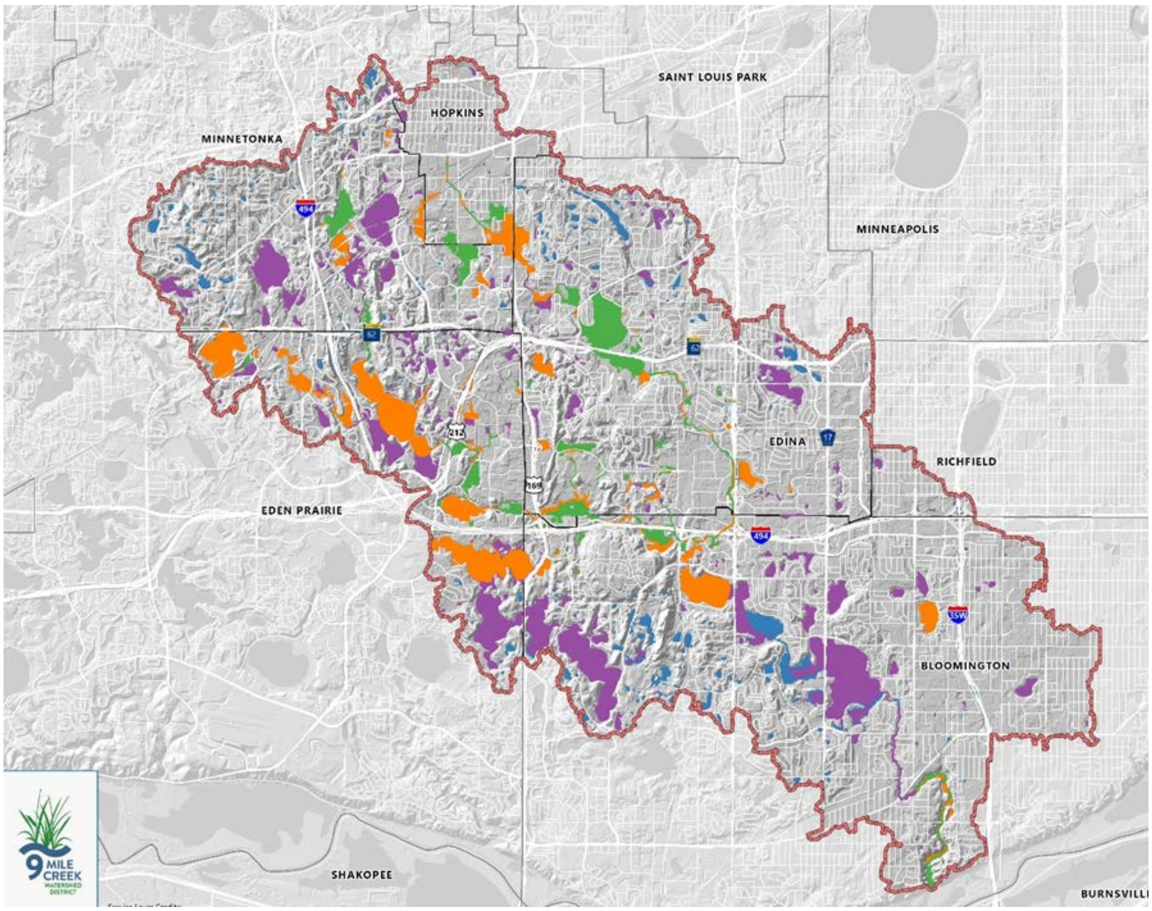
BARR

Evaluation of Groundwater and Surface Water Interaction within the Nine Mile Creek Watershed



November 2019

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Evaluation of Groundwater and Surface Water Interaction within the Nine Mile Creek Watershed

November 2019

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Certification

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Geologist under the laws of the state of Minnesota

Evan G. Christianson
PG # 51379

November 13, 2019
Date

1.0 Introduction

Understanding the interaction between groundwater and surface water is important for the sustainable management and protection of water resources in the Nine Mile Creek Watershed District (District). How groundwater and surface water interact affects how they may respond to seasonal changes (such as drought or wet periods), long-term climate change, or groundwater pumping. Changes in the groundwater system may affect water levels, stream flow, and water quality.

The susceptibility of surface waters to changes in groundwater levels has been a topic of great interest for water bodies across the Twin Cities metro area in general. Record low water levels in White Bear Lake from 2008 to 2017 have, in part, been attributed to increased groundwater pumping in the northeast metro area (Jones et. al., 2013). In 2012, the Minnesota State Legislature gave the Minnesota Department of Natural Resources (MNDNR) authority to designate groundwater management areas to "ensure sustainable use of groundwater that protects ecosystems, water quality, and the ability of future generations to meet their own needs" (MN 103G.287 Subd. 4). In 2016, the MNDNR released their report *Definitions and Thresholds for Negative Impacts to Surface Waters*, which outlines the methodologies to define protected flows, elevations, and target wetland hydrographs (acceptable seasonal variability in wetland levels) for water bodies in areas where groundwater pumping may exceed sustainable supplies.

Until recently much of the focus on evaluating and managing the effects of groundwater and surface water interactions has focused on reductions in groundwater levels and subsequent effects on surface-water bodies. However, it is important to recognize that the groundwater/surface water connection also plays a role in how surface waters respond to prolonged wet periods. Increases in groundwater levels can result in additional groundwater inflow to surface waters or can restrict seepage out. These changes can alter the normal water balances and often occur over time scales of months to years. The prolonged wet period that the Twin Cities metro area is currently in has resulted in high water levels for a number of lakes across the region. Lakes with no natural outlet have been effected more so than those with surface outlets. For these closed depression lakes, seepage to groundwater (groundwater recharge) can often be a significant component for their water budget. High groundwater levels can limit the potential for this seepage to occur, resulting in increased water levels for these lakes. In the last several years, pumping has been implemented to try and alleviate prolonged high water levels in many of these lakes.

This study compiled and analyzed surface water, groundwater, and other data to determine how groundwater and surface water interact across the District and then used that data to identify surface waters that may be particularly sensitive or vulnerable to changes in groundwater levels.

2.0 Evaluation of Regional Groundwater/Surface Water Interaction

To evaluate regional groundwater/surface water interaction across the District, publicly available data sets were compiled and further analyzed. A number of different agencies and organizations collect groundwater, surface water, and other environmental data throughout the District for many different purposes.

Some of the major datasets compiled for this study include:

- Surficial and bedrock geology
- Lake bathymetry
- Surface topography and morphology
- Observation well data
- Well records and boring logs
- Soil surveys
- Data from the Twin Cities Metropolitan Area Groundwater Flow Model (Metro Model 3)

Evaluating the relationship between surface waters and groundwater involves the following three fundamental steps:

1. Determining whether a connection between surface water and groundwater is likely or not.
2. Categorizing the connection based on how groundwater and surface water interact.
3. Evaluating the degree of influence groundwater has on individual surface-water features and if the surface water is potentially vulnerable to changes in the groundwater system.

How vulnerable a surface-water feature is to changes in the groundwater system depends on a combination of how groundwater and surface water interact, physical characteristics of the water body (depth, bed permeability) and the local geology.

Surface-water features analyzed for this project were compiled from several different sources. Lake and wetland data from the National Wetland Inventory (NWI) (East-Central Minnesota updates; MN DNR, 2013), the National Hydrography Dataset (NHD) (Simley and Carswell, 2009) and the MNDNR Public Waters Inventory (PWI) Basin Delineations dataset (MN DNR, 2008a) were combined for the analysis. Where features from each of these dataset overlap, feature geometry and attributes from the MNDNR Public Waters Inventory were used.

Streams features were obtained from the Minnesota DNR PWI Watercourses Delineations dataset (MN DNR, 2008b). Streams in this dataset were broken into approximately 200 meter (about 650 feet) segments for analysis. A segment length of 200 meters was chosen as it allows for sufficient detail in determining stream segments that are disconnected from groundwater without having too many segments making the analysis for the entire District overwhelming. For each 200 meter segment, a polygon was created in GIS using stream widths approximated from aerial photos. Each stream segment polygon was then analyzed in a similar manner to analysis of wetland and lake basins. A total of 2,114 lakes, wetlands, and stream segments were used for analysis in this study and are shown on Figure 1.

2.1 Regional Groundwater Table

A regional water table surface was developed to evaluate the connection of each surface-water feature to the regional groundwater system. The regional water table surface is different than a map of the phreatic surface (upper-most surface of saturation) in that the phreatic surface includes perched groundwater zones (sits above the regional water table) and small local groundwater flow systems. Small local groundwater flow systems may interact with some surface-water features; however, the scale of this study and density of available data do not support evaluation of local groundwater flow systems or their interaction with surface waters.

To construct the regional water table surface, water-level data from a number of different sources were compiled. The main sources of data included static water levels from the Minnesota Well Index (MWI) and District groundwater observation well data (Figure 2). Both historical and recent data from the District groundwater observations wells were used. Well data for the District extends back to the late 1960s though more recent data since 2000 were primarily used for this study. Results from the regional groundwater flow model (Metro Model 3; Metropolitan Council, 2014) and surface-water elevations for reaches of some streams known to be gaining were also used as a qualitative source of information to check results, but were not used explicitly in the creation of the regional water table surface. Surface-water elevations for lakes and wetlands are commonly used in defining the water table surface; however, they were not used for this study as they would skew the intended purpose of the regional water table surface – evaluating the potential connection of surface-water features to groundwater.

All water level data went through a series of preprocessing and filtering steps to eliminate outliers and remove water-level data points that represent perched zones. The majority of the data processing focused on the static water levels from the MWI. The MWI is a valuable source of data as it extensively covers the District; however, the disadvantage of the MWI is the large degree of erroneous and conflicting data. Sources of error include: inaccuracy of water level measurement, well location, and well elevation; misidentification of hydrostratigraphic units, and water levels affected by season and/or year of installation. Given these sources of unavoidable uncertainty, water levels are typically assigned a likely error of +/- 20 feet. It is not uncommon to find two nearby measurements in the same aquifer with substantially different values.

Several methods were used to filter the MWI data. First, wells screened in deep bedrock aquifers were excluded. Next, wells open to unconsolidated sediments but deeper than 200 feet were removed and wells deeper than 150 feet were flagged and removed if the data were suspect. After filtering the MWI data to those wells representative of the regional water table, cross validation was performed to remove outliers. Cross validation compares an observed value to that of an estimated, or interpolated, value at the location of the observed value. It is an iterative process where, first, a single data point is removed from the dataset. Then, a value is interpolated at the location of the removed data point. A residual, or error, is then calculated as the difference between the interpolated value and the observed value. The value that was removed from the dataset is then put back into the dataset and the process is repeated for all observed data points. Data points with high residuals were investigated and suspect erroneous data points were removed.

After cross validation of the MWI dataset, data from all sources were combined and interpolated to create an approximated regional water table surface. The regional water table surface was visually inspected for localized highs and lows potentially representing outliers or perched zones. In suspect areas, the local geology and, if available, results from groundwater flow models were used to determine if the data point(s) should be removed from the dataset. This process was repeated several times until a satisfactory regional water table surface was established (Figure 3).

2.2 Classification of Groundwater/Surface Water Interaction

Each surface-water feature was categorized based on how groundwater and surface water interact. For each surface-water feature, the maximum depth of the feature and the stage of the feature were compared to the elevation of the regional water table. A surface-water feature is considered to be in connection with the regional groundwater system if the regional water table intersects (or nearly intersects) the surface-water feature.

Water depth, and hence elevation of bed sediments, for each surface-water feature was determined in several ways. Where available, bathymetry survey information was used. Bathymetry data were obtained from the MNDNR, previous projects competed for the District, and from individual cities. For lakes and wetlands for which bathymetry is not available, water depth was estimated based on Cowardin wetland class as defined in the NWI dataset (Cowardin et. al., 1979). For streams, a depth of 3 feet was assumed for larger stream segments (those in the PWI) and a depth of 1 foot was assumed for smaller stream segments (those in the NHD dataset but not public waters). A visual analysis suggested that the majority of the features mapped in the NHD that were not mapped in the public waters inventory were shallow ditches or small intermittent tributaries. Surface-water elevations were determined using the following hierarchy based on data availability: current and historical District monitoring data, the Minnesota DNR lake stage data, or minimum surface elevation from a 3m LiDAR derived digital elevation model.

Surface-water features with bottoms greater than 25-feet above the regional water table were considered to be perched and not connected to the regional groundwater system. For the purpose of this study all other features are considered connected to groundwater. However, it is recognized that for some surface features the groundwater connection may be seasonal, or due to the density and accuracy of available data, the determination of the groundwater and surface water connection is somewhat indeterminate. This is generally true for surface-water features with bottom elevations between 5 feet and 25 feet above the regional water table.

Table 1 describes classifications used to define groundwater and surface water interaction for each feature. It is important to note when reading about these types of interactions that the terminology may seem counter-intuitive from the perspective of surface water. For this discussion, a “discharge” lake refers to the case where groundwater is discharging *into* the lake, and a “recharge” lake refers to the case where groundwater is recharged by water flowing *out of* the lake into groundwater. The fact that a surface-water feature is hydraulically connected to the groundwater system does not necessarily mean that it is vulnerable to changes in the groundwater system, but is the first step in the evaluation. The classification of groundwater and surface water interaction for each surface-water feature in the District is shown on Figure 4.

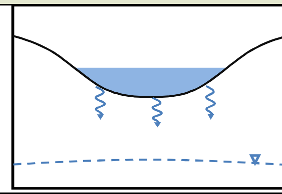
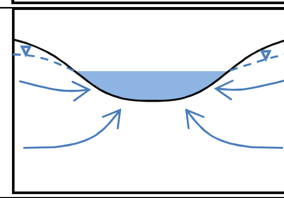
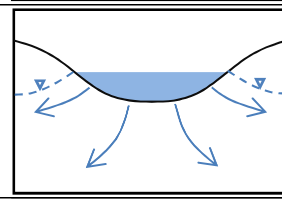
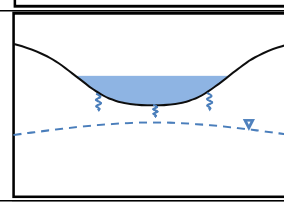
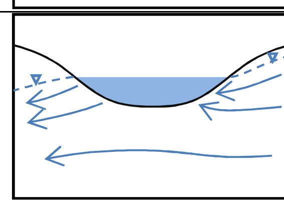
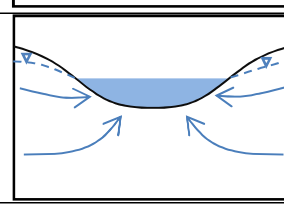
2.3 Vulnerability to Changes in Groundwater Flow System

To evaluate the potential vulnerability of surface-water features to changes in the groundwater flow system, each feature was classified based on the geologic setting surrounding the feature. The vulnerability assessment was conducted in two ways: (1) considering vulnerability to changes in the shallow surficial aquifer system, and (2) considering vulnerability to changes in the deeper bedrock aquifer system. Changes in the surficial aquifer system are primarily driven by climate and in some cases changes in land use. For the deeper bedrock aquifers, change is primarily driven by groundwater pumping associated with municipal and industrial supply. Aquifer level drawdowns in the deep bedrock system from groundwater pumping can propagate up, eventually affecting shallow groundwater and connected surface-water features.

Surface waters classified as perched (see Figure 4 and Section 3.2) are inherently not vulnerable to changes in the regional groundwater system but may be highly sensitive to hydrologic changes in their watershed. While these features lose water to groundwater, the rate of loss is not dependent on groundwater levels. Losing streams or recharge lakes (Figure 4) may be vulnerable to changes in the groundwater system because the rate of flow from the surface water to groundwater is in part controlled by the groundwater system. A drop in the groundwater levels of the upper aquifer, may cause an increase in the loss of water from these surface waters to the groundwater system. Alternatively, a rise in the groundwater levels may cause a decrease in loss of water to the groundwater system which may result in higher stage levels for the surface-water feature, particularly for closed basins. Discharge lakes and gaining stream reaches (Figure 4) may be vulnerable because a change in the groundwater system will affect the amount of groundwater inflow to these surface waters.

The properties of geologic units beneath a surface-water feature affect the way that feature responds to changes in the regional groundwater system. For example, a lake that sits directly within low permeability glacial till is likely influenced very little by changes in regional groundwater levels, with the lake water-budget more likely controlled by surface-water flows. The presence of low permeability sediments may attenuate or eliminate effects from a changing groundwater system, depending on the hydraulic properties, thickness, and horizontal extent. Alternatively, a lake that sits within higher permeability sand and gravel sediments is likely very sensitive to regional groundwater changes and a larger component of the water budget for the lake is likely controlled by groundwater flows.

Table 1 Groundwater/surface water interaction classes

Type	Description	
Perched lake/ wetland or stream with deep water table	Water table deep below feature. Loss of water into the unsaturated zone. Change in water table has no effect on feature. Considered to be disconnected from groundwater	
Discharge lake/wetland	Mostly receives groundwater inflow	
Recharge lake/wetland or losing stream	Connected to groundwater. Mostly loses water as seepage to groundwater	
	Intermittently connected to groundwater. Water table slightly below lake bottom. Fluctuations in the water table can affect the flow dynamics out of lake.	
Flow-through lake/wetland	Groundwater flow both into and out of lake/ wetland	
Graining Stream	Groundwater flow into stream	

Each surface-water feature was evaluated to determine if it is in direct connection with low permeability sediments using a three-dimensional Quaternary stratigraphy model (Berthold, 2018a) and mapped surficial geology (Figure 5; Berthold, 2018b) developed by the Minnesota Geological Survey for Hennepin County. The Quaternary stratigraphy model defines the thickness and extent of lower permeability glacial till and lacustrine sediments and higher permeability sand and gravel deposits. If low permeability sediments of at least 10-feet in thickness completely surround a surface- water feature, it was classified as being not vulnerable to changes in both the surficial and bedrock aquifer systems. If a surface-water feature is not completely surrounded by low permeability sediments, it is considered potentially vulnerable to changes in the shallow surficial groundwater system and additional evaluation is necessary to determine the vulnerability to changes in the deeper bedrock aquifer system as described below. The potential vulnerability of District surface waters to changes in the shallow groundwater system is shown on Figure 6.

In addition to determining if a surface water is surrounded by low permeability sediments, the total cumulative thickness of low permeability sediments, and the presence or absence of bedrock confining units (low permeability bedrock) above major source aquifers was determined to evaluate vulnerability to changes in the deep bedrock aquifer system. If the cumulative thickness of low permeability sediments within a 500-meter buffer surrounding each feature was at least 20-feet thick, the surface feature was classified as not vulnerable to changes in the bedrock aquifer system.

The majority of the water supply for municipal and industrial use across the District is from the Prairie du Chien and/or Jordan aquifers. It is anticipated that any future high capacity water supply will also be sourced from these two aquifers or potentially deeper aquifers such as the Tunnel City Formation and Wonewoc Sandstone. The Platteville Formation is a recognized bedrock confining unit that overlies these major bedrock aquifers in the northern part of the District. Figure 7 shows the upper most bedrock unit across the District. Figure 8 shows a geologic cross section of the bedrock units developed by the Minnesota Geological Survey that runs along a path north and east of the District. The layering of bedrock units shown on Figure 8 is similar within the District. Similar to the cumulative thickness of low permeability sediments, if the Platteville Formation is present across a 500 foot buffer area surrounding a surface-water feature, it was classified as being not vulnerable to changes in the bedrock aquifer system. The thickness of the Platteville Formation was not considered because the continuity of this bedrock unit is much more certain than with low permeability glacial sediments, which are typically discontinuous. The potential vulnerability of District surface waters to changes in the deep bedrock aquifer system is shown on Figure 9.

The bathymetry, or geometry, of a lake basin is important in determining potential impacts from groundwater pumping. While the bathymetry plays no role in determining if a lake is vulnerable or not, it does indicate how changes in the groundwater table may impact the lake. Lakes with wide littoral zones have a greater potential of being negatively impacted by changes in lake stage. Lakes that are less than 5 feet deep over more than 20% of the total surface area are considered to be more sensitive to reductions in lake level. These lakes are generally disproportionately shallow as indicated by the relative hypsographic curves (depth vs. area) presented in Appendix A. All the lakes analyzed in the District, with the exception of Mirror Lake in northwest Edina, were characterized as having a wide littoral zone and being disproportionately shallow. This indicates that, across the District, the lakes are particularly vulnerable to changes in groundwater that result in a drop of the water table, and a potential subsequent drop in lake stage. While bathymetric data are not available for wetlands, it is assumed that all wetlands are less than 5 feet deep over more than 20% of their surface area and are therefore considered to be similarly vulnerable as lakes that fall into this category.

3.0 Conclusions and Recommendations

Results of this study highlight that groundwater/surface water interaction does occur across much of the Nine Mile Creek watershed. Local geologic controls such as the distribution of low permeability glacial tills or higher permeability sand and gravel glacial outwash greatly influence the groundwater surface water interaction and the vulnerability of surface waters to changes in the groundwater system. As shown in Figure 4, **many of the surface waters across the District are connected to and interact with the groundwater system**. Some smaller surface waters are perched, meaning they have little interaction with groundwater; however, these waterbodies comprise a small percentage of all the surface waters in the District.

This study also included evaluation of the potential vulnerability of surface-water features to changes in the groundwater flow system. The vulnerability assessment was conducted in two ways: (1) considering vulnerability to changes in the shallow surficial aquifer system, and (2) considering vulnerability to changes in the deeper bedrock aquifer system. **Many of the surface waters across the District were identified as being vulnerable to changes in the shallow surficial aquifer system** (Figure 6). The shallow surficial aquifer system responds primarily to climatic changes; both periods of drought or prolonged wet periods. This is particularly true for lakes and wetlands with no surface outlet (closed or "land-locked" basins). **Fewer surface waters across the District were identified as vulnerable to changes in the deep bedrock aquifers** (Figure 8). For the deeper bedrock aquifers, change is primarily driven by groundwater pumping associated with municipal and industrial supply. Large areas of low permeability glacial till at depth and bedrock confining units help to minimize the effects of change in the deep bedrock aquifers on surface waters within the District.

Information developed as part of this study will help District staff and stakeholders better understand the impacts of groundwater on lake, wetland, and stream hydrology. The groundwater/surface water interaction information can be used help improve understanding of water budgets for surface waters across the District. Knowing how groundwater and surface water interact can help to better understand the potential role groundwater may play in water level fluctuations. The results of this study will also be used to evaluate and consider potential impacts from climate change. The information can help District staff and stakeholders better understand which water bodies may be more vulnerable to climatic variations, including both periods of drought and prolonged wet periods. Results of this study could also be used to understand and promote groundwater recharge.

The following recommendations were developed based on the results of this study:

- Continue collection of static groundwater levels from the remaining active groundwater observation wells throughout the District.
- Enhance the monitoring well network to provide more spatial coverage across the District. Focus placement of new monitoring wells in areas where surface waters have been identified as vulnerable to changes in the surficial aquifer system. Consider working with municipal partners to share monitoring well locations to minimize costs related to installation of new wells.

- Consider establishing a formal process for tracking groundwater data and geologic data submitted to the District with permit applications. This would include water level measurements and associated boring records into a GIS style database
- Consider developing a fully coupled groundwater-surface water model for the District. To fully understand how surface waters are affected by changes in the groundwater system, a model capable of tracking the full water balance for both groundwater and surface water is necessary.

Several of the recommendations above pertain to the District's groundwater monitoring program. As follow-up to this study, the status of the District's current groundwater monitoring program and recommendations for modifications to the monitoring program will be developed and summarized for Board review and consideration. Establishment of a process for tracking groundwater data and geologic data submitted to the District with permit applications will also be considered.

4.0 References

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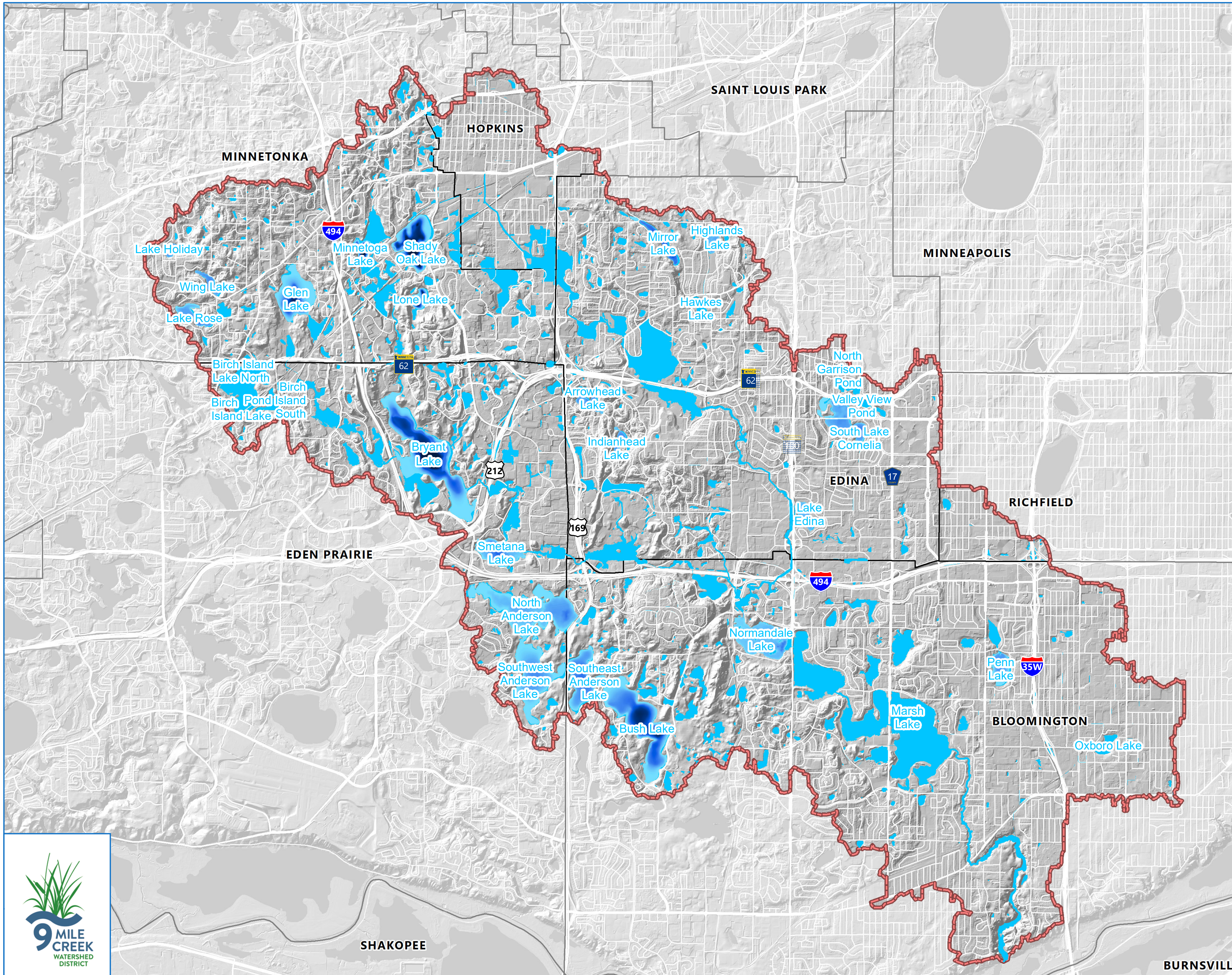
Figures



District Surface Water Features Included in Study

District Hydrologic Boundary

0 1 2

Miles

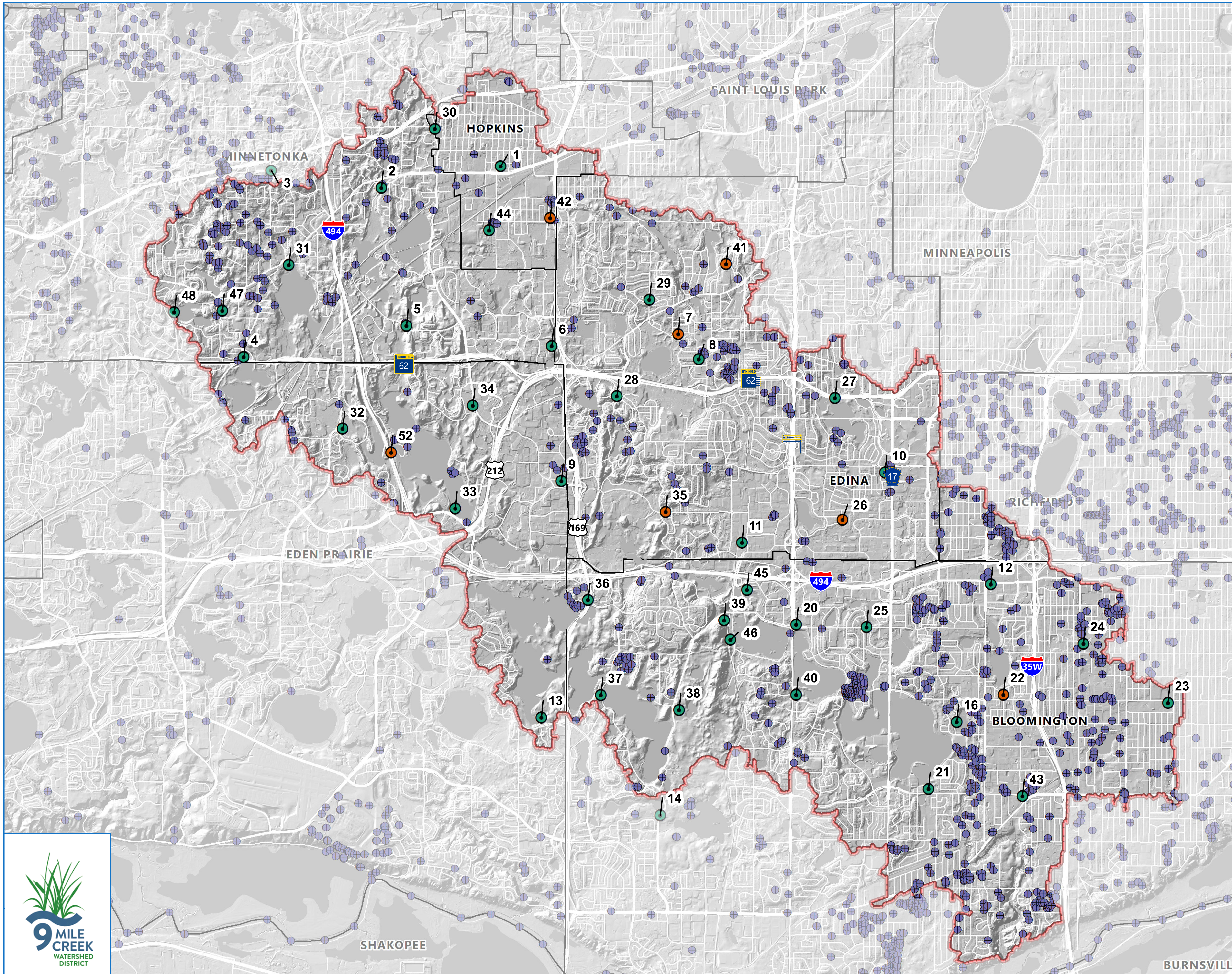
Feature data from Minnesota Public Waters Inventory (PWI), National Wetland Inventory (NWI), and National Hydrography Dataset (NHD)

Lakes with bathymetry information shown with dark blue shading indicating depth

SURFACE WATER FEATURES ANALYZED FOR STUDY
Groundwater and Surface Water Interaction
Nine Mile Creek Watershed District

Figure 1

Barr Footer: ArcGIS 10.6.1, 2019-08-20 20:12 File: I:\Client\Nine_Mile_Creek_WD\Work_Orders\23271711_GW_SW\Maps\FIGURE 1 SITE OVERVIEW.mxd User: egc



Inactive NMCWD Groundwater Observation Wells

Active NMCWD Groundwater Observation Wells

Minnesota Well Index Data Used in Anaysis

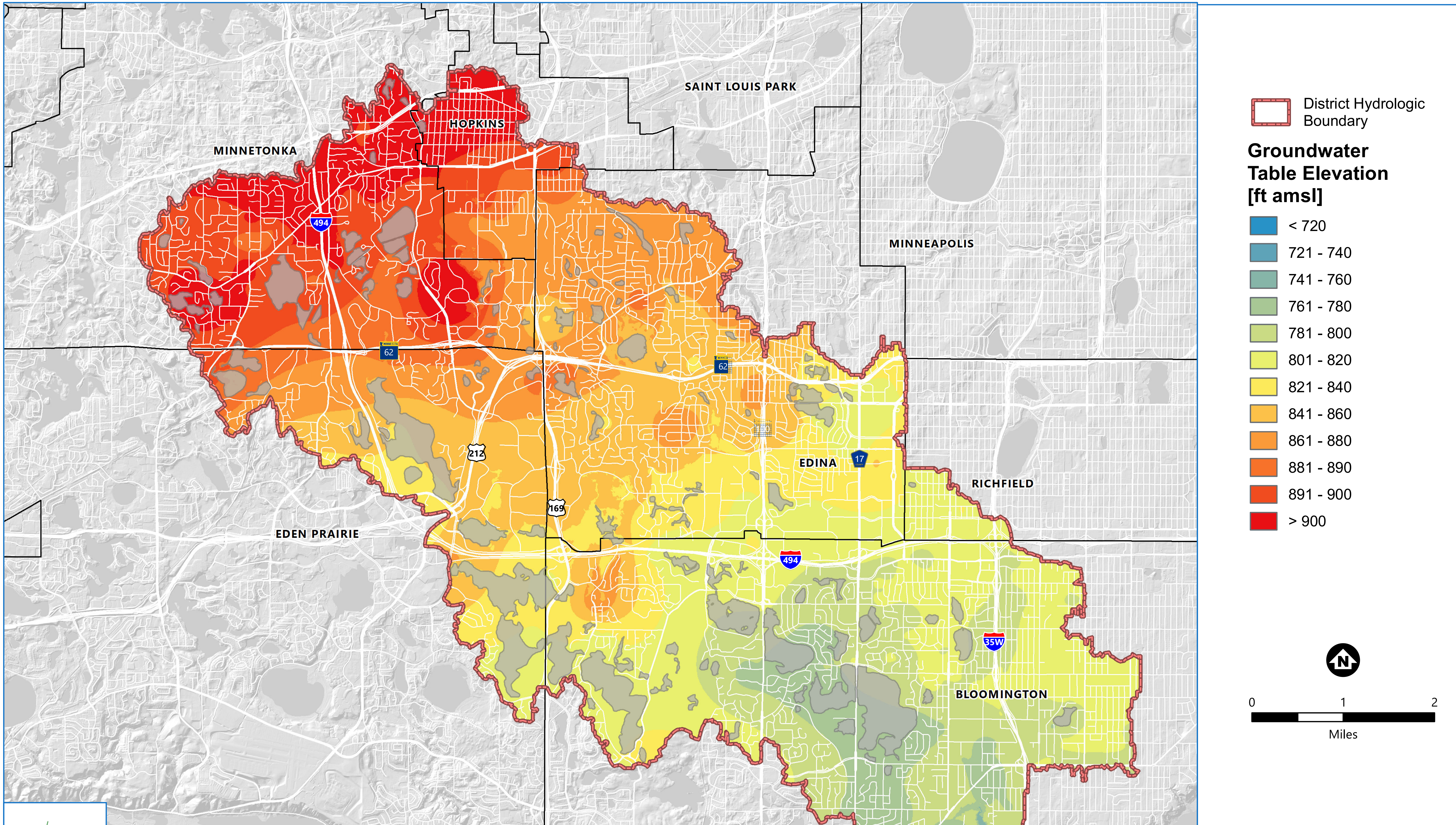
District Hydrologic Boundary

0 1 2

Miles

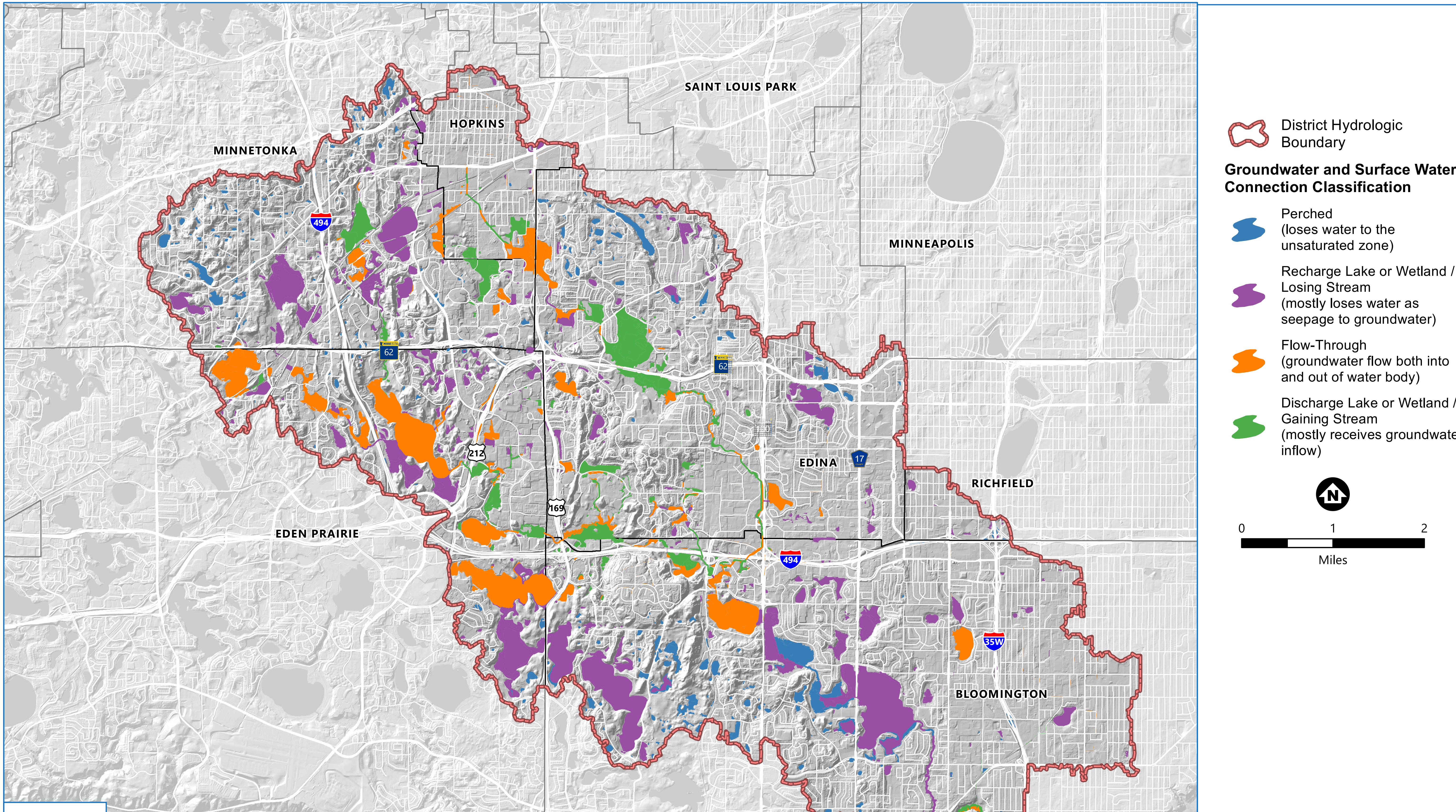
PUBLIC AND DISTRICT WELL DATA
Groundwater and Surface Water Interaction
Nine Mile Creek Watershed District

Figure 2



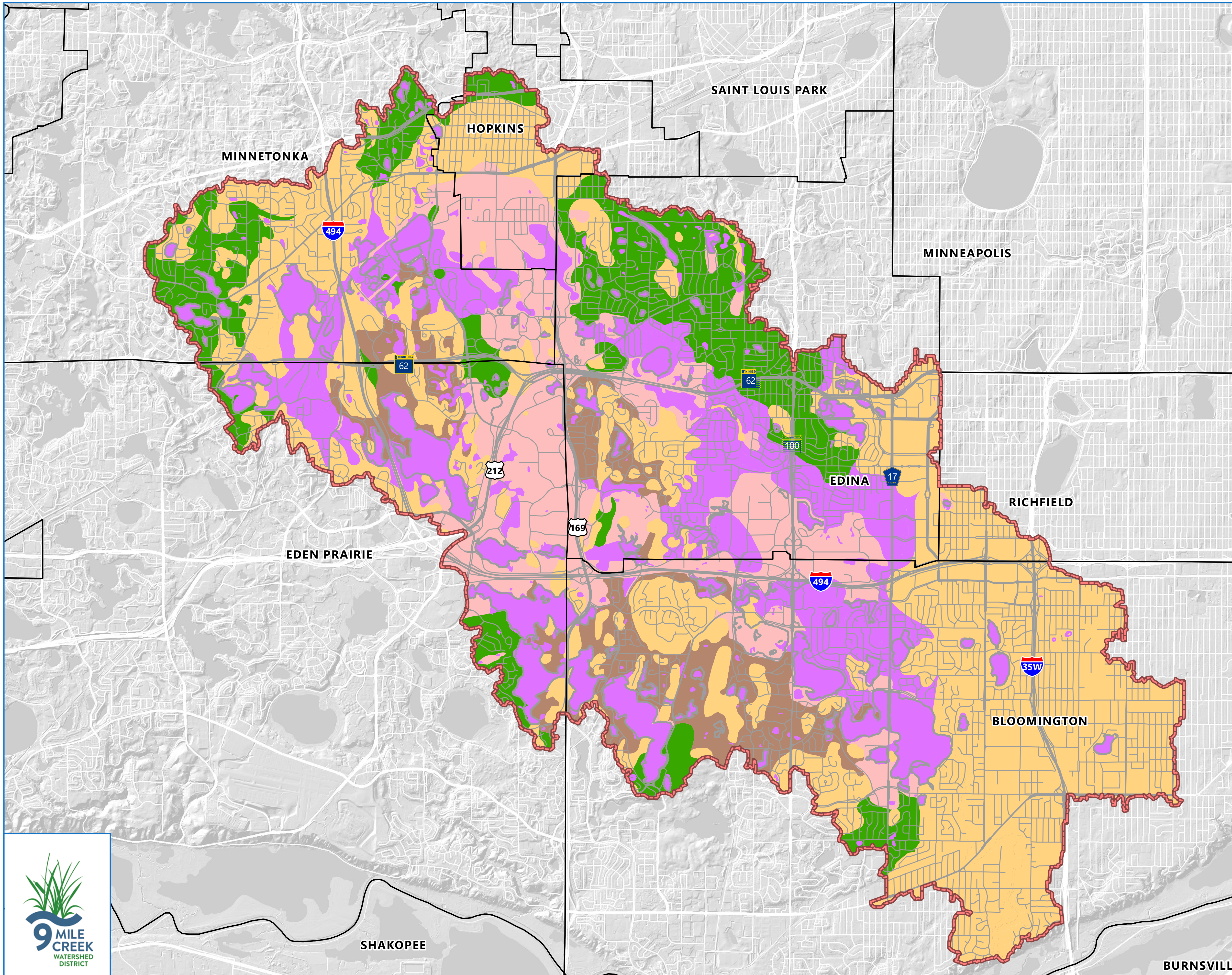
REGIONAL GROUNDWATER TABLE
Groundwater and Surface Water Interaction
Nine Mile Creek Watershed District

Figure 3



CLASSIFICATION OF GROUNDWATER AND SURFACE WATER INTERACTION
Groundwater and Surface Water Interaction
Nine Mile Creek Watershed District

Figure 4



District Hydrologic Boundary

Simplified Surficial Geology

- Artificial surface
- Colluvium
- Lacustrine
- Sand and gravel
- Tills

0 1 2

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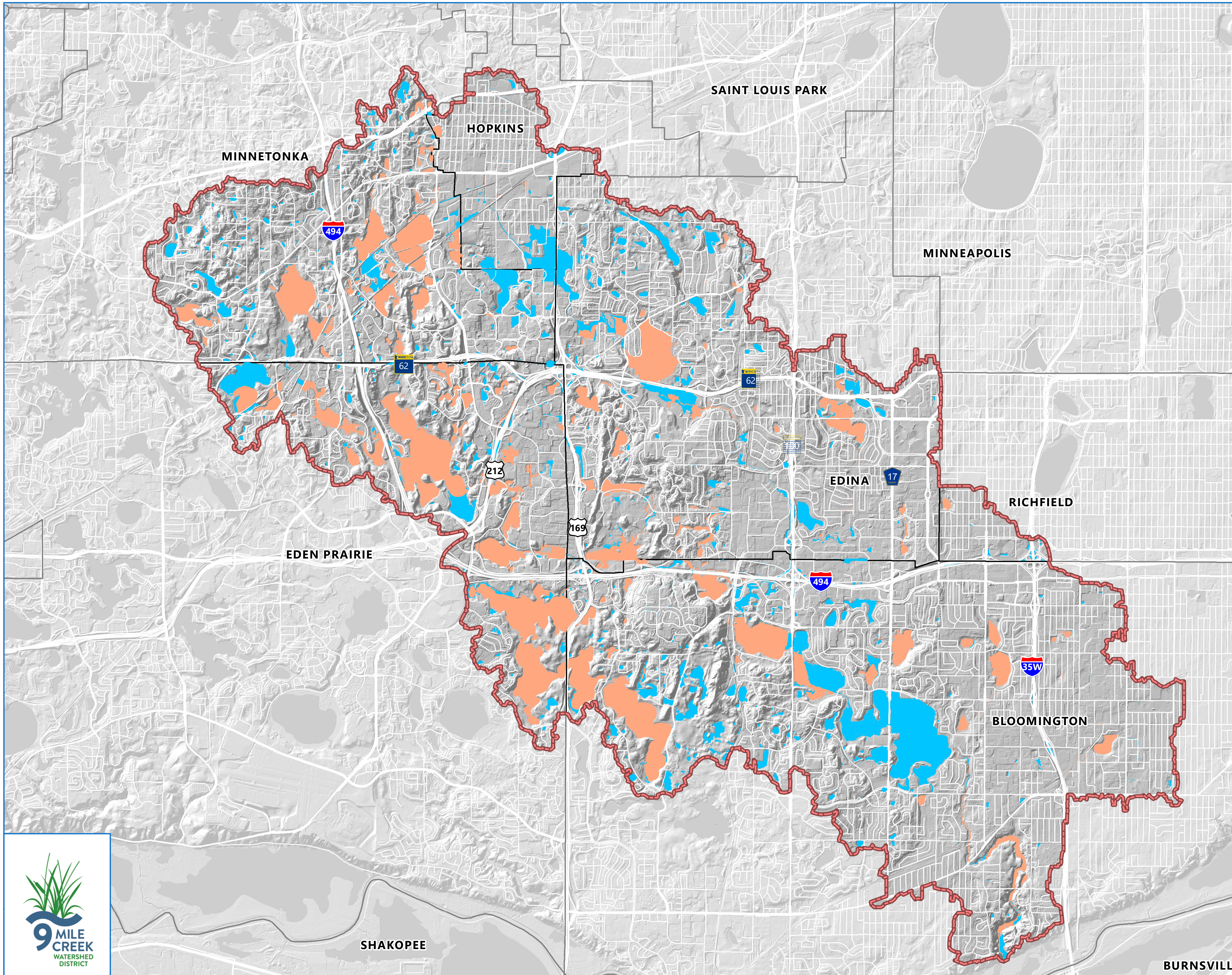
Surficial geology depicts the origin and distribution of surficial geologic sediments typical from ground surface to a depth of approximately 20 feet. For more detail on the provenance, age, additional subdivisions of each unit shown see Plate 3 of the Hennepin County Geologic Atlas (Berthold, 2018).

SURFICIAL GEOLOGY
Groundwater and Surface Water Interaction
Nine Mile Creek Watershed District

Figure 5



District Hydrologic Boundary

Vulnerability to Changes in Surficial (shallow) Groundwater Aquifers

Not Vulnerable

Vulnerable

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VULNERABILITY TO CHANGES IN GROUNDWATER – SURFICIAL AQUIFERS
Groundwater and Surface Water Interaction
Nine Mile Creek Watershed District

Figure 6

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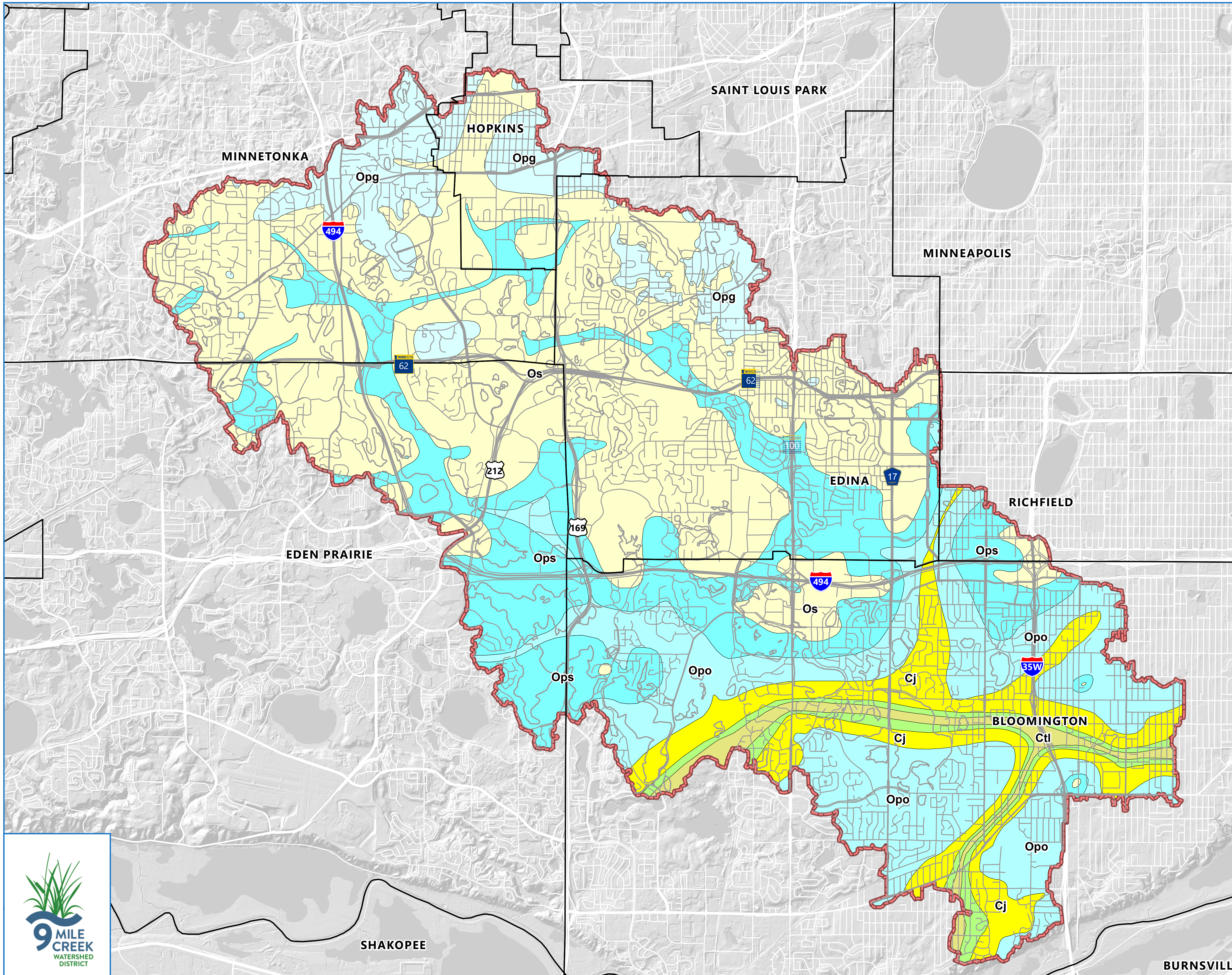

District Hydrologic Boundary

Bedrock Geology

Lithostratigraphic Unit

- Platteville & Glenwood Formations (Opg)
- St. Peter Sandstone (Os)
- Prairie du Chein Group, Shakopee Formation (Ops)
- Prairie du Chein Group, Oneota Dolomite (Opo)
- Jordan Sandstone (Cj)
- St. Lawrence Fm (Cs)
- Tunnel City Group, Lone Rock Fm (Ctm)

Data from Plate 2 of the Hennepin County Geologic Atlas (Retzler, 2018)

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BEDROCK GEOLOGY
Groundwater and Surface Water Interaction
Nine Mile Creek Watershed District

Figure 7

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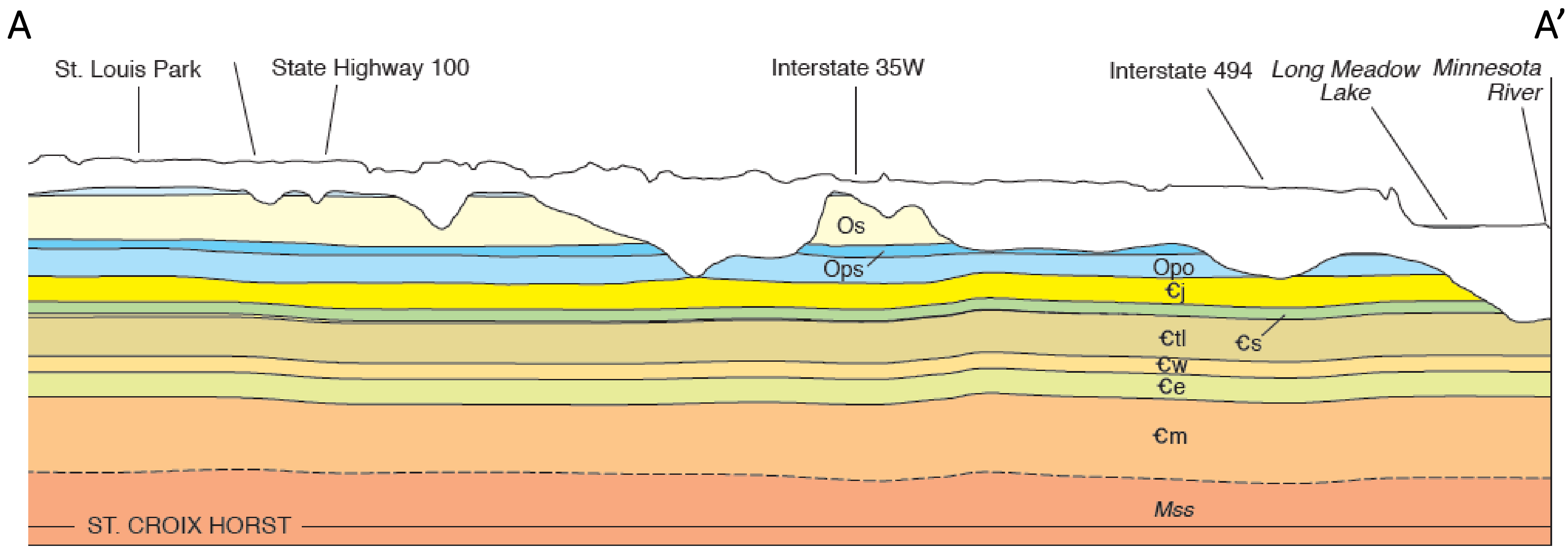
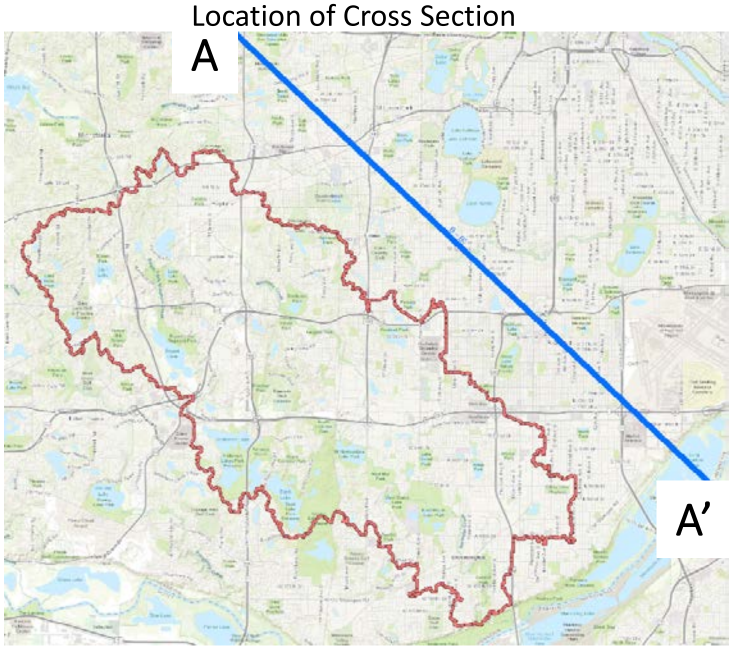


Modified from Plate 2 of the Hennepin County Geologic Atlas (Retzler, 2018)

Location of Cross Section

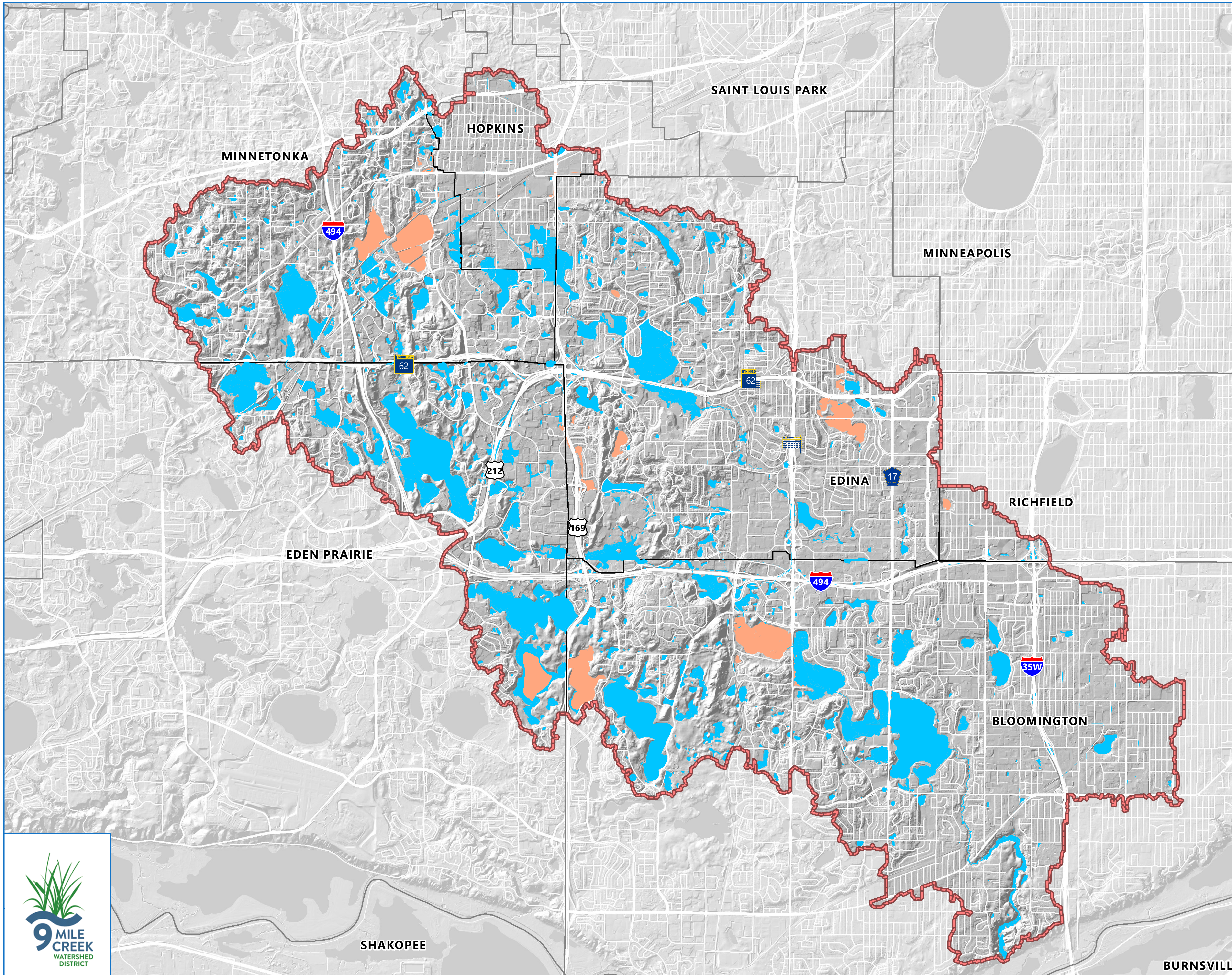


Os – St. Peter Sandstone
Ops – Prairie du Chien Group, Shakopee Formation
Opo – Prairie du Chien Group, Oneota Dolomite
Cj – Jordan Sandstone
Cs – St. Lawrence Formation
Ctl – Tunnel City Group, Lone Rock Formation
Cw – Wonewoc Sandstone
Ce – Eau Claire Formation
Cm – Mt. Simon Sandstone
Mss – Mesoproterozoic sandstone, and siltstone

GEOLOGIC CROSS SECTION

Groundwater and Surface Water Interaction
Nine Mile Creek Watershed District

FIGURE 8



District Hydrologic Boundary

Vulnerability to Changes in Bedrock (deep) groundwater aquifers

Not Vulnerable

Vulnerable

0 1 2

Miles

Service Layer Credits:

VULNERABILITY TO CHANGES IN GROUNDWATER – BEDROCK AQUIFERS

Groundwater and Surface Water Interaction

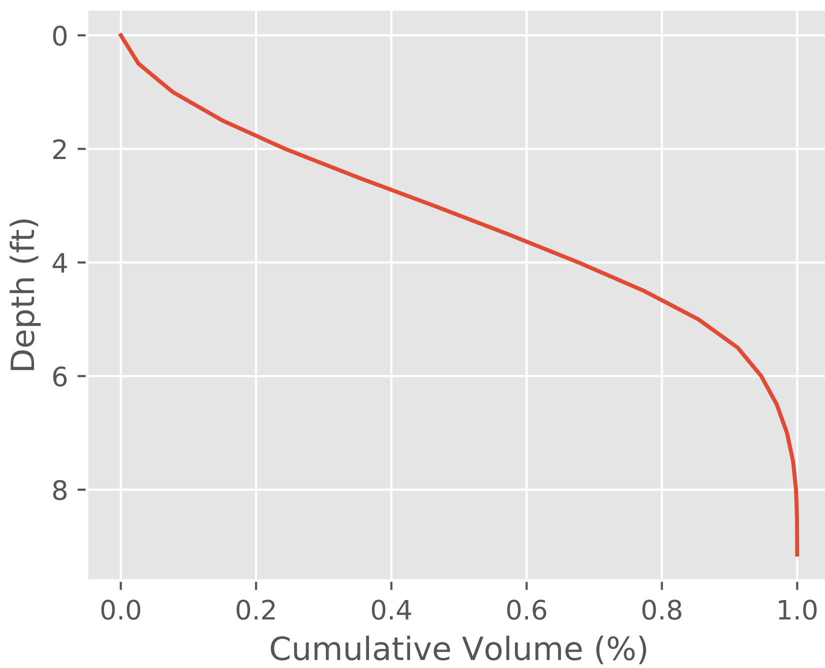
Nine Mile Creek Watershed District

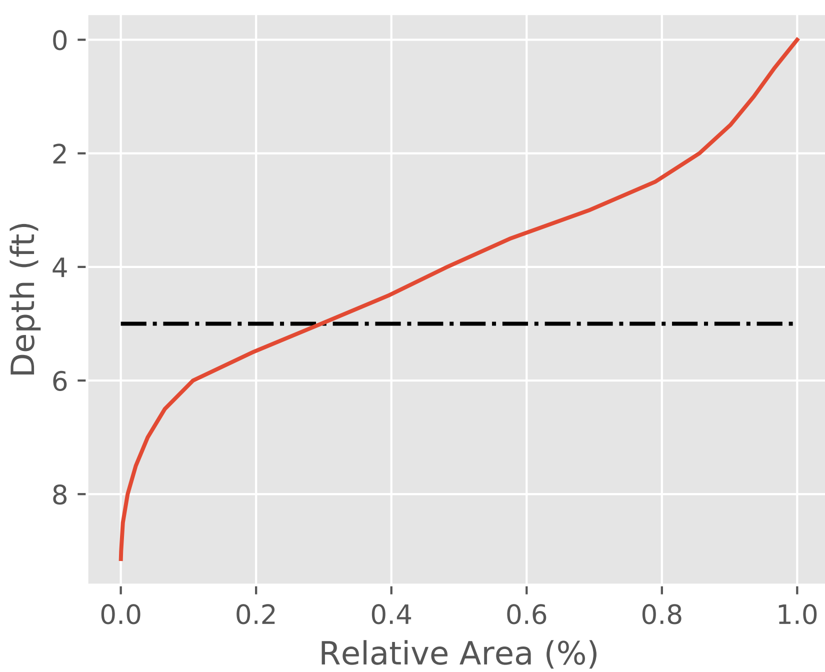
Figure 9

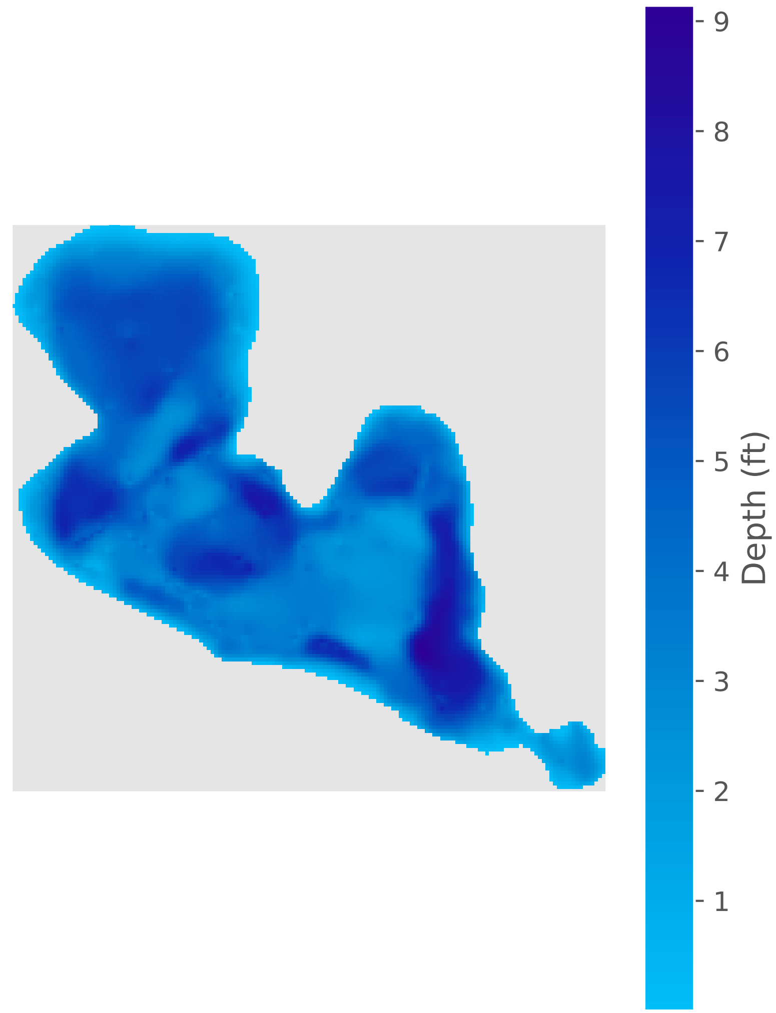
Appendix A

Basin Bathymetry and Geometry

Arrowhead Lake





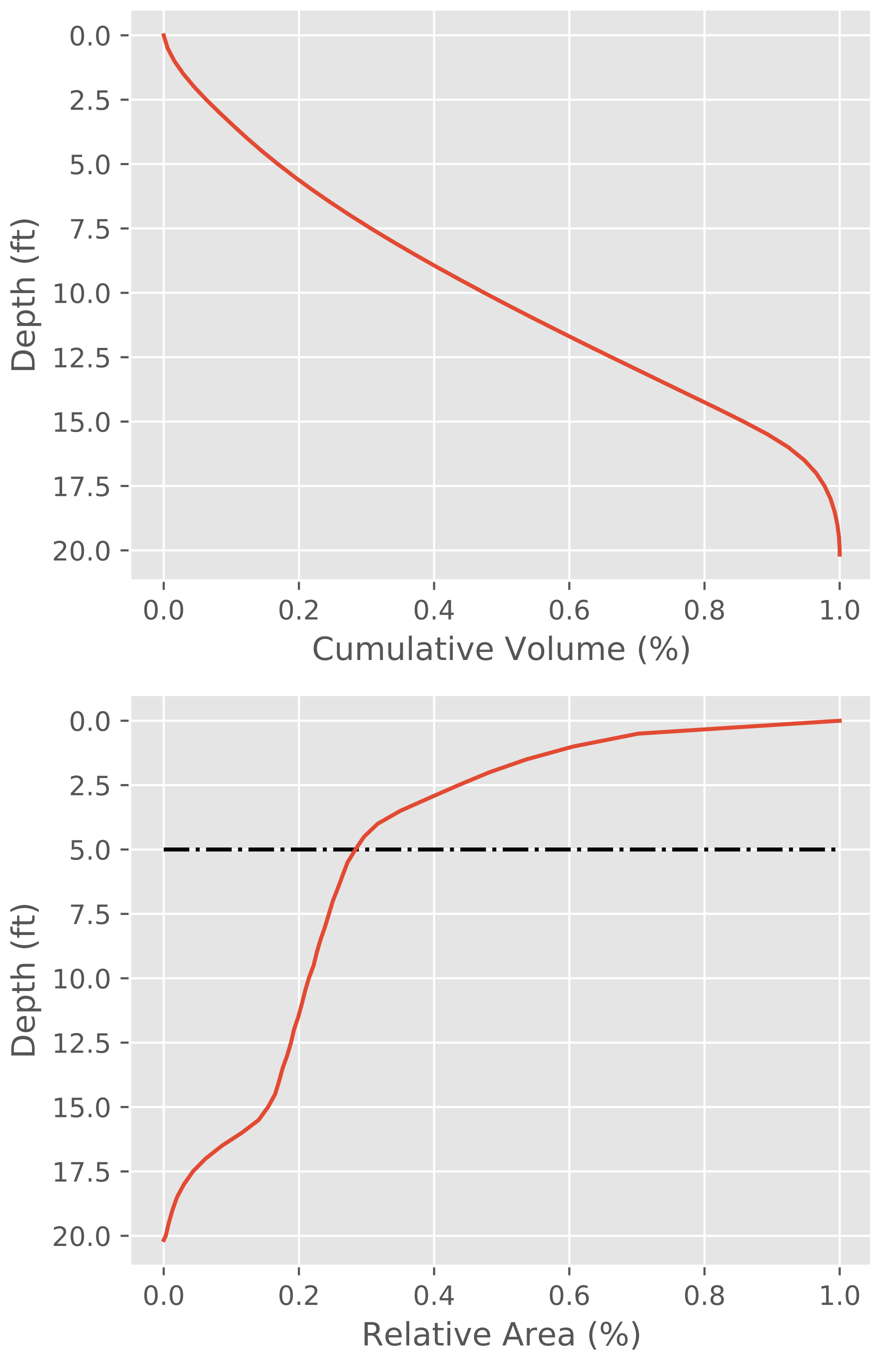


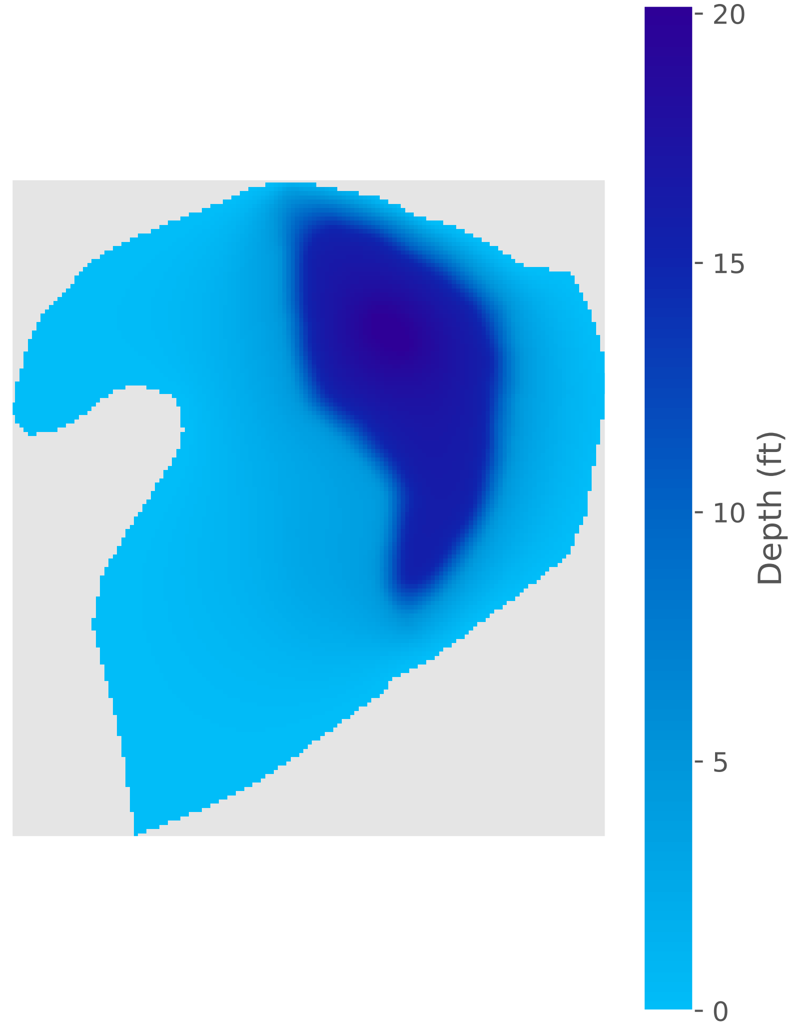
Percent area less than 5 feet deep: 70.4

Maximum depth: 9 feet

Mean depth: 3.9 feet

Birch Island Lake



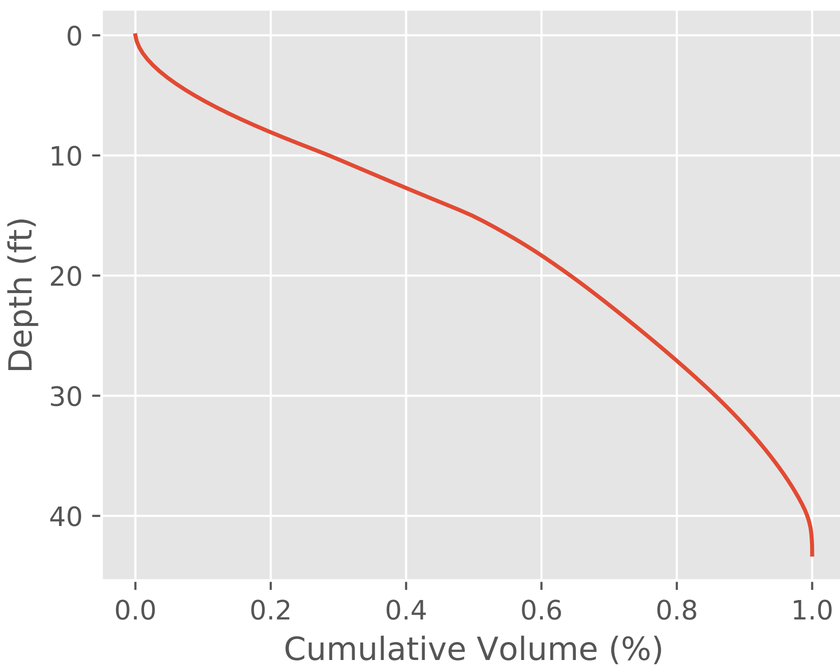


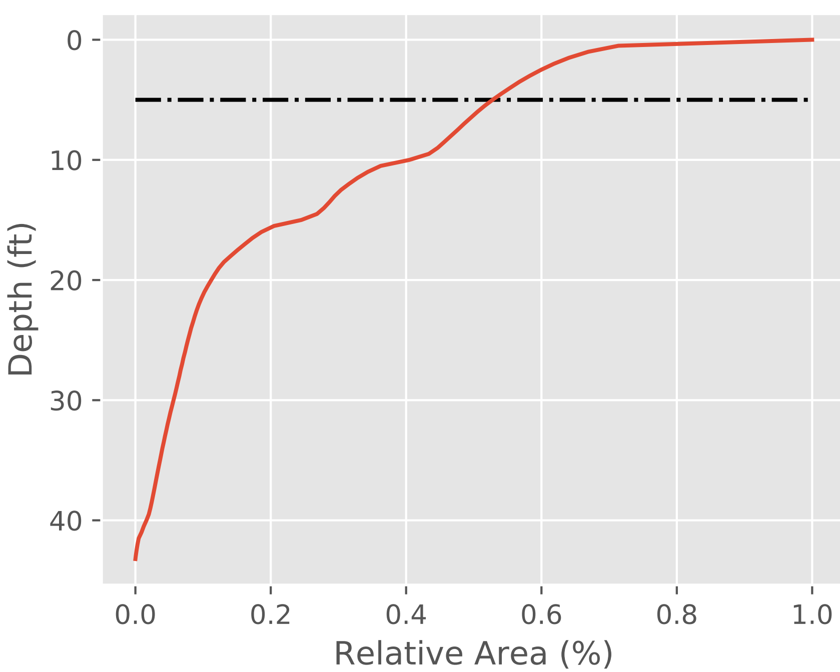
Percent area less than 5 feet deep: 71.6

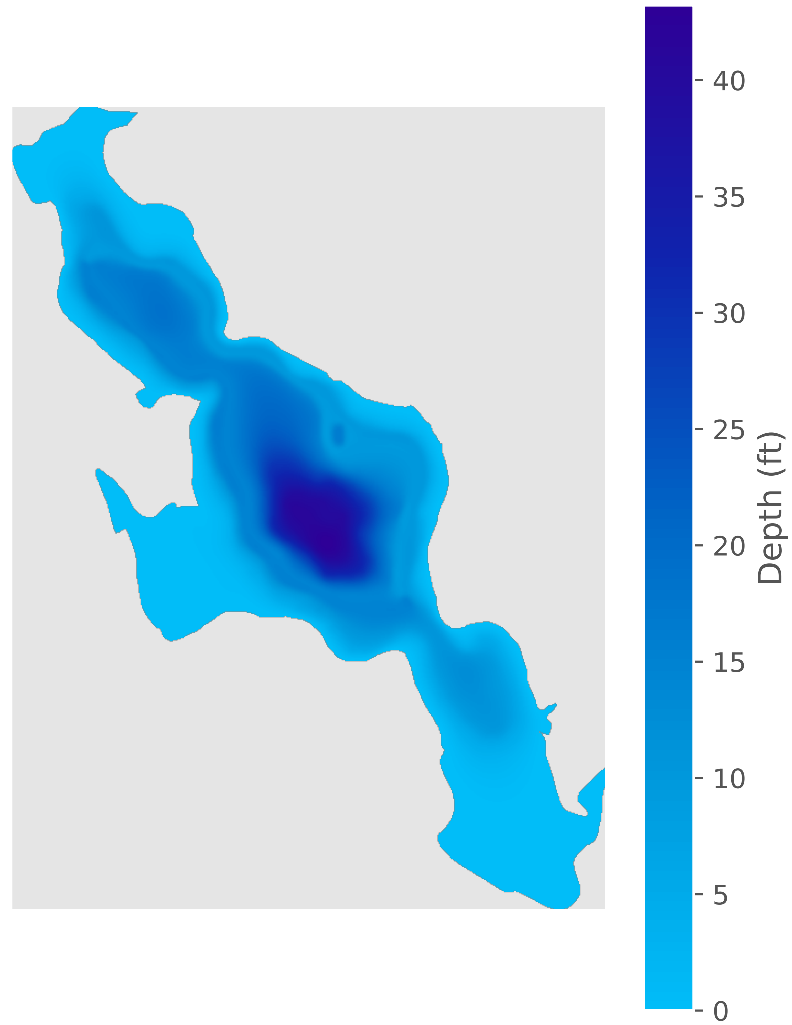
Maximum depth: 20 feet

Mean depth: 4.8 feet

Bryant Lake





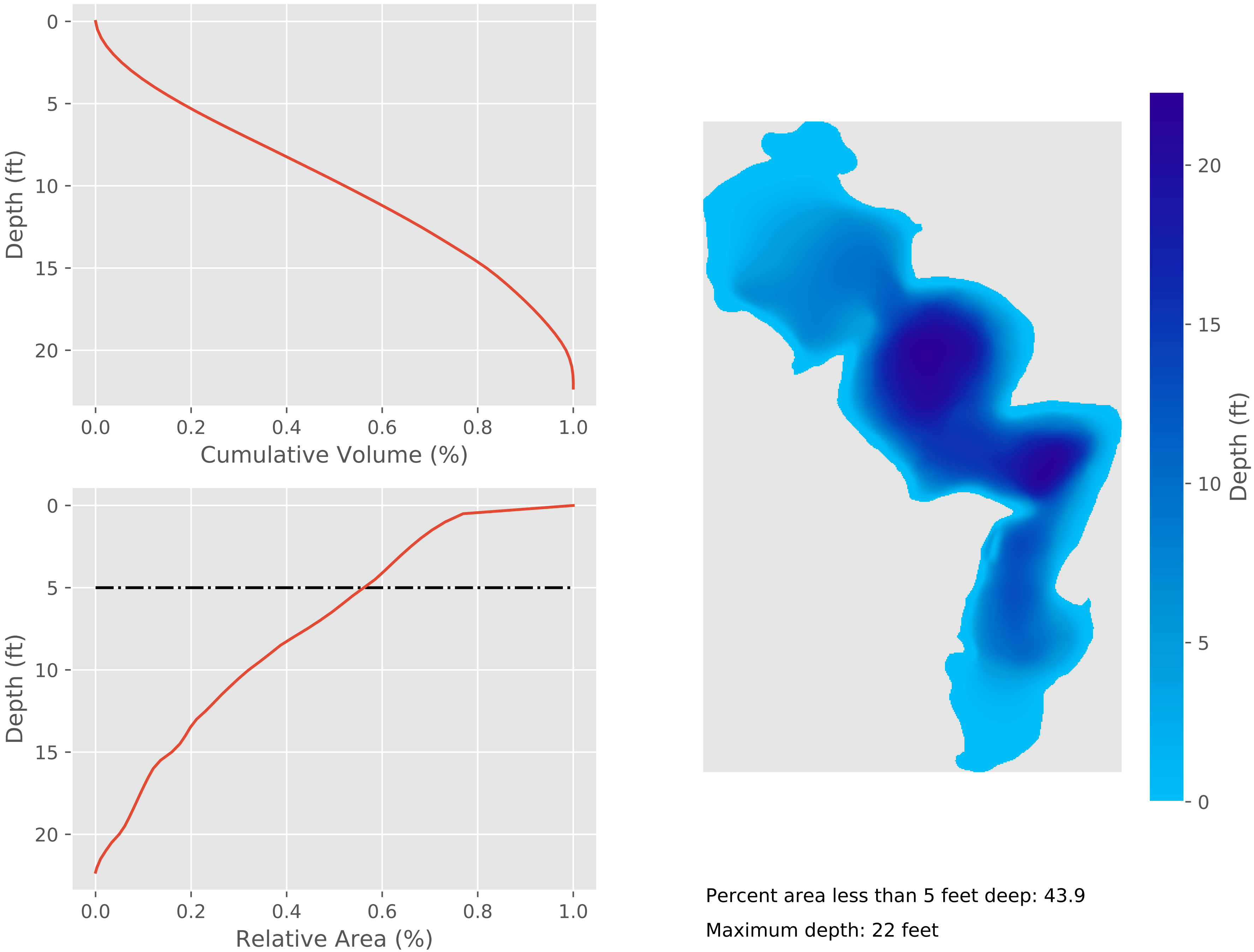


Percent area less than 5 feet deep: 47.2

Maximum depth: 43 feet

Mean depth: 9.0 feet

Bush Lake

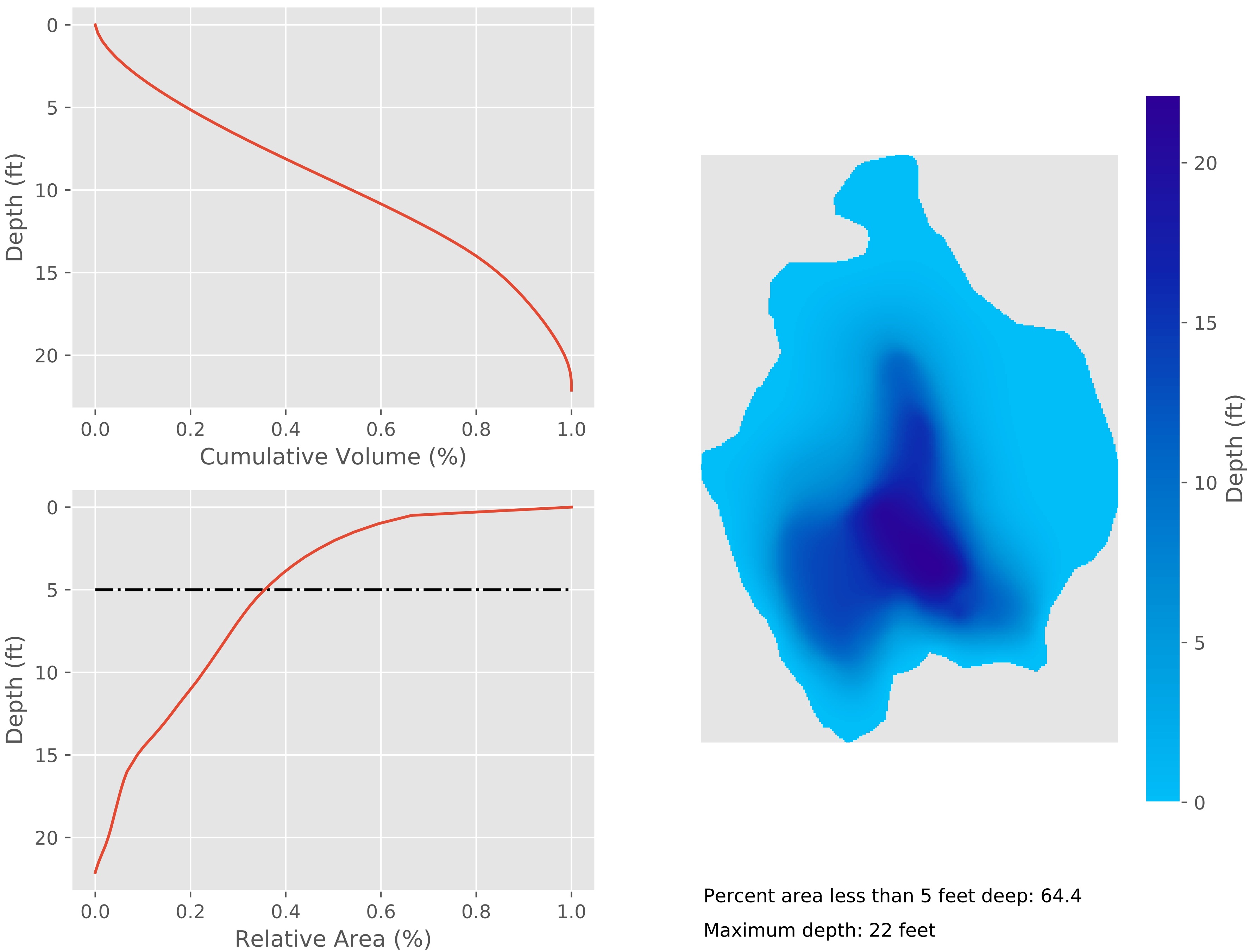


Percent area less than 5 feet deep: 43.9

Maximum depth: 22 feet

Mean depth: 7.2 feet

Glen Lake

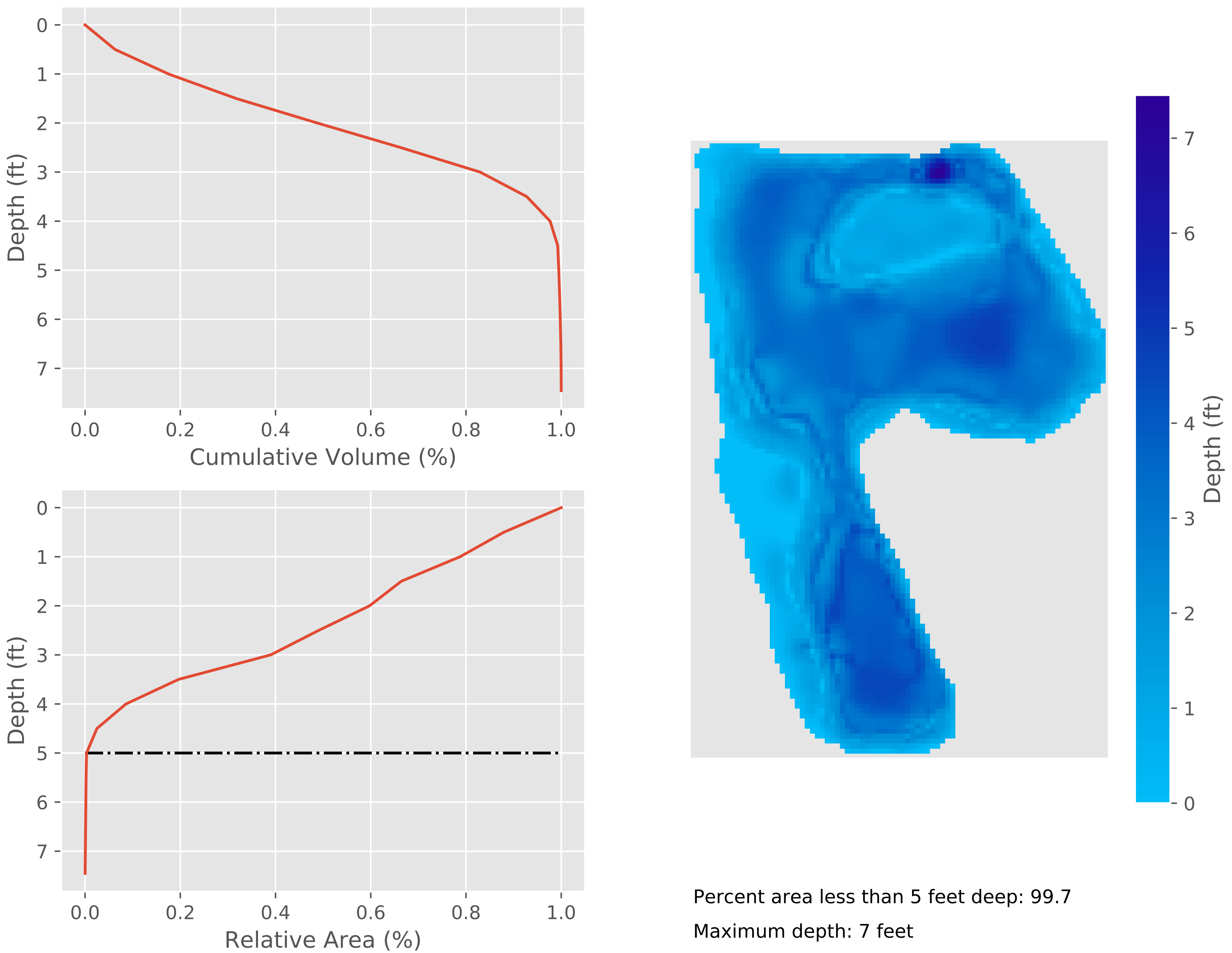


Percent area less than 5 feet deep: 64.4

Maximum depth: 22 feet

Mean depth: 5.0 feet

Highlands Lake

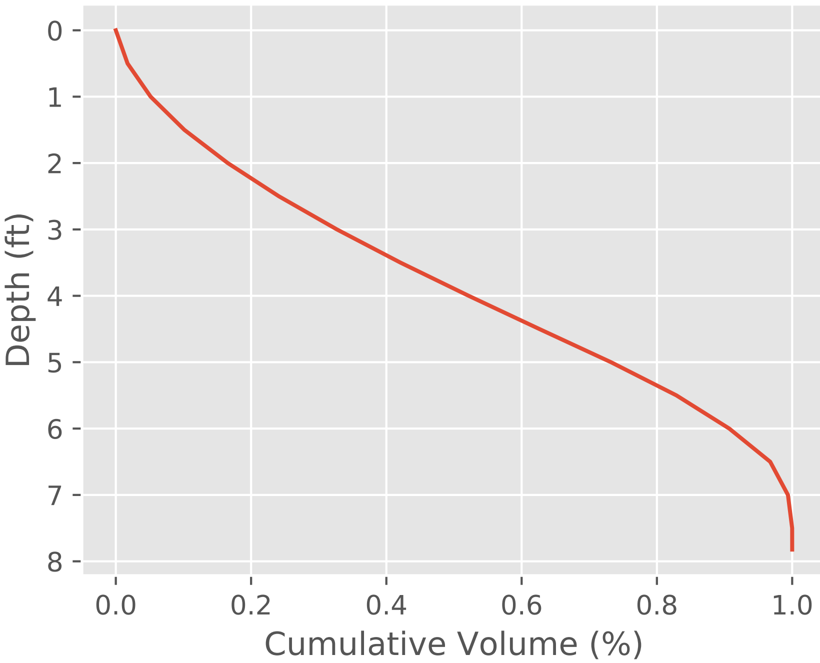


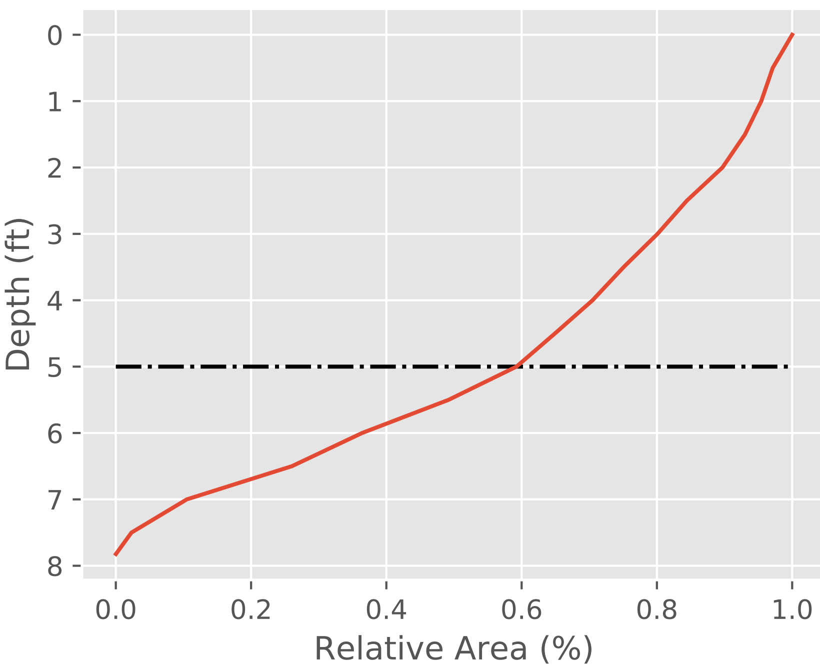
Percent area less than 5 feet deep: 99.7

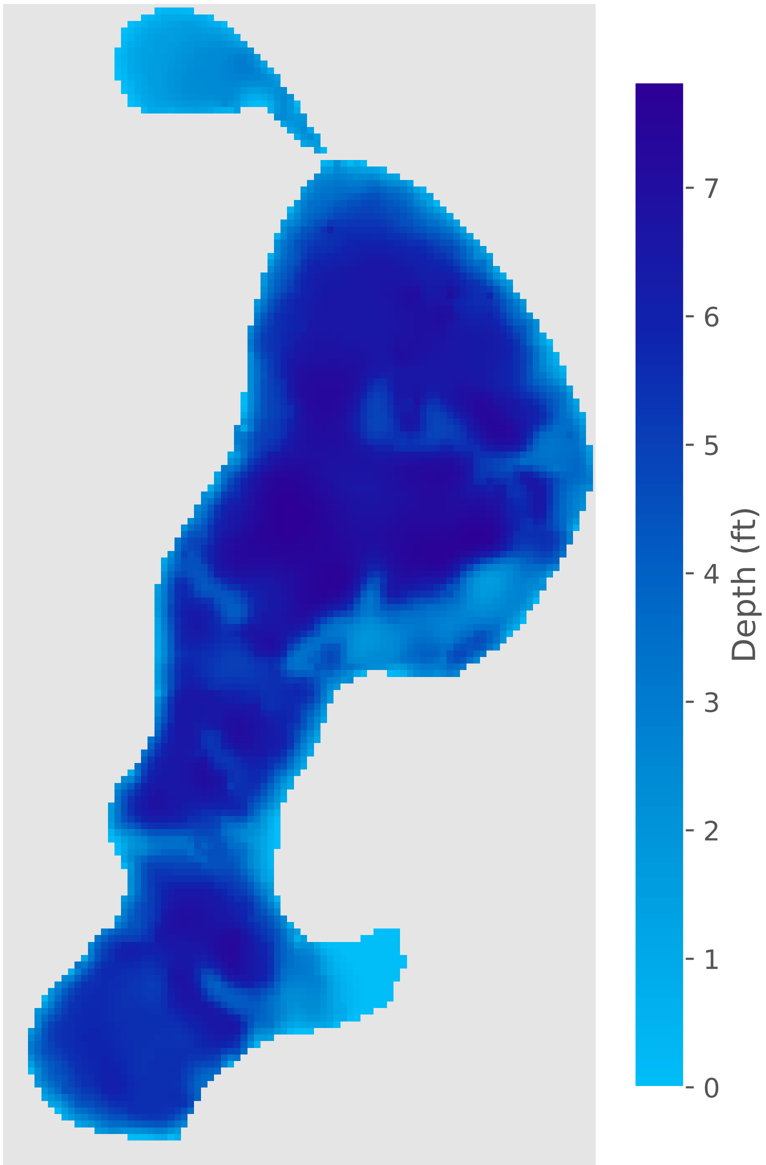
Maximum depth: 7 feet

Mean depth: 2.3 feet

Indianhead Lake





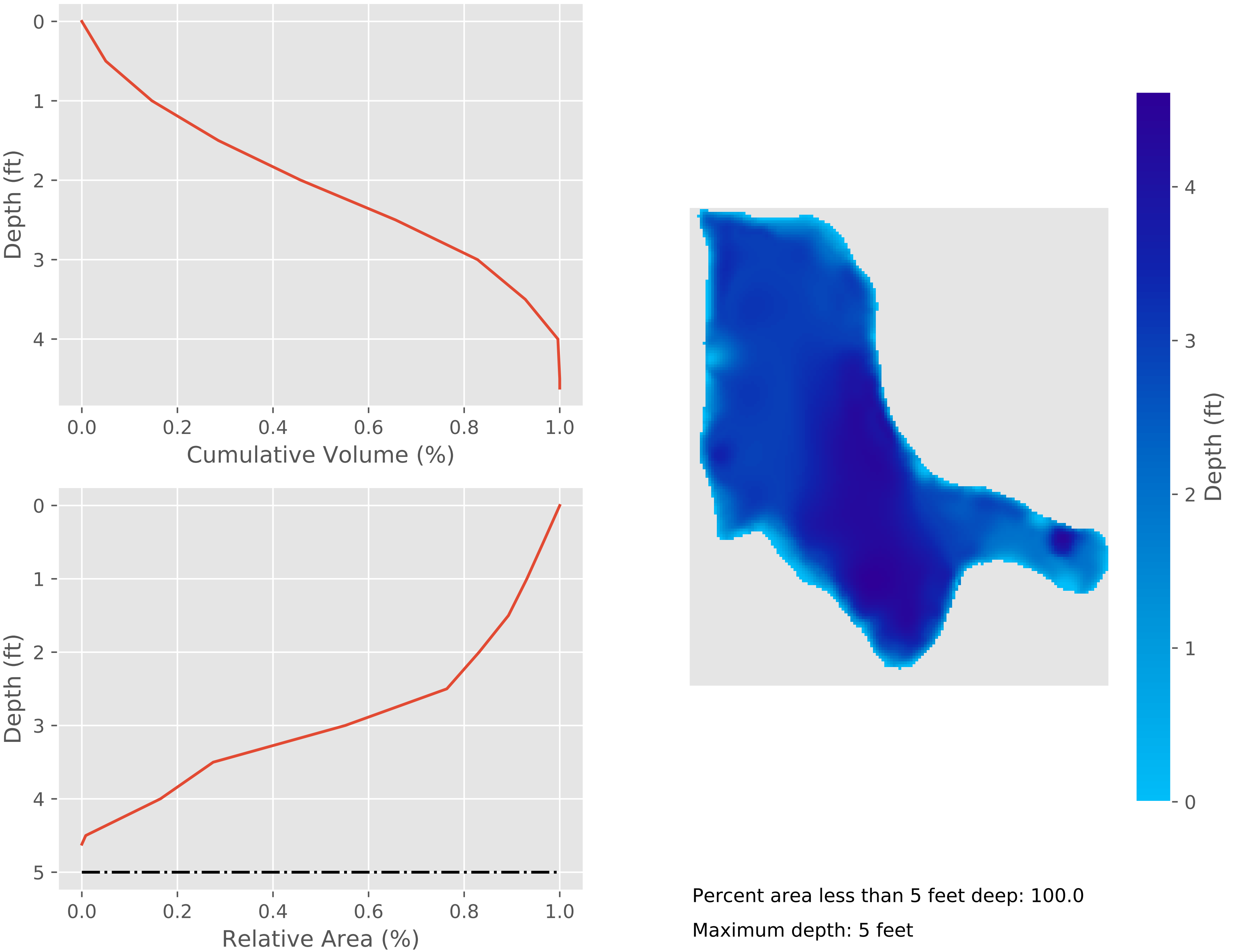


Percent area less than 5 feet deep: 40.8

Maximum depth: 8 feet

Mean depth: 4.9 feet

Lake Edina

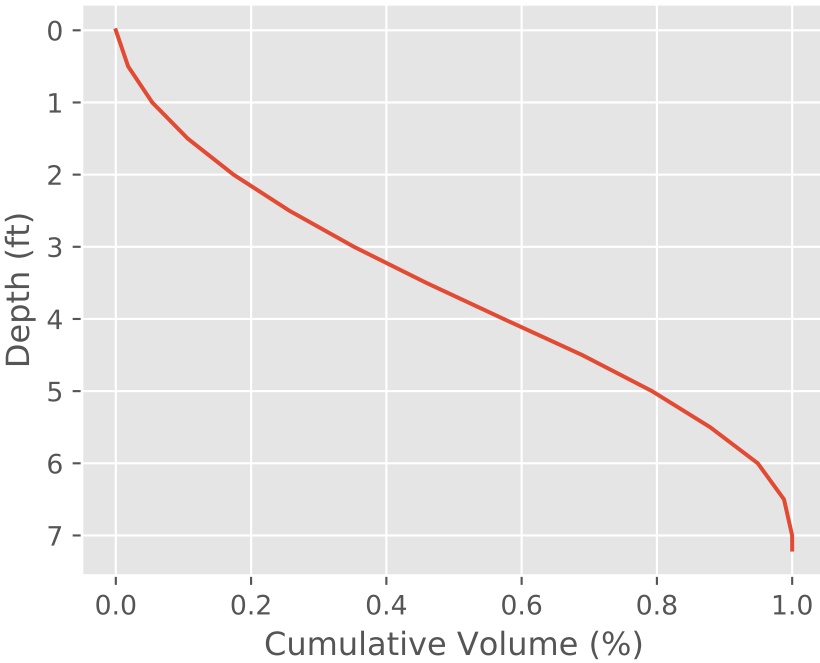


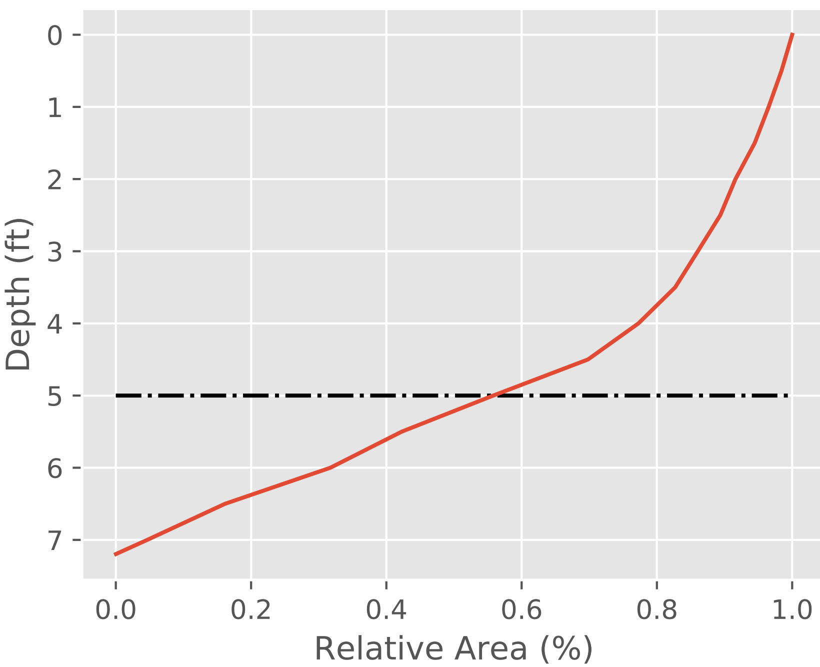
Percent area less than 5 feet deep: 100.0

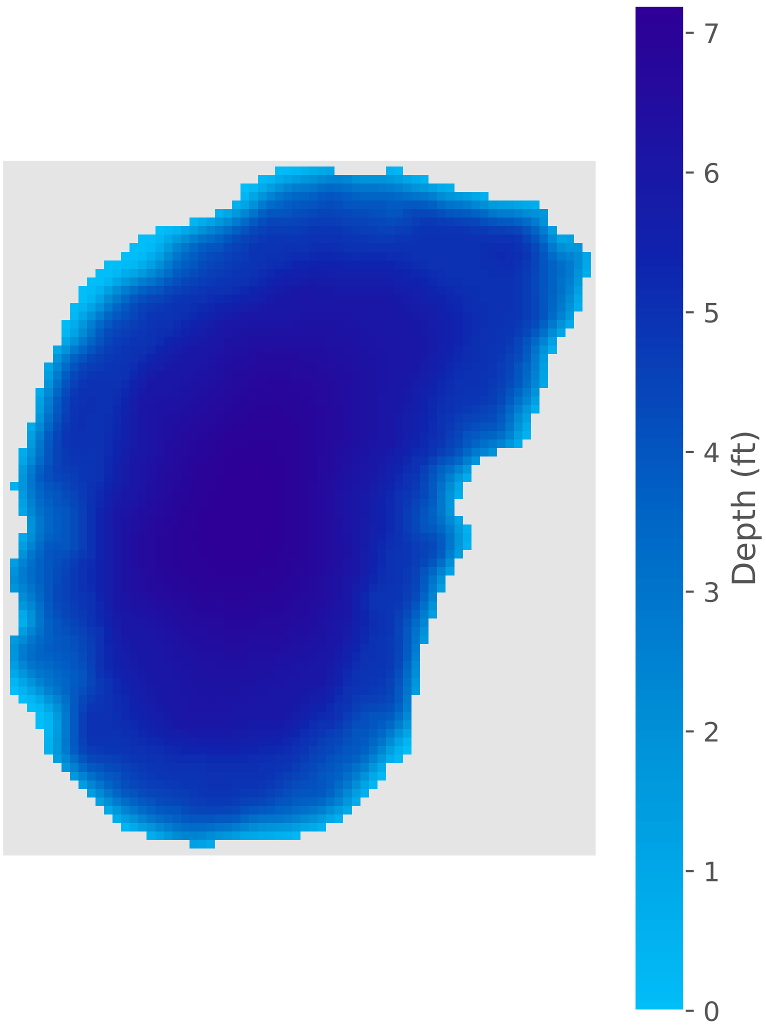
Maximum depth: 5 feet

Mean depth: 2.9 feet

Lake Holiday





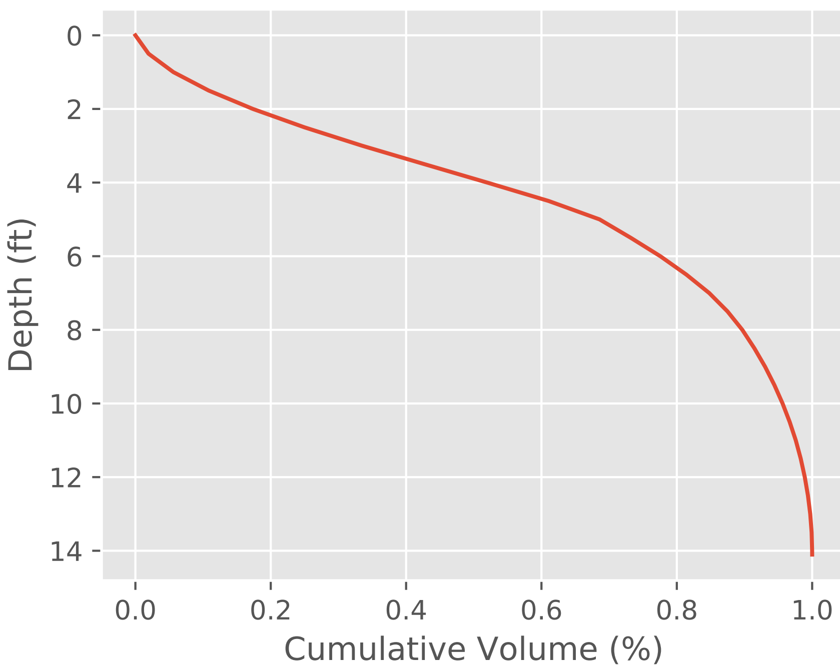


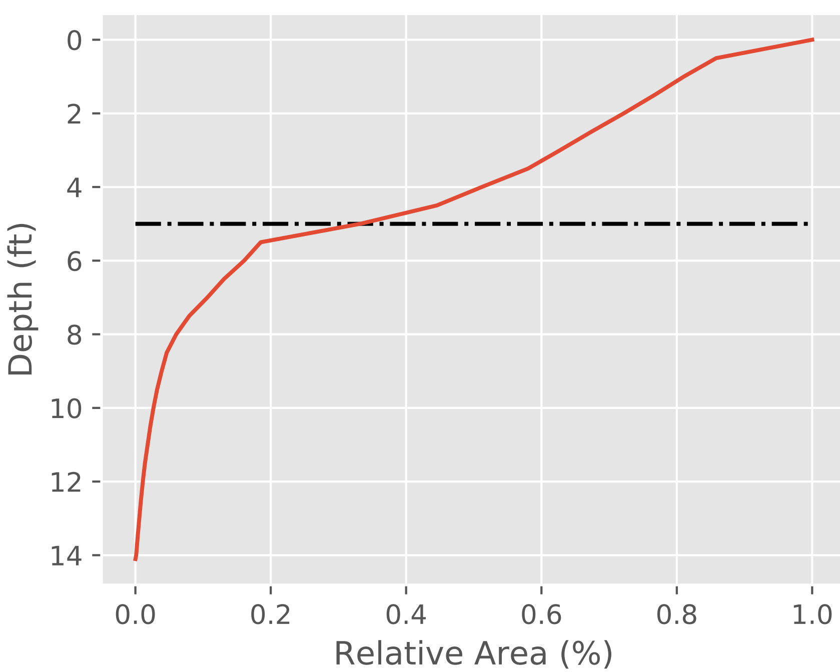
Percent area less than 5 feet deep: 44.2

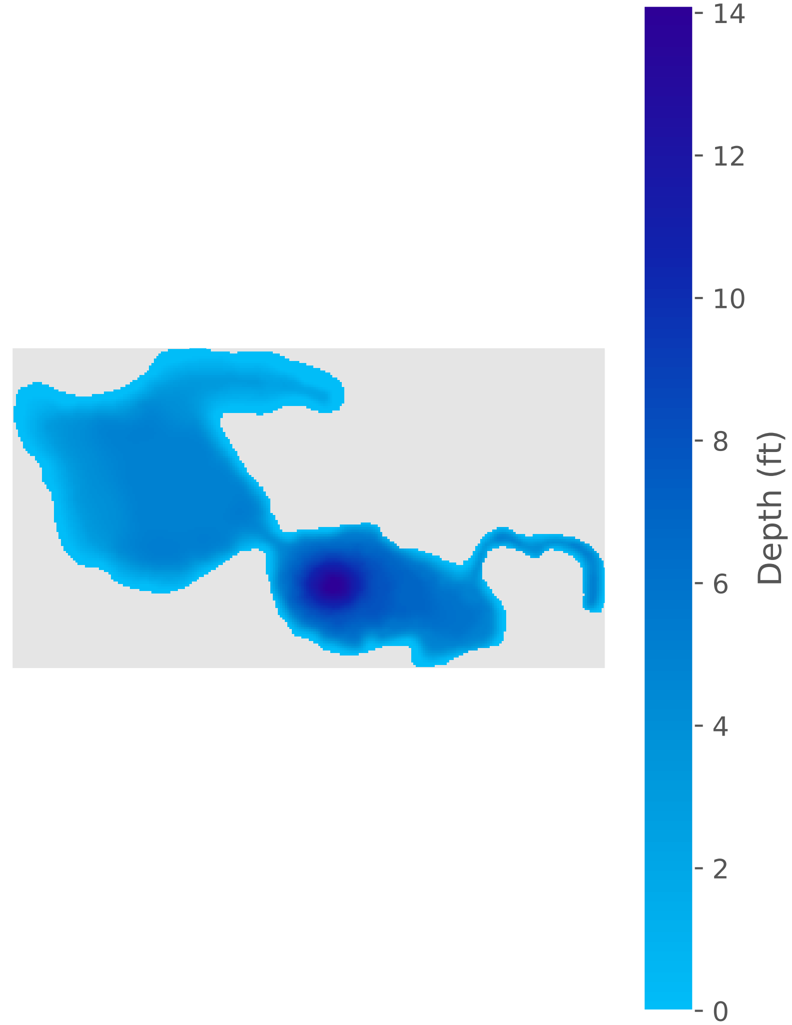
Maximum depth: 7 feet

Mean depth: 4.9 feet

Lake Rose





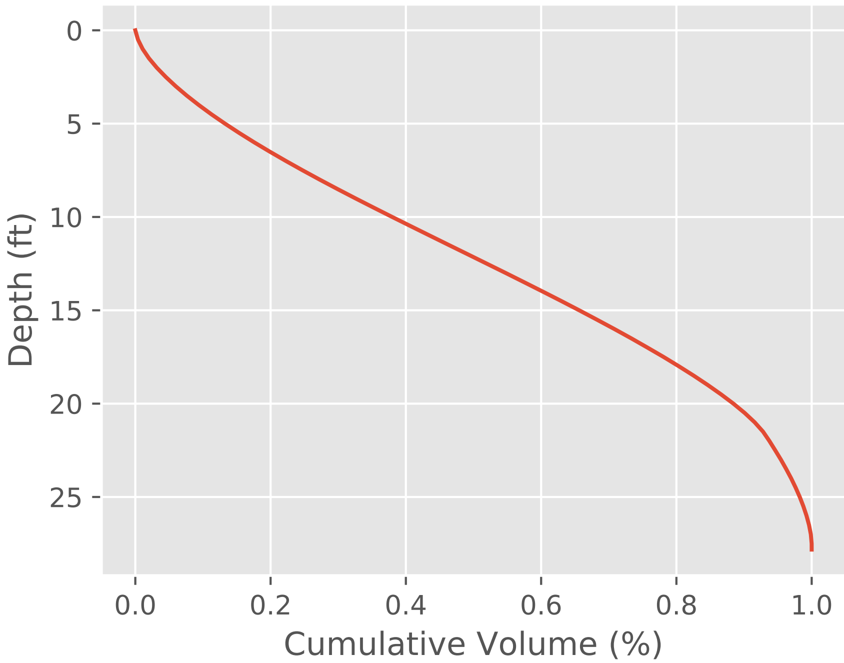


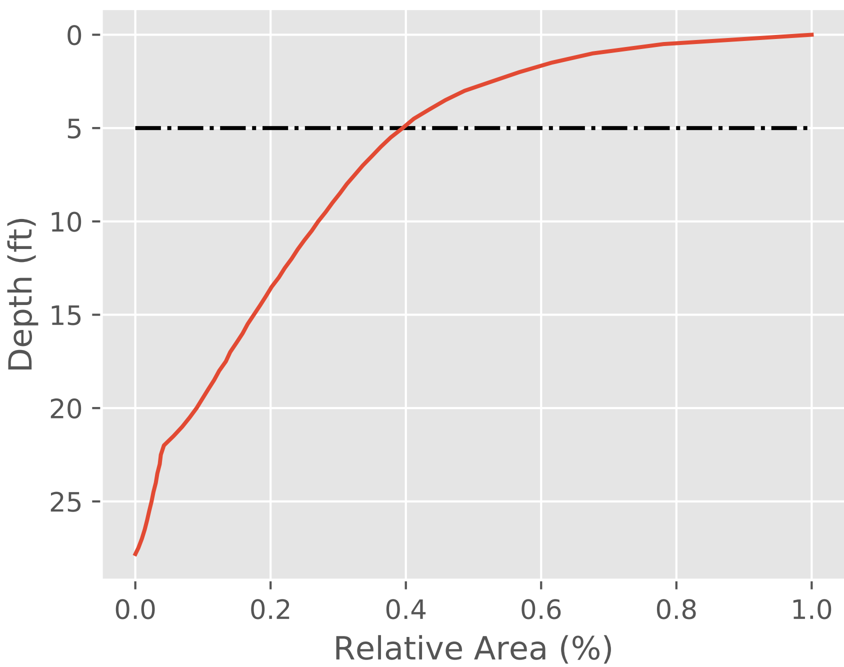
Percent area less than 5 feet deep: 66.8

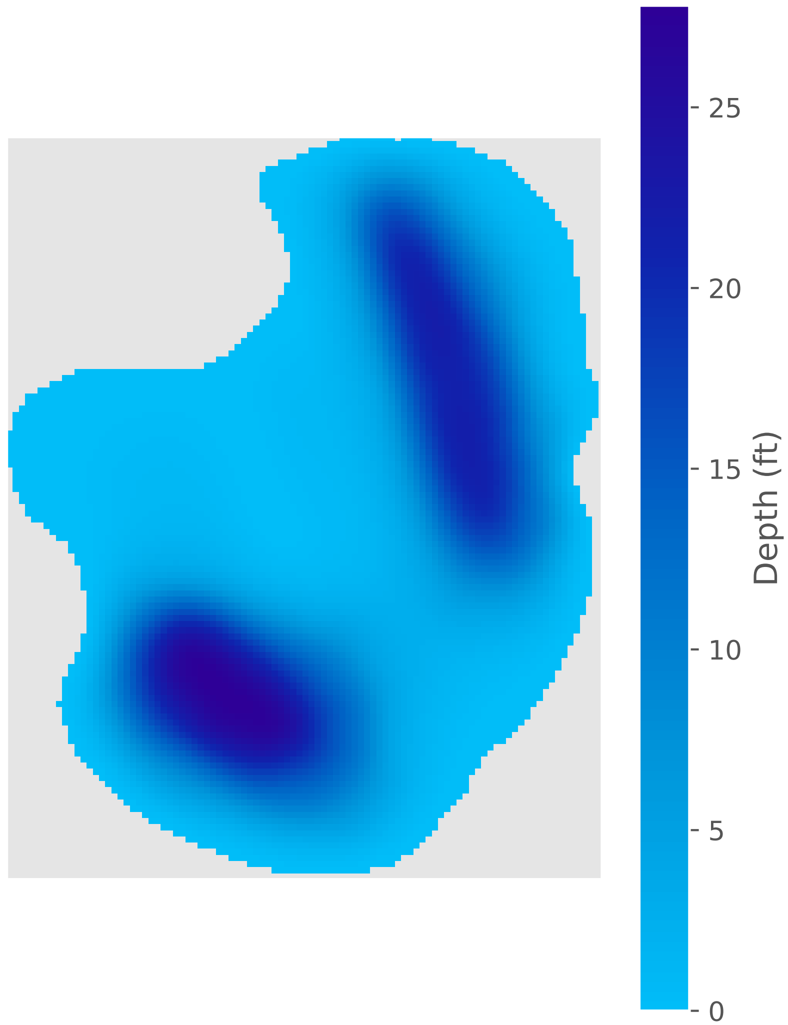
Maximum depth: 14 feet

Mean depth: 3.9 feet

Lone Lake





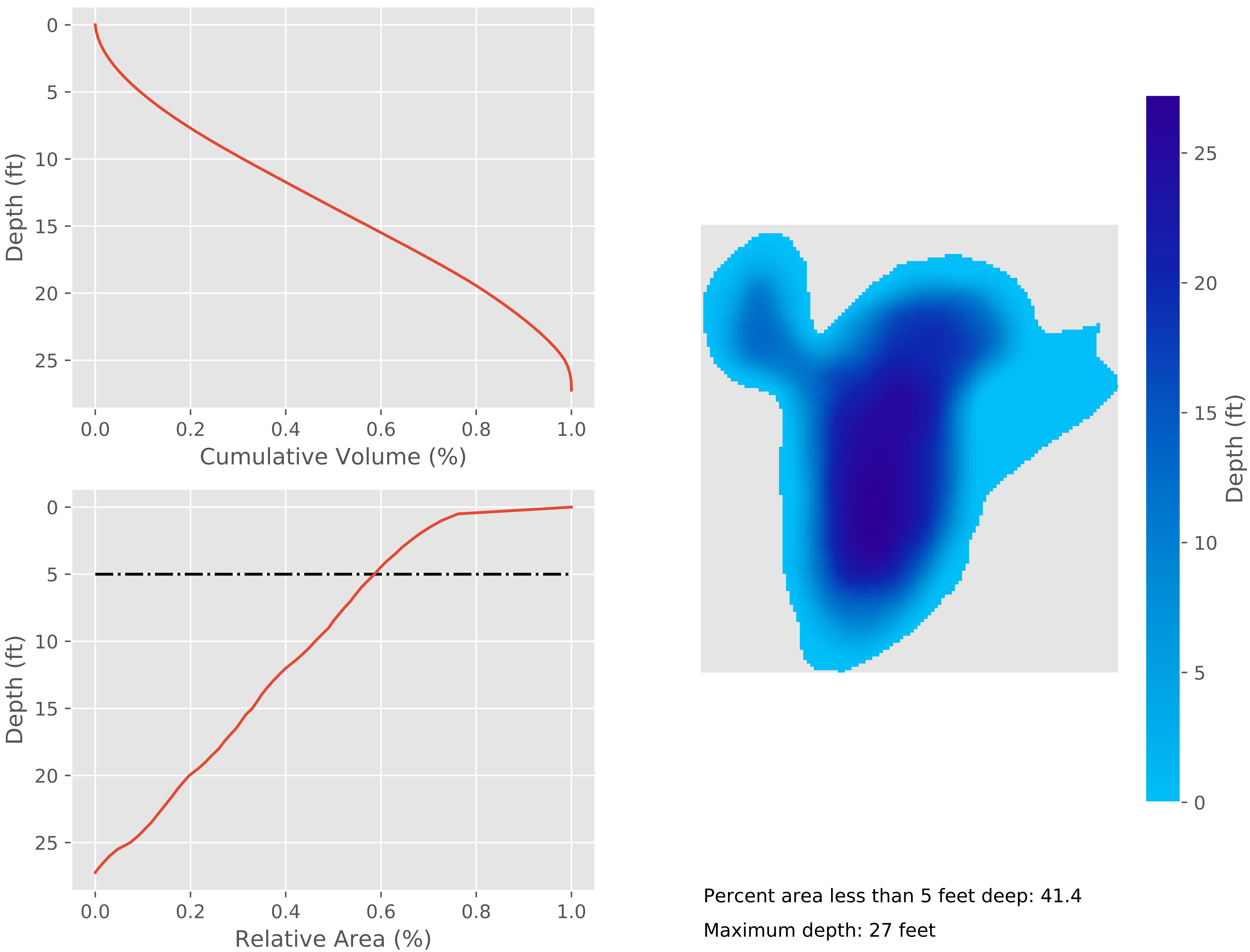


Percent area less than 5 feet deep: 60.5

Maximum depth: 28 feet

Mean depth: 6.5 feet

Minnetoga Lake

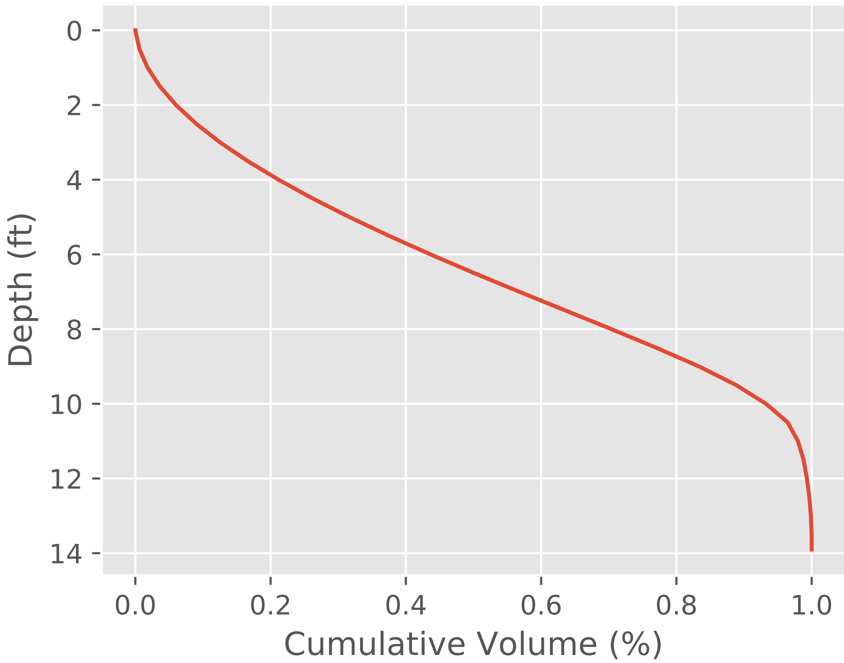


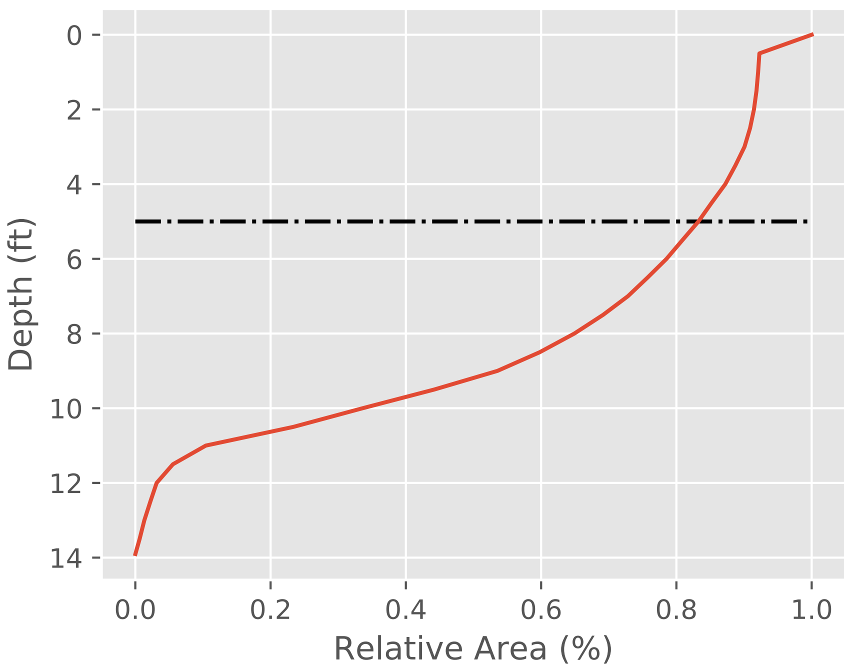
Percent area less than 5 feet deep: 41.4

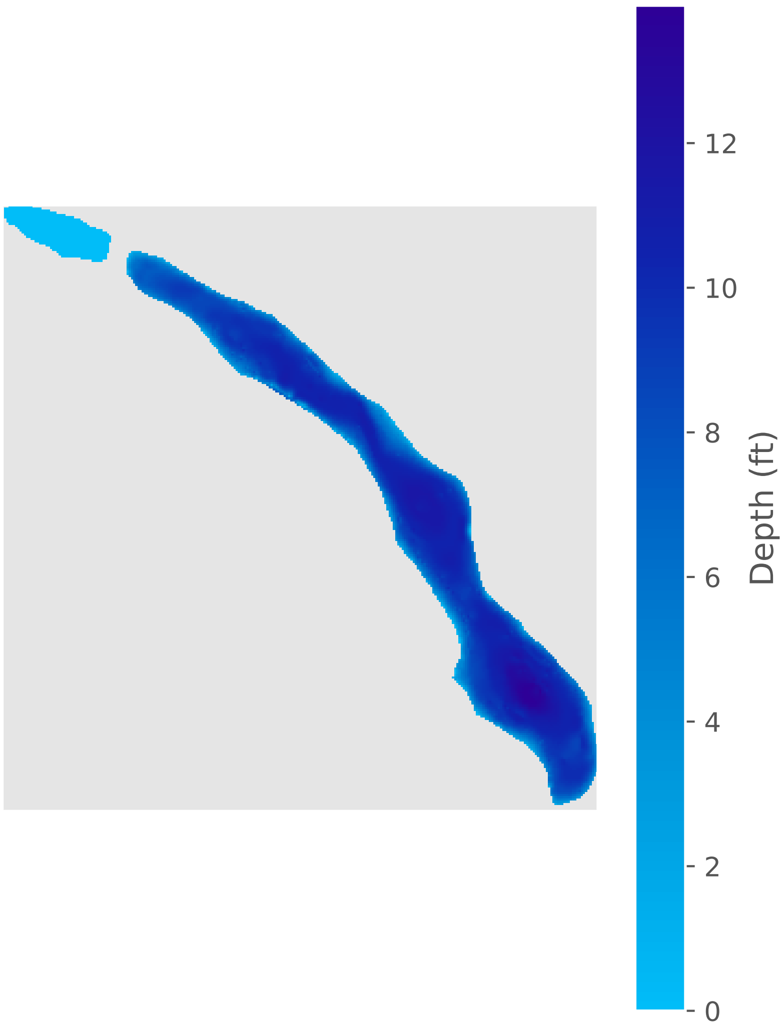
Maximum depth: 27 feet

Mean depth: 10.0 feet

Mirror Lake





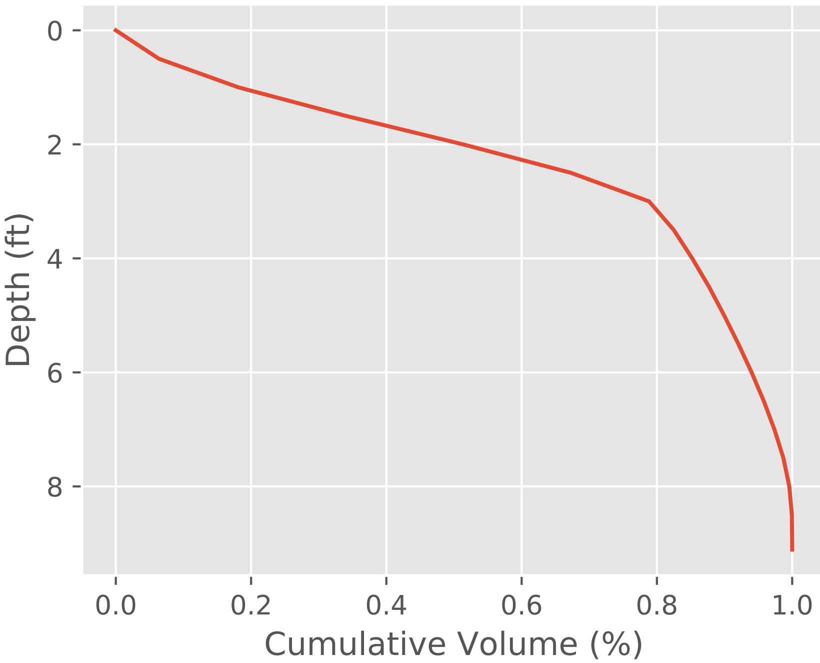


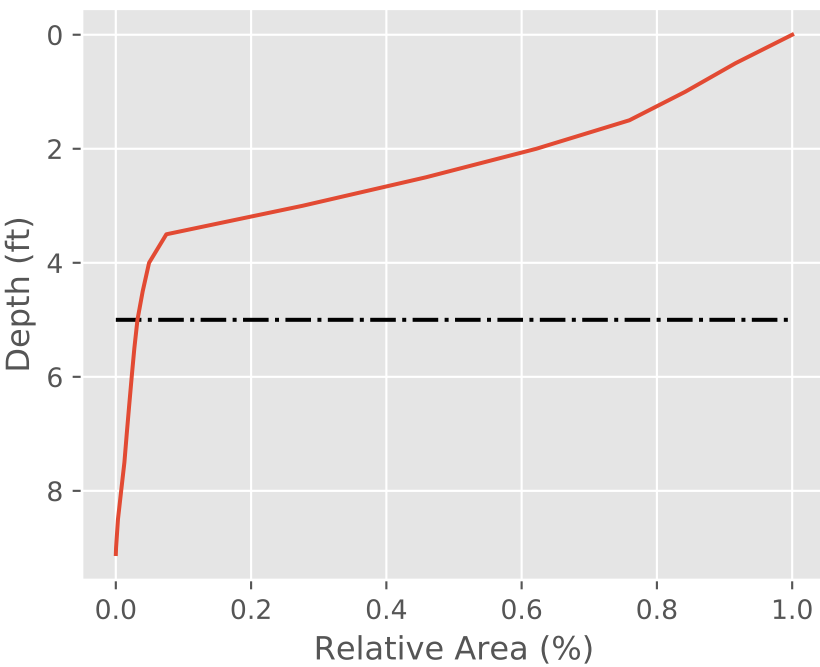
Percent area less than 5 feet deep: 16.7

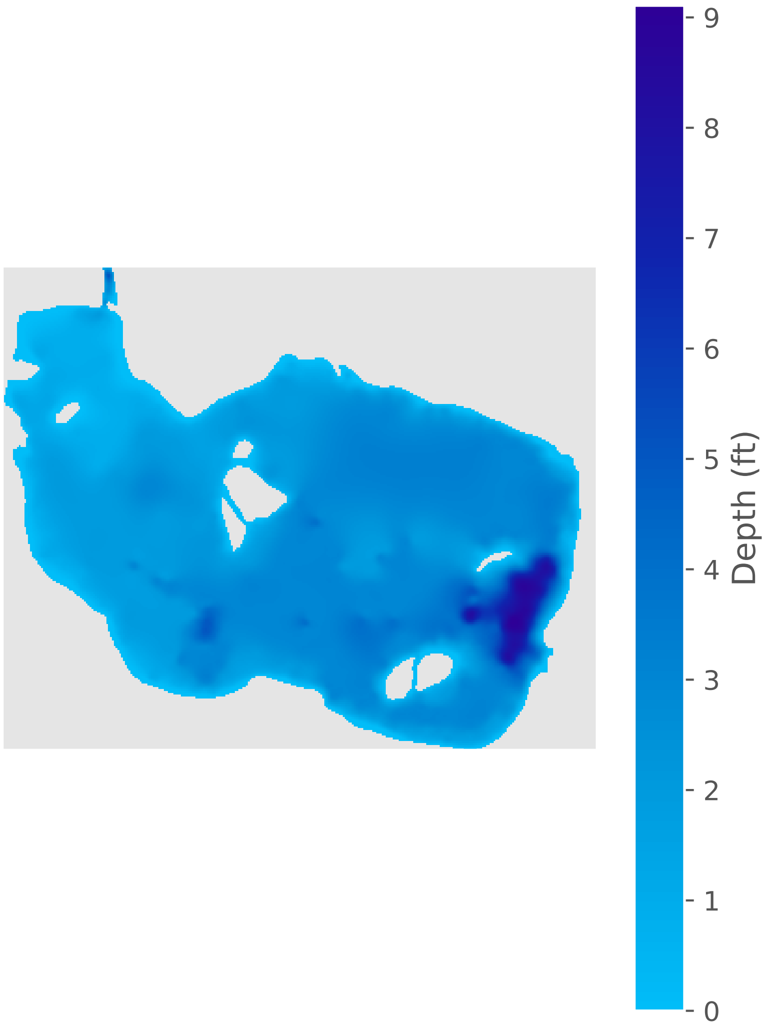
Maximum depth: 14 feet

Mean depth: 8.1 feet

Normandale Lake





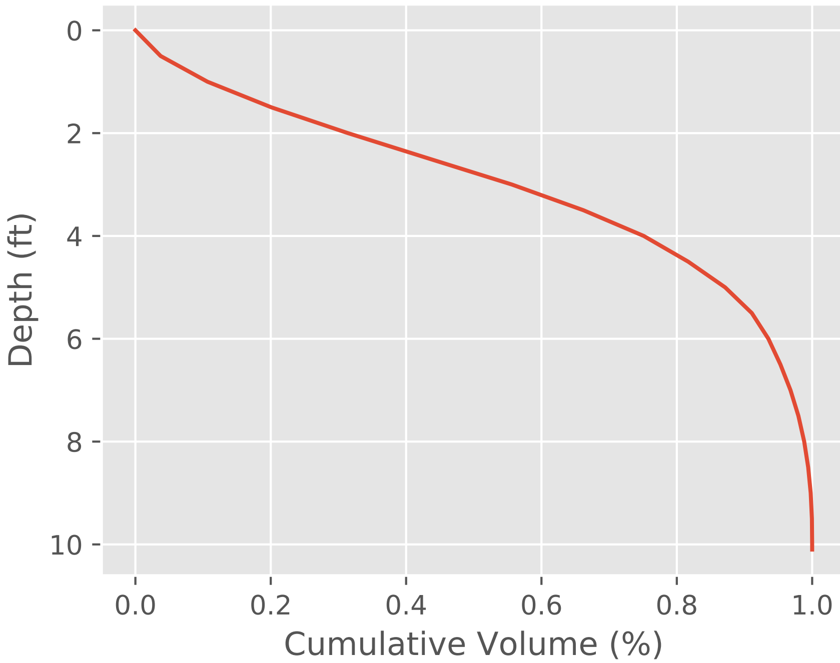


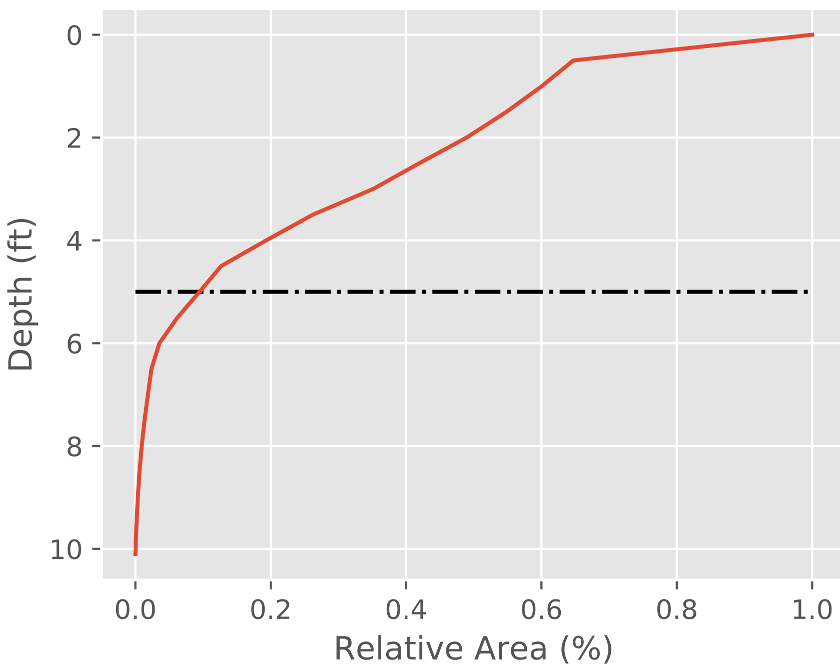
Percent area less than 5 feet deep: 96.8

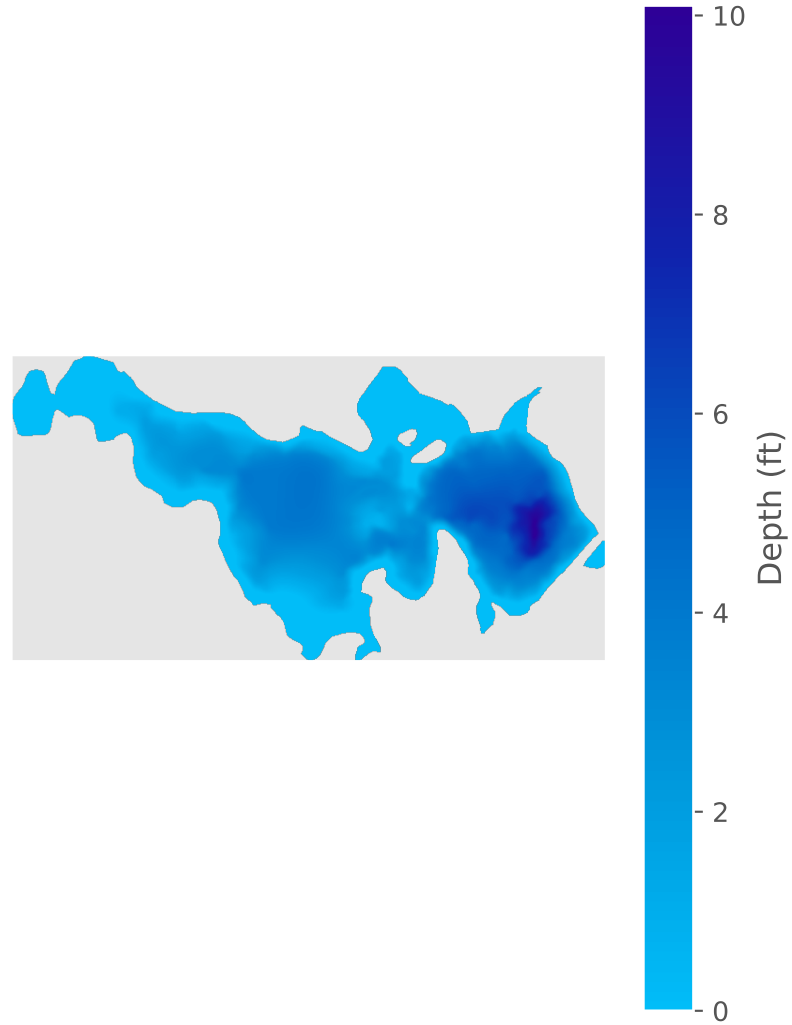
Maximum depth: 9 feet

Mean depth: 2.3 feet

North Anderson Lake





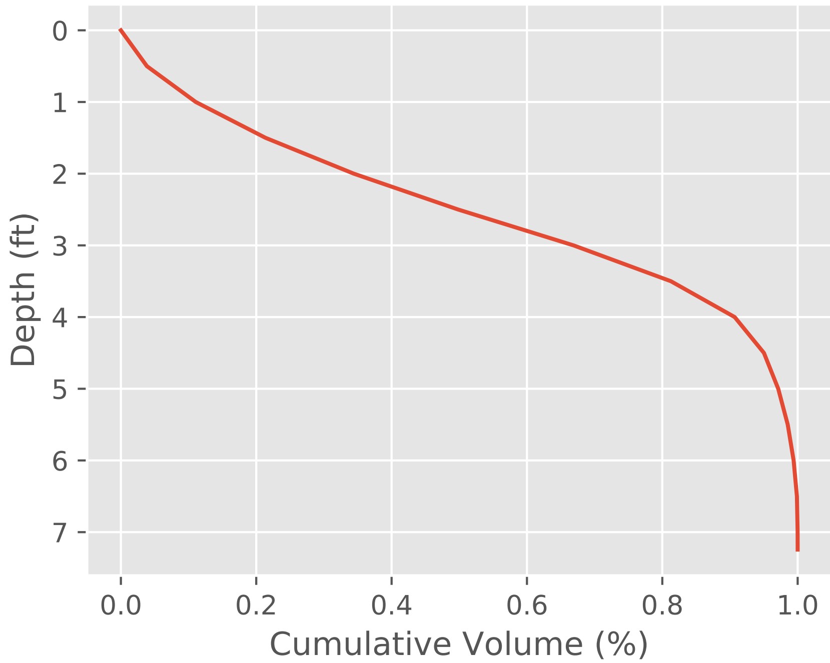


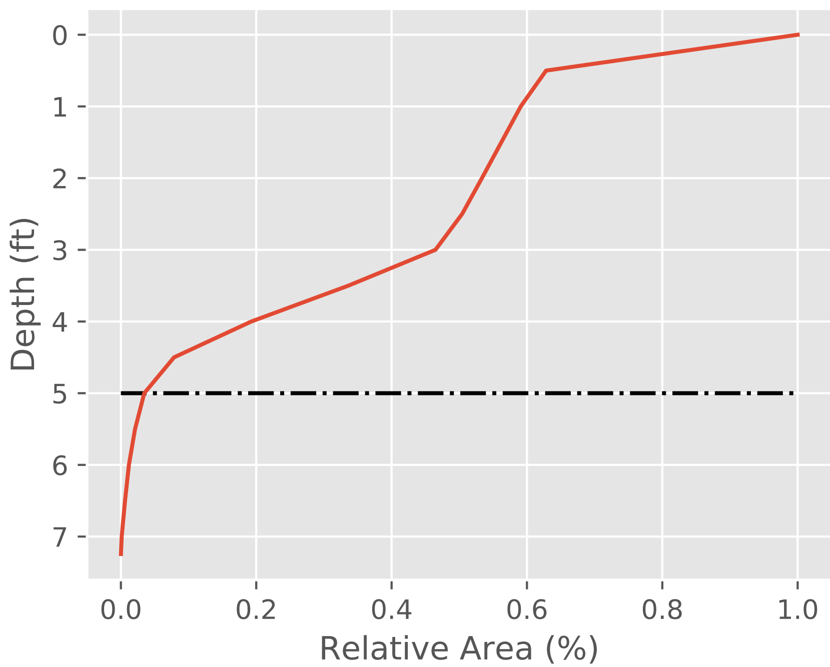
Percent area less than 5 feet deep: 90.5

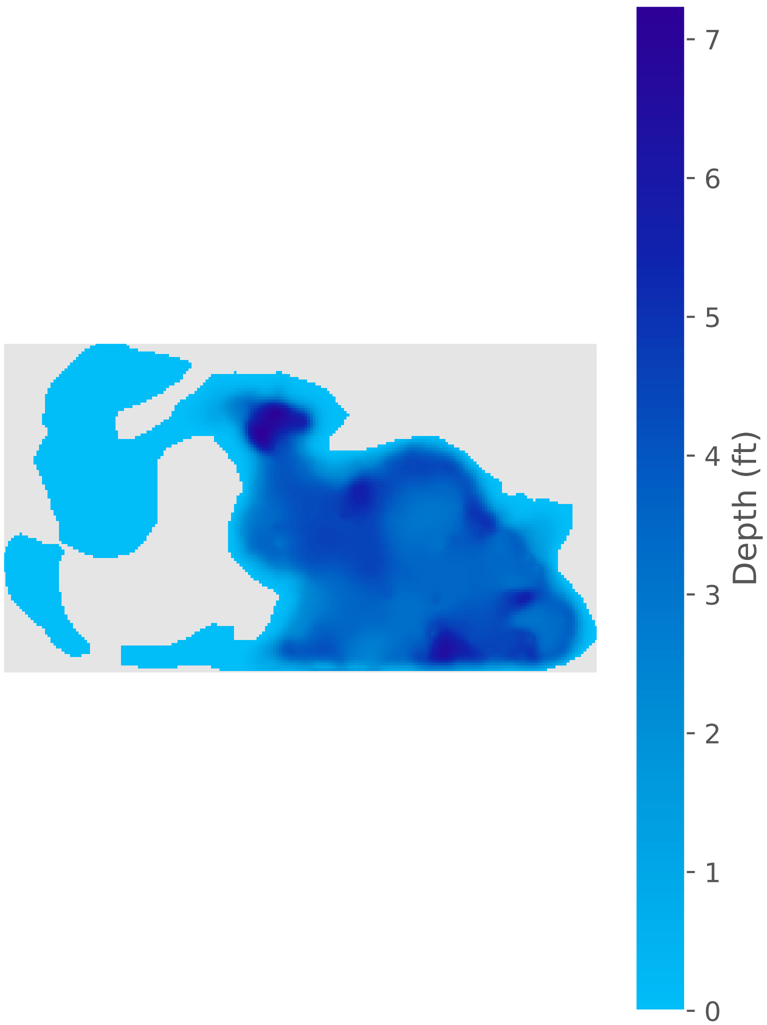
Maximum depth: 10 feet

Mean depth: 2.1 feet

North Lake Cornelia





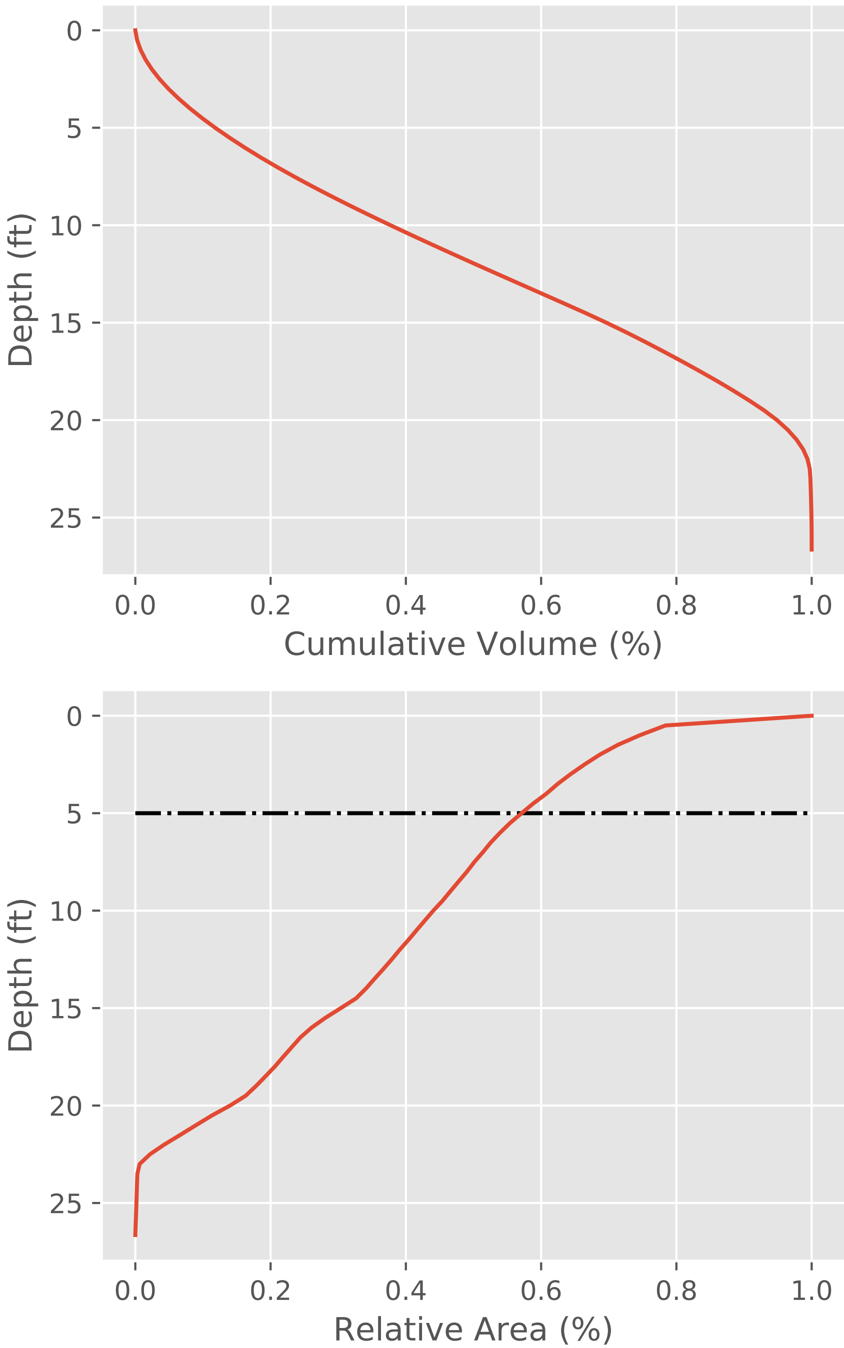


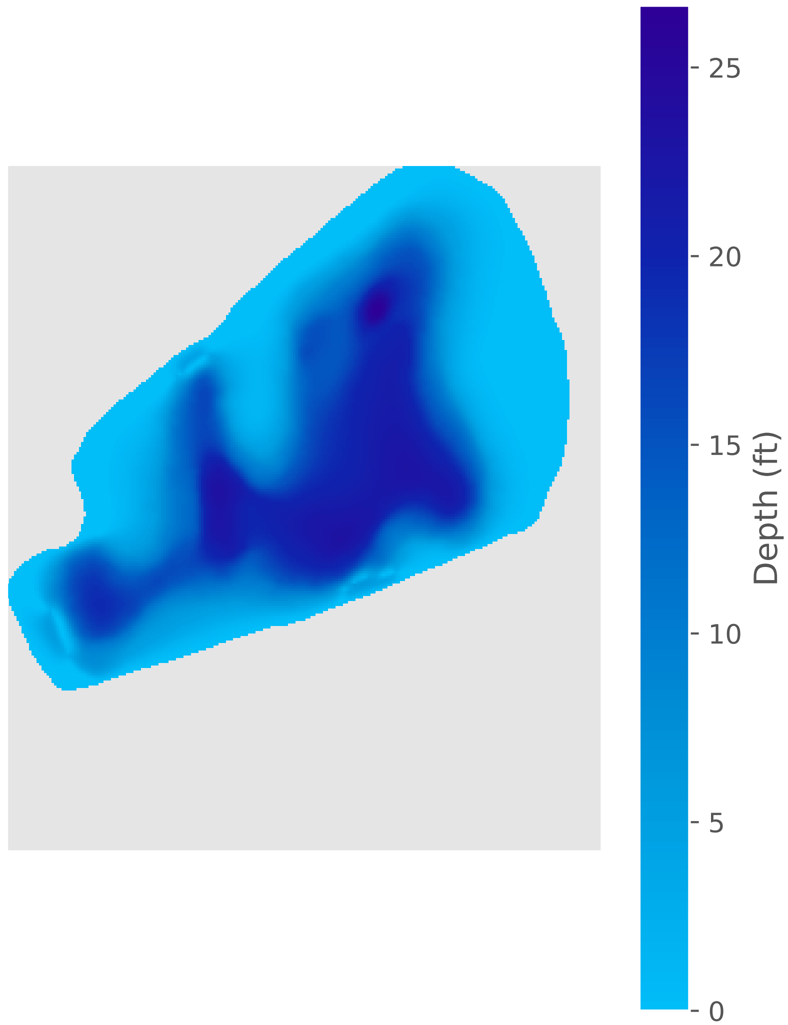
Percent area less than 5 feet deep: 96.5

Maximum depth: 7 feet

Mean depth: 2.2 feet

North Shady Oak Lake



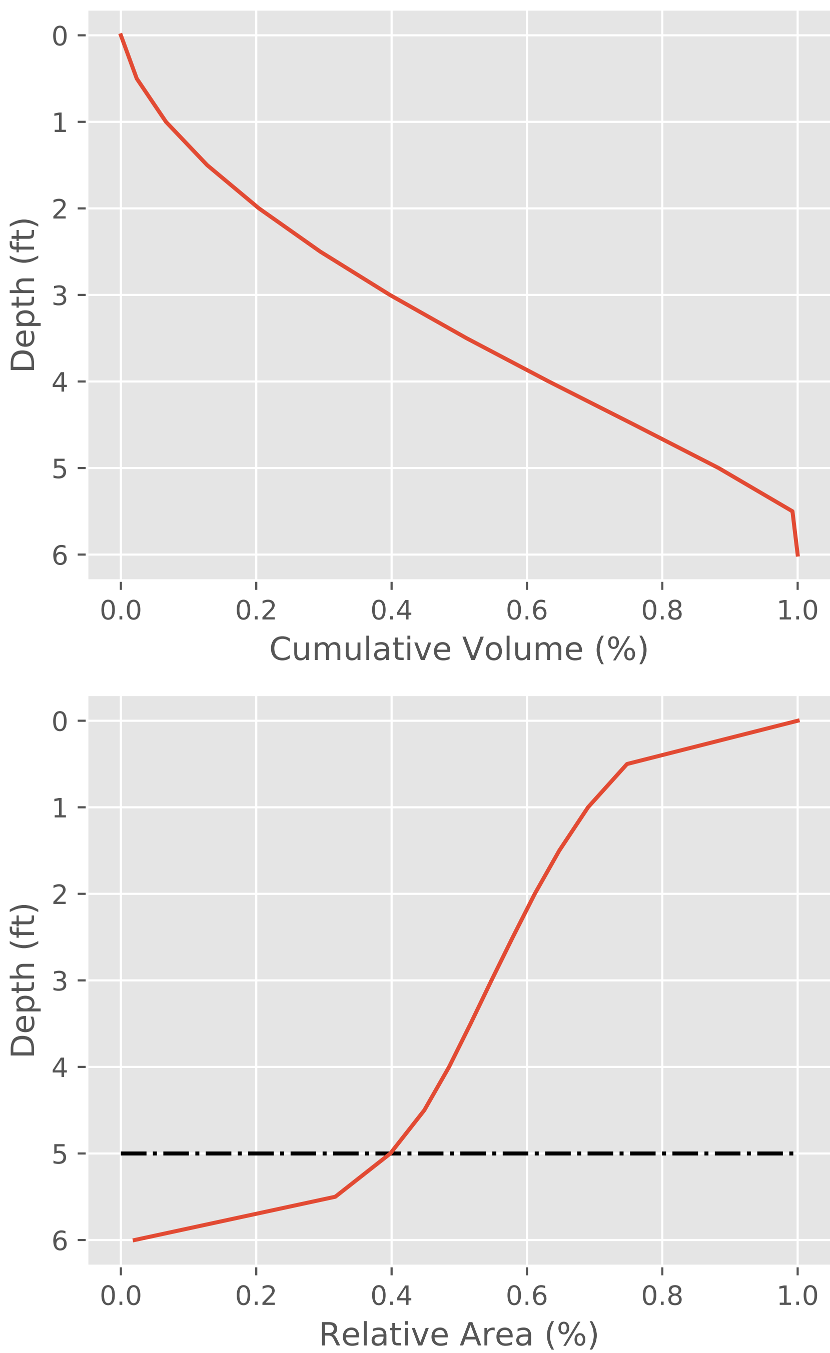


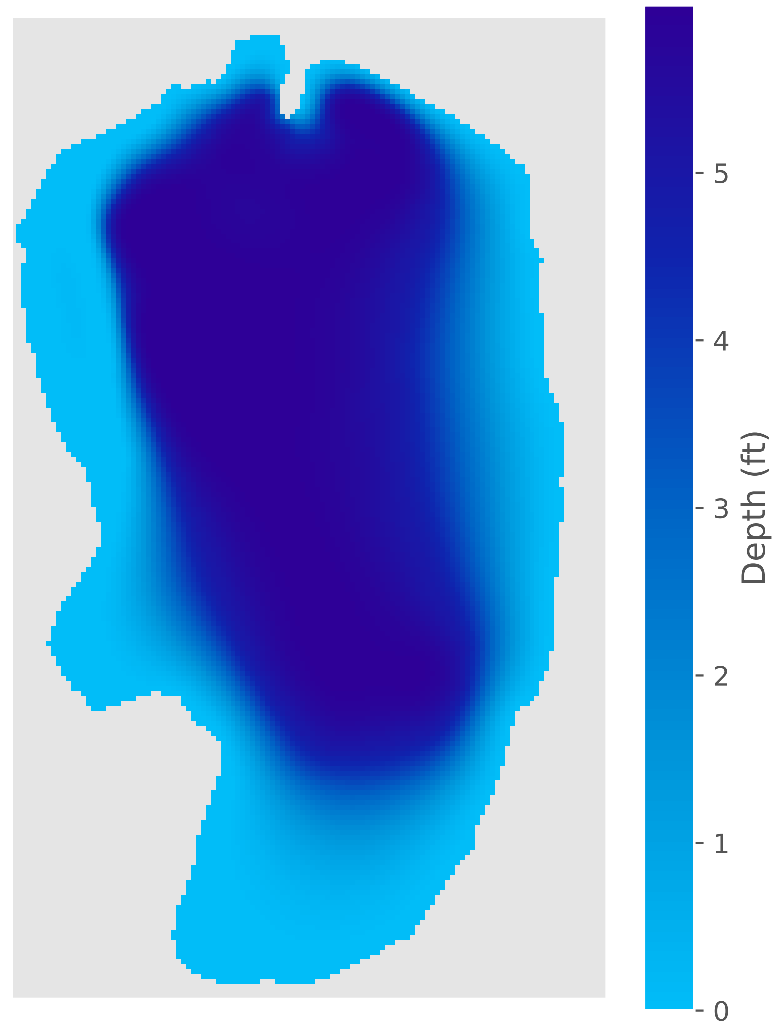
Percent area less than 5 feet deep: 42.9

Maximum depth: 27 feet

Mean depth: 9.1 feet

Penn Lake



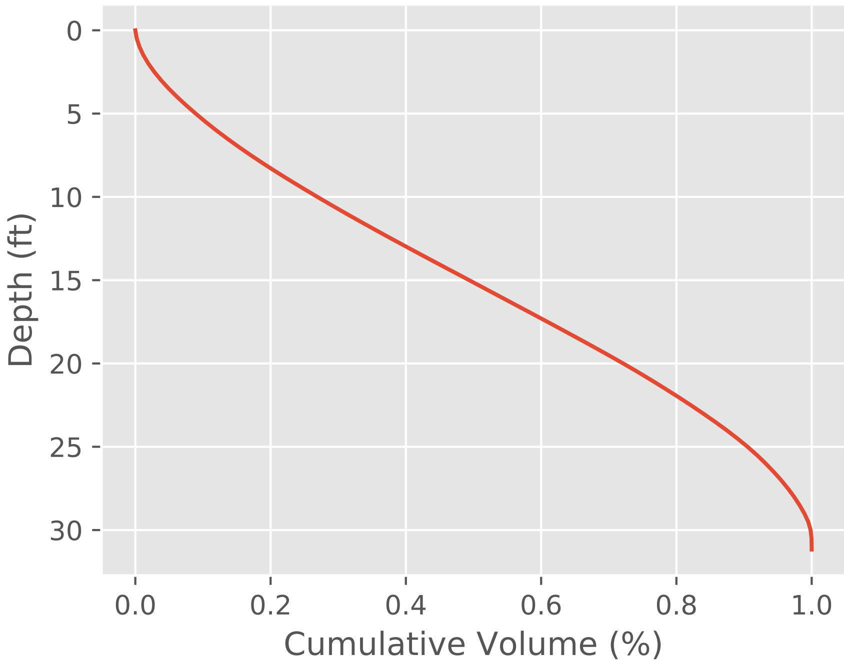


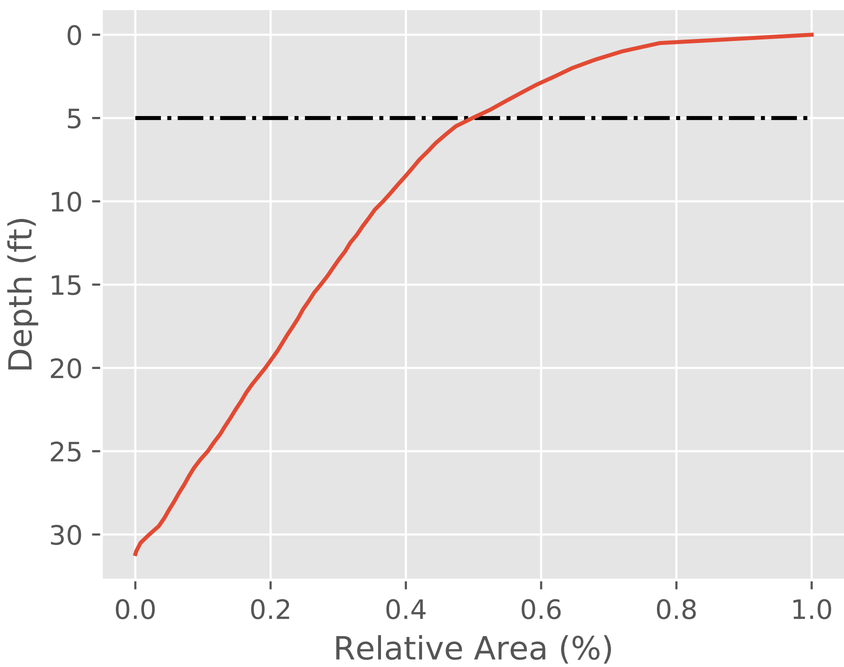
Percent area less than 5 feet deep: 60.2

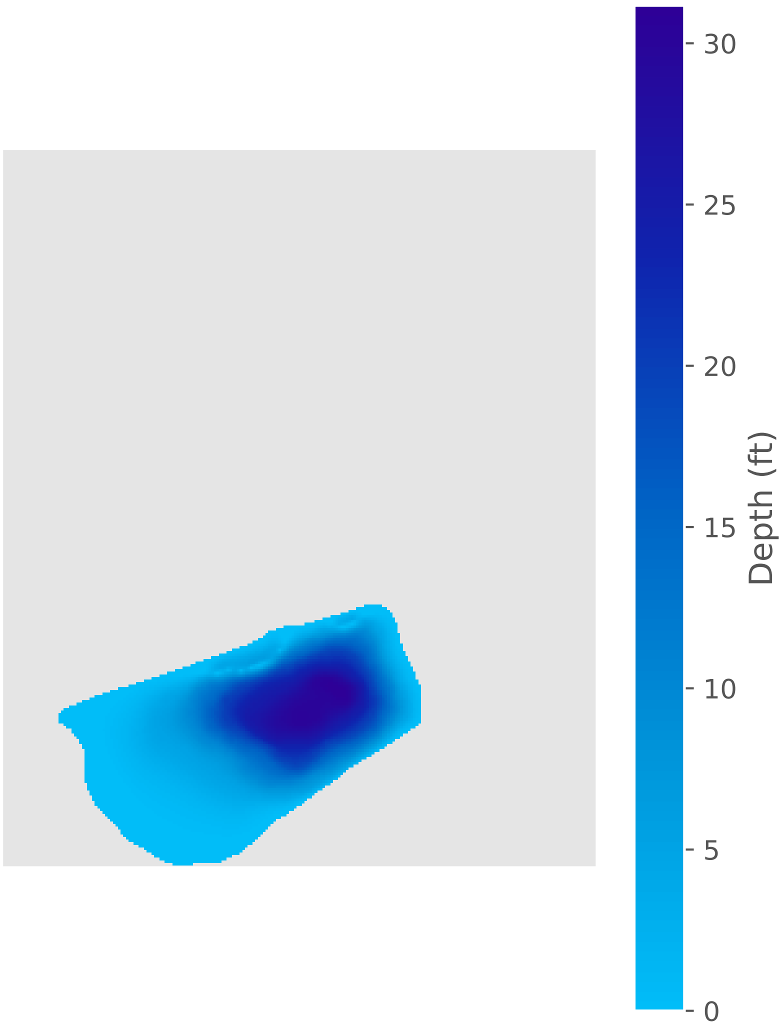
Maximum depth: 6 feet

Mean depth: 3.2 feet

Shady Oak Lake





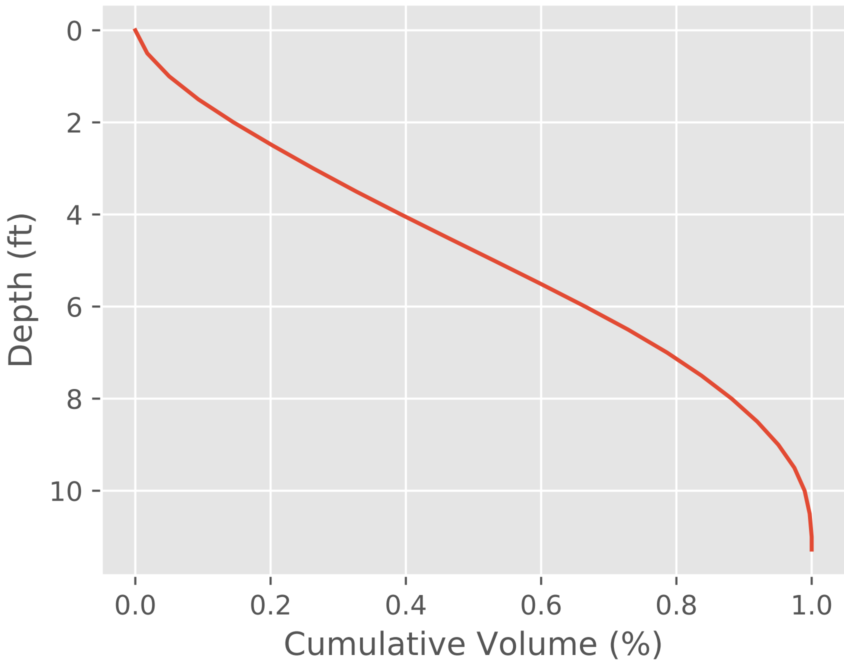


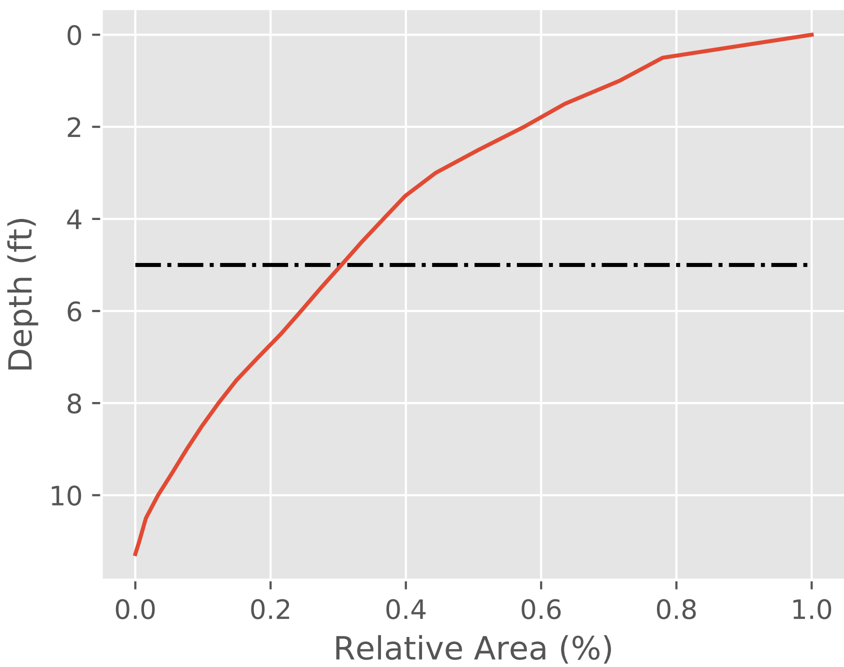
Percent area less than 5 feet deep: 50.2

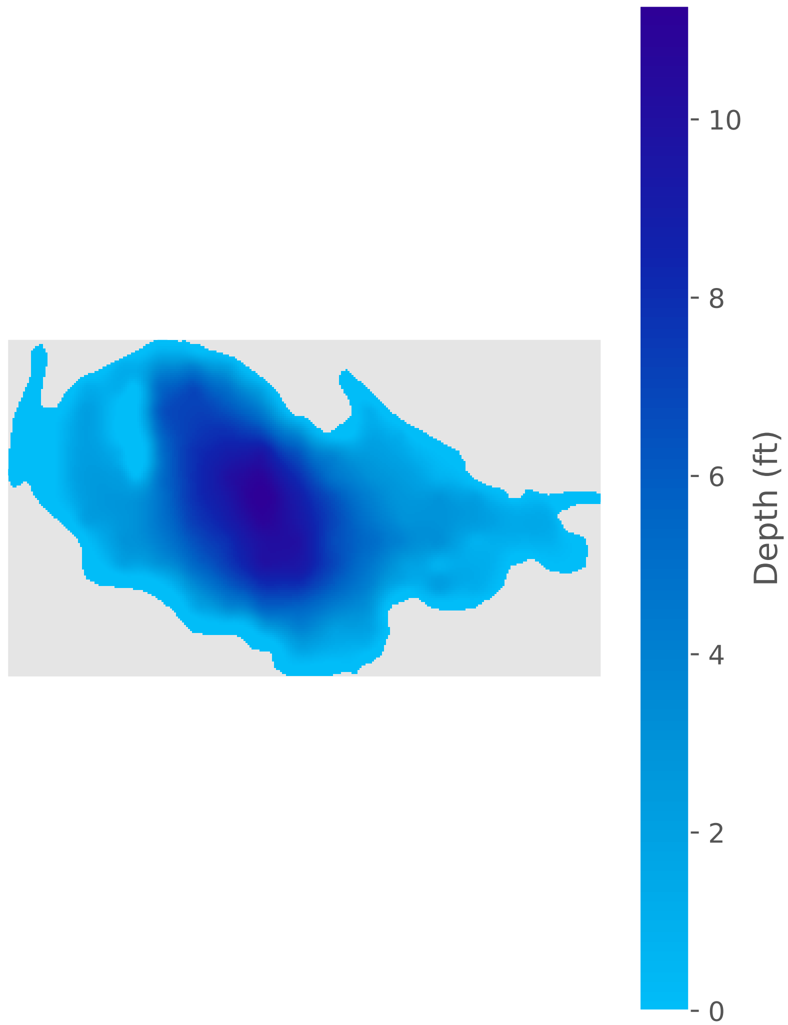
Maximum depth: 31 feet

Mean depth: 9.1 feet

Smetana Lake





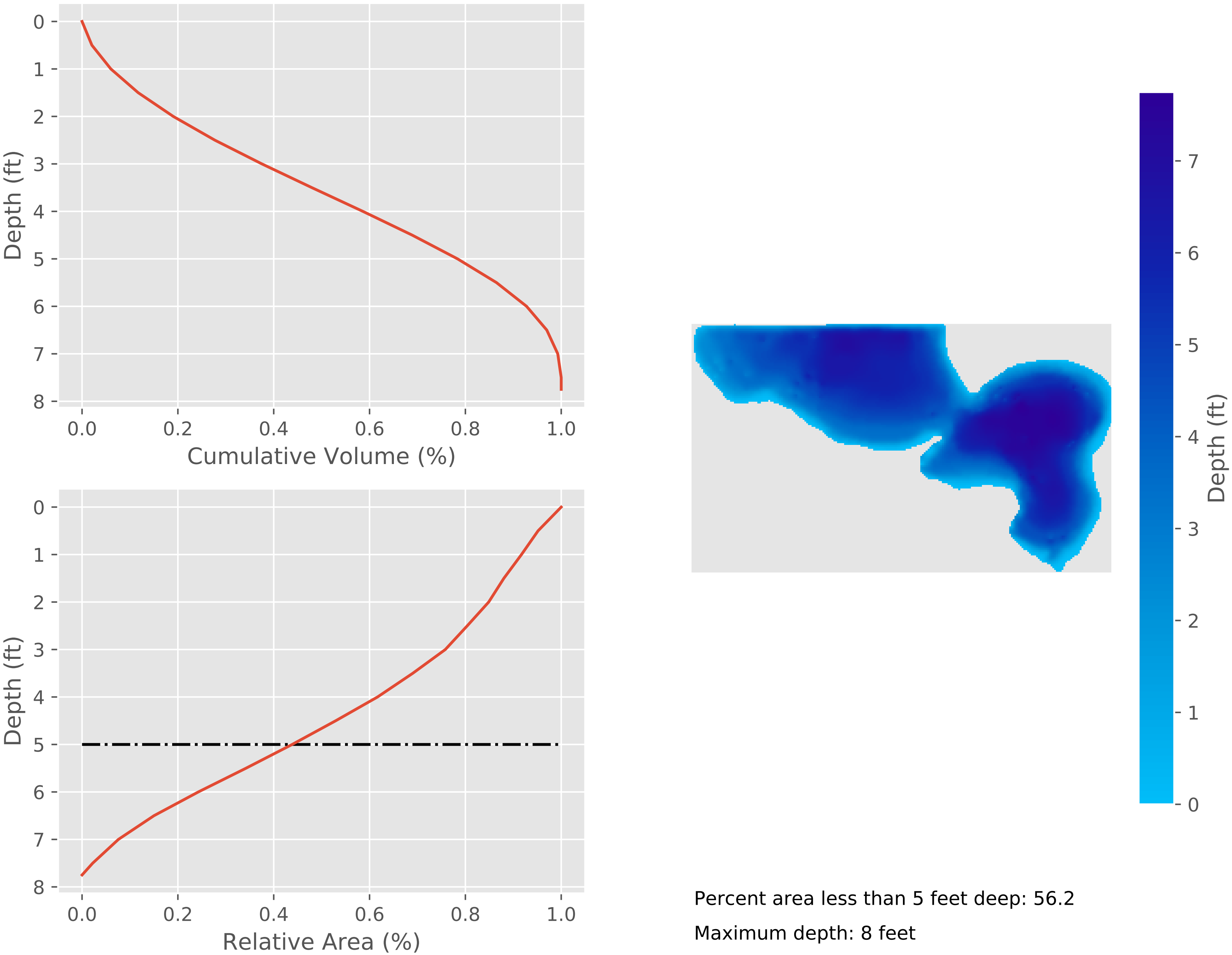


Percent area less than 5 feet deep: 69.5

Maximum depth: 11 feet

Mean depth: 3.5 feet

South Lake Cornelia

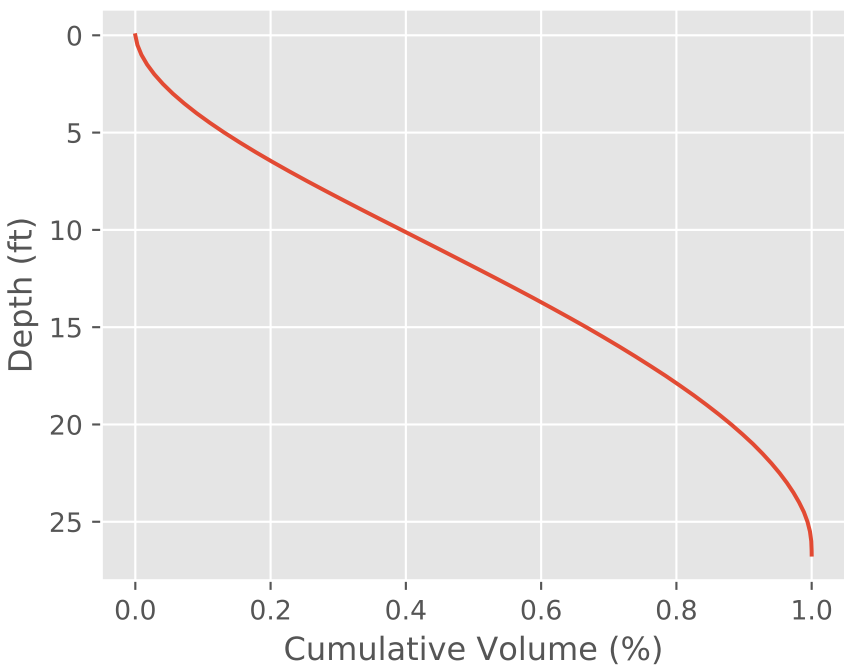


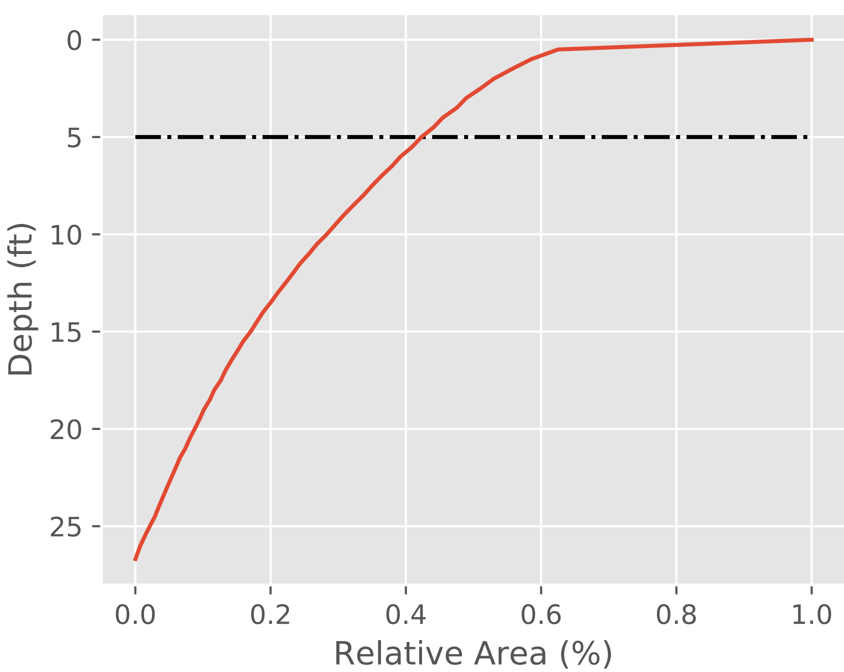
Percent area less than 5 feet deep: 56.2

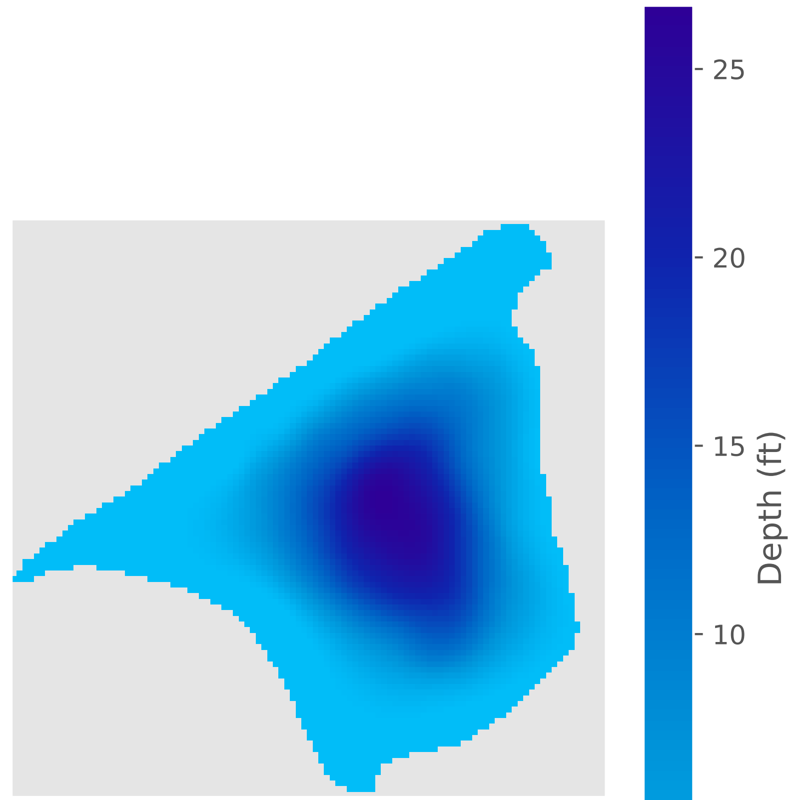
Maximum depth: 8 feet

Mean depth: 4.4 feet

South Shady Oak Lake





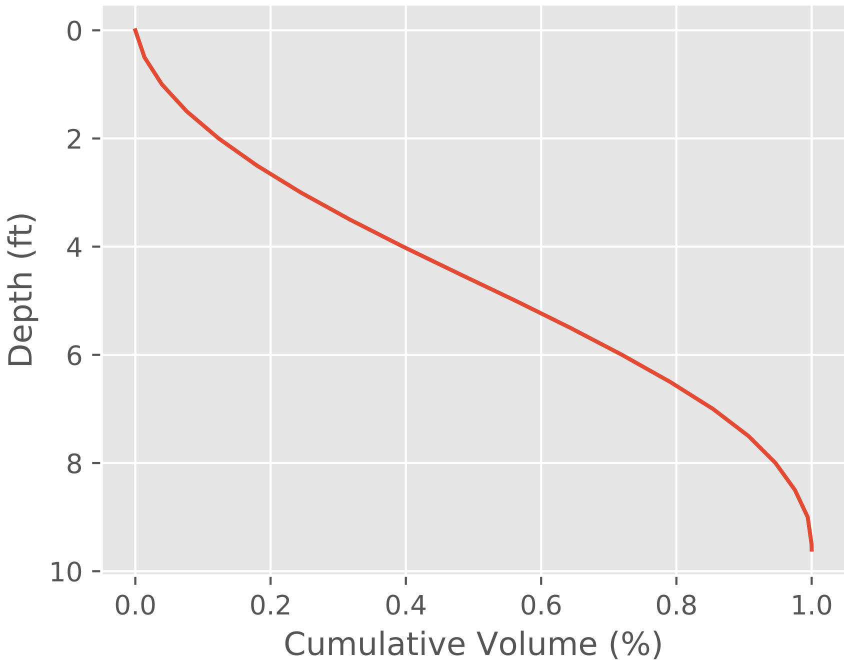


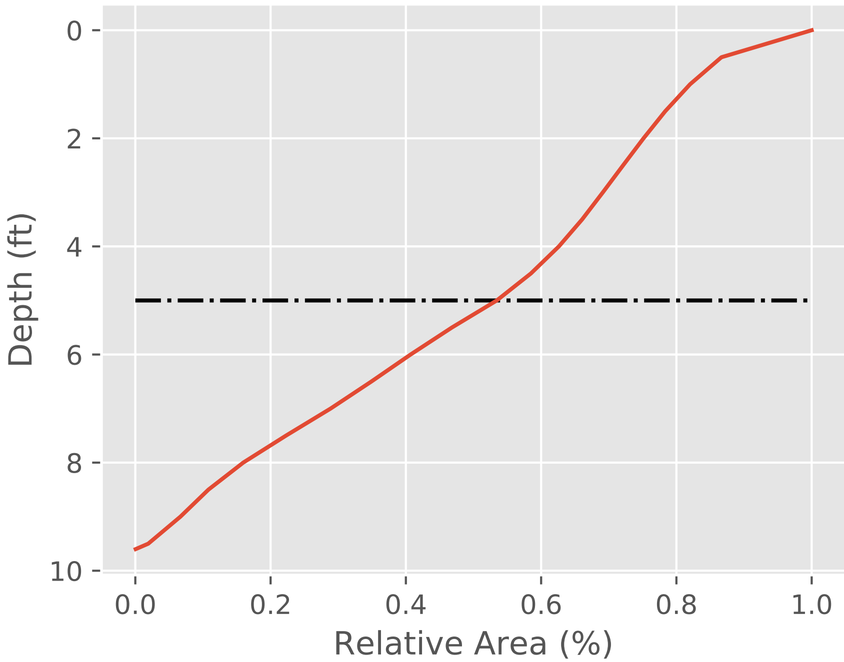
Percent area less than 5 feet deep: 57.7

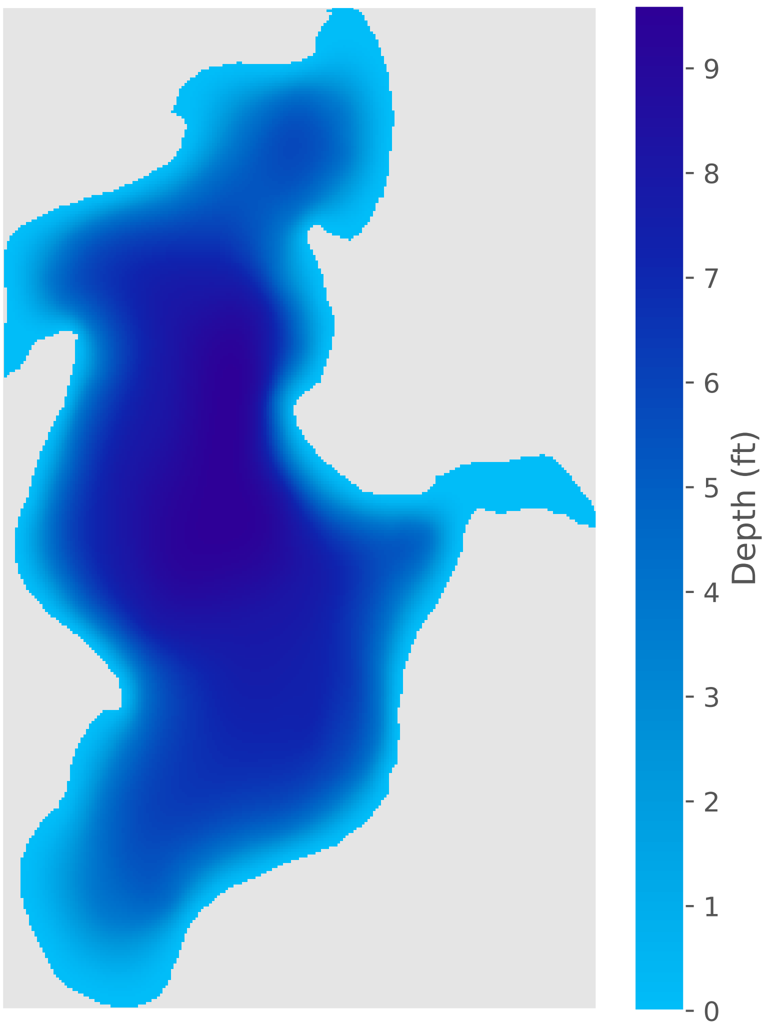
Maximum depth: 27 feet

Mean depth: 6.4 feet

Southeast Anderson Lake





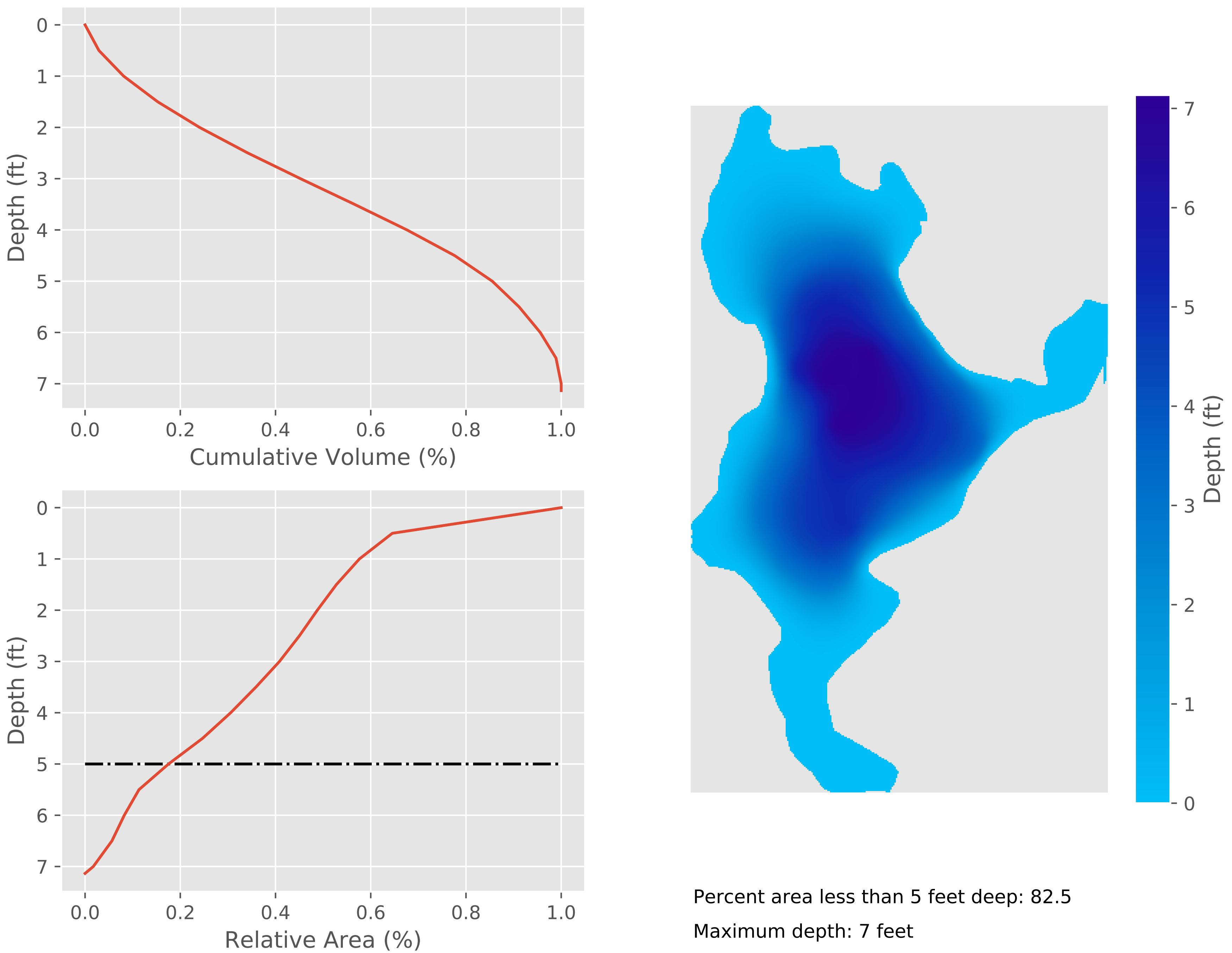


Percent area less than 5 feet deep: 46.6

Maximum depth: 10 feet

Mean depth: 4.8 feet

Southwest Anderson Lake

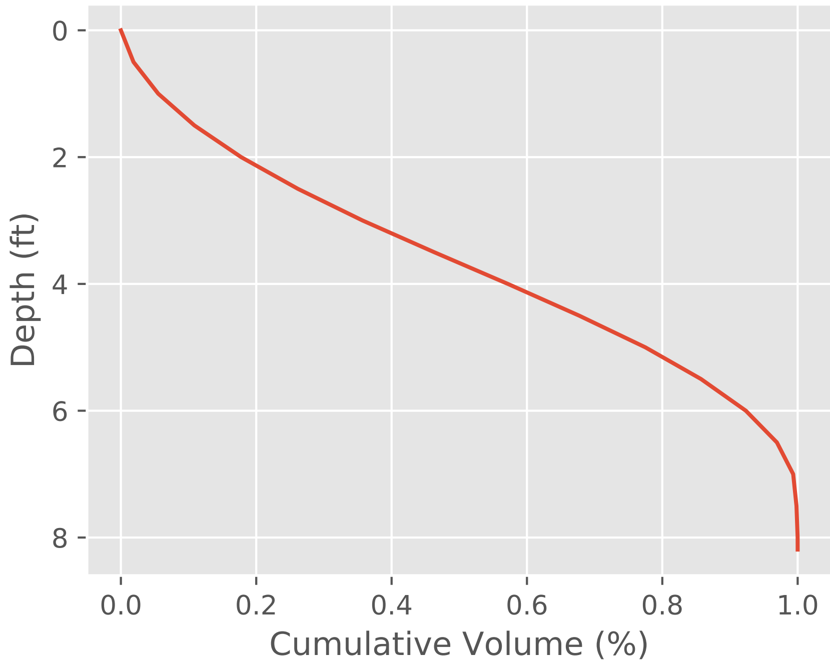


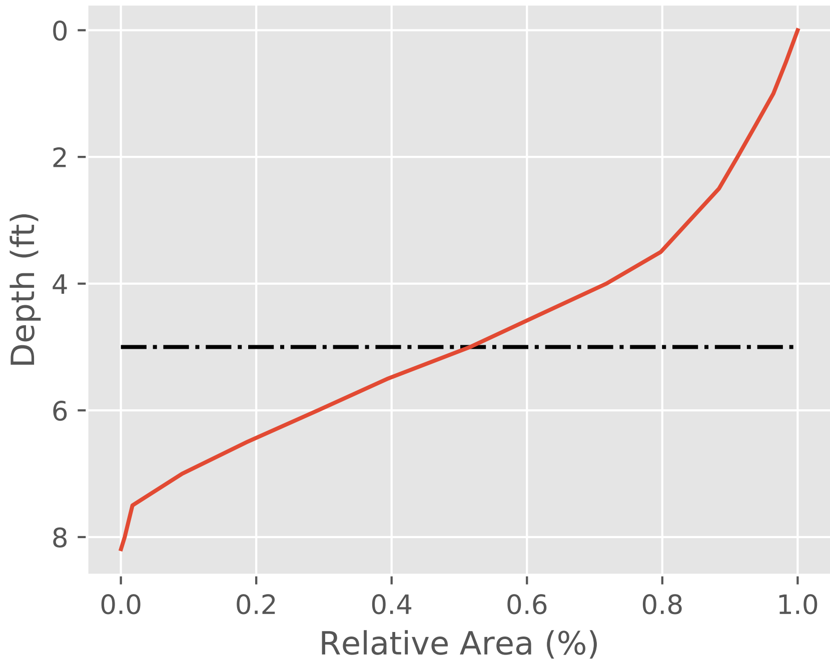
Percent area less than 5 feet deep: 82.5

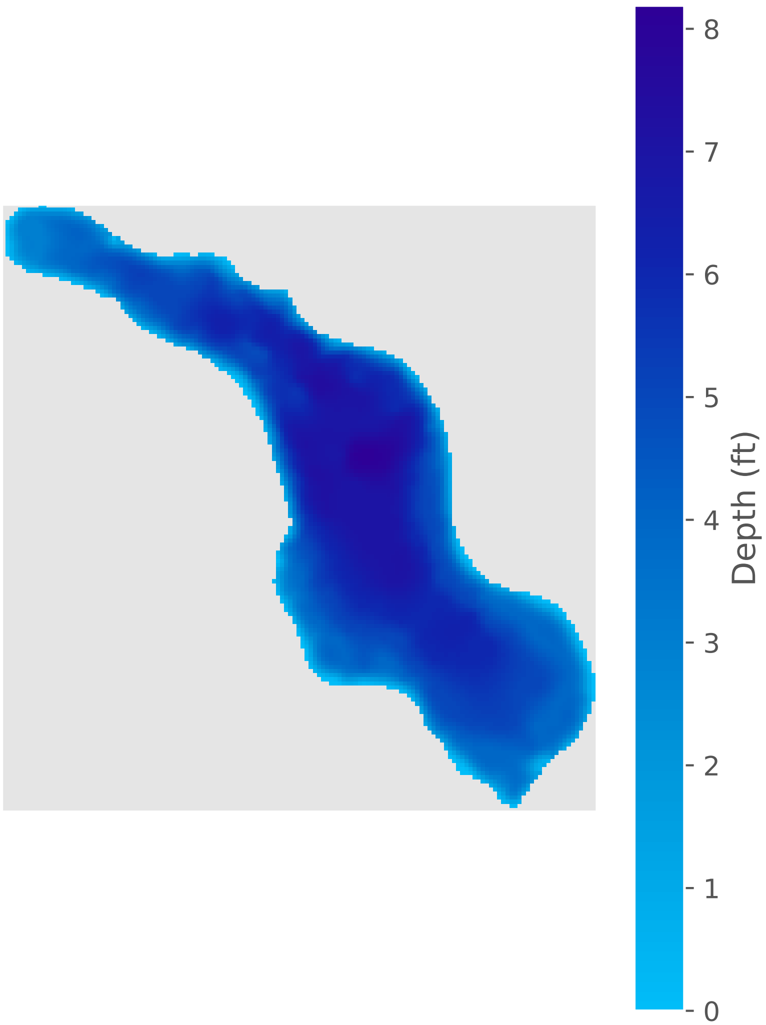
Maximum depth: 7 feet

Mean depth: 2.4 feet

Wing Lake







Percent area less than 5 feet deep: 48.4

Maximum depth: 8 feet

Mean depth: 4.8 feet