Watershed

March 2019

Lower Red River of the North Watershed Restoration and Protection Strategy Report

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

Project Partners

Rachel Olm, Tim Erickson, and Mark Deutschman
Houston Engineering, Inc.
6901 East Fish Lake Road, Suite 140
Maple Grove, Minnesota 55369

Mr. Cary Hernandez and Ms. Danielle Kvasager
Minnesota Pollution Control Agency
714 Lake Avenue, Suite 220
Detroit Lakes, Minnesota 56501

Mr. Dan Money
Two Rivers Watershed District
410 South 5th Street, Suite 112
Hallock, Minnesota 56728

Mr. Danny Omdahl
Middle-Snake-Tamarac Rivers Watershed District
453 North McKinley Street, PO Box 154
Warren, Minnesota 56762

Cover Photo Credit:

Minnesota Pollution Control Agency. Tamarac River at U.S. Highway. 75 (August 14, 2014)

Minnesota Pollution Control Agency

520 Lafayette Road North | Saint Paul, MN 55155-4194 |

651-296-6300 | 800-657-3864 | Or use your preferred relay service. | Info.pca@state.mn.us

This report is available in alternative formats upon request, and online at www.pca.state.mn.us.

Document number: wq-ws4-48a

Table of Contents

Key Terms

Assessment Unit Identifier (AUID): The unique waterbody identifier for each river reach comprised of the USGS eight-digit HUC plus a three-digit code unique within each HUC (e.g., 09020311-503).

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, total suspended solids, or certain chemical standards are not met.

Aquatic recreation impairment: Streams are considered impaired for impacts to aquatic recreation if fecal bacteria (i.e., *Escherichia coli* [*E. coli*]) standards are not met. Lakes are also considered impaired for impacts to aquatic recreation if total phosphorus, chlorophyll-a, and/or Secchi disc depth standards are not met.

Hydrologic Unit Code (HUC): A HUC is assigned by the USGS for each watershed. HUCs are organized in a nested hierarchy by size. For example, the Red River Basin is assigned a HUC-4 of 0902 and the Lower Red River of the North Watershed is assigned a HUC-8 of 09020311.

Impairment: Waterbodies 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 0 (lowest quality) to 100 (highest quality).

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.

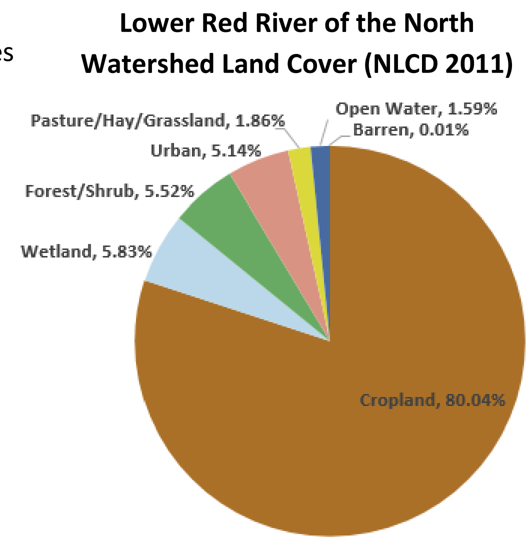
Source (or Pollutant Source): This term is distinguished from 'stressor' to mean only those actions, places, or entities that deliver/discharge pollutants (e.g., sediment, phosphorus, nitrogen, pathogens).

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.

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 (including natural background), an allocation for future growth (i.e., reserve capacity), and a margin of safety as defined in the Code of Federal Regulations.

Executive Summary

The Lower Red River of the North Watershed (LRRW) (Hydrologic Unit Code [HUC] 09020311), which encompasses 886 square miles, is located in the far northwestern corner of Minnesota and is situated within portions of Kittson, Marshall, and Roseau Counties. Land cover within the LRRW is predominantly crops, comprising 80% of the landscape (pie chart at right). The Lower Red River Watershed Restoration and Protection Strategy (WRAPS) Project included and built upon public participation, collaboration with local working/government groups, sampling waterbodies, assessing the ability of waterbodies to support designated uses, identifying stressors to biological communities, writing Total Maximum Daily Loads (TMDLs), and identifying implementation strategies to protect and restore waterbodies. This document, the WRAPS Report, summarizes the condition of surface water, the scale and types of changes needed to restore and protect waters, and options and available tools to prioritize and target conservation work on the landscape in the LRRW. The focus of this report is on the tributaries within the LRRW, which flow to the main channel of the Red River of the North (Red River). Water quality in the main channel of the Red River is not addressed in this WRAPS Report.



Information from multiple resources was used to evaluate the potential point and nonpoint sources of pollutants and ultimate health of waterbodies, including (but not limited to): stressor identification (SID) studies, Hydrological Simulation Program – FORTRAN (HSPF) modeling, analysis of the available water quality data for the last 10 years, and Geographic Information System (GIS) analyses. In 2011, data for the previous 10 years showed that the following pollutants were exceedingly high in at least one stream reach in the LRRW: total suspended solids (TSS), chloride, and *Escherichia coli* (*E. coli*); and a report published in 2015 shows that the following stressors are adversely affecting impaired biological communities in one stream reach: high TSS, low dissolved oxygen (DO), altered hydrology, poor habitat, and lack of connectivity. In addition, in 2013, chlorpyrifos (a pesticide) was determined to be exceedingly high in one waterbody, and in 2005, pH was found to be too high (however, the 2011 assessment found that pH meets standards).

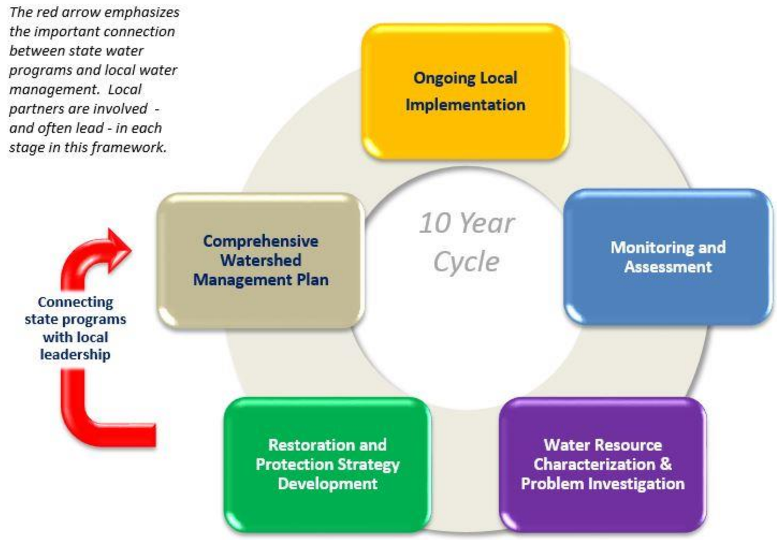
Strategies to reduce pollutants/stressors listed above (with the exception of pH since it was found to meet standards during its most recent assessment in 2011) and restore waterbodies to conditions where they are able to support their designated uses are identified in this document. All waterbodies in the LRRW that already support their designated use(s) have strategies of protection in this document that aim to prevent them from degrading in condition. However, only a fraction of the total waterbodies in the LRRW were sampled and even fewer were assessed.

The LRRW TMDL Report was concurrently developed with the WRAPS Report and the two TMDLs are summarized in this document. Thirteen impairments in the LRRW are listed on the 2018 303(d) list as impaired and needing a TMDL. Eleven of these impairments are not yet addressed with a TMDL, because either they are located on the mainstem of the Red River (n=7; these will be addressed in a separate TMDL report written specifically for the Red River), or because more information is needed (n=4). The remaining two impairments (1 caused by a poor aquatic macroinvertebrate community and the other caused by a poor fish community) on the same reach were addressed using one TSS TMDL. Although not yet listed as of the draft 2018, 303(d) list, one additional impairment was also addressed with a TSS TMDL, based on data that indicates an impairment caused by TSS.

This LRR WRAPS Report, as well as numerous other technical reports referenced in this document, are publicly available on the MPCA's Lower Red River website located at:

http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/red-river-of-the-north-tamarac-river.html

What is the WRAPS Report?



Minnesota has adopted a watershed approach to address the state's 80 major watersheds The Minnesota watershed approach incorporates **water quality assessment, watershed analysis, public participation, 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 development. WRAPS reports have two parts: impaired waters have strategies for restoration, and waters that are not impaired have strategies for protection.

Waters not meeting state standards are listed as impaired and TMDL studies are developed for them. TMDLs are incorporated into WRAPS. In addition, the watershed approach process facilitates a more cost-effective and comprehensive characterization of multiple waterbodies 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 for addressing 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 as a resource addressing the U.S. Environmental Protection Agency's (EPA's) Nine Minimum Elements of watershed plans to help 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: •*Lower Red River Watershed Monitoring and Assessment* •*Lower Red River Watershed Biotic Stressor Identification* •*Lower Red River Watershed 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

The LRRW[1] is located in the far northwestern corner of Minnesota. The LRRW has a drainage area of approximately 886 square miles within portions of Kittson, Marshall, and Roseau Counties (**Figure 1**). The LRRW includes all or portions of three watershed districts, including the Joe River Watershed District (JRWD) to the north, the southwest portion of the Two Rivers Watershed District (TRWD) in the center, and the Tamarac portion of the Middle-Snake-Tamarac Rivers Watershed District (MSTRWD) to the south. The LRRW is located in the Red River of the North (Red River) Basin, and is entirely within the Lake Agassiz Plain ecoregion, much of which has been drained for agricultural use. Historically, land cover in the LRRW during European settlement times (mid-late 1800s) consisted almost entirely of prairies (**Figure 2**). Current land use within the watershed is predominantly agricultural (**Figure 1**). Municipalities within the LRRW include Donaldson, Halma, Humboldt, Karlstad, Kennedy, Saint Vincent, Stephen, and Strandquist. Additional background information about the LRRW can be found in the resources listed below.

Additional Lower Red River of the North Watershed Resources
Lower Red River of the North Watershed Conditions Report (HEI 2013)
USDA Natural Resources Conservation Service (NRCS) Rapid Watershed Assessment for the Lower Red River of the North Watershed: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_023205.pdf
Minnesota Department of Natural Resources (DNR) Watershed Health Assessment Framework for the Lower Red River of the North Watershed: http://files.dnr.state.mn.us/natural_resources/water/watersheds/tool/watersheds/ReportCard_Major_69.pdf
Lower Red River of the North Monitoring and Assessment Report (January 2013): https://www.pca.state.mn.us/sites/default/files/wq-ws3-09020311b.pdf
Lower Red River of the North Stressor Identification Report (December 2015): https://www.pca.state.mn.us/sites/default/files/wq-ws5-09020311.pdf
The Joe River Watershed District's Overall Plan – this district covers the northern part of the LRRW
The Two Rivers Watershed District's Overall Plan – a portion of this district covers the middle part of the LRRW
The Middle-Snake-Tamarac Rivers Watershed District's Overall Plan – a portion of this district covers the southern part of the LRRW

[1] Also known as Red River of the North – Tamarac River Watershed

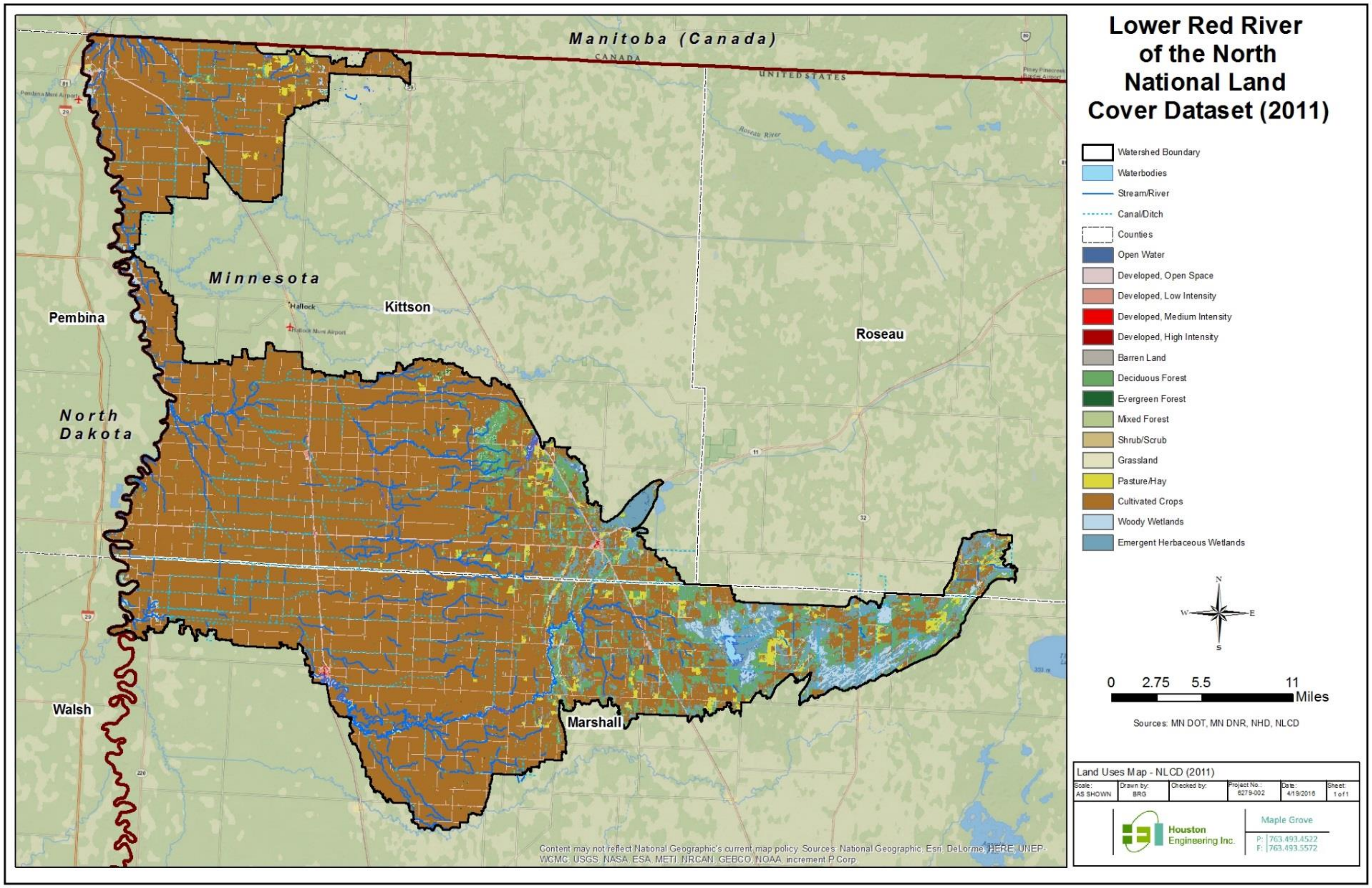


Figure 1: Land cover in the Lower Red River Watershed (NLCD 2011).

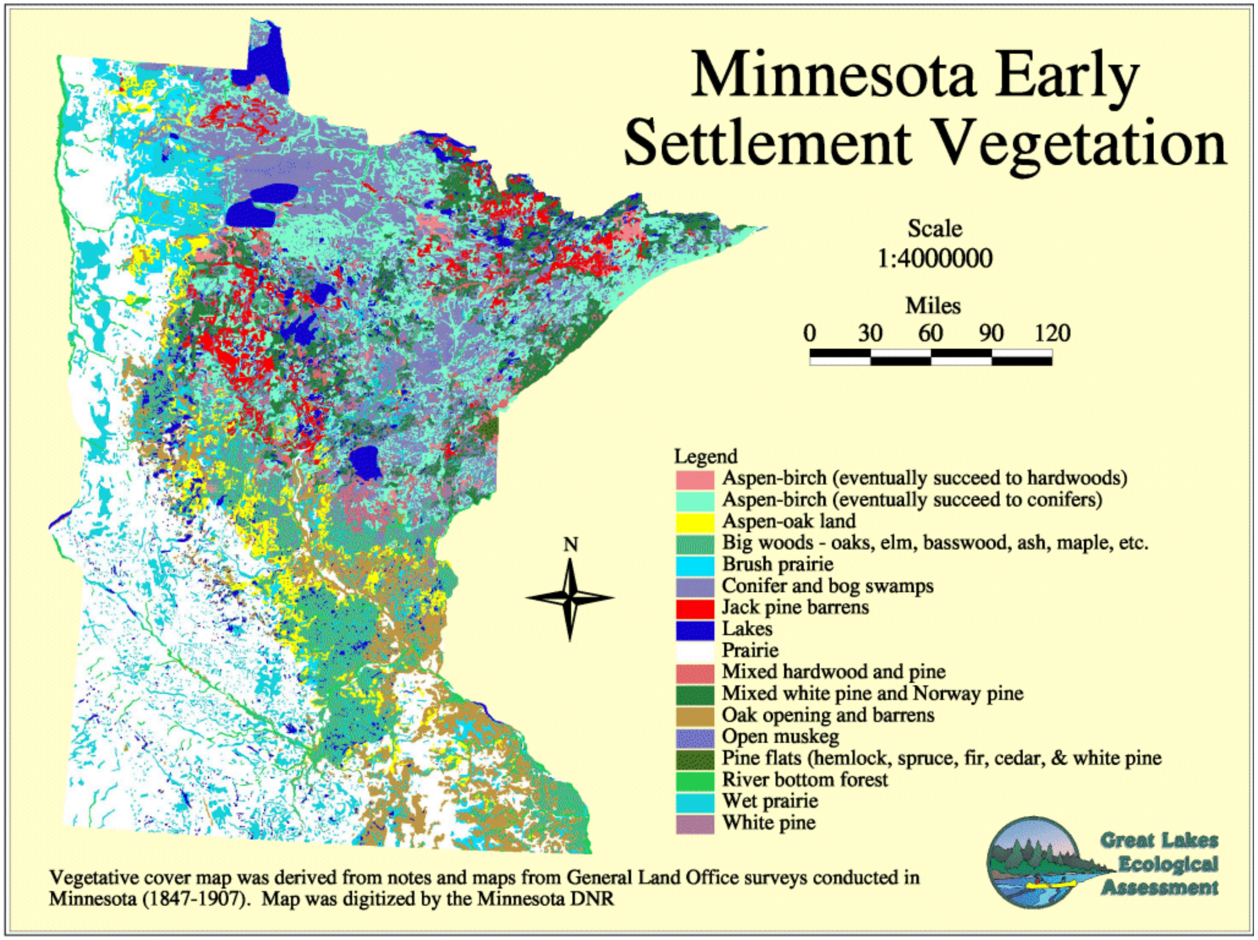


Figure 2: Historical map of land cover in Minnesota based on European settlement data. The original version is the "Marschner's Map", created by Francis J. Marschner in 1930.[2]

[2] http://www.mngeo.state.mn.us/chouse/land_use_historic.html

2. Watershed Conditions

Water resources in the LRRW include the Red River along the western boundary, its tributaries, a few lakes, wetlands, and an extensive drainage network (HEI 2013). While the LRRW includes a segment of the Red River mainstem, this report includes only data collected from its tributaries.

The LRRW contains 42 stream reaches (not including the Red River mainstem) and 38 small lakes that are defined by the state of Minnesota (i.e., have an Assessment Unit Identifier [AUID] or Minnesota Department of Natural Resources [DNR] lake number, respectively) (MPCA 2013). In 2008-2009, the MPCA conducted an intensive watershed monitoring (IWM) effort of the LRRW, in which 21 stream sites were sampled for biology within 15 AUIDs (MPCA 2013). The data were assessed in 2011. Thirteen of the 15 AUIDs were deferred for biological assessments due to extensive channelization (greater than 50% channelized), pending the implementation of the MPCA's Tiered Aquatic Life Use (TALU) standards (MPCA 2015). Only 2 of the 15 AUIDs were assessed for both aquatic life and aquatic recreation; 1 was found to be supportive of both aquatic life and recreation (09020311-511), while the other reach was determined to be supportive of aquatic recreation, but not aquatic life due to poor fish and aquatic macroinvertebrate communities, resulting in impairments (09020311-503) (**Figure 3**). Also identified was a potential (i.e., not yet listed on the state's impaired waters list as of 2018) aquatic life impairment due to high suspended sediment on deferred AUID 09020311-505 (MPCA 2013). While these three were not the only impairments or potential impairments identified in the LRRW, they are the only ones that are addressed in the concurrently developed TMDL report (See **Section 2.4)** for more information on these TMDLs and a description of why TMDLs were not written for additional impairments on the 303(d) list). The nature of the impairments, leading to the lack of support for aquatic life, are those commonly occurring in highly modified landscapes. See **Section 2.1** for additional assessment results and impairments of other streams.

While there are lakes, as defined by the state of Minnesota, within the LRRW, the MPCA collected very little lake water chemistry data and was not able to assess any of the LRRW's lakes during the IWM effort. This is primarily due to the LRRW's limited natural ability for water retention (for example, one waterbody with a DNR lake number did not meet the 14 day residence time requirement in order to be assessed as a lake) (MPCA 2013).

There are four wastewater National Pollutant Discharge Elimination System (NPDES) permitted point sources currently active in the LRRW, including three wastewater treatment facilities (WWTFs in Karlstad, Kennedy, and Stephen) and one industrial discharger (CHS Hallock). The Stephen WWTF (MNG580162) discharges directly to TSS-exceeded AUID 09020311-505, which is addressed in the TMDL report, and the Kennedy WWTF (MN0029751) discharges directly to TSS-exceeded AUID 09020311-509. Neither of these AUIDs are listed as having aquatic life use impairments due to TSS as of the 2018 305[b] list due to having deferred aquatic life use assessments. In addition, there are 17 permitted feedlots, 30 Construction Stormwater Permits, and 8 Industrial Stormwater Permits, none of which require Individual NPDES Permits (HEI 2013). Nonpoint sources of pollution and biotic stressors in the LRRW are typical of those found in the agricultural watersheds of the Red River Basin, and are the primary causes of the impairments.

A more detailed analysis of the quality of the waters within the LRRW can be found in the Watershed Conditions Report (HEI 2013), the Monitoring and Assessment Report (MPCA 2013) (https://www.pca.state.mn.us/sites/default/files/wq-ws3-09020311b.pdf), and the SID Report (MPCA 2015) (https://www.pca.state.mn.us/sites/default/files/wq-ws5-09020311.pdf). The conditions and associated pollutant sources of these individual streams are summarized in the following sections.

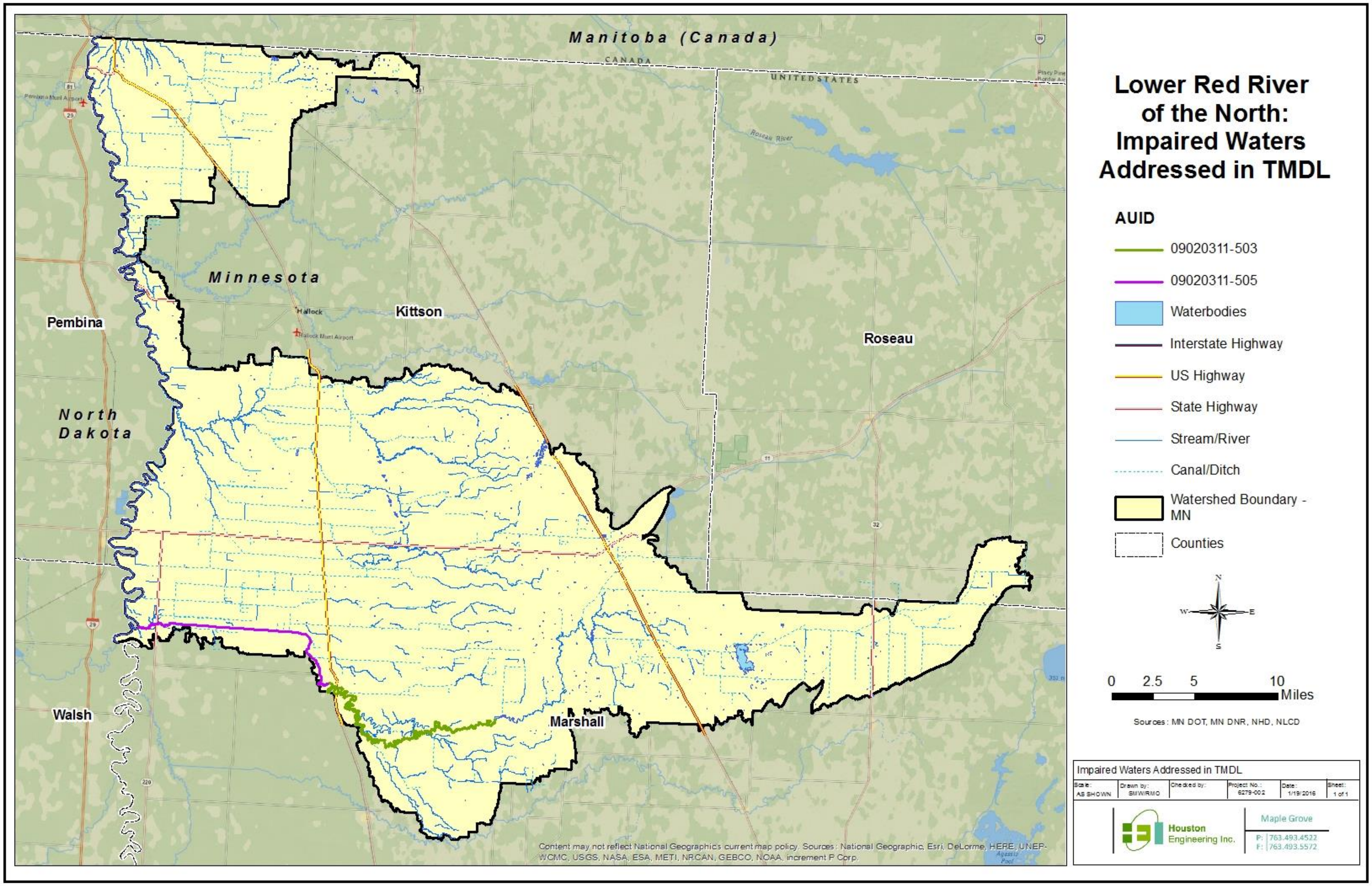


Figure 3: Lower Red River Watershed impaired waters that were addressed in the TMDL report (HEI 2018).

2.1 Condition Status

This section describes the streams and lakes within the LRRW that are impaired or in need of protection. Impaired waters are targets for restoration efforts, while waters currently supporting aquatic life and recreation are subject to protection efforts (**Section 2.5**).

Water quality conditions in the LRRW are generally poor. Many streams in the LRRW have been altered to provide drainage. Land use modifications such as removal of perennial vegetation next to watercourses, tiling, and agricultural development can result in increased sediment and pollutant loading to surface waters. In addition, hydrologic modification, including channelization, ditching, and groundwater withdrawal may be contributing factors to the observed poor water quality conditions (MPCA 2013).

Factors used to determine whether a stream is capable of supporting and harboring aquatic life (generally fish and aquatic insects) include the fish index of biological integrity (F-IBI), the macroinvertebrate index of biological integrity (M-IBI), the concentration of DO, and the sediment level, expressed as TSS. Factors used to assess the suitability of a waterbody for aquatic recreation include the amount of bacteria for streams and the levels of nutrients for lakes. For each waterbody, these factors are compared against state standards to determine whether standards are met (not impaired and in need of protection efforts) or not met (impaired and in need of restoration efforts).

Streams

A range of parameters were used to assess LRRW streams for aquatic life and recreation, including F-IBI and M-IBI, and the concentrations of DO, turbidity/suspended solids, chloride, pH, ammonia (NH_3), pesticides, and bacteria. Water quality measures were compared to the state standards, as well as the normal range for the ecoregion where the stream is located. The aquatic life standards are based on the IBI scores, DO, turbidity/suspended solids, chloride, pH, NH_3, and pesticides, while the aquatic recreation standard is based on bacteria.

Excluding the mainstem of the Red River, the LRRW Monitoring and Assessment Report (MPCA 2013) lists 42 stream reaches with unique AUIDs, only 2 of which were fully assessed for both aquatic life and aquatic recreation in 2011 (09020311-511 and 09020311-503). Thirty-five of the 42 AUIDs were not able to be assessed for any water quality parameters due to lack of data or insufficient data or deferment. Aquatic life assessments on 13 AUIDs were deferred due one or more biological sampling stations being located on an extensively channelized portion of the streams (assessment standards [TALU] for these modified streams had not yet been developed). The 42 AUID stream segments are included in **Table 1**, with stream condition summaries provided for each of the segments. Information used to create this table was summarized using the 2018 305(b) and 303(d) lists, the MPCA's Watershed Monitoring and Assessment Report (MPCA 2013), and the MPCA's Watershed Biotic SID Report (MPCA 2015).

Table 1: Status of stream reaches in the Lower Red River Watershed, presented (mostly) from south to north.

UC-10 Subwatershed	AUID[a] (Last 3 digits)	Stream	Reach Description	Aquatic Life								Aq. Rec
				Fish IBI	Macroinvertebrate IBI	Dissolved Oxygen	Turbidity	Chloride	pH	NH3	Pesticides	Bacteria
Lower Tamarac River (0902031102)	503[b]	Tamarac River	Florian Park Reservoir to Stephen Dam	Imp[def]	Imp[def]	IF	Sup	Sup	Sup	Sup	NA	Sup
	505[c]	Tamarac River	Stephen Dam to Red R	Sup	Exs	IF	Exs[df]	Sup	Sup	Sup	NA[ef]	Sup
	510	Tamarac River	Florian Park Reservoir (45-0119-00)	NA	NA	NA	NA	NA	NA	NA	NA	NA
	511[b]	Tamarac River	Headwaters to Florian Park Reservoir	Sup	Sup	IF	Sup	Sup	Sup	Sup	NA	Sup
	529	County Ditch 16	Unnamed ditch to Tamarac R	NA	NA	NA	NA	NA	NA	NA	NA	NA
	547	Unnamed creek	Unnamed ditch to Tamarac R	NA	NA	NA	NA	NA	NA	NA	NA	NA
	548	Unnamed ditch	Unnamed cr to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA
Upper Tamarac River (0902031101)	516[c]	Judicial Ditch 19	Headwaters to Tamarac R	NA	NA	IF	Sup	Sup	Sup	Sup	NA	Imp[f]
	526[c]	State Ditch 90	Unnamed ditch to Lateral Ditch 5	NA	NA	NA	NA	NA	NA	NA	NA	NA
	527[c]	Lateral Ditch 5	Headwaters to State Ditch 90	NA	NA	NA	NA	NA	NA	NA	NA	NA
	528	State Ditch 90	Lateral Ditch 5 to Tamarac R	NA	NA	NA	NA	NA	NA	NA	NA	NA
	541[c]	Judicial Ditch 19	Unnamed ditch to Unnamed ditch	NA	NA	NA	NA	NA	NA	NA	NA	NA
	542	Judicial Ditch 19	Unnamed ditch to Unnamed ditch	NA	NA	NA	NA	NA	NA	NA	NA	NA
	543	Judicial Ditch 19	Unnamed ditch to Unnamed ditch	NA	NA	NA	NA	NA	NA	NA	NA	NA
	544	Judicial Ditch 19	Unnamed ditch to Unnamed ditch	NA	NA	NA	NA	NA	NA	NA	NA	NA
	545[c]	Judicial Ditch 19	Unnamed ditch to Unnamed ditch	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 1: Status of stream reaches in the Lower Red River Watershed, presented (mostly) from south to north.

UC-10 Subwatershed	AUID[a] (Last 3 digits)	Stream	Reach Description	Aquatic Life								Aq. Rec
				Fish IBI	Macroinvertebrate IBI	Dissolved Oxygen	Turbidity	Chloride	pH	NH3	Pesticides	Bacteria
	546	Judicial Ditch 19	Unnamed ditch to Unnamed ditch	NA	NA	NA	NA	NA	NA	NA	NA	NA
Judicial Ditch No 10 (0902031103)	512	County Ditch 10	Headwaters to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA
	518[c]	County Ditch 10	Unnamed cr to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA
	519	County Ditch 10	Unnamed cr to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA
	520	Judicial Ditch 10	Unnamed cr to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA
	521[c]	Judicial Ditch 10	Unnamed cr to CD 16	NA	NA	NA	NA	NA	NA	NA	NA	NA
	522	Judicial Ditch 10	CD 16 to CD 7	NA	NA	NA	NA	NA	NA	NA	NA	NA
	523	Judicial Ditch 10	CD 7 to Unnamed ditch	NA	NA	NA	NA	NA	NA	NA	NA	NA
	524[c]	Judicial Ditch 10	Unnamed ditch to CD 19	NA	NA	NA	NA	NA	NA	NA	NA	IF
	525	Judicial Ditch 10	CD 19 to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA
	540[c]	Unnamed creek	Unnamed cr to CD 10	NA	NA	NA	NA	NA	NA	NA	NA	NA
City of Drayton-Red River (0902031105)	530	Judicial Ditch 10	JD 3 to Red R	NA	NA	NA	NA	NA	NA	NA	NA	NA
	531	Judicial Ditch 3	Headwaters to JD 10	NA	NA	NA	NA	NA	NA	NA	NA	NA
	532	Judicial Ditch 27	Headwaters to JD 8	NA	NA	NA	NA	NA	NA	NA	NA	NA
	533	Judicial Ditch 8	JD 27 to Red R	NA	NA	NA	NA	NA	NA	NA	NA	NA
	534	Judicial Ditch 8	CD 11 to JD 27	NA	NA	NA	NA	NA	NA	NA	NA	NA
Unnamed Coulee (0902031104)	509[c]	Unnamed creek (County Ditch 27)	Headwaters to Red R	Exs	NA	IF	Exs	NA	Sup	Sup	NA	IF
	514	Unnamed creek	Headwaters to Unnamed cr	NA	NA	NA	NA	Sup	NA	NA	NA	NA
	535	Unnamed creek	Headwaters to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA
	536	Unnamed creek	Unnamed cr to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 1: Status of stream reaches in the Lower Red River Watershed, presented (mostly) from south to north.

UC-10 Subwatershed	AUID[a] (Last 3 digits)	Stream	Reach Description	Aquatic Life								Aq. Rec
				Fish IBI	Macroinvertebrate IBI	Dissolved Oxygen	Turbidity	Chloride	pH	NH3	Pesticides	Bacteria
	537	Unnamed creek	Unnamed cr to State Ditch 1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	538[c]	State Ditch 1	Unnamed cr to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA
	539	Unnamed creek	Unnamed cr to Unnamed cr	NA	NA	NA	NA	NA	NA	NA	NA	NA
Joe River (0902031108)	513[c]	Joe River	Salt Coulee to MN/Canada border	NA	NA	IF	NA	Imp[f]	Sup[e]	Sup	NA	IF
	515	Joe River	Headwaters to Salt Coulee	NA	NA	NA	NA	NA	NA	NA	NA	NA
	517	Salt Coulee	Unnamed cr to Joe R	NA	NA	NA	NA	NA	NA	NA	NA	NA

The following are based on the 2011 assessment of LRRW waterbodies: **Sup** = found to meet the water quality standard, **Imp** = does not meet the water quality standard and therefore, is listed on the impaired waters list, **IF** = the data collected were insufficient to make a finding, **NA** = not assessed, **Exs** = Exceeds criteria, potential severe (new) impairment that's not yet listed on the impaired waters list.

[a] Red River mainstem AUIDs are not listed in this table.

[b] Fully assessed for both aquatic life and aquatic recreation in 2011.

[c] Aquatic life assessment was deferred in 2011 due to ≥50% channelization at one or more biological sampling stations. If one or more biological station was located on a portion of the AUID that was <50% modified, an assessment of the station(s) was done and is included in the table.

[d] Addressed in the concurrently developed TMDL report.

[e] Determined to be impaired based on an assessment cycle other than 2011.

[f] Addressed with restoration strategies in this document.

Lakes

The LRRW contains 38 lakes that are defined by the state of Minnesota (i.e., have a DNR lake number) (MPCA 2013). However, the MPCA collected very little lake water chemistry data during the IWM, and was not able to assess any of the LRRW's lakes due to the LRRW's limited natural ability for water retention. For example, Secchi depth and TP data from 2008 and 2010 were available for Florian Park Reservoir (45-0119-00; shown in **Table 1** as AUID 09020311-510); however, residence time was estimated to be between 3 to 7 days, which does not meet the 14-day residence time requirement to be assessed as a lake (MPCA 2013). This limited natural ability for water retention may be attributed to the topography of the watershed, low abundance of wetlands, and the presence of hydrologic class D, C/D, or C soil types consisting mainly of clay and silt that are characterized by low permeability and high runoff rates (MPCA 2013). Lakes may require more thorough sampling and assessment during the second cycle of the WRAPS Project.

Fortunately, the DNR utilized the aforementioned Florian Park Reservoir data for a Geographic Information System (GIS) layer called Lakes of Phosphorus Sensitivity Significance (LPSS). **Table 2** shows the results of LPSS for Florian Park Reservoir; it is estimated that TP load needs to be reduced by 17.5% to meet the target TP load.

Table 2: DNR LPSS summary of Florian Park Reservoir (45-0119-00).

Waterbody Name (ID)	Depth Class	Area (ac)	Mean Secchi depth (m)	Mean TP (µg/L)	Target TP (µg/L)[a]	Predicted TP Load (lb/yr)	Target TP Load (lb/yr)	Load Reduction to meet Target TP (lb/yr)	Percent Load Reduction to meet Target	Priority Class[b]
Florian Park Reservoir (45-0119-00 / 09020311-510)	Deep	49	0.94	62.4	52.2	4511.4	3721.5	789.9	17.5	High

[a] Calculated independently of the TP standard of 65 µg/L, as it is based on an estimate of the 25th percentile of the summer mean TP concentration.
[b] Possible priority classes are High, Higher, and Highest.
See https://gisdata.mn.gov/dataset/env-lakes-phosphorus-sensitivity for additional information.

In addition, Florian Park Reservoir has an aquatic consumption impairment (which isn't covered in this WRAPS Report) due to mercury in fish tissue, and has been addressed in 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. No other TMDLs have been developed for lakes in the LRRW.

2.2 Water Quality Trends

In 2008-2009, the MPCA conducted its IWM program in the LRRW. IWM was conducted in addition to the standard water quality monitoring conducted over the past 10-year period. Many of the LRRW's monitoring sites have the required number of observations needed for formal assessment, per the MPCA guidelines (MPCA 2016), for a number of constituents. The available data show high turbidity and bacteria concentrations at many of the LRRW's monitoring sites.

The MPCA, JRWD, TRWD, and MSTRWD continue to monitor water quality and evaluate water quality trends at several locations within the LRRW. In addition to water quality impacts and issues in the LRRW, there are downstream water quality problems that the watershed contributes to, including sediment and phosphorus problems in the greater Red River Basin, and excess phosphorus and nitrates in Lake Winnipeg.

No trend analysis for the available water quality data was conducted. Water quality trend analysis was conducted in the neighboring watershed, Two Rivers Watershed. Since both watersheds are similar, trends in LRRW should follow similar trends. The water quality site Two Rivers on US-75, 1 mile North of Hallock (S000-186) is a milestone site that water quality trend analysis was conducted in 2014 (MPCA

2014a). The MPCA found long term decreasing trends in total phosphorus (TP) and biochemical oxygen demand (BOD) and no trends in TSS, Nitrate/Nitrite, Ammonia, and Chloride for the period 1971 through 2010. TP was found to be decreasing at a rate of 2.1% per year. BOD was found to be decreasing at a rate of -3.5% per year (MPCA 2014a).

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 SID is done for streams with either fish or macroinvertebrate biota impairments, and encompasses both evaluation of pollutants (e.g., sediment, DO, and pesticides) and non-pollutant-related factors (e.g., altered hydrology, fish passage, and habitat) as potential stressors. Pollutant source assessments are done for pollutants identified as biological stressors, as well as for any conventional pollutant impairment.

Stressors of Biologically-Impaired Stream Reaches

The primary stressors for the two biological impairments (located on Tamarac River: Florian Park Reservoir to Stephen Dam [AUID 09020311-503]) in the LRRW are listed in **Table 3**. The biologically impaired reach of the Tamarac River is situated between two dams (i.e., Florian dam and Stephen dam), which obstruct fish passage and limit the potential of the fish community (MPCA 2015). The natural flow regime of the reach has been altered because of intensive agricultural drainage and the presence of the dams, resulting in a more rapid hydrologic response and increased peak flows, and prolonged periods of low discharge. This “flashy” flow regime may inhibit biotic diversity. These hydrologic alterations can result in the degradation of physical habitat, high suspended sediment, and low DO conditions, which limit the diversity of fish and macroinvertebrate communities within the reach (MPCA 2015).

Further detailed SID information can be found in the MPCA’s Lower Red River of the North Watershed Biotic SID Report (MPCA 2015).

Table 3: Primary stressors to aquatic life in the biologically-impaired reach in the Lower Red River Watershed.

HUC-10 Subwater-shed	AUID (Last 3 digits)	Stream	Reach Description	Biological Impairment	Primary Stressor				
					Fish Passage (dams)	Altered Hydrology	Habitat	Suspended Sediment	Dissolved Oxygen
Lower Tamarac River (0902031102)	503	Tamarac River	Florian Park Reservoir to Stephen Dam	Fish	●	◉	◉	○	◉
				Macroinvert.		◉	◉	○	○

Key: ●= High risk, ◉= Medium risk, ○= Low risk

Pollutant sources

Point (wastewater) and nonpoint sources of pollutants are identified in **Table 4** and **Table 5**, respectively. **Table 4** and **Table 5** are summarized from the MPCA's LRRW SID Report (MPCA 2015) and the LRRW TMDL Studies (HEI 2018). More specific information regarding the geographic location of nonpoint source locations and prioritization is detailed in **Section 3** where various methods of targeting and evaluating geographic areas are described.

In addition to point and nonpoint sources identified within **Table 4** and **Table 5**, a Wind Erosion Prediction System (WEPS) model was developed for the LRRW. The importance of this effort is driven primarily by the magnitude of wind erosion contributing to nonpoint source pollution throughout the LRRW, caused by both environmental and anthropogenic factors. The LRRW is located in the Glacial Lake Agassiz lake plain, which is extraordinarily flat. With grade changes on the order of inches per mile across the LRRW, there is limited landscape relief to dampen high wind gusts. Anthropogenic factors affecting wind erosion include intensive agriculture with crops such as soybeans, sugar beets, spring wheat, and numerous hay varieties, loss of pre-settlement forested areas and native grasslands, and lack of shelter belts and conservation wind breaks (HEI 2016b). Hay land has very low susceptibility to wind erosion. However, under-utilization of cover crops and poor residue management contribute greatly to wind erosion susceptibility. The combination of these factors leads to conditions which promote high rates of sediment loss through wind forces. Further documentation of this model is provided in **Section 3.1** of this report.

Table 4: Wastewater point sources with permits in the Lower Red River Watershed.

HUC-10 Subwatershed	Point Source			Pollutant reduction needed beyond current permit conditions/limits?	Notes
	Name	Permit #	Type		
Judicial Ditch No 10 (0902031103)	Karlstad WWTP	MNG580146	Municipal wastewater	No	WLAs based on current permitted TSS limit of 45 mg/L and fecal coliform limit of 200 organisms/100 mL
Unnamed Coulee (0902031104)	Kennedy WWTP	MN0029751	Municipal wastewater	No	WLAs based on current permitted TSS limit of 45 mg/L and fecal coliform limit of 200 organisms/100 mL
Lower Tamarac River (0902031102)	Stephen WWTP[a]	MNG580162	Municipal wastewater	No	WLAs based on current permitted TSS limit of 45 mg/L and fecal coliform limit of 200 organisms/100mL
Unnamed Coulee (0902031104)	CHS Hallock wastewater	MN0068969	Industrial wastewater	No	WLAs based on current permitted TSS limit of 45 mg/L and fecal coliform limit of 200 organisms/100 mL

[a] WWTF is located in the Grand Marais Creek Watershed but discharges to waters within the LRRW.

Table 5: Nonpoint Sources in the Lower Red River Watershed. Relative magnitudes of contributing sources are indicated.

HUC-10 Subwatershed	Stream/Reach (AUID) or Lake (ID)	Pollutant	Pollutant Sources			
			Poor riparian vegetation cover	Upland soil erosion	Flow Alteration	Bank Erosion
Lower Tamarac River (0902031102)	Tamarac River Florian Park Reservoir to Stephen Dam (503)	TSS	●	●	●	●
	Stephen Dam to Red River of the North (505)	TSS	●	●	●	●

Key: ● = High risk ◘ = Moderate risk ○ = Low risk

2.4 TMDL Summary

Thirteen impairments on six LRRW streams are listed on the draft 2018 303(d) list as being impaired and needing a TMDL. Eleven of these impairments are being deferred, as they are not yet addressed with a TMDL. Seven of the deferred impairments are located on reaches of the Red River mainstem, and those two will be addressed in a separate TMDL Report for the Red River. The remaining four deferred impairments on three stream reaches in the LRRW were not addressed with TMDLs for the following reasons. A TMDL for the *E. coli* impairment on 09020311-516 is being deferred due to lack of observed and simulated flow data during the years when *E. coli* exceeded standards. The impairments for pH and chloride on 09020311-513 are being deferred pending more data to determine the most appropriate EPA category (pH was found to meet standards in 2011 so more data may support delisting and/or more data may show that the high pH and chloride are due to natural conditions). The chlorpyrifos (a pesticide) impairment on 09020311-505 will be addressed by the Minnesota Department of Agriculture (MDA) and the MPCA by 2025, as estimated in the draft 2018 303(d) list.

Two impairments (one caused by poor fish communities and the other caused by poor aquatic macroinvertebrate communities) on the same stream reach (AUID 09020311-503) are addressed in the concurrently developed TMDL report with a TSS TMDL to identify current loading reduction goals to achieve the numeric water quality standards. This TSS TMDL is used as a surrogate to address the two biological impairments, because high suspended sediment was identified as a stressor to the biological communities and the LRRW HSPF model estimates that TSS exceeds the water quality standard between 1% and 22% of the time on this AUID from 1996 to 2009. Additionally, the discrete TSS data (2002 through 2010; *n*=69) for the reach had a range of 3 to 69 mg/L. This data indicates that the reach is prone to high suspended sediment (MPCA 2015a). A third potential impairment on 09020311-505 that is not yet on the 303(d) list as of 2018 is addressed with another TSS TMDL, based on data that indicates a TSS-caused impairment.

The two tables below show the maximum allowable load (loading capacity), and the amount which comes from nonpoint sources (load allocation) and point sources (wasteload allocation). The tables also show the reduction from the existing load needed based on load duration curves (LDCs). A portion of the allowable load (an explicit 10%) is placed in the “margin of safety” category reflecting a level of uncertainty in the analysis. The critical duration period for each of the waterbodies is available within the Lower Red River Watershed Load Duration Curve technical memorandum (**Appendix A**; HEI 2016a).

A nonpoint source that is implicitly incorporated into each TMDL is natural background. Natural background conditions refer to inputs that would be expected under natural, undisturbed conditions that occur outside of human influence. Minn. R. 7050.0150, subp. 4, defines the term “Natural causes” as the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in a waterbody in the absence of measurable impacts from human activity or influence. Natural background sources include inputs from natural processes (e.g., soil loss from upland erosion and stream development, atmospheric deposition, and loading from forested land, wildlife, etc.).

For each impairment, natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment; therefore, natural background is included in the MPCA’s waterbody assessment process. There were no data to explicitly determine whether natural background sources are a major driver of any of the impairments and/or that they affect the waterbodies’ ability to meet state water quality standards. For all impairments addressed in the TMDL report, natural background sources are implicitly included in the LA portion of the TMDL allocation tables and TMDL reductions should focus on the major anthropogenic sources such as livestock, cropland, streambank, WWTFs, failing SSTSs, and others.

Total Suspended Solids

In January of 2015, the EPA issued an approval of the adopted amendments to the Minnesota State Water Quality Standards, replacing the historically-used turbidity standard with TSS standards. **Table 6** and **Table 7** show the existing TSS contributions, along with the wasteload and load allocations to meet the TSS standard for the following Tamarac River reaches: Florian Park Reservoir to Stephen Dam (AUID 09020311-503; TSS was identified as a stressor to the biological communities on this reach) and Stephen Dam to Red River (AUID 09020311-505), respectively. The analysis is based on concentrations of TSS utilizing the load duration curve method (**Appendix A**; HEI 2016a). The loading capacity is established using the flow condition requiring the greatest estimated load reduction.

Table 6: TSS loading capacities and allocations for AUID 09020311-503 (Tamarac River: Florian Park Reservoir to Stephen Dam).

TSS		Flow Condition				
		Very High	High	Mid	Low	Very Low
		Tons per day				
Loading Capacity		**114.94**	**20.80**	**5.91**	**1.53**	**0.08**
Wasteload Allocation	**Total WLA**	**0.10**	**0.02**	**0.01**	**0.002**	**0.0001**
	Construction/ Industrial Stormwater	0.10	0.02	0.01	0.002	<0.0001
Load Allocation	**Total LA**	**103.35**	**18.70**	**5.31**	**1.38**	**0.07**
Margin of Safety (MOS)		**11.49**	**2.08**	**0.59**	**0.15**	**0.01**
Existing Load		**131.66**	**9.06**	**1.73**	**0.48**	**0.004**
Unallocated Load		**0.00**	**9.66**	**3.59**	**0.90**	**0.07**
Estimated Load Reduction		**13%**	**0%**	**0%**	**0%**	**0%**

Very high flow regime is the critical flow condition with maximum reduction needed.
Existing load estimated based on the 90th percentile exceedance concentration and the mid-point flow for the flow regime.

Table 7: TSS loading capacities and allocations for AUID 09020311-505 (Tamarac River: Stephen Dam to Red River).

TSS		Flow Condition				
		Very High	High	Mid	Low	Very Low
		Tons per day				
Loading Capacity		**156.98**	**31.19**	**8.29**	**2.06**	**0.19**
Wasteload Allocation	**Total WLA**	**0.36**	**0.25**	**0.23**	**0.222**	*
	Construction/ Industrial Stormwater	0.14	0.03	0.01	0.002	0.0002
	Stephen WWTF	0.22	0.22	0.22	0.22	*
Load Allocation	**Total LA**	**140.92**	**27.82**	**7.23**	**1.63**	**0.17**
Margin of Safety (MOS)		**15.70**	**3.12**	**0.83**	**0.21**	**0.02**
Existing Load		**3,067.22**	**130.07**	**38.14**	**4.18**	**0.21**
Unallocated Load		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Estimated Load Reduction		**95%**	**76%**	**78%**	**51%**	**13%**

Very high flow regime is the critical flow condition with maximum reduction needed.
Existing load estimated based on the 90th percentile exceedance concentration and the mid-point flow for the flow regime.
* The outflow from the WWTF will be greater than the median flow under this condition. Since outflow is a portion of streamflow, loading under this condition is unlikely to occur. If outflow from this WWTF occurs during this flow condition, the WLA will be the permitted outflow concentration multiplied by the flow rate.

Table 7 shows the need for considerable reduction in TSS, based on the load duration curve analysis. The load reductions are based solely on the need to achieve the numeric standard of 65 mg/L.

2.5 Protection and Restoration Considerations

Designating stream river reaches as candidates for protection or restoration is important for identifying resource management needs, and for aligning with the Nonpoint Priority Funding Plan for Clean Water Implementation Funding (http://www.bwsr.state.mn.us/planning/npfp/NPFP%20Final.pdf) and Minnesota's Clean Water Roadmap (https://www.pca.state.mn.us/sites/default/files/wq-gov1-07.pdf). For this reason, assessed stream and river reaches within the LRRW are designated as either "protection" or "restoration" candidates based on the available water quality monitoring data. Once designated as protection or restoration, LRRW stream and river reaches are further divided into subcategories to guide management efforts. For example, considerable energy and fiscal investment is needed to restore some resources. This energy and fiscal investment could be invested in other resources more likely to be successfully restored and attain water quality standards.

Streams and rivers currently supporting aquatic life and aquatic recreation in the LRRW are candidates for protection. The purpose of protection strategies are to reasonably ensure that the designated beneficial uses are maintained into the future, by focusing implementation strategies on protecting these waters. This means ensuring that the existing pollutant loads for the critical flows and time periods of the year are maintained or reduced.

Healthy watersheds provide a variety of ecological benefits that have high value and may be challenging to reestablish once compromised. Research demonstrates that protecting healthy watersheds can reduce capital costs for water treatment plants and reduce damage to property and infrastructure due to flooding, thereby avoiding future costs. Additionally, protecting healthy watersheds can generate revenue through property value premiums, recreation, and tourism.

Stream Protection and Restoration Categories

The MPCA is currently developing an approach to prioritizing streams for protection to help watershed stakeholders set protection goals for unimpaired waters. In addition to stream water quality data, the Streams Protection Strategy will consider other water "values" such as economic value, aesthetics, and tourism. The Streams Protection Strategy will be available for use in setting protection goals in future LRRW plans. For the purposes of this WRAPS Report, stream reaches in the LRRW were prioritized and categorized into Protection or Restoration categories based on their existing water quality. Both protection and restoration categories are further broken down into subcategories. Streams within the "protection" category are subdivided into three subcategories: Above Average Quality, Potential Impairment Risk, and Threatened Impairment Risk. Streams within the "restoration" category are subdivided into two subcategories: Low Restoration Effort and High Restoration Effort.

Stream protection and restoration categories are based on existing water quality data for the assessment period of 2005 through 2015. In order to categorize more stream reaches, the lower limit on the number of required observations was set below that required for assessments. Stream assessments typically require 20 water quality samples over 10 years, except for *E. coli,* which requires five samples in a given month over a two-year period. This modified method requires a minimum of only five water quality samples (three for *E. coli*). This modified method allows for more stream reaches to be included in the stream categorization. Descriptions of the stream categories and water quality attributes for each category follows.

Stream protection and restoration categories were compiled for TSS, TP, Inorganic Nitrogen (NO_2+NO_3) (as a surrogate for total nitrogen), and *E. coli*. It should be noted, there is no NO_2+NO_3 water quality standard for Class 2 streams. In order to include nitrogen in the protection strategies, the Class 1 (Minn. R. 7050) water quality standard for NO_2+NO_3 (for drinking water) of 10 mg/L was used to categorize streams. In addition, for TP assessment and impairments, secondary water quality parameters (chlorophyll-*a*, five-day BOD, diel DO flux, or pH levels) need to be considered. For this TP stream categorization effort, only the TP concentrations are considered. Due to these limiting factors and the minimum number of samples used to qualify for a stream categorization, a restoration categorization may not mean a waterbody is impaired by a specific parameter.

Descriptions of the stream protection and restoration categories and water quality attributes for each category are described below, followed by maps of the stream categories by protection and restoration subcategory (**Figure 4** for Above Average Quality, **Figure 5** for Potential Impairment Risk, **Figure 6** for Threatened Impairment Risk, and **Figure 7** for High Restoration Effort).

Protection Categories

All streams currently supporting aquatic life and aquatic recreation in the LRRW are candidates for protection efforts. Over time, if these waters are not subject to protection strategies, they may become impaired. For purposes of this WRAPS report, LRRW streams within the "protection" category are subdivided into three subcategories: Above Average Quality, Potential Impairment Risk, and Threatened Impairment Risk.

Surface waters exhibiting Above Average Quality for a water quality parameter are defined as those portions of a river or stream (i.e., AUID Number) which:

1. have no impairments and meet the full MPCA assessment methods for determining whether an impairment exists, and the 90^{th} percentile (TSS, TP, NO_2+NO_3) or the geometric mean (*E. coli*) are less than 75% of the numeric standard; or
2. do not meet the data requirements of the MPCA assessment methods (i.e., have less than 20 samples, or less than 5 samples per month for *E. coli*), yet still have a minimum of 5 samples (or 3 samples per month for *E. coli*), none of those samples exceed the numeric water quality standard for the AUID Number, and the 90th percentile concentration (geometric mean for *E. coli*) of a water quality parameter is less than 75% of the numeric water quality standard.

Surface waters in the LRRW exhibiting Above Average Quality for a water quality parameter are shown in **Figure 4**.

Potential Impairment Risk for a water quality parameter is defined as those portions of a river or stream (i.e., AUID Number) with water quality conditions "near" but not exceeding the numeric water quality standard for a given parameter. Surface waters exhibiting Potential Impairment Risk are defined by the following circumstances:

1. When the data requirements of the MPCA assessment methods are met (i.e., number of samples is greater than 20, or 5 samples per month for *E. coli*), surface waters in the Potential Impairment Risk subcategory for *E. coli*, NO_2+NO_3, TP, or TSS are defined by the 90th percentile (geometric mean for *E. coli*) concentration exceeding 75%, but less than 90%, of the numeric water quality standard; or
2. When the data requirements of the MPCA assessment methods are not met (number of samples is less than 20, but greater than or equal to 5; or less than 5 but at least 3 samples per month for *E. coli*), a Potential Impairment Risk is defined as the 90th percentile (geometric mean for *E. coli*) concentration exceeding 75% of the water quality standard, but not exceeding the water quality standard for a given water quality parameter.

Surface waters in the LRRW exhibiting Potential Impairment Risk for a water quality parameter are shown in **Figure 5**.

Surface waters exhibiting Threatened Impairment Risk are defined as those portions of a river or stream (i.e., AUID number) with water quality conditions "very near" and periodically exceeding numeric standards. An AUID is categorized as Threatened Impairment Risk under the following conditions:

1. When the data requirements of MPCA assessment methods are met (i.e., number of samples is greater than 20, or 5 samples per month for *E. coli*), the 90th percentile (geometric mean for *E. coli*) concentration exceeds 90%, but is less than the numeric water quality standard;
2. When the 90th percentile (or geometric mean for *E. coli*) concentration is below 110% of the water quality standard when an AUID number has more than 10 samples but less than 20; or
3. When the number of samples is less than 10 but greater than 5, a Threatened Impairment Risk is defined as the 90th percentile (or geometric mean for *E. coli*) concentration less than 120% of the water quality standard. This limits the amount of exceedances to one or two observances.

Surface waters in the LRRW exhibiting Threatened Impairment Risk for a water quality parameter are shown in **Figure 6**.

For streams, rivers, and lakes, the protection strategy consists of working toward ensuring the existing loads for the critical duration periods are not exceeded. Strategies for addressing protection of these waters are discussed in more detail in **Section 3** of this report.

Restoration Categories

LRRW streams in the "restoration" category fail to achieve some minimum threshold condition. Example minimum threshold conditions include failure to achieve a water quality standard, or a condition considered degraded or unstable such as areas of accelerated stream bank erosion. Restoration categories are further divided into two different subcategories: Low Restoration Effort and High Restoration Effort.

Low Restoration Effort is defined as a degraded condition but a condition near the designated minimum threshold. An example is a portion of a river or stream where the numeric standard is exceeded (and therefore is "impaired"), but with restoration has a high probability of attaining the numeric water quality standard. Surface waters are defined as a Low Restoration Effort if five or more samples are collected, of which no more than 25% of the samples exceed the water quality standard. Surface waters may also be in the Low Restoration Effort category if the 90th percentile of the samples (five or more required) is within 125% of the water quality standard. There are no surface waters within the LRRW, which are in the Low Restoration Effort category, therefore, no figure of this category is provided.

Surface waters in the High Restoration Effort category are degraded, and are no longer near the designated threshold. These surface waters have a lower probability of attaining the numeric water quality standard and may require a large effort to attain water quality compliance. High Restoration Effort surface waters are impaired, with the 90th percentile of at least five samples exceeding 125% of the water quality standard. Impaired waters are also categorized as High Restoration Effort if more than 25% of samples (five or more required) exceed the water quality standard. Surface waters in the LRRW in the High Restoration Effort category are shown in **Figure 7**.

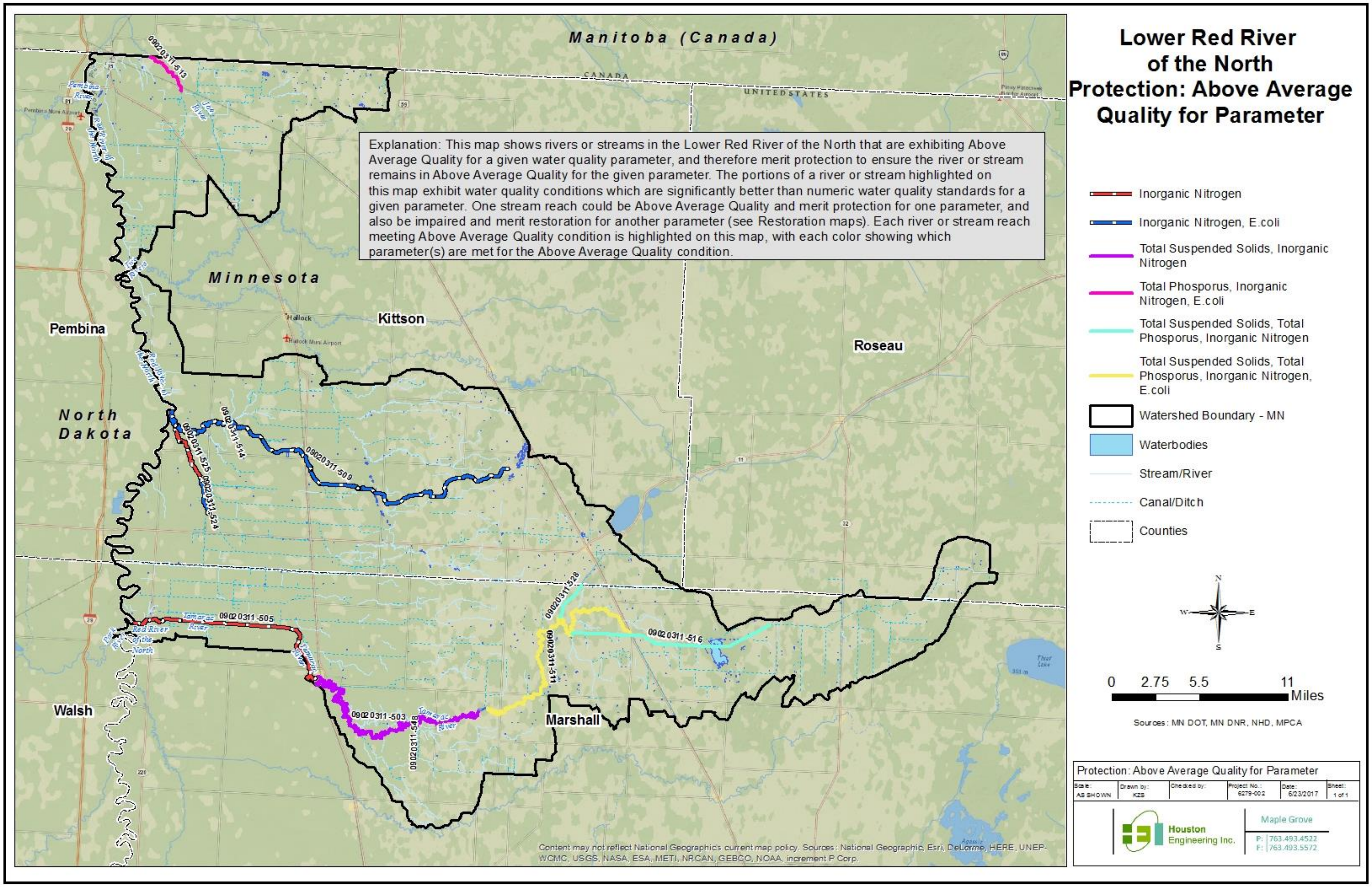


Figure 4: Surface waters exhibiting Above Average Quality for a given water quality parameter, and therefore merit protection.

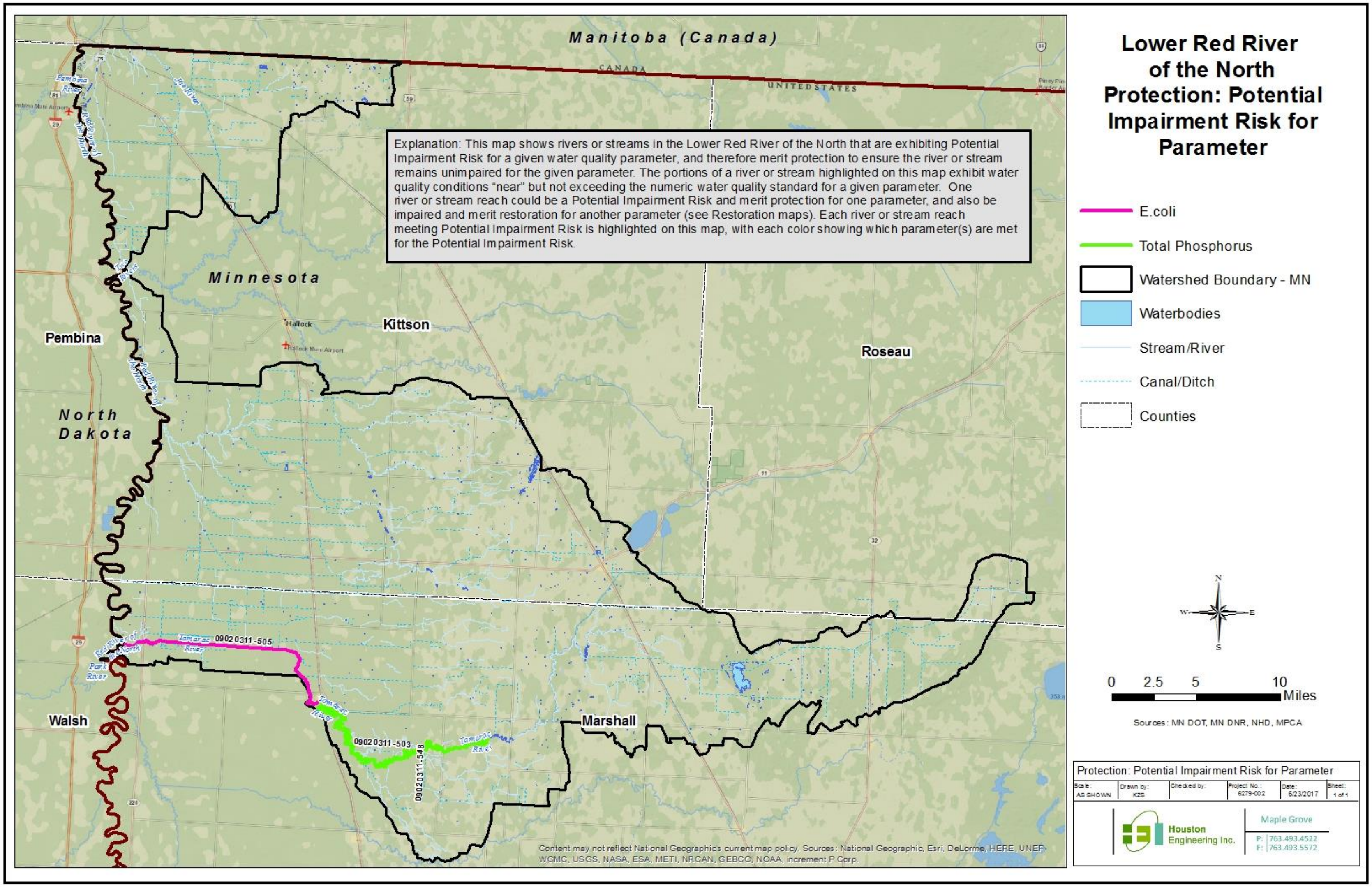


Figure 5: Surface waters exhibiting Potential Impairment Risk for a given water quality parameter, and therefore merit protection.

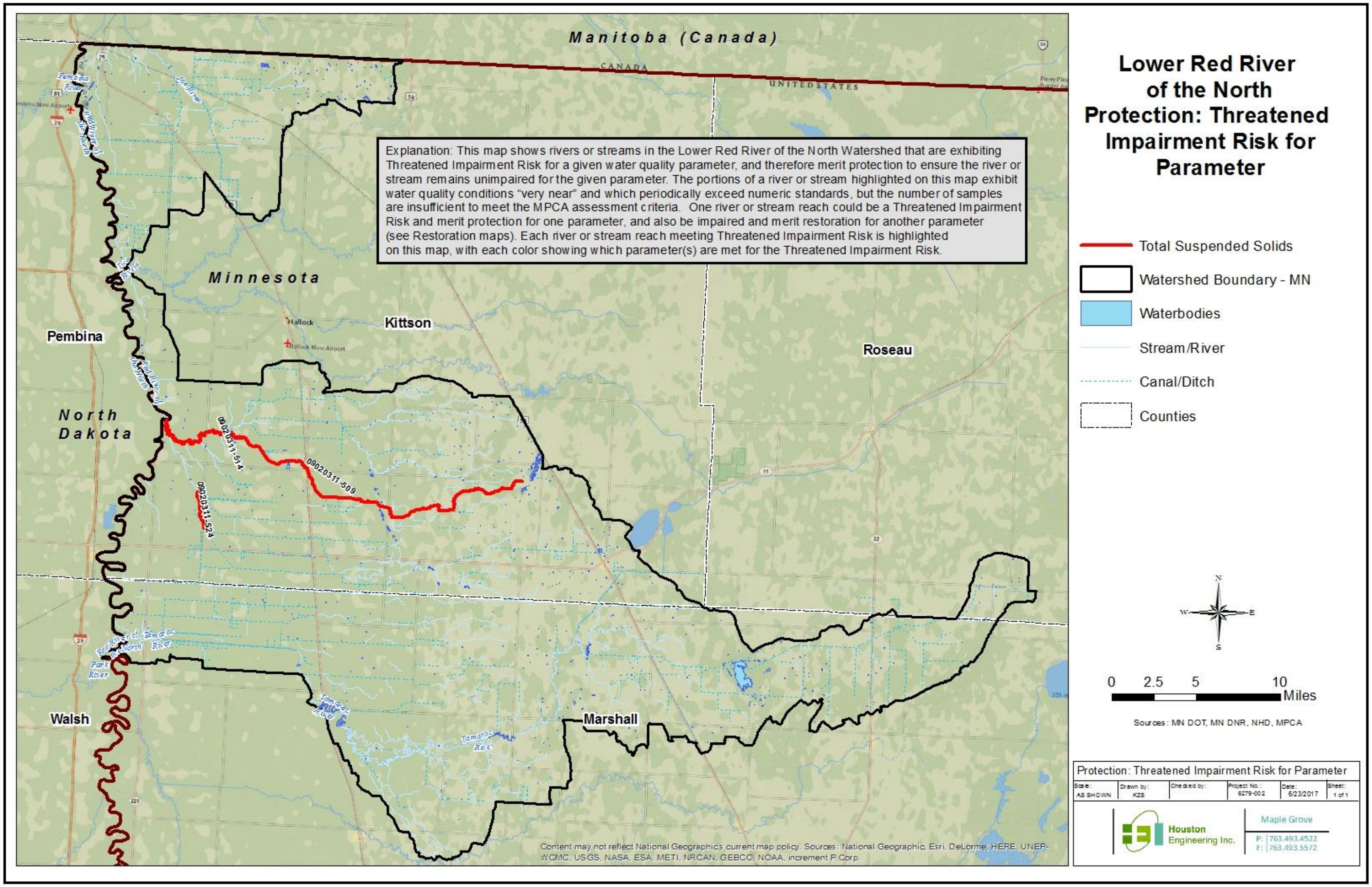


Figure 6: Surface waters exhibiting Threatened Impairment Risk for a given water quality parameter, and therefore merit protection.

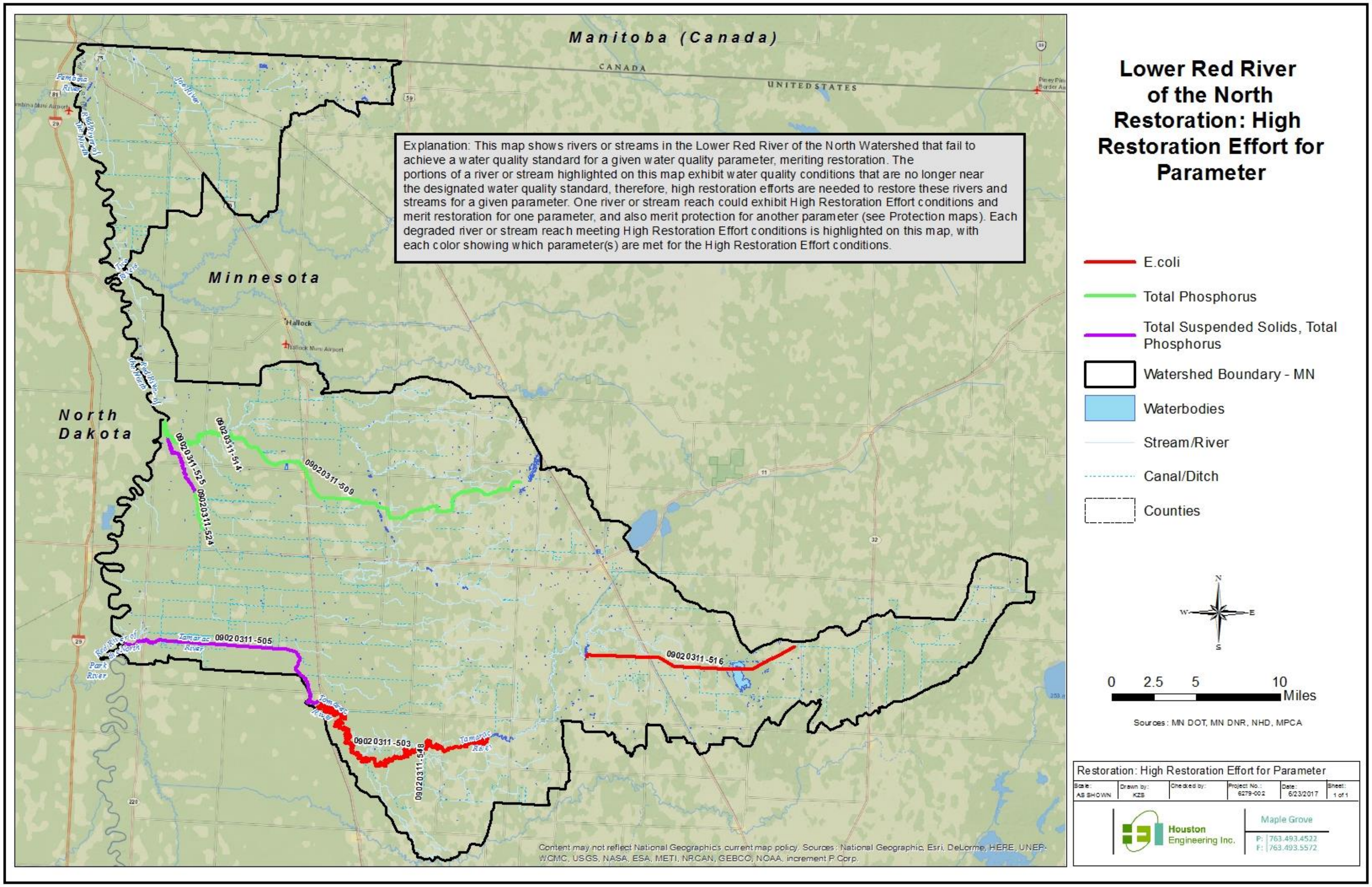


Figure 7: Surface waters categorized as Restoration: High Restoration Effort by water quality parameter.

In addition to mapping the stream category, the loading capacity, existing loads, and remaining loading capacity were calculated for any stream reaches with available water quality data and that were explicitly represented in the HSPF model or had observed daily streamflows. Loading capacities and existing loads were calculated for each of the parameters (TSS, TP, NO2+NO3, and *E. coli*), and a summary of the results are provided in **Table 8**. **Table 8** shows the critical flow regime where the lowest percentage of remaining load occurs based on any existing loads and the calculated load capacities. If the percentage of remaining load is negative, this means a load reduction is necessary.

As demonstrated in **Table 8**, most of the available water quality data were collected along the main stem of the Tamarac River and its associated ditches. As a protection strategy, it is recommended that future monitoring plans address more of the LRRW than just the Tamarac River main stem and ditches. It should be noted that the existing loads shown in **Table 8** may be estimated based on one sample; no considerations for the number of water quality samples was given and official assessment by the MPCA is needed to confirm impairment. For TSS, most stream reaches exceed the TSS load capacity (based on the 65 mg/L numeric standard) for at least one flow regime. Likewise for TP, most stream reaches with water quality data (where an existing load can be computed) have at least one flow regime exceeding the load capacity (based on the 0.15 mg/L numeric standard). All stream reaches show good water quality relating to NO2+NO3 and are well below the loading capacity (based on the Class 1 numeric standard of 10 mg/L).

The results shown in **Table 8** and the protection/restoration categorization maps (**Figures 4** to **7**) should be used to provide guidance for the prioritizing of protection strategies.

Table 8: Critical flow regimes and percentage of remaining load capacity of stream reaches in Lower Red River Watershed.

HUC-10 Sub-watershed	AUID (Last 3 digits)	Stream	TSS		TP		NO2+NO3		*E. coli*	
			Critical Flow Regime	Remaining Load (%)[1]	Critical Flow Regime	Remaining Load (%)[1]	Critical Flow Regime	Remaining Load (%)[1]	Critical Flow Regime	Remaining Load (%)[1]
Lower Tamarac River	503	Tamarac River	Very High	-20%	Very High	-43%	High	98%	Low	45%
	505	Tamarac River	Very High	-1900%	Very High	-424%	Very High	96%	Low	-19%
	510	Tamarac River	--	--	--	--	--	--	--	--
	511	Tamarac River	Very High	27%	Very High	49%	High	99%	--	--
	529	County Ditch 16	--	--	--	--	--	--	--	--
	547	Unnamed creek	--	--	--	--	--	--	--	--
	548	Unnamed ditch	--	--	--	--	--	--	--	--
Upper Tamarac River	516	Judicial Ditch 19	Very High	59%	Very High	63%	Very High	100%	High	57%
	526	State Ditch 90	--	--	--	--	--	--	--	--
	527	Lateral Ditch 5	--	--	--	--	--	--	--	--
	528	State Ditch 90	Very Low	-46%	Very Low	-255%	Very High	98%	--	--
	541	Judicial Ditch 19	--	--	--	--	--	--	--	--
	542	Judicial Ditch 19	--	--	--	--	--	--	--	--
	543	Judicial Ditch 19	--	--	--	--	--	--	--	--
	544	Judicial Ditch 19	--	--	--	--	--	--	--	--
	545	Judicial Ditch 19	--	--	--	--	--	--	--	--
	546	Judicial Ditch 19	--	--	--	--	--	--	--	--
Judicial Ditch no 10	512	County Ditch 10	--	--	--	--	--	--	--	--

Table 8: Critical flow regimes and percentage of remaining load capacity of stream reaches in Lower Red River Watershed.

HUC-10 Sub-watershed	AUID (Last 3 digits)	Stream	TSS		TP		NO2+NO3		*E. coli*	
			Critical Flow Regime	Remaining Load (%)[1]	Critical Flow Regime	Remaining Load (%)[1]	Critical Flow Regime	Remaining Load (%)[1]	Critical Flow Regime	Remaining Load (%)[1]
	518	County Ditch 10	--	--	--	--	--	--	--	--
	519	County Ditch 10	--	--	--	--	--	--	--	--
	520	Judicial Ditch 10	--	--	--	--	--	--	--	--
	521	Judicial Ditch 10	--	--	--	--	--	--	--	--
	522	Judicial Ditch 10	--	--	--	--	--	--	--	--
	523	Judicial Ditch 10	--	--	--	--	--	--	--	--
	524	Judicial Ditch 10	High	-3%	High	-283%	High	94%	Mid	13%
	525	Judicial Ditch 10	--	--	--	--	--	--	--	--
	540	Unnamed creek	--	--	--	--	--	--	--	--
City of Drayton-Red River	530	Judicial Ditch 10	--	--	--	--	--	--	--	--
	531	Judicial Ditch 3	--	--	--	--	--	--	--	--
	532	Judicial Ditch 27	--	--	--	--	--	--	--	--
	533	Judicial Ditch 8	--	--	--	--	--	--	--	--
	534	Judicial Ditch 8	--	--	--	--	--	--	--	--
Unnamed Coulee	509	Unnamed creek (County Ditch 27)	High	-296%	High	-477%	High	98%	High	66%
	514	Unnamed creek	--	--	Very High	-494%	Very High	81%	--	--
	535	Unnamed creek	--	--	--	--	--	--	--	--

Table 8: Critical flow regimes and percentage of remaining load capacity of stream reaches in Lower Red River Watershed.

HUC-10 Sub-watershed	AUID (Last 3 digits)	Stream	TSS		TP		NO2+NO3		*E. coli*	
			Critical Flow Regime	Remaining Load (%)[1]	Critical Flow Regime	Remaining Load (%)[1]	Critical Flow Regime	Remaining Load (%)[1]	Critical Flow Regime	Remaining Load (%)[1]
	536	Unnamed creek	--	--	--	--	--	--	--	--
	537	Unnamed creek	--	--	--	--	--	--	--	--
	538	State Ditch 1	--	--	--	--	--	--	--	--
	539	Unnamed creek	--	--	--	--	--	--	--	--
Joe River	513	Joe River	Very High	-214%	Very High	-459%	Very High	68%	Low	-19%
	515	Joe River	--	--	--	--	--	--	--	--
	517	Salt Coulee	Very High	-1467%	--	--	--	--	--	--

[1]Percentage of remaining load capacity, negative number means existing load exceeds load capacity

--No Available Data

3. Providing Information and Tools for 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, identify point sources, and identify 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 best management practices (BMPs). Thus, effective ongoing public participation is a part of the overall plan for moving forward.

The successful implementation of restoration and protection strategies requires a combined effort from multiple entities within the LRRW, including local and state partners (i.e., soil and water conservation districts [SWCDs], JRWD, TRWD, MSTRWD, MPCA, DNR, and the Board of Water and Soil Resources [BWSR]). By bringing these groups together in the decision making process, it will increase the transparency and eventual success of the implementation. Collaboration and compromise will also ensure that identified priorities and strategies are incorporated into local plans, future budgeting, and grant development.

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 securing needed funding. As such, the proposed actions outlined are subject to adaptive management—an iterative approach of implementation, evaluation, and course correction.

The LRRW WRAPS effort has been led by the JRWD, TRWD, and MSTRWD. All three of the watershed districts have a long history of collaborating with local and state partners (i.e., SWCDs, MPCA, DNR, and BWSR) to prioritize, implement, and fund restoration and protection activities within its jurisdiction. Future restoration and protection work in the area will benefit from these relationships, building on previous successes.

3.1 Targeting of Geographic Areas

The LRRW's hydrology and water quality (i.e., sediment, nutrients, and bacteria) were simulated and evaluated using watershed modeling tools and plans. Tools and plans used in this WRAPS effort include:

- HSPF watershed model
- Prioritize, Target and Measure Application (PTMApp)
- WEPS

- JRWD Overall Plan (2004)
- Overall Plan of the TRWD (2004)
- MSTRWD: Final 10-Year Watershed Management Plan (WMP 2011)

This section gives an overview of the development of these tools and plans, their results, and an outline of how the tools and plans can be used in identifying restoration and protection target areas in the LRRW.

HSPF Model

HSPF is a watershed-scale model that simulates hydrology and water quality for both conventional and toxic organic pollutants from pervious and impervious land. The model incorporates watershed-scale and nonpoint source models into a basin-scale analysis framework. It addresses runoff and constituent loading from lumped pervious land surfaces, runoff and constituent loading from impervious land surfaces, and flow of water and transport/transformation of chemical constituents in stream reaches. The output from the HSPF model is used to identify those locations where pollutant yields are greatest on average at the subwatershed outlet. HSPF model results are included in this WRAPS as means to assist with future targeting of practice locations in local water planning activities. More information on the LRRW HSPF model's development and calibration can be found in the modeling reports (RESPEC 2014). The full results of the priority ranking of subwatersheds in the LRRW using HSPF results have been provided in **Appendix B**.

Prioritize, Target, and Measure Application (PTMApp)

The PTMApp for implementing water quality improvement plans was developed as part of BWSR's One Watershed, One Plan (1W1P) initiative. The tool enables local practitioners to prioritize subwatersheds for BMP and conservation practice (CP) implementation (based upon outputs of HSPF models), target specific fields for implementation (based upon yield [mass/area/time] of sediment, total nitrogen, and TP estimated with terrain analysis techniques), assess technical feasibility for placing BMPs and CPs on the landscape, and measure the water quality benefits of potential BMPs and CPs.

Future use of PTMApp in restoration and protection efforts will include the identification of field-scale priority management areas within the LRRW. The PTMApp products are especially helpful for understanding the delivery of loads to specific waterbodies and targeting specific fields for placing implementation practices.

Prioritized and Targeted Implementation Scenario

A bacteria risk assessment was completed to identify areas in the LRRW that pose the greatest risk for contributing bacteria to surface water resources. GIS and PTMAppp datasets were used to identify high-risk areas based on sources of bacteria and hydrology in the LRRW. Bacteria sources were identified by source type and some datasets were only available at county level. Malfunctioning subsurface sewage treatment systems (SSTSs) can be an important source of fecal contamination to surface waters; thus, the number of potential Imminent Public Health Threats (IPHTs) systems and potentially failing SSTSs were computed per county and in the LRRW overall. Livestock populations for cattle, chickens, goats, horses, sheep, and turkeys were also estimated for each county within the LRRW.

The risk rankings of potential sources of bacteria in the LRRW by AUID are shown in **Table 9**. Livestock sources of bacteria consistently posed the greatest risk of contributing disproportionately larger quantities of bacteria to the outlets to the Red River of the North in the LRRW. Human and wildlife sources of bacteria posed relatively lower risks. This information can be used to prioritize management efforts for the potential sources of bacteria that pose the greatest risk of impacting surface waters in the LRRW.

Table 9: Relative sources of *E.coli* in the Lower Red River Watershed.

AUID	Restoration or Protection	Humans				Livestock				Wildlife					Upstream Sources	
		All	WWTF Effluent	Septic Systems	Domestic Animals	All	Grazing	Manure	AFO Open Lots	All	Deer	Ducks	Geese	Other	Level	Estimated Percentage
Watershed	NA	○	○	○	○	●	●	●	**O**	○	○	○	○	○	NA	NA
501	Protection	○	○	○	○	●	●	●	**O**	○	○	○	○	○	●	100%
502	Protection	○	○	○	○	●	●	●	●	○	○	○	○	○	●	99%
503	Protection	○	○	○	○	●	●	●	●	○	○	○	○	○	●	95%
504	Protection	○	○	○	○	●	●	●	**O**	○	○	○	○	○	●	100%
505	Protection	○	○	○	○	●	●	●	●	○	○	○	○	○	●	96%
506	Protection	○	○	○	○	●	●	●	**O**	○	○	○	○	○	●	100%
509	Protection	○	○	○	○	●	●	**O**	**O**	○	○	○	○	○	**O**	45%
511	Protection	○	○	○	○	●	●	●	●	○	○	○	○	○	●	90%
513	Protection	○	○	○	○	●	●	**O**	**O**	○	○	○	○	○	○	0%
514	Protection	○	○	○	○	●	○	●	○	**O**	○	**O**	○	○	○	0%
516	Restoration	○	○	○	○	●	●	●	**O**	○	○	○	○	○	○	0%
524	Protection	○	○	○	○	●	●	**O**	**O**	○	○	○	○	○	○	0%

● = high risk, **O** = medium risk, ○ = low risk

Figure 8 shows ranks based on the area weighted magnitude of bacterial delivery for major stream branches within LRRW. Higher rates equate to a greater risk of bacterial delivery from the watershed to the outlet of the LRRW. Similar to the results shown in **Table 9**, livestock sources consistently posed the greatest risk of bacterial delivery. The results in **Figure 8** are area weighted, so comparisons can be made between subwatersheds. This information can be used to inform the prioritization of local management efforts aimed at reducing bacterial delivery to surface waters in the LRRW. In addition, **Figure 8** can also be used to begin targeting specific subwatersheds for bacterial restoration and protection strategies. It is important to note that the data used to develop **Figure 8** are based on county-wide data that were aggregated to subwatersheds within the study area. Therefore, the source magnitudes should not be interpreted to represent the source loading of specific fields within the subwatersheds. For example, Roseau County only occupies a small portion of the study area, but was aggregated into the Upper Tamarac River Subwatershed (**see Figure 8**), which was ranked high relative to other subwatersheds. However, the portion of Roseau County contributing bacteria to the Upper Tamarac River Subwatershed is likely minor. This result is driven by the county-wide scale of the bacteria input data.

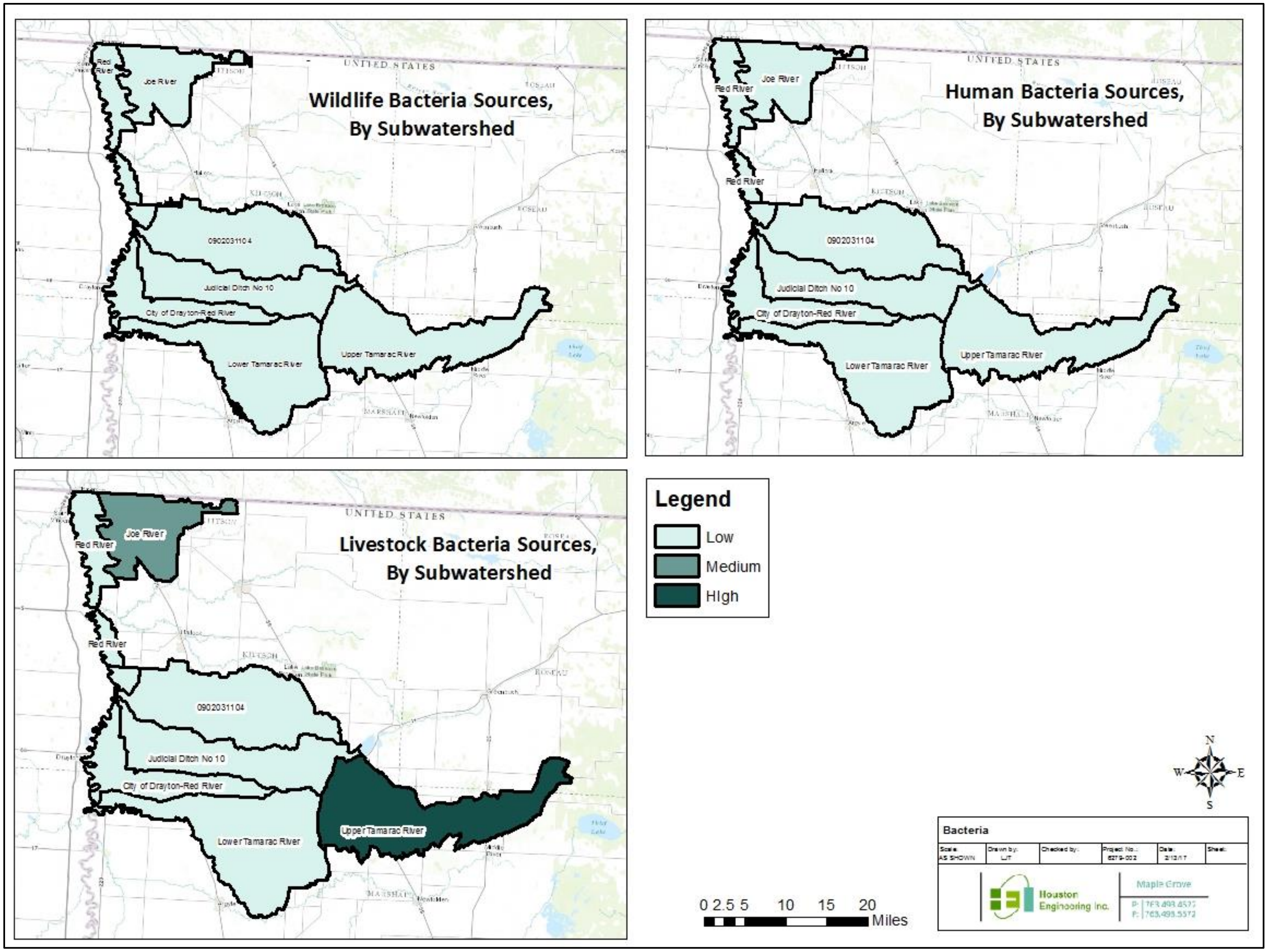


Figure 8: Ranked HUC-10 subwatersheds based upon magnitude of bacterial delivery to the outlet of the LRRW. ***Note: Boundaries used within bacteria risk assessment and PTMApp are different, as they rely upon existing hydroconditioned digital elevation models.***

A source assessment was also completed to identify the magnitude and spatial distribution of potential pollution sources across the landscape. PTMApp – Desktop creates three source assessment products: load and yields leaving the landscape; delivered to a waterway; and delivered to a downstream resource of interest (e.g., lake or river reach). By completing a source assessment, an understanding is obtained of how various parts of the watershed affect a resource. The sediment yield (tons/acre/year) delivered to the outlet of LRRW (where the Red River of the North intersects the Minnesota, North Dakota, and Canadian border) for the study area is shown in **Figure 9**. Similar products can be developed for TN and TP for any priority resource point input during processing. The results indicate that the highest areas of overland sediment loading to the outlet of LRRW are concentrated near the outlet of the watershed. For strategies aimed at reducing sediment delivered to the outlet of LRRW, the "High" sediment yield areas would provide ideal locations to target practices. However, the feasibility of implementing BMPs and CPs in those areas must first be evaluated. In other words, the highest loading (sediment, TN, or TP) areas on the landscape might have limited opportunities or may be cost prohibitive for implementing a practice to address the issue.

The feasibility of placing a BMP or CP on the landscape depends on several factors. These factors include the size of the contributing drainage area, the land slope, the type of flow regime, and local topography. Practice feasibility is based solely on technical factors largely based on field office technical guides developed by the Natural Resources Conservation Service (NRCS), and excludes social factors like landowner willingness. Locations shown as "feasible" are candidates for implementing practices and require further technical evaluation to confirm feasibility. The potential opportunities for BMPs and CPs within the LRRW study area are shown in **Figure 10**. The opportunities are displayed by PTMApp treatment group (HEI 2014). It's important to note that that these are only potential locations at this point in the business workflow. Local knowledge is still needed to refine the locations to identify a realistic set of targeted practices. These BMP and CP opportunities can be combined with the source assessment data in PTMApp to estimate the "measurable" water quality benefits for implementing the practices.

One of the means of selecting specific practices for implementation is based on their probable benefits. The probable benefits of a practice can be described by either the amount of a parameter like sediment or phosphorus removed, or the cost to remove one unit of the parameter (e.g., dollars per pound of phosphorus annually reduced). Practice benefits can be estimated at the location of the practice or the resource. The estimated benefits at a lake or river are more valuable from a decision-making perspective. The estimated sediment load reduction, tons/year, for reducing sediment using storage practices at the outlet of LRRW is shown in **Figure 11**. The areas providing the largest load reduction are in the High category. These results can be used to target practice locations to implement BMPs and CPs that provide the largest sediment load reductions to make progress towards local, state, and regional water quality management goals.

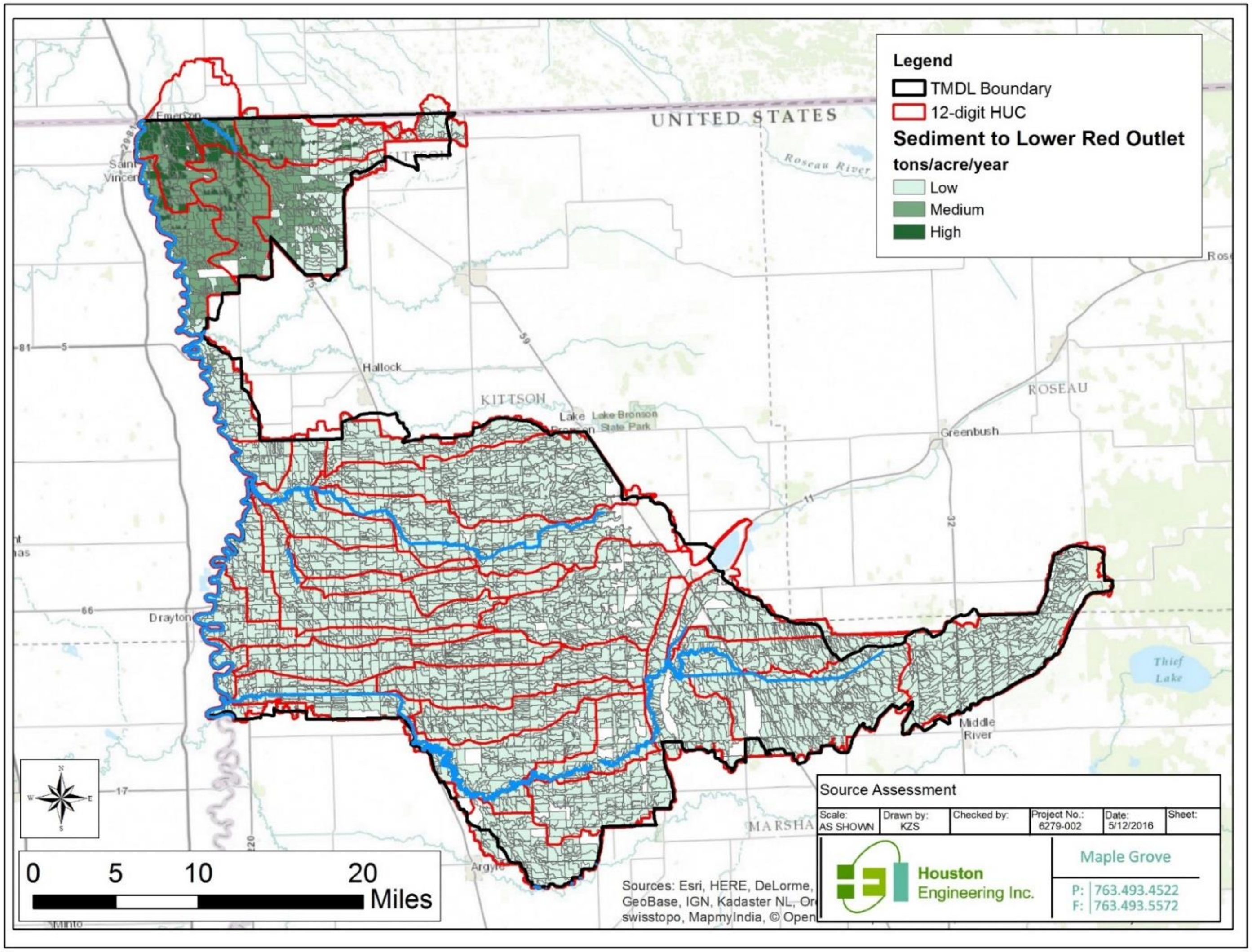


Figure 9: Lower Red River Watershed source assessment for sediment yield delivered to the outlet of Lower Red River Watershed. Total nitrogen and TP were also assessed (not shown in map). *Note: Boundaries used within PTMApp are different, as they rely upon existing hydroconditioned digital elevation models.*

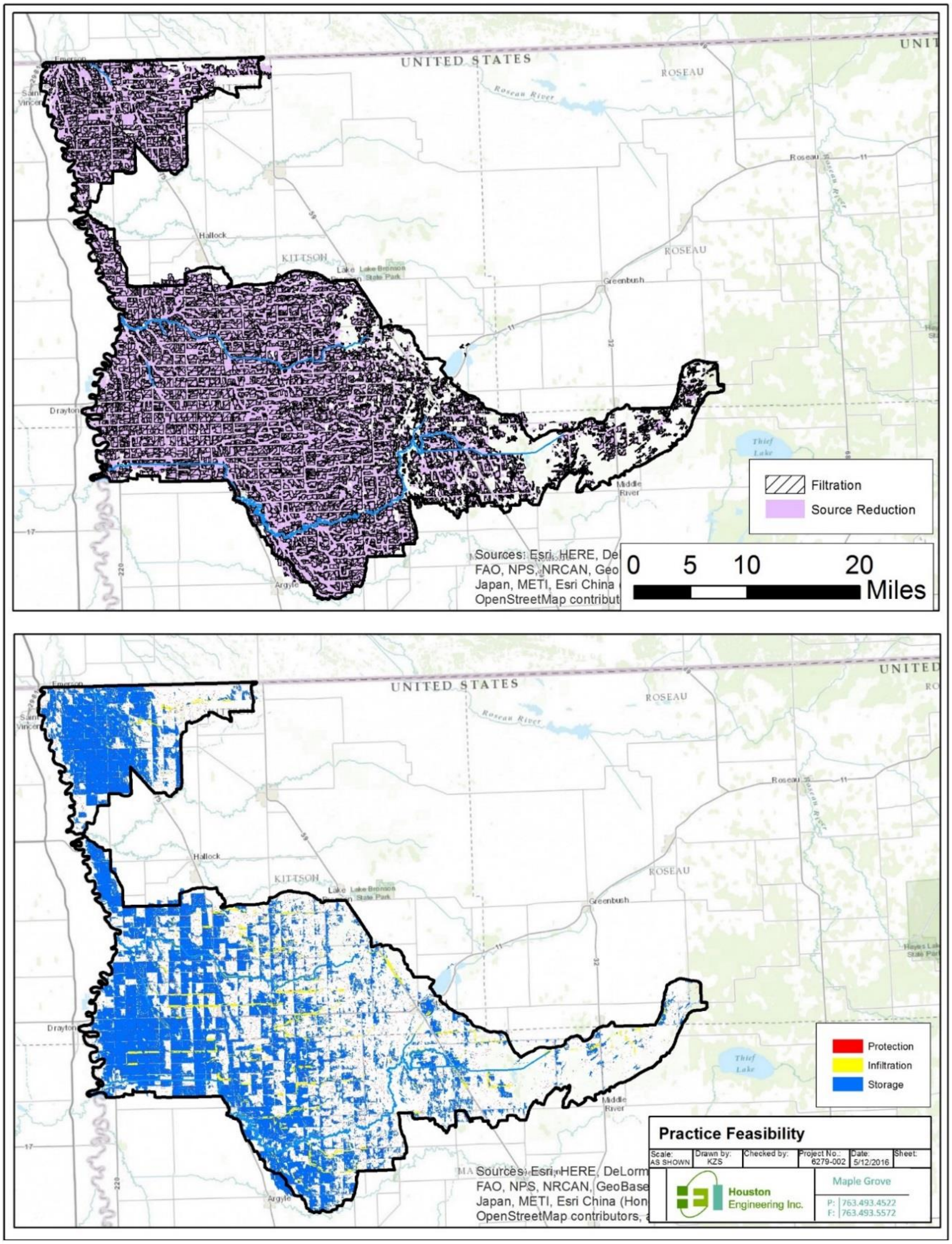


Figure 10: Potential locations for BMPs and CPs based on technical feasibility within the Lower Red River Watershed study area. ***Note: Boundaries used within PTMApp are different, as they rely upon existing hydroconditioned digital elevation models.***

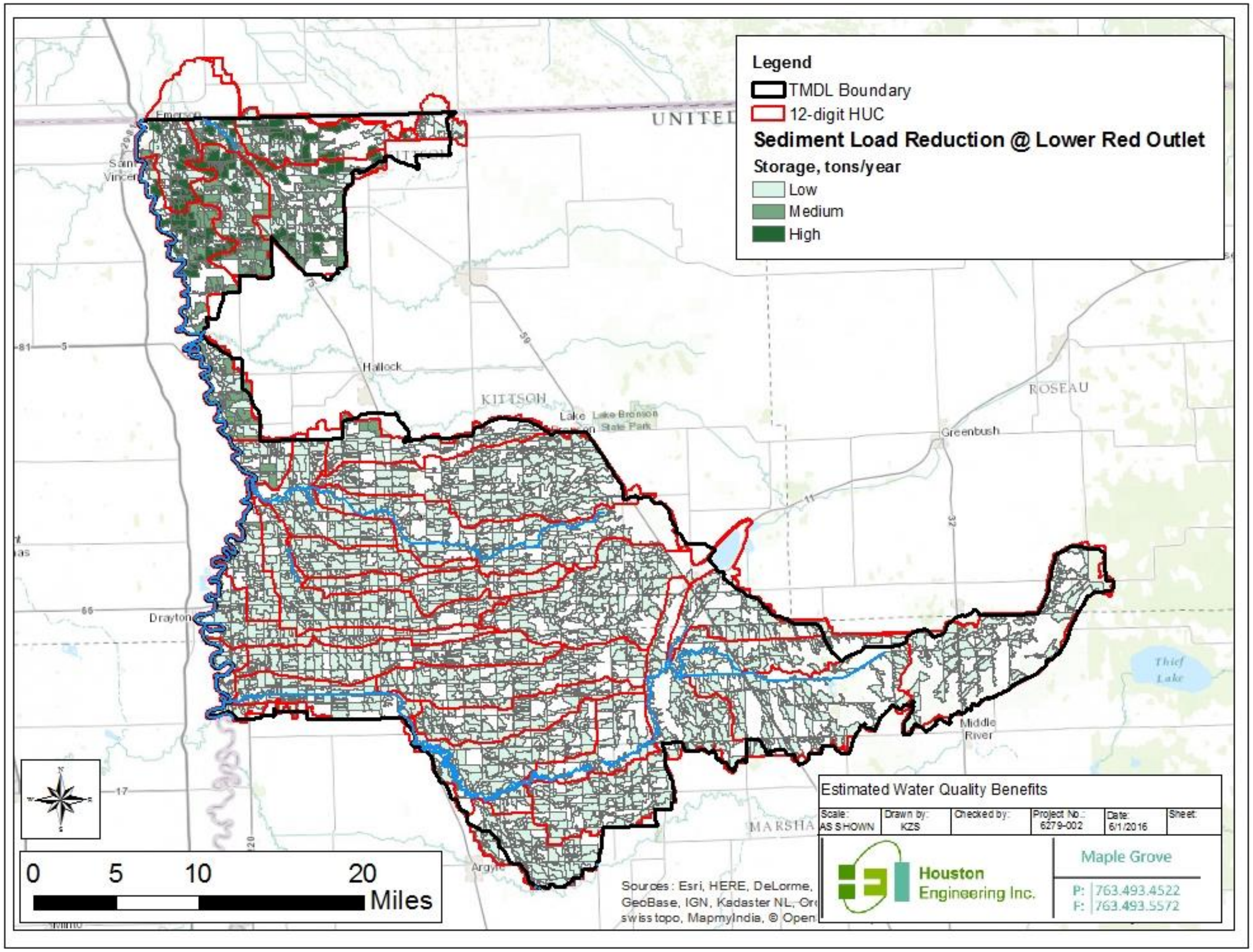


Figure 11: The load reduction (tons/year) of reducing sediment delivered to the outlet of the Lower Red River Watershed study area using storage practices. Similar products can be developed for total nitrogen and TP. ***Note: Boundaries used within PTMApp are different, as they rely upon existing hydroconditioned digital elevation models.***

Wind Erosion Prediction System

A WEPS model was developed to help quantify the magnitude of wind (i.e., aeolian) erosion in the LRRW relative to other sources, and to inform restoration and protection strategies. Wind erosion zones (WEZs) were established to estimate field-scale erosion in WEPS, while generalizing factors across multiple fields within the LRRW study area. Wind-driven sediment erosion modeling is controlled by parameters including, but not limited to, soil character and moisture content, crop type, field management practices, field orientation and barriers, topography, and local meteorology. In an attempt to summarize these parameters, three factors were used to develop a manageable number of WEZs:

1. Agricultural parcels determined from the U.S. Department of Agriculture's (USDA) Common Land Unit (CLU) database;
2. Information on crop rotations derived from the National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL); and
3. Revised Universal Soil Loss Equation (RUSLE) K_w factor.

Field-scale erosion was aggregated within each 10-digit HUC to determine subwatershed-scale field losses (**Table 10**; **Figure 12**, **Figure 13**). Wind erosion was largest in the southern LRRW subwatersheds, and particularly large in the Lower Tamarac River Subwatershed (**Table 10**; **Figure 12**, **Figure 13**). Elevated Lower Tamarac River loading appears to be primarily due to the large proportion of soybean and non-alfalfa hay acreage conversion from traditionally perennial cover to row crops in the basin, which were found to be some of the largest contributors to wind erosion on a per-acre basis. The Lower Tamarac River Subwatershed also had the second highest wind erosion yield, at 6.25 tons/acre/year. In terms of erosive sediment loss per acre, the Upper Tamarac River Subwatershed was highest, at 9.52 tons/acre/year. Incidentally, this subwatershed has the smallest agricultural acres as it is has a greater percentage of forest and wetland area, with a combined 44% of land area within the HUC-10, as compared to 5% on average for other HUCs. A complete summary of the LRRW WEPS model development and results can be found within **Appendix C** (HEI 2016b). A limitation of the wind erosion modeling is the inability to deterministically estimate the amount of sediment that reaches a watercourse.

Table 10: Total wind erosion summarized by HUC-10 codes. 'Other 10-digit HUCs' include portions of fields outside the hydrologic boundary of each HUC-10.

HUC-10	HUC-10 Name (if any)	Agricultural Area (acres)	Total Erosion by HUC-10		Erosion Yield (tons/acre)
			tons/yr.	%	
902031101	Upper Tamarac River	20,201	192,357	11.5%	9.52
902031102	Lower Tamarac River	106,261	663,714	39.5%	6.25
902031103	Judicial Ditch No 10	63,508	209,743	12.5%	3.30
902031104	(No Common Name)	84,213	255,795	15.2%	3.04
902031105	City of Drayton-Red River	47,976	173,598	10.3%	3.62
902031107	Red River	24,696	43,062	2.6%	1.74
902031108	Joe River	49,245	96,939	5.8%	1.97
	Other 10-digit HUCs	10,803	43,229	2.6%	4.00
	TOTAL =	406,902	1,678,438		

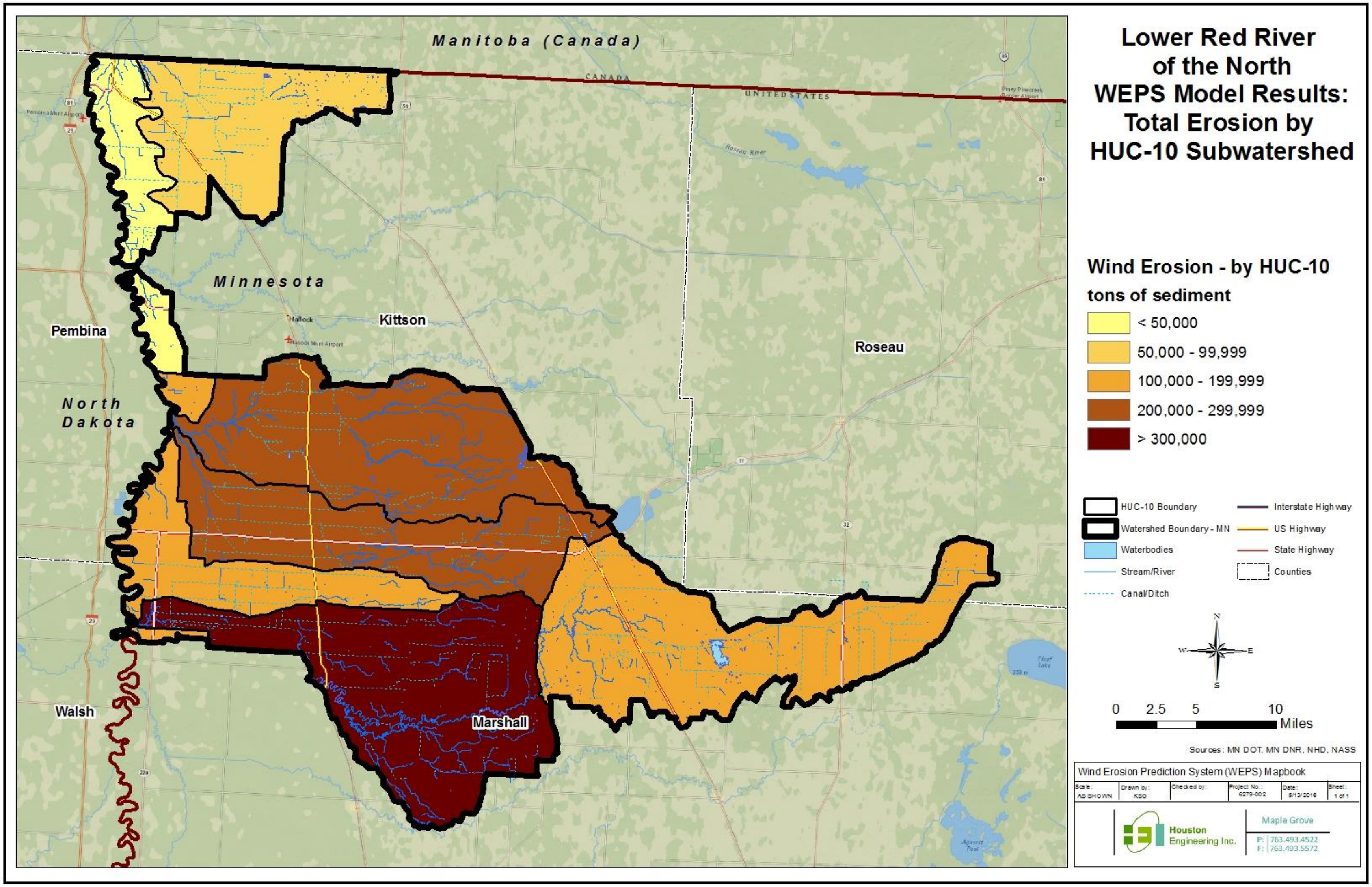


Figure 12: Total estimated sediment wind erosion (tons/year) by 10-digit HUC within the Lower Red River Watershed, as estimated by the WEPS model. ***Note: Boundaries used within WEPS align with PTMApp analysis.***

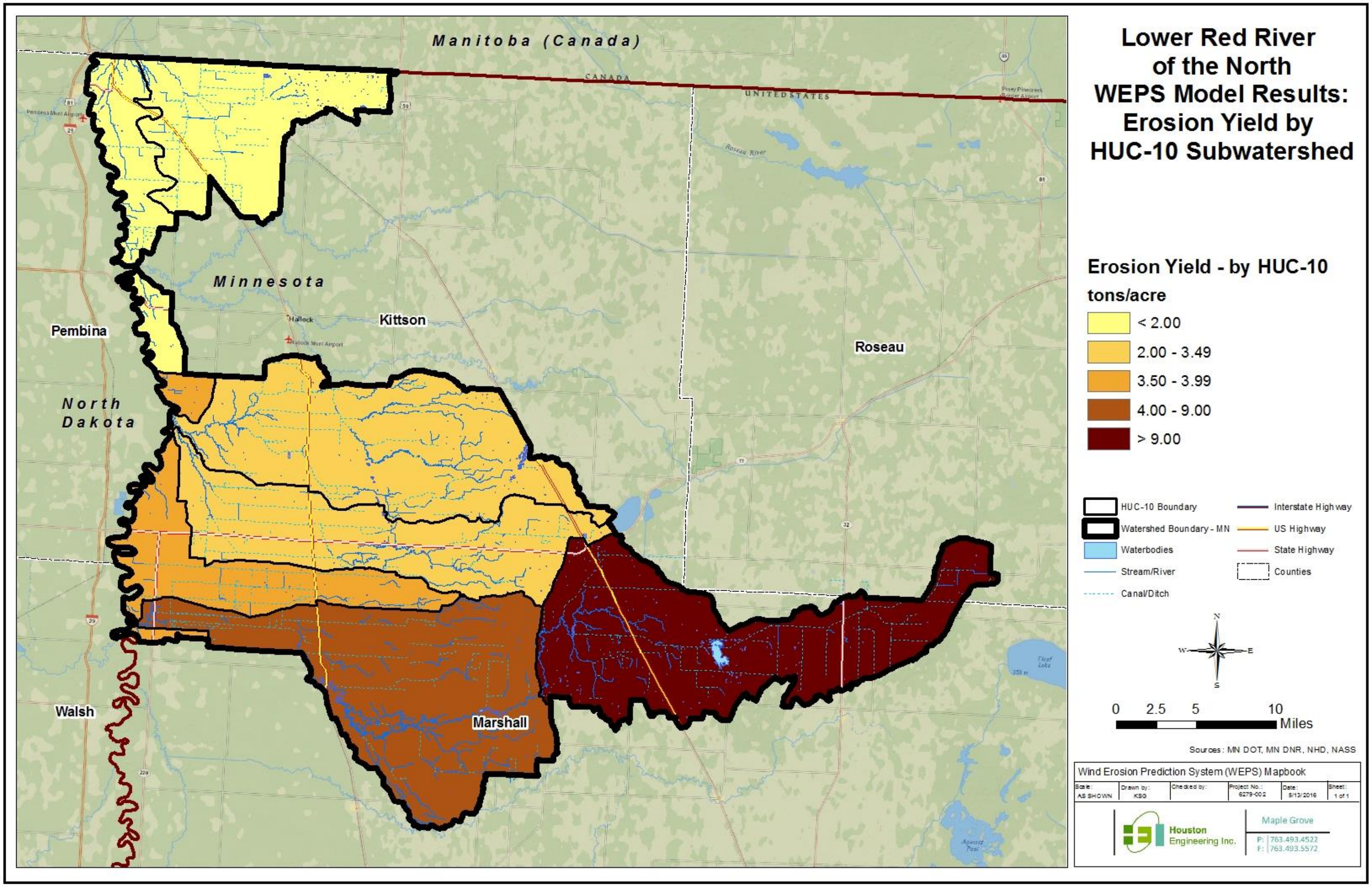


Figure 13: Annual mean erosive yield (tons/acre/year) by 10-digit HUC within the Lower Red River Watershed, as estimated by the Wind Erosion Prediction System (WEPS) model. ***Note: Boundaries used within WEPS align with PTMApp analysis.***

Watershed Management Plans

Pursuant to Minnesota Statute, the JRWD, TRWD, and MSTRWD are each required to prepare a WMP and to continually update and revise the plan every 10 years. The WMP is an important tool for identifying problems, issues, and goals, and developing long and short-term strategies to address these issues and attain the goals. The WMP also inventories resources, assesses resource quality, and establishes regulatory controls, programs, or infrastructure improvements needed to manage the resources within the watershed. The WMP provides guidance for each of the three watershed districts to manage the water and natural resources within their watershed boundary.

The JRWD Overall Plan and the TRWD Overall Plan were most recently updated in 2004 (JRWD 2004). The MSTRWD WMP (MSTRWD 2011) was most recently updated in 2011. In all three of the updated plans, great efforts were made to quantify the goals and suggest implementation strategies for managing water quantity and quality, as well as natural resource enhancement. Results of the WRAPS will be directly incorporated into the next scheduled updates of the JRWD, TRWD, and MSTRWD plans and/or BWSR's voluntary 1W1Ps[3]. Two 1W1P planning regions include parts of the LRRW; neither region has a plan written as of 2018 but intend to apply for 1W1P in 2018. Future use of the three watershed district plans and 1W1Ps, in water quality restoration and protection efforts, will include integrating the principles, goals, and policies of the JRWD, TRWD, and MSTRWD into the efforts and providing a management framework under which the efforts will occur.

Additional Tools

A number of additional tools are available for use in restoration and protection of impaired waters in the LRRW. A non-exhaustive list of some of these tools, their description, and how they may be utilized is listed in **Table 11**.

[3] http://bwsr.state.mn.us/planning/1W1P/index.html

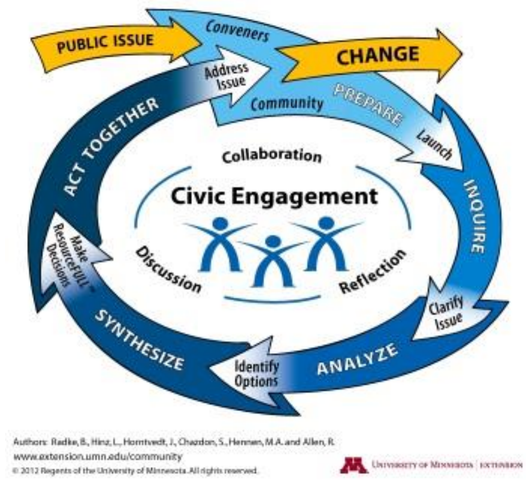
Table 11: Additional Tools Available for Restoration and Protection of Impaired Waters

Tool	Description	How can the tool be used?	Notes	Link to Information and data
Ecological Ranking Tool (Environmental Benefit Index - EBI)	This dataset consists of three GIS raster data layers including soil erosion risk, water quality risk, and habitat quality. The 30-meter grid cells in each layer contain scores from 0-100. The sum of all three scores is the EBI score (max of 300). A higher score indicates a higher priority for restoration or protection.	The three layers can be used separately, or the sum of the layers (EBI) can be used to identify priority areas for restoration or protection projects. The layers can be weighted or combined with other layers to better reflect local values.	These data layers are available on the BWSR website. In addition, a GIS data layer that shows the 5% of each 8-digit watershed in Minnesota with the highest EBI scores is available for viewing in the MPCA 'water quality targeting' web map, and download from MPCA.	BWSR MPCA Web Map MPCA download
Zonation	This tool serves as a framework and software for large-scale spatial conservation prioritization, and a decision support tool for conservation planning. The tool incorporates values-based priorities to help 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.)	Software Examples
Restorable Wetland Inventory	A GIS data layer that shows potential wetland restoration sites across Minnesota. Created using a compound topographic index (CTI) (10-meter resolution) to identify areas of ponding, and USDA NRCS SSURGO soils with a soil drainage class of poorly drained or very poorly drained.	Identifies potential wetland restoration sites with an emphasis on wildlife habitat, surface and ground water quality, and reducing flood damage risk.	The GIS data layer is available for viewing and download on the Minnesota 'Restorable Wetland Prioritization Tool' web site.	Restorable Wetlands
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 this data set is to identify riparian buffers around rivers.	The layers are available on the USGS website.	USGS
Light Detection and Ranging (LiDAR)	Elevation data in a digital elevation model (DEM) GIS layer. Created from remote sensing technology that uses	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	The layers are available on the Minnesota Geospatial Information Office website.	MGIO

	laser light to detect and measure surface features on the earth.	application of the data set is to delineate small catchments.		
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. Scenario Application Manager (SAM) is a downloadable and much more user friendly graphical interface to HSPF models.[4]	*USGS /MPCA*

[4] https://www.respec.com/product/scenario-application-manager/

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: https://extension.umn.edu/community-development/leadership-and-civic-engagement.

A specific goal of the civic engagement process for this WRAPS project was to work closely with the residents, cities, counties, businesses, and other stakeholders to ensure that their ideas, concerns, and visions for future conditions were understood and utilized throughout the WRAPS process. The WRAPS process is most likely to be successful when average citizens play a greater role in helping to frame the water quality issues in their own community, as well as in the creation of the solutions to those problems. Given this, the civic engagement process included two primary components: technical stakeholder engagement and citizen engagement.

A Technical Stakeholder Group (TSG) was developed to share local knowledge about problems and to guide the development of potential implementation strategies based on technical data. The WRAPS TSG included representatives from the JRWD, TRWD, MSTRWD, the SWCDs, and state agencies. This group was primarily engaged to discuss products developed to identify geographic areas for implementing potential projects.

Accomplishments and Future Plans

The civic engagement efforts related to the LRR WRAPS have been overseen and carried out through a coordinated effort led by JRWD, TRWD, and MSTRWD. Numerous public meetings and open house events were held at key points in the WRAPS process to update stakeholders on the WRAPS efforts, as well as to receive input and guidance on water quality values and concerns in the area. A core team, including JRWD, TRWD, and MSTRWD board members and local/state agency partners, was also established and kept abreast of technical components of the work.

Since water quality is among the priorities of the JRWD, TRWD, and MSTRWD management activities, future civic engagement will continue to be led by the three watershed districts. The Kittson, Marshall, and Roseau SWCDs will also continue with their civic engagement programs and activities. The watershed districts and SWCDs will update, educate, and engage stakeholders on water quality issues through the normal communications, including plan update events and on the MSTRWD website.

Expectations are that future implementation will occur either through the existing water related plans, implementing 1W1P, and/or through the Flood Damage Reduction Workgroup.

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 August 13, 2018 through September 12, 2018.

3.3 Restoration & Protection Strategies

Water quality restoration and protection strategies within the LRRW were identified through collaboration with local and state partners (i.e., SWCDs, WDs, MPCA, DNR, and BWSR). Due to the homogeneous nature of the LRRW, most of the suggested strategies are applicable throughout the LRRW.

Fish passage has been cited as a primary stressor to the biological impairments in the LRRW (MPCA 2015). The natural flow regime of the impaired reach has been substantially altered resulting in "flashy" flow regimes, which is largely responsible for the degradation of physical habitat, high suspended sediment, and low DO conditions that are also limiting the fish and macroinvertebrate communities within the impaired reach (MPCA 2015). Based on the results of the LRRW SID Report (MPCA 2015), restoration and protection strategies can be developed to prevent or mitigate activities that further alter the hydrology of the LRRW, improve upland storage capacity, restore connectivity to allow for greater fish passage, and improve riparian condition in an effort to restore the hydrology of the LRRW.

A study has been completed for the LRRW that identifies areas that are suitable for BMPs, based on sediment, TP, and TN delivery from priority ranking of subwatersheds in the LRRW using HSPF and PTMApp-Desktop Results (**Appendix B**). Bacteria risk areas have also been identified (HEI 2016c). Based upon the HEI studies, the subwatersheds where BMP projects could be implemented are defined in **Table 12** and **Table 13**.

Table 12 contains a list of the impaired waters of the LRRW, along with goals for restoration, suggested implementation strategies, estimated adoption rates needed to achieve milestones (or alternatively, outcome benchmarks), units/metrics to track progress towards goals, the governmental unit responsible for implementation, and the timeline to achieve those goals. All other waters in the LRRW are assumed to be unimpaired and, therefore, are subject to protection strategies. Given the homogeneity of the LRRW, protection strategies are identified on a watershed-wide basis and generalized for all unimpaired streams.

Restoration strategies are not listed for excess chloride on AUID 09020311-513 as the road salt management strategy listed in **Table 13** is not relevant. The watershed of this AUID is sparsely populated and the majority of the roads are gravel and thus are not salted.

Examples of Past Watershed Implementation Projects

The JRWD, TRWD, MSTRWD, and the Kittson, Marshall, and Roseau SWCDs have a long history of improving water quality. These local government units have been actively seeking grants to improve local water quality since the passage of the Clean Water, Land, and Legacy Amendment and before.

In 1963, the JRWD partnered with the NRCS, formerly Soil Conservation Service, and the Kittson SWCD to plan for flood control under the Federal Public Law 566 Program. Installation of the structures and channel work took place between 1968 and 1971. The improved system consists of 26.47 miles, which removes excess water within the JRWD. The JRWD has also been involved with a cost share program to construct farmstead ring dikes. Under this program, state funding and funding from the Red River Watershed Management Board is utilized to plan, design, and construct ring dikes around eligible farmsteads for the purpose of flood protection.

The TRWD has constructed several projects within the Unnamed Coulee system of the LRRW. Between 2005 and 2008, the TRWD partnered with federal, state, and local funding sources to construct a flood control project, Springbrook/CR61. A setback dike along 3.5 miles of existing ditch and a meandering channel was constructed to take the place of the ditch. The project will prevent overland flooding from channel breakouts, and created 3.5 miles of a meandering stream with grass buffer on either side. In 2009, TRWD constructed a flood control and water conveyance project for the city of Kennedy (Kennedy #6), consisting of two miles of legal ditch system to convey flows from a 50-square mile upstream drainage area through the city, minimizing the flood damages that occur. In 2013, the TRWD completed Springbrook #10 PL566, which included set back dikes and side water inlets along existing waterways. The TRWD also operates and maintains several legal ditch systems, including Kittson County Ditch (KCD) 10, JD 10, JD 3, and KCD 7. Although these flood protection projects were implemented for flood protection, there are additional water quality benefits associated with them. Impounding water during flood periods, reduces the peak flows and may reduce the sediment load in a stream. The critical flow regime for sediment in the impaired reaches is the very high flows (flood flows). Reducing the peak flows, reduces the magnitude of the critical flows, therefore reduces the maximum sediment loads.

The MSTRWD has planted riparian grass buffer strips along the legal drains to improve water quality throughout the district

The Marshall SWCD has a history of partnership with the USDA NRCS/Farm Service Agency to provide funded programs for CP implementation, BMP implementation, and conservation easements. These programs have been delivered through the Environmental Quality Incentives Program (EQIP), the Wildlife Habitat Incentive Program (WHIP), the Conservation Stewardship Program (CSP), and the Conservation Reserve Program (CRP).

Implementation Milestones

Interim 10-year milestones are identified in **Table 12** for each impaired subwatershed so incremental progress is achieved. On-going water quality monitoring data will be used in future components of the WRAPS process to judge the effectiveness of the proposed strategies and inform adaptive implementation toward meeting the identified long-term goals. The timeline for the identified protection strategies is on-going.

Stormwater Crediting

It is important to note that load reductions from some implementation actions listed in **Table 12** are creditable to the load allocation and some to the wasteload allocation. Examples of non-WLA creditable projects include strategies aimed at reducing in-stream loading (e.g., streambank and shoreline protection/stabilization). For clarification on a particular project, proposers should contact the MPCA Stormwater Program.

Table 12: Strategies and actions proposed for the Lower Red River Watershed.

HUC-10 Subwater-shed	Waterbody and Location		Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy scenario showing estimated scale of adoption to meet 10 yr. milestone and final water quality targets. Scenarios and adoption levels may change with additional local planning, research showing new BMPs, changing financial support and policies, and experience implementing the plan.					Governmental Units with Primary Responsibility					Estimated Year to Achieve Water Quality Target
								Estimated Adoption Rate									
	Waterbody (ID)	Location and Upstream Influence Counties		Current Conditions (load or concentration)	Goals / Targets and Estimated % Reduction		Strategy Type	Current strategy adoption level, if known	Interim 10-year Milestone	Suggested Goal	Units	Watershed District	SWCD	MPCA	County	DNR	
All	All	All	Parameters cited in permit	-	-	Wastewater facilities -- compliance with NPDES permits								•			-
			Parameters cited in permit	-	-	Construction and Industrial Stormwater permittees -- compliance with general permits								•			-
			All	-	-	Social infrastructure --- education / outreach, relationship building, demonstration projects, etc.						•	•		•		-
			Nitrogen (TN) or Nitrate		13% load reduction per Nutrient Reduction Strategy (MPCA 2014b)	The primary strategies examined are included as rows below, and one example scenario is depicted in the adoption rate columns. Note that these adoption rates vary relatively and there are many combinations that would result in goal attainment.											
						Increase fertilizer and manure efficiency	Increase row crop acres utilizing U of MN recommendations for the economic optimal nitrogen rate after crediting all legumes and manure, varying with level of adoption of vegetative cover BMP.	20%	50%	100%	% row crop acres		•				2040 per Nutrient Reduction Strategy (MPCA 2014b)
						Store and treat tile drainage waters	Treat tiled cropland using constructed/restored wetlands or other practices	2%	5%	10%	% of agricultural areas	•					
							Controlled drainage on tile-drained row cropland	3%	15%	30%	% of row crop acres		•				
						Increase vegetative cover/root duration [to reduce nitrate leaching]	Cover crops on: a) earlier harvest crops (EHC); and b) corn and soybean lands (C/S)	<1 % EHC <1% C&S	5% of EHC 5% of C/S	10% of EHC 10% of C/S	% of crop land in each category (EHC and C/S)		•				
							Convert marginal lands to perennial cover (marginal lands as determined by using Crop Productivity Index)	60%	80%	100%	% of qualifying acres		•				
			TSS, TP	(See watersheds below)		**Improve upland/field surface runoff controls** [to reduce or intercept farm field erosion]	50-ft buffers on all streams and all buffer requirements met	70%	100%	100%	% of streams	•	•				-
							HEL lands and >3% sloped cropland at ≥30% residue cover or equivalent	20%	50%	100%	% of priority lands with residue protection		•				
							Open tile inlets with either riser pipes, rock inlets or other protection	50%	70%	100%	% of open tile inlets	•	•				
							Tilled sloping row-cropped lands protected with grassed waterways, WASCOBs, contour farming and/or other BMPs	60%	80%	100%	% of applicable lands with listed BMPs		•				

HUC-10 Subwater-shed	Waterbody and Location		Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy scenario showing estimated scale of adoption to meet 10 yr. milestone and final water quality targets. Scenarios and adoption levels may change with additional local planning, research showing new BMPs, changing financial support and policies, and experience implementing the plan.					Governmental Units with Primary Responsibility					Estimated Year to Achieve Water Quality Target
								Estimated Adoption Rate									
	Waterbody (ID)	Location and Upstream Influence Counties		Current Conditions (load or concentration)	Goals / Targets and Estimated % Reduction		Strategy Type	Current strategy adoption level, if known	Interim 10-year Milestone	Suggested Goal	Units	Watershed District	SWCD	MPCA	County	DNR	
			TSS, TP, Altered hydrology			Increase vegetative cover/root duration	Cover crops on early harvest crops and fallow land	0%	5%	15%	% of early harvest and fallow lands with cover		•				
			TP, *E. coli*			Prevent feedlot runoff	Fix open lot runoff problems per Minn. R. ch.7020 and open lot agreement.	80%	90%	100%	% open lots in compliance		•		•		
						Improve fertilizer and manure application management	Applying P fertilizer only on fields needing P for optimal crop growth	40%	70%	90%	% of agricultural acres		•				
							Fertilizer and manure injected or immediately incorporated	40%	70%	90%	% of agricultural acres		•				
						Improve livestock and manure management	All Minn. R. ch. 7020 manure spreading setbacks are met	60%	80%	100%	% of agricultural acres		•				
							Winter manure spreading reduced	20%	40%	60%	% of agricultural acres		•				
							Inject or immediately incorporate manure where currently surface applied	20%	40%	60%	% of agricultural acres		•				
Lower Tamarac River (0902031102)	Tamarac River (09020311-503)	Marshall	**TSS**	Very High = 75 mg/L; High = 28 mg/L; Mid = 19 mg/L; Low = 21 mg/L; Very Low = 3 mg/L	65 mg/L met >90% of the time in Apr-Sep	**Improve upland/field surface runoff controls** [to reduce or intercept farm field erosion]	Increase living cover through cover crops, perennials and well-managed pastures	15%	20%	30%	% of watershed area		•				2025
							50-ft buffers on all streams and all buffer requirements met	70%	100%	100%	% of streams	•	•				
							HEL lands and >3% sloped cropland at ≥30% residue cover or equivalent	80%	90%	100%	% of priority lands with residue protection		•				
							Open tile inlets with either riser pipes, rock inlets or other protection	40%	80%	100%	% of open tile inlets	•	•				
							Tilled sloping row-cropped lands protected with grassed waterways, WASCOBs, contour farming and/or other BMPs	50%	70%	100%	% of applicable lands with listed BMPs		•				
						Protect/stabilize banks/bluffs	*See all examples for "Altered hydrology; peak flow (Fish/Macroinvertebrate IBI)"*	--	--	--	--						
							Highly-eroding banks identified and stabilized	20%	40%	100%	% of banks identified and stabilized		•				
							50-ft buffers on all streams and all buffer requirements met	70%	100%	100%	% of streams	•	•				

HUC-10 Subwater-shed	Waterbody and Location: Waterbody (ID)	Waterbody and Location: Location and Upstream Influence Counties	Parameter (incl. non-pollutant stressors)	Water Quality: Current Conditions (load or concentration)	Water Quality: Goals / Targets and Estimated % Reduction	Strategies (see key below)	Strategy scenario showing estimated scale of adoption to meet 10 yr. milestone and final water quality targets. Scenarios and adoption levels may change with additional local planning, research showing new BMPs, changing financial support and policies, and experience implementing the plan. Strategy Type	Estimated Adoption Rate: Current strategy adoption level, if known	Estimated Adoption Rate: Interim 10-year Milestone	Estimated Adoption Rate: Suggested Goal	Estimated Adoption Rate: Units	Governmental Units with Primary Responsibility: Watershed District	SWCD	MPCA	County	DNR	Estimated Year to Achieve Water Quality Target
							Livestock exclusion on pastures near streams	75%	100%	100%	% of stream miles		•				
							Construct floodwater impoundments	0	10000[1]	25000[1]	Acre-feet of storage impoundments		•				
							Accurately size bridges and culverts to improve stream stability	80%	90%	100%	% complete	•	•				
							Improve/increase natural habitat in riparian, control invasive species	2%	5%	10%	% of watershed area addressed	•	•				
							Tree and grass planting for stabilization on streams	0	2	5	stream miles		•				
						Stream channel restoration	Install two-stage ditches on drainage ditches	< 10,000	10,000	25,000	Feet of ditch	•					
							Re-meander channelized stream reaches	2	10	30	stream miles		•			•	
							Identify alternative buffer strip options for landowners, including the development of a local buffer strip cost share program, the application of the state standard and the enforcement of 50-foot buffers along DNR Public Waters.	40%	100%	100%	% of impacted landowners		•				
							Large-scale restoration – channel dimensions match current hydrology & sediment loads, connect the floodplain, stable pattern, (natural channel design principals)	0	25	30	stream miles					•	
						Stabilize ravines	*See all examples for TSS - reducing upland/field surface runoff*	--	--	--	--						
							Stabilization within ravines--vegetative practices and/or engineered structures	60%	70%	100%	% High-priority ravines addressed		•				
						Improve urban stormwater management [to reduce sediment and flow]	Combination of practices to achieve sediment reduction from baseline levels	60%	70%	100%	% sediment reduction for unpermitted areas			•			
						Improve wind erosion controls	Install field edge buffers, borders, windbreaks and/or filter strips	30%	60%	100%	% of agricultural areas	•	•				
							Utilize stripcropping	5%	25%	50%	% of agricultural areas	•	•				
							80% row cropland at 30% residue cover	60%	80%	100%	% row cropland at 30% residue cover	•	•				
			Dissolved Oxygen	<5 mg/L during low flow	≥5 mg/L	**Reduce phosphorus**	*See TP strategies*	--	--	--	--		•				2030

HUC-10 Subwater-shed	Waterbody and Location		Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy scenario showing estimated scale of adoption to meet 10 yr. milestone and final water quality targets. Scenarios and adoption levels may change with additional local planning, research showing new BMPs, changing financial support and policies, and experience implementing the plan.					Governmental Units with Primary Responsibility					Estimated Year to Achieve Water Quality Target
	Waterbody (ID)	Location and Upstream Influence Counties		Current Conditions (load or concentration)	Goals / Targets and Estimated % Reduction		Strategy Type	Estimated Adoption Rate: Current strategy adoption level, if known	Interim 10-year Milestone	Suggested Goal	Units	Watershed District	SWCD	MPCA	County	DNR	
						Increase river flow during low flow years	*See Altered hydrology; low base flow strategies*	--	--	--	--	•	•				
						Restore stream channel	Restore over-widened reaches	2	10	30	stream miles	•				•	
			Altered hydrology; peak flow and/or low base flow (Fish/Macroinvertebrate IBI)	Fish IBI = 30, 34, 42, 44, 49, 51 Macro IBI = 21, 26, 33, 33, 71	20% reduction in peak flows; Fish IBI ≥ 45 Macro IBI ≥ 38.3	**Increase living cover** [to increase infiltration and evapotranspiration]	Increase living cover in watershed through cover crops, perennials and well-managed pastures	25%	30%	40%	% of watershed area		•				2030
							Conservation cover (easements & buffers of native grass & trees, pollinator habitat)	10%	15%	15%	% of watershed area		•				
						Improve drainage management [to store and control the release of tile drainage water]	Increase tile drainage waters draining into wetlands, saturated buffers and other practices	5%	10%	15%	% of drained cropland acres going into treatment systems	•	•				
							Restored / treatment wetlands	0	100	200	acres of wetland		•				
							Controlled drainage on suitable tile-drained row cropland	10%	50%	75%	% of watershed area	•	•				
						Reduce flashiness of waterways	Construct floodwater impoundments	0	10000[1]	25000[1]	Acre-feet of storage impoundments		•				
						Reduce rural runoff by increasing infiltration, residue management	80% row cropland at 30% residue cover	60%	80%	100%	% row cropland at 30% residue cover		•				
							Tilled sloping lands with WASCOBs, terraces, contour farming and/or other BMPs (to store and infiltrate water)	30%	60%	100%	% of qualifying acres		•				
						Improve urban stormwater management [to decrease urban stormwater volume]	Reduce post-construction stormwater volume for redevelopment projects	60%	80%	100%	Percent flow reduction for unpermitted areas			•			
						Improve irrigation water management [to decrease ground water withdrawals]	Irrigation water management plans to minimize water withdrawals on irrigated crops	10%	20%	50%	% of qualifying acres	•	•				

HUC-10 Subwater-shed	Waterbody and Location: Waterbody (ID)	Waterbody and Location: Location and Upstream Influence Counties	Parameter (incl. non-pollutant stressors)	Water Quality: Current Conditions (load or concentration)	Water Quality: Goals / Targets and Estimated % Reduction	Strategies (see key below)	Strategy Type	Estimated Adoption Rate: Current strategy adoption level, if known	Estimated Adoption Rate: Interim 10-year Milestone	Estimated Adoption Rate: Suggested Goal	Estimated Adoption Rate: Units	Watershed District	SWCD	MPCA	County	DNR	Estimated Year to Achieve Water Quality Target
							Strategy scenario showing estimated scale of adoption to meet 10 yr. milestone and final water quality targets. Scenarios and adoption levels may change with additional local planning, research showing new BMPs, changing financial support and policies, and experience implementing the plan.					Governmental Units with Primary Responsibility					
			Poor Habitat (Fish/Macroinvertebrate IBI)	Fish IBI = 30, 34, 42, 44, 49, 51 Macro IBI = 21, 26, 33, 33, 71	Fish IBI ≥ 45 Macro IBI ≥ 38.3	**Improve riparian vegetation**	50-ft buffers on all streams and all buffer requirements met	70%	100%	100%	% of stream miles	•	•				2025
							Increase conservation cover: in/near waterbodies, to create corridors	10%	15%	15%	% of watershed area	•	•				
							Improve/increase natural habitat in riparian, control invasive species	2%	5%	10%	% of watershed area addressed	•	•				
							Restore riparian wetlands	20	100	500	acres of wetland		•				
							Accurately size bridges and culverts to improve stream stability	80%	90%	100%	% complete	•	•				
							Streambank protection / stabilization	0	5000	10000	Feet of shoreline		•				
						Restore/enhance channel	Dam removals and dam improvements to mimic natural conditions	0	2	3	# dam improvements					•	
							Install two-stage ditches on drainage ditches	< 10,000	10,000	25,000	Feet of ditch	•	•				
							Apply habitat improvement work [per Trout Unlimited habitat improvement methods, NRCS practices and DNR stream restoration principles]	0	5000	10000	Feet of stream					•	
			Connectivity (Fish IBI)	Fish IBI = 30, 34, 42, 44, 49, 51	Fish IBI ≥ 45	**Remove fish passage barriers**	Dam removal or fish passage project	0	2	3	# dam improvements					•	2025
							Replace hanging/undersized culverts	80%	90%	100%	% complete					•	
	Tamarac River (09020311-505)	Marshall	**TSS**	Very High =1270 mg/L High = 271 mg/L Mid = 299 mg/L Low = 132 mg/L Very Low = 75 mg/L	65 mg/L met >90% of the time in Apr-Sep; estimated	**Improve upland/field surface runoff controls** [to reduce or intercept farm field erosion]	Increase living cover through cover crops, perennials and well-managed pastures	15%	20%	30%	% of watershed area		•				2025
							50-ft buffers on all streams and all buffer requirements met	70%	100%	100%	% of streams	•	•				
							HEL lands and >3% sloped cropland at ≥30% residue cover or equivalent	80%	90%	100%	% of priority lands with residue protection		•				
							Open tile inlets with either riser pipes, rock inlets or other protection	40%	80%	100%	% of open tile inlets	•	•				
							Tilled sloping row-cropped lands protected with grassed waterways, WASCOBs, contour farming and/or other BMPs	50%	70%	100%	% of applicable lands with listed BMPs		•				
						Protect/stabilize banks/bluffs	*See all examples for "Altered hydrology; peak flow (Fish/Macroinvertebrate IBI)"*	--	--	--	--						
							Highly-eroding banks identified and stabilized	20%	40%	100%	% of banks identified		•				

HUC-10 Subwatershed	Waterbody and Location		Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy scenario showing estimated scale of adoption to meet 10 yr. milestone and final water quality targets. Scenarios and adoption levels may change with additional local planning, research showing new BMPs, changing financial support and policies, and experience implementing the plan.					Governmental Units with Primary Responsibility					Estimated Year to Achieve Water Quality Target
								Estimated Adoption Rate									
	Waterbody (ID)	Location and Upstream Influence Counties		Current Conditions (load or concentration)	Goals / Targets and Estimated % Reduction		Strategy Type	Current strategy adoption level, if known	Interim 10-year Milestone	Suggested Goal	Units	Watershed District	SWCD	MPCA	County	DNR	
											and stabilized						
							50-ft buffers on all streams and all buffer requirements met	70%	100%	100%	% of streams	•	•				
							Livestock exclusion on pastures near streams	75%	100%	100%	% of stream miles		•				
							Construct floodwater impoundments	0	10000[1]	25000[1]	Acre-feet of storage impoundments		•				
							Accurately size bridges and culverts to improve stream stability	80%	90%	100%	% complete	•	•				
							Improve/increase natural habitat in riparian, control invasive species	2%	5%	10%	% of watershed area addressed	•	•				
							Tree and grass planting for stabilization on streams	0	2	5	stream miles		•				
						Stream channel restoration	Install two-stage ditches on drainage ditches	< 10,000	10,000	25,000	Feet of ditch	•					
							Re-meander channelized stream reaches	2	10	30	stream miles		•			•	
							Identify alternative buffer strip options for landowners, including the development of a local buffer strip cost share program, the application of the state standard and the enforcement of 50-foot buffers along DNR Public Waters.	40%	100%	100%	% of impacted landowners		•				
							Large-scale restoration – channel dimensions match current hydrology & sediment loads, connect the floodplain, stable pattern, (natural channel design principals)	0	25	30	stream miles					•	
						Stabilize ravines	*See all examples for TSS - reducing upland/field surface runoff*	--	--	--	--						
							Stabilization within ravines--vegetative practices and/or engineered structures	60%	70%	100%	% High-priority ravines addressed		•				
						Improve urban stormwater management [to reduce sediment and flow]	Combination of practices to achieve sediment reduction from baseline levels	60%	70%	100%	% sediment reduction for unpermitted areas			•			
						Improve wind erosion controls	Install field edge buffers, borders, windbreaks and/or filter strips	30%	60%	100%	% of agricultural areas	•	•				
							Utilize stripcropping	5%	25%	50%	% of agricultural areas	•	•				

HUC-10 Subwater-shed	Waterbody and Location		Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy scenario showing estimated scale of adoption to meet 10 yr. milestone and final water quality targets. Scenarios and adoption levels may change with additional local planning, research showing new BMPs, changing financial support and policies, and experience implementing the plan.					Governmental Units with Primary Responsibility					Estimated Year to Achieve Water Quality Target
	Waterbody (ID)	Location and Upstream Influence Counties		Current Conditions (load or concentration)	Goals / Targets and Estimated % Reduction		Strategy Type	Estimated Adoption Rate: Current strategy adoption level, if known	Interim 10-year Milestone	Suggested Goal	Units	Watershed District	SWCD	MPCA	County	DNR	
							80% row cropland at 30% residue cover	60%	80%	100%	% row cropland at 30% residue cover	•	•				
			Pesticides (Chlorpyrifos)	> 0.041 ug/L	< 0.041 ug/L	Increase fertilizer and manure efficiency	Increase row crop acres utilizing U of MN recommendations for the economic optimal nitrogen rate after crediting all legumes and manure, varying with level of adoption of vegetative cover BMP.	20%	50%	100%	% of row crop acres		•				2030
						Store and treat tile drainage waters	Treat tiled cropland using constructed/restored wetlands or other practices	2%	5%	10%	% of agricultural areas	•					
							Controlled drainage on tile-drained row cropland	3%	15%	30%	% of row crop acres		•				
						Increase vegetative cover/root duration [to reduce leaching]	Cover crops on: a) earlier harvest crops (EHC); and b) corn and soybean lands (C/S)	<1% EHC <1% C&S	5% of EHC 5% of C/S	10% of EHC 10% of C/S	% of crop land in each category (EHC and C/S)		•				
							Convert marginal lands to perennial cover (marginal lands as determined by using Crop Productivity Index)	80%	80%	100%	% of qualifying acres		•				
Upper Tamarac River (0902031101)	Judicial Ditch 19 (09020311-516)	Roseau, Kittson, Marshall	*E. coli*	Very High = 12 org/100mL High = 54 org/100mL Mid = 31 org/100mL Low = 23 org/100mL Very Low = N/A	Geometric mean ≤ 126 org/100mL, April - October	Improve livestock and manure management	*See strategies to reduce field TSS (applied to manured fields)*	--	--	--	--						
							Livestock exclusion on pastured stream miles	75%	100%	100%	% of priority sites		•				2022
							Animal mortality storage areas consistent with Bd. Animal Health rules and feedlot permits.	0	0	0	# noncompliant mortality storage sites		•				
							All Minn. R. ch. 7020 manure spreading setbacks are met	50%	75%	100%	% of priority sites		•				
							Total containment of manure storage	50%	75%	100%	% of animal units with manure going to storage		•				
							Inject or immediately incorporate manure where currently surface applied	95%	100%	100%	% of priority sites		•				
						Address failing septic systems	Maintain septic (SSTS) systems	90%	100%	100%	% compliant septic systems				•		
All		All	All			Implement volume control / limited-impact development	Apply to all projects when developing undeveloped land to provide no net increase in volume and pollutants	60%	80%	100%	Percent flow reduction for			•			

HUC-10 Subwater-shed	Waterbody and Location		Parameter (incl. non-pollutant stressors)	Water Quality		Strategies (see key below)	Strategy scenario showing estimated scale of adoption to meet 10 yr. milestone and final water quality targets. Scenarios and adoption levels may change with additional local planning, research showing new BMPs, changing financial support and policies, and experience implementing the plan.					Governmental Units with Primary Responsibility					Estimated Year to Achieve Water Quality Target
								Estimated Adoption Rate									
	Waterbody (ID)	Location and Upstream Influence Counties		Current Conditions (load or concentration)	Goals / Targets and Estimated % Reduction		Strategy Type	Current strategy adoption level, if known	Interim 10-year Milestone	Suggested Goal	Units	Watershed District	SWCD	MPCA	County	DNR	
											unpermitted areas						
	Note: Many entries from the above restoration rows may be translated for use in protection rows. Additional protection-related guidance is in development.																

[1] Watershed-wide goals, exact amount in subwatershed may vary, depending on suitable locations within the drainage area

- Restoration
- Protection
- Strategies to address downstream impairments
- Point Sources

Table 13: Key for Strategies Column.

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
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
		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
		Forest Roads - Cross-Drainage
		Maintaining and aligning active Forest Roads
		Closure of Inactive Roads & Post-Harvest

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
		Location and 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 waters	Nitrogen rates at Maximum Return to Nitrogen (U of MN recommendations)
		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)
		Perennials grown on marginal lands and riparian lands
		Cover crops
		Rotations that include perennials
	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 Minn. R. ch. 7020
		Store manure 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 Minn. R. ch. 7020 setback requirements
		Sewering around lakes

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
	Address failing septic systems: Fixing septic systems so that on-site sewage is not released to surface waters. Includes straight pipes.	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 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
		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
		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 surface waters. 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	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]

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
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 and buffers of native grass and 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
	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 (16.5 feet) ditch buffers
		Lake shoreland buffers
		Increase conservation cover: in/near waterbodies, to create corridors
		Improve/increase natural habitat in riparian, control invasive species
		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
		Riparian vegetative buffers

Parameter (incl. non-pollutant stressors)	Strategy Key	
	Description	Example BMPs/actions
	Improve riparian vegetation: Actions primarily to increase shading, but also some infiltration of surface runoff.	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

Stream monitoring within the LRRW will continue primarily through the efforts of the JRWD, TRWD, and the MSTRWD.

The JRWD Overall Plan (JRWD 2004) outlines the monitoring activities within the JRWD. The JRWD coordinates and contributes resources to carry out a water quality monitoring program with the Kittson SWCD as the lead agency. Three locations on the Joe River have been monitored for various parameters, including DO, pH, alkalinity, temperature, NH_3, Kjeldahl and total nitrogen, ortho phosphorous, alkalinity, and fecal coliform bacteria. In addition, some water samples have been tested for the presence of pesticides. Stream flow monitoring and data collection has been undertaken by the U.S. Geological Survey at selected points on the Red River and during periods of flooding at various other locations within the JRWD.

As outlined in the TRWD 2014 Annual Report updates to the 2004 Overall Plan (TRWD 2014), water quality, stream flow, and velocities will continue to be monitored and recorded for selected sites on the rivers, coulees, and ditches within the TRWD. Stream flows and velocities will be measured by TRWD staff at each site during runoff events and data will be reported to interested agencies and persons, including the National Weather Service, DNR, and various other state and local agencies. The long-range goal is to record data not only for the high flow events but for summer low flows as well (TRWD 2014).

As outlined in the Section 5.1.5 of the MSTRWD WMP (MSTRWD 2011), the MSTRWD has established regional assessment locations (RALs) in streams throughout the LRRW, and is currently employing a water quality monitoring program that consists of financial support to the River Watch Program and International Water Institute. Samples are collected and analyzed for flow, stage-elevation, biology (IBI), turbidity, *E. coli*, and water chemistry.

In addition to the stream monitoring sponsored by the JRWD, TRWD, and the MSTRWD, the MPCA also has on-going monitoring in the LRRW. The MPCA's major watershed outlet monitoring will continue to provide a long-term on-going record of water quality at the LRRW outlet. The MPCA will return to the LRRW under the IWM program in 2023.

5. References and Further Information

Houston Engineering, Inc. (HEI). 2013. Lower Red River of the North Watershed: Watershed Restoration & Protection Plan: Watershed Conditions Report. Final Report January 11, 2013.

Houston Engineering, Inc. (HEI). 2014a. Categorization of best management practices and conservation practices for estimating pollutant removal effectiveness part 1. Technical memorandum to the Minnesota Board of Water and Soil Resources.

Houston Engineering, Inc. (HEI). 2014b. Categorization of best management practices and conservation practices for estimating pollutant removal effectiveness part 2. Technical memorandum to the Minnesota Board of Water and Soil Resources.

Houston Engineering, Inc. (HEI). 2014c. Water quality decision support application enhance geographic information system water quality data products. Technical memorandum to the Minnesota Board of Water and Soil Resources.

Houston Engineering, Inc. (HEI). 2016a. Lower Red River Watershed Load Duration Curves. For MPCA. February 2016.

Houston Engineering, Inc. (HEI). 2016b. Lower Red WEPS Modeling, Technical Memorandum. May 2016.

Houston Engineering, Inc. (HEI). 2016c. PTMApp to aid in the development of WRAPS strategies, Technical Memorandum. May 2016.

Houston Engineering, Inc. (HEI). 2018. Lower Red River of the North Watershed TMDL Report. August 2018.

Joe River Watershed District (JRWD). 2004. Overall Plan of the Joe River Watershed District.

Middle-Snake-Tamarac Rivers Watershed District (MSTRWD). 2011. Final Ten Year Watershed Management Plan. May 2011. Available at: http://mstrwd.org/wp-content/uploads/MSTRWD-FINAL-PLAN-MAY_2011.pdf

Minnesota Pollution Control Agency (MPCA). 2013. Lower Red River of the North Watershed Monitoring and Assessment Report. January 2013.

Minnesota Pollution Control Agency (MPCA). 2014a. Water Quality Trends for Minnesota Rivers and Streams at Milestone Sites. June 2014.

Minnesota Pollution Control Agency (MPCA). 2014b. The Minnesota Nutrient Reduction Strategy. wq-s1-80. St. Paul, MN. September 2014.

Minnesota Pollution Control Agency (MPCA). 2015. Lower Red River of the North Watershed Stressor Identification Report. December 2015.

Minnesota Pollution Control Agency (MPCA). 2016. Guidance manual for assessing the quality of Minnesota surface waters for determination of impairment: 305 (b) report and 303 (d) list.

National Land Cover Dataset (NLCD). 2011. United States Geological Survey. https://www.mrlc.gov/nlcd11_data.php

RESPEC. 2014. Hydrological and Water Quality Calibration and Validation of Lower Red Watershed HSPF Model. Memorandum to Minnesota Pollution Control Agency, Detroit Lakes, MN.

Two Rivers Watershed District (TRWD). 2014. Two Rivers Watershed District 2014 Annual Report. Available at: http://www.tworiverswd.com/pdf/2014%20TRWD%20Annual%20Report%20.pdf

Lower Red River of the North Watershed Reports

This report along with several other referenced works are available at the Lower Red River of the North Watershed webpage: https://www.pca.state.mn.us/water/watersheds/red-river-north-tamarac-river

6. Appendices

Appendix A

Lower Red River of the North Watershed Load Duration Curves Memo

MEMO

(External Correspondence)

To:	Dan Money, TRWD Tara Mercil, MPCA	**From:**	Timothy Erickson, PE Mark R. Deutschman, Ph.D., P.E.
Date:	February 2, 2016	**Subject:**	Lower Red River Watershed Load Duration Curves
File:	6279-002		

INTRODUCTION

This memorandum summarizes the methods used and results for creating load duration curves (LDCs) for impaired stream segments (delineated by assessment unit identification [AUID] numbers) in the Lower Red River Watershed (LRRW)[5]. One segment (09020311-505) exceeds total suspended solids (TSS) standards, and available evidence supports elevated turbidity/high TSS as a stressor for aquatic macroinvertebrate/fishes bioassessments impairments in a second segment (09020311-503). Preparation of the load duration curves (LDCs) includes computing necessary load reductions within each flow regime of the curve, which will be used to develop TMDLs for impaired reaches.

A list of the two AUIDs addressed in this memorandum is included in **Table A1**. Also included is the pollutant (turbidity) that LDCs will be used to address, a list of water quality monitoring stations located along each AUID and the associated HSPF (Hydrologic Simulation Program-Fortran) model sub-basin, which was used to represent flows for creating the curves (no U.S. Geological Survey [USGS] gauging sites were present for observed flow). In addition, the two AUIDs and monitoring locations are mapped in **Figure A1**.

Table A1. AUIDs associated with LDCs, pollutants, and data used.

AUID Suffix (09020311-XXX)	Reach Name	Pollutant/Stressor	Water Quality Stations	HSPF Flow RCHRES ID
503	Tamarac R.: Florian Park Reservoir to Stephen Dam	Turbidity	S002-992, S002-993, S005-569	RCHRES 360
505	Tamarac R.: Stephen Dam to Red R.	Turbidity	S002-100, S002-990, S002-991, S005-788	RCHRES 490

[5] Also known as the Red River of the North - Tamarac River Watershed

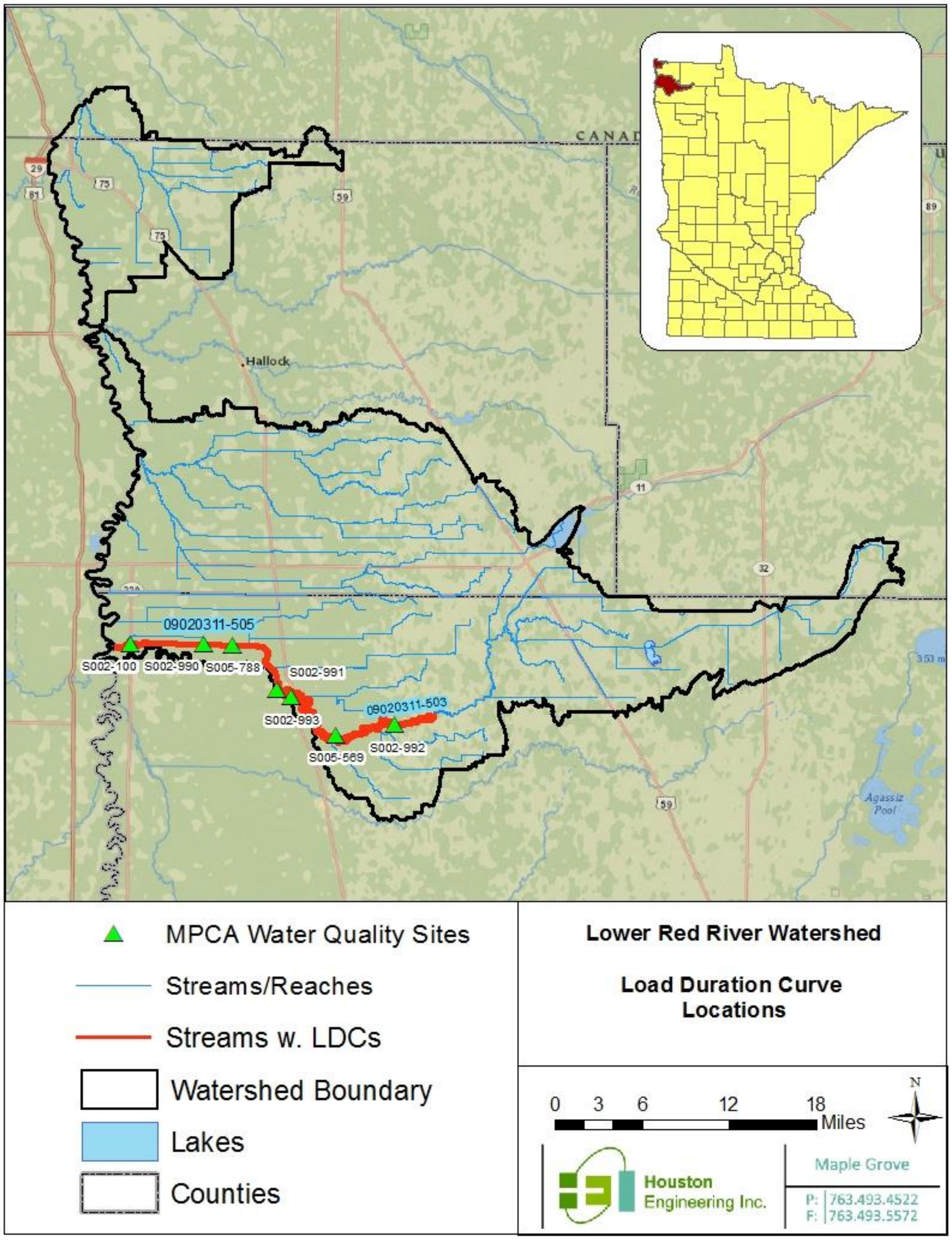


Figure A1. Map of AUIDs and water quality monitoring locations used for LDCs in the Lower Red River Watershed.

METHODOLOGY

LDCs were developed for each of the two AUIDs listed in **Table A1**. Each LDC was developed by combining the (simulated or observed) river/stream flow at the downstream end of the AUID with the measured concentrations available within the segment. Methods detailed in the EPA document *An Approach for Using Load Duration Curves in the Development of TMDLs* were used in creating the curves (EPA 2007). A summary of this methodology, as applied in the LRRW, is provided below. Full details on LDC methods can be found in the EPA guidance (EPA 2007).

Data

Observed daily flow data is limited within the LRRW and no USGS gauging stations were in reaches needing LDCs. Therefore, simulated daily mean flows from the LRRW HSPF model (RESPEC 2014) were used to create the LDCs for both AUIDs. The HSPF model simulates flows from 1995 through 2009. In order to best capture the flow regimes of each AUID, the period 1996 through 2009 was used in development of the LDCs and 1995 was used as a warm-up period for the model; however, simulated flow should not be considered an exact representation of actual flow (RESPEC 2014).

The water quality data used in this work was obtained from the MPCA through their EQuIS (Environmental Quality Information System) database. For the purposes of creating the curves (which will inform TMDL development), water quality data during the simulation period (1996 through 2009) was used. While data exists for turbidity, and TSS beyond 2009, the HSPF model only estimates flows for 1995 through 2009.

Table A2 summarizes the water quality data used in the TSS LDCs for two AUIDs in the LRRW.

Table A2. Water quality data used for each LDC.

AUID Suffix (09020301-XXX)	Water Quality Monitoring Locations	Turbidity/ TSS Data
503	S002-992, S002-993, S005-569	2002-2009
505	S002-100, S002-990, S002-991, S005-788	2000-2009

Total Suspended Solids LDCs

The TSS LDCs were created using the Southern Region TSS standard of 65 mg/L. The TSS LDCs were calculated using the TSS data collected during the assessment period, April through September. In addition to TSS data, the useable dataset was expanded using converted turbidity data. The proposed standard only applies during the months of April through September. Therefore, the proposed TSS standard LDCs were created using turbidity/TSS data and flow data from this period.

When available, TSS was used as the preferred value for calculating solids loading. However, since turbidity data may be prevalent in the historic record, turbidity was used to expand the TSS dataset. This is consistent with MPCA guidance (MPCA 2012). To convert turbidity to TSS, paired TSS and turbidity data were analyzed and a regression was applied to find a relationship (**Figure A2**). The resulting regression equation for converting turbidity values (in NTU/NTRU) in the LRRW to TSS (in mg/L) is:

$$TSS = 1.1438 * Turbidity - 5.6379$$

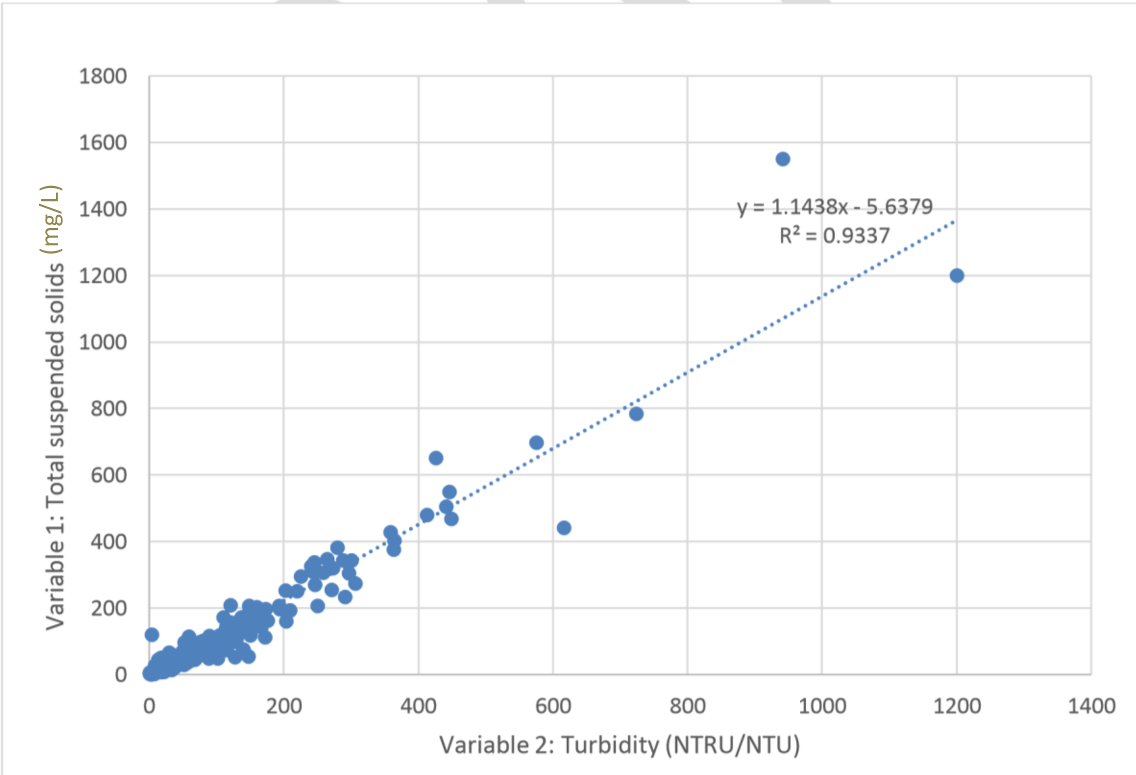


Figure A2: Relationship between Turbidity and Total Suspended Solids in the LRRW.

A 10% margin of safety (MOS) was applied to each of the "allowable" loading curves.

Flow Regimes and LDCs

A system's water quality often varies based on flow regime, with elevated pollutant loadings sometimes occurring more frequently under one regime or another. Loading dynamics during certain flow conditions can be indicative of the type of pollutant source causing an exceedance (e.g., point sources contributing more loading under low flow conditions). The LDC approach identifies these flow regimes and presents the observed and "allowable" loading within each regime, to compute necessary load reductions. To represent different types of flow events and pollutant loading during these events, five flow regimes were identified in the LRRW LDCs based on percent exceedance: Very High Flows (0%-10%), High Flows (10%-40%), Mid Flows (40%-60%), Low Flows (60%-90%), and Very Low Flows (90%-100%). An example TSS LDC (for AUID 09020311-505) is shown in **Figure A3**, identifying the flow regimes.

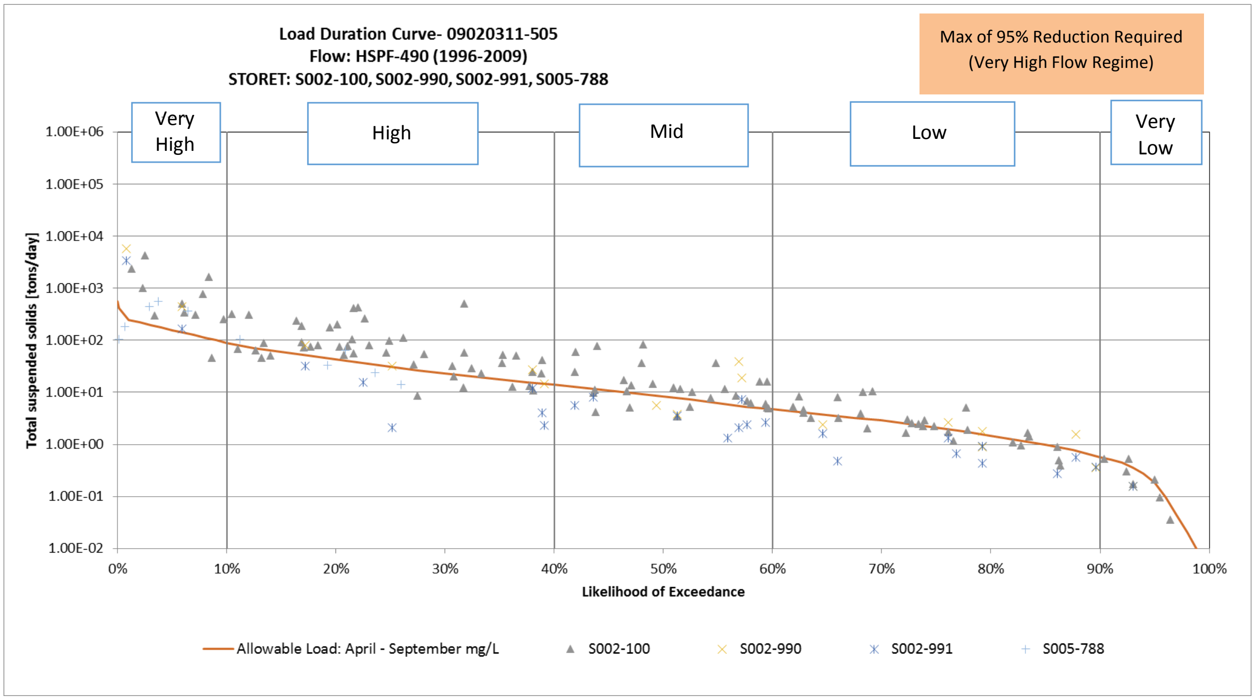


Figure A3. Example TSS LDC (AUID 09020311-505) showing flow regimes.

The example LDC in **Figure A3** was created with flow and water quality data from April through September. The percent likelihood of flow exceedance is shown on the x-axis, while the computed TSS loading is shown on the y-axis. “Allowable” loadings under each flow condition, based on the water quality standards, is shown with an orange line. Observed loads are also shown, indicated by points on the plot. Observed loads are broken out by station, allowing for a detailed examination of where loading exceedances have occurred.

RESULTS

Tamarac River
AUID 09020311-503 TSS

A TSS LDC was generated for AUID 09020311-503 in the Tamarac River and is shown in **Figure A4**. The orange line shows the allowable load for the southern nutrient region TSS standard of 65 mg/L in **Figure A4**. AUID 09020311-503 is listed on the 303(d) list as having aquatic life use impairments due to aquatic macroinvertebrate bioassessments and fishes bioassessments. The LDC was generated for TSS/turbidity as a surrogate for the biological impairments. Available evidence supports TSS as a stressor to both biological communities (MPCA 2015).

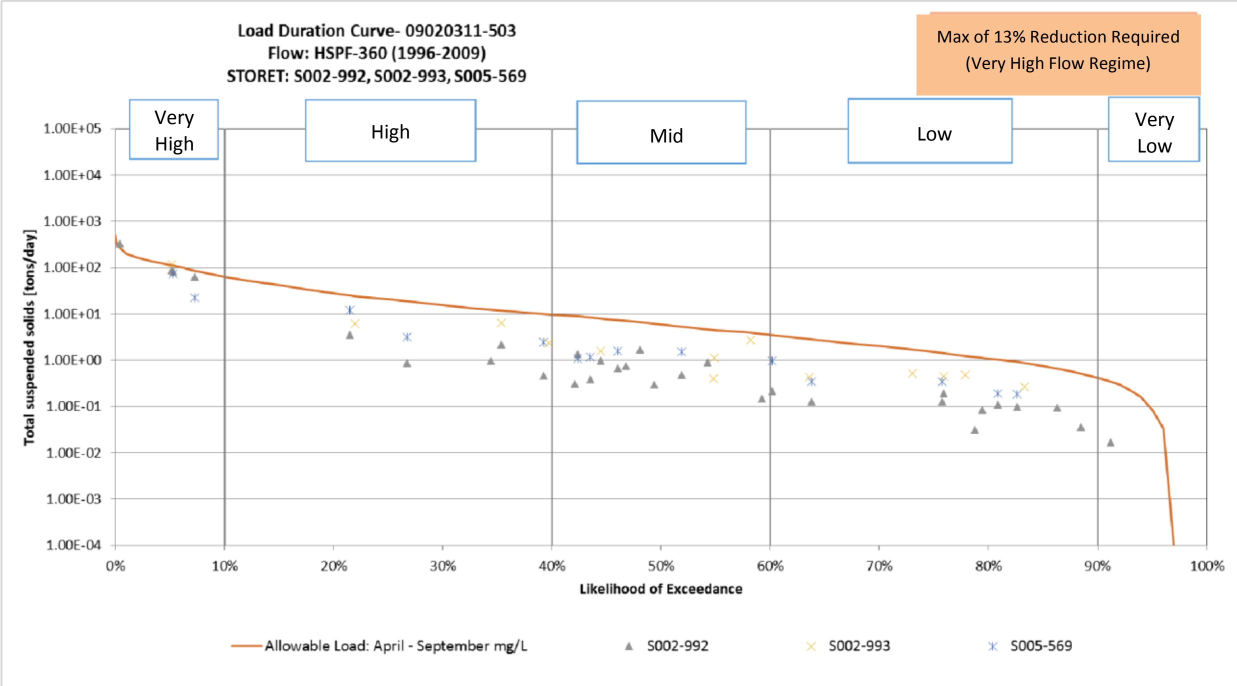


Figure A4. AUID 09020311-503 TSS LDC.

Table A3. AUID 09020311-503 TSS Load Reduction Table.

Flow Regime	Median Flow [cfs]	Observed Concentration [mg/L]	Observed Load [tons/day]	Target Load [tons/day]	Load minus MOS [tons/day]	Load Reduction [tons/day]	Percent Load Reduction
0%-10%	655.7	74.5	131.66	114.9	103.4	16.72	13%
10%-40%	118.6	28.3	9.06	20.8	18.7	-11.74	-130%
40%-60%	33.7	19.0	1.73	5.9	5.3	-4.18	-242%
60%-90%	8.7	20.6	0.48	1.5	1.4	-1.04	-216%
90%-100%	0.48	3.3	0.004	0.1	0.1	-0.08	-1866%

Table A3 shows the observed loads, allowable loads, and load reductions for the five flow regimes. As shown in **Table A3**, a maximum load reduction of 13% during very high flow conditions is required to meet the water quality standard.

Tamarac River
AUID 09020311-505 TSS

A TSS LDC was generated for AUID 09020311-505 in the Tamarac River and is shown in **Figure A5**. The orange line shows the allowable load for the southern nutrient region TSS standard of 65 mg/L in **Figure A5**. As of the proposed 2018 303(d) list, this AUID is not yet listed as having an aquatic life use impairment due to TSS, because an assessment of aquatic life use was deferred pending implementation of TALU (MPCA 2013). The LDC was still developed, because data clearly indicates exceedingly high TSS.

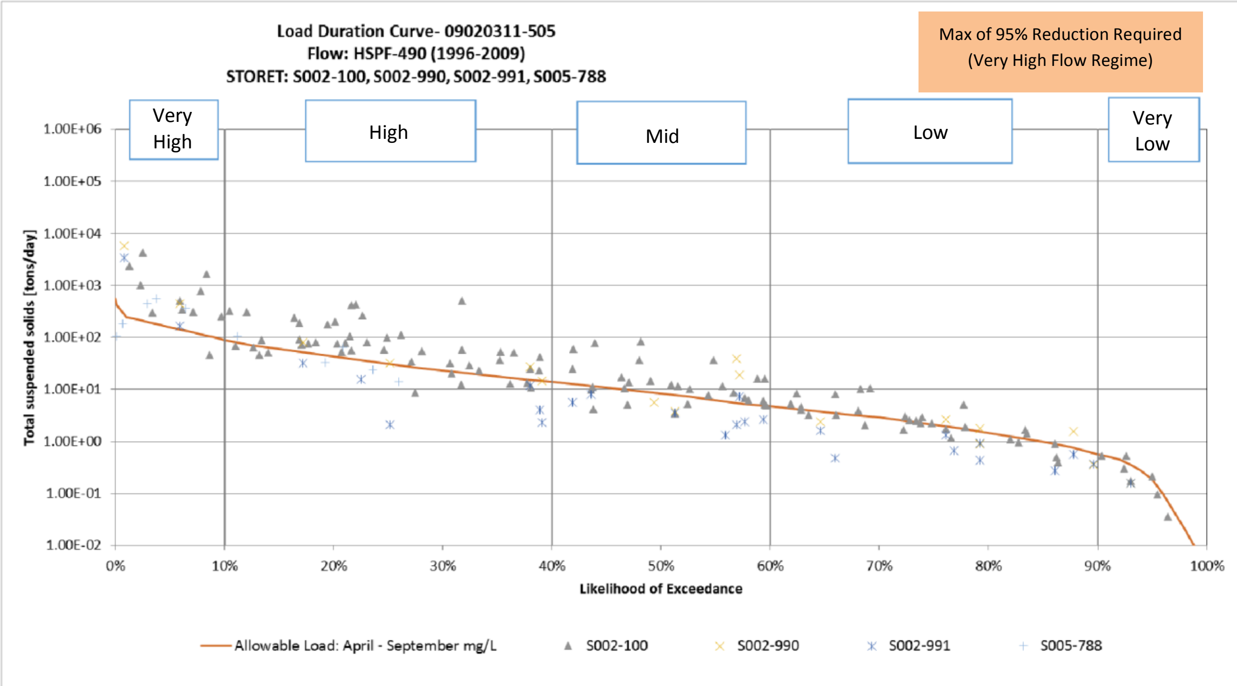


Figure A5. AUID 09020311-505 TSS LDC.

Table A4. AUID 09020311-505 TSS Load Reduction Table.

Flow Regime	Median Flow [cfs]	Observed Concentration [mg/L]	Observed Load [tons/day]	Target Load [tons/day]	Load minus MOS [tons/day]	Load Reduction [tons/day]	Percent Load Reduction
0%-10%	895.6	1270.0	3067.2	157.0	141.3	2910.2	95%
10%-40%	177.9	271.1	130.1	31.2	28.1	98.9	76%
40%-60%	47.3	299.2	38.1	8.3	7.5	29.9	78%
60%-90%	11.8	131.7	4.18	2.1	1.9	2.12	51%
90%-100%	1.06	74.8	0.21	0.2	0.2	0.03	13%

Table A4 shows the observed loads, allowable loads, and load reductions for the five flow regimes. As shown in **Table A4**, a maximum reduction of 95% is needed during the very high flow condition to meet the water quality standard.

Critical Condition

A summary of the TSS standard load reduction results can be found in **Table A5**. Results are summarized by indicating the maximum required percent load reduction for each curve and the flow regime and water quality criteria under which this maximum reduction occurred (i.e., the critical flow regime and criteria). The critical flow regime for the two TSS LDCs is very high flow conditions.

Table A5. Maximum required *E coli* and sediment load reductions for the LRRW.

AUID Suffix (09020311-XXX)	TSS Standard	
	Max. % Load Reduction	Critical Flow Regime
516	---	---
503	13%	Very High
505	95%	Very High

CONCLUSION

TSS standard LDCs were developed for two AUIDs in the LRRW based on impairment, exceedance of the standard, and/or stressor status. The curves were developed following the methods in the EPA guidance document, *An Approach for Using Load Duration Curves in the Development of TMDLs* (EPA 2007). For TSS, a 13% load reduction during very high flow conditions is necessary for AUID 09020311-503, and a 95% load reduction during the very high flow conditions for AUID 09020311-505.

REFERENCES

Minnesota Pollution Control Agency (MPCA). 2012. Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List. Minnesota Pollution Control Agency. St. Paul, MN.

Minnesota Pollution Control Agency (MPCA). 2013. Lower Red River of the North Watershed Monitoring and Assessment Report. January 2013.

Minnesota Pollution Control Agency (MPCA). 2015. Lower Red River of the North Watershed Stressor Identification Report. December, 2015.

RESPEC. 2014. Hydrological and Water Quality Calibration and Validation of Lower Red Watershed HSPF Model. Memorandum to Minnesota Pollution Control Agency, Detroit Lakes, MN.

United States Environmental Protection Agency (EPA). 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. August 2007.

Appendix B

Priority Ranking of Subwatersheds in the Lower Red River Watershed Using HSPF Results

Appendix B: Priority Ranking of Subwatersheds in the Lower Red River Watershed Using HSPF Results.

Using results from the Low Red River Watershed (LRRW) Hydrologic Simulation Program FORTRAN (HSPF) model (RESPEC 2014), areas within the watershed were prioritized based upon the magnitude of nonpoint sources, to identify subwatersheds where restoration and protection strategies would be most beneficial. Subwatersheds were prioritized by ranking the area-averaged yields (pounds/acre/year) from the HSPF model for unit runoff (RO), TP, total nitrogen (TN), and total sediment. Prioritization is based solely on the estimated mass leaving the landscape. The consideration of other factors could change the prioritization outcome.

The LRRW HSPF Model

The LRRW HSPF model was constructed (RESPEC 2014) to inform the WRAPS and watershed-wide TMDL Projects currently being undertaken by the MPCA and Houston Engineering Inc (HEI). The LRRW HSPF model simulates hydrology and water quality for the Lower Red River Watershed 8-digit Hydrologic Code (HUC) 09020311 (see **Figure B1**).

In HSPF, a watershed is divided into “model segments”, usually called hydrozones, based on the locations of the climate stations. Each model segment uses a unique set of climate data. Each model segment is further divided into subwatersheds with each subwatershed containing one hydrologic reach (lake, reservoir, or river). Each modeling segment is composed of multiple land segments called PERLNDs (pervious areas) and IMPLNDs (impervious areas). These PERLNDs and IMPLNDs are typically based on land uses and soil types and a subwatershed can be composed of multiple PERLND/IMPLND types. Runoff and water quality loadings are simulated for each PERLND/IMPLND in a modeling segment, i.e. the same flows and loadings are used across all subwatersheds in a modeling segment for each individual PERLND/IMPLND type. The amount of runoff and loading differ between subwatersheds based on differing acreage of each PERLND/IMPLND type.

The LRRW HSPF model is composed of 16 modeling segments, or hydrozones (**Figure B1**) and further divided into 131 subwatersheds (**Figure B1**). Each modeling segment, and therefore subwatershed, is divided by up to 10 landuse/soil classes (PERLNDs) and one impervious land use class (IMPLND), for a total of 176 possible land segments (PERLNDs & IMPLNDS) in the HSPF model (see **Figure B2**). The PERLND classes include Urban, Forest, Cropland-high tillage with low runoff potential (soil hydrologic class A or B), Cropland-low tillage with low runoff potential, Cropland-high tillage with high runoff potential (soil hydrologic class C or D), Cropland-low tillage with high runoff potential, grasslands, pasture, wetlands, and feedlots.

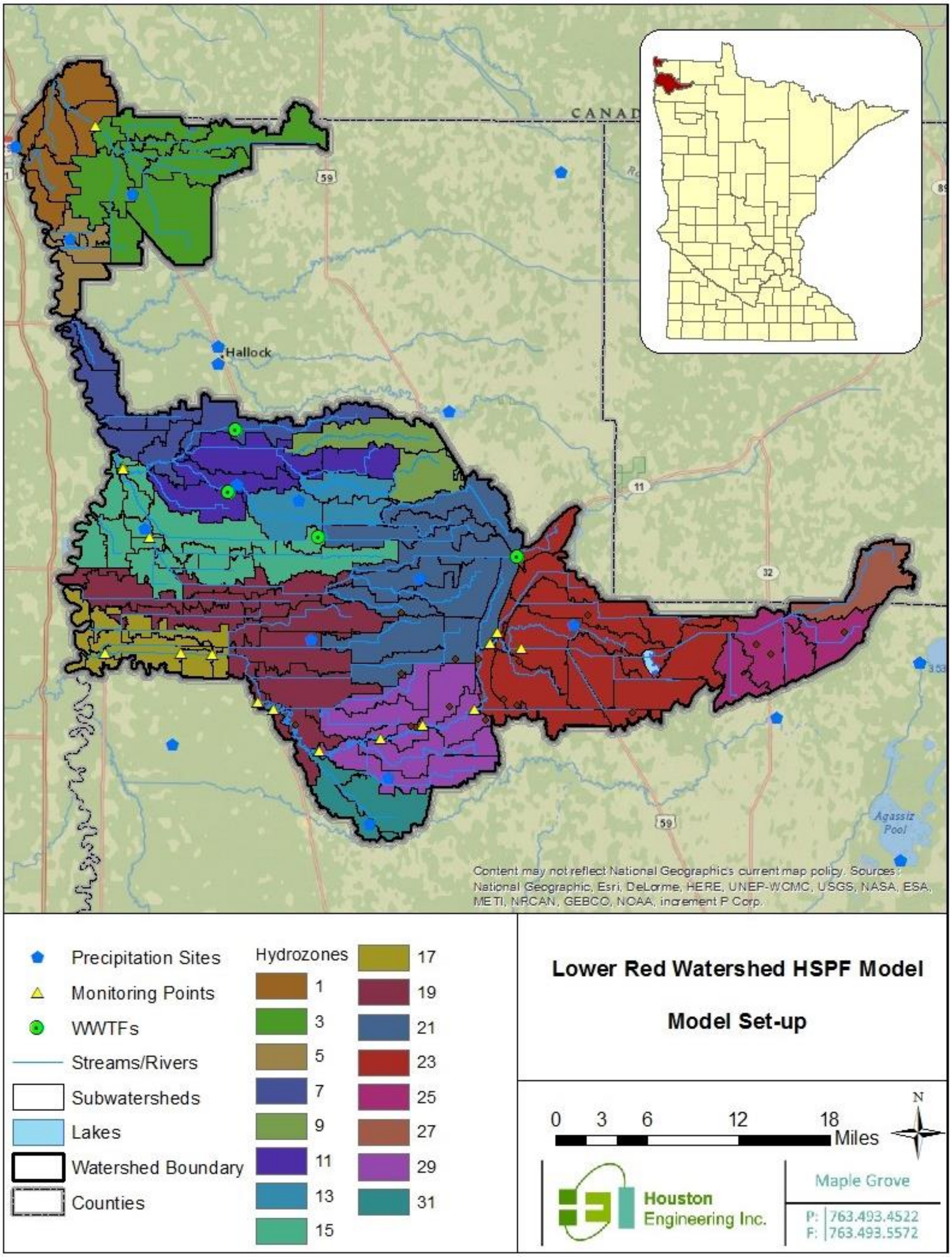


Figure B1: Set-up for the Lower Red River Watershed HSPF model.

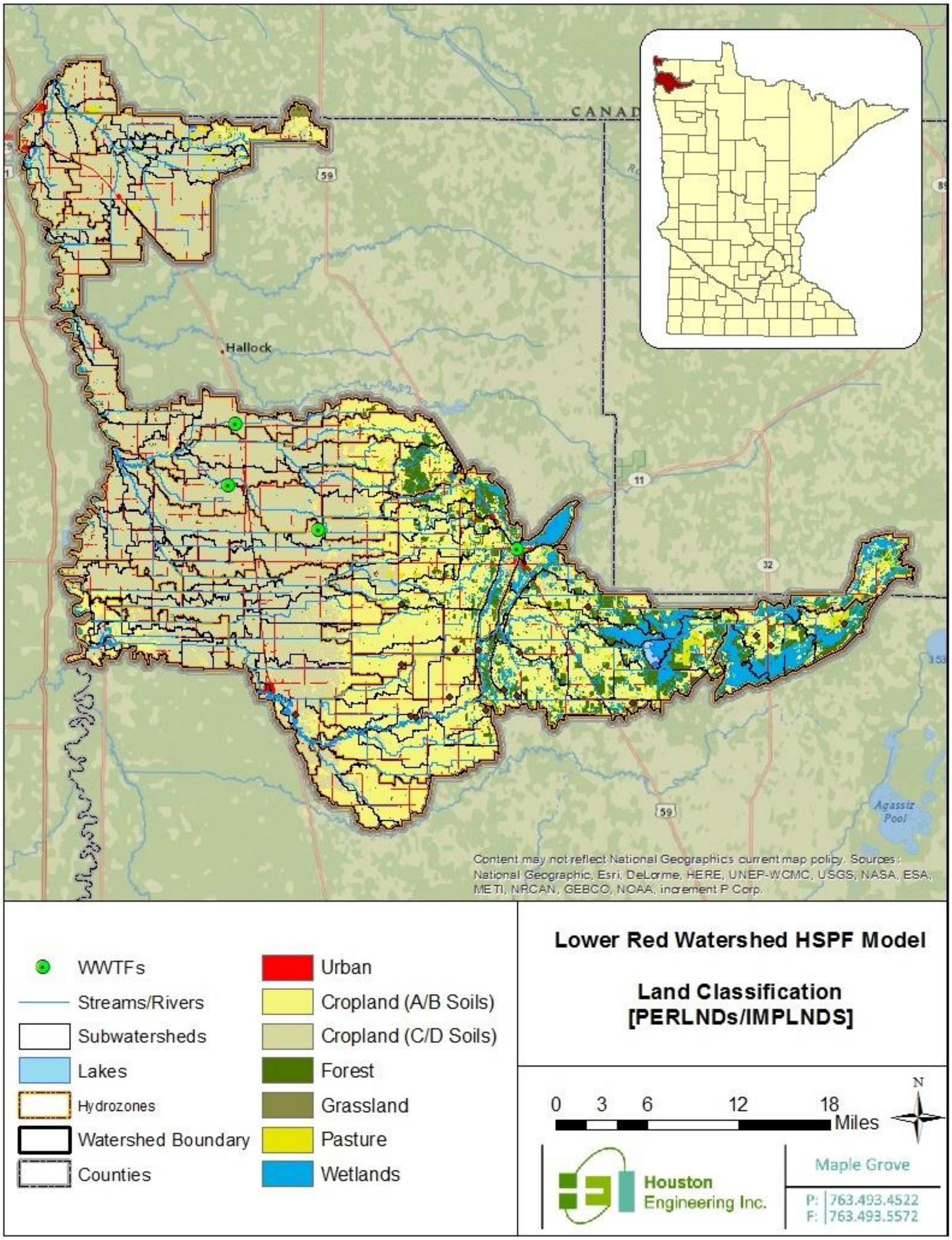


Figure B2: Land Classifications (PERLNDs) in the Lower Red River Watershed HSPF model.

Using the HSPF Model Output for Prioritization

Subwatershed priority rankings were developed for several stressors including altered hydrology (expressed as RO), excess nutrients (TP, TN) and turbidity and habitat alteration/geomorphology (total sediment). **Table B1** shows the required outputs, by constituent and land class (PERLND, IMPLND, or RCHRES), in the HSPF model. The following is a brief description of the components used to develop the maps and shown in **Table B1**.

In HSPF, RO from a land segment has three components: surface runoff, interflow, and active groundwater flow. For PERLNDs, RO is taken as the sum of the three flow components and is outputted. RO from IMPLNDs only has a surface runoff component. In-channel (RCHRES) streamflow was not used in this analysis.

Overland TP loading is the sum of inorganic phosphorus loading and organic phosphorus loading. Inorganic phosphorus in simulated directly using the PQUAL group. Inorganic phosphorus is taken as a fraction of the organic material simulated as biological oxygen demand (BOD). For pervious land segments (PERLNDs), differing factions of organic phosphorus is used for surface runoff, interflow, and active groundwater flow (see **Table B1**). In channel TP loading has various forms but can be extracted from HSPF as TP using the PLANK group. In channel TP flux is taken as the difference between TP inflow and TP outflow for the hydrologic reach.

Like phosphorus, overland TN has multiple forms and is taken as the summation of NH_3, nitrate-nitrite (NO2NO3), and organic nitrogen loadings. NH3 and NO2NO3 are simulated directly using the PQUAL group. Organic nitrogen is taken as a fraction of the organic material simulated as BOD with varying fractions for different flow types (surface runoff, interflow, and active groundwater) (see **Table B1**). In channel TN loading has various forms but can be extracted from HSPF as TN using the PLANK group. In channel TN flux is taken as the difference between TN inflow and TN outflow for the hydrologic reach.

Overland sediment can be extracted directly from the HSPF model as total sediment from overland sources using the SEDMNT group for PERLNDs and SOLIDS group for IMPLNDs. In channel sediment loading and sediment flux can be extracted directly using the SEDTRN group. In channel sediment flux can be taken as the change in bed storage.

Table B1: HSPF Model Outputs for RO, TP, TN, and Total Sediment Used to Prioritize Subwatersheds for Implementation.

WQ Parameter	Description	Volume	Group	Variable	x1	x2	Factor
Unit Runoff	Total runoff from pervious areas	PERLND	PWATER	PERO	1	1	
	Surface water runoff for impervious areas	IMPLND	IWATER	SURO	1	1	
Total Phosphorus	Total flux of inorganic P (PO4)	PERLND	PQUAL	POQUAL	3	1	
	Portion of BOD composed of organic P in Surface runoff	PERLND	PQUAL	SOQUAL	4	1	0.0005
	Portion of BOD composed of organic P in active groundwater	PERLND	PQUAL	AOQUAL	4	1	0.0004

WQ Parameter	Description	Volume	Group	Variable	x1	x2	Factor
	Portion of BOD composed of organic P in interflow	PERLND	PQUAL	IOQUAL	4	1	0.0005
	Total flux of inorganic P (PO4)	IMPLND	IQUAL	SOQUAL	3	1	
	Portion of BOD composed of organic P in Surface runoff	IMPLND	IQUAL	SOQUAL	4	1	0.0005
	Total inflow of TP	RCHRES	PLANK	TPKIF	5	1	
	Total outflow of TP	RCHRES	PLANK	TPKCF1	5	1	
Total Nitrogen	Total flux of Ammonia (NH_3)	PERLND	PQUAL	POQUAL	1	1	
	Total flux of Nitrate-Nitrite (NO2NO3)	PERLND	PQUAL	POQUAL	2	1	
	Portion of BOD composed of organic N in Surface runoff	PERLND	PQUAL	SOQUAL	4	1	0.0407
	Portion of BOD composed of organic N in active groundwater	PERLND	PQUAL	AOQUAL	4	1	0.0488
	Portion of BOD composed of organic N in interflow	PERLND	PQUAL	IOQUAL	4	1	0.0407
	Total flux of Ammonia (NH_3)	IMPLND	IQUAL	SOQUAL	1		
	Total flux of Nitrate-Nitrite (NO2NO3)	IMPLND	IQUAL	SOQUAL	2		
	Portion of BOD composed of organic N in Surface runoff	IMPLND	IQUAL	SOQUAL	4	1	0.0407
	Total inflow of TN	RCHRES	PLANK	TPKIF	4	1	
	Total outflow of TN	RCHRES	PLANK	TPKCF1	4	1	
Total Sediment	Total Sediment	PERLND	SEDMNT	SOSED	1	1	
	Total Solids	IMPLND	SOLIDS	SOSLD	1	1	
	Inflow of Sediment	RCHRES	SEDTRN	ISED	4	1	
	Outflow Sediment	RCHRES	SEDTRN	ROSED	4	1	
	Sediment Flux/Change in Storage	RCHRES	SEDTRN	DEPSCR	4	1	

Developing Subwatershed Priority Maps Using Yields

The prioritization of subwatersheds based on nonpoint source loads, occurred at two scales; i.e., the entire watershed and major tributary (**Figure B3**). Prioritization at multiple scales is necessary, because the results change depending upon the location of the impaired resource (or resource being protected) in the watershed. Subwatershed priority maps were generated using results extracted from the LRRW HSPF model. Maps were developed for RO, TP, TN, and total sediment. Maps generated at the watershed scale using the entire simulation period (i.e., multiple years, 1996 through 2009) included average land segment yield maps (**Figures B4-B7**), averaged subwatershed yield maps (**Figures B8-B11),** subwatershed priority rankings maps (**Figures B12-B15**), water quality index (WQI) map (**Figure B16**), and field stream index maps (**Figures B17-B19**). Maps were also generated at the major tributary drainage scale for the three main drainage areas in the LRRW watershed (**Figure B3**). Map sets for each of major tributary drainage include the subwatershed priority ranks (Joe River **Figures B20-B23**; JD 10/Unnamed Coulee **Figures B25-B28**; Tamarac River **Figures B30-B33**) and the water quality index maps (Joe River **Figure B24**; JD 10/Unnamed Coulee **Figure B29**; Tamarac River **Figure B34**).

The yield maps (**Figures B4-B11**) can be used to complete pollutant sources assessments. They show which land segments and subwatersheds are the largest sources of runoff, nutrients and sediment per area and time (annual average) delivered to the channel (edge of field). Maps represent different stressors, which can lead to impairment. The maps show those subwatersheds having the greatest unit area, average annual yields of each subwatershed for RO (**Figure B8**), TP (**Figure B9**), TN (**Figure B10**), and total sediment (**Figure B11**). These maps were generated by extracting the flow and loadings from each PERLND and IMPLND (**Figures B4-B7**), averaging the annual total flows and loads over the modeling period (1996 through 2009) for each PERLND/IMPLND, and using the areas of each PERLND/IMPLND in each subwatershed to get a subwatershed unit area, annual average yield. The numeric values for each subwatershed is provided in the Supplemental Table section.

The priority rankings maps (**Figures B12-B15**) use the information in the yield maps to identify specific priority subwatersheds which should be preferentially considered for targeting fields for practice implementation based solely on water quality. These maps were developed by taking the yields at the watershed and major tributary scales and ranking them smallest to largest and calculating their percentile rank. The ranks are summarized as the lowest implementation priority (lowest 10%), low priority (10%-25%), moderate priority (25%-75%), high priority (75%-90%), and highest priority (highest 10%). The highest priority subwatersheds with the highest yields and most likely would benefit the most from implementation and protective strategy management. For the major tributary maps, the yields were re-ranked, only using the subwatersheds draining to the tributary.

In addition to the priority rankings maps, an overall water quality index (WQI) map was generated. The WQI (**Figure B16**) represents the combined importance of nutrients and sediment and is estimated using:

$$WQI = 0.5*\text{Sediment Ranking} + 0.25*\text{TP Ranking} + 0.25*\text{TN Ranking}$$

These maps should be used when the practitioner wishes to consider establishing priority based on both excess nutrients and sediment as stressors.

The Field Stream Index maps (**Figures B17-B19**) provide guidance, subject to field verification, about where field practices rather than in-stream implementation activities, provide the largest potential water quality benefit. These maps show the magnitude of field source loads relative to in-stream sources and are taken as the overland field load divided by the in-channel flux. Positive numbers represent a source of in-stream materials and a negative number represents a sink for in-stream materials. If the FSI is between -1 and 1, the dominate process in the subwatershed are in-channel, meaning the in-channel flux is larger than the overland sources. If the FSI is less than -1 or greater than 1, field sources are larger than the in-stream sources.

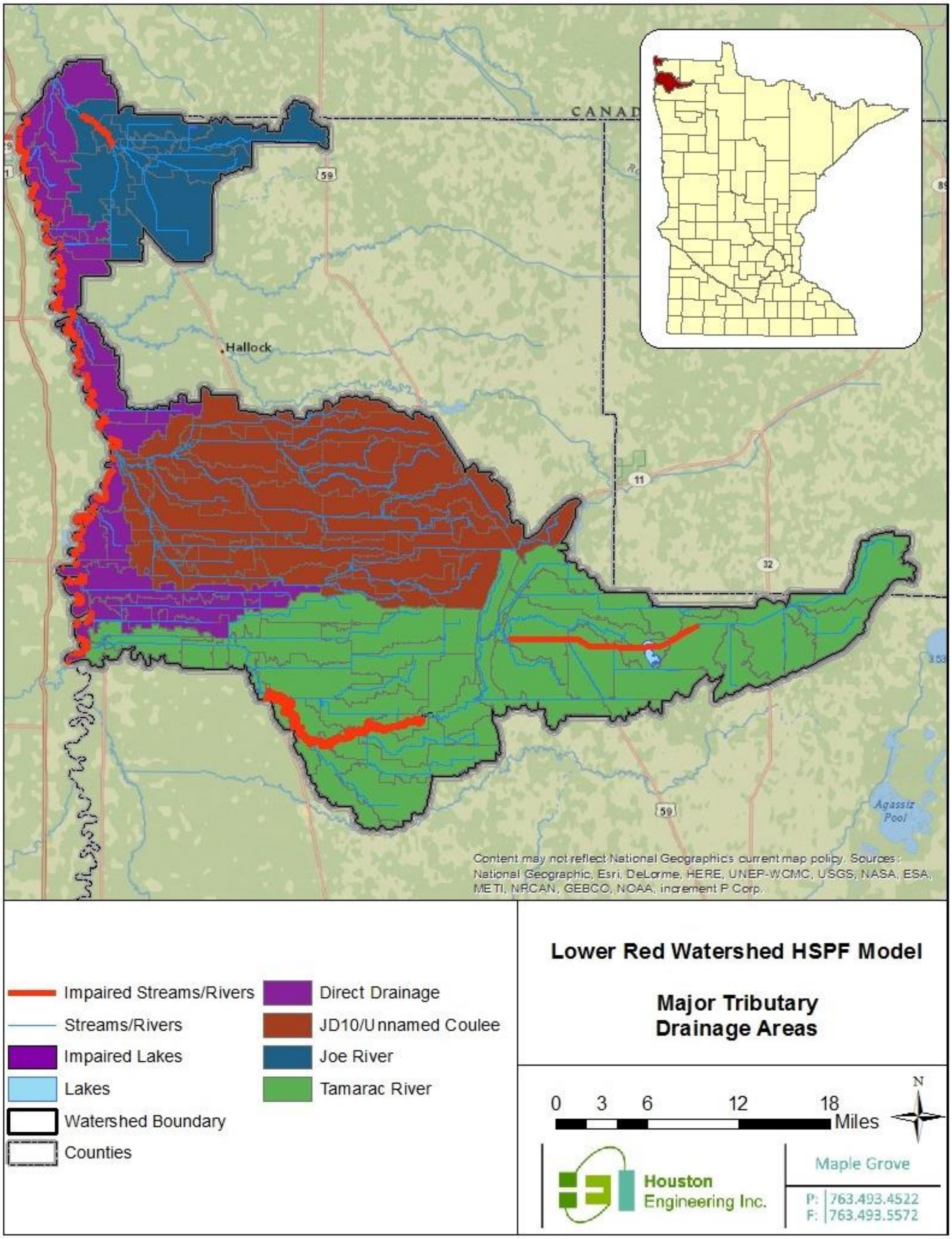


Figure B3: Drainage basins of the impaired AUIDs in the Lower Red River Watershed.

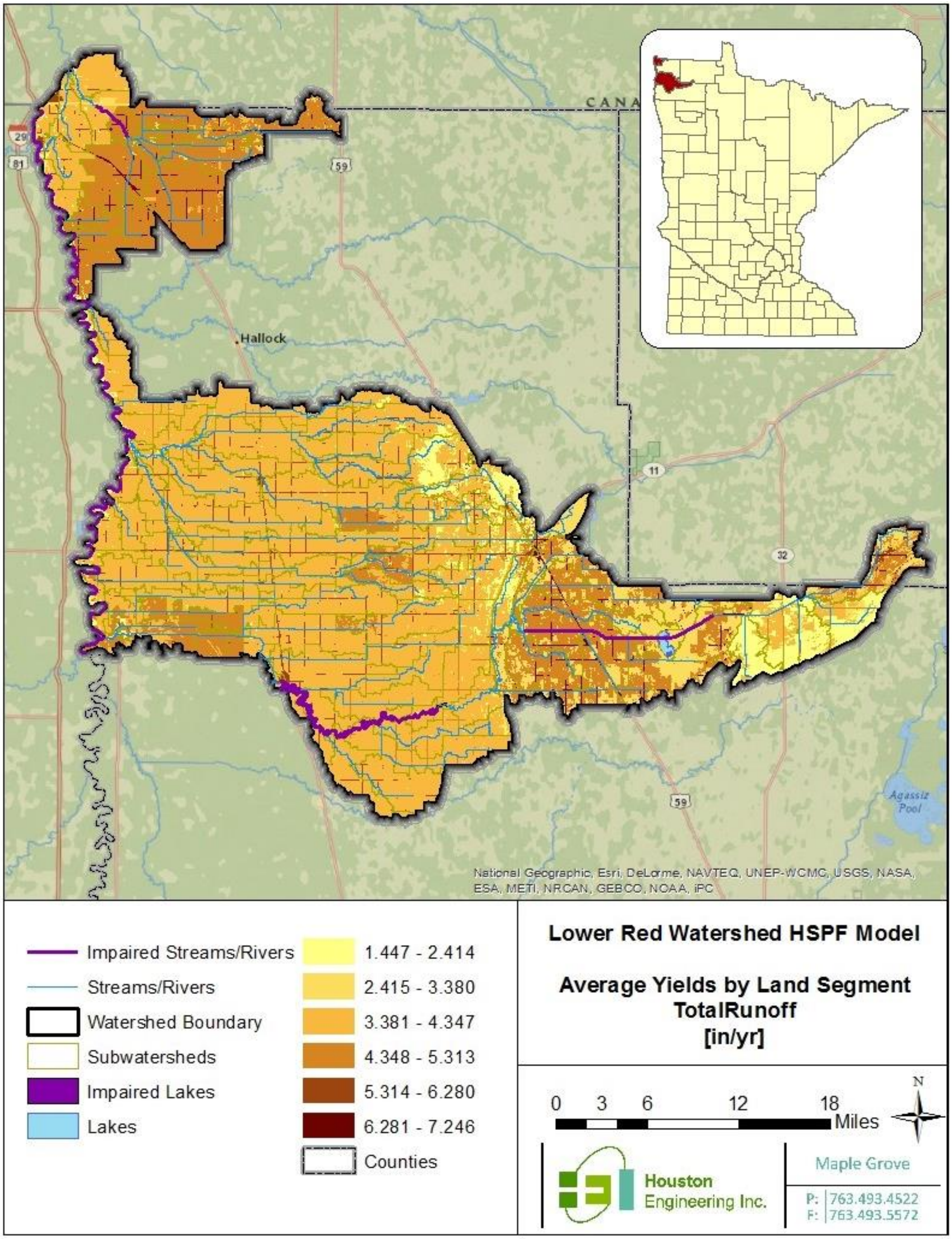


Figure B4: Average (1996-2009) Unit Runoff delivered to the channel from the LRRW HSPF model by land segment.

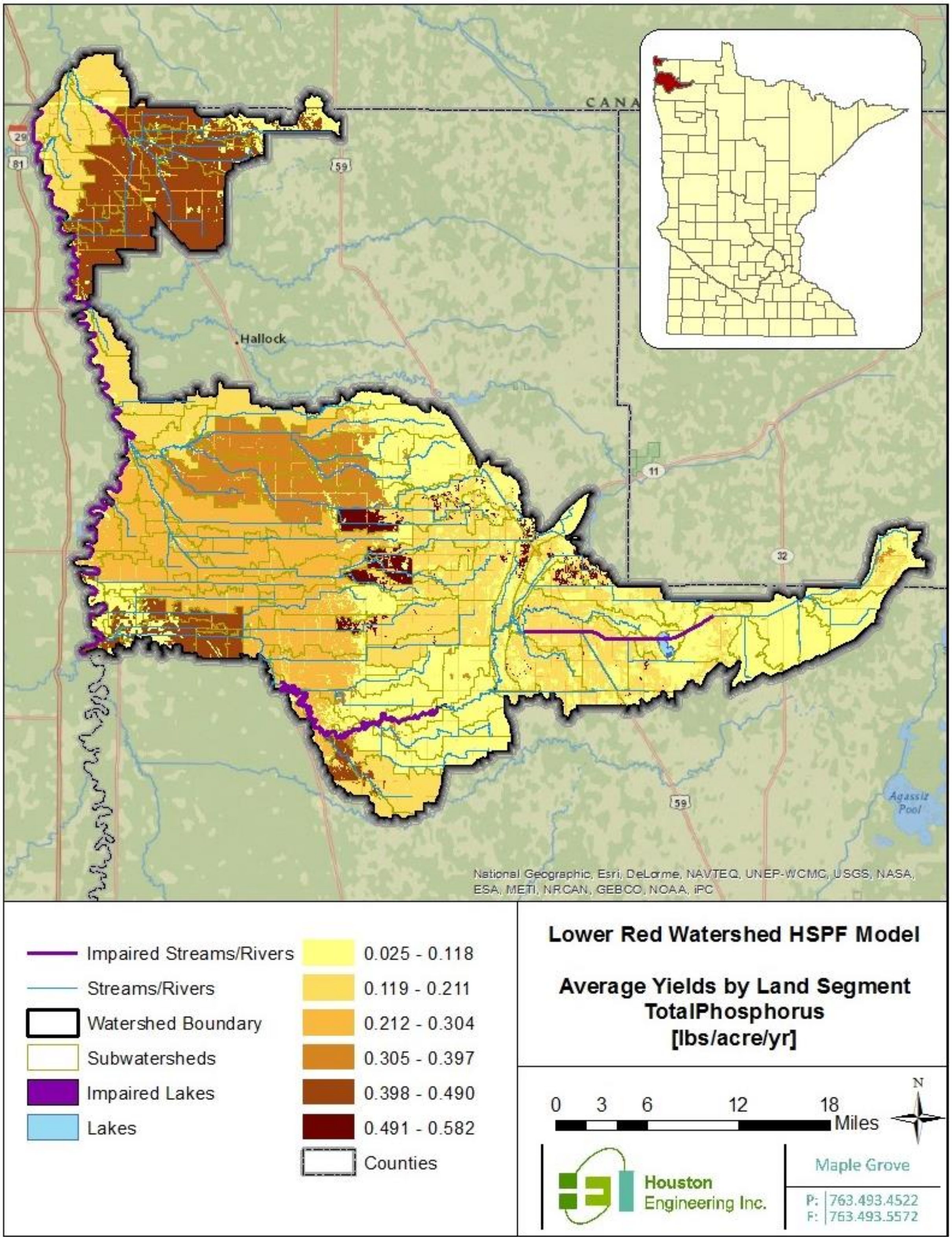


Figure B5: Average (1996-2009) Total Phosphorus Yield delivered to the channel from the LRRW HSPF model by land segment.

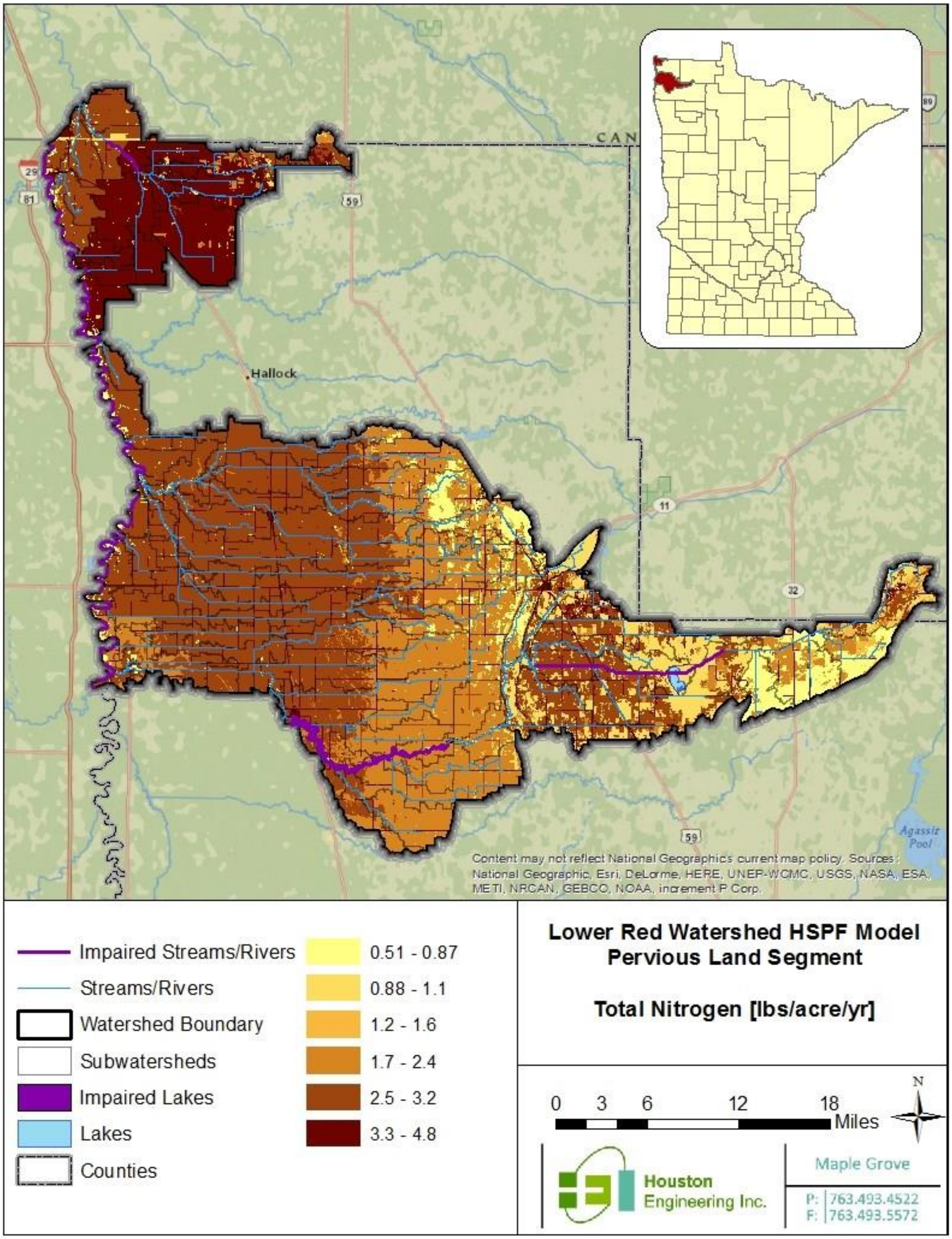


Figure B6: Average (1996-2009) Total Nitrogen Yield delivered to the channel from the LRRW HSPF model by land segment.

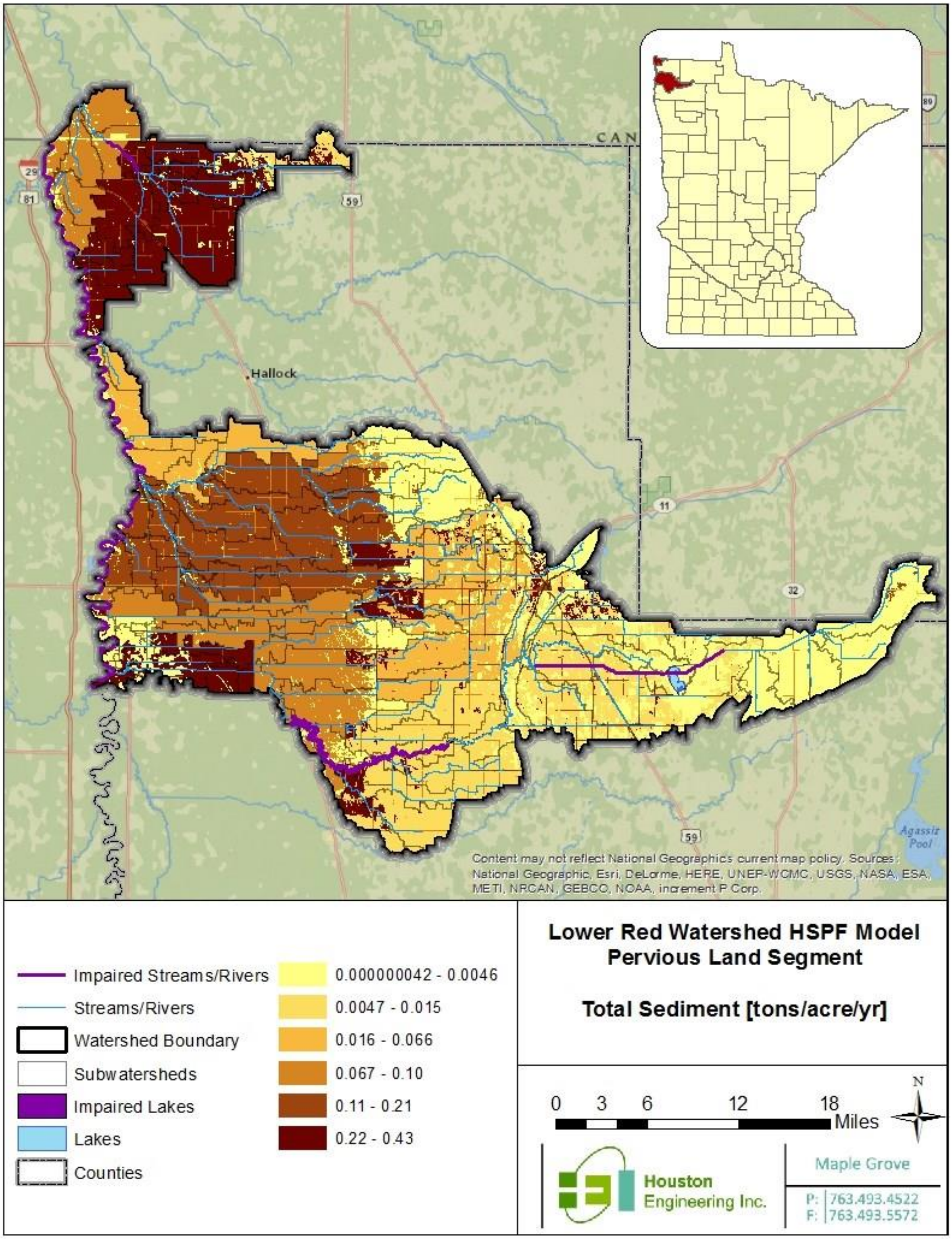


Figure B7: Average (1996-2009) Total Sediment Yield delivered to the channel from the LRRW HSPF model by land segment.

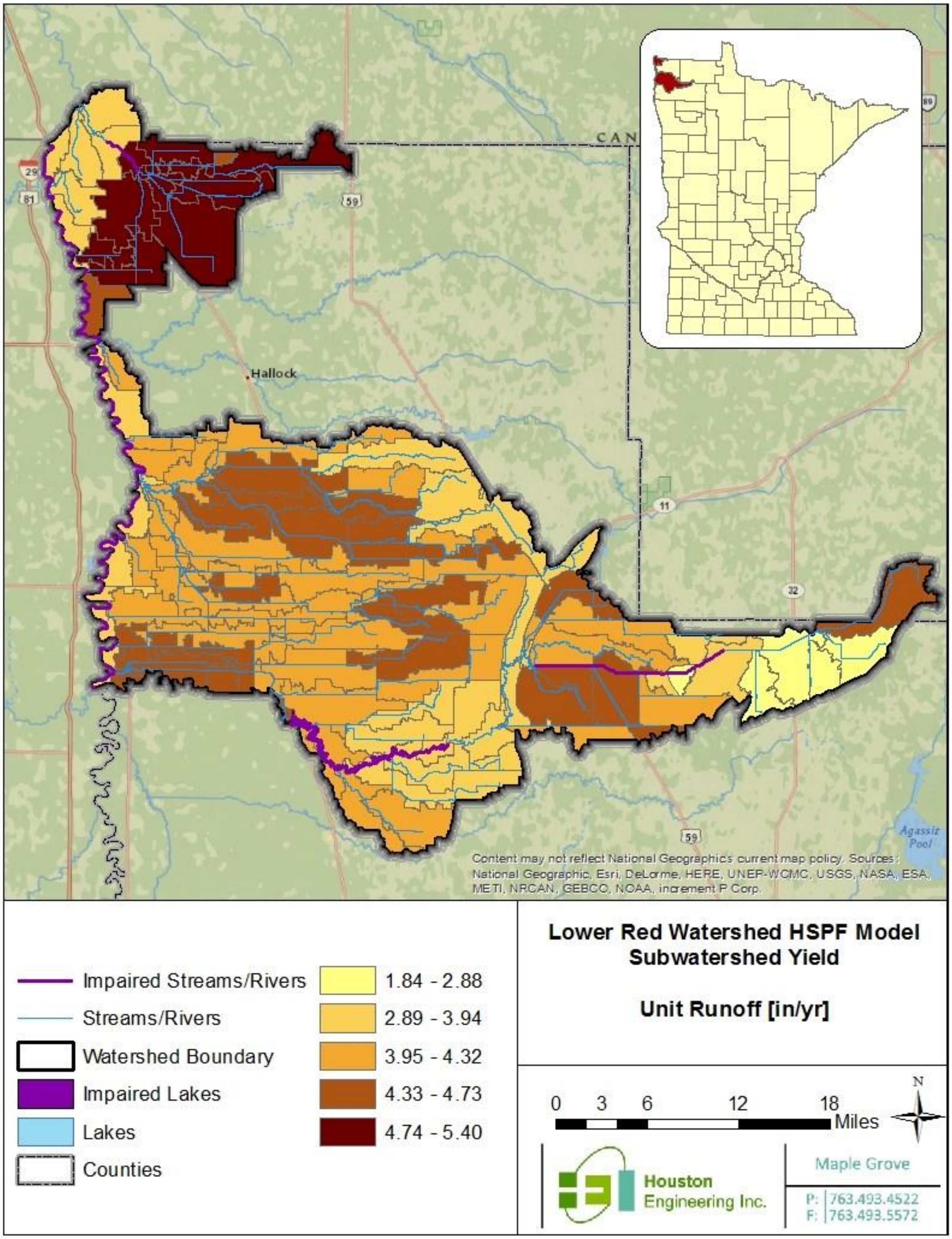


Figure B8: Average (1996-2009) Unit Runoff delivered to the channel from the LRRW HSPF model by subwatershed.

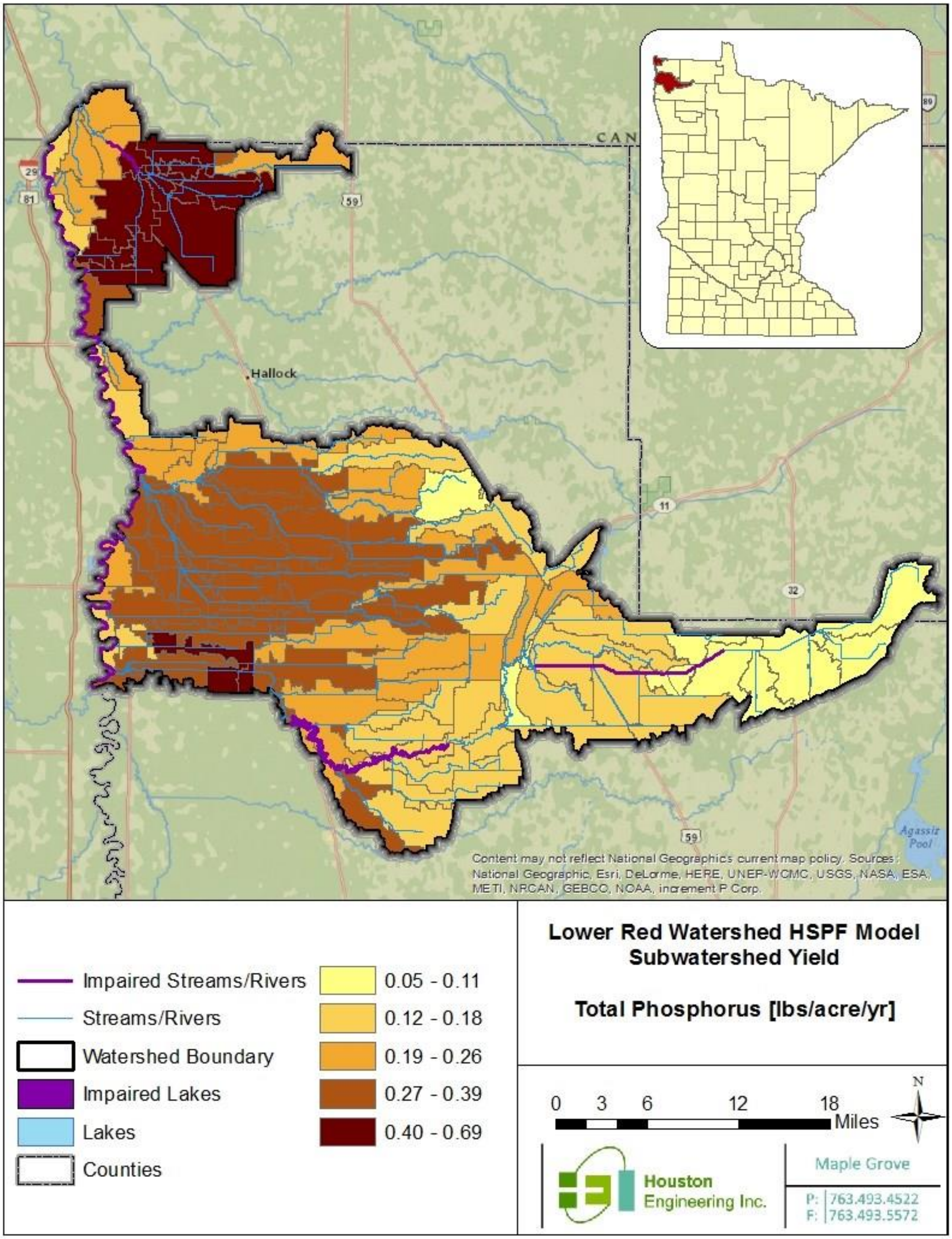


Figure B9: Average (1996-2009) Total Phosphorus Yield delivered to the channel from the LRRW HSPF model by subwatershed.

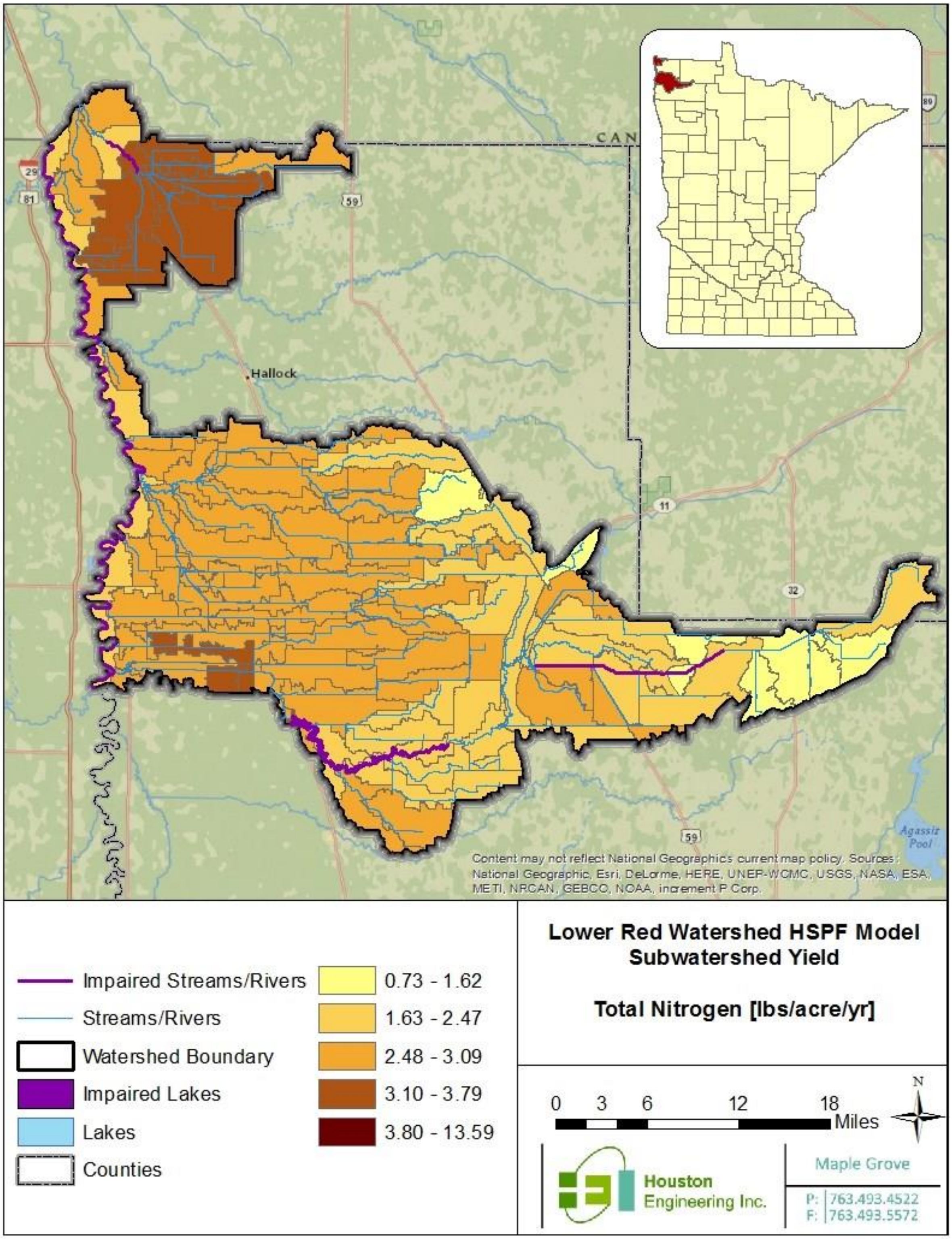


Figure B10: Average (1996-2009) Total Nitrogen Yield delivered to the channel from the LRRW HSPF model by subwatershed.

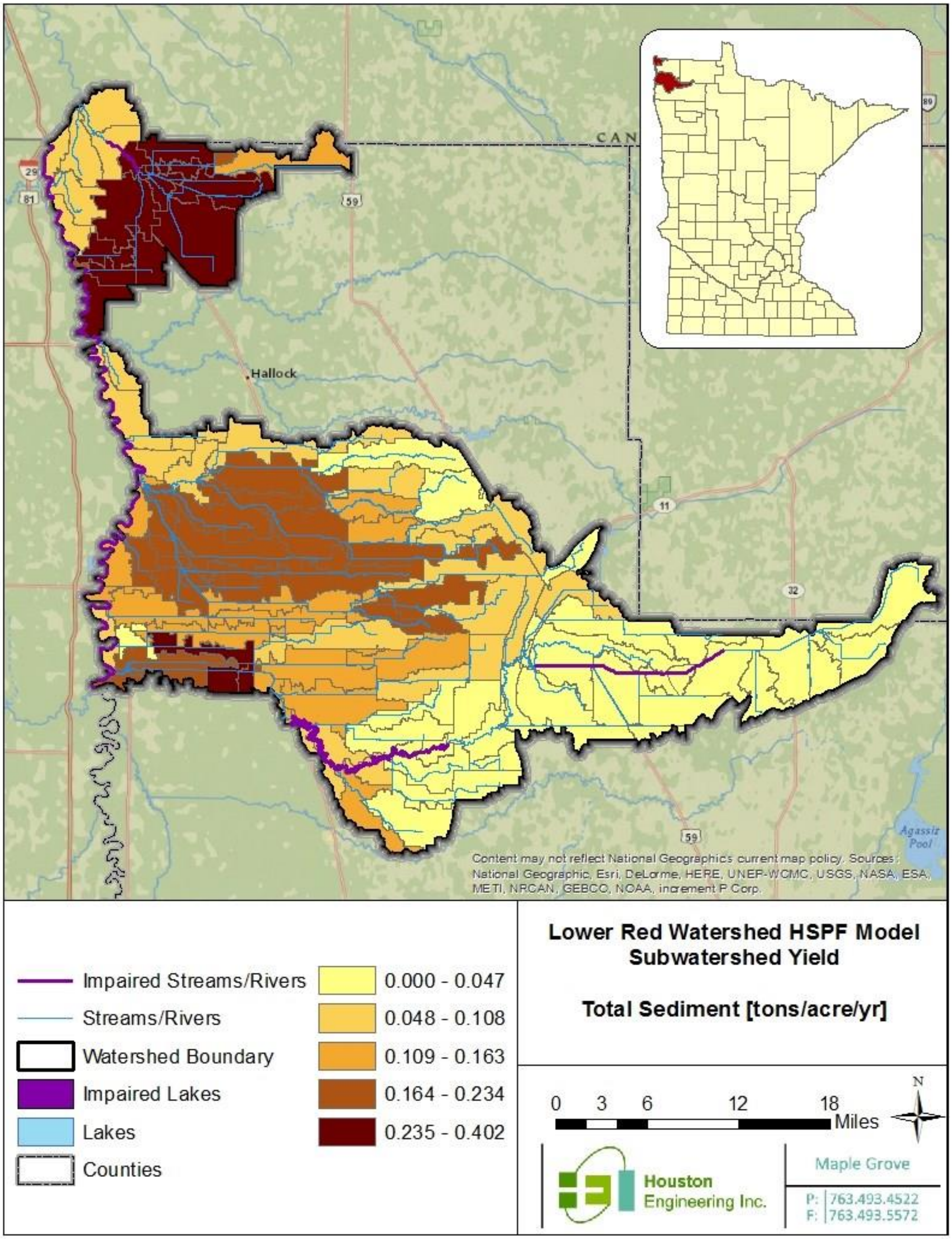


Figure B11: Average (1996-2009) Total Sediment Yield delivered to the channel from the LRRW HSPF model by subwatershed.

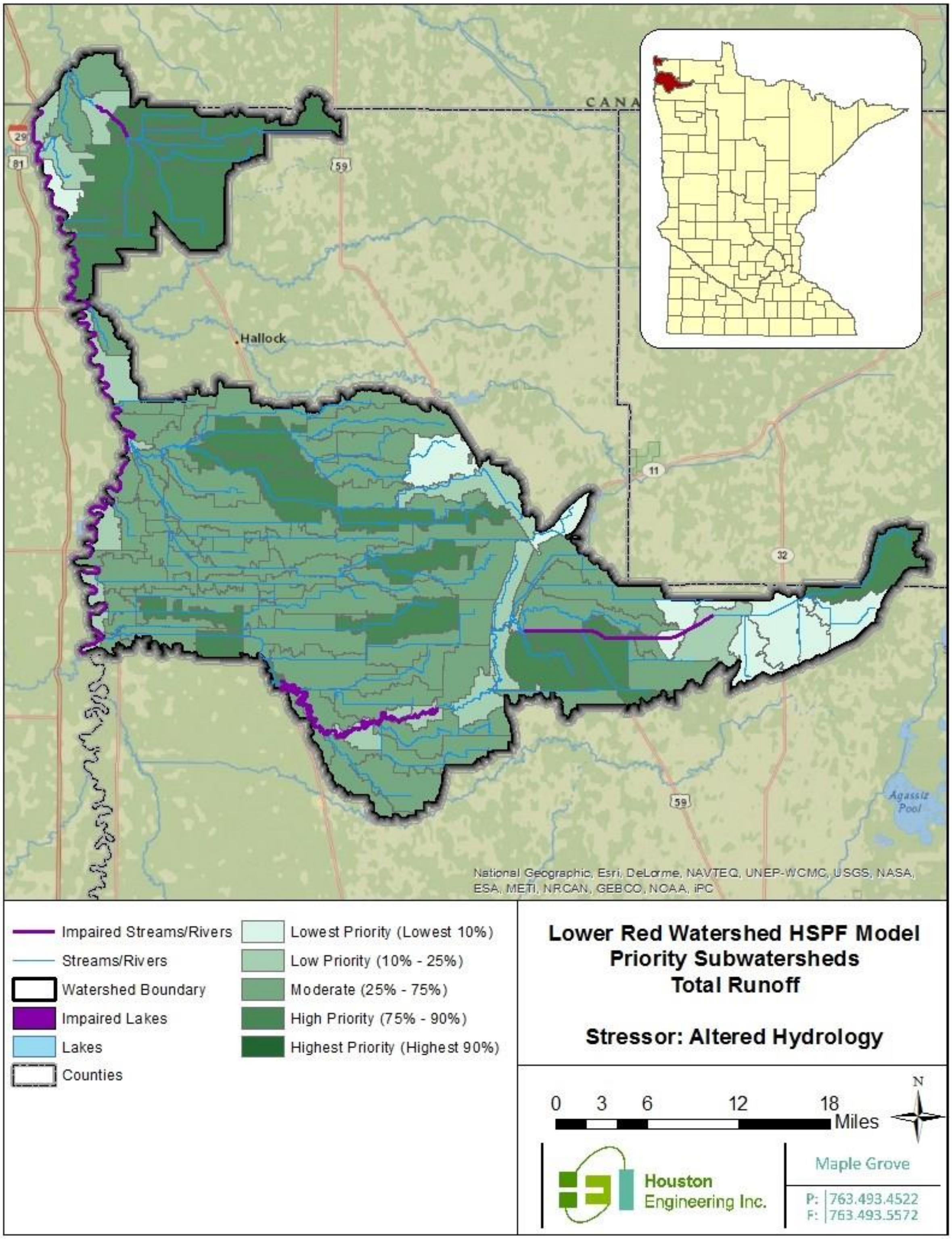


Figure B12: Watershed scale subwatershed priority for implementation for the stressor altered hydrology, using average (1996-2009) annual unit runoff.

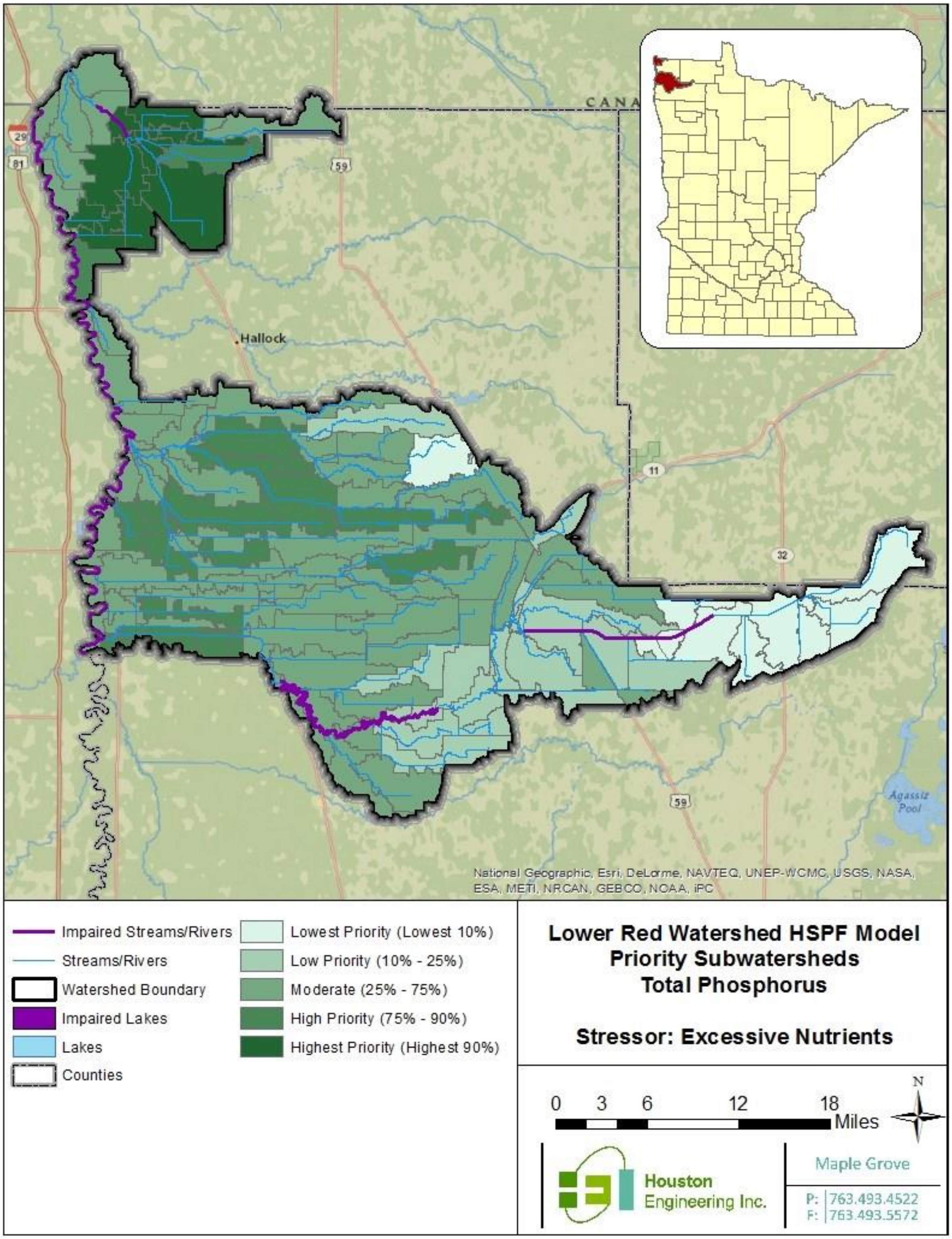


Figure B13: Watershed scale subwatershed priority for implementation for the stressor excessive nutrients, using average (1996-2009) total phosphorus yields.

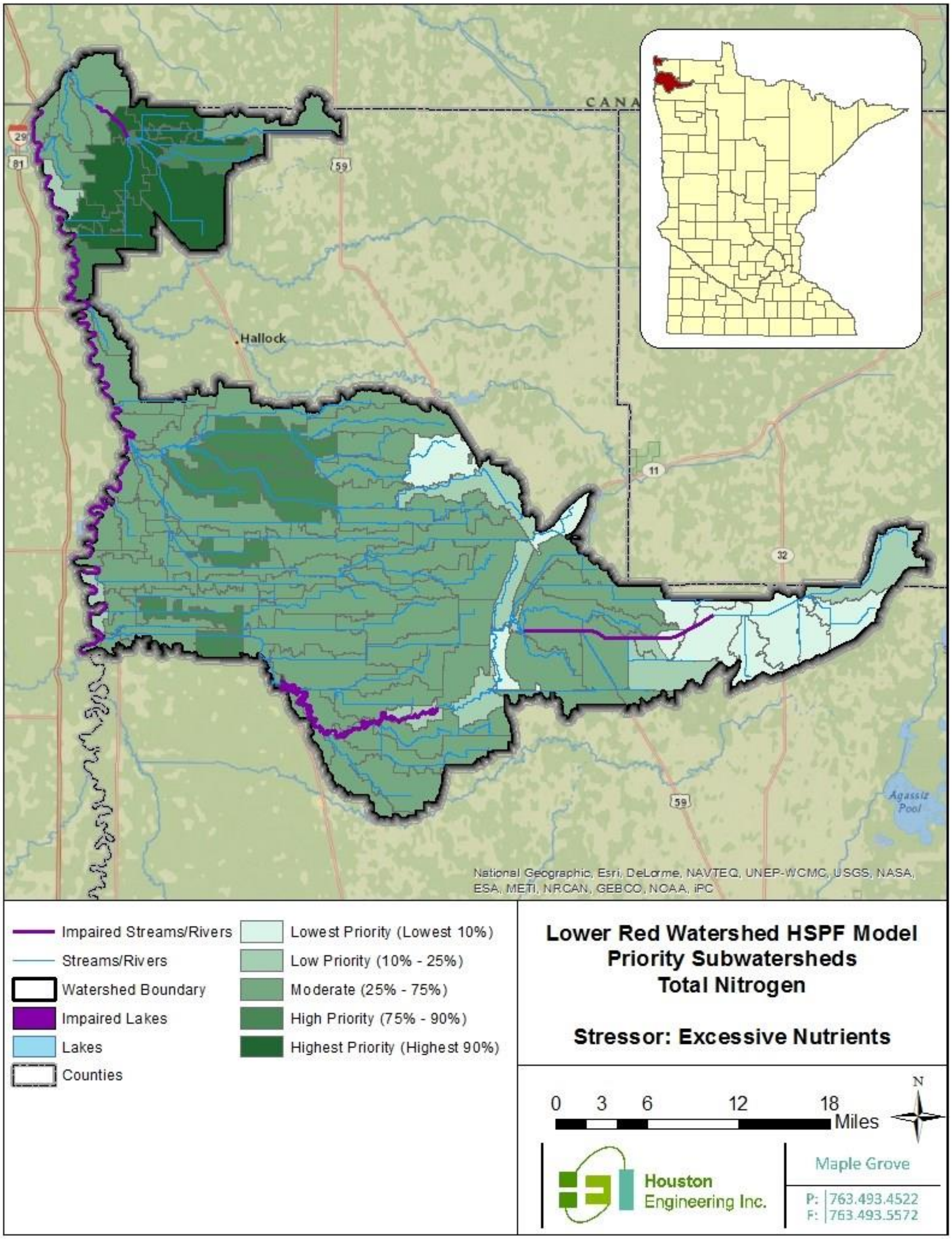


Figure B14: Watershed scale subwatershed priority for implementation for the stressor excessive nutrients, using average (1996-2009) total nitrogen yields.

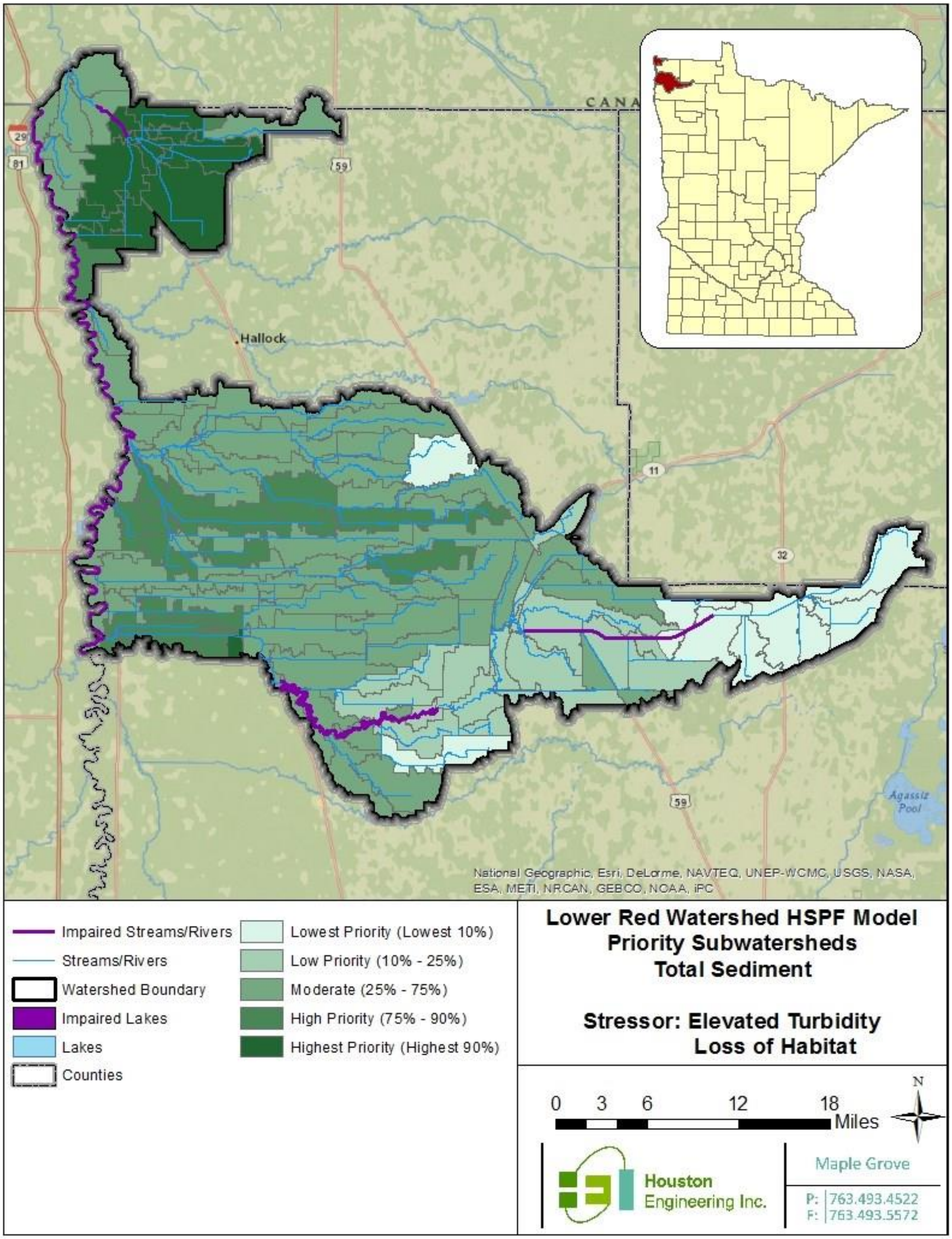


Figure B15: Watershed scale subwatershed priority for implementation for the stressors elevated turbidity and loss of habitat, using average (1996-2009) total sediment yields.

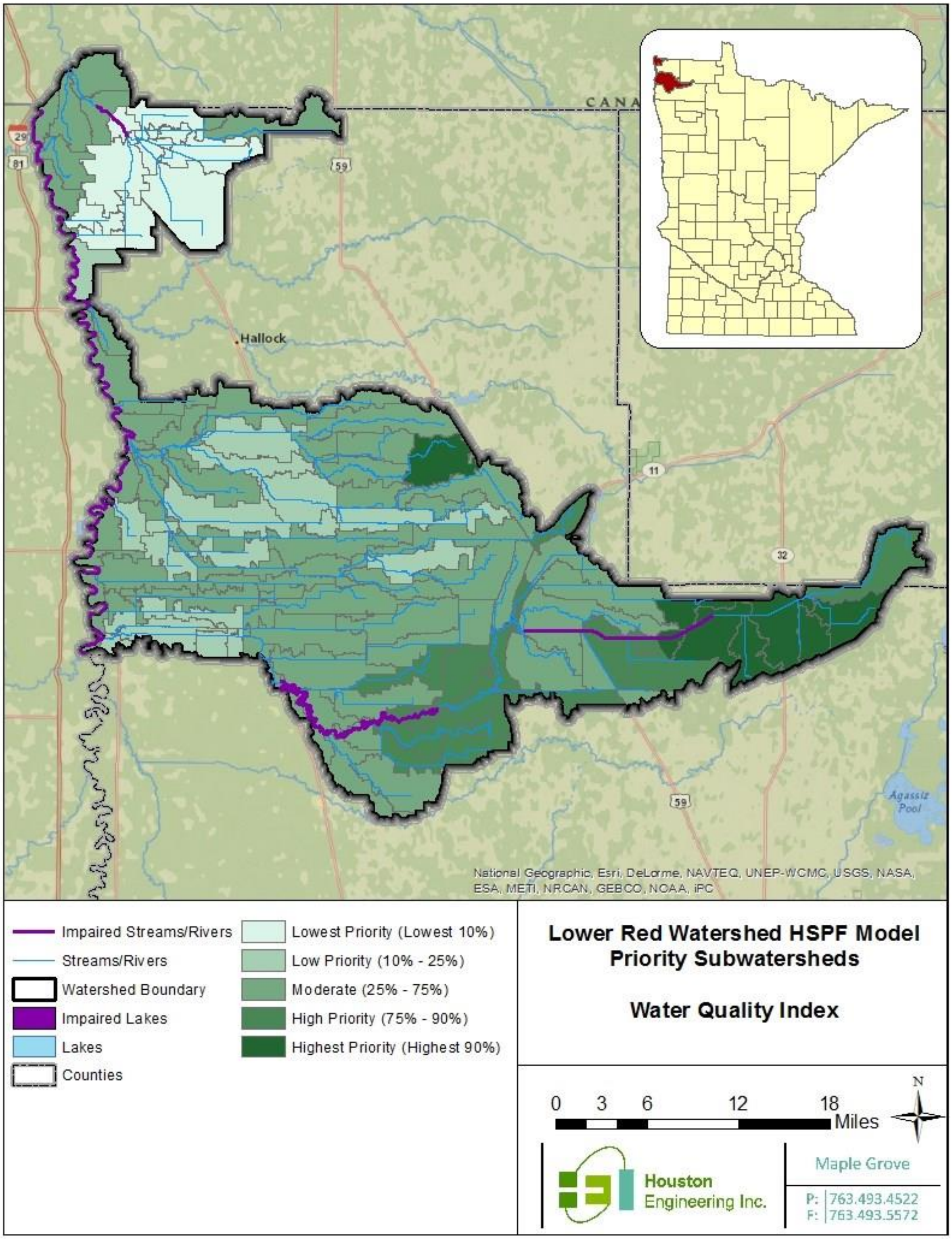


Figure B16: Watershed scale subwatershed priority for implementation, using the average (1996-2009) water quality index.

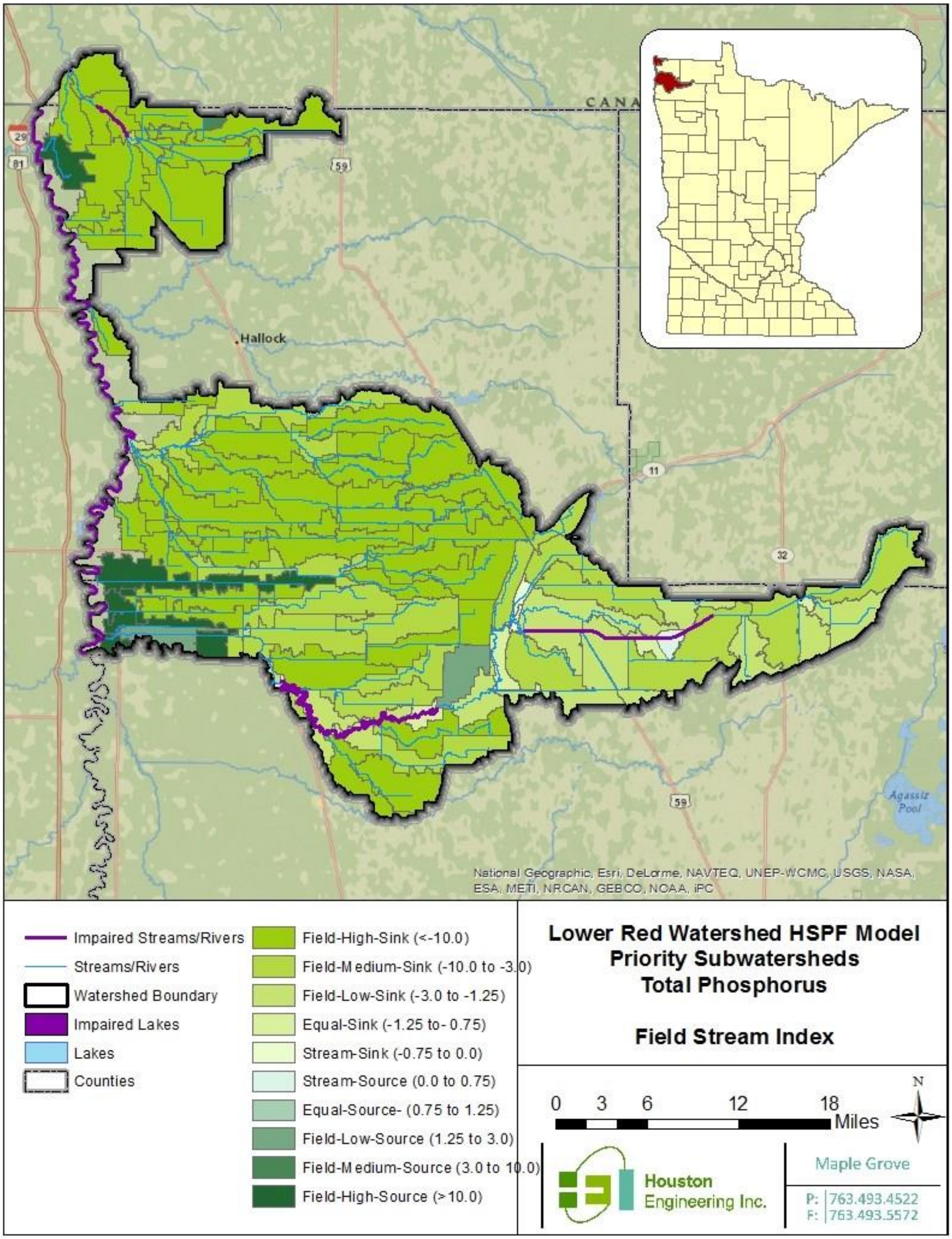


Figure B17: Watershed scale subwatershed priority for implementation of field and stream practices (Field Stream Index) for the stressor excess nutrients using total phosphorus (1996-2009) annual average load.

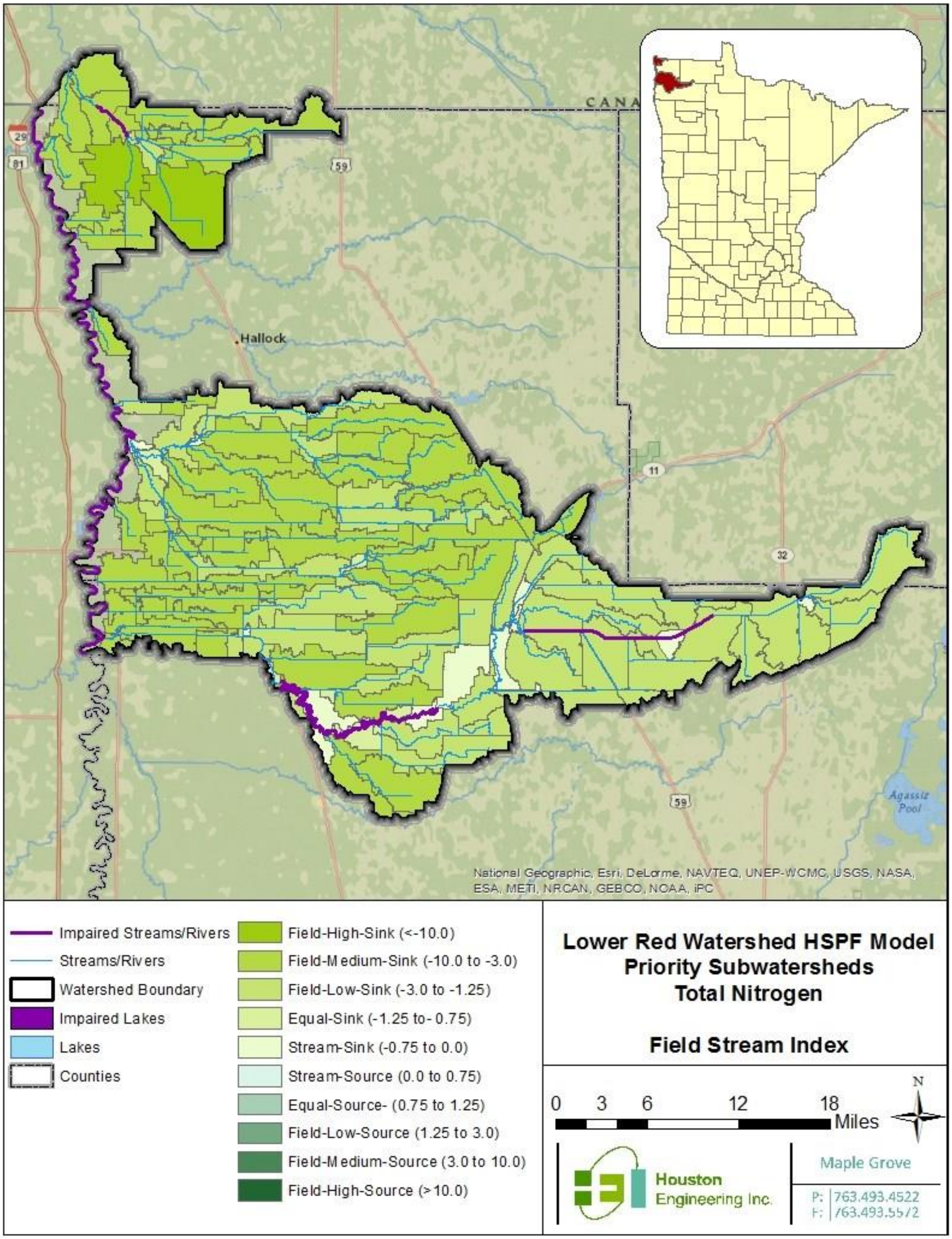


Figure B18: Watershed scale subwatershed priority for implementation of field and stream practices (Field Stream Index) for the stressor excess nutrients using total nitrogen (1996-2009) annual average load.

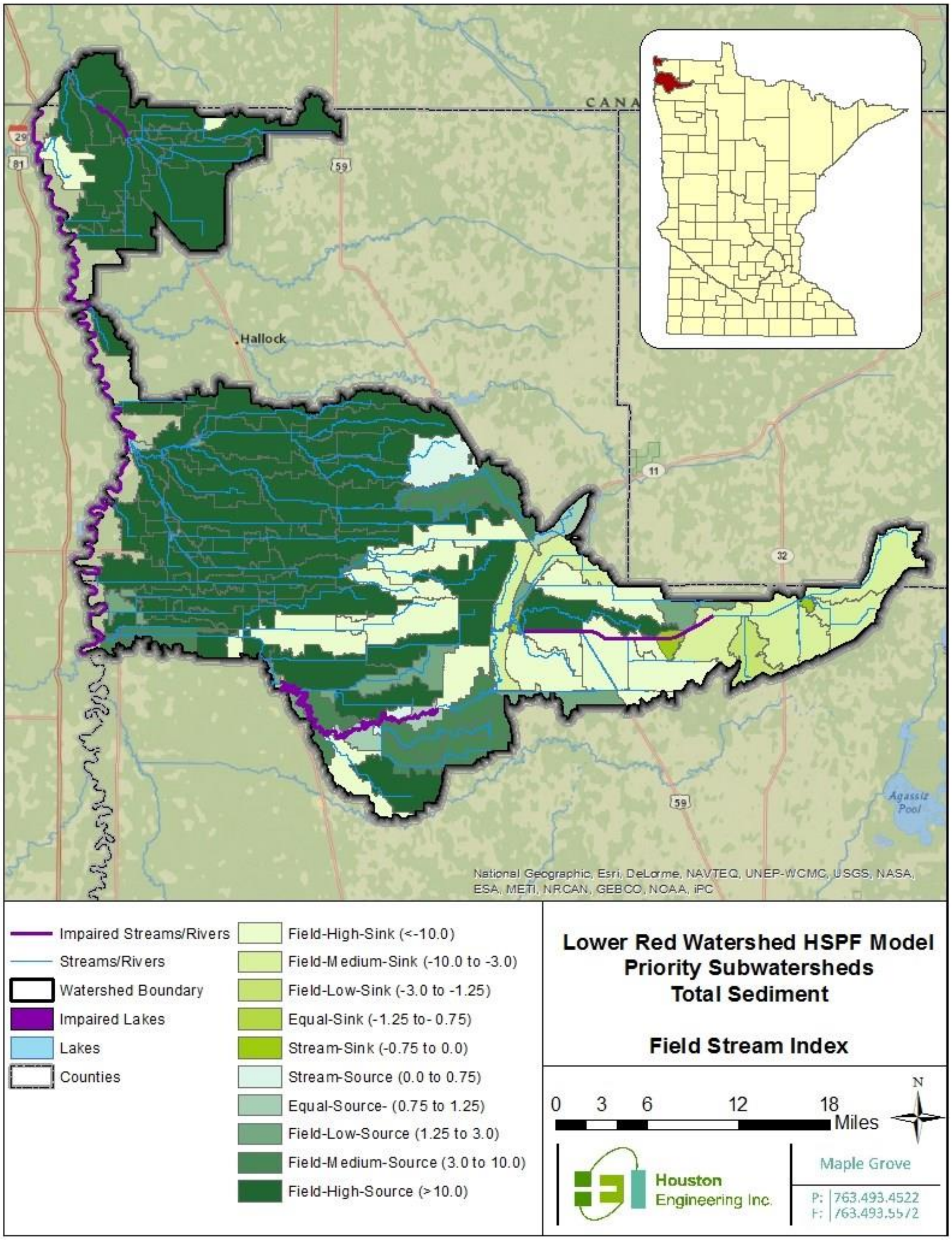


Figure B19: Watershed scale subwatershed priority for implementation of field and stream practices (Field Stream Index) for the stressor elevated turbidity using total sediment (1996-2009) annual average load.

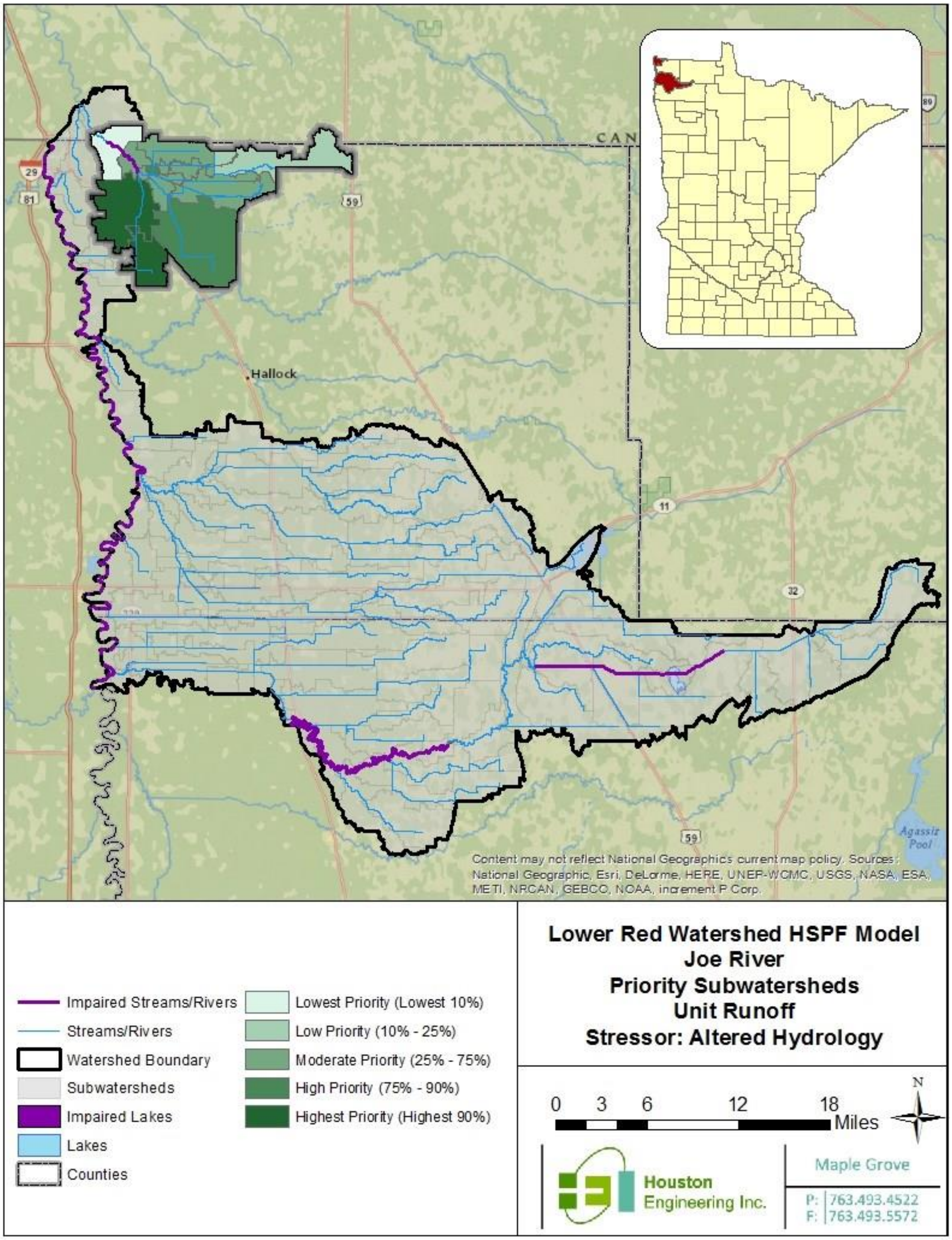


Figure B20: Tributary scale subwatershed priority for implementation for the stressor altered hydrology for Joe River, using average (1996-2009) annual unit runoff.

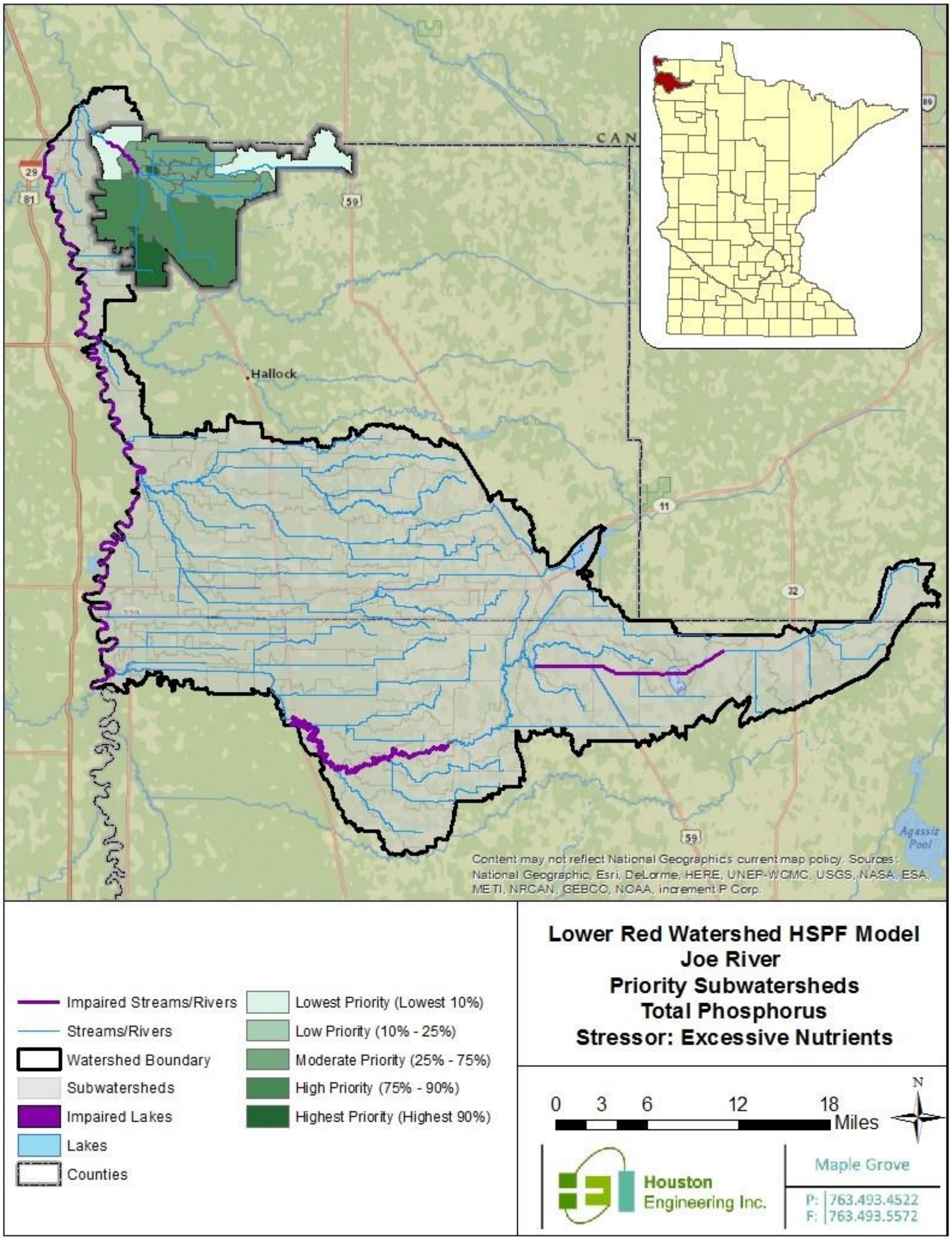


Figure B21: Tributary scale subwatershed priority for implementation for the stressor excessive nutrients for Joe River, using average (1996-2009) annual total phosphorus yields.

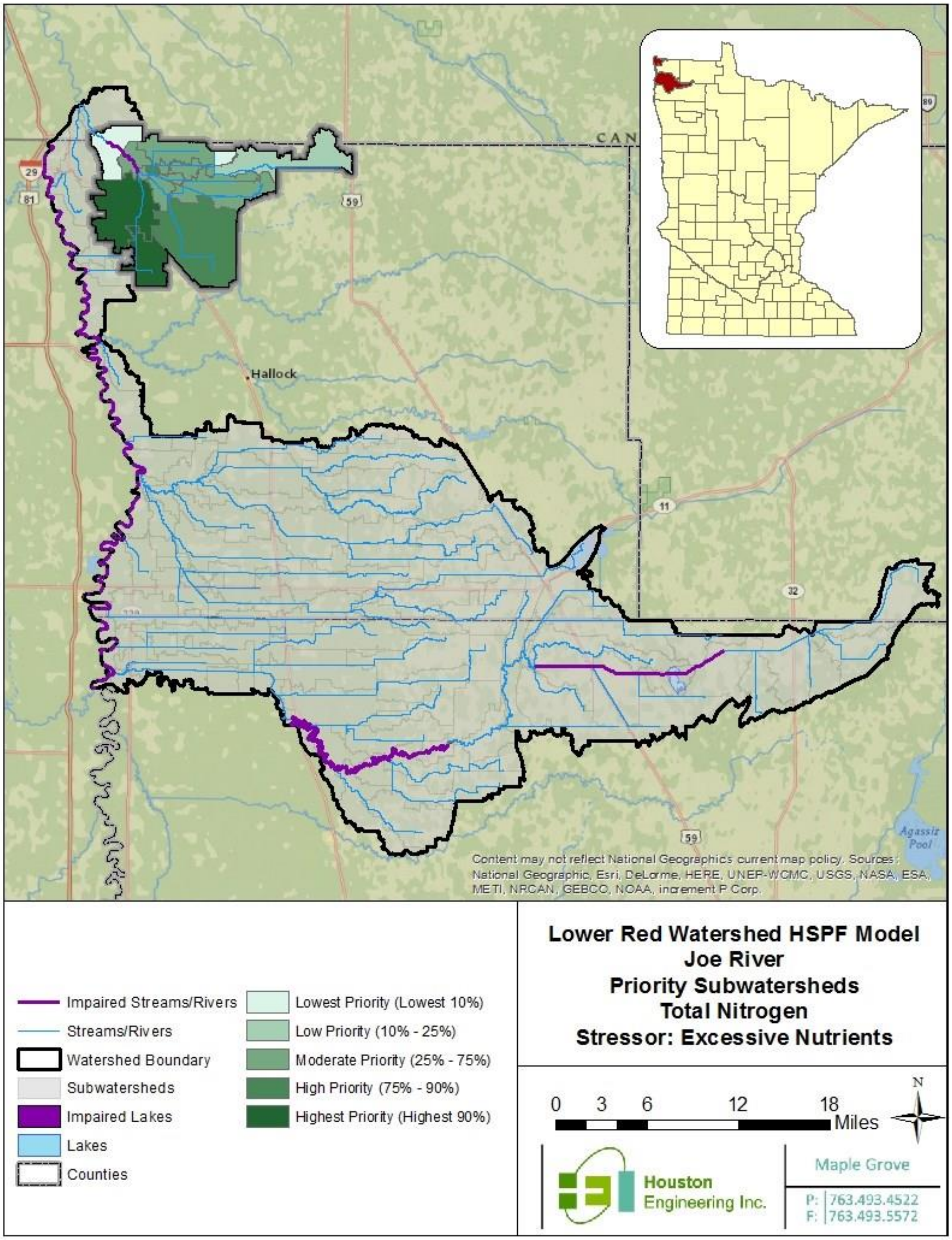


Figure B22: Tributary scale subwatershed priority for implementation for the stressor excessive nutrients for Joe River, using average (1996-2009) annual total nitrogen yields.

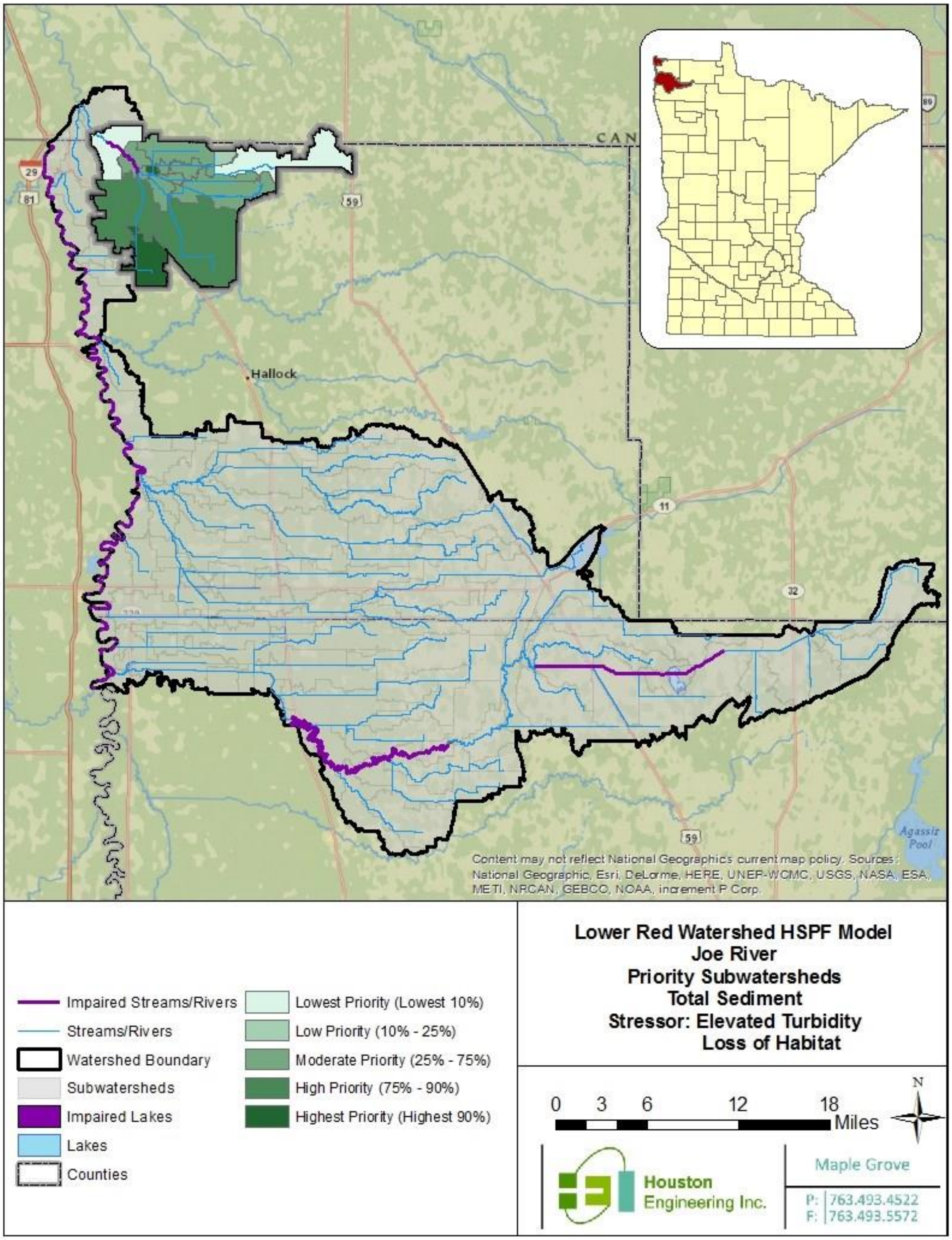


Figure B23: Tributary scale subwatershed priority for implementation for the stressors elevated turbidity and loss of habitat for Joe River, using average (1996-2009) annual total sediment yields.

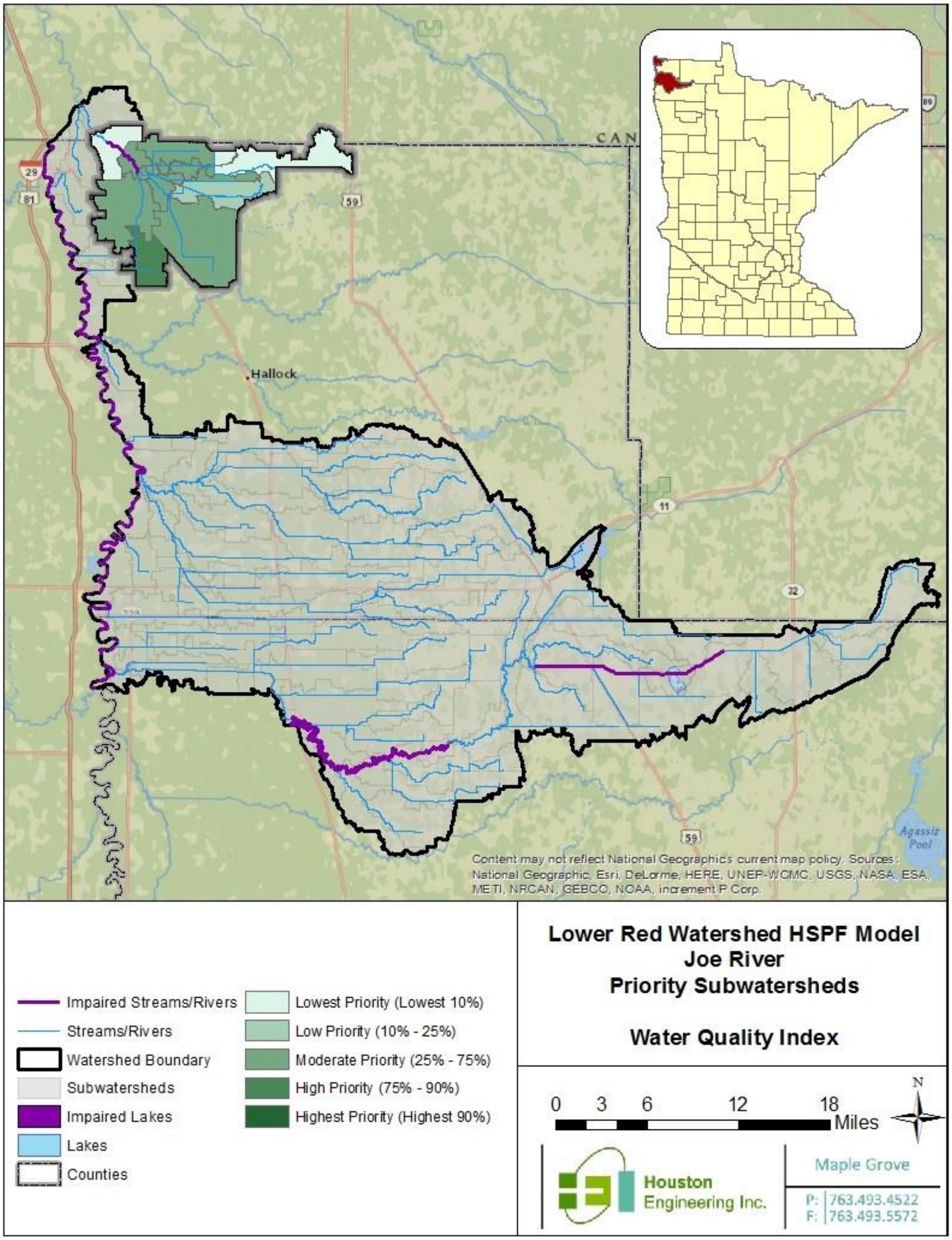


Figure B24: Tributary scale subwatershed priority for implementation for Joe River, using the average (1996-2009) water quality index.

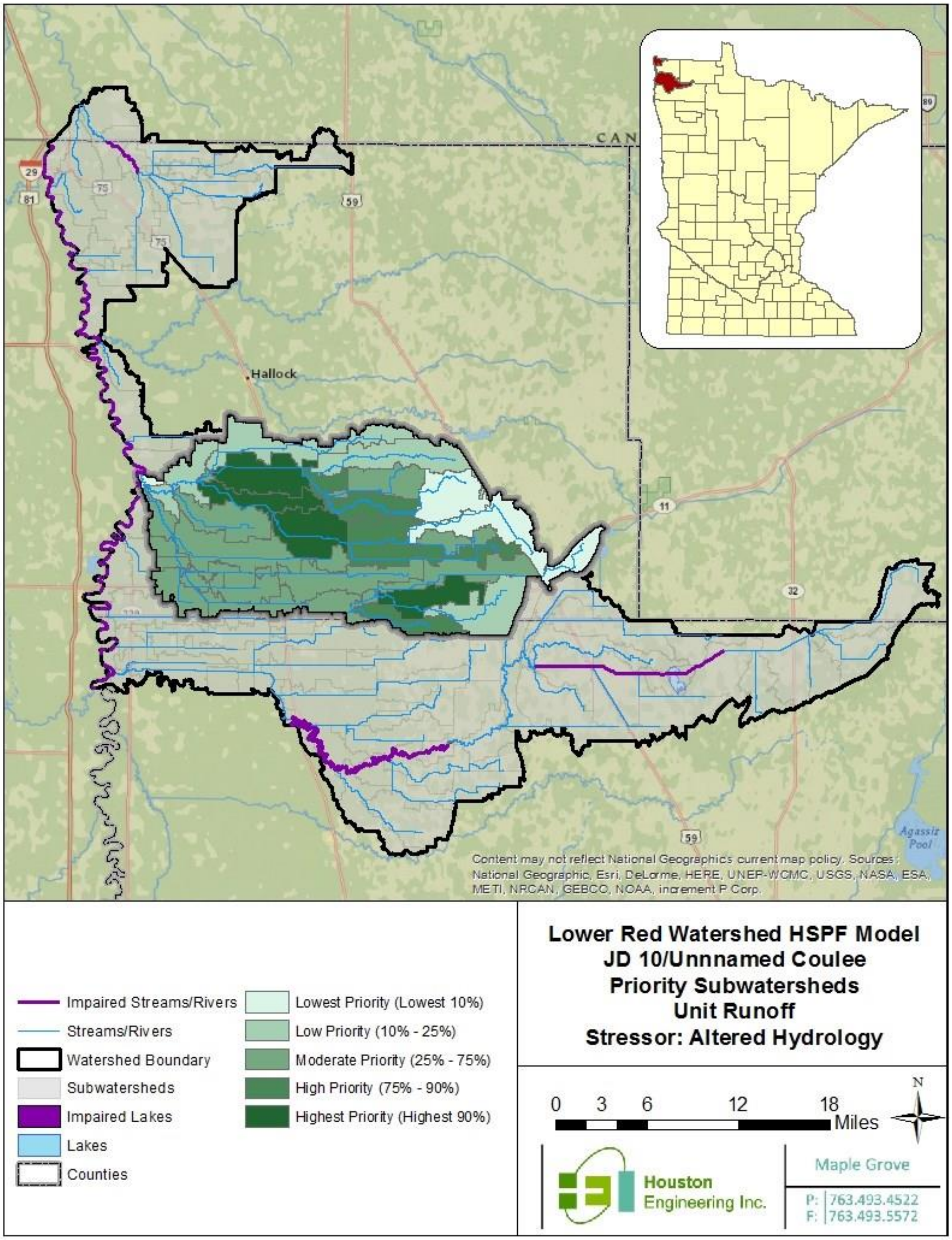


Figure B25: Tributary scale subwatershed priority for implementation for the stressor altered hydrology for JD 10/Unnamed Coulee, using average (1996-2009) annual unit runoff.

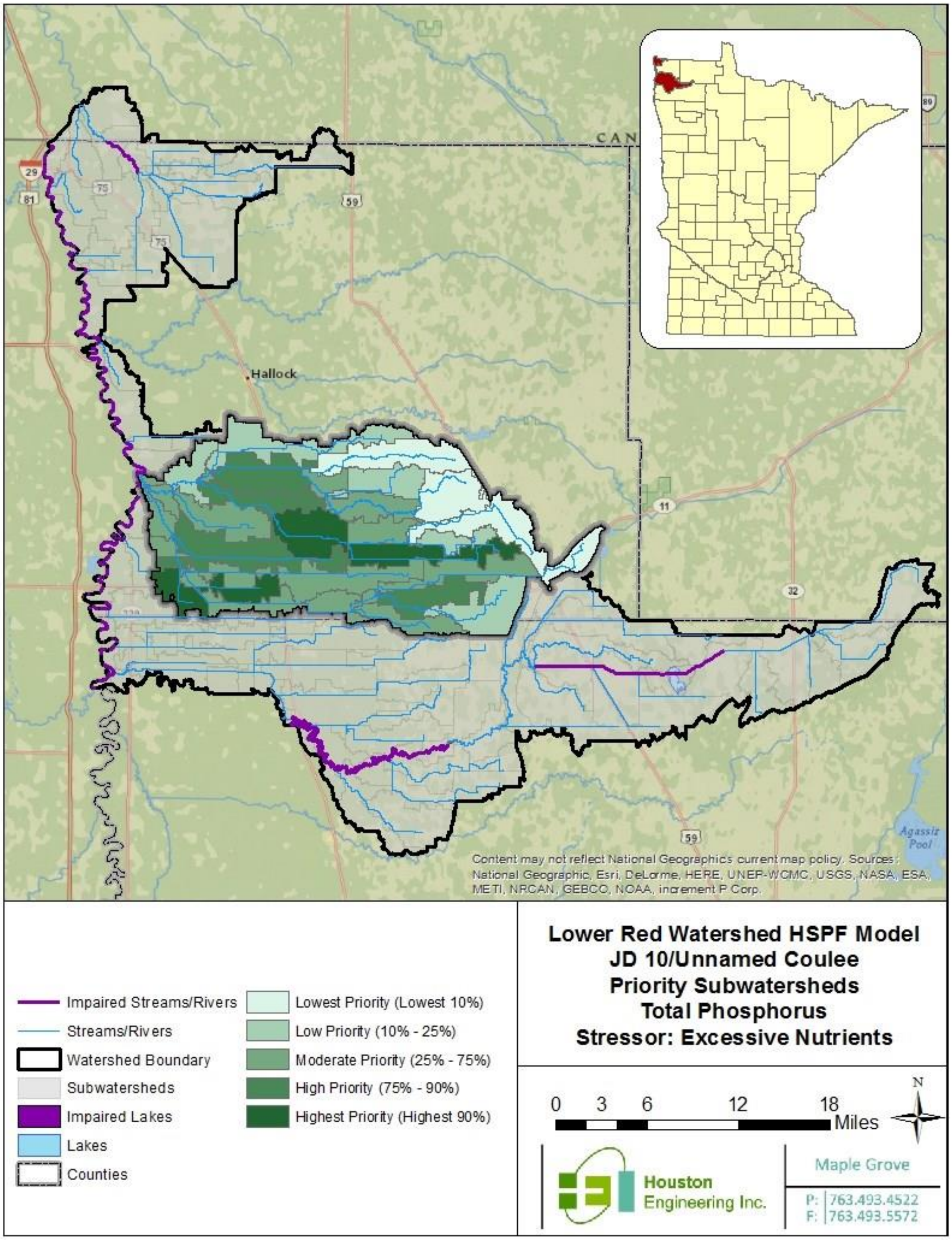


Figure B26: Tributary scale subwatershed priority for implementation for the stressor excessive nutrients in for JD 10/Unnamed Coulee, using average (1996-2009) annual total phosphorus yields.

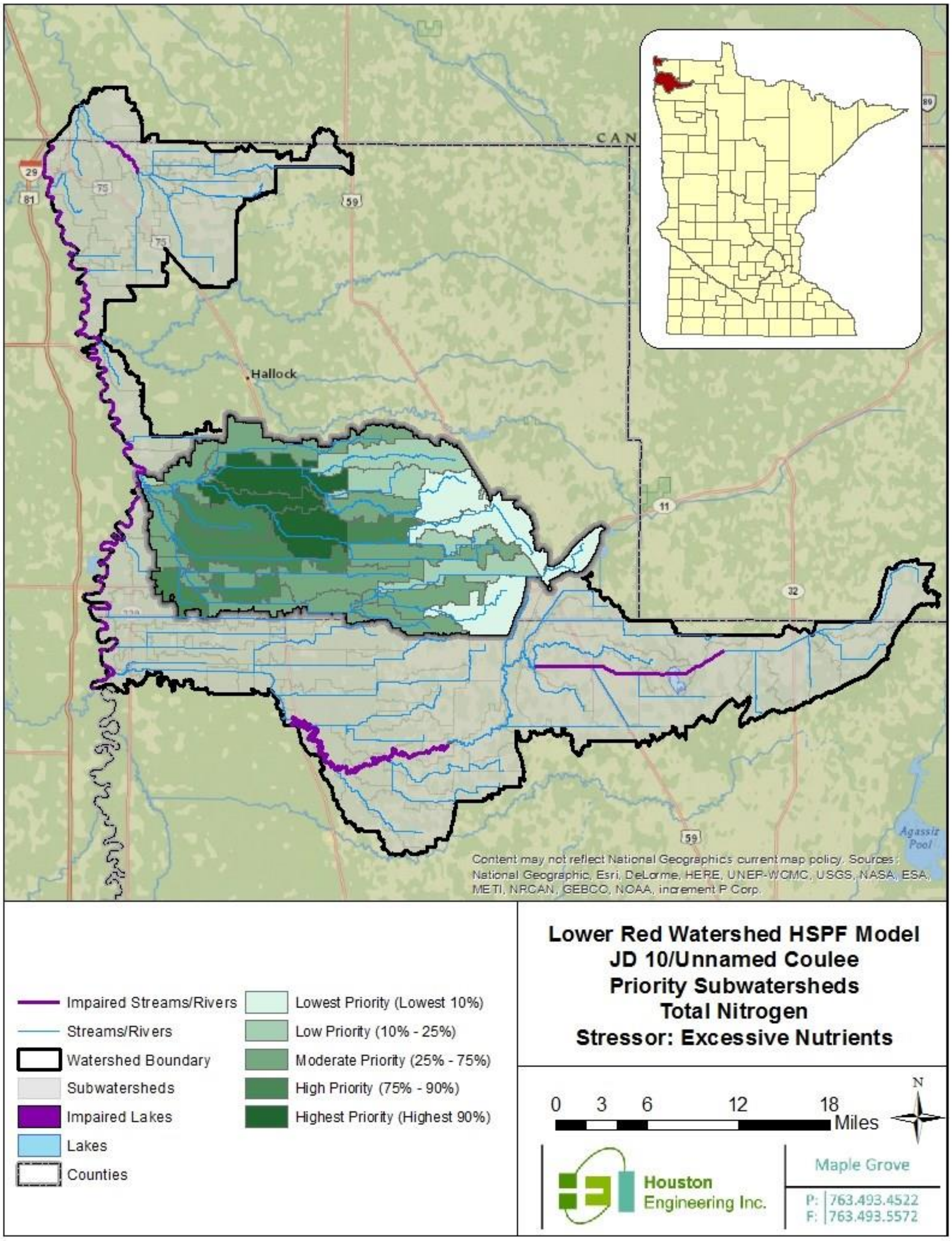


Figure B27: Tributary scale subwatershed priority for implementation for the stressor excessive nutrients in for JD 10/Unnamed Coulee, using average (1996-2009) annual total nitrogen yields.

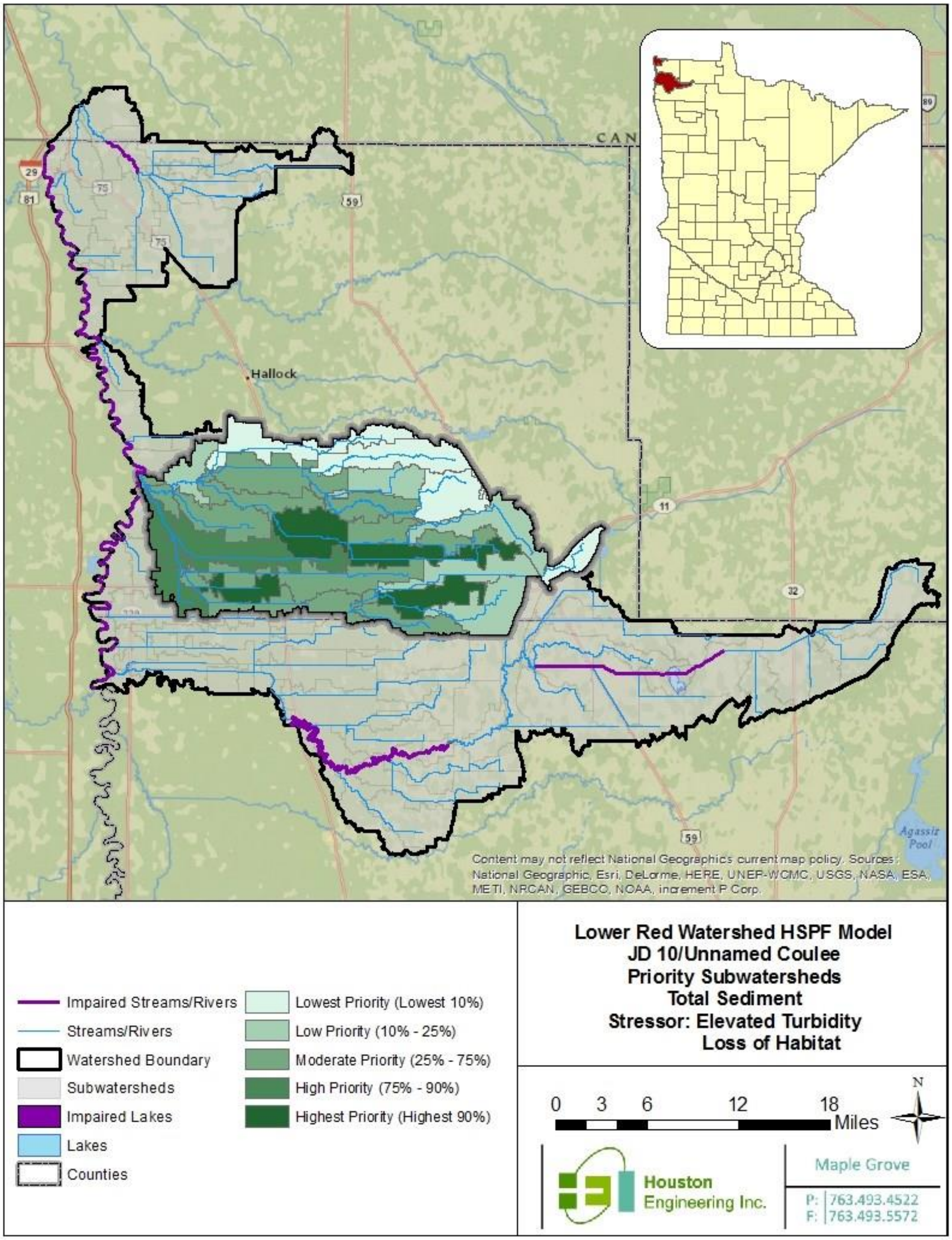


Figure B28: Tributary scale subwatershed priority for implementation for the stressors elevated turbidity and loss of habitat for JD 10/Unnamed Coulee using average (1996-2009) annual total sediment yields.

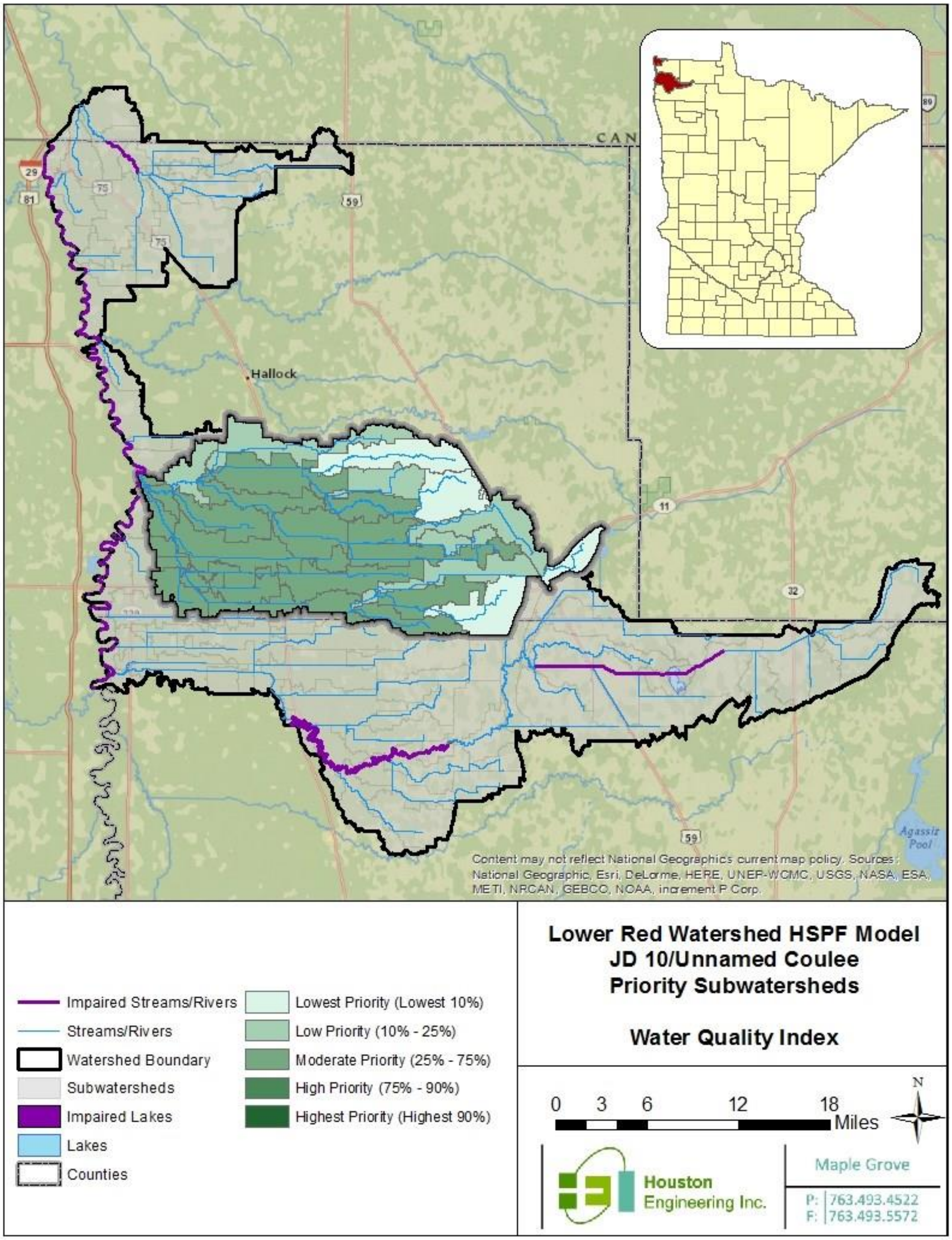


Figure B29: Tributary scale subwatershed priority for implementation for JD 10/Unnamed Coulee, using the average (1996-2009) water quality index.

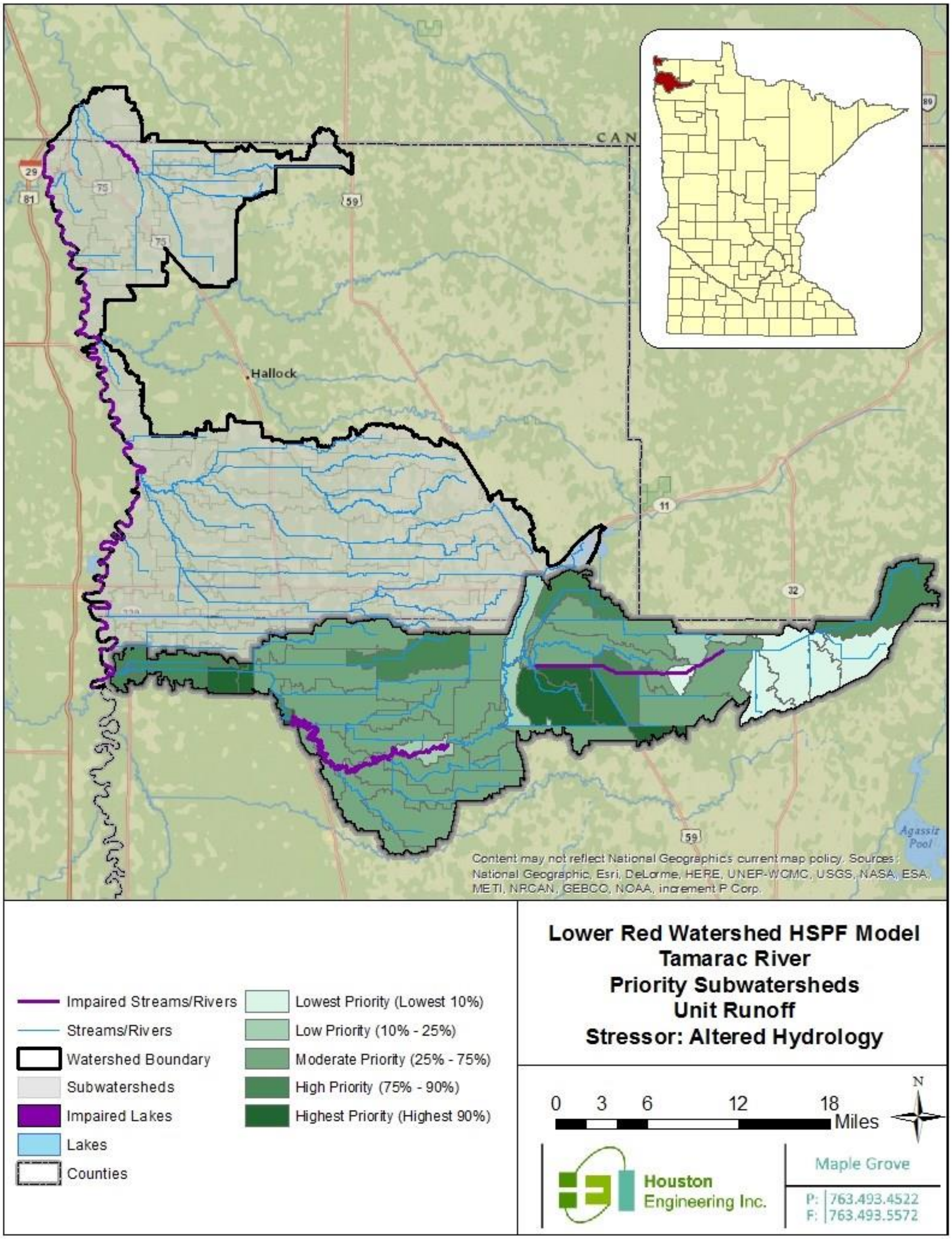


Figure B30: Tributary scale subwatershed priority for implementation for the stressor altered hydrology for Tamarac River, using average (1996-2009) annual unit runoff.

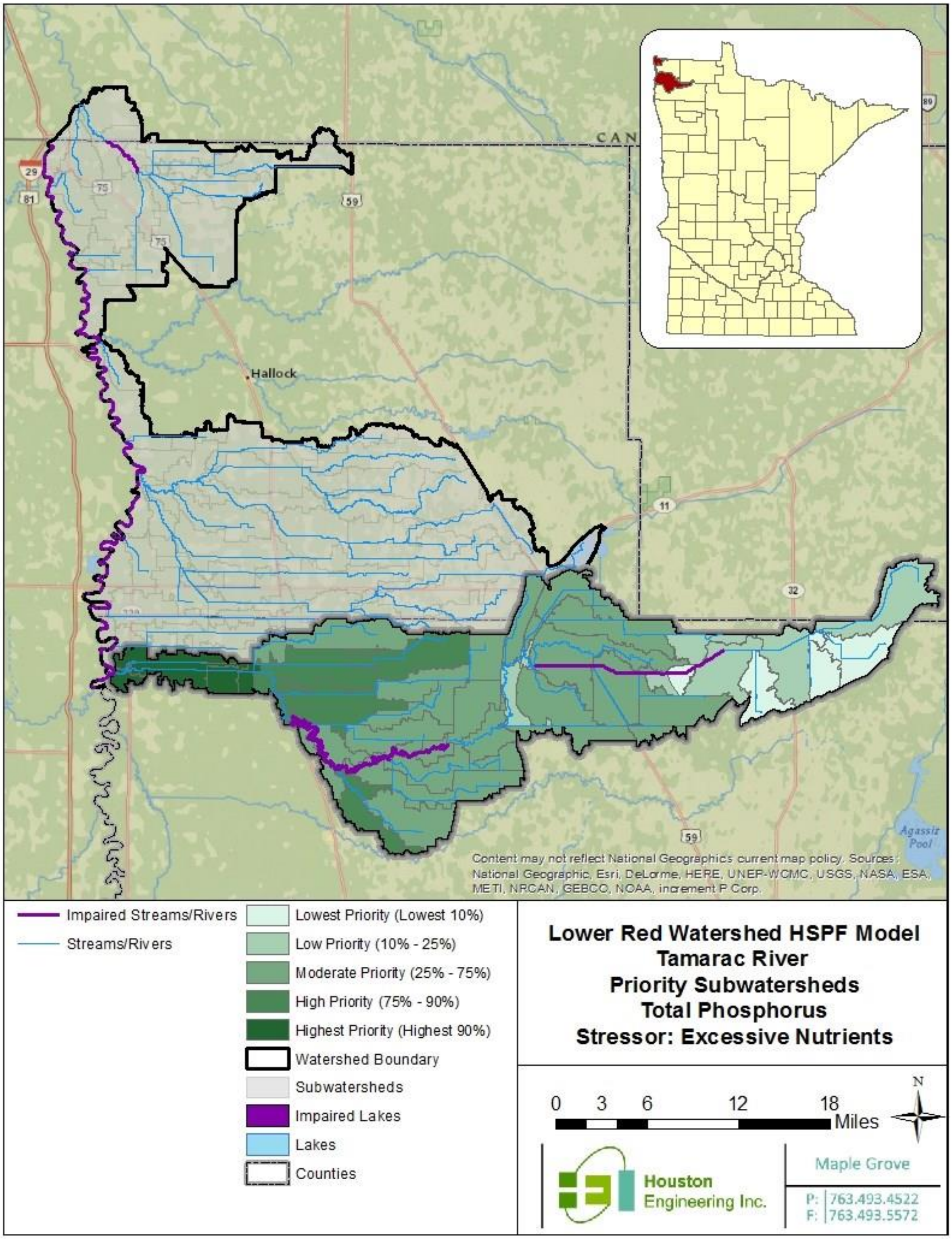


Figure B31: Tributary scale subwatershed priority for implementation for the stressor excessive nutrients for Tamarac River, using average (1996-2009) annual total phosphorus yields.

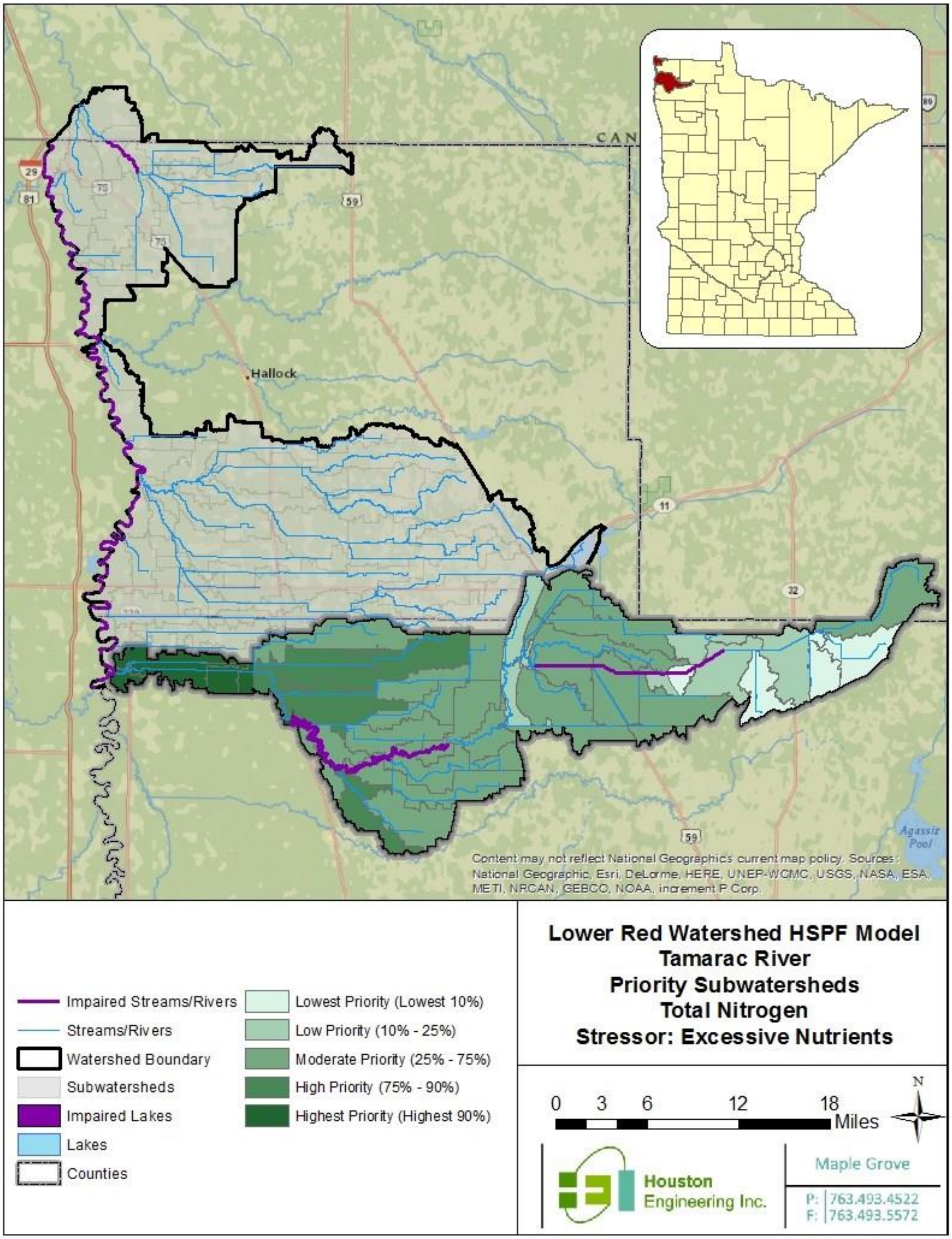


Figure B32: Tributary scale subwatershed priority for implementation for the stressor excessive nutrients for Tamarac River, using average (1996-2009) annual total nitrogen yields.

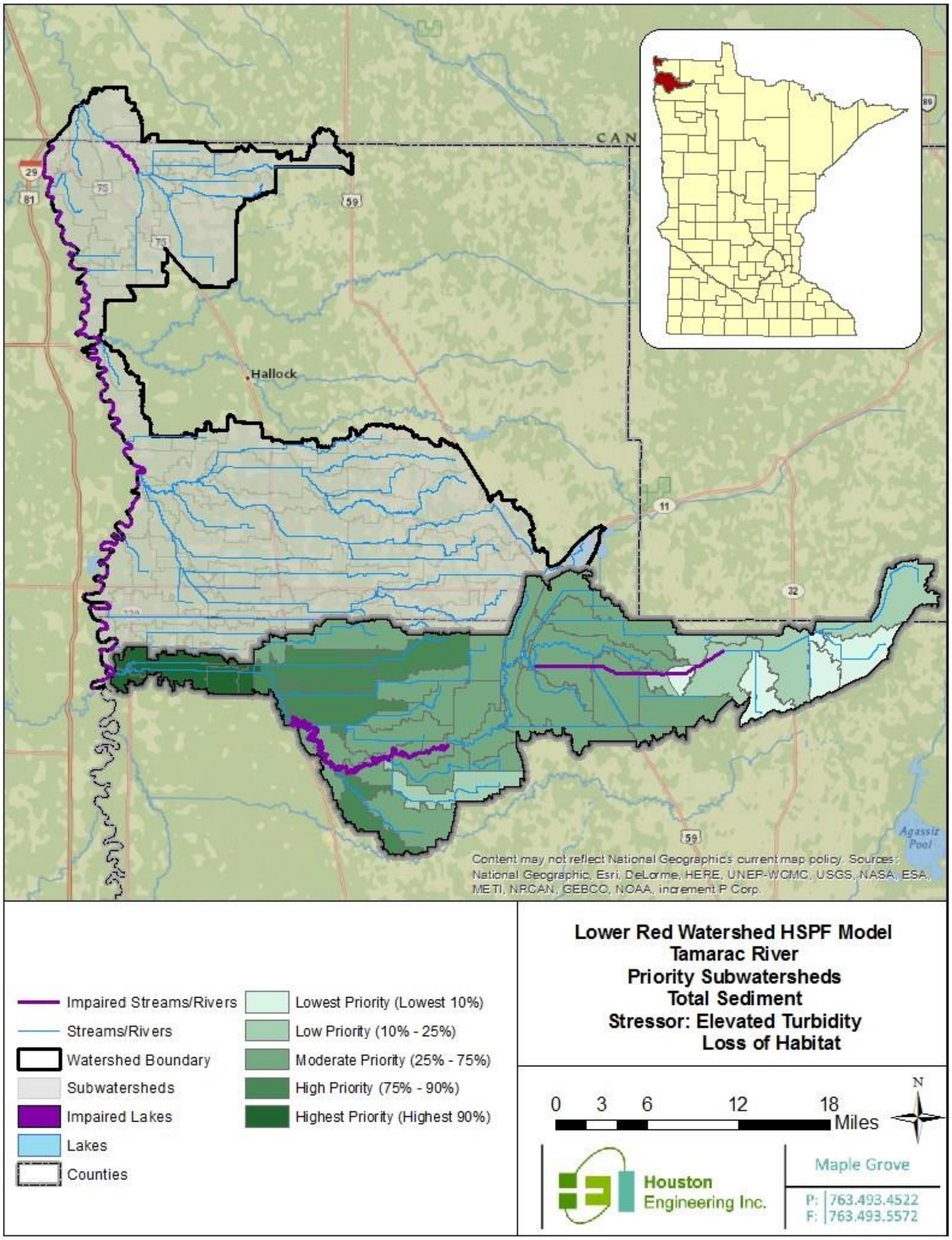


Figure B33: Tributary scale subwatershed priority for implementation for the stressors elevated turbidity and loss of habitat for Tamarac River, using average (1996-2009) annual total sediment yields.

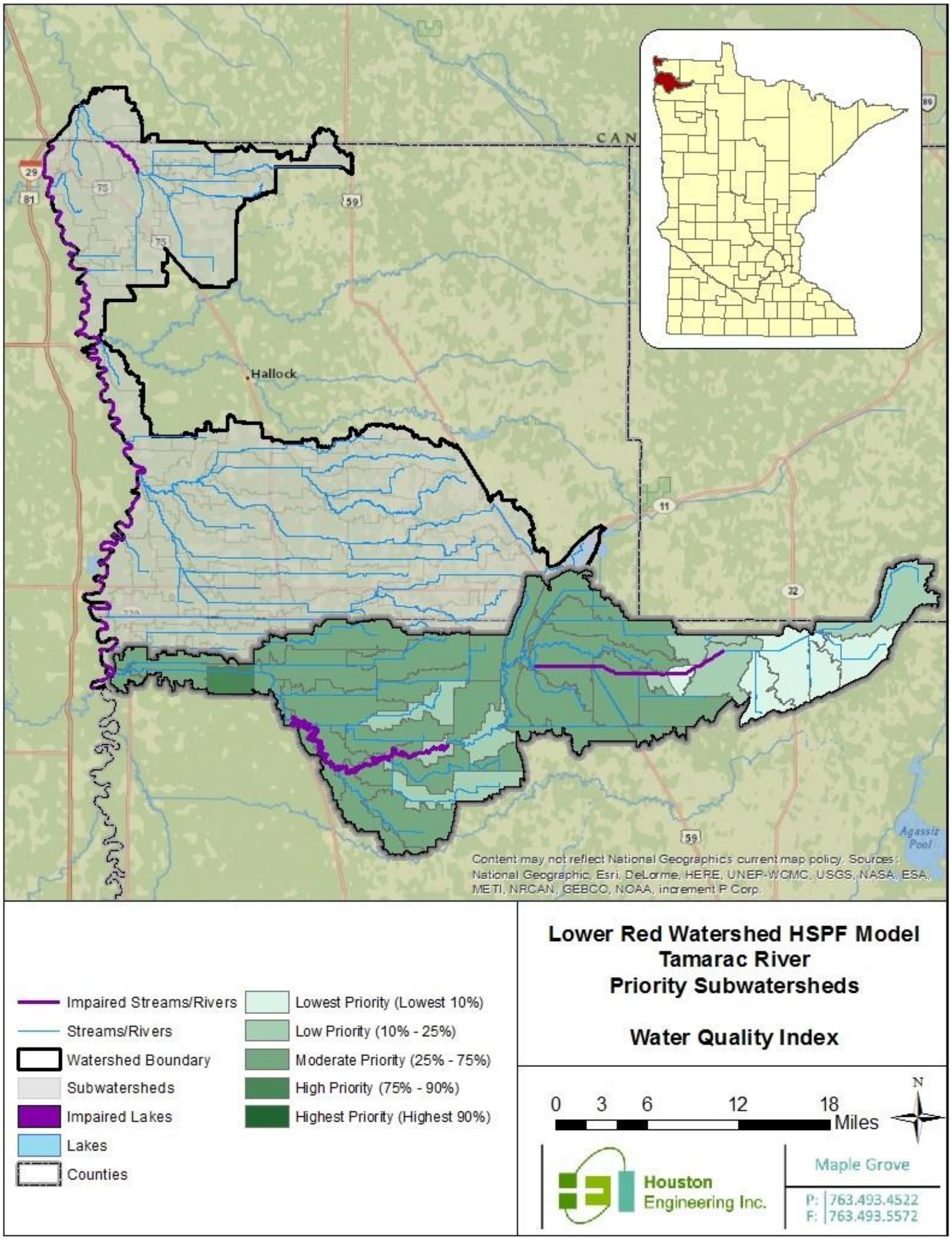


Figure B34: Tributary scale subwatershed priority for implementation for Tamarac River, using the average (1996-2009) water quality index.

Supplemental Table: HSPF Results

Table B2: Water Quality Yields by Subwatersheds (RCHRES).

HSPF RCHRES	Runoff		TP		TN		Sediment		WQI
	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Rank
10	4.41	76.1%	0.11	10.0%	2.11	17.6%	0.008	6.9%	8.1%
11	2.64	2.3%	0.07	3.8%	1.21	4.6%	0.002	3.8%	3.1%
30	1.84	0.0%	0.05	0.7%	0.73	0.0%	0.0002	0.0%	0.0%
31	2.31	1.5%	0.06	3.0%	1.01	1.5%	0.001	2.3%	1.6%
50	2.81	4.6%	0.08	6.1%	1.42	5.3%	0.006	6.1%	4.5%
51	2.08	0.7%	0.06	2.3%	0.89	0.7%	0.001	1.5%	1.0%
70	3.75	22.3%	0.10	8.4%	1.79	9.2%	0.011	8.4%	6.7%
80	2.69	3.8%	0.08	5.3%	1.10	3.8%	0.004	5.3%	3.7%
90	3.91	31.5%	0.11	9.2%	2.01	13.8%	0.014	10.0%	8.7%
91	4.12	43.0%	0.12	13.0%	2.16	19.2%	0.020	16.9%	13.6%
110	4.48	80.0%	0.13	20.7%	2.47	40.0%	0.020	16.1%	18.6%
111	4.68	86.9%	0.15	26.1%	2.65	53.0%	0.033	26.1%	27.0%
130	4.63	85.3%	0.14	23.0%	2.60	48.4%	0.022	20.0%	22.7%
131	4.56	84.6%	0.14	24.6%	2.54	45.3%	0.025	22.3%	23.1%
150	2.88	6.1%	0.06	1.5%	1.06	3.0%	0.001	0.7%	1.1%
151	4.31	63.0%	0.13	21.5%	2.37	36.1%	0.024	21.5%	20.3%
170	3.75	23.0%	0.11	10.7%	1.88	10.7%	0.022	18.4%	12.1%
171	4.34	67.6%	0.20	40.0%	2.50	43.0%	0.087	44.6%	34.1%
173	3.30	8.4%	0.09	6.9%	1.52	6.9%	0.010	7.6%	5.7%
175	4.26	55.3%	0.15	26.9%	2.30	30.7%	0.044	27.6%	22.1%
177	4.32	65.3%	0.13	20.0%	2.36	33.8%	0.023	20.7%	19.3%
190	3.26	7.6%	0.09	7.6%	1.48	6.1%	0.016	11.5%	7.5%
191	3.67	16.1%	0.19	37.6%	2.05	14.6%	0.099	46.9%	28.0%
210	3.74	20.0%	0.11	11.5%	1.84	10.0%	0.022	19.2%	12.4%
211	4.29	59.2%	0.12	16.1%	2.30	30.0%	0.020	15.3%	15.6%
230	3.75	21.5%	0.12	13.8%	2.09	15.3%	0.019	13.8%	11.1%
240	3.88	30.0%	0.13	18.4%	2.22	22.3%	0.020	14.6%	13.3%
250	3.72	19.2%	0.12	15.3%	2.10	16.9%	0.018	13.0%	11.1%
270	3.68	17.6%	0.14	23.8%	2.10	16.1%	0.032	25.3%	17.3%
271	3.85	27.6%	0.13	19.2%	2.19	20.7%	0.021	17.6%	14.5%
273	3.92	33.0%	0.12	14.6%	2.24	23.0%	0.013	9.2%	10.7%
275	3.91	32.3%	0.12	17.6%	2.24	23.8%	0.016	10.7%	11.7%
290	3.81	24.6%	0.18	34.6%	2.25	24.6%	0.065	32.3%	23.2%
310	3.48	11.5%	0.23	50.0%	2.13	18.4%	0.119	50.7%	31.2%
311	4.15	44.6%	0.17	31.5%	2.57	46.1%	0.045	28.4%	26.5%
313	4.27	56.1%	0.27	58.4%	2.84	73.0%	0.137	56.1%	47.8%
330	3.99	36.1%	0.22	47.6%	2.41	36.9%	0.101	47.6%	34.2%
331	3.86	29.2%	0.12	16.9%	2.21	21.5%	0.017	12.3%	11.9%
333	3.94	34.6%	0.14	25.3%	2.29	27.6%	0.032	23.8%	19.4%
335	4.32	64.6%	0.29	62.3%	2.79	66.1%	0.151	60.7%	48.4%
350	4.07	40.7%	0.23	49.2%	2.49	42.3%	0.105	48.4%	36.0%
360	5.29	95.3%	0.29	63.0%	3.79	99.2%	0.158	64.6%	58.7%
390	4.43	76.9%	0.29	64.6%	2.88	74.6%	0.155	63.0%	51.8%
391	4.31	63.8%	0.19	36.1%	2.49	41.5%	0.080	40.7%	31.6%
393	4.22	50.0%	0.25	53.0%	2.69	56.9%	0.120	51.5%	41.3%

HSPF RCHRES	Runoff		TP		TN		Sediment		WQI
	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Rank
410	4.23	51.5%	0.30	70.0%	2.77	64.6%	0.163	66.1%	51.0%
411	4.08	42.3%	0.21	46.1%	2.49	40.7%	0.091	46.1%	34.4%
413	4.45	78.4%	0.24	50.7%	2.67	54.6%	0.129	53.8%	41.8%
415	4.25	53.0%	0.28	60.0%	2.73	58.4%	0.141	56.9%	44.6%
417	4.25	52.3%	0.31	71.5%	2.81	69.2%	0.170	69.2%	53.7%
430	4.55	83.0%	0.44	89.2%	3.27	88.4%	0.296	90.0%	69.3%
450	4.56	83.8%	0.43	88.4%	3.25	87.6%	0.286	89.2%	68.7%
470	4.39	73.8%	0.32	77.6%	2.91	80.0%	0.193	80.0%	61.9%
471	4.37	70.7%	0.31	73.0%	2.88	76.9%	0.184	76.9%	59.5%
490	4.34	66.9%	0.34	83.0%	2.91	79.2%	0.208	84.6%	64.2%
510	3.68	16.9%	0.29	63.8%	2.34	32.3%	0.182	75.3%	47.3%
530	3.60	14.6%	0.16	29.2%	2.01	13.0%	0.067	33.8%	20.9%
531	4.25	53.8%	0.29	65.3%	2.76	63.0%	0.154	61.5%	48.1%
533	4.53	82.3%	0.41	87.6%	3.19	86.9%	0.268	86.9%	67.4%
535	4.40	74.6%	0.16	30.0%	2.59	47.6%	0.047	29.2%	27.3%
550	3.45	10.7%	0.15	27.6%	1.88	11.5%	0.062	30.7%	18.9%
551	4.27	56.9%	0.29	66.9%	2.76	61.5%	0.156	63.8%	48.9%
570	3.90	30.7%	0.25	52.3%	2.44	38.4%	0.129	54.6%	38.2%
590	3.75	23.8%	0.26	55.3%	2.35	33.0%	0.146	57.6%	38.4%
591	4.28	57.6%	0.33	80.0%	2.86	73.8%	0.193	80.7%	60.8%
610	3.82	25.3%	0.27	59.2%	2.42	37.6%	0.154	62.3%	42.0%
611	3.34	9.2%	0.11	12.3%	1.62	8.4%	0.029	23.0%	13.9%
613	4.22	50.7%	0.21	45.3%	2.45	39.2%	0.107	49.2%	35.5%
615	4.05	38.4%	0.17	33.0%	2.28	26.9%	0.071	35.3%	25.2%
617	4.48	80.7%	0.33	80.7%	2.77	65.3%	0.212	85.3%	61.0%
619	4.21	48.4%	0.25	53.8%	2.64	52.3%	0.124	52.3%	40.6%
621	4.39	73.0%	0.30	67.6%	2.67	55.3%	0.179	73.8%	52.4%
623	4.31	62.3%	0.30	69.2%	2.81	70.0%	0.161	65.3%	51.9%
625	4.35	68.4%	0.34	83.8%	2.93	81.5%	0.199	83.0%	64.0%
627	4.29	58.4%	0.30	68.4%	2.81	68.4%	0.168	67.6%	52.6%
629	4.30	60.0%	0.31	70.7%	2.82	70.7%	0.173	70.7%	54.8%
631	4.17	45.3%	0.31	72.3%	2.74	59.2%	0.179	74.6%	53.9%
633	4.32	66.1%	0.34	82.3%	2.90	77.6%	0.198	82.3%	62.6%
635	4.26	54.6%	0.33	78.4%	2.83	72.3%	0.190	79.2%	59.6%
637	4.22	49.2%	0.32	76.1%	2.80	66.9%	0.185	77.6%	57.4%
639	4.31	61.5%	0.33	81.5%	2.88	76.1%	0.195	81.5%	61.8%
641	4.18	46.1%	0.32	74.6%	2.76	60.7%	0.183	76.1%	55.1%
643	3.17	6.9%	0.07	4.6%	1.58	7.6%	0.003	4.6%	4.3%
645	4.36	70.0%	0.26	54.6%	2.80	67.6%	0.127	53.0%	44.8%
647	4.20	47.6%	0.19	36.9%	2.50	43.8%	0.072	36.1%	29.9%
649	4.39	72.3%	0.32	75.3%	2.95	82.3%	0.173	70.0%	57.5%
651	3.92	33.8%	0.13	22.3%	2.29	29.2%	0.034	26.9%	21.3%
653	4.44	77.6%	0.33	79.2%	3.00	83.0%	0.179	73.0%	59.2%
655	4.06	40.0%	0.19	38.4%	2.63	51.5%	0.066	33.0%	30.3%
657	4.30	60.7%	0.27	56.1%	2.76	62.3%	0.132	55.3%	44.6%
659	4.08	41.5%	0.21	44.6%	2.33	31.5%	0.108	50.0%	34.0%
661	3.55	13.8%	0.16	30.7%	1.90	12.3%	0.079	40.0%	23.8%
663	4.38	71.5%	0.29	61.5%	2.88	75.3%	0.149	59.2%	50.0%
665	4.40	75.3%	0.35	85.3%	2.75	60.0%	0.234	86.1%	60.2%

HSPF RCHRES	Runoff		TP		TN		Sediment		WQI
	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Rank
667	4.46	79.2%	0.35	84.6%	3.09	86.1%	0.201	83.8%	65.5%
669	4.49	81.5%	0.32	76.9%	3.03	84.6%	0.174	71.5%	58.8%
671	4.04	37.6%	0.20	41.5%	2.68	56.1%	0.073	36.9%	33.5%
673	4.36	69.2%	0.32	73.8%	2.93	80.7%	0.169	68.4%	56.2%
675	4.04	36.9%	0.29	66.1%	2.61	50.0%	0.166	66.9%	47.6%
677	3.74	20.7%	0.27	56.9%	2.36	34.6%	0.151	60.0%	40.1%
690	3.98	35.3%	0.20	42.3%	2.63	50.7%	0.075	37.6%	32.5%
691	4.20	46.9%	0.22	48.4%	2.82	71.5%	0.083	43.0%	40.6%
693	4.06	39.2%	0.21	43.8%	2.69	57.6%	0.077	38.4%	34.7%
710	3.55	13.0%	0.17	33.8%	2.25	25.3%	0.062	30.0%	22.2%
711	4.14	43.8%	0.22	46.9%	2.77	63.8%	0.081	41.5%	37.9%
730	2.68	3.0%	0.05	0.0%	1.03	2.3%	0.002	3.0%	2.1%
750	4.71	87.6%	0.39	86.1%	3.05	85.3%	0.271	87.6%	67.3%
751	5.26	94.6%	0.47	92.3%	3.56	92.3%	0.334	91.5%	71.1%
770	3.85	28.4%	0.27	57.6%	2.26	26.1%	0.176	72.3%	44.1%
771	5.20	91.5%	0.47	91.5%	3.51	90.7%	0.331	90.7%	70.3%
790	3.37	10.0%	0.17	32.3%	2.19	20.0%	0.070	34.6%	23.1%
792	3.72	18.4%	0.19	39.2%	2.50	44.6%	0.083	42.3%	33.3%
810	3.53	12.3%	0.16	28.4%	2.29	28.4%	0.064	31.5%	23.6%
811	3.84	26.1%	0.20	40.7%	2.59	46.9%	0.086	43.8%	34.6%
830	2.82	5.3%	0.69	100.0%	13.59	100.0%	0.032	24.6%	39.8%
831	5.25	93.8%	0.49	94.6%	3.61	93.8%	0.368	93.8%	72.7%
832	4.73	88.4%	0.28	60.7%	2.66	53.8%	0.186	78.4%	54.2%
835	4.89	89.2%	0.24	51.5%	2.91	78.4%	0.147	58.4%	50.1%
837	5.32	96.9%	0.51	96.1%	3.64	95.3%	0.387	96.9%	74.7%
839	5.35	97.6%	0.53	99.2%	3.70	96.9%	0.402	99.2%	76.3%
841	5.23	93.0%	0.49	93.0%	3.54	91.5%	0.370	95.3%	72.9%
843	4.66	86.1%	0.39	86.9%	3.02	83.8%	0.284	88.4%	67.3%
845	5.18	90.7%	0.46	90.0%	3.46	90.0%	0.345	92.3%	70.9%
847	5.37	98.4%	0.51	96.9%	3.68	96.1%	0.390	97.6%	75.2%
849	5.31	96.1%	0.49	93.8%	3.61	94.6%	0.368	94.6%	73.3%
851	5.15	90.0%	0.47	90.7%	3.43	89.2%	0.347	93.0%	71.1%
853	5.40	99.2%	0.53	98.4%	3.73	97.6%	0.402	100.0%	76.9%
855	5.40	100.0%	0.52	97.6%	3.73	98.4%	0.395	98.4%	76.2%
857	5.23	92.3%	0.49	95.3%	3.58	93.0%	0.372	96.1%	73.7%
859	3.66	15.3%	0.18	35.3%	2.36	35.3%	0.078	39.2%	29.3%
861	3.85	26.9%	0.21	43.0%	2.61	49.2%	0.090	45.3%	36.0%

Appendix C

Lower Red WEPS Modeling, Technical Memorandum

Technical Memorandum

To: Dan Money, Two Rivers Watershed District

Danny Omdahl, Middle – Snake – Tamarac Rivers Watershed

Cary Hernandez, Minnesota Pollution Control Agency

From: Kris Guentzel; Drew Kessler Ph.D.

Houston Engineering, Inc.

Through: Mark R. Deutschman Ph.D., P.E.

Subject: Lower Red WEPS Modeling

Date: May 31, 2016

Project: 6279-002 Lower Red TMDL/WRAPS

INTRODUCTION

Houston Engineering, Inc. (HEI) has been retained to develop WEPS models for the Lower Red River (LRR) WRAPS study area. The WEPS assessment is being conducted to help quantify the magnitude of Aeolian (i.e., wind) erosion in the LRRW relative to other sources, and to inform restoration and protection strategies. This effort was initiated based on comments provided during a November 19, 2015 meeting of the Snake-Two-Joe Joint Powers Board (JPB), concerning the inclusion of wind erosion within the WRAPS and TMDL reports. A motion was made and carried during the meeting to amend the contract to include wind erosion estimates within the LRRW study area.

"Lower Red Watershed Restoration and Protection Project – Phases 1 and 2" work plan as 'Objective 8' (hereafter referred to as the work plan), which tasks the consultant contractor (HEI) with three specific components associated with the collection and preparation of model data, model running and analysis, and the creation of output products and maps which could be incorporated into the WRAPS development.

This technical memorandum (TM) discusses the methods and information used to run the WEPS models, along with results and a discussion of the implications of those results. The memorandum was written to accompany a mapbook detailing the agricultural fields most susceptible to wind erosion based on existing crop and field conditions. Therefore, this TM is designed to discuss these results and provide a framework with which to apply them to LRRW conservation planning.

The importance of this effort is driven primarily by the magnitude of wind erosion through the LRR valley, caused by both environmental and anthropogenic factors. The valley overlays the Glacial Lake Agassiz lake plain, which is extraordinarily flat. With grade changes on the order of inches per mile across the watershed, there is limited landscape relief to dampen high wind gusts. Anthropogenic factors affecting wind erosion include intensive agriculture with crops such as soybeans, sugarbeets, spring wheat, and numerous hay varieties, loss of pre-settlement forested areas and native grasslands, and the continued reduction in shelter belts and conservation wind breaks. The combination of these factors lead to conditions which promote high rates of sediment loss through Aeolian forces, create intensive maintenance needs to public and private landowners, and negatively impact priority resources through sediment and nutrient pollution (**Figure C1**).

Figure C1: Photos illustrating (a) edge-of field wind erosion following a high wind event, and (b) ditch maintenance to remove eroded sediment.

METHODS

Wind Erosion Processes

Wind erosion is primarily driven by three processes:

1. Creep – medium to very coarse sand particles and small clods 0.84 - 2.00 mm (0.033 - 0.078 in.) in diameter which roll along the ground surface as they are often too large to be lifted off the soil surface by wind alone;
2. Saltation – fine to medium coarse sand particles 0.10 – 0.84 mm (0.040 - 0.033 in.) in diameter which "hop" over the soil surface and have the ability to erode still more particles as grains strike the ground with each "hop". As a result, saltation can lead to even more particle transport through creep and suspension as it breaks additional dirt clods from the soil; and
3. Suspension – smaller particles < 0.10 mm (0.040 in.) such as clay, silt, and very fine sands which are lifted from the soil surface and are often deposited great distances from the site of erosion. Because of this suspended particles can be a detriment to both water and air quality. WEPS distinguishes PM10 particles, or particulate matter with a diameter < 10 microns (0.0004 in.), from other suspended particles as they greatly degrade air quality and are particularly hazardous to human health.

WEPS models each of these processes discretely, but reports:

1. Creep and saltation values together, and
2. PM10 particle values separately from the larger suspended grains.

Therefore, the three reported erosion terms are creep/saltation, suspension, and PM10. When reporting total annual erosion (tons) and annual erosive yield (tons/acre), these processes will be reported together. Additional information on wind erosion and its use in WEPS is detailed by Wagner (2013) and Presley & Tatarko (2009).

Determination of Wind Erosion Zones

WEZs were established to estimate field-scale erosion in WEPS while generalizing factors across multiple fields within the LRRW study area. Wind-driven sediment erosion is controlled by parameters including, but not limited to, soil character and moisture content, crop type, field management practices, field orientation and barriers, topography, and local meteorology. In an attempt to summarize these parameters, three factors were used to develop a manageable number of WEZs:

1. Agricultural parcels determined from USDA CLU database;
2. Information on crop rotations derived from the NASS CDL; and
3. Revised Universal Soil Loss (RUSLE) K_w factor.

Although developed for sheet and rill erosion, the RUSLE K_w factor can also be an indicator of soil susceptible to Aeolian erosion. K_w factors were grouped to reduce the number of potential zones and to categorize soil types based on erodibility. K_w factors in the LRRW study area ranged from 0 to 0.55, and were grouped in increments of 0.05 based on the average soil K_w factor within each CLU. In total, eight K_w factor groups were created with field-averaged K_w factors ranging from 0 to 0.37.

Only parcels designated as agricultural within the CLU database were included in determining wind erosion in the LRRW, as agricultural fields tend to be more susceptible to wind erosion than other land uses, particularly when bare soils are exposed (i.e. early spring and following autumn harvest). Land uses removed from analysis included low and medium density housing, rural homesteads, forests, pastureland, fallow/grasslands, wetlands, and open water. No wind erosion will be assigned for these parcels.

Any CLU either completely within or intersecting with the hydrologic boundary was included as part of the study area. Wind erosion, unlike sheet and rill erosion caused by precipitation events and snowmelt, does not follow hydrologic boundaries such as those set by the TMDL and WRAPS studies. Including the portions of fields which were initially excluded from previous hydrologic analyses in the watershed added 10,803 acres. Even with including this additional adjacent acreage, the exclusion of non-agricultural area reduced the study area for this analysis to 636 mi^2 from the 886 mi^2 used for the TMDL/WRAPS studies.

Agricultural CLUs were then divided based on crop type using the NASS CDL from 2011 to 2014 to establish the primary summer crop for each agricultural parcel. The crop planted most frequently within a 4-year rotation was used to determine the primary crop type for a particular field. In the case of a single crop being planted each of those years, or in the case that two crops are rotated every other year, the crop planted most recently (2014) was used as the primary crop type for the given field.

The dominant crop planted on agricultural CLUs was combined with the K_w groups to cluster all agricultural parcels into 108 distinct WEZs within the LRRW study area. WEZs larger than 1,000 acres, 23 in total across the LRRW (**Table C1**), were selected from the group of 108 for WEPS modeling. These 23 WEZs were selected for two reasons. First, the total area of the excluded zones (15,160 acres) represents a very small portion of the LRRW study area (2.3%; and 3.7% of the agricultural CLU acreage). Second, the inclusion of all 108 WEZs would have greatly increased the number of zones to model, lessening the amount of parcels that could be modeled in each zone. Areas excluded from these zones were later added to the most similar zone modeled based on primary crop type and RUSLE K_w. For example, no WEZs were created for barley, oats, or millet. Acreage from these fields were instead included with WEZs for spring wheat (another small grain with comparable planting, harvesting, and tillage techniques) with similar K_w factors.

Lastly, a random, stratified sample was generated using the ESRI Sampling Design Tool to find two parcels within each of the 23 WEZs. The latitude and longitude generated for each of these points are listed in **Table C2** and the 46 fields subsequently modeled in WEPS based on these points are shown in **Figure C2**. Annual erosive yield (tons/acre/year) predicted for each of the WEPS erosion processes (creep/saltation, suspension, and PM10) was totaled for each field and averaged across the two sample fields to determine a total annual erosive yield for each WEZ. This yield was then extrapolated to other parcels within each respective WEZ and aggregated with other WEZs in the LRRW study area to estimate wind erosion generated within each 10-digit HUC.

Climate and meteorological information were also explored as a potential summary parameter in addition to land cover and soil erodibility. Wind power classes developed by the National Renewable Energy Laboratory were initially used as a summary variable but only a single class was found to have a WEZ larger than 1,000 acres. Although a wind parameter wasn't included in the aggregation of WEZs, spatial variability of wind speed and direction was still taken into account as part of the model run for each parcel as WEPS drew local meteorological information from one of multiple climate stations throughout the LRRW study area. Those climate data also implicitly included information on local topology, as the flat terrain has very limited means for reducing wind speeds in the region.

Table C1: Wind erosion zones modeled using the Wind Erosion Prediction System, based on primary crop type and RUSLE K_w factor group.

Wind Erosion Zone	Dominant Crop Type in Rotation	K_w Factor Group
1	Alfalfa	0.16-0.20
2	Alfalfa	0.21-0.25
3	Canola	0.16-0.20
4	Corn	0.21-0.25
5	Corn	0.26-0.30
6	Non-Alfalfa Hay	0.06-0.10
7	Non-Alfalfa Hay	0.11-0.15
8	Non-Alfalfa Hay	0.16-0.20
9	Non-Alfalfa Hay	0.21-0.25
10	Non-Alfalfa Hay	0.26-0.30
11	Soybeans	0.11-0.15
12	Soybeans	0.16-0.20
13	Soybeans	0.21-0.25
14	Soybeans	0.26-0.30
15	Soybeans	0.31-0.35
16	Spring Wheat	0.11-0.15
17	Spring Wheat	0.16-0.20
18	Spring Wheat	0.21-0.25
19	Spring Wheat	0.26-0.30
20	Spring Wheat	0.31-0.35
21	Sugarbeets	0.16-0.20
22	Sugarbeets	0.21-0.25
23	Sugarbeets	0.26-0.30

Table C2: Wind Erosion Prediction System model input values for each wind erosion zone, excluding natural and conservation wind breaks constituting edge of field barriers.

Model Run	Wind Erosion Zone (WEZ)	Field	Field Location		Field Area (acres)	Crop - Based on Rotation Year				SSURGO Soil		
			Latitude	Longitude		1	2	3	4	Name	MUSYM	Kw
1	Alfalfa; 0.16-0.20	1	48.68183	-96.98849	5.3	Spring Wheat	Non-Alfalfa Hay	Non-Alfalfa Hay	Alfalfa Hay	Northcote	I133A	0.17
2		2	48.95359	-96.97417	0.00	Alfalfa Hay	Alfalfa Hay	Spring Wheat	Winter Wheat	Northcote	I140A	0.17
3	Alfalfa; 0.21-0.25	1	48.44974	-96.68156	24.66	Alfalfa Hay	Alfalfa Hay	Alfalfa Hay	Alfalfa Hay	Garborg	I57B	0.17
4		2	48.51462	-96.58964	54.74	Non-Alfalfa Hay	Non-Alfalfa Hay	Alfalfa Hay	Alfalfa Hay	Rosewood	I194A	0.28
5	Canola; 0.16-0.20	1	48.69114	-96.98438	141.29	Soybeans	Spring Barley	Canola		Northcote	I133A	0.17
6		2	48.61224	-96.88300	55.07	Sunflower	Spring Barley	Spring Wheat	Canola	Northcote	I140A	0.17
7	Corn; 0.21-0.25	1	48.46040	-96.52064	51.94	Corn	Soybeans	Corn	Alfalfa Hay	Enstrom	I113A	0.43
8		2	48.51311	-97.03045	305.80	Spring Wheat	Soybeans	Sugarbeets	Corn	Bearden	I124A	0.43
9	Corn; 0.26-0.30	1	48.70545	-96.79154	151.30	Soybeans	Spring Wheat	Sugarbeets	Corn	Lindaas	I119A	0.32
10		2	48.51870	-96.71702	160.70	Spring Wheat	Dry Beans	Sugarbeets	Corn	Augsburg	I111A	0.24
11	Other Hay/Non Alfalfa; 0.06-0.10	1	48.60048	-96.69046	137.38	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Karlsruhe	I98A	0.24
12		2	48.57426	-96.58935	159.39	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Maddock	I118A	0.2
13	Other Hay/Non Alfalfa; 0.11-0.15	1	48.69072	-96.66366	79.78	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Redby	I91A	0.2
14		2	48.57491	-96.61440	149.91	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Maddock	I118A	0.2
15	Other Hay/Non Alfalfa; 0.16-0.20	1	48.56056	-96.65803	153.93	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Eckvoll	I114A	0.28
16		2	48.42847	-96.61057	66.29	Non-Alfalfa Hay	Non-Alfalfa Hay	Soybeans	Barley	Poppleton	I15A	0.1
17	Other Hay/Non Alfalfa; 0.21-0.25	1	48.42599	-96.66657	80.31	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Poppleton	I15A	0.1
18		2	48.62638	-96.61279	11.80	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Strandquist	I101A	0.24
19	Other Hay/Non Alfalfa; 0.26-0.30	1	48.97085	-96.93132	134.68	Non-Alfalfa Hay	Soybeans	Soybeans	Non-Alfalfa Hay	Boash	I84A	0.28
20		2	48.69500	-96.75599	32.35	Spring Wheat	Non-Alfalfa Hay	Non-Alfalfa Hay	Non-Alfalfa Hay	Skagen	I125A	0.32
21	Soybeans; 0.11-0.15	1	48.55280	-96.73520	23.36	Soybeans	Non-Alfalfa Hay	Soybeans	Soybeans	Karlsruhe	I98A	0.24
22		2	48.47867	-96.94369	157.29	Spring Wheat	Soybeans	Spring Wheat	Soybeans	Bearden	I132A	0.28
23	Soybeans; 0.16-0.20	1	48.59109	-96.86187	465.69	Soybeans	Winter Wheat	Soybeans	Soybeans	Northcote	I140A	0.17
24		2	48.60255	-96.87274	151.27	Soybeans	Soybeans	Soybeans	Soybeans	Northcote	I140A	0.17
25	Soybeans; 0.21-0.25	1	48.34535	-96.67215	159.71	Soybeans	Spring Wheat	Corn	Soybeans	Poppleton	I65A	0.02
26		2	48.90022	-97.09071	617.41	Corn	Soybeans	Corn	Soybeans	Hegne	I123A	0.28
27	Soybeans; 0.26-0.30	1	48.99962	-97.19211	136.42		Sugarbeets	Spring Wheat	Soybeans	Lindaas	I119A	0.32
28		2	48.53511	-97.09781	139.27	Soybeans	Sugarbeets	Soybeans	Soybeans	Bearden	I123A	0.43

Model Run	Wind Erosion Zone (WEZ)	Field	Field Location		Field Area (acres)	Crop - Based on Rotation Year				SSURGO Soil		
			Latitude	Longitude		1	2	3	4	Name	MUSYM	Kw
29	Soybeans; 0.31-0.35	1	48.37631	-96.70649	153.55	Soybeans	Soybeans	Soybeans	Soybeans	Perella	I376A	0.28
30		2	48.32026	-96.71930	94.97	Soybeans	Soybeans	Corn	Soybeans	Wheatville	I23A	0.55
31	Spring Wheat; 0.11-0.15	1	48.51623	-96.84399	158.85	Spring Wheat	Spring Wheat	Soybeans	Spring Wheat	Eaglepoint	I33A	0.17
32		2	48.64005	-96.68926	19.72	Spring Wheat	Soybeans	Spring Wheat	Sugarbeets	Karlsruhe	I98A	0.24
33	Spring Wheat; 0.16-0.20	1	48.94293	-97.00123	292.34		Spring Wheat	Soybeans	Spring Wheat	Northcote	I32A	0.17
34		2	48.96507	-96.98149	291.48	Spring Wheat	Spring Wheat	Spring Wheat	Soybeans	Northcote	I140A	0.17
35	Spring Wheat; 0.21-0.25	1	48.68761	-96.81516	157.20	Soybeans	Spring Wheat	Spring Wheat	Sugarbeets	Lindaas	I119A	0.32
36		2	48.45515	-96.77502	155.25	Spring Wheat	Soybeans	Spring Wheat	Sugarbeets	Perella	I376A	0.28
37	Spring Wheat; 0.26-0.30	1	48.59176	-96.74965	234.09	Spring Wheat	Spring Wheat	Soybeans	Spring Wheat	Glyndon	I111A	0.43
38		2	48.48814	-96.70440	159.06	Soybeans	Spring Wheat	Soybeans	Spring Wheat	Wheatville	I23A	0.55
39	Spring Wheat; 0.31-0.35	1	48.41815	-96.77365	160.39	Spring Wheat	Dry Beans	Spring Wheat	Sugarbeets	Bearden	I467A	0.37
40		2	48.72409	-96.79745	287.56	Spring Wheat	Soybeans	Spring Wheat	Sugarbeets	Glyndon	I111A	0.43
41	Sugarbeets; 0.16-0.20	1	48.98635	-97.03940	96.21	Sugarbeets	Soybeans	Spring Wheat	Sugarbeets	Northcote	I145A	0.17
42		2	48.49684	-97.10079	43.60	Spring Wheat	Soybeans	Soybeans	Sugarbeets	Bearden	I130A	0.28
43	Sugarbeets; 0.21-0.25	1	48.67796	-97.06192	153.57	Sugarbeets	Soybeans	Spring Wheat	Sugarbeets	Hegne	I123A	0.28
44		2	48.49257	-96.78705	155.78	Spring Wheat	Sugarbeets	Spring Wheat	Sugarbeets	Huot	I9A	0.24
45	Sugarbeets; 0.26-0.30	1	48.99708	-97.18231	172.91	Sugarbeets	Soybeans	Spring Wheat	Sugarbeets	Lindaas	I119A	0.32
46		2	48.56697	-97.13356	132.99	Sugarbeets	Soybeans	Spring Wheat	Sugarbeets	Hegne	I123A	0.28

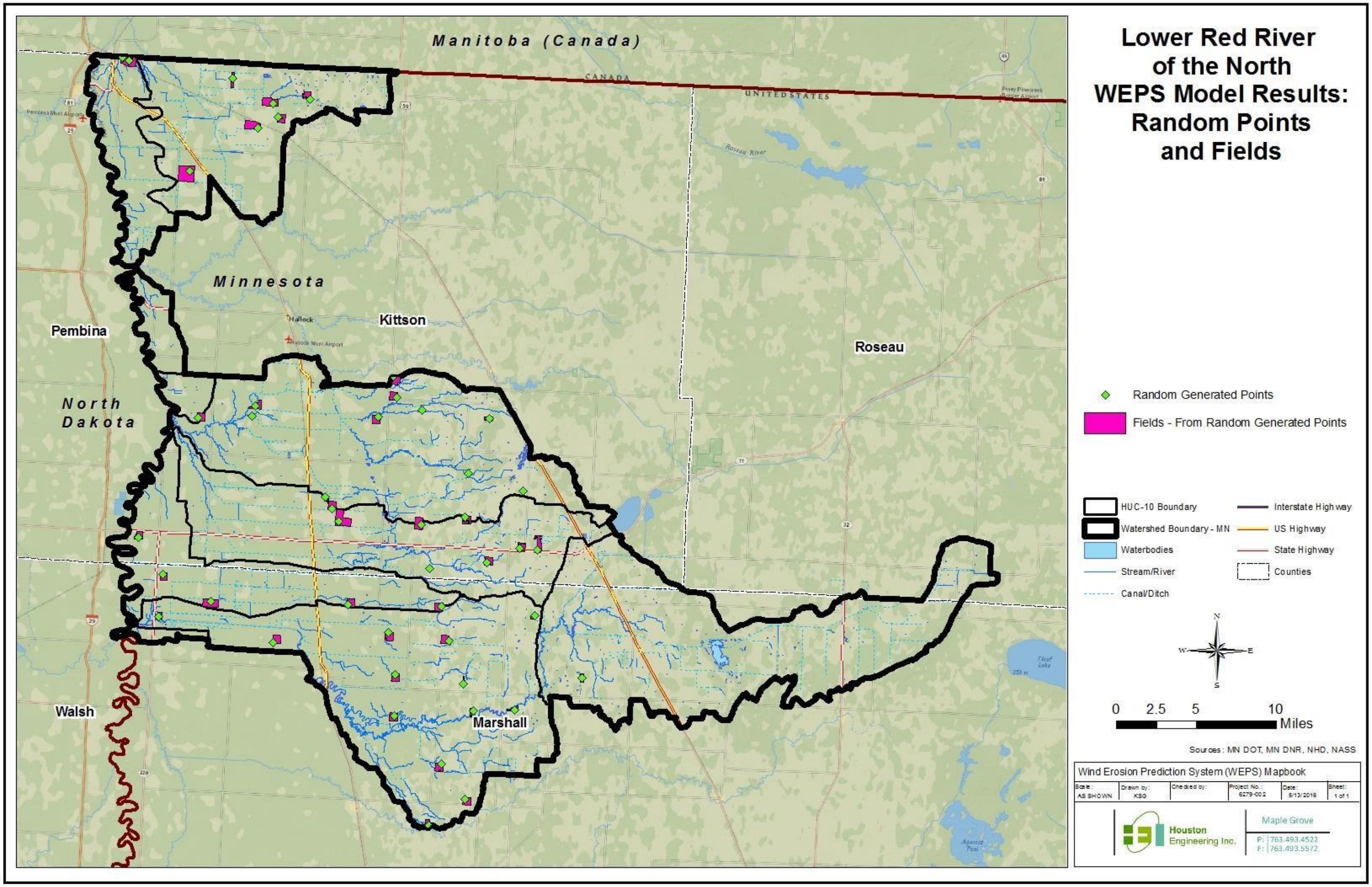


Figure C2: Sample points generated through the random, stratified sample, with their accompanying fields. Wind erosion estimates were modeled using the Wind Erosion Prediction System for the locations shown.

Additional WEPS Modeling Considerations

Crop type and field management activities can have a significant effect on field wind erosion in a given year, so inclusion of on-field management and operations within WEPS is very important. In an effort to properly describe field practices, a set of typical farming operations were determined for each crop utilizing resources from Minnesota and North Dakota Extension Services as well as the US and Minnesota Departments of Agriculture. Specific sources are listed in the References section of this TM. The operations used for WEPS modeling are detailed in **Table C3**. Please note that the operations listed in **Table C3** primarily use implements common in conventional tillage practices. Although reduced till and no-till are increasing in the Red River Valley, conventional tillage is still most prevalent for many crop types.

Additional assumptions and strategies were followed for each emboldened item as listed below:

1. **Irrigation** was only proposed to be included when it was apparent in aerial photography (e.g. center pivot or lateral side roll). Analyzing aerials for each of the 46 fields chosen by the random, stratified sample, no evidence of surficial irrigation practices were found. Therefore, irrigation was not included with any of the WEPS models.

2. Similar to irrigation, **field barriers** were only included when evident through aerial photography or first-person knowledge of the field. Due to the ephemeral nature of most conservation field breaks, these were modeled separately from the "base" model, or the model used to determine existing field conditions. Natural field barriers were included with the base model, such as forested parcels or riparian corridors, which had evidence of:

   i. Being in place for at least the last 20 years based on historical aerial photographs, and
   ii. Were at least 50 feet in width, which is larger than the width of most conservation wind breaks and equivalent to the average buffer width proposed along public waters according to the new Minnesota buffer law.

   Both conservation and natural wind breaks were modeled with their width (ft.), height (ft.), and porosity based on the most recent (2015) aerial photographs available.

3. WEPS only allows for a single **soil type** to be modeled for each field, so the most erosive soil (based on K_w factor) greater than 20% of CLU area was modeled across the entire field.

4. Orientation and shape of the field can be important as wind speed, direction, and field barrier size and orientation can have a significant effect on annual wind erosion loads. **Field shape** was represented within WEPS as a standard polygon, such as a square, circle, or half-circle. Fields were characterized as close as possible to their actual shape and orientation.

5. **Crop Rotations** also play a big role in determining the wind erosion capacity of a field, as annual erosion rates from a particular field may change based on the crop(s) planted, tillage practices used to plant and harvest the crop, and the residue remaining on the field following harvest. Rotation information derived from NASS CDL data for years 2011-2014 were used to assign farming operations for up to four years for each of the two parcels randomly generated within each WEZ. The typical operations schedules and practices listed in **Table C3** were used as model input for each rotation year.

Table C3: Typical field management operations based on crop type modeled using the Wind Erosion Prediction System.

Crop Types	Spring/Early Year Tillage: First Operation Date	Spring/Early Year Tillage: First Operation Information	Spring/Early Year Tillage: Second Operation (if necessary) Date	Spring/Early Year Tillage: Second Operation (if necessary) Information	Planting Date[1]	Planting Operation Information	Irrigation[2] Prevalence (High/Med./Low)	Harvest: First Operation Date[1]	Harvest: First Operation Information	Harvest: Second Operation (if necessary) Date[1]	Harvest: Second Operation (if necessary) Information	Fall/Late Year Tillage Date	Fall/Late Year Tillage Operation Information
Small Spring Grains (Barley, Oats, Wheat)	8-Apr	Cultivator, 6-12" field sweeps	11-Apr	Cultivator, 6-12" field sweeps	15-Apr	Drill or airseeder, double disk	Low	26-Jul	Harvest grains, killing crop, leaving %50 standing stubble			1-Aug	Chisel with sweep shovel
Wheat, Winter	18-Aug	Cultivator, 6-12" field sweeps	21-Aug	Cultivator, 6-12" field sweeps	25-Aug	Drill or airseeder, double disk	Low	20-Jul	Harvest grains, killing crop, leaving %50 standing stubble			26-Jul	Chisel with sweep shovel
Hay, Alfalfa and other varieties[3, 4]	23-Apr	Heavy tandem disk			1-May	Drill or airseeder, double disk	Low	25-May	Harvest, hay and/or legume			1-Jun	Chisel with spike points
Corn[5]	15-Apr	Heavy offset disk	18-Apr	Cultivator, 6-12" field sweeps	22-Apr	Planter, double disk opnr	Medium-High	27-Aug	Harvest for grain, killing crop			1-Sep	Heavy tandem disk
Beans (Dry)	28-Apr	Cultivator, 6-12" field sweeps	3-May	Cultivator, 6-12" field sweeps	7-May	Planter, double disk opnr	Medium	29-Aug	Harvest, combine windrows			3-Sep	Chisel with sweep shovel
Soybeans	23-Apr	Disk, offset, heavy	28-Apr	Cultivator, 6-12" field sweeps	2-May	Planter, double disk opnr	Medium	20-Sep	Harvest soybeans, killing crop, leaving 20% standing stubble			27-Sep	Chisel with sweep shovel
Sugarbeets	11-Apr	Cultivator, 6-12" field sweeps	15-Apr	Cultivator, 6-12" field sweeps	18-Apr	Planter, double disk opnr	Low	14-Sep	Flail or rotary shredder (to remove foliage)	16-Sep	Sugarbeet harvester	28-Sep	Cultivator, 6-12" field sweeps
Sunflower/Canola	1-May	Heavy tandem disk	4-May	Tine Harrow	7-May	Drill or airseeder, double disk	Low	26-Sep	Harvest row crop, leaving 50% standing stubble			No fall tillage recommended	

[1]Planting and Harvest dates for Minnesota crops provided in USDA Agricultural Handbook Number 628
[2]For parcels in which irrigation is applied, irrigation schedules start a day after planting and last until 3 weeks before harvest
[3]Timothy grass modeled for the 'Non-alfalfa hay' category
[4]Alfalfa and non-alfalfa hay harvested on the 25th of each month following first harvest; 5 harvests per year
[5]Modeled as corn for grain based on its prevalence over silage in Kittson and Marshall County NASS statistics

RESULTS

Field-scale Summary

Modeling inputs and results for each field are listed in detail in **Table C2** in the Methods section and in **Table C7** in the Supplemental Tables section, respectively. These results are also shown visually in the accompanying “HUC-10 WEPS Mapbook”.

Table C4 shows field-scale results summarized by primary crop type for the 46 fields modeled with WEPS. For each field the primary crop type was the most frequently planted crop during the summer months in the last four years or the crop planted most recently in the case that no one crop is planted more frequently. Total planting and wind erosion in the LRRW is dominated by rotations featuring three primary crops: soybeans, spring wheat, and non-alfalfa hay. By acreage, soybeans are the most prevalent crop and represent greater than half of the wind erosion (**Table C4**). Spring wheat represents just under 40% of the acreage, but only contributes 9.7% of the field losses due to wind erosion. Conversely, non-alfalfa hay (modeled as ‘Timothy Grass’) represents just 10.2% of acreage but contributes 32.9% of the total field losses due to Aeolian erosion.

The disproportionate contribution from non-alfalfa hay, as compared to spring wheat, is likely not due to harvesting techniques, as the average annual Soil Tillage Intensity Rating (STIR, which is a RUSLE2-derived value describing the amount of soil disturbance based on field management practices) is significantly lower for non-alfalfa hay as compared to spring wheat (**Table C4**). The factors best able to describe the disproportionately large contribution for non-alfalfa hay are the Natural Resource Conservation Service (NRCS) SSURGO Wind Erodibility Index (WEI) and the NRCS Soil Conditioning Index (SCI). For non-alfalfa hay, the high WEI value and low SCI value indicate soils highly susceptible to entrainment due to soil dryness, a lack of organic matter, or a soil texture prone to loss from wind erosion. Although the current management on these hay fields isn’t intensive (mean annual STIR = 93.8), the highly erodible soils underlying the hay crop are still a threat to erode without significant protection.

Subwatershed Summary

Field-scale erosion was aggregated within each 10-digit HUC to determine subwatershed-scale field losses (**Table C5; Figure C3**). Acreage and total erosion in **Table C5** include values estimated within the 23 modeled WEZs, along with values assigned to the remaining 85 WEZs smaller than 1,000 acres in size based on similar cropping and soil properties. Therefore, estimates in **Table C5** are for all agricultural acres within the LRRW.

Erosion was largest in the southern LRR subwatersheds, and particularly large in the Lower Tamarac River subwatershed (**Table C5; Figure C3**). Elevated Lower Tamarac River loading appears to be primarily due to the large proportion of soybean and non-alfalfa hay acreage in the basin, which were found to be some of the largest contributors to wind erosion on a per-acre basis (**Table C4; Table C5; Figure C4**). The Lower Tamarac River subwatershed also had the second highest wind erosion yield, at 6.25 tons/acre/year. In terms of erosive sediment loss per acre, the Upper Tamarac River subwatershed was highest, at 9.52 tons/acre/year. Incidentally, though, this subwatershed has the smallest agricultural acres as it is has a greater percentage of forest and wetland area, with a combined 44% of land area

Table C4: Summary of field-scale wind erosion as predicted with the Wind Erosion Prediction System. Soil and field management factors are mean values for each primary crop type, and include the Soil Tillage Intensity Rating (STIR), the SSURGO Wind Erodibility Index (WEI), and the Soil Conditioning Index (SCI).

Primary Crop Type	Fields Modeled	Area		Aeolian Erosion		Mean Erosive Yield	Soil and Field Management Factors			
		acres	*% of fields*	*tons/yr*	*% of total erosion*	*tons/acre/yr*	Annual STIR	RUSLE Kw	SSURGO WEI	SCI
Alfalfa	4	4,040	1.0%	12,225	0.7%	3.03	97.2	0.20	98.0	-0.2
Canola	2	1,046	0.3%	5	0.0%	0.01	84.4	0.17	86.0	0.3
Corn	4	4,342	1.1%	18,934	1.2%	4.36	103.8	0.36	88.5	-0.1
Non-Alfalfa Hay	10	40,078	10.2%	537,417	32.9%	13.41	93.8	0.22	138.0	-0.8
Soybeans	10	178,485	45.6%	895,558	54.9%	5.02	109.9	0.27	94.8	-0.5
Spring Wheat	10	155,737	39.8%	158,159	9.7%	1.02	105.4	0.31	78.4	0.0
Sugarbeets	6	7,454	1.9%	8,725	0.5%	1.17	104.8	0.26	79.7	-0.1

Table C5: Total wind erosion summarized by HUC-10. 'Other 10-digit HUCs' include portions of fields outside the hydrologic boundary of each HUC-10.

HUC-10	HUC-10 Name (if any)	Agricultural Area *acres*	Total Erosion by HUC-10		Erosion Yield *tons/acre*
			tons/yr	*%*	
902031101	Upper Tamarac River	20,201	192,357	11.5%	9.52
902031102	Lower Tamarac River	106,261	663,714	39.5%	6.25
902031103	Judicial Ditch No 10	63,508	209,743	12.5%	3.30
902031104	(No Common Name)	84,213	255,795	15.2%	3.04
902031105	City of Drayton-Red River	47,976	173,598	10.3%	3.62
902031107	Red River	24,696	43,062	2.6%	1.74
902031108	Joe River	49,245	96,939	5.8%	1.97
Other 10-digit HUCs		10,803	43,229	2.6%	4.00
	TOTAL =	406,902	1,678,438		

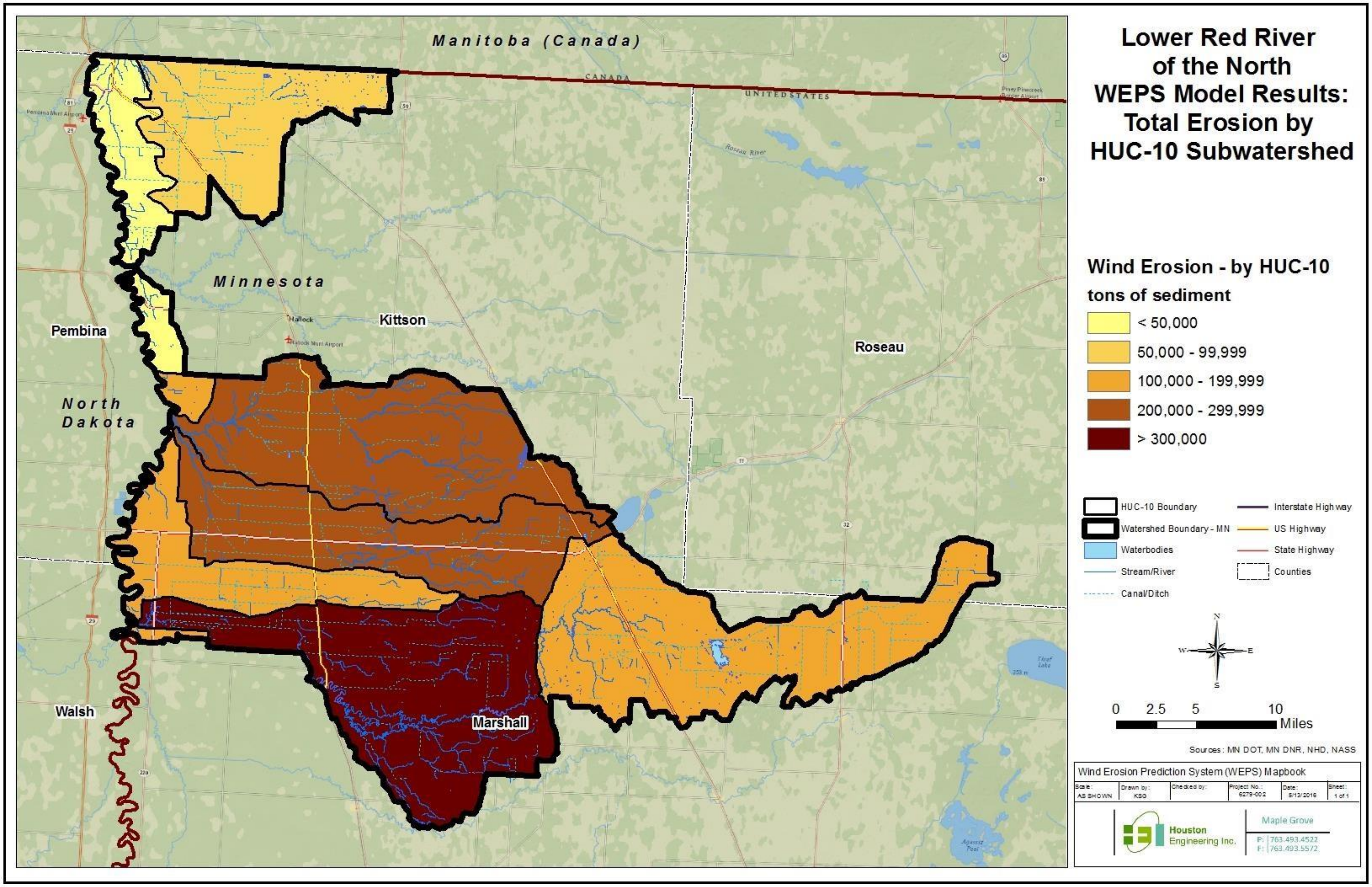


Figure C3: Total estimated sediment wind erosion (tons/year) by 10-digit HUC within the Lower Red River Watershed, as estimated by the Wind Erosion Prediction System model.

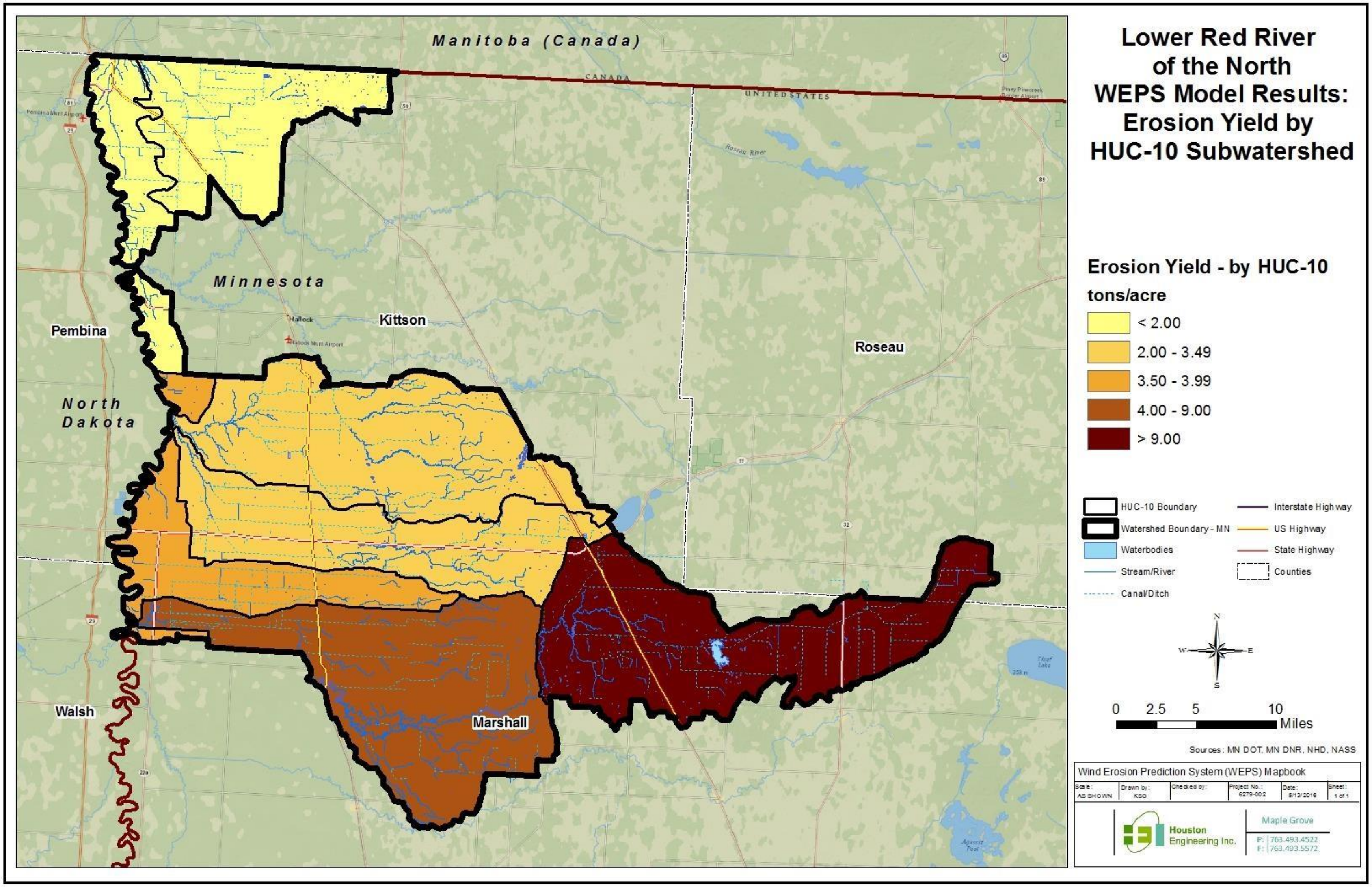


Figure C4: Annual mean erosive yield (tons/acre/year) by 10-digit HUC within the Lower Red River Watershed, as estimated by the Wind Erosion Prediction System model.

Aggregating across all seven of the 10-digit HUCs in the LRRW, along with portions of adjacent fields outside the LRRW hydrologic boundary summarized in the 'Other 10-digit HUCs' category, a total of 1,678,438 tons of sediment are estimated to be lost from agricultural fields annually (**Table C5**). Across the 406,902 acres included in this study area this constitutes a mean erosive yield of 4.12 tons/acre/year. Total erosion and mean erosive yield values both assume existing conditions without conservation wind breaks and shelter belts, which were found on 17% (8 of 46) of agricultural fields. Therefore, both the 4.12 tons/acre/year yield and the 1,678,438 tons of estimated sediment loss across the watershed are likely higher than the amount physically leaving many of the fields in the study area annually.

Wind Break Efficacy

Conservation wind breaks and shelter belts are potentially valuable tools for reducing on-field wind erosion and can be very effective when planted within limited-grade landscapes such as the LRR valley. In addition to reducing wind erosion, wind breaks reduce crop stress, increase local humidity, and in many cases increase crop productivity (Zamora et al. 2016). Recently, due to a variety of factors (e.g. high commodity prices, maintenance issues, among other concerns), wind breaks and shelter belts have been removed and replaced with newly tilled land. Because of the transient nature of these practices, this analysis only included a review of wind breaks as a conservation practice, and not as an existing and long-term part of the field, such as adjacent forest parcels or riparian corridors.

WEPS model input for wind breaks is detailed in **Table C8** in the Supplemental Tables section. Eight of the 46 modeled parcels had a conservation wind break on at least one of the field borders. On average, fields with at least one conservation wind break experienced a 21.6% (combined 2.5 tons across all eight fields) reduction in on-field wind erosion as compared to conditions without the breaks and likely stemmed from lower soil losses from the creep/saltation term, which decreased by 32.9% across the eight fields. This significant reduction is most likely a result of the diminished high wind gusts necessary to initiate erosion for the larger soil particles and aggregates (> 0.10 mm diameter).

Although not modeled as a conservation wind break/shelter belt, natural wind breaks also decreased overall wind erosion on fields adjacent to these forested areas by 42.1% on average (combined 9.2 tons across all eight fields with natural breaks). Similar to the conservation practices, this was largely driven by a significant decrease in wind erosion through creep/saltation (51.0%).

DISCUSSION

WEZ sorting parameters, including the USDA CLU, NASS CDL, and RUSLE K_w factor, were chosen because of their extensive dataset and spatial coverage as well as their ability to summarize features within the landscape that may drive soil erosion by wind. The USDA CLU and NASS CDL data allowed for the determination of field management and rotations on agricultural fields within the LRRW. The RUSLE K_w factor describes soil qualities which generally drive sheet and rill erosion. Incidentally, neither soil nor field management alone could explain variations in wind erosion losses for agricultural fields. **Table C6** details regression analysis results correlating on-field wind erosion predicted by WEPS for all 46 fields (excluding conservation wind breaks) with a variety of soil and field management parameters. Neither the RUSLE K_w factor ($R^2 = 0.14$, $P > 0.05$) nor the mean annual STIR rating ($R^2 = 0.01$, $P > 0.05$) were able to predict the variance in mean annual wind erosion across the 46 LRRW fields. It's much more likely that a combination of these factors should be used to determine overall losses. This may be seen in the relationship between total mean erosion and the NRCS SCI, which describes the presence of organic matter, and is based on soil type, field management, and soil erosive properties. Here a strong, negative relationship is found ($R^2 = 0.98$, $P < 0.05$), signifying that as the SCI decreases, wind erosion increases. A low (and negative) SCI is indicative of a soil with more crop residue and higher soil organic matter and moisture content, which can help to bind the soil and keep soil particles from entraining during high winds or getting released if struck by another entrained particle. The SSURGO WEI also proved to be a strong indicator of sediment erosion from wind. This value is used by the Wind Erosion Equation, which is an NRCS predecessor to the WEPS modeling software, and is used to estimate a soil's potential to erode through Aeolian forces.

Table C6: Simple linear regression equations and the amount of variation explained (R^2) for total mean erosion (tons/acre/year; x-axis) with soil and field management parameters (y-axis). R^2 values in bold are significantly different ($P < 0.05$) from total mean erosion as determined by one-way ANOVA.

Parameter (y-value)	Slope	Y-Intercept	R^2
RUSLE Kw factor	-0.005	0.287	0.140
Mean Annual STIR Rating	-0.107	102.53	0.009
Wind Erodibility Index (WEI)	4.812	75.352	**0.814**
Soil Conditioning Index (SCI)	-0.081	0.086	**0.977**

Sediment erosion values listed in **Table C4** and **Table C5** are estimated for losses from the field surface. WEPS was designed by NRCS to help practitioners work with farmers to mitigate sediment losses from their fields. For this use WEPS is very effective in determining losses from specific fields. Where WEPS falls short is in determining the fate of eroded sediment once it leaves the field's edge. This sediment may be deposited elsewhere in the field, along nearby roads, within adjacent shelter belts, or on neighboring fields. Conversely, the sediment may reach a ditch or stream where it is more likely to be carried by water downstream to a priority waterbody. Without the use of more advanced watershed modeling software, which can take into account various transport processes, we are unable to estimate the potential for soil to reach major waterbodies.

For this reason, sediment erosion estimates predicted within WEPS can only be compared to similarly-derived values for sheet and rill erosion at the field surface. In preparing the LRR WRAPS, the Prioritize, Target, and Measure Application (PTMApp) software was used to estimate soil erosion from precipitation events (Kessler & Deutschman 2016). PTMApp uses RUSLE to estimate erosion from the sediment surface and applies transport equations to determine the amount of sediment that actually reaches downstream waterbodies. For comparison to WEPS results only the RUSLE value, or the value immediately eroded from the landscape, was used. Comparing mean erosive yield (tons/acre/year) across the 46 fields modeled with WEPS, the PTMApp-predicted value of 0.34 tons/acre/year was more than an order of magnitude less than the wind erosion value estimated by WEPS (4.12 tons/acre/year). Unfortunately, without having a systematic method to estimate the fate of wind-eroded sediment once it leaves the landscape the fraction of the 4.12 tons/acre/year which reaches receiving waterbodies, is retained on the landscape, or is advected outside the LRRW remains unknown. Until such technology is available it can at least be surmised that wind erosion is a significant contributor to sediment pollution in the LRRW, potentially on par or greater than sheet and rill erosion.

Because of the potentially great impact of wind erosion in the LRRW, conservation planning and landscape protection should be prioritized with practices for reducing sheet and rill erosion. BMPs such as retaining crop residue following harvest, no-till or strip till management, and permanent vegetative cover have all been shown to protect soils from both wind and sheet/rill erosion. In addition, shelter belts, wind breaks, and perennial grasses on the edge of fields can deflect high wind gusts and reduce the highly erosive qualities of the wind. This may be of particular use on the hay fields in the watershed which see limited tillage but are still losing sediment from its topsoil.

CONCLUSION

This TM provides an analysis for estimating wind erosion on agricultural fields with the LRRW. A methodology was developed for summarizing and grouping fields into 23 WEZs across the watershed based on soil characteristics and crop rotation information. A random, stratified sampling was applied across the 23 WEZs to find two fields within each WEZ which were then modeled with WEPS to estimate wind-driven sediment erosion. When excluding conservation wind breaks and shelter belts, total erosion across the LRRW was estimated to be 1,678,438 tons, with an average erosive yield of 4.12 tons/acre/year on agricultural parcels. Total sediment erosion and erosive yield were compared across the LRRW to determine key sources and processes to target for conservation practices. The efficacy of wind breaks was also explored, finding a 21.6% reduction in sediment losses with the installation of breaks along eight of the 46 fields. Lastly, average sediment yield from the 46 fields modeled in WEPS was compared with values generated in PTMApp for sheet and rill erosion on the same fields. The mean WEPS-generated value, 4.12 tons/acre/year, was an order of magnitude greater than the PTMApp-generated value for sheet and rill erosion, 0.34 tons/acre/year.

Additional conclusions include:

- Wind erosion was not found to be controlled by a specific factor, such as soils, tillage practices, or field management, but more likely a group of parameters (such as those summarized in the SCI).
- Because the fate of wind-eroded sediment particles is more complicated due to the additional pathways (both in the air and on the landscape), an estimation of the fraction of on-field losses which actually reaches a priority waterbody is difficult to determine.
- Nonetheless, due to the magnitude of Aeolian erosion as compared to sheet and rill for the 46 fields modeled, it is impossible to disregard this process as a significant contributor to the degradation of downstream waterbodies.
- To determine the precise scale of the impact of Aeolian erosion and deposition on receiving waterbodies such as the LRR, transport processes must be determined that can extrapolate on-field losses to downstream locations.

These results show the importance of completing comprehensive estimates of sediment sources, which include sheet and rill erosion, wind erosion, and near channel sources to guide implementation efforts.

REFERENCES

Bennett, J.M. et al., 2014. *The Minnesota Soybean Field Book*, Available at: http://www.extension.umn.edu/agriculture/soybean/docs/minnesota-soybean-field-book.pdf.

Fisher, S.J. & Moore, R., 2008. *2007 Tillage Transect Survey*, Mankato, MN. Available at: http://mrbdc.mnsu.edu/sites/mrbdc.mnsu.edu/files/public/transect/pdf/Tillage_Transect_2007_Final_R eport_HiRes.pdf.

Kessler, D. & Deutschman, M., 2016. *Technical Memorandum - PTMApp to Aid in the Development of WRAPS Strategies,* Minneapolis, MN.

Nass, 2010. *Field Crops Usual Planting and Harvesting Dates, Agricultural Handbook Number 628*, Available at: http://usda01.library.cornell.edu/usda/current/planting/planting-10-29-2010.pdf.

North Dakota State University Extension Service, 2014. *Sunflower Production*. North Dakota State Extension Service, A-1331. Available at: https://www.ag.ndsu.edu/publications/landing-pages/crops/sunflowerproduction-a-1331.

Nowatzki, J., *Harvesting Dry Bean*, Available at: https://www.ag.ndsu.edu/pubs/plantsci/rowcrops/a1133l.pdf.

Presley, D. & Tatarko, J., 2009. *Principles of Wind Erosion and its Control*, Manhattan, KS.

Undersander, D. et al., 2015. *Alfalfa Management Guide* L. Al-Amoodi, ed., Madison, WI: American Society of Agronomy, Inc.

United States Department of Agriculture Agricultural Research Service, 2010. *The Wind Erosion Prediction System: WEPS 1.0 User Manual.*

University of Minnesota Extension. *Corn Production*. Available at: http://www.extension.umn.edu/agriculture/corn/.

University of Minnesota Extension. *Small Grains Production*. Available at: http://www.extension.umn.edu/agriculture/small-grains/.

Wagner, L.E., 2013. A history of Wind Erosion Prediction Models in the United States Department of Agriculture : The Wind Erosion Prediction System (WEPS). *Aeolian Research*, 10, pp.9–24. Available at: http://dx.doi.org/10.1016/j.aeolia.2012.10.001.

Wilson, R.G., Smith, J.A. & Miller, S.D., 2016. *Sugarbeet Production Guide*. , p.242. Available at: http://www.ianrpubs.unl.edu/pages/publicationD.jsp?publicationId=1061.

Zamora, D. et al., 2016. Windbreaks, Available at: http://www.extension.umn.edu/environment/agroforestry/windbreaks/windbreaks.html

Supplemental Tables

Table C7: Field-scale Wind Erosion Prediction System model results for each rotation year summarized by erosion process. These results do not include conservation wind breaks.

			Net Soil Loss From Field (tons/acre) by Erosion Process – With Forested Areas But Without Conservation Wind Breaks[1]																				
Model Run	Wind Erosion Zone (WEZ)	Field	Creep/Saltation[2] 1	Creep/Saltation[2] 2	Creep/Saltation[2] 3	Creep/Saltation[2] 4	Creep/Saltation[2] MEAN	Suspension[2] 1	Suspension[2] 2	Suspension[2] 3	Suspension[2] 4	Suspension[2] MEAN	PM10[2] 1	PM10[2] 2	PM10[2] 3	PM10[2] 4	PM10[2] MEAN	Total Mean Erosion (tons/acre)	Mean Erosion by WEZ (tons/acre)	SD of Mean Erosion by WEZ (tons/acre)	WEZ Area (acres)	Mean Erosion by WEZ (tons)
1	Alfalfa; 0.16-0.20	1	0.01	0	0	0	0.00	0.01	0	0	0	0.00	0	0	0	0	0.00	0.01	0.01	0.00	1,969	12
2		2	0	0	0.01	0	0.00	0	0	0.01	0	0.00	0	0	0.01	0	0.00	0.01				
3	Alfalfa; 0.21-0.25	1	2.3	1.8	3.8	2.2	2.53	4.8	2.6	5.7	3.1	4.05	0.11	0.07	0.15	0.09	0.11	6.68	5.90	1.11	2,071	12,213
4		2	4.1	4.3	1.1	0.2	2.43	4.4	4.7	1.2	0.2	2.63	0.1	0.11	0.03	0.01	0.06	5.11				
5	Canola; 0.16-0.20	1	0	0.01	0		0.00	0	0.01	0		0.00	0	0.01	0		0.00	0.01	0.01	0.01	1,046	5
6		2	0	0	0	0	0.00	0	0	0	0	0.00	0	0	0	0	0.00	0.00				
7	Corn; 0.21-0.25	1	2.9	3.2	3.8	0.5	2.60	11.8	10.9	12.4	3	9.53	0.54	0.51	0.55	0.14	0.44	12.56	6.68	8.32	2,369	15,817
8		2	0.1	0.1	0.6	0.1	0.23	0.1	0.1	1.7	0.3	0.55	0.01	0.01	0.05	0.01	0.02	0.80				
9	Corn; 0.26-0.30	1	0	0	0.01	0	0.00	0	0	0.01	0	0.00	0	0	0.01	0	0.00	0.01	1.58	2.22	1,973	3,117
10		2	0.5	0.4	2.4	1.1	1.10	0.7	0.6	4.8	1.9	2.00	0.02	0.02	0.12	0.05	0.05	3.15				
11	Other Hay/Non Alfalfa; 0.06-0.10	1	0.8	0.5	0.8	0.7	0.70	2.5	1.7	2.3	2	2.13	0.06	0.04	0.06	0.05	0.05	2.88	5.68	3.96	2,354	13,371
12		2	0.7	0.5	0.7	0.7	0.65	7.7	5.5	9	7.8	7.50	0.34	0.25	0.4	0.34	0.33	8.48				
13	Other Hay/Non Alfalfa; 0.11-0.15	1	3	2.5	3.1	3.1	2.93	18.1	11.1	8.6	11.4	11.00	0.69	0.48	0.38	0.49	0.47	14.40	13.78	0.88	9,110	125,501
14		2	1.6	1.1	1.8	1.6	1.53	11.2	8.3	13.6	11.6	11.18	0.46	0.34	0.55	0.48	0.46	13.16				
15	Other Hay/Non Alfalfa; 0.16-0.20	1	1.6	1.2	1.7	1.7	1.55	8.7	6.6	9.4	9	8.43	0.34	0.26	0.36	0.35	0.33	10.30	15.94	7.98	8,912	142,082
16		2	4	2.9	9.6	9.3	6.45	11.2	9.1	19.5	18.9	14.68	0.36	0.3	0.62	0.55	0.46	21.58				
17	Other Hay/Non Alfalfa; 0.21-0.25	1	8.8	8.1	9.9	7.8	8.65	23.3	20.4	25.2	20.4	22.33	0.72	0.64	0.79	0.65	0.70	31.68	15.87	22.36	16,157	256,370
18		2	0	0	0.1	0.1	0.05	0	0	0.01	0.01	0.01	0	0	0.01	0.01	0.01	0.06				
19	Other Hay/Non Alfalfa; 0.26-0.30	1	0	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.02	0.03	0.01	3,545	93
20		2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03				
21	Soybeans; 0.11-0.15	1	4.1	2.9	2.3	3	3.08	3.7	2.8	2.1	2.5	2.78	0.09	0.07	0.06	0.06	0.07	5.92	3.08	4.02	20,179	62,101
22		2	0.1	0.1	0.1	0.1	0.10	0.1	0.1	0.2	0.1	0.13	0.01	0.01	0.01	0.01	0.01	0.24				
23	Soybeans; 0.16-0.20	1	0.01	0	0.1	0	0.03	0.1	0	0.3	0	0.10	0.01	0	0.01	0	0.01	0.13	0.07	0.09	88,173	6,073
24		2	0.001	0	0	0	0.00	0.01	0	0	0	0.00	0.01	0	0	0	0.00	0.01				
25	Soybeans; 0.21-0.25	1	10	9.3	13.7	11	11.00	30.4	26	41.4	27.4	31.30	0.86	0.75	1.19	0.81	0.90	43.20	21.60	30.55	35,735	771,914
26		2	0	0	0	0	0.00	0	0	0	0	0.00	0	0	0	0	0.00	0.00				
27	Soybeans; 0.26-0.30	1		0.01	0.01	0	0.01		0.1	0.01	0	0.04		0.01	0	0	0.00	0.05	1.06	1.44	26,404	28,109
28		2	0.4	1.4	0.8	0.5	0.78	0.5	2.4	1.5	0.7	1.28	0.01	0.06	0.04	0.02	0.03	2.08				
29	Soybeans; 0.31-0.35	1	0.3	0.2	0.3	0.2	0.25	0.3	0.2	0.4	0.2	0.28	0.01	0.01	0.01	0.01	0.01	0.54	3.42	4.08	7,994	27,360
30		2	1	1.7	3.5	1.1	1.83	2.9	3.6	8.8	2.2	4.38	0.07	0.09	0.22	0.06	0.11	6.31				
31	Spring Wheat; 0.11-0.15	1	0.01	0.01	0.1	0.01	0.03	0.01	0	0.2	0.01	0.06	0.01	0	0.01	0.01	0.01	0.10	2.66	3.63	12,944	34,464
32		2	2.4	1.7	3.5	4.1	2.93	2	1.3	2.8	2.9	2.25	0.05	0.03	0.07	0.07	0.06	5.23				
33	Spring Wheat; 0.16-0.20	1		0.1	0	0.01	0.04		0.1	0	0.01	0.04		0.01	0	0.01	0.01	0.08	0.04	0.05	73,235	3,204
34		2	0	0.01	0	0	0.00	0	0.01	0	0	0.00	0	0.01	0	0	0.00	0.01				
35	Spring Wheat; 0.21-0.25	1	0	0	0.01	0	0.00	0	0	0.01	0	0.00	0	0	0.01	0	0.00	0.01	0.16	0.21	24,350	3,866
36		2	0.1	0.2	0.1	0.1	0.13	0.1	0.3	0.2	0.1	0.18	0.01	0.01	0.01	0.01	0.01	0.31				
37	Spring Wheat; 0.26-0.30	1	0.2	0.01	0.2	0.1	0.13	1	0.2	1.1	0.6	0.73	0.03	0.01	0.03	0.02	0.02	0.88	2.97	2.96	32,212	95,670
38		2	1.2	0.8	1.8	1.5	1.33	3.3	2.2	5.3	3.8	3.65	0.08	0.05	0.13	0.1	0.09	5.07				
39	Spring Wheat; 0.31-0.35	1	0.2	0.1	0.01	0.8	0.28	0.2	0.1	0.1	1.2	0.40	0.01	0.01	0.01	0.03	0.02	0.69	1.61	1.30	12,996	20,955
40		2	0.3	0.2	0.5	0.3	0.33	1.8	1.5	3.4	1.9	2.15	0.05	0.04	0.09	0.05	0.06	2.53				
41	Sugarbeets; 0.16-0.20	1	0.1	0.01	0.1	0.01	0.06	0.2	0.01	0.1	0.1	0.10	0.01	0.01	0.01	0.01	0.01	0.17	0.33	0.23	2,783	911
42		2	0.1	0.1	0.1	0.6	0.23	0.1	0.1	0.1	0.7	0.25	0.01	0.01	0.01	0.02	0.01	0.49				
43	Sugarbeets; 0.21-0.25	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	5.74	8.07	1,339	7,680
44		2	4.6	2.3	3.8	2.4	3.28	10.6	5.5	10	5.7	7.95	0.29	0.15	0.27	0.16	0.22	11.44				
45	Sugarbeets; 0.26-0.30	1	0.01	0.01	0.01	0.01	0.01	0.1	0.01	0.01	0.01	0.03	0.01	0	0.01	0.01	0.01	0.05	0.04	0.01	3,332	133
46		2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03				

[1] Natural wind breaks created by forested parcels and riparian corridors included within base model

[2] 'Trace' amounts of erosion reported as 0.01 tons/acre

Table C8: Field-scale Wind Erosion Prediction System model results for each rotation year summarized by erosion process for fields with at least one conservation wind break.

		Net Soil Loss From Field (tons/acre) by Erosion Process - With Forested Areas and Conservation Wind Breaks															
		Creep/Saltation					Suspension					PM10					Total Mean Erosion (tons/acre)
Wind Erosion Zone (WEZ)	Field	1	2	3	4	MEAN	1	2	3	4	MEAN	1	2	3	4	MEAN	
Other Hay/Non Alfalfa; 0.06-0.10	1	0.8	0.5	0.8	0.7	0.70	2.5	1.7	2.3	2	2.13	0.06	0.04	0.06	0.05	0.05	2.88
Other Hay/Non Alfalfa; 0.11-0.15	2	1.6	1.1	1.8	1.6	1.53	11.2	8.3	13.6	11.6	11.18	0.46	0.34	0.55	0.48	0.46	13.16
Other Hay/Non Alfalfa; 0.16-0.20	1	1.6	1.2	1.7	1.7	1.55	8.7	6.6	9.4	9	8.43	0.34	0.26	0.36	0.35	0.33	10.30
Soybeans; 0.11-0.15	1	4.1	2.9	2.3	3	3.08	3.7	2.8	2.1	2.5	2.78	0.09	0.07	0.06	0.06	0.07	5.92
Soybeans; 0.11-0.15	2	0.1	0.1	0.1	0.1	0.10	0.1	0.1	0.2	0.1	0.13	0.01	0.01	0.01	0.01	0.01	0.24
Soybeans; 0.21-0.25	1	10	9.3	13.7	11	11.00	30.4	26	41.4	27.4	31.30	0.86	0.75	1.19	0.81	0.90	43.20
Soybeans; 0.31-0.35	1	0.3	0.2	0.3	0.2	0.25	0.3	0.2	0.4	0.2	0.28	0.01	0.01	0.01	0.01	0.01	0.54
Sugarbeets; 0.26-0.30	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03

*'Trace' reported as 0.01 tons/acre