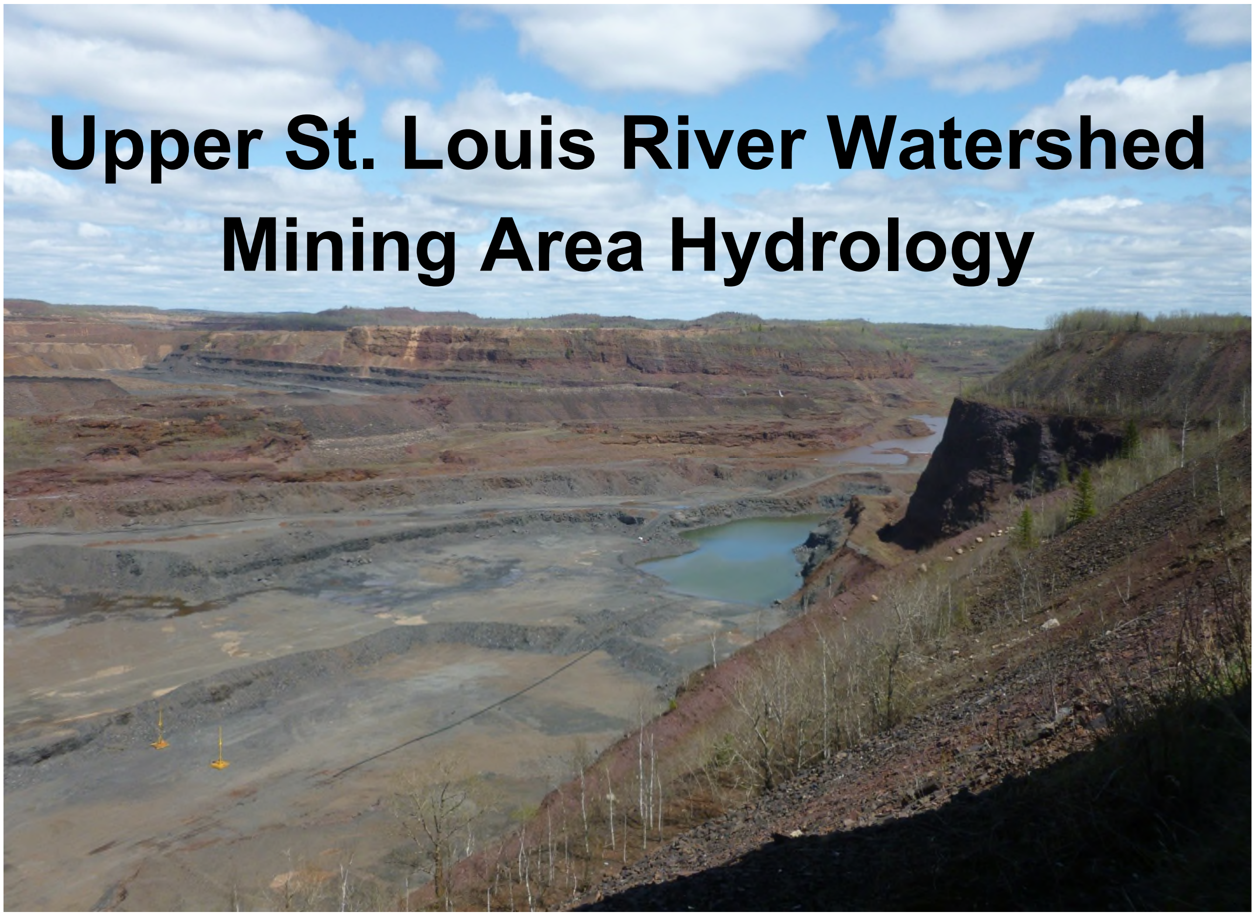
Upper St. Louis River Watershed Mining Area Hydrology



Prepared for

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1 Introduction

This document is a revision of a report originally released on September 30, 2014. It has been revised to reflect additional and corrected information on point source discharges in the model area.

The Minnesota Pollution Control Agency (MPCA) retained Tetra Tech, Inc. to develop analyses of hydrology and surface water – ground water interactions in the St. Louis River portion of the taconite mining area of the Minnesota Iron Range. This work is supplemental to ongoing work being conducted to develop a comprehensive watershed model of the St. Louis River basin.

An important aspect of hydrology and water quality in the St. Louis River watershed is the operation of numerous taconite open pit mines in the Minnesota Iron Range. Taconite processing involves large quantities of water. In addition, open pit mining requires dewatering of the mine pits, which intersect regional groundwater flows. Appropriations of surface and groundwater, as well as discharges from mining operations, are regulated and controlled by the Minnesota Department of Natural Resources (MDNR) and MPCA.; however, there are various unresolved questions regarding the overall impact of mining operations on the hydrology of the Iron Range watersheds, such as the St. Louis River watershed. Better understanding of the interaction of mining operations with surface and groundwater hydrology is needed to adequately manage surface water and mining activities in the Iron Range.

The goal of this project was to develop a more detailed understanding of the impacts of mining operations on the surface water hydrology of streams in the St. Louis River portion of the Minnesota Iron Range. This required a better understanding of the details of the water balance and water management at Iron Range taconite mining and processing operations, including the interactions of surface and ground water. This work is designed to increase understanding of these interactions in concert with the development of watershed and surface water models of hydrology and water quality in the St. Louis watershed.

Spatial analyses and simulation modeling was conducted to evaluate surface water – ground water interactions and to investigate fine-scale hydrology in the mining areas. The surface water – ground water interactions were investigated using the steady-state analytical element groundwater model GFLOW. GFLOW (http://www.haitjema.com/) is a two-dimensional, steady-state, analytical element model of groundwater flow that is strongly focused on the evaluation of surface and ground water interactions.

Section 2 of this report examines the extent to which mining has reshaped and altered the natural watersheds of headwater streams in the Iron Range using spatial analyses. In Section 3 we present the results of the GFLOW model of groundwater flow and the interactions of surface and ground water under current conditions. The spatial analysis and groundwater modeling results are combined with output from the HSPF surface water model of the St. Louis watershed, also being developed by Tetra Tech under a separate work assignment, to estimate headwater stream water balances under both natural and existing conditions in Section 4.

It should be noted that the GFLOW model application is a simplified representation of the ground water flow system that represents average conditions and is based on limited data, both in regards to stratigraphy and measured head elevations. The results reported here are thus only a preliminary insight into the ground water, surface water, and mining interactions in the St. Louis River watershed. More refined results will be forthcoming if and when MNDNR constructs a dynamic MODFLOW model of the area. Developing and calibrating such a model will, however, require extensive data collection and a program of regular monitoring of water elevations in wells throughout the area of interest.

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2 Spatial Analysis of Mining Impacts

Mining of iron ore in the Iron Range of the St. Louis River watershed has dramatically altered natural hydrology (surface and subsurface) in the area. Active mining pits must be continuously de-watered in order to extract ore, while inactive mines often fill with water to become new lakes in the landscape.

Initial analyses of mining impacts were conducted in GIS with the intention of determining the extent to which natural drainages have been altered or intercepted by mining operations. This GIS analysis is combined with groundwater modeling in Section 3 and with surface water modeling in Section 4 to determine the total impacts of mining operations on the water balance of headwater streams.

2.1 FOCUS AREA

All mining features in the landscape are highlighted in Figure 1, based on spatial coverages provided by MDNR. Detailed analyses were conducted on a smaller focus area of 320 square miles (yellow outline in Figure 1) that includes the cities of Virginia and Eveleth as well as several large active and inactive mines. This focus area was selected because it is an area where extensive modification of headwater streams is known to have occurred as well as due to database size limitations in the ground water model that make analysis of a larger area difficult. A close-up of the focus area and the associated mining features is shown in Figure 2.

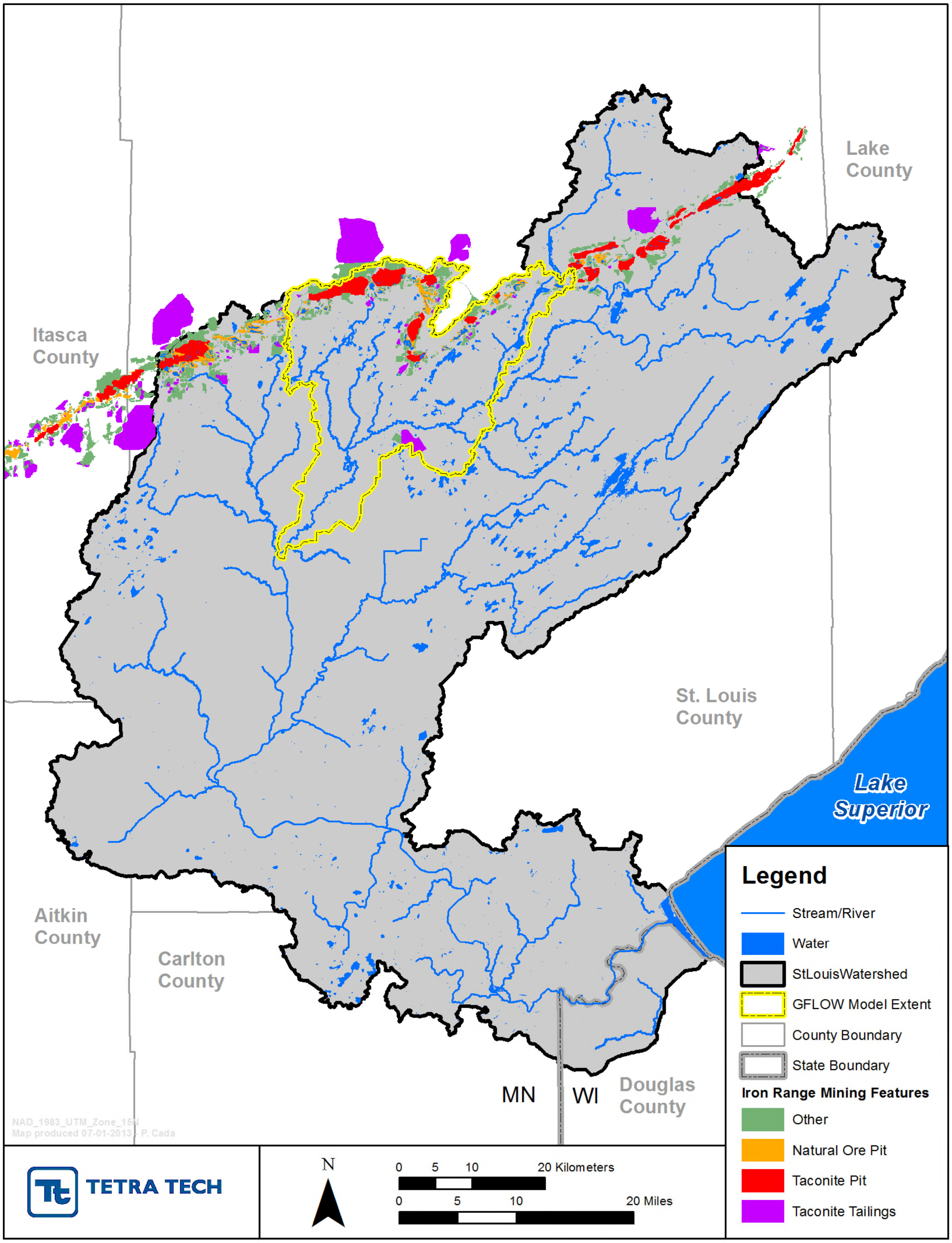

Figure 1. Mine Features and GFLOW Model Extent - Mesabi Iron Range, St. Louis River Watershed

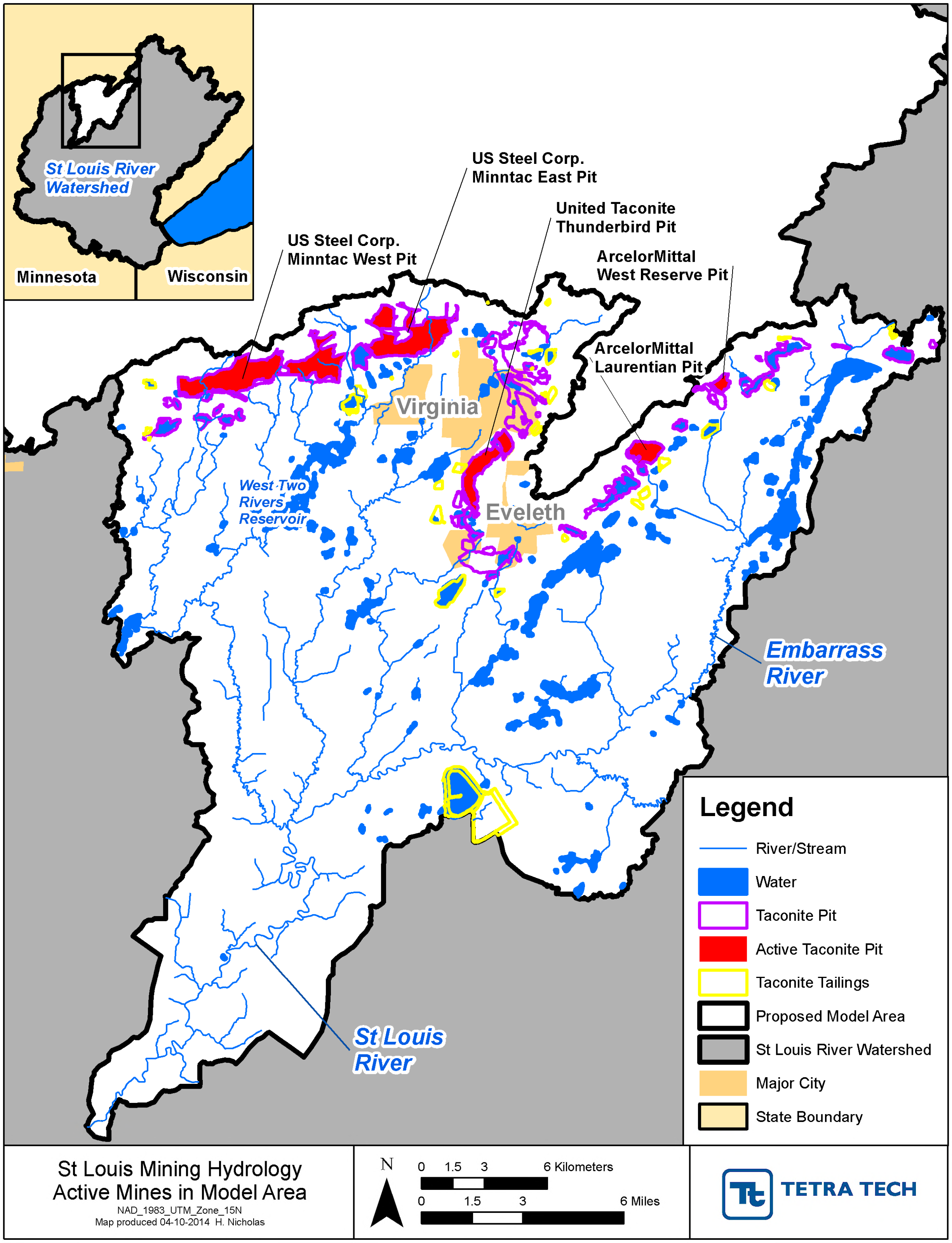

Figure 2. Mine Features within GFLOW Model Extent, St. Louis River Watershed

2.2 GIS ANALYSIS METHODOLOGY

Using GIS processing, impacted MNDNR Level 08 catchments for the GFLOW modeling area were identified, as were the estimated contributing drainage areas for active and inactive mining pits.

First, the major taconite mining pits were identified (both active dry pits and inactive water-filled pits) from the mining features shapefile. Next, recent aerial imagery, discharge flow routing, and permitted takings and discharges were employed to verify, and modify when needed, the boundaries and water level status (i.e., dry or filled) of both active and inactive pits. Finally, LiDAR (Light Detection And Ranging) data obtained from the Minnesota Geospatial Information Office is available at a 1-meter resolution for the entire modeling extent from flights flown in May 2011. In addition to topography, the LiDAR data identifies the water surface elevation in lakes and un-pumped mine pits as of mid-May 2011.

The LiDAR raster coverage was analyzed to delineate drainage areas associated with mine features. Raster processes were applied to the 1-m LiDAR DEM (digital elevation model) in the following steps:

1. Conversion of major taconite mining pits to raster (i.e., grid) format to serve as outlets for subsequent GIS-based hydrologic modeling.
2. “Fill” Tool was run on the 1-m LiDAR DEM to fill pits in the landscape which should not be used to determine larger scale drainage areas.
3. “Flow Direction” Tool was run on the filled 1-m LiDAR DEM to identify flow directions within the raster to steepest downslope neighboring grid cell.
4. “Watershed” Tool was run on the 1-m LiDAR DEM using the resultant “Flow Direction” output and raster-based major taconite mining pits to delineate drainage.
5. Areas outside of MNDNR watershed boundary dataset’s version of the St Louis River watershed were removed.

2.3 MINE PIT AND NATURAL HEADWATERS DRAINAGE AREAS

Drainage areas for each major mine pit feature and the natural pre-mining drainage areas (represented by MNDNR’s Level 08 catchments) were overlain to visualize the impact of the mining operations on the landscape (Figure 3). Detailed visualizations of the Virginia/Eveleth and Minntac areas are shown in Figure 4 and Figure 5, respectively

The figures show a variety of different types of modifications of the natural drainage areas. Some parts of the original headwater watersheds (shown in pink) drain directly to and are intercepted by pumped mine pits (which include both active mines and former mine pits that are pumped to provide process and water supply water, such as Missabe Mountain Lake). Other areas (shown in purple) drain to inactive, unpumped pits. Because active mines incur a significant energy cost in pumping water, avoidance of inflow is desirable. In several cases, surface runoff has been maintained along roadways between pits, but subsurface flow is intercepted by the adjoining pumped pits (shown by green horizontal hatching on the figure). Finally, the topography of some areas along the ridge line has been modified so that water now drains out of the basin.

Table 1 shows the total area of each mining pit drainage area, as well as the area of the pre-mining drainages.

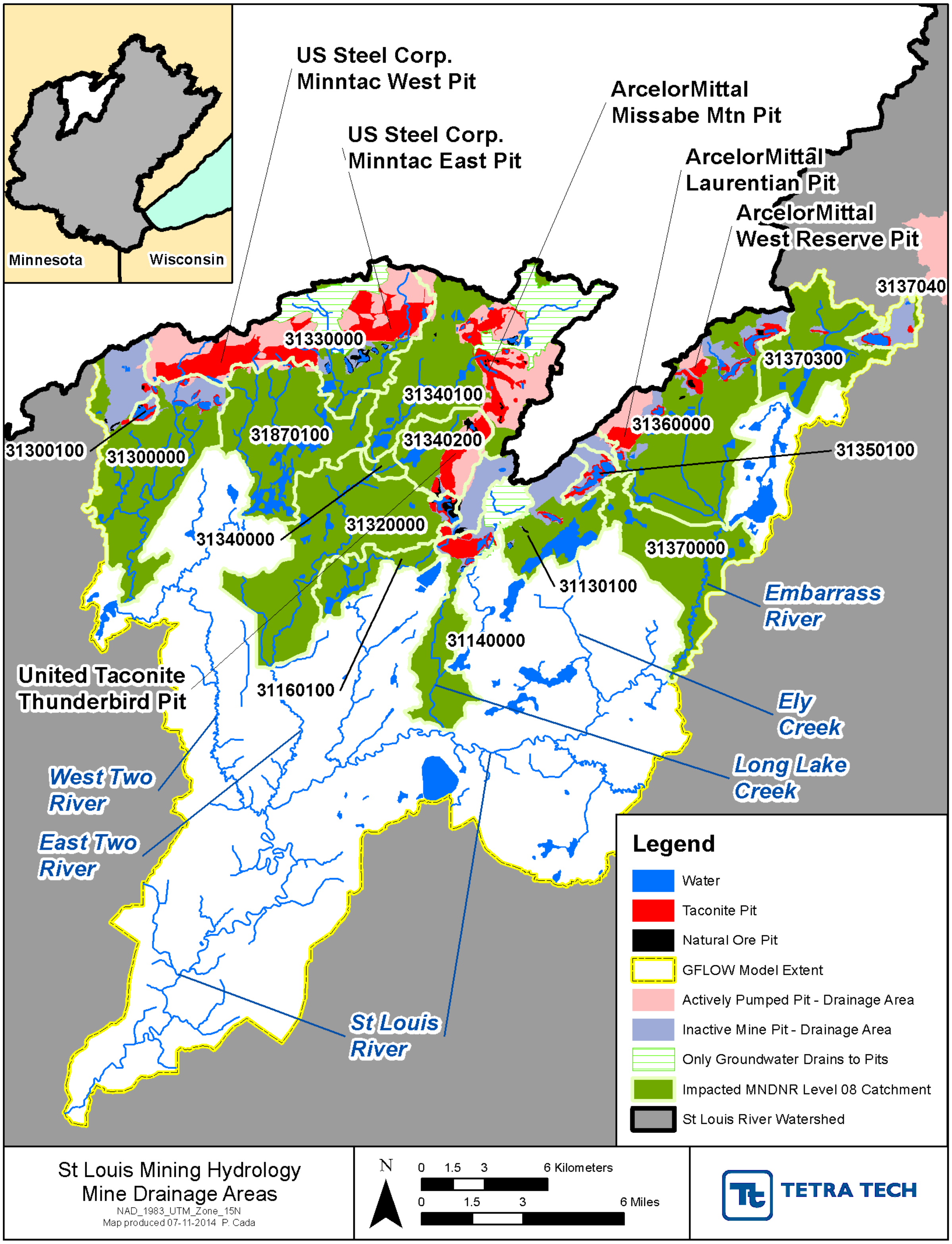

Figure 3. Major Mine Pit Footprints, Associated Drainage Areas, and Impacted DNR Catchments

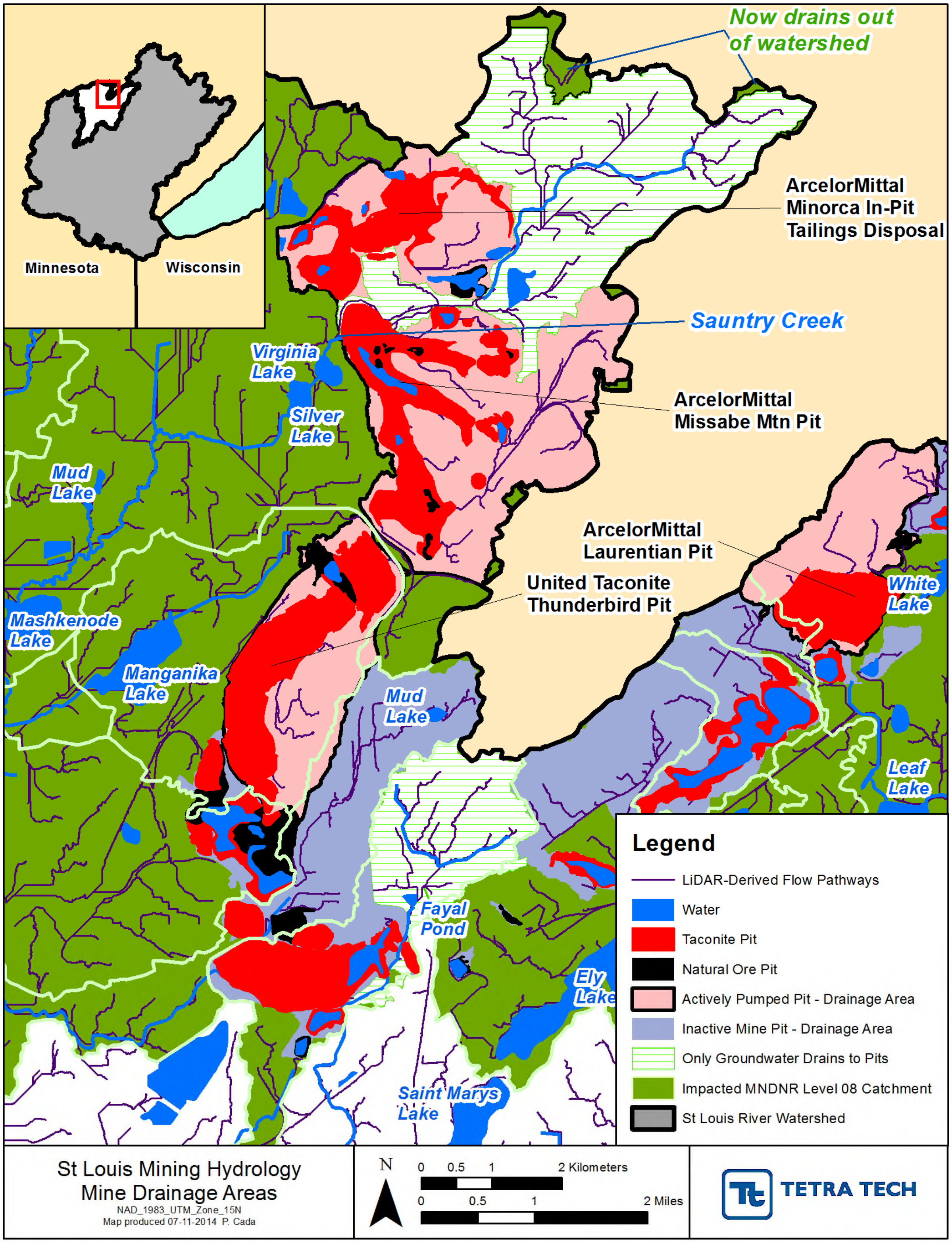

Figure 4. Major Mine Pit Footprints, Associated Drainage Areas, and Impacted DNR Catchments – Detail of Virginia/Eveleth Area

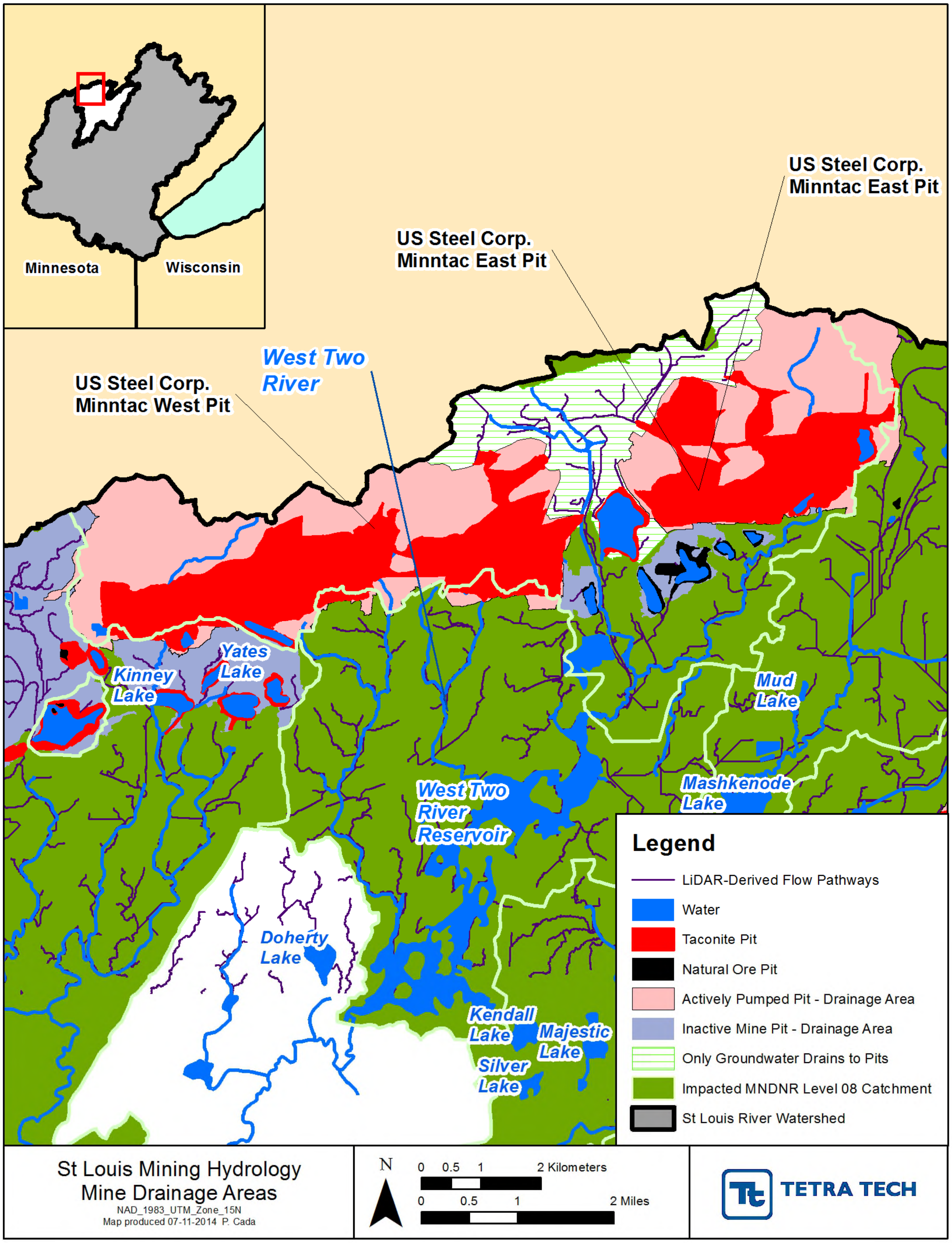

Figure 5. Major Mine Pit Footprints, Associated Drainage Areas, and Impacted DNR Catchments – Detail of US Steel Corp. - Minntac Pit Areas

Table 1. Area of MNDNR Level 08 Catchments, Mining Drainage Areas, and Percentage of Pre-Mining Drainages Intercepted by Mining Operations in the GFLOW Model Area of the St. Louis River Watershed

MNDNR Level 08 Catchment	Drainage Area (acres)	HUC-12 Name	Active Pit		Inactive Pit		Total Area of Subsurface Intercepted Flows	Percent of DNR Catchment Subsurface Flow Intercepted
			Only subsurface flow intercepted	Surface and subsurface flow intercepted	Only subsurface flow intercepted	Surface and subsurface flow intercepted		
0311301	4,162	Ely Creek-St. Louis River			31	1,131	1,162	28
0311400	5,253	Long Lake Creek-St. Louis River			1,024	842	1,866	36
0311601	3,610	Elbow Creek		100	7	1,248	1,355	38
0313000	10,990	Kinney Lake		149		2,611	2,760	25
0313001	283	Kinney Lake				273	273	96
0313200	10,708	East Two River		73		296	369	3
0313300	11,653	Mountain Iron Mine	2,022	7,011		525	9,558	82
0313401	13,486	East Two River	2,853	4,073		2	6,928	51
0313402	3,394	East Two River		1,398		135	1,533	45
0313501	889	Embarrass River				840	840	94
0313600	12,147	Leaf Lake		1,403		1,910	3,313	27
0313700	6,594	Embarrass River		61		244	305	5
0313703	5,614	Embarrass River				75	75	1
0313704	1,115	Embarrass River				940	940	84
0318701	8,358	West Two River Reservoir		202		1	203	2

In several instances the DNR Level 08 catchments reflect current, mining-altered topography and not the original drainage pattern. We therefore identified eleven natural headwater catchments for further analysis. Two of these headwater catchments (3 and 8) were further subdivided for more detailed analysis. These are shown in Figure 6 (with the additional subdivisions shown in pink) and Table 2; intercepted areas for these watersheds are shown in Table 3.

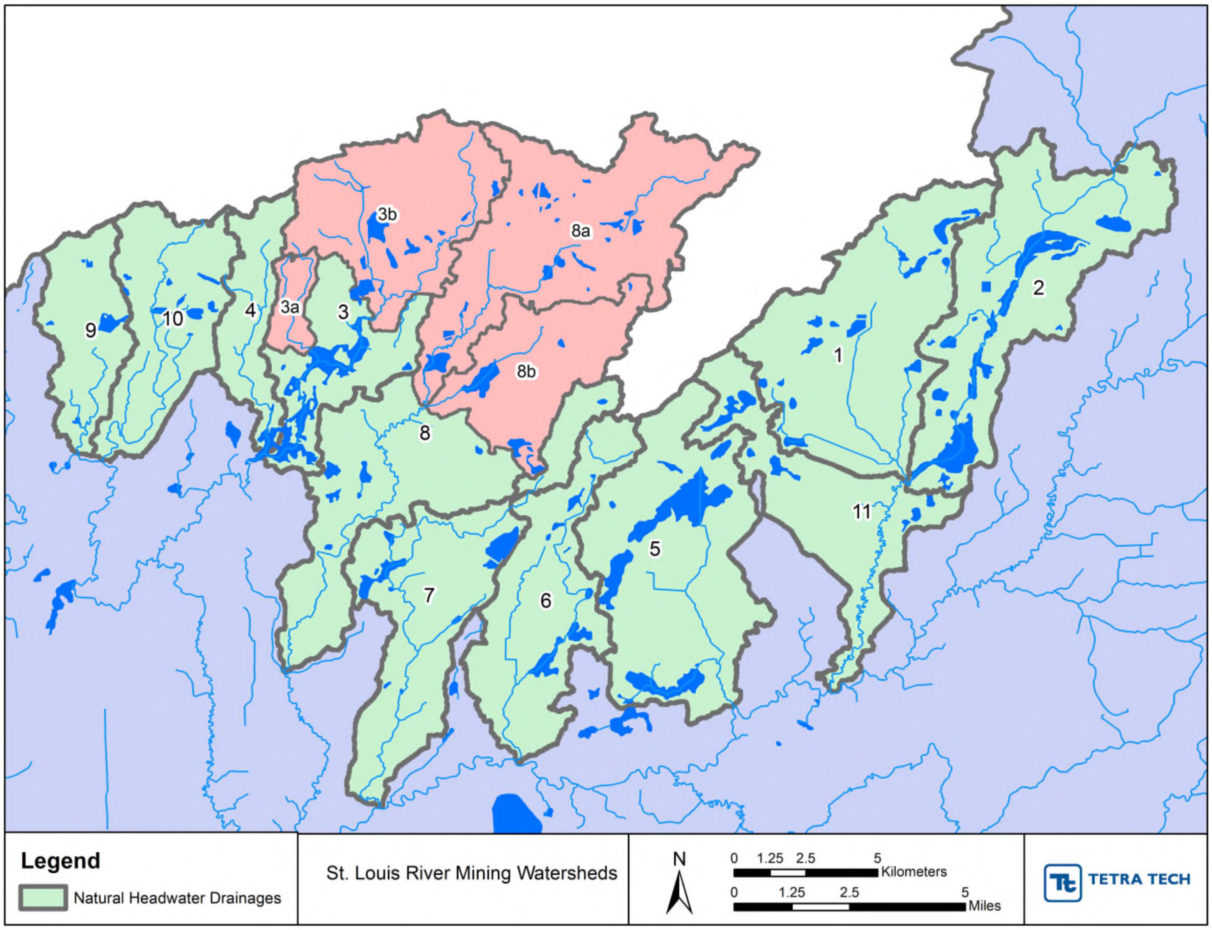

Figure 6. St. Louis River Mining Area Headwater Watersheds

Table 2. Identification of Headwater Watersheds

Key	Drainage
1	Unnamed Trib to Embarrass River
2	Upper Embarrass River
3	West Two River
3a	West Two River upstream of Reservoir
3b	Parkville Creek
4	Unnamed Trib to West Two River
5	Ely Creek
6	Long Lake Creek
7	Elbow Creek
8	Manganika and Sauntry Creeks
8a	Sauntry Creek and Mashkenode Lake
8b	Manganika Creek
9	Unnamed Trib to Kinney (McQuade) Creek
10	Kinney (McQuade) Creek
11	Middle Embarrass River

Table 3. Area of Headwater Watersheds, Mining Drainage Areas, and Percentage of Pre-Mining Drainages Intercepted by Mining Operations in the GFLOW Model Area of the St. Louis River Watershed

Headwater Watershed	Drainage Area (acres)	Active Pit		Inactive Pit		Total Area of Subsurface Intercepted Flows	Percent of Subsurface Area Intercepted
		Only subsurface flow intercepted	Surface and subsurface flow intercepted	Only subsurface flow intercepted	Surface and subsurface flow intercepted		
1. Unnamed Trib to Embarrass River	12,125		1,398		1,908	3,306	27%
2. Upper Embarrass River	12,057				1,038	1,038	9%
3. West Two River	14,319	1,997	4,003		481	6,481	45%
3a. West Two River above Reservoir	1,114		81			81	7%
3b. Parkville Creek (trib to West Two River)	8,383	1,979	3,820		465	6,264	75%
4. Unnamed Trib to West Two River	3,424	19	985		1	1,004	29%
5. Ely Creek	12,462			37	1,136	1,172	9%
6. Long Lake Creek	8,198			1,034	840	1,874	23%
7. Elbow Creek	9,630		102	8	1,247	1,357	14%
8. Manganika and Sauntry Creeks	26,537	2,845	5,539		434	8,818	33%
8a. Sauntry Creek and Mashkenode Lake (East Two River Headwaters)	11,921	2,840	3,150		397	6,387	54%
8b. Manganika Creek	5,854		2,346		397	2,743	47%
9. Unnamed Trib to Kinney Creek	4,349		25		1,971	1,996	46%
10. Kinney (McQuade) Creek	6,516		2,338		962	3,300	51%
11. Middle Embarrass River	7,464	62			1,081	1,143	15%

2.4 SUMMARY OF SPATIAL ANALYSIS

The drainage areas of headwater watersheds are significantly affected by mining operations along this section of the Iron Range. In some cases both surface and groundwater flows are intercepted and diverted from headwater streams by actively pumped pits. Much of this water is used in taconite processing with a portion ultimately discharged in other locations. In two areas, subsurface flow is intercepted and diverted, but surface flow is not. Other drainage areas pass through abandoned, unpumped pits. This situation should ultimately reduce peak runoff but have a relatively small impact on the overall water balance, except for the evaporation losses from the abandoned pits. Passage of water through abandoned pits may also have impacts on geochemistry.

3 GFLOW Groundwater Model

This section describes the development and calibration of the GFLOW ground water model for the mining focus area of the upper St. Louis River watershed (Figure 7). The surface water – ground water interactions were investigated using the steady-state analytical element groundwater model GFLOW. GFLOW (http://www.haitjema.com/) is a two-dimensional, steady-state, analytical element model of groundwater flow that is strongly focused on the evaluation of surface and ground water interactions. Use of a steady-state model approximation is appropriate for the relatively sparse hydrogeological data that are available for the watershed.

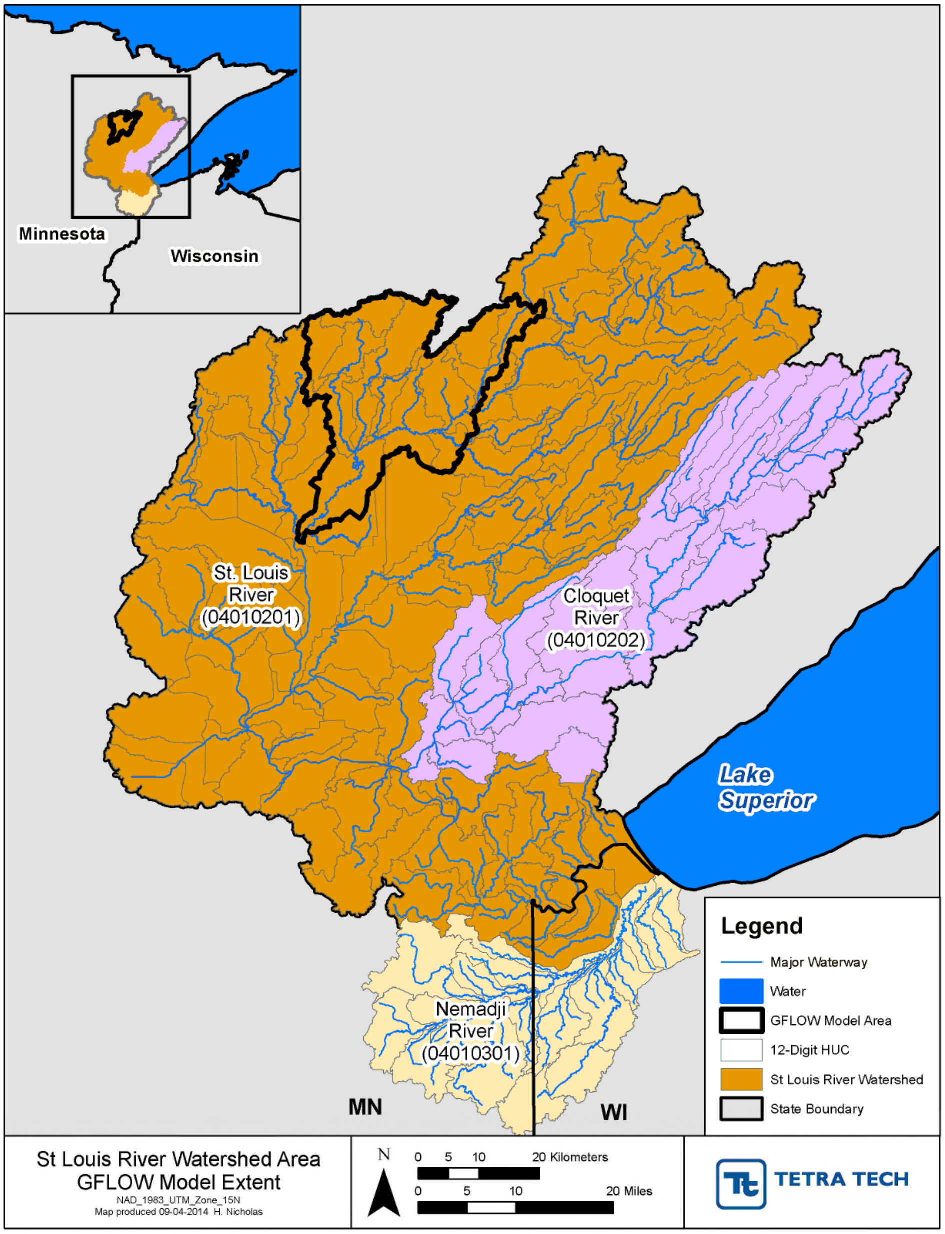

Figure 7. Location of the GFLOW Model Extent in the St. Louis River Watershed

3.1 GFLOW MODEL SETUP

3.1.1 Model Extent

The general objective of this study is to develop a better understanding of the small scale groundwater and surface water interactions associated with mining operations in the Mesabi Iron Range. In addition to local impacts on headwater streams, the groundwater model will also provide information to the larger scale HSPF surface water model of the entire St. Louis River watershed being developed for MPCA. To facilitate model inter-comparison, sub-watershed boundaries consistent with the HSPF surface water model are used to define the area of interest for the groundwater model. Specifically, the GFLOW model extent aligns with the HPSF model subbasins 242-253, and 271.

The GFLOW model area of interest encompasses a number of active and inactive mine sites in the vicinity of the towns of Virginia and Eveleth, Minnesota. The focus area is bounded by the Iron Range divide along the north, the Embarrass River is included along the eastern edge, and the East and West Two Rivers are included along the western edge. The southern edge of the modeling extent falls at the confluence of the East Swan River and the St. Louis River main stem (Figure 8).

3.1.2 Aquifer Properties

The basic aquifer parameters required by GFLOW are aquifer base elevation, aquifer thickness, hydraulic conductivity, porosity, and recharge rates. Areas with properties significantly different from the main aquifer are modeled as inhomogeneities. Inhomogeneities are subset domains where the aquifer properties are redefined. In this model, the Iron Range and the southern part of the model extent are given distinct characteristics. Well logs and geologic studies provide the major source of information for these inputs.

The Iron Range geology is that of the Biwabik Iron Formation which is characterized by lower hydraulic conductivity and a higher bedrock elevation, while the rest of the watershed is Proterozoic Metasedimentary rock, characterized by relatively higher hydraulic conductivity and lower bedrock elevation which decreases further toward the outlet of this extent (Figure 9; Walsh, 2004; Adolphson, et al., 1981; Jennings and Reynolds, 2005; Jirsa et al., 2005). The entire model area is within state Ground Water Province 4 (Drivas, 2004).

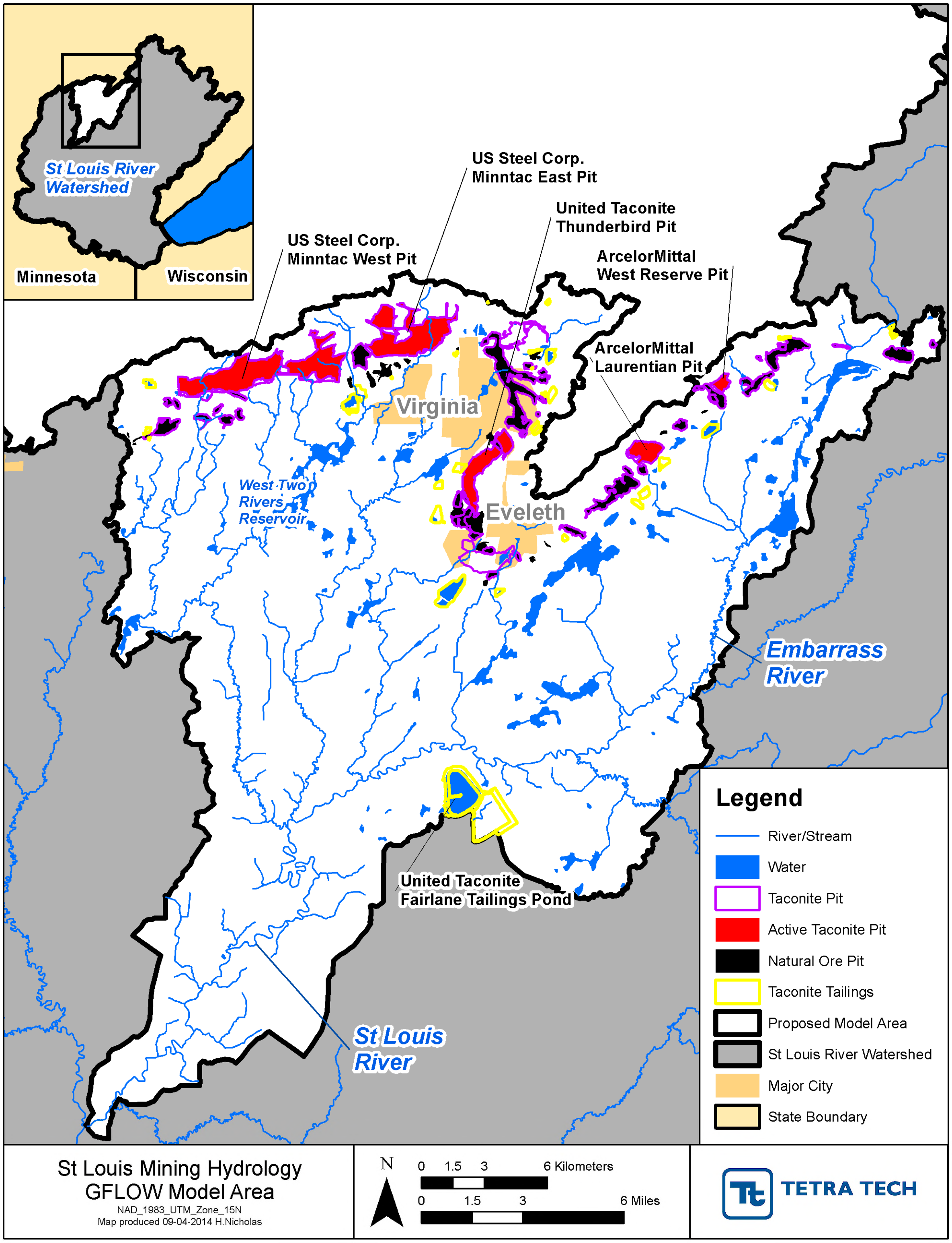

Figure 8. GFLOW Model Extent in the upper St Louis River Watershed

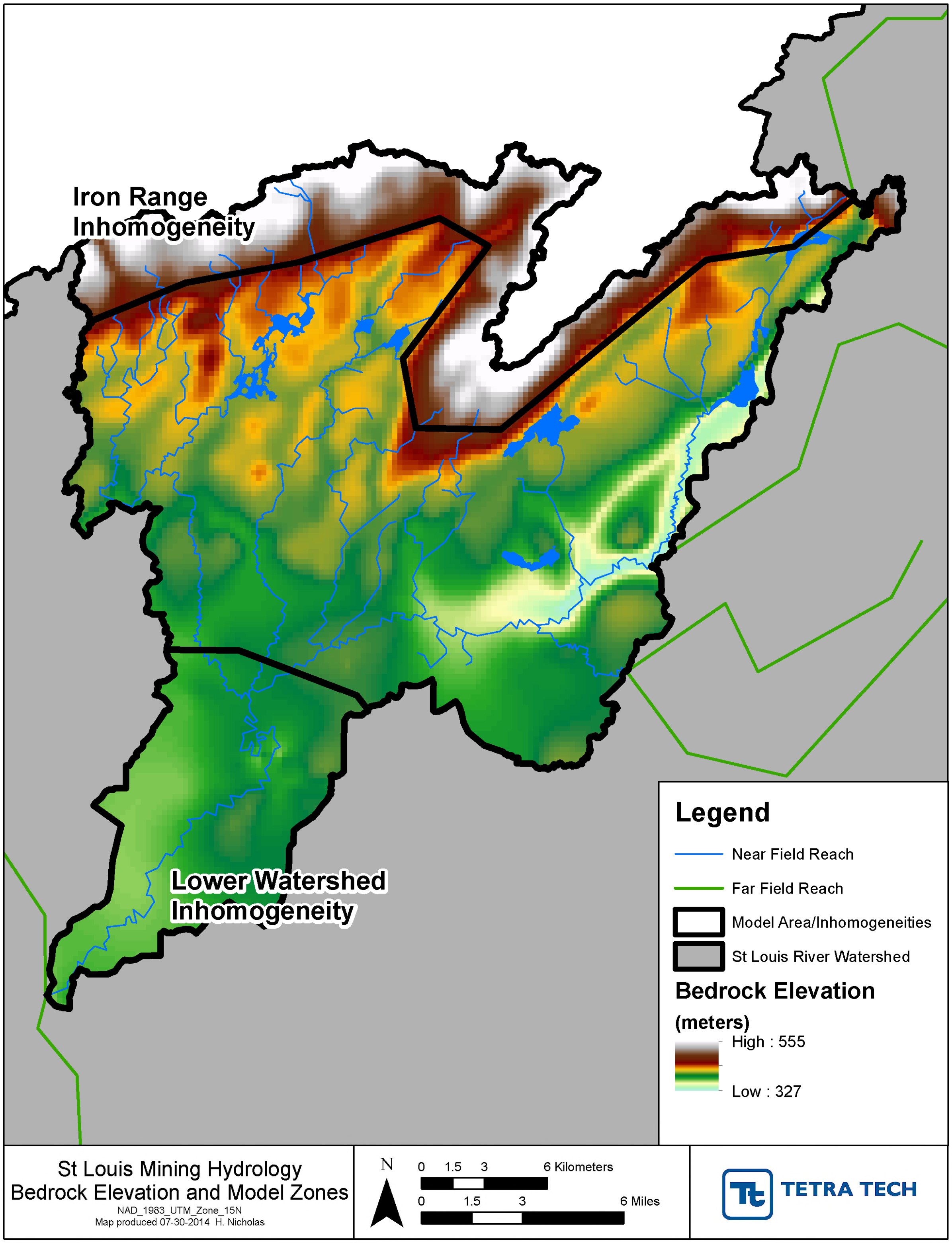

Figure 9. Bedrock Elevation and Location of Inhomogeneities in the GFLOW Model Area

Bedrock topography and depth-to-bedrock GIS layers were obtained from the MN DNR website and static water elevations from construction logs of overburden wells from the MN County Well Index were used to provide basic model inputs for each part of the model. In GFLOW, aquifer thickness is defined as the total thickness of the aquifer material for confined aquifers, while for unconfined aquifers the thickness should be set to an arbitrarily large value to that the model can resolve elevation of the water table. The main middle section of the watershed was assigned a base elevation of 350 m. The inhomogeneity representing the Iron Range was given a base elevation of 416 m and the inhomogeneity representing the southernmost part of the watershed was given a base elevation of 330 m. Hydraulic conductivity, which was adjusted during calibration, was set to 1 m/d in the Iron Range, 12 m/d in the central part of the watershed, and 13 m/d in the lower part of the watershed.

Aquifer recharge is set to an annual average rate of 0.00057 m/d based on an area-weighted average from the aquifer Regional Regression Recharge (RRR) grid developed by Minnesota DNR (Lorenz and Delin, 2007; Delin and Falteisek, 2007). Aquifer porosity was set to the GFLOW default value of 0.2 for the entire model area.

3.1.3 Representation of Stream Network

The hydrologic network of the upper St Louis River watershed is a complex matrix of streams, lakes, wetlands, active and inactive mine pits, and tailings ponds. In the GFLOW environment, rivers and streams, as well as unpumped lakes connected to the stream network, are represented as line-sinks which are assigned specific geometry, routing, and several hydraulic properties. NHDPlusV2 flow lines (McKay et al., 2012) were used as a basis for providing the locations of all waterways. There are two types of line-sinks in the model, far-field line-sinks which provide constant boundary conditions to the model, and near-field line-sinks which are assigned specific routing and hydraulic properties. The location of both types of line sinks are shown in Figure 10. Numbering of the line sink segments is shown in Appendix A. These flow lines were simplified in GIS for the GFLOW model by removing the myriad of oxbow lakes, as well as the minor and hydrologically insignificant tributaries. The maximum number of line-sinks (individual segments between vertices) as allowed in a single GFLOW model is 3,000. The near-field flow lines were simplified in GIS to decrease the number of line-sink segments but maintain the general shape and character of each stream. The far-field line sinks, which provide boundary conditions to the domain, are represented with coarser approximations.

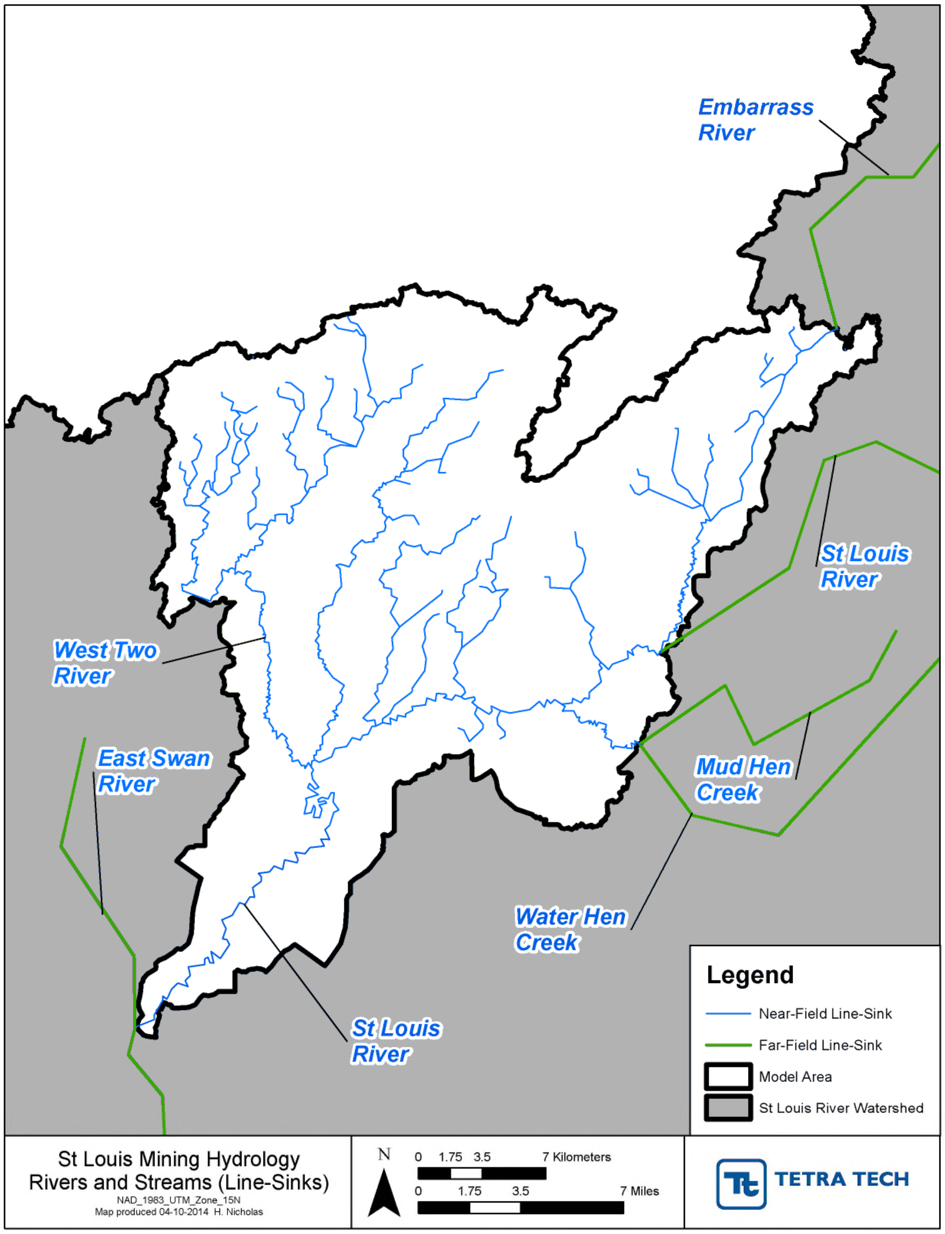

Figure 10. GFLOW Model Inputs for Stream Network as Near-Field and Far-Field Line-Sinks

Hydraulic properties specified for near-field line-sink model input include “resistance” which is a measure of the head gradient between the stream and aquifer based on the thickness of the stream bottom material, “width” which is the true width of the water body, and “depth” which is related to the distance between the surface water elevation and the bottom of the resistance layer. The water level elevations at the upstream and downstream nodes of each line-sink were assigned in the model based on GIS sampling of LIDAR data flown mid-May, 2011 which did not penetrate the water surface. These head-specified line-sinks are set up to provide heads “along stream centerline” in the model environment. The depth parameter for all near-field line-sinks was set to 0.1 m, and resistance was set to 25 days for all reaches except for the St Louis River main stem which was set to 75 days. Using LiDAR and aerial imagery as a reference, widths for major rivers were defined as: St Louis River 37.75 m, Mud Hen Creek 10m, West Two River 10m, Embarrass River 18 m, East Two River 7 m, and a width of 5 m was applied to all other tributaries. For a detailed input of head and width inputs for all reaches, refer to Appendix A.

A portion of Sauntry Creek (Near Field Reach 0850) is a special case as it is carried along a narrow causeway between the ArcelorMittal Minorca Pit and Missabe Mountain Lake. This segment was assigned a very high resistance to prevent it attempting to equilibrate with the adjacent pits.

3.1.4 Representation of Major Lakes

There are a large number of lakes within the model extent. These are represented in several different ways depending on their characteristics. Lakes that are not connected to the surface stream network and which have approximately static water levels that reflect ambient water table elevation function as calibration test points and are discussed in Section 3.2.2. There are several large lakes in the model area, however, which are not static due to the impact of water appropriations, or because they are connected to the stream network. In particular, Missabe Mountain Lake, although no longer mined, serves as a water supply and is actively pumped. It is therefore grouped with the pumped mine pits discussed in Section 3.1.5.

Seven major lakes along the stream network were added to the model area as constant head boundaries and were represented as line-sinks with heads defined "along surface water boundary" (Table 4, Figure 11). All of these lakes were assigned the same parameterization: line-sink widths of 1 m, depth layers of 25 m, and resistances of 1 day. Head boundary conditions were determined from May 2011 LiDAR. All of these lakes fall in the upper half of the modeling extent (Table 4, Figure 11).

Table 4. Major Lakes on Stream Network and Included in GFLOW Model

Lake Name	Water Level Elevation (m)
West Two River Reservoir	424.52
Ely Lake	419.50
Esquagama Lake	410.50
Embarrass Lake	415.30
Pleasant Lake	408.40
Manganika Lake	428.20
Mashkenode Lake	428.80

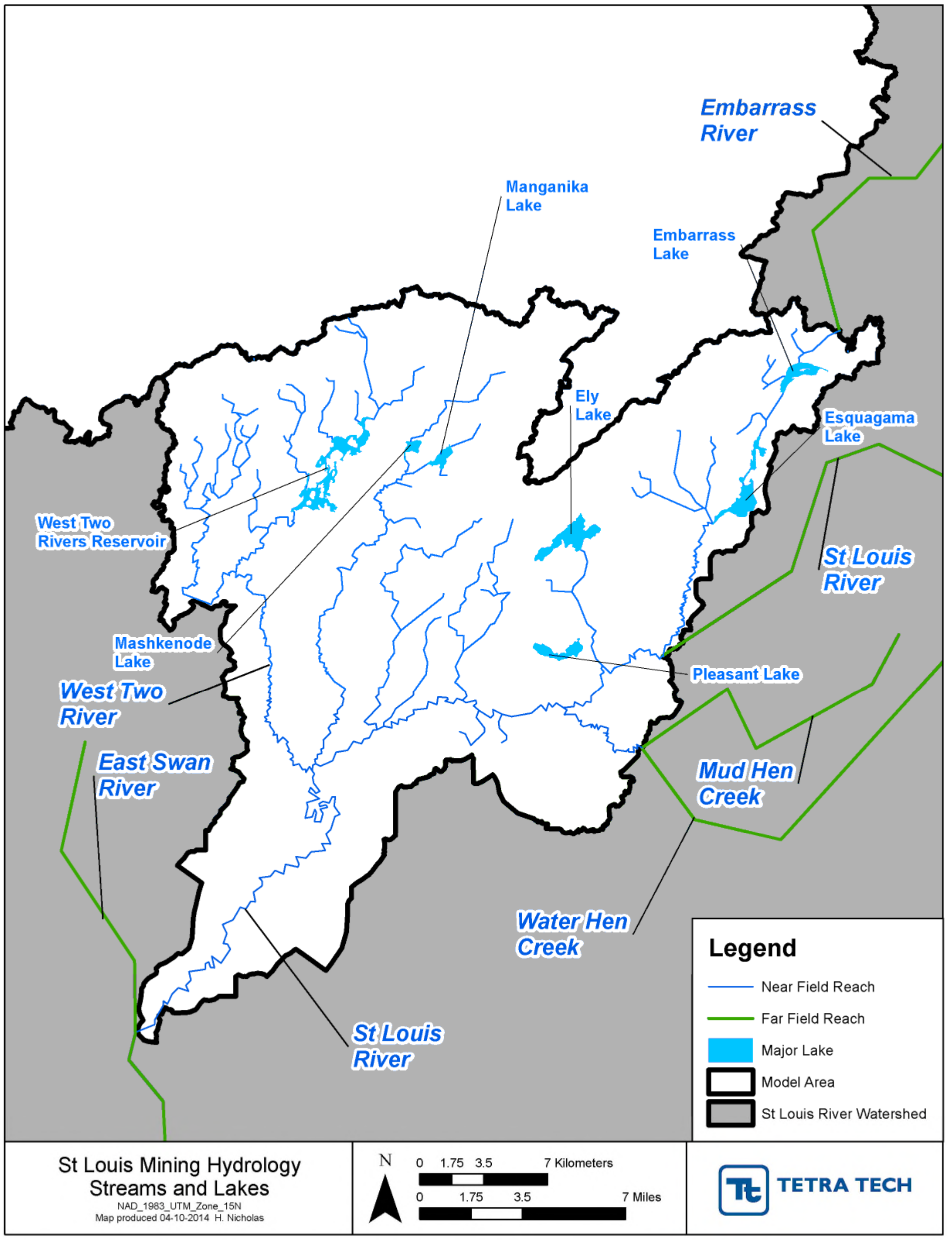

Figure 11. Major Lakes Connected to Stream Network in GFLOW Model

3.1.5 Representation of Active Mining Features

Active taconite mining operations within the model extent are large open pits which are continuously dewatered throughout the year. Pit dewatering is required for these operations because they receive surface water runoff from upland areas and intercept up-gradient groundwater inflow (Green et al., 2005). Pumping occurs as-needed with mobile sump pumps in the lowest elevation location in each pit. Pit dewatering is covered by water appropriation permits and monthly volumes are reported to MNDNR. Missabe Mountain Lake, an inactive mine pit, is modeled as an actively pumped feature, although it is not pumped dry, because it is appropriated for water supply in the City of Virginia as well as make-up process water at the ArcelorMittal taconite plant.

In the model, active mine pits are represented as far-field line-sinks with constant head boundaries as per the recommendation of Henk Haitjema, the developer of the GFLOW model. In order to drain water down to the base of the pit along the pit perimeter, the constant head boundaries assigned to each pit were the minimum bedrock elevations within each pit boundary (Table 5), allowing drawdown to the base of the overburden aquifer at the pit wall. There is also a large mine tailings basin in the southern part of the model extent that is modeled in the same fashion as the active pits (head-specified far-field line-sink) although it represents an area of mounded water above ground which seeps into the earth. As expected, the mine pits cause drawdown within the surrounding aquifer, and the tailings basin causes mounding in the surficial aquifer. The location of these mine features are highlighted in Figure 12.

Table 5. Active Mine Features Included in the GFLOW Model

Appropriation Permit Number	Installation	Organization	Mine Feature	Elevation Assigned (m)
1980-2084	3	US Steel Corp.	Minntac West Pit (east half)	460.2
1980-2084	6	US Steel Corp.	Minntac West Pit (west half)	442.3
1980-2085	PRIND	US Steel Corp.	Minntac East Pit (east half)	433.6
1980-2085	2SMP	US Steel Corp.	Minntac East Pit (west half)	421.5
1991-2017	1	ArcelorMittal	Laurentian Pit	432.8
1975-2137	5	United Taconite	Thunderbird Pit	426.9
2008-0216	1	ArcelorMittal	Missabe Mountain Lake[1]	399.2
N/A	N/A	United Taconite	Fairlane Tailings Basin	434.0

[1] Note that Missabe Mountain Lake (aka Mineview-in-the-Sky) is not pumped dry, but has actively held appropriations that maintain the static water level.

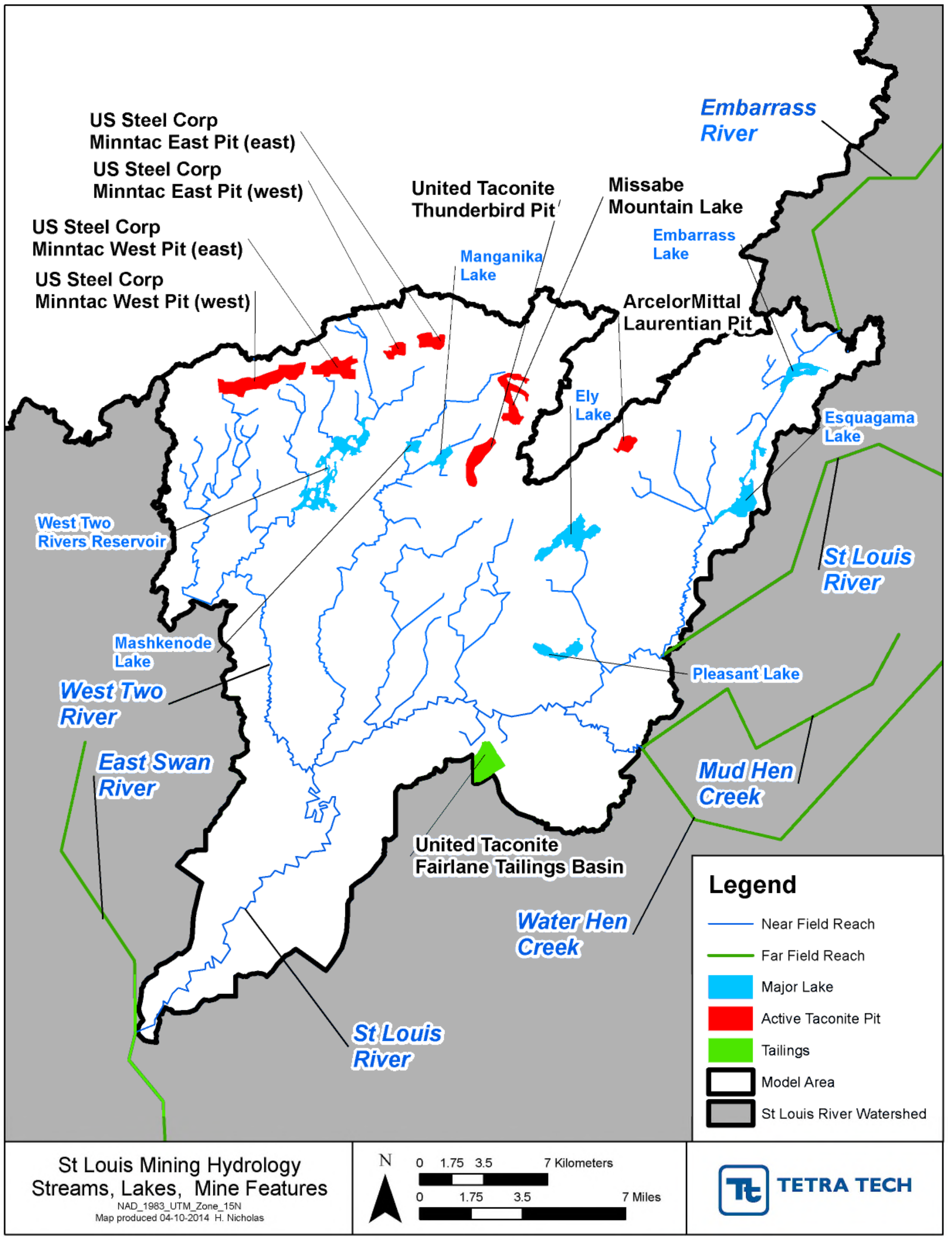

Figure 12. GFLOW Model Inputs for Active Mining Operations

3.1.6 Combined Model Elements and Model Environment

All of the physical features (rivers, lakes, mine features, aquifer parameters) in the model are shown within the model environment in Figure 13. No-flow boundaries were generalized in the model as line-sinks that fall: along the northern edge along the ride of the Iron Range, along the western edge of the hydrologic divide between the East Swan River and the Two River, as well as in several locations along the eastern edge of the model extent where no flow enters the model area between major tributaries.

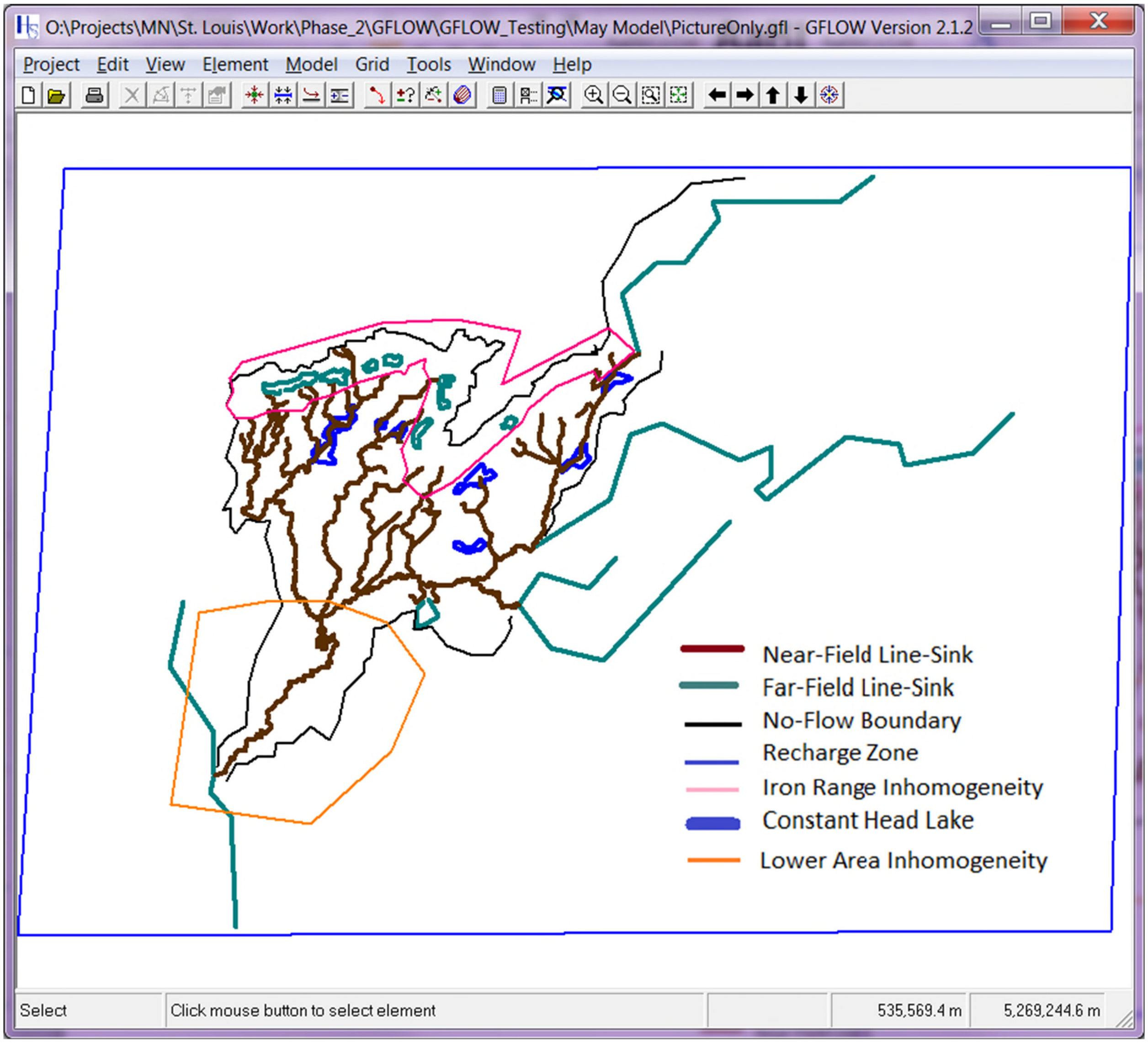

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Figure 13. GFLOW Model Environment and Model Inputs for the St Louis River Iron Range Area

3.2 GFLOW CALIBRATION

3.2.1 Calibration Approach

Environmental simulation models are simplified mathematical representations of complex real world systems. Models cannot accurately depict the multitude of processes occurring at all physical and temporal scales. Models can, however, make use of known interrelationships among variables to predict how a given quantity or variable would change in response to a change in an interdependent variable or forcing function. In this way, models can be useful frameworks for investigations of how a system would likely respond to a perturbation from its current state. To provide a credible basis for prediction and the evaluation of mitigation options, the ability of the model to represent real world conditions must be evaluated through a process of model calibration and corroboration.

The principal study questions for this project address the interaction of surface water and ground water hydrology in the mining areas of the watershed. Groundwater hydrology is represented by a steady-state model. As a steady-state model, the technique of comparing observed and simulated time series is not relevant. Instead, the objective is to make the model as realistic as possible in representing long-term, seasonally averaged water potentiometric surface elevations and fluxes between surface and groundwater. The primary test of model realism is comparison to potentiometric heads. Few continuous piezometer data series are available in this region. Therefore, the comparison relies primarily on static water levels recorded when new wells are drilled and the water levels observed in closed mine pits that do not have significant inflows or outflows and are in approximate equilibrium with the water table in the surface aquifer.

Calculated heads are expected to differ from observed heads for many reasons, most importantly because the model aquifer is merely an abstraction of the real aquifer system. A successful model will show deviations relative to observed heads that are both positive and negative with a spatial distribution of deviations that is not strongly clustered. Hydrologic calibration for the GFLOW model focused on comparing observed water level data to model output hydraulic heads. The observed data ("test points" in the GFLOW environment) are the measured water elevations from LiDAR in static lakes and elevations in a few monitored observation wells, plus interpolated water level surfaces inferred from well construction logs using the County Well database from Minnesota Department of Health (see Appendix B). Statistics used for model calibration are relative percent difference, standard error, mean difference, along with the slope and squared correlation coefficient (R^2) for a linear regression between the simulated and observed data.

3.2.2 Test Points: Static Lakes

In the GFLOW model environment, several large lakes were included as constant head boundaries, most of which are found in-line with the stream network. Lakes with static water levels through time which are not in-line with the stream network were used as calibration test points because they are assumed to represent the static overburden water level of the area at equilibrium. Some of these lakes are natural waterbodies while others are inactive mine pits that have reached equilibrium with the local ground water. The status of lake equilibrium was based on personal observations by Michael Crotteau, Hydrologist with MDNR. Static waterbodies were simulated in the model as "test points" or nominal piezometers with observed heads sampled from the May 2011 LiDAR data (Figure 14).

3.2.3 Additional Test Points: Head Surface from Overburden Wells

We used well construction data from the Minnesota County Well Index to generate additional calibration test points across the model extent. The database contains construction details for 80 wells within the GFLOW model extent that are screened in the overburden and thus represent the surficial aquifer in the model. Unlike the static lake elevation data, which comes from the LiDAR of May 2011, the well construction water levels come from multiple decades and various seasons and do not necessarily represent current conditions. Therefore, a smoothed, interpolated surface through the available elevations is used to create surrogate test points, rather than using the well elevations directly (see Appendix B).

Using the static water elevations noted for overburden wells, water table elevations were interpolated across the model extent using inverse distance weighting (IDW). Using the IDW raster generated from the CWI wells, 27 test points were created as equal intervals across the model extent by sampling the raster at those locations (Figure 17). Data processing to create these 27 test points can be found in Appendix B.

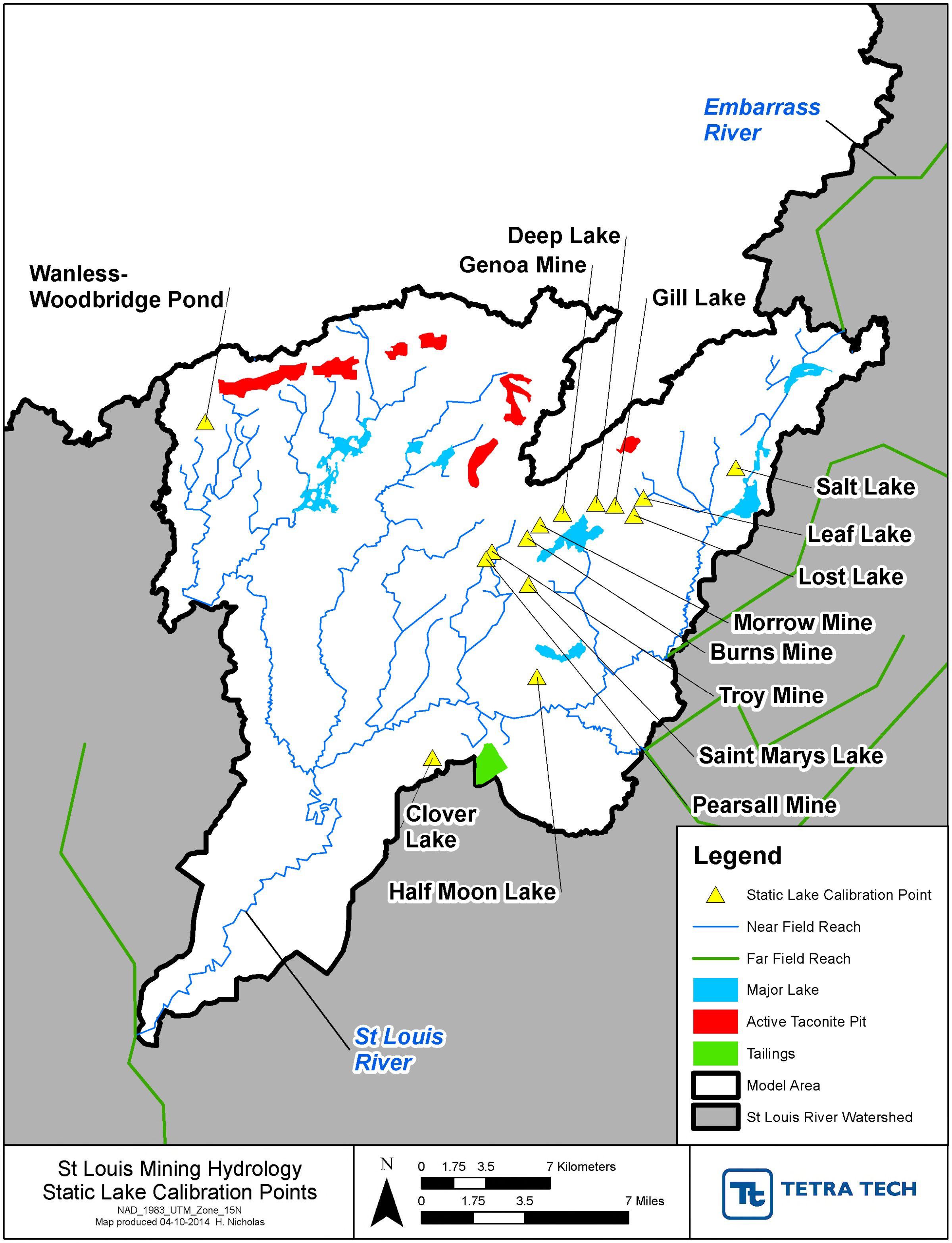


Figure 14. GFLOW Static Lake Calibration Points

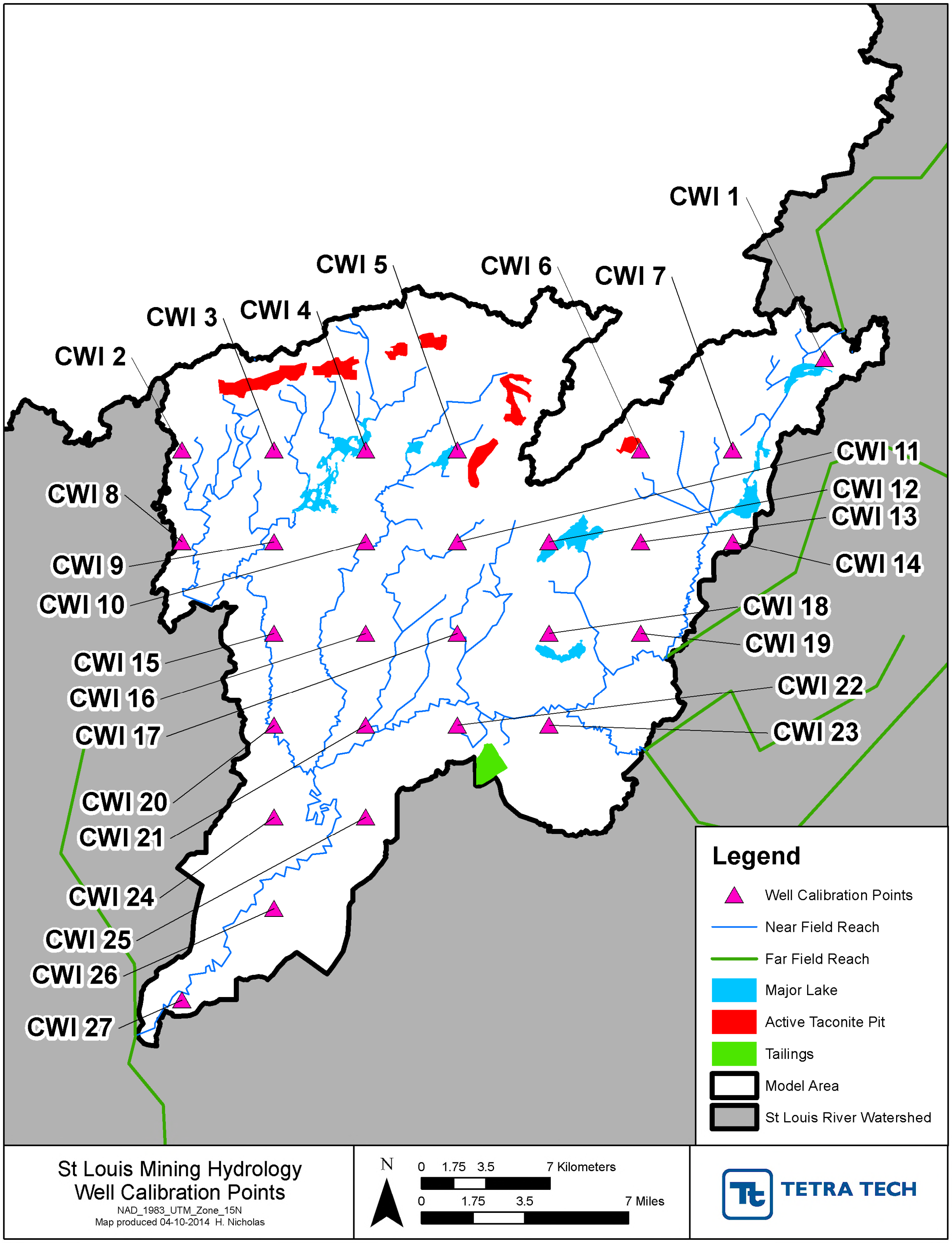


Figure 15. GFLOW Model Inputs for Overburden Well Calibration Points

3.2.4 GFLOW Model Calibration

Model calibration was completed based on minimizing the differences between observed and modeled hydraulic head at the test point locations across the model extent. Comparison of observed and modeled water level elevations at individual calibration test points is provided in Appendix D. There were a total of 42 test points which were equally weighted across the modelling area, and overall a reasonably good match was achieved for the data (Table 6). Note that calibration statistics were calculated for the entire set, as well as differentiated between the two different types of test points.

Table 6. GFLOW Model Calibration Statistics

Statistic	Test Point Results: Both Types	Test Point Results: Static Lakes	Test Point Results: Overburden Wells
Number of Observations	42	15	27
Maximum Difference (m)	18.77	6.77	18.77
Minimum Difference(m)	-17.62	-7.83	-17.62
Mean Relative Percent Difference	-0.03%	0.10%	-0.10%
Mean Relative Percent Absolute Difference	1.09%	0.66%	1.33%
Mean Difference(m)	-0.12	0.43	-0.43
Mean Absolute Difference	4.59	2.87	5.55
Median Difference(m)	0.28	0.20	0.36
Standard Deviation of Differences	6.32	3.81	7.40
Standard Deviation of Absolute Differences	4.28	2.43	4.79
Standard Error(m)	6.25	3.95	7.28
R^2 for Modeled:Observed Regression	0.83	0.93	0.71
Regression Slope	0.91	0.94	0.83

The model provides a reasonable fit to water elevations for both static lakes and the head in the surface aquifer estimated from overburden well construction logs (Figure 16). A regression of modeled on observed heads (Figure 17) shows a strongly significant correlation with an R^2 of 83 percent, indicating that the model explains most of the observed variability in head. The slope coefficient (0.9113) is highly significant ($p = 6.7 \times 10^{-17}$) but has 95% confidence bounds that include 1 (a 1:1 relationship between modeled and observed values). The intercept term is not significantly different from zero.

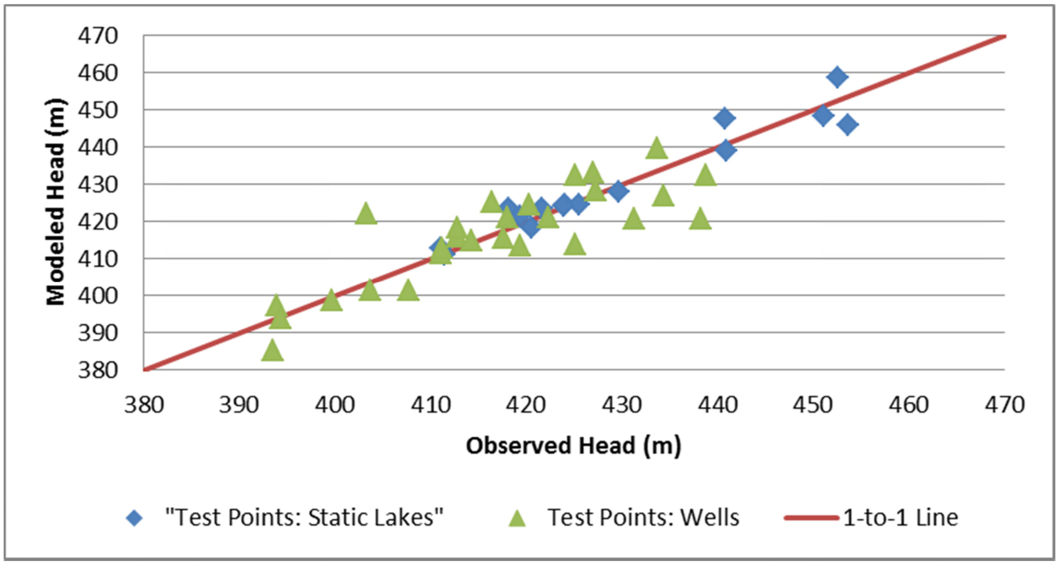


Figure 16. Calibration Results of Modeled vs. Observed Water Levels at Lake and Well Test Points

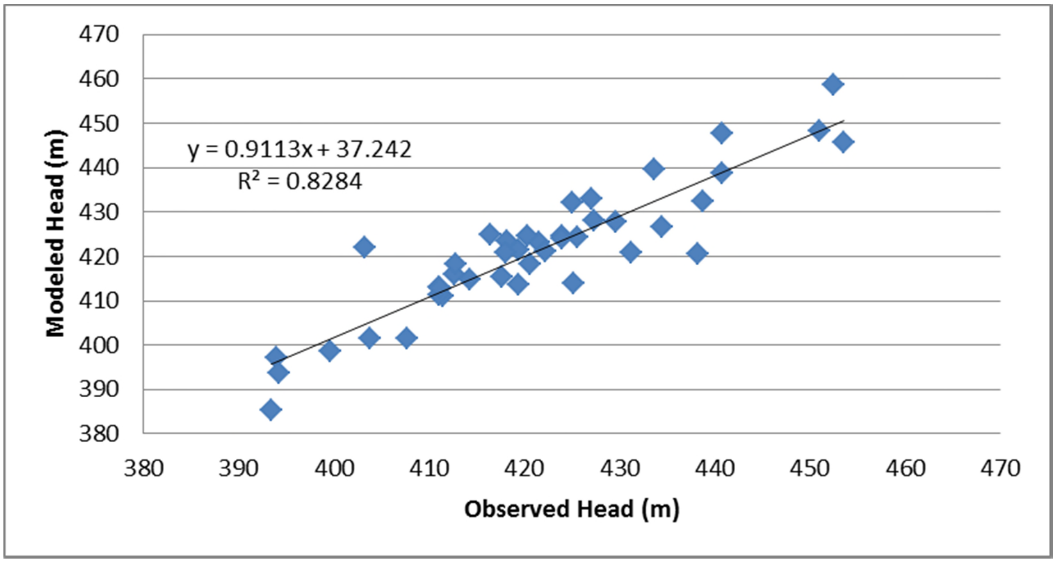


Figure 17. Regression of Modeled vs. Observed Water Levels at Test Points

3.3 GFLOW MODEL APPLICATIONS

3.3.1 Head Contours and Flow Lines

The calibrated GFLOW model produces estimates of the groundwater head and stream lines in the study area. The stream lines are normal to the head contours. Simplified results for the entire study area are summarized in Figure 18.

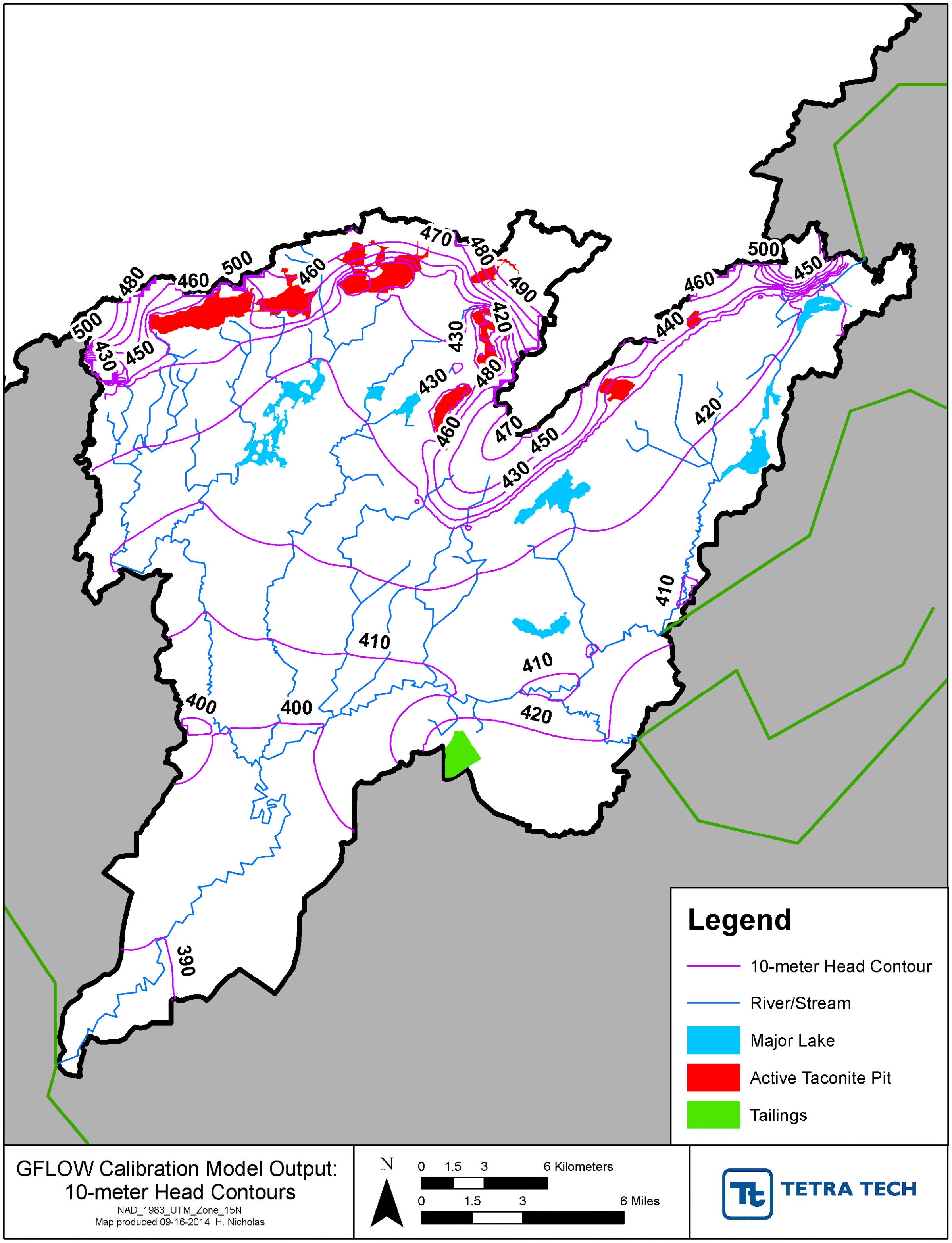


Figure 18. GFLOW Simulation of Head Contours for Annual Average Recharge Conditions with Existing Mining Operations

Figure 19 and Figure 20 show detailed examples of head contours in the vicinity of the actively pumped Minntac East Pit and Pleasant Lake, which serves as a constant head boundary because it is connected to the active stream network. The pumped pit shows sharp head gradients, particularly on the north side, as ground water is intercepted by the pit and pumped away. Pleasant Lake shows only a minor impact on local head elevation because the overall system is nearly in equilibrium with all surface water features in this region.

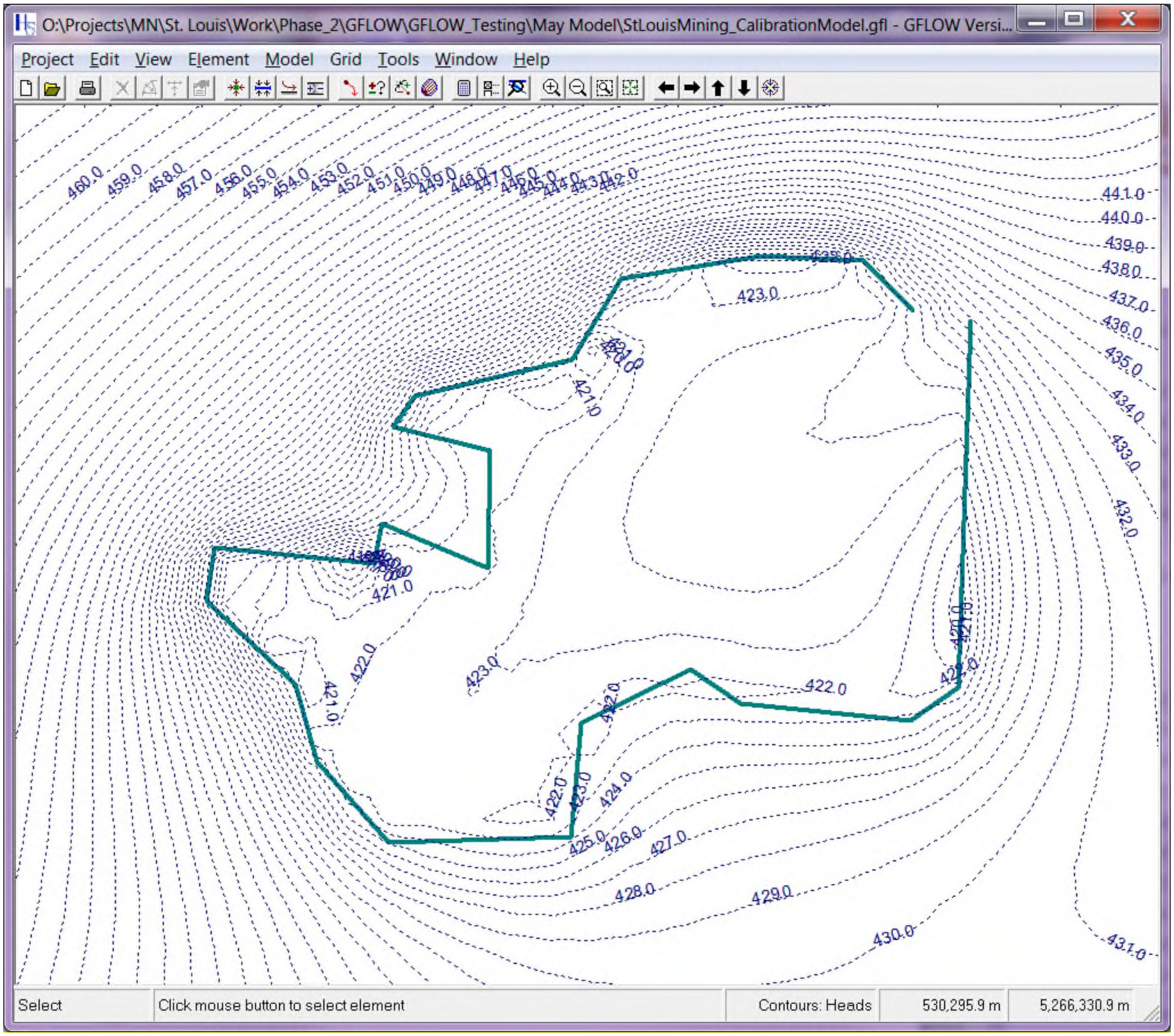
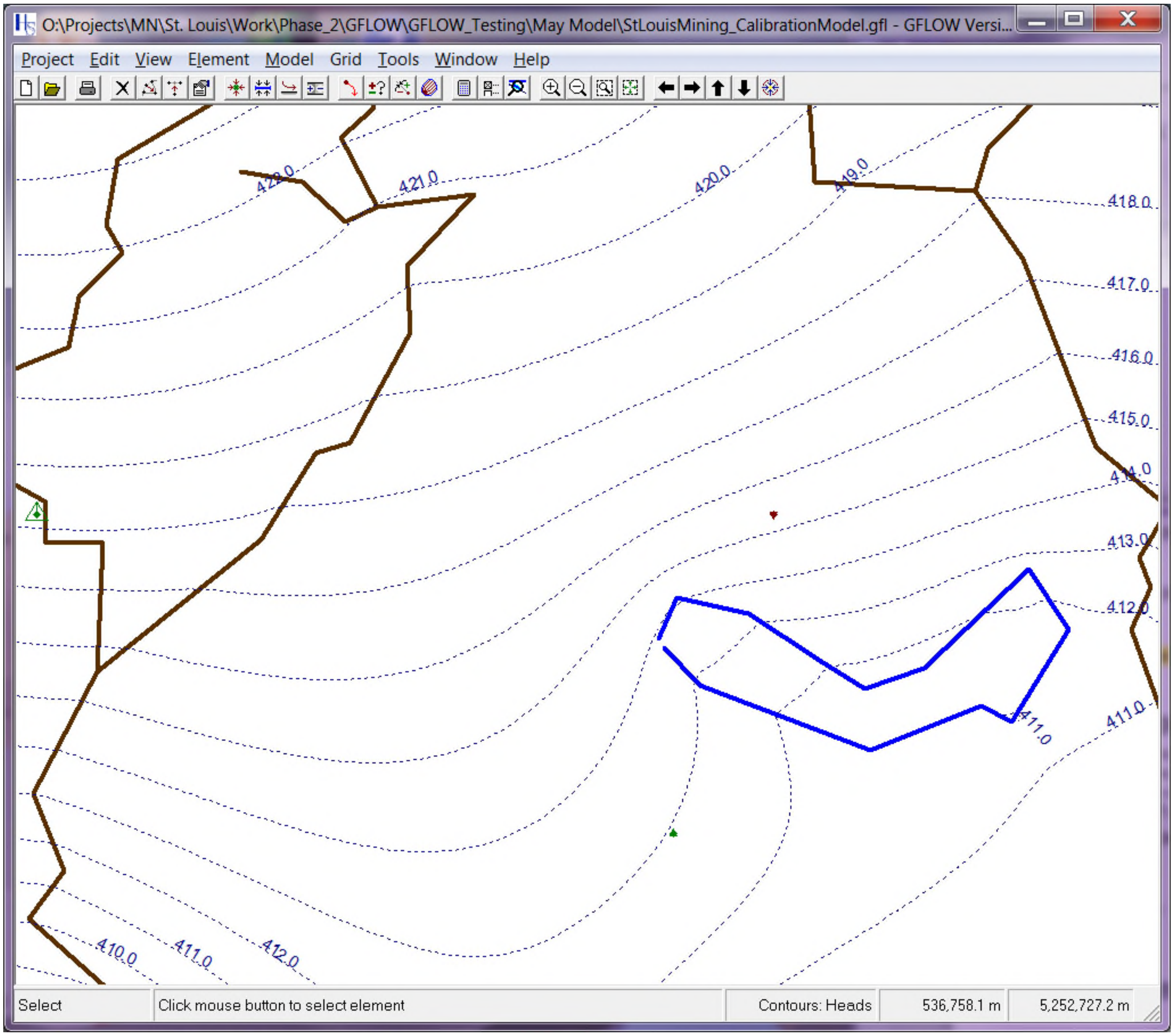


Figure 19. GFLOW Model Outputs: Head Contours in the Vicinity of Minntac East Pit (West Side)



O:\Projects\MN\St. Louis\Work\Phase_2\GFLOW\GFLOW_Testing\May Model\StLouisMining_CalibrationModel.gfl - GFLOW Versi...

Select | Click mouse button to select element | Contours: Heads | 536,758.1 m | 5,252,727.2 m

Figure 20. GFLOW Model Outputs: Head Contours in the Vicinity of Pleasant Lake

3.3.2 Surface Water Exchanges

The GFLOW line sink outflow provides estimates of exchange rates along each line sink segment in units of m^2/d. The results (Figure 21) show that there are only a few losing stream reaches (red circles in figure). However, there is a large group of segments down-gradient from mining features that have essentially zero exchanges with ground water (yellow circles). These segments are predicted to have depleted baseflows due to the combination of the interception of up-gradient groundwater and lowering of the local water table elevation due to appropriations from mine pits.

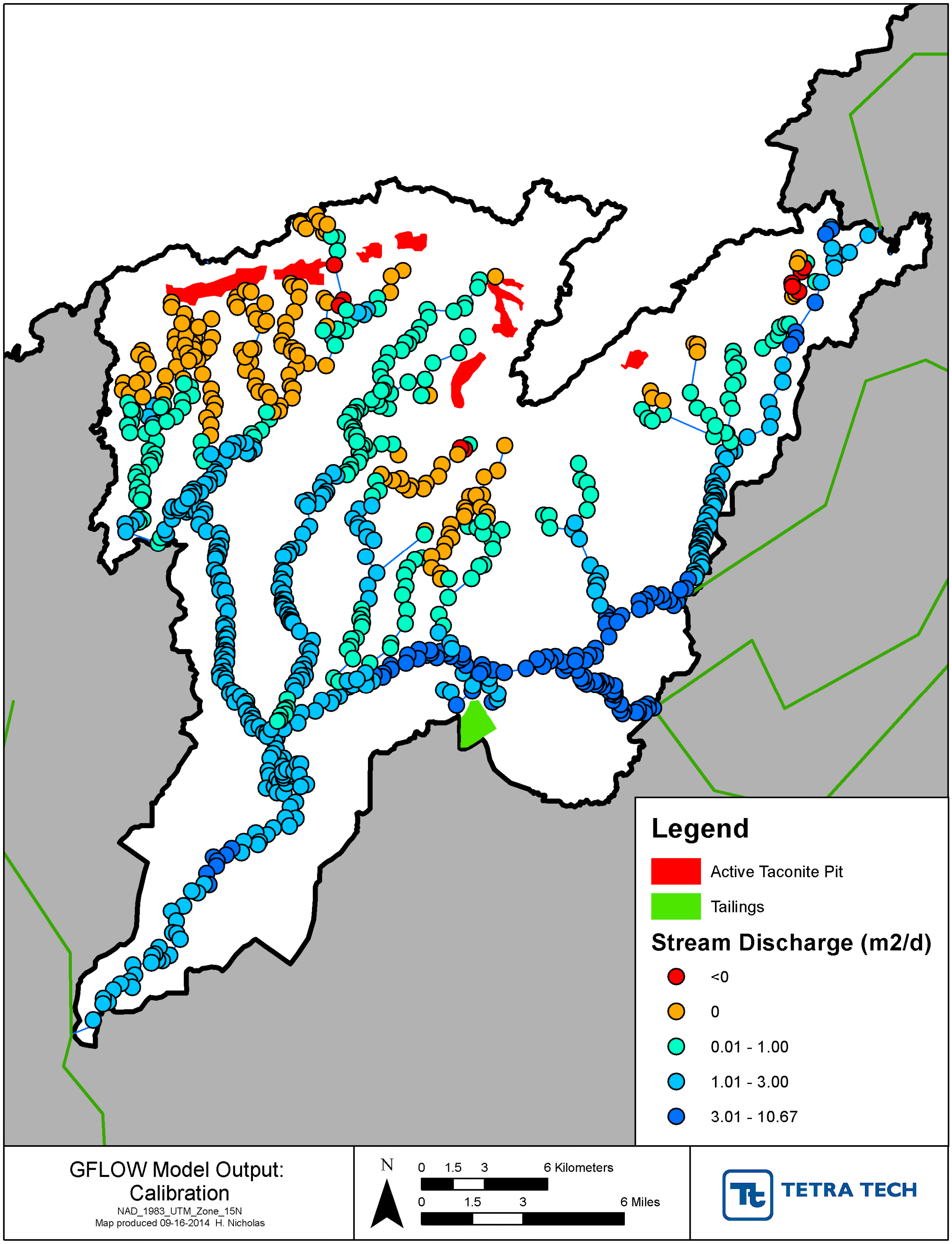


Figure 21. Estimated Line Sink Exchange Rates under Current Conditions (positive from aquifer to stream)

3.3.3 Dry Season Model

The model was re-configured (not calibrated) with dry season (late summer and early fall) recharge rates to investigate likely seasonal variability in groundwater flow. The physical elements remain the same for this model, and all major aquifer and inhomogeneity parameters were kept constant, as well as mine features in the model area. For this model scenario to represent the dry season, lake levels were held constant, however the recharge rate was decreased by 23% to 0.000438 m/d based on the ratio between August-October and whole year average percolation to ground water predicted by the HSPF model. Near field and far field line-sink heads were decreased by 0.3048 m (1 ft) to represent the lower flows and surface water elevations typical of late summer and early fall.

Dry season results are shown in Table 7. Across the entire model extent, the head at test points is, on average, 1.8 m lower and the net discharge from the aquifer to stream reaches decreases by 18 percent.

Table 7. Dry Season Model Run Results

	Calibration Model	Dry Season Model
Average Test Point Head (m)	421.22	419.42 (-0.43%)
Average Reach Discharge (m/d)	1.75	1.42 (-18.43%)

3.3.4 Natural Conditions Model

The model was also configured to represent the natural, pre-mining conditions of this region. For this scenario, all model elements were retained from the calibration model except that the mine pits, their associated water appropriations, and discharges to the Fairlane Tailings Basin were removed. This scenario represents an estimate of how the groundwater system hydrology functioned prior to the start of mining operations.

Summary results for this scenario (Table 8) suggest that, in the absence of mining operations, base flow discharges from the aquifer to the stream network were about 8 percent greater on average over the entire model extent. Results are more dramatic for individual segments, as is shown in the detailed water balance analysis in Section 4. Head contours for average natural conditions are displayed in Figure 22, which can be compared to Figure 18 above, showing contours for existing conditions.

Table 8. Natural Conditions Model Run Results

	Calibration Model	Natural Conditions Model
Average Test Point Head (m)	421.22	421.61 (+0.09%)
Average Reach Discharge (m/d)	1.75	1.88 (+7.78%)

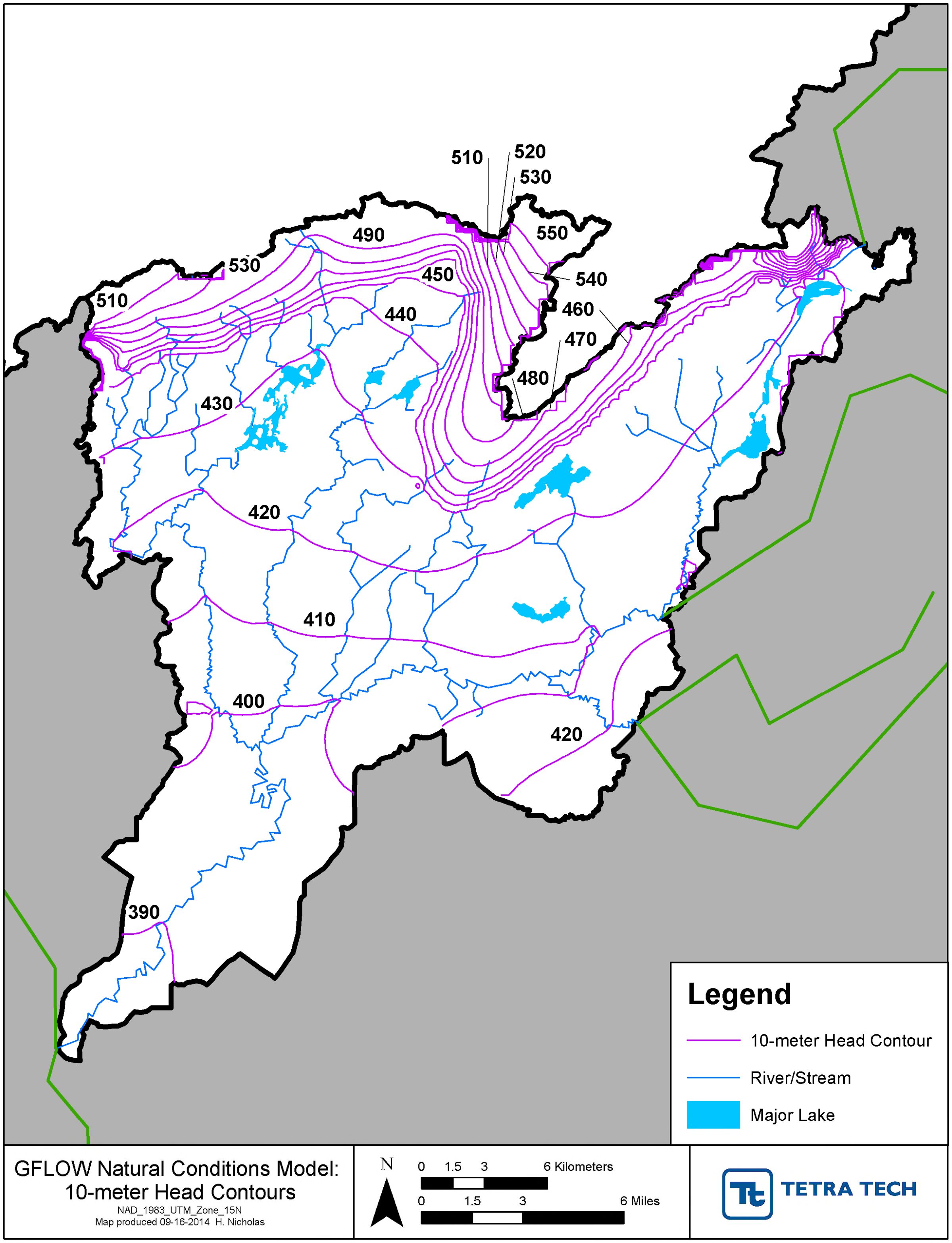


Figure 22. GFLOW Simulation of Head Contours for Annual Average Recharge Conditions prior to Mining Operations

3.3.5 Linking the GFLOW and HSPF Models

Linking the results from the GFLOW model to the HSPF surface water model requires matching GFLOW line sink segments with HSPF model reaches. The HSPF model was created for the entire St Louis River Watershed and therefore is on a larger scale than the GFLOW model, so single HSPF model reaches are represented by smaller segments in the GFLOW model (Table 9).

Table 9. GFLOW and HSPF Model Reach Alignment

HSPF Reach	GFLOW Segments	Discharge (cfs/mi)
242	70, 120, 130, 170, 80	1.65
243	310	1.25
244	440, 330	0.66
245	360, 450, 590, 750	0.78
246	870	0.35
247	390, 510	0.59
248	210, 340	0.32
249	160, 140, 150	3.48
250	180, 200	2.51
251	380	1.48
252	660, 420	0.22
253	720,0830, 910, 940	1.59
271	90	3.51

The GFLOW model simulations suggest that there are few losing reaches outside of the area where drainage is directly intercepted by active mining features, and that losses due to backflow from down-gradient areas into mine pits is relatively small. Therefore, the approach in the larger scale HSPF model of eliminating areas identified as upstream of active mining features (removing all flow or subsurface flow only, as discussed in Section 2) is a reasonable approximation. Further, analysis of the HSPF water balance suggests it is compatible with the GFLOW steady state solution. In GFLOW, the groundwater recharge rate is set at 0.0057 m/d or 7.78 in/yr. In HSPF, recharge to the surface groundwater system is output as the variable AGWI. Over the simulated period of water years 1993-2012, the average of AGWI, area-weighted over the portion of the GFLOW study area not intercepted by active mining features and corrected for baseflow ET, is 8.58 in/yr, or about 110 percent of the GFLOW estimate. The two values are thus in good agreement, considering that the GFLOW recharge is a long-term steady-state estimate not specific to the period simulated in HSPF.

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4 Water Balance Analysis of Mining Area Streams

Results of the previous sections are combined with output from the calibrated HSPF model to estimate the pre-mining water balance of the mining area watersheds and the extent to which total flow and baseflow has been altered by mining operations. The analysis is presented for the eleven affected subbasins discussed above, as well as for smaller subareas (3a, 3b, 8a, and 8b) within subbasins 3 and 8, representing, respectively, West Two River upstream of West Two River Reservoir, Parkville Creek (tributary to West Two River Reservoir), Sauntry Creek above Mashkenode Lake, and Manganika Creek (Figure 6 and Table 2).

The HSPF model provides estimates of runoff on a unit-area basis for each of the hydrological response units (HRUs) in the study area. The HRUs represent combinations of land cover, soil characteristics, and local meteorology. Annual average results for the period 1993-2012, tabulated separately for surface runoff, interflow, and groundwater discharge, are used to analyze the water balance. Multiplying these unit area rates by the total area upstream of each analysis point yields an estimate of the average native flows expected.

To estimate flows under existing conditions, the native flow estimates are modified in a number of ways:

1. Portions of the original drainage area are intercepted by actively pumped pits, as described in Section 2.3. Total flow is thus re-calculated with the intercepted areas removed. Note that in some cases (e.g., upper Sauntry Creek), surface flow is routed downstream, but subsurface flow is intercepted by mine pits. The portion of total flow simulated by HSPF as interflow is assumed to be routed with surface flow as interflow typically re-emerges to the surface after short flow pathways.
2. Pumping of the mine pits potentially causes backflow of groundwater from down gradient areas as well. Only a few stream segments are simulated as losing water, but for a number of segments normal groundwater discharge is effectively curtailed (see Section 3.3.2). Net losses incurred in this way are estimated based on flow into the pits from the down-gradient side (Table 10.
3. Where the drainage area contains inactive mine pits that are not pumped and have approximately equilibrated with the regional groundwater these pits are assumed to essentially be part of the groundwater flow system and do not cut off upstream flow. However, they do subject the regional groundwater flow, which would otherwise be sequestered in the subsurface, to evaporation. Therefore, evaporation from inactive pits is simulated based on their surface area and the average free water surface evaporation rate simulated by HSPF for the area (30.53 in/yr).
4. Point source discharges are added to the water balance. Most of these surface water discharges are relatively small, although there are a few large ones, particularly in the Manganika Creek area near Virginia (subbasin 8b; see Table 11). Note that some of the mining discharges have varied substantially over time.

Table 10. Discharge into Mine Pits from Down-Gradient Back Flow

Mine Pit	Mining Subbasin	Back-Flow Discharge (cfs)
Minntac West Pit (western half, western side)	10	2.31
Minntac West Pit (western half, eastern side)	4	0.59
Minntac West Pit (eastern half)	3b	-0.88
Minntac East Pit (western half)	3b	0.70
Minntac East Pit (eastern half)	3b	0.85
Thunderbird Mine	8b	1.33
Laurentian Mine	1	0.17
Missabe Mountain Lake	8a	1.32
Missabe Mountain Lake	8b	0.32

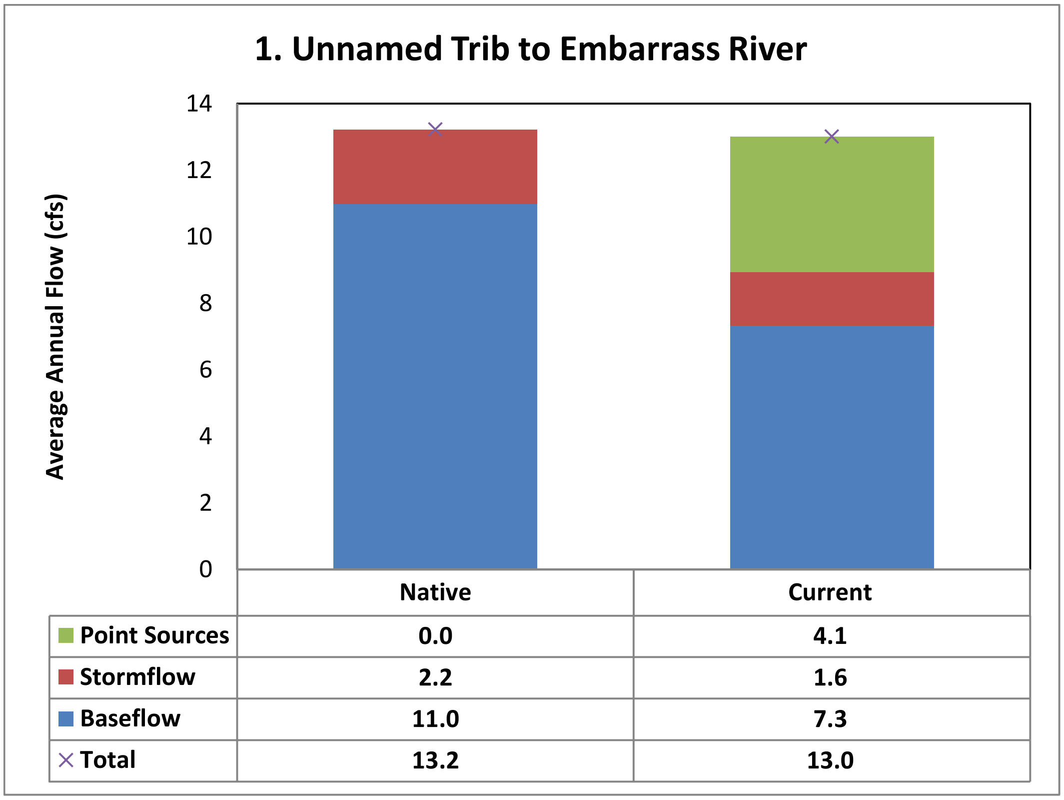
The combined estimates of changes in flow of individual headwater streams are shown in Figure 23 through Figure 30. Table 12 provides a summary of estimated impacts on baseflow. While some streams have little impact (due to limited mining), native baseflow is drastically reduced in some streams – with a reduction of up to 92 percent predicted for Parkville Creek. However, at the subbasin scale, many of these impacts are compensated, on average, by point source discharges – although the mining discharges can be highly variable from year to year. The most dramatic effect is in Manganika Creek (subbasin 8b), where mine pumping is predicted to reduce baseflow by 84 percent, but the addition of three large point source discharges from Virginia and United Taconite results in a net gain relative to native baseflow of 396 percent. Much of this "extra" water ultimately derives from Missabe Mountain Lake (mostly in subbasin 8a), which is not actively mined but is pumped to provide municipal water supply to the City of Virginia as well as to provide plant make-up water for ArcelorMittal.

Table 11. Point Source Discharges in the Study Area

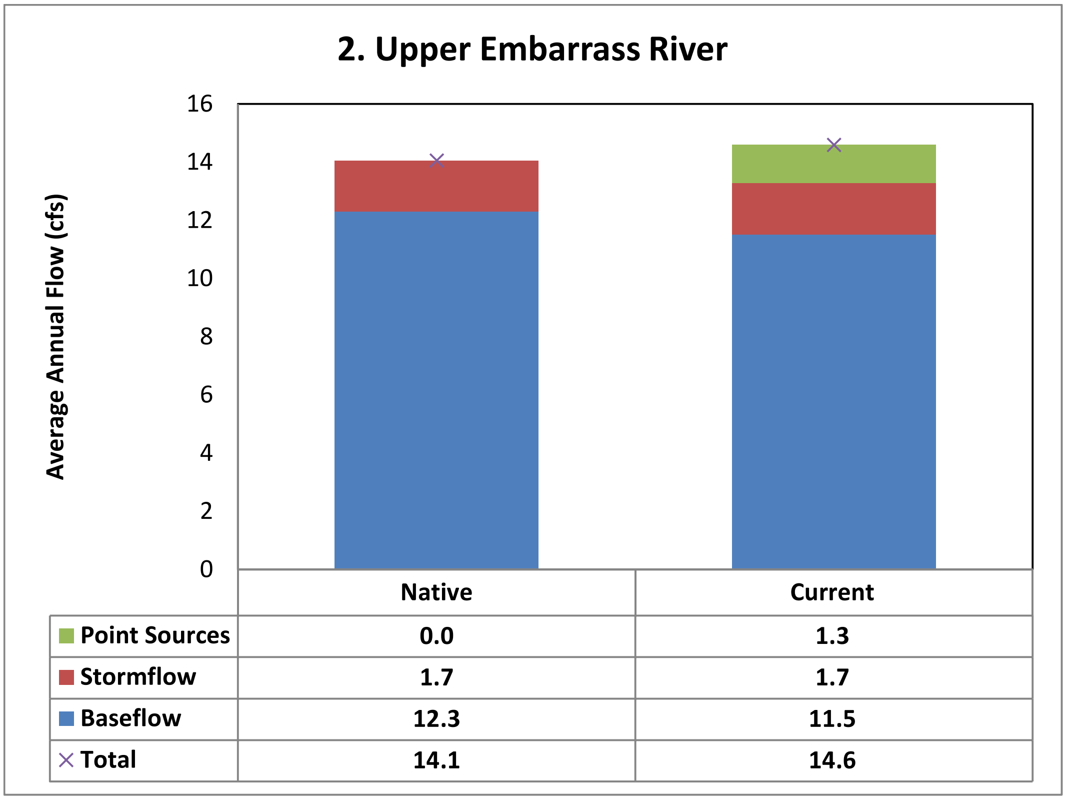
Subbasin	Name	Permit Number	Average Flow, 1993-2012 (MGD)
1	McKinley WWTP	MN0024031	0.0363
1	Arcelor Mittal	MN0059633	2.5849
1	McKinley WTP	MNG820019	0.00650
2	Biwabik WWTP	MN0053279	0.8518
2	Dyno Nobel	MN0060704	0.00046
3	Mountain Iron WWTP	MN0040835	0.0016
3 (b)	Mountain Iron WWTP	MN0040835	0.4258
3 (b)	US Steel Minntac	MN0052493	6.4906
5	Babbitt WTP	MNG82011	0.0725
6	United Taconite -Thunderbird	MN0044946	2.3577
7	United Taconite -Thunderbird	MN0044946	0.00486
7	Eveleth WWTP	MN0023337	0.7041
7	Iron Junction WWTP	MNG580049	0.0251
8 (b)	Virginia WWTP	MN0030163	2.039
8 (b)	Virginia DPU	MN0003379	15.491
8(b)	United Taconite -Thunderbird	MN0044946	1.1683
10	U.S. Steel Minntac	MN0052493	1.9356
11	Gilbert WWTP	MN0020125	0.2904

Table 12. Estimated Reductions in Baseflow Associated with Current Taconite Mining Operations

Watershed	Change in Native Baseflow	Net Baseflow Change with Discharges and Appropriations
1. Unnamed Trib to Embarrass River	-33%	+4%
2. Upper Embarrass River	-6%	+4%
3. West Two River	-51%	+30%
3a. West Two River above Reservoir	-7%	-7%
3b. Parkville Creek (trib to West Two River)	-92%	+15%
4. Unnamed Trib to West Two River	-40%	-40%
5. Ely Creek	-10%	-17%
6. Long Lake Creek	-25%	+25%
7. Elbow Creek	-3%	+10%
8. Manganika and Sauntry Creeks	-45%	+78%
8a. Sauntry Creek and Mashkenode Lake (East Two River Headwaters)	-69%	-69%
8b. Manganika Creek	-84%	+396%
9. Unnamed Trib to Kinney (McQuade) Creek	-17%	-17%
10. Kinney (McQuade) Creek	-53%	-14%
11. Middle Embarrass River	-18%	-12%

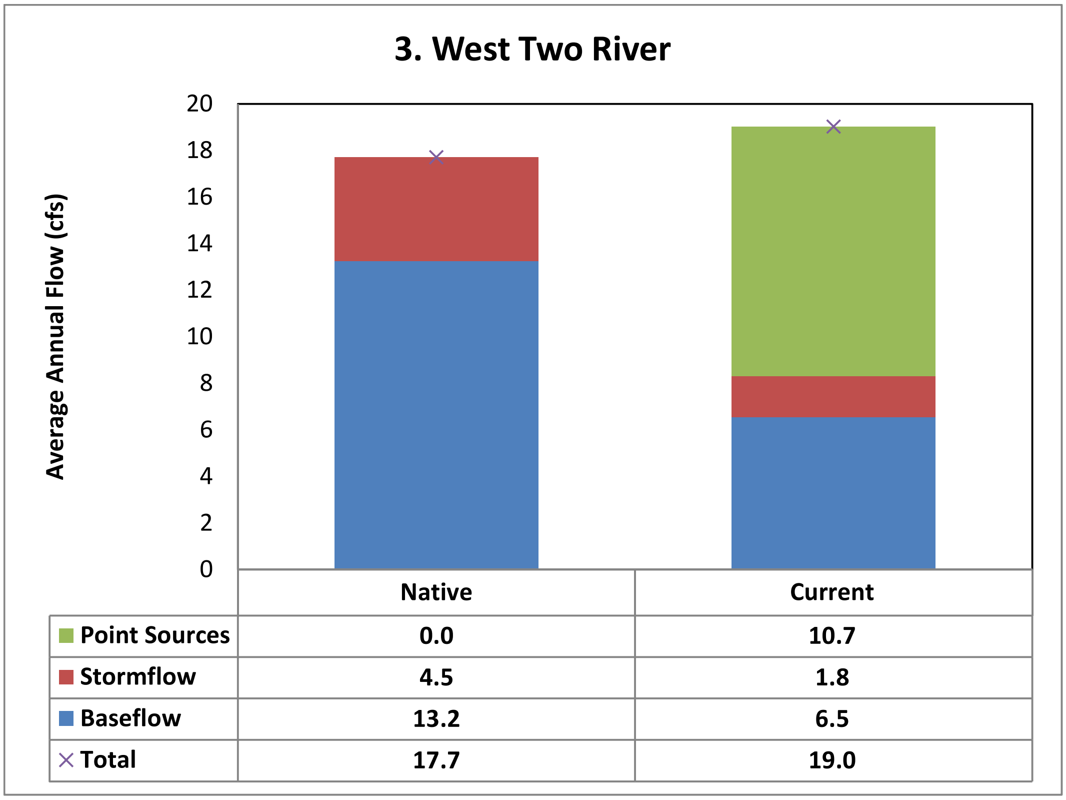

1. Unnamed Trib to Embarrass River

	Native	Current
🟩 Point Sources	0.0	4.1
🟥 Stormflow	2.2	1.6
🟦 Baseflow	11.0	7.3
× Total	13.2	13.0

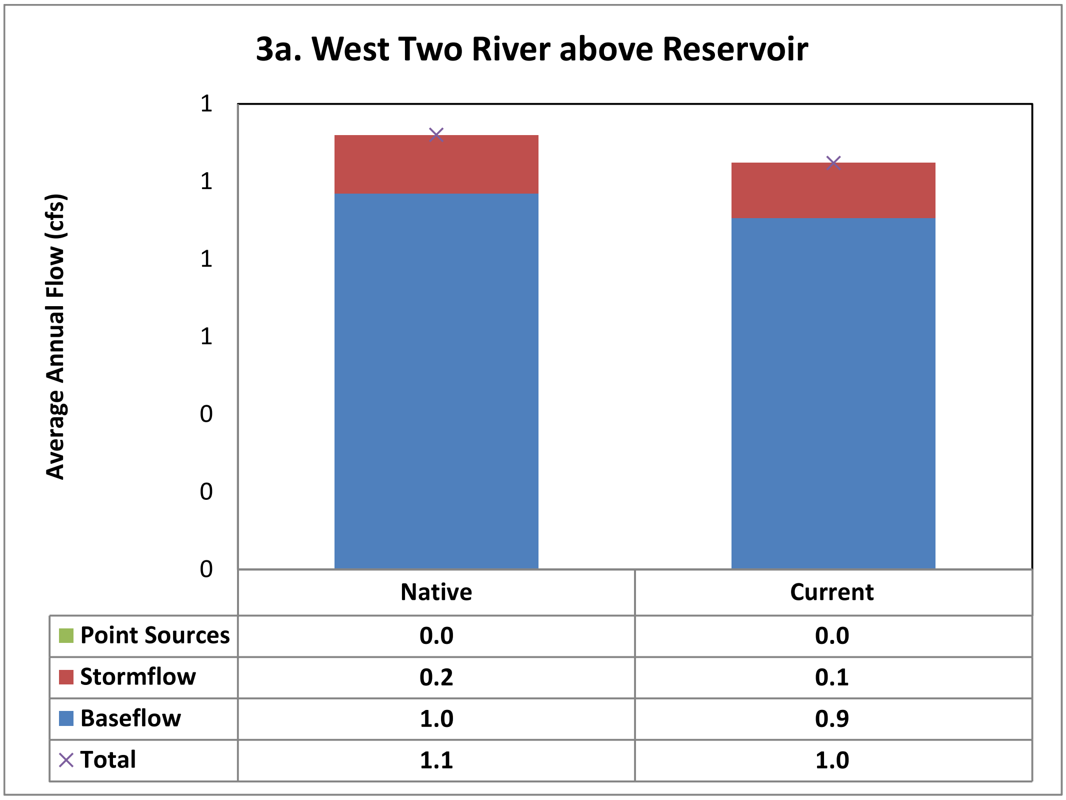

2. Upper Embarrass River

	Native	Current
🟩 Point Sources	0.0	1.3
🟥 Stormflow	1.7	1.7
🟦 Baseflow	12.3	11.5
× Total	14.1	14.6

Figure 23. Water Balance Results for Subbasins 1 and 2

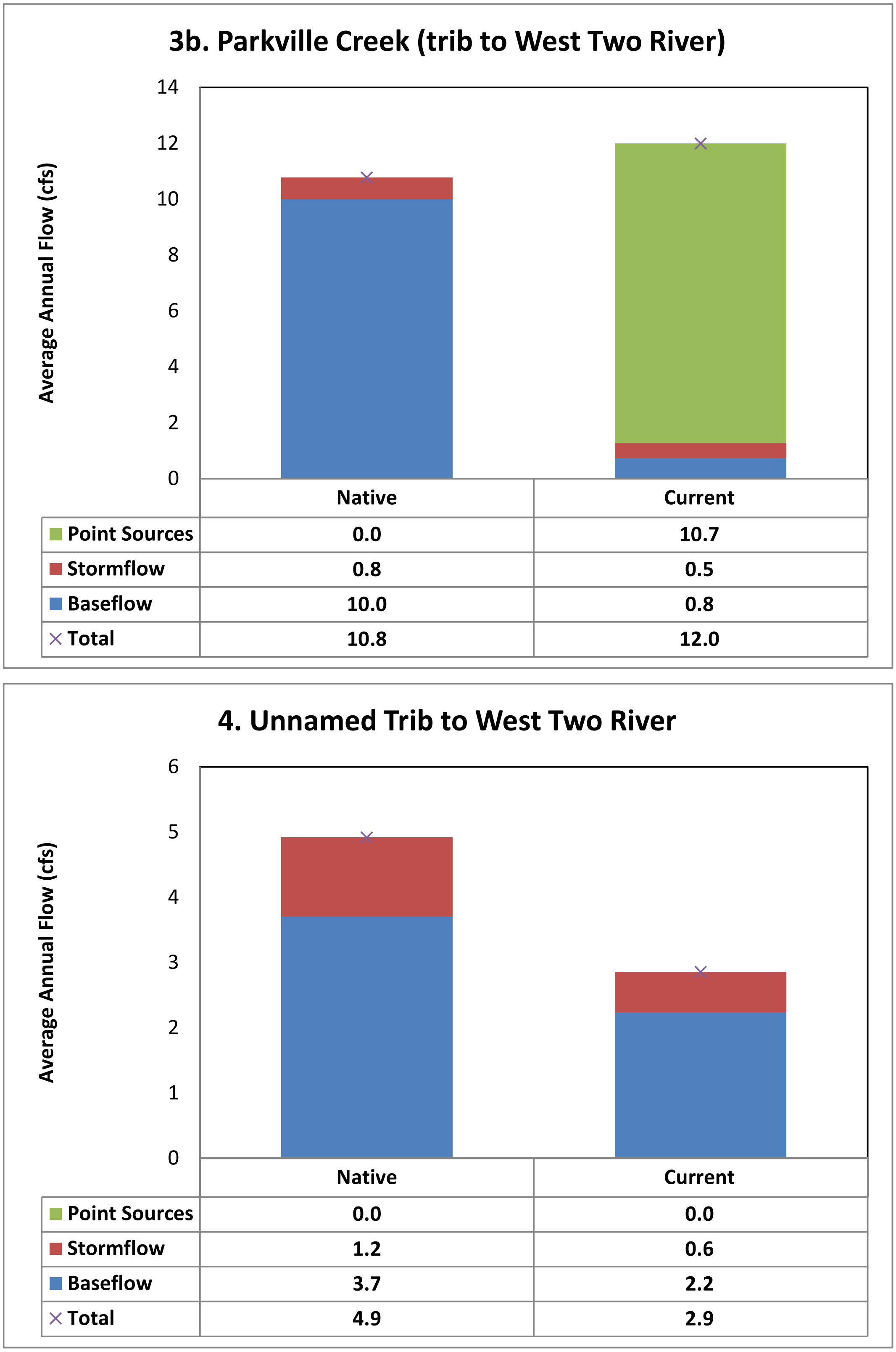


	Native	Current
🟩 Point Sources	0.0	10.7
🟥 Stormflow	4.5	1.8
🟦 Baseflow	13.2	6.5
× Total	17.7	19.0



	Native	Current
🟩 Point Sources	0.0	0.0
🟥 Stormflow	0.2	0.1
🟦 Baseflow	1.0	0.9
× Total	1.1	1.0

Figure 24. Water Balance Results for Subbasins 3 and 3a



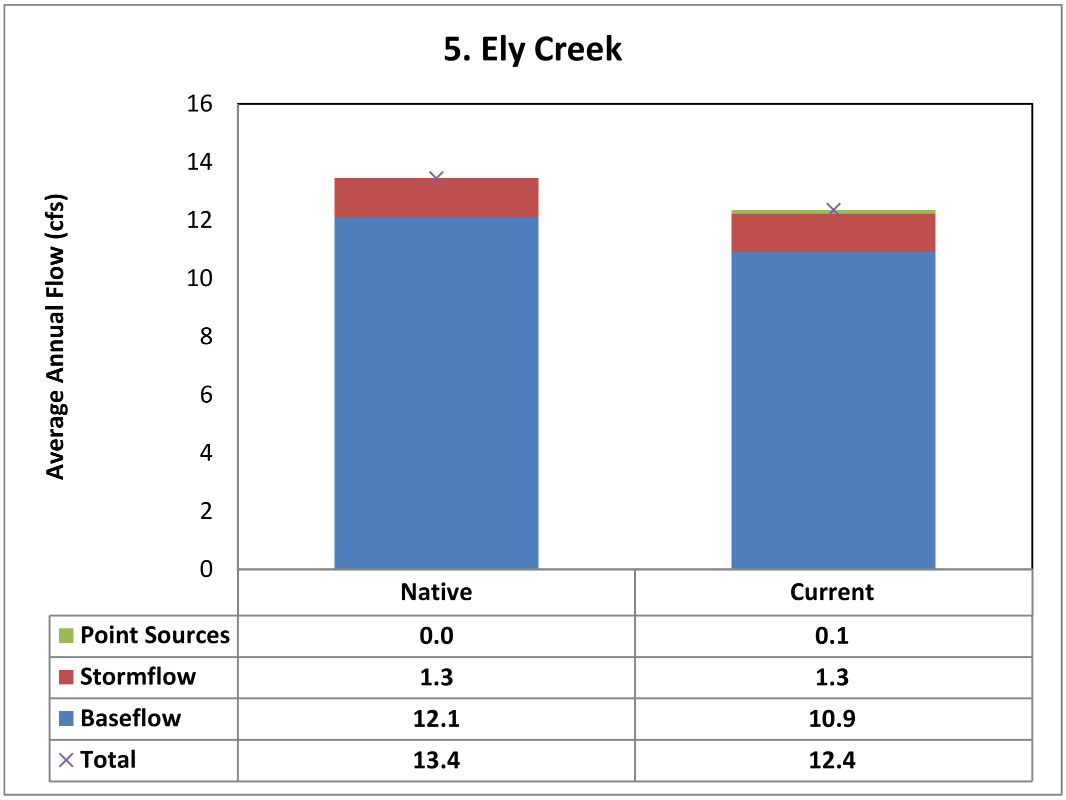
3b. Parkville Creek (trib to West Two River)

	Native	Current
🟩 Point Sources	0.0	10.7
🟥 Stormflow	0.8	0.5
🟦 Baseflow	10.0	0.8
× Total	10.8	12.0

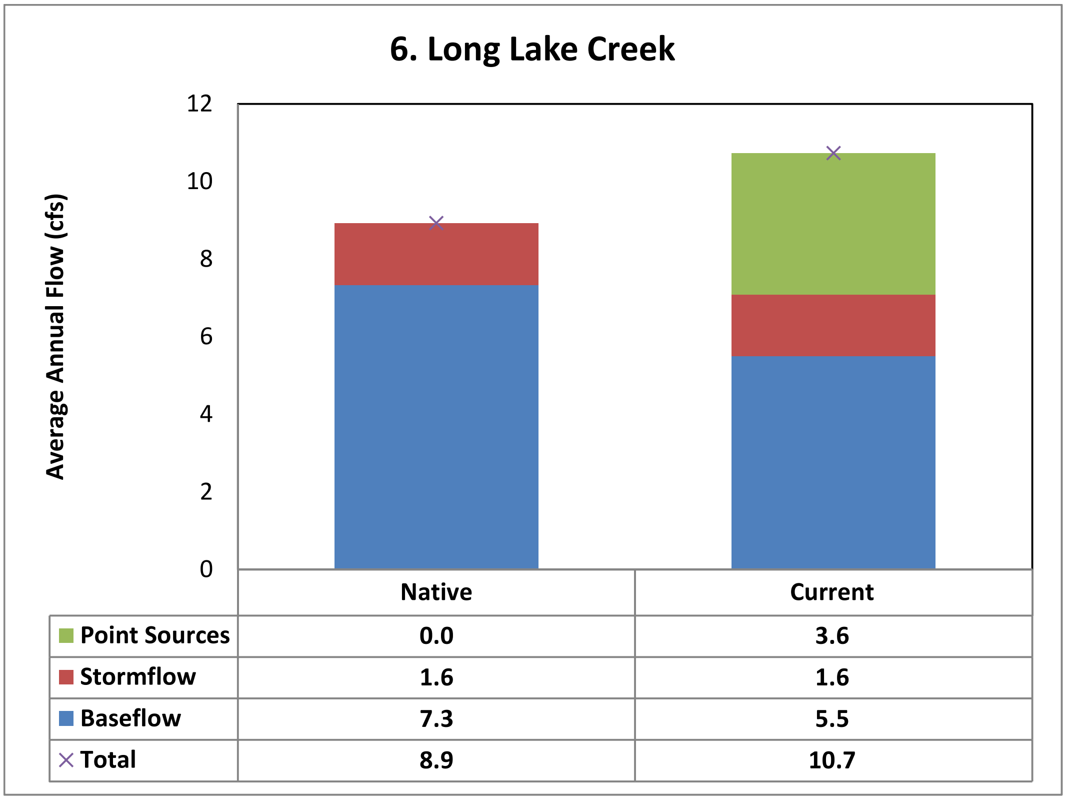
4. Unnamed Trib to West Two River

	Native	Current
🟩 Point Sources	0.0	0.0
🟥 Stormflow	1.2	0.6
🟦 Baseflow	3.7	2.2
× Total	4.9	2.9

Figure 25. Water Balance Results for Subbasins 3b and 4

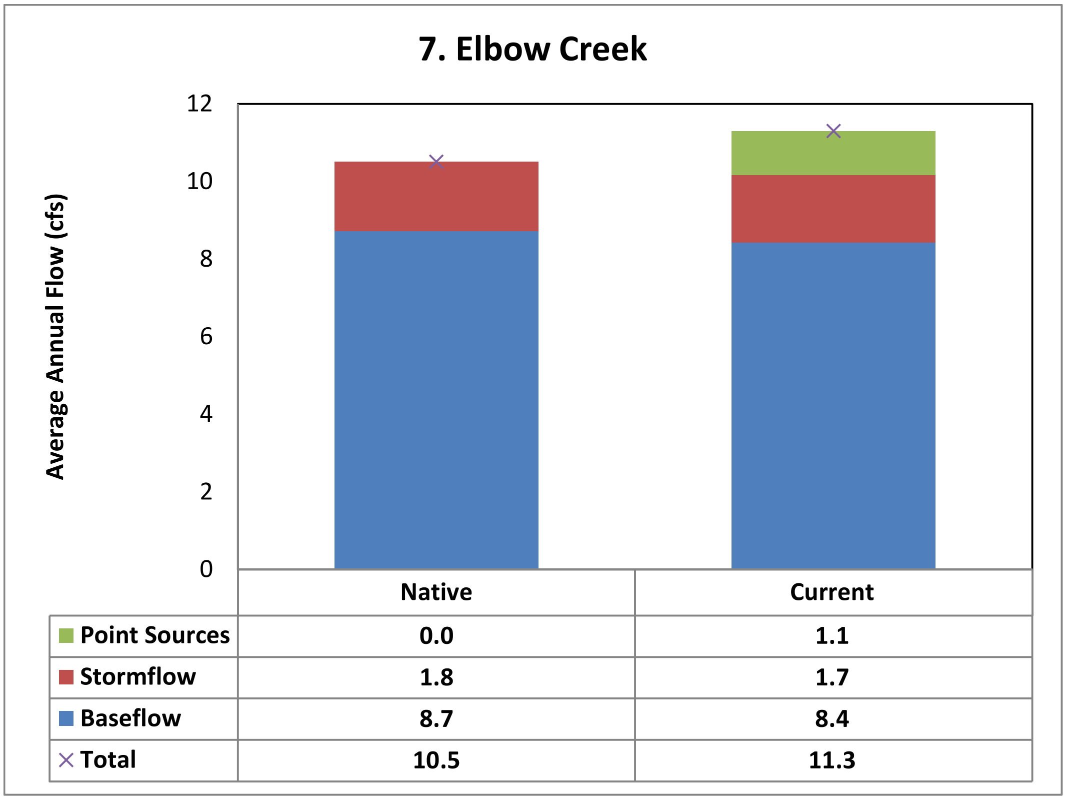


	Native	Current
🟩 Point Sources	0.0	0.1
🟥 Stormflow	1.3	1.3
🟦 Baseflow	12.1	10.9
× Total	13.4	12.4

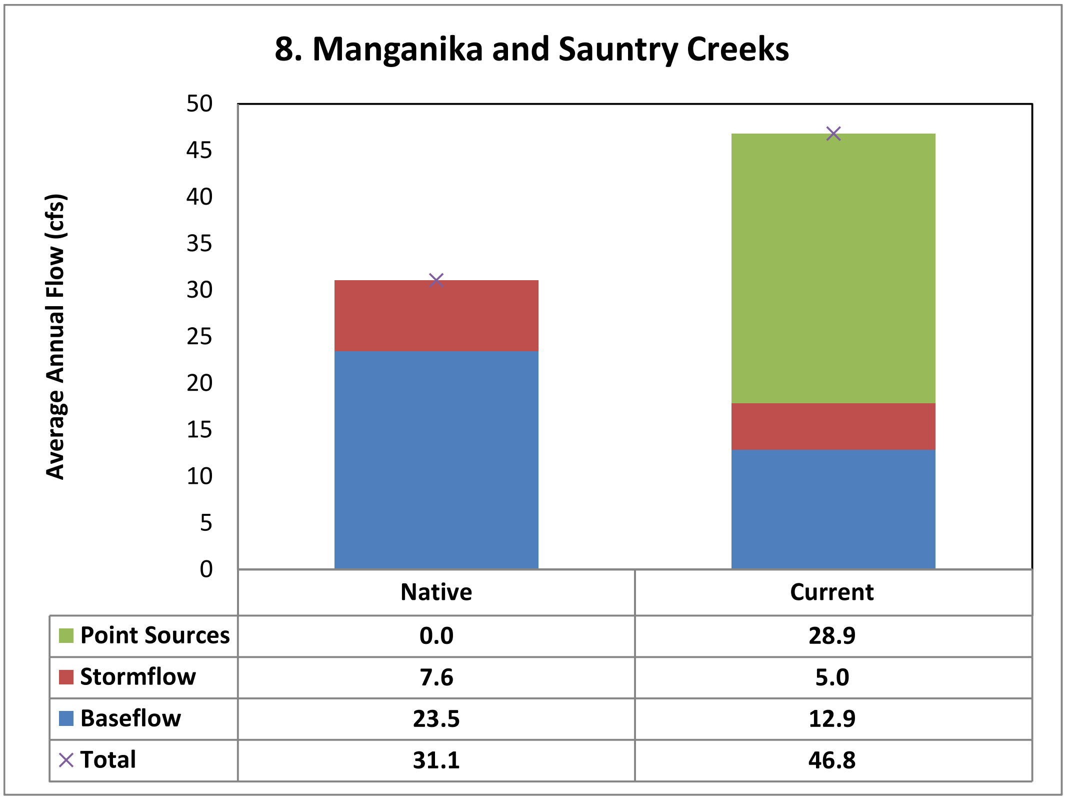


	Native	Current
🟩 Point Sources	0.0	3.6
🟥 Stormflow	1.6	1.6
🟦 Baseflow	7.3	5.5
× Total	8.9	10.7

Figure 26. Water Balance Results for Subbasins 5 and 6

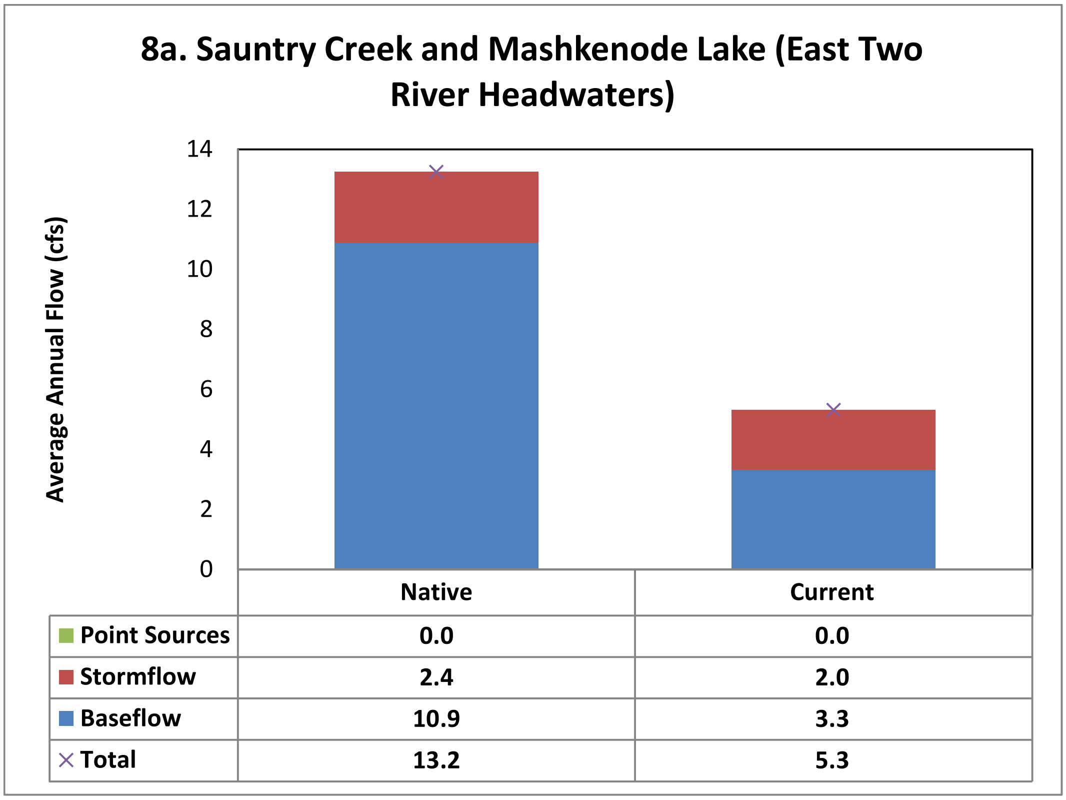


	Native	Current
🟩 Point Sources	0.0	1.1
🟥 Stormflow	1.8	1.7
🟦 Baseflow	8.7	8.4
× Total	10.5	11.3

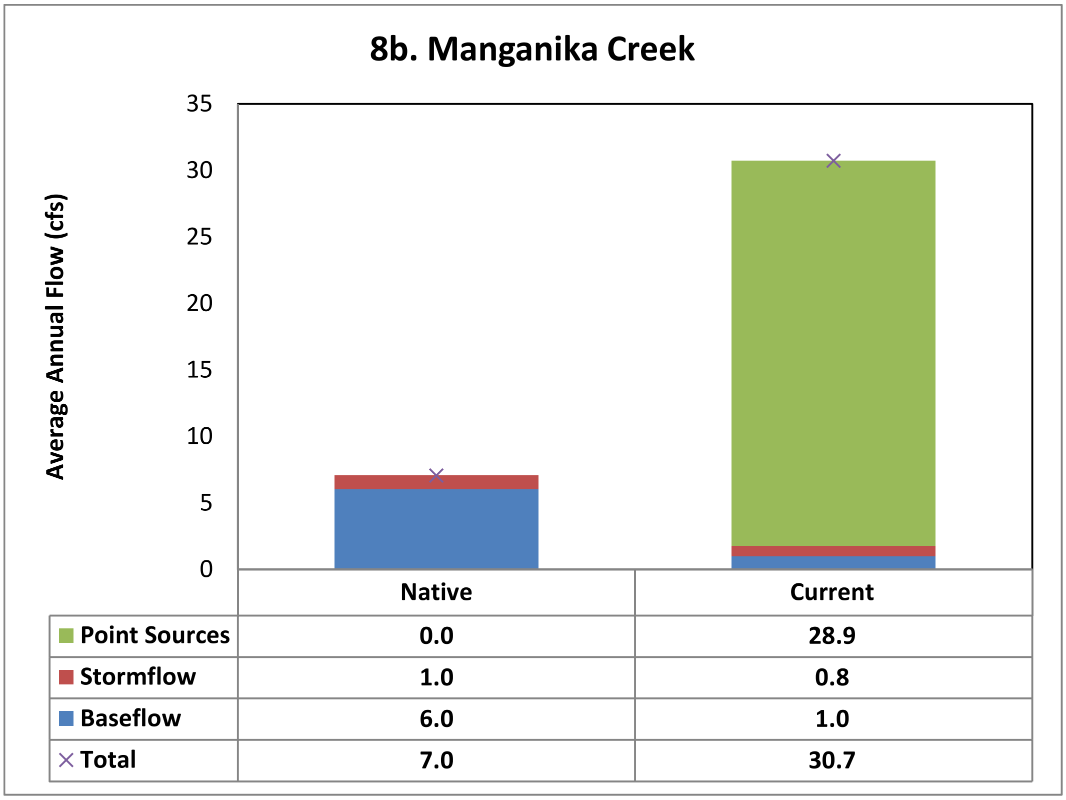


	Native	Current
🟩 Point Sources	0.0	28.9
🟥 Stormflow	7.6	5.0
🟦 Baseflow	23.5	12.9
× Total	31.1	46.8

Figure 27. Water Balance Results for Subbasins 7 and 8

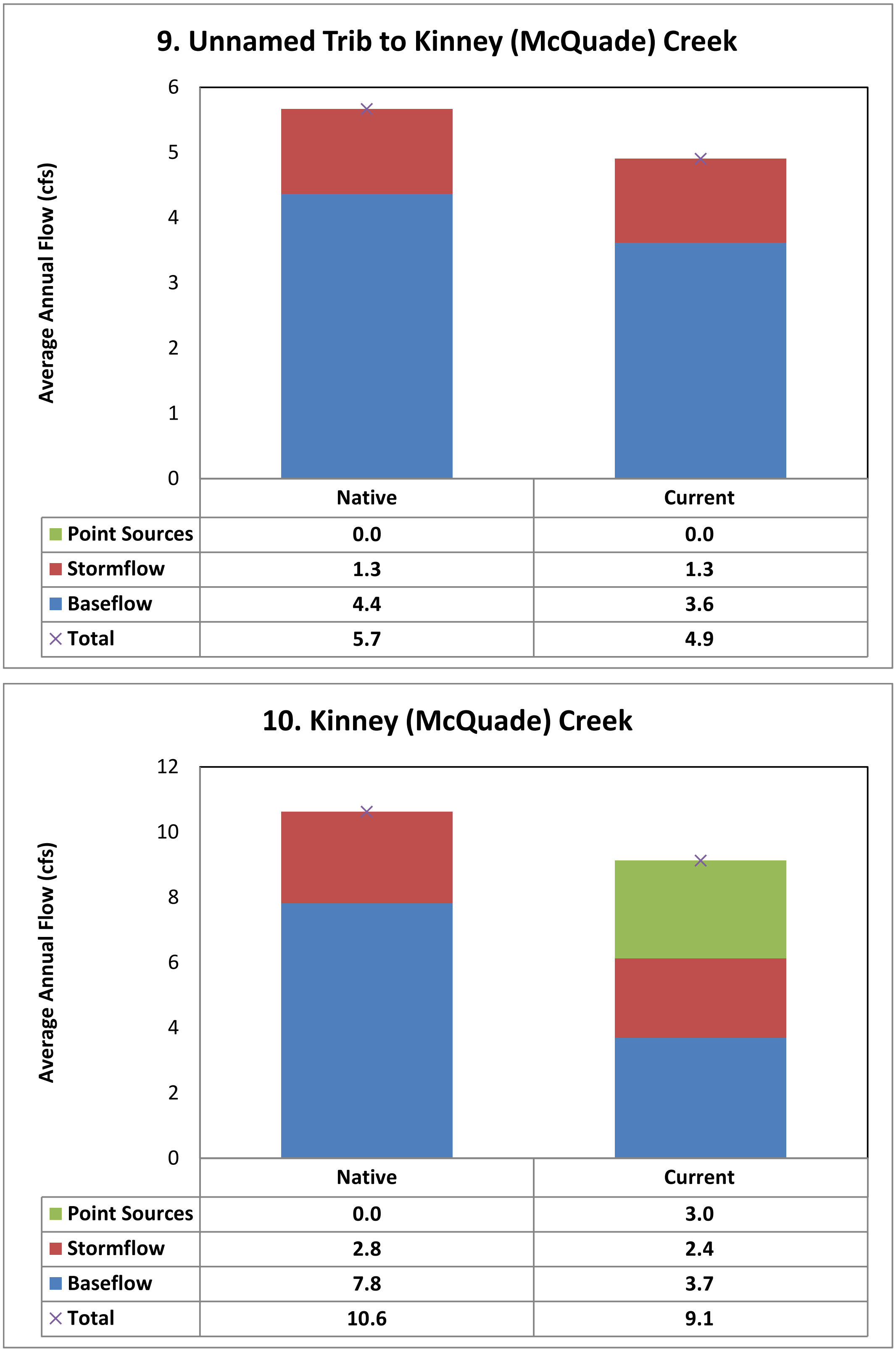

8a. Sauntry Creek and Mashkenode Lake (East Two River Headwaters)

	Native	Current
🟩 Point Sources	0.0	0.0
🟥 Stormflow	2.4	2.0
🟦 Baseflow	10.9	3.3
× Total	13.2	5.3


8b. Manganika Creek

	Native	Current
🟩 Point Sources	0.0	28.9
🟥 Stormflow	1.0	0.8
🟦 Baseflow	6.0	1.0
× Total	7.0	30.7

Figure 28. Water Balance Results for Subbasins 8a and 8b



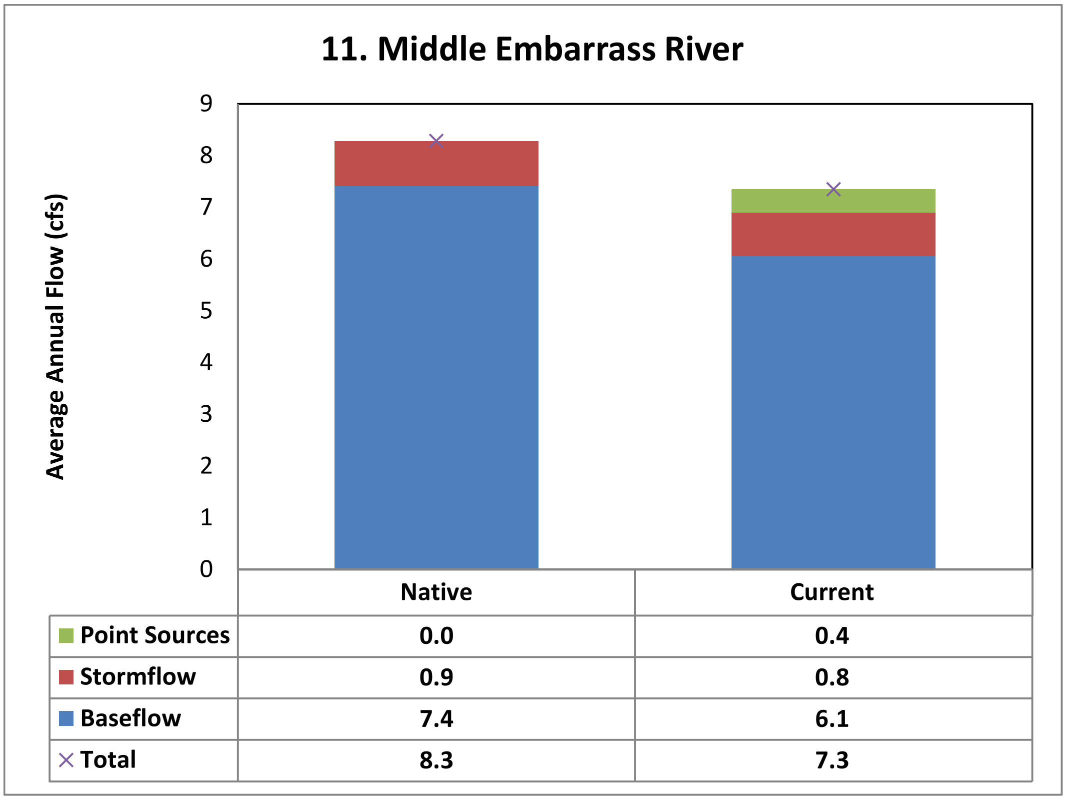
9. Unnamed Trib to Kinney (McQuade) Creek

	Native	Current
🟩 Point Sources	0.0	0.0
🟥 Stormflow	1.3	1.3
🟦 Baseflow	4.4	3.6
× Total	5.7	4.9

10. Kinney (McQuade) Creek

	Native	Current
🟩 Point Sources	0.0	3.0
🟥 Stormflow	2.8	2.4
🟦 Baseflow	7.8	3.7
× Total	10.6	9.1

Figure 29. Water Balance Results for Subbasins 9 and 10



	Native	Current
🟩 Point Sources	0.0	0.4
🟥 Stormflow	0.9	0.8
🟦 Baseflow	7.4	6.1
× Total	8.3	7.3

Figure 30. Water Balance Results for Subbasin 11

5 References

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Appendix A. GFLOW Line-Sink Inputs

The specific model inputs associated with all near-field and far-field line-sinks that represent the stream network are shown below (Figure A-1 and Table A-1). The depth parameter for all near-field line-sinks was set to 0.1 m, and resistance was set to 25 days for all reaches except for the St Louis River main stem which was set to 75 days and Near Field Reach 0850 (Sauntry Creek), for which a high resistance of 10,000 days because it is carried in a causeway between Minorca and Missabe Mountain Pits.

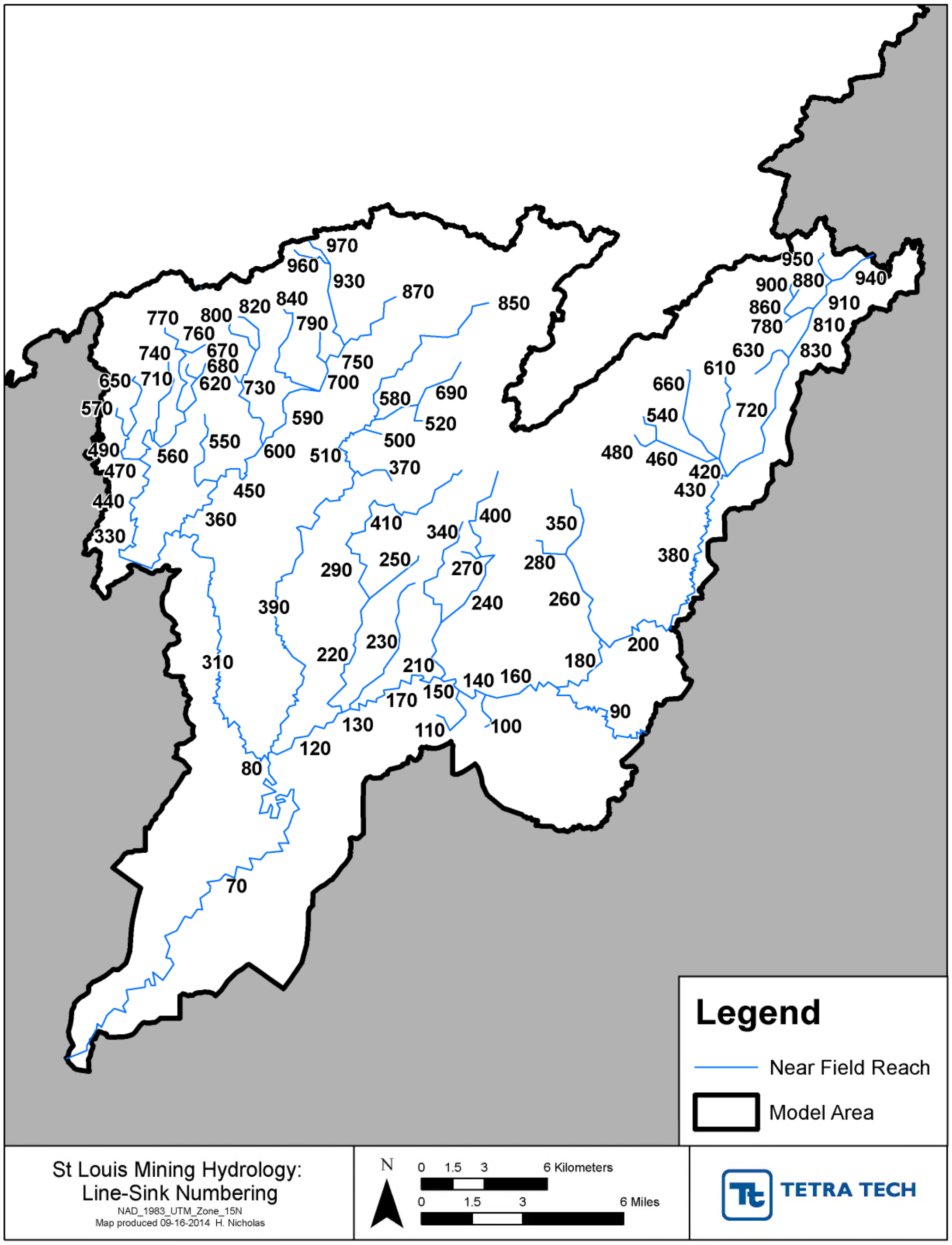

Figure A-1. Numbering of Near-Field Line Sinks in the GFLOW Model

Table A-1. Line-Sink Reach Inputs for GFLOW Model.

Index	Reach Line-Sink	Reach Name	Upstream Head (m)	Downstream Head (m)	Width (m)
1	Far Field 010	St Louis River	380.27	377.32	N/A
2	Far Field 020	Water Hen Creek	445.02	404.14	N/A
3	Far Field 030	East Swan River	393.62	380.62	N/A
4	Far Field 040	Mud Hen Creek	426.81	404.14	N/A
5	Far Field 050	St Louis River	508.82	405.35	N/A
6	Far Field 060	Embarrass River	448.03	415.87	N/A
7	Near Field 070	St Louis River	392.32	380.19	37.75
8	Near Field 080	St Louis River	392.60	392.32	37.75
9	Near Field 090	Mud Hen Creek	404.87	400.82	10.00
10	Near Field 0100		411.06	398.78	5.00
11	Near Field 0110		411.27	398.77	5.00
12	Near Field 0120	St Louis River	394.92	392.60	37.75
13	Near Field 0130	St Louis River	394.90	394.88	37.75
14	Near Field 0140	St Louis River	398.78	398.77	37.75
15	Near Field 0150	St Louis River	398.91	398.77	37.75
16	Near Field 0160	St Louis River	401.02	398.57	37.75
17	Near Field 0170	St Louis River	398.78	394.85	37.75
18	Near Field 0180	St Louis River	402.70	401.02	37.75
19	Near Field 0200	St Louis River	405.26	402.35	37.75
20	Near Field 0210	Long Lake Creek	414.05	398.78	5.00
21	Near Field 0220	Elbow Creek	411.43	394.88	5.00
22	Near Field 0230		419.31	394.90	5.00
23	Near Field 0240	Long Lake Creek	416.23	413.54	5.00
24	Near Field 0250		424.92	411.43	5.00
25	Near Field 0260	Ely Creek	412.88	402.56	5.00
26	Near Field 0270		422.80	416.23	5.00

Index	Reach Line-Sink	Reach Name	Upstream Head (m)	Downstream Head (m)	Width (m)
27	Near Field 0280		420.46	412.88	5.00
28	Near Field 0290	Elbow Creek	416.88	411.43	5.00
29	Near Field 0310	West Two River	409.81	392.32	10.00
30	Near Field 0330		415.81	409.81	5.00
31	Near Field 0340		444.63	414.05	5.00
32	Near Field 0350	Ely Creek	419.62	412.88	5.00
33	Near Field 0360	West Two River	414.57	409.81	10.00
34	Near Field 0370		429.93	424.37	5.00
35	Near Field 0380	Embarrass River	411.55	405.16	18.00
36	Near Field 0390	East Two River	424.37	392.60	7.00
37	Near Field 0400	Long Lake Creek	472.05	416.23	5.00
38	Near Field 0410	Elbow Creek	460.72	415.67	5.00
39	Near Field 0420		413.41	411.55	5.00
40	Near Field 0430		413.80	413.41	5.00
41	Near Field 0440		423.74	415.81	5.00
42	Near Field 0450	West Two River	425.62	414.57	10.00
43	Near Field 0460		423.81	413.80	5.00
44	Near Field 0470		426.71	423.26	5.00
45	Near Field 0480		423.83	423.58	5.00
46	Near Field 0490		430.73	423.74	5.00
47	Near Field 0500		430.00	426.84	5.00
48	Near Field 0510	East Two River	426.84	424.37	7.00
49	Near Field 0520		432.48	428.47	5.00
50	Near Field 0530	East Two River	428.31	426.83	7.00
51	Near Field 0540		426.43	423.81	5.00
52	Near Field 0550		442.13	414.57	5.00

Index	Reach Line-Sink	Reach Name	Upstream Head (m)	Downstream Head (m)	Width (m)
53	Near Field 0560		431.37	426.71	5.00
54	Near Field 0570		441.17	430.73	5.00
55	Near Field 0580		429.83	428.31	5.00
56	Near Field 0590	West Two River	452.20	425.44	10.00
57	Near Field 0600		439.31	425.33	5.00
58	Near Field 0610		422.55	413.41	5.00
59	Near Field 0620		441.71	431.37	5.00
60	Near Field 0630		421.86	414.12	5.00
61	Near Field 0640		445.63	439.31	5.00
62	Near Field 0650		454.42	430.73	5.00
63	Near Field 0660		430.04	413.80	5.00
64	Near Field 0670		451.30	441.71	5.00
65	Near Field 0680		448.42	441.71	5.00
66	Near Field 0690		436.15	428.47	5.00
67	Near Field 0700	West Two River	425.46	425.44	10.00
68	Near Field 0710		460.05	426.71	5.00
69	Near Field 0720	Embarrass River	414.12	410.46	18.00
70	Near Field 0730		446.18	439.01	5.00
71	Near Field 0740		457.76	431.37	5.00
72	Near Field 0750		426.99	425.46	5.00
73	Near Field 0760		467.06	457.76	5.00
74	Near Field 0770		484.51	457.76	5.00
75	Near Field 0780		431.81	430.85	5.00
76	Near Field 0790		452.40	425.46	5.00
77	Near Field 0800		496.63	446.18	5.00
78	Near Field 0810		430.85	415.32	5.00

Index	Reach Line-Sink	Reach Name	Upstream Head (m)	Downstream Head (m)	Width (m)
79	Near Field 0820		497.07	446.18	5.00
80	Near Field 0830	Embarrass River	415.32	414.12	18.00
81	Near Field 0840	West Two River	485.35	425.44	10.00
82	Near Field 0850	Sauntry Creek	439.09	427.87	7.00
83	Near Field 0860		436.12	430.85	5.00
84	Near Field 0870		444.96	426.90	10.00
85	Near Field 0880		442.19	436.12	5.00
86	Near Field 0900		448.46	436.12	5.00
87	Near Field 0910	Embarrass River	418.43	415.32	18.00
88	Near Field 0930		465.89	426.90	5.00
89	Near Field 0940	Embarrass River	418.43	415.76	18.00
90	Near Field 0950		499.40	418.43	5.00
91	Near Field 0960		508.91	465.89	5.00
92	Near Field 0970		519.63	465.89	5.00

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Appendix B. Minnesota Well Database and Analysis

Well construction data from throughout Minnesota is available in the County Well Index database maintained by Minnesota Department of Health (http://www.health.state.mn.us/divs/eh/cwi/). Records for the study area extend back to the start of the 20th Century. The well construction logs generally provide information on depth to water table. This information is useful as a surrogate for estimating the steady-state water table; however, it is important to note that the data are not from a single point in time and are affected by seasonal cycles, changes in climatic conditions, and changes in mining operations over time.

Due to weather constraints, most wells have been constructing in the summer season. The table below summarizes the seasons screened.

Table B-1. Count of Static Water Elevation screenings per season at wells within a 5 mile buffer of the model area

Season	# Wells Screened
JFM	121
AMJ	412
JAS	1,285
OND	296
Unknown	47

The following table summarizes the number count of overburden/bedrock per month screened.

Table B-2. Count of Static Water Elevation screenings per month at bedrock and overburden wells within a 5 mile buffer of the model area

Month	Bedrock Screening	Overburden Screening
Jan	34	1
Feb	34	3
Mar	48	1
Apr	58	2
May	125	1
Jun	216	10
Jul	445	17
Aug	420	21
Sep	366	16
Oct	133	6
Nov	86	1
Dec	68	2
No Month Indicated	44	3
Total	2,033	81

Static water elevations were interpolated using inverse distance weighting to map static water elevations for the model area. Reported static water elevation values ranged from 710 ft at one well (possibly a data error, as the next lowest well elevation is reported at 1,232 ft) to 1,664 ft. The lowest static water elevations are centered in the north-west and south-west corners of the model area with the highest state water elevations in the north central portion of the model area.

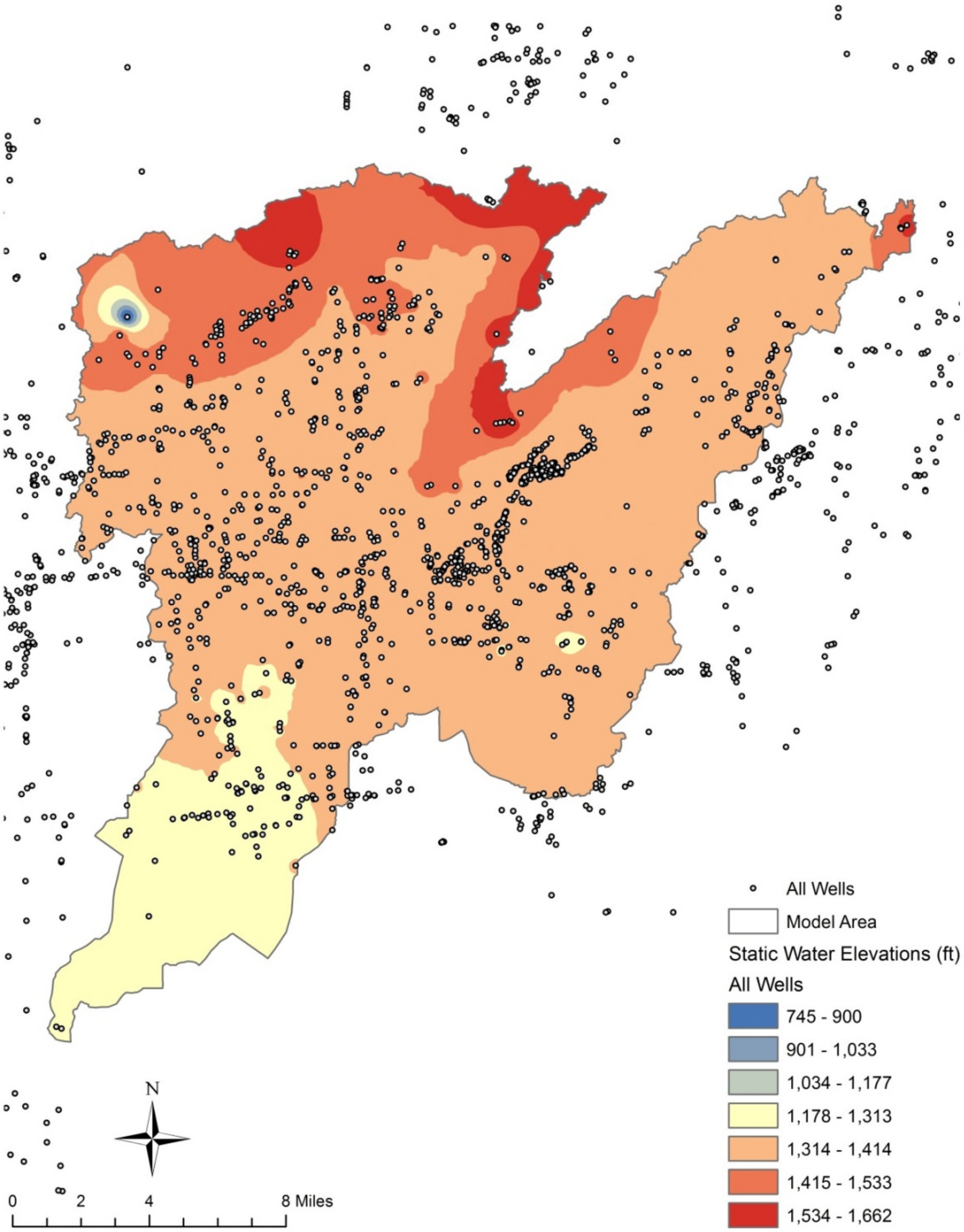

Figure B-1. Inverse Distance Weighting Map of Static Water Elevations for all Wells Based on Wells within a 5 mile Buffer of the Model Area

Static water elevations for bedrock screened wells do not vary much from the elevations of all of the wells because bedrock screened wells make up 96% of the wells. There is a little variability in the north central portion of the model area that had overburden screened wells sampled at a higher static water elevation. The high and low wells are the same as those from all the screened wells.

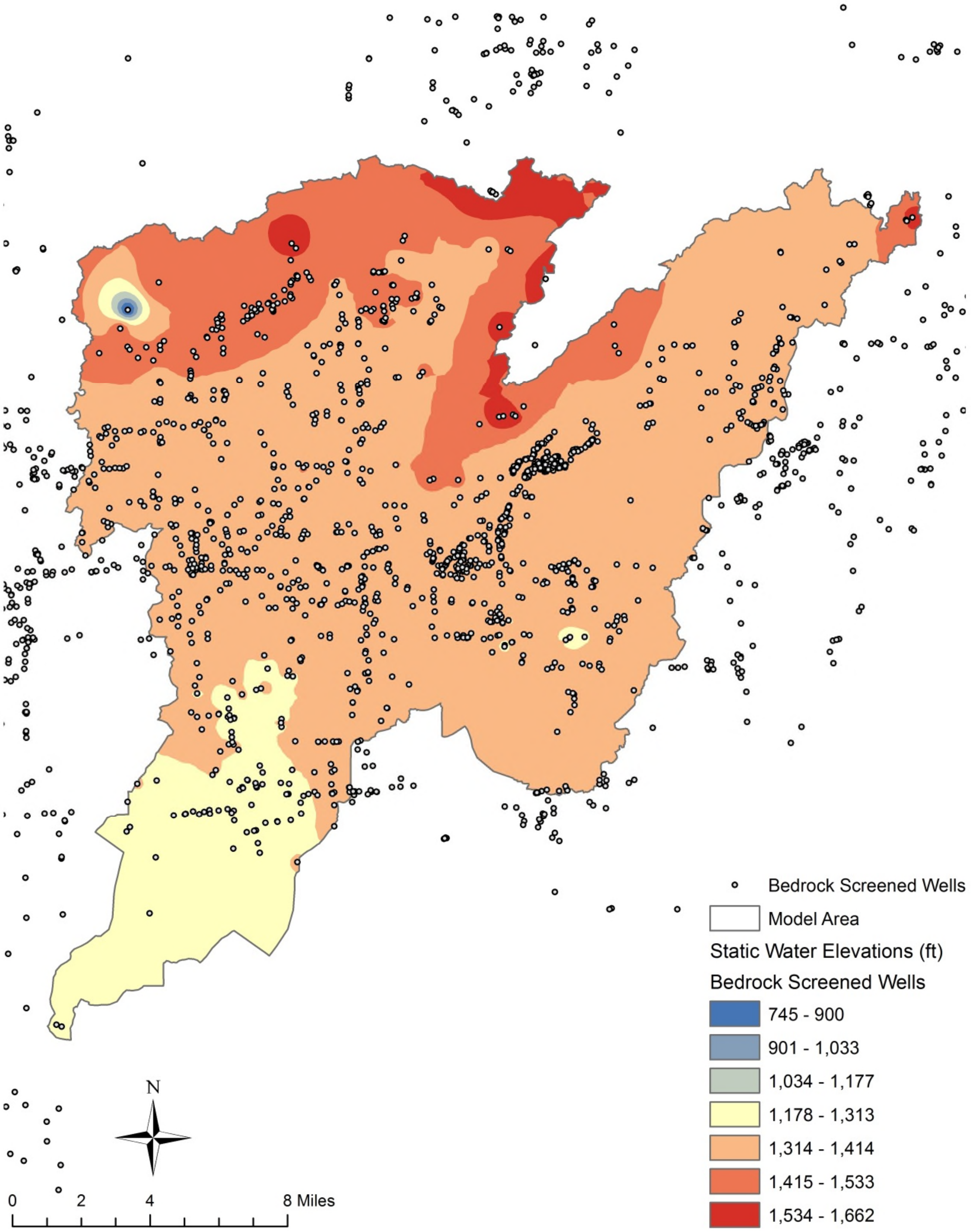

Figure B-2. Inverse Distance Weighting Map of Static Water Elevations for Bedrock Wells Based on Wells within a 5 mile Buffer of the Model Area

Static water elevations for overburden screened wells cannot be accurately mapped based on only 84 wells that aren't evenly spread throughout the model area. Static water elevations for those screened in overburden ranged from a low of 1,269 to a high of 1,637 feet. In general the elevation trends follow those of the bedrock screened wells with the lowest static water elevations in the south west corner of the model area, and the high areas in the north central portion of the model area.

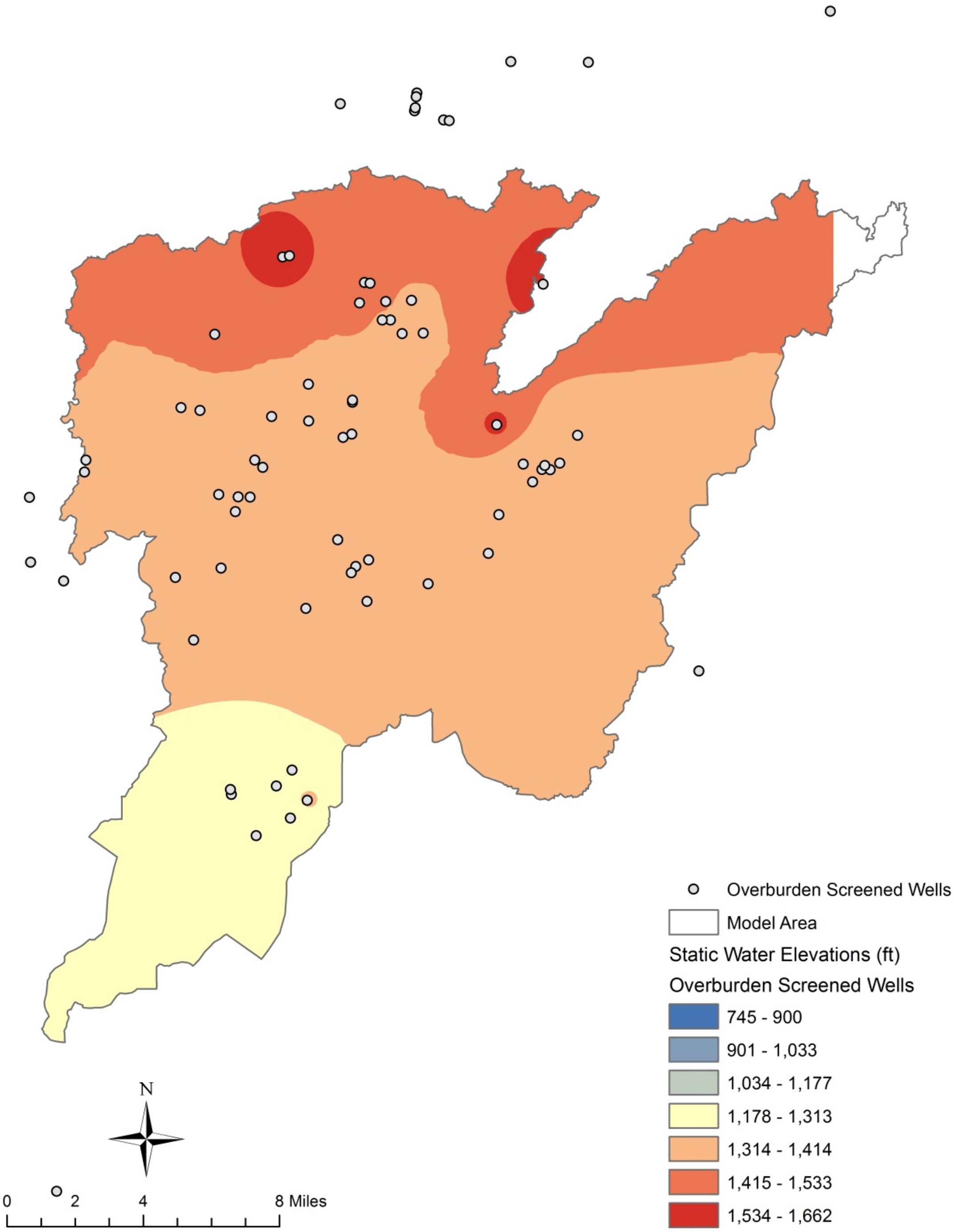

Figure B-3. Inverse Distance Weighting Map of Static Water Elevations for Overburden Wells Based on Wells within a 5 mile Buffer of the Model Area

Static water elevations are likely affected by mining operation changes over time. 630 wells screened after 1/1/1984 are mapped below to show static water elevation for the past 30 years. Static water elevations for those screened since 1984 ranged from a low of 1,232 to a high of 1,664 feet. Figure B-4 shows static water elevations for 1,512 wells screened before 1984. Static water elevations for those screened before 1984 ranged from a low of 710 ft to a high of 1,625 ft. In general since 1984 static water elevations in the northern portion of the model area have increased and there is less variability.

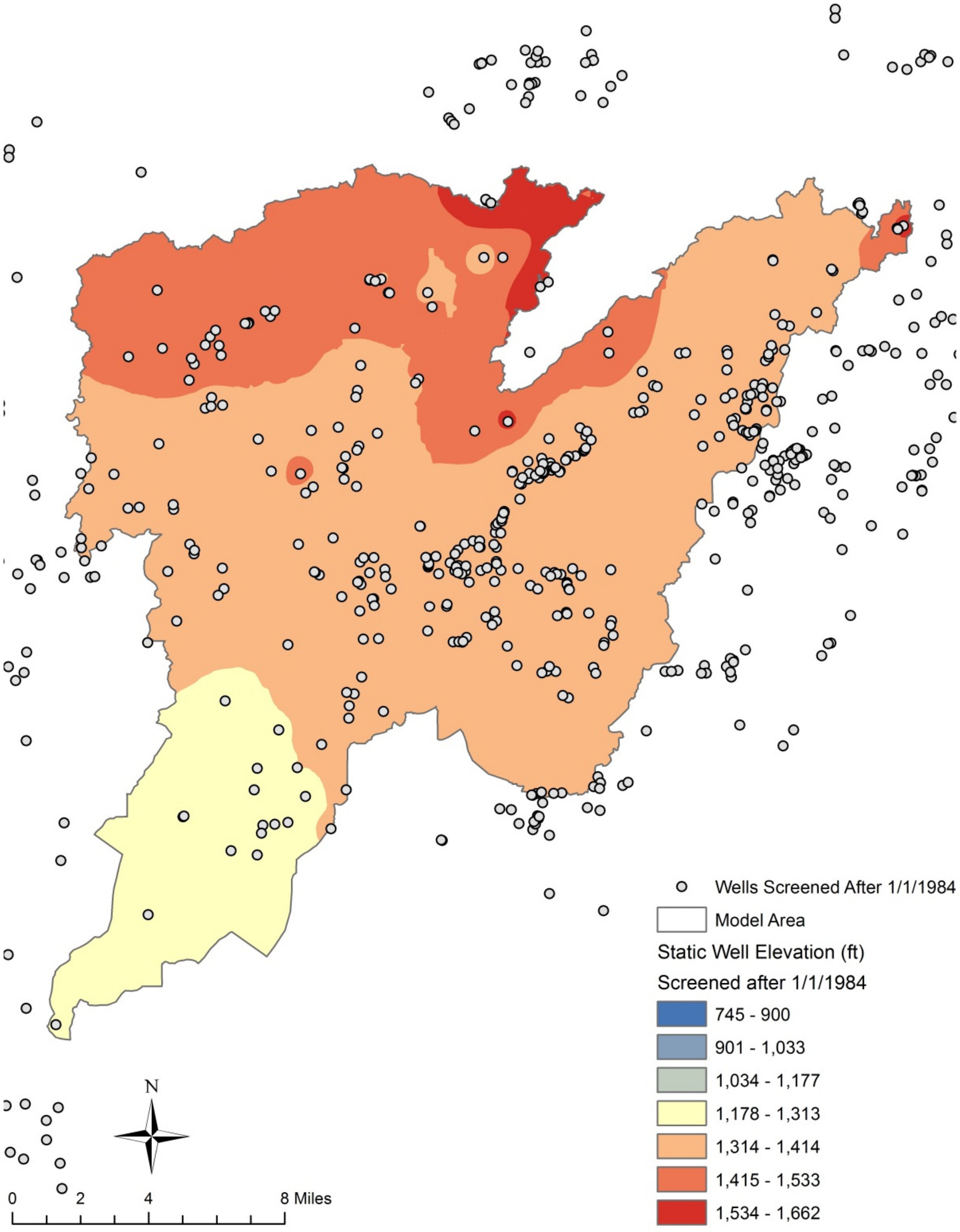

Figure B-4. Inverse Distance Weighting Map of Static Water Elevations for Wells Screened after 1984 Based on Wells within a 5 mile Buffer of the Model Area

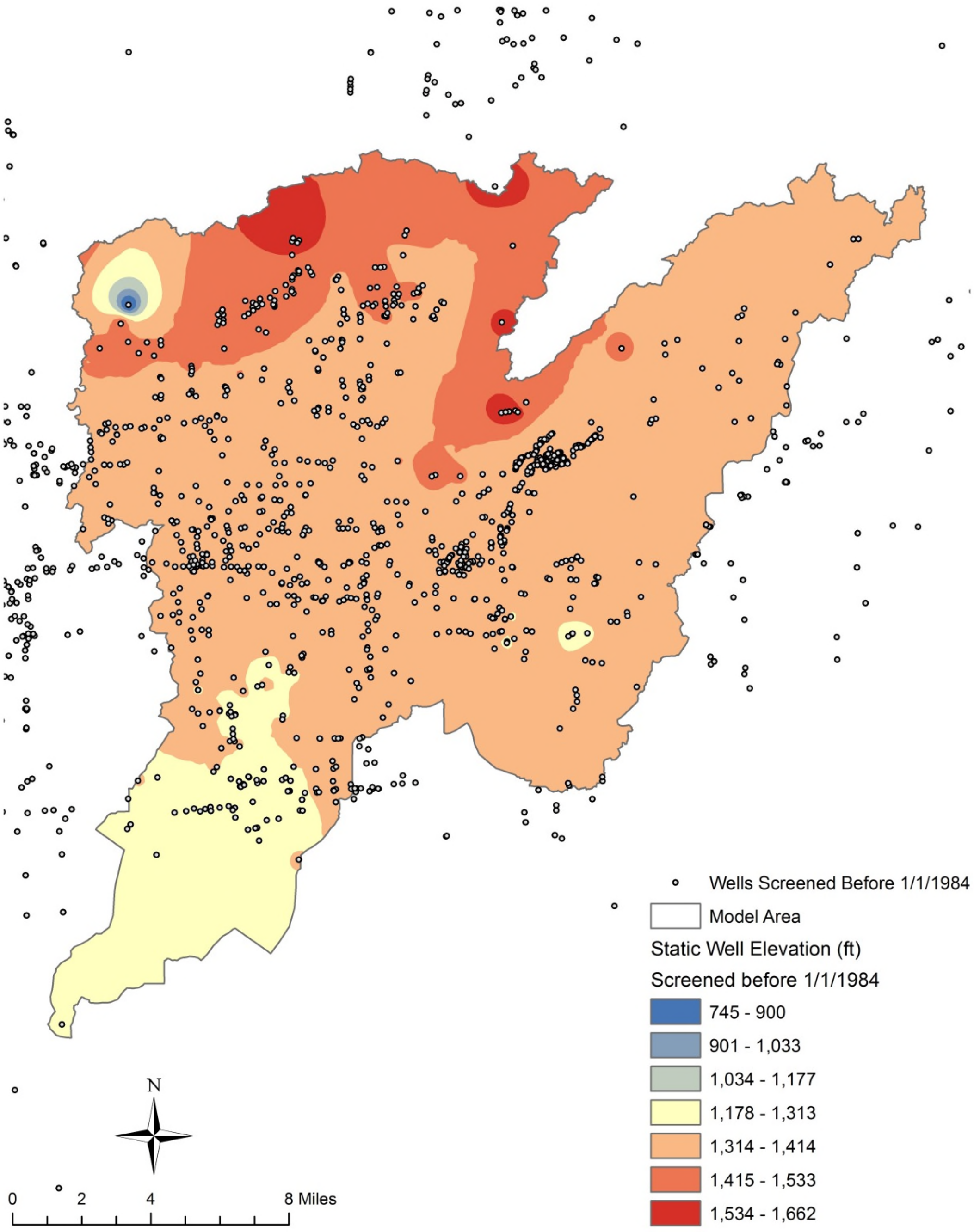

Figure B-5. Inverse Distance Weighting Map of Static Water Elevations for Wells Screened before 1984 Based on Wells within a 5 mile Buffer of the Model Area

Static water depth below surface measurements were interpolated using inverse distance weighting to map static water depths for the model area. Depth below surface values ranged from -12 ft to 208 ft with the lowest depths observed in the northern portion of the model area. Overburden screened well depths ranged from 0 ft to 90 ft below surface averaging 20 ft below surface. Bedrock screened well depths ranged from -12 ft to 208 ft averaging 19 ft below surface.

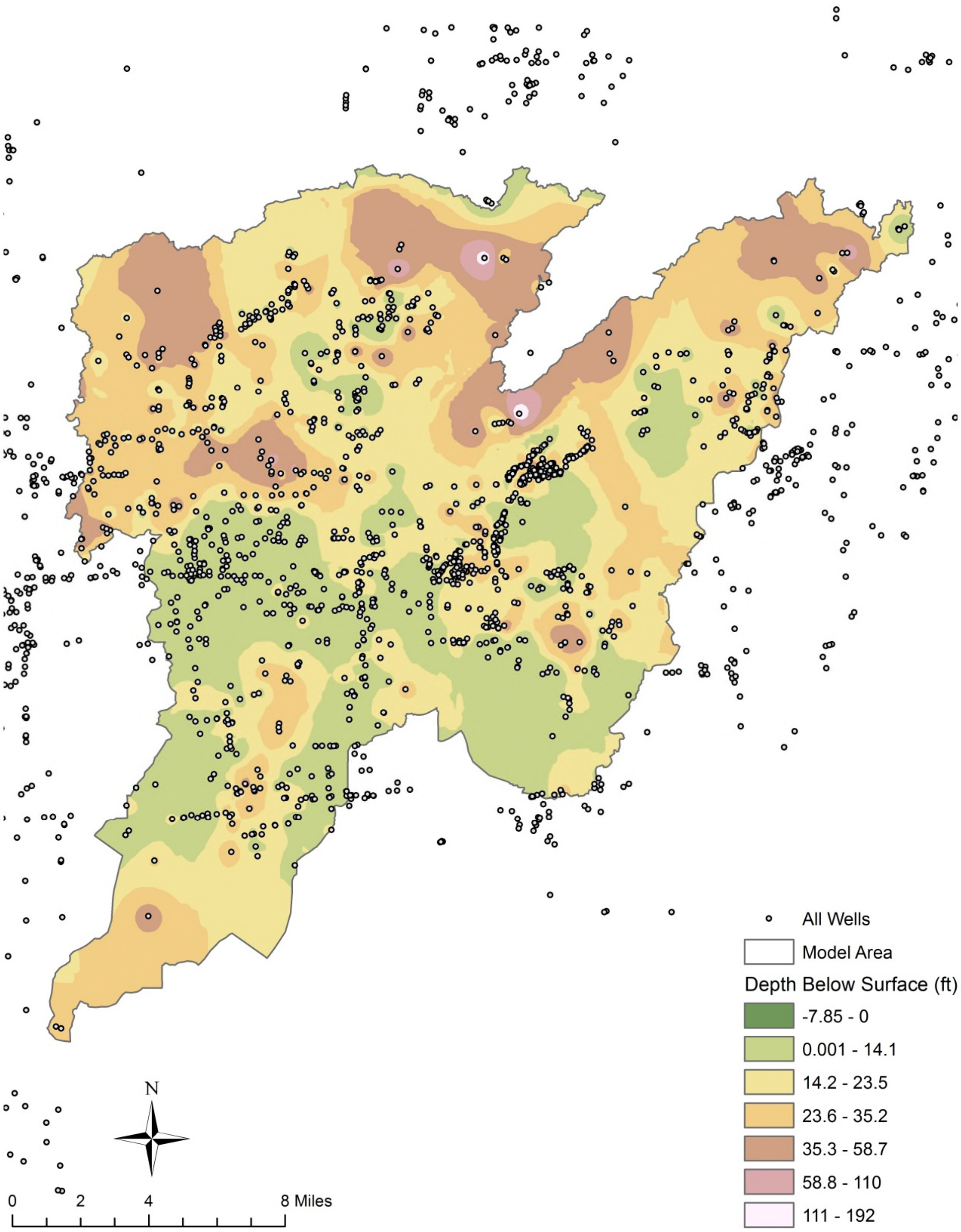

Figure B-6. Inverse Distance Weighting Map of Static Water Depth Below Surface for all Wells Based on Wells within a 5 mile Buffer of the Model Area

Although the number of overburden wells was small the data was analyzed for seasonal variability in the static water elevation surfaces. The table below summarizes the data for 84 overburden wells. The average static water elevation ranges from 1,393 in spring (April through June) to 1,456 in fall (October through December). The max static water elevation is also highest during the fall at 1,637 ft and lowest in winter at 1,447 ft.

Table B-3. Static Water Elevations per season at overburden wells within a 5 mile buffer of the model area

Season	Number of screened wells	Average SWE (ft)	Min SWE (ft)	Max SWE (ft)
JFM	5	1,400	1,351	1,447
AMJ	13	1,393	1,286	1,524
JAS	54	1,384	1,269	1,588
OND	9	1,456	1,320	1,637
Unknown	3	1,448	1,385	1,575

The table below summarizes seasonal variability in bedrock static water elevation surfaces. The average, minimum, and maximum elevations do not vary much from season to season with one minimum outlier in the spring.

Table B-4. Static Water Elevations per season at bedrock wells within a 5 mile buffer of the model area

Season	Number of screened wells	Average SWE (ft)	Min SWE (ft)	Max SWE (ft)
AMJ	399	1,387	1,248	1,622
JAS	1,231	1,366	710	1,650
OND	287	1,372	1,251	1,664
JFM	116	1,375	1,250	1,571
Unknown	44	1,427	1,277	1,556

The majority of overburden screenings were performed during 1950. There are no apparent trends in static water elevations over time. The average static water elevation in overburden wells ranges from 1,370 in the 1970s to 1,499 in the 1960s with majority of static water elevations around 1,380 to 1,400 ft.

Table B-5. Static Water Elevations per Decade at overburden wells within a 5 mile buffer of the model area

Decade	Number of screened wells	Average SWE (ft)	Min SWE (ft)	Max SWE (ft)
1910	1	1,385	1,385	1,385
1930	1	1,380	1,380	1,380
1950	50	1,393	1,269	1,588
1960	3	1,499	1,496	1,503
1970	6	1,370	1,288	1,405
1980	14	1,387	1,281	1,524
1990	5	1,401	1,292	1,637
2000	3	1,413	1,375	1,437
2010	1	1,481	1,481	1,481

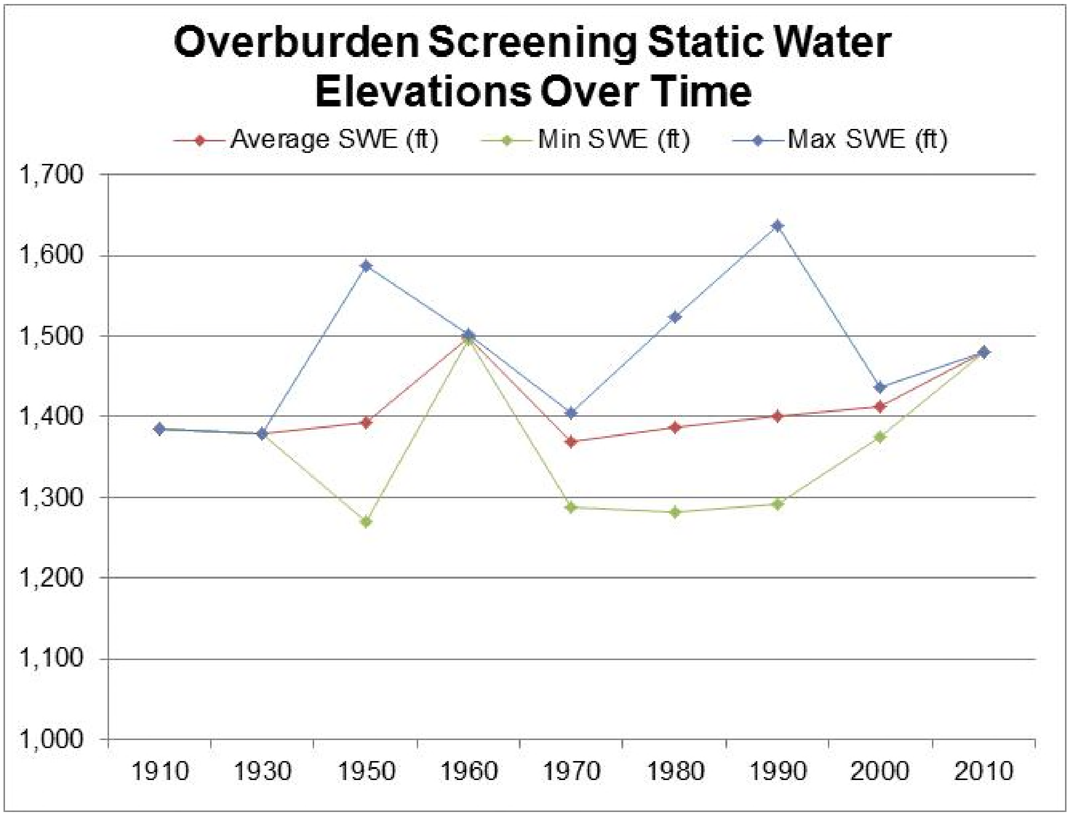

Figure B-7. Static Water Elevations per Decade at overburden wells within a 5 mile buffer of the model area

Static water elevations appear to be trending upwards in all screened wells within a 5 mile buffer of the model study area starting at an average of 1,348 ft in the 1900s and going up to an average of 1,462 ft in the 2010s.

Table B-6. Static Water Elevations per Decade at all wells within a 5 mile buffer of the model area

Decade	Number of screened wells	Average SWE (ft)	Min SWE (ft)	Max SWE (ft)
1900	1	1,348	1,348	1,348
1910	2	1,402	1,385	1,418
1920	1	1,457	1,457	1,457
1930	4	1,384	1,330	1,439
1940	4	1,410	1,344	1,499
1950	916	1,375	1,242	1,625
1960	17	1,405	710	1,505
1970	370	1,367	1,243	1,603
1980	354	1,364	1,245	1,530
1990	359	1,376	1,232	1,664
2000	106	1,389	1,250	1,607
2010	8	1,462	1,338	1,599

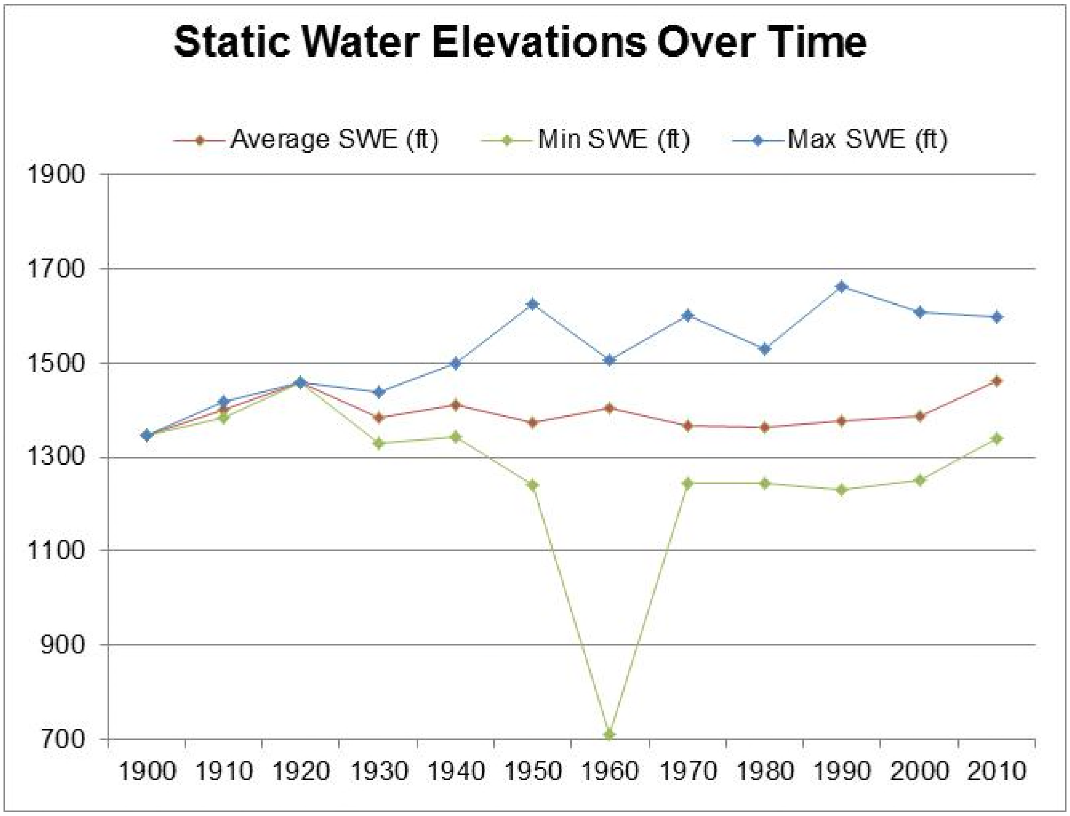

Figure B-8. **Static Water Elevations per Decade at all wells within a 5 mile buffer of the model area**

Appendix C. Data on Mining Appropriations and Discharges

This appendix provides documentation of permitted water appropriations and discharges present within the St. Louis Watershed associated with taconite mining operations.

Taconite mining involves the manipulation of large volumes of water. The northern edge of the St. Louis River watershed is the Mesabi Range, which contains extensive deposits of iron ore. Mining in the area began in the late 19th century, and initially focused on high grade hematite ore, which is readily processed into steel. The high grade ore was largely depleted by the 1950s. The industry was rejuvenated by the development of means to extract iron from low grade taconite ore. Most of the taconite is exposed close to the surface, allowing mining in open pits. Continuous dewatering is required to work in the pits, resulting in large volumes of produced water. Some of this water is discharged to the environment, while other portions are used in taconite processing. The conversion of raw ore to taconite pellets requires grinding and creation of a slurry, again involving large volumes of water. Waste material is discharged in slurry form to unlined tailings basins, where the solids settle out. Most of the decanted water in tailings basins is reused in taconite processing and not discharged to the environment, although seeps from tailings basins also occur.

Locations of major mining features in the watershed are shown in Figure C-1, using coverages provided by MDNR. It will be noted that there are multiple mine pits within the St. Louis watershed; however, the majority of the active tailings basins lie just over the ridgeline in adjacent watersheds.

Both appropriations and discharges of water involved in taconite mining and processing are regulated by the State of Minnesota. Water withdrawals are subject to appropriation permits issued by MDNR, whether from surface or ground water, and include permits for mine dewatering. Discharges of water to the environment are regulated by MPCA, with permits for discharge to surface water covered under the NPDES system. Reporting of flow volumes is part of both permit systems. It should be noted, however, that certain other major flows of water involved in taconite processing (notably, discharges from taconite processing plants to tailings ponds and some recycle flows of water back to processing facilities) are internal to the industrial process and do not require environmental permits. As a result, data on the volumes of these flows are not publicly available.

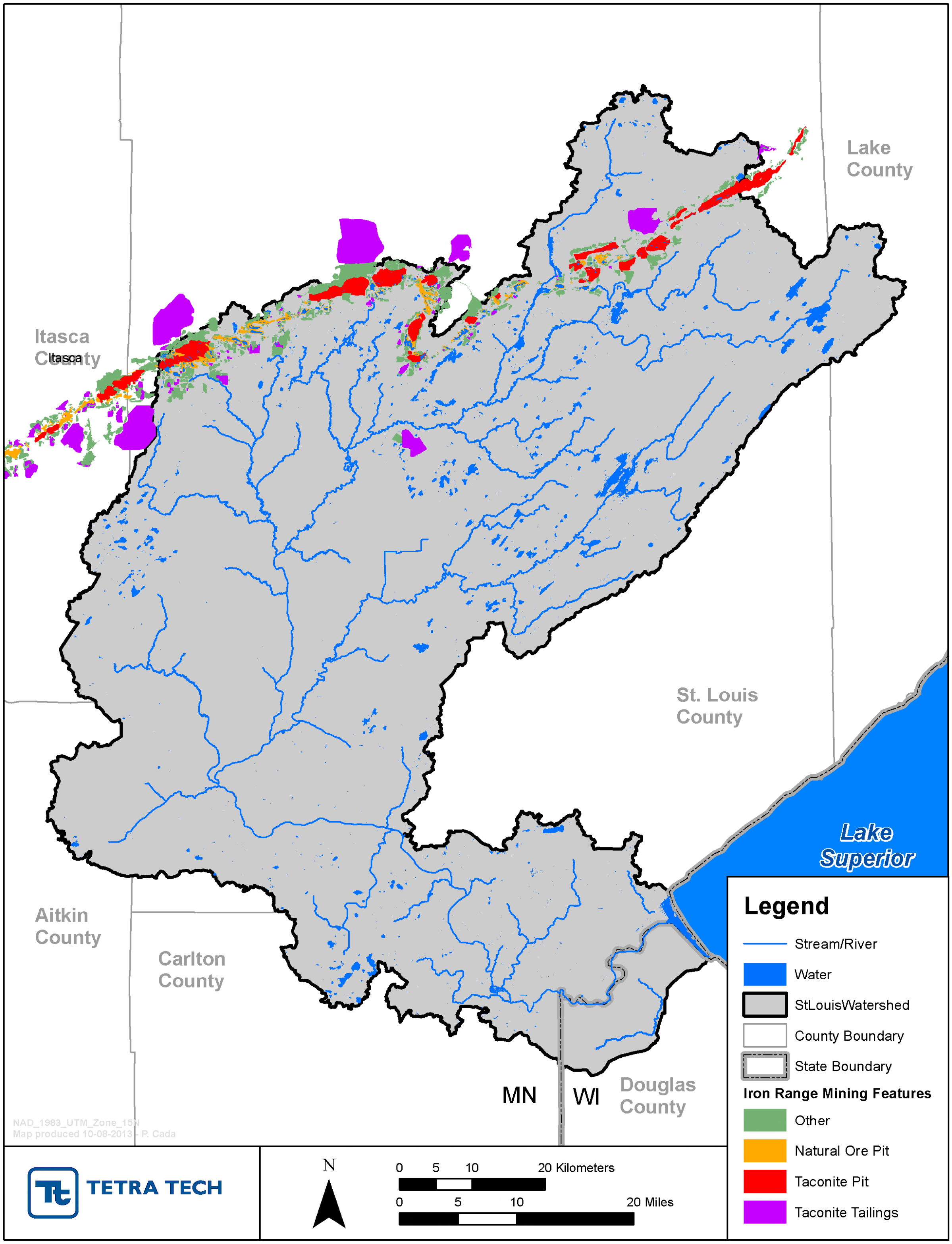

Figure C-1. **Mine Features along the Mesabi Iron Range Intersecting the St. Louis River Watershed**

C-1. MINING WATER APPROPRIATIONS

Minnesota Department of Natural Resources (MDNR) grants water appropriation permits for withdrawals greater than 10,000 gallons per day or one million gallons per year. Many of the provided appropriations consist of mine dewatering or withdrawal of water from abandoned mine pits; others come direct from rivers and lakes. Direct appropriations from groundwater via wells are generally small, but appropriations from mine pits include intercepted groundwater.

MDNR provided a spatial coverage of “Points of Taking” for mine appropriations, along with monthly volumes of appropriated water provided by permittees and contained in the MPARS database. Data for appropriation 1949-0135 (Minnesota Power and Cliffs Erie) was provided separately by MDNR. Active and recent mining appropriations are compiled by mining operation and permit number in Table C-1. Locations are shown in Figure C-2.

The great majority of the water appropriations are from mine pits – either for the dewatering of actively mined pits or for taconite process water obtained from abandoned mine pits that do not have surface outlets. Both types of pits are effectively cut off from the larger stream network and intercept groundwater from up-gradient. Therefore, these appropriations are not directly represented in the basin-scale HSPF model; rather, the area that drains to these pits is eliminated from the basin-scale model. There are a limited number of current or former direct withdrawals from surface water, including a withdrawal direct from the St. Louis River by United Taconite. These are incorporated into the HSPF model at the reach locations shown in the first column of Table C-1. A more detailed study of the interaction of pit dewatering and the adjacent surface water network in the central part of the Iron Range is being undertaken as part of a separate study using a ground water model.

Table C-1. Water Appropriation Permits for Mining Operations in the St. Louis River Watershed, 1988-2013

HSPF Reach (post 1993)	Mining Operation	Permit #	Installation	Period of Active Use	Intake Resource	Average Monthly Pumping (MG)
	ArcelorMittal	1973-5095	1	1988-2013	See note 1.	62.61
		1980-2095	1	1988-2013	Well 248579	0.25
			2	1989-1991	Well 192380	26.31
			3	None	Well 192380	0.00
		1991-2017	1	1995-2013	Laurentian Mine	83.44
			2	2002-2002	Corsica II	5.73
		2007-0559	1	2008-2013	McKinley Pit	80.54
			2	2008-2013	Mary Ellen Pit	94.89
			3	2008-2008	East Reserve Pit	3.50
			4	None	West Reserve Pit	0.00
		2008-0216	1	2008-2013	Missabe Mountain Pit	59.21
	Auburn Minerals	1997-2114	1	1999-1999	Security Mine	17.06

HSPF Reach (post 1993)	Mining Operation	Permit #	Installation	Period of Active Use	Intake Resource	Average Monthly Pumping (MG)
254	Cliffs Erie, LLC	1970-0998	1	1989-1993	Embarrass River	34.65
		1973-5182	1	2000-2000	Pit Dewatering	79.22
			2	None	Pit Dewatering	0.00
			3	None	Pit Dewatering	0.00
		1973-5183	1	1988-2012	Pit Dewatering	61.27
			2	1988-1988	Pit Dewatering	211.81
			3	1988-1990	Pit Dewatering	12.47
		1973-5184	1	1988-1998	Pit Dewatering	72.48
		1973-5185	1	None	Pit Dewatering	0.00
			2	1989-2000	Pit Dewatering	61.83
		1973-5188	1	1988-1997	Pit Dewatering	29.01
		1979-2204	1	None	Pit Dewatering	0.00
			2	1994-1995	Pit Dewatering	23.57
			3	1988-2000	Pit Dewatering	57.34
			4	1988-1997	Pit Dewatering	43.45
262	Minnesota Power & Cliffs Erie, LLC	1949-0135	1	1988-2001	Colby Lake	315.26
	Cyprus Northshore Mining	1982-2098	1	None	Peter Mitchell Mine	0.00
	Hibbing Taconite Co.	1968-1558	1	2007-2007	Susquehana Mine	129.69
			2	2007-2012	Long Year Mine	298.26
			3	1990-2012	Scranton Mine	552.59
		1970-1081	1	1990-2013	Morton Mine	42.98
			2	1988-1989	Pit Dewatering	56.45
			3	1988-1989	Pit Dewatering	171.18
	Inland Steel Mining	1981-2173	1	1988-2000	Minorca Pit	30.61
	LTV Steel Company	1970-0731	1	1988-1991	Donora Pit	95.67

HSPF Reach (post 1993)	Mining Operation	Permit #	Installation	Period of Active Use	Intake Resource	Average Monthly Pumping (MG)
		1975-2246	1	1988-1992	Second Creek	18.41
	Steel Dynamics, Inc.	2005-2058	AREA 1	2008-2013	Area 1 Pit	118.33
			2WEST X	None	2 West X Pit	0.00
		2008-0326	AREA 9	None	Pit Dewatering	0.00
		2008-0327	AREA 6	None	Pit Dewatering	0.00
		2008-0328	AREA 9S	None	Pit Dewatering	0.00
		2008-0329	AREA 2WX	None	Pit Dewatering	0.00
245	US Steel Corp	1963-0846	2RIV	2007-2013	West Two River Res.	107.43
			MTIR	1988-2013	Mt Iron Pit Res.	149.99
			TAIL	1988-1989	Minntac Tailings	1,708.68
		1980-2084	1	1988-1994	Minntac West Pit	148.62
			#11	None	Minntac West Pit	0.00
			#3	1993-2013	Minntac West Pit	178.55
			#6	1993-2013	Minntac West Pit	127.67
			TRK03	1999-2008	Minntac West Pit	12.00
			TRK06	1999-2013	Minntac West Pit	9.81
			TRK11	None	Minntac West Pit	0.00
		1980-2085	1	1988-1994	Minntac East Pit	67.83
			#2SMP	1999-2013	Minntac East Pit	94.06
			PRIND	1995-2013	Minntac East Pit	94.39
			TRK02	1999-2010	Minntac East Pit	7.18
			TRKPR	2005-2013	Minntac East Pit	7.72
			TRKWH	1999-2000	Minntac East Pit	0.13
			WHEEL	None	Minntac East Pit	0.00
		1998-2002	1	1997-2013	Well 233047	0.20
249	United Taconite, LLC	1963-0691	1	1988-2013	St Louis River	205.80

HSPF Reach (post 1993)	Mining Operation	Permit #	Installation	Period of Active Use	Intake Resource	Average Monthly Pumping (MG)
		1963-1089	1	1988-2013	Well 255209	0.02
		1975-2130	1	None	Well 255208	0.00
			2	1988-1994	Groundwater	0.42
			3	1990-1998	Groundwater	0.41
			12	1999-2002	Well 255207	0.35
		1975-2137	1	1988-1992	Fayal #3	70.59
			2	1988-2013	Expansion	41.85
			3	2008-2013	Spruce/Nelson	1.35
			4	1988-1989	Pearsall Mine	50.00
			5	1988-2013	Thunderbird Mine	51.36
			6	1988-2013	Spruce Mine	126.23
			7	1990-1990	Leonides Mine	47.89
		1981-2043	1	1988-2013	Well 120663	0.24
			2	1989-2007	Well 120809	0.35
			3	None	Well 759302	0.00
		1981-2044	1	1988-2013	Well 759302	0.00
		1981-2045	1	1988-2013	Well 759302	0.01
		1981-2046	1	1988-2011	Well 120673	0.03
			2	1988-2013	Well 120673	0.06
	USX Corporation	1990-2076	1	None	Pit Dewatering	0.00
		1990-2077	1	1990-1990	Pit Dewatering	18.00
	Mining Resources, LLC	2012-0230	1	2012-2013	Pit Dewatering	0.84
		2012-0261	1	None	Pit Dewatering	0.00
	Northshore Mining Co.	1982-2097	3	2003-2012	Peter Mitchell Mine	181.35

Notes: 1. Database shows source as “Sauntry Res.” and use “for mine processing.” The location of the appropriation and the plotted pipeline routes suggest the appropriation is actually from the northern part of the Mineview in the Sky Pit (Missabe Mountain Lake) and not the surface water feature labeled Sauntry Reservoir. Accordingly, this appropriation is not included explicitly in the HSPF model.

2. Average pumping is calculated for years in which the appropriation was active.

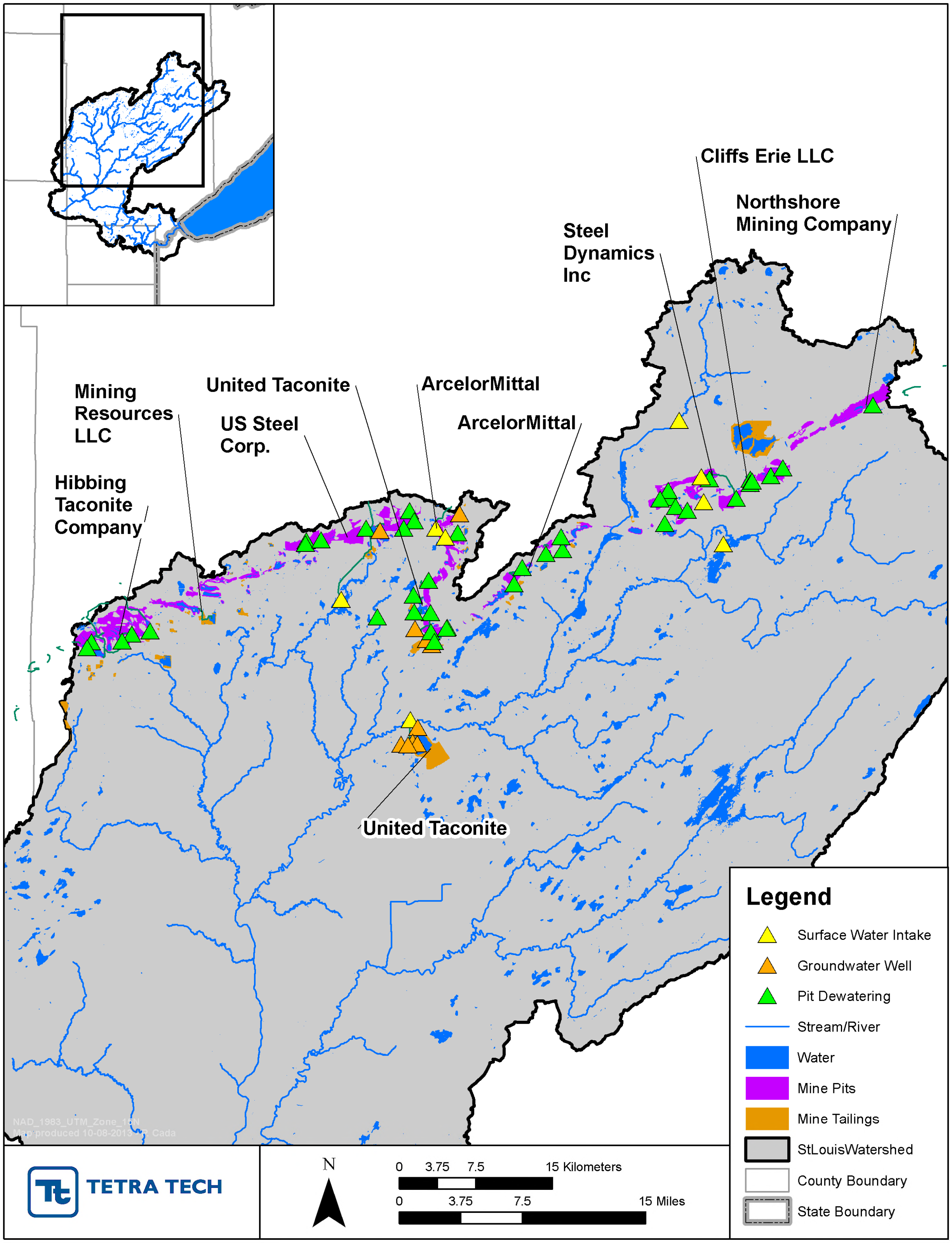

Figure C-2. Permitted Mining Appropriations in the Upper St. Louis River Watershed

C-2. MINING PERMITTED DISCHARGES

In August 2013 MPCA provided a spatial coverage of all permitted discharges in the St. Louis River watershed, including mine discharge permits, along with data from discharge monitoring reports. This addresses all permits that were in place in 1999 or thereafter, and it is possible that some permits that were discontinued prior to 1999 are omitted (the modeling period starts in 1993). Locations for the mine discharges were checked against a separate mining point of discharge coverage provided by MDNR.

A large number of the permits are for incidental discharges, stormwater, and small seeps. These types of permits do not require flow monitoring and generally represent small volumes. In addition, stormwater flows from plant facilities are represented directly by HSPF. Where discharge volumes are reported these have been included as point sources in the HSPF model after aggregating to the scale of model subbasins.

The mining-related NPDES discharge permits in the upper St. Louis River Watershed are compiled in Table C-2 and their locations are shown in Figure C-3.

Table C-2. Active and Recent NPDES Discharges for Mining Operations in the St. Louis River Watershed

Mining Operation	NPDES Permit	Outfall	Mine Name	Period Listed (post 1998)	Discharges to:	Period of Available Flow Data	Average Discharge (MGD)	HSPF Model Reach
Arcelor Mittal	MN0059633	1	Laurentian Mine	1999- present	Unnamed Creek	NA	Minor, Not Reporting	Reach 252
		2	Laurentian Mine	1999-present	White Lake	NA	Minor, Not Reporting	
		3	Laurentian Mine	1999- present	Unnamed Wetlands	1990-2013	2.55	
		5	East Pit #1	2007- present	Not reported	2007-2013	1.12	
		6	East Pit #2	2007- present	Not reported	NA	Not reported	
Premier Aggregates Inc.	MN0058751	1	Auburn Mine	1999-2002	Not Listed	1999-2002	0.31	
Cliffs Erie, LLC	MN0042536	1	Hoyt Lake Mine Area	1999-2007	Colby Lake Watershed	1994-1998	0	Reaches 256, 260, 262, 263
		2	Hoyt Lake Mine Area	1999-2001	Unnamed Creek	NA	Minor, Not Reporting	
		3	Hoyt Lake Mine Area	1999-2005	Unnamed Wetlands	NA	Minor, Not Reporting	
		4	Hoyt Lake Mine Area	1999-2007	Unnamed Creek	NA	Minor, Not Reporting	
		5	Hoyt Lake Mine Area	1999-2007	First Creek	NA	Minor, Not Reporting	
		6	Hoyt Lake Mine Area	1999-2007	Second Creek	1989-1999	0.02	
		7	Hoyt Lake Mine Area	1999-2007	First Creek	NA	Minor, Not Reporting	
		8	Hoyt Lake Mine	1999- present	Second Creek	1989-2013	0.38	

Mining Operation	NPDES Permit	Outfall	Mine Name	Period Listed (post 1998)	Discharges to:	Period of Available Flow Data	Average Discharge (MGD)	HSPF Model Reach
			Area					
		9	Hoyt Lake Mine Area	1999- present	Second Creek	NA	Minor, Not Reporting	
		10	Hoyt Lake Mine Area	1999- present	Unnamed Wetlands	NA	Minor, Not Reporting	
		11	Hoyt Lake Mine Area	1999- present	Unnamed Wetlands	NA	Minor, Not Reporting	
		12	Hoyt Lake Mine Area	1999- present	Wyman Creek	1997-2013	0.36	
		13	Hoyt Lake Mine Area	1999- present	Unnamed Creek	NA	Minor, Not Reporting	
		14	Hoyt Lake Mine Area	1999-2007	Unnamed Wetlands	NA	Minor, Not Reporting	
		15	Hoyt Lake Mine Area	1999-2007	Unnamed Wetlands	NA	Minor, Not Reporting	
		16	Hoyt Lake Mine Area	1999-2007	Unnamed Wetlands	1994-1995	0.01	
		17	Hoyt Lake Mine Area	1999-2007	Unnamed Wetlands	NA	Minor, Not Reporting	
		18	Hoyt Lake Mine Area	1999-2007	Unnamed Creek	NA	Minor, Not Reporting	
		19	Hoyt Lake Mine Area	1999-2007	Wyman Creek Watershed	1992-1999	0.02	
		20	Hoyt Lake Mine Area	1999-2007	Unnamed Creek	1991-1997	0.01	
		21	Hoyt Lake Mine Area	1999-2007	Unnamed Creek	NA	Minor, Not Reporting	
		22	Hoyt Lake Mine Area	1999-2007	Unnamed Creek	NA	Minor, Not Reporting	

Mining Operation	NPDES Permit	Outfall	Mine Name	Period Listed (post 1998)	Discharges to:	Period of Available Flow Data	Average Discharge (MGD)	HSPF Model Reach
		23	Hoyt Lake Mine Area	1999-2007	First Creek	NA	Minor, Not Reporting	
		24	Hoyt Lake Mine Area	1999-2007	First Creek	1996-1997	0.01	
		25	Hoyt Lake Mine Area	1999-2001	Second Creek	1991-1999	0.01	
		26	Hoyt Lake Mine Area	1999- present	Second Creek	1991-2013	0.4	
		28	Hoyt Lake Mine Area	1999-2001	Second Creek	1993-1995	0	
		29	Hoyt Lake Mine Area	1999-2001	Second Creek	1993	0	
		30	Hoyt Lake Mine Area	2001- present	Wyman Creek	2001-2013	0.01	
		33	Hoyt Lake Area	2001- present	Spring Mine Creek	2001-2013	0.75	
Cliffs Erie – Hoyt Lakes	MN0054089	1	HL Tailings Basin Area	2001- present	Unnamed Creek and Wetlands	2001-2013	0.00	Reach 254
		2	HL Tailings Basin Area	2001- present	Unnamed Wetlands	2001-2013	0.00	
		4	HL Tailings Basin Area	2001- present	Unnamed Stream/ Wetland	2001-2013	0.03	
		5	HL Tailings Basin Area	2001- present	Unnamed Wetlands	2001-2013	0.00	
		6	HL Tailings Basin Area	2001- present	Unnamed Stream/Wetland	2001-2013	0.50	

Mining Operation	NPDES Permit	Outfall	Mine Name	Period Listed (post 1998)	Discharges to:	Period of Available Flow Data	Average Discharge (MGD)	HSPF Model Reach
Mesabi Nugget LLC	MN0067687	1	Area 1 Pit	2005- present	Second Crk	2002-2013	3.17	Reach 260
	MN0069078	1	Pit 2WX	2007-2013	No Info	NA	No data	
		4	Pit 1	2007- present	No Info	NA	No data	
		5	Pit 9	2007- present	No Info	NA	No data	
		6	Pit 6	2007- present	No Info	NA	No data	
		7	Pit 9S	2007- present	No Info	NA	No data	
		14	Pit 2WX	2007- present	No Info	NA	No data	
		15	Pit 2WX	2007- present	No Info	NA	No data	
		16	Pit 2WX	2007- present	No Info	NA	No data	
		17	Pit 2WX	2007- present	No Info	NA	No data	
		18	Pit 2WX	2007- present	No Info	NA	No data	
		19	Pit 2WX	2007- present	No Info	NA	No data	
		20	Pit 2WX	2007- present	No Info	NA	No data	
		21	Pit 2WX	2007- present	No Info	NA	No data	
		22	Pit 9	2007- present	No Info	NA	No data	
		23	Pit 9S	2007- present	No Info	NA	No data	
		24	Pit 6	2007- present	No Info	NA	No data	
Northshore Mining Co	MN0046981	1	Peter Mitchell	1999- present	Unnamed Creek	1991-2010	0.67	Reach 265
		2	Peter Mitchell	1999- present	Unnamed Creek	1989-2010	0.73	
		3	Peter Mitchell	1999-present	Unnamed Creek	1991-2010	2.19	
		4	Peter Mitchell	1999- present	Unnamed Wetlands	1991-2010	1.84	
		5	Peter Mitchell	1999- present	Unnamed Wetlands	1991-2010	0.83	
		6	Peter Mitchell	1999- present	One Hundred Mile Swamp	1992	0	

Mining Operation	NPDES Permit	Outfall	Mine Name	Period Listed (post 1998)	Discharges to:	Period of Available Flow Data	Average Discharge (MGD)	HSPF Model Reach
		7	Peter Mitchell	1999- present	One Hundred Mile Swamp	1999-2013	1.8	
		8	Peter Mitchell	1999- present	One Hundred Mile Swamp	1999-2013	0	
		9	Peter Mitchell	1999-present	One Hundred Mile Swamp	1999-2013	1.17	
		10	Peter Mitchell	1999- present	One Hundred Mile Swamp	1992-2013	0.15	
		11	Peter Mitchell	1999- present	One Hundred Mile Swamp	1992-2013	0	
		12	Peter Mitchell	1999- present	One Hundred Mile Swamp	1999-2013	0	
		13	Peter Mitchell	1999- present	One Hundred Mile Swamp	1990-2013	0	
		14	Peter Mitchell	1999- present	Unnamed Creek	1990-1991	0	
		15	Peter Mitchell	1999- present	Unnamed Creek	1991-2010	0	
		16	Peter Mitchell	1999- present	Partridge River	1991-2013	0.06	
		17	Peter Mitchell	1999- present	Unnamed Creek	1991-2010	3.65	
		18	Peter Mitchell	1999- present	Unnamed Creek	1991-2010	0	
		19	Peter Mitchell	1999- present	Unnamed Creek	1991-2010	2.81	
		20	Peter Mitchell	1999-2013	Colby Lake Watershed	1999-2013	0	
		23	Peter Mitchell	2002-2009	One Hundred Mile Swamp	2002-2005	1.43	
Auburn Minerals	MN0063878	1	Pearsall Mine	1999-2000	Trib. to Long Lake Creek	NA	Minor, Not Reporting	

Mining Operation	NPDES Permit	Outfall	Mine Name	Period Listed (post 1998)	Discharges to:	Period of Available Flow Data	Average Discharge (MGD)	HSPF Model Reach
Inland Steel Mining	MN0052311	1	Sauntry Creek	1999-2000	Not Listed	NA	Unknown	
		2	Sauntry Creek	1999-2000	Not Listed	NA	Unknown	
		6	Sauntry Creek	1999-2000	Not Listed	NA	Unknown	
United Taconite LLC	MN0044946	1	Thunderbird Mine	1999- present	Not Listed	1989-1992	0.32	Reaches 248, 249, and 602
		2	Thunderbird Mine	1999- present	Not Listed	NA	Minor, Not Reporting	
		3	Thunderbird Mine	1999- present	Not Listed	1989-2013	1.73	
		4	Thunderbird Mine	1999- present	Not Listed	1989-2013	0.01	
		5	Thunderbird Mine	1999- present	Not Listed	1992-2013	1.55	
		6	Thunderbird Mine	1999- present	Not Listed	1999-2013	0.00	
		7	Thunderbird Mine	1999- present	Not Listed	1992-2013	1.13	
		8	Thunderbird Mine	1999- present	Not Listed	1992-2013	0.03	
		9	Thunderbird Mine	1999- present	Manganika Creek	1992-1999	0.00	

Mining Operation	NPDES Permit	Outfall	Mine Name	Period Listed (post 1998)	Discharges to:	Period of Available Flow Data	Average Discharge (MGD)	HSPF Model Reach
United Taconite LLC	MN0052116	1	Fairlane Tailings Basin	1999- present	Little Tony Lake	1992-2013	0.00	Reach 249
		2	Fairlane Tailings Basin	1999- present	Unnamed Wetlands	1992-2013	0.00	
		3	Fairlane Tailings Basin	No Record	Seep	1999-2013	2.93	
		4	Fairlane Tailings Basin	2005- present	No Info	NA	Unknown	
US Steel Corp.	MN0052493	1	Minntac Mining Area	1999- present	East Branch of the West Two River	1999-2013	3.11	Reaches 244 and 246
		2	Minntac Mining Area	1999- present	Unnamed Creek	NA	Minor, Not Reporting	
		3	Minntac Mining Area	1999- present	Kinney Creek	1999-2013	4.30	
		4	Minntac Mining Area	1999- present	Parkville Creek	1999-2013	3.54	
		7	Minntac Mining Area	1999- present	Kinross Creek	1999-2013	0.00	
		9	Minntac Mining Area	1999- present	Parkville Creek	NA	Minor, Not Reporting	
		10	Minntac Mining Area	1999- present	Western Drainage Ditch	1999-2013	0.00	

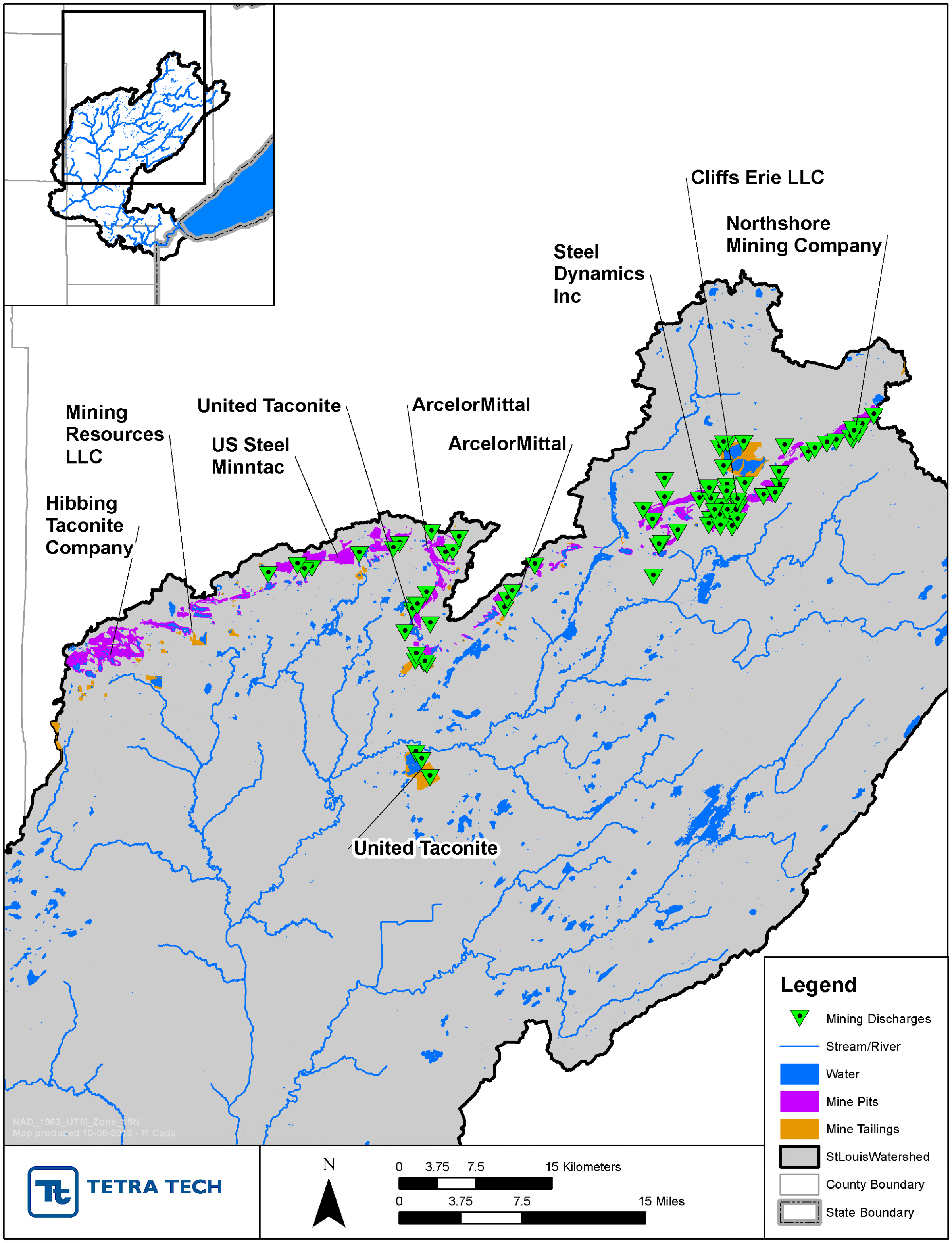

Figure C-3. Permitted Mining Discharges in the Upper St. Louis River Watershed

Appendix D. GFLOW Test Point Calibration Results

The observed and modeled head values for each test point in the model are listed below. These include the water surface elevation in lakes/abandoned pits that are believed to be in equilibrium with the groundwater and overburden test points, which are samples from the interpolated surface aquifer head contours developed from well construction logs (see Appendix B).

Table D-1. Test Points for Model Calibration.

Waterbody Name	Test Point Type	Observed/Estimated Water Level Elevation (m)	Modelled Water Level Elevation (m)
Wanless-Woodbridge Pond	Static Lake	452.48	458.52
Pearsall Mine	Static Lake	440.82	438.86
Troy Mine	Static Lake	440.76	447.53
Burns Mine	Static Lake	453.58	445.75
Morrow Mine	Static Lake	451.04	448.14
Genoa Mine	Static Lake	429.60	427.78
Saint Marys Lake	Static Lake	419.33	421.41
Embarrass Mine	Static Lake	418.18	423.52
Clover Lake	Static Lake	411.42	411.11
Half Moon Lake	Static Lake	410.98	412.94
Deep Lake	Static Lake	423.97	424.60
Gill Lake	Static Lake	425.51	424.36
Lost Lake	Static Lake	421.59	423.27
Leaf Lake	Static Lake	423.91	424.11
Salt Lake	Static Lake	420.53	418.20
CWI 1	Overburden	438.27	420.65
CWI 2	Overburden	433.67	439.62
CWI 3	Overburden	438.75	432.39
CWI 4	Overburden	427.28	428.12
CWI 5	Overburden	426.99	433.03
CWI 6	Overburden	434.38	426.71

Waterbody Name	Test Point Type	Observed/Estimated Water Level Elevation (m)	Modelled Water Level Elevation (m)
CWI 7	Overburden	431.28	420.85
CWI 8	Overburden	416.37	424.98
CWI 9	Overburden	417.99	420.95
CWI 10	Overburden	420.32	424.56
CWI 11	Overburden	425.08	432.22
CWI 12	Overburden	403.27	422.04
CWI 13	Overburden	422.23	421.03
CWI 14	Overburden	425.10	413.82
CWI 15	Overburden	411.03	411.39
CWI 16	Overburden	412.72	416.00
CWI 17	Overburden	412.73	418.29
CWI 18	Overburden	417.60	415.36
CWI 19	Overburden	419.34	413.58
CWI 20	Overburden	403.73	401.47
CWI 21	Overburden	407.71	401.51
CWI 22	Overburden	411.13	412.79
CWI 23	Overburden	414.29	414.75
CWI 24	Overburden	393.93	397.27
CWI 25	Overburden	399.64	398.70
CWI 26	Overburden	394.25	393.71
CWI 27	Overburden	393.48	385.23