RJN Environmental Services, LLC
Surface Water Studies
Groundwater Studies
Site Investigations

MEMORANDUM

DATE: **May 3, 2021**

TO: **Lake Beulah Management District**

FROM: **Bob Nauta**

SUBJECT: **Lake Monitoring Summary**

As requested by the Lake Beulah Management District (LBMD), RJN Environmental Services, LLC (RJN) has prepared this memorandum to summarize the on-going lake protection and monitoring activities. As always, the LBMD continues to be very proactive in the protection of Lake Beulah and its associated environments, as evidenced by the following discussion. Currently, the following activities are on-going:

- Monitoring of potential water quality impacts at the lake bed, caused by the pumping of East Troy Well 7 (Dr. Tim Ehlinger);
- Monitoring of the groundwater levels adjacent to the lake to monitor the impacts of pumping of East Troy Well 7;
- Monitoring of lake water quality at three locations and at various depths (USGS); and
- Review data pertaining to the potential input of water from Booth Lake.

Additionally, RJN has provided input with respect to potential developments on and along the lake shore (i.e., Stoss pier and potential hotel development).

This memorandum provides a discussion of the four bullet-items listed above.

Lake Bed Monitoring

Water temperature and quality at the lake bed are sensitive conditions that are crucial to healthy aquatic plants and wildlife. Essential to these and other conditions is the flow of groundwater discharging through the lake bed. Lake bed monitoring is being conducted at four locations on the lake, as shown on Figure 1 by Dr. Tim Ehlinger of the University of Wisconsin-Milwaukee. Dr. Ehlinger placed data loggers in these locations in November 2020, and has recently downloaded the data collected through the winter. These loggers are monitoring the temperature and conductivity of the water at these locations.

Figure 2 is a plot of the data collected over the winter. Groundwater entering the lake carries dissolved minerals like calcium carbonates (limestone). The higher the concentration of dissolved solids, the higher specific conductance. The ice forms in the lake in the fall, the ice gives up its dissolved minerals and the remaining unfrozen water may experience increased

conductivity (see red line, Bitter site in the lower lake). This effect is less pronounced in the other sites in the upper lake, due to the higher level of groundwater input that swamps out this effect (see less change in blue and purple lines). The reverse occurs in the spring when ice melts (see the decrease in conductivity in the red line which is less pronounced in the other sites).

During the winter when ice is on the lake, there are noticeable fluctuations and rapid variations in conductance that appear to be closely associated with the rise and fall of groundwater elevations in the monitoring wells. This is strongly suggestive of a linkage between groundwater input and dissolved mineral concentrations in the lake water. This rapid response by the monitoring devices strongly indicates that the "signal" of the pumping activity is observed in the lake. It's important to note that this pattern demonstrates a chemical signal response, but does not necessarily show ecological impact on the lake as a whole. Additional monitoring and analysis will be required.

Groundwater Level Monitoring

Figure 3 shows the monthly groundwater withdrawals from East Troy well 7 for 2019 and most of 2021. Prior to April 2019, the Village of East Troy pumped minimal volumes from well 7, primarily to keep it in good working order; however, as of April 2019, use of the well increased significantly. In the years leading up to the Wisconsin Department of Natural Resources approval of the well, the LBMD authorized significant studies and analyses of potential impacts to Lake Beulah, caused by high capacity pumping near the lake shore. One outcome of these studies and discussions with the Village of East Troy was the construction of groundwater monitoring well nests at three locations. Since then, one nest has been abandoned, and two nests remain, located between East Troy well 7 and the Lake Beulah shoreline, as shown on Figure 4.

Each nest consists of one well with its screen intersecting the water table, and a second well that is screened 15 to 20 feet below the adjacent well. A water level in the deeper well that is shallower than in the adjacent well indicates an upward groundwater flow, which is indicative of groundwater discharging through the lake bed; however, if the water level in the shallow well is higher than in the deeper well, the gradient is downward, meaning that groundwater is not discharging through the lake bed.

Each well has a pressure transducer with a data logger that records the depth to groundwater on an hourly basis. Figure 5 shows a plot of the hourly water levels in the well MW-1 nest, and Figure 6 shows the plots for the MW-2 nest. Each "dip" in the line indicates a period of time when the Village of East Troy is pumping well 7. When conditions are static (i.e., well 7 is not pumping), the orange line is above the blue line, indicating upward groundwater flow. However, when the orange line drops below the blue line, that means that the vertical gradient is reversed, and groundwater is flowing downward. Clearly, the pumping of well 7 results in a reversal of the vertical gradient at both locations, resulting, at a minimum, of a reduction of groundwater discharge into Lake Beulah.

Monitoring of Lake Water Quality

The LBMD has contracted with the United States Geological Survey (USGS) to collect and analyze water samples from Lake Beulah since 2007. The USGS uses global positioning system (GPS) coordinates to collect samples at three locations, shown on Figure 7: Inlet, deep hole and station 2. Tables 1, 2 and 3 summarizes water quality data for Secchi depth, phosphorus and chlorophyll-*a* since the start of the USGS sampling program for the inlet, deep hole and station 2, respectively. Note that numerous additional parameters are analyzed; however, only the parameters used for calculation of the trophic state index (TSI) are included in Table 1.

The TSI is a widely-recognized measure of a lake's chemical and biological health. Based on calculations from the measurements of the Secchi disk depth, total phosphorus and chlorophyll-*a*, a water body is designated as oligotrophic (deficiency of nutrients), mesotrophic (intermediate level of nutrients) or eutrophic (nutrient-rich), (Robert E. Carlson, March 1977). The desired trophic level for a lake is mesotrophic, meaning that there are enough nutrients for aquatic life to thrive, but not so much that aquatic life is choked out by overgrowth of algae and other aquatic plant life.

Based on the work of Carlson, the following equations were used to calculate the TSI:

TSI_P = 4.15 + 14.42 x (*ln*[total phosphorus concentration x 1000])
TSI_{SD} = 60.0 – 14.41 x (*ln*[Secchi depth])
TSI_C = 30.6 + 9.81 x (*ln*[chlorophyll-*a* concentration])

Where:

TSI_P = TSI for phosphorus, based on total phosphorus concentration in mg/L;
TSI_{SD} = TSI for Secchi disk, based on Secchi depth in meters;
TSI_C = TSI for chlorophyll-a, based on chlorophyll-a concentration in mg/L; and
ln = natural log.

Figures 8, 9 and 10 are plots of the TSI calculations since the start of the USGS sampling program for the inlet, deep hole and station 2, respectively. The preferable condition for a lake is mesotrophic, which is the orange area on the plots, and most data are within that area. The most variations in data are from chlorophyll-*a* and Secchi depths, both of which can have some seasonal variation. The phosphorus levels, however, are very stable within the mesotrphic zone. Trend lines have been added for each parameter on the plots. While some deviation from "flat" would be natural, all trend lines appear quite stable.

The most variation outside of the mesotrophic zone is in the samples from the inlet. This water is entering the Lake Beulah environment from another watershed, and is not indicative of the overall water quality in the lake. Because this water is flowing, the Secchi depths are very shallow, as well. However, the samples from the deep location show that by the time the inlet water reaches the main portion of the lake, the water quality improves significantly.

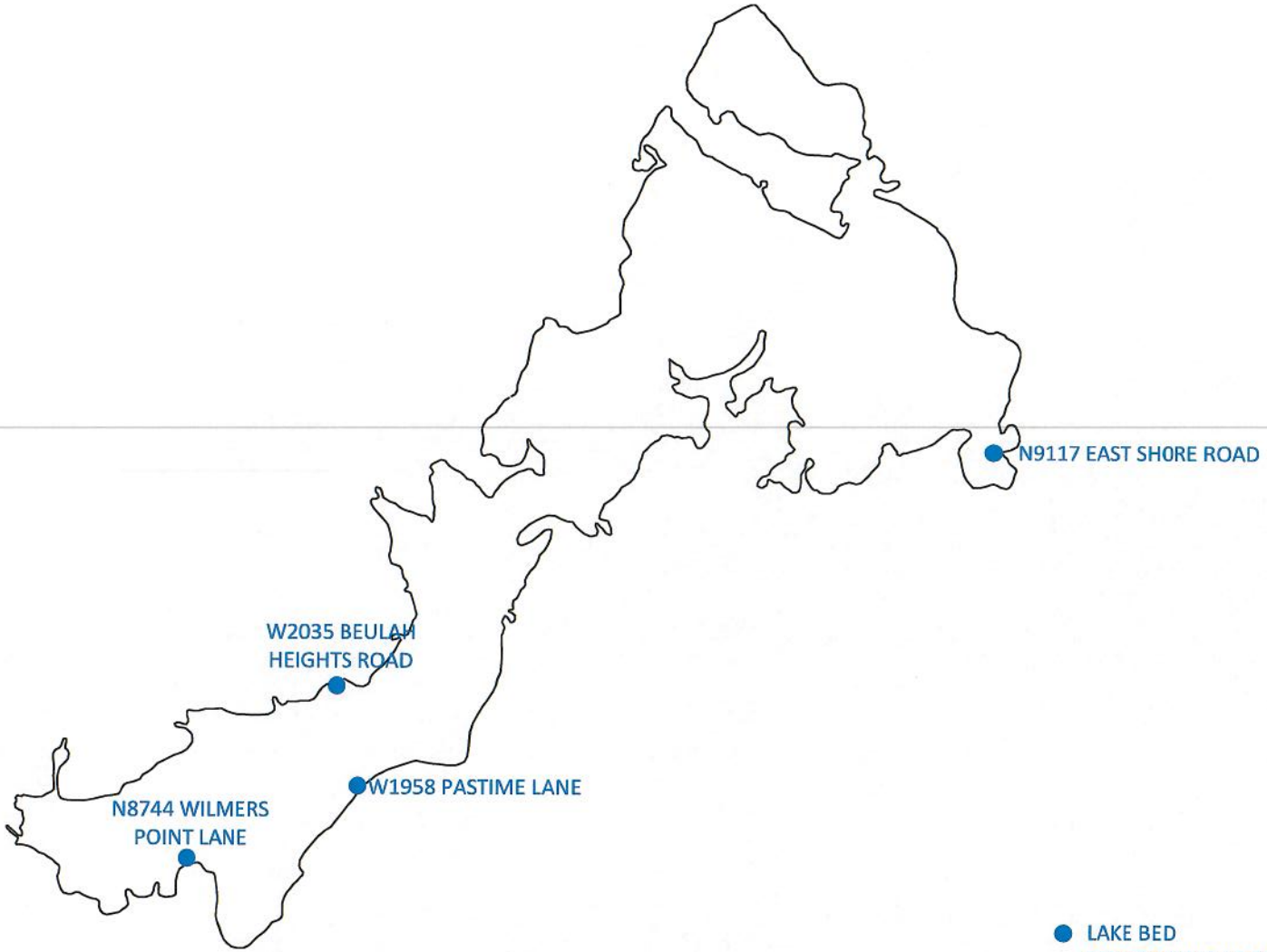
Potential Inflow From Booth Lake

Recently, the LBMD requested that I review data pertaining to the input of water from Booth Lake, that has been requested by the Booth Lake Management District. At this point, little information is available, and the proposed transfer is in the early permit stages with the Wisconsin Department of Natural Resources. Additional studies need to be completed by the Booth Lake Management District, including water quality analyses and the development of a completed route for the transfer of water from Booth Lake to Lake Beulah. As more information is developed, we will continue to evaluate it.

Conclusions and Recommendations

Lake Beulah continues to be a very healthy lake. As with other lakes in the area, Lake Beulah is under constant threat from issues such as invasive species and eutrophication; however, in my opinion, the LBMD continues to be very proactive in their efforts to maintain the environment of both the lake, and the water shed in general.

However, as we have seen, the Wisconsin Department of Natural Resources themselves have violated their restrictions on development in the Sensitive Areas, and RJN commends the LBMD's efforts to strengthen the protective status of those areas. Additionally, studies have shown the detrimental impact that boat traffic can have on vegetation in shallow areas, and therefore RJN recommends that the LBMD continue to monitor, and to the extent possible, control the amount of boat traffic and wakes in shallow, sensitive areas.



NORTH

RJN Environmental Services, LLC
Surface Water Studies
Groundwater Studies
Site Investigations
4631 COUNTY ROAD A, OREGON, WISCONSIN 53575

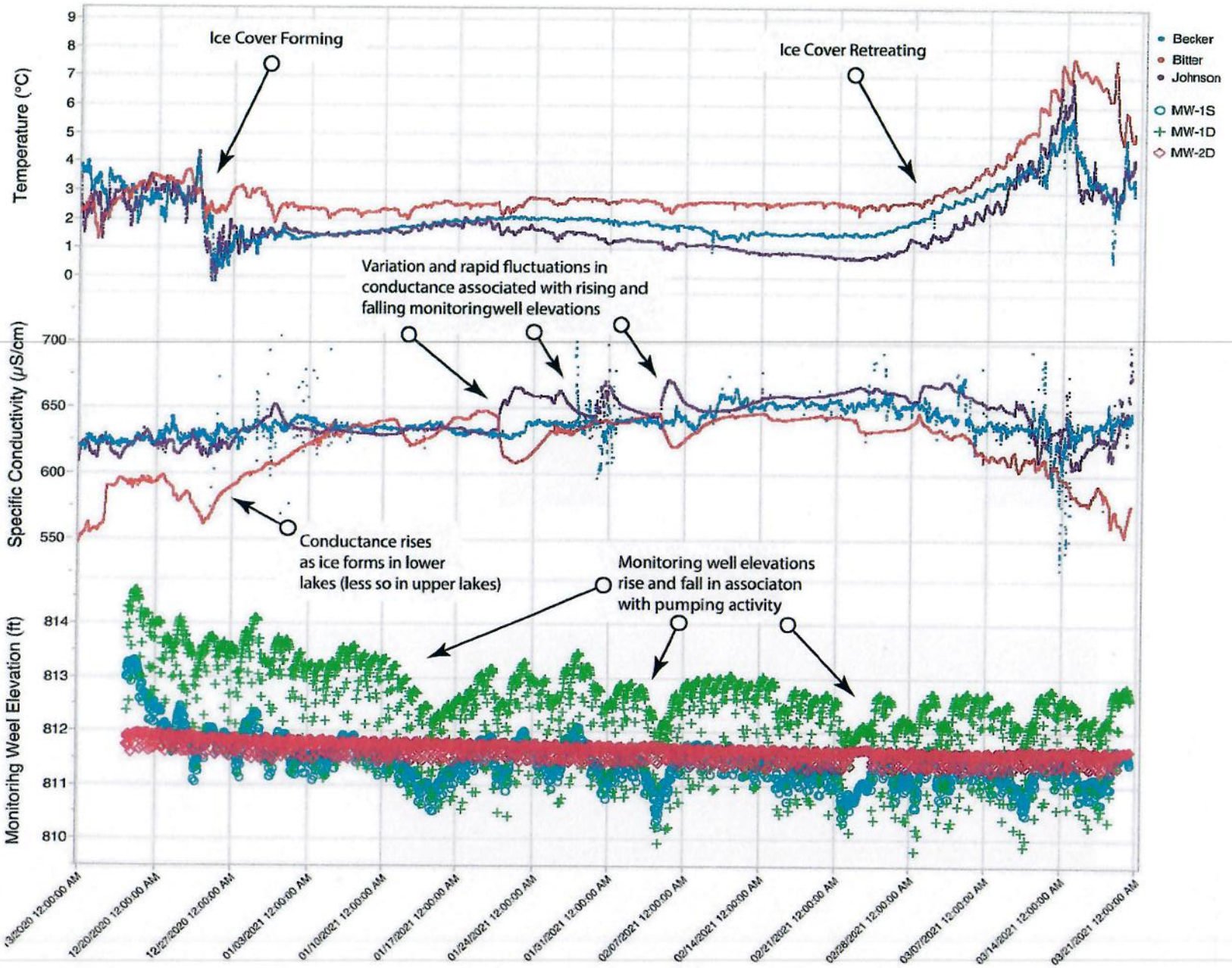
LAKE BEULAH MANAGEMENT DISTRICT
WALWORTH COUNTY, WISCONSIN
LAKE BED MONITORING LOCATIONS

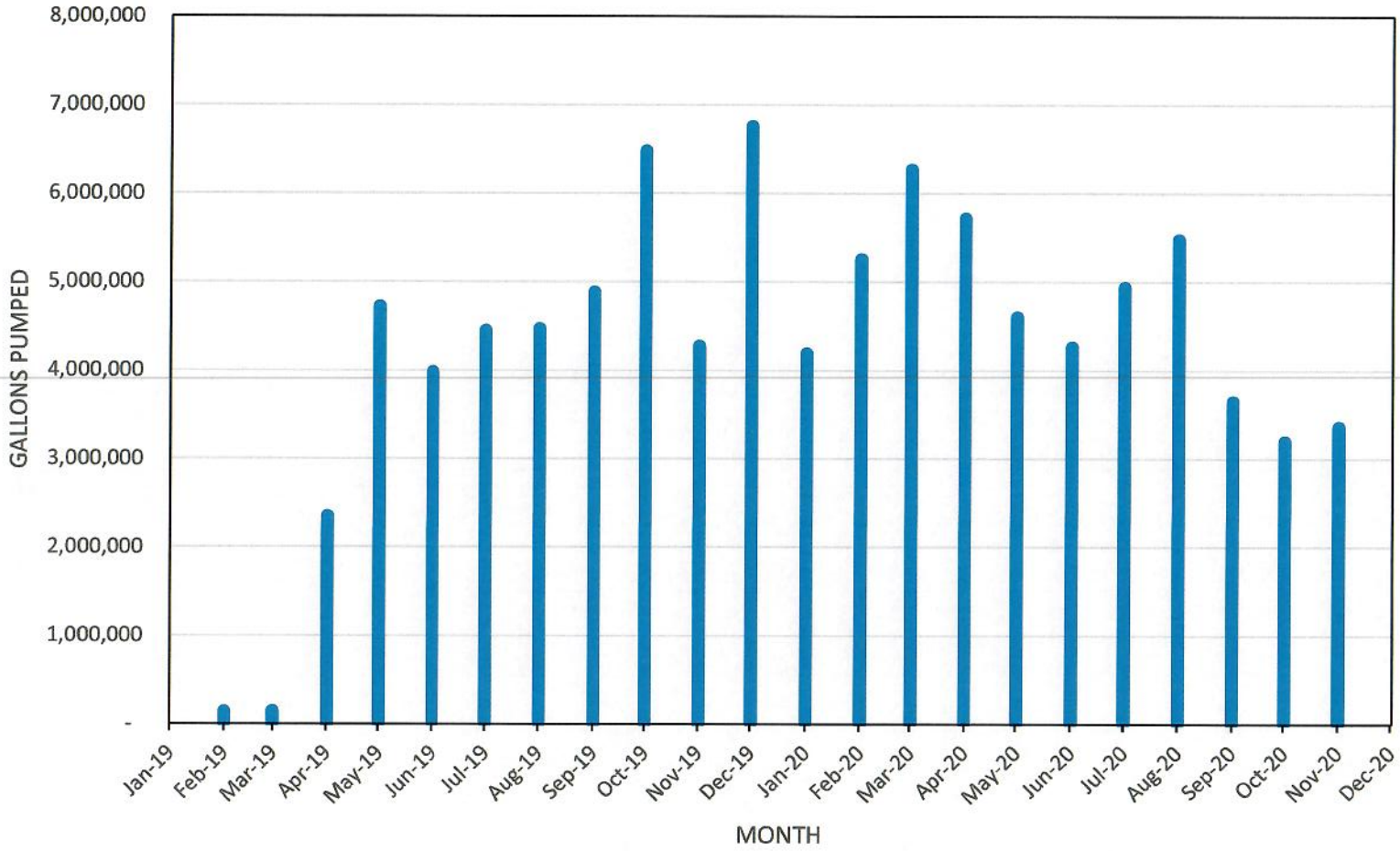
FIGURE 1

DRAWN BY	PROJ. No.	DATE	FILE
RN	09-201	01 MAR 21	LAKE BED

FIGURE 2

Lake Beulah -- Temperature, Specific Conductance and Monitoring Well Elevation





RJN Environmental Services, LLC
Surface Water Studies
Groundwater Studies
Site Investigations
4631 COUNTY ROAD A, OREGON, WISCONSIN 53575

LAKE BEULAH MANAGEMENT DISTRICT
WALWORTH COUNTY, WISCONSIN
MONTHLY PUMPING RATES - WELL 7

FIGURE 3

DRAWN BY	PROJ. No.	DATE	FILE
RN	09-201	25 FEB 21	ET WELL 7

MONITOR WELL NEST

WELL 7

NORTH

RJN Environmental Services, LLC

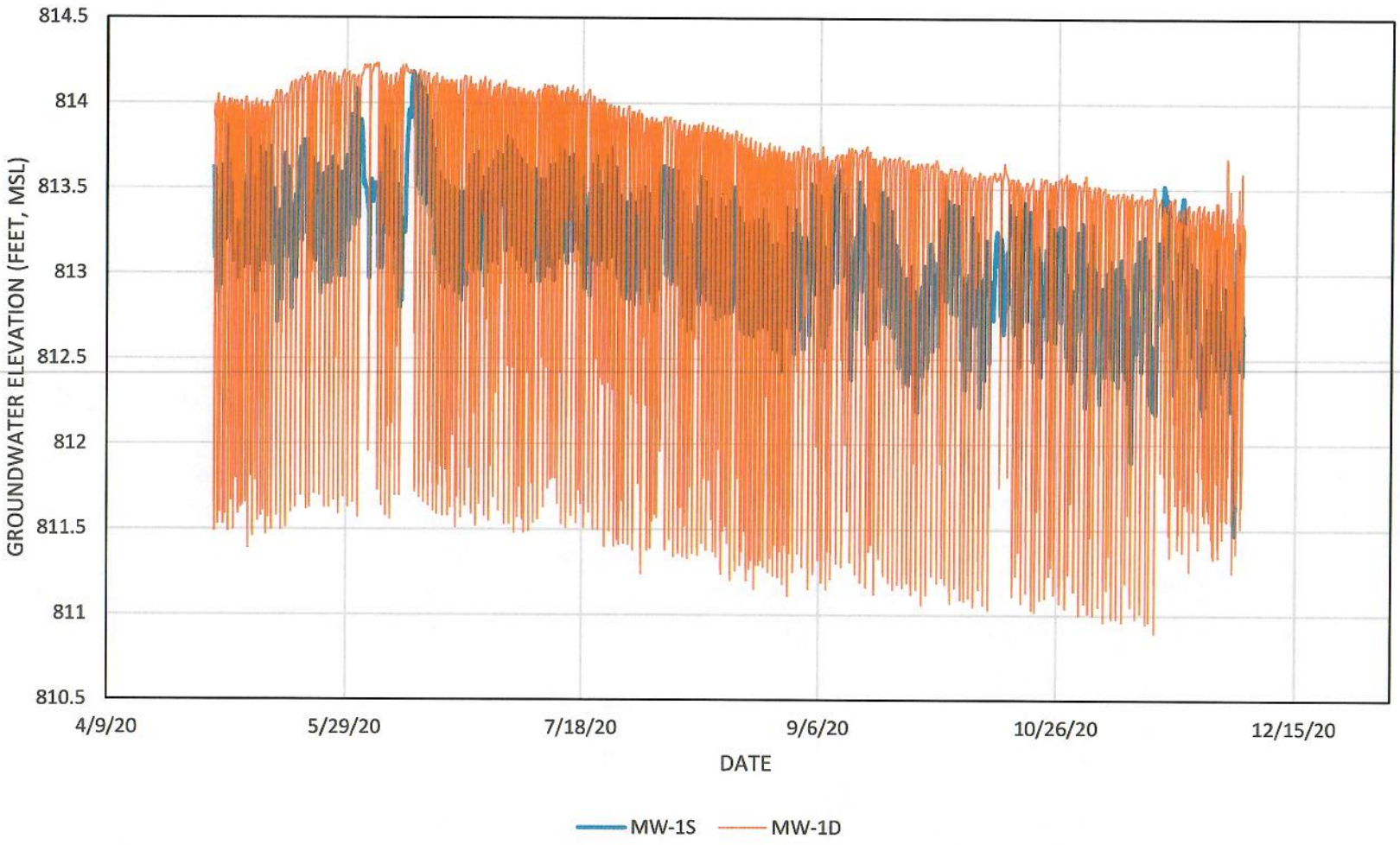
Surface Water Studies
Groundwater Studies
Site Investigations

4631 COUNTY ROAD A OREGON, WISCONSIN 53575 (608) 576-3001

LAKE BEULAH MANAGEMENT DISTRICT
WALWORTH COUNTY, WISCONSIN
WELL LOCATIONS

FIGURE 4

DRAWN BY	PROJ. No.	DATE	FILE
RN	09-201	01 MAR 21	WELL LOCATIONS

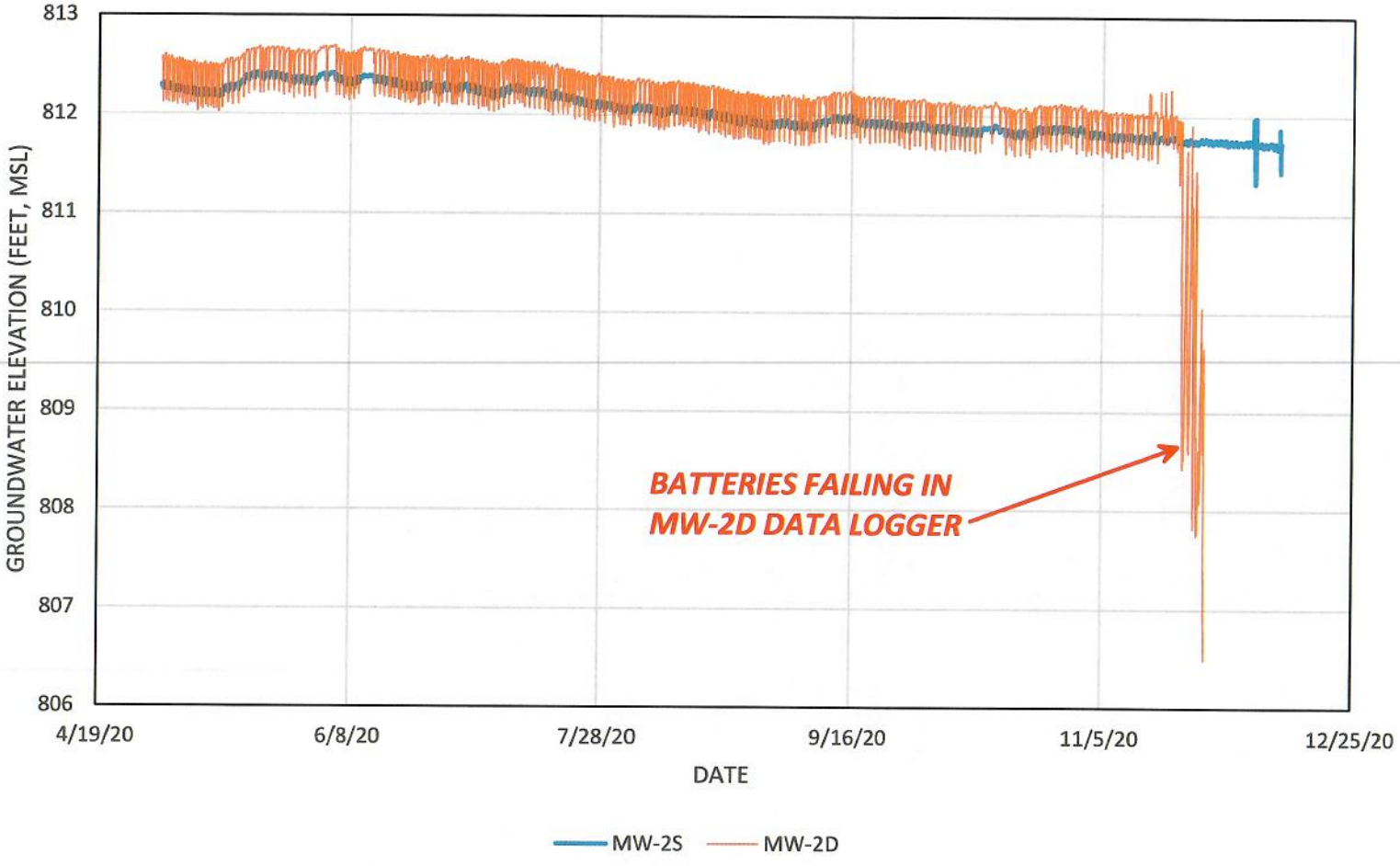


RJN Environmental Services, LLC
Surface Water Studies
Groundwater Studies
Site Investigations
4631 COUNTY ROAD A, OREGON, WISCONSIN 53575

LAKE BEULAH MANAGEMENT DISTRICT
WALWORTH COUNTY, WISCONSIN
GROUNDWATER ELEVATIONS - MW-1

FIGURE 5

DRAWN BY	PROJ. No.	DATE	FILE
RN	09-201	25 FEB 21	MW-1 NEST

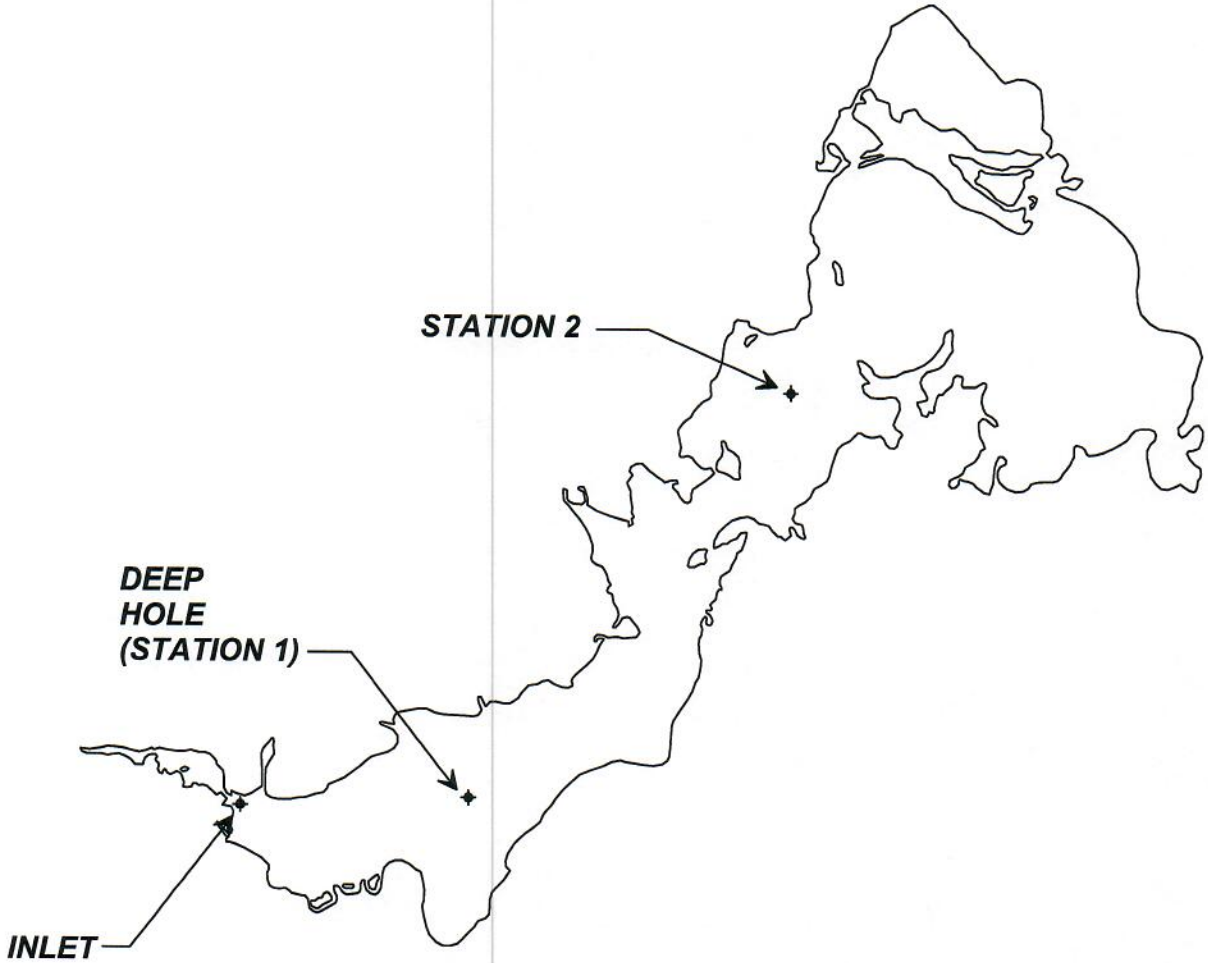


RJN Environmental Services, LLC
Surface Water Studies
Groundwater Studies
Site Investigations
4631 COUNTY ROAD A, OREGON, WISCONSIN 53575

LAKE BEULAH MANAGEMENT DISTRICT
WALWORTH COUNTY, WISCONSIN
GROUNDWATER ELEVATIONS - MW-2

FIGURE 6

DRAWN BY	PROJ. No.	DATE	FILE
RN	09-201	25 FEB 21	MW-2 NEST



NORTH

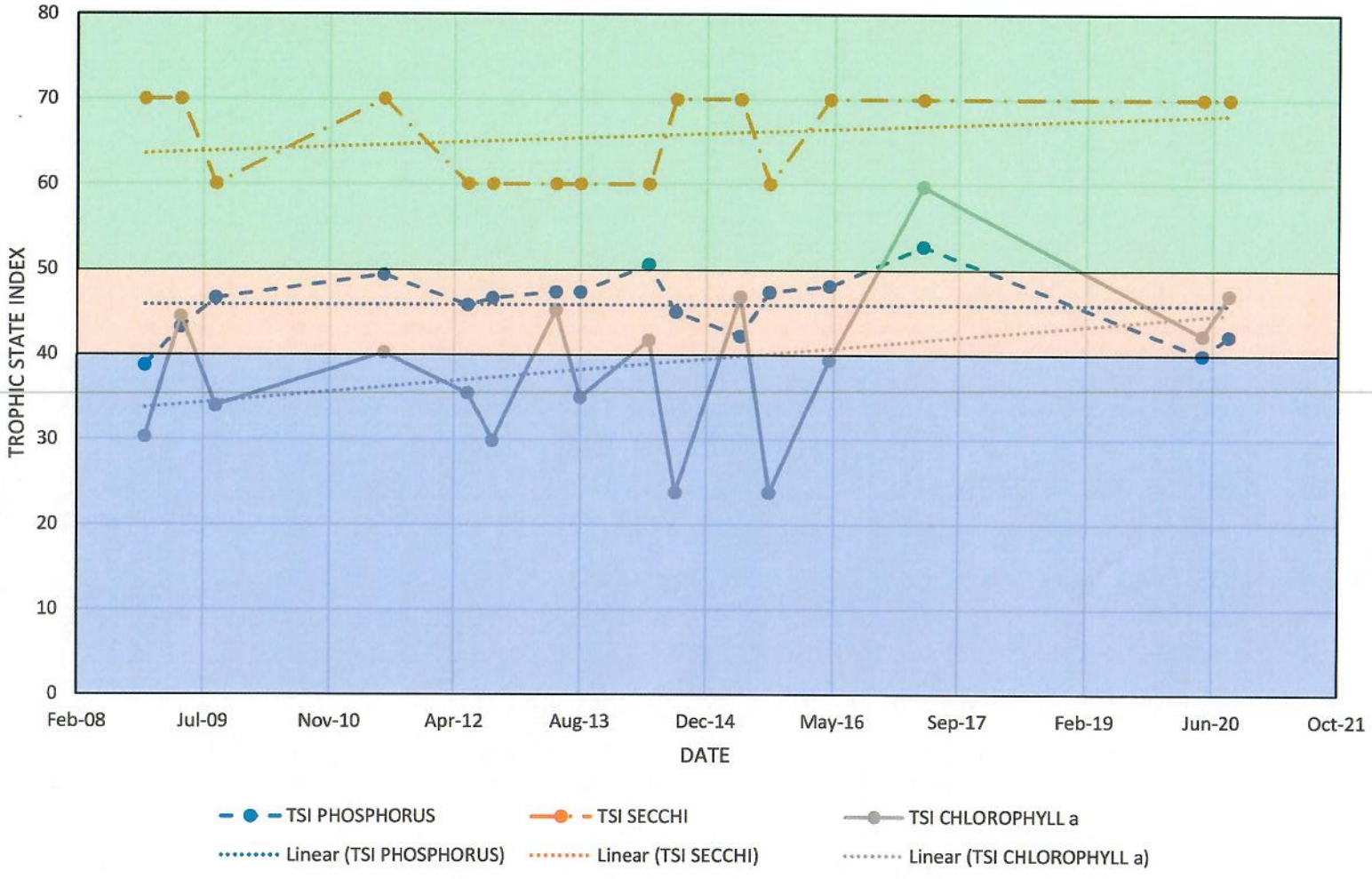
RJN Environmental Services, LLC
Surface Water Studies
Groundwater Studies
Site Investigations

4631 COUNTY ROAD A OREGON, WISCONSIN 53575 (608) 576-3001

LAKE BEULAH MANAGEMENT DISTRICT
WALWORTH COUNTY, WISCONSIN
LAKE SAMPLING LOCATIONS

FIGURE 7

DRAWN BY	PROJ. No.	DATE	FILE
RN	09-201	16 FEB 15	LAKE SAMPLES



EUTROPHIC

MESOTROPHIC

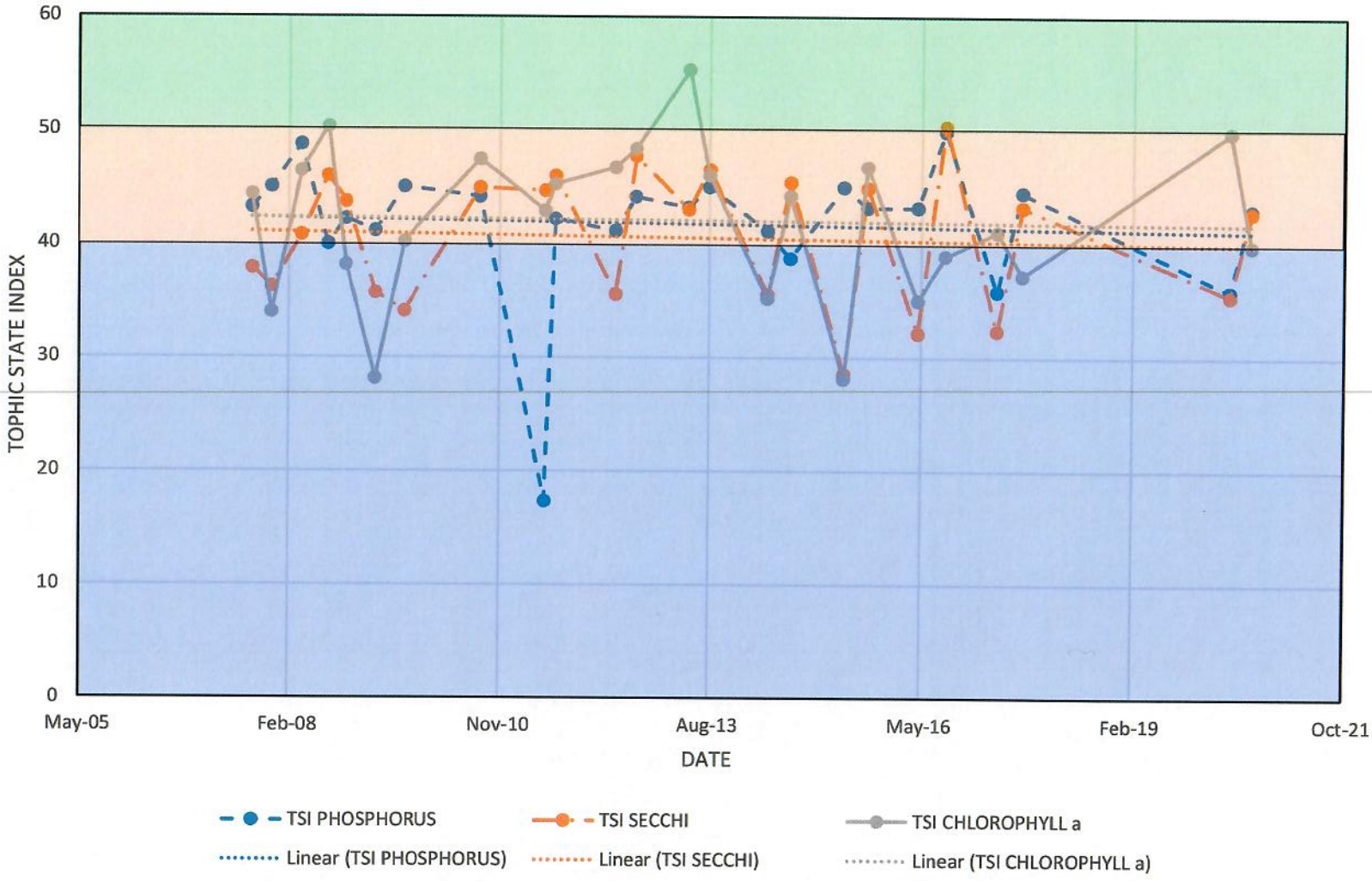
OLIGOTROPHIC

RJN Environmental Services, LLC
Surface Water Studies
Groundwater Studies
Site Investigations
4631 COUNTY ROAD A, OREGON, WISCONSIN 53575

LAKE BEULAH MANAGEMENT DISTRICT
WALWORTH COUNTY, WISCONSIN
TSI VALUES - INLET

FIGURE 8

DRAWN BY	PROJ. No.	DATE	FILE
RN	09-201	24 FEB 21	TSI INLET



EUTROPHIC

MESOTROPHIC

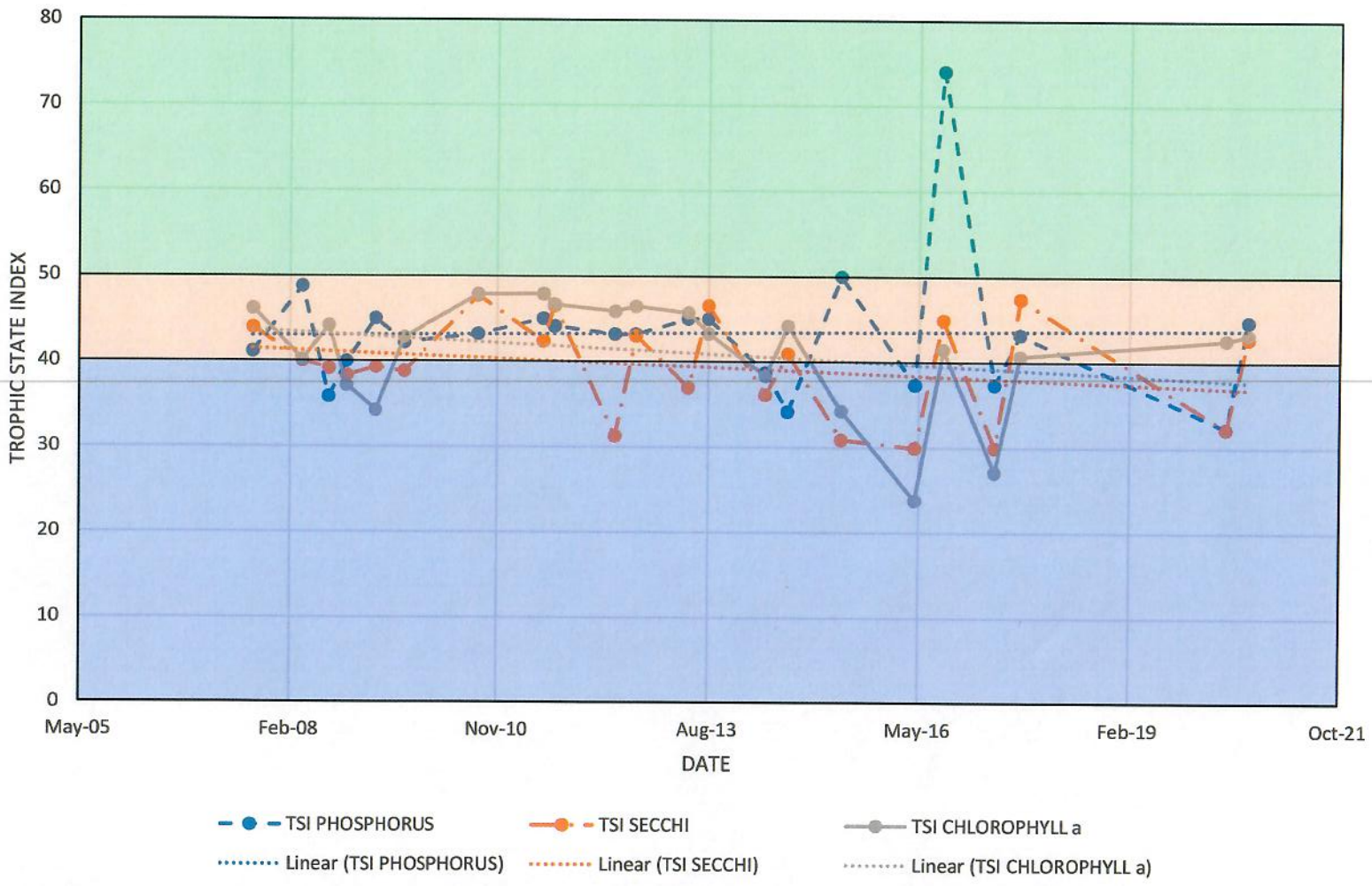
OLIGOTROPHIC

RJN Environmental Services, LLC
Surface Water Studies
Groundwater Studies
Site Investigations
4631 COUNTY ROAD A, OREGON, WISCONSIN 53575

LAKE BEULAH MANAGEMENT DISTRICT
WALWORTH COUNTY, WISCONSIN
TSI VALUES - DEEP HOLE

FIGURE 9

DRAWN BY	PROJ. No.	DATE	FILE
RN	09-201	24 FEB 21	TSI DEEP



EUTROPHIC

MESOTROPHIC

OLIGOTROPHIC

RJN Environmental Services, LLC
Surface Water Studies
Groundwater Studies
Site Investigations
4631 COUNTY ROAD A, OREGON, WISCONSIN 53575

LAKE BEULAH MANAGEMENT DISTRICT
WALWORTH COUNTY, WISCONSIN
TSI VALUES - STATION 2

FIGURE 10

DRAWN BY	PROJ. No.	DATE	FILE
RN	09-201	24 FEB 21	TSI SITE 2