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SEWRPC Staff Memorandum

GROUNDWATER INVESTIGATION FOR GILBERT LAKE WASHINGTON COUNTY, WISCONSIN

INTRODUCTION

Gilbert Lake is a 43-acre lake, with a maximum depth of nine feet, located in the Town of Barton in Washington County, Wisconsin. It is a spring lake, meaning that it has no defined inlet, but does have a defined outlet (i.e., the inlet to Big Cedar Lake) and that its water is supplied primarily by groundwater inputs, including through springs, as well as, to a lesser extent, by direct precipitation on the Lake's surface and on the surrounding lands. Gilbert Lake lies within the Milwaukee River watershed and is within easy reach of the Milwaukee metropolitan area. The entire Lake is considered a Wisconsin Department of Natural Resources (WDNR) sensitive area, although access channels are maintained in the Lake (as shown on Map 1). Access to the Lake can be obtained from Big Cedar Lake (which has adequate public access), through the inlet channel, although depth and plant growth generally restricts access to canoes and kayaks only.

The hydrology of Gilbert Lake (see Table 1), in general and as the head waters to Big Cedar Lake, has been an ongoing concern of the Lake's residents and the Big Cedar Lake Protection and Rehabilitation District (BCLPRD), especially in light of ongoing and planned urban-density development within the areas tributary to the Lakes and in the Lakes' groundwatersheds.[1] This concern was further exacerbated by observations made by Lake users which indicated that one of the well-known springs within Gilbert Lake appeared to have reduced flow. As a result of this concern, the BCLPRD applied for and received a WDNR Lake Management Planning Grant for the specific purpose of monitoring the springs that were known to contribute to Gilbert Lake's water supply and for the purpose of further developing management and monitoring suggestions that will help protect the groundwater which feeds Gilbert, and in turn, Big Cedar Lake.

This report details all the components that went into completing this planning project, as well as discusses next steps in terms of management and monitoring efforts. This project was undertaken as a collaborative effort between U.S. Geological Survey (USGS) staff, Southeastern Wisconsin Regional Planning Commission (SEWRPC) staff, and the BCLPRD.

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[1]*SEWRPC Community Assistance Planning Report No. 287,* A Multi-Jurisdictional Comprehensive Plan for Washington County: 2035, *April 2008.*

PROJECT SCOPE AND OBJECTIVES

The purpose of this study was to acquire baseline knowledge necessary for characterizing groundwater and surface water interactions affecting Gilbert and Big Cedar Lakes. The project was also undertaken to develop a future program of monitoring and management that would protect the water quantity and quality in Gilbert Lake and, in turn, Big Cedar Lake. In order to accomplish this purpose, specific goals were developed, including:

1. To identify the thermal "signature" of groundwater entering Gilbert Lake (and flowing into Big Cedar Lake) from two springs located at the northern extreme of the Lake;

2. To estimate flows from the two springs known to contribute groundwater to Gilbert Lake (and Big Cedar Lake) as a prerequisite for ultimately documenting the water budgets of the Lakes; and

3. To locate other major points of groundwater flow into the Lakes.

In addition to these goals, SEWRPC staff added an additional goal: To develop an inventory of all the relevant information that is presently available about the groundwater resources of Gilbert Lake. This additional component was used to interpret the monitoring data that was obtained as a part of this study, as well as to develop future management and monitoring recommendations.

PROJECT COMPONENTS

To accomplish the goals of this project, seven tasks were undertaken by SEWRPC and USGS staff. These include:

1. Acquisition and analysis of flow and water chemistry data for sites of interest in Gilbert Lake (including at the spring that was observed as an issue of concern).

2. Acquisition and analysis of temperature data for sites of interest throughout Gilbert Lake (including at the spring that was observed as an issue of concern).

3. Review of historical information and completion of a field reconnaissance to determine the location of known and unknown springs within the Gilbert and Big Cedar Lake watersheds.

4. Delineation of a surface watershed based on two-foot contour interval elevation maps to determine if there are any "internally drained areas"[2] as well as to determine where inventories should be focused. This was undertaken because groundwatersheds (i.e., the areas where infiltrated water contributes to the groundwater supply of the Lake) can often be influenced by surface topography.[3]

5. Inventory of "watershed characteristics" which could provide insight into the dynamics of the groundwater contributing to Gilbert Lake's water supply.

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[2] *"Internally drained areas" are areas which, as a result of their surface topography, trap surface waters and prevent them from entering Gilbert Lake via surface runoff (although the water which enters these areas may still drain to the Lake through a groundwater connection).*

[3] *Surface watersheds are the areas which drain through overland flow towards the waterbody being investigated. A groundwatershed (i.e., an area which contributes groundwater to the waterbody) can sometimes mimic the surface watershed, as long as there aren't complicating factors such as semi-permeable or impermeable subsurface formations or fractures and fissures which redirect the flow of groundwater.*

6. Review of land use plans and proposals to determine current and potential future risks to groundwater recharge in the areas which are expected to contribute to the groundwater supply to Gilbert Lake.

7. Compilation of the relevant information obtained within this study to determine future management and monitoring recommendations.

The methodologies and results associated with each of these components are discussed below. The seventh component is discussed in the "Summary and Recommendations" section of this report.

Component 1: Flow and Chemistry Data for Gilbert Lake

Flow and water chemistry data was obtained at specific sites of interest for the purpose of producing baseline information that can be used for comparison with future monitoring efforts. Additionally, the information obtained was used to provide an approximate estimate of the contribution of groundwater (either via springs or diffuse discharge) to the Lake water budget. While the scope of this study was not designed to be sufficient to compute a water budget directly, the measured data provides important information for evaluating the importance of groundwater to the Lake's hydrology. This estimate is further discussed in the "Analysis" subsection below.

Water Chemistry Measurements

Water quality samples were collected by USGS staff on four occasions between April 2012 and April 2013 at four locations of interest for this study. These locations include the Gilbert Lake deep hole site, the vents for two springs which discharge to the tributary of Gilbert Lake (the "Spring #2" site is the one that was observed to have reduced flow), and a tributary stream at a point located between Spring #1 and Spring #2. The location and pictures of the sites sampled for water chemistry are shown on Map 2.

During each sample trip, field measurements of temperature, pH, specific conductance, dissolved oxygen, and Secchi depth were made. The water samples were also analyzed for total phosphorus, chlorophyll-*a*, calcium (Ca), and magnesium (Mg) for each quarterly sample. Table 2 describes the importance of each of these parameters. Additionally, the water samples were analyzed for nutrients, cations, and dissolved solids for one sample in April 2012 to provide a baseline for comparison with future monitoring efforts.[4]

A summary of median, minimum, and maximum values for select field parameters, TSI results, and Ca and Mg concentrations are reported for each site in Table 3. Appendix A shows and explains the baseline nutrient, cation and dissolved solid raw data.

Flow Measurements

Flow measurements (i.e., the volume of water per unit of time that is discharged at different sites) were also planned to be taken for the tributary stream, the outlet of each spring pond, and the Gilbert Lake outlet (also shown on Map 2). Flows were measured by USGS staff at the tributary stream site during each quarterly visit; however, flow measurements at the other sites were limited by shallow depths, a high-degree of interference from vegetation, and low water velocities that were often affected by surface winds. As consequence, no flow measurements were attainable at the Gilbert Lake outlet, and flows were only obtainable at the springs during the July 2012 sampling trip. Each flow measurement was rated as poor quality based on the site conditions. All measured streamflows for this study are provided in Table 4.

Given the limited data that was obtained from this portion of the study, including only one data point from the springs, it is not possible to draw any conclusions about loss of flow in Spring #2. However, these measurements

[4]*Standard USGS field methods (U.S. Geological Survey, variously dated) were followed for all samples collected as part of this study.*

(especially those taken at the tributary) could potentially be used as a comparative point if any flow measurements are taken in the future.

Analysis

Water Chemistry

Through looking at the different water chemistry parameters that were obtained for this study it is possible to develop conclusions about the four sites that were sampled. For example, the two spring sites clearly have a groundwater signature, as can be seen when looking at the dissolved oxygen levels at those sites, as shown in Figure 1 (dissolved oxygen is characteristically low in groundwater due to it coming from subterranean environments). Additionally, all four sites, including the Lake itself, appear to have similar water chemistry as it pertains to calcium, magnesium, specific conductance, and hardness as shown in Figure 2. Given that two of the sample sites were springs, these results indicate that the water throughout the system is dominated by groundwater sources (as surface water sources would have different chemical signatures with respect to these parameters).

Additionally, as shown in Figure 3, the parameters which are used to determine trophic status[5] (i.e., phosphorus, chlorophyll-*a,* and Secchi depth) indicate that the springs provide a clean nonpolluted water source to Gilbert Lake, which is likely a major contributor to the Lake being considered mesotrophic (i.e., a lake with moderate amounts of nutrients) despite its marsh-like nature. This helps further emphasize the importance of the groundwater contributing to this system relative to the water quality of the Lake.

Groundwater Contributions

Though the flow measurements were primarily inconclusive, they can be used in conjunction with the water chemistry information obtained from the study to quantify the importance of groundwater to Gilbert Lake as a source of water. As discussed above, for example, the high specific conductance, hardness, calcium, and magnesium values (see Table 2) indicate a high degree of dissolved minerals in both the groundwater (spring water) and the surface water (both the tributary stream and Gilbert Lake). These similarly high values in both groundwater and surface water indicate only moderate dilution of the Lake water due to overland runoff and precipitation (i.e., the water itself has characteristics of groundwater rather than surface water runoff). Thus, it was concluded that the solute mass balance equation developed by Stauffer (1985) (which uses solute tracers, such as calcium and magnesium, to estimate the amount of groundwater inflow) could be used to roughly estimate the percentage of groundwater contributions to the Lake.[6] The Stauffer equation is as follows:

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[5]*Trophic status refers to lake classification categories. The classifications include eutrophic (nutrient rich), mesotrophic (moderate nutrients), and oligotrophic (nutrient poor). These classifications are determined by interpreting water quality data (see Figure 3 and Table 5).*

[6]*The Stauffer (1985) methodology was meant to be applied to seepage lakes (i.e., lakes that do not have a stream entering or leaving the lake). However, the use of the Stauffer equation on Gilbert Lake is justified due to the tributary stream being assumed as being fed solely by groundwater and, thereby, included as part of the estimated groundwater inflow to the Lake. To the extent that this assumption is in error, the estimated groundwater contribution will be overestimated. A second limitation of the solute tracer method is that it can only be applied with conservative solutes, or solutes that don't participate in chemical reactions that could alter their concentrations in a lake. However, as magnesium does not typically precipitate unless the Mg:Ca ratio in lake water is greater than 2 (which was not observed for Gilbert Lake) magnesium concentrations in the water samples were used to estimate the net groundwater input to Gilbert Lake.*

$$Q_i = \frac{(P-E)C_o + EC_e - PC_p - F}{C_i - C_o}$$

Where Q_i is the net groundwater inflow to the lake, P is precipitation on the lake surface, E is evaporation from the lake surface, C_o is the concentration of the solute tracer in lake water, C_e is the concentration in evaporating water, C_p is the concentration in precipitation, C_i is the concentration in groundwater flowing into the lake, and F represents a source-sink function for sediment-water exchanges, etc. For strictly conservative solutes, such as Mg, F = 0. In addition, C_e is typically negligible for large atoms, such as Ca and Mg. Long-term average precipitation (P = 32 inches per year) and evaporation (E = 29 inches per year) rates were obtained from Linsley and others (1982), as guided by Feinstein and others (2010).

USGS staff calculations applying the Stauffer (1985) equation (using conservative and moderate calculations to define a possible range of flow),[7] estimated Gilbert Lake's groundwater flow as between 25 inches per year (44 percent of the total water budget) or 1.5 cubic feet per second (cfs) and 120 inches per year over the area of the Lake (79 percent of the total water budget), or about 7.0 cfs. As the total stream flow from the tributary stream and springs (one of the major sources of water to the Lake) was about 0.71 cfs on July 31, 2012, the lower estimate appears to be closest to reality, although more studies would be needed to make a definitive conclusion. Nonetheless, these calculations help definitively determine that groundwater provides a significant portion of the water supply to the Lake and that further monitoring and investigations should be aimed at monitoring and protecting this source of water to Gilbert Lake.

Component 2: Temperature Data for Gilbert Lake

Temperature is a very important factor in surface water systems. This is often because certain aquatic organisms can only survive in specific temperature conditions or because warm temperatures can indicate standing or polluted waters. In this study, however, temperature was also considered to be an important indicator of

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[7] *When calculating the groundwater inflow, the magnesium concentration in precipitation (C_p) was obtained from the estimated value (0.1 mg/L) for south-central Wisconsin by Stauffer (1985) while the remaining two variables, C_i and C_o were informed by the water samples collected as part of this study (see Table 2). Using the median Mg concentration in Gilbert Lake (39.55 mg/L) for C_o, and the average (40.5 mg/L) of the median values for the tributary stream, spring #1, and spring #2 for C_i, the net groundwater inflow (including the tributary stream) to Gilbert Lake is estimated at approximately 120 inches per year over the area of the lake (79 percent of the total water budget), or about 7.0 cubic feet per second (cfs). This estimate is expected to approach the high range of reasonable groundwater inflow rates considering the challenges with measuring flows within the tributary stream, the springs, and the Gilbert Lake outlet. Thus, additional sensitivity analyses were performed.*

The solute mass balance method is highly sensitive to the specified groundwater and lake water concentrations (Ci and Co), which varied among the individual water samples. For example, samples were collected from the bottom of the spring ponds in an attempt to sample groundwater as it discharged from the spring vent. To the extent that the sample could inadvertently include some lake water, the Mg concentration of the sample would logically be diluted. A more conservative estimate of the groundwater inflow is obtained by using the maximum Mg concentration among the tributary stream and spring samples (44.2 mg/L from spring #2 on 4/26/12) for the groundwater inflow concentration (Ci). Using this maximum Ci value and the median concentration for Gilbert Lake (39.55 mg/L) for Co, groundwater inflow (including the tributary) to Gilbert Lake is approximately 25 inches per year (about 44 percent of the water budget), or about 1.5 cfs.

groundwater flow. This connection was made because groundwater naturally remains at a constant temperature throughout the year in a more consistent manner than surface waters. Consequently, when groundwater consistently flows, the temperature in the surface waterbody area near the discharge tends to remain constant, even with changing air temperatures.

To evaluate these thermal signatures and detect the influence of groundwater flows at certain points in Gilbert Lake, SEWRPC staff employed five temperature loggers at five separate sites including the two tributary springs (Spring #1 and #2 from the water chemistry sampling sites), a site on the shore of Gilbert Lake, the outlet to Gilbert Lake, and at the outflow from a detention basin located upstream from the Lake which periodically stops discharging (see Map 3). The loggers recorded hourly temperature data from 6:00 p.m. on July 25, 2012, until 9:00 a.m. on May 9, 2013. In addition to these five sites, SEWRPC staff also deployed an air temperature logger at a nearby Lake in Washington County (as a part of a separate project). This logger recorded hourly air temperature data on the dates mentioned above. This data was, therefore, included in this dataset for comparative purposes. A time series of the data obtained at each site is included in Figure 4.

Analysis

Through comparing the time series of the temperature data at each site, it is possible to see patterns. The upstream detention basin site (which is known to not flow at times), for example, often closely mimics the air temperature, with some periodic less drastic fluctuations, as shown in Figure 5. Review of this data enables identification of potential periods where this discharge was flowing and not flowing (i.e., when the temperature mimics air temperature closely, it is likely that this site was not flowing).

Another comparison that can be made is the comparison of the temperatures at the two spring sites, the air temperature site, and the "in-lake" site (see Figure 6). By looking at these time series it is possible to see that the water temperatures of the two springs stay significantly more constant than the air temperature site. In fact throughout the year both of these sites have similar thermal signatures, with the Spring #2 site (southern spring) remaining slightly warmer than the Spring #1 site (northern spring) on a fairly consistent basis. This signature indicates that these two sites, as expected, are influenced by groundwater discharges to a greater extent than they are influenced by air temperature; thereby leading to the conclusion that these springs are constantly flowing. However, in the Spring of 2013, the southern spring site (the one that sometimes appeared to stop flowing based on local observations) mimics the air temperature to a much greater extent than it did previously in the sampling period and to a much greater extent than the northern spring site. Given this change in temperature influences, it is likely that the southern spring site had a lower groundwater input during this recorded period (thereby allowing air temperature to have a greater influence on its temperature).

These conclusions indicate that the southern spring site does in fact appear to have periods of reduced flow in comparison to both previous measurements at that spring and the northern spring. Consequently, it is possible that this spring is being influenced by a factor that is reducing the groundwater that feeds its supply.

Component 3: Spring Locations in Gilbert and Big Cedar Lake

The identification of additional springs is an important factor for future monitoring of groundwater flows to the Lake. As changes occur in the watershed, the monitoring of the water supply to Gilbert and Big Cedar Lake will be a crucial step in identifying water quantity and quality issues as soon as possible. Additionally, if management needs to be undertaken, the data obtained from monitoring spring sites, will provide justification for actions that would potentially be difficult to identify without supporting data.

A first step toward identifying the location of additional springs around Gilbert and Big Cedar Lakes involved a search of historical datasets. This involved searching the Macholl database, which is a comprehensive data base which attempted to compile all known spring sites within the state of Wisconsin.[8] The Macholl (2007) database did not contain information on any springs previously located and documented adjacent to Gilbert Lake or Big Cedar Lake.

In recognition that the historical springs database was incomplete in the area around Gilbert Lake and Big Cedar Lake, a reconnaissance survey was conducted by USGS staff, in collaboration with a long-time resident of Gilbert Lake, Dr. Ralph Olsen. In addition to the two monitored spring vents that are documented in this report, four additional springs on Gilbert Lake and two springs on Big Cedar Lake were located and documented in the USGS National Water Information System database (NWIS; Dempster, 1990).[9] Map 4 shows the location of these identified springs. Photographs of select springs are provided in Appendix B.

Component 4: Watershed Delineation for Gilbert and Big Cedar Lake

Generally, a watershed is defined as the land area that contributes surface runoff to a waterbody. Sometimes the area is referred to as a drainage basin because the area "drains towards the waterbody." Delineating this area is important because it helps managers to understand the factors that influence their lake (i.e., the conditions, activities, and land use within the watershed), as well as to understand the factors that do not influence their watershed (e.g., if an area is internally drained, the land use in that area is unlikely to contribute to surface runoff pollution).

It is important to note, however, that there are two types of watersheds which affect lakes and rivers. There are surface watersheds (i.e., the surface area which drains to the lake or river) and the groundwatershed (i.e., the area which supplies the groundwater which moves towards, and supplies, the Lake). Though both of these watersheds are important, the groundwatershed can be influenced by more complicating factors such as rock formations, soil types, and fractures. In short, groundwater is not always contributed by the same area as surface water, thereby complicating the process of determining the groundwatershed boundary.

Given the complicating factors which influence the delineation of a groundwatershed, and due to the limited scope of this study, SEWRPC staff focused this component on delineating the surface watershed, which can be determined using ground elevation contours. This surface watershed was then used to determine an area to focus the inventories completed as a part of this study. The delineated Gilbert and Big Cedar Lake watersheds are shown on Maps 5 and 6. Of note in the watersheds is the newly delineated internally drained area located at the northern end of the Gilbert watershed.[10] This area is not contributing to surface water flow (although it may still contribute to groundwater flow to the Lake).

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[8]*A major effort was undertaken in 2007 by the Wisconsin Geological and Natural History Survey, Wisconsin Wildlife Federation, University of Wisconsin (UW), Beloit College, WDNR, and the USGS to share and compile data on springs in Wisconsin (Macholl, 2007). The resulting database compiled the location of all springs identified by previous surveys in the State. Discharge information was also available for some springs. The most extensive source of data for this database was a "Springs Survey" completed by the former Wisconsin Conservation Department between 1956 and 1962. Washington County was not included in the survey. The database compiled by Macholl (2007) incorporated additional sources of information on spring locations, including: Surface Water Resources Publications (1961-85) by the WDNR, several UW studies, USGS topographic maps, and a survey by the Wisconsin Land Economic Inventory (1927-47) which is also referred to as the "Bordner Survey" after the Director of the inventory.*

[9]*G.R. Dempster, Jr., National water information system user's manual, U.S. Geological Survey, 1990.*

[10]*This region was not shown to be internally drained in previous reports on the Lake.*

Component 5: Watershed Characteristic Inventory for Gilbert Lake
Watershed information which can provide insight into the factors that influence the groundwater supply to a lake or river can be used to guide management and monitoring recommendations. To ensure that the recommendations of this plan are as accurate as possible, SEWRPC staff undertook an inventory of the available information that could improve the understanding of the groundwater contributing to the Lake, and of the factors which affect that groundwater.

To obtain this inventory, SEWRPC staff reviewed available studies that were completed near the Lake and databases that were created for the State of Wisconsin. This review helped SEWRPC staff obtain:

1. The groundwater elevation contours in the areas surrounding Gilbert and Big Cedar Lakes

2. The groundwater recharge potential in the areas surrounding Gilbert and Big Cedar Lakes; and

3. The natural areas which exist in the areas recharging the Lake.

Each of these different inventories is discussed below.

Groundwater Elevation Contours
When attempting to ensure adequate baseflow to a lake, it is important to know where the groundwater is coming from. In fact, groundwater recharge which feeds the aquifer system (and in turn feeds the Lake) does not always come from areas solely within the surface watershed. This is because subterranean geologic formations can direct the flow of groundwater in a different direction than the surface water. To make an approximate determination of this direction of flow, it is possible to analyze groundwater elevation contours which are established from depth measurements taken at different groundwater wells within the Region and referenced to a common datum, such as National Geodetic Vertical Datum, 1929 adjustment (NGVD 29). These boundaries are interpreted in a similar way to surface elevation data (i.e., water flows downhill), and can be used to get general groundwater flow directions.

In Gilbert Lake the groundwater elevation contours, as shown on Map 7, show that groundwater flows from west to east. However, as can also be seen on the map there is potentially a northwest to southeast flow in the northern part of the watershed. Though these flow directions do not show the whole picture as to which areas contribute groundwater to Gilbert Lake, they can give an idea of where to focus further investigation and management.

Groundwater Recharge Potential
Groundwater recharge potential is based on the presence of impervious cover and on soil characteristics of the land. An area with no impervious cover and highly permeable soils, for example, would be classified as having high or very high groundwater recharge potential, whereas an area with lower permeability (e.g., clay soils) would be classified as low potential. Establishing areas of groundwater recharge potential enables determination of the highest priority areas for which infiltration functions should be protected (e.g., the areas where impervious surfaces should be avoided or where appropriate infiltration facilities should be implemented).

As can be seen on Map 8, the groundwater recharge potential within the Gilbert Lake watershed is moderate to very high . The potential is greatest in the areas adjacent to the Lake. This information indicates that the entire watershed should be considered a priority area for groundwater recharge maintenance.

Natural Areas
Natural areas such as wetlands and woodlands may play a role in groundwater recharge due to the their ability to slow down surface runoff, thereby causing the water to infiltrate into the ground as opposed to directly flowing to a lake or river. Given this relationship, evaluating the presence of natural landscapes around the Lake can help provide insight into the areas which may contribute to groundwater recharge.

In order to look at this factor, SEWRPC staff compiled an inventory of all the wetlands, woodlands, and prairies in the Gilbert and Big Cedar watersheds and combined them to create an inventory of the "buffers"[11] which exist around the Lakes. This buffer layer was then completed by looking at aerial photography to determine if there were areas that were not classified as a "natural area" that could serve this function of "slowing down water" (e.g., manmade buffers, wooded residential areas).

Map 9 shows the buffer map that was created for the Gilbert Lake watershed and reveals that the majority of the area surrounding the Lake actually serves a buffering function. This further emphasizes the need to protect these areas to the greatest extent practical.

Component 6: Current and Future Land Use for Gilbert Lake Watershed
The amount of impervious cover (e.g., driveways, rooftops, parking lots) present in a watershed greatly influences the rate of groundwater recharge. This is because impervious cover both prevents precipitation from immediately soaking into the ground it falls on, and causes water to accumulate and move faster on the landscape, thereby reducing the amount of time the water remains in contact with soils. Consequently, as some land uses , characteristically contain a larger amount of impervious cover, it is important to understand the current and potential future land uses in the areas which contribute to groundwater supply.

The current land use (2010) in the Gilbert Lake watershed is shown on Map 10, while planned land use (2035) is shown on Map 11. The existing land use in the watershed, as summarized in Table 6, is primarily composed of land uses which allow for infiltration of water, such as agriculture and open spaces, further showing this importance of this land for recharge rates. However, under year 2035 planned land use conditions (also summarized in Table 5), the majority of the existing areas with little to no impervious cover would be expected to be converted to residential uses. This change potentially jeopardizes future groundwater recharge rates, indicating this land use change as an issue of concern.

Another important part of the land use data is the presence of the extraction site located in the internally drained site on the north end of the Gilbert Lake watershed (also shown on Map 10). Extraction sites often require the pumping of water out of the excavated area created as rock and/or sand are removed. This process of pumping could potentially influence groundwater flow/supplies to Gilbert Lake. The groundwater elevation contours are not completely clear on directions of flow from that particular site; consequently, it is possible that the pumping from this site may be influencing the southern spring (Spring #2) where water flow issues were identified earlier in this report. The land use data (2010 and 2035) for this internally drained area is shown in Table 7.

SUMMARY AND RECOMMENDATIONS

Summary
This section presents relevant information for the development of management and monitoring recommendations for Gilbert Lake and its watershed. To help with this analysis, the relevant results and information that were developed under this study are summarized below in the order they were presented:

1. Water chemistry and flow data revealed that the groundwater flowing to Gilbert Lake represents a significant portion of the Lake's water supply and provides a clean source of water that helps contribute to the health of the Lake, thereby indicating the maintenance of this groundwater flow is crucial to this waterbody.

[11] *For the purposes of this buffer analysis, a buffer is defined as a connected, well vegetated area which could play the role of slowing down and filtering surface runoff.*

2. The temperature data from the southern spring (Spring #2) indicates that there was likely reduced flow in spring of 2013, signaling that there may be activities in the surface watershed or groundwatershed that are affecting this spring.

3. Four additional springs were identified in the Gilbert Lake watershed, as well as two springs in the Big Cedar Lake watershed, thereby providing guidance of potential areas to monitor in the future.

4. The Gilbert Lake watershed has an area of 1,078 acres, and a large portion of that area (167 acres) is internally drained. The internally drained area would not contribute surface runoff, but could be a source of groundwater inflow to the Lake.

5. The groundwater elevation contours indicate that groundwater moves towards Gilbert Lake from the west, indicating that groundwater recharge from this area is crucial to the Lake's water supply. Additionally, the less easily interpreted contours north of the Lake indicate that the previously discussed internally drained area may be contributing to the Lake's water supply (although further investigation would be necessary to confirm this).

6. The moderate to very high groundwater recharge potential characteristics in the Gilbert Lake watershed suggest that the groundwater is a significant component of the water supply to Gilbert Lake, thereby indicating that protecting recharge in these areas is crucial to the Lake's health and resilience.

7. The buffer analysis indicates that Gilbert Lake is currently very well buffered by wetlands and woodlands adjacent to the Lake. These areas would provide water quality benefits to the Lake and may promote groundwater recharge, thereby indicating that protecting these areas will help protect the Lake.

8. The comparison of existing (2010) and planned (2035) land use in the Gilbert Lake watershed indicates that future land use changes could affect the groundwater recharge rates supplying Gilbert Lake. Measures to prevent this loss of recharge should be seen as a priority by the District and by local government. The provision of adequate stormwater infiltration facilities to serve new development could help to mitigate the loss of recharge potential from new impervious surfaces.

Recommendations

Based on the information presented above, a number of recommendations have been formulated to help the BCLPRD protect the water supply to Gilbert Lake.

The first set of recommendations seeks to monitor the known springs within Gilbert and Big Cedar Lake, and also to determine the extent of the areas which contribute to the Lake's water supply. These recommendations call for further investigation to fill in gaps in knowledge of the watershed hydrology. They are as follows:

1. <u>Establish a monitoring protocol</u> to detect any changes in groundwater discharge (e.g., the permanent deployment of temperature gauges at major identified springs as well as monitoring water quality[12] and chemistry in the Lake). This monitoring program would help obtain the data necessary to detect any patterns in discharge and could help determine potential sources of water loss (e.g., drought or over pumping).

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[12]*The Citizen Lake Monitoring Network (CLMN) is a State monitoring program that uses volunteer monitors and provides support services that could help cover the cost of monitoring the water quality in Gilbert Lake.*

2. Investigate the shallow aquifer groundwatershed contributing to Gilbert Lake and potentially Big Cedar Lake. This monitoring program could give a good indication of the areas outside of the Gilbert Lake watershed where groundwater recharge needs to be protected.

3. Investigate the area which contributes groundwater to the southern spring that was monitored in this study (e.g., through tracers deployed in suspected recharge areas). This investigation should include a component to help determine why groundwater discharge seemed to decrease at this site in the spring in 2013.

The second set of recommendations, shown on Map 12, relate to action items to protect potential groundwater recharge sources. These general recommendations are included because it may be more feasible and effective to begin action on them without further monitoring, especially given the small size of the watershed relative to the lake size. They are as follows:

1. Encourage the maintenance of infiltration functions (i.e., groundwater recharge) in the Gilbert Lake watershed, *with a particular focus on the high and very high recharge potential areas.* This could be undertaken simply by encouraging the maintenance of the natural areas and open spaces which exist in these areas.

2. Enhance groundwater recharge by encouraging the additional use of best management practices (e.g., rain gardens, porous pavement, infiltration basins) in the residential and agricultural areas which currently exist in the Gilbert Lake watershed. This could help the watershed cope with any droughts or pumping which may affect the Lake's water supply.

3. Advocate and encourage the use of green technology and infiltration projects (including best management practices) in any new residential areas within the Gilbert Lake watershed and in new commercial areas with appropriate pretreatment to protect the groundwater. This should be considered a priority to maintain current infiltration rates and ensure that future development does not jeopardize the quantity and quality of water that is supplied to the Lake.

CONCLUSIONS

Gilbert Lake is a high-quality lake that should be protected. The Big Cedar Lake Protection and Rehabilitation District has thus far been proactive in attempting to ensure the protection of Gilbert Lake. However, there are issues of concern which require further monitoring and management efforts to ensure that Gilbert Lake remains a high-value Lake. The implementation of the recommendations set forth in this memorandum will help focus future management efforts, and maintain the Lake's water quality and quantity now and in the future.

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SEWRPC Staff Memorandum

GROUNDWATER INVESTIGATION FOR GILBERT LAKE WASHINGTON COUNTY, WISCONSIN

TABLES

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Table 1

HYDROLOGIC CHARACTERISTICS OF GILBERT LAKE

Parameter	Measurement
Size	
Surface Area of Lake	43 acres
Total Tributary Area	1078 acres[a]
Lake Volume	108.1 acre-feet
Shape	
Length of Shoreline	2.1 miles
General Lake Orientation	N-S
Depth	
Maximum Depth	9 feet
Mean Depth	3 feet
Percentage of Lake Area	
Less than Three feet	80 percent
Greater than 20 feet	0 percent

[a] *The tributary area includes the area which directly drains to Gilbert Lake (911 acres) as well as an internally drained area on the north end of the watershed (167 acres).*

Source: Wisconsin Department of Natural Resources, and SEWRPC.

Table 2

DESCRIPTION OF WATER QUALITY PARAMETERS AND THEIR REGIONAL AVERAGES

Parameter (in milligrams per liter (mg/l) unless otherwise noted)	Description	Regional Average	Existing Standards
Alkalinity	The measure of the ability of a lake to absorb and neutralize acidic loadings, aka buffering; influenced by the soils and bedrock of the watershed due to any calcium carbonates ($CaCO_3$) – **higher levels of Ca CO_3 indicate a more alkaline lake with a higher buffering capacity**	173	- -
Calcium	Related to the growth of phytoplankton due to its reactive nature with phosphorus. **High values indicate groundwater inputs**	36	
Chlorophyll-*a*	The major photosynthetic, "green," pigment in algae. The amount of chlorophyll-*a* present in the water is an indication of the biomass, or amount of algae, in the water. **Chlorophyll-*a* levels above 0.10 mg/l generally result in a green coloration of the water** that may be severe enough to impair recreational activities, such as swimming or waterskiing	43	- -
Water Clarity (feet)	Measured with a Secchi disk, a black-and-white, eight-inch-diameter disk, which is lowered into the water until a depth is reached at which the disk is no longer visible. It can be affected by physical factors, such as suspended particles, and by various biologic factors, including planktonic algal populations living in a lake. **Groundwater inputs generally tend to be clearer due to the filtration which often naturally occurs during infiltration**	5	- -
Conductivity (MicroSiemens per centimeter – µS/cm)	The measure of how much resistance to electrical flow exists in the water, thereby indirectly estimating the amount of dissolved ions in the water; **increased conductivity measurements can signal a potential pollution problem or can indicate a high percentage of groundwater**	500-600	- -
Dissolved Oxygen	Dissolved oxygen levels are one of the most critical factors affecting the living organisms of a lake ecosystem. Generally, dissolved oxygen levels are higher at the surface of a lake, where there is an interchange between the water and atmosphere, stirring by wind action, and production of oxygen by plant photosynthesis. Dissolved oxygen levels are usually lowest near the bottom of a lake, where decomposer organisms and chemical oxidation processes deplete oxygen during the decay process. A concentration of about 5.0 mg/l is considered the minimum level below which oxygen-consuming organisms, such as fish, become stressed, while fish are unlikely to survive when dissolved oxygen concentrations drop below 2.0 mg/l. **Groundwater inputs tend to have lower dissolved oxygen due to extended time in subterranean environments**	10-12	- -
Hardness	Measure of multivalent metallic ion concentrations such as calcium and magnesium in a lake; lakes with higher hardness levels tend to produce more fish and aquatic plants	- -	- -
Magnesium	A fundamental building block of chlorophyll and a vital nutrient to all green plants. **High levels can be an indicator of groundwater contributions**	32	- -
pH (Standard Units – S.U.)	Measures the hydrogen ion concentration on a scale from 0 (alkaline) to 14 (acidic); it influences how much nutrients (e.g., phosphorus, nitrogen) can be utilized and **can affect the solubility and toxicity of heavy metals** (e.g., lead, copper, cadmium), all of this affects the organisms living in a lake	7-8.5	- -
Total Phosphorus	Phosphorus, which can enter a lake from natural and manmade sources, is a fundamental building block for plant growth. However, excessive levels of phosphorus in lakes can lead to nuisance levels of plant growth, unsightly algal blooms, decreased water clarity, and oxygen depletion that can stress or kill fish and other aquatic life. Statewide standards exist for phosphorus concentrations in lakes. **A concentration of less than 0.040 mg/l is the concentration considered necessary to limit algal and aquatic plant growths to levels consistent with recreational water use objectives**	- -	0.02

Source: SEWRPC.

Table 3

MINIMUM, MEDIAN, AND MAXIMUM VALUES FOR WATER CHEMISTRY SAMPLES TAKEN FROM GILBERT LAKE SAMPLING SITES

Site Name	Value	Dissolved Oxygen (mg/L)	pH	Specific Conductance (µS/cm)	Temperature (°C)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)	Magnesium (mg/L)	Phosphorus (mg/L)	Chlorophyll-*a* (mg/L)	Transparency Secchi Depth (meters)
Tributary	Median	8.95	7.80	812.5	10.50	355.5	75.75	40.40	0.0330	2.23	0.200
	Minimum	8.10	7.50	625.0	6.10	296.0	64.30	32.80	0.0190	0.88	0.200
	Maximum	15.10	8.20	900.0	16.20	380.0	82.00	42.50	0.0600	27.80	0.450
Spring #1	Median	3.70	7.70	785.0	9.50	355.0	75.15	40.50	0.0090	1.00	2.000
	Minimum	2.00	7.60	769.0	8.60	344.0	71.80	39.90	0.0060	<0.26	1.500
	Maximum	4.60	8.60	819.0	10.20	358.0	76.40	41.00	0.0120	1.84	2.000
Spring #2	Median	4.75	7.75	909.0	9.45	378.0	81.30	42.40	0.0095	0.32	1.500
	Minimum	3.10	7.60	702.0	8.70	323.0	65.50	38.80	0.0070	<0.26	1.000
	Maximum	5.70	8.40	947.0	10.60	400.0	87.10	44.20	0.0110	0.72	2.000
Deep Hole	Median	12.00	8.40	732.0	9.15	306.0	60.85	39.55	0.0285	9.05	2.025
	Minimum	7.50	7.90	682.0	4.70	277.0	40.20	34.80	0.0210	5.51	1.000
	Maximum	12.70	8.60	867.0	26.60	329.0	67.10	42.80	0.0450	28.80	2.500

Source: U.S. Geological Survey.

Table 4

MEASURED STREAMFLOW IN GILBERT LAKE SAMPLING SITES

Site Name	Date	Streamflow (feet^3/second)	Measurement rating
Tributary	04/26/2012	0.31	Poor
	07/31/2012	0.23	Poor
	11/01/2012	0.05	Poor
	04/04/2013	0.67	Poor
Spring #1	07/31/2012	0.31	Poor
Spring #2	07//31/2012	0.17	Poor

Source: U.S. Geological Survey.

Table 5

STANDARDS FOR CLASSIFYING TROPHIC STATUS DESIGNATIONS

Trophic Status	Total phosphorus	Chlorophyll-*a*	Secchi Depth
Oligotrophic	3	2	12
	10	5	8
Mesotrophic	18	8	6
	27	10	6
Eutrophic	30	11	5
	50	15	4

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table 6

EXISTING AND PLANNED LAND USE WITHIN THE DIRECT DRAINAGE AREA TRIBUTARY TO GILBERT LAKE: 2010 AND 2035

Land Use Categories[a]	2010 Acres	2010 Percent of Total	2035 Acres	2035 Percent of Total
Urban				
Residential				
Single-Family, Suburban Density	5	0.5	206	22.6
Single-Family, Low Density	104	11.4	135	14.8
Single-Family, Medium Density	3	0.3	3	0.3
Single-Family, High Density	- -	- -	- -	- -
Multi-Family	- -	- -	- -	- -
Commercial	8	0.9	40	4.4
Industrial	15	1.7	18	2.0
Governmental and Institutional	4	0.4	4	0.4
Transportation, Communication, and Utilities	44	4.8	91	10.0
Recreational	- -	- -	- -	- -
Subtotal	183	20.0	497	54.5
Rural				
Agricultural and Other Open Lands	463	50.9	149	16.4
Wetlands	131	14.4	131	14.4
Woodlands	84	9.2	84	9.2
Water	50	5.5	50	5.5
Extractive	- -	- -	- -	- -
Landfill	- -	- -	- -	- -
Subtotal	728	80.0	414	45.5
Total	911	100.0	911	100.0

[a] *Parking included in associated use.*

Source: SEWRPC.

Table 7

EXISTING AND PLANNED LAND USE WITHIN THE INTERNALLY DRAINED AREA WITHIN THE GILBERT LAKE WATERSHED: 2010 AND 2035

Land Use Categories[a]	2010		2035	
	Acres	Percent of Total	Acres	Percent of Total
Urban				
Residential				
Single-Family, Suburban Density	- -	- -	- -	- -
Single-Family, Low Density	4	2.4	18	10.7
Single-Family, Medium Density	- -	- -	- -	- -
Single-Family, High Density	- -	- -	- -	- -
Multi-Family	- -	- -	- -	- -
Commercial	- -	- -	11	6.6
Industrial	- -	- -	- -	- -
Governmental and Institutional	- -	- -	- -	- -
Transportation, Communication, and Utilities	4	3.6	6	3.6
Recreational	- -	- -	- -	- -
Subtotal	10	6.0	35	20.9
Rural				
Agricultural and Other Open Lands	40	23.9	15	9.0
Wetlands	- -	- -	- -	- -
Woodlands	7	4.2	7	4.2
Water	- -	- -	- -	- -
Extractive	110	65.9	110	65.9
Landfill	- -	- -	- -	- -
Subtotal	157	94.0	132	79.1
Total	167	100.0	167	100.0

[a] *Parking included in associated use.*

Source: SEWRPC.

SEWRPC Staff Memorandum

GROUNDWATER INVESTIGATION FOR GILBERT LAKE WASHINGTON COUNTY, WISCONSIN

FIGURES

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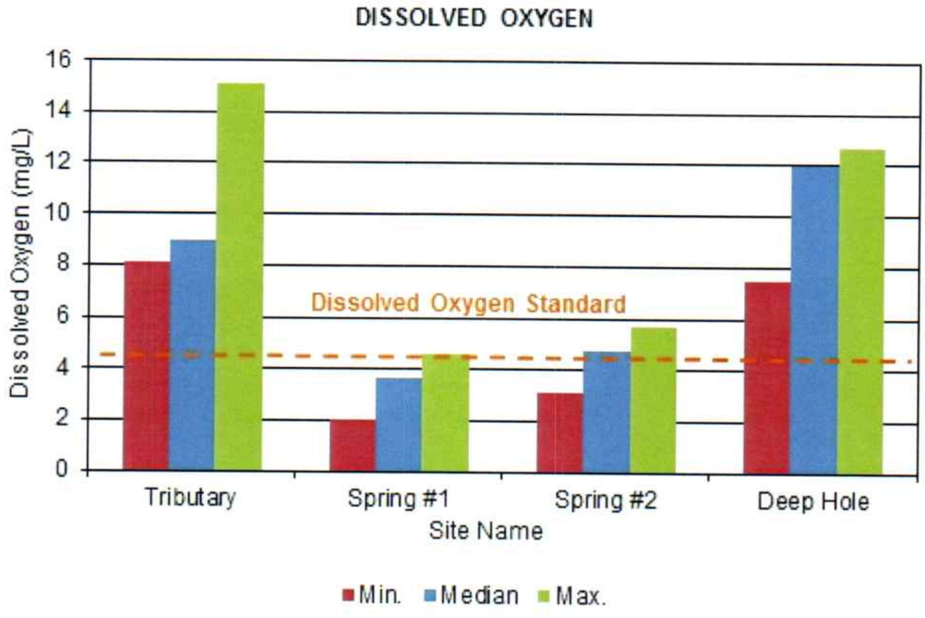
Figure 1

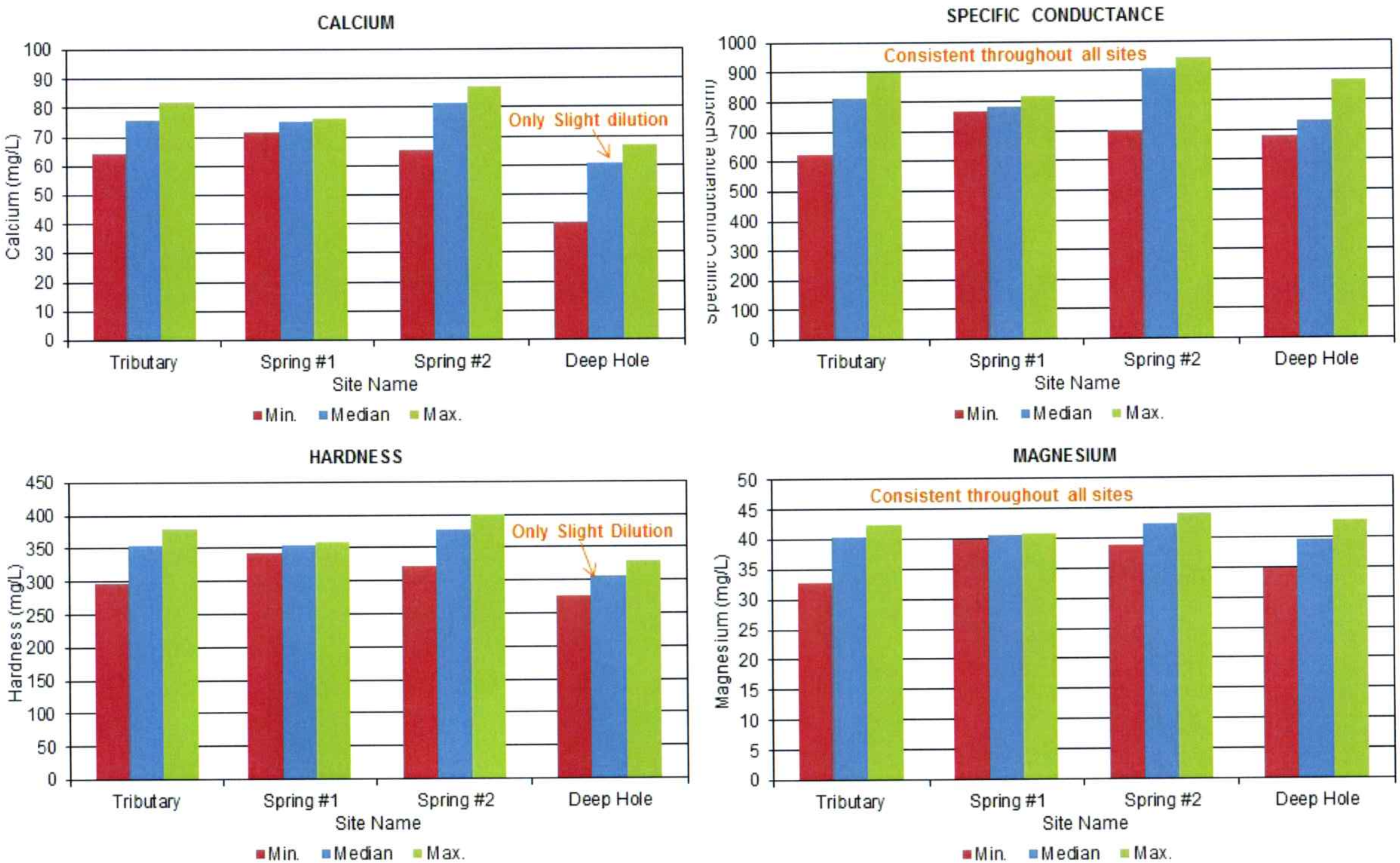
SUMMARY OF DISSOLVED OXYGEN DATA FOR GILBERT LAKE SAMPLING SITES



Source: U.S. Geological Survey and SEWRPC.

Figure 2

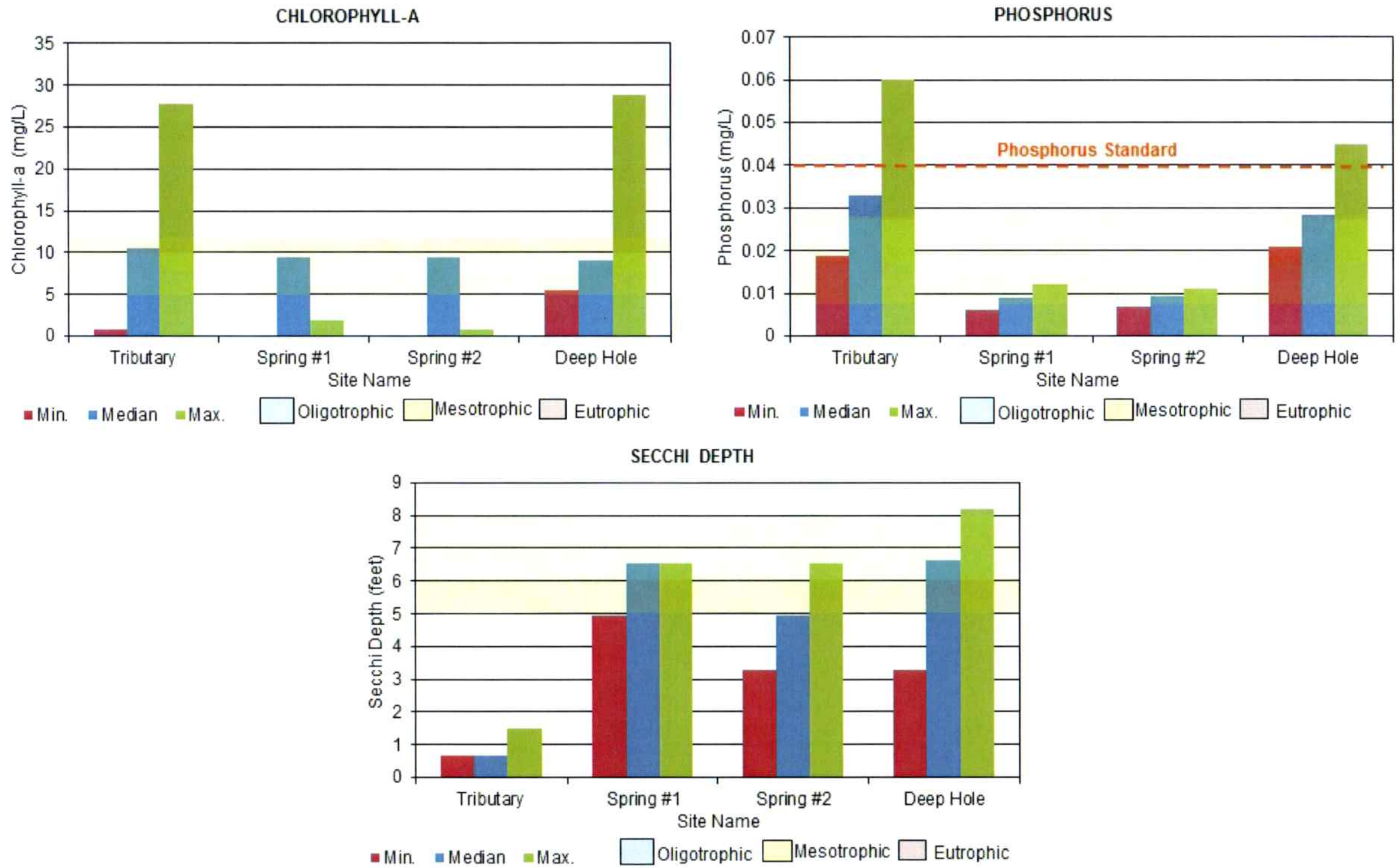
SUMMARY OF WATER CHEMISTRY DATA FOR GILBERT LAKE SAMPLING SITES



Source: U.S. Geological Survey and SEWRPC.

Figure 3

TROPHIC STATUS INDICATOR PARAMETERS GILBERT LAKE SAMPLING SITES



Source: U.S. Geological Survey and SEWRPC.

Figure 4

HOURLY TEMPERATURE MEASUREMENTS FOR GILBERT LAKE SAMPLING SITES

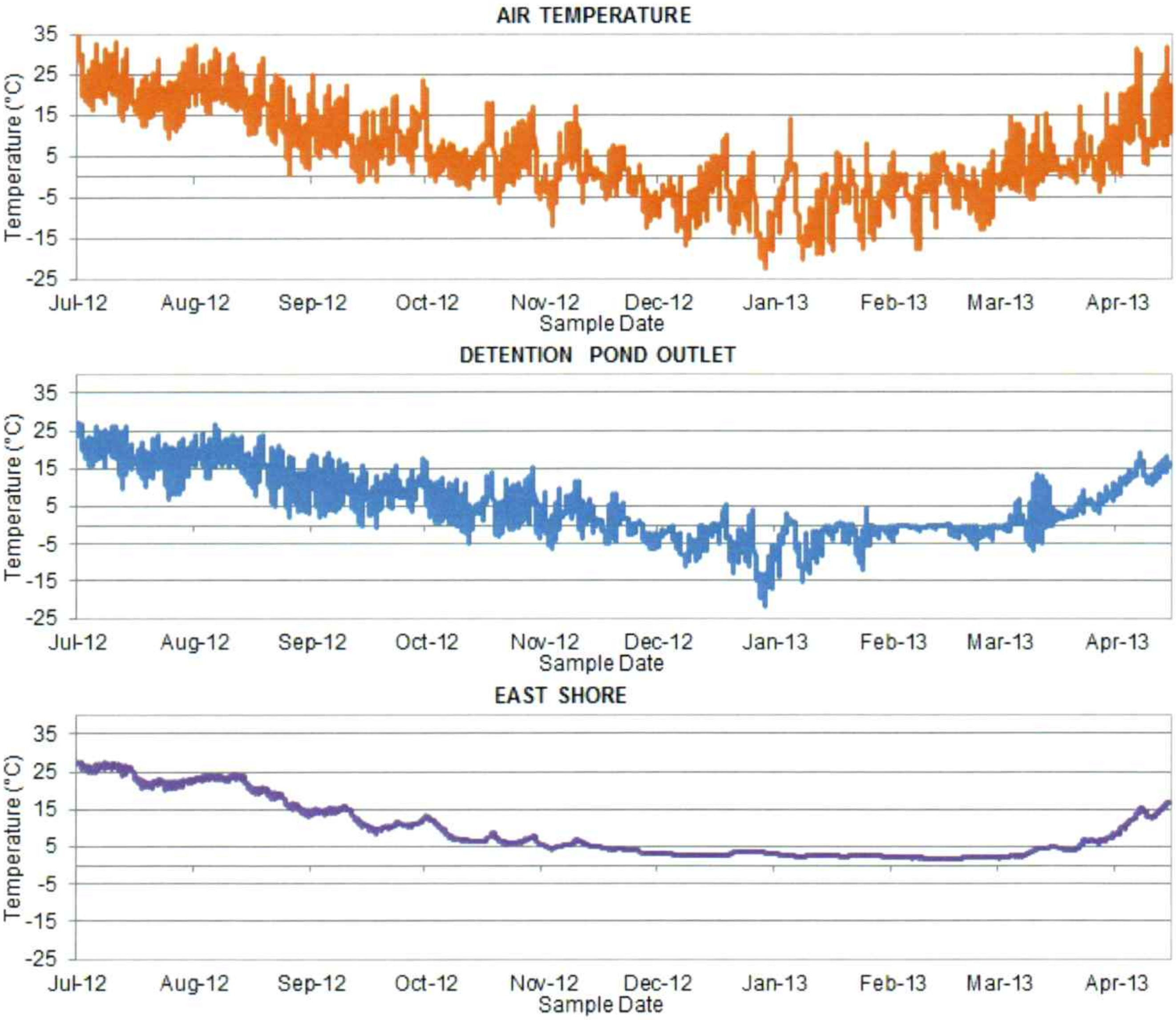
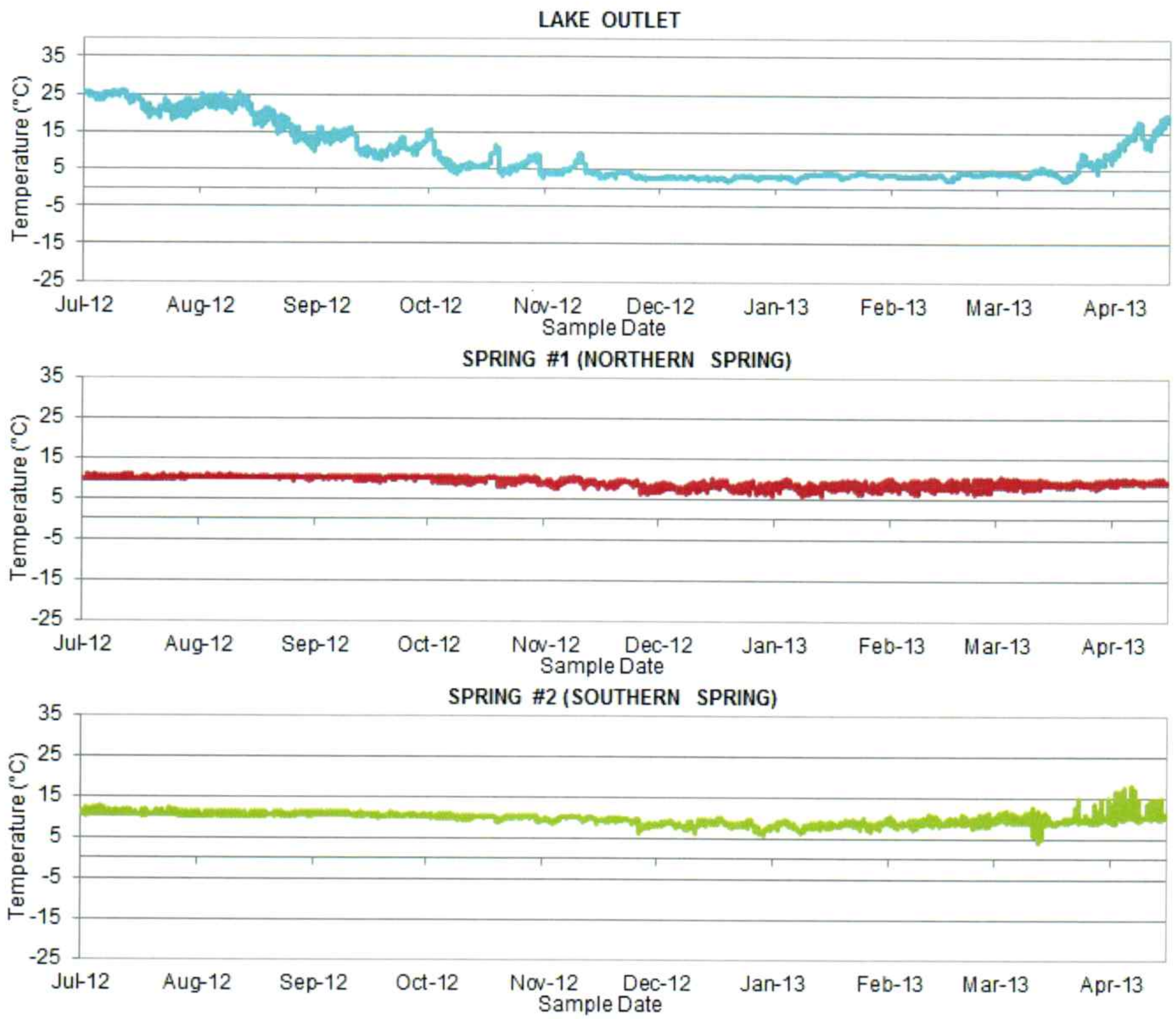


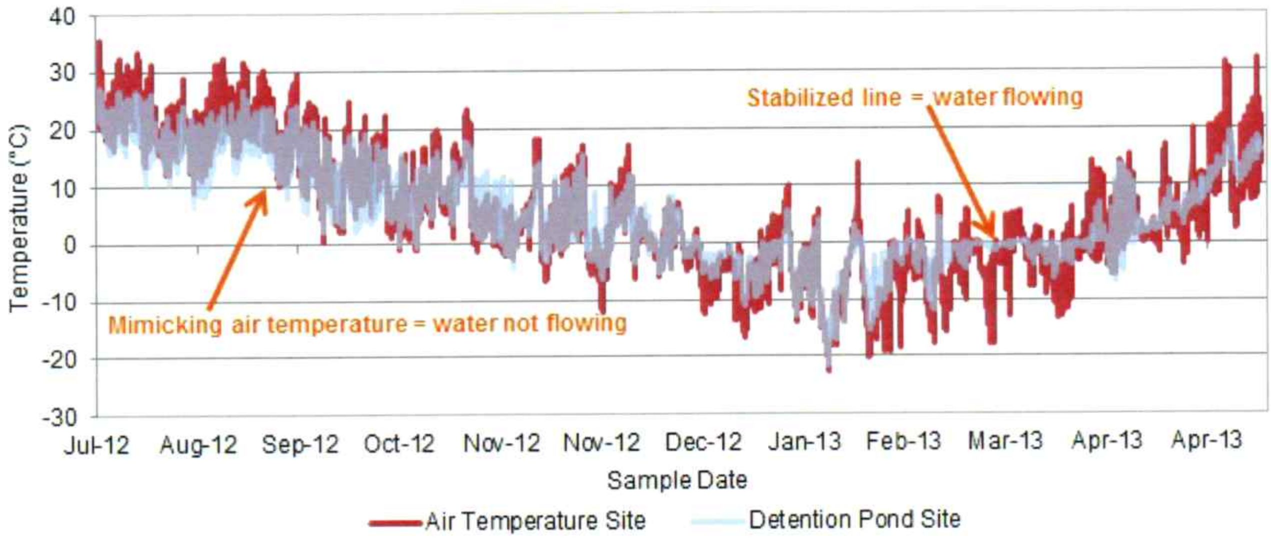
Figure 4 (continued)



Source: SEWRPC.

Figure 5

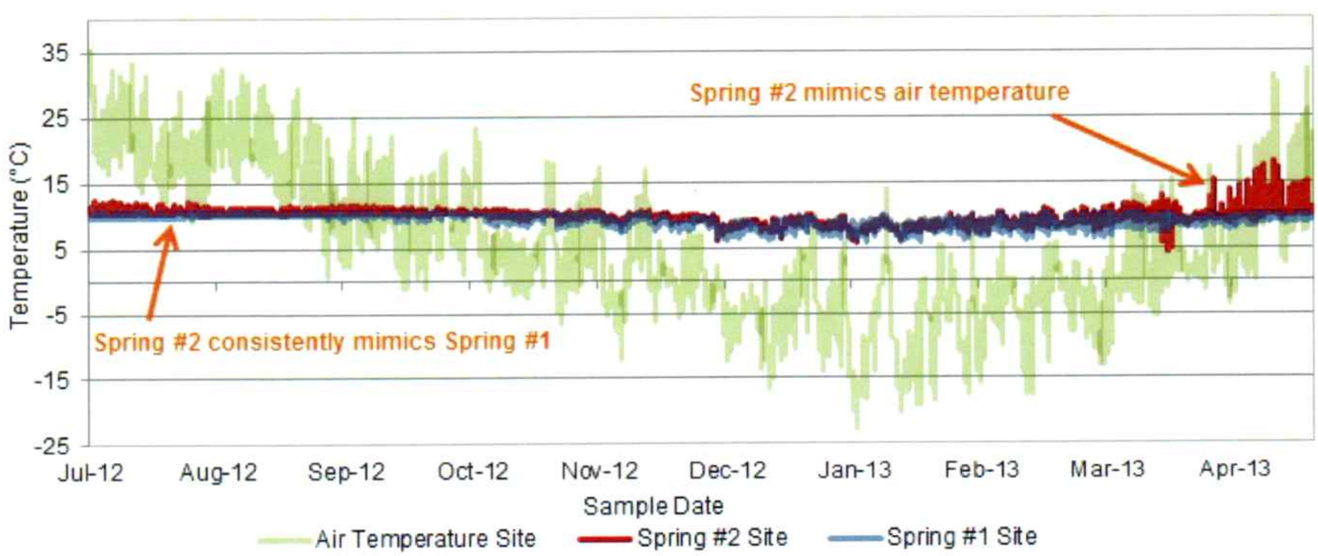
COMPARISON OF HOURLY TEMPERATURE DATA FOR THE AIR TEMPERATURE AND DETENTION POND OUTLET SITES



Source: SEWRPC.

Figure 6

COMPARISON OF HOURLY TEMPERATURE DATA FOR THE AIR TEMPERATURE AND TWO SPRING SITES



Source: SEWRPC.

SEWRPC Staff Memorandum

**GROUNDWATER INVESTIGATION FOR GILBERT LAKE
WASHINGTON COUNTY, WISCONSIN**

MAPS

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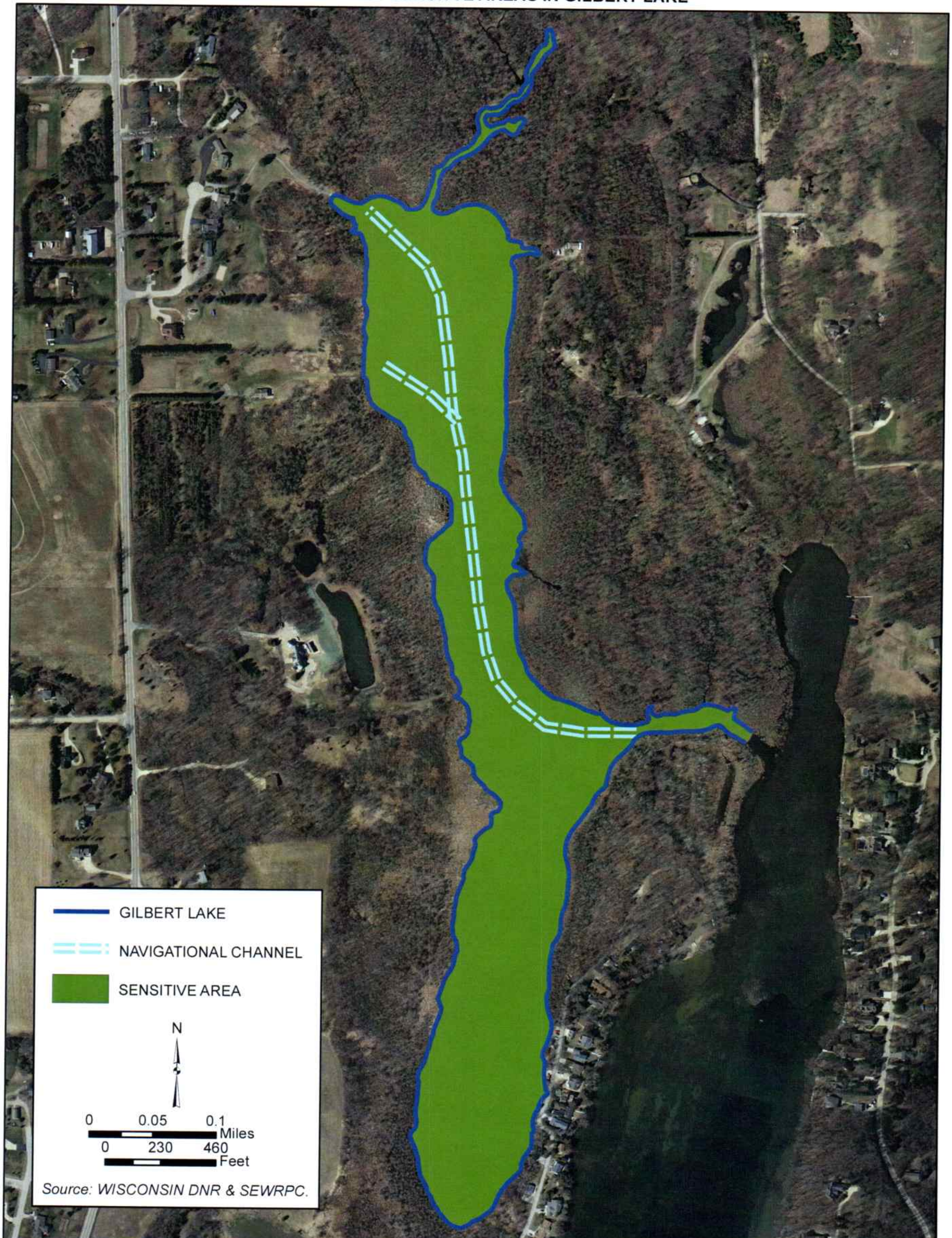
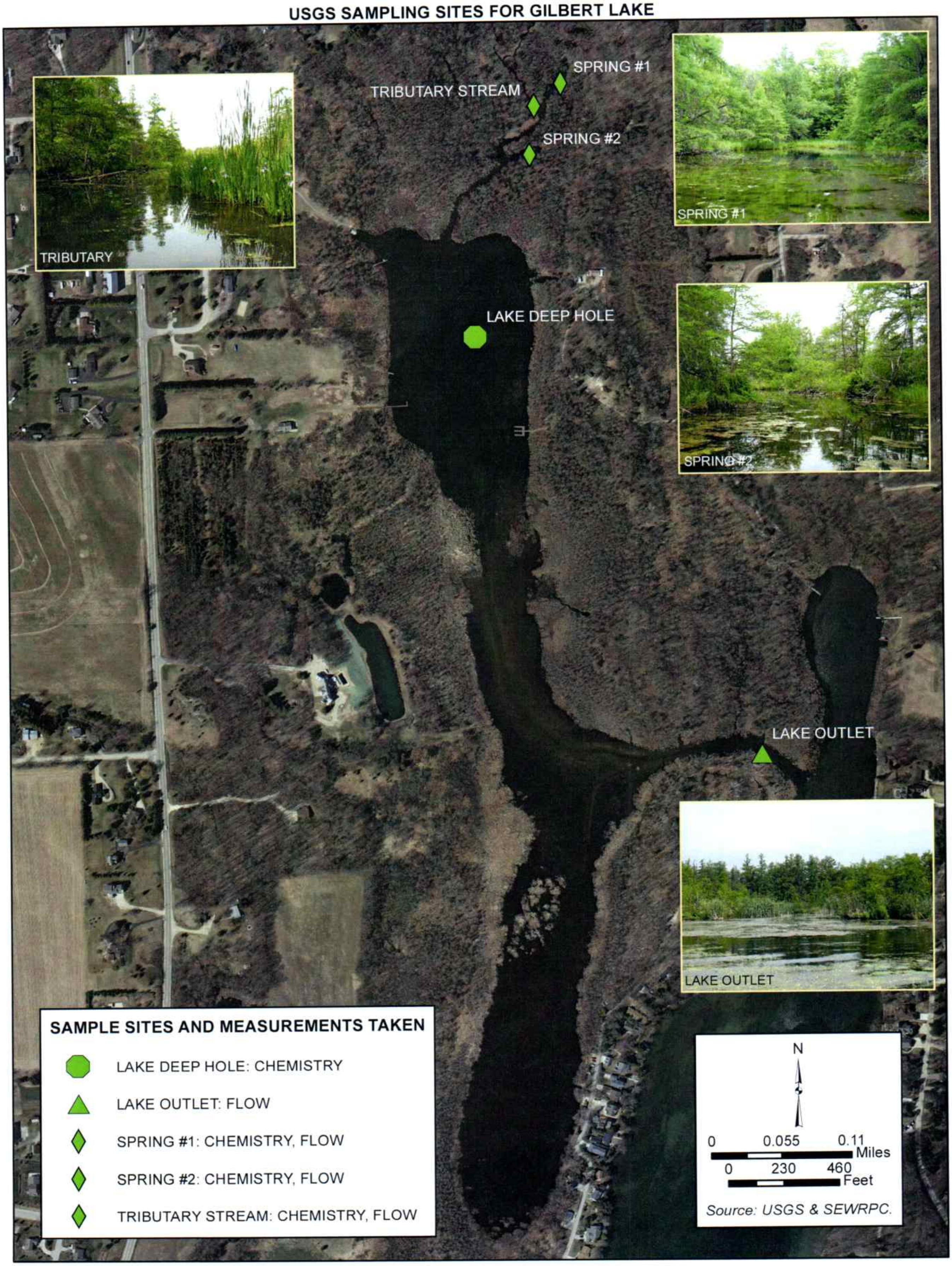
Map 1

DESIGNATED SENSITVE AREAS IN GILBERT LAKE



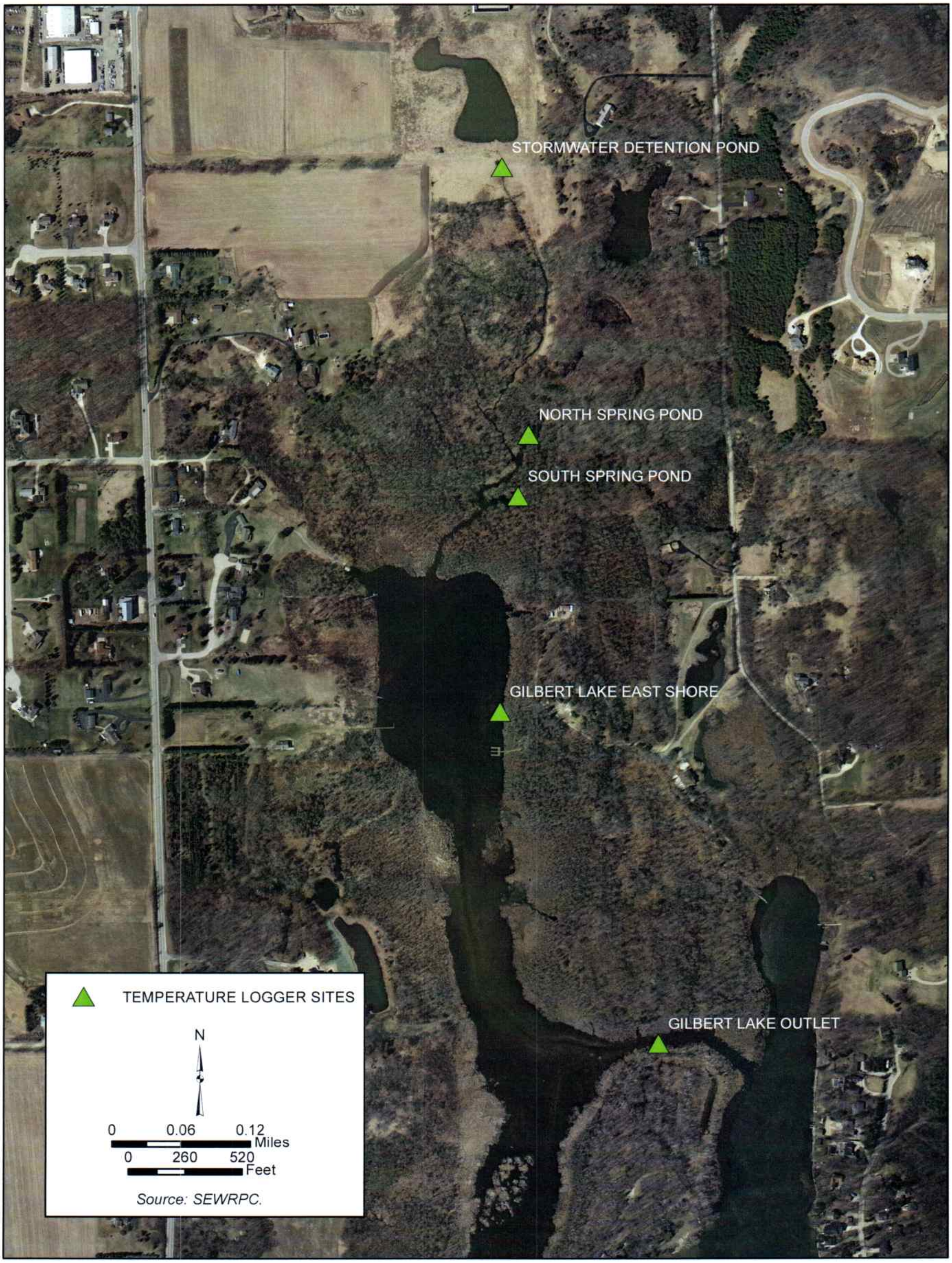
Map 2

USGS SAMPLING SITES FOR GILBERT LAKE



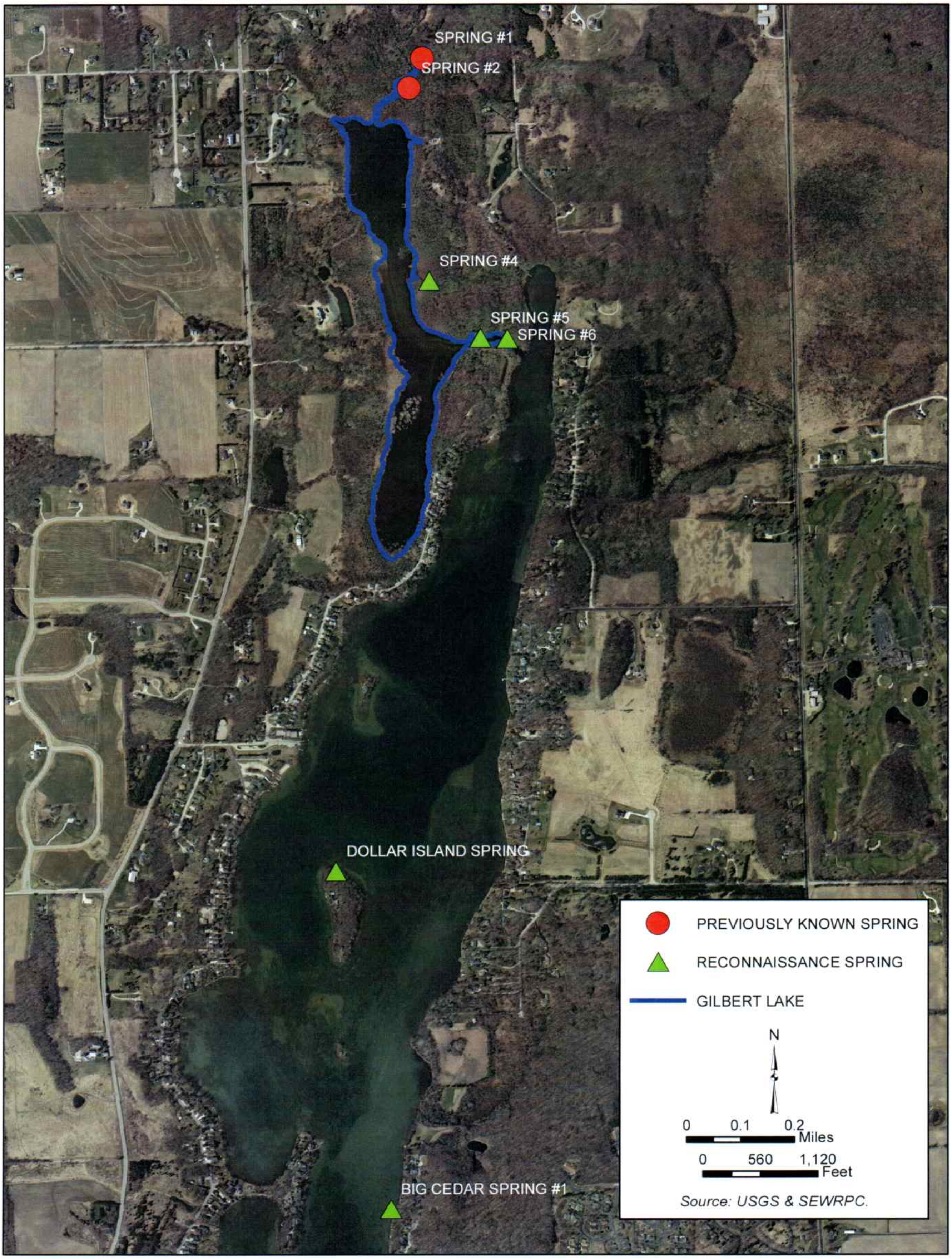
Map 3

TEMPERATURE DATA LOGGER LOCATIONS FOR GILBERT LAKE



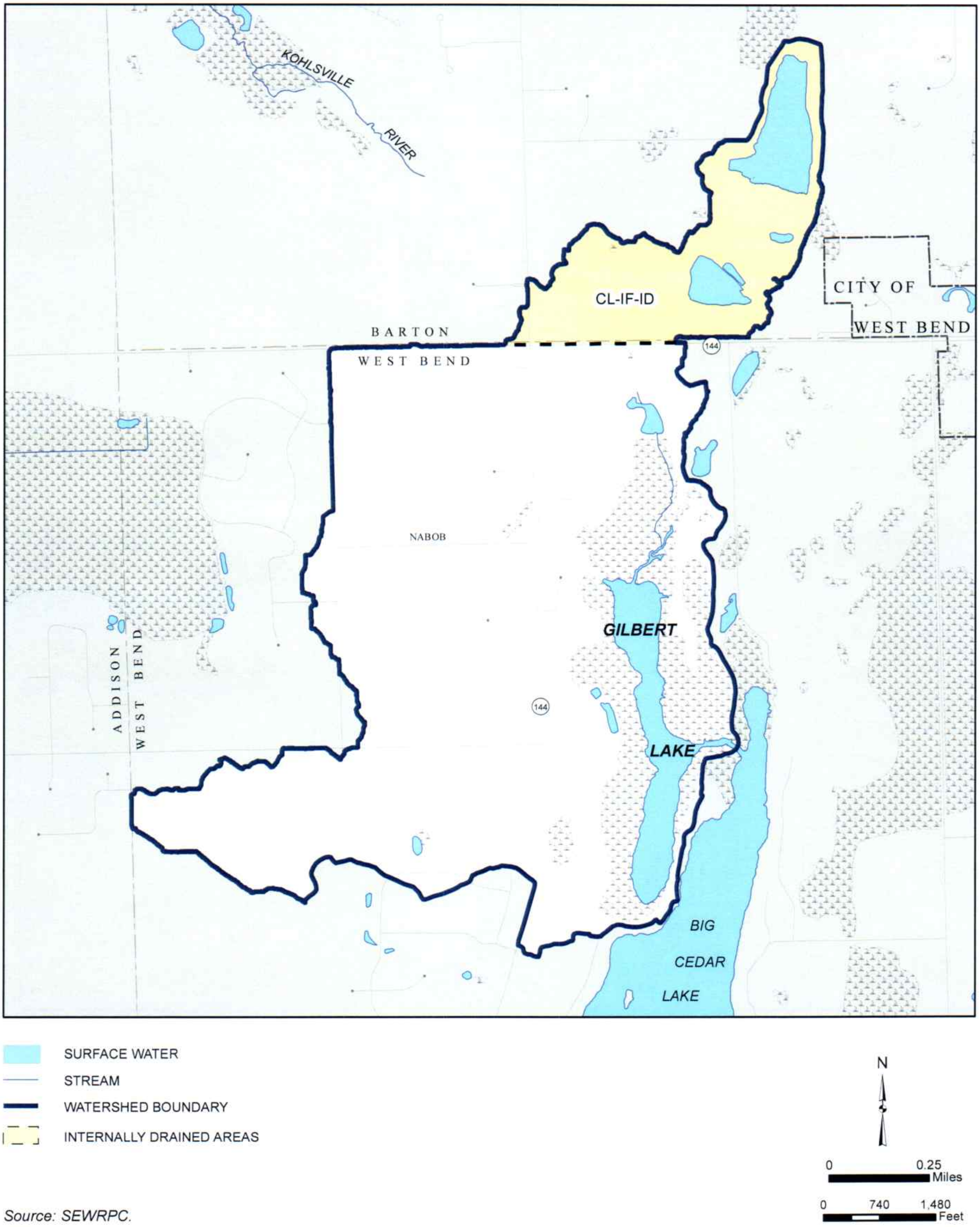
Map 4

LOCATION OF SPRINGS WITHIN THE GILBERT/CEDAR LAKE WATERSHED



Map 5

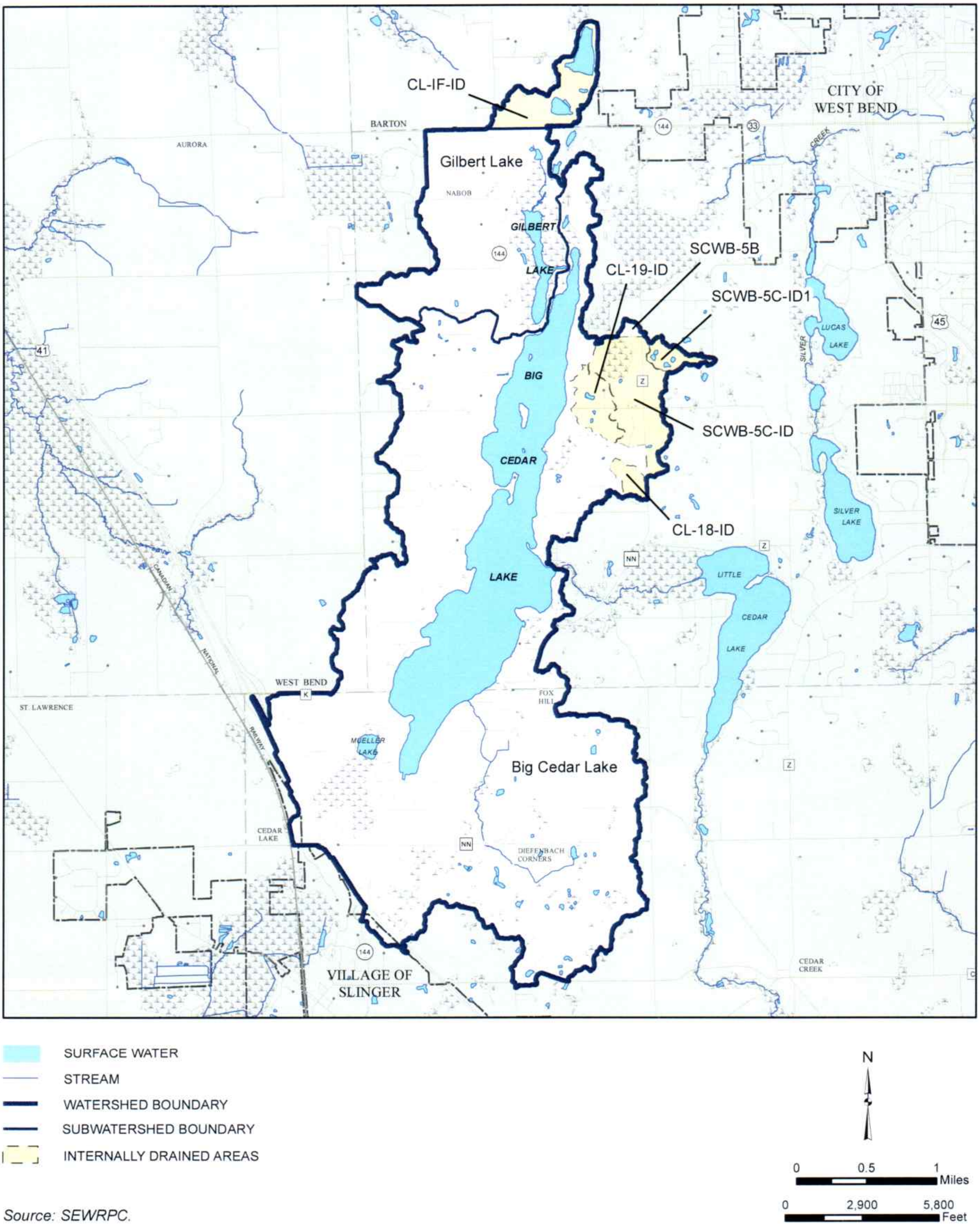
SURFACE WATER RESOURCES WITHIN THE GILBERT LAKE WATERSHED: 2005



Source: SEWRPC.

Map 6

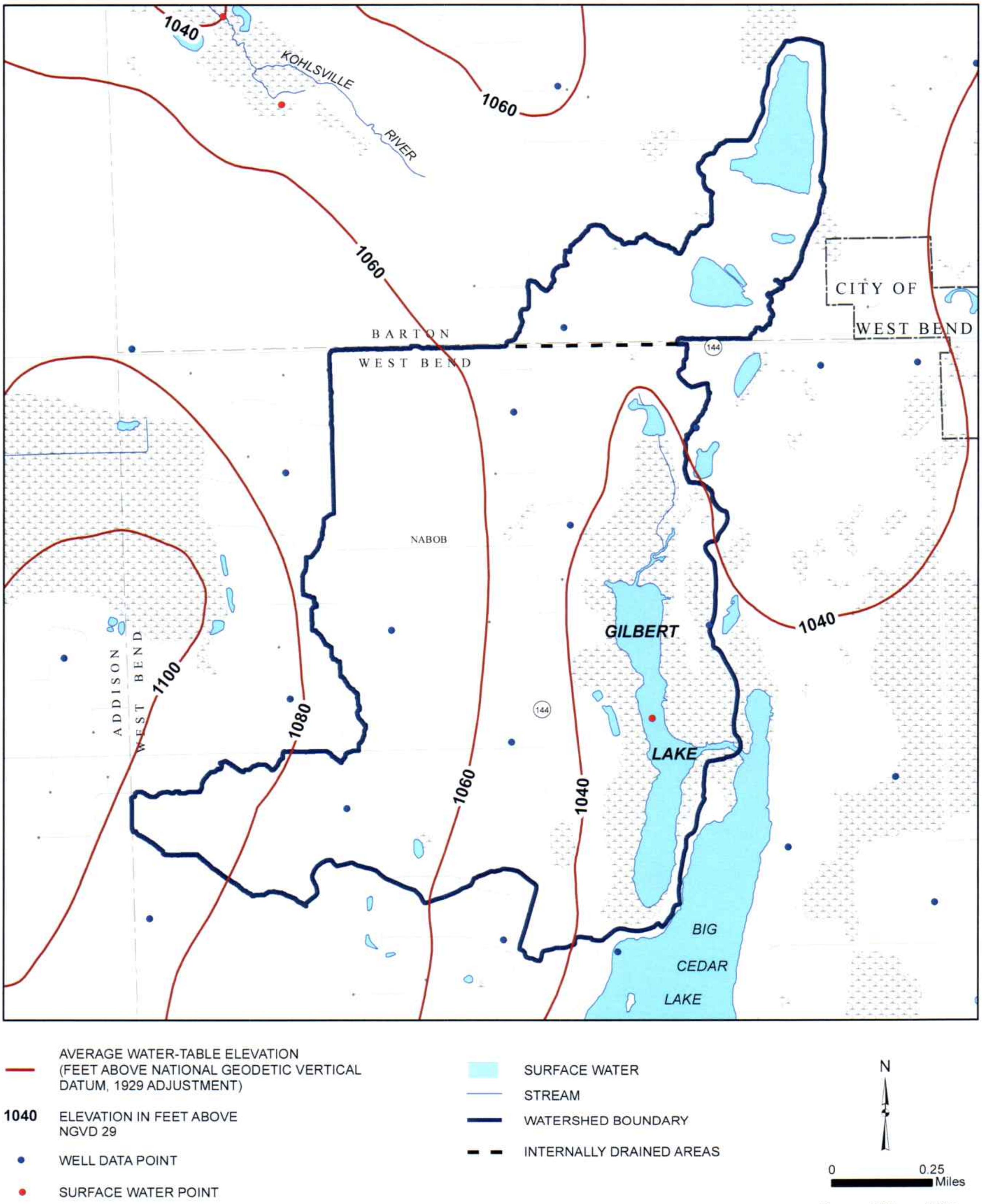
SURFACE WATER RESOURCES WITHIN THE GILBERT/CEDAR LAKE WATERSHED: 2005



Source: SEWRPC.

Map 7

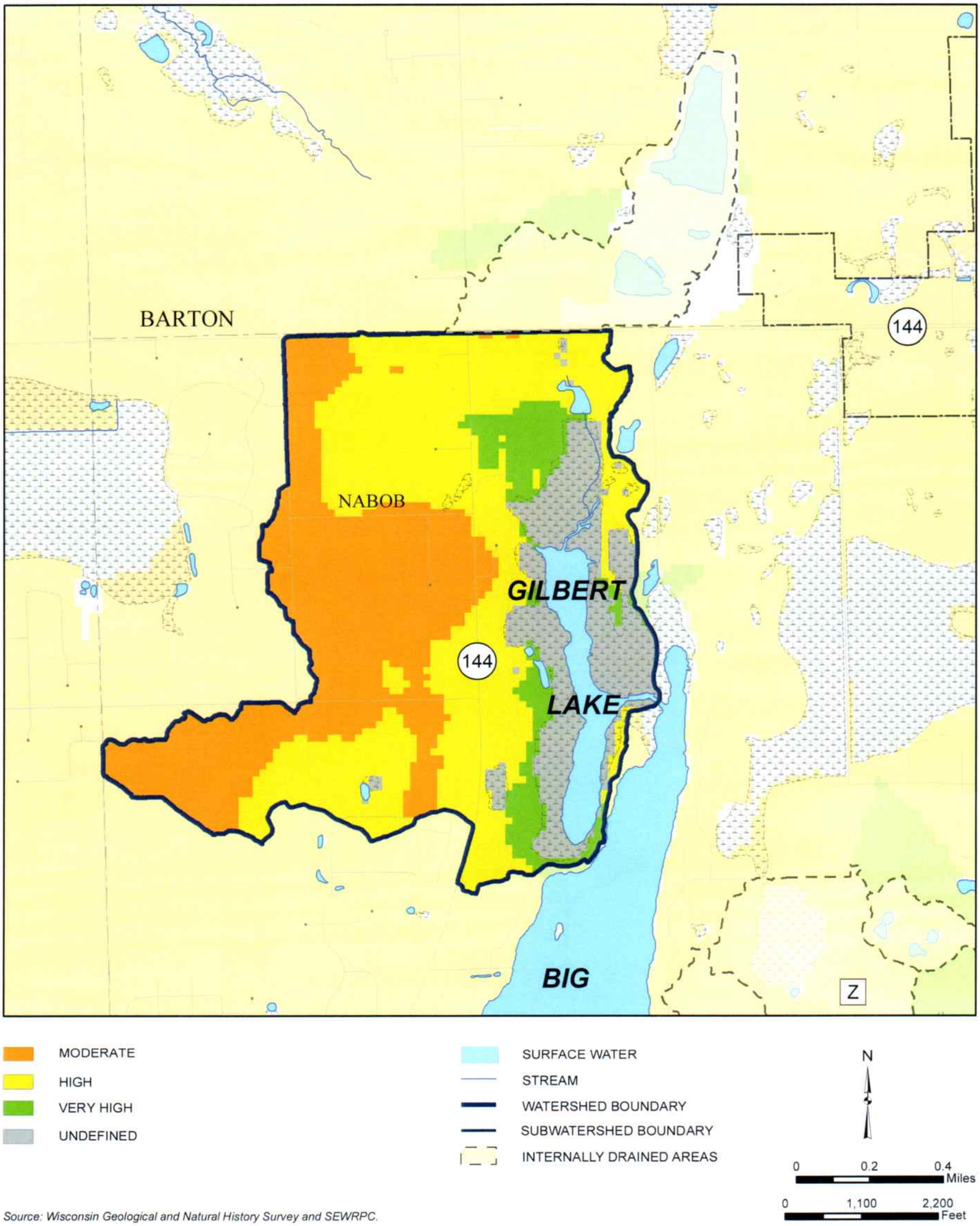
GROUNDWATER ELEVATION CONTOURS WITHIN THE GILBERT LAKE WATERSHED



Source: Wisconsin Geological and Natural History Survey and SEWRPC.

Map 8

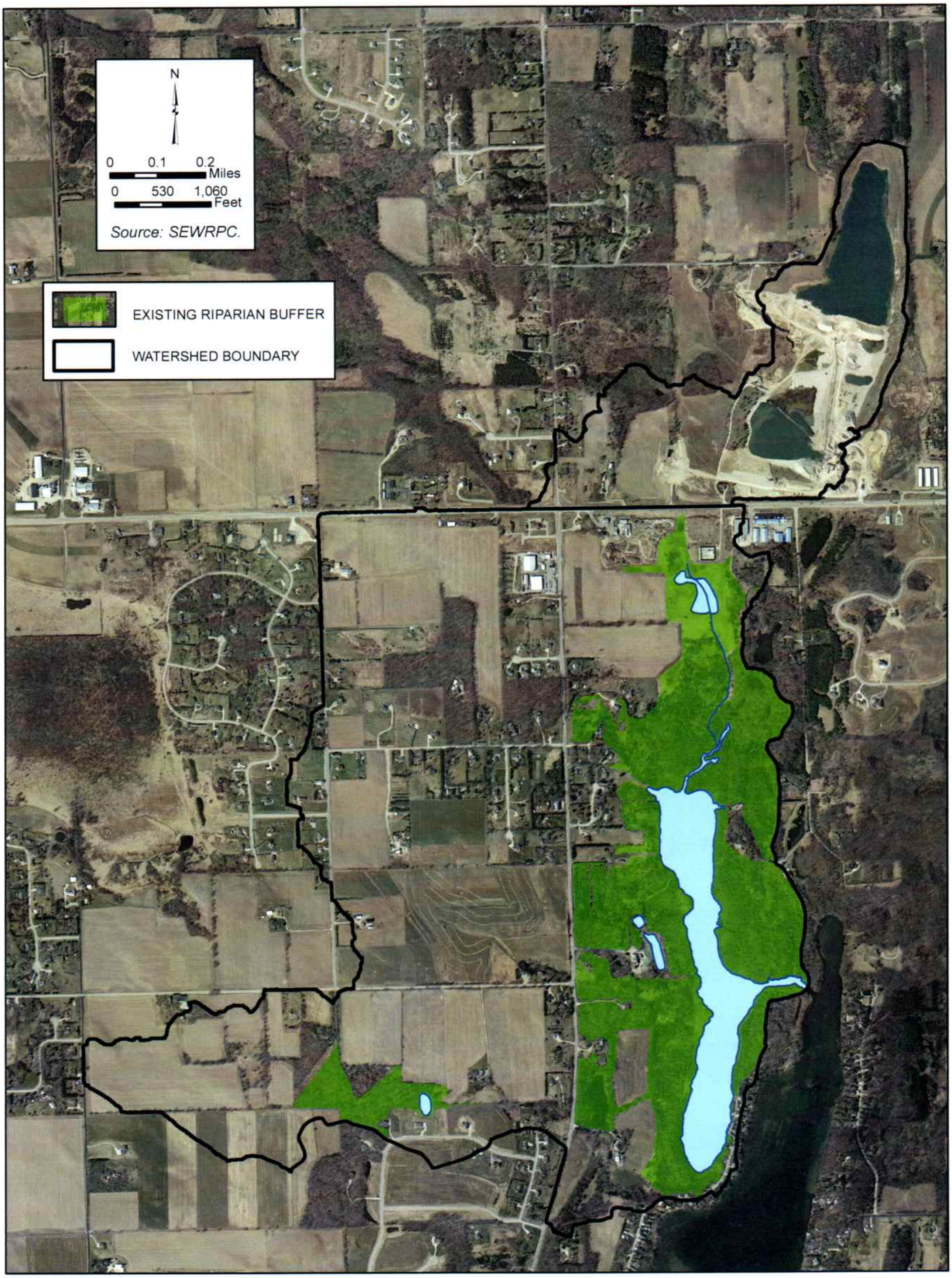
ESTIMATES OF GROUNDWATER RECHARGE POTENTIAL WITHIN THE GILBERT LAKE WATERSHED



Source: Wisconsin Geological and Natural History Survey and SEWRPC.

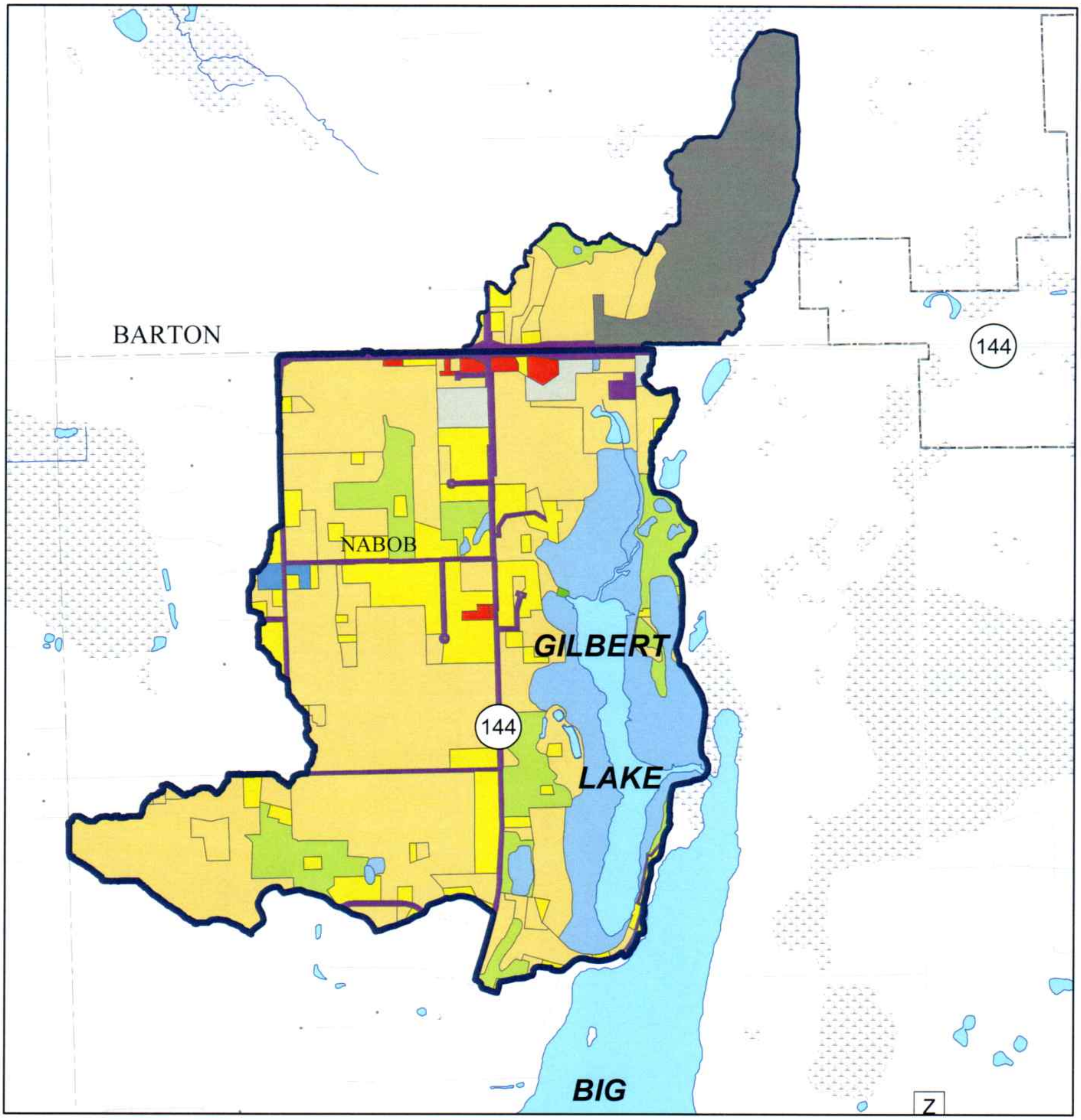
Map 9

EXISTING BUFFER AREAS IN THE GILBERT LAKE WATERSHED



Map 10

EXISTING LAND USE IN THE GILBERT LAKE WATERSHED: 2010



SINGLE-FAMILY RESIDENTIAL
MULTI-FAMILY RESIDENTIAL
COMMERCIAL
INDUSTRIAL
TRANSPORTATION, COMMUNICATIONS, AND UTILITIES
GOVERNMENT AND INSTITUTIONAL
RECREATION
WETLANDS
WOODLANDS
SURFACE WATER
AGRICULTURAL, UNUSED, AND OTHER OPEN LANDS
EXTRACTIVE AND LANDFILL
STREAM
WATERSHED BOUNDARY
SUBWATERSHED BOUNDARY

N

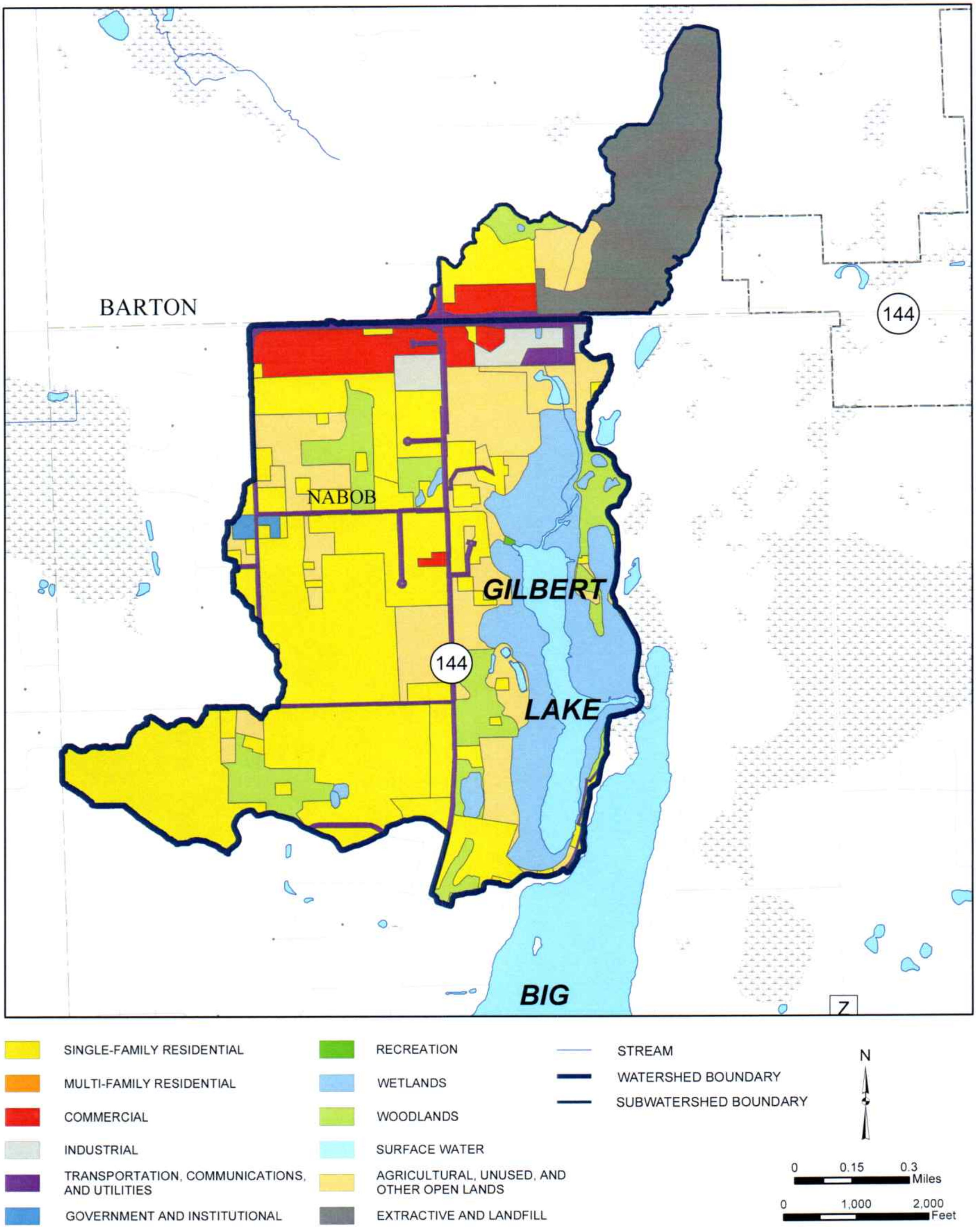
0 0.15 0.3 Miles

0 1,000 2,000 Feet

Source: SEWRPC.

Map 11

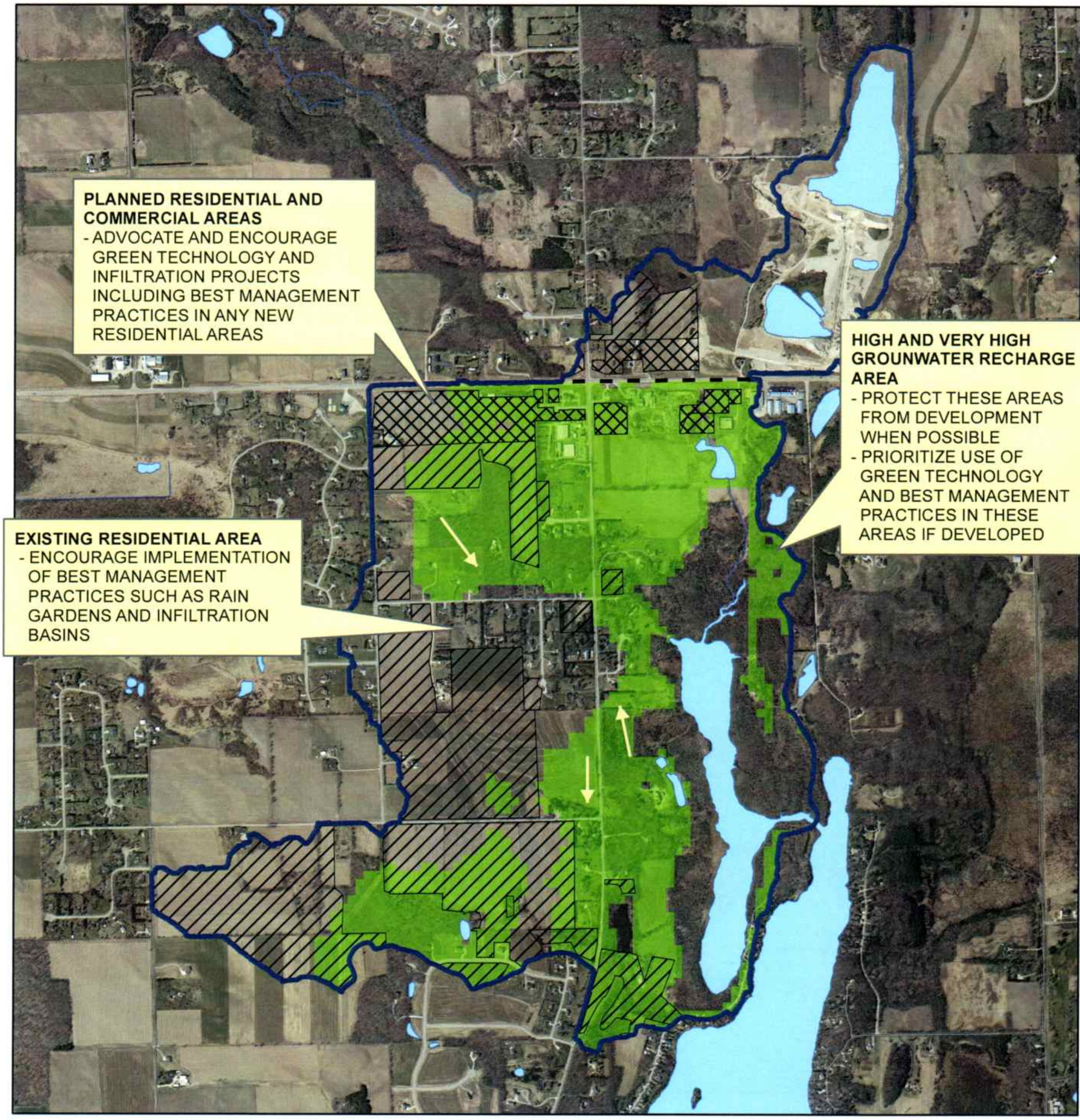
PLANNED LAND USE IN THE GILBERT LAKE WATERSHED: 2035



Source: SEWRPC.

Map 12

RECOMMENDED MANAGEMENT ACTIONS FOR THE GILBERT LAKE WATERSHED



HIGH AND VERY HIGH GROUNDWATER RECHARGE POTENTIAL AREAS

AGRICULTURAL, OPEN SPACE, AND NATURAL AREAS LOST IN 2035 LAND USE PLANS

COMMERCIAL, INDUSTRIAL

RESIDENTIAL

SURFACE WATER

STREAM

WATERSHED BOUNDARY

INTERNALLY DRAINED AREAS

N

0 0.25 Miles

0 750 1,500 Feet

Source: SEWRPC.

SEWRPC Staff Memorandum

GROUNDWATER INVESTIGATION FOR GILBERT LAKE
WASHINGTON COUNTY, WISCONSIN

Appendix A

GILBERT LAKE WATER QUALITY DATA

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Table A-1

SELECTED BASELINE NUTRIENT, CATION, AND DISSOLVED SOLIDS DATA FOR GILBERT LAKE SAMPLING SITES

Location	Dissolved Solids, Dried at 180°C (mg/l)	Potassium (mg/l)	Sodium (mg/l)	Alkalinity, CaCO3, Lab (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	Total Nitrogen (mg/l)	Ammonia, N (mg/l)	Ammonia + Org-N, N (mg/l)	Nitrate + Nitrite, N (mg/l)
Tributary	438	1.9	28.7	270	70.4	27.6	1.3	< 0.015	0.32	0.949
Spring 1	470	1.7	27	276	70.9	32.3	1.9	< 0.015	0.32	1.570
Spring 2	512	1.7	32.1	307	75.7	34.7	5.3	< 0.015	0.15	5.190
Deep Hole	410	1.5	30.4	243	73.1	26.1	1.2	0.031	0.70	0.504

NOTE: All data was taken at a depth of 0.5 meters on April 26, 2012.

**Data for some parameters (orthophosphate, organic nitrogen, carbon dioxide, lead, iron, and manganese) are not included in this appendix; however, they are available for download on the USGS website.*

Source: U.S. Geological Survey.

Table A-2

DESCRIPTION OF WATER QUALITY PARAMETERS AND THEIR REGIONAL AVERAGES

Parameter (in milligrams per liter (mg/l) unless otherwise noted)	Description	Regional Average	Existing Standards
	General Water Quality Parameters		
Alkalinity	The measure of the ability of a lake to absorb and neutralize acidic loadings, aka buffering; influenced by the soils and bedrock of the watershed due to any calcium carbonates ($CaCO_3$) – **higher levels of Ca CO_3 indicate a more alkaline lake with a higher buffering capacity**	173	- -
Ammonia	A gaseous biological byproduct of decomposing nitrogenous organic matter, it reacts when mixing with water producing ammonium	- -	- -
Chloride	Small quantities are normal in lakes due to natural weathering of bedrock and soils, while large concentrations (from road salts and effluents from wastewater treatment plants or septic systems) have an unknown impact on the ecosystem; however, **can serve as an indicator of increases in other pollutants**	19	- -
Potassium	Linked to the growth of cyanobacteria (blue-green algae), which can sometimes contain toxic byproducts	- -	- -
Sodium	Linked to the growth of cyanobacteria (i.e., blue-green algae), which can sometimes contain toxic byproducts	- -	- -
Sulfate	A form of sulfur that is an important nutrient for many aquatic organisms occurs in rocks and fertilizers, affecting the lake's eutrophication process. In high concentrations, especially in highly industrialized areas, can have a deleterious effect on some aquatic plants	20-40	- -
Total Dissolved Solids	An estimation of the total amount of inorganic solids dissolved in water due to the predominant bedrock, topography, climate, and land use in the watershed	- -	- -
Total Nitrogen	Essential to plant growth; natural sources include precipitation, nitrogen fixation in lake water and sediments, groundwater input, and surface runoff; man-made sources include livestock waste, fertilizers, and human sewage	1.43	- -

Source: SEWRPC.

SEWRPC Staff Memorandum

**GROUNDWATER INVESTIGATION FOR GILBERT LAKE
WASHINGTON COUNTY, WISCONSIN**

Appendix B

PHOTOS OF SELECT SPRINGS SURROUNDING GILBERT LAKE AND BIG CEDAR LAKE

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Figure B-1

SPRING #1

USGS STATION NUMBER: 432514088151601

Source: U.S. Geological Survey.

Figure B-2

SPRING #5

USGS STATION NUMBER: 432447088151001

Source: U.S. Geological Survey.

Figure B-3

SPRING #6

USGS STATION NUMBER: 432447088151601

Source: U.S. Geological Survey.

Figure B-4

DOLLAR ISLAND SPRING

USGS STATION NUMBER: 432356088153001

Source: U.S. Geological Survey.

Figure B-5

BIG CEDAR LAKE, SPRING #1

USGS STATION NUMBER: 432323088152301

NOTE: Spring water has been routed to Big Cedar Lake through a steel pipe, as shown within the red circle.

Source: U.S. Geological Survey.