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TECHNICAL MEMORANDUM

To:	Rex Vaughn Cedar Lake Improvement Board	**Date:**	March 2, 2020
From:	Mark Kieser, K&A Josh Kieser, K&A	**cc:**	Doug Pullman, Aquest

RE: **Findings for 2019 Cedar Lake Groundwater/Surface Water Level Monitoring**

This memorandum presents 2019 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 2019 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 becoming particularly important as lake level management activities are now underway.

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 in 2014, the construction of a wetland enhancement berm in 2017, and the recent 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 from 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 year-round inflows to Cedar Lake while 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. If necessary, the installation contractor, under their contracted services will make requested grade structure elevation changes in the late Spring of 2020 as necessitated by monitoring and operational observations.

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. Other potential future management strategies per the WMP include improving Jones Creek water retention and utilizing deep groundwater withdrawal augmentation wells. Use of augmentation wells may not prove viable in the near-term given recently discovered groundwater contamination in the area related to the common fire-retardant chemical known as PFAS.

Proposed groundwater modeling using 2019 and spring 2020 groundwater monitoring data will also be used to assess the success of the CLIB water and groundwater elevation control projects as well as forecast future additional needs for summer lake level controls. Though groundwater levels are quite high at present, modeling will help assess expected lake levels under future lower groundwater conditions.

This technical memorandum therefore presents findings of the ongoing water level studies in Cedar Lake and discusses these in the context of ongoing and other 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 2019 water level monitoring program included 27 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 were likewise included in the 2019 monitoring program to assist with calculating estimates of surface water flows into Cedar Lake. Also included were flows through the new wetland berm spillway, just upstream of the King's Corner culvert.

In 2019, K&A also installed three new piezometers and moved two original piezometers on the west side of Cedar Lake, near the King's Corner area (Figure 1). In May, 2019, the two piezometers at Site 6, PZ-6s (near the lake) and PZ-6s2 (near the road), were moved 50 ft south to a neighboring property, at the request of the original site's property owner. Two new monitoring sites, PZ-12s and "West Kings", were also installed along King's Corner Road in May. A third new monitoring site, LWSPC, was installed in August, 2019, along Phelan Creek within the Lakewood Shores Golf Course. These new monitoring site locations were chosen to more effectively triangulate groundwater movement throughout the critical King's Corner area.

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. Water levels were used to estimate surface water flows occurring through the wetland berm spillway in 2018 and 2019. The wetland berm was designed with a stone-laden spillway meant to overflow at an elevation of 611.0 feet so as not to permanently alter historic high-water levels flowing southward out of this area and out of the Cedar Lake drainage. After heavy spring rains and snowmelt in spring of 2018 led to a breach at the berm's east end causing minor erosion, the berm spillway was reconstructed to better match the engineering specifications. The wetland berm monitoring station provides important information regarding water retention improvements in the northwest cedar swamp, including those related to the 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 also recalculated flow equations for Jones Creek surface flows in 2018 based on the as-built dimensions of the newly installed 48-inch culvert. Beaver activity at the culvert effected a portion of the 2019 flow data before the obstructions were cleared and fencing was installed to prevent damming. The surface flow equations will continue to be refined with manual measurements in future monitoring seasons.

The need to replace aging level loggers, highlighted in the 2018 hydrology report, led to the purchase and deployment of nine new water level loggers and one new barometric pressure logger in 2019. These were deployed during for the typical March-November monitoring season. In order to monitor groundwater and surface water levels during the winter months in the Sherman Creek cedar swamp area, an additional three new loggers and one new barometric pressure logger were purchased and deployed in November, 2019. These three loggers, designed to withstand freezing conditions, will be dedicated to measuring water levels between November and March. The logger manufacturer suggests ten years to be the predicted lifespan of the level loggers, so continued replacement of "aged-out" level loggers is suggested for 2020 and 2021. Table 1 illustrates the age and predicted lifespan of the current Cedar Lake level logger regime.

Additionally, evaluation of volunteer precipitation data collected using a more than ten-year old rain gauge at Cedar Lake and submitted by Rex Vaughn, showed significant errors for a portion of the dataset compared to nearby weather stations and past rainfall records. This report therefore relies on average rainfall data for 2019 triangulated from nearby weather stations. These issues highlight the need to continue replacing aging level logger and rain gauge equipment in the proposed manner in order to prevent data loss from equipment failure.

2019 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 average 2019 precipitation data available from: Harrisville 2 NNE (USC00203628), East Tawas (USC00202423), and Oscoda Wurtsmith Airport (Station #14808), as well as historic rain gauge data from a Cedar Lake rain gauge monitored by volunteers. Available rainfall data from 1998 to 2019 (minus 2006 when there were no local functioning rain gauges) reflect a 21-year summer average (June-September) of 12.02 inches of rainfall. Although observed 2019 data showed above-average rainfall for the early spring months of 2019, the observed 2019 data for June-September showed below-average rainfall, totaling 10.66 inches during the summer months.

As Figure 2 illustrates, the previous summer of 2018 exhibited near-average summer precipitation amounting to 11.81 inches. Summer-month rainfall in 2017 was similarly just below-average, while 2016 rainfall was average, and 2015 was 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. With new efforts to better manage water levels and water retention in the northwest cedar swamp, we expect this critical rainfall threshold to decrease 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 2019, water levels were plotted with recorded rainfall to illustrate lake level response to precipitation (Figure 3). As illustrated in Figure 3, the local precipitation has a direct impact on Cedar Lake water levels with observed responses corresponding to local rain events. The 2019 level logger data collected near the Cedar Lake outflow structures showed surface water levels fluctuated within a maximum of 10 inches above (April) and 6 inches below (October) 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 early August. 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 in 2019, Cedar Lake water levels steadily declined from April to August, after heavy spring rain, snowmelt, and early summer rain events. Lake levels dropped to within 6-inches below the legal lake level from early August to the end of the monitoring season in November. This drop corresponded with low precipitation levels of 2.46 inches in July and 1.61 inches in August. As Cedar Lake levels rose and fell in response to rain events during the summer months of June-September, water levels reached a maximum of 7-inches above (June) and 5-inches below (August) the legal lake level. The greatest drop during the monitoring season, within 6-inches below the legal lake level, occurred in mid-October. Lake levels returned to just-below the legal lake level in response to heavy rainfall in early November.

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.

In previous years, a beaver dam has inhibited lake outflow volumes and effected lake levels. The presence of the beaver dam just upstream of the Cedar Lake outlet structures during the 2016 monitoring season, for example, significantly affected lake levels. The dam was mechanically removed in October 2017 and therefore did not affect lake levels in 2018. Evidence of renewed beaver activity, however, was noted in late fall of 2018 and early spring of 2019, occurring atop the outflow structures. This activity may have partially blocked the west outflow structure for a portion of the 2019 monitoring season and likely effected water levels during that time.

Note also that 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 2019 Cedar Lake Hydrology Report references the legal lake limit at an elevation of 608.2, with outflows occurring at a water level of 608.3 or higher. 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.

Additionally, a Special Assessment Notice was issued in November of 2019 to notify residents of planned upcoming reconstruction of the lake outlet structures. The Iosco and Alcona County Drain Commissioners as the delegated authorities of the Cedar Lake Level District, held a public hearing on November 12, 2019 regarding this work, scheduled for late winter of 2020. K&A therefore removed the original Lake Out piezometer in early November of 2019 in preparation of this pending project. K&A was also in communication with Spicer Group, Inc to prepare for installation of a new Lake Out monitoring station in spring 2020.

Groundwater Levels and Gradients

The 2019 groundwater elevation data from the groundwater monitoring Sites 1-11 and new sites PZ-12, West Kings, and LWSPC, are graphically illustrated along with Cedar Lake water levels in Figures 4-17, respectively. These data help to reveal the complexity and seasonality of shallow groundwater movement in critical areas of the Cedar Lake watershed.

Sites 1, 4, and 5 (Figures 4, 7, and 8, respectively), on the lake’s east side, are in locations where shallow groundwater is typically moving away from Cedar Lake toward Lake Huron. This trend is reflected in the 2019 as well as historic piezometer water levels that were generally below the Cedar Lake surface water level. Site 3 (Figure 6), on the lake’s southwest side, is also in an area where shallow groundwater is typically moving away from Cedar Lake, in this case toward Phelan Creek to the southwest.

Site 6 (Figure 9) on the lake's west side about 1,100 ft south of King's Corner, is in an area which historically exhibited groundwater gradients as level or moving away from Cedar Lake, similar to Site 3. The Site 6 piezometers were moved 50 ft south of the original site in May 2019. The 2019 data, as shown in Figure 9 for the newly installed Site 6, suggest that groundwater at this site tended to move toward Cedar Lake during the 2019 monitoring season.

To further explore these assessments, K&A evaluated monthly average groundwater gradients for the 2016-19 monitoring seasons at Sites 3 and 6. Figure 19 plots the average monthly groundwater gradients for both sites against the 2019 Cedar Lake water level. Figures 19.1-19.8 illustrate this analysis for each year 2016-2019. These figures affirm that shallow groundwater is typically moving away from the lake at Site 3. Data from 2016-2018 at the original Site 6 typically exhibited a similar trend, except during several months with heavy rainfall when shallow groundwater was observed to flow toward the lake. Data from 2019 at the new Site 6, however, exhibited shallow groundwater gradients tending toward the lake throughout the monitoring period. K&A will reaffirm piezometer elevations at this new site in 2020 to ensure accuracy in future evaluations of this condition.

Site 12, installed in 2019, is about 1,750 ft south of Sherman Creek and about 85 ft southeast from the intersection of Cedar Lake Road and King's Corner Road. Figure 15 shows that in 2019, shallow groundwater at PZ-12 was consistently lower than at Sherman Creek and King's Corner culvert but above the Cedar Lake surface water level. This would suggest that shallow groundwater is typically moving southeast from the King's Corner area, toward Cedar Lake.

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 2019 monitoring period. 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 dropped below those at PZ-6s during the month of August before rising again to levels between the two Site 6 piezometers during September and October, then rising above PZ-6s2 levels once more in November.

Data collected in 2019 from new piezometers West Kings and LWSPC (Figures 16 and 17, respectively), both in the area west of King's Corner culvert, provide additional insight into shallow groundwater movement in this area. The 2019 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 mid-July. From mid-July to November, shallow groundwater observed at West Kings dipped below, but remained within 4 inches of that at King's Corner culvert throughout the monitoring period. The 2019 data for LWSPC, installed in August 2019, showed shallow groundwater on the east bank of Phelan

Creek within the Lakewood Shores Golf Course to be well-below other stations in the King's Corner area. Relative to Site 3, about 0.75 miles to the south, LWSPC groundwater elevations were generally above those observed at PZ-3s2 (near Teal St.), and roughly equivalent to those observed at PZ-3s (near Cedar Lake). All of the King's Corner area groundwater elevations for 2019 are plotted together for comparison in Figure 18.

Sites 2, 7, and 12 (Figures 5, 10, and 15, respectively) on the lake's west side, 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. 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 5, further emphasizes the importance of wetland protection and enhancement in this critical watershed area.

Figure 10, 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.

Sites 8, 9, 10, and 11 (east side of Cedar Lake, Figures 11, 12, 13, and 14, respectively) document conditions beyond the lake toward the southeast within an area of Lakewood Shores that is well-drained. Water level data for these sites continue to confirm shallow groundwater loss towards Lake Huron with increasing distance from the lake.

K&A will utilize the expanded set of shallow groundwater data collected in 201, in conjunction with data to be collected from over-wintering loggers in early spring 2020 to perform a deeper examination of groundwater movement and trends over time. These efforts will include historic data sets as well as groundwater modeling for estimation of potential future dry and wet weather conditions. This expanded effort will be particularly important for assessing the effectiveness and potential impacts of ongoing WMP implementation such as the wetland berm and Sherman Creek instream grade structures.

2019 Estimated Surface Flows

Introduction to Surface Flows

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 immediately draining 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. An over-wintering logger, installed in November 2019, will help to provide an expanded set of groundwater data for the cedar swamp in 2020.

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, will help to provide an expanded set of surface water data for Sherman Creek and the cedar swamp in 2020.

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 20, 21, 22, and 23 illustrate calculated surface water inflows and outflows including estimated volumes associated with the entire 2019 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 2019 monitoring season from these critical locations were combined and plotted together in Figure 24.

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 2014-2019 for comparison. During the 153-day period from May 1 to September 30, 2019, the Jones Creek and Sherman Creek monitoring data reveal inflows of 87.5 and 446.8 million gallons (Mgal), respectively into Cedar Lake.

The 2019 inflow volumes were greater in both Sherman Creek and Jones Creek than in 2018 (in spite of slightly higher summer precipitation in 2018). The 2019 inflow volumes for Jones Creek were higher compared to all other years 2014-2018. The 2019 inflow volumes were adjusted to account for beaver activity at the culvert which effected a portion of the 2019 water level data before the obstructions were cleared and fencing was installed to prevent damming. The 2019 inflow volumes for Sherman Creek were also higher compared to all other years in the same period, with the exception of 2017 (refer to Table 2). Figures 20 and 21 illustrate Jones Creek and Sherman Creek flows throughout the 2019 monitoring period.

Measured outflow volumes leaving Cedar Lake at the north outlet structures totaled 143.2 Mgal during the May 1 to September 30, 2019 time period. Discernable 2019 lake outflows occurred from spring into mid-summer as shown in Figure 22. The 2019 outflow volumes were the highest on record compared to outflow volumes from 2014-2018. Outflow volumes in 2016 and 2017 were affected by the presence of a beaver dam upstream of the outlet structures.

Figure 23 summarizes observed flows associated with the King's Corner culvert location for the entire 2019 monitoring season. The plotted flows from the 2019 monitoring period reflect a total discharge volume of 23.9 Mgal over 210 days. During the shorter May 1 to September 30, 2019 recreational season, an estimated 10.2 Mgal flowed out of the Cedar Lake watershed via the King's Corner road culvert. Surface water outflows at King's Corner during May-September 2019 measured approximately 28 Mgal less than in 2017 prior to construction of the wetland berm; a year with comparable flows observed in Sherman Creek. These 2019 flows were greater than those observed in 2018 but significantly less than observed outflow volumes during the same months in each year 2014-2016 (refer to Table 2). The maximum observed high water elevation at the King's Corner culvert in 2019 was 610.71. 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.

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.

Figure 25 illustrates the 2019 water elevations at the wetland berm monitoring station positioned at the upstream side of the berm spillway compared to lake levels. Figure 26 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 27 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, 2019, roughly 62.9 Mgal of surface water flowed through the wetland berm spillway, while only 10.2 Mgal was lost via King's Corner culvert, as graphically depicted in Figure 27, largely in the Spring under high groundwater conditions. Approximately 16% of the water leaving the wetland berm left through the culvert; for the remainder, it is assumed this water infiltrated to shallow groundwater or, under high flows, out of a second King's Corner Road culvert to the west.

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. The study assesses potential water control implementation options and their feasibility related to multiple indicators including cost, total available volume, and other restrictions.

The 2019 level logger data, consistent with 2018 data, suggest that in the spring-summer months May-September since 2014 volumes contributed to Cedar Lake via Sherman and Jones Creek have increased dramatically (refer to Figure 28). Inflow volumes during these months from 2014-2016 averaged 209.1 Mgal, while inflow volumes in 2019 were estimated at 534.3, a comparative increase of 325.2 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 10.2 Mgal during 2019.

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 may offset any immediate need to pursue other, potentially costlier management options such as augmentation wells. Figure 28 illustrates this analysis by comparing 2014-2019 May 1 to September 30 monthly rainfall totals with monthly combined total volumes contributed to Cedar Lake via Sherman and Jones Creeks and volumes lost from the Cedar Lake watershed via King's Corner culvert.

Conclusions and Recommendations

Data from the 2019 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 2019 appear to have been within the WMP desired levels in spite of rainfall occurring below the observed historic average for June through September, perhaps as a function of water flow and retention improvements in the northwest cedar swamp. Lake outflow data and lake levels still suggest that 2019 lake levels were adequate for targeted summer conditions.

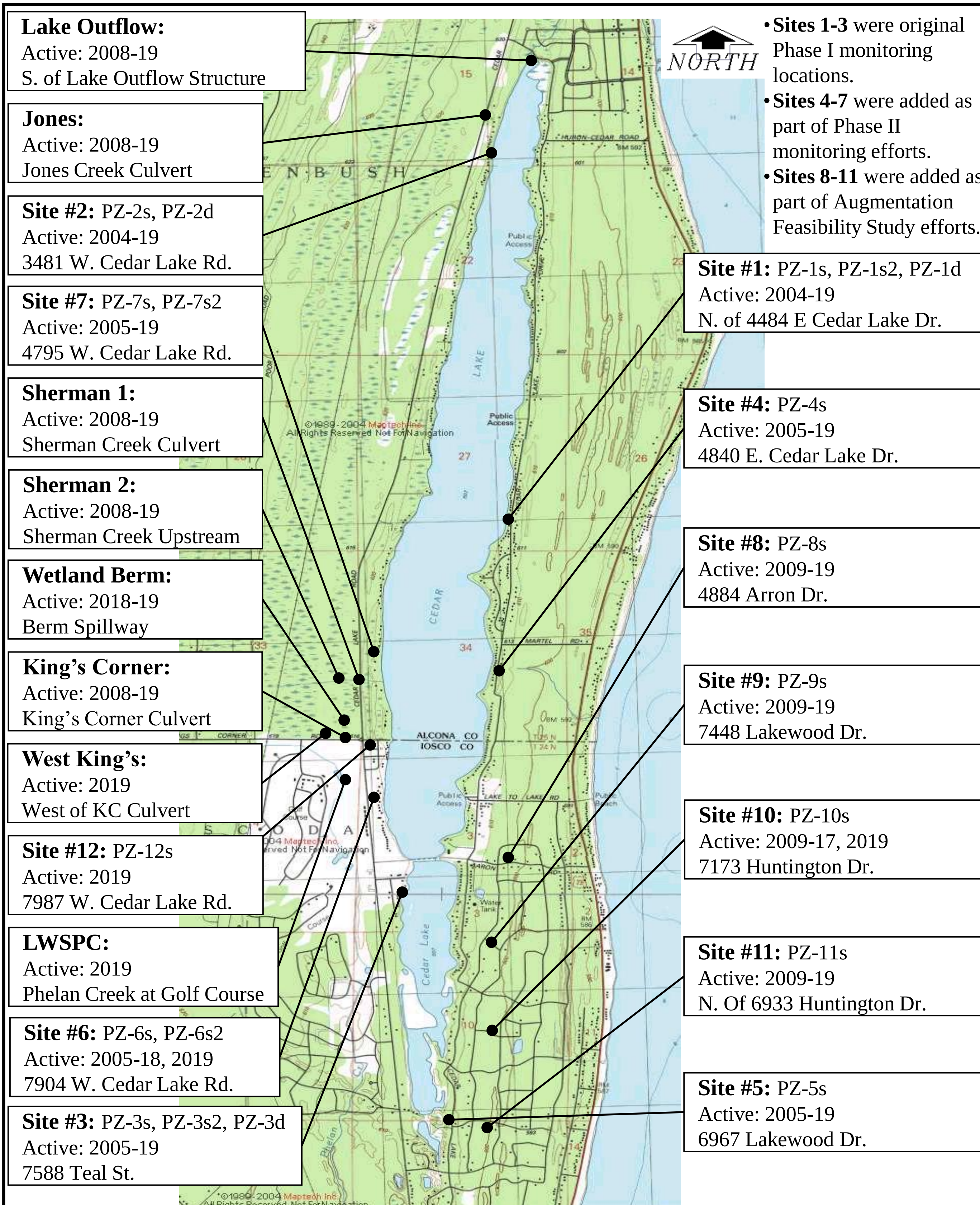
The 2019 data also demonstrate an overall decrease in the volume of water lost through the King's Corner culvert, in spite of comparable precipitation in past years. The wetland berm was completed and active during the 2018 monitoring period and likely accounts for the decreased losses from King's Corner 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. Further improvements are expected in 2020 as a result of the completion of the instream grade structures in Sherman Creek.

Figure 28 demonstrates the overall increase in surface water volume entering Cedar Lake through Sherman and Jones Creeks 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. Moreover, the completed instream grade structures at Sherman Creek may ultimately provide the naturalized solution to mitigate long-term concerns of future lake level drops during dry summers. This improvement will also benefit the ecology of the lake by protecting important springtime fish-spawning habitat.

Based on 2019 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 2020 calendar year. Additional statistical analyses and groundwater monitoring are planned for 2020 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, and 4) other important watershed issues related to the movement of shallow groundwater in the Cedar Lake watershed.

Continuing the monitoring program will necessitate the acquisition of several new water level loggers in 2020 as part of a phased approach to replace those in danger of "aging out" (see Table 1). Additionally, a new rain gauge may need to be acquired in 2020 to continue volunteer precipitation monitoring at Cedar Lake. These considerations will be vital to maintaining a comprehensive and unbroken historic water level record.

2019 Cedar Lake Hydrology Report: List of Tables and Figures



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Map of 2019 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 2019

Piezometer ID #	LL Manufactured Year	LL Age (yrs)	Predicted LL Lifespan (yrs)	Predicted Year of LL "Age-Out"	Status
PZ-01s	2004	14	10	2014	*Functioning but beyond predicted lifespan*
PZ-01s2	2004	14	10	2014	*Functioning but beyond predicted lifespan*
PZ-01d	2004	14	10	2014	*Functioning but beyond predicted lifespan*
PZ-02d	2004	14	10	2014	*Functioning but beyond predicted lifespan*
PZ-03s	2004	14	10	2014	*Functioning but beyond predicted lifespan*
PZ-03s2	2004	14	10	2014	*Functioning but beyond predicted lifespan*
PZ-03d	2004	14	10	2014	*Functioning but beyond predicted lifespan*
PZ-04s	2005	13	10	2015	*Functioning but beyond predicted lifespan*
PZ-04s Barlog (backup)	2005	13	10	2015	*Functioning but beyond predicted lifespan*
PZ-07s	2005	13	10	2015	*Functioning but beyond predicted lifespan*
PZ-07s2	2005	13	10	2015	*Functioning but beyond predicted lifespan*
PZ-10s	2005	13	10	2015	*Functioning but nearing predicted lifespan*
Jones Creek	2008	10	10	2018	*Functioning but beyond predicted lifespan*
PZ-05s	2009	9	10	2019	*Functioning but beyond predicted lifespan*
PZ-08s	2009	9	10	2019	*Functioning but beyond predicted lifespan*
PZ-09s	2009	9	10	2019	*Functioning but beyond predicted lifespan*
PZ-11s	2009	9	10	2019	*Functioning but beyond predicted lifespan*
Wetland Berm	2017	1	10	2027	*New (Added site in 2017)*
PZ-02s	2017	1	10	2027	*New, replaced "Aged-Out" Logger in 2017*
Sherman 1 (Culvert)	2018	0	10	2028	*New, replaced "Aged-Out" logger in 2019*
Sherman 2 (Wetland)	2018	0	10	2028	*New, replaced "Aged-Out" logger in 2019*
Kings Corner	2018	0	10	2028	*New, replaced "Aged-Out" logger in 2019*
Kings Corner Barlog	2018	0	10	2028	*New, replaced "Aged-Out" logger in 2019*
Lake Out	2018	0	10	2028	*New, replaced "Aged-Out" logger in 2019*
PZ-12s	2018	0	10	2028	*New (Added site in 2019)*
WEST Kings	2018	0	10	2028	*New (Added site in 2019)*
LWSPC	2018	0	10	2028	*New (Added site in 2019)*
PZ-06s	2018	0	10	2028	*New (Moved site in 2019)*
PZ-06s2	2018	0	10	2028	*New (Moved site in 2019)*

Table 2. Comparison of Surface Water Volumes from May 1 to Sep 30, 2014 to 2019.

Site	Surface Water Volume (Mgal)					
	2014	2015	2016	2017	2018	2019
Sherman Creek (inflow to CL)	136.04	190.929	198.126	449.441*[3]	328.134	446.753
Jones Creek (inflow to CL)	64.817	21.587	17.964	59.784**	10.121	87.514
Cedar Lake Outlet (outflow from CL)	13.003	109.5	0.162*[1]	26.123	51.975	143.156
Kings Corner (outflow away from CL)	32.208	46.862	17.049*[2]	38.053	4.384	10.161

*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 2. 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
East Tawas (US

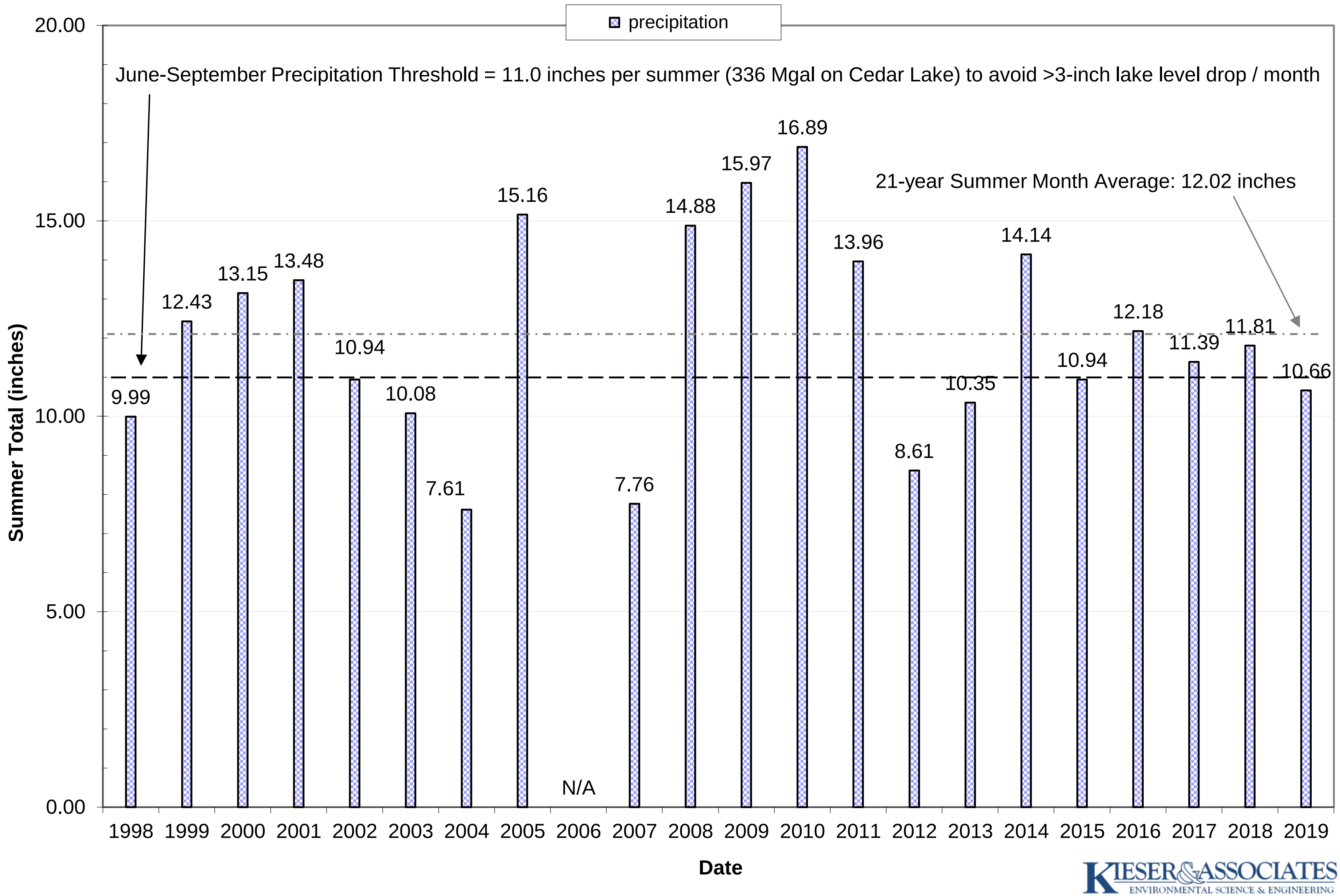

Figure 3. 2019 Cedar Lake Water Elevation and Measured Rainfall

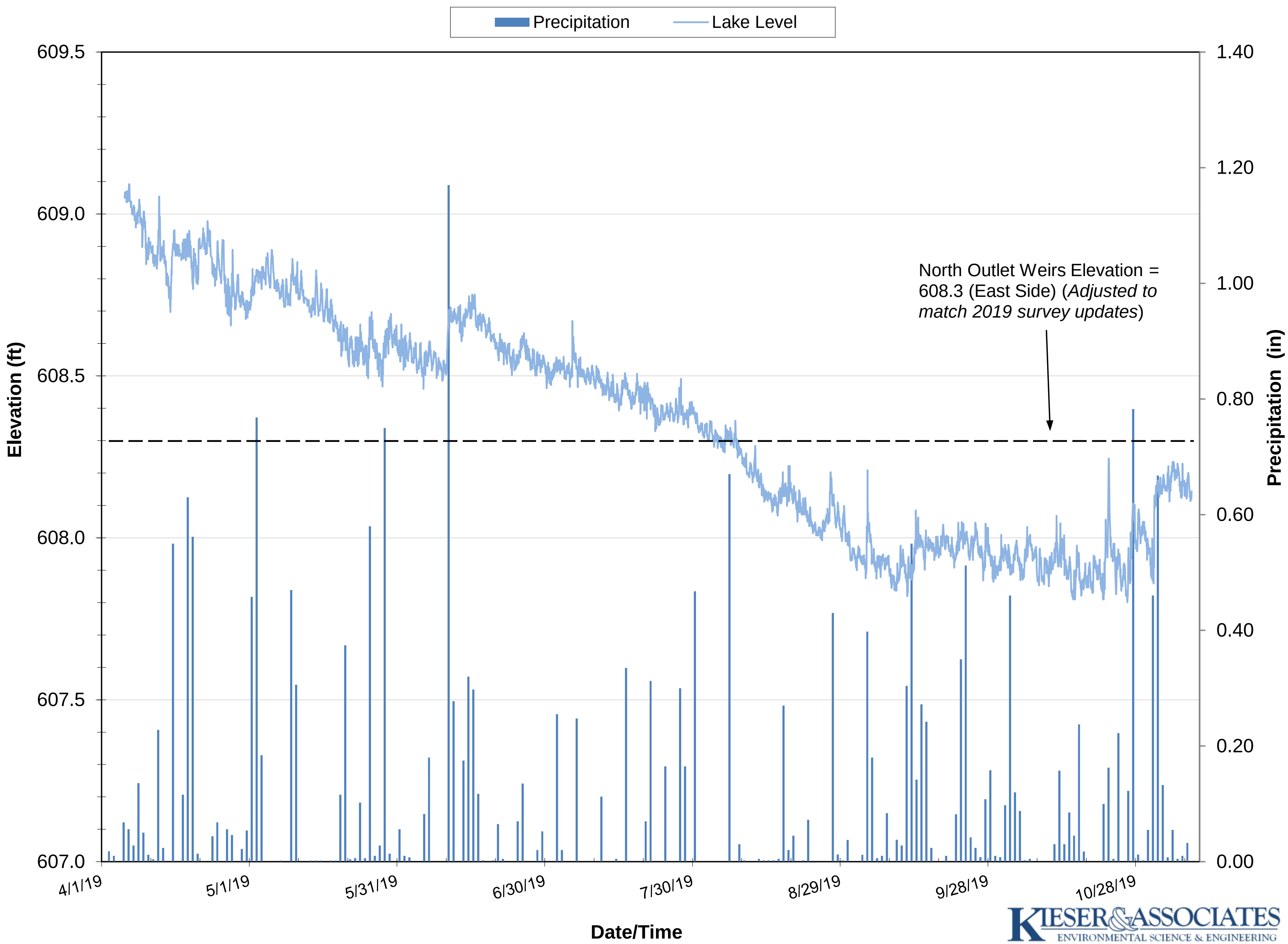

Figure 4. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 1)

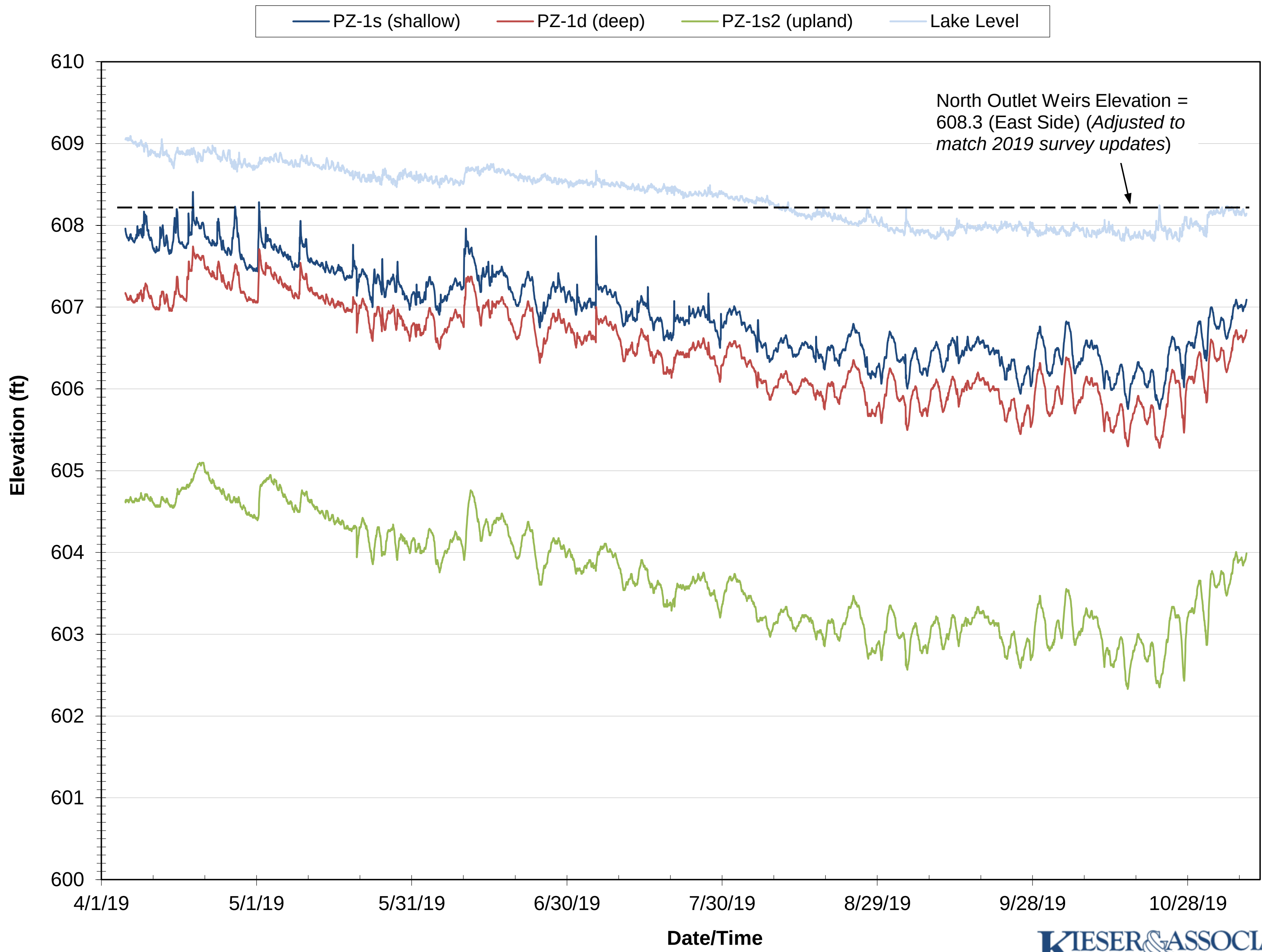

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Figure 5. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 2)

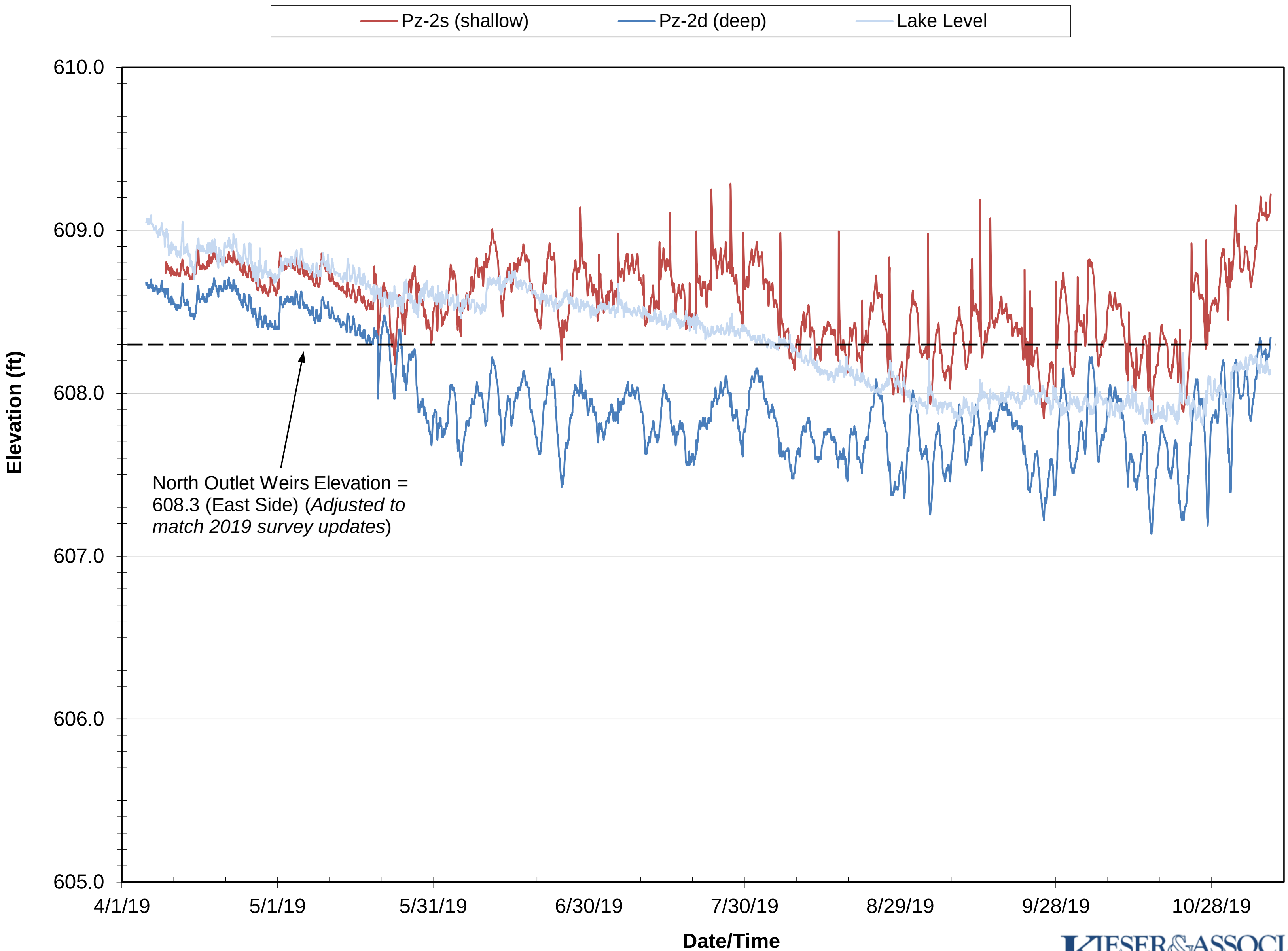

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Figure 6. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 3)

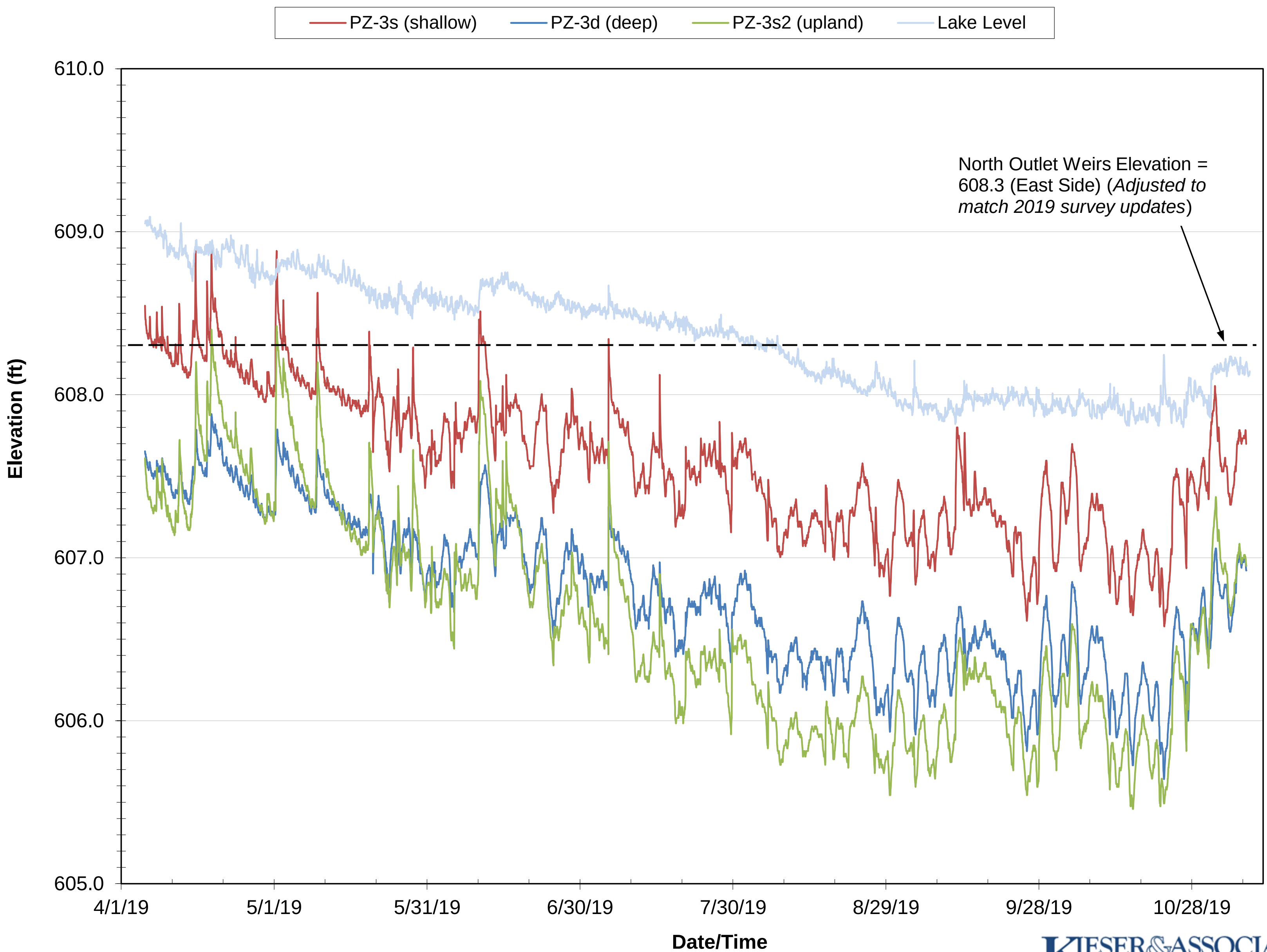

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Figure 7. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 4)

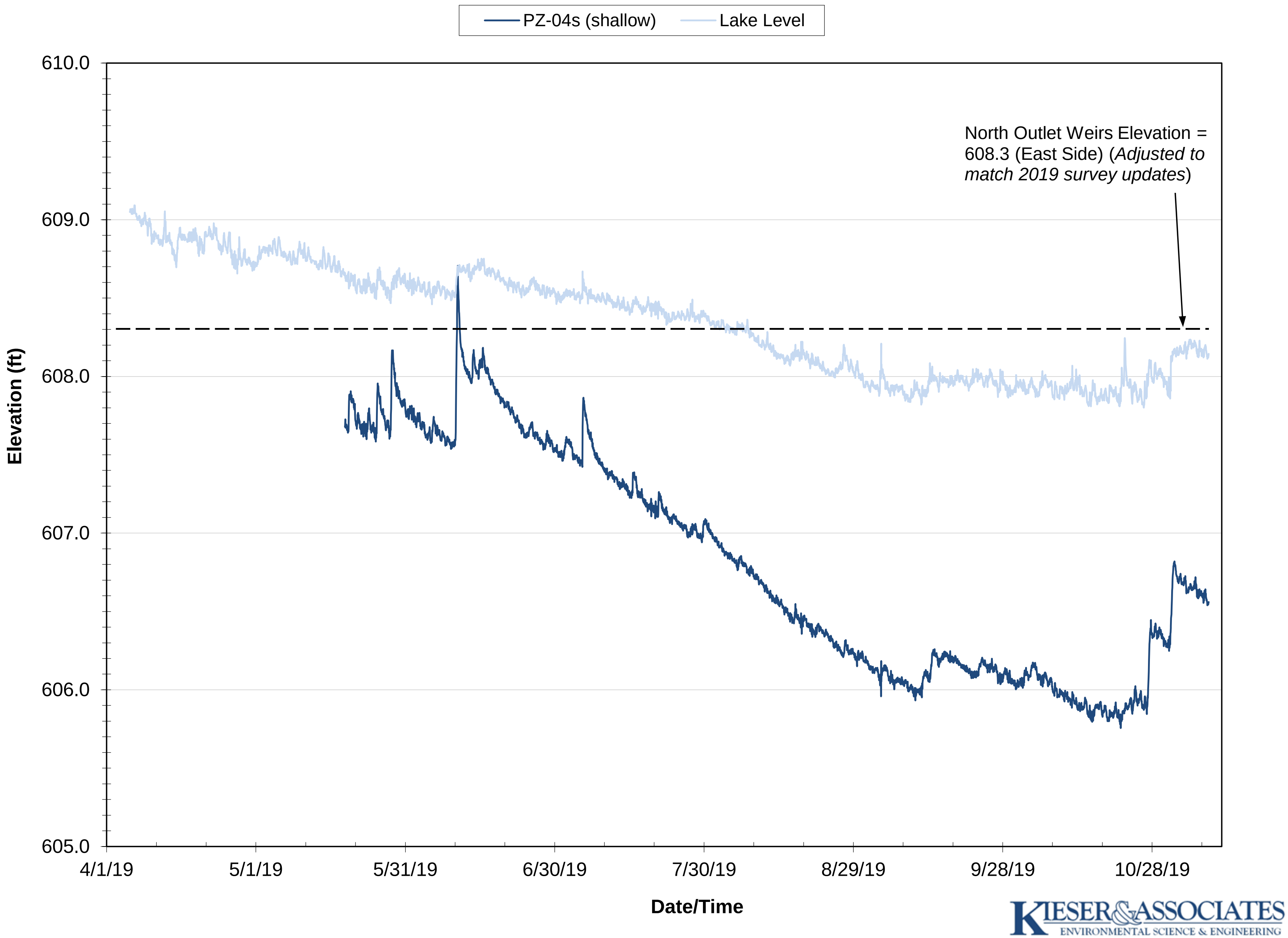

Figure 8. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 5)

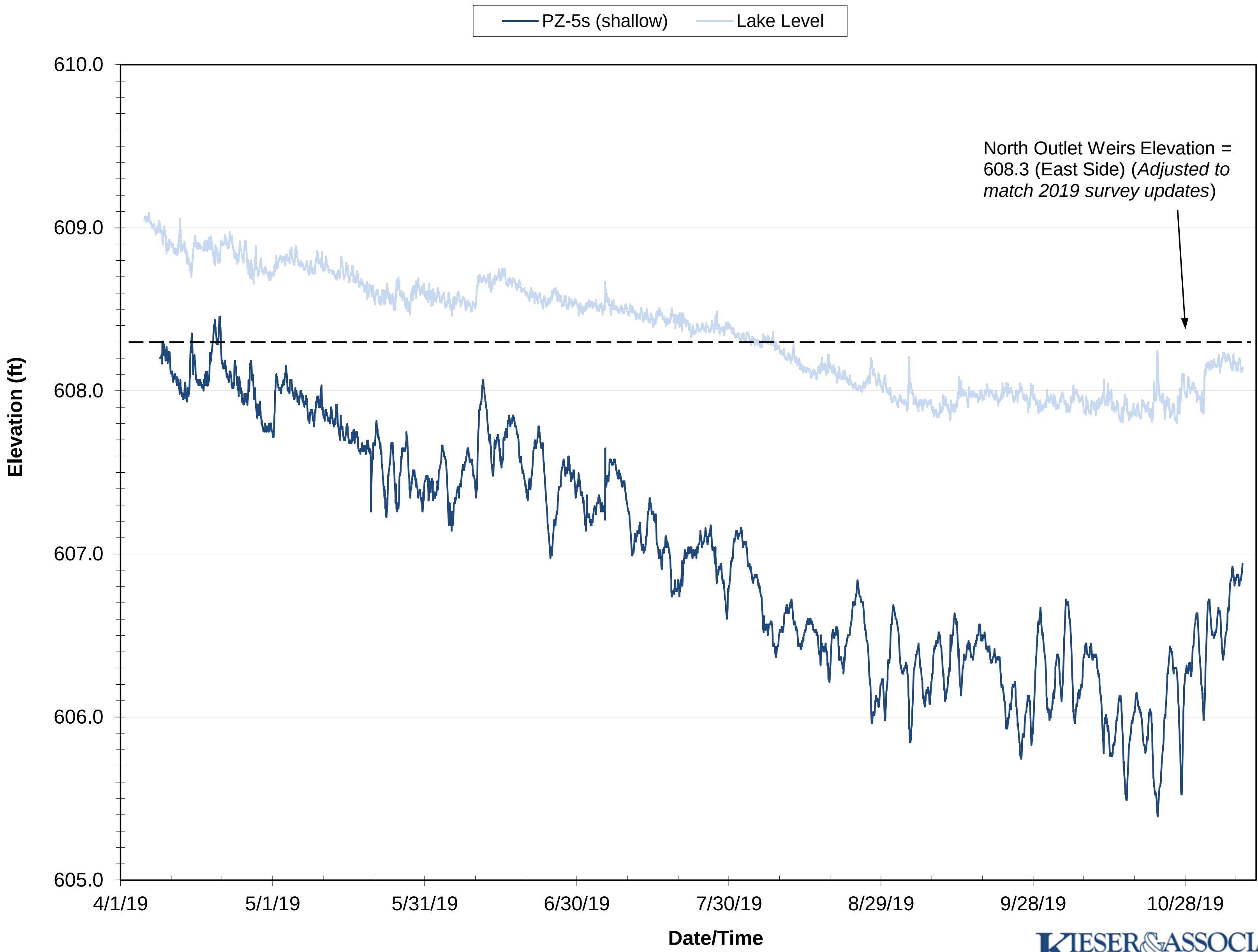

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Figure 9. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 6 - *New Location, 2019*)

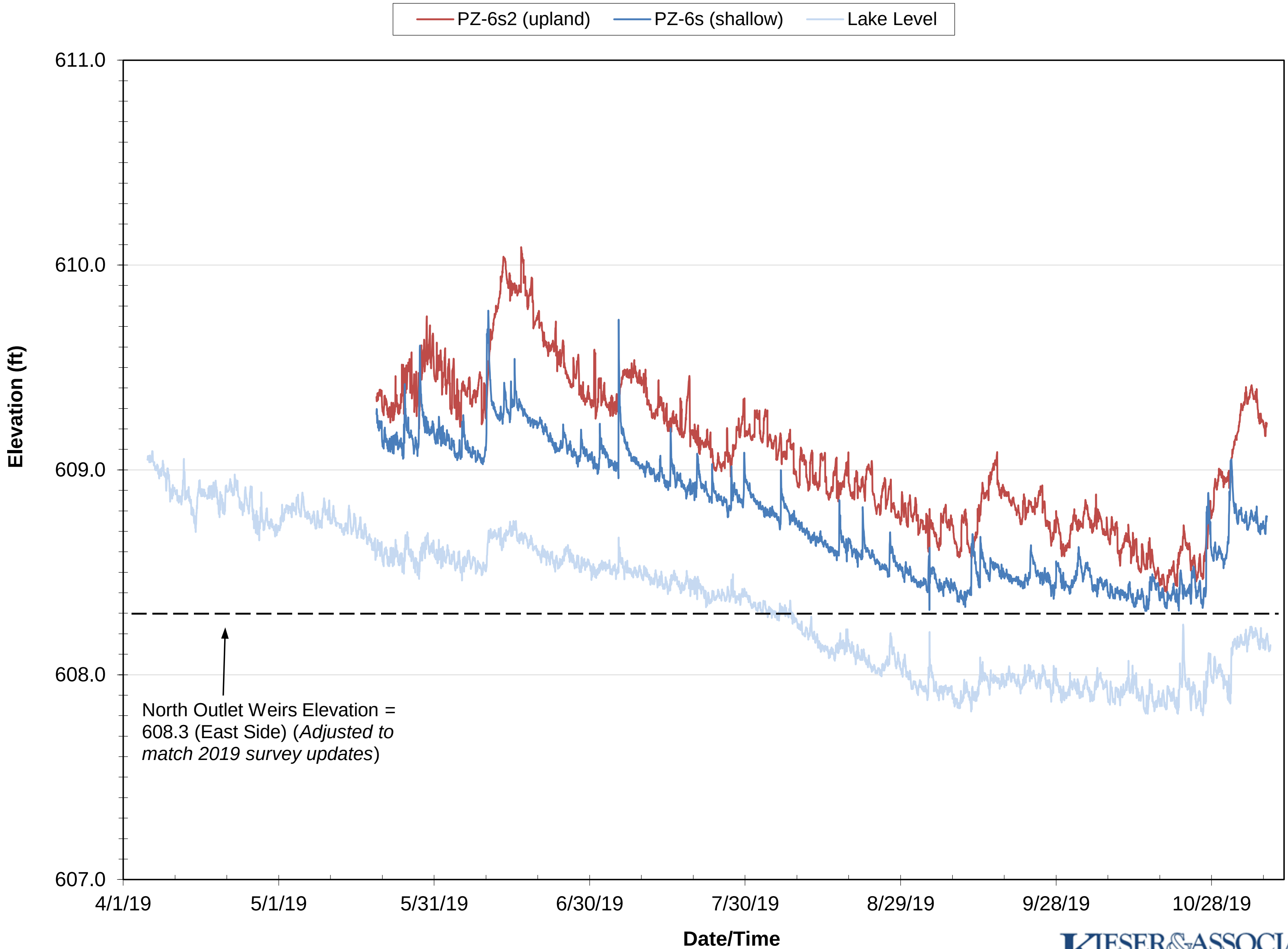

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Figure 10. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 7)

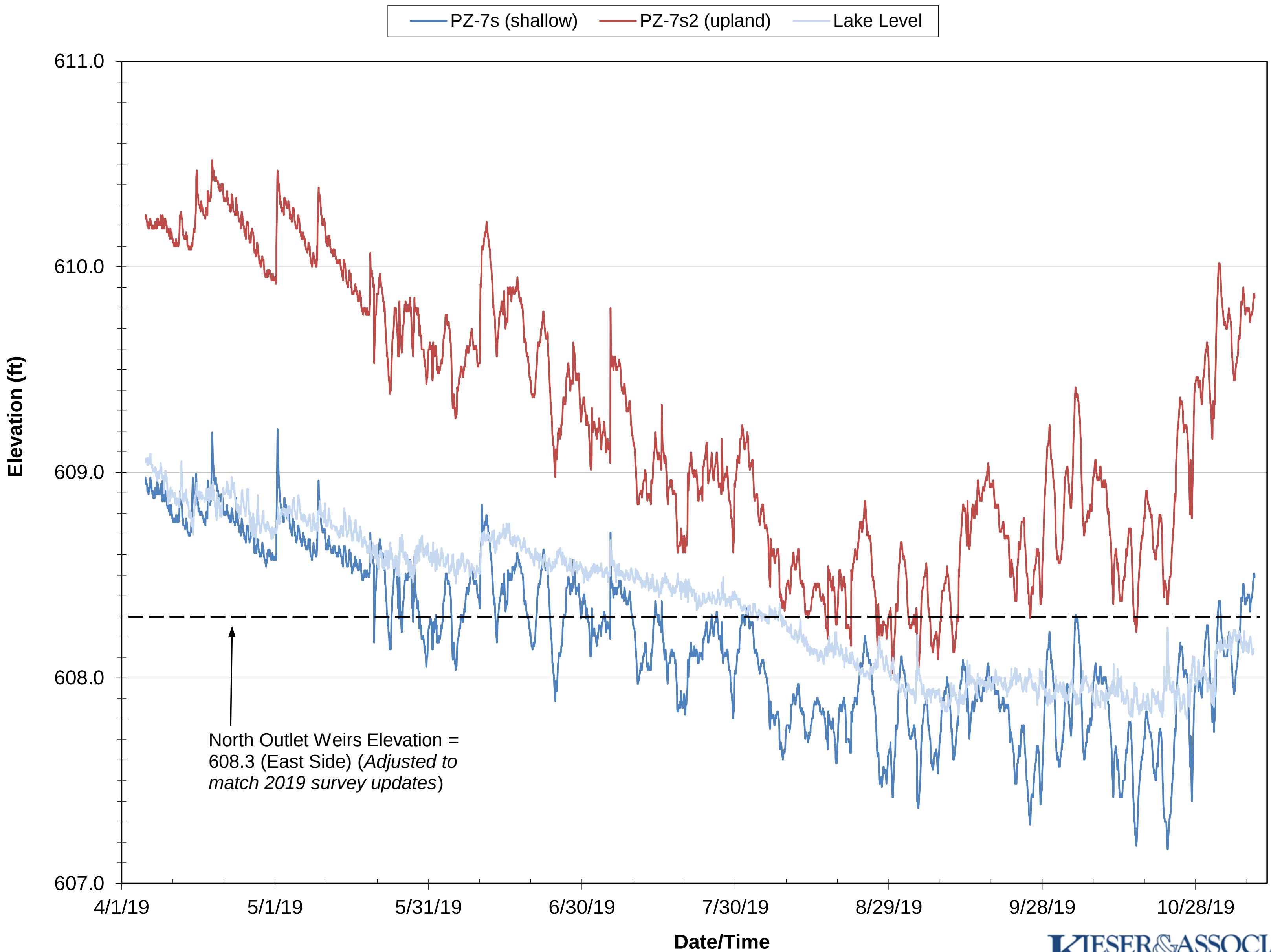

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Figure 11. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 8)

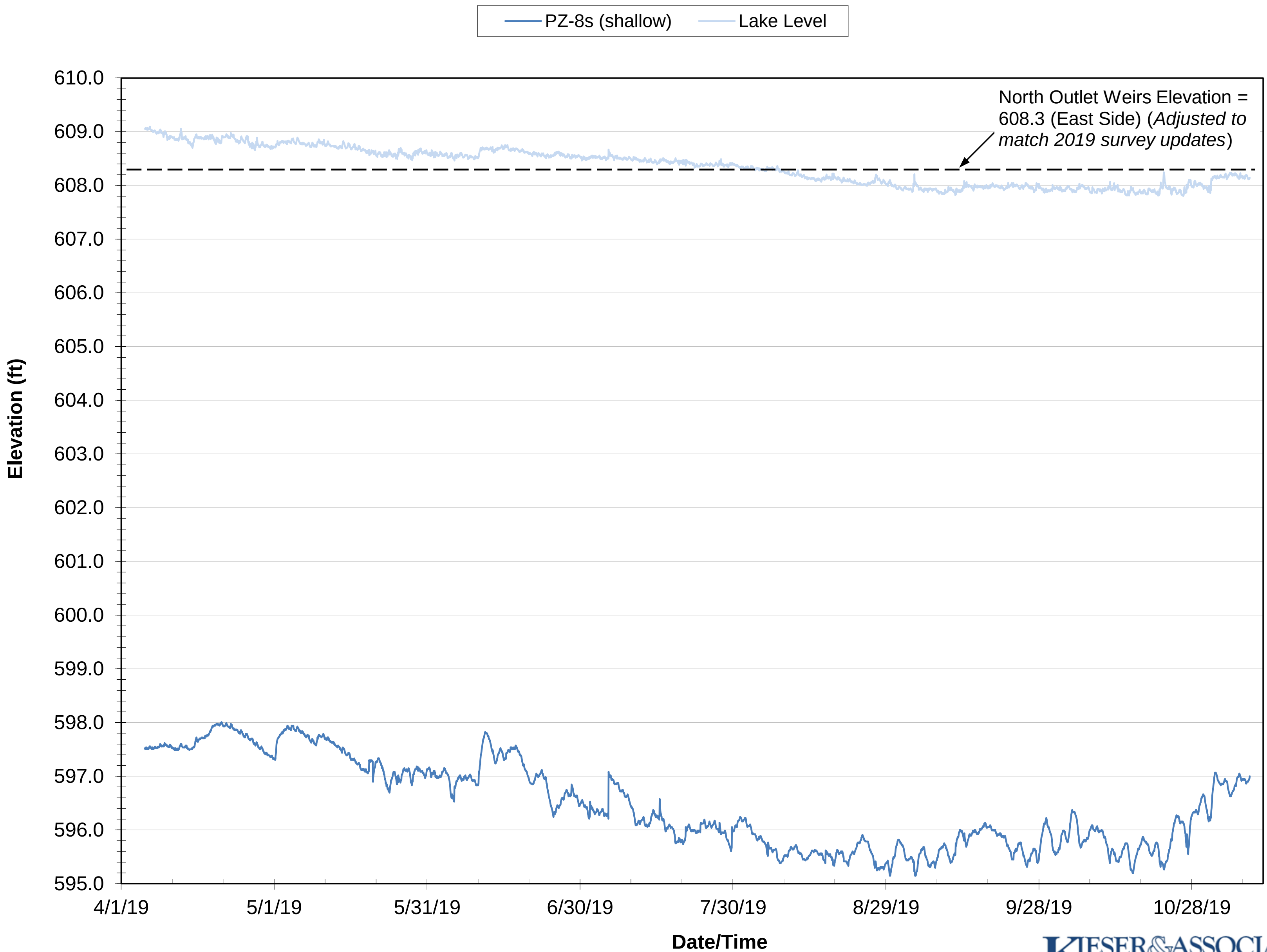

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Figure 12. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 9)

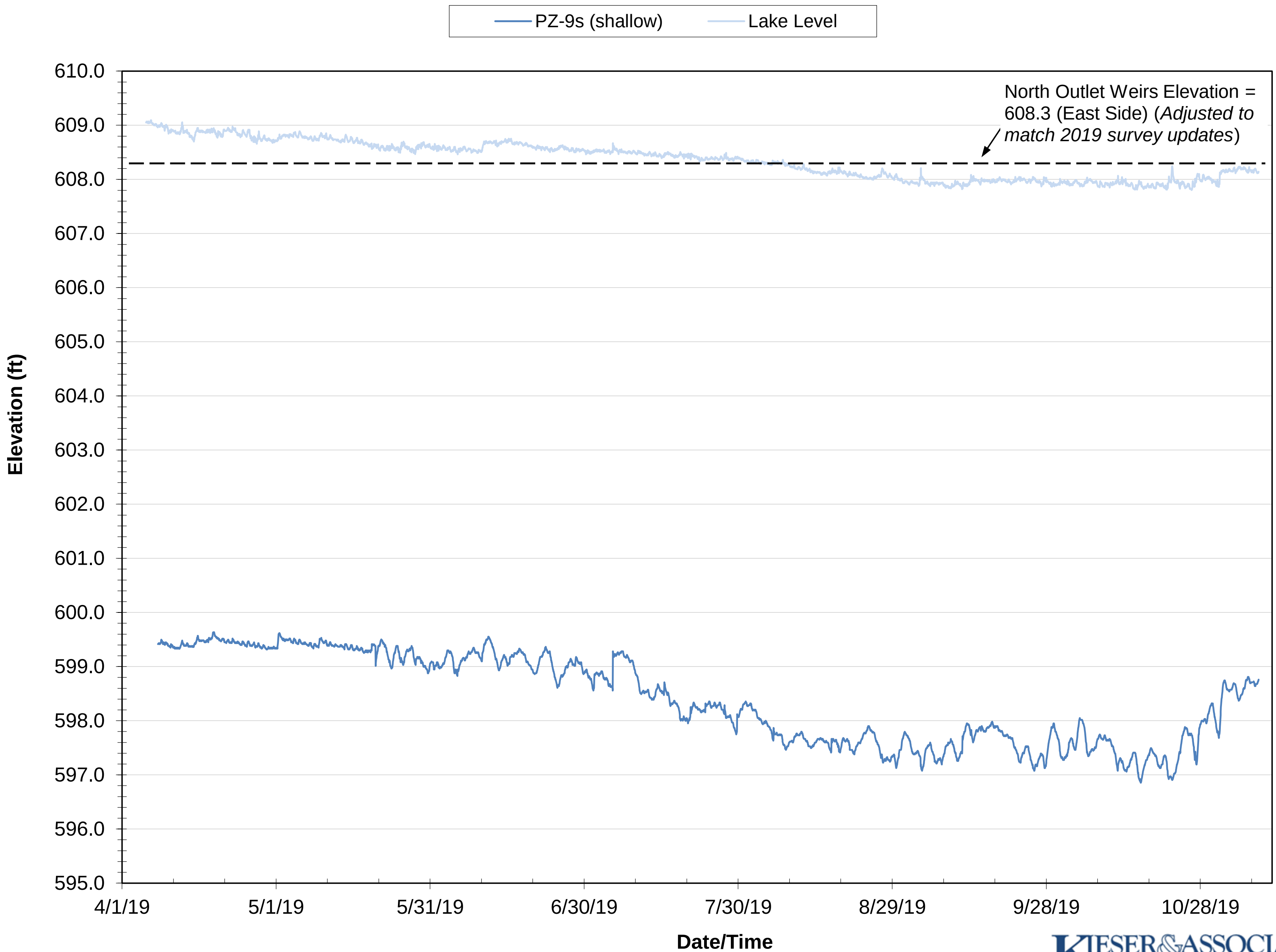

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Figure 13. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 10)

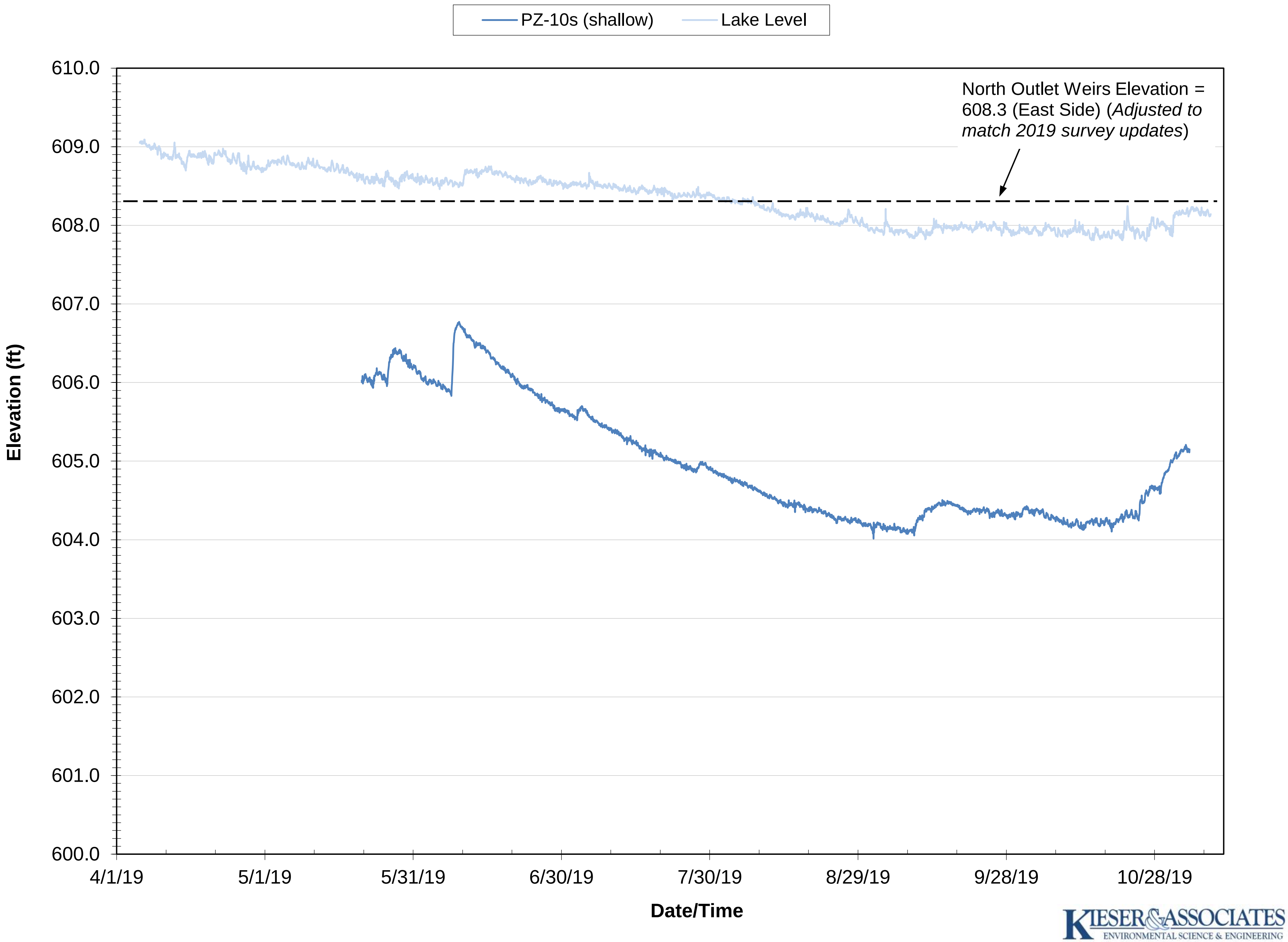

Figure 14. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 11)

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Figure 15. 2019 Cedar Lake Groundwater / Surface Water Elevations (Site 12)

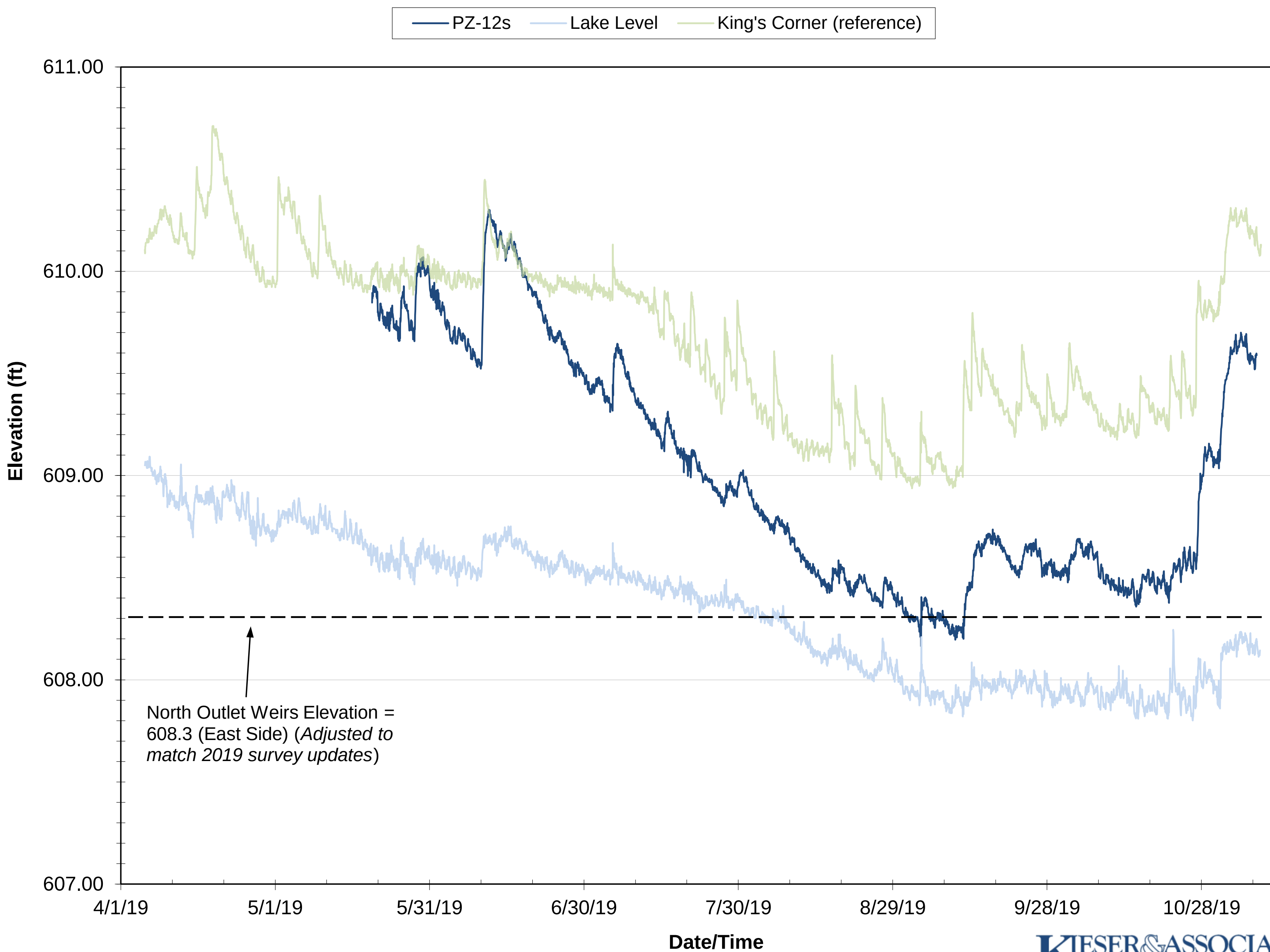

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Figure 16. 2019 Cedar Lake Groundwater / Surface Water Elevations (West Kings)

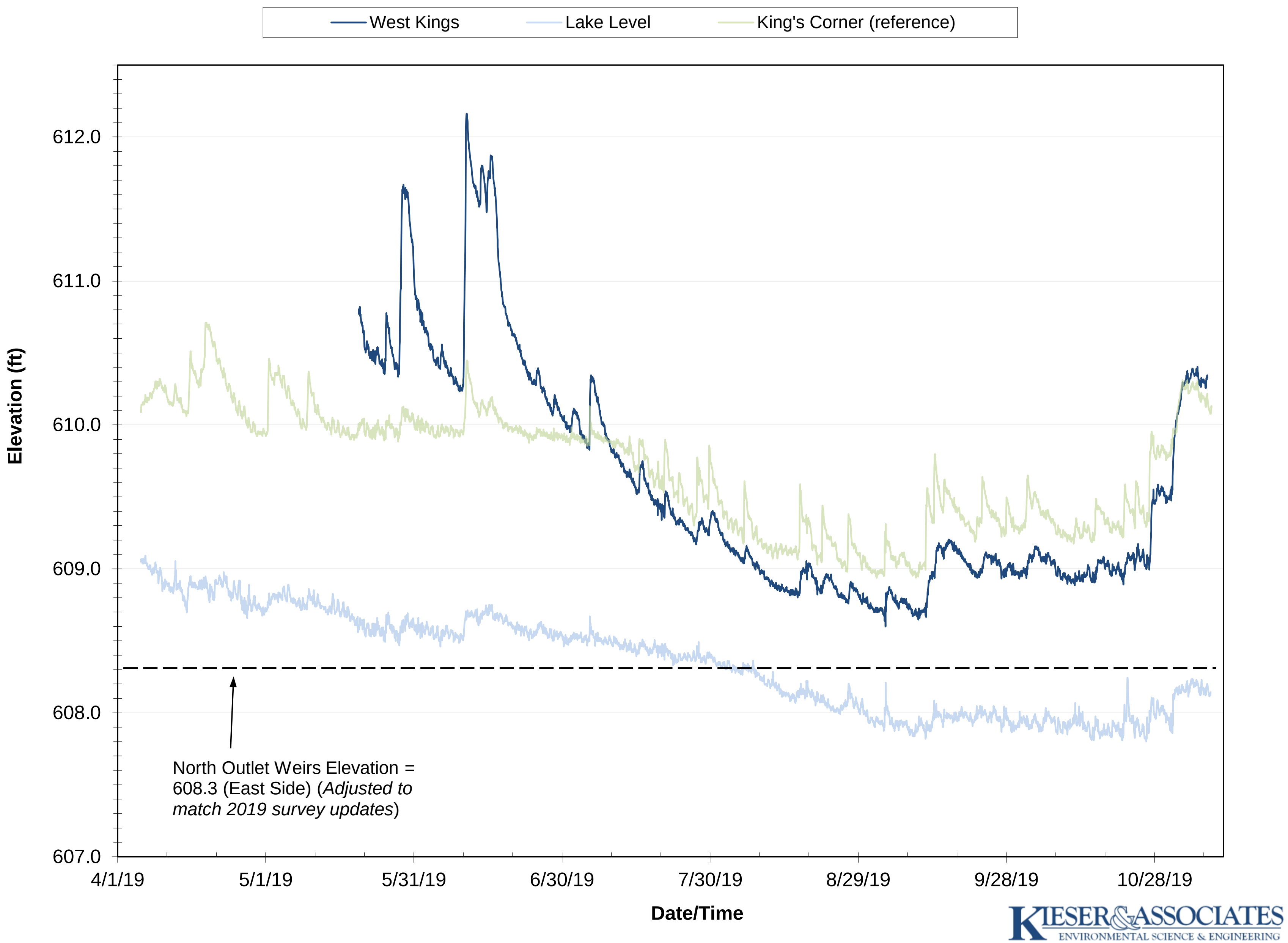


Figure 17. 2019 Cedar Lake Groundwater / Surface Water Elevations (Lakewood Shores Phelan Creek: LWSPC)

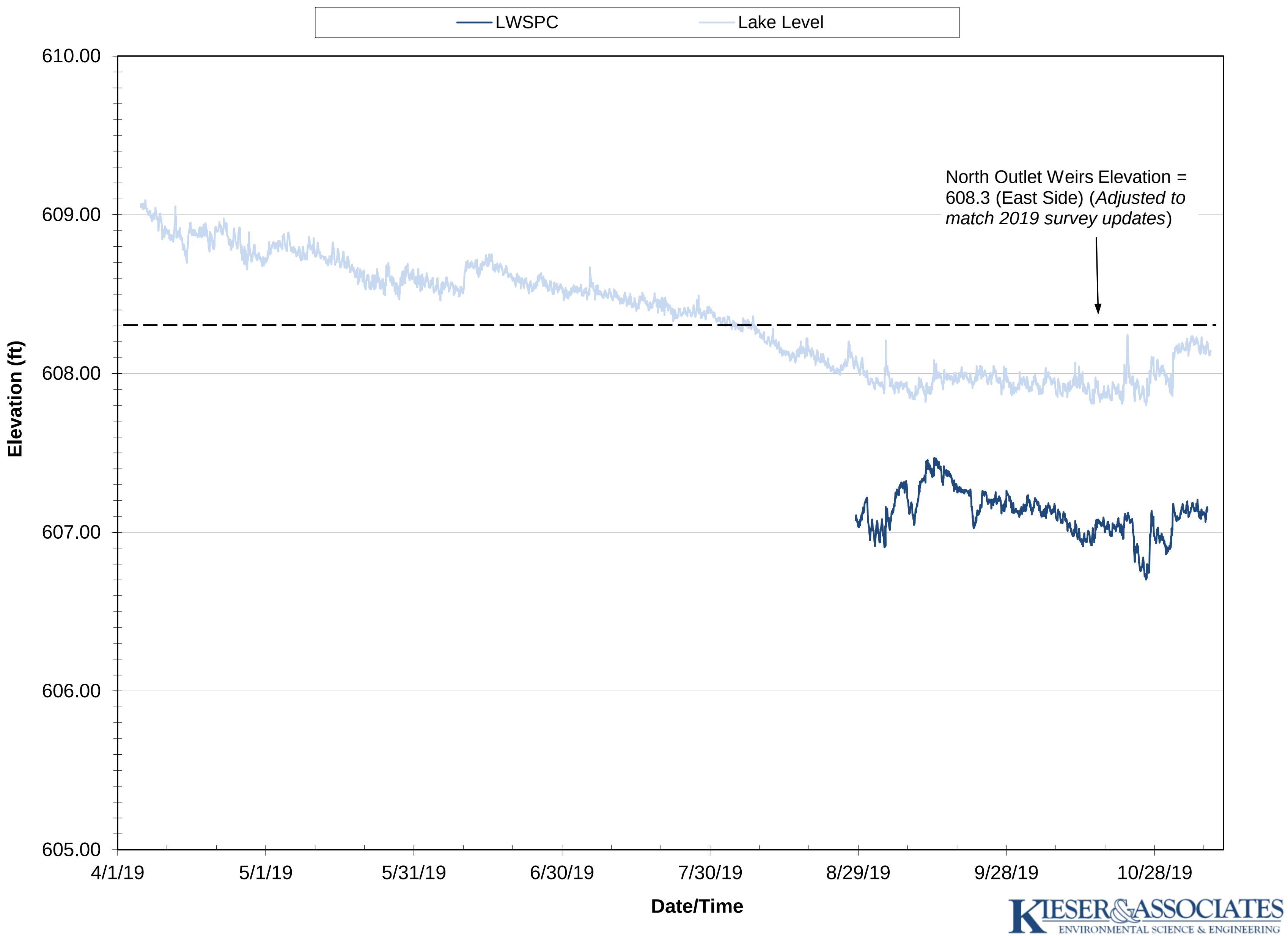


Figure 18. 2019 Groundwater / Surface Water Elevations
King's Corner Area Loggers

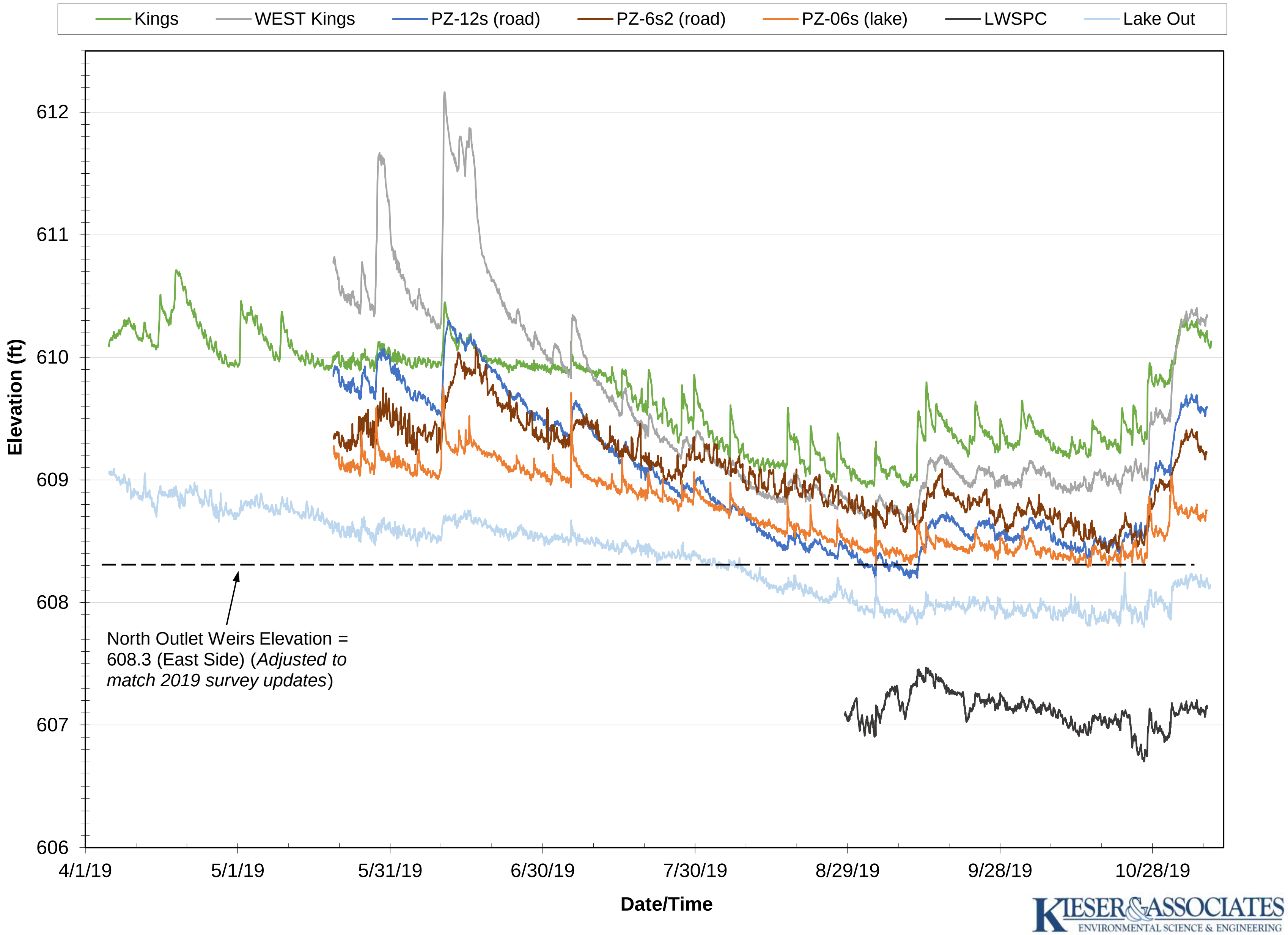
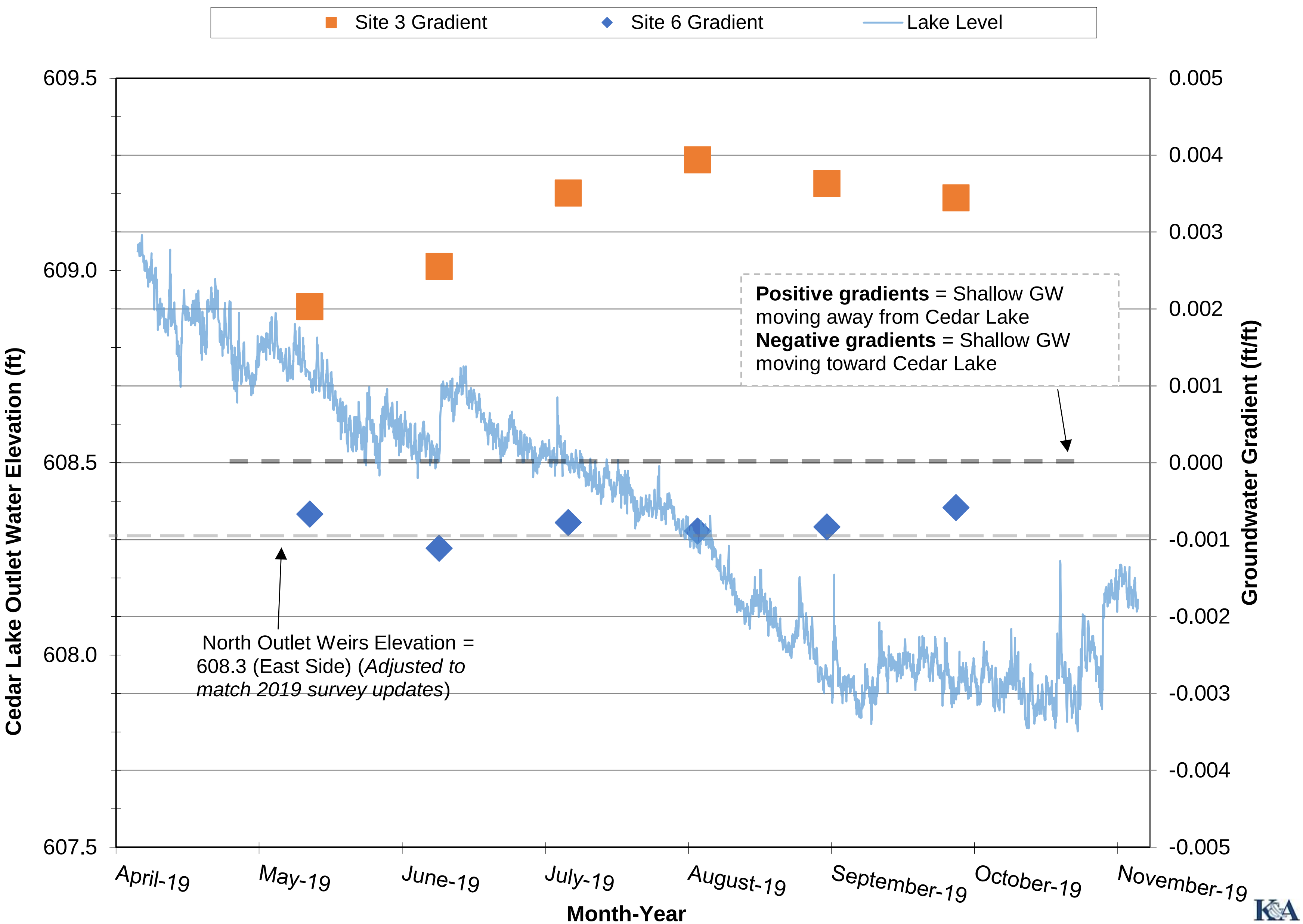


Figure 19. 2019 Monthly Avg. Groundwater Gradients, Site 3 and Site 6



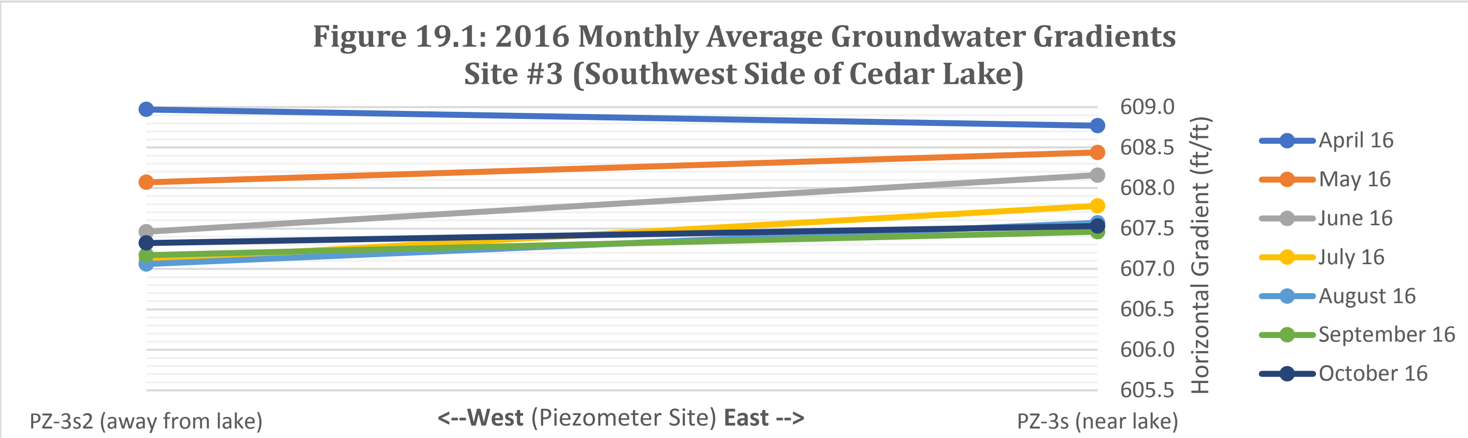


Figure 19.1: 2016 Monthly Average Groundwater Gradients
Site #3 (Southwest Side of Cedar Lake)
609.0
608.5
608.0
607.5
607.0
606.5
606.0
605.5
Horizontal Gradient (ft/ft)
April 16
May 16
June 16
July 16
August 16
September 16
October 16
PZ-3s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-3s (near lake)

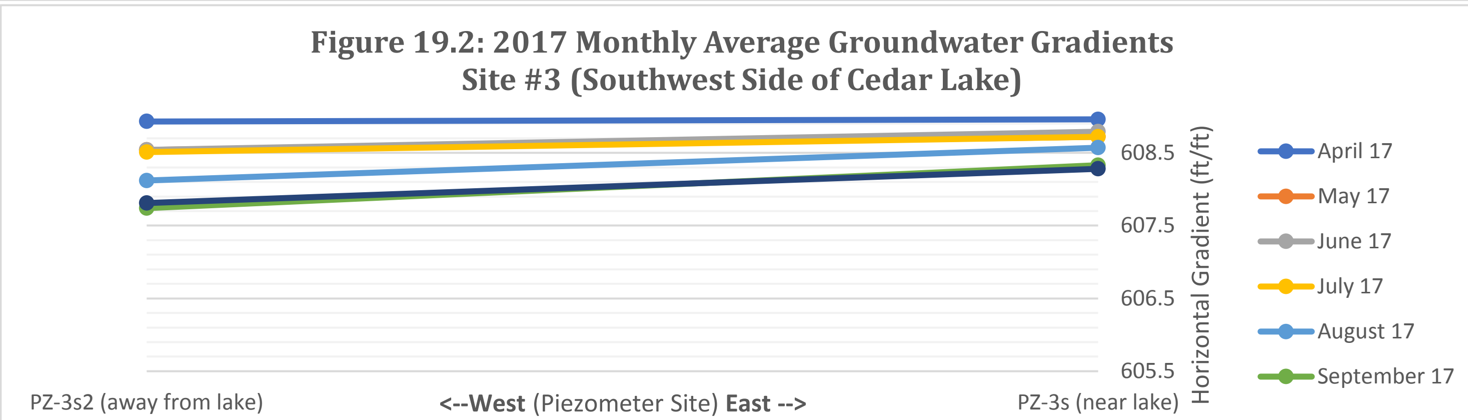


Figure 19.2: 2017 Monthly Average Groundwater Gradients
Site #3 (Southwest Side of Cedar Lake)
608.5
607.5
606.5
605.5
Horizontal Gradient (ft/ft)
April 17
May 17
June 17
July 17
August 17
September 17
PZ-3s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-3s (near lake)

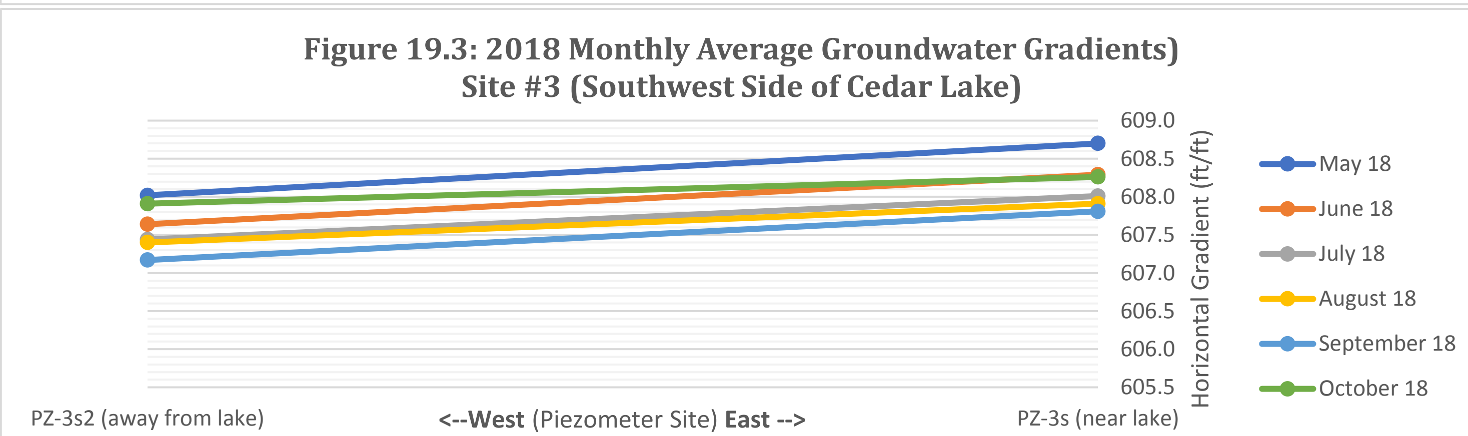


Figure 19.3: 2018 Monthly Average Groundwater Gradients)
Site #3 (Southwest Side of Cedar Lake)
609.0
608.5
608.0
607.5
607.0
606.5
606.0
605.5
Horizontal Gradient (ft/ft)
May 18
June 18
July 18
August 18
September 18
October 18
PZ-3s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-3s (near lake)

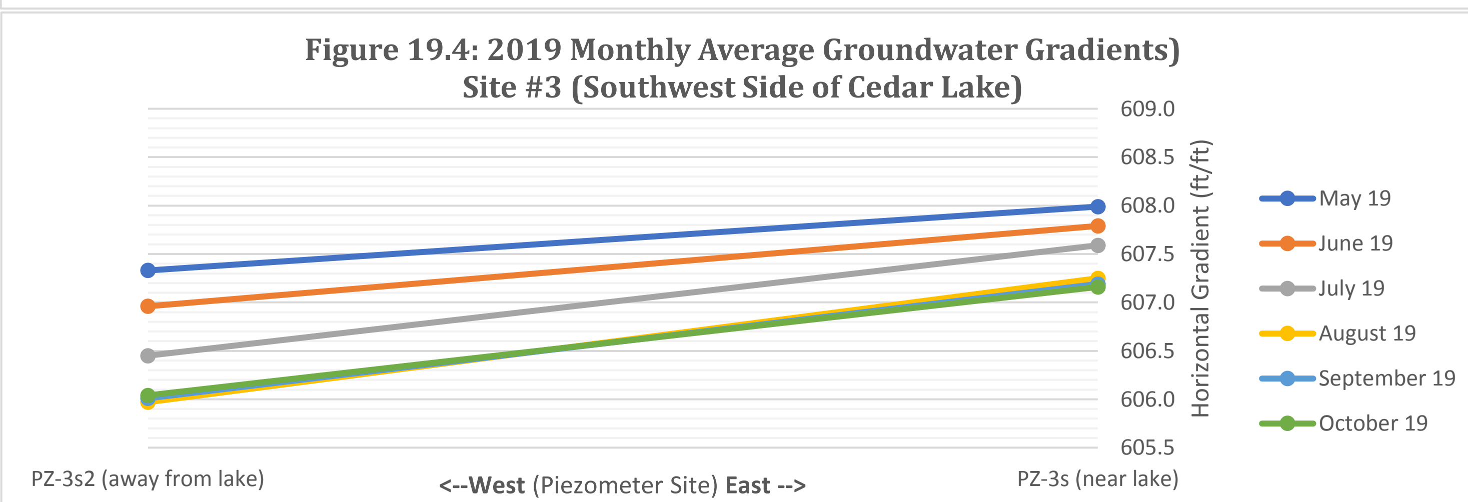


Figure 19.4: 2019 Monthly Average Groundwater Gradients)
Site #3 (Southwest Side of Cedar Lake)
609.0
608.5
608.0
607.5
607.0
606.5
606.0
605.5
Horizontal Gradient (ft/ft)
May 19
June 19
July 19
August 19
September 19
October 19
PZ-3s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-3s (near lake)

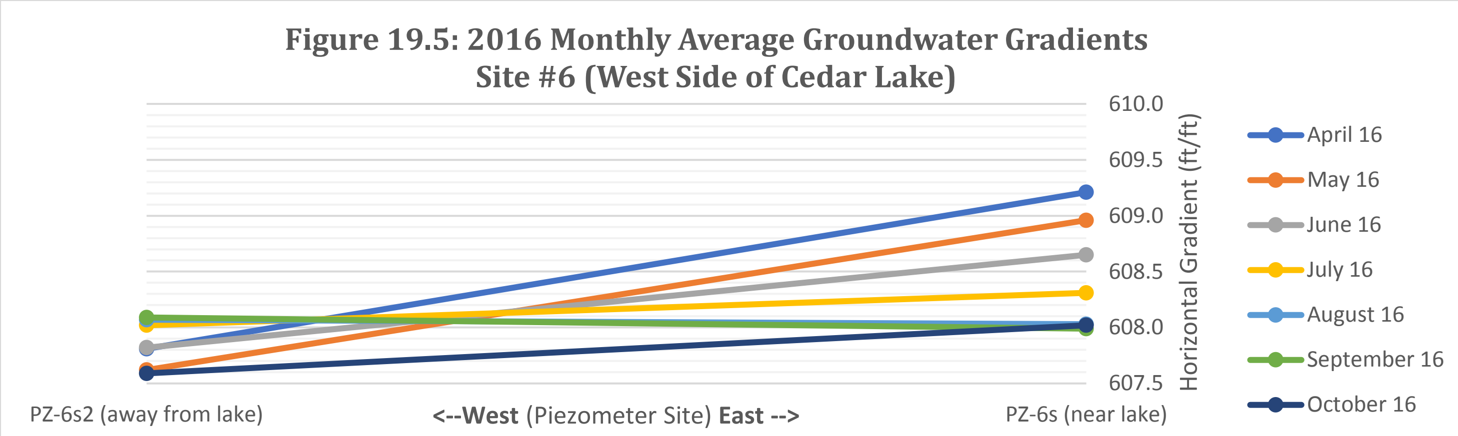


Figure 19.5: 2016 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
610.0
609.5
609.0
608.5
608.0
607.5
Horizontal Gradient (ft/ft)
PZ-6s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-6s (near lake)
April 16
May 16
June 16
July 16
August 16
September 16
October 16

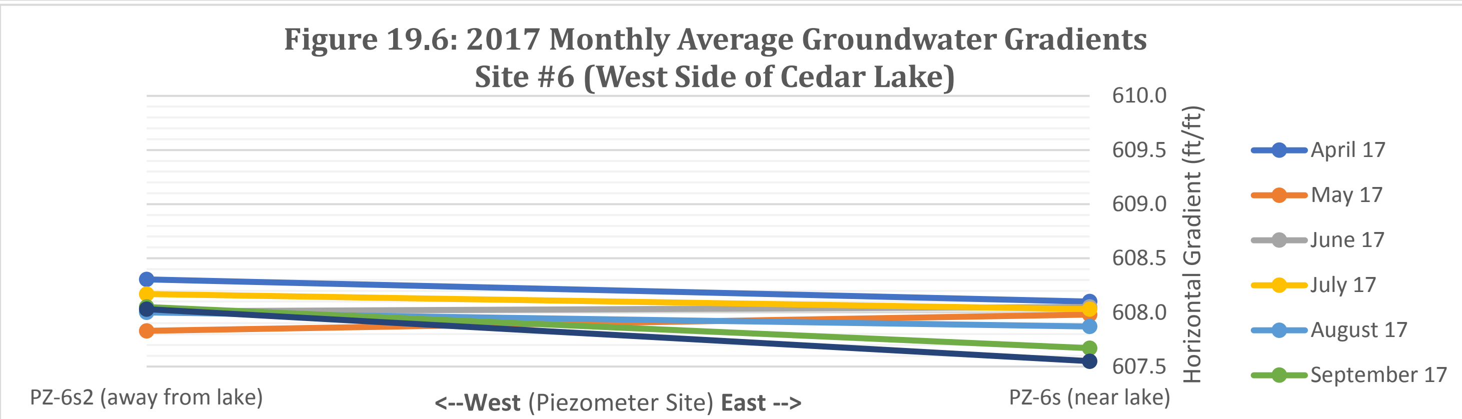


Figure 19.6: 2017 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
610.0
609.5
609.0
608.5
608.0
607.5
Horizontal Gradient (ft/ft)
PZ-6s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-6s (near lake)
April 17
May 17
June 17
July 17
August 17
September 17

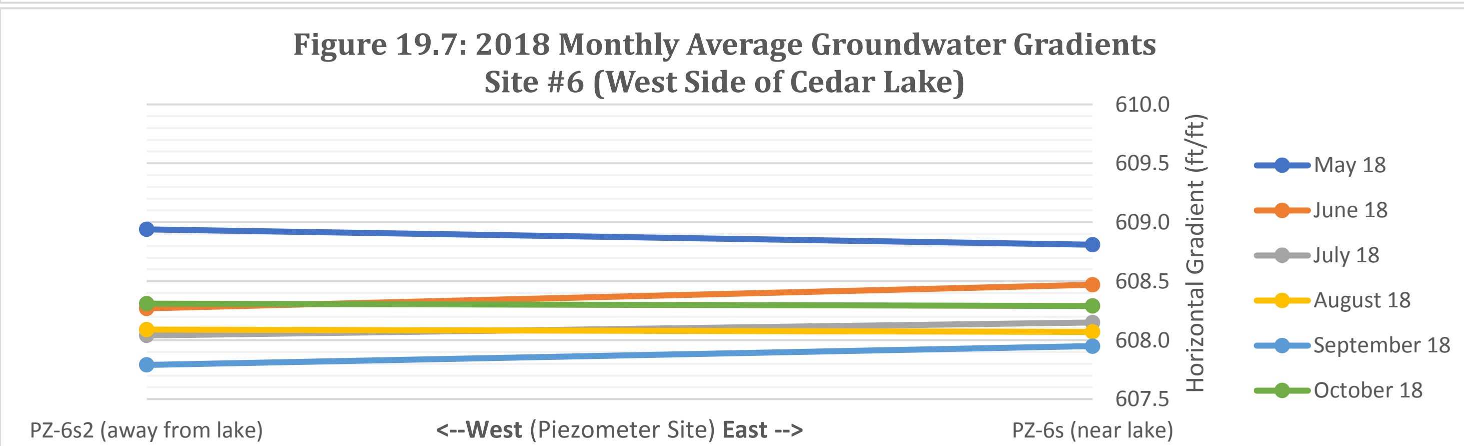


Figure 19.7: 2018 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
610.0
609.5
609.0
608.5
608.0
607.5
Horizontal Gradient (ft/ft)
PZ-6s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-6s (near lake)
May 18
June 18
July 18
August 18
September 18
October 18

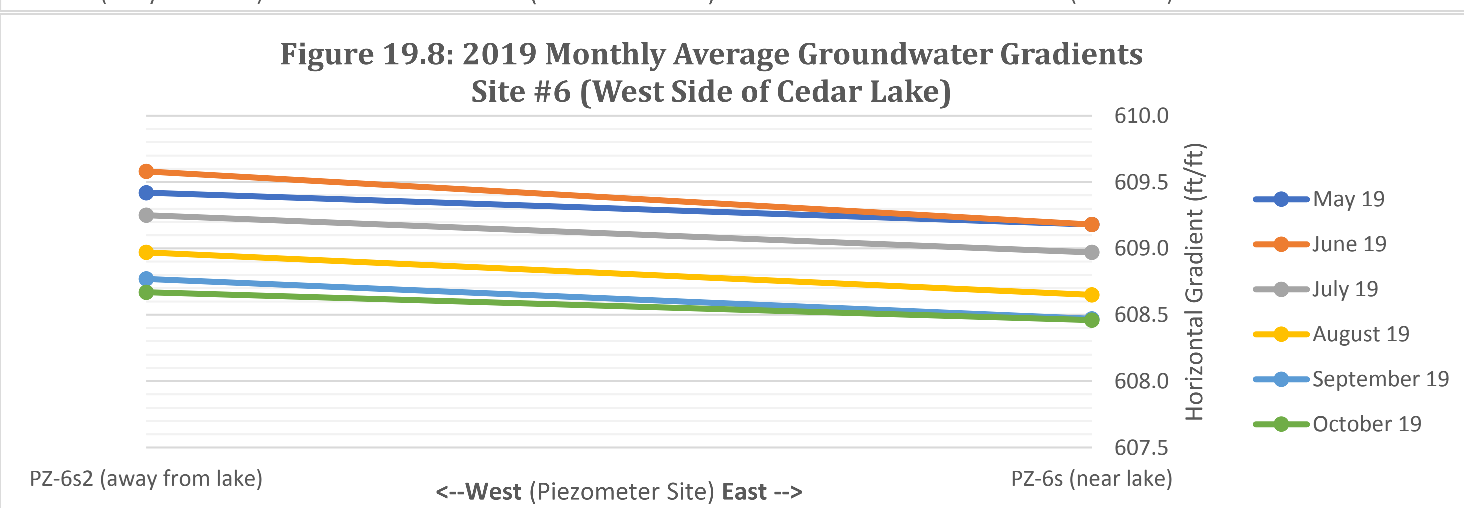


Figure 19.8: 2019 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
610.0
609.5
609.0
608.5
608.0
607.5
Horizontal Gradient (ft/ft)
PZ-6s2 (away from lake)
<--West (Piezometer Site) East -->
PZ-6s (near lake)
May 19
June 19
July 19
August 19
September 19
October 19

Figure 20. 2019 Estimated Jones Creek Flows

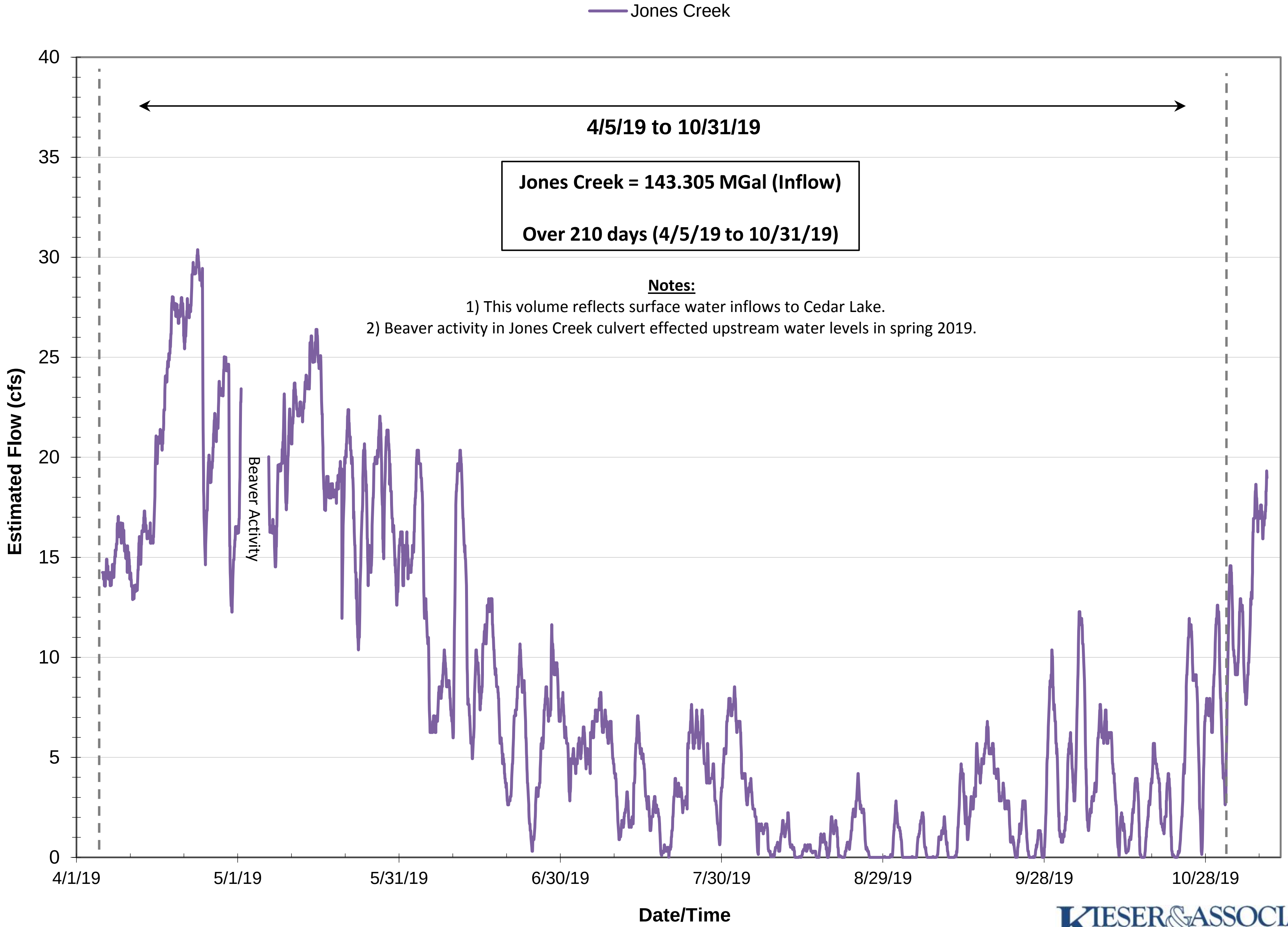


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Figure 21. 2019 Estimated Sherman Creek Flows

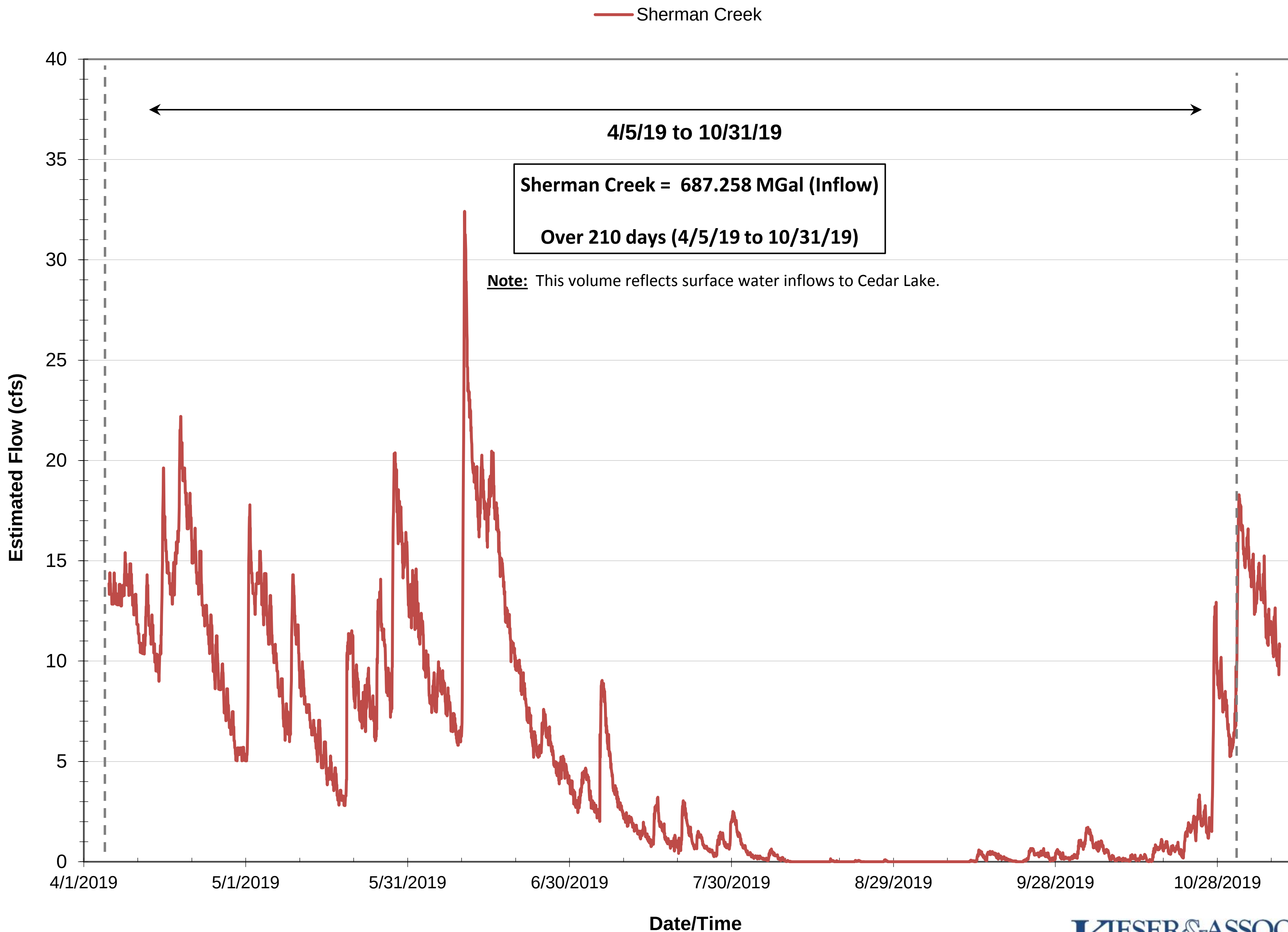

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Figure 22. 2019 Estimated Cedar Lake Outflows

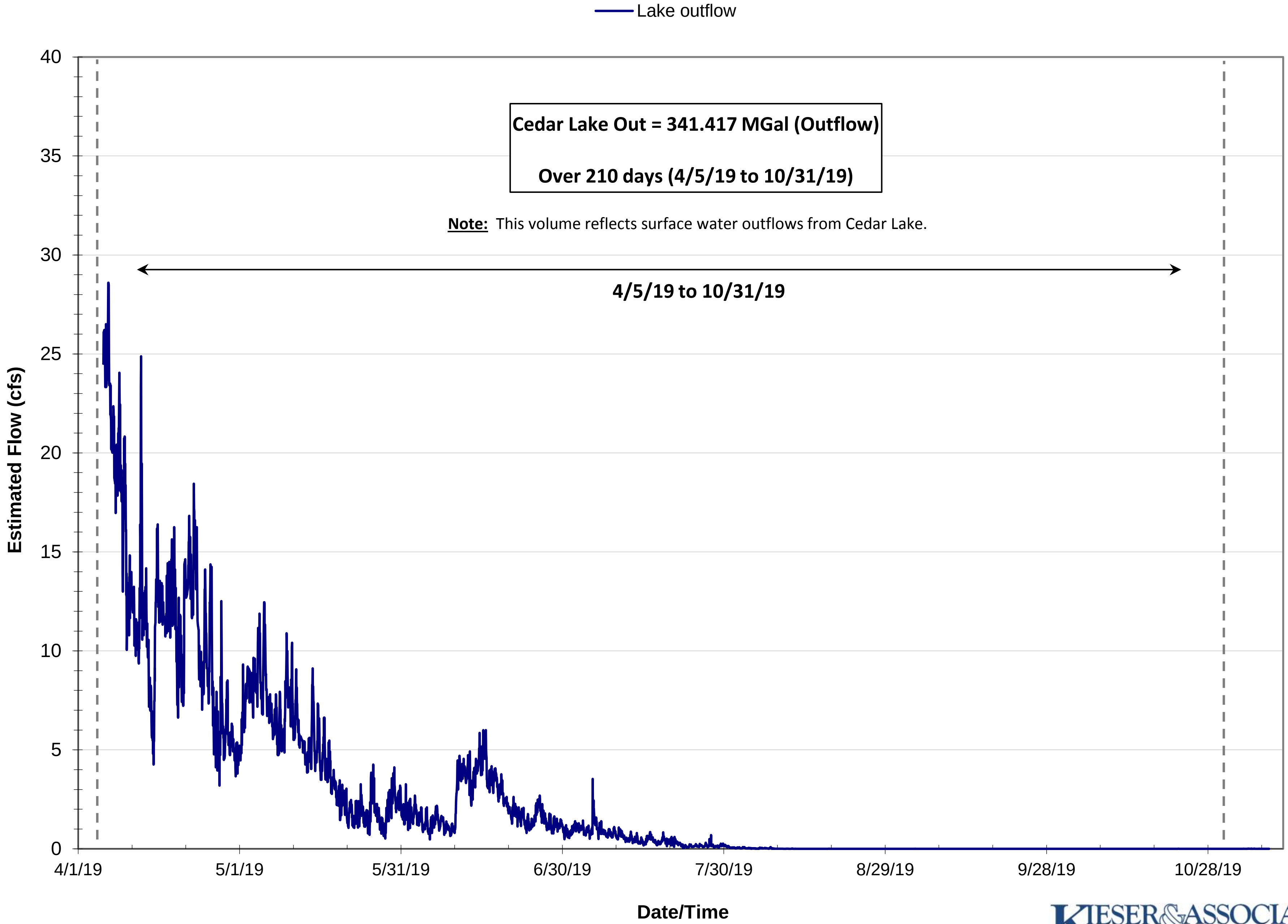

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Figure 23. 2019 Estimated Kings Corner Outflow

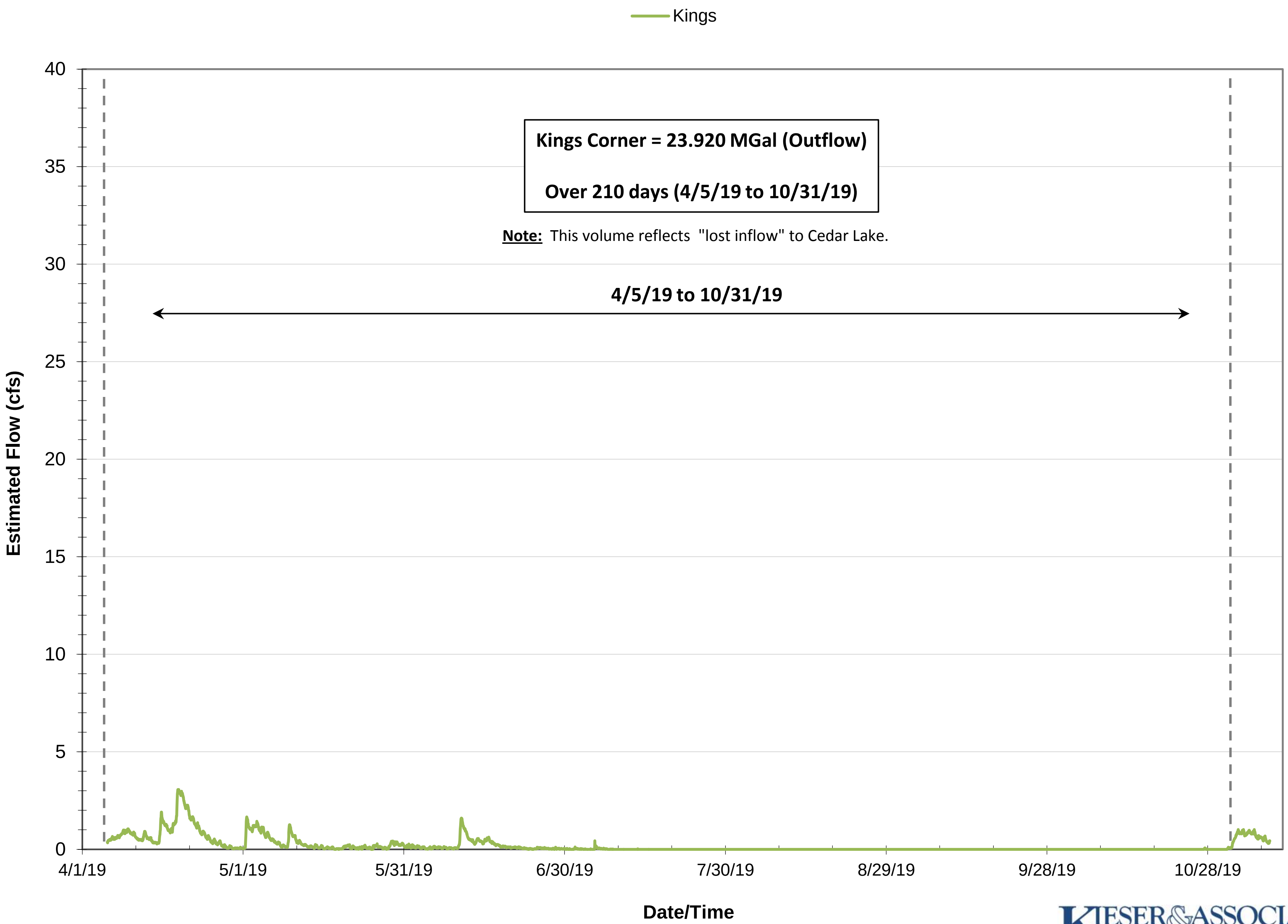

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Figure 24. 2019 Estimated Cedar Lake Inflows/Outflows

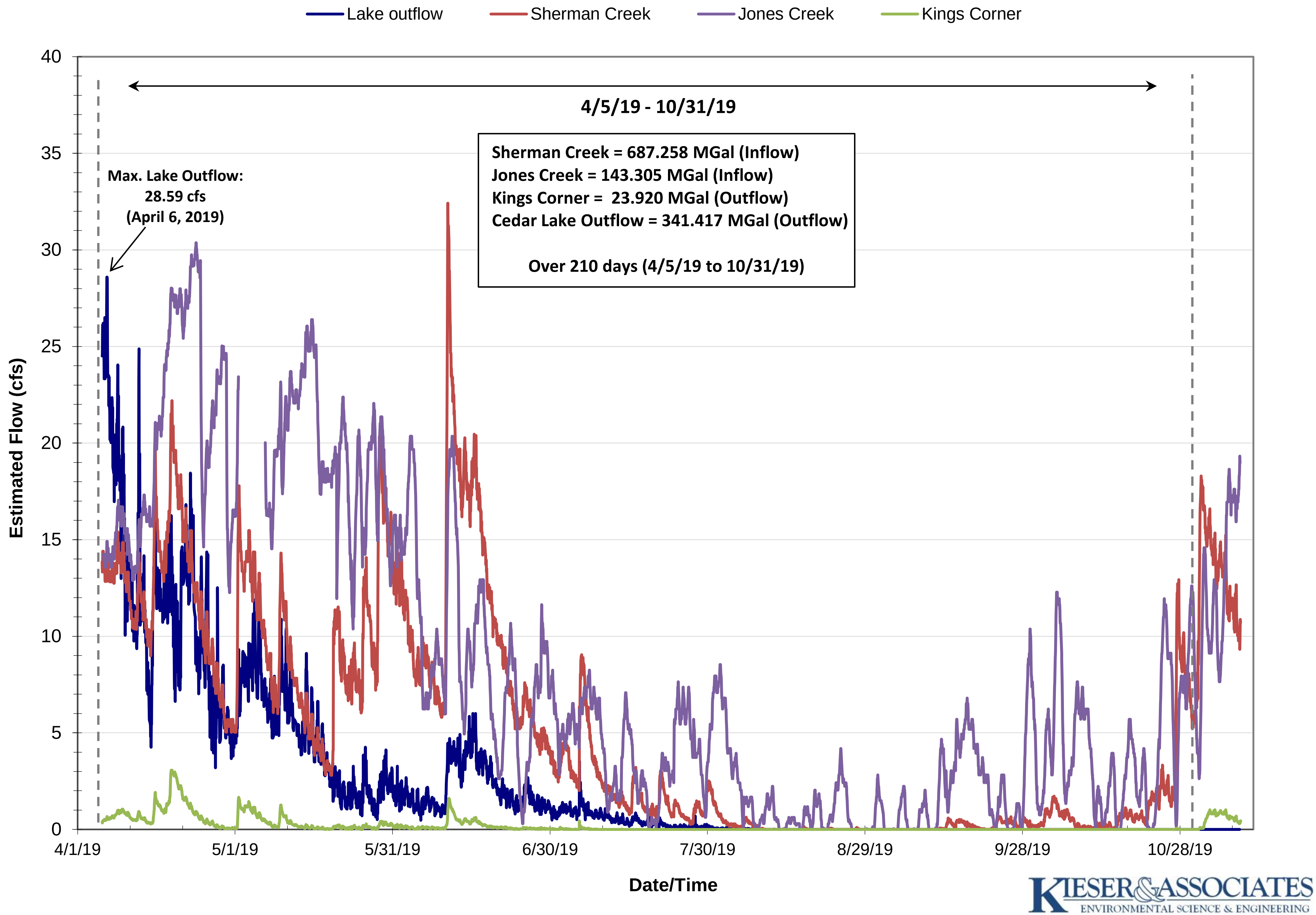

Figure 25. 2019 Cedar Lake Groundwater / Surface Water Elevations (Wetland Berm)

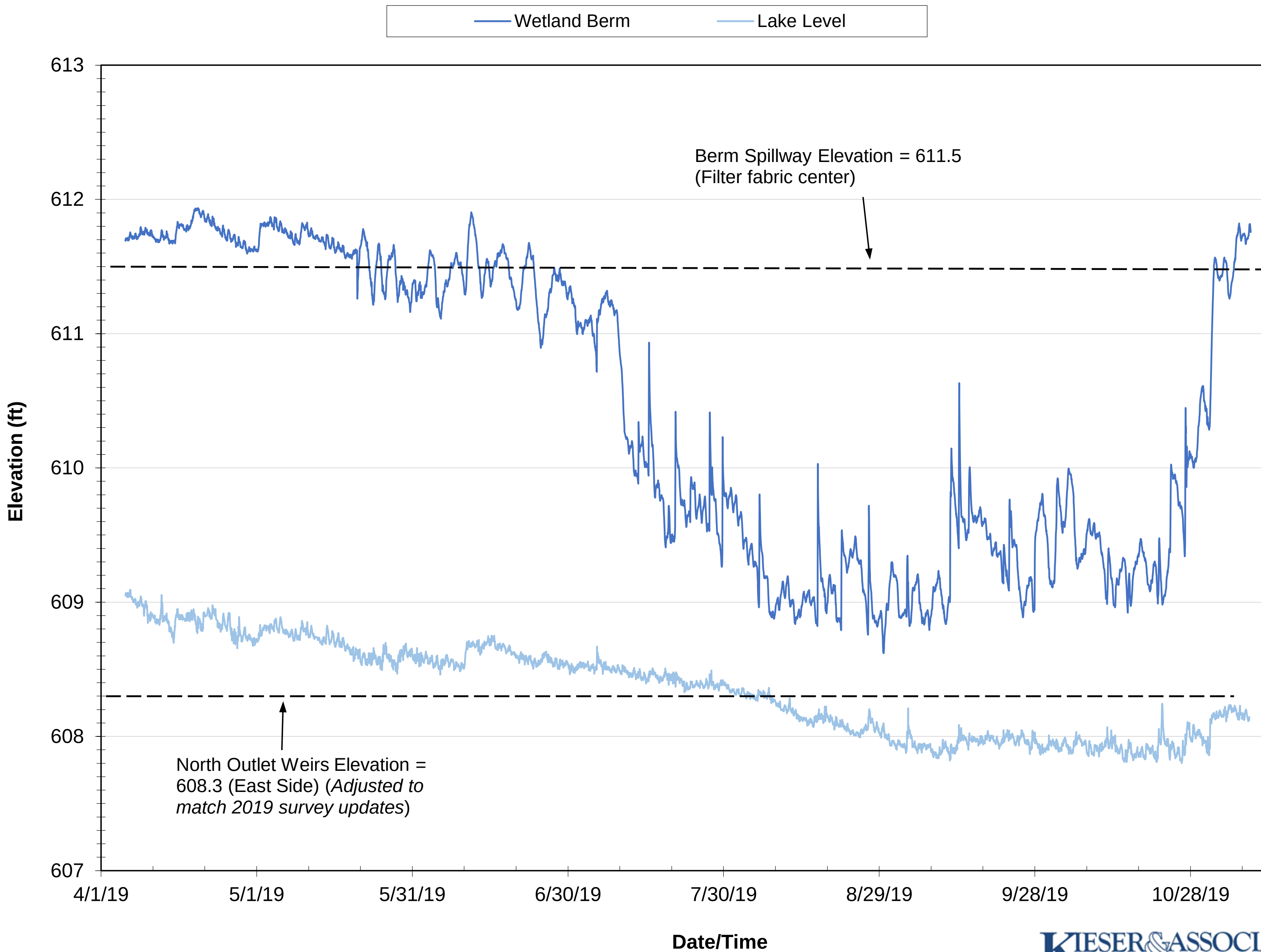

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Figure 26. 2019 Cedar Lake Groundwater / Surface Water Elevations (Wetland Berm, King's Corner, and Sherman 2)

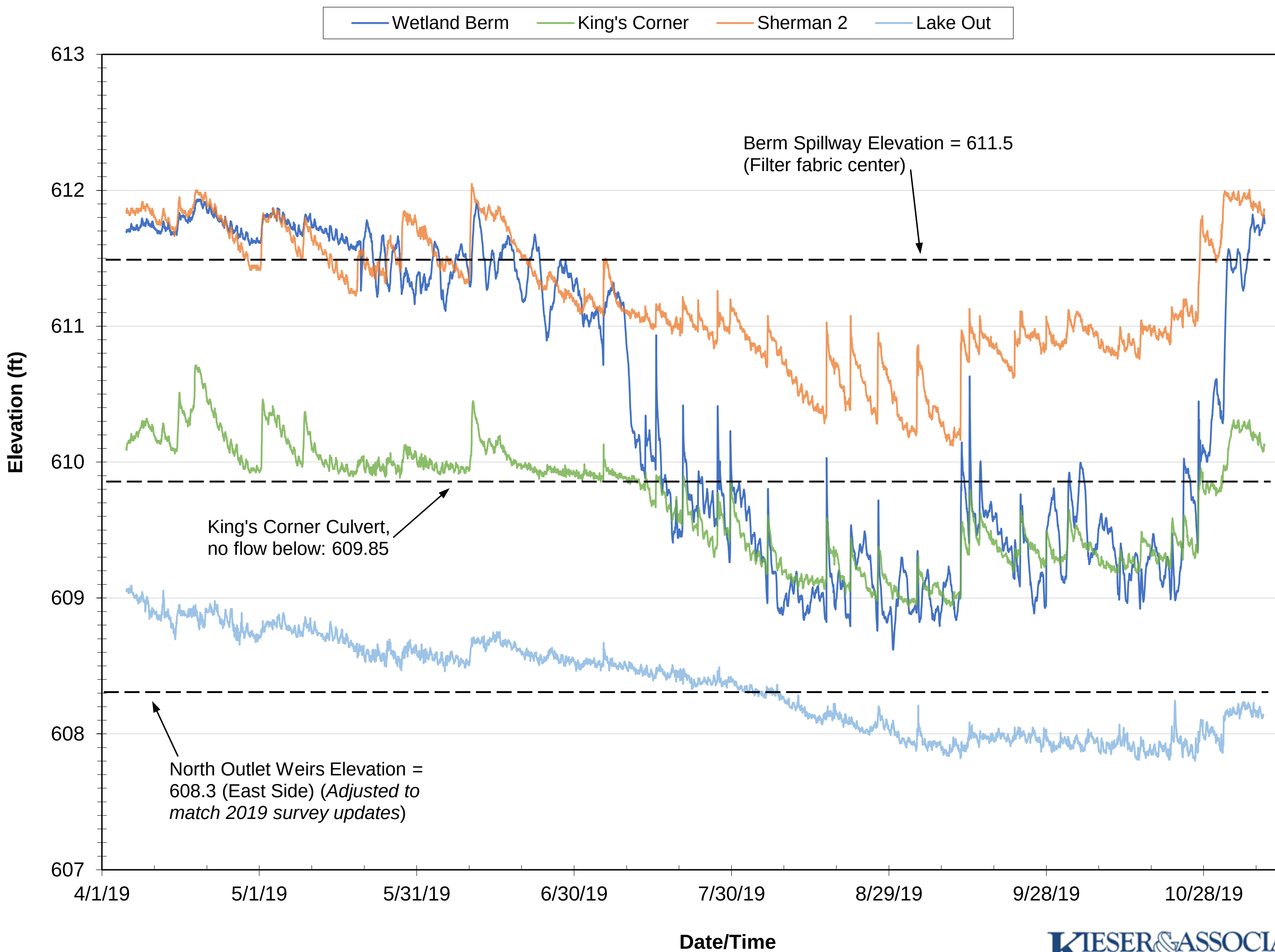

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Figure 27. 2019 Estimated Wetland Berm Spillway and King's Corner Outflows

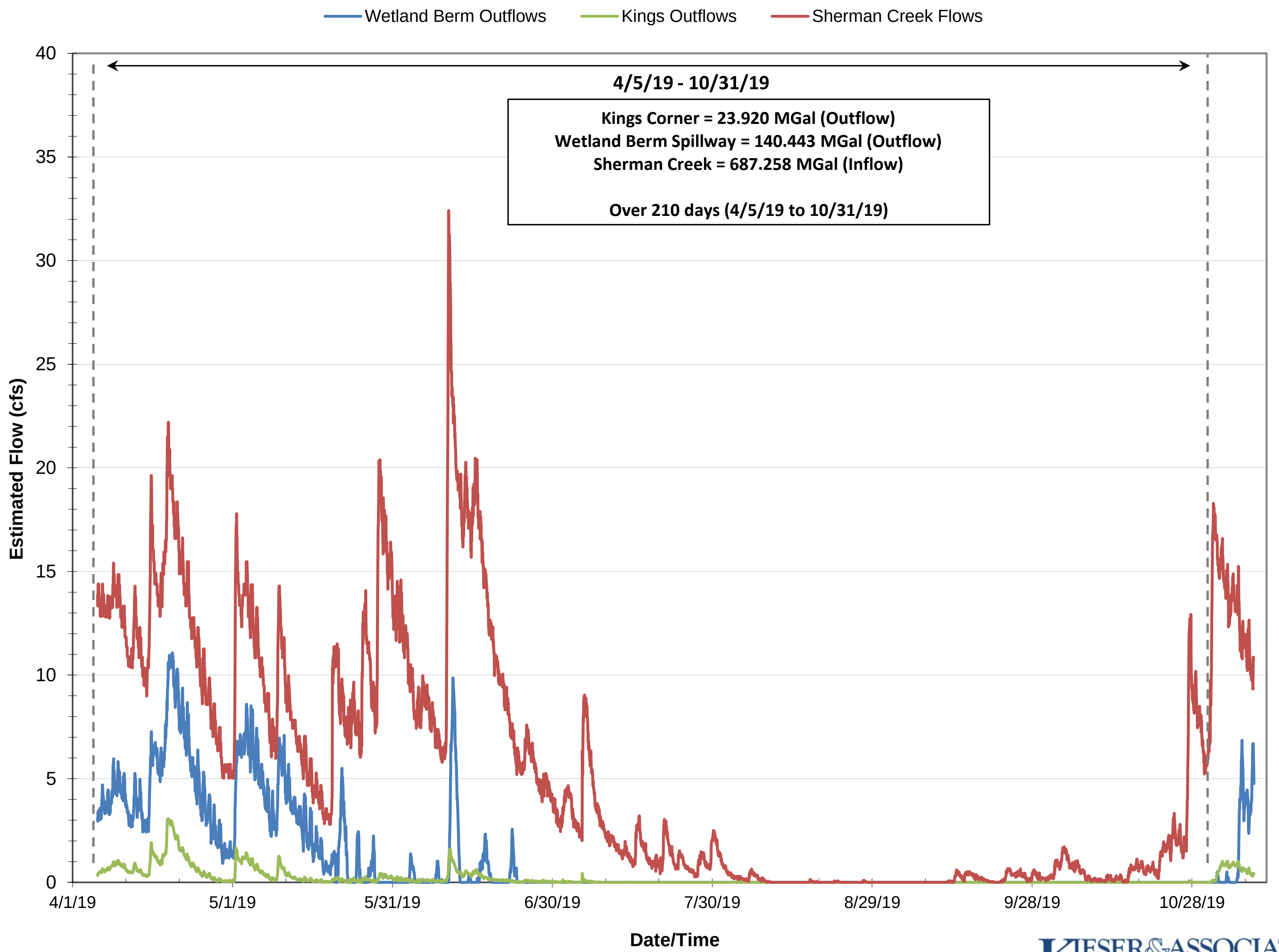

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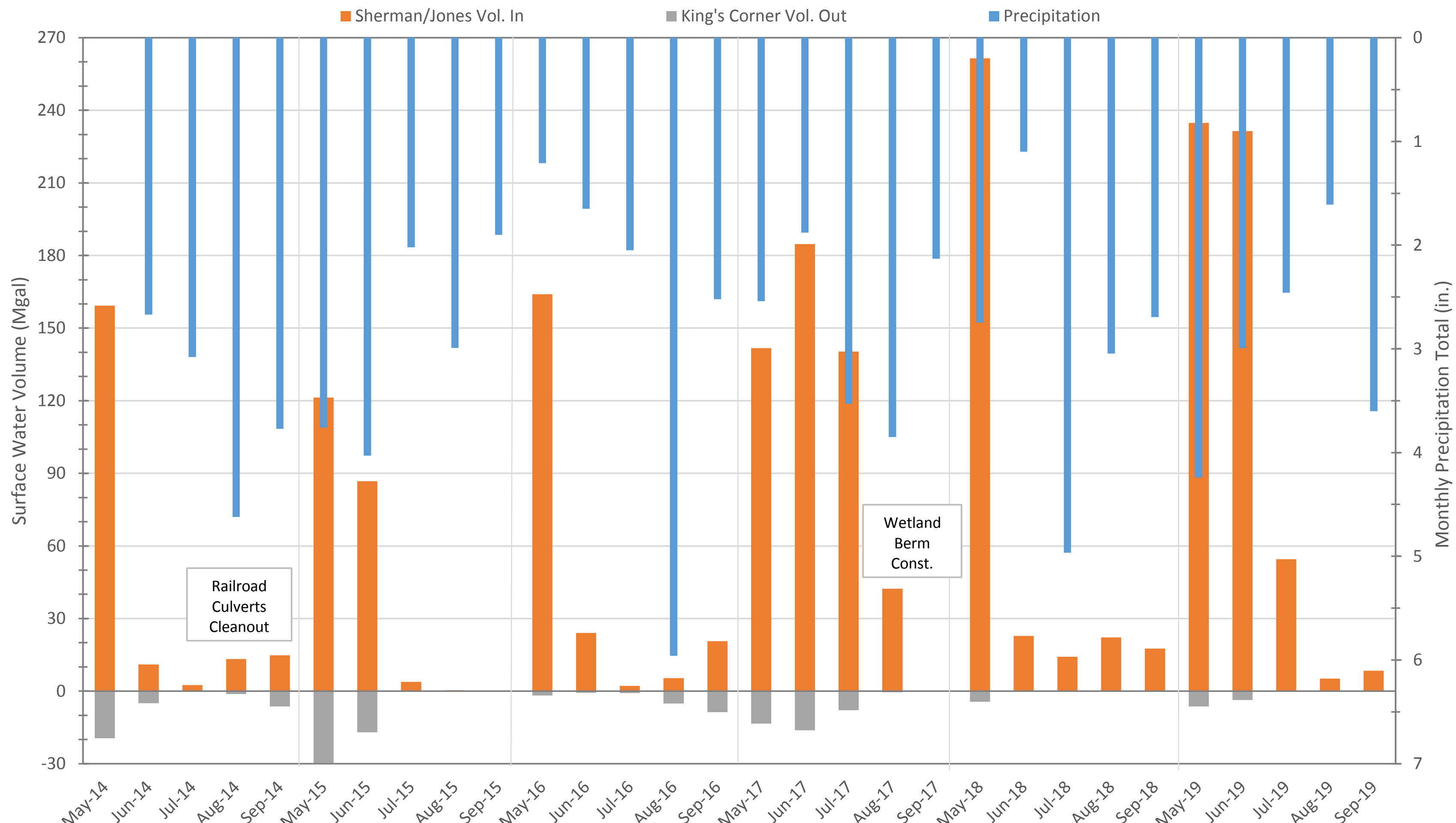
Figure 28. May-Sep, 2014-19: Precipitation, Sherman/Jones Creeks Combined Surface Water Volume into Cedar Lake, and King's Corner Surface Water Volume Away from Cedar Lake



2014 May-September:
Precipitation: 14.14 in.
Inflow Vol.: 200.9 Mgal
King's Vol. Out: 32.2 Mgal

2015 May-September:
Precipitation: 14.70 in.
Inflow Vol.: 212.5 Mgal
King's Vol. Out: 46.9 Mgal

* **2016 May-September:**
Precipitation: 13.39 in.
Inflow Volume: 216.1 Mgal
King's Vol. Out: 17.1 Mgal

* **2017 May-September:**
Precipitation: 13.93 in.
Inflow Vol.: 509.2 Mgal
King's Vol. Out: 38.1 Mgal

2018 May-September:
Precipitation: 14.55 in.
Inflow Vol.: 338.3 Mgal
King's Vol. Out: 4.3 Mgal

2019 May-September:
Precipitation: 14.90 in.
Inflow Vol.: 534.3 Mgal
King's Vol. Out: 10.2 Mgal

**Represents updated surface water volume data for Sherman Creek and Jones Creek.*

K&A