Creating regional watershed based groundwater, hydraulic, and nutrient models for local-scale use in the Upper St Croix – Eau Claire Rivers Watershed

UW-Stevens Point Center for Watershed Science and Education
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Executive Summary

This report summarizes data collected for a hydrologic and water quality study of the Upper St. Croix – Eau Claire Rivers Watershed (USCECRW) conducted in 2008 and 2009. This study was designed to evaluate the current conditions in the USCECRW by monitoring 10 stream sites throughout the watershed, by collecting lake overturn, groundwater, and synoptic stream samples, by modeling the hydrology and water quality of the watershed, and by analyzing the build out potential within the watershed. The study was performed cooperatively by the Upper St. Croix Watershed Alliance, Wisconsin Department of Natural Resources, UW-Stevens Point Center for Watershed Science and Education, and U.S. Army Corps of Engineers.

The USCECRW covers 335 square miles with extensive areas of internal drainage, particularly east of the Upper St. Croix River. The streams in the USCECRW obtain the majority of their flow from groundwater, which provides sustained flows to many of the streams throughout the year. The Upper St. Croix River has one impoundment, the Gordon (St. Croix) Flowage, after which the St. Croix National Scenic Riverway begins. The Eau Claire River has four impoundments, one creates the Eau Claire River Flowage near Gordon and three others are located at the lake outlets of the Eau Claire chain of lakes in the town of Barnes. Lakes occur in natural abundance, particularly within the glacial outwash plain of the north-eastern portion of the watershed. The land uses in the watershed are predominantly forests, wetlands, and grasslands with much of the development located around lakes and along streams.

Water quality conditions vary seasonally and annually throughout the watershed. Numerous sampling sites suggested that cultural impacts to water quality are very minimal at this time. Total suspended solids and phosphorus primarily enter the surface waters via snow melt and rainfall runoff; however, water quality in the USCECRW is also strongly influenced by groundwater discharging to surface waters. This is evident in the higher baseflow concentrations of chloride and nitrogen. The highest chloride concentrations are found exiting the Upper St. Croix Lake watershed which reflects the relatively intense land use practices, associated with development, in that sub-watershed. Although elevated, the observed concentrations are not harmful to fish and wildlife.

Annual total phosphorus exports were highest at the monitoring sites at the Cut-Away Dam recreational bridge crossing and at Old Highway 53, both on the St. Croix River. The high exports at these sites may be a reflection of the large percentage of wetlands bordering the Upper St. Croix River. Throughout the St. Croix River Headwaters, higher nutrient concentrations are associated with sub-watersheds with higher percentages of wetlands covering the landscape. The highest concentrations of total phosphorus were measured at the St. Croix River at Old Hwy 53 with the uppermost concentrations measured during rain events. A decrease in total phosphorus and total suspended solids in the St. Croix River from Old Highway 53 to the Gordon Flowage outflow indicates that the Gordon Flowage is acting as a sink for these constituents. In the Eau Claire River sub-basin, total phosphorus exports increased from the Eau Claire chain of lakes to the confluence of the Eau Claire and St. Croix Rivers. Monitoring of the Gordon cranberry bog outlets identified elevated phosphorus and chloride concentrations. Diazinon and chlorpyrifos were present at both sites some time during the year and malathion was detected near the southern channel of the bog in August and September.

Areas of the USCECRW with higher background concentrations of phosphorus were identified through an analysis of groundwater samples and synoptic baseflow sampling of first and second-order streams. The primary regions identified are the Horseshoe Springs area in the central part of the USCECRW and to the north and west of the Upper St. Croix River. A preceding study of the Upper St. Croix Lake sub-basin also identified the western part of that sub-basin as having greater phosphorus concentrations. It is especially important to mitigate anthropogenic sources of phosphorus and other water quality constituents in regions with high background concentrations; additional inputs to a loaded system are apt to rapidly impact surface water.

Hydrologic modeling was used to evaluate increases in streamflow (with assumed increases in sediment and nutrient loads). An increase of 6% impervious surfaces in parts of the watershed that are indirectly connected to the streams are estimated to result in a 5% increase in streamflow; however, if the areas of the watershed are directly connected to the streams, the increase in streamflow would be closer to 25%. Over the short term this would result in a greater volume of water moving through the streams in a short period of time which typically results in greater in-stream erosion and increases in sediments, nutrients, and temperature. Over the long term a decrease in groundwater recharge would result in a decrease in the volume of stream water low flow periods.

There are 197 lakes in the USCECRW ranging from less than an acre to the 2,200 acre Gordon Flowage. Seventy percent of the lakes are seepage, 17% spring/groundwater drainage, 9% drainage, 4% reservoir/impoundments. Water chemistry from a subset of the lakes was evaluated using data dating back to 1979

to assess mineralogy, and data from the last ten years were used to evaluate nutrients and water clarity. The majority of the lakes are considered soft with total hardness concentrations ranging from less than 4 to 90 mg/L. Sodium and chloride concentrations were elevated in the reservoir/impoundments suggesting cultural inputs to the water from road salts, septic systems, etc. Few lakes exceeded the phosphorus criteria (by lake type), but eight lakes exceeded the WDNR's flag values for phosphorus. Median water clarity measures ranged from 7.9 feet for reservoir/impoundments to 10.9 for spring/groundwater drainage lakes.

A build-out analysis of the USCECRW was conducted to help understand potential development patterns that are possible with the current zoning and constraints. The findings in this analysis show that the current zoning in the watershed aims to concentrate development in meaningful patterns in an effort to reflect appropriate land use policies; however, a great portion of the development potential occurs in resource-sensitive areas. More importantly, the build-out analysis shows that much of the land in the watershed is off limits to development because of environmental and physical constraints. A large portion of the remaining developable lands are in close proximity to surface water. If the most connected drainage lands completely develop at the maximum density allowed under the current zoning, roughly 3,260 new homes could be built in the most connected lands to surface water features. Other portions of the watershed not only residentially-zoned areas, but also in forestry-zoned districts, are ripe for development. For example, industrial forest companies currently own nearly 58,000 acres in the watershed. Most of their forestland is zoned F-1 which allows for residential development on 4.5 acres in Douglas County. If these companies decide to divest and develop some of their more amenity-rich tracts of land, it could result in an additional 2,963 residential units and increase the amount of impervious surface coverage to nearly 8%.

Numerous tools were developed as a part of this study to help identify important areas in the USCECRW based on geology, hydrology, topography, soil, water quality, and zoning. These tools may be used to create good plans and make good decisions that will minimize impacts to the water resources in the USCECRW from existing and future land management practices. Best management practices, such as the use of retention ponds and shoreline buffers, should be used to slow and reduce the movement and volume of runoff throughout the watershed particularly in areas directly connected to surface waters. Reviews of new culvert placement, culvert repair, and new road construction and maintenance should be performed with an eye on the potential effects to stream connectivity at both the water quality and biologic (e.g. fish passage) levels. Vegetation on the landscape and maintaining wetlands are essential for habitat and water quality. These practices can reduce sediment and phosphorus transport to streams and lakes in the USCECRW. Distribution of information, understanding, and implementation is essential for all of the land managers that make decisions in the USCECRW. These land managers include property owners, municipal boards, highway departments, agency staff, schools, and not for profit organizations.

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Introduction

This report provides results of the Upper St. Croix – Eau Claire River Watershed (USCECRW) hydrologic study, located in the headwaters of the St. Croix River National Scenic Waterway. The study was a cooperative effort between the volunteers of the Upper St. Croix Watershed Alliance (USCWA), UW-Stevens Point Center for Watershed Science and Education (CWSE), West Wisconsin Land Trust, Wisconsin Department of Natural Resources (WDNR), U.S. Geological Survey (USGS), and U.S. Army Corps of Engineers (USACOE).

The USCECRW covers an area of 335 mi^2 within Douglas and Bayfield Counties, Wisconsin (FIGURE 1). The watershed is drained by approximately 160 mi of rivers and streams which make up two major river systems, the St. Croix and Eau Claire Rivers, and numerous tributaries. There are 197 lakes within the watershed, of which 70% are seepage lakes, 17% are spring/groundwater drainage lakes, 9% are drainage lakes, and 4% are reservoir/impoundments.

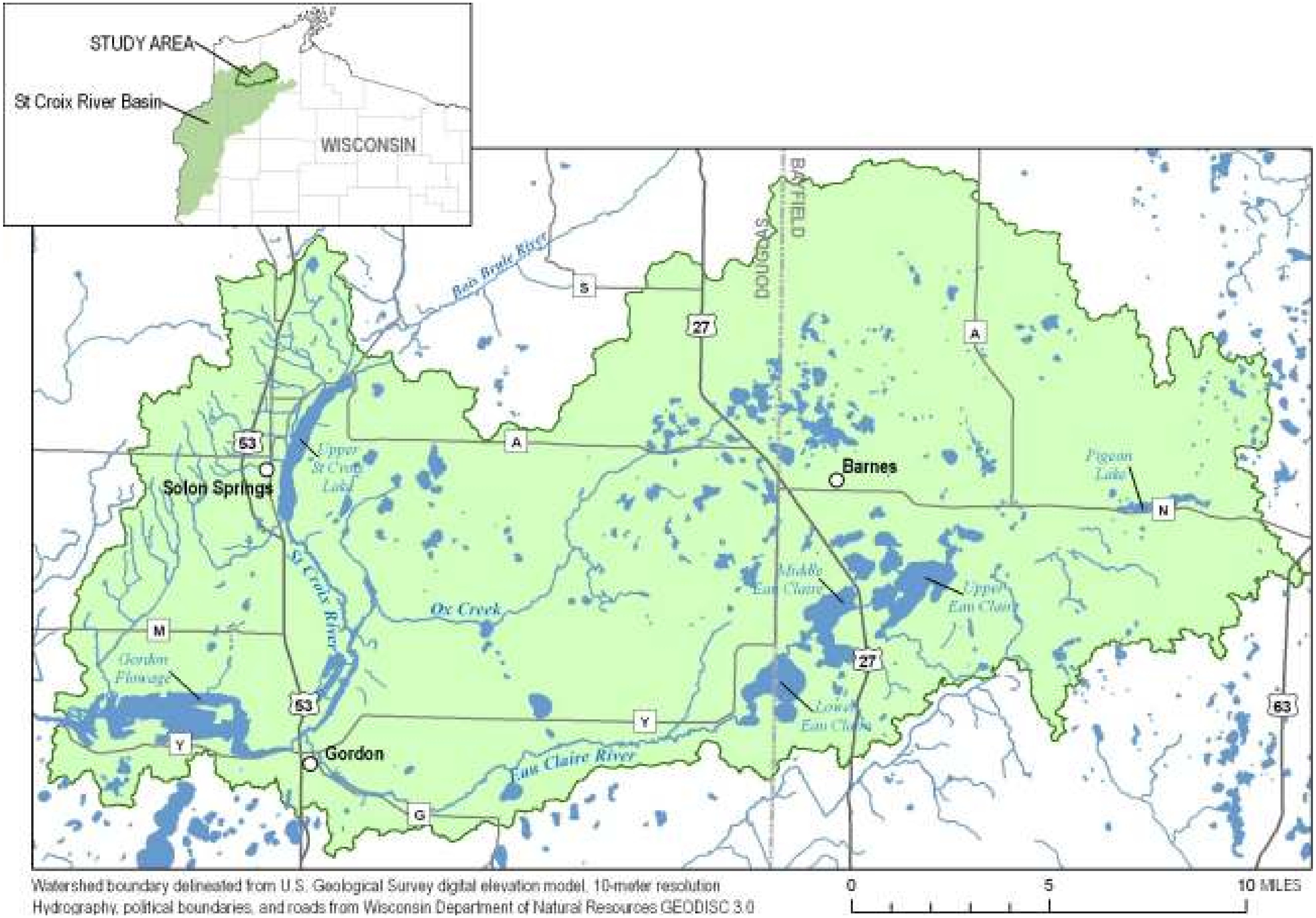
The USCECRW was identified as a Priority Watershed by the WDNR in 1994. The Priority Watershed program provided financial assistance to governmental units for projects focused on water quality improvements or protection within selected watersheds. The segment of the river between Upper St. Croix Lake and the Gordon Flowage ranks 5th among the rivers listed in the WDNR Northern Rivers Initiative. The Northern Rivers Initiative is focused on retaining the wild and scenic characteristics of northern Wisconsin streams and rivers by providing protection opportunities by means of addressing riparian zone development pressures.

Data collected between 1997 and 1999 indicated that the USCECRW contributes a substantial amount of phosphorus and sediment relative to other sub-basins of the St. Croix River. Relative to other Wisconsin streams, the overall water quality of USCECRW has historically been good to excellent; though in the last decade there has been a marked increase in sedimentation and nutrient loading, notably in the Upper St. Croix Lake sub-watershed (Young and Hindall, 1973; Hlina, 1997; Garrison, 2004). In the fall of 2005, Cyanobacteria, or blue-green algae, species (*Aphanizomenon* sp., *Anabaena* sp.) were identified in Upper St. Croix Lake water samples in concentrations above World Health Organization standards. Blue-green algae blooms are often indicative of elevated phosphorus within a lake.

The source of excessive nutrients in surface waters may eventually cause other water quality issues from decreased water clarity to groundwater contamination. Human activities are often attributed to an increase of nutrients in surface water and groundwater. Without the implementation of best management practices in the watershed, a projected population growth of 5% by 2010 in the USCECRW could potentially continue to degrade the water resources, particularly if this growth is focused around lakes and streams (Davis, 2004). The Friends of the St. Croix Headwaters (FOTSCH), a local stewardship group with an interest in the water quality of the watershed, took an active role in evaluating the water quality conditions.

Between 2005 and 2007, FOTSCH and the CWSE conducted several small scale water quality monitoring studies in the USCECRW funded through WDNR Aquatic and Terrestrial Resources Inventory (ATRI) grants and a WDNR Lake Planning grant. The studies focused on water quality sampling throughout the watershed and included pesticide analysis of sediment samples collected in the St. Croix River near the cranberry marsh north of Gordon. In addition, FOTSCH volunteers have measured water quality throughout the watershed following Wisconsin's Water Action Volunteer (WAV) Tier 1 and Tier 2 protocols.

In response to increased awareness of water quality and stewardship concerns, the USCWA was formed in 2006. The USCWA is a coalition consisting of 21 local and national lake and river volunteer organizations, non-governmental organizations, and governmental agencies. A complete listing of member organizations can be found in Appendix G. The coalition's aim is to protect and improve water quality and habitat within the St. Croix River Headwaters watershed. In 2007, the USCWA obtained a WDNR Lake Protection grant to fund a cooperative project with the CWSE to gather water quality data and create watershed-scale hydraulic and nutrient models for local-scale use in the Upper St. Croix – Eau Claire River Watershed.



Watershed boundary delineated from U.S. Geological Survey digital elevation model, 10-meter resolution
Hydrography, political boundaries, and roads from Wisconsin Department of Natural Resources GEODISC 3.0

FIGURE 1. Location of the Upper St. Croix-Eau Claire River Watershed (USCECRW) in Douglas and Bayfield Counties, Wisconsin.

Objectives

The overarching goal of this project was to develop a hydrologic understanding of water resources and water quality in the USCECRW to guide planning, protection, and implementation of best management practices. The CWSE's objectives were to provide the community and agencies with the information and tools necessary to develop science-based management strategies by:

- assessing the current water quality in the watershed,
- identifying and prioritizing contributing areas to surface waters,
- developing stream hydrologic budgets and characterizing baseflow and response to events,
- developing a conceptual model and flow model,
- estimating background concentrations and loads in order to develop goals for problem areas,
- understanding the potential for future residential development in the watershed in accordance with current land regulations,
- providing actionable conclusions and recommendations.

Study Area

The following sections provide an overview of the physical setting of the USCECRW. Additional information of the watershed in general, geology, and ecoregion can be found in Cahow and Roesler (1997), Clayton (1984), and DNR Ecosystem Management Team (2007), respectively.

Geology, Soils, and Topography

Geology, soils, and topography provide the foundational drivers of the hydrology and water quality within a watershed. Each plays a role in how much water runs off the landscape or infiltrates to groundwater, the connection between groundwater and surface water, and the type and amount of dissolved and suspended constituents (i.e. minerals, nutrients, and sediments) in groundwater and surface water.

Four rock units of Middle Proterozoic age make up the bedrock of the USCECRW, predominantly the Copper Harbor Conglomerate (Mudrey et al., 2007). The bedrock also consists of sedimentary rocks and basaltic igneous intrusions. A map of the bedrock geology can be found in Appendix J. Different types of bedrock can have various effects on surface water and groundwater, and the stream flow network. Sandstones are generally good sources of groundwater because of the many small spaces between sand grains. Igneous rocks on the other hand vary greatly in hydrologic properties. Basaltic rocks can supply water if joints and fractures are common (Schwartz and Zhang, 2003). Both bedrock types can supply dissolved constituents to the hydrologic system. Iron, for example, is common in both the cement holding sandstones together and in the minerals that make up basalts. Dissolved iron adsorbs phosphorus strongly; however, in high concentrations iron can lower dissolved oxygen concentrations in surface waters. The post-glacial sediments that overlie the bedrock result from a multitude of glacial advances and retreats, the most recent being the Lake View Advance, which retreated c.a. 9500 years before present (Clayton, 1984). The glacial sediments can be up to approximately 200 feet thick within the USCECRW.

The variability of soil type and texture, and the source of the soil play a large role in water quality. Sandy soils have a greater potential to infiltrate and transport water and contaminants than organic and clay-rich soils. The majority of the USCECRW is covered in sand-textured soils with quick infiltration rates. Although higher infiltration rates reduce runoff volumes, there is an inherent increase in the potential for groundwater contamination. The ability of an aquifer to recharge during periods of abundant precipitation or following a drought, the capacity for contaminant removal, and background nutrient concentrations are some of the factors affected by soil type and genesis. The soils in the USCECRW are of the Copper Falls Formation and were formed from the sands and gravels carried by glacial melt-water streams (Clayton et al., 2006). The soils in the watershed are distributed such that sand-textured soils cover the upland areas and loams and organics fill the depressions and bogs (Sather and Johannes, 1973). A map of the general soil textures in the USCECRW is provided in Appendix J. Research has identified the Copper Falls Formation as a source of phosphorus in groundwater (Muldoon et al., 1990). Soil type is also used to help predict the fraction of precipitation that infiltrates or becomes runoff and the potential movement of pollutants within a watershed.

Topography plays an important role in water quality by influencing runoff generation, erosion rates, and groundwater recharge rates. The hummocky (irregularly rolling) topography of the USCECRW, a product of the multiple glaciations of the region, has many gradual slopes which allows for the slowing and infiltration of runoff. Closed depressions and irregular surface features, created from the collapse of proglacial stream sediments, interrupt surface drainage patterns forming large, internally drained areas (Clayton, 1984). Areas of internal drainage provide groundwater recharge by capturing runoff in a basin which allows for infiltration.

Surface elevations range from 1000 to 1530 ft above mean sea level with areas of high relief along stream valleys and lake shores. Gully and rill erosion are evident throughout the USCECRW along stream banks and road cuts because the associated steep slopes lower infiltration rates which leads to higher runoff and erosion rates compared to the more gradual slopes throughout the rest of the watershed.

Land Use

Both land cover and land use management practices have a strong influence on water quality. Development often leads to modifications of natural drainage patterns and changes in vegetative cover. Impervious surfaces, such as roads, rooftops, and compacted soils, and water diversions via culverts drainage systems and road cuts, can reduce or prevent the infiltration of runoff. This can result in a decrease in groundwater recharge and an increase in the amount of stormwater flowing directly to lakes and streams. The removal of native plants, which provide shade and filter and decelerate runoff, can lead to warmer water and higher sediment and nutrient loads in a water body. Possible long-term effects on a stream from these changes include a decrease in stream baseflow, a flashier stream response to rain events, and an increase in stream temperatures. This effect is more pronounced during periods of below-normal precipitation. The warmer water may distress aquatic organisms and the changed stream bed materials and dynamics may alter the entire stream ecosystem. For both lakes and streams, the removal of riparian vegetation causes an increase in the amount of nutrient rich soil particles transported to the water body during precipitation events.

The land use, classified under NLCD 2001 (USGS, 2007), is primarily forests and grasslands, which make up 66% and 17% of the 335 mi^2 watershed, respectively (Appendix I). Wetlands and surface water cover approximately 12% of the land surface and agricultural and developed lands combined make up approximately 5% of the land use. Though only a fraction of the land is developed, a concern arises due to the development being concentrated around Upper St. Croix Lake and the Eau Claire chain of lakes.

Climate

The St. Croix River is within the humid continental climate, characterized by variable weather patterns and large seasonal temperature changes. Most of the precipitation historically occurs from May through August (Sather and Johannes, 1973). The average annual precipitation for this area is approximately 31 inches, 18 of which return to the atmosphere via evaporation and transpiration (Cahow and Roesler, 1997). The remaining 13 inches recharges groundwater or contributes to surface runoff.

During the past four years, precipitation has fallen below normal values particularly during the summer months (FIGURE 2). Precipitation events of a large enough intensity to produce runoff during the growing season (May – September) were uncommon during the last four years, notably from 2005 through 2008 (Turyk et al., 2008). A total of 17.2 in and 11.8 in of precipitation fell during the 2008 and 2009 growing seasons, respectively; the normal precipitation for the growing season is 20.1 in. The results of this study are therefore representative of a dry period and not of normal or wet conditions in the USCECRW.

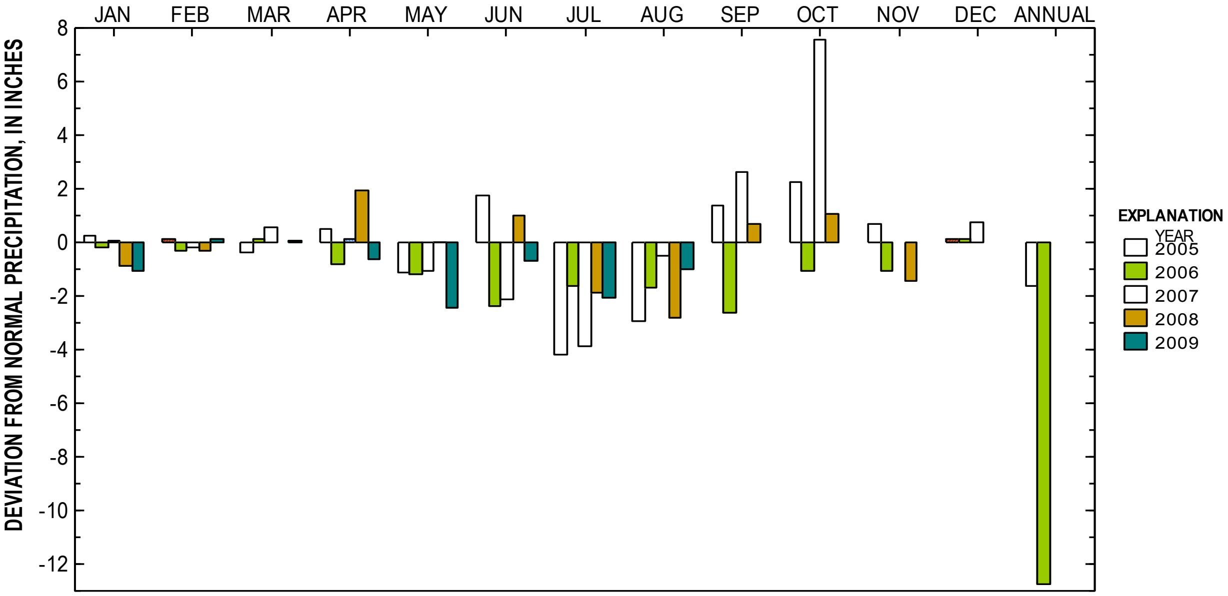


FIGURE 2. Monthly deviation from normal precipitation at the NOAA weather station located in Gordon, Wisconsin. NOAA lacked data for November in 2007, for March and December in 2008, and for January and September–December of 2009; measurements taken in Solon Springs and the Richard I. Bong Airport in Superior, Wisconsin were substituted for missing values when available.

Methods

Stream Sampling Strategy

The water quality and flow in the watershed were evaluated by monitoring eight sites within the USCECRW in 2008 and ten sites in 2009 throughout the growing season of May through September (FIGURE 3). The sites on Ox Creek (OX01) and Lord Creek (LD01) were selected because those tributaries drain a large portion of the watershed. The sites on the Eau Claire River (EC04, EC02) were chosen to monitor the water leaving and entering the Eau Claire chain of lakes and the site in Gordon (EC01) was chosen to represent the water quality and streamflow of the Eau Claire River watershed. A site on the St. Croix River located at the Cut-Away Dam Road recreational trail bridge (SX03) was used to monitor the outflow of the Upper St. Croix Lake watershed. The samples collected at Old Hwy 53 in Gordon (SX02) represent the flow and upstream nutrient and constituent contributions to the St. Croix River before it enters the Gordon Flowage. During 2008, the quantity and quality of water leaving the USCECRW was monitored at Scott's Bridge on West Mail Road (SX00). In 2009, the water quality at the outlet of the Gordon Dam and the streamflow and quality of the Moose River (MS01) were also monitored. The Moose River is located just upstream of SX00 and was investigated to identify its portion of water volume and quality that was measured at SX00.

Water samples at sites SX00, SX02, SX03, and EC01 in 2008 and at SX00, SX01, and MS01 in 2009 were collected following a modified sample regime described by Robertson and Roerish (1999). The sampling regime, summarized in TABLE 1, involved collecting water samples at the sites every two weeks and collecting samples during runoff events. Samples were analyzed for total phosphorus (TP), dissolved reactive phosphorus (DRP), total Kjedahl nitrogen (TKN), nitrite and nitrate-N (NO2+NO3-N), ammonium-N (NH4-N), total suspended solids (TSS), and chloride (Cl). During the first year of the study, samples were collected from sites LD01, OX01, EC02, and EC04 once a month and analyzed for TP. Samples collected during runoff events were analyzed for the entire nutrient suite above during both years of the study.

A total of 203 and 97 samples were collected in 2008 and 2009, respectively, at the monitoring sites and analyzed for nutrients at the state-certified Water and Environmental Analyses Laboratory (WEAL) located on the UWSP campus. Analytical procedures can be found in Appendix B.

Pesticide samples were also collected from the St. Croix River near the cranberry bog in Gordon on two different occasions during the summer of 2008 and monitored throughout the growing season of 2009 using POCIS devices deployed on a monthly basis. The POCIS devices were placed in the St. Croix River near the southern (CB01) and northern (CB02) bog outlets and nutrient samples were collected at the locations of the pesticide monitoring devices on a monthly basis.

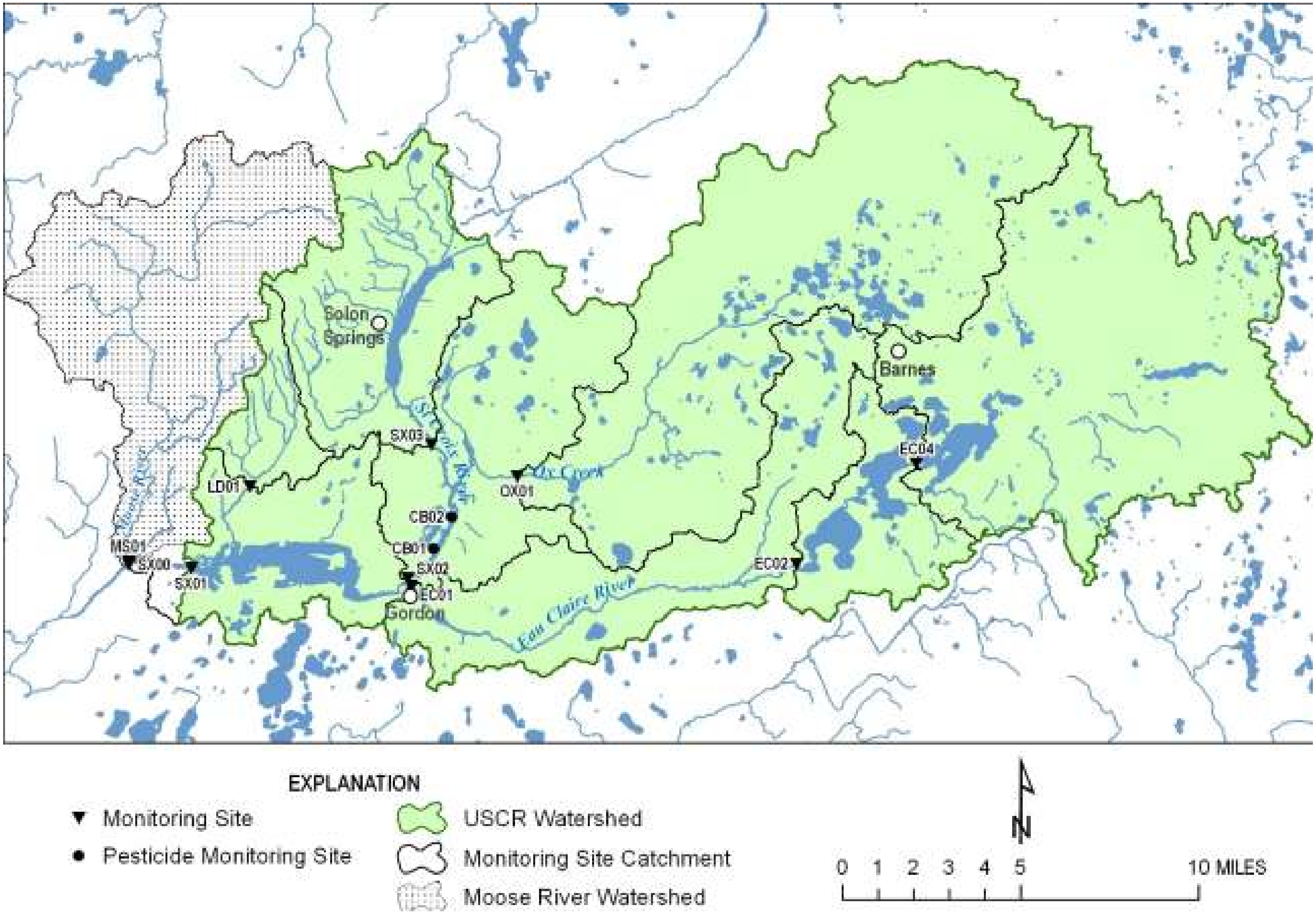


FIGURE 3. Monitoring site locations in the Upper St. Croix – Eau Claire River Watershed.

TABLE 1. Sample frequency at monitoring sites in the Upper St. Croix – Eau Claire River Watershed during the 2008 and 2009 growing season (May-September).

		2008			2009		
			Baseflow			Baseflow	
Stream, location	**Site ID**	**Event**	**Semimonthly**	**Monthly**	**Event**	**Semimonthly**	**Monthly**
St Croix Rv, Cut-Away Brdg	SX03	x	x		x		
St Croix Rv, Old HWY 53	SX02	x	x		x		
St. Croix Rv, Gordon Dam	SX01				x	x	
St Croix Rv, Scotts Bridge	SX00	x	x		x	x	
Eau Claire Rv, Gile's Dock	EC01	x	x		x		
Eau Claire Rv, E Mail Rd	EC02	x		x	x		
Eau Claire Rv, Outlet Bay Rd	EC04	x		x	x		
Ox Ck, Flat Lake Rd	OX01	x		x	x		
Lord Ck, CTH M	LD01	x		x	x		
Moose Rv, West Mail Rd	MS01					x	
Cranberry Bog, upper outlet	CB01						x
Cranberry Bog, lower outlet	CB02						x

Stream Baseflow Samples

Baseflow represents the stream flow when runoff is negligible and groundwater is the dominant contributor to the stream. Baseflow samples were collected from May through October of 2008 and May through September of 2009. When samples were to be analyzed for the total nutrient suite, they were collected using three bottles per site, one 500 ml bottle, filled with unfiltered water and left unpreserved, and two 60 ml bottles both preserved with 1 molar H_2SO_4 . One of the 60 ml bottles was filled with filtered sample and the other with unfiltered sample. The samples were collected at mid-depth of the stream from the stream thalweg using the 500 ml bottle. From this bottle, water was transferred to the unfiltered 60 ml bottle. The water for the second 60 ml bottle was first transferred to a 60 ml syringe which was attached to an in-line filter cassette. The cassette contained a 934/AH glass fiber pre-filter and a 0.45 micron membrane filter.

For analysis of TP, a 60 ml preserved bottle was filled with unfiltered stream water. After collection, the bottles were immediately placed on ice and transported to the WEAL lab for analysis. In this report, all data falling below detection limits were censored to half the detection limit. Water quality measurements taken in the field included pH, conductivity, water temperature, and dissolved oxygen (DO). The field measurements were obtained using a Hach HydroLab Quanta data sonde. Stream stage was recorded from a staff gauge placed at each site.

Stream Event Samples

Event, or runoff, samples were collected from each monitoring site in the USCECRW. A total of 57 event samples were collected in 2008 and 36 in 2009. Event sampling was accomplished by collecting grab samples, as with stream baseflow, or by using siphon samplers (FIGURE 4). The siphon samplers used in this study are similar to a model designed by the USGS (Edwards and Glysson, 1988). At all sample sites except for SX01, two siphon samplers were attached to fence posts within the stream channel and positioned to sample an anticipated rise in the stream caused by a rain event. The river bed at Site SX01 is comprised of exposed bedrock, which prevented the installation of siphon devices. When the water crested above the peak of the lower tube, the stream water entered the bottom tube and filled a 500 ml Polypropylene sample bottle. Before sample collection, the level of the collection tube was referenced to the staff gauge to approximate the stream stage at the time of the sample bottle filling. The sample was transferred from the 500 ml sample bottle and analyzed as described in the Stream Baseflow section. When possible, the sample preservation and filtering process was done within 24 hours of the siphon sampler being filled.

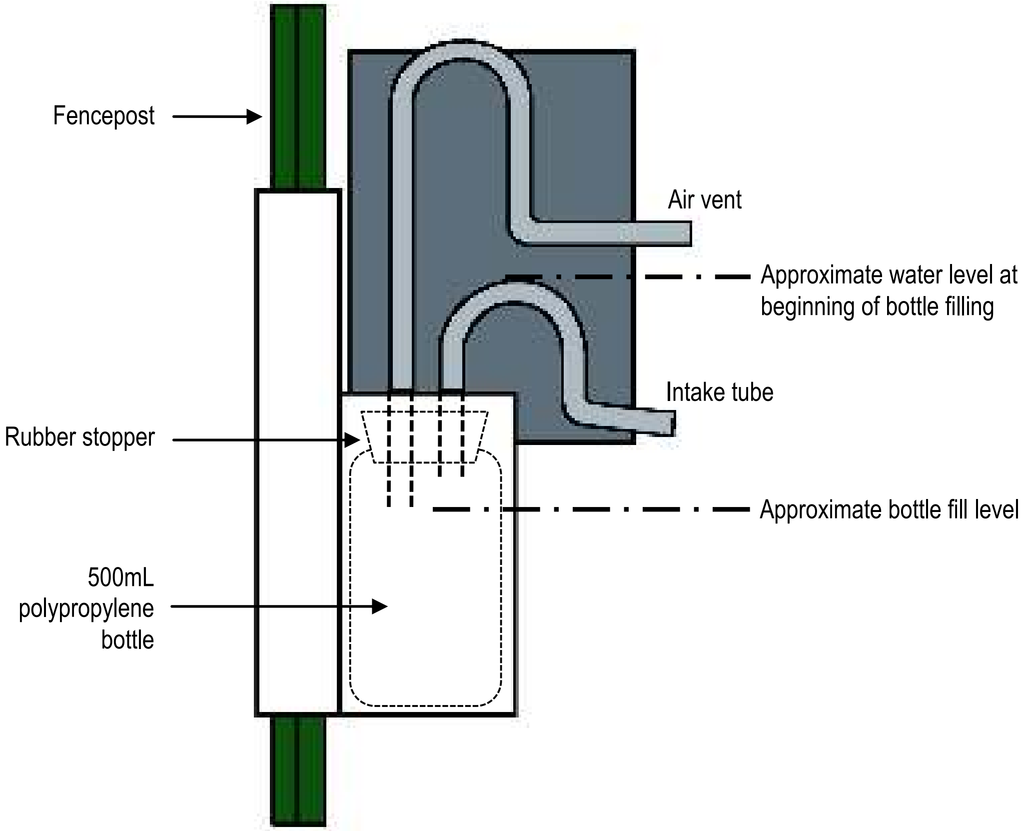


FIGURE 4. A schematic of the siphon sampler devices used in this study.

Stream Synoptic Samples

The spatial variability of stream chemistry and flow were investigated through synoptic or "snapshot" sampling. Stream water samples were collected from a total of 41 sites during three baseflow synoptic sampling events on June 16-17, July 6-7, and August 12-13, 2009. The July sample period was focused on the Ox Creek and Eau Claire River. During the August sample period some sites were stagnant or dry so no sample was collected. Baseflow conditions were considered the period between rainfall events when the hydrograph was in the latter stages of the recession limb. The sample sites were located at road crossings to allow for rapid sample collection. At each site a 60 cc syringe was rinsed three times with stream water and a sample was drawn from the stream thalweg. The sample was passed through an in-line filter cassette containing a 934/AH glass-fiber pre-filter and a 0.45 µm membrane filter into a 15 ml vial containing HNO_3 as a preservative. The vial was stored on ice for transport to the WEAL for analysis.

Stage and Discharge Measurements

Stream Flow Measurements

Stream flow, or discharge, was measured at sample sites multiple times throughout the study. The CSWE measured stream flow using a Marsh McBirney Flo-Mate Model 2000 flow meter and a SonTek FlowTracker Handheld Acoustic Doppler Velocimeter (ADV). The in-stream flows were measured and computed using the USGS velocity-area method (Buchanan and Somers, 1976). The USGS performed discharge measurements at sites SX00, SX02, and SX03 in 2008.

Continuous Stage Recording

To compute the average daily flows of a stream, a continuous flow record is needed. Solinst Levelogger Model 3001 Gold Series pressure transducers were used to obtain continuous measurements of stream temperature and stream depth, or stage, at each sample site. Pressure transducers were located in the stream at a fixed location near the staff gauge and set to record the stream stage every 15 minutes. The pressure transducer data was adjusted for changes in barometric pressure by using a barometric (baro) logger exposed to the atmosphere. During the first year of the study, the baro logger was located in Solon Springs, Wisconsin and in Gordon, Wisconsin during the second year.

Staff gauges, essentially long rulers used to read water depth, were placed at stream monitoring sites near where flow was measured. Rating curves were developed by the CWSE and USGS using the streamflow and staff gauge measurements. The curves are based on the relationship between stream depth and stream flow, which varies from stream to stream, and need to be periodically recalibrated with measured flows to adjust for natural changes in stream morphology. To estimate continuous flow values, the recorded pressure transducer stages were adjusted to the staff gauges. The flows were then calculated using the rating curves.

Lakes

Lake water samples were taken during the spring overturn period (April-May) of 2009 from 42 lakes located in the USCECRW. Samples were collected by local volunteers and by CWSE staff. Lake stratification conditions were assessed by taking a temperature and a dissolved oxygen reading 1 ft below the lake surface and at 1 ft above the deepest point or midpoint of the lake. Samples were collected from 1 ft below the lake surface following the filtration and preservation methods of stream samples described above.

Groundwater

Groundwater Measurements

In June 2008, groundwater flow conditions (inflow, outflow, or static) of the St. Croix River at Cut Away Dam Road were assessed using mini-piezometers. Well positions were recorded using a handheld GPS and labeled on a map for future reference and investigation. Lab analyses were completed on 11 water samples for concentrations of NO_2+NO_3, NH_4-N, DRP, Cl, sulfate (SO_4), copper (Cu), iron (Fe), potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg).

The mini-piezometers were constructed from 5 ft lengths of 3/16 inch inside-diameter polypropylene tubing with a point formed on the bottom end. A small diameter ball-point sewing needle was used to perforate the bottom 4 inches of the tubing starting 2.5 inches from the point. A 1 ml pipette tip was attached to the pointed end to protect the mini-piezometer tip during installation. The mini piezometers were installed 2 ft into the river sediment in 1.5 ft of water. At each sample site measurements of water depth, installation depth, static head height, and slug height (length of tube above static head) were recorded. Static head identifies whether groundwater is entering the stream (inflow) or whether water is leaving the stream (outflow); a static head above the stream surface indicates inflow and a static head below the stream surface indicates outflow. A site where the head is level with the surface of the stream is considered a no-flow or static site.

The velocity of groundwater inflow, or seepage rate, was estimated by conducting falling head tests to determine the hydraulic conductivity (Fetter, 2001). The test was performed by timing the fall of water from the top of the mini-piezometer to a black O-ring placed at 37% of the slug height above the static head. This procedure was repeated three times to determine an average falling head time. The hydraulic conductivity was calculated using the average falling head time and design specifications of the mini-piezometer. The groundwater seepage rate, or flux, was estimated by multiplying the hydraulic conductivity to the vertical hydraulic gradient (the difference in water levels between the mini-piezometer and surface water divided by the depth from the sediment surface to the middle of the screened area).

Areas of groundwater inflow and the locations of springs were identified throughout the watershed using a variety of techniques. During early spring of 2008, the CWSE identified areas of open water on some of the streams and lakes. Areas that remain open early in the day or during cool and cloudy days are assumed to be indicative of warmer groundwater entering the stream or lake and preventing ice from forming. Citizen volunteers also mapped areas of open water and ice-melt during the spring of 2008 and 2009. This additional information contributes to a more complete understanding of water table elevations and the location and extent of groundwater inflow to lakes and streams.

Groundwater Synoptic Sampling

Groundwater samples from 50 domestic wells were collected by local volunteers from October 2-4, 2009 to investigate the spatial distribution of groundwater quality within the USCECRW. To collect samples representative of groundwater, the sample was collected from a faucet that was purged by being full-on for at least five minutes. A 15 ml vial containing HNO_3 (nitric acid) as a preservative was filled with sample water and shipped on ice to the laboratory for analysis.

Groundwater watershed

The groundwater watershed is the land area where groundwater flows to wetlands, streams, and lakes. A contour map of water-table elevations (10 ft interval), covering the USCECRW and the immediate surroundings, was created using surface elevations of water bodies found on USGS 7.5-minute topographic maps and using water-table elevations from the WDNR water well data files. Lake surface and stream elevations during baseflow are considered a reflection of water-table elevations. The water-table map was used to delineate the USCECRW groundwater watershed. When viewing a water-table map, groundwater flow paths are assumed to be perpendicular to water-table elevation lines, with groundwater flowing from areas of higher water-table elevation to areas of lower water-table elevation.

Stream temperature data, collected by FOTSCH and CWSE, were used to identify areas of groundwater inflow. Stream reaches with relatively cooler summer temperatures indicate areas of greater groundwater inputs. The winter open water observations were also used to aid in refining the water-table map by indicating areas of lakes and streams located up-gradient within local groundwater flow systems.

Stream Connectivity

Watershed Delineation

During the 2008 field season, ground truth of the surface watershed was performed to identify discrepancies between actual and the computer-generated boundaries created using ArcHydro software and digital elevation models. This was accomplished primarily in the northern part of the watershed. The watershed boundaries depicted in this report were created using the most up to date 10-meter resolution digital elevation model available at the time from the U.S. Geological Survey.

Internal Drainage

Internally drained areas are closed depressions that do not contribute overland flow to the stream network as a result of topography. In the USCECRW, multiple glaciations have left a relatively flat landscape with many potholes, wetlands, and lakes topographically isolated from the drainage network. Precipitation that infiltrates in these internally drained areas may eventually reach a stream via groundwater, but runoff generated in these areas may only contribute to streamflow during the most extreme flooding events.

The PCSA program (Richards and Brenner, 2004) was used to identify the areas of the watershed physically capable of providing runoff to the stream drainage network, termed *potential contributing areas*, and in turn, the areas of internal drainage. Potential contributing areas are the areas with an uninterrupted downhill slope to the drainage network.

A ground truth of potential contributing areas was conducted for various portions of the USCECRW during the summer of 2008. The Eau Claire River and Lower Eau Claire Lake were specifically targeted during July of 2008 by canoeing down the Eau Claire River and around Lower Eau Claire Lake. Observations of land use adjacent to the stream banks were also recorded. An ArcGIS shapefile was created with the data.

Culvert Inventory

Anthropogenic changes to the landscape, such as culvert placement and road fills or cuts, can also have an effect on the connectivity of the drainage network. During the summer of 2008, some culverts in the USCECRW were inventoried and information such as road surface type, culvert type, condition and size, and drop to outlet pool were recorded. Near the completion of this inventory, a copy of the Bad River Watershed Association's Culvert Inventory Data Sheet (CIDS) was acquired. The CIDS can be utilized in an inventory of culverts and aid in identifying those in most need of repair within the St. Croix River Headwaters with very little modification.

From a fishery standpoint, any culverts above a streambed may be of concern; however, restriction of fish movement varies from species to species. In addition, culverts with sharp edges and in degraded condition, which can be found throughout the USCECRW, can be problematic to many fish regardless of species.

Due to the investigative nature of the inventory, not all the attributes were measured for every culvert. A more comprehensive culvert inventory is recommended. An ArcGIS shapefile of culvert locations was populated with the measured attributes and presented to FOTSCH. In 2009, County Road A, which runs along the western side of Upper St. Croix Lake, was resurfaced and many of the culverts replaced, though the status of the new culverts is not known at this time.

Hydrologic Modeling

Hydrology

The Soil and Water Assessment Tool (SWAT) was used to model the stream flow in the USCECRW. This model uses daily precipitation and temperature to simulate plant growth, hydrology, sediment, and nutrient movement. The selection of a SWAT quality model was based on balancing the complexities of water movement at very small scales with the relatively coarse level of detail on land elevation, soils, and land management that is available. A review of modeling requirements suggested that the model should be able to accommodate the following conditions:

1) Differentiate between portions of the watershed that topographically drain internally into closed basins or depressions. Those areas could still be a source of groundwater recharge, but they would not be contributing surface runoff or event flow to the river network.

2) The model should use a rainfall/runoff simulation approach that can accommodate differences in infiltration characteristics of undeveloped and developed soils and impervious surfaces in the watershed (both now and for various planning scenarios). It would also be useful to accommodate the day to day variations in soil moisture from drainage and vegetative uptake.

3) It is useful to be able to link the model with existing data on flow and water quality. Ideally, the model results could be compared with the reported long-term average annual water budget

(Young and Hindall, 1973) and measured rainfall event responses (2007-2008 monitoring as part of the current study). This information could be used to adjust (calibrate) the stream flow and water quality aspects of the model.

Calibration of the model was done using flow data collected during this study. The model was used to estimate changes in stream response to precipitation events due to various development scenarios.

Water Quality

The water quality computer model FLUX (Walker, 1999) was used to explore nutrient loads throughout the USCECRW. FLUX is designed for the analysis and reduction of tributary monitoring data. This model simulates the total load, in pounds per year (lbs/year), through flow-concentration relationships developed using average daily flows and sample concentrations. The estimated values can be used to calculate nutrient budgets and refine sampling regimes (Walker, 1999). Each primary and secondary stream monitoring site was modeled with this approach to identify growing season total phosphorus and TSS loads. The model results were used to identify the sub-watersheds which provide the greatest amount of nutrients to the St. Croix River.

Historic Data Collection

Water quality data for lakes and streams in the USCECRW were collected from several sources including the WDNR Surface Water Integrated Monitoring System (SWIMS), the EPA water quality repository Storage and Retrieval (STORET), WEAL domestic well sample data, and published reports (Sather and Johannes, 1973; Robertson et al., 2006). The majority of these data are water quality measures for various lakes in the watershed. The ACOE is completing a summary of the data to evaluate trends in water quality.

Quality Control

Quality control and quality assurance techniques were observed when performing field and lab work. All analyses not conducted in the field were completed at the WDNR-certified Water and Environmental Analysis Lab (WEAL) at the University of Wisconsin-Stevens Point (UWSP).

Metadata

ArcMap 9.3 software (ESRI Inc., 2008) was used with WDNR hydrology-version 5, road coverages, and political boundaries for data interpretation. Land use coverages were obtained from the U.S. Geological Survey (2007) National Land Cover Database 2001. Bedrock geology is from Wisconsin Geological and Natural History Survey data (Mudrey et al., 2007), and the State Soil Geographic (STATSGO) database was used for the soil coverage (Soil Survey Staff, 1994). Watersheds were created with the ArcHydro 1.2 toolset. The 30 meter and 10 meter digital elevation data is from the USGS. Additional maps were digitized at UWSP. Statistical analyses were completed using Minitab 15.1.1.0 software.

Results and Discussion

Within a watershed, an understanding of how water moves across the landscape and knowledge of the water quality conditions in streams, lakes, and groundwater helps to identify where and which strategies to implement to maintain healthy aquatic ecosystems and the actions necessary to improve existing problematic conditions. In the USCECRW, the St. Croix River and its tributaries receive water from direct precipitation, surface runoff from rainstorms and snowmelt, groundwater inflow, and periodic discharge from wetlands. Although much of the riparian, or near-shore, area between Upper St. Croix Lake and the Gordon Flowage has intact vegetation, the hydrology in various portions of the watershed has been altered by the filling of wetlands, the addition of culverts and impervious surfaces, and the creation of stream impoundments. Some of these alterations in the hydrology can result in more runoff moving to a water body during storms or snowmelt and less water infiltrating to groundwater. Most of the lakes and streams in the USCECRW receive water from groundwater, which is their predominant source of water during periods without precipitation, so a reduction in the amount of infiltration can affect the amount of water in a stream during dry periods. Decreased water during dry periods can result in increases in temperature, and longer retention time in lakes which may lead to increased aquatic plant or algal growth.

Water flowing over land can pick up and carry soil and other particulates. These particulates have nutrients and other pollutants that can affect water quality. The particulates themselves can also affect a lake or stream by changing the substrate that is used by aquatic insects, fish, and other aquatic biota and/or increasing water temperature. Reduction of particulates in runoff can occur in natural conditions or can be replicated in altered landscapes by allowing the sediments in water to settle out. These are areas where a depression on the lands surface slows the runoff; if these areas also have sufficient vegetation (a combination of grasses, forbs, shrubs, and trees) additional filtering and/or nutrient uptake can occur prior to the water arriving at the lake or river. Currently, the primary impacts to water quality in this stretch of the St. Croix River occur near Upper St. Croix Lake, runoff from Highway 53, the cranberry marsh, domestic septic tanks, and possibly from groundwater discharge potentially contaminated by leaky storage ponds at the Solon Springs wastewater treatment plant.

When water quality issues arise because of increased nutrient loading and sedimentation rates, the problem is often visible in lakes and streams as an overgrowth of algae and aquatic plants. This overgrowth can result in a change in habitat, increases in stream temperatures, a decline in water clarity, changes in dissolved oxygen concentrations, and alterations of the aquatic biotic communities. Several areas of abundant filamentous algae can be observed in the St. Croix River, notably near the Cut-Away Dam Road recreational trail bridge and just outside of the cranberry marsh and in smaller regions within the Gordon Flowage. During cooler periods of the year, the invasive aquatic plant curly-leaf pondweed (*Potamogeton crispus*) has been identified in abundance in a stretch of the river near the cranberry marsh. Beds of curly-leaf pondweed release a fair amount of phosphorus when the plants die back which typically occurs in June. The warm water and additional phosphorus input from the decomposing curly-leaf pondweed provide ideal conditions for algae growth for the remainder of the summer.

Wetlands, which are common in the USCECRW, particularly along the St. Croix River valley, perform a variety of roles in the watershed. Wetlands near or adjacent to streams and lakes affect the water quantity and quality by absorbing, circulating, and chemically altering the composition of the water before slowly releasing it. Floods can flush wetlands, releasing large amounts of nutrients to surface water. Wetlands also act as sponges that capture nutrients and reduce runoff during rain and snowmelt events. During times of low or no precipitation, this stored water is slowly released from wetlands which help to stabilize stream flows. Wetlands also provide unique ecosystems with complex habitat structures, sometimes playing a key role in various developmental stages of aquatic organisms that inhabit the streams during parts of their life cycle.

Contributing Area: The Watershed and Groundwater Basin

It is helpful to understand both where water is originating in a watershed and how the water is moving within the watershed. The contributing area of the USCECRW is comprised of both the surface watershed and groundwater watershed (FIGURE 5). A surface watershed is the land area where runoff from precipitation drains to a water body or wetland. The watershed is determined by topography and drainage patterns. Contributions of water from within a watershed are not uniform, with areas closer to a water body having greater and swifter impacts to lakes and streams than other areas within the watershed. In some parts of the watershed, runoff may drain to a depression in the landscape and where the water collects and infiltrates to groundwater. From the standpoint of surface runoff, this type of area is considered disconnected from the lakes and streams. Between these two extremes are areas within the watershed that are less connected to the water bodies, only becoming connected following snowmelt or very large rain storms. Identifying these different areas within a watershed can help in the development of equitable rules across the watershed. In areas with a more direct connection to the surface water, more stringent practices pertaining to runoff should be applied and in areas disconnected from surface drainage, more stringent practices pertaining to maintaining groundwater quality should be applied.

Watersheds with an abundance of both steeply sloped land and impervious surfaces can deliver large volumes of surface runoff by avoiding infiltration and swiftly funneling runoff directly to a water body. The amount of the landscape connected to surface water and the slope of the landscape affect both the stream response to rain events and the amount and timing of sediment and pollutant delivery to a stream. Small streams receiving high volumes of runoff tend to be flashier, that is, have a more pronounced change in stream stage in a shorter amount of time, than larger streams.

The groundwater watershed of the USCECRW is different than the surface watershed, notably in the northeast. The USCECR groundwater watershed can be thought of as an underground drainage basin where groundwater flows slowly through the sandy aquifer to wetlands, streams, and lakes. This area provides the baseflow to streams and maintains the levels of seepage- and spring-fed lakes. The groundwater contains dissolved minerals and nutrients and can transport pollutants.

A water-table map is a useful tool for the management of groundwater resources. A contour map of the water-table, which tends to be a subdued version of the local topography, is provided in Appendix F. It can be used to identify upland recharge and lowland discharge areas, which can then be afforded the proper consideration or protection. Groundwater flow directions determined from the map allow for the delineation of groundwater watersheds on a smaller scale and can also assist in land management decisions. For example, if groundwater is entering a lake from the east, a possible management action would be to implement rules to minimize the impacts from septic systems servicing a large number of people on the east side of the lake. Another use of water-table maps is defining wellhead protection areas for high capacity/municipal wells. The water-table map indicates the primary flow direction of groundwater is east to west in the St. Croix River Headwaters and was used to delineate the groundwater watershed for the study area (FIGURE 5).

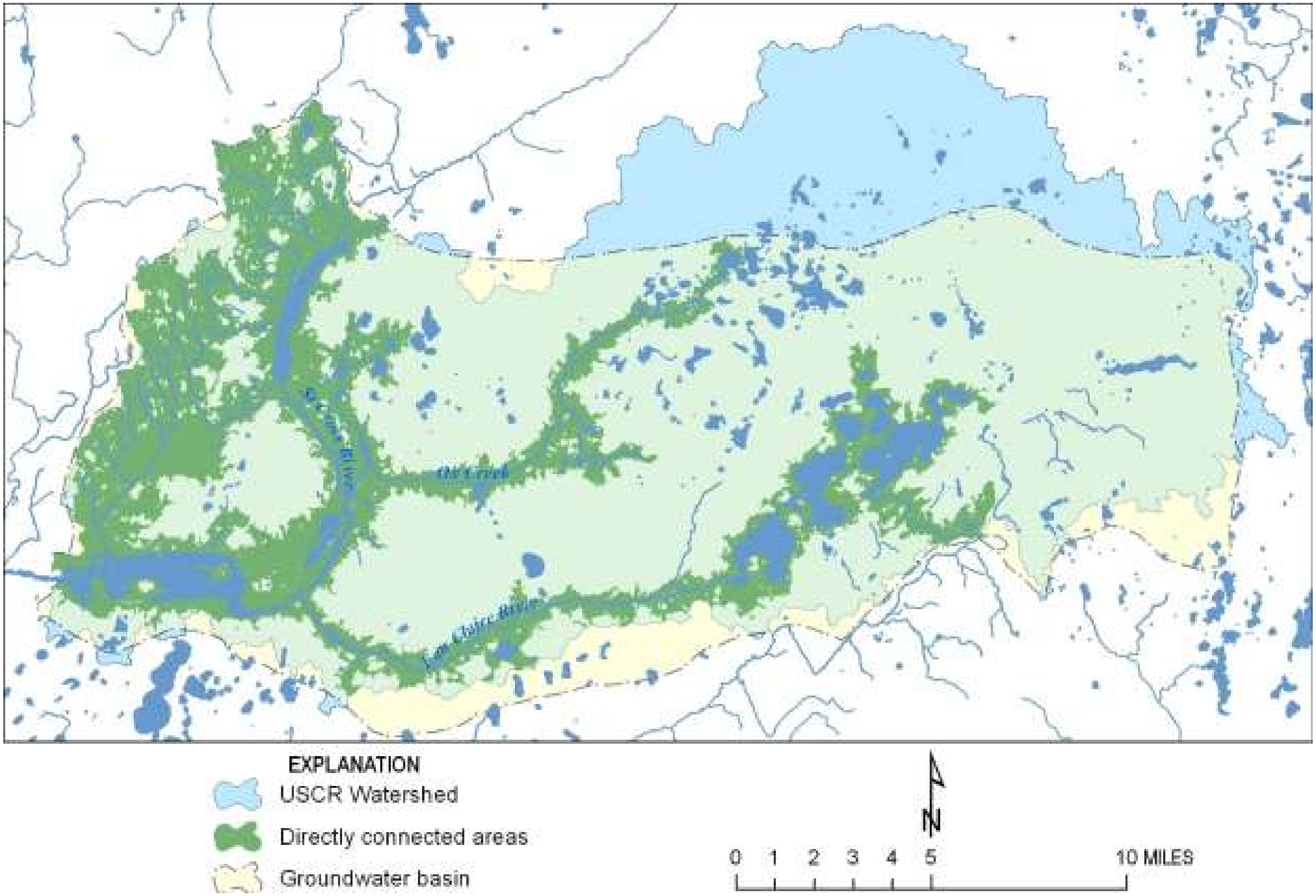


FIGURE 5. The estimated contributing area of the St. Croix River Headwaters and the location of directly connected areas. The area covered by the groundwater basin and surface watershed is the contributing area.

Hydrology

The long term hydrologic budget of the USCECRW (Cahow and Roesler, 1997) found that 42% of the precipitation falling on the watershed either becomes runoff or infiltrates to the groundwater where it may eventually provide stream baseflow or potentially follow deep groundwater flow paths out of the watershed. The remaining 58% of the precipitation returns to the atmosphere via evaporation and transpiration. During the periods of monitored flow in 2008 and 2009 (5/29 - 11/5/2008 and 3/27 - 10/17/2009) at SX00, streamflow accounted for an average of 24% of the precipitation that fell, suggesting that approximately half of the precipitation that does not return to the atmosphere infiltrates to groundwater. Water in groundwater storage provides baseflow during drought conditions and sustained flow during winter months.

The Web-based Hydrograph Analysis Tool (WHAT) was used to separate baseflow and event flows from stream hydrographs. These data were used to calculate the baseflow index, which is the ratio of baseflow to total stream flow which is used to identify the dominant source of flow to the streams. The streamflow in USCECRW is baseflow dominated (TABLE 2) with the groundwater discharge observed to be occurring through stream beds and riparian (near shore) seeps and springs. At the St. Croix River Headwaters watershed outflow sites (SX00 and SX01), at the Eau Claire River monitoring sites, and at the Ox Creek site, baseflows are influenced by impoundments or lake outflow. The groundwater contribution to streamflow for 2008 and 2009 was also influenced by the dry conditions of those years; in wetter years, there would likely be a slight decrease of the baseflow index.

TABLE 2. 2008 and 2009 growing season baseflow conditions at monitoring sites in the USCECRW.

	Average Baseflow, CFS		**Baseflow Index**	
Site	**2008**	**2009**	**2008**	**2009**
EC01	77.9	59.8	0.95	0.95
EC02	51.9	41.3	0.94	0.90
EC04	21.7	19.4	0.94	0.87
LD01	1.8	1.1	0.55	0.66
OX01	18.8	11.0	0.90	0.94
SX00	165.1	152.0	0.84	0.91
SX02	117.1	131.1	0.88	0.93
SX03	30.7	19.0	0.89	0.92
MS01	n.d.	13.9	n.d.	0.78

[n.d., no data]

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Hydrologic Modeling

A hydrologic model was developed as part of the USCECRW investigation to develop a planning-level tool for evaluating how land management changes in the watershed could influence streamflow. The overall objective of the model was to explore the potential impact of development on water movement to the stream system, particularly the effects of increased impervious area within the USCECRW.

Modeling Approach

A review of modeling requirements suggested that the model should be able to:

1) Differentiate portions of the watershed that topographically drain internally into closed basins or depressions. Those areas could still be a source of groundwater recharge, but they would not be contributing surface runoff or event flow to the river network.

2) Include a rainfall/runoff simulation approach that accommodates differences in infiltration characteristics of undeveloped and developed soils and impervious surfaces in the watershed (both now and for the different development scenarios). It would also be useful to accommodate the daily variations in soil moisture from drainage and vegetative uptake.
3) Compare model results with measured flow. Existing data could be used to make some adjustments in the model and verify that the model provides a reasonable description of current conditions.

After a review of modeling tools, we selected to use a modification of the Soil Water Assessment Tool (SWAT) model. The SWAT model can provide a continuous simulation of precipitation and temperature, estimate vegetative interception and evapotranspiration, and incorporate indirect drainage and impervious surface in hydrologic response units.

SWAT Model

The SWAT model was developed for the entire watershed. The watershed was subdivided into 15 sub-watersheds. The sub-watersheds and stream networks are shown in FIGURE 6. Initial parameter values for the watershed were based on SWAT default values (Neitsch et al., 2005). Surface runoff was simulated with the runoff curve number method and daily updating of soil moisture and adjustment for frozen soil conditions. Impervious surfaces were included in the model as either directly or indirectly connected to the stream system. The indirectly drained areas were treated as separate hydrologic response units with low runoff curve numbers to reduce the amount of surface runoff but still retain their groundwater contribution. The relatively low baseflow for some of the sub-watersheds draining to Upper St. Croix Lake was attributed to groundwater movement to lower aquifers and eventual discharge to springs and artesian wells near the lake. In SWAT, this was simulated as water going to a deep aquifer. Unfortunately, in a SWAT model, that water does not reenter the stream and is lost from the model. Because this modeling evaluation focused on sub-watershed runoff volumes, and because the Upper St. Croix Lake sub-watersheds are relatively small, this was not considered a significant problem.

The model was calibrated using trial and error adjustment of model parameters. A goal in the calibration was to make adjustments to the model as parsimoniously as possible and minimize the number of sub-watershed-specific adjustments. The comparison of measured and modeled flow is shown in the Appendix for each of the monitoring locations. The parameter values used in the SWAT model are also shown in the APPENDIX.

Model Results

The SWAT model was used to compare the impact of development on runoff volume. In the fully developed scenario, it was assumed that six percent of the directly draining land would be impervious. Two developed cases were evaluated: 1) all the impervious surface was indirectly connected, meaning that runoff from the impervious surfaces drains to pervious areas where it can infiltrate; or, 2) all the impervious surface was directly connected, meaning that runoff from the impervious surfaces drains directly to the stream system.

The SWAT modeling results project that with an increase to six percent of directly connected impervious surface the amount of runoff that would take surface runoff pathways to the stream would approximately double (0.6 inches/year to 1.1 inches/year). Overall, that is a relatively small percentage of the total streamflow (the annual total flow corresponds to 12.7 inches/year) because only forty percent of the watershed drains topographically to the streams and the increase in surface runoff is accompanied by a decrease in groundwater recharge. This increase in surface runoff does, however, have important implications for nutrient and sediment movement, and changes in streamflow during storm events. Surface runoff typically has much higher concentrations of sediment and nutrients compared to groundwater (Graczyk et al., 2003). As a result, the doubling of the surface runoff volume predicted in SWAT would suggest there would be a significant increase in both sediment and nutrient export with directly connected impervious surfaces.

The addition of impervious surfaces can also increase streamflow during storms. The model was used to simulate daily flows that correspond to different occurrence frequencies. For example, the flow that is equaled or exceeded only twenty-five times in a twenty-five year simulation was used as the flow likely to occur on average only once per year. This annual maximum daily flow volume is summarized in TABLE 3 and FIGURE 7. Those results show when the six percent impervious is not directly connected to the stream, the increase in flow on the annual maximum day is five percent larger than the baseline condition. If the six percent impervious surfaces are directly connected, there is a twenty-five percent increase in the annual maximum daily flow. It is important to note that the analysis here is based on daily total flow, not peak flow in the stream. The SWAT model uses a continuous simulation to develop a water volume each day in the watershed, and cannot be used to examine the routing of peak flows through the stream system. As a result, the percentage increase in daily total flow could underestimate the percentage increase that would occur in instantaneous peak flow.

TABLE 3. Largest daily total flow from each sub-watershed that occurs with an average frequency of once every year for baseline and additional impervious surface scenarios.

Sub-watershed	**Million Cubic Feet**			**% Increase over Baseline**	
	Baseline	**6%/0.5% (disconnected)**	**6%/6%**	**6%/0.5% (connected)**	**6%/6%**
1 – Catlin Cr	4.0	4.0	4.6	0%	16%
2 – Beebe Cr	2.1	2.3	3.2	8%	52%
3 - Rock Cut Cr	1.7	1.8	2.0	3%	14%
4 – Smith/Spring Cr	1.4	1.5	1.7	6%	17%
5 – Park Cr	0.9	1.0	1.4	12%	48%
6 – Leo Cr	3.2	3.5	4.3	7%	31%
7 – Un mon.	16.6	17.2	20.7	4%	25%
8 – Upper Eau Claire	12.4	12.6	14.5	2%	17%
9 – Upper Ox	12.4	13.0	13.8	4%	11%
10 – Lord Creek	7.8	8.1	9.8	4%	26%
11 – Moose River	45.1	48.3	54.3	7%	20%
12 – Moose River	120.6	124.3	150.6	3%	25%
13 – Scott’s Bridge	75.5	81.3	95.9	8%	27%
14 - Middle Eau Claire	17.0	17.2	20.7	1%	22%
15 - Hwy 53 to Gordon Outflow	74.8	80.6	95.5	8%	28%
16 – Lower Ox	61.9	65.9	80.0	6%	29%
17 - Lower Eau Claire	28.1	28.6	31.9	2%	13%
Average Difference				**5%**	**25%**

* Baseline assumes a total impervious of 1% with half directly connected
6% / 0.5 % scenario assumed 6% impervious and 0.5% directly connected impervious
6% / 6% scenario used 6% total impervious with all of it directly connected

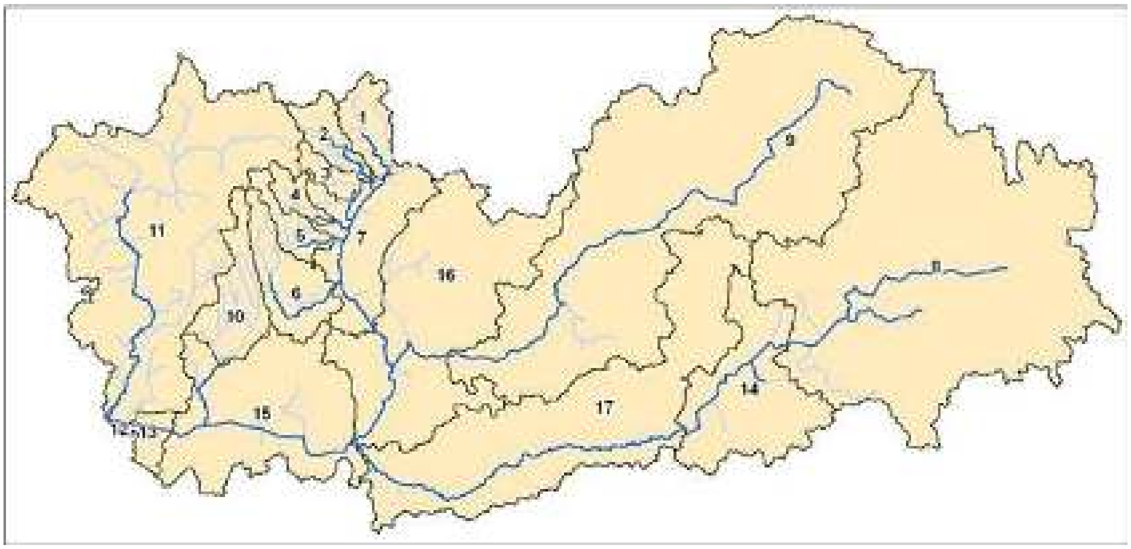


FIGURE 6. USCECRW showing sub-watershed numbering used in SWAT model.

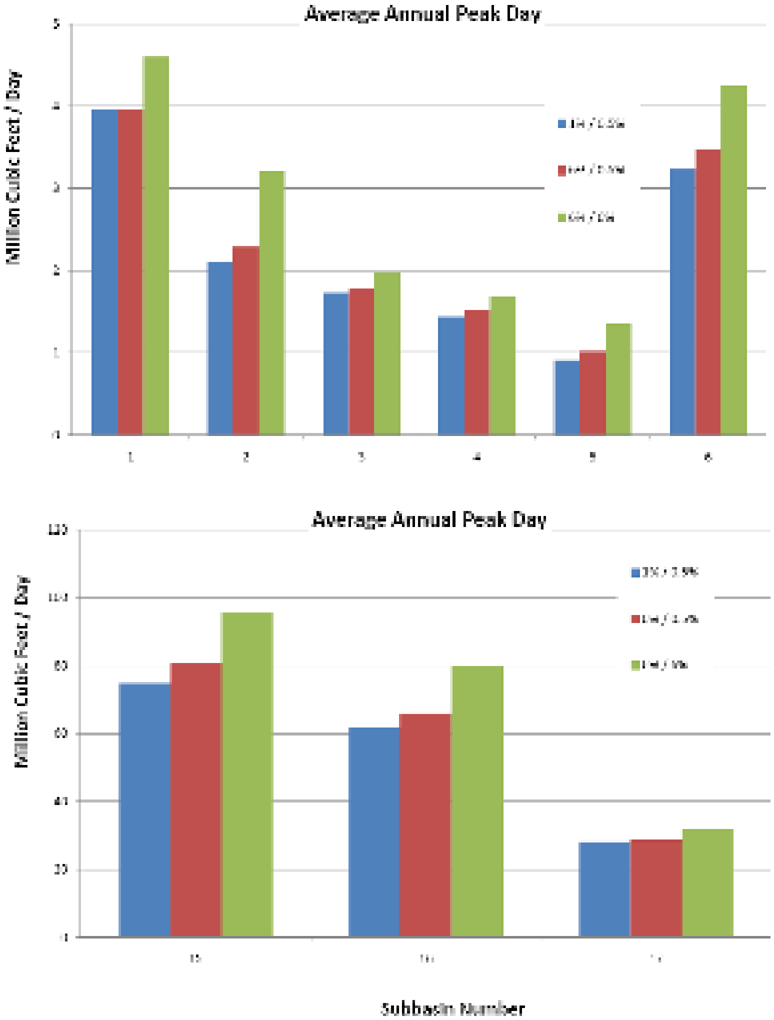


FIGURE 7. Comparison of flow for average annual peak day for subbasins 1-6 (above) and 15-17 (below). Results based on SWAT simulation using historical precipitation and temperature from 1983 – 2008.

Water Quality

Since 2006, UWSP and FOTSCH have been collecting water quality measurements and water samples from the USCECRW. Other data were previously collected in the watershed during historic investigations including the Priority Watershed study (Hlina, 1997) and a more recent USGS study (Robertson et al., 1999 and Robertson et al., 2006). Some of the historic data lack stream flow measurements which are necessary for the in-depth analyses that were conducted on the recent data.

Both surface runoff and groundwater can carry nutrients (nitrogen and phosphorus) and pollutants (sediment, chloride, and others) to the lake. The amount of any nutrient exported from the land to a water body over the course of a year is known as a nitrogen or phosphorus "load" which is a mass that is reported in units of tons in this document. Different types of land uses and land use practices influence the nutrient load to the lake or tributaries. In the USCECRW, sediment and total phosphorus (TP) are the primary water chemistry measures of interest, though other measures were taken to evaluate their presence and assist with interpretation of data.

Generally, nutrient and pollutant export is low from undeveloped and undisturbed lands (Lillie et al., 1993). Forests and wetlands are the major types of undeveloped land in the USCECRW. Several characteristics in forested landscapes contribute to low nutrient and pollutant export rates. The canopy cover of a forest intercepts rainfall, which reduces runoff. The well-structured soils (not compacted) in forest floors and below native forbs and grasses allow adequate infiltration of rain, and fewer nutrients are available to be transported by groundwater because of vegetation uptake.

Wetlands are a critical component in healthy watersheds. Wetlands act as pollutant filters for surface water and groundwater. Stream flow and runoff slows in wetlands, allowing sediment and other pollutants to settle out and/or become filtered out by vegetative stems and leaves. This is especially important during storms when streams are most likely to be carrying high sediment loads. During some high flow periods, wetlands can be a source of nutrients.

Developed areas can also deliver nutrients and pollutants including chloride. Chloride readily dissolves in water, so it is easily transported to lakes and streams by runoff and groundwater yet it is not utilized by biota so it makes a good tracer of cultural sources of contaminants. During the thaw and storms of early spring, chloride concentrations can be remarkably high in runoff and streams. Sources of chloride can include fertilizers, animal waste, septic systems, municipal wastewater and road salt. Depending upon land management practices, residential areas can contribute large nutrient loads, particularly when directly connected impervious surfaces lead to runoff from even small storms allowing nitrogen and phosphorus in soils, vegetation, and fertilizers to run off and/or infiltrate to groundwater.

Exposed soil can be another large source of sediment and nutrients. During rainstorms and snow melt the nutrient-rich soil can move with runoff to the rivers and lakes. Exposed soil can be a result of many types of land use practices, but in the USCECRW is probably most prevalent in certain types of forestry practices, road management and construction, and residential and urban construction. Reducing exposed soil and controlling runoff from rooftops, roads, parking lots, construction sites, and forest management can all help to reduce the amount of nutrients entering surface water in USCECRW. This can be accomplished by minimizing impervious surfaces and redirecting runoff for infiltration using bioretention techniques near impervious surfaces. Near the edge of lakes and streams (i.e. the riparian zones), "vegetative buffers" comprised of tall native grasses, forbs, shrubs, and trees can help foster infiltration and filter runoff water before it enters the water. Fully intact riparian vegetation can provide the final filtering process before runoff enters a stream. A compromised riparian zone is not only inefficient in removing nutrients and pollutants from the water, but also may be a sediment source due to increased erosion. Eliminating/minimizing the use of fertilizers will also reduce nutrients that are potentially delivered to the lake. This area also provides habitat that is essential for an intact aquatic ecosystem.

TP concentrations from samples collected during this study and during previous studies are compared in FIGURE 8. Concentrations greater than the WDNR TP criteria for wadeable streams (74 $\mu g \cdot L^{-1}$) were only measured during rainfall runoff flows. During this study, precipitation in the watershed was less than normal (FIGURE 2), which prevented routine event sampling throughout the year. Continued monitoring of runoff water quality and flow will aid in identifying if these concentrations represent only dry conditions or are the norm in the USCECRW.

Estimated nutrient loading in the monitored streams in this study are presented below. An overview of water quality measures and the impact of various constituents can be found in Appendix A. For the purpose of discussing water quality, the USCECRW has been divided into four sub-watersheds (FIGURE 9) which are discussed separately and then compared. Since it is not part of the USCECRW, data collected from the Moose River watershed is discussed separately. Data are presented as box-plots; a box-plot primer is in Appendix H. Summary statistics of laboratory analyses and field measures from 2008 and 2009 can be found in Appendix C and Appendix D, respectively.

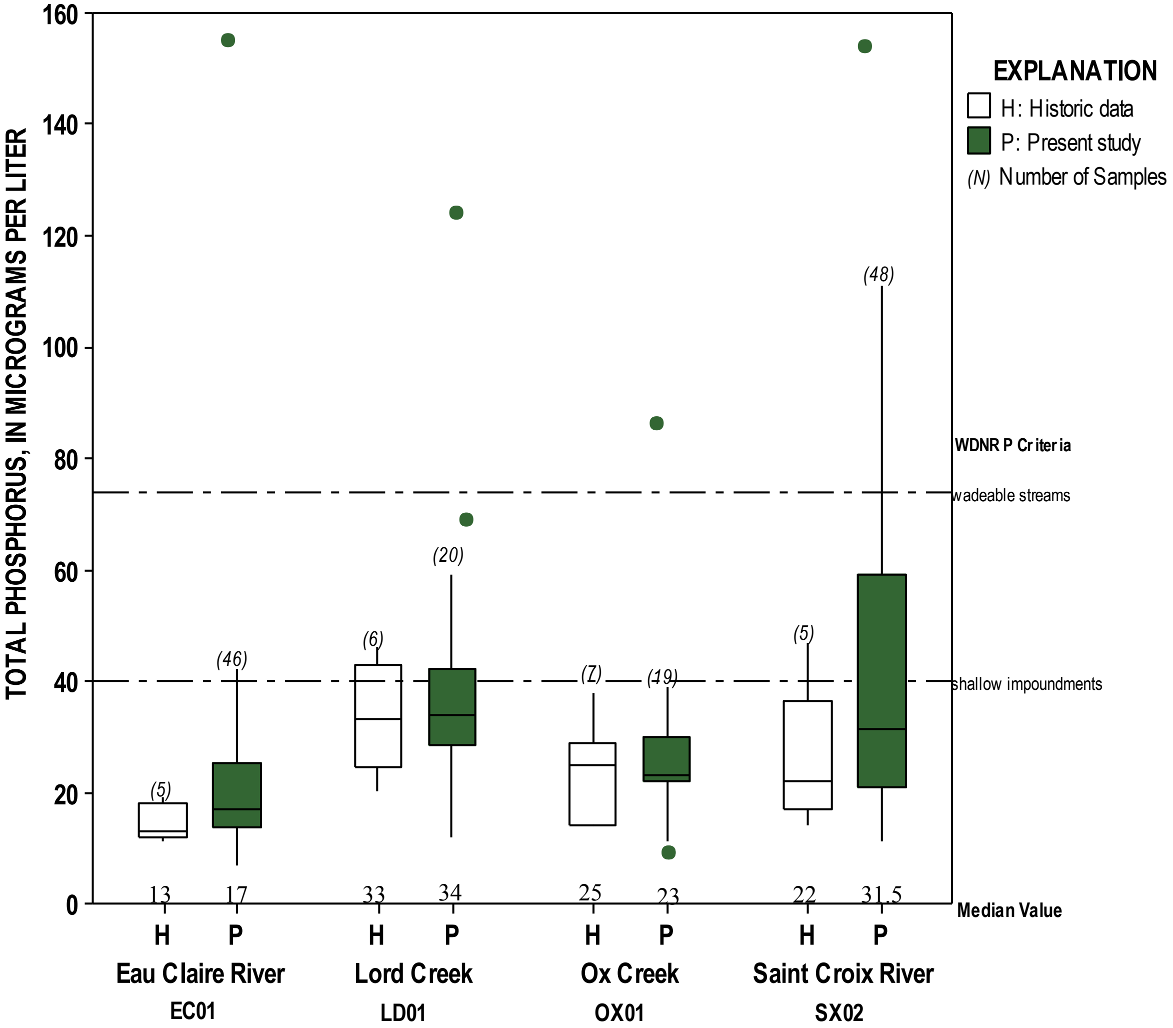


FIGURE 8. Comparison between historic and recent total phosphorus concentrations measured in the Upper St. Croix – Eau Claire River Watershed. Historic data were collected between 1995 and 2005; present data were collected from 2006 through 2009 by CWSE. Upper outliers (dots) are measures from event runoff samples; three runoff measures from the St. Croix River (243, 348, and 401 $\mu g \cdot L^{-1}$) and one measure from the Eau Claire River (422 $\mu g \cdot L^{-1}$) fell outside of the graph scale.

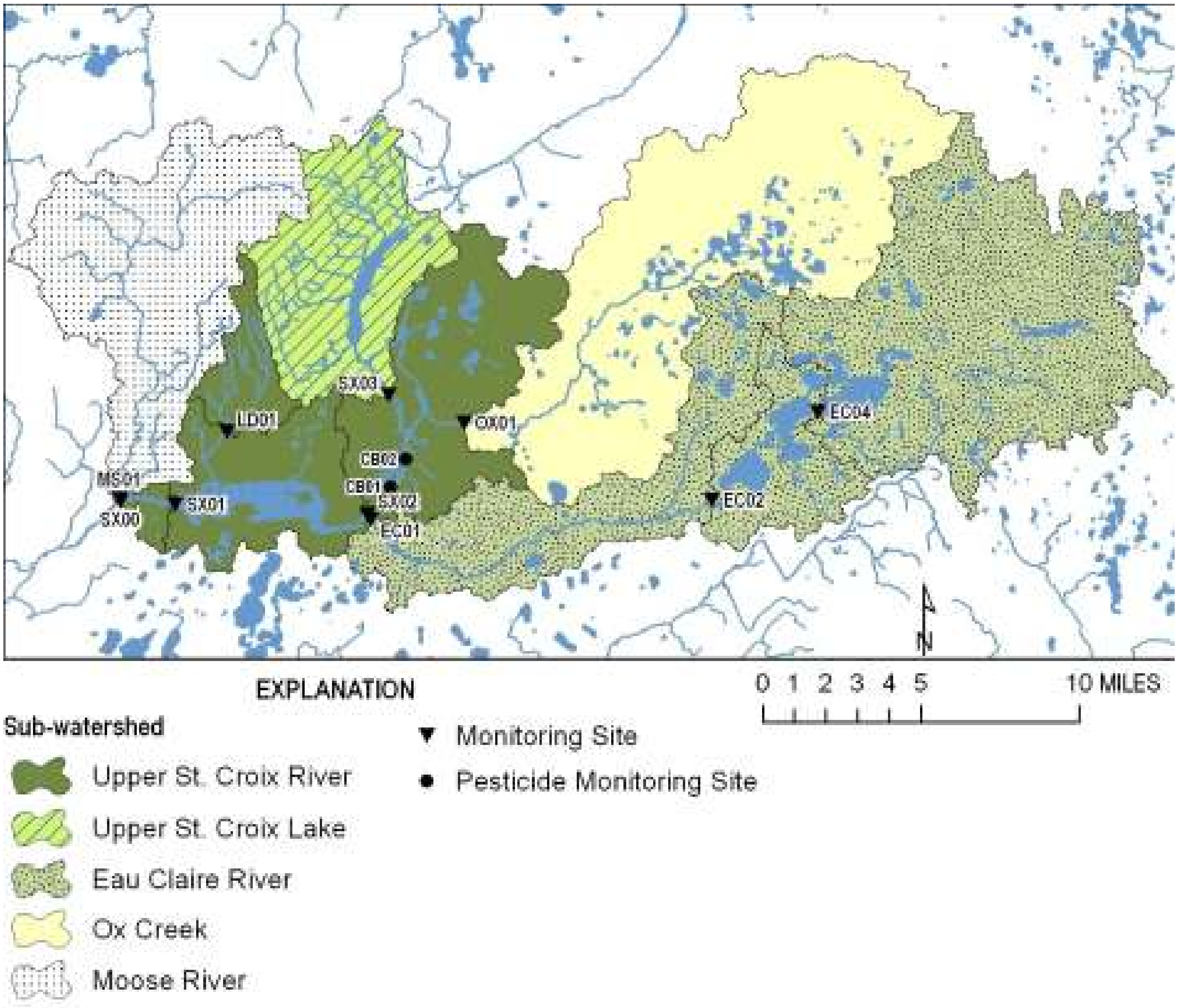


FIGURE 9. Sub-watersheds and monitoring sites in the Upper St. Croix – Eau Claire River Watershed.

Upper St. Croix Lake Sub-Watershed

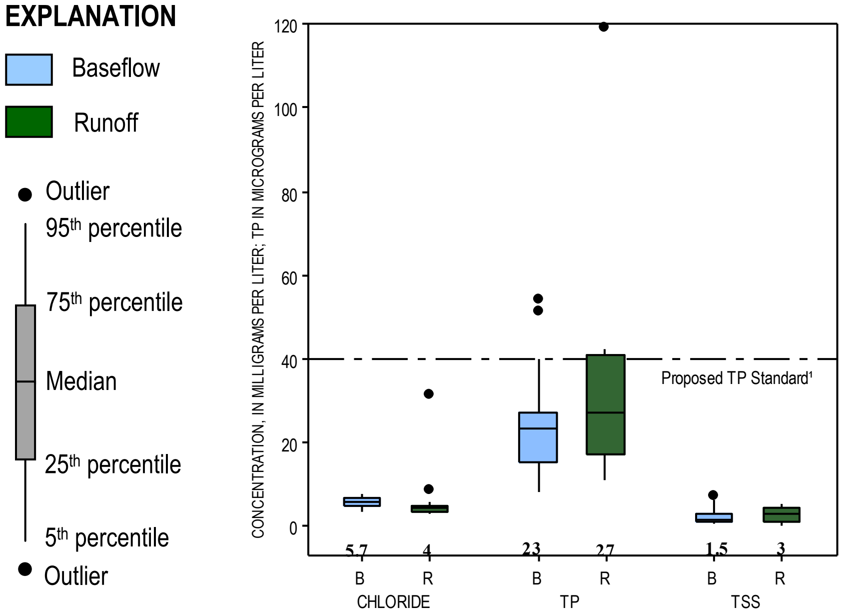
The Upper St. Croix Lake sub-watershed is located in the north-western part of the USCECRW and covers an area of 34.8 mi^2 which includes Upper St. Croix Lake and its tributaries (FIGURE 9). The monitoring site located at the recreational trail bridge near the end of Cut-Away Dam Road (SX03) is considered the outlet of this sub-watershed. Detailed examination of this watershed and sub-units was completed in 2009 and can be found in Turyk and Macholl, 2009.

Forests and wetlands are the primary land cover in the sub-watershed, making up 57% and 25% of the land use, respectively. Streams and lakes in the Upper St. Croix Lake sub-watershed are fed primarily by groundwater which sustains stream baseflow, even in drought years (Turyk et al., 2008). An interesting occurrence in this sub-watershed is the seasonal backwater flow conditions which cause an increase in the depth of Upper St. Croix Lake and of the St. Croix River and a subsequent decrease in the discharge from the lake. This backwater effect was observed in later summer when growth within the river channel is peak. One of the driving forces behind the increase in lake and stream stage is that the relatively high-gradient tributaries to Upper St. Croix Lake provide good conduits for water while the low-gradient St. Croix River is a poor conduit for water (Manners et al., 2001). Another important factor in the development of backwater conditions is the substantial vegetative growth in the stream channel which also slows the flow of water leaving Upper St. Croix Lake, compounding the backwater conditions observed during parts of the summer.

The concentration of chloride in samples collected for water quality analysis decreases slightly during runoff flow compared to baseflow (FIGURE 10). This is an indication that runoff is diluting solutes that are moving into the stream with groundwater. The Upper St. Croix Lake sub-watershed has the highest chloride concentrations of the four USCECRW sub-watersheds. Chloride is evaluated as an indicator of human activities due to its low natural concentrations. A combination of road salt, fertilizer use, septic system effluent, and municipal wastewater discharge are likely sources of these elevated concentrations. The measured chloride concentrations are not problematic to aquatic organisms.

Total phosphorus (TP) and total suspended solids (TSS) have similar trends during the different flow regimes. The median concentrations of both constituents increased slightly during event flows (FIGURE 10). These relatively minor differences between baseflow and event flow are not unusual from the outflow of a lake. The median total phosphorus concentration for this site was 24 $\mu g \cdot L^{-1}$, well below the WDNR's wadeable stream TP criteria of 74 $\mu g \cdot L^{-1}$, and the criteria of 40 $\mu g \cdot L^{-1}$ for shallow drainage lakes.

The slight increase in TSS during runoff flows is from the overland flow washing soil off the land surface and lake sediments from Upper St. Croix Lake becoming re-suspended and transported downstream. Total suspended solids increase from 1.5 $mg \cdot L^{-1}$ during baseflow to 3 $mg \cdot L^{-1}$ during event flow. Factors that contribute to the low values of TSS include the abundant vegetative cover and the low gradient of the river at the sample site.



WDNR TP criteria for shallow drainage lakes is:40 $\mu g \cdot L^{-1}$; (wadeable streams: 74 $\mu g \cdot L^{-1}$).

FIGURE 10. Box-plot showing baseflow and runoff concentrations at site SX03 of chloride, total phosphorus (TP) and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots.

Ox Creek Sample Site Sub-Watershed

The Ox Creek sub-watershed drains a large portion of the north-eastern part of the USCECRW (FIGURE 9). The sample site was located off of Flat Lake Road, midway between Upper and Lower Ox Lakes. The dominant land cover in this 91 mi^2 watershed is forests (64%) followed by grassland/shrubland (29%). Ox Creek currently has very little development (4%) within its watershed. The development that exists is predominantly low intensity but includes lawns and unpaved roads.

Large areas of internal drainage, where surface runoff infiltrates to groundwater rather than draining to a stream, are present within this sub-watershed. Ox Creek flows through two lakes, Upper Ox and Lower Ox, before reaching the St. Croix River midway between Upper St. Croix Lake and the Gordon Flowage. During the summers of 2008 and 2009, large mats of filamentous algae were observed floating down the creek and stuck to over-hanging vegetation. The filamentous algae were observed only downstream of Upper Ox Lake.

Chloride concentrations are very low in the Ox Creek watershed, reflecting both its undeveloped nature and its location near a groundwater divide (FIGURE 11). Runoff and baseflow concentrations were often at or very near detection limits. The highest chloride measured (32.6 µg·L^{-1} during early spring 2009) is likely due to the sample being collected downstream of the road during runoff conditions, likely capturing road salts.

Runoff TP and TSS concentrations were higher than those of baseflow conditions (FIGURE 11). The highest concentration of TP (86 µg·L^{-1}) was measured during late August 2009 and is slightly higher than the WDNR TP concentration criteria of 74 µg·L^{-1} for wadeable streams in Wisconsin; however, it should be noted that this criteria is not intended to be applied as a standard for single measures. The increase of median TSS values from baseflow to runoff is attributed to the sample site located downstream from a steep-banked gravel road, from which sediments are carried to the stream during rainfall events.

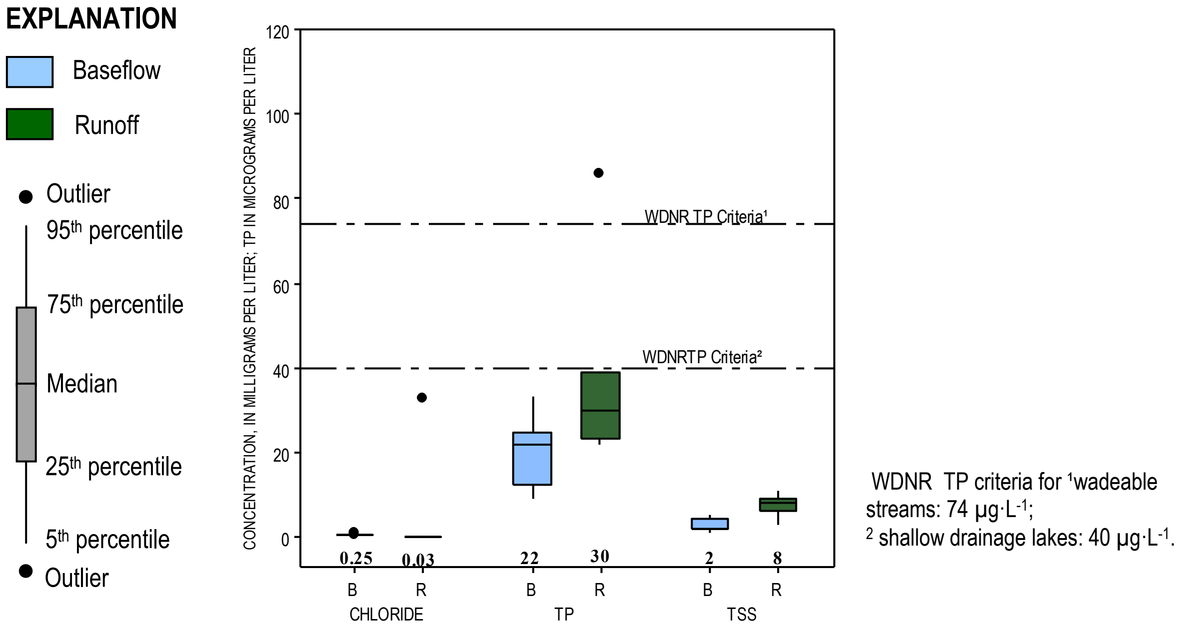


FIGURE 11. Box-plot showing baseflow and runoff concentrations at site OX01 of chloride, total phosphorus (TP) and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots.

A synoptic sampling event with a focus on Ox Creek was conducted on July 6, 2009. These samples were collected to identify localized water quality changes in the stream baseflow and potential problem areas. A total of nine locations were sampled on the Ox Creek (FIGURE 12). Results of the field measures and laboratory analyses are presented in FIGURE 13 through FIGURE 15.

Other than dissolved oxygen which increased downstream in Ox Creek, constituent concentrations had a general decreasing trend from headwaters to the stream confluence with the St. Croix River. Flow increased in the downstream direction except for a slight decrease in flow from site 2 to site 1 in Ox Creek which is attributed to backwater conditions caused by vegetation, primarily rice, in the stream channel and not to the stream losing water to groundwater.

In Ox Creek, TP concentrations are higher near the headwaters, decrease sharply at site 8, and steadily increase to Lower Ox Lake. TP concentrations decrease as water flows from Lower Ox Lake to the St. Croix River. The higher TSS concentration near the Ox Creek headwaters is likely a reflection of the stream bed materials. The stream bed at site 9 was sandy and clear of vegetation leading to a less stable substrate (which is more easily disturbed) whereas the stream bed was comprised of cobbles and sand at sites 8, 7, 6, and 5, and cobbles, sand, and vegetation at sites 4, 3, 2, and 1. Velocity remained relatively constant between at the sites upstream of Lower Ox Lake and decreased downstream of the lake.

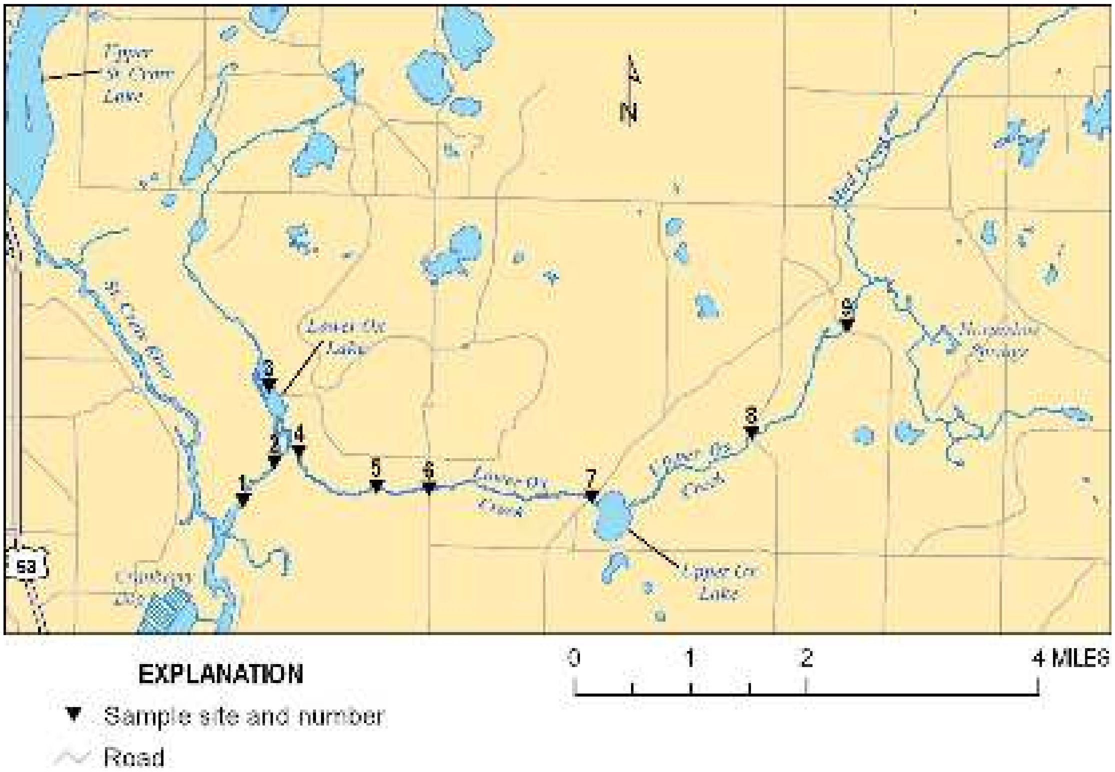


FIGURE 12. Synoptic sample locations on the Ox Creek. Flow measures and samples for water quality analysis were collected on July 6, 2009 during baseflow conditions.

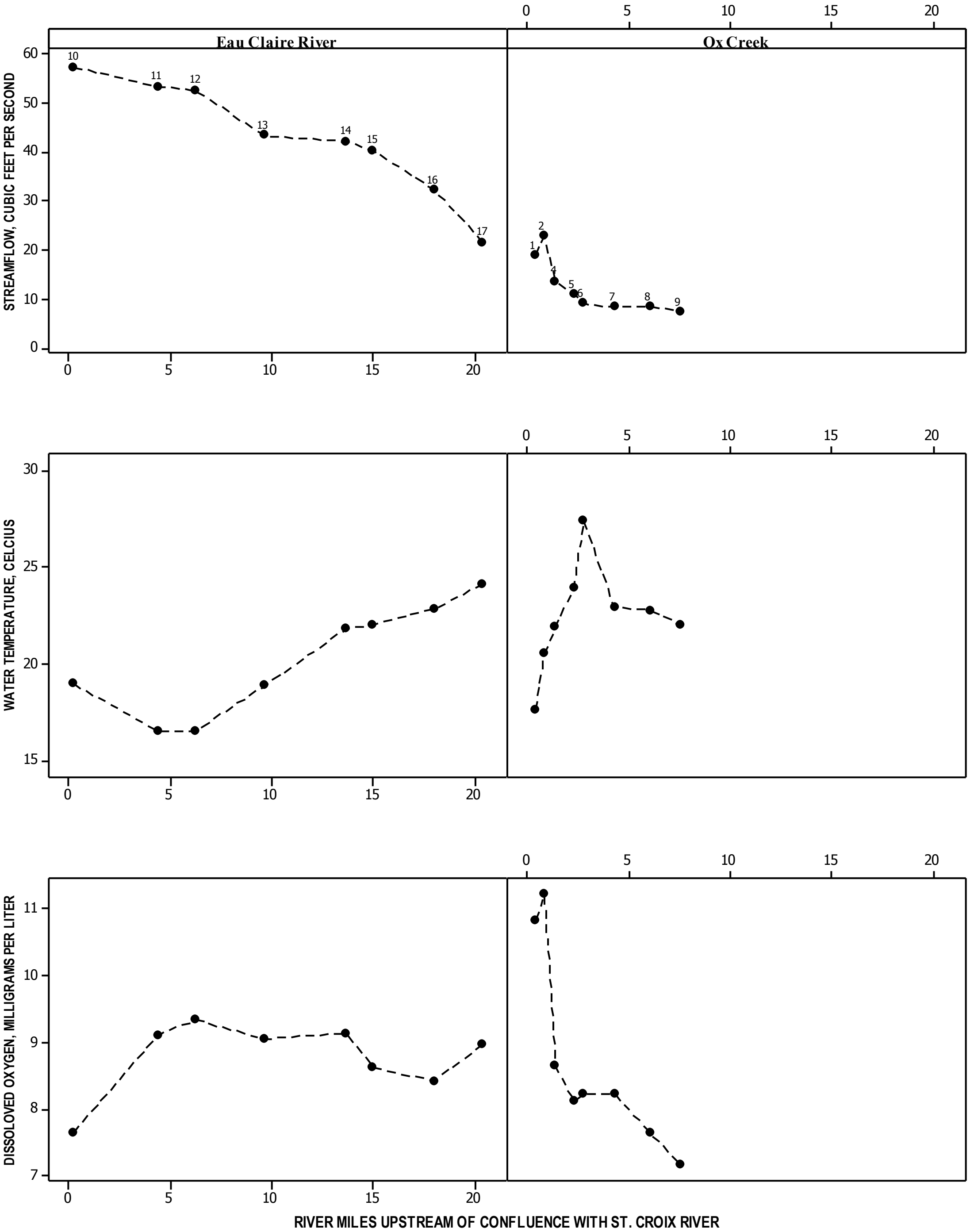


FIGURE 13. Variation in field measured water quality parameters at synoptic sample locations on the Ox Creek and Eau Claire River, July 6 and 7, 2009. The streamflow graph includes site ID's; sample site 3, Lower Ox Lake, is not included on the graphs.

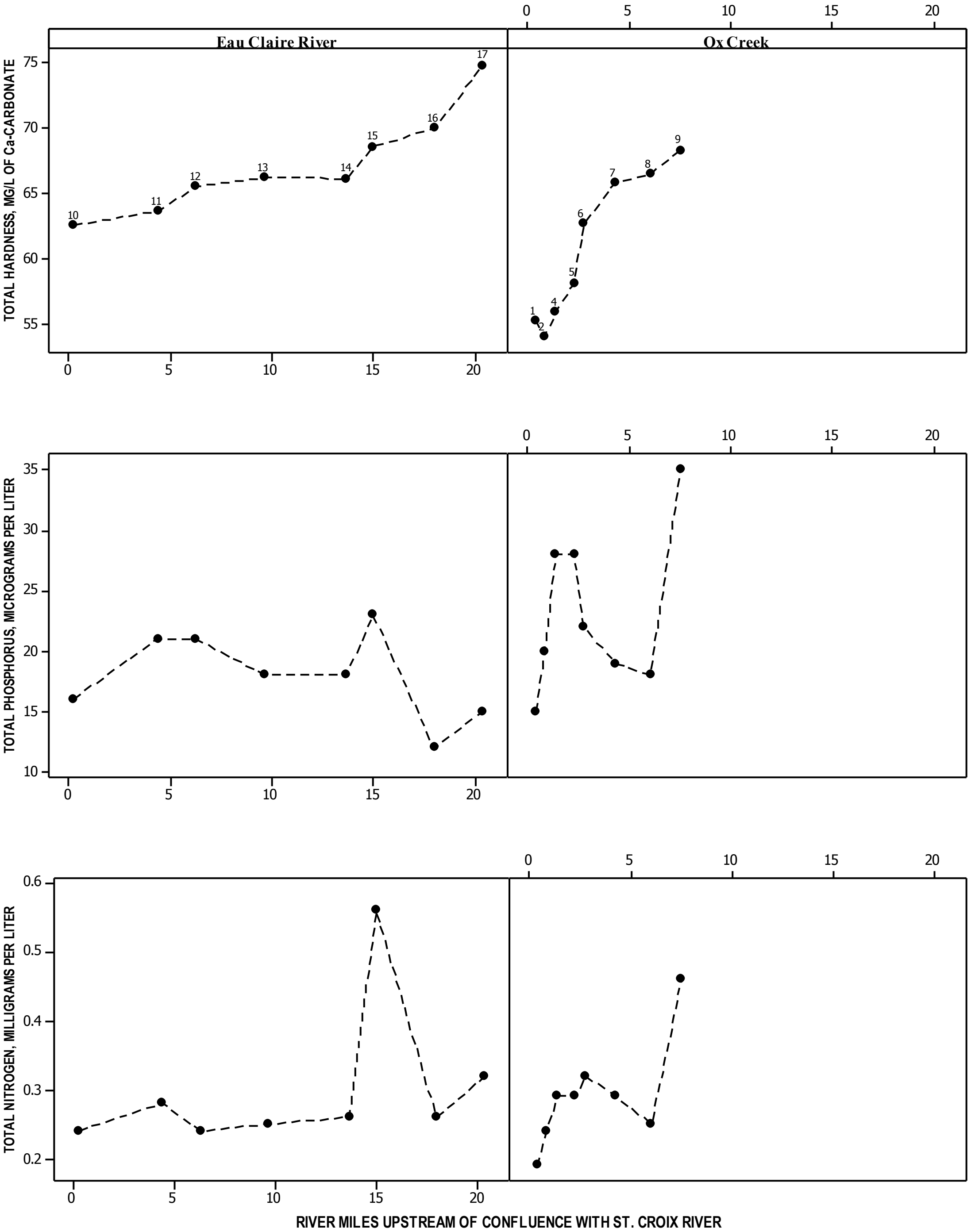


FIGURE 14. Variation in total hardness, total phosphorus, and total nitrogen at synoptic sample locations in Ox Creek and Eau Claire River, July 6 and 7, 2009. The graph of total hardness includes site ID's; sample site 3, Lower Ox Lake, was not included on the graphs.

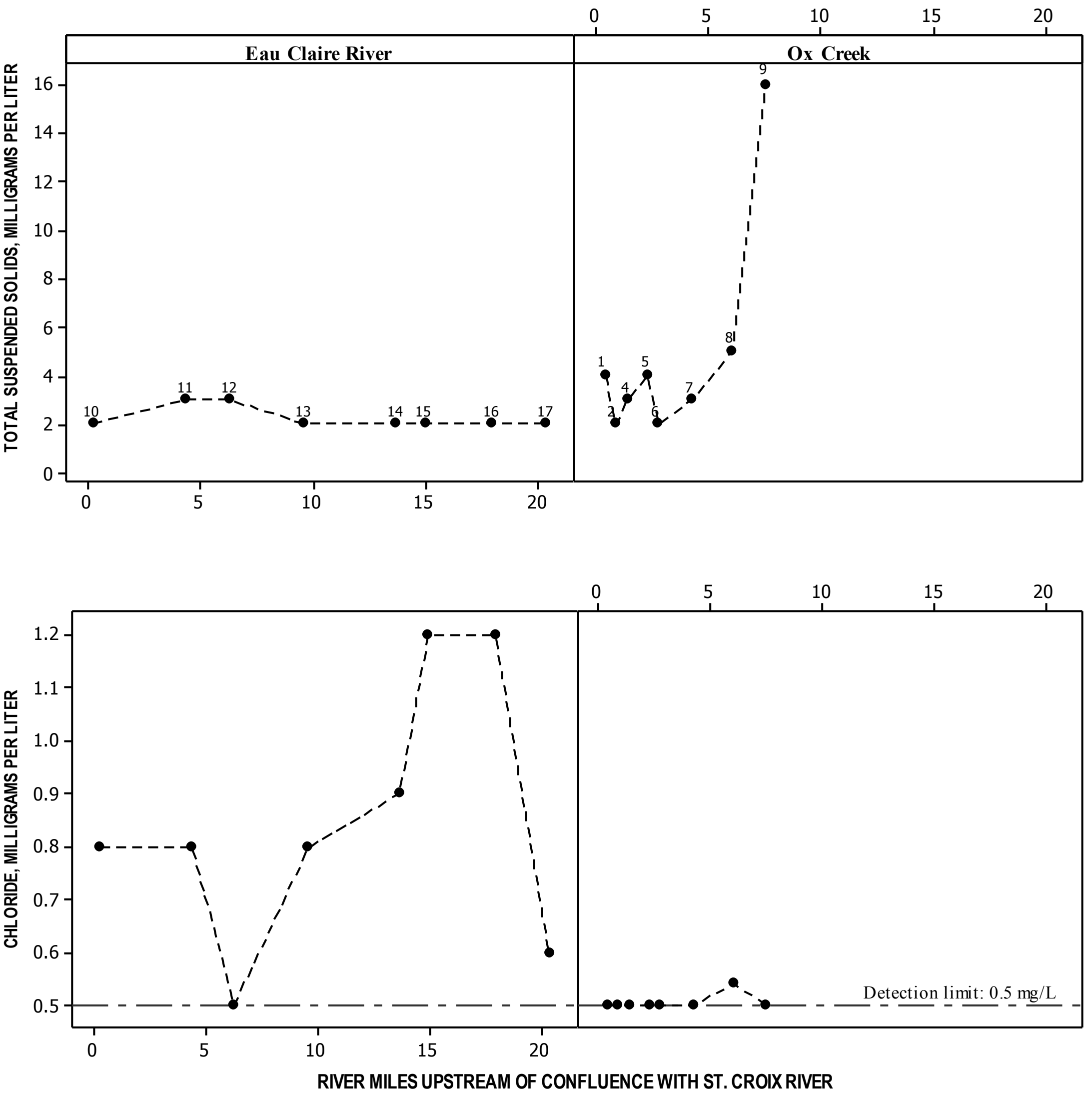


FIGURE 15. Variation in total suspended solids and chloride concentrations at synoptic sample locations in Ox Creek and Eau Claire River, July 6 and 7, 2009. The graph of total suspended solids includes site ID's; sample site 3, Lower Ox Lake, was not included on the graphs.

Eau Claire River Sub-Watershed

The Eau Claire River sub-watershed is in the south-eastern part of the USCECRW and covers approximately 141 mi^2 (FIGURE 9). The sub-watershed includes sample sites EC01, EC02, and EC04. Site EC04 is located between Upper and Middle Eau Claire Lakes on Outlet Bay Road. Site EC02 is located on East Mail Road, downstream from the Mooney Dam outlet of Lower Eau Claire Lake. Site EC01 is located near the end of Finstad Road at the Gile residence in Gordon, approximately 600 ft upstream of the confluence of the Eau Claire River with the St. Croix River. The primary land uses in the sub-watershed are forests (77%) and grassland (11%). Relatively dense development is present around the Eau Claire chain of lakes, in part of the Town of Barnes, and near the Village of Gordon, though less than 4% of the basin as a whole is classified as developed.

Stream baseflow increases from the outlet of Upper Eau Claire Lake to EC01. Average baseflows measured during this study were found to increase from 21.1 cfs at EC04 to 35.4 cfs at South

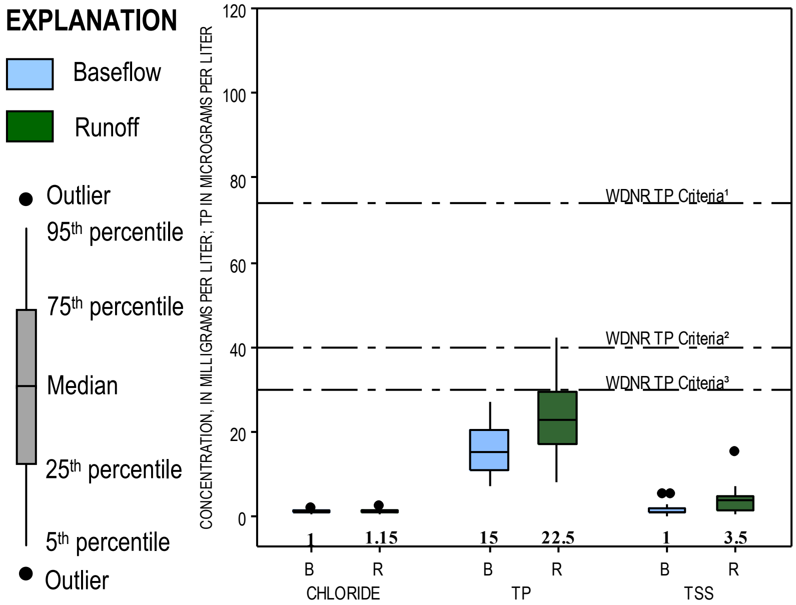
Shore Road (unmonitored location between Middle Eau Claire and Lower Eau Claire Lakes), and further increase to 45.6 cfs at EC02 near the outlet of Lower Eau Claire Lake. The average baseflow measured at site EC01 shows another increase to 66.3 cfs. This indicates the groundwater and precipitation fed Eau Claire chain of lakes provide a significant increase in flow (55%) to the Eau Claire River. There are no perennial tributaries to the Eau Claire River below EC02, so it is assumed that groundwater contributions are the source of the 20.8 cfs of baseflow measured at EC01.

Chloride concentrations remained relatively stable in samples collected from baseflow and runoff flows. This relationship can be seen for site EC01 in FIGURE 16, site EC02 in FIGURE 17, and EC04 in FIGURE 18. The slight increase observed in baseflow concentrations between sites EC04 and EC02 may be due to the more concentrated development around the lakes. Dilution of stream water chloride concentrations by groundwater with lower concentrations of chloride may be the cause of the lower median chloride concentrations at site EC01.

Baseflow median TP concentrations were 11.5, 18, and 15 $\mu g \cdot L^{-1}$ at EC04, EC02, and EC01, respectively. Runoff median concentrations increased in TP at each site to 18 $\mu g \cdot L^{-1}$ at EC04, 26.5 $\mu g \cdot L^{-1}$ at EC02 and 22.5 $\mu g \cdot L^{-1}$ at EC01. These values all fall below the WDNR TP criteria of 40 $\mu g \cdot L^{-1}$ for shallow impoundments and 30 $\mu g \cdot L^{-1}$ for stratified drainage lakes and reservoirs. The highest concentrations of TP were measured at EC04 and are associated with rain events; the graph scale for EC04 (FIGURE 18) is different than the other graphs to accommodate the higher measures. The decrease in median TP concentrations from EC02 to EC01 is likely due to the increase in the groundwater contributions and subsequent dilution of the water; groundwater concentrations of TP are generally much lower than surface water concentrations. The lower TP concentrations measured at EC01 may also be influenced by the Eau Claire River Flowage, near Gordon, acting as a nutrient trap by decreasing water velocities which leads to an increase in aquatic plant growth.

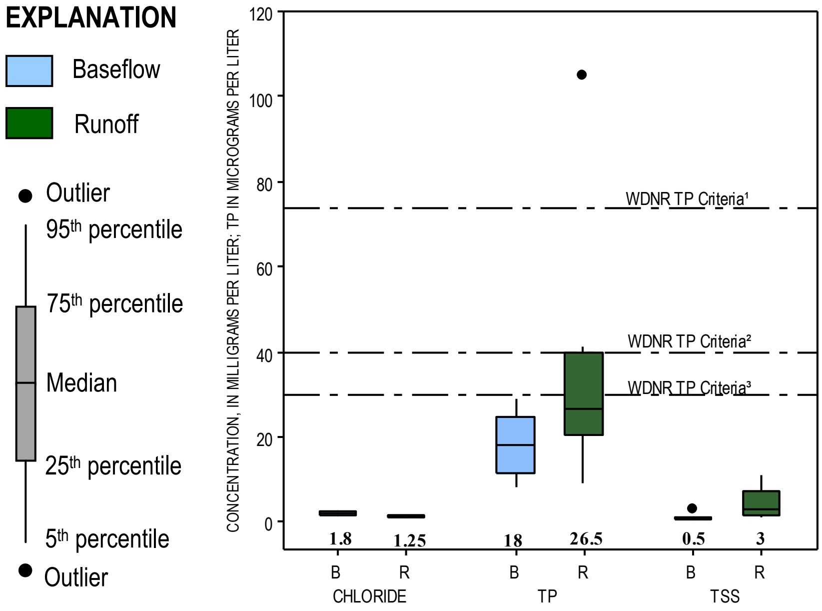
The increase of TP during runoff conditions at the monitoring sites may be due to runoff from the watershed and turbulence causing the re-suspension of sediment in the lakes which can transport TP. Wetland release of phosphorus may be a source of higher TP at EC02 relative to the other monitoring sites on the Eau Claire River. Cranberry Lake, which drains into Lower Eau Claire Lake upstream of site EC02, is surrounded by wetlands.

Baseflow median TSS concentrations were below detection limits (<1 $mg \cdot L^{-1}$) for sites EC04 and EC02 and 1 $mg \cdot L^{-1}$ at site EC01 (FIGURE 16) and similar (approx. 3 $mg \cdot L^{-1}$) between all sites. The low concentrations are likely due to the slower moving waters of the lakes allowing suspended particles to drop out of the water column. The highest TSS concentration of 15 $mg \cdot L^{-1}$ occurred at EC01 during a flood event in October 2007.



WDNR TP criteria for
¹wadeable streams: 74 µg·L-1
²shallow impoundments: 40 µg·L-1;
³stratified drainage lakes/ reservoirs: 30

FIGURE 16. Box-plot showing baseflow and runoff concentrations at site EC01 of chloride, total phosphorus (TP) and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots.



WDNR TP criteria for
¹wadeable streams: 74 µg·L-1
²shallow impoundments: 40 µg·L-1;
³drainage lakes/deep reservoirs: 30 µg·L-1.

FIGURE 17. Box-plot showing baseflow and runoff concentrations at site EC02 of chloride, total phosphorus (TP) and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots.

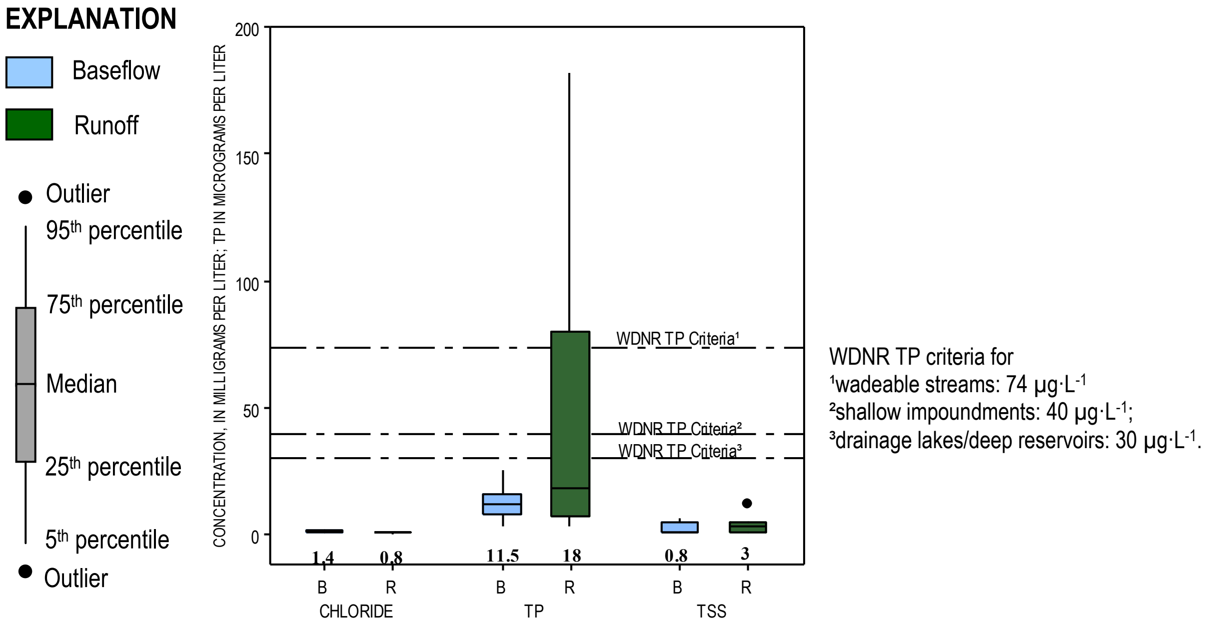


FIGURE 18. Box-plot showing baseflow and runoff concentrations at site EC04 of chloride, total phosphorus (TP) and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots; note y-axis scale different than previous graphs.

A synoptic sampling event with a focus on the Eau Claire River was conducted July 7, 2009. These samples were collected to identify localized water quality changes in the stream baseflow and potential problem areas. A total of eight sites were sampled on the Eau Claire River (FIGURE 19). Results of the field measures and laboratory analyses are presented in FIGURE 13 through FIGURE 15.

Notable changes in water quality in the Eau Claire River includes a spike in chloride, total nitrogen (TN), and TP concentrations at the site downstream of the outlet of Lower Eau Claire Lake (site 15/EC02). High chloride and nitrogen concentrations in baseflow point towards septic systems as a likely source.

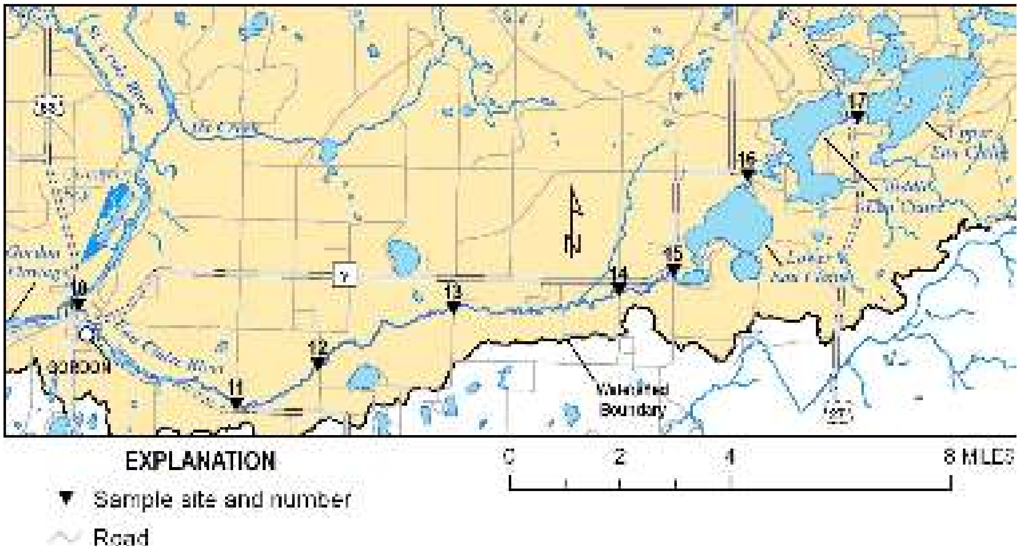


FIGURE 19. Synoptic sample locations on the Eau Claire River. Samples were collected on July 7, 2009 during baseflow conditions.

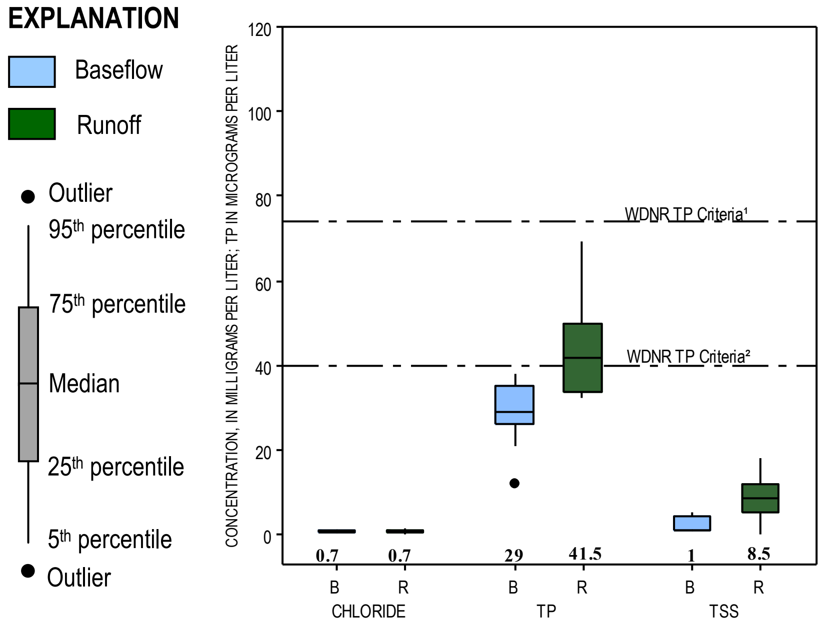
Upper St. Croix River Sub-Watershed

The monitoring sites on Lord Creek at CTH M (LD01) and the St. Croix River at Old Hwy 53 near Gordon (SX02) were the monitored inputs to the Gordon Flowage. The quality of water leaving the Gordon Flowage was evaluated through sampling of the St. Croix River at Scott's Bridge on West Mail Road (SX00) in 2008 and 2009 and also immediately downstream of the Gordon Dam in 2009. Site LD01 has an 8.4 mi² watershed dominated by forests (51%) and wetlands (37%). The 304 mi² watershed of site SX02 includes the Ox Creek, Eau Claire, and Upper St. Croix Lake sub-basins which were discussed in previous sections. The primary land uses in this watershed are forests (69%) and grasslands (17%) with only 4 % of the land classified as developed.

The distribution of chloride, TSS, and TP concentrations for the inflow monitoring sites, LD01 and SX02, and the outflow monitoring sites, SX01 and SX00, can be found in FIGURE 20, FIGURE 21, FIGURE 22, and FIGURE 23, respectively. Chloride concentrations were found to decrease from the outflow of Upper St. Croix Lake to the site at Old Hwy 53 (SX02), suggesting dilution by groundwater and low chloride tributaries. Median chloride concentrations remained similar in baseflow and runoff samples whereas TP and TSS concentrations were higher in samples collected during runoff events.

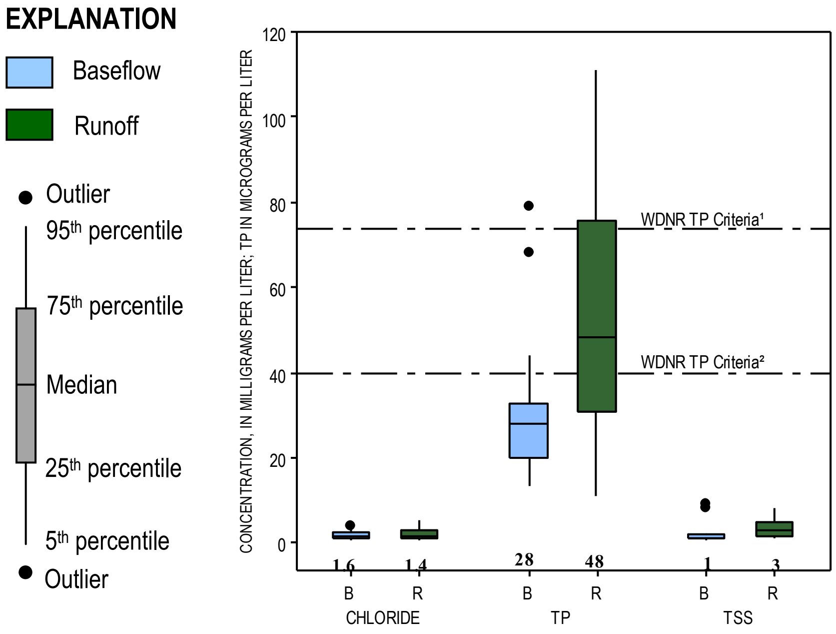
Baseflow concentrations of TP at the Gordon Flowage inflow monitoring sites LD01 and SX02 were 29 and 28 $\mu g \cdot L^{-1}$, respectively, and were lower at the outflow sites, measuring 17 and 21 $\mu g \cdot L^{-1}$ at site SX01 (the Gordon Dam) and SX00 (Scott's Bridge). During event flows, the median concentrations of TP were substantially lower at the outflow sites than at the inflow sites. The TP measured at LD01 may originate from the large percentage of wetlands in the watershed. In-stream nutrient cycling and the Gordon Flowage, acting as a nutrient sink, are likely reasons for the higher baseflow and runoff TP concentrations at the inflow sites than at the outflow sites. The Gordon Flowage may also act as a source of excessive nutrients at specific times of the year. In early summer, relatively elevated TP was observed and may be related to the senescence of curly leaf pondweed (*Potamogeton crispus).* During other periods of the year (particularly September and October) the die-off of other aquatic macrophytes and algae may also result in a temporary increase in TP.

The median concentrations of TSS increased during runoff flows at the inflow monitoring sites and were similar at the outflow monitoring sites. Sites SX02 and SX00 both had median runoff concentrations of 3 $mg \cdot L^{-1}$. During runoff conditions at sites SX00 and SX02, the measured increase in TSS was found to have a positive correlation with the measured increase in TP suggesting that TP is associated with sediment moving to and/or in the stream.



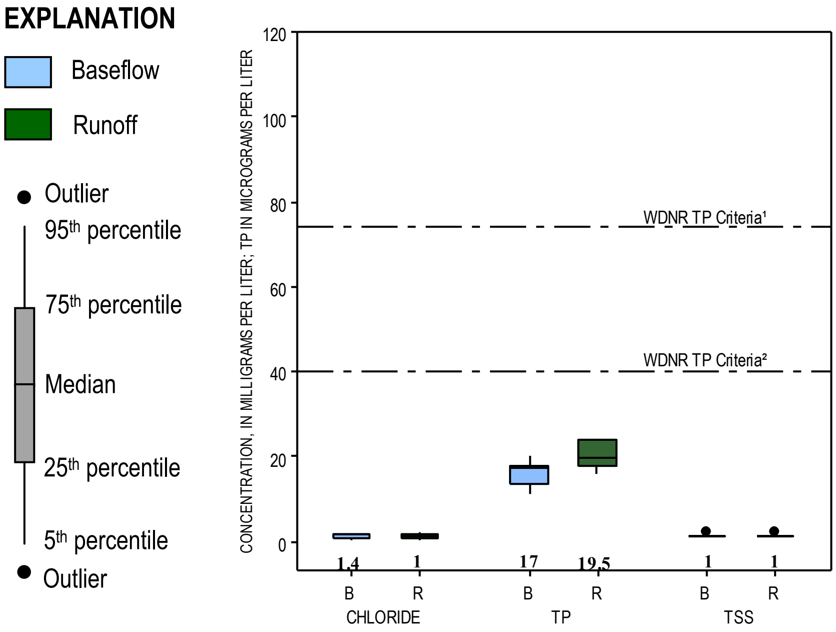
WDNR TP criteria for
¹wadeable streams: 74 µg·L-1
²shallow impoundments: 40 µg·L-1;

FIGURE 20. Box-plot showing baseflow and runoff concentrations at site LD01 of chloride, total phosphorus (TP), and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots.



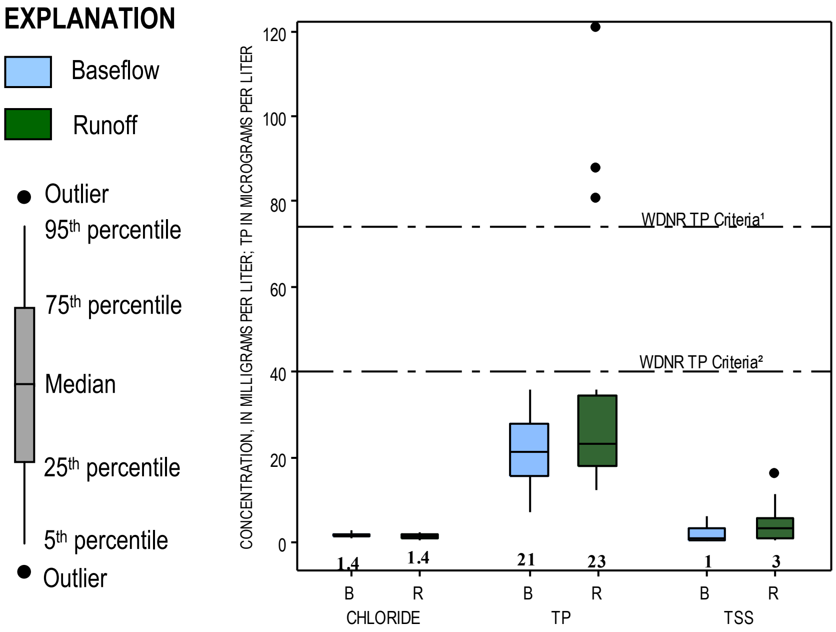
WDNR TP criteria for
¹wadeable streams: 74 µg·L-1
²shallow impoundments: 40 µg·L-1;

FIGURE 21. Box-plot showing baseflow and runoff concentrations at site SX02 of chloride, total phosphorus (TP), and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots.



WDNR TP criteria for
¹wadeable streams: 74 µg·L^{-1}
²shallow impoundments: 40 µg·L^{-1};

FIGURE 22. Box-plot showing baseflow and runoff concentrations at site SX01 of chloride, total phosphorus (TP), and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots.



WDNR TP criteria for
¹wadeable streams: 74 µg·L^{-1}
²shallow impoundments: 40 µg·L^{-1};

FIGURE 23. Box-plot showing baseflow and runoff concentrations at site SX00 of chloride, total phosphorus (TP), and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots.

Cranberry Bog

The St. Croix River immediately downstream of the north (CB02) and south (CB01) cranberry bog outlets were monitored for pesticides and water quality constituents. Surface water enters the cranberry bog from a natural wetland to the north and west and from occasional withdrawals from the St. Croix River for cranberry bog management related to frost protection, irrigation, and flooding. For example, on June 26, 2009, water from the St. Croix River was flowing into the south cranberry bog out at approximately 7 cfs. In general, the channels near the cranberry bog outlet were observed as being stagnant or draining very slowly and were oftentimes covered with duckweed.

Loads and yields were not calculated due to the difficulties of quantifying streamflow. Water quality measures were taken to identify the general contribution of nutrients provided by the bog to the St. Croix River. Water entering the cranberry bog from the natural bog to the north and west was sampled on July 7, 2008 and is used for comparison with the bog outlets. Field and laboratory water quality measures indicate the water leaving the bog is of poorer quality than the water entering the bog. In FIGURE 24, measures from the natural bog are indicated by the solid symbols. Water temperatures were lower and pH increased slightly (more neutral) in the water exiting the bog, but dissolved oxygen decreased and conductivity increased substantially.

Laboratory analyses show a decrease in TSS and nitrogen species (TKN, NH_4, and NO_2+NO_3) from the inflow to the outflow. Total phosphorus, reactive phosphorus, and chloride were found to increase from the inflow to the outflow (FIGURE 25). Phosphorus is often added to increase production of plants so the source is likely from the bog operation. Chloride concentrations may be a result of nearby road salting and/or other compounds used in the bog operation.

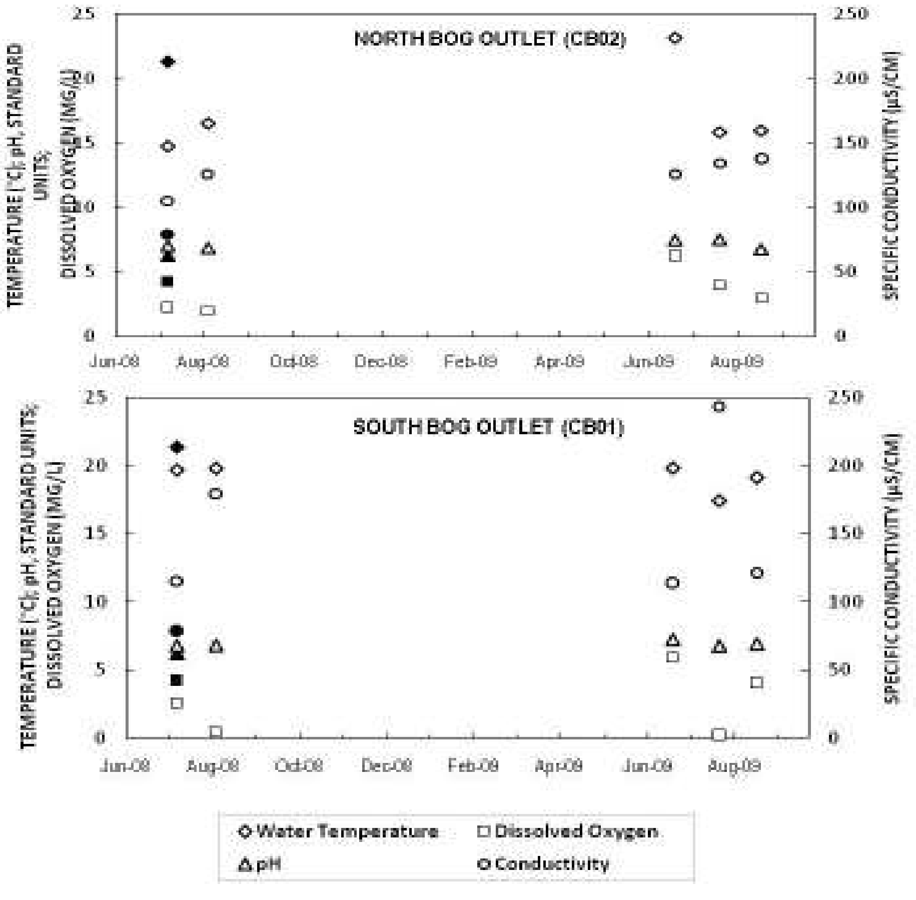


FIGURE 24. Field water quality measurements of the cranberry bog in Gordon, WI. Measures were taken near the bog outflow channels (hollow symbols) in 2008 and 2009 and at the natural bog inflow on July 7, 2008. Solid symbols identify samples collected from the natural bog to the north west of the cranberry bog.

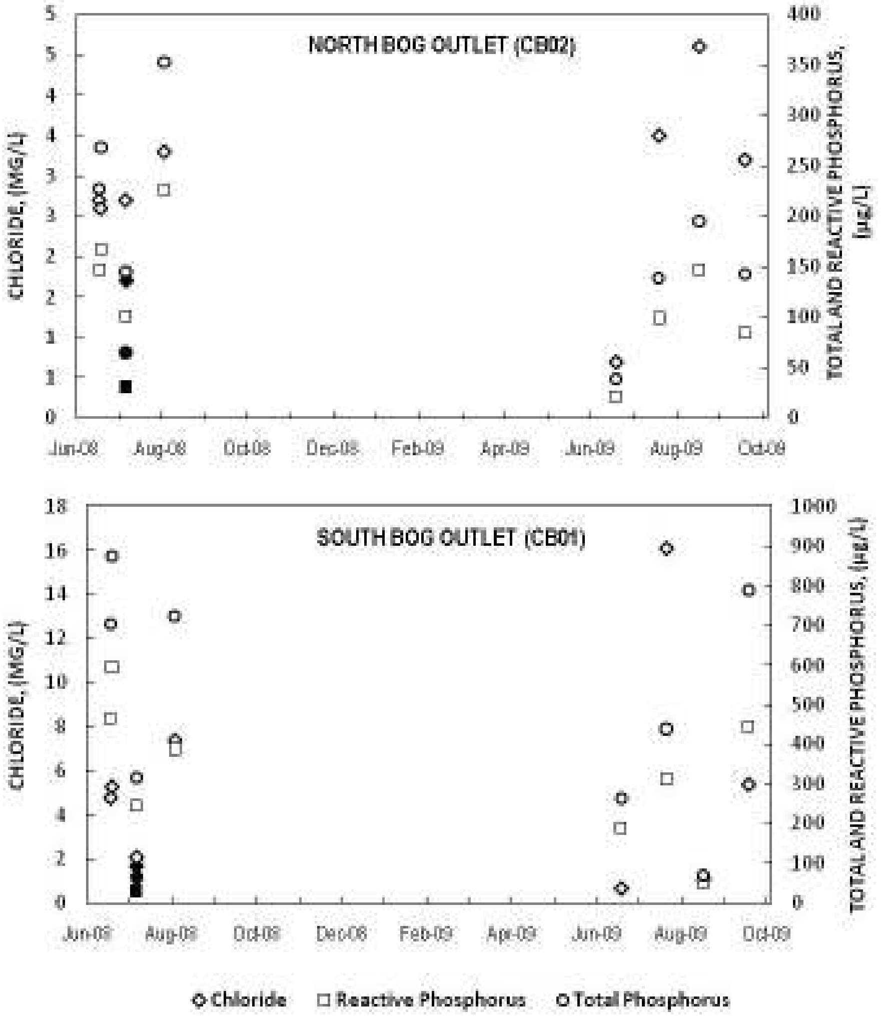


FIGURE 25. Total and reactive phosphorus concentrations of the cranberry bog in Gordon, WI. Samples were taken near the bog outflow channels (hollow symbols) in 2008 and 2009 and at the natural bog inflow on July 7, 2008. Solid symbols identify samples collected from the natural bog to the north west of the cranberry bog.

Elevated concentrations of phosphorus and chloride suggested that the cranberry bog might be a source of these constituents; other substances were evaluated in the St. Croix that may originate in a cranberry operation. Depending upon the type of management, in addition to nutrients non-organic cranberry operations often use herbicides, fungicides, and other pesticides. Within this discussion these different types of compounds are all grouped under the name pesticide.

Sediment samples were collected near the cranberry bog in June 2006 and May 2007 (FIGURE 26) and analyzed for some typical pesticides used both currently and historically in cranberry bogs in Wisconsin, including DDT and its degradates. None of the sediment samples were found to have any of these pesticide concentrations above the limits of detection (LOD). In April 2007, semi-permeable membrane device (SPMD) passive samplers were deployed near the cranberry bog. The SPMDs also had no concentrations above the LOD for the pesticides that were tested (Macholl and Turyk, 2008).

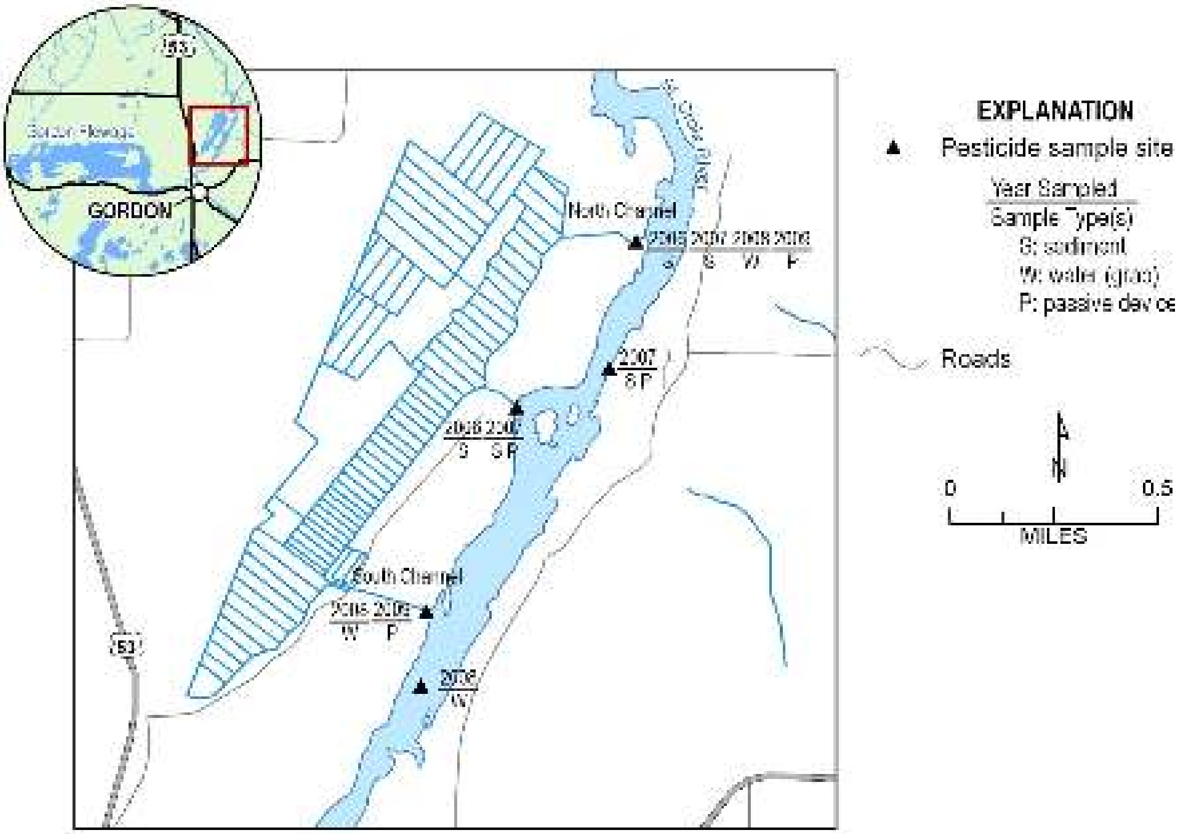


FIGURE 26. Location of pesticide sample sites in the St. Croix River near the cranberry bog above Gordon, WI, 2006 through 2009.

During summer 2008, the northern and southern channels of the cranberry bog were identified as the primary water discharge channels and the central channel identified as the primary inflow (irrigation) channel for the bog. Grab samples were taken on June 18 and 19, 2008 following a pesticide application within the bog on June 17, 2008. Grab samples taken near the northern and southern channels were found to have detectable concentrations of the pesticide diazinon (TABLE 4). Of the 26 pesticide compounds analyzed, none were detected in follow-up samples taken on July 20, 2008.

TABLE 4. Concentrations of the pesticide diazinon detected in the St. Croix River near the cranberry bog north of Gordon, WI in summer 2008.

Sample Site	Sample Date	Diazinon (µg/L)
Northern Channel	6/18/2008	0.76
Southern Channel	6/18/2008	*0.27*
Northern Channel	6/19/2008	*0.33*
Southern Channel	6/19/2008	0.81
Northern Channel	7/30/2008	<LOD
Southern Channel	7/30/2008	<LOD
250 yds Downstream of S. Channel	7/30/2008	<LOD

Italicized values are above limit of detection (LOD) but below limit of quantitation (LOQ).

<LOD, less than limit of detection.

Polar Organic Chemical Integrative Sampler (POCIS) devices were deployed to monitor pesticide concentrations in the St. Croix River near the cranberry bog during the 2009 field season (FIGURE 27). POCIS devices were selected because they can accumulate water soluble compounds in low concentrations, provide qualitative and quantitative measurements of compounds, and are more logistically sound than grab samples. POCIS devices can remain in-stream for extended periods of time, generally one month, which provides time-weighted average concentrations of compounds. This extended sampling period also captures low concentrations and episodic events that could otherwise be missed in grab samples and can provide an exposure assessment of aquatic organisms.

FIGURE 27. POCIS devices (discs with white centers) shown mounted in a deployment canister. Note: In the figure, three POCIS are mounted, whereas this study deployed one POCIS per canister. (Source: www.est-lab.com/pocis.php)

A POCIS canister, containing one POCIS device, was installed near both the northern and southern channels of the cranberry bog. The devices were deployed from May through September 2009 for five consecutive periods that ranged from 20 to 39 days in length. Upon collection, the POCIS devices were immediately bagged and transported on ice to the UWSP Water and Environmental Analysis Lab (WEAL) Trace Organics Laboratory for analysis.

If the sampling rate (the rate in which a compound can be absorbed) of a particular compound is known, the time-weighted average concentration measured by the POCIS device can be converted to an estimate of the ambient water concentration. Sampling rates are empirically determined and are a function of water temperature, water velocity, surface area of the sampling device, and the amount of sediment accumulation on the device (Alvarez et al., 2008). Estimates of average ambient water concentration are found by dividing the POCIS concentration by the volume of water sampled, where the volume of water sampled is the product of the sampling rate and the number of days the POCIS was deployed. Preliminary sampling rates of detected pesticides under turbulent conditions at 20C were obtained for the detected pesticides (D. Alvarez, personal communication, 2010). These sampling rate data are appropriate for this study; water temperature ranged from 13 to 23C and was generally below 20C, and although the water at the sampling sites was generally quiescent, some flow was often visible in the channel.

The estimated volume of water sampled can be used to adjust the limits of detection (LOD) and limits of quantitation (LOQ). The LOD and LOQ for a constituent provided by the WEAL are in terms of concentration detectable or quantifiable, respectively for a 1 L water sample. Dividing the LOD and LOQ by the sample volume provides an adjusted value. The volume of water sampled for diazinon and chlorpyrifos ranged from 8.5 to 16.5 L and for malathion from 1 to 2 L. All reported values are above the adjusted LOD; however, due to the preliminary nature of the constituent sampling rates and the theoretical adjusted LOD concentrations, the POCIS concentrations and the estimates of ambient water concentration above established LOD are provided for qualitative and informational purposes only and should not be considered definitive values.

The pesticides detected in the St. Croix River were diazinon, chlorpyrifos, and malathion (TABLE 5). Diazinon, chlorpyrifos, and malathion are organophosphates, which are used in agriculture and are known to be toxic to aquatic organisms including fish, amphibians, and particularly invertebrates. According to the USEPA (2005), diazinon is a compound that is mobile and moderately persistent. EPA has both acute and chronic aquatic life criteria for diazinon. Similarly, EPA also has acute and chronic aquatic life criteria for malathion. They indicate that salmonids and centrarchids are some of the most sensitive fish species and invertebrates are more sensitive than fish. The Wisconsin DNR has acute toxicity criteria for chlorpyrophos in surface water (WDNR, 2008). Additional sampling and measurements would be required to quantify concentrations in the St. Croix River for comparison to these criteria. Concentrations from 2008 and estimated ambient water concentrations from 2009 were below toxic levels; however, the interaction of exposure to more than one of these compounds or exposure coupled with other environmental factors is unknown. A study performed by Sparling and Fellers (2007) determined that the oxons (formed when oxygen replaces sulfur in a phosphorus-sulfur bond) derived from the three pesticides detected are 10- to 100-times more toxic than the parent compounds.

Diazinon and chlorpyrifos were present at both sites some time during the year and malathion was detected near the southern channel of the bog in August and September. None of the 26 pesticide compounds that were analyzed in samples collected between September 27 and October 17 were detected. It is interesting to note that from June through July, the diazinon concentration increased near the southern bog channel and decreased near the northern channel. Knowledge of the hydraulics of the cranberry bog (i.e., the movement and volume of water throughout the bog) and of pesticide application times and locations are required to perform a full qualitative evaluation of pesticide inputs to the St. Croix River.

TABLE 5. Pesticide concentrations in POCIS devices and estimated average ambient water concentrations in the St. Croix River near the cranberry bog in Gordon, WI.
Note: values are appropriate for adjusted limits of detection (LOD), but have been identified if values fell below established LOD for grab samples due to the preliminary nature of the constituent sampling rates. These estimates are provided for qualitative and informational purposes only and should not be considered definitive values. [L, liter; µg, microgram; ng, nanogram]

Site Location	Collection Date	Days Deployed	Diazinon		Chlorpyrifos		Malathion	
			µg/POCIS	ng/L water	µg/POCIS	ng/L water	µg/POCIS	ng/L water
Northern	6/26/2009	39	15	0.9	44	2.7	<LOD	ND
	7/27/2009	31	**D**	ND	<LOD	ND	<LOD	ND
	8/25/2009	29	380	30.9	<LOD	ND	<LOD	ND
	9/27/2009	33	**D**	ND	<LOD	ND	<LOD	ND
	10/17/2009	20	<LOD	ND	<LOD	ND	<LOD	ND
Southern	6/26/2009	28	<LOD	ND	29	2.4	<LOD	ND
	7/27/2009	31	20	1.5	<LOD	ND	<LOD	ND
	8/25/2009	29	6	0.5	<LOD	ND	360	243
	9/27/2009	33	**D**	ND	<LOD	ND	130	77.2
	10/17/2009	20	<LOD	ND	<LOD	ND	<LOD	ND

"<LOD" indicates sample was below limits of detection (LOD) for established grab sample analyses.

"ND" indicates POCIS sample was <LOD.

Underlined values were detected concentration, but below LOD for grab sample analyses.

"**D**" indicates compound was detected, but well below LOD and therefore not assigned a value.

Moose River

The hydrology and water quality of the Moose River was monitored in 2009 to identify the affect it has on the quality and flow of the St. Croix River because the sample site downstream of Gordon Flowage (Scott's Bridge) includes inputs from Moose River. The Moose River enters the St. Croix approximately 100 yards upstream of SX00. When standing on Scott's Bridge on West Mail Road, the different streams are easily distinguished; water from the Moose River contains more tannins than the St. Croix and is noticeably brown in color whereas the water of St. Croix River is blue-hued. During this study the line of separate waters was visible during the high spring melt-water flows.

The Moose River watershed has a well developed drainage network leading to flashy stream flows. During the 2009 growing season flows ranged from 1.2 to 120 cfs and spring melt-water flows on March 27-2009 were estimated at 250+ cfs. During this period, the Moose River was found to provide an average of 18.4 cfs to the flow of the St. Croix River. The continuous flow measurements of the Moose River were subtracted from the continuous flow measures of SX00 to approximate the flow at SX01. The distributions of the chloride, TSS, and TP concentrations in samples collected from the Moose River are displayed in FIGURE 28. Chloride concentrations were generally below detection limits, indicating a system with minimal cultural impacts. Both TP and TSS concentrations were found to increase during runoff conditions.

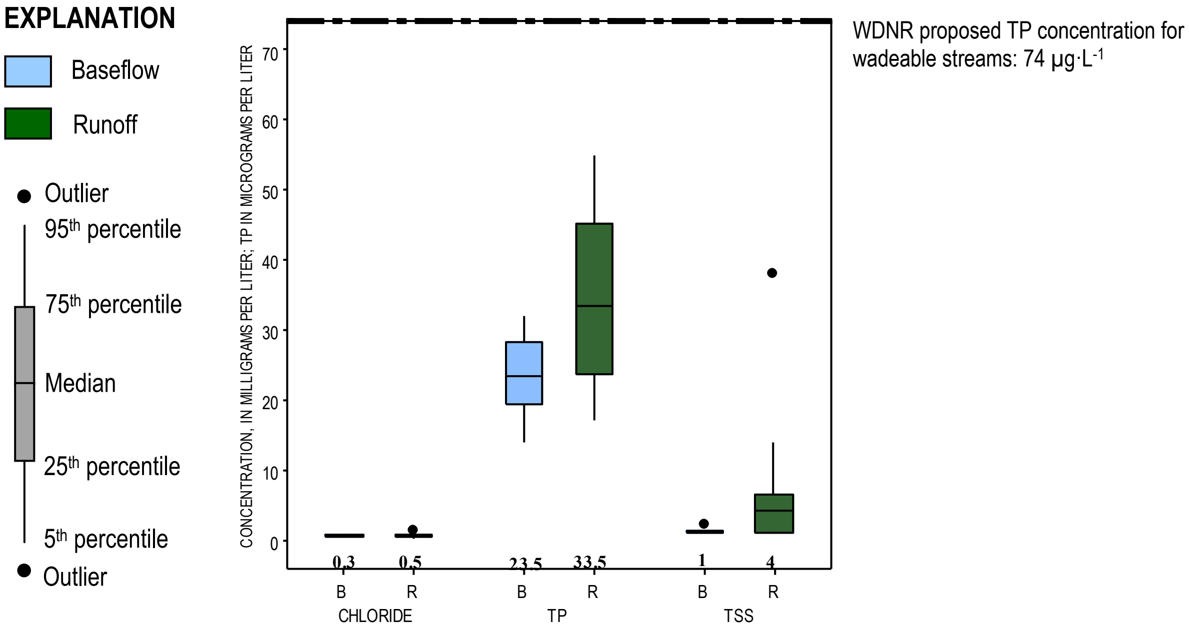


FIGURE 28. Box-plot showing baseflow and runoff concentrations at site MS01of chloride, total phosphorus (TP), and total suspended solids (TSS). The light blue (B) and the dark green (R), represent baseflow and runoff concentrations, respectively. Median values are below the box-plots.

Sub-Watershed Comparison

It is evident that constituents are entering the St. Croix River system through groundwater discharge and runoff events. Chloride concentrations are similar throughout the watershed, with higher concentrations occurring during baseflow conditions. This implies that in most cases, groundwater discharge is the primary source of chloride in the surface water. The highest chloride concentrations are found in the Upper St Croix Lake watershed, sourced from activities associated with the greater development present in that watershed.

Based on EPA (2001) suggested stream ambient TP concentrations, the streams at sites SX02 and LD01 can be classified as moderately fertile and the remainder as low in plant nutrients. The WDNR

(2007) suggest a median TP concentration of 74 µg·L^{-1} for streams in Wisconsin, which all of the USCECRW monitoring sites fall below. The effect of this concentration on lakes and impoundments will vary among water bodies. The measured low dissolved mineral concentrations observed in the St. Croix River Headwaters would likely result in an increase in algae and aquatic plant growth with minimal additions of phosphorus.

Because many of the streams in the St. Croix River Headwaters drain to impoundments situated along the Eau Claire River and to the Gordon Flowage, it may be more appropriate to refer to WDNR water quality standards for shallow impoundments, drainage lakes, and deep impoundments. The WDNR standards to prevent nuisance algal blooms in these water bodies are TP concentrations below 40 µg·L^{-1} for shallow impoundments like the Gordon Flowage, and 30 µg·L^{-1} for drainage lakes and deep impoundments such as the Eau Claire chain of lakes.

When comparing a number of streams or stream reaches and their contributions to a system, it is often preferable to look at loads and yields of constituents. These values are obtained by multiplying concentrations by the stream flow. A load represents mass per time, for example pounds of phosphorus per year. Loads are estimated using continuous flow records and a number of water quality samples representing a variety of flow regimes. Loads may vary significantly during a single rain event as flow and concentrations change throughout the storm. Before calculating loads, multiple samples during single events were summarized to a single value in FLUX. The results included the event mean flow and a flow-weighted mean concentration (Walker, 1999).

Yields represent an area weighted average of the nutrient load and are often reported as the estimated annual average pounds of nutrient per acre (lbs·ac^{-1}·yr^{-1}). In this document total suspended solids and chloride yields are reported as tons per acre per year (ton·ac^{-1}·yr^{-1}). Loads and yields were computed for each monitoring site, including the Moose River, for the 2008 and 2009 sample periods. The highest TP loads were found in the St. Croix River at Old Hwy 53 (SX02) and at the St. Croix River at Scott's Bridge (SX00) (FIGURE 29). Annual TP exports were highest upstream of the Gordon Flowage at SX02 and at the Cut Away Dam Road recreational trail bridge (SX03) (FIGURE 30). SX02 also had the highest TP concentrations which occurred during rain events. Lord Creek at CTH M (LD01), the Eau Claire River at Outlet Bay Road (EC04), the Moose River (MS01), and Ox Creek (OX01), with relatively undeveloped watersheds, were found to have the lowest TP loads. In both 2008 and 2009, TP yields from EC04 and OX01 were the lowest. The Eau Claire River was found to increase in both TP load and yield in the downstream direction.

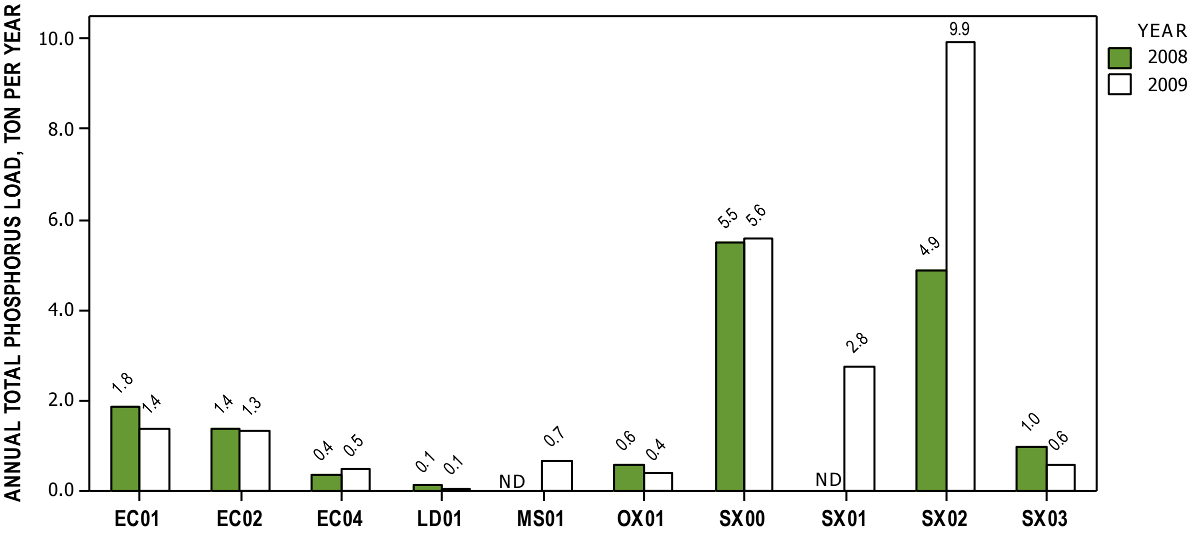


FIGURE 29. Estimated total phosphorus loads in tons per year for 2008 and 2009 in the St. Croix River Headwaters at each monitoring site. Estimated values are displayed above the bars; ND, no data.

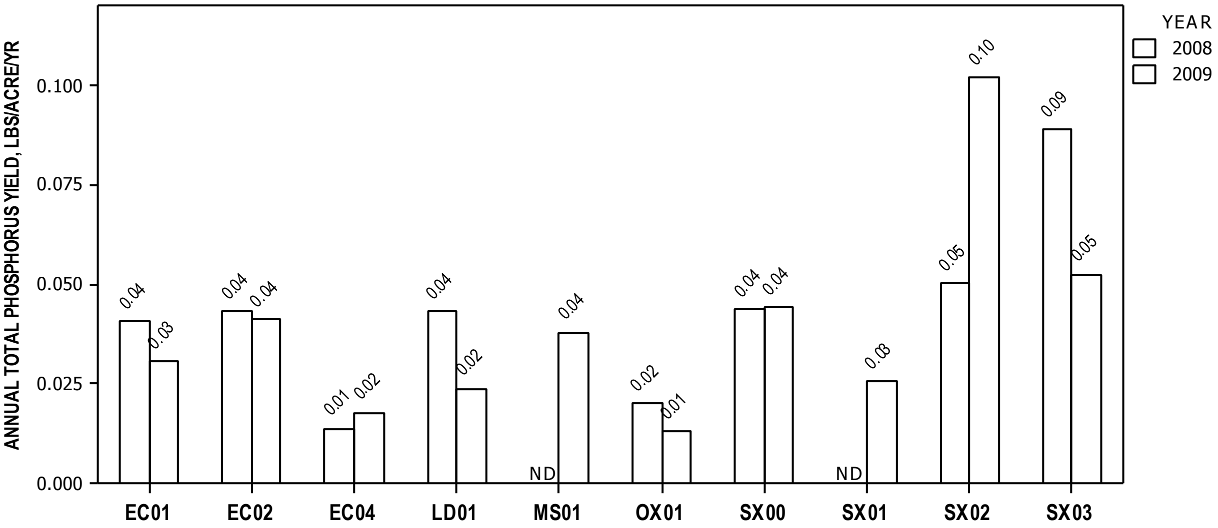


FIGURE 30. Estimated total phosphorus yields in pounds per acre per year for 2008 and 2009 in the St. Croix River Headwaters at each monitoring site. Estimated values displayed above the bars; ND, no data.

The average annual (2008 and 2009) TP yield in the USCECRW (SX00) was found to be 0.04 lbs·ac^{-1}·yr^{-1}. This is lower than other watersheds of similar size in the St. Croix River basin. For example, the Willow River below Little Falls Lake in St. Croix County, with a watershed of 278 mi², was found to have a TP export of 0.13 lbs·ac^{-1}·yr^{-1} (K. Schreiber, unpublished data). Other northern Wisconsin streams with similar sized watersheds with greater TP yields include the Yellow River in north central Wisconsin with a drainage area of 369 mi² and a yield of 0.44 lbs·ac^{-1}·yr^{-1}, and the South Fork of the Hay River in northern Dunn County, with a 418 mi² watershed and an estimated yield of 0.79 lbs·ac^{-1}·yr^{-1} (K. Schreiber, unpublished data). It is likely that the low precipitation during this study resulted in lower than typical loads and yields of TP in the tributaries and rivers. The low TP loads and yields suggest that the USCECRW is in a state where thoughtful planning for future development and implementation of appropriate land management practices could prevent damage to the waters and associated environmental and economic costs.

Chloride concentrations measured in the streams of the USCECRW are generally representative of the background groundwater concentrations which have been identified as less than 2 mg·L^{-1}. Near the Eau Claire chain of lakes, the baseflow and runoff chloride median values increase slightly from 1.4 mg·L^{-1} at site EC04 to 1.8 mg·L^{-1} at site EC02. This very small increase translates to a difference in the 2008 and 2009 average annual load of approximately 50 tons·yr^{-1} (FIGURE 31). This increase may be due to higher concentrations of chloride in the groundwater, sourced from residential uses such as water-softeners and road de-icing activities, entering the stream. Estimated household contributions of chloride to lakes, primarily sourced from septic systems, range from approximately 10 to 45 lbs·yr^{-1} (McGinley, 2008).

The highest chloride yield was found to be from the Upper St. Croix Lake sub-watershed (SX03). This reflects the greater development in that watershed. Chloride yields were found to decrease traveling downstream in the St. Croix River, likely due to the inputs of streams and groundwater with more dilute concentrations. As with TP, the lowest chloride load and yield were found in the OX01 and EC04 sub-watersheds (FIGURE 32). The low chloride concentrations found in these sub-watersheds can be attributed to the relatively undeveloped nature of the sub-watersheds, and the minimal human presence.

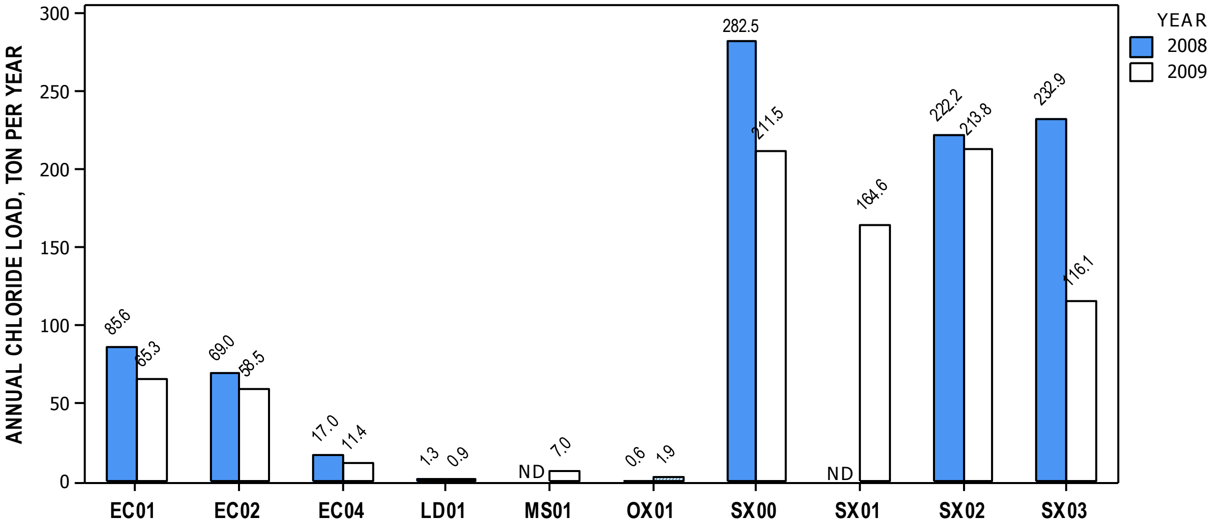


FIGURE 31. Estimated chloride loads in tons per year for 2008 and 2009 in the St. Croix River Headwaters at each monitoring site. Estimated values displayed above the bars; ND, no data.

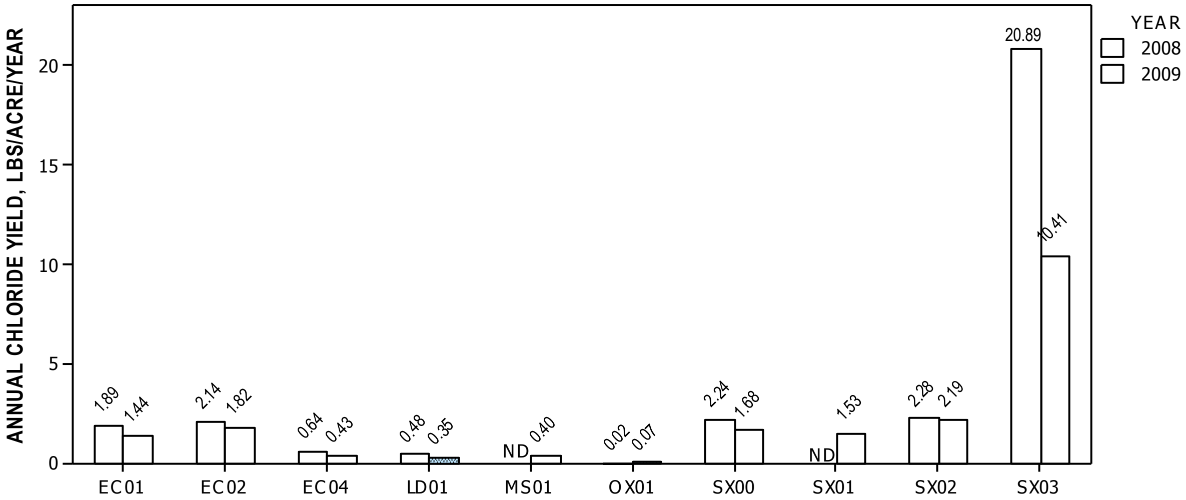


FIGURE 32. Estimated chloride yields in pounds per acre per year for 2008 and 2009 in the St. Croix River Headwaters at each monitoring site. Estimated values displayed above the bars; ND, no data.

The average TSS load of the USCECRW to the St. Croix River Basin, as measured at SX00 in 2008 and 2009, was approximately 460 ton·yr^{-1} (FIGURE 33). This load is an order of magnitude smaller than the loads of similarly sized watersheds in northern Wisconsin (K. Schreiber, unpublished data). The relatively small estimated TSS loading of the USCECRW is likely a reflection of the dry years in which this study was performed. With fewer large rain events generating runoff in 2008 and 2009, the TSS loads and yields are likely less than normal. The highest TSS load within the sub-watersheds was measured at the St. Croix River at Old Hwy 53 (SX02), which during this study supplied and average of approximately 290.6 ton·yr^{-1} (FIGURE 34). The TSS load at SX00 may be higher due to the increase in stream energy (due to a higher stream slope) and the resulting increase in stream velocity below the dam which allows for the transport of more suspended particles.

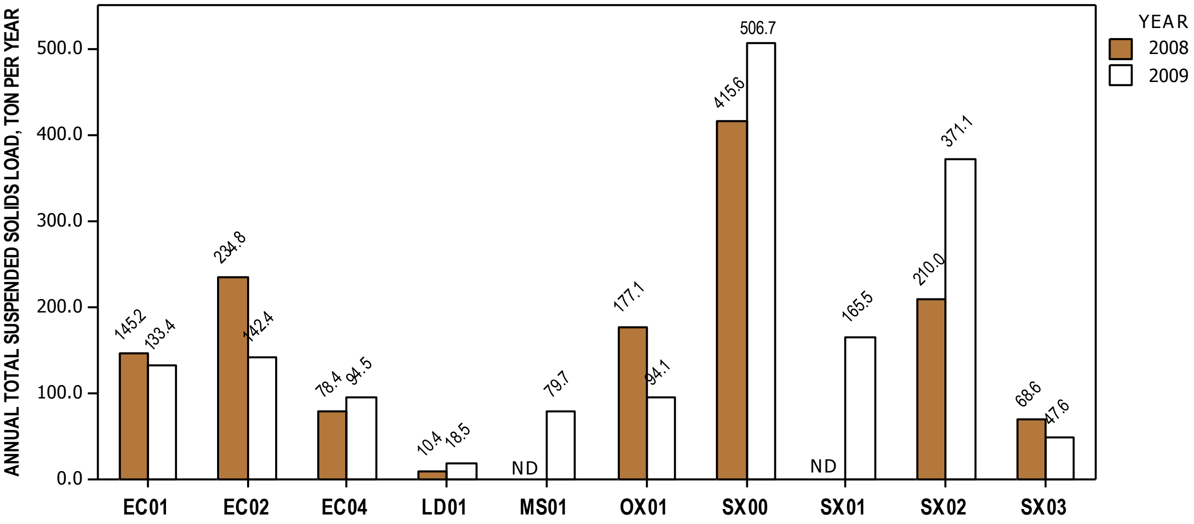


FIGURE 33. Estimated total suspended solids loads in tons per year for 2008 and 2009 in the St. Croix River Headwaters at each monitoring site. Estimated values above bars; ND, no data.

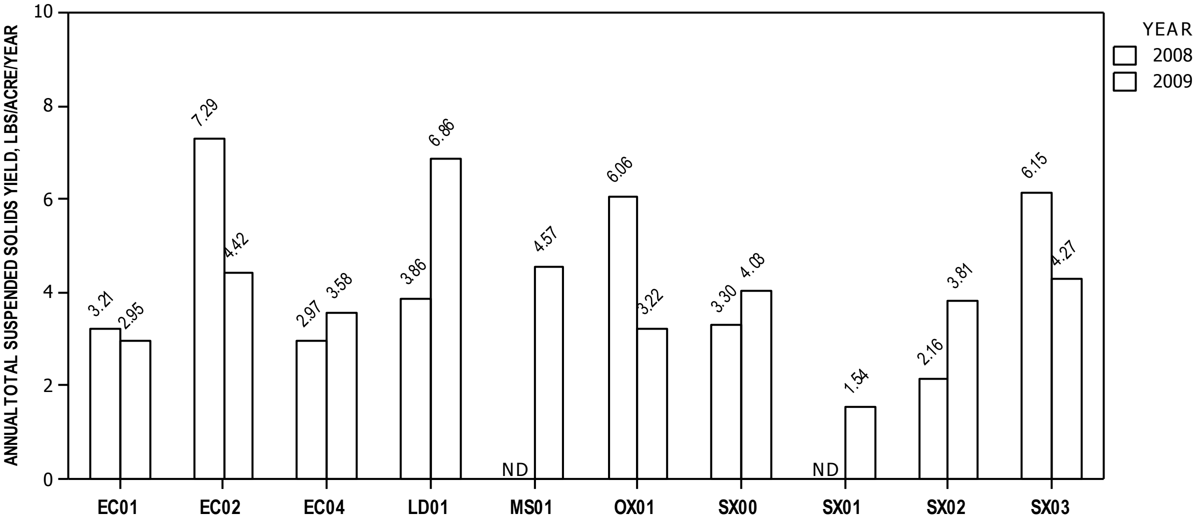


FIGURE 34. Estimated total suspended solids yields in pounds per acre per year for 2008 and 2009 in the St. Croix River Headwaters at each monitoring site. Estimated values displayed above the bars; ND, no data.

Concentrations of nitrogen species (different forms) were low throughout the watershed (Appendix C) and can remain so with the implementation of best management practices. All sites in the St. Croix River Headwaters were found to decrease in mean nitrate+nitrite-N concentration from baseflow to runoff conditions, except EC01 which remained similar. This indicates that runoff is diluting baseflow concentrations and suggests groundwater discharge is the primary source of nitrates in the watershed.

Field chemistry varied throughout the watershed. Descriptive statistics (minimum, median, maximum, etc.) for pH, dissolved oxygen (DO), and specific conductance (conductivity) can be found in Appendix D. During this study, all monitoring sites except LD01and SX03 had pH values which were consistently slightly alkaline. Slightly acidic pH values measured at LD01 and SX03. At LD01, these values are likely due to the large amount of wetlands in that watershed and the associated organic acids produced by decaying vegetation. Acidic conditions at SX03 occurred during August 2009 during the height of backwater flow conditions; the low flow (approximately 10 cfs) and large amount of vegetation in the channel mimicked wetland conditions. High pH values (greater than 9) were measured at sites SX01, SX02, and SX03, though only once at each site in the early growing seasons in 2008 and 2009. High pH is associated with productive waters, where high rates of photosynthesis lower the dissolved carbon dioxide concentration which causes an increase in the pH. Low pH levels (less than 5), which are detrimental to immature fish and aquatic insects, were not observed during this study.

Conductivity varied throughout the watershed (Appendix D). High variations in specific conductance are not uncommon in natural systems but can also be increased by cultural inputs. The greatest site-specific variations occurred at SX03, MS01, and LD01. Measured values at SX03 ranged from 42 to 157 micro-Siemens per centimeter ($\mu S \cdot cm^{-1}$), from 44 to 160 $\mu S \cdot cm^{-1}$ at MS01, and from 42 to 162 $\mu S \cdot cm^{-1}$ at LD01. The higher conductivities at LD01 were associated with runoff flows, during which the water was stained brown. The higher values at SX03 were measured during back-water flow conditions, when lower volumes of water were moving past the monitoring site.

Wisconsin has a dissolved oxygen (DO) water quality standard of 5 $mg \cdot L^{-1}$, which is considered the minimum concentration necessary to support aquatic life. The Eau Claire River sites, OX01 and SX00 had similar median DO concentrations with values of approximately 9 $mg \cdot L^{-1}$ (Appendix D). Site SX02 had a slightly lower median concentration (approximately 8.5 $mg \cdot L^{-1}$) and SX03 had the lowest median DO (7.4 $mg \cdot L^{-1}$). Though DO concentrations vary throughout the day, very low concentrations

(<5 mg·L^{-1}) were measured during the day at site SX03 in August and September 2008 and August 2009 during the height of the back-water conditions. The low concentrations may be due to the warming of the slow moving, shallow water at the site during these conditions.

Synoptic Sampling

Groundwater

To obtain a general view of groundwater quality in the USCECRW, groundwater samples from 50 domestic wells were collected by volunteers from October 2-4, 2009 (FIGURE 35). One sample was omitted from the analysis due to the water being softened. The samples were distributed throughout the watershed and provide a baseline for comparison with future measurements and to augment river data collected during baseflow conditions. Well construction reports were located for 22 wells. These records indicated that the average depth to the screen (the open portion of the well) was 92.7 feet. Of the known well construction, none of the wells were completed to bedrock.

Groundwater samples collected from domestic wells were interpreted as representing relatively young groundwater with travel times from surface to spigot estimated to be approximately one year. Many of the parameters that were analyzed were minerals that would be present from the water's contact with the local geology. The median phosphorus (TP) concentration of the groundwater samples is similar, though less than, the concentrations measured in the streams during baseflow conditions (TABLE 6). Additional phosphorus in the streams is a result of inputs from the land's surface. Slightly higher concentrations of phosphorus (>25µg·l^{-1}) were measured in the northern half of the watershed (FIGURE 36). Higher phosphorus concentrations were also measured in some of the wells that were used to sample groundwater entering Upper St. Croix Lake (Turyk and Macholl 2009). In high enough concentrations, several naturally occurring elements in water might reduce the impacts of phosphorus in a water body by co-precipitating with phosphorus which makes it less available for use by algae and aquatic plants (Wetzel 2001).

TABLE 6. Summary statistics for domestic well water samples collected from October 2-5, 2009 in the St. Croix River Headwaters watershed.

All values expressed as mg·l^{-1}

	As	Ca	Fe	K	Mg	Mn	Na	P	SO_4
Min	ND	ND	0.001	ND	0.003	ND	0.54	ND	0.06
Max	0.004	24.9	4.615	1.66	9.332	0.092	53.28	0.042	9.82
Average	**	13.0	0.261	0.55	3.586	0.016	3.42	0.012	4.28
Median	**	13.0	0.049	0.48	3.310	0.003	1.09	0.012	4.42
Detection Limit	0.004	0.01	.0010	0.01	0.001	0.001	0.10	0.006	0.01
Number of Detects	2	49	50	49	50	42	50	37	50

ND, Non-Detect

** *n* non-detect greater than *n* detect

Iron and calcium both have these attributes and occur in the USCECRW and are being transported to some of the water bodies via groundwater. Their effectiveness at combining with phosphorus depends not only on their presence, but also their chemical form. For survey purposes, we did not evaluate these forms but can infer that water bodies within the watershed that have very low concentrations of these elements are more susceptible to phosphorus inputs. Compared with other regions of the state, the calcium concentrations in the groundwater are low; however, even in the low range there is variability in USCECRW (FIGURE 37). Iron concentrations were low in the majority of wells within the watershed, providing little protection for phosphorus inputs to surface water. From a drinking water perspective iron concentrations greater than 0.3 mg·l^{-1} can produce taste, odor, color, and staining. For this region of the state background concentrations of sodium in groundwater would be less than 2 mg·l^{-1}. All but six of the wells were considered background concentrations; two of the wells had very high concentrations which may be attributed to softened water, road salt, and/or septic systems (FIGURE 39).

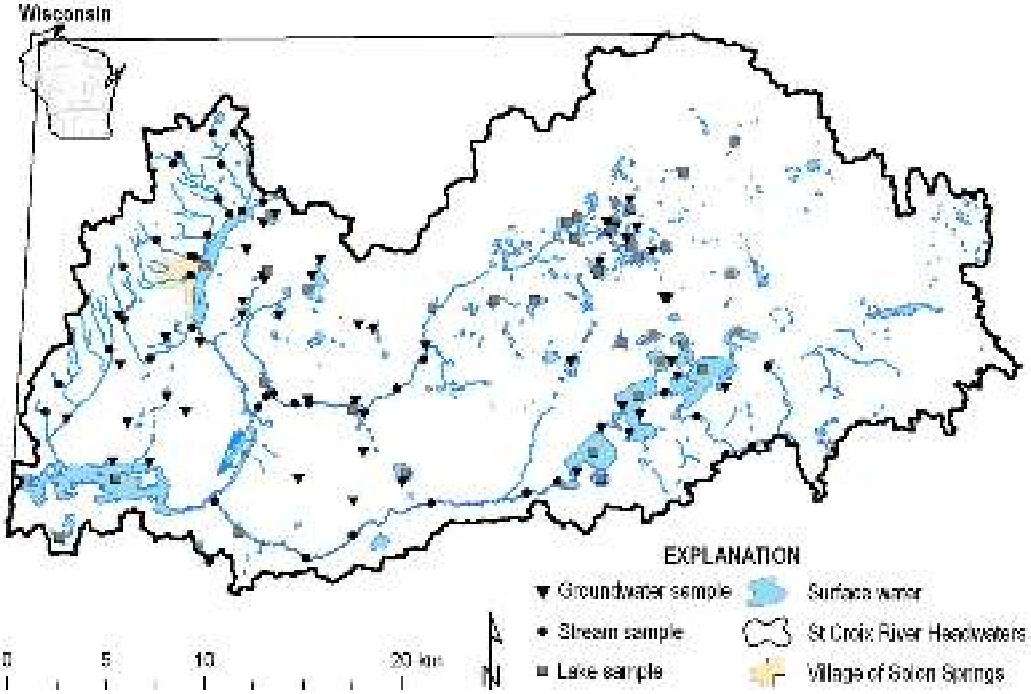
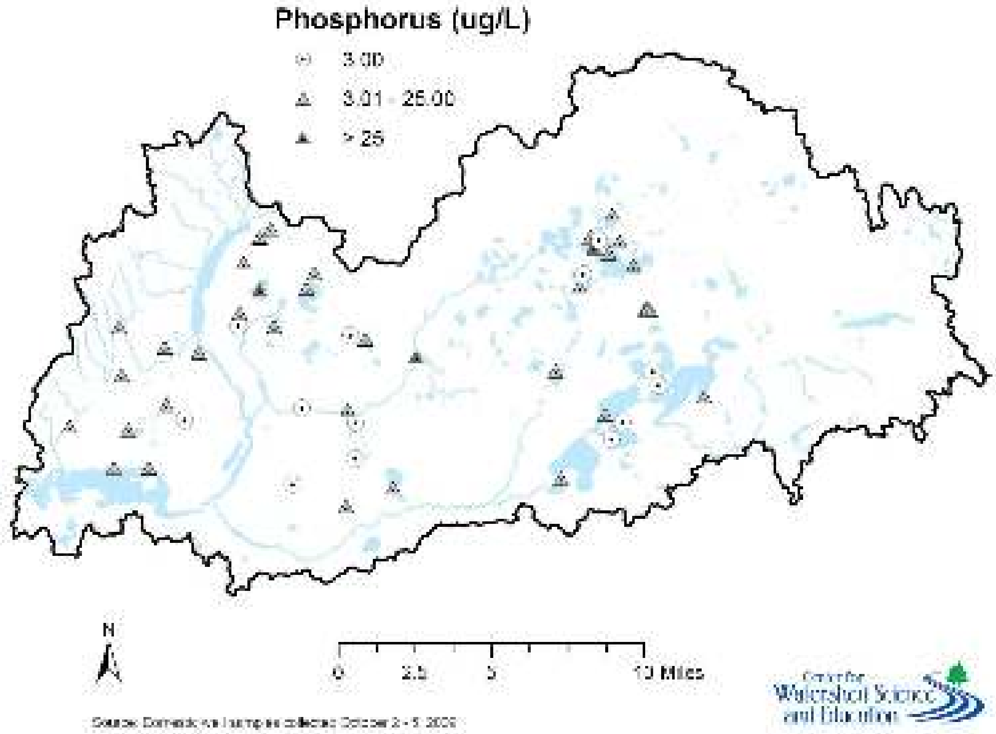
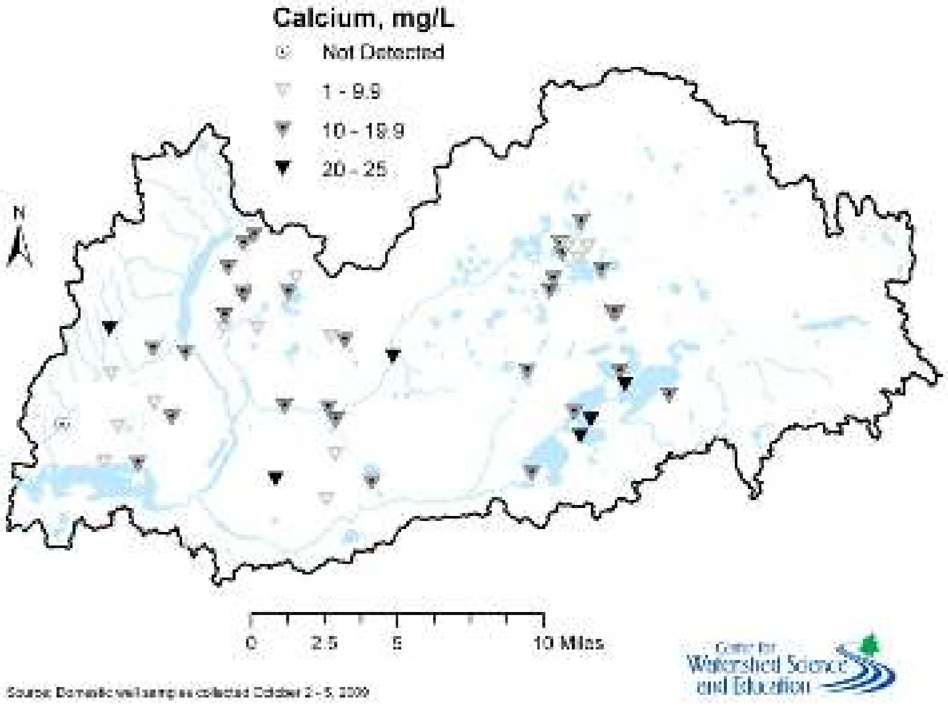


FIGURE 35. Locations of groundwater and surface water samples collected in the St. Croix River headwaters, Douglas and Bayfield Counties, Wisconsin. Stream samples were collected during synoptic sampling rounds in June, July, and August 2009, with a focus on the Eau Claire River and Ox Creek in July; lake samples were collected from April-May 2009; groundwater samples were collected in October 2009.



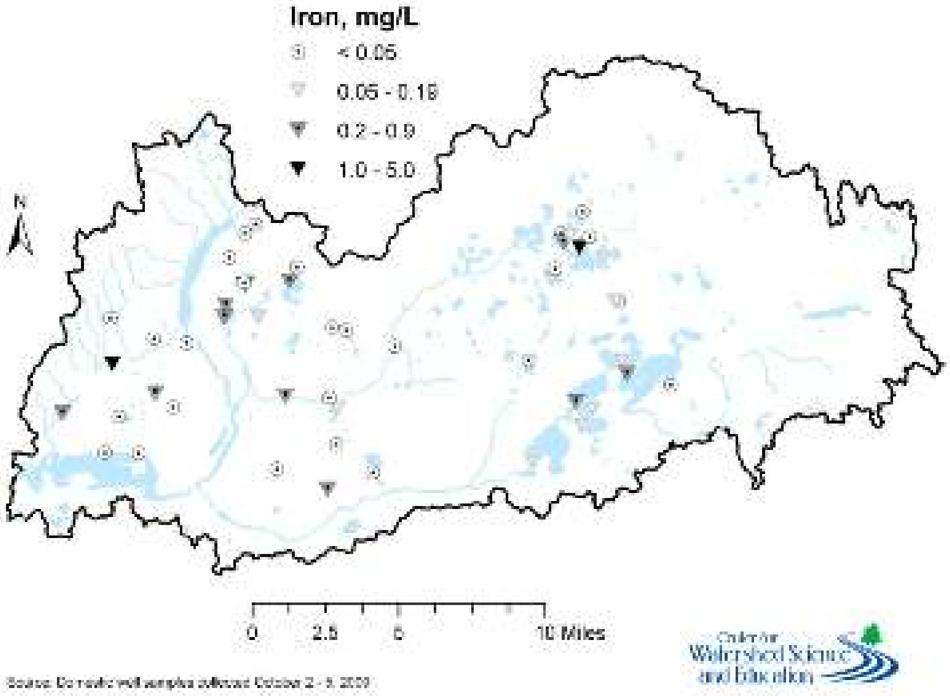
Source: Domestic well samples collected October 2 - 5, 2009

FIGURE 36. Ranges of phosphorus concentrations in private well samples collected in October 2009.



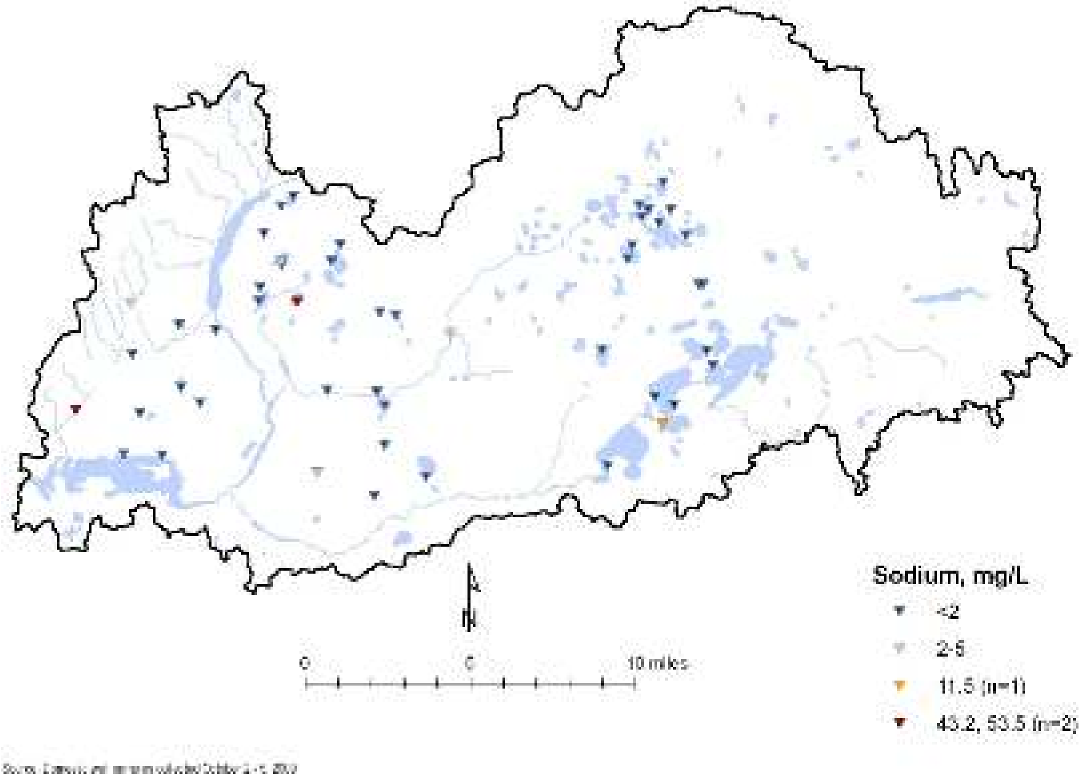
Source: Domestic well samples collected October 2 - 5, 2009

FIGURE 37. Ranges of calcium concentrations in private well samples collected in October 2009.



Source: Domestic well samples collected October 2 - 5, 2009

FIGURE 38. Ranges of iron concentrations in private well samples collected in October 2009.



Source: Domestic well samples collected October 2 - 5, 2009

FIGURE 39. Ranges of sodium concentrations in private well samples collected in October 2009.

First- and Second-Order Streams

Because groundwater is the primary source of the water in the streams (TABLE 2), synoptic sampling during June and August focused on first- and second-order (or headwater) streams (FIGURE 35) during baseflow (groundwater dominated) conditions. A total of 41 stream sites were sampled and little variability of the constituent concentrations between the sites and between sample dates was observed.

Lakes

(J. Brodzeller and N. Turyk)

Lake data were evaluated to obtain an overview of lake health within the headwaters. This should not be interpreted as a thorough investigation of each lake in the headwaters. Data used in this lakes analysis came from the WDNR SWIMS database, as well as from spring turnover samples collected in May 2009 by the CWSE staff. Phosphorus and water clarity measures were restricted to those from July and August for their most consistent representation of the summer growing season within a lake, while turnover periods (April 15-May 30 and September 15-October 31) were selected for all other analyses to ensure data came from mixed samples, using vertical temperature and dissolved oxygen measurements as a check for stratification. Sampling protocol used temperature and dissolved oxygen readings at one foot below the lake surface and one foot above the lake bed as an initial check for stratification. Because water at the bottom of a stratified lake can have very different chemistry than the shallower depths, any measurements taken at a depth greater than 15 feet were excluded. Devils and Lund Lakes were stratified at the time of sampling. More detailed vertical temperature and dissolved oxygen profiles were taken to help interpret the results in lakes exhibiting stratification. Data sets containing nutrient and water clarity measurements were restricted to the last 10 years, while mineralogy data was used as far back as 1979, as these parameters are less likely to change over time.

Lake Types

Lake types, as defined by water source and type of outflow, are classified into four categories: seepage, spring/groundwater drainage, drainage, and reservoir/impoundment. All lakes in the USCECRW share a common set of characterizing variables such as inputs from direct precipitation and surface runoff, loss of water through evaporation, and many receive water from and discharge to groundwater. Going beyond this shared set of attributes, lakes can be further characterized by having no significant inputs or outputs through stream flow (seepage), only an outflow (spring/groundwater drainage), both inflow and outflow (drainage), or inflow and restricted outflow due to damming of a stream (reservoir/impoundment).

The USCECRW includes 197 lakes, with most clustered in the northeast. Ranging in size from less than one acre up to the 2,200+ acre Gordon Flowage created by the damming of the St. Croix River, all four lake types are found in the watershed with seepage lakes being the dominant lake type of those lakes which have been classified by the WDNR (FIGURE 40). In their natural state, during most parts of the year, land within the watersheds of these lakes would have limited runoff and good infiltration to groundwater. This is due to the highly permeable soils, abundant wetlands, relatively flat topography, and well vegetated landscape which results in a large proportion of internally drained areas. These watershed characteristics suggest that many of the currently unclassified lakes are likely seepage lakes, which is also supported further by the area's glaciated history. In an attempt to provide an accurate depiction of the lakes within the watershed as a whole, we utilized seepage lakes as the dominant lake type in our set of study lakes (FIGURE 41). The study lakes were also classified into depth classes. These classes were based on the same classes used in the WDNR phosphorus standards; shallow seepage and drainage lakes have maximum depths less than 18 feet and deep seepage and drainage lakes are defined as having maximum depths greater than 18 feet. Of the seepage and drainage study lakes, 55% were categorized as shallow seepage lakes, 33% were deep seepage lakes, 7% were shallow drainage lakes, and 5 % were deep drainage lakes.

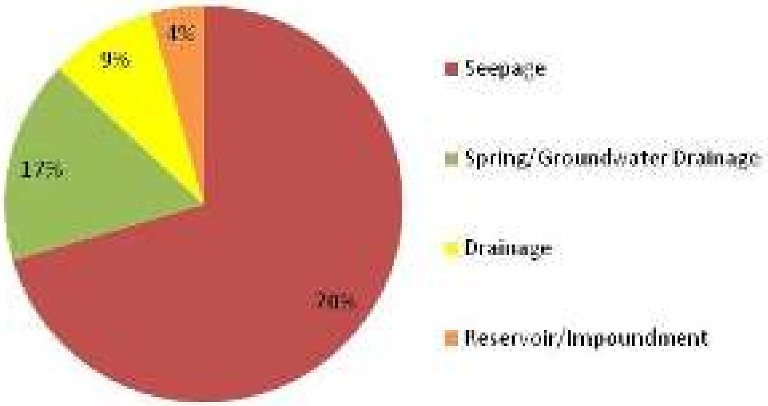


FIGURE 40. Lake type distribution of WDNR classified lakes in the USCECR watershed.

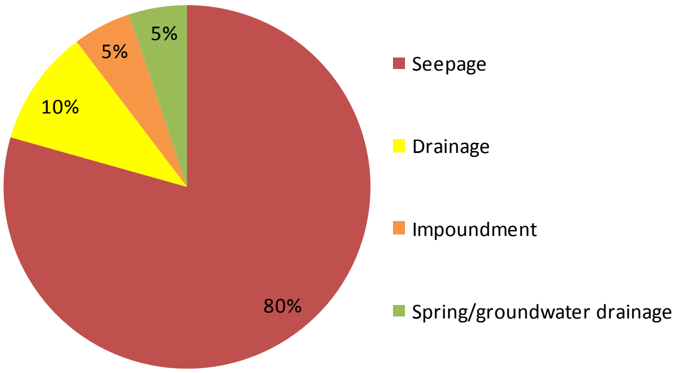


FIGURE 41. Lake type distribution of the study lakes in USCECR watershed.

Geology and Soil

The composition of the geology in the watershed affects the water quality of the lakes which in turn affect the type and amount of organisms within a lake. Some of the minerals in soil or rock (such as iron and calcium) may reduce some of the affects of phosphorus inputs to a lake. Soils of the region consist of deep, stratified outwash sands from past glaciations, overlying iron-rich bedrock. In areas where there is a shallow depth to bedrock elevated iron concentrations can occur in groundwater causing higher iron concentrations in the lakes. Differences in the degree of water table-bedrock interaction help explain the variability in lake iron concentrations observed in the USCECRW (FIGURE 42 and FIGURE 43).

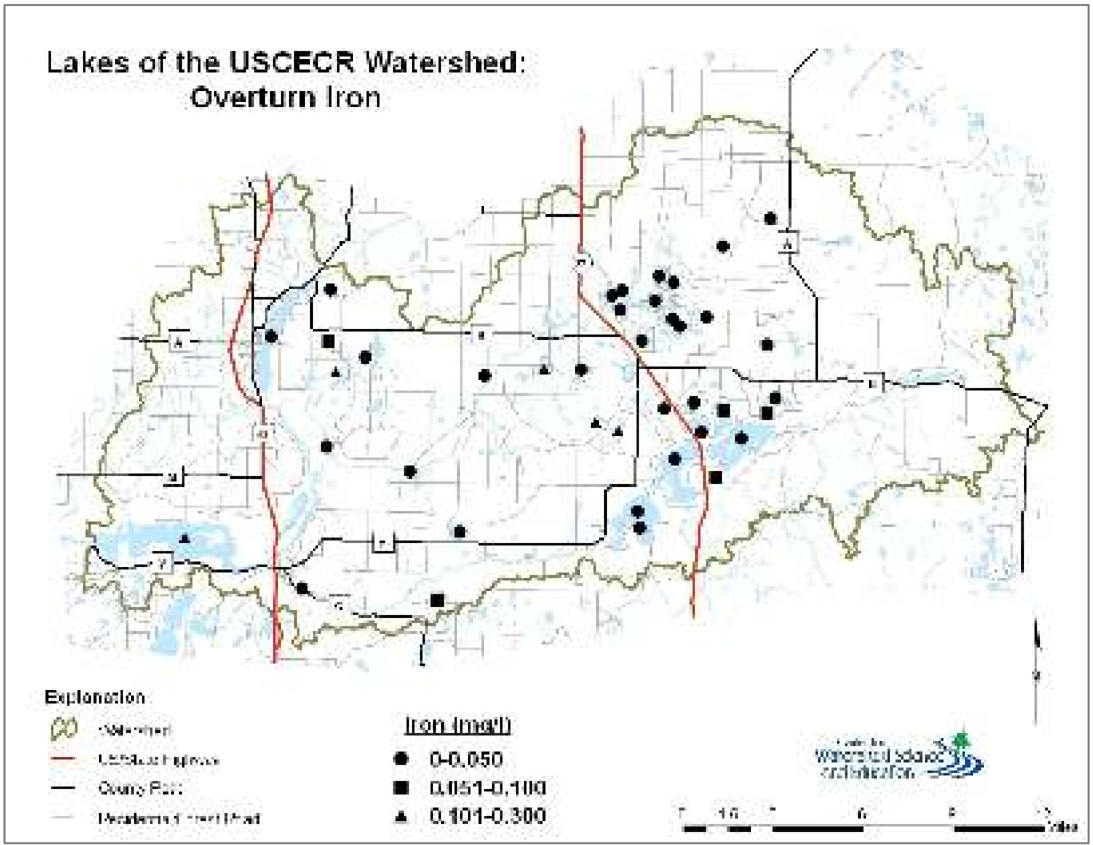


FIGURE 42. Average concentrations (mg·l^{-1}) of iron in study lakes during overturn periods, 1979-2009.

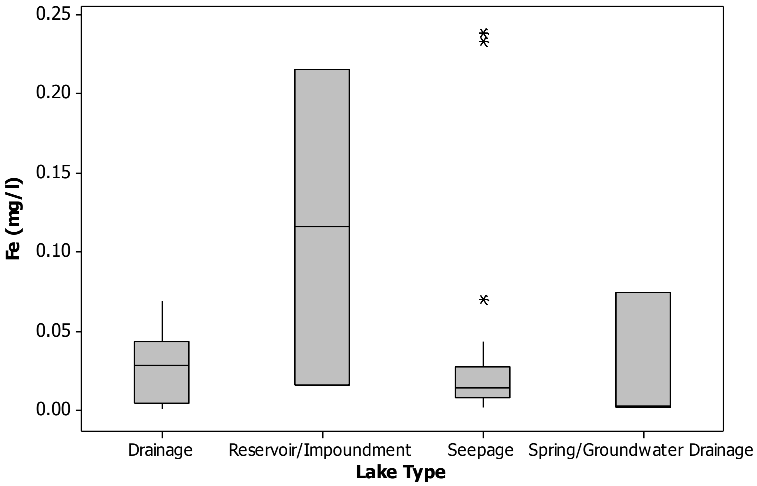
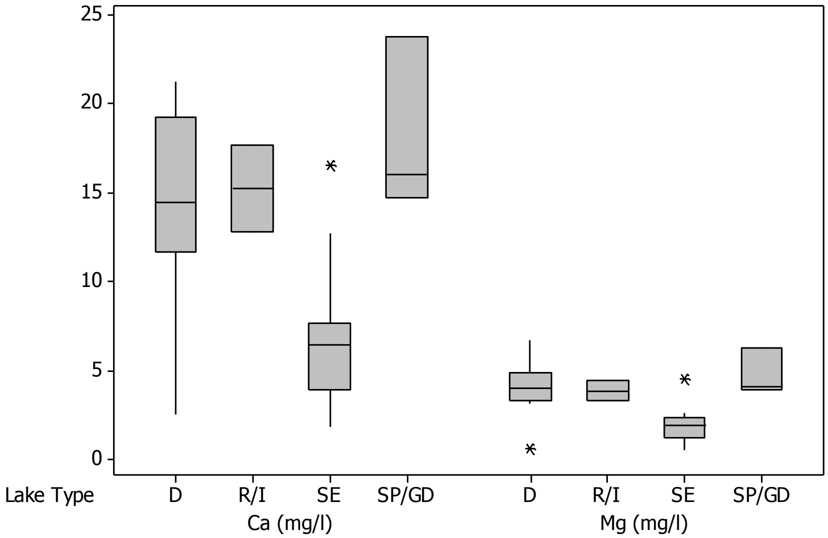


FIGURE 43. Iron concentrations (mg·l^{-1}) in study lakes by lake type during overturn periods, 1979-2009.

Conversely to iron, the lack of carbonate in the soils and rock results in consistently scarce amounts of calcium and magnesium in groundwater and surface water in the USCECRW. These two minerals are the primary components of "total hardness" which correlates to a lakes productivity by affecting the ability of aquatic organisms to grow calcium-rich shells and bones, and alkalinity which determines a lake's ability to resist changes in pH due to inputs such as acid rain. All of the 42 study lakes had total hardness concentrations less than 90 mg/l (TABLE 7 and FIGURE 44); lakes with concentrations less than 90 mg/l have a greater response by algae to phosphorus additions, and may benefit from phosphorus management (Shaw et al., 2009). Lakes with total hardness concentrations less than 60 mg·l^{-1} $CaCO_3$ are termed soft water lakes. Total hardness concentrations less than 25 mg·l^{-1} $CaCO_3$ also present an increased risk from their susceptibility to acid rain and a limited capacity to neutralize toxins. These lakes may benefit from efforts to prevent surface runoff containing phosphorus from reaching the lake (Shaw et. al, 2009). Of the 42 lakes analyzed for total hardness, 16 had an average concentration less than 25 mg·l^{-1} $CaCO_3$, with 15 of the 16 being seepage lakes (TABLE 7). The Eau Claire River area had higher concentrations of total hardness and alkalinity (FIGURE 45 and FIGURE 46).



D = Drainage, R/I = Reservoir/Impoundment, SE = Seepage, SP/GD = Spring/Groundwater Drainage.

FIGURE 44. Calcium and magnesium concentrations (mg·l^{-1}) in study lakes by lake type during overturn periods, 1979-2009.

TABLE 7. Summary of total hardness statistics by lake type.

	Total Hardness (mg·l^{-1} $CaCO_3$)				
Lake Type	**Min**	**Mean**	**Max**	**n $_{<25\ mg/l}$**	**n $_{<90\ mg/l}$**
Seepage	7	23	60	15	27
Drainage	9	51	74	1	10
Reservoir/Impoundment	50	57	63	0	2
Spring/Groundwater Drainage	53	65	86	0	3

n = number of lakes meeting subscripted criteria.

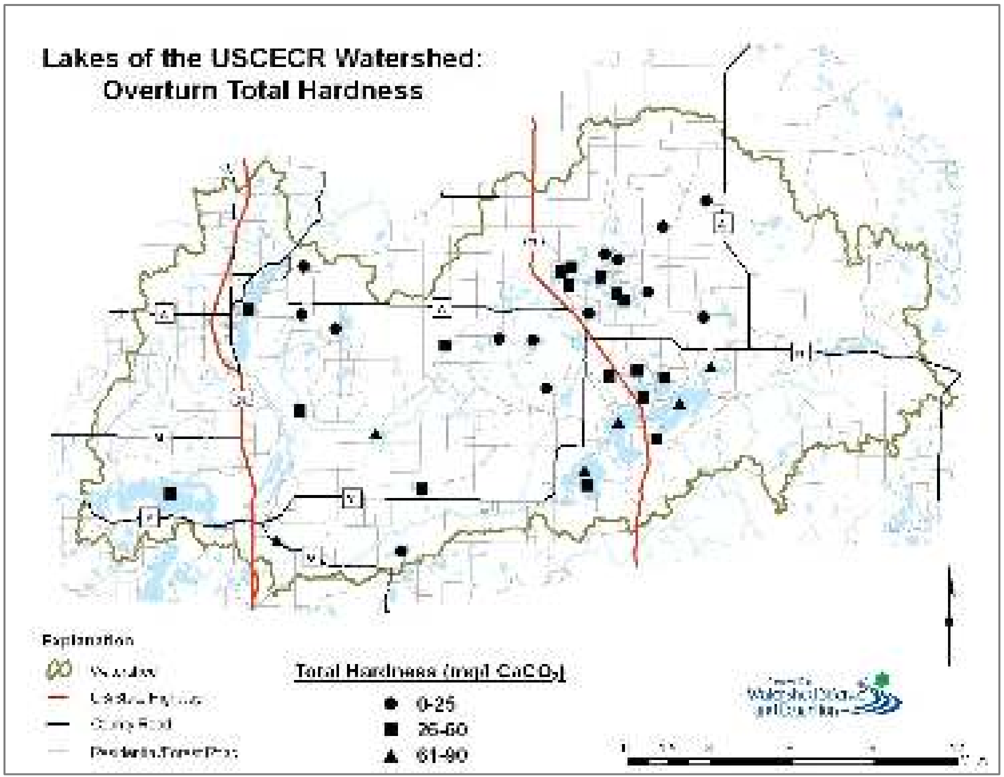


FIGURE 45. Average concentrations of total hardness (mg·l^{-1} $CaCO_3$) in study lakes during overturn periods, 1979-2009.

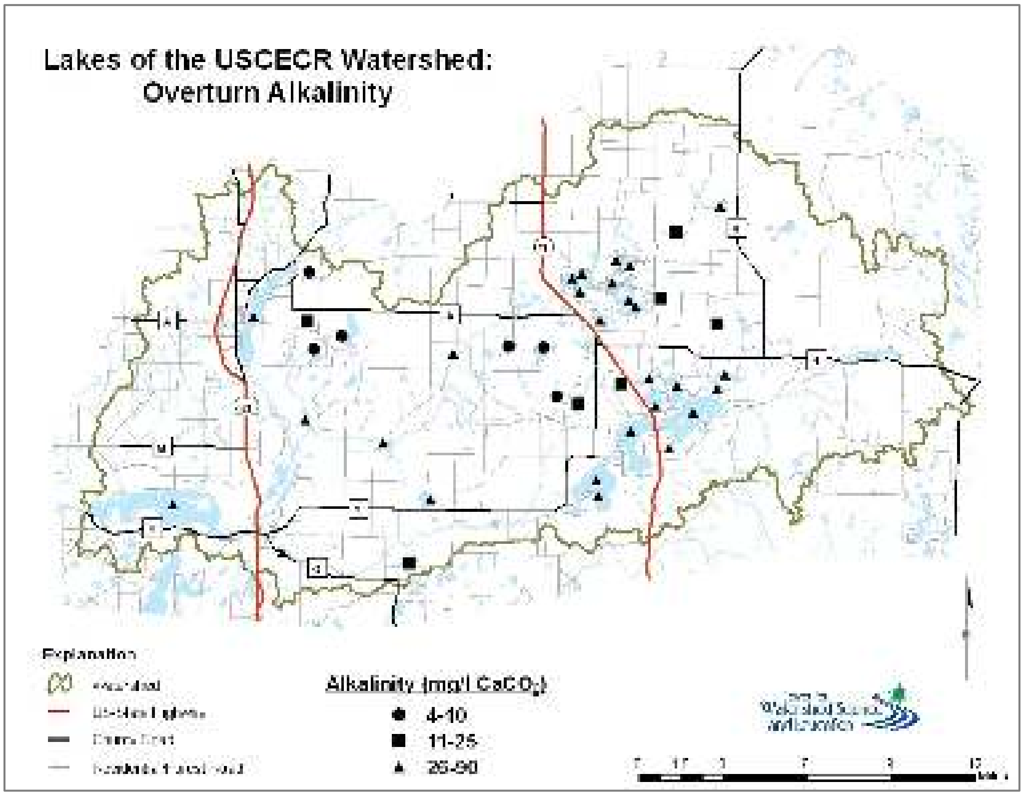


FIGURE 46. Average concentrations of alkalinity (mg·l^{-1} $CaCO_3$) in study lakes during overturn periods, 1979-2009.

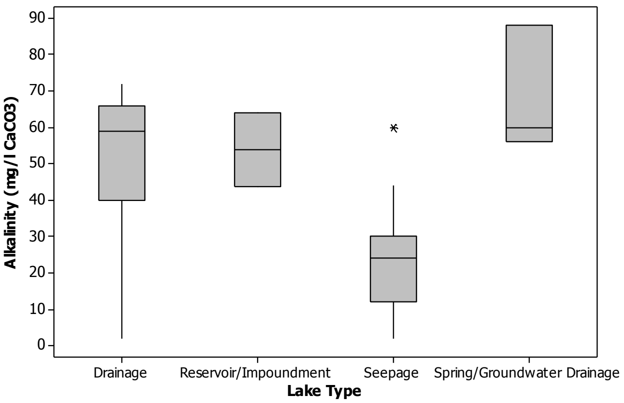


FIGURE 47. Boxplot of alkalinity (mg·l^{-1} $CaCO_3$) by lake type during overturn periods. 1979-2009.

Potassium, Sodium, and Chloride

In Wisconsin, natural occurring concentrations of potassium, sodium, and chloride are very minimal, making elevated concentrations of these minerals a good indicator of contaminants from human activity (Shaw et al., 2002). As mentioned earlier in this document, the primary sources for these minerals include road salt, fertilizers, and human and animal waste. Although they do not pose any major toxicity issues in lakes, they may be associated with other more problematic compounds.

There were no significantly elevated concentrations of potassium in the study lakes, with concentrations below 1 mg·l^{-1}. Sodium and chloride concentrations showed a little more variability, and appeared related to roadways and developed areas. Highly traveled roadways such as county and state highways, and developed areas such as the Village of Solon Springs, serve as primary contributors to elevated sodium and chloride levels from road salting. There was an observed trend of slightly higher concentrations of all potassium, sodium, and chloride in lakes with a higher degree of shoreline development, such as Upper St. Croix, and Middle and Upper Eau Claire Lakes (FIGURE 48 and FIGURE 49). This is likely a result of road salting and/or effluent from septic systems. When evaluating these data by lake type, little variability occurred with potassium and chloride but some variability occurred with sodium with higher sodium concentrations measured in the impoundments (FIGURE 50).

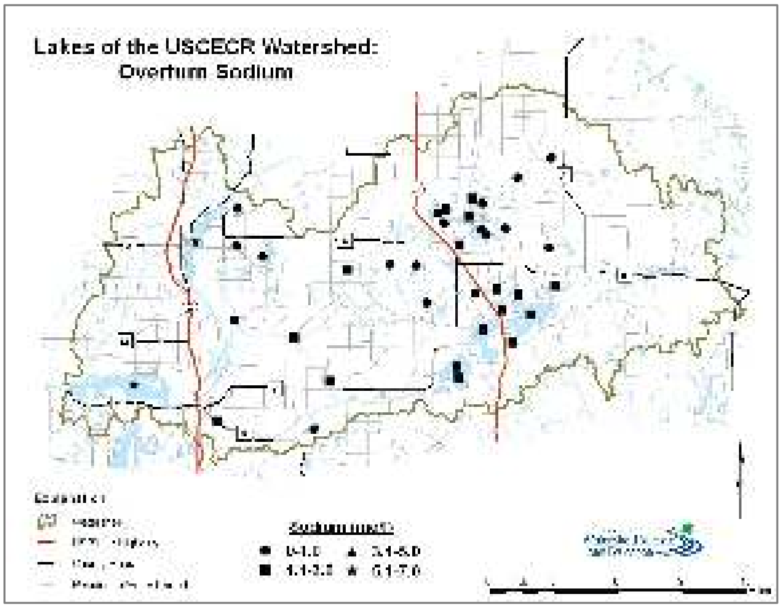


FIGURE 48. Average sodium concentrations (mg·l^{-1}) in samples from study lakes during overturn, 1999-2009.

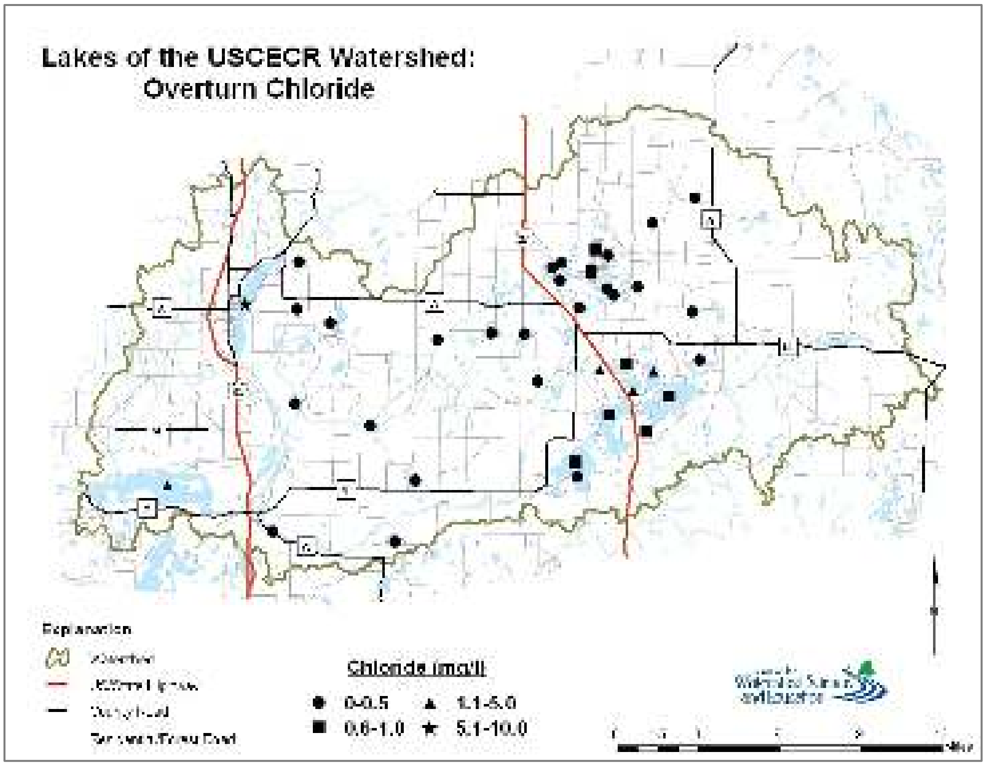
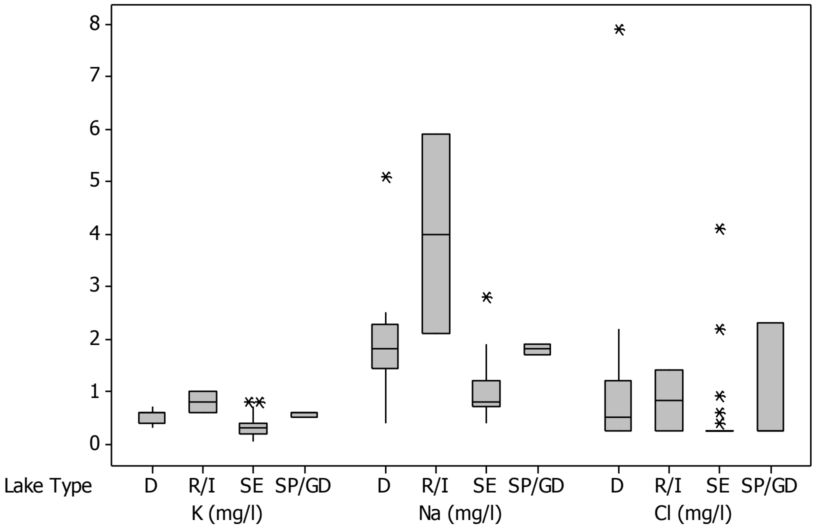


FIGURE 49. Average chloride (mg·l^{-1}) in samples from study lakes during overturn, 1999-2009.



D = Drainage, R/I = Reservoir/Impoundment, SE = Seepage, SP/GD = Spring/Groundwater Drainage.

FIGURE 50. Boxplot of average potassium, sodium, and chloride concentrations (mg·l^{-1}) by lake type during overturn periods.

Nitrogen and Phosphorus

Phosphorus limits plant and algae growth in 80% of Wisconsin's lakes (Shaw et. al, 2002). Second only to phosphorus is nitrogen. Nitrogen sources can occur naturally but many anthropogenic sources also exist including fertilizer, exposure of soil, septic systems, and domestic animals. Nitrogen can exist as a variety of organic and inorganic forms, and is most readily available to plants as inorganic nitrate (NO_3^-) and ammonium (NH_4^+). Therefore, a common measure of nitrogen is inorganic nitrogen, consisting of nitrate and ammonium. If the combination of these inorganic forms exceeds 0.3 $mg \cdot l^{-1}$ (as N) in lake water during spring, there is sufficient nitrogen present to support summer algal blooms (Shaw et. al, 2002). Nitrogen can also enhance the growth of aquatic vegetation. Although some variability occurred between the lakes, all of the 41 study lakes had mean spring inorganic nitrogen concentrations less than 0.3 $mg \cdot l^{-1}$ (FIGURE 51).

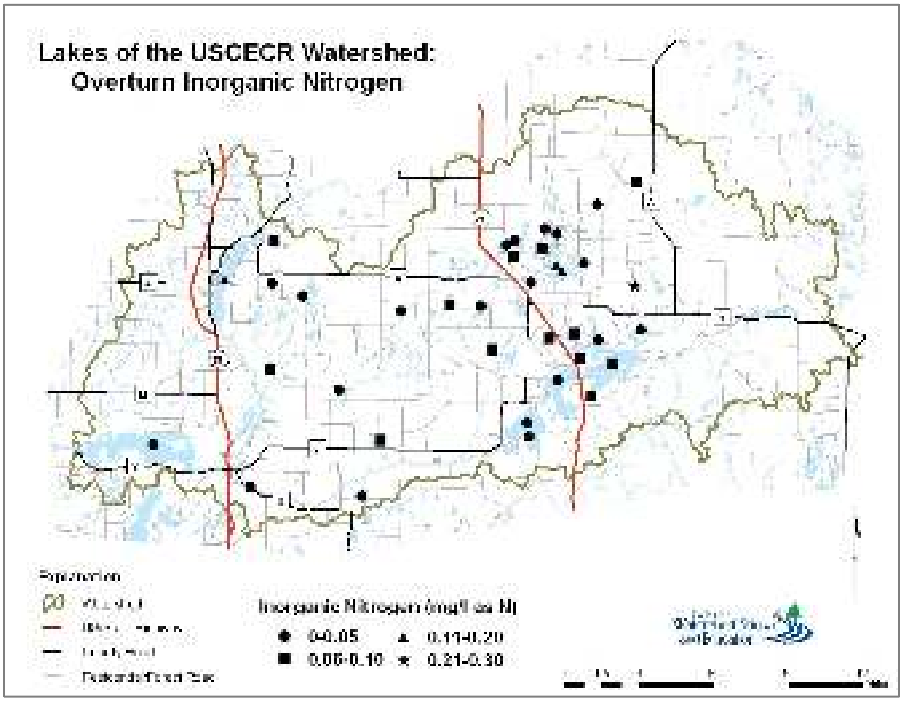


FIGURE 51. Average inorganic nitrogen ($mg \cdot l^{-1}$ as N) from study lakes during overturn, 1999-2009.

TABLE 8. Inorganic nitrogen concentrations by lake type.

	Inorganic Nitrogen ($mg \cdot l^{-1}$ *as N)*				
Lake Type	**Min**	**Mean**	**Max**	**Reference Value**	**ncv**
Seepage	0.005	0.06	0.28	0.30	0
Drainage	0.005	0.04	0.11	0.30	0
Reservoir/Impoundment	-	0.02	-	0.30	0
Spring/Groundwater Drainage	0.005	0.01	0.01	0.30	0

ncv = number of lakes exceeding the reference value.

Many natural and altered characteristics can contribute phosphorus to a lake including soil type, geology, topography along with near shore and watershed land covers, land uses, and land management practices. Results were summarized and interpreted using the WDNR phosphorus standards (TABLE 9). These standards were developed to interpret median values from a set of a minimum of four samples collected between May 1 and October 31, with at least one sample per 30 day period. In TABLE 9, the flag values for each lake type category indicate the threshold where lakes may begin to benefit from the implementation of phosphorus management strategies to prevent phosphorus concentrations from creating in-lake problems; criteria values are levels where actions to reduce a lake's phosphorus concentrations are warranted. The more problematic criteria concentration is the point at which phosphorus concentrations are likely to cause excessive aquatic plant and algal growth which may lead to winter fish kills and poor aesthetics (green, turbid, odorous water).

Of the 17 lakes analyzed for phosphorus, eight had individual mean concentrations exceeding the respective flag value (based on lake type). Overall, phosphorus concentrations measured in the study lakes should only present minor to moderate increases in algae and/or aquatic plants. Two exceptions to this generalization are Upper St. Croix Lake in Douglas County and Pickerel Lake in Bayfield County; both have average total phosphorus concentrations which exceed the criteria concentrations (FIGURE 52).

TABLE 9. Total phosphorus statistics by lake type and associated WDNR standards. Shaded values exceed the flag value.

	Total Phosphorus (µg/l)					
Lake Type	**Min**	**Mean**	**Max**	**Flag Value**	**Criteria Concentration**	**n**
Shallow Seepage	12	14	16	≥15	≥40	1
Deep Seepage	11	16	31	≥15	≥20	2
Shallow Drainage	23	24	25	≥28	≥40	0
Deep Drainage	9	26	44	≥20	≥30	1
Reservoir/Impoundment	22	26	30	≥15	≥40	4
Spring/Groundwater Drainage	-	17	-	NA	NA	NA

NA = Not Applicable, n = number of lakes exceeding the flag value.

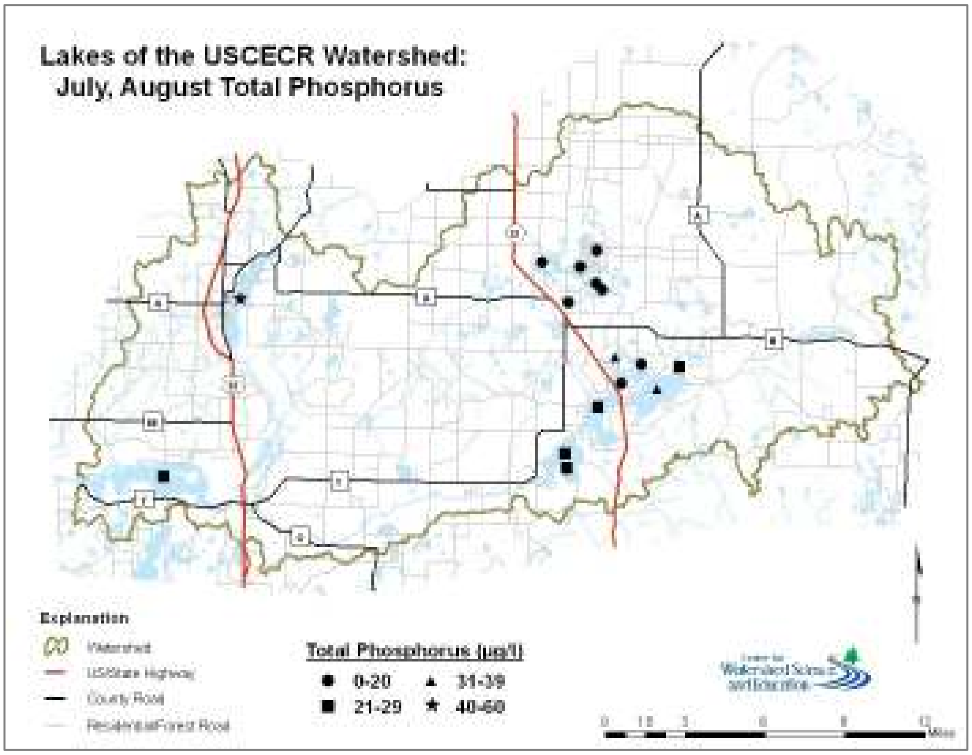


FIGURE 52. Average total phosphorus ($\mu g \cdot l^{-1}$), in samples collected from study lakes in July-August, 1999-2009.

Water Clarity

Water clarity is often a good indicator of water quality; the amount of suspended solids (turbidity) within the water column, the color of the water, and algae largely affect water clarity measures. A Secchi disc is the most common tool for measuring water clarity, and consists of an 8-inch diameter disc, painted black and white in alternating quarter sections (FIGURE 53). The disc is used to measure the depth that light penetrates into the water and roughly represents the depth that aquatic plants can grow.

An evaluation of 72 lakes displayed a broad range of water clarity measurements across the USCECRW (FIGURE 54). When summarized by lake type, there was no statistically significant difference between lake type classes as given by mean Secchi depth, with lake type mean values ranging from 7.9 ft in reservoirs/impoundments to 10.9 ft in the spring/groundwater drainage class (FIGURE 55).

FIGURE 53. Example of a Secchi disc used for measuring water clarity.

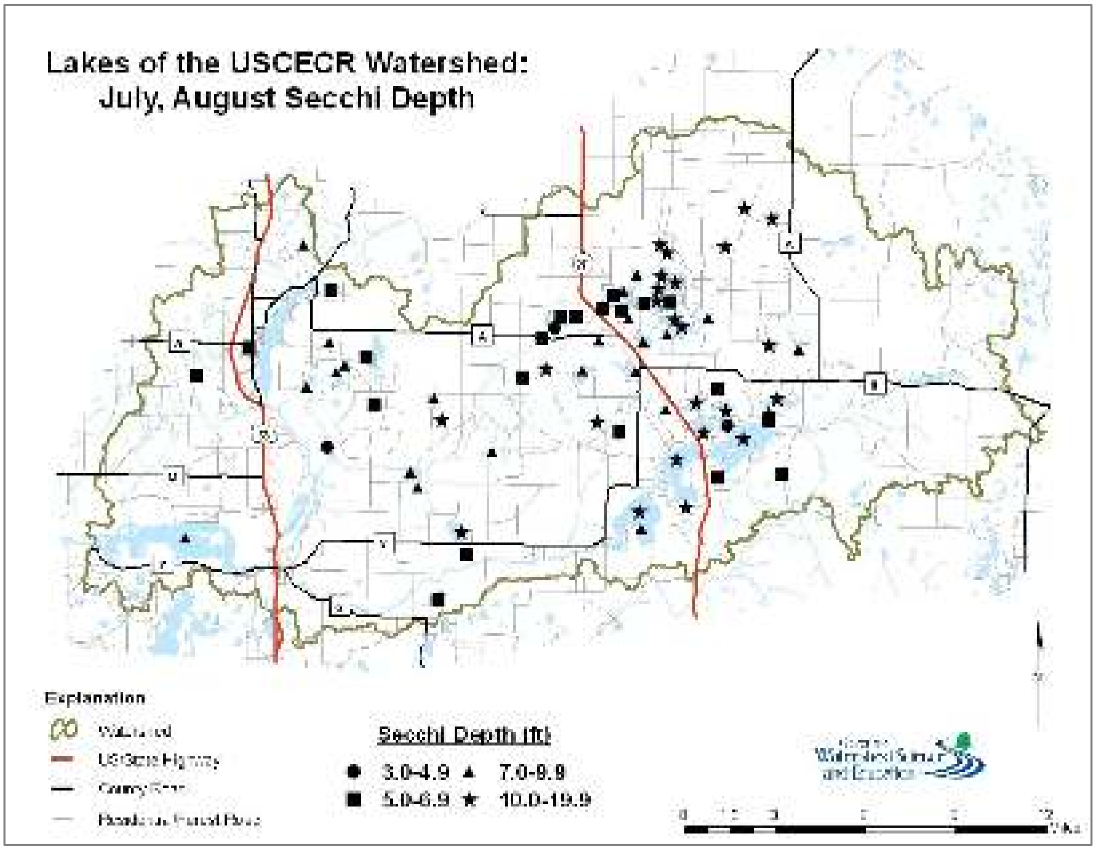


FIGURE 54. Average Secchi depth (ft) measured in lakes in July-August, 1999-2009.

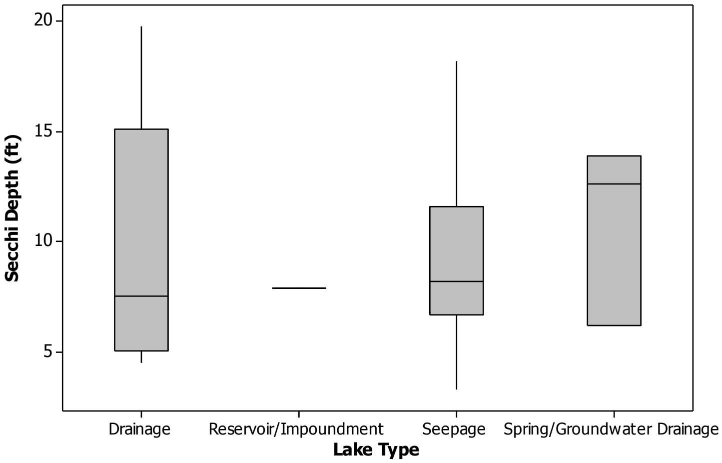


FIGURE 55. Box plot showing range of Secchi depth (ft) by lake type measured in 72 lakes in the USCECRW, July-August, 1999-2009.

Since water clarity measures can be affected by the color of water and the amount of suspended sediment and/or algae, we can look at the relationships to other water quality measures to determine the primary driver related to water clarity measures in a lake or set of lakes. Same date concentrations of TP were plotted against measures of Secchi depth to evaluate the relationship of these measures in the study lakes. A positive correlation resulted regardless of lake type' however, the relationship was weak (FIGURE 56). It should be noted that despite this positive relationship in many of the lakes, many of the measures don't fall on this line or exhibit this relationship. This is likely due to the fact that many of the water bodies in the USCECRW have stained dark brown colored water (associated with natural tannins in the water) which would reduce water clarity measures. We were not able to substantiate this supposition because there was insufficient color data from the lakes in this dataset.

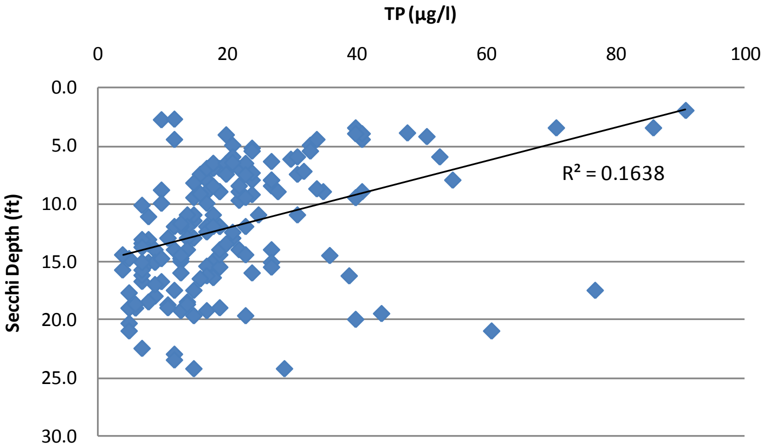


FIGURE 56. Secchi depth (ft) observations vs. TP ($\mu g \cdot l^{-1}$) concentrations in samples collected from all lake types, 1973-2007.

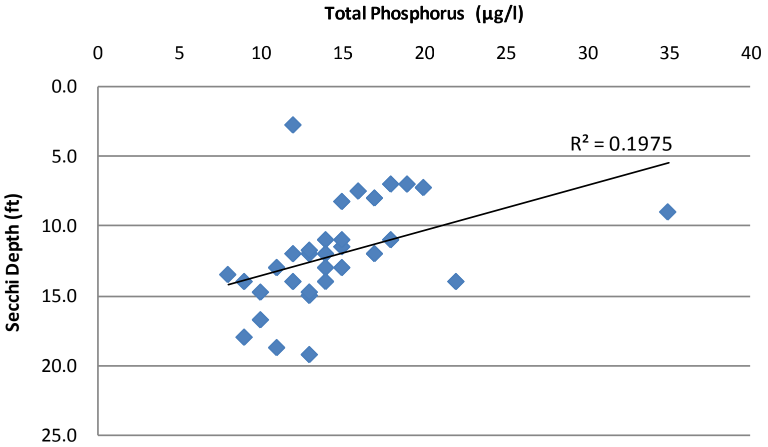


FIGURE 57. Secchi depth (ft) observations vs. TP ($\mu g \cdot l^{-1}$) concentrations for seepage lakes in the USCECRW, 2001-2007.

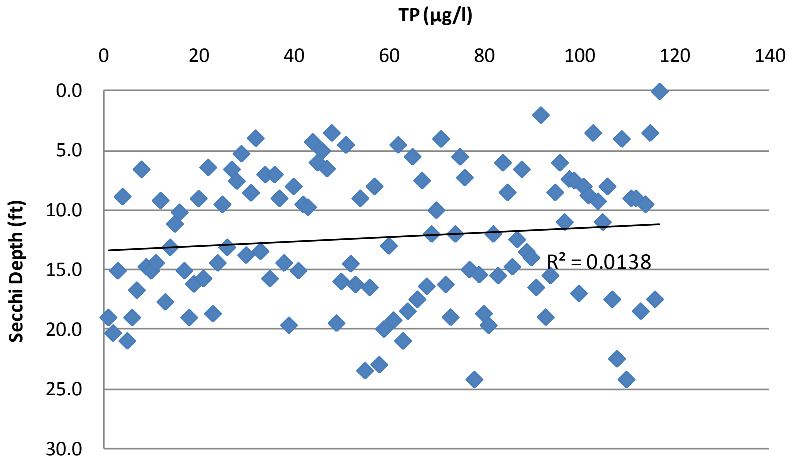


FIGURE 58. Secchi depth (ft) observations vs. TP ($\mu g \cdot l^{-1}$) concentrations for drainage lakes in the USCECRW, 1988-2007.

Surface Water and Groundwater Comparison

Data collected from synoptic sampling of groundwater, lakes, and streams were compared to provide a greater understanding of water quality and relationships to geology in the USCECRW. Major differences between the types of water are related to the amount of time the water has spent in the watershed. Older water would result in higher iron, manganese, magnesium, and calcium and less substantial loadings of sodium, potassium, and phosphorus (TABLE 10).

Stream baseflow samples are interpreted as having higher concentrations of dissolved constituents because the residence times and flow-paths of groundwater discharging to streams are generally longer than those of domestic wells, allowing for the dissolution of more materials. Groundwater may take decades to discharge to a stream whereas the contributing areas of relatively shallow domestic wells in sandy soils capture younger water (less than ten years) from near the well (Gotkowitz et al., 2005).

TABLE 10. Mean concentrations ± 1 S.E. for each synoptic sample water type and for all water types combined. All measurements are in $mg \cdot l^{-1}$; n = number of samples; means with the same letter are not significantly different across water types (using natural-log transformed variables to address normality).

Variable	Stream Baseflow	Lake Overturn	Groundwater	All Water Types	Detection Limit
Calcium	17.9 ± 0.8 a	9.8 ± 0.9 c	13.3 ± 0.7 b	13.7 ± 0.5	0.1
Iron	0.493 ± 0.078 a	0.025 ± 0.006 c	0.261 ± 0.111 b	0.263 ± 0.051	0.001
Potassium	0.6 ± 0.04 a	0.4 ± 0.03 b	0.6 ± 0.04 a	0.5 ± 0.02	0.1
Magnesium	5.68 ± 0.33 a	2.68 ± 0.24 b	3.66 ± 0.22 c	4.00 ± 0.19	0.01
Manganese	0.057 ± 0.010 a	0.004 ± 0.001 c	0.016 ± 0.004 b	0.026 ± 0.004	0.0001
Sodium	3.3 ± 0.4 a	1.4 ± 0.1 b	2.6 ± 1.1 b	2.4 ± 0.4	0.1
Phosphorus	0.016 ± 0.001 a	0.010 ± 0.001 b	0.013 ± 0.001 ab	0.013 ± 0.001	0.003
n	*41*	*39*	*49*	*129*	

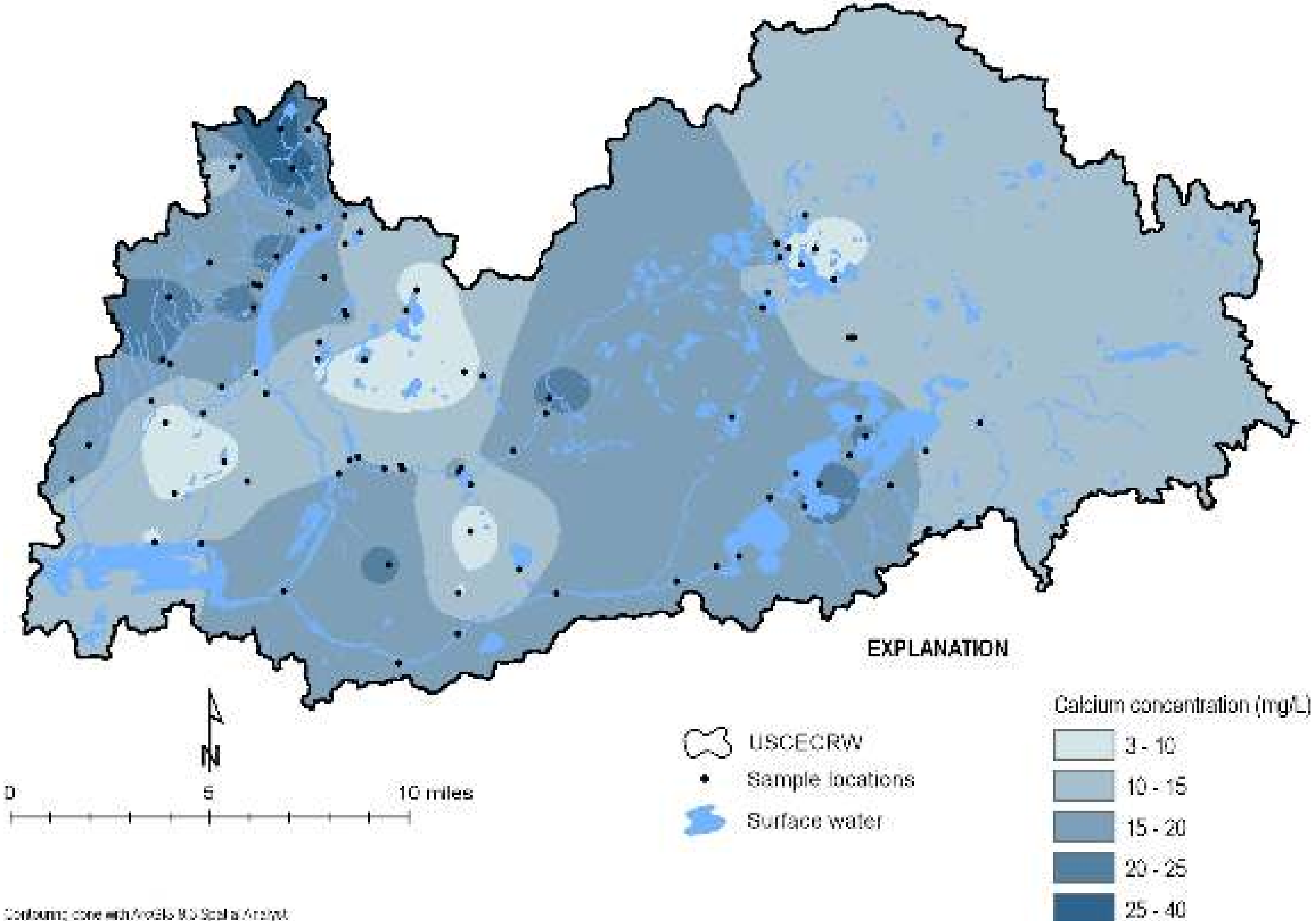
These data were also combined to developed watershed scale maps of the dominant water quality measures including calcium, iron, and phosphorus. Although all of the calcium concentrations measured in USCECRW would be considered soft water, concentrations of calcium ranged from 3-40 $mg \cdot l^{-1}$ (FIGURE 59). Much of the variability can be attributed to the type of geology and the age of the water. The amount of calcium in water affects both plants and animals playing a large role in the productivity of a body of water; greater concentrations result in greater productivity. Calcium has been declining in some of the soft water lakes in North America which can result in reduced productivity of daphnia and other organisms that are at the base of the food web. The decline in calcium appears to be related to acid rain (Jeziorski, et al. 2008).

Iron is a naturally occurring metal which can play a role in reducing impacts of phosphorus to surface water by co-precipitating soluble phosphorus (Stauffer and Armstrong 1986). While in this form, phosphorus is not available for use by aquatic plants and algae. In the USCECRW the higher iron concentrations are a result of groundwater in contact with igneous rock which can be found in the northwest and southeast parts of the watershed (FIGURE 60).

Natural concentrations of phosphorus in groundwater are quite variable across the UWCECRW. Pockets of elevated phosphorus can be found in the northwest and central regions of the watershed (FIGURE 61). Surface water that receives phosphorus from groundwater may exhibit a greater response by algae and aquatic plants to external/cultural sources of phosphorus than surface water with lower background groundwater phosphorus concentrations.

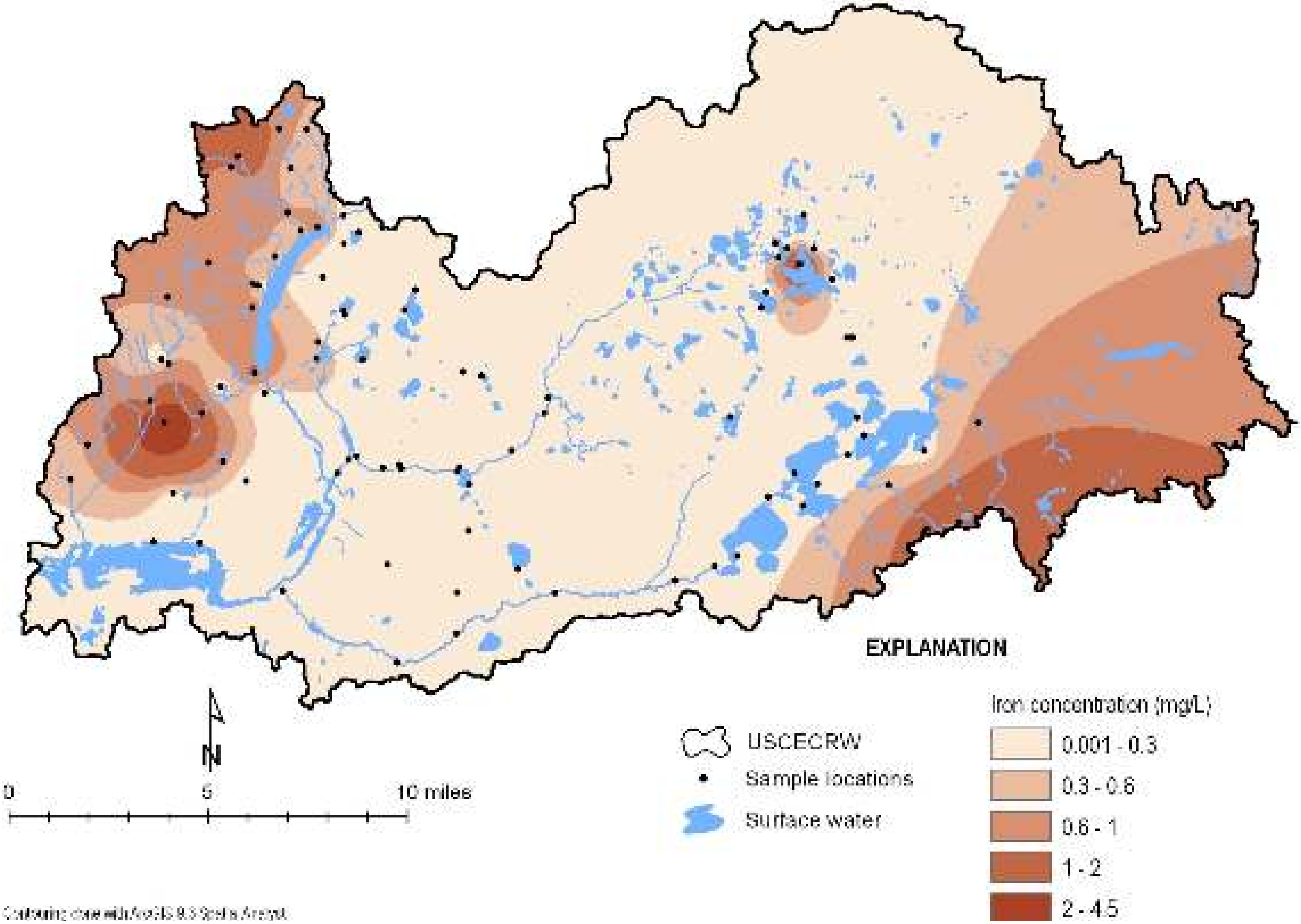
The groundwater and stream synoptic samples were used to create color contour maps of phosphorus (dissolved reactive phosphorus), iron, and calcium concentrations in the USCECRW (Appendix L). The color contour maps spatially represent the distribution of the constituents across the landscape. Phosphorus was mapped because of its significance in the surface water, and calcium and iron were mapped because they can react with phosphorus to create insoluble precipitates, essentially removing phosphorus from the water.

Background concentrations of phosphorus, calcium and iron occur at higher concentrations in the north-west part the USCECRW. Since all three constituents occur at relatively high concentrations, additional phosphorus from anthropogenic sources may have greater impact to surface water. The central part of the watershed has higher concentrations of phosphorus and calcium and can behave similarly. The south-eastern part of the watershed has relatively lower phosphorus concentrations and high iron concentrations; some mitigation of anthropogenic sources of phosphorus may occur in this area.



Contouring done with ArcGIS 8.3 Spatial Analyst

FIGURE 59. Estimated distribution of calcium in the USCECRW (based on concentrations measured in groundwater, mixed lakes, and stream baseflow.



Contouring done with ArcGIS 9.3 Spatial Analyst

FIGURE 60. Estimated distribution of iron in the USCECRW (based on concentrations measured in groundwater, mixed lakes, and stream baseflow.

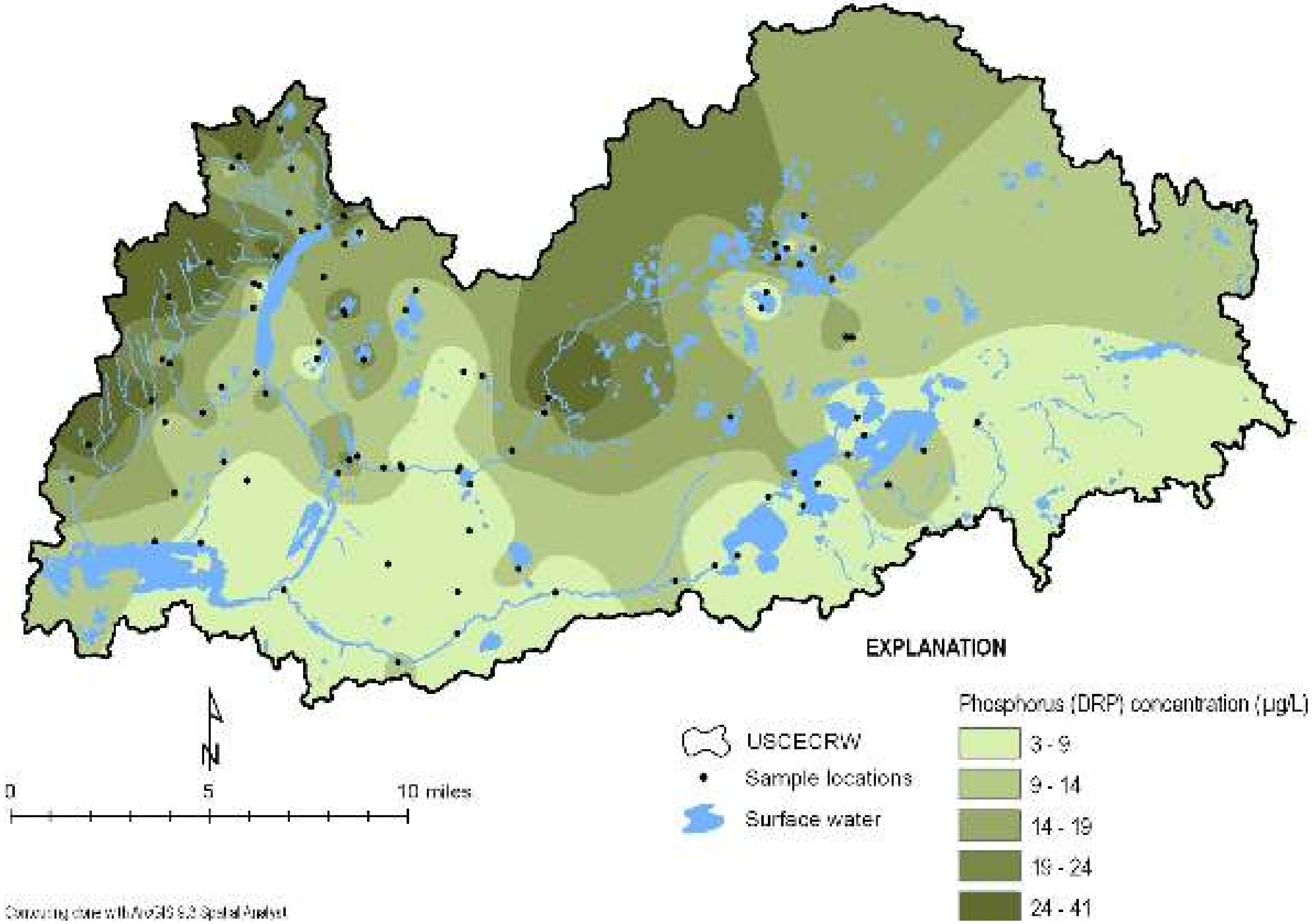


FIGURE 61. Estimated distribution of phosphorus in the USCECRW (based on concentrations measured in groundwater, mixed lakes, and stream baseflow.

Contributing Area Classification and Conservation Buffers

Although the water falling on the landscape within a watershed can potentially affect water quality in the river system, some areas within the watershed are likely to have a more direct impact than others. These most connected areas in the USCECRW were ranked based on their potential to effect surface water quality. The potential to impact water quality was based on the distribution of slopes, soil type, and direct or internal drainage. Internally drained areas are depressions on the landscape that prohibit runoff from reaching surface water. Some of the runoff water that is directed to the depression will infiltrate to groundwater or, if the soil is not permeable, the water may remain on the land's surface in a wetland.

Using a computer model based on land topography and hydrology, the model tracks from the stream uphill until a plateau is reached. All of these areas are ranked as Tier 1. Tier 1 areas have the greatest potential to impact water quality because the land within those areas has an uninterrupted slope to the drainage network, making it a potential source of storm runoff. Tier 2 represents areas that may be connected to the potential contributing areas (i.e. Tier 1) by changes to the landscape. Tier 2 areas are especially sensitive to road construction and the associated cut and fill and installation of culverts; these practices could artificially connect portions of the watershed to the stream drainage network, shifting them from a Tier 2 area to a Tier 1 area.

The maps below (FIGURE 62- FIGURE 65) show the tier and slope classification for the USCECRW. The brown regions on the maps represent internally drained areas in which the slope classifications are not displayed. This information has been used in the build-out scenarios and in the development of the educational and policy recommendations based on tiers and various slopes.

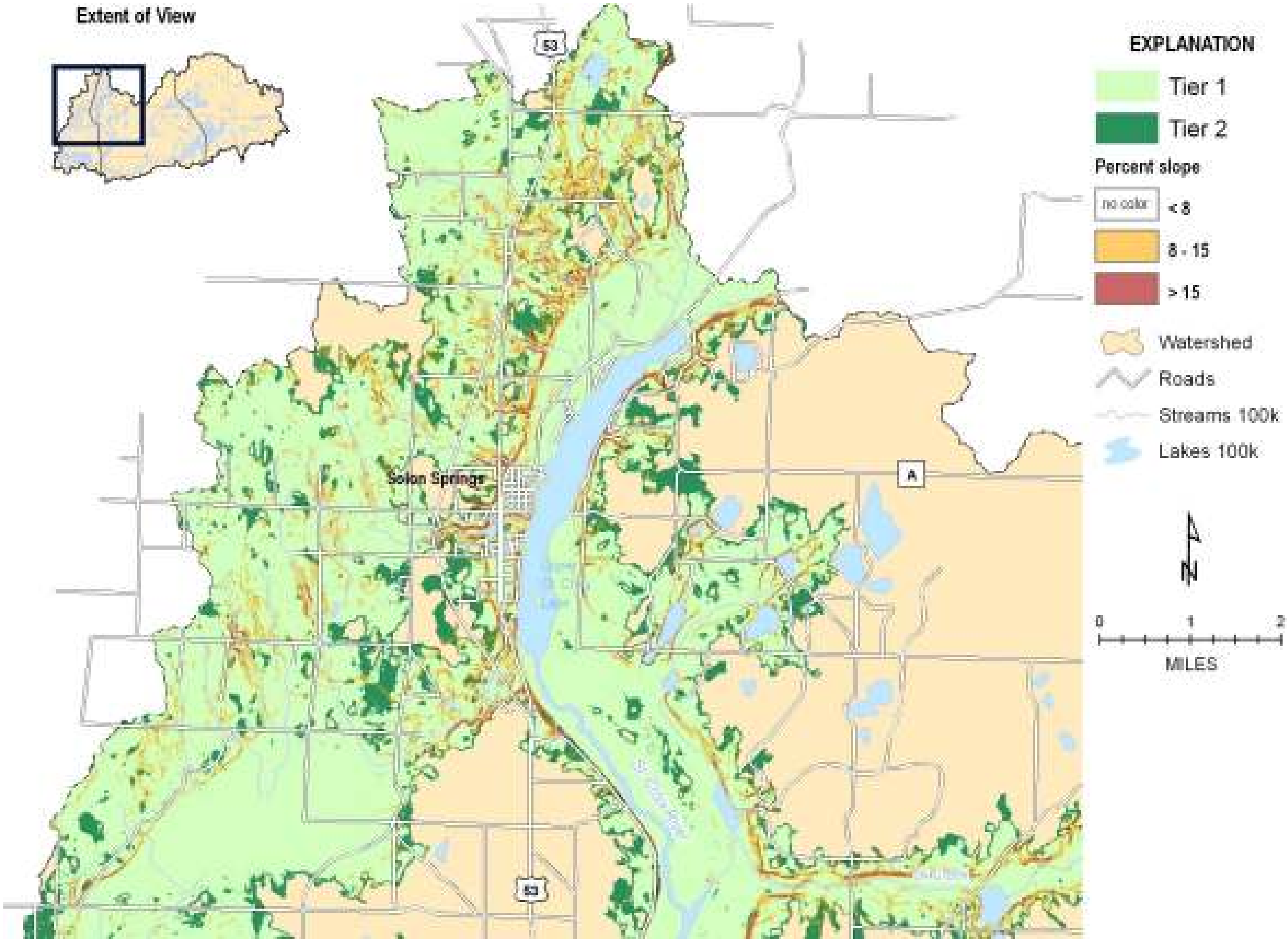


FIGURE 62. Tiers and slope classification of northwestern-part of the St. Croix River Headwaters.

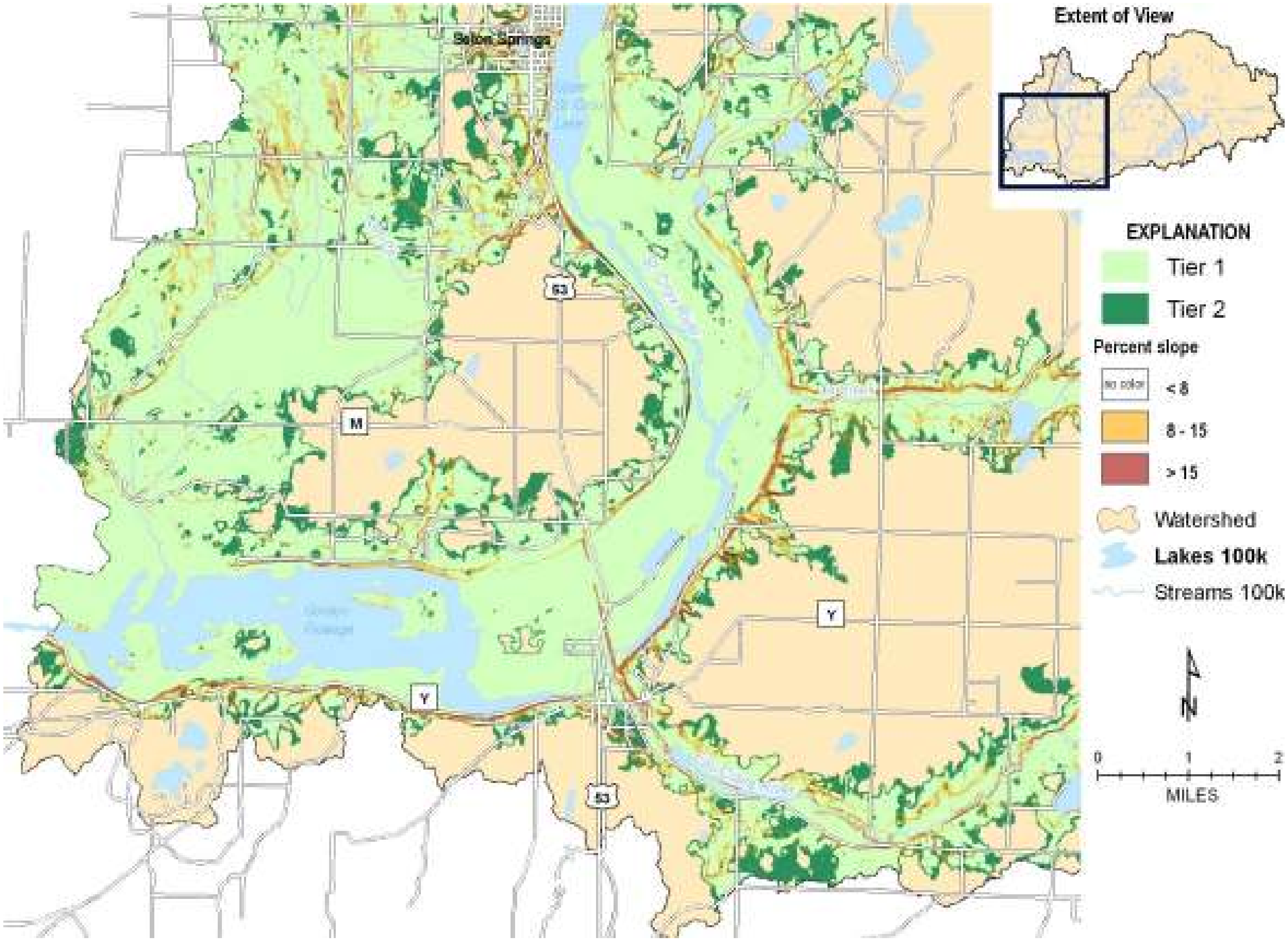


FIGURE 63. Tiers and slope classification of southwestern-part of the St. Croix River Headwaters.

FIGURE 64. Tiers and slope classification of central-part of the St. Croix River Headwaters

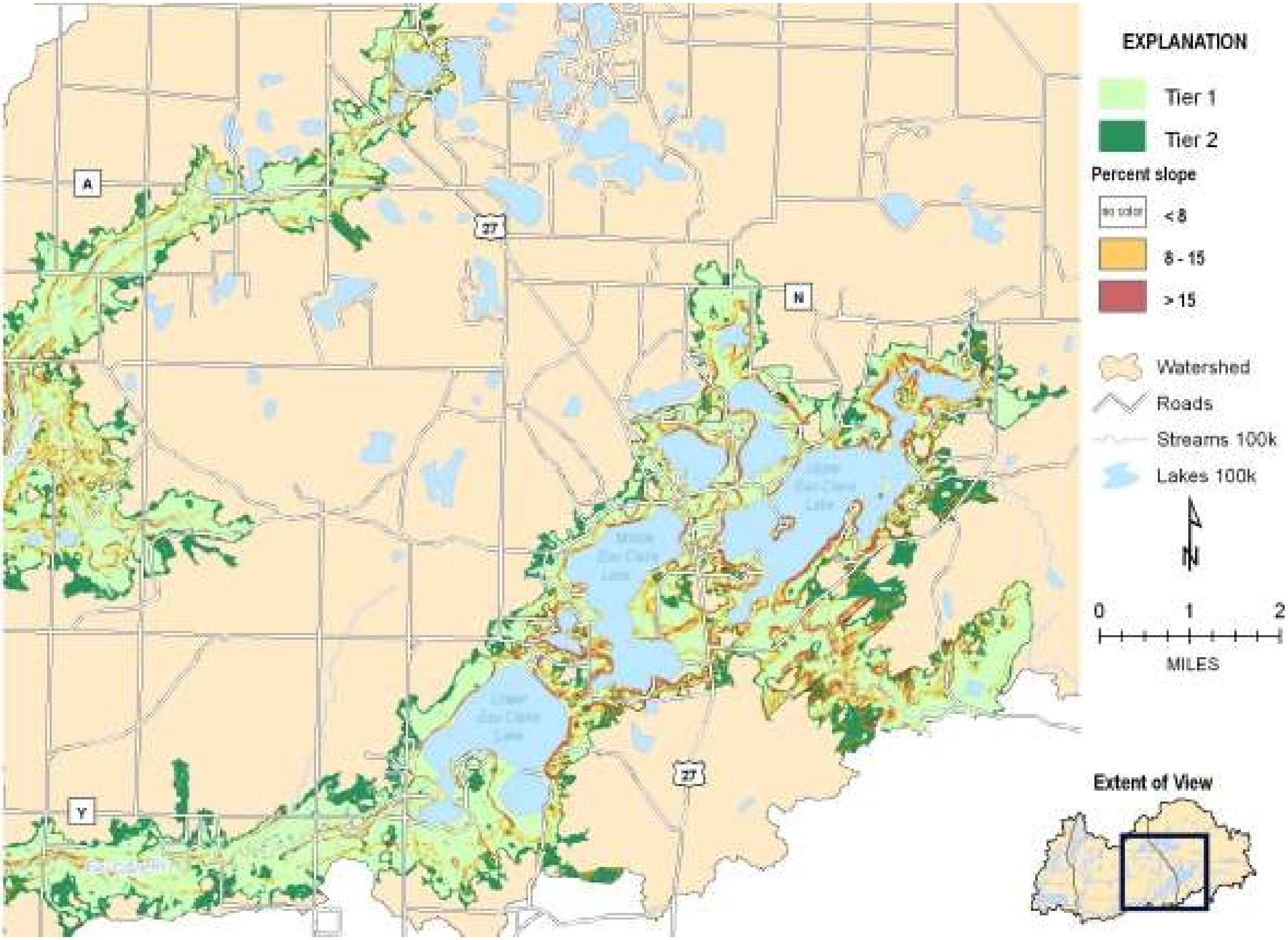


FIGURE 65. Tiers and slope classification of western-part of the St. Croix River Headwaters.

Build-out Analysis

The following is abridged from *Residential Build-Out Assessment for the Upper St. Croix Watershed* by Dan McFarlane and Anna Haines, Center for Land Use Education, UW-Stevens Point.

As part of the lake and watershed management planning process, Center for Land Use Education (CLUE) conducted a residential build-out analysis for the USCECRW to identify future residential development potential in accordance with current land regulations. The results are displayed in two ways: for the entire watershed and within direct drainage areas. We used Geographic Information Systems (GIS) software, land information, and Community Viz™ to identify and quantify development constraints (i.e., land-based features that restrict future development) and land yet available for future development. Current zoning regulations (mapped at the parcel level) were applied to the net developable land to produce maps and tables of build-out numbers in terms of the total and location of potential residential development. Finally, future land use maps were created to reflect the watershed as if it were completely built-out. The process produced theoretical growth scenarios for the watershed based on development constraints and the effect of specific zoning regulations. In total, three build-out scenarios were generated taking into account various wetland alternatives. We used a range of data sources to identify potential wetland areas as possible constraints to development in addition to other environmental and physical constraints. Results of the build-out scenarios were incorporated into a Soil Water & Assessment Tool (SWAT) to quantify the potential water quality impact of allowable development in the watershed (included earlier in this report). This analysis is functional for generalized land and watershed planning, and is not meant for site specific applications such as plotting a subdivision. Areas that would be developed to provide goods and services to a larger population are not considered in this build-out analysis.

Introduction

As rural areas continue to outpace urban areas in terms of population growth, the demands on the attractive natural amenities (i.e., riparian areas) for development has been growing. Adding new homes to the landscape increases the amount of impervious surface in the form of rooftops, driveways, asphalt, and compacted earth, preventing the infiltration of water into the ground. As a result, stormwater runoff over the land surface greatly increases, even during small rainstorm events. This alteration of the water cycle can have significant impacts to waters and habitat of the USCECRW.

To cope with this demand and to better understand the development potential around some of the region's water bodies, the CLUE conducted a residential build-out analysis for the entire USCECRW. The USCECRW was determined to be about 215,537 acres or about 337 square miles in size. Over the years, parts of the watershed have experienced waves of growth and development. FIGURE 66 illustrates the results of more than 50 years of land division in the Town of Barnes in Bayfield County, with lots created at or near the minimum lot size. One can see that in 1954 the area was mostly undeveloped, with few landowners. Over the years, hundreds of small lots have been created, and although many remain undeveloped, the stage has been set for high residential density. Conducting a build-out analysis provides visual evidence of what certain land use regulations can potentially look like in terms of density and location. An understanding of the potential of future growth can have wide ranging effects on local government decisions. Policies from housing to economic development to transportation are all influenced by the quantity and quality of future growth, so the ability to "see into the future" can help local decision makers make more informed decisions.

The USCECRW is located in both Bayfield and Douglas Counties, encompassing one incorporated village and nine unincorporated towns. The residents of the area have or are currently going through the comprehensive planning process which contains specific goals and objectives for a desired future landscape. The primary tools for achieving many of these goals are the county's zoning ordinances.

The build-out analysis is a tool used to project all possible future growth potential in a community given present environmental and physical constraints and current land use regulations using GIS. Build-out analysis can be used to visualize current land use in an area, such as a town or watershed, and to simulate where and how much future development can occur under current zoning regulations. The analysis can reflect the density of development, the consequences of zoning ordinances (and alternative scenarios), and the effects of those changes on future resources, like water quality, infrastructure costs, and population, to name a few. While build-out studies are useful, they generally cannot predict when full development will occur. This depends on many pressures, such as the local or regional economy and other socioeconomic variables.

In this study, we used the number, location, and disturbance area of potential dwelling units to quantify the amount of development and land use change possible at complete build-out. These are indicators of impervious surfaces related to non-point source pollution. By understanding the potential changes of these indicators, decision-makers and citizens can better identify actions needed to protect the resources of the USCECRW.

It is important to note that this build-out analysis projects what could happen under the current regulatory framework. This analysis makes no prediction about when, or even whether, complete build-out will occur. The build-out assessment is only concerned with what the maximum permitted development is under a certain set of regulations.

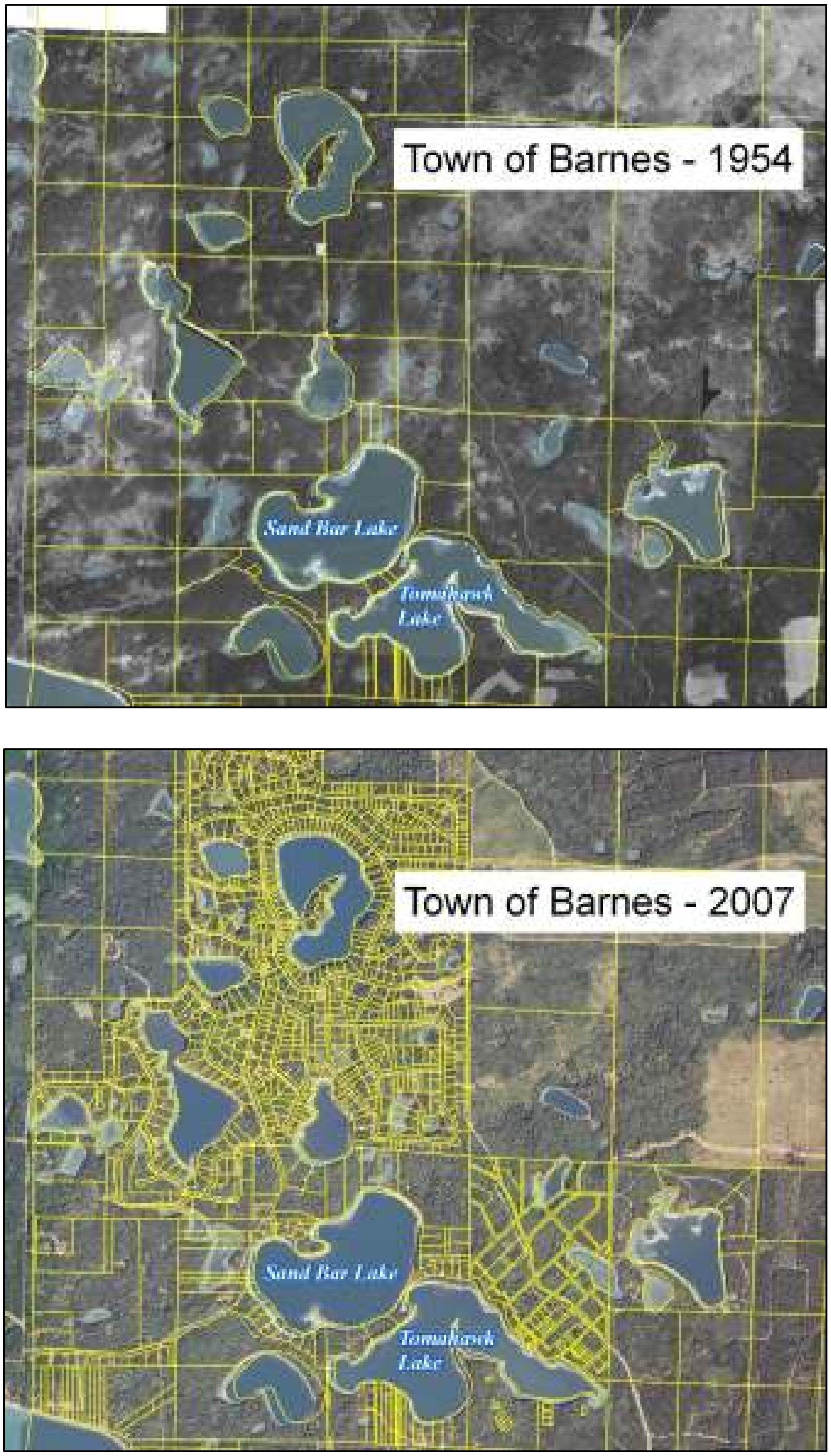


FIGURE 66. Early and current parcel patterns in the Town of Barnes in Bayfield County. Some areas have experienced complete build-out in terms of lot creation. This sets the stage for future development patterns and density.

Forecasting Future Development

We began the build-out analysis by collecting available land information layers, listed in TABLE 11, to prepare alternative build-out scenarios for the USCECRW. Available information on slopes, existing development, land use, wetlands, surface waters, roads, and public and industrial lands was combined in ArcGIS to create a comprehensive view of the watershed's environmental and physical resources.

TABLE 11. Data collection and formatting requirements.

Data	Source	Formatting
Digital tax parcels	LIO	P, C, Q
Zoning districts	LIO	P, C, Q
Land Use	USGS	P, C
Wetlands	LIO, DNR, NRCS	P, C, Q
Slopes	LIO, USGS	P, C, SA
Building points	LIO	D
DNR land	DNR	P, C, Q
County forests	LIO, DNR	P, C, Q
Industrial forests	LIO	P, C, Q
Minor civil divisions	DNR	P, Q
Road centerlines	LIO	P, C, Q, SA
Floodplains	LIO	P, C
Hydric soils	NRCS	P, C, Q
DNR wetland points	DNR	D
Surface water	DNR	P, C

Baseline Use

Current land use data was established from updating the USGS 2001 National Land Cover Dataset (NLDC) with current building locations. We digitized buildings using 2008 orthophoto for the watershed portion of Douglas County (a building point shapefile was available for Bayfield County). Buildings were then buffered by 30 meters to create a developed and disturbance area for each structure. We then combined this layer with the 2001 NLDC to produce a current landcover/use dataset.

Parcels

The digital tax parcel layers, provided by each county's Land Information Office, were crucial to the build-out analysis. First, all parcels that were not within the watershed boundary were immediately removed. We then queried the parcel database to indentify and flag publicly owned lands and industrial forest parcels. We also excluded parcels that were no longer buildable by removing developed lots within platted subdivisions because it is unlikely that they will further split and develop. Finally, the two separate county parcel layers were combined into one using the Union tool. FIGURE 67 shows current building locations and the 2009 parcel pattern. We estimate there to be 3,817 buildings in the watershed (excluding secondary buildings).

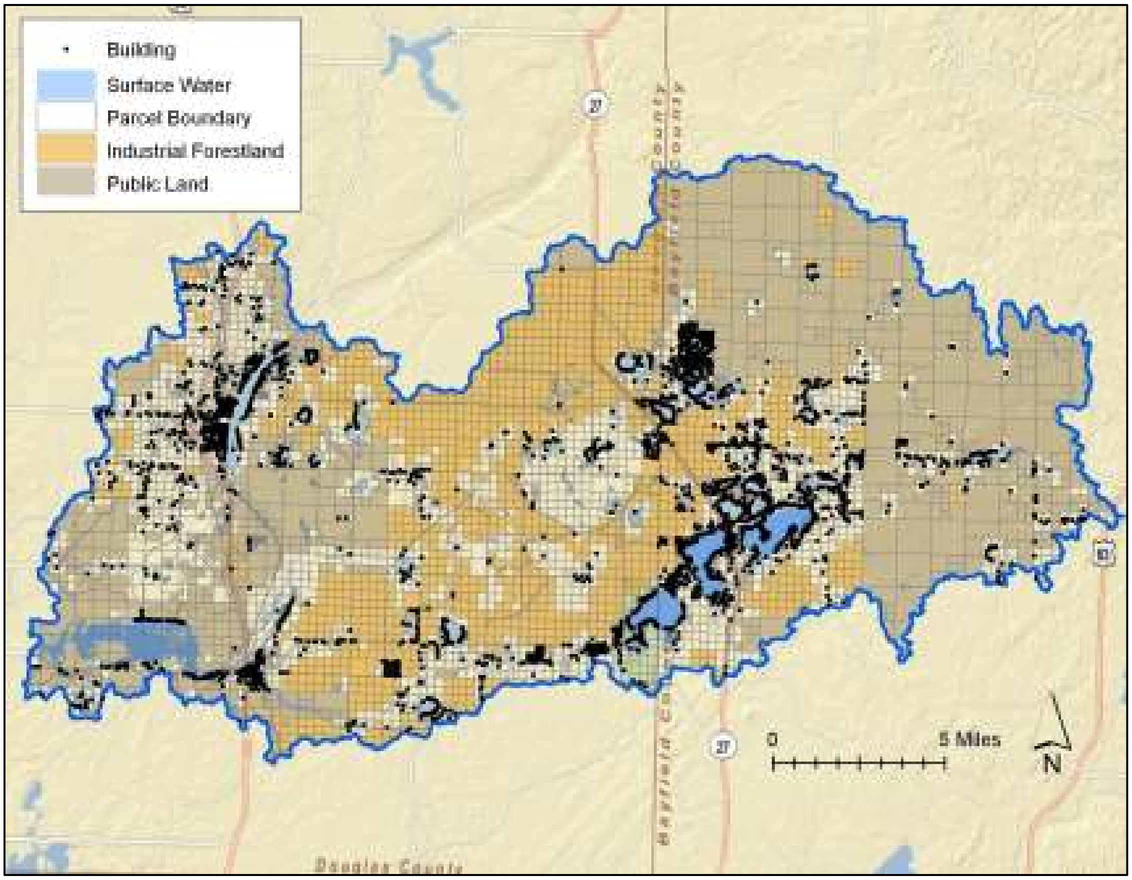


FIGURE 67. Current building locations and parcel pattern.

Zoning

Also critical to a build-out analysis is the feasibility of modeling zoning requirements. The analysis is actually a matter of dividing land areas, while not determining the real site design potential of a sub-dividable lot. Using overlay techniques, we assigned zoning districts to each lot in the parcel layer. Parcels were split where they overlapped multiple zoning districts. FIGURE 68 illustrates the 2009 zoning status for the Upper St. Croix Headwaters and shows that a large portion of residentially zoned land in the watershed is near surface water features. Oftentimes minimum lot sizes are reduced for parcels serviced by public sewer and water. Because GIS data on public services was not available, we used the municipal boundary Solon Springs as the extent of these services. We manually mapped zoning districts in Solon Springs based on a hard copy zoning map provided by the village.

This analysis made use of the following assumptions in determination of the final build-out scenarios.

- Future dwelling units will be built on the smallest sized lot allowable for the zoning district, taking into account the minimum lot size and minimum buildable area.
- There will be one dwelling unit per new lot.
- Potential unit types are not specified; they can be of any permitted use of the zoning district.
- Rezones and variances were not modeled. (Conditional use permits were modeled for the F-1 district in Douglas County)
- Cluster subdivisions and multi-family developments are not modeled in this study.
- The size of each buildable parcel was reduced by a factor that accounts for land dedicated for roads and open space requirements (this typical ranged from 0% for larger minimum lot sizes to 20% for smaller minimum lot sizes).

- Only residential development was modeled in this analysis
- Existing dwelling units were subtracted from the total allowable development for each parcel.

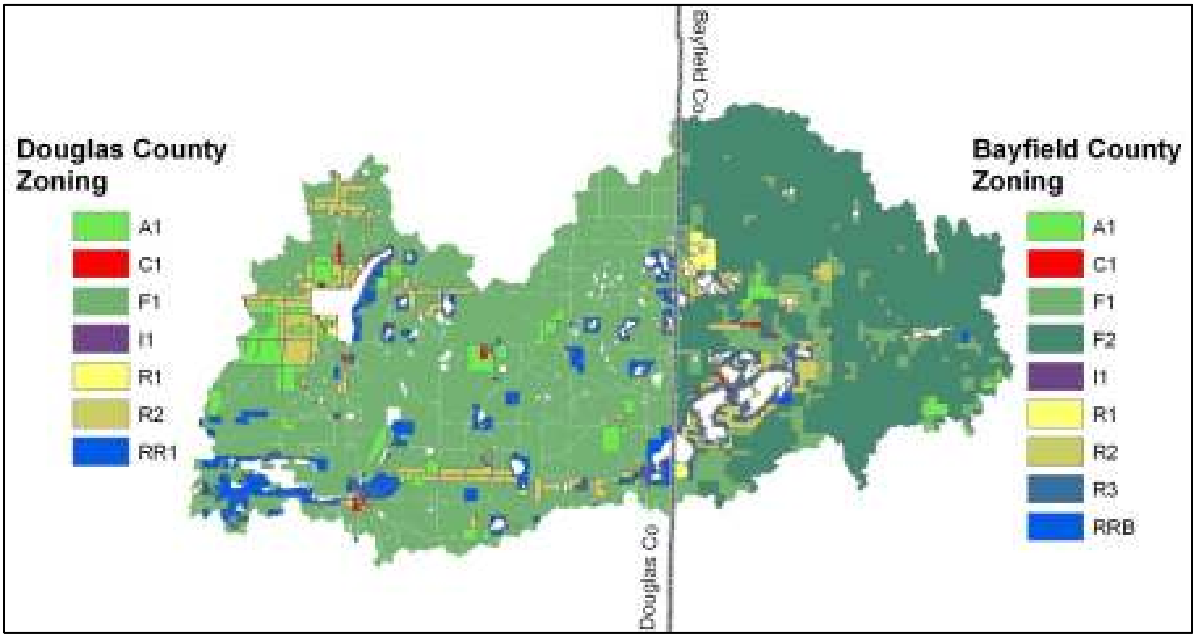


FIGURE 68. Bayfield and Douglas County zoning configuration.

Dimensional requirements, such as, setbacks, minimum lot sizes, and separation distances were obtained from each county's zoning ordinance and entered into an Excel spreadsheet. During the build-out process, buildings are modeled as point locations, with building size included in the minimum allowable distance between buildings. Each building was assumed to be 60 feet wide on all sides. Thus, for modeling purposes, the potential buildings are round with a radius of 30 feet. The additional distance between buildings was given as the average of the front, side and rear setbacks (TABLE 12).

TABLE 12. Zoning dimensional requirements for A) Bayfield County and B) Douglas County, excluding shoreland overlay standards.

A)

Zone	**R1**	**R2**	**R3**	**RRB**	**A1**	**F1**	**F2**
Minimum Lot Size	30,000 sqft	4.5 acres	2 acres	30,000 sqft	4.5 acres	4.5 acres	35 acres
Front Setback	30	50	30	30	50	50	50
Side Setback	10	75	20	10	75	75	75
Rear Setback	10	75	20	10	75	75	75
Building Radius	30	30	30	30	30	30	30
Building Separation	86	135	94	86	135	135	135

B)

Zone	**R1**	**R2**	**RR1**	**A1**	**F1**	**SS-R1**	**SS-R2**
Minimum Lot Size	20,000 sqft	5 acres	5 acres	5 acres	10 acres	.20 acres	.20 acres
Front Setback	30	50	30	50	30	6	6
Side Setback	10	20	10	20	10	6	6
Rear Setback	40	50	40	50	40	50	50
Building Radius	30	30	30	30	30	30	30
Building Separation	113	140	113	133	113	101	101

Shoreland Zoning Overlay

The shoreland zoning district, as modeled in this analysis, comprises all lands within 1,000 feet of navigable lakes and within 300 feet from navigable stream. The shoreland overlay district was created by buffering navigable waters by either 1,000 or 300 feet in unincorporated areas. The new polygon layer was then used to assign shoreland zoning attributes to the parcel layer. Dimensional requirements for each zoning district within the shoreland overlay zone can be found in the zoning ordinance text available on each county's website. The dimensional requirements, such as lot size and setbacks, are based on a lake classification system and are too detailed to describe in this document. Potential residential development was restricted to specific lot sizes and frontage lengths within the required setbacks from the ordinary high water mark, generally between 75 and 125 feet, depending on the lake class. We used the WDNR hydro layer as the basis for determining the ordinary high water mark to buffer from.

Road Setbacks

Each county's zoning ordinance provided road centerline setback distances based on a road classification (TABLE 13). Residential development within these distances is prohibited. Class A roads include state and numbered highways, Class B roads comprise all county roads, and Class C roads are all town roads. We buffered the street centerline layers based on the road classification attribute by the distances in Table 13. The resulting road setback polygon layer was then used as a constraint to development during the build-out process.

TABLE 13**.** Road setback distances in feet.

	Class A	Class B	Class C
Bayfield	110	75	63
Douglas	130	75	63

Community Viz Build-Out Wizard

Next, we used the Community Viz™ Build-Out Wizard, an ArcGIS extension, to generate future development scenarios of the entire watershed. The Build-Out Wizard includes tools for performing a spatial analysis in which it attempts to place as many buildings within the buildable parts of each parcel. The buildable sections are the areas that are outside the development constraint layers. The buildings are also placed at user specified minimum separation distances. The parcel based zoning layer was added as the input data to the wizard. Environmental and physical constraints layers were added to the build-out wizard as areas off limits to development.

The wizard was used to create three scenarios (TABLE 14) of future development at complete build-out in the watershed based on alternative wetland layers. The WDNR wetland points are potential wetlands under five acres in size. They were collected as a point layer from the WDNR's Surface Water Data Viewer and buffered to create polygons of 2.5 acres to represent their approximate size and location.

TABLE 14. Build-out scenario descriptions

Scenario	Description
1	Wisconsin Wetland Inventory (WWI) used as the only wetland constraint.
2	WWI and NRCS hydric/partially hydric soils as wetland constraints.
3	WWI, NRCS hydric/partially hydric soils, and DNR wetland points as wetland constraints.

Estimating Impervious Surfaces

The amount of impervious surface associated with different development patterns was estimated from locally derived impervious surface coefficients. An impervious surface layer containing roads, driveways, structures, and yards of Douglas County was collected from UW-Superior (original data was developed by Community GIS). The impervious surfaces were combined with the digital parcel layer to calculate an average percent imperviousness for different residential lot sizes. The following list provides the impervious surface coefficients for the various lot sizes. We applied the impervious surface coefficients to each build-out scenario to calculate the approximate amount of impervious surface per new residential building (TABLE 15). The buffered building points represent roughly the amount of area that would be converted to residential development. Finally, we combined the build-out results to the current land use coverage to calculate potential change for the entire watershed and within direct drainage areas.

TABLE 15. Coefficients for impervious surfaces for lot sizes in the USCECRW.

Lot Size	Impervious Coefficient
0.25	19.5%
0.5	17.9%
1	13%
2	19%
5	6.5%
10	9.8%
40	1%

Build-out Results

Under the watershed's current zoning density, the model projects a theoretical maximum of 12,088 buildings, including 8,223 new buildings and the 3,817 existing buildings. The distribution of these new units is indicated in FIGURE 69. Each red dot represents a potential new residential development that could be built. One can see that much of the watershed is not developable because of the abundance of both public lands and industrial forests. However, a significant amount of development exists throughout the watershed, especially along roads and in close proximity to riparian areas (FIGURE 70).

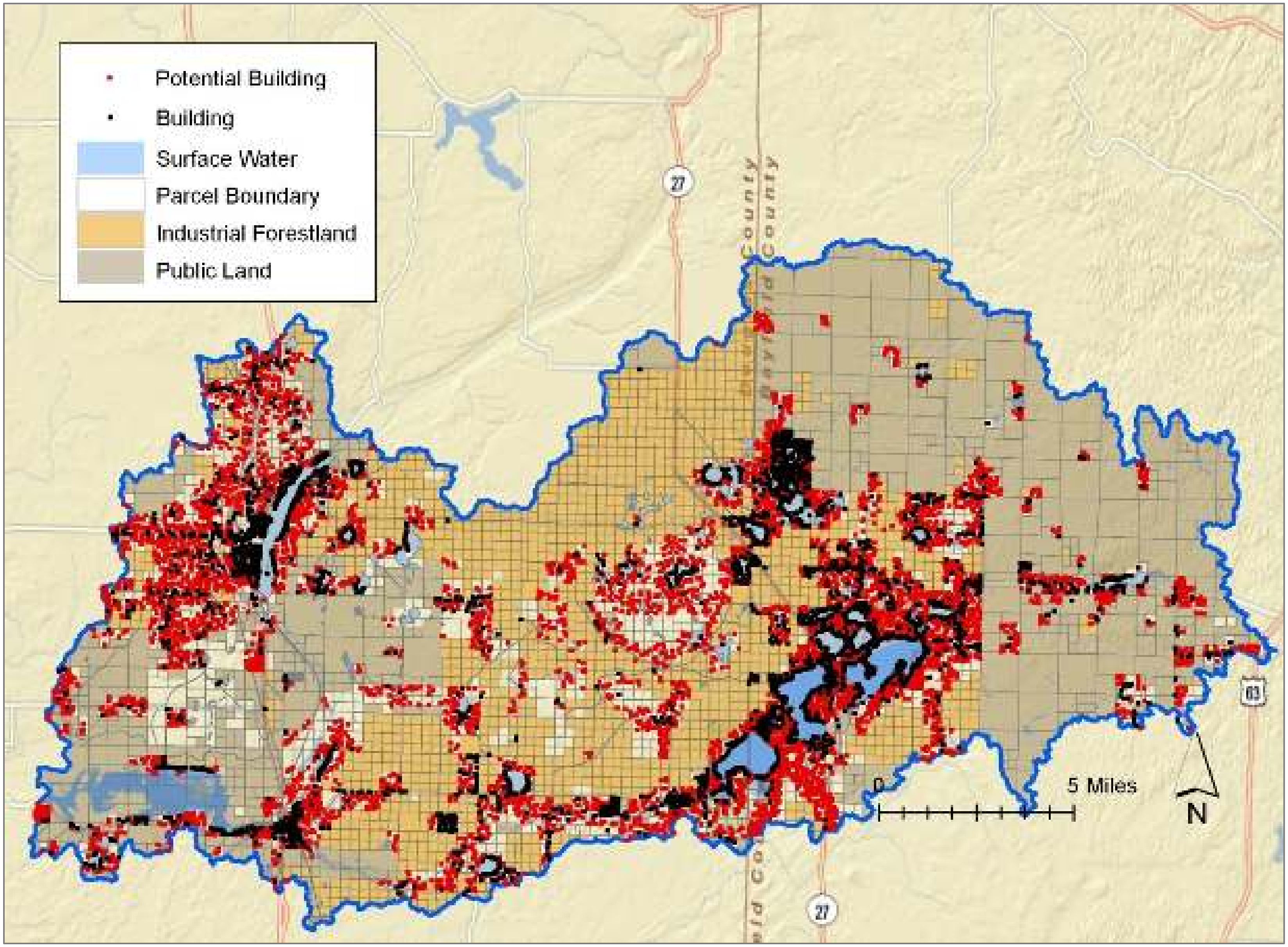


FIGURE 69. Residential build-out results for the USCECRW.

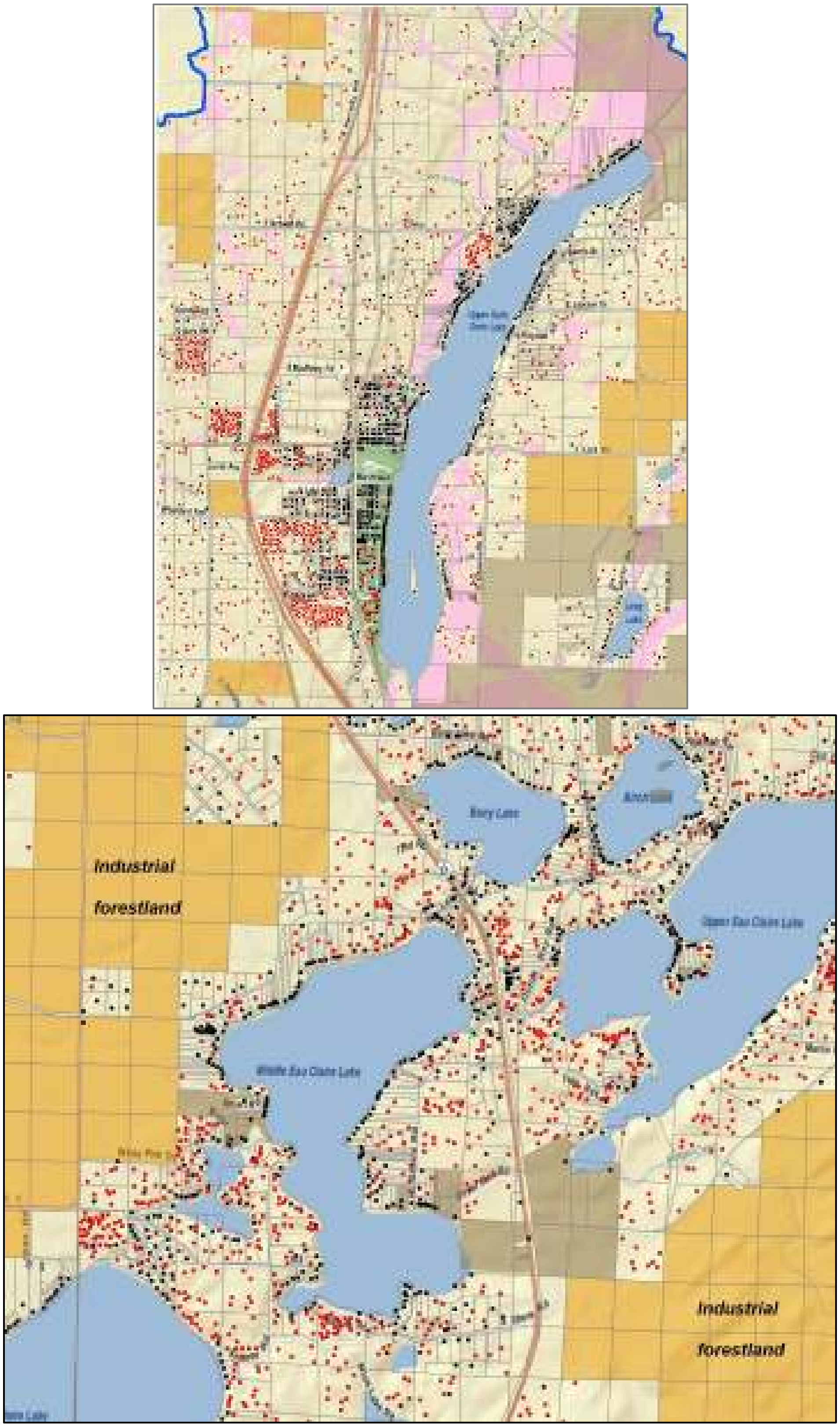


FIGURE 70. Close-up view of the build-out results of Upper St.Croix Lake and in the Town of Barnes in Bayfield County. Due to development constraints and the location of residential zoning districts, most of the potential development is on or near surface water features.

Contributing Areas

The contributing areas were analyzed (FIGURE 62 - FIGURE 65). These lands are directly connected to surface water features and make up a significant portion of the watershed. Tier 1 areas – the most connected lands – take up nearly 58,000 acres or 27% of the watershed. Tiers 2 and 3 are less connected to surface water features and take up only 6,200 and 5,500 acres respectively.

Dwelling units

FIGURE 71shows the results of the number of residential buildings in the direct drainage areas. Nearly 40 percent of potential residential dwelling units are located in Tier 1. Less development can be expected in the second and third tiers because those tiers only make up a small portion of the entire watershed. Also presented in FIGURE 71 are the number of existing residential units and the projected amount for each of the three scenarios. **Scenario 1** allows for the most residential development in the entire watershed, 8,223 because it only incorporates the Wisconsin Wetland Inventory (WWI) areas as the individual wetland constraint. **Scenarios 2** and **3** include other potential wetlands that are not mapped in the WWI as constraints to development and, therefore, allow less development – approximately 700 fewer dwelling units. The difference in dwelling units between scenarios 2 and 3 is insignificant. The additional wetland constraints (hydric soils and buffered DNR wetland points) in Scenario 3 are under public and industrial forest ownership where development is already restricted.

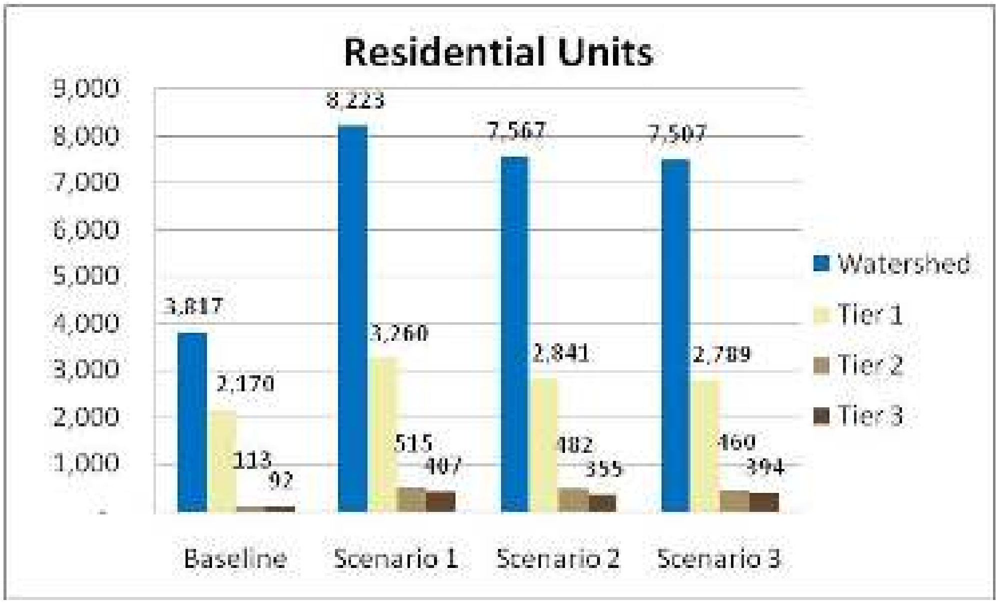


FIGURE 71. Number of new dwelling units in each Tier and for each scenario.

Land Use

The alternative land use scenarios to current landscape in the whole watershed and for each of the contributing area tiers were compared. Results for the three scenarios are shown in TABLE 16. The entire watershed's existing developed area is roughly 9,600 acres, or 3% of the watershed. This includes roads, yards, structures, and other impervious surfaces. The projected land uses patterns for complete build-out for Scenario 1 yielded an increase of 1,784 developed acres or roughly 5.5%t impervious. The amount of additional impervious surface at the entire watershed scale decreases slightly with Scenarios 2 and 3 at 5.4% because of the added wetland constraints.

Presently, there are 3,980 acres of developed land, or roughly 5.4% impervious within the contributing areas. The projected amount of additional development and impervious surface for all three scenarios yields 4,893 acres. Even though the total land area of the tiers accounts for about 33% of the entire watershed, 50% of potential new residential development takes place within connected areas.

TABLE 16. Current and projected land use (in acres) in the entire watershed and within each direct drainage tier for the three build-out scenarios.

Type	Connectivity	2009	Scenario 1	Scenario 2	Scenario 3
Developed	Entire Watershed	9,601	11,385	11,236	11,221
	Connected Areas	3,980	4,893	4,785	4,771
Forest	Entire Watershed	142,555	141,138	141,219	141,237
	Connected Areas	41,411	40,730	40,778	40,794
Non Forest	Entire Watershed	17,255	17,027	17,088	17,096
	Connected Areas	19,912	19,769	19,816	19,814

Build-out Conclusions

Residential build-out analysis of the USCECRW was conducted to gain a better understanding of the potential growth in the watershed. The potential number of dwelling units and the amount impervious surface were estimated at build-out under several different scenarios. The build-out model estimates that the number of dwelling units could increase 115% from the baseline conditions. An additional 3 to 4% increase of land area, up from 3%, in the watershed is predicted to be covered by impervious surface at complete build-out. This number represents a significant dwelling unit growth for the area, but a modest increase in the number of developed acres. The findings in this analysis show that the current zoning in the watershed aims to concentrate development in meaningful patterns in an effort to reflect appropriate land use policies, however; a great portion of the development potential occurs in resource-sensitive areas. More importantly, the build-out analysis shows that much of land in the watershed is off limits to development because of environmental and physical constraints. A large portion of the remaining developable lands are in close proximity to surface water features. If the most connected drainage lands completely develop at the maximum density allowed under the current zoning, roughly 3,260 new homes could be built in the most connected lands to surface water features. Other portions of the watershed not only residentially-zoned areas, but also in forestry-zoned districts, are ripe for development. For example, industrial forest companies, like Plum Creek or Wausau Paper currently own nearly 58,000 acres in the watershed. Most of their forestland is zoned F-1, which allows for residential development on 4.5 acres in Douglas County. If these companies decide to divest and develop some of their more amenity-rich tracts of land, it could result in an additional 2,963 residential units and increase the amount of impervious surface coverage to nearly 8%.

Implementation of land use policies and regulations, and non-regulatory strategies are a critical component for protecting valuable aquatic resources and water quality. In addition to benefits for aquatic resources, planning, zoning, and other conservation tools are used for ensuring the management of wildlife habitat, providing for sustainable development, protecting property values, and maintaining community character.

Phosphorus Loading Estimate for Build out Scenarios

A SWAT model was developed for the watershed and used to estimate annual flow from the watershed in the baseline condition and with additional impervious surfaces. Those results were described earlier in this report. The results of the SWAT hydrologic modeling were used to estimate the change in nutrient loading that could occur through development.

The results of the hydrologic modeling showed how adding additional impervious area to the watershed would lead to increased surface runoff. The results of the scenarios examined are shown in TABLE 17.

Table 17. Hydrological Modeling Results for the Upper St. Croix watershed based on twenty-five year historical simulation for baseline and developed scenarios

Scenario	Total Impervious Area (%)	Directly Connected Impervious (%)	Average Total Annual Runoff (million cubic feet)	Average Total Annual Runoff (inches)	Average Surface Runoff (inches)
Baseline	**1%**	**0.5%**	**9622**	**12.7**	**0.60**
6 / 0.5	**6%**	**0.5%**	**9626**	**12.7**	**0.65**
6 / 6	**6%**	**6%**	**9675**	**12.8**	**1.11**

*Directly connected and increased impervious surface applied only to contributing watersheds. Internally drained watersheds were assumed to have a total impervious of 1.0% with 0.1% directly connected in all scenarios.

The hydrologic modeling was used to estimate nutrient loading by assuming phosphorus concentrations for the baseflow and surface runoff. The Upper St. Croix watershed study found a flow-weighted phosphorus concentration of approximately 0.02 – 0.03 mg/L at the downstream monitoring locations (SX00 and SX01). Table 2 shows how distribution of phosphorus between baseflow and surface runoff was used to match the existing stream concentration and estimate export. The estimates assume a baseflow phosphorus range of 0.01 to 0.02 based on groundwater monitoring and the surface runoff concentration range of 0.2 to 0.3 mg/l based on the observations at previous studies of subdivision and urban areas (Waschbusch, 1999; Clausen, 2007; Selbig and Bannerman, 2008).

The results in Table 18 show an increase in total phosphorus with increasing watershed development. This model estimates an increase of approximately 2,000 kg/year with an increase to 6% directly connected impervious. That increase is similar using different concentration assumptions. The increase is considerably smaller if that impervious is not directly connected to the stream system. The increase in flow-weighted stream phosphorus concentration is projected to be approximately 0.01 mg/l. The baseline phosphorus export estimated in Table 18 is larger than that described in the Flux estimates for the watershed describe in the report. The estimates in Table 18 are based on flow estimated using the long-term (25 year) SWAT modeling and concentrations shown in the Table. The Flux phosphorus loads described earlier were based only on results from 2008-2009 and extrapolating from the growing season monitoring.

Table 18. Total Phosphorus Load and Concentration in Baseline and Developed Scenarios.

Scenario	Average Total Annual Runoff (million cubic feet)	% Surface Runoff(1)	Kg P (mg P/l)(2) Assuming 0.01/0.2(3)	Kg P (mg P/l) Assuming 0.01/0.3*	Kg P (mg P/l) Assuming 0.02/0.2*
Baseline	**9622**	**4.7**	**5,175 (0.019)**	**6,455 (0.024)**	**7,775 (0.028)**
6 / 0.5	**9626**	**5.1**	**5,380 (0.020)**	**6,775 (0.025)**	**7,975 (0.029)**
6 / 6	**9675**	**8.7**	**7,285 (0.027)**	**9,675 (0.035)**	**9,795 (0.036)**

(1) % Surface runoff based on distribution shown in Table 1
(2) Kilogram phosphorus and flow-weighted mean concentration
(3) Kilogram phosphorus estimates using baseflow /surface runoff concentrations.

Conclusions

The USCECRW covers 335 square miles with extensive areas of internal drainage, particularly east of the Upper St. Croix River. The streams in the USCECRW obtain the majority of their flow from groundwater, which provides sustained flows to many of the streams throughout the year. The Upper St. Croix River has one impoundment, the Gordon (St. Croix) Flowage, after which the St. Croix National Scenic Riverway begins. The Eau Claire River has four impoundments, one creates the Eau Claire River Flowage near Gordon and three others are located at the lake outlets of the Eau Claire chain of lakes in the town of Barnes. Lakes occur in natural abundance, particularly within the glacial outwash plain of the north-eastern portion of the watershed. The land uses in the watershed are predominantly forests, wetlands and grasslands with much of the development located around lakes and along streams.

Water quality conditions vary seasonally and annually throughout the watershed. Numerous sampling sites suggested that cultural impacts to water quality are very minimal at this time. Total suspended solids and phosphorus primarily enter the surface waters via snow melt and rainfall runoff; however, water quality in the USCECRW is also strongly influence by groundwater discharging to surface waters. This is evident in the higher baseflow concentrations of chloride and nitrogen. The highest chloride concentrations are found exiting the Upper St. Croix Lake watershed which reflects the relatively intense land use practices, associated with development, in that sub-watershed. Although elevated, the observed concentrations are not harmful to fish and wildlife.

Annual total phosphorus exports were highest at the monitoring sites at the Cut-Away Dam recreational bridge crossing and at Old Highway 53, both on the St. Croix River. The high exports at these sites may be a reflection of the large percentage of wetlands bordering the Upper St. Croix River. Throughout the St. Croix River Headwaters, higher nutrient concentrations are associated with sub-watersheds with higher percentages of wetlands covering the landscape. The highest concentrations of total phosphorus were measured at the St. Croix River at Old Hwy 53 with the uppermost concentrations measured during rain events. A decrease in total phosphorus and total suspended solids in the St. Croix River from Old Highway 53 to the Gordon Flowage outflow indicates that the Gordon Flowage is acting as a sink for these constituents. In the Eau Claire River sub-basin, total phosphorus exports increase from the Eau Claire chain of lakes to the confluence of the Eau Claire and St. Croix Rivers. Monitoring of the Gordon cranberry bog outlets identified elevated phosphorus and chloride concentrations. Diazinon and chlorpyrifos were present at both sites some time during the year and malathion was detected near the southern channel of the bog in August and September.

Areas of the USCECRW with higher background concentrations of phosphorus were identified through an analysis of groundwater samples and synoptic baseflow sampling of first- and second-order streams. The primary regions identified are the Horseshoe Springs area in the central part of the USCECRW and to the north and west of the Upper St. Croix River. A preceding study of the Upper St. Croix Lake sub-basin also identified the western part of that sub-basin as having greater phosphorus concentrations. It is especially important to mitigate anthropogenic sources of phosphorus and other water quality constituents in regions with high background concentrations; additional inputs to a loaded system are apt to rapidly impact surface water.

Hydrologic modeling was used to evaluate increases in streamflow (with assumed increases in sediment and nutrient loads). Increases of 6% impervious surfaces in parts of the watershed that are indirectly connected to the streams are estimated to result in a 5% increase in streamflow; however, if the areas of the watershed are directly connected to the streams, the increase in streamflow would be closer to 25%. Over the short term this would result in a greater volume of water moving through the streams in a short period of time which typically results in greater in-stream erosion, and increases in sediments, nutrients, and temperature. Over the long term a decrease in groundwater recharge would result in a decrease in the volume of stream water low flow periods.

There are 197 lakes in the USCECRW ranging from less than an acre to the 2,200 acre Gordon Flowage. Seventy percent of the lakes are seepage, 17% spring/groundwater drainage, 9% drainage, 4% reservoir/impoundments. Water chemistry from a subset of the lakes was evaluated using data dating back to 1979 to assess mineralogy, and data from the last ten years were used to evaluate nutrients and water clarity. The majority of the lakes are considered soft with total hardness concentrations ranging from less than 4 to 90 mg/L. Sodium and chloride concentrations were elevated in the reservoir/impoundments suggesting cultural inputs to the water from road salts, septic systems, etc. Few lakes exceeded the phosphorus criteria (by lake type), but eight lakes exceeded the WDNR's flag values for phosphorus. Median water clarity measures ranged from 7.9 feet for reservoir/impoundments to 10.9 for spring/groundwater drainage lakes. When compared to UW Madison's LakeSat estimates, 38% of the study lakes were within 1 foot of water clarity estimated by LakeSat; suggesting that the LakeSat estimates should be considered with caution for the majority of lakes in the UWCECRW.

A build-out analysis of the USCECRW was conducted to help understand potential development patterns that are possible with the current zoning and constraints. The findings in this analysis show that the current zoning in the watershed aims to concentrate development in meaningful patterns in an effort to reflect appropriate land use policies, however; a great portion of the development potential occurs in resource-sensitive areas. More importantly, the build-out analysis shows that much of land in the watershed is off limits to development because of environmental and physical constraints. A large portion of the remaining developable lands are in close proximity to surface water. If the most connected drainage lands completely develop at the maximum density allowed under the current zoning, roughly 3,260 new homes could be built in the most connected lands to surface water features. Other portions of the watershed not only residentially-zoned areas, but also in forestry-zoned districts, are ripe for development. For example, industrial forest companies currently own nearly 58,000 acres in the watershed. Most of their forestland is zoned F-1, which allows for residential development on 4.5 acres in Douglas County. If these companies decide to divest and develop some of their more amenity-rich tracts of land, it could result in an additional 2,963 residential units and increase the amount of impervious surface coverage to nearly 8%.

Numerous tools were developed as a part of this study to help identify important areas in the USCECRW based on geology, hydrology, topography, soil, water quality and zoning. These tools may be used to create good plans and make good decisions that will minimize impacts to the water resources in the USCECRW from existing and future land management practices. Best management practices, such as the use of retention ponds and shoreline buffers, should be used to slow and reduce the movement and volume of runoff throughout the watershed particularly in areas directly connected to surface waters. Reviews of new culvert placement, culvert repair, and new road construction and maintenance should be performed with an eye on the potential effects to stream connectivity at both the water quality and biologic (e.g. fish passage) levels. Vegetation on the landscape and maintaining wetlands are essential for habitat and water quality. These practices can reduce sediment and phosphorus transport to streams and lakes in the USCECRW. Distribution of information, understanding, and implementation is essential for all of the land managers that make decisions in the USCECRW. These land managers include property owners, municipal boards, highway departments, agency staff, schools, and not for profit organizations.

Recommendations

Making good land management decisions in the USCECRW should result in good water quality and quantity for generations to come. As a part of this study, we developed multiple tools that can be used as guidance to direct the implementation of appropriate land management practices and decisions to the areas of the USCECR watershed that have the greatest impacts to water quality and quantity.

To implement these practices, watershed residents, landowners, and decision-makers will need to become familiar with concepts related to good land management practices and will need to become familiar with and learn how to use the maps and recommendations. Some of the suggestions are good-sense land management practices that don't lead to more runoff, sediments and nutrients to the lakes and rivers while others are related to planning, zoning, land purchase, etc. The list of recommendations provides a number of options; no single tool or recommendation should be considered the best tool for every situation.

Some areas within the USCECR watershed have greater influence the water quality and quantity than others. The following recommendations were identified for different parts of the watershed and vary depending upon connection of the land with surface water, slope of the landscape, and soil type. The recommendations should be used in conjunction with the Tier and Slope maps displayed in Figures 62-65 in this report. Recommendations listed under "all tiers" should be implemented throughout the watershed; recommendations for Tier 1 should be implemented within the corresponding Tier 1 regions of the map that share corresponding slopes. Tier 2 areas have slightly less direct connection to water bodies than Tier 1 areas but these areas could easily become Tier 1 by connecting the drainage directly to Tier 1 through the installation of a culvert or change in the slope of the land.

We strongly suggest a USCECR the development of a management plan to guide the implementation of these and other relevant recommendations.

Recommendations for the Upper St. Croix Eau Claire River Watershed

Contributing Areas – All Tiers

Recommendations for Contributing Areas – All Tiers	Non-regulatory	Regulatory
1. Impervious surface should be less than 10% of the contributing area. Impervious surfaces within the contributing areas should be inventoried at least annually. Buildings, driveways, roads, compacted surfaces, etc. are considered impervious surface.	Annual inventory	
2. Land use activities that are likely to result in greater than 10% impervious surface or provide additional connectiveness (culverts, roads, industry, box stores, hotels, barnyards, etc) should be sited outside of contributing areas. (FIGURE 62 to FIGURE 65).	Education –. Town, Village and County	1, 2
3. Erosion control measures should be in place and maintained during periods when vegetation is removed or soil is disturbed. Vegetation should be re-established as quickly as possible.	Information/Education Citizens should keep a watch to be sure erosion control measures are controlling erosion.	
4. Landowners should receive information indicating that their land is within a contributing area of local lakes/streams and should provide suggestions to minimize impacts to these waterbodies. Many brochures already exist.	Information/Education	
5. Conversion and development of industrial forestland should be done at extremely low densities (i.e. 1 dwelling unit/40 acres) or with a conservation design to limit the amount of impervious surface and conversion of forestland. Presently, 25% of the watershed is under industrial forestland ownership and zoned for 4.5 acre lot sizes. At this size, an additional 2,963 could be built if the land was divested and developed.	Education –. Town, Village and County	1, 4
6. Target land protection efforts to the locations that need them most – highlighted areas of greatest potential change from the build-out results.	Information/Education	
7. Design road stream crossings in ways that minimize impacts to the streams from runoff that carries sediment and nutrients. Poorly placed culverts and direct runoff to the stream can affect the type of sediment in a stream and can obstruct the movement of fish and other aquatic organisms.	Education – Highway Dept. Town, Village and County Boards	
a. Plan roads to minimize the number of stream crossings.	Education – Highway Dept. Town, Village and County Boards	

b. Construct bridges as stream crossings whenever possible and replace culverts with bridges when possible. Bridges can be designed to have less impact to a stream than culverts.	Education – Highway Dept. Town, Village and County Boards	
c. Capture bridge runoff in a vegetated depression prior to its discharge into the stream.	Education – Highway Dept. Town, Village and County Boards	
d. Construct swales to infiltrate water rather than swiftly deliver it to wetlands, streams, and lakes.	Education – Highway Dept. Town, Village and County Boards	
e. State and Federal rules for protecting wetlands should be followed. If wetland disturbance is necessary mitigation should take place within the same tier of the watershed.	Education – Highway Dept. Town, Village and County Boards	

Contributing Areas – Tier 1

SCENARIO A - Tier 1 with steep slope (>15%)	Non-regulatory	Regulatory
1. These areas are very susceptible to erosion and should remain vegetated.	Landowner Information	
2. Consider conservancy easements or other voluntary deed restrictions.	Landowner Information	1, 2
3. Restrict development in these areas.		1, 2, 3
4. Citizen groups and County Land Conservation Depts work with landowners experiencing erosion to implement mitigation.	Landowner Information	

SCENARIO B - Tier 1 with moderate slope (8-15%)	Non-regulatory	Regulatory
1. These areas are susceptible to erosion. Minimize exposed soil.	Landowner Information	
2. Minimize development and/or protect shoreline, increase setbacks through conservancy easements or voluntary deed restrictions using the using the build-out results to identify sensitive areas with extensive development potential .	Landowner Information	1, 2
3. Development could be considered if there is mitigation for storm water creating additional runoff and erosion controls are in place until vegetation is reestablished.	Education – Town, Village and County Boards Local developers Landowners	1, 2
4. Runoff mitigation efforts (raingardens, infiltration basins, swales, etc) should be monitored to ensure they remain in place over the long term.	Landowner information Citizen groups	

SCENARIO C - Tier 1 with <8% slope	Non-regulatory	Regulatory
1. Large buildings (multifamily homes, businesses, etc) should be considered if an approved storm water plan is in place.	Education – Town, Village and County Boards	1, 2
2. Minimize development through conservancy easements or voluntary deed restrictions using the build-out results to identify sensitive areas with extensive development potential.	Landowner information 1, 2	

SCENARIO D – Tier 1 Shoreland	Non-regulatory	Regulatory
1. Work with County to ensure that the new shoreland zoning ordinance will minimize impact to water quality and habitat.	County Land Conservation Dept and Zoning	
2. Keeping a tree canopy will prevent additional runoff which increases (along with erosion potential) when the canopy is removed.	Landowner information	
3. Septic systems should be sited as far from the water as possible.	Landowner information	
4. Additional setback of structures (>75 feet) would allow for more runoff to infiltrate into the ground.	Landowner information	1, 2, 4
5. Consider large lot zoning or extensive frontage requirements for lands adjacent to designated trout streams.		1, 2, 3

Contributing Areas – Tier 2

Recommendations	Non-regulatory	Regulatory
1. Do not connect areas in Tier 2 with Tier 1 (though the use of culverts, roads, etc). Identify areas where culverts, roads, etc. should not be placed.	Education – Highway Dept. Town, Village and County Boards	
2. If lands in Tier 2 are connected to Tier 1 via culvert, road, etc. follow the appropriate Tier 1 recommendations.		

Watershed-wide

Recommendations	Non-regulatory	Regulatory
1. Fertilizer should only be used if soil tests indicate a nutrient or mineral is lacking for target vegetation.	Landowner information	
2. Land should be managed to reduce runoff and infiltrate storm water.	Landowner information	
3. Encourage and support local businesses that enhance the enjoyment of this water-rich area without impacting water quality.	Marketing, education	

Cranberry Marsh

Recommendations	Non-regulatory	Regulatory
1. Do not use chemicals if the label states that it should not to be used in or near aquatic environments.		
2. Consider managing the marsh without using chemicals to market cranberries as a value added products such as “Grown in harmony with the St. Croix River”.		

Non Regulatory

1. Purchase of Development Rights (PDR) – A TDR is a voluntary program used to permanently protect sensitive landscapes while retaining private ownership and management of the land. (For more information on this tool, see Purchase of Development Rights at http://www.uwsp.edu/CNR/landcenter/pdffiles/implementation/PDR.pdf)
2. Conservation Easement – An incentive based legal agreement voluntarily placed on a piece of property to restrict the development, management or use of the land in order to protect a resource. (For more information on this tool, see Conservation Easements at http://www.uwsp.edu/CNR/landcenter/pdffiles/implementation/ConservationEasement.pdf)

Regulatory

1. Zoning Ordinance – Zoning is one of the most common methods of land use control used by local governments. At its core, zoning regulates how a parcel of land in a community may be used and the density of development. (For more information on this tool, see Zoning Ordinances at http://www.uwsp.edu/CNR/landcenter/pdffiles/implementation/Zoning.pdf)
2. Overlay Zoning – Overlay zoning is a regulatory tool that creates a special zoning district, placed over an existing base zone (s), which identifies special provisions in addition to those in the underlying base zone. The overlay district can share common boundaries with the base zone or cut across base zone boundaries. Regulations or incentives are attached to the overlay district to protect a specific resource. (For more information on this tool, see Overlay Zoning at

http://www.uwsp.edu/CNR/landcenter/pdffiles/implementation/OverlayZoning.pdf)

3. Land Division Ordinance – Land division and subdivision ordinances provide standards and procedures for dividing and recording individual parcels of land within a community. (For more information on this tool, see Land Division Ordinance at http://www.uwsp.edu/CNR/landcenter/pdffiles/implementation/Land_Division_Ordinances.pdf)
4. Conservation Design – Conservation design encourages the clustering of buildings and lots on a development site in order to preserve specific resources. (For more information on this tool, see Conservation Design at http://www.uwsp.edu/CNR/landcenter/pdffiles/implementation/ConservationDesign.pdf)

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