Pine River Watershed

Restoration and Protection Strategy Report

October 2017

wq-ws4-33a

Project Partners

Crow Wing Soil and Water Conservation District (Crow Wing SWCD)

Crow Wing County

Cass County Environmental Services

Pine River Watershed Alliance (PRWA)

Whitefish Property Owners Association (WAPOA)

Leech Lake Area Watershed Foundation (LLAWF)

Crow Wing County Master Gardeners

Minnesota Pollution Control Agency (MPCA)

Minnesota Department of Natural Resources (DNR)

University of Minnesota Extension Service

Minnesota Department of Health (MDH)

Minnesota Board of Soil and Water Resources (BWSR)

Minnesota Department of Agriculture (MDA)

Emmons and Olivier Resources, Inc. (EOR)

RESPEC Consulting and Services (RESPEC)

Lindner Media Productions

The Nature Conservancy (TNC)

Hunt Utilities Group (Happy Dancing Turtle)

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Key Terms and Acronyms

Assessment Unit Identifier (AUID): The unique water body identifier for each river reach comprised of the USGS eight-digit HUC plus a three-character code unique within each HUC.

Aquatic life impairment: The presence and vitality of aquatic life is indicative of the overall water quality of a stream. A stream is considered impaired for impacts to aquatic life if the fish Index of Biotic Integrity (IBI), macroinvertebrate IBI, dissolved oxygen, turbidity, or certain chemical standards are not met.

Aquatic recreation impairment: Streams are considered impaired for impacts to aquatic recreation if fecal bacteria standards are not met. Lakes are considered impaired for impacts to aquatic recreation if total phosphorus, chlorophyll-a, or Secchi disc depth standards are not met.

BWSR: Board of Soil and Water Resources

CWLA: Clean Water Legacy Act

CLMP: Citizen Lake Monitoring Program

DNR: Minnesota Department of Natural Resources

DWSMA: Drinking Water Supply Management Area

EPA: Environmental Protection Agency

GRAPS: Groundwater Restoration and Protection Strategies

HSPF: The hydrologic and water quality model **H**ydrologic **S**imulation **P**rogram **F**ortran.

Hydrologic Unit Code (HUC): A Hydrologic Unit Code (HUC) is assigned by the USGS for each watershed. HUCs are organized in a nested hierarchy by size. For example, the Minnesota River Basin is assigned a HUC-4 of 0702 and the Pomme de Terre River Watershed is assigned a HUC-8 of 07020002.

Impairment: Water bodies are listed as impaired if water quality standards are not met for designated uses including aquatic life, aquatic recreation, and aquatic consumption.

Index of Biotic integrity (IBI): A method for describing water quality using characteristics of aquatic communities, such as the types of fish and invertebrates found in the waterbody. It is expressed as a numerical value between zero (lowest quality) to 100 (highest quality).

IWM: MPCA's **I**ntensive **W**atershed **M**onitoring, which includes chemistry, habitat, and biological sampling.

MDA: Minnesota Department of Agriculture

MIDS: Minimal Impact Development Standards

MPCA: Minnesota Pollution Control Agency

Protection: This term is used to characterize actions taken in watersheds of waters not known to be impaired to maintain conditions and beneficial uses of the waterbodies.

Restoration: This term is used to characterize actions taken in watersheds of impaired waters to improve conditions, eventually to meet water quality standards and achieve beneficial uses of the waterbodies.

Source (or Pollutant Source): This term is distinguished from 'stressor' to mean only those actions, places or entities that deliver/discharge pollutants (e.g., sediment, phosphorus, nitrogen, pathogens).

Stressor (or Biological Stressor): This is a broad term that includes both pollutant sources and non-pollutant sources or factors (e.g., altered hydrology, dams preventing fish passage) that adversely impact aquatic life.

SFIA: Sustainable Forest Incentive Act

SWAG: Surface Water Assessment Grant

Total Maximum Daily Load (TMDL): A calculation of the maximum amount of a pollutant that may be introduced into a surface water and still ensure that applicable water quality standards for that water are met. A TMDL is the sum of the wasteload allocation for point sources, a load allocation for nonpoint sources and natural background, an allocation for future growth (i.e., reserve capacity), and a margin of safety as defined in the Code of Federal Regulations.

WRAPS Core Team: A team of individuals including technical staff or representatives from The MPCA, the DNR, Local Governments, non-profits and citizen groups that collaborated to produce or identify the data and materials to produce the WRAPS report and all of its components.

Executive Summary

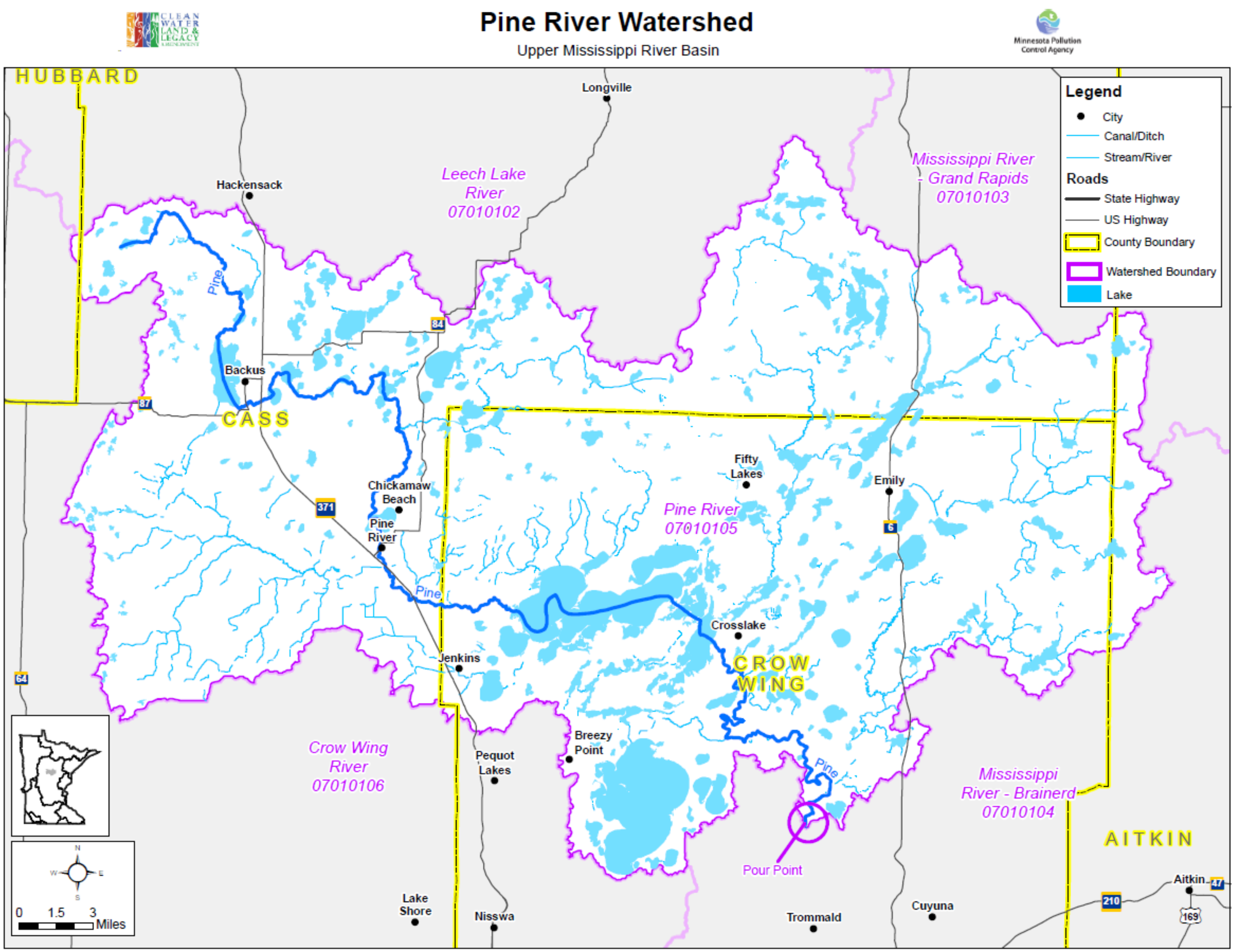
The Pine River Watershed (the Pine) consists of approximately 501,000 acres (783 square miles) of mostly forests, wetlands, and lakes, and increasing residential development. It is located in the center of the northern half of the Upper Mississippi Basin. The major communities in the Pine include Breezy Point, Crosslake, Fifty Lakes, Pine River, Manhattan Beach, Emily, Jenkins, and Chickamaw Beach. Major Lakes include The Whitefish Chain of Lakes, Pelican Lake, Lake Emily, Roosevelt, and Pine Mountain. Counties in the Pine include parts of Crow Wing, Cass, Aitkin and Hubbard (Figure 1).

The Pine has over 500 miles of rivers and streams, and over 400 lakes of 10 acres or larger. The quality of surface waters in the Pine is largely very good, and the Pine River Watershed is a popular tourist and vacation destination for people from all over the United States for its water recreation, fishing, hunting, and general "up-north" feel. The strength of the Pine, and the reason for its high-value waters, is the large (49%) extent of forest cover, which provides erosion protection, rainfall infiltration, and nutrient absorption. All of these components contribute to a healthy water cycle, which science has shown is key to healthy waters. The Pine has high importance because water that leaves the Pine enters the Mississippi River, and thus contributes to drinking water supplies for communities downstream of the Pine, such as St. Cloud and the Twin Cities.

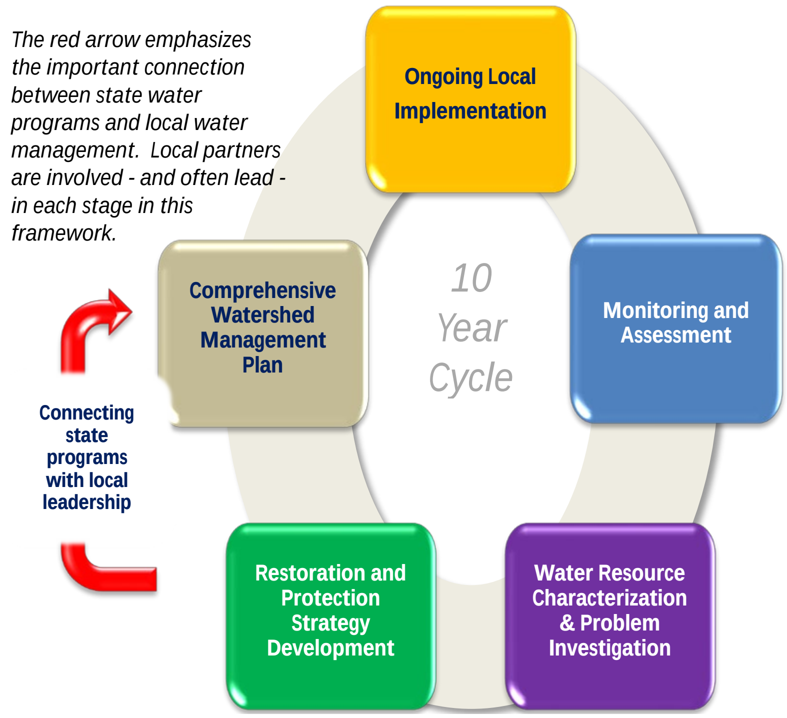
During the intensive watershed monitoring (IWM) process for the Pine, 25 streams and 112 lakes were assessed, and data was utilized from a combination of Surface Water Assessment Grant (SWAG) work, the Citizen Lake and Stream Monitoring Programs (CMPs), and Minnesota Pollution Control Agency (MPCA) lake sampling. Although water quality is generally good in the Pine, there are important lakes and streams that are showing trends toward declining water quality, such as Whitefish Lake, Bertha Lake, Deep Portage Lake, and Island-Loon Lake. In addition to water bodies showing declining trends (but still meeting aquatic life and aquatic use standards), several water bodies have been identified as having impaired biology (streams) or impaired by nutrients (lakes). These include Jail Lake, Kego Lake, Lows Lake, Lake Emily, and Mitten Lake, and Arvig Creek, Willow Creek, Wilson Creek, and the South Fork of the Pine River. Three of these lakes, Mitten, Lows, and Emily, and all four streams were listed as impaired in 2016, after the draft TMDL for the Pine had already been completed. TMDLs for Mitten Lake and Lake Emily will be completed at a later time, Lows Lake was determined to have a "natural background" impairment and so no TMDL will be completed for that lake.

There is a clear connection between water quality and forest cover, and wherever forest is permanently removed, water quality is negatively affected. For that reason, the primary strategy for maintaining good water quality in the Pine is protection of existing forest cover through conservation easement or other means. This is the legacy of the Pine, and if forests are protected into the future, then good water quality will continue to benefit the people who live here, as well as those who drink the water downstream.

Figure 1. Map of Pine River Watershed



What is the WRAPS Report?



The State of Minnesota has adopted a watershed approach to address the state's 80 major watersheds, denoted by an 8-digit hydrologic unit code or HUC. The Minnesota Watershed Approach incorporates **water quality assessment, watershed analysis, civic engagement, planning**, **implementation**, and **measurement of results** into a 10-year cycle that addresses both restoration and protection.

Along with the watershed approach, the Minnesota Pollution Control Agency (MPCA) developed a process to identify and address threats to water quality in each of these major watersheds. This process is called WRAPS or the Watershed Restoration and Protection Strategy. WRAPS reports have two parts: impaired waters will have strategies for restoration, and waters that are not impaired will have strategies for protection.

Waters not meeting state standards are listed as impaired and Total Maximum Daily Load (TMDL) studies are performed, as they have been in the past. TMDLs are developed for impaired waters in each watershed as part of Minnesota's watershed approach and folded into WRAPS. In addition, the watershed approach process facilitates a more cost-effective and comprehensive characterization of multiple water bodies and overall watershed health, including both protection and restoration efforts. A key aspect of this effort is to develop and utilize watershed-scale models and other tools to identify strategies and actions for point and nonpoint source pollution that will cumulatively achieve water quality targets. For nonpoint source pollution, this report informs local planning efforts, but ultimately the local partners decide what work will be included in their local plans. This report also serves to at least partially address Environmental Protection Agency's (EPA's) Nine Minimum Elements, helping to qualify applicants for eligibility for Clean Water Act Section 319 implementation funds.

Purpose	• Support local working groups and jointly develop scientifically-supported restoration and protection strategies to be used for subsequent implementation planning
	• Summarize Watershed Approach work done to date including the following reports:
	  • *Pine River 2016 Watershed Monitoring and Assessment*
	  • *Pine River Watershed 2015 Biotic Stressor Identification*
	  • *Pine River Watershed 2017 Total Maximum Daily Load*

Scope	• Impacts to aquatic recreation and impacts to aquatic life in streams • Impacts to aquatic recreation in lakes
Audience	• Local working groups (local governments, SWCDs, watershed management groups, etc.) • State agencies (MPCA, DNR, BWSR, etc.)

1. Watershed Background & Description

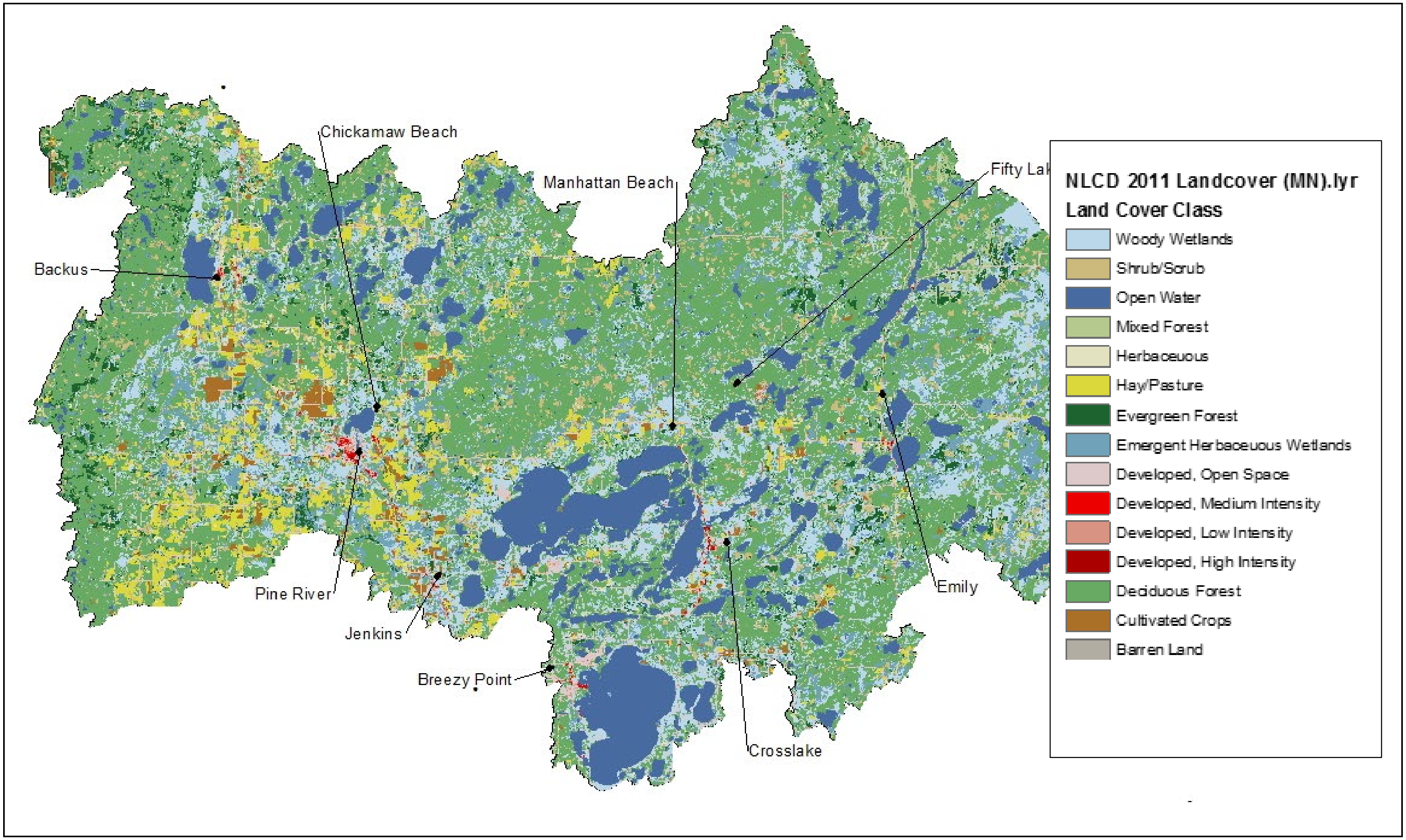


Figure 2. Land Use in the Pine River Watershed

The Pine lies within the Northern Lakes and Forests ecoregion of North Central Minnesota. The watershed encompasses an area of approximately 501,180 acres (783 square miles) in size and is known for clean surface water and drinking water. It was identified in a report by the U.S. Department of Agriculture (USDA) Forest Service (USFS 2009) as one of the top watersheds in the entire northeast United States (Maine to Minnesota and south to Missouri) and the top clean water producing watershed in Minnesota. The heavily forested watershed contains numerous wetlands and over 400 lakes greater than 10 acres in size. The Whitefish Chain of Lakes and Pelican Lake, two prominent resources used heavily for recreation, are located within the watershed. Over 500 miles of streams and rivers flow through the watershed. Major rivers and streams include the Pine River, Little Pine River, South Fork Pine River, Daggett Brook, and Mud Brook. The watershed drainage for the Pine contains parts of Aitkin, Cass, Crow Wing and Hubbard counties, and empties into the Mississippi River at the southeast edge of the watershed via the Pine River.

Residential and commercial development throughout the watershed is light, and primarily concentrated around several municipalities or recreational lakes in the area. Limited amounts of agricultural land use, primarily pasture and hay, occur in the southeast portion of the watershed. The pristine nature of the watershed promotes good water quality and diverse ecological communities.

The Pine is primarily forested with 48.6% covered by forested land, roughly half of which is state owned and half privately owned; 11.7% is open water; 24% wetland; 6.3% herbaceous and shrub cover, 5.5% crop and pasture, and 3.8% is developed land (Figure 2). Pressure for additional development is increasing and is continuing to occur around the Whitefish Chain and Pelican Lake, as well as municipalities such as Crosslake, Manhattan Beach, Fifty Lakes, Emily, Breezy Point, Pine River, Jenkins, and Pequot Lakes.

The history of the Pine is similar to many other areas within the Upper Mississippi Basin where the presence of rich fur and timber resources directed much of the early settlement and development in the watershed. Fur trading in the area began during the mid-seventeenth century and continued as the most prominent industry in the watershed until the mid-1800s when the white pine logging industry took over. The logging industry helped to settle the state of Minnesota by providing jobs, construction materials, and new markets for agriculture. The expansion of the railroads used to haul lumber also helped to open up the Upper Mississippi Valley area to settlement. By the early 1900s, almost all of the white pine in the state had been harvested, which significantly changed the landscape of the Pine. Logging companies sold much of the cut over land to farmers and other settlers. Many farms failed, however, due to the work intensity of removing pine stumps from the cleared land, and the difficulty of growing crops in soils that were often acidic, sandy, or water-logged.

These same soil conditions exist today, limiting row crop production to less than 4% of the land use in the watershed, while 1.5% is in pastures and hay. Much of the forest cover that was lost in the mid-1800s has now returned, albeit in a more diverse landscape, including aspen, birch, spruce, and other conifers and hardwoods. A 2014 estimate by the Natural Resource Conservation Service (NRCS) indicated that 355 farms were found in the watershed with over half being smaller operations of less than 180 acres in size.

Recollection:

> *"My Grandfather purchased a cabin on the Lower Whitefish in 1935. The lake was beautiful, clean and clear. I can remember seeing large fish swim in and out of the weed line in about eight feet of water. We bathed and washed clothes in the lake. Cedar strip wood boats were the norm and a 16-foot boat was considered large. Most boats were built by Ralph Brooks here in Crosslake, now known as C & C Boatworks. Other models that I can remember were made in Little Falls by the Larson Boats. A big outboard motor was a 15 horsepower. Later inboards appeared, I can remember waiting for the wake from the mail boat across the lake going to Upper Whitefish and Father Foley's Camp.*
>
> *Long trips on the lake were half or whole day events. South Cross Lake was shallow and was wonderful pan fish fishing. Father Foley's bar was always good for walleyes. The water was so clear one could see the schools of fish.*
>
> *The lake seemed to not grow algae. My first boat lift was hauled from the Twin Cities in about 1970. I used to disassemble it in the fall so I could store it by hand up on the "bank". It would come out of the lake as clean as it went in. Sometime after that it was like someone turned the switch and the lake began to grow algae. I maintain that something happened in the mid to late 1970's and the lake has become progressively more nutrient laden."*
>
> *-Steve R., Age 70, Citizen, Pine River Watershed*

Additional Pine River Watershed Resources

USDA Natural Resources Conservation Service (NRCS) Rapid Watershed Assessment for the Pine River Watershed:
http://www.nrcs.usda.gov/wps/portal/nrcs/detail/mn/technical/dma/rwa/?cid=nrcs142p2_023658

Minnesota Department of Natural Resources (DNR) Watershed Assessment Mapbook for the Pine River Watershed http://arcgis.dnr.state.mn.us/ewr/whaf/Explore/#

Pine River Watershed Alliance web page: http://www.prwa.us/

Crow Wing Soil and Water Conservation District: http://crowwingswcd.org/

Cass County Environmental Services:
http://www.co.cass.mn.us/government/county_directory/environmental_services/index.php

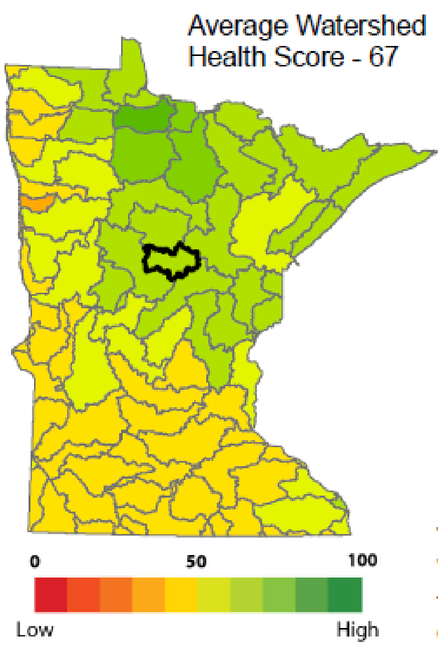
Pine River Watershed Alliance Facebook Page:
https://www.facebook.com/search/top/?q=pine%20river%20watershed%20alliance

Whitefish Area Property Owners Association web page:
http://minnesotawaters.org/whitefishareapropertyowners/

Minnesota Department of Health Groundwater Restoration and protection Strategies page:
http://www.health.state.mn.us/divs/eh/water/dwp_cwl/localimplem/index.html

Minnesota Pollution Control Agency Pine River Watershed page:
https://www.pca.state.mn.us/water/watersheds/pine-river

2. Watershed Conditions



Connectivity

Component Health Score (index average) 46

Index Scores

Terrestrial Habitat Connectivity	30
Aquatic Connectivity*	72
Riparian Connectivity*	97

Water Quality

Component Health Score (index average) 95

Index Scores

Non-Point Pollution Sources	90
Sub-Score Phosphorus Risk*	87
Localized Pollution Sources*	89
Assessments	95

Hydrology

Component Health Score (index average) 91

Index Scores

Perennial Cover*	94
Impervious Cover*	86
Water Withdrawal*	99
Flow Variability	68
Hydrologic Storage	94
Sub-Scores	
Altered Streams*	91
Surface Storage	98

Geomorphology

Component Health Score (index average) 59

Index Scores

Soil Erosion Potential*	75
Groundwater Susceptibility	31
Climate Vulnerability	70

Biology

Component Health Score (index average) 43

Index Scores

Terrestrial Habitat Quality*	21
Stream Species Quality*	58
Species Richness	54
At-Risk Species Richness	38

Watershed Health Assessment Framework
Health score methodology - **www.dnr.state.mn.us/whaf/about/scores**

Figure 3. The Minnesota Department of Natural Resources Watershed Health Assessment Framework scores for the Pine River Watershed.

The Pine River Watershed, by most metrics, is one of the cleanest and most pristine watersheds in the state of Minnesota (Figure 3). The scores for the components in the DNR Watershed Health Assessment Framework (WHAF) displayed above range from 0-100. In each instance, the higher scores imply higher quality components (natural resources or ecological systems), and lower scores imply lower quality components.

The Pine River originates from a series of small wetlands located approximately 3.5 miles southwest of Hackensack, Minnesota (Figure 1). Early in its course the river is a very small and gentle low gradient stream meandering southward through the heavily forested region near the Foothills State Forest. The river enters the north end of Pine Mountain Lake and passes the community of Backus. After passing through the dam on the south end of Pine Mountain Lake, the Pine River flows predominantly eastward through several small developed lakes. The river consists of several small connecting channels between Bowen, Lindsey, Brockway, and Lake Hattie. Dams are present on the outlet of Bowen Lake and Lake Hattie. From the outlet of Lake Hattie, the Pine River flows south for approximately five miles before entering Norway Lake. The community of Pine River is located on the southern shore of Norway Lake. The South Fork of the Pine River, a major tributary, joins the Pine River 1.5 miles downstream of the Norway Lake dam. The South Fork of the Pine River drains the southwest portion of the Pine. Flowing from west to east, the South Fork of the Pine River is primarily low gradient and has a considerable amount of agricultural land use within its drainage area. After the confluence of the South Fork of the Pine River, the Pine River flows toward the east and the stream gradient increases. Swifter velocity and more frequent sections of riffle occur along the five-mile stretch of river between the confluence of the South Fork of the Pine River and the Whitefish Chain of Lakes.

The Pine River enters the Whitefish Chain of Lakes on the western side of Whitefish Lake. The Whitefish Chain of Lakes covers 14,000 acres and consists of 14 interconnected lakes. Lake basin morphology varies considerably among lakes within the Whitefish Chain. Moderate to heavy development occurs around several lakes and within the vicinity of the Whitefish Chain of Lakes. Numerous tributaries flow directly into the lakes associated with this system. One of the more prominent tributaries to the lake system is Daggett Brook. Daggett Brook drains 149 square miles of the northeast portion of the Pine. Flowing from north to south, Daggett Brook passes through heavily forested land, numerous wetlands, and several lakes before entering the Whitefish Chain of Lakes.

The Pine River exits the Whitefish Chain of Lakes through the Cross Lake Dam and flows toward the south. The river passes through an impounded wetland area on the north end of Pine Lake before flowing through Big Pine Lake dam. Pelican Brook joins the Pine River three miles downstream of Big Pine Lake dam. Pelican Brook flows east out of Ossawinnamakee Lake. After joining with Pelican Brook, the Pine River winds eastward through the Crow Wing State Forest for several miles before turning toward the south. At this location, the Pine River is joined by the Little Pine River. The Little Pine River flows toward the southwest and drains 141 square miles of the eastern portion of the Pine. Numerous wetlands and several lakes are within the Little Pine River drainage area. Mud Brook, a significant low gradient tributary, enters the Little Pine River a few miles upstream of Olander Road. Over much of its course, the Little Pine River is a low gradient wetland influenced stream; however, some sections of riffle do occur in the lower reaches. After the confluence of the Little Pine River, the Pine River continues winding south until it enters the Mississippi River. The average gradient of the Pine River from Norway

Lake Dam to the confluence with the Mississippi River is 2.3 feet per mile (DNR 2014). Less than 10% of the streams within the Pine have been straightened or received other hydrologic alterations. In general, most watersheds in the north central and northeast region of Minnesota have a lower percentage of modified stream channels when compared to other regions of the state.

In most cases across the Pine, protection, rather than restoration, is the primary focus, as far and away most water bodies in the Pine meet water quality standards. Focus in this watershed must be directed toward maintaining, to the extent possible, the natural forests and wetlands that continue to provide clean surface and groundwater.

Groundwater

The Pine is characterized by sand aquifers in generally thick sandy and clayey glacial drift overlaying bedrock in the Central Groundwater Province. Sand and gravel aquifers supply water to most of the 3,120 private wells and the 286 public water supply wells in the watershed (DNR 2016).

Land cover within the Pine is dominated by deciduous forest, followed by woody wetlands and open water. No townships in the Pine have more than 6% of the area in row crop production. The high percentage of natural cover is one of the key reasons good water quality exists. In the absence of vegetation, contaminants at the land surface are more likely to infiltrate into groundwater because the surficial aquifer is very sensitive to land use changes that convert, degrade, or eliminate natural habitats.

While water quantity use is limited within the watershed, groundwater withdrawals exhibit a statistically significant rising trend, whereas surface water withdrawals are declining. Approximately 93% of all water appropriated in 2014 within the watershed was groundwater, 7% of appropriated water came from surface water sources (DNR Permitting and Reporting System (MPARS)).

Additional information on groundwater conditions can be found in the Pine River Groundwater Restoration and Protection Strategies (GRAPS) Report, which can be requested from the Minnesota Department of Health (MDH).

Recollections:

> *My first trip into the waters of Deep Portage was in the early 1960's. Even as a teenager, I was enamored by the beautiful, pristine waters. At that time there were few cabins/homes on the lake and the water was so clear that you felt as if you could drink it. Fast forward to 1975 when we purchased our property on Deep Portage. Still a beautiful lake with very clear water and on our side (SW) a sandy bottom with little silt or muck. Reeds growing about 25' off the shore. Some weed growth around the lake with reeds and lillypads being predominant. The lake was so clear that we could sit on our deck (75' from water's edge) and see fish swimming around our dock area. The channel leading into Deep Portage was narrow, shallow and surrounded on each side by bogs where bull rushes and cattails grew in abundance.*
>
> *While Deep Portage is still quite a clear, pristine lake, we have observed a number of changes during the intervening years. Most noticeably is the addition of weed growth, predominantly wild rice. No wild rice was present on Deep Portage until the last few years. It has now spread to many areas around the lake's shores. We are also seeing an increase of bushy pondweed on the*

western corner and an increase in what I believe to be a type of duckweed. Over all, weed growth has increased in all areas near shore. Since it is such a Deep Lake, we observe no additional weed growth in the main area of the lake. Clarity has also decreased, although not dramatically. The channel area has seen the most change; we believe it to be severe and detrimental to our lake quality. Not only has it been widened, but boats have created a trench down the middle, the bog sides have been torn away (we often find bits of the bog floating in the lake), and there are numerous side channels. Wild rice is now prevalent throughout the channel area. Historically, water flowed from Deep Portage into Rice Portage; we now see, on occasion that reversed due to the opening of the channel.

I would like to see our lake protected in order to maintain its condition today. Restoring its clarity and limiting the weed growth would be ideal. My biggest concern is the channel area. The frequent passage of large pontoon boats, high horsepower motors, and carelessness of people is destroying this historically narrow passage. I believe it to be a fragile, sensitive habitat for native plants and animals. I would truly like to see it protected. I realize that we cannot prohibit passage, but somehow it should be protected and restored or I believe it will create additional concerns for Deep Portage Lake in the years ahead.

Nancy T., Age 69, Citizen, Pine River Watershed

2.1 Condition Status

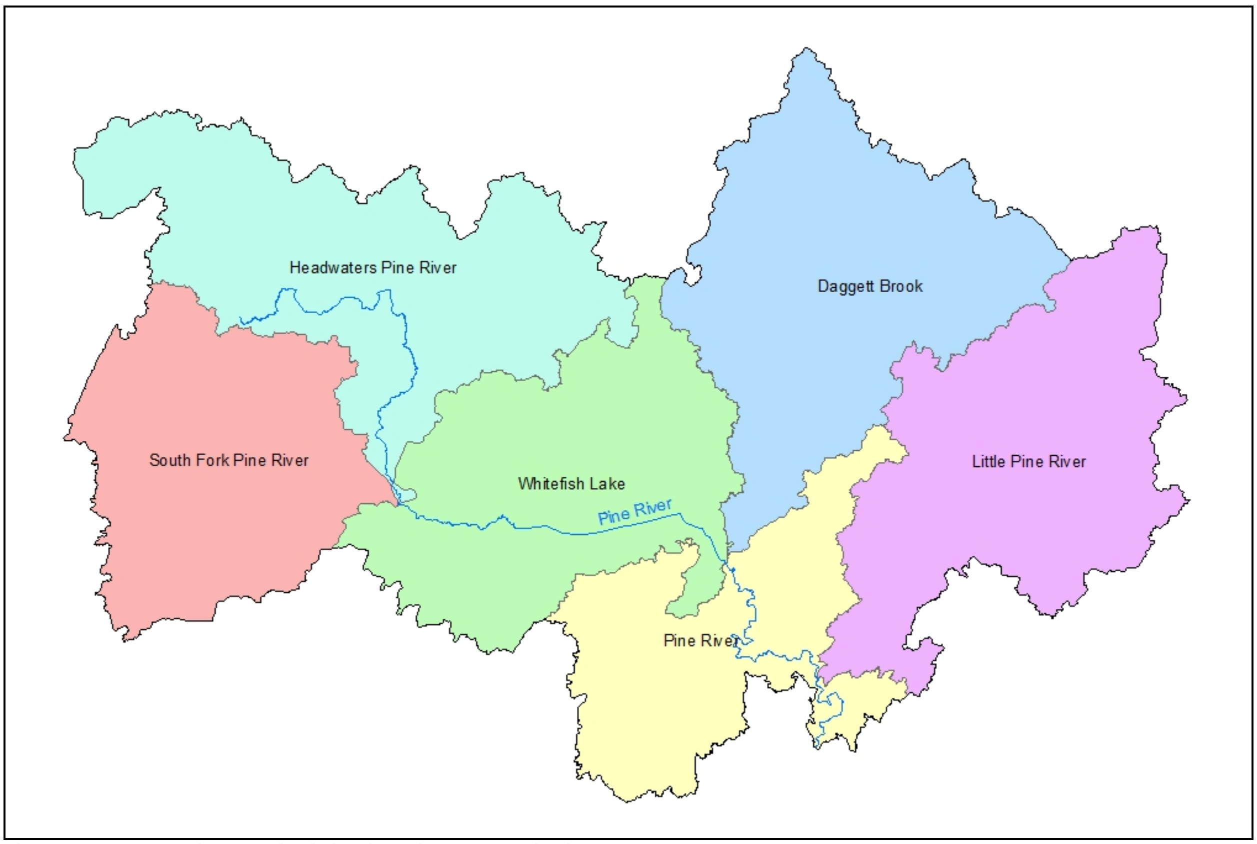


Figure 4. HUC 10 subwatersheds in Pine River Watershed

The following section summarizes impairment assessments for streams and lakes in the Pine at the HUC-10 subwatershed scale (Figure 4).

The MPCA uses data collected over the most recent 10-year period for all water quality assessments. This time frame provides a reasonable assurance that data will have been collected over a range of weather and flow conditions and that all seasons will be adequately represented; however, data for the entire period is not required to make an assessment. The goal is to use data that best represents current water quality conditions. Therefore, recent data for pollutant categories such as toxics, lake eutrophication and fish contaminants may be given more weight during assessment.

Some of the waterbodies in the Pine are impaired by mercury. For more information on mercury impairments, please refer to the statewide mercury TMDL at:
http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/tmdl-projects/special-projects/statewide-mercury-tmdl-pollutant-reduction-plan.html.

Stream Assessments and Impairments

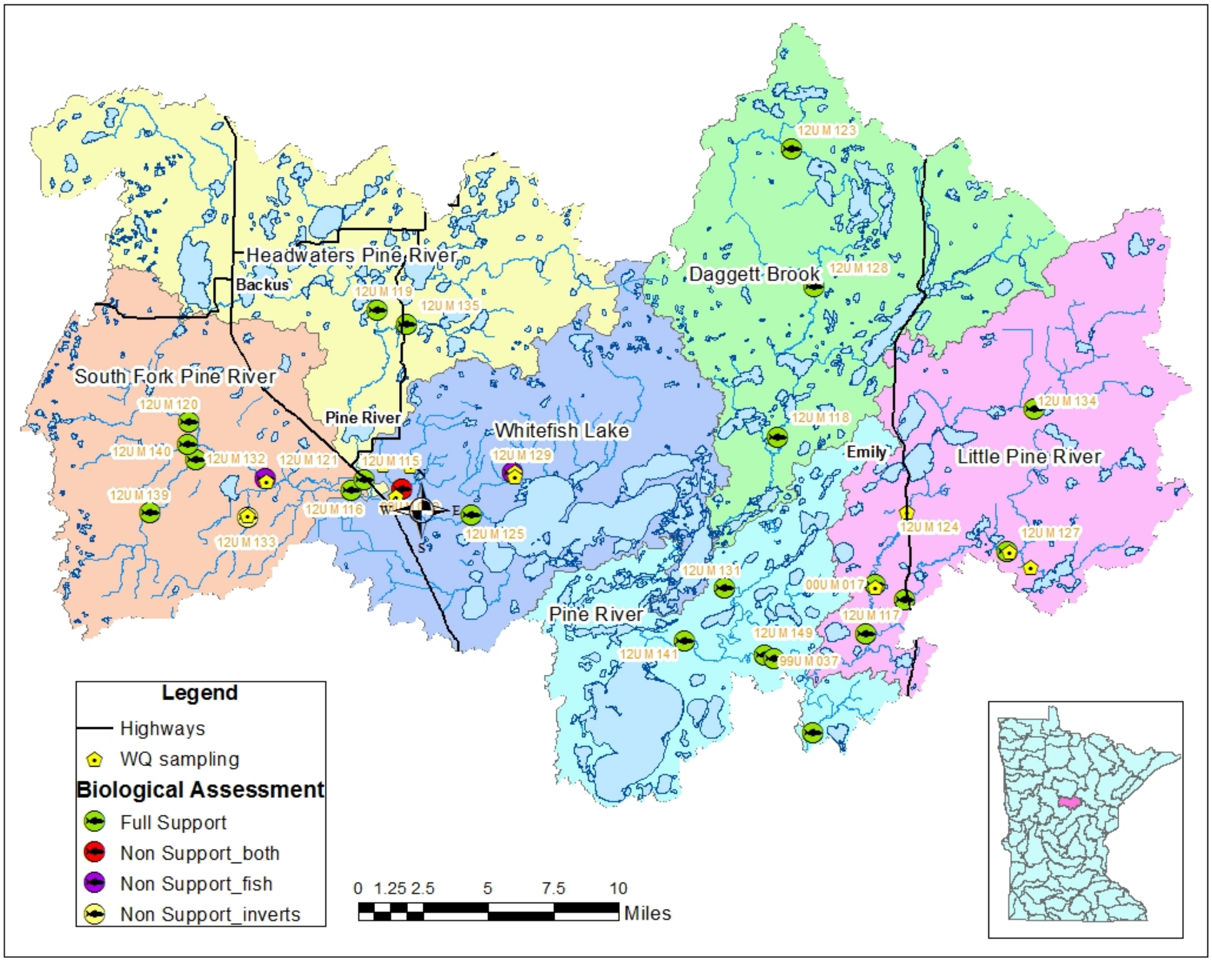


Figure 5. Biological Assessments within the Pine River Watershed.

The current IWM process began in 2012. From May through September 2012, and June through August in 2013, five stream water chemistry stations were sampled intensively. Streams in the Pine were assessed for both aquatic life and aquatic recreation, which means they were analyzed to determine if they are able to support healthy fish, bugs, and plant communities, as well as fishing, swimming and other forms of recreation (Figure 5).

Of the 25 stream Assessment Unit Identifier (AUIDs) that were assessed for aquatic life, four were found to be non-supportive, or 16% of assessed reaches (Table 1). This is likely to be an accurate representation of stream reaches in the Pine that are non-supportive for aquatic life, as these reaches were selected using a randomized, unbiased selection process. As the four streams found to be non-supportive were impaired due to habitat damage and not excessive loading by any parameter, TMDLs will not be completed for these.-Of the 25 streams that were assessed for aquatic life, nine were also assessed for aquatic recreation, all of which were found to be fully supportive.

Table 1. Stream Aquatic Life Use and Aquatic Recreation Use Assessment Summary

HUC 10 Subwatershed	Total Assessed Stream Reaches	Aquatic Life Use				Aquatic Recreation Use			
		SUP	IMP	IF	NA	SUP	IMP	IF	NA
Headwaters Pine River	**3**	3	-	-	-	2	-	-	1
South Fork Pine River	**6**	4	2	-	-	1	-	-	5
Daggett Brook	**3**	3	-	-	-	1	-	-	2
Whitefish Lake	**4**	1	2	1	-	2	-	-	2
Little Pine River	**5**	5	-	-	-	1	-	-	4
Pine River	**4**	4	-	-	-	2	-	-	2
Total	**25**	**20**	**4**	**1**	**-**	**9**	**-**	**-**	**16**
SUP = found to meet the water quality standard									
IMP = does not meet the water quality standard and therefore is impaired									
IF = the data collected was insufficient to make a finding									
NA = not assessed									

In Willow and Arvig Creeks in particular, in the Whitefish Lake Subwatershed, the causes of the impairments were determined to be habitat alteration resulting from livestock grazing near and into the streams. This caused deep-rooted riparian vegetation to be lost along the stream bank, which in turn caused erosion of the banks, causing widening of the stream and aquatic habitat loss due to sedimentation.

Members of the Pine River Watershed Alliance and staff from the Crow Wing Soil and Water Conservation District (SWCD) have already met with landowners in key locations along Arvig Creek and Willow Creek on strategies to exclude cattle from the river and restore the native vegetation along the bank**.** This effort is expected to help to normalize the flow through the streams, reduce channelization and erosion, and thus reduce sediment transport that has damaged habitat in the streams. The landowners have been willing to work with the team to fence off key areas and keep livestock away from stream banks to allow them to re-vegetate with native grasses, sedges, and shrubs. This in turn should help restore the natural stream channels, reduce sedimentation, and improve habitat for aquatic wildlife.

The other two impaired stream reaches are in the South Fork Pine River Subwatershed. Wilson Creek was found to not fully support healthy bug populations. The stressor causing the impairment is thought to be lack of diverse habitat, as the woody debris located in the stream are primarily small willow twigs that appear to be mobile during high flow periods, so there is not sufficient stable habitat for healthy bug populations.

The South Fork Pine River from Bungo Creek to Hoblin Creek did not support a healthy fish community. Sections of altered stream channel located in tributaries to the South Fork Pine River may be altering the delivery of flow and possibly changing the hydrology of the receiving stream. More study would need to be conducted to determine if altered hydrology is affecting the South Fork Pine River. The South Fork Pine River has multiple road crossings, most of which are bridges that would have no impact on fish migration. However, there are two crossings that have culverts that can impact fish migration. One of these crossings at 36th Avenue appears to be changing the slope of the channel on the upstream side and may also be preventing fish from passing during periods of high flow. Stream slope and velocities increase on the downstream side of the 36th Avenue culverts. The slope of the channel is flat above the culverts at 36th Avenue and this appears to be causing excessive fine sediment deposition and loss of stream features. Excessive fine sediment results in the loss of egg laying habitat and food sources for fish.

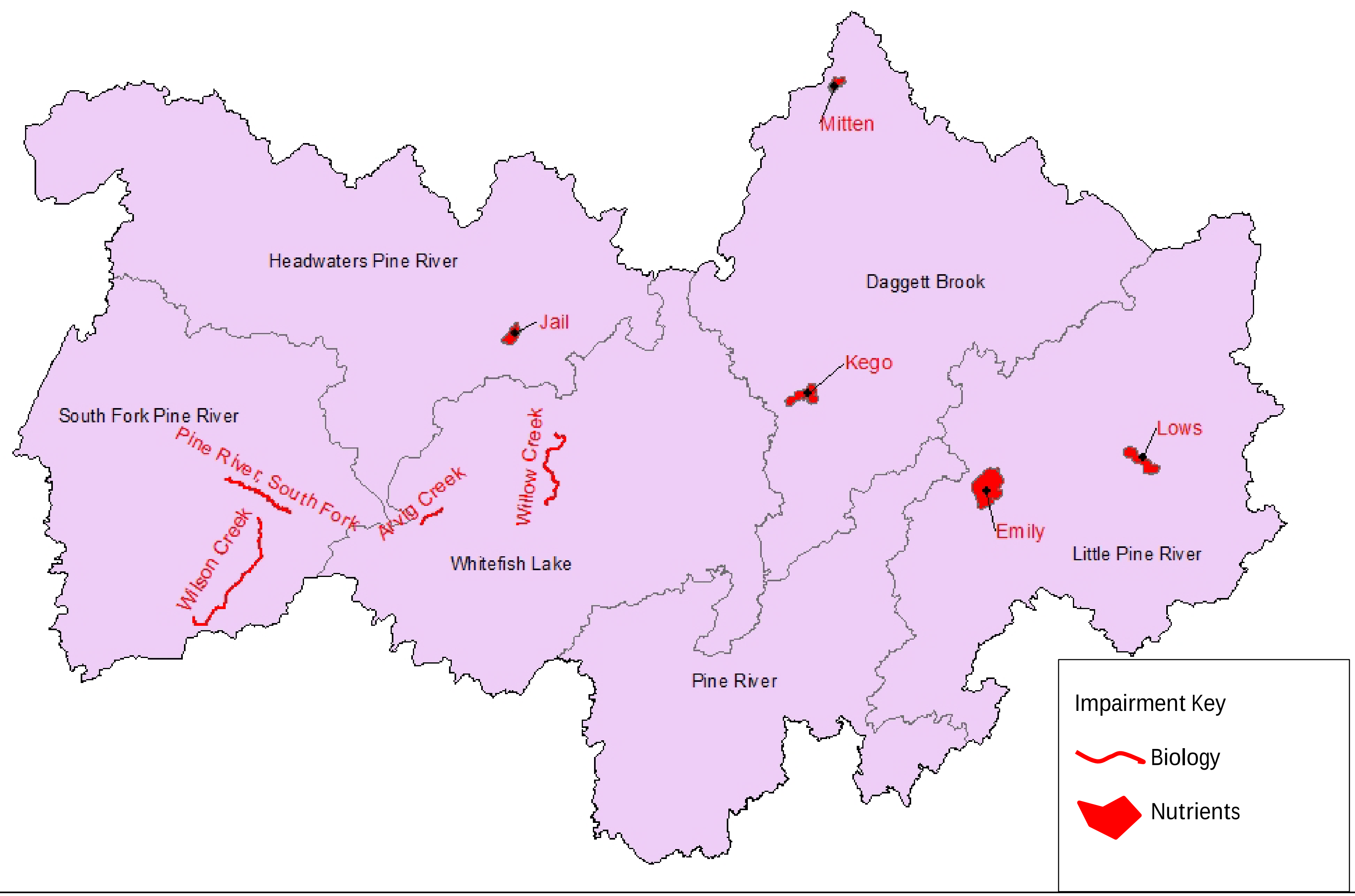
Lake Assessments and Impairments

From 2012 through 2014, 112 lakes were assessed from data collected by the MPCA, through a SWAG awarded to the Crow Wing SWCD and Cass County Environmental Services efforts, or by citizens following MPCA's Citizens Lake Monitoring Program (CLMP) protocol. One of those lakes, Kego (18-0293-00, Daggett Brook Subwatershed) had been listed as impaired since 2010, and assessment data taken during the current IWM period confirmed that the lake still exceeds phosphorus standards, although the exceedance is typically seen during late summer months. A second lake that had been listed as impaired prior to the current IWM period, Jail Lake, was not assessed during the current IWM period but was included on the assessed lakes list in Appendix 3 because of its impaired listing in 2012. TMDL studies were conducted in conjunction with this WRAPS report for Jail and Kego lakes. Three more lakes were found to exceed phosphorus standards during the IWM process; Mitten (11-0114-00, Daggett Brook), Lows (18-0180-00, Little Pine), and Emily (18-0203-00, Little Pine). No TMDLs are being developed for Mitten, Lows, and Emily lakes, as described below. Figure 6 shows the impaired lakes and streams in the Pine.

An extensive natural background review was conducted for Lows Lake, which has data indicating the lake basin is non-supportive for aquatic recreational use. Review of county, state, geospatial, and modeling analysis determined that anthropogenic sources of phosphorus were unlikely to be causing the eutrophication. Lows Lake is also a shallow lake and internal loading is likely driving the increased concentrations of phosphorus seen in the water column. Considering the contributing watershed is heavily forested with wetland complexes present and little human activity evident in combination with the modeling and other data, Lows lake will be placed into a 4D (impaired due to natural sources) category.

Limited chloride data was available on lakes in this watershed; all fell well below the chronic standard of 230 mg/L. Elevated chloride concentrations are often due to excessive road salt contamination (typically found in metropolitan areas) or indirectly from a point source discharge such as in home water softeners. Neither of these inputs is of significant concern in the Pine.

Figure 6. Non-Mercury stream and lake impairments by HUC10 in the Pine River Watershed.



Headwaters Pine River HUC 10 Subwatershed

Twenty lakes had sufficient data to assess for aquatic recreation; of these, 19 were found to be fully supporting. The fully supporting lakes include flow through, seepage, and headwater lakes such as Pine Mountain, Big Portage, Jackpine, and Ada. Water chemistry data collected from Horseshoe Lake indicate it is one of the highest quality lakes in Headwaters Pine River Subwatershed. The good water quality can be attributed to relatively undisturbed forest and wetland dominated land, as well as light to moderate shoreline development. The development of lake protection strategies at a local level would be beneficial for maintaining the current water quality conditions of lakes in this subwatershed.

Jail Lake was assessed in 2011 based on data collected from 2006 through 2011. The lake is considered to have impaired aquatic recreation due to excessive nutrient levels. Secchi observations collected since the initial assessment indicate that the lake is still impaired. Poor land use practices in this small watershed could be a potential contributor to nutrient loading. See the Pine River Watershed TMDL Report for details.

South Fork Pine River HUC 10 Subwatershed

The South Fork Pine River Watershed contains many small lakes with limited access; as a result, Eagle Lake was the only lake with enough data for assessment. Eagle Lake easily met all three nutrient ecoregion standards. The mostly undeveloped shoreline and predominately forested watershed contributed to high water quality. Land conversion is more prevalent within this subwatershed; therefore, best management practices (BMPs) that mimic natural systems (infiltration, filter strips, runoff control) will be vital as forest is increasingly replaced by other land uses and resulting deforestation.

Daggett Brook HUC 10 Subwatershed

Water chemistry data was collected on 27 lakes in the Daggett Brook Subwatershed. Eighteen of the 20 lakes had sufficient data to confirm they fully support aquatic recreation. The abundance of undisturbed forest and wetland complexes throughout this subwatershed helps to protect the recreational quality of the lakes. High quality lakes such as Morrison, Leavitt, Lawrence, Roosevelt (north and south), and Blue are connected by small tributaries and have moderate shoreline development when compared to other nearby lakes in the watershed. Responsible shoreline management practices should continue wherever possible. Additional implementation of lake friendly shoreline management practices will ensure that the high quality of these lakes is preserved.

Kego and Mitten Lakes in the Daggett Brook Subwatershed failed to support aquatic recreation. The recent data collected from Kego Lake (listed in 2010) during 2010 and 2011 indicate phosphorus, chlorophyll-a, and Secchi exceedances still occur during the summer months. The lake is not a candidate for delisting at this time. The stressors impacting Kego Lake are addressed in the Pine River TMDL study. Mitten Lake has shown a consistent pattern of exceedances between 2012 and 2013. A detailed natural background review of Mitten Lake could not definitively conclude that elevated nutrient levels are solely attributed to natural processes. Further investigation will be needed to identify sources of nutrients that could be enriching Mitten Lake, and as Mitten was not officially listed as impaired until early 2017, no TMDL is being conducted at this time.

Whitefish Lake HUC 10 Subwatershed

In the Whitefish Lake Subwatershed, 13 lakes had data available within the 10-year assessment window; 11 of these had sufficient datasets available to make an aquatic recreation assessment. All 11 lakes with sufficient assessment data fully supported aquatic recreation. Most of the lakes in the subwatershed are either flow through lakes on the Pine River or indirectly connected to the river through other lakes or channels. The deep lake basins in the southeastern portion of the subwatershed known as the Whitefish Chain have good water quality despite high development density on shorelines. Deep lakes have the ability to assimilate higher amounts of phosphorus at depth without negatively impacting surface conditions until mixing occurs in the fall. Four lakes (Whitefish, Island, Bertha, Pig) have a decreasing trend in historical Secchi data suggesting that a potential change in water quality could be imminent. Implementing development practices that limit runoff to the lakes will be very important.

Little Pine River HUC 10 Subwatershed

In the Little Pine Subwatershed, there was sufficient data for 9 lakes greater than 28 acres in surface area to assess them for aquatic recreation. Of these nine lakes, seven fully supported aquatic recreation and two did not. Lake Emily, a relatively shallow flow through lake on the Little Pine River, does not support aquatic recreation due to excess nutrients. The excess nutrients could be attributed to past wastewater treatment practices and shoreline development adjacent to the lake. Because the lake was listed as impaired so late in this process, a TMDL will be developed at a later time. Lows Lake also does not support aquatic recreation, and as discussed previously is proposed to be listed as impaired due to natural sources, and if accepted as such, will not require a TMDL study. Adney and Ruth lakes are two high quality lakes with developed shorelines; both fully supported aquatic recreation. With high shoreline development densities on both lakes, it is imperative that responsible shoreline management practices continue into the future to maintain and protect water quality. The high water quality of other fully supporting lakes in this subwatershed can be attributed to mostly undisturbed upstream watersheds and responsible shoreline management.

Pine River HUC 10 Subwatershed

Data was available for 29 lakes in the Pine River Subwatershed. Twenty-one of those lakes had sufficient data to assess, all of which were found to support aquatic recreation.

The aesthetic beauty of Pelican Lake attracts heavy recreational use by local citizens and tourists year round. Development in the watershed continues to increase, highlighting the need for effective water management practices. Proper shoreline management practices will help alleviate stress from dense development. The lake appears to be a prime candidate for protection strategies and future implementation efforts. Maintaining good water quality will ensure that other benefits, such as tourism dollars and higher property values, will continue into the future.

Table 3 summarizes the ability of assessed lakes to support aquatic recreation uses in the Pine. For more detailed information about specific lakes and their assessment and trend status, refer to the IWM report, found at https://www.pca.state.mn.us/sites/default/files/wq-ws3-07010105.pdf.

Table 2. Lake Aquatic Recreation Use and Impairment Summary

Aggregated HUC 12 Subwatershed	Total Lakes Assessed	Aquatic Recreation Use		
		SUP	IMP	IF
Headwaters Pine River	**34**	20	1	13
South Fork Pine River	**1**	1	-	-
Daggett Brook	**27**	18	2	7
Whitefish Lake	**13**	11	-	2
Little Pine River	**16**	7	2	7
Pine River	**29**	21	-	8
Total	**112**	71	5	36
SUP = found to meet the water quality standard				
IMP = does not meet the water quality standard and therefore is impaired				
IF = the data collected was insufficient to make a finding				

2.2 Water Quality Trends

The Pine has long had engaged and active citizen groups that spend considerable time and resources to monitor and study water quality in the Pine. In part, because of these groups and individuals, there is a good store of data for the watershed going back for well over a decade.

Water Clarity Trends at Citizen Monitoring Sites

Citizen volunteer monitoring occurs at 23 stream and 72 lake stations throughout the Pine. At this time, only one stream has sufficient data to calculate a long-term trend, indicating no significant trend over the dataset. Fifteen lakes show an increasing trend in water clarity, while 10 appear to be declining in water clarity. Maintaining citizen data collection at these locations is vital to strengthen long-term datasets. Local advocacy is also necessary for recruiting new volunteer monitors within the watershed. Citizen monitoring data can be used to fill in data gaps between IWM years and other local ongoing projects.

Pine River Watershed HUC 07010105	Citizen Stream Monitoring Program	Citizen Lake Monitoring Program
number of sites w/ increasing trend	0	15
number of sites w/ decreasing trend	0	10
number of sites w/ no trend	1	54

Table 3. Water clarity trends at Citizen Stream Monitoring Sites.

Further analysis on secchi trends in the Pine was done during the development of the Lakes of Phosphorus Sensitivity Significance. The analysis used in that process can be found in Appendix 1, and further discussion is found in Section 3. Of the 19 lakes with outstanding Phosphorus Sensitivity

Significance, six show a decreasing trend in secchi depth, which indicates a decrease in water clarity, and three show an increasing trend. Six show no trend, and four had insufficient data.

2.3 Stressors and Sources

In order to develop appropriate strategies for restoring or protecting waterbodies, the stressors and/or sources impacting or threatening them must be identified and evaluated. Biological stressor identification (SID) is a process completed for streams with either fish or macroinvertebrate biota impairment. SID evaluates both pollutants and non-pollutant-related factors as potential stressors (e.g. altered hydrology, fish passage, habitat) to the fish and bug populations in streams. When SID identifies a pollutant as a stressor, then a pollutant source assessment is completed. This section provides further detail on stressors and pollutant sources as found during the SID study. The complete report can be found here: https://www.pca.state.mn.us/sites/default/files/wq-ws5-07010105a.pdf. Table 4 shows the primary stressors found for the stream reaches studied.

Stressors of Biologically-Impaired Stream Reaches

Low dissolved oxygen (DO) has been identified as an issue in various parts of the watershed, but most notably in Arvig Creek. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species.

Altering natural stream channels can impact stream flow and alter the amount of available stream habitat. Nearly 10% of the watershed's 590 stream miles have been altered. Stream channelization is scattered throughout the watershed with many of the biologically impaired stream reaches located downstream of channelized stream reaches, most notably in Wilson Creek.

When excess amounts of sediment, suspended solids and fine material are transported downstream, it can settle out and fill in pools, smother rock riffles, and cause a general degradation of in-stream habitat. The loss of coarse stream substrate directly affects the biological communities that depend on this type of stream bottom. Though there is indication that this is a potential stressor in the South Fork Pine River, at this point it does not seem to be a watershed-wide problem.

Increased nutrients, like nitrogen and phosphorus, can cause excessive plant and algal growth, which can alter physical habitat, alter food chains, and create toxic conditions. This does not appear to be a watershed-wide problem, but rather isolated to a few tributaries, most notably in Wilson Creek.

Lack of physical habitat, caused by human activities and land uses, leads to decreased streambanks and woody debris, altered discharge patterns, and increased sediment. Forestry, urbanization, agriculture, and industry are all example causes. Lack of physical habitat is present in Wilson Creek, the South Fork Pine River, Arvig Creek, and Willow Creek.

			Stressors						
HUC 10 Watershed	**Stream Name**	**AUID #**	**Low Dissolved Oxygen**	**Flow Alteration**	**Increased Sediment**	**Increased Bedded Sediment**	**Elevated Nutrients**	**Lack of Physical Habitat**	**Physical Connectivity**
South Fork Pine River	Wilson Creek	07010105-529				X		X	
South Fork Pine River	South Fork Pine River	07010105-531				X		X	X
Whitefish Lake	Arvig Creek	07010105-509	X			X		X	
Whitefish Lake	Willow Creek	07010105-631				X		X	X

Table 4. Primary stressors to aquatic life in biologically impaired reaches in the Pine River Watershed.

Networks of road crossings scattered throughout a watershed pose a threat to the physical connectivity of streams and rivers. Sometimes culverts are set at elevations that, depending on high or low flow conditions, can create barriers to fish passage. The South Fork Pine River has an elevated set of culverts at 36th Avenue that are limiting fish passage and depositing excess sediments upstream of the road. Willow Creek also has a physical connectivity problem with culverts along Long Farm Road.

Pollutant sources

Point Sources-

The following table identifies point sources within the Pine River Watershed by National Pollutant Discharge Elimination System (NPDES) Permit (Permit) type and HUC-10 subwatershed. NPDES/State Disposal System (SDS) Construction Stormwater (CS) Permits were not included in this table, but are shown on the map in Figure 7 because they are temporary permits, and very often permits remain on the "active" list well after the site has been closed down and stabilized.

Current databases examined show that the sites identified in Figure 5 have active permits as of the writing of this document.

Figure 7 indicates the locations of NPDES permitted sites in the Pine. The triangles indicate the locations of sites with open CS Permits. Open Permits in the CS program do not necessarily mean active or open sites; permits often stay open as a result of a failure of a regulated party to file a "Notice of Termination" once the project has been completed. The hexagons on the map represent open Industrial Stormwater (IS) Permits, and the circle represents a multiple program site, including Resource Conservation and Recovery Act (RCRA) remediation sites, wastewater (WW), and IS.

Table 5. Point Sources in the Pine River Watershed.

HUC-10 Subwatershed	Point Source			Pollutant reduction needed beyond current permit conditions/ limits?	Notes
	Name	Permit #	Program Type		
Headwaters Pine River	Pine River Wood Products, Inc.	A00002308	Industrial Stormwater	No	
	Grinning Bear Roll-Off Services	MNR053CV3	Industrial Stormwater	No	
	Pine River Airport	MNR0539FL	Industrial Stormwater	No	
	Backus Municipal Airport	MNR053CN3	Industrial Stormwater	No	
South Fork Pine River	Cass County Transfer/Recycling Station	MNR05364L	Industrial Stormwater	No	
	Pine River Iron & Metal	MNR053BSM	Industrial Stormwater	No	
	Stockman Transfer, Inc.	MNR05379P	Industrial Stormwater,	No	
South Fork Pine River	Mid-State Recycling	A00014320	Industrial Stormwater,	No	
Daggett Brook	Cass County Longville-Remer Landfill	MNRNE3675	Industrial Stormwater	No	
Whitefish Lake	Fifty Lakes Modified Sanitary Landfill	MNRNE3BVP	Industrial Stormwater	No	
	Whitefish Lake Bertha Boatworks Inc.	83454926	Industrial Stormwater	No	
	Maple Sanitary Landfill	MNRNE368X	Industrial Stormwater	No	
	LME Inc.	MNURNE3CX6	Wastewater	No	Facility now closed per MPCA staff
Pine River	Crosslake Ready Mix Inc	MNRNE3CX6	Industrial Stormwater	No	

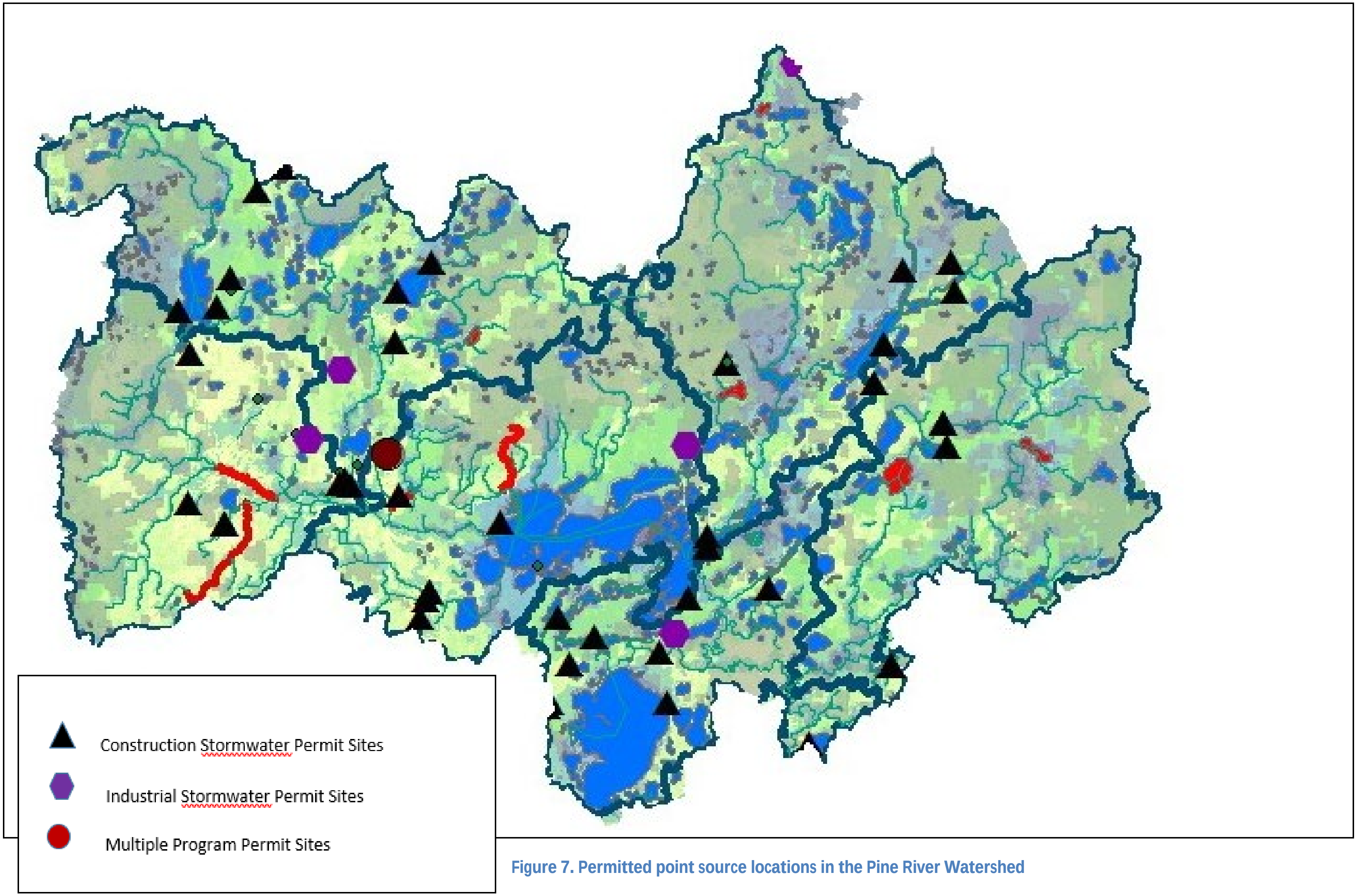


Figure 7. Permitted point source locations in the Pine River Watershed

Nonpoint Sources

The Pine, although largely forest covered, still has enough development and land use alteration to allow phosphorus levels to increase in surface waters throughout the watershed. According to the Hydrologic Simulation Program FORTRAN (HSPF) Scenarios Report that was developed by RESPEC, further discussed in Section 3 of this document, the current phosphorus loading level in the Pine stands at about 46,000 pounds per year. Refer to Figure 8 for a map depicting the current phosphorus loading in the Pine. Figure 9 refers to current runoff in the watershed, with the areas in dark red contributing the most runoff to the surface waters within those areas.

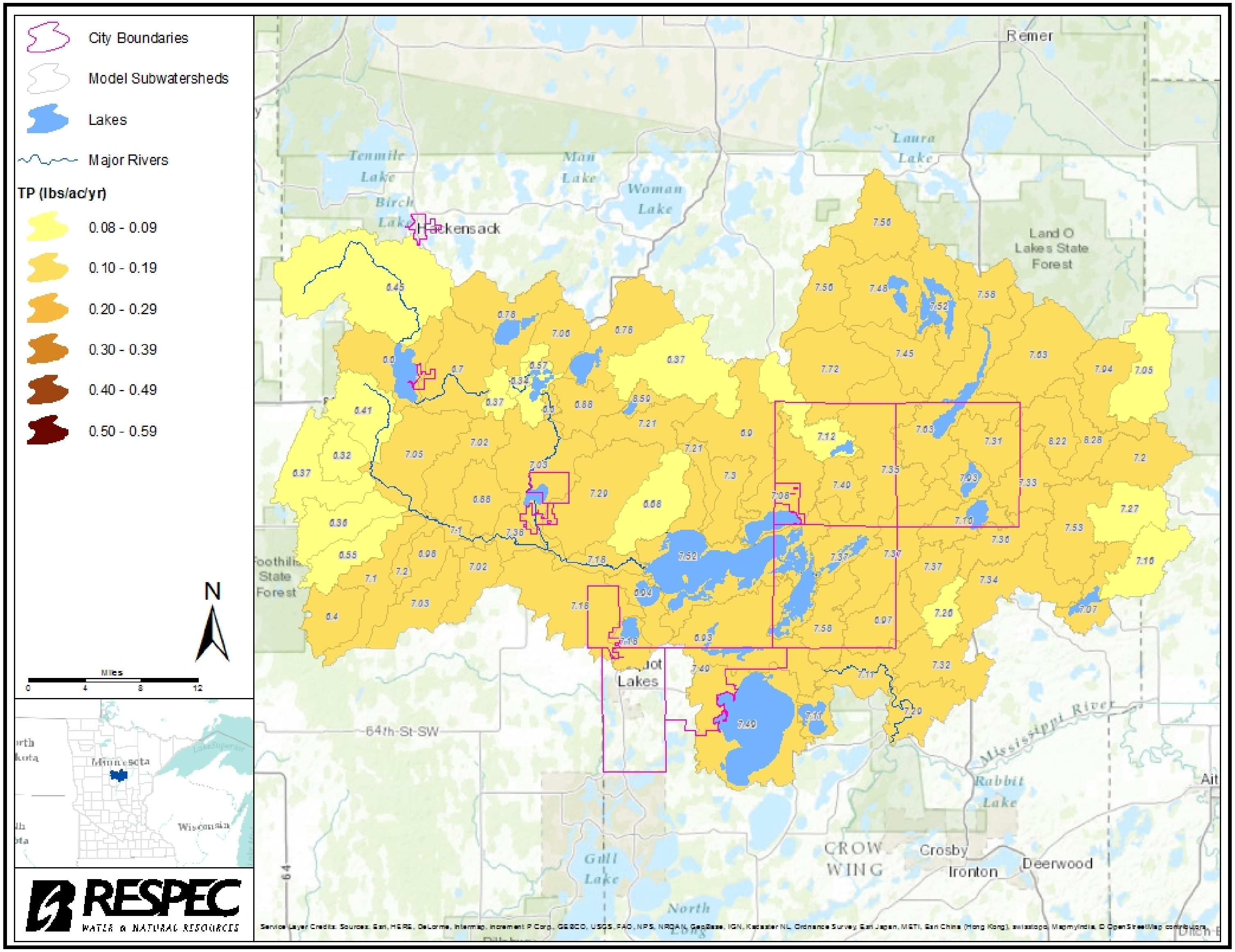


Figure 8. Current phosphorus loading in the Pine River Watershed.

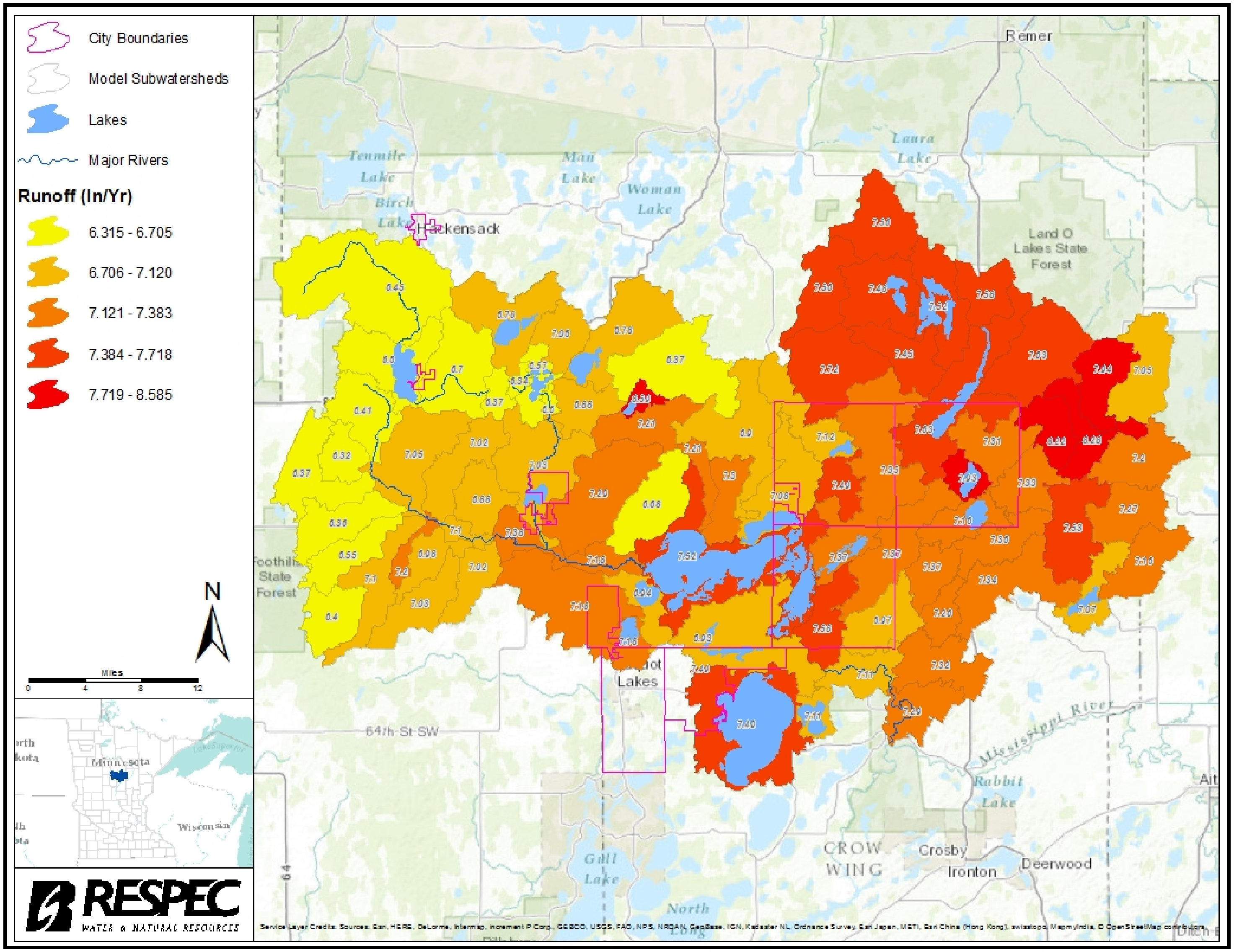


Figure 9. Current runoff in Pine River Watershed (inches/year)

2.4 TMDL Summary

The Clean Water Act (1972) requires that each State develop a TMDL study to guide restoration of any waterbody that is deemed impaired by state regulations. A TMDL identifies the pollutant that is causing the impairment and how much of that pollutant from each source can enter the waterbody and still meet water quality standards.

The Pine River Watershed TMDL study includes two lakes that are on the draft 2014 MPCA 303(d) list of impaired waters.

Information from multiple sources was used to evaluate the ecological health of each lake:

- All available water quality from 2003 through 2012
- Fisheries surveys
- Plant surveys
- Stakeholder input

The following pollutant sources were evaluated for each lake: watershed runoff, loading from upstream lakes, atmospheric deposition, lake internal loading, point sources, feedlots, and septic systems. An inventory of pollutant sources was used to develop a lake response model for each impaired lake. These models were then used to determine the pollutant reductions needed for the impaired lakes to meet water quality standards.

Table 6. Pine River Watershed TMDL Summary

EPA/MPCA Required Elements	Summary
Location	The Pine River Watershed (07010105) is a tributary to the Mississippi River located in north-central Minnesota
303(d) Listing Information	**Impaired waterbodies on the State's 303(d) list**:
	Jail Lake (aka Big Rice Lake), DNR ID 18041500
	Kego Lake, DNR ID 18029300
	Impaired Beneficial Use(s): Aquatic Recreation
	Pollutant of Concern: Nutrients (Phosphorus) /Eutrophication Biological Indicators
	TMDL Target Start/Completion: 2012/2016
	Original listing year: 2010 (Kego), 2012 (Jail)
Applicable Water Quality Standards/ Numeric Targets	Class 2B Waters Lake Eutrophication Standards, Minn. R. 7050.0222, subp. 4, Northern Lakes and Forests Ecoregion (NLF): TP (µg/L) < 30, Chl-a (µg/L) < 9, Secchi (m) > 2.0.
	Based on clear relationships established between TP, Chl-a, and Secchi for Minnesota lakes it is expected that by meeting the TP goal, Chl-a and Secchi will also be met (Heiskary and Wilson 2005).

<table>
<tr><th>EPA/MPCA Required Elements</th><th colspan="3">Summary</th></tr>
<tr><td rowspan="3">Loading Capacity (expressed as daily load)</td><td colspan="2">Impaired Lake</td><td>Loading Capacity (kg/day)</td></tr>
<tr><td colspan="2">Jail</td><td>0.453</td></tr>
<tr><td colspan="2">Kego</td><td>0.679</td></tr>
<tr><td rowspan="5">Wasteload Allocation</td><td>Source (Permit #)</td><td>Impaired Lake</td><td>WLA (kg/day)</td></tr>
<tr><td rowspan="2">Construction Stormwater (MNR100001)</td><td>Jail</td><td>0.0014</td></tr>
<tr><td>Kego</td><td>0.0016</td></tr>
<tr><td rowspan="2">Industrial Stormwater (MNR50000)</td><td>Jail</td><td>0.0014</td></tr>
<tr><td>Kego</td><td>0.0016</td></tr>
<tr><td>Load Allocation</td><td>Impaired Lake</td><td colspan="2">LA (kg/day)</td></tr>
<tr><td></td><td>Jail</td><td colspan="2">0.405</td></tr>
<tr><td></td><td>Kego</td><td colspan="2">0.608</td></tr>
<tr><td>Margin of Safety</td><td colspan="3">An explicit 10% margin of safety (MOS) was accounted for in the TMDL for each lake. This MOS is sufficient to account for uncertainties in predicting loads to the lakes and predicting how lakes respond to changes in phosphorus loading.</td></tr>
<tr><td>Seasonal Variation</td><td colspan="3">Critical conditions in these lakes occur in the summer, when TP concentrations peak and clarity is worst. The water quality standards (Minn. R. 7050.0220) are based on growing season (June through September) averages. The load reductions are designed so that the lakes will meet water quality standards over the course of the growing season.</td></tr>
<tr><td>Reasonable Assurance</td><td colspan="3">Refer to TMDL Report Section 5 Reasonable Assurances</td></tr>
<tr><td>Monitoring</td><td colspan="3">Refer to TMDL Report Section 6 Monitoring Plan</td></tr>
<tr><td>Implementation</td><td colspan="3">Refer to TMDL Report Section 7 Implementation Strategy</td></tr>
<tr><td rowspan="2">Public Participation</td><td colspan="3">Public Comment period (dates)</td></tr>
<tr><td colspan="3">Refer to TMDL Report Section 8 Public Participation for a complete list of meetings</td></tr>
</table>

2.5 Protection Considerations

There are a number of factors that influence the best approach to take to protect high quality waters in a watershed such as the Pine River. However, there are numerous waters within the watershed that, although still meeting state standards for nutrients, clarity, and other parameters are either trending downward in quality or are potentially threatened by land use or recreational use activities. This WRAPS report attempts to identify those lakes in need of special protection considerations and prioritize those waters for strategic protection-related activities.

In the case where a surface water is already trending downward, any new implementation strategies will likely need to be somewhat aggressive in order to counteract negative effects that are already being seen and having an impact. Many changes on the land that are the result of human activity tend to have impacts on surface and ground water over time. Protection-oriented land use practices that mimic natural systems, such as infiltration, buffers, or increased water storage in the form of retention basins, can be very effective in reducing the impacts of human activity.

The Pine is also home to some very clean waters with little disturbance surrounding them - waters with no apparent water quality trend, or that are even improving water quality. In these scenarios, current and historical land uses surrounding these water bodies has allowed them to remain in a protected state. In these subwatersheds, continued vigilance and monitoring of land use activities may be all that is needed to ensure continuation of the high level of water quality.

The HSPF model developed by RESPEC, Inc. helped to identify areas in the watershed where vigilance of existing land use practices and conditions should suffice, as well as areas where a more aggressive approach to improving or protecting water quality might be called for (Figure 10). The risk levels identified in the maps are defined as:

- **Vigilance**: Watershed with more than 50% protected lands, less than 8% land use disturbance, and no risk factors.
- **Protection**: Watershed with 40% to 65% protected lands, 8% to 30% land use disturbance, minimal risk factors, water quality that is stable or improving, and multiple high-quality resources that could be protected.
- **Enhance/Protection**: Watershed with less than 40% protected lands; moderate amount of risk factors; water quality that is stable, declining, or impaired; manageable risk factors; and one or more water resources that could be protected.
- **Enhance**: Watershed with less than 40% protected lands, more than 30% land use disturbance, multiple and/or significant risk factors, and limited resources to protect.

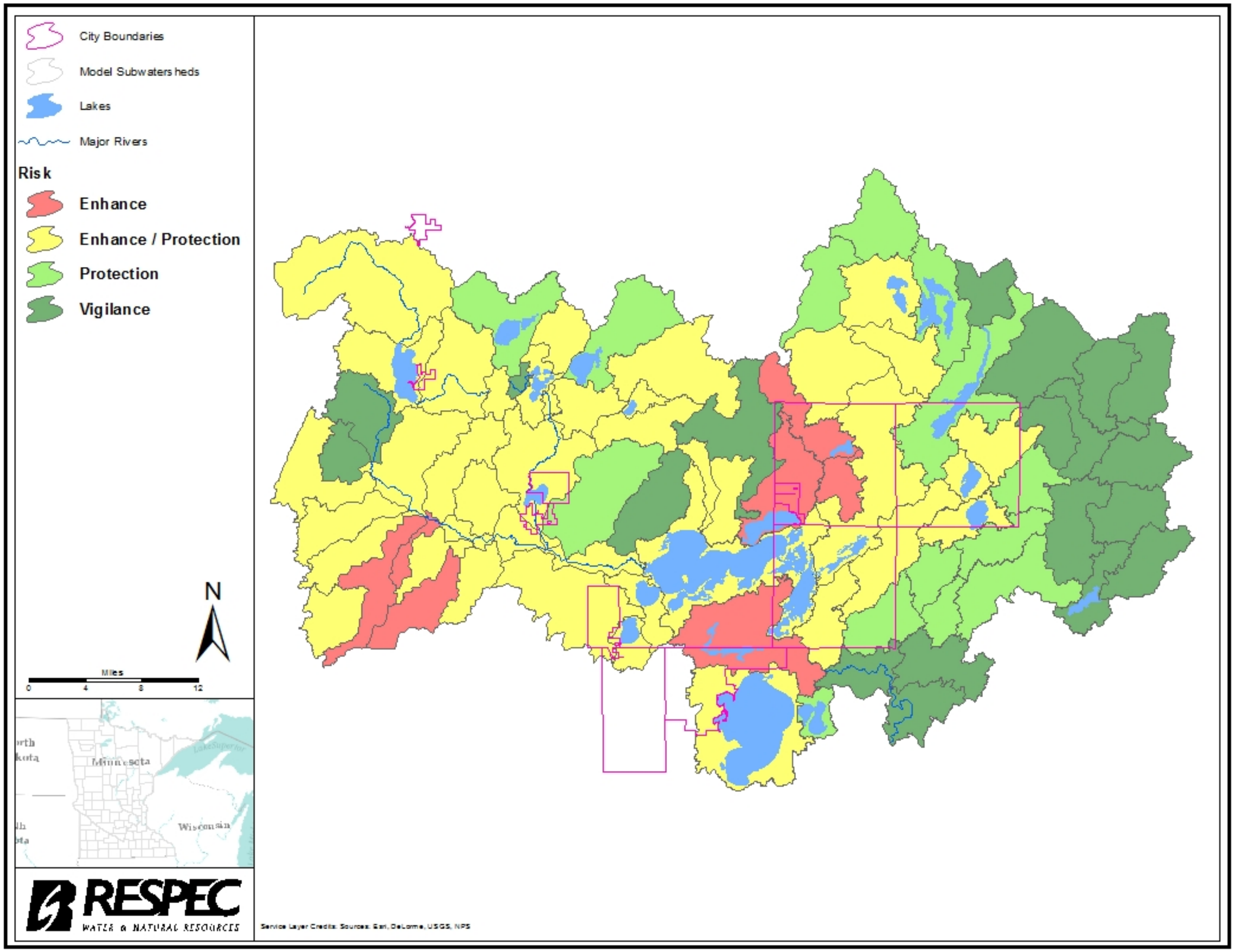


Figure 10. Risk Levels in the Pine River Watershed

Another consideration is future population increase in the Pine, and the land use changes that may affect vulnerable waters. State agencies recently developed a tool to aid in prioritizing surface waters for protection. The Lakes of Phosphorus Sensitivity Significance approach considers a number of variables to prioritize lakes for protection (an approach for prioritization of rivers is currently under development). The model, which is described in detail and can be found in Appendix 1- Lake Prioritization based on Phosphorus Sensitivity Significance, and is also discussed in Section 3 of this document, is based on five elements:

- A summary of historic and current water quality data
- Establishing a phosphorus water quality goal for each lake
- Ranking of the "high quality unimpaired waters at greatest risk" (based on proximity to impairment threshold, trend data and phosphorus sensitivity)
- Incorporation of recreational, aesthetic, or economic values of surface waters that contribute to watershed health
- Recommendation of protection implementation approaches tailored to watershed-specific conditions and stressors.

Based on the matrix that was developed, 19 lakes in the Pine were identified as the highest priority lakes for protection (Figure 11).

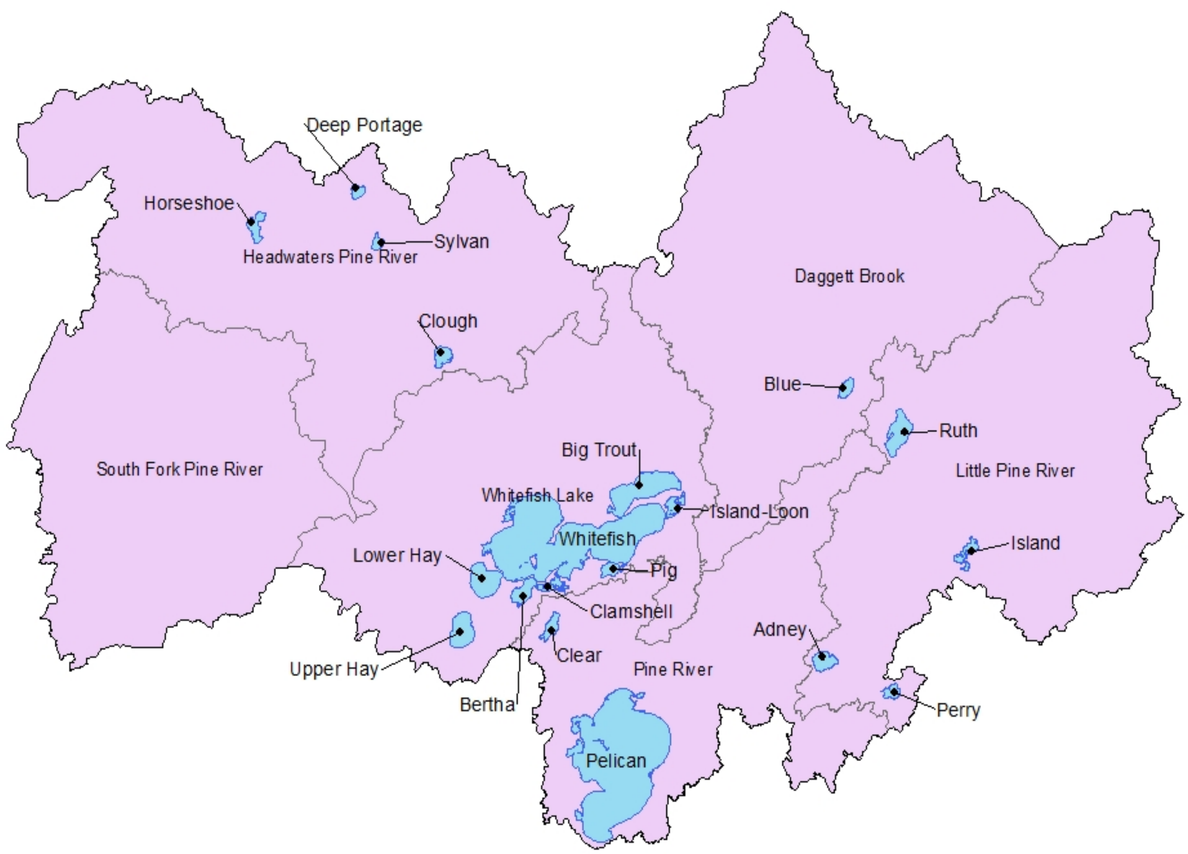


Figure 11. Lakes in the Pine River Watershed that were determined to be high priority for protection during the WRAPS process.

The resulting prioritization matrix considers current conditions, as well as potential future changes and how lakes might react to those. This formula is helpful in that it gives those planning for future development in the Pine a sense of which lakes might be better left undisturbed, as well as what lakes may be able to withstand additional development. It also gives us some perspective as to which lakesheds have suffered the most due to past practices, and perhaps where local governments could focus on retrofitting implementation projects.

Groundwater

Often there are many parallels to managing groundwater and surface water resources. In both cases, it is important to manage nutrient loss, stormwater runoff and changes in vegetation to protect water quality. The primary difference is the pathway of where the water goes. In areas of vulnerable geology, the impacts from pollution are more widespread as water recharges the aquifer at a rapid rate with shorter retention time. These are priority areas for protection in the Pine. Figure 12 shows the areas where the aquifers are at highest risk of contamination. Prioritization can be further refined by targeting a vulnerable aquifer with the greatest concentration of people or utilization of the resource.

Groundwater protection can be challenging because you cannot see it or measure a direct response like you can in surface water. Furthermore, there are few sufficient models and/or tools to quantify the reduction of pollutants entering the aquifer from changes in land use. This is one of the difficulties resource professionals will have in trying to measure the impact of implementing groundwater protection strategies. Therefore, the MDH suggests using methodologies applied by their agency to prioritize and target implementation activities in the Source Water Protection program.

These methodologies for public water supply systems include:

- Identifying Drinking Water Supply Management Areas (DWSMA) located in the watershed.
- Examining the vulnerability of the aquifer to contamination risk to determine the level of management required to protect groundwater quality. For example, a highly vulnerable setting requires many different types of land uses to be managed, whereas a low vulnerability setting focuses on a few land uses due to the long recharge time and protective geologic layer.

These methodologies for private wells include:

- Evaluating the vulnerability of the upper most aquifers to determine the areas within the watershed most at risk from different land uses. Geologic atlases provide this information where available, as well as the statewide geomorphology layer found at: http://www.dnr.state.mn.us/whaf/about/scores/geomorphology/gw_contamination.html, or the DNR's statewide aquifer sensitivity layer found at https://gisdata.mn.gov/dataset/water-aquifer-vulnerability.

There are some emerging technologies, however, that could potentially help in this regard. The Minnesota Department of Agriculture (MDA) is contracting with the University of Minnesota to identify, develop, enhance and demonstrate predictive modeling tools for nitrate losses under common crop production systems, soil types and climate conditions across the state. The modeling tools incorporate the dominant physical, chemical and biological processes related to nitrogen conversion, uptake, release, turnover and transport within the soil-plant-atmosphere continuum and their responses to changing conditions, such as different rainfall patterns, climate conditions and agricultural management practices. The tools are intended to quantify the potential success of implementing agricultural BMPs and other technology advancements for improving nitrogen conservation and utilization, and reducing nitrate-leaching losses to groundwater. These tools are still under development.

Once the tools are ready, the University of Minnesota will reach out to producers, farm organizations, fertilizer dealerships and state and local government staff to discuss the tools, their utility and modeling results. The MDA has requested the information is delivered in a manner that does not require a full understanding of the modeling tools used to make predictions.

The only other effective method for measuring results is by taking raw water samples from a well. The challenge for this is establishing a baseline trend coupled with a long response time in the recharge area. This can be many years and thus will require dedication of significant time and resources.

Drinking water

Protecting existing drinking water quality is a critical need in the Pine because of the vulnerability of the underlying aquifer. Small changes in land use, especially in highly vulnerable geologic areas where the aquifer receives recharge from the land surface within very short periods (days to months – (Geologic Sensitivity Project Workgroup, 1991)), has the potential to degrade groundwater quality because contaminants may reach the aquifer without significant dilution.

Development pressure on the lakes can threaten these aquifers, in particular the Whitefish Chain and Pelican Lake located in highly vulnerable geologic areas, where homeowners maintain their own private well and septic system in concentrated areas. Nitrate concentrations measured in well water above the non-detect threshold of 2.0 mg/l is most prevalent in this part of the watershed, as are arsenic concentrations. Although it can be naturally occurring, nitrate-nitrogen (nitrate) levels above 3 mg/l are considered to exceed what can be expected from natural background (Mueller and Helsel 1996), and instead likely reflect human activity such as chemical fertilizer or human or animal waste.

The city of Pine River has a highly vulnerable Wellhead Protection Area (WHPA) and is at risk of contamination from a variety of different land uses in their DWSMA. Examples of some of these land use-related impacts include infiltration of stormwater contaminants, leaky underground tanks, improper disposal of hazardous waste, poor well management, or agricultural leaching of fertilizers. A copy of the city’s Wellhead Protection Plan can be requested from the city of Pine River or MDH. A wellhead protection plan includes the delineation of the WHPA and DWSMA, as well as an assessment of the wells’ vulnerability.

It is important to note that maintaining ground cover and clean surface water not only benefits those living in the Pine, but also helps produce clean water for downstream populations via the Mississippi River including St. Cloud and the Twin Cities. What happens in the Pine affects not only the people who live here, but also millions of people who drink the water further downstream.

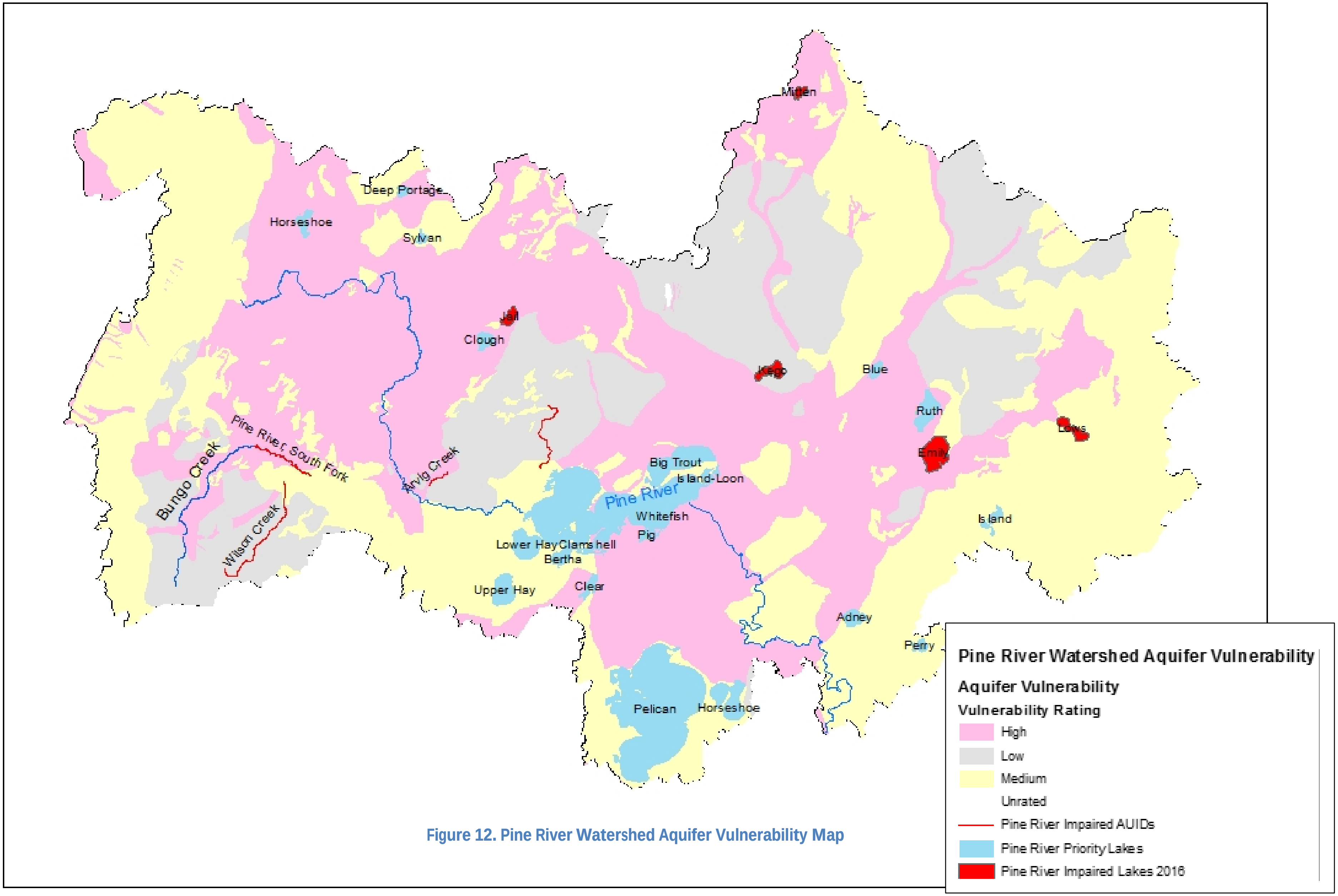


Figure 12. Pine River Watershed Aquifer Vulnerability Map

3. Prioritizing and Implementing Restoration and Protection

The Clean Water Legacy Act (CWLA) requires that WRAPS reports summarize priority areas for targeting actions to improve water quality, and identify point sources and nonpoint sources of pollution with sufficient specificity to prioritize and geographically locate watershed restoration and protection actions. In addition, the CWLA requires including an implementation table of strategies and actions that are capable of cumulatively achieving needed pollution load reductions for point and nonpoint sources.

This section of the report provides the results of such prioritization and strategy development. Because much of the nonpoint source strategies outlined in this section rely on voluntary implementation by landowners, land users, and residents of the watershed, it is imperative to create social capital (trust, networks and positive relationships) with those who will be needed to voluntarily implement BMPs. Thus, effective ongoing civic engagement is an integral part of the overall plan for moving forward.

The implementation strategies, including associated scales of adoption and timelines, provided in this section are the result of watershed modeling efforts and professional judgment based on what is known at this time and, thus, should be considered approximate. Furthermore, many strategies are predicated on needed funding being secured. As such, the proposed actions outlined are subject to adaptive management—an iterative approach of implementation, evaluation and course correction.

The Pine is considered, according to a USDA Forest Service Report, one of the primary watersheds in the Upper Northeast (according to the boundaries set in the report, Maine to Minnesota and south to Missouri) United States for producing clean water. This is due largely to the substantial amount of forest cover that has been maintained in the Pine. Maintaining this forest cover to the greatest extent possible will continue to be the primary strategy for protecting groundwater and surface water. Additionally, the working group that developed this WRAPS report used a number of tools to identify critical areas for implementation.

There is a significant amount of data available in the Pine from a number of entities, which has the potential to assist in determining protection strategies. The challenge is how to best utilize the data to identify areas best suited for protection strategies, and what strategies are best suited for each area. Tools available for using the data for prioritization in this WRAPS include: the HSPF model and the SAM tool; the Zonation model; the Lakes of Phosphorus Sensitivity Significance approach; a prioritization method developed by Emmons and Olivier Resources; The Nature Conservancy's "Healthy Waters Protection" project (HWP-PR); and DNR's Lake Habitat Conservation Framework; and the MDH "GRAPS". Before attempting to suggest ways of best utilizing these tools, a brief description of each will be provided.

HSPF Model

The Hydrological Simulation Program-FORTRAN (HSPF) watershed modeling system is a comprehensive package for simulating watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF is capable of simulating the hydrologic and associated water quality processes on pervious and impervious land surfaces, in streams, and in well-mixed impoundments.

HSPF is used to assess the effects of land use change, reservoir operations, point-source or nonpoint-source treatment alternatives, and flow diversions. The model contains hundreds of process algorithms developed from theory, laboratory experiments, and empirical relations from instrumented watersheds. The model simulates processes such as: evapotranspiration; interception of precipitation; snow accumulation and melt; surface runoff; interflow; base flow; soil moisture storage; groundwater recharge; nutrient speciation; biochemical oxygen demand; heat transfer; sediment (sand, silt, and clay) detachment and transport; sediment routing by particle size; channel and reservoir routing; algae growth and die-off; bacterial die-off and decay; and build-up, wash-off, routing, and first-order decay of water quality constituents. Continuous rainfall and other meteorological records are input at an hourly time step into the model algorithms to compute streamflow, pollutant concentrations, and loading time series. Hydrographs can then be created, and frequency and duration analyses can be performed for any output time series.

An HSPF model application for the Pine was developed for the MPCA by RESPEC, a consulting firm, in 2013 as part of a larger effort to develop model applications also for the Leech Lake River Watershed and the Mississippi River Headwaters Watershed. The full report can be found in Appendix 2- PINE RIVER WATERSHED POLLUTANT SOURCE ASSESSMENT AND PRECIPITATION SCENARIOS.

During the development of the HSPF model for the Pine by RESPEC, a number of alternative scenarios were run to try to determine how the watershed might respond under different development patterns. The WRAPS working group determined that the following activities are anticipated to occur in the coming years:

- **Intensification of Agriculture -** 15% of private forest land converted to agriculture and 50% increase of animal units on existing feedlots.
- **Shoreland development -** 15% impervious surface within 500 feet of lakes (currently 10%).
- **City growth -** All land within city boundaries converted to developed land with 13% effective impervious area.
- **Hwy 371 expansion -** Highway 371 throughout the watershed was expanded from a 2-lane to a 4-lane corridor. This process has already begun.

Based on the above development forecast, the HSPF scenarios included:

1. Baseline scenario- current land use practices
2. Above land use change without BMPs.
3. Above land use change with BMPs (riparian buffers in agricultural areas and treating 1.1 inches of runoff from impervious surfaces).
4. Above land use change with BMPs (shoreline buffers, wetland preservation, preservation of 75% of natural areas within city boundaries, and cluster development).
5. Climate change induced precipitation changes.
6. Climate change with above land use change and BMPs from Scenario 3.

Based on above land use change and with no additional BMPs being put in place (Scenario 1), the model shows phosphorus loading in the Pine is likely to increase to nearly double its current rate of 46,000 pounds per year to approximately 88,000 pounds per year. At that projected rate, a significant decrease in water quality will occur. Further, even implementing Minimal Impact Development Standards (MIDS) by treating 1.1 inches of runoff from all impervious surfaces by increasing the retention storage parameter by 1.1 inches, and installing high quality 16-foot riparian buffers in agricultural areas while utilizing no other protection practices, phosphorus loading can be expected to increase to approximately 74,000 pounds per year (Scenario 3).

Based on the model outputs, in order to hold phosphorus loading rates to near current levels, a combination of practices would have to be implemented. These would include protection of wetlands within city boundaries, implementation of 50 foot shoreland buffers on lake shores, cluster type developments where open space is preserved, and preservation of 75% of current natural areas in city boundaries. Seldom is there one “silver bullet” that will solve environmental problems, and such is the case in the Pine as well.

Table 7 below shows the percent change in runoff volume between the different scenarios. Figure 13 displays the amount of surface runoff and total phosphorus runoff depending on which scenario is modeled.

Scenario	Percent Change Runoff Volume (%)	Percent Change Total Phosphorus Runoff (%)
0 to 1	13	87
1 to 2	-4	-18
2 to 3	-5	-32
0 to 3	3	4
0 to 4	20	20
0 to 5	23	24

Table 7. Predicted runoff volume and total phosphorus change for each of the alternative scenarios that were modeled for the Pine River Watershed in the HSPF model.

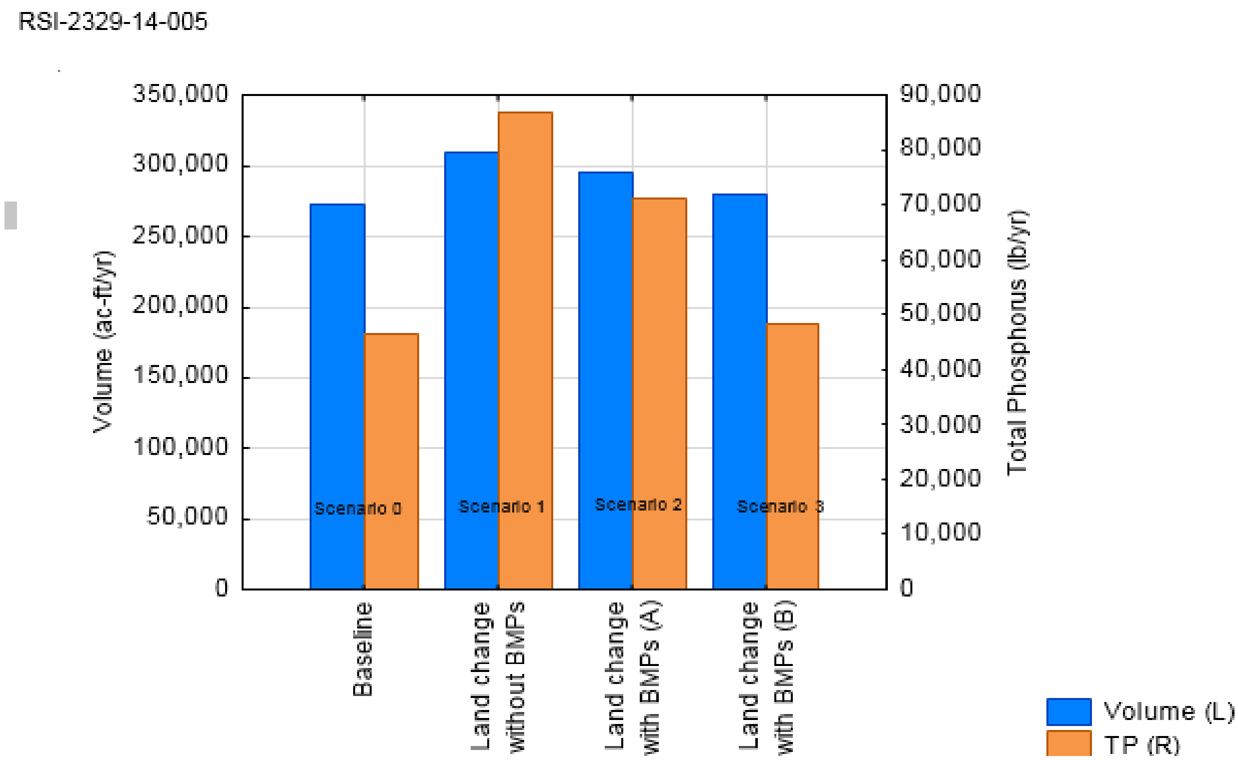


Figure 13. Volume and Total Phosphorus predictions for each of the Scenarios run in the HSPF Model for the Pine River Watershed.

A tool that is being developed to better utilize the HSPF model, called the "**SAM tool (Scenario Application Manager)**" will assist in strategy development by identifying and quantifying pollutant sources, estimating load reductions needed, simulating and evaluating management scenarios, and helping to guide future implementation. The tool is expected to be ready for use in the spring of 2017.

Zonation Model

One method that was implemented to identify and prioritize waters in need of protection or restoration was the Zonation model as developed by the DNR. The Zonation Model is a values-based model based on fundamental conservation principles, including biodiversity and connectivity. The model uses the DNR's five-component WHAF to facilitate an organized process to assess and review watershed problems and solutions. The five components for a healthy watershed are: biology, hydrology, water quality, geomorphology, and connectivity. The process used an Analytic Hierarchy Process (AHP) to assign numeric weights to values determined by groups of local citizens and technical staff making value judgements through pair-wise comparisons. The categories that were weighed included "protect water quality," "reduce erosion and runoff," "protect timber and protected land," "protect shoreland," "minimize interference with ag land," and "protect fish & wildlife habitat." Based on these comparisons, and utilizing the WHAF data to a large extent, as well as inputs from HSPF modeling and citizen input, maps identifying areas best suited for protection-based projects as well as restoration-based projects were developed. This approach recognizes that attempts to solve our clean water needs are not separate from our other conservation needs; rather, each conservation activity can provide multiple benefits. For example, for both the protection and restoration prioritizations, goals were to obtain both clean water benefits and other conservation benefits. The values-based model used in this process helps achieve this multiple benefits goal by identifying landscape areas that optimize benefits by incorporating features valued by the community. The methods utilized for the development of this "value-based" model are described in greater detail in Appendix 3.

The Zonation model was also used as a civic engagement tool. As part of this process, participants decided what landscape features were valued and ranked those valued features within the model. As a final step, WRAPS participants were given the opportunity to revise the model results to create a map that will be used to help identify areas within the watershed for potential future conservation investments. This synthesis step captured the knowledge and experiences of the people interested in and informed about the stresses, risks, and vulnerability of water resources within the watershed. See Appendix 4A for details on methods and results.

The final prioritization maps created are presented as Figure 14 and Figure 15. The protection priority map identified several general priority areas. High rankings were given to shorelands, and in particular, sensitive shorelands (as identified by the DNR's Sensitive Lakeshore Assessment). Because runoff from lands close to lakes is more likely to contribute to declining water quality, protection of these areas will be important in maintaining good water quality. High priority rankings were also given to lands associated with municipal DWSMAs. These areas are critical for the protection of potable water for large populations. Undisturbed riparian areas associated with the Pine River and its tributaries would also benefit from protection. The area west of the city of Pine River has a considerable number of wetlands and streams with extensive floodplains, so protecting these natural lands may reduce nutrient pollution from adjacent agricultural lands. Finally, protection of existing valuable timber lands north of Fifty Lakes would provide multiple conservation benefits.

Several priority management areas were also identified in the synthesis analysis. There was consensus on the need to focus protection efforts on the shorelands on the north side of the Whitefish Chain of Lakes, with specific attention to the catchment of Big Trout Lake. Second, the catchment of Kego Lake, an impaired lake, would benefit from focusing efforts that would provide water quality benefits. It was also recognized that protecting the city of Pine River's drinking water supply should be a high priority. With regard to reducing nutrient loading to the Whitefish Chain of Lakes, emphasis on the riparian lands of the south fork of the Pine River (and associated tributaries) was identified. Adding riparian buffers, increasing riparian buffer width, and holding more water longer on the land would improve water quality. Increases in riparian buffer width would also improve stream habitat. Several forest areas were identified where protection efforts related to BMPs can be explored and implemented (these areas of forests were largely old growth or areas home to important wildlife species). Lastly, the catchment of Pelican Lake and lands within Breezy Point were recognized as a priority area. This high value lake would benefit from greater water quality protection efforts.

The maps created during the Zonation process can be overlaid with other maps that have been created for this WRAPS (HSPF, groundwater vulnerability areas, and others) to determine what the best areas will be to implement projects with multiple benefits.

The restoration priority map was similar to the protection map; differences were primarily seen in areas near agricultural lands in the watershed. The restoration map highlights potential project areas on agricultural lands and other developed areas. These projects would include engineered BMPs or restoration of those lands to natural conditions for multiple benefits.

In comparing the protection priority map versus the restoration priority map, it is apparent the areas where protection activities can be effective, and their associated priority management areas, cover a significantly larger area than do areas where restoration activities can be effective. It is fairly well understood that protection activities are typically less expensive than are restoration activities; these maps indicate that there may also be a wider range of options for protection strategy implementation, thus increasing the opportunity and likelihood of successful adoption of practices.

Figure 14. Final protection priority map from Zonation and synthesis analysis. Priority management areas (shaded areas) were identified in the synthesis analysis. The areas in red have been determined to be the areas where protection implementation will be most effective.

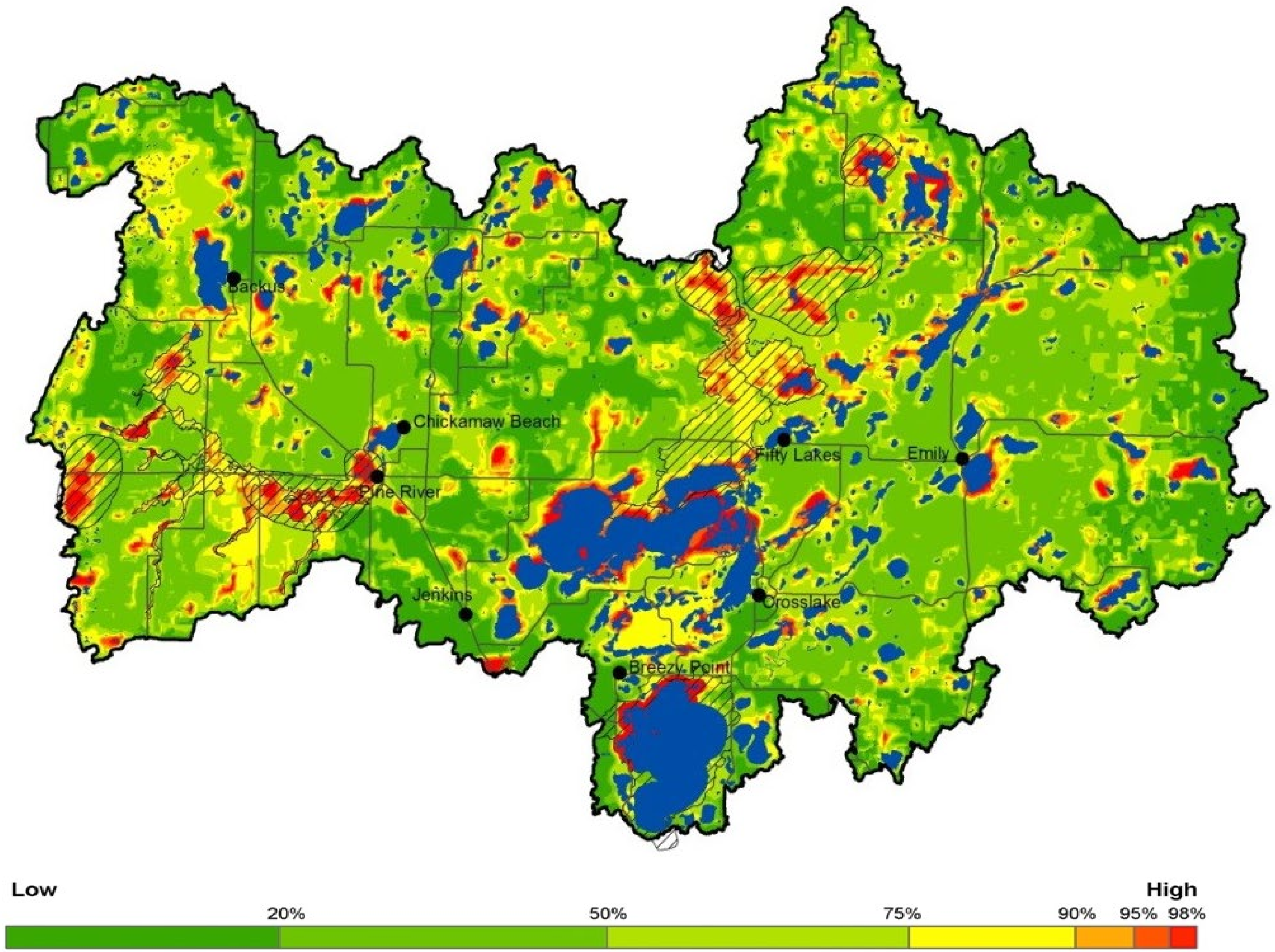
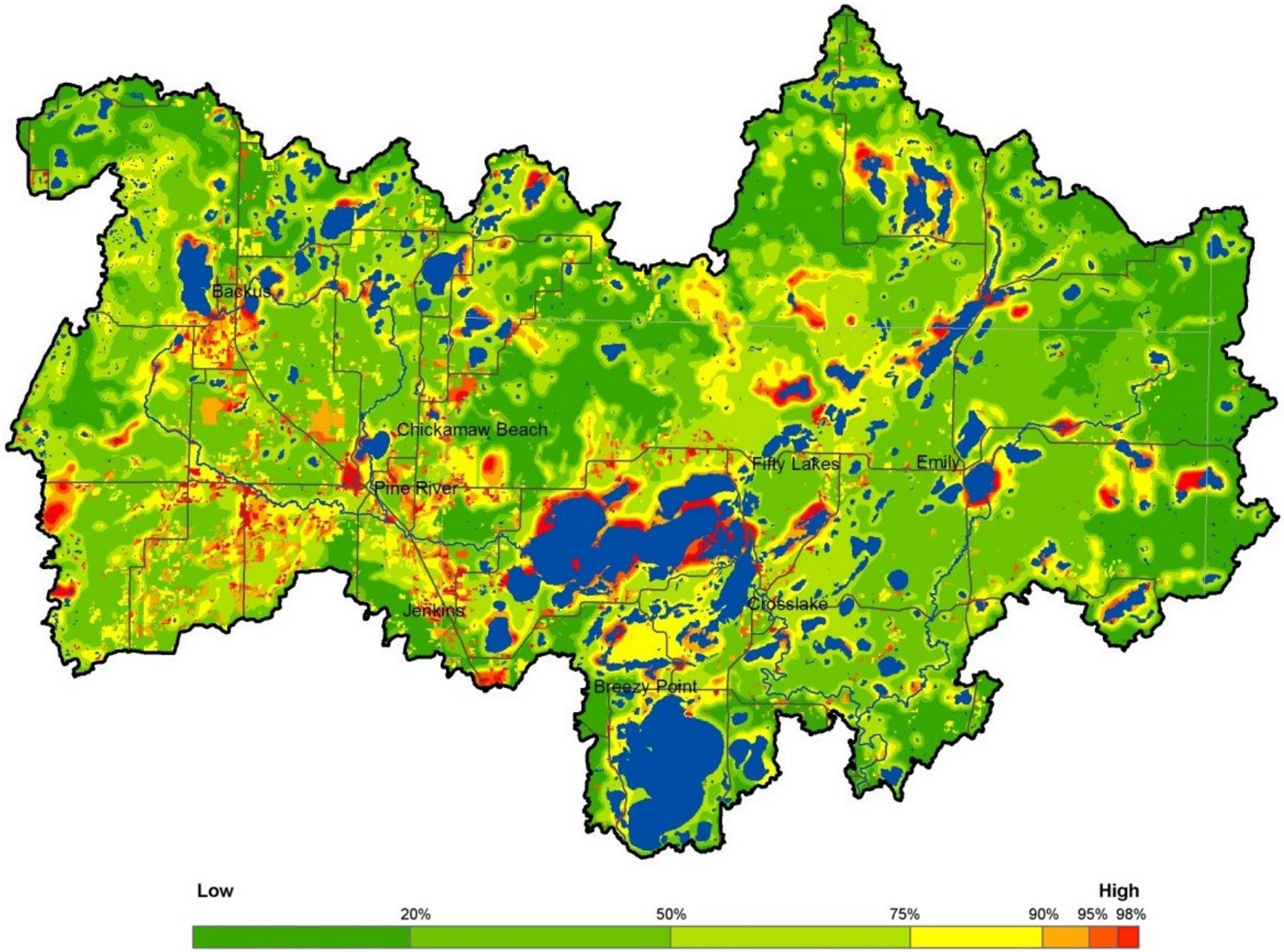


Figure 15. Final restoration priority map from Zonation analysis. The bar indicates the level of priority for restoration implementation across the watershed, with red being the highest priority.



Lakes of Phosphorus Sensitivity Significance

After the Zonation model was developed, the DNR and the MPCA technical and leadership staff collaborated on the development of a lake-only protection prioritization matrix based on the following elements:

1. Summarize current water quality status for non-impaired lakes and rivers.
2. Quantify and target the amount and types of protection needed.
3. Summarize and rank "high quality unimpaired waters at greatest risk."
4. Incorporate recreational, aesthetic, or economic values of surface waters or waters that contribute to watershed health.
5. Recommended protection implementation approaches tailored to watershed-specific conditions and stressors.

Utilizing data from the DNR Hydrography dataset, lakes with sufficient data were sorted into categories including the following:

- Depth Type (Shallow or deep)
- Maximum Depth
- Mean Depth
- Lake area
- Watershed Acres
- Proportion of Watershed Disturbed
- Mean TP
- Mean Secchi reading
- Slope description (Secchi trend)

Based on this data, the following scores were developed:

- Target Mean TP
- Load Reduction needed to meet Target
- Secchi Inches lost per 100 lbs TP added to lake
- Sensitivity Significance score
- Priority score
- Priority ranking vs. other lakes in the state
- Priority (H,M,L)

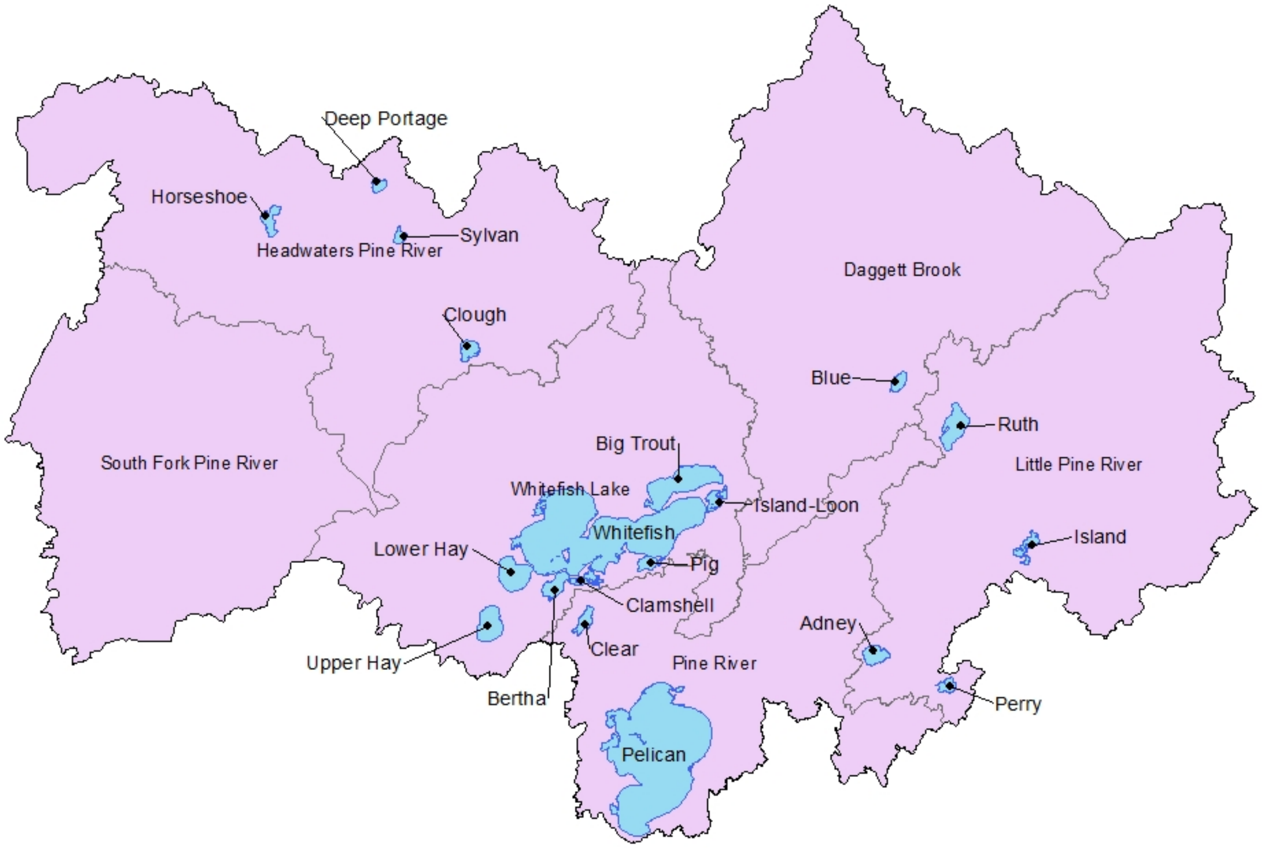


Figure 16. Lakes in the Pine River Watershed that were determined to be high priority during the WRAPS process.

Based on these criteria, 19 lakes in the Pine were identified as high priority lakes for protection. The data inputs and ranking scores are shown in Appendix 1.

Emmons and Olivier Resources matrix

Several attempts have been made at developing a prioritization matrix that would work not only for the Pine, but also other protection priority watersheds throughout the state. Emmons and Olivier Resources (EOR), the consultant responsible for development of the TMDL for Jail and Kego lakes, attempted to prioritize the lakes. The EOR model, which is further described in Appendix 4, utilizes the following criteria to determine lakes that were "high priority" for protection:

- One of the top 25 largest lakes in the Pine by surface area
- DNR designated tullibee (cisco) or trout lake
- Lakes included in the Cass County or Crow Wing County Large Lakes Assessment
- Lakes with an active lake association
- Lakes expected to be assessed as impaired on the 2016 Impaired Waters List
- Based on these criteria, 56 lakes were identified in the EOR model as priority protection lakes in the Pine.

Although there are benefits to this system, such as compatibility with existing plans and inclusion of active lake associations to improve the potential for implementation, the inclusion of impaired lakes in this list is inconsistent with developing rationale for protection, in that they are already impaired and are now candidates for restoration rather than protection. However, this prioritization was used to help reinforce the choice of lakes that were listed on the strategy table later in this document.

The Nature Conservancy- Healthy Waters Protection

Four key analytical efforts have identified the Pine as one of the top priority source water value protection watersheds in the state of Minnesota. The USFS Forests, Water and People Analysis (2009) lists the Pine as the #1 ranking watershed for its ability to produce clean water (APCW). Crow Wing County in its water plan developed a minor watershed risk assessment model to help guide county priorities for policy and practices. The collaborative North Central Conservation Roundtable (NCCR) Zonation derived decision support tool, which prioritizes water quality and habitat values, ranks much of the Pine in the top quartile scoring. Finally, The Nature Conservancy's multiple benefits analysis scores the Pine in the top quartile, due to its source water attributes.

Based on this strong science backed watershed scale prioritization for multiple benefits and source water protection, the Nature Conservancy, in collaboration with Board of Water and Soil Resources (BWSR), local SWCD Directors in Crow Wing and Cass counties, and local Water Plan Coordinators have developed a HWP-PR program for riparian protection in the Pine. The guiding principles for this program include: a fixed riparian easement rate (60%) based on formula-driven parcel values similar to other Reinvest in Minnesota (RIM) projects in the Mississippi Headwaters; coordinated delivery through local SWCD staff linking landowners to the RIM program and local water plan priorities; permanent protection leveraging multiple public and private fund sources; and riparian forest protection targeting the main stem corridor of the Pine River system that connects protected lands to private protected land corridors. Prioritization criteria were developed to give the highest return on conservation investment, water quality benefits and local water plan priorities focus. A local technical advisory committee (TAC) made up of BWSR, DNR, SWCD, TNC and Water Plan staff will score and rank parcel priorities and support landowner solicitation from willing land owners in what is intended to be a sustained long-term protection program. The HWP-PR program will encourage a working forests approach while prioritizing source water protection values. The intent of this program is to implement a HWP-PR with a transferable methodology, which will have the ability to be utilized in other high priority protection watersheds in the Mississippi Headwaters region. The Nature Conservancy has experience doing this on lakes, and this demonstrates a river system approach.

The scoring table for this prioritization method can be found in Appendix 5. This scoring sheet is the starting document used to establish a consistent and transparent process for the TAC. Parts of this scoring sheet come from the BWSR Wild Rice program, Camp Ripley Army Compatible Use Buffer (ACUB) program, the Mississippi Headwaters Board and the Leech Lake Area Watershed Foundation LCCMR funded program.

An additional product that has been developed as part of the TNC work is a map package that depicts layers ranking areas of the Pine into various modules, including Multiple Benefits, Fish and Wildlife, Ground Water Recharge, Flooding and Erosion, and Drinking Water. These maps were created in part by utilizing the DNR Zonation Model, another way that multiple agencies have worked together to provide useful data for the WRAPS. Appendix 10 includes the explanation of this product, as well as the maps for each of the modules for the Pine.

Lake Habitat Conservation Framework

The Minnesota DNR publication "Fish Habitat Plan: A strategic Guidance Document" (http://files.dnr.state.mn.us/fish_wildlife/fisheries/habitat/2013_fishhabitatplan.pdf) states, "watersheds with at least 75% of their area in protected status are reasonably protected from future disturbances at the watershed level." Protected land refers to land publicly owned or protected by conservation easement in 2008 Minnesota Gap Analysis Program ownership data. Maintenance of land protection is the primary goal within those watersheds at the 75% protection level and the suggested management approach is vigilance. Similarly, lakes with watersheds that are less than 25% disturbed but also less than 75% protected need additional protection to avoid future water quality degradation. Lakes with more than 25% disturbance would benefit from watershed-level restoration.

These estimates were developed through modeling efforts by the DNR staff, and the 75% "undisturbed" percentage for protection was based on evidence suggesting that total phosphorus concentrations increase significantly over natural concentrations in lakes with watershed land use disturbances greater than roughly 25%. The strategy table reflects these suggested percentages by recommending a minimum of 75% forested ground cover in lakesheds/watersheds where protection of water quality is the focus.

Table 8 below shows four pilot minor watersheds (14 HUC) in the Pine for which analysis was done to determine the amount of land within the minor watershed that was already protected, the percentage of land that was disturbed (in each case less than 25%), and the amount of acres still needed within the minor watershed to achieve the 75% protection goal. The prioritization tool in this case is referred to as "Private Forest Management (PFM) by Prioritization, Targeting, and Measuring (PTM), and was accomplished through collaboration between BWSR, the DNR, and the Minnesota Forest Resources Council (MFRC). Mitch Brinks performed the analysis of GIS data.

Table 8. Pilot HUC 14 watersheds with Lake Habitat Conservation Protection and Disturbance levels

HUC 14 Watersheds	Percent Protected (including SFIA)	Percent Disturbed	Acres Needed to Reach 75% protection level
Pine Mountain Lake	75%	8%	0-Goal met
Arvig Creek	45.1%	23.3%	3320
Lake Ossawinnamakee	34.6%	9.5%	5208
Big Trout Lake	52.6%	7.60%	1850

Table 9 describes additional tools that are available to assist identify, locate and prioritize watershed restoration and protection actions in this and other watersheds. Some of these tools were used in the Pine River WRAPS process; others were not.

Table 9. Tools and methodology available for evaluating and prioritizing watershed health.

	Description	How can the tool be used?	Notes	Link to Information and data
Ecological Ranking Tool (Environmental Benefit Index - EBI)	Three GIS layers containing: soil erosion risk, water quality risk, and habitat quality. Locations on each layer are assigned a score from 0-100. The sum of all three layer scores (max of 300) is the EBI score. This higher the score, the higher the value in applying restoration or protection.	Any one of the three layers can be used separately or the sum of the layers (EBI) can be used to identify areas that are in line with local priorities. Raster calculator allows a user to make their own sum of the layers to better reflect local values.	GIS layers are available on the BWSR website.	*BWSR*
Zonation	A framework and software for large-scale spatial conservation prioritization; it is a decision support tool for conservation planning. This values-based model can be used to identify areas important for protection and restoration.	Zonation produces a hierarchical prioritization of the landscape based on the occurrence levels of features in sites (grid cells). It iteratively removes the least valuable remaining cell, accounting for connectivity and generalized complementarity in the process. The output of Zonation can be imported into GIS software for further analysis. Zonation can be run on very large data sets (with up to ~50 million grid cells).	The software allows balancing of alternative land uses, landscape condition and retention, and feature-specific connectivity responses. (Paul Radomski, DNR, has expertise with this tool.)	*CBIG*
National Hydrography Dataset (NHD) & Watershed Boundary Dataset (WBD)	The NHD is a vector GIS layer that contains features such as lakes, ponds, streams, rivers, canals, dams and stream gages, including flow paths. The WBD is a companion vector GIS layer that contains watershed delineations.	General mapping and analysis of surface-water systems. These data have been used for: fisheries management, hydrologic modeling, environmental protection, and resource management. A specific application of the data set is to identify buffers around riparian areas.	The layers are available on the USGS website.	*USGS*

	Description	How can the tool be used?	Notes	Link to Information and data
Light Detection and Ranging (LiDAR)	Elevation data in a digital elevation model (DEM) GIS layer. Created from remote sensing technology that uses laser light to detect and measure surface features on the earth.	General mapping and analysis of elevation/terrain. These data have been used for: erosion analysis, water storage and flow analysis, siting and design of BMPs, wetland mapping, and flood control mapping. A specific application of the data set is to delineate small catchments.	The layers are available on the MN Geospatial Information website for most counties.	MGIO
Hydrological Simulation Program – FORTRAN (HSPF) Model	Simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants from pervious and impervious land. Typically used in large watersheds (greater than 100 square miles).	Incorporates watershed-scale and nonpoint source models into a basin-scale analysis framework. Addresses runoff and constituent loading from pervious land surfaces, runoff and constituent loading from impervious land surfaces, and flow of water and transport/ transformation of chemical constituents in stream reaches.	Local or other partners can work with MPCA HSPF modelers to evaluate at the watershed scale: 1) the efficacy of different kinds or adoption rates of BMPs, and 2) effects of proposed or hypothetical land use changes.	USGS
MPCA/DNR Lakes of Phosphorus Sensitivity Significance	In 2015, the MPCA and DNR completed a statewide analysis of lake sensitivity to additional phosphorus loading and the significance of that sensitivity in terms of high-quality, unimpaired lakes at risk of becoming impaired. Lakes were ranked and then assigned to one of three priority classes (high, higher, or highest).	These rankings can be used to identify and prioritize lakes that should be targeted for phosphorus reduction projects in their watersheds.	The phosphorus sensitivity significance index generally produced high values for large, oligotrophic lakes that were vulnerable to phosphorus loading and near their estimated loading threshold and low values for small, hypereutrophic lakes with high estimated phosphorus loading and watershed disturbance.	MPCA

	Description	How can the tool be used?	Notes	Link to Information and data
DNR Watershed Health Assessment Framework (WHAF)	Calculates watershed health for all 80 HUC-8 watersheds based on five components: Biology, Connectivity, Geomorphology, Hydrology, and Water Quality	Statewide GIS data is used to calculate scores for each of the five components to provide an overall watershed health report. A portion of the statewide GIS data is available at a finer scale, allowing some relationships to be downscaled to the DNR catchment scale.	Suitable GIS data for each of the five components available at the DNR catchment scale can provide meaningful comparisons between individual DNR catchments within the HUC-8 watershed.	*DNR*

3.1 Targeting of Geographic Areas

Agency staff and citizens working in the Pine are the beneficiaries of a large amount of data that can be effectively used to protect our surface and ground water resources. Ideally, a principal strategy that can be applied is simply conservation of the forest and natural vegetation in the watershed that has allowed the ground and surface water quality to remain clean, despite increased development of riparian areas and ongoing increases in impervious surfaces. The Nature Conservancy is the primary organization targeting areas where conservation easements are practical, and good use of conservation easements is an excellent strategy for allowing nature to protect water quality as it has for thousands of years. Such an approach reduces erosion, allows the continued benefits of the water cycle, and allows the ecosystem to utilize nutrients that would otherwise be delivered to surface and ground water.

The Nature Conservancy has developed datasets that indicate the number of parcels, both state land and tax forfeit land that could be available for use as conservation easements or managed for protection by state agencies. Most of the state owned lands in the Pine are managed by the counties. These publicly owned lands, although considered as protected from development because they are in public ownership, are also subject to logging and other similar activities, which can impact water quality to some extent, although if managed correctly the impact can be short-term or minimal.

In November 2005, the DNR acquired a perpetual conservation easement from Potlatch Corporation on 3,136 acres in Crow Wing County (shown in orange on the maps below). This property contains: a variety of forest types, including red pine, jack pine, oak, aspen, and lowland hardwoods; more than 350 acres of wetlands; more than 3.4 miles of frontage on the Pine River; and 1.4 miles of frontage on Pelican Creek. There is also nearly one mile of lake frontage on several small lakes. Portions of the property adjoin state and county forest lands. The agreement with Potlatch opens the property to public hunting, fishing, skiing, snowshoeing, nature viewing, and hiking. Grant-in-aid snowmobile trails cross the property. The Potlatch Corporation does allow motorized travel on the property's forest roads. Figure 17 shows the public land and Potlatch Forest Legacy in the Pine. Figure 18 adds in the private land that is in 20 acre parcels or greater, with the smallest squares in the map equal to 40 acres. The intent would be target to conservation easements for these 20 acre or larger parcels. It is apparent that although this strategy is a viable option in parts of the watershed, it is not a viable option for other areas. For example, the Whitefish Chain or the Pelican Lakeshed are examples of areas with significant existing development of smaller parcels where larger tracts of land are unavailable for successful use of conservation easements (shown as white on the map). Figure 19, created with data provided by The Nature Conservancy, shows this in greater detail.

In the Lake Habitat Conservation Framework, school trust lands are considered to be protected lands. State law provides that it is the goal of the permanent school fund to secure the maximum long-term economic return from the school trust lands, consistent with the fiduciary responsibilities imposed by the trust relationship established in the Minnesota Constitution, with sound natural resource conservation and management principles. However, the highest economic value does not necessarily equate with highest environmental value. This creates risk to water quality when school trust lands are adjacent to high priority water bodies. In order to safeguard water quality, one strategy may be to utilize marginal shoreland in a way that is beneficial to both the schools and to the environment. Consideration should be given to using private donations for education to purchase conservation easements on school trust lands that are adjacent to priority waters. This creates an upfront economic benefit as well as ongoing easement payments to the school fund. As Figure 18 shows, several of the water bodies identified as priority in this WRAPS are immediately adjacent to school trust lands; therefore, mutually beneficial financial arrangements are not only possible, but practical and efficient as well.

Figure 17. State owned and Potlatch Forest Legacy lands in the Pine River Watershed.

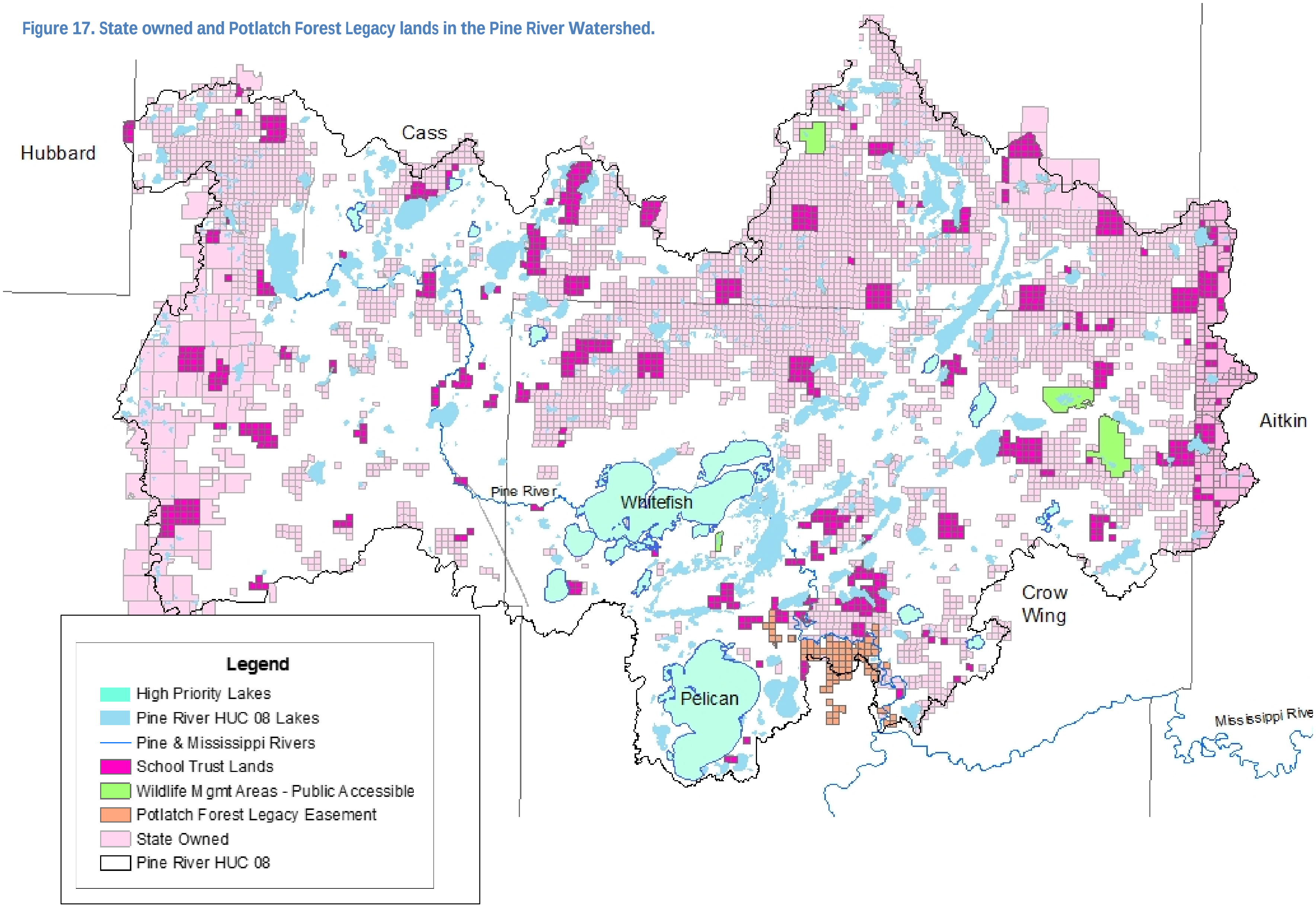
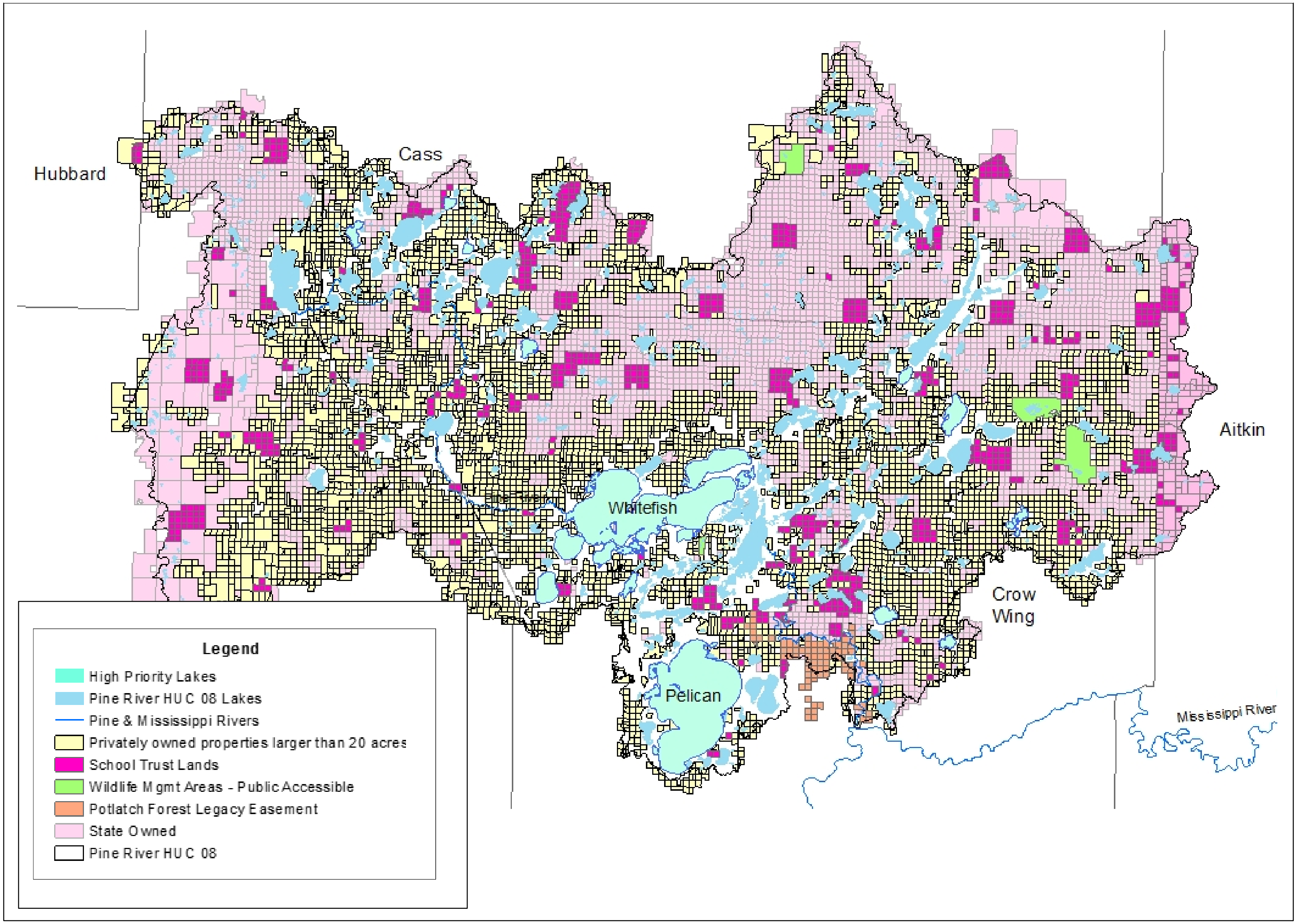


Figure 18. Land ownership in the Pine River Watershed- public and private larger than 20 acres.



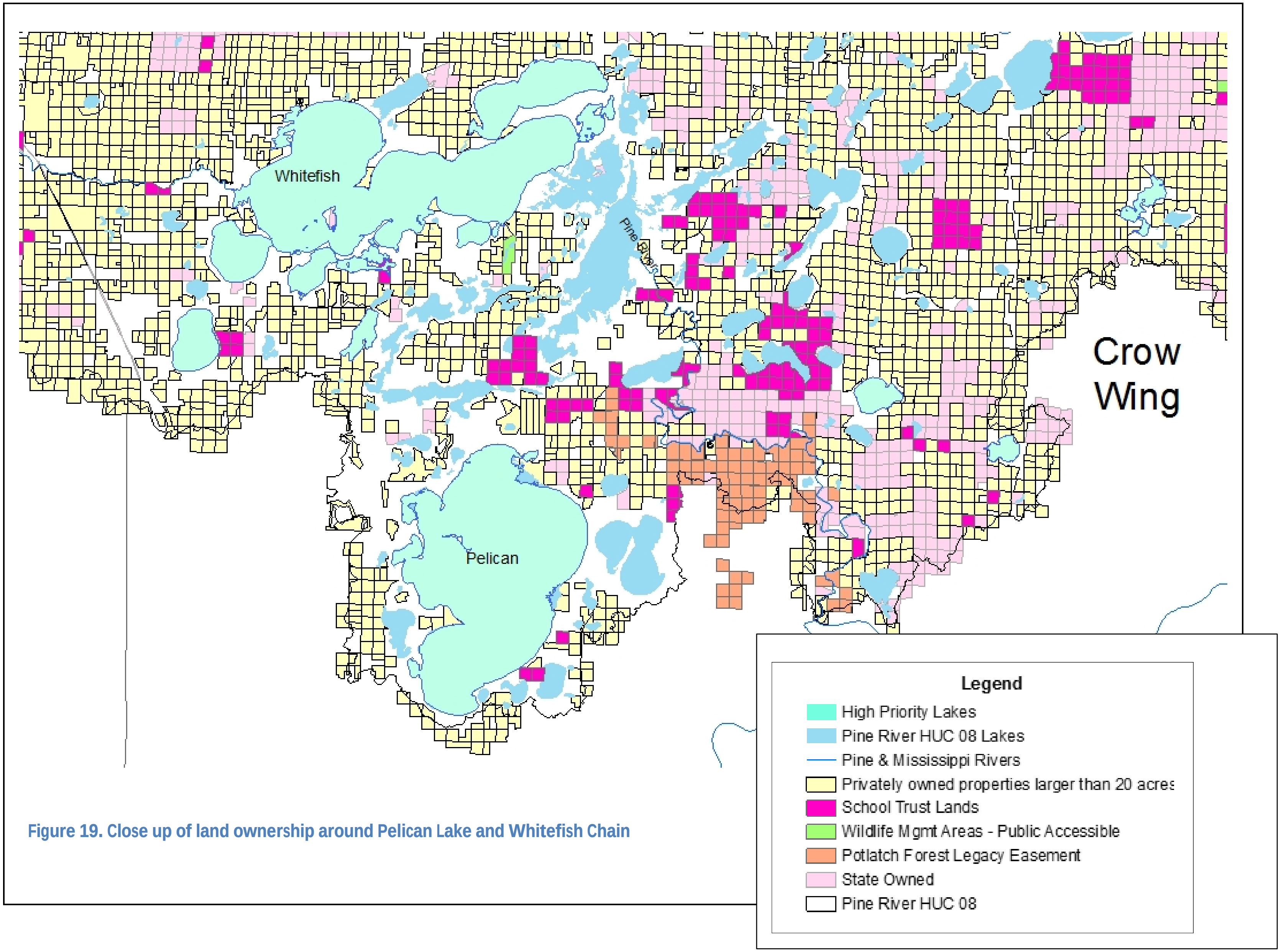


Figure 19. Close up of land ownership around Pelican Lake and Whitefish Chain

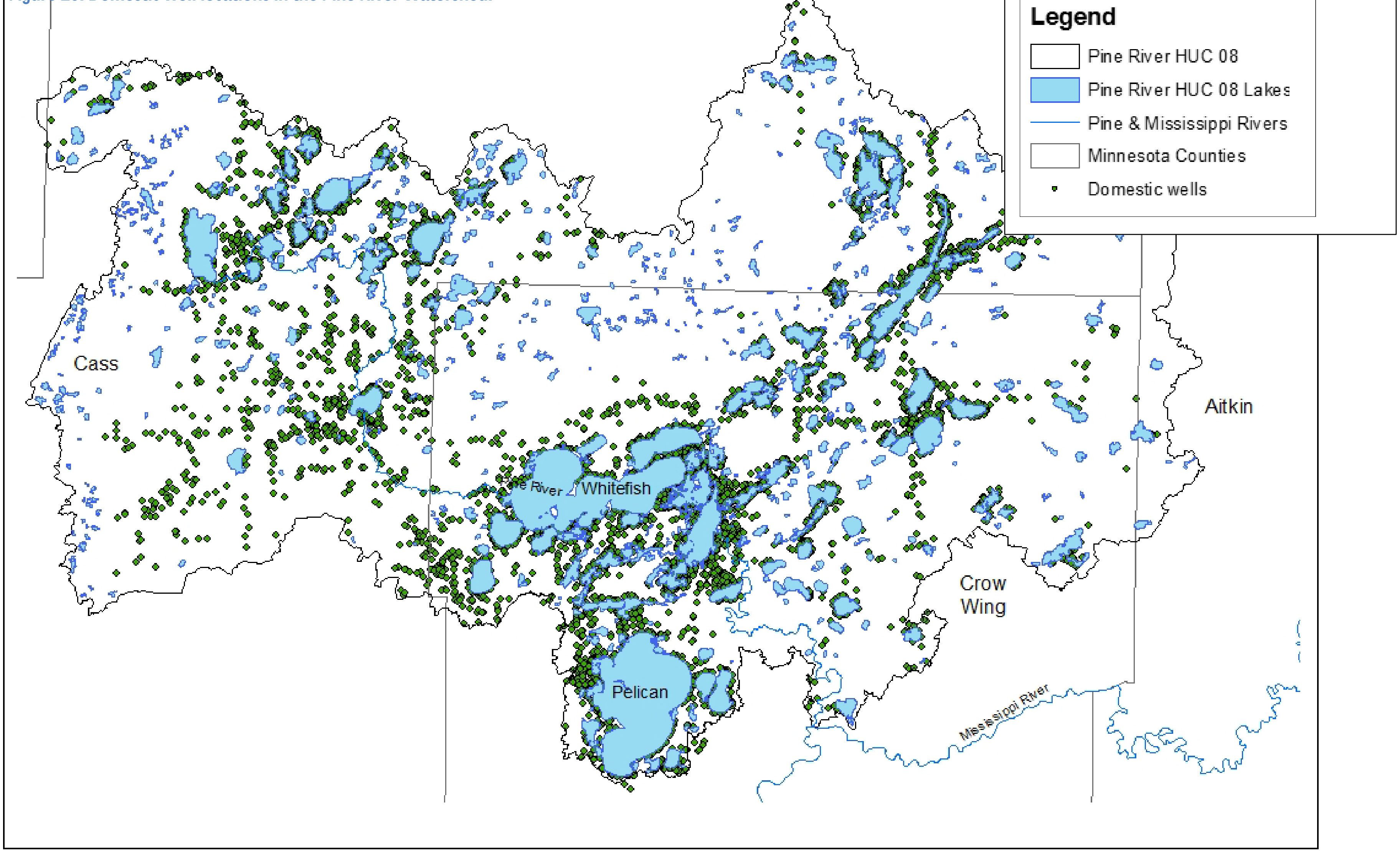
The state of Minnesota recently passed a law requiring riparian buffers (Laws of Minn. ch. 85, S.F.2503) of perennial vegetation of specified widths along all rivers and lakes. This law will unquestionably help protect and improve water quality by filtering runoff and stabilizing banks, but the effectiveness of a buffer is also dependent on how it is implemented. Ideally, a buffer should be a combination of larger woody vegetation (trees), native, long-rooted grasses, and shrubs. The trees help open the soil to allow larger-pore soil permeability and protect the ground from direct particle erosion, shrubs add sturdy understory while providing stability, shade for certain native grasses, and browse for wildlife, and grasses allow for dense ground cover, which slows runoff and also a deep root system that helps water penetrate the soil into the ground water table. All of the plants help to remove nutrients from the runoff so that what reaches surface water is cleaner. Buffers combined with emergent vegetation near the shoreline in the lake also help reduce damage from ice ridges in the winter. When ice ridges do occur, the native vegetation helps to create a more stable shoreline that is less likely to erode than artificial hard-armor techniques such as riprap. Short-rooted perennial vegetation, however, such as turf grass, provides few of the benefits of native buffers, and is far less effective at protecting surface water. A combination of sturdy, native, deep-rooted vegetation is an excellent BMP for protecting water quality and shoreline/bank stability in the Pine, and is easily and inexpensively implemented.

Infiltration is an excellent practice for protecting water quality as well. Whereas properly maintained buffers provide natural infiltration, rain gardens and constructed infiltration basins provide an adequate and often effective mimic to natural processes. These systems, as with any man-made practice, do have potential limitations. Many areas of the Pine have vulnerable ground/drinking water. The MDH has provided data that help to identify these areas. Smaller infiltration systems, especially when planted with deep-rooted native shrubs, can help to absorb nutrients and contaminants that could affect ground water. However larger-scale systems, especially without buffers and native plantings, and those located in relatively heavily developed areas with a greater volume of potential contaminants (such as industrial or commercial areas), can pose a threat to vulnerable groundwater. It is also important that these systems are properly constructed with a minimum of heavy equipment compaction and proper siting, elevation, and contours. Again, choices of vegetation are important to proper functioning of the basin. Crow Wing SWCD, Cass County Environmental Services, DNR and Minnesota Extension staff are excellent sources of expertise for proper infiltration basin construction. Properly constructed infiltration basins are good choices where natural vegetation has been altered, compacted, or replaced with moderate impervious surface.

In areas where development has occurred and natural infiltration systems have been altered or compacted, infiltration is a useful and effective strategy. Suggestions for bio-infiltration practices would include areas with residential lakeshore development such as the Whitefish Chain, Lake Emily or Pelican Lake. Other areas, where careful construction or retrofitting of infiltration systems such as pervious pavement, rain gardens, or “silva cell” (below sidewalk structural cellular system with posts, beams and decks designed to be filled with planting soil for tree rooting and/or for water storage) tree plantings, include municipalities with relatively high levels of impervious surface such as Crosslake, Pine River, Fifty Lakes, Manhattan Beach, Breezy Point, or Emily. Again, ground water levels must be determined before a basin is installed to ensure that a minimum of 3 feet of separation exists between the bottom of any infiltration basin and the seasonally high ground water table. In areas where this is not possible, a filtration system can be designed using enough filter medium to filter out the targeted contaminants and the water can be piped to a receiving basin once the contaminants have been removed. In addition, treatment train systems with swales and filter strips and/or various types of energy dissipation can be utilized to mitigate potential negative effects of an infiltration system. Reference the MPCA Stormwater manual for infiltration practices: https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices

The map below (Figure 20) indicates the location of domestic wells in the Pine. This map was chosen as a surrogate for impervious surface or developed areas because it gives a clear indication of the locations of residential development. These are areas where houses, patios, driveways, garages, grass lawns, and most importantly, roads, have replaced forest cover. Roads are actually responsible for over half of impervious surface as a result of development, as described in: (http://files.dnr.state.mn.us/waters/watermgmt_section/shoreland/SEA_080925_density.pdf). Further overlay with the Zonation Model results, shown in Figure 21, identifies areas with the most value for protection-based focus and further narrows the preferred locations for implementation, as the areas in red are the best for multiple benefits based on the zonation model. The location of the wells indicate residential development where practices to replicate natural systems (infiltration, filtration, diversion, retention, buffers, etc.) would be a preferred strategy.

Figure 20. Domestic well locations in the Pine River Watershed.



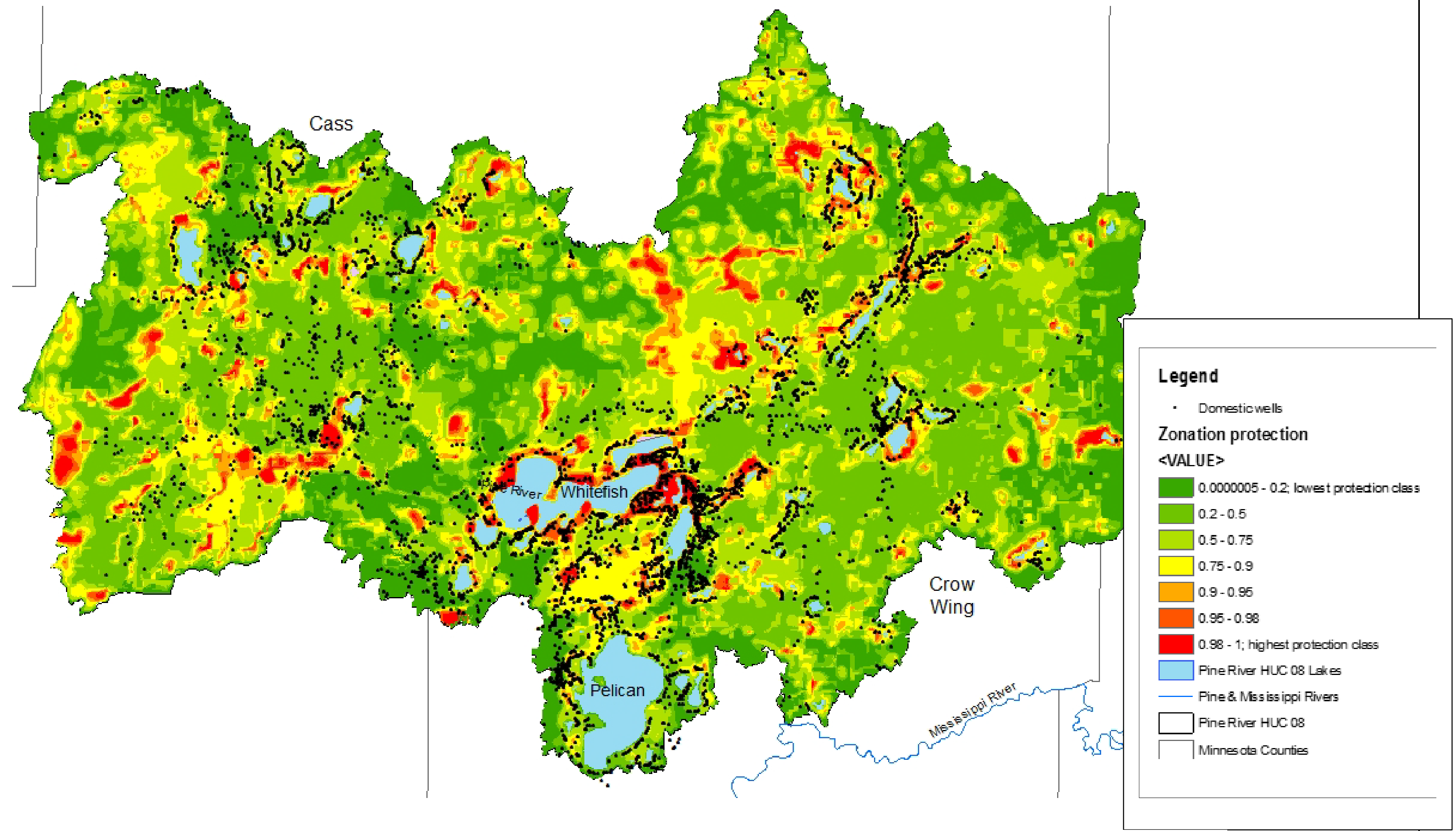


Figure 21. Residential well locations highlighted with key Zonation protection areas. The red colored areas are the highest value for protection implementation.

Analysis of the Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (SSURGO) can be used to estimate the historic wetland extent prior to European settlement. Analysis of SSURGO map units whose drainage condition was classed as “Poorly Drained” or “Very Poorly Drained” suggests that approximately 134,250 acres or 27% of the Pine may have historically been wetland. Comparing this estimate to the 21% of the watershed mapped as wetland today represents a 6.0% estimated rate of wetland loss. Estimates of wetland loss rates are not consistent across the Pine. Headwaters, Whitefish Lake, and South Fork Pine River Subwatersheds have lost 5.0%, 5.4%, and 7.4%, respectively. The Daggett Brook Subwatershed was estimated to have lost 12.8% of its historic wetlands - the greatest loss among all of the 10-HUC watersheds. The Little Pine River Subwatershed was estimated to have lost 4.7% of its historic wetlands. The Pine River Subwatershed had a small (1%) increase in wetlands, but overall supports the least amount of wetland compared with the other 10-HUC watersheds in the Pine. Wetland loss is not always attributed to drainage or filling activities, but can also result from conversion of wetlands to deep water habitats.

The disparity in wetland loss appears logical. Subwatersheds such as Pine River or Whitefish Lake, which are more highly developed with small parcels, are more likely to have significant wetland fill as residents try to maximize use of smaller parcels. The populace and their values are diverse as well, and many people value wetlands differently. Education as to the ecological benefits of wetlands may encourage people to either maintain existing wetlands on their parcels, or restore historical wetlands. The map below, Figure 23, developed by the Minnesota DNR, indicates the approximate depth to groundwater throughout the watershed. The areas in red are indicative of groundwater depths between 0 and 10 feet, meaning that a high percentage of the watershed may have conditions conducive to wetland restoration or even man-made construction. As infiltration is only an option if the base of the basin is at least three feet from the seasonal high-water table, wetland construction may actually be a more suitable practice to store and filter surface runoff than the construction of infiltration basins. However, it is important that constructed or restored wetlands include adequate amounts of the correct vegetation to most effectively perform their ecological function. Areas must meet the criteria for three parameters to be considered wetlands; hydrology, soils, and vegetation. There are wetland specialists that work with Cass and Crow Wing Counties, as well as the DNR, SWCD, BWSR, and the University of Minnesota Extension Office who can help to determine whether a site in a specific area would be suitable for wetland restoration or creation. Wetlands can help improve or protect water quality by storing, settling, filtering, and cooling runoff, as well as providing habitat for birds and mammals.

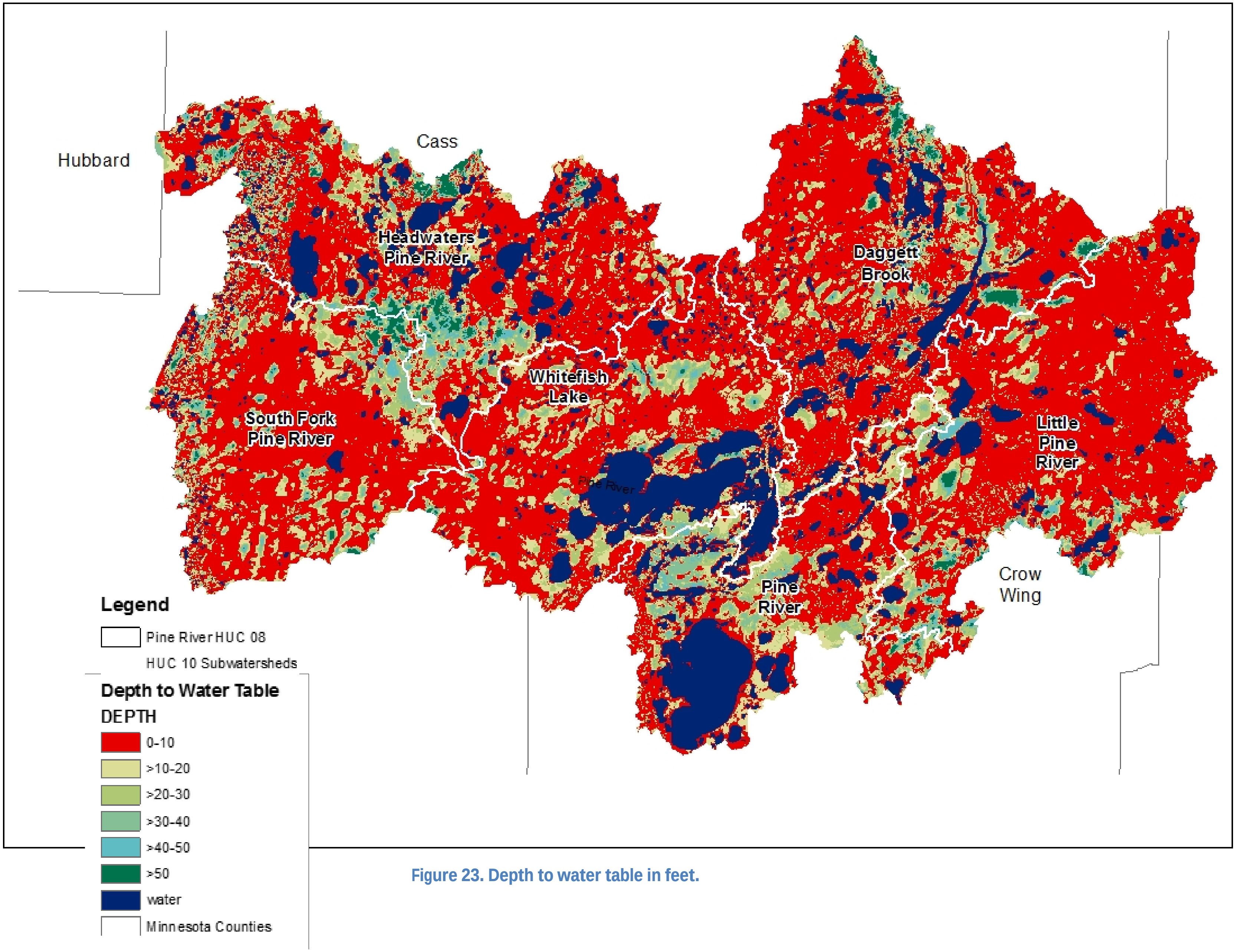
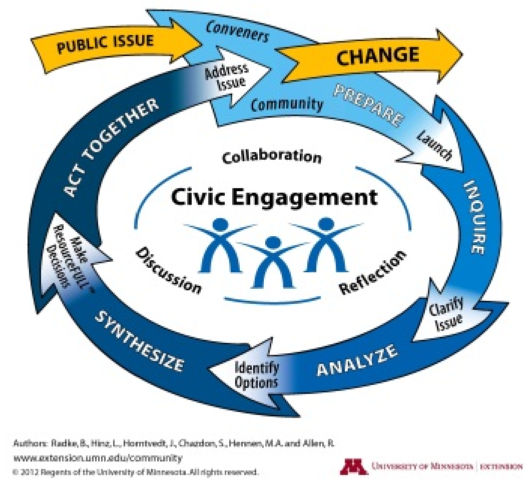


Figure 23. Depth to water table in feet.

3.2 Civic Engagement



A key prerequisite for successful strategy development and on-the-ground implementation is meaningful civic engagement. This is distinguished from the broader term 'public participation' in that civic engagement encompasses a higher, more interactive level of involvement. The MPCA has coordinated with the University of Minnesota Extension Service for years on developing and implementing civic engagement approaches and efforts for the Watershed Approach. Specifically, the University of Minnesota Extension's definition of civic engagement is "Making 'resourceFULL' decisions and taking collective action on public issues through processes that involve public discussion, reflection, and collaboration." Extension defines a resourceFULL decision as one based on diverse sources of information and supported with buy-in, resources (including human), and competence. Further information on civic engagement is available at: http://www1.extension.umn.edu/community/civic-engagement/.

Accomplishments and Future Plans

In the Pine River Watershed, citizen involvement was incorporated into all phases of the WRAPS development from the beginning. Involved citizens representing the Pine Alliance (PRWA) and the Whitefish Area Property Owners Association (WAPOA) were invited to all WRAPS core team meetings, and were kept abreast of all communications between state agencies involved with the WRAPS development, including MPCA, DNR, BWSR, MDH, and local government units (LGUs) such as Crow Wing SWCD and Cass County Environmental Services.

In August of 2013, the Crow Wing SWCD partnered with the MPCA and University of Minnesota Extension to utilize Clean Water Fund grant monies to develop and present a workshop entitled "Fostering Citizen Leadership." The Project included Citizens from five different watersheds in the Upper Mississippi Basin, and involved training at least five citizen leaders from each watershed in communication and leadership skills. The project included two five-part series of workshops (each of the two with different citizens participating), including three in-person seven hour workshops and two, two hour webinars.

The dates of the workshops were as follows:

First series:

- October 6, 2013 (in person)
- Dec 12, 2013 (2 hour webinar)
- February 12, 2014 (2 hour webinar)
- April 12, 2014 (in person)
- June 7, 2014 (In person)

Second Series:

- October 11, 2014 (in person)
- November 1, 2014 (2 hour webinar)
- March 24, 2015 (2 hour webinar)
- April 25, 2015 (in person)

These sessions received high ratings from attendees, and provided skills and training that will, hopefully, be carried forward by dedicated leadership of local citizens.

A separate CWF grant helped the Crow Wing SWCD to create a 14-minute "Pine River Watershed documentary," in which numerous citizens, agency personnel, and television personalities provided personal reflections on what clean water meant to them, and the importance of maintaining the high standard of clean water in the Pine. The video was well received, and has been used as an educational tool throughout the watershed at numerous public gatherings. It is currently viewable on YouTube at https://www.youtube.com/watch?v=WGF6RvxpIVs .

During the course of meetings with citizens during the WRAPS process, it was determined that one of our strategies for preparing implementation priorities would be to meet with Lake Associations to discuss the WRAPS process and end product while gaging interest in doing implementation projects in their areas. Specific Lake Associations were identified through a prioritization process described earlier in Section 3. The team included several citizens of the Pine River Watershed, and staff from the MPCA, DNR, and Crow Wing SWCD. Through the prioritization process, 19 lakes in the Pine were identified as "high-priority" lakes for protection or restoration. Crow Wing SWCD staff worked with the citizen members of the committee to visit the following groups:

Date (All 2016) Time Association Attendees
Tues, Jan 26 Upper Hay 2
Sat, May 21, 9am Upper Hay 55
Thurs, May 12 7pm Emily Lakes/Rivers Board 4
Thurs, April 21 WAPOA 30-50
Fri, April 29 am Pelican Lake 10
Friday, April 29 2pm Lower Hay 5
Sat, May 28 9am Lower Hay 45
Tues, May 17 7pm Bertha/Clamshell 13
Sat, May 21 10:30am Portage Chain of Lakes 10
Friday, May 13 10am Multiple 25

In addition to these group meetings, the group met or spoke individually with homeowners on Clough Lake and Ruth Lake.

Public Notice for Comments

An opportunity for public comment on the draft WRAPS report was provided via a public notice in the State Register from April 10, 2017 through May 10, 2017.

3.3 Restoration & Protection Strategies

The restoration and protection strategies presented in this section were drafted and compiled via interactions with local units of government and citizen groups between 2013 and 2016. The strategies are listed by lake or stream, and can be spatially targeted using any number of risk assessment tools available, some of which are presented and discussed throughout this report. Eventually, the refined restoration and protection strategies should be incorporated into local water plans, comprehensive watershed plans, and applications for federal and state funds.

The HSPF SAM (Scenario Application Manager) modeling tool is available for use. The estimated reductions and the scales of adoption of various practices that are needed to meet those reductions can be accurately and easily calculated using SAM tool. The SAM tool can utilize information on hydrology and loading that has been modeled by HSPF to determine how effective various practices will be at reducing phosphorus and other contaminants in the surface waters down to a 14 HUC subwatershed level. It will also make it easier for users to determine which BMPs are most cost effective for reducing targeted contaminants.

The NRCS has published documents on the importance of increasing the organic matter in soil to benefit water quality. One of the documents, "Guidelines for Soil Quality Assessment in Conservation Planning," is cited in this report, and shows the connections between improving the health of soil on agricultural land and reducing runoff and erosion. Implementation of soil health principals is an important strategy for ground and surface water quality improvement and protection in agricultural areas of the Pine. See Appendix 9 for a short white paper on 'Soil Health for Conservation benefits'.

The Nature Conservancy has provided datasets for this report identifying areas that are possible targets for conservation easement purchase, another primary strategy for protecting water quality. For areas with numerous parcels of privately owned lands of over 20 acres, or significant areas of state tax-forfeit lands, "conservation easement acquisition" is identified as a strategy for protection of surface waters on the strategy table.

Use of the Lakes of Phosphorus Sensitivity Significance to determine Implementation Potential in the Pine River Watershed

A small team of citizens, MPCA, DNR, and LGU staff were assembled to determine what water bodies would be included in the strategy table, and further, how to prioritize those surface waters for implementation in the short term.

Ultimately, it was decided that all lakes identified as "Highest Priority" on the DNR/MPCA matrix would be included on the implementation strategy table. This list included 19 Lakes, all of which are identified with the letter "E" in the "Data Source" column on the strategy table.

In addition, any water bodies for which special studies had been completed by local citizens or government units were included. This included Lake Emily and Bungo Creek. The Lake Emily Study, entitled “Lake Emily Outlet Modification and Lake Plan Analysis” was completed by Short, Elliot, Hendrickson for the city of Emily, while the Bungo Creek Study, entitled “Land Use and Phosphorus in Bungo Creek Watershed” was completed by Ann Lewandowski, University of Minnesota Water Resources Center for the Pine River Watershed Alliance.

Waters impaired for reasons other than mercury identified during the 2012 through 2014 IWM process by the MPCA were also listed as priorities on the strategy table, and included four lakes and four stream reaches. A fifth Lake that was identified as impaired by nutrients but not listed on the table was Lows Lake. Lows Lake (18-0180-00), although determined to be impaired, was classified as having been impaired due to natural causes rather than man-made causes; and thus was left off of the strategy table because there were no man-caused stressors to mitigate for.

The group also developed an approach to identify lakes that are good candidates for protection implementation activities. The group started with lakes that made the priority lists for both Lakes of Phosphorus Sensitivity Significance (Appendix 1) and the Emmons and Oliver Resources prioritization matrix (Appendix 3). The list was then trimmed by eliminating lakes that did not show up as priorities in the Zonation Model. To further prioritize those eleven lakes, the group made an effort to meet with citizens or lake associations on each lake to determine whether there was interest in participating in early project implementation when the WRAPS was finalized. Groups that showed interest in implementing water quality projects would then be followed up with at a later date once grant funding became available.

The Citizens and Local government staff are continuing to measure interest in implementation of projects, preferably in areas identified as “multiple benefit” locations in the zonation model.

Implementation Tables

The strategy tables are broken down by HUC 10 subwatershed, with maps for each subwatershed paired with the prioritized water bodies and strategies for that subwatershed.

Data Source Key for Strategy Tables

A(1)	Zonation Model - Protection
A(2)	Zonation Model - Restoration
B	Hydrologic Simulation Program FORTRAN (HSPF)
C	The Nature Conservancy (TNC)
D	Crow Wing County
E	Lakes of Phosphorus Sensitivity Significance
F	EOR Prioritization
G	The Pine River Ground Water Restoration & Protection Strategy (GRAPS)
H	Specialized Studies. See Appendices 7 & 8.
I	Stressor ID Report

The strategy table contains the following information:

High Groundwater Vulnerability Area**:** The following map was used to determine groundwater vulnerability for each priority water that was identified in the Strategy Table. This map allows us to further determine what strategies will also serve the benefit of protecting groundwater, and conversely, for which waters infiltration (especially large scale) may not be a preferred strategy where water tables are shallow and in vulnerable soils. A column was added to the strategy table to show which priority waters are located in areas that are also deemed to have highly vulnerable groundwater.

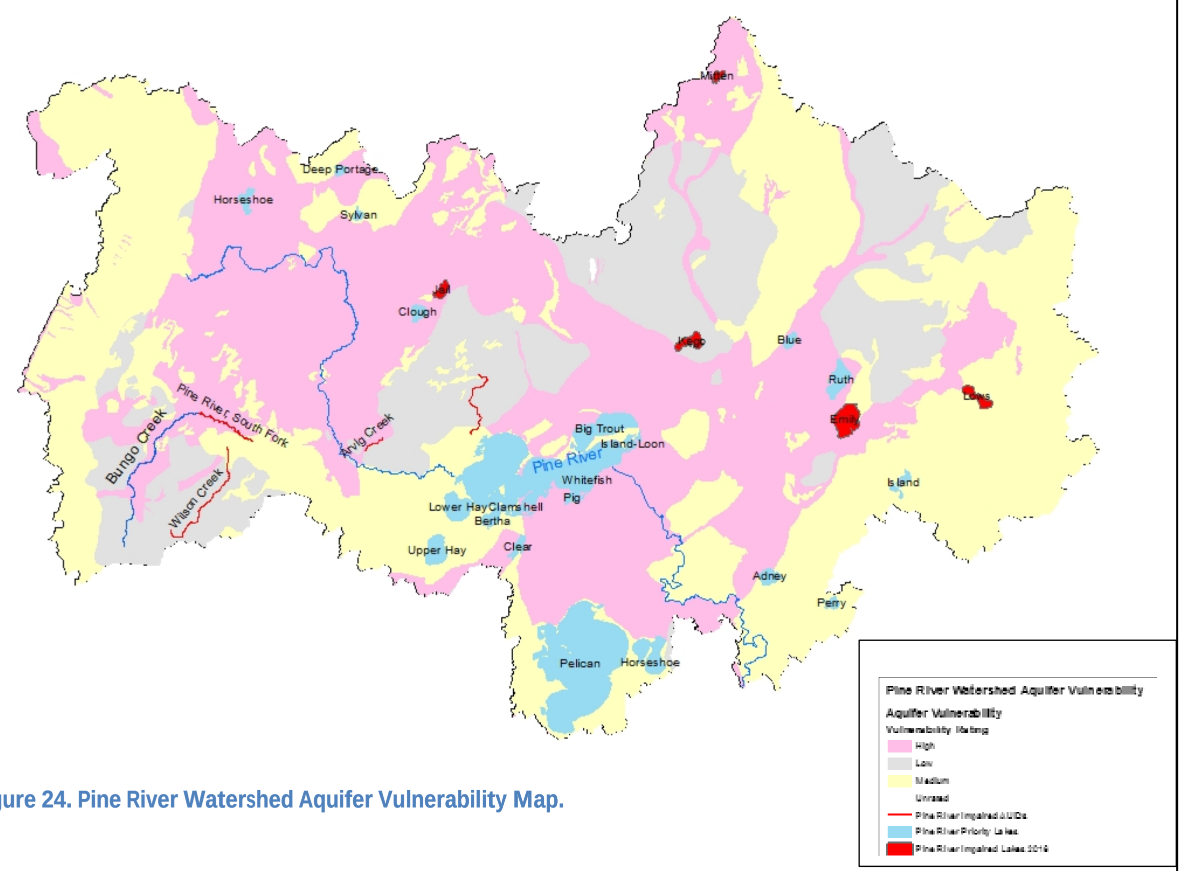


Figure 24. Pine River Watershed Aquifer Vulnerability Map.

Water Quality – Current Conditions: "Current" condition is interpreted as the baseline condition over some evaluation period for the pollutant or non-pollutant stressor identified in the previous column. This is in some instances a numeric descriptor and unit of measurement of load of a specific parameter, and in other cases a description of the general status of the water body with regard to a specific parameter (e.g., biology).

Water Quality – Goals / Targets: This is expressed in the same terms as applied in the previous column (Current Conditions) and will generally be a load target (could be percent reduction or a load value) or a water quality concentration target. For some parameters (e.g. phosphorus reduction in a lake watershed), load targets were used. For others (e.g., *E. coli*) a concentration may be used. For protection, a numeric goal/target is used if available.

Strategies: This column provides the high-level strategies to be used for both protection and restoration. Strategies outline the method, approach or combination of approaches that could be taken to achieve water quality goals. This field is not intended to prescribe specific projects and practices. The strategies should be briefly stated and then further described in Table 8. In these template materials, Table 8 includes an extensive list of example strategies (in the 'Descriptions' column) with accompanying example BMPs/actions for those strategies.

Strategy Type and Estimated Scale of Adoption Needed to Meet Final Water Quality Target: This column ties to the Strategies column and provides the basic outcome of a modeling scenario (or similar analysis) that generally describes the collective magnitude of effort (over however many years or decades) that it will take to achieve the water quality target. This estimate is meant to describe approximately "what needs to happen" but does not need to detail precisely "how" goal attainment will be achieved (the latter is left to subsequent planning steps). As such, it is acknowledged that this is an approximation only and subject to adaptive management. Detail regarding degree of implementation of various BMPs were in some cases added per stakeholder design/support.

Interim 10-yr Milestones: This column ties to the Estimated Scale of Adoption column, and either describes the degree of progress that the prioritization team hoped to be made toward implementing the strategy in the first 10 years from completion of the WRAPS report, or describes the type of tool that would be utilized to achieve a goal within the next 10 years.

Governmental Units with Primary Responsibility: Identifies the governmental unit with primary responsibility. It should be noted that identifying a responsible party does not imply any newly associated or suggested authority or regulation.

Estimated Year to Achieve Water Quality Targets: This applies to the waterbody, specifically the year it is reasonably estimated by the prioritization team that applicable water quality targets will be achieved.

Headwaters Pine River HUC 10 Watershed (0701010501)

Figure 26. HUC 10 Subwatersheds within Pine River Watershed.

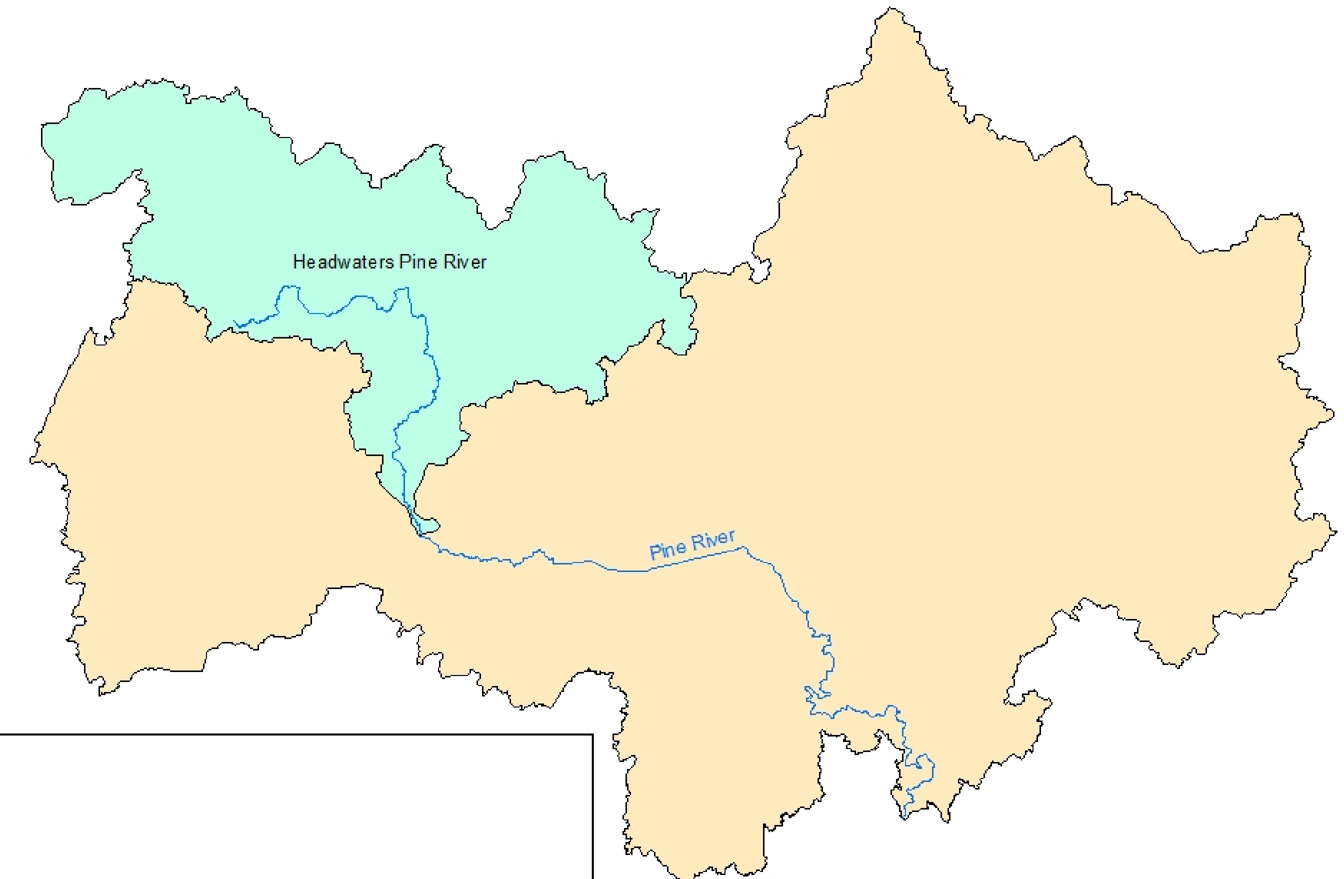


Figure 25. Headwaters Pine River HUC 10.

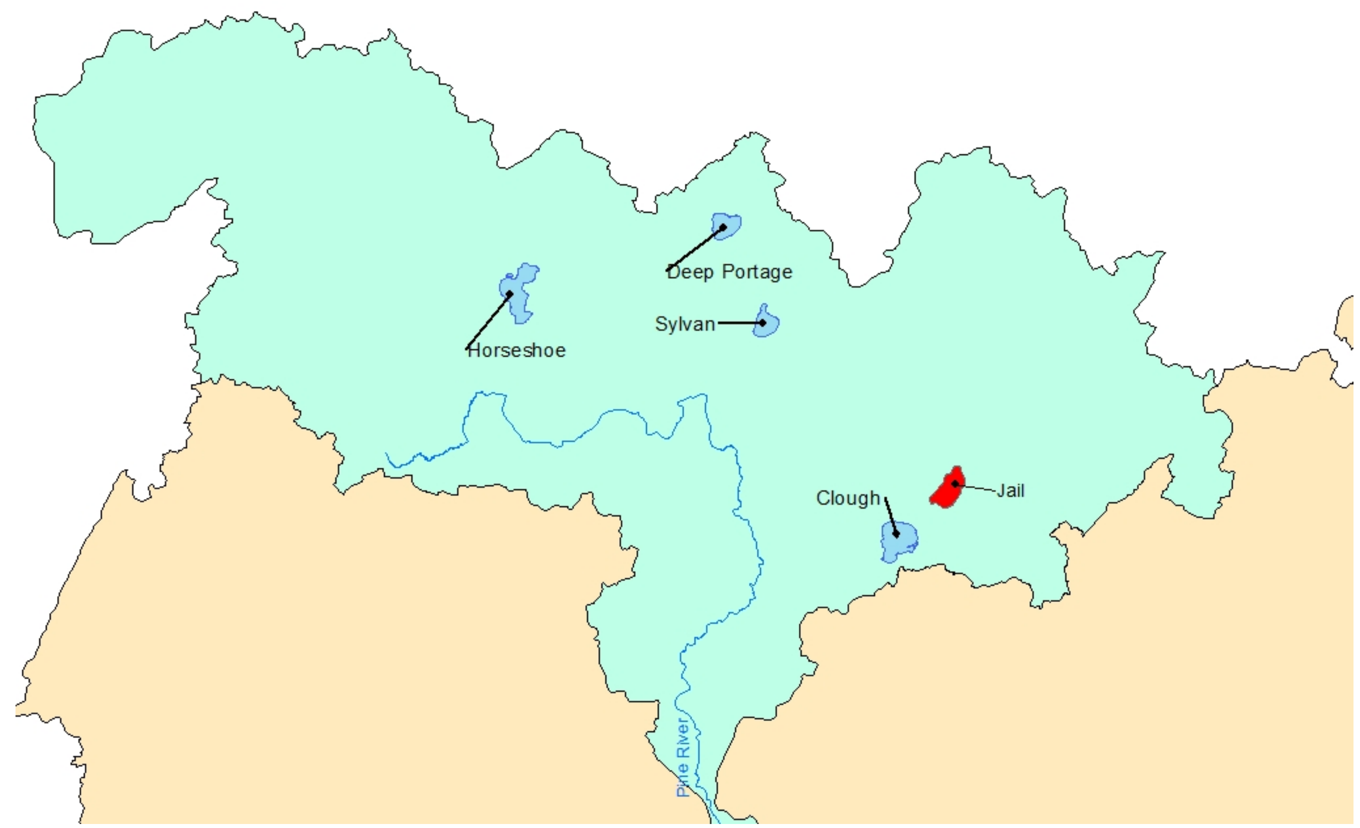


Figure 27. Lakes identified in strategy table for Headwaters Pine River Subwatershed.

Headwaters Pine River HUC 10 Watershed (0701010501)

Table 10. Strategies and actions proposed for the Headwaters Pine River Subwatershed. Red rows = impaired waters requiring restoration; Green rows = unimpaired waters requiring protection

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality: Current Conditions	Water Quality: Goals / Targets and Estimated % Reduction	Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility: SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	Estimated Year to Achieve Water Quality Target
Headwaters Pine River (0701010501)	Cass	Deep Portage Lake (11023700)	A1, A2, E, F, G	Yes	Phosphorus (influenced most strongly by watershed Ph. Loads)	12 ug/l	Target Mean TP ≤ 10.0 ug/l	Conservation easement acquisition (possible W and N of lake)	Approx. 1000 acres Tax Forfeit land available NW of Lake. At least 75% of lake shed must be left in forestland.	50 "hotspot" acres in Conservation easement	X				X	X	X	X	2026
								Shoreline Protection	Native buffers along 50% of the shoreline	Work with private landowners to install buffers along 50% of shoreline.	X				X	X	X	X	2026
								Infiltration on developed properties	25% of residential properties install infiltration basins	25% of lots install infiltration basins	X			X	X	X	X	X	2024
	Cass	Horseshoe (11-0358-00)	A2, C, E, F, G,	Yes	Phosphorus (influenced most strongly by watershed Ph. Loads)	16.5 ug/l	Target Mean TP ≤ 14.0 ug/l	Shoreline Protection	Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X				X	X	X	X	2026
								Infiltration on developed properties	10% of residential properties install infiltration basins	10% of lots install infiltration basins	X			X	X	X	X	X	2024
	Cass	Sylvan (11024600)	A2, C, E, F	No	Phosphorus (influenced most strongly by watershed Ph. Loads)	13 ug/l	Target Mean TP ≤ 10.5 ug/l	Shoreline Protection	Work with private landowners to install buffers along shoreline.	50 foot native buffers along 75% of residential shoreline	X						X	X	2026
									Increase number of residential properties with infiltration basins in areas south of lake	Utilize SAM tool to determine scale of adoption necessary to meet targets	X				X	X	X	X	2026
								Increased forest acres	Add upland forest acreage and use conservation easements to protect existing forest.	Increase existing forest cover to 75% in lake shed	X			X	X	X	X	X	2024
	Crow Wing	Clough (18041400)	C, E, F, G	Yes	Phosphorus	21 ug/l	Target Mean TP ≤ 17.5 ug/l	Conservation easement acquisition (possible NE of Lake)	Roughly 150 acres Tax Forfeit Land available. 200 acres+ of large parcel private land SE of Lake	Work with private landowners and programs to enroll landowners in conservation easements. The goal is 75% forest land in lake shed.	X				X	X	X	X	2026
								Shoreline Protection	Work with private landowners to install buffers along shoreline.	Implement buffers along 50% of the shoreline	X				X	X	X	X	2026

Headwaters Pine River HUC 10 Watershed (0701010501)

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets and Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
Headwaters Pine River (0701010501)								Increased forest acres	Add forest acreage to attain 75% of forested land cover in lake shed.	Work with private landowners to complete forest management and develop plans	X			X	X	X	X	X	2024
	Crow Wing	Jail (18041500)	A2, C, E, F, G, I	Yes	Phosphorus	53 ug/l	P. R. Target Mean TP ≤ 37.4 ug/l , TP reduction of 62% annually	Conservation easement acquisition (Possible N and E of Lake)	Over 1,000 acres of Tax-forfeit and State Land north of lake, 200+ acres private large parcels to east	Work with private landowners and programs to enroll landowners in conservation easements. Increase forested land cover to 75% of lake shed.	X				X	X	X	X	2026
								Shoreline Protection	Work with private landowners to install buffers along shoreline.	Implement buffers along 25% of the shoreline	X				X	X	X	X	2026
								Ordinance change and education	Reduce outboard motor HP or implement "no-wake zones" to address internal loading post signage explaining correlation between boat traffic and loading in shallow lakes	No wake ordinances in place for areas less than 10 feet in depth-	X				X	X	X	X	2024
								Address failing septic systems: Fixing septic systems so that on-site sewage is not released to surface waters.	Inspect septic systems for compliance	100% compliance			X				X		2022
								Improve upland/field surface runoff controls: Soil and water conservation practices that reduce soil erosion and field runoff, or otherwise minimize sediment from leaving farmland	Implement native buffers and cover crops along shoreline where cropland is adjacent to shoreline.	Increase organic content of cropland by 2%	X			X		X	X	X	2026

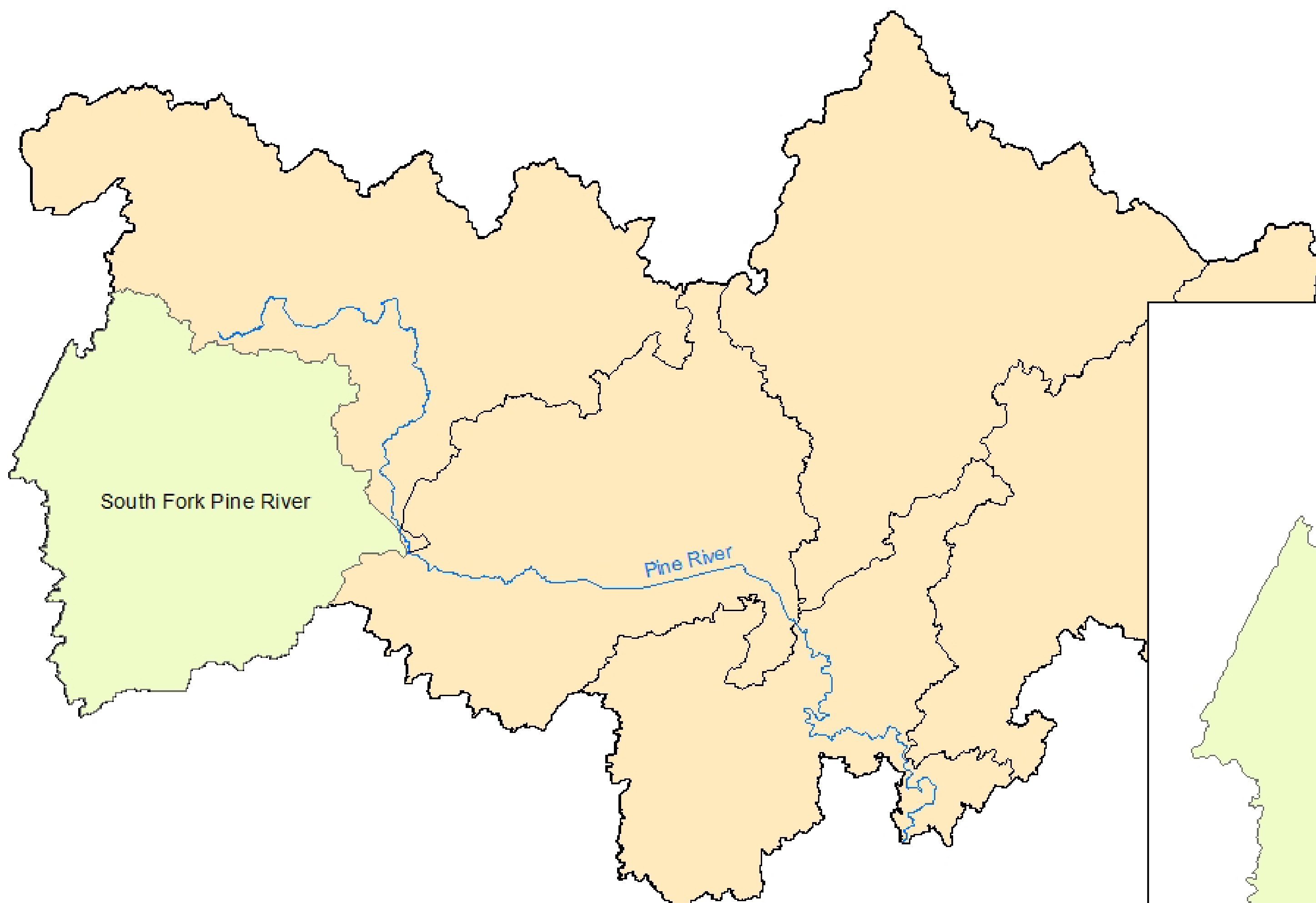


Figure 28. South Fork Pine River Subwatershed.

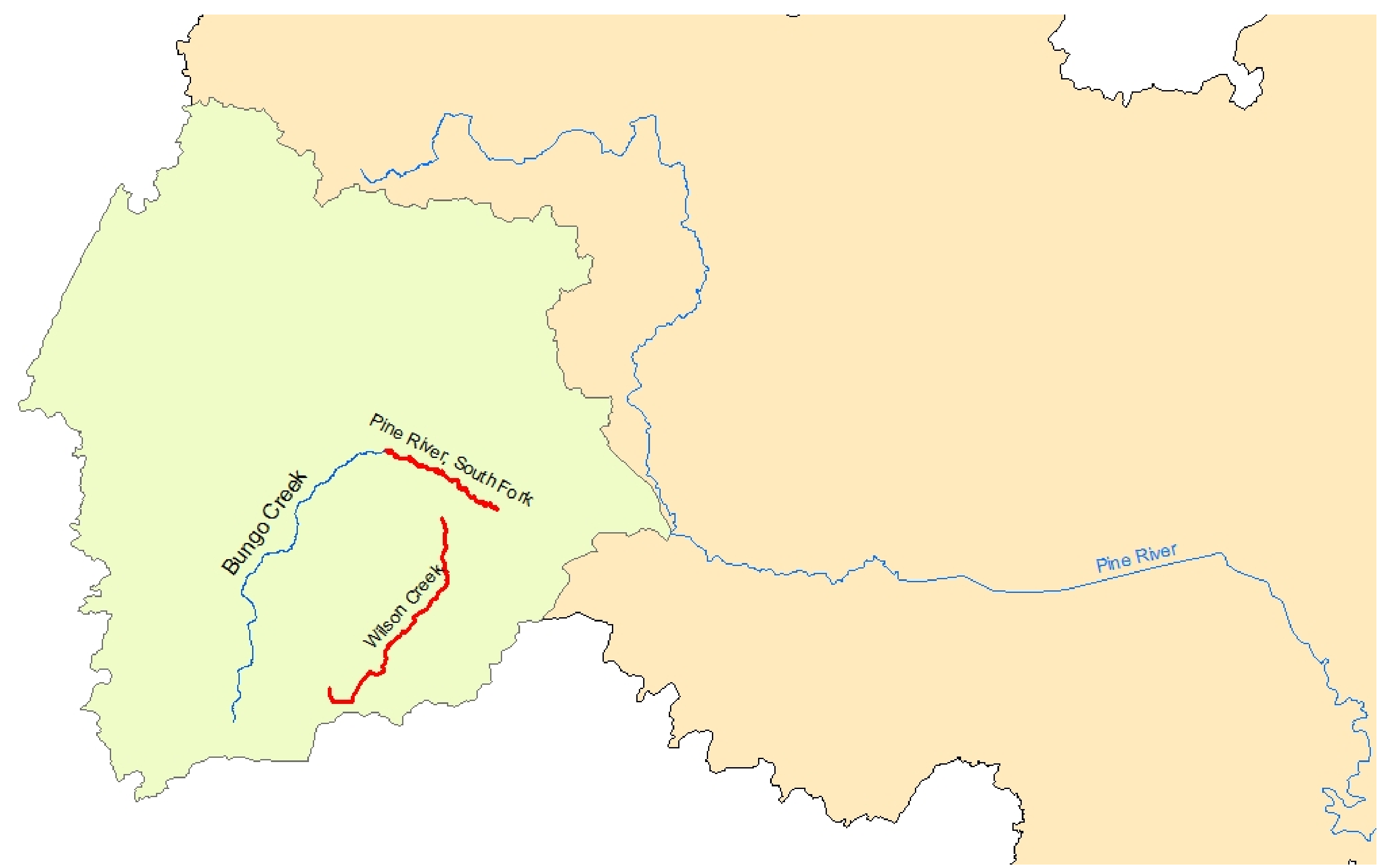


Figure 29. South Fork Pine River with Targeted waterbodies.

Daggett Brook HUC 10 Watershed (0701010503)

Table 11 Strategies and actions proposed for South Fork Pine River Subwatershed. Red rows = impaired waters requiring restoration; Green rows = unimpaired waters requiring protection, Blue rows = strategies addressing downstream pollutant reductions

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets and Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
South Fork Pine River (0701010502)	Cass, Crow Wing	Bungo Creek	A2, C, H	Yes	Phosphorus	315 ug/L	Utilize SAM tool to identify practices for implementation and estimated reductions	Iron and Sand Filter	Implement BMPs in key locations identified by Zonation or SAM tool	Installation of Iron/Sand filter	x					X	X	X	2026
								Find source of Phosphorus (predominantly draining from S 23)	Have a professional geohydrologist locate the source of surfacing ground water and determine its phosphorus content.										
			A2, H	Yes	Sediment Erosion			Agricultural Practices to prevent runoff	100% Cover crops overwinter; implementation of other soil health principles (increasing crop diversity, rotational grazing, integrated livestock into cropping systems);	Increase soil organic matter of soil by 2% to increase water holding capacity and reduce runoff									2026
	Cass, Crow Wing	South Fork (07010105-531)	A2, C, G, I	Yes	Phosphorus	71 ug/L	TP<=50 ug/L	Conservation easement acquisition (W end of system)	Several hundred acres of privately owned large parcels to west of shed.	TP< 50 ug/L						X	X	X	2026
								Shoreline Protection	Implement native buffers along 50% of the shoreline	Implement native buffers along 50% of the shoreline									
								Vigilance for state owned land	Over 1000 acres state land near source	75% of watershed in permanent forest cover						X	X	X	
			I		Fish IBI	Not supporting fish population	Meet/Exceed Fish IBI	Improve connectivity	Replace improperly installed culverts on 36th Ave	Research funding to replace culverts									2026
	Cass, Crow Wing	Wilson Creek	A2, C, E, I	No	Phosphorus	48-104 ug/L	target TP >=50 ug/L	Native buffer along stream channel in upstream area where row cropping and pasture are present	Exclude cattle from stream riparian corridor with fencing, or intensive rotational grazing management (100% adoption) plant willow stakes if vegetation fails to re-establish	Native vegetation buffer along 100% of stream corridor						X	X	X	2026
					Invert IBI	Not supporting invertebrate population	Meet/Exceed Invert IBI	Livestock management	Exclude cattle from stream riparian corridor with fencing, or intensive rotational grazing management (100% adoption)		X			X					2026

Daggett Brook HUC 10 Watershed (0701010503)

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets and Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
								establish woody riparian corridor	Willow stakes if native vegetation fails to establish		X						X		2026

Daggett Brook HUC 10 Watershed (0701010503)

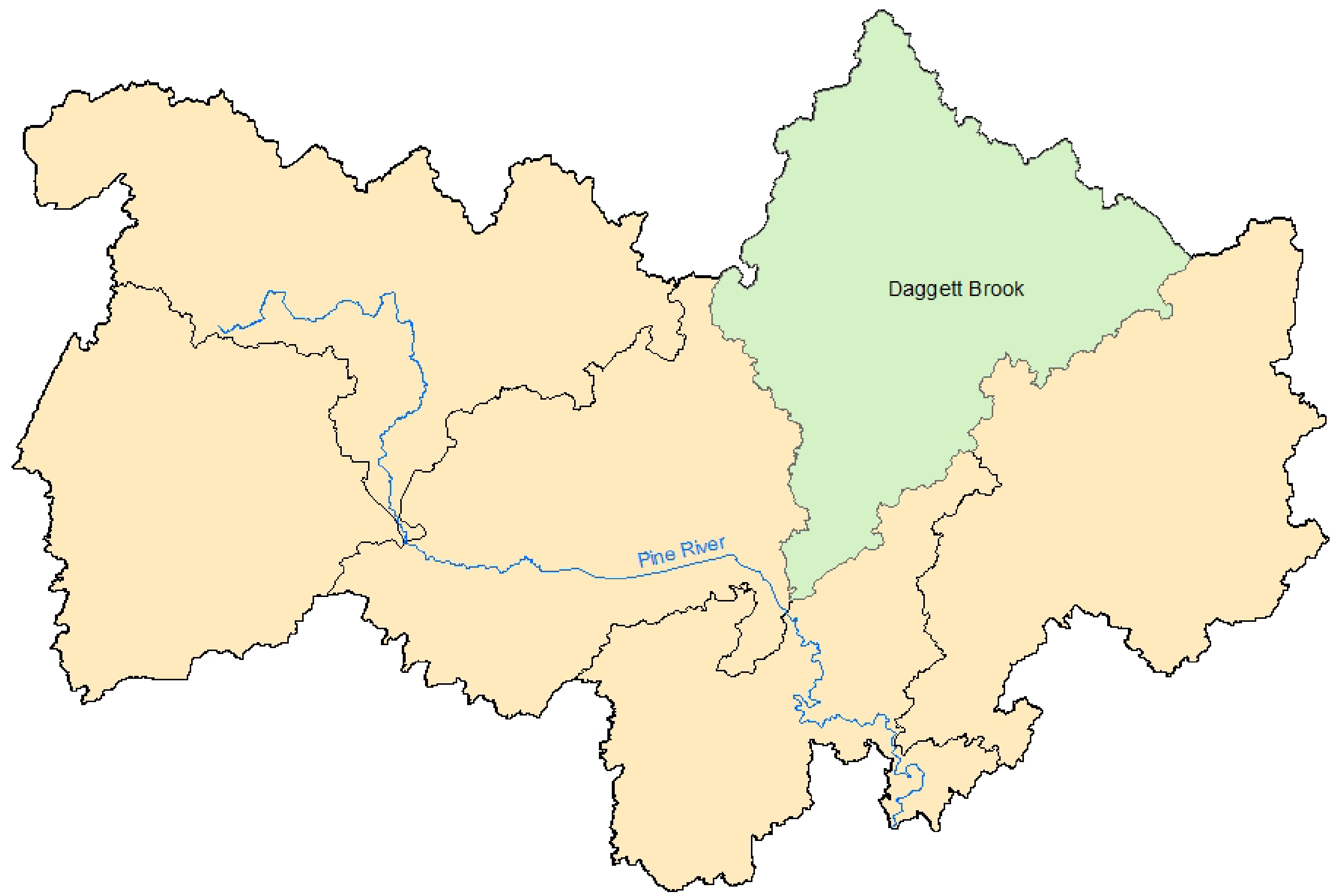


Figure 30. Daggett Brook Subwatershed.

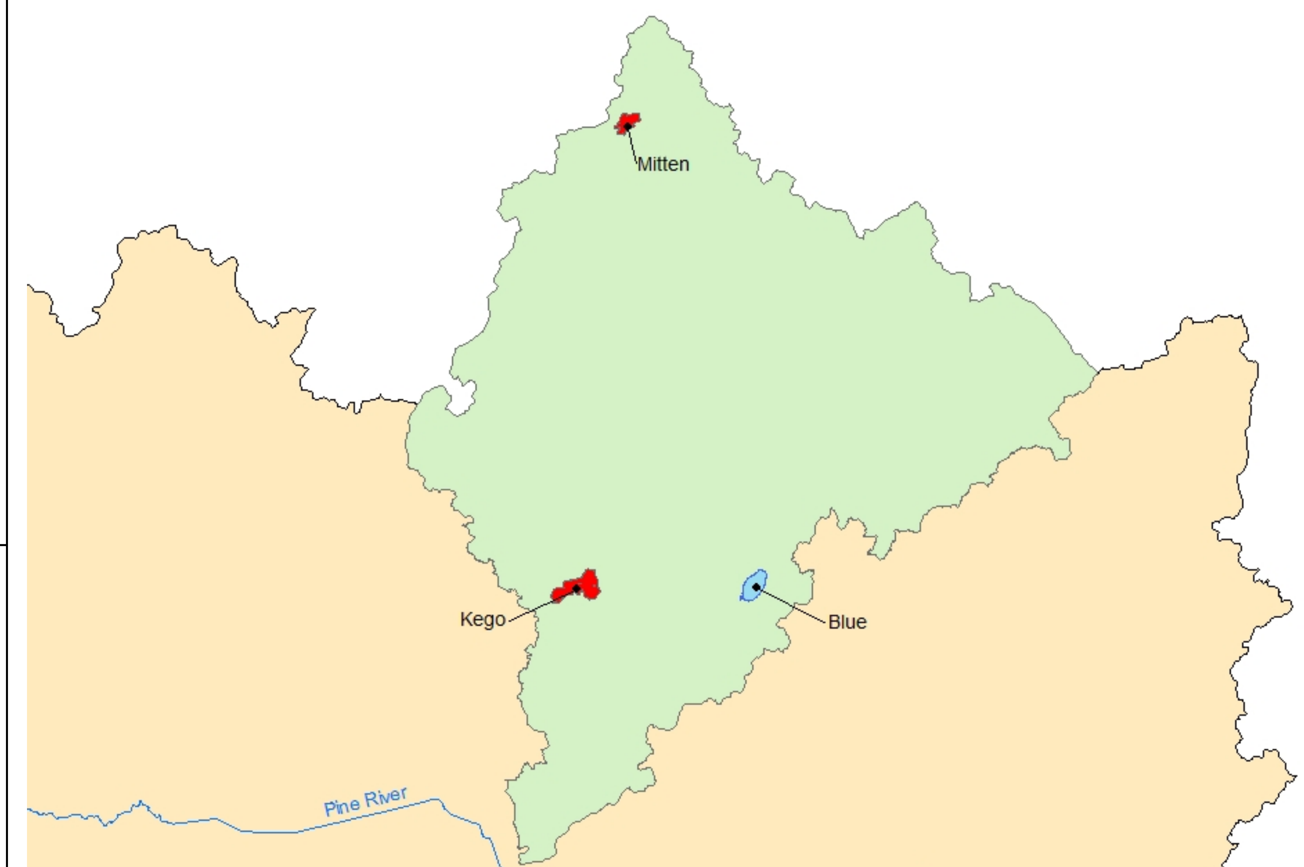


Figure 31. Targeted waterbodies in Daggett Brook Subwatershed.

Daggett Brook HUC 10 Watershed (0701010503)

Table 12. Strategies and proposed actions for Daggett Brook Subwatershed. Red rows = impaired waters requiring restoration; Green rows = unimpaired waters requiring protection, Blue rows = strategies addressing downstream pollutant reductions

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets and Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
Daggett Brook (0701010503)	Cass	Mitten (11011400)	C, E, F, I	Yes	Phosphorus	TP = 37.1 ug/l	P. R. Target Mean TP ≤ 34.6 ug/l	Vigilance strategy on state land south of lake	Approx. 400 acres school trust land near south shore. This land potentially could be purchased for easement	Leave state land undisturbed, protect wetland areas adjacent to shore	X				X	X	X	X	2026
								Shoreline Protection	Work with private landowners to install buffers along shoreline.	Implement buffers along 50% of the residential shoreline	X			X	X	X	X	X	2026
								Increased forest acres	Add forest acreage to bring forested land cover to 75% of lakeshed	Work with private landowners to complete forest management and develop plans	X				X	X	X	X	2024
	Crow Wing	Blue (18021100)	E	Yes	Phosphorus	TP = 7.1 ug/l	Target Mean TP ≤ 5.8 ug/l	Shoreline Protection	Protect sensitive shoreline	Work with private landowners and programs to enroll landowners in conservation easements.	X				X	X	X	X	2026
									Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026
								Maintain and protect forest acres in lake shed	75% forested land cover in lake shed (currently met)	Work with private landowners to complete forest management and develop plans	X				X	X	X	X	2024
	Crow Wing	Kego (18029300)	A1, C, E, F, I	No	Phosphorus	TP = 33.4 ug/l	Target Mean TP ≤ 29.5 ug/l consult .TP reduction of 22% annually (per TMDL).	Vigilance strategy on state owned land around lake, school trust land to west can be sold into easements, possible conservation easement acquisition	Over 1000 acres tax-forfeit land available in northwest lakeshed, large private parcels to S and NE	Work with private landowners and programs to enroll landowners in conservation easements. 75% of lake shed in permanent easement.	X				X	X	X	X	2026
								Shoreline Protection	Implement buffers along 50% of the shoreline-preserve wetland areas	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026

Daggett Brook HUC 10 Watershed (0701010503)

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets and Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
Daggett Brook (0701010503)								Ordinance change	Reduce outboard motor HP or implement "no-wake zones" to address internal loading	No wake ordinances in place for areas less than 10 feet in depth	X			X	X	X	X	X	2024

Whitefish Lake HUC 10 Watershed (0701010504)

Figure 32. Whitefish Lake Subwatershed.

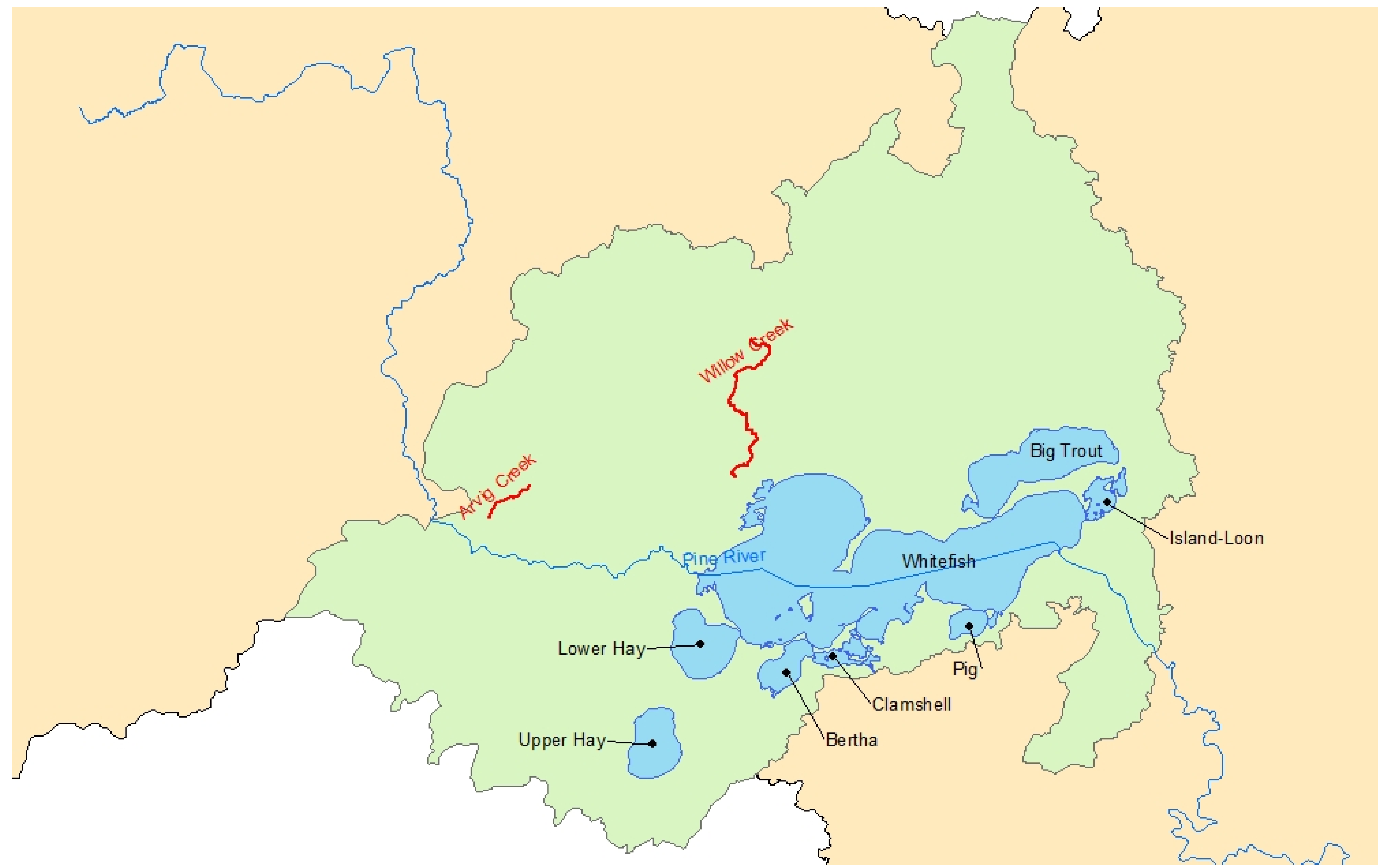


Figure 33. Targeted waterbodies in Whitefish Lake Subwatershed.

Whitefish Lake HUC 10 Watershed (0701010504)

Table 13. Strategies and actions for Whitefish Lake Subwatershed. Red rows = impaired waters requiring restoration; Green rows = unimpaired waters requiring protection, Blue rows = strategies addressing downstream pollutant reductions

						Water Quality					Governmental Units with Primary Responsibility								
HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Current Conditions	Goals / Targets or Estimated % Reduction	Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	Estimated Year to Achieve Water Quality Target
Whitefish Lake (0701010504)	Crow Wing	Pig (18035400)	A1, E, F, G	Yes	Phosphorus	15.4 ug/l	TP ≤ 12.6 ug/l	Shoreline Protection	Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026
			D		Risk Classification	> 40 % protected	75% protected	Increased forest acres	Add forest acreage	Work with private landowners to complete forest management and develop plans, purchase easements to increase permanent forest cover by 75% in lake shed.	X				X	X	X	X	2024
			D		Water Clarity	increasing trend													
	Crow Wing	Bertha (18035500)	A1,A2, E, F	No	Phosphorus	TP = 15.4 ug/l	TP ≤ 12.7 ug/l	Shoreline Protection	Implement buffers along 50% of the shoreline/ reduce fertilizer application along steep slopes/shoreline side of property.	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026
								Increased forest acres	Add forest acreage, purchase easements or enroll landowners in SFIA	Work with private landowners to complete forest management and develop plans-goal is 75% of land cover in lake shed is forested.	X				X	X	X	X	2024
	Crow Wing	Clamshell (18035600)	A1, E, F	No	Phosphorus (influenced most strongly by watershed Ph. Loads)	17.6 ug/l	TP ≤ 14.5 ug/l	Shoreline Protection	Protect sensitive shoreline	Work with private landowners and programs to enroll landowners in conservation easements. (Large parcels S of Lake)	X				X	X	X	X	2026
									Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026
								Increased forest acres	Add forest acreage	Work with private landowners to complete forest management and develop plans	X				X	X	X	X	2024
	Crow Wing	Whitefish (18031000)	A1, A2, E, F	Yes- Lower Whitefish; No- Upper Whitefish	Phosphorus	15.8 ug/l	TP ≤ 13.3 ug/l	Shoreline Protection	Protect sensitive shoreline	Work with private landowners and programs to enroll landowners in conservation easements.	X				X	X	X	X	2026

Whitefish Lake HUC 10 Watershed (0701010504)

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets or Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
Whitefish Lake (0701010504)									Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026
								Increased forest acres	Add forest acreage	Work with private landowners to complete forest management and develop plans	X				X	X	X	X	2024
	Crow Wing	Big Trout (18031500)	A1, A2, E, F, G, H	Yes	Phosphorus	10.7 ug/l	TP ≤ 9.2 ug/l	Shoreline Protection	Protect 2,250 acres of private forest land in the watershed with conservation easements (Per appendix I)	Work with private landowners and programs to enroll landowners in conservation easements.	X				X	X	X	X	2026
									Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026
									Runoff Reduction	Install practices such as rain gardens or runoff diversion and retention along 50% of shoreline	X				X	X	X	X	2024
	Crow Wing	Island-loon (18026900)	A1, A2, E, G	Yes	Phosphorus	11.8 ug/l	TP ≤ 9.9 ug/l	Shoreline Protection	Protect sensitive shoreline	Work with private landowners to install buffers along 50% of shoreline.	X			X	X	X	X	X	2026
								Increased forest acres	Add forest acreage	Work with private landowners to complete forest management and develop plans	X				X	X	X	X	2024
	Crow Wing	Upper Hay (18041200)	A1, E, F	No	Phosphorus	31.3 ug/l	TP ≤ 29.9 ug/l	Vigilance strategy- protect school trust land east of lake, consider purchase of conservation easements if possible.	Approx. 100 acres school trust land to east of lake. Privately owned larger parcels in lake shed to east. Maintain 75% forest cover in lake shed	Work with private landowners and programs to enroll landowners in conservation easements.	X				X	X	X	X	2026

Whitefish Lake HUC 10 Watershed (0701010504)

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets or Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
Whitefish Lake (0701010504)								Shoreline Protection	Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026
								Increased forest acres	Add forest acreage	Work with private landowners to complete forest management and develop plans	X				X	X	X	X	2024
	Crow Wing	Lower Hay (18037800)	A1, A2, E, F	No	Phosphorus	13.2 ug/l	TP ≤ 11 ug/l	Shoreline Protection	Protect sensitive shoreline	Work with private landowners and programs to enroll landowners in conservation easements. Privately owned larger parcels to W and N of lake	X				X	X	X	X	2026
									Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026
								Protect existing forest cover in lake shed, opportunities to increase forest cover west of lake	Maintain at least 75% forest cover in lake shed	Work with private landowners to complete forest management and develop plans	x								2026
	Crow Wing	Willow Creek	C, G, I	No	Phosphorus	57 ug/L	below 50 ug/L	Investigate upstream sources to determine where elevated TP is sourced	Install appropriate runoff control or phosphorus reduction practices to reduce phosphorus at source	Reduce phosphorus to below 50 ug/l	X			X		X	X	X	2026
Whitefish Lake (0701010504)					Biota-Fish	Downstream channel over widened and shallow. Little habitat diversity making fish passage improbable. Fish refuge areas also limited.	Fully supporting Aquatic Life	Livestock management	Exclude cattle from stream riparian corridor with fencing, or intensive rotational grazing management (100% adoption)	Establishment of 50 foot native vegetative buffer along 100% of stream corridor	X			X		X	X	X	2026

Whitefish Lake HUC 10 Watershed (0701010504)

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality: Current Conditions	Water Quality: Goals / Targets or Estimated % Reduction	Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility: SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	Estimated Year to Achieve Water Quality Target
					Altered hydrology(Human caused)	Stream discharge is very flashy. Bounces rapidly in response to rainfall	stabilize flow	Agricultural Practices to prevent runoff	100% Cover crops overwinter; implementation of other soil health principles (increasing crop diversity, rotational grazing, integrated livestock into cropping systems);	Increase organic content of soil by 2% to increase water holding capacity and reduce runoff	X			X		X	X	X	2026
								Native Vegetation in riparian corridor	Restoring native vegetation along the stream bank allowing the banks to stabilize and stream to narrow down. Decreasing stream width/depth ratio and reconnecting stream to floodplain. (100% of impacted areas)	100% of impacted areas	X			X		X	X	X	2026
	Crow Wing	Arvig Creek	C,I, G, A2	Yes	Biota-Fish and Inverts	Not supporting Aquatic Life	Fully supporting Aquatic Life	Livestock management	Exclude cattle from stream riparian corridor with fencing, or intensive rotational grazing management	100% adoption	X				X		X	X	2026
								Native Vegetation in riparian corridor	Restoring native vegetation along the stream bank allowing the banks to stabilize and stream to narrow down. Decreasing stream width/depth ratio and reconnecting stream to floodplain. (100% of impacted areas)	100% scale of adoption of native vegetative buffer									2026
					Dissolved Oxygen	2.52-11.65 mg/L	5 mg/L	Nutrient reduction. Analyze if riffle structures should be installed to reaerate stream	Conduct DO model for TMDL appropriation. Find source of low DO water. Possibly TP reduction or combination	Determine source of Low DO and implement practices to address cause if possible (Groundwater influence would be difficult to address)									2026
Whitefish Lake (0701010504)					Phosphorus	155 ug/l	reduce TP to 50 ug/L in stream	Investigate upstream sources to determine where elevated TP is sourced	Install riparian buffer along stream and tributary.	50 foot native buffers along 100% of shoreline	X				X	X	X	X	2026

Little Pine River HUC 10 Watershed (0701010505)

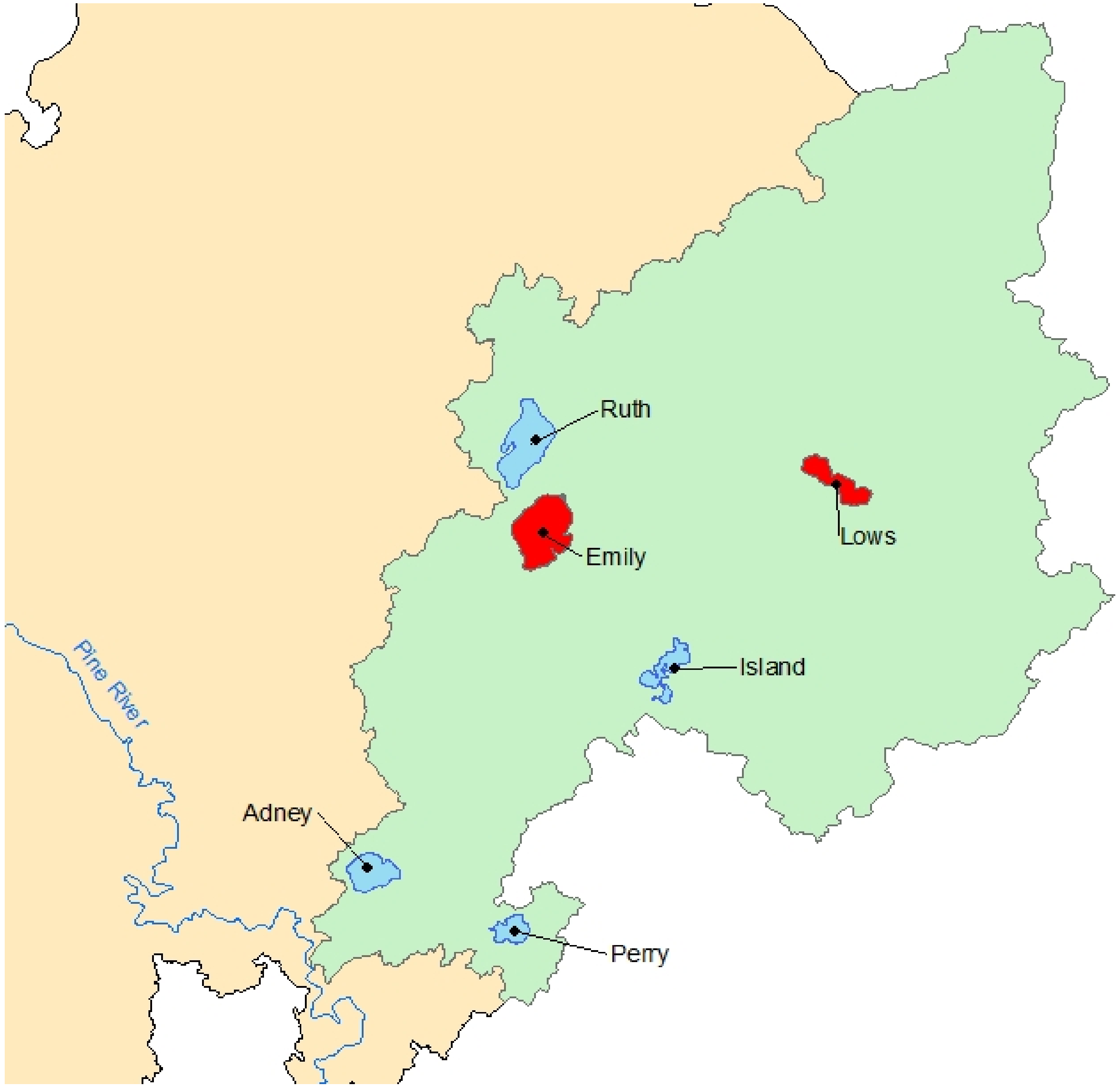
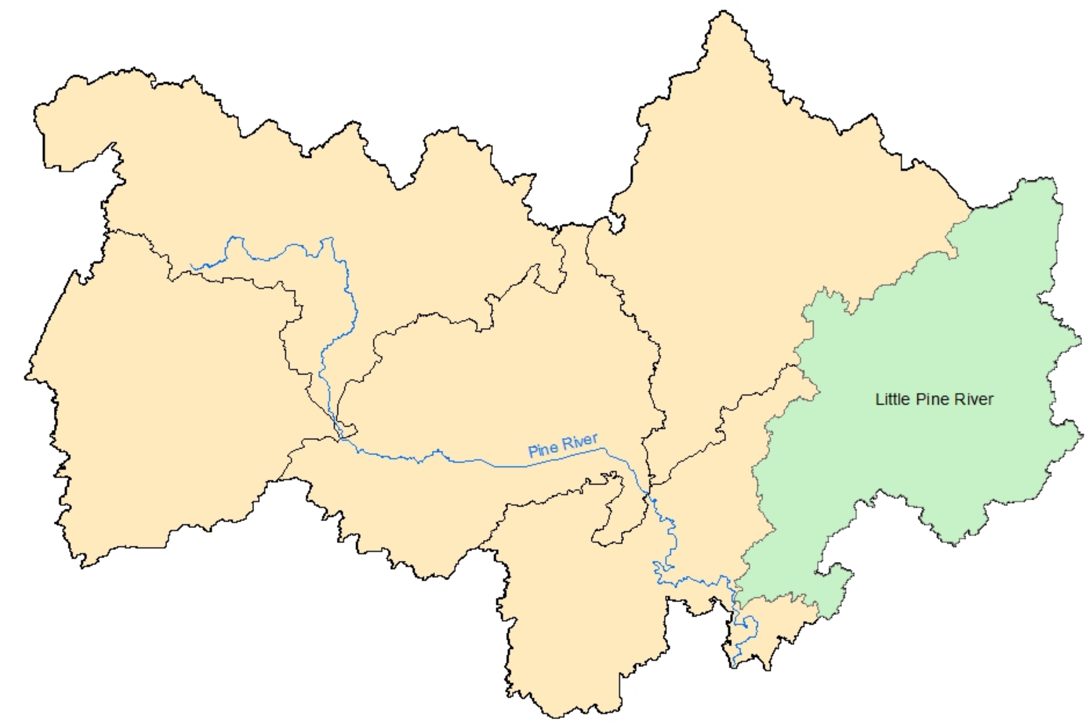


Figure 34. Targeted waterbodies in Little Pine River Watershed.

Figure 35. Little Pine River Subwatershed.



Little Pine River HUC 10 Watershed (0701010505)

Table 14. Strategies and targeted actions for Little Pine River Subwatershed. Red rows = impaired waters requiring restoration; Green rows = unimpaired waters requiring protection, Blue rows = strategies addressing downstream pollutant reductions

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets and Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
Little Pine River (0701010505)	Crow Wing	Emily (18020300)	A1, A2,C, D, F, G, H (SEH, RMB Lab), I	Yes	Phosphorus	Growing season average TP = 44 ug/l	TP ≤ 35 ug/l TMDL	Address failing septic systems: Fixing septic systems so that on-site sewage is not released to surface waters.	Compliance inspections for residential properties	100% compliance for septic systems in lakeshed									2026
								Shoreline Protection	Stabilize shoreline with multi-tiered vegetation (trees, shrubs, grasses),	100% native vegetated buffer on shoreline	X				X	X	X	X	2026
								Runoff reduction	Infiltration basins, raingardens	25% of residences	X				X	X	X	X	2026
								Stormwater controls for roads and urbanized areas	Two stage ditches, retention basins, buffer strips	25% less runoff from roads and impervious								X	2026
	Crow Wing	Island (18018300)	E,C	No	Phosphorus	Growing season average TP = 15.5 ug/l	TP ≤ 13 ug/l	Shoreline Protection	Work with private landowners to install buffers along shoreline.	Implement buffers along 50% of the shoreline	X			X	X	X	X	X	2026
								Protect existing forest cover-significant privately owned large parcels surrounding lake	Purchase conservation easements, maintain at least 75% of existing forest cover in lakeshed.	Work with private landowners to complete forest management and develop plans	X				X	X	X	X	2024
	Crow Wing	Ruth (18021200)	E, F,C	Yes	Phosphorus	Growing season average TP = 21.8 ug/l	TP ≤ 19.4 ug/l	Conservation easement acquisition	Over 200 acres tax forfeit land north of lake, large private parcels N and W	Work with private landowners and programs to enroll landowners in conservation easements.	X				X	X	X	X	Perpetual
								Shoreline Protection	Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	10
									Rain gardens or other runoff control on 25% of residential shoreland properties	25% of residences	X			X	X	X	X	X	2026

Little Pine River HUC 10 Watershed (0701010505)

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets and Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
Little Pine River (0701010505)	Crow Wing	Perry (18018600)	E, A1,C	No	Phosphorus	Growing season average TP = 30.4 ug/l	TP ≤ 26.6 ug/l	Conservation easement acquisition, vigilance strategy on state owned land in lakeshed.	Over 120 acres tax-forfeit land west of lake, private large parcels N and S	Work with private landowners and programs to enroll landowners in conservation easements.	X				X	X	X	X	Perpetual
								Shoreline Protection	Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026
								Increased forest acres	Encourage silvopasturing for active pastures	Work with private landowners to complete forest management and develop plans	X				X	X	X	X	2024
	Crow Wing	Adney (18022500)	E,C	No	Phosphorus	Growing season average TP = 16.8 ug/l	TP ≤ 14.1 ug/l	Shoreline Protection	Protect sensitive shoreline	Implement buffers along 50% of the shoreline	X				X	X	X	X	Perpetual
								Wetland restoration or enhancement	Increase wetland acreage	Work with private landowners to restore or enhance wetlands areas in lakeshed	X				X	X	X	X	2024

Pine River HUC 10 Watershed (0701010506)

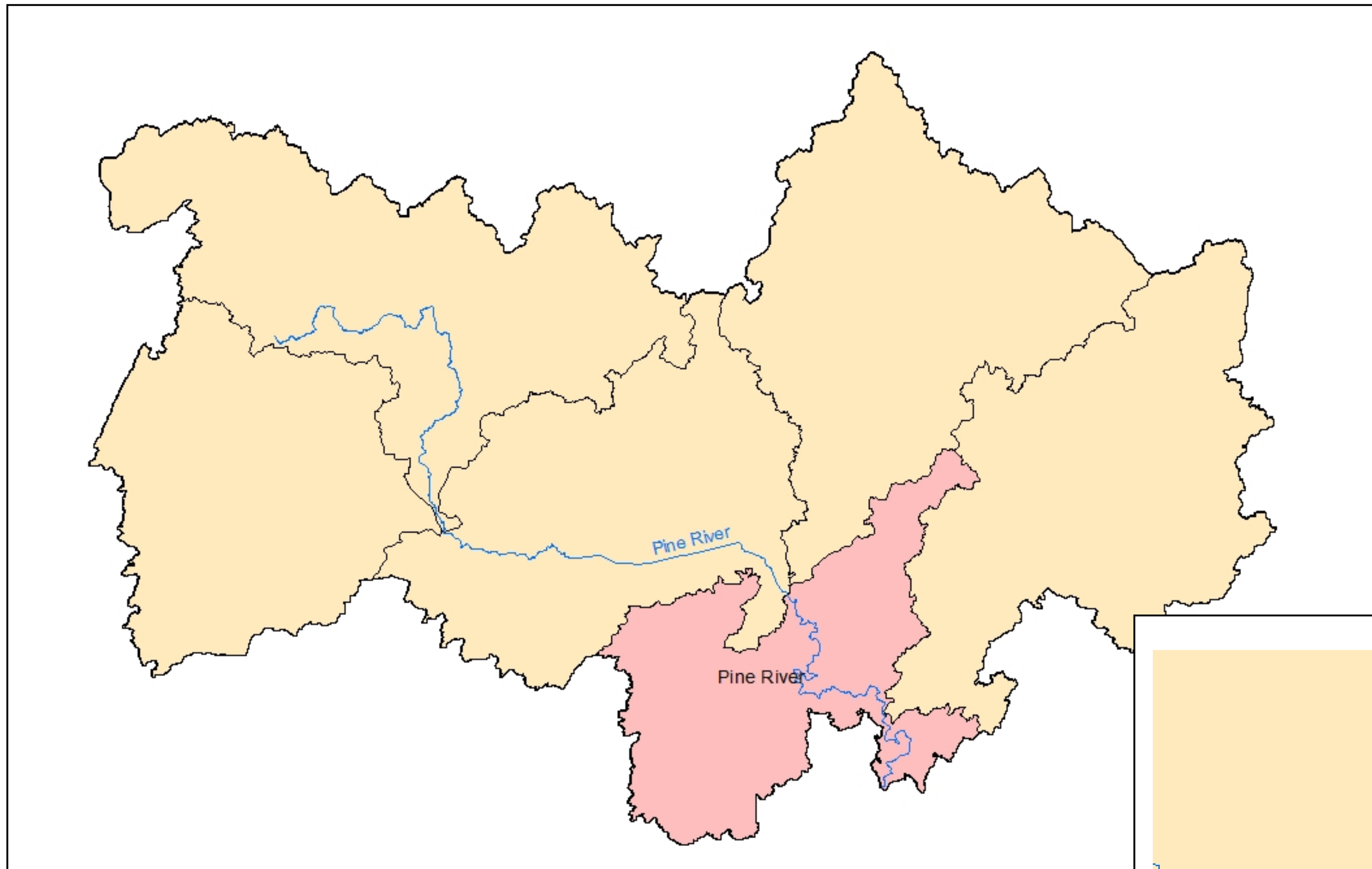


Figure 36. Pine River Subwatershed.

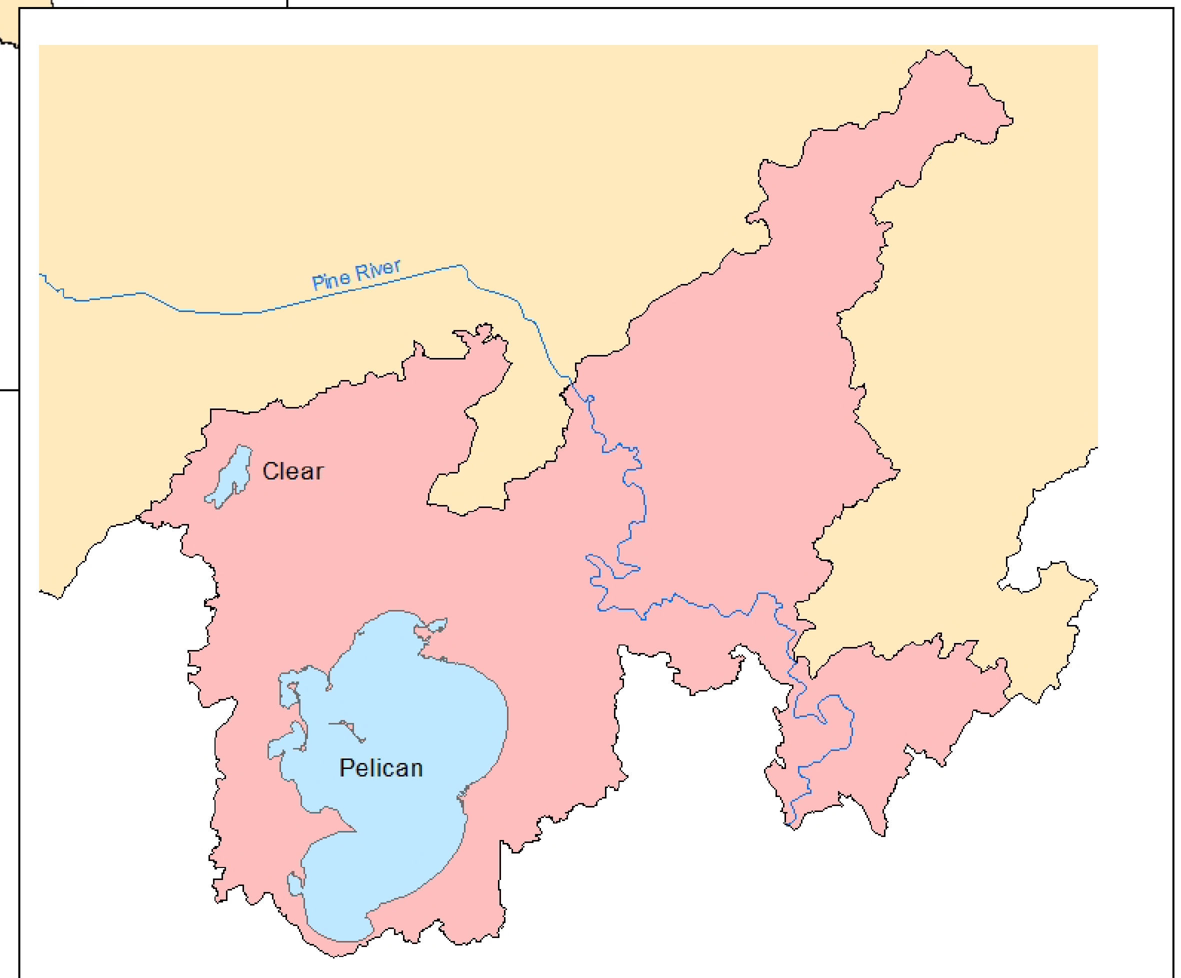


Figure 37. Targeted lakes in Pine River Subwatershed.

Pine River HUC 10 Watershed (0701010506)

Table 15. Strategies and actions for Pine River Subwatershed. Red rows = impaired waters requiring restoration; Green rows = unimpaired waters requiring protection, Blue rows = strategies addressing downstream pollutant reductions

HUC-10 Subwatershed	Location & Upstream Influence Counties	Waterbody	Data Source	In a High Groundwater Vulnerability Area	Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy types and estimated scale of adoption needed to meet final water quality target	Interim 10-yr Milestones	Governmental Units with Primary Responsibility								Estimated Year to Achieve Water Quality Target
						Current Conditions	Goals / Targets and Estimated % Reduction				SWCD	MDH	MPCA	NRCS	DNR	Non-profits	Landowners	LGUs	
Pine River (0701010506)	Crow Wing	Pelican Lake (18030800)	E, F	No	Phosphorus	Growing season average TP = 13 ug/l	TP ≤ 10.6 ug/l	Shoreline Protection	Protect sensitive shoreline	Install practices such as rain gardens or runoff diversion and retention along 20% of shoreline	X				X	X	X	X	2024
										Work with private landowners to install native buffers along 50% of shoreline.	X			X	X	X	X	X	2026
	Crow Wing	Clear (18036400)	E, F	Yes	Phosphorus	Growing season average TP = 9.3 ug/l	TP ≤ 8.1 ug/l	Shoreline Protection	Protect sensitive shoreline	Work with private landowners and programs to enroll landowners in conservation easements (north and south ends of lake)	X				X	X	X	X	2024
									Implement buffers along 50% of the shoreline	Work with private landowners to install buffers along shoreline.	X			X	X	X	X	X	2026

Key for Strategies for all Watersheds

Table 16. Key for Strategies Column.

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
Total Suspended Solids (TSS)	Improve upland/field surface runoff controls: Soil and water conservation practices that reduce soil erosion and field runoff, or otherwise minimize sediment from leaving farmland	Cover crops
		Water and sediment basins, terraces
		Rotations including perennials
		Conservation cover easements
		Grassed waterways
		Strategies to reduce flow- some of flow reduction strategies should be targeted to ravine subwatersheds
		Residue management - conservation tillage
		Forage and biomass planting
		Open tile inlet controls - riser pipes, french drains
		Contour farming
		Field edge buffers, borders, windbreaks and/or filter strips
		Stripcropping
	Protect/stabilize banks/bluffs: Reduce collapse of bluffs and erosion of streambank by reducing peak river flows and using vegetation to stabilize these areas.	Strategies for altered hydrology (reducing peak flow)
		Streambank stabilization
		Riparian forest buffer
		Livestock exclusion - controlled stream crossings
	Stabilize ravines: Reducing erosion of ravines by dispersing and infiltrating field runoff and increasing vegetative cover near ravines. Also, may include earthwork/regrading and revegetation of ravine.	Field edge buffers, borders, windbreaks and/or filter strips
		Contour farming and contour buffer strips
		Diversions
		Water and sediment control basin
		Terrace
		Conservation crop rotation
		Cover crop
		Residue management - conservation tillage
	Stream Channel Restoration	Addressing road crossings (direct erosion) and floodplain cut-offs
		Clear water discharge: urban areas, ag tiling etc. – direct energy dissipation
		Two-stage ditches
Total Suspended Solids (TSS)		Large-scale restoration – channel dimensions match current hydrology & sediment loads, connect the floodplain, stable pattern, (natural channel design principals)
		Stream channel restoration using vertical energy dissipation: step pool morphology
	Improve forestry management	Proper Water Crossings and road construction

Key for Strategies for all Watersheds

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
		Forest Roads - Cross-Drainage
		Maintaining and aligning active Forest Roads
		Closure of Inactive Roads & Post-Harvest
		Location & Sizing of Landings
		Riparian Management Zone Widths and/or filter strips
	Improve urban stormwater management [to reduce sediment and flow]	See MPCA Stormwater Manual: http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
Nitrogen (TN) or Nitrate	Increase fertilizer and manure efficiency: Adding fertilizer and manure additions at rates and ways that maximize crop uptake while minimizing leaching losses to surface and groundwater.	Nitrogen rates at Maximum Return to Nitrogen (U of MN rec's)
		Timing of application closer to crop use (spring or split applications)
		Nitrification inhibitors
		Manure application based on nutrient testing, calibrated equipment, recommended rates, etc.
	Store and treat tile drainage waters: Managing tile drainage waters so that nitrate can be denitrified or so that water volumes and loads from tile drains are reduced.	Saturated buffers
		Restored or constructed wetlands
		Controlled drainage
		Woodchip bioreactors
		Two-stage ditch
	Increase vegetative cover/root duration: Planting crops and vegetation that maximize vegetative cover and capturing of soil nitrate by roots during the spring, summer and fall.	Conservation cover (easements/buffers of native grass & trees, pollinator habitat)
		Perennials grown on marginal lands and riparian lands
		Cover crops
		Rotations that include perennials
		Crop conversion to low nutrient-demanding crops (e.g., hay).
Phosphorus (TP)	Improve upland/field surface runoff controls: Soil and water conservation practices that reduce soil erosion and field runoff, or otherwise minimize sediment from leaving farmland	Strategies to reduce sediment from fields (see above - upland field surface runoff)
		Constructed wetlands
		Pasture management
	Reduce bank/bluff/ravine erosion	Strategies to reduce TSS from banks/bluffs/ravines (see above for sediment)
	Increase vegetative cover/root duration: Planting crops and vegetation that maximize vegetative cover and minimize erosion and soil losses to waters, especially during the spring and fall.	Conservation cover (easements/buffers of native grass & trees, pollinator habitat)
Phosphorus (TP)		Perennials grown on marginal lands and riparian lands
		Cover crops
		Rotations that include perennials

Key for Strategies for all Watersheds

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
	Preventing feedlot runoff: Using manure storage, water diversions, reduced lot sizes and vegetative filter strips to reduce open lot phosphorus losses	Open lot runoff management to meet 7020 rules
		Manure storage in ways that prevent runoff
	Improve fertilizer and manure application management: Applying phosphorus fertilizer and manure onto soils where it is most needed using techniques, which limit exposure of phosphorus to rainfall and runoff.	Soil P testing and applying nutrients on fields needing phosphorus
		Incorporating/injecting nutrients below the soil
		Manure application meeting all 7020 rule setback requirements
	Address failing septic systems: Fixing septic systems so that on-site sewage is not released to. Includes straight pipes.	Sewering around lakes
		Eliminating straight pipes, surface seepages
	Reduce in-water loading: Minimizing the internal release of phosphorus within lakes	Rough fish management
		Curly-leaf pondweed management
		Alum treatment
		Lake drawdown
		Hypolimnetic withdrawal
	Improve forestry management	See forest strategies for sediment control
	Reduce Industrial/Municipal wastewater TP	Municipal and industrial treatment of wastewater P
		Upgrades/expansion. Address inflow/infiltration.
	Treat tile drainage waters: Treating tile drainage waters to reduce phosphorus entering water by running water through a medium which captures phosphorus	Phosphorus-removing treatment systems, including bioreactors
	Improve urban stormwater management	See MPCA Stormwater Manual: http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
E. coli	Reducing livestock bacteria in surface runoff: Preventing manure from entering streams (and potential drinking water sources) by keeping it in storage or below the soil surface and by limiting access of animals to waters.	Strategies to reduce field TSS (applied to manured fields, see above)
		Improved field manure (nutrient) management
		Adhere/increase application setbacks
E. coli		Improve feedlot runoff control
		Animal mortality facility
		Manure spreading setbacks and incorporation near wells and sinkholes
		Rotational grazing and livestock exclusion (pasture management)
	Reduce urban bacteria: Limiting exposure of pet or waterfowl waste to rainfall	Pet waste management
		Filter strips and buffers

Key for Strategies for all Watersheds

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
		See MPCA Stormwater Manual: http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
	Address failing septic systems: Fixing septic systems so that on-site sewage is not released to ground and surface waters (and potential drinking water sources). Includes straight pipes.	Replace failing septic (SSTS) systems
		Maintain septic (SSTS) systems
	Reduce Industrial/Municipal wastewater bacteria	Reduce straight pipe (untreated) residential discharges
		Reduce WWTP untreated (emergency) releases
Dissolved Oxygen (DO)	Reduce phosphorus	See strategies above for reducing phosphorus
	Increase river flow during low flow years	See strategies above for altered hydrology
	In-channel restoration: Actions to address altered portions of streams.	Goal of channel stability: transporting the water and sediment of a watershed without aggrading or degrading.
		Restore riffle substrate
Chloride	Road salt management	[Strategies currently under development within Twin Cities Metro Area Chloride Management Plan]
Altered hydrology; peak flow and/or low base flow (Fish/Macroinvertebrate IBI)	Increase living cover: Planting crops and vegetation that maximize vegetative cover and evapotranspiration especially during the high flow spring months.	Grassed waterways
		Cover crops
		Conservation cover (easements & buffers of native grass & trees, pollinator habitat)
		Rotations including perennials
	Improve drainage management: Managing drainage waters to store tile drainage waters in fields or at constructed collection points and releasing stored waters after peak flow periods.	Treatment wetlands
		Restored wetlands
	Reduce rural runoff by increasing infiltration: Decrease surface runoff contributions to peak flow through soil and water conservation practices.	Conservation tillage (no-till or strip till w/ high residue)
		Water and sediment basins, terraces
Altered hydrology; peak flow and/or low base flow (Fish/Macroinvertebrate IBI)	Improve urban stormwater management	See MPCA Stormwater Manual: http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
	Improve irrigation water management: Increase groundwater contributions to surface waters by withdrawing less water for irrigation or other purposes.	Groundwater pumping reductions and irrigation management
Poor Habitat (Fish/Macroinvertebrate IBI)	Improve riparian vegetation: Planting and improving perennial vegetation in riparian areas to stabilize soil, filter pollutants and increase biodiversity	50' vegetated buffer on waterways
		One rod ditch buffers
		Lake shoreland buffers
		Increase conservation cover: in/near water bodies, to create corridors
		Improve/increase natural habitat in riparian, control invasive species

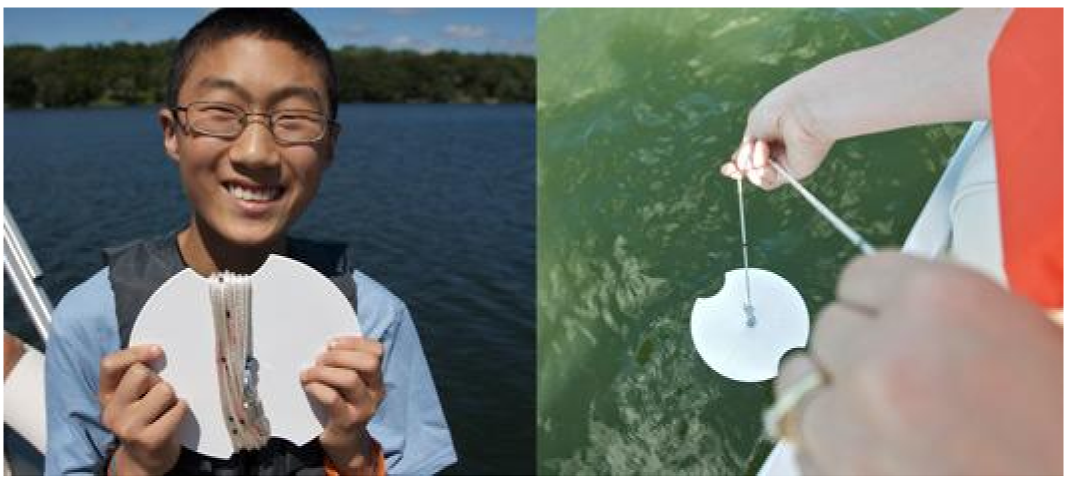
Key for Strategies for all Watersheds

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
		Tree planting to increase shading
		Streambank and shoreline protection/stabilization
		Wetland restoration
		Accurately size bridges and culverts to improve stream stability
	Restore/enhance channel: Various restoration efforts largely aimed at providing substrate and natural stream morphology.	Retrofit dams with multi-level intakes
		Restore riffle substrate
		Two-stage ditch
		Dam operation to mimic natural conditions
		Restore natural meander and complexity
Water Temperature	Urban stormwater management	See MPCA Stormwater Manual: http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
	Improve riparian vegetation: Actions primarily to increase shading, but also some infiltration of surface runoff.	Riparian vegetative buffers
		Tree planting to increase shading
Connectivity (Fish IBI)	Removal fish passage barriers: Identify and address barriers.	Remove impoundments
		Properly size and place culverts for flow and fish passage
		Construct by-pass
All [protection-related]	Implement volume control / limited-impact development: This is aimed at development of undeveloped land to provide no net increase in volume and pollutants	See MPCA Stormwater Manual: http://stormwater.pca.state.mn.us/index.php

4. Monitoring Plan

Data from three monitoring programs will continue to be collected and analyzed for the Pine River Watershed as part of *Minnesota's Water Quality Monitoring Strategy - 2011-2021* (MPCA 2011). These monitoring programs are summarized below:

1. IWM is the first step in the WRAPS process. Through the IWM approach, chemistry and biological data is collected throughout each major watershed once every 10 years. This work is scheduled for its second iteration in the Pine River Watershed in 2022. This data provides a periodic but intensive "snapshot" of water quality throughout the watershed. In addition to the monitoring conducted in association with this process, other watershed partner organizations (e.g. local, state, and federal) within the watershed may have their own monitoring plan. All data collected locally should be submitted regularly to the MPCA for entry into the EQuIS database system
2. The Watershed Pollutant Load Monitoring Network collects pollutant samples and flow data to calculate daily sediment and nutrient loads on an annual or seasonal (no-ice) basis.
3. The Citizen Water Monitoring Program is a network of volunteers who make monthly lake and river transparency readings. Several dozen data collection locations exist within the Pine River Watershed. This data provides a continuous record of transparency/turbidity for streams and clarity for lakes throughout much of the watershed.



In addition to the monitoring conducted in association with these processes noted above, there are other monitoring programs where data has been and will continue to be collected on surface water resources within or associated with this watershed, many of which are done by lake associations on their own lakes, with the data sent to the MPCA and recorded.

Minnesota's Fish Contaminant Monitoring Program (MPCA 2008) - This program helps support human health and environmental protection programs within Minnesota by providing information for fish consumption, mercury cycling/trends and analysis of potential newly identified bioaccumulative pollutants.

In 2012, a fish contaminant survey was conducted at the pour point of the Pine River Watershed near the intersection of County Road 11 and State Highway 6 near Crosby, Minnesota. The results were found to be skewed, and a second survey was taken in 2013. It is anticipated that a survey at the same location will be done in 2022.

Wetland monitoring and assessment - Wetlands are an integral part of Minnesota's water resources, and wetland monitoring information will be an essential component in the implementation of efforts to protect and restore lakes and streams.The MPCA began biological monitoring of wetlands in the early 1990s, focusing on wetlands with emergent vegetation (i.e., marshes) in a depressional geomorphic setting. This work resulted in the development of plant and macroinvertebrate (aquatic bugs, snails, leeches, and crustaceans) IBIs for evaluating the ecological condition or health of depressional wetlands. Recently the MPCA wetland plant monitoring effort has begun transitioning toward use of Floristic Quality Assessment (FQA) for assessing wetland condition based on the plant community. Future watershed wetland assessment reports will begin to use FQA wetland assessment results. One advantage to the FQA approach is the methods have been adapted to assess all of Minnesota's wetland classes (types) in contrast to wetland IBIs that are used only in depressional or 'marsh' type wetlands having a seasonal to permanent water column.

IBI information was collected by the MPCA at four depressional wetlands in the Pine River Watershed. These sites were well distributed across the Pine River Watershed. One of these study sites (04Crow004) was sampled in 2004 as an initial IBI development data set for the Mixed Wood Shield Ecoregion. The other three wetland sites were sampled as part of the baseline statewide depressional wetland survey.

5. References and Further Information

Pine River Watershed Stressor ID Report: https://www.pca.state.mn.us/sites/default/files/wq-ws5-07010105a.pdf

Pine River Watershed Stressor ID Summary: https://www.pca.state.mn.us/sites/default/files/wq-ws5-07010105b.pdf

Pine River Watershed Monitoring and Assessment Report: https://www.pca.state.mn.us/sites/default/files/wq-ws3-07010105.pdf

Lakes of Phosphorus Sensitivity Significance- ftp://ftp.gisdata.mn.gov/pub/gdrs/data/pub/us_mn_state_dnr/env_lakes_phosphorus_sensitivity/metadata/Lakes%20of%20Phosphorus%20Sensitivity%20Significance%2020160614.pdf

USDA NRCS "Guidelines for Soil Quality Assessment in Conservation Planning" https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051259.pdf

Forests, Water, and People, MN Fact Sheet-Drinking water supply and forest lands in Minnesota http://www.na.fs.fed.us/watershed/factsheets/fwap/FWAP_state_sheet_MN.pdf

Forests, Water and People: Drinking water supply and forest lands in the Northeast and Midwest United States (USFS). June 2009. http://na.fs.fed.us/pubs/misc/watersupply/forests_water_people_watersupply.pdf

One Watershed, One Plan, Tools for Prioritizing, Targeting, and Measuring

http://www.bwsr.state.mn.us/planning/1W1P/1W1P_PTM_Fact_Sheet.pdf

Appendix 1- Lake Prioritization based on Phosphorus Sensitivity Significance

Input Data															Modeling Outputs						Prioritization rankings						
DOW LK NUM	LAKE NAME	DEPTH TYPE	LAKE AREA ACRES	ECOREGION	Water-shed acres	Prop-ortion Distur-bed (%)	MEAN TP (ug/L)	Years with TP meas-ured	TP MIN (ug/L)	TP MAX (ug/L)	TP STD DEV	MEAN SECCHI (meters)	Slope Descrip-tion*	Evidence Descrip-tion	TARGET MEAN TP (ug/L)	Load Reduc-tion to meet Target (lbs/yr)	Percent Load Reduc-tion to meet Target	Pred-icted TP Load (lbs/yr)	Thres-hold TP Load (lbs/yr)	Target TP Load (lbs/yr)	Sensitivity **	Sensitivity Rank (1=highest)	Sens-itivity Significance	Sensitivity Significance Rank (1=highest)	Priority (0-100; low to high)	Priority Rank (1 is highest priority)	Priority Class
18021100	Blue	DEEP	177	NLF	581	0.04	7.1	4	4.75	9.25	1.92	7.19	No Evidence of Trend	No evidence of trend	7.4	6	18	36	149	30	119.1	13	31.85	339	23.60	382	Highest
18036400	Clear	DEEP	226	NLF	1530	0.08	9.3	10	5	20	4.10	4.34	No Evidence of Trend	No evidence of trend	8.1	31	29	109	336	78	57.3	149	38.07	277	28.20	308	Highest
18031500	Big Trout	DEEP	1363	NLF	8150	0.07	10.7	10	6.75	14.25	2.12	4.56	No Evidence of Trend	No evidence of trend	9.2	90	12	778	1900	687	11.9	962	40.75	259	30.19	289	Highest
18026900	Island-Loon	DEEP	232	NLF	519	0.08	11.8	6	10	16.25	2.33	4.49	Decreasing Trend	Weak evidence for possible trend	9.9	7	13	57	141	49	72.4	81	42.86	234	40.08	186	Highest
11023700	Deep Portage	DEEP	129	NLF	1599	0.03	12.0	6	8.5	16	3.07	4.25	Decreasing Trend	Strong evidence for trend	10.0	22	17	134	326	112	42.5	292	5.03	1079	37.06	204	Highest
11024600	Sylvan	DEEP	113	NLF	3237	0.23	13.0	2	10.5	15.5	3.54	3.98	Insufficient Data	NA	10.5	35	19	186	442	151	29.1	490	24.81	434	18.38	481	Highest
18030800	Pelican	DEEP	8367	NLF	20253	0.04	13.0	17	6.89	33.75	7.28	4.52	Increasing Trend	Strong evidence for trend	10.6	838	32	2614	5198	1777	3.4	1530	47.71	194	35.34	220	Highest
18037800	Lower Hay	DEEP	693	NLF	18197	0.20	13.2	9	8	20	3.60	4.05	No Evidence of Trend	No evidence of trend	11.0	247	17	1493	3117	1246	5.1	1363	26.37	405	19.53	452	Highest
18035400	Pig	DEEP	181	NLF	465	0.06	15.4	9	10.67	37.25	8.40	4.18	Decreasing Trend	Strong evidence for trend	12.6	24	36	68	130	44	58.3	143	21.59	492	49.33	132	Highest
18035500	Bertha	DEEP	337	NLF	1880	0.14	15.4	8	13	17.5	1.66	4.03	Decreasing Trend	Evidence for possible trend	12.7	15	7	225	423	210	26.1	549	41.58	250	47.47	141	Highest

Input Data															Modeling Outputs						Prioritization rankings						
DOW LK NUM	LAKE NAME	DEPTH TYPE	LAKE AREA ACRES	ECOREGION	Water-shed acres	Prop-ortion Distur-bed (%)	MEAN TP (ug/L)	Years with TP meas-ured	TP MIN (ug/L)	TP MAX (ug/L)	TP STD DEV	MEAN SECCHI (meters)	Slope Descrip-tion*	Evidence Descrip-tion	TARGET MEAN TP (ug/L)	Load Reduc-tion to meet Target (lbs/yr)	Percent Load Reduc-tion to meet Target	Pred-icted TP Load (lbs/yr)	Thres-hold TP Load (lbs/yr)	Target TP Load (lbs/yr)	Sensitivity **	Sensitivity Rank (1=highest)	Sens-itivity Significance	Sensitivity Significance Rank (1=highest)	Priority (0-100; low to high)	Priority Rank (1 is highest priority)	Priority Class
18018300	Island	DEEP	240	NLF	26191	0.03	15.5	4	12.75	20.5	3.67	1.81	Decreasing Trend	Evidence for possible trend	13.0	230	16	1459	2812	1229	4.5	1427	1.03	1587	17.43	510	Highest
18031000	Whitefish	DEEP	7716	NLF	248558	0.12	15.8	10	10.67	19.43	2.45	3.53	Decreasing Trend	Strong evidence for trend	13.3	1846	8	21797	36564	19951	0.3	2020	11.20	757	41.63	171	Highest
11035800	Horseshoe	DEEP	260	NLF	1166	0.08	16.5	4	7.2	30	10.78	5.37	No Evidence of Trend	No evidence of trend	14.0	64	43	149	266	85	33.4	415	22.67	477	16.79	527	Highest
18022500	Adney	DEEP	310	NLF	1021	0.11	16.8	3	14.4	18	2.08	4.10	Insufficient Data	NA	14.1	11	8	135	238	124	34.7	391	39.64	262	29.37	292	Highest
18035600	Clamshell	DEEP	211	NLF	655	0.17	17.6	8	12.5	30	5.31	3.11	Increasing Trend	Evidence for possible trend	14.5	17	21	83	143	66	43.0	284	50.91	176	37.71	196	Highest
18041400	Clough	SHALLOW	245	NLF	1273	0.13	21.0	4	15.6	27	4.79	1.78	Insufficient Data	NA	17.5	25	16	162	233	136	24.5	576	25.44	418	18.85	466	Highest
18021200	Ruth	DEEP	599	NLF	2553	0.10	21.8	9	13.63	35.75	7.20	4.92	Increasing Trend	Strong evidence for trend	19.4	89	21	424	571	335	12.7	931	24.98	428	18.51	476	Highest
18018600	Perry	DEEP	164	NLF	1628	0.12	30.4	2	23.75	37	9.37	1.12	Insufficient Data	NA	26.6	57	21	270	266	213	13.1	914	25.75	414	19.07	462	Highest
18041200	Upper Hay	DEEP	596	NLF	14799	0.24	31.3	10	21	56.75	10.65	2.26	No Evidence of Trend	No evidence of trend	29.9	489	22	2261	2170	1772	2.0	1717	26.63	399	19.73	447	Highest

Key for Appendix 1 Table

DNR ID	Lake ID as assigned by the Department of Natural Resources
LAKE_NAME	Lake name as assigned by the Department of Natural Resources
HUC8	8 digit Hydrologic Unit Code for the watershed
Watershed	Watershed Name
DEPTH_TYPE	Depth categorization for assessment based on definition in statute
LAKE Acres	Surface area of waterbody in acres
Watershed Acres	Lake watershed (acres) based on DNR's lake catchments layer
Lake_ID for TP/Impairment	Lake ID as assigned by the MPCA used for TP measure and impairment classification
Impaired (Y/N)?	Impaired or proposed as Impaired (Yes/No)
ECOREGION	Omnerik's Level III Ecoregion
% Disturbed Land Use	Proportion of land use in the watershed composed of urban and row crop cultivated (based on the 2011 National Land Cover Dataset).
Mean TP	Average mean summer total phosphorus (TP) in ug/L (June-September).
Years TP	Number of years with total phosphorus data occurring June - September
Mean Secchi	Average mean summer Secchi transparency (June-September).
Presence of Trend	If a trend was detected based on the Seasonal Kendall-Mann statistical analysis completed on lakes with a minimum of 8 years of Secchi transparency
Trend Slope Description	The description of the trend
Predicted Load	The predicted total phosphorus load (pounds/year) for the lake. These estimates have large uncertainties (i.e., wide confidence intervals).
Target TP	Target total phosphorus (TP) concentration for the lake (ug/l) based on an estimate of the 25th percentile of the summer mean TP concentration.
Load Target	The estimated total phosphorus load (pounds/year) to meet target total phosphorus concentration for the lake.
Load Goal	The estimated total phosphorus load (pounds/year) to meet a 5% reduction goal for the lake.
Load Reduction Goal	The estimated total phosphorus load reduction (pounds/year) to meet a 5% reduction goal for the lake.
Sensitivity	A measure of phosphorus sensitivity expressed as inches lost in water clarity with an increase in 100 pounds of phosphorus loading.
Priority Class	Grouping of waterbodies was based on ranks related to the state's priority of focusing on "high quality, unimpaired lakes at greatest risk of becoming impaired." The phosphorus sensitivity significance index is a function of phosphorus sensitivity, lake size, lake total phosphorus concentration, proximity to PCA's phosphorus impairment thresholds, and watershed disturbance.

Appendix 2- PINE RIVER WATERSHED POLLUTANT SOURCE ASSESSMENT AND PRECIPITATION SCENARIOS

PINE RIVER WATERSHED POLLUTANT SOURCE ASSESSMENT AND EVALUATION OF RESOURCE MANAGEMENT AND PRECIPITATION SCENARIOS

Topical Report RSI-2435

prepared for

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May 2014

RESPEC
CONSULTING & SERVICES

PINE RIVER WATERSHED POLLUTANT SOURCE ASSESSMENT AND EVALUATION OF RESOURCE MANAGEMENT AND PRECIPITATION SCENARIOS

Topical Report RSI-2435

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May 2014

EXECUTIVE SUMMARY

Development of the Watershed Restoration and Protection Strategies (WRAPS) for the Pine River Watershed is underway by the Minnesota Pollution Control Agency (MPCA), the Crow Wing Soil and Water Conservation District (SWCD), and other local partners. A hydrologic and water-quality model of the Pine River Watershed was developed with HSPF for the MPCA [Kenner, 2013][1]. The HSPF model application was used to complete a pollutant source assessment for the Pine River Watershed and evaluate phosphorus loads to surface waters under multiple resource management scenarios.

Average simulated phosphorus concentrations in watershed runoff are fairly low throughout the watershed, with higher rates in the southwestern portion of the watershed where agricultural practices are more intensive. Spatial patterns of nitrogen and sediment concentrations are similar. The largest source category of nutrient loading is deciduous forests, which make up approximately 43 percent of the watershed area, followed by wetlands and agriculture, which make up 29 percent and 6 percent of the watershed, respectively. The highest phosphorus, nitrogen, and sediment unit-area loading rates are from feedlots, agriculture, and developed land uses.

The following five scenarios were modeled:

- **Land change without best management practices (BMPs) (Scenario 1).** This scenario was developed to answer the question, How would the projected watershed threats affect watershed phosphorus loads if watershed BMPs were not used to mitigate the changes? The scenario incorporated intensification of agriculture, shoreland development, city growth, and expansion of Highway 371.
- **Land change with BMPs (A) (Scenario 2).** This scenario was developed to answer the question, How would the projected watershed threats affect watershed phosphorus loads if watershed BMPs were used to mitigate the changes? The scenario incorporated riparian buffers in agricultural areas and capturing and retaining 1.1 inches of runoff from impervious surfaces.
- **Land change with BMPs (B) (Scenario 3).** This scenario is similar to the previous one but simulates additional BMPs. The scenario incorporated shoreline buffers around lakes in developed areas, wetland preservation, preservation of 75 percent of natural areas within city boundaries, and cluster development.

[1] **Kenner, S. J., 2013.** *Model Development for Mississippi River Headwaters (07010101), Leech Lake River (07010102), and Pine River Watersheds (07010105),* Letter RSI(RCO)-2046/6-13/40, prepared by RESPEC, Rapid City, SD, for the Minnesota Pollution Control Agency, St. Paul, MN, June 20.

- **Climate change-induced precipitation changes (Scenario 4).** Climate change is expected to affect many factors that influence water quality, including air temperature, precipitation, and land cover. Projected changes to precipitation patterns were simulated in the Pine River Watershed to evaluate the impact to water quality of this one aspect of climate change.
- **Cumulative scenario (Scenario 5).** A cumulative scenario was simulated by using a combination of the land change with BMPs (B) and the climate change-induced precipitation scenario.

The simulated riparian buffers in agricultural areas were enough to mitigate the projected increases in phosphorus loads from the intensification of agriculture. However, in developed areas, the load reductions achieved through capturing and retaining 1.1 inches of runoff from all impervious surfaces were not enough to mitigate the projected increases in load from new development, which consists of over 85 percent pervious areas. When shoreline buffers were added to lakes and 75 percent of natural areas was preserved within city boundaries, the load increase in the land change scenario relative to baseline conditions was minimal.

These results apply to the specific scenarios in this project. If development were to proceed differently than what is presented here, the overall pattern of the predictions would apply. For example, development might occur outside of city boundaries, in areas within townships that are adjacent to highways. If this land change were to occur without BMPs, phosphorus loads would be expected to increase by similar percentages as those presented in Scenario 1 relative to the baseline. The BMPs modeled in Scenarios 2 and 3 would be expected to mitigate the increase in loads by similar percentages.

The changes in precipitation predicted to result from climate change resulted in a 20 percent increase in runoff volumes and phosphorus loads. These increases were not mitigated by the BMPs modeled in these scenarios.

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1.0 INTRODUCTION

Development of the Watershed Restoration and Protection Strategies (WRAPS) for the Pine River Watershed is underway by the Minnesota Pollution Control Agency (MPCA), the Crow Wing Soil and Water Conservation District (SWCD), and other local partners. A hydrologic and water-quality model of the Pine River Watershed was developed with HSPF for the MPCA [Kenner, 2013a]. The HSPF model application was used to complete a pollutant source assessment for the Pine River Watershed and evaluate phosphorus loads to surface waters under multiple resource management scenarios.

HSPF is a continuous simulation model that typically produces data on a daily basis using an hourly time step. The model application was developed for the Pine River Watershed to simulate the time period from January 1, 1995, to December 31, 2009, and it incorporates both point- and nonpoint-source loads. The fully functioning, calibrated, and validated HSPF model application for the Pine River Watershed simulates hydrology and water quality at a management-unit level. This model development was completed by RESPEC through their Master Services Contract with the MPCA.

2.0 POLLUTANT SOURCE ASSESSMENT

2.1 METHODS

The HSPF watershed modeling system is a comprehensive package for simulating watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF is capable of simulating the hydrologic and associated water-quality processes on pervious and impervious land surfaces, in streams, and in well-mixed impoundments. HSPF incorporates the watershed-scale Agricultural Runoff Management (ARM) and nonpoint-source models into a basin-scale analysis framework that includes fate and transport in one-dimensional stream channels. It is a comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment/chemical interactions. The result of this coupled simulation is a continuous record of the runoff flow rate and sediment, nutrient, and other water-quality constituent concentrations at any point in a watershed [Bicknell et al., 2001].

HSPF is used to assess the effects of land-use change, reservoir operations, point-source or nonpoint-source treatment alternatives, and flow diversions. The model contains hundreds of process algorithms developed from theory, laboratory experiments, and empirical relations from instrumented watersheds. The model simulates processes such as evapotranspiration; interception of precipitation; snow accumulation and melt; surface runoff; interflow; base flow; soil moisture storage; groundwater recharge; nutrient speciation; biochemical oxygen demand; heat transfer; sediment (sand, silt, and clay) detachment and transport; sediment routing by particle size; channel and reservoir routing; algae growth and die-off; bacterial die-off and decay; and build-up, wash-off, routing, and first-order decay of water-quality constituents. Continuous rainfall and other meteorological records are input at an hourly time step into the model algorithms to compute streamflow, pollutant concentrations, and loading time series. Hydrographs and pollutographs can then be created, and frequency and duration analyses can be performed for any output time series.

An HSPF model application for the Pine River Watershed was developed for the MPCA in 2013 as part of a larger effort to develop model applications for the Leech Lake River Watershed and the Mississippi River Headwaters Watershed in addition to the Pine River Watershed. Details about the model construction and hydrology calibration can be found in Kenner [2013a; 2013b]. The water-quality calibration of the Pine River Watershed model application was completed as part of a current project to complete the calibration for eight major watersheds in the Upper Mississippi River Basin; the memorandum documenting this process will be available upon completion of the full project in May 2015. The model application simulates hydrology and water quality from January 1, 1995, through December 31, 2009; results are reported for the years 1996 through 2009.

Total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) pollutant loads generated from the land surface were summed by source and by model subwatershed. The source categories are based primarily on land use and land cover (Figure 2-1) and consist of the following land classifications that were defined in the HSPF model application [Kenner, 2013a]:

- Old deciduous forest
- Old evergreen forest
- Young forest
- Grassland
- Agriculture (pasture/hay and cultivated crops)
- Feedlot
- Wetland
- Developed
- Septics

2.2 RESULTS

2.2.1 Loads by Subwatershed

Average simulated phosphorus concentrations in watershed runoff are fairly low throughout the watershed, with higher rates in the southwestern portion of the watershed where agricultural practices are more intensive (Figure 2-2). Spatial patterns of nitrogen and sediment concentrations are similar (Figure 2-3 and Figure 2-4). Subwatershed loading rates for phosphorus, nitrogen, and sediment are provided in Appendix A.

2.2.2 Loads by Source Category

The largest source category of nutrient loading is deciduous forests, which make up approximately 43 percent of the watershed area, followed by wetlands and agriculture, which make up 29 percent and 6 percent of the watershed, respectively (Table 2-1, Figure 2-1). The highest phosphorus, nitrogen, and sediment unit-area loading rates are from feedlots, agriculture, and developed land uses.

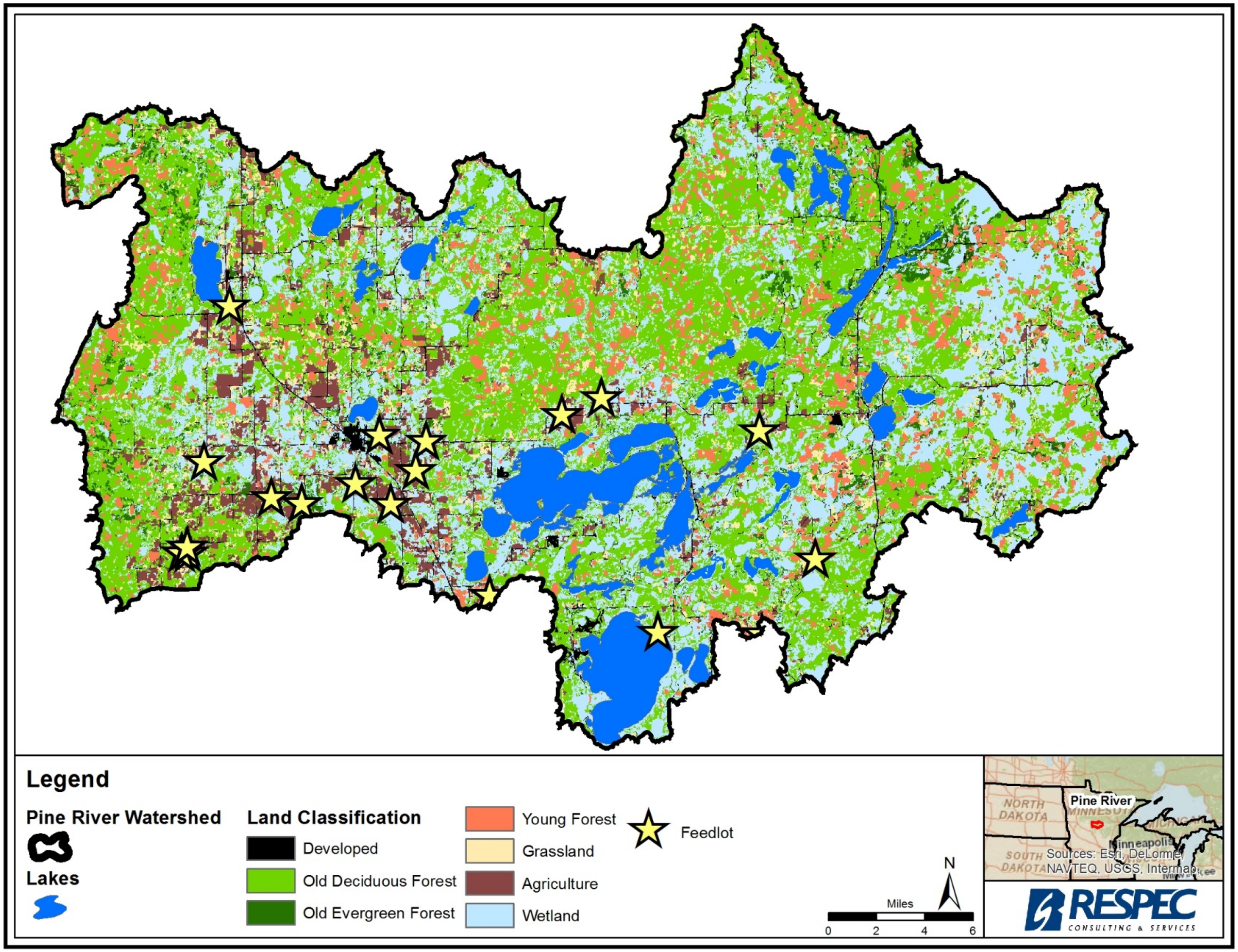

Figure 2-1. Land Classification.

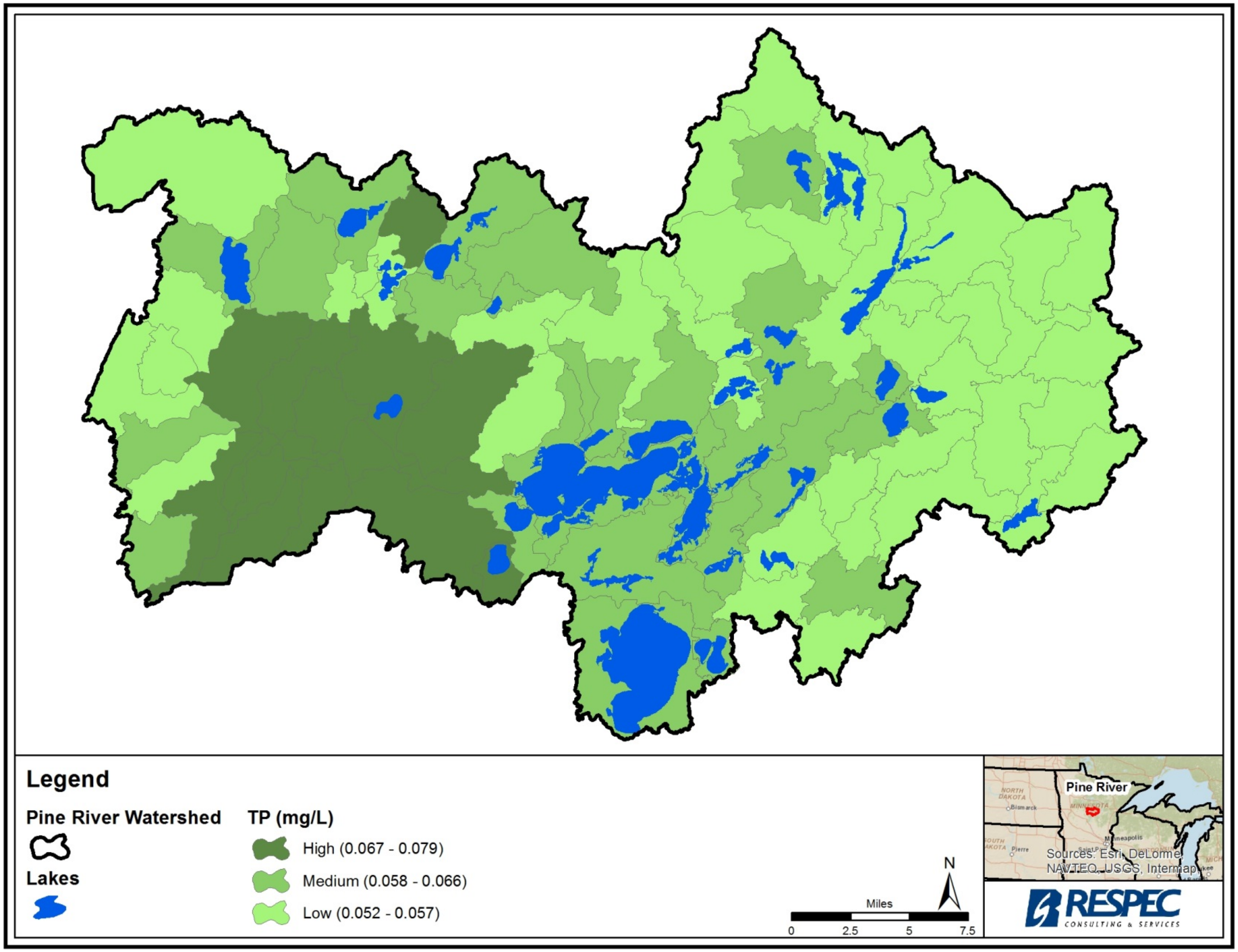

Figure 2-2. Average Simulated Total Phosphorus Concentration by Subwatershed, 1996–2009.

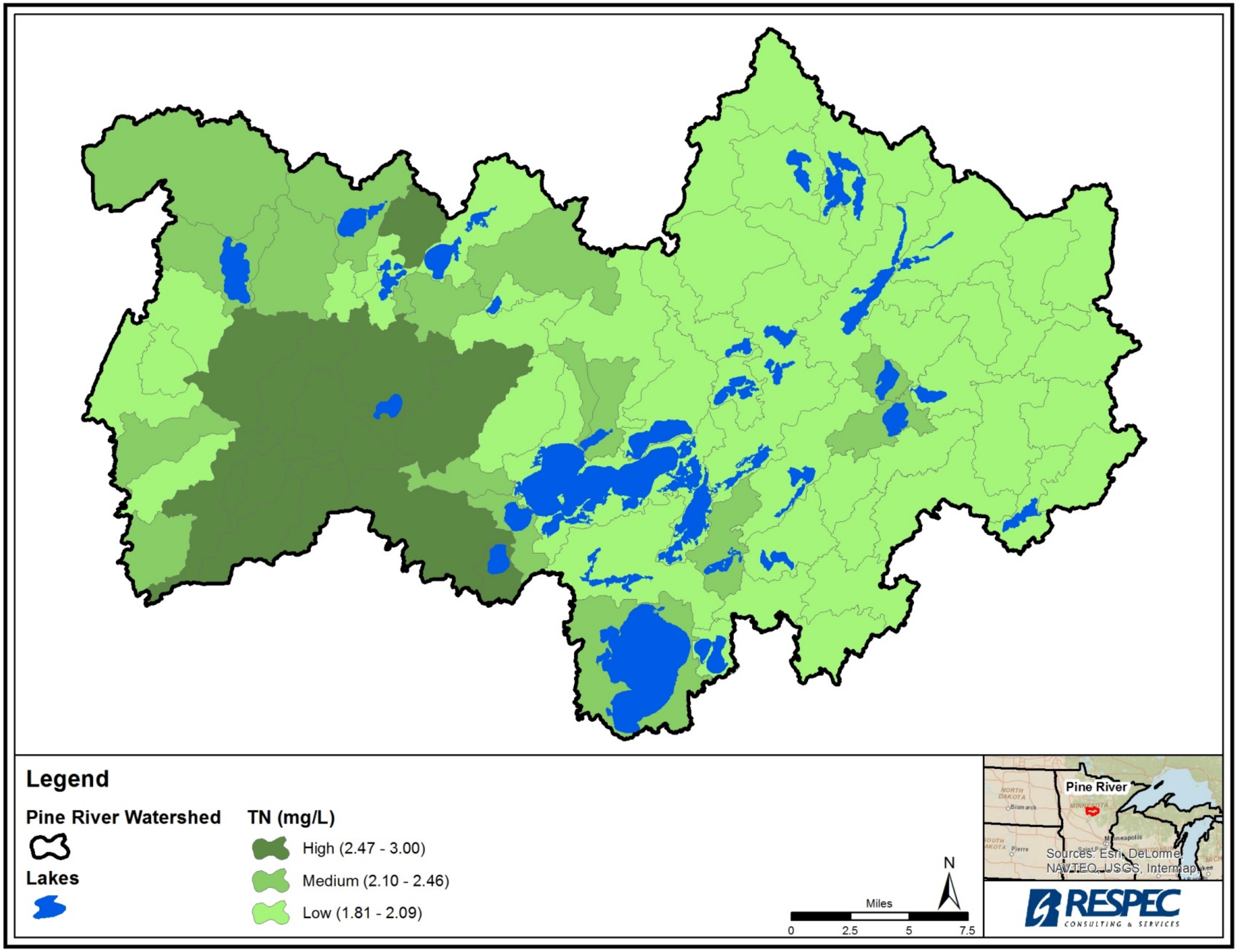

Figure 2-3. Average Simulated Total Nitrogen Concentration by Subwatershed, 1996–2009.

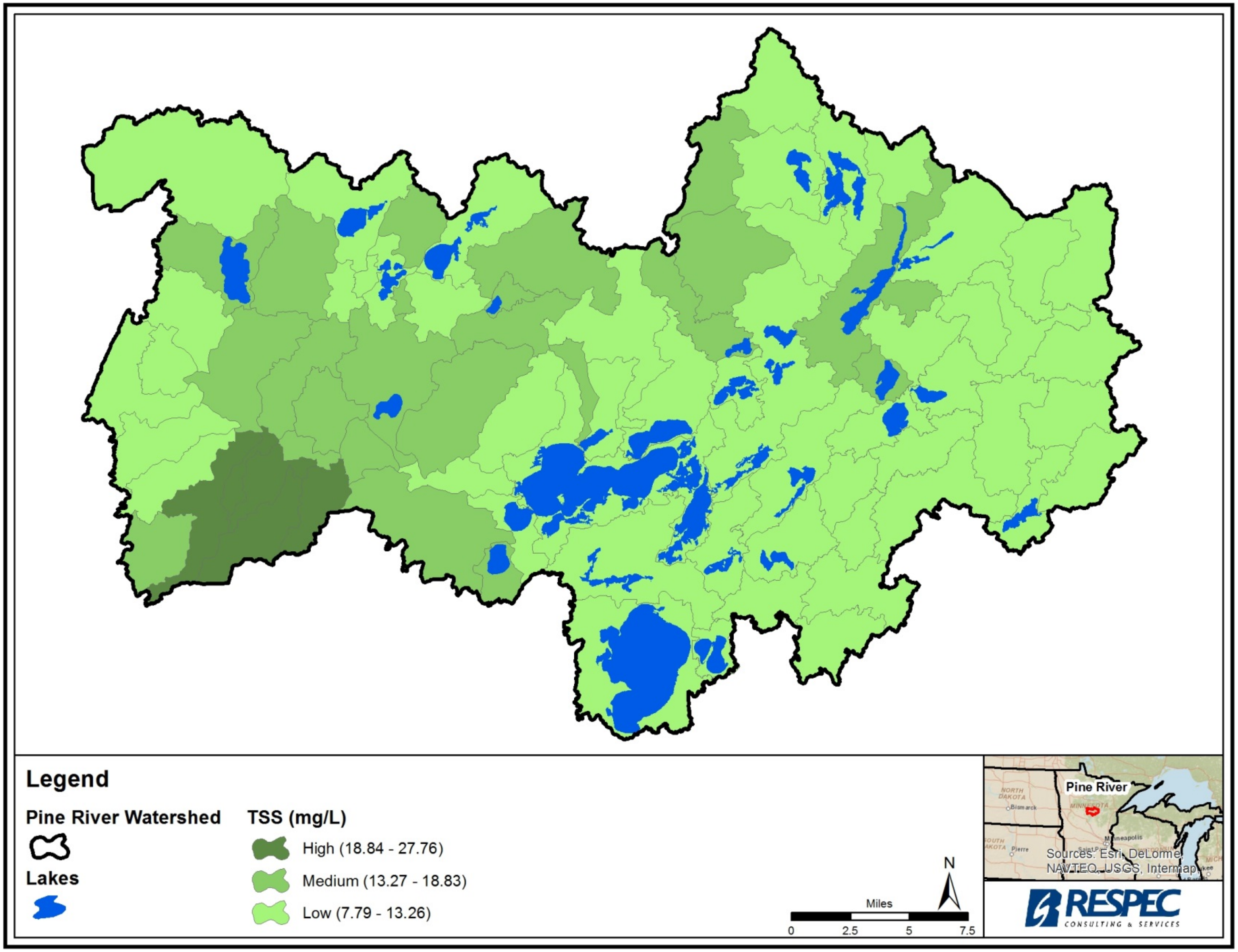

Figure 2-4. Average Simulated Total Suspended Solids Concentration by Subwatershed, 1996–2009.

Table 2-1. Average Annual Pollutant Loads and Flow Rates by Land Classification, 1996–2009

Source Category	Area (ac)	Percent Area (%)	Total Phosphorus			Total Nitrogen			Total Suspended Solids			Flow		
			Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Percent Watershed Load (%)	Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Percent Watershed Load (%)	Unit-Area Load (ton/ac-yr)	Annual Load (ton/yr)	Percent Watershed Load (%)	Unit-Area Rate (in/yr)	Rate (ac-ft/yr)	Percent Watershed Flow (%)
Old deciduous forest	198,633	43	0.08	15,751	36	2.9	575,046	36	0.011	2,116	43	6.1	1.0×10^5	37
Old evergreen forest	17,685	4	0.06	1,045	2	2.4	42,256	3	0.008	134	3	5.7	8.4×10^3	3
Young forest	40,933	9	0.07	2,982	7	2.9	120,390	8	0.013	539	11	7.1	2.4×10^4	9
Grassland	30,168	7	0.06	1,911	4	3.0	91,080	6	0.017	503	10	8.4	2.1×10^4	8
Agriculture	27,458	6	0.24	6.562	15	9.3	256,081	16	0.030	832	17	8.0	1.8×10^4	7
Feedlot	29	< 1	0.36	10	< 1	17.2	503	< 1	0.219	6	< 1	9.0	2.2×10^1	< 1
Wetland	134,649	29	0.09	11,820	27	2.9	384,117	24	0.002	263	5	6.5	7.3×10^4	27
Developed	10,185	2	0.26	2,599	6	10.5	106,602	7	0.048	486	10	10.3	8.7×10^3	3
Septics	NA	NA	NA	1,566	4	NA	22,736	1	NA	-	< 1	NA	1.8×10^4	7

NA = not applicable.

3.0 EVALUATION OF RESOURCE MANAGEMENT AND PRECIPITATION SCENARIOS

Five model scenarios were developed to evaluate the hydrologic and water-quality impacts of resource management options or changes in the watershed. The scenario results will inform the implementation strategies selected for the Pine River WRAPS. Concerns about and threats to the watershed's surface water resources were identified at stakeholder meetings and were narrowed down to the following based on those that can be appropriately evaluated with the HSPF model:

- Surface water protection
- Protection of forests
- Intensification of agriculture
- Lakeshore development
- Population growth in cities
- Climate change

The details of the scenarios were determined though input from the WRAPS stakeholder group.

3.1 METHODS

3.1.1 Land Change Without Best Management Practices (Scenario 1)

This scenario was developed to answer the question, How would the projected watershed threats affect watershed phosphorus loads if watershed best management practices (BMPs) were not used to mitigate the changes? The threats were translated into model inputs and parameters according to the following:

- **Intensification of agriculture.** Fifteen percent of private forest land was converted to agriculture (a mix of pasture/hay and cultivated crops). The private forest land eligible for conversion is based on areas indicated as forest in the 2006 National Land Cover Database (NLCD) and indicated as private industrial, private nonindustrial, private, and tribal in the Minnesota Department of Natural Resources' GAP Stewardship 2008 data. Land under a state conservation easement or with slope greater than 8 percent was not considered eligible for conversion. In the original and new agricultural areas, more intense use of the land was simulated by lower rates of infiltration, interception, and evapotranspiration, in addition to a 50 percent increase of animal units on existing feedlots.

- **Shoreland development.** Shoreland development was simulated on all areas within 500 feet of lakes in the MPCA's Assessed Lakes 2010 GIS data. Land under conservation easements and county, state, and federal public lands were considered not to be eligible for development. The median existing effective impervious area[2] of subwatersheds in the Pine River Watershed is 10 percent. The effective impervious area of newly developed land was increased to 15 percent to reflect the larger scale homes with higher amounts of impervious surfaces that are common in new shoreland development.
- **City growth.** All land within city boundaries was converted to developed with a 13 percent effective impervious area, which is the level of imperviousness from existing developed areas within cities in the Pine River Watershed.
- **Highway 371 expansion.** Highway 371 throughout the watershed was expanded from a 2-lane to a 4-lane corridor by adding a 35-foot buffer on each side of the highway and assigning a 75 percent effective impervious area. This level of imperviousness corresponds to the highly developed land class in the NLCD.

3.1.2 Land Change With Best Management Practices (A) (Scenario 2)

This scenario was developed to answer the question, How would the projected watershed threats affect watershed phosphorus loads if watershed BMPs were used to mitigate the changes? The land change with BMPs scenario was used as a starting point and the following model inputs and parameters were used to simulate the effects of watershed BMPs:

- **Intensification of agriculture.** Watershed phosphorus loads from agricultural areas were reduced by 50 percent, which assumes a high-quality, 16-foot buffer on all surface waterbodies [Nieber et al., 2011]. The rates of infiltration, interception, and evaporation were changed back to the rates used to represent existing conditions.
- **Shoreland development, city growth, and Highway 371 expansion.** 1.1 inches of runoff from all impervious surfaces were captured and retained by increasing the retention storage parameter by 1.1 inches. This volume is based on Minnesota's Minimal Impact Design Standards (MIDS) work group performance goal for new development.

3.1.3 Land Change With Best Management Practices (B) (Scenario 3)

This scenario is similar to the previous one but simulates additional BMPs. In addition to the simulated practices described under the first land change with BMPs scenario (Scenario 2), the following model inputs and parameters were used to simulate the effects of watershed BMPs:

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[2] Effective impervious area represents the level of impervious surfaces that are directly connected to a local hydraulic conveyance system (e.g., gutter, storm sewer, stream, or river). Effective impervious area is estimated from mapped percent imperviousness based on an equation in Sutherland [1995].

- **Shoreline buffers.** Watershed phosphorus loads from newly developed areas around the lakes were reduced by 68 percent, which assumes a high-quality, 50-foot shoreline buffer [Nieber et al., 2011].
- **City growth.** In the land change without BMPs scenario (Scenario 1), development was allowed to occur on all lands within city boundaries, which includes wetlands. For Scenario 3, land developed within city boundaries followed the following guidelines:
  - All wetlands within city boundaries were preserved.
  - Seventy-five percent of natural areas within city boundaries was preserved. These natural areas include forests, grassland, and all wetlands.
  - For the remaining 25 percent of areas within city boundaries, cluster development was simulated. The effective impervious area was lowered from 13 percent (in Scenarios 1 and 2) to 10 percent of the entire city boundary, and the remaining 15 percent was simulated as developed pervious areas (such as lawns). Cluster development typically has lower levels of impervious surfaces than traditional development [Center for Watershed Protection, 2000].

3.1.4 Climate Change-Induced Precipitation Changes (Scenario 4)

Climate change is expected to affect many factors that influence water quality, including air temperature, precipitation, and land cover. Projected changes to precipitation patterns were simulated in the Pine River Watershed to evaluate the impact to water quality of this one aspect of climate change. The National Climate Assessment and Development Advisory Committee (NCADAC) released their draft climate report in 2013, which summarizes climate observations and research from across the country and analyzes the impacts on seven selected sectors, one of which is water. Predictions from Chapter 18. Midwest [Pryor et al., 2013] of the NCADAC report were used to manipulate the hourly precipitation data in the model. Projected changes based on Global Climate Model output for the middle of this century (2041–2070) relative to the end of the last century (1971–2000) are summarized in Figure 18.7 of their report. The following predictions for the Pine River Watershed were used as the basis of the precipitation change scenario:

- Precipitation increase of 1.4–1.7 inches per year.
- An increase of 0.4–1.1 days of heavy precipitation per year. Heavy precipitation is defined as the top 2 percent of all days with precipitation.
- 0–4 fewer dry days per year. Dry days are defined as days with less than 0.1 inch of precipitation.
- An increase of 0–0.2 inch of precipitation during the wettest 5-day period.

The Climate Assessment Tool within BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) Version 4 was used to facilitate the manipulation of precipitation data.

Extreme storm events were added to yield a 4 percent increase in annual volume. This is done in the Climate Assessment Tool by specifying event parameters; the tool searches the precipitation record to find events that meet the specifications and then duplicates these storms randomly in the precipitation record. Extreme events were classified as having a total volume greater than 1.7 inches and a total duration above 24 hours, allowing gaps up to 6 hours. In addition to the 4 percent increase from extreme events, a 2 percent increase was applied to every record in the original hourly precipitation record to yield a total volume increase of 6 percent at each of the six precipitation time series across the watershed. Most of the NCADAC predictions were met by the simulated changes in precipitation with a few of the summary statistics falling outside of the preferred ranges (Table 3-1).

Table 3-1. Summary of Simulated Precipitation Changes

Precipitation Time-Series I.D.	Precipitation Increase (in/year)	Increase in Days of Heavy Precipitation (day/year)	Precipitation Increase in the Wettest 5 Days (in/year)
Target:	*1.4–1.7*	*0.4–1.1*	*0–0.2*
3910	1.5	0.3	0.2
4110	1.7	0.6	0.1
4310	1.7	0.4	1.0
4510	1.7	0.6	0.1
4710	1.8	0.6	0.1
4910	1.7	0.7	0.1

3.1.5 Cumulative Scenario (Scenario 5)

A cumulative scenario was simulated by using a combination of the second land change with BMPs scenario (Scenario 3) and the climate change-induced precipitation scenario (Scenario 4).

3.2 RESULTS

3.2.1 Land Change Scenarios

The land change without BMPs scenario (Scenario 1) led to a 13 percent increase in runoff volume and an 87 percent increase in phosphorus runoff relative to baseline conditions (Figure 3-1, Table 3-2). The first land change with BMPs scenario (Scenario 2) mitigated the increase in loads but only slightly. The second land change with BMPs scenario (Scenario 3) further mitigated the increase in loads such that, when comparing the baseline to the second land change with BMPs scenario (Scenarios 0 and 3), the phosphorus loads increased only 4 percent (Table 3-2).

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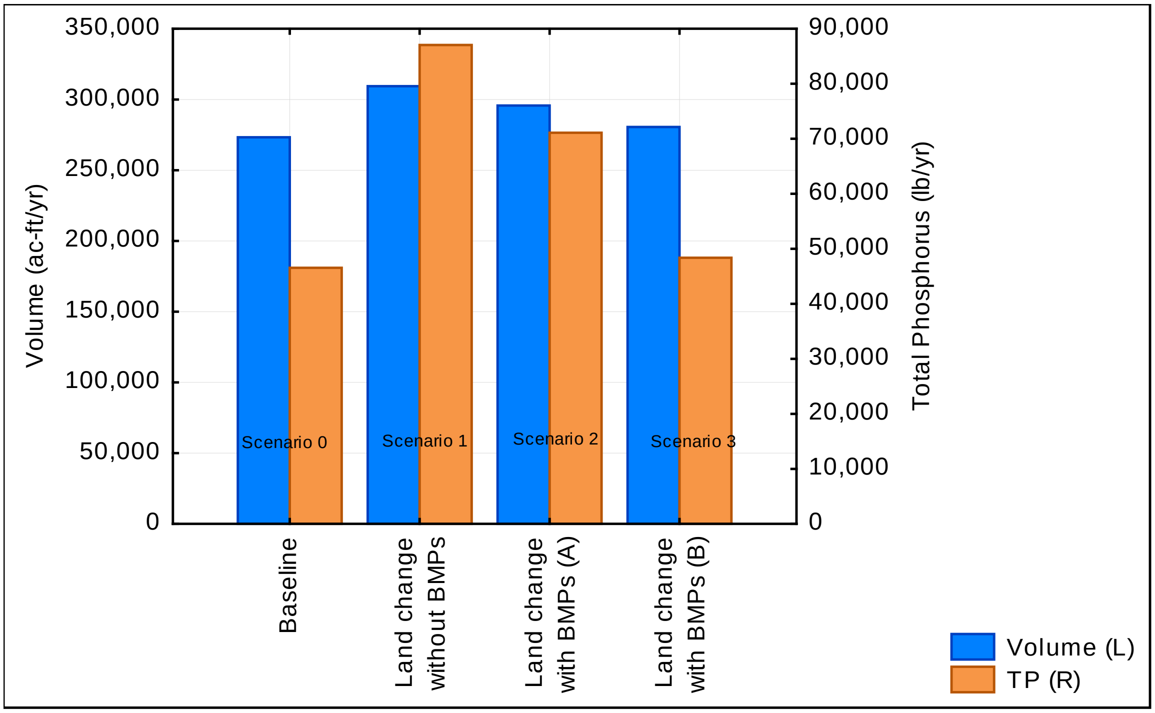

Figure 3-1. Watershed Runoff Volumes and Phosphorus Loads From Baseline and Land Change Scenarios.

Table 3-2. Pine River Watershed Runoff Volume and Phosphorus Load Changes

Scenario	Percent Change Runoff Volume (%)	Percent Change TP Runoff (%)
0 to 1	13	87
1 to 2	–4	–18
2 to 3	–5	–32
0 to 3	3	4
0 to 4	20	20
0 to 5	23	24

The majority of the increase in phosphorus loads was because of the increase in developed areas (Figure 3-2). The increase in loads from the intensification of agriculture was more than mitigated by the load reductions provided by the riparian buffers in the agricultural areas.

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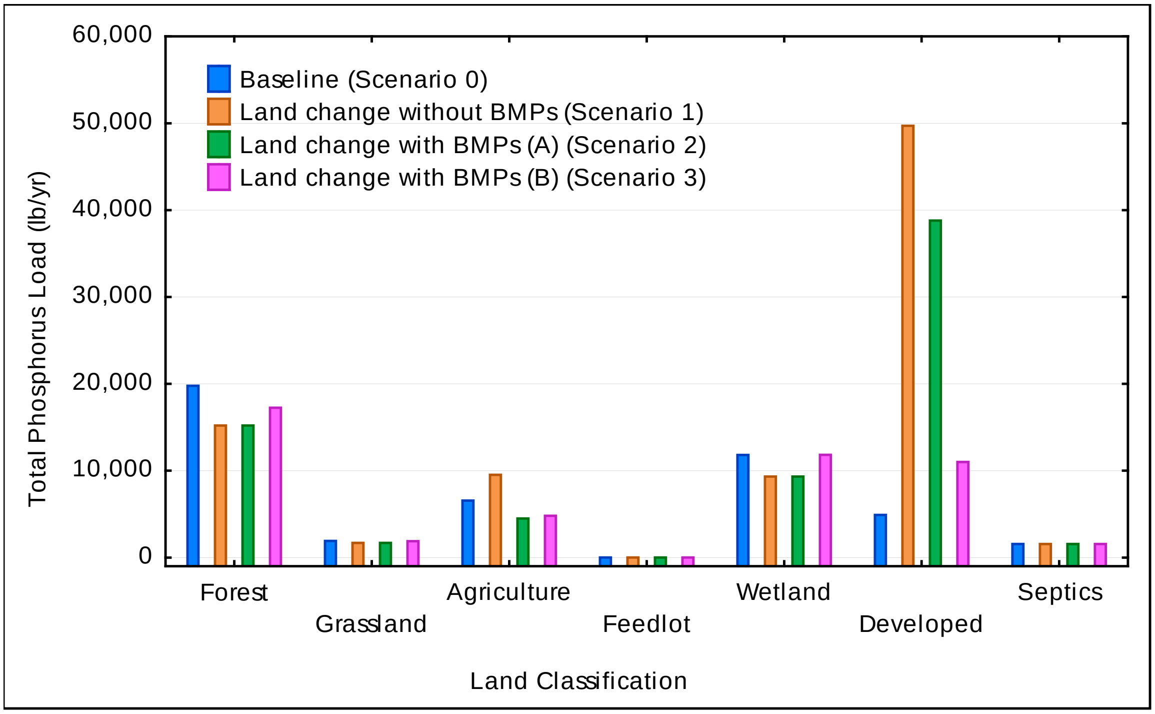

Figure 3-2. Watershed Runoff Volumes and Phosphorus Loads by Land Classification From Baseline and Land Change Scenarios.

The phosphorus load increases occurred primarily in the subwatersheds that intersect existing city boundaries and lakes (Figure 3-3) because these are the areas where most of the land change occurred.

3.2.2 Climate Change-Induced Precipitation Changes (Scenario 4)

The climate change-induced precipitation changes led to a 20 percent increase in watershed runoff volume and total phosphorus loads across the Pine River Watershed (Figure 3-4, Table 3-2). The percent increase in runoff was higher than the percent increase in volume of precipitation (20 versus 6) because the precipitation increase was achieved partly through the addition of extreme precipitation events. A greater amount of runoff is generated from extreme events relative to precipitation volume than is generated in more moderate events.

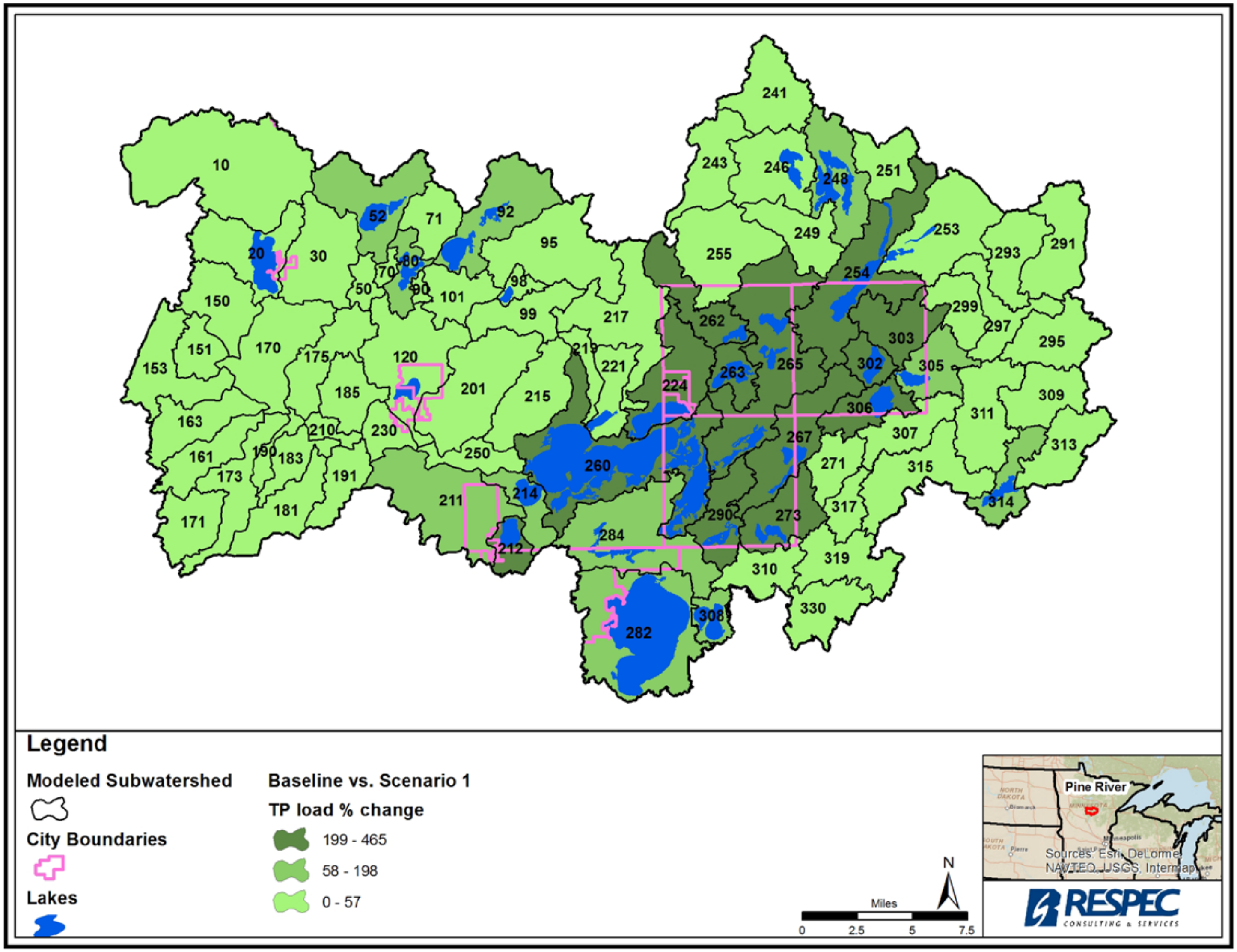

Figure 3-3. Percent Change in Phosphorus Loads by Subwatershed From Land Change Without Best Management Practices Scenario Relative to Baseline Conditions (Scenarios 1 and 0).

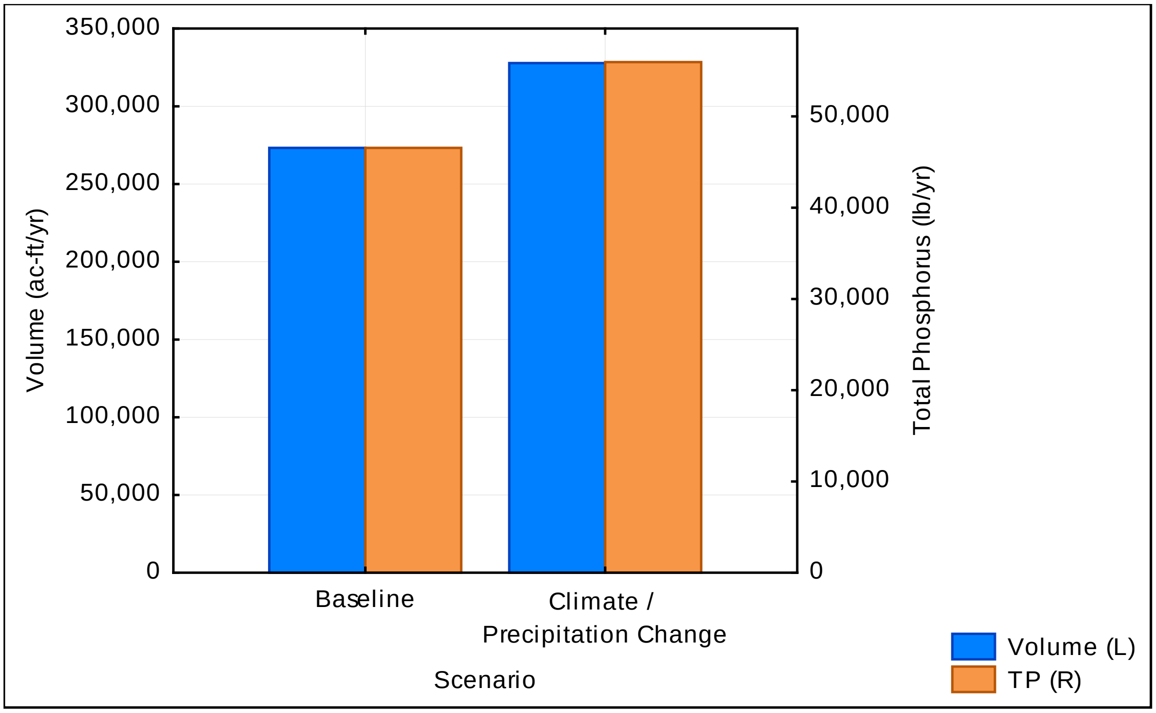

Figure 3-4. Watershed Runoff Volumes and Phosphorus Loads From Baseline and Climate Change Scenarios.

3.2.3 Cumulative Scenario

The BMPs in the land change scenarios were not able to mitigate the projected increases in volumes or phosphorus loads from the precipitation change scenarios; the cumulative scenario led to a 23 percent increase in runoff volumes and a 24 percent increase in phosphorus loads relative to baseline conditions (Table 3-2). The BMPs in the land change scenarios were targeted at mitigating the projected load increases caused by intensification of agriculture, shoreland development, and city growth. The BMPs were not targeted at mitigating the runoff changes resulting from changes in precipitation patterns.

3.3 CONCLUSIONS

The riparian buffers in agricultural areas were enough to mitigate the projected increases in phosphorus loads from the intensification of agriculture. However, in developed areas, the load reductions achieved through capturing and retaining 1.1 inches of runoff from all impervious surfaces were not enough to mitigate the projected increases in load from new development, which consists of over 85 percent pervious areas. When shoreline buffers were added to lakes and 75 percent of natural areas was preserved within city boundaries, the load increase in the land change scenario relative to baseline conditions was minimal.

These results apply to the specific scenarios in this project. If development were to proceed differently than what is presented here, the overall pattern of the predictions would apply. For example, development might occur outside of city boundaries, in areas within townships that are adjacent to highways. If this land change were to occur without BMPs, phosphorus loads would be expected to increase by similar percentages as those presented in Scenario 1 relative to the baseline. The BMPs modeled in Scenarios 2 and 3 would be expected to mitigate the increase in loads by similar percentages.

The changes in precipitation predicted to result from climate change resulted in a 20 percent increase in runoff volumes and phosphorus loads. These increases were not mitigated by the BMPs modeled in these scenarios.

4.0 REFERENCES

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APPENDIX A

POLLUTANT LOADING TABLES

APPENDIX A
POLLUTANT LOADING TABLES

Subwatershed loading rates for phosphorus, nitrogen, and sediment are provided in Table A-1. Figure A-1 contains the key of the subwatershed locations.

Table A-1. Average Annual Pollutant Loads and Flow Rates by Subwatershed, 1996–2009 (Page 1 of 4)

Subwatershed	Area (ac)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit-Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit-Area Rate (in/yr)	Rate (ac-ft/yr)
10	20,492	0.082	1,688	3.1	63,269	0.009	193	6.4	11,009
20	5,988	0.087	522	3.3	19,636	0.011	68	6.6	3,293
30	8,459	0.100	844	3.7	31,538	0.012	99	6.7	4,726
50	1,738	0.081	141	3.0	5,171	0.008	15	6.4	923
52	7,742	0.090	695	3.3	25,507	0.009	73	6.8	4,377
70	741	0.079	59	2.8	2,090	0.008	6	6.3	391
71	3,908	0.110	430	4.1	15,907	0.011	43	7.1	2,298
80	2,252	0.080	180	3.0	6,652	0.009	19	6.6	1,234
90	575	0.095	54	3.5	2,035	0.011	6	6.6	316
92	7,525	0.089	668	3.2	23,844	0.008	63	6.8	4,251
95	10,747	0.084	902	3.1	33,790	0.012	131	6.4	5,705
98	1,052	0.113	119	4.0	4,174	0.016	17	8.6	753
99	4,920	0.091	448	3.2	15,907	0.012	60	7.2	2,955
101	4,092	0.093	381	3.3	13,631	0.009	35	6.9	2,345
120	10,108	0.110	1,110	4.3	43,241	0.014	137	7.0	5,924
150	5,867	0.079	466	3.0	17,316	0.009	53	6.4	3,133
151	3,146	0.075	236	2.8	8,667	0.008	26	6.3	1,655
153	6,946	0.077	533	2.9	19,883	0.009	63	6.4	3,688
161	4,627	0.082	381	3.0	13,999	0.010	44	6.6	2,526
163	5,552	0.084	467	3.1	17,333	0.010	53	6.4	2,941
170	8,993	0.113	1,014	4.2	37,906	0.012	107	7.1	5,284
171	4,723	0.092	433	3.4	16,090	0.013	59	6.4	2,518

Table A-1. Average Annual Pollutant Loads and Flow Rates by Subwatershed, 1996–2009 (Page 2 of 4)

Subwatershed	Area (ac)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit-Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)
173	5,992	0.122	731	4.6	27,799	0.019	113	7.1	3,547
175	5,833	0.106	620	4.0	23,395	0.012	70	7.0	3,413
181	5,412	0.126	681	4.8	25,769	0.022	119	7.0	3,171
183	3,207	0.121	388	4.5	14,482	0.016	51	7.0	1,864
185	4,393	0.108	472	4.0	17,658	0.011	47	6.9	2,519
190	1,497	0.128	191	4.9	7,263	0.019	28	7.2	898
191	3,776	0.122	462	4.6	17,340	0.019	72	7.0	2,208
201	11,112	0.117	1,296	4.3	48,172	0.014	151	7.3	6,747
210	1,319	0.113	149	4.2	5,534	0.011	15	7.1	780
211	12,201	0.120	1,458	4.4	53,783	0.013	161	7.2	7,302
212	1,800	0.114	205	4.2	7,547	0.015	27	7.2	1,077
214	2,619	0.097	253	3.4	8,994	0.010	25	6.9	1,514
215	6,916	0.084	579	3.1	21,147	0.010	67	6.7	3,847
217	9,981	0.089	888	3.2	31,754	0.010	103	6.9	5,737
219	1,819	0.104	190	3.9	7,042	0.012	22	7.2	1,093
221	3,553	0.100	355	3.7	13,069	0.011	39	7.3	2,162
224	6,899	0.094	648	3.3	23,095	0.009	59	7.1	4,071
230	2,545	0.125	318	4.8	12,105	0.016	40	7.4	1,566
241	6,736	0.098	658	3.5	23,635	0.010	65	7.6	4,244
243	5,929	0.092	543	3.3	19,728	0.012	70	7.6	3,737
246	6,878	0.098	671	3.5	23,830	0.011	73	7.5	4,286
248	5,748	0.094	539	3.4	19,643	0.010	56	7.5	3,601

Table A-1. Average Annual Pollutant Loads and Flow Rates by Subwatershed, 1996–2009 (Page 3 of 4)

Subwatershed	Area (ac)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit-Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)
249	5,377	0.094	507	3.4	18,103	0.010	55	7.5	3,340
250	2,993	0.109	326	4.0	11,861	0.010	29	7.2	1,790
251	4,221	0.095	399	3.4	14,529	0.011	46	7.6	2,668
253	9,478	0.095	896	3.4	32,166	0.010	95	7.6	6,027
254	12,068	0.098	1,187	3.5	42,592	0.012	141	7.6	7,670
255	9,321	0.094	874	3.4	31,417	0.013	124	7.7	5,995
262	5,315	0.085	451	3.0	16,009	0.011	59	7.1	3,153
260	9,562	0.103	986	3.6	34,012	0.008	78	7.5	5,990
263	2,312	0.095	218	3.2	7,489	0.010	23	7.5	1,442
265	15,570	0.097	1,516	3.4	53,430	0.011	171	7.4	9,537
267	7,759	0.096	746	3.3	25,814	0.010	79	7.4	4,767
271	3,579	0.091	325	3.1	11,233	0.009	32	7.4	2,198
273	5,098	0.090	456	3.1	16,023	0.007	36	7.0	2,962
282	8,731	0.103	902	3.6	31,258	0.010	83	7.5	5,451
284	12,007	0.092	1,107	3.2	38,802	0.008	94	6.9	6,934
290	4,651	0.106	492	3.7	17,245	0.009	43	7.6	2,939
291	7,021	0.084	587	2.9	20,627	0.008	57	7.1	4,126
293	5,302	0.098	522	3.4	18,235	0.009	50	7.9	3,510
295	6,078	0.089	540	3.1	18,631	0.008	47	7.2	3,649
297	4,675	0.106	497	3.7	17,262	0.010	47	8.3	3,224
299	3,941	0.097	383	3.4	13,281	0.009	37	8.2	2,700
302	1,743	0.113	197	4.0	7,047	0.015	26	7.9	1,152

Table A-1. Average Annual Pollutant Loads and Flow Rates by Subwatershed, 1996–2009 (Page 4 of 4)

Subwatershed	Area (ac)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit-Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit-Area Load (lb/ac-yr)	Annual Load (lb/yr)
303	5,359	0.089	476	3.1	16,552	0.010	54	7.3	3,266
305	4,260	0.091	386	3.1	13,141	0.009	38	7.3	2,601
306	3,326	0.096	320	3.4	11,352	0.010	33	7.2	1,985
307	4,728	0.092	434	3.2	15,013	0.009	44	7.4	2,898
308	1,470	0.093	136	3.2	4,648	0.006	9	7.1	871
309	5,259	0.087	459	3.0	15,872	0.008	41	7.3	3,185
310	4,231	0.089	375	3.2	13,727	0.009	37	7.1	2,506
311	7,314	0.094	688	3.3	23,832	0.009	63	7.5	4,589
313	5,408	0.086	463	3.0	16,050	0.008	42	7.2	3,227
314	3,513	0.088	310	3.1	10,896	0.009	32	7.1	2,069
315	8,094	0.093	750	3.2	26,265	0.011	87	7.3	4,951
317	2,595	0.088	228	3.0	7,888	0.010	25	7.3	1,571
319	6,196	0.097	600	3.4	20,844	0.009	55	7.3	3,777
330	4,829	0.092	444	3.2	15,295	0.007	33	7.3	2,932

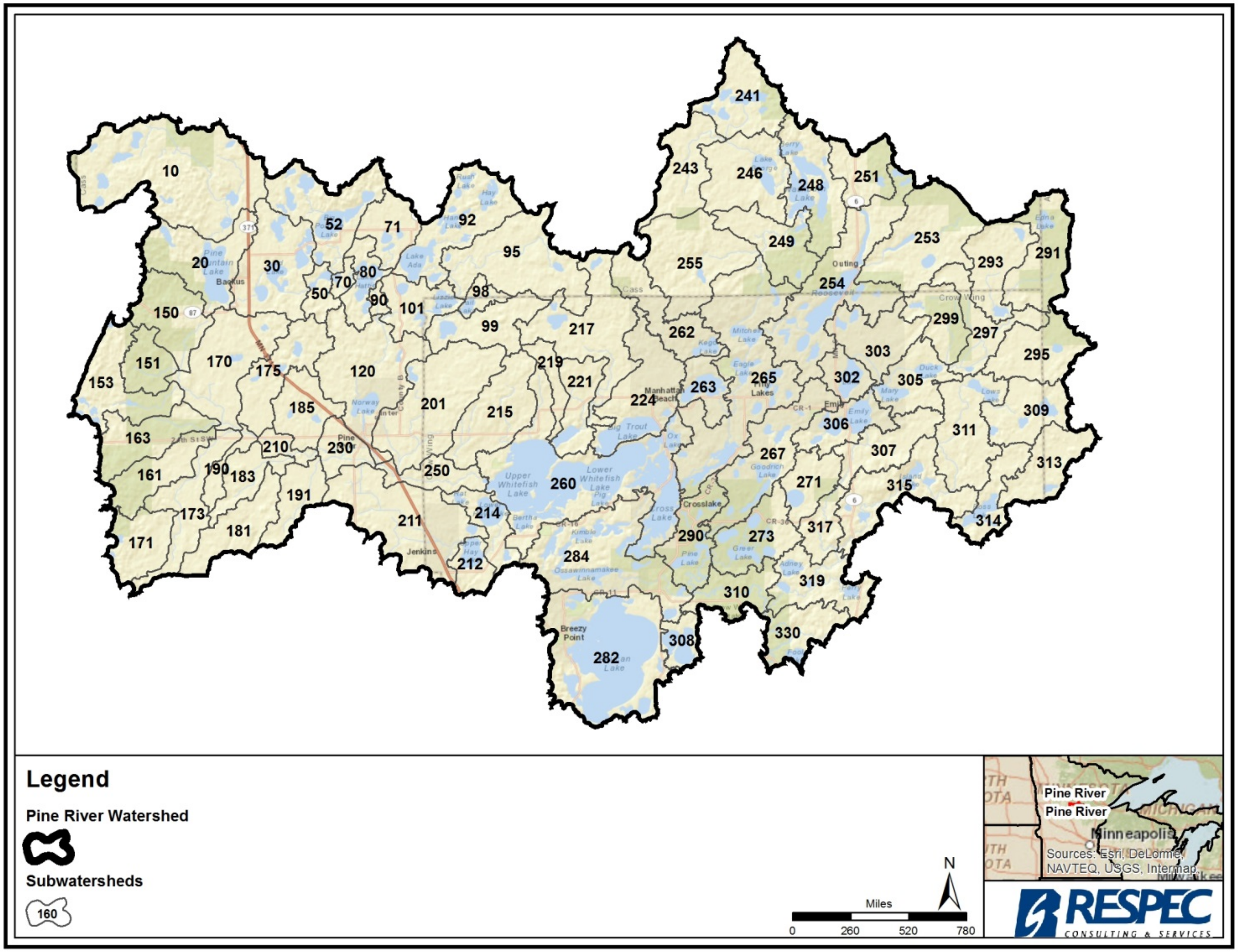


Figure A-1. Subwatershed Key.

Appendix 3- The Zonation Model for the Pine River Watershed

Prioritizing and Implementing Protection and Restoration

The CWLA requires that the WRAPS report summarize priority areas for targeting actions to improve water quality, and identify point sources and nonpoint sources of pollution with sufficient specificity to geographically locate and prioritize watershed protection and restoration actions. In addition, the CWLA requires including an implementation table of strategies and actions that are capable of cumulatively achieving needed pollution load reductions for point and nonpoint sources. This section of the report provides the results of such prioritization and strategy development.

Targeting and Prioritization of Geographic Areas

A values-based model was used to prioritize areas for protection and restoration. This model was based on fundamental conservation principles, including biodiversity and connectivity. We used the DNR's five-component healthy watershed conceptual framework to facilitate an organized process to assess and review watershed problems and solutions. The five components for a healthy watershed are biology, hydrology, water quality, geomorphology, and connectivity. This approach recognizes that attempts to solve our clean water needs are not separate from our other conservation needs; each conservation activity should provide multiple benefits. For example, for both the protection and restoration prioritizations, goals were to obtain both clean water benefits and other conservation benefits. The values-based model used in this process helps achieve this multiple benefits goal by identifying areas that optimize benefits by incorporating data valued by the community. The model used a compilation of individual and aggregated criteria of valuable landscape features with the objective of providing data and maps that prioritize places on the landscape for protection or restoration.

The value model was also used in a civic engagement process. As part of this process, participants decided on what landscape features were valued and the ranking of those valued features within the model. As a final step, WRAPS participants were given the opportunity to revise the model results to create a map that will be used to help identify areas within the watershed for potential future conservation investments. This synthesis step captured the knowledge and experiences of the people interested in and informed about the stresses, risks, and vulnerability of water resources within the watershed. See Appendix 3a for details on methods and results.

The final prioritization maps created are presented in Figure 38 and Figure 39. The protection priority map identified several general priority areas. High rankings were given to shorelands, especially sensitive shorelands (as identified by the DNR's Sensitive Lakeshore Assessment). Because runoff from lands close to lakes is more likely to contribute to declining water quality, protection of these areas will be important in maintaining good water quality. High priority rankings were also given to lands associated with municipal DWSMAs. These areas are critical for the protection of potable water for large populations. Undisturbed riparian areas associated with the Pine River and its tributaries would also benefit from protection. The area west of the city of Pine River has a considerable number of wetlands and streams with extensive floodplains, so protecting these natural lands may reduce nutrient pollution from adjacent agricultural lands. Finally, protection of existing valuable timber lands north of Fifty Lakes would provide multiple conservation benefits.

The restoration priority map was similar to the protection map. The difference in these two maps was clearly related to the location of agricultural lands in the watershed. The restoration map provides guidance related to potential project areas on agricultural lands for engineered BMPs or restoration of those lands to natural conditions for multiple benefits.

Several priority management areas were also identified in the synthesis analysis. There was consensus on the need to focus protection efforts on the shorelands on the north side of the Whitefish Chain of Lakes, with specific attention to the catchment of Big Trout Lake. Second, the catchment of Kego Lake, an impaired lake, would benefit from focusing efforts that would provide water quality benefits. It was also recognized that protecting the city of Pine River's water supply should be a high priority. With regard to reducing nutrient loading to the Whitefish Chain of Lakes, emphasis on the riparian lands of the south fork of the Pine River (and associated tributaries) was identified. Adding riparian buffers, increasing riparian buffer width, and holding more water longer on the land would improve water quality. Increases in riparian buffer width would also improve stream habitat. Several forest areas were identified where protection efforts related to BMPs can be explored and implemented. Lastly, the catchment of Pelican Lake and lands within Breezy Point were recognized as a priority area. This high value lake would benefit from greater water quality protection efforts. Priority management areas were also identified in the synthesis analysis.

Figure 38. Final protection priority map from Zonation analysis and synthesis analysis.

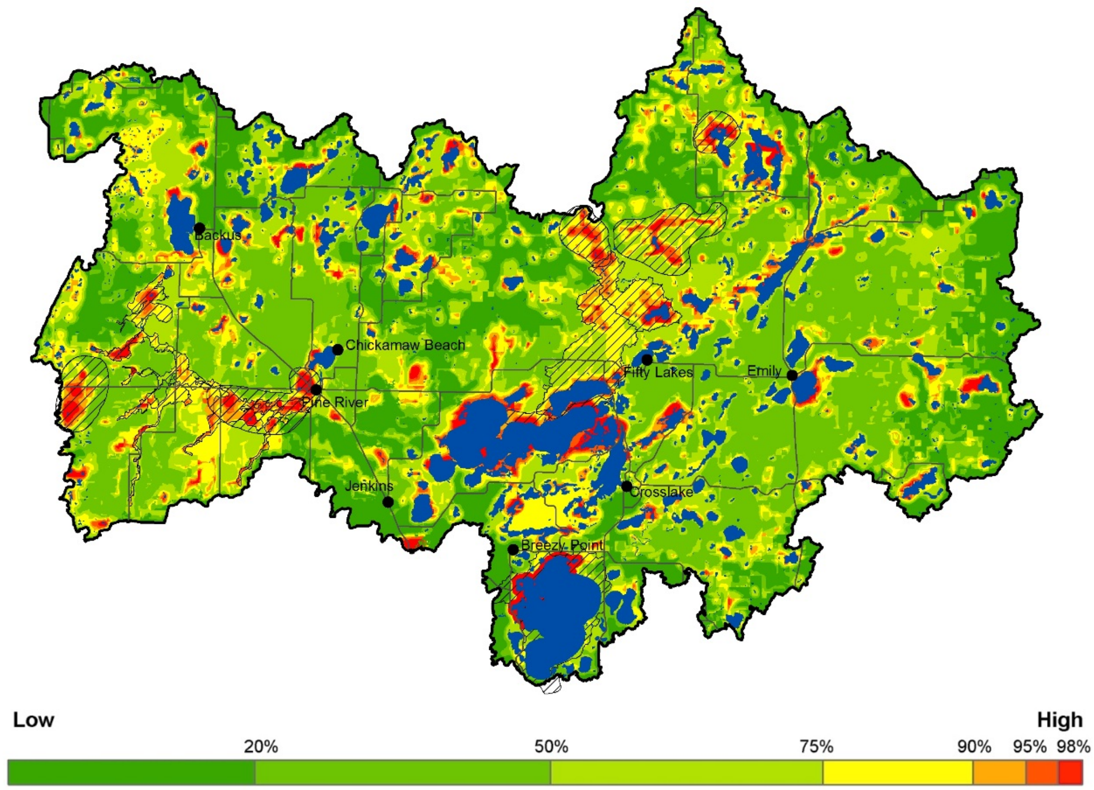
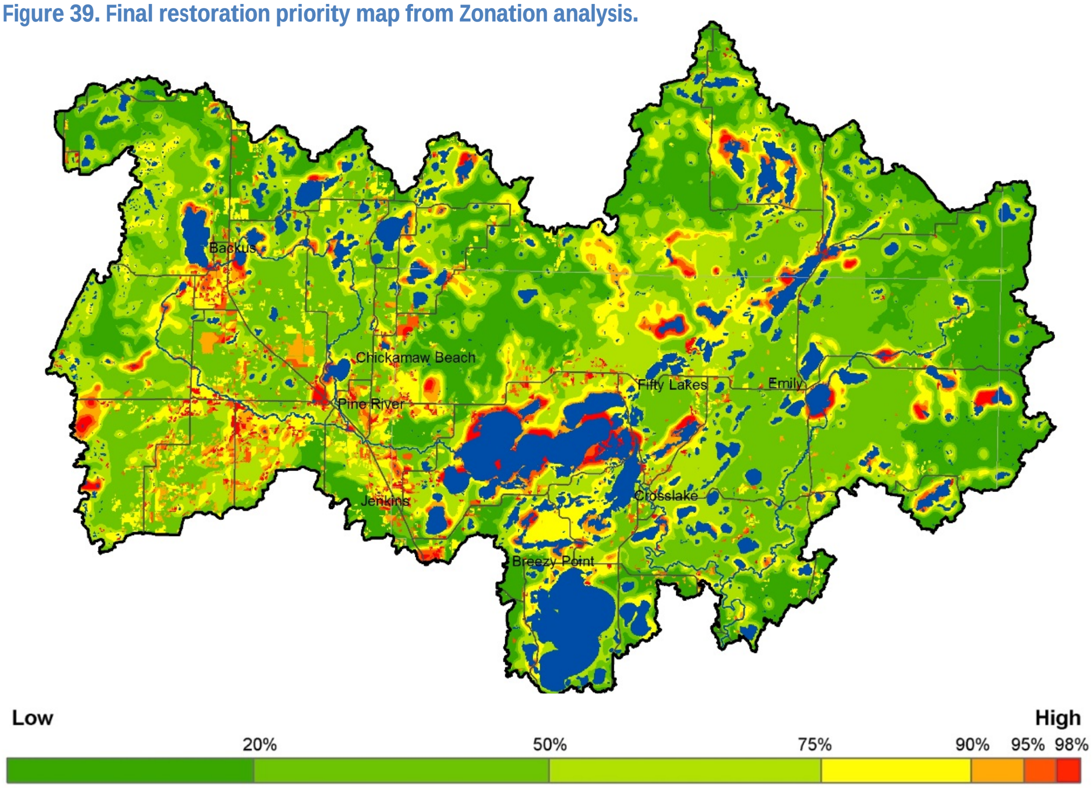


Figure 39. Final restoration priority map from Zonation analysis.



Appendix 3A.

Description of Prioritization Approach and Methods

By Paul J. Radomski and Kristin Carlson

Prioritization Overview

As threats to Minnesota's watersheds continue to mount, it is becoming increasingly important to identify and conserve high-priority areas. There are multiple opportunities for protection or restoration in any watershed. Identifying which practices to implement and where in the landscape to implement them can help more effectively target efforts and more efficiently utilize limited resources. A number of information technology tools are available for prioritizing and targeting land for restoration and protection efforts within a watershed.

A systematic approach aimed at optimizing environmental benefits while reducing interference between competing land uses will be critical. Two of the most common approaches for conservation prioritization are system-based models and value-based models. One of the major strengths of system-based models is that they require us to think deeply about a system by writing down our mental models of how we believe the system functions. For many watersheds, this has been done using the HSPF hydrologic system model, which simulates watershed hydrology and water quality at the catchment scale. However, we often do not have system models that can accurately identify where in the watershed specific good management practices should be applied or that have the ability to simulate alternative land management actions and predict consequences at specific locations in the watershed.

Values-based models use a compilation of individual criteria of valuable landscape features (heterogeneous content) and aggregated criteria (context and connections) with an objective function to prioritize places within the landscape for conservation. Although there are some shortcomings of using value models over system models (value models only allow exploration of tradeoffs and optimization, and they do not provide guidance on what practices should be implemented where), the use of value models is an efficient method for prioritizing places for protection or restoration.

The values-based model prioritization approach we used is based on fundamental conservation principles, including content, context, heterogeneity, and connectivity. We used the DNR's five-component healthy watershed conceptual model to facilitate an organized process to assess and review watershed problems and solutions. The five components are: biology, hydrology, water quality, geomorphology, and connectivity. This approach recognizes that attempts to solve our clean water needs are not separate from our other conservation needs; each conservation activity should provide multiple benefits. Value models help achieve this multiple benefits goal by identifying areas that optimize benefits by accounting for what the community values. The use of an additive benefits objective function in the value model allows for the retention of high quality occurrences of as many conservation features as possible while reducing interference between competing land uses (e.g., row crop areas). Value models also can be used in a public participation process, whereby participants can decide on what features are valued and the ranking of those valued features. Addressing conservation goals effectively necessitates a collaborative approach, and value-based models provide a structure for collaborative efforts. In addition, value models and the five-component conceptual model used to structure the content in the value models are simple concepts that are easy to explain and apply at the local government scale.

Methods

The value models were developed using Zonation software (Moilanen et al. 2009). Zonation produces a nested hierarchy of conservation priorities. It begins with the full landscape and iteratively removes parcels (cells) that contribute least to conservation; therefore, the removal order is the reverse order of the priority ranking for conservation. Zonation assumes that the full watershed is available for conservation. In our models, the lakes were masked out prior to analysis. This focused the prioritization on the terrestrial parcels, in accordance with the conservation and restoration goals of our partners. Zonation's algorithms seek maximal retention of weighted normalized conservation features.

Weights are used to influence which features are valued more. Within the five-component healthy watershed framework, for example, water quality conservation features could be weighted higher than biological features. The feature-specific weights used in the value models reflect social valuation, and they were set using the AHP (Saaty and Peniwati 2007). A survey comprised of pairwise comparisons was used to solicit the preferences of individuals. Features used in the comparison were based loosely on the DNR's five-component healthy watershed approach, with the addition of alternative land uses or economic features representing a social component. The pairwise survey was structured to gather value preferences for both a protection and a restoration scenario. Each individual taking the survey used his or her judgment about the relative importance of all elements at each level of the hierarchy. The relative importance values included "equal," "prefer," and "strongly prefer." The use of abbreviated pairwise importance values helped reduce the cognitive burdens associated with a large number of pairwise comparisons. Individual responses were aggregated with a geometric mean, and the pairwise comparison survey was constructed to compute the feature-specific weights consistent with the AHP.

There are three commonly definable objective functions possible in Zonation: core area, target-based planning, and additive benefit functions. The core area objective function aims to retain high-quality occurrences of each feature. This function is most appropriate when there is a definite set of conservation features and all of them are to be conserved. The target-based planning objective function is a prescriptive approach where requirements are specified *a priori* for each feature. This function produces a minimum set coverage solution, and is most appropriate when a defined proportion of the watershed is assigned for conservation.

We used the additive benefit function variant of Zonation, which aggregates values by summation across features:

$$V(P) = \Sigma w_j N_j(P)^{z_j} - \Sigma w_k N_k(P)^{z_k}$$

where the value of a parcel *V(P)* is equal to the summation of weighted *w* normalized conservation features of the parcel $N_j(P)$, squashed to the power of *z*, minus the summation of the weighted normalized alternative land use features of the parcel $N_k(P)$, squashed by *z*.

The conservation features used in the analysis are found in Table 1, and each layer was on the same grid with a resolution of 30 by 30m. We used high-resolution data to maximize conservation planning realism and for greater practicality in local government conservation planning and implementation.

We used $z_j = 0.25$ for conservation features and $z_k = 4$ for alternative land uses. The additive benefit function is appropriate when tradeoffs between conservation features are allowed and it is necessary to account for alternative land use features. In our analyses, we developed prioritizations that would minimize interference with important agricultural areas. Additionally, Zonation allows ranking to be influenced by neighboring parcels, so that highly valued areas can be aggregated. This minimizes fragmentation of conservation within the landscape. We utilized the distribution-smoothing algorithm in Zonation, which uses an aggregation kernel a parameter. Using this algorithm assumes that fragmentation (low connectivity) generally should be avoided for all conservation features. Initial analyses indicate that an aggregation kernel a of 0.01, which corresponds to a connectivity distance of 200m, may be appropriate for conservation efforts targeted at the watershed scale. We found that very small connectivity distances made no difference in parcel prioritization, since the connectivity effect did not extend very far into neighboring parcels, and very large connectivity distances aggregated parcels across unrealistically large areas. We also found that across a modest range of connectivity distances the results were minor. The connectivity distance can be conservation feature-specific, for a biological example, if a species dispersal capability or fragmentation vulnerability was known, then a species-specific parameter could be explicitly used. We did not use distributing smoothing for alternative land uses or economic features.

The final step in identifying areas for potential protection and restoration included two mapping exercises. First before the Zonation analysis, participants were asked to identify valuable areas for protection or restoration. Later, participants used their knowledge and experiences within the watershed to revise the Zonation output protection map to create a final map that may be used to provide guidance on which areas within the watershed may be priorities for potential future conservation investments. This synthesis step captured the wisdom of the group of people interested and knowledgeable about the stresses, risks, and vulnerability of water resources within the watershed.

Results

The pairwise questionnaire survey results identified *Protect Water Quality* as the highest weight for protection and *Reduce Flooding & Erosion* received the highest weight of the value model components for restoration (Table 2). Using the weighted components, two priority maps were created with the Zonation value model. The first map was a protection priority map where lands were ranked as to their importance for land management activities that would provide greater protection of ecosystem functions, especially water quality (Figure 1). The second map was a restoration priority map where lands were ranked as to their importance for application of various land BMPs (Figure 2). The final prioritization map created from Zonation and synthesis analysis is presented in Figure 3. Figures 4 & 5 serve as examples on how land managers can use GIS systems to probe the Zonation output and various land characteristics.

References

Moilanen, A., H. Kujala, and J. Leathwick. 2009. The Zonation framework and software for conservation prioritization. Pages 196-210 in A. Moilanen, K. A. Wilson, and H. P. Possingham, editors. Spatial conservation prioritization: quantitative methods and computational tools. Oxford University Press, Oxford, UK.

Saaty, T.L., and K. Peniwati. 2007. Group decision-making: Drawing out and reconciling differences. Pittsburgh, PA: RWS Publications.

Table 17. Variable descriptions for content used in land prioritization value models.

Objective	Description
Protect or Improve Water Quality	
Focus on Drinking water management supply area vulnerability	The likelihood for a potential contaminant source within the DWSMA to contaminate a public water supply well. This likelihood is based on the aquifer's inherent geologic sensitivity and the composition of the groundwater.
Focus on Impaired waters	Catchments (i.e., drainage basins) upstream of aquatic life impaired lakes within the watershed. Identified as impaired by the MPCA.
Focus on Catchments with high pollution	Estimated total suspended solids, total nitrogen, and total phosphorus by catchment as determined by hydrological models.
Focus on Catchments of lakes with declining water quality	Lakes where long-term data suggest declining water quality.
Focus on Groundwater contamination susceptibility	The relative susceptibility of an area to groundwater contamination (based on soil type, aquifer makeup, and recharge potential).
Focus on Areas with high erosive potential	Stream Power index: This is an index of the channelized flow erosive potential. Calculated from LiDAR data.
Focus on Areas close to water	Lands close to a stream and lake are more valuable in the protection of water quality than those farther away. The data are the inverse distance from water.
Focus on Catchments identified as at risk by DNR-Fisheries	Catchments that have between 25% and 60% land cover disturbance and that are less than 75% protected (publicly owned or protected by conservation easement). Determined by Minnesota Department of Natural Resources (DNR) – Section of Fisheries for water quality habitat purposes.
Reduce Erosion & Runoff	
Protect Existing wetlands	Remaining wetlands as documented by the National Wetland Inventory (NWI).
Restore Drained wetlands	Drained, potentially restorable wetlands in agricultural landscapes (based on an inventory or an assessment using the compound topographic index).
Protect or Restore Stream riparian areas	Stream riparian areas and potential flood zones (based on location, elevation and soil type).
Protect or Restore Vulnerable/Eroding lakeshore banks	Unstable lake bank areas on the Whitefish Chain of Lakes (i.e., areas susceptible to extensive erosion).
Protect Timber & Protected Land	
Protect Valuable timber lands	Forest lands that have been identified by forestry managers as important.
Protect Lands close to protected lands	Lands close to protected lands may be more important for conservation, as larger, contiguous areas often have more value than smaller, fragmented lands. The data are the inverse distance to existing protected lands.
Protect or Restore Shoreland	
Protect or Restore Shoreland	Land within 1000 feet of lake shoreline.

Protect or Improve Fish & Wildlife Habitat	
Protect Rare features	Locations of species currently tracked by the DNR, including Endangered, Threatened, and Special Concern plant and animal species as well as animal aggregation sites.
Protect Sites of biodiversity significance	Areas with varying levels of native biodiversity that may contain high quality native plant communities, rare plants, rare animals, and/or animal aggregations. Identified by Minnesota Biological Survey.
Protect or Restore Sensitive lakeshore	Lakeshore areas that provide unique or critical ecological habitat. Protocols for identifying these areas were developed by the DNR.
Protect or Restore Lakes of biological significance	Catchments of high quality lakes (designated cisco and wild-rice lakes).
Protect High Value Forests	DNR designated high conservation value forests due to plant and animals present and DNR designed old-growth forests.
Protect or Restore Ecological connections	Ecological corridors between generally large, intact, native or "semi-natural" terrestrial habitat patches.
Minimize Interference with or Restore Agricultural Land	
Pasture/hay	Land cover type is pasture or hay (areas used for livestock grazing or planted with perennial seed or hay crops).
Cultivated croplands	Land cover type is cultivated crops (areas used for the production of annual crops or actively tilled areas).

Table 18. Broad-scale and fine-scale weights used in the value models from a questionnaire using the AHP (weights sum to 100). Red values indicate alternative land uses in the model.

Broad-Scale Prioritization	**AHP Derived Weight**	**Protection Weight Used in Model**	**Restoration Weight Used in Model**
Protect Fish & Wildlife Habitat	13	13	
Protect Water Quality	20	20	
Protect Shoreland	15	15.2	
Protect Timber & Protected Land	18	18	
Reduce Erosion & Runoff	19	19	
Minimize Interference with Ag Land	15	15	
Improve Fish & Wildlife Habitat	22		22
Improve Water Quality	18		18
Restore Shoreland	18		17.6
Reduce Erosion & Runoff	22		22
Restore Ag Land	20		20
Fine-scale Prioritization			
Protect Rare Features	9.2	1.2	2.0
Protect Sites of biodiversity significance	17.0	2.1	3.8
Protect/Restore Sensitive lakeshores	20.4	2.6	4.5
Protect/Restore Lakes of biological significance	21.6	2.7	4.8
Protect High value forests	14.7	1.8	3.3
Protect/Restore Ecological connections	17.1	2.1	3.8
Focus on Impaired waters	15.3	1.5	1.4
Focus on Catchments with High Pollution	24.8	2.5	2.2
Focus on Catchments of lakes with declining water quality	30.4	3.0	2.7
Focus on Catchments identified at risk (Fisheries)	29.5	2.9	2.6
Focus on Drinking water management supply areas	23.3	2.3	2.1
Focus on Groundwater contamination susceptibility	28.8	2.9	2.6
Focus on Areas with high erosive potential	21.8	2.2	2.0
Focus on Areas close to water	26.2	2.6	2.3
Protect Riparian areas	33.9	6.5	
Protect Vulnerable lakeshore banks	30.4	5.8	
Protect Existing wetlands	35.7	6.8	
Restore Riparian areas	37.5		11.6
Restore Eroding lakeshore banks	33.8		10.8

Restore Drained wetlands	28.7		
Minimize Interference w/Row Crop Land	33.8	5.1	
Minimize Interference w/Pasture/Hay	66.2	10.0	
Restore Row Crop Land to natural conditions	54.4		10.9
Restore Pasture/Hay Land to natural conditions	45.6		9.1
Protect Timber Lands	39.9	7.3	
Protect Lands Close to Protected Lands	60.1	11.0	

Figure 40. Protection priority map from Zonation analysis (upper). Potential project areas were also identified in the first mapping exercise (lower).

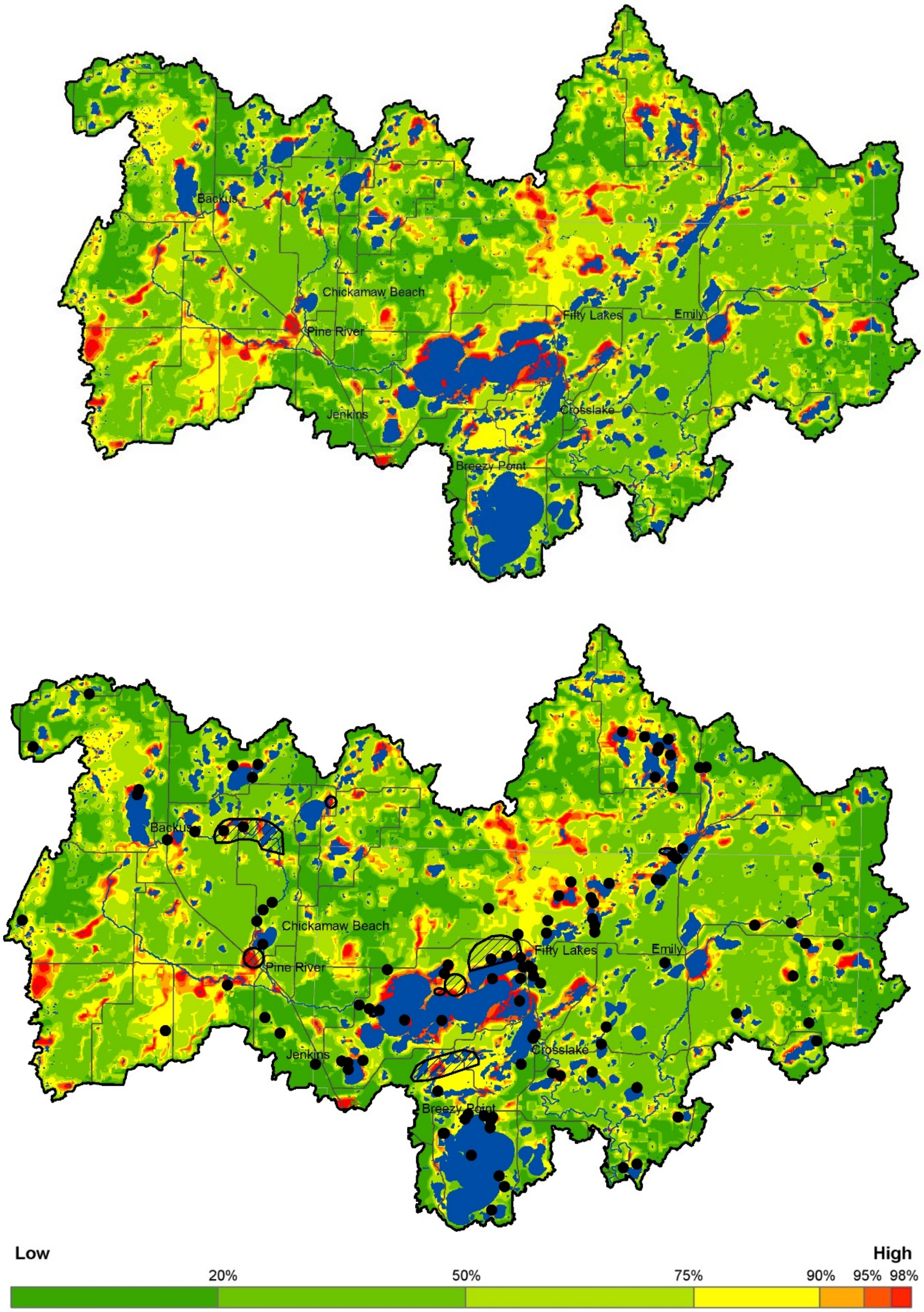


Figure 41. Restoration priority map from Zonation analysis (upper). Potential project areas were also identified in the first mapping exercise (lower).

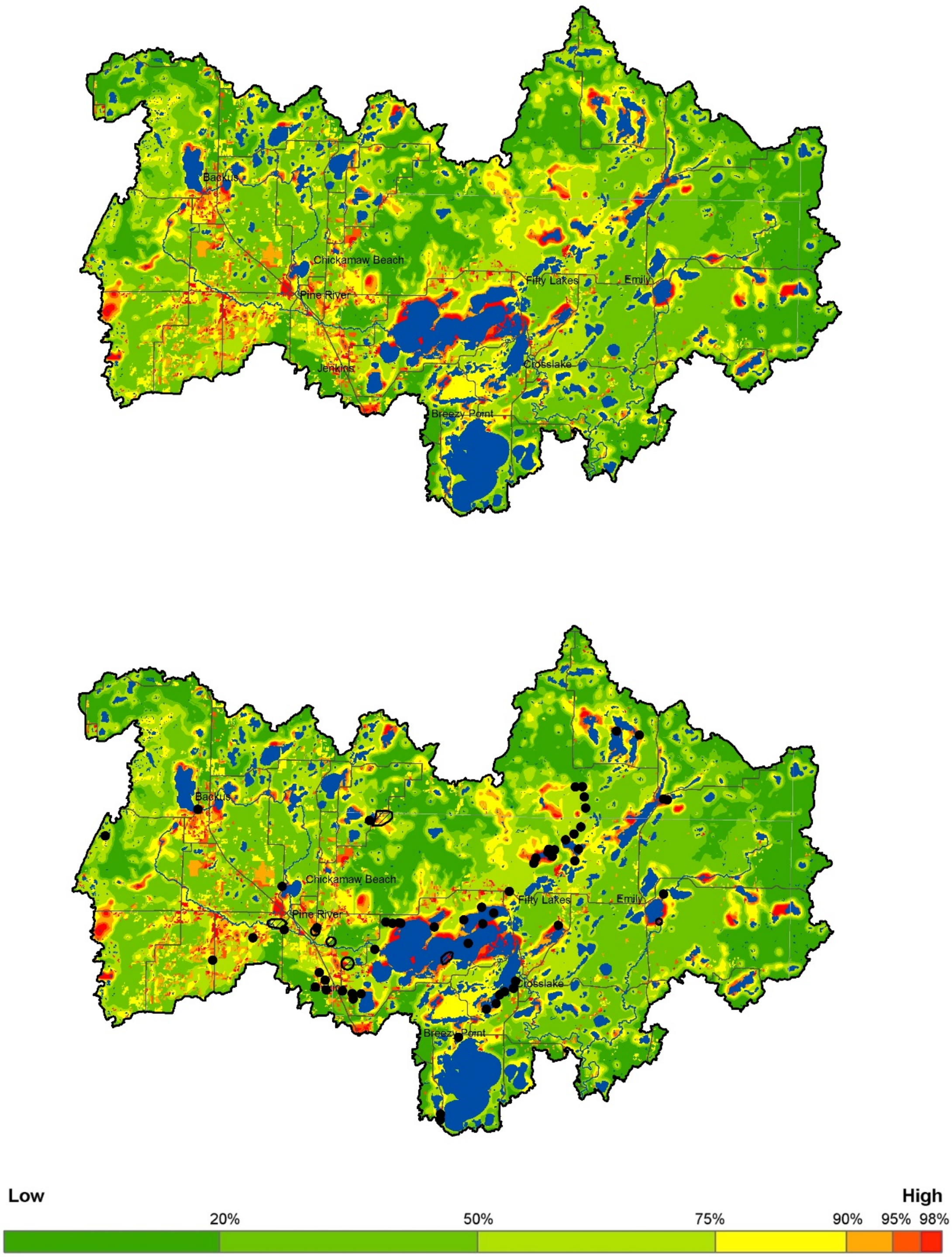


Figure 42. Protection priority map from Zonation analysis and synthesis analysis.

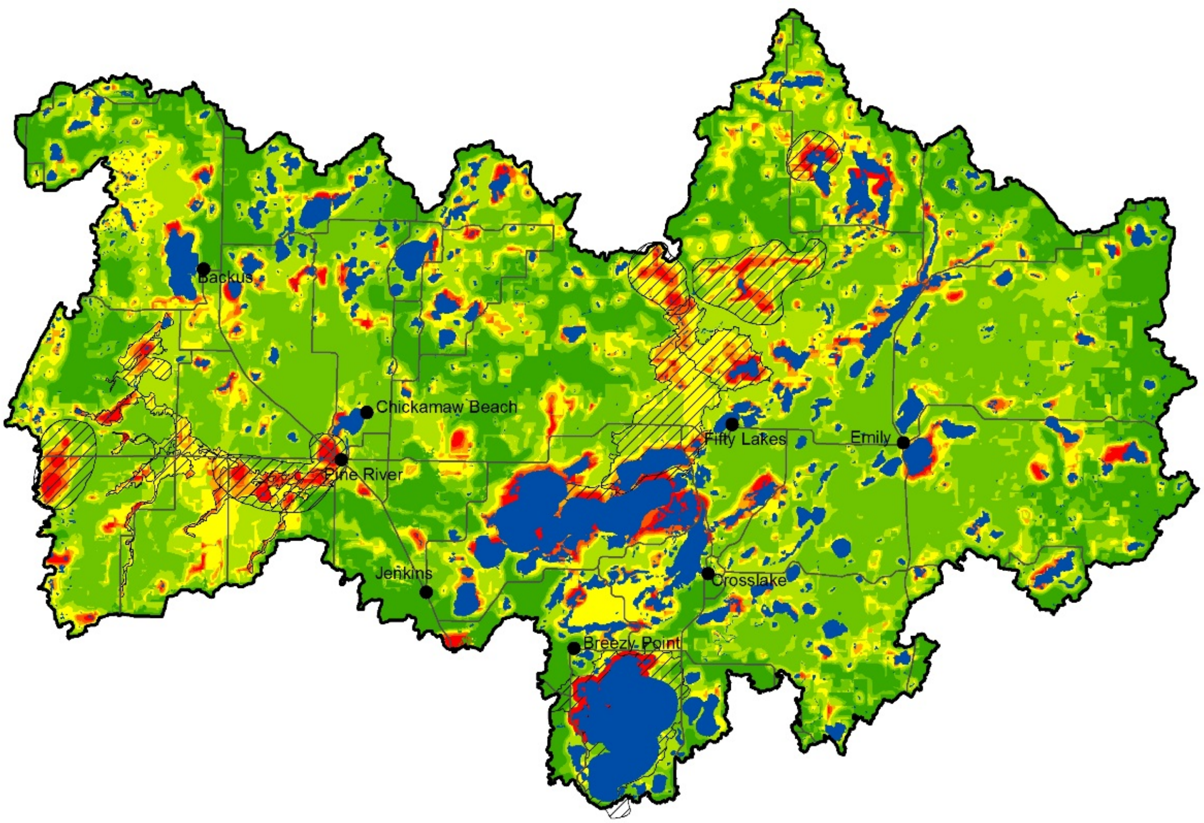
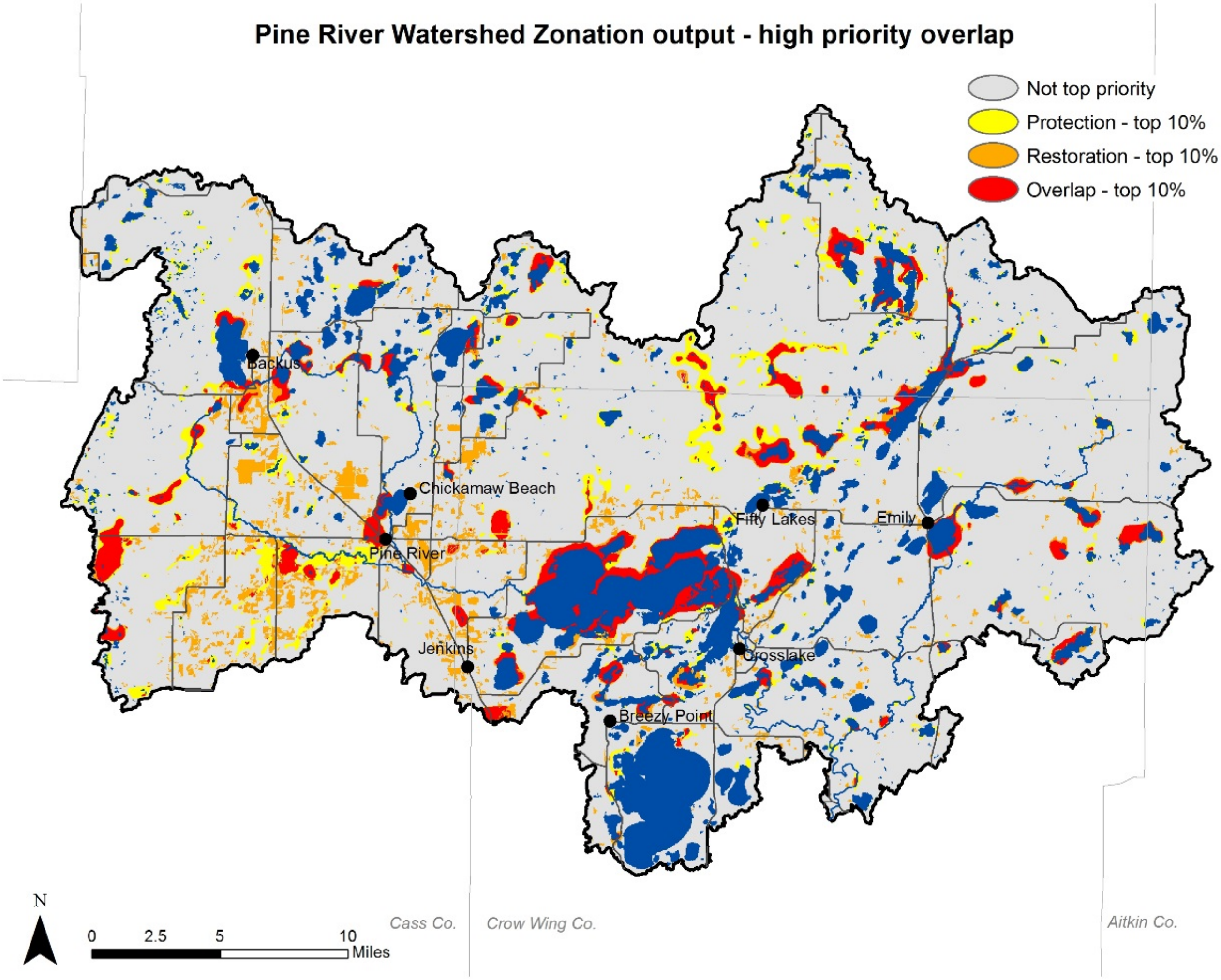


Figure 43. The overlap in protection and restoration Zonation priority maps.



Appendix 4: EOR Lake Prioritization Method

Lake Prioritization

There are 400 lakes or bays larger than 10 acres in the Pine River Watershed. The objective of this method was to prioritize those 400 lakes into a smaller subset of lakes that will be the focus of restoration and protection efforts in the watershed. In addition, phosphorus management strategies and feasible phosphorus load reduction goals were identified for each priority lake to guide the selection of restoration and protection strategies in Section 3.3 of this report.

Prioritization Criteria

Fifty-six priority lakes for protection (**Figure 44**) were chosen based on the criteria of having one or more of the following attributes:

- One of the top 25 largest lakes in the Pine River Watershed by surface area
- DNR designated tullibee (cisco) or trout lake
- Lakes included in the Cass County or Crow Wing County Large Lakes Assessment
- Lakes with an active lake association
- Lakes expected to be assessed as impaired on the 2016 Impaired Waters List

Descriptions, data sources, and categories of lake characteristics used to prioritize the lakes in the Pine River Watershed are summarized in **Table 19**. Table 20 and 5 accompanying maps summarize the lake physical characteristics, biological attributes (Figure 45), trophic state (Figure 46), long-term water quality trends (Figure 47), watershed loading approximation (**Figure** 48), and number of upstream lakes (Figure 49) of the 56 priority lakes.

Phosphorus Management Strategies

Based on certain lake characteristics, the 56 priority lakes were further categorized by one of the following phosphorus management strategies (Table 21) to guide later selection of restoration and protection strategies (see Section 3.3):

- **Monitor**: Existing in-lake water quality is unknown and a monitoring plan should be developed.
- **Restoration**: In-lake water quality does not meet state water quality standards and water quality is expected to be strongly influenced by in-lake and watershed phosphorus loads
- **In-Lake Load Management**: In-lake water quality is expected to be most strongly influenced by in-lake aquatic plant and fish population dynamics and in-lake sediment phosphorus release (internal loading)
- **Upstream Load Management**: In-lake water quality is expected to be most strongly influenced by upstream lake phosphorus loads
- **Mixed Load Management**: In-lake water quality is expected to be equally influenced by watershed phosphorus loads and upstream lake phosphorus loads
- **Watershed Load Management**: In-lake water quality is expected to be most strongly influenced by watershed phosphorus loads

In addition, maps identifying watershed flow accumulation lines and basins were created in GIS using digital elevation models for the entire Pine River Watershed that can be used by local agencies and partners to more specifically target BMP locations throughout the watershed (see **Appendix A**).

Phosphorus Load Reduction Goals

Phosphorus load reduction goals and/or BMP recommendations are needed for the priority lakes with a restoration, watershed, or mixed management focus to guide the targeting and prioritization of BMP implementation and for grant applications by local agencies and partners.

Monitoring and BMPs recommendations are provided in **Lake Protection Reports** completed by RMB Environmental Laboratories in collaboration with the Minnesota BWSR, Cass County Environmental Services, and Crow Wing County for the following 15 priority lakes with a mixed or watershed phosphorus load management focus. The RMB Lake Protection Reports are publicly available online at the following websites: Cass County Lake Water Quality webpage (http://www.co.cass.mn.us) and Crow Wing County Large Lake Assessments webpage (http://www.crowwing.us/705/Large-Lake-Assessments).

- Big Portage (11-0308-00)
- Big Trout (18-0315-00)
- Cross Lake Reservoir (18-0312-00)
- Emily (18-0203-00)
- Horseshoe (18-0251-00)
- Lower Hay (18-0378-00)
- Mitchell (18-0294-00)
- Norway (11-0307-00)
- Ossawinnamakee (18-0352-00)
- Pelican (18-0308-00)
- Roosevelt (11-0043-00)
- Ross (18-0165-00)
- Upper Hay (18-0412-00)
- West Fox (18-0297-00)
- Whitefish (18-0310-00)

Phosphorus load reduction goals are provided for the following 13 priority lakes with a mixed or watershed management focus in the **2012 Whitefish Chain of Lakes Clean Water Partnership Diagnostic Study** completed by the MPCA and WAPOA.

- Arrowhead (18-0366-00)
- Bertha (18-0355-00)
- Big Trout (18-0315-00)
- Clamshell (18-0356-00)
- Cross Lake Reservoir (18-0312-00)
- Daggett (18-0271-00)
- Island (18-0269-00)
- Little Pine (18-0266-00)
- Lower Hay (18-0378-00)
- Pig (18-0354-00)
- Rush (18-0311-00)
- Upper Hay (18-0412-00)
- Whitefish (18-0310-00)

For the remaining 22 priority lakes with a restoration, mixed or watershed management focus not included in an existing assessment report, phosphorus load reductions (**Table 22**) were calculated from the management of cropland, developed land covers (urban), feedlots, and septic systems in the direct drainage area of each lake (located downstream of an upstream lake) based on the assumptions listed in Table 23 and Table 24.

- Ada (11-0250-00)
- Clear (18-0364-00)
- Deep Portage (11-0237-00)
- Eagle (11-0342-00)
- East Fox (18-0298-00)
- George (11-0101-00)
- Goodrich (18-0226-00)
- Jail (18-0415-00)
- Kego (18-0293-00)
- Kimball (18-0361-00)
- Lawrence (11-0053-00)
- Leavitt (11-0037-00)
- Mitten (11-0114-00)
- O'Brien (18-0227-00)
- Ox (18-0288-00)
- Pine Mountain (11-0411-00)
- Ruth (18-0212-00)
- Smokey Hollow (18-0220-00)
- Star (18-0359-00)
- Sylvan (11-0246-00)
- Velvet (18-0284-00)
- Washburn (11-0059-00)

Table 19. Lake characteristic description, data source, and categories

Characteristic	Description	Data Source	Categories
Surface Area (ac)	The surface area of each individual lake in acres	DNR Data Deli	None
Surface Area (%ile)	The percentile of the individual lake surface area compared to the Minnesota Lake Water Quality Assessment Data for the Northern Lakes and Forest & Northern Minnesota Wetlands ecoregion	Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria, Third Edition	5 %ile < 15 acres 10 %ile < 22 acres 25 %ile < 49 acres 50 %ile < 129 acres 75 %ile < 347 acres 90 %ile < 835 acres 95 %ile < 1,654 acres >95 %ile >= 1,654 acres
Max Depth (feet)	The maximum depth of each individual lake in feet	DNR Data Deli MPCA Assessment Data	Horizontal bars scaled between the smallest and largest maximum depth of all lakes listed in the table
Tullibee	Lakes that support populations of tullibee (cisco or lake herring). These coldwater fish provide excellent forage for trophy walleye, northern pike, muskellunge, and lake trout. They require cold, well-oxygenated water of deep, high water quality lakes.	The Minnesota DNR Fisheries Research Unit, in conjunction with the University of Minnesota, has identified tullibee refuge lakes in Minnesota that are deep and clear enough to sustain tullibees even after climate warming occurs.	Yes or no
Trout	DNR designated trout lake	Minnesota Rules 6264.0050	Yes or no
Wild Rice	DNR designated wild rice lake	Minnesota DNR statewide inventory of wild rice waters (2008-02-15)	Yes or no
LLIR	Lakes that are located in the Leech Lake Indian Reservation	Reservation boundary downloaded from MnDOT http://www.dot.state.mn.us/maps/gdma/gis-data.html	Yes or no
HSPF	Lakes that were explicitly modeled in the Leech Lake River Watershed HSPF model	HSPF model supporting documentation (RESPEC)	Yes or no
Lake Assoc.	Lakes with known lake associations	RMB Lake Summary Reports, Cass County website, Crow Wing County website, and individual lake association websites.	Yes or no
Trophic Index	The average of the total phosphorus, chlorophyll-a, and Secchi depth Carlson Trophic State Indices.	Calculated	**Oligotrophic (light blue)**: TSI < 40 **Mesotrophic (light green)**: TSI 40-50 **Eutrophic (dark green)**: TSI 50-70
Nutrients (TP) (ppb), Algae (Chl-a) (ppb), and Clarity (ft)	The 10-year (2004-2013) growing season (June-September) mean total phosphorus (TP) concentration in parts per billion (ppb), chlorophyll-a (Chl-a) concentration in parts per billion (ppb), and Secchi transparency depth (a measure of water clarity) in feet (ft)	MPCA EQuIS database	None
Nutrients (TP), Algae (Chl-a), and Clarity (%ile)	The percentile of the 10-year growing season mean average compared to the Minnesota Lake Water Quality Assessment Data for the Northern Lakes and Forest & Northern Minnesota Wetlands ecoregion	Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria, Third Edition	5 %ile < 7 ppb TP, 2 ppb Chl-a, and 0.9 m Secchi 10 %ile < 9 ppb TP, 2 ppb Chl-a, and 1.2 m Secchi 25 %ile < 13 ppb TP, 3 ppb Chl-a, and 1.8 m Secchi 50 %ile < 21 ppb TP, 5 ppb Chl-a, and 2.8 m Secchi 75 %ile < 30 ppb TP, 8 ppb Chl-a, and 4.0 m Secchi 90 %ile < 45 ppb TP, 14 ppb Chl-a, and 5.1 m Secchi 95 %ile < 58 ppb TP, 22 ppb Chl-a, and 5.9 m Secchi >95 %ile >= 58 ppb TP, 22 ppb Chl-a, and 5.9 m Secchi
Clarity RMB	Long-term trend of lake water transparency	Mann Kendall Trend Analysis of >8 years of MPCA Secchi transparency depth data with 4 or more readings per season reported by RMB Environmental Laboratories in the Cass County and Crow Wing County Large Lake Assessment reports.	**Up Arrow**: improving trend **Right Arrow**: no evidence of trend **Down Arrow**: declining trend **No Arrow**: insufficient data for trend analysis
CWP Study	Included in the 2012 Whitefish Chain of Lakes Clean Water Partnership Diagnostic Study	MPCA and WAPOA	Yes or no

Characteristic	Description	Data Source	Categories
Protection Report	Lake Protection Report that summarizes lake water quality and lakeshed data, and provides monitoring and BMPs recommendations	RMB Environmental Laboratories Cass County Lake Water Quality (www.co.cass.mn.us/esd/water_quality.html) Crow Wing County Large Lake Assessments (crowing.us/index.aspx?NID=705)	Yes or no
Lakeshed Assess.	Lake Report that summarizes lake water quality and lakeshed data but does not provide monitoring and BMPs recommendations		Yes or no
Sensitive Shore Study	Sensitive shoreline areas that provide unique or critical ecological habitat have been identified using DNR sensitive lakeshore protocols: field surveys to assess habitat quality and use by high priority animal species, an ecological model that objectively incorporates various field assessments into a sensitivity index, and the compilation and delivery of information on sensitive lakeshores to various land and resource managers.	DNR Sensitive Lakeshore Identification website: http://www.dnr.state.mn.us/eco/sli/index.html	Yes or no
Poor U/S Lake WQ	Lakes that have a smaller 10-year growing season mean TP concentration than the next most upstream lake(s)	Calculated	**Red symbol**: next most upstream lake TP is at least 4 ppb greater than the lake TP **Yellow symbol**: next most upstream lake TP > lake TP **Green symbol**: next most upstream lake TP <= lake TP **No symbol**: no TP data for either the next most upstream lake or the lake
Upstream Load	An estimate of the relative fraction of phosphorus load originating from upstream lakes compared to the direct drainage area based on the approximate number of lakes located upstream that are connected in part by surface water to the lake	HSPF model subbasin and reach shapefiles	**Red symbol**: > 20 lakes are located upstream **Yellow symbol**: 10-19 lakes are located upstream **Green symbol**: < 10 lakes are located upstream
Directly U/S Lakes	The number of lakes that are located directly upstream of the lake and connected in part by surface water	HSPF model subbasin and reach shapefiles	**Red symbol**: 3 or more lakes located directly upstream **Yellow symbol**: 2 lakes located directly upstream **Green symbol**: 0-1 lakes located directly upstream
Watershed: Surface	The ratio of the estimated total watershed area to lake surface area	DNR lake catchment shapefiles (It was assumed that all of the catchment area contributes drainage to each located in the catchment, even if more than one lake was located in the catchment)	**Red symbol**: > 20 watershed to surface area ratio **Yellow symbol**: 10-19 watershed to surface area ratio **Green symbol**: < 10 watershed to surface area ratio
% Littoral	The percent of the littoral (water depths < 15 feet) zone area compared to the total lake surface area	DNR Data Deli	Horizontal bar scaled between 0% and 100% of littoral zone
Fisheries Focus	Suggested approaches for watershed protection and restoration of DNR managed fish lakes in Minnesota	Peter Jacobson and Michael Duval, DNR Fisheries Research Unit	**Vigilance**: Watershed disturbance < 25% and watershed protection > 75%. Sufficiently protected. Water quality supports healthy and diverse fish communities. Keep public lands protected. **Protection**: Watershed disturbance < 25% and watershed protection < 75%. Excellent candidates for protection. Water quality can be maintained in a range that supports healthy and diverse native fish communities. Disturbed lands should be limited to less than 25%.

Table 20. Attributes of 56 priority lakes

LAKE	BAY	ID	COUNTY	SURFACE AREA (acres)	MAX DEPTH (feet)	TULLIBEE	TROUT	WILD RICE	HSPF	LAKE ASSOC.	TROPHIC INDEX	NUTRIENTS (TP) (ppb)	NUTRIENTS (TP) (%ile)	ALGAE (CHL-A) (ppb)	ALGAE (CHL-A) (%ile)	CLARITY (ft)	CLARITY RMB	CLARITY (%ile)	CWP Study	Protection Report	Lakeshed Assess.	Sensitive Shore Study	POOR U/S LAKE WQ	UPSTREAM LOAD		DIRECTLY U/S LAKES		WSHED: SURFACE		% LITTORAL	FISHERIES FOCUS
Pelican		18030800	Crow Wing	8,367	104	❘			❘	❘	34	12	G	3.6	Y	17	→	G		❘	❘	❘	G	G	1	G	0	G	2	63	Protection
Whitefish		18031000	Crow Wing	7,715	138	❘		❘	❘	❘	38	16	Y	4.8	Y	12	↓	Y	❘	❘	❘	❘	R	R	29	R	7	G	1	43	Protection
Cross Lake Reservoir		18031200	Crow Wing	1,787	84				❘	❘	36	15	Y	3.3	Y	14	→	G	❘	❘	❘	❘	R	R	50	Y	2	G	2	51	Protection
Pine Mountain		11041100	Cass	1,612	78			❘	❘		39	18	Y	5.8	Y	12		Y			❘	❘	G	G	5	G	1	G	5	38	Protection
Washburn		11005900	Cass	1,590	110	❘		❘	❘		37	14	Y	5.0	Y	13	↑	G			❘	❘	R	G	3	G	1	G	5	44	Protection
Roosevelt	S Bay	11004302	Cass	1,511	129	❘	❘			❘	38	17	Y	4.8	Y	12	↑	Y		❘	❘	❘	Y	G	3	Y	2	Y	11		Protection
Roosevelt	N Bay	11004301	Cass	1,511	129	❘	❘			❘	38	17	Y	4.4	Y	13	→	G		❘	❘	❘	G	G	3	G	0	Y	11		Protection
Big Trout		18031500	Crow Wing	1,363	128	❘	❘		❘	❘	32	11	G	2.8	G	21	↓	G	❘	❘	❘	❘	G	G	1	G	0	G	6	37	Protection
Ada		11025000	Cass	963	60				❘	❘	34	11	G	3.6	Y	14	↑	G			❘	❘	G	G	1	G	0	G	3	54	Protection
Horseshoe	E Bay	18025101	Crow Wing	922	40					❘	36	13	Y	5.3	Y	15	→	G		❘	❘		G	G	1	G	0	G	2		Protection
Horseshoe	W Bay	18025102	Crow Wing	922	55					❘	37	15	Y	5.1	Y	14	→	G		❘	❘		G	G	1	G	0	G	2		Protection
Big Portage	E Bay	11030802	Cass	902	12						42	20	Y	5.5	Y	8	→	Y		❘	❘	❘	G	G	1	G	0	G	8	100	Protection
Big Portage	W Bay	11030801	Cass	902	19						46	27	Y	14.5	R	8	→	Y		❘	❘	❘	G	G	1	G	0	G	8	98	Protection
Rush		18031100	Crow Wing	858	105	❘			❘	❘	35	13	G	3.7	Y	14	↓	G	❘		❘	❘	Y	R	30	G	1	G	4	57	Protection
Emily		18020300	Crow Wing	722	13			❘	❘	❘	40	23	Y	3.5	Y	9	↓	Y		❘	❘		R	G	7	G	1	G	8	100	Protection
Lower Hay		18037800	Crow Wing	693	100	❘	❘		❘	❘	34	11	G	2.8	G	14	→	G	❘	❘	❘	❘	R	G	2	G	1	G	8	23	Protection
Ossawinnamakee		18035200	Crow Wing	691	63	❘		❘	❘	❘	35	18	Y	2.4	G	17	↑	G		❘	❘		G	G	3	Y	2	R	28	46	Protection
George		11010100	Cass	607	20			❘	❘		51	33	R	25.1	R	6		R					G	G	2	G	1	R	25	100	Vigilance
Ruth		18021200	Crow Wing	599	39				❘	❘	39	23	Y	4.6	Y	15		G			❘		G	G	1	G	0	G	4	43	Protection
Upper Hay		18041200	Crow Wing	596	42			❘	❘	❘	45	34	R	7.0	Y	8	→	Y	❘	❘	❘		G	G	1	G	0	R	25	45	Protection
Hattie		11023200	Cass	590	30			❘	❘		42	18	Y	9.9	R	9		Y					G	Y	12	Y	2	G	7	42	Protection
Norway		11030700	Cass	515	13			❘	❘	❘	46	31	R	10.7	R	8	→	Y		❘	❘		G	R	20	Y	2	R	24	100	Protection
Ross		18016500	Crow Wing	492	31				❘	❘	52	22	Y	19.7	R	3	→	R		❘	❘		G	G	1	G	0	Y	19	64	Protection
West Fox		18029700	Crow Wing	449	55	❘				❘	36	17	Y	3.5	Y	16	→	G		❘	❘		R	G	2	G	1	Y	12	31	Vigilance
Mitchell		18029400	Crow Wing	429	78			❘		❘	39	19	Y	2.2	G	6	→	Y		❘	❘		G	Y	11	R	3	R	54	28	Protection
Pine		18026100	Crow Wing	426	17			❘			41	23	Y	6.2	Y	11		Y					G	R	57	R	3	Y	20	99	Protection
Mary		18018500	Crow Wing	413	34					❘	45	29	Y	5.2	Y	6		R					R	G	6	Y	2	Y	17	25	Protection
Goodrich		18022600	Crow Wing	382	35			❘		❘	37	18	Y	3.1	Y	13		Y					G	G	4	G	1	Y	18	66	Protection
Bertha		18035500	Crow Wing	337	70	❘			❘	❘	37	16	Y	3.5	Y	13		G	❘			❘	Y	G	2	G	1	G	2	37	Protection
Little Pine		18026600	Crow Wing	330	36			❘	❘	❘	41	19	Y	7.0	Y	10		Y	❘			❘	G	Y	17	Y	2	R	25	54	Protection
Arrowhead		18036600	Crow Wing	296	12			❘		❘	44	26	Y	7.8	Y	8		Y	❘			❘	G	G	1	G	0	R	31	100	Protection
Kego		18029300	Crow Wing	296	20				❘	❘	46	33	R	8.8	R	7		Y					G	G	1	G	0	R	21	63	Vigilance
Daggett		18027100	Crow Wing	258	25				❘	❘	42	19	Y	8.0	R	10		Y	❘			❘	G	Y	19	G	1	R	32	52	Protection
East Fox		18029800	Crow Wing	241	65	❘				❘	32	14	Y	1.7	G	17		G					Y	G	3	G	1	R	23	46	Vigilance
Ox		18028800	Crow Wing	241	74					❘	31	11	G	2.2	G	21		G					G	G	0	G	0	G	7	55	Protection
Island		18026900	Crow Wing	232	76	❘				❘	35	12	G	3.3	Y	15		G	❘			❘	G	G	1	G	0	G	2	54	Protection
Clear		18036400	Crow Wing	226	63	❘				❘	32	8	G	3.3	Y	17		G					G	G	0	G	0	G	7	27	Protection
Lawrence		11005300	Cass	225	71					❘	41	20	Y	5.1	Y	9		Y				❘	G	G	2	G	1	R	38	41	Vigilance
Clamshell		18035600	Crow Wing	211	44				❘	❘	38	18	Y	4.6	Y	14		G	❘			❘	G	G	1	G	0	G	3	70	Protection
Butterfield		18023100	Crow Wing	194	20			❘		❘	37	17	Y	4.2	Y	14		G					G	G	0	G	0	G	7		Protection
Kimball		18036100	Crow Wing	190	77	❘					35	15	Y	2.8	G	14		G					G	G	0	G	0	G	9	43	Protection
O'Brien	NE Bay	18022702	Crow Wing	186	49					❘	31	11	G	2.0	G	19		G					R	G	5	G	1	R	37	38	Protection
Pig		18035400	Crow Wing	181	56	❘			❘	❘	37	17	Y	3.8	Y	13		Y	❘			❘	G	G	1	G	0	R	230	37	Protection
Jail		18041500	Crow Wing	180	22			❘			54	52	R	29.1	R	4		R					G	G	1	G	0	R	23	33	Protection
Velvet		18028400	Crow Wing	167	29			❘		❘	38	18	Y	3.4	Y	11		Y					G	G	0	G	0	G	3	50	Protection
Deep Portage		11023700	Cass	129	105	❘					33	11	G	2.5	G	15		G				❘	G	G	0	G	0	Y	12		Vigilance
Star		18035900	Crow Wing	127	83	❘				❘	33	11	G	2.7	G	16		G					G	G	0	G	0	Y	10		Protection
Smokey Hollow		18022000	Crow Wing	125	25					❘	42	19	Y	5.2	Y	7		Y					G	G	0	G	0	Y	12		Protection
Leavitt		11003700	Cass	122	60					❘	39	19	Y	3.1	Y	9		Y					G	G	1	G	0	R	67	29	Vigilance
Eagle		11034200	Cass	118	10					❘	32	11	G	1.6	G	13		Y					G	G	0	G	0	R	23		Protection
Sylvan		11024600	Cass	113	26						35	13	Y	3.4	Y	15		G					G	G	1	G	0	R	29		Protection
Mitten		11011400	Cass	113	28						54	37	R	21.9	R	3		R					G	G	0	G	0	G	9		Protection
Allen		18020800	Crow Wing	44	46		❘																	G	0	G	0	R	217	45	
Little Andrus		11005400	Cass	27	25		❘																	G	0	G	0	R	469	55	
Pleasant		18027800	Crow Wing	22	69		❘																	G	0	G	0	R	58	39	
Strawberry		18036300	Crow Wing	20	41		❘																	G	1	G	0	R	988		
Margaret		11004500	Cass	18	49		❘																	G	0	G	0	R	424		
Marion		11004600	Cass	12	55		❘																	G	0	G	0	R	665		
Willard		11056400	Cass	8	?		❘																	G	0	G	0	R	214		

Table 21. Phosphorus load management strategy for the 56 priority lakes in the Pine River Watershed

Bold lake names indicate lakes with a completed RMB Laboratories Lake Protection Plan or were included in the 2012 Whitefish Chain of Lakes Clean Water Partnership Diagnostic Study and Implementation Plan.

Phosphorus Load Management Strategy	Priority Lakes		Rationale	Lake Characteristics	Protection Strategies
Monitor (7 lakes)	Allen (18-0208-00) Little Andrus (11-0054-00) Margaret (11-0045-00) Marion (11-0046-00)	Pleasant (18-0278-00) Strawberry (18-0363-00) Willard (11-0564-00)	Existing in-lake water quality is unknown and a monitoring plan should be developed	No TP data	Water quality monitoring
Restoration (3 lakes)	Jail (18-0415-00) Kego (18-0293-00)	Mitten (11-0114-00)	In-lake water quality does not meet state water quality standards	TP > 30 AND Chl-a > 9 OR Secchi < 2.0	TMDL and restoration
In-Lake (3 lakes)	**Big Portage (11-0308-00)** Butterfield (18-0231-00)	**Emily (18-0203-00)**	In-lake water quality is expected to be most strongly influenced by in-lake aquatic plant and fish population dynamics, and/or sediment phosphorus release (internal loading)	watershed to surface area ratio < 10 AND > 80% littoral area OR maximum depth < 20 feet	In-lake aquatic plant and fish management
Upstream (9 lakes)	**Cross Lake Reservoir (18-0312-00)** **Daggett (18-0271-00)** Hattie (11-0232-00) **Little Pine (18-0266-00)** Mary (18-0185-00)	**Ossawinnamakee (18-0352-00)** Pine (18-0261-00) **Rush (18-0311-00)** **Whitefish (18-0310-00)**	In-lake water quality is expected to be most strongly influenced by upstream lake phosphorus loads	> 10 upstream lakes AND/OR > 1 directly upstream lake Greater upstream lake TP concentration	Protecting upstream lake water quality
Mixed (9 lakes)	**Bertha (18-0355-00)** East Fox (18-0298-00) **Lower Hay (18-0378-00)** **Mitchell (18-0294-00)** **Norway (11-0307-00)**	O'Brien (18-0227-00) **Roosevelt (11-0043-00)** Washburn (11-0059-00) **West Fox (18-0297-00)**	In-lake water quality is expected to be equally influenced by watershed phosphorus loads and upstream lake phosphorus loads	< 10 total upstream lakes AND/OR Greater upstream lake TP concentration	Watershed BMPs Protecting upstream lake water quality
Watershed (25 lakes)	Ada (11-0250-00) **Arrowhead (18-0366-00)** **Big Trout (18-0315-00)** **Clamshell (18-0356-00)** Clear (18-0364-00) Deep Portage (11-0237-00) Eagle (11-0342-00) George (11-0101-00) Goodrich (18-0226-00) **Horseshoe (18-0251-00)** **Island (18-0269-00)** Kimball (18-0361-00) Lawrence (11-0053-00)	Leavitt (11-0037-00) Ox (18-0288-00) **Pelican (18-0308-00)** **Pig (18-0354-00)** Pine Mountain (11-0411-00) **Ross (18-0165-00)** Ruth (18-0212-00) Smokey Hollow (18-0220-00) Star (18-0359-00) Sylvan (11-0246-00) **Upper Hay (18-0412-00)** Velvet (18-0284-00)	In-lake water quality is expected to be most strongly influenced by watershed phosphorus loads	All remaining lakes	Watershed BMPs

Figure 44. Priority lakes in the Pine River Watershed

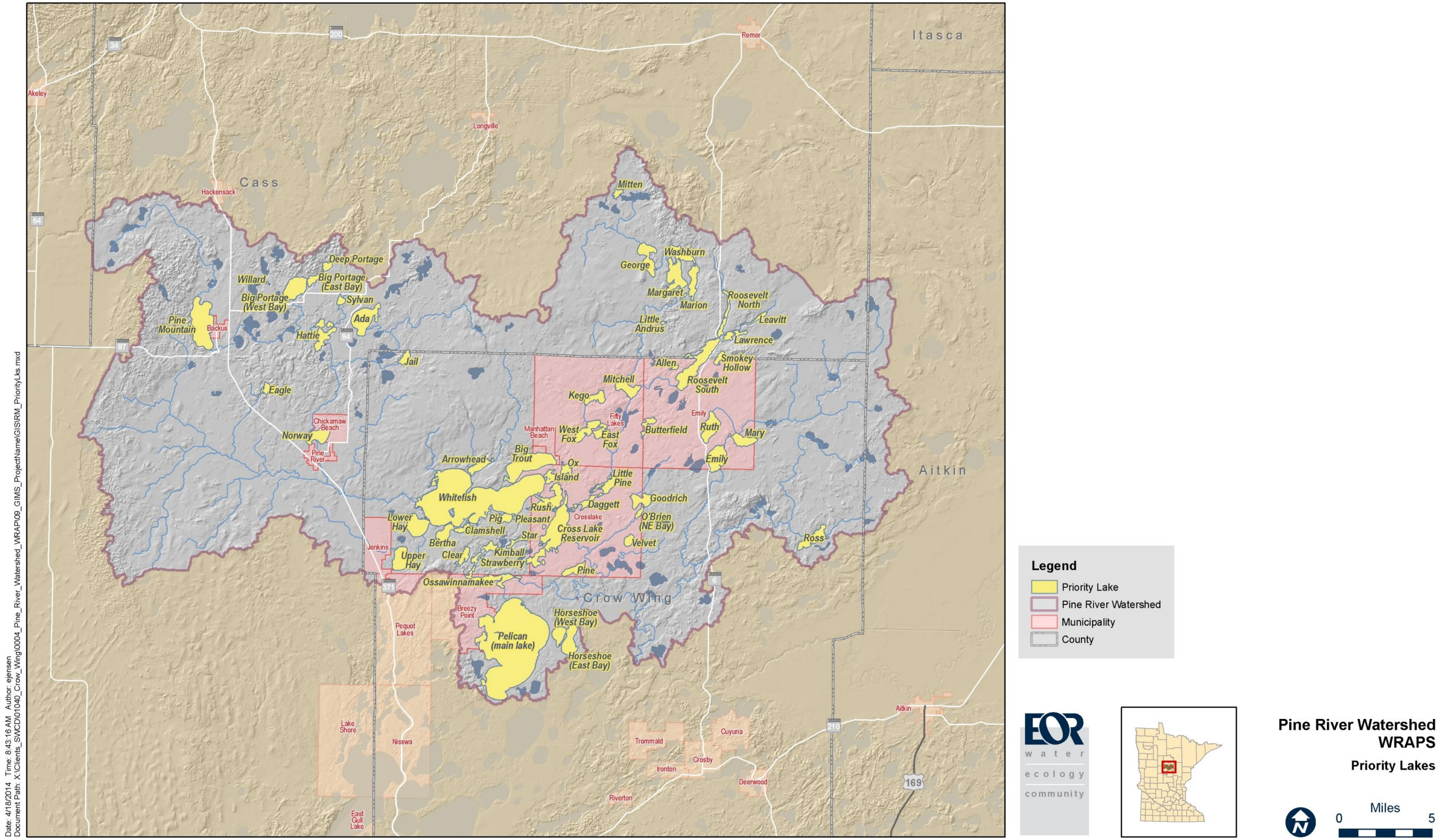


Figure 45. Pine River Watershed DNR designated tullibee (cisco), trout, and/or wild rice priority lakes

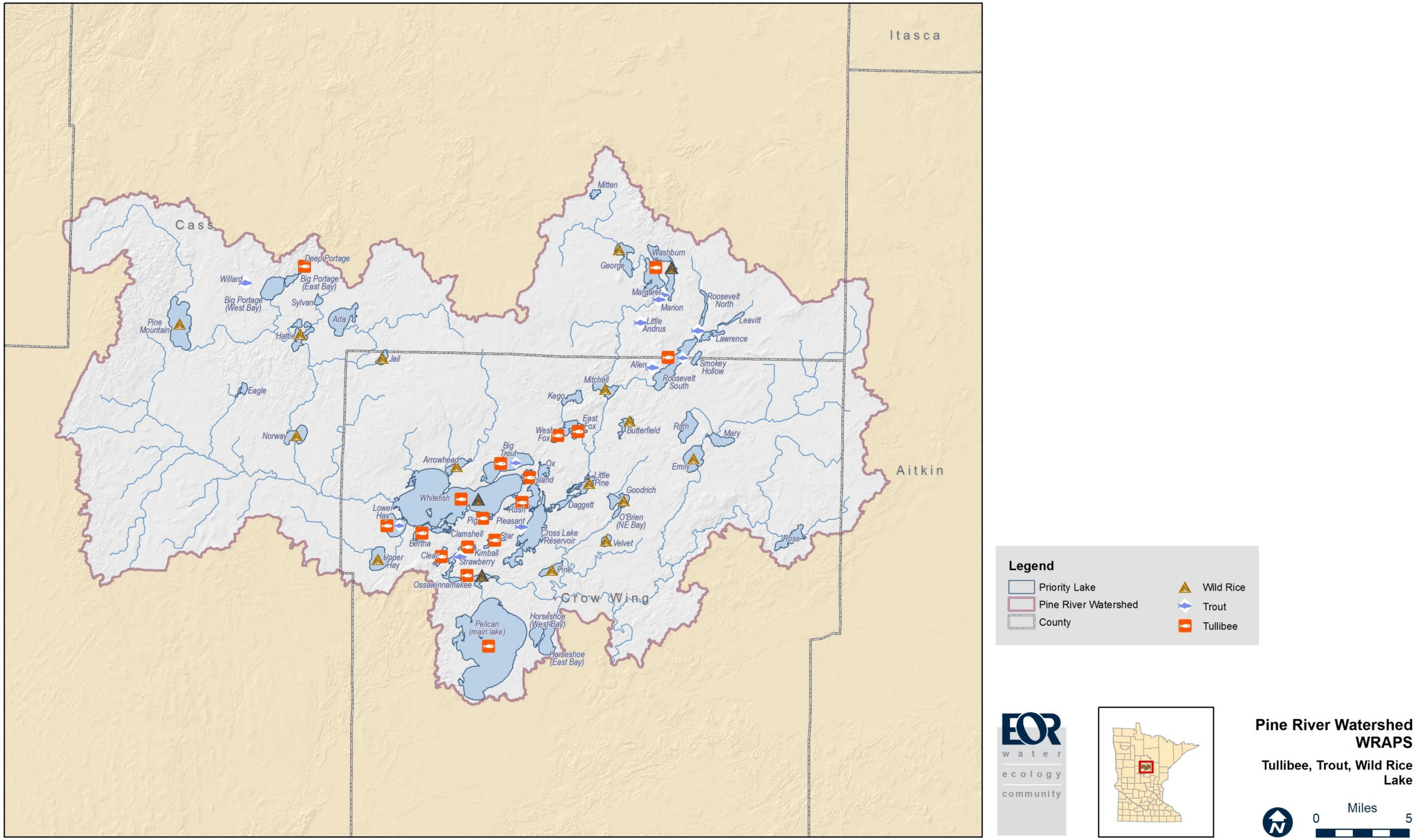


Figure 46. Pine River Watershed priority lake average trophic state

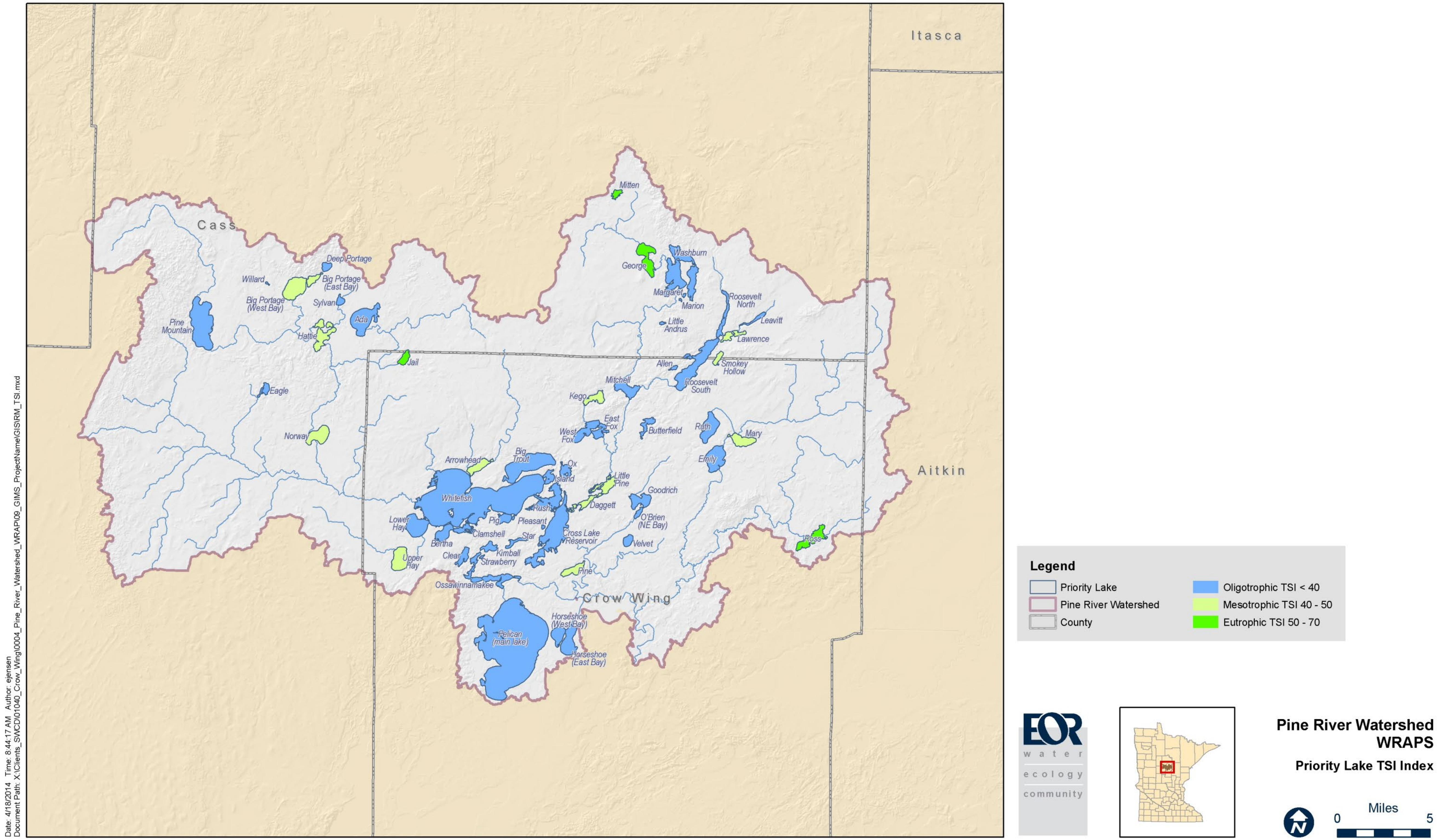


Figure 47. Pine River Watershed priority lake long-term trends in water clarity (RMB Laboratories)

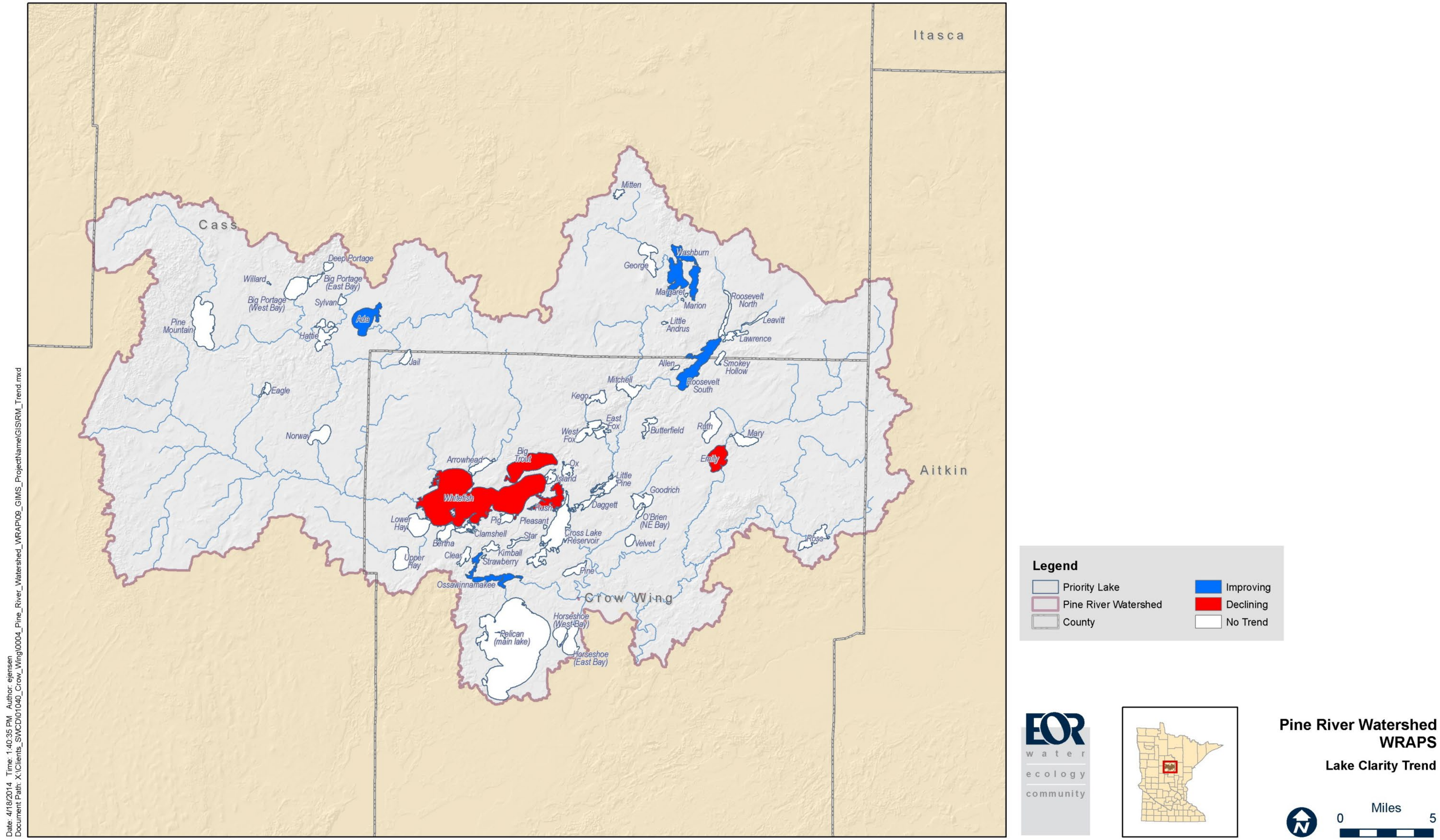


Figure 48. Pine River Watershed priority lakes approximated watershed to lake surface area ratios

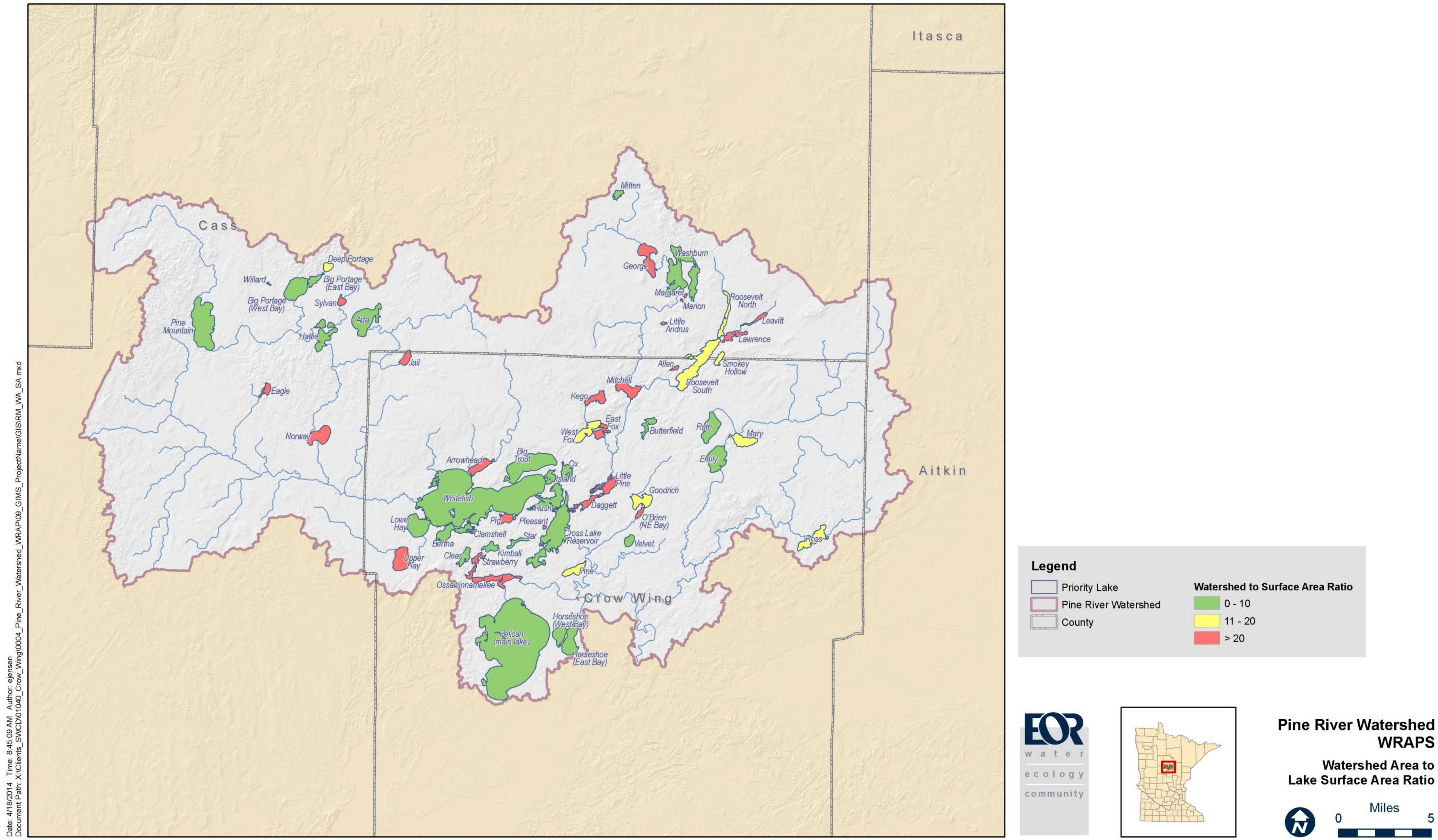


Figure 49. Pine River Watershed priority lakes approximated upstream lake phosphorus load as a proportion of the total phosphorus load

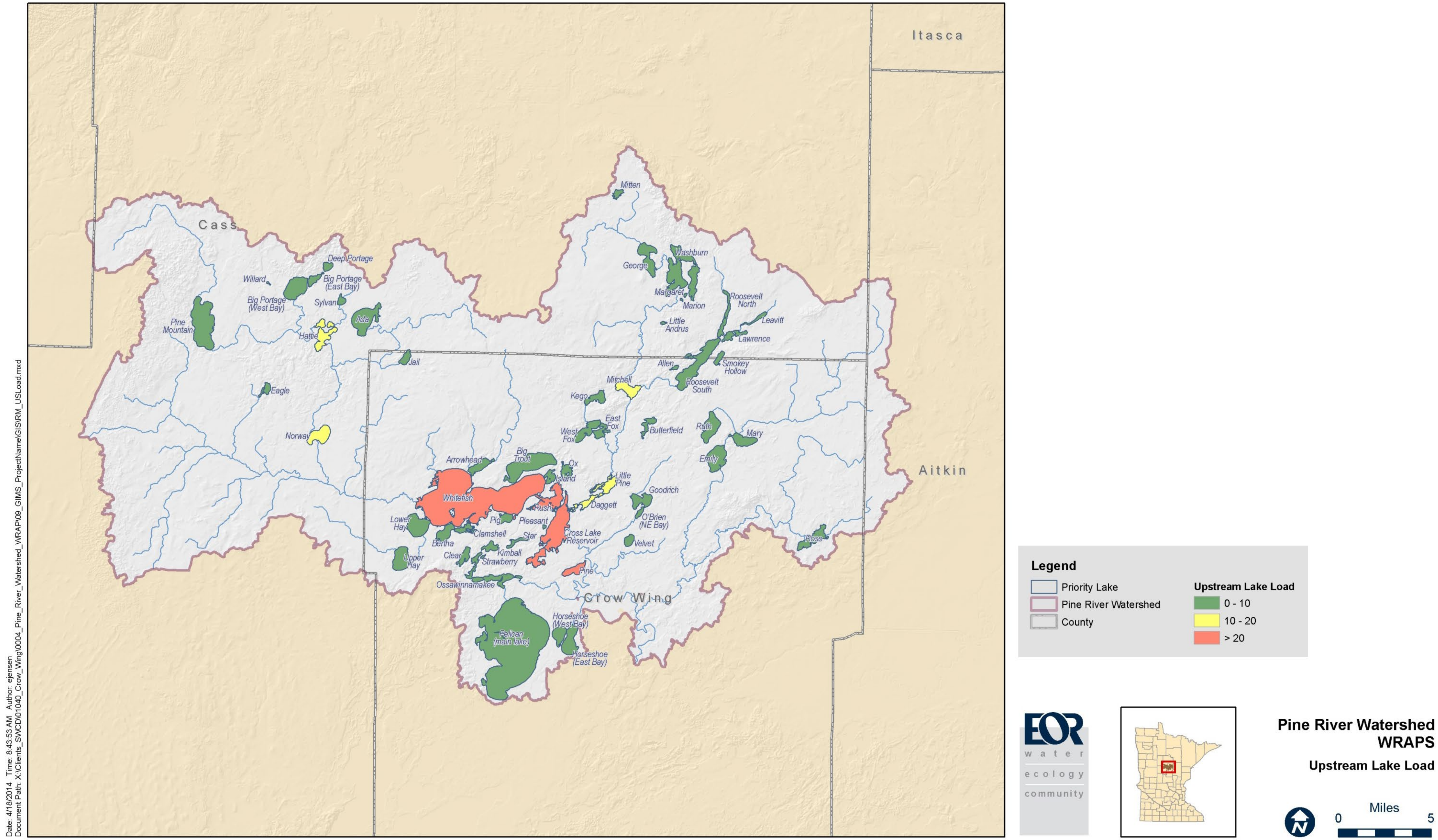


Figure 50. Pine River Watershed priority lakes phosphorus load management strategies

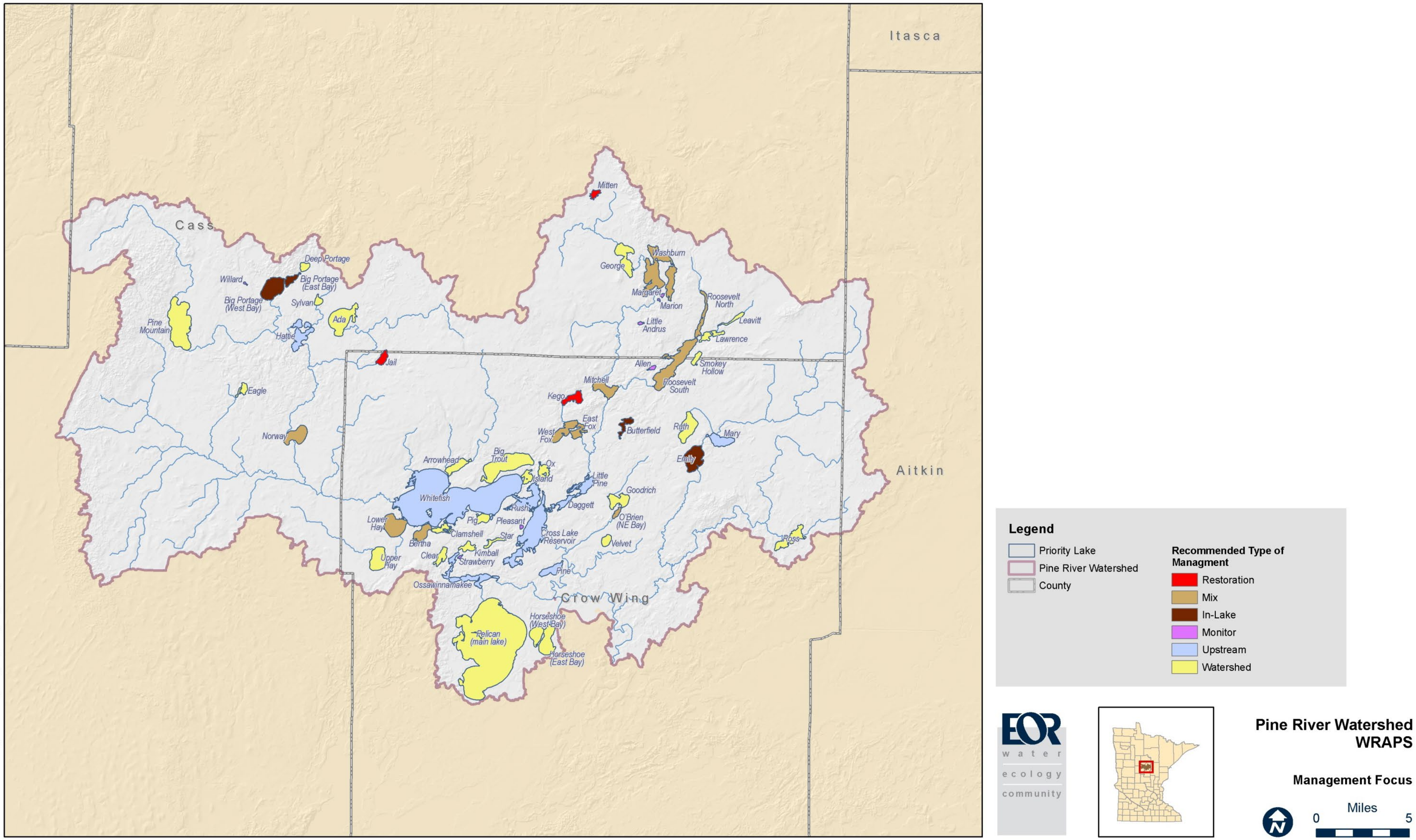


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Table 22. Pine River Watershed priority lake phosphorus load reductions by management category

Lake ID	Lake Name	Direct Drainage Area [ac]	Upstream Lake Load [lb/yr]	Direct Drainage Load [lb/yr]	Cropland Reductions [lb/yr]	Urban Reductions [lb/yr]	Feedlot Reductions [lb/yr]	Septic Reductions [lb/yr]	Total Reductions [lb/yr]	Total Reductions [% Direct DrainageLoad]	Total Reductions [% Total Load]
11025000	**Ada**	2,449	76	258	-	1.8	-	18.0	**19.9**	8%	6%
18036400	**Clear**	1,299	-	126	0.0	2.1	-	4.3	**6.4**	5%	5%
11023700	**Deep Portage**	651	-	63	-	0.4	-	2.1	**2.6**	4%	4%
11034200	**Eagle**	2,595	-	288	0.2	1.1	-	1.4	**2.7**	1%	1%
18029800	**East Fox**	391	118	45	0.2	0.7	-	5.0	**5.9**	13%	4%
11010100	**George**	18,542	44	1,373	0.1	4.9	-	2.5	**7.5**	1%	1%
18022600	**Goodrich**	3,745	86	367	0.6	3.8	0.2	4.7	**9.3**	3%	2%
18036100	**Kimball**	7,717	28	678	0.4	6.9	-	5.9	**13.2**	2%	2%
11005300	**Lawrence**	1,555	250	161	-	1.9	-	11.2	**13.1**	8%	3%
11003700	**Leavitt**	7,964	-	735	-	2.2	-	12.6	**14.7**	2%	2%
18022700	**O'Brien (NE bay)**	381	116	41	-	0.4	-	7.5	**7.9**	19%	5%
18028800	**Ox**	689	-	27	-	0.0	-	2.4	**2.4**	9%	9%
11041100	**Pine Mountain**	26,678	-	1,573	0.8	5.3	-	14.1	**20.2**	1%	1%
18021200	**Ruth**	1,745	-	197	0.0	2.7	-	7.6	**10.4**	5%	5%
18022000	**Smokey Hollow**	1,630	-	153	-	0.2	-	1.0	**1.2**	1%	1%
18035900	**Star**	1,132	-	108	0.0	0.5	-	2.9	**3.4**	3%	3%
11024600	**Sylvan**	3,116	-	354	-	3.2	-	4.0	**7.3**	2%	2%
18028400	**Velvet**	238	-	33	-	0.6	-	2.1	**2.7**	8%	8%
11005900	**Washburn**	5,825	-	539	0.1	2.8	-	36.0	**38.9**	7%	7%
18029300	**Kego**	5,311	-	986	-	2.4	-	1.4	**3.8**	0%	0%
18041500	**Jail**	1,056	-	24	-	0.2	-	1.0	**1.2**	5%	5%
11011400	**Mitten**	377	-	47	-	0.5	-	1.1	**1.5**	3%	3%

Table 23. Priority lake load reduction data sources and assumptions

Implementation Category	Example Activities	Phosphorus Load	Removal Efficiency	Implementation Rate
Cropland Management	Conservation tillage, nutrient management planning, cover crops, and other agricultural BMPs	Area-weighted HSPF modeled load by the percent of cultivated crops land cover (NLCD 2006)	50%	10%
Urban Management	Biofilters (buffers and vegetated swales), rain gardens, and other infiltration BMPs	Area-weighted HSPF modeled load by the percent of developed, open space and developed, low intensity land covers (NLCD 2006)	50%	25%
Feedlot Management	Manure management and rotational grazing	Phosphorus load of total number of registered cattle and dairy cow animal units based on assumptions in MPCA 2004 ()	75%	50%
Septic System Management	Upgrade failing shoreline septic systems	Phosphorus loads of shoreline septic systems based on assumptions in MPCA 2004 (**Error! Reference source not found.**), county average % failing rates from MPCA 2012 SSTS Annual Report, and county parcels	0.45 lb/capita-year	100%

Table 24. Pine River Watershed priority lake phosphorus load reduction data summary

		CROPLAND MANAGEMENT				URBAN MANAGEMENT				FEEDLOT MANAGEMENT									SEPTIC SYSTEM MANAGEMENT			
Lake ID	Lake Name	Cropland Area [ac]	Cropland Area [%]	Implementation Rate [%]	Removal Efficiency [%]	Developed Area [ac]	Developed Area [%]	Implementation Rate [%]	Removal Efficiency [%]	Registered Cattle [AU]	Registered Dairy Cows [AU]	P Load per Cattle AU [lb/yr]	P Load per Dairy Cow AU [lb/yr]	% Load Contributing to Surface	% Load Delivered Downstream	Feedlot Load [lb/yr]	Implementation Rate [%]	Removal Efficiency [%]	Shoreline SSTS [#]	Shoreline population [cap/parcel]	Failing SSTS [%]	Shoreline failing to conforming P reduction [lb/cap-yr]
11025000	Ada	-	0.0%	10%	50%	139.0	6%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	205	2.17	9%	0.45
18036400	Clear	1.0	0.1%	10%	50%	175.6	14%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	105	2.28	4%	0.45
11023700	Deep Portage	-	0.0%	10%	50%	36.8	6%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	24	2.17	9%	0.45
11034200	Eagle	37.3	1.4%	10%	50%	77.2	3%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	16	2.17	9%	0.45
18029800	East Fox	26.4	6.8%	10%	50%	51.2	13%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	121	2.28	4%	0.45
11010100	George	40.0	0.2%	10%	50%	529.6	3%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	28	2.17	9%	0.45
18022600	Goodrich	112.9	3.0%	10%	50%	308.3	8%	25%	50%	6	-	63.9	69.9	35%	0.0044	0.5	50%	75%	115	2.28	4%	0.45
18036100	Kimball	84.3	1.1%	10%	50%	629.5	8%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	143	2.28	4%	0.45
11005300	Lawrence	-	0.0%	10%	50%	148.3	10%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	127	2.17	9%	0.45
11003700	Leavitt	-	0.0%	10%	50%	188.0	2%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	143	2.17	9%	0.45
18022700	O'Brien (NE bay)	-	0.0%	10%	50%	27.4	7%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	183	2.28	4%	0.45
18028800	Ox	-	0.0%	10%	50%	7.4	1%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	58	2.28	4%	0.45
11041100	Pine Mountain	280.5	1.1%	10%	50%	717.3	3%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	160	2.17	9%	0.45
18021200	Ruth	6.2	0.4%	10%	50%	191.2	11%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	186	2.28	4%	0.45
18022000	Smokey Hollow	-	0.0%	10%	50%	16.8	1%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	24	2.28	4%	0.45
18035900	Star	7.4	0.7%	10%	50%	42.0	4%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	71	2.28	4%	0.45
11024600	Sylvan	-	0.0%	10%	50%	228.1	7%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	46	2.17	9%	0.45
18028400	Velvet	-	0.0%	10%	50%	34.5	14%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	51	2.28	4%	0.45
11005900	Washburn	15.1	0.3%	10%	50%	243.9	4%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	410	2.17	9%	0.45
18029300	Kego	-	0.0%	10%	50%	102.3	2%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	35	2.28	4%	0.45
18041500	Jail	-	0.0%	10%	50%	53.4	5%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	25	2.28	4%	0.45
11011400	Mitten	-	0.0%	10%	50%	31.2	8%	25%	50%	-	-	63.9	69.9	35%	0.0044	-	50%	75%	12	2.17	9%	0.45

Appendix 5: Criteria for prioritization (The Nature Conservancy-Healthy Waters protection)

			2/1/2016
- Pine River Watershed Ranking			
Score	**Max Score**	**Criteria**	**Guidelines:**
	30	# Feet of Shoreline	5 points for minimal river frontage on Little Pine, Upper Pine, or Lower Pine Rivers (<500ft)
			10 points for at least 500 - 999 feet of shoreland on a Little Pine, Upper Pine, or Lower Pine Rivers
		1500 feet	15 points for 1,000 - 2,000 feet of shoreland on a Little Pine, Upper Pine, or Lower Pine Rivers
			20 points for 2,000 - 3,000 feet of shoreline on a Little Pine, Upper Pine, or Lower Pine Rivers
			30 points for more than 3,000 feet of shoreland on a Little Pine, Upper Pine, or Lower Pine Rivers
	15	% of Tract Developable	1-15 points base on the proportion of the tract that is developable (10%=1.5pts)
	10	Wetland fringe width	1-10 points based on the distance between upland & the bank/water (0'=10pts, 300'=0pts, -1pt/30' wet)
	20	Urgency	Property opportunity is likely to be lost if we do not act quickly
	20	Professional Judgement	0-20 Points based on Landowner actively managing their land & Riparian/Streamshore Needs
	15	Drinking Water Score	5 Points for Second Quartile Drinking Water Benefits
			10 Points for Third Quartile Drinking Water Benefits
			15 Points for Fourth Quartile Drinking Water Benefits
	15	Adjoining Applications	15 points for land adjoining another application
	15	Adjoining Public Land	15 points for land adjoining public land on the Little Pine, Upper Pine, or Lower Pine Rivers
			adjoining land permanently protected by other easement program
	10	Habitat Value	1-10 points based on the habitat value of the property, uniqueness, and
			lack of existing development and shoreline alterations
	10	% of Parcel/Tract	1-10 points based on the proportion of the parcel enrolled (10% = 1 pt)
	10	% Forest of the parcels	1-10 points based on the proportion of parcel that is forest (10% = 1 pt)
	15	Minor Watershed Risk Classification County Waterplan	1-15 Points for Classification Enhancement and Protection. Less points for Villigance. Additional points for moving that needle.
	20	Bargain Sale/Leverage	1-20 Points based on percent discount or other funds leveraged
	205	**TOTAL GROSS SCORE**	*Other factors may raise or lower the priority of a parcel
	102.5	**Final Score (Total / 2)**	

Appendix 6-Water Quality Trends in the Pine River Watershed

Lake Name	Clarity Trend
Pig	Decreasing Trend
Bertha	Decreasing Trend
Whitefish	Decreasing Trend
Deep Portage	Decreasing Trend
Clamshell	Increasing Trend
Upper Hay	No Evidence of Trend
Island-Loon	Decreasing Trend
Emily	Decreasing Trend
Eagle (West Bay)	Decreasing Trend
Adney	Insufficient Data
Kego	Decreasing Trend
Pelican	Increasing Trend
Ruth	Increasing Trend
Clough	Insufficient Data
Island	Decreasing Trend
Big Trout	No Evidence of Trend
Horseshoe	No Evidence of Trend
Ox Yoke	No Evidence of Trend
Clear	No Evidence of Trend
Lower Hay	No Evidence of Trend
Sylvan	Insufficient Data
Mitten	Insufficient Data
Big Portage (East Bay)	Decreasing Trend
Lougee	Increasing Trend
Trout	No Evidence of Trend
Perry	Insufficient Data
Dolney	Insufficient Data
Velvet	No Evidence of Trend
Horseshoe (East Bay)	Increasing Trend
Blue	No Evidence of Trend
Sanborn	No Evidence of Trend
Ada	Increasing Trend
Five Point	No Evidence of Trend

Lake Name	Clarity Trend
Little Pelican	No Evidence of Trend
Big Portage (West Bay)	No Evidence of Trend
Twenty-Six	Insufficient Data
Goodrich	No Evidence of Trend
Butterfield	Increasing Trend
Horseshoe (West Bay)	No Evidence of Trend
Kimball	No Evidence of Trend
Duck	Insufficient Data
Jackpine	Insufficient Data
Greer	Insufficient Data
Hand	No Evidence of Trend
George	No Evidence of Trend
Island	No Evidence of Trend
Pine Mountain	No Evidence of Trend
Wood	Insufficient Data
Ox	No Evidence of Trend
Markee	No Evidence of Trend
Bass	No Evidence of Trend
Young	No Evidence of Trend
Lind	Insufficient Data
Jail	No Evidence of Trend
East Twin	Insufficient Data
Star	Increasing Trend
Washburn	Increasing Trend
Papoose	Insufficient Data
Moulton	Insufficient Data
Little Emily	Insufficient Data
Stevens	Insufficient Data
Hay	Increasing Trend
Lows	Insufficient Data
Beuber	Insufficient Data
Anna	No Evidence of Trend
Arrowhead	Insufficient Data
Norway	No Evidence of Trend
Roosevelt - South	Increasing Trend
Ossawinnamakee	Increasing Trend
Variety	Insufficient Data

Lake Name	Clarity Trend
Island	Insufficient Data
O'Brien (Northeast Bay)	Increasing Trend
Morrison	Insufficient Data
West Fox	No Evidence of Trend
Fool	No Evidence of Trend
Hattie	No Evidence of Trend
East Fox	No Evidence of Trend
Lizzie	Insufficient Data
Little Star	No Evidence of Trend
Smokey Hollow	No Evidence of Trend
Rush-Hen	No Evidence of Trend
West Twin	Insufficient Data
Cross Lake Reservoir	No Evidence of Trend
Lawrence	No Evidence of Trend
Birchdale	Insufficient Data
Ross	No Evidence of Trend
Bowen	Insufficient Data
Roosevelt - North	No Evidence of Trend
Duck	Insufficient Data
Leavitt	No Evidence of Trend
Mary	No Evidence of Trend
Long	Insufficient Data
Pine	Insufficient Data
Mitchell	No Evidence of Trend
Little Pine	Increasing Trend
Hen	No Evidence of Trend
Daggett	Increasing Trend
Margaret	Insufficient Data
Pistol	Insufficient Data
Eagle (Main Bay)	No Evidence of Trend
Pavelgrit	Insufficient Data
Twin (West Basin)	No Evidence of Trend
Eagle (East Bay)	No Evidence of Trend
Twin (East Basin)	Insufficient Data
Marion	Insufficient Data

Appendix 7- Lake Emily Outlet Modification and Lake Plan Analysis

http://www.cityofemily.com/vertical/sites/%7BE8201241-7911-48E2-AB81-4B9553A32090%7D/uploads/Lake_Emily_Outlet_Modification_and_Lake_Plan_Analysis_7302015.pdf

Appendix 8- Land Use and Phosphorus in Bungo Creek Watershed

Land Use and Phosphorus in Bungo Creek Watershed

A report prepared for the Pine River Watershed Alliance

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A. Background: Water Quality in the Whitefish Chain of Lakes

Phosphorus (P) is the component of water that most impacts the water quality of the Whitefish Chain of Lakes. As P levels in water increase, algae and chlorophyll levels rise, and dissolved oxygen and water clarity decline.

Water quality in the Whitefish Lakes and its watershed have been monitored for years (Table 1, Figure 1). Data for the Chain of Lakes is summarized in a large lake assessment completed by RMB Environmental Laboratories for Crow Wing County (see references). They report that P concentration data has been too sparse to describe a trend. However, transparency data has shown a decline from approximately 13 feet down to 9 feet between 1984 and 2008 in Upper Whitefish Lake.

According to current monitoring, phosphorus levels in Whitefish Lake range from about 15 to 40 ppb (µg/l), which is below the MPCA criteria of 30 ppb for an impaired lake in the Northern Lakes and Forests ecoregion. Addressing P inputs to the Chain of Lakes before they reach the criteria of "impaired water" reduces the amount of P deposited attached to the sediments in the Lakes. These sediments will release P for many years, even if P inputs into the lakes were reduced. This source of P is called "internal loading".

The variations in estimates of P loads in the following studies may be a result of different methods of measurement and year-to-year variation in weather and stream flow.

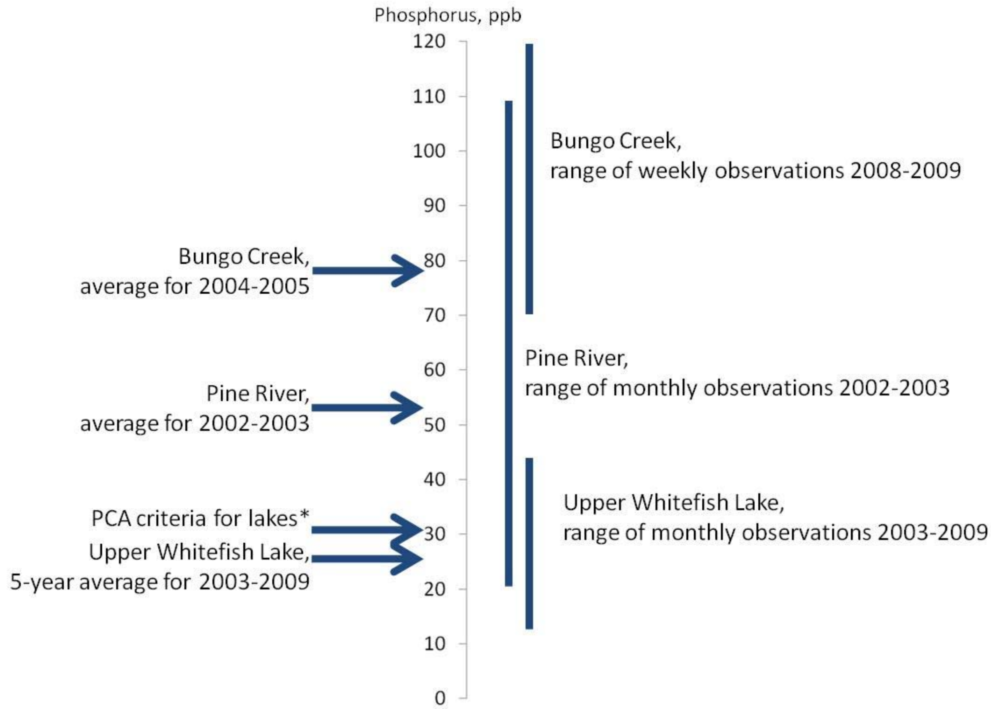
In 2001, the Whitefish Area Property Owners Association (WAPOA) conducted a P loading study of the Whitefish Chain of Lakes (Wallschlaeger, 2001). The Pine River dominated the flow and thus P inputs into the Chain, providing 75% of the flow and 40% of the P from all sources, and 53% of the P from all tributaries going into the Chain. This study estimated that the Pine River contributed 15,664 pounds of P annually, and had an average P concentration of 26 ppb.

In 2002 and 2003, the Pine River Watershed Protection Foundation (PRWPF) sponsored a study of P export from the tributaries of the Pine River (Wallschlaeger, 2003). Of the seven tributaries studied, Bungo Creek had the highest average P concentrations and was among the top three for flow volume (the other two being the North Fork and the South Fork before being joined by Brittan/Dabill and Bungo Creeks). The high concentration combined with the high volume meant that Bungo Creek was contributing about 40% of the P load in the Pine River. The study estimated that the Pine River near where it empties into Whitefish Lake contributed about 25,700 lbs of P per year, and had an average concentration of 52 ppb. Bungo Creek contributed about 10,400 lbs of P per year, and had an average P concentration of 93 ppb.

In 2004 and 2005, WAPOA sponsored another study: "Phosphorus Export from Bungo Creek" (Wallschlaeger, 2005). Flow and P concentrations were measured at six sites along the Creek. The results reflected the complicated hydrology of the Bungo Creek watershed. P concentrations were highest at site C – just downstream from the confluence of the north and south forks and at the point where year-around flow becomes reliable. P concentrations declined somewhat downstream from site C. Flow rates were also uneven. Flow began fairly high at site C, dropped downstream at site D, rose again at site E, and dropped again at site F (near a beaver dam blockage). Shallow groundwater flow is apparently important in the hydrology. This study estimated that Bungo Creek contributed 4800 lbs of P per year near the outlet to Pine River.

Table 1: Water Quality Monitoring in the Whitefish Chain of Lakes Watershed
1990 – 1999 Lake monitoring showed declining transparency (RMB Env. Lab.)
1999 – 2001 All 2500 shoreline septics inspected. Failing systems were corrected.
2000 – 2001 P measured in 13 lakes & 6 streams (Wallschlaeger, 2001)
2002 – 2003 P measured in Pine River & tributaries (Wallschlaeger, 2003)
2004 – 2005 P measured in Bungo Creek (Wallschlaeger, 2005)
2008 – 2009 Detailed P measures in Bungo Creek
2010 – 2011 Land use effects on P export (this report)

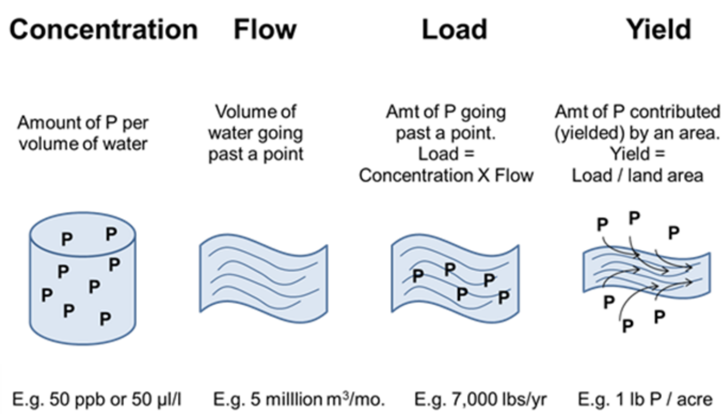
Figure 1: Measured Phosphorus Concentrations



*See full detail of eutrophication standards for the Northern Lakes and Forest Ecoregion in Minnesota Rule 7050.0222 https://www.revisor.mn.gov/rules/?id=7050.0222.
For status of the development of P standards for streams, see the MPCA's Proposed Water Quality Standards Rule Revisions at http://www.pca.state.mn.us/qzqh5e3.

Data sources: Wallschlaeger 2001, 2003, 2005; RMB Laboratories; John Moncrief, personal communication

Figure 2: Terms Used to Express the Amount of Phosphorus in Water



B. Phosphorus Dynamics

Phosphorus (P) is an integral component of all living organisms and some minerals, and is naturally present in soil and water. Phosphorus may be stored in one form (e.g. in plant matter or attached to soil particles) for days, months, or years before it is transformed through biological activity or chemical changes (such as oxidation) to become more mobile and available to algae and other microbes or plants.

Algal growth in Minnesota lakes is typically restricted by a lack of P and thus is triggered when P concentrations rise above a critical threshold, typically around 20 ppb (µg/l). Crops and other plants draw P from soil water – the thin film of water around and between soil particles. For plants to thrive, the concentration of P in soil water must be at least 200 ppb, i.e. ten times the critical concentration in lakes. Concentrated sources of P to soil and water include fertilizer (on the order of 20% P), manure (2% P) and plant tissue (0.2% P) (Table 2).

Table 2: Typical Phosphorus Concentrations

20 ppb	The concentration that triggers algal growth in lakes
200 ppb	The concentration in soil solution needed for plant growth
2,000,000 ppb	Plants (0.2% P)
20,000,000 ppb	Manure (2% P)
200,000,000 ppb	Fertilizer (20% P)

From John Moncrief

The amount of phosphorus that reaches a lake depends on three characteristics of phosphorus in the watershed (Figure 3):

- **P sources** (Is it coming into the watershed?)
- **P transformations** (Is it in a form that can move?)
- **P transport** (Is it being carried to the lake?)

Phosphorus sources

- **Fertilizer** may be applied to crops or lawns. This is probably small because P fertilizer is unnecessary on most agricultural soils in the watershed.
- **Animal waste** is either dispersed over fields by grazing animals, stored and then mechanically spread over land, or concentrated in stockpiles or at feeding and watering areas. Given the number of animals, this is a large pool of P in the watershed. To the extent that the feed comes from within the watershed, the P is not being imported, however, manure handling practices determine how available this source becomes for transport downstream.
- **Human waste** in septic systems. This is a tiny fraction of the P generated by animals.
- **Soils** vary greatly in native P levels. Soil P levels will rise if applications from manure or other sources exceed that removed by plant harvest.
- **Peat**, or organic soil, forms over centuries from partially decomposed plant matter. If a peat soil is drained and thus aerated, the peat will decompose and release P.
  Peatlands (even undrained) normally store and release phosphorus. Clausen and Brooks (1983) measured water characteristics of streams flowing out of undisturbed peatlands in northern Minnesota. Phosphorus concentrations ranged from 50-80 ppb.
- **Atmosphere** – P is present in both wet and dry precipitation that falls on the ground and water bodies.

Phosphorus transformations

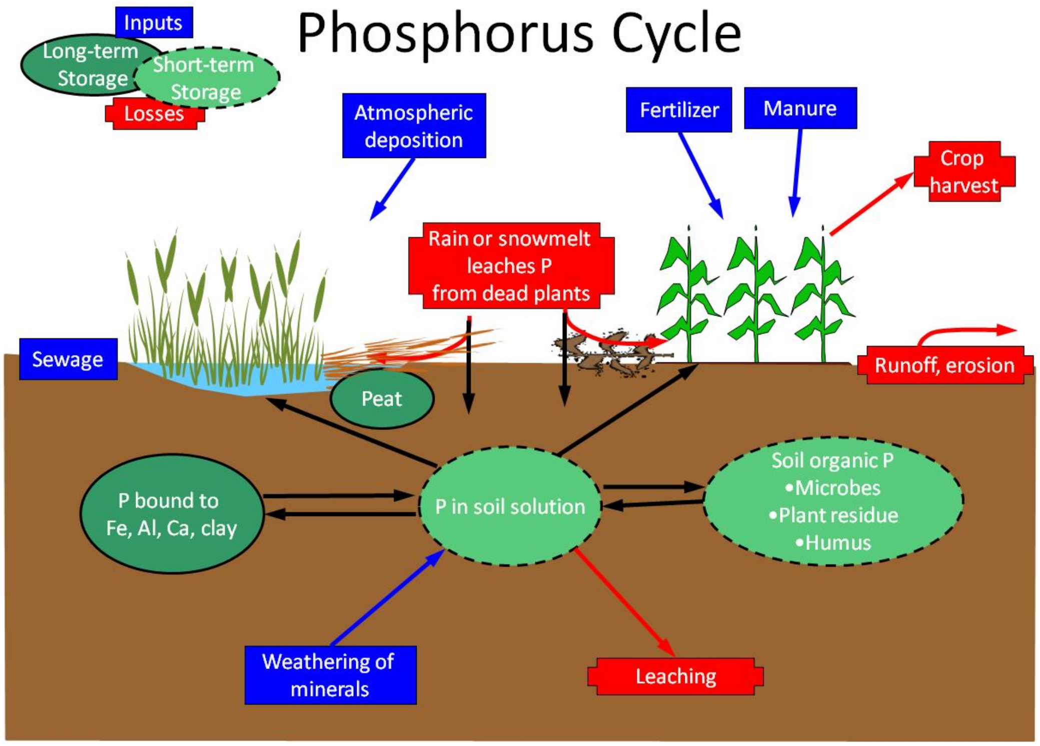
- **Plants** draw P from the soil, immobilize it in organic compounds, and release it when they die back. For example, soluble P is released to the soil from fallen leaves, forages after a frost, or after a timber harvest or burn. If a heavy rain occurs shortly after a frost, soluble P will be transported away in runoff before the soil has a chance to adsorb the P.
- **Soil particles** adsorb phosphorus, holding on to it and preventing movement of P through the soil.
- **Iron, aluminum,** and **calcium** in soil and water form insoluble complexes with phosphorus, preventing leaching of P through soil.
- A few of the soils in Bungo Creek watershed have high **calcium carbonate** levels which may help immobilize P.

- In **low oxygen conditions** (saturated soil), the Fe^{+3} in iron-phosphate complexes is reduced to Fe^{+2} and soluble P is released.
- **Soil organic matter** decomposes and releases soluble P when water levels are low and soil is aerated. When water levels rise again, the soluble P is carried away in the water.

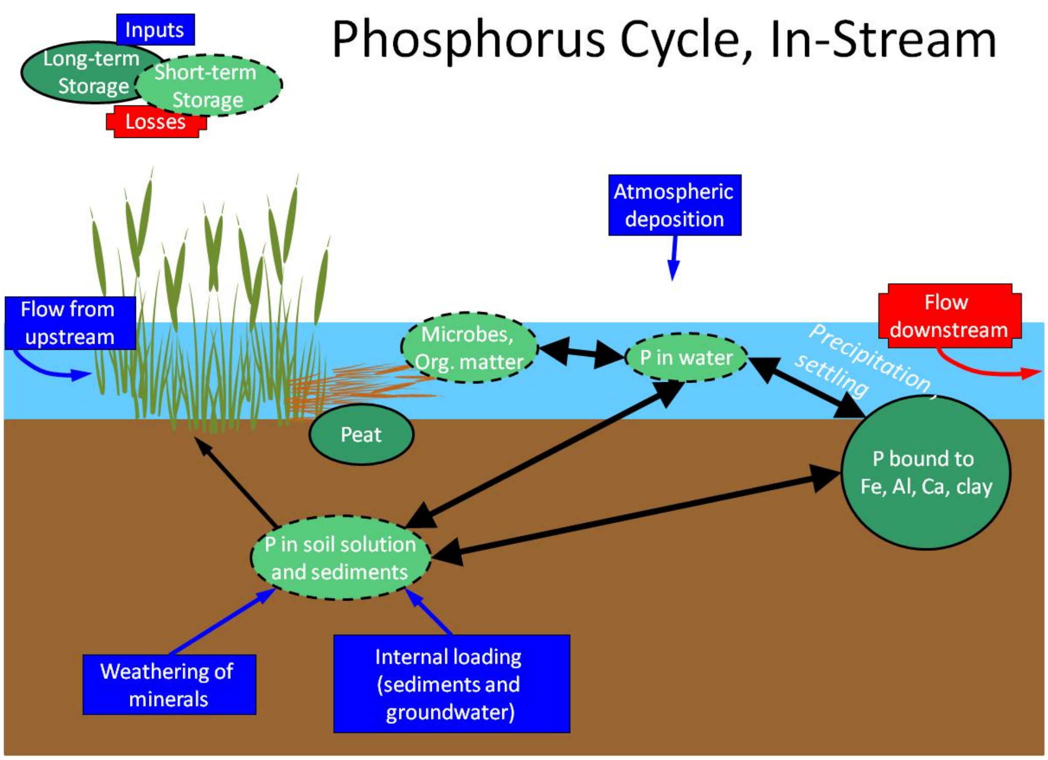
Phosphorus transport

- **Overland flow** – Runoff over the top of the soil surface can carry both **dissolved P** (from plant debris, fertilizer, or manure) and **sediments** with attached P. Runoff rates are accelerated from building sites, roads, tilled or highly compacted fields, and from impervious surfaces (pavement, roofs, packed ground). **Snowmelt runoff** is a significant transporter of P in Minnesota, carrying surface P sources such as plant matter that senesced the previous fall and manure deposited over the winter.
- **Streams and concentrated flow** – Once P in any form reaches a concentrated flow channel, it will eventually be carried to downstream lakes.
- **Settling** – particulate P that is part of sediments or organic matter will settle out when moving water slows as it reaches a pond or a widening. Increased flow can remobilize the particles.
- **Shallow groundwater**. Phosphorus typically binds readily to soil particles leaving it insoluble and mostly immobile. However, in some situations, P is not readily adsorbed to soil particles and may persist in a soluble form long enough to be transported by soil water. Three situations where P can move through soil either vertically or laterally are (a) if the soil is P saturated (due to long term P additions), (b) through organic soils, or (c) to a lesser extent in coarse textured soils (loamy sand and sand). All three of these situations are present in Bungo Creek watershed.
  In a 2001 study, the MPCA measured phosphorus levels under about 10 different types of feedlots and manure storage facilities around the state. They measured the plume of high P concentrations underneath and horizontally away from these manure concentrations, demonstrating that P at high concentrations does move somewhat through soil, though not very far. "Concentrations at most sites approached background concentrations within 100 feet of the storage system. Concentrations of more than 1.0 mg/L were not observed more than 50 feet from a storage system [p. 97]."
  Three other studies have quantified P movement through soil in Minnesota. Zvomuya et al. (2005) demonstrated P loss from high phosphorus sandy soils. Rosen and Bloom (2011) measured P leaching of 50 to 2000 ppb from unfertilized organic soils and much higher from fertilized soils. Gafni and Brooks (1990) measured lateral water movement (groundwater velocities) through peat of 0.49 cm/hr (43 meters/year) in the upper layers of peat and less than 0.03 cm/hr (2.6 m/yr) below 35 cm. This is comparable to velocities in mineral aquifers.

Figure 3. The Phosphorus Cycle



Modified from Pierzynski et al., 2005



Modified from Pierzynski et al., 2000; and Melchior (2007), Figure 11. Ref: Debusk, W.F. 1999.

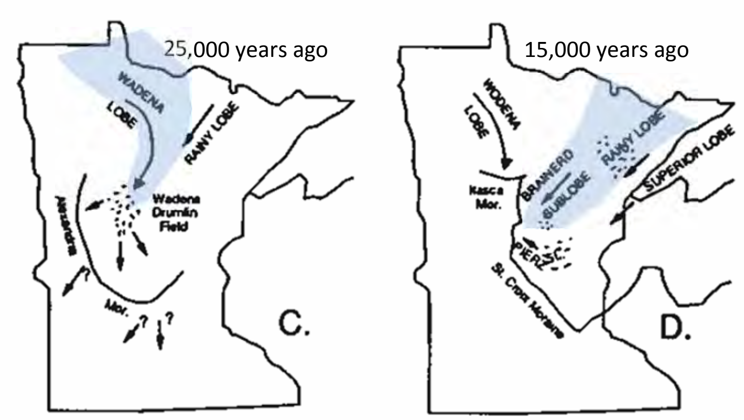
Glacial geology affects P sources and transport

Twenty-to-thirty thousand years ago, the Wadena Lobe deposited a ground moraine across the Bungo Creek area (Melchior, 2007). Ten thousand years later, the Brainerd sublobe of the Rainy lobe advanced and retreated leaving another layer of sandy till on top of the Wadena till (Figure 4). The result is a discontinuity at the boundary of the two layers. Water percolates downward through the top layer and then moves laterally when it reaches the denser Wadena till. According to Melchior, the boundary between the two layers is 10-15 feet below the surface, and up to 30 feet deep near the stream and in the northeastern part of the drainage system. The Soil Survey describes some of the soils in the area as having a restrictive layer at about 5 feet deep.

To the west of Bungo Creek are the Foothills – the St. Croix moraine left by the Rainy Lobe. Groundwater generated in these hills likely flows through the ground and emerges as springs in the Bungo Creek and other watersheds.

Deposits from the Wadena Lobe were calcareous, so the lower layers of some soils contain carbonates. Brainerd till forming the surface soil in Bungo Creek watershed had low levels of calcium carbonates (which can bind phosphorus), relatively high phosphorus content (perhaps 0.05%), high acidity, and a sandy texture. Together, those features mean that the soil in the watershed has a reduced capacity to bind phosphorus compared to soils in other parts of the state. Soluble P from manure and other sources that leaches into the soil may remain in a soluble and mobile form longer than it would in the calcareous, alkaline, fine-textured soils formed from Des Moines till in southern Minnesota.

Figure 4: Glacial history of central Minnesota



Wright, H.W., Jr. 1972. Quaternary history of Minnesota.

C. Watershed Hydrology

Method

Stream water was tested to learn about the sources of water in various parts of the creek. The proportion from shallow groundwater, deep groundwater, surface runoff, and precipitation may vary in different parts of a creek network. We characterized the water by measuring hydrogen and oxygen isotopes, dissolved oxygen, conductance, pH, temperature, total P, and ortho-P; and then compared the character of the water from different parts of the network.

Samples were taken from eight sites at three time points: in May at the end of spring runoff, in June the day after a heavy summer rainfall, and in September at low flow conditions after a dry period.

Isotopes provide clues about the source of water. A small fraction of water is made of heavy isotopes of oxygen and/or hydrogen. The proportion of heavy isotopes changes whenever water changes phase: evaporating, condensing, freezing, or thawing. The isotopic characteristic of rain water depends on where (i.e., from which ocean) the water evaporated, and the temperature and humidity when the water condensed during rain or snowfall. In turn, the isotopic characteristics of stream water depends on what proportion of the water is rain that fell days ago, snowmelt that has been stored in the soil for weeks, or groundwater that has been stored for years or decades. By comparing the isotopic signature of water along Bungo Creek, we can tell if different stream segments are supplied by different water sources. (The units are parts per thousand variation from a standard. I.e., a negative number means the sample is lighter than the standard. A less negative value is heavier than a more negative value.)

Results and Interpretations

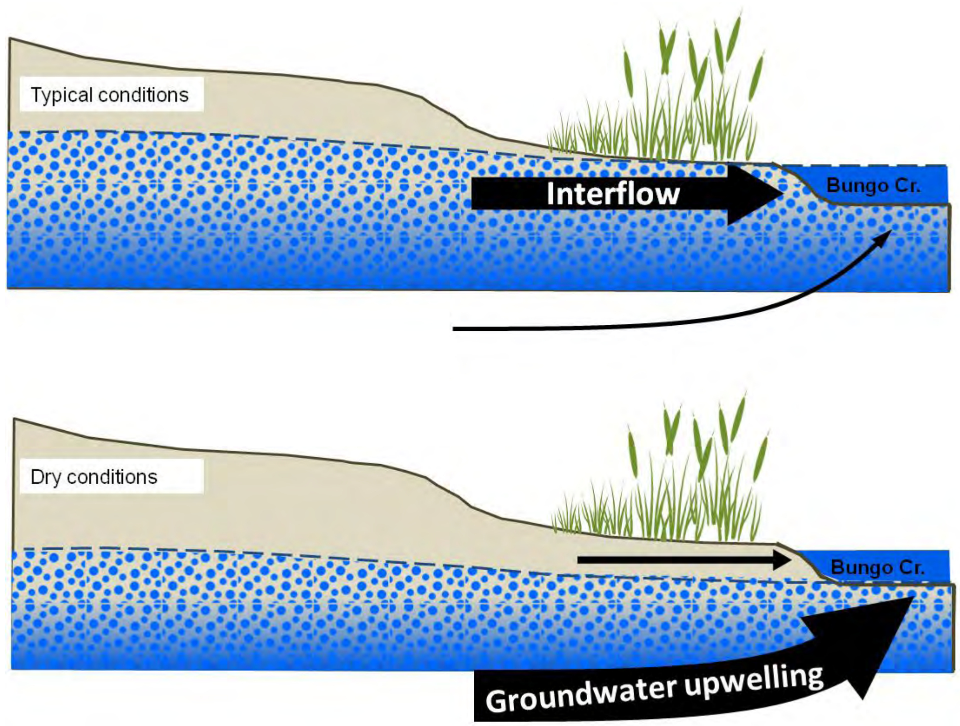
Results of water tests are shown in the appendix. The absolute values are less important than the differences between sample sites indicating which sites are more or less similar than others. Interpretations of the water test data are based on conversations with Dr. Joseph Magner (MPCA and UM Department of Biosystems and Bioproducts Engineering).

- Rain and snowmelt move quickly through the system, perhaps having a residence time in the watershed of only days. Many of the soils have high water tables (Figure 9) so there is little capacity for infiltration and temporary storage of the water before it moves into the drainage system.
- Creek flow is dominated by "interflow" – water that moves laterally through the upper layers of soil into the creek bed. Interflow water has a residence time of weeks.
- Isotope values did not vary substantially across the watershed, implying that the flow paths are similar across the system, and the water residence time in the ground is the same all along the course.
- Isotope values at the Cedar Creek site were different than Bungo Creek and suggest a greater contribution from deep groundwater to Cedar Creek.
- The lower flow at the Dabill site (Site #2 in Figure 14) compared to upstream sites could be explained as water going below the surface and emerging again downstream. Hydrologically, this is of little significance since at all sites the main contributor to flow is the same near-surface interflow water with a consistent residence time. However, there may be opportunities for phosphorus to become less mobile as it moves through the soil.
- The dramatic increase in flow at the Pelcl site (Site #3 in Figure 14) relative to upstream sites is probably an effect of elevation, rather than a spring. In other words, the creekbed has come down to an elevation where interflow water is easily released.
- Little interflow occurs during drought periods when soil water levels are low and thus hydraulic head is low (Figure 5). This is accentuated by growing plants which draw down the water table around their roots. With little pressure from interflow, deeper groundwater begins to contribute more to creek flow. This was evidenced by the manganese which was only measured in September at two low-flow headwater sites. The manganese may be from groundwater, which has a much longer residence time than soil water.

- The high elevation of groundwater in the foothills creates a high hydraulic head pushing water into the headwater creekbeds in the foothills. This is seen in the higher groundwater component at the Cedar Creek site. It is not seen in the Bungo Creek sites, where interflow pressure apparently dominates.

Figure 5: Bungo Creek profile and water sources

Under typical moisture conditions, water levels are high in soil. This “interflow” water has more hydraulic pressure than groundwater and thus is the dominant flow into the creek bed. When conditions are dry, interflow pressure is low and groundwater has the opportunity to flow into the creek bed.



Beaver Ponds and Other Wetlands

Several beaver ponds exist along Bungo Creek. Across the country, beaver populations have been building from a historical low level around 1900 (Naiman et al, 1988). Bungo Creek watershed follows this trend. Beaver dams and ponds are dynamic along Bungo Creek. A couple significant ponds visible in 2010 aerial photos are much smaller a decade earlier, non-existent in 1939 photos, and rumored to have been larger in between. The pond in section 14 appears to have been in pasture in 1939. Perhaps the land was much drier after the droughts of the 1930’s. Dams can be built rather quickly, followed by several years of pond filling. A pond may empty suddenly when a dam breaks due to human intention, inattention, or natural events. Beaver ponds impact groundwater flow patterns under and downstream of the pond, and thus impact upwelling into the streambed. The eager reader is directed to the introduction to Fuller and Peckarsky (2011) for a summary of the diverse impacts that beaver dams have on hydrology and water quality.

Generally, ponds may reduce the sediment in stream flow as sediments settle out, but soluble P may increase as it is mobilized under the low-oxygen conditions. In reality, the impact of beaver ponds on downstream phosphorus is notoriously unpredictable. Fuller and Peckarsky (2011) measured downstream nutrient levels that were both higher and lower compared to levels above the beaver ponds. The levels were somewhat, but not reliably, associated with the shape of the pond. For example, in a low-flow year, high-head, small ponds tended to increase downstream P concentrations while low-head, large ponds tended to reduce downstream P. They theorized that this was due to greater groundwater upwelling in the downstream reach below high-head ponds. (Note that soluble reactive P levels measured in this study were quite low (< 12 ppb) compared to values in Bungo Creek.)

The Fuller and Peckarsky study looked at the impact of stable beaver ponds, while Muskopf (2007) looked at the impact of dam removal. She measured much higher P levels in streams leading into Lake Tahoe after the removal of beaver dams. This could be explained as a flush of P-rich sediments being washed out of the pond. However, this doesn't provide information about how the flush compares to the P stored and kept out of the system over the years before the dam removal.

Wetlands, in general, are quite variable in their ability to retain phosphorus, and much less effective than terrestrial systems at conserving phosphorus (Richardson, 1985). The developers of the Ontario Lakeshore Capacity Model (Paterson et al. 2006) showed that P loading from a watershed increases with percentage of the watershed in wetlands (as indicated by percent peat). According to their formula (Figure 6), Bungo Creek watershed would export 1,878 lbs of P per year – far less than estimates based on monitoring in the watershed.

To summarize, the impact of beaver ponds is not straight forward. A few water tests would be needed to determine the impact of a specific pond or the removal of a specific dam.

Figure 6: Relationship of P yield to proportion of wetlands in a watershed.

TP (kg/yr) = catchment area (km^2) * (0.47 * % peat soil + 3.82)
(R^2 = 0.57)

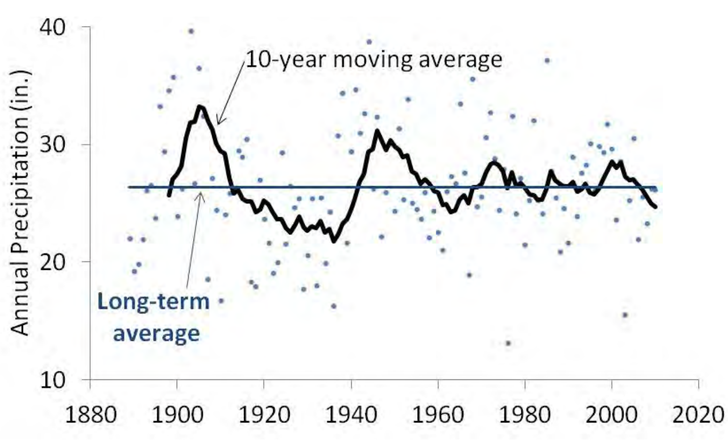
Relationship is from Paterson et al. (2006) and is based on measurements in 20 forested watersheds on the Precambrian Shield of south-central Ontario. The watersheds ranged from 0% to 25% peat, with most of them less than 12%. Bungo Creek watershed is 34% peat.

Precipitation

Long-term precipitation trends are less extreme, more consistent now than early in the century (Figure 7). Total precipitation has declined over the last decade.

Figure 7: Local annual precipitation.

National Weather Service data from stations within 20 miles of Bungo Creek. Accessed from the State Climatology Office http://climate.umn.edu/doc/historical.htm.



D. Soils

Characteristics of Soils in Bungo Creek Watershed

Phosphorus release in Bungo Creek soils may be driven by iron (Fe) chemistry. Calcium levels are indeed high in some soils in the watershed (Figure 8), but in high iron soils, the iron will drive P release even if calcium levels are high (Berryman et al., 2009; Richardson, 1985). High water tables are common in the watershed (Figure 9). When soil is saturated by a high water table, oxygen levels go down, iron is reduced from the Fe^{3+} form to Fe^{2+}, and the phosphate that was complexed with the Fe^{3+} is released and becomes mobile. If the water moves, such as receding floodwaters on the floodplain of the creek, the phosphate will be carried along.

Figure 8: Soils with high calcium levels.

Soils with 5% to 25% calcium carbonate.

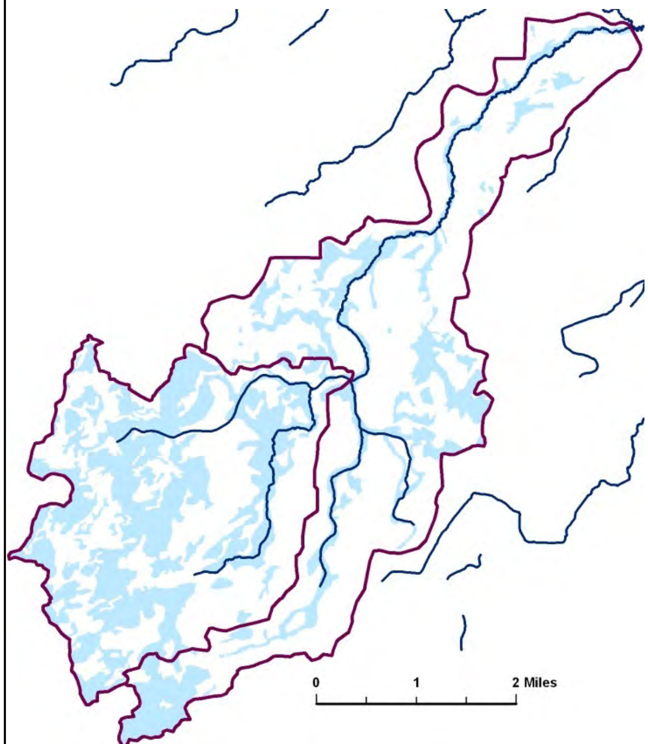


Figure 9: Soils with high water tables.

Soils with a highest water table of 0" to 6" from the surface.

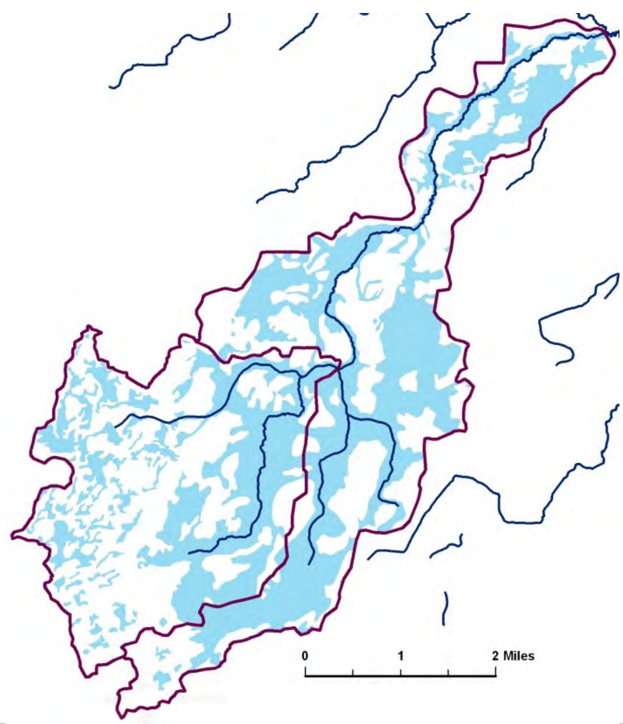
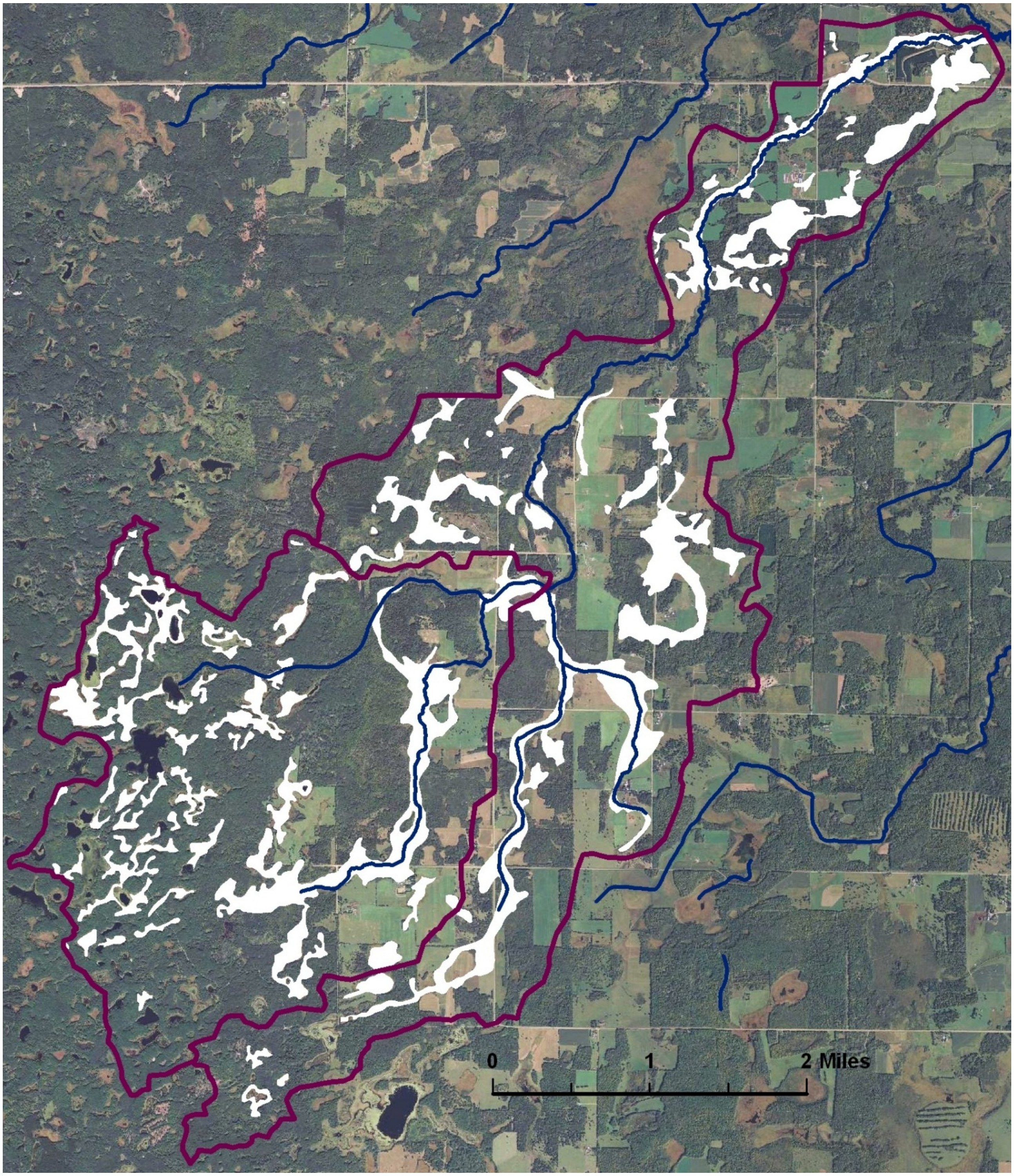


Figure 10: Organic soils in Bungo Creek watershed.

Cathro muck, Seelyeville muck, and Markey muck are the prominent types of organic soils.



Soil Test Methods

We sampled soil from several farmed and non-farmed sites. Where possible, we took both a surface and subsurface sample. Samples were tested using standard methods for agronomic soil testing for phosphorus, potassium, organic matter, and pH. In addition, samples were tested for water soluble P – an indicator of P mobility.

Soil Test Results

Test results and interpretations are shown in Table 3, Table 4, and Table 5. In most cases we were not able to sample below about 10-12". The soil probes may have been hitting the gravel that is common in these soils, or a plow pan, which forms just below the depth of moldboard plowing. Plow pans are persistent in coarse soils because drying/wetting cycles do not cause much shrinking and swelling. Plow pans may reflect plowing done years ago.

Table 3: Soil Test Results

Site ID‡	Land use	Soil texture	Distance to nearest farmstead (ft.)	Phos-phorus (ppm)§	Organic matter (%)	pH	Potas-sium (ppm)	Water soluble P (ppm)†
8	Ag - hay	muck	1000	7	28.2	7	22	0.68
8 sub.	Ag - hay	muck	1000	1	6.1	7.5	36	0.17
4	Ag - hay	loamy sand	3000	44	1.7	6.8	79	0.45
4 sub.	Ag - hay	loamy sand	3000	38	1.2	6.5	45	0.04
2	Ag - hay	loamy sand	2800	56	2.3	6.4	45	0.53
3	Ag - hay	loamy sand	2800	59	2.2	6.3	77	0.58
5	Ag - hay	loamy sand	1000	69	1.6	6.5	73	0.6
5 sub.	Ag - hay	loamy sand	1000	49	0.6	6.2	36	0.27
9	Ag - corn	loamy sand	500	93	2	6.4	71	1.27
9 sub.	Ag - corn	loamy sand	500	67	1.5	6.4	75	0.62
1	Ag - hay	loamy sand	150	96	4.1	7.2	189	0.83
11	Ag - corn	loamy fine sand	100	206	3.2	5.7	137	14.02
11 sub.	Ag - corn	loamy fine sand	100	215	1.6	6	149	6.63
10	Ag - corn	loamy fine sand	200	214	2.6	5.9	120	11.36
6	wooded wetland	mucky peat	2200	4	74.6	5.8	21	0.5
6 sub.	wooded wetland	mucky peat	2200	2	76.8	5.8	13	0.32
12	woods	loamy sand	1000	6	2.8	5.5	59	0.02
12 sub.	woods	loamy sand	1000	5	1.1	5.5	23	0.24
7	drained pond	silt loam	400	9	4	6	41	0.24
7 sub.	drained pond	silt loam	400	24	1.4	6.2	26	0.24

‡We were not able to gather a subsurface soil sample at all sites.

§Bray 1-phosphorus extractant

†0.01M $CaCl_2$ extractable PO_4-P

Table 4: Phosphorus Soil Test Interpretations

Bray-P soil test (ppm)	UMN description	Agronomic response and UMN recommendations	In Bungo Creek Watershed
< 10 ppm	Very low to Low	60-85 lbs of P fertilizer per acre is recommended to grow 140-bu corn. 45-65 lbs of P is recommended for 4-ton alfalfa hay.	Levels in native soils – both mineral and organic
11 – 20 ppm	Medium to High	10-35 lbs of P fertilizer is recommended for corn, and 10-25 lbs of P for hay.	
21+ ppm	Very high	Broadcast fertilizer is not expected to have an effect on improving yields. 10-15 lbs of P banded next to the seeds at planting may be beneficial.	Common in many agricultural soils
80+ ppm			Probably common in isolated spots that have received long term heavy manure application, e.g. winter loafing areas and near barns.
200+ ppm			Can be found in locations of very heavy manure applications

Fertilizing Corn in Minnesota. 2006. Rehm, G.; Randall, G.; Lamb, J.; Eliason, Roger University of Minnesota Extension 03790.

Fertilizing Alfalfa in Minnesota. 2000. Rehm, G.; Schmitt, M.; Munter, R. University of Minnesota Extension 03814.

Table 5: UMN Potassium Soil Test Interpretations

Potassium soil test	UMN description
0-40 ppm	Very low
41-80 ppm	Low
81-120 ppm	Medium
121-160 ppm	High
160+ ppm	Very high

Fertilizing Corn in Minnesota. 2006. Rehm, G.; Randall, G.; Lamb, J.; Eliason, Roger University of Minnesota Extension 03790.

Soil Test Interpretations

The soil testing demonstrated several points:

- **Extreme P levels have built up in some soils.** A corn field that was used as a winter feeding area measured extremely high P. This is consistent with the Minnesota Phosphorus Index model results showing that winter feeding areas can have extremely high P levels. These extreme levels are expected in many sites near barns and where animals have been concentrated over the decades.
- **Leaching processes are evident.** Soil test potassium (K) levels were relatively low compared to P levels. Potassium leaches more easily than P, especially from sandy soils. Despite the high leaching potential in the soil, P is staying adsorbed to the mineral soil and not leaching. P is likely forming complexes with aluminum and iron.
- **Peat does not hold P.** Both the farmed and the non-farmed peat soils had the lowest soil test P levels. As would be expected, these high organic matter soils do not adsorb P as strongly as do mineral soils.
- **P is more mobile in high-P soils.** Mineral soils did not show evidence of P leaching downward through the soil, however we were not able to get good sub-plow layer samples that would have demonstrated this. The water soluble P test shows that in soils with extremely elevated P levels (>200 ppm Bray), a greater quantity and a greater proportion of the P is mobile. Soil has a limited capacity to bind P, so at extremely high levels, P leaching rates increase. The threshold at which P leaching increases varies with soil type. Expensive soil testing is required to determine that threshold. Regardless of the precise threshold, extreme build-up of P levels substantially raises the risk of P loss due to both sediment loss and soluble runoff losses.

E. Land Use Changes

An abandoned farmstead, phosphorus-laden sediments at the bottom of a lake, and other remnants of past land use may contribute phosphorus to a water body long after the original P source has been stemmed. Thus, understanding current phosphorus levels and dynamics must include an understanding of past P sources and transport dynamics. We examined aerial photography and historical records to identify changes in land-based sources of phosphorus over the past 70 years.

Methods

Change in agricultural land use over the past 70 years.

Aerial photos from 1939 (the earliest year available) were scanned, imported into ArcGIS, and rectified to match the scale, projection, and position of the other GIS layers (Figure 13). FSA color photos from 2010 were imported from the Minnesota Geospatial Information Office (MnGeo) (Figure 14). Polygons were drawn around all agricultural land on both the 1939 and 2010 layers. "Agricultural land" included farmsteads, tilled fields, perennial crops, pasture, and some isolated trees and small tree patches. In the upper part of the watershed, treeless wetlands and pasture appeared similar and may have been mistakenly identified. This was especially a problem in the 1939 images where an estimated 100 to 200 acres may have been misidentified.

Land use interpretations based on Landsat data are available at land.umn.edu. This data set was not used because it was found to be less accurate. It identified 1,906 acres as agricultural land in 2000. However, pastures are a significant agricultural land use, but were lumped together in a separate category that included wetlands and grassland.

Agricultural acreage for the two time periods was totaled and compared. Buffers along the creek were compared qualitatively.

Change in land use and sites over the past 20 years.

A more detailed examination of recent land changes was done by visually comparing 1991 black and white USGS photography with the 2010 color FSA photography. When a difference was identified, images from 2009, 2008, 2006, and 2003 were examined to get a closer estimate of when the change occurred. Changes included sites (e.g. buildings), lines (e.g. roads), and areas (e.g., fields). The changes were described qualitatively in relation to their impact on P dynamics.

Results

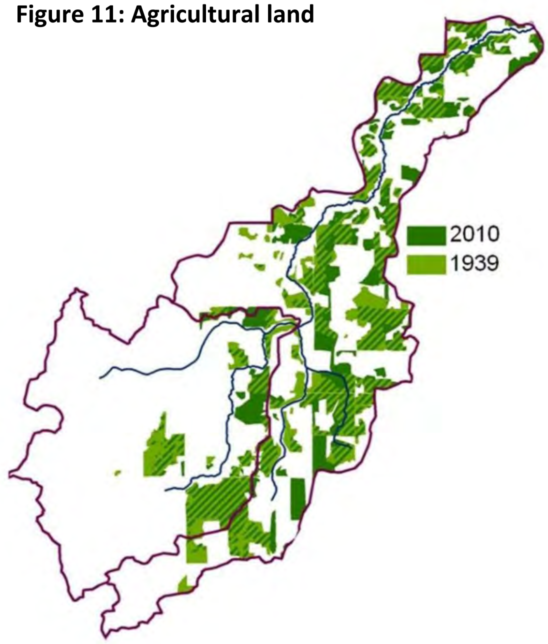
Increases in all agricultural land uses

Since 1939, agricultural land area increased 10%, rising from 2,058 acres (19% of the watershed) to 2,268 (21% of the watershed) in 2010 (Figure 11). Given the difficulty interpreting the aerial photos, the agricultural acreage in 1939 may have been as low as 1,800 acres (17% of the watershed).

The location of lands taken out of agriculture between 1939 and 2010 may have had a positive impact on water quality. Reductions were largely in the headwaters and along the creek. Land that was newly converted to agriculture between 1939 and 2010 was distributed across the watershed. The hills of the southwestern part of the watershed were not farmed at either time point.

The width of buffer vegetation between the creek and agriculture or other development activities has changed little between the two points in time. However, the characteristics of the creek and vegetation have changed. In general, the upper reaches appear wetter in 2010, with more ponded water and more areas that appear treeless now, perhaps due to saturation. On the other hand, tree growth appears denser in other upland areas. Perhaps in 1939 these areas were still regrowing from logging.

Figure 11: Agricultural land



Details of recent land use changes

Since 1991, land use or management has changed on 200 acres, or 2% of the watershed (Table 6). Of that, 122 acres were shifted from one agricultural use to another, including from perennial crops to what looks like corn, and what appears to be linear plantings of trees. Changes near the stream and in the upper parts of the watershed were primarily open water filling in with vegetation and grass wetlands becoming more vegetated. If the changes in the images have been correctly interpreted, then the denser vegetation may be an indicator of increased nutrients in the water (Melchior, 2007). The other land use changes are not likely to change runoff enough to impact P loss. An increase in artificial drainage or an increase in manure applications within the watershed could impact P delivery to the creek, but neither of these can be inferred from the photographs.

Since 1991, 57 building sites were added. Many were new homesteads; others were new buildings added to existing home/farmsteads. Because the sites are dispersed, the additional impervious area is not likely to impact phosphorus runoff losses. If septic systems were installed with the buildings, they may be new P sources, but any impact would likely not be seen for many years.

Table 6: Land use changes, 1991-2010, Bungo Creek watershed

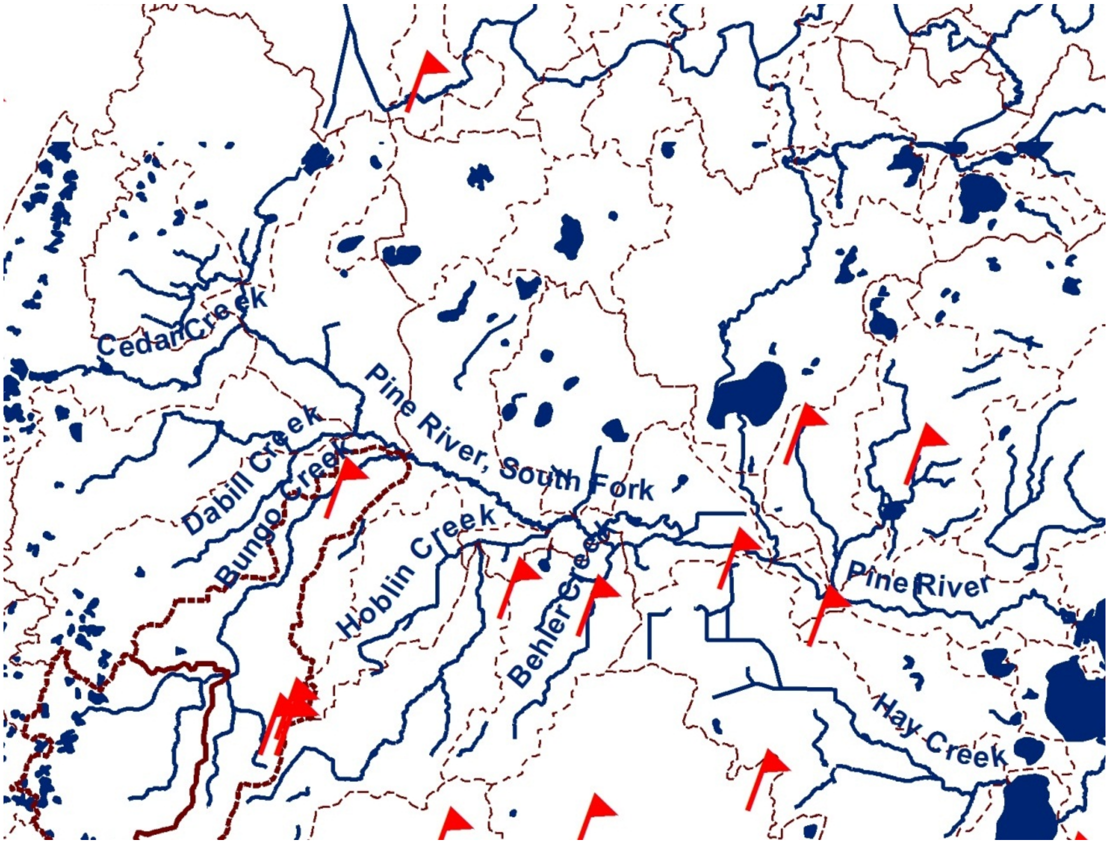
Acres	Type of change
14.4	Reverted to trees from pasture or hayland.
29.7	Wetlands becoming more densely vegetated.
34.3	Converted from natural vegetation to agricultural.
121.8	Change in agricultural uses.

Number of livestock facilities

In general, the number of farm animals in Cass County has declined in the past decade. (See graphs in appendix.) Over the past several decades, pasture acres have been replaced by hayland and some corn. Bungo Creek may not be experiencing the countywide trend of declining livestock.

The watershed includes one permitted livestock facility and three more registered with the Pollution Control Agency (Figure 12**)**. In addition, there are quite a few smaller animal operations that are not required to be registered. In contrast, the watersheds of the North Fork of the Pine River, Hoblin Creek, and Behler Creek each have one registered or permitted livestock facility. Hay Creek and Arvig Creek watersheds each have two.

Figure 12: Livestock facilities registered with the MPCA in 2009.



Implications

Several changes in land use in the watershed have slightly increased the risk of P loss:

- increased agricultural acreage
- slightly larger fields
- more building sites and higher population.

None of these are so dramatic as to expect they would significantly alter P loading patterns.

Livestock numbers are reasonable for the land area, yet Bungo Creek watershed has a relatively high number of livestock facilities compared to neighboring watersheds. Even with modest livestock numbers and recommended manure management practices, P loss may be a risk because of the hydrology and soil types. Details about how to mitigate these risks are detailed below.

Figure 13. Aerial photographs of Bungo Creek Watershed, 1939.

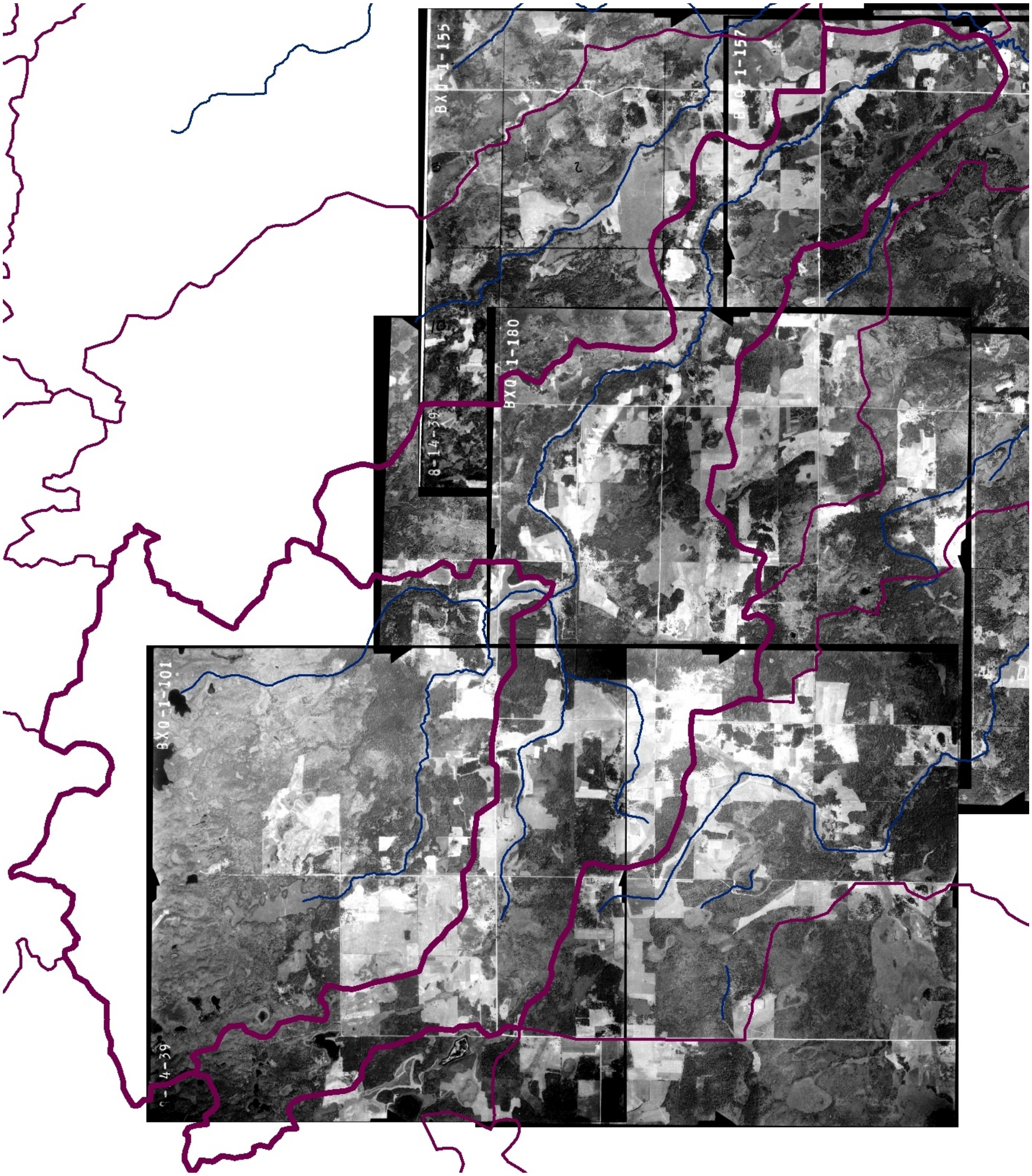
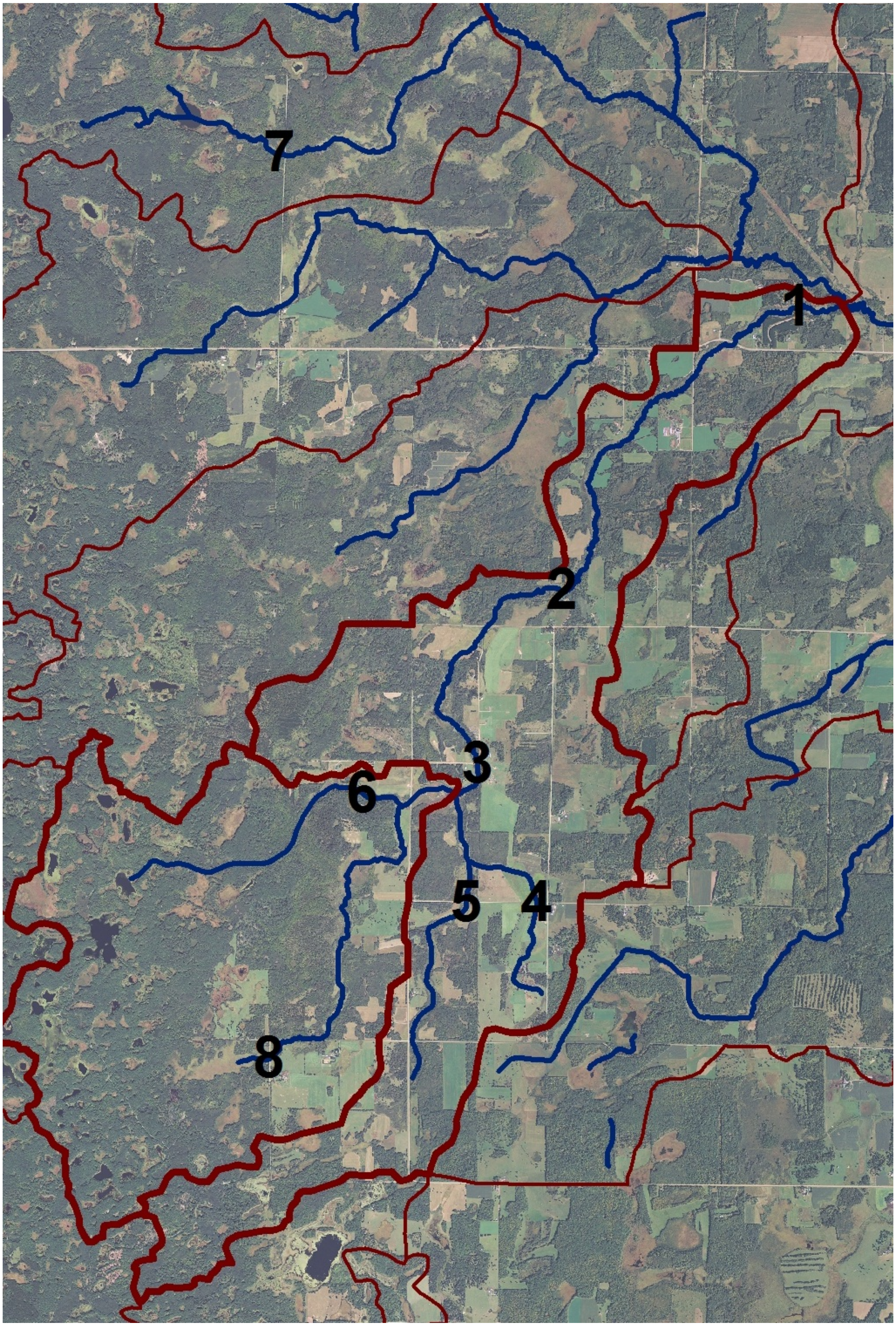


Figure 14. Aerial photograph of Bungo Creek Watershed, 2010. Numbers indicate water sample sites.



F. Farming Practices

To learn about farming practices in the watershed, we met with several farmers on June 22nd, 2011. We discussed:

- Manure storage and land application practices and locations;
- Cropping systems, including information about rotations, tillage, and soil amendments such as fertilizer and lime;
- Livestock systems, including number and type of animals, summer and winter housing, and pastures;
- Other land information such as past land uses, beaver ponds, changes in the creek and nearby forests, springs, and drainage systems.

This information was used to determine the inputs for the MN Phosphorus Index modeling (p. 23) and to help interpret soil test results (p. 13).

Virtually all agriculture in the watershed is livestock farming – mostly beef cattle, as well as dairy cows, and some horses. Farmland is used either for pasture or to grow feed including hay, haylage, silage, and corn.

Practices that Impact P Movement

Taken as a whole, the agricultural acres in the watershed are enough to support the amount of P generated by the animals in the watershed. Beef and dairy cattle generate roughly 30 pounds of P per animal per year; horses generate roughly 13 pounds (MidWest Plan Service, 2001). Crop harvest removes roughly 30 pounds of P per acre per year. Thirty pounds is also the recommended fertilizer rate for growing corn on soils with medium P levels (i.e., soils that have not been receiving large manure applications). Therefore, the 2,300 acres of agricultural land in the watershed could theoretically absorb the P generated by the 1000+ animals in the watershed.

However, manure is not spread evenly across all acres and phosphorus does not move evenly off the landscape. P loss occurs from critical sites. Here are some of the practices that determine whether a site has a high or low risk of P loss.

Manure application. Much of the manure in the watershed is collected in barns or manure pits and spread periodically on the land as liquid or solid manure. This manure is not a threat to water quality if state requirements and recommendations are followed:

- Application is set back from water courses by 25 to 100 feet. (See "Applying Manure in Sensitive Areas" http://www.pca.state.mn.us/index.php/view-document.html?gid=3530)
- Manure within 300 feet of water courses is incorporated within 24 hours of application.
- In the winter, manure is not applied on steeply sloping land or within 300 feet of water courses.
- Manure is applied at modest rates, preferably no more than to meet UM recommended fertilizer needs. On fields with a long manure history, no P is recommended. On other fields, rates should be based on soil tests and manure tests. The resulting rates are likely to be in the range of 2 to 20 tons/acre of solid manure or 1000 to 5000 gallons/acre of liquid manure.

Pastures. Much of the manure in the watershed is distributed across the land by the animals as they graze. Risk of P loss from pastures is low if setbacks listed above are followed and stocking rates are low enough that the soil has good vegetative cover.

Animal concentrations. Animals are often held at densities where manure becomes concentrated and there is not a continuous vegetative cover – areas such as feedlots[1], loafing areas, exercise lots, or areas within pastures around feed and water areas and walkways. Risk of P loss can be high because of the combination of high rates of unincorporated manure, compacted soil, and lack of vegetation to slow runoff. Situations where animals become concentrated include:

- near barns where animals are held during calving periods and for access to milking facilities,
- on corn fields for gleaning in the fall or spring between crops,
- around feed and water sources in winter pastures, and around water sources in summer pastures.

Risk of P loss can be managed if areas of concentrated animals are set back from water courses and organic soil. De-vegetation can be reduced by managing water and feeding sites so animals do not concentrate in one area for extended periods.

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[1] The MPCA defines feedlots as sites where livestock are confined and fed for 45 days or more in a 12-month period, and that lack vegetative cover.

See appendix for resources on managing animals.

Fertilizer, tillage. Fertilizer can be a source of P if applied excessively. This is unlikely in Bungo Creek watershed. Excessive tillage raises the risk of loss of sediment-bound P during soil erosion. This is also unlikely to be a significant issue because of the low slopes in the watershed and the high use of perennial forages and pasture.

Drainage. Drainage ditches are evident in the area, but their extent is not clear. They can impact hydrology and movement of P to the creek. Ditches dug to drain high organic matter soils will be a long term source of P. By draining peat, the organic matter is exposed to oxygen and will steadily decompose, releasing P and other nutrients.

G. Modeling Agricultural P Loss Risk: The Minnesota Phosphorus Index

What is the MN P Index?

The Minnesota Phosphorus Index (MN P Index) is a model for estimating the risk of phosphorus (P) loss from agricultural land. The model is available at http://www.mnpi.umn.edu. The MN P Index is a decision-making tool to help users identify and refine site-specific methods to reduce P loss. The model can account for the interaction of a range of risk factors including landscape characteristics, cropping and tillage practices, and P application methods.

The MN P Index assesses P loss risk by modeling three major pathways of P movement from fields to water: erosion, rainfall runoff, and snowmelt runoff (Figure 15). For each pathway a transport mechanism is multiplied by P sources to calculate a P loss risk for that pathway. The three pathways are summed to get a total P loss risk value. Usually one pathway plays a bigger role in overall P loss risk than others. Management changes that address that pathway will be the most effective method for reducing the overall risk.

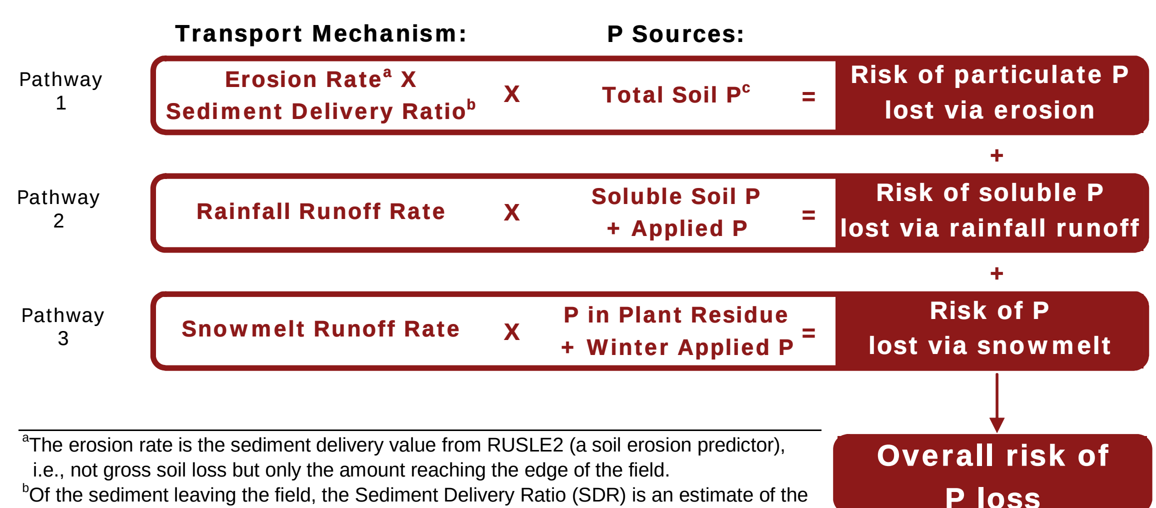
Phosphorus can travel by other pathways not considered by the MN P Index including leaching through the soil, and via wind or gully erosion. Leaching is generally a minor concern, but may be significant in the high organic matter soils found in Bungo Creek watershed. Gully erosion can be significant but is difficult to model at a field scale and is probably uncommon in the Bungo Creek watershed. Neither leaching nor gully erosion are accounted for in the MN P Index.

The MN P Index is a management decision-making tool. The inputs are easily available and it generates results that are reliable for making farm-level decisions or for watershed planning. The output is an estimate of the relative risk of P loss from a farm field. It is not reliable as a quantitative estimate of P delivery.

Inputs

The MN P Index model was run using inputs representing several scenarios typical in Bungo Creek watershed. The scenarios include:

- Dairy rotation – 4 years of alfalfa rotated with 3 years of corn silage. Manure applied to corn at "agronomic rates", i.e. no more than needed to meet crop nitrogen needs.
- Pasture – permanent pasture and wintering area with a stocking rate of 0.5 animals/acre June through September and 1.5 animals/acre October through March.
- Corn – long term corn production with high levels of manure applied either from animals gleaning the field or applications from manure



[a]The erosion rate is the sediment delivery value from RUSLE2 (a soil erosion predictor), i.e., not gross soil loss but only the amount reaching the edge of the field.
[b]Of the sediment leaving the field, the Sediment Delivery Ratio (SDR) is an estimate of the proportion that reaches surface water. The SDR is based on distance from field to water.
[c]Total soil P is estimated from soil test P and soil organic matter.

storage areas.

- Hay – long-term grassy hay with no manure applications.

All scenarios were run on Friendship loamy sand (a common agricultural soil in the watershed), and a starting soil test P level of 80 ppm Bray (a high but not uncommon test level in the watershed). The details of the scenarios are shown in an appendix.

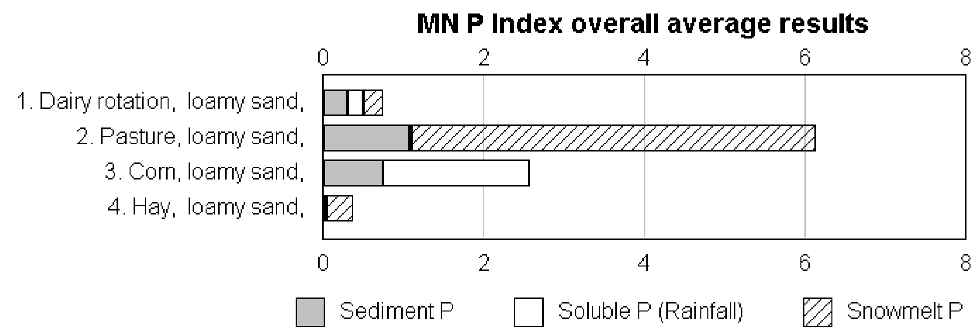
Results

P loss risk less than 2 is considered “low”; 2 to 4 is “medium”; and greater than 4 is considered “high”. The pasture scenario had very high risk of P loss, primarily due to snowmelt losses of manure P (Figure 16). The manure generated by 1.5 animal units per acre left over 50 pounds of P_2O_5 per acre on the soil surface exposed to snowmelt runoff. During the snowmelt period, little runoff infiltrates into the soil, so any P on the surface is highly susceptible to movement.

Soluble P losses were high from the corn scenario because very high rates of manure were being applied.

P loss risk for the dairy rotation was very low. There was some risk of loss of sediment-bound P, especially in the years following fall tillage. There is also a risk of loss of soluble P following manure applications, however the risk is low because the manure is incorporated and applied at moderate rates.

Figure 16: MNPI results for typical scenarios in the Bungo Creek watershed.



Sensitivity Study Inputs and Results

Starting with scenarios 1 and 2 (dairy rotation and pasture) as the base scenarios, single input variables were changed one at a time to see how sensitive P loss risk was to that variable. Results are shown in Table 7.

Table 7: MN P Index Sensitive to Input Changes

Input variable Values tested	Notes	Results
Soil test P 10, 50, 80, 300 ppm Bray	10 ppm Bray is consider low soil test P for crop production and might be found in native soils. Above 20 ppm Bray P, fertilizer would not be recommended because a corn yield response is not expected. Values of 60 to 100 ppm Bray are expected to be common on soils in the region that have been receiving long-term manure applications. Levels of 300 ppm Bray could be found in isolated areas after decades of manure storage, heavy manure applications, or in animal loafing areas.	Soil test P most strongly impacts risk of sediment-bound P losses. Sed-bound P loss was greater on the pasture scenario than the dairy rotation scenario, so it showed greater sensitivity to increased soil test P. Risk of sed-bound P loss more than doubled from 0.8 to 1.9 when soil test P rose from 10 ppm Bray to 300 ppm Bray. In the dairy rotation, risk rose from 0.2 to 0.5 (for sed-bound P loss, only).

Distance to water 0 ft, 100 ft	Soils typically adsorb P, so delivery to the Creek declines the further a field is from the Creek.	Sediment-bound P loss risk dropped from 1.1 to 0.4 on the pasture scenario when the distance from the pasture to the creek was increased from 0 to 100 feet. However, on muck soils and coarse mineral soils with very high P, P does not adsorb well and can leach out. In these cases, distance from the Creek will have less of an effect on reducing P delivery than is suggested by the model.
Soil type Sandy loam, muck 65% OM	High organic matter soils can leach P, but little will flow over the soil surface because of the low slopes.	In the pasture scenario, risk of sediment-bound P losses dropped to 0 on the muck soils (compared to 1.1 on the loamy sand), but risk of soluble P in runoff rose from 0 to 0.7. When soil test P was increased from 80 to 300 ppm Bray on muck soils, risk of soluble P loss rose from 0.7 to 1.6. On mineral soils, soil test P affected sediment-bound P (rather than soluble P).
Manure incorporation Chisel plow, vs. no incorporation	Manure can only be incorporated on tilled fields.	Incorporation of manure substantially reduced P loss risk via pathway 2 (overland soluble-P), compared to unincorporated manure. The benefit of incorporation was even more dramatic with larger rates of manure.

Interpretations

Based on the MNPI, in Bungo Creek watershed, the highest risks of P loss are from

- pastures with dense stocking rates,
- feeding and watering areas in winter pastures, and
- small areas receiving high "disposal" rates of manure.

Based on measured P loss from studies around the Midwest, these high risk areas may deliver 1.5 lbs of P per acre to the creek. Agricultural areas with lower manure applications and where manure is incorporated into the soil may only deliver 0.2 lbs of P per acre (Lewandowski and Moncrief, 2007. p. 14).

Risk of P loss is also high where manure is applied to high (>50%) organic matter soils, but this is not modeled well in the MNPI. The model shows that high soil test P increases overland soluble-P losses from muck soils. However, leaching losses are not accounted for in the MN P Index. Leaching may be significant from muck soils and from mineral soils with extremely high P levels (>200 ppm Bray).

The model shows that for Bungo Creek soils, risk of P loss from agricultural lands can be reduced by following these guidelines, which were described in the "Farming Practices" section (p. 21).

- Minimize winter manure applications.
- Manage winter feeding and watering areas.
- Maximize the number of acres for distributing manure and for pasturing animals.
- Incorporate manure shortly after application. Avoid applications right before forecast rain.
- Do not apply manure to or pasture animals on high organic matter soils that border the creek. Establish no-manure buffers between these high organic matter soils and fields that receive manure.

H. Modeling Watershed P Sources: The MN Phosphorus Source Assessment Tool

What is the Minnesota PSAT?

The MPSAT was based on the Watershed Treatment Model (WTM) developed by the Center for Watershed Protection. The WTM was designed especially for urbanizing watersheds in the northeastern United States. The MPSAT was created by adjusting WTM default values to reflect conditions typical in central Minnesota.

Like the MN P Index, the MPSAT results are not rigorous enough to be used as loading estimates. Results should be used to understand the relative contribution of various P sources and the range of possible contributions from a particular source. The MPSAT generates annual loads, so it cannot account for critical conditions that occur during the year.

The assumptions and data behind the MPSAT are detailed in Lewandowski and Moncrief (2007).

Inputs

Table 8: Explanation of inputs to the MPSAT.

Input	Data source and assumptions	Sensitivity **These examples show how much results would change by using different assumptions.**
<u>**Land use area**</u>	Landsat satellite data analyzed by the U of M Remote Sensing and Geospatial Analysis Laboratory (http://land.umn.edu)	
Urbanized area ***172 acres***	This number is high because the LandSat data includes paved roads which are accounted for in the rural land P loading assumptions.	
Forest, shrub ***8,142 acres***	This is the forest, brush, and grassland acreage identified using the Landsat data, minus 362 acres of agricultural land that was mis-identified (see next item).	
Agriculture ***2,268 acres***	The Landsat data identified 1,906 acres of agricultural land, but did not include pastures identified as wetlands. Instead, we used the value of 2,268 acres identified as agricultural in the aerial photo (subtracting the difference from the wetland category). This, too, is probably an underestimate because it does not include some woodlands that may be grazed. About 1000 animals are registered with the MPCA. Assuming another 300 unregistered animal units are in the watershed, and assuming the 1300 animals are held at an average stocking rate of 5 animals per acre in the winter, 260 acres would be needed for winter pastures.	Agriculture generates the highest P losses of any of the land uses. If an additional 300 acres of woodland were counted as agricultural land, total estimated P loading from the watershed would increase 4% from about 2500 units to 2600 units per year.
<u>**P loading factors**</u>	These are estimates of the amount of P going into a stream divided by the number acres in the watershed. They are based on watershed-scale measurements from several studies. More weight was given to studies in landscapes similar to that of Bungo Creek.	

Brush, forest, grassland	The default loading factors assume the soil is generally undisturbed and not compacted. A factor of 0.1 is typical for measurements taken in northern Wisconsin watersheds (Panuska and Lillie, 1995; Clesceri, 1986)	
Agriculture	The loading factors are based on MN P Index modeling. (See section above.) Mixed cropping and hayland has a moderate risk of P loss so the loading factor was set at 0.4 lbs P/acre. Losses from winter pasture areas can be much larger so the loading factor was set at 1.5 lbs P/acre.	
<u>Secondary Sources</u>	P loading from these sources is estimated for each item, rather than per acre.	
Dwellings and population ***66 households and 142 people***	Population is used to estimate the number of septic systems and amount of septic effluent. Sixty-six dwellings were counted in the watershed on an aerial photo. Multiplied by 2.15 persons per household (the average for Cass County from 2010 Census Data) there are **142** people in the watershed. The population in the watershed may be **205** based on Census data as follows: The US Census (http://factfinder.census.gov/home/en/official_estimates_2009.html), estimates the population of Bungo Township to be 222 in 2009. A watershed population was estimated by adding in the 14 residences (times 2.15 persons/household) who are outside the township, and subtracting 22 residences inside the township but outside the watershed. (The PRWA watershed Plan lists the 2007 population of Bungo Township as 167 Implying a watershed population of **150**.)	Any change in the estimated population or dwelling units would proportionately increase the estimated P load from septic systems. Thus, 205 people would generate 44% more P loading than 142 people.
Soil P	These values only affect the estimates of P losses from construction areas and channel erosion, neither of which are estimated for Bungo Creek.	
Septic systems	According to 2010 data submitted to the MPCA, an estimated 88% of Cass County septic systems are in compliance, 10% failing, and 2% IPHT (imminent public health threat). For the estimated 66 systems in Bungo Creek, that translates into 58, 7, and 1 system, respectively.	If 5 (instead of 1) of the estimated 66 septic systems are “straight pipes” going directly into the creek or a ditch, the watershed P load from septic systems would be almost 20% higher.

Livestock on open lots	This section accounts for animals in confined areas. Animals kept in covered barns are not included; only animals exposed to rainfall runoff. Animals on pasture are accounted for in the land use or "Primary Sources" section. From interviews with landowners (see p. 21) and records submitted to the MPCA, we estimated the type and number of animals, and the percent of the year that they are concentrated in an area exposed to rainfall (i.e., not on pasture or under a roof). That number is multiplied by the pounds of P produced by each animal, and then by a delivery factor representing the proportion of P that reaches the creek. The delivery factor was determined using the MinnFARM model (see references) to analyze nutrient losses from areas where animals are highly concentrated. The highest rate of loss modeled was about 3.5% of the P in the manure generated by the animals on the lot. We used a delivery factor of 3.5% for a quarter of the animals, and a factor of 2% for the remaining animals.

Scenarios

The inputs described in Table 8 represent a base scenario – a best guess of current conditions. To account for uncertainty in these numbers, several scenarios were developed that show the range of possible values. The actual picture of P sources in Bungo Creek watershed probably falls within the range of these scenarios (Figure 17).

For the "high ag" scenario (a) 300 acres of forest was converted to pasture, (b) the P yield for ag land was raised from 0.4 to 0.6 lbs per acre, leaving the winter pasture at 1.5 lbs per acre, and (c) the time that livestock are on feedlots was increased from half to three-quarters of the time.

The "low ag" scenario leaves the land-use acreages the same as the base scenario, but assumes a P yield from all ag land of 0.3 instead of 0.4 and 1.5 lbs.

"High septic" assumes the population of the watershed is 205, and 5 systems have direct pipes into the creek.

The "1939" scenario uses 2,058 acres of agricultural land (10% less than the base scenario), 7,091 acres of forest (increased by the 210 acres that ag land was reduced), a population of 109 (about 72% of the current population, consistent with the county population trend), and increased the proportion of failing septic systems to 30%, assuming human waste was not handled as carefully. The number of animals in feedlots and acres of winter loafing areas were left the same, consistent with county animal trends.

Results

According to this model (Figure 17), forest land makes up over 70% of the watershed and contributes about a third of the P load to the Creek. Crops and pasture cover less than 20% of the land. Crop production and livestock manure contribute over half the P load, but this value depends heavily on several management assumptions, such as where and when animals are pastured and how manure is applied.

Septic systems may contribute about 2% of the P load.

Caveats and Interpretations

PSAT results are annual averages that give no indication of variation within or between years. When planning treatment, consider critical conditions during the year and plan for major events such as snowmelt or large runoff events.

Loading factors are estimates of the annual amount of phosphorus delivered to the mouth of the creek, divided by the total number of acres in the watershed. In reality, phosphorus comes from critical areas in the landscape and does not flow equally from all areas. When planning treatment, focus on these critical areas. Critical areas are those with concentrated P sources (e.g. long term manure storage or application), or high transport (e.g. organic soils that don't adsorb P).

PSAT does not differentiate between dissolved and particulate P. The tool considers total P on the assumption that all P has the potential to become biologically available eventually.

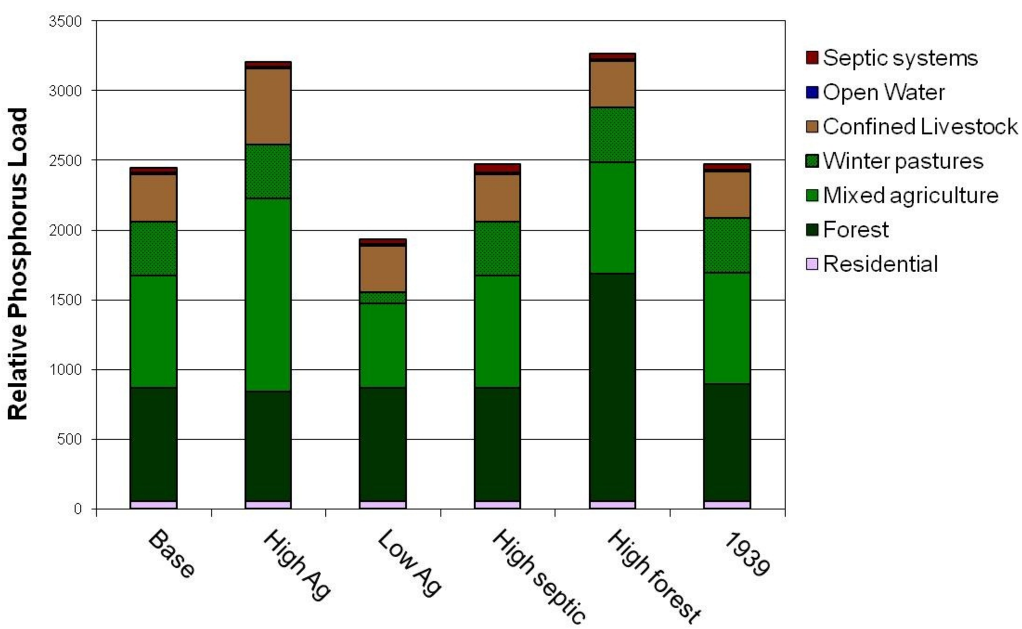
Any failing septic systems or direct pipes of untreated sewage would be significant sources of P and a health threat, and thus should be remedied. However, the amount of P contributed is still small compared to that contributed by animals in the watershed.

The scenarios assume 260 acres of agricultural land have high P losses (1.5 lbs/ac). (These acres are called winter pasture in the graph.) This assumption makes a big difference. Doubling or halving the number of high-P-loss acres results in a 14% increase or 8% decrease of total P loading. This has two implications: the total loading estimate could be far off, and identifying and addressing these critical acres could have a substantial impact on reducing P loading.

Phosphorus loss is normal and expected from all lands. The target should not be near-zero but to reduce those losses that can be economically reduced.

Figure 17: MN PSAT Model Results for Bungo Creek Watershed

Each bar represents a different set of assumptions about P sources with the base scenario being the best guess. "Reality" probably falls within this range of scenarios. Details about the assumptions are in the "Inputs" and "Scenarios" section above.



I. Conclusions and Recommendations

Conclusions

Hydrology and P cycling in Bungo Creek watershed is complex.

P concentrations in water flowing from peat areas are naturally high. Glacial geology impacts the soil chemistry and hydrology of the region. Still, P levels leaving Bungo Creek are elevated compared to what is expected for this landscape and region of the state.

The combination of lateral flow of near-surface groundwater and low P-binding capacity of the soils suggests that standard manure and fertilizer management practices may have a risk of P loss to streams and lakes. This hypothesis can be tested through the measurement of soil and groundwater P and nitrate or bacteria levels. If manure is the source of soluble P traveling through the soil, then nitrate and bacteria would be moving with it. High P without high NO_3 levels would suggest a P source other than manure. (Nitrate can be denitrified into nitrogen gas and lost to the atmosphere, so monitoring plans must account for the fact that nitrate levels in water rise and fall quickly.)

Phosphorus from Bungo Creek cannot explain all the increases in P loading to Whitefish Lake, and no single source of P explains the P levels in Bungo Creek. Any reductions in P will require addressing multiple sites and sources.

Livestock are important in Bungo Creek watershed, and probably more numerous than in other subwatersheds. Still, the numbers are manageable and within what the land can hold. Improved manure management is part of the solution to reducing P loss from the watershed.

Recommendations

Monitor to track trends. The recommendations below reflect a best estimate of P dynamics in the watershed, but understanding is incomplete. Because of the complexity of the hydrology and P dynamics, it will be useful to take an adaptive management approach – that is, monitor the impact of changes and adjust as needed. Measuring flow will be impractical and thus estimating P loading will not be possible. Instead, use periodic grab samples at several sites, on the same days as Pine River sampling. This will show relative differences in total and ortho-P concentrations across the Bungo Creek watershed. Especially note the ratio of ortho-P to total P. At a minimum, sample at the Rollins, Dabill, Pelcl, and 60th Avenue sites (Sites 1, 2, 3, and 8 in Figure 14).

Provide manure management education. Provide technical assistance to help farmers adjust their practices to reduce risk of P loss. Work with farmers to identify training needs and appropriate advisors. Provide workshops and perhaps individual consulting to help landowners develop practical manure management plans, and to improve forage production and grazing management.

Focus on concentrated animals. In examining agricultural practices, especially look at loafing areas, winter feeding areas, and any other places where animals concentrate.

Keep manure off peat. Eliminate manure application and grazing from organic soils (**Error! Reference source not found.**).

Reduce soil phosphorus levels. On and near organic soils, consider planting trap crops that will take up phosphorus which can then be harvested and removed from the site. Grasses make good trap crops because they grow at low phosphorus levels. Corn also removes large amounts of phosphorus, but only if there is adequate phosphorus in the soil.

Help landowners develop site specific solutions. Recommended agricultural practices include:

- Soil testing to determine phosphorus needs and to identify P “hot spots”.
- Applying manure at rates needed by crops.

Applying these recommendations will require solutions specific to each site and operation. For example, a plan for distributing manure must be compatible with the manure storage capacity and manure handling equipment on the farm. Identifying low and high risk areas for winter feeding requires considering the combination of soils, slopes, distance to barns and shelters, and practical access to water and feed. If given adequate technical and financial support, landowners are best able to design effective solutions that fit their complex operation.

Remove phosphorus-laden sediments. Sediment-bound phosphorus settles out whenever water flow slows down, such as in beaver ponds or on flood plains. The phosphorus can be mobilized when these areas are saturated. Theoretically, these sediments could be removed to a site away from the creek, but this is unlikely to be cost-effective.

Address septic systems. The amount of people in Bungo Creek watershed is small relative to the number of animals. Thus, identifying and fixing a single direct pipe going into the creek drainage system will have a relatively small effect on P loads (though, an important effect on bacteria). Septic systems next to the creek should be viewed in the same light as septic systems next to lakeshores.

Look beyond Bungo Creek. Consider how these recommendations apply to other subwatersheds. For example, look at patterns of organic soils and concentrated animal areas elsewhere. Promote education programs to landowners across the watershed.

Appendices

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K. Resources for Agriculture

Expertise in forages, grazing, and livestock in northern Minnesota

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Managing Winter Feeding Areas and Feedlots

U of M Extension

- The U of M Beef Center http://www.extension.umn.edu/beef/
- Managing Winter Feeding Areas for Beef Cattle in Minnesota http://www.ansci.umn.edu/beef/2010-11%20MN%20BEEF/files/cow-calf/2008/e4-managing_winter_feeding_areas.pdf
- Establishing Winter Feeding Areas for Grazing. 2008. Ryon S. Walker and Russ Mathison http://www.extension.umn.edu/beef/components/pdfs/WinterFeeding_Walker.pdf
- Establishing Annual Forages on Winter-Feeding Areas http://www.extension.umn.edu/forages/pdfs/february_2010_fq_umeft.pdf
- Methods to Establish Grazing of Annual Forages for Beef Cows on Winter Feeding Areas. 2009. R.S. Walker, S.L. Bird, P.R. Peterson, R.D. Mathison. *2009 Minnesota Beef Cow/Calf Days*, p. 62-66. http://www.extension.umn.edu/Forages/pdfs/r6_walker.pdf

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Consider sheep, which don't need water if they have access to snow.

L. Data Sources

The following data were used in this study.

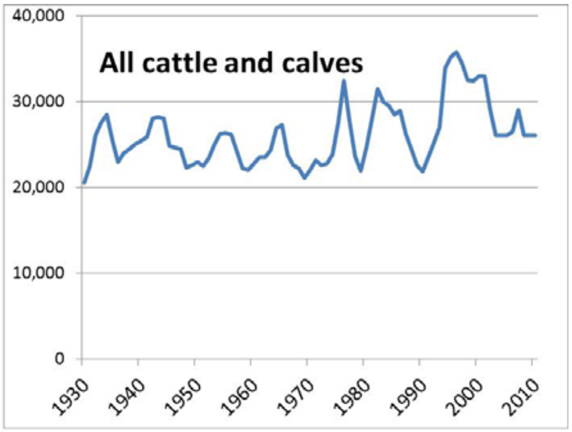
Source	Description of Data
DNR Data Deli http://deli.dnr.state.mn.us/	GIS layers of: • HUC 8 and HUC 12 watershed boundaries • streams • county boundaries • USGS topographic quads • Public Land Survey
NRCS Soil Data Mart http://soildatamart.nrcs.usda.gov/	Soil survey maps and soil data
Borchert Map Library http://map.lib.umn.edu/apindex.phtml	Website has a comprehensive list of and links to aerial photography. Library has hard copies of historical aerial photos.
Cass County Environmental Services http://www.co.cass.mn.us/maps/map_home.html	Additional aerial photos, including infrared. Look for links to the interactive "Web Mapping", and "Online Plat Book".
Environmental Data Access (EDA) from the MPCA http://www.pca.state.mn.us/index.php/data/index.html	Sampling data from wells, and spatial data of impaired waters and NPDES permitted feedlot sites
Monitoring Minnesota's Changing Landscapes http://land.umn.edu	Land use and land cover data based on landsat images
Minnesota Climatology Working Group http://climate.umn.edu/	Monthly precipitation totals from within 20 miles of the Bungo Creek watershed.
MnGeo (Minnesota Geospatial Information Office) http://www.mngeo.state.mn.us/chouse/airphoto/	Aerial photography is available for download or can be accessed via ArcGIS without downloading by using their WMS service. Includes color images from 2010, 2009, 2008, 2006, and 2003; color infrared images from 2008; and B&W image from 1991.

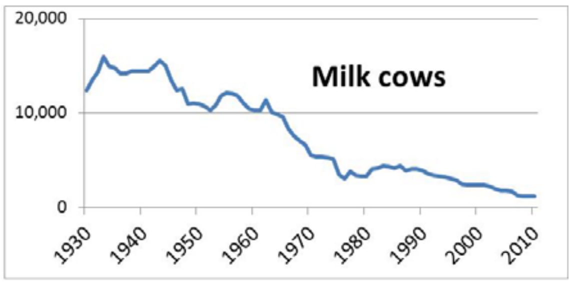
M. Inputs to the Minnesota Phosphorus Index

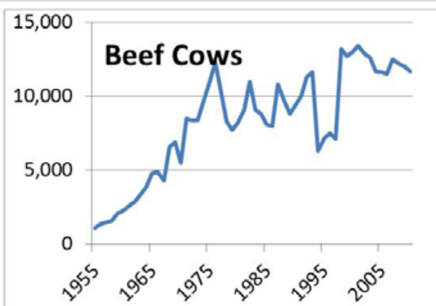
Inputs	**Scenario 1: Alfalfa and corn silage rotation**	**Scenario 2: Permanent pasture**	**Scenario 3: Low input corn**	**Scenario 4: Long term hay**
Distance from field to water	0 ft	0 ft	0 ft	0 ft
Soil type	Friendship loamy sand (MU 564)	Friendship loamy sand (MU 564)	Friendship loamy sand (MU 564)	Friendship loamy sand (MU 564)
Slope gradient & length	1%, 200 ft	1%, 200 ft	1%, 200 ft	1%, 200 ft
Artificial drainage	None	None	None	None
Soil test P	80 ppm Bray	80 ppm Bray	80 ppm Bray	80 ppm Bray
Soil percent organic matter	1.3%	1.3%	1.3%	1.3%
Crop rotation	4 yrs alfalfa (4 t/ac), 3 yrs corn silage (5 t/ac)	Pasture, per acre stocking rate of 0.5 animal unit June through September; 1.5 au October through March.		
Tillage	MB plow and spring disc before and after corn yrs	None	MB plow and spring disc	None
Manure applications	100 lbs P2O5/ac (10 lbs P2O5 per 1000 gals. 10,000 gals/ac). Applied in the fall before 3 years of corn and 1st year of alfalfa. Incorporated with MB plow.	11.7 lbs P2O5/ac in July; 52.5 lbs P2O5/ac in January. (Assumes 70 lbs P2O5 generated per animal per year.)	300 lbs P2O5/ac in October, not incorporated	None
P fertilizer applications	None	None	None	None

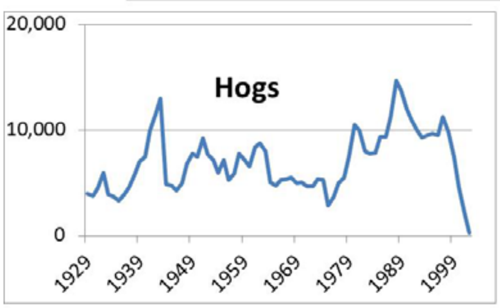
N. Cass County Livestock Inventories

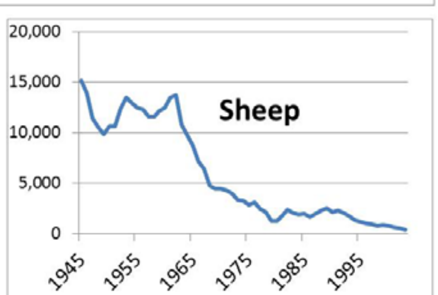
From the National Agricultural Statistics Service. This is county-level data and may not reflect Bungo Creek trends.











Appendix 9- Soil Health for Conservation Benefits

Soil Health for Conservation Benefits

Soil Health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. There are five basic principals to building soil health.

- Minimize Tillage
- Keep soil covered
- Incorporate cover crops/ living roots in the soil year around
- Increase plant biodiversity, crop rotations
- Livestock integration using adaptive rotational grazing techniques

Though it once was thought to take decades to build an inch of top soil, we now know it can be restored much faster. Producers across the country are increasing soil organic matter by two percent or more within a decade. By using a combination of modern no-till diversified cropping, cover crops, and adaptive high stock density rotational grazing, gains of one percent annually are reported. There are many benefits in managing for soil health.

Economics/ Productivity

- Healthy soil increases nutrient availability, reducing the need for purchased fertilizers.
  - The economic value of the ecological services provided by soil biota is approximately $US 1.5 trillion.[1]

Assumptions:

- 2,000,000 lbs. soil in top 6 in.
- 1% organic matter = 20,000 lbs.

Value of 1% Soil Organic Matter(SOM) Nutrients/Acre = $751

Source: J. Soil and Water Conserv. B. Hudson. 49 (2) 189-194

Nutrients

- Nitrogen: 1,000 lbs. x 56¢/lb. N = $560
- Phosphorus: 100 lbs. x 67¢/lb. P = $67
- Potassium: 100lbs. x 54¢/lb. K = $54
- Sulfur: 100 lbs. x 50¢/lb. S = $50

- Crop yields from healthy soil are equivalent to yields from chemical intensive production systems, and in years of stress, drought or excess moisture, is more productive.[4]

Water Quality

- Healthy soil conserves and protects water quality.

- 1% SOM = 25,000 gallons of water holding capacity. (NRCS)
- Increased SOM increases crop resilience to drought and excess rainfall.
- Increased SOM augments stream flows – reduced stream bank erosion, improved aquatic habitat and fisheries.[2]
  - Reduces nutrient leaching and runoff. Though science has been able to measure soil respiration since the 1860's, only recently have we been able to do it efficiently, allowing for accurate biologically available nitrogen estimates.[3]

Climate Mitigation

- Current agriculture is a net producer of greenhouse gas emissions both directly through conventional farming practices that deplete soil carbon stocks while emitting nitrous oxide (N2O), and indirectly through land-use change.[5]
- Improved management of agricultural land with known soil building practices has the potential to both reduce net greenhouse gas emissions and to act as a direct CO2 sink.[5,6]

Soil Biology

- While the understanding of soil carbon stabilization mechanisms is evolving, it is clear that soil biota play an important role here. In general, there is a positive relationship between abundance of fungal biomass and soil carbon.[7] This is just one of the benefits of a biologically health soil.

1. Brussaard L, dr Ruiter PC and Brown GG. (2007) Soil biodiversity for agricultural sustainability. Agriculture, Ecosystems and Environment 121: 233-244.

2. Daniel Engstrom, Shawn Schottler, Dylan Blumentritt, and Carrie Jennings. 2008. Minnesota River Turbidity TMDL Fingerprinting Sediment Sources. Presentation to the Minnesota River Turbidity TMDL Stakeholder Advisory Committee, March 10, 2008. http://wrc.umn.edu/prod/groups/cfans/@pub/@cfans/@wrc/documents/asset/cfans_asset_271297.pdf

3. Brinton, W and R. Haney 2013 Solvita CO2-Burst Respiration: A Rapid Means to Gauge Soil Biological Activity and Potentially Mineralizable Nitrogen. International Symposium on Soil and Plant Analysis, ISSPA, New Zealand - See more at: http://solvita.com/publications#sthash.FdULlOjH.dpuf

4. http://rodaleinstitute.org/our-work/farming-systems-trial/farming-systems-trial-30-year-report/

5. Lal, R. Soil carbon sequestration to mitigate climate change. Geoderma 123, 1–22 (2004)

6. . Smith, P. et al. Greenhouse gas mitigation in agriculture. Philos. Trans. R. Soc. B Biol. Sci. 363, 789–813 (2008).

7. .Vries, F. T. de et al. Soil food web properties explain ecosystem services across European land use

systems. Proc. Natl. Acad. Sci. 110, 14296–14301 (2013)

Appendix 10 – TNC Multiple Benefits for People and Nature

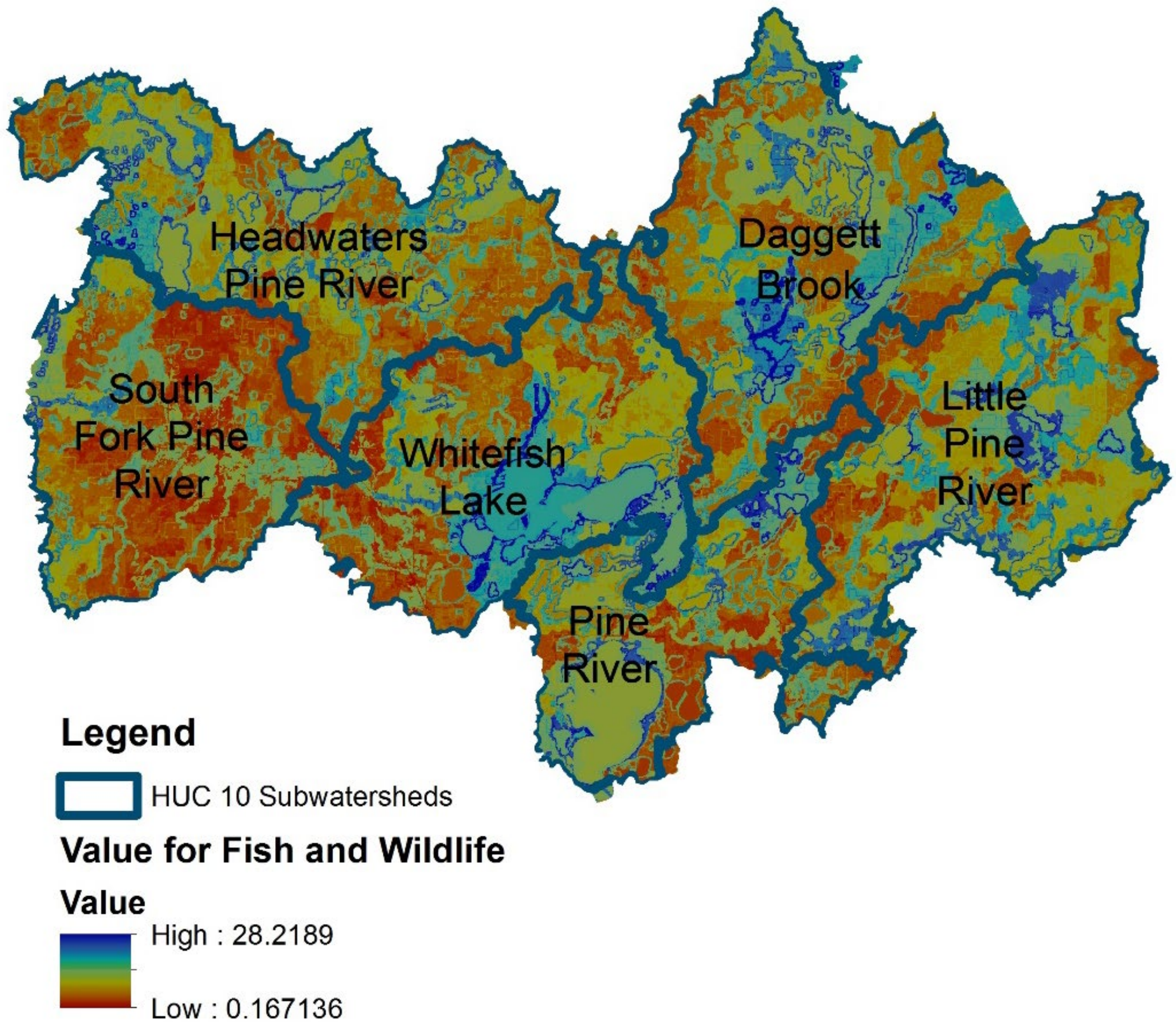


Figure 51. Areas where implementation would best benefit fish and wildlife. Dark blue areas are highest priority.

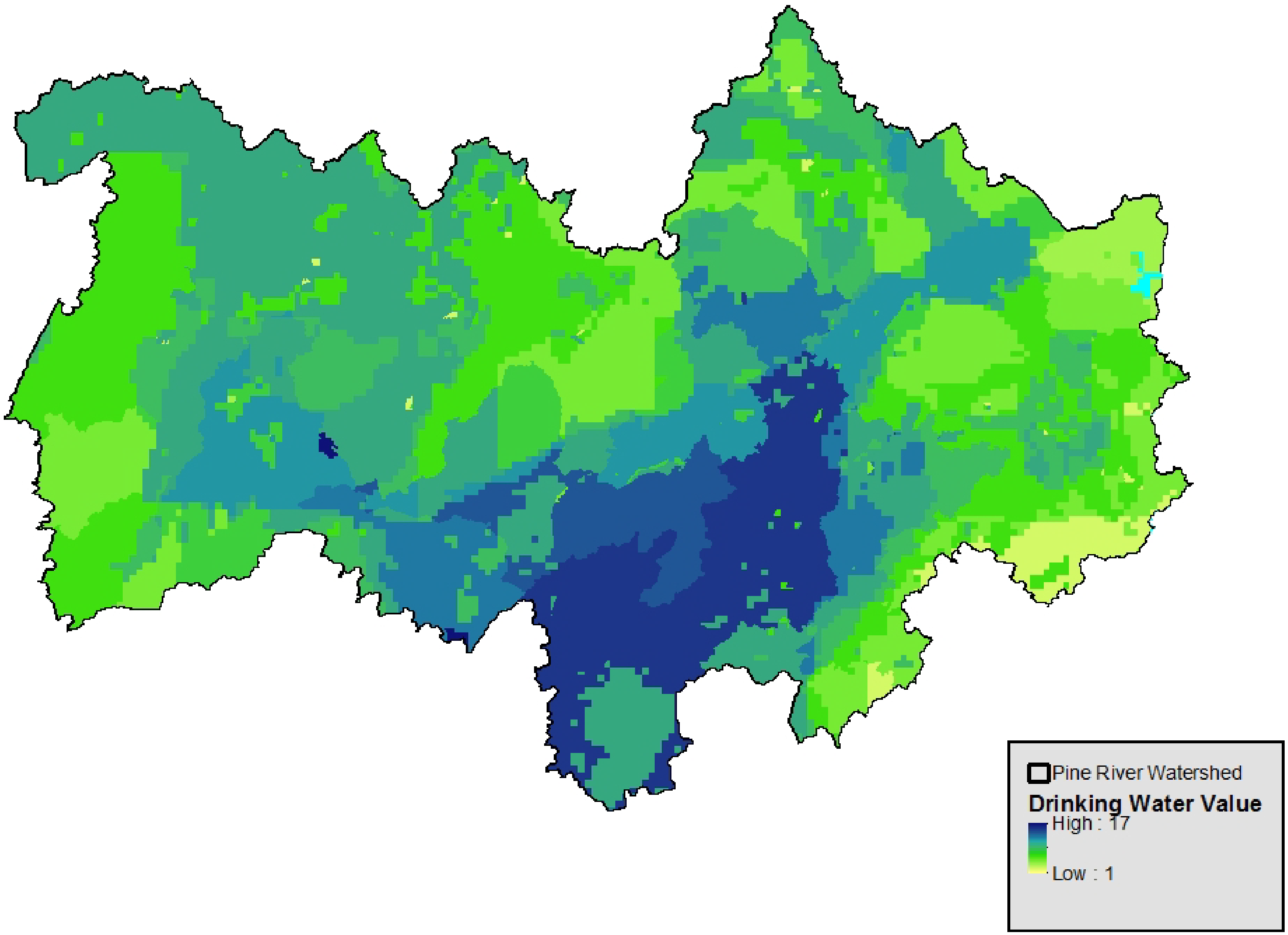


Figure 52. Drinking Water priority areas for protection and/or restoration.

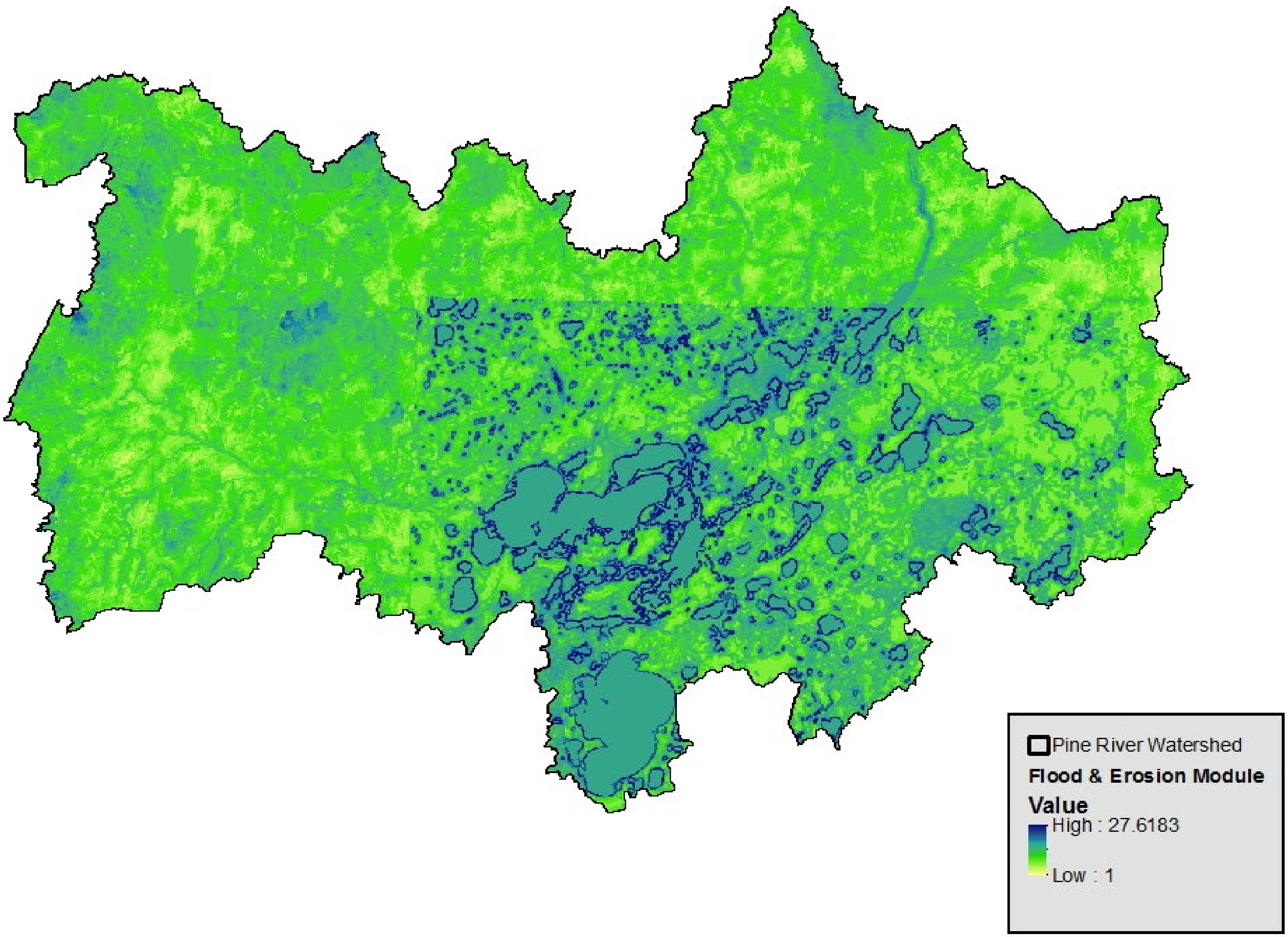


Figure 53. Potential water quality benefits in the form of reduced erosion risk from wetland restoration or protection.

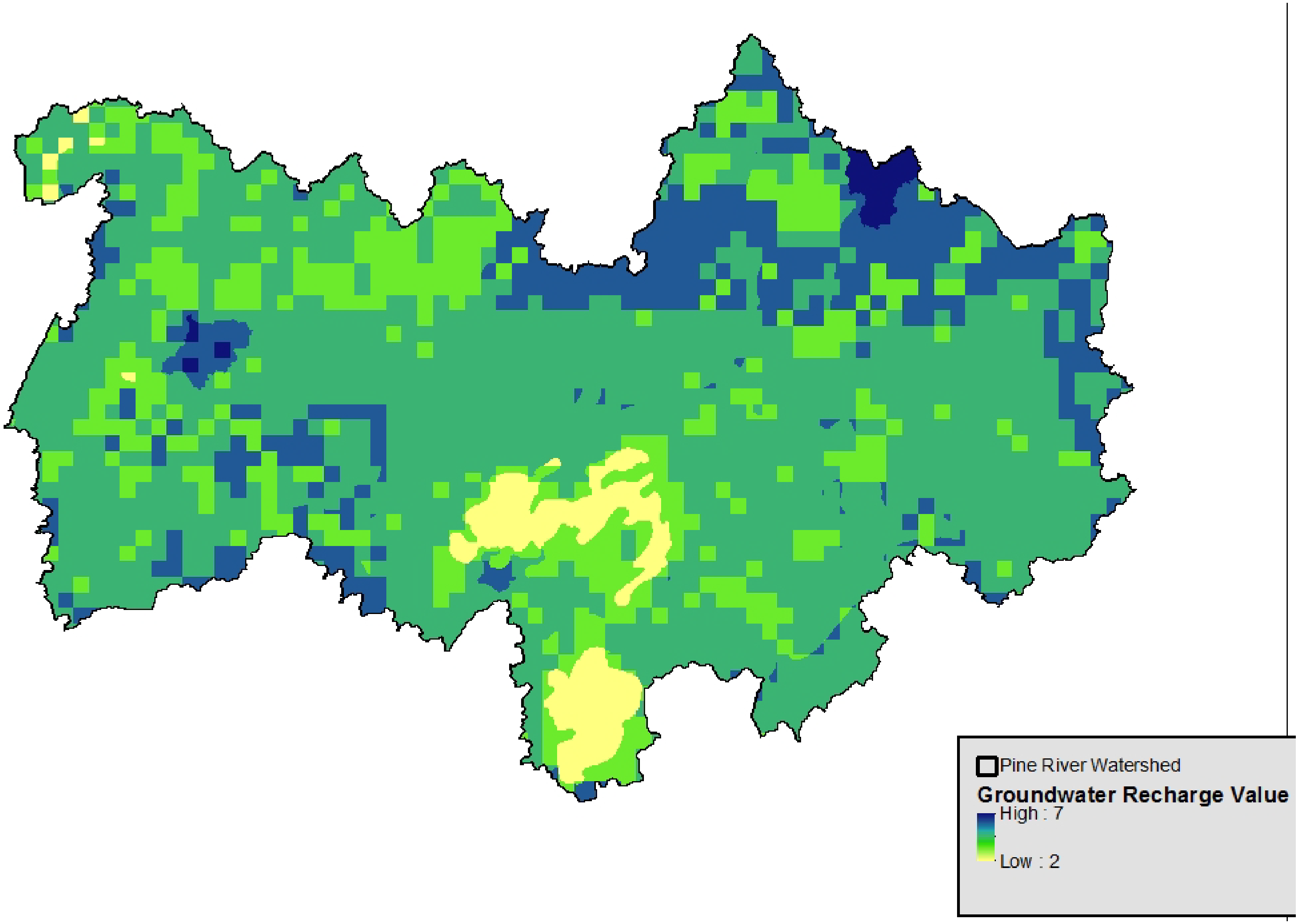


Figure 54. Long term potential average Groundwater recharge.

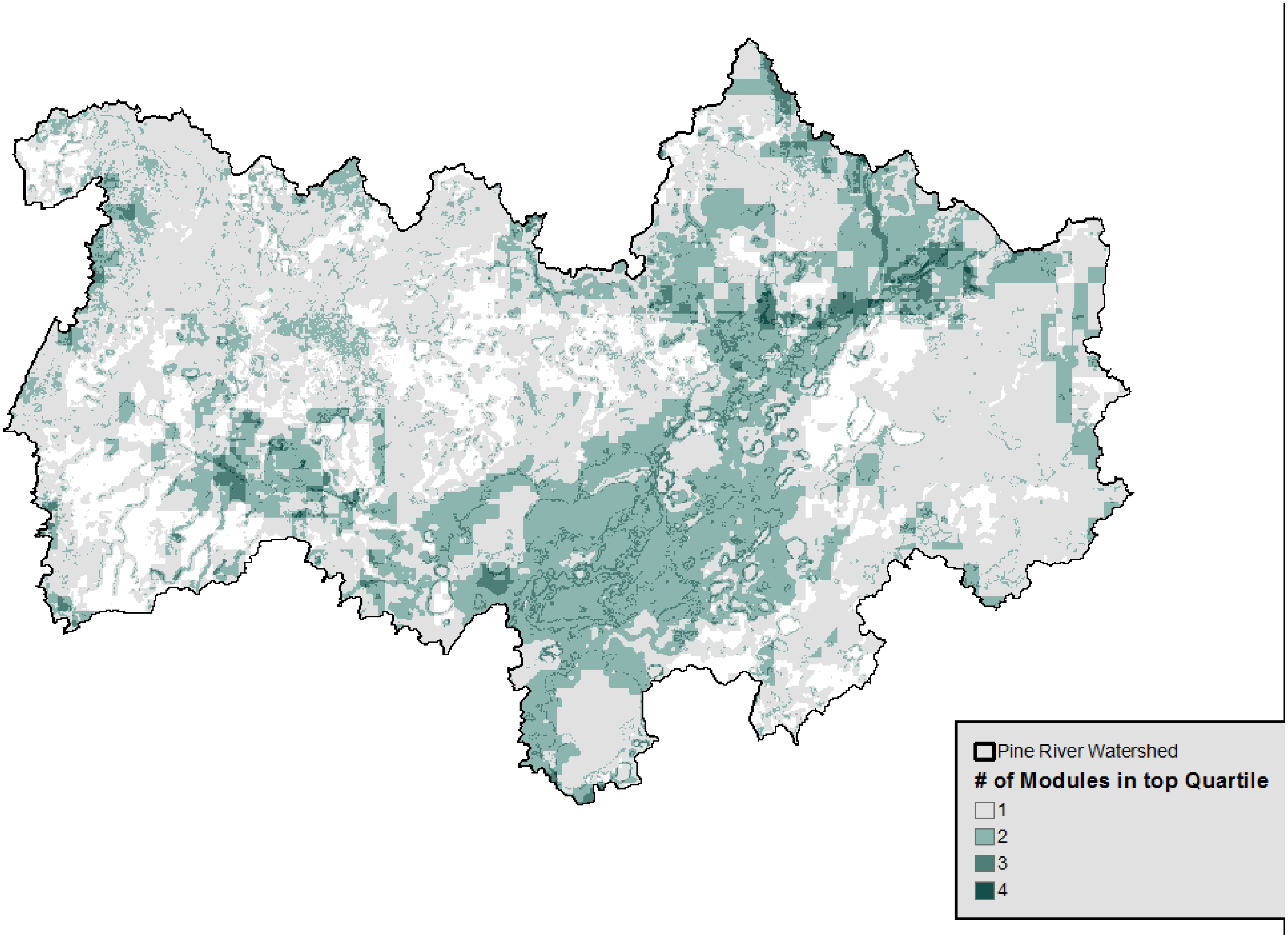


Figure 55. Multiple Benefits Map-overlay of the previous modules.

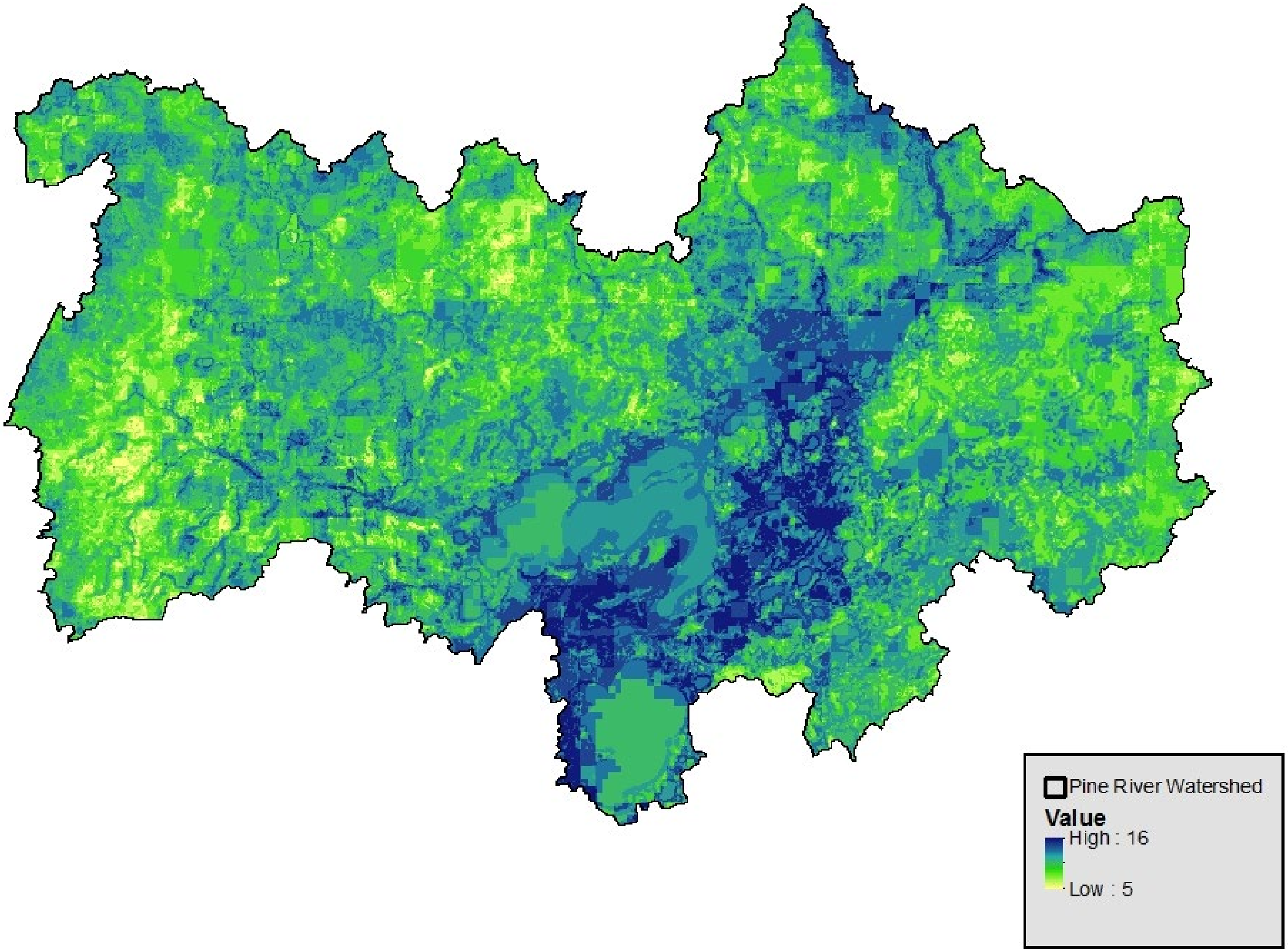


Figure 56. Value of Combined Scores of previous modules.