



Groundwater/Surface Water Interaction Study

Prepared for
Ramsey-Washington Metro Watershed District



September 2015

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1.0 Introduction

Understanding how changes in the groundwater system may affect water levels, stream flow, and water quality is an important component of long-term planning and protection of water resources in the Ramsey-Washington Metro Watershed District (District). How well connected, or disconnected, surface waters are to the groundwater system affects how they may respond to seasonal changes (such as drought), long-term climate change, or groundwater pumping.

The susceptibility of surface waters to changes in groundwater levels has been a topic of great interest for water bodies across the District and the north and east Twin Cities metro area in general. Record low water levels in White Bear Lake have, in part, been attributed to increased groundwater pumping in the area (Jones, 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). With this new authority, the MNDNR initiated three pilot groundwater management areas (GWMA), one being the North and East Metro GWMA, which encompasses the entire District. The draft groundwater management plan was released by the MNDNR in February 2015 and outlines the actions the MNDNR will take to sustainably manage groundwater in the area (MNDNR, 2015). The two most important items in the draft groundwater management plan as it relates to this report are:

- The MNDNR will work with watershed districts to evaluate lakes and basins in the GWMA that are susceptible to changing groundwater levels. The MNDNR will develop thresholds to determine negative impacts to basins and wetlands.
- The MNDNR will promote groundwater recharge in the GWMA and work with watershed districts to identify important groundwater recharge areas and opportunities to enhance recharge

This report first discusses how groundwater and surface water interact across the District and identifies surface waters that may be susceptible to changes in groundwater levels. The second part of this report identifies areas for focused groundwater recharge to achieve dual goals of replenishing stressed aquifers while also achieving stream-flow volume reductions and water quality improvements.

2.0 Evaluation of groundwater/surface water interaction

To evaluate 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 and used for this study include:

- Surficial and bedrock geology
- Lake bathymetric data
- Surface topography and morphology
- Observation well data
- Well records and boring logs
- Soil survey data
- Data from the Twin Cities Metropolitan Area Groundwater Flow Model (Metro Model 3)
- Water use and projected demand

Evaluating the relationship between surface waters and groundwater involves 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; and (3) evaluating the degree of influence groundwater has on individual surface water features and if the surface water is vulnerable to changes in the groundwater system — either pumping-induced or resulting from longer climatic changes. 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), local geology, and sensitivity of biota.

2.1 Regional Water Table

To evaluate the connection of surface water features to the groundwater system a map of the regional water table surface was created (Figure 1). 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 and small local flow systems. Inclusion of perched groundwater zones is not appropriate for this study as they likely show no response to changes in the regional groundwater flow system. Small local 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 flow systems or their interaction with surface waters.

To construct the regional water table map, water-level data from a number of different sources were compiled. The main sources of data included; MNDNR water table observation wells, static water levels from the Minnesota County Well index (CWI), and monitoring well data compiled by Barr Engineering Co.

for this study and development of the Twin Cities Metropolitan Area Groundwater Model (Metro Model 3; Metropolitan Council, 2014). Results from the Metro Model 3 and reaches of streams known to be well connected with groundwater were used as control points, particularly where data from other sources were sparse. Surface elevations from 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 map – evaluating the 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 CWI. The CWI is a valuable source of data as it extensively covers the District; however, the disadvantage of the CWI is the large degree of erroneous and conflicting data. Sources of error include:

- Inaccuracy of water level measurement—drilling contractors (especially for wells drilled decades ago) may not have used precise measuring devices.
- Inaccuracy in well location—many wells are identified only to the nearest quarter-quarter-quarter section (300 to 600 feet of location error).
- Inaccuracy in well elevation—well elevations are typically estimated using 7.5-minute topographic maps and are also subject to errors in location.
- Water levels may not have stabilized at the time of measurement—water levels are typically collected during or immediately after well installation or development and may not have reached equilibrium with the aquifer.
- Hydrostratigraphic units misidentified or screened/opened intervals not correctly assigned in the databases—the well may actually be screened in a different unit or in multiple units.
- Water level affected by seasonal pumping—depending on where the well is located and at what time of year it was installed, the water level measured by the drilling contractor may have been affected by seasonal pumping.
- Water levels affected by season and year of installation—water levels from different wells typically represent the entire range of possible dates and times of the year and thus are a composite of many years of data.

Given these sources of unavoidable uncertainty, water levels are typically assigned a likely error of at least +/- 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 CWI data. First, wells not screened near the water table, or wells open to multiple aquifers, were removed. A cutoff of 30 feet between the top of the screen and the static water level was used as defining wells screened near the water table. A distance of 30 feet was chosen based on potential error in the CWI dataset and distribution of wells remaining after this step. A smaller cutoff, such as 5, or 10 feet, could have been used but would have left a small number of wells with an uneven distribution.

After filtering the CWI data to those wells representative of the 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. All observations with an absolute residual of 20 feet from the cross validation were removed.

After cross validation the regional water table surface was inspected for localized highs that could represent perched zones. In these suspect areas the local geology was evaluated to determine if the data represent an area of perched groundwater and if the data point should be removed. This process was repeated several times until a satisfactory regional water table surface was established (Figure 1).

2.2 Connection of surface water with the regional groundwater system

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. 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.

Surface water features not connected to the regional groundwater system are considered perched. Perched features were identified by comparing the regional water table elevation to the elevation of the bottom of the surface water feature (e.g., elevation of the lake at maximum depth). Bottom elevations for features were determined in several ways. Where available, lake-bathymetry data were used to define bottom elevations. For features without bathymetry data, depth estimates were based on Cowardin class (Cowardin et al., 1979) as defined in the NWI dataset.

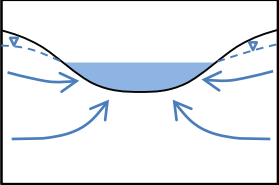
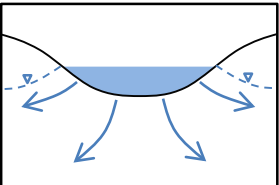
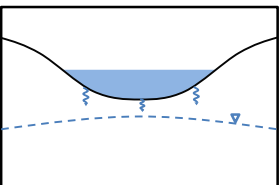
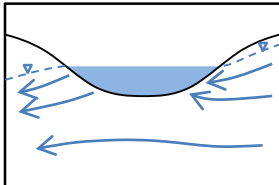
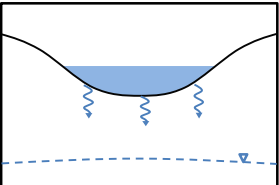
Surface water features greater than 25 feet above the water table were considered to be perched. The connection between groundwater and surface water was considered to be indeterminate for surface water features 5 feet to 25 feet above the regional water table. For these features the hydraulic connection between groundwater the surface water may be seasonal, or the data are simply not sufficient to definitively say the feature is perched above the regional groundwater system. Surface water features less than 5 feet above the regional water table surface are generally considered connected to groundwater.

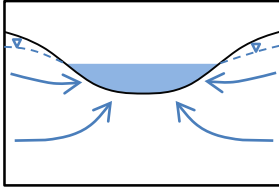
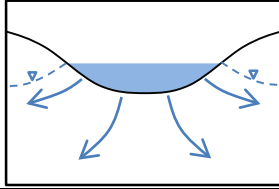
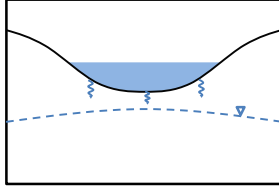
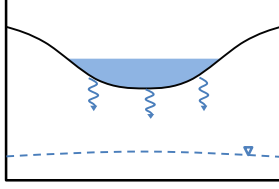
2.3 Classification of groundwater/surface water interaction

Each surface water feature was categorized based on how groundwater and surface water interact (Figure 2). How they interact can aid in management or monitoring of individual features. This analysis involved comparing the surface water elevation for each feature to the regional water table. Surface water elevations were obtained from LIDAR data. LIDAR stage data allows for consistency across all surface water features. Differences between LIDAR stage and measured stage were not significant for this study. The table below describes each interaction type and qualifiers used in defining the interaction type for

each feature. It is important to note when reading about these types of interactions that the terminology may seem counter-intuitive when reading 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.

Table 1 Groundwater/surface water interaction classes

Type	Description		Qualifiers
Discharge lake/wetland	Mostly receives groundwater inflow		Connected to groundwater, surface water elevation below regional water table
Recharge lake/wetland or Indeterminate	Connected to groundwater. Mostly loses water as seepage to groundwater		Groundwater connection is indeterminate, regional water table lower than surface water elevation. Uncertainty in regional water table make it difficult to distinguish between features that are connected and those that are disconnected to groundwater.
	Disconnected 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		Connected to groundwater, surface water elevation above or equal to regional water table
Perched lake/wetland 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		Disconnected from groundwater

Type	Description		Qualifiers
Gaining Stream	Groundwater flow into stream		Connected to groundwater, surface water elevation below regional water table
Losing Stream or Indeterminate	Mostly loses water to aquifer system		Groundwater connection is indeterminate, regional water table lower than surface water elevation. Uncertainty in regional water table makes it difficult to distinguish between features that are connected and those that are disconnected from groundwater.
	Water table slightly below stream bottom. Loss of water to the unsaturated zone. Fluctuations in the water table can affect the flow dynamics out of the stream.		
Perched Stream with deep water table	Water table deep below stream bottom. Loses water to the unsaturated zone. Change in water table has no effect on stream.		Disconnected from groundwater

2.4 Vulnerability to changes in groundwater flow system

To evaluate the potential vulnerability of surface water features to changes in the groundwater flow system each was classified based on the geologic setting and specific characteristics of the feature itself (Figure 3).

Surface waters classified as perched or disconnected are inherently not vulnerable to changes in the groundwater system. While these features lose water to groundwater the rate of loss is not dependent on groundwater levels. Losing streams or recharge lakes maybe vulnerable to changes in the groundwater system because the rate of flow from the surface water to groundwater may be controlled by the groundwater system. A drop in the water table, or hydraulic head of the upper aquifer, may cause an increase in the loss of water to the groundwater system.

The nature of geologic units beneath a surface water feature affects the way that feature responds to changes in the groundwater system, either from pumping or climatic changes. It is assumed that a lake that sits directly within low permeability glacial till is likely influenced very little by changes in 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 of groundwater pumping, depending on their hydraulic properties, thickness, and horizontal extent. Alternatively, a lake that sits within a higher permeability sand and gravel glacial outwash 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.

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 water table may impact the lake. Lakes with wide littoral zones have a greater potential of being negatively impacted by changes in water levels. For lakes where bathymetry data are available, additional basin characteristics were calculated. For this study, lakes that are less than 5 feet deep over more than 20% of the total surface area are considered to be more sensitive to changes in lake level. These lakes are generally disproportionately shallow as indicated by the relative hypsographic curves (depth vs. area) presented in Appendix A. Many of these lakes may be relatively deep but tend to have broad, shallow shorelines. Lakes that are considered vulnerable to changes in the groundwater system and fall within these criteria may require greater priority in setting up potential monitoring and/or management plans. While bathymetric data are not available for most wetlands, almost all wetlands are less than 5 feet deep over more than 20% of the surface area and should be considered to be similarly vulnerable as lakes that fall into this category.

3.0 Opportunities for focused groundwater recharge

Data compiled and developed to assess the connection of groundwater and surface water was used to identify opportunities for focused groundwater recharge via infiltrating storm water. Areas for focused infiltration are identified to achieve dual goals of replenishing stressed aquifers while also achieving stormwater runoff volume reductions, stream-flow volume reductions and water quality improvements. The effectiveness of infiltrating storm water to enhance groundwater recharge is dependent on several factors, including:

- Local geology (e.g., surficial soils, and geology of the unsaturated zone)
- Depth to groundwater
- Proximity to surface waters
- Volume of stormwater available

Infiltrating in some areas may have more benefit than other areas. For example, if infiltrating to replenish the Prairie du Chien aquifer, the presence of confining units above the Prairie du Chien aquifer (e.g., Decorah Shale) may prevent any positive impact. Infiltration can also be used to help offset impacts occurring, or projected to occur, due to increased pumping. An example is infiltrating to increase baseflow to a stream, or increase groundwater inflow to a lake. These infiltration strategies are highly dependent on proximity to such features.

The quality of water is also a concern for infiltrating stormwater to enhance recharge to drinking water aquifers. As part of our analysis, we reviewed existing water supply management areas and aquifer vulnerability mapping done as part of individual communities well head protection plans.

3.1 Methodology Used to Rank Areas for Focused Infiltration

To identify the areas most suitable for focused infiltration, a scoring system was developed to help weigh all the different types of data that must be considered. This process helps to rank areas of the District where focused infiltration projects should be considered. While the process considers as much information as possible, site-specific data such as geologic borings, piezometers, and other engineering studies will be required prior to implementing any large scale infiltration at a specific site. The scale and scope of this study was focused on identification of areas of the watershed best suited for infiltration practices. This study does not consider site-specific details such as site access, aesthetics, and fit with surrounding infrastructure.

The scoring system developed for this study maps and ranks all different information to consider when identifying locations for infiltration. All data are mapped to a 3 meter by 3 meter grid and then assigned a score. For example, areas with sandy soils receive a higher score than areas with clay soils. Scores for each dataset (e.g., soils, depth to water table, bedrock geology) are then added together to obtain a composite score. The composite score allows for ranking different areas of the watershed that are most suitable for

infiltration, higher scores indicating more suitable areas. In some instances, certain components suggest that focused infiltration should perhaps not occur in certain areas. For example, areas where the water table is very near the ground surface are not suitable for focused infiltration. The shallow water table dramatically limits the ability to infiltrate large volumes of water, even if very sandy soils exist. In the final composite score these areas receive a score of zero. The 3 meter by 3 meter grid is used as it is the smallest scale of the input data used (Lidar topography data). Some data sets are originally at a much coarser scale but were resampled to the 3 meter by 3 meter grid. The resampling was done to allow for consistent input to the scoring system but does not mean that all datasets are accurate to such a fine scale.

3.1.1 Depth to Water Table

The Minnesota Pollution Control Agency (MPCA) requires a minimum separation of 3 feet between the bottom of an infiltration practice and the elevation of the seasonally high water table. However, depth to water table should be much greater in most instances. Infiltration of water will form a mound at the water table below the site of infiltration. If the mound becomes too high the effectiveness of the infiltration practice can be compromised. Also, in some instances if mounding at the water table gets too high it may have negative consequences for nearby structures; for example, wet basements, or development of unstable soils. The size of the mound that will develop below an infiltration practice is a function of the permeability (hydraulic conductivity) of soils and infiltration rate.

A map of the depth to the water table is shown on Figure 4. For this study, the following scoring system was used for depth to the water table in ranking areas conducive to focused infiltration (Figure 5):

- 3 points = Depth to water table > 20 feet
- 2 points = Depth to water table > 15 feet and < 20 feet
- 1 point = Depth to water table > 10 feet and < 15 feet
- 0 points = Depth to water table < 10 feet
- Area not suitable regardless of other information where depth to water table < 5 feet

3.1.2 Soils

Hydrologic soil types, as mapped by the Natural Resources Conservation Services (NRCS), are shown on Figure 6. Hydrologic soil groups (A, B, C, D) are grouped primarily to assess the runoff potential of a soil but can also be used to assess the ability of a soil to infiltrate water. In general, soils in hydrologic soil group A have the greatest capacity to infiltrate water and soils in group D have the least capacity.

Hydrologic Soil Group A—(Low runoff potential): Group A soils have a high infiltration rate and are typically composed of more than 90 percent sand and gravel.

Hydrologic Soil Group B—(Moderately low runoff potential): Group B soils have a moderate infiltration rate and are typically composed of 50-90 percent sand.

Hydrologic Soil Group C—(Moderately high runoff potential): Group C soils have a slow infiltration rate and are composed of less than 50 percent sand.

Hydrologic Soil Group D—(High runoff potential): Group D soils have a very slow infiltration rate and are composed of more than 40 percent clay. These soils have of combination of high swelling potential, a permanently high water table, and a clay layer at or near the surface.

Dual hydrologic groups, A/D, B/D, and C/D, are soils that are considered D soils primarily because of a high water table. However, if the soil were drained it would be classified into a different group. The second group listed for dual hydrologic group soils is for a drained condition. For the purpose of infiltration all dual hydrologic groups are considered as D soils.

Many areas of the district have unclassified soil hydrologic classes. This is primarily because much of the area was developed prior to mapping hydrologic classes. These soils were given a score of zero in the scoring system, allowing these areas to still be considered but also allowing for the uncertainty in the soil conditions to still be accounted for.

For this study, the following scoring system was used for hydrologic soil groups in ranking areas conducive to focused infiltration (Figure 7):

- Group A = 4 Points
- Group B = 2 Points
- Group C and Undefined = 0 Points
- Group D (also A/D, B/D, and C/D) = Not suitable for focused infiltration

3.1.3 Surficial Geology

Surficial geology, simplified and grouped by lithology (e.g., sand, silt) as mapped by Meyer (2007), is presented on Figure 8. When infiltrating large volumes of water (typically above the water storage capacity of the soil zone) the surficial geology often plays a larger role than soil hydrologic group in dictating the infiltration capacity of an area. Surficial geology shown on Figure 8 is a generalization of the type of material from ground surface to a depth of approximately 20 feet. This is in contrast to the soil hydrologic groups that are classified based on soil properties from ground surface to a depth of approximately 40 inches. Also, soils across much of the District have not been assigned a hydrologic class. To fill this gap and to assess infiltration below the soil profile the surficial geology was also used in the scoring system.

For this study the following scoring system was used surficial geology in ranking areas conducive to focused infiltration (Figure 9):

- Sand = 2 points
- Diamicton (Glacial Till) = 1 points
- Unspecified = 0 Points
- Organic, Clay, Silt = Not Suitable

3.1.4 Bulk Unsaturated Hydraulic Conductivity

To capture the ability of sediments at depth to transmit water, the bulk hydraulic conductivity of the unsaturated zones was considered. Data compiled by Tipping (2011) which mapped textural characteristics of the Quaternary sediments in the eleven-county metropolitan area and correlated those textures to representative ranges in hydraulic conductivity values (Table 2) was implemented into the scoring system. The material types classified by Tipping (2011) are mapped as a matrix of points spaced 250 meters (820 feet) apart in the horizontal direction and 6.1 meters (20 feet) apart in the vertical direction. The point data set from Tipping (2011) was converted to a series of raster grids, each representing material types along a single elevation (each elevation raster was spaced 20 feet apart). The raster grids were then resampled to a grid spacing of 3 meters by 3 meters to be consistent with other datasets used the scoring system. Equations 3-1 and 3-2 (Anderson and Woessner, 1992) were used to calculate an effective bulk vertical hydraulic conductivity of the unsaturated zone. (Figure 10).

$$(K_z)_{i,j} = \frac{B_{i,j}}{\sum_{g=1}^m \frac{b_{i,j,g}}{K_{z,i,j,g}}} \quad (\text{Eqn. 3-1})$$

$$B_{i,j} = \sum_{g=1}^m b_{i,j,g} \quad (\text{Eqn. 3-2})$$

where:

$B_{i,j}$ is the thickness of a model cell

$b_{i,j,g}$ is the thickness of an individual material type

$K_{x,i,j,g}$ is the horizontal hydraulic conductivity of an individual material type

$K_{z,i,j,g}$ is the vertical hydraulic conductivity of an individual material type

Table 2 Representative hydraulic conductivity values by material type

Material Type	Representative Hydraulic Conductivity (ft/day)	Material Type	Representative Hydraulic Conductivity (ft/day)
Loam to Clay Loam	1.0	Sandy Silt	3.0
Loam to Sandy Loam	0.0017	Loam to clay loam – deep	0.548
Loam, silt rich, silt and clay	1.4	Loam to sandy loam – deep	0.0000173
Loam to sandy clay loam	0.002	Loam, silt rich; silt and clay – deep	0.014
Sand and Gravel	1.4	Loam to sandy clay loam – deep	0.0000245
Fine Sand	707	Data from Tipping (2011)	

Areas of high hydraulic conductivity are preferable for infiltration. Low hydraulic conductivity materials impede infiltration and are less desirable.

For this study the following scoring system was used for bulk vertical hydraulic conductivity in ranking areas conducive to focused infiltration (Figure 11):

- > 10 ft/day = points
- 1 to 10 ft/day = 2 points
- 0.1 to 0.9 ft/day = 1 point
- < 0.1 ft/day = Not Suitable for infiltration

3.1.5 Shallow bedrock confining units

Shallow bedrock confining units restrict movement of water to deeper aquifers. Infiltration in these areas may be suitable for some goals such as sustaining base flow in a stream. However, these areas are not good candidates if the goal is to help replenish deeper bedrock aquifers. A map of the upper most bedrock unit is shown on Figure 12. Shallow bedrock confining units include: base of St. Peter Sandstone, Platteville Formation, and Decorah Shale.

For this study the following scoring system was used for presence of shallow bedrock confining units (Figure 13):

- 3 points = Prairie du Chien is upper most bedrock unit
- 2 points = St. Peter Sandstone is upper most bedrock (basal St. Peter Confining unit present)
- 1 point = Platteville Formation is upper most bedrock (basal St. Peter and Platteville confining units present)
- 0 points = Decorah Shale is upper most bedrock (basal St. Peter, Platteville, and Decorah Shale confining units present)

3.1.6 Drinking Water Supply Management Areas

Communities on the north and east side of the District use groundwater as their municipal water source (Figure 14). Communities in the central and western part of the District use both surface water and groundwater as a water source, primarily supplied by St. Paul Regional Water Services. St. Paul Regional Water Services' wells are located in Little Canada and Vadnais Heights. The Minnesota Department of Health regulates municipal water supplies and has guidance regarding infiltration of storm water in vulnerable drinking water supply management areas (DWSMA) (Figure 15). The vulnerability of DWSMAs are classified into five groups: very-high, high, moderate, low, and very-low. Vulnerability is based on how easily groundwater may be impacted by activities at the surface. Local geology and geochemical data are used to assess how quickly groundwater infiltrating at the surface may reach a source aquifer.

Aquifer vulnerability assessments are used to: (1) assess the level of risk that land use may have on groundwater entering a public water supply; (2) guide efforts to inventory potential contaminant sources; and (3) define measures to control potential contaminant sources. Composite aquifer vulnerabilities within individual communities DWSMAs are shown on Figure 15. Because storm water may contain contaminants that could lead to adverse health effects, the Minnesota Department of Health stresses that care be

exercised in planning projects that involve infiltrating storm water in DWSMAs, especially if the aquifer vulnerability is moderate, high, or very-high. There is generally little concern for potential impacts to a drinking water aquifer from infiltration within a DWSMA if the aquifer vulnerability is classified as very-low or low. Infiltration within a DWSMA with aquifer vulnerability of very-high, high, or moderate is considered appropriate if:

- The receiving aquifer does not exhibit fracture or solution enhanced groundwater flow.
- The infiltration site is not in a 1-year capture zone.
- The land uses for the infiltration site and water drained to the site are forest, parkland, open space, low density residential, high density residential, golf course, or agricultural. Commercial, industrial, municipal, and transportation corridors may be acceptable if an emergency spill response plan is acceptable. MPCA does not allow infiltration of runoff from potential storm water hotspots (PSHs).
- Infiltrated water is able to meet federal drinking water standards through pre-treatment, secondary containment, or natural attenuation in the vadose zone.

For this study the following scoring system was used for DWSMA vulnerability (Figure 16):

- High and Very High = 1 point
- Moderate = 2 points
- Low and Very low = 3 points
- Not in a DWSMA = 4 points
- 1-year capture zones = Area not suitable for infiltration

3.1.7 Karst Areas

Karst is a type of landscape that develops when soluble bedrock is dissolved by water. Most of southeast Minnesota is underlain by carbonate bedrock that is conducive to karst development. The MPCA classifies karst into three categories; active, transition, and covered. The classification depends on the depth to bedrock (Figure 17); active karst occurs where the depth to the bedrock is less than 50 feet, transition karst where depth to the bedrock is between 50 and 100 feet and covered karst where the depth to bedrock is more than 100 feet. Classifications are shown on Figure 18. Karst areas, in particular active karst areas, are of concern for infiltrating large volumes. Excessive volumes of water may help to dissolve carbonate bedrock enlarging fractures and caverns leading to eventual collapse. The weight of any ponded water may also lead to collapse of any existing or filled karst features. A recent and well known example of this is from the collapse event at the Dancing Waters development in Woodbury in October, 2005. The MPCA does not define specific rules regarding infiltrating storm water in karst areas. However, additional pre-treatment may be necessary and site-specific geotechnical investigations are typically required.

For this study the following scoring system was used for presence of karst areas (Figure 19):

- Active Karst = 1 point
- Transition Karst = 2 points
- Covered Karst or No Karst = 3 points

3.1.8 Areas of potential future groundwater drawdown

The Metropolitan Council conducts water supply planning for the Twin Cities metro area. Current projections of population and water demand for the District for 2020, 2030, and 2040 are shown in Table 3 below (Metropolitan Council, 2015). The demand projections include use of both surface water and groundwater. The distribution in the water demand growth between groundwater and surface water is uncertain. St. Paul uses a mixture of surface water and groundwater and their water treatment plant has capacity to grow. Many of the communities in the north and northeast part of the District use groundwater (Figure 14) and would prefer to continue to use groundwater. However, as part of a legal agreement related to low water levels in White Bear Lake, the MNDNR is currently looking into long-term sustainable water use for these communities; many solutions involve more use of surface water for municipal supply.

Table 3 Projected Population and Water Use for the District

	2020	2030	2040
Population Served	654,557	697,820	731,402
Total Population	523,680	556,770	575,280
Projected Average Daily Water Use (Million Gallons)	72	74	75
Total Per Capita Water Use (Gal/Person/Day)	114	114	114

Source: Metropolitan Council. 2015. Water Supply Master Plan (Draft)

The Metropolitan Council uses demand projections and a groundwater flow model (Metro Model 3) to assess potential groundwater drawdowns under future conditions. The Metropolitan Council does not estimate changes to surface waters as a result of the increased pumping. However, in general it is expected that areas of greater drawdown will have greater impacts to surface waters that are connected to the groundwater system. The results of these model simulations were not available at the time of this report but it is expected that projected drawdown will be greatest for in communities supplied by groundwater in the north and east part of the District. Because final simulations are not available, areas of potential future groundwater drawdown were not included in the scoring system. However, areas in the north and east part of the District would receive a more favorable score because infiltration in these areas would have more potential to offset impacts from future groundwater drawdown.

3.2 Results of Infiltration Areas Assessment

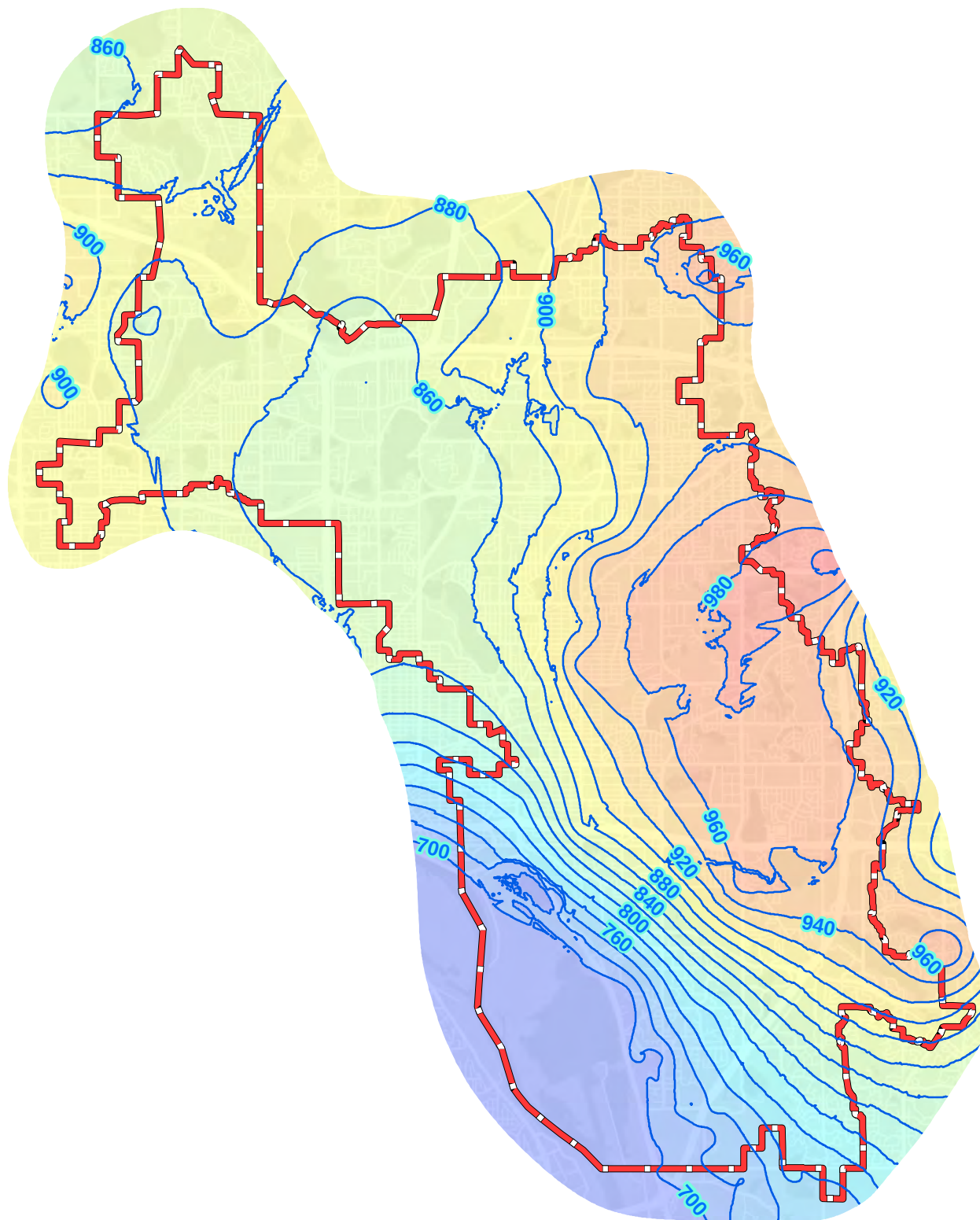
The results of the assessment of areas of the District most suitable for focused infiltration, as described in Section 3.1 are presented on Figure 20. The areas darkest blue in color on Figure 20 are areas that scored the highest, indicating they are most suitable for large scale infiltration. Areas in lighter green on Figure 20 are suitable for infiltration but may have some limitations. Areas shown in gray or with no color on Figure 20 are considered not suitable for large scale focused infiltration; review of individual scoring components will indicate why for different areas.

The map on Figure 20 can be used to guide planning for infiltration projects across the District. However, site-specific data and engineering studies are necessary prior to implementation of any large scale infiltration projects. Site-specific data necessary as part of project design include: geologic borings, water table elevations from site-specific piezometers, and hydraulic conductivity data for soils and unconsolidated sediments at the site. Additionally, hydraulic analysis/modeling will be necessary to obtain volumes and rates of water that will be routed to an infiltration area and groundwater modeling will likely be needed to assess infiltration capacity along with the size and extent of a groundwater mound that may develop at the water table

4.0 References

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- Jones, P.M., Trost, J.J., Rosenberry, D.O., Jackson, P.R., Bode, J.A., and O'Grady, R.M., 2013. Groundwater and surface-water interactions near White Bear Lake, Minnesota, through 2011: U.S. Geological Survey Scientific Investigations Report 2013-5044, 73 p.
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- Meyer, G.N. 2007. M-178 Surficial Geology of the Twin Cities Metropolitan Area, Minnesota. Minnesota Geological Survey. Scale, 1:125:000.
- Minnesota Department of Natural Resources. 2015. North & East Metro Groundwater Management Area Plan, Draft, February 2, 2015.
- Tipping, R.G. 2011. Distribution of vertical recharge to upper bedrock aquifers, Twin Cities metropolitan area. Minnesota Geological Survey report submitted to Metropolitan Council, November, 2011.

Figures



RWMWD Boundary

Regional Water Table

ft, MSL

675 - 680

681 - 700

701 - 720

721 - 740

741 - 760

761 - 780

781 - 800

801 - 820

821 - 840

841 - 860

861 - 880

881 - 900

901 - 920

921 - 940

941 - 960

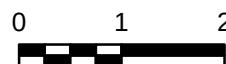
961 - 980

981 - 1,000

1,001 - 1,020



Miles



Kilometers



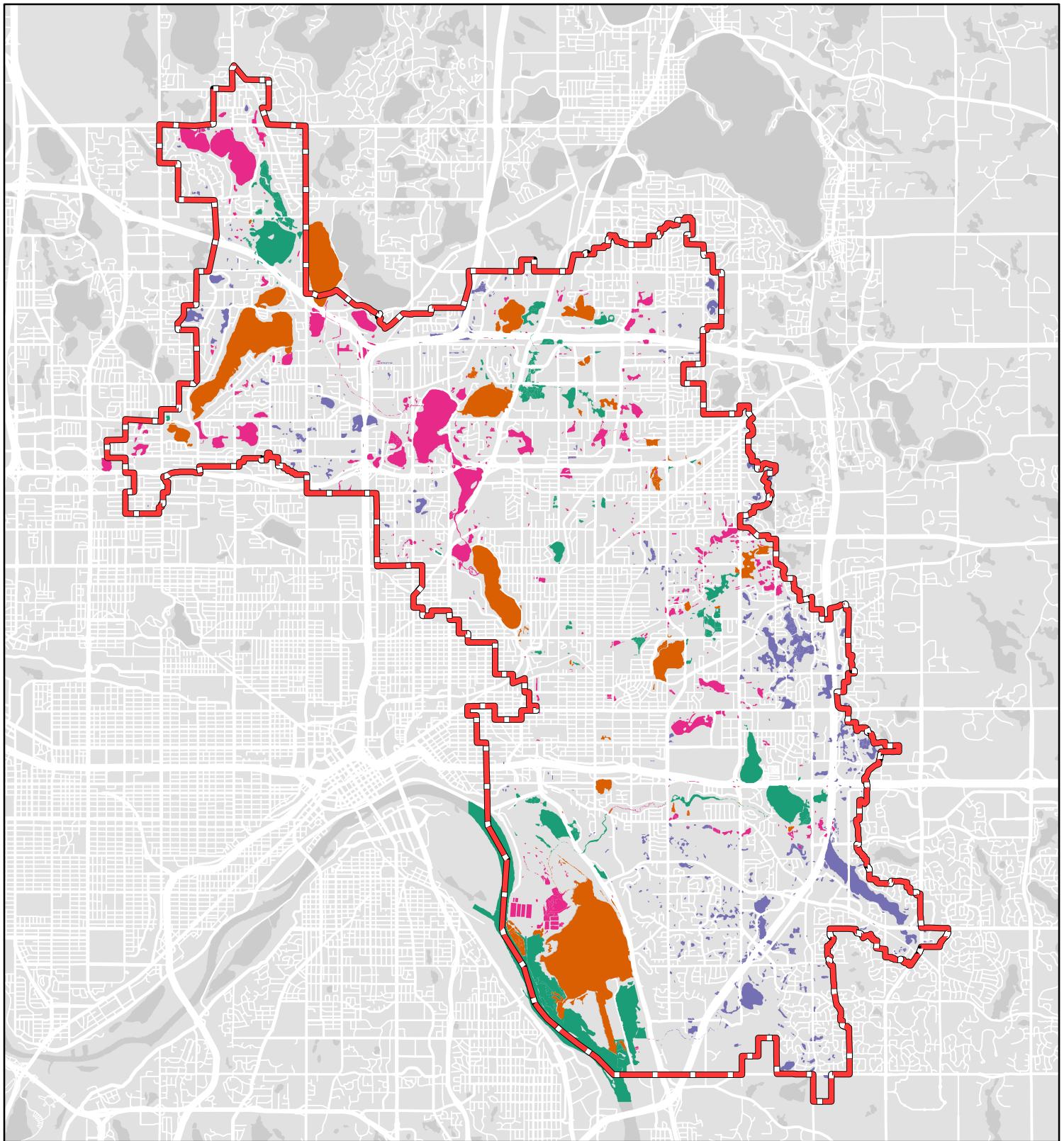
Figure 1

Regional Water Table
Groundwater/Surface Water
Interaction Study

Ramsey-Washington Metro



District



RWMWD Boundary

Connection with Regional Groundwater System



Discharge Lake/Wetland, Gaining Stream



Flow-Through Lake/Wetland/Stream



Perched Lake/Wetland/Stream



Recharge Lake/Wetland, Losing Stream



Miles



Kilometers

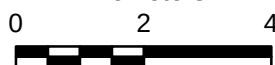
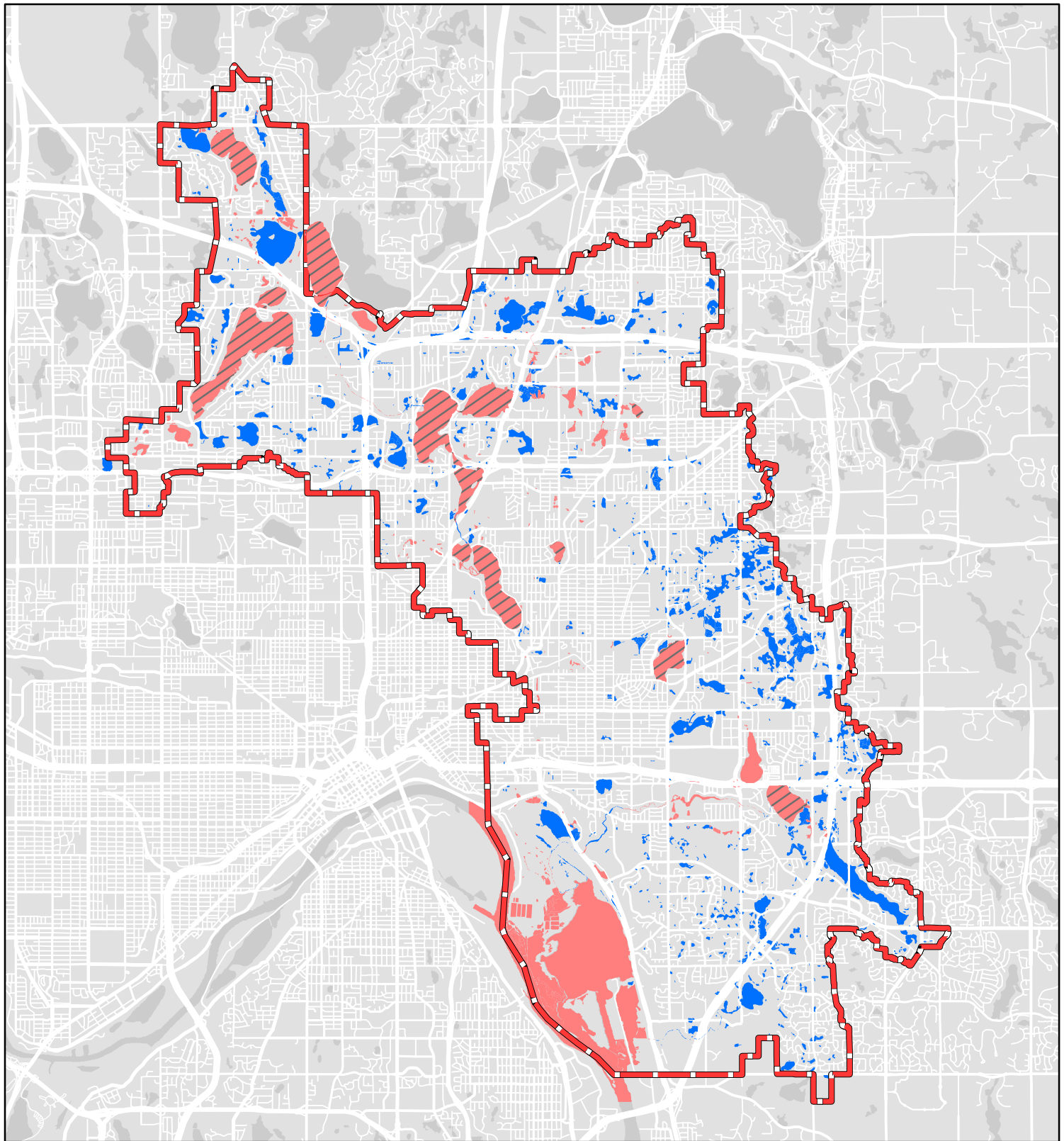


Figure 2

Classification of Groundwater and Surface Water Interaction
Groundwater/Surface Water Interaction Study

Ramsey-Washington Metro





RWMWD Boundary

Vulnerability to changes in groundwater system



Not Vulnerable



Vulnerable



Vulnerable with wide littoral zone



Miles

0 1 2



Kilometers

0 2 4

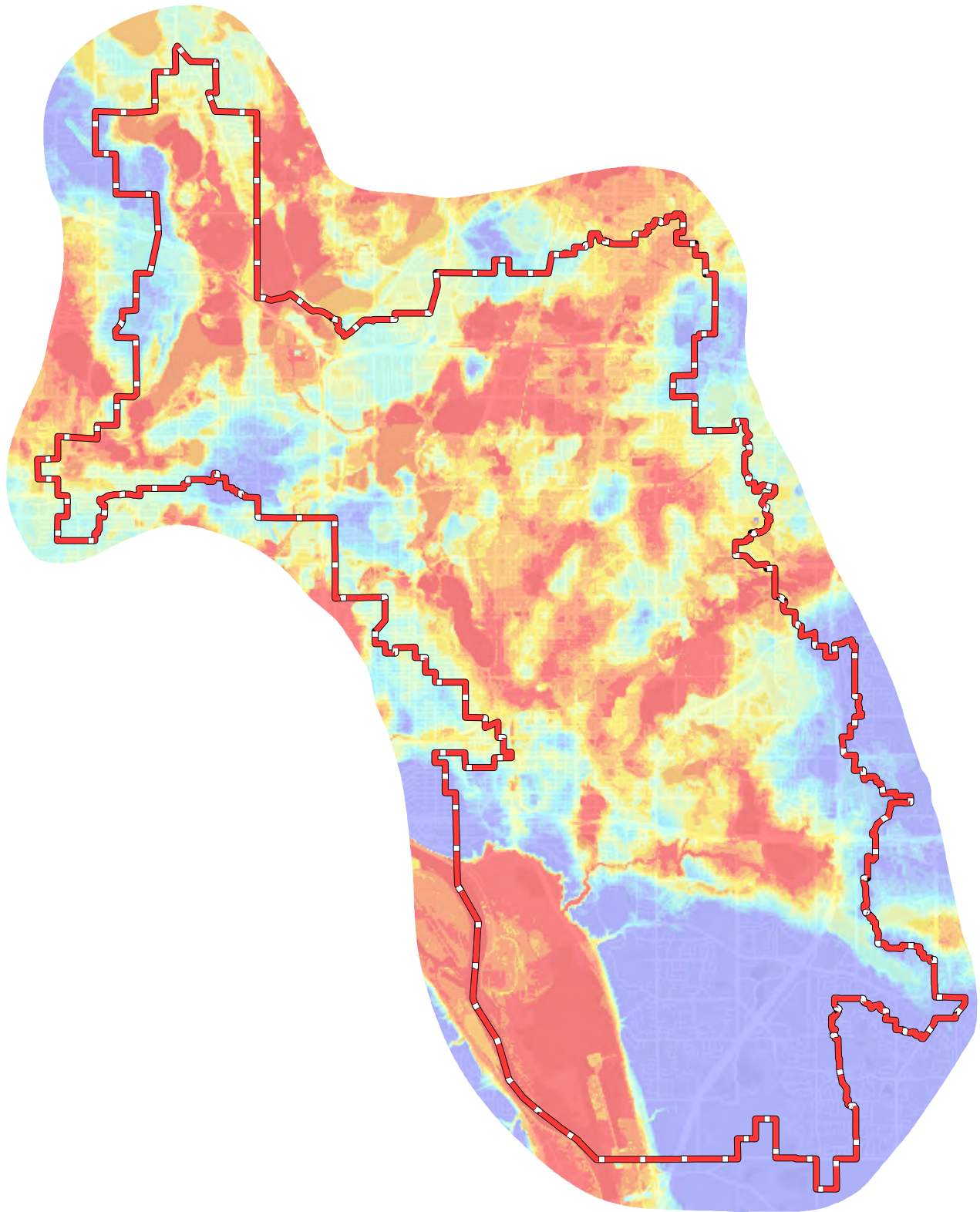


Figure 3

Vulnerability of Surface Waters
to Changes in Groundwater System
Groundwater/Surface Water
Interaction Study

Ramsey-Washington Metro





**Unsaturated
Zone
Thickness**



RWMWD
Boundary



Miles



Kilometers



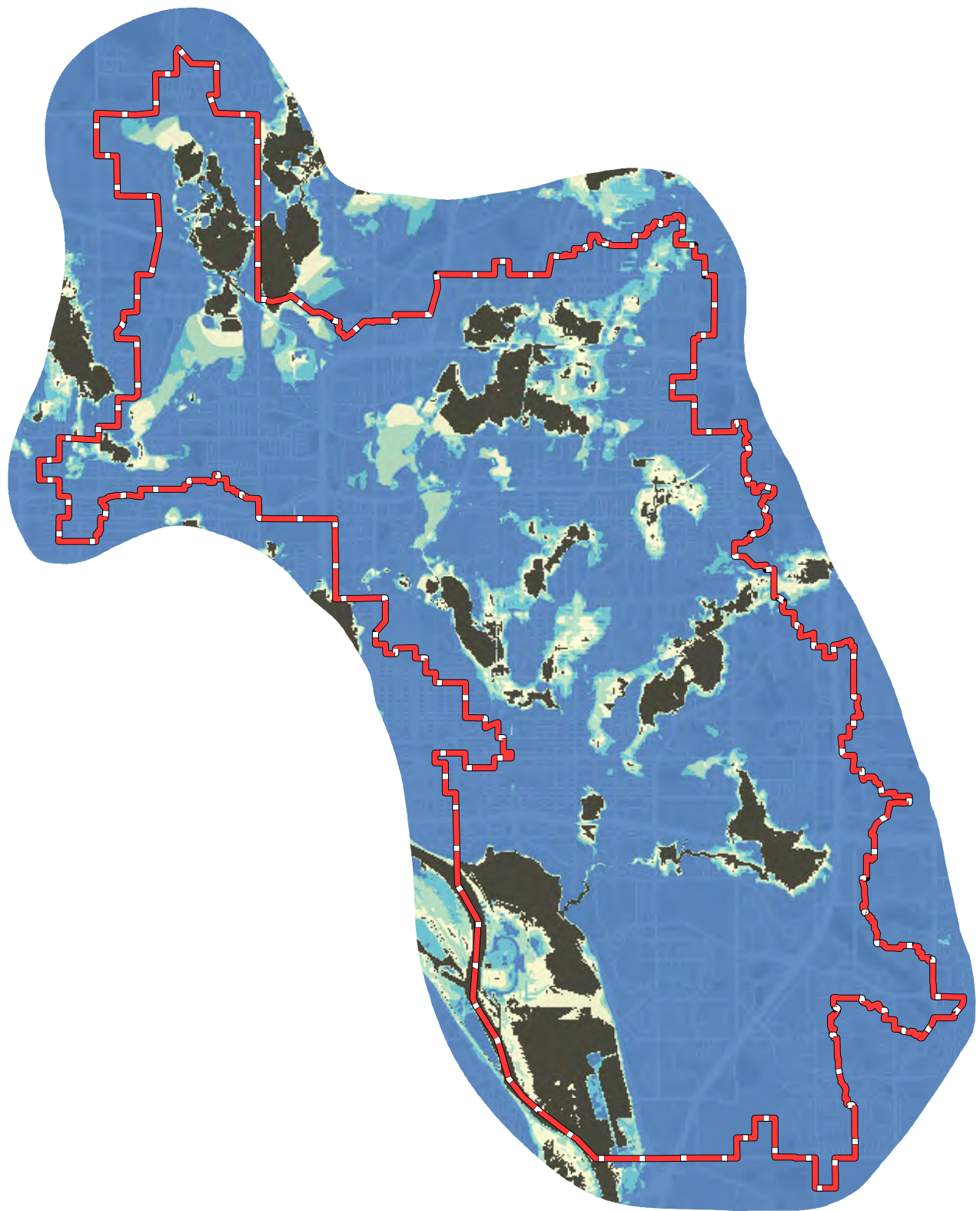
Figure 4

Depth to Water Table
Groundwater/Surface Water
Interaction Study

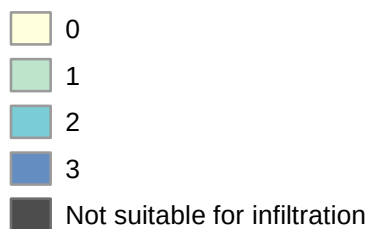
Ramsey-Washington Metro



District



Depth to Water Table Score



RWMWD Boundary



Miles



Kilometers

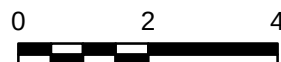
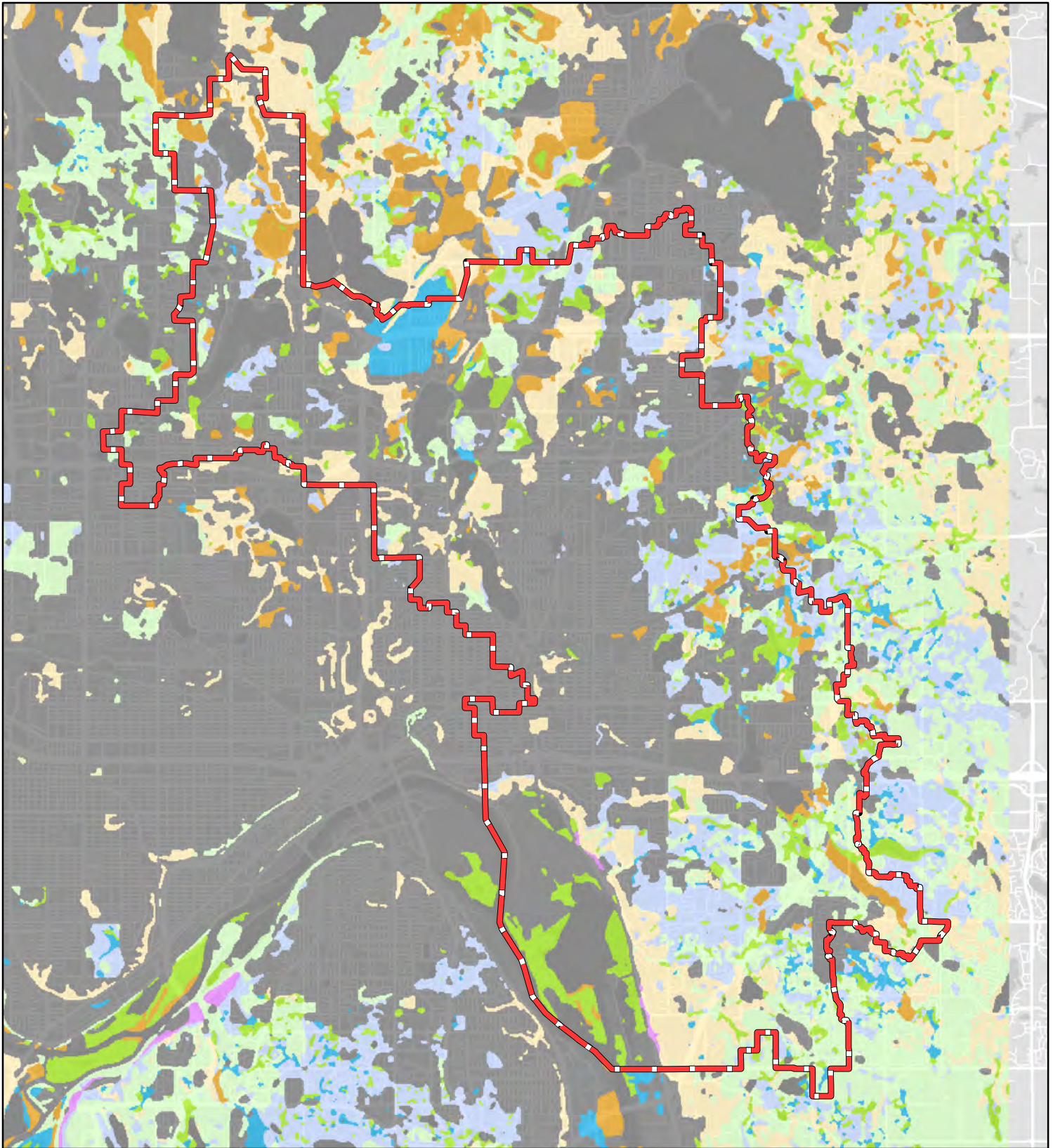


Figure 5

Depth to Water Table Score
Groundwater/Surface Water
Interaction Study





**Soil
Hydrologic
Group**

Undefined
A
A/D

B
B/D
C
C/D
D



RWMWD
Boundary



Miles



Kilometers

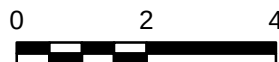
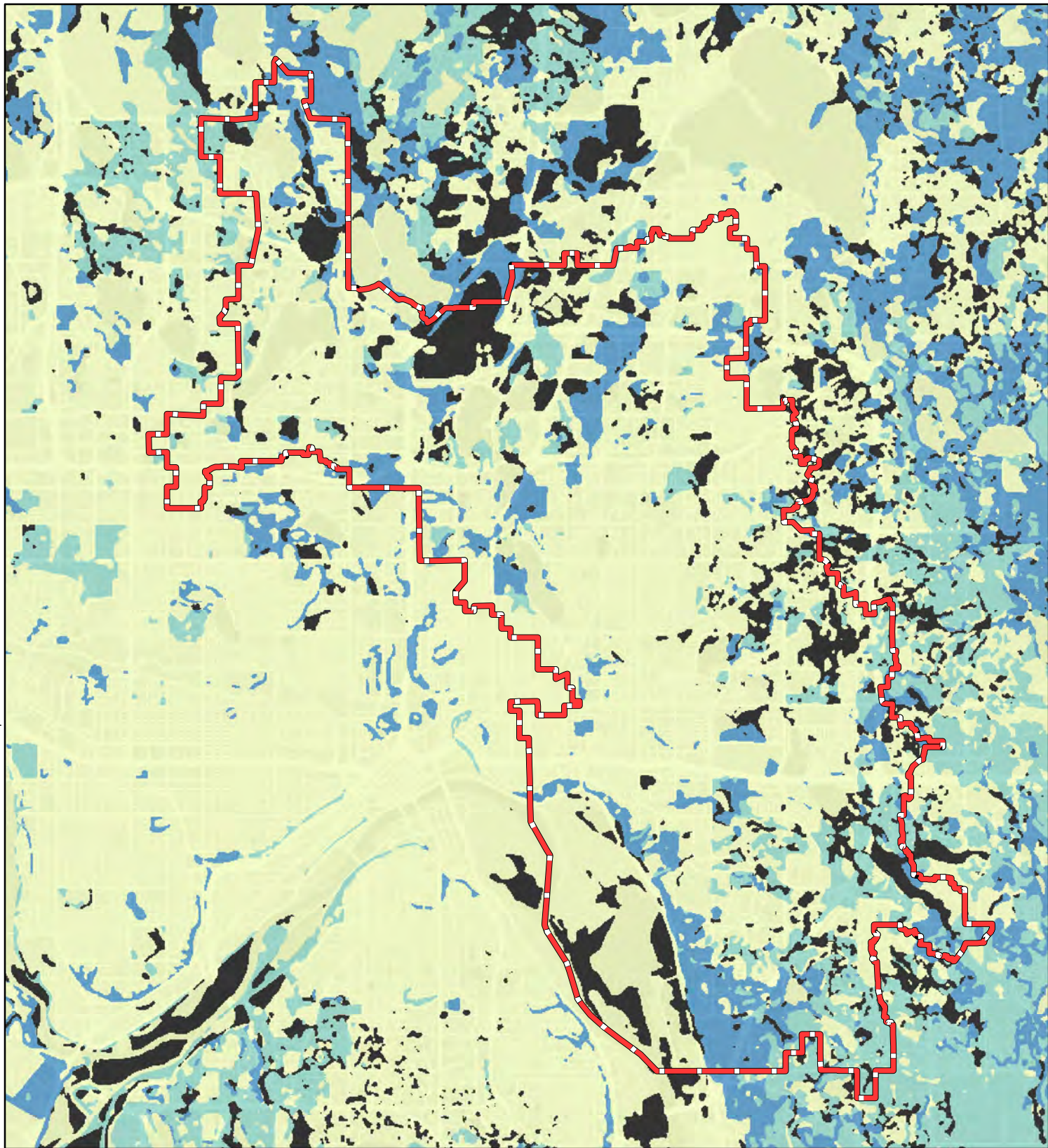


Figure 6

Soil Hydrologic Groups
Groundwater/Surface Water
Interaction Study

Ramsey-Washington Metro





Soil Hydrologic Group Score

-  0
-  2
-  4
-  Not suitable for infiltration



RWMWD Boundary



Miles



Kilometers

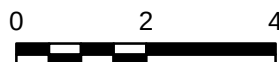


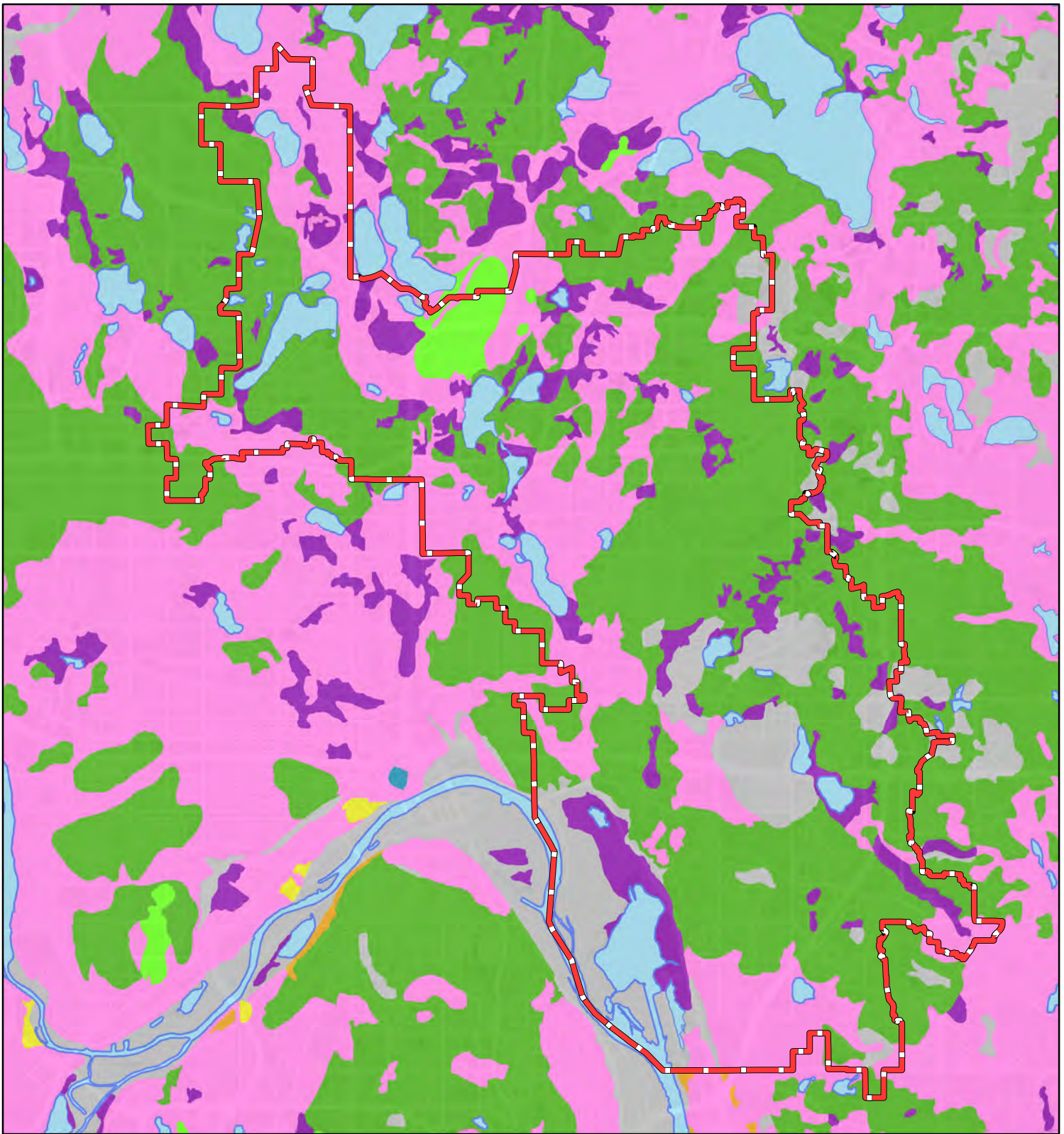
Figure 7

Soil Hydrologic Group Score
Groundwater/Surface Water
Interaction Study

Ramsey-Washington Metro



District



Simplified Surficial Geology **RWMWD Boundary**

-  Gravel
-  Clay
-  Diamicton (Glacial Till)
-  Organic
-  Rock
-  Sand
-  Silt
-  Unspecified
-  Water



Miles

0 1 2



Kilometers

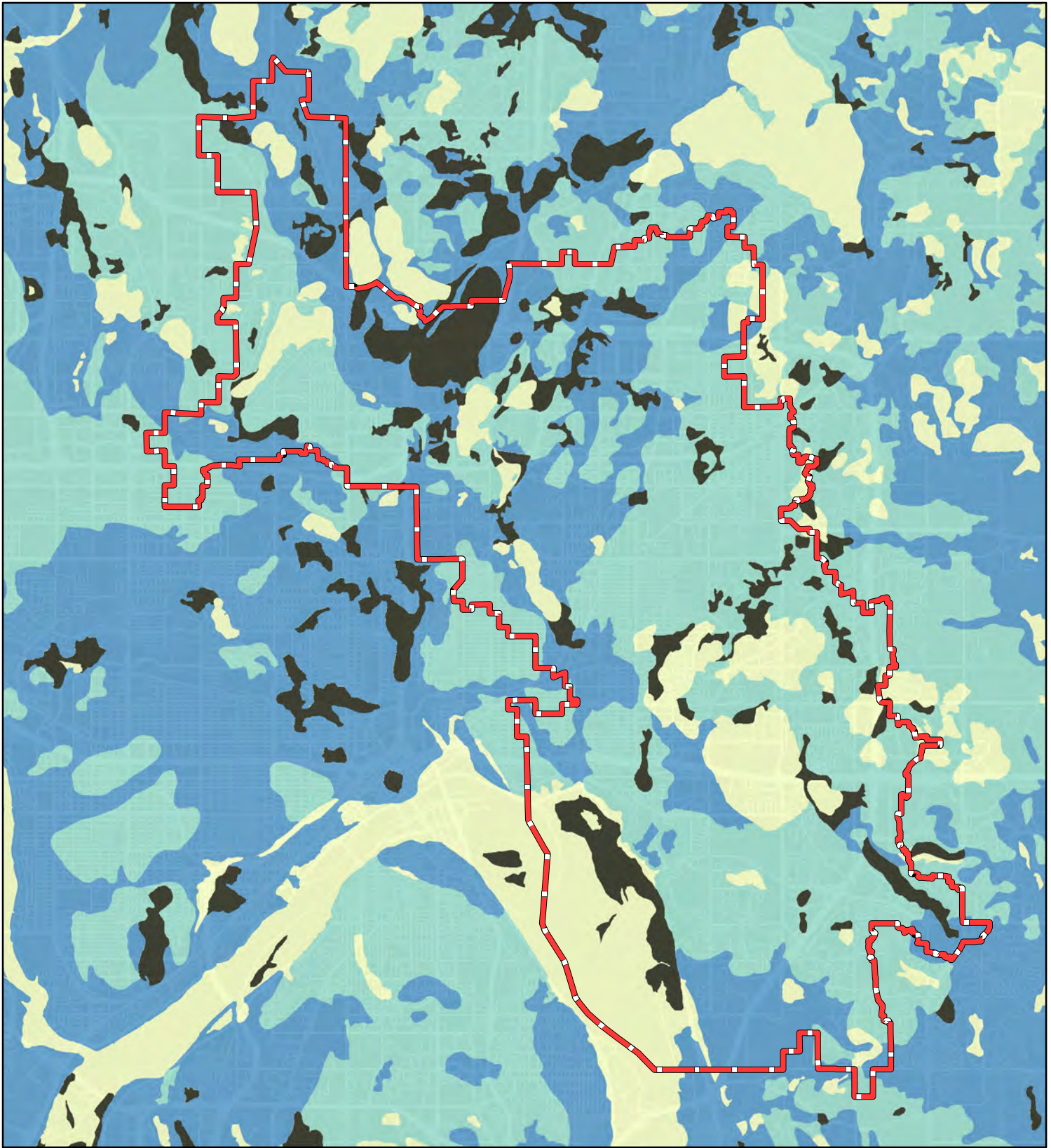
0 2 4



Figure 8

Simplified Surficial Geology
Groundwater/Surface Water
Interaction Study





RWMWD Boundary

**Surficial Geology
Score**



0



1



3



Infiltration no suitable



Miles

0 1 2



Kilometers

0 2 4



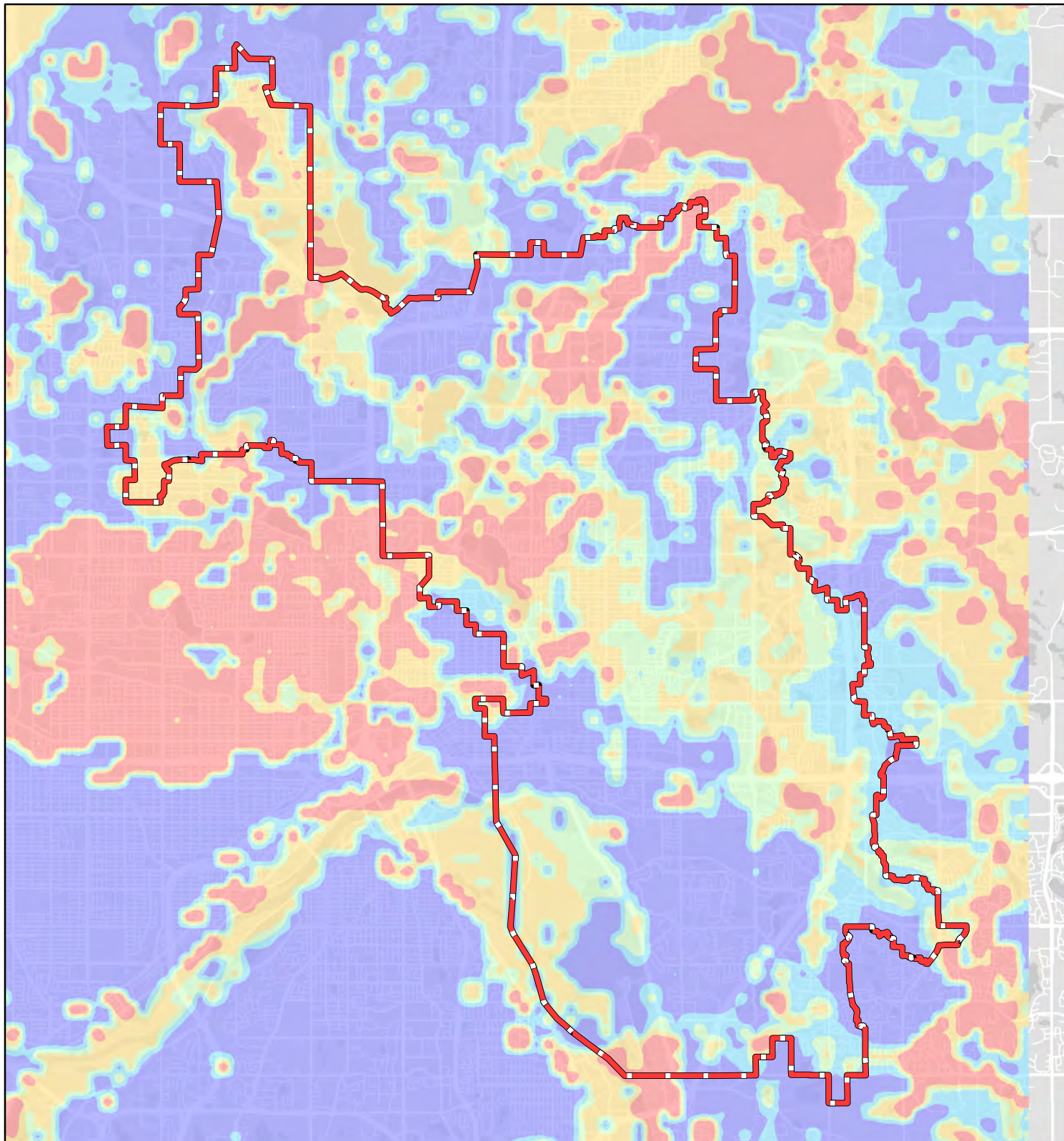
Figure 9

Surficial Geology Score
Groundwater/Surface Water
Interaction Study

Ramsey-Washington Metro

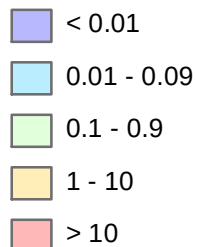


District



**Bulk Unsaturated
Hydraulic Conductivity**

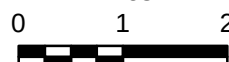
(ft/day)



RWMWD Boundary



Miles



Kilometers

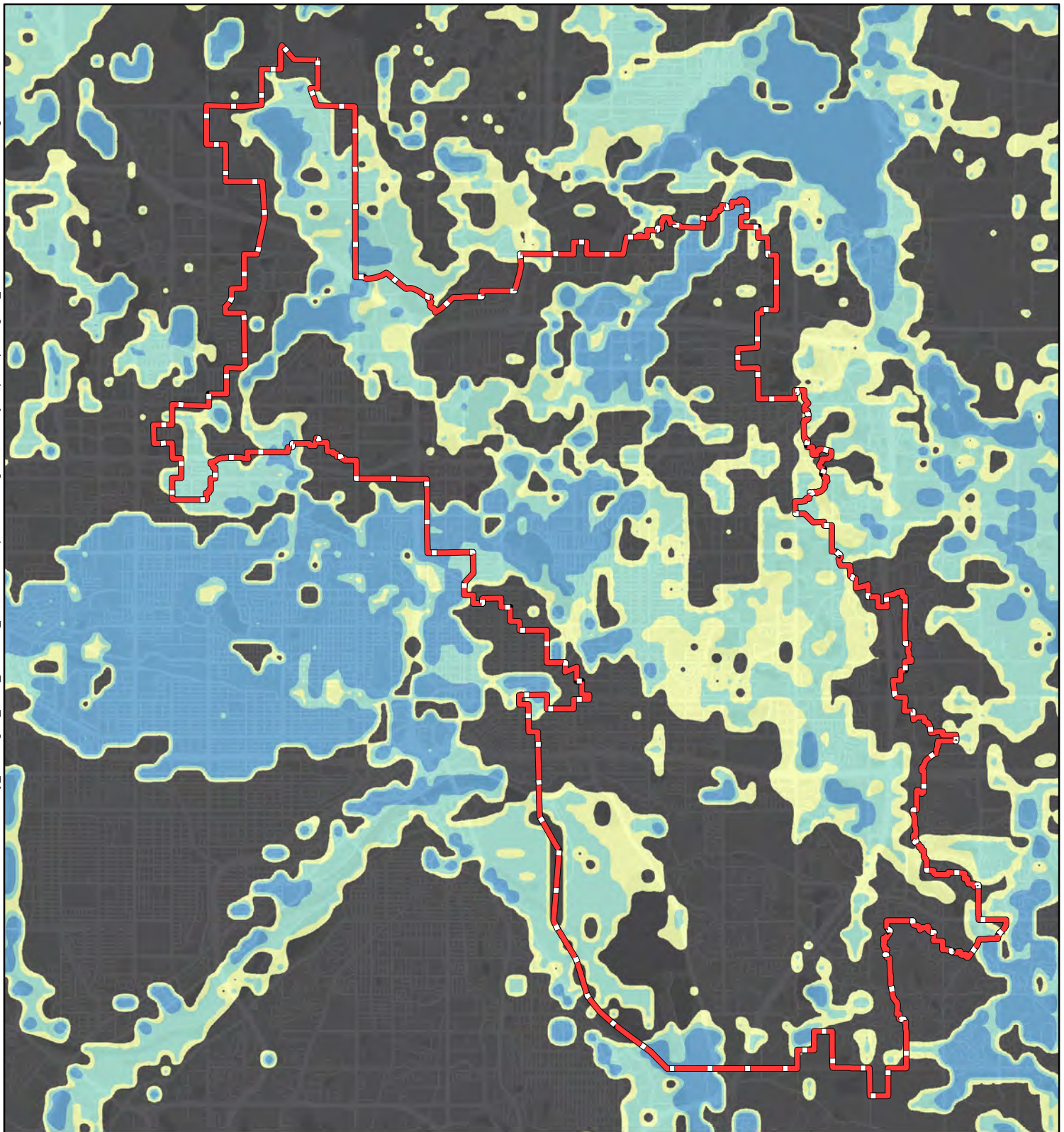


Figure 10

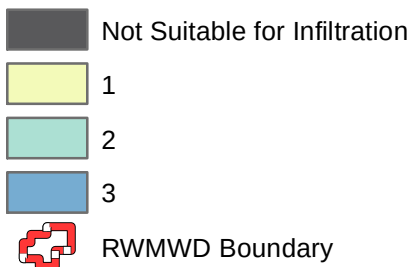
Bulk Unsaturated Zone
Hydraulic Conductivity
Groundwater/Surface Water
Interaction Study

Ramsey-Washington Metro

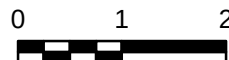




Bulk Unsat K Score



Miles



Kilometers

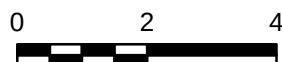
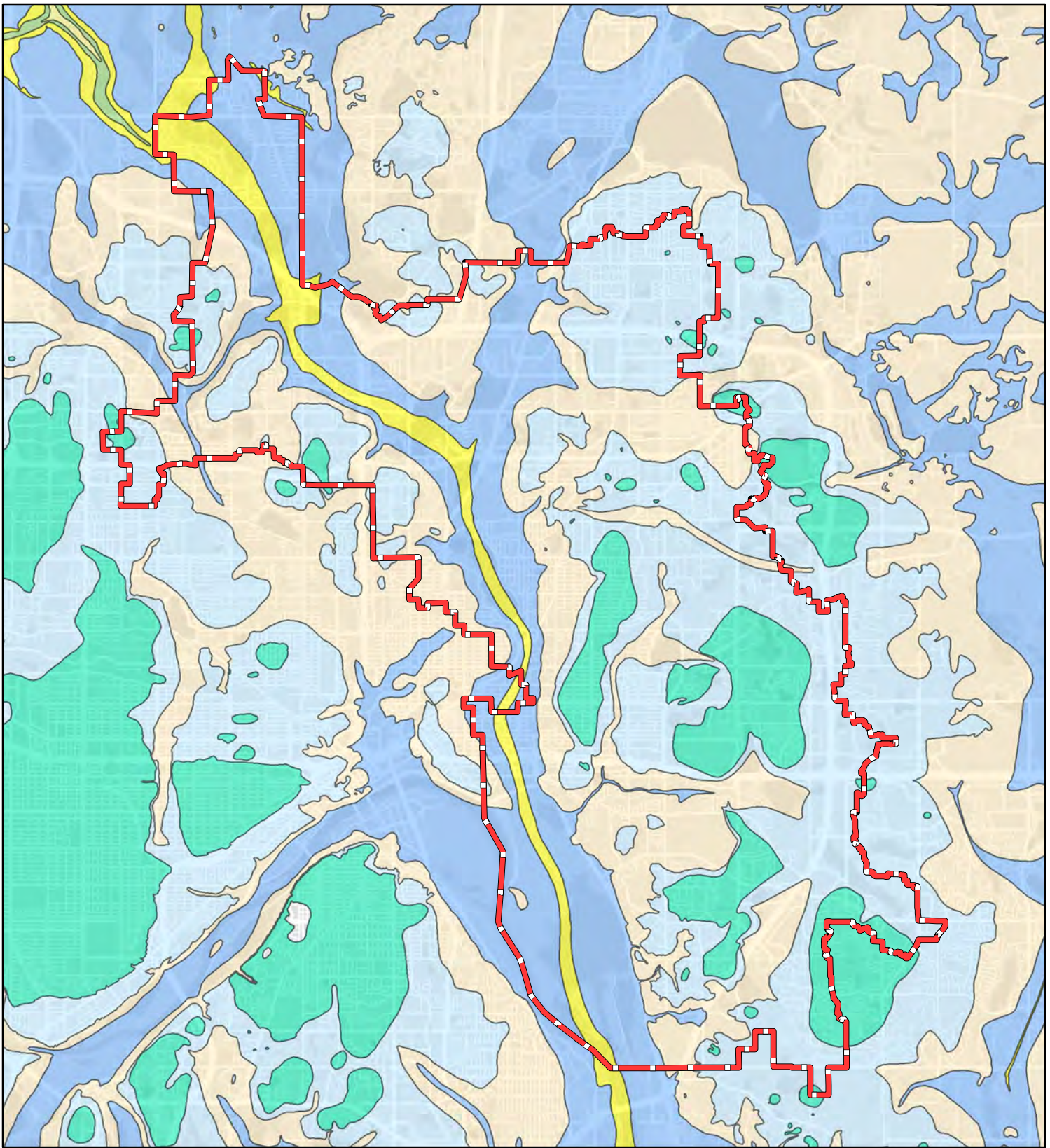


Figure 11

Bulk Unsat Saturated Hydraulic
Conductivity Score
Groundwater/Surface Water
Interaction Study





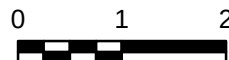
RWMWD Boundary

Bedrock Geology

- Decorah Shale, Galena Group
- Plattreville and Glenwood Fms
- St. Peter Sandstone
- Prairie du Chien Group
- Jordan Sandstone
- St. Lawrence Formation
- Tunnel City Group



Miles



Kilometers

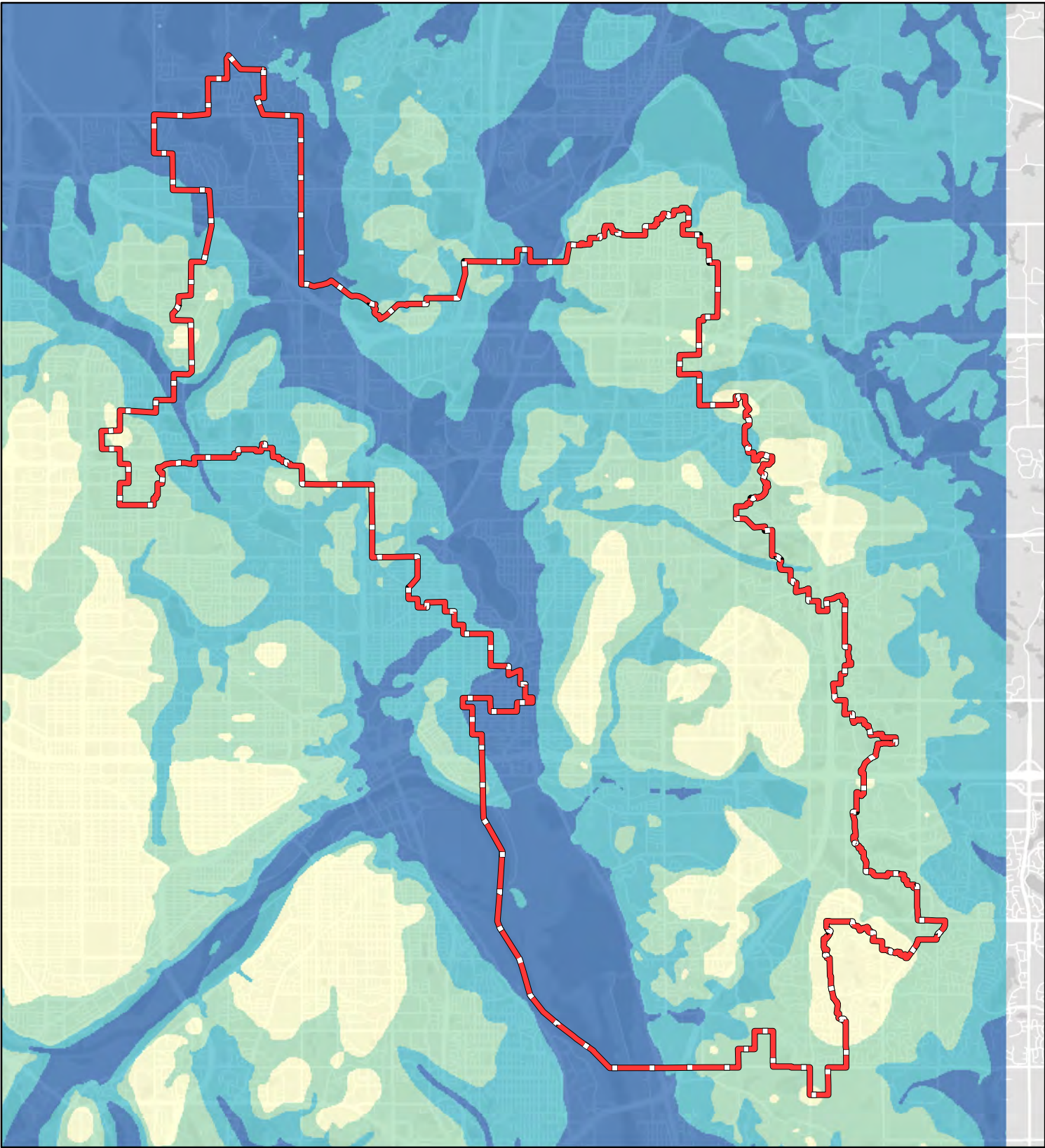


Figure 12

Bedrock Geology
Groundwater/Surfacewater
Interaction Study

Ramsey-Washington Metro





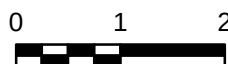
**Upper Bedrock
Confining Unit
Score**



RWMWD Boundary



Miles



Kilometers

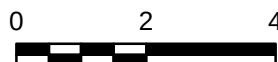
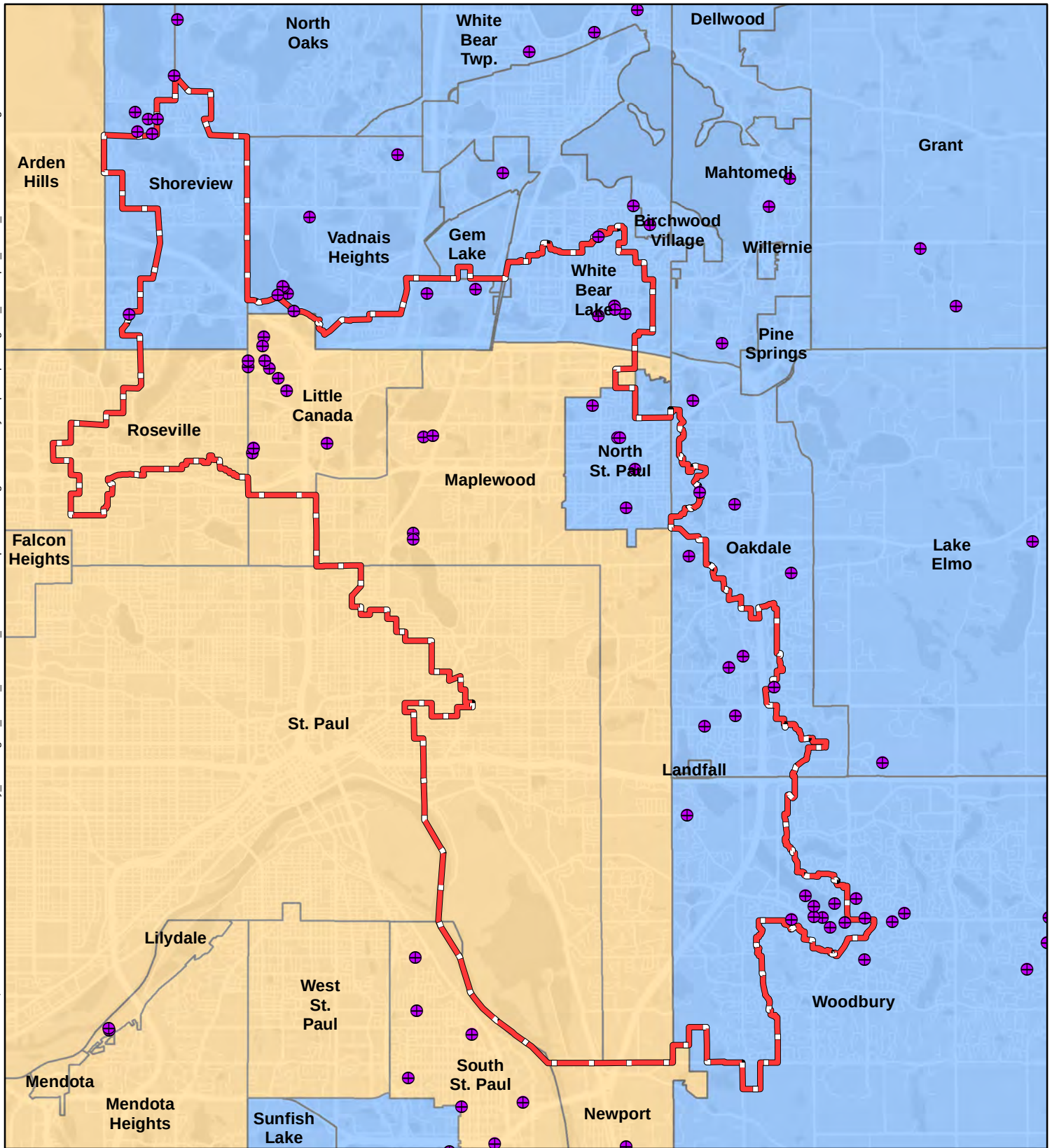


Figure 13

Upper Bedrock Confining Unit Score
Groundwater/Surface Water
Interaction Study





RWMWD Boundary



Municipal Supply Well

Municipal Water Source



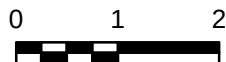
Surface-water and
groundwater



Groundwater



Miles



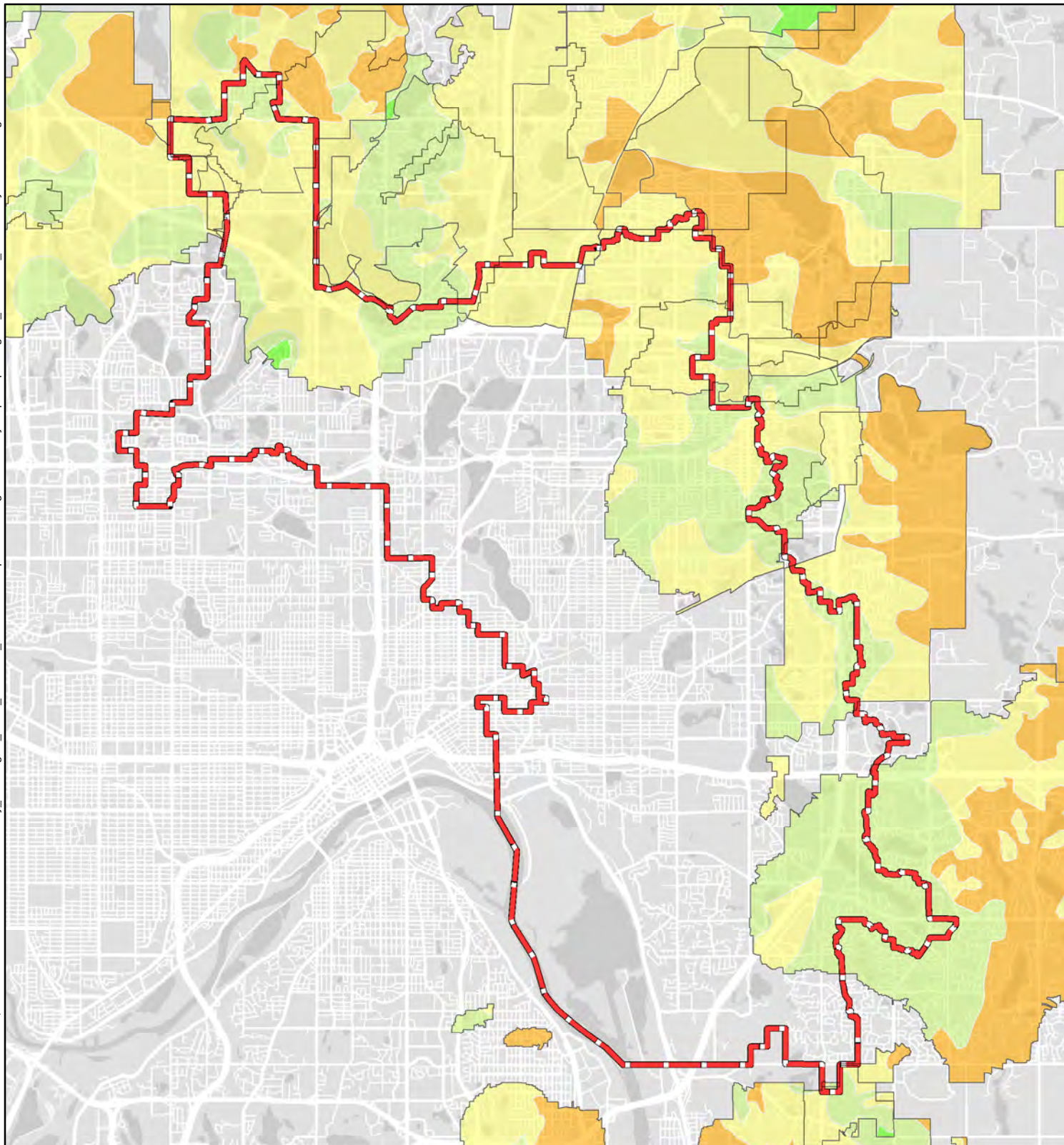
Kilometers



Figure 14

Municipal Water Source
Groundwater/Surface Water
Interaction Study





 RWMWD Boundary

 Drinking Water Supply Management Area (DWSMA)

DWSMA Vulnerability

 Very High

 High

 Moderate

 Low

 Very Low



Miles

0 1 2



Kilometers

0 2 4

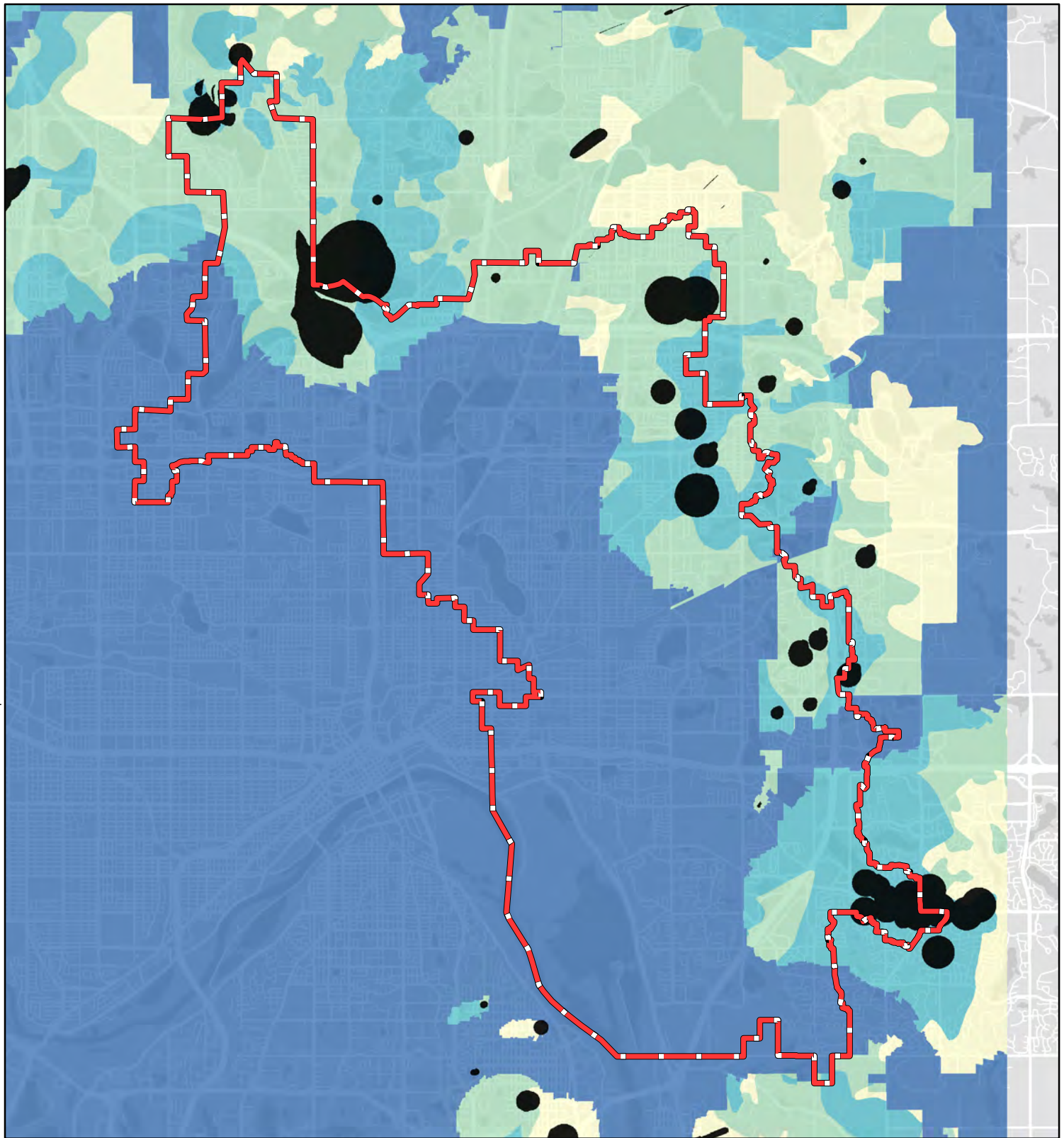


Figure 15

Drinking Water Supply
Management Areas
Groundwater/Surface Water
Interaction Study

Ramsey-Washington Metro





RWMWD Boundary

DWSMA Vulnerability Score



1



2



3



4



1-yr capture zone, infiltration not appropriate



Miles

0 1 2



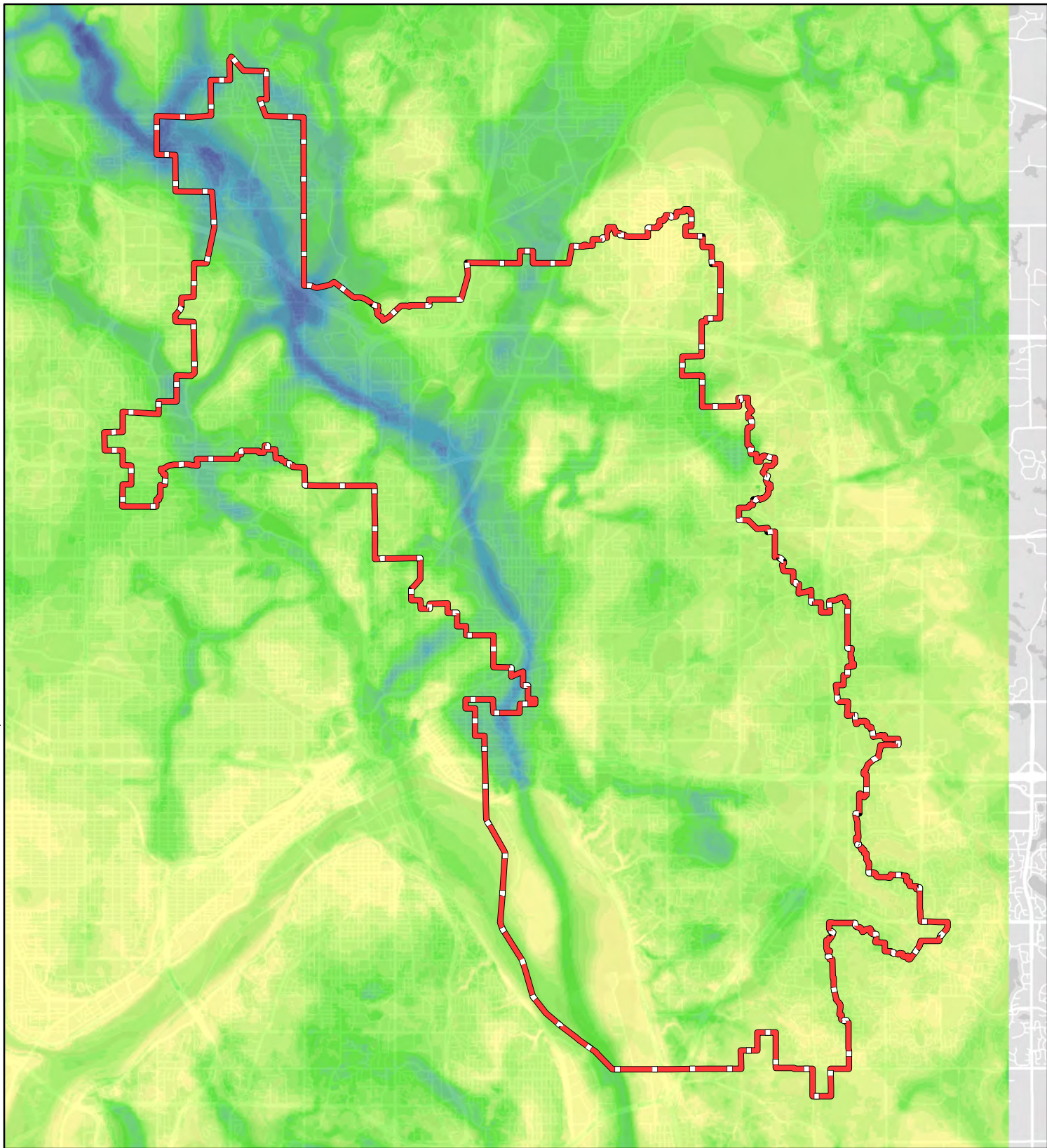
Kilometers

0 2 4



Figure 16

DWSMA Vulnerability Score
Groundwater/Surface Water
Interaction Study



RWMWD Boundary

Depth to Bedrock

(feet)

0 - 25

26 - 50

51 - 75

76 - 100

101 - 125

126 - 150

151 - 175

176 - 200

201 - 225

226 - 250

251 - 275

276 - 300

301 - 325

326 - 350

351 - 375

376 - 400

401 - 425

426 - 450

451 - 475

476 - 500

501 - 525

526 - 550



Miles



Kilometers

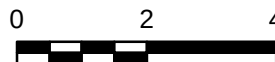
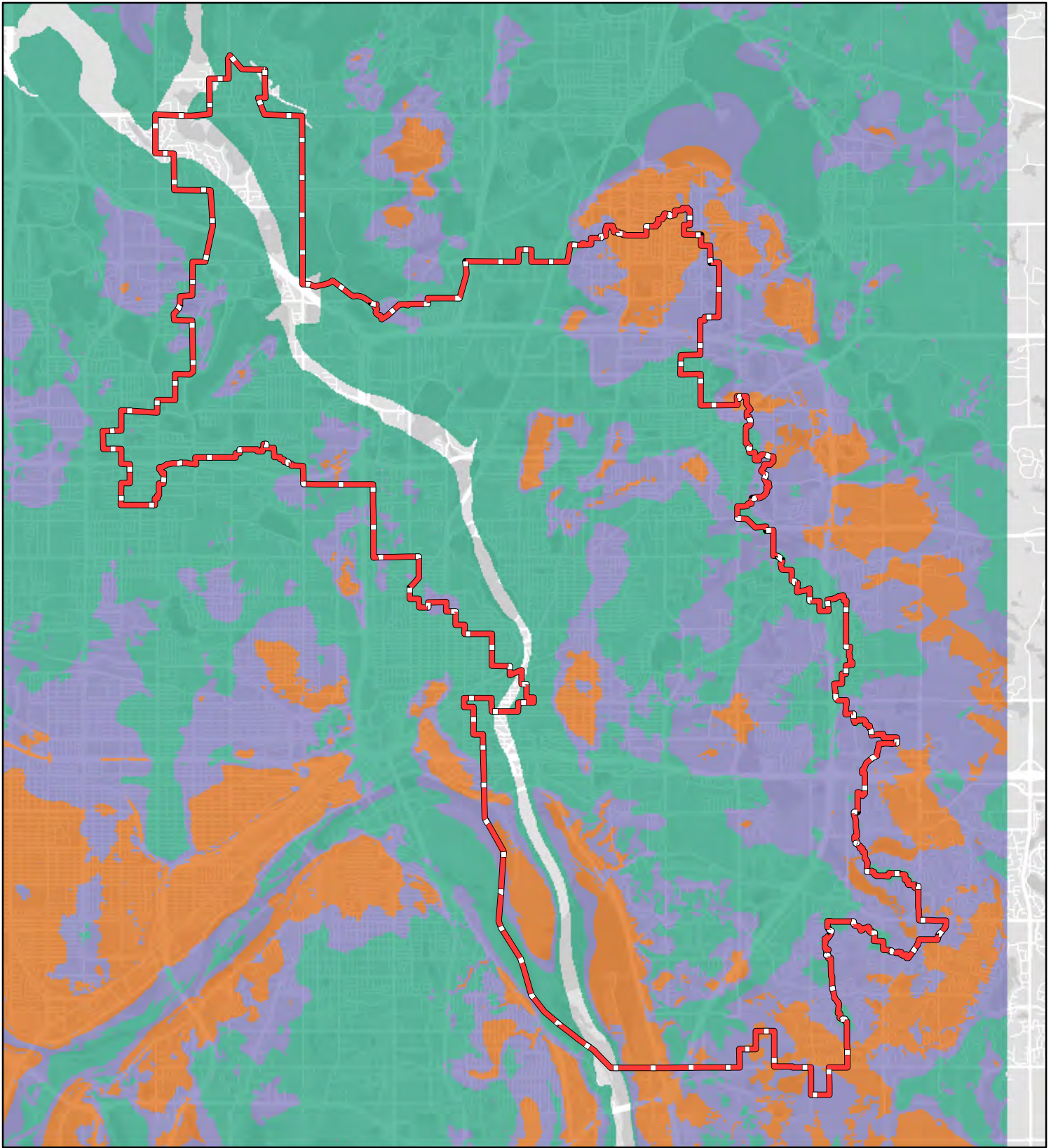


Figure 17

Depth to Bedrock
Groundwater/Surface Water
Interaction Study

Ramsey-Washington Metro





-  RWMWD Boundary
-  Covered Karst
-  Transition Karst
-  Active Karst

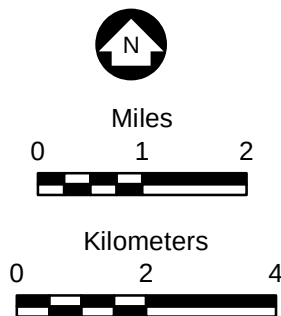
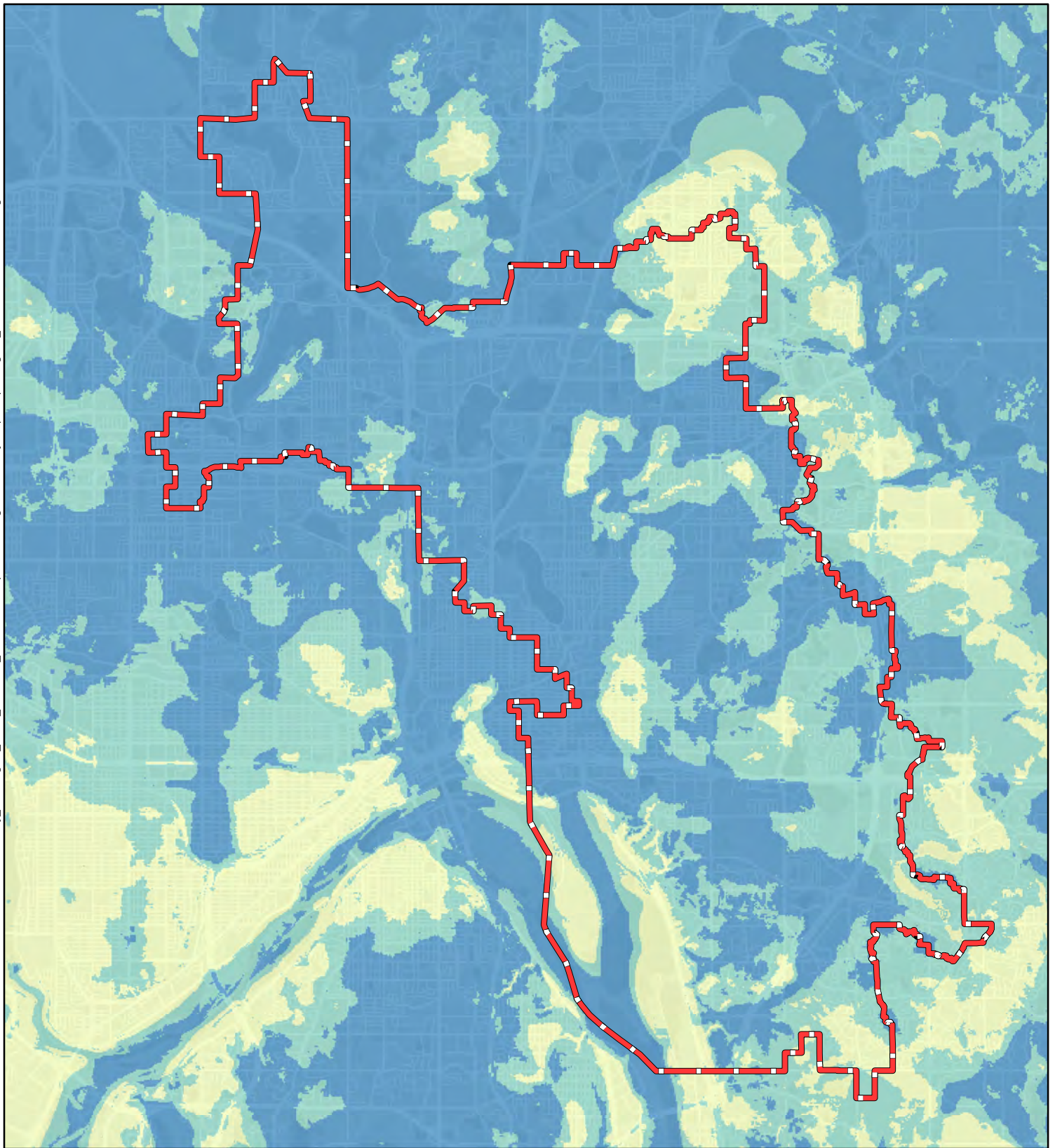


Figure 18

Karst Areas
Groundwater/Surface Water
Interaction Study





Karst Areas



RWMWD Boundary



Miles



Kilometers

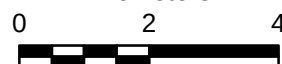


Figure 19

Karst Areas Score
Groundwater/Surface Water
Interaction Study



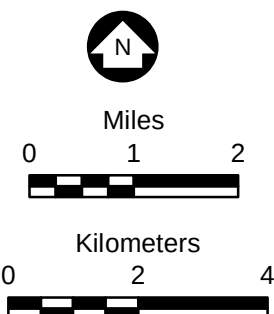
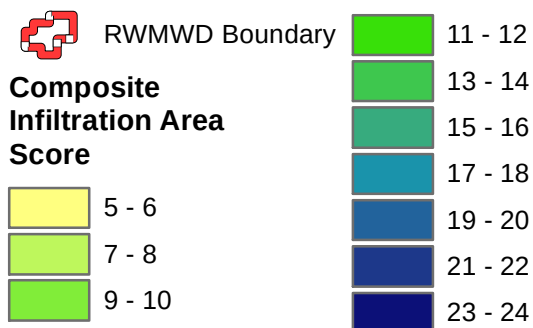
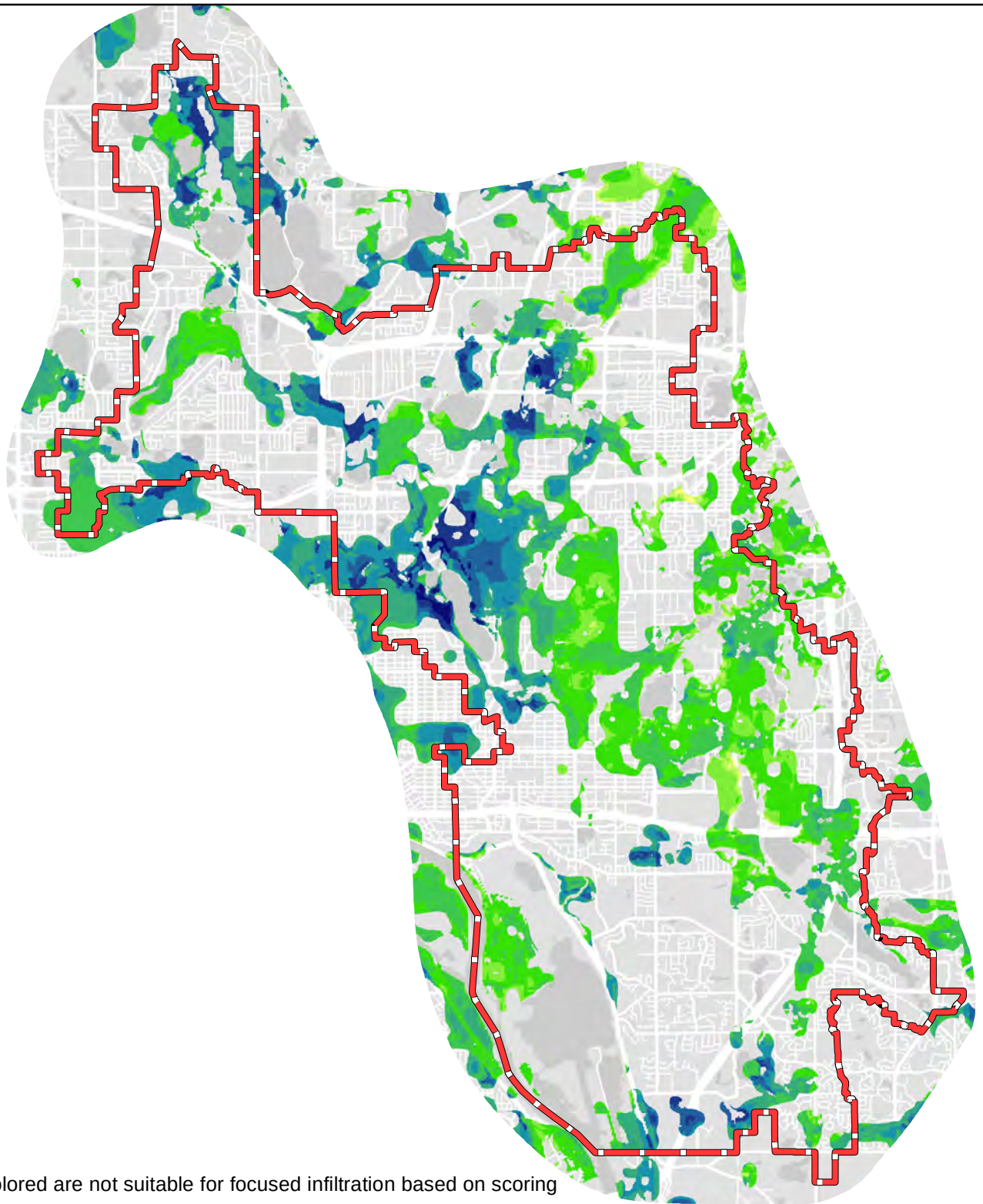


Figure 20

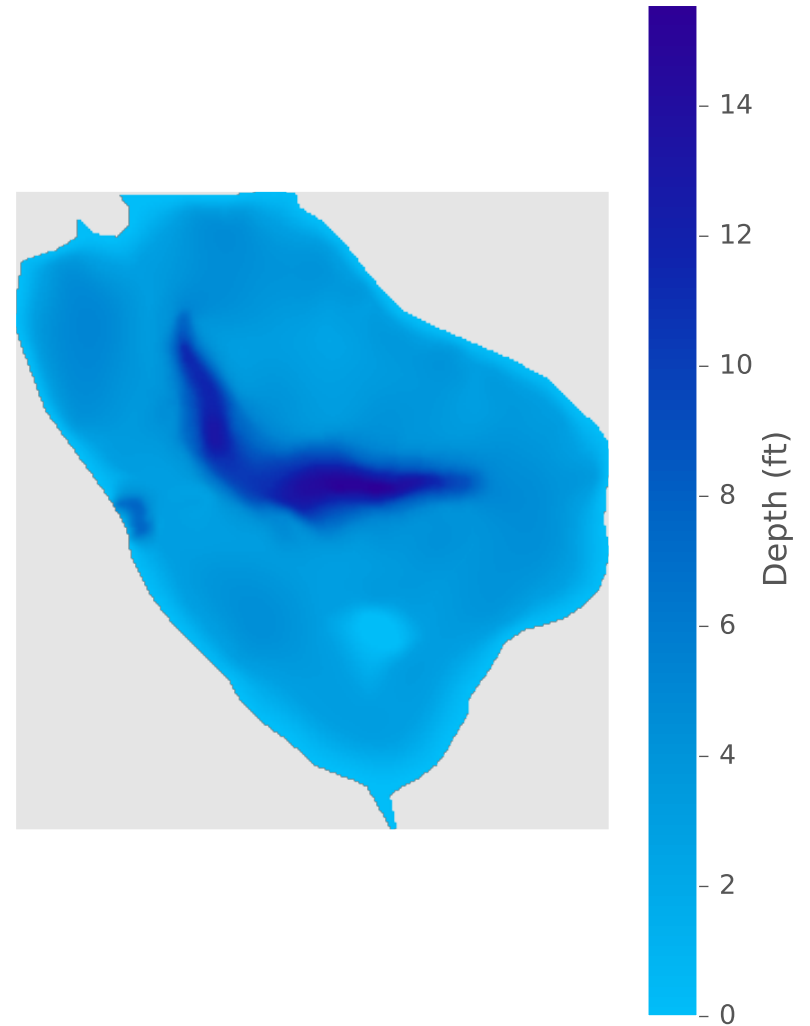
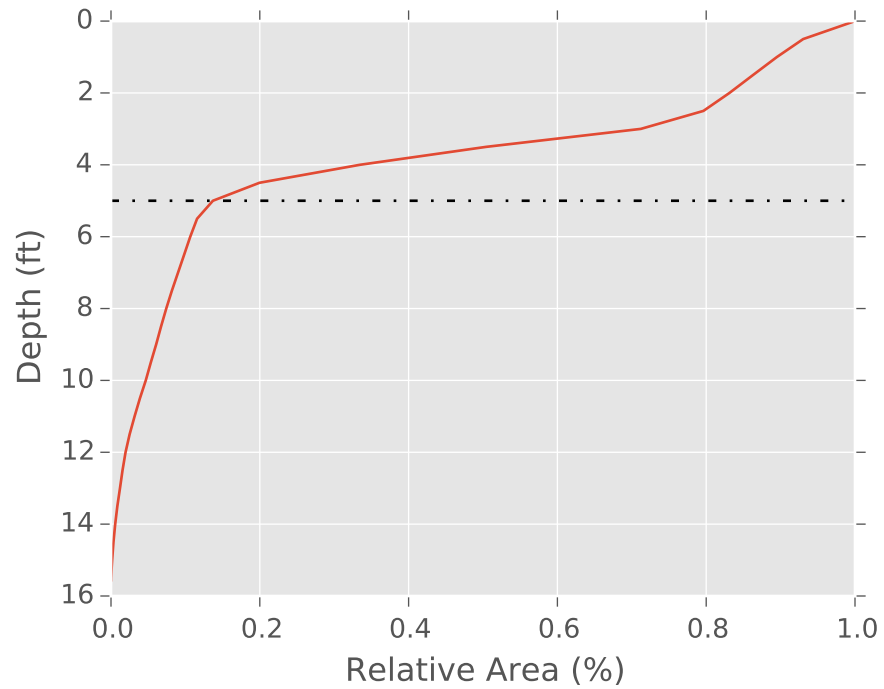
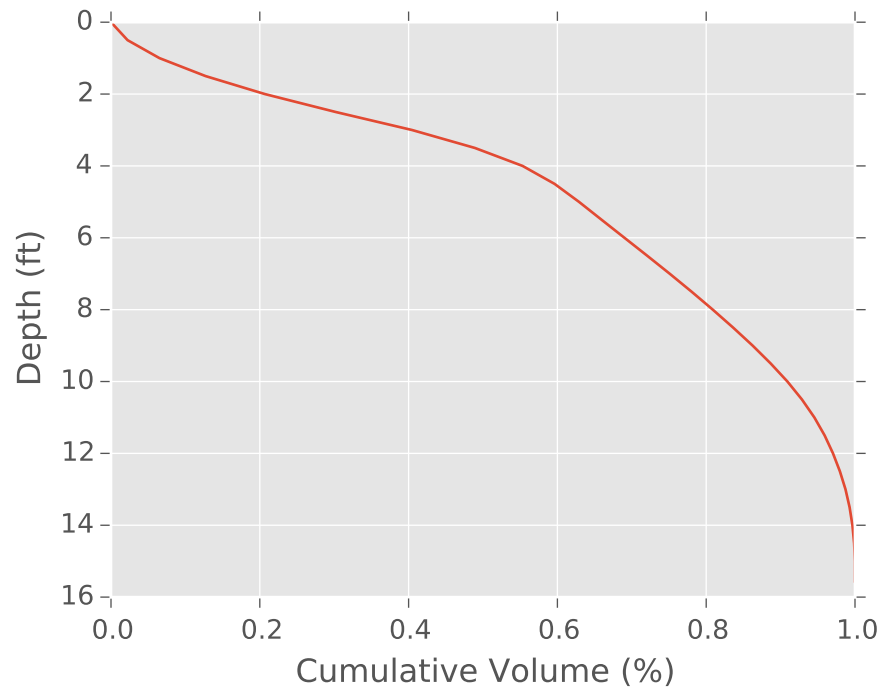
Composite Infiltration
Area Score
Groundwater/Surface Water
Interaction Study
Ramsey-Washington Metro
 District

Appendices

Appendix A

Basin Bathymetry and Geometry

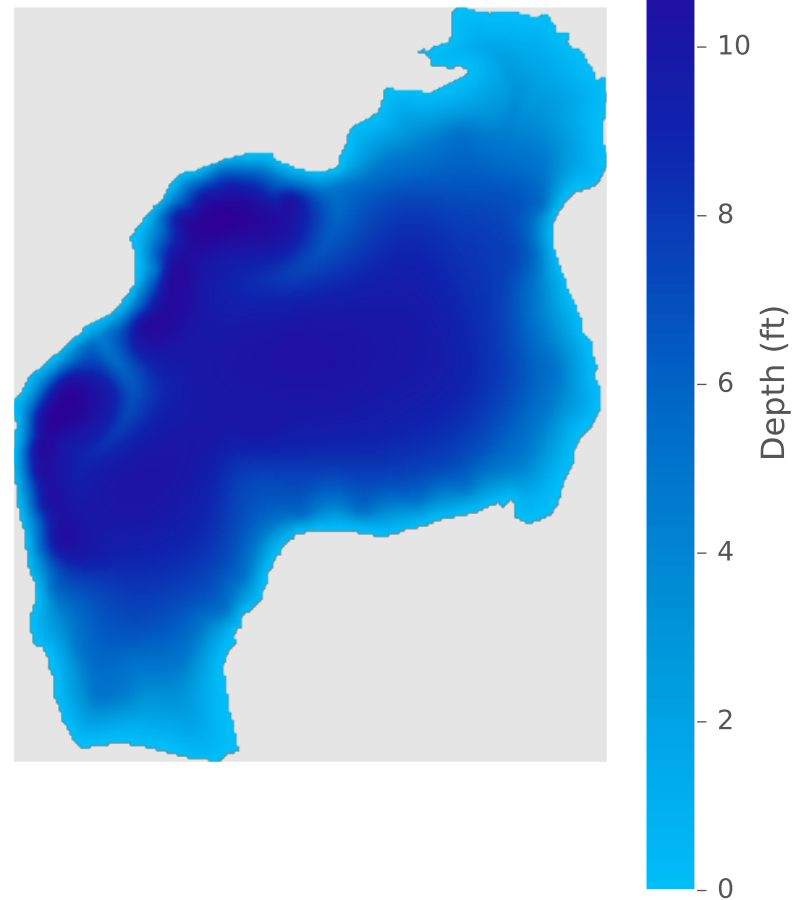
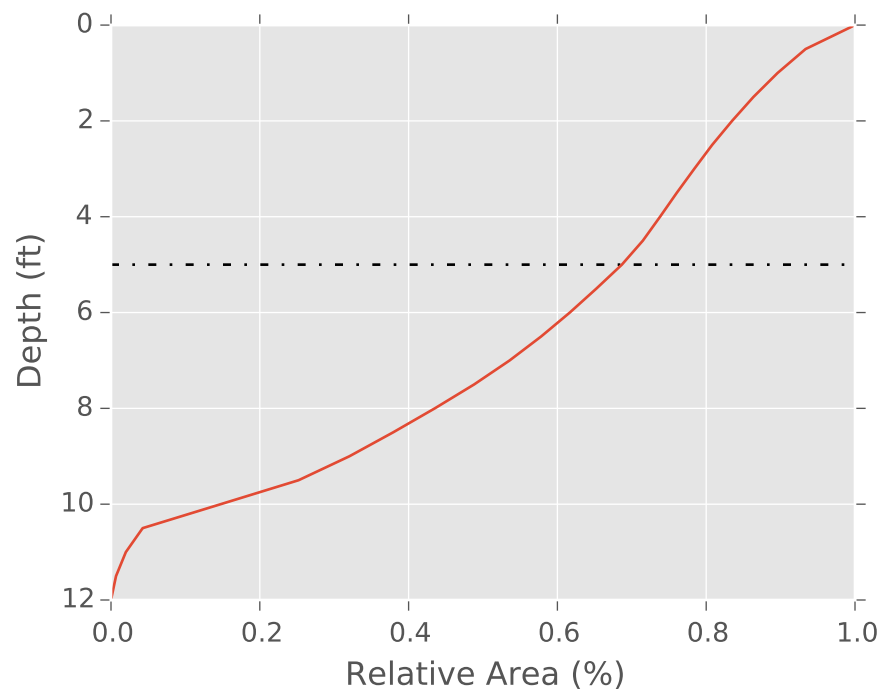
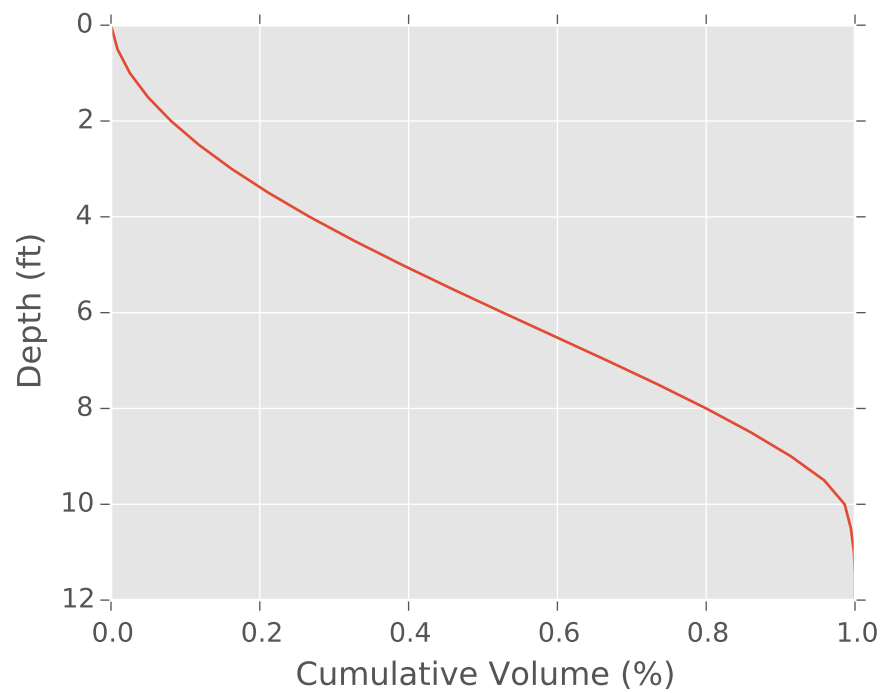
Battle_Creek



Maximum depth: 16 feet

Mean Depth: 3.8 feet

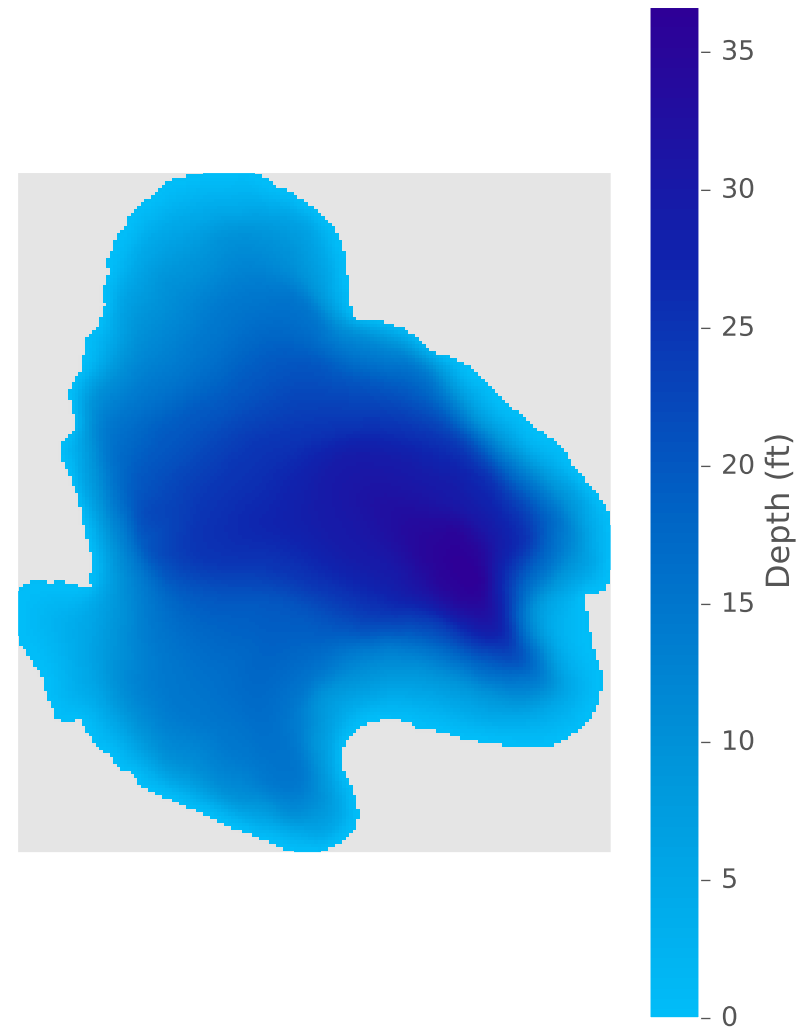
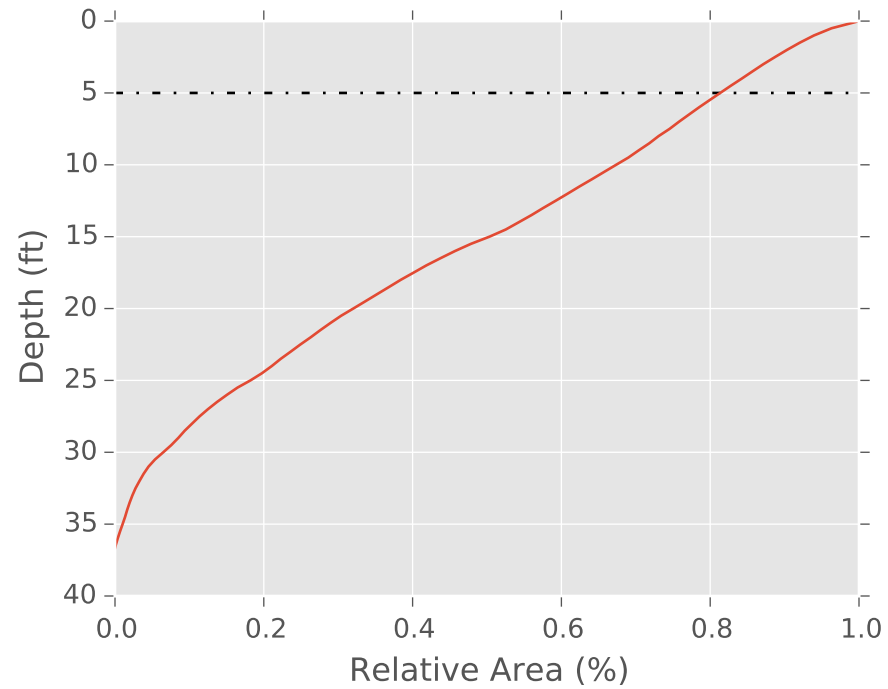
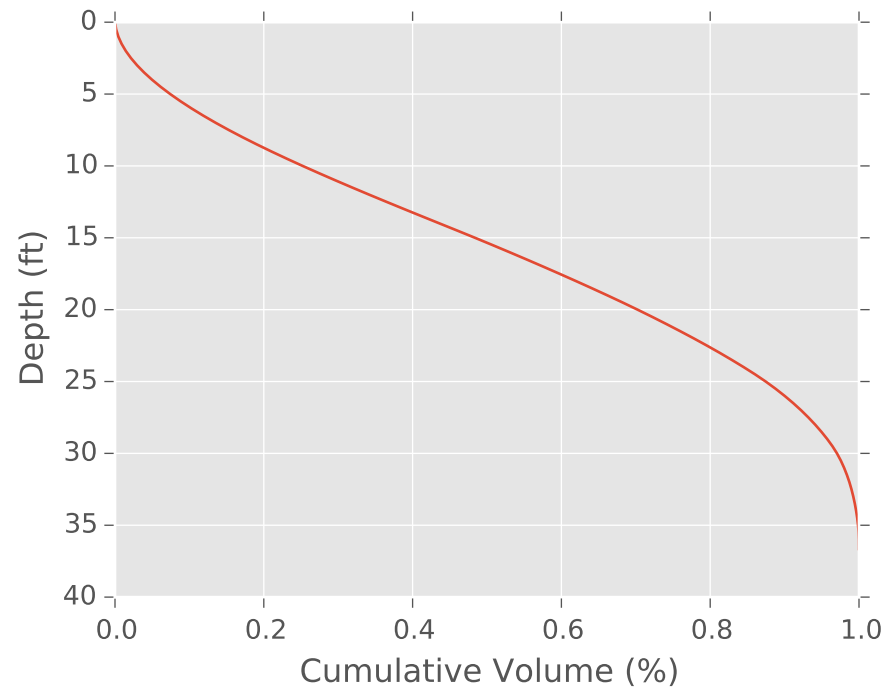
Beaver



Maximum depth: 12 feet

Mean Depth: 6.5 feet

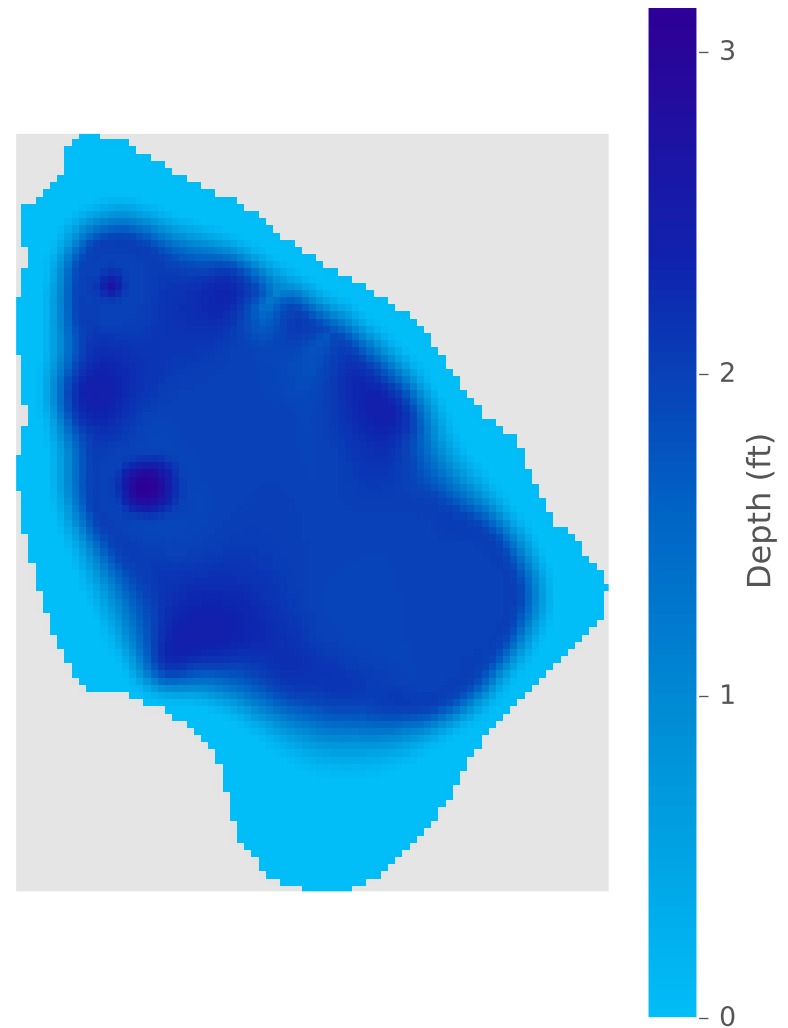
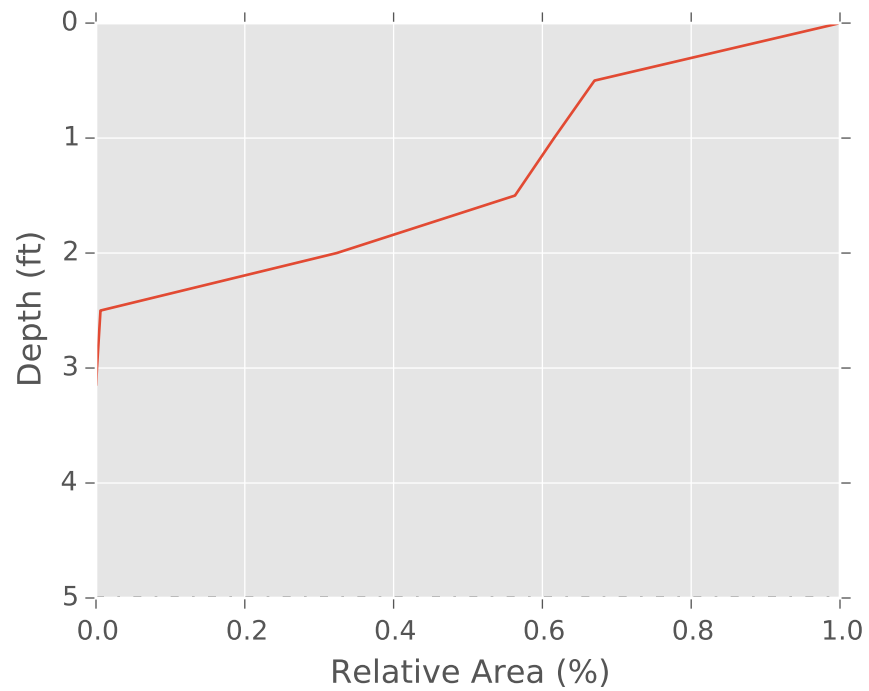
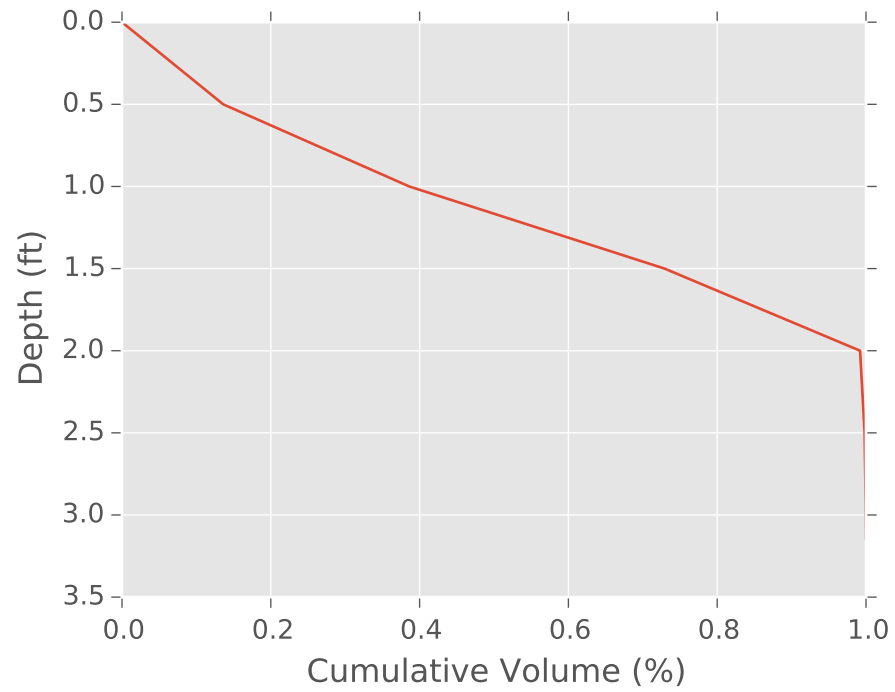
Carver



Maximum depth: 37 feet

Mean Depth: 15.2 feet

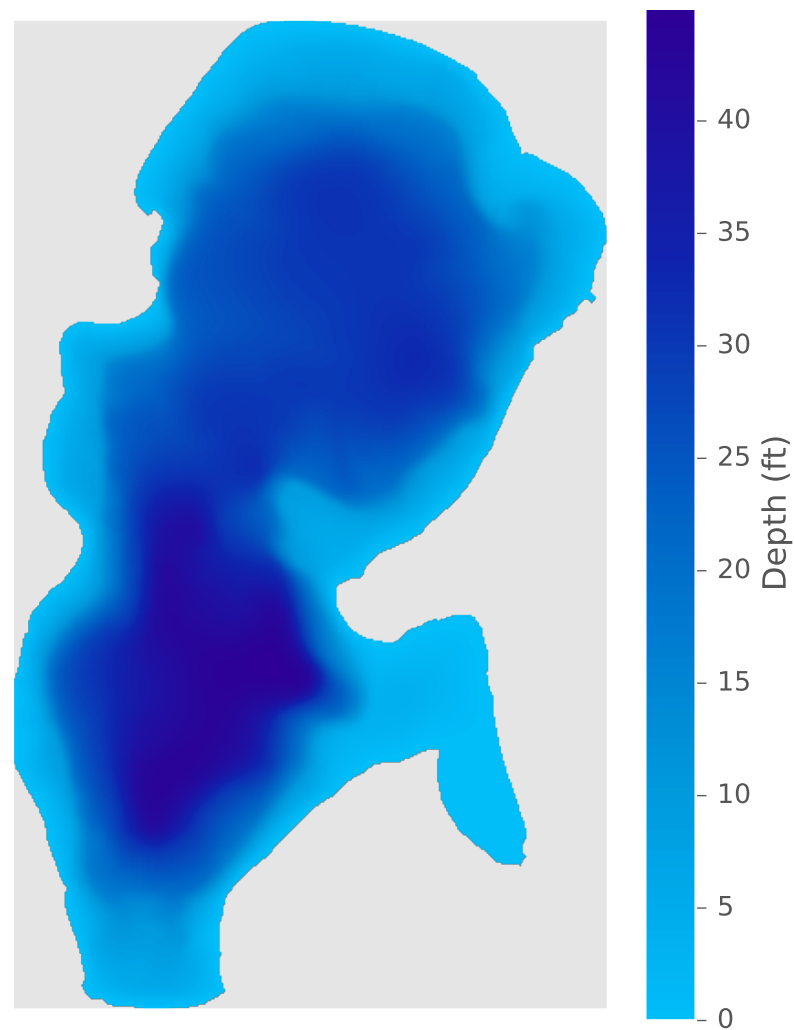
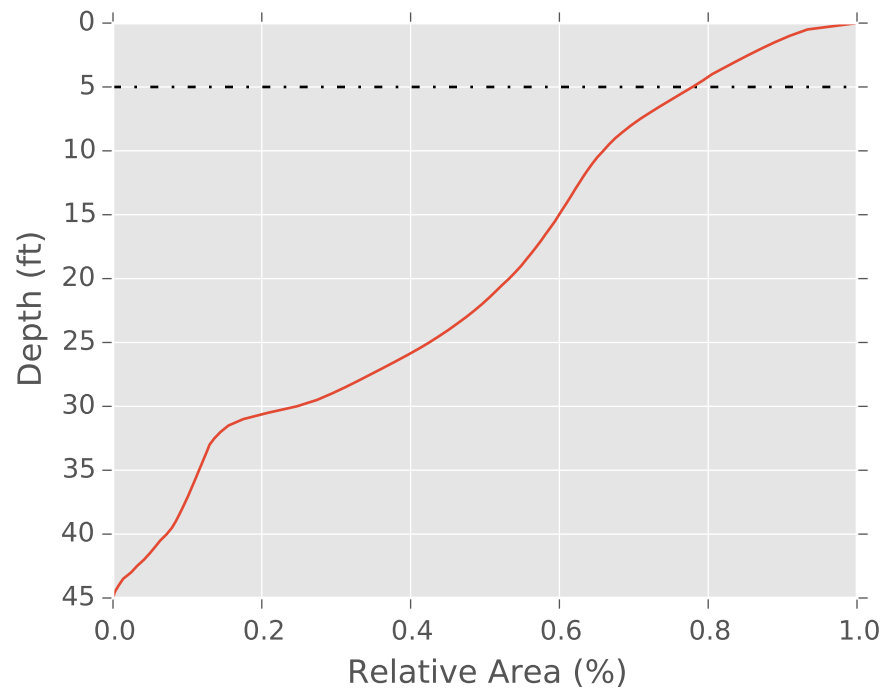
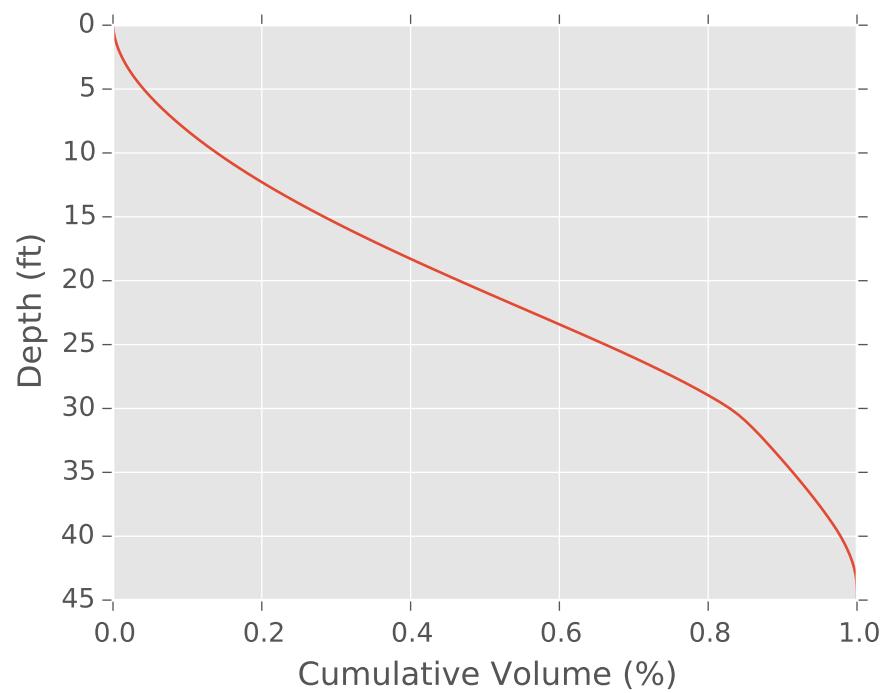
Casey



Maximum depth: 3 feet

Mean Depth: 1.3 feet

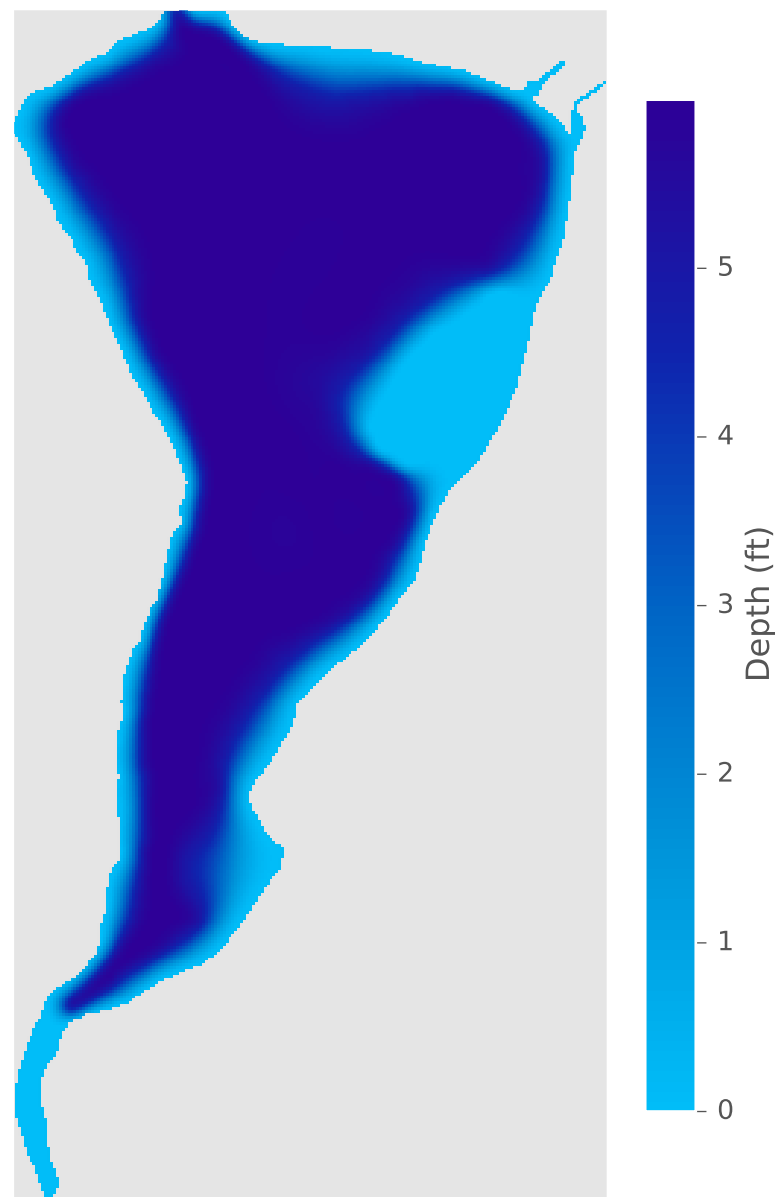
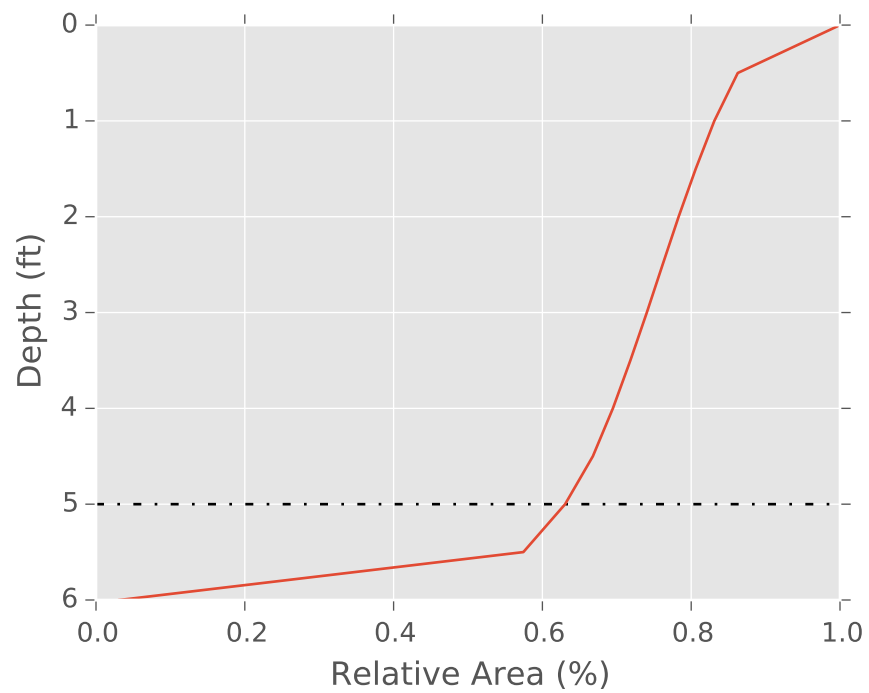
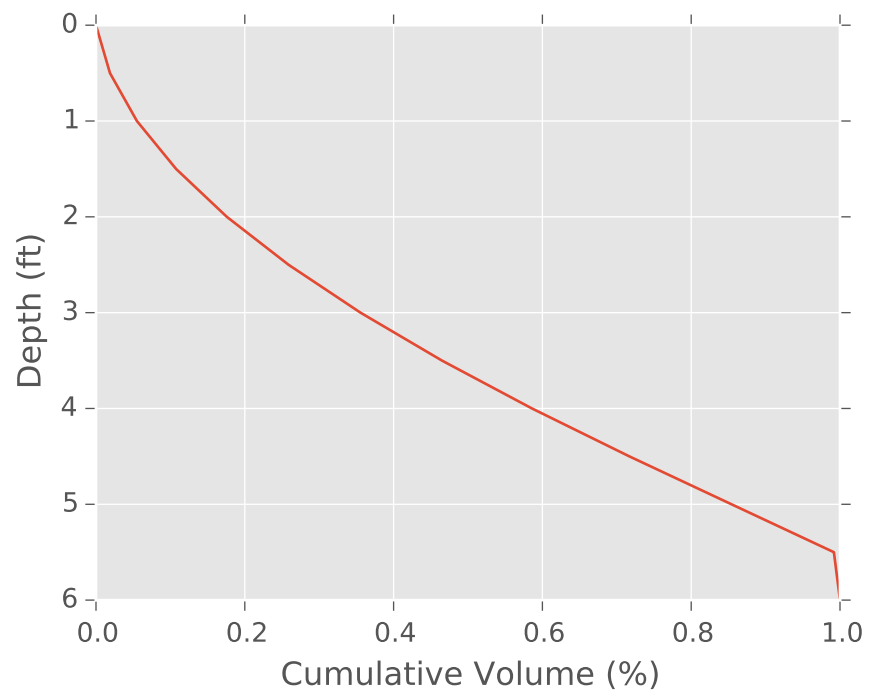
Gervais



Maximum depth: 45 feet

Mean Depth: 19.4 feet

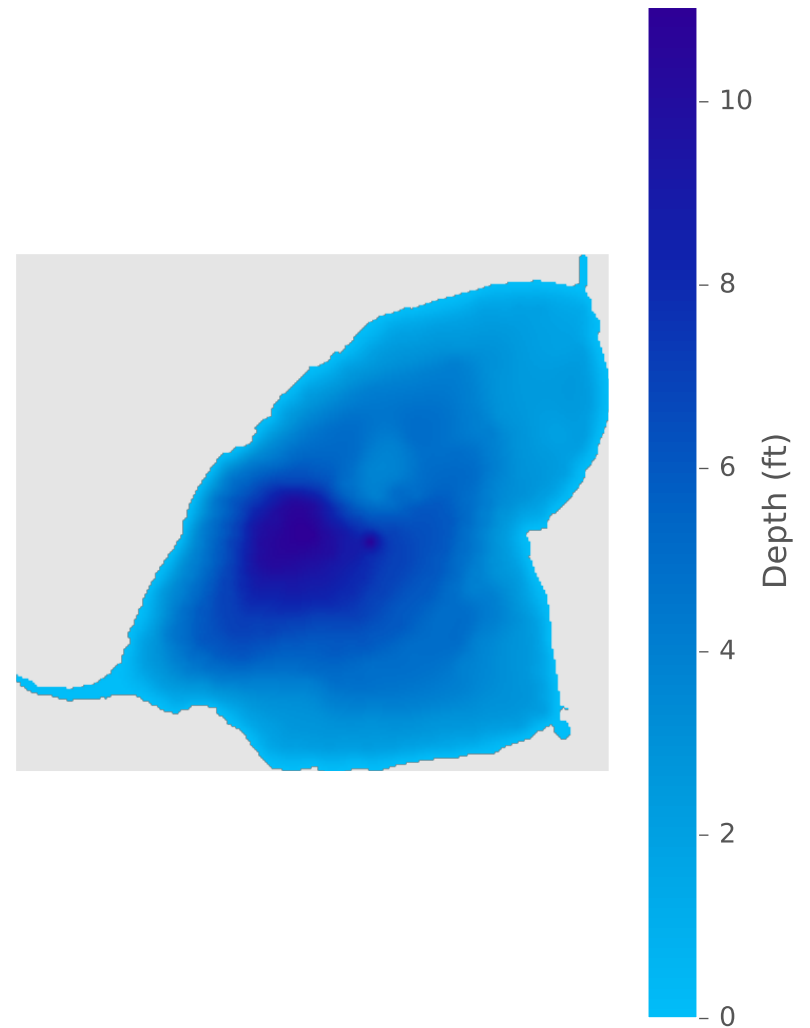
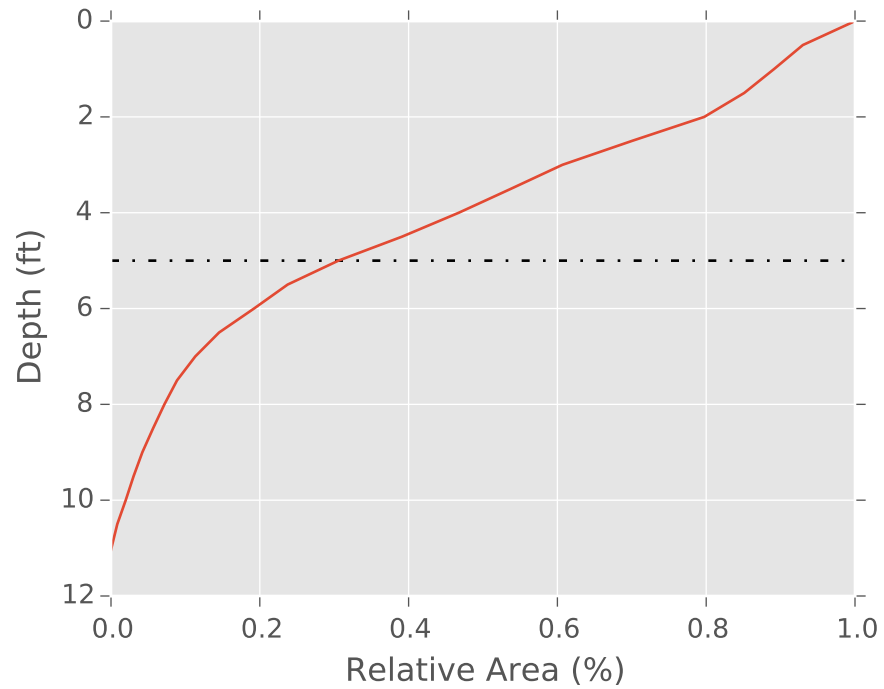
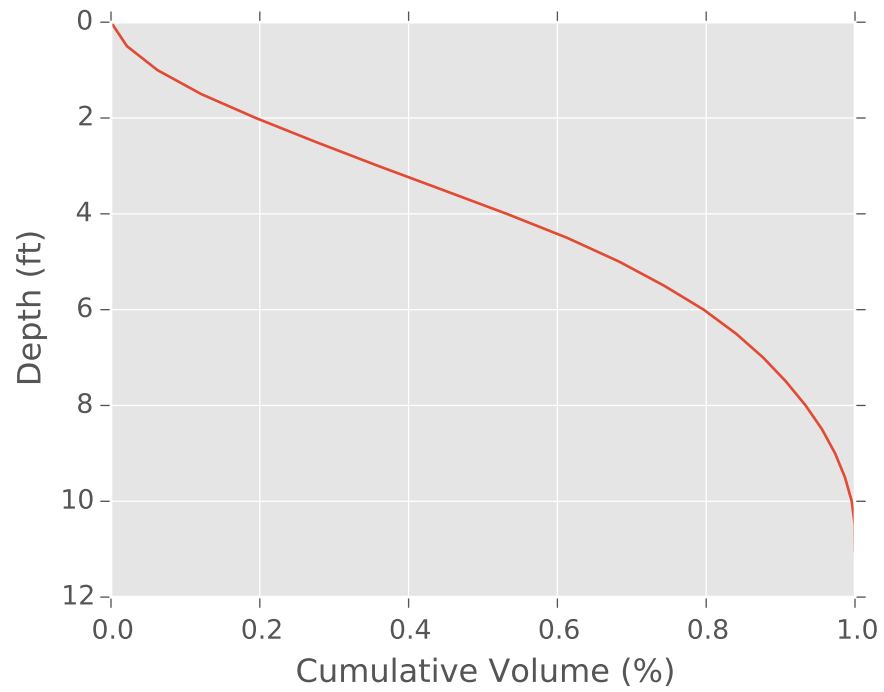
Keller



Maximum depth: 6 feet

Mean Depth: 4.4 feet

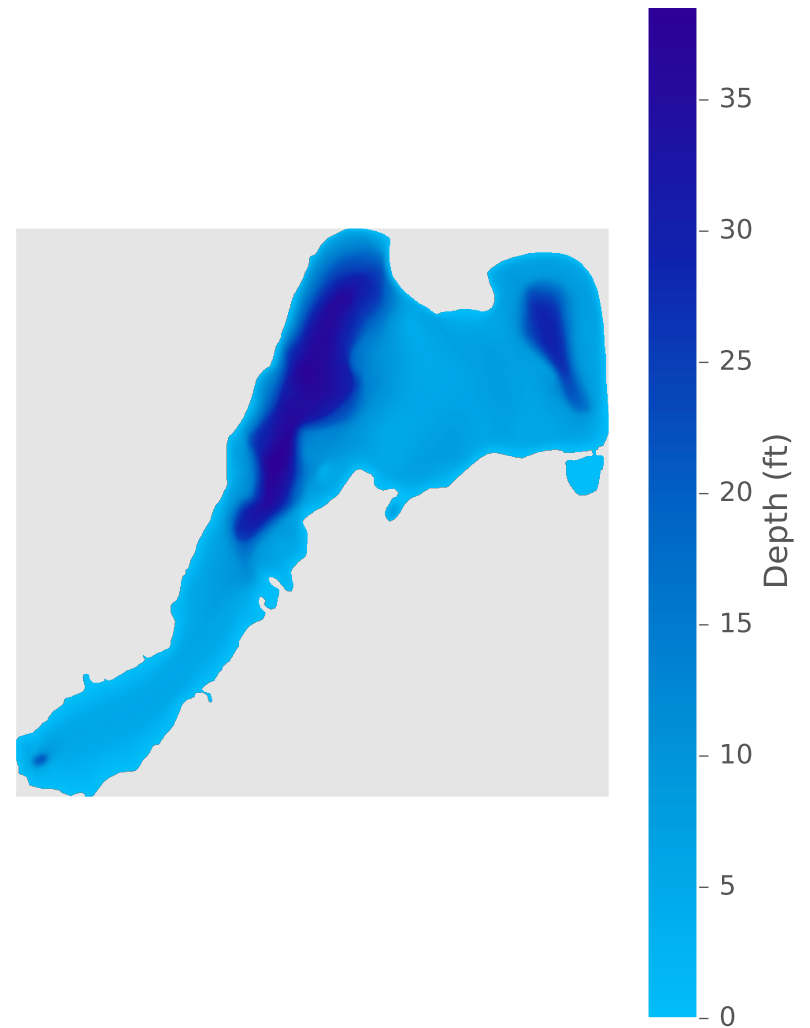
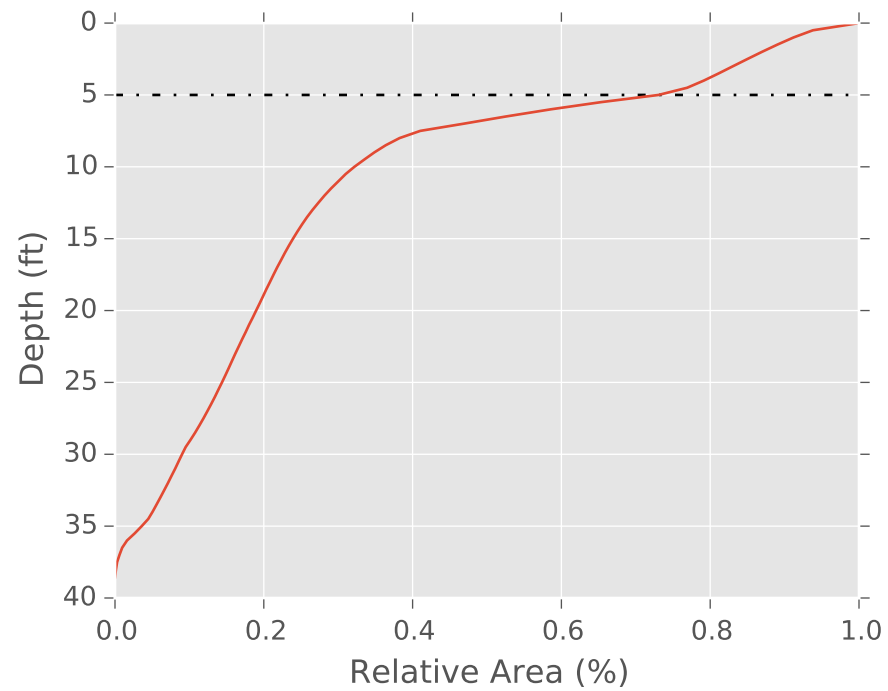
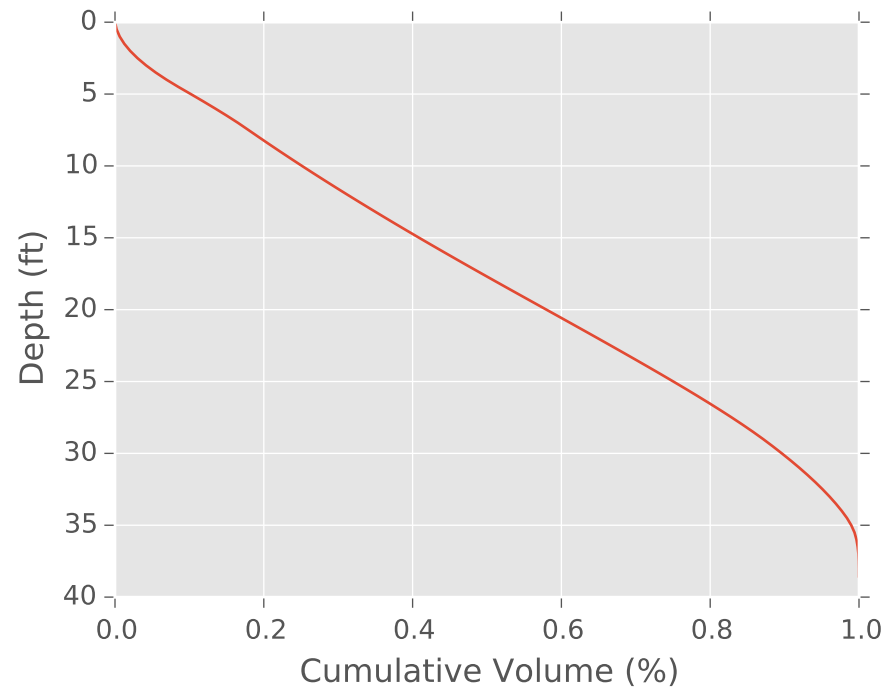
Kohlman



Maximum depth: 11 feet

Mean Depth: 4.0 feet

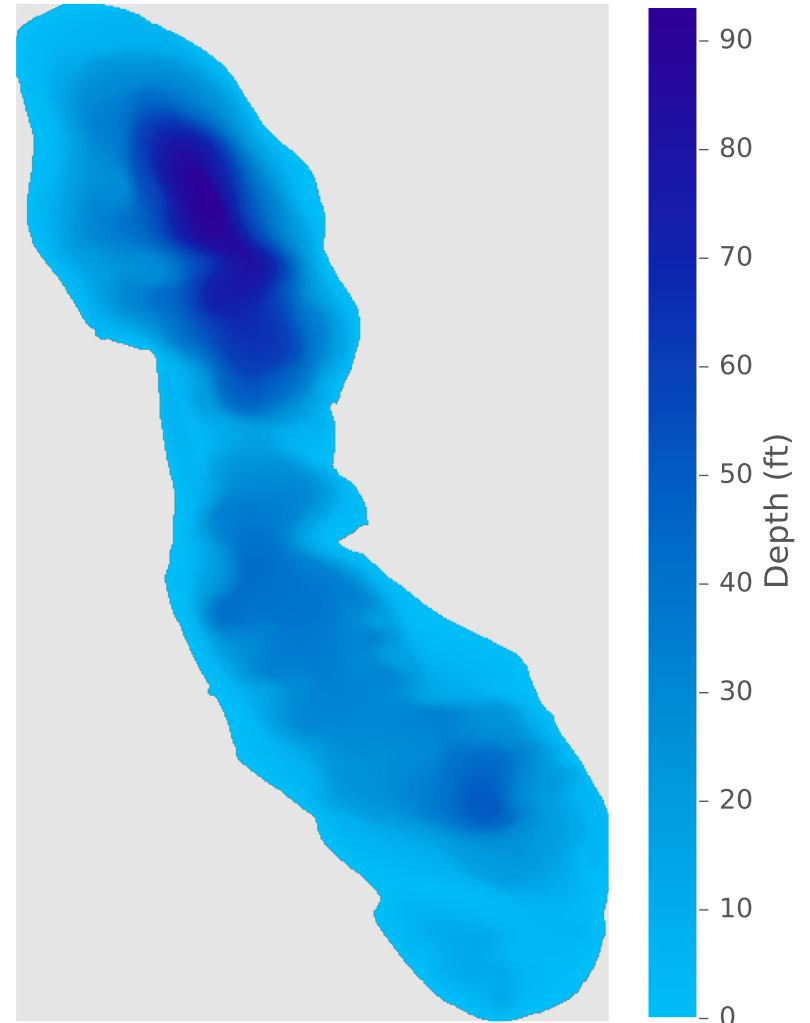
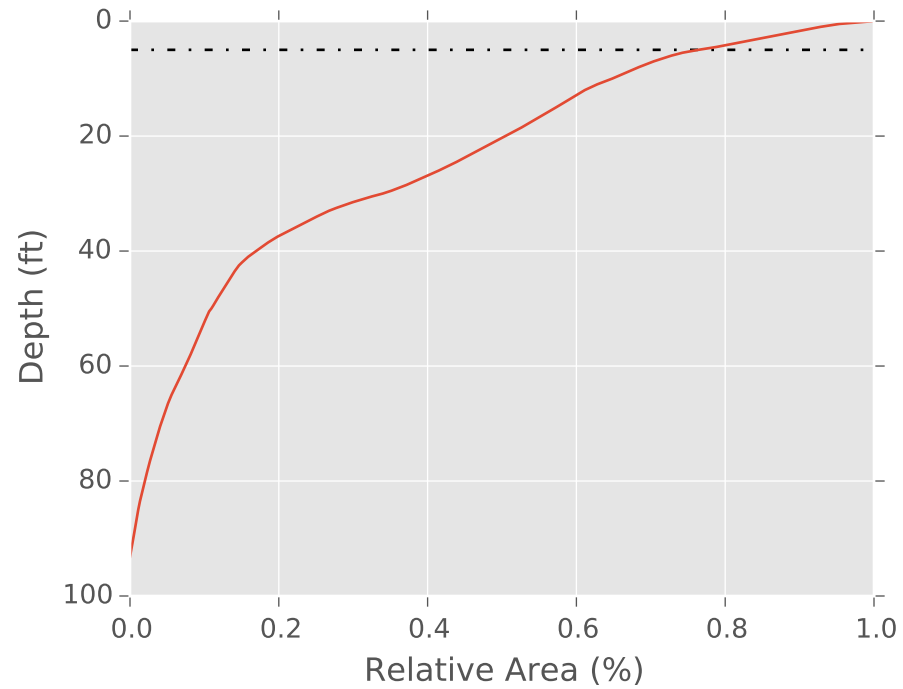
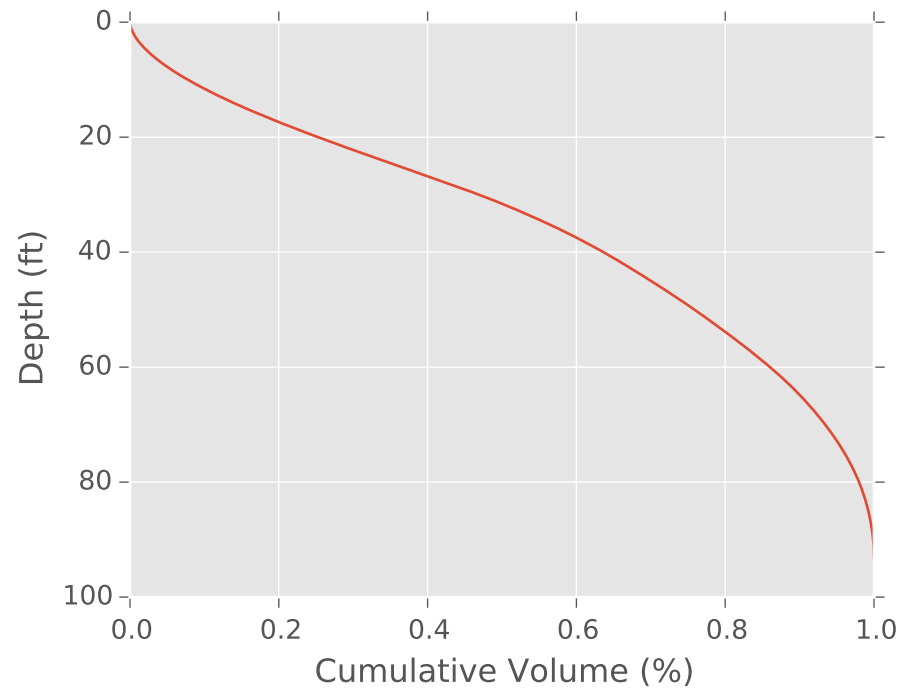
Owasso



Maximum depth: 39 feet

Mean Depth: 10.8 feet

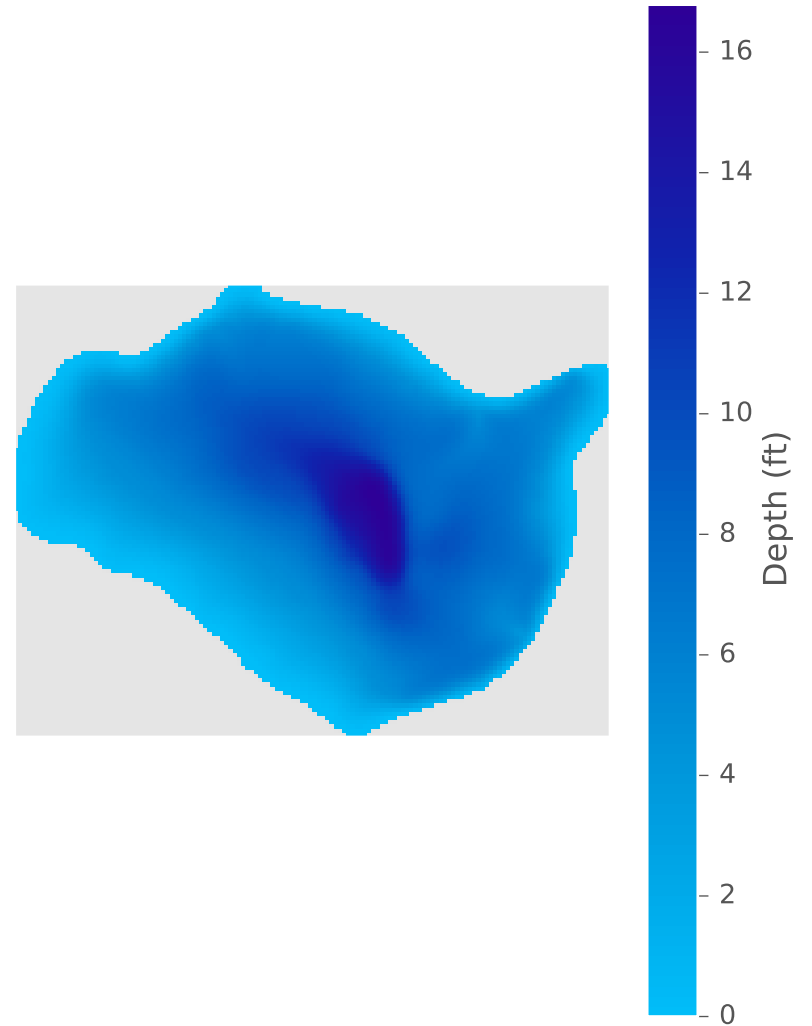
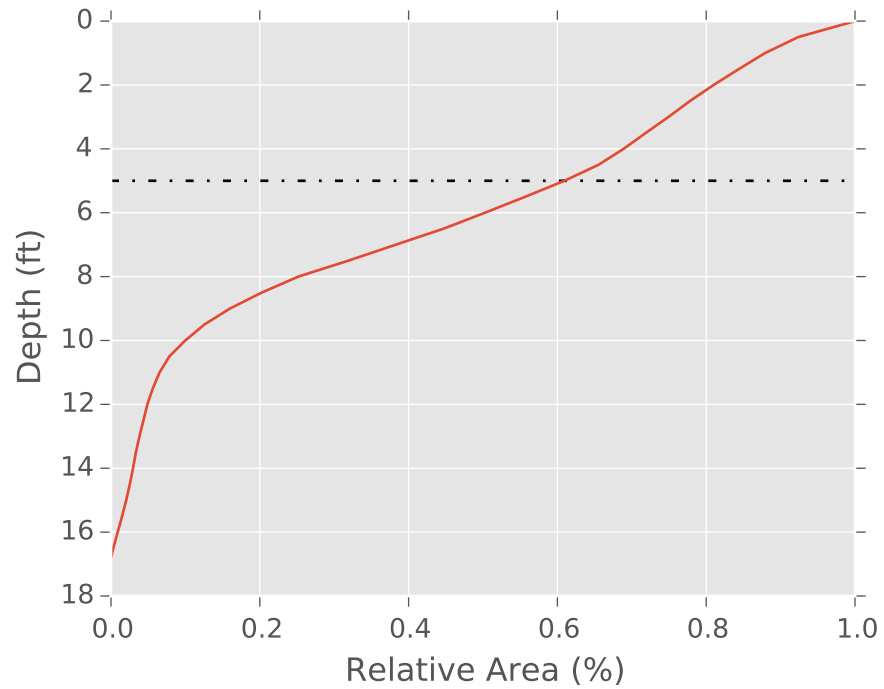
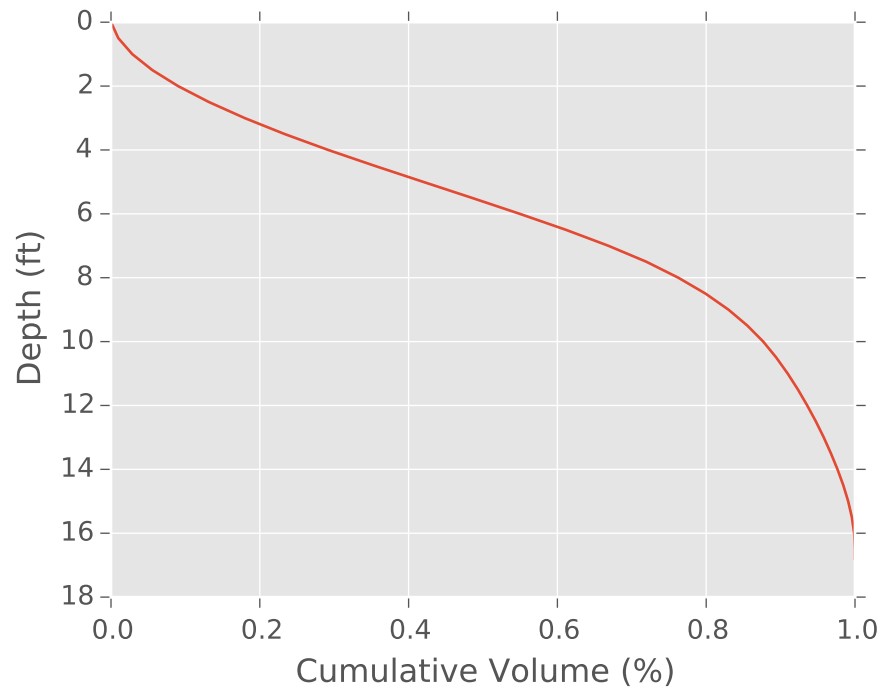
Phalen



Maximum depth: 93 feet

Mean Depth: 23.5 feet

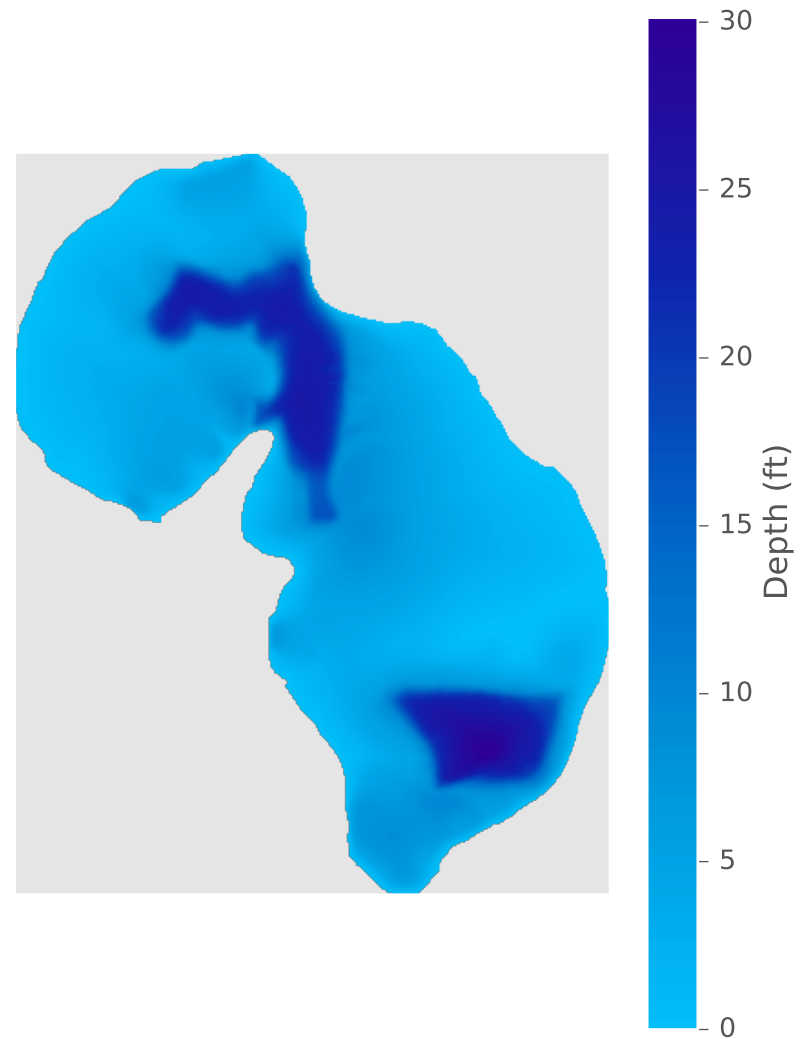
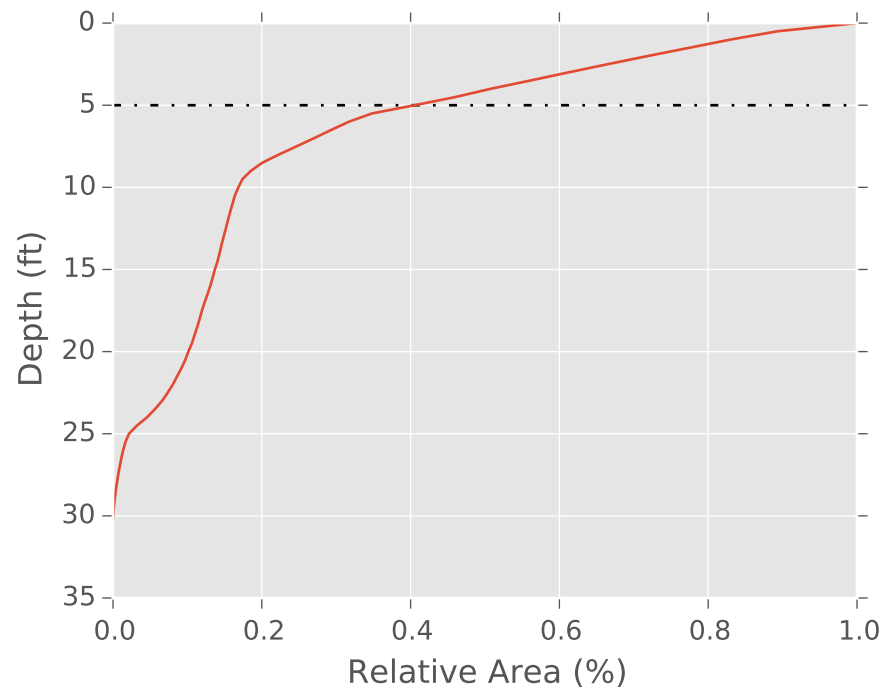
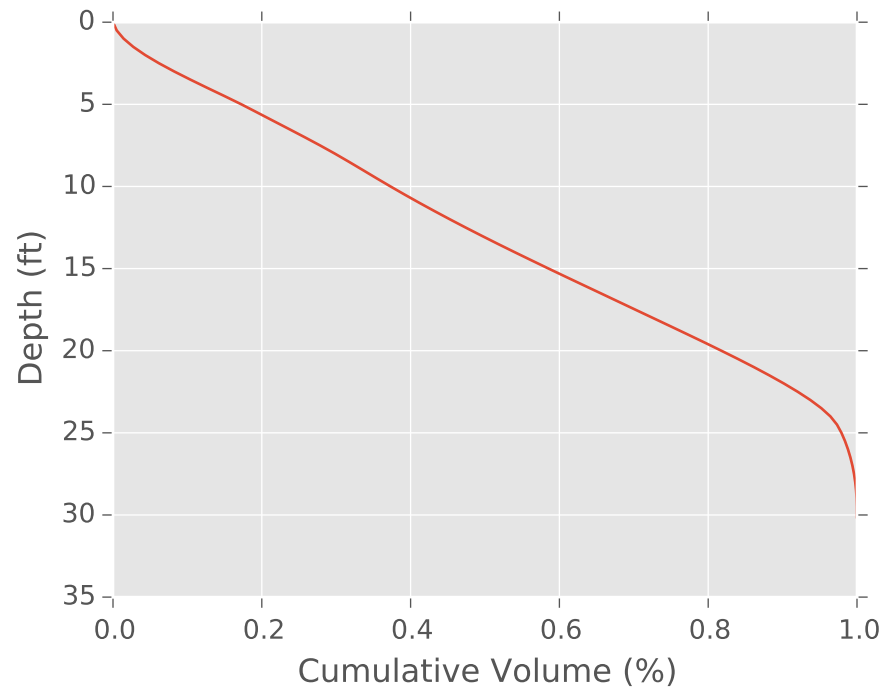
Round



Maximum depth: 17 feet

Mean Depth: 5.8 feet

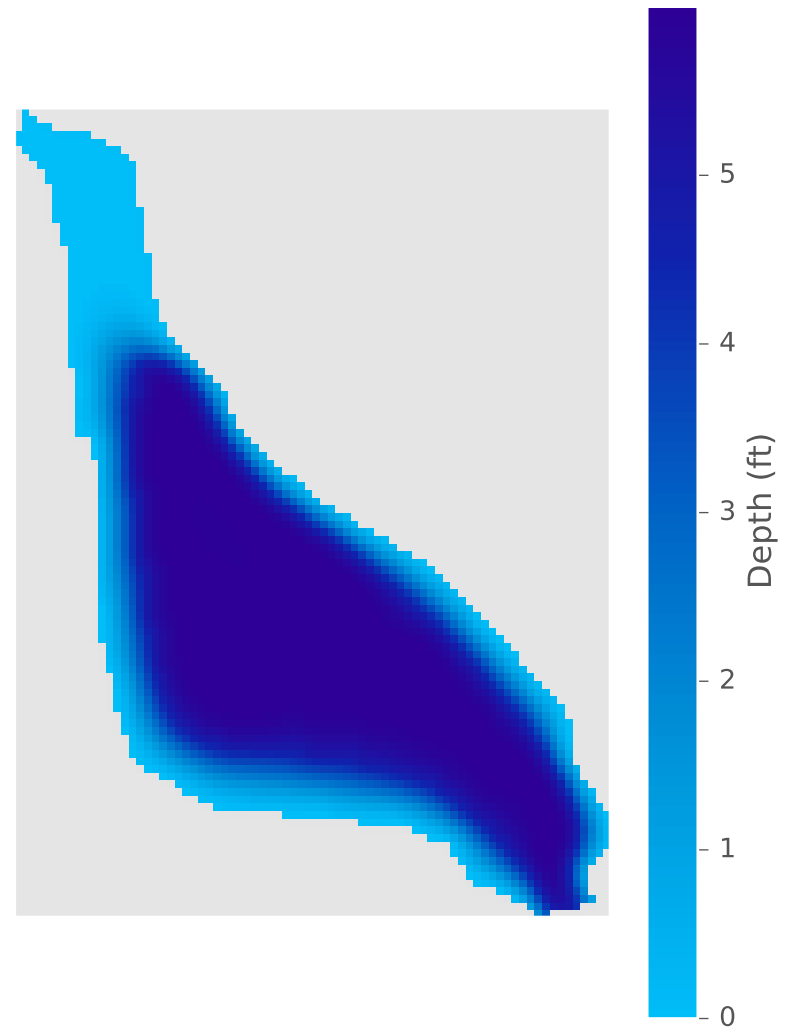
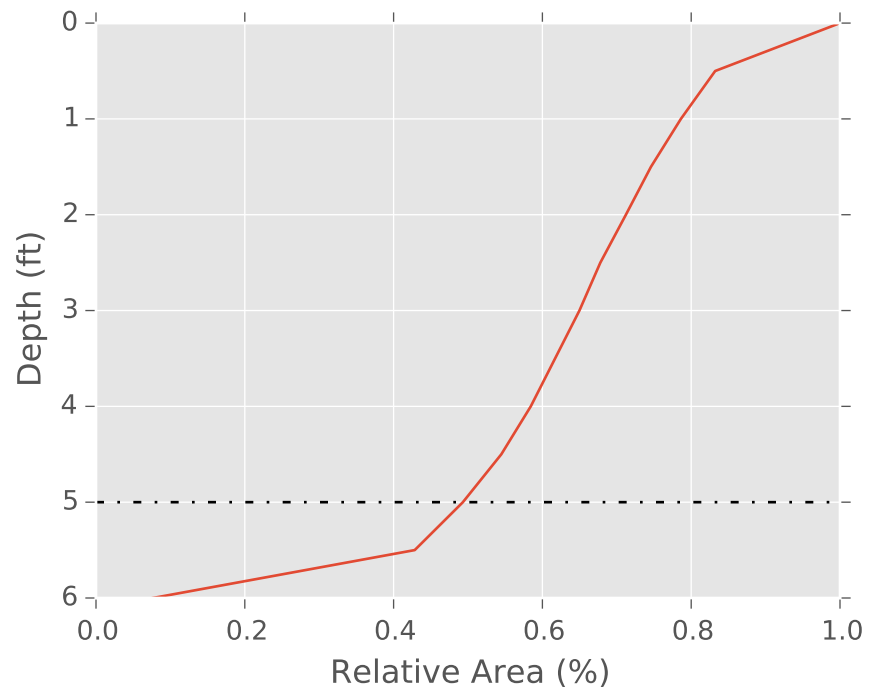
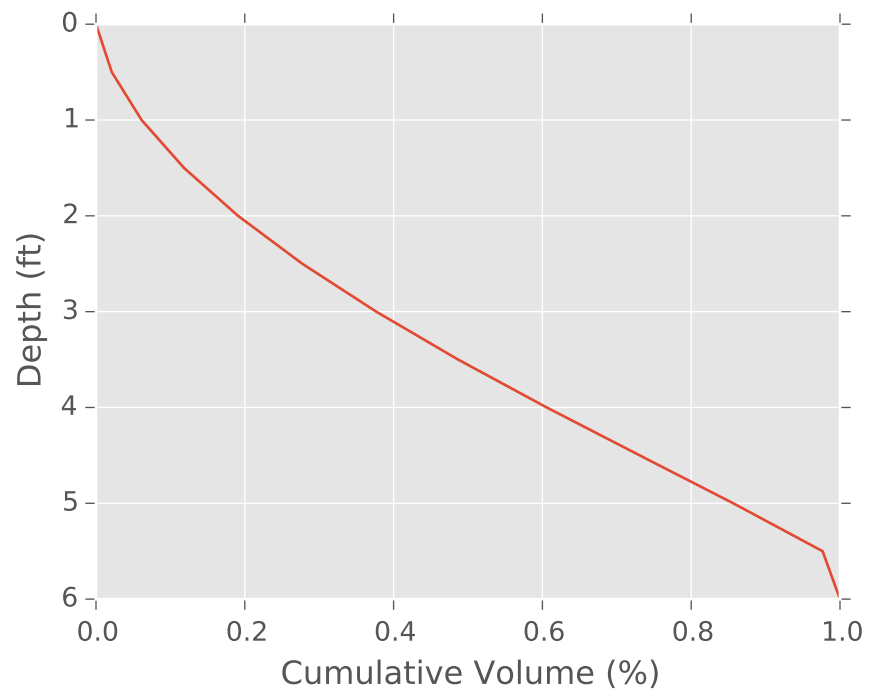
Snail



Maximum depth: 30 feet

Mean Depth: 6.4 feet

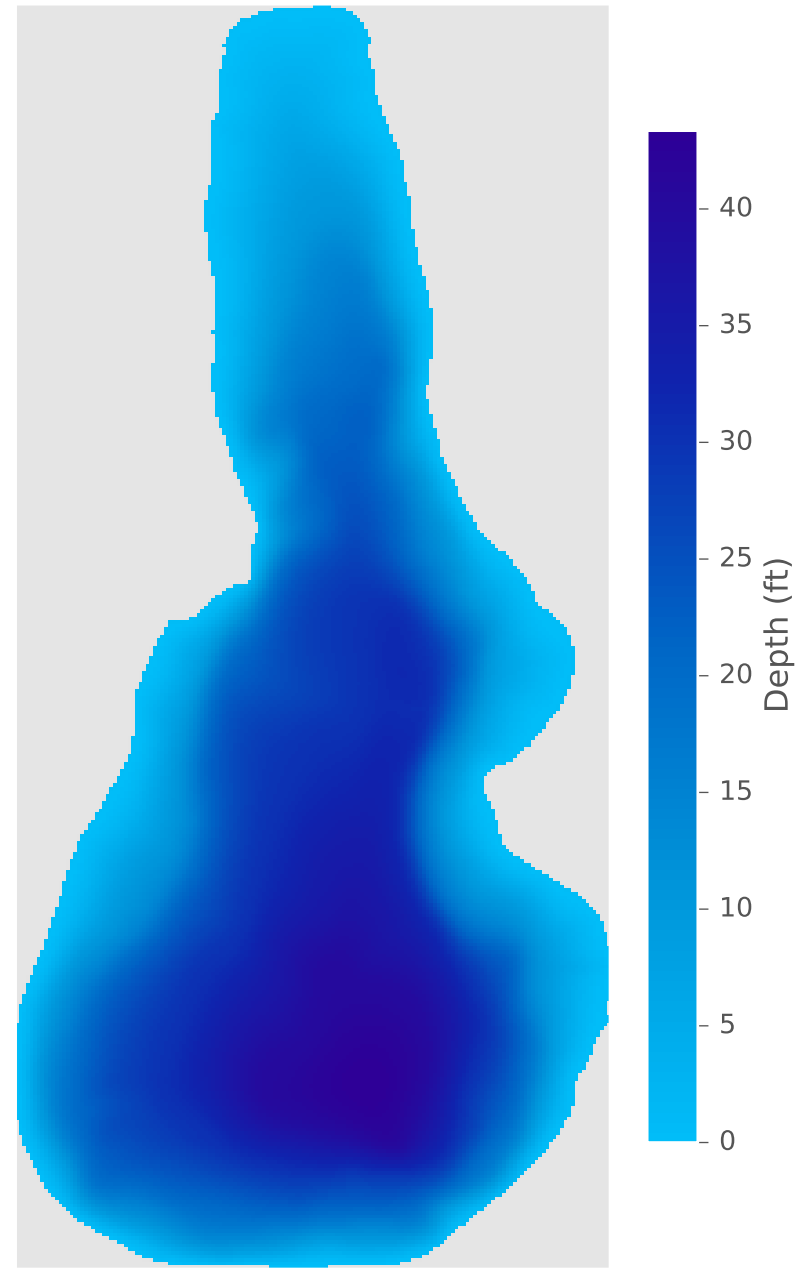
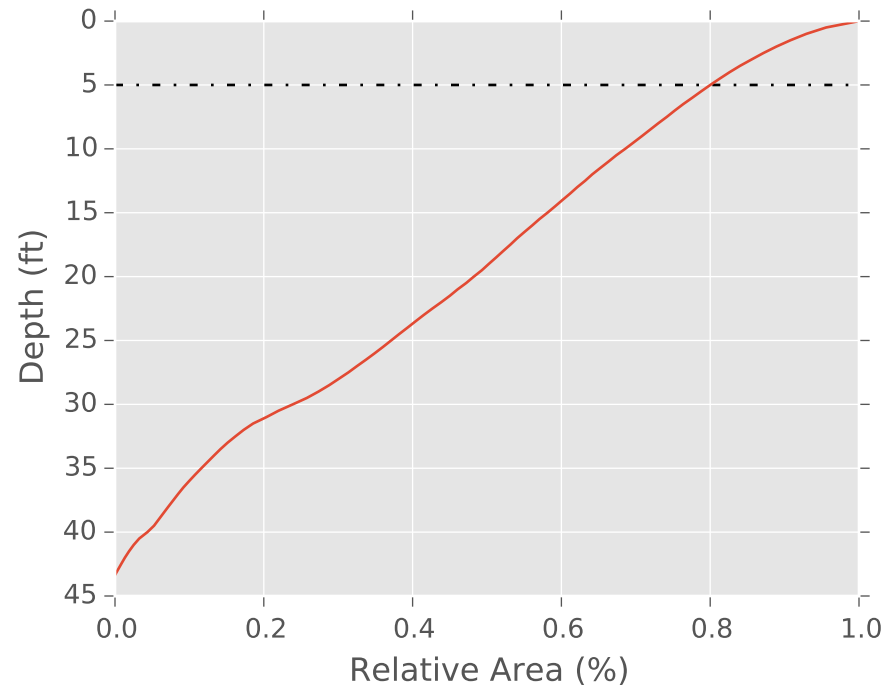
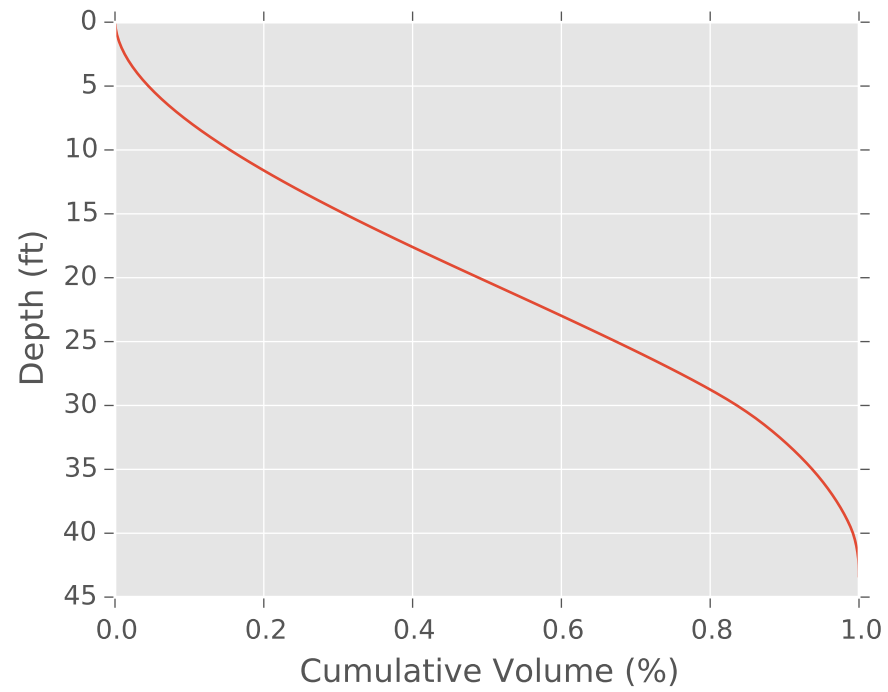
Spoon



Maximum depth: 6 feet

Mean Depth: 3.8 feet

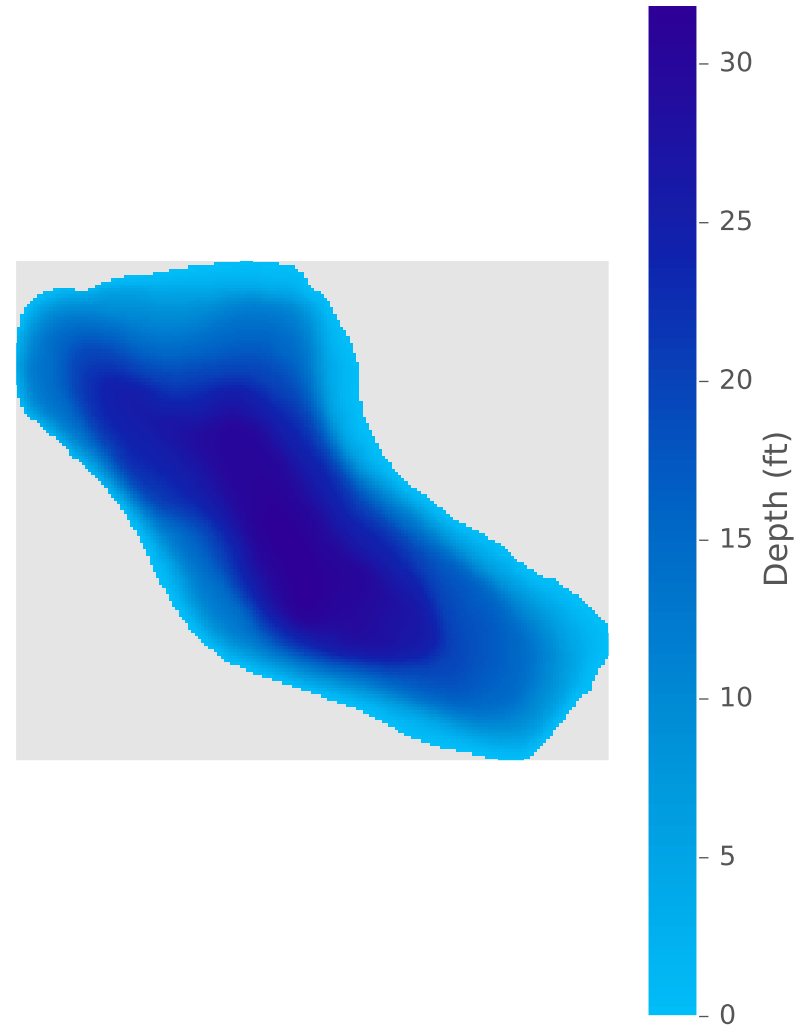
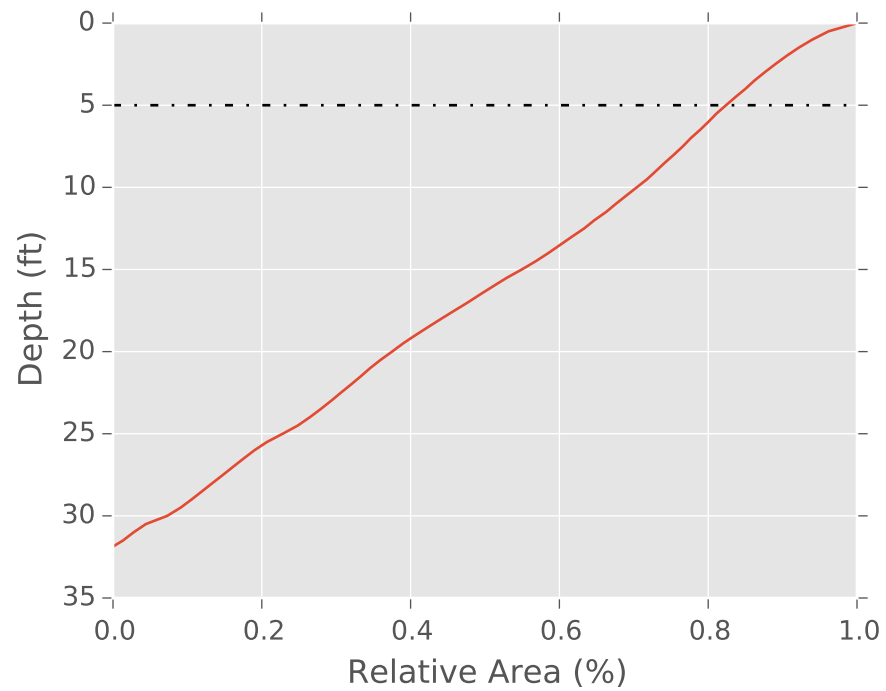
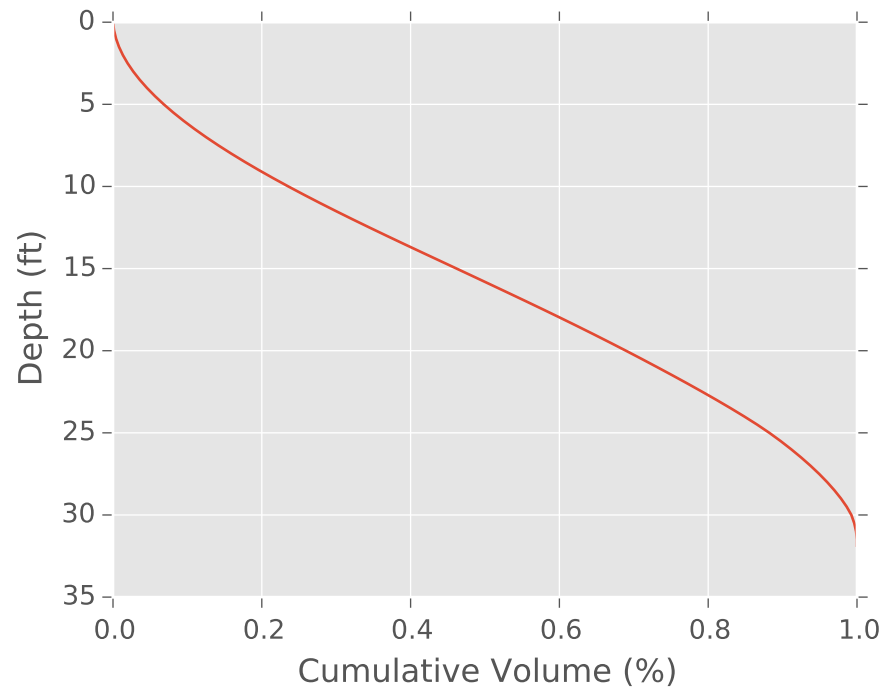
Tanners



Maximum depth: 43 feet

Mean Depth: 18.9 feet

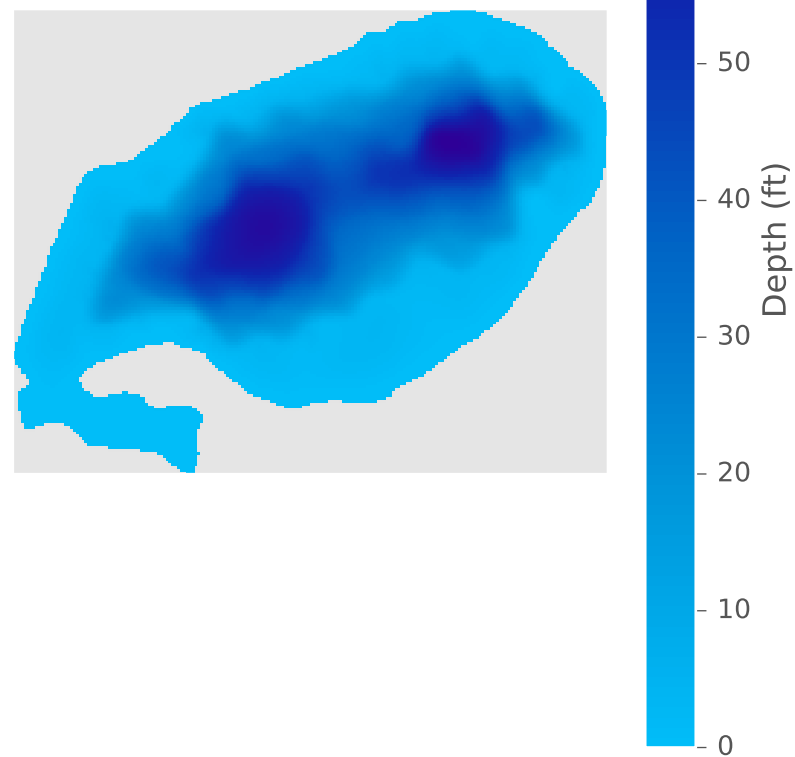
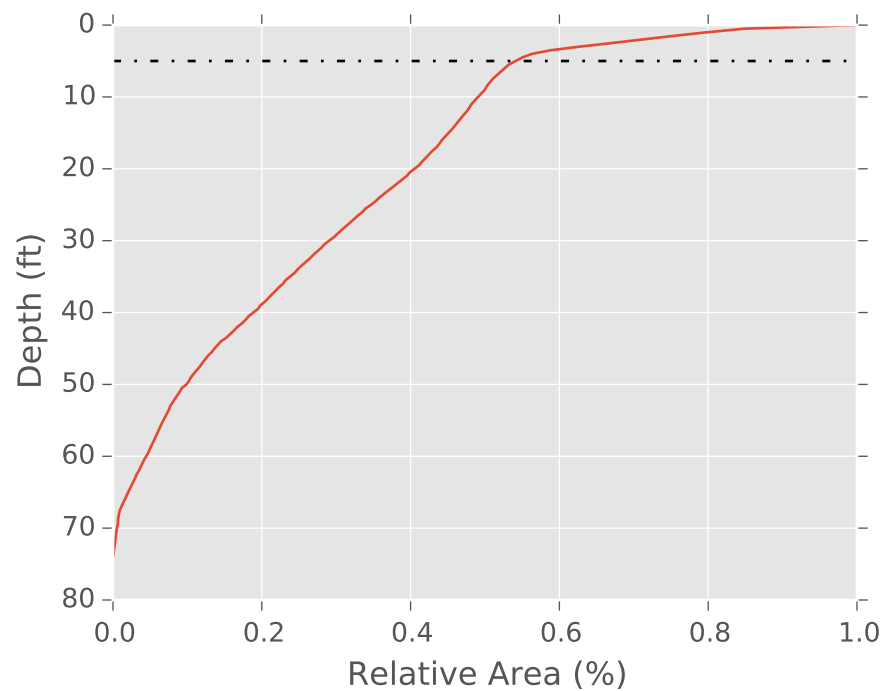
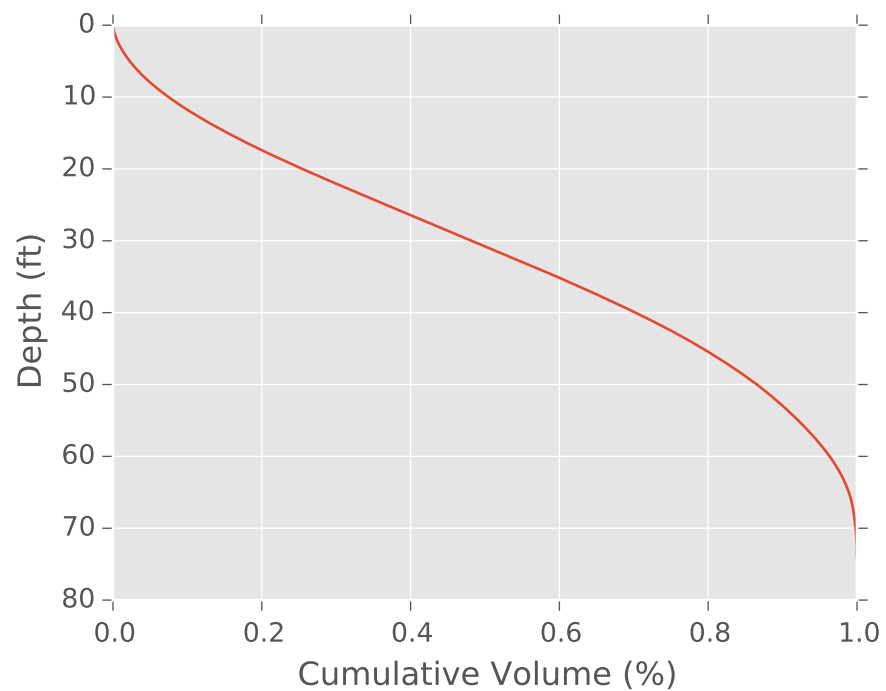
Twin



Maximum depth: 32 feet

Mean Depth: 16.1 feet

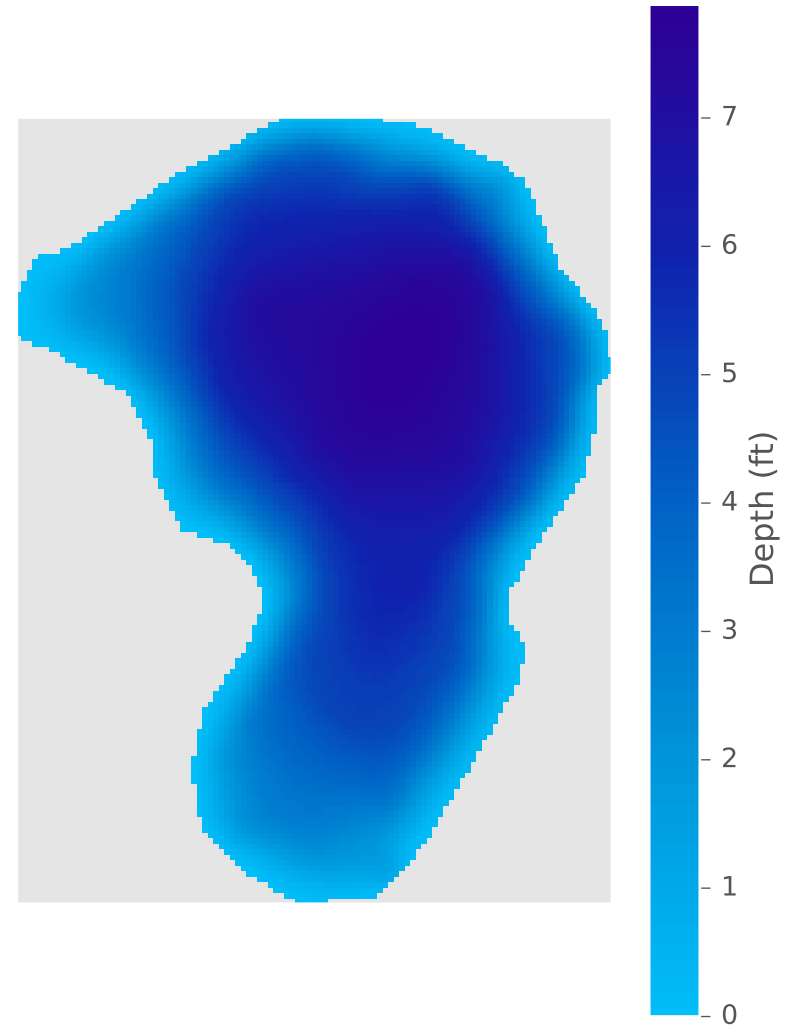
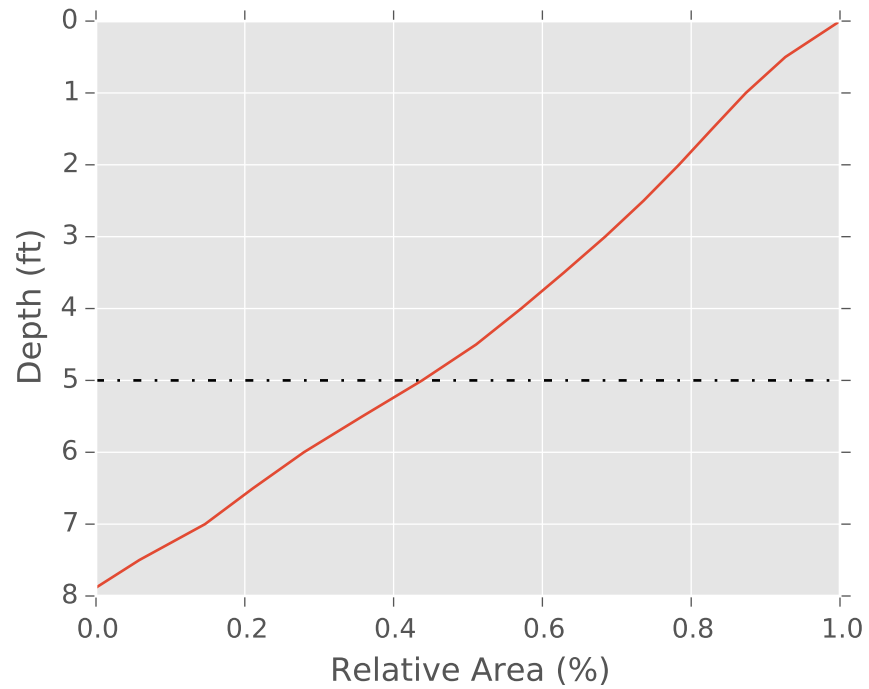
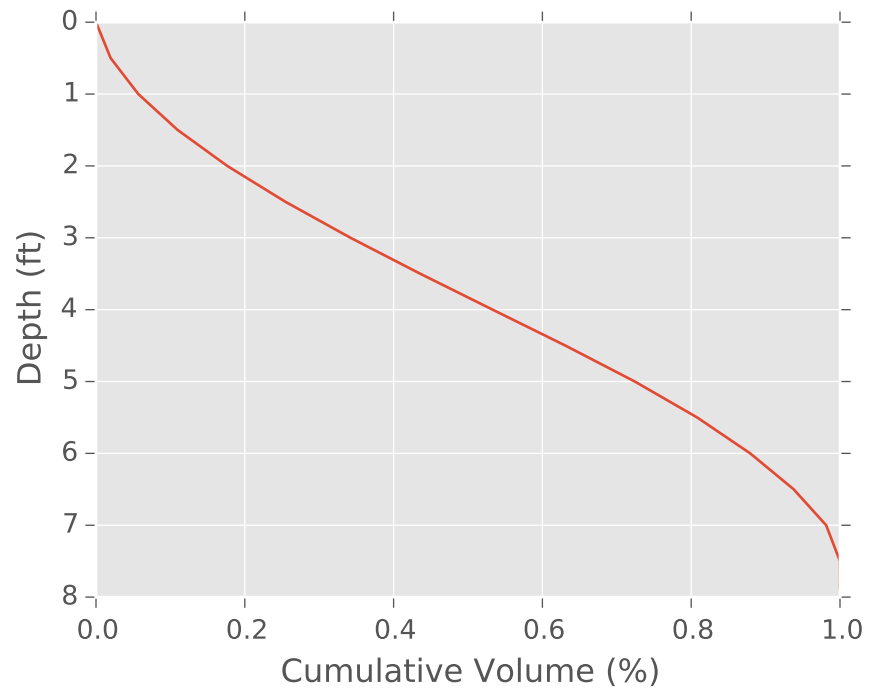
Wabasso



Maximum depth: 74 feet

Mean Depth: 18.7 feet

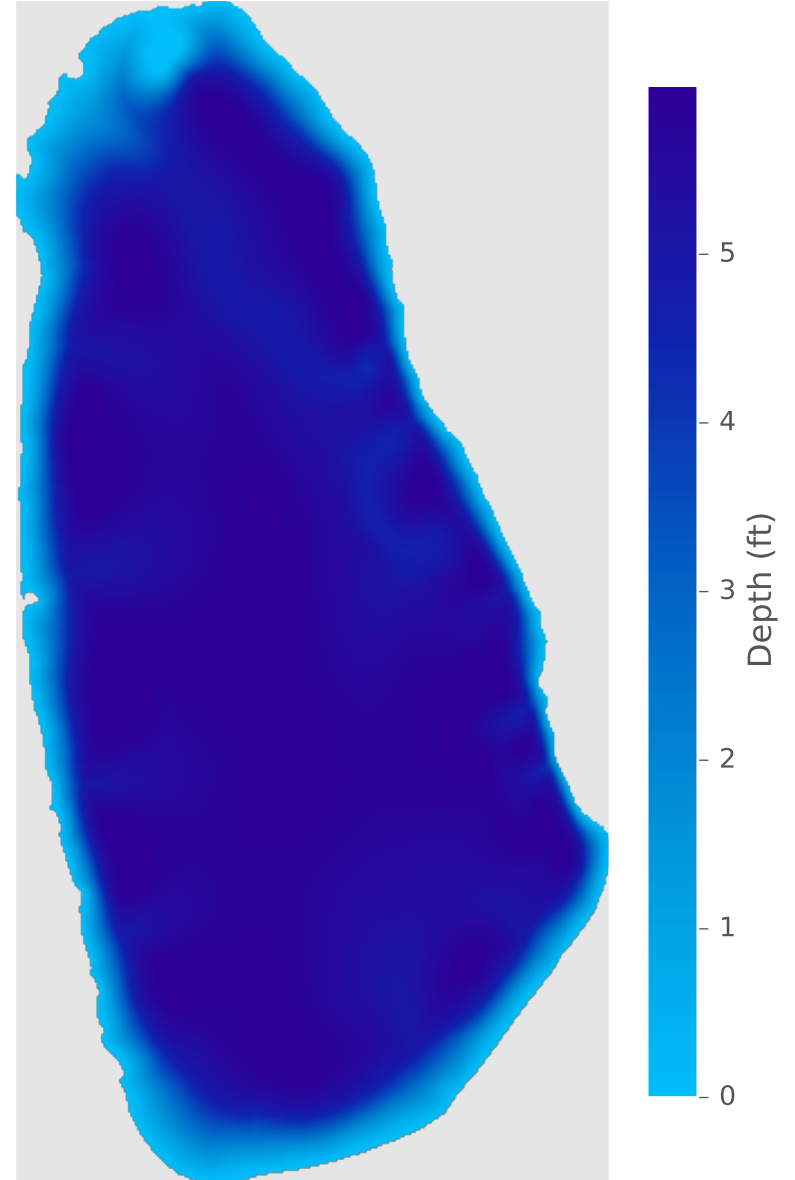
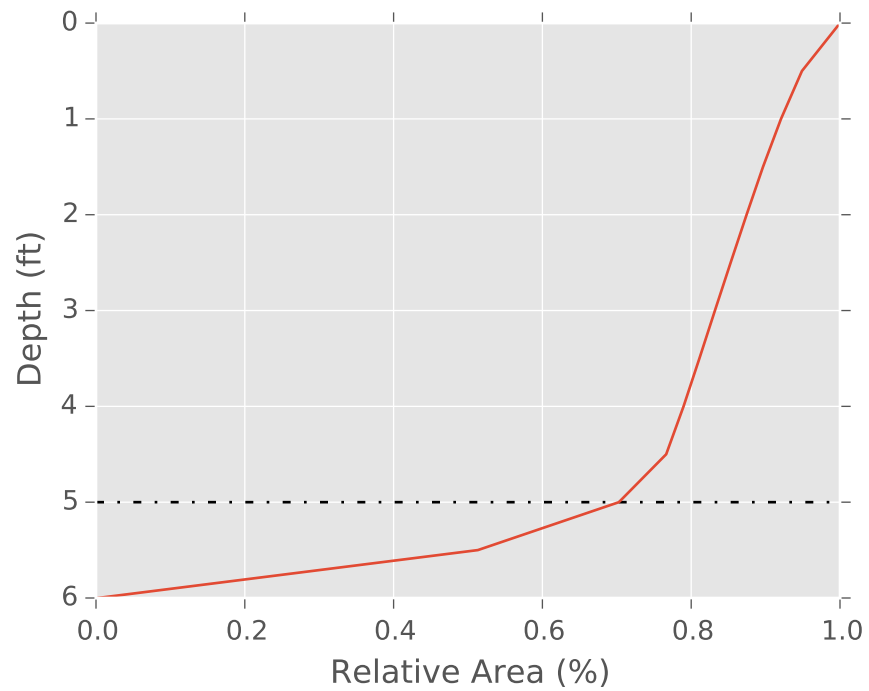
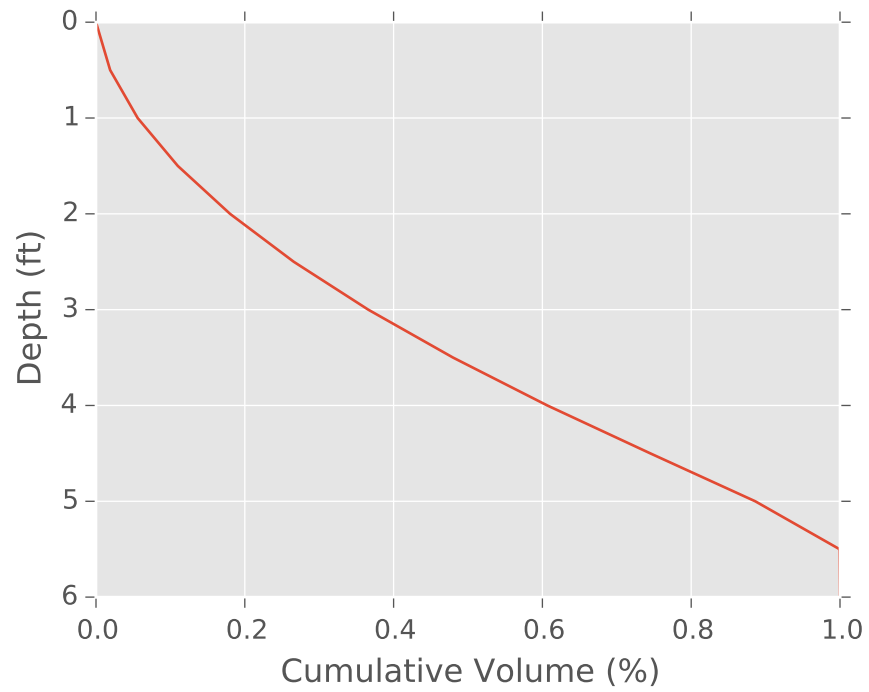
Wakefield



Maximum depth: 8 feet

Mean Depth: 4.3 feet

West_Vadnais



Maximum depth: 6 feet

Mean Depth: 4.7 feet