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ENVIRONMENTAL SCIENCE & ENGINEERING

TECHNICAL MEMORANDUM

To:	Rex Vaughn Cedar Lake Improvement Board	**Date:**	April 15, 2022
From:	Mark Kieser, K&A John Jacobson, K&A	**cc:**	Zach Harrison, K&A Mike Foster, K&A

RE: **Findings for 2021 Cedar Lake Groundwater/Surface Water Level Monitoring**

This memorandum presents 2021 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 2021 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 intermittent 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. A Jones Creek culvert replacement under Cedar Lake Road was completed in 2018 by the Alcona County Road Commission. The hydrologic impacts of this replacement are discussed in detail in K&A's 2022 Groundwater Augmentation Well Report.[1]

The Sherman Creek 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.

The new Cedar Lake outlet structure, designed to maintain the lake at the legal lake level of 608.20 feet, was constructed beginning in September of 2020. A year-round level logger was

[1] K&A, 2022. Technical Memorandum: Findings for Stage 2 of Task 6 – Cedar Lake Phase III Augmentation Assessment. Prepared for the Cedar Lake Improvement Board, March 8, 2022, 51 pp. See: https://img1.wsimg.com/blobby/go/a080ee0a-11db-41bd-8830-a064f9457faa/downloads/2022%20Cedar%20Lake%20Well%20Augmentation%20Study%20-%20Fina.pdf?ver=1647356532664

deployed near the outlet structure in November 2020, and its data were downloaded in March, June, and November of 2021. Visual inspections of the outlet structure during site visits by K&A staff revealed a semi-constant loss of water, either from groundwater or surface water from Cedar Lake. Ongoing concerns regarding the loss of water from the outlet structure have been voiced by Cedar Lake stakeholders, and the efficacy of the outlet structure will be further discussed herein. Future monitoring efforts will continue to closely inspect the outlet structure and will guide any action needed to correct the loss of water through the structure.

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 low-level conditions observed in 2021. Other future management strategies actively being pursued include water retention improvements to Jones Creek and utilizing deep groundwater withdrawal augmentation wells.[2] Preliminary water quality sampling of the deep aquifer augmentation well near Sherman Creek revealed no PFAS contamination above Michigan regulatory limits as of August 2021. With no contamination present, the implementation of this management effort in the near-future is increasingly likely.

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 2021 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 the interactions between surface water, groundwater, and Cedar Lake water levels. Sherman Creek, Jones Creek, and the King's Corner Road culvert continued to be monitored in 2021 to calculate estimates of surface water flows into Cedar Lake. Level loggers were also deployed in the three in-stream stilling wells in Sherman Creek to further understand the impacts of the instream grade structures on creek water levels and discharges. Additional loggers deployed at the wetland berm spillway monitored water levels and discharges upstream and north of King's Corner culvert.

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 2018-2021 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

[2] See Footnote 1.

levels flowing southward out of this area and out of the Cedar Lake watershed. The wetland berm monitoring station provides critical information regarding water retention improvements in the northwest cedar swamp, including those related to the 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. In previous 2018-2020 reporting, the equation used to estimate flows through the new Jones Creek culvert had underestimated inflow volumes occurring over the March-November monitoring period. In 2021, the equation was modified to more accurately quantify flow data which suggest Jones Creek, under certain conditions, contributes more surface water to Cedar Lake than Sherman Creek. This supply of Jones Creek water has significant implications for future engineering designs and lake level management efforts as denoted in the recent K&A Augmentation Report.[3]

Notable at the new Jones Creek culvert, sedimentation has continued to constrict flows impact flow measurement methods. The Alcona County Road Commission has attempted to keep the culvert clear of sediment with intermittent clearing events. During routine annual logger recovery on November 17, 2021, K&A field staff were made aware of a culvert clearing conducted on the previous day, November 16, 2021. The piezometer immediately adjacent to the Jones Creek Culvert was seemingly damaged as a result of this clearing event. While logger data appear uncompromised, the installation of a new piezometer and/or resurvey of the top-of-casing measurement may be necessary for future monitoring. Nonetheless, surface flow equations from Jones Creek will continue to be refined with manual measurements in future monitoring seasons while continuous flow measurement approaches are reviewed to ensure optimal data collection.

All 30 level loggers around Cedar Lake were replaced between 2018 and 2020, to ensure a high degree of confidence in the level logger 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 that are resistant to winter conditions continue to measure water levels in critical areas around Cedar Lake including Sherman Creek, the lake outlet structure, and the wetland berm between November and March. The lifespan of level loggers is roughly ten years. Loggers and their data should be closely monitored to ensure a high level of accuracy in the dataset. Table 1 illustrates the current age and predicted lifespan of the updated Cedar Lake level logger regime.

2021 Precipitation and Water Level Data

Precipitation Analysis

Historic summer precipitation totals for the Cedar Lake area are presented in Figure 2. These represent 2021 summer precipitation data available from the Cedar Lake volunteer rain gauge for each June through September period back to 1998. In 2021, the volunteer rain gauge was replaced with a new unit to limit erroneous data that were associated with aging equipment. Rain

[3] See Footnote 1.

gauge data were analyzed for quality against other weather stations in the area, Harrisville 2 NNE (USC00203628), and Oscoda Wurtsmith Airport (Station #14808), and were deemed the most representative data available for Cedar Lake hydrology applications. From 2016 to 2020, rainfall data used for reporting were triangulated from these weather stations and the on-lake rain gauge due to malfunctions associated with the aging volunteer equipment. Available rainfall data from 1998 to 2021 (minus 2006 when there were no local functioning rain gauges) reflect a 23-year summer average (June-September) of 12.06 inches of rainfall.

In 2021, June was the only summer month with below-average precipitation that totaled 2.55 inches. Precipitation that fell in July totaled 6.74 inches, the highest single-month precipitation total among all historical data analyzed. August precipitation of 3.27 inches was above the August historic period average of 3.06 inches. September precipitation totaled 3.94 inches, well-above the historic September average of 2.81 inches. The total summer-month precipitation was 16.50 inches in 2021, the highest total since 2010 and the second highest since 1998.

The 2011 Cedar Lake Augmentation Feasibility Study conducted by K&A[4] revealed that in order to avoid a lake level drop of 3 inches per summer month (June-September), precipitation of 2.75 inches during each month is necessary. As such, in any summer month that does not exceed the 2.75-inches-of-precipitation threshold, a drop in lake level of 3 inches or more is expected. Since 2011, this summer precipitation threshold of 11 inches (i.e., 2.75 inches multiplied by 4 months) has guided lake-wide assessments of summer conditions and their effect on desirable lake levels. Figure 2 includes this critical precipitation threshold among the 23-year summer precipitation average. Cedar Lake precipitation in 2021 exceeded this critical threshold of lake-elevation drop for all summer months except June. Previous and ongoing lake level augmentation efforts aim to lower this influence on the water budget of Cedar Lake to limit the impact of low summer precipitation on lake levels.

Cedar Lake Water Elevation

Figure 3 plots the 2021 Cedar Lake water elevation from March to November with daily precipitation data recorded from the Cedar Lake volunteer rain gauge to elucidate the importance of precipitation on lake elevation. Lake elevations above 607.20 ft (one-foot below the legal lake limit) have been characterized as “desirable conditions” during the summer recreational season. If the lake’s elevation exceeds 608.20, flow through the Cedar Lake outlet would occur along with a proportionate drop in lake elevation.

In the spring of 2021 (March-May), moderate precipitation and low snowpack left lake levels more than one foot below an outlet discharge elevation of 608.2. There were minimal daily lake level fluctuations during this period, with below average precipitation in June. With increasing air temperatures and solar radiation (driving higher lake surface evaporation), lake level dropped to 606.5 by late June. This was the lowest lake elevation recorded in 2021 and approximately 21.1 inches below the legal lake limit. This dry June timeframe produced the steepest drop in lake elevation beginning June 6 until June 16 with approximately 200 million gallons exiting Cedar Lake in this ten-day span. Over this same time period, only 0.07 inches of rainfall were

[4] See: https://img1.wsimg.com/blobby/go/a080ee0a-11db-41bd-8830-a064f9457faa/downloads/cedar_lake_augmentation_feasibility_study_8_25.pdf?ver=1647356532176

recorded. Lake levels otherwise rebounded quickly with above average precipitation events from July through September, though also receded rapidly between rain events. Cedar Lake level elevations at no point exceeded the legal lake level of 608.20 feet during the 2021 monitoring period.

Since the construction of the Cedar Lake outlet structure in the fall of 2020, Cedar Lake stakeholders have voiced concerns of a constant "leak" of water coming from the outlet structure despite the lake elevation remaining below the legal lake level and outlet elevation of 608.20 ft. Without comprehensive dye testing, the source of the water exiting through the outlet structure remains unclear. During several site visits in 2021, K&A field staff manually measured the velocity and channel area of the outlet structure and downstream channel to understand the discharge (flow) rates of water flowing through the outlet structure. Discharge data and resultant drops in Cedar Lake water elevation are presented in Table 2.

If the discharge downstream of the outlet structure is entirely attributed to Cedar Lake surface water, under the highest-measured flow (November) conditions the resultant drop in lake elevation across the 1,075-acre lake surface would be approximately 0.000522 feet per day; a level so small that it would be difficult to actually measure. If the downstream discharge is attributed entirely to groundwater, the outflow structure impact to Cedar Lake's water level may be nil. In any case, the loss of water through the Cedar Lake outlet is relatively minor, and does not appear to influence large-scale lake level fluctuations; evaporation and seepage to groundwater remain the leading losses of water from Cedar Lake during critical summer months.

In contrast, precipitation remains as the most important hydrologic process influencing Cedar Lake water levels in summer months. The following narrative describes past and on-going management efforts that aim to lessen the effect of low summer precipitation on lake elevations in the summer during dry conditions.

Figure 4 presents the relationship between summer precipitation and water elevation fluctuations with respect to the critical summer precipitation threshold, water level goals designed in the Cedar Lake WMP, and the legal lake level. The average water elevation of Cedar Lake in 2021 was the lowest recorded since lake-level monitoring began on Cedar Lake in 2004. Despite above-average and above-threshold summer precipitation, Cedar Lake's average water elevation was lower in 2021 compared to other years that received less summer precipitation (e.g., 2015-2020). Perhaps this relationship emphasizes the importance of the individual summer month threshold of 2.75 inches compared to the summer month total threshold of 11.00 inches of precipitation. In other words, an individual month's precipitation total has more impact to Cedar Lake's water elevation than the whole summer's precipitation total. As evident in the 2021 lake elevation data, June low-precipitation conditions (and starting one foot lower than the outlet in the late winter/early spring) resulted in Cedar Lake losing over 200 million gallons of water over a ten-day period from June 6 through June 16. Despite record July precipitation, the lake elevation remained historically low throughout the rest of the monitoring period highlighting the importance of a single month's precipitation and a starting summer lake level at 608.2.

Prior to 2021, a 10-year trend of average summer lake levels relative to the Cedar Lake outlet suggests that the average lake elevation throughout the summer had increased despite a declining trend of precipitation. The relationship between increasing summer lake level and decreasing precipitation is indicative of the success of Cedar Lake historical and ongoing water elevation management.

Data for 2021 suggest how relevant off-season (winter/spring) snow pack is critical to starting the recreational season with saturated conditions and lake levels at 608.2. Notable, and potentially influential, is the new outlet discharge capacity in post-ice spring conditions. The previous outlet structures tended to extend spring-time discharges such that water levels would remain above 608.2, saturating groundwater conditions around the lake. This discharge limitation was likely due to frequent debris clogging these outlets, and/or structural design limitations for rapid discharge. The new outlet structure likely accommodates greater spring outflows when the lake level is above the legal level of 608.2, equilibrating to this level rapidly by allowing early season water levels to discharge at greater volumes and rates than the previous structures. This design helps avoid property damage associated with spring-time, high water levels. It also likely creates an earlier starting point for lake level declines that naturally accelerate in summer months with higher temperatures and evaporation rates. Further examination of 2022 outflows will help define these conditions if there are outlet discharges.

Groundwater Levels and Gradients

The 2021 groundwater elevation data from the monitoring Sites 1-12, “West Kings”, and “LWSPC” (refer to Figure 1 for locations) are presented graphically along with Cedar Lake water levels in Figures 5-18, respectively.

Level loggers located along the eastern portion of Cedar Lake at Sites 1, 4, and 5 (Figures 5, 8, and 9, respectively) recorded lake groundwater elevations consistently below the elevation of Cedar Lake. Given this gradient, groundwater continues to move from Cedar Lake eastward towards Lake Huron. This gradient is well-documented historically and has been present since monitoring began. Level loggers on the southeast side of Cedar Lake at Sites 8, 9, 10, and 11 similarly report groundwater gradients consistent the movement of groundwater away from Cedar Lake towards the southeast.

Sites 2 and 7 are located in the northwest cedar swamp and serve as monitoring stations within the region that contributes a large amount of water to Cedar Lake via groundwater recharge. Figures 6 and 11 represent Site 2 and Site 7 level logger data from the 2021 monitoring period, respectively. As shown in Figure 11, groundwater elevations at Site 7 exceed lake levels in Cedar Lake, and considerably throughout the monitoring period. Both shallow and deep groundwater at this station flow towards Cedar Lake. Shallow groundwater at Site 7 also generally exhibits similar elevations to water flowing in Sherman Creek. Figure 6 illustrates the large difference in groundwater elevations at Site 2 and Cedar Lake water elevation. Given the substantial gradient, groundwater flows relatively quickly from the wetland complex into Cedar Lake. This area is critical in maintaining Cedar Lake’s water level and should continue to be monitored closely.

Historically, Site 3 (Figure 7) level loggers would report shallow groundwater movement away from Cedar Lake towards Phelan Creek. However, in 2021 shallow groundwater generally moved towards Cedar Lake. The upgradient monitoring well detected variable water levels consistent with water moving both away and towards Cedar Lake during various times throughout the year. From March to early-June, upgradient groundwater generally moved away from Cedar Lake. By mid-June, groundwater flowed towards Cedar Lake for the remainder of the monitoring period. Deep groundwater consistently moved away from Cedar Lake throughout 2021, and serves as a continual loss of water from the Cedar Lake watershed.

Findings in 2020 suggested that the shallow groundwater gradient had lessened further north. As shown in the 2021 Site 6 data (Figure 10), the groundwater gradient to the lake here, was actually steeper than at Site 3. Previous groundwater movement at this site was variable throughout the year and would change directions seasonally. During the 2021 groundwater monitoring period, Site 6 shallow and deep groundwater always moved towards Cedar Lake. This novel observation of groundwater flow may be a function of record low spring lake elevations of Cedar Lake during 2021. This could also be the cumulative benefit of Sherman Creek groundwater and hydrology improvements with the expansion of localized groundwater mounding.

Site 12 (Figure 16) is stationed approximately 1,750 ft south of Sherman Creek and 85 ft southeast from the intersection of W. Cedar Lake Road and King's Corner Road. Groundwater levels recorded during the 2021 monitoring period suggest groundwater always flowed towards Cedar throughout the monitoring period, consistent with findings in 2020. In 2020 and 2019, groundwater elevations at Site 12 were variable and fluctuated above and below groundwater elevations at Site 6, directly south of Site 12. However, in 2021, groundwater elevations at Site 12 were consistently higher than at Site 6. This relationship is consistent with other 2021 findings that Site 6 groundwater elevations were higher than Site 3 (south of Site 6 and Site 12) again suggesting desired groundwater mounding effects with Sherman Creek and King's Culvert berm projects.

The West Kings and King's Corner culvert level logger data provide important insight into the function of the wetland berm and limiting flows out of the Cedar Lake watershed (Figure 17). During the 2021 monitoring period, the groundwater elevation of King's Corner culvert was generally (though only slightly) higher than the elevation at the West Kings monitoring station. Following the intense rains observed from July 25 to August 3, water from wetlands complex adjacent to Sherman Creek spilled over the wetland berm likely causing water elevations at West Kings to exceed elevations at King's Corner culvert. Therefore, during this brief time period, water flowed east towards the King's Corner culvert and out of the Cedar Lake watershed.

All level loggers in the King's Corner area are collectively presented together in Figure 19. Consistent with 2020 groundwater observations, the LWSPC monitoring station recorded the lowest groundwater elevations of all stations within King's Corner area in 2021. The groundwater elevations at the LWSPC station from March to June were below the Cedar Lake elevation. As such, groundwater would expectedly flow westward away from Cedar Lake during this timeframe. Following heavy rains in July, LWSPC groundwater elevations generally remained above Cedar Lake elevations with periodic and infrequent dips below the Cedar Lake elevation.

2021 Estimated Surface Flows

Water level loggers located in or near the Cedar Lake outlet, Sherman Creek, Jones Creek, and the King's Corner culverts were used to monitor incoming and outgoing surface water discharges. Sherman Creek and Jones Creek are critical vectors by which surface water flows from the northwest wetland complex into Cedar Lake. The King's Corner Road culvert historically diverted water from the southernmost portion of the wetland complex away from the Cedar Lake watershed to the south towards Phelan Creek and Van Etten Lake. The wetland enhancement berm constructed in 2017 serves to retain surface water in the Cedar Lake swamp and limit surface water losses through the King's Corner culvert. The new Cedar Lake outlet structure constructed in September 2020 functions to maintain the legal lake level of 608.20 feet. If the lake elevation exceeds this limit, water spills over the outlet and eventually drains to Lake Huron through Cedar Creek.

Efforts regarding water retention improvements in Sherman Creek were conducted in September 2019 with the implementation of three 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 under West Cedar Lake Road. These instream structures serve to retain water in the northwestern wetlands complex by slowing discharge rates into Cedar Lake during snowmelt and rain events in the spring. By lengthening the time needed for surface water in these wetlands to reach Cedar Lake, typical spring high flow conditions can be extended into the summer when lake inputs become critically important for lake level. Four water level loggers stationed near each instream grade structure and the Sherman Creek culvert provided surface water flow data for Sherman Creek in 2021.

Surface water discharge rates and total volumes associated with the full 2021 monitoring period at Jones Creek, Sherman Creek, Cedar Lake outlet, and the King's Corner culvert are presented in Figures 20, 21, 22, and 23, respectively. Figure 24 illustrates the very limited wetlands outflow during high rainfall conditions in late July; otherwise, there were no other surface outflows from the wetlands berm in 2021. All flow data are derived from water level stage-discharge relationships specific to each monitoring station that have been calibrated and validated using previous data collected on Cedar Lake. The discharge data and estimated total volumes are graphically displayed together in Figure 25.

The water level stage-discharge relationship for Jones Creek was re-calibrated in 2018 following the installation of the new culvert that allowed increased flows under West Cedar Lake Road. In 2021, the formulated approach was found to be substantially underestimating the surface water inflows that Jones Creek contributes to Cedar Lake during the peak recreation months from 2018-2020. This development has beneficial implications for future engineering and water retention efforts.

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 3 summarizes estimated inflow and outflow volumes for surface water stations from May-September 2014-2021 for comparison. From May 1 to September 30, 2021, Jones Creek and Sherman Creek inflows into Cedar Lake totaled 799.97 and 195.17 million gallons (Mgal), respectively.

The 2021 cumulative discharge from Sherman Creek was the lowest discharge recorded since 2015. May discharge was the lowest recorded since 2014 due to limited snowpack and low precipitation. Below-average June precipitation induced an early-summer water-budget imbalance in favor of losses through evapotranspiration from the wetland complex that contributes surface water to Sherman Creek. Therefore, heavy rains falling in July likely functioned to recharge the wetland complex before producing surface water discharges to Cedar Lake through Sherman Creek.

Jones Creek cumulative summer discharge was the highest on record since 2014. Prior to 2018 and the installation of the new Jones Creek culvert structure, Jones Creek surface flows were approximately one-tenth to one-half of flows contributed by Sherman Creek. In 2021, Jones Creek discharges were over four times larger than Sherman Creek inflows. The higher Jones Creek flows are due to a larger culvert inlet and lower invert elevation more rapidly releasing stormwater falling onto the creek's large drainage area. Sediment buildup in the Jones Creek culvert may have impeded some surface water flow discharges, but the larger and lower culvert allows for much greater water releases than the previous smaller orifice and higher invert elevation.

Figures 20 and 21 illustrate extended Jones Creek and Sherman Creek flows throughout the 2021 monitoring period, respectfully. The updated 2018-2020 Jones Creek outflows suggest how important Jones Creek now is as a source of clean water to Cedar Lake during the summer recreational season by now transferring captured rainwater in the Jones Creek drainage more rapidly to the lake. The 2022 K&A Cedar Lake Augmentation memo[5] further addresses this important surface water flow improvement to helping to maintain summer lake levels.

During the May-September monitoring period, the Cedar Lake outlet had no outflow from the lake (Figure 22). The outflow volume that exited the Cedar Lake watershed through the King's Corner culvert during the May-September period totaled only 0.158 Mgal (Figure 23). This outflow volume is the lowest since 2014 and approximately only 3.6% of the second-lowest outflow volume of 4.384 Mgal reported in 2018. Since the construction of the wetland enhancement berm in 2017, outflows through King's Corner have remained substantially lower than pre-2017 values.

This historically low outflow volume reported in 2021 at King's Corner is a reflection of the intended design of the wetland enhancement berm and prevailing 2021 low-moisture conditions in the wetland complex. Prior to 2017, throughout the summer months surface water would flow unimpeded through the culvert following intense rain events. Losses at the wetland berm for the entire 2021 monitoring period totaled 2.485 Mgal (Figure 24). However, the entirety of this volume was lost during a ten-day period from July 25 to August 3. The difference of this higher berm outflow volume compared to that measured at the King's Corner culvert (Figure 23), is attributed to localized wetland recharge and high evapotranspiration during the July 2021 period. Historically, losses through King's Corner were upwards of 24% of the total gains entering

[5] See Footnote 1.

Cedar Lake through Sherman Creek. Since berm implementation, this ratio has been substantially lower and in 2021, was approximately 0.08%.

Surface Water Retention Design Implications

The historical differences between water lost through King's Corner prior to and after the wetland berm construction emphasize the effectiveness of the berm in mitigating water losses from the Cedar Lake watershed. Figure 25 summarizes lake inflows and outflows for the 2021 monitoring. This illustrates the massive inflow of water to the lake from Sherman and Jones Creeks compared the minimal losses from the King's Corner berm, and even smaller losses the King's Corner culvert.

Figure 26 presents the surface/groundwater elevations at each of the Sherman Creek stations. These data are consistent with observations from previous years of improved water retention and storage in the wetland complex even in years of below-average precipitation. Notable in this figure, however, are the level data at the Sherman 100' location that appear to indicate instrument failure about mid-May through the remainder of the monitoring period. (This should necessitate replacement.) Figure 27 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 28 compares surface water flows and volumes for the 2021 monitoring season at the wetland berm spillway to outflows at King's Corner Culvert and inflows to Cedar Lake via Sherman Creek.

Prior to 2021, 2017-2020 data suggested a substantial increase in Sherman Creek discharge relative to 2014 values. However, in 2021, an above average, mid- to late-summer rainfall period, Sherman Creek summer discharge had returned to 195.2 Mgal, slightly above 2015 levels by July.

Since 2014, May is generally the month in which inflows to Cedar Lake are the greatest as shown in Figure 29. In 2021, July inflows were higher by approximately 32 Mgal while the average lake level in 2021 was the lowest on record since 2004. Comparable precipitation fell in 2016, yet the average lake level was over 6 inches higher. This difference is due most likely to a greater snowpack in 2016 than the very dry winter/spring conditions observed in 2021. This points to consideration for artificial lake level augmentation when late winter/early spring conditions have not yet attained the typical summer recreational seasonal start at the legal lake level.

Conclusions and Recommendations

Findings in this report once again emphasize the importance of summer precipitation in maintaining Cedar Lake's water elevation within the desirable range for the recreational season. Limited snowpack and low precipitation contributed to the lowest May cumulative stream discharge to the lake recorded since 2014. Throughout June, precipitation was sparse while in subsequent months precipitation worked to counteract the drastic drops in lake level attributed to early summer infrequent and low precipitation. July precipitation was record-high, and with Jones Creek culvert modifications allowing more runoff transfer to the lake, lake levels rebounded rapidly, though were short-lived. Ultimately, the average lake level of Cedar Lake in the summer of 2021 was the lowest since 2004 with the lowest drop in lake elevation to 606.44 ft in June.

Despite low water levels, watershed improvements in water retention were perhaps even more pronounced in 2021 with a wet July-September. Water retention/watershed discharge improvements are reflected in the lowest seasonal watershed losses from the King's Corner culvert (<160,000 gallons) since 2014. This can be compared to the 2021 Jones Creek inflows at nearly 800,000,000 gallons, and Sherman Creek inflows of >195,000,000 gallons during the 5 months of May-September, 2021.

Previously, the smaller diameter/higher elevation Jones Creek culvert under West Cedar Lake Road (replaced in 2018), mainly trapped precipitation runoff in upstream wetlands, forcing it into shallow groundwater (which eventually makes it to the lake over time—weeks to months) or accelerating losses through evapotranspiration. Now, these wetlands-cleansed flows are largely transferred to the lake through the larger diameter, lower invert elevation Jones Creek replacement culvert. This occurred despite significant sediment accumulation in this culvert. In 2021, the greatly increased contributions from Jones Creek resulted in lake level peak runoff responses (i.e., increased lake levels) within approximately 18 hours of rain events. This is a major hydrologic improvement for the lake, putting this on par with, or exceeding improved Sherman Creek inflows. Precise monitoring of Jones Creek flows and assessment of the contributing drainage are next recommended steps for better understanding this drainage and how it could be improved, and/or be a part of future well augmentation siting.

Cedar Lake stakeholders voiced concerns over whether the new outlet structure in the northern portion of Cedar Lake was contributing to lake level losses. K&A's 2021 outlet channel flow measurements ultimately showed that whether flows downstream of the outlet were surface water leaks from the new structure, or attributable to localized groundwater venting, the amount of water measured was inconsequential. The vast majority of lake level losses in the summer is still attributable to evaporation and seepage to groundwater. To fully understand the minor role of the outlet structure in Cedar Lake's water budget during the summer period (when the outlet weir is not overtopping with lake discharges above the legal lake level of 608.2), dye testing or similar water molecule tracking methods through the outlet would be necessary to address this question.

Given the findings reported herein and those included in the 2021 Augmentation Study, it is recommended the Cedar Lake hydrology monitoring program be continued in 2022. Hydrology data will continue to highlight historical trends and the emergence of new ones in light of further water budget augmentation. New data collected in 2022 and 2023 will be used to further evaluate:

1) Lake outlet direct measurements (requiring new equipment at the outlet);

2) Ongoing water level management improvements and groundwater conditions in relation to hydraulic improvements for both Sherman Creek and Jones Creek areas;

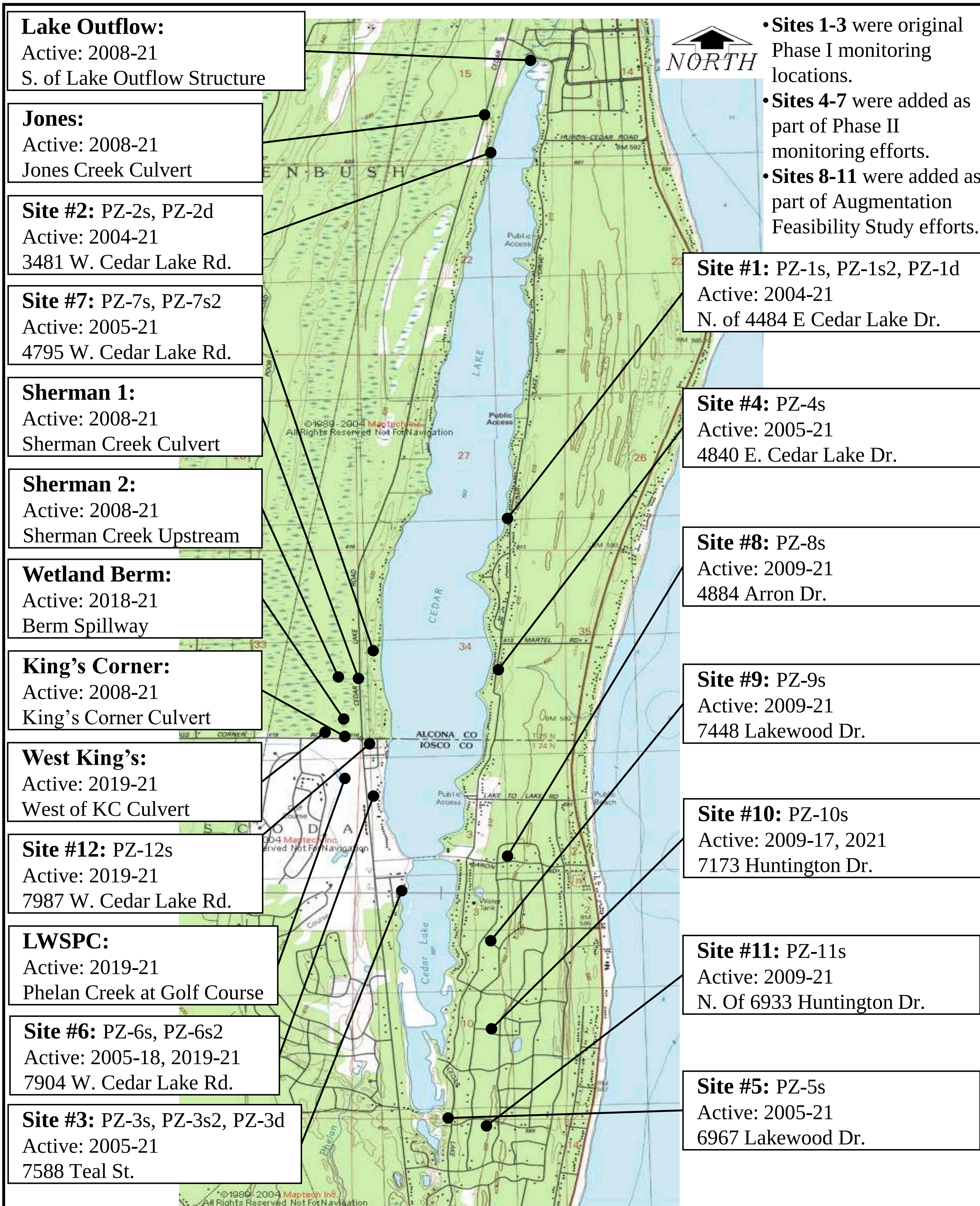
3) Viability of proposed deep groundwater augmentation wells to improve Cedar Lake water levels in critical summer months if pursued;

4) Quantifiable effect of sedimentation in the Jones Creek culvert on inflow volumes;

5) Potential Jones Creek drainage responses to managed drainage improvement opportunities;

6) Water retention improvements resulting from Sherman Creek wetland berm maintenance.

2021 Cedar Lake Hydrology Report: List of Tables and Figures



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Map of 2021 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 2021

Piezometer ID #	LL Manufactured Year	LL Age (yrs)	Predicted LL Lifespan (yrs)	Predicted Year of LL "Age-Out"	Status
Wetland Berm	2017	4	10	2027	*New (Added site in 2017)*
PZ-02s	2017	4	10	2027	*New, replaced "Aged-Out" Logger in 2017*
Sherman 1 (Culvert)	2018	3	10	2028	*New, replaced "Aged-Out" logger in 2019*
Sherman 2 (Wetland)	2018	3	10	2028	*New, replaced "Aged-Out" logger in 2019*
Kings Corner	2018	3	10	2028	*New, replaced "Aged-Out" logger in 2019*
Kings Corner Barlog	2018	3	10	2028	*New, replaced "Aged-Out" logger in 2019*
Lake Out	2018	3	10	2028	*New, replaced "Aged-Out" logger in 2019*
PZ-12s	2018	3	10	2028	*New (Added site in 2019)*
WEST Kings	2018	3	10	2028	*New (Added site in 2019)*
LWSPC	2018	3	10	2028	*New (Added site in 2019)*
PZ-06s	2018	3	10	2028	*New (Moved site in 2019)*
PZ-06s2	2018	3	10	2028	*New (Moved site in 2019)*
PZ-01s	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-01s2	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-01d	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-02d	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-03s	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-03s2	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-03d	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-04s	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-04s Barlog (backup)	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-07s	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-07s2	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-10s	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
Jones Creek	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-05s	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-08s	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-09s	2019	2	10	2029	*New, replaced "Aged-Out" logger in 2020*
PZ-11s	2019	2	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

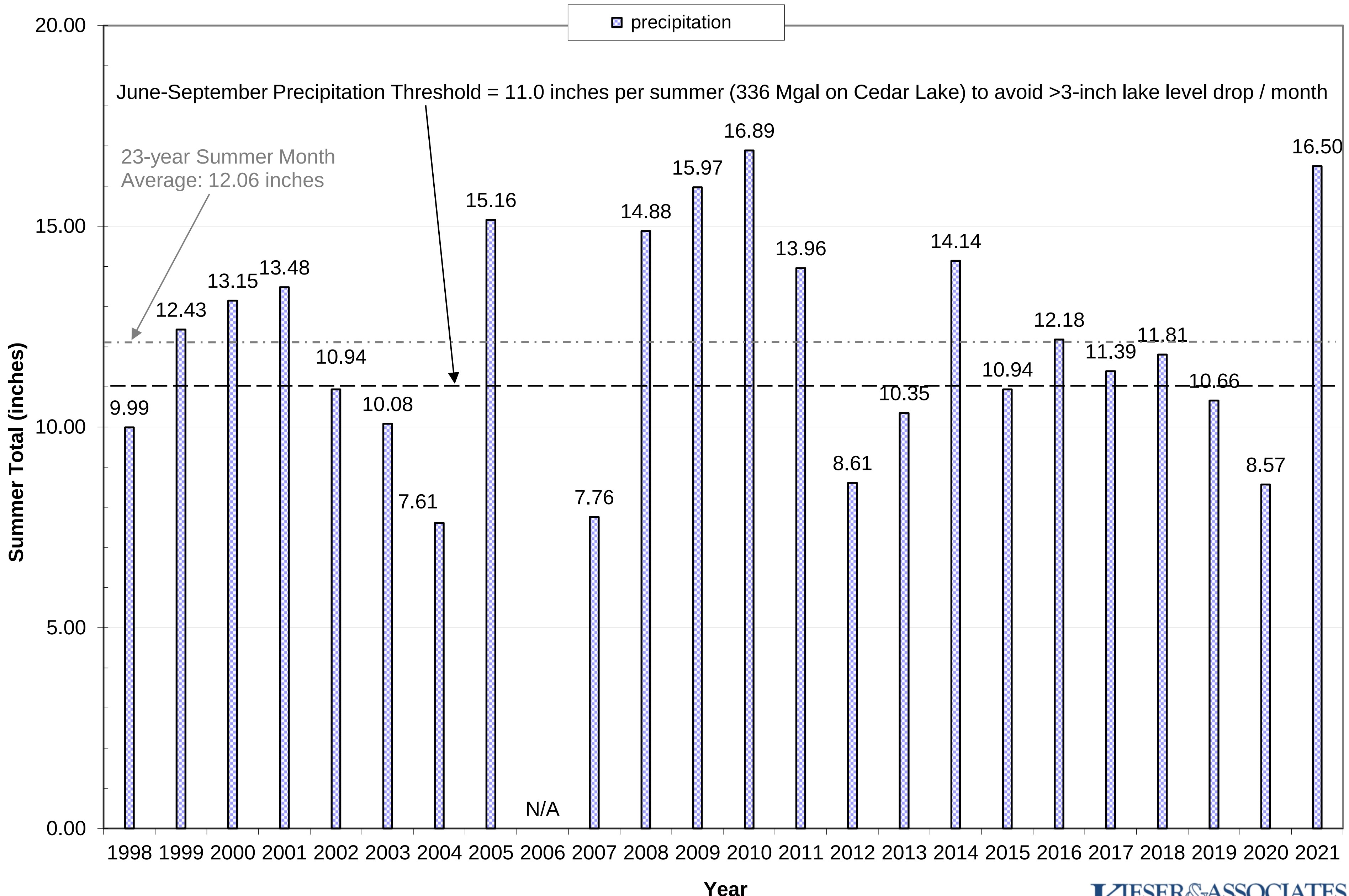

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Figure 3. 2021 Cedar Lake Water Elevation and Measured Rainfall

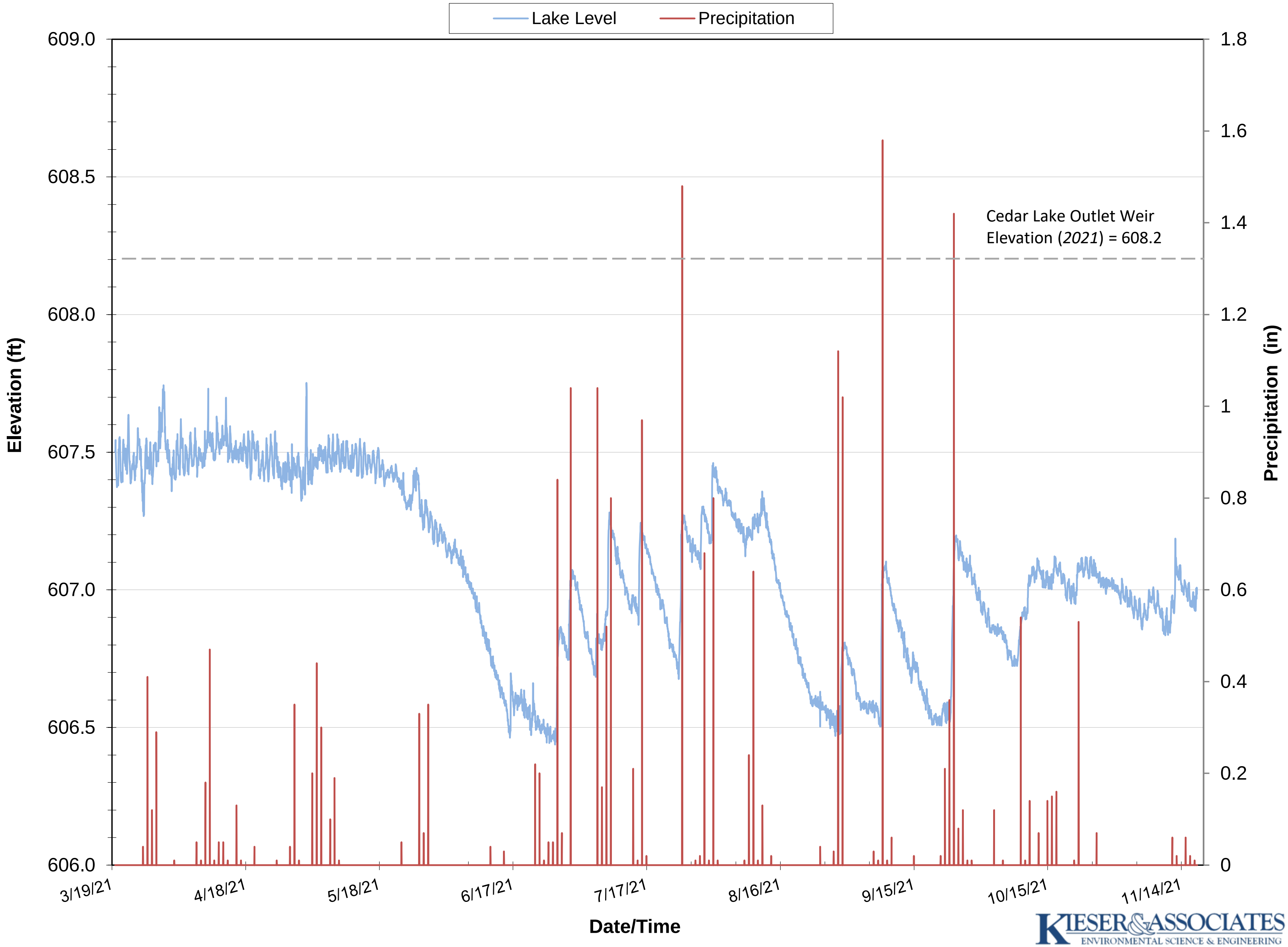

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Table 2. Cedar Lake Outlet field measurements & estimated elevation drop

Date	Outlet Discharge (GPD)	30' Downstream Discharge (GPD)	Equivalent Elevation Loss (ft/day)
3/19/2021	45,306.25	48,320.80	0.00014
6/16/2021	32,830.62	40,723.75	0.00012
8/24/2021	29,507.23	46,269.04	0.00013
11/17/2021	15,051.51	74,952.58	0.00021
Average:	30,673.90	52,566.54	0.00015

Table 3. Comparison of Surface Water Volumes from May 1 to Sep 30, 2014 to 2021.

Site	Volume (Mgal)							
	2014	2015	2016	2017	2018	2019	2020	2021
Sherman Creek (inflow to CL)	136.04	190.929	198.126	449.441	328.134	446.753	359.857	195.171
Jones Creek (inflow to CL)	64.817	21.587	17.964	59.784*	75.712	654.691	177.250	799.967
Cedar Lake Outlet (outflow from CL)	13.003	109.5	0.162**	26.123**	51.975	143.156	21.560	0.000
Kings Corner (outflow away from CL)	32.208	46.862	17.049	38.053	4.384	10.161	21.819	0.158

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

**Affected by presence of beaver dam upstream of Cedar Lake outlet, mechanically removed in fall 2017.

Figure 4. Cedar Lake Summer (Jun-Sep) Lake Level Fluctuations and Precipitation
Lake Level Maximum, Minimum, and Average Relative to Legal Lake Level (Outlet)

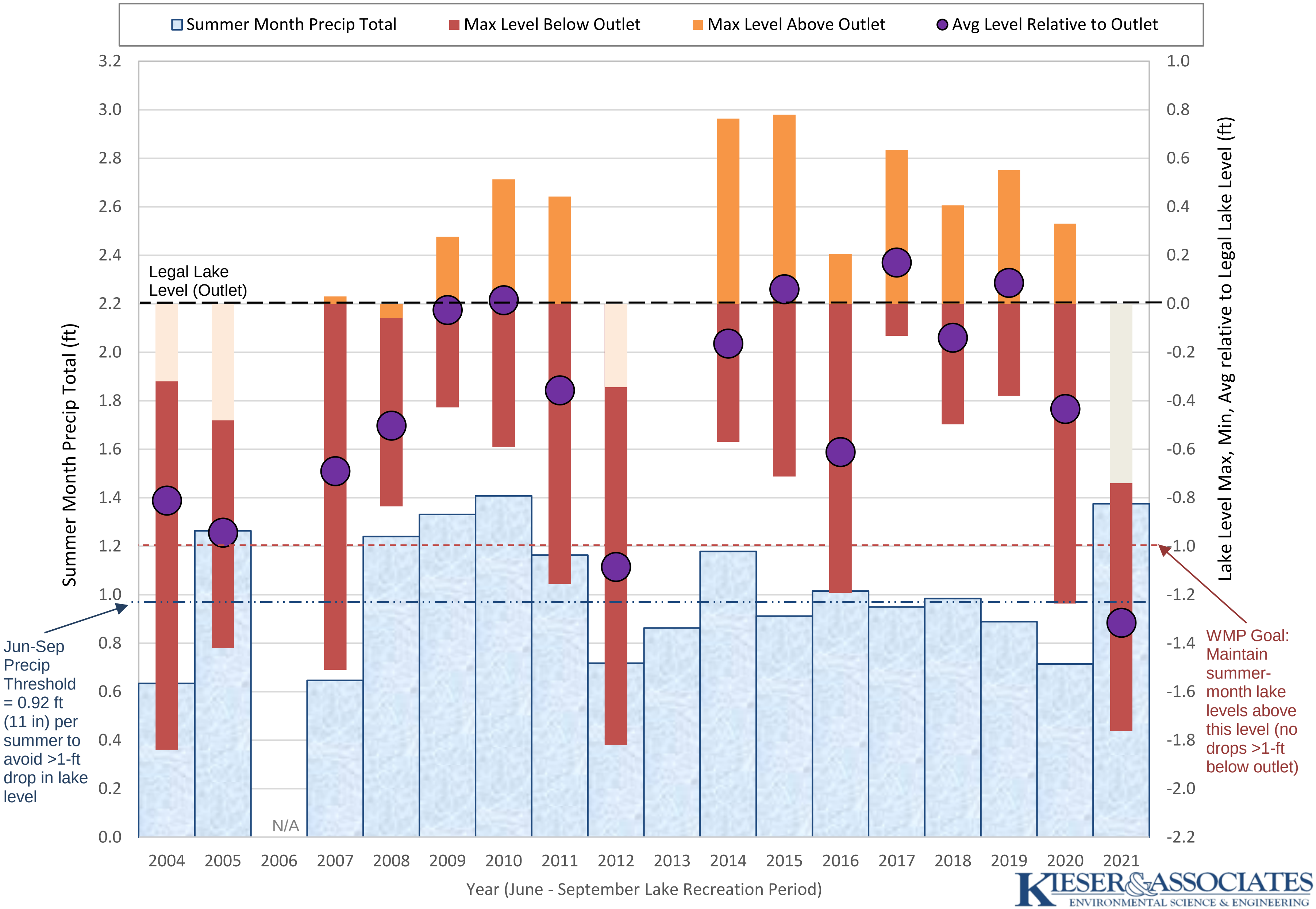

Figure 5. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 1)

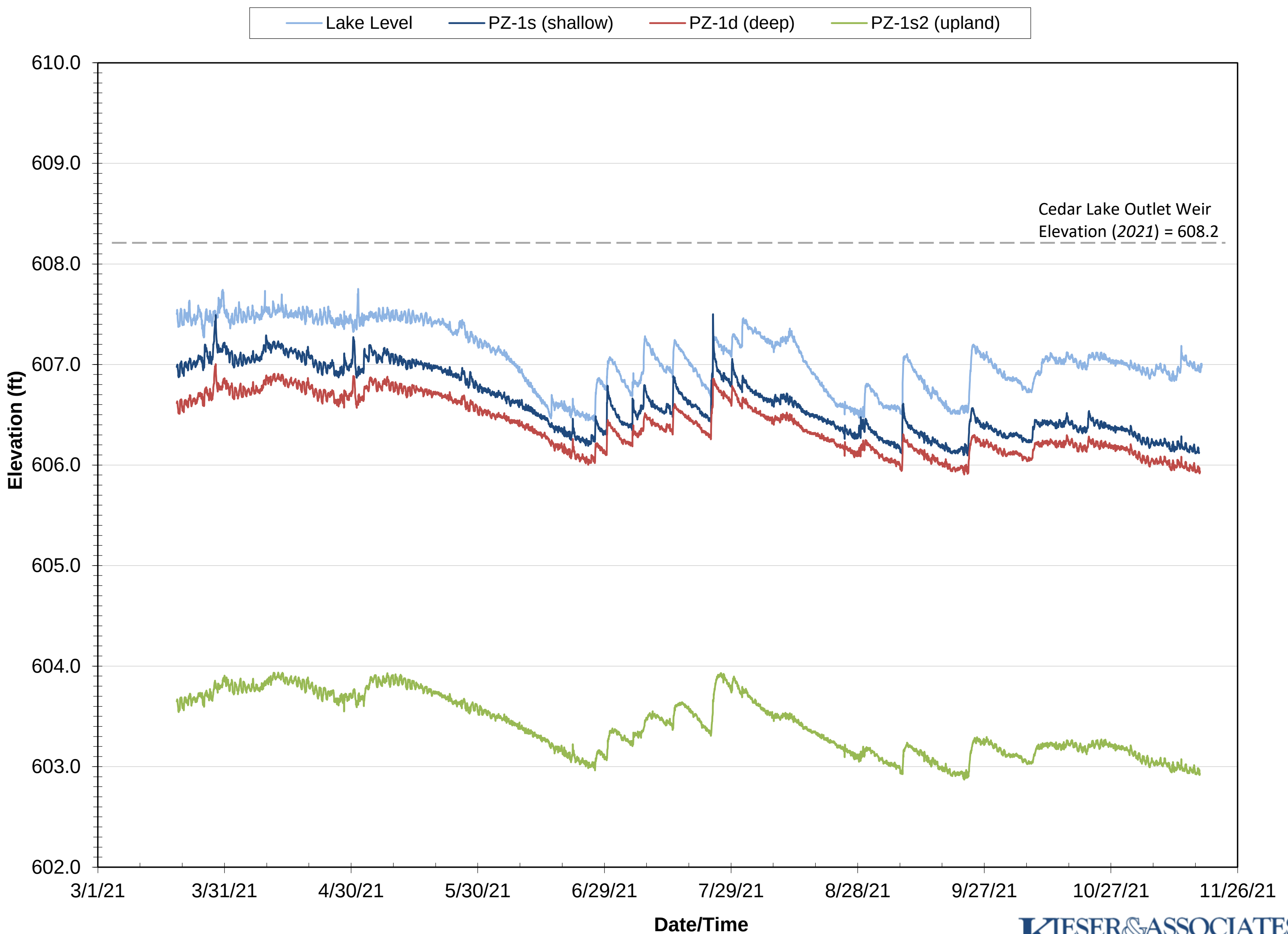

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Figure 6. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 2)

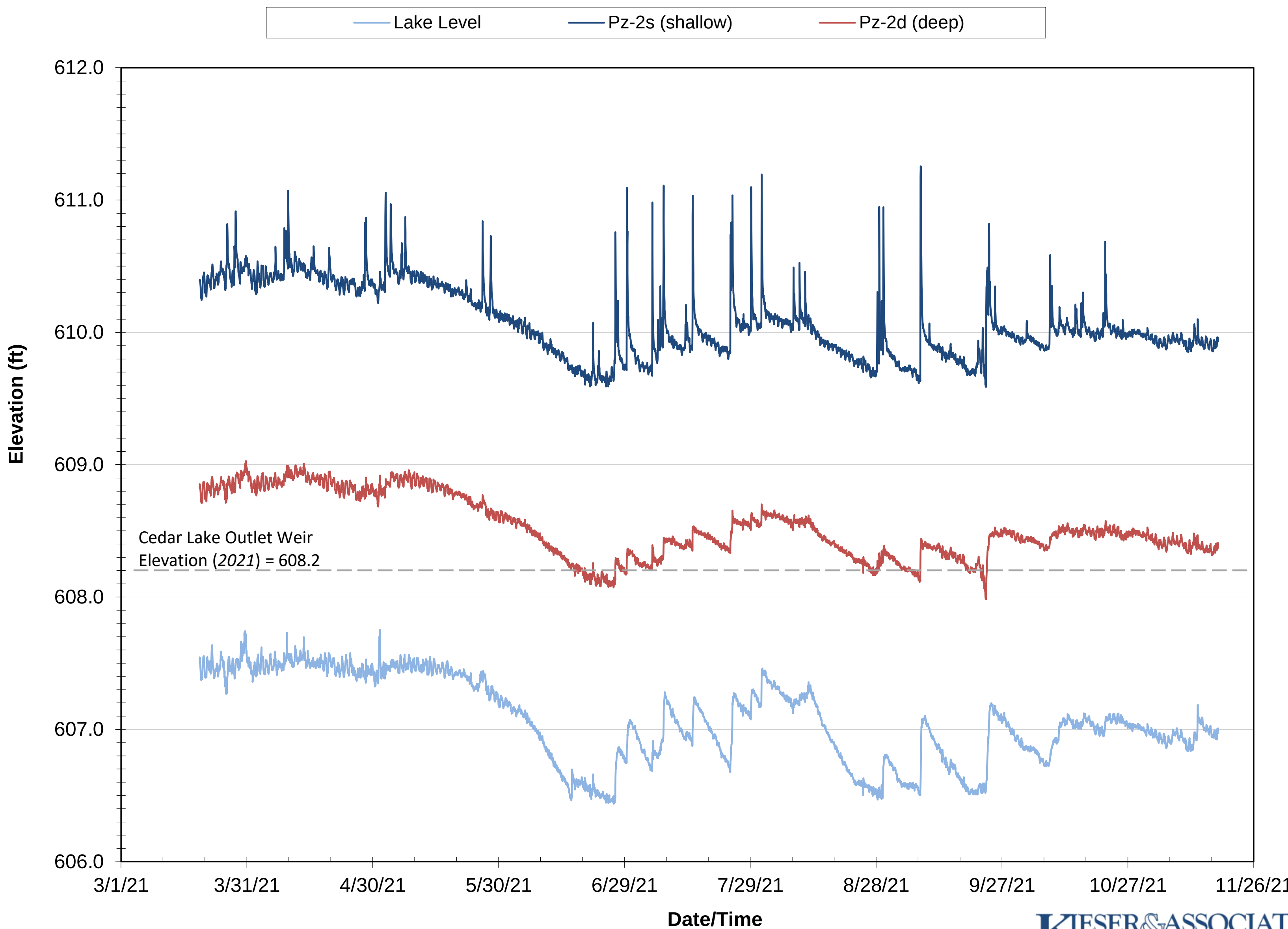

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Figure 7. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 3)

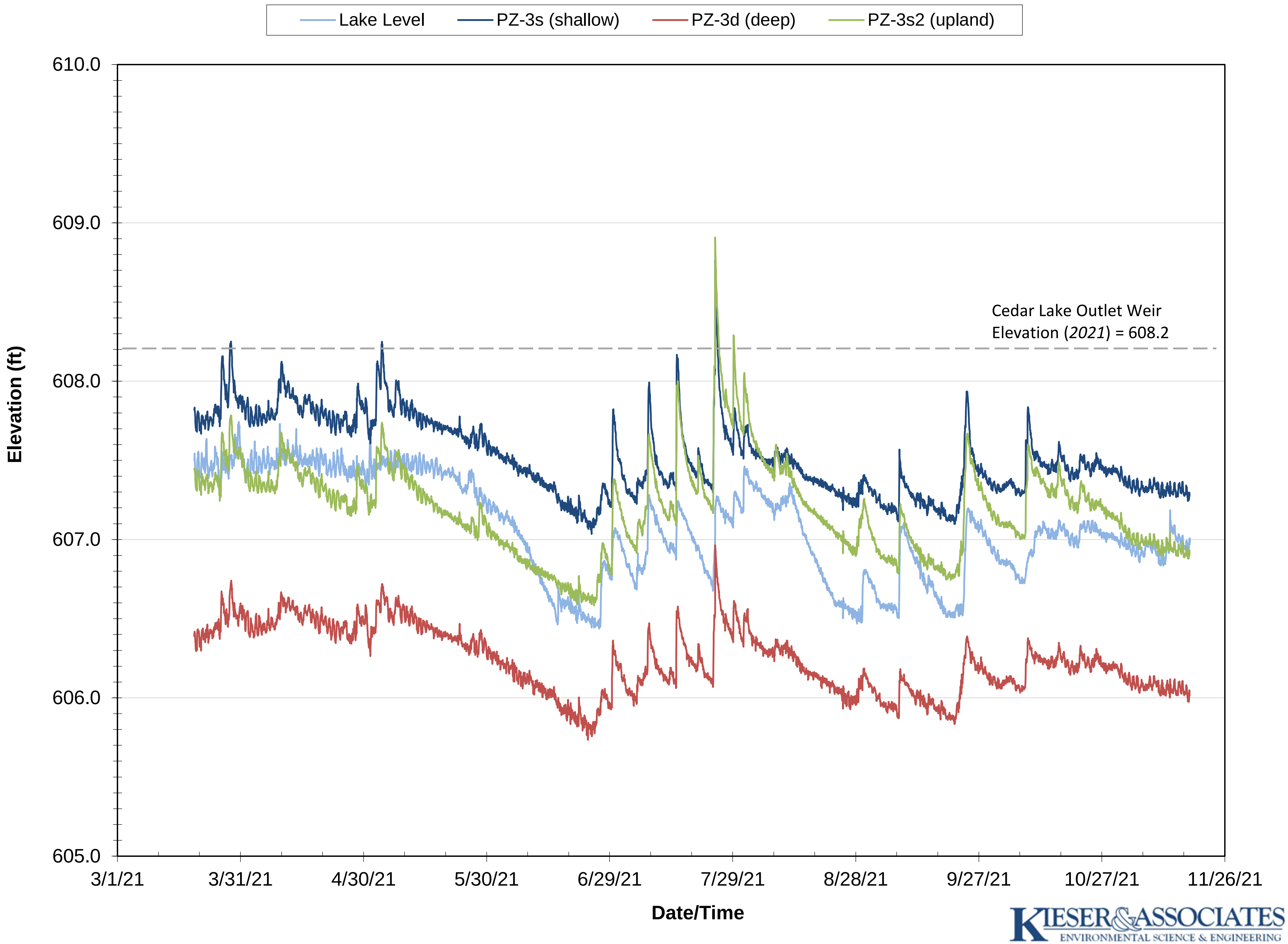

Figure 8. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 4)

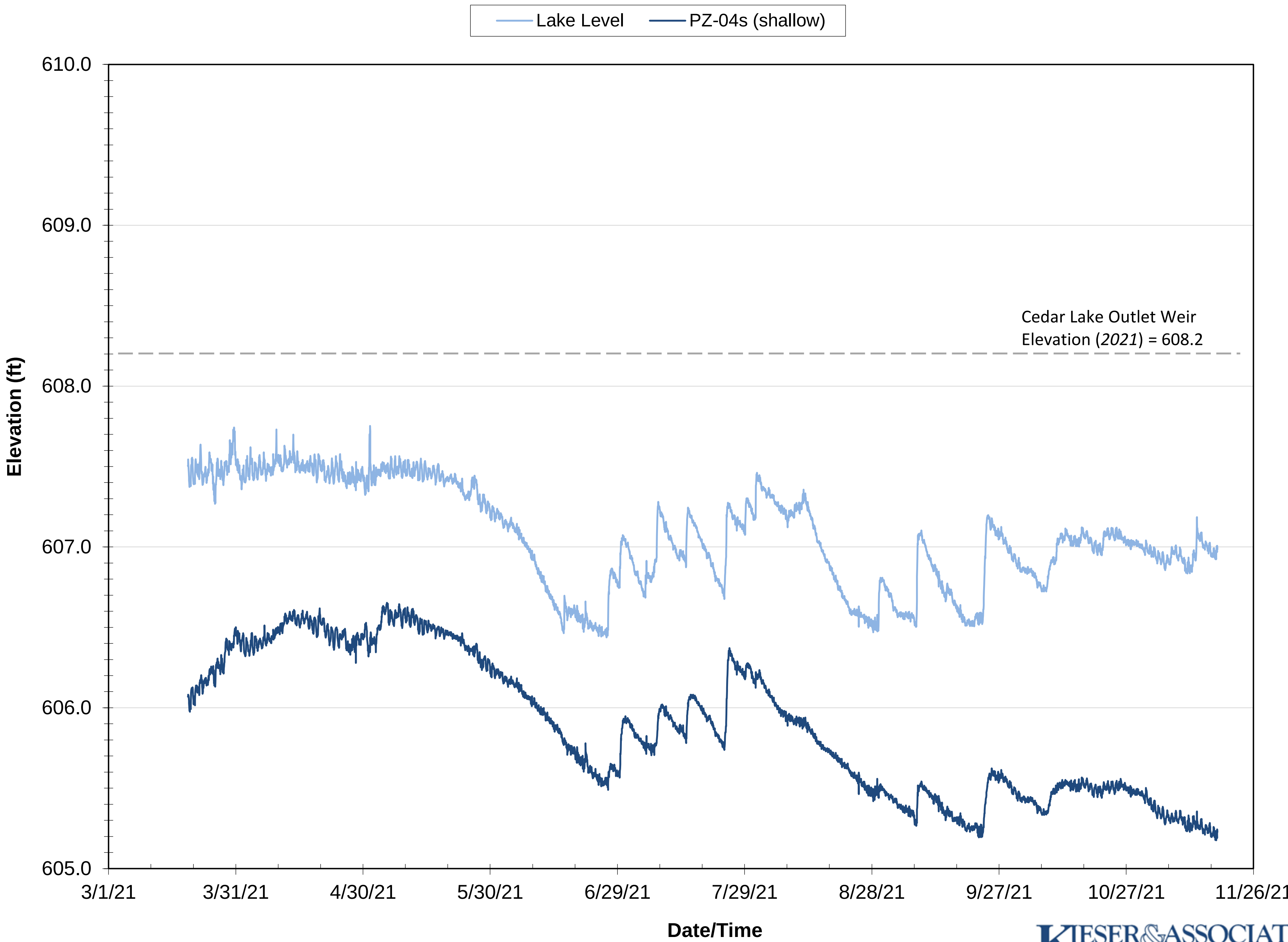

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Figure 9. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 5)

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Figure 10. 2021 Cedar Lake Groundwater / Surface Water Elevations
(Site 6 - *New Location, 2019*)

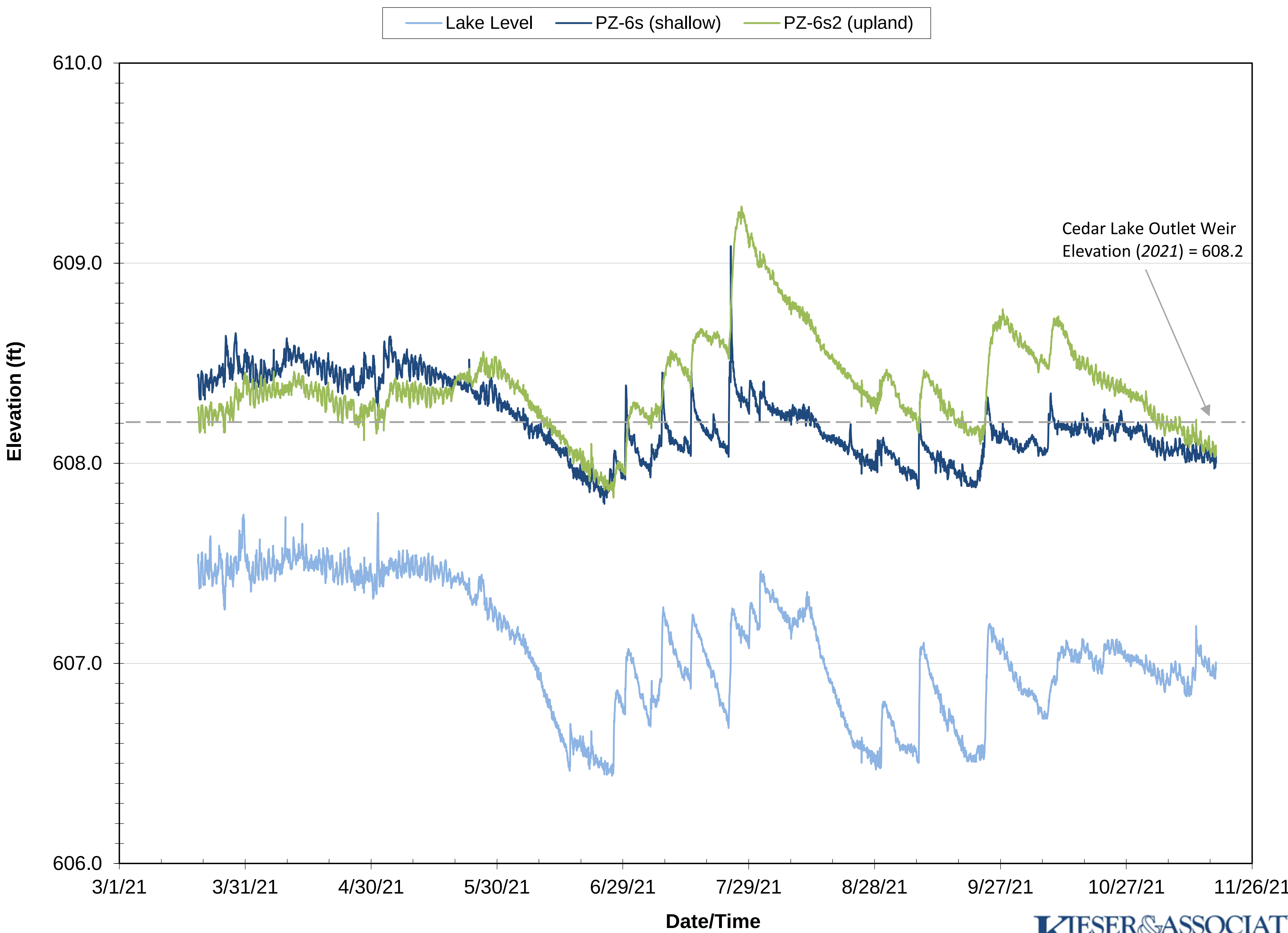

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Figure 11. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 7)

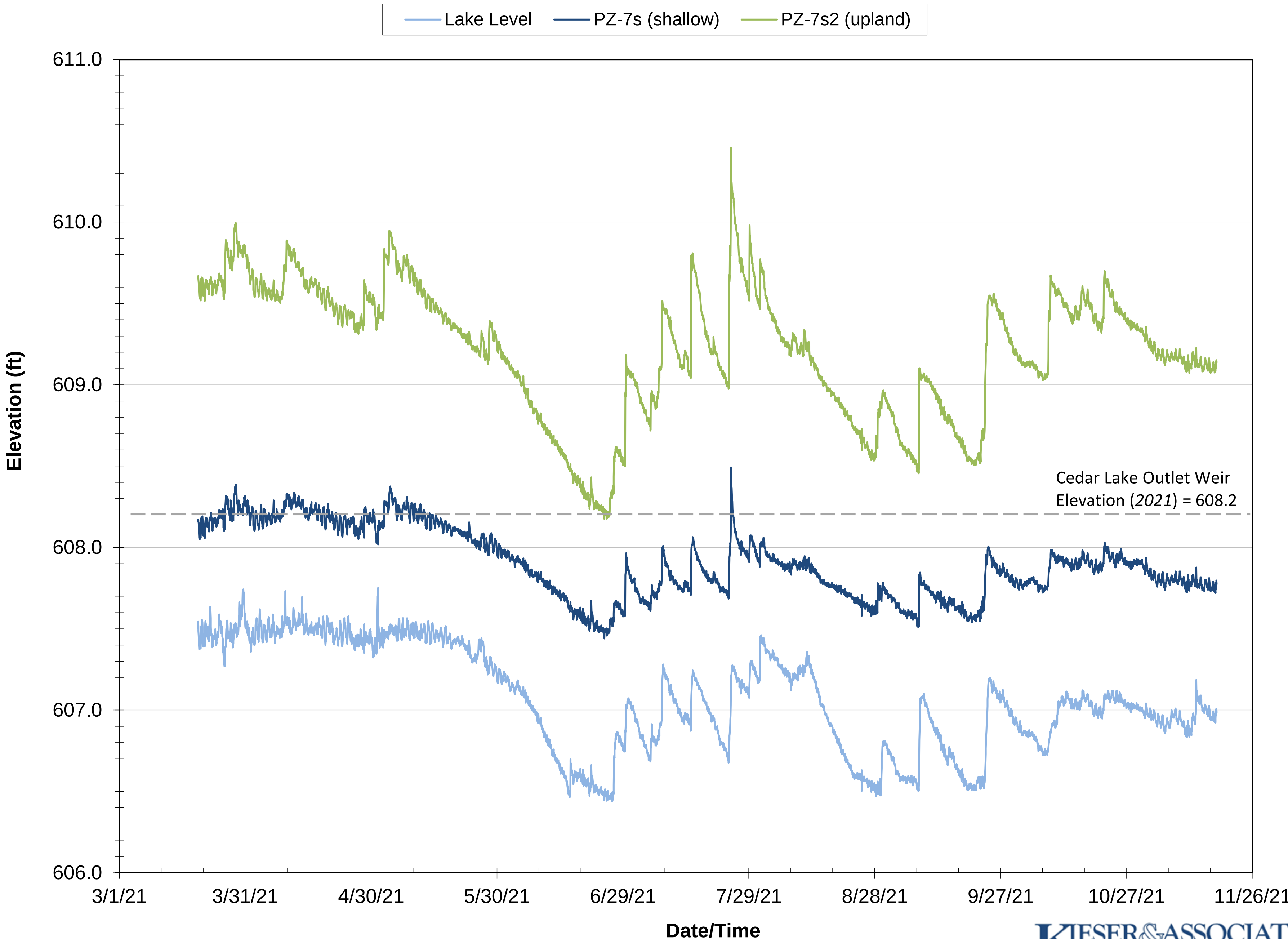

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Figure 12. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 8)

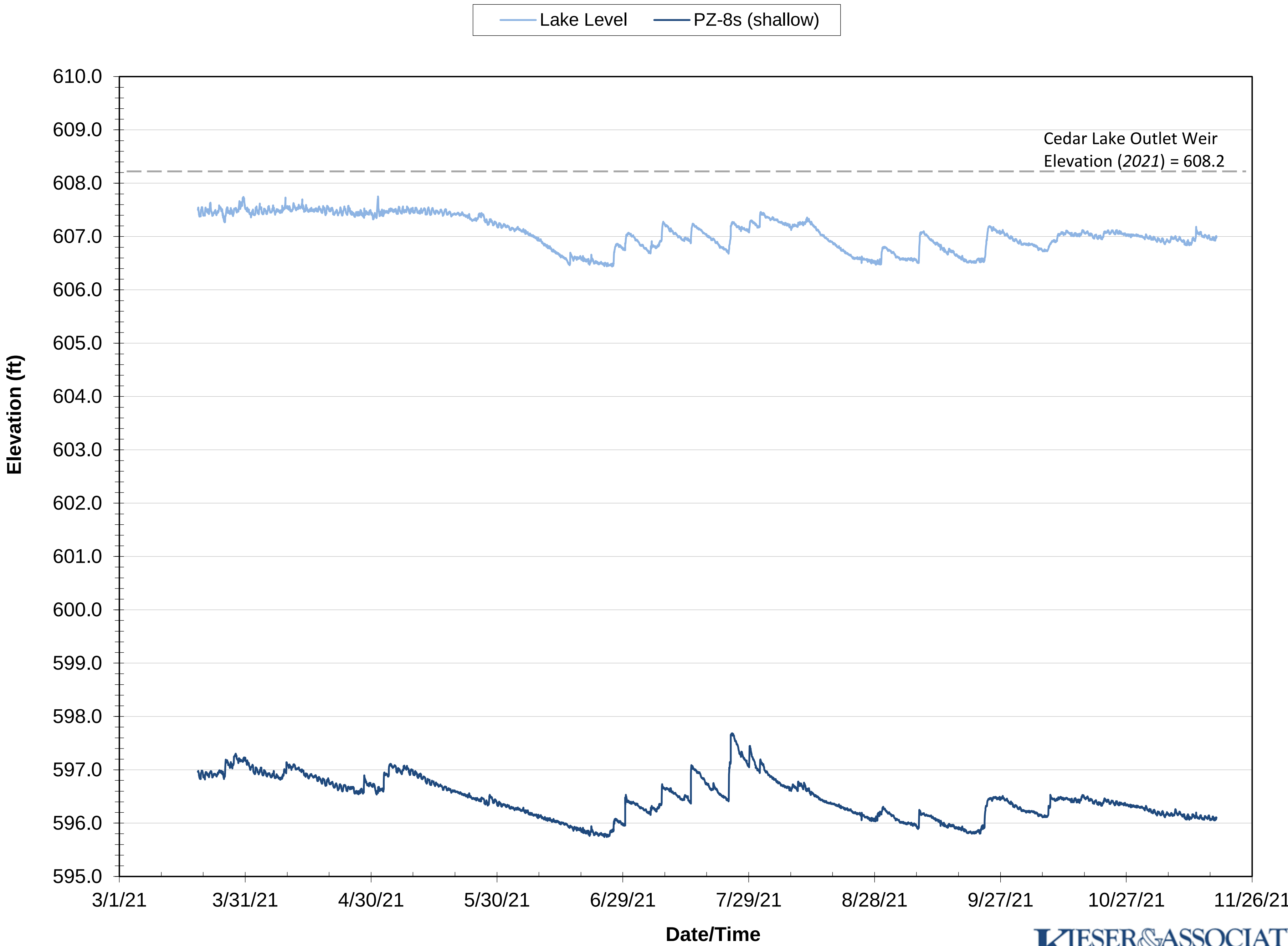

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Figure 13. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 9)

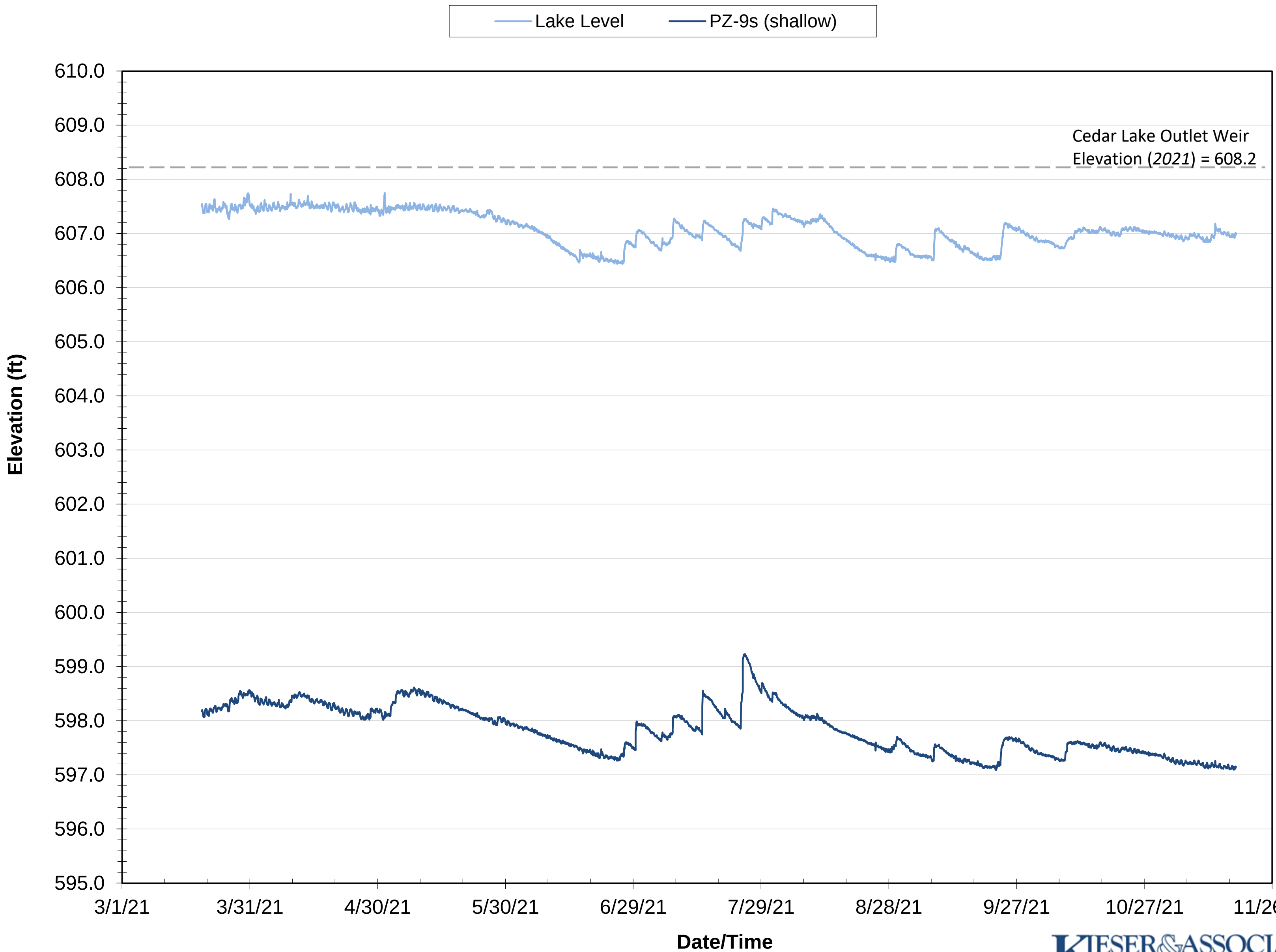

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Figure 14. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 10)

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Figure 15. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 11)

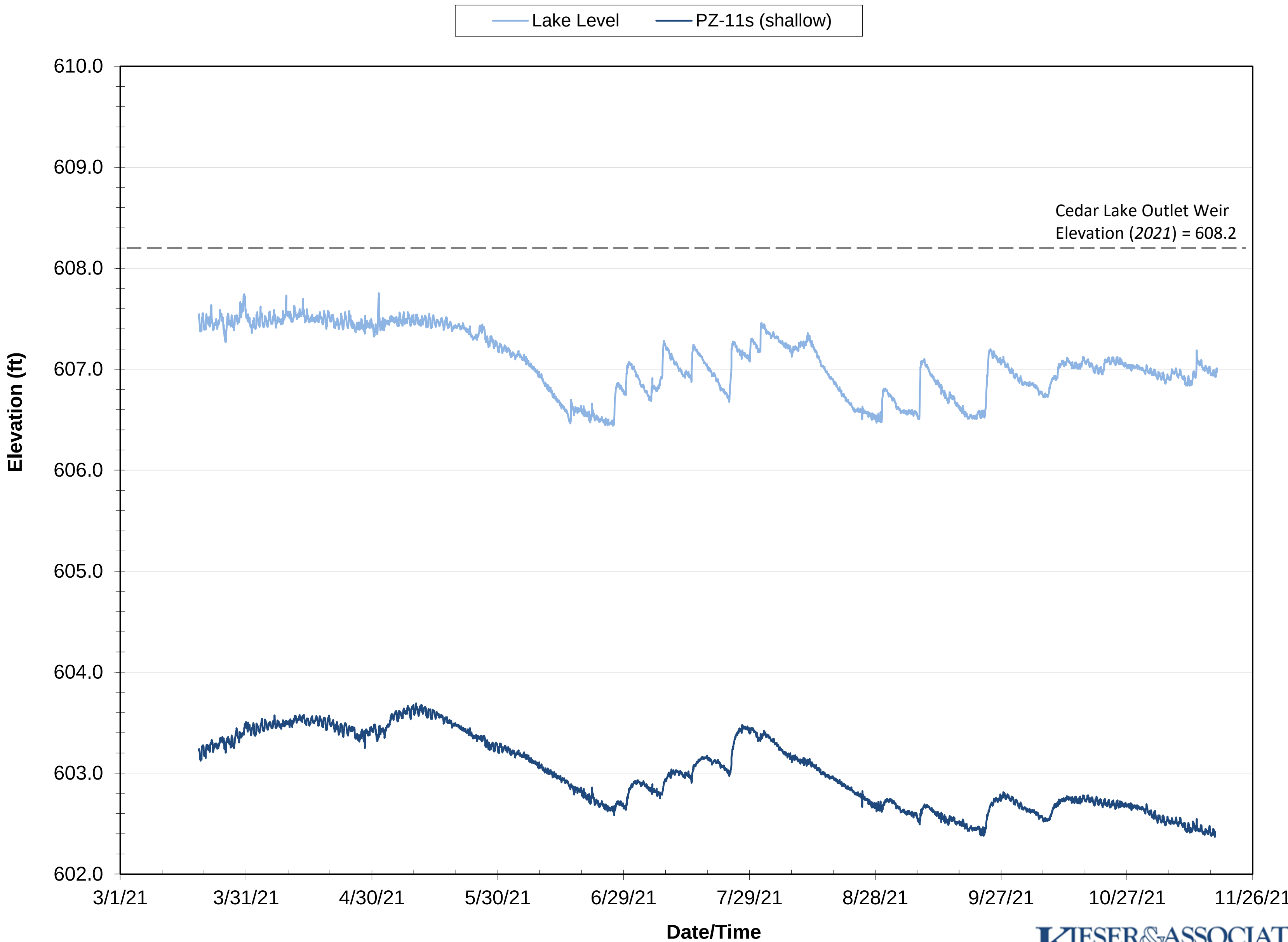

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Figure 16. 2021 Cedar Lake Groundwater / Surface Water Elevations (Site 12)

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Figure 17. 2021 Cedar Lake Groundwater / Surface Water Elevations (West Kings)

Figure 18. 2021 Cedar Lake Groundwater / Surface Water Elevations (Lakewood Shores Phelan Creek: LWSPC)

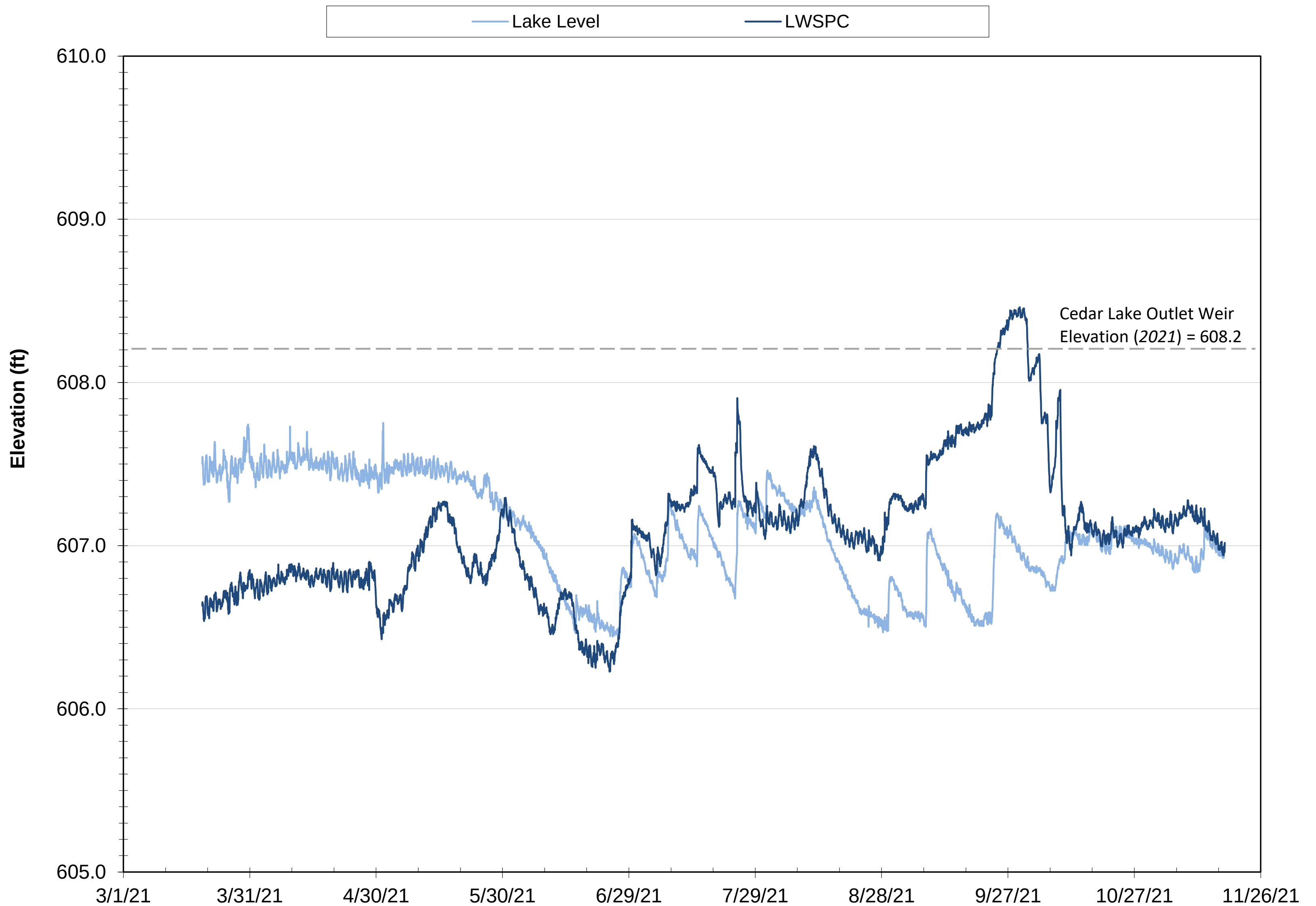

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Figure 19. Cedar Lake Groundwater / Surface Water Elevations (King's Corner Area Loggers)

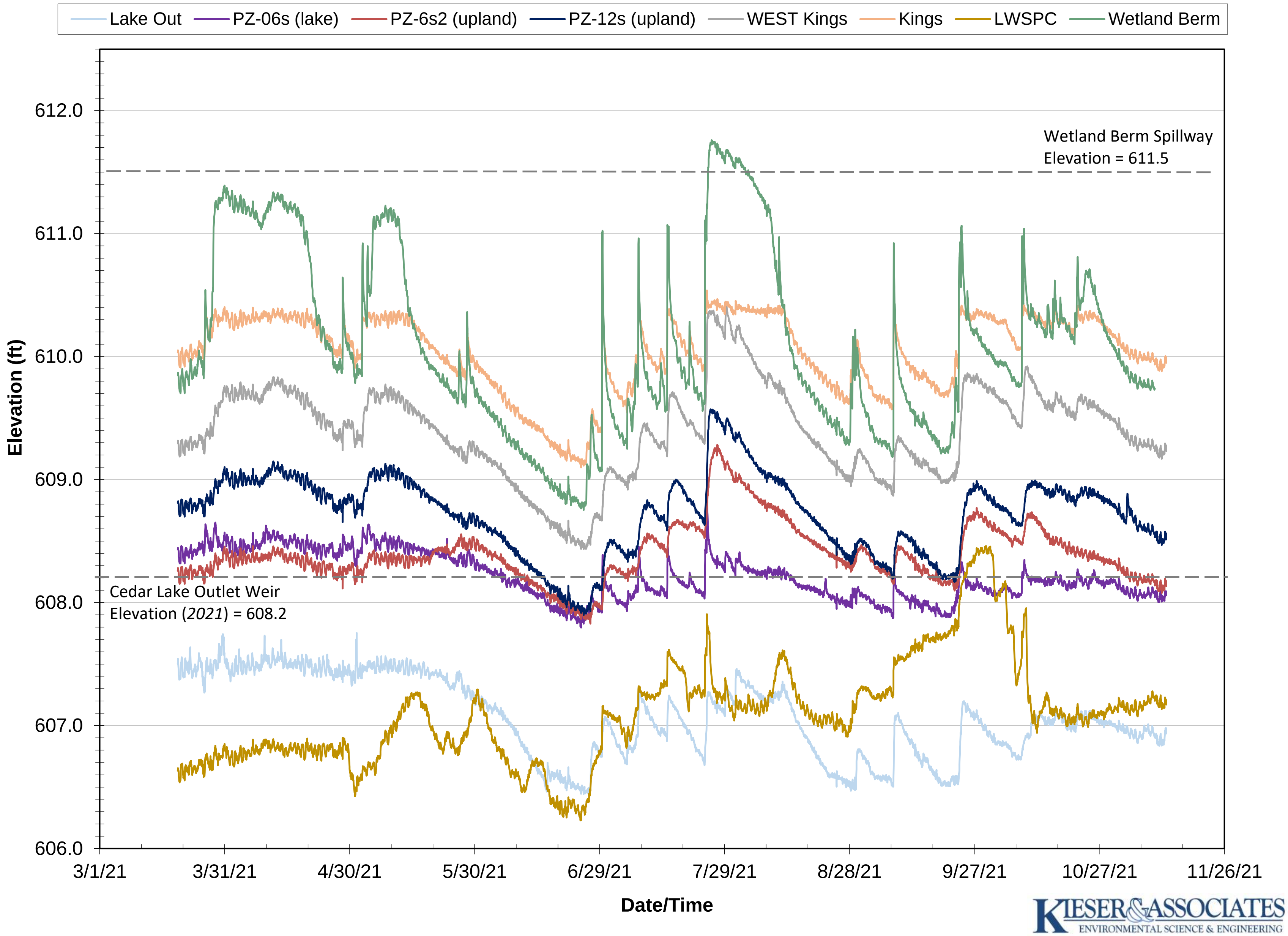

Figure 20. 2021 Estimated Jones Creek Flows

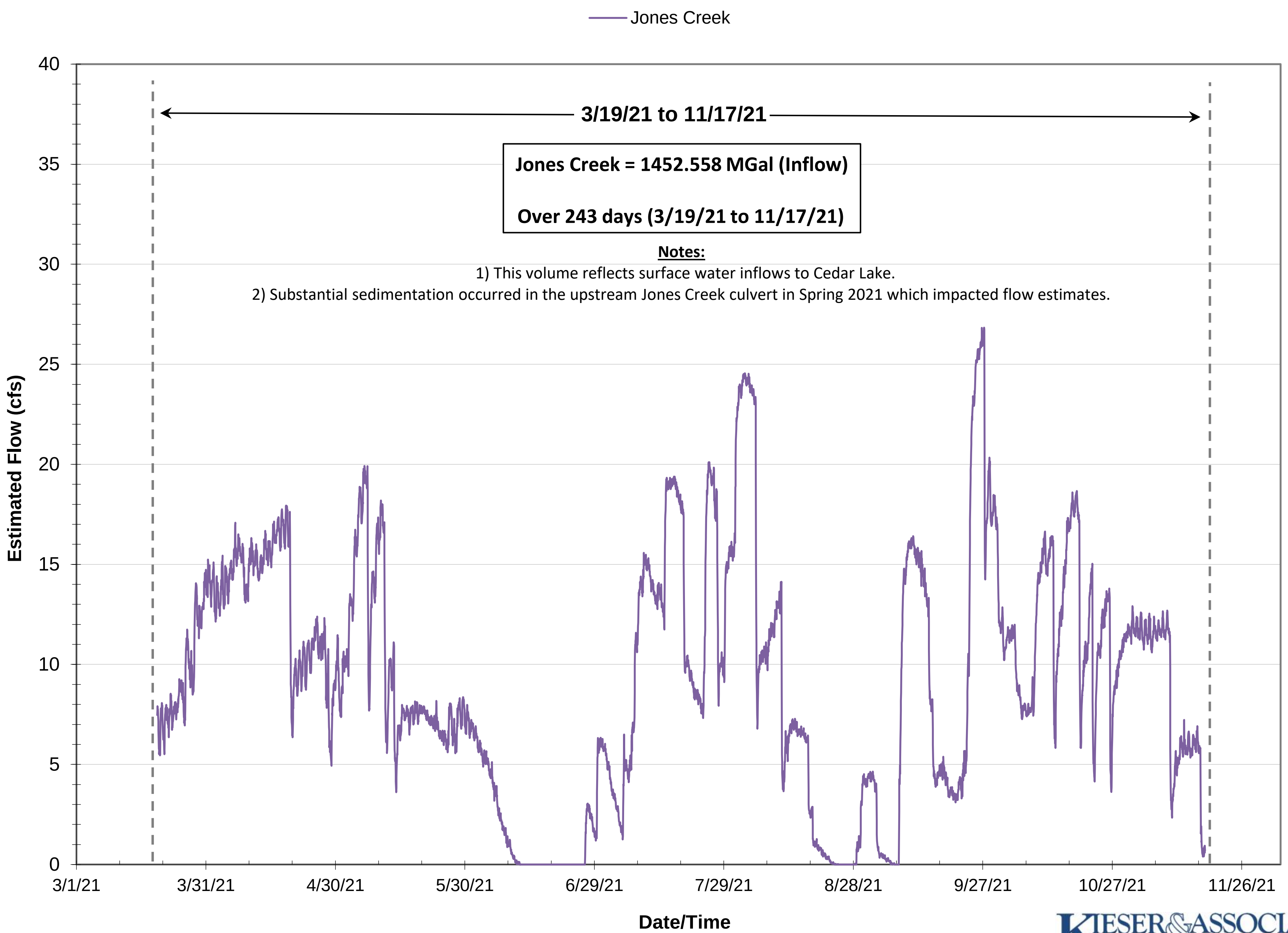

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Figure 21. 2021 Estimated Sherman Creek Flows

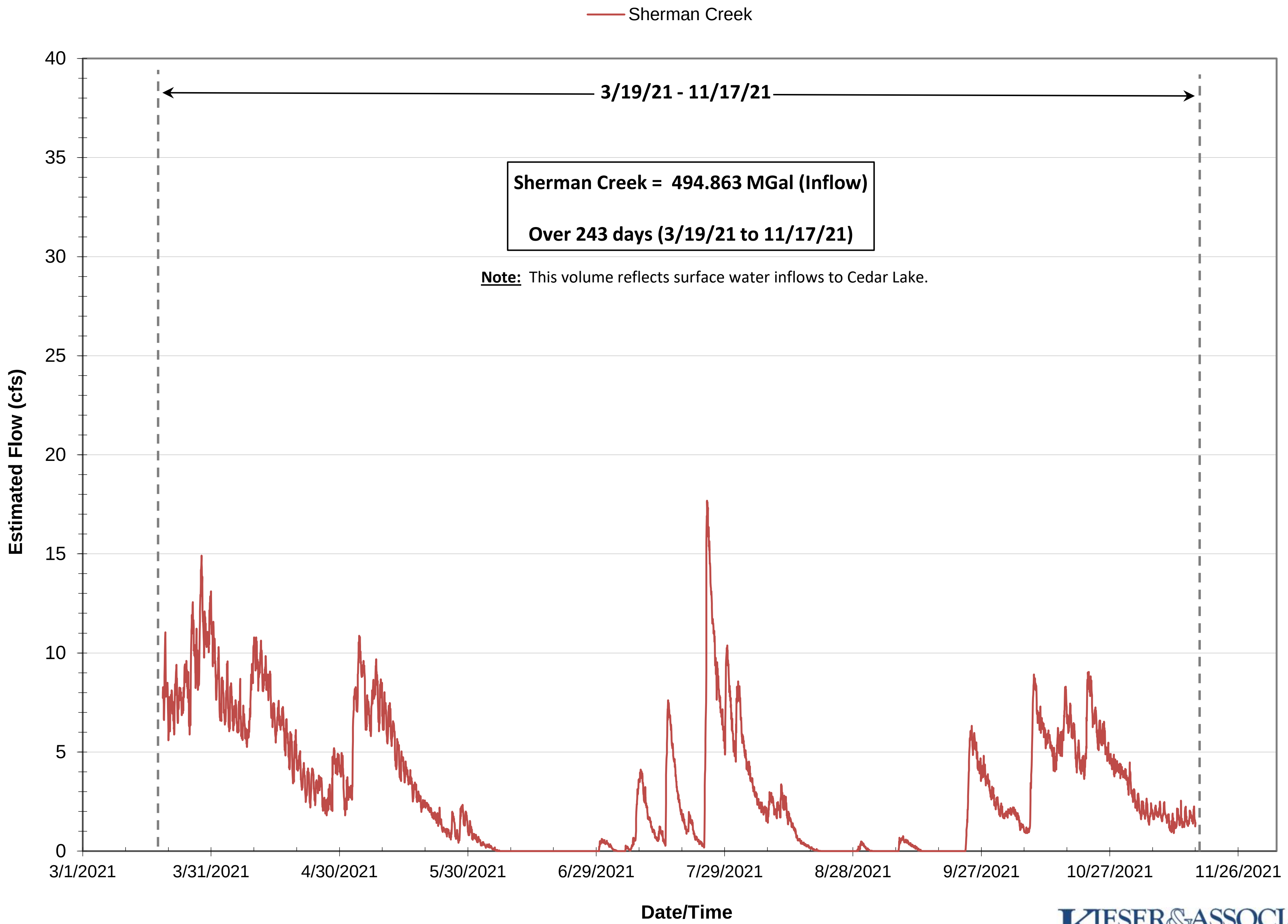

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Figure 22. 2021 Estimated Cedar Lake Outflows

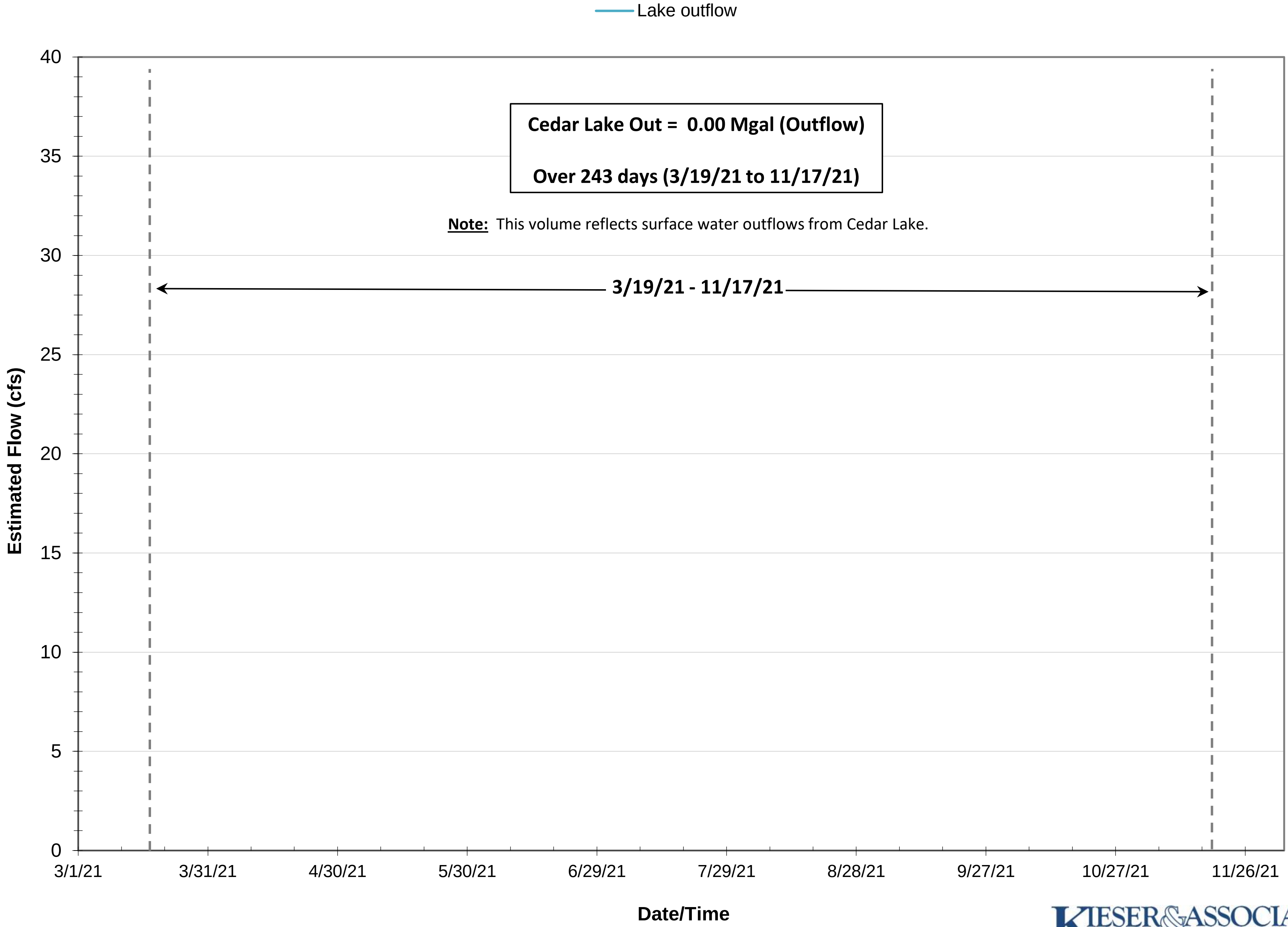

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Figure 23. 2021 Estimated Kings Corner Outflow

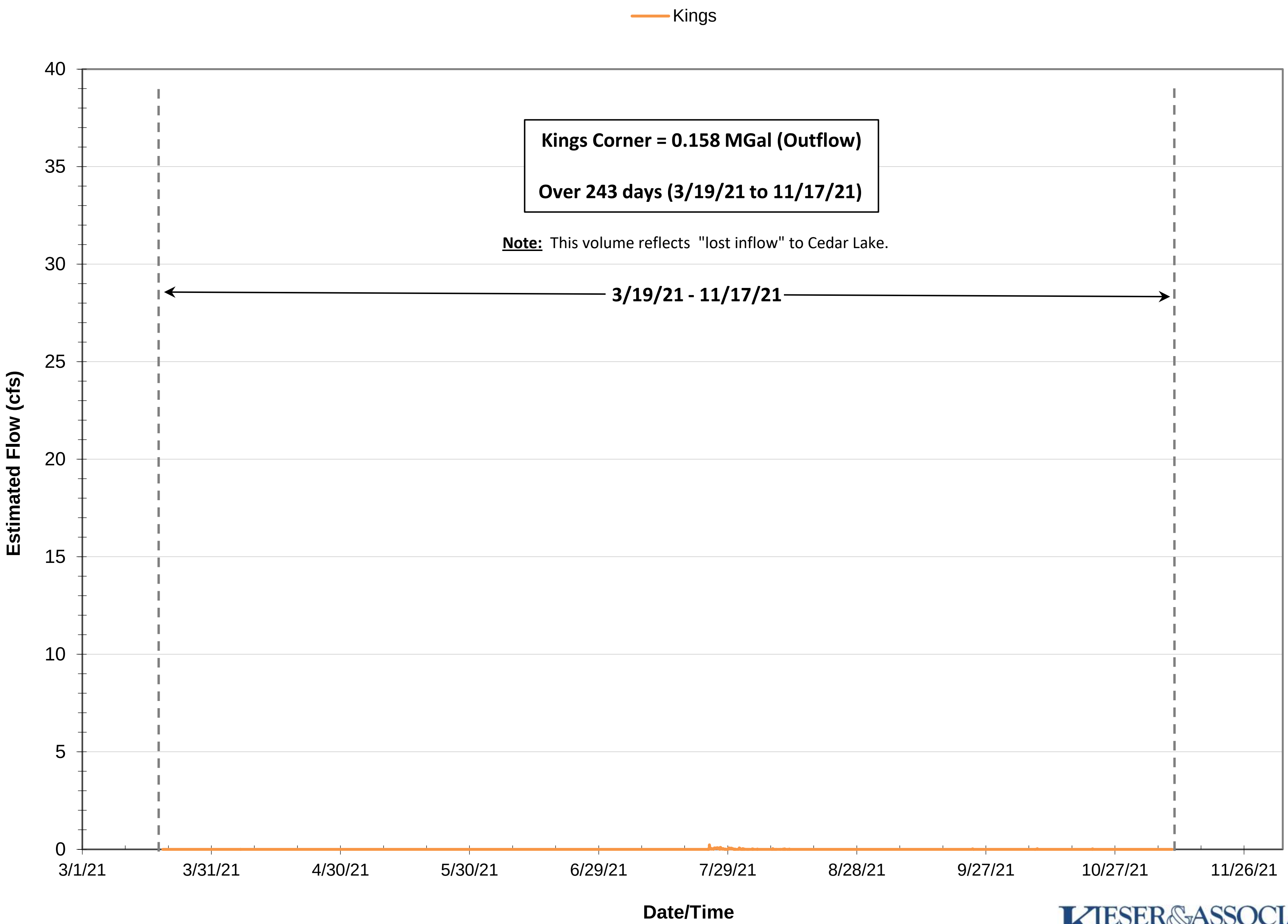

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Figure 24. 2021 Estimated Wetland Berm Spillway Flows

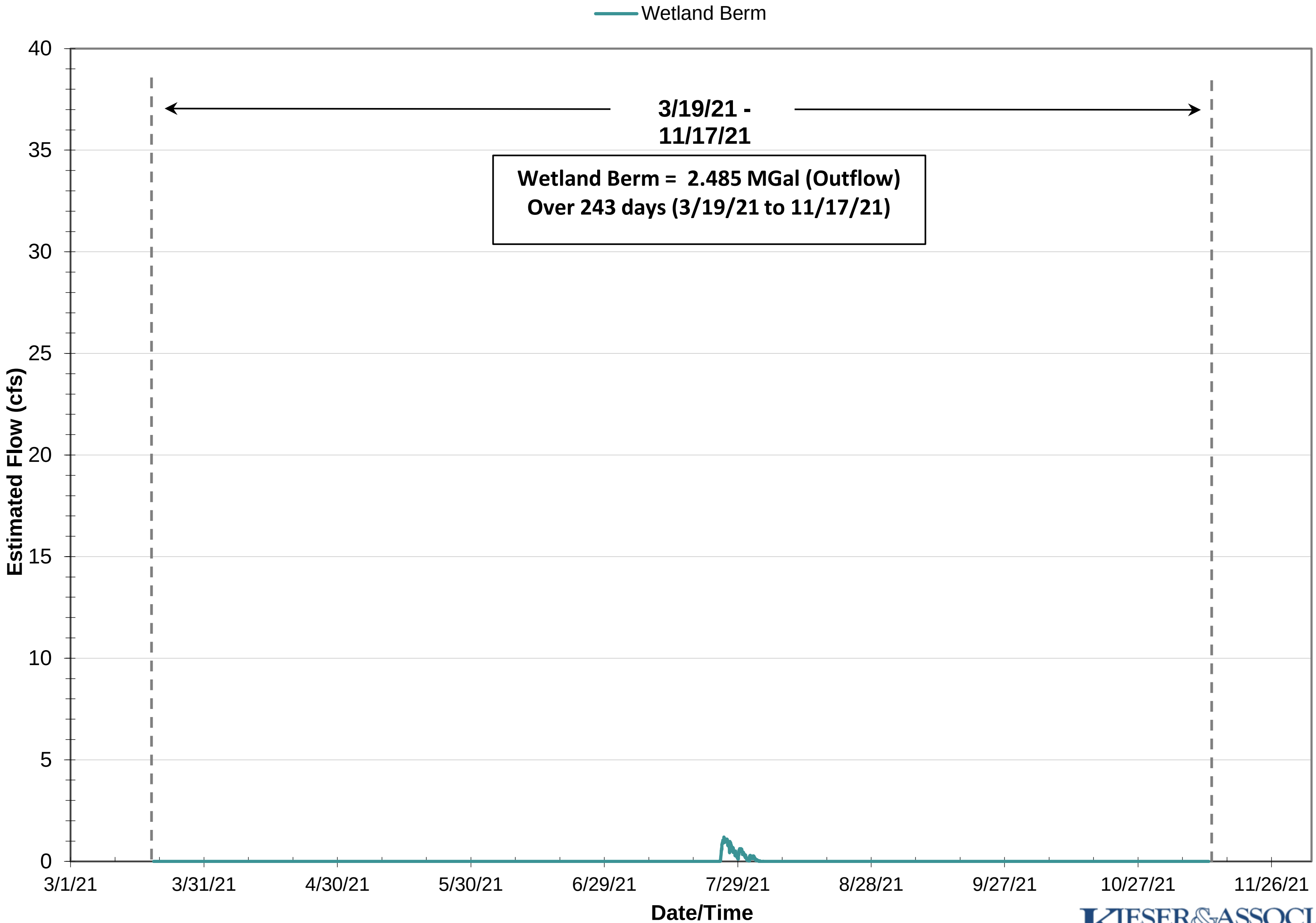

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Figure 25. 2021 Estimated Cedar Lake Inflows/Outflows

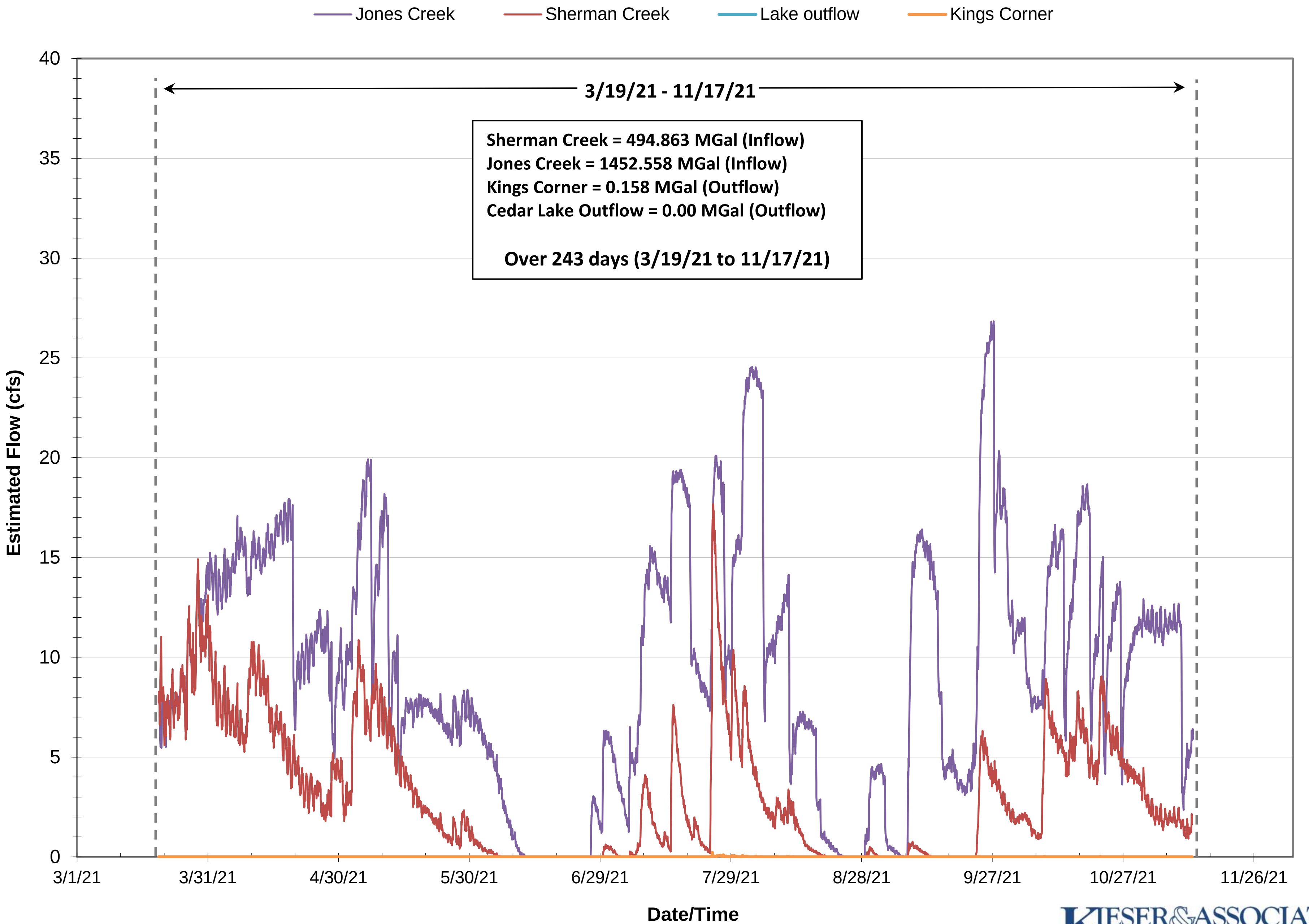

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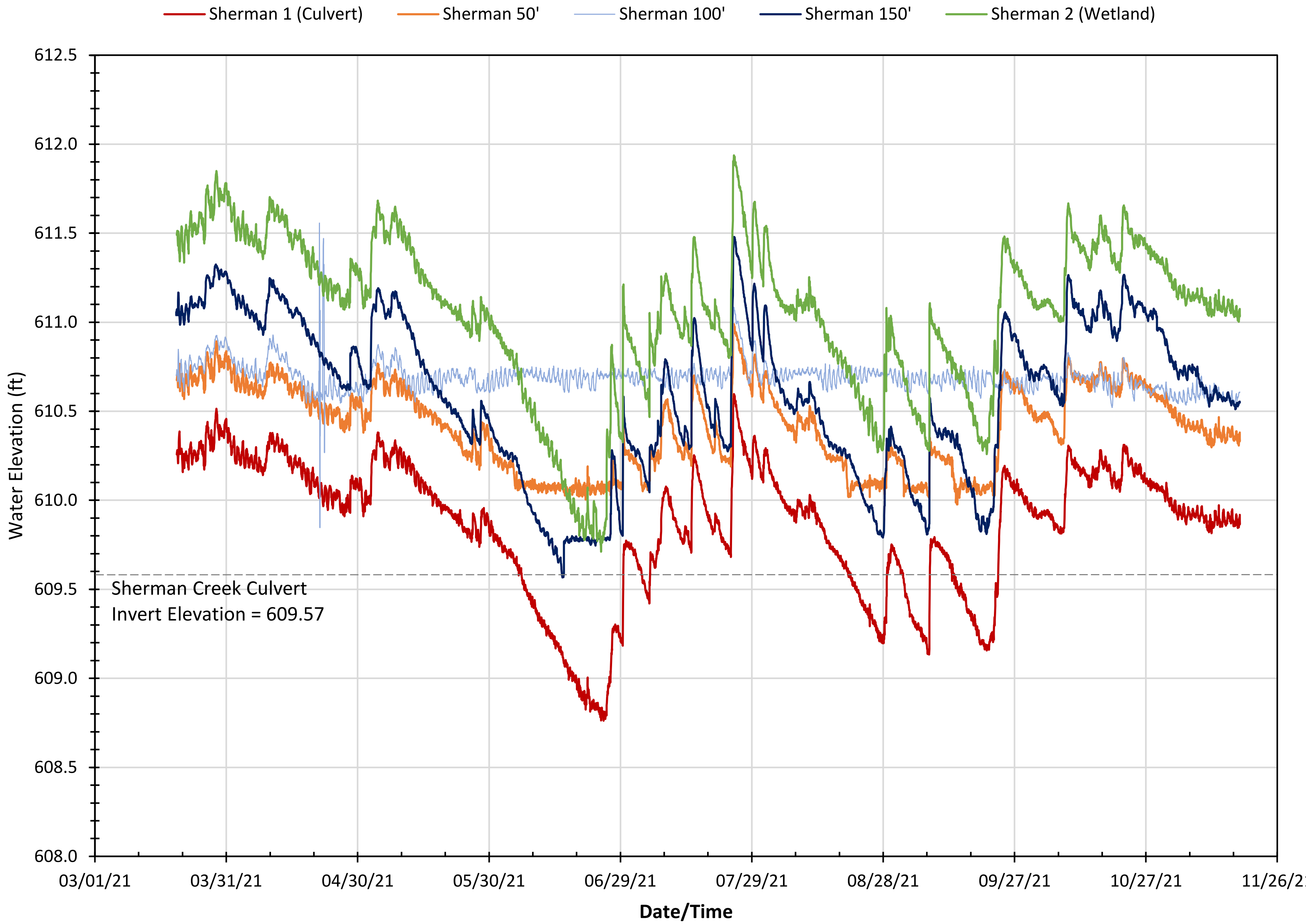
Figure 26. Sherman Creek Stations: Surface Water / Groundwater Elevations



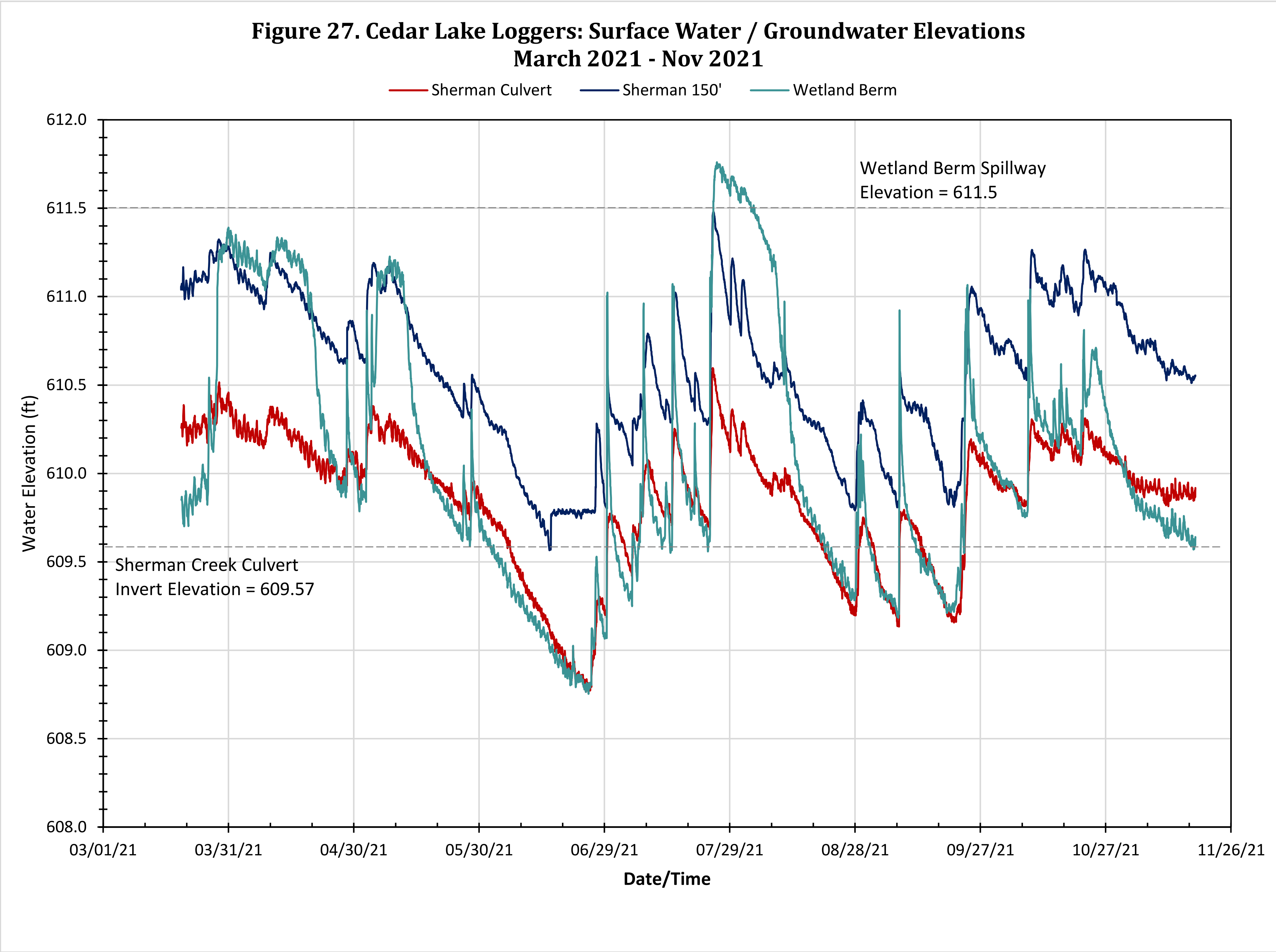


Figure 27. Cedar Lake Loggers: Surface Water / Groundwater Elevations
March 2021 - Nov 2021
Sherman Culvert
Sherman 150'
Wetland Berm
Wetland Berm Spillway
Elevation = 611.5
Sherman Creek Culvert
Invert Elevation = 609.57
Water Elevation (ft)
612.0
611.5
611.0
610.5
610.0
609.5
609.0
608.5
608.0
03/01/21
03/31/21
04/30/21
05/30/21
06/29/21
07/29/21
08/28/21
09/27/21
10/27/21
11/26/21
Date/Time

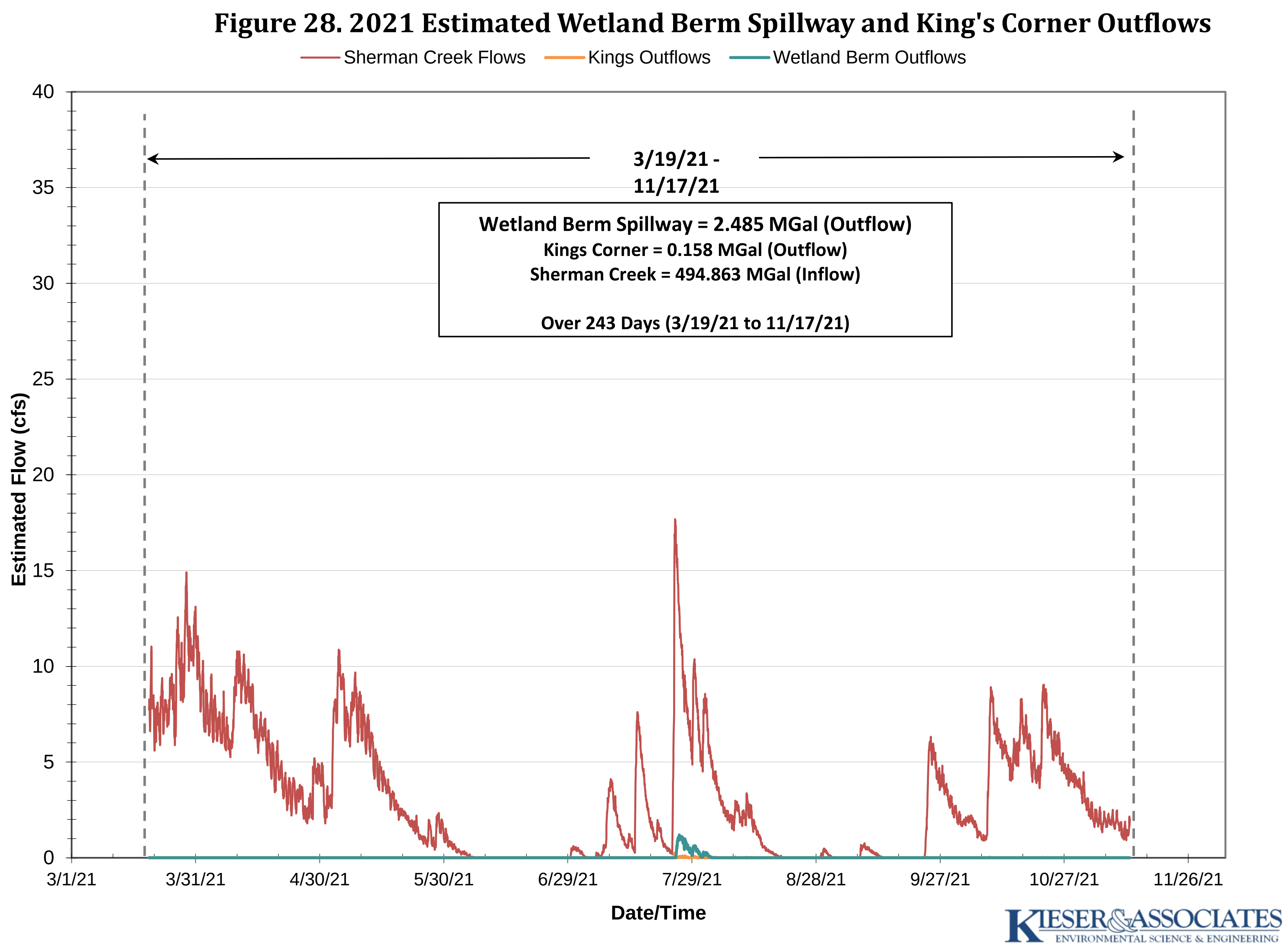


Figure 28. 2021 Estimated Wetland Berm Spillway and King's Corner Outflows
Sherman Creek Flows
Kings Outflows
Wetland Berm Outflows
3/19/21 - 11/17/21
Wetland Berm Spillway = 2.485 MGal (Outflow)
Kings Corner = 0.158 MGal (Outflow)
Sherman Creek = 494.863 MGal (Inflow)
Over 243 Days (3/19/21 to 11/17/21)
Estimated Flow (cfs)
40
35
30
25
20
15
10
5
0
3/1/21
3/31/21
4/30/21
5/30/21
6/29/21
7/29/21
8/28/21
9/27/21
10/27/21
11/26/21
Date/Time
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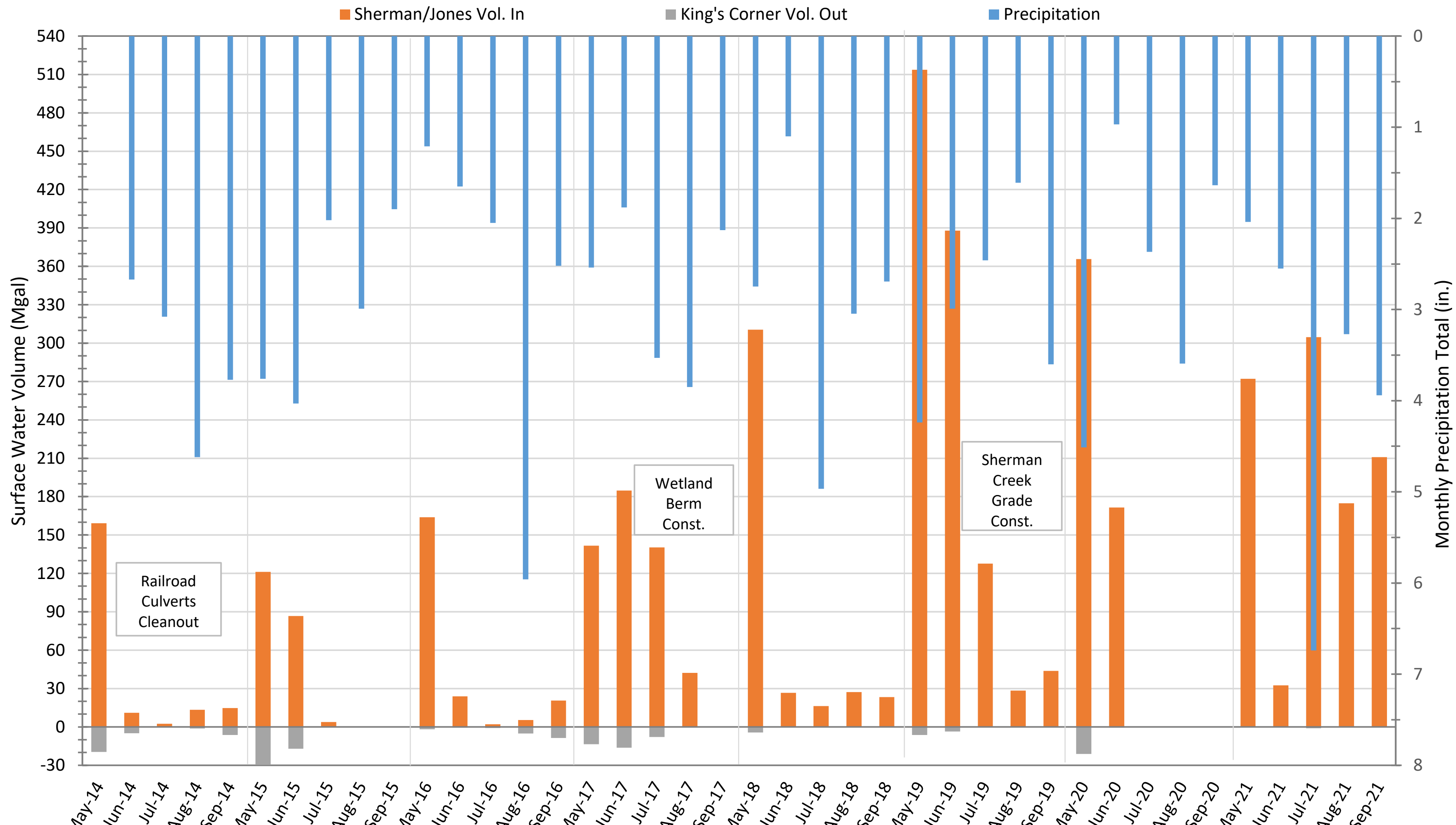
Figure 29. May-Sep, 2014-21: Precipitation, Sherman/Jones Creeks Combined Surface Water Volume into Cedar Lake, and King's Corner Surface Water Volume Away from Cedar Lake



2014 May-Sep:	**2015 May-Sep:**	**2016 May-Sep:**	**2017 May-Sep:**	**2018 May-Sep:**	**2019 May-Sep:**	**2020 May-Sep:**	**2021 May-Sep:**
Precip: 14.14 in.	***Precip:*** 14.70 in.	***Precip:*** 13.39 in.	***Precip:*** 13.93 in.	***Precip:*** 14.55 in.	***Precip:*** 14.90 in.	***Precip:*** 13.08 in.	***Precip:*** 18.54 in.
Inflow Vol.: 200.9 Mgal	***Inflow Vol.:*** 212.5 Mgal	***Inflow Vol.:*** 216.1 Mgal	***Inflow Vol.:*** 509.2 Mgal	***Inflow Vol.:*** 338.3 Mgal	***Inflow Vol.:*** 534.3 Mgal	***Inflow Vol.:*** 383.5 Mgal	***Inflow Vol.:*** 995.138 Mgal
King's Vol. Out: 32.2 Mgal	***King's Vol. Out:*** 46.9 Mgal	***King's Vol. Out:*** 17.1 Mgal	***King's Vol. Out:*** 38.1 Mgal	***King's Vol. Out:*** 4.3 Mgal	***King's Vol. Out:*** 10.2 Mgal	***King's Vol. Out:*** 21.8 Mgal	***King's Vol. Out:*** 0.158 Mgal