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ENVIRONMENTAL SCIENCE & ENGINEERING

TECHNICAL MEMORANDUM

To:	Rex Vaughn Cedar Lake Improvement Board	**Date:**	April 16, 2021
From:	Mark Kieser, K&A Josh Kieser, K&A	**cc:**	John Jacobson, K&A Mike Foster, K&A

RE: **Findings for 2020 Cedar Lake Groundwater/Surface Water Level Monitoring**

This memorandum presents 2020 results compiled by Kieser & Associates, LLC (K&A) related to the ongoing water level monitoring program at Cedar Lake, Alcona and Iosco Counties, MI. K&A staff were authorized to continue management and oversight of ongoing data collection efforts in 2020 on behalf of the Lake Board. The purpose of the long-term monitoring program is to best understand critical needs and relevant influences on water levels in Cedar Lake. These are particularly important as several lake level management activities have been recently completed.

Desirable summer month water levels in Cedar Lake are a function of both rainfall and management strategies designed to support water level maintenance in dry summer months. These management strategies, as defined in the approved Cedar Lake Watershed Management Plan (WMP), relate to ongoing efforts to bolster water retention in the northwest cedar swamp throughout the year. Water control management efforts to date have included railroad culvert cleanouts ongoing since 2014, the construction of a wetland enhancement berm in fall 2017, and the implementation of instream grade structures within Sherman Creek in September 2019.

The wetland berm effort serves to retain water levels in immediately-adjacent areas of the northwest cedar swamp on CLIB property, while reducing out-of-watershed losses through King's Corner Culvert. Design, permitting and installation of instream grade structure controls within Sherman Creek were initiated in 2018. Construction and implementation occurred from September to October, 2019. The Sherman Creek instream grade structure effort serves to further retain water levels in the cedar swamp with the intention of promoting extended surface water inflows and enhanced groundwater volume inputs to Cedar Lake, as well as enhancing northern pike spawning habitat. K&A and CLIB representatives will continue to monitor and observe flow conditions around these new structures to ensure they are operating as designed. Attachment 1 provides a summary and figures from the groundwater modeling effort undertaken using 2020 data to estimate changes to groundwater storage and contribution volumes by modeling pre-implementation and post-implementation groundwater gradients in the Sherman Creek wetland and surrounding area. This effort was used to further assess the extent of hydrology improvements from the CLIB groundwater augmentation projects and to support forecasts for future additional needs for summer lake level augmentation.

The Cedar Lake outlet structure, designed to maintain the lake at the legal lake level of 608.20-ft, was replaced beginning in September of 2020. A single-weir outlet structure was constructed to replace the former two-drop-box outlet structure. Water level impacts to Cedar Lake resultant from this new structure are yet unknown. A year-round level logger capable of withstanding freezing conditions was installed at the lake outlet monitoring station in November 2020 for continuous over-winter measurement of lake levels relative to the new Cedar Lake outlet structure. A staff gage was also installed to allow for public viewing of water levels relative to the outlet spillway. Additional future direct monitoring of water levels and flows below the outlet will be necessary to assess spillway efficacy and structural efficacy to ensure that lake water is not being inadvertently discharged via surface water or groundwater losses through the new outlet structure. A concern over these potential losses have been anecdotally observed since construction of the new outlet. These will need to be addressed if corroborated with evidence from future direct monitoring.

Water level data collected for Cedar Lake continue to be vital for assessing, understanding, and cost-effectively pursuing appropriate water level control options in a phased manner. These are particularly relevant given the aforementioned recent changes and their impacts to water levels in respect to the below-average precipitation conditions observed in 2020. Other potential future management strategies per the WMP include possible improvements for Jones Creek water retention and utilizing deep groundwater withdrawal augmentation wells. Additional hydraulic diversions into the cedar swamp in the northwest corner of the watershed along more western portions of Kings Corner Road are also under discussion with the CLIB and being included in a 2021 WMP update. Surface water flooding and related ditch and stream discharges in the Timberlakes subdivision just beyond the northern extent of the Cedar Lake watershed and just downstream of the new outlet structure were brought to the attention of the CLIB in 2020. A limited assessment of hydrology in this area is being contemplated for 2021 investigations which would become a part of the 2021 hydrology report if implemented. Finally, use of augmentation well by Sherman Creek will need to be pre-empted by water quality sampling of the deep aquifer to decide whether or not this is a viable near-term augmentation option. This relates to concerns of potential deep groundwater contamination related to relevant regional historic uses and disposal of the common fire-retardant chemical PFAS in the region.

This technical memorandum therefore presents findings of the ongoing water level studies in the Cedar Lake watershed and discusses these in the context of implemented, ongoing, and potential future water level management strategies being contemplated. All tables and figures referenced in the body of this memo are provided separately at the end of the memo narrative.

Program Background

A volunteer water level monitoring program was initially developed at select groundwater and surface water monitoring sites around Cedar Lake in 2004. Since then, water level monitoring efforts have expanded to include additional critical areas using automated water level logger equipment in lieu of intermittent volunteer measurements. The 2020 water level monitoring program included 30 level loggers located around the lake, as shown on the map in Figure 1.

Consistent with previous years, a combination of surface water stations along with shallow and deep groundwater stations were monitored to document surface/groundwater interactions and their influence on Cedar Lake water levels. Sherman Creek, Jones Creek, and the King’s Corner road culvert continued to be monitored in the 2020 monitoring program to assist with calculating estimates of surface water flows into Cedar Lake. Three additional in-stream stilling tubes were monitored in Sherman Creek to better understand the impacts of the new in-stream grade structures on creek water levels and flows. Also included were water levels and flows through the wetland berm spillway just upstream (and north) of the King’s Corner culvert.

K&A also continues to monitor water levels at the new Wetland Berm station, installed in 2018 north of the King's Corner culvert, to measure surface and groundwater elevations at the berm spillway. The wetland berm was constructed in fall of 2017 as part of the ongoing efforts to retain water levels in the cedar swamp. Direct field measurements of water levels and flows from 2018-2020 were used to estimate surface water flows occurring through the wetland berm spillway based on continuous water level data. The wetland berm was designed with a stone-laden spillway meant to overflow at an elevation of 611.50 feet so as not to permanently alter historic high-water levels flowing southward out of this area and out of the Cedar Lake drainage. The wetland berm monitoring station provides important information regarding water retention improvements in the northwest cedar swamp, including those related to the recent 2019 Sherman Creek instream grade structures.

In 2018, K&A reinstalled the Jones Creek monitoring station that was removed in anticipation of a culvert replacement as part of the Alcona County Road Commission project along West Cedar Lake Road. K&A staff continues to recalibrate their flow equation for Jones Creek based on the as-built dimensions of the new culvert as well as the ongoing sedimentation occurring therein. Significant sedimentation occurred in 2020 which severely constricted flows through the culvert and impacted flow measurements. Whether this sedimentation was related to beaver damming activity at the culvert, which effected a portion of the 2019 flow data, is unclear. Surface flow equations will continue to be refined with manual measurements in future monitoring seasons.

The entire set of previous-generation aging level loggers was replaced between 2018 and 2020, in order to ensure continued accuracy and efficacy of the dataset. Seventeen replacement loggers were purchased and deployed in May of 2020. Several additional loggers were also purchased between 2019 and 2020 to support monitoring of groundwater and surface water levels during the frozen winter months in Sherman Creek, the wetland berm, and at the lake outlet. These seasonal loggers, designed to withstand freezing conditions, will be dedicated to measuring water levels at critical stations between November and March. The logger manufacturers suggest ten years to be the predicted lifespan of all replacement level loggers. Table 1 illustrates the current age and predicted lifespan of the updated Cedar Lake level logger regime.

2020 Precipitation and Water Level Data

Precipitation Comparisons

Historic summer precipitation totals for the Cedar Lake area are presented in Figure 2. These data represent triangulated 2020 precipitation data available from: Cedar Lake volunteer rain gauge, Harrisville 2 NNE (USC00203628), and Oscoda Wurtsmith Airport (Station #14808), as well as historic rain gauge data from similar sources. Available rainfall data from 1998 to 2020 (minus 2006 when there were no local functioning rain gauges) reflect a 22-year summer average (June-September) of 11.85 inches of rainfall.

Although observed 2020 precipitation data showed near-average rainfall for the early spring months of March-May 2020, the observed 2020 data for June-September showed well-below-average rainfall, totaling 8.57 inches during this summer-month period. As Figure 2 illustrates, the previous summer of 2019 exhibited slightly below-average summer precipitation amounting to 10.66 inches. Summer-month rainfall totals in 2018 and 2017 were near or just below-average, while 2016 rainfall was average, and 2015 below-average. Summer precipitation in 2014 was above-average, while in the years 2012-2013 rainfall was recorded below-average, and in 2008-2011 summer precipitation was above-average.

Importantly, with respect to rainfall the Cedar Lake Augmentation Feasibility Study completed by K&A in 2011 revealed that in order to avoid lake level decreases greater than 3-inches per month during the critical summer months (June-September), an average summer monthly rainfall of 2.75 inches would be necessary. Thus, in a given summer month if natural rainfall patterns result in less than 2.75 inches, a lake level drop of approximately 3 inches or more per month can be expected. A June-September average of 11 inches of rainfall (i.e., 2.75 inches multiplied by 4 months) is therefore used to assess each summer season as a whole with regards to desired lake level conditions. This target threshold is plotted on Figure 2 for sake of comparison. Efforts to better manage water levels and water retention in the northwest cedar swamp are expected to decrease this critical rainfall threshold over time. Such would mean that in a drier summer, one might expect less extreme water level drops than experienced in the past.

Cedar Lake Water Levels

The Cedar Lake April-November 2020 water levels were plotted with recorded rainfall to illustrate lake level response to precipitation (Figure 3). As noted in Figure 3, the local precipitation has a direct impact on Cedar Lake water levels, with observed responses corresponding to local rain events. The 2020 level logger data collected near the Cedar Lake outlet showed surface water levels fluctuated within a maximum of 6 inches above (March and May) and 15 inches below (September) the northern lake outflow structure elevations.

Cedar Lake remained above the legal lake level with outflow conditions occurring from the beginning of the monitoring season to the end of June. Consistent with the rainfall threshold data plotted on Figure 2 (i.e., 2.75 inches per month or 11 inches total for the summer season), Figure 3 shows that Cedar Lake water levels steadily declined following spring rain and snowmelt. The lack of substantial summer rain events increased the rate of lake level decline through the summer months and the lake level remained below the spillway. Lake levels dropped to 6-inches below the legal lake level by July of 2020 and continued to steadily decline to a maximum of 15 inches below the legal lake level by the end of September. No outflows occurred at the Cedar Lake outlet from the end of June to the end of the monitoring period in November. Fluctuations in lake level noted during September and October of 2020 at the lake outlet, as observed in Figure 3, are attributed to rainfall events occurring during that period, however, the slope and intensity of these fluctuations, which occurred after construction of the new lake outlet, may warrant further investigation in comparison to past and future lake level data.

The lake level drop observed in 2020 directly corresponded with lower than average precipitation levels during the summer months of June-September. As Cedar Lake levels fluctuated in response to rain events during the summer months of June-September, water levels dropped from a summer-month maximum of 4-inches above (June) to 15-inches below (September) the legal lake level. The greatest drop during the monitoring season occurred from July to September. Lake levels in October and November remained below the legal lake level.

Due to the relatively small size of the Cedar Lake watershed contributing area, summer rainfall is an important factor in maintaining Cedar Lake levels. Those years with below-average rainfall result in significant drops in Cedar Lake water levels as water losses exceed water gains to the lake. As described in the next sections, several management implementations undertaken since 2014 to improve the connectivity and retention of water in the northwest cedar swamp are positively affecting the aforementioned target threshold for rainfall by lessening the effect of low precipitation on lake level drops during dry summer months.

Figure 4 compares the impact of summer month precipitation on Cedar Lake water level fluctuations over time, using available lake outlet station data from 2004-2020. This graph shows the extent of fluctuations for each summer month period (June-September) by charting the average lake level and maximum water level above and below the legal lake level during summer of each year. Summer month precipitation totals are also graphed to illustrate lake level fluctuation responses to precipitation in the recreational season. Water levels above the legal lake level represent periods with active outflows over the lake outlet spillway, while below that level no surficial outflows occur.

Linear trend lines were applied to two datasets in Figure 4 for consideration: summer month precipitation totals and the maximum water level below the spillway. The summer month precipitation trend line showed a slightly decreasing trend (less summer month rainfall) over the 16-year period. The trend line for maximum water level below the legal lake level showed an upward trend, suggesting that summer water level drops below the spillway have become less drastic over time; such reductions in fluctuations of lake levels are desirable.

The extent to which improved conditions resulting from Lake Board wetland enhancements in the Sherman Creek contributing area since 2017 continues to be monitored and analyzed. In 2018-2019, average summer month water levels were above the legal lake level and maximum water levels below the outlet were closer to the legal lake level compared to other years with similar near-average summer month rainfall. During the very-low rainfall summer period of 2020, lake levels averaged 0.33-ft below the spillway and dropped to a maximum of 1.24-ft below the legal lake level. While still a substantial drop, the 2020 average lake level and maximum lake level drop were less drastic than comparable low-rainfall years of 2004 and 2012.

The maximum water level above the legal lake level also shows an increased trend in the last decade. This could relate to repairs made to the outlet structure which prevented leakage beneath the spillway. Intermittent beaver activity has also caused substantial hydrological modifications and debris build-up at the outlet from 2016-2018 until there was consistent beaver management via trapping.

In previous years, the Cedar Lake Hydrology Report referenced the lake outflow structure at an elevation of 608.64 as previously surveyed. In August 2018, Spicer Group, Inc. resurveyed the "as constructed" outlet structure on behalf of Alcona and Iosco Counties, and reported the outlet structure elevation at 608.2. An October 2018 petition of the County Board of Supervisors for Alcona and Iosco Counties was therefore filed to correct the legal lake level to 608.2. As such, this 2020 Cedar Lake Hydrology Report references the legal lake limit at an elevation of 608.2, with outflows occurring above that elevation. The elevation of the "Lake Out" piezometer was adjusted accordingly and calibrated with manual measurements so that reported Cedar Lake surface water levels reflect these elevations updates. Notably, the historic outlet structures were replaced with a new structure in fall of 2020. The new outlet structure design is intended to prevent large fluctuations above the legal lake level; intensive monitoring is recommended to monitor how the new structure will impact lake levels going forward.

Groundwater Levels and Gradients

The 2020 groundwater elevation data from the groundwater monitoring Sites 1-12, "West Kings", and "LWSPC" are graphically illustrated along with Cedar Lake water levels in Figures 5-18, respectively. These data help to reveal the complexity and seasonality of shallow groundwater movement in critical areas of the Cedar Lake watershed, and were utilized as part of the groundwater modeling effort discussed in Attachment 1.

On the lake's east side, Sites 1, 4, and 5 (Figures 5, 6, and 7, respectively) are in locations where shallow groundwater is typically moving away from Cedar Lake, towards Lake Huron. This trend is reflected in the 2020 and historic groundwater piezometer water levels that were generally below the Cedar Lake surface water level. On the east-southeast side of Cedar Lake, Sites 8, 9, 10, and 11 (Figures 12, 13, 14, and 15, respectively) document conditions within a well-drained area of Lakewood Shores which similarly move groundwater away from Cedar Lake to the east-southeast. Water level data for these sites continue to confirm consistent shallow groundwater losses towards Lake Huron.

On the lake's southwest side, Site 3 (Figure 7) is also in an area where shallow groundwater is typically moving away from Cedar Lake, in this case towards Phelan Creek (Van Etten Lake watershed) to the southwest. Shallow groundwater gradients become less steep further north along the lake's southwest shore as seen at Site 6, about 1,100 ft south of King's Corner Road. Site 6 (Figure 10) experiences periods during each year when groundwater moves gently away from Cedar Lake and other periods when groundwater moves gently toward Cedar Lake. The Site 6 piezometers were moved 50 ft south of the original site in May 2019 to accommodate a landowner request. The 2020 data for Site 6 as shown in Figure 10, suggest that groundwater at this site on average tended to move towards Cedar Lake from May-August and away from Cedar Lake during September and October of 2020. Attachment 1 summarizes the modeling effort which utilized data from these stations to estimate impacts to groundwater gradients, storage, and contribution volumes resultant from the wetland enhancement implementations in the Sherman Creek area.

To further explore these assessments, K&A evaluated monthly average groundwater gradients for the 2016-20 monitoring seasons at Sites 3 and 6. Figure 20 plots the average 2020 monthly groundwater gradients for both sites against the 2020 Cedar Lake water level. Figures 20.1 and 20.2 illustrate this analysis at Sites 3 and 6 for each month monitored during 2020. In order to compare changes over time at each site, Figures 20.3 and 20.4 plot the monthly average groundwater gradients for each summer (Jun-Sep) 2016-2020 at Sites 3 and 6, respectively for comparison. These figures affirm that shallow groundwater typically moves away from Cedar Lake at Site 3 during the summer months (Figure 20.3). Data from Site 6, however, show a mixed trend with average summer month gradients tending slightly away from the lake in 2016 and 2018, but slightly toward the lake in 2017, 2019, and 2020 (Figure 20.4). It appears that regional mounding is occurring with hydrology improvements north of King's Corner pushing more groundwater to the lake from this area than in the past.

Site 12 (Figure 16), installed in 2019, is about 1,750 ft south of Sherman Creek and about 85 ft southeast from the intersection of W. Cedar Lake Road and King's Corner Road. Figure 16 shows that in 2020, shallow groundwater at PZ-12 follows similar patterns in response to rainfall but remained at a lower elevation throughout the monitoring period compared to nearby groundwater levels recorded at King's Corner culvert and Sherman Creek culvert. On the other hand, groundwater at PZ-12 remained above the Cedar Lake water level throughout 2020, suggesting that shallow groundwater is moving southeast toward Cedar Lake from the King's Corner area. These findings are corroborated by the modeling efforts included as Attachment 1.

Interestingly, shallow groundwater levels at PZ-12 fluctuate from above to below shallow groundwater levels at PZ-6s2 and PZ-6s, about 1,000 ft to the south, throughout the 2020 monitoring period, concurrent with observations from 2019. Shallow groundwater levels at PZ-12 were observed above those at PZ-6s2 (near the road) from April to early July when they were observed between the levels at PZ-6s2 and PZ-6s (near the lake). Groundwater levels at PZ-12 remained at or below those at PZ-6s during the month of August before rising again to levels near or above the two Site 6 piezometers during September through November.

Data collected in 2020 from piezometers West Kings and LWSPC (Figures 17 and 18, respectively), both also newly installed in spring 2019 and both in the area west of King's Corner culvert, provide additional insight into shallow groundwater movement in this area. The 2020 data for West Kings, 450 ft west of King's Corner culvert on the north side of King's Corner Road, showed shallow groundwater levels above those at the King's Corner culvert from May to early-July. From July to November, shallow groundwater observed at West Kings dipped below, but remained within less than 6 inches of that at King's Corner culvert, throughout the monitoring period. This condition is reflected in roadside ditch surface water flows observed on the north side of King's Corner Road contributing to the culvert outflows during spring months.

The 2020 data for LWSPC showed shallow groundwater on the east bank of Phelan Creek within the Lakewood Shores Golf Course to be well-below all other nearby stations in the King's Corner area. Relative to Site 3 (which is about 0.75 miles to the southeast), LWSPC groundwater elevations were below those observed at PZ-3s2 (near Teal St.), and those observed at PZ-3s (near Cedar Lake), throughout the monitoring period. LWSPC water levels were also below Cedar Lake water levels for the monitoring period duration. All of the King's Corner area groundwater elevations for 2020 are plotted together for comparison in Figure 19.

On the lake's west and northwest side, Sites 2 and 7 (Figures 6 and 11, respectively) are located in areas where shallow groundwater is consistently moving toward the lake, with groundwater levels typically near or above those measured in the lake. These represent critical groundwater recharge areas from the northwest cedar swamp which contribute to Cedar Lake. Figure 11, illustrating groundwater elevations at Site 7 about 410 ft north of Sherman Creek, shows how shallow groundwater in this area moves generally northeast toward Cedar Lake. Shallow groundwater levels at PZ-7s2 near the road, are observed consistently below those at Sherman Creek and well above the Cedar Lake water level. Shallow groundwater levels at PZ-7s along the lake shore east of PZ-7s2, are observed consistently below those at PZ-7s2 and very near to the Cedar Lake surface water level. Site 2, located nearest to the wetland complex northwest of the lake, signifies why this area is an important groundwater source to the lake. Site 2 data, illustrated in Figure 6, further emphasize the importance of wetland protection and enhancement in this critical watershed area.

K&A will utilize an expanded set of shallow groundwater data in 2021 which will include data collected from over-wintering loggers in winter of 2020 and 2021, to perform a deeper examination of groundwater movement and trends over time. These efforts will be compared to historic data sets and to the groundwater modeling results in order to estimate potential future dry and wet weather conditions. This expanded effort will be particularly important for assessing the effectiveness and potential benefits of WMP implementations such as the wetland berm and Sherman Creek instream grade structures and the need for additional future efforts.

2020 Estimated Surface Flows

Introduction

Water level loggers located at the Cedar Lake outflow area (north end), Sherman Creek, Jones Creek, and King's Corner culverts (west side of the lake) were used to monitor incoming and outgoing surface water flows. Both Jones Creek and Sherman Creek are important sources of incoming surface water flows into Cedar Lake from the wetland complex to the northwest. At the southern end of this wetland complex, the King's Corner road culvert has historically diverted water from the Cedar Lake immediately-contributing watershed, to the south toward Phelan Creek and Van Etten Lake. This diversion through the King's Corner culvert resulted in reduced water volumes reaching Cedar Lake from its natural watershed.

A major water retention effort to reduce water losses through the King's Corner culvert began in fall 2017 with the construction of a wetland enhancement berm on the newly acquired Lake Board property, parallel to King's Corner Road. The berm is designed to retain water in the cedar swamp which contributes inflows to Cedar Lake via Sherman Creek. Construction of the berm began in August and was completed by October 20, 2017. A groundwater monitoring station was installed at the upstream side of the berm spillway in April 2018 to measure the effectiveness of the berm at retaining water in the cedar swamp and decreasing water losses through King's Corner culvert. This site has been monitored for water levels year-round since November 2019 to provide an expanded set of groundwater data for the cedar swamp in 2020 (Figure 27).

Further improvements to water retention were undertaken in September 2019 with the implementation of Sherman Creek instream grade structures. Large stone instream grade structures were installed at approximately 50 ft, 100 ft, and 150 ft upstream of the Sherman Creek culvert. Following completion of these structures in late October 2019, K&A installed three instream stilling tubes to be utilized for additional monitoring of water levels upstream of each new grade structure. Two over-wintering loggers, installed in November 2019 at the Sherman Creek 1 station near the culvert and at the Sherman Creek 150-ft stilling tube, provided an expanded set of surface water data for Sherman Creek in 2020 (Figure 27).

The two Cedar Lake outflow structures at the north end of the lake discharge to Lake Huron once water levels exceed the legal lake level. Figures 21, 22, 23, and 24 illustrate calculated surface water inflows and outflows including estimated volumes associated with the entire 2020 monitoring season at the Jones Creek, Sherman Creek, Cedar Lake Out, and King's Corner stations, respectively. All flow monitoring data are derived from water level stage-discharge relationships specific to each location. Estimated flow data and volumes for the 2020 monitoring season from these critical locations were combined and plotted together in Figure 25.

Surface Water Inflows and Outflows

The following discussion of estimated surface water flows and volumes focuses on the late-spring to late-summer period of May 1 to September 30 to assess the impact of inflows and outflows on lake levels during the summer recreational months. Table 2 summarizes estimated inflow or outflow volumes for surface water stations from May-September 2014-2020 for comparison. During the 153-day period from May 1 to September 30, 2020, the Jones Creek and Sherman Creek monitoring data reveal inflows of 33.79 and 359.86 million gallons (Mgal), respectively into Cedar Lake.

The 2020 inflow volumes were lesser in both Sherman Creek and Jones Creek than in 2019 (due to substantially lower summer precipitation in 2020). The 2020 inflow volumes for Jones Creek were lower than 2019 and average compared to all other years 2014-2018. The 2020 inflow volumes were adjusted to account for major sedimentation which occurred at the upstream side of the Jones Creek culvert during summer of 2020, impacting a portion of the 2020 water level data; the source of the sedimentation is yet unknown and the culvert remained highly sedimented to the end of the monitoring period. Quite notably, the 2020 inflow volumes for Sherman Creek were also lower than 2020 but remain higher than all years prior to 2017 in spite of the very-low precipitation during the summer months (refer to Table 2). Figures 21 and 22 illustrate Jones Creek and Sherman Creek flows throughout the 2020 monitoring period.

Measured outflow volumes leaving Cedar Lake at the north outlet structures totaled 21.56 Mgal during the May 1 to September 30, 2019 assessment period. Discernable 2020 lake outflows occurred from spring into early-summer and no surface water outflows occurred for the rest of the monitoring period, as shown in Figure 23. The 2020 outflow volumes were the third lowest on record compared to outflow volumes from 2014-2019. Outflow volumes in 2016 and 2017 were affected by the presence of a beaver dam upstream of the outlet structures. Construction of the new Cedar Lake outlet structure was completed during the low lake level period in Autumn 2020 and will need to be more-closely monitored in the coming years.

Figure 24 summarizes observed flows associated with the King’s Corner culvert location for the entire 2020 monitoring season. The plotted flows from the 2020 monitoring period reflect a total discharge volume of 25.78 Mgal over the entire 234-day monitoring period. During the shorter May 1 to September 30, 2020 recreational season, an estimated 21.82 Mgal flowed out of the Cedar Lake watershed via the King’s Corner road culvert (refer to Table 2). Surface water outflows at King’s Corner during May-September 2020 measured approximately 16 Mgal less than in 2017 prior to construction of the wetland berm, but represents the highest-outflow year at King’s Corner since implementation of the berm in 2017. The maximum observed high water elevation at the King’s Corner culvert in 2020 was 611.22. Since 2008, this location has had an average high-water elevation of 610.82 and a maximum observed elevation of 612.84 (2011).

The lower than average high-water elevations in 2018 and 2019, despite generally average precipitation are attributable to the wetland berm as intended by design. Higher than average water elevations at King’s Corner in 2020 in spite of much lower-than average rainfall likely reflects additional water storage in the Sherman Creek area wetlands resultant from the in-creek grade structures; a higher water retention volume in the wetlands led to more water flowing across the wetland berm spillway and lost through King's Corner culvert than in 2018 and 2019 prior to implementation of the grade structures. These losses made up about 6% of the total inflow measured from Sherman Creek in 2020, compared to about 2% lost in 2018 and 2019, but still remain substantially lower than the approximately 24% lost in years prior to the wetland hydrology management implementations.

Surface Water Retention Design Implications

Comparing historic volume losses from the King's Corner culvert demonstrates how the wetland enhancement berm constructed on the Lake Board property is mitigating water losses from this historic diversion out of the basin. The wetland berm monitoring station installed in April 2018 provides important information regarding water retention improvements in the northwest cedar swamp. Water elevations and flows through the wetland enhancement berm on the Lake Board parcel should continue to be closely monitored to definitively demonstrate additional long-term improvements to water retention in the wetlands via reductions to water volume lost through King's Corner culvert. The over-wintering logger at this station is an important element in this regard.

The presence of the wetland berm should also continue to improve lake inflow volumes through Sherman Creek and increase localized groundwater contributions, further improved with the newly installed instream grade structures within Sherman Creek. The new Sherman Creek in-stream grade structures, installed in fall of 2019, are now being closely monitored with several in-creek stilling tube level loggers. These data for 2020 from the five stations within Sherman Creek to monitor surface/groundwater elevations are shown in Figure 26. Data from 2020 suggest that the structures have increased storage within the wetlands even during a year with less than average rainfall. These data also suggest that this increased storage may have increased the outflow through the berm spillway and contributed to slightly higher outflows through King's Corner culvert than in the two previous years (after berm implementation but prior to grade structure implementation). These conditions will continue to be closely monitored with a network of 7 data loggers in Sherman Creek and its contributing wetlands, including 3 year-round loggers (Wetland Berm, Sherman Creek culvert, and Sherman 150' just upstream of the 150' grade structure). Figure 27 shows a full year of data from November 2019 to November 2020 at these three year-round logger stations.

Figure 28 illustrates the 2020 water elevations at the wetland berm monitoring station positioned at the upstream side of the berm spillway compared to lake levels. Figure 29 compares water elevations at the wetland berm spillway, King's Corner culvert, and "Sherman 2" located in the cedar swamp upstream of the Sherman Creek culvert monitoring stations. Figure 30 compares surface water flows and volumes for the 2019 monitoring season at the wetland berm spillway to outflows at King's Corner Culvert and inflows to Cedar Lake via Sherman Creek.

From May 1 through the end of September, 2020, roughly 57.6 Mgal of surface water flowed through the wetland berm spillway, while only 21.8 Mgal was lost via King's Corner culvert, as graphically depicted in Figure 30, largely in the early-spring under high groundwater conditions. Approximately 38% of the water leaving the wetland berm left through the culvert; for the remainder, it is assumed this water infiltrated to shallow groundwater.

Notably, the 2011 Cedar Lake Augmentation Feasibility Study suggested that the volume required to offset a 1-month lake level drop of 3-inches in Cedar Lake equates to approximately 91 Mgal per month (of inflow and direct rainfall), totaling 364 Mgal over the four-month summer season. Figure 4 showed the maximum lake level fluctuations during each recreational season 2004-2020. The study assessed potential water control implementation options and their feasibility related to multiple indicators including cost, total available volume, and other constraints.

The 2020 level logger data, consistent with 2018 and 2019 data, suggest that in the spring-summer months of May-September since 2014, volumes contributed to Cedar Lake via Sherman Creek have increased dramatically (refer to Figure 31). Sherman Creek inflow volumes during these months from 2014-2017 averaged 243.6 Mgal, while inflow volumes in 2020, a relatively low rainfall year, were estimated at 359.8 Mgal, an increase of more than 100 Mgal. Following the two Sherman Creek area wetland retention implementation projects, inflow volumes have averaged 378.2 Mgal, a comparative average increase of 134.6 Mgal into Cedar Lake. Meanwhile, surface water volume losses through King's Corner culvert have significantly lessened, from an average May to September loss of 33.5 Mgal from 2014-2017 to an estimated average of 12.1 Mgal for 2018-2020.

Comparing these findings to the aforementioned 364 Mgal 4-month season total calculated in 2011 to offset lake level drops in dry years shows that the improvements to wetland connectivity and water retention is buffering the need for potentially costlier management options such as augmentation wells as a foregone next step. Figure 31 illustrates this analysis by comparing 2014-2020 May 1 to September 30 monthly rainfall totals with monthly total volumes contributed to Cedar Lake via Sherman Creek and volumes lost from the Cedar Lake watershed via King's Corner culvert.

Notably, however, the majority of inflows in 2020 occurred in May, prior to the June-September recreational period during which the region experienced well-below average rainfall amounts. Combined Sherman and Jones Creek surface water inflows from June-September only amounted to an estimated 93.2 Mgal, well below the 364 Mgal summer month threshold for avoiding a 1-ft drop in lake level. Figure 4 showed that the lake level dropped to a maximum of 1.24-ft below the legal lake level in 2020. While this is still a dramatic drop in lake level, it is more than half a foot less of a drop than experienced in comparable rainfall years (2004, 2007, and 2012) which averaged a maximum lake level drop of 1.86-ft. This suggests that wetland retention efforts will have a positive impact on reducing lake level fluctuations even during dry years but may not prevent a substantial lake level drop during the driest recreational summer month periods. These findings and their implications for lake level augmentation management strategies will continue to be refined with data from future years of monitoring and additional assessments for Jones Creek hydraulic retention as well as possible improvements to the Sherman Creek projects.

Conclusions and Recommendations

Data from the 2020 lake level monitoring season continue to demonstrate how Cedar Lake first and foremost responds quite directly to prevailing summer month rainfall amounts. Lake levels for 2020 appeared to fall below the WMP desired levels during late-summer due to rainfall occurring well-below the observed historic average for June through September. This drop was less dramatic than in previous low-rainfall summers as a function of water flow and retention improvements in the northwest cedar swamp. Lake outflow data and lake levels suggest that 2020 lake levels were adequate for most of the targeted summer conditions (June-August) but dipped below the 1.0-ft lake level drop goal during and after the month of September 2020.

While the 2018 and 2019 data demonstrated substantial reductions in the volume of water lost through the King's Corner culvert compared to previous years, the 2020 data demonstrated a slight increase in outflows compared to the previous two years. The wetland berm was and likely accounts for the decreased losses from King's Corner in 2018 and 2019. Comparisons of 2017 to 2018 and 2019 precipitation and outflow losses demonstrate these improvements in wetland water retention as a result of the berm. Additional wetland storage and retention improvements were noted in the Sherman Creek wetlands in 2020 as a result of the completion of the instream grade structures in 2019. This increased storage capacity may have also slightly increased water losses through King's Corner culvert compared to the previous two years, but out-of-watershed losses remain very low compared to years prior to 2017. While this increase is relatively very small compared to the increased storage capacity in the Sherman Creek wetlands, this trend will be closely examined in 2021 in order to assess the feasibility of minor adjustments to the berm spillway which could prevent additional undesired water losses through King's Corner.

Figure 31 demonstrates the overall increase in surface water volume entering Cedar Lake through Sherman Creek during summer months since 2014. These watershed improvements may prove to mitigate any immediate need to pursue deep groundwater withdrawal augmentation wells as outlined in the WMP and feasibility study. The completed instream grade structures at Sherman Creek appear to be providing the naturalized solution to mitigate currently observed drier season concerns in 2020. This improvement will also benefit the ecology of the lake by protecting important springtime fish-spawning habitat.

As discussed in Attachment 1, however, if exceptionally low rainfall conditions persist, the additional groundwater storage capacity alone will not be enough to maintain desired Cedar Lake water levels absent surface water flows. While the increase in surface flows from the engineering modifications may be enough to maintain a desirable lake level during a moderately dry to average precipitation year, the extra groundwater flow introduced by the engineering modifications is not sufficient on its own to maintain a desirable lake level. This finding suggests that the feasibility of alternative WMP augmentation strategies will still need to be investigated and if possible pursued.

Based on 2020 observations and the noted importance of scientifically valid water level data for making informed watershed management decisions, K&A recommends the Cedar Lake monitoring program be continued during the 2021 calendar year. Additional statistical analyses using the year-round data sets and comparisons to groundwater modeling outputs will continue in 2021 to further understand long-term trends and relationships.

Future data will be used to further evaluate:

1) Effectiveness of the completed Sherman Creek instream grade control structure improvements;

2) Quantified improvements on wetland water level retention resulting from the newly constructed wetland berm and instream grade structures, including identifying future maintenance needs for both project sites;

3) Ongoing improvements and future maintenance needs associated with the 2014 culvert flow repair efforts conducted by the railroad in the northwest cedar swamp area;

4) Efficacy of the new outlet structure and comparisons of surface water loss to comparable rainfall years across the old outlet structure;

5) Extent of groundwater losses potentially occurring through the northeast Timberlakes development stormwater drainage system (following the installation of recommended new piezometers in that area);

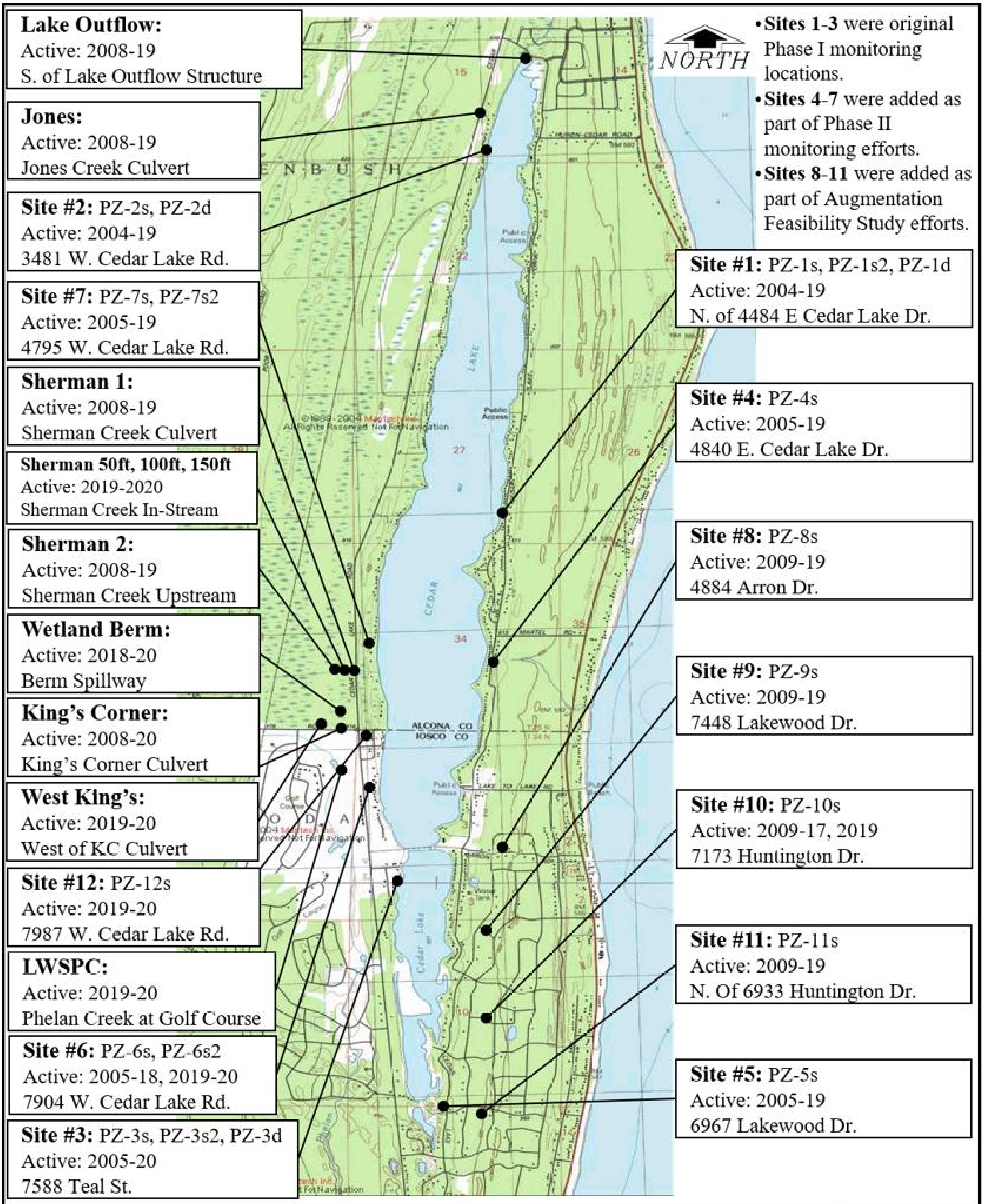
6) Flow reduction options through the Sherman Creek wetland berm;

7) Additional hydraulic improvements for both Sherman Creek and Jones Creek areas;

8) Deep groundwater PFAS concerns with the existing augmentation well; and,

9) Other prevailing watershed issues related to the movement of shallow groundwater in the Cedar Lake watershed that may be encountered.

2020 Cedar Lake Hydrology Report: List of Tables and Figures



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Map of 2020 groundwater and surface water elevation monitoring sites with piezometers & level loggers, located around the perimeter of Cedar Lake.

Figure 1

Table 1. Cedar Lake Heron DipperLog Level Loggers' (LL) Status, November 2020

Piezometer ID #	LL Manufactured Year	LL Age (yrs)	Predicted LL Lifespan (yrs)	Predicted Year of LL "Age-Out"	Status
Wetland Berm	2017	3	10	2027	*New (Added site in 2017)*
PZ-02s	2017	3	10	2027	*New, replaced "Aged-Out" Logger in 2017*
Sherman 1 (Culvert)	2018	2	10	2028	*New, replaced "Aged-Out" logger in 2019*
Sherman 2 (Wetland)	2018	2	10	2028	*New, replaced "Aged-Out" logger in 2019*
Kings Corner	2018	2	10	2028	*New, replaced "Aged-Out" logger in 2019*
Kings Corner Barlog	2018	2	10	2028	*New, replaced "Aged-Out" logger in 2019*
Lake Out	2018	2	10	2028	*New, replaced "Aged-Out" logger in 2019*
PZ-12s	2018	2	10	2028	*New (Added site in 2019)*
WEST Kings	2018	2	10	2028	*New (Added site in 2019)*
LWSPC	2018	2	10	2028	*New (Added site in 2019)*
PZ-06s	2018	2	10	2028	*New (Moved site in 2019)*
PZ-06s2	2018	2	10	2028	*New (Moved site in 2019)*
Sherman 50'	2019	1	10	2029	*New (Added site in 2019)*
Sherman 100'	2019	1	10	2029	*New (Added site in 2019)*
Sherman 150'	2019	1	10	2029	*New (Added site in 2019)*
PZ-01s	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-01s2	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-01d	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-02d	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-03s	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-03s2	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-03d	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-04s	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-04s Barlog (backup)	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-07s	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-07s2	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-10s	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
Jones Creek	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-05s	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-08s	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-09s	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-11s	2019	1	10	2029	*New, replaced "Aged-Out" logger in 2020*

Figure 2. Historic Summer (Jun - Sep) Precipitation Totals for Cedar Lake
(*Precipitation Sources:* Cedar Lake Rain Gauge, Alcona County, MI,
Harrisville 2 NNE (USC00203628), Alcona County, MI
Oscoda Wurtsmith Airport (Station #14808), Iosco County, MI

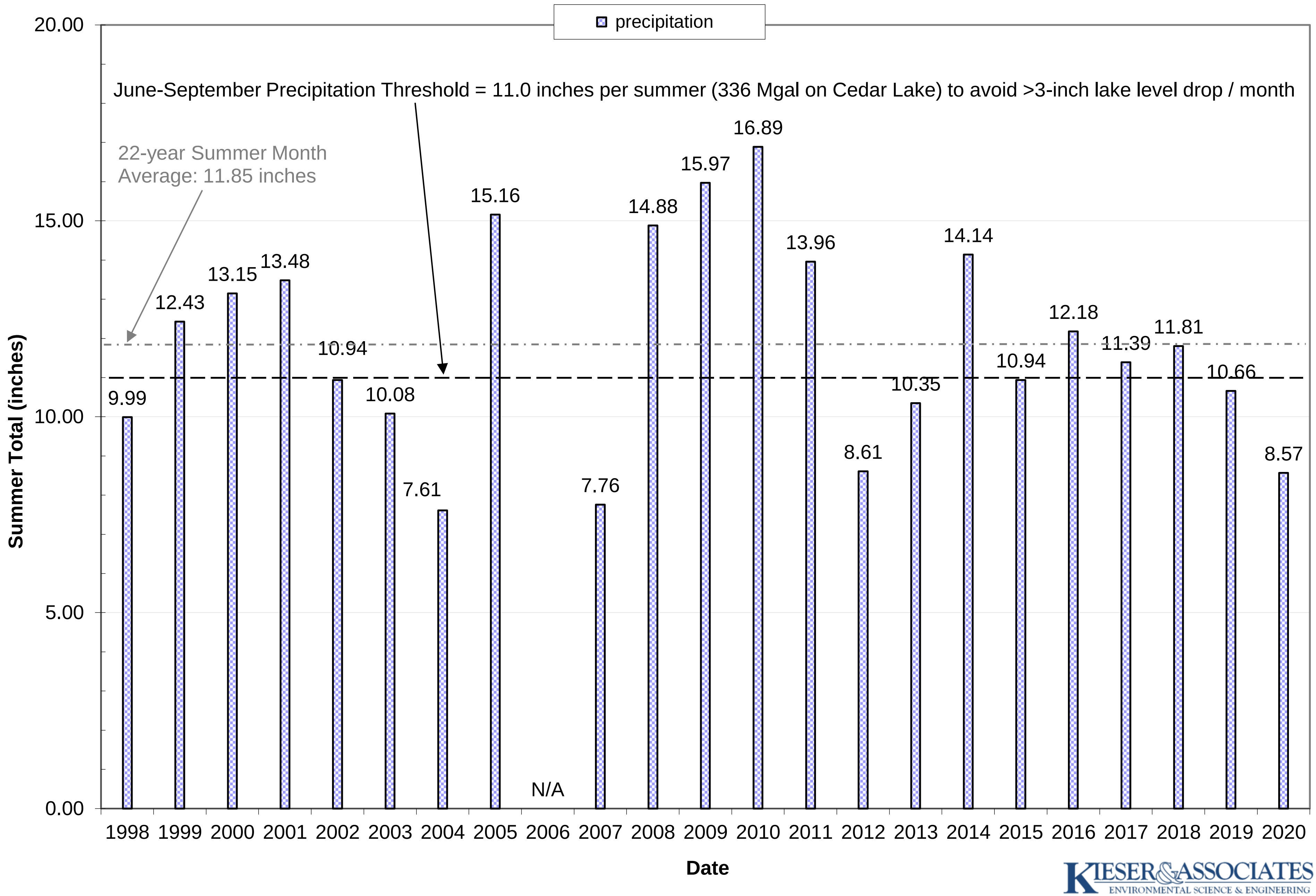


Table 2. Comparison of Surface Water Volumes from May 1 to Sep 30, 2014 to 2020.

Site	Surface Water Volume (Mgal)						
	2014	2015	2016	2017	2018	2019	2020
Sherman Creek (inflow to CL)	136.040	190.929	198.126	449.441*[3]	328.134	446.753	359.857
Jones Creek (inflow to CL)	64.817	21.587	17.964	59.784**	10.121	87.514	33.790
Cedar Lake Outlet (outflow from CL)	13.003	109.500	0.162*[1]	26.123	51.975	143.156	21.560
Kings Corner (outflow away from CL)	32.208	46.862	17.049*[2]	38.053	4.384	10.161	21.819

*Updates to previous volume calculations for May 1 to September 30:

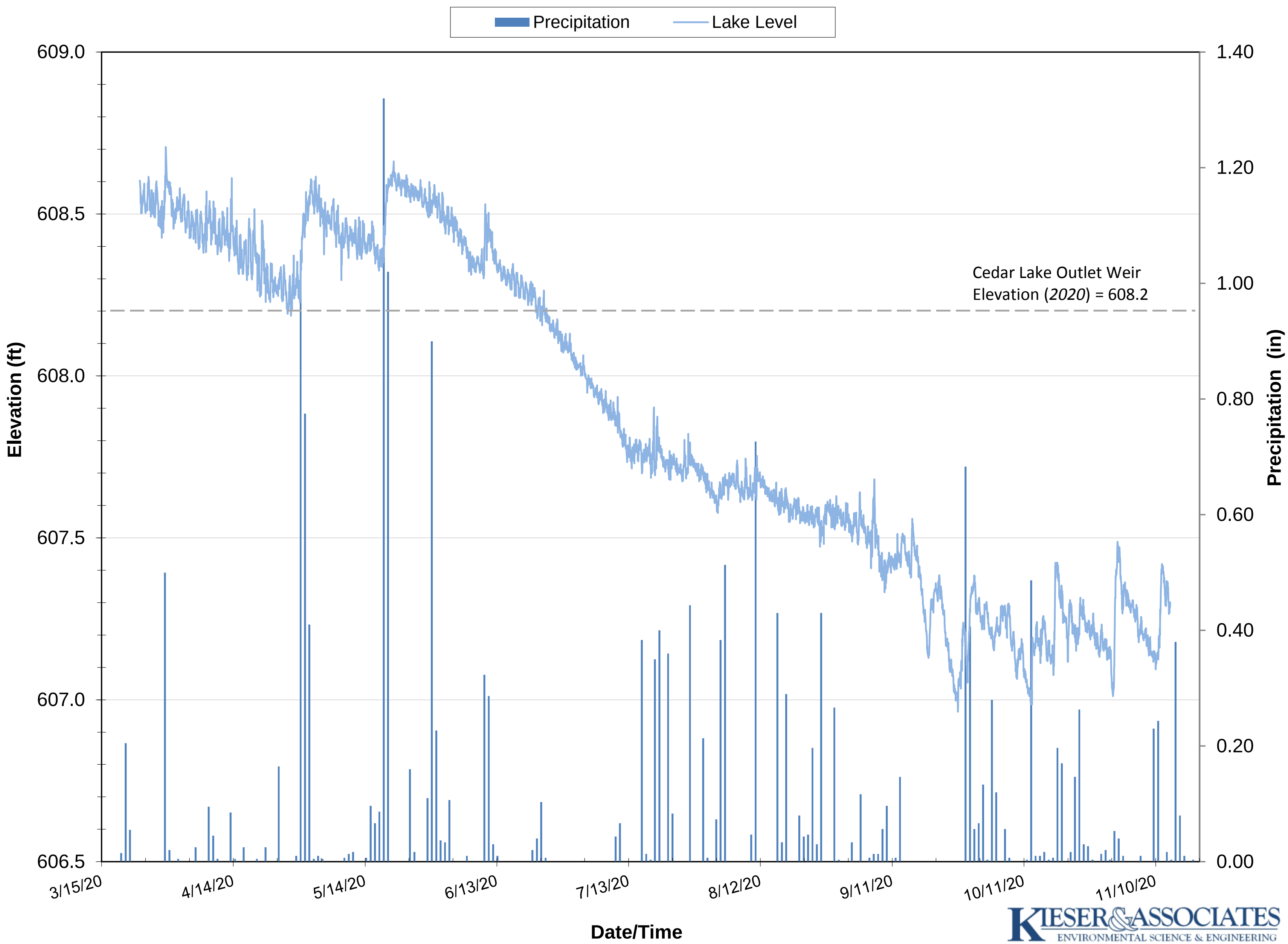
[1]Lake Outlet 2016 volume previously calculated at 1,049 Mgal updated to reflect the affect of a beaver dam, mechanically removed in fall 2017.

[2]Kings Corner 2016 volumes previously calculated at 8.2 Mgal.

[3]Sherman Creek 2017 volumes previously calculated at 747.514 Mgal.

**Jones Creek 2017 volumes available from 5/1/17 to 9/1/17 only.

Figure 3. 2020 Cedar Lake Water Elevation and Measured Rainfall



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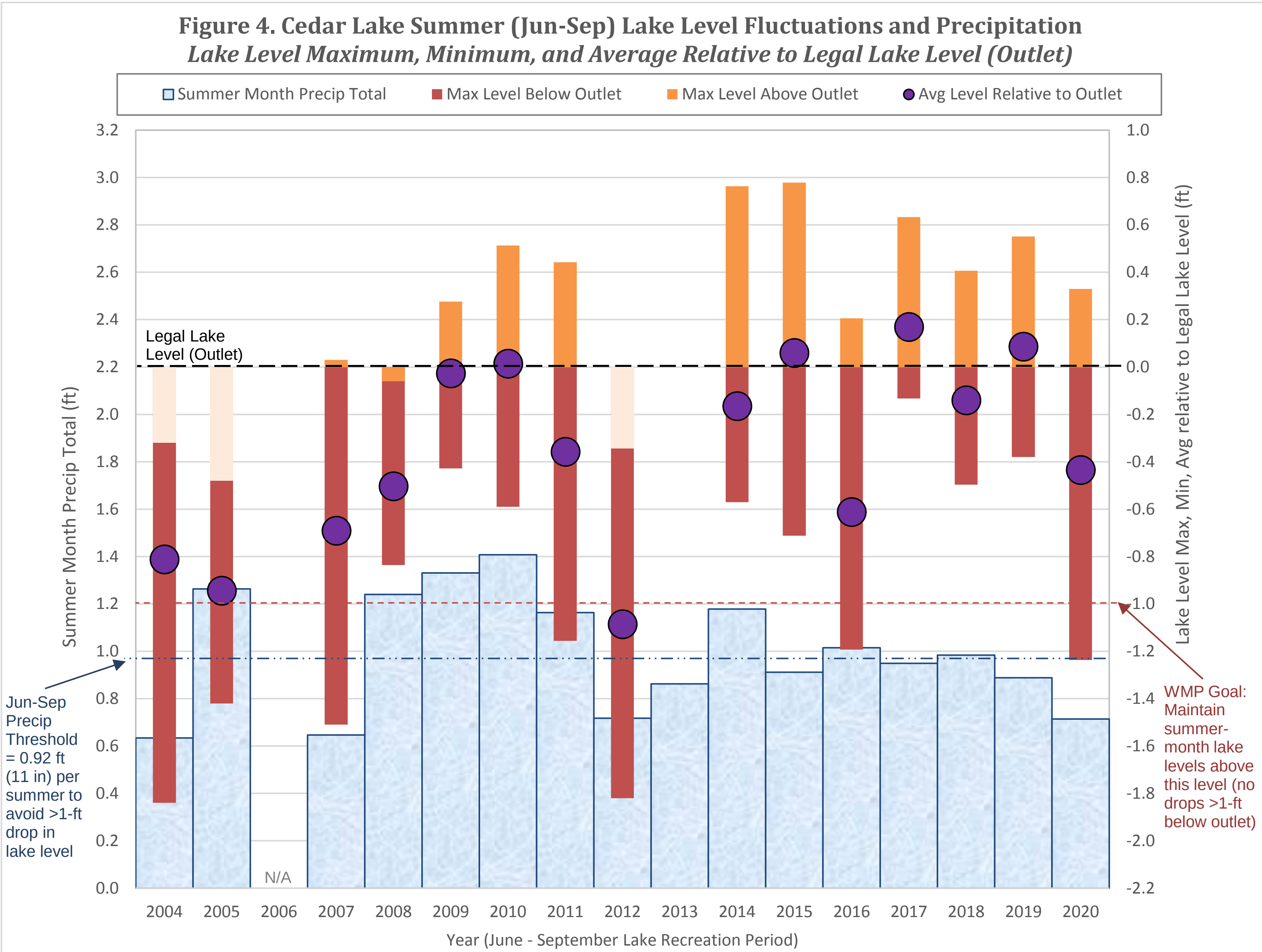

Figure 4. Cedar Lake Summer (Jun-Sep) Lake Level Fluctuations and Precipitation
Lake Level Maximum, Minimum, and Average Relative to Legal Lake Level (Outlet)
Summer Month Precip Total
Max Level Below Outlet
Max Level Above Outlet
Avg Level Relative to Outlet
Legal Lake Level (Outlet)
Summer Month Precip Total (ft)
Lake Level Max, Min, Avg relative to Legal Lake Level (ft)
Jun-Sep Precip Threshold = 0.92 ft (11 in) per summer to avoid >1-ft drop in lake level
WMP Goal: Maintain summer-month lake levels above this level (no drops >1-ft below outlet)
N/A
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Year (June - September Lake Recreation Period)

Figure 5. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 1)

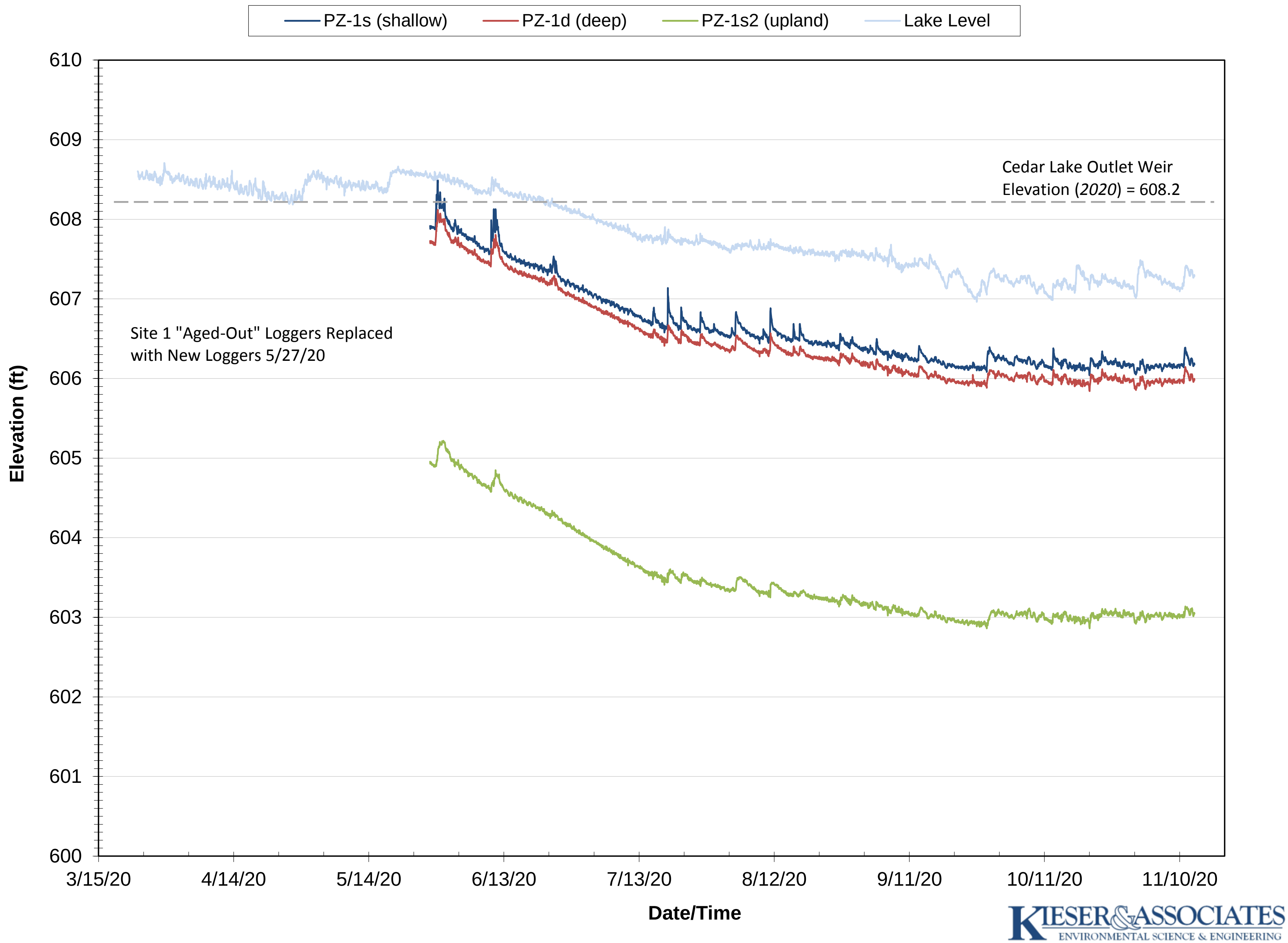

Figure 6. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 2)

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Figure 7. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 3)

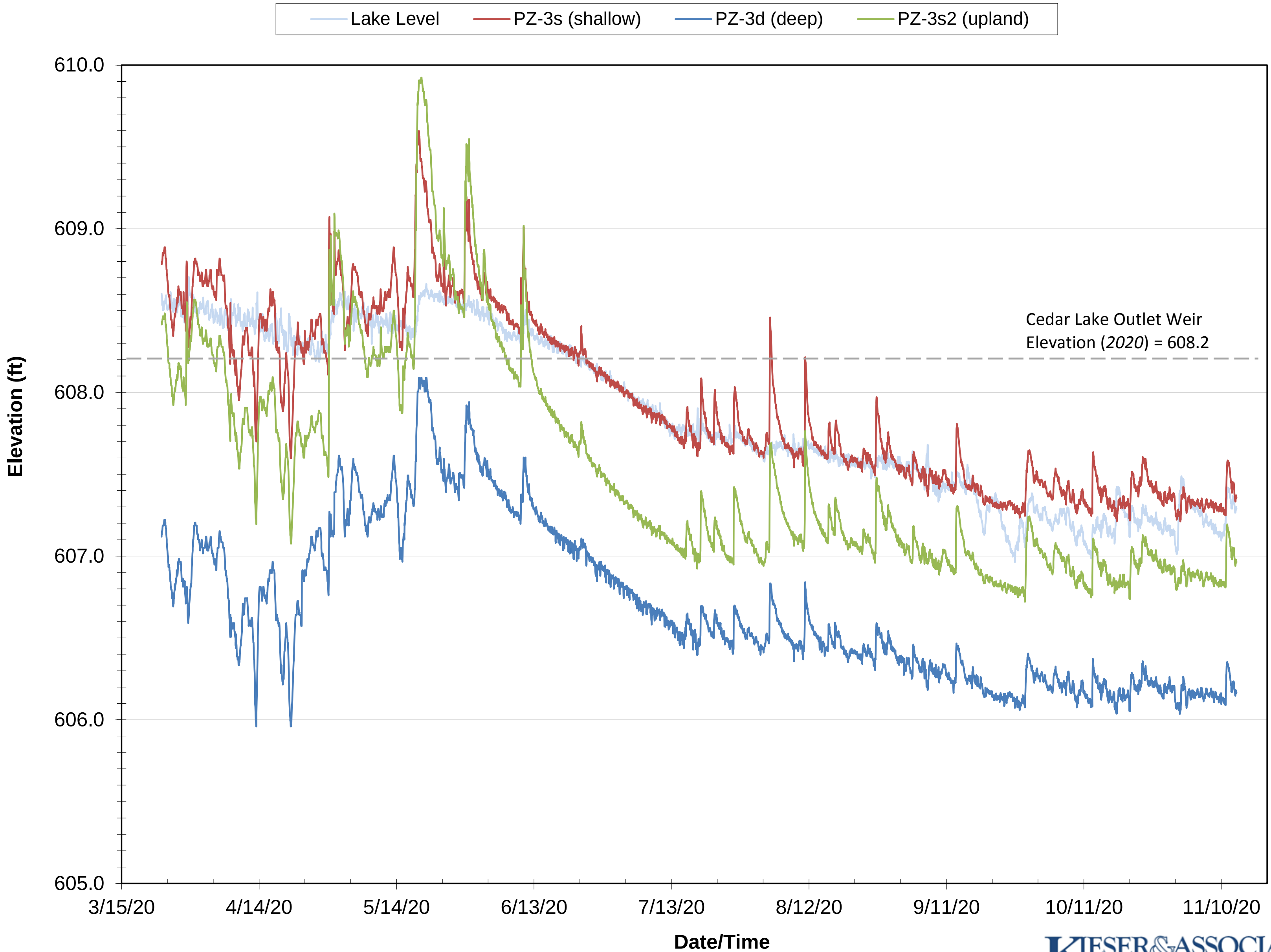

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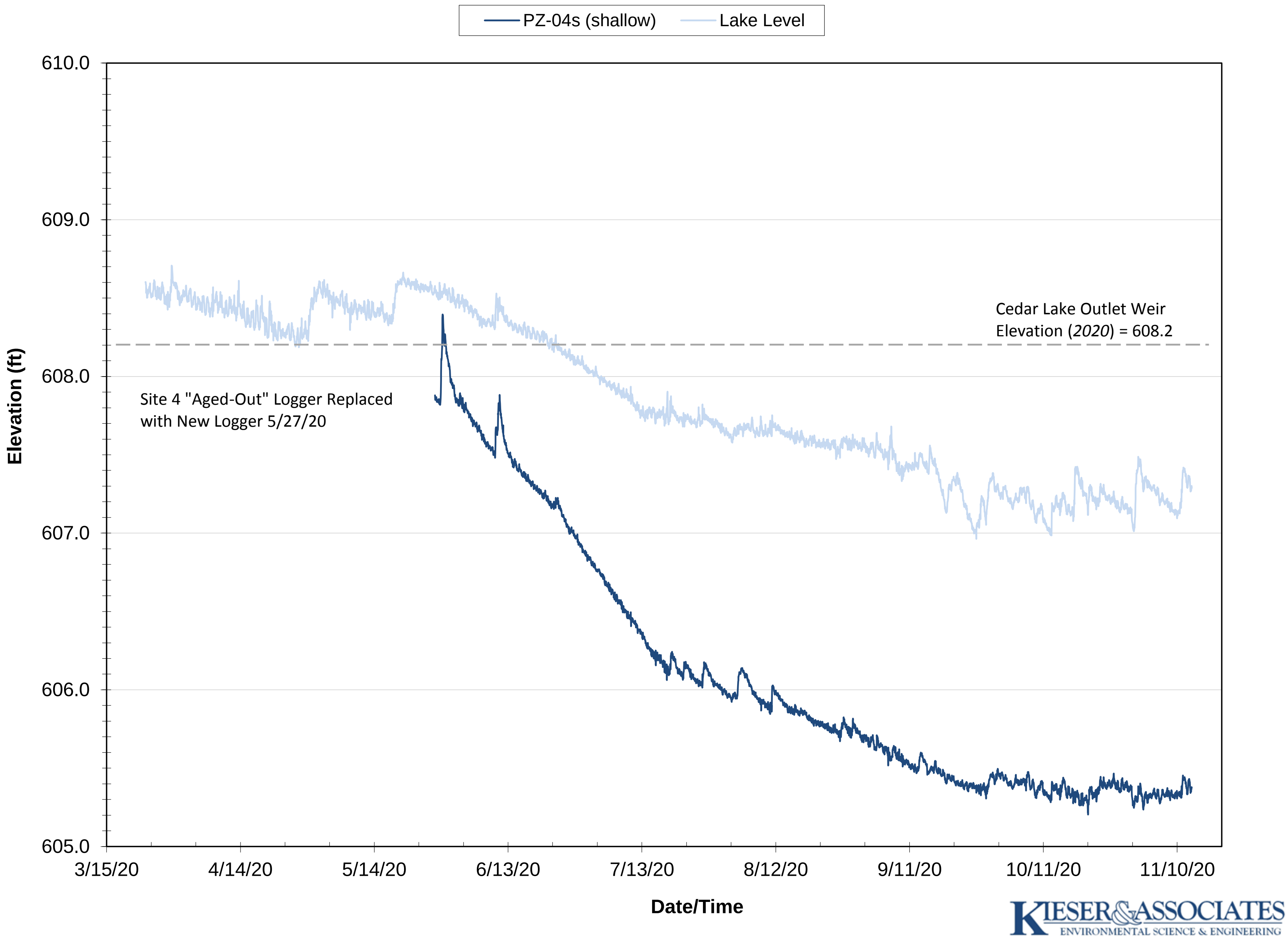
Figure 8. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 4)



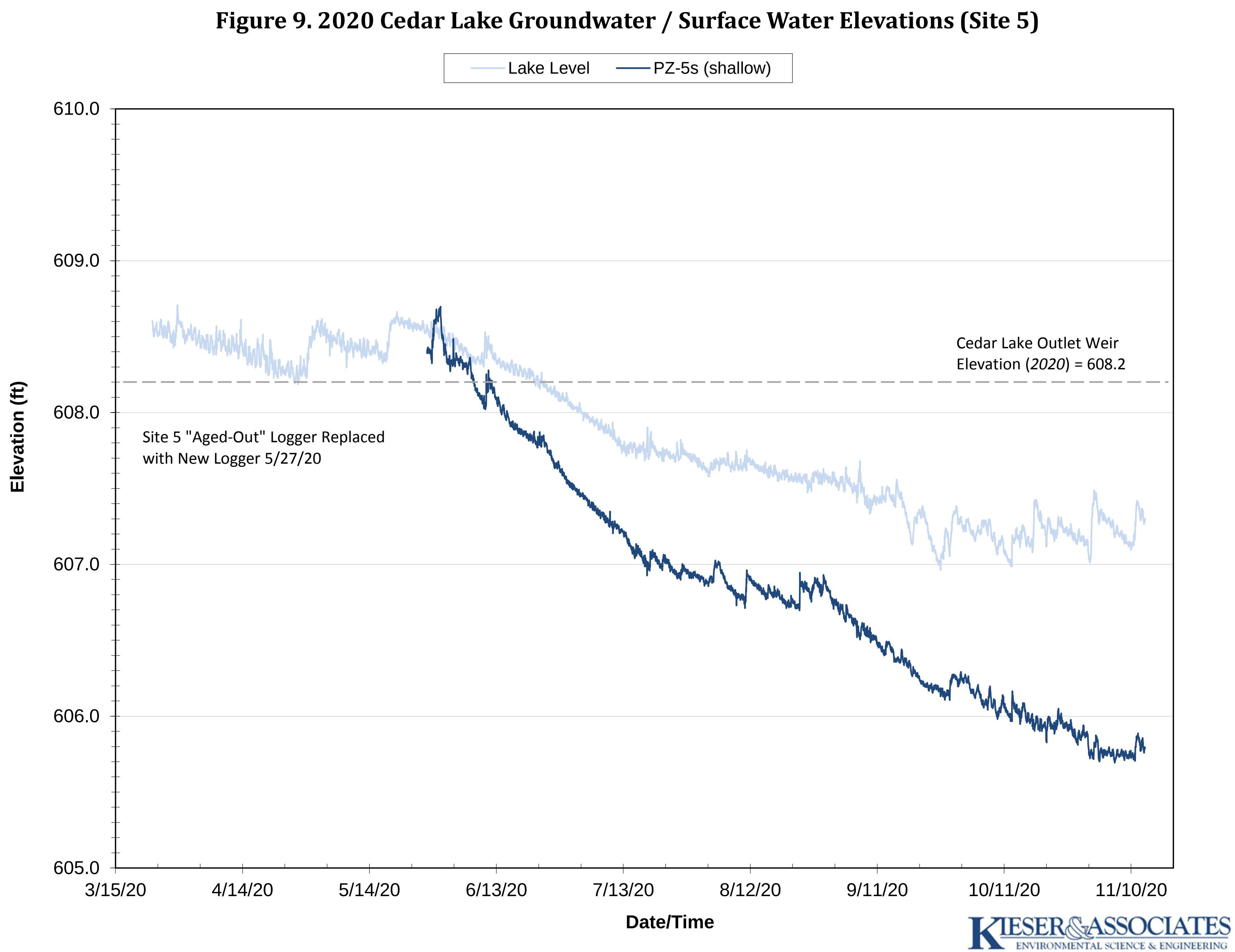


Figure 9. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 5)
Lake Level
PZ-5s (shallow)
Elevation (ft)
610.0
609.0
608.0
607.0
606.0
605.0
Cedar Lake Outlet Weir Elevation (2020) = 608.2
Site 5 "Aged-Out" Logger Replaced with New Logger 5/27/20
3/15/20
4/14/20
5/14/20
6/13/20
7/13/20
8/12/20
9/11/20
10/11/20
11/10/20
Date/Time
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Figure 10. 2020 Cedar Lake Groundwater / Surface Water Elevations
(Site 6 - *New Location, 2019*)

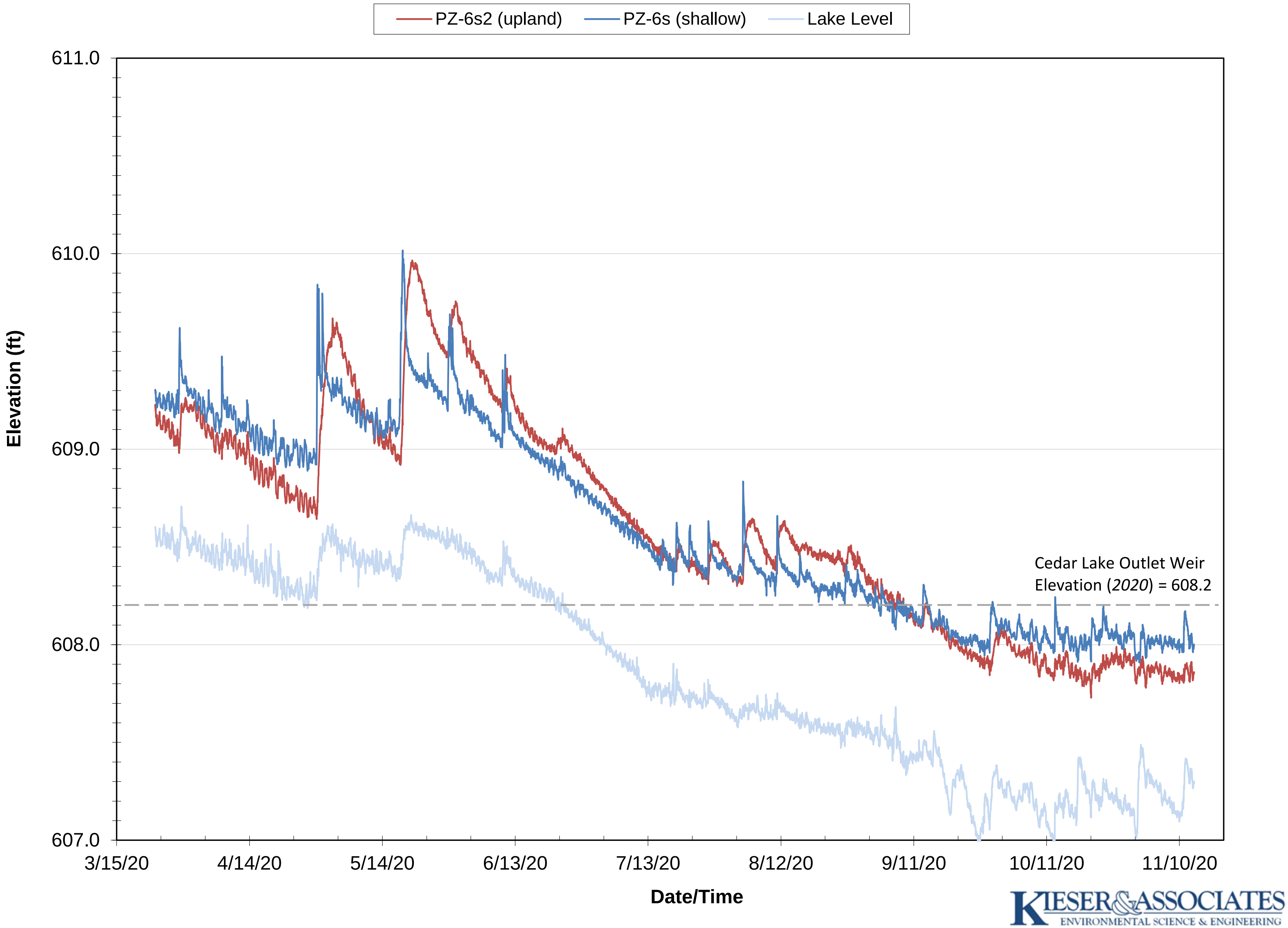

Figure 11. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 7)

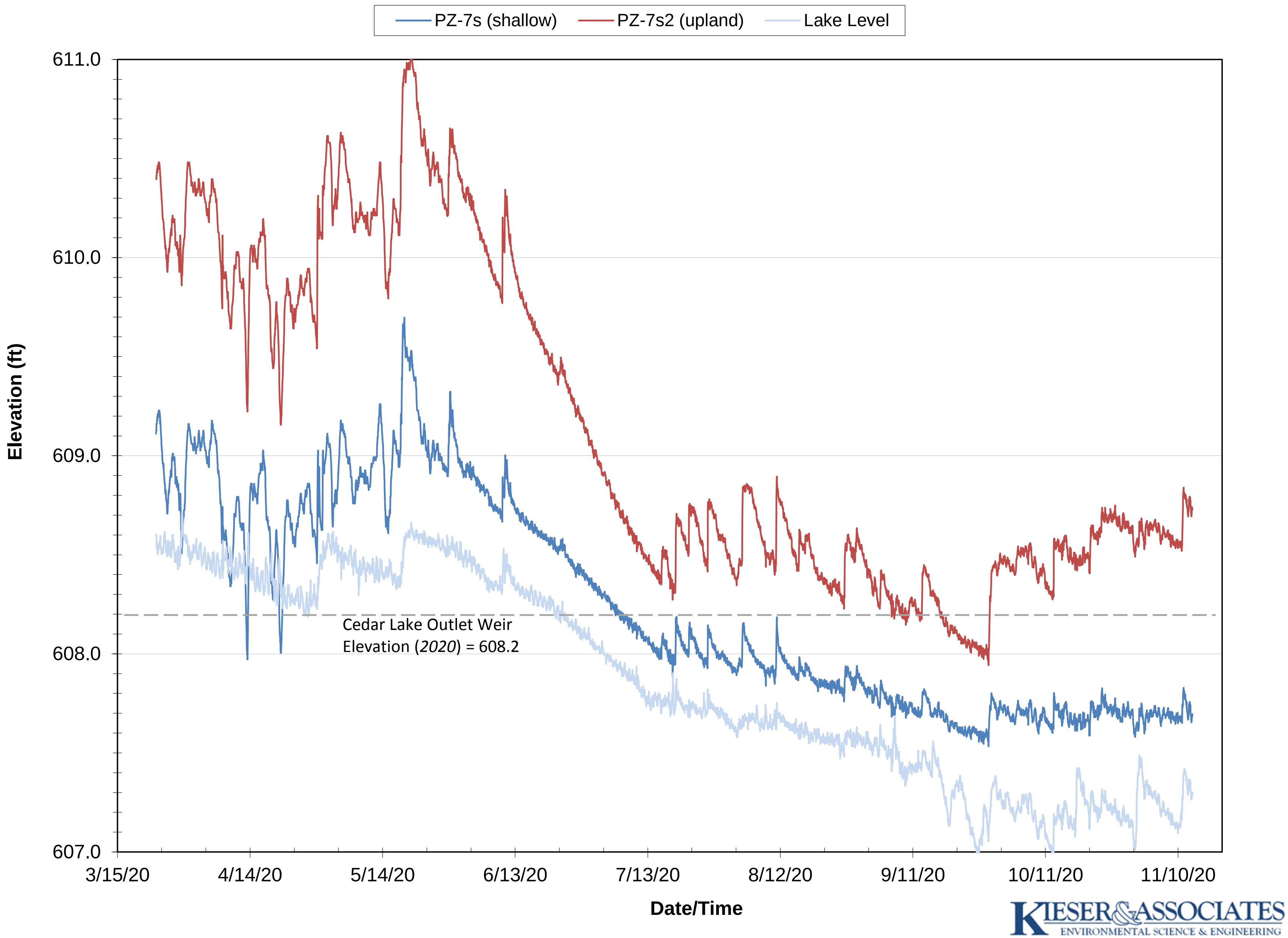

Figure 12. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 8)

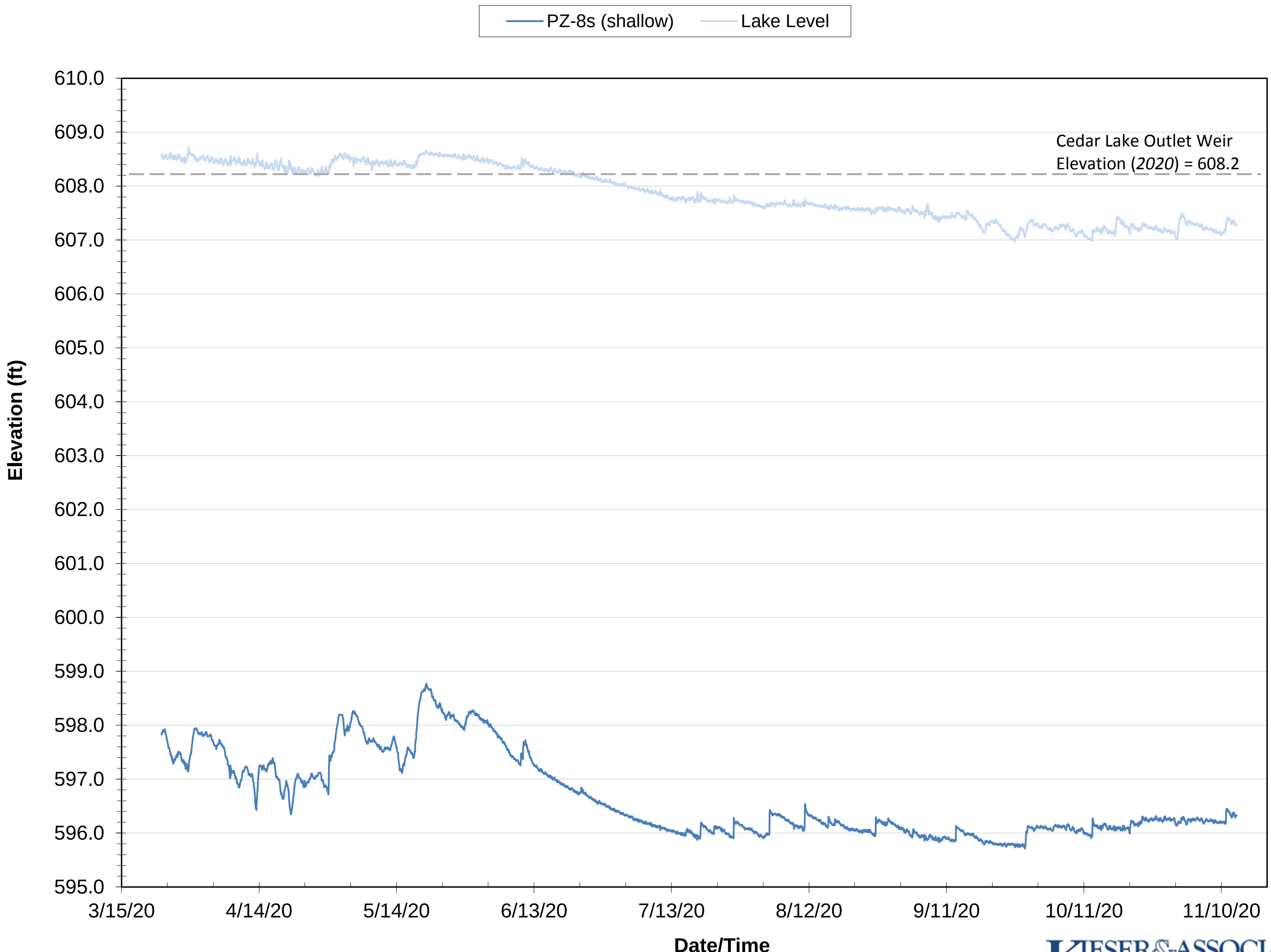

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Figure 13. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 9)

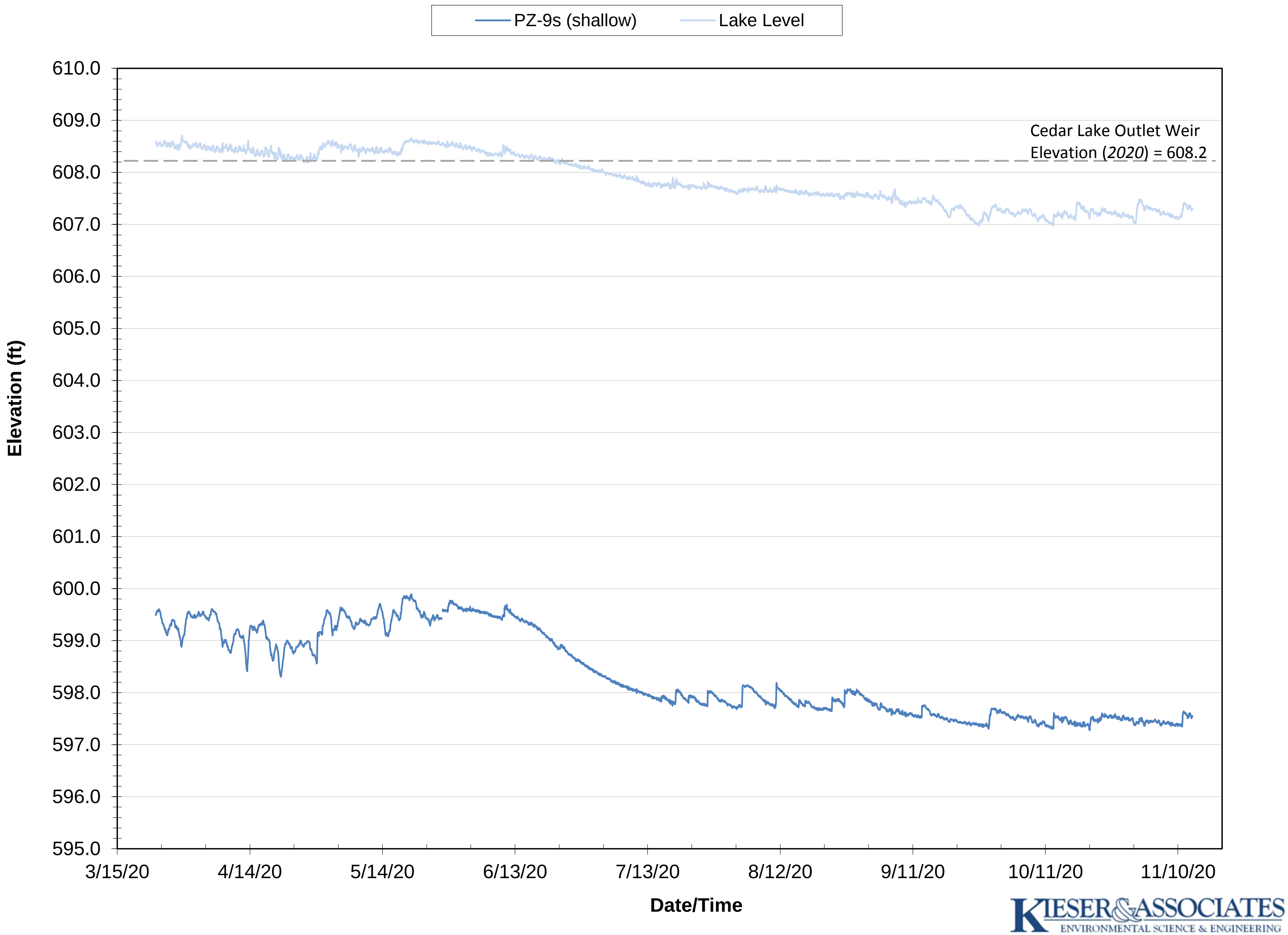
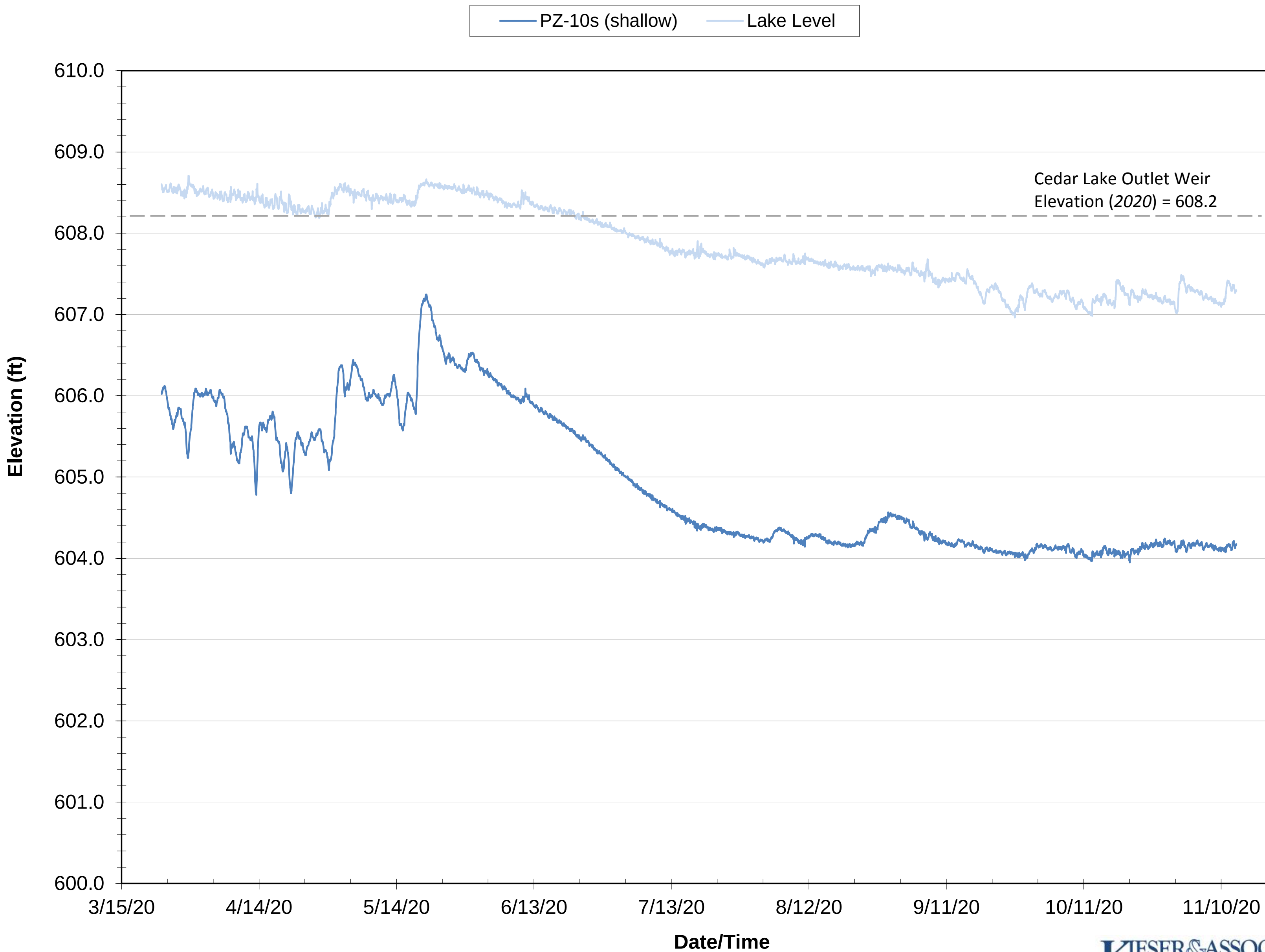


Figure 14. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 10)



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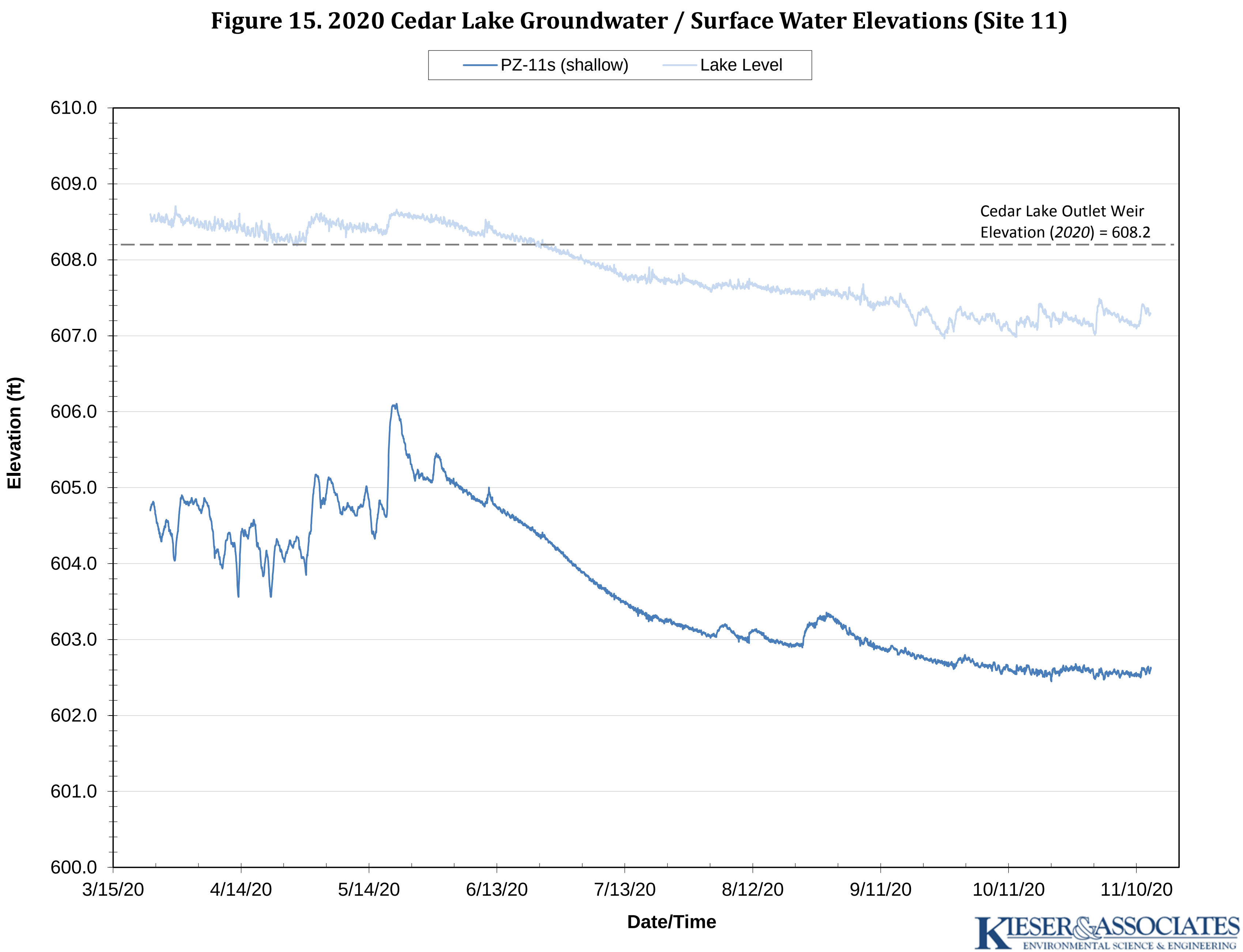

Figure 15. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 11)
PZ-11s (shallow)
Lake Level
Cedar Lake Outlet Weir Elevation (2020) = 608.2
Elevation (ft)
610.0
609.0
608.0
607.0
606.0
605.0
604.0
603.0
602.0
601.0
600.0
3/15/20
4/14/20
5/14/20
6/13/20
7/13/20
8/12/20
9/11/20
10/11/20
11/10/20
Date/Time
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Figure 16. 2020 Cedar Lake Groundwater / Surface Water Elevations (Site 12)

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Figure 17. 2020 Cedar Lake Groundwater / Surface Water Elevations (West Kings)

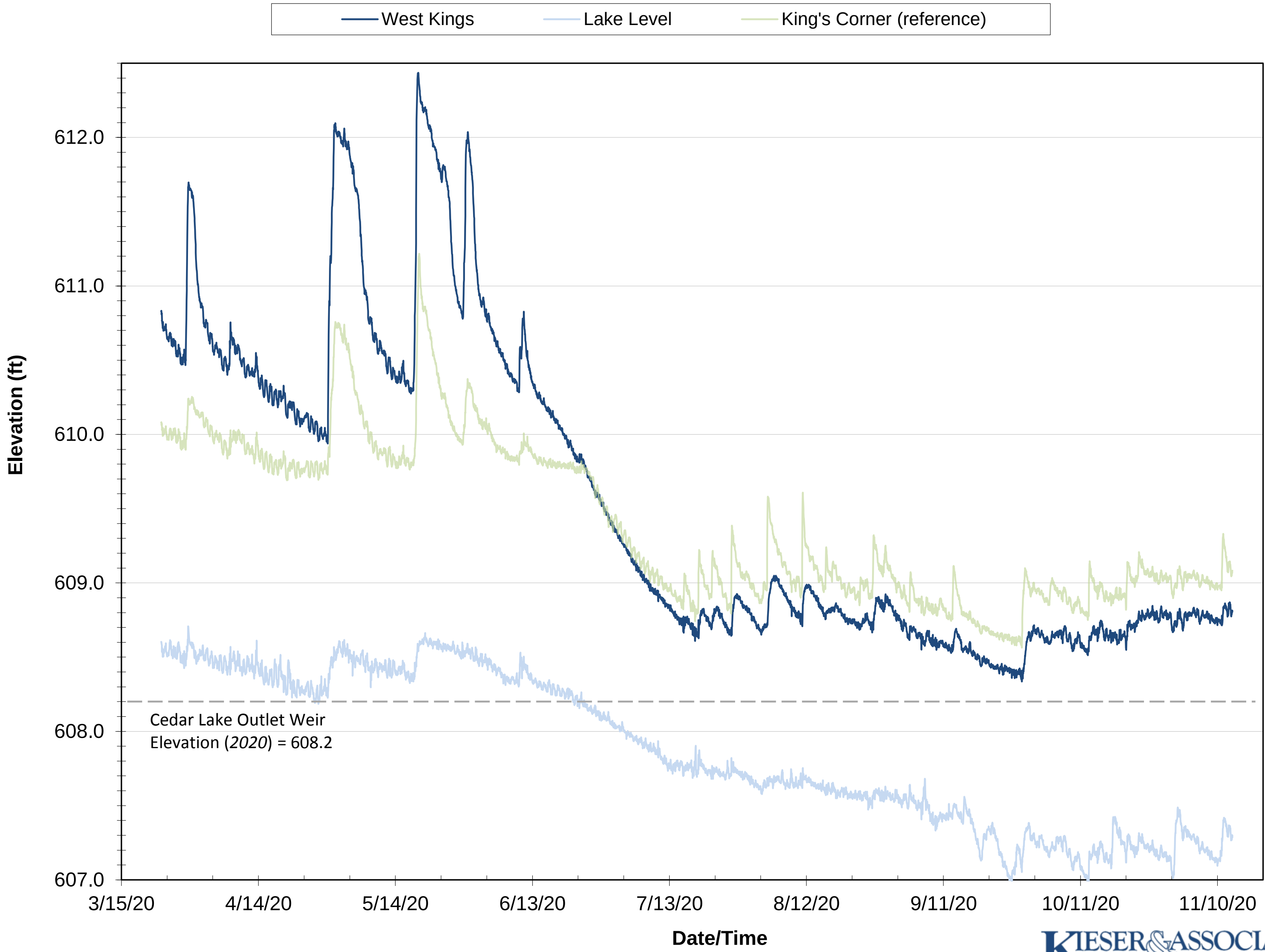

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Figure 18. 2020 Cedar Lake Groundwater / Surface Water Elevations (Lakewood Shores Phelan Creek: LWSPC)

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Figure 19. Cedar Lake Groundwater / Surface Water Elevations (King's Corner Area Loggers)

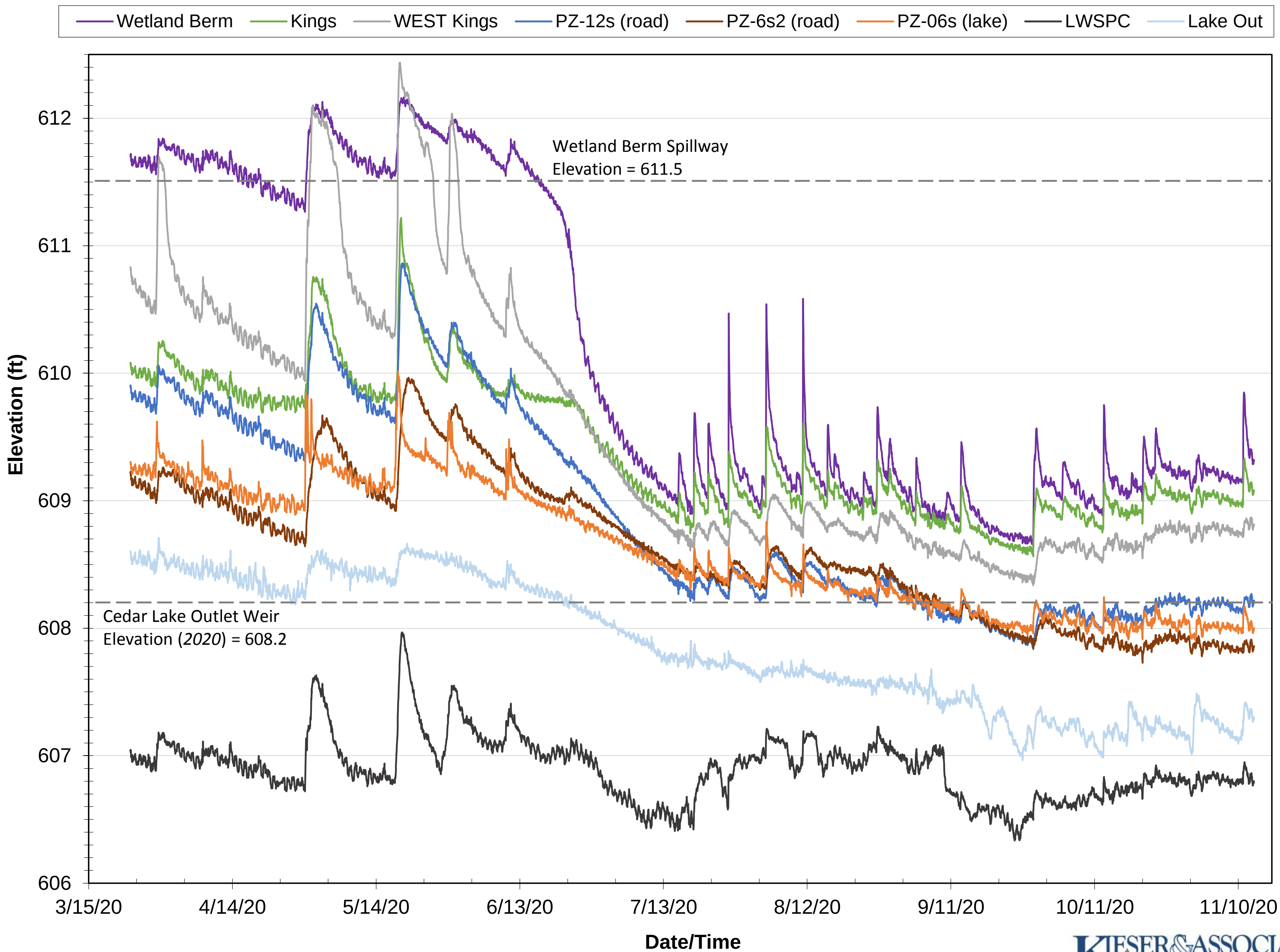

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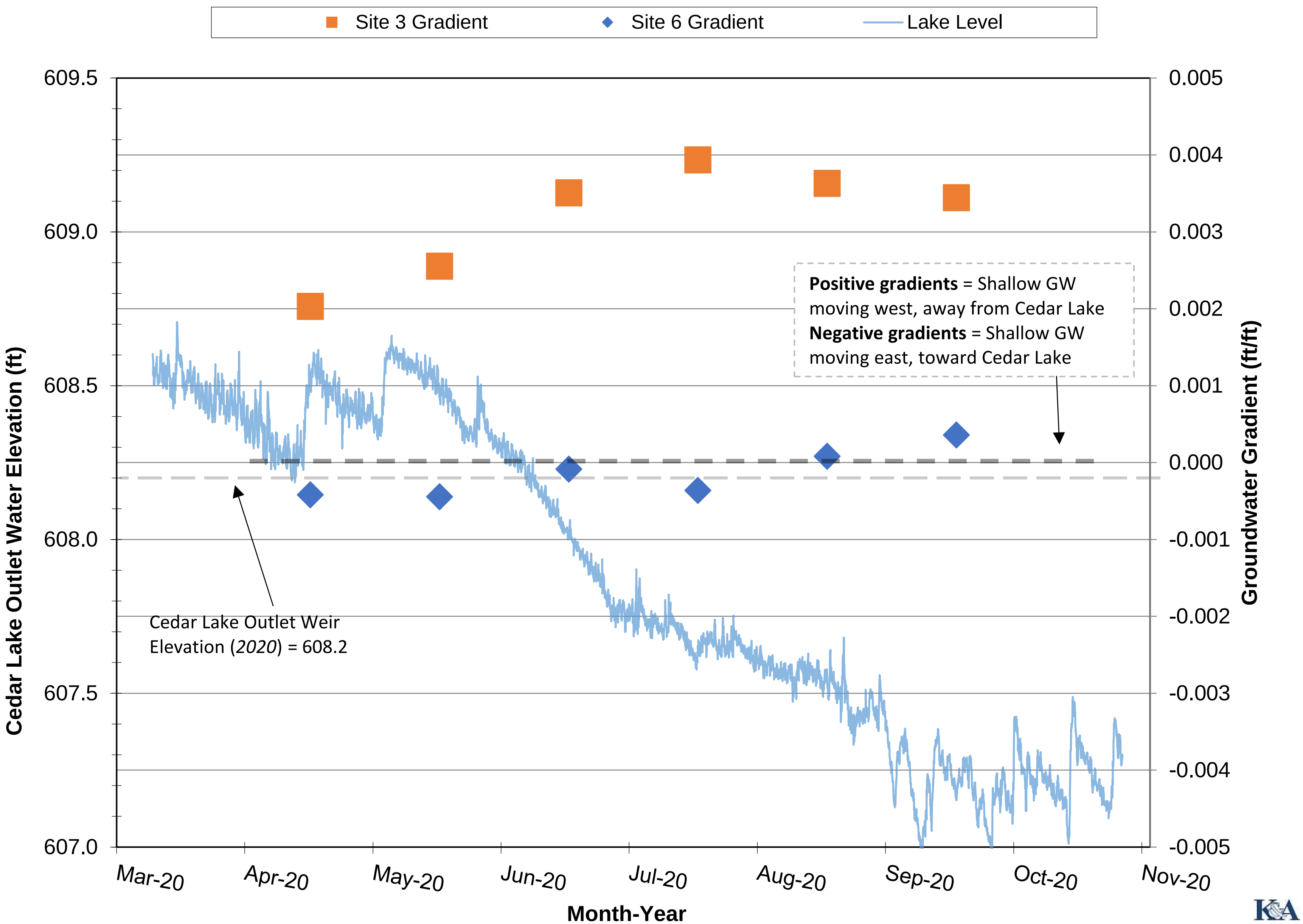
Figure 20. 2020 Monthly Avg. Groundwater Gradients, Site 3 and Site 6



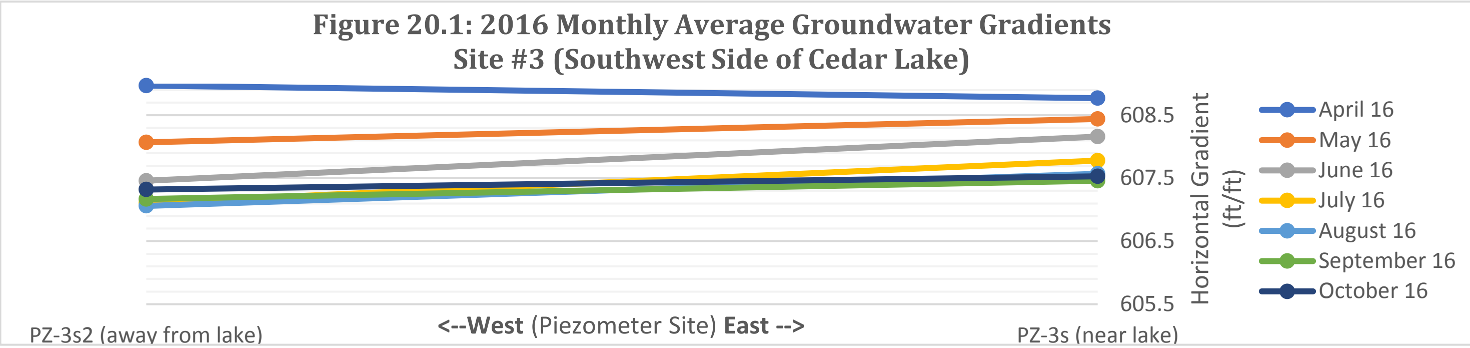


Figure 20.1: 2016 Monthly Average Groundwater Gradients
Site #3 (Southwest Side of Cedar Lake)
608.5
607.5
606.5
605.5
Horizontal Gradient (ft/ft)
April 16
May 16
June 16
July 16
August 16
September 16
October 16
PZ-3s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-3s (near lake)

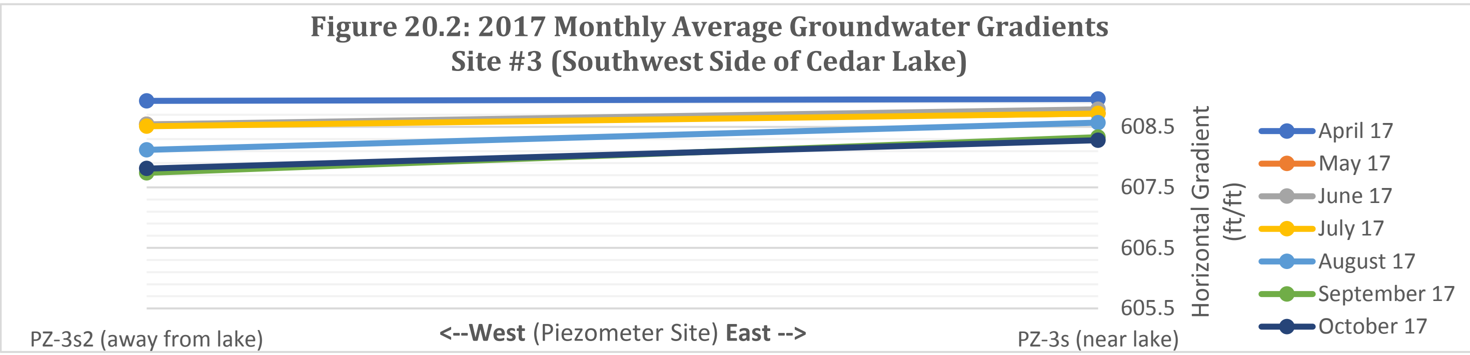


Figure 20.2: 2017 Monthly Average Groundwater Gradients
Site #3 (Southwest Side of Cedar Lake)
608.5
607.5
606.5
605.5
Horizontal Gradient (ft/ft)
April 17
May 17
June 17
July 17
August 17
September 17
October 17
PZ-3s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-3s (near lake)

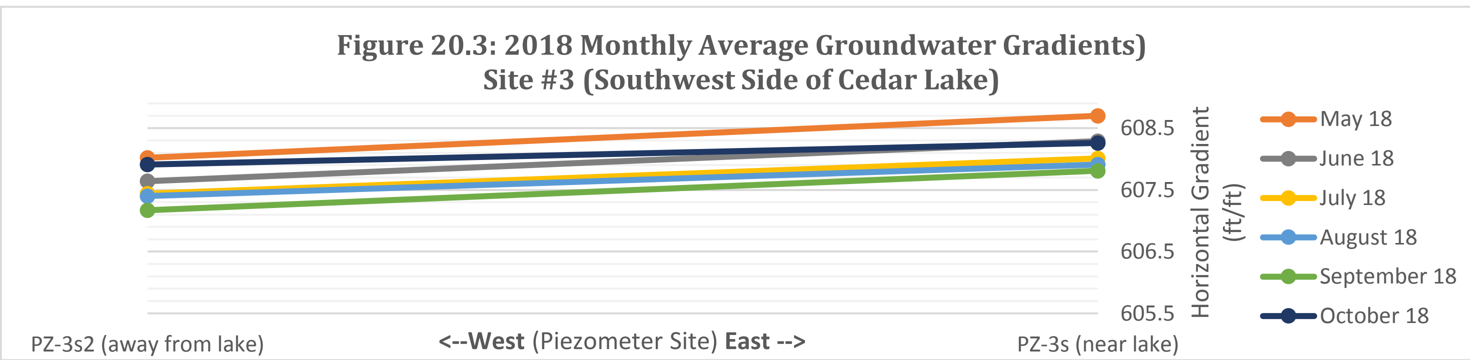


Figure 20.3: 2018 Monthly Average Groundwater Gradients)
Site #3 (Southwest Side of Cedar Lake)
608.5
607.5
606.5
605.5
Horizontal Gradient (ft/ft)
May 18
June 18
July 18
August 18
September 18
October 18
PZ-3s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-3s (near lake)

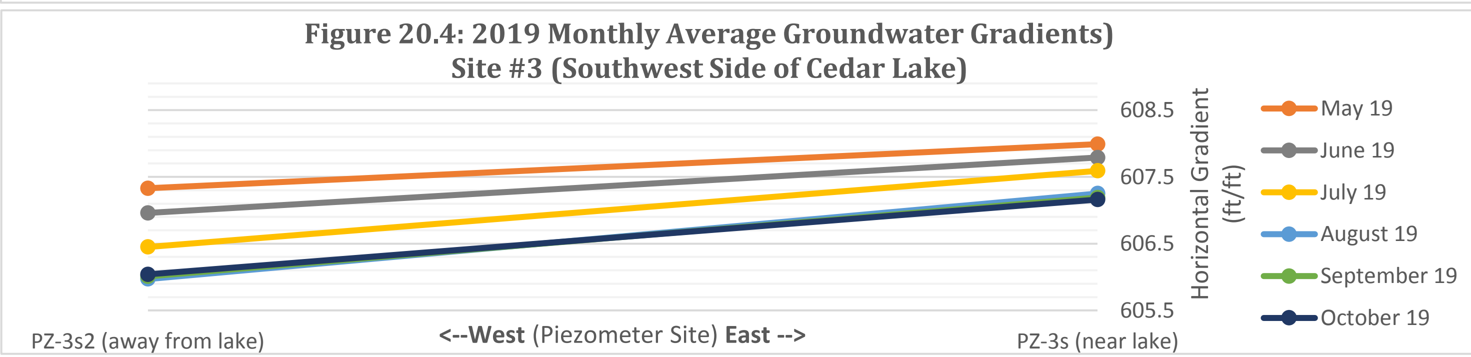


Figure 20.4: 2019 Monthly Average Groundwater Gradients)
Site #3 (Southwest Side of Cedar Lake)
608.5
607.5
606.5
605.5
Horizontal Gradient (ft/ft)
May 19
June 19
July 19
August 19
September 19
October 19
PZ-3s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-3s (near lake)

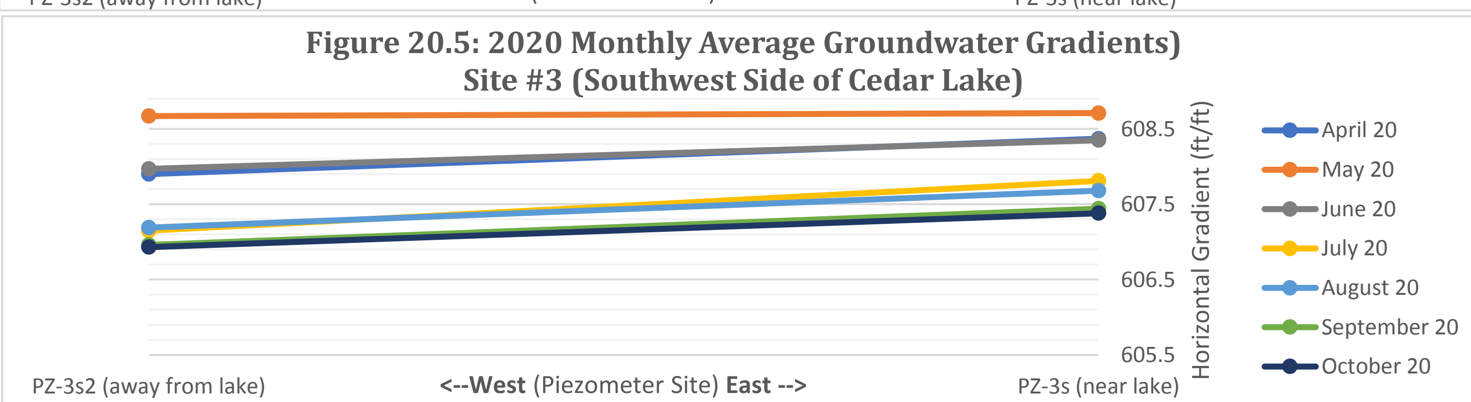


Figure 20.5: 2020 Monthly Average Groundwater Gradients)
Site #3 (Southwest Side of Cedar Lake)
608.5
607.5
606.5
605.5
Horizontal Gradient (ft/ft)
April 20
May 20
June 20
July 20
August 20
September 20
October 20
PZ-3s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-3s (near lake)

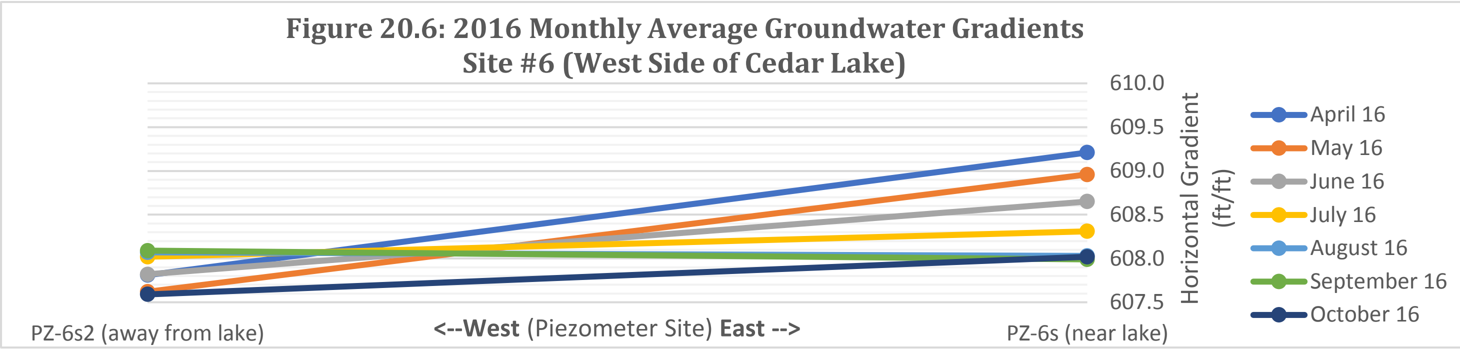


Figure 20.6: 2016 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
610.0
609.5
609.0
608.5
608.0
607.5
Horizontal Gradient (ft/ft)
April 16
May 16
June 16
July 16
August 16
September 16
October 16
PZ-6s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-6s (near lake)

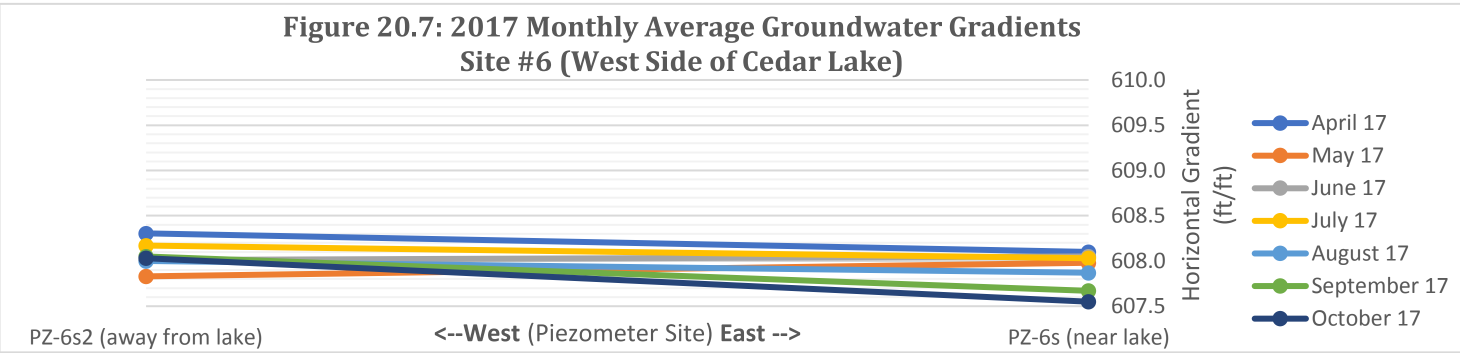


Figure 20.7: 2017 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
610.0
609.5
609.0
608.5
608.0
607.5
Horizontal Gradient (ft/ft)
April 17
May 17
June 17
July 17
August 17
September 17
October 17
PZ-6s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-6s (near lake)

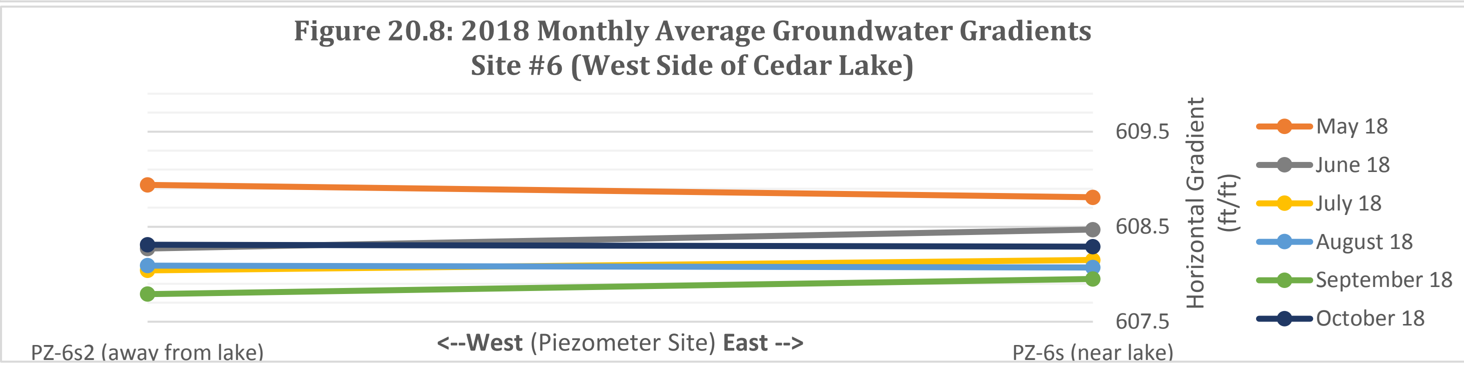


Figure 20.8: 2018 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
609.5
608.5
607.5
Horizontal Gradient (ft/ft)
May 18
June 18
July 18
August 18
September 18
October 18
PZ-6s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-6s (near lake)

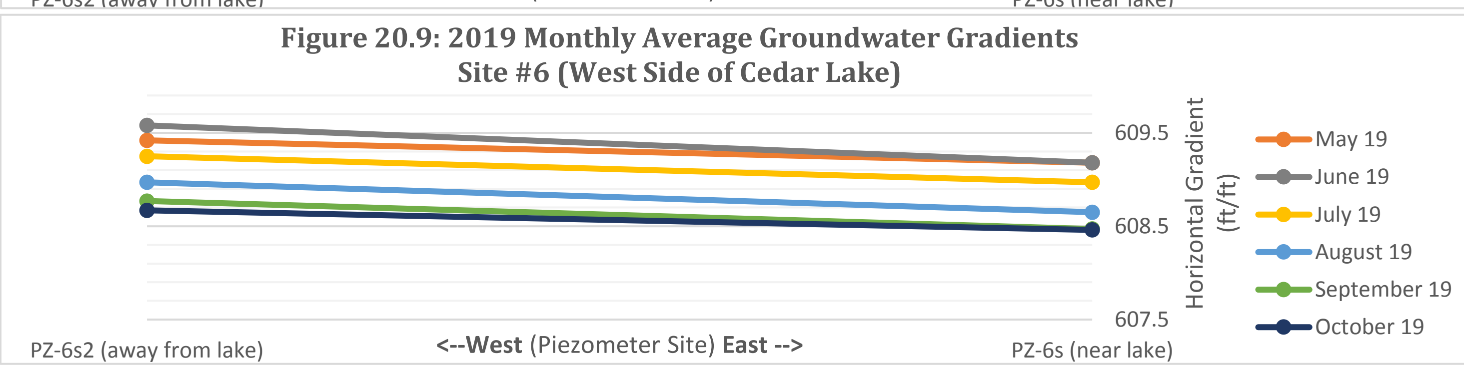


Figure 20.9: 2019 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
609.5
608.5
607.5
Horizontal Gradient (ft/ft)
May 19
June 19
July 19
August 19
September 19
October 19
PZ-6s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-6s (near lake)

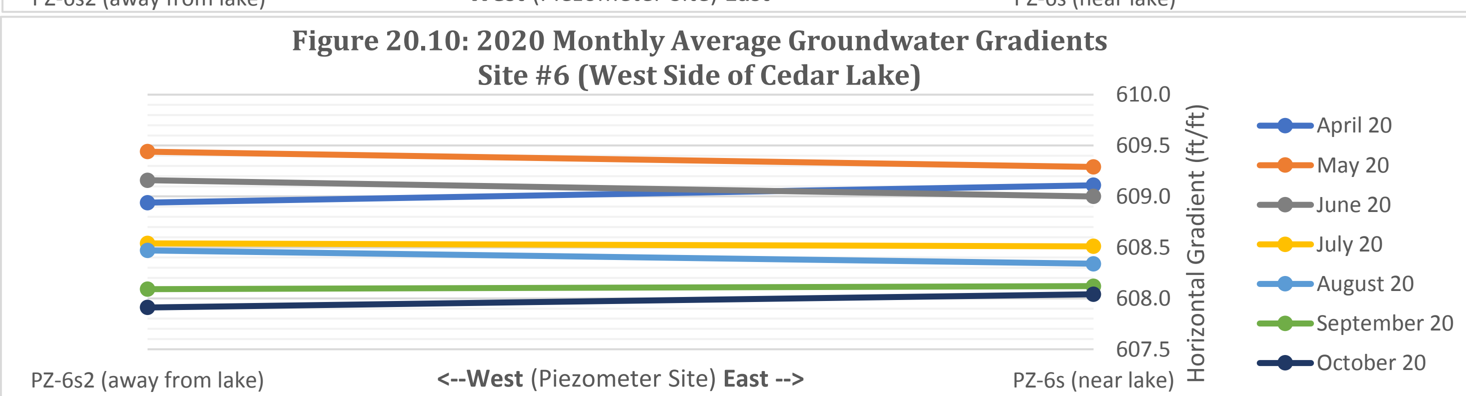


Figure 20.10: 2020 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
610.0
609.5
609.0
608.5
608.0
607.5
Horizontal Gradient (ft/ft)
April 20
May 20
June 20
July 20
August 20
September 20
October 20
PZ-6s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-6s (near lake)

Figure 21. 2020 Estimated Jones Creek Flows

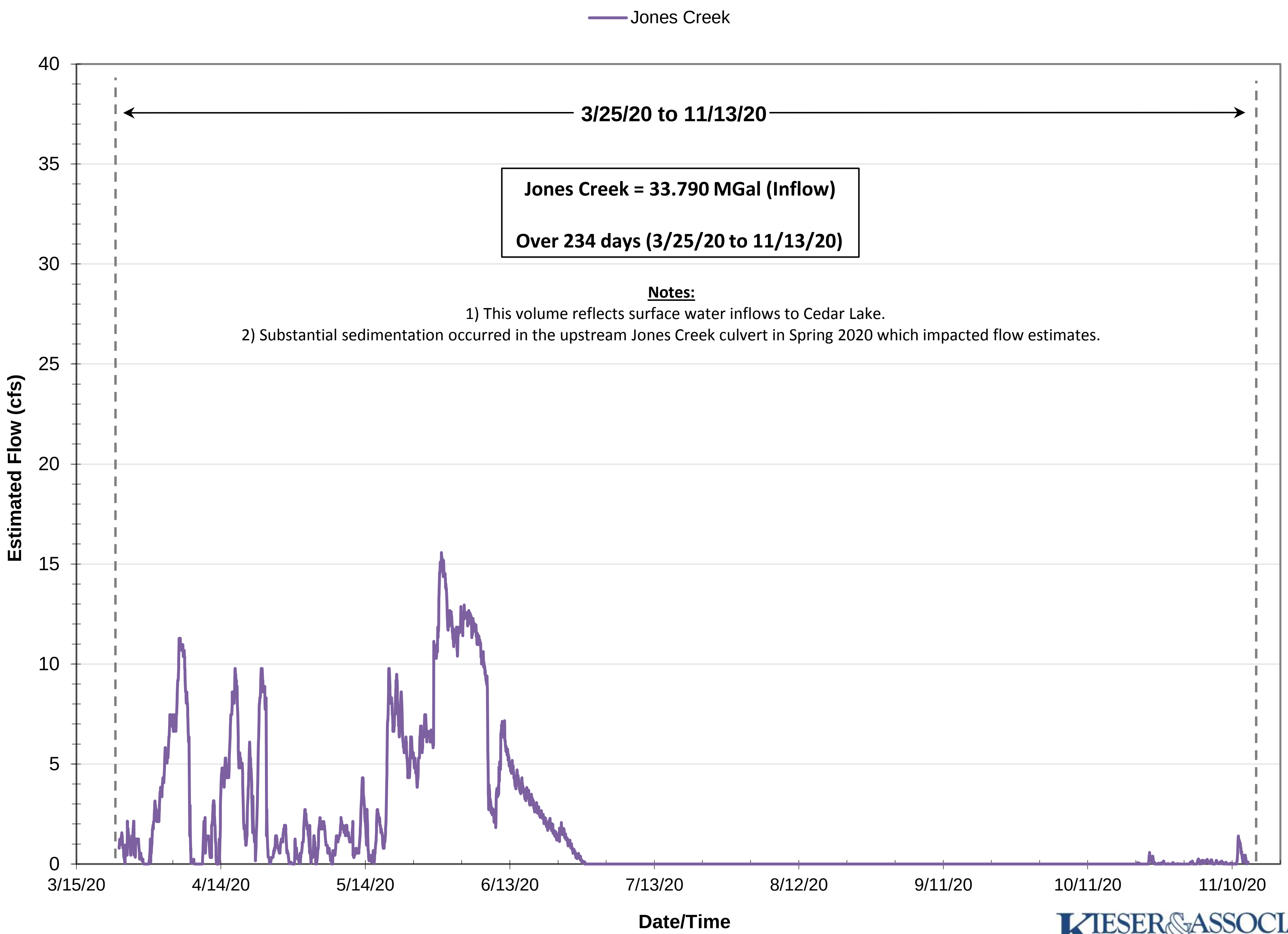


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Figure 22. 2020 Estimated Sherman Creek Flows

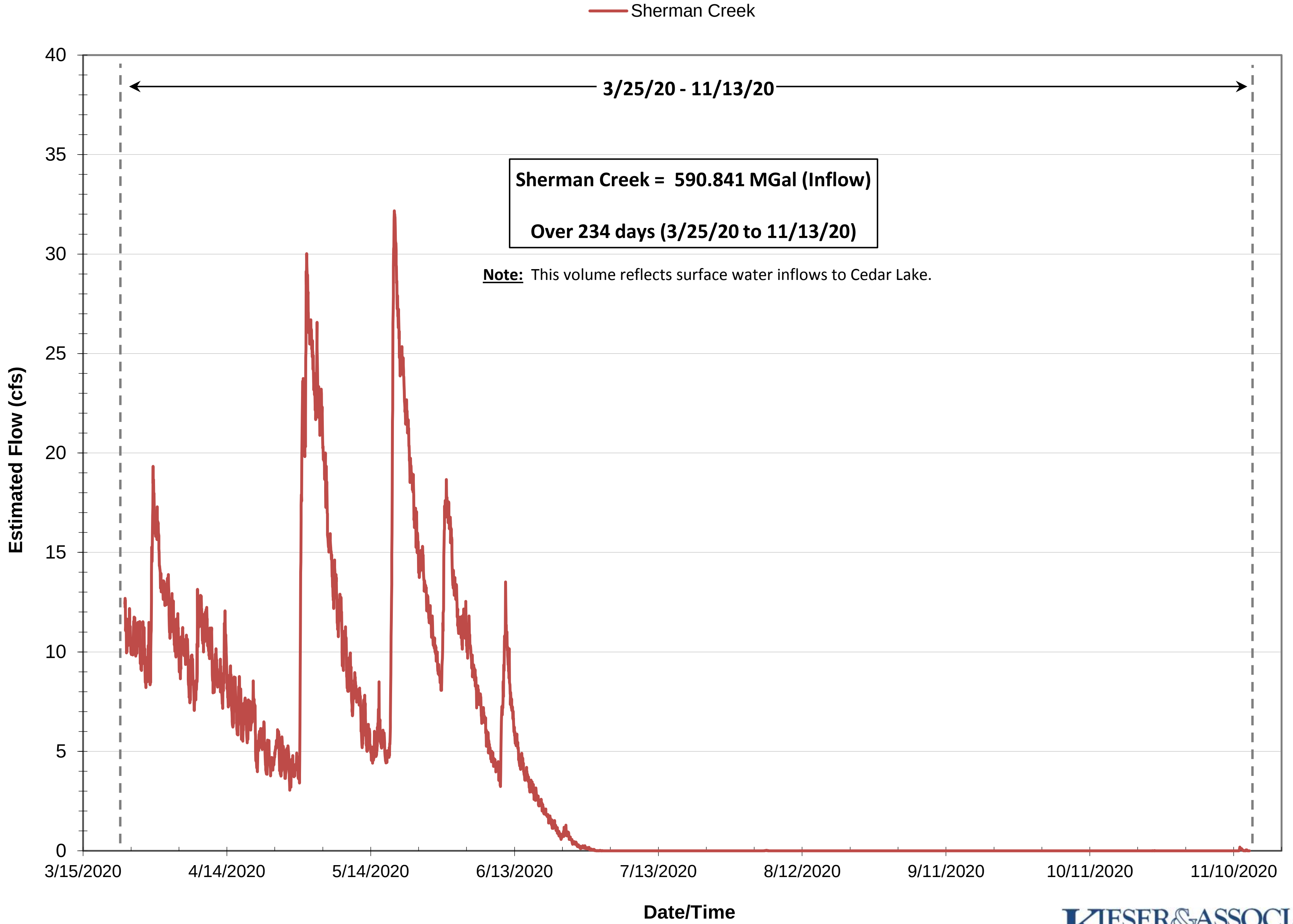

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Figure 23. 2020 Estimated Cedar Lake Outflows

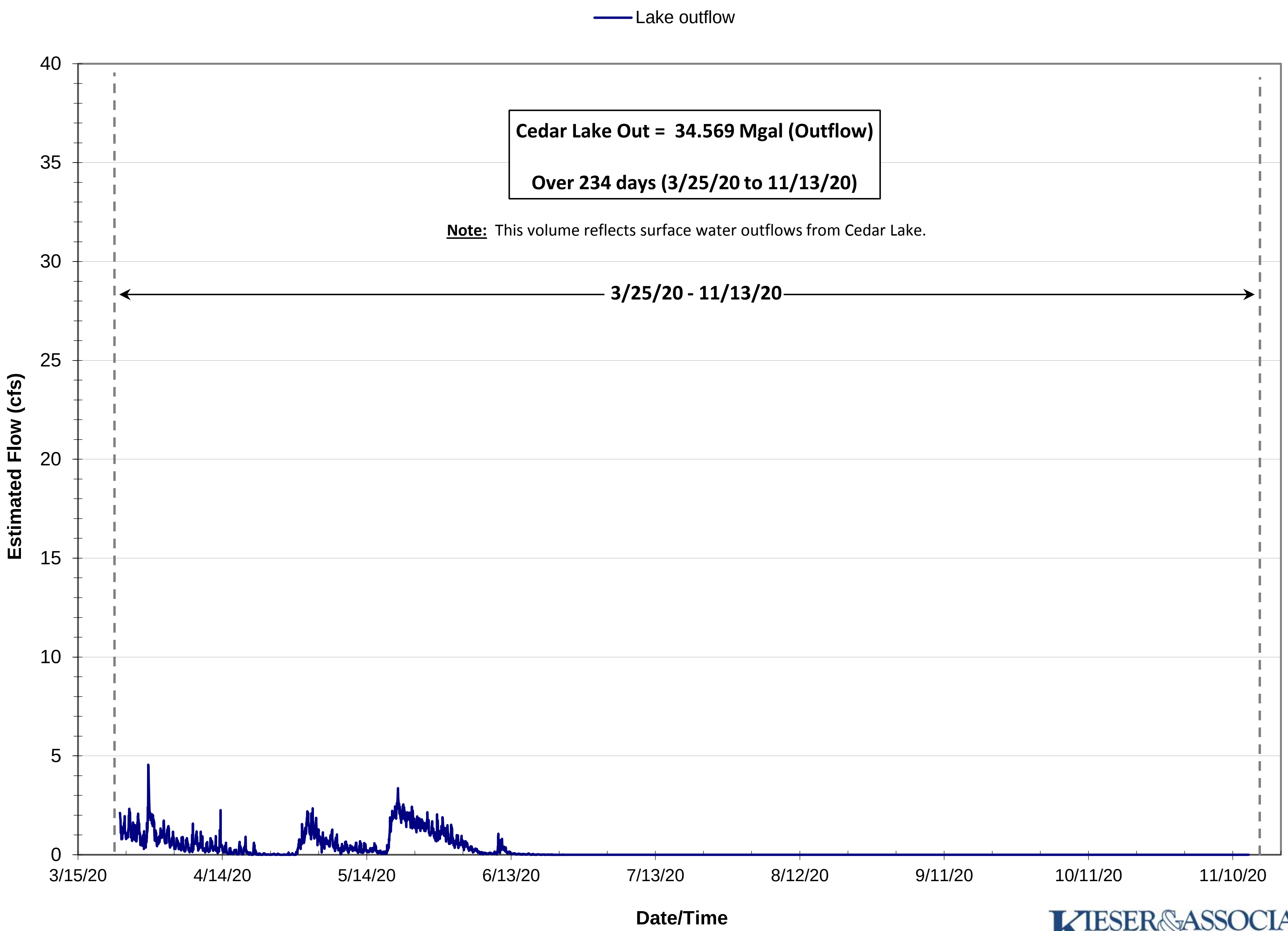

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Figure 24. 2020 Estimated Kings Corner Outflow

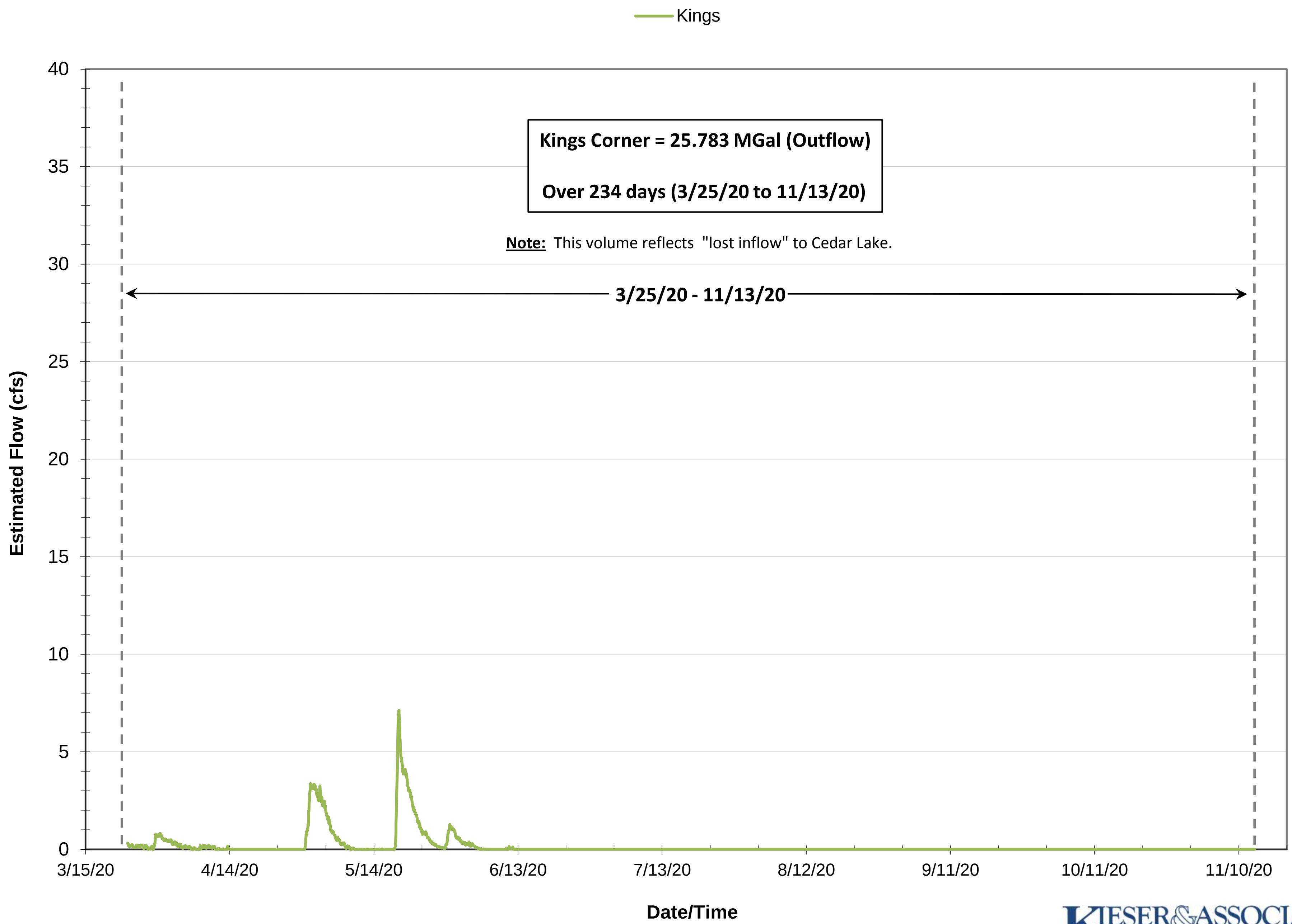

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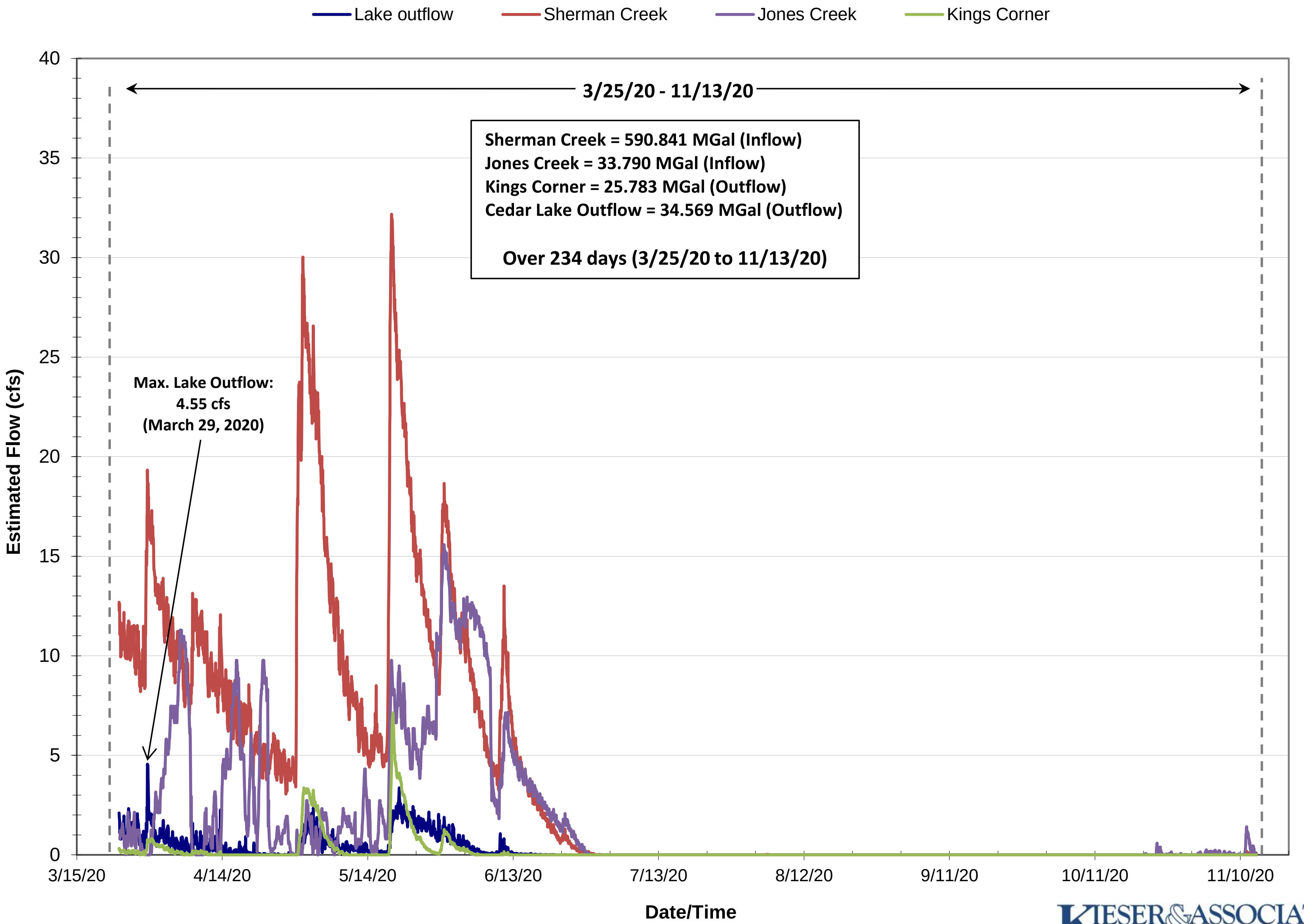
Figure 25. 2020 Estimated Cedar Lake Inflows/Outflows



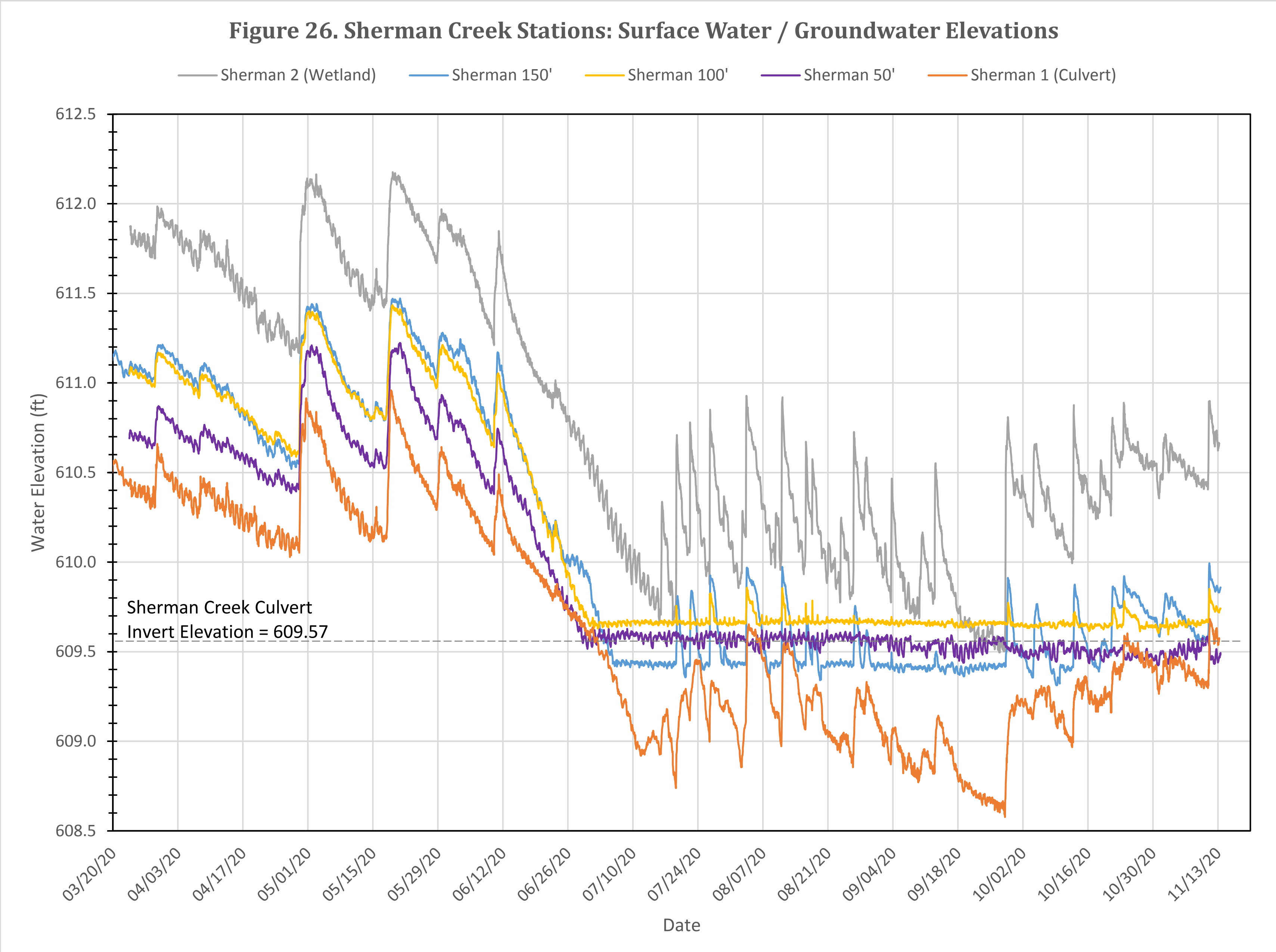


Figure 26. Sherman Creek Stations: Surface Water / Groundwater Elevations
Sherman 2 (Wetland)
Sherman 150'
Sherman 100'
Sherman 50'
Sherman 1 (Culvert)
Water Elevation (ft)
612.5
612.0
611.5
611.0
610.5
610.0
609.5
609.0
608.5
Sherman Creek Culvert
Invert Elevation = 609.57
03/20/20
04/03/20
04/17/20
05/01/20
05/15/20
05/29/20
06/12/20
06/26/20
07/10/20
07/24/20
08/07/20
08/21/20
09/04/20
09/18/20
10/02/20
10/16/20
10/30/20
11/13/20
Date

Figure 27. Cedar Lake Year-Round Loggers: Surface Water / Groundwater Elevations Nov 2019 - Nov 2020

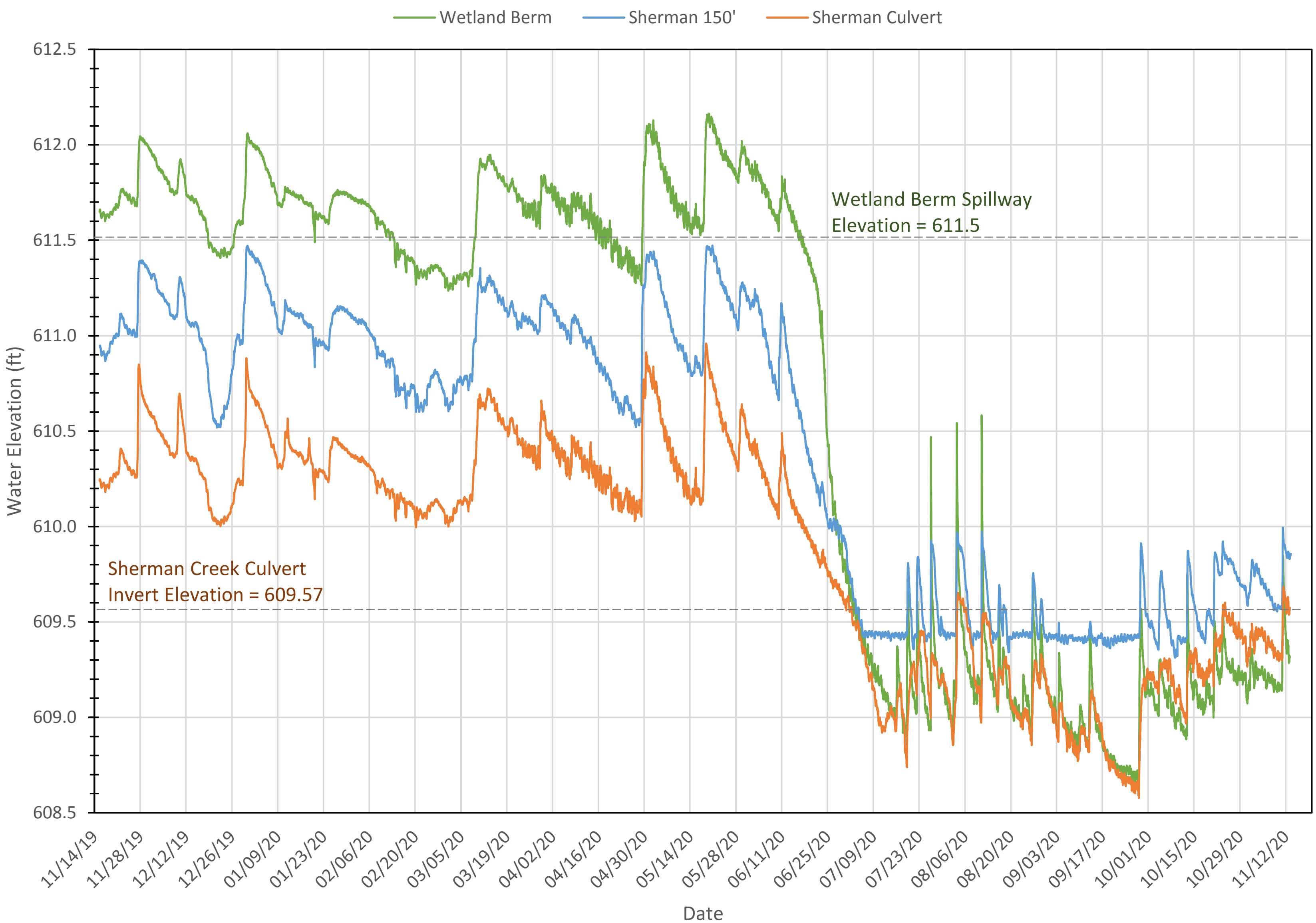


Figure 28. 2020 Cedar Lake Groundwater / Surface Water Elevations (Wetland Berm)

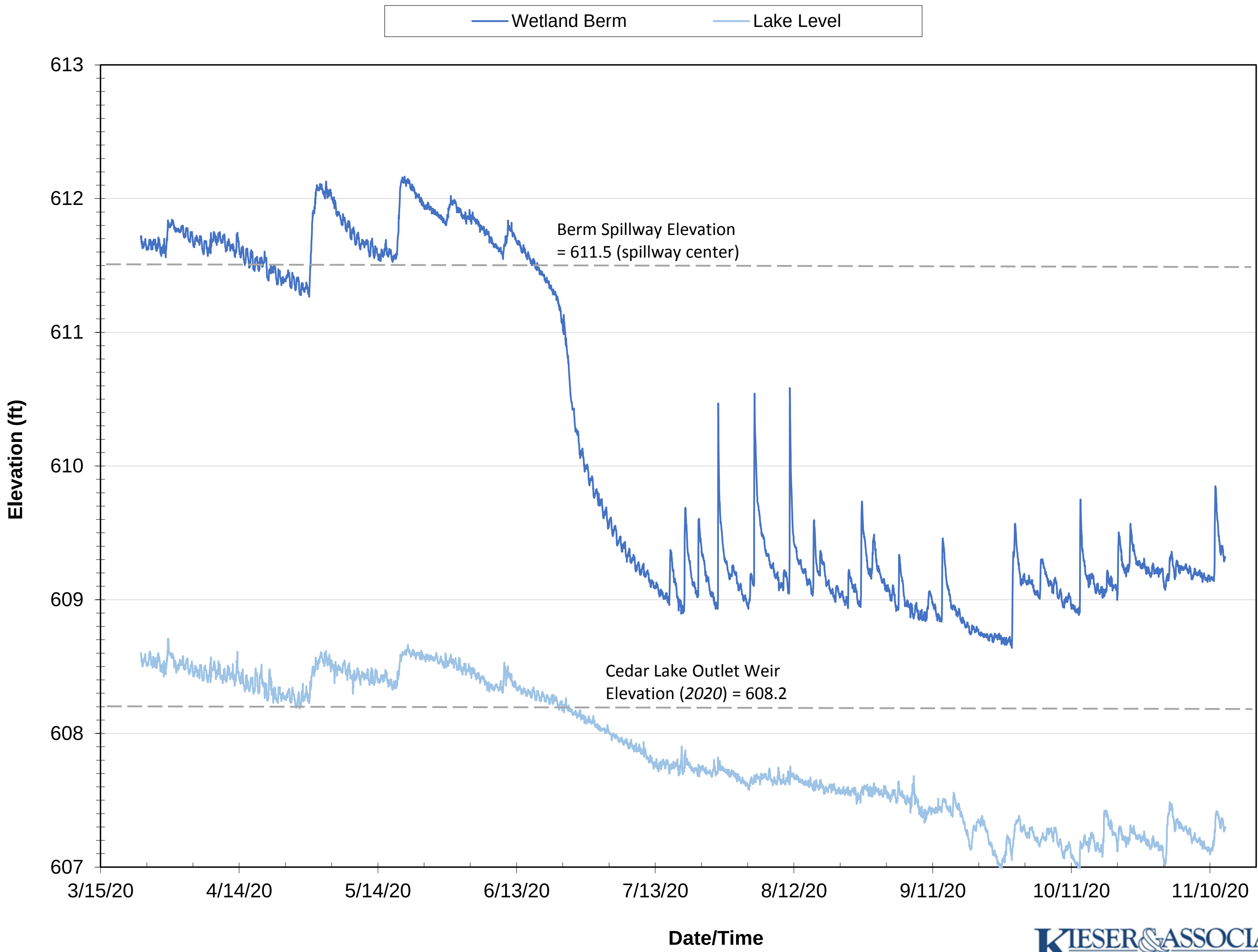


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Figure 29. 2020 Cedar Lake Groundwater / Surface Water Elevations (Wetland Berm, King's Corner, and Sherman 2)

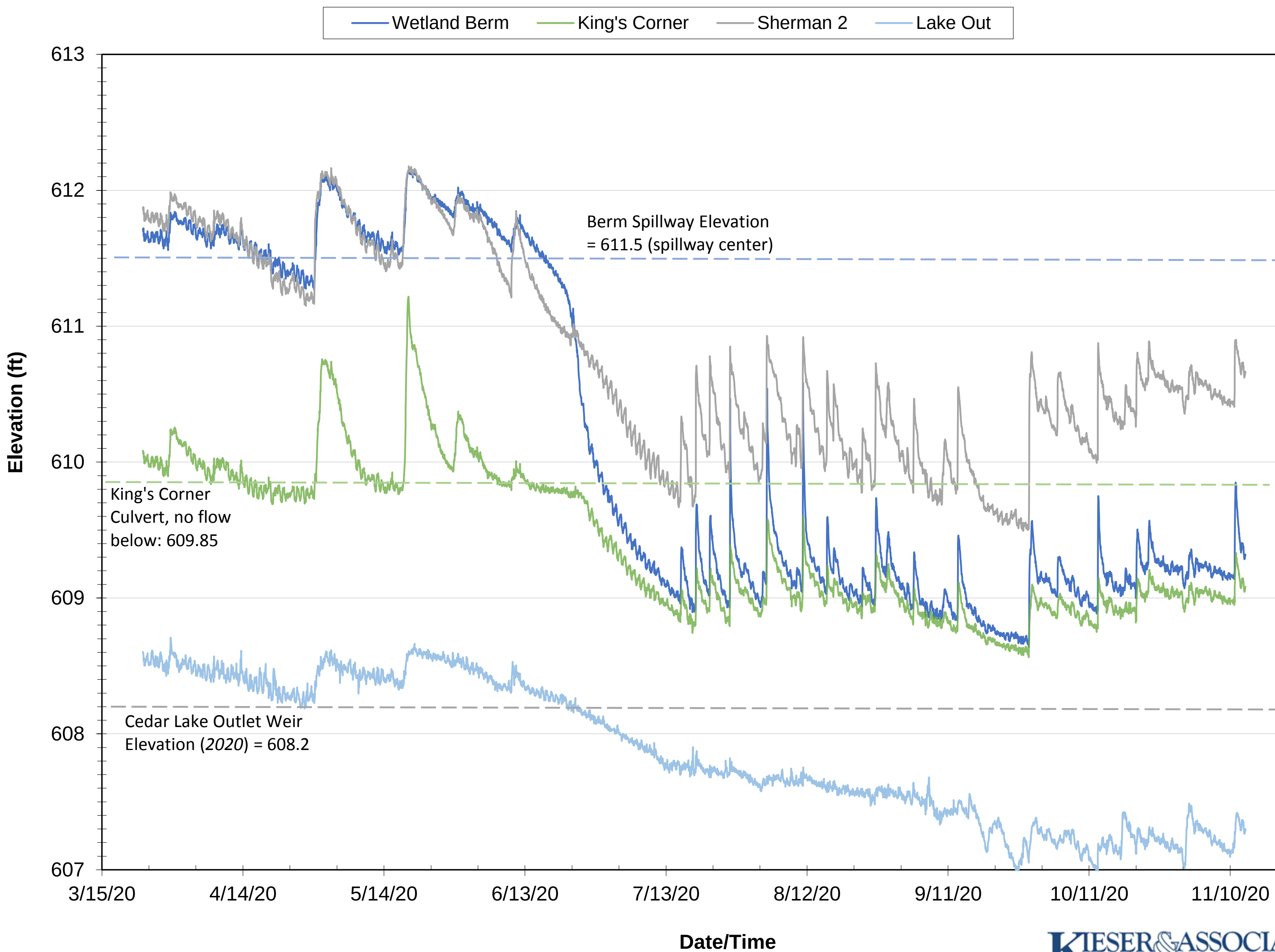

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Figure 30. 2020 Estimated Wetland Berm Spillway and King's Corner Outflows

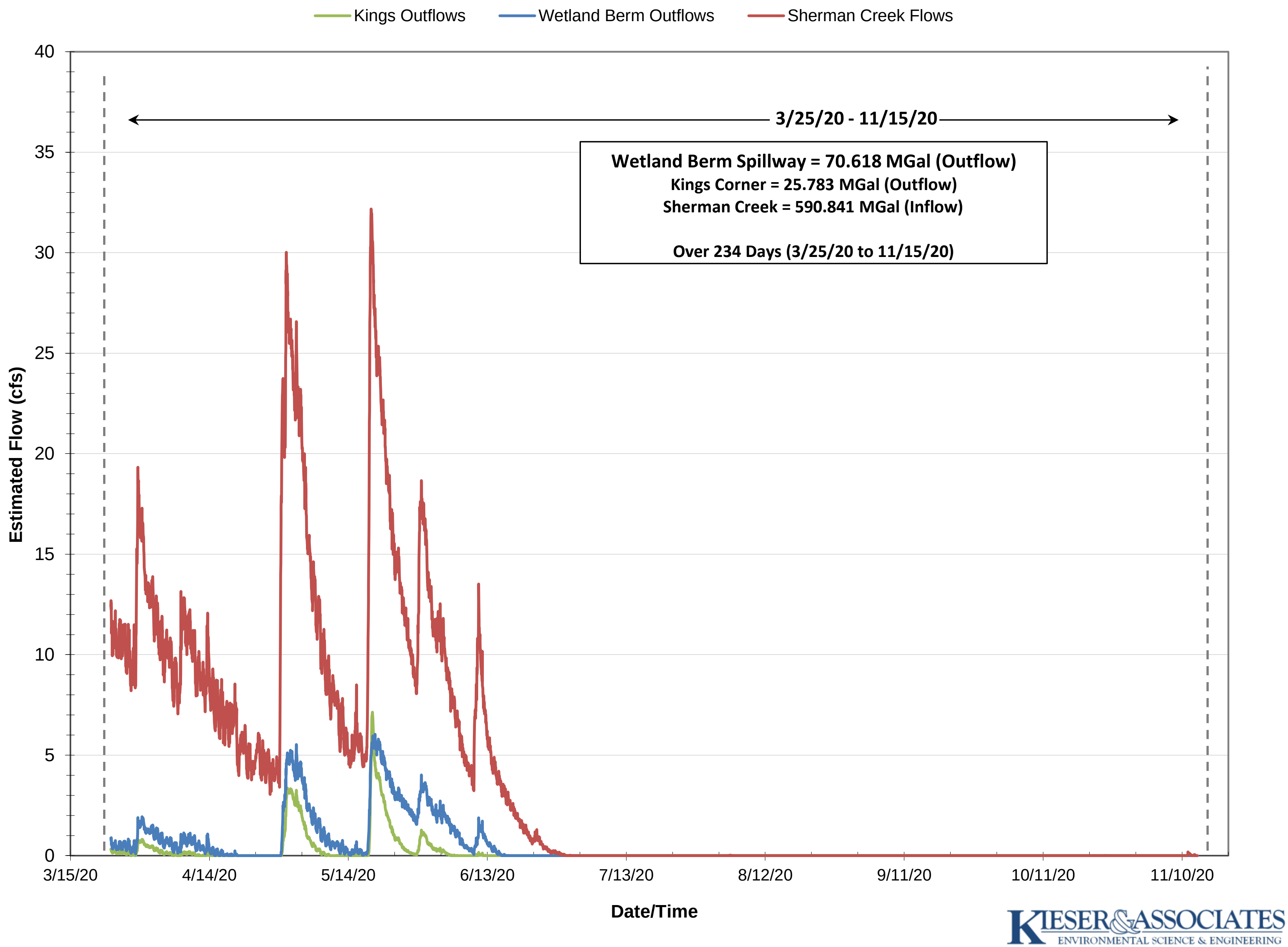
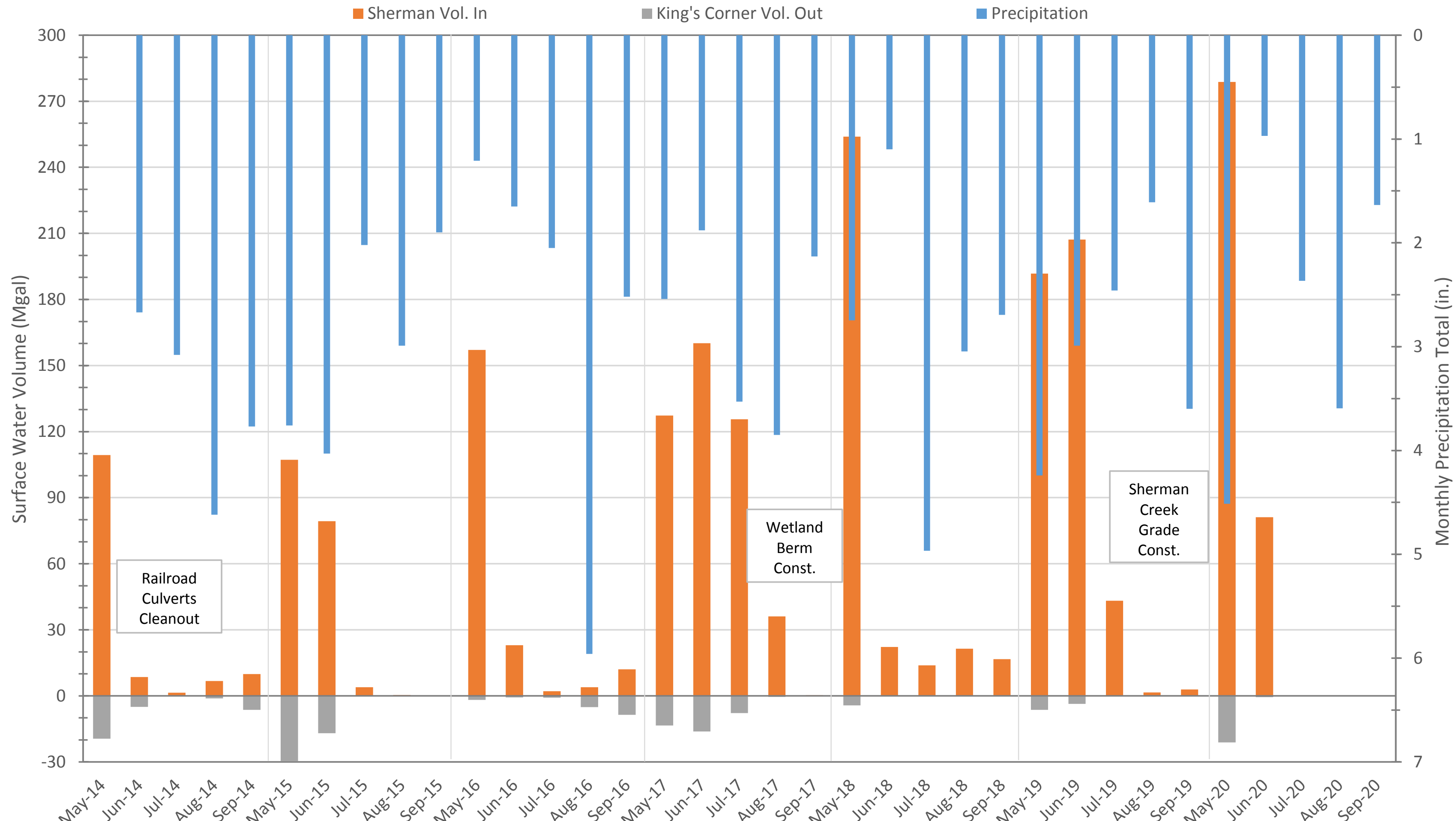


Figure 31 May-Sep, 2014-20: Precipitation, Sherman Creek Surface Water Volume into Cedar Lake, and King's Corner Surface Water Volume Away from Cedar Lake



2014 May-Sep:
Precip: 14.14 in.
Inflow Vol.: 136.0 Mgal
King's Vol. Out: 32.2 Mgal

2015 May-Sep:
Precip: 14.70 in.
Inflow Vol.: 190.9 Mgal
King's Vol. Out: 46.9 Mgal

2016 May-Sep:
Precip: 13.39 in.
Inflow Vol.: 198.1 Mgal
King's Vol. Out: 17.1 Mgal

2017 May-Sep:
Precip: 13.93 in.
Inflow Vol.: 449.4 Mgal
King's Vol. Out: 38.1 Mgal

2018 May-Sep:
Precip: 14.55 in.
Inflow Vol.: 328.1 Mgal
King's Vol. Out: 4.3 Mgal

2019 May-Sep:
Precip: 14.90 in.
Inflow Vol.: 446.7 Mgal
King's Vol. Out: 10.2 Mgal

2020 May-Sep:
Precip: 13.08 in.
Inflow Vol.: 359.8 Mgal
King's Vol. Out: 21.8 Mgal

Overview

Cedar Lake is unique in that it has a large surface area relative to its shallow depth and small contributing watershed area. This makes the lake susceptible to water level fluctuations when below average influent volumes from the watershed struggle to replace the lake's evaporation and outflow losses. Kieser & Associates, LLC has engineered and installed modifications to the contributing wetland to the northwest of the lake around Sherman Creek with the goal of increasing the volume of inflow to the lake as well as delaying that inflow over a longer period of time. The first modification was the installation of an east-west berm just north of the King's Corner culvert. This culvert drained surface water away from the northwest wetland and out of the Cedar Lake watershed, principally in the late winter/early spring snowmelt periods. The new berm now acts to retain water in the wetland so that it can instead exit via Sherman Creek as surface water to Cedar Lake. This berm also surcharges the local groundwater.

The second modification was the installation of instream grade structures in Sherman Creek. These structures act to reduce flow rates in the stream such that the wetland water volume exits over a longer period of time while also increasing groundwater storage. Both of these installations have been assessed by monitoring and groundwater modeling, the details of the latter of which are described herein.

Modeling Methods

Groundwater scenarios were modeled using the MODFLOW program.[1] MODFLOW utilizes a finite-difference numerical analysis method to calculate groundwater elevations based on user inputs. The model operates on a grid defined by the user, with ground elevations for each grid cell being input prior to running the model. Known groundwater elevations are also input at the appropriate cells, from which the model can then interpolate to calculate groundwater elevations for all cells where a groundwater elevation was not otherwise measured. Groundwater flow direction and velocity are also output for each cell.

Two model scenarios were created to assess changes in groundwater conditions related to the wetland berm and Sherman Creek instream grade structures. These included: a pre-modification scenario and a post-modification scenario. The pre-modification scenario represents conditions before the two engineering modifications were installed, while the post-modification scenario represents conditions with the engineering modifications in place. Each scenario can then utilize historical piezometer data to explore the potential groundwater storage benefits of the engineering modifications.

A grid 15 cells wide by 25 cells in height was defined to cover the area west of Cedar Lake including Sherman Creek, King's Corner Road, and nearby piezometers. Grid cell size is a 116m by 116m square. The modeled area contains 13 piezometer locations (Figure 1), and groundwater elevations measured from these locations were input into the model for the appropriate cells. The lake elevation was input as a boundary condition in representative cells on the eastern grid area. Piezometer groundwater elevations were plotted against their respective ground surface elevations, and the correlation of these two variables was used to set a groundwater elevation boundary condition on the west side of the grid where only surface elevations were known.

[1] Langevin, C. D., Hughes, J. D., Banta, E. R., Niswonger, R. G., Panday, S., & Provost, A. M. (2017). Documentation for the MODFLOW 6 groundwater flow model (No. 6-A55). US Geological Survey.

Precipitation in 2020 at Cedar Lake was below the annual average, making it a good year to analyze in regards to the potential benefits of the engineering modifications. The additional piezometers installed in 2019 also enabled more accurate MODFLOW output for 2020 and subsequent years as compared to using data prior to 2019. The analysis presented here compares conditions for different dates during 2020.

Figure 1 - MODFLOW grid and input piezometer locations overlayed on Cedar Lake topography. Shading represents the different regions the model output grouped for spatial analysis: teal represents the northwest wetland, green represents the groundwater contributing areas of the shoreline, and red represents the non-contributing region where groundwater does not move to Cedar Lake via groundwater directional flow or via surface water.

Results

Simulations of the pre-modification (Figure 2) and post-modification (Figure 3) conditions showed that engineering modifications in and around Sherman Creek progressed towards their goals of increasing storage volume in the northwest wetland and increasing flow volume to Cedar Lake. A composite of the two scenarios' contour lines is illustrated in Figure 4. Storage volume changes are shown in Table 1. (Please note that grid and contour numbers within Figures 2-4 indicate meters, as the MODFLOW model operates using metric inputs.)

Table 1 - MODFLOW groundwater storage volume change due to engineering modifications.

Region	Storage Increase (Million gallons)
Northwest Wetland	16.6
Contributing Shoreline	1.8
Combined Contributing Area	18.5
Non-Contributing Area	6.8

The arrows in Figures 2 and 3 represent groundwater flow: the arrow direction indicates the flow direction, while the arrow's tail length represents the flow velocity. Tail lengths are relative, not absolute. For reference, the greatest flow velocities are around 1-2m per day, while the majority of flow velocities are less than 0.5m per day. Note that the arrows indicate flow *into* a cell, not *through* a cell – which is why cells occupying water along the shoreline have arrows in them.

As Figure 4 illustrates, modeling output shows that the engineering modifications in and around the northwest wetland have a mounding effect, raising the groundwater elevation by up to 0.5m in some locations. The 186.2m contour line, which cuts across the very northwest portion of the model region in the pre-modification scenario, is extended to encompass the majority of the wetland in the post-modification scenario. The model shows that this groundwater mounding increases groundwater flows from the wetland to the east and raises groundwater elevations in the vicinity immediately south of the wetland. This can be seen in Figure 4 as the 185.6m, 185.8m, and 186.0m contours extending further south and slightly east in the post-modification scenario.

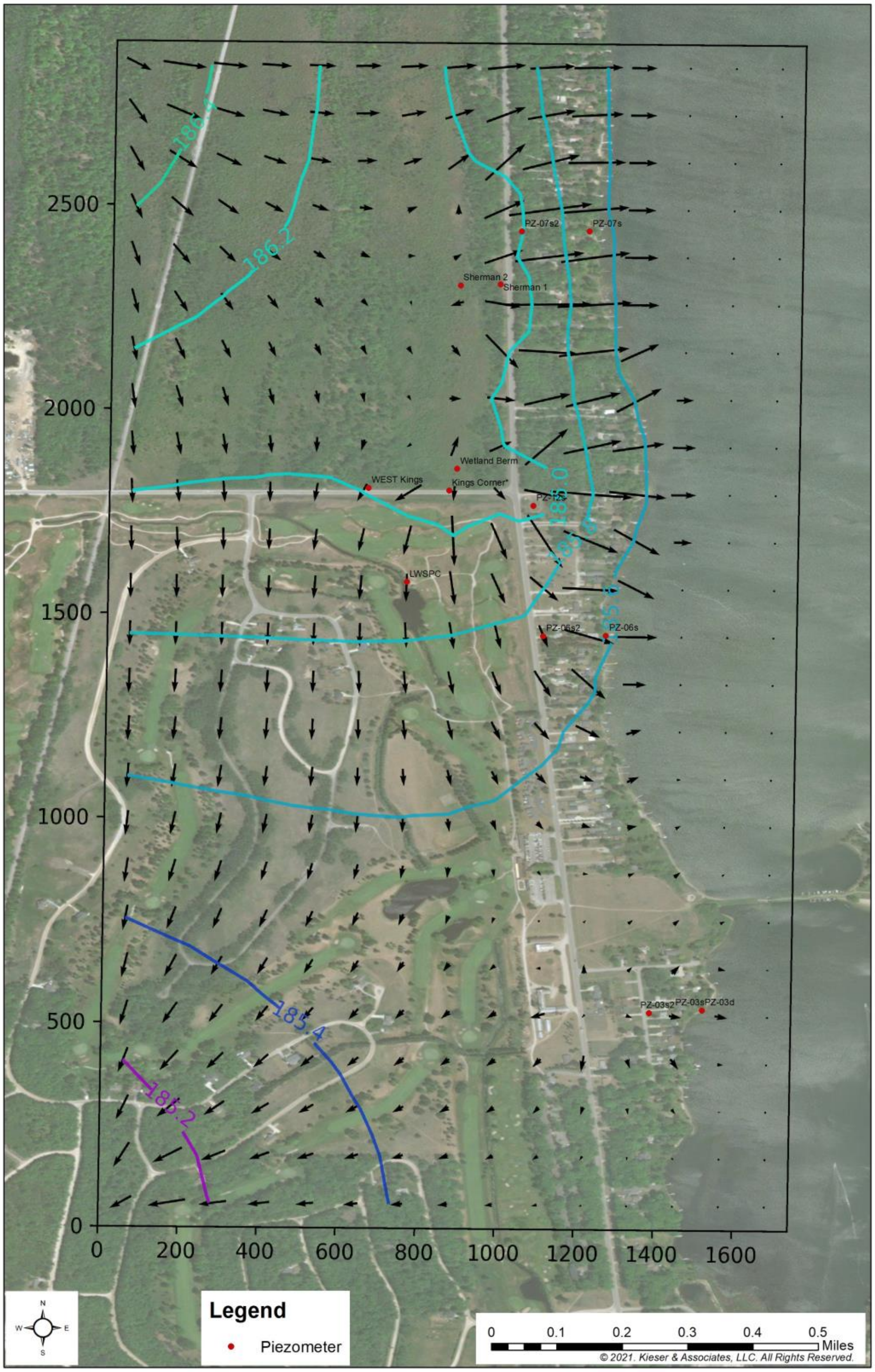


Figure 2 - MODFLOW output for the pre-modification scenario using piezometer data from 5/1/2020.

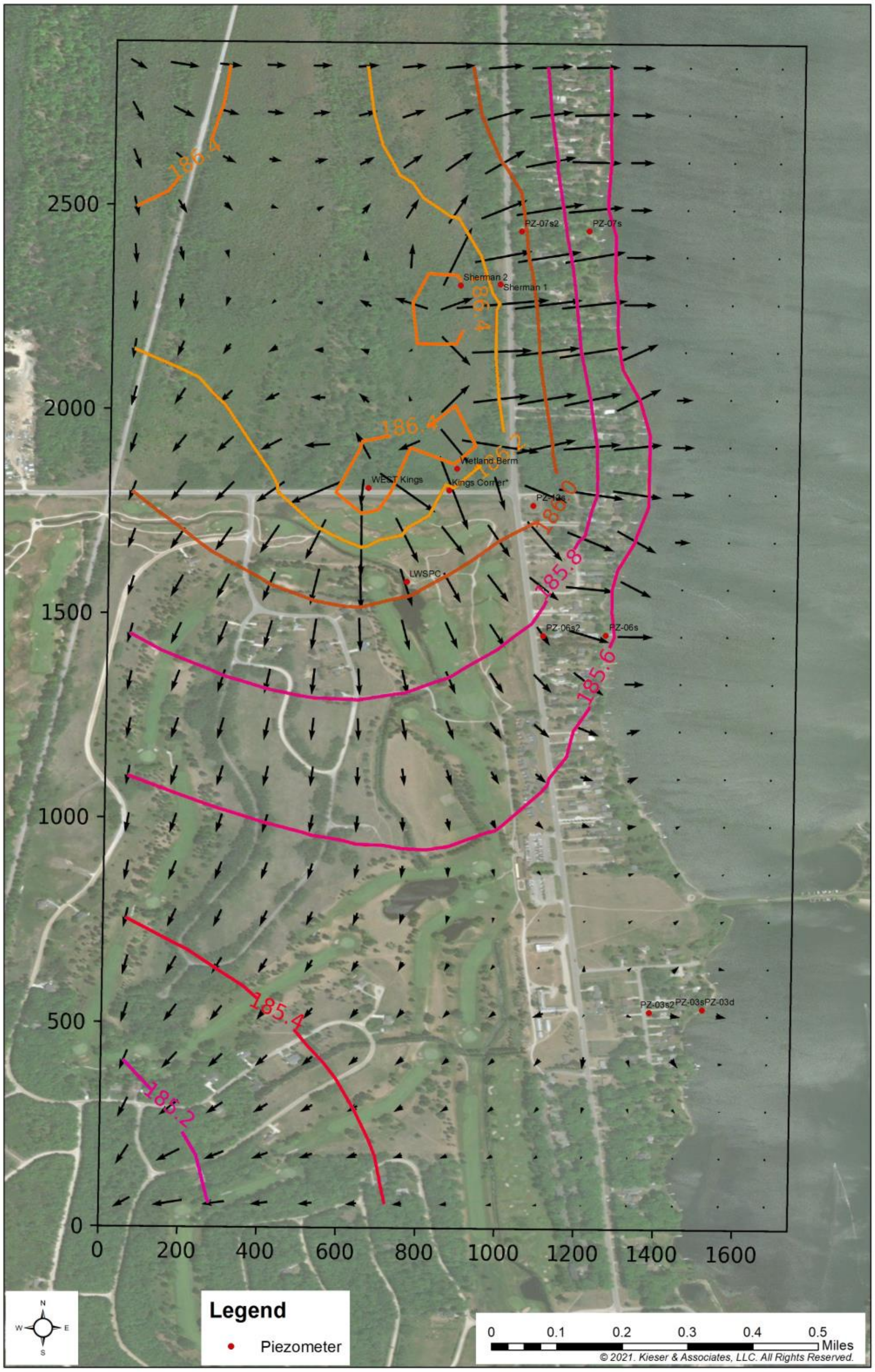


Figure 3 - MODFLOW output for the post-modification scenario using piezometer data from 5/1/2020.

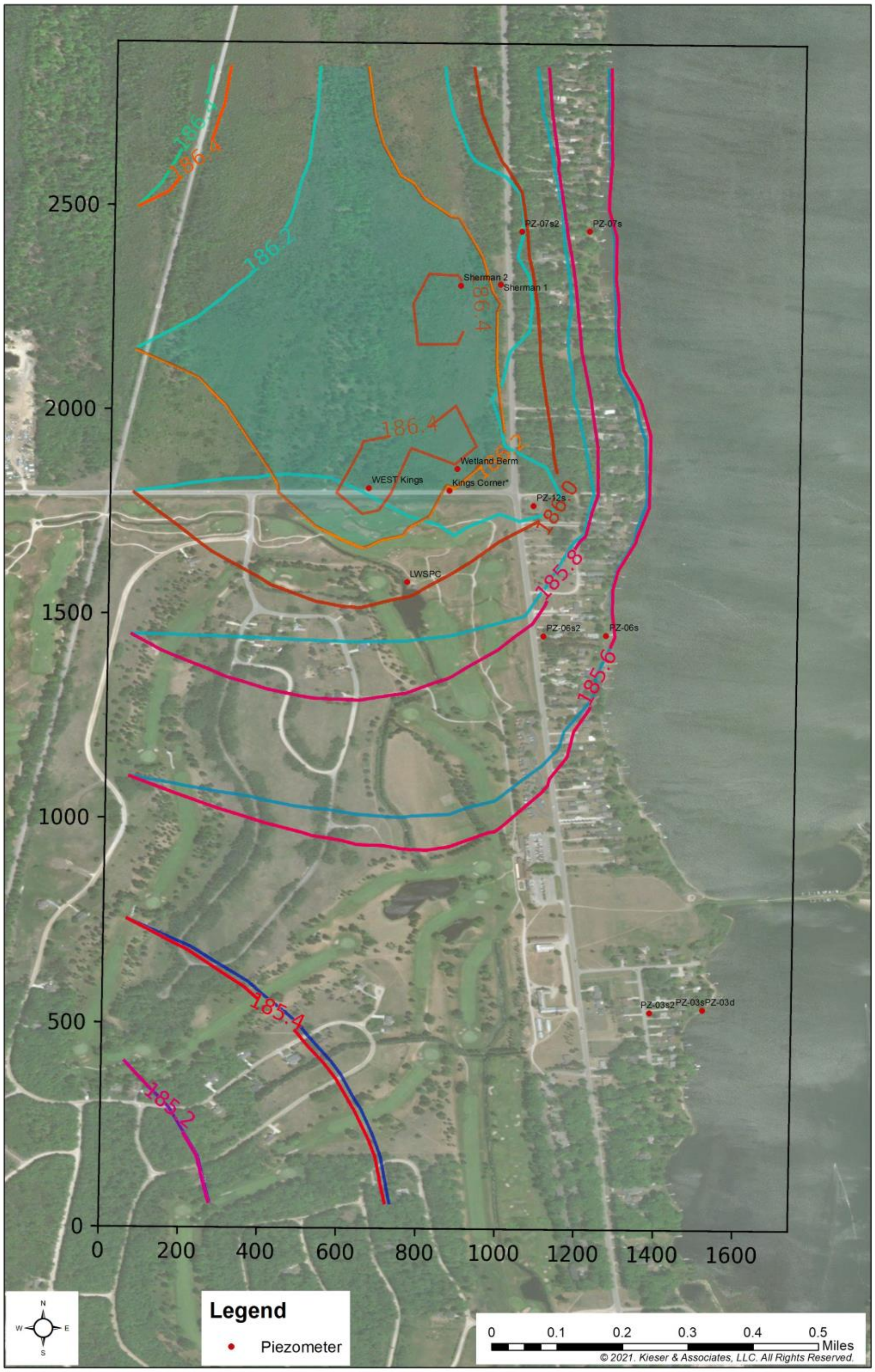


Figure 4 - Composite of MODFLOW pre- and post-modification output groundwater contours using piezometer data from 5/1/2020: pre-modification contours are shaded teal to blue, while post-modification contours are shaded orange to violet. Teal shading indicates the region in which the 186.2m contour line has shifted/expanded with the benefit of the engineering modifications causing more groundwater mounding.

Groundwater storage volume in the region of the model contributing to the lake increased by of 18.5 million gallons in the post-modification scenario over the pre-modification scenario. This was calculated by analyzing groundwater elevations in each cell during the period from April 1st to July 1st in the model. Pre-modification scenario elevations were subtracted from post-modification scenario elevations, and the difference was multiplied by both the cell area (13,456m^2) and a soil porosity value (0.4) to give a volume in m^3. This volume was then converted to millions of gallons for Table 1.

In contrast to the contributing area, groundwater storage volume in the non-contributing area of the model only increased by 6.8 million gallons in the post-modification scenario. The majority of the storage increase in the non-contributing area is located along King's Corner Road, a function of raising the water table in the adjacent northwest wetland.

These storage changes are indicative of the engineering modifications successfully limiting water in the wetland from leaving Cedar Lake's watershed. Surface water is kept within the northwest wetland, raising the localized water table while it slowly drains out via Sherman Creek. These flows no longer exit the watershed to the south. In addition, the change to groundwater contour patterns caused by this increase in groundwater storage appears to have slightly increased the size of the area that contributes groundwater to Cedar Lake. This has been partially confirmed by piezometer observations that have shown a reversal in groundwater gradients in some locations, where in the past groundwater sloped away from the lake and now is sloping towards the lake.

As can be seen in the main hydrology report, surface flows via Sherman Creek into Cedar Lake have increased after the construction of the berm. This increase in flows is likely driven by two processes: the wetland berm cutting off surface water flows from exiting south, and raising the water table such that an increased portion of precipitation becomes surface flow rather than infiltration. The groundwater mounding effect seen in the model indicates that groundwater storage has increased, and consequently there is less available space for precipitation to infiltrate.

While the engineering modifications have had a very positive impact on surface flow volumes to Cedar Lake, the groundwater flow benefits are less noticeable. The model output only predicts 3-5 million gallons per year of additional groundwater flow under 2020 precipitation conditions as a function of the engineering modifications. Due to the relatively slow velocities typical of groundwater, it takes a long time for that added groundwater storage to reach the lake. The increase in surface flows from the engineering modifications may be enough to maintain a desirable lake level during a moderately dry to average precipitation year. However, during an exceptionally dry year when Sherman Creek has minimal or even no flow, the extra groundwater flow introduced by the engineering modifications is not sufficient on its own to maintain a desirable lake level. During these extreme years, pumped flows from augmentation wells may become necessary to ensure the lake elevation does not drop to undesirable levels; a critical finding absent any other hydraulic modifications to the northwest Cedar Lake wetlands.