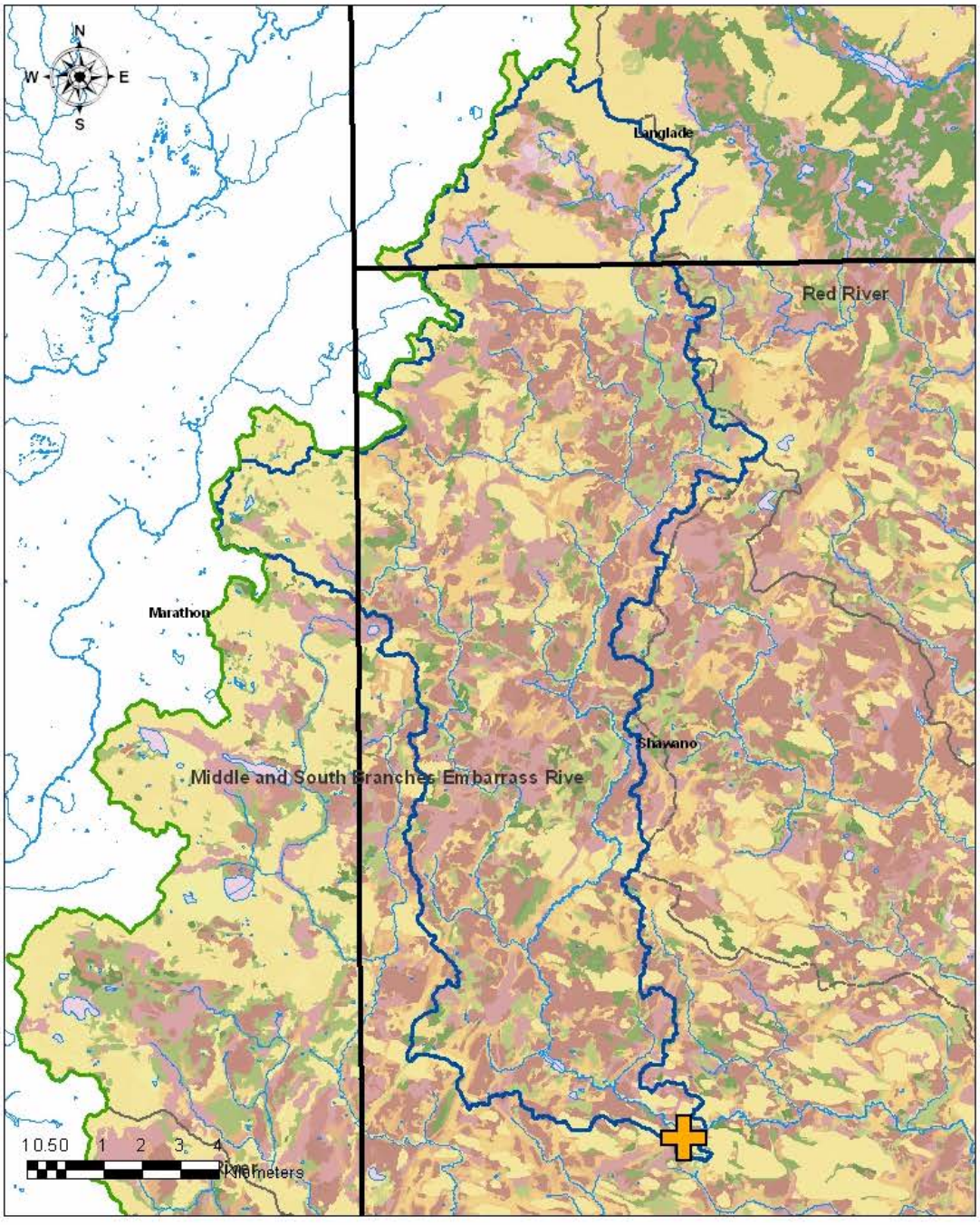
Little Wolf River near Galloway, Wolf River Watershed

Soils



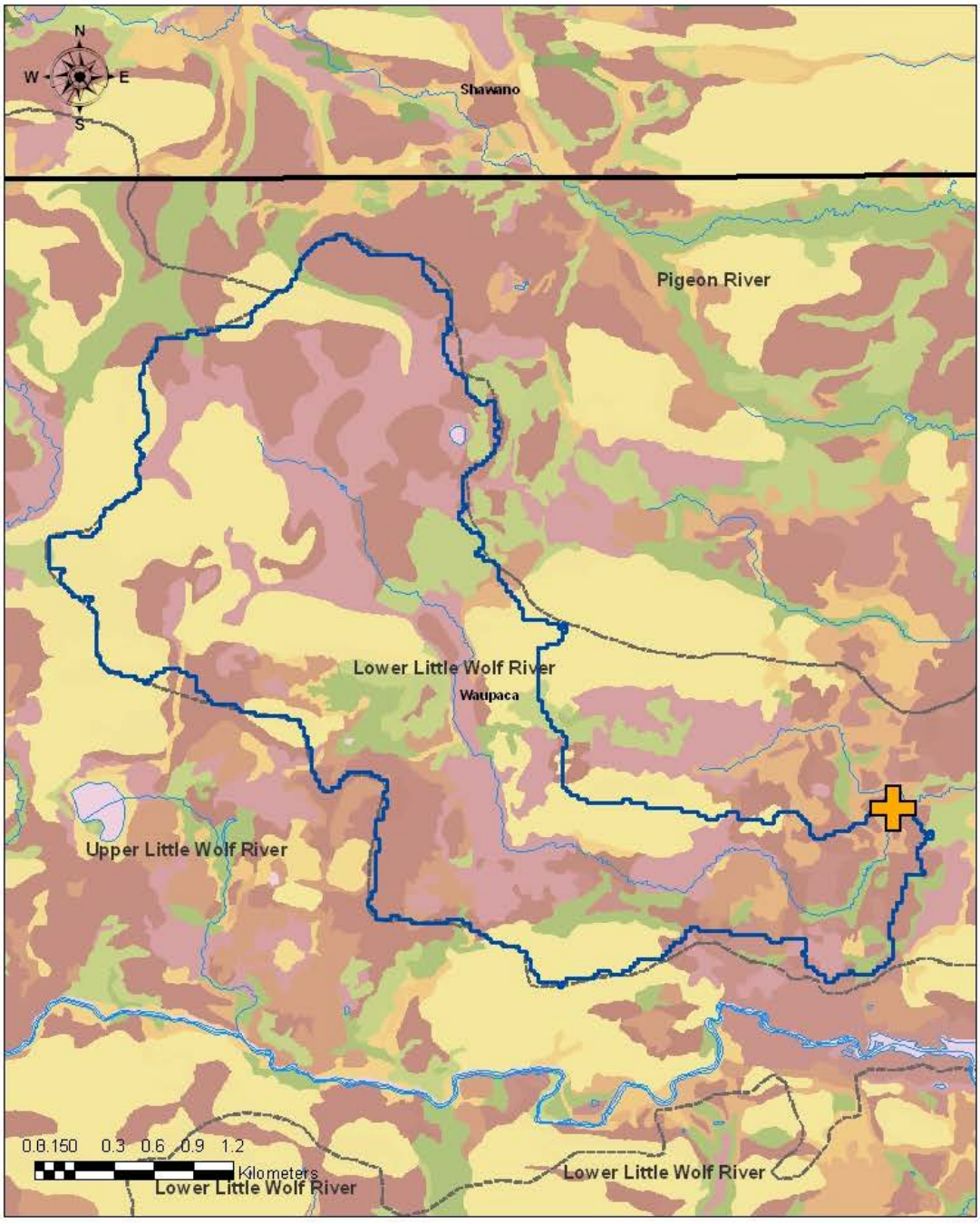
Middle Branch Embarrass River, Wolf River Watershed

Soils



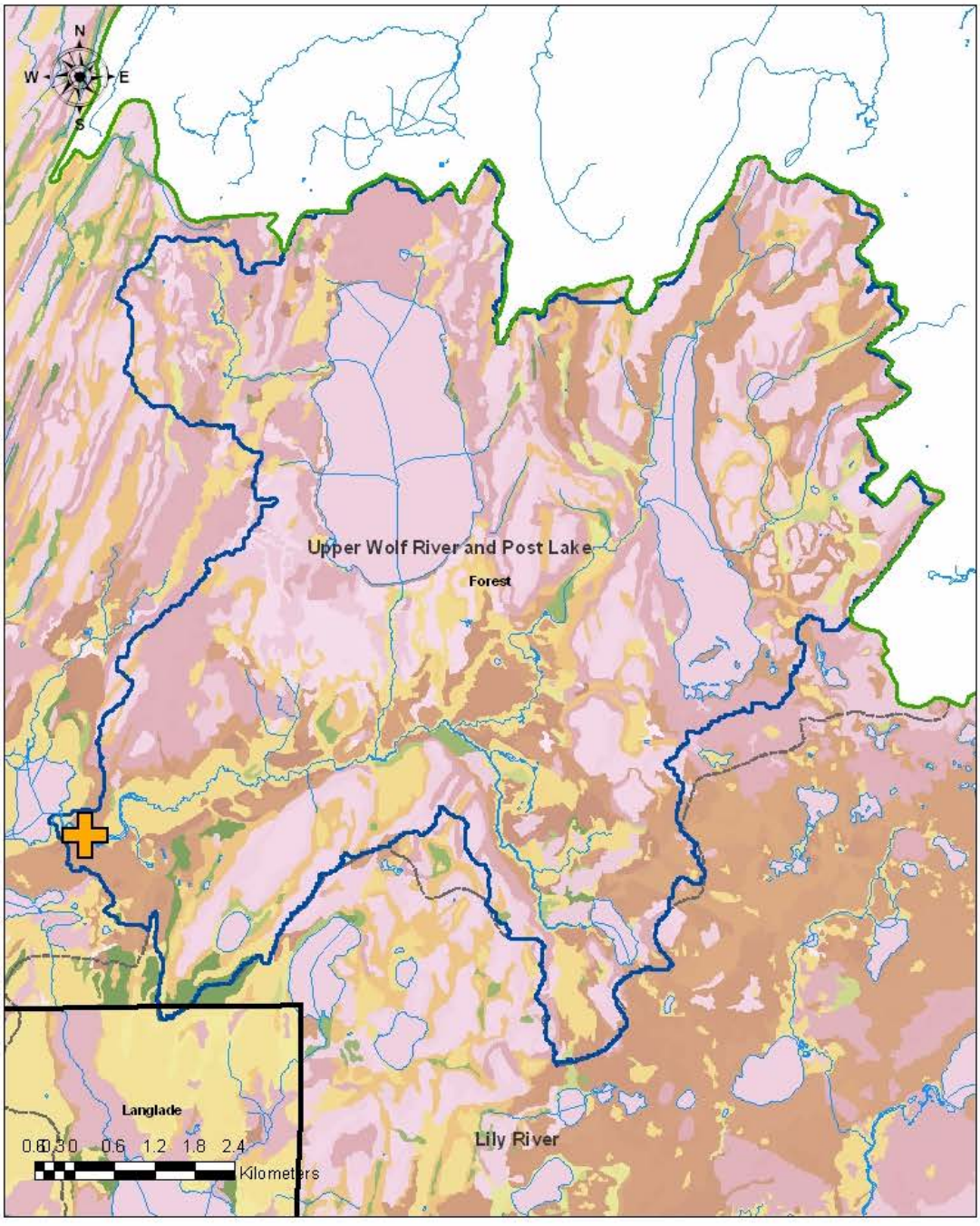
Spaulding Creek near Big Falls, Wolf River Watershed

Soils



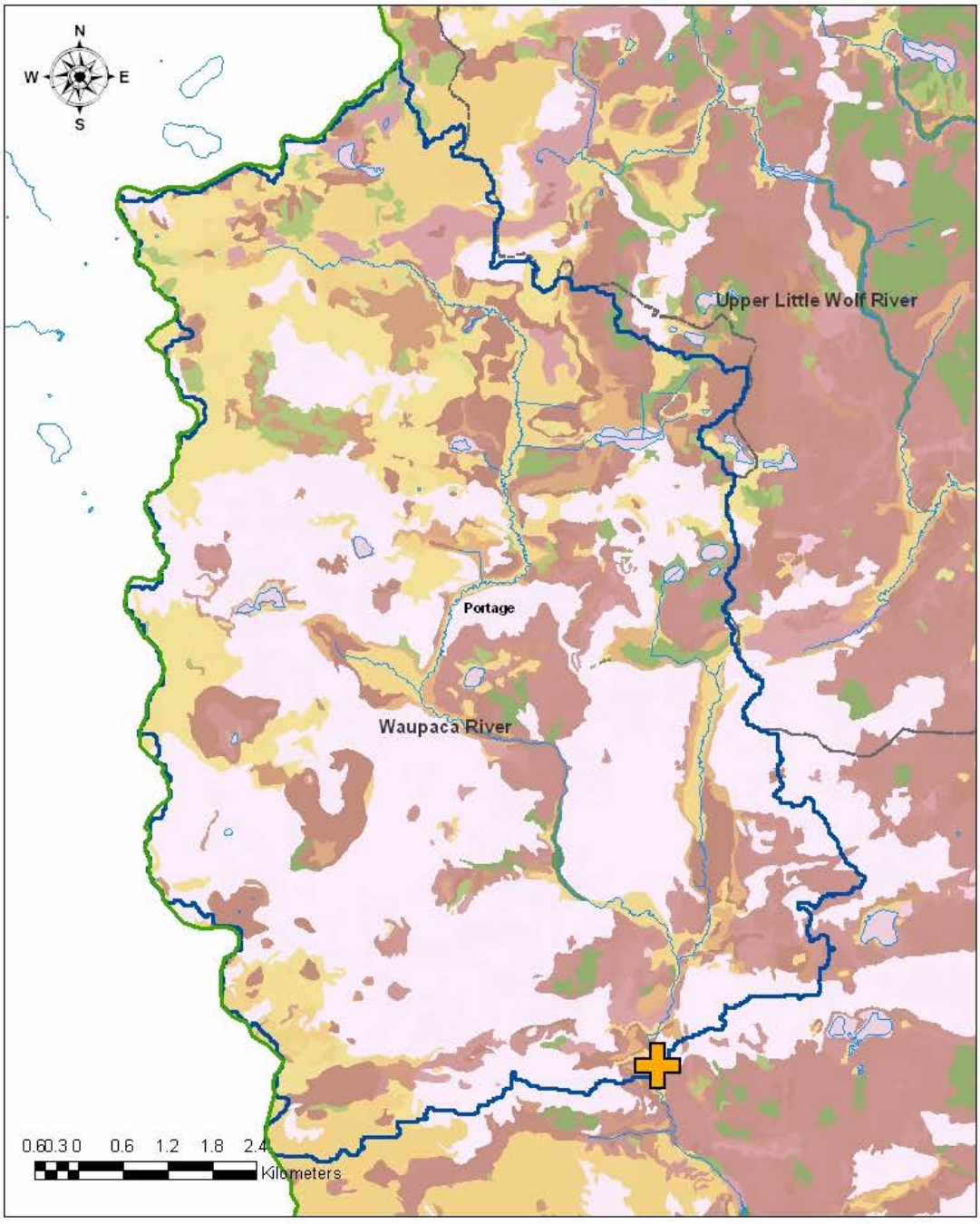
Swamp Creek above Mole Lake, Wolf River Watershed

Soils



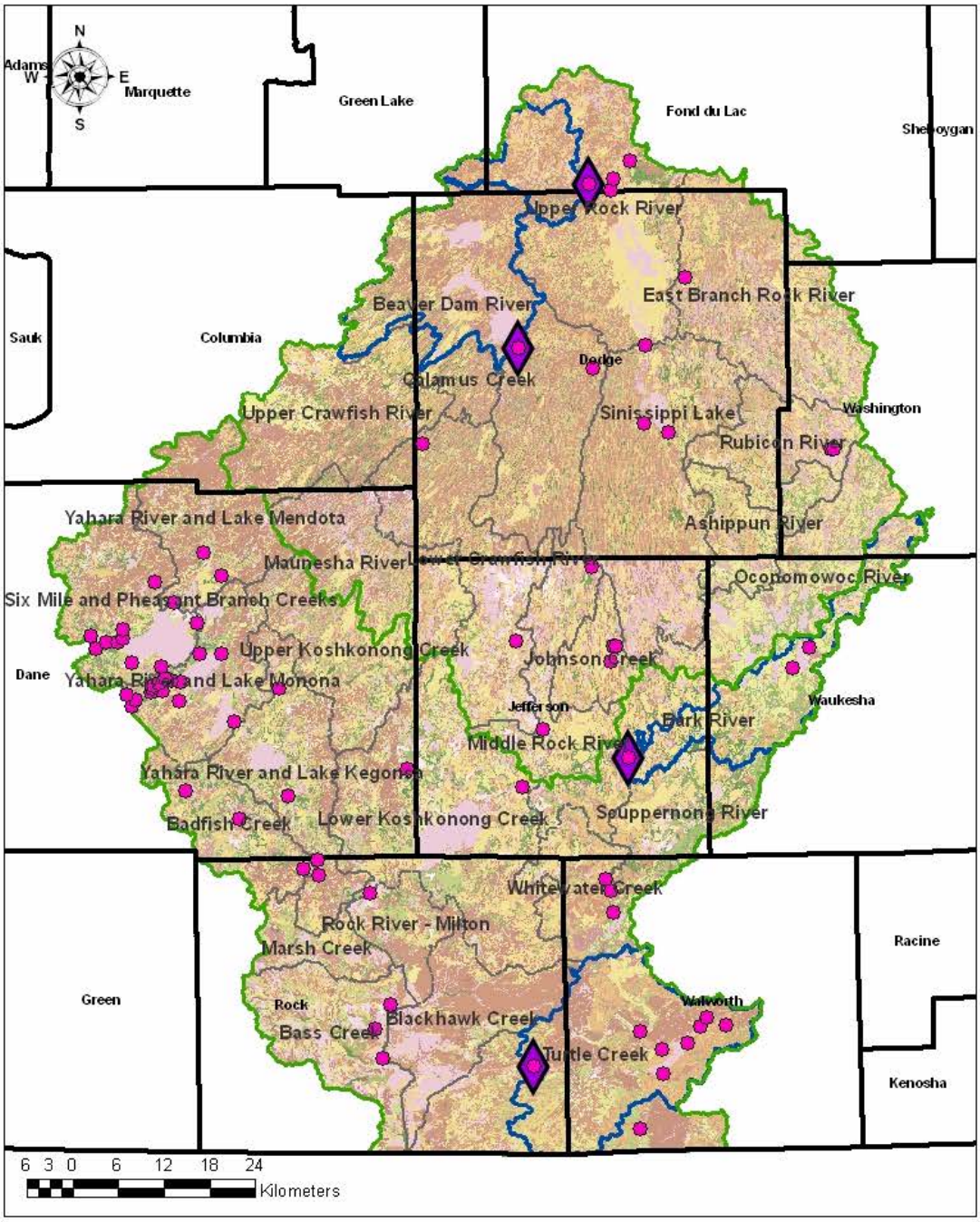
Tomorrow River near Nelsonville, Wolf River Watershed

Soils



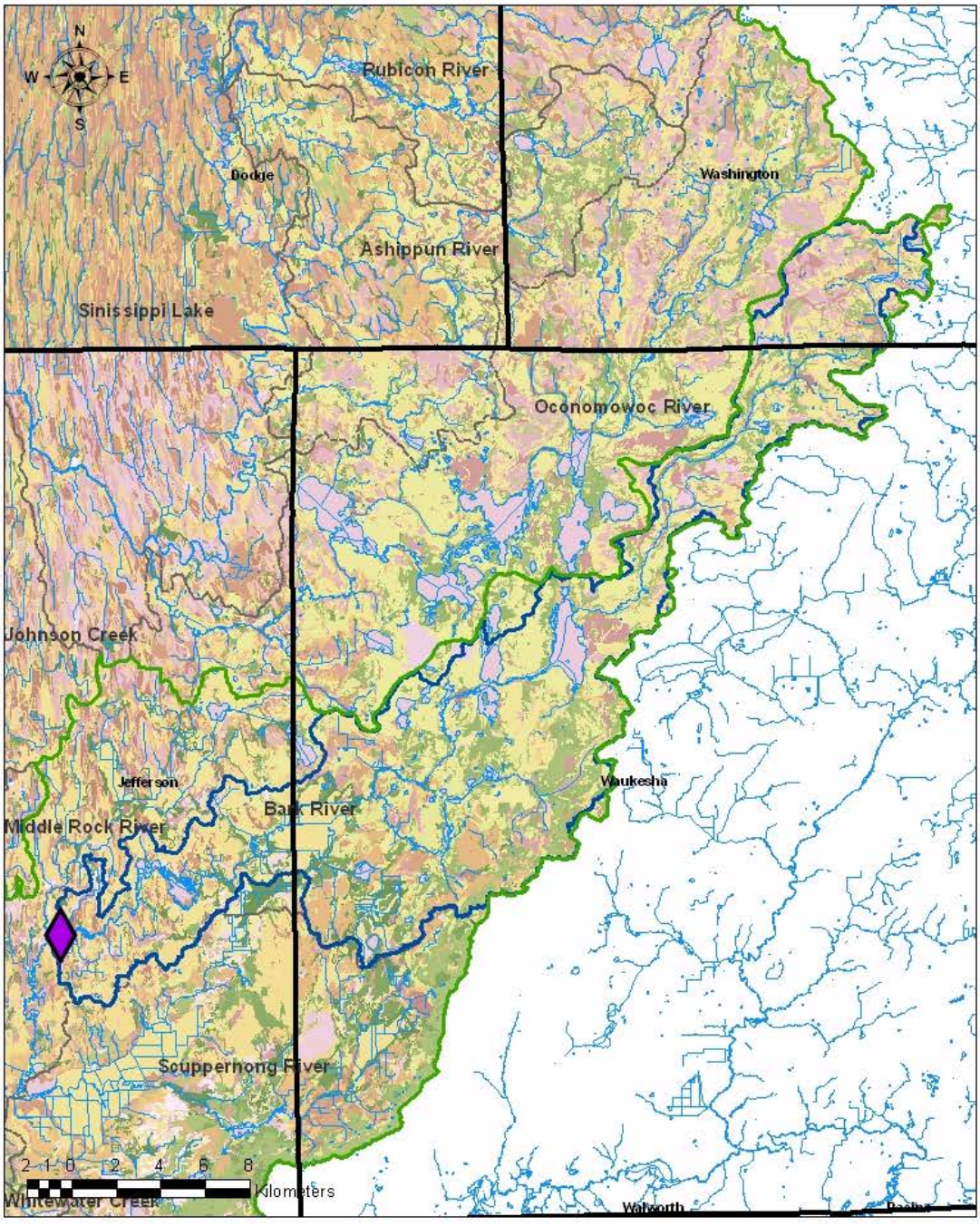
Rock River Watershed

Soils



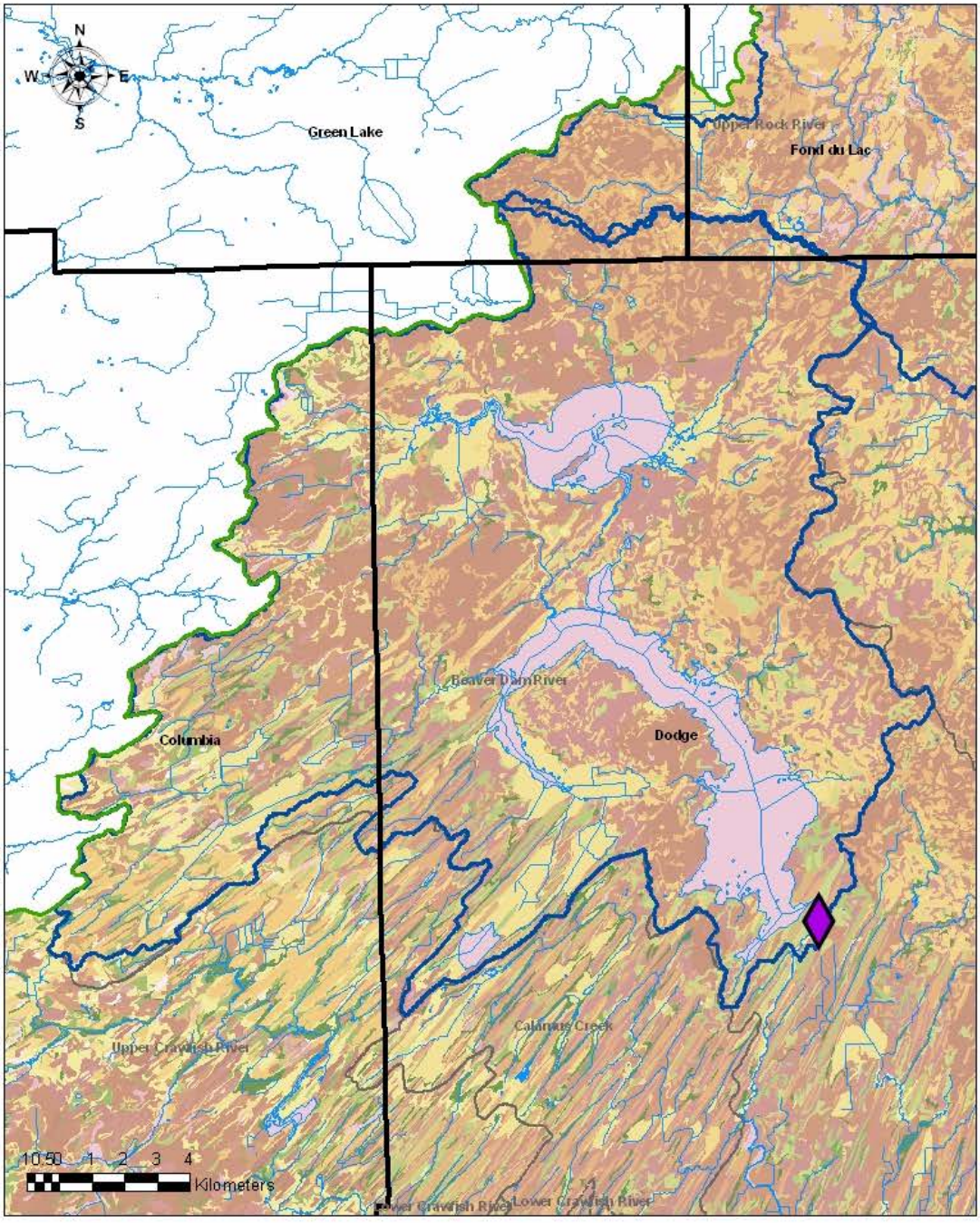
Bark River near Rome, Rock River Watershed

Soils

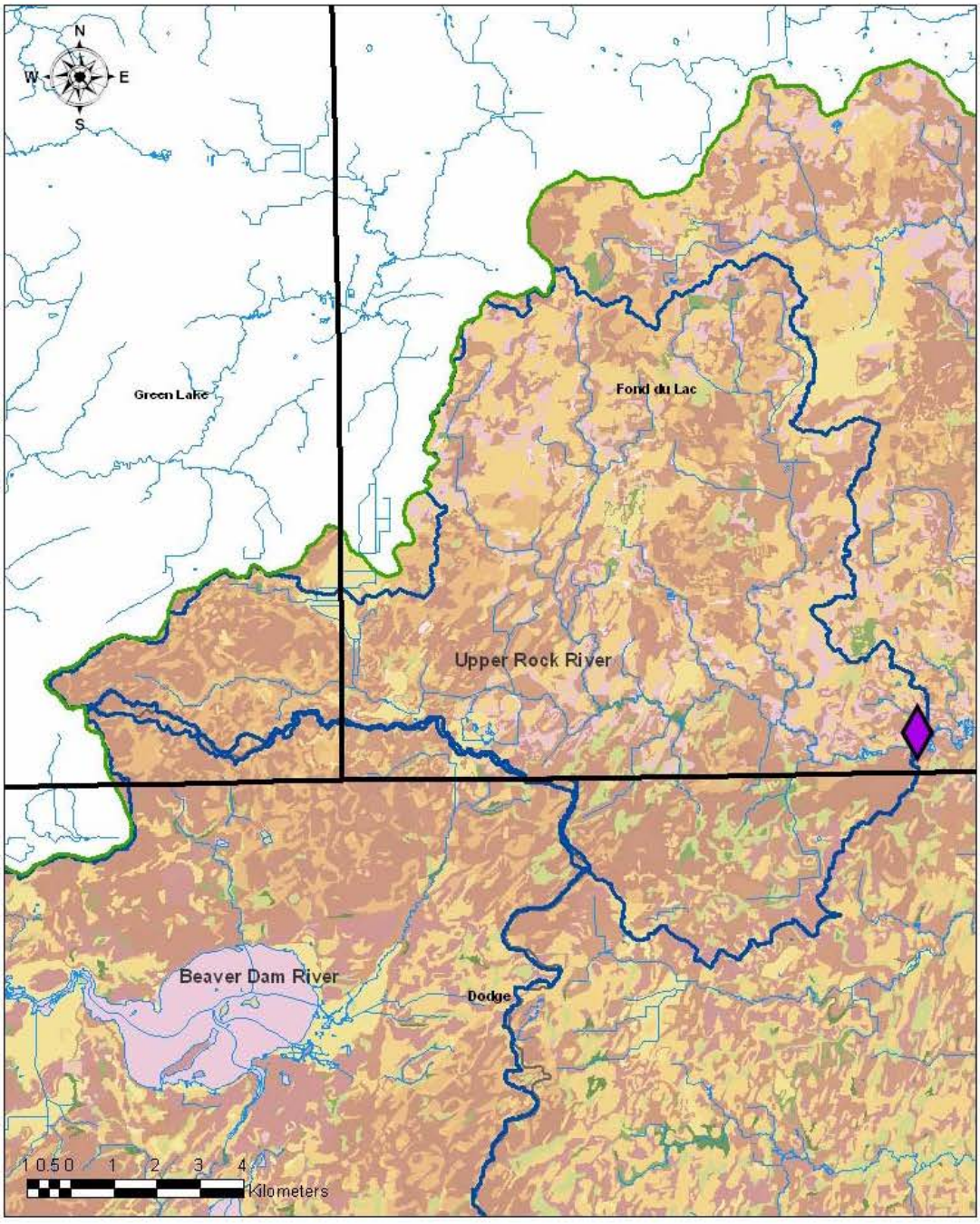


Beaver Dam at Beaver Dam, Rock River Watershed

Soils

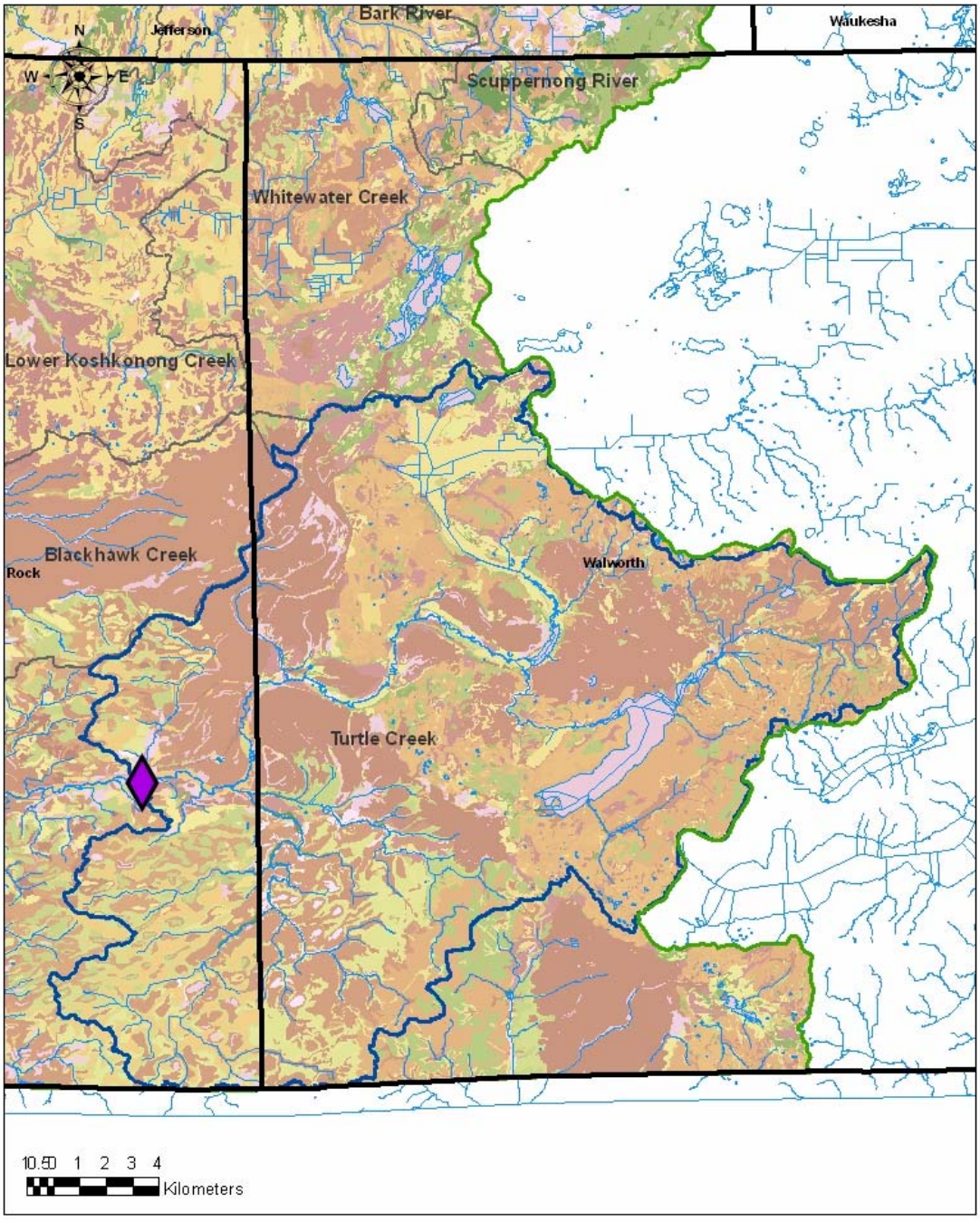


South Branch Rock River at Waupun, Rock River Watershed
Soils

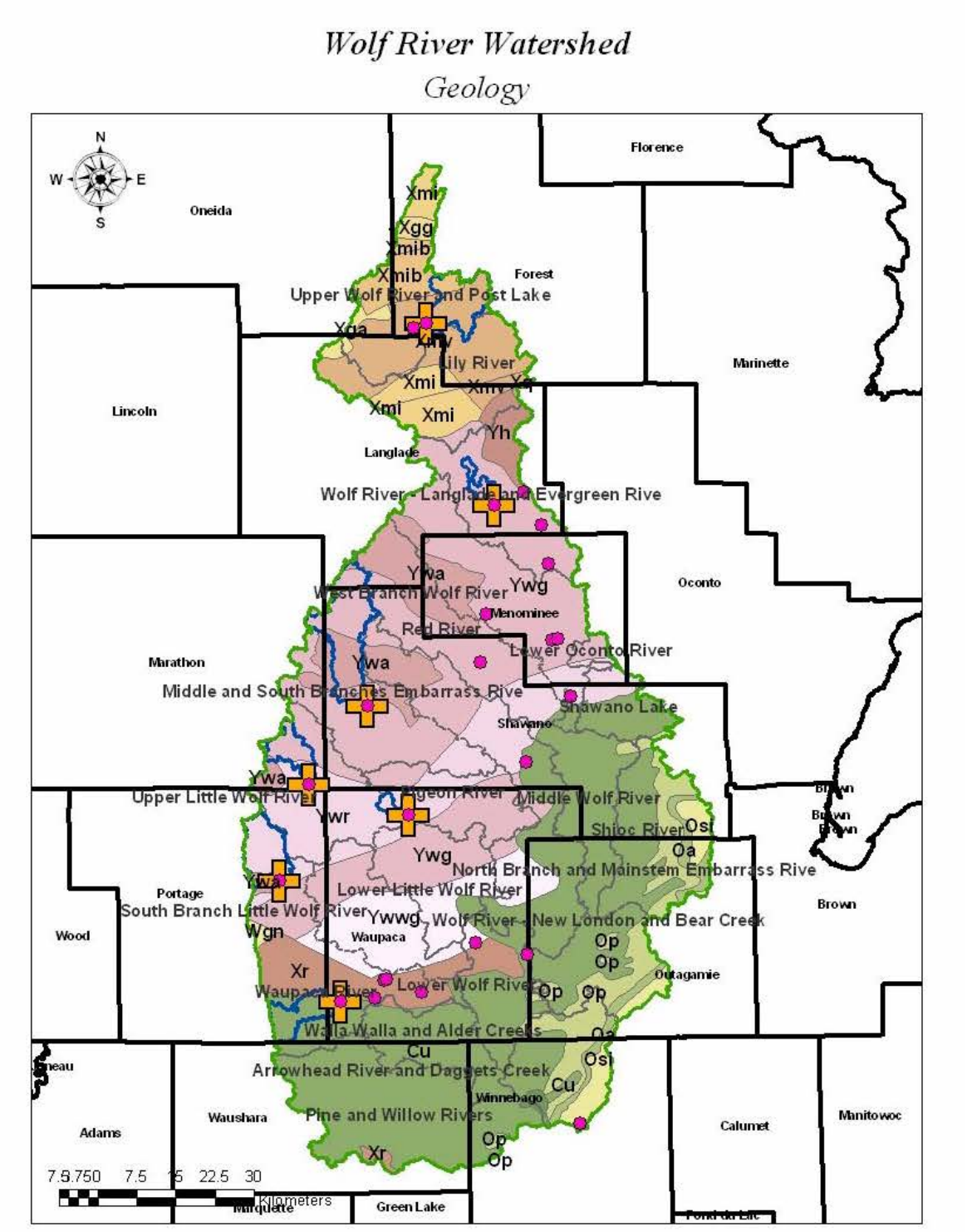


Turtle Creek at Carvers Rock, Rock River Watershed

Soils

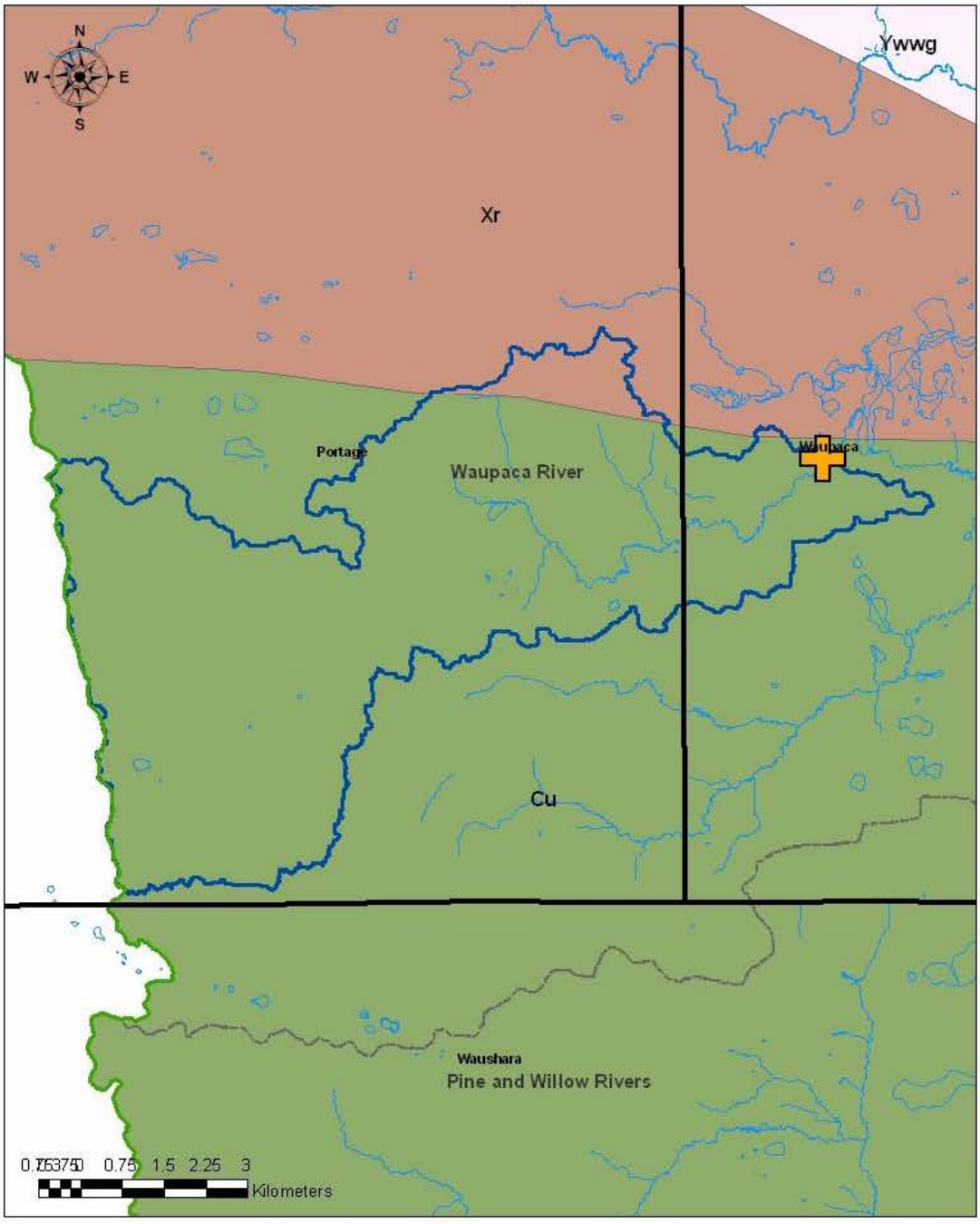


Appendix I: Geology Delineation, by site


Wolf River Watershed
Geology
N
W
E
S
Florence
Oneida
Forest
Upper Wolf River and Post Lake
Marinette
Lily River
Lincoln
Langlade
Wolf River - Langlade and Evergreen Rive
Oconto
West Branch Wolf River
Menominee
Red River
Lower Oconto River
Marathon
Middle and South Branches Embarrass Rive
Shawano Lake
Shawano
Upper Little Wolf River
Pigeon River
Middle Wolf River
Shioc River
Brown
Portage
Lower Little Wolf River
North Branch and Mainstem Embarrass Rive
South Branch Little Wolf River
Wolf River - New London and Bear Creek
Wood
Waupaca
Outagamie
Lower Wolf River
Walla Walla and Alder Creeks
Arrowhead River and Daggets Creek
Winnebago
Pine and Willow Rivers
Waushara
Adams
Calumet
Manitowoc
Green Lake
Kilometers

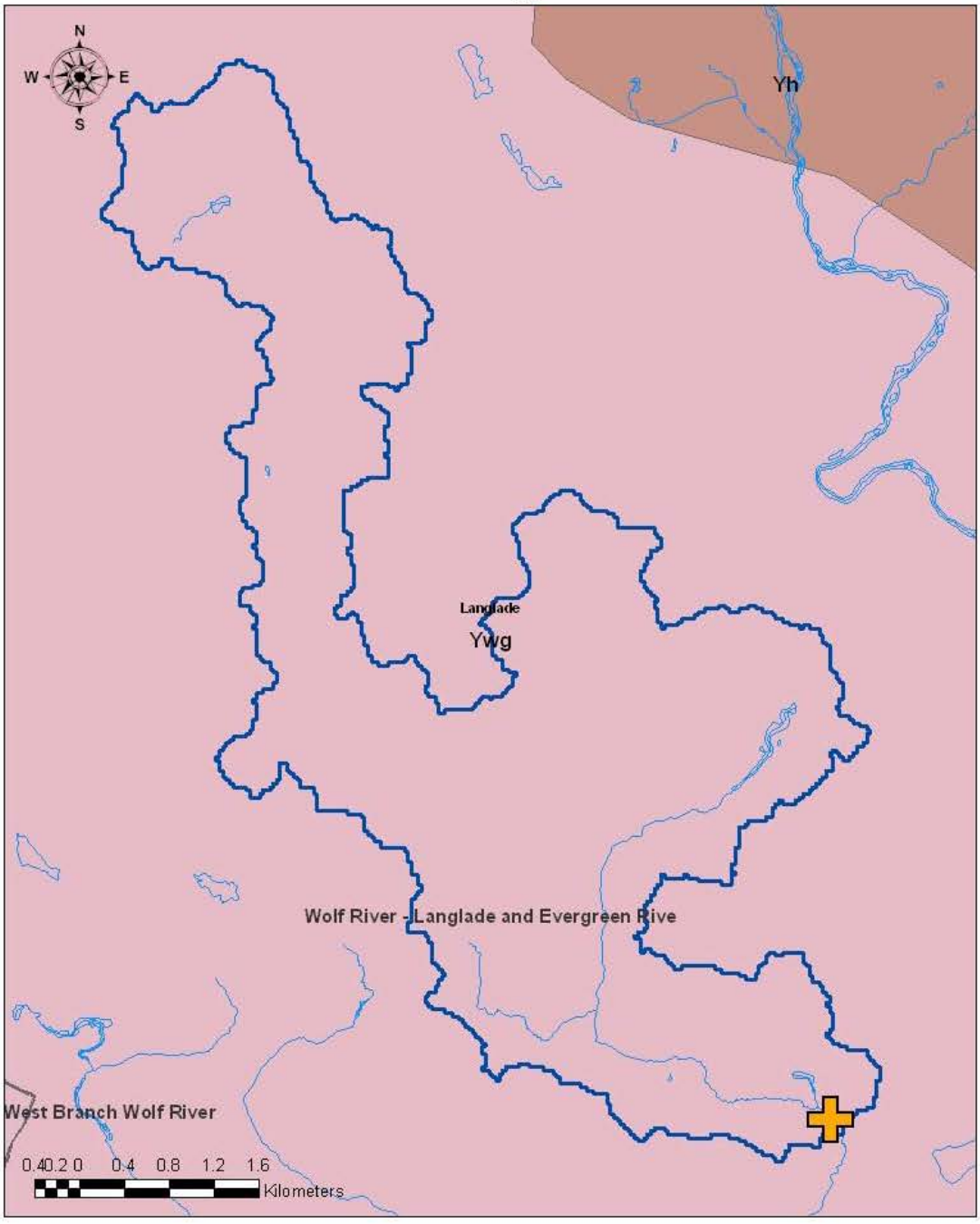
Emmons Creek at Rural, Wolf River Watershed

Geology



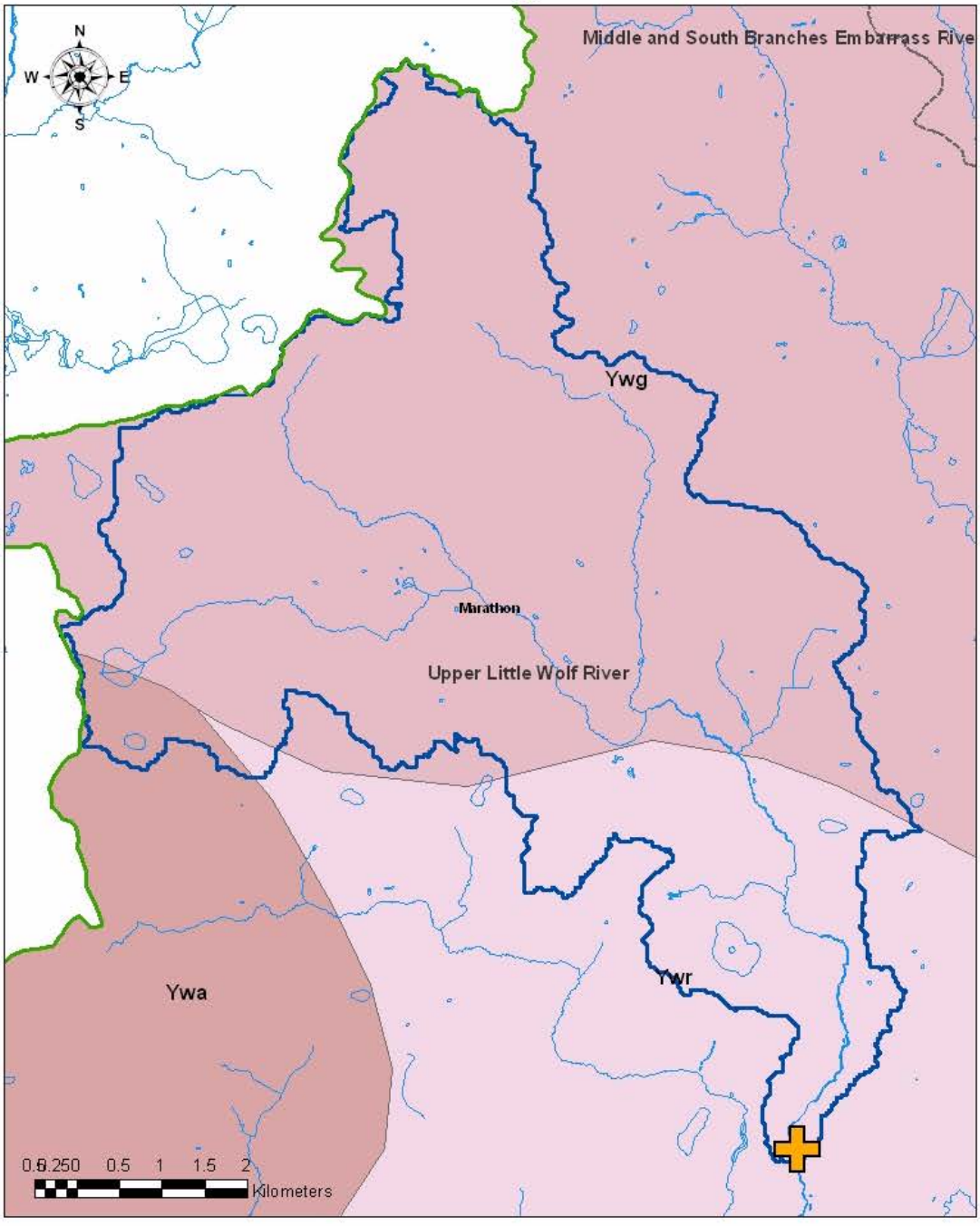
Evergreen River near Langlade, Wolf River Watershed

Geology



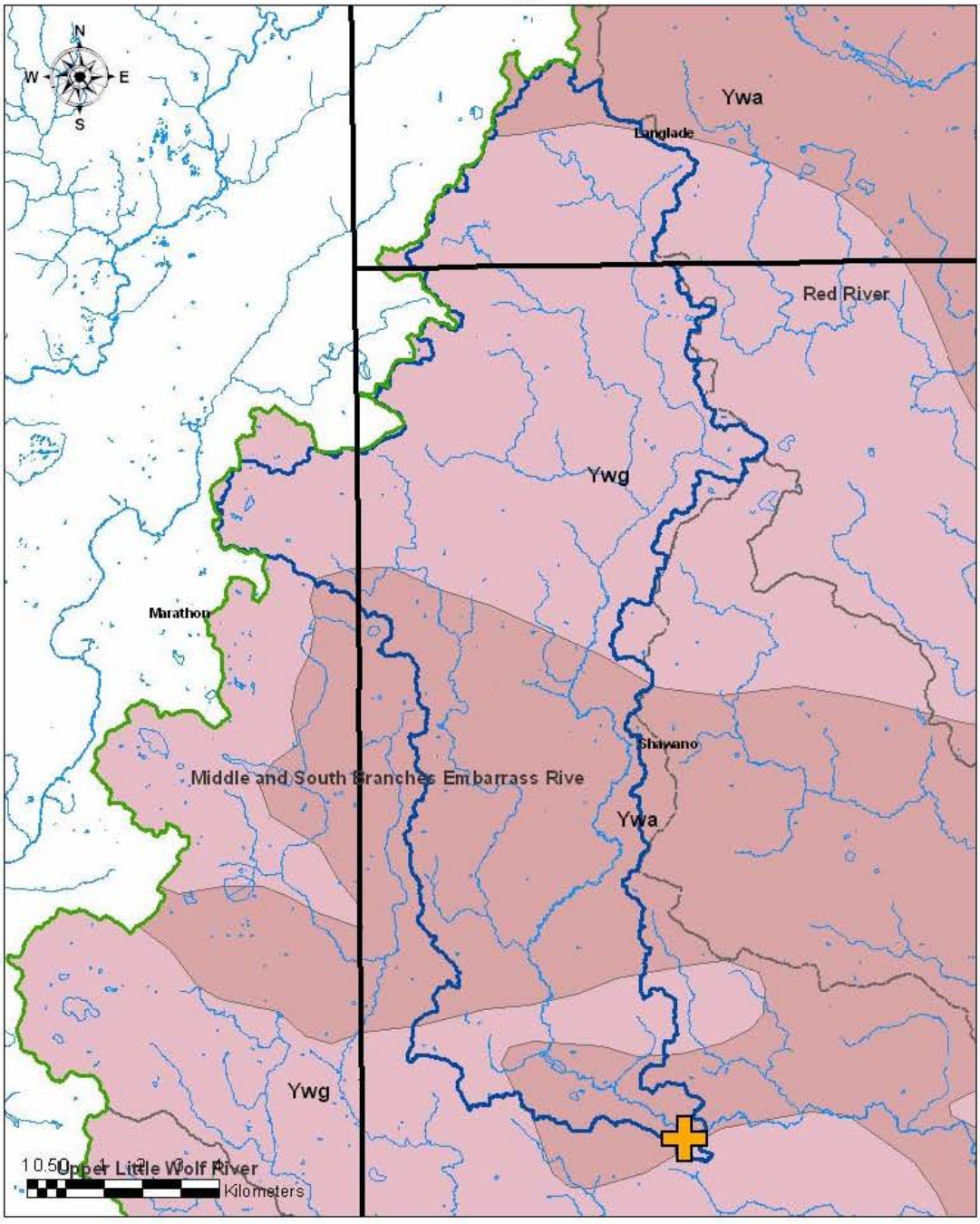
Little Wolf River near Galloway, Wolf River Watershed

Geology



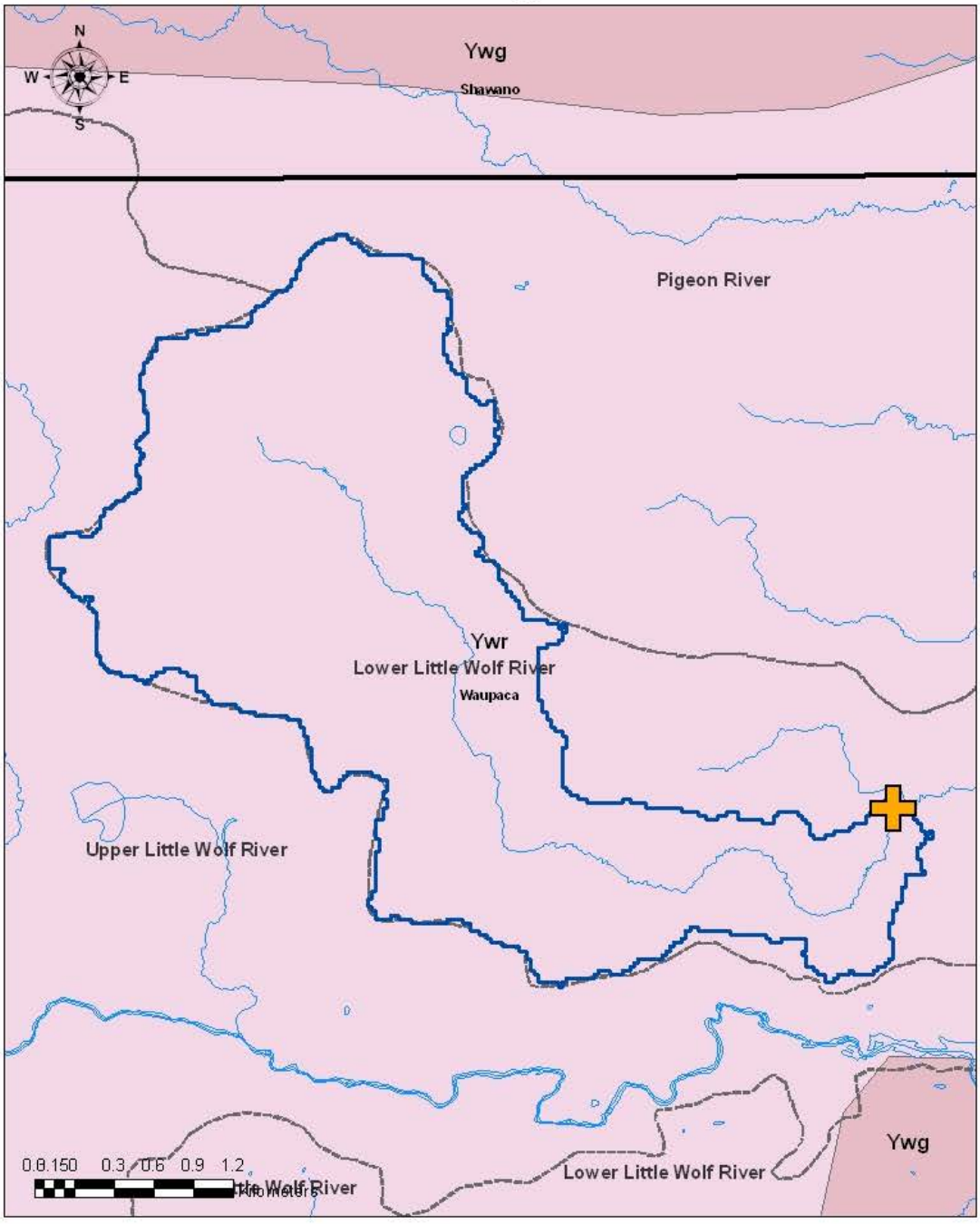
Middle Branch Embarrass River, Wolf River Watershed

Geology



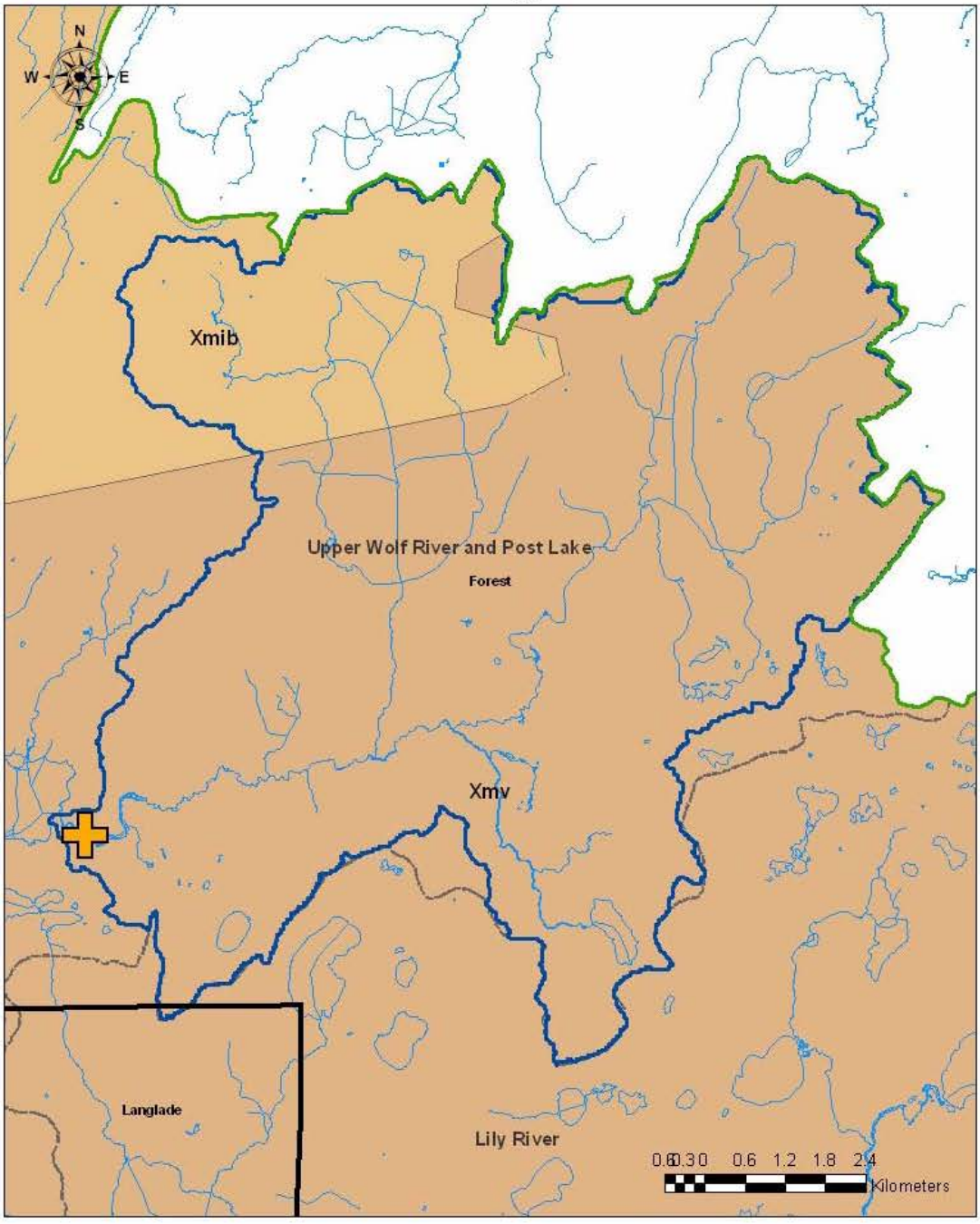
Spaulding Creek near Big Falls, Wolf River Watershed

Geology



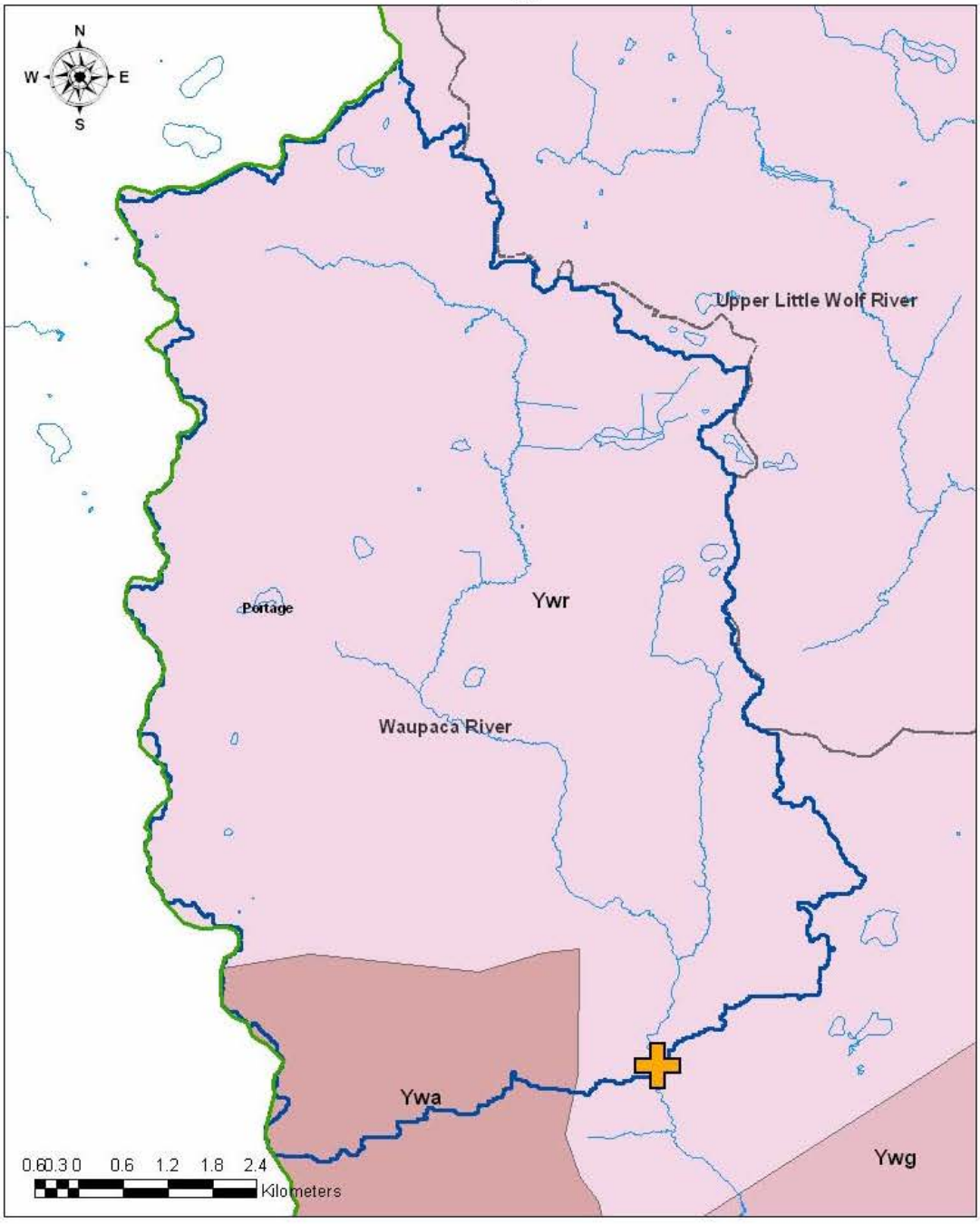
Swamp Creek above Mole Lake, Wolf River Watershed

Geology



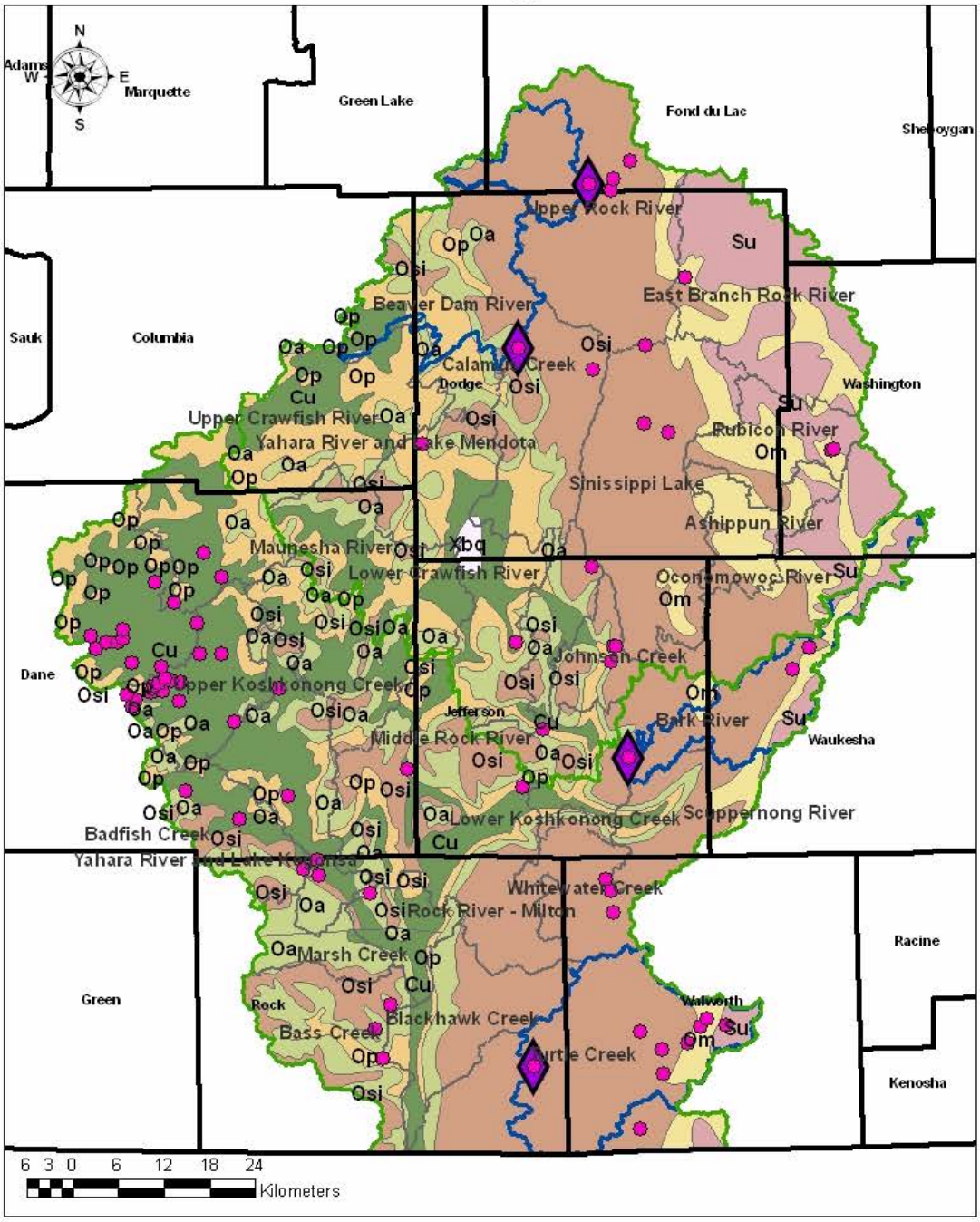
Tomorrow River near Nelsonville, Wolf River Watershed

Geology



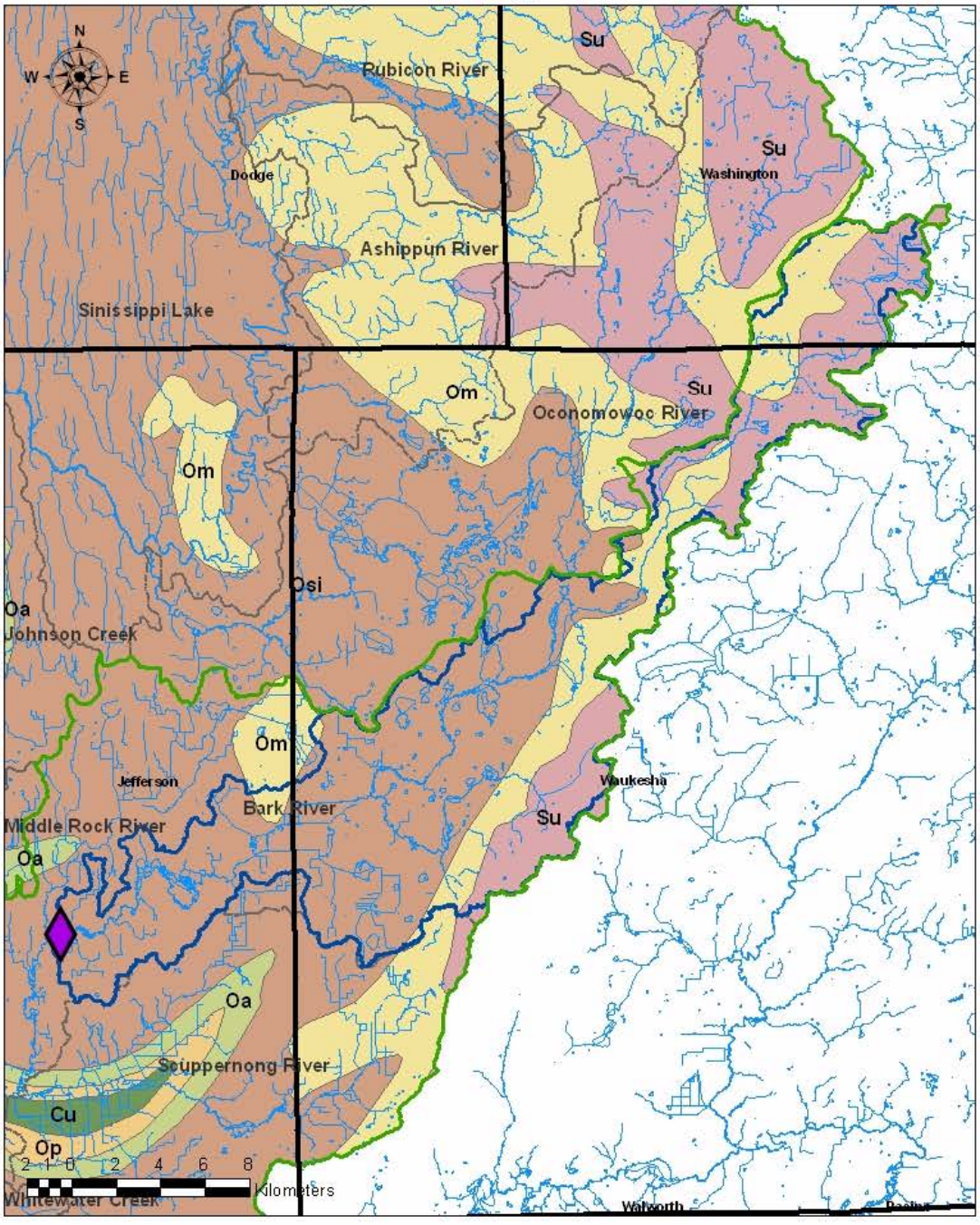
Rock River Watershed

Geology



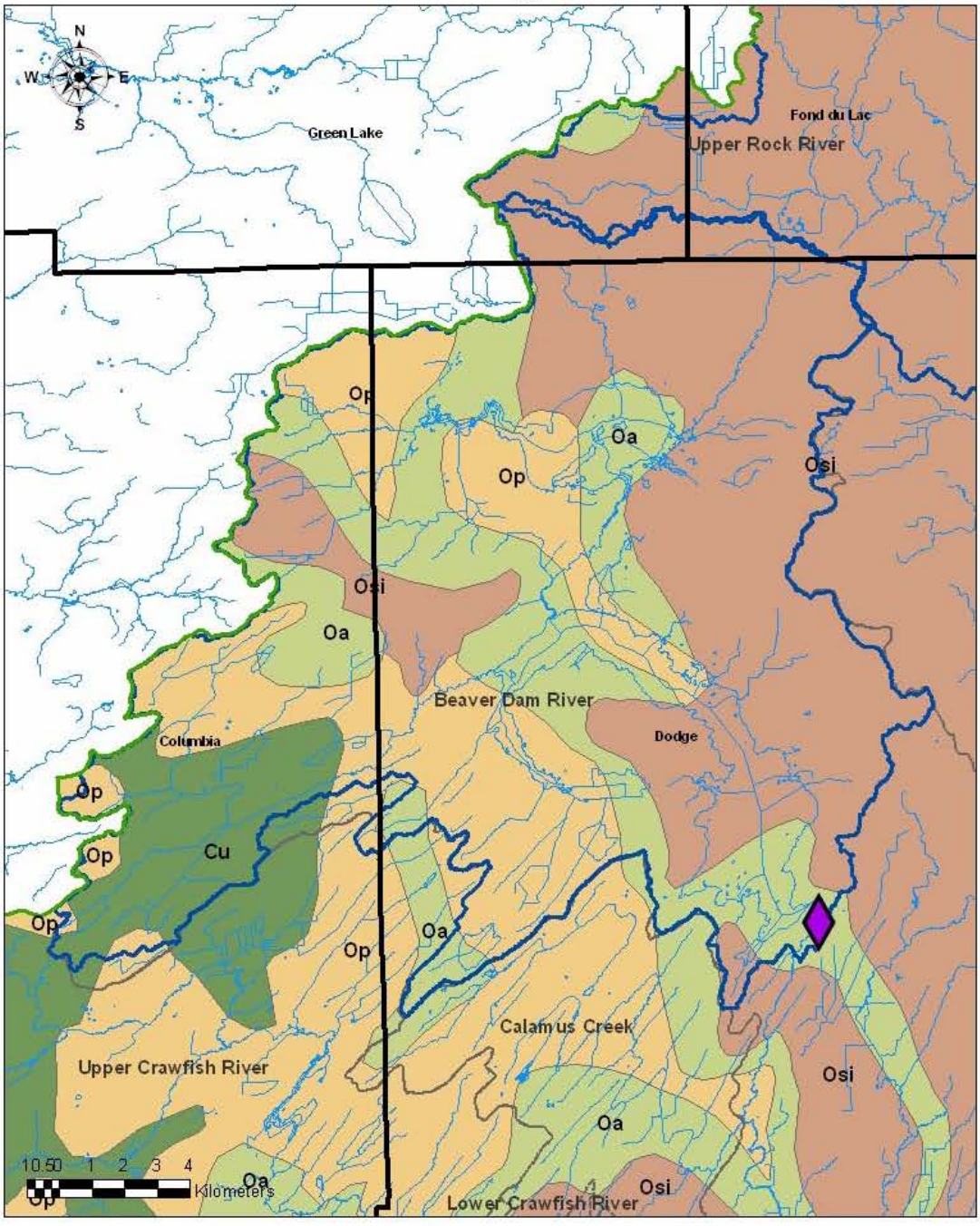
Bark River near Rome, Rock River Watershed

Geology



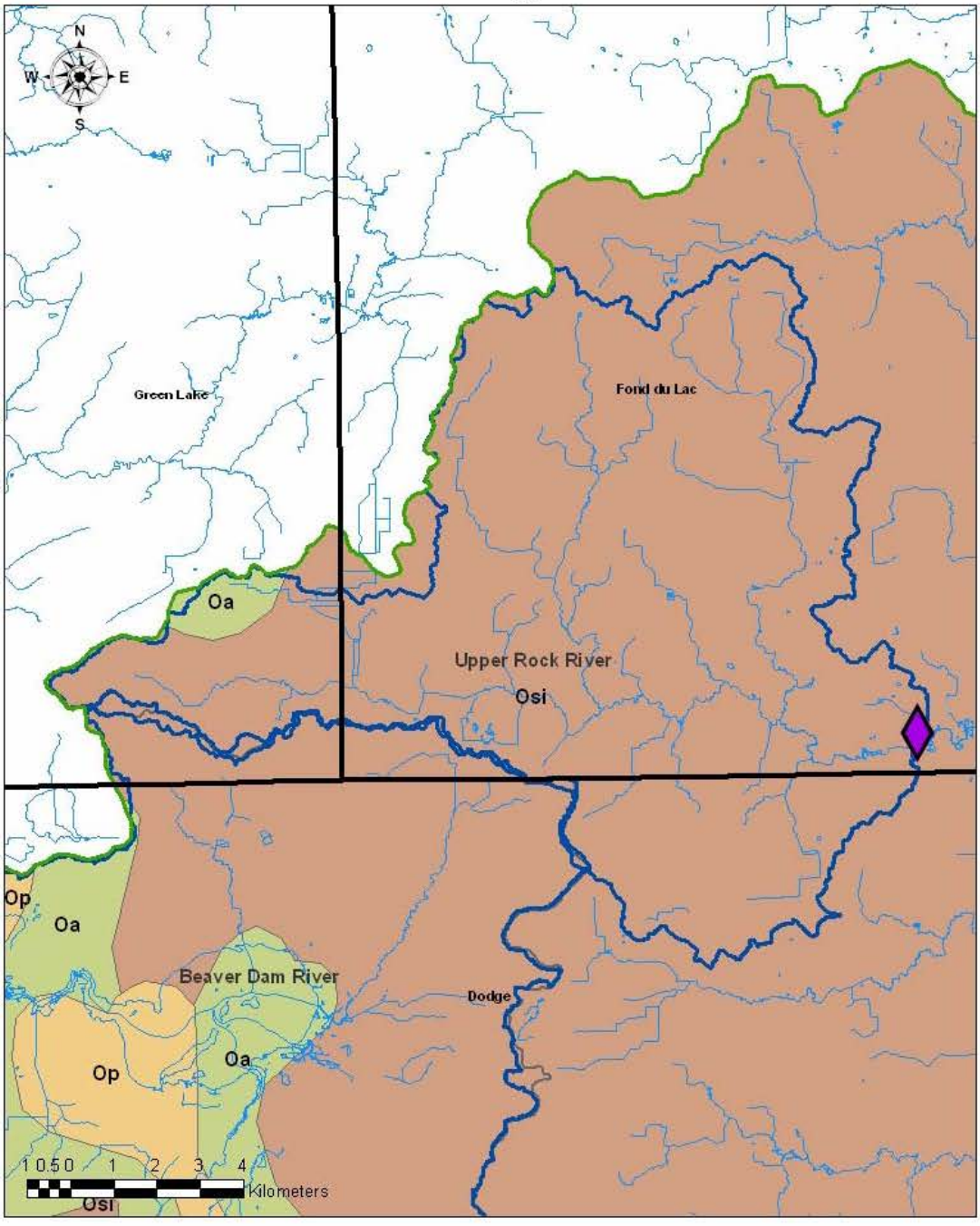
Beaver Dam at Beaver Dam, Rock River Watershed

Geology



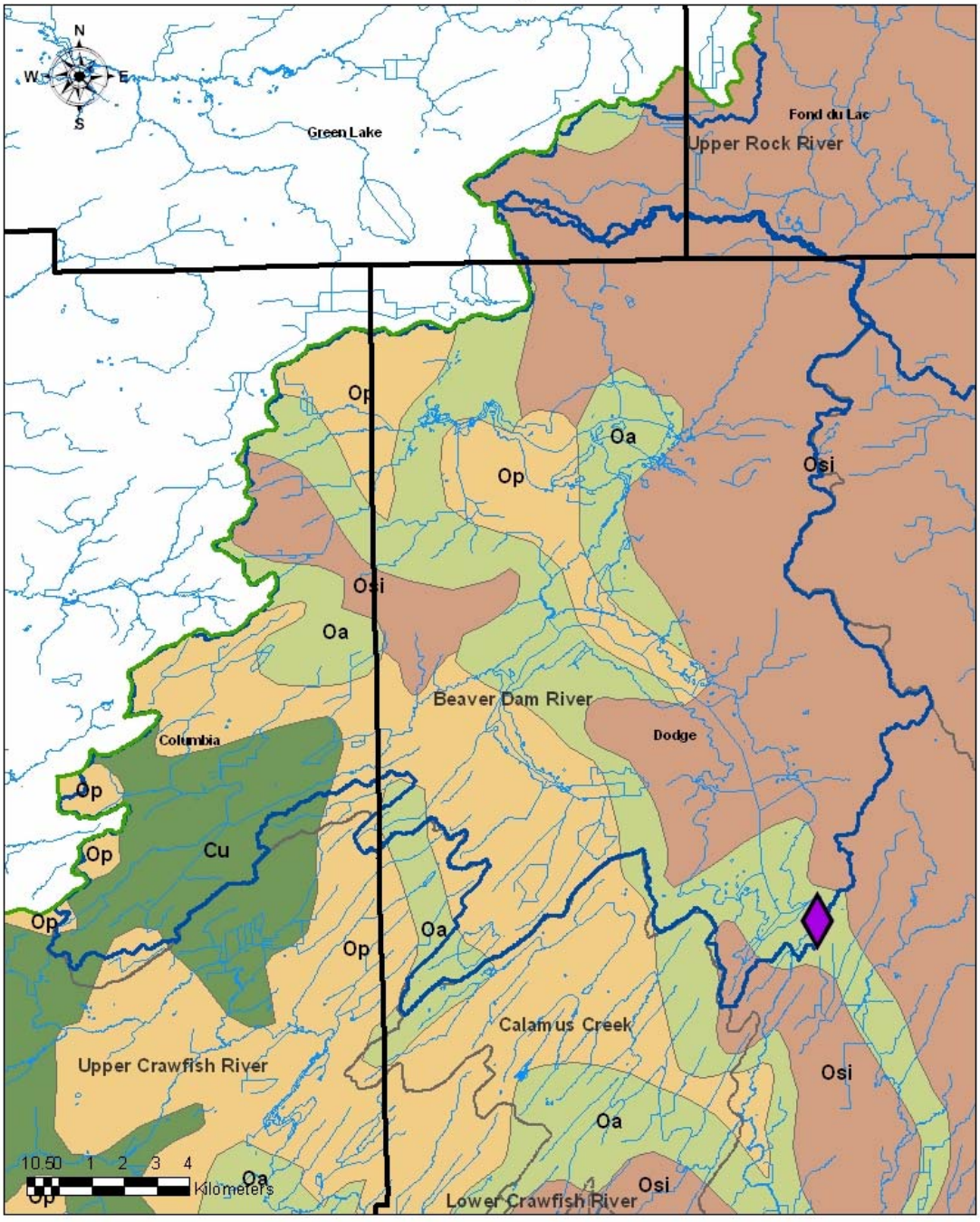
South Branch Rock River at Waupun, Rock River Watershed

Geology



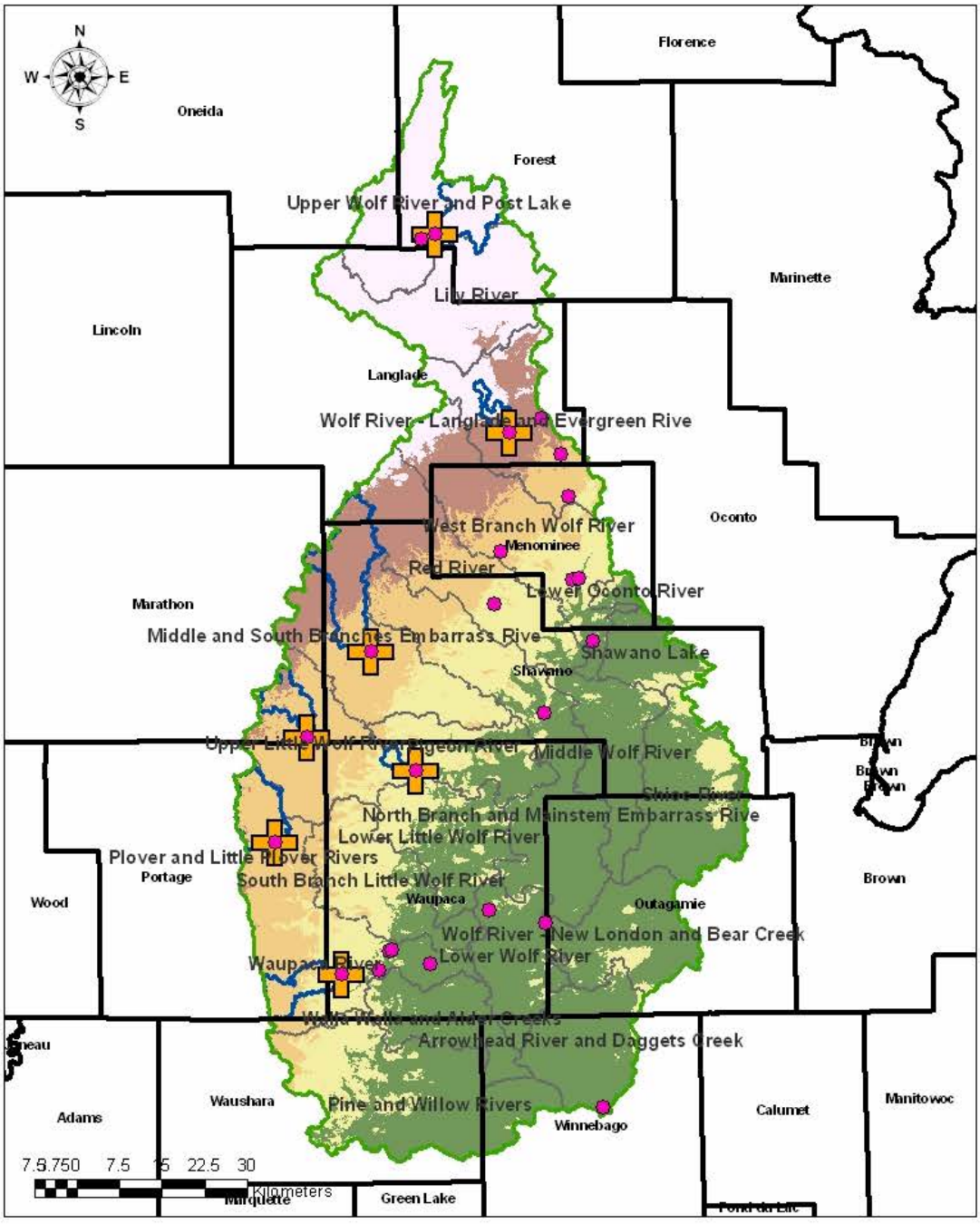
Turtle Creek at Carvers Rock, Rock River Watershed

Geology



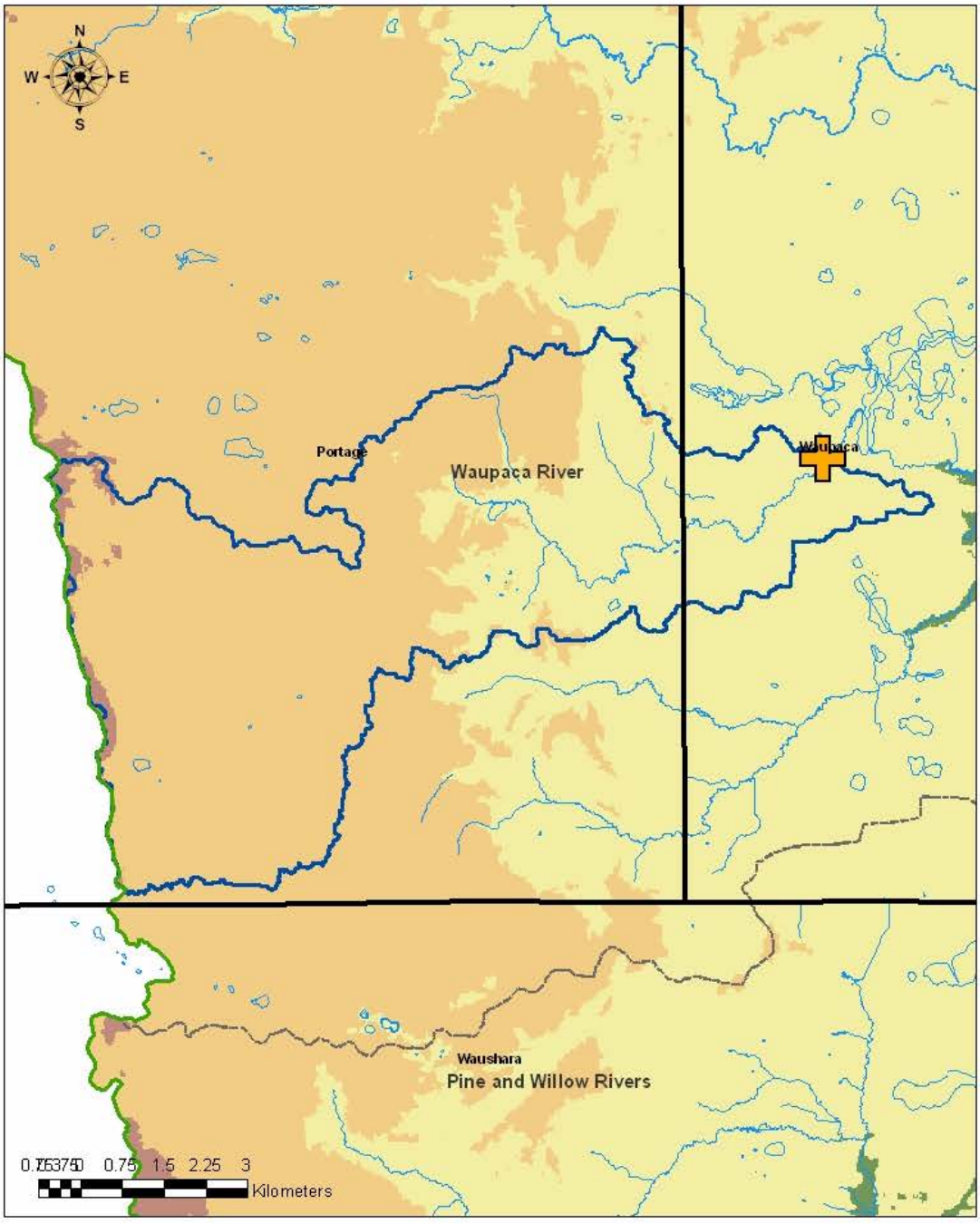
Appendix J: DEM, by site

Wolf River Watershed
Digital Elevation Model



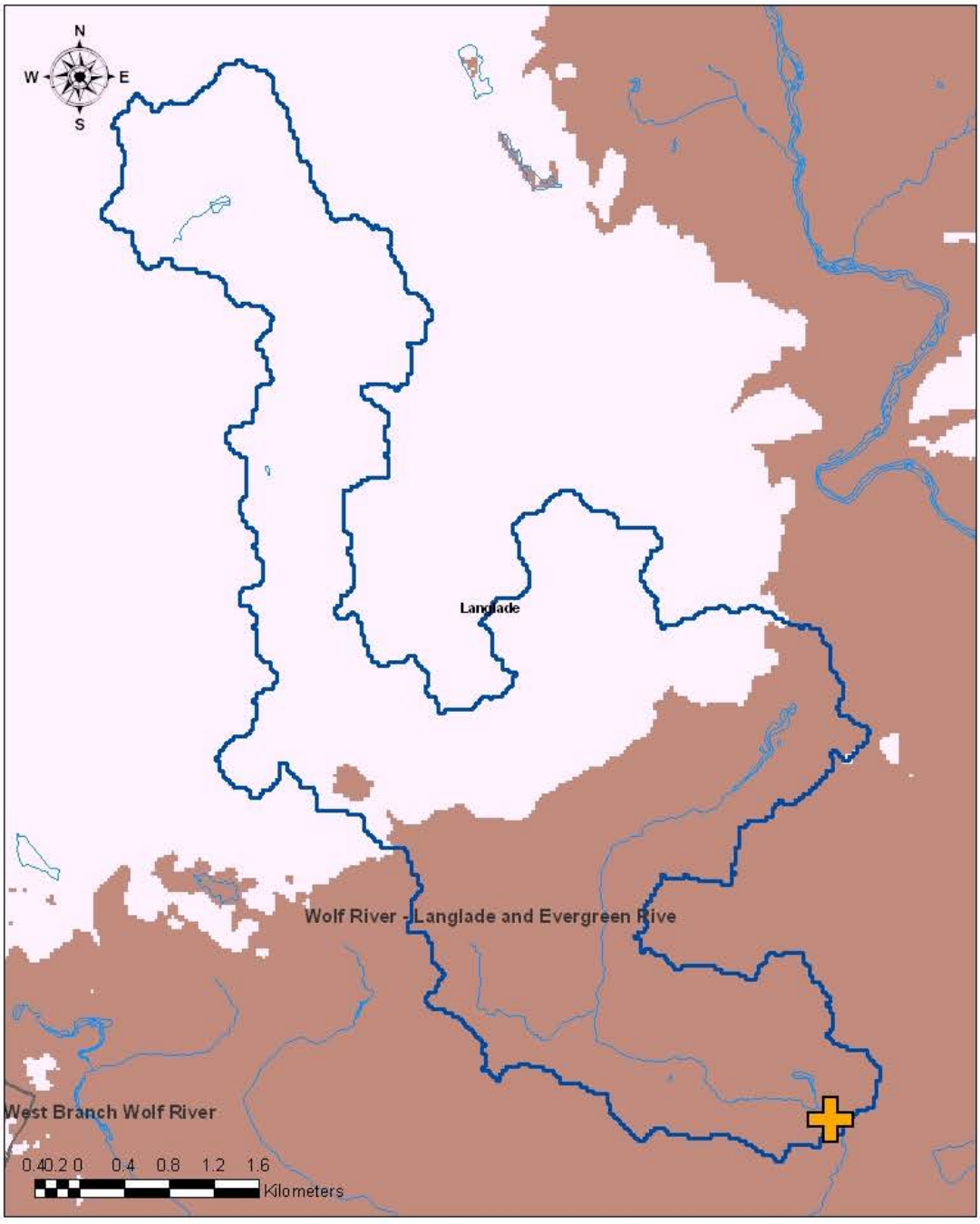
Emmons Creek at Rural, Wolf River Watershed

Digital Elevation Model



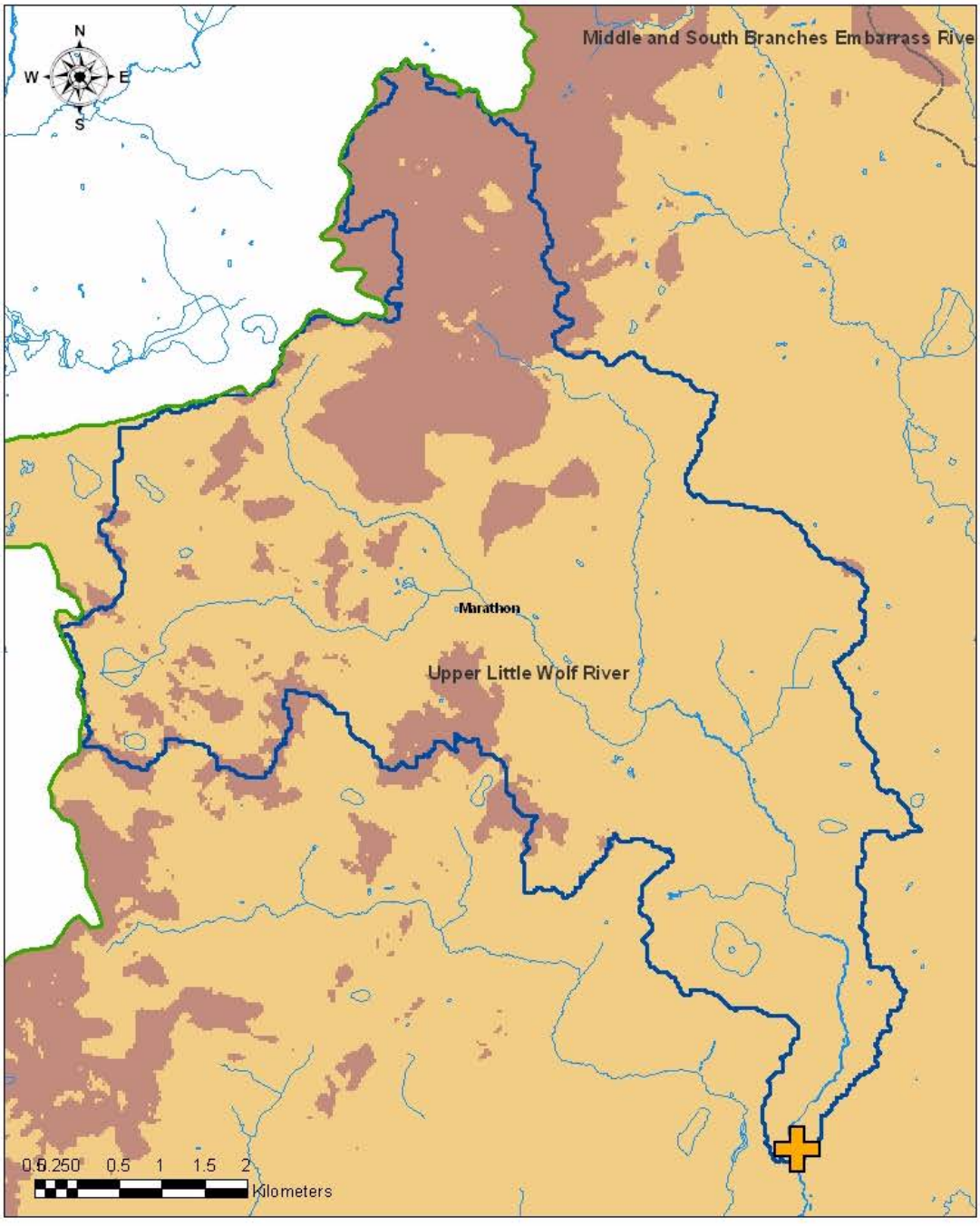
Evergreen River near Langlade, Wolf River Watershed

Digital Elevation Model



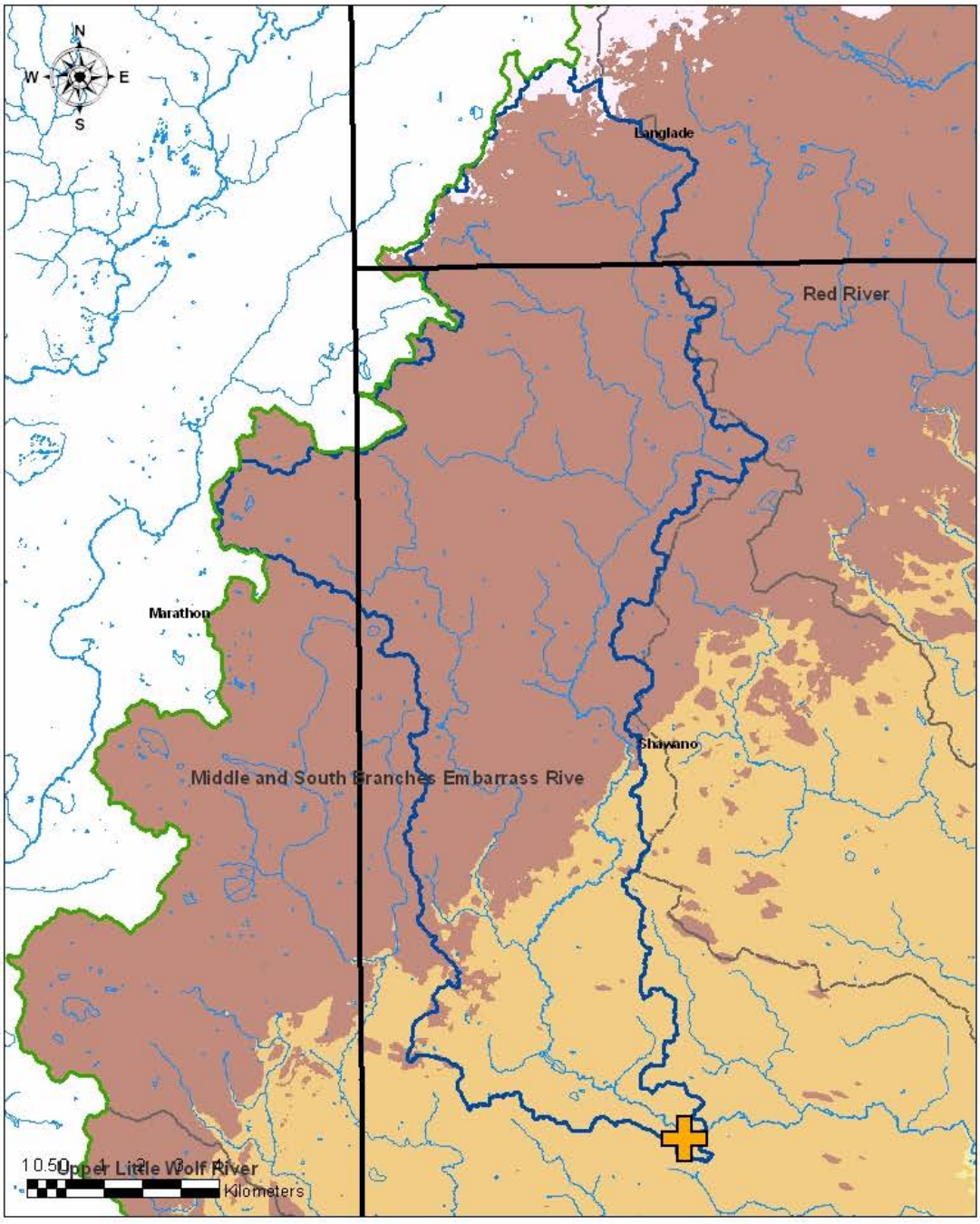
Little Wolf River near Galloway, Wolf River Watershed

Digital Elevation Model



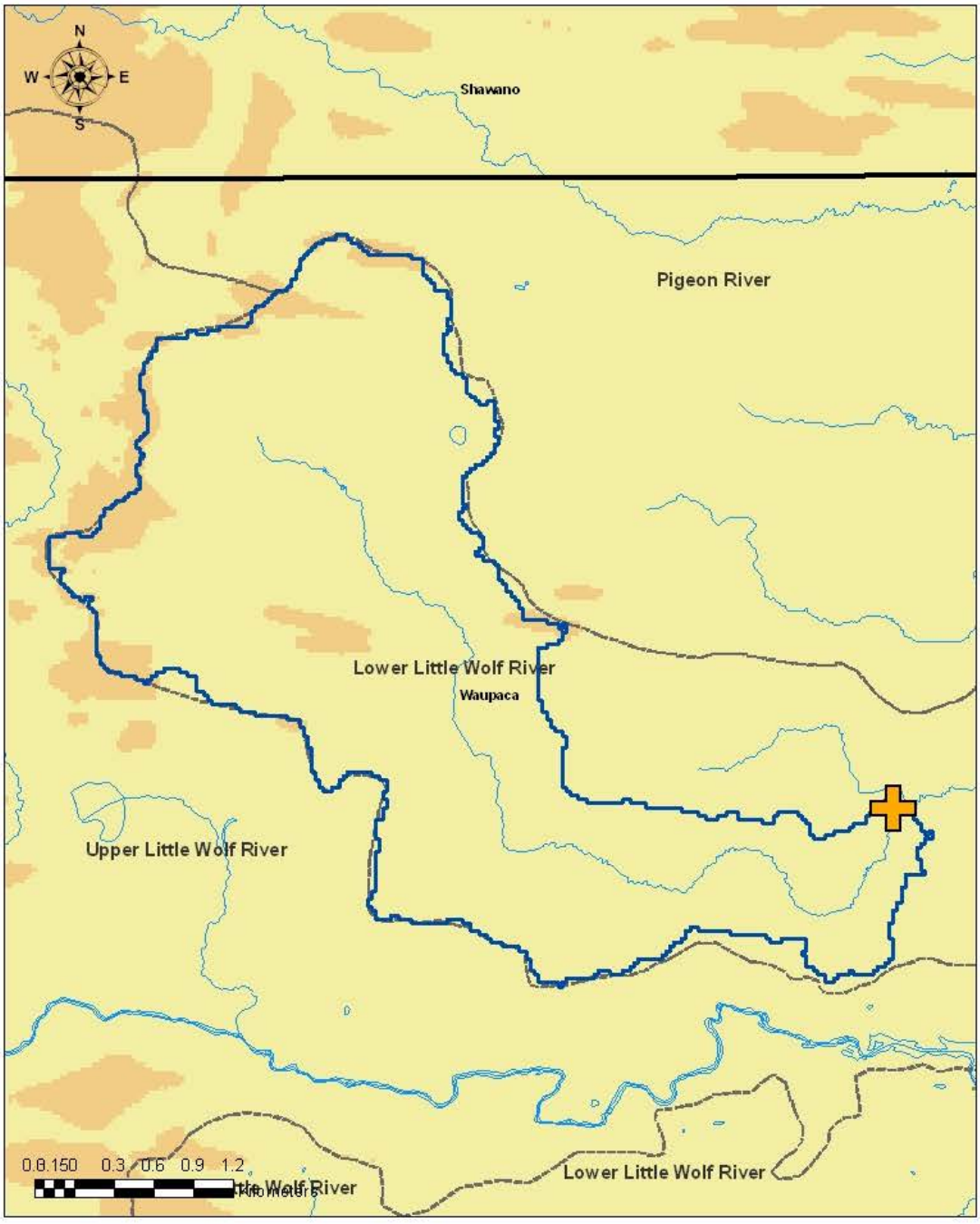
Middle Branch Embarrass River, Wolf River Watershed

Digital Elevation Model



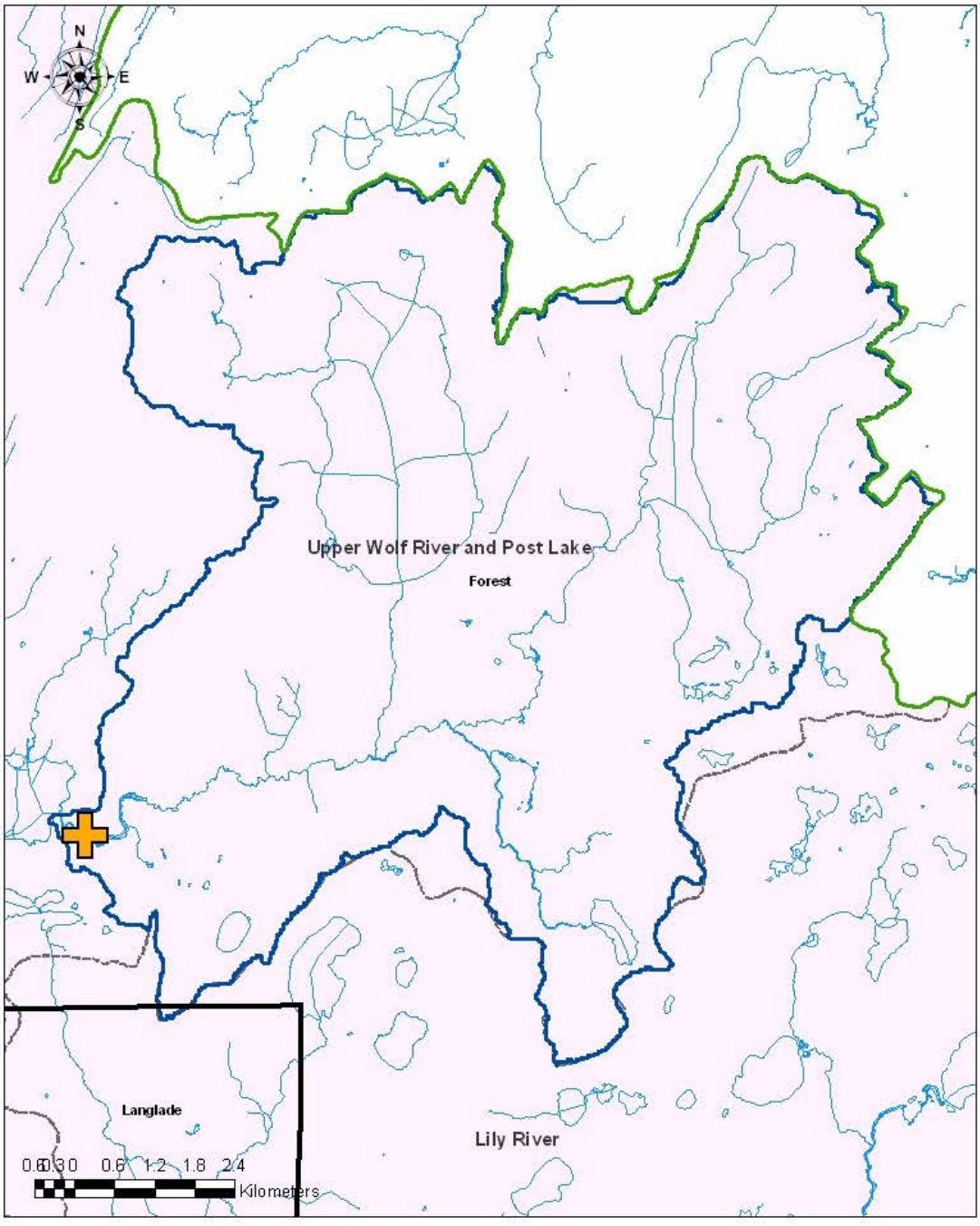
Spaulding Creek near Big Falls, Wolf River Watershed

Digital Elevation Model



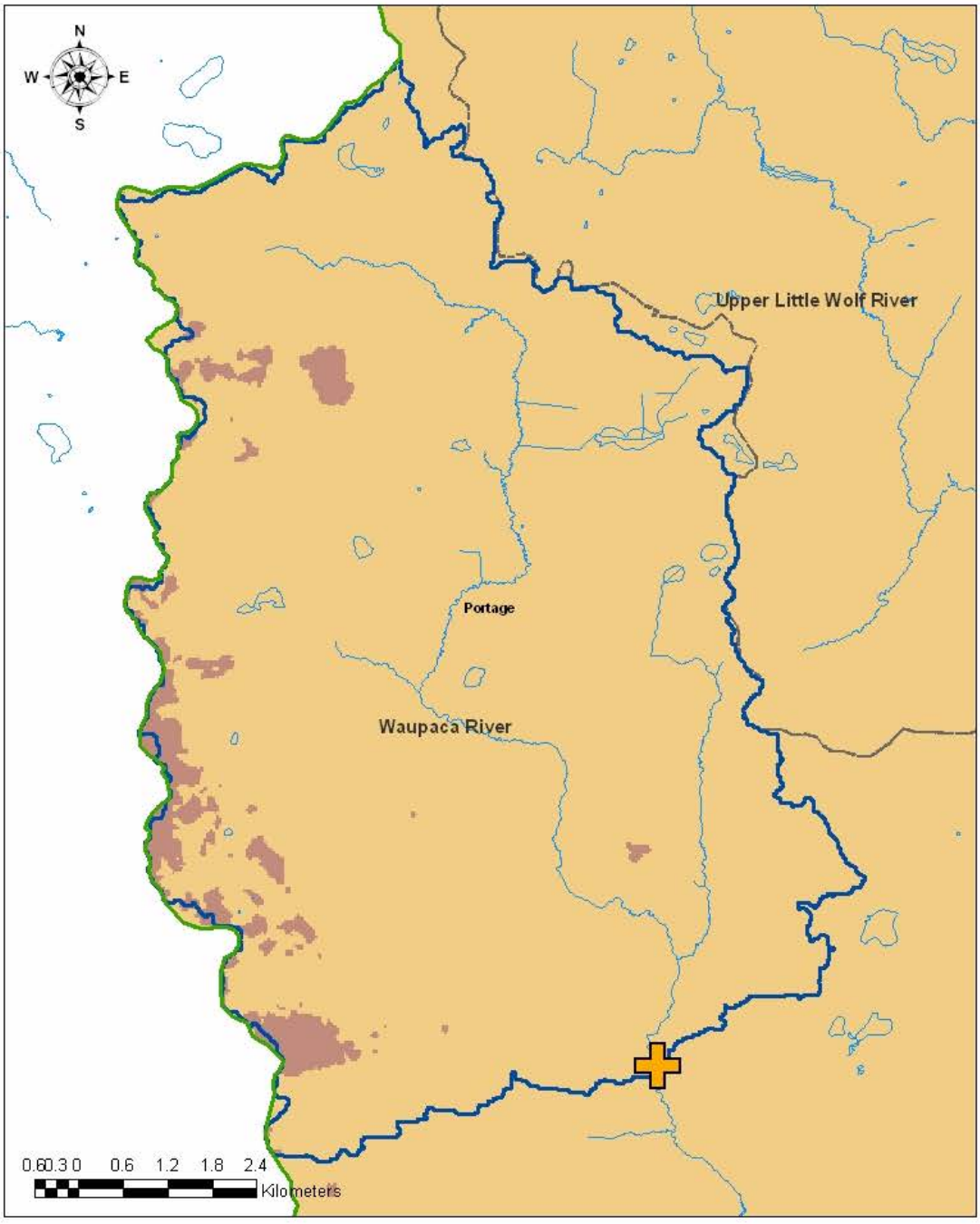
Swamp Creek above Mole Lake, Wolf River Watershed

Digital Elevation Model



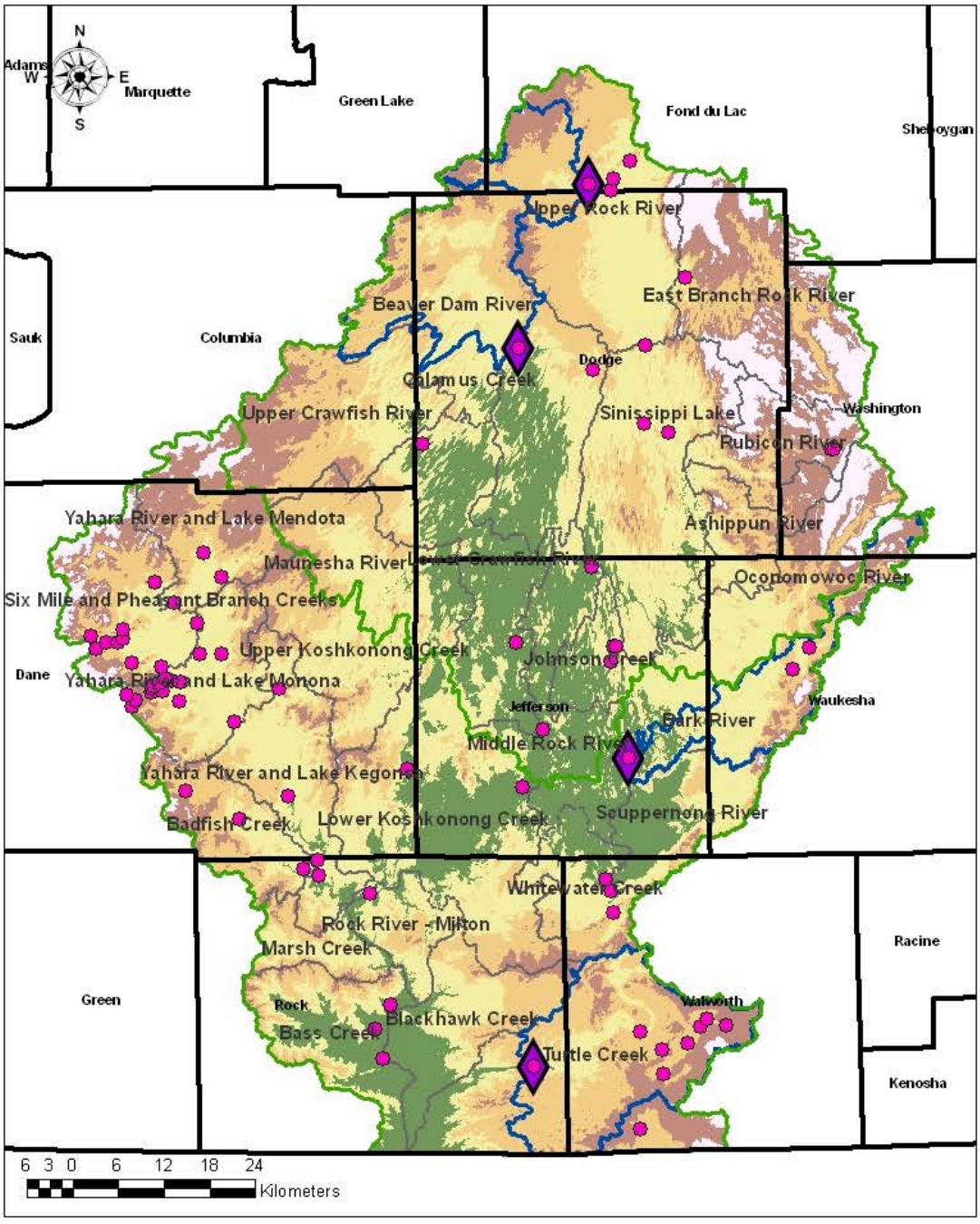
Tomorrow River near Nelsonville, Wolf River Watershed

Digital Elevation Model



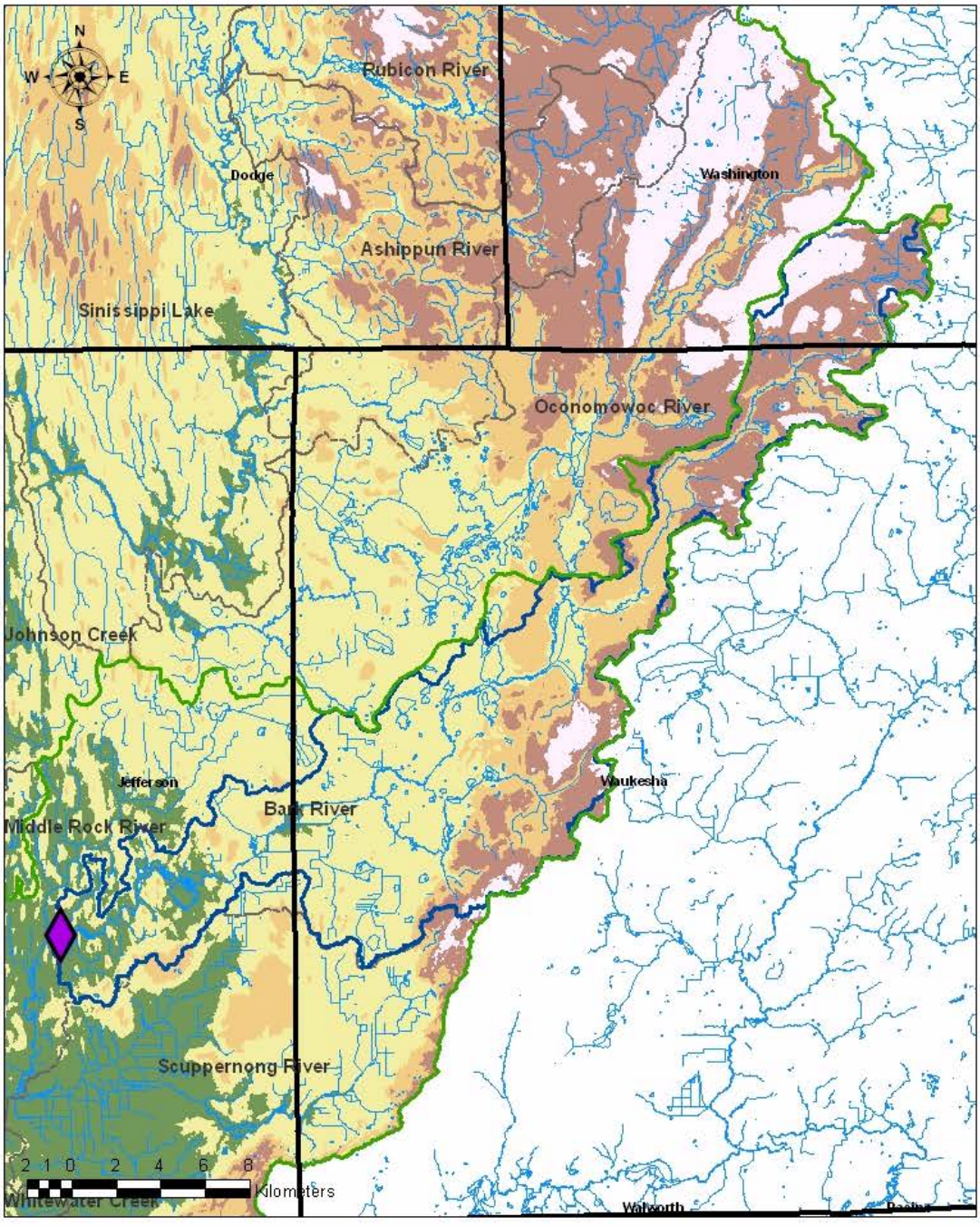
Rock River Watershed

Digital Elevation Model



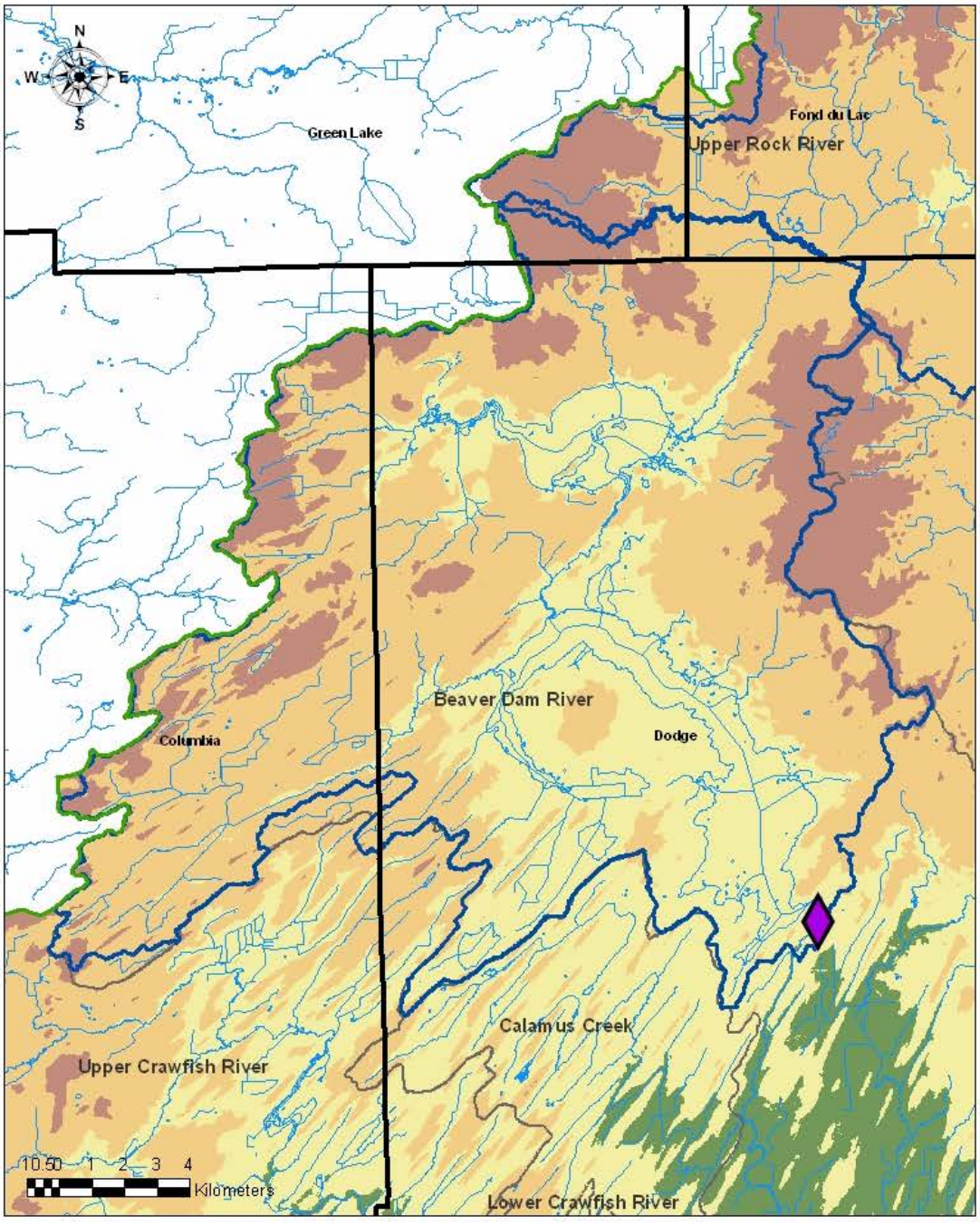
Bark River near Rome, Rock River Watershed

Digital Elevation Model



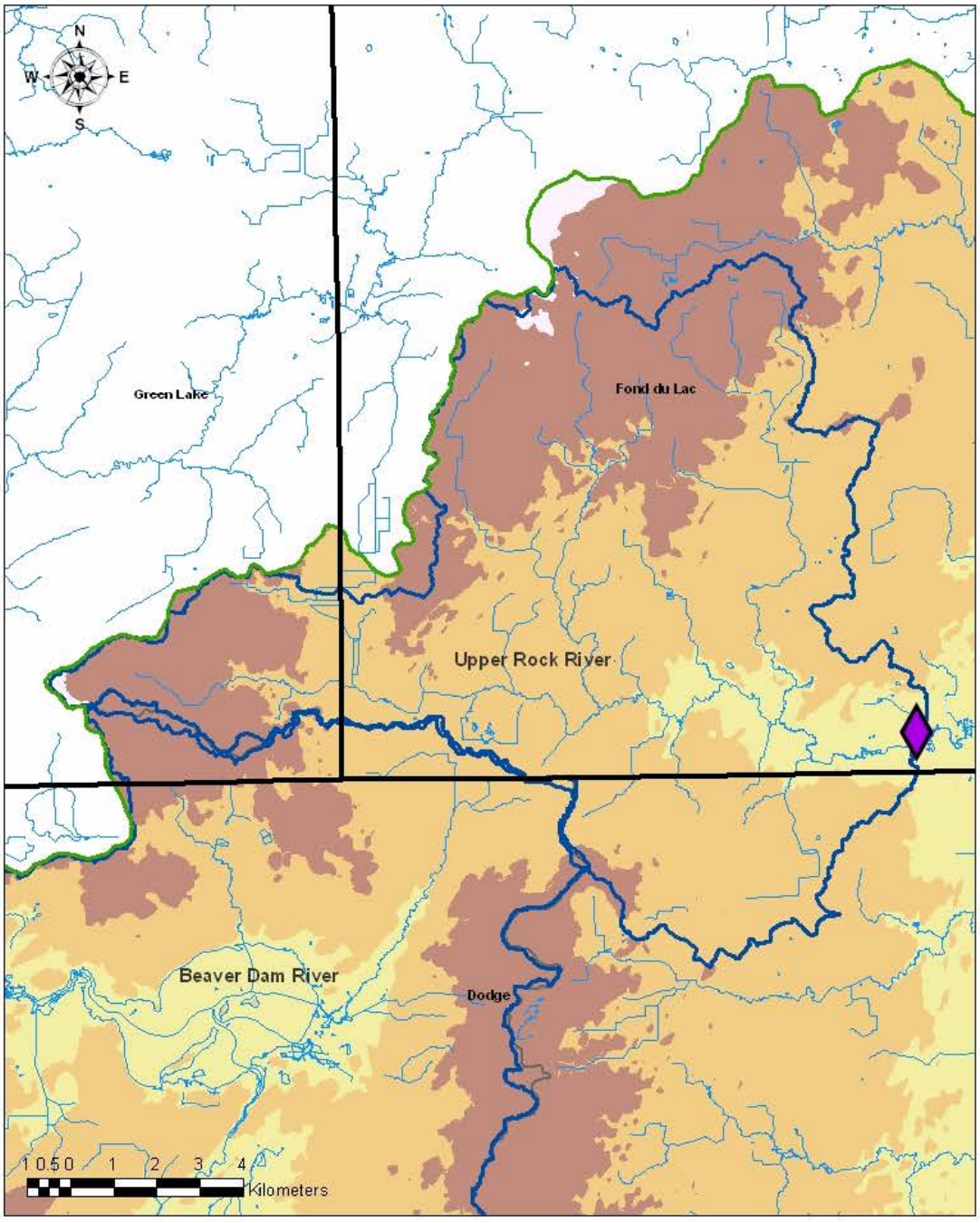
Beaver Dam at Beaver Dam, Rock River Watershed

Digital Elevation Model



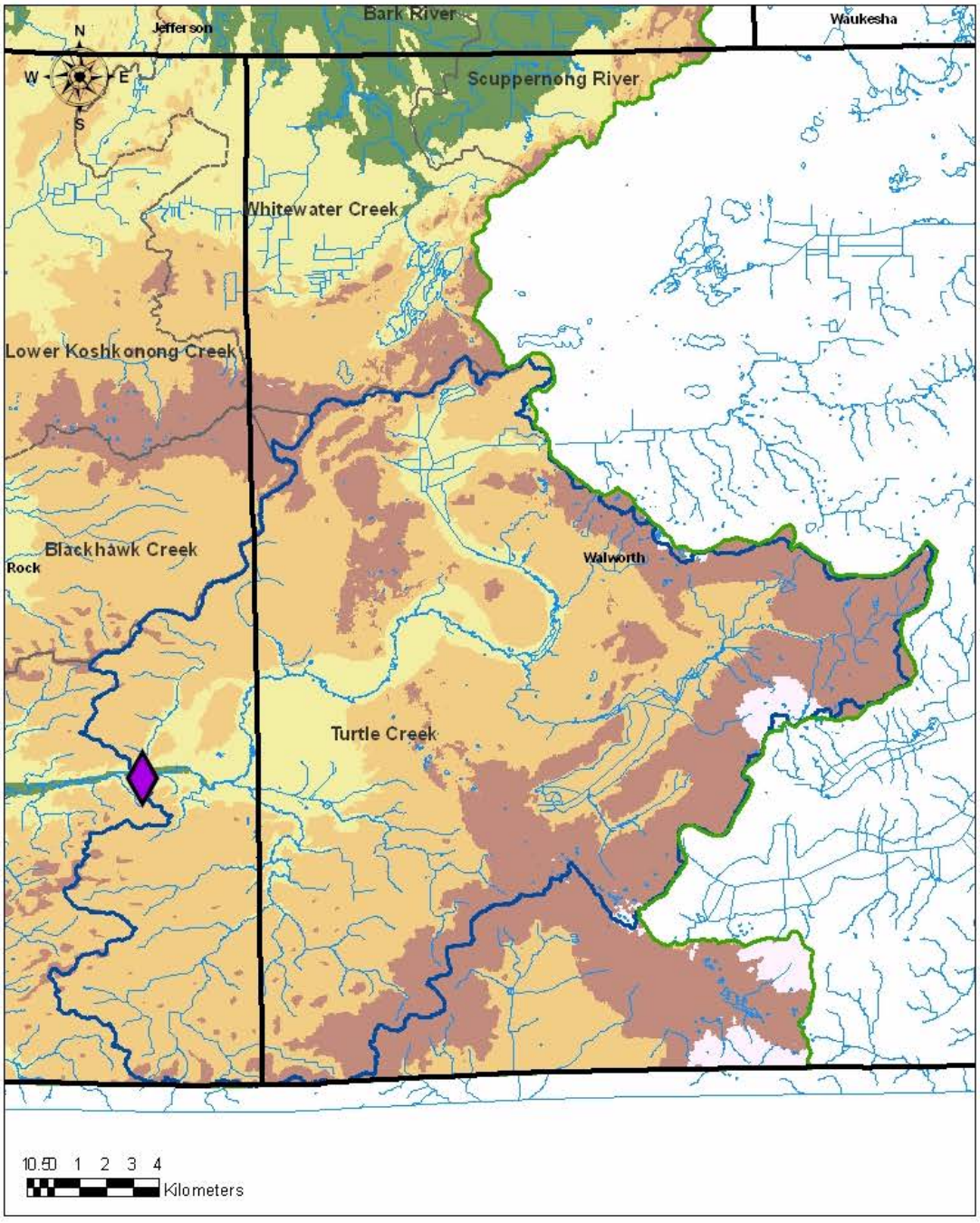
South Branch Rock River at Waupun, Rock River Watershed

Digital Elevation Model



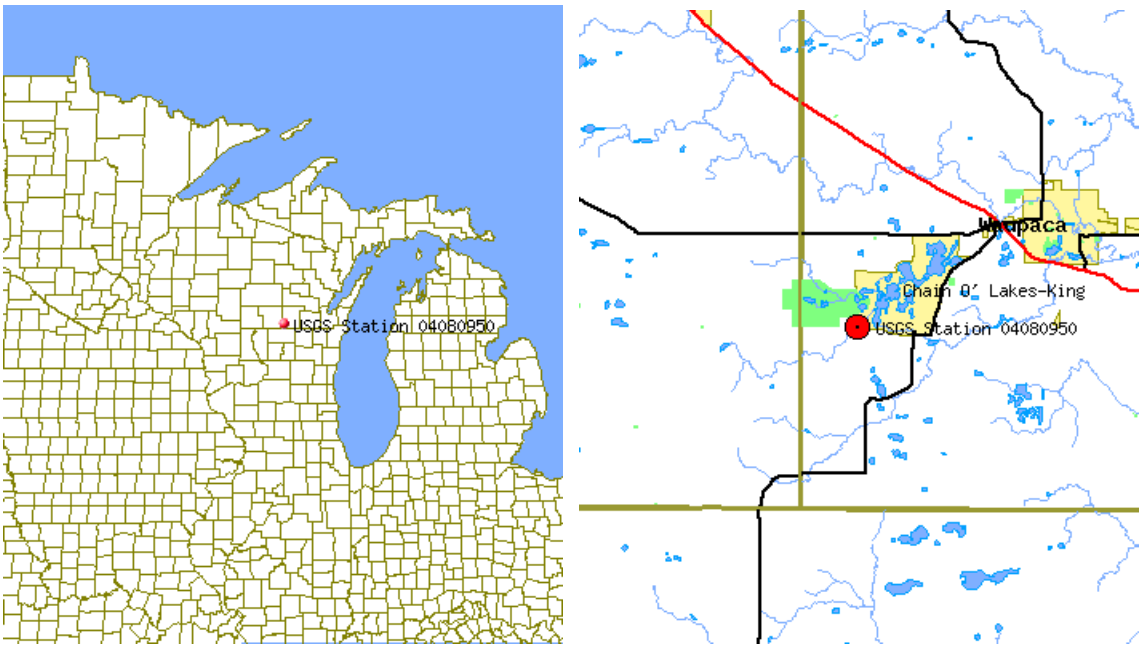
Turtle Creek at Carvers Rock, Rock River Watershed

Digital Elevation Model

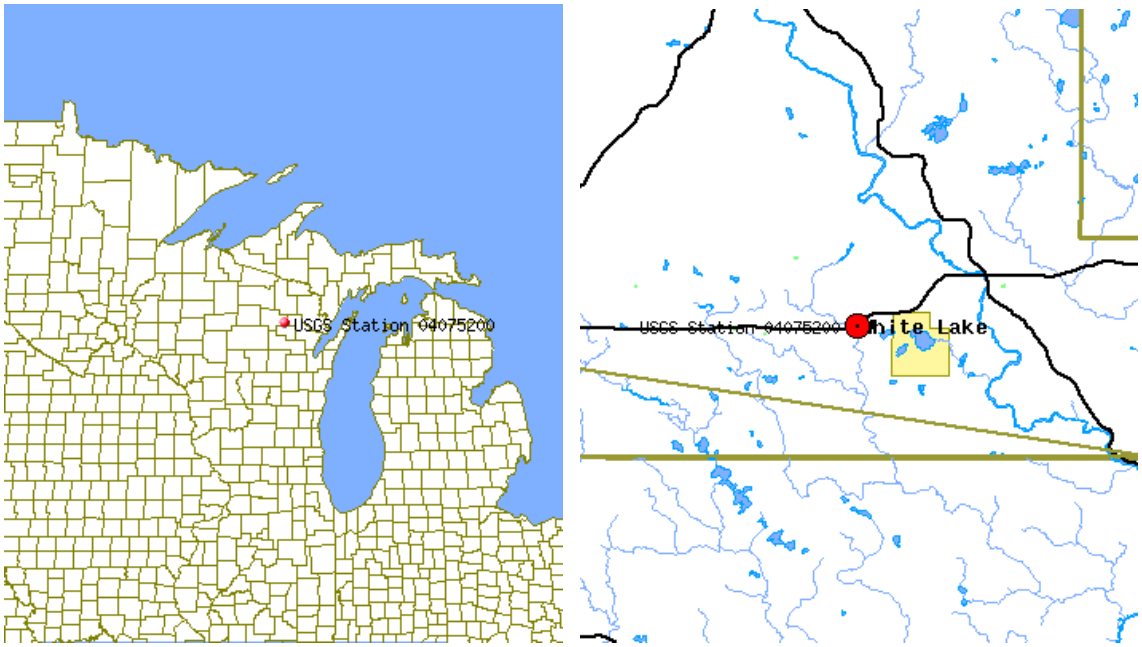


Appendix K: USGS Maps, by site

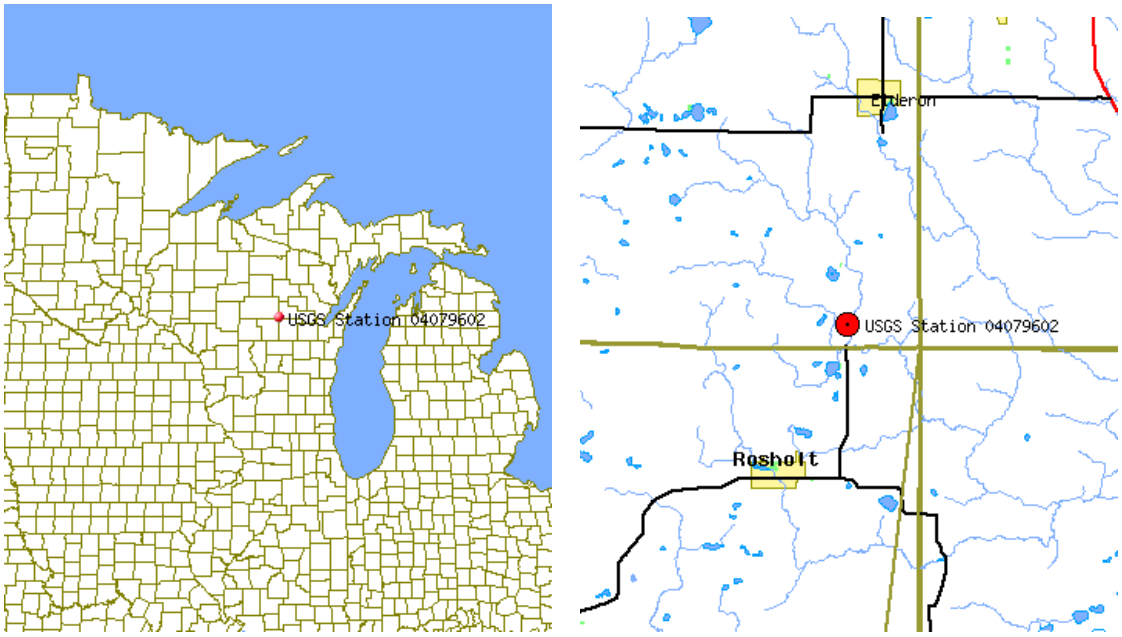
Emmons Creek near Rural



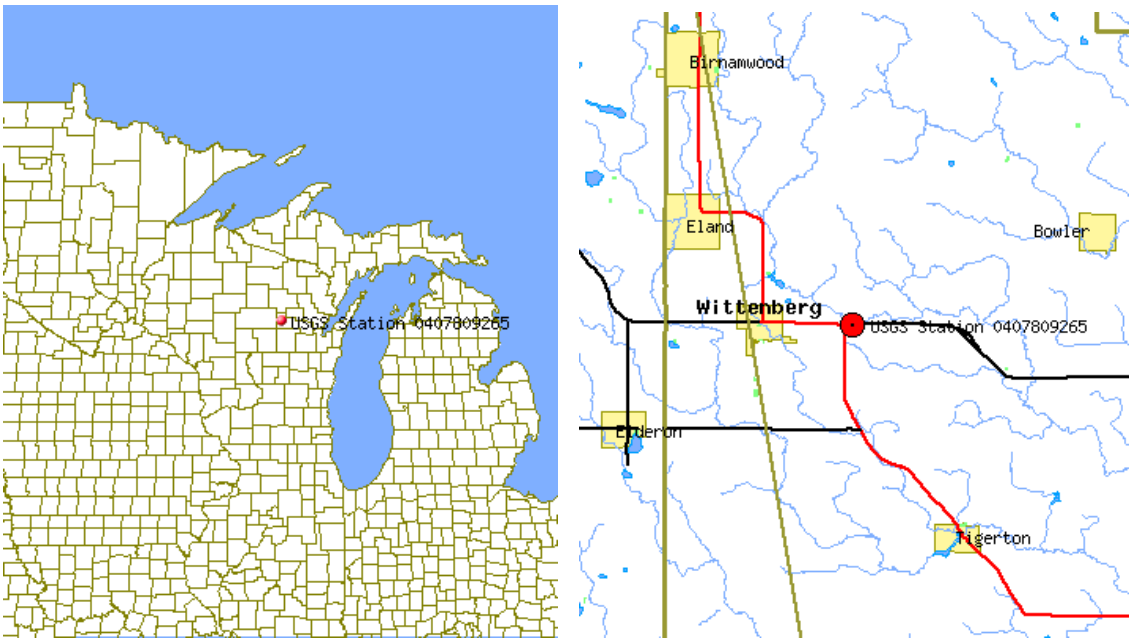
Evergreen Creek near Langlade



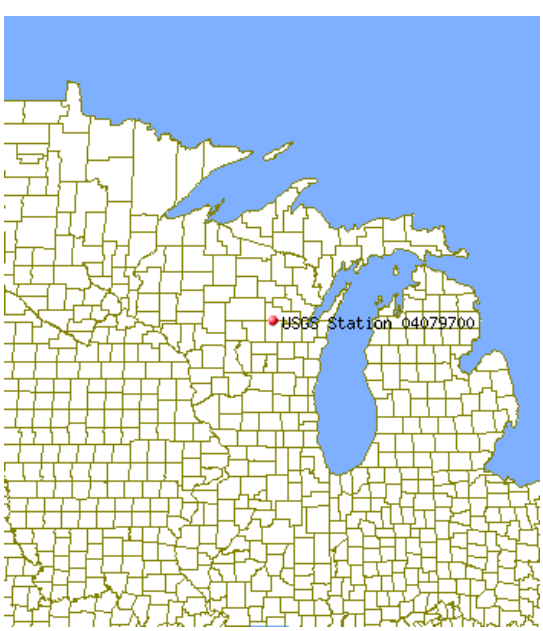
Little Wolf River near Galloway

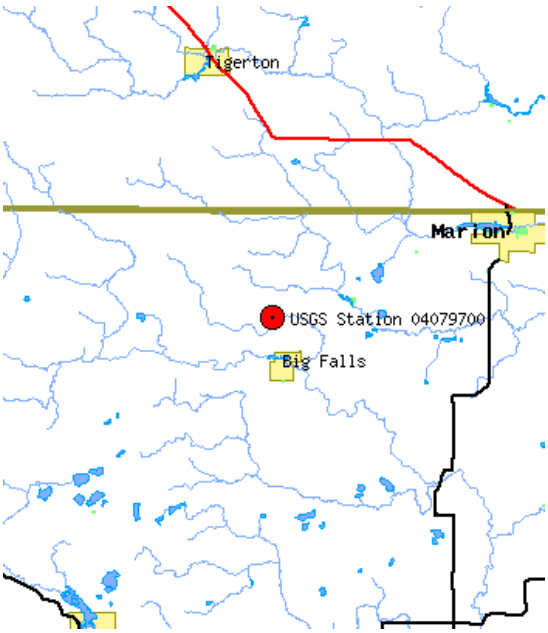


Middle Branch Embarrass at Wittenberg

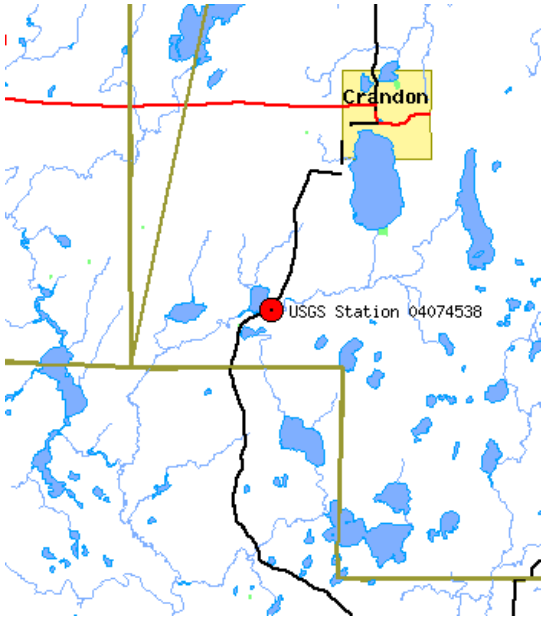


Spaulding Creek near Big Falls

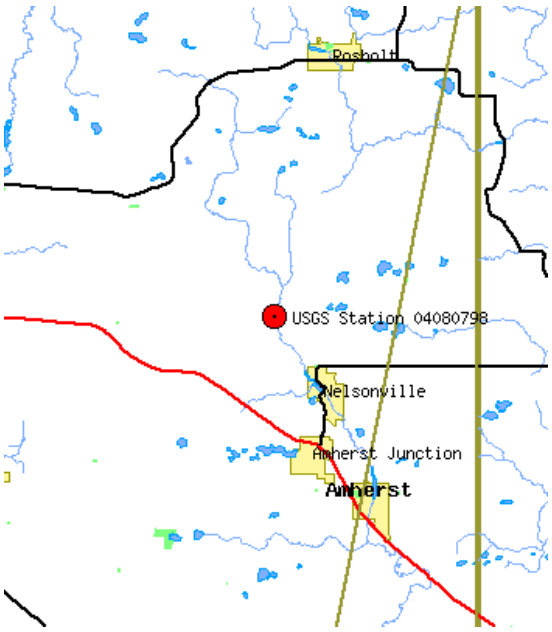




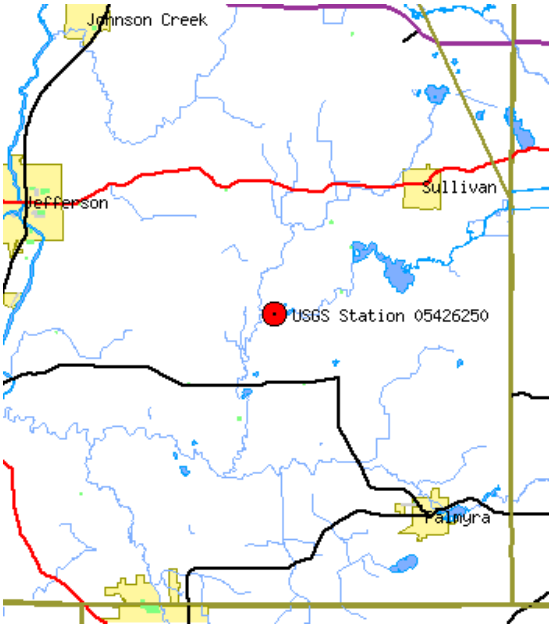
Swamp Creek above Rice Lake at Mole Lake



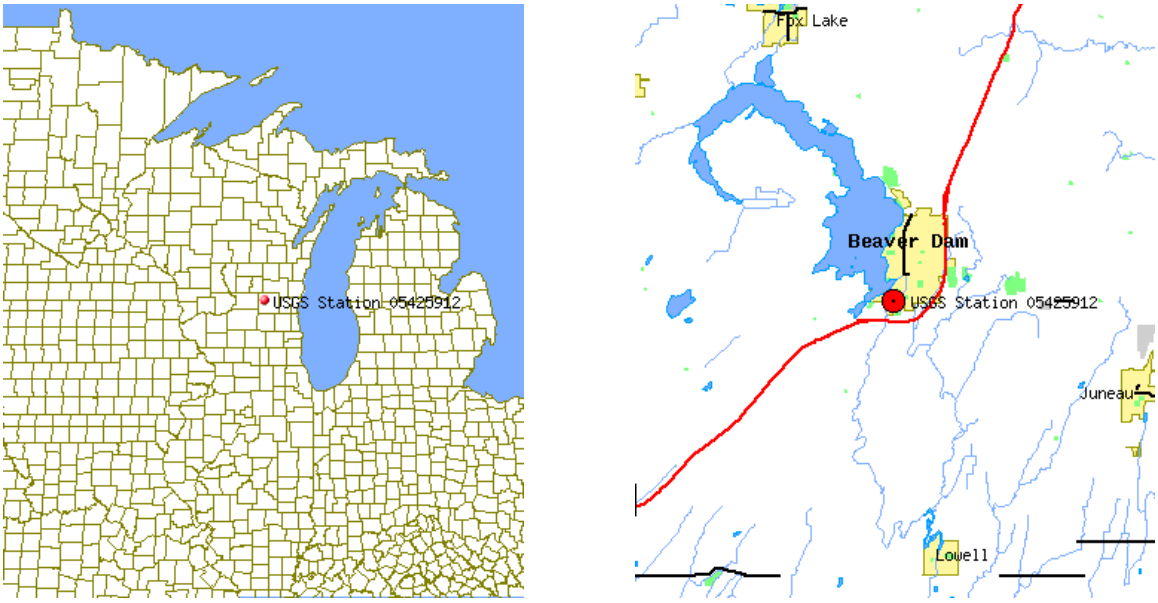
Tomorrow River near Nelsonville



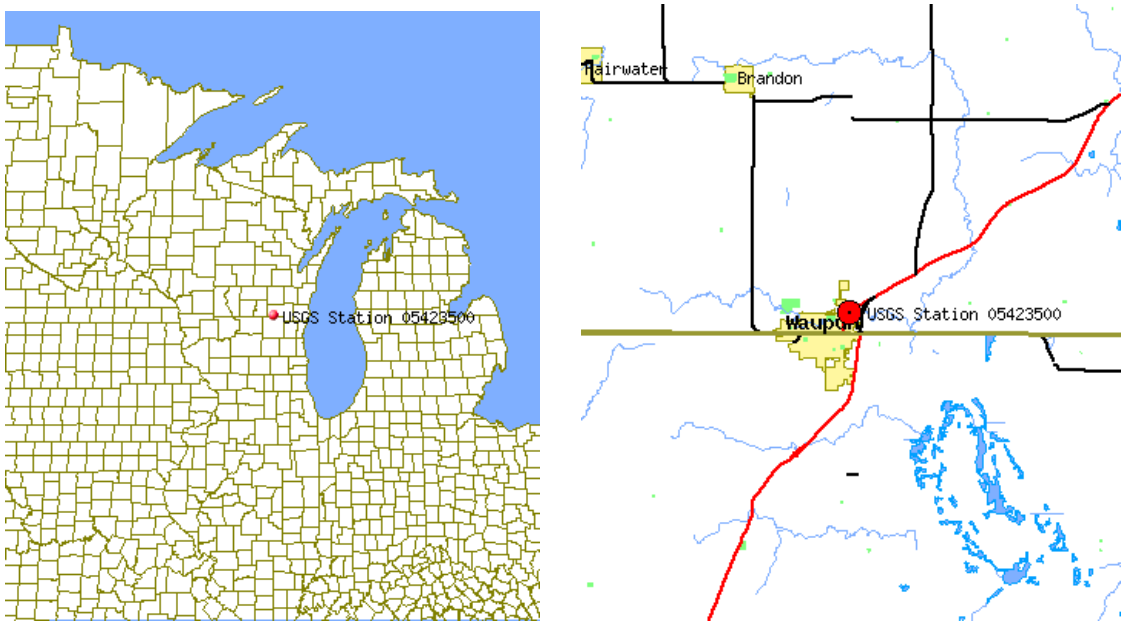
Bark River at Rome



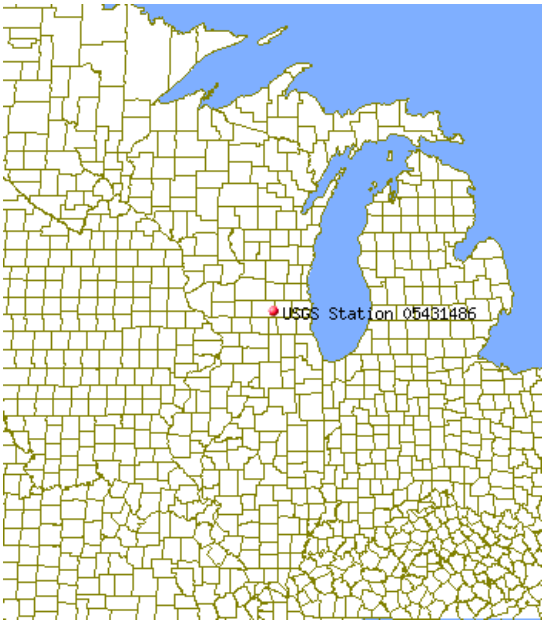
Beaver Dam at Beaver Dam

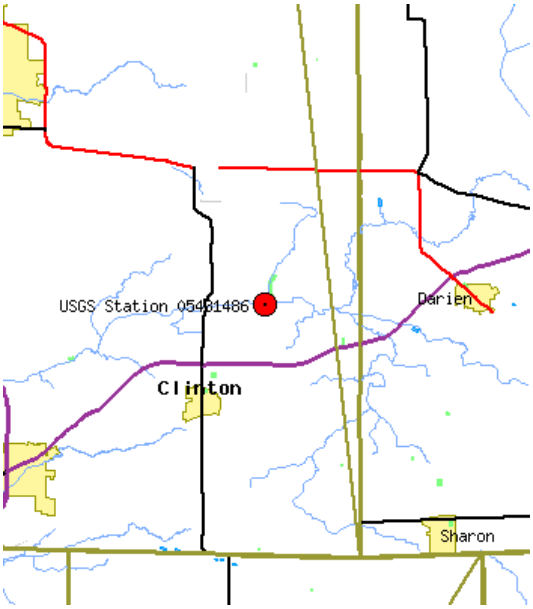


South Branch Rock River at Waupun

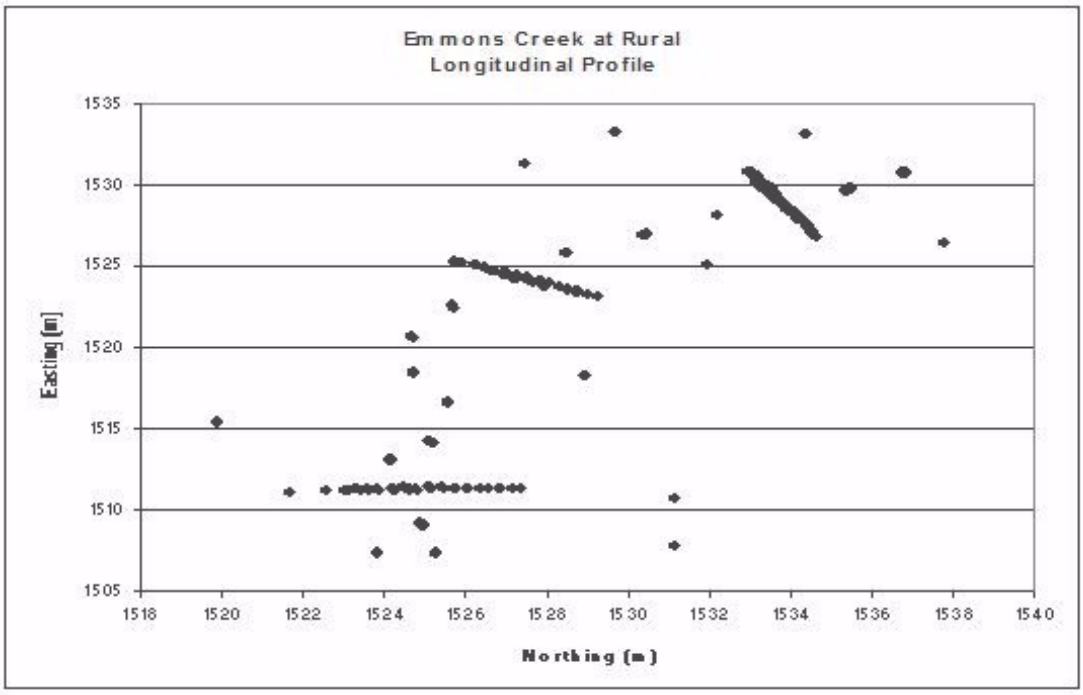


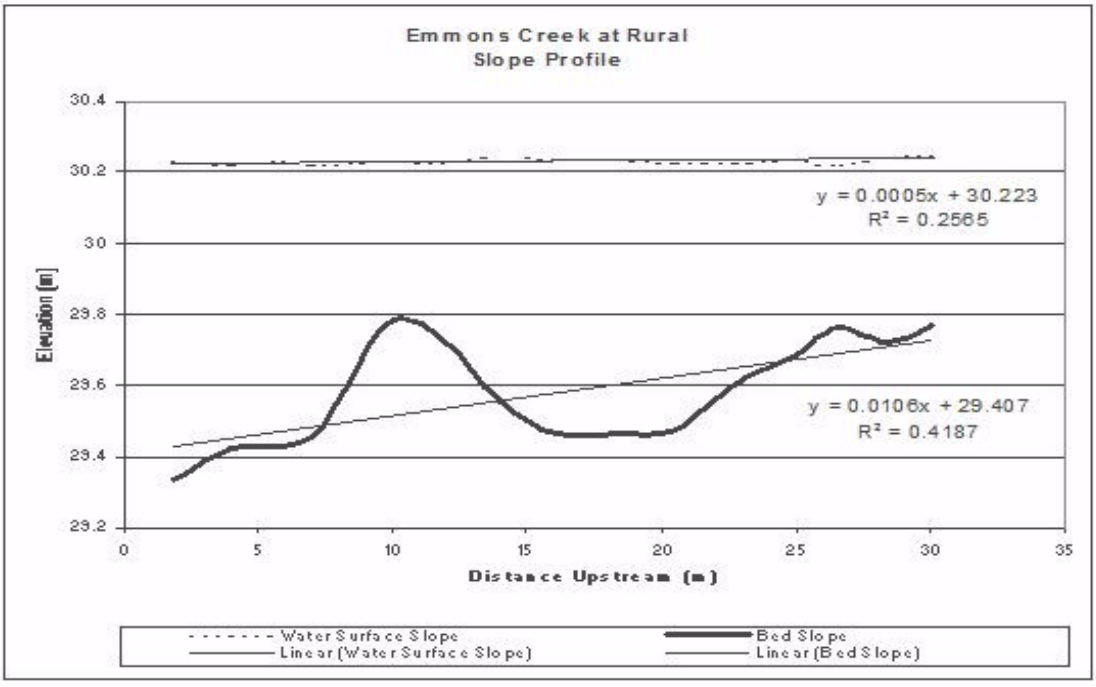
Turtle Creek at Carvers Rock

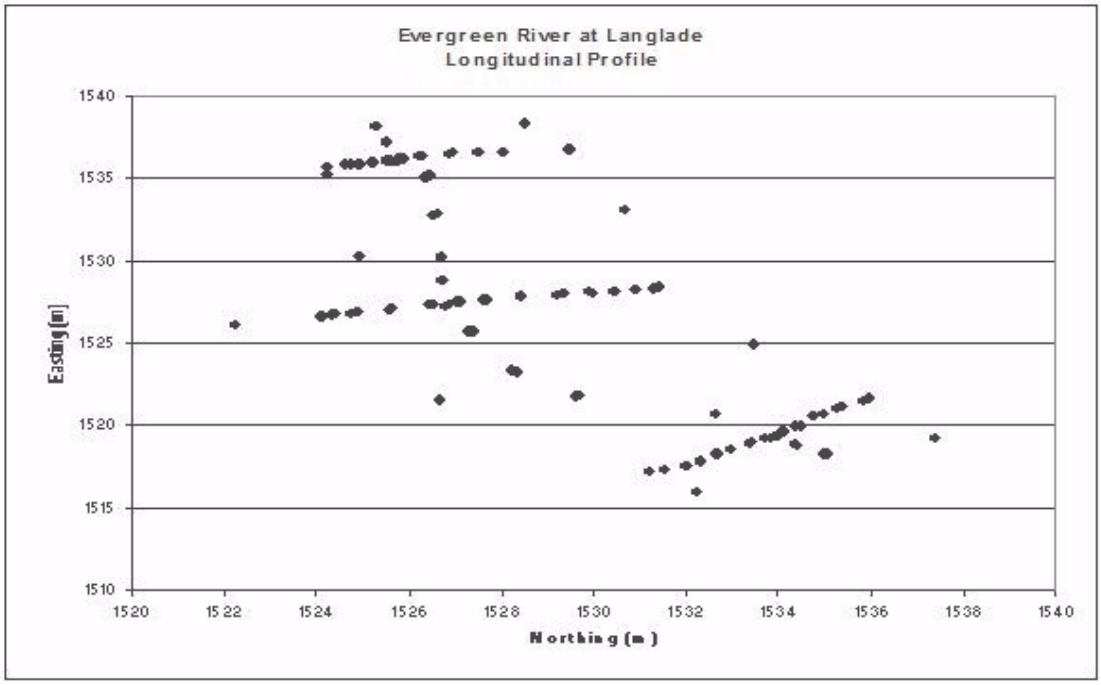


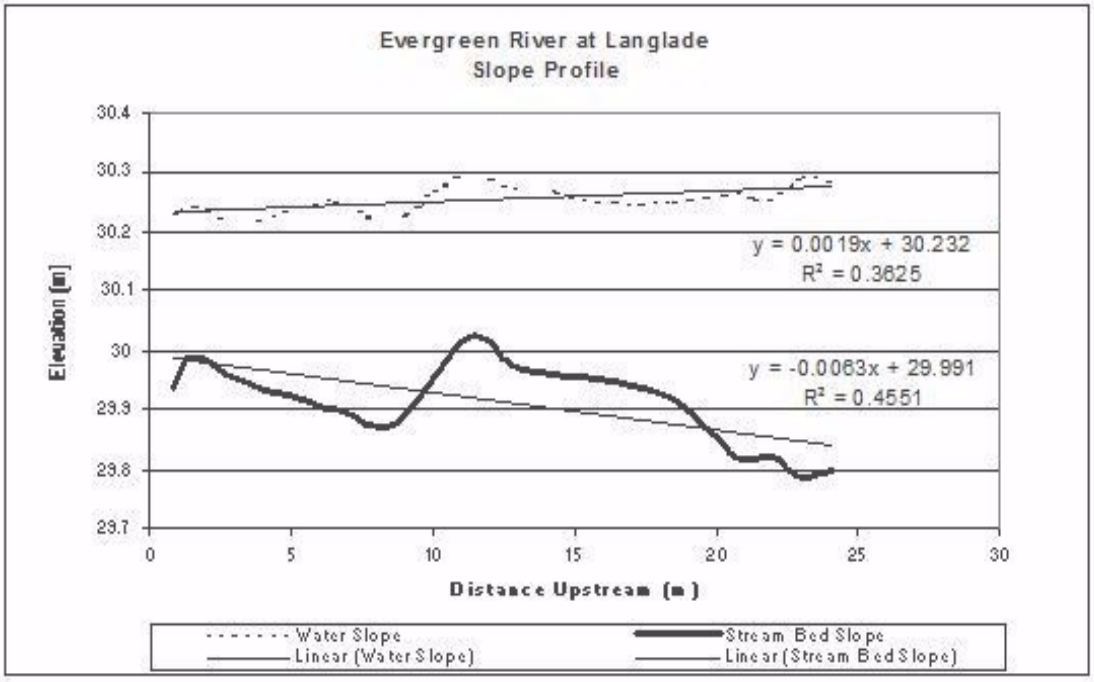


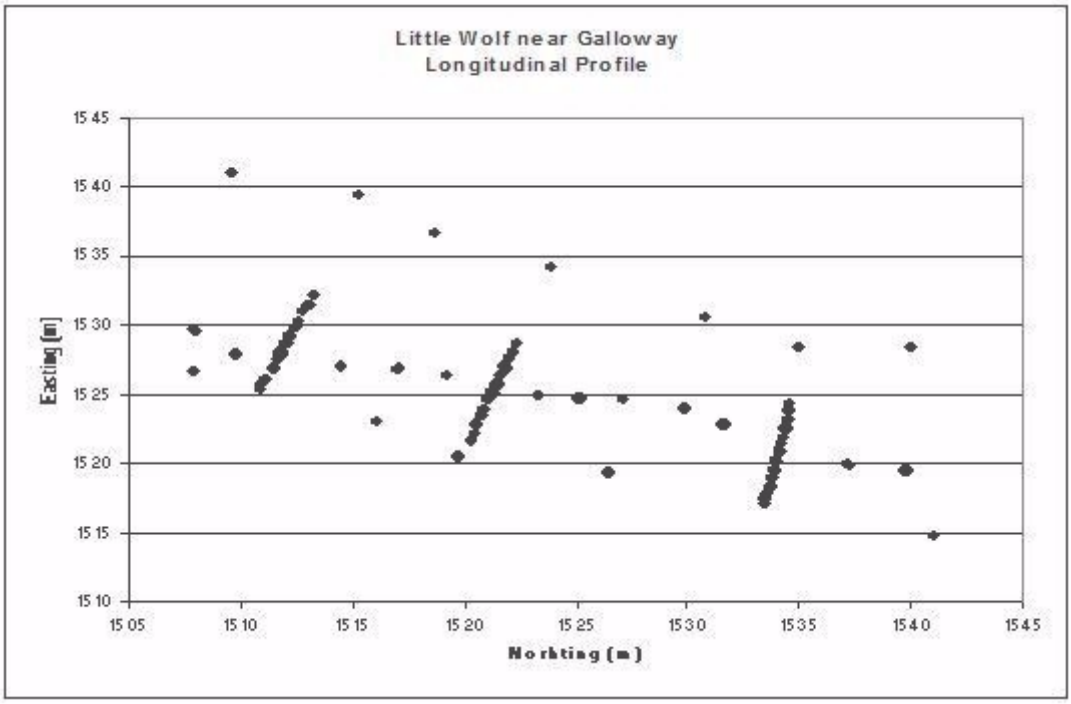
Appendix L: Longitudinal Profiles, by site

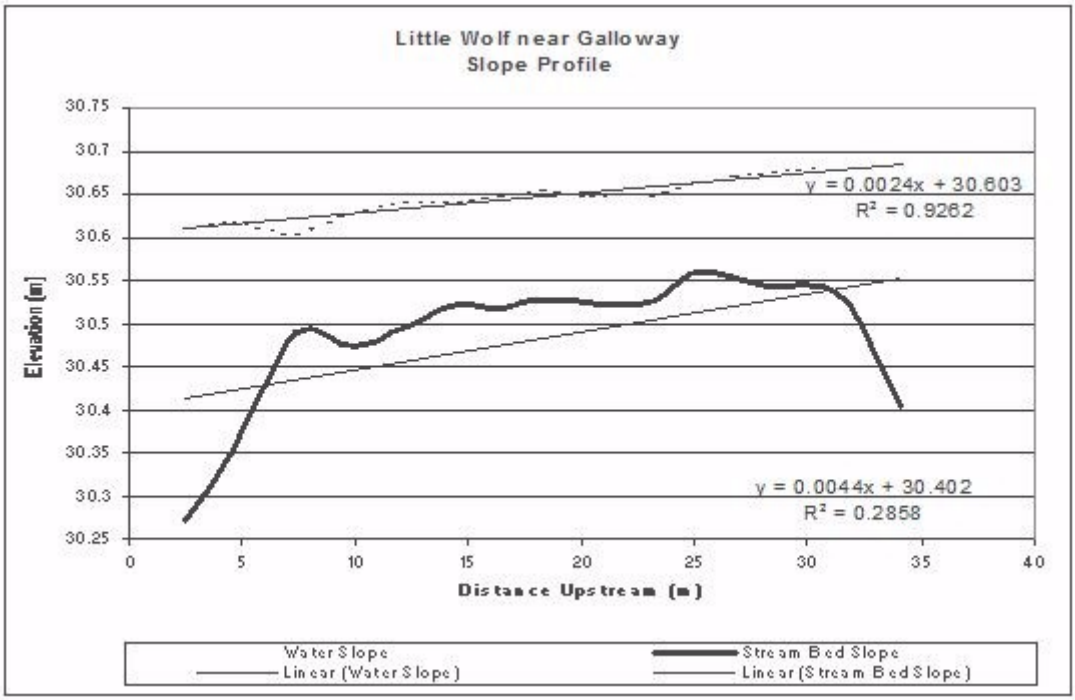

Emmons Creek at Rural
Longitudinal Profile
Easting (m)
1535
1530
1525
1520
1515
1510
1505
1518
1520
1522
1524
1526
1528
1530
1532
1534
1536
1538
1540
Northing (m)

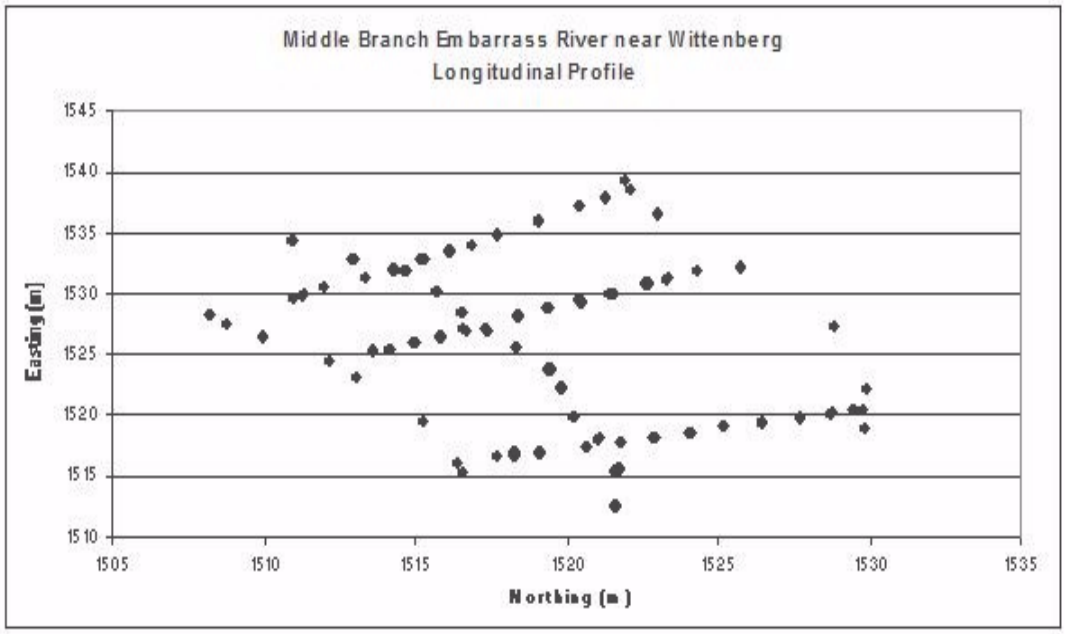

Emmons Creek at Rural
Slope Profile
Elevation (m)
30.4
30.2
30
29.8
29.6
29.4
29.2
y = 0.0005x + 30.223
R² = 0.2565
y = 0.0106x + 29.407
R² = 0.4187
0
5
10
15
20
25
30
35
Distance Upstream (m)
Water Surface Slope
Linear (Water Surface Slope)
Bed Slope
Linear (Bed Slope)

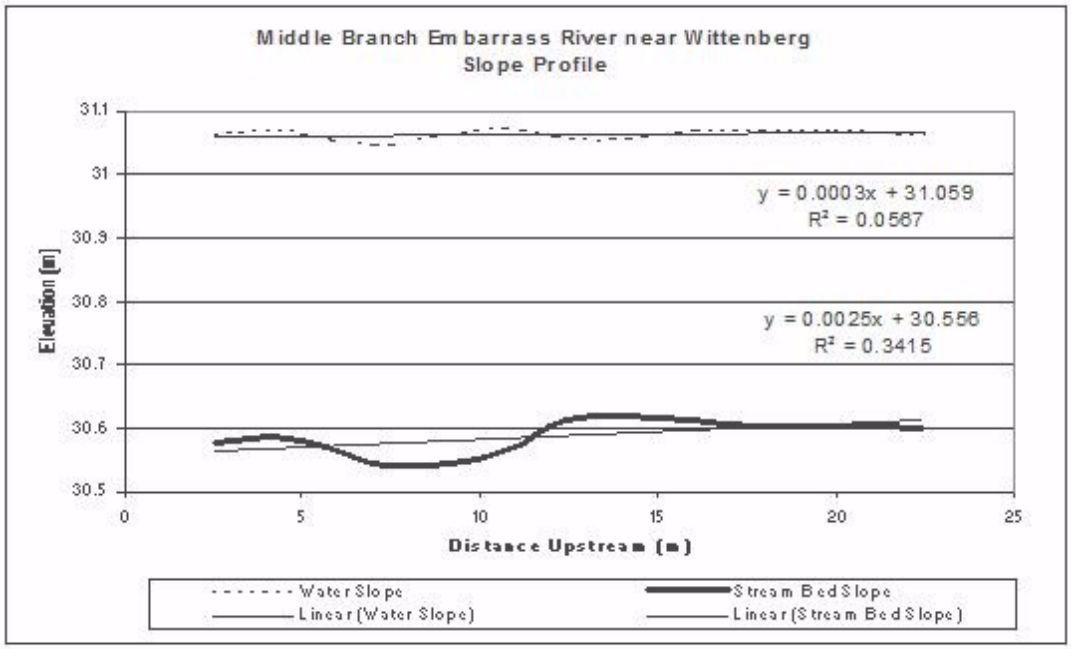

Evergreen River at Langlade
Longitudinal Profile
Easting (m)
Northing (m)
1540
1535
1530
1525
1520
1515
1510
1520
1522
1524
1526
1528
1530
1532
1534
1536
1538
1540

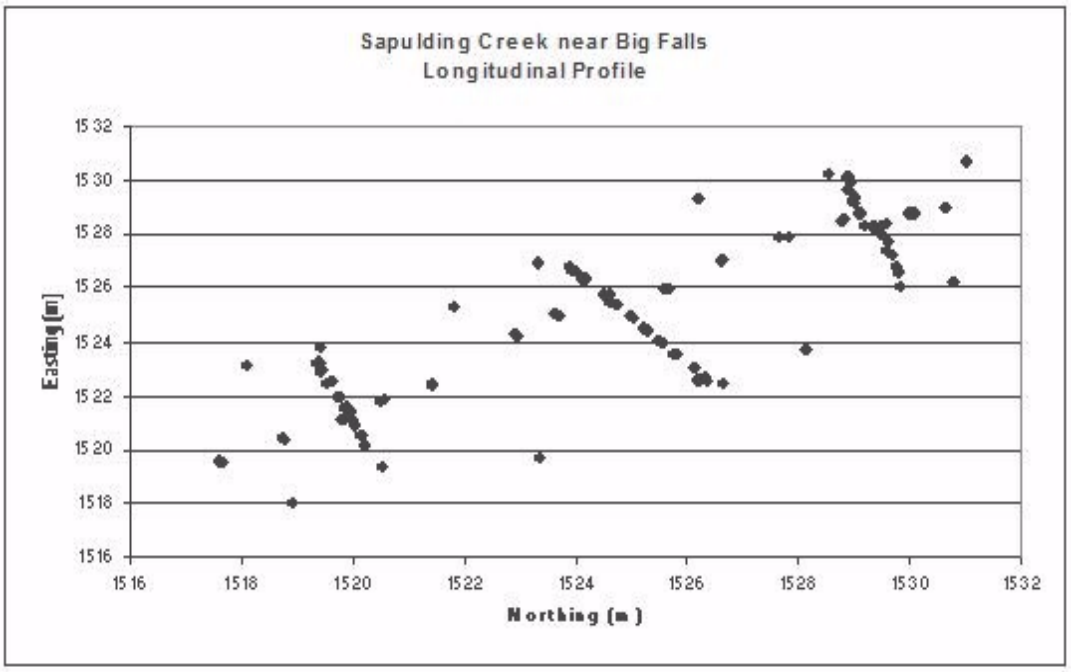

Evergreen River at Langlade
Slope Profile
Elevation (m)
Distance Upstream (m)
y = 0.0019x + 30.232
R² = 0.3625
y = -0.0063x + 29.991
R² = 0.4551
30.4
30.3
30.2
30.1
30
29.9
29.8
29.7
0
5
10
15
20
25
30
Water Slope
Linear (Water Slope)
Stream Bed Slope
Linear (Stream Bed Slope)

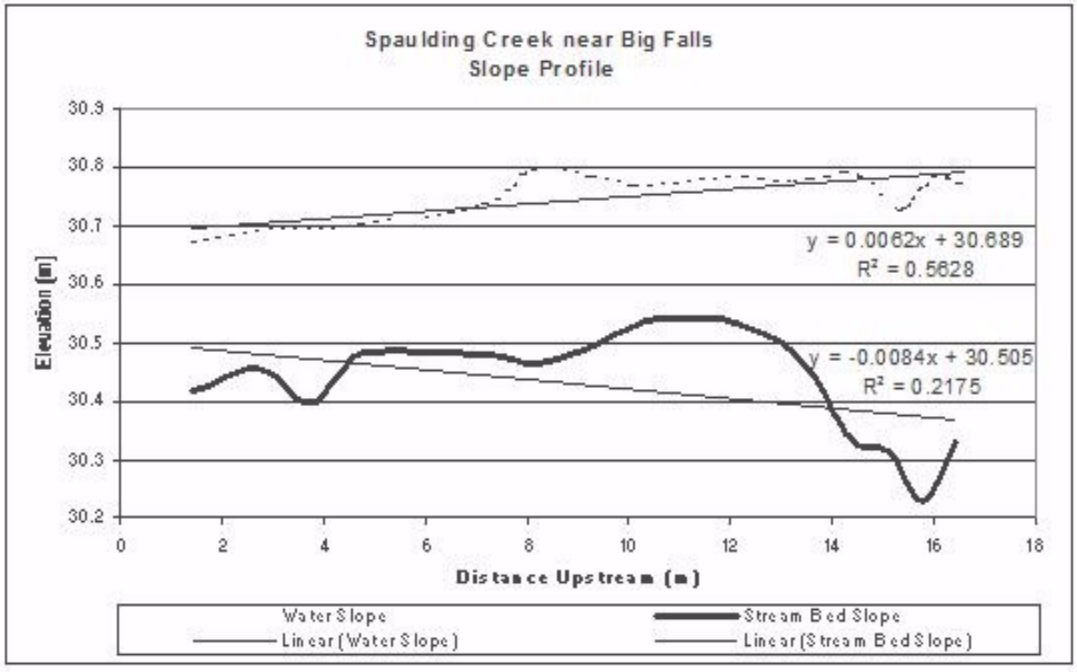

Little Wolf near Galloway
Longitudinal Profile
Easting (m)
Northing (m)
15 45
15 40
15 35
15 30
15 25
15 20
15 15
15 10
15 05
15 10
15 15
15 20
15 25
15 30
15 35
15 40
15 45

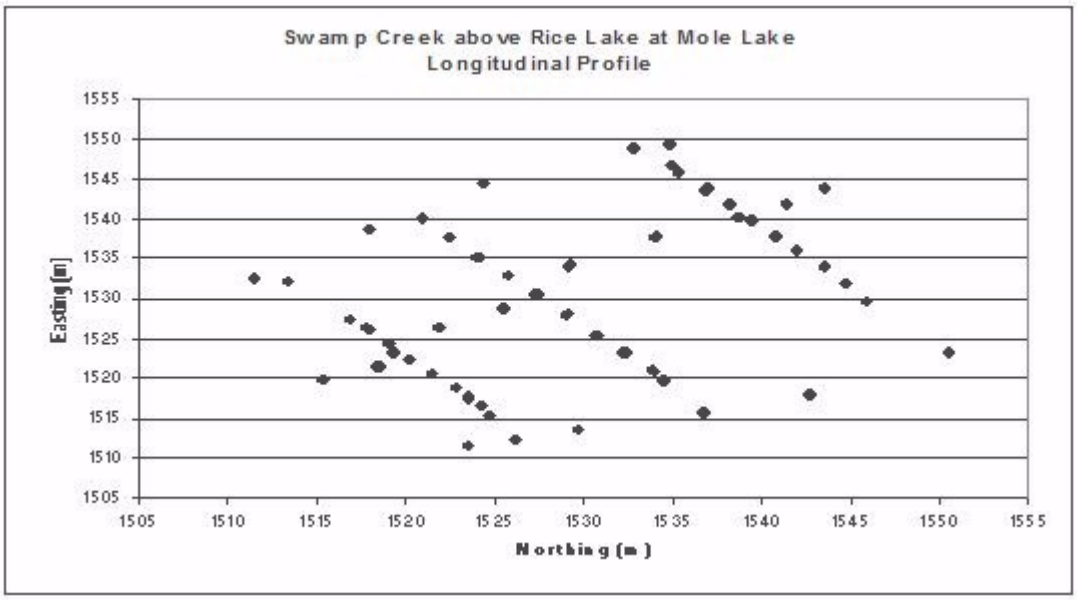

Little Wolf near Galloway
Slope Profile
Elevation (m)
Distance Upstream (m)
y = 0.0024x + 30.603
R² = 0.9262
y = 0.0044x + 30.402
R² = 0.2858
30.75
30.7
30.65
30.6
30.55
30.5
30.45
30.4
30.35
30.3
30.25
0
5
10
15
20
25
30
35
40
Water Slope
Linear (Water Slope)
Stream Bed Slope
Linear (Stream Bed Slope)

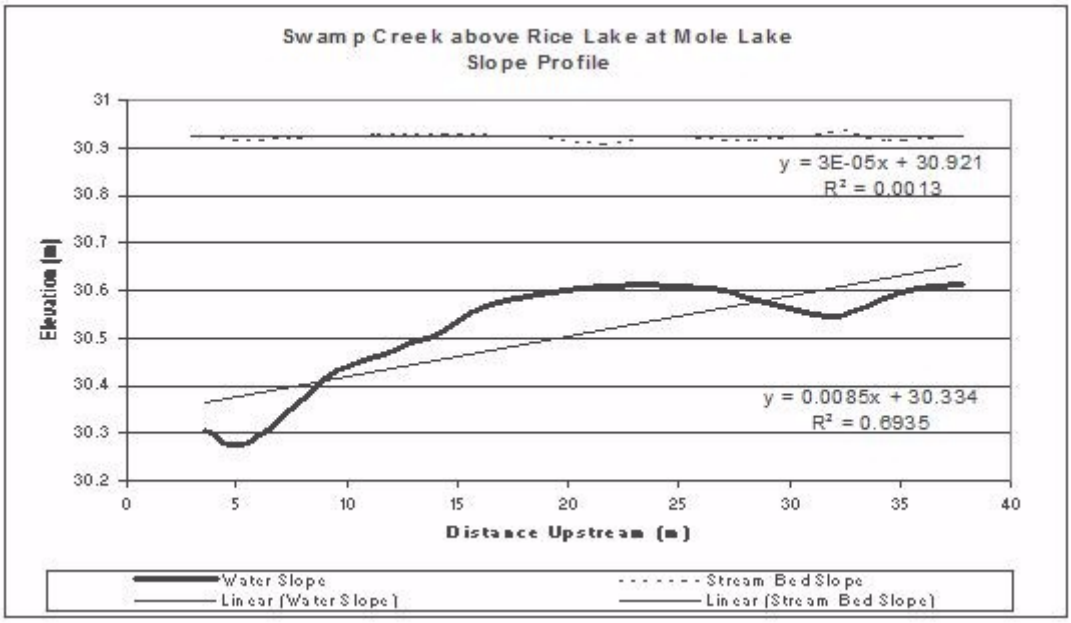

Middle Branch Embarrass River near Wittenberg
Longitudinal Profile
Easting (m)
1545
1540
1535
1530
1525
1520
1515
1510
1505
1510
1515
1520
1525
1530
1535
Northing (m)

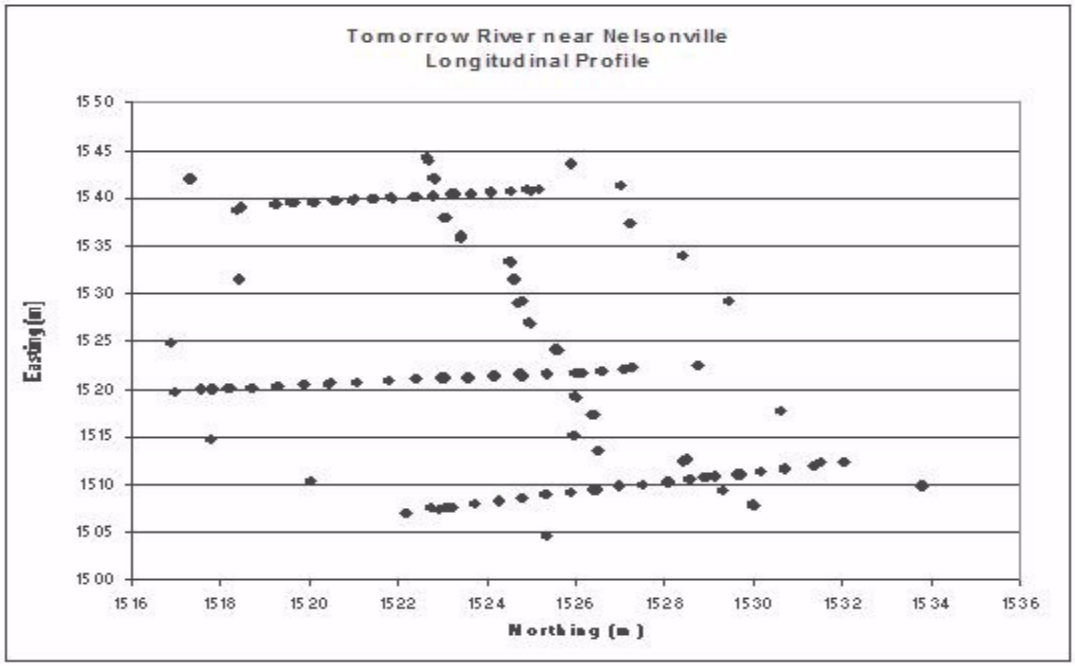

Middle Branch Embarrass River near Wittenberg
Slope Profile
Elevation (m)
31.1
31
30.9
30.8
30.7
30.6
30.5
y = 0.0003x + 31.059
R² = 0.0567
y = 0.0025x + 30.556
R² = 0.3415
0
5
10
15
20
25
Distance Upstream (m)
Water Slope
Stream Bed Slope
Linear (Water Slope)
Linear (Stream Bed Slope)

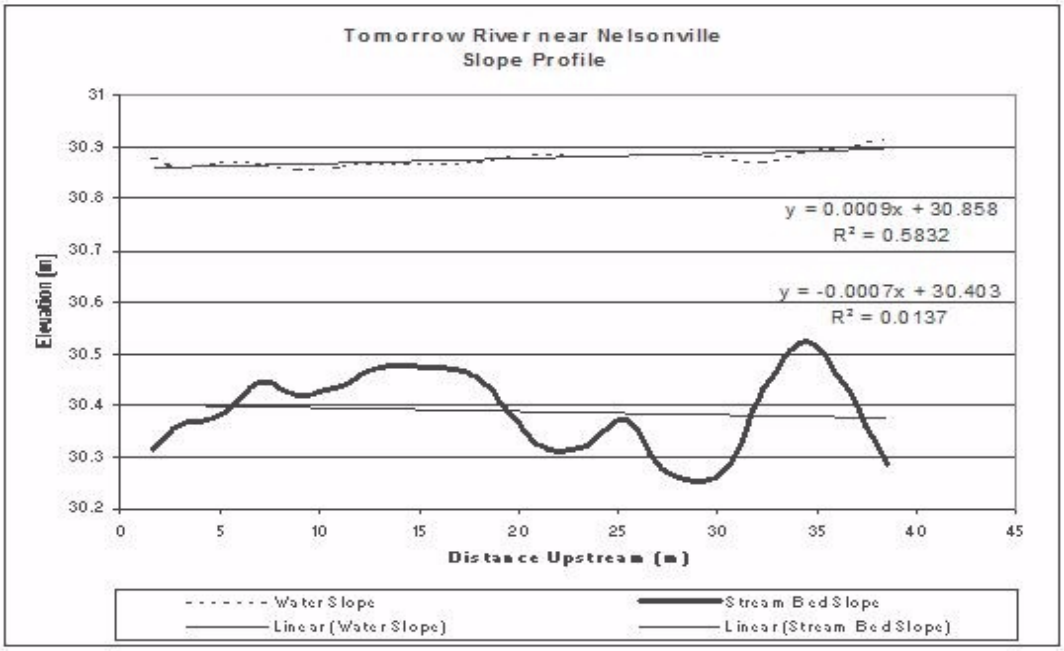

Sapulding Creek near Big Falls
Longitudinal Profile
Easting (m)
Northing (m)
1532
1530
1528
1526
1524
1522
1520
1518
1516
1516
1518
1520
1522
1524
1526
1528
1530
1532

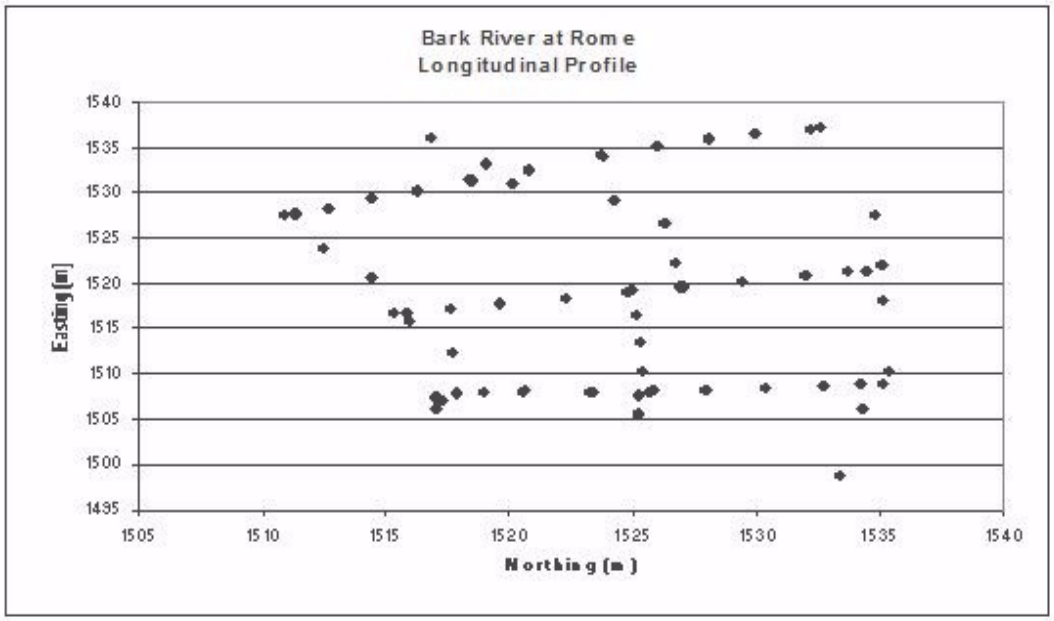

Spaulding Creek near Big Falls
Slope Profile
Elevation (m)
Distance Upstream (m)
y = 0.0062x + 30.689
R² = 0.5628
y = -0.0084x + 30.505
R² = 0.2175
30.9
30.8
30.7
30.6
30.5
30.4
30.3
30.2
0
2
4
6
8
10
12
14
16
18
Water Slope
Stream Bed Slope
Linear (Water Slope)
Linear (Stream Bed Slope)

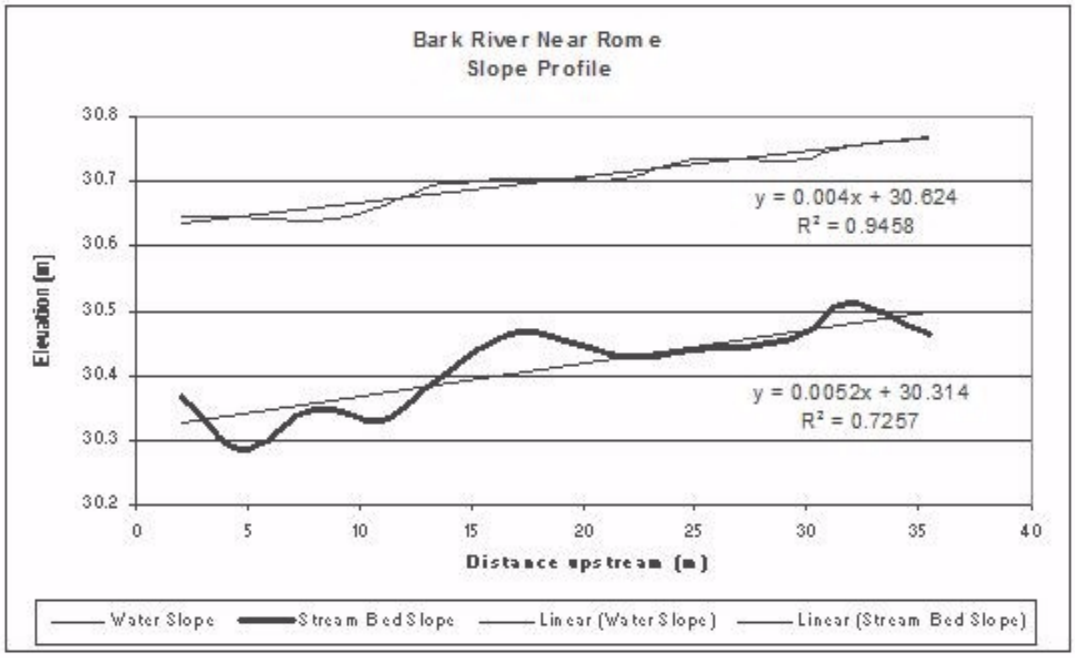

Swamp Creek above Rice Lake at Mole Lake
Longitudinal Profile
Easting (m)
Northing (m)
1555
1550
1545
1540
1535
1530
1525
1520
1515
1510
1505
1505
1510
1515
1520
1525
1530
1535
1540
1545
1550
1555

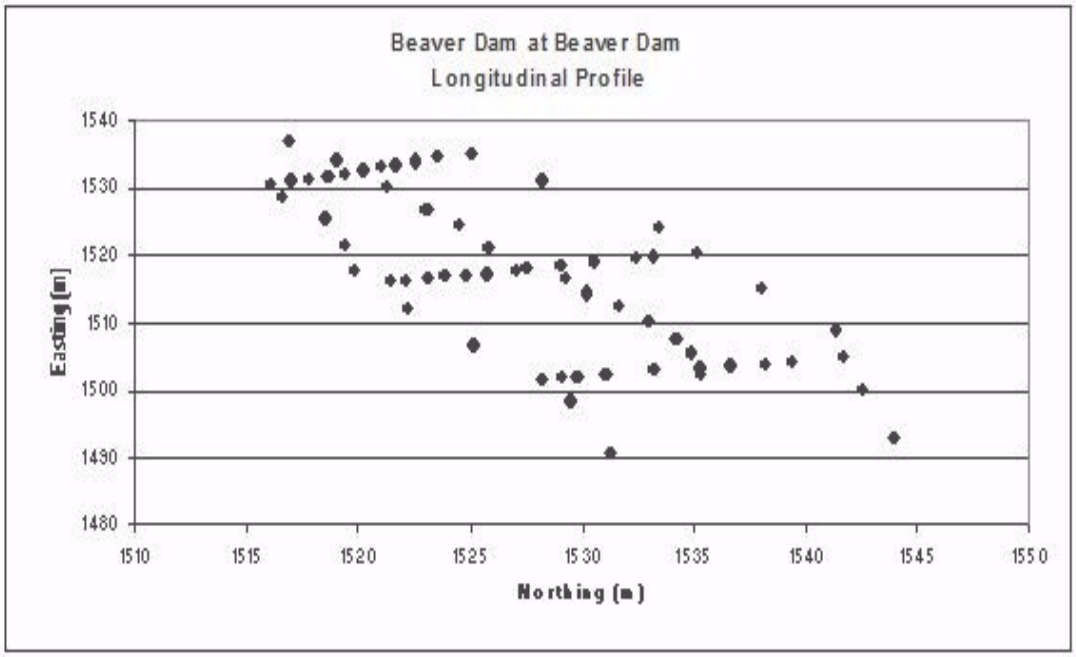

Swamp Creek above Rice Lake at Mole Lake
Slope Profile
Elevation (m)
Distance Upstream (m)
y = 3E-05x + 30.921
R² = 0.0013
y = 0.0085x + 30.334
R² = 0.6935
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
30.2
0
5
10
15
20
25
30
35
40
Water Slope
Stream Bed Slope
Linear (Water Slope)
Linear (Stream Bed Slope)

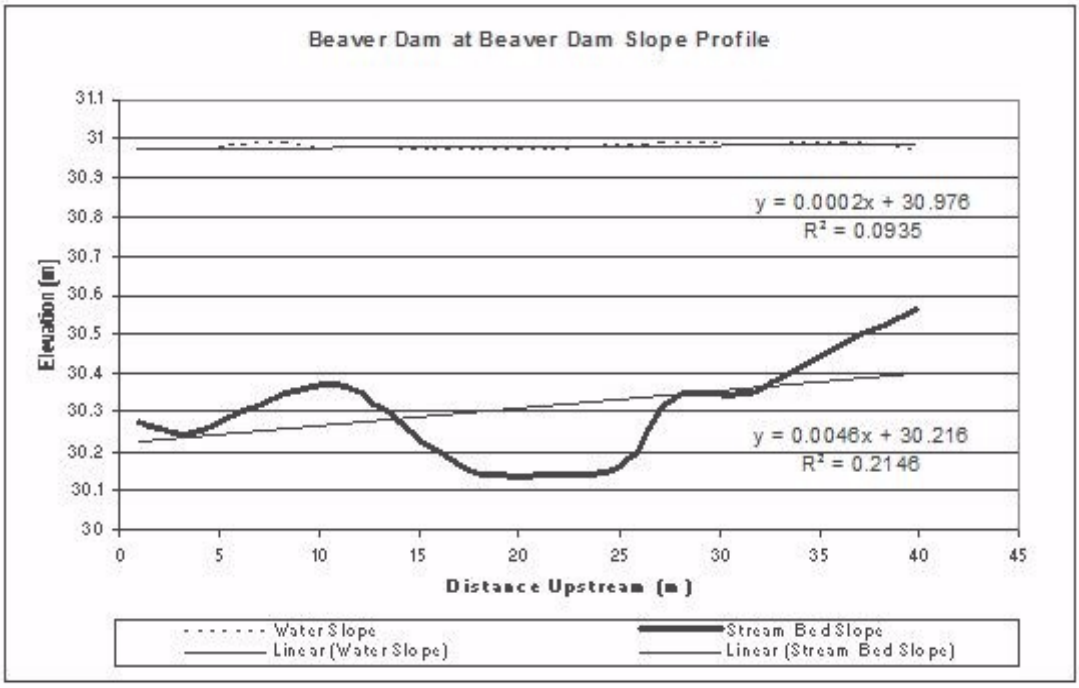

Tomorrow River near Nelsonville
Longitudinal Profile
Easting (m)
15 50
15 45
15 40
15 35
15 30
15 25
15 20
15 15
15 10
15 05
15 00
15 16
15 18
15 20
15 22
15 24
15 26
15 28
15 30
15 32
15 34
15 36
Northing (m)

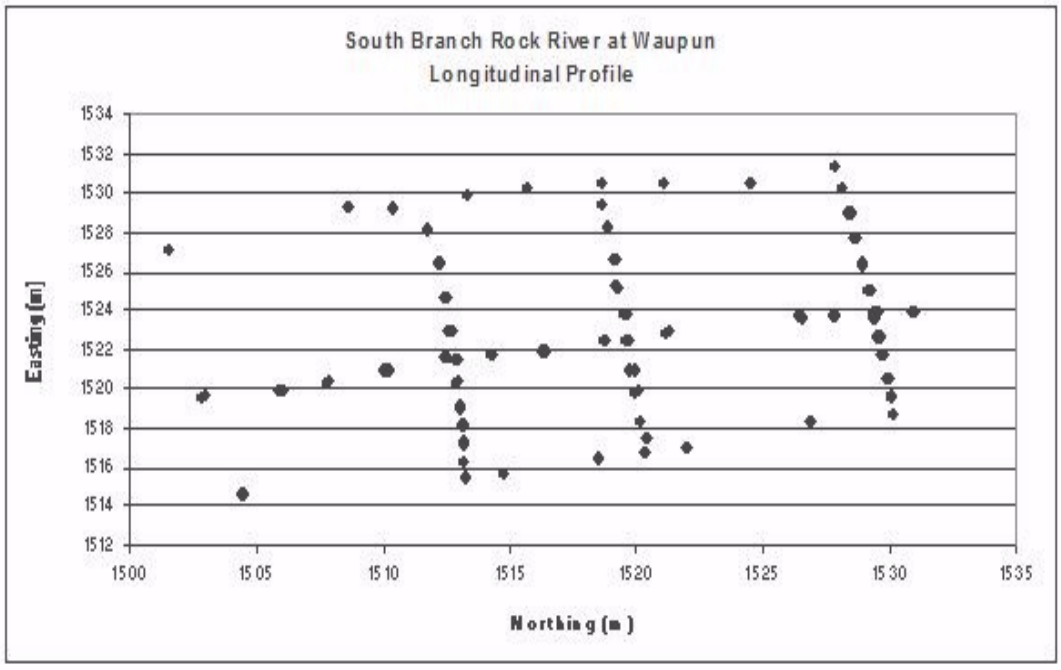

Tomorrow River near Nelsonville
Slope Profile
Elevation (m)
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
30.2
y = 0.0009x + 30.858
R² = 0.5832
y = -0.0007x + 30.403
R² = 0.0137
0
5
10
15
20
25
30
35
40
45
Distance Upstream (m)
Water Slope
Stream Bed Slope
Linear (Water Slope)
Linear (Stream Bed Slope)

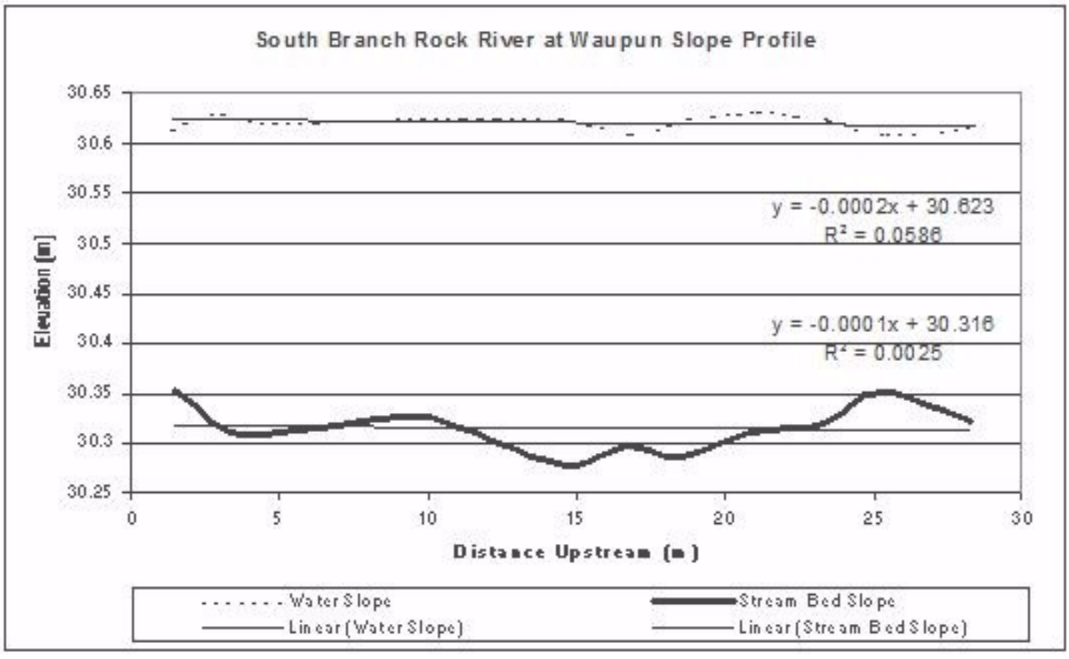

Bark River at Rome
Longitudinal Profile
Easting (m)
1540
1535
1530
1525
1520
1515
1510
1505
1500
1495
1505
1510
1515
1520
1525
1530
1535
1540
Northing (m)

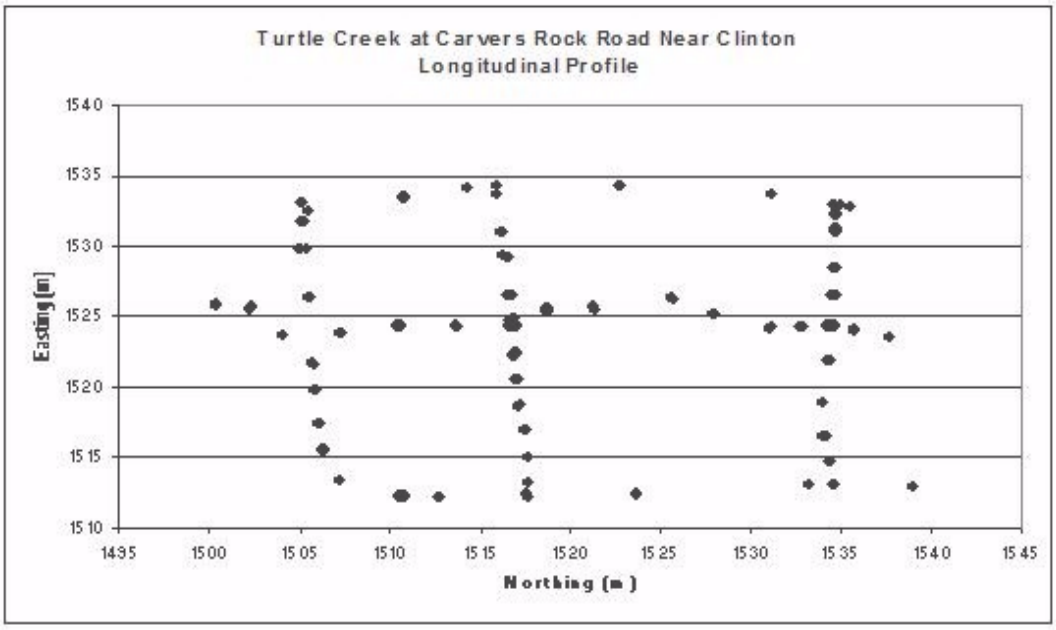

Bark River Near Rome
Slope Profile
Elevation (m)
30.8
30.7
30.6
30.5
30.4
30.3
30.2
y = 0.004x + 30.624
R² = 0.9458
y = 0.0052x + 30.314
R² = 0.7257
0
5
10
15
20
25
30
35
40
Distance upstream (m)
Water Slope
Stream Bed Slope
Linear (Water Slope)
Linear (Stream Bed Slope)

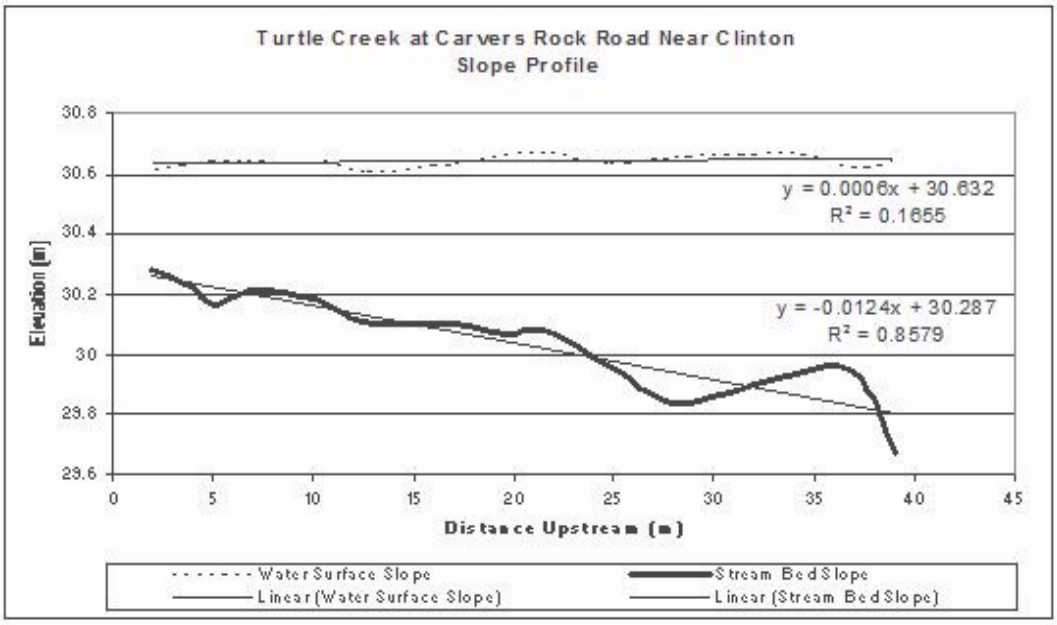

Beaver Dam at Beaver Dam
Longitudinal Profile
Easting (m)
1540
1530
1520
1510
1500
1490
1480
1510
1515
1520
1525
1530
1535
1540
1545
1550
Northing (m)


Beaver Dam at Beaver Dam Slope Profile
Elevation (m)
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
30.2
30.1
30
y = 0.0002x + 30.976
R² = 0.0935
y = 0.0046x + 30.216
R² = 0.2146
0
5
10
15
20
25
30
35
40
45
Distance Upstream (m)
Water Slope
Linear (Water Slope)
Stream Bed Slope
Linear (Stream Bed Slope)

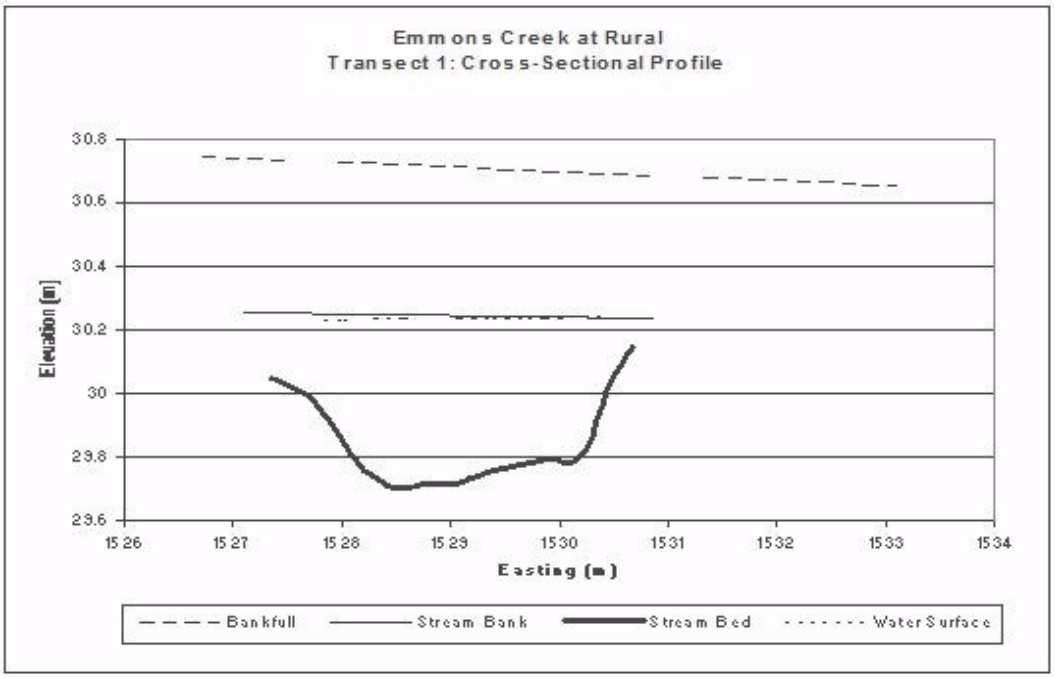

South Branch Rock River at Waupun
Longitudinal Profile
Easting (m)
1534
1532
1530
1528
1526
1524
1522
1520
1518
1516
1514
1512
1500
1505
1510
1515
1520
1525
1530
1535
Northing (m)

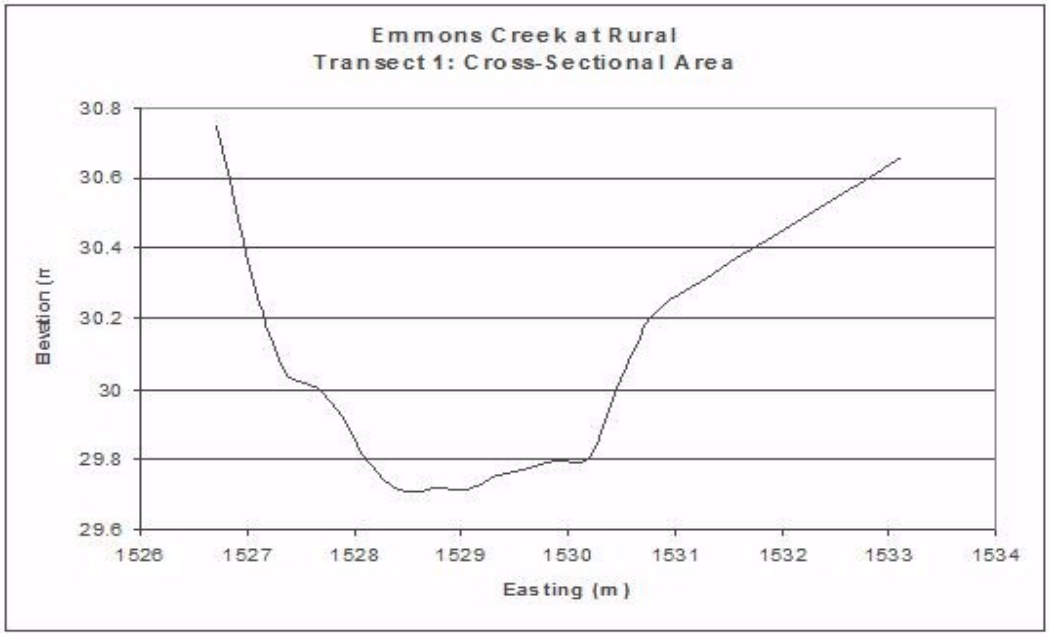

South Branch Rock River at Waupun Slope Profile
Elevation (m)
30.65
30.6
30.55
30.5
30.45
30.4
30.35
30.3
30.25
y = -0.0002x + 30.623
R² = 0.0586
y = -0.0001x + 30.316
R² = 0.0025
0
5
10
15
20
25
30
Distance Upstream (m)
Water Slope
Stream Bed Slope
Linear (Water Slope)
Linear (Stream Bed Slope)

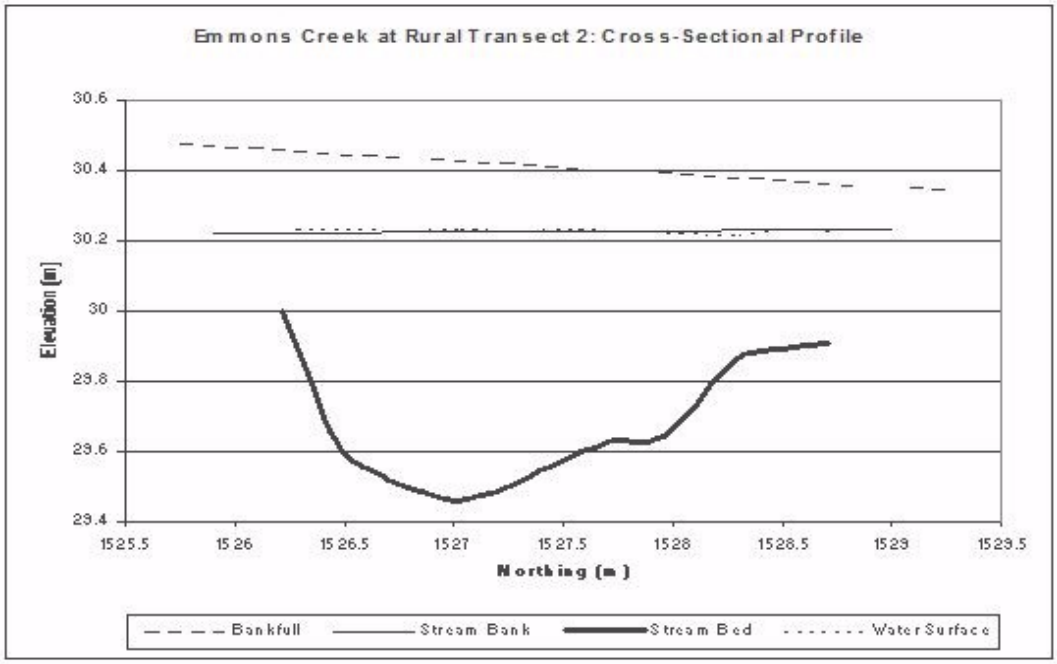

Turtle Creek at Carvers Rock Road Near Clinton
Longitudinal Profile
Easting (m)
1540
1535
1530
1525
1520
1515
1510
1495
1500
1505
1510
1515
1520
1525
1530
1535
1540
1545
Northing (m)

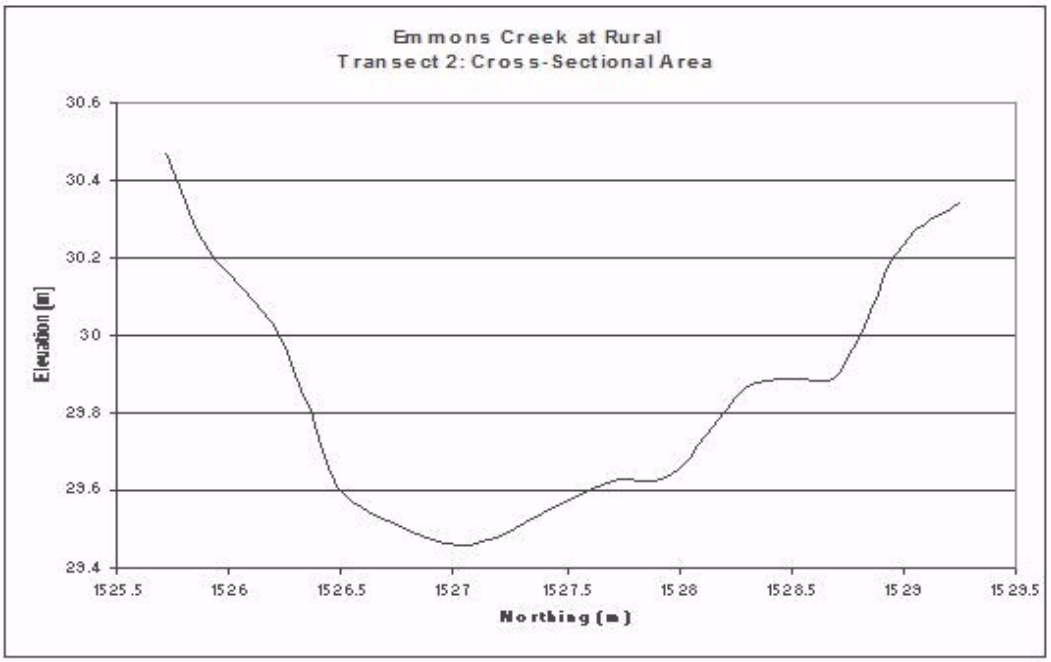

Turtle Creek at Carvers Rock Road Near Clinton
Slope Profile
Elevation (m)
30.8
30.6
30.4
30.2
30
29.8
29.6
y = 0.0006x + 30.632
R² = 0.1655
y = -0.0124x + 30.287
R² = 0.8579
0
5
10
15
20
25
30
35
40
45
Distance Upstream (m)
Water Surface Slope
Stream Bed Slope
Linear (Water Surface Slope)
Linear (Stream Bed Slope)

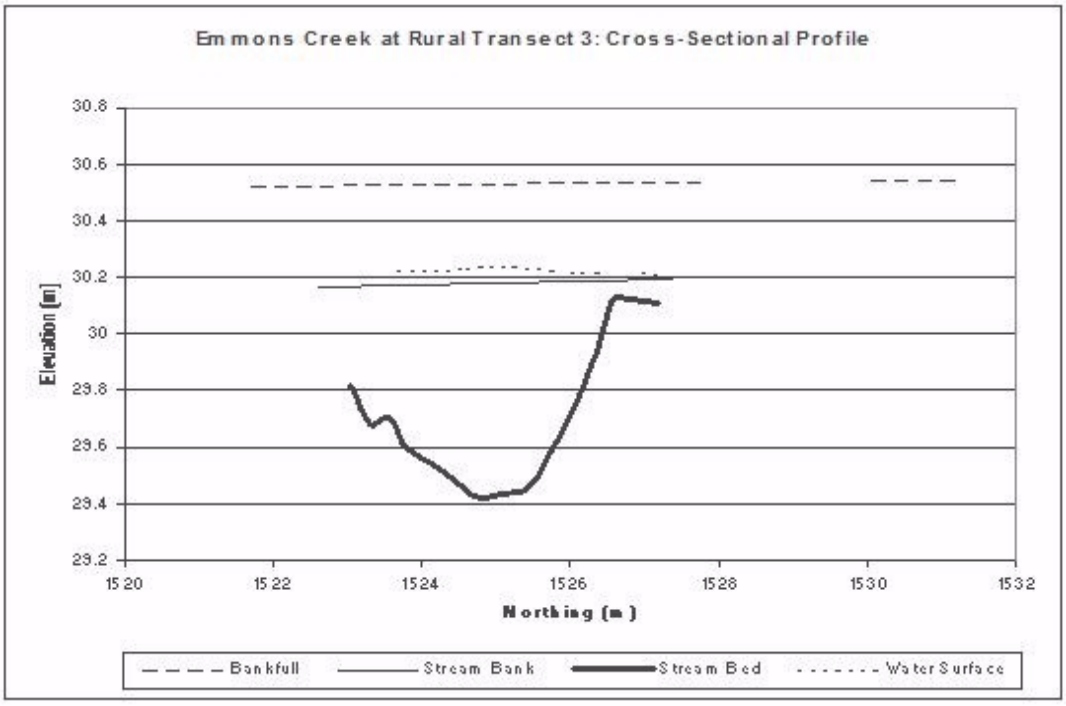
Appendix M: Transect Cross-Sectional Area, by site

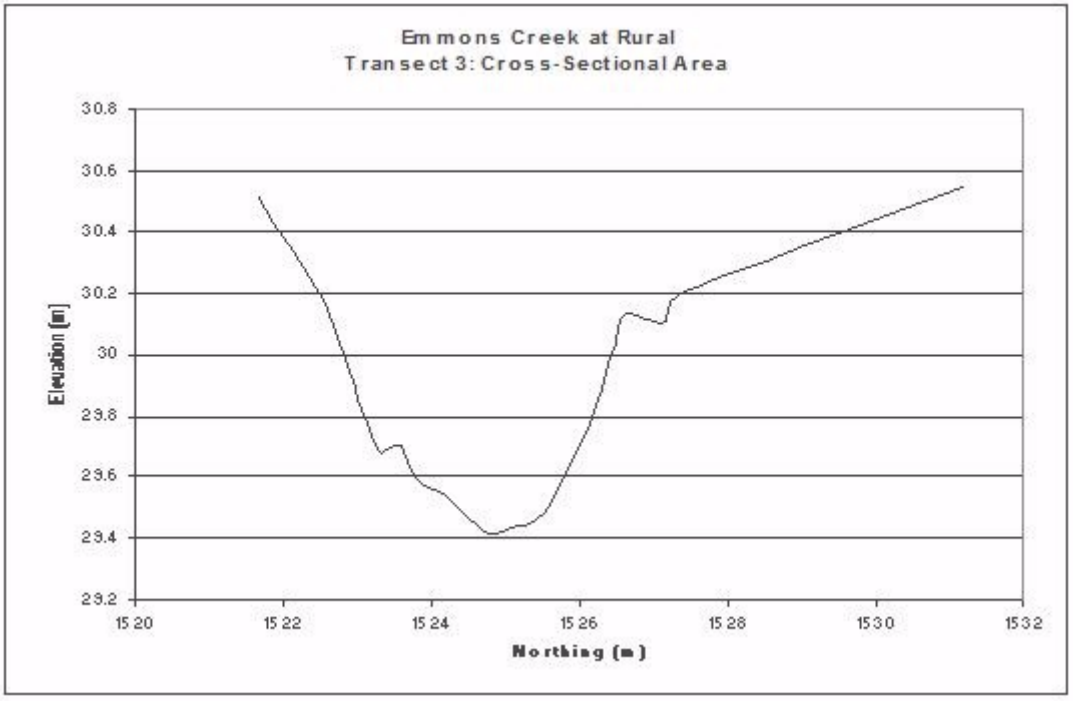

Emmons Creek at Rural
Transect 1: Cross-Sectional Profile
30.8
30.6
30.4
30.2
30
29.8
29.6
Elevation (m)
1526
1527
1528
1529
1530
1531
1532
1533
1534
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

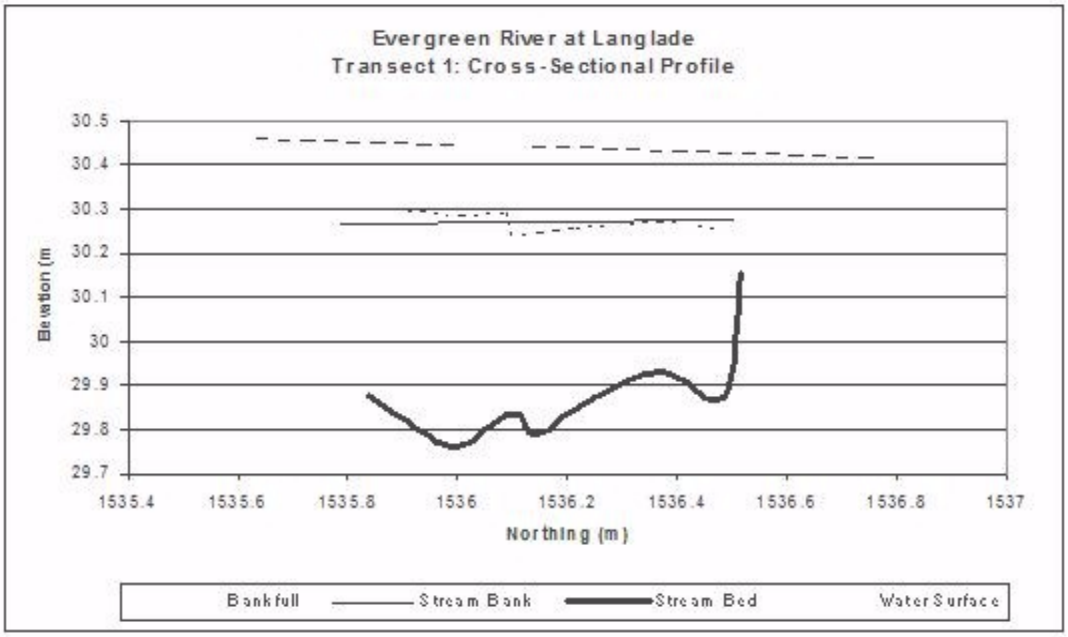

Emmons Creek at Rural
Transect 1: Cross-Sectional Area
30.8
30.6
30.4
30.2
30
29.8
29.6
1526
1527
1528
1529
1530
1531
1532
1533
1534
Easting (m)

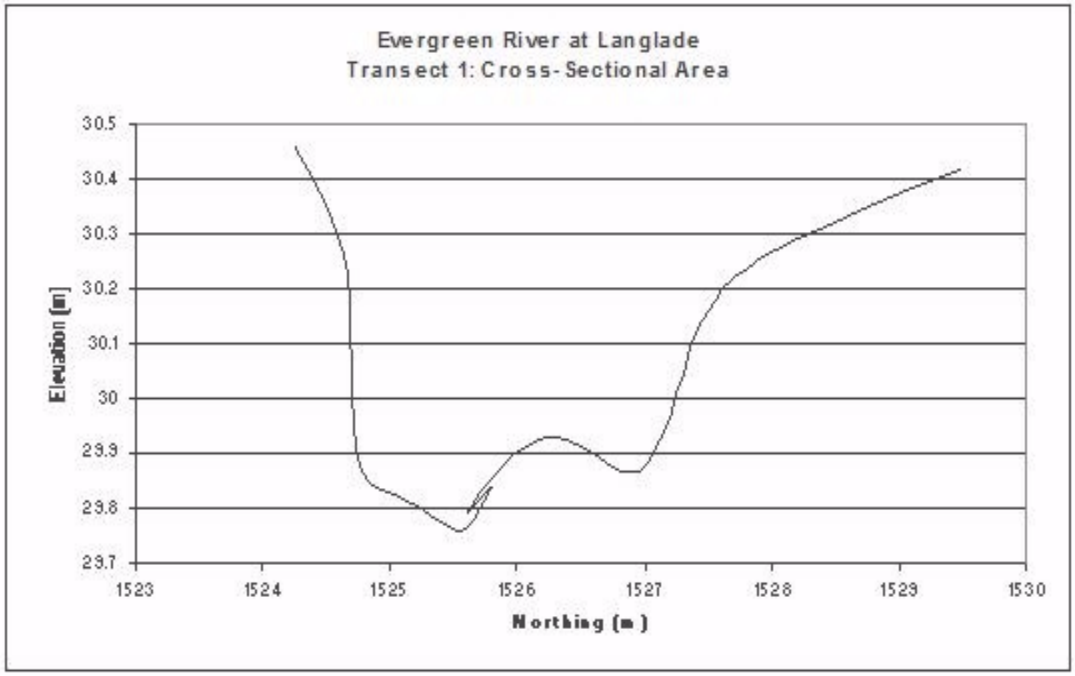

Emmons Creek at Rural Transect 2: Cross-Sectional Profile
30.6
30.4
30.2
30
29.8
29.6
29.4
Elevation (m)
1525.5
1526
1526.5
1527
1527.5
1528
1528.5
1529
1529.5
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

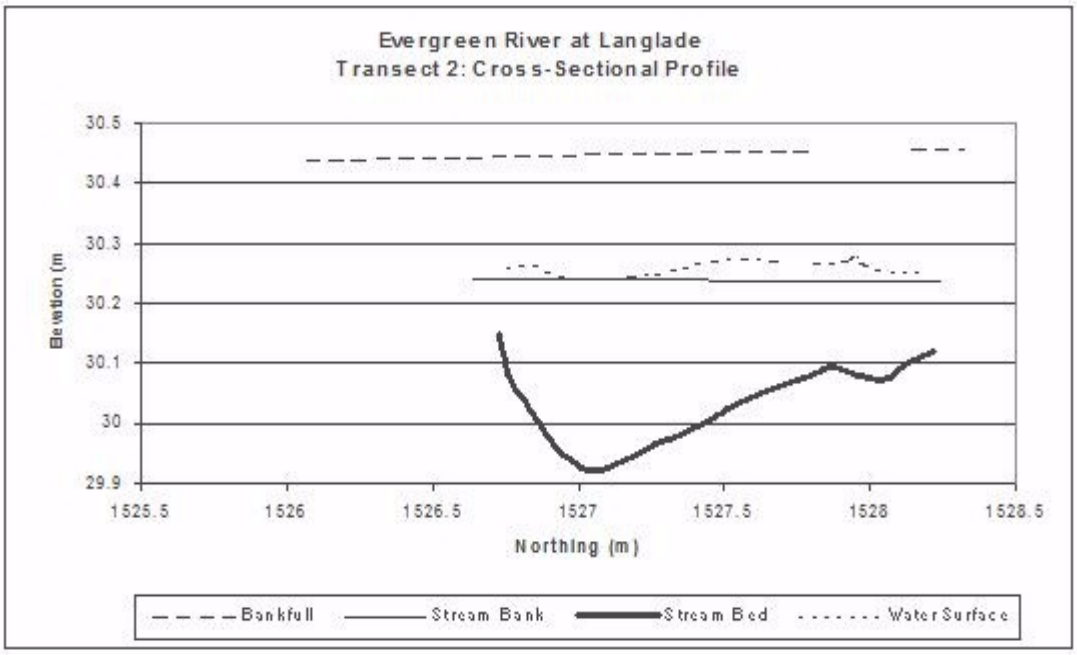

Emmons Creek at Rural
Transect 2: Cross-Sectional Area
30.6
30.4
30.2
30
29.8
29.6
29.4
Elevation (m)
1525.5
1526
1526.5
1527
1527.5
1528
1528.5
1529
1529.5
Northing (m)

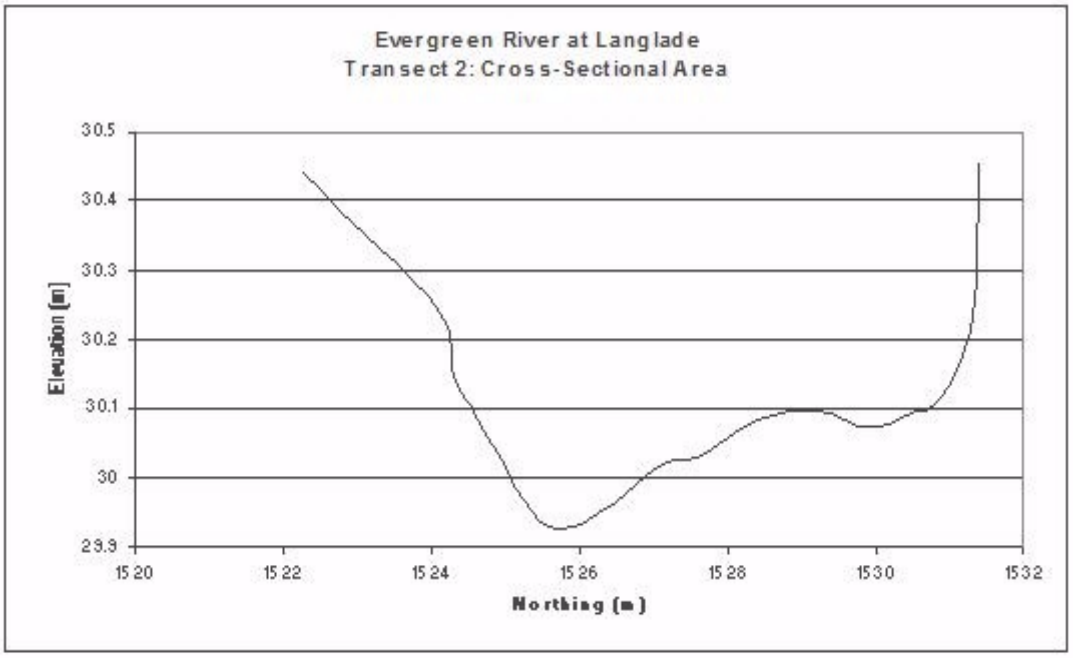

Emmons Creek at Rural Transect 3: Cross-Sectional Profile
Elevation (m)
30.8
30.6
30.4
30.2
30
29.8
29.6
29.4
29.2
1520
1522
1524
1526
1528
1530
1532
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

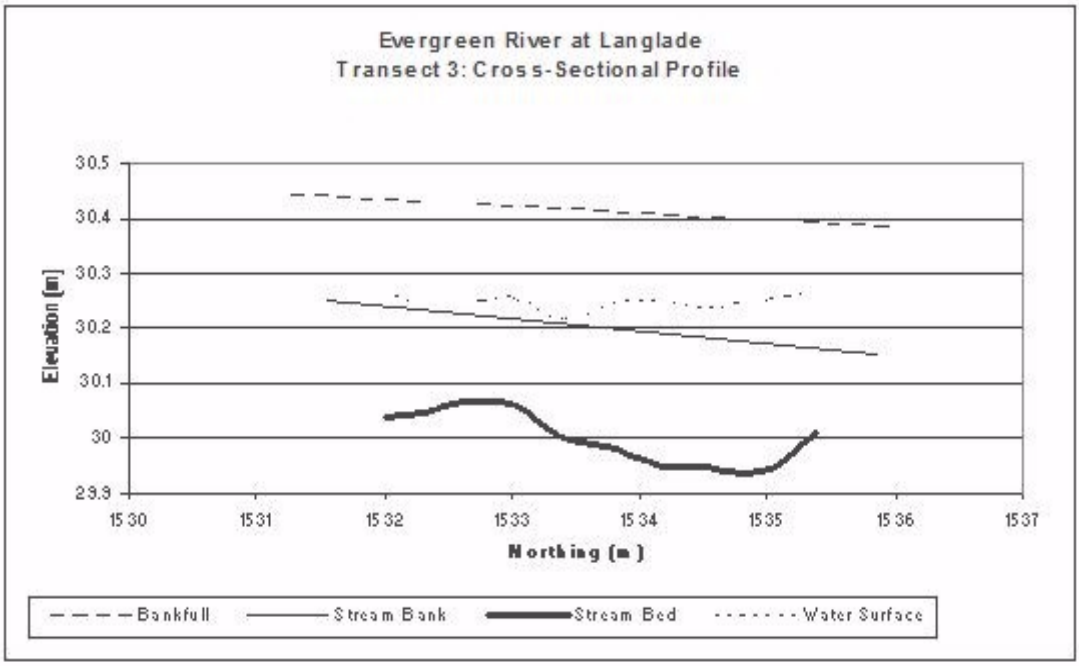

Emmons Creek at Rural
Transect 3: Cross-Sectional Area
Elevation (m)
30.8
30.6
30.4
30.2
30
29.8
29.6
29.4
29.2
1520
1522
1524
1526
1528
1530
1532
Northing (m)

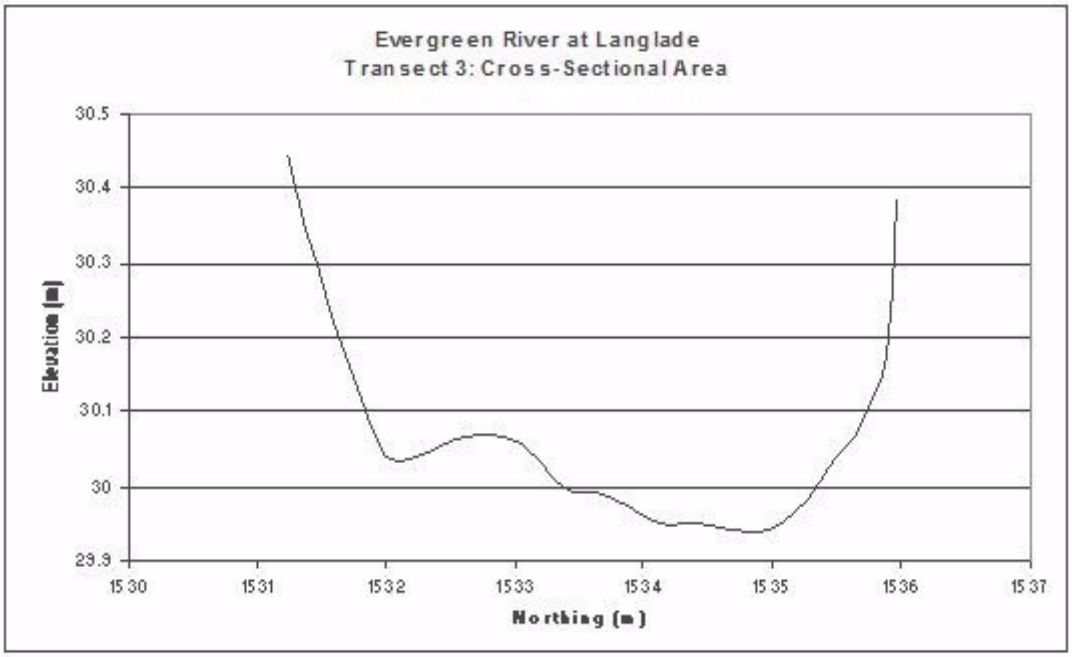

Evergreen River at Langlade
Transect 1: Cross-Sectional Profile
Elevation (m
30.5
30.4
30.3
30.2
30.1
30
29.9
29.8
29.7
1535.4
1535.6
1535.8
1536
1536.2
1536.4
1536.6
1536.8
1537
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

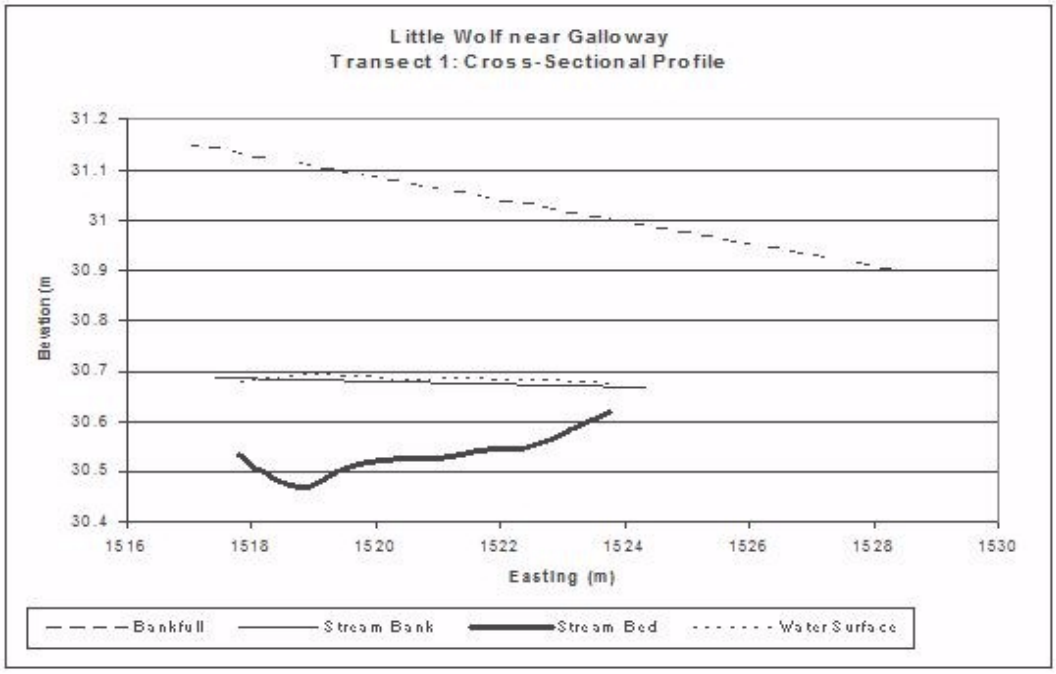

Evergreen River at Langlade
Transect 1: Cross-Sectional Area
Elevation (m)
30.5
30.4
30.3
30.2
30.1
30
29.9
29.8
29.7
1523
1524
1525
1526
1527
1528
1529
1530
Northing (m)

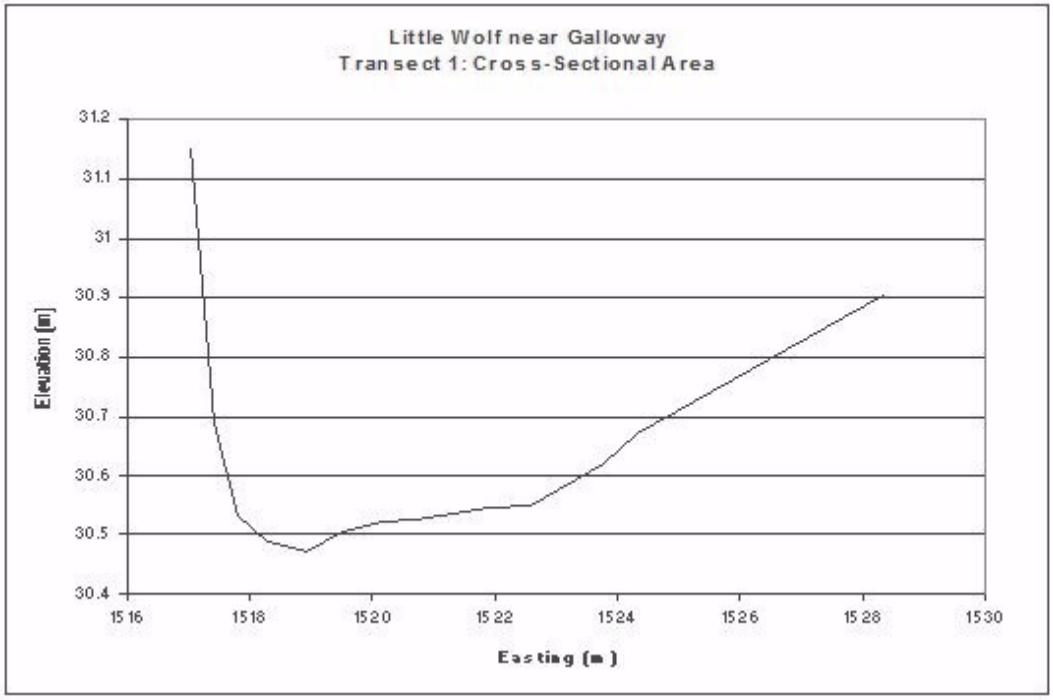

Evergreen River at Langlade
Transect 2: Cross-Sectional Profile
Elevation (m
30.5
30.4
30.3
30.2
30.1
30
29.9
1525.5
1526
1526.5
1527
1527.5
1528
1528.5
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

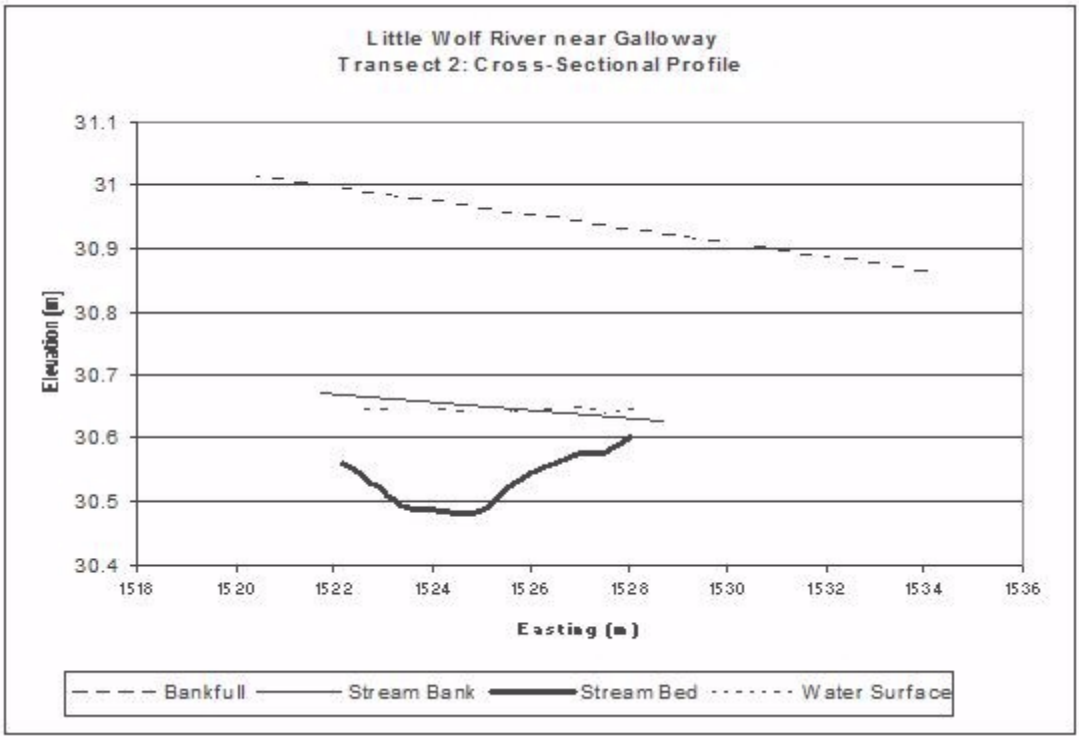

Evergreen River at Langlade
Transect 2: Cross-Sectional Area
Elevation (m)
30.5
30.4
30.3
30.2
30.1
30
29.9
1520
1522
1524
1526
1528
1530
1532
Northing (m)

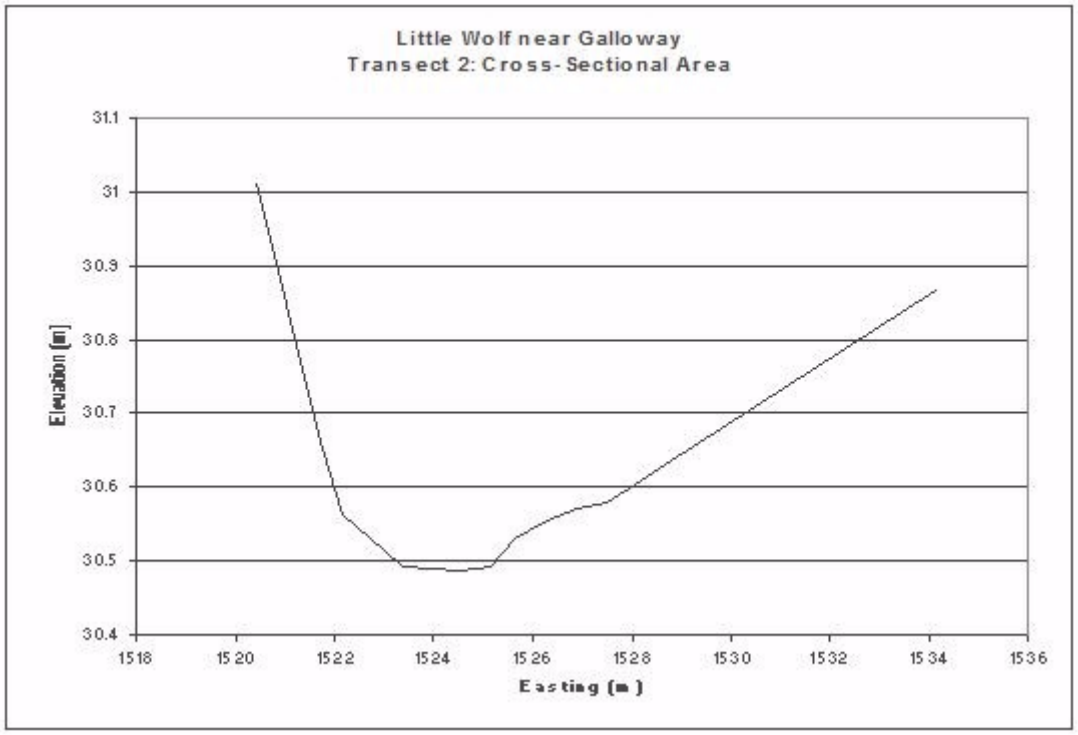

Evergreen River at Langlade
Transect 3: Cross-Sectional Profile
Elevation (m)
30.5
30.4
30.3
30.2
30.1
30
29.9
1530
1531
1532
1533
1534
1535
1536
1537
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

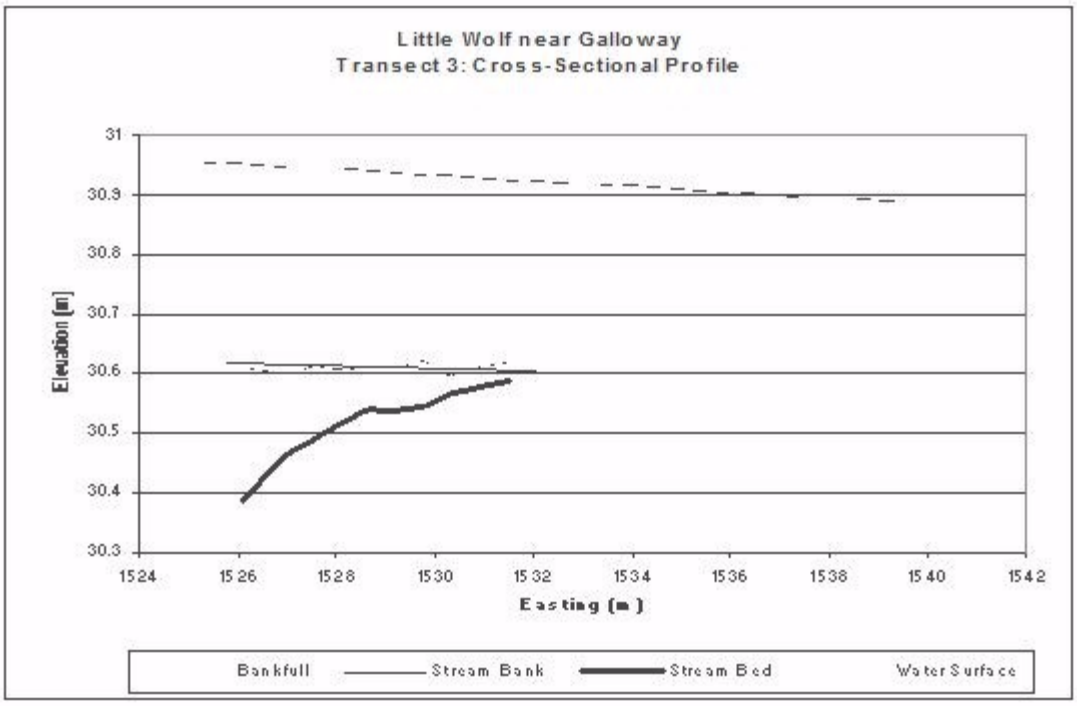

Evergreen River at Langlade
Transect 3: Cross-Sectional Area
Elevation (m)
30.5
30.4
30.3
30.2
30.1
30
29.9
1530
1531
1532
1533
1534
1535
1536
1537
Northing (m)

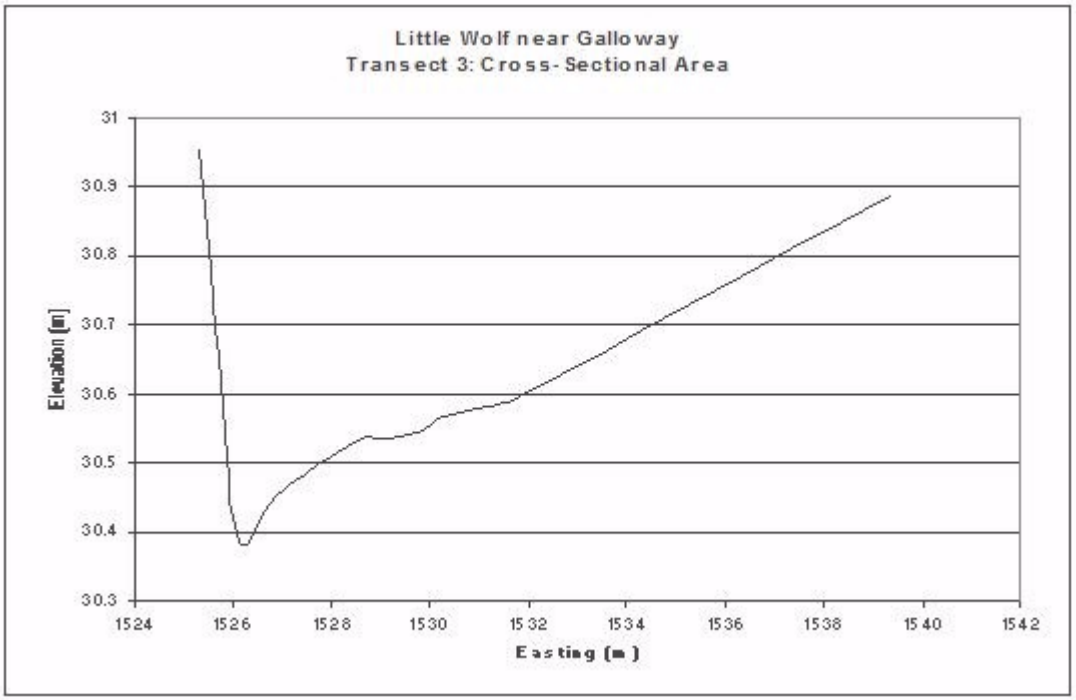

Little Wolf near Galloway
Transect 1: Cross-Sectional Profile
Elevation (m
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
1516
1518
1520
1522
1524
1526
1528
1530
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

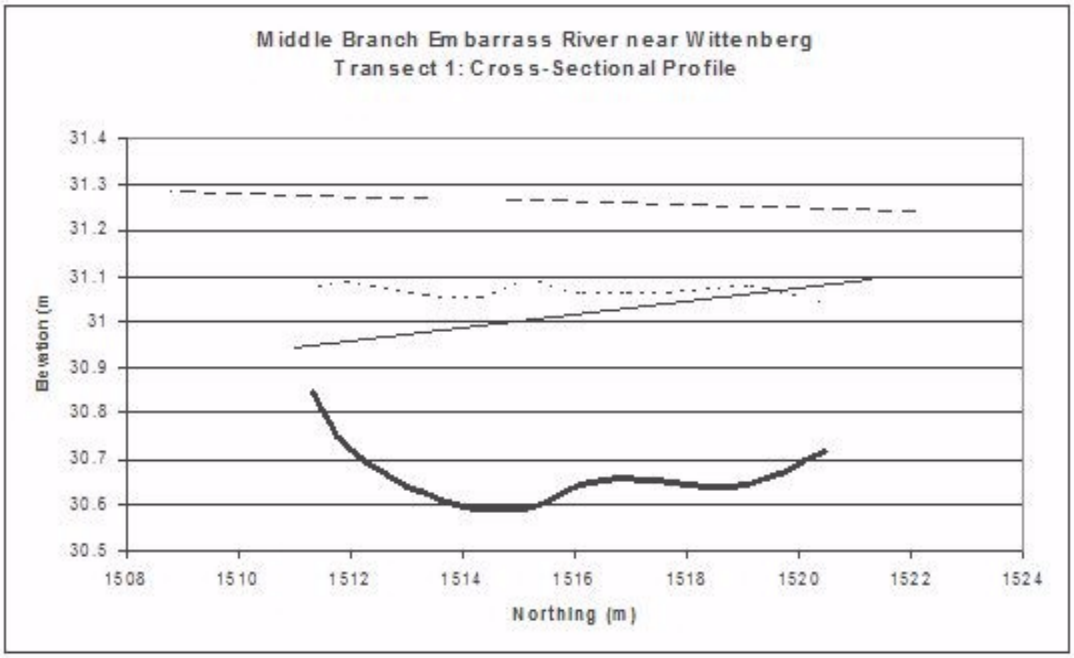

Little Wolf near Galloway
Transect 1: Cross-Sectional Area
Elevation (m)
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
1516
1518
1520
1522
1524
1526
1528
1530
Easting (m)

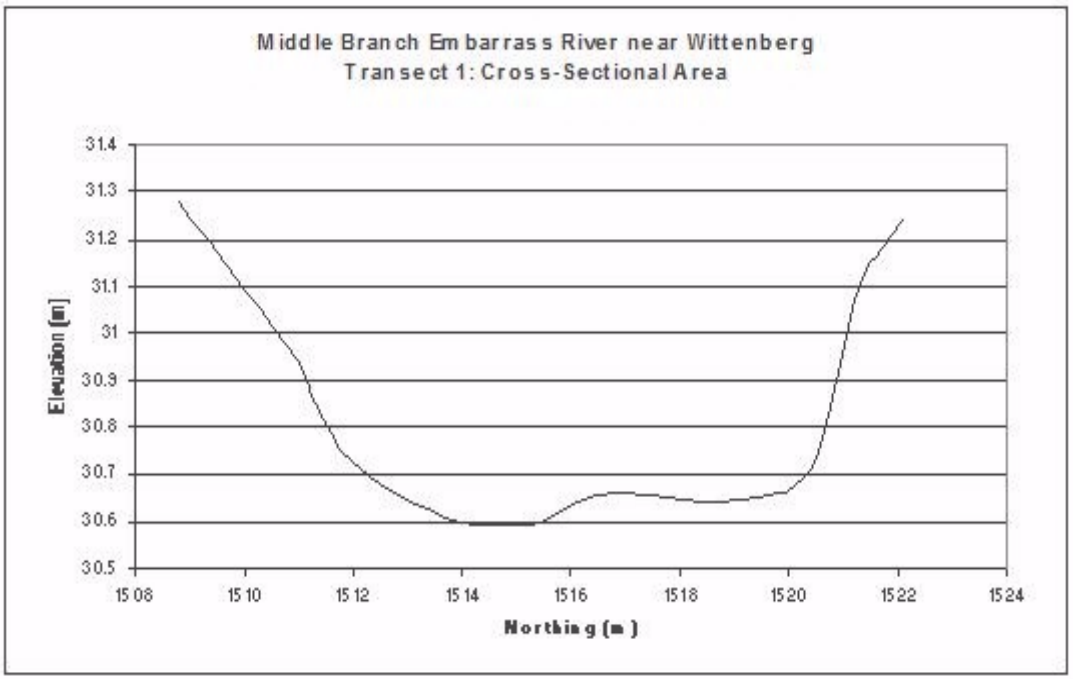

Little Wolf River near Galloway
Transect 2: Cross-Sectional Profile
Elevation (m)
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
1518
1520
1522
1524
1526
1528
1530
1532
1534
1536
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

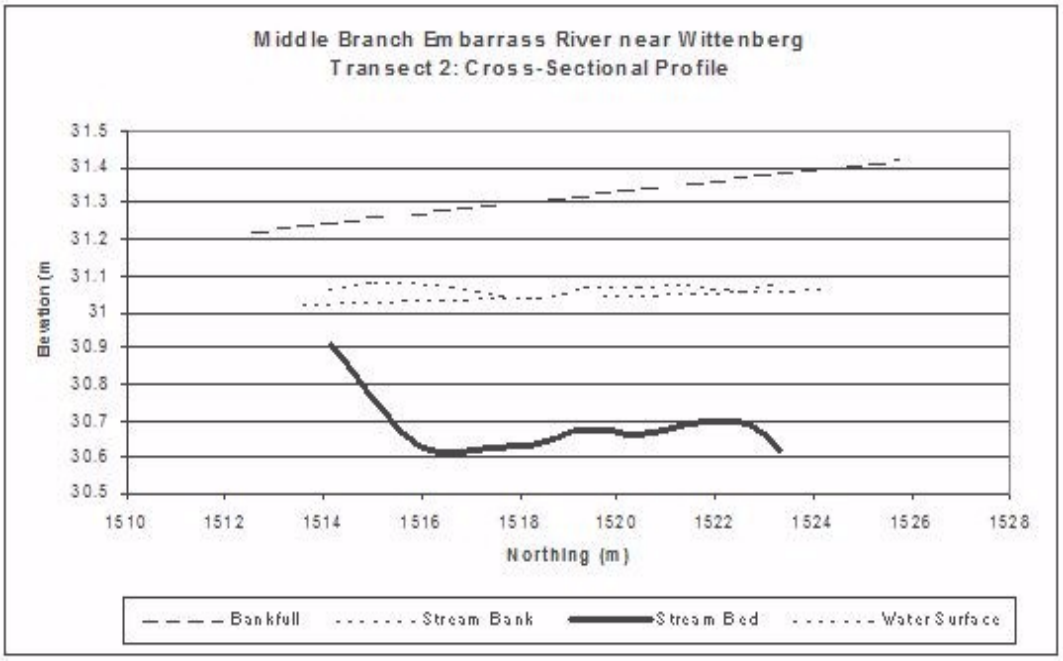

Little Wolf near Galloway
Transect 2: Cross-Sectional Area
Elevation (m)
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
1518
1520
1522
1524
1526
1528
1530
1532
1534
1536
Easting (m)

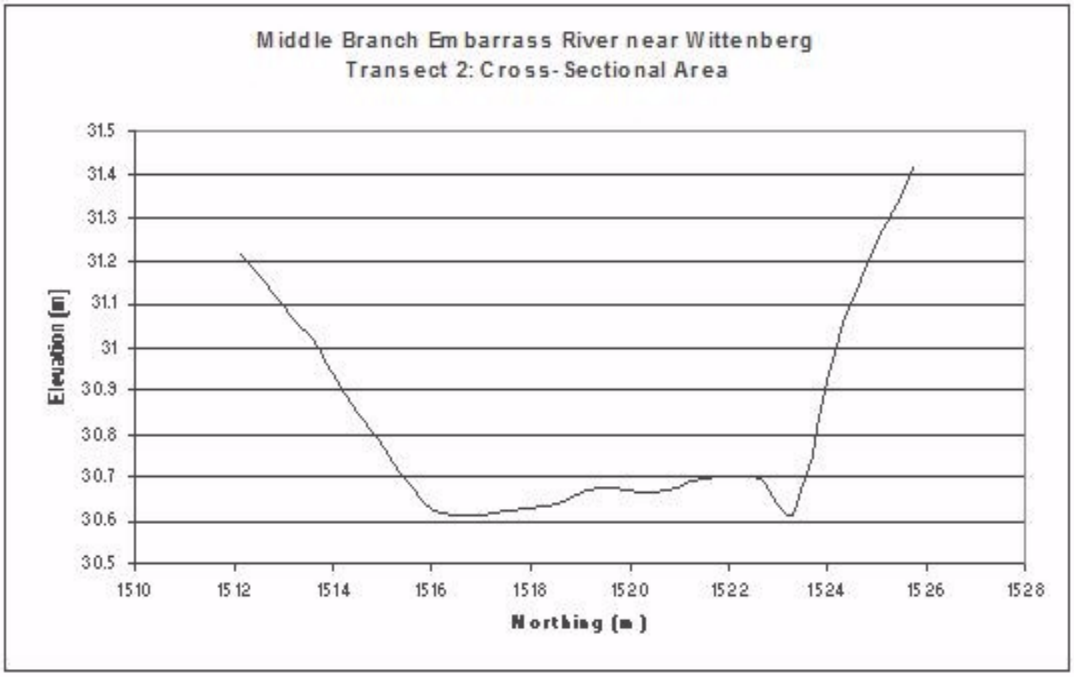

Little Wolf near Galloway
Transect 3: Cross-Sectional Profile
Elevation (m)
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1524
1526
1528
1530
1532
1534
1536
1538
1540
1542
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

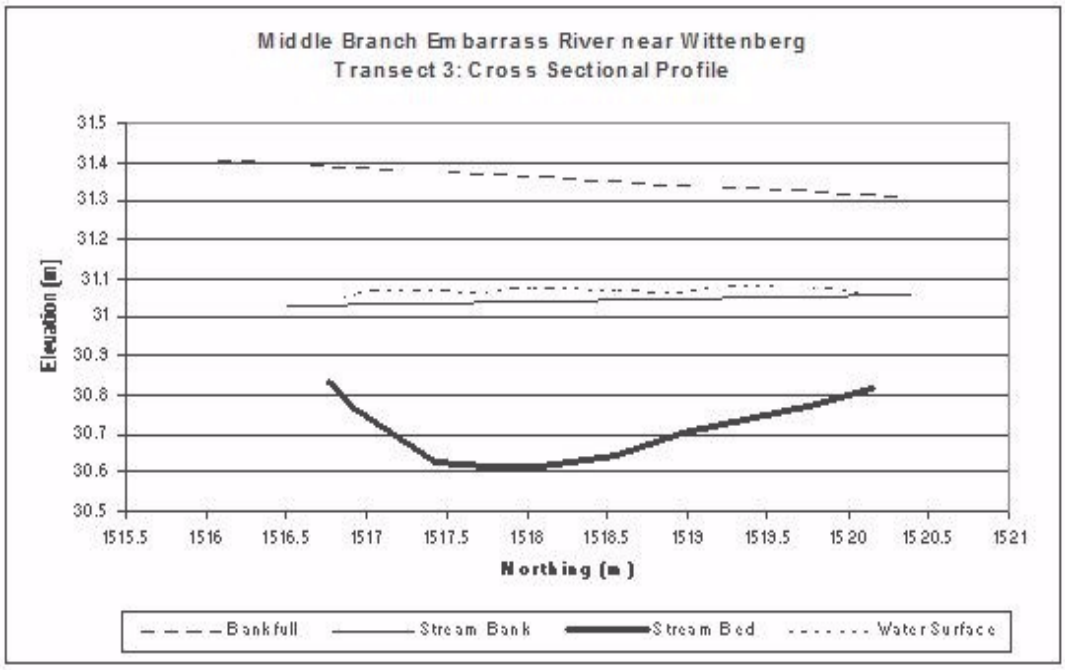

Little Wolf near Galloway
Transect 3: Cross-Sectional Area
Elevation (m)
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1524
1526
1528
1530
1532
1534
1536
1538
1540
1542
Easting (m)

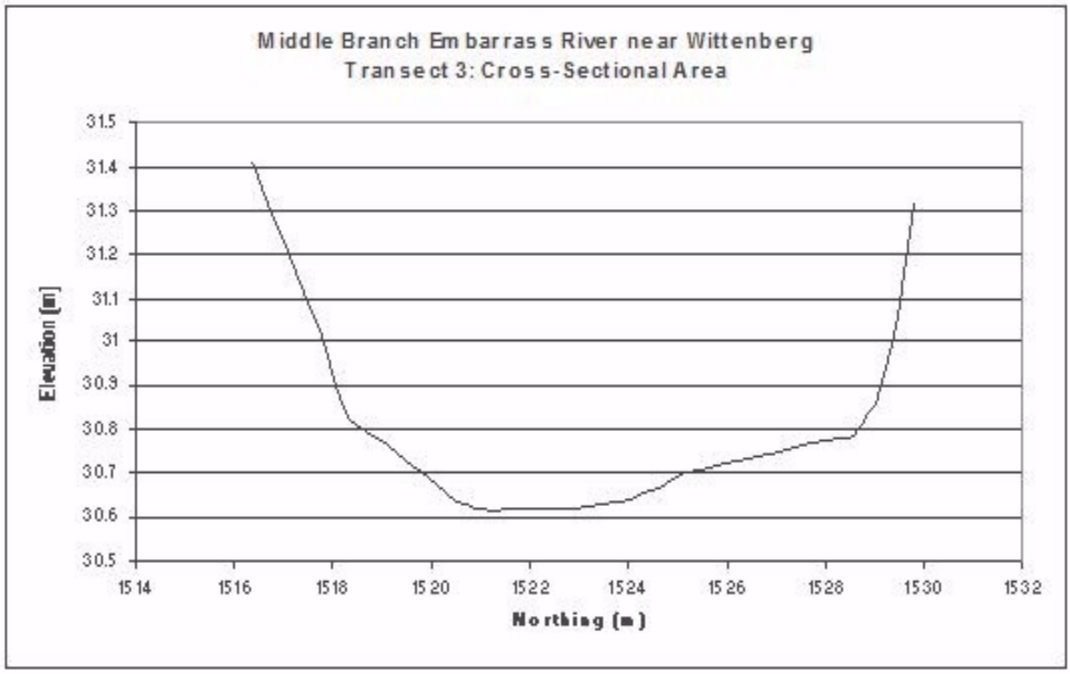

Middle Branch Embarrass River near Wittenberg
Transect 1: Cross-Sectional Profile
Elevation (m
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
1508
1510
1512
1514
1516
1518
1520
1522
1524
Northing (m)

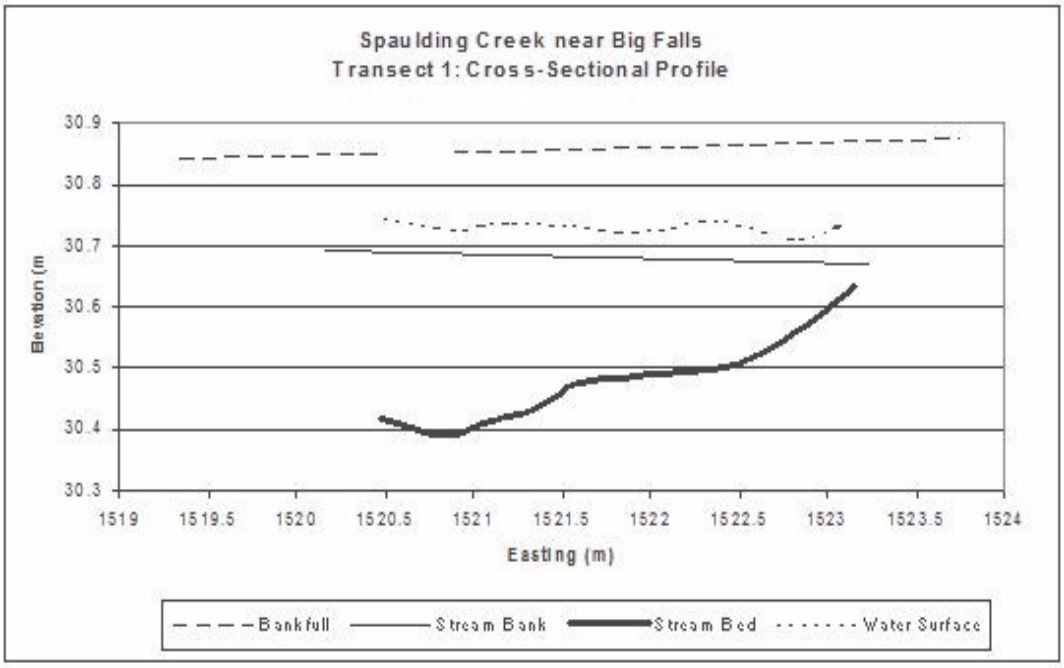

Middle Branch Embarrass River near Wittenberg
Transect 1: Cross-Sectional Area
Elevation (m)
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
1508
1510
1512
1514
1516
1518
1520
1522
1524
Northing (m)

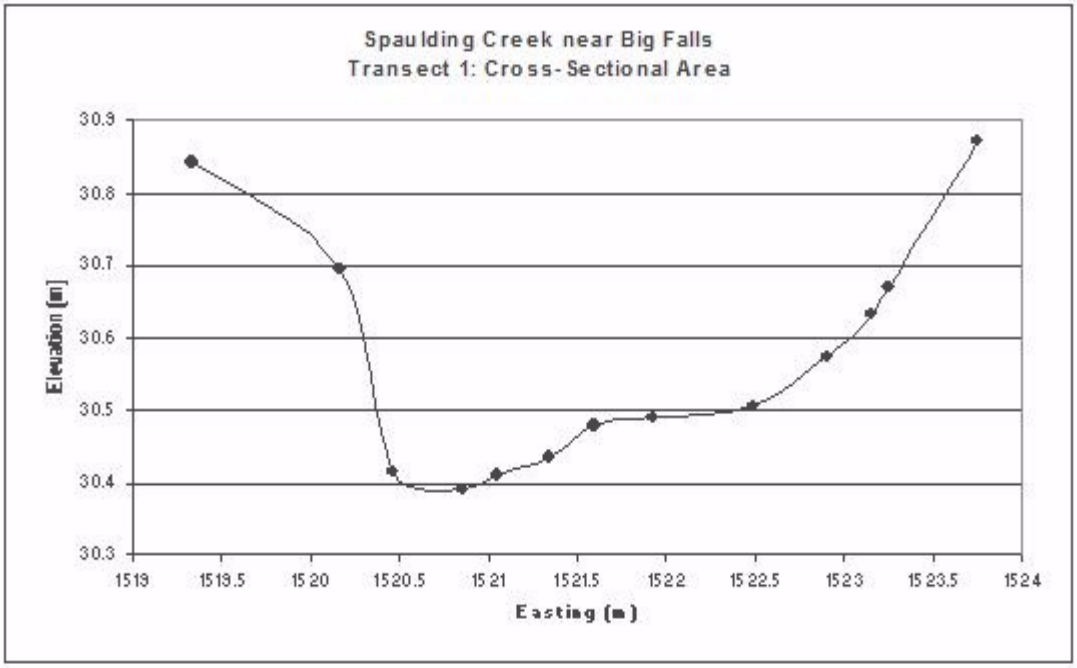

Middle Branch Embarrass River near Wittenberg
Transect 2: Cross-Sectional Profile
Elevation (m
31.5
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
1510
1512
1514
1516
1518
1520
1522
1524
1526
1528
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

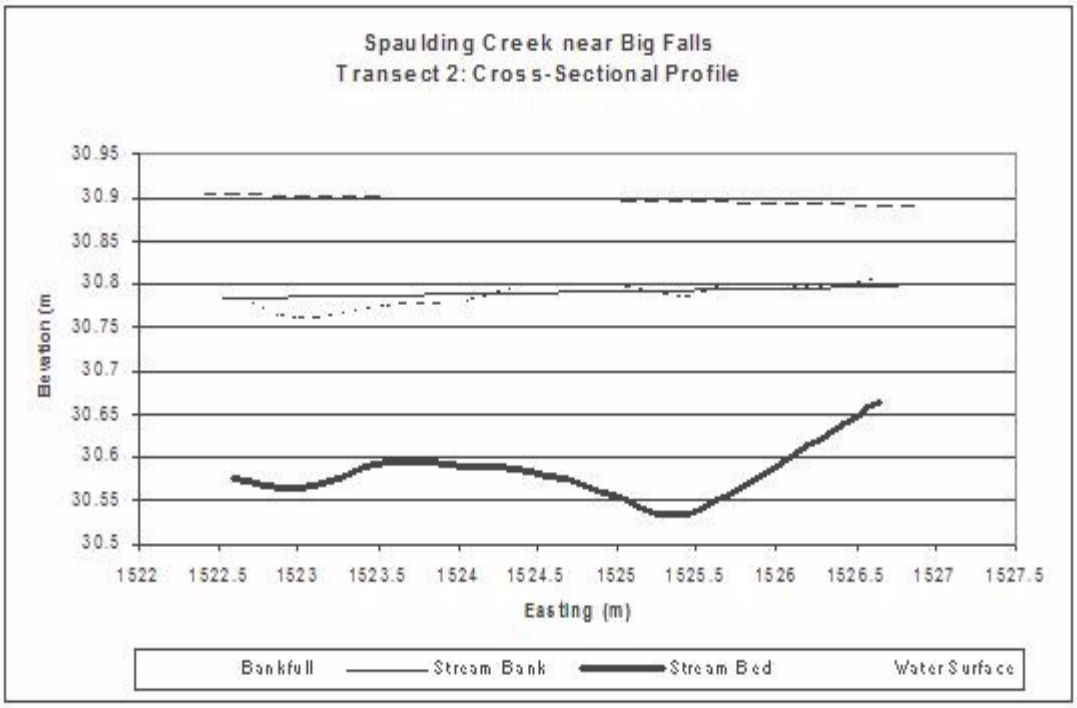

Middle Branch Embarrass River near Wittenberg
Transect 2: Cross-Sectional Area
Elevation (m)
31.5
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
1510
1512
1514
1516
1518
1520
1522
1524
1526
1528
Northing (m)

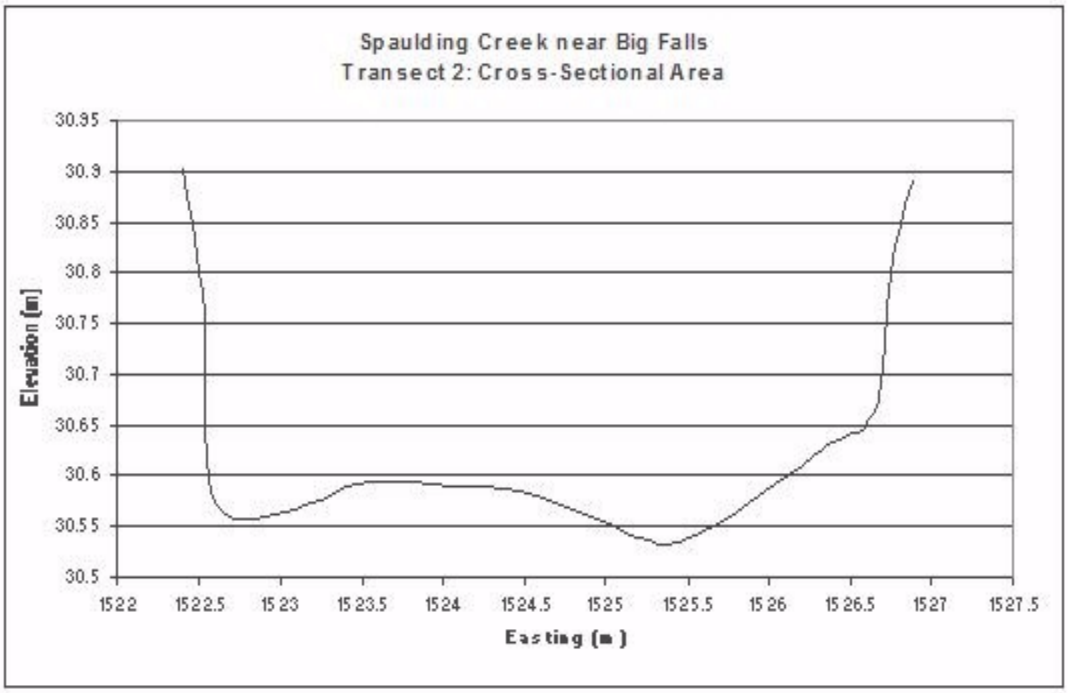

Middle Branch Embarrass River near Wittenberg
Transect 3: Cross Sectional Profile
Elevation (m)
31.5
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
1515.5
1516
1516.5
1517
1517.5
1518
1518.5
1519
1519.5
1520
1520.5
1521
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

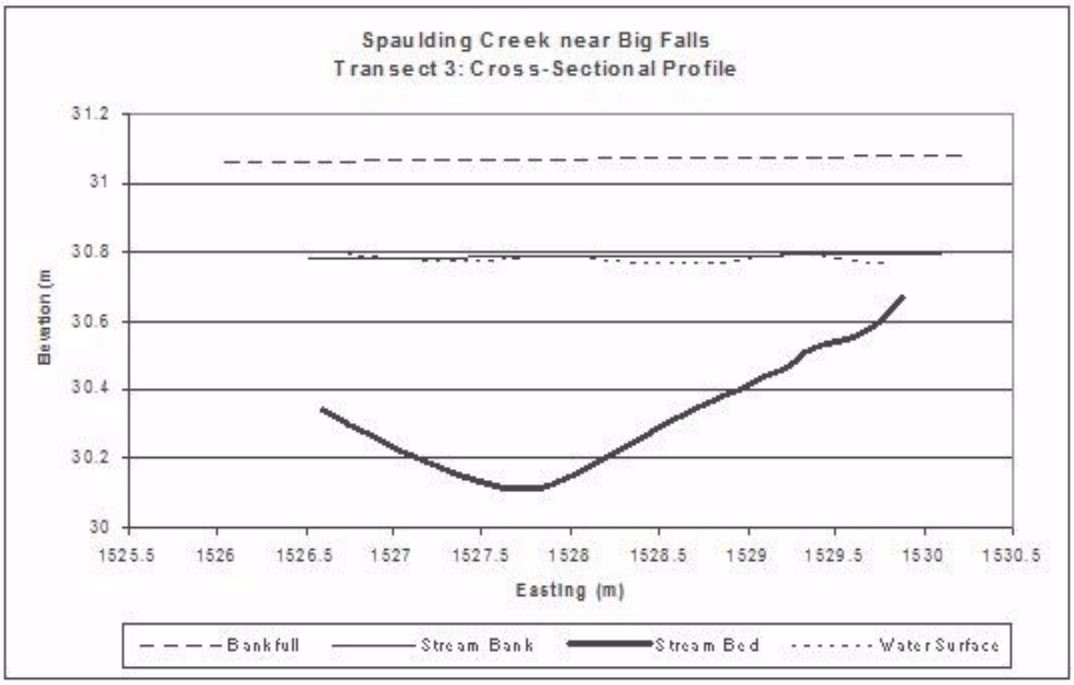

Middle Branch Embarrass River near Wittenberg
Transect 3: Cross-Sectional Area
Elevation (m)
31.5
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
1514
1516
1518
1520
1522
1524
1526
1528
1530
1532
Northing (m)

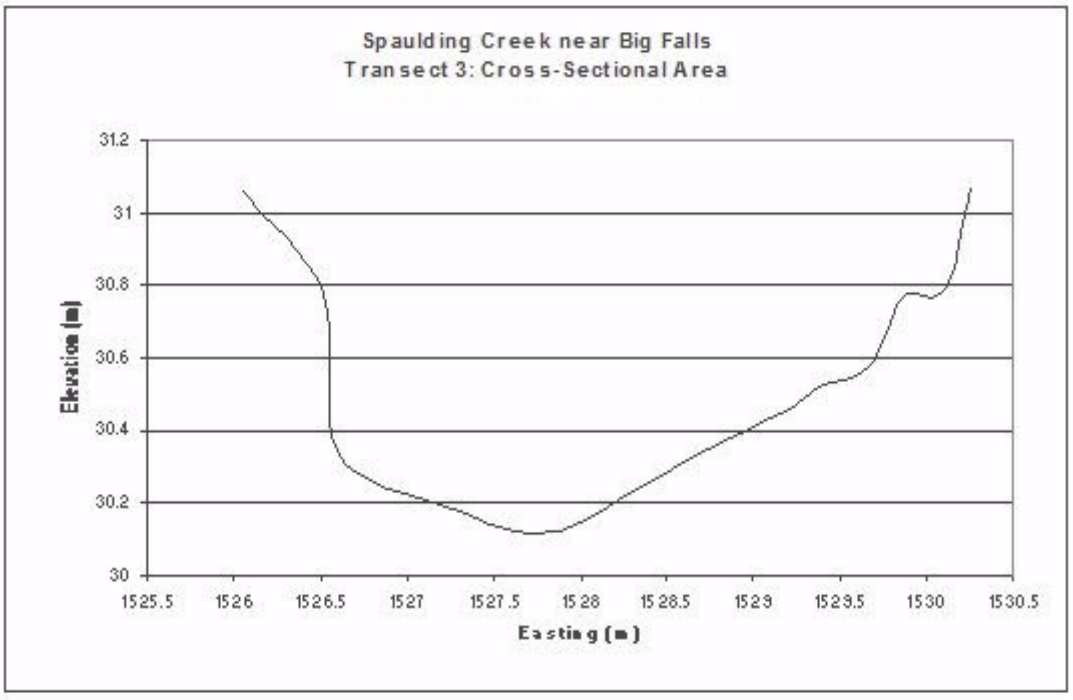

Spaulding Creek near Big Falls
Transect 1: Cross-Sectional Profile
Elevation (m
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1519
1519.5
1520
1520.5
1521
1521.5
1522
1522.5
1523
1523.5
1524
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

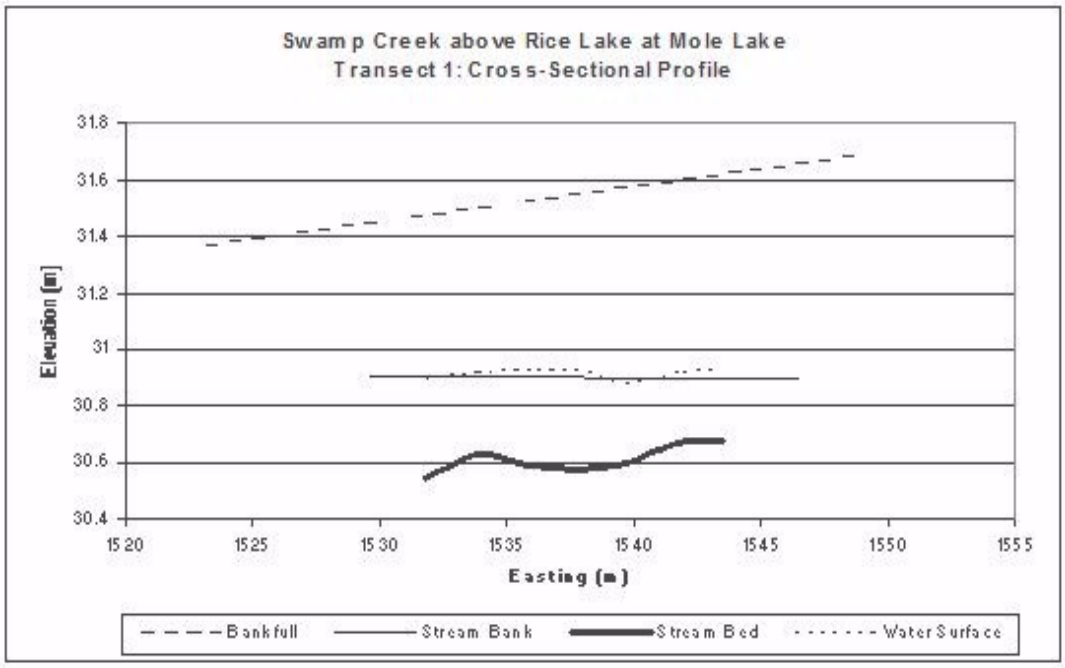

Spaulding Creek near Big Falls
Transect 1: Cross-Sectional Area
Elevation (m)
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1519
1519.5
1520
1520.5
1521
1521.5
1522
1522.5
1523
1523.5
1524
Easting (m)

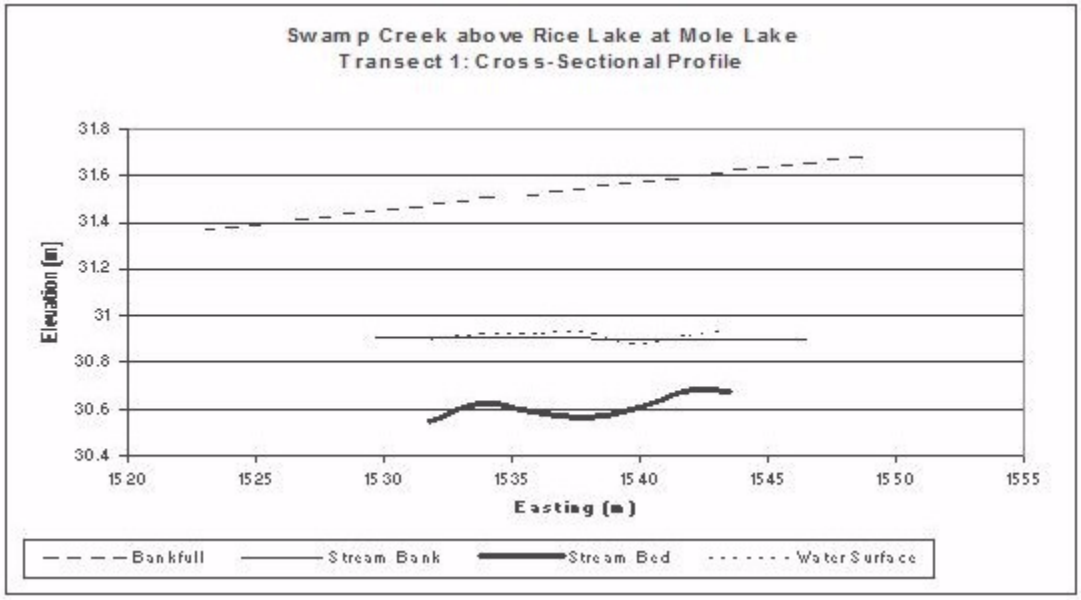

Spaulding Creek near Big Falls
Transect 2: Cross-Sectional Profile
Elevation (m
30.95
30.9
30.85
30.8
30.75
30.7
30.65
30.6
30.55
30.5
1522
1522.5
1523
1523.5
1524
1524.5
1525
1525.5
1526
1526.5
1527
1527.5
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

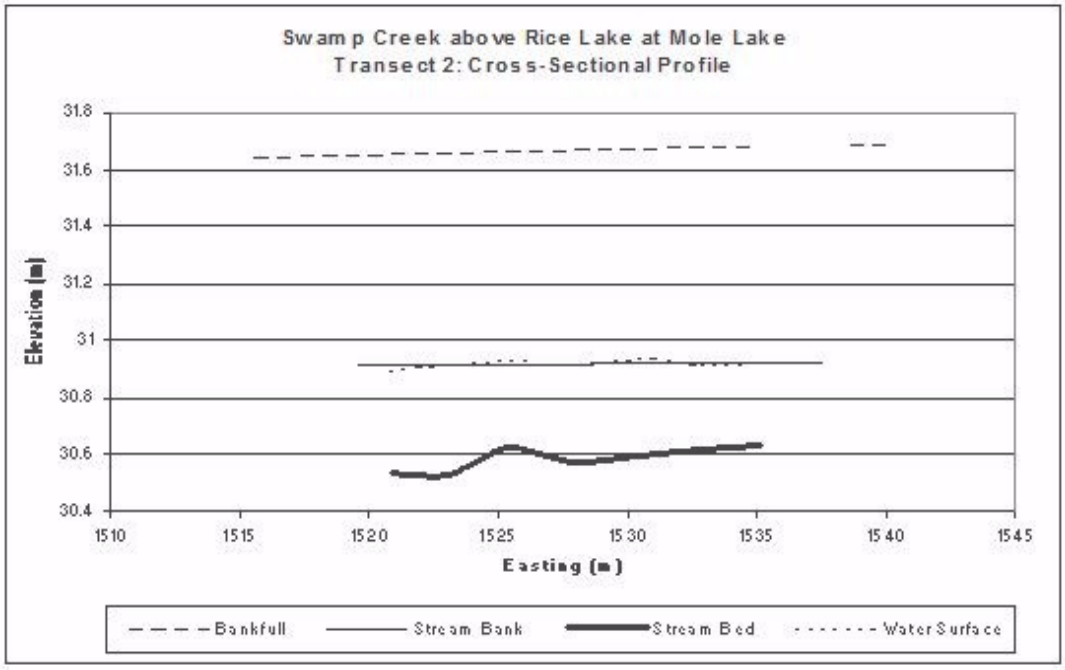

Spaulding Creek near Big Falls
Transect 2: Cross-Sectional Area
Elevation (m)
30.95
30.9
30.85
30.8
30.75
30.7
30.65
30.6
30.55
30.5
1522
1522.5
1523
1523.5
1524
1524.5
1525
1525.5
1526
1526.5
1527
1527.5
Easting (m)

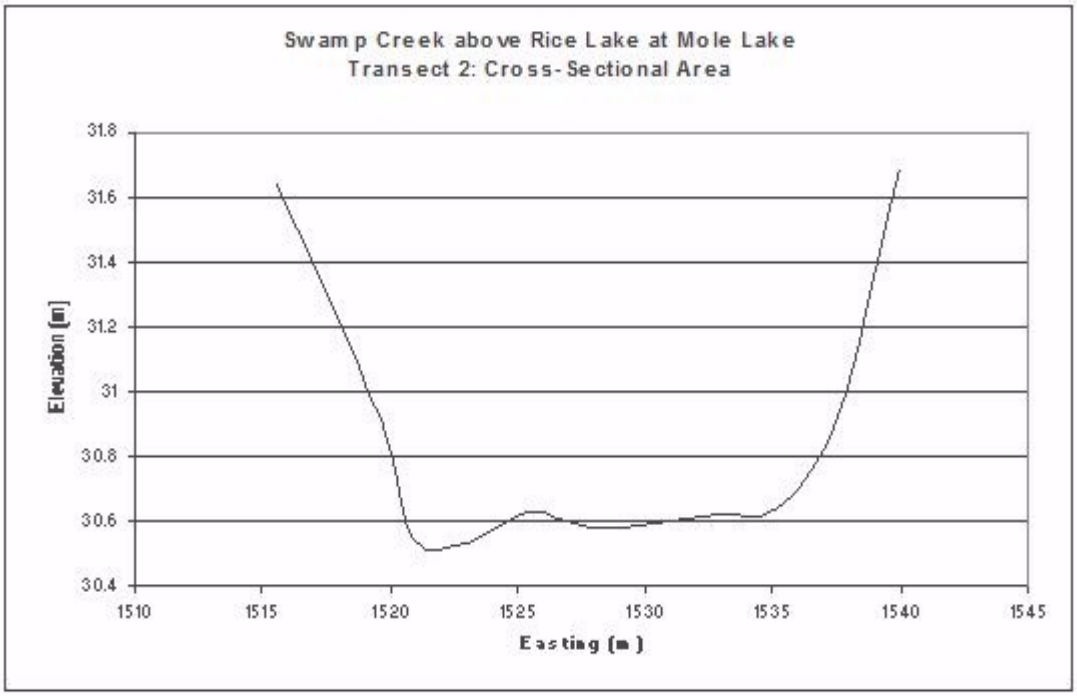

Spaulding Creek near Big Falls
Transect 3: Cross-Sectional Profile
Elevation (m
31.2
31
30.8
30.6
30.4
30.2
30
1525.5
1526
1526.5
1527
1527.5
1528
1528.5
1529
1529.5
1530
1530.5
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

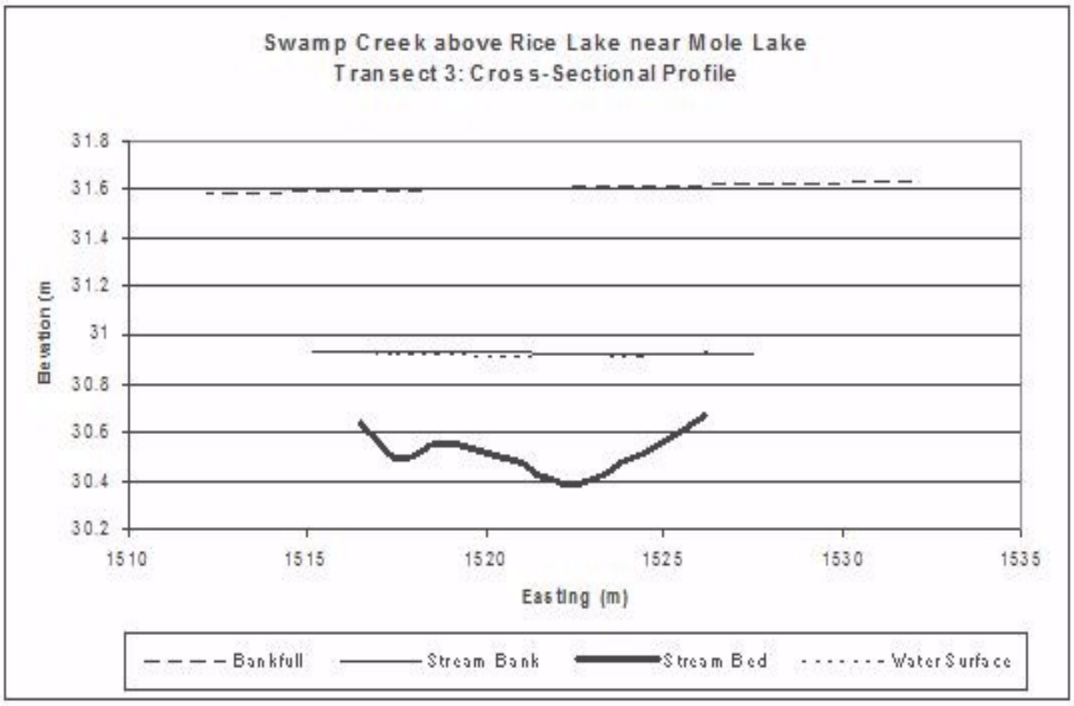

Spaulding Creek near Big Falls
Transect 3: Cross-Sectional Area
Elevation (m)
31.2
31
30.8
30.6
30.4
30.2
30
1525.5
1526
1526.5
1527
1527.5
1528
1528.5
1529
1529.5
1530
1530.5
Easting (m)

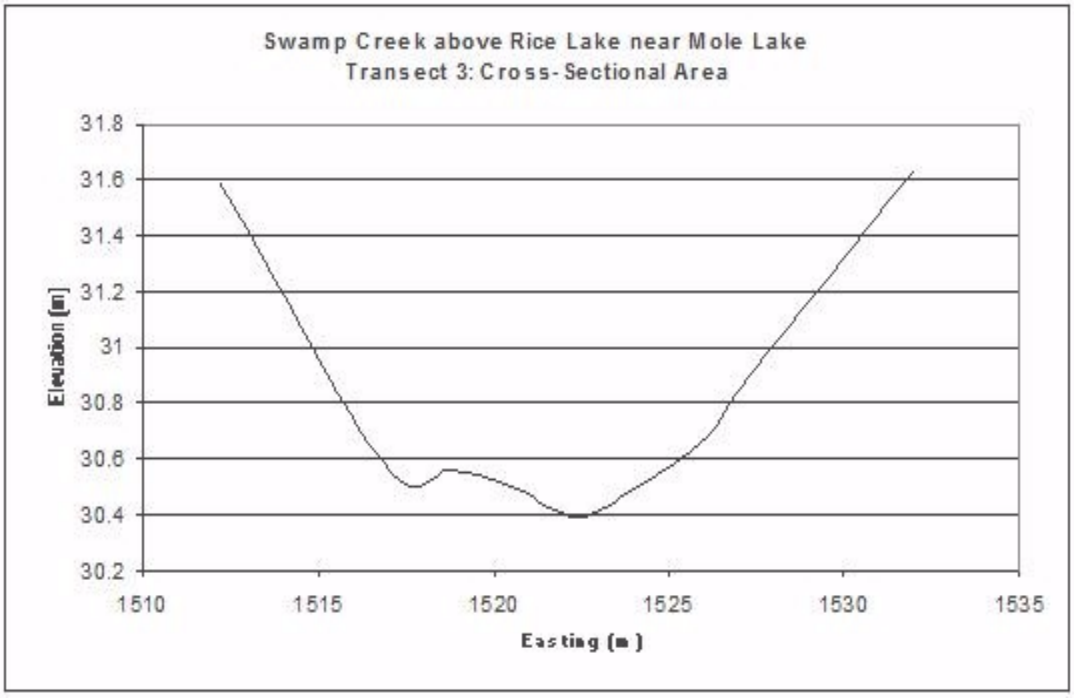

Swamp Creek above Rice Lake at Mole Lake
Transect 1: Cross-Sectional Profile
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
1520
1525
1530
1535
1540
1545
1550
1555
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

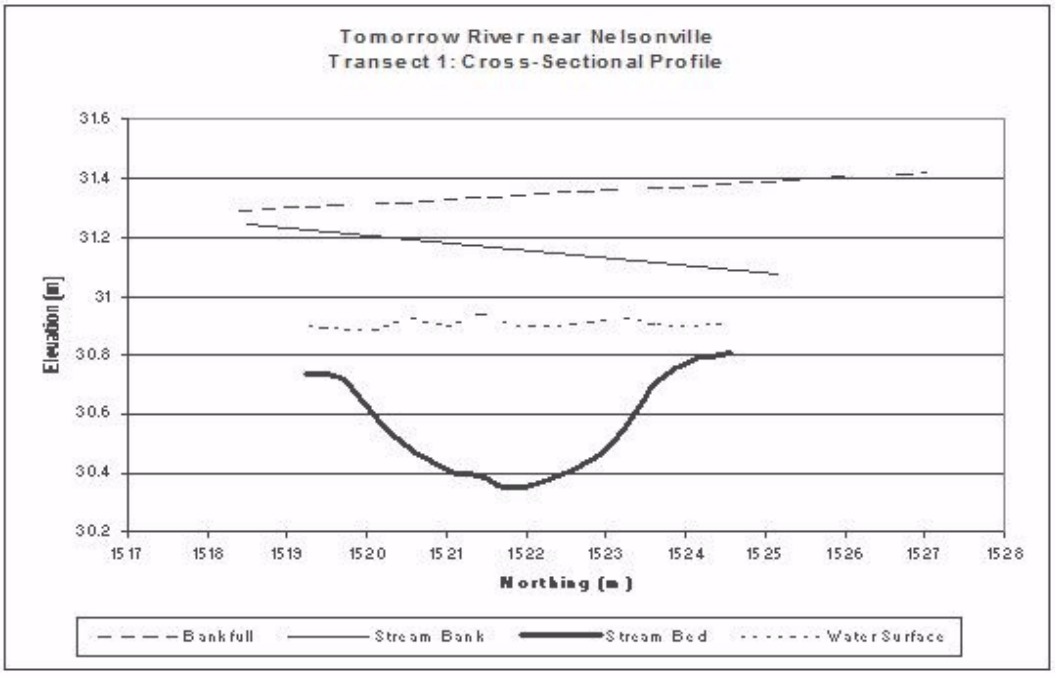

Swamp Creek above Rice Lake at Mole Lake
Transect 1: Cross-Sectional Profile
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
1520
1525
1530
1535
1540
1545
1550
1555
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

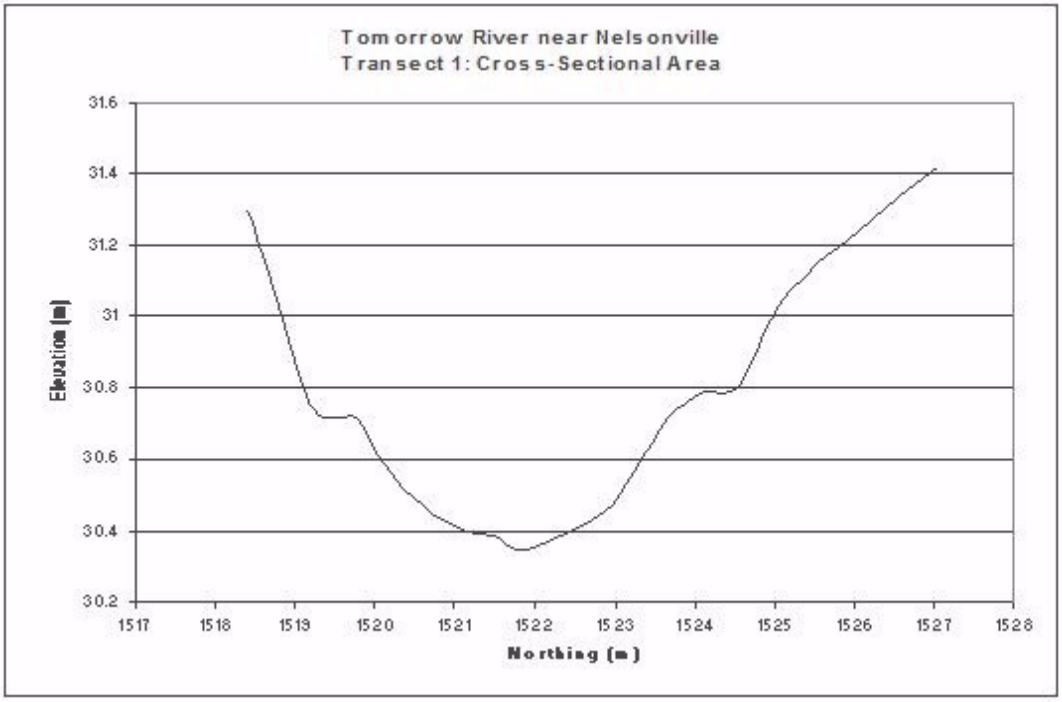

Swamp Creek above Rice Lake at Mole Lake
Transect 2: Cross-Sectional Profile
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
1510
1515
1520
1525
1530
1535
1540
1545
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

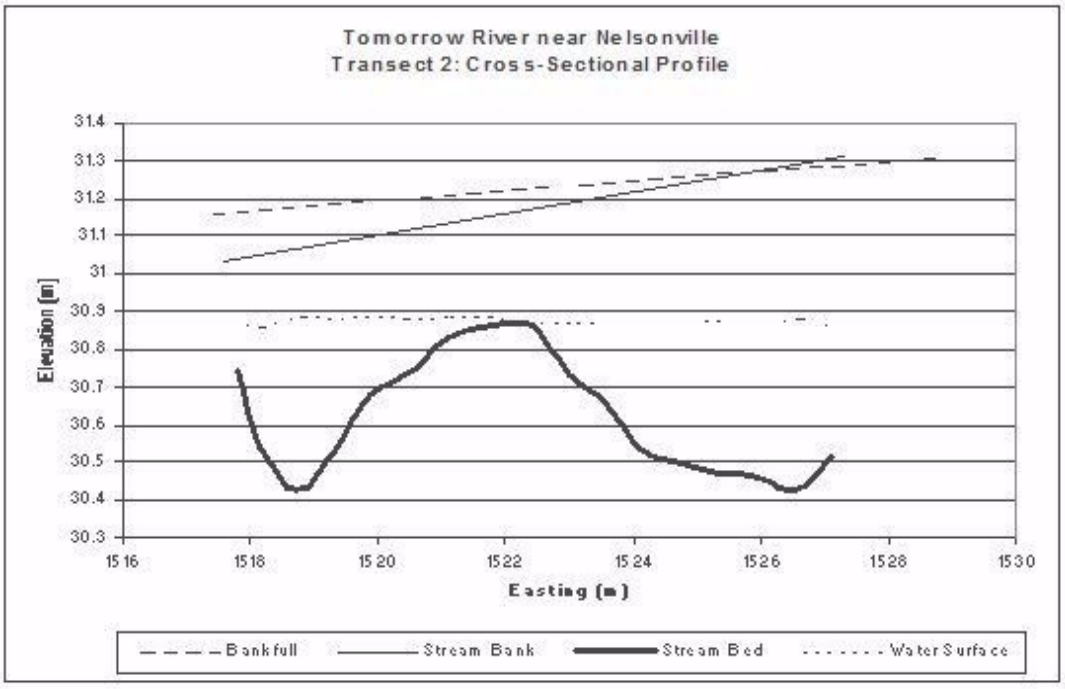

Swamp Creek above Rice Lake at Mole Lake
Transect 2: Cross-Sectional Area
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
1510
1515
1520
1525
1530
1535
1540
1545
Easting (m)

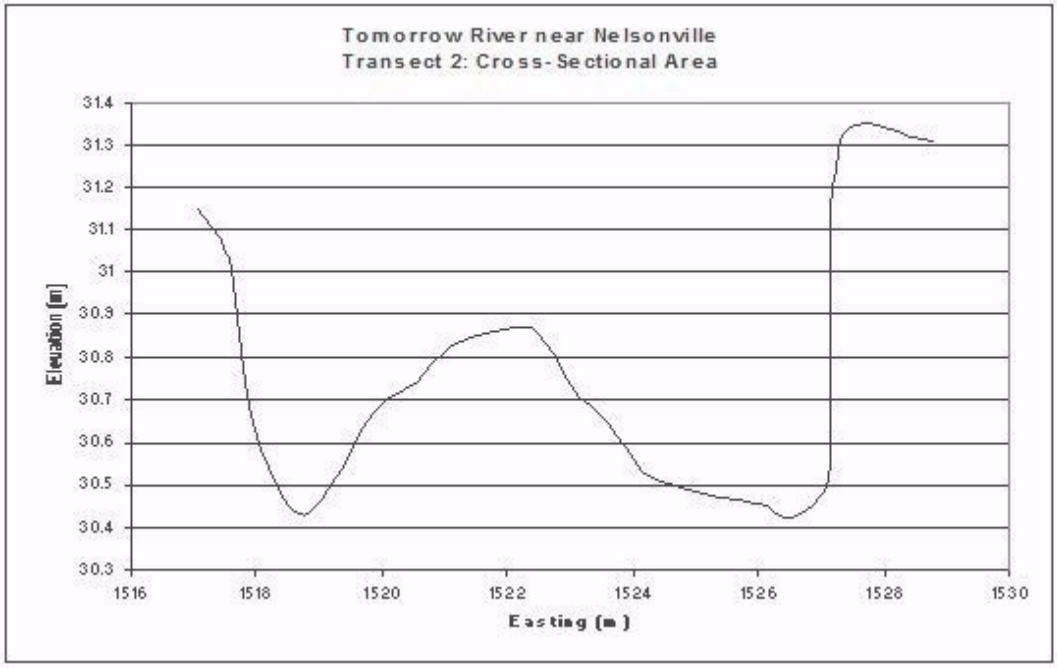

Swamp Creek above Rice Lake near Mole Lake
Transect 3: Cross-Sectional Profile
Elevation (m
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
1510
1515
1520
1525
1530
1535
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

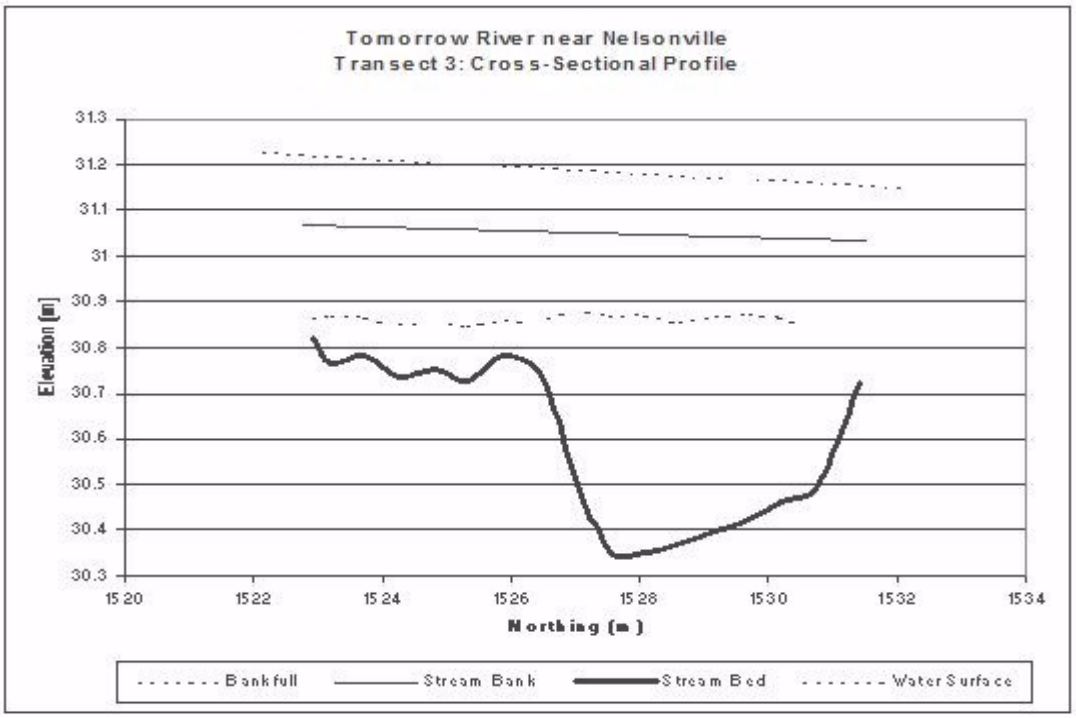

Swamp Creek above Rice Lake near Mole Lake
Transect 3: Cross-Sectional Area
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
1510
1515
1520
1525
1530
1535
Easting (m)

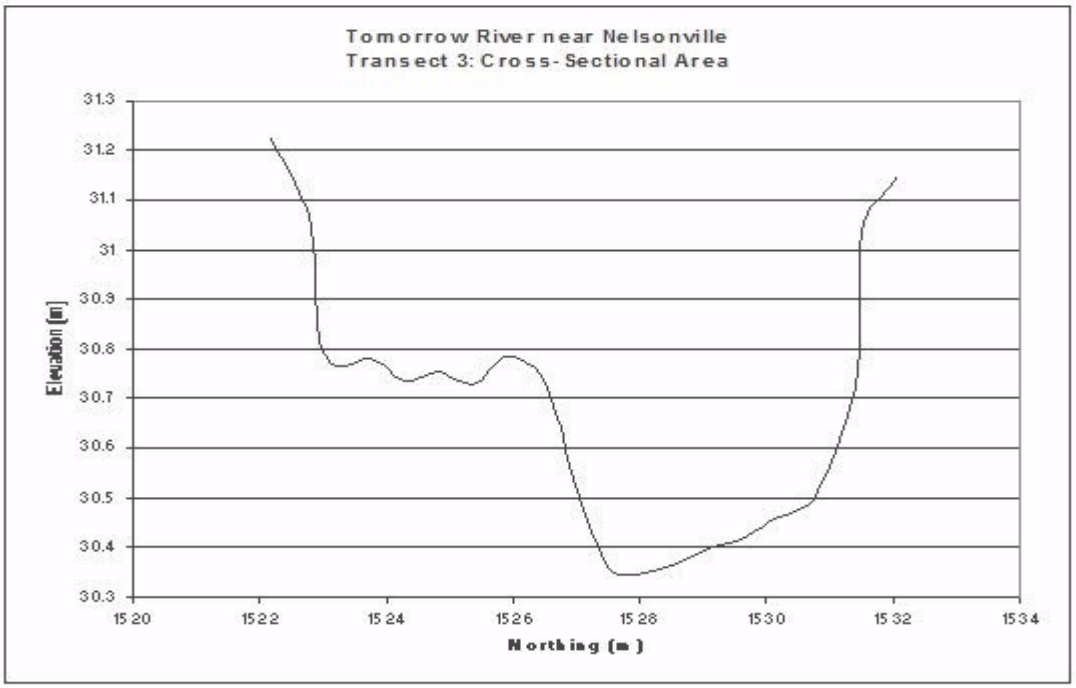

Tomorrow River near Nelsonville
Transect 1: Cross-Sectional Profile
Elevation (m)
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

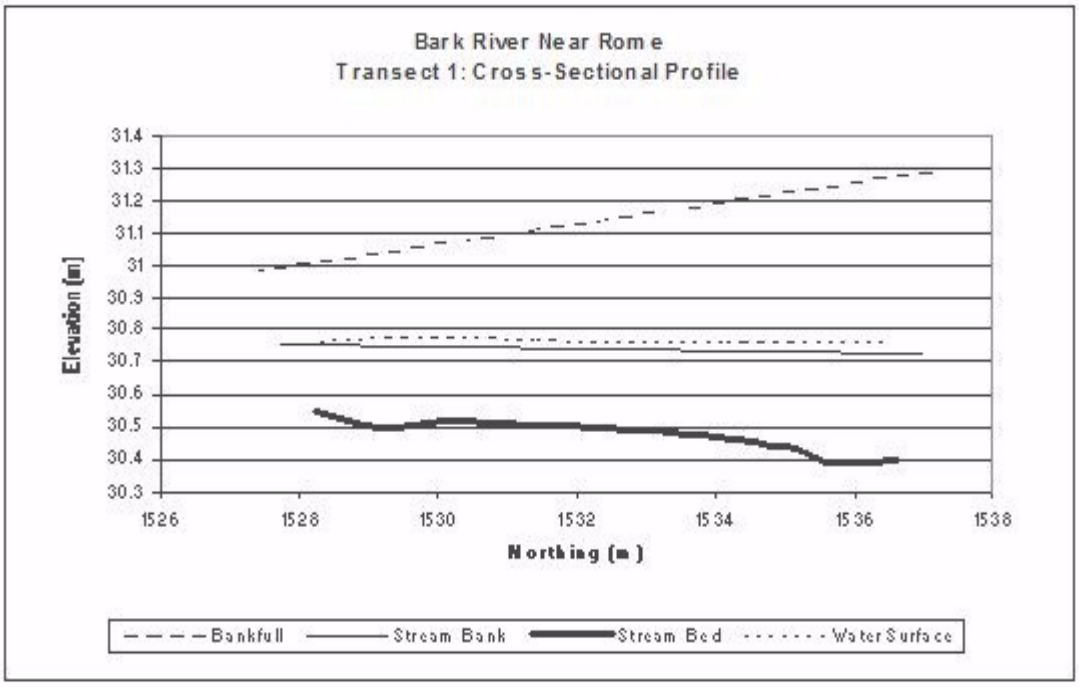

Tomorrow River near Nelsonville
Transect 1: Cross-Sectional Area
Elevation (m)
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
Northing (m)

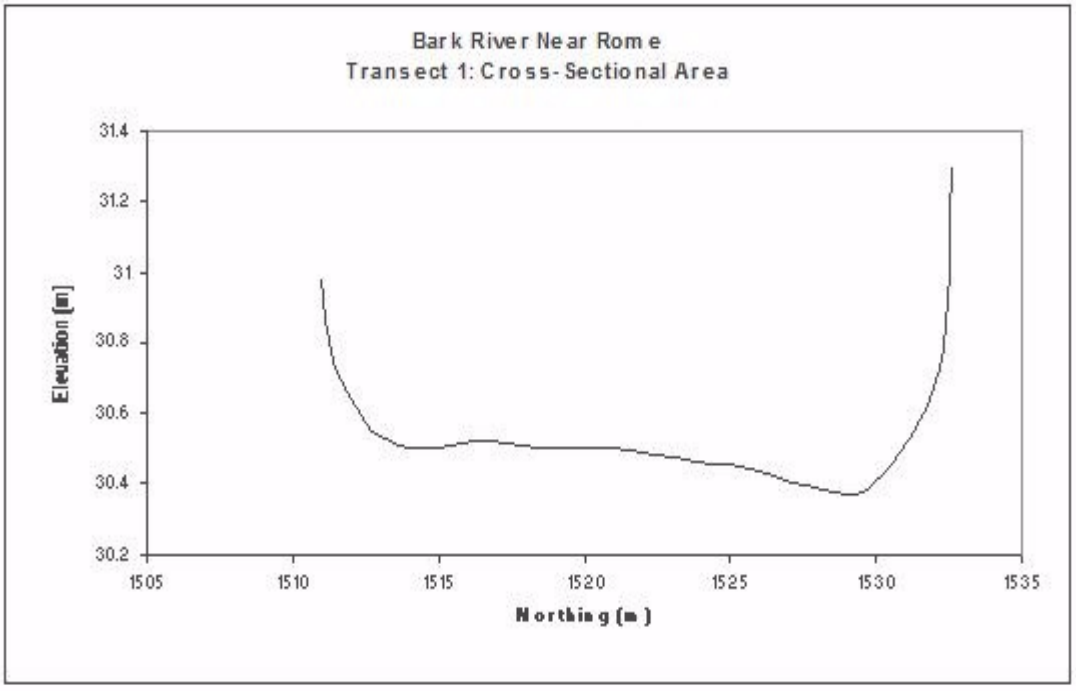

Tomorrow River near Nelsonville
Transect 2: Cross-Sectional Profile
Elevation (m)
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1516
1518
1520
1522
1524
1526
1528
1530
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

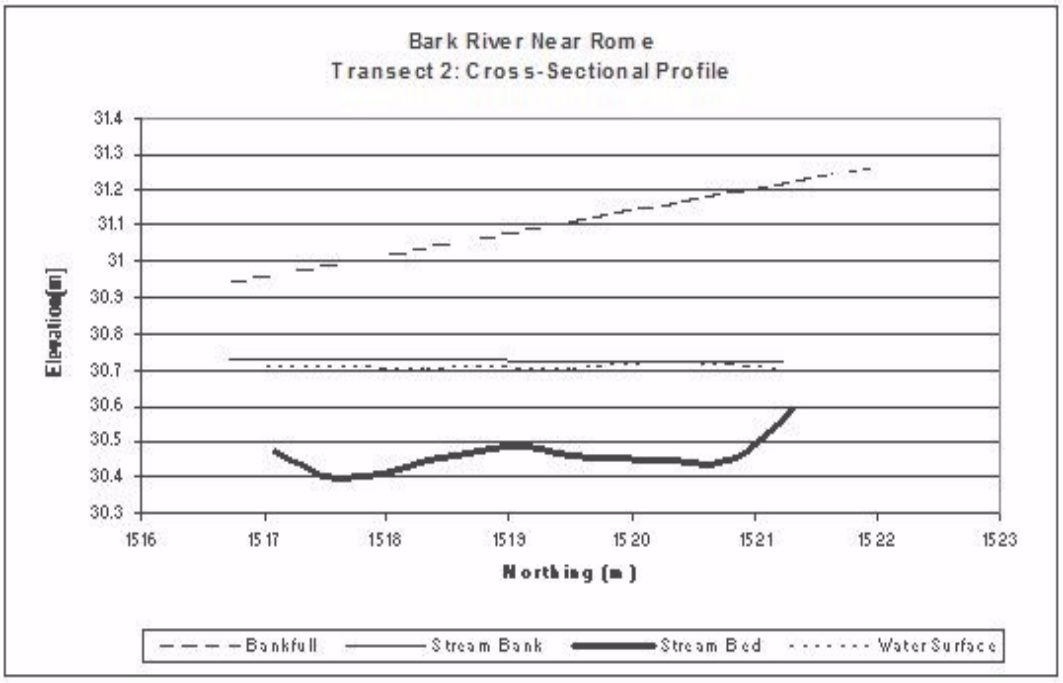

Tomorrow River near Nelsonville
Transect 2: Cross-Sectional Area
Elevation (m)
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1516
1518
1520
1522
1524
1526
1528
1530
Easting (m)

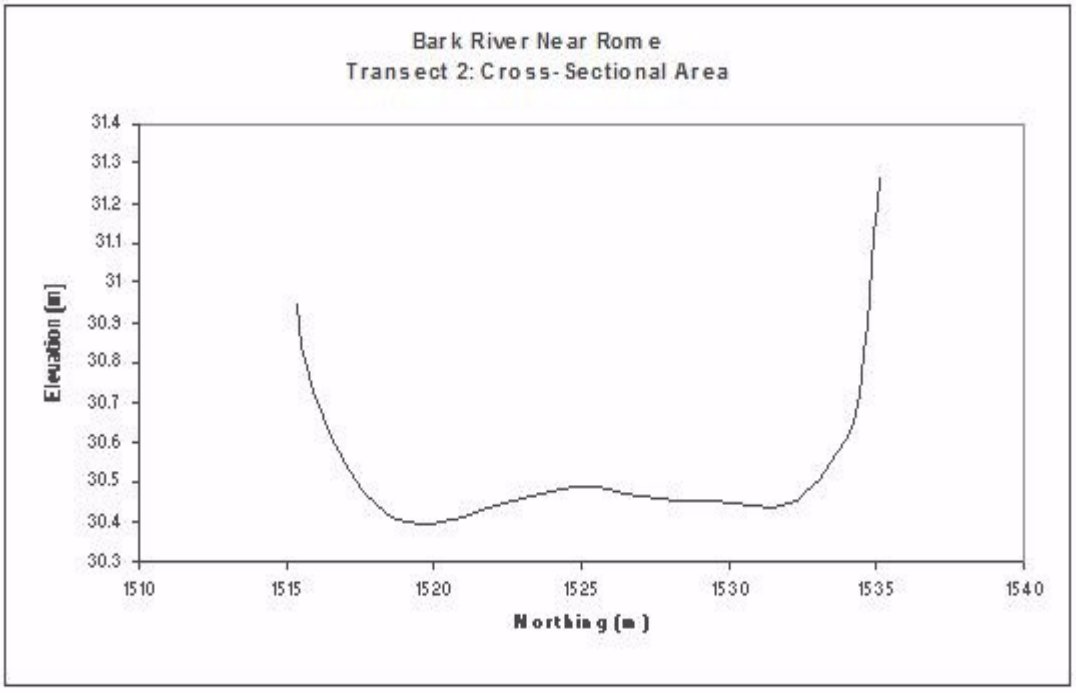

Tomorrow River near Nelsonville
Transect 3: Cross-Sectional Profile
Elevation (m)
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1520
1522
1524
1526
1528
1530
1532
1534
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

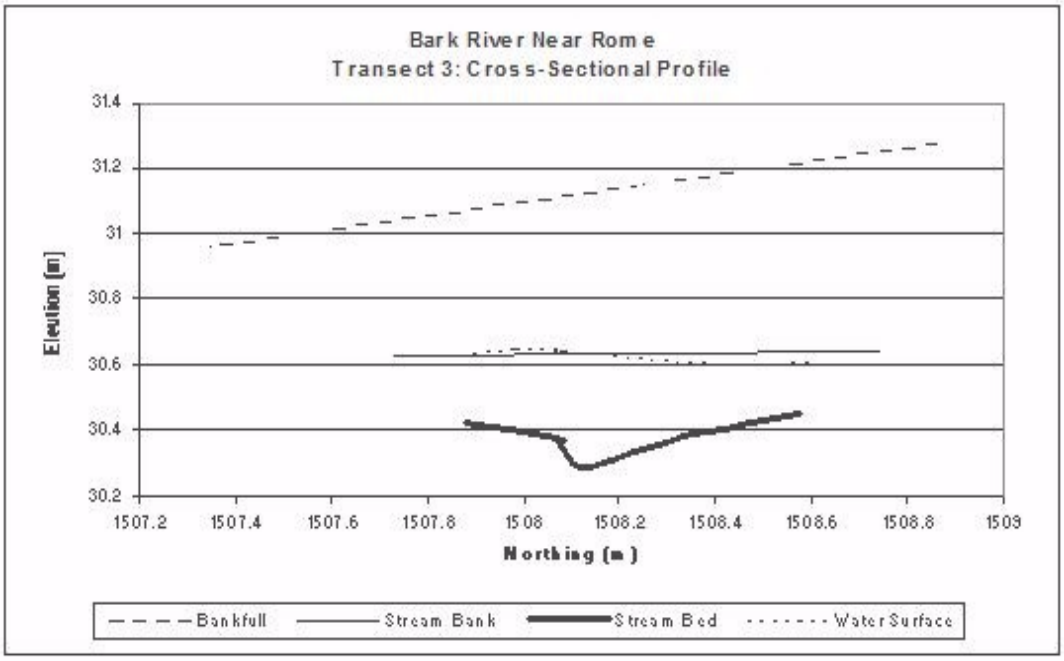

Tomorrow River near Nelsonville
Transect 3: Cross-Sectional Area
Elevation (m)
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1520
1522
1524
1526
1528
1530
1532
1534
Northing (m)

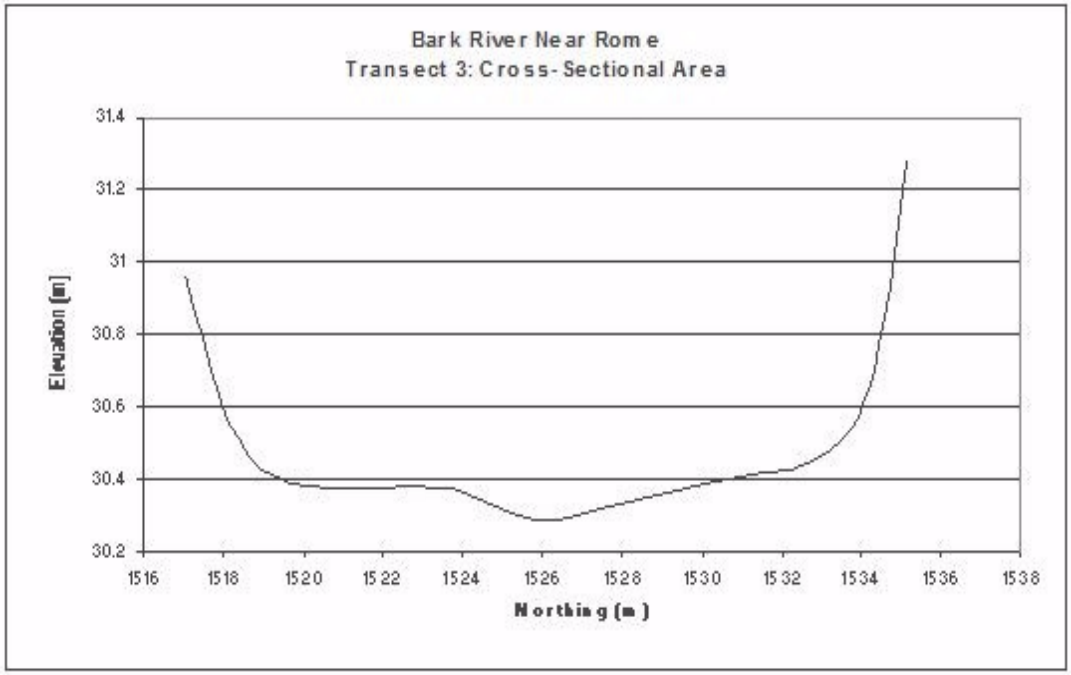

Bark River Near Rome
Transect 1: Cross-Sectional Profile
Elevation (m)
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1526
1528
1530
1532
1534
1536
1538
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

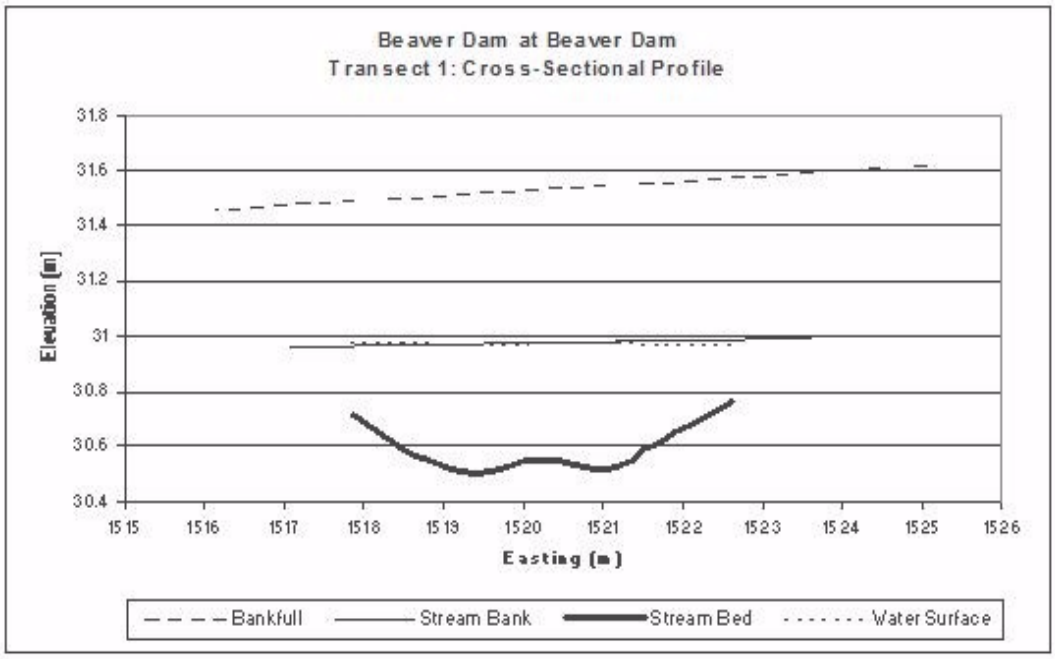

Bark River Near Rome
Transect 1: Cross-Sectional Area
Elevation (m)
31.4
31.2
31
30.8
30.6
30.4
30.2
1505
1510
1515
1520
1525
1530
1535
Northing (m)

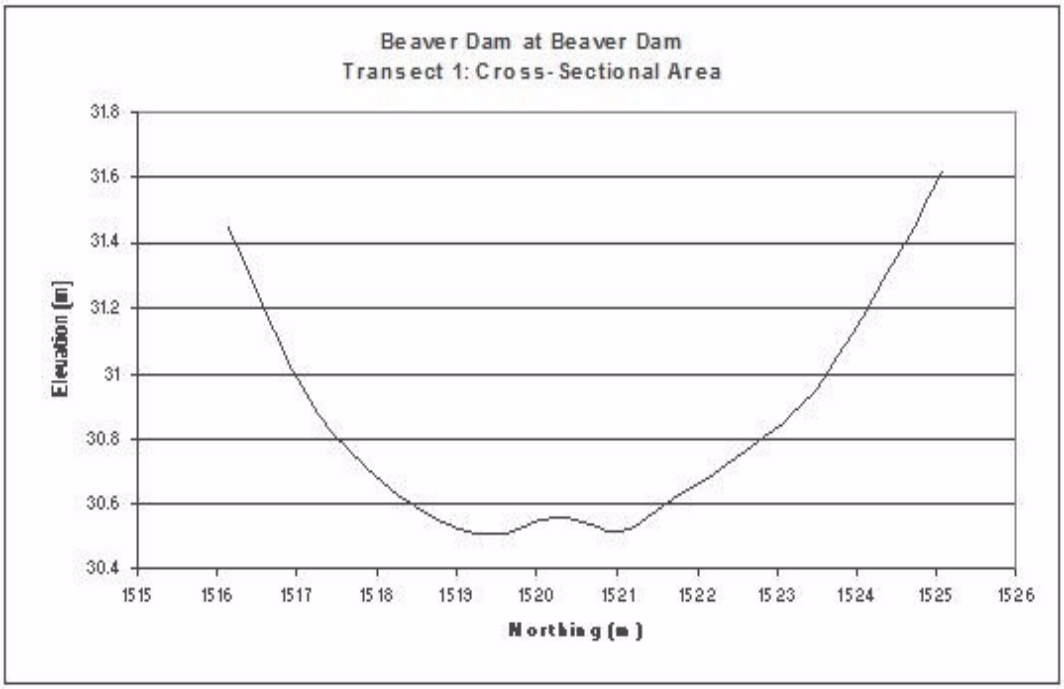

Bark River Near Rome
Transect 2: Cross-Sectional Profile
Elevation(m)
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1516
1517
1518
1519
1520
1521
1522
1523
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

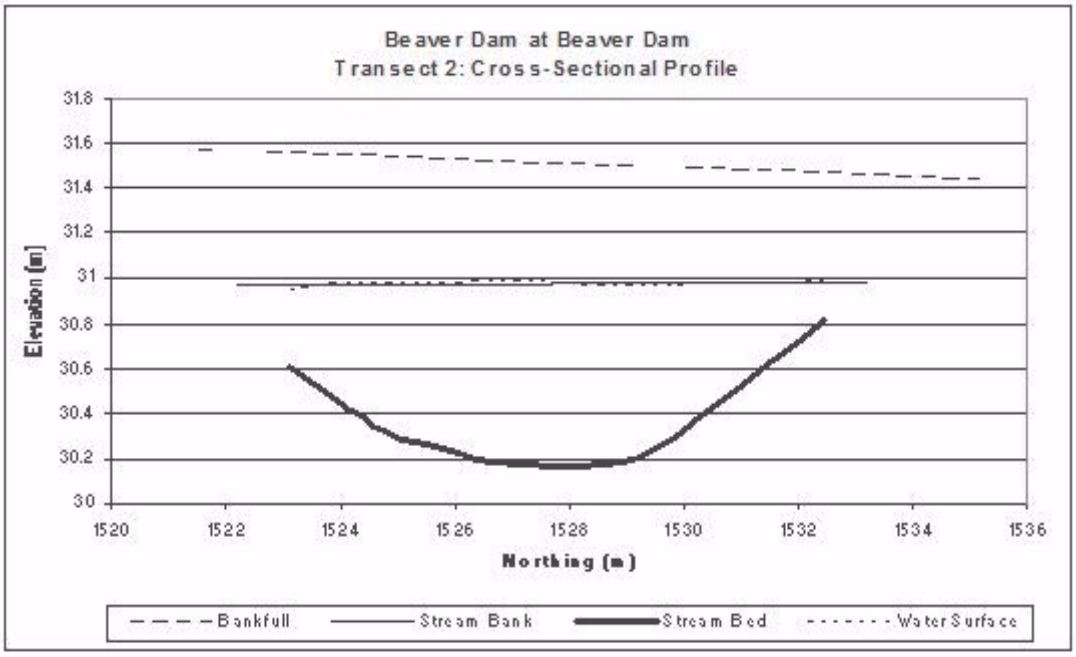

Bark River Near Rome
Transect 2: Cross-Sectional Area
Elevation (m)
31.4
31.3
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
1510
1515
1520
1525
1530
1535
1540
Northing (m)

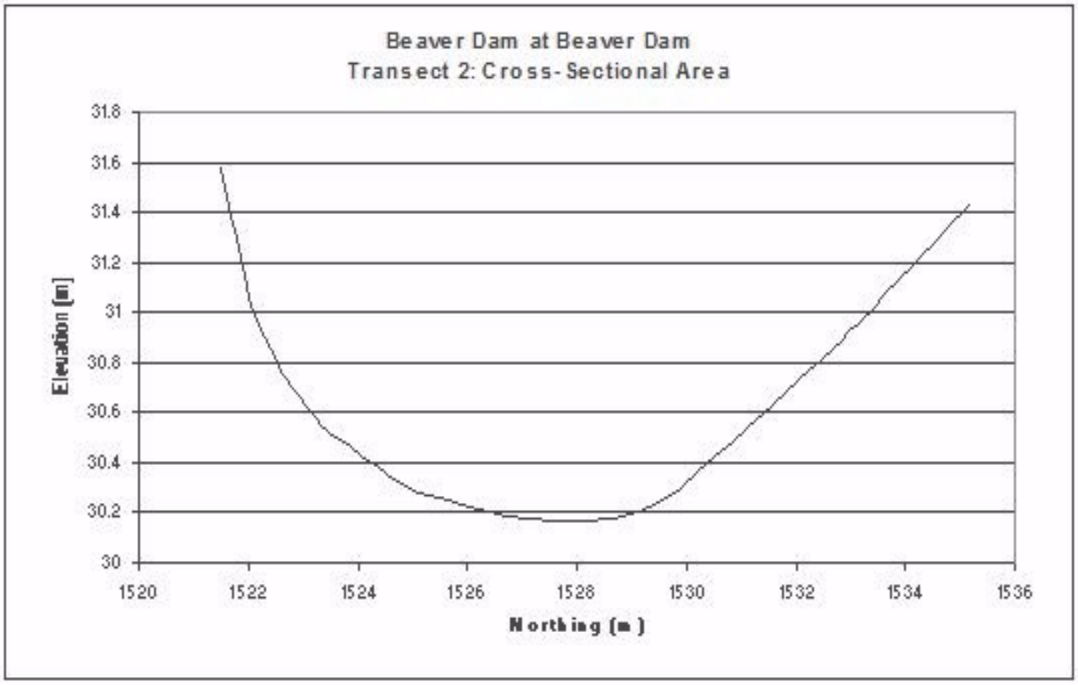

Bark River Near Rome
Transect 3: Cross-Sectional Profile
Elevation (m)
31.4
31.2
31
30.8
30.6
30.4
30.2
1507.2
1507.4
1507.6
1507.8
1508
1508.2
1508.4
1508.6
1508.8
1509
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

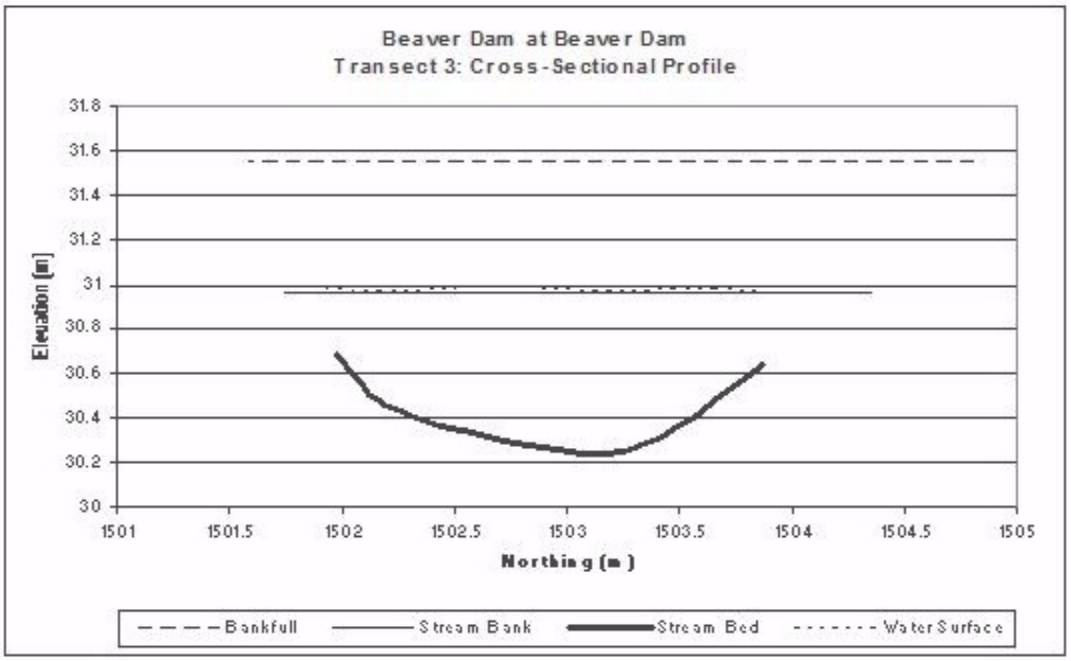

Bark River Near Rome
Transect 3: Cross-Sectional Area
Elevation (m)
31.4
31.2
31
30.8
30.6
30.4
30.2
1516
1518
1520
1522
1524
1526
1528
1530
1532
1534
1536
1538
Northing (m)

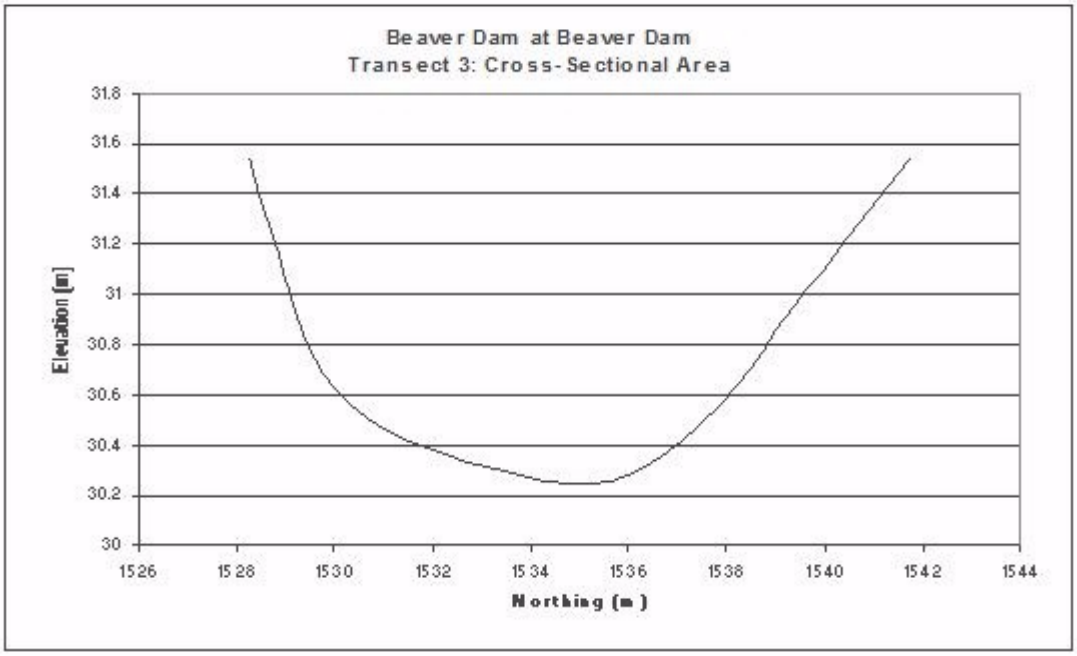

Beaver Dam at Beaver Dam
Transect 1: Cross-Sectional Profile
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

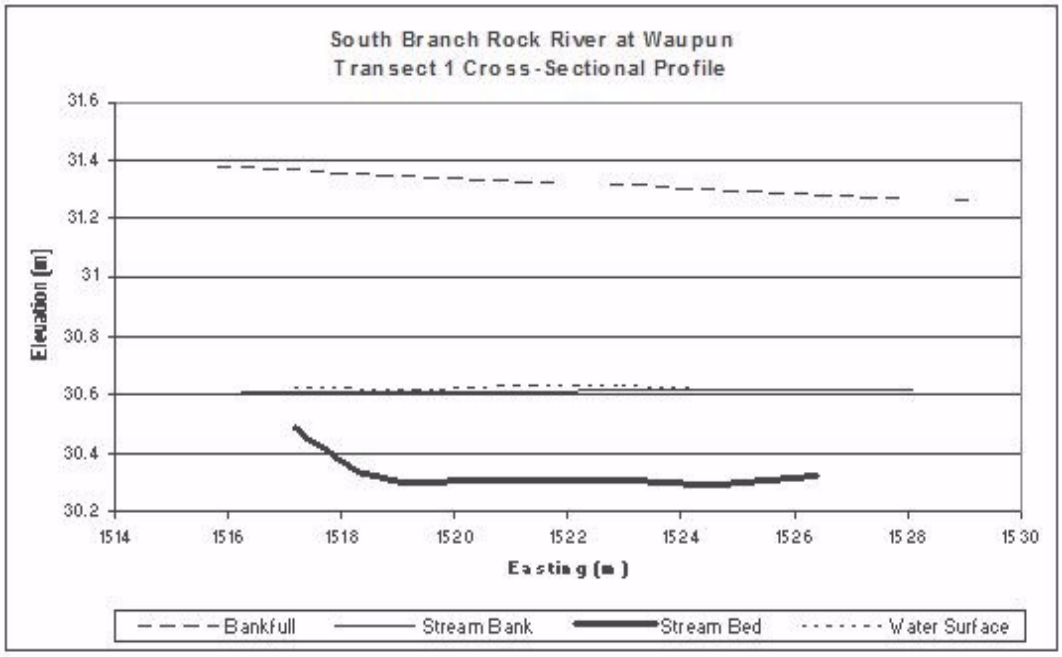

Beaver Dam at Beaver Dam
Transect 1: Cross-Sectional Area
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
Northing (m)

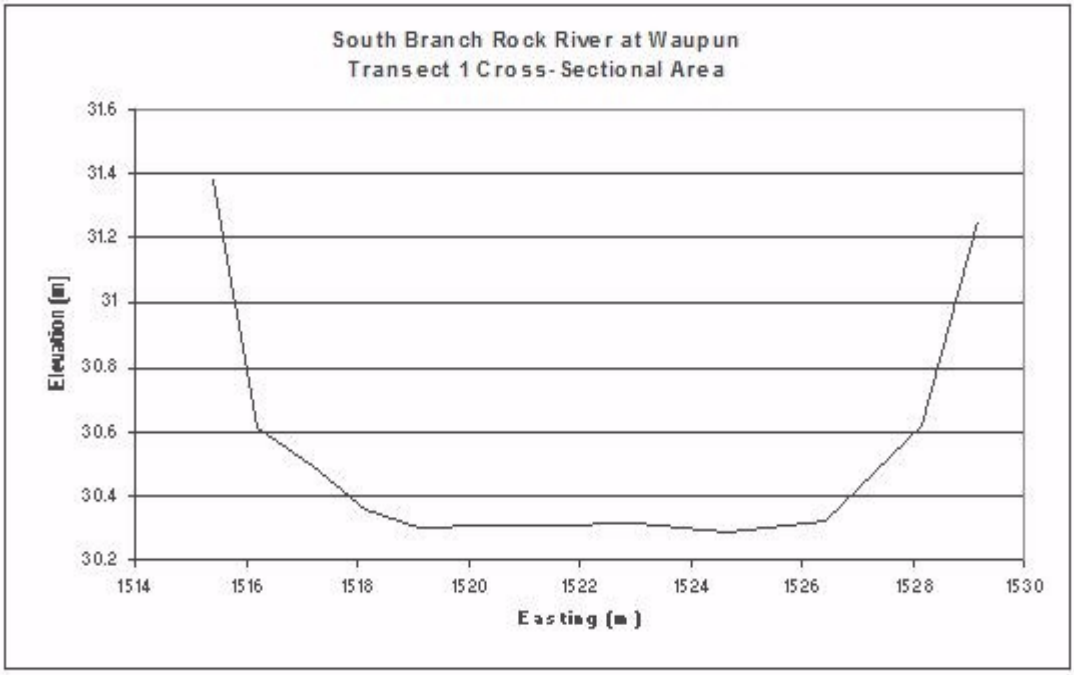

Beaver Dam at Beaver Dam
Transect 2: Cross-Sectional Profile
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
30
1520
1522
1524
1526
1528
1530
1532
1534
1536
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

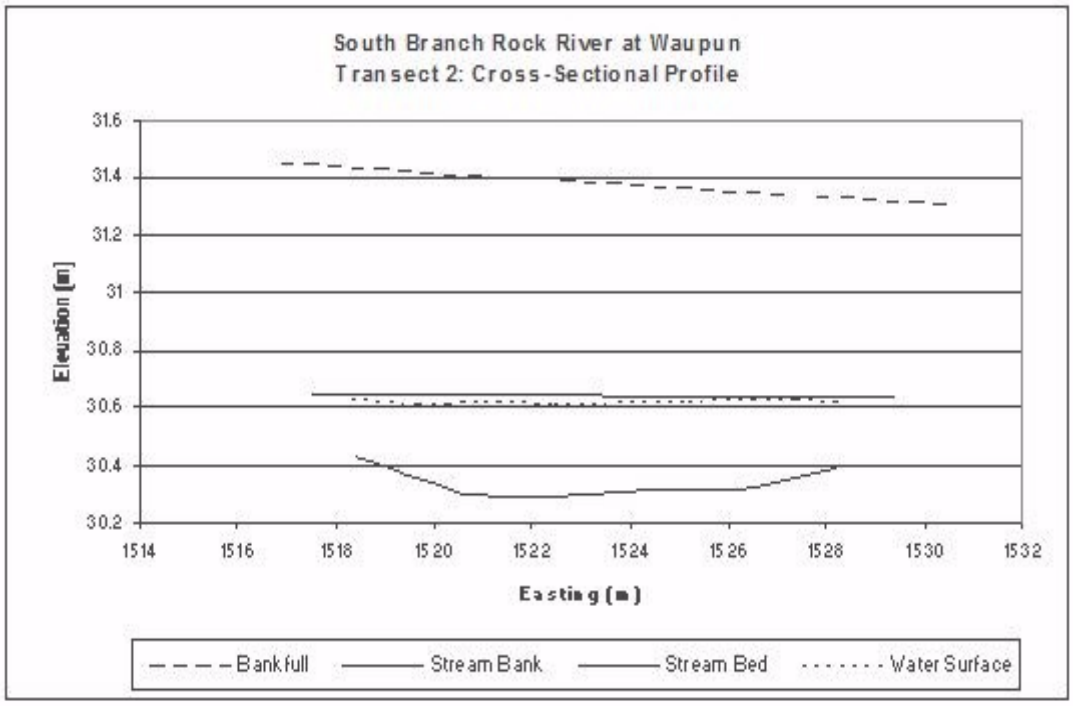

Beaver Dam at Beaver Dam
Transect 2: Cross-Sectional Area
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
30
1520
1522
1524
1526
1528
1530
1532
1534
1536
Northing (m)

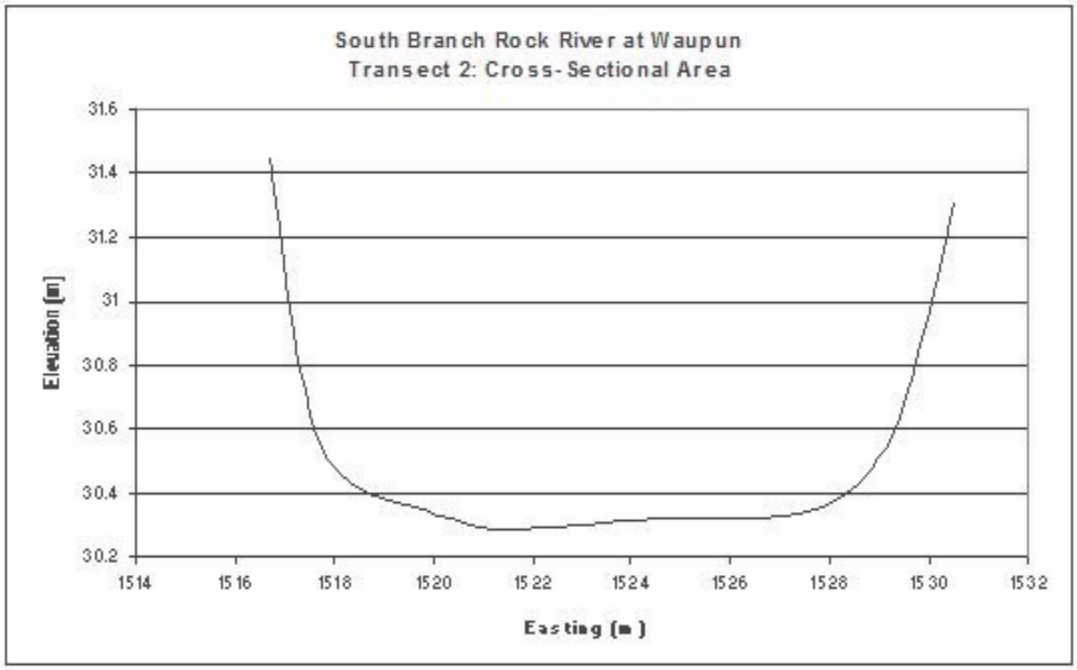

Beaver Dam at Beaver Dam
Transect 3: Cross-Sectional Profile
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
30
1501
1501.5
1502
1502.5
1503
1503.5
1504
1504.5
1505
Northing (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

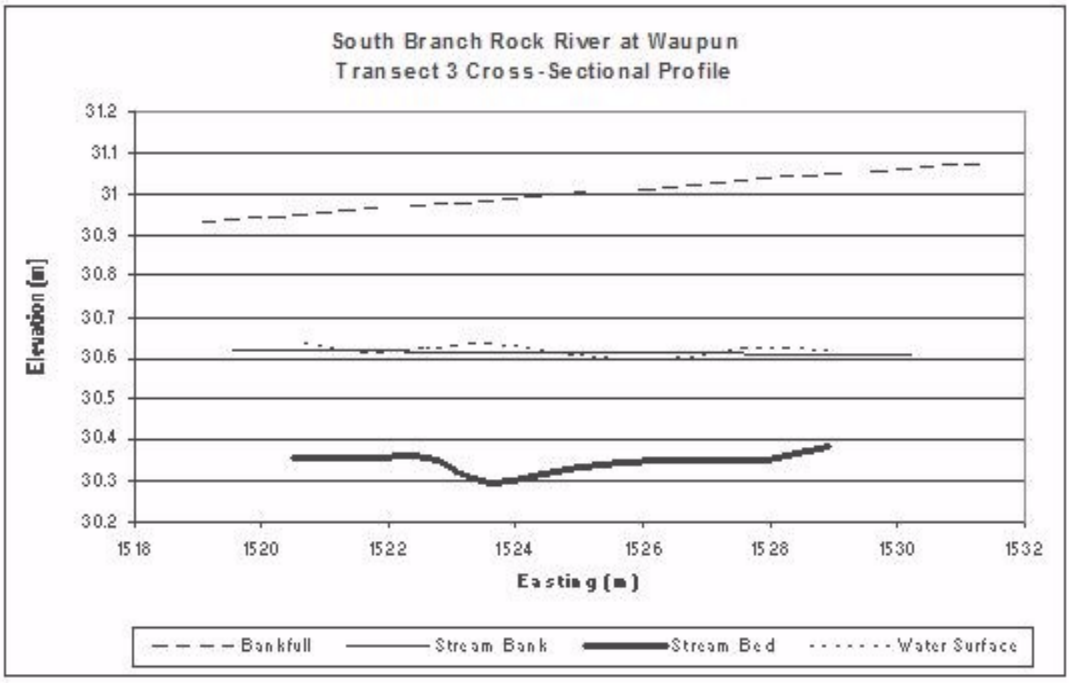

Beaver Dam at Beaver Dam
Transect 3: Cross-Sectional Area
Elevation (m)
31.8
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
30
1526
1528
1530
1532
1534
1536
1538
1540
1542
1544
Northing (m)

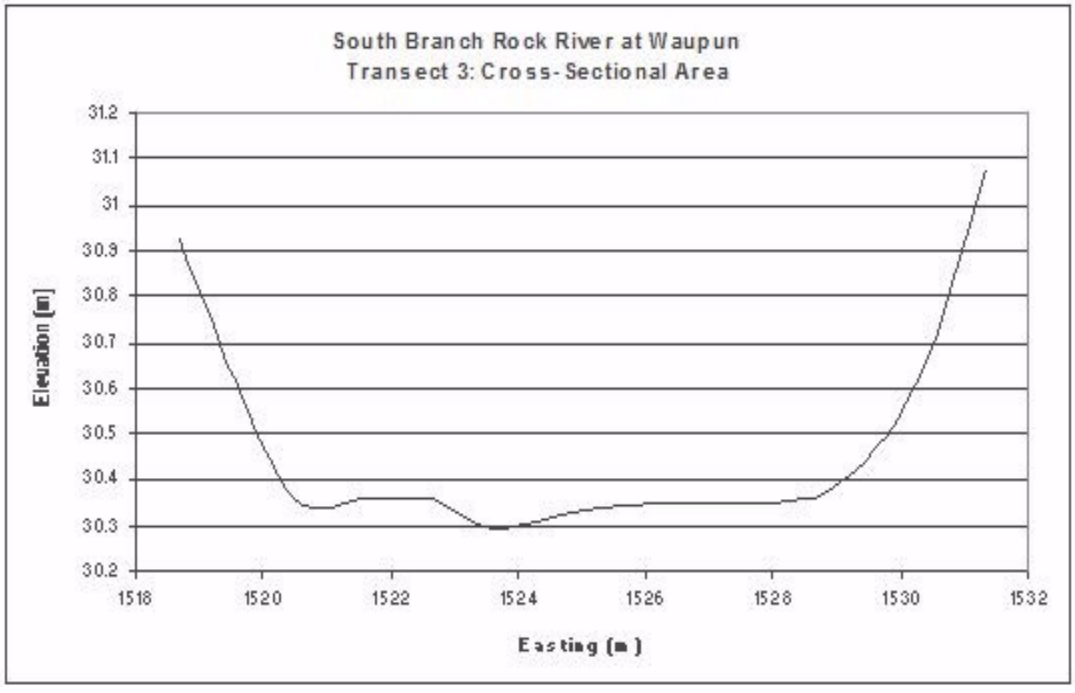

South Branch Rock River at Waupun
Transect 1 Cross-Sectional Profile
Elevation (m)
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
1514
1516
1518
1520
1522
1524
1526
1528
1530
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

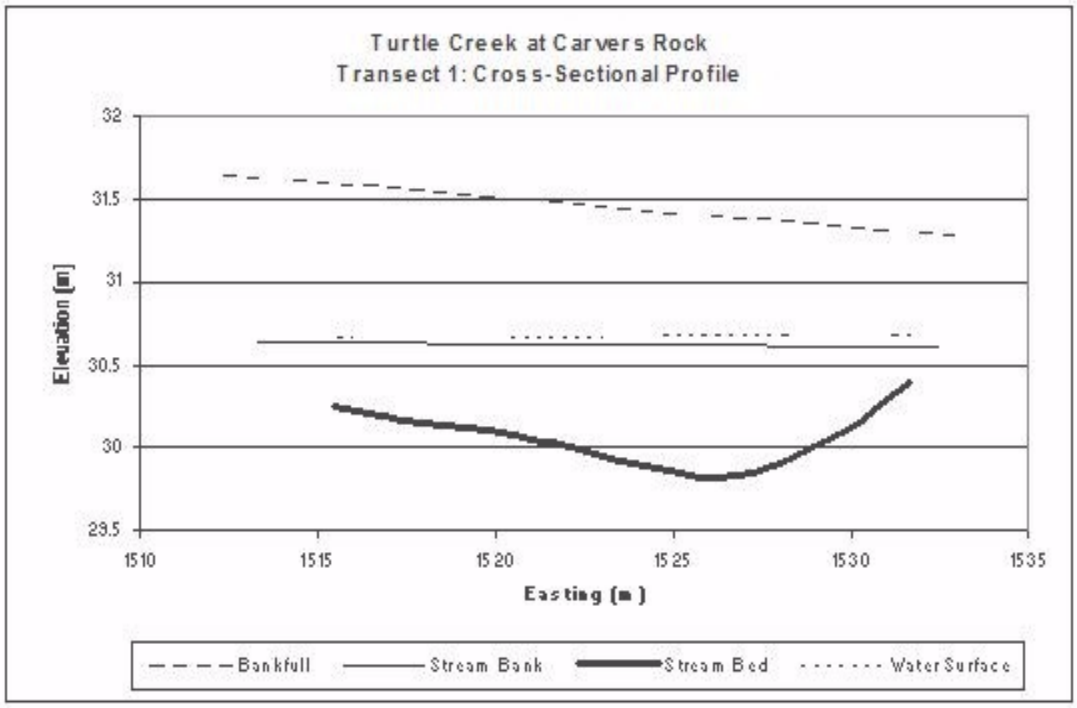

South Branch Rock River at Waupun
Transect 1 Cross-Sectional Area
Elevation (m)
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
1514
1516
1518
1520
1522
1524
1526
1528
1530
Easting (m)

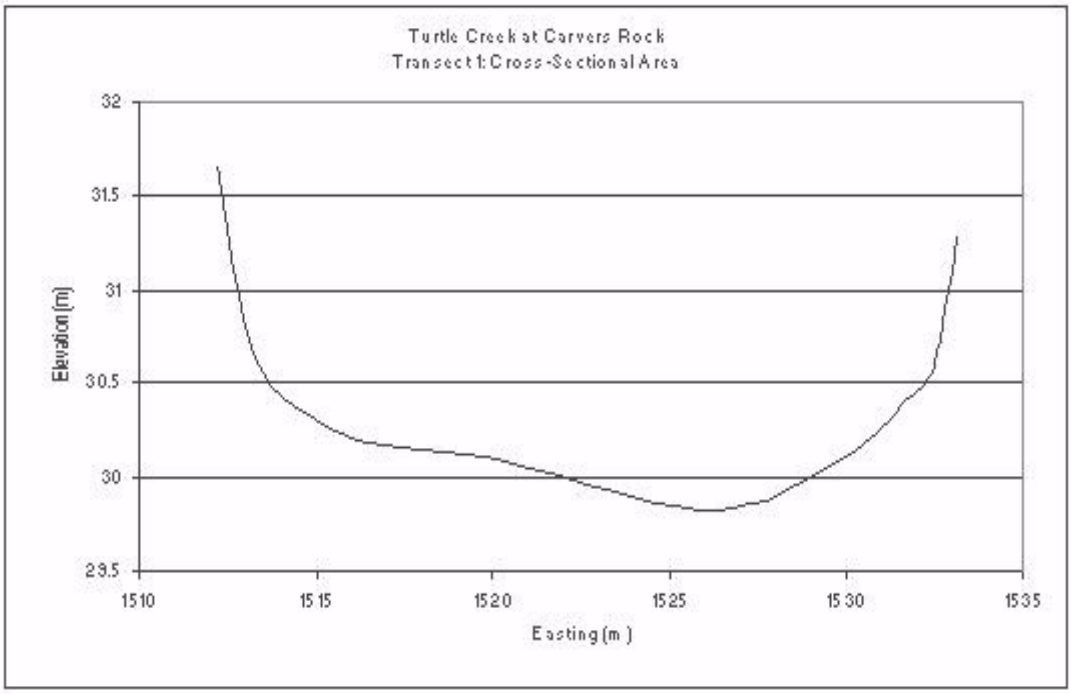

South Branch Rock River at Waupun
Transect 2: Cross-Sectional Profile
Elevation (m)
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
1514
1516
1518
1520
1522
1524
1526
1528
1530
1532
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

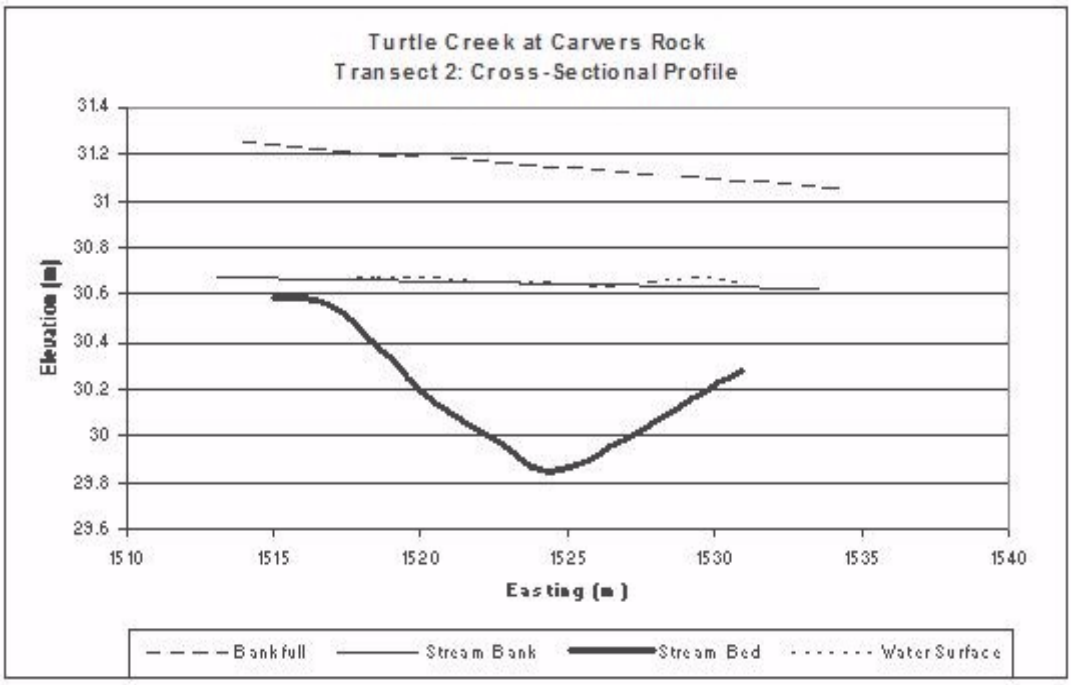

South Branch Rock River at Waupun
Transect 2: Cross-Sectional Area
Elevation (m)
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
1514
1516
1518
1520
1522
1524
1526
1528
1530
1532
Easting (m)

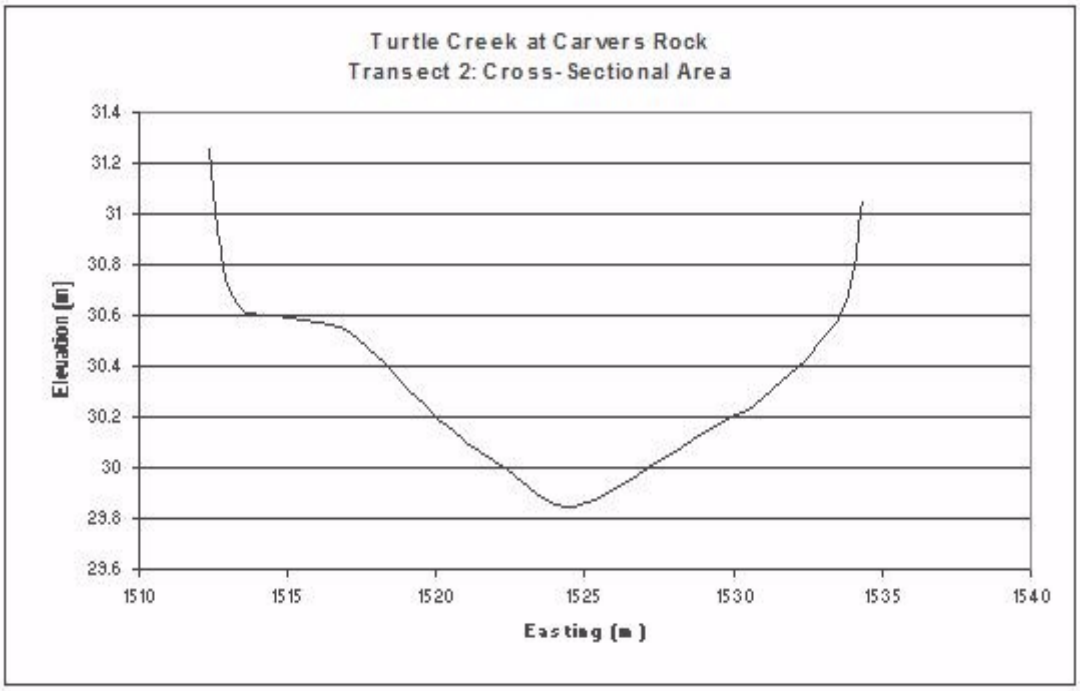

South Branch Rock River at Waupun
Transect 3 Cross-Sectional Profile
Elevation (m)
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
30.2
1518
1520
1522
1524
1526
1528
1530
1532
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

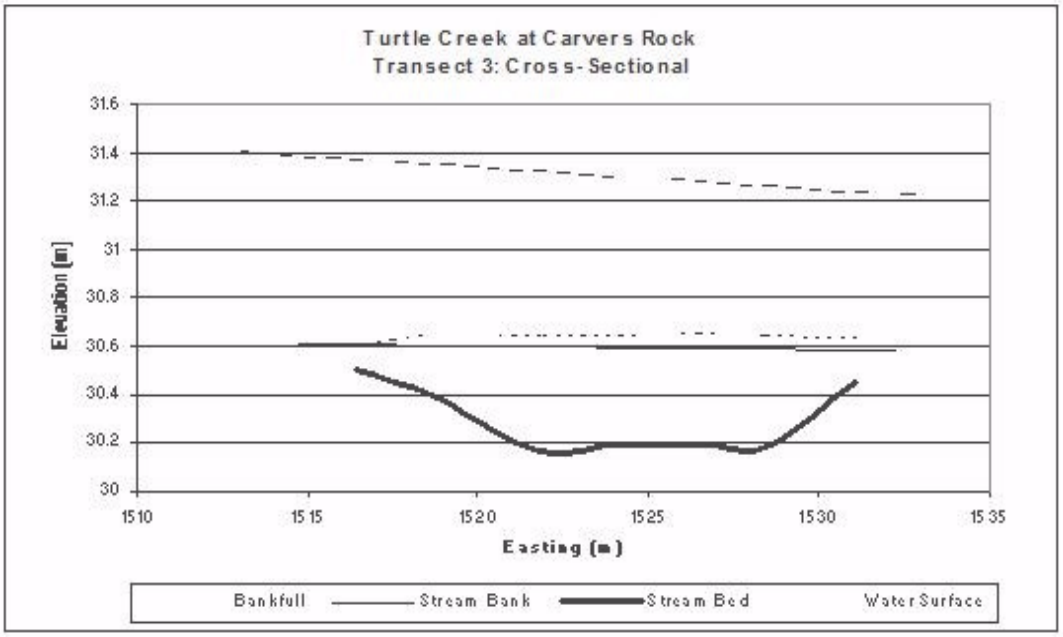

South Branch Rock River at Waupun
Transect 3: Cross-Sectional Area
Elevation (m)
31.2
31.1
31
30.9
30.8
30.7
30.6
30.5
30.4
30.3
30.2
1518
1520
1522
1524
1526
1528
1530
1532
Easting (m)

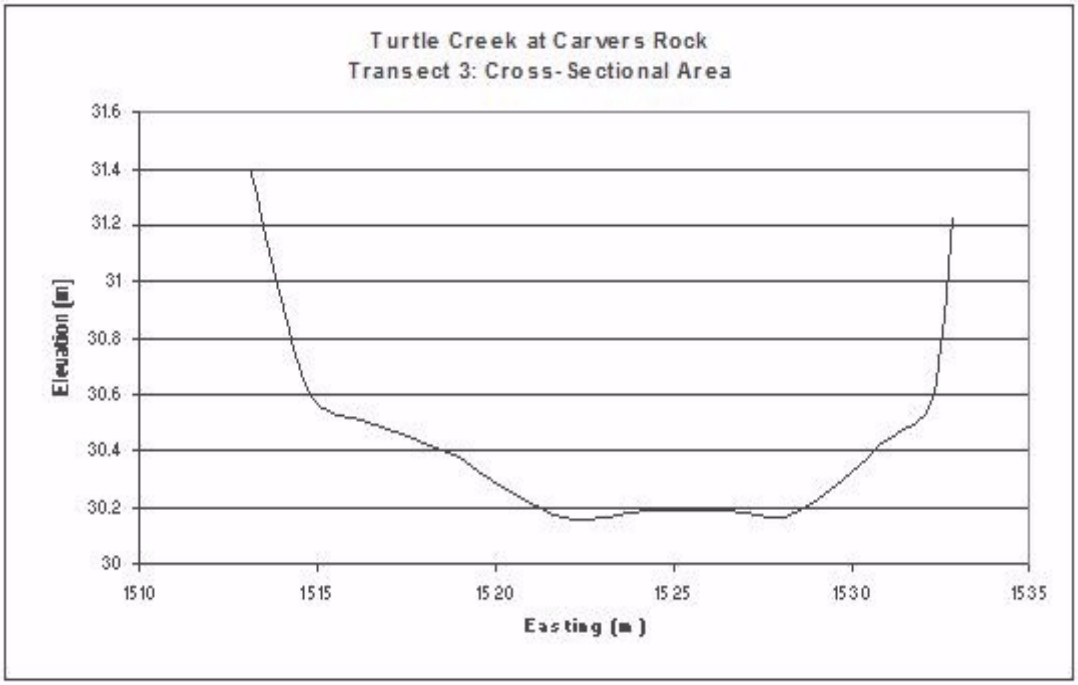

Turtle Creek at Carvers Rock
Transect 1: Cross-Sectional Profile
Elevation (m)
32
31.5
31
30.5
30
29.5
1510
1515
1520
1525
1530
1535
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface


Turtle Creek at Carvers Rock
Transect 1: Cross-Sectional Area
Elevation (m)
32
31.5
31
30.5
30
29.5
1510
1515
1520
1525
1530
1535
Easting (m)

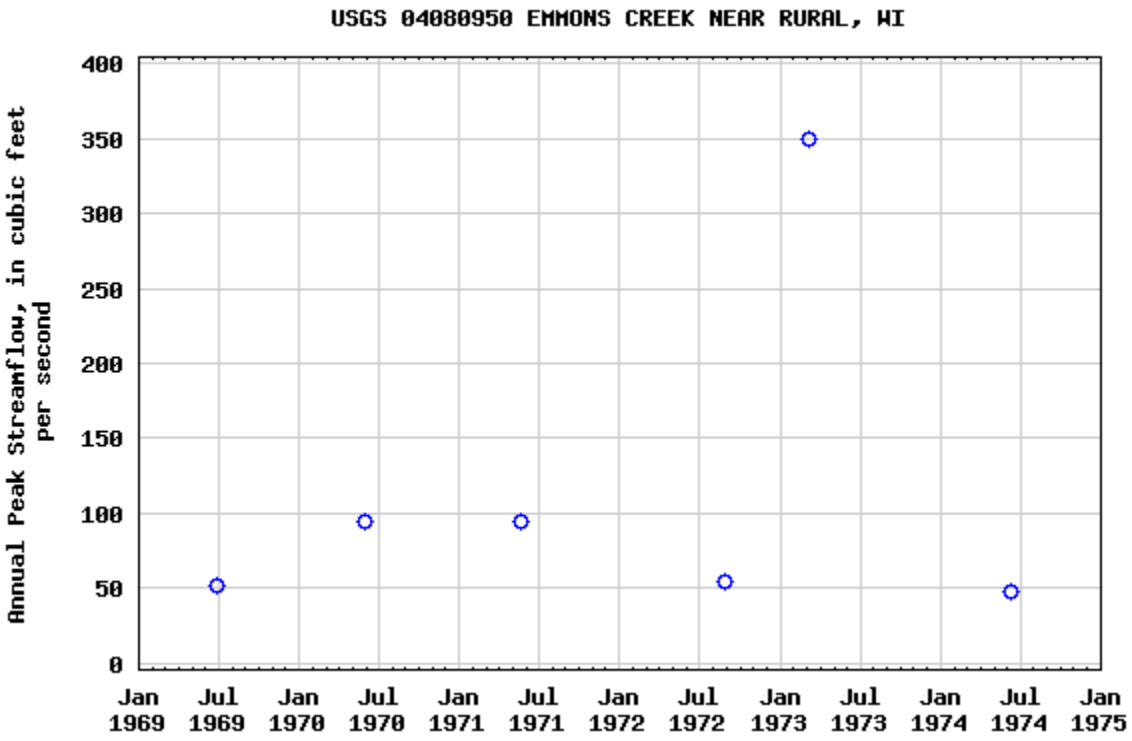

Turtle Creek at Carvers Rock
Transect 2: Cross-Sectional Profile
Elevation (m)
31.4
31.2
31
30.8
30.6
30.4
30.2
30
29.8
29.6
1510
1515
1520
1525
1530
1535
1540
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

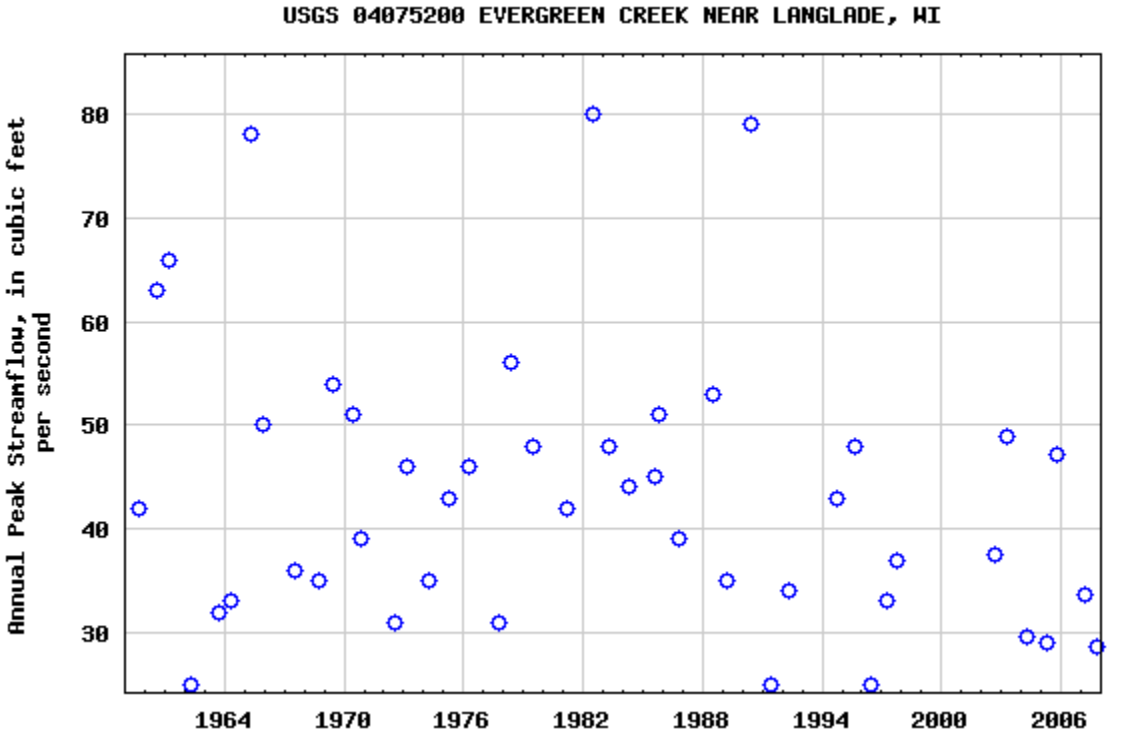

Turtle Creek at Carvers Rock
Transect 2: Cross-Sectional Area
Elevation (m)
31.4
31.2
31
30.8
30.6
30.4
30.2
30
29.8
29.6
1510
1515
1520
1525
1530
1535
1540
Easting (m)

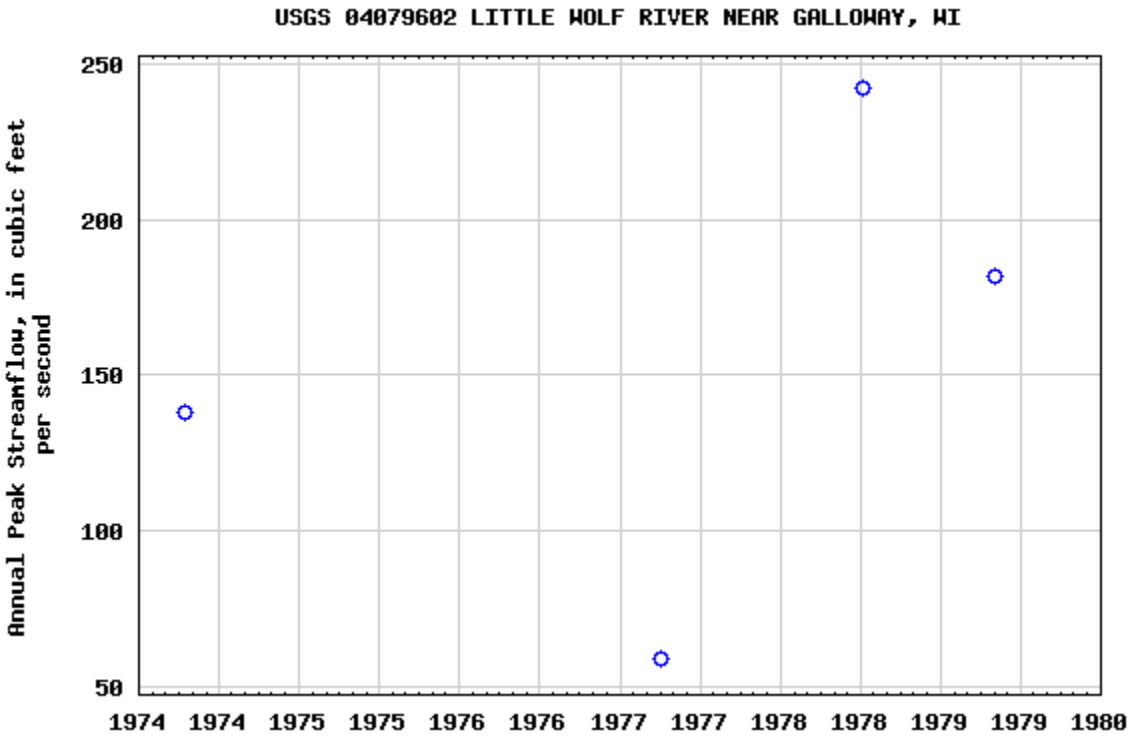

Turtle Creek at Carvers Rock
Transect 3: Cross-Sectional
Elevation (m)
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
30
1510
1515
1520
1525
1530
1535
Easting (m)
Bankfull
Stream Bank
Stream Bed
Water Surface

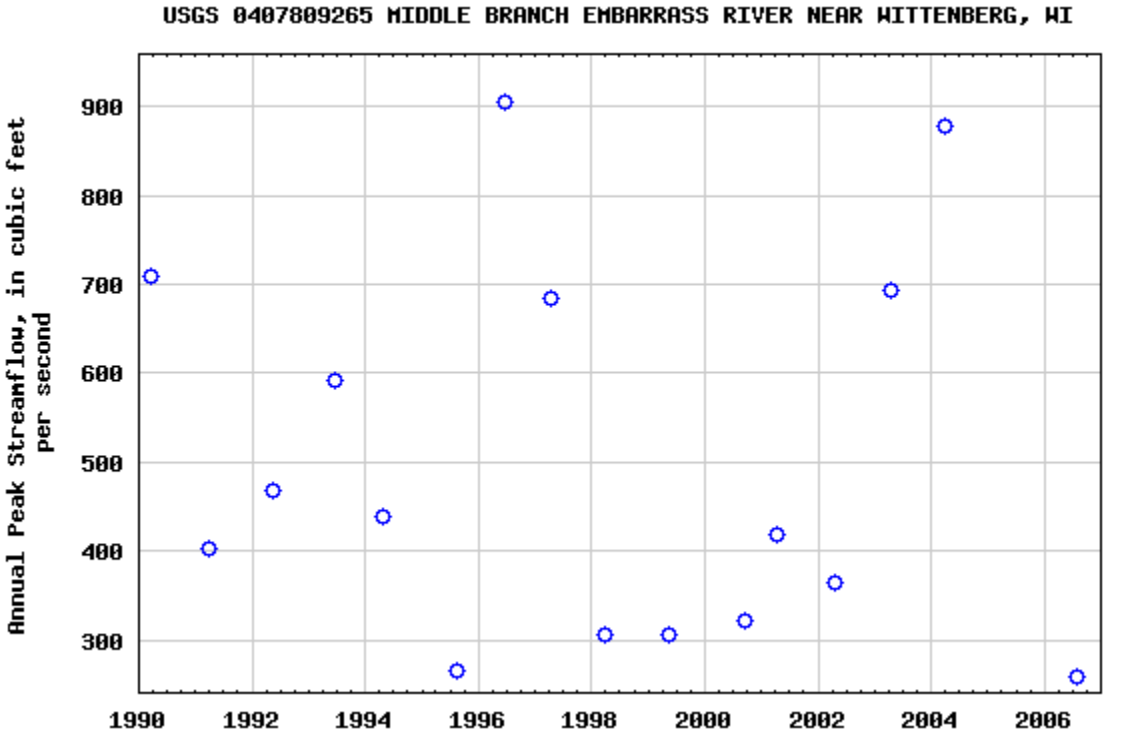

Turtle Creek at Carvers Rock
Transect 3: Cross-Sectional Area
Elevation (m)
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
30
1510
1515
1520
1525
1530
1535
Easting (m)

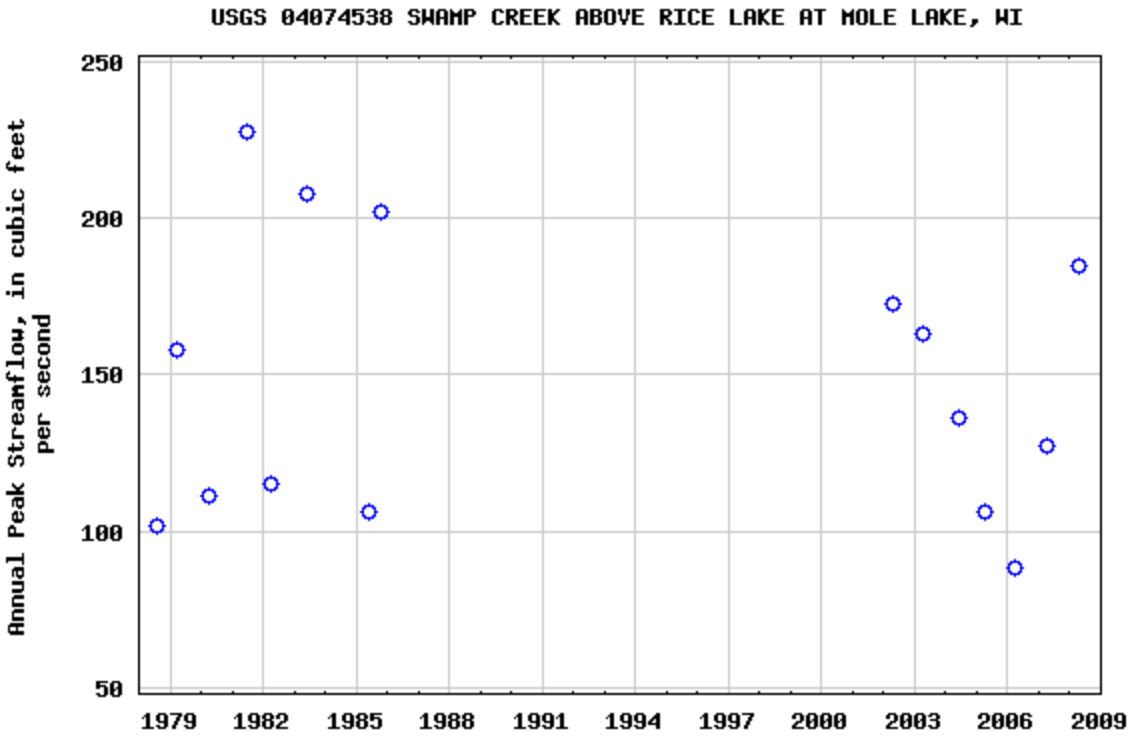
Appendix N: USGS Gauging Station Graphs

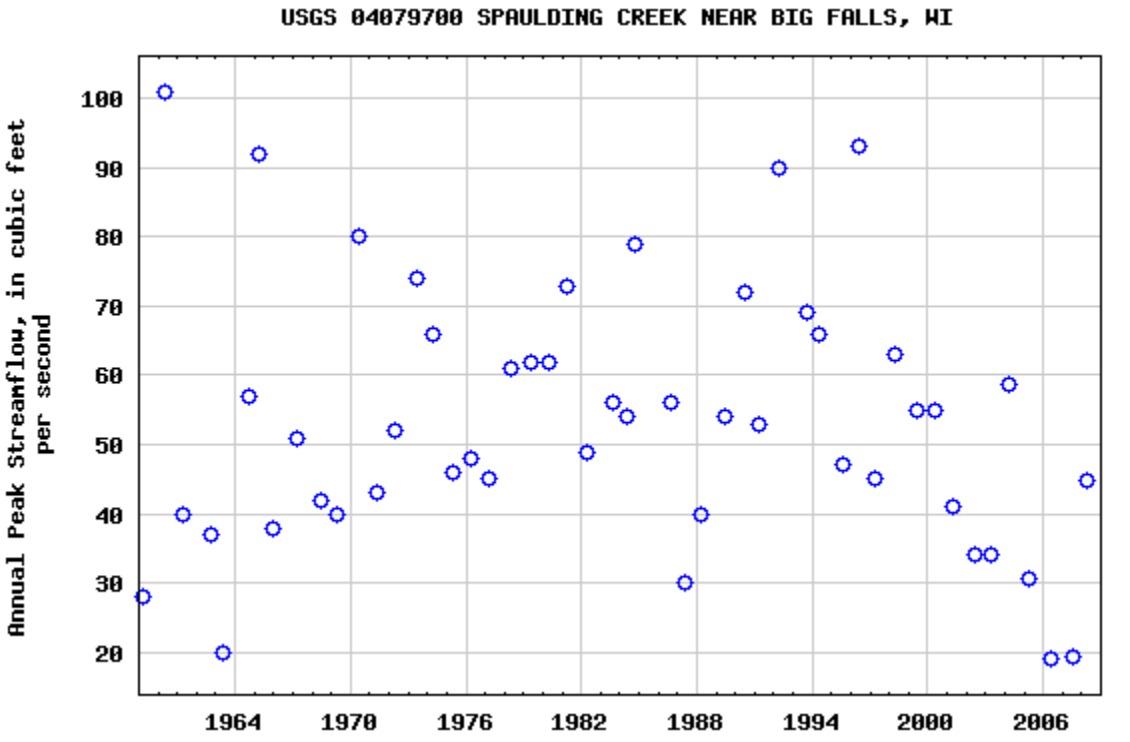

USGS 04080950 EMMONS CREEK NEAR RURAL, WI
Annual Peak Streamflow, in cubic feet per second
400
350
300
250
200
150
100
50
0
Jan 1969
Jul 1969
Jan 1970
Jul 1970
Jan 1971
Jul 1971
Jan 1972
Jul 1972
Jan 1973
Jul 1973
Jan 1974
Jul 1974
Jan 1975

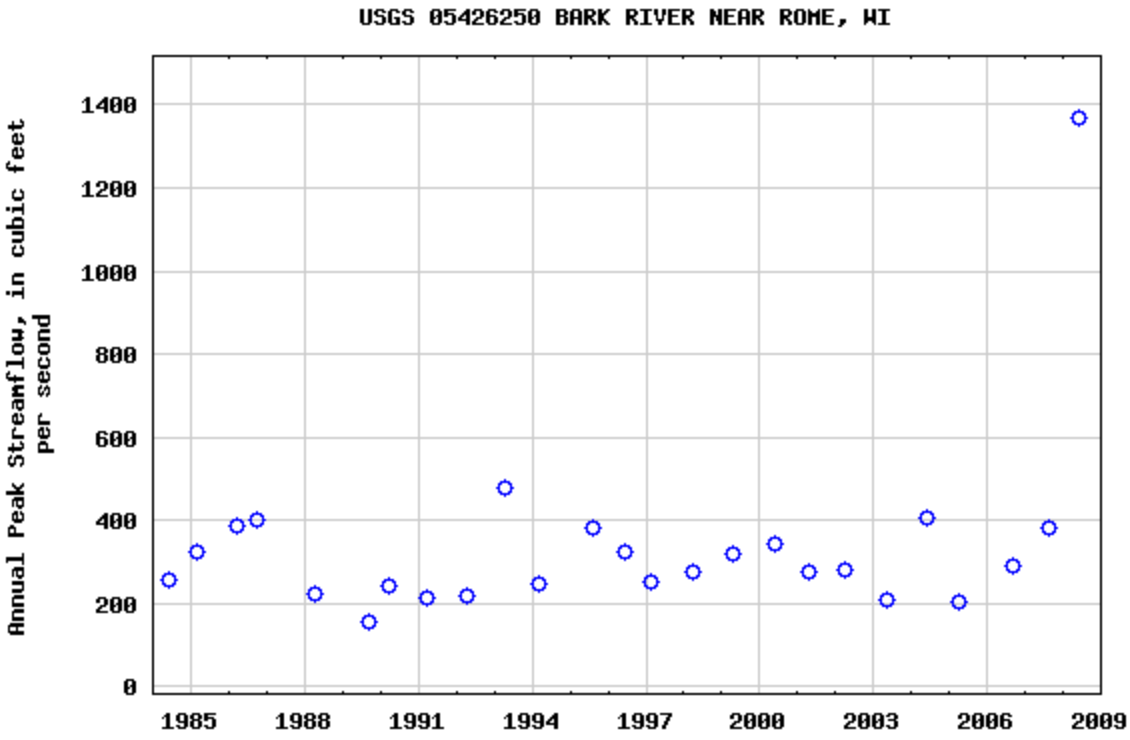

USGS 04075200 EVERGREEN CREEK NEAR LANGLADE, WI
Annual Peak Streamflow, in cubic feet per second
80
70
60
50
40
30
1964
1970
1976
1982
1988
1994
2000
2006

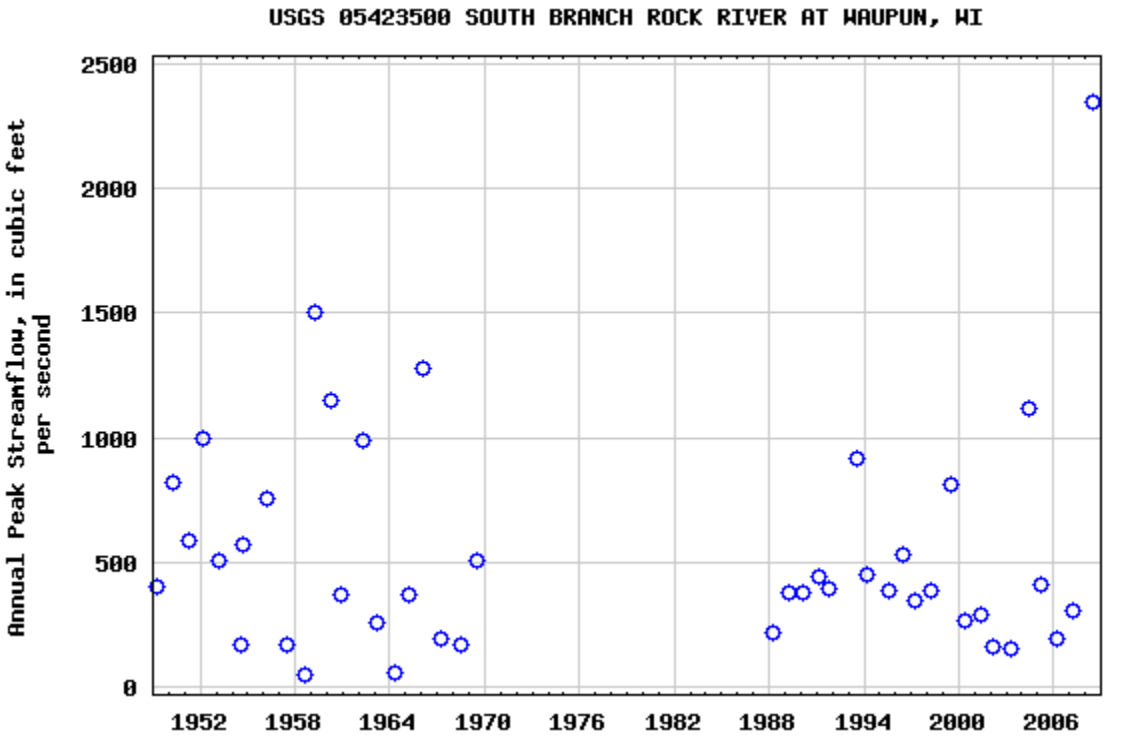

USGS 04079602 LITTLE WOLF RIVER NEAR GALLOWAY, WI
Annual Peak Streamflow, in cubic feet per second
250
200
150
100
50
1974
1974
1975
1975
1976
1976
1977
1977
1978
1978
1979
1979
1980

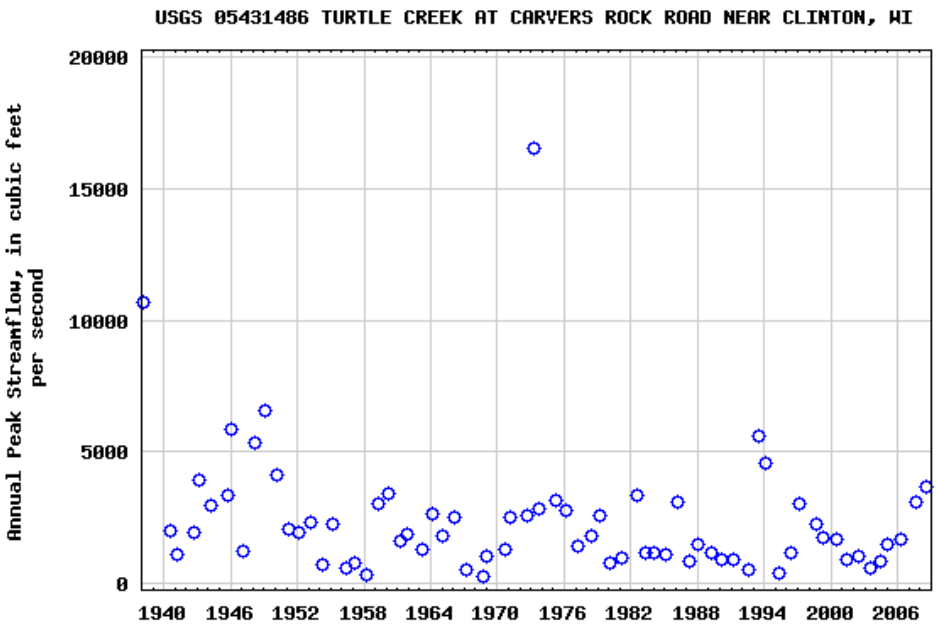

USGS 0407809265 MIDDLE BRANCH EMBARRASS RIVER NEAR WITTENBERG, WI
Annual Peak Streamflow, in cubic feet per second
900
800
700
600
500
400
300
1990
1992
1994
1996
1998
2000
2002
2004
2006


USGS 04074538 SWAMP CREEK ABOVE RICE LAKE AT MOLE LAKE, WI
Annual Peak Streamflow, in cubic feet per second
250
200
150
100
50
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009


USGS 04079700 SPAULDING CREEK NEAR BIG FALLS, WI
Annual Peak Streamflow, in cubic feet per second
100
90
80
70
60
50
40
30
20
1964
1970
1976
1982
1988
1994
2000
2006


USGS 05426250 BARK RIVER NEAR ROME, WI
Annual Peak Streamflow, in cubic feet per second
0
200
400
600
800
1000
1200
1400
1985
1988
1991
1994
1997
2000
2003
2006
2009


USGS 05423500 SOUTH BRANCH ROCK RIVER AT WAUPUN, WI
Annual Peak Streamflow, in cubic feet per second
0
500
1000
1500
2000
2500
1952
1958
1964
1970
1976
1982
1988
1994
2000
2006


USGS 05431486 TURTLE CREEK AT CARVERS ROCK ROAD NEAR CLINTON, WI
Annual Peak Streamflow, in cubic feet per second
20000
15000
10000
5000
0
1940
1946
1952
1958
1964
1970
1976
1982
1988
1994
2000
2006

Appendix O: Beaver Dam Site Description

Site Example: The Beaver Dam at Beaver Dam Site

The Beaver Dam River at Beaver Dam gauging station is a deeply entrenched, murky site with boulders and interlaying silt located directly downstream from a functioning dam. This site is located in an area of approximately 71% ag/grasslands, 7% residential and 18% marshlands. It is located in Dodge County. The watershed is 157 mi^2 and is associated with 20 years of historical data from 1986 to 2005, with some years missing. All historical discharges from this gauging station are a result of dam releases throughout the year, and therefore not natural flood levels. These unnatural discharges have scoured the banks and created unnatural channel geometry at the gauging site, that were not appropriate for stream restoration design. The width, depth, and area of the stream are assumed to be greater than what would naturally occur at that site, and the historical bankfull discharge was calculated at a much higher level than the bankfull survey calculations. Although bankfull was present at the site, and survey bankfull was calculated, the discharge levels throughout the year as unnaturally high and affected the 1.5-year recurrence interval, making the calculation significantly higher than it would have been using natural flood levels. Due to this the site was left out of the regional curve development. This site would not serve well as a reference for stream restoration.

The Beaver Dam Manning's *n* and bankfull discharge calculations were considerably larger than was estimated. It is also known that the Beaver Dam at Beaver Dam gauging station is located directly downstream from a dam structure. Historical

USGS data clearly states that every historical peak discharge from the Beaver Dam gauging station is a result of annual dam discharge. These discharges affect not only the historical 1.5-year recurrence interval, estimating a much higher peak annual discharge than what would naturally occur, but also affects the geometry of the stream channel downstream from the gauging station, where the transects were located and survey data collected. The result is not only dam influenced historical data but also dam influenced survey data. In comparison, historical and survey calculations coincided well within the Wolf River Watershed.

Appendix P: Photos, by site

Emmons Creek at Rural: photos looking up and downstream from the total station meter. We assumed, from the bunkers and highly entrenched stream channel, that this site had recently experienced stream restoration for trout habitat.

Jessica Haucke, an enthusiastic and knowledgeable field assistant who helped me with some of my rivers! She's very excited about chaining pins at this moment.

Evergreen River at Langlade: photos looking up and downstream from the total station meter. This site was particularly difficult to get readings from, due to the heavy brush. However, it was a beautiful, pristine site.


7 19'08

Little Wolf River near Galloway: photos looking up and downstream from the banks. This site was very wide and very shallow, set back into a beautiful woods. Unfortunately, the site was about a mile downstream from a scrap-metal yard. There weren't many plants growing in the stream, but we did see fish.

Middle Branch Embarrass River near Wittenberg: a photo looking down at the river site from the bridge. The actual transects were setup upstream of the large rock-rubble bank seen in the background. All other photos from this site were lost, but the transects were muddy and murky, most likely influenced by the golf course further upstream.

Spaulding Creek near Big Falls: photos looking upstream from the highway and from the stream bank. This site was difficult to get readings at, due to the brush and treefalls blocking the banks and the stream channel. Fortunately the stream was very small.

Swamp Creek above Rice Lake at Mole Lake: Photos looking upstream from the road. This was a large and difficult river to work on – in fact my sister cracked her kneecap falling on debris under the water. This river was also a consistent outlier in all data analysis. Morphologically and physiologically this site was very different from the others. I considered taking it out of the regional curve but left it in as a comparison.

My sister Julie, who helped me with most of my field work. It’s raining at this particular moment. We finished collecting data and got the total station under cover just as the skies opened up.

Tomorrow River near Nelsonville: photos looking up and downstream. The total station can be seen in the distance in this photo. Just beyond is a narrow reach of the stream with wingdams from a stream restoration project.

The wingdams upstream from the total station. As you can see the channel was narrowed and deepened at this point.

This site was conducted in late fall. It was ridiculously cold but most of the leaves were off the trees, which was the only reason we could get total station readings. I took some pretty pictures of the fall leaves in the crystal clear water.

Bark River at Rome: photos looking downstream from the upstream bridge. This stream had more vegetation than any other we worked on. My Dad and sister are in the background trying to get through the brush.

Beaver Dam at Beaver Dam: photos looking downstream from the bridge. This stream was mucky, smelly, and wholly unhealthy. It was located in Beaver Dam, downstream from a functioning dam.

South Branch Rock River at Waupun: photos looking upstream. This was the first river Jessica and I worked on. It was located on the edge of Waupun along a large park. It was very shallow and warm, with some plants and a lot of crawfish.

Turtle Creek at Carvers Rock: photos looking upstream from the bridge. This river was the largest we worked on the entire project, and the first I made my sister help me with. She was understandably unhappy, but after this everything else was easy.

Au revoir!