Flood Study

Prepared for

Charter Township of Texas

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2180465

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EXECUTIVE SUMMARY

In 2018, many residents of the Charter Township of Texas have been impacted by flooding not observed since at least the 1950's. Several lakes within the township, including Eagle Lake, Crooked Lake, and Duck Lake, as well as Pine Island Lake, Pine Island Plats and Vineyard Plat are experiencing flooding of their homes and property, and the whole region has a high water table. The impact area is shown in Figure 1.

Since some residents have experienced flooding for much of 2018 and are in need of immediate relief, a mitigation plan for short-term and long-term relief was considered. Various alternatives were evaluated and each resulted in a recommendation to provide a positive outlet to the northeast. A positive outlet ensures that when the lakes levels (and the water table) exceed higher levels, water will be conveyed out of the area and eventually to Lake Michigan.

The short-term analysis resulted in a recommendation to pump 3,000 gpm of water from Crooked Lake to a storm sewer in Bentwood Trail, which discharges into the wetland to the northeast. This will lower the lake level and water table in the entire area. The lake level is recommended to be lowered to at least a foot below normal levels, which will also drop the lake levels in Eagle Lake, Pine Island Lake, Duck Lake and Pretty Lake, as well as the groundwater level in Pine Island Plats and Vineyard Plat. The short-term recommendation also includes pumping water from Eagle Lake to Crooked Lake at 1,500 gpm to lower Eagle Lake more quickly.

In the long term, outflow structures on Crooked Lake and Eagle Lake are recommended to reduce the risk of flooding on these lakes as well as in the entire area due to better controlling the groundwater levels. These structures are configured with an overflow and 18" pipe from Eagle Lake to Crooked Lake and from Crooked Lake to the wetland to the northeast. These are considered emergency overflow structures.

In order to move forward with short-term or long-term recommendations, the Township must obtain a permit from the Michigan Department of Environmental Quality. To obtain this permit, the Township must demonstrate that the project will not have an adverse impact to other property owners, specifically those where the water is to be discharged downstream. This evaluation includes environmental impacts and hydraulic impacts.

1 INTRODUCTION

The Charter Township of Texas is located in Kalamazoo County in southwest Michigan. This is a primarily residential community with many lakes and very few drains and streams. Figure 1 shows the locations of critical flooding areas including lakes.

As this year began, the water table was higher than normal due to above average rainfall in 2016 and 2017, and a resulting higher Lake Michigan level. In February of 2018, a 3.8 inch storm (approximately 10% frequency or 10-year event) passed through the region, melting snow and causing substantial flooding in the area. Since that time, the water table has remained at levels near or above the 1% frequency event (100-year event). Typically residents would expect significant evaporation and transpiration through the summer so that lake and groundwater levels do not remain high.

Water levels have not been at flood stage typically through the years, according anecdotal information. In fact, augmentation wells have been used to maintain a minimum lake level for both Eagle Lake and Crooked Lake in past years. Despite the lack of historically high water levels, the water table has been very high over the past year and many homes adjacent to the lakes have flooded, experienced property loss, and have in some cases caused residents to been displaced from their homes or lose access.

The purpose of this study is to investigate the hydrologic and hydrogeologic conditions in the area and to identify short-term and long-term alternatives to reduce high water levels and reduce the risk of flooding in the future.

2 STORMWATER MANAGEMENT

No comprehensive surface stormwater "system" exists within the Township. Stormwater is managed by a few surface drains or isolated storm sewer systems but is predominantly influenced by surface topography and groundwater flow.

Surface topography in the Township is split roughly in half from north to south with the easterly half of the township contributing to the Portage Creek and tributary system and the westerly half of the Township contributing to the Paw Paw River and tributary system. The Township has approximately 18 ponds or lakes greater than 5 acres in size but very few positive outlets through small drains or creeks. Most of the Township has non-contributing areas where lakes or ponds collect, retain, and infiltrate storm water runoff from a watershed area. The stormwater system relies on evapotranspiration and groundwater flow to control water levels.

2.1 System Layout

A discussion of the pertinent surface water features and flooding locations follows: See Figure 2 for location of surface water features.

2.1.1 Atwater Pond and Downstream

Atwater Pond is located just south of I-94 and west of 12th Street. This pond collects water from a channel fed by Bass Lake to the southwest. The pond has a surface area of approximately 43 acres and a normal water surface elevation of about 870 feet. The pond outlets to a channel, eventually crossing under I-94 to the northeast. The water is then conveyed to Portage Creek and the Kalamazoo River, which ultimately outlets at Lake Michigan.

2.1.2 Bass Lake and Downstream

Bass Lake is located on the east side of 8th Street between Texas Drive and West O Avenue. The surface area of the lake is approximately 44.5 acres with a contributing watershed area of approximately 186 acres. The primary outlet from Bass Lake is a 24” corrugated metal pipe (CMP) culvert located at the northeast corner of the lake set at an invert elevation of 883.07 feet. High water in the lake will flow over an auxiliary spillway over the culvert with a crest elevation of 885.06 feet. Discharge from the lake flows in a northeast direction into the West Fork of Portage Creek towards the Atwater Millpond.

The normal lake elevation is approximately 883.1 feet and the current water surface elevation as of September 20, 2018 is 883.6 feet, a difference of approximately 6 inches.

2.1.3 Crooked Lake

Crooked Lake is located on the west side of 8th Street between West Q Avenue and West PQ Avenue. The surface area of the lake is approximately 170.8 acres with a contributing watershed area of approximately 768 acres (1.2 square miles). While the contributing area is relatively small, the total drainage area for Crooked Lake is 11.46 square miles. The total drainage area can be assumed to contribute infiltrated stormwater to the groundwater system around Crooked Lake.

No positive outlet currently exists for Crooked Lake, though historic aerial images and other records indicate a channel did exist many years ago approximately at the 1% frequency flood elevation (this channel would likely just barely be activated based on current lake levels). All discharge is assumed to be a function of groundwater discharge, generally contributing to the wetland located on the east side of the lake, bounded by 8th Street, Bentwood Trail, and Hidden Cove Place.

The normal pool elevation is approximately 893.9 feet and the current water surface elevation as of September 20, 2018 is 897.3 feet, a difference of approximately 3.4 feet.

2.1.4 Eagle Lake

Eagle Lake is located north and west of Crooked Lake bounded on the east and west by 3rd Street and 6th Street, respectively, and bounded on the north and south by OP Avenue and PQ Avenue, respectively. Approximately 320 parcels abut the lake. The surface area of the lake is approximately 249 acres with a contributing watershed area of approximately 3.2 square miles. The total drainage area for Eagle Lake is approximately 10.1 square miles.

No positive outlet currently exists for Eagle Lake. All discharge is assumed to be a function of groundwater flow.

The normal pool elevation is approximately 899.8 feet and the current water surface elevation as of September 20, 2018 is 902.0 feet, a difference of approximately 2.2 feet.

2.1.5 Duck Lake, Pine Island Lake and Pretty Lake

Duck Lake, Pine Island Lake and Pretty Lake are located southwest of Crooked Lake on the south side of Q Avenue. The water level in Duck Lake is approximately 3 feet higher than normal and the water level in Pretty Lake is approximately 4 feet higher than normal. Pine Island Lake has a surveyed water surface elevation of 902.08 which is approximately 4.3 feet higher than normal. None of the 3 lakes has a positive outlet and all discharge is assumed to be a function of groundwater, generally proceeding northeast towards Crooked Lake.

2.1.6 Additional Flooded Areas

Homes in the Pine Island Plats, south of PQ Avenue have also experienced high water levels contributing to property damage. Similarly, homes along Vineyard Plat have experienced substantial flooding due to high groundwater levels. A boundary showing the identified area of most significant flooding is shown on Figure 1.

It should be noted that the Bob-O-Link Drain in Antwerp Township, Van Buren County, MI, which is located approximately 3 miles west and 2 miles north of Eagle and Crooked Lakes, has experienced similar flooding conditions to the Charter Township of Texas. Flooding has been significant due to the lack of a positive outlet and an extension of drains is proposed for flood relief.

2.2 Local Soils

The soil conditions were studied in this area to assist with development of alternatives for relief. This includes review of available soil borings, well logs, well pumping tests, and anecdotal information as well as the USGS Soil Survey for the area.

The USGS Soil Survey shows most of the surface soils around the lakes as being sandy loam or loamy sand. Soil units are approximately evenly divided between the Coloma loamy sand, Oshtemo sandy loam, and the Spinks loamy sand. This is consistent with sand observed at the surface in most area well logs reviewed.

A soil boring was completed in the Bentwood Trail cul-de-sac just east of Crooked Lake. This boring is provided in Appendix A. The approximate ground elevation at the boring was 918 feet amsl (above mean sea level). Relatively recent fill material was observed from the ground surface to a depth of 13 feet (905 feet amsl). Older fill material was then observed to a depth of 21 feet (897 feet amsl). Evidence of roots and topsoil was present from 897 to approximately 893.5 feet amsl. This does appear to confirm that there was an overflow channel from Crooked Lake to the wetlands that was only activated when the lake was at very high levels of about 897 feet. Clay was observed from 891 feet amsl to the bottom of the boring at 888 feet amsl.

The water level observed in the boring was approximately 889.5. This water level was significantly lower than the nearby Crooked Lake level of approximately 897 feet amsl. This suggests groundwater flow above the clay layer at 889.5 is restricted and the primary groundwater flow path may be under the clay layer observed in the soil boring. This clay layer may extend to approximately elevation 880 based on a well log for the lake augmentation well located on the east end of the lake. The well log for this well is also included in Appendix A.

Other well logs reviewed in the area of Crooked Lake, Eagle Lake, and Duck Lake show the presence of a sand aquifer of varying thickness with variable presence of clay or clay with sand layers at various elevations. In general, the lakes appear to be continuous with the groundwater, but it appears that the uppermost portion of the sand aquifer is thinner in some areas due to the presence of the clay layers. The result is that all of the lakes are connected through the groundwater, but the flow is restricted in some areas since the saturated sand thickness is less in those areas. The clay or clay and sand layers present within 50 feet of the groundwater surface appear to range in thickness from about 5 to 30 feet and do not appear to be fully continuous. There is saturated sand below the clay layers as well. The groundwater flow into and out of the lakes may also be impacted by flow upward or downward between the shallower sand aquifer and the deeper sand.

Most wells logs did not go to the bottom of the sand layer in which they were screened. It appears that the sand below the clay layers described above is present to around 100 feet or more below the water table.

2.3 Rainfall

Rainfall obviously provides a critical role in flooding when there is no positive outlet. In fact, the entire Great Lakes region has been impacted by higher than normal rainfall, as lake levels have risen to recent highs. Figure 3 shows the lake levels for Lake Michigan, and the other Great Lakes have seen similar increased over the past year. Though not nearly record highs, the Great Lakes are their highest in 20 years.

More critical is the local rainfall since the lack of a positive outlet from the local area has caused the water table to increase dramatically. And the local rainfall has increased over the past several years even as compared to other communities in West Michigan. Figure 4 shows that the rainfall has been greater over about 3 years, which does have an impact on the water table. Rainfall in Kalamazoo County, VanBuren County and Barry County has created a high water table in these areas, especially in places where there is a lack of drains and streams to provide relief. The blue bars in Figure 4 show the higher local rainfall.

3 Methods of Analysis

Previous reports and studies, historical documents, hydrogeologic conditions, and GIS base mapping information were collected and reviewed. Some topographical survey data was obtained, including pipe inverts and specific elevations. However, survey and testing was somewhat limited due to the emergency nature of the flooding. Topographic analysis was mostly based on Kalamazoo County's two-foot contours, aerial photography, and site visits.

Basic hydraulic computer modeling of the Basin was completed using available information and two software packages. Visual Modflow was used for groundwater flow modeling and HEC-HMS was used for surface water modeling.

The analyses included a determination of potential outlet routes including reviewing the USGS and other topographical maps to ascertain the location of streams, ponds or other water bodies within an approximately 3-mile radius of the flooded area.

Major factors considered in the analysis were the following:

- Distance from Basin to potential receiving water body (first "daylight" for piped outlet)
- Topography at and between Basin and potential receiving water body to determine if a gravity outlet is feasible or if pumping is required
- Apparent hydraulic capacity of potential receiving water body
- Type of property impacted by potential construction (public right-of-way, public property)
- Necessity of private easements for pipeline construction and/or creation of county drain
- Regulatory requirements
- Short-term and long-term operation and maintenance requirements
- Potential environmental impacts on downstream water bodies and/or properties

3.1 Hydrologic Method

Peak discharge flow rates were provided by the MDEQ for contributing areas greater than 2 square miles. Peak discharges were provided for Eagle Lake and the outlet from the Atwater Millpond (calculated from drainage area ratio to a nearby USGS gage). The MDEQ did not provide peak discharge calculations for Crooked Lake or Bass Lake because the contributing area for each lake is less than 2 square miles.

For locations with less than 2 square miles contributing, the hydrologic analysis was performed rainfall-runoff unit hydrograph techniques as outlined in “Computing Flood Discharges for Small Ungaged Watersheds,” by Richard C. Sorrell, P.E., Michigan Department of Environmental Quality (MDEQ), July 2003. The MDEQ makes available an Excel spreadsheet, MDEQ SCS Method Spreadsheet, which utilizes this method. The spreadsheet only provides a hydrograph for the 1% annual chance storm event; therefore, HEC-HMS was used in this analysis to produce hydrographs for all design storms.

The MDEQ SCS spreadsheet was used to develop the input parameters (time of concentration, design rainfall, and runoff curve number) for the HEC-HMS model. The spreadsheet also produced peak flow rates for all design storms. The HEC-HMS model was calibrated by adjusting the storage coefficients to match the peak flow rate results of the MDEQ SCS spreadsheet.

Design rainfall data was based on the “Rainfall Frequency Atlas of the Midwest, Bulletin 71,” by Huff & Angel in 1992, as recommended by the MDEQ for a 24-hour storm event and compared to Atlas 14 rainfall data. The MDEQ SCS Method Excel Spreadsheet automatically provides Bulletin 71 rainfall data based on the county of the flooding source, and adjusts it based on the size of the watershed to account for uncertainty in the aerial distribution.

For each design point, a time of concentration was determined utilizing the MDEQ SCS Method Excel Spreadsheet in accordance with “Computing Flood Discharges for Small Ungaged Watershed.” This method bases the time of concentration calculations on the longest travel route, three flow types, and their associated flow coefficients.

A runoff curve number (RCN) was determined for each of the specified design points using the MDEQ SCS Method Excel Spreadsheet. Soil data was obtained from the NRCS’s Web Soil Survey and land use was confirmed based on aerial photography. Automated GIS methods were used to intersect the land use and soils data to obtain percentages of land use for each of the corresponding hydrologic soils group. These percentages were entered into the MDEQ SCS Method Excel Spreadsheet to determine a composite RCN. Assumptions made in the RCN methods were:

- Developed land (residential, commercial, agricultural, etc.) was assumed to be a drained condition
- Undeveloped land (forested, swamp, etc.) was assumed to be an undrained condition

3.2 Hydraulic Method

Elevation-area tables were developed for Bass Lake, Crooked Lake, Duck Lake, and Eagle Lake and input into the HEC-HMS model to simulate level-pool routing. Survey data collected was used to develop the outlet structure geometry, or lack thereof, for each lake.

Several hydraulic scenarios were evaluated for short- and long-term impacts to the system:

Existing Conditions

- No transfer of surface water out of Crooked Lake, Duck Lake, or Eagle Lake. The purpose of this scenario is to establish baseline water surface elevations for downstream receiving waterbodies if Crooked Lake and Eagle Lake were to be positively drained.

Short-Term Impacts

- Pumping from Crooked Lake into Bass Lake at rates from 0 to 3,000 gpm. The existing outlet configuration for Bass Lake was maintained.
- Pumping at 3,000 gpm from Crooked Lake into Bass Lake with concurrent 1, 10, and 100 year storm events. The existing outlet configuration for Bass Lake was maintained.
- Pumping from Crooked Lake into Bass Lake with a concurrent 10 year storm with a sensitivity analysis on changing the Bass Lake outlet configuration to minimize water surface elevation rise on Bass Lake.
- Pumping from Eagle Lake to Crooked Lake has no short-term impact downstream since the pumping rate from Crooked Lake remains the same.

Long-Term Impacts

- Permanent positive outlet from Crooked Lake
- Permanent positive outlet from Eagle Lake

Existing and short-term scenarios were modeled assuming each lake started with a water surface elevation equal to the surveyed elevation on September 20, 2018. The long-term simulations assume a drawdown of each lake to its normal lake elevation as noted in Section 2.

4 Alternatives Considered

The stereotypical flood event lasts a short period of time, often less than a day, before the water levels subside. In this case, the water table has been near flood level for many residents since February 2018. Flooding for this length of time presents a high health risk for residents, especially since it is unknown how much longer the levels would remain this high if nothing is done.

Various alternatives were considered both for short-term flood relief and long-term flood relief.

4.1 Positive Outlet

The most reliable and cost-effective long-term approach is to provide a positive outlet for relief of high groundwater levels. This provides a direct route for conveyance of flood waters out of the area and ultimately to Lake Michigan.

Two critical requirements for providing a positive outlet are:

- The water quality is acceptable for the receiving waters. The MDEQ will not permit release of flood water unless an environmental review is provided that shows that the flood waters will not have an adverse impact on downstream receiving waters.
- The additional water from the new tributary area may not have an adverse impact to areas downstream – primarily the peak water levels.

As a short-term solution, the pumping of water from the flooded lakes to a stream is proposed. This approach has a high operational cost with less capital costs and maintenance costs. Screens are required to control invasive species, and these must be cleaned periodically along with maintenance associated with the pumps.

As a long-term solution, the positive outlet has no operational costs. However, the capital costs for constructing the outlet can be significant. The only follow-up costs after the initial investment would be for maintenance purposes.

4.2 Operate Nearby Wells More Frequently

In some cases where water supply wells are located near flooding due to a high water table, the wells could be operated more frequently to draw down the water table. This could be both a short-term and long-term alternative.

There is a wellfield to the northeast of Crooked Lake that is operated by the City of Kalamazoo. Water supply is typically limited by the demand of the customers. In this case, the City wells are drawing water from a lower aquifer approximately 300 feet below ground that is separated by a clay layer from the aquifer that is connected to Eagle, Duck, and Crooked Lakes. Data from the City well field suggests the clay layer is “leaky” so water does flow between the aquifers through the clay layer, but any impact on the lake area from the City wells would be significantly reduced by the clay layer. Therefore, this option does not appear to be feasible for this situation.

4.3 Injection Into Groundwater

In some areas where the water supply is limited, innovative approaches have been considered and applied. One of these is pumping treated wastewater into deep aquifers to replenish them.

The same approach could be considered to mitigate surface water flooding conditions. However, the water would require treatment prior to injection as an injection wells would be prone to clogging due to sediments and microorganisms in the water. Treatment of the flow necessary to make a significant impact on the lake level would be cost prohibitive.

5 Hydrogeologic Analysis

5.1 Background Information

As noted in the discussion in Section 2.2, groundwater exists in an unconfined sand aquifer in the area with the lakes essentially exposed portions of the groundwater. The MDEQ GeoWebFace website provides hydrogeologic mapping of the area. The area around Kalamazoo including the study area has glacial deposits present from the ground surface to over 300 feet deep. Bedrock in the area at the bottom of the glacial deposits is the Coldwater Shale. Figure 5 shows the glacial geology in the area mapped as glacial outwash and ice-contact outwash. These areas often contain coarse sands and gravels with a relatively high hydraulic conductivity.

Flow between the lakes is occurring continuously through the ground. Based on water levels observed in the wells historically and during recent measurements, groundwater flows generally from southwest to northeast, with some east-southeast component out of Eagle Lake. This flow direction is also seen in the direction of flow of the City of Kalamazoo wellhead protection areas for the well field northeast of Bass Lake. As discussed previously, the thickness of the shallow sand aquifer at the elevation of the lakes varies substantially due to variable presence and thickness of clay and clay/sand layers.

According to residents of the area, the lake levels in 2018 are among the highest in memory. While historic lake level data other than levels published in USGS topographic maps is not available, daily water levels are available in two wells near the Kalamazoo Pump Station 24 well field, located approximately 2,000 feet northeast of Scouters Pond and Bass Lake. These wells are monitored daily by the USGS. One of the wells is completed to a depth similar to the City of Kalamazoo wells and the other is approximately 40 feet deep. It appears that the shallow well is completed in the same aquifer that is associated with Crooked, Eagle, and Duck Lakes. A graph of historic water level from these wells is provided in Figure 6. The graph shows the water level being the highest ever measured in spring of 2018. The up and down patterns observed in both wells are likely due to impacts from pumping in the Kalamazoo Pump Station 24 well field with the highest levels the closest to the "natural" level without influence of pumping. This confirms that there has been a higher than typical groundwater level in the region in 2018.

5.2 Methods of Hydrogeologic Analysis

In an effort to simulate groundwater flow through this lake system, a basic groundwater flow model was developed using Visual MODFLOW software. The goal of the modelling effort was to simulate flow through the lake system including groundwater flow between the lakes. The model was set up to allow for varying aquifer parameters in an effort to reasonably match existing conditions and to investigate the potential impact on water levels in Duck, Eagle, and Crooked Lakes due to removal of water from Crooked Lake.

The thickness of the aquifer and properties of the aquifer material are not known and were not fully investigated. A more detailed model could be constructed after a full review of area well logs, potential installation of additional borings, and multiple aquifer performance tests. Aquifer performance testing would involve pumping wells in the target aquifer and measuring water level changes in multiple other wells.

However, due to time constraints, a relatively simple model was constructed and the input parameters that were unknown were varied over a reasonable range to investigate a likely reasonable range of impacts.

In addition to the Visual MODFLOW model, estimations of impact to the groundwater and lake levels were made using the Theis equation for groundwater flow. Theis developed an equation that describes the drawdown at a radius from the extraction of groundwater as a function of the flow rate, the aquifer transmissivity (hydraulic conductivity multiplied by aquifer thickness), the storage coefficient of the aquifer, and time.

5.3 Visual MODFLOW

In an effort to simulate a range of actual aquifer thickness, presence of clay layers, and conductivity of the saturated sand, the model was run with a range of hydraulic conductivities. The recharge rate to groundwater was similarly varied. It was found that the existing groundwater surface as observed in the lake levels was best simulated at a conductivity of 150 feet/day and a recharge rate of 9 inches per year. The conductivity value of 150 ft/day is a reasonable value for the glacial outwash mapped in this area.

The model then simulated groundwater flow as observed in water levels in the lakes fairly well with the exception that the approximately difference in lake levels between Eagle Lake and Crooked Lake was under predicted. It appears that groundwater flow out of Eagle Lake may be restricted by a smaller sand thickness above a clay or clay/sand layer in the area east and south of the Lake. Therefore, an area of lower conductivity was added to this area to approximate the higher level in Eagle Lake. Again, this could be refined considerably with a more detailed model with substantially more effort in reviewing existing data and collecting additional information from the subsurface.

The model was then run with a simulated "drain" to remove water from the system at the east end of Crooked Lake. Properties of the drain were varied to remove more or less flow. The model predicted a drop in Crooked Lake level of 3.4 feet at a withdrawal rate of 1,535 gpm. The model was solving for a steady state condition, meaning it was assuming a rate of 1,535 gpm for a long time period that would allow the impacts to stabilize. This is anticipated to be on the order of a year. It does not account for natural drop in the regional water level, but gives an idea of the magnitude of impact that pumping or gravity flow Crooked Lake could have in addition to natural variations in groundwater level.

The impacts on Eagle Lake and Duck Lake under the same conditions were predicted to be 1.9 and 2 feet, respectively.

5.4 Analytical Solution

Since the model was not being used to solve for how long it would take to achieve the above impacts, some estimations were also completed using the Theis groundwater equation for impact over time on water level at a given distance from the point of groundwater withdrawal. A rough estimate of the impact at the edge of a lake can be made by solving for the impact at a radius from the center of the lake to the edge of the lake. This works best for circular lakes, but can give a sense of the decrease in water level in a lake over time due to removal of water from the lake.

Again, the aquifer properties including thickness and conductivity are not well defined, so a range of values was used to produce a range of potential impacts on the levels in the lakes. For a withdrawal from Crooked Lake, an estimated effective radius of 3,000 feet was used to estimate impacts to Crooked Lake itself. A radius of 7,500 feet was used to estimate impacts on Duck and Eagle Lakes. Flows were varied from 1,000 to 3,000 gpm and times for the flow leaving Crooked Lake were varied from 15 to 365 days.

At the modeled condition with an aquifer 100 feet thick, a conductivity of 150 feet per day and a withdrawal rate of 1,500 gpm, the resulting predicted impact of 3.5 feet at 365 days essentially matched the steady-state result from Visual MODFLOW. Note that under these conditions, the analytical solution shows the withdrawal would need to occur for 90 days to achieve a drop of 1.6 feet and 180 days to achieve a drop of 2.5 feet in Crooked Lake.

Note that Crooked Lake is currently approximately 3.4 feet above its normal level. At the same 150 feet per day with a 100-foot thick aquifer, the analytical solution predicts the following impacts to Crooked Lake if withdrawing 3,000 gpm.

30 days – 1 foot

45 days – 1.7 feet

90 days – 3.2 feet

180 days – 5.0 feet

To give a sense of the effect of the assumed hydraulic conductivity, the Theis equation predicts it would take 90 days of pumping at 3,000 gpm to drop Crooked Lake 1.8 feet if the conductivity was 25 ft/day instead of 150 ft/day. It predicts a drawdown of 2.9 feet in 90 days if the conductivity is 200 ft/day.

If withdrawing 3,000 gpm from Crooked Lake for 90 days with a conductivity of 150 ft/day, the estimated drawdown at Eagle and Duck Lakes is as follows:

30 days – < 0.01feet

45 days – 0.03feet

90 days – 0.3 feet

180 days – 0.98 feet

365 days – 2.23 feet

These results are shown graphically in Figure 7a and 7b. The results are shown in "bands" to indicate possible ranges in model assumptions. The slow response at Eagle Lake suggests that pumping from Crooked Lake may not provide quick relief to the elevated levels in Eagle Lake. However, if Crooked Lake is maintained near its historic level of 894, Eagle Lake will eventually return to its typical level. Lowering Crooked Lake to a foot below normal levels is intended to lower the water table in the entire area more quickly. This would require that periodic pumping to maintain the level of Crooked Lake at approximately a foot below normal levels.

To lower Eagle Lake more quickly, pumping was considered at a rate of 1,500 gpm to Crooked Lake while water was pumped from Crooked Lake at 3,000 gpm. As expected, Crooked Lake drops at a slower rate but Eagle Lake drops much more rapidly. The results for Crooked and Eagle Lake are shown in Figures 7c and 7d, respectively.

5.5 Groundwater Modeling Results

Groundwater modeling provides information regarding the impacts of providing some relief to the system. The intention is to estimate the groundwater flow as well as groundwater levels if lake levels are dropped.

5.5.1 Short-Term Impacts

Groundwater flow occurs from higher energy potential to lower energy potential (higher elevated lakes to lower elevated lakes). Thus as a lower lake level drops, the groundwater flow to that lake will equalize the water table, filling in behind it but at a slower rate than the removal. As a result, removal of a fixed volume of water from a lake will not lower the lake by the corresponding volume. The estimates provided by this analysis account for this impact while removing water from a lake. They show, as expected, that a significant impact can be made on a lake where the pumping occurs, and that the impact on surrounding lakes by inducing more groundwater flow is lesser and slow-acting.

Continuous pumping from Crooked Lake into the wetland to the northeast provides a solution to reduce Crooked Lake and the surrounding areas. The impacts of pumping from Crooked Lake are shown in Figures 7a and 7b. It is evident from the figures that Crooked Lake can be lowered to the normal levels (about 3.3 feet in Figure 7a) in about 3 or 4 months if pumping at 3,000 gpm. However the surrounding area will drop at a much slower rate during the same time frame, as shown in Figure 7b. For example, Eagle Lake would drop less than 1 foot during that 3 to 4 month period.

To lower the level of Eagle Lake more quickly, pumping from Eagle Lake to Crooked Lake was evaluated with a flow rate of 1,500 gpm. Eagle Lake would need to be pumped for about 6 months to return to normal levels with Crooked Lake pumping longer, say 8 months to drop to normal levels. These results are shown in Figures 7c and 7d along with 7a once Eagle Lake has been restored to normal levels.

5.5.2 Long-Term Impacts

The groundwater flow becomes much less critical if outlet structures are provided at nearby lakes. At present, the groundwater flow is the only relief for stormwater besides evaporation and transpiration. As long as a positive outlet is provided to reduce the risk of higher water levels, the impact of groundwater flow on flooding is negligible.

Section 6 discusses the surface water evaluation used for the long-term solution.

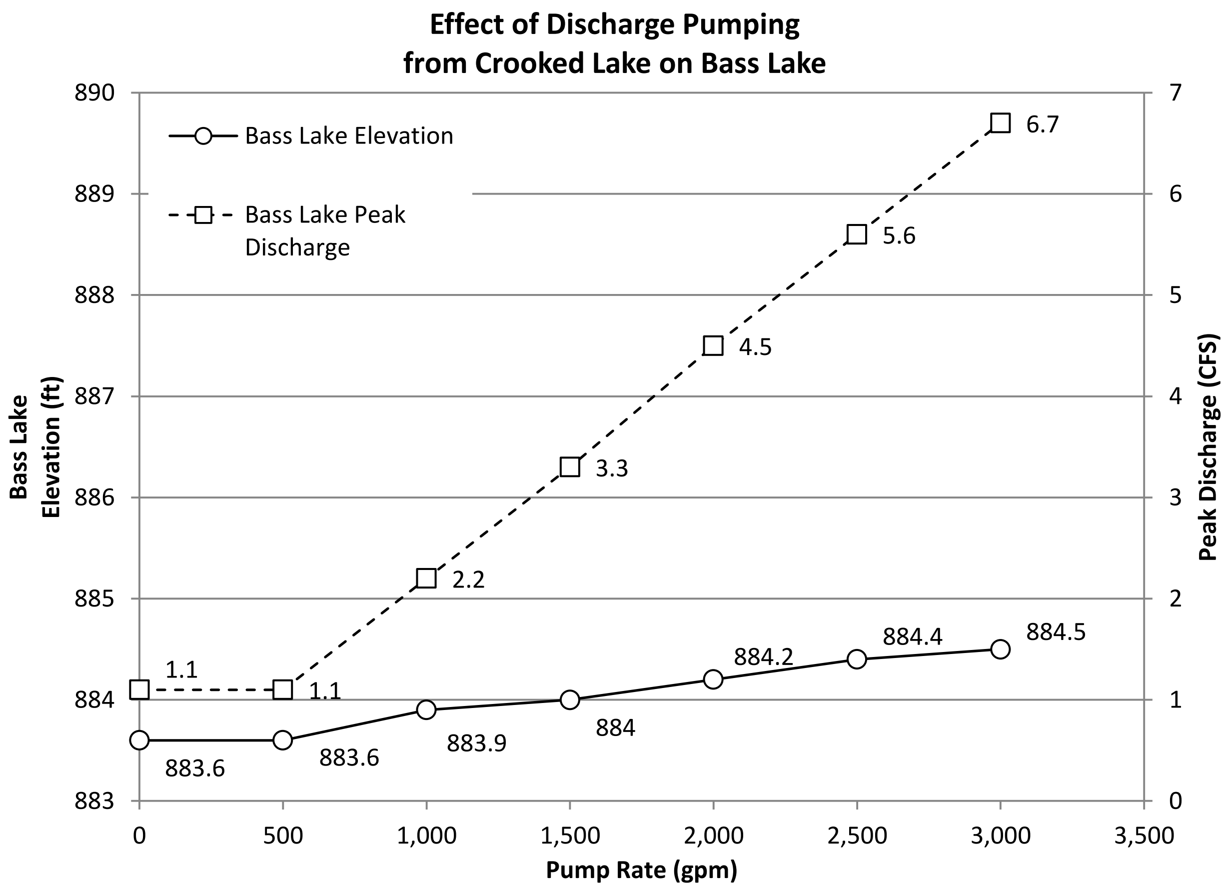
6 Surface Water Analysis

6.1 Short-Term Surface Water Modeling Results

As previously mentioned, immediate flood relief can be provided to Crooked Lake by installing a temporary pump and discharging into the existing storm sewer system in Bentwood Trail, which discharges to Bass Lake via a wetland area.

Continuous pumping from Crooked Lake to Bass Lake is expected to impact the normal water surface elevation on Bass Lake. Pumping at various rates will result in a slow increase in Bass Lake elevation reaching a steady state elevation in approximately 12-30 days, depending on pumping rate. At the proposed pumping rate of 3,000 gpm (6.7 cfs), the Bass Lake elevation will increase to elevation 884.5 which is approximately 0.9 feet over the existing water surface elevation. Bass Lake will reach this elevation in 12 days and maintain a steady-state elevation while the pump from Crooked Lake is operated.

The chart below illustrates the relationship between pumping rate from Crooked Lake and the water surface elevation and peak discharge rate from Bass Lake.



The potential exists for even higher water surface elevations if a storm were to occur during continuous pumping. Two scenarios were evaluated: a storm occurring at the beginning of pumping before Bass Lake reaches a steady-state elevation, and a storm that occurs after Bass

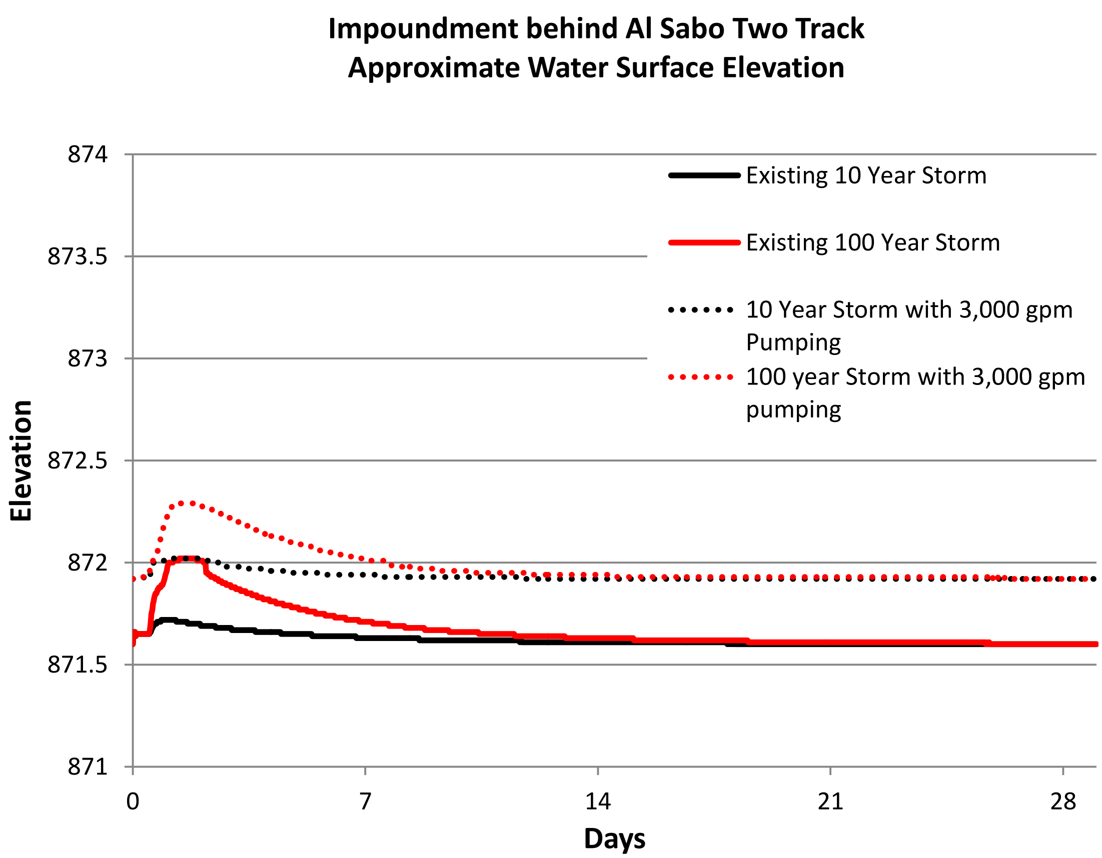
Lake has reached a steady-state elevation of 884.5. The worst case scenario is when the storm occurs after Bass Lake has reached steady-state conditions at approximately 12 days after initiating pumping. The impact of 1, 10, and 100 year storms with concurrent pumping at 3,000 gpm was evaluated and the results tabulated below.

Flow Condition	Existing	Storm occurs at beginning of Pumping	Storm occurs at Steady State Pumping
No Storm	883.6	884.50	884.50
1 year	883.7	884.50	884.57
10 year	883.9	884.50	884.78
100 year	884.4	884.70	885.20

A pump discharge rate of 3,000 gpm with no concurrent storm event results in a steady-state peak elevation on Bass Lake of 884.5 feet. A concurrent 1 year storm results in a 0.87-feet increase compared to existing conditions and a 0.07-feet increase compared to the steady state elevation from pumping. A concurrent 100 year storm results in a 0.8-feet increase compared to existing conditions and a 0.5-feet increase compared to pumping alone; however, the water level will subside and stabilize within 5 days to a steady-state elevation of 884.5 feet. Under the worst case scenario of a 100 year storm occurring during steady-state pumping, high flows will overtop the auxiliary spillway elevation of 885.1.

The results also indicate that the flow rate out of Bass Lake will increase during the short-term pumping scenario. For example, the peak discharge will increase from 2.7 cfs under a 10 year storm alone to 6.7 cfs under a 10 year storm/3,000 gpm pumping scenario. Bass Lake discharges into the West Fork of Portage Creek which passes through several impoundment type areas restricted by culverts. The stream pass through a 30" culvert approximately 400 feet downstream of the Bass Lake outlet and a 48" culvert exists under a two track path through the Al Sabo Land Preserve before reaching the Atwater Millpond and discharging through a culvert under South 12th Street. At the time of the survey, there was approximately 2.5 feet of flow through the 48" culvert under the Al Sabo two-track path (approximately 16 cfs with current tailwater conditions). The model simulation assumes that any storage behind the culvert will act as a reservoir and that the initial water surface elevation as surveyed will remain consistent through the pumping timeline.

Results for the 10 and 100 year storms with concurrent pumping indicate an increase in peak elevation at the Al Sabo two-track path of 0.30 and 0.29 feet for the 10 and 100 year storms, respectively, compared to storm flows alone. See the graph below for comparison of the existing storm hydrographs and the concurrent pumping/storm hydrographs.



Two alternatives exist to mitigate the water level rise on Bass Lake or the Al Sabo two-track path culvert: first, increase the outlet flow rate from Bass Lake by changing the outlet which would pass higher peak flows downstream or, second, monitor the water elevation during rain events and reduce or cease pumping activity to allow for the steady-state water elevation in Bass Lake to recede and allow for storm-flood volume.

A new outlet configuration was simulated assuming removal of the 24" CMP culvert and replacement with a weir at the same invert of 883.1 feet. The effect of changing the outlet was simulated under a 10 year design storm event with concurrent pumping at a rate of 3,000 gpm.

Construction of a 6 foot wide weir at elevation 883.1 feet results in a peak elevation on Bass Lake of 883.8 feet which is 0.1 feet below the peak elevation for a 10 year storm/3,000 gpm pumping with the current 24” CMP culvert outlet.

6.2 Long-term Surface Water Modeling Results

Currently, no surface water discharges from Eagle Lake to Crooked Lake and from Crooked Lake to Bass Lake. Therefore, the addition of any water, whether baseflow or storm flows, is anticipated to result in increased water surface elevations on each downstream receiving waterbody. The goal of this analysis is to quantify the change in water surface elevation and determine if that change will cause detrimental impact on resources downstream.

6.2.1 Crooked Lake

Simulations were evaluated to determine a possible outlet configuration to provide a positive outlet from Crooked Lake to Bass Lake (See Figure 8). The outlet configurations assume a sharp-crested weir set at the ordinary lake elevation of 893.87 and an 18 inch outlet pipe that will discharge into the wetland between Crooked Lake and 8th Street. Water surface elevations were evaluated under a 100-year, 24 hour flood event.

Crooked Lake Weir Length	Crooked Lake Elevation	Bass Lake Elevation	Al Sabo Two Track Elevation
0	894.91	884.08	872.02
2	894.73	884.17	872.05
4	894.70	884.42	872.09
10	894.63	884.87	872.23
20	894.55	885.20	872.30

A 2 foot wide weir controlling discharge from Crooked Lake will result in a 0.09 feet increase in the 100-year flood elevation on Bass Lake and a 0.03 foot increase in the 100-year flood elevation at the two track in the AL Sabo Land Preserve.

6.2.2 Eagle Lake

An additional positive outlet from Eagle Lake was simulated. The outlet configurations assume a sharp-crested weir set at the ordinary lake elevation of 899.84 and an 18 inch outlet pipe that discharges into Crooked Lake (See Figure 9). Multiple iterations were considered to determine the effect of weir length on the peak water elevation for a 100-year storm on Eagle, Crooked, and Bass Lakes.

Eagle Lake / Crooked Lake Weir Lengths	Eagle Lake Elevation	Crooked Lake Elevation	Bass Lake Elevation
0 / 0 feet	901.50	894.91	884.08
1 / 2 feet	901.47	894.79	884.31
2 / 4 feet	901.44	894.79	884.84
4 / 4 feet	901.38	894.87	885.17
4 / 10 feet	901.38	894.74	885.30
10 / 10 feet	901.26	895.00	885.45

Construction of 1 foot wide outlet weir from Eagle Lake and a 2 foot wide outlet weir from Crooked Lake would result in a decrease in 100-year flood elevation of 0.03 feet and 0.12 feet for Eagle Lake and Crooked Lake, respectively. The 100-year flood elevation on Bass Lake would increase by 0.13 feet. Further downstream, the increase on 100-year flood elevation at the Al Sabo two-track is 0.03 feet. If a project progresses toward constructing an outlet on either Crooked Lake or Eagle Lake, additional survey on low-lying structures will need to be collected to determine if the 0.13 feet increase on Bass Lake will cause detrimental impacts.

The installation of positive outlets from Eagle Lake and Crooked Lake has implications for future floodplain regulation. Michigan Department of Environmental regulates natural resources impacts when the contributing drainage area exceeds 2 square miles. Crooked Lake and Bass Lake currently do not have an existing contributing area that exceeds 2 square miles; however, with construction of an outlet on both Eagle Lake and Crooked Lake, Crooked Lake and Bass Lake will now have a contributing area exceeding 2 square miles.

Lake	Existing Contributing Area (sq. mi)	Future Area with Crooked Lake Outlet (sq. mi.)	Future Area with Crooked Lake and Eagle Lake Outlets (sq. mi.)
Eagle Lake	3.20	3.20	3.20
Crooked Lake	1.20	1.20	4.40
Bass Lake	0.29	1.49	4.69

7 Recommendations

In choosing a final design alternative to provide short-term and long-term flood relief to the area, several factors including environmental impact, hydraulic impact, constructability, and cost should be considered. Preliminary estimates of cost are provided for the recommendations.

7.1 Short-Term Flood Relief Recommendation

The short-term recommendation is intended to provide relatively immediate impact. As discussed, any solution to produce a significantly reduced flooding condition cannot be centered on the flow of groundwater due to the relatively low velocities. Short-term flood relief can, however, be provided with a temporary pump discharging at a rate of 3,000 gpm from Crooked Lake into the storm sewer system in Bentwood Trail. This will provide relief on Crooked Lake and to a lesser degree to the entire surrounding area.

Similarly, short-term flood relief for Eagle Lake residents can be realized more quickly by pumping from Eagle Lake to Crooked Lake at a lesser rate than the discharge from Crooked Lake. The recommended pumping rate from Eagle Lake is 1,500gpm.

With any pumping from Crooked Lake to the northeast, the water surface elevation on Bass Lake will rise slightly as a result of increased flow and during concurrent storm events. The impacts can be minimized by observing the water surface rise and metering pump discharge if the water level exceeds the crown elevation of the Bass Lake outlet pipe. This report recommends monitoring of the downstream water surface elevations and metering or ceasing the pump activity if water surface elevations appear to be detrimental to surrounding resources.

Drawdown of Crooked Lake by more than 4 feet is estimated to take 100-150 days with only a 3,000 gpm pumping from Crooked Lake. If Eagle Lake is discharging into Crooked Lake at 1,500 gpm simultaneously, the pumping will be required for approximately 6 to 8 months to match normal levels.

7.2 Long-Term Flood Relief Recommendation

We recommend implementing a phased approach for long-term flood relief to the lakes by constructing an outlet on Crooked Lake and monitoring the impact to Eagle Lake, Duck Lake, and Pretty Lake. A permanent outlet on Crooked Lake will provide improved control of the water table in the local area. An outlet can then be constructed on Eagle Lake in a second phase to safeguard against even more extreme flooding conditions.

A third positive outlet, from Duck Lake to Crooked Lake, would reduce flood risk further; however, the other two outlets would have very positive combined impact on the water table in the area without the need for a third outlet structure.

7.2.1 Crooked Lake

The recommended solution to provide a positive outlet from Crooked Lake is to install a 2-foot weir and outlet control structure on the east side of Crooked Lake and 18-inch pipe from the outlet control structure to the wetland between Crooked Lake and 8th Street. This recommended alternative has several desirable characteristics that include:

- Provides a positive outlet for baseflow and storm flows from Crooked Lake.
- Lowers the 100-year storm elevation on Crooked Lake
- Allows for ease of construction

This alternative will require acquisition of land or right-of-way to place the outlet control structure and pipe. Permits would be required pursuant to Part 91, Soil Erosion and Sedimentation Control, Part 301, Inland Lakes and Streams, and Part 303, Wetlands Protection of the Natural Resources and Environmental Protection Act (NREPA), 1994 P.A. 451, as amended.

This alternative has an estimated construction cost of $350,000 to 400,000.

7.2.2 Eagle Lake

Installation of a positive outlet will lower the water on Eagle Lake and surrounding groundwater. A 1-foot wide weir and outlet control structure could be constructed at the south end of a channel near the south end of Aquaview Drive. Approximately 280 feet southeast of the channel is a sanitary sewer gravity main and force main within an easement.

We propose placing an 18-inch outlet pipe from the outlet control structure to the sanitary easement and then proceeding south to PQ Avenue within the easement and parallel to the sanitary sewer mains. The outlet pipe will be laid within the PQ Avenue right-of-way and proceed east to Crooked Lake Drive and then south along Crooked Lake Drive before connecting to an existing storm sewer system that collects local runoff from Crooked Lake Drive and discharging into Crooked Lake in a drainage easement.

A positive outlet on Eagle Lake will provide for continuous discharge of high water elevations and result in a lower 100-year flood elevation on the lake. Construction of the outlet pipe will be challenging as the proposed route along PQ Avenue has numerous utility conflicts and the depth of cut to install the 18-inch pipe will range from 15 to 25 feet.

This alternative will require acquisition of land or right-of-way to place the outlet control structure and pipe. Permits would be required pursuant to Part 91, Soil Erosion and Sedimentation Control, Part 301, Inland Lakes and Streams, Part 303, Wetlands Protection, and Part 31, Floodplains of the Natural Resources and Environmental Protection Act (NREPA), 1994 P.A. 451, as amended.

This alternative has an estimated construction cost of $750,000 to $800,000

8 Conclusion

The Charter Township of Texas has experienced flooding and high groundwater throughout the township but notably on Crooked Lake, Eagle Lake, and other low-lying areas adjacent to waterbodies and adjacent areas. The causes of flooding and high groundwater have been evaluated to determine alternatives for lowering the water.

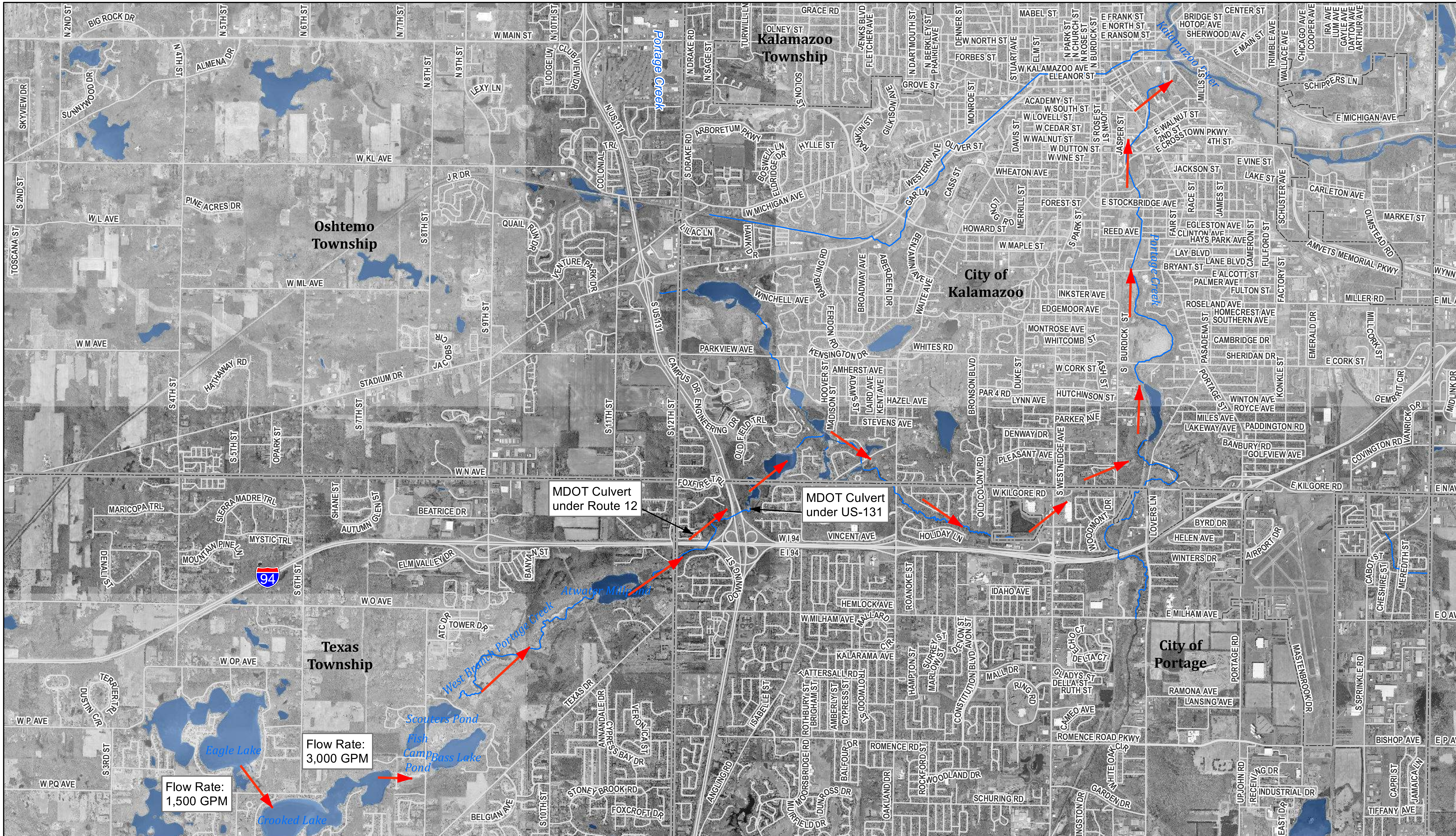
The recommended solutions are:

- Install a temporary pump to discharge approximately 3,000 gpm of water from Crooked Lake to a storm sewer in Bentwood Trail. This will drop the Crooked Lake level and water table down in the entire area.
- Install a temporary pump to discharge approximately 1,500 gpm of water from Eagle Lake through temporary piping to Crooked Lake. This will drop the Eagle Lake level and water table down in the area, though it will increase the amount of time needed to draw down Crooked Lake.
- Construct an outflow structure on Crooked Lake with a positive outlet to the east. This would include approximately 700 feet of outlet pipe under Bentwood Trail.

- Construct an outflow structure on Eagle Lake with a positive outlet to Crooked Lake. This would include approximately 2,300 feet of outlet pipe from Eagle Lake to PQ Avenue and then west to West Crooked Lake Drive before discharging into Crooked Lake.

Based on our analysis and evaluation of construction costs, permitting requirements, estimated drawdown time, and other factors, it is our opinion that the solutions identified will result in a lower water level on Crooked Lake, Eagle Lake and the entire area.

Figures



SCALE: 1 " = 3,750 '

LEGEND

Flow Direction

CHARTER TOWNSHIP OF TEXAS

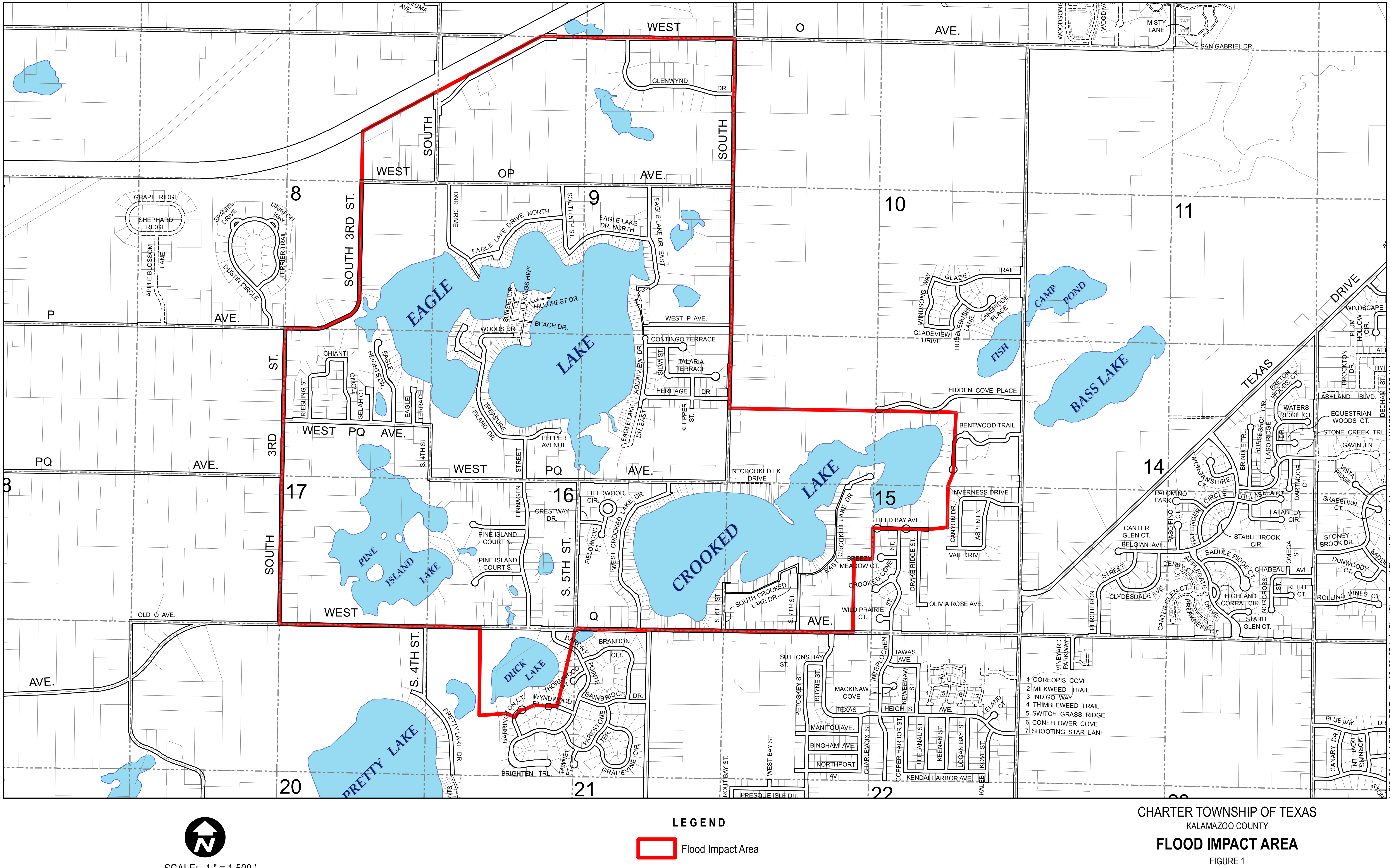
KALAMAZOO COUNTY

FLOW DIRECTION MAP

FIGURE

Prein&Newhof

2180465



CHARTER TOWNSHIP OF TEXAS

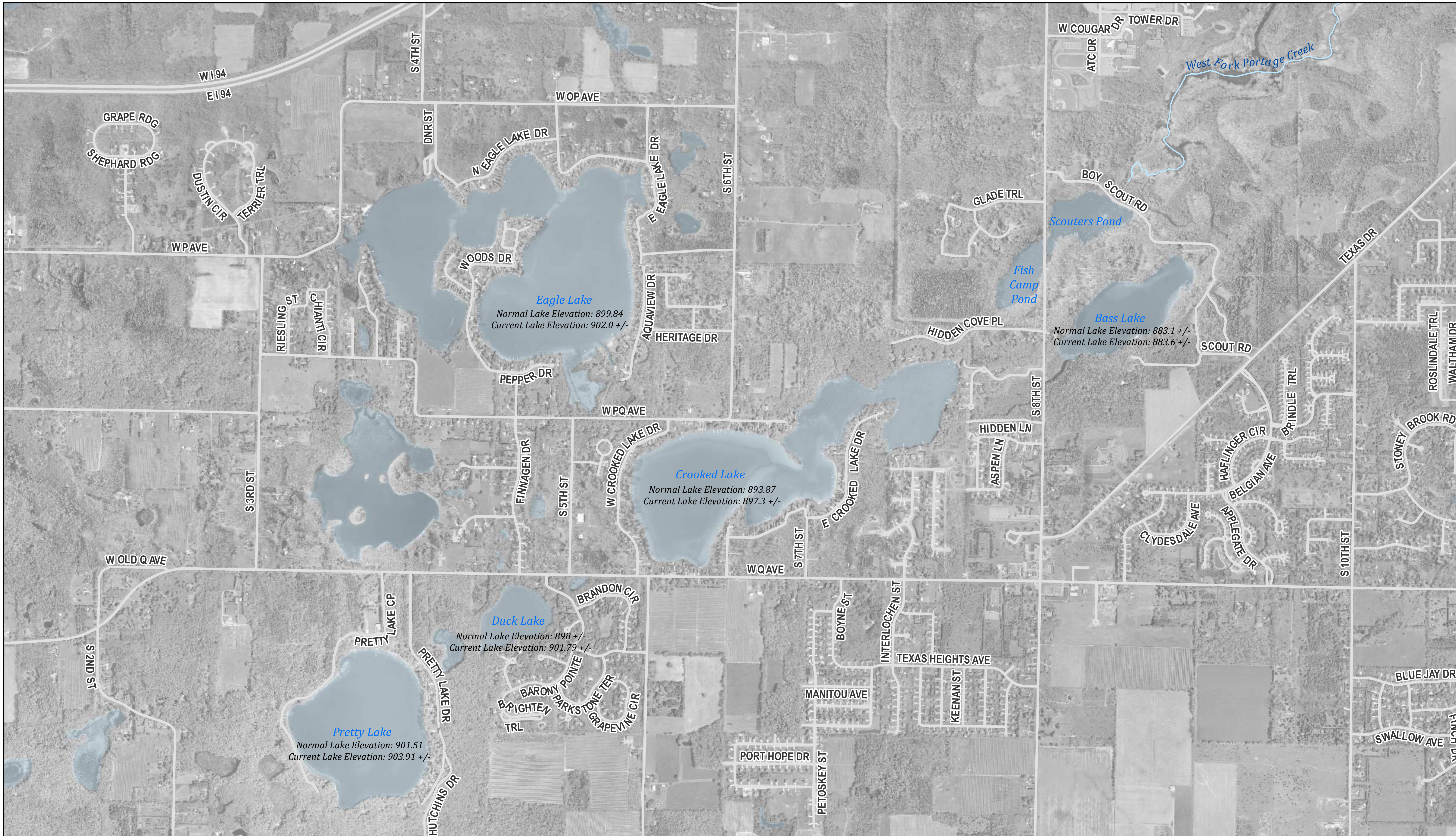
KALAMAZOO COUNTY

FLOOD IMPACT AREA

FIGURE 1

Prein&Newhof

2180465



SCALE: 1 " = 1,500 '

NOTES:

1. Current lake elevations based on survey collected Sept. 20, 2018.
2. Normal lake elevations based on Charter Township of Texas Zoning Ordinance.

CHARTER TOWNSHIP OF TEXAS

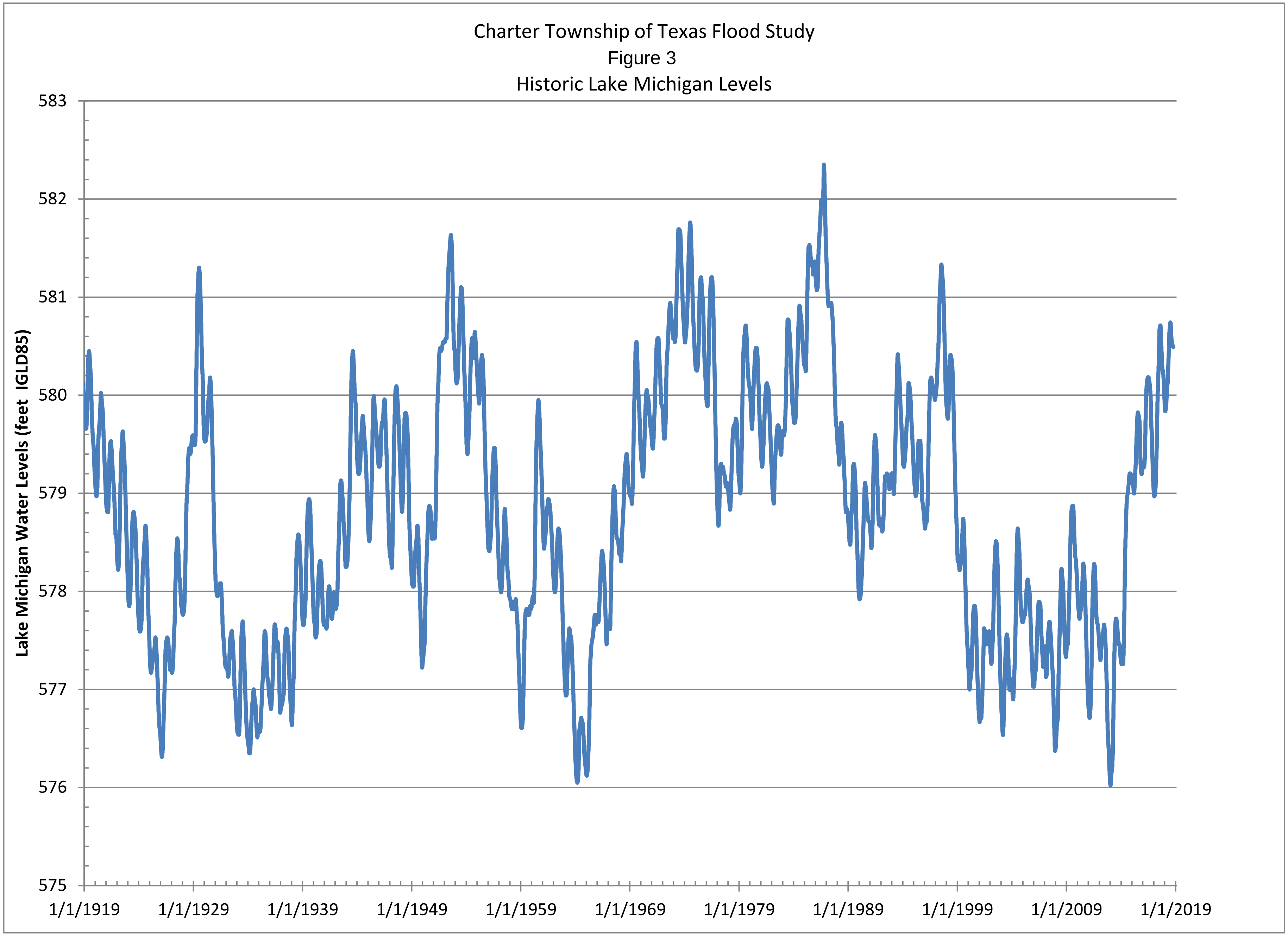
KALAMAZOO COUNTY

SITE LOCATION

FIGURE 2

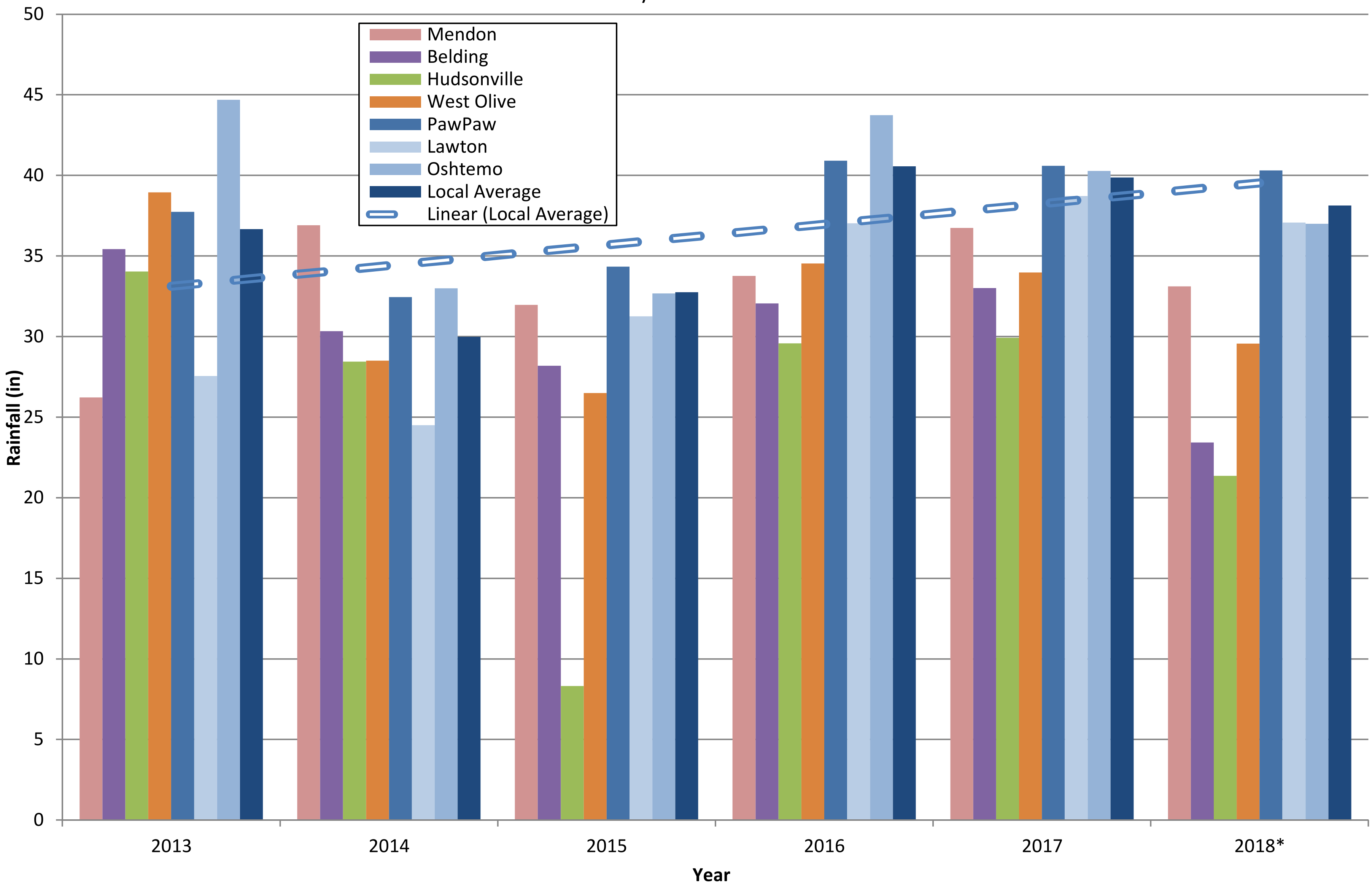
Prein&Newhof

2180465



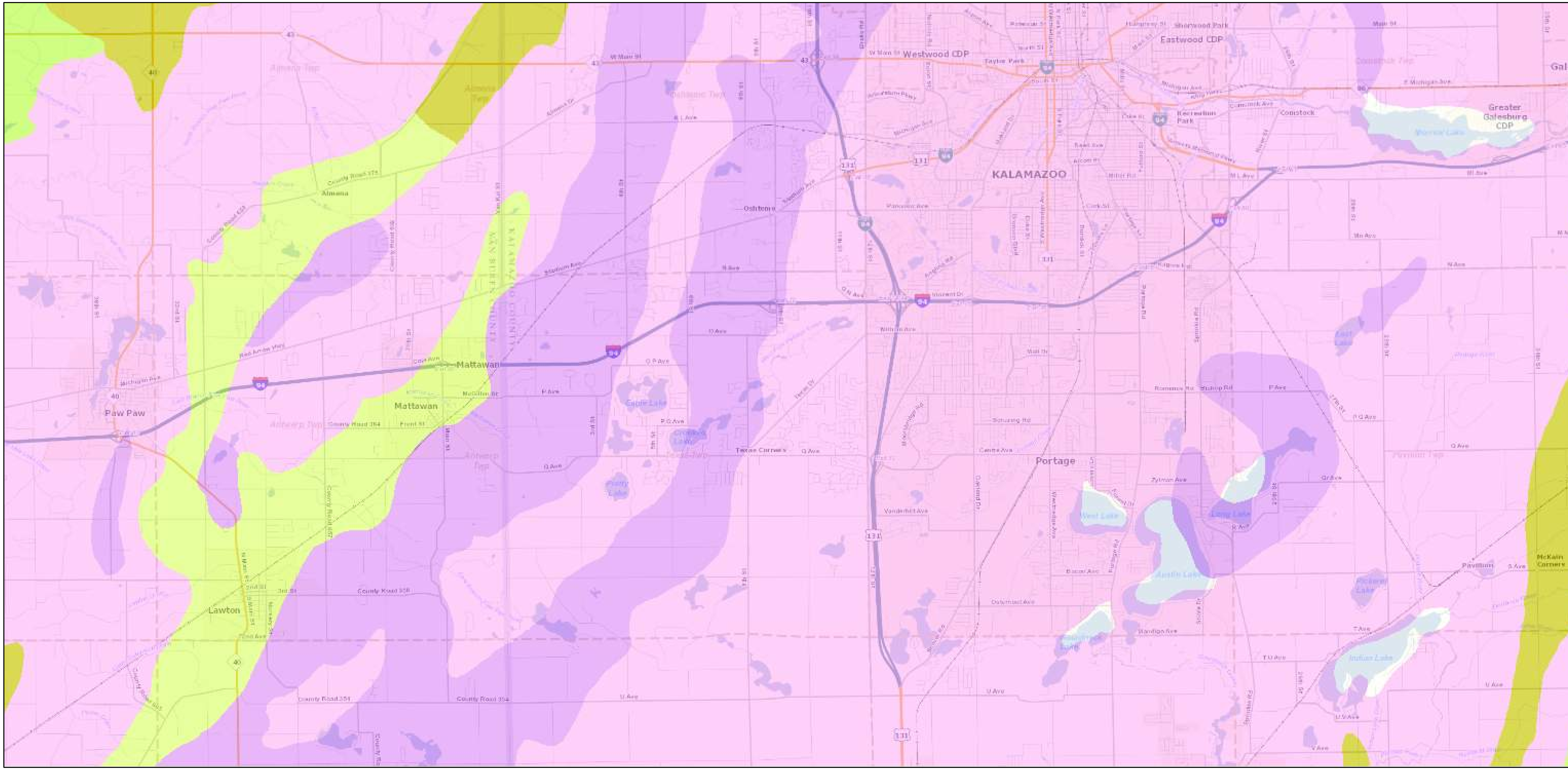
Charter Township of Texas Flood Study
Figure 3
Historic Lake Michigan Levels
Lake Michigan Water Levels (feet IGLD85)
583
582
581
580
579
578
577
576
575
1/1/1919
1/1/1929
1/1/1939
1/1/1949
1/1/1959
1/1/1969
1/1/1979
1/1/1989
1/1/1999
1/1/2009
1/1/2019

Charter Township of Texas Flood Study
Figure4
Yearly Rainfall Totals



Note: Precipitation for 2018 is January 1 through October 31

GeoWebFace



October 26, 2018

Quaternary Geology

- Peat and muck
- Postglacial alluvium
- Dune sand
- Lacustrine clay and silt
- Lacustrine sand and gravel
- Glacial outwash sand and gravel and postglacial alluvium
- Ice-contact outwash sand and gravel
- Fine-textured glacial till
- End moraines of fine-textured till
- Medium-textured glacial till
- End moraines of medium-textured till
- Coarse-textured glacial till
- End moraines of coarse-textured till
- Thin to discontinuous glacial till over bedrock
- Artificial fill
- Exposed bedrock surfaces
- Water

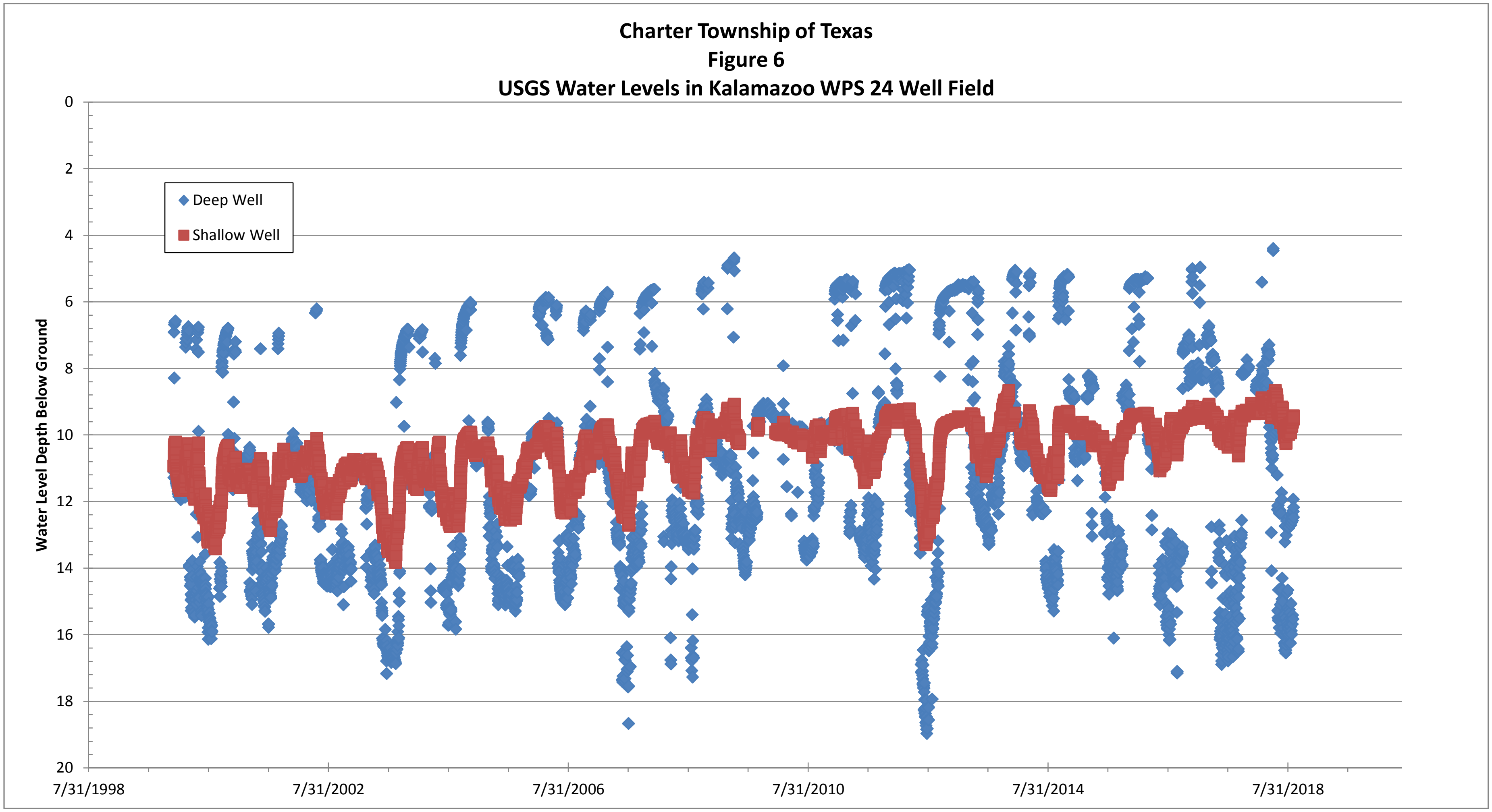
1:103,462

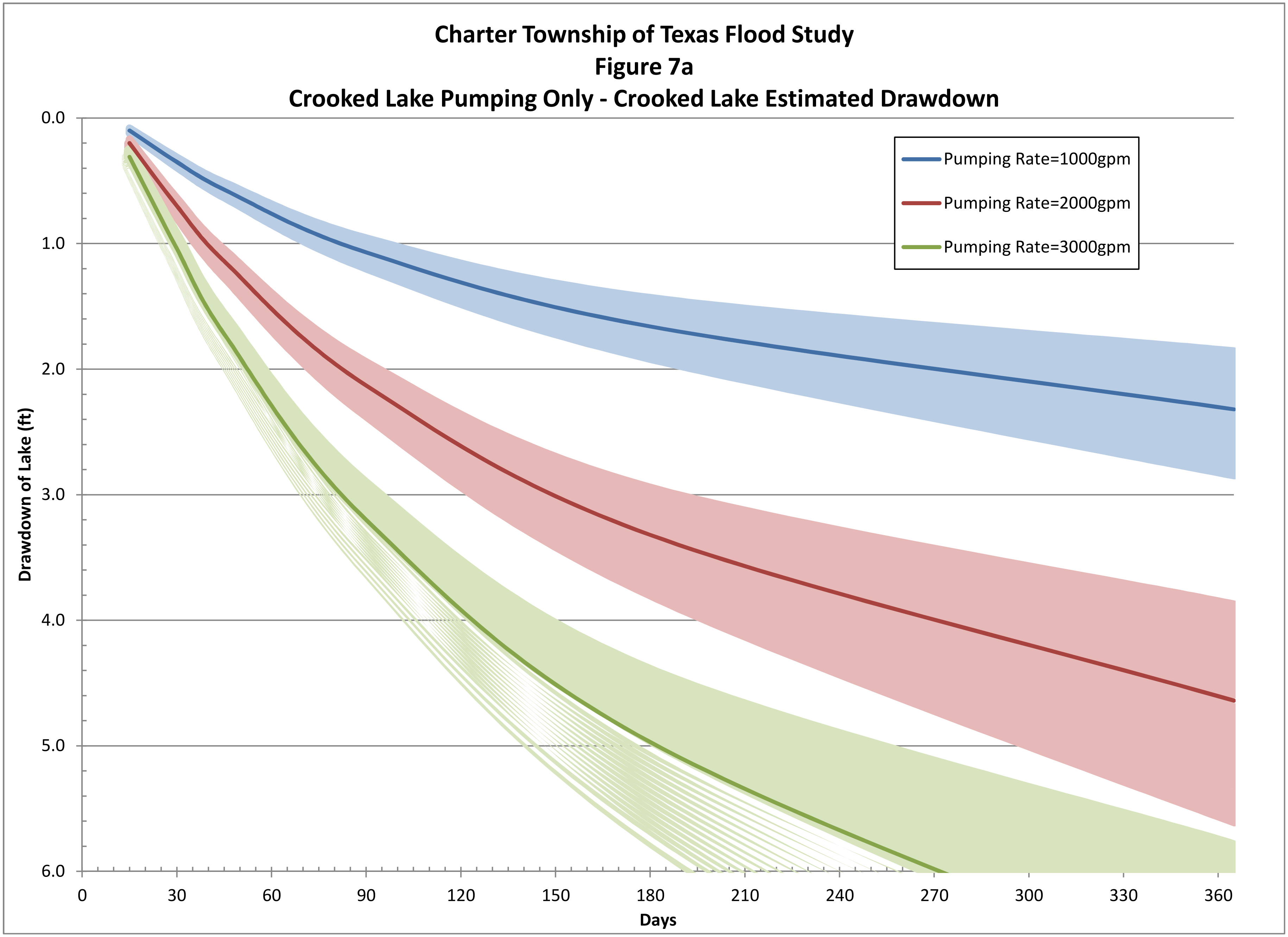
0 1.25 2.5 5 mi

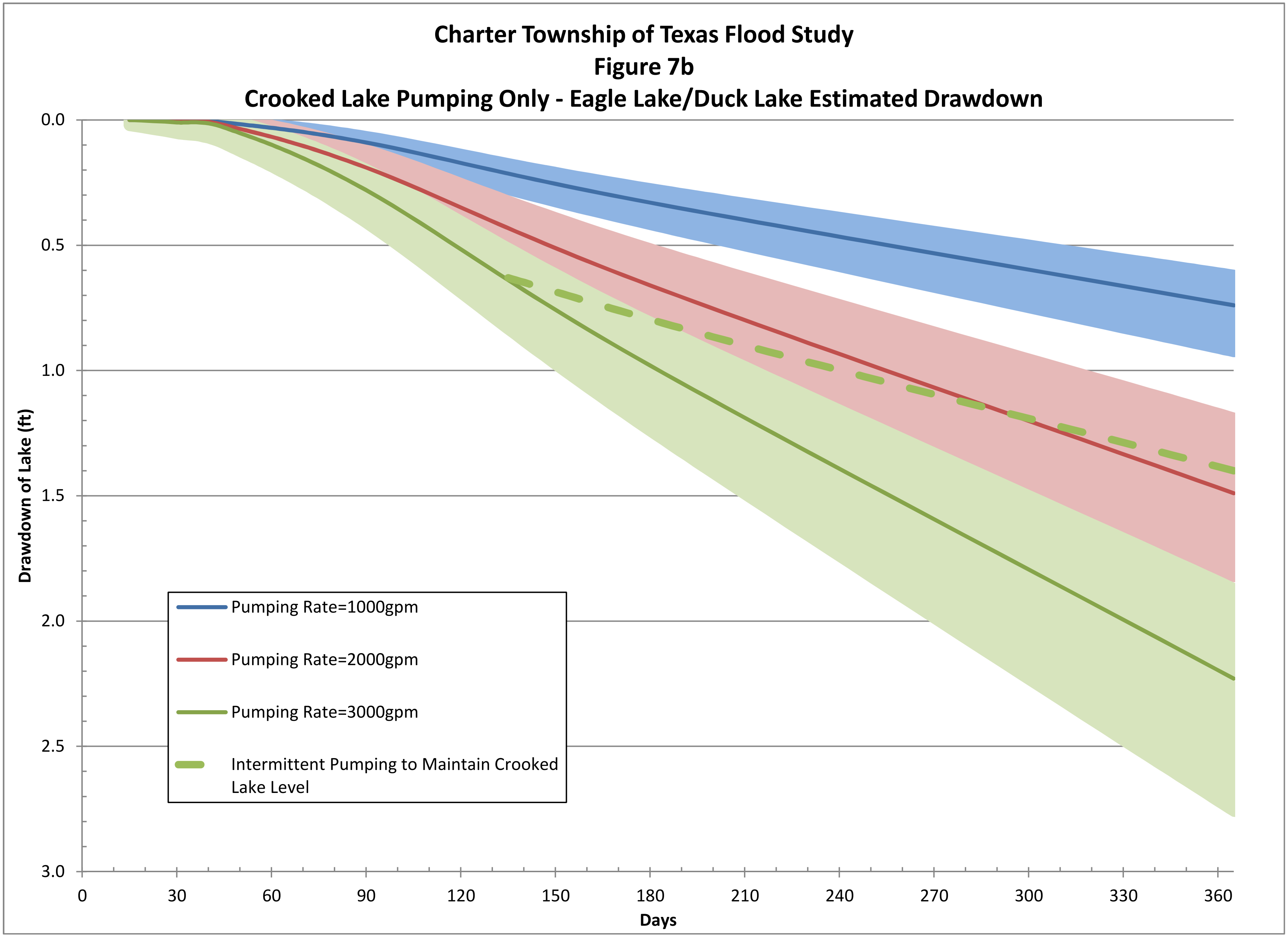
0 2 4 8 km

Charter Township of Texas Flood Study
Figure 5
Glacial Geology

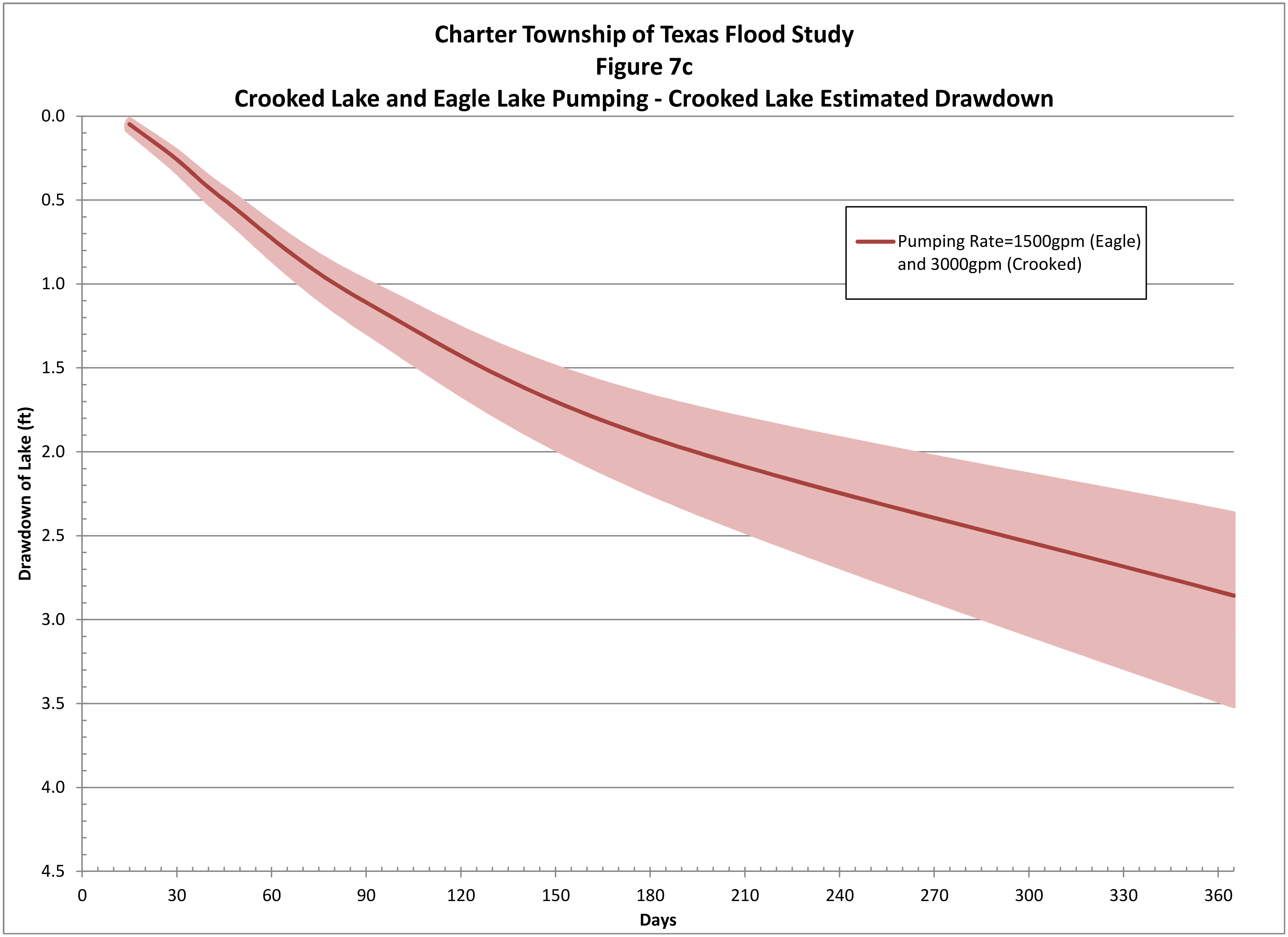
Map by: State of Michigan - CSS


Charter Township of Texas
Figure 6
USGS Water Levels in Kalamazoo WPS 24 Well Field
Deep Well
Shallow Well
Water Level Depth Below Ground
0
2
4
6
8
10
12
14
16
18
20
7/31/1998
7/31/2002
7/31/2006
7/31/2010
7/31/2014
7/31/2018

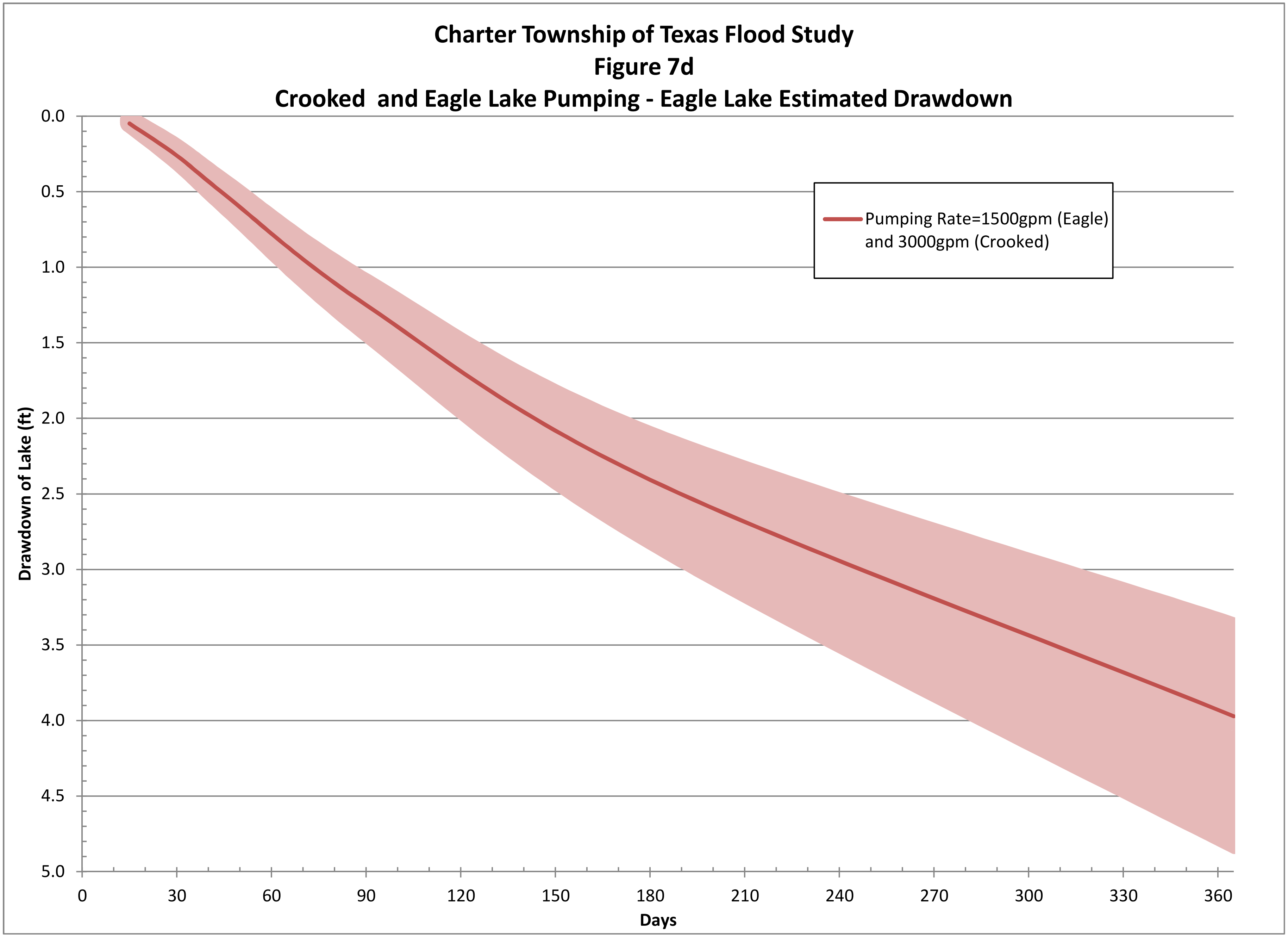

Charter Township of Texas Flood Study
Figure 7a
Crooked Lake Pumping Only - Crooked Lake Estimated Drawdown
Pumping Rate=1000gpm
Pumping Rate=2000gpm
Pumping Rate=3000gpm
Drawdown of Lake (ft)
Days
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
30
60
90
120
150
180
210
240
270
300
330
360

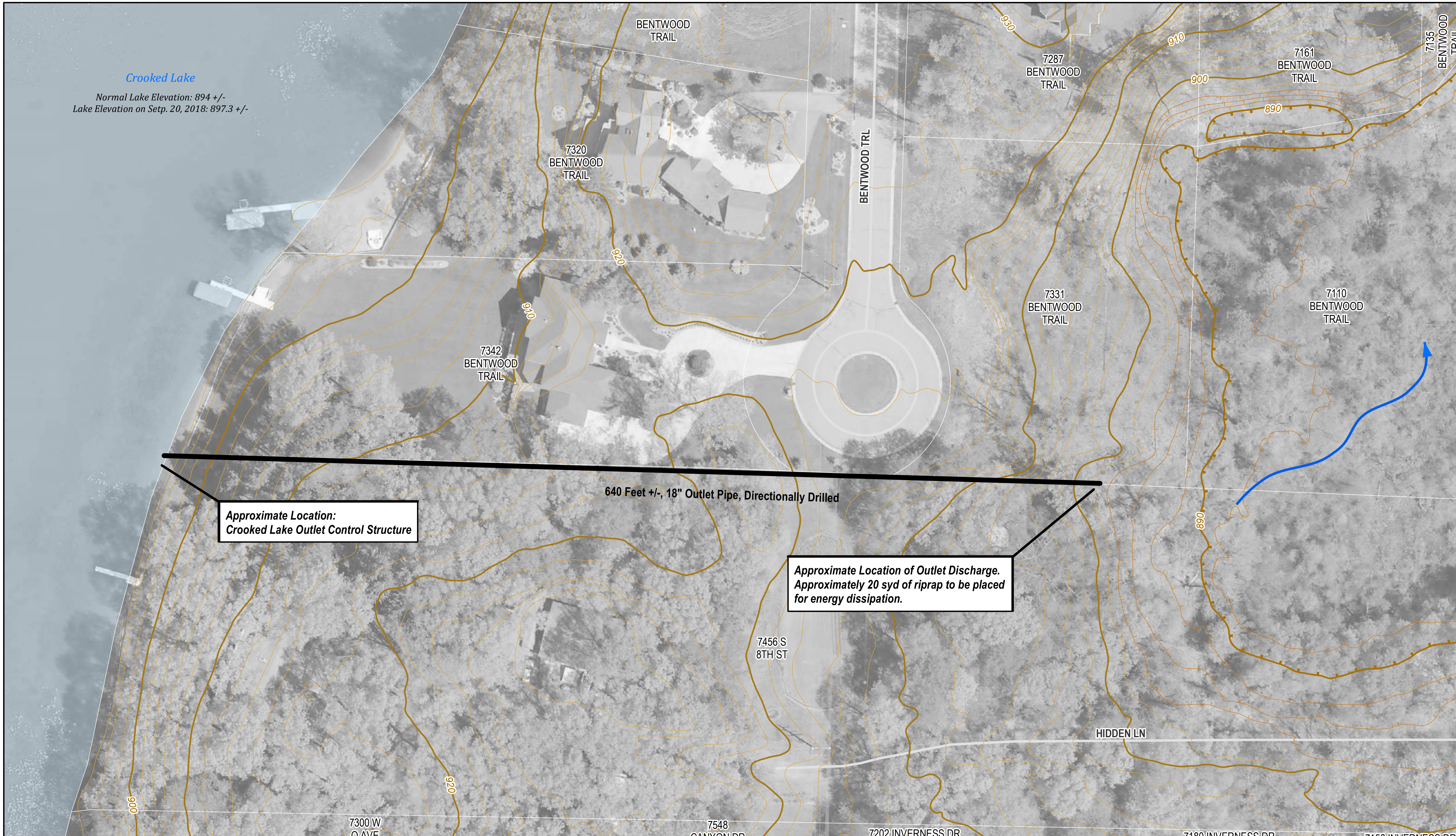


Charter Township of Texas Flood Study
Figure 7b
Crooked Lake Pumping Only - Eagle Lake/Duck Lake Estimated Drawdown
Drawdown of Lake (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
30
60
90
120
150
180
210
240
270
300
330
360
Days
Pumping Rate=1000gpm
Pumping Rate=2000gpm
Pumping Rate=3000gpm
Intermittent Pumping to Maintain Crooked Lake Level



Charter Township of Texas Flood Study
Figure 7c
Crooked Lake and Eagle Lake Pumping - Crooked Lake Estimated Drawdown
Drawdown of Lake (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
30
60
90
120
150
180
210
240
270
300
330
360
Days
Pumping Rate=1500gpm (Eagle) and 3000gpm (Crooked)


Charter Township of Texas Flood Study
Figure 7d
Crooked and Eagle Lake Pumping - Eagle Lake Estimated Drawdown
Pumping Rate=1500gpm (Eagle) and 3000gpm (Crooked)
Drawdown of Lake (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
0
30
60
90
120
150
180
210
240
270
300
330
360
Days



J:\GIS_Client\Kal-GD\Tex-GD\Twp_Proj\2180465_LakeFloodStudy\Report Figure 2 Crooked Lake Outlet Route.mxd - PNEJD - 10/26/2018 2:47:37 PM

SCALE: 1 " = 60 '

NOTES:

1. Current lake elevations based on survey collected Sept. 20, 2018.

2. Normal lake elevations based on contours provided by Charter Township of Texas.

CHARTER TOWNSHIP OF TEXAS

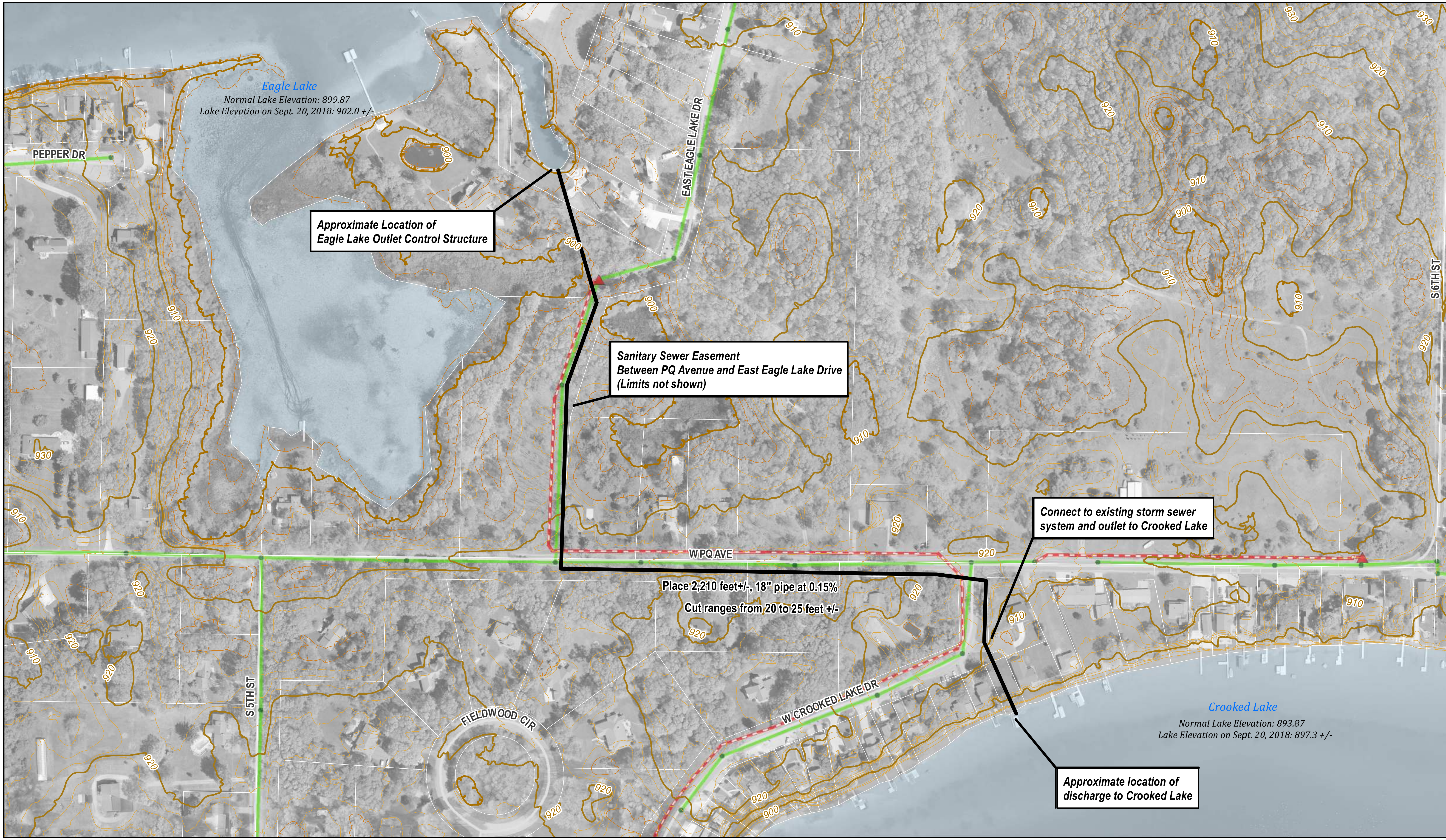
KALAMAZOO COUNTY

CROOKED LAKE
PROPOSED OUTLET LOCATION

FIGURE 8

Prein&Newhof

2180465



J:\GIS_Client\Kal-GD\Tex-GD\Twp_Proj\2180465_LakeFloodStudy\Report Figure 3 Eagle Lake Outlet Route.mxd - PNEJD - 10/29/2018 9:12:07 AM

N

SCALE: 1 " = 200 '

NOTES:

1. Current lake elevations based on survey collected Sept. 20, 2018.

2. Normal lake elevations based on Charter Township of Texas Zoning Ordinance.

LEGEND

- Eagle Lake Outlet Route
- Sanitary Force Main
- Sanitary Sewer Line

CHARTER TOWNSHIP OF TEXAS

KALAMAZOO COUNTY

EAGLE LAKE

PROPOSED OUTLET LOCATION

FIGURE 9

Prein&Newhof

2180465

Appendix A

Soil Boring

Prein&Newhof
Engineers • Surveyors • Environmental • Laboratory
3355 Evergreen Drive NE Grand Rapids, Michigan 49525
Telephone : (616) 364-8491 Fax : (616) 364-6955

LOG OF SB-1

DESCRIPTION :	Bentwood Trail Cul-De-Sac
LOCATION :	Texas Township
PROJECT NO. :	2180136
INSPECTOR :	J. Cruickshank
DRILLING CONTRACTOR:	T. West
DRILLER :	Great Lakes Drilling
DRILL RIG :	CME-75
BORING METHOD :	Split Spoon (ASTM D 1587)
SURFACE ELEVATION :	918 +/-
TOTAL DEPTH :	30'
WATER ENCOUNTERED AT :	28.5'
WATER AFTER COMPLETION :	Wet Cave-in at 28.5'
START DATE :	10/12/2018
CHECKED BY :	JTC

SAMPLE	PENETRATION (BLOWS/6")	STD. PEN. N-VALUE	MOISTURE (%)	DRY DENSITY (PCF)	UNCONF. COMP. STRENGTH (PSF)	PID READING (PPM)
SS-1	2 2 3	5				
SS-2	6 6 7	13				
SS-3	11 25 29	54				
SS-4	21 25 18	43				
SS-5	9 6 7	13				
SS-6	5 3 3	6				
SS-7	3 2 2	4				
SS-8	10 7 6	13			4000*	

DEPTH (FT.)	SUBSURFACE PROFILE
0 – 4.5'	FILL: LOOSE DARK BROWN FINE SAND WITH LITTLE SILT, TRACE TO LITTLE CLAY, TRACE GRAVEL AND OCCASIONAL PIECES OF BRICK, BROKEN ASPHALT AND CONCRETE (SM/ SC-MISC FILL)
4.5' – 13.0'	FILL: LOOSE TO MEDIUM DENSE YELLOW-BROWN FINE SAND WITH LITTLE TO SOME SILT, TRACE GRAVEL (SM-FILL)
13.0' – 17.5'	FILL: DENSE BROWN FINE SAND WITH LITTLE CLAY, LITTLE SILT, TRACE TO LITTLE GRAVEL (SC-FILL)
17.5' – 21.0'	FILL: MEDIUM DENSE BROWN FINE SAND WITH TRACE SILT, TRACE GRAVEL (SP-FILL)
21.0' – 24.5'	LOOSE TO VERY LOOSE GRAY-BROWN FINE SAND WITH LITTLE SILT, TRACE GRAVEL AND OCCASIONAL ROOT FIBERS AND LENSES OF BLACK ORGANICS (SM)
24.5' – 27.0'	VERY LOOSE YELLOW-BROWN FINE SAND WITH TRACE TO LITTLE SILT, TRACE GRAVEL (SP/ SM)
27.0' – 30.0'	STIFF TO VERY STIFF BROWN SILTY CLAY WITH LITTLE TO SOME SAND, TRACE GRAVEL AND FREQUENT SEAMS OF CLAYEY SAND (CL/SC)
30.0'	END OF BORING

Depth scale (FT.): 5, 10, 15, 20, 25, 30
Elevation scale (FT.): 915, 910, 905, 900, 895, 890, 885

NOTES : *Pocket Penetrometer Value