KIESER & ASSOCIATES
ENVIRONMENTAL SCIENCE & ENGINEERING

TECHNICAL MEMORANDUM

To:	Rex Vaughn, Chair Cedar Lake Improvement Board	**Date:**	April 8, 2024
From:	Mark Kieser, Senior Scientist John Jacobson, PE, Senior Engineer Mike Foster, Environmental Engineer Kieser & Associates, LLC	**cc:**	Files

RE: Data and Findings from 2023 Cedar Lake Groundwater/Surface Water Level Monitoring

This memorandum presents 2023 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 2023 on behalf of the Cedar Lake Improvement Board (CLIB). The purpose of this long-term monitoring program is to best understand critical needs and relevant influences on water levels in Cedar Lake for optimizing management efforts.

Desirable summer month water levels in Cedar Lake are a function of late winter snow pack, summer-time rainfall, evaporation, groundwater losses and watershed management strategies designed to support water level maintenance in dry summer months. These management strategies, as denoted in the approved Cedar Lake Watershed Management Plan (WMP), relate to ongoing efforts to bolster water retention, and in turn, watershed discharges to the lake, particularly during the recreational season.

Water level control efforts have been implemented in the Cedar Lake watershed since 2017 including the construction of the Sherman Creek wetland enhancement berm and the implementation of the Sherman Creek instream grade structures in 2019. A Jones Ditch 2018 culvert replacement along North Cedar Lake Road now greatly enhances northwest cedar swamp watershed discharges to the lake. Reconstruction of the lake outlet in 2020 represents a significant water level control feature, replacing dual sheet steel box outlets. A summary of water level control outcomes associated with these changes is provided herein.

The wetland berm adjacent to and south of Sherman Creek was constructed in 2017 and serves to retain water 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. Sherman Creek instream grade structures serve 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. These structures were designed to also enhance northern pike spawning wetland habitat under high water, spring-time flow conditions. K&A and CLIB representatives continue to monitor and observe flow conditions around these structures to ensure they are operating as

designed, and to verify benefits under a range of spring snowpack and summer-time precipitation conditions for bolstering lake level management during open-water recreational periods.

The 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 has been deployed in the lake outlet since March of 2021. Visual inspections of the outlet structure during site visits by K&A staff reveal 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. Streamflow data collected through previous monitoring periods suggested low-flow groundwater is likely the culprit of the continual trickle exiting through the lake outlet structure. Previous calculations of these losses showed they where not of relevant concern. Thus, downstream channel flow monitoring efforts were discontinued.

This technical memorandum presents findings of these water level conditions observed in Cedar Lake and its watershed in 2023 with discussions of implemented, ongoing, and potential future water level management strategies. All tables and figures referenced in the body of this memorandum 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 2023 water level monitoring efforts totaled 31 level loggers in operation around the Cedar Lake from March to December. Select loggers remain in place throughout the year. The location and addresses of the sites of the level loggers are provided in Figure 1.

The combination of surface water level stations, shallow piezometers, and deep piezometers allow for and facilitate observations of the interactions between surface water, groundwater, and Cedar Lake water levels. Sherman Creek, Jones Ditch, and the King's Corner Road culvert continued to be monitored in 2023 to calculate estimates of surface water flows into Cedar Lake. Level loggers were also deployed in one of three instream stilling wells in Sherman Creek to further understand the impacts of the instream grade structures on creek/wetland water levels and discharges.

Two additional instream level loggers were deployed in Jones Ditch in 2022 and continue to be monitored in 2023. An additional logger was also deployed upstream of West Cedar Lake Road in 2022 within the wetland complex that contributes surface flows to Jones Ditch. These additional loggers in the Jones Ditch drainage will continue to further define the hydrologic contributions in 2024. These data will be relevant for proposed efforts to restore the Jones Ditch channel adjacent to the lake to provide improved channel access for spring Pike spawning into the upstream wetlands, as well as ensure summer-time rainfall event flows readily reach the lake.

The Sherman Creek wetland berm on CLIB property was constructed in fall of 2017 as part of the ongoing efforts to retain water levels in the cedar swamp. The wetland berm was designed with a stone-laden spillway meant to overflow at an elevation of 611.50 feet so as not to

permanently alter historic high-water levels in the swamp or alter any historic flooding or outflow 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 Ditch 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 Ditch culvert had underestimated inflow volumes occurring over the March-November monitoring period. In 2021, the equation was updated to better estimate flows.

Revisions suggest Jones Ditch, under certain conditions, now contributes more surface water to Cedar Lake than Sherman Creek following replacement with a larger diameter culvert and a lower invert elevation. This discovery has significant implications for future engineering designs and management efforts. The additional instream level loggers in Jones Ditch and the connected wetland implemented in 2022 provide further insight into interactions between surface water groundwater in and along the northwest corner of the Cedar Lake watershed. The surface flow equations from Jones Ditch will continue to be refined with the data provided by additional loggers and field measurements taken during site visits.

All 31 level loggers around Cedar Lake have been replaced since 2018 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 2017 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. The three additional loggers in Jones Ditch and an additional one near the Timberlakes club house property on the northeast side of Cedar Lake were purchased in 2022. The lifespan of these level loggers is roughly ten years. Loggers and their data are 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.

2023 Precipitation and Water Level Data

Precipitation Analysis:

Historic summer precipitation totals for the Cedar Lake area are presented in Figure 2. These data represent calculated 2023 summer precipitation as triangulated from three rain gauges: the Cedar Lake volunteer rain gauge, Harrisville State Park (Station # USC00203628) via NOAA, and Oscoda Wurtsmith Airport (Station #14808) via Weather Underground. Triangulated data were tested against a watershed and lake level model calibrated for Cedar Lake. The model showed a better fit with lake levels than relying on any one single weather station. Available rainfall data from 1998 to 2023 (minus 2006 when there were no local functioning rain gauges) reflect a 25-year summer average (June-September) of 11.54 inches of rainfall.

In 2023, the monthly total precipitation fell within 25-year averages for each month except July. July exceeded the 25-year precipitation average (3.17 inches) with a total of 6.73 inches. June monthly precipitation totaled 1.11 inches, the lowest since 2020. September precipitation totaled

only 1.27 inches, making two relatively dry Septembers in a row after several wet years. The resulting summer precipitation total was 12.12 inches, a slightly above-average value.

The 2011 Cedar Lake Augmentation Feasibility Study conducted by K&A revealed that in order to avoid a lake level drop of 3-inches per summer month (June-September), 2.75 inches of precipitation 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 presents the critical precipitation threshold among the 25-year summer precipitation average. Cedar Lake precipitation in 2023 exceeded this critical threshold of lake-elevation drop only in June and September. Previous and ongoing management efforts aim to lower this threshold or augment the water budget of the Cedar Lake watershed to limit the impact of low summer precipitation on lake level.

Cedar Lake Water Elevation:

Figure 3 plots the 2023 Cedar Lake water elevation from March to mid-December, with daily precipitation data recorded from the Cedar Lake volunteer rain gauge to visualize the importance of precipitation on lake elevation. Lake elevations above 607.2 ft (one foot below the legal lake limit) have been discussed as a "desirable condition." If the lake elevation exceeds 608.20, flow over the Cedar Lake outlet weir will occur.

High spring discharge from Sherman Creek and Jones Ditch resulting from snowpack melt and precipitation induced a lake level elevation above the outlet from April through the middle of May. As a result, Cedar Lake lost approximately 18.1 MGal of surface water through the lake outlet between April 1 and May 16, 2023. High summer precipitation resulted in a rise in lake level, but elevations remained below the Cedar Lake outlet for the remainder of the monitoring period, fluctuating between 607.5 ft and 608.2 ft. The lake elevation did not fall below the desirable threshold (607.2 ft) throughout the entire monitoring period, with the lowest recorded elevation being 607.5 ft on June 28, 2023.

Cedar Lake's mid to late-summer water levels remained stable and desirable, despite the intermittent rain events through the end of August. Low precipitation in the first of the critical summer months (June) of 2023 caused a drop in lake level after exceeding the outlet elevation at a maximum elevation of 608.54 ft. Due to high mid-summer precipitation, Cedar Lake remained above the desirable threshold through recreation season. Recreation conditions remained optimal throughout the entire summer season despite decreasing precipitation, which underscores the effectiveness of water retention efforts implemented in the watershed.

Figure 4 illustrates the relationship between summer precipitation and water elevation fluctuations with respect to the critical summer precipitation threshold, water level goals considered in the Cedar Lake WMP, and the legal lake level. The average water elevation of Cedar Lake in 2023 was 607.97 ft, exceeding the average level for each of the past three years. Notably, total summer precipitation in 2023 was over 13 inches more than in 2022 and the highest recorded summer precipitation since 2010 at 22.62 inches.

Notable with Figure 4 (June-September averaged water level data) is that lake level dynamics appear to have changed since installation of the outlet structure was completed in late 2020. Consistently throughout the period of lake level monitoring, low snowpack and dry spring-time conditions typically create an early season deficit which only ample summer rainfall can overcome. In past early season conditions with spring high water, water levels above the legal lake level would persist well into the June-September timeframe, allowing the lake to reach and exceed legal lake levels (often due to debris clogging of the outlet structures) during this targeted recreational period. In 2009, 2010, 2015, 2017 and 2019 prior to the new outlet, overall recreational season water levels averaged at or higher than the legal lake level. Following significant watershed flow improvements made from 2017-2019, water levels remained very close to or above the legal level, even with precipitation below critical maintenance levels with the old outlet structures.

These pre-2020 higher summer average water level conditions will not likely be experienced again as the new lake outlet is designed to rapidly reduce spring water levels to the legal lake level. This creates a cap on early season water storage capacity whereby there will nearly always be a deficit starting condition below the legal level coming into the recreational season. This is evidenced by the maximum water level differences before and after outlet construction during this June-September period. This also likely explains why the 2023 average recreational season water level remained below the legal level despite wet conditions in May, and above average seasonal rainfall. Looking back at seasonal data since 2020, this deficit condition becomes evident in Figure 4 compared to 2017-2019 despite watershed flow improvements, even with lower rainfall. Correlation with snowpack conditions will also be examined in future analyses of the recreational season lake levels.

Historic concerns with beaver activity just south of the lake outlet led to the installation of an additional lake level piezometer near the northeast corner of the lake ("TL Lake 1") at the Timberlakes clubhouse in 2022. This location is south of traditional beaver dam activities near the outlet. In July of 2023, an additional piezometer (i.e., "TL Lake 2") was installed nearby on land, just inside of the seawall with the TL 1 level logger to log groundwater levels just feet from the shoreline. This was also to fill a gap in groundwater data for this northeast portion of the lakeshore. A groundwater logger more distant from the lake (i.e., piezometer "TL Road)" was also installed in 2023. Ice damage over the winter destroyed the TL 1 level logger stilling tube rendering it unusable for a logger through the remainder of the 2023 summer season. However, close correlations between groundwater Site 2 (on the west side of the lake), TL 2, and the Lake Outlet logger show that lake levels did not differ between the main portion of the lake and the outlet in 2023. This indicates no beaver activity impacts on lake levels in 2023.

Groundwater Levels and Gradients

The 2023 groundwater elevation data from groundwater monitoring Sites 1-12, "TL Lake 2", and "TL Road" 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 and 4 (Figures 5 and 8, respectively) continue to record groundwater elevations below Cedar Lake level. However, there were two brief instances at these locations where elevations surpassed the

lake level. Site 1, specifically PZ-01s, peaked at an elevation of 608.79 on July 5, and Site 4 peaked at an elevation of 608.25 the same day related to an intense summer rain event.

Site 5 (Figure 9), unlike past years, was higher than the Cedar Lake level over a cumulative 41 days. Otherwise, the gradient throughout the summer remains northeastward signifying a loss vector from Cedar Lake. This movement away from Cedar Lake 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 reveal groundwater gradients consistent with the movement of groundwater away from Cedar Lake towards the southeast due to groundwater elevations being consistently below the lake level.

Site 3 (Figure 7) shows the movement of shallow groundwater towards Cedar Lake during rainy periods of the summer (particularly with higher Sherman Creek elevations). For example, beginning in April of 2023, shallow groundwater primarily moved towards Cedar Lake until mid-May, when groundwater levels dropped below the lake elevation. A heavy precipitation event (July 5, 2023) induced shallow groundwater to again flow towards Cedar Lake that remained throughout the remainder of the monitoring period. Prior to the wetland berm construction and instream Sherman Creek grade structures, groundwater at this location consistently moved away from Cedar Lake. Since construction, area groundwater conditions have periodically shown much greater contributions to Cedar Lake than were observed historically.

Prior to 2021, shallow groundwater at Site 6 (Figure 10) experienced intermittent flow patterns under dry or wet conditions like at Site 3. Since 2021, groundwater has consistently moved towards Cedar Lake at this location due to increased groundwater elevations. This relatively novel pattern of recurrent groundwater movement towards Cedar Lake reflects the high summer precipitation observed in 2023 as well as an increase in the groundwater elevation due to the wetland berm installation and creek enhancements. Under average conditions, groundwater flows at Site 6 are expected to experience some degree of seasonality but generally flow toward Cedar Lake due to these enhancements.

Site 12 (Figure 16) is stationed approximately 1,750 ft south of Sherman Creek and 85 ft southeast from the intersection of West Cedar Lake Road and King's Corner Road. Despite low lake level elevations in the summer of 2022, flow towards Cedar Lake from Site 12 persisted for the entire monitoring period. This flow pattern increased in 2023 and showed a marked improvement in groundwater flow towards the lake. The groundwater elevation at Site 12 was 2 feet above lake level during the spring, peaked in the early summer at 2.5 feet above lake level and remained flowing toward the lake all summer, although it decreased to an elevation difference of one foot by mid-September.

Site 7 and Site 12 also show an increase of groundwater elevation in the Spring of 1 to 2 feet but decreased during mid-October as lake level and precipitation decreased. This consistent groundwater gradient towards the lakes can be attributed to berm and instream grade structure enhancements that promote groundwater recharge. This condition was not evident at these locations prior to 2017 actions.

The West King's Corner level logger and the LWSPC logger were relocated to the northeast side of the lake partway through the monitoring period (July 13, 2023) and were named "TL Lake 2" (Figure 17) and "TL Road" (Figure 18), respectively. The goal for installing these new piezometers is to monitor groundwater elevation on the northeast side of the lake, near the Timberlake subdivision. Like other eastern level loggers (i.e., 1, 4, and 8-10), TL Road showed a four to five ft loss in elevation compared to lake level. This indicates flow away from the lake consistent with other eastern shoreline monitoring locations.

The cedar swamp complex northwest of Cedar Lake continues to contribute a critical supply of groundwater throughout the recreational season. Sites 2 and 7 are in this area and depict groundwater movement throughout the monitoring period (Figures 6 and 11, respectively) Both shallow and deep groundwater at Sites 2 and 7 suggest a continual flow of both deep and shallow groundwater towards Cedar Lake at these locations throughout the monitoring period.

2023 Estimated Surface Flows

Water level loggers located in or near the Cedar Lake outlet, Sherman Creek, Jones Ditch, and the King's Corner culverts were used to monitor incoming and outgoing surface water discharge. Sherman Creek and Jones Ditch 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 608.2 feet. If the lake elevation exceeds this limit, water spills over the outlet and eventually drains away to Lake Huron.

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. These instream barriers serve to retain water in the northwestern wetland 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 the wetland complex to reach Cedar Lake, the high flows present in spring can be extended into the summer when lake inputs become critically important for lake level.

Surface water estimated flows associated with the full 2023 monitoring period at Jones Ditch, Sherman Creek, Cedar Lake outlet, the King's Corner culvert, and the Sherman Creek wetlands berm are presented in Figures 21, 22, 23, 24 and 25, respectively. 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 26.

In 2023, the Jones Ditch wetland logger experienced a deployment issue noted with late season 2023 equipment recovery. An over-wintering logger was alternatively redeployed in December.

A March 2024 site check (during the planned early-season 2024 redeployment of level loggers) confirmed re-established logger operation in the Jones Ditch wetland.

Jones Ditch elevations (above and below the culvert) are presented in Figure 20 illustrating what are likely beaver dam cleanouts on the upstream side of the culvert in 2023. These cleanouts are reflective of the instant equilibration in water levels above and below the culvert following substantial periods of elevation difference. By late season, an alternative beaver diversion cage was deployed with stabilized upstream and downstream elevations noted in the monitoring record beginning in mid-October.

The water level stage-discharge relationship for Jones Ditch was re-calibrated in 2018 following the installation of the new culvert that allowed increased flows under King's Corner Road. The stage-discharge equation was updated in 2021 to quantify the increased flow more accurately through the larger diameter culvert. In September of 2022, two additional loggers placed upstream and downstream of the culvert and were utilized to further refine the flow equation in 2023. For 2023 estimated flows, the downstream Jones Ditch in-channel logger was used because of upstream beaver activity impacting water elevations.

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 2014-2023 for comparison. From May 1 to September 30, 2023, Jones Ditch and Sherman Creek inflows into Cedar Lake totaled 756.8 and 364.4 million gallons (MGal), respectively.

From 2019 to 2022, Sherman Creek had contributed a decreasing volume of cumulative discharge to Cedar Lake throughout the recreational season. However, in 2023, the total volume of discharge exceeded the volume of both 2021 and 2022 combined. Considering early-season snowpack melt, the frequent precipitation events in the spring provided low but consistent discharge to Cedar Lake through early summer. Low precipitation briefly caused the creek to run dry from June 21 to July 5, 2023 (Figure 22), but frequent and high precipitation throughout the rest of the summer months provided flow into Cedar Lake and induced the highest Sherman Creek cumulative summer discharge since 2019. Rain events throughout the summer increased lake level for the remainder of the recreational season and cumulative rainfall in the connected wetland complex allowed Sherman Creek to continue flowing the entire summer.

Jones Ditch cumulative summer discharge increased to 756.8 MGal after a 512.2 MGal decrease from 2021 (i.e., 800.0 MGal to 287.8 MGal in 2022). Wet conditions in 2023 are likely the source of this increase. The cumulative discharge from Jones Ditch was approximately two times larger than the Sherman Creek discharge in the same period as shown in Figures 21 and 22. In conjunction with culvert replacement, wetland connectivity in the Jones Ditch drainage generally allows precipitation to now run off rather than infiltrate to groundwater. This geomorphic feature and the larger surface area of the Jones Ditch wetland complex represent the difference in outflows between the Sherman Creek and Jones Ditch cumulative discharges.

During the May-September monitoring period, 18.1 MGal discharged through the outlet from Cedar Lake. This cumulative discharge exited Cedar Lake between April 1, 2023, and May 16, 2023. For the remainder of the monitoring period, no surface water was lost through the outlet.

The outflow volume that exited the Cedar Lake watershed through the King's Corner culvert during the May-September period totaled 10.4 MGal. This volume is nearly identical to the amount observed in 2019 and represents a relatively low flow since monitoring of this outflow began in 2014 despite having twice the summer precipitation compared to 2019. The implementation of the wetland berm continues to retain water within the Sherman Creek wetland and limits losses through the King's corner culvert.

Low discharge exiting the Cedar Lake watershed relative to pre-2017 values is a result of the intended design of the wetland enhancement berm and low-moisture conditions in the wetland complex. Prior to 2017, surface water would be lost in the early-spring due to runoff from snowmelt and precipitation.

Surface Water Retention Design Implications:

The wetland berm continues to prove highly effective in limiting losses through the King's Corner culvert and out of the Cedar Lake watershed. The ratio of water volume passing through Sherman Creek versus exiting the King's Corner culvert has increased more than 5 times since the wetland berm was installed. 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.

Sherman Creek cumulative discharge in 2023 remained higher than the historic average of 281.6 MGal. Improvements to water retention bolstered by the wetland berm and instream grade structures prevent further decreases in the cumulative summer discharge in dry years. Ultimately, snowpack and spring precipitation are the biggest factors in Sherman Creek contributions. Wetter than normal conditions in 2023 likely resulted in high Sherman Creek discharges.

Instream grade structures extended the high discharge period into June. Figure 27 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. Future conditions will continue to be closely monitored with a network of seasonal (March-November) and year-round loggers at the wetland berm, King's Corner culvert, and logger within the Sherman Creek connected wetland.

Figure 28 illustrates the 2023 water elevations at the wetland berm monitoring station positioned at the upstream side of the berm spillway compared to lake levels. Figure 29 compares water elevations at the wetland berm spillway, King's Corner culvert, and "Sherman 2" located in the cedar swamp upstream of the Sherman Creek culvert monitoring stations. Figure 30 compares surface water flows and volumes for the 2023 monitoring season at the wetland berm spillway to outflows at King's Corner Culvert and inflows to Cedar Lake via Sherman Creek.

The 18.1 MGal that overtopped the wetland berm from March 30 through May 18 and July 5 through August 2 were largely from heavy precipitation events following high surface water and groundwater elevation conditions attributable to spring snowmelt, and intermittent rainfall. King's Culvert lost 10.4 MGal indicating some water had been picked up between the berm and the culvert during these flow events and eventually exited the Cedar Lake watershed. Frequent precipitation continued after August 2, but no additional losses were observed through the wetland berm for the remainder of the monitoring period.

May is generally the month in which inflows to Cedar Lake are the greatest. However, in 2023, September had the highest surface water inflows as shown in Figure 30. Wet conditions in the summer months (June through September) allowed flow to Cedar Lake through the rest of the monitoring period. These observations once again underscore the importance of precipitation as the ultimate factor in limiting substantial decline in lake level throughout the monitoring period. Continued monitoring is necessary to determine viable lake level augmentation strategies and improve on previously implemented projects and their effectiveness in maintaining Cedar Lake's water elevation within the desirable range. This might include augmentation, but now these will additionally inform proposed Jones Ditch improvements and upstream railroad culvert enhancements.

Conclusions and Recommendations

Water retention improvements for Sherman Creek continue to be reflected in the limited outflows through King's Corner culvert as a percentage of the total Sherman Creek outflow (Sherman Creek and King's Corner culvert). King's Corner culvert losses routinely made up 20% of this flow prior to the installation of the wetland berm, after which this percentage now averages 2%. Higher and more stabilized groundwater levels redirected to the lake in the vicinity of Sherman Creek also demonstrate improved hydrology for maintaining water levels. These relate to the wetlands berm, and instream grade structure improvements.

Jones Ditch continues to supply an increased and dominant amount of watershed flow contributions following the culvert replacement in 2018. The additional lake level piezometers placed in Jones Ditch in 2022 further augment the current stage-discharge relationship, and serve to quantify incoming flows more accurately from Jones Ditch. These efforts are expected to guide any future action in augmenting Jones Ditch flows in an effort to improve Cedar Lake water levels throughout the summer recreation months. The purchasing of the parcel adjacent to Jones Ditch will allow the CLIB to continue to protect Jones Ditch and further facilitate improved connectivity between the northwest wetland complex and Cedar Lake.

Spring snow melt, precipitation, northwest cedar swamp watershed contributions (surface and groundwater), summertime evaporation, groundwater losses along the eastern shoreline, beaver activities, and lake outlet level control serve as the dominant factors that influence Cedar Lake elevation throughout the summer. While lake level stability has improved with hydraulic enhancements through watershed connectivity actions, hydrology conditions have changed with the new outlet structure which more rapidly dissipates high water conditions to legal lake level. This outlet function caps wet spring conditions to the established lake level whereas former outlet structures allowed higher water levels to persist into the recreational season.

While 2022 lake level data revealed beaver activity near the lake outlet creating higher recreational season water levels, such observations were not evident in 2023. Late 2023 beaver management improvements upstream of the Jones Ditch culvert on West Cedar Lake Road appear to have been effective for mitigating water level backups at this location. Effective management of flow impediments at the culvert will help ensure transmission of timely wetland discharges to the lake.

Planning and coordination by the CLIB and K&A will continue to monitor emerging trends within the watershed and implement engineering designs as needed. As such, the continuation of the hydrology monitoring program will be used to identify:

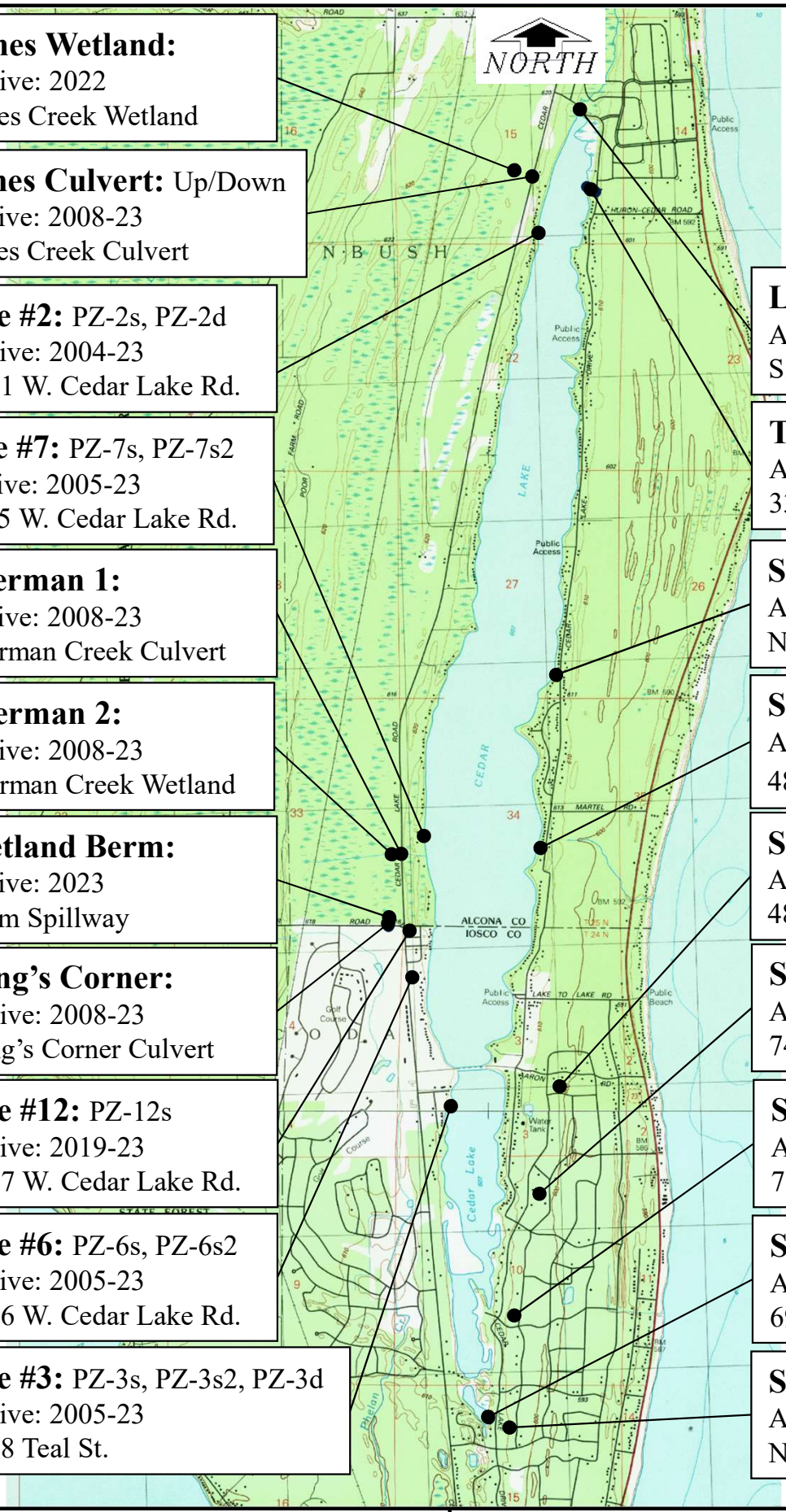
1) Additional hydraulic improvement options for Jones Ditch and contributing areas including improved maintenance and/or potential reconstruction of the northern-most railroad culverts to increase watershed flows.

2) Potential Jones Ditch channel reconfiguration and beaver removal/management activities upstream and downstream of the West Cedar Lake Road culvert to maintain and enhance surface water discharges to the lake during summer wet weather conditions.

3) Snowpack and spring-time wet weather conditions pre-/post-construction of the new outlet as well as related relationships with Sherman Creek and Jones Ditch actions to aid understanding how future lake level management actions will benefit lake levels.

4) Relevant support of potential options for artificial water returns to Cedar Lake with any re-construction of stormwater drainage improvements in Lakewood Shores.

2023 Cedar Lake Hydrology Report: List of Tables and Figures.



Jones Wetland:
Active: 2022
Jones Creek Wetland

Jones Culvert: Up/Down
Active: 2008-23
Jones Creek Culvert

Site #2: PZ-2s, PZ-2d
Active: 2004-23
3481 W. Cedar Lake Rd.

Site #7: PZ-7s, PZ-7s2
Active: 2005-23
4795 W. Cedar Lake Rd.

Sherman 1:
Active: 2008-23
Sherman Creek Culvert

Sherman 2:
Active: 2008-23
Sherman Creek Wetland

Wetland Berm:
Active: 2023
Berm Spillway

King's Corner:
Active: 2008-23
King's Corner Culvert

Site #12: PZ-12s
Active: 2019-23
7897 W. Cedar Lake Rd.

Site #6: PZ-6s, PZ-6s2
Active: 2005-23
7906 W. Cedar Lake Rd.

Site #3: PZ-3s, PZ-3s2, PZ-3d
Active: 2005-23
7588 Teal St.

- **Sites 1-3** were original Phase I monitoring locations.
- **Sites 4-7** were added as part of Phase II monitoring efforts.
- **Sites 8-11** were added as part of Augmentation Feasibility Study efforts.

Lake Outflow:
Active: 2008-23
S. of Lake Outflow Structure

Timberlakes: TL2, TL-Rd
Active: 2023
3376 E Cedar Lake Dr.

Site #1: PZ-1s, PZ-1s2, PZ-1d
Active: 2004-23
N. of 4484 E Cedar Lake Dr.

Site #4: PZ-4s
Active: 2005-23
4840 E. Cedar Lake Dr.

Site #8: PZ-8s
Active: 2009-23
4884 Arron Dr.

Site #9: PZ-9s
Active: 2009-23
7448 Lakewood Dr.

Site #10: PZ-10s
Active: 2009-17, 2022-23
7173 Huntington Dr.

Site #5: PZ-5s
Active: 2005-23
6967 Lakewood Dr.

Site #11: PZ-11s
Active: 2009-23
N. Of 6933 Huntington Dr.

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

FIGURE 1

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

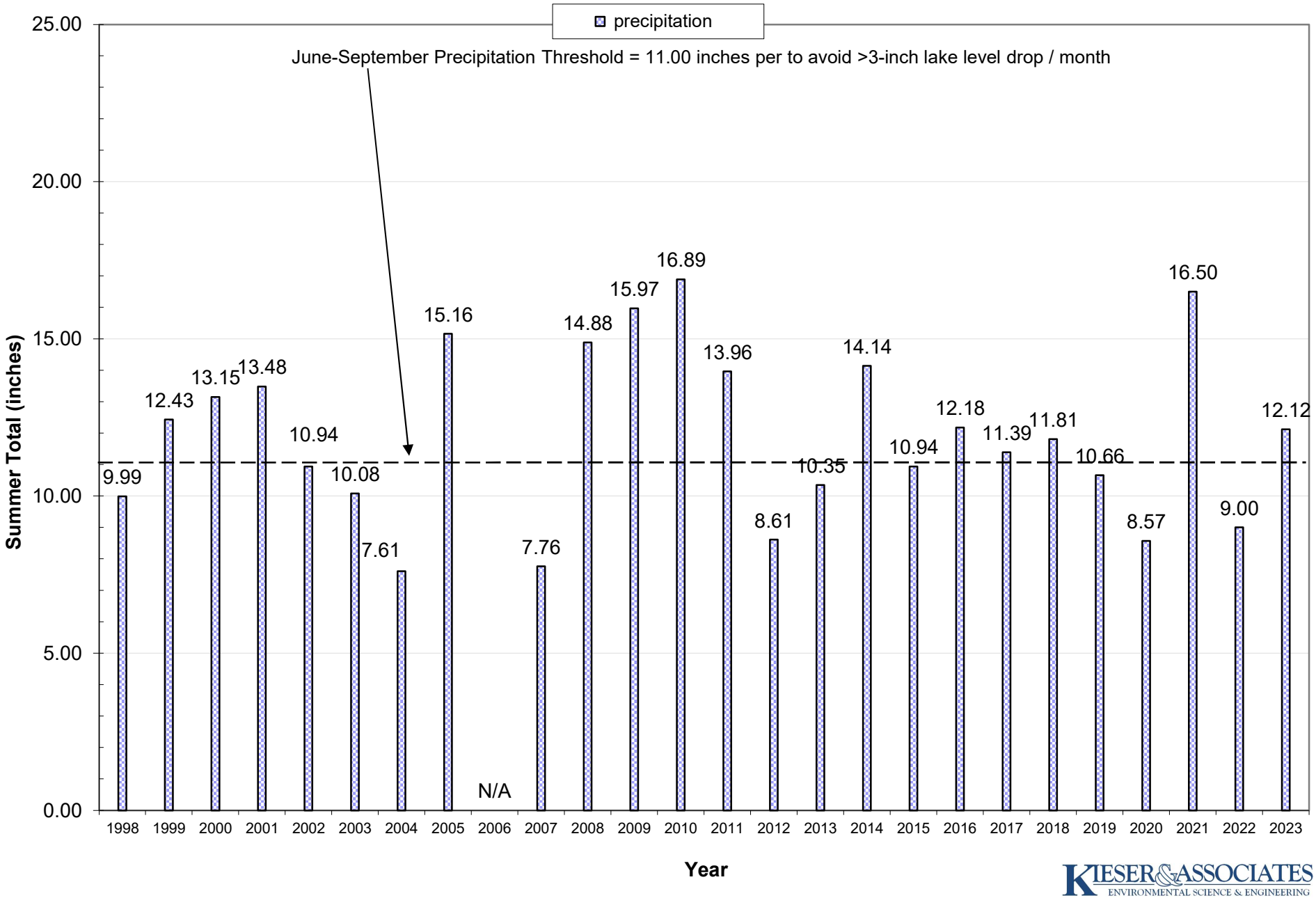

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Figure 3. 2023 Cedar Lake Elevation and Measured Rainfall

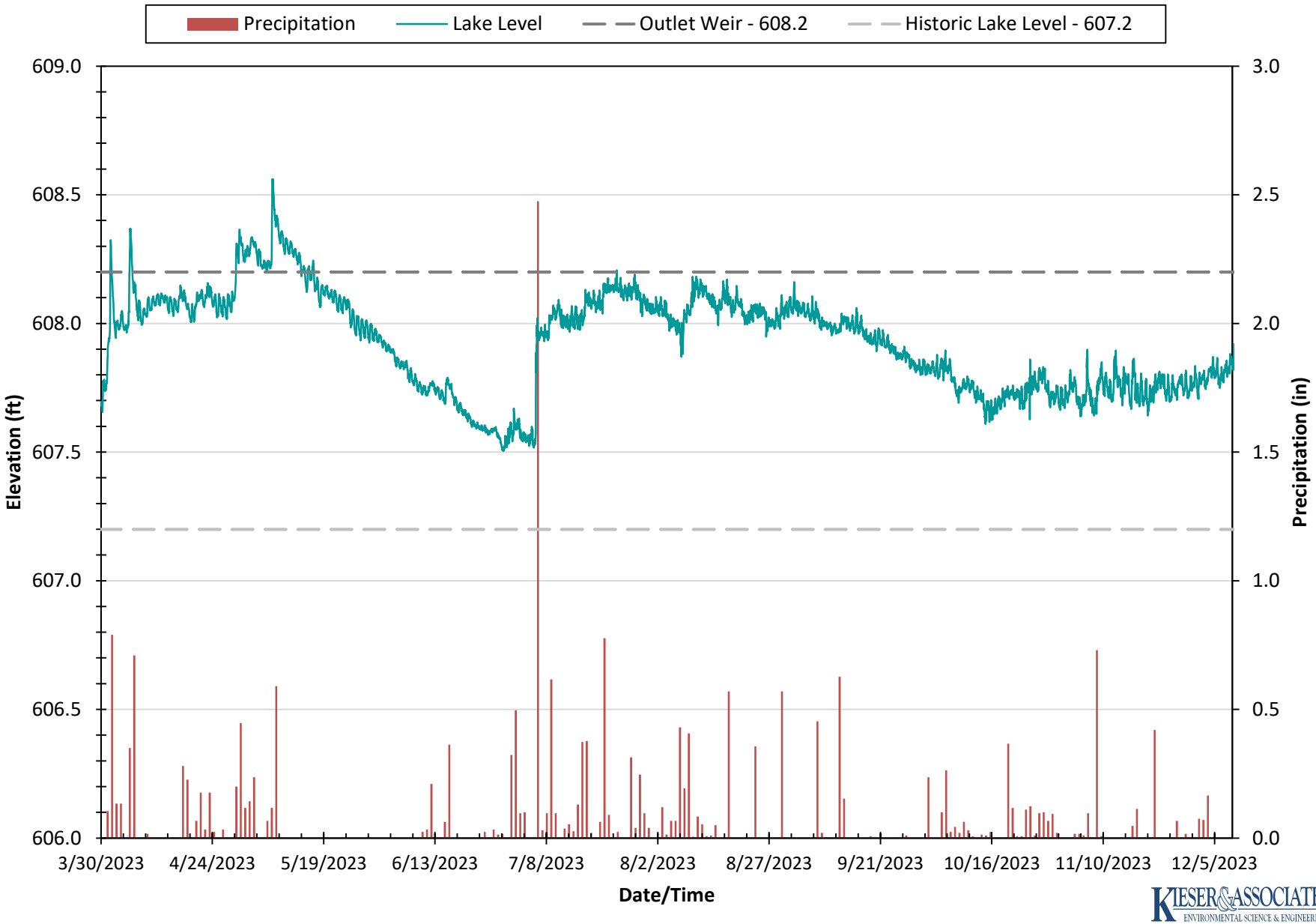

Figure 4. Cedar Lake Summer (Jun-Sep) Lake Level Fluctuations and Precipitation
Lake Level Maximum, Minimum, and Average Relative to Legal Lake Level (Outlet)

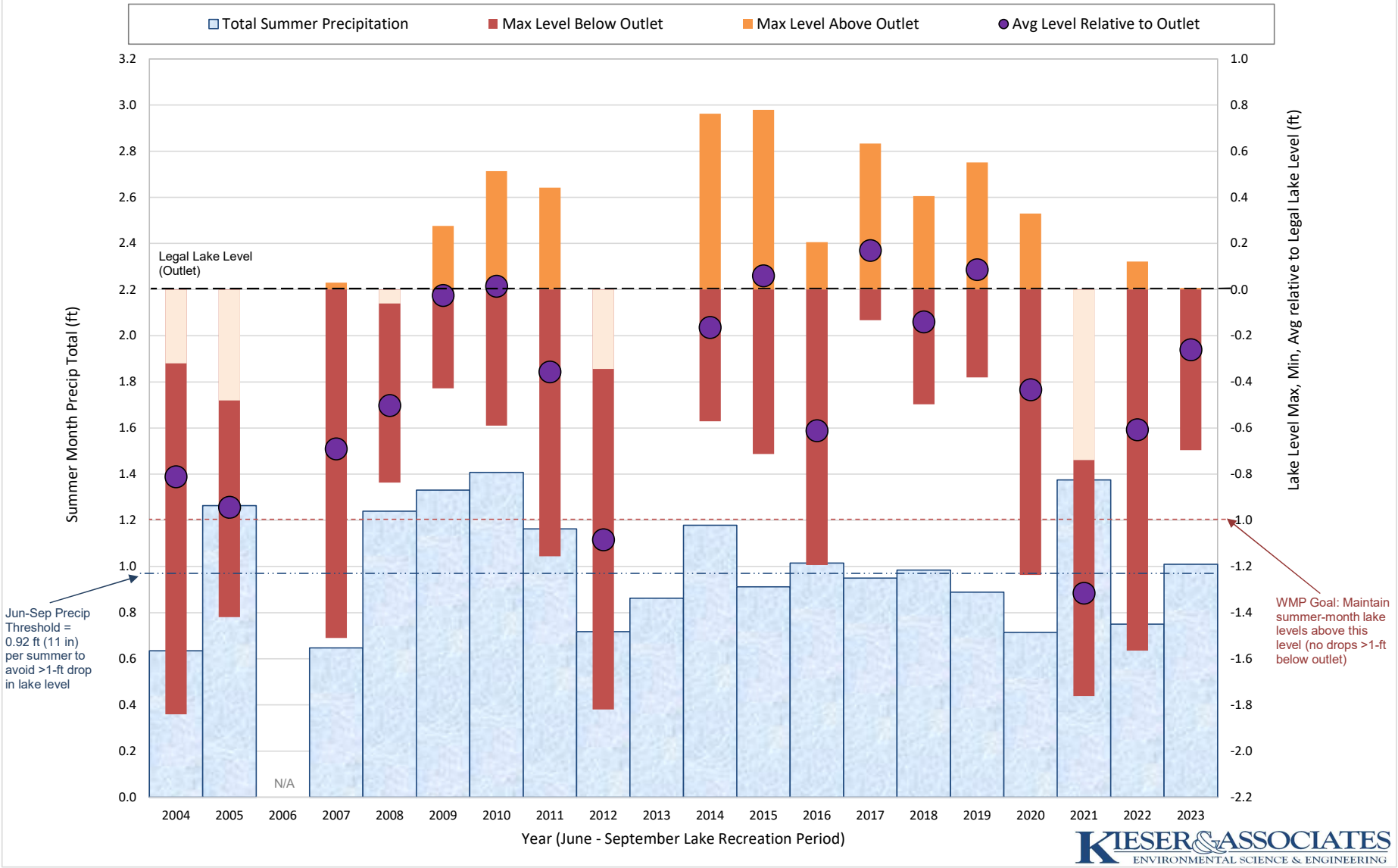

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Figure 5. 2023 Cedar Lake Groundwater / Surface Water Elevations (Site 1)

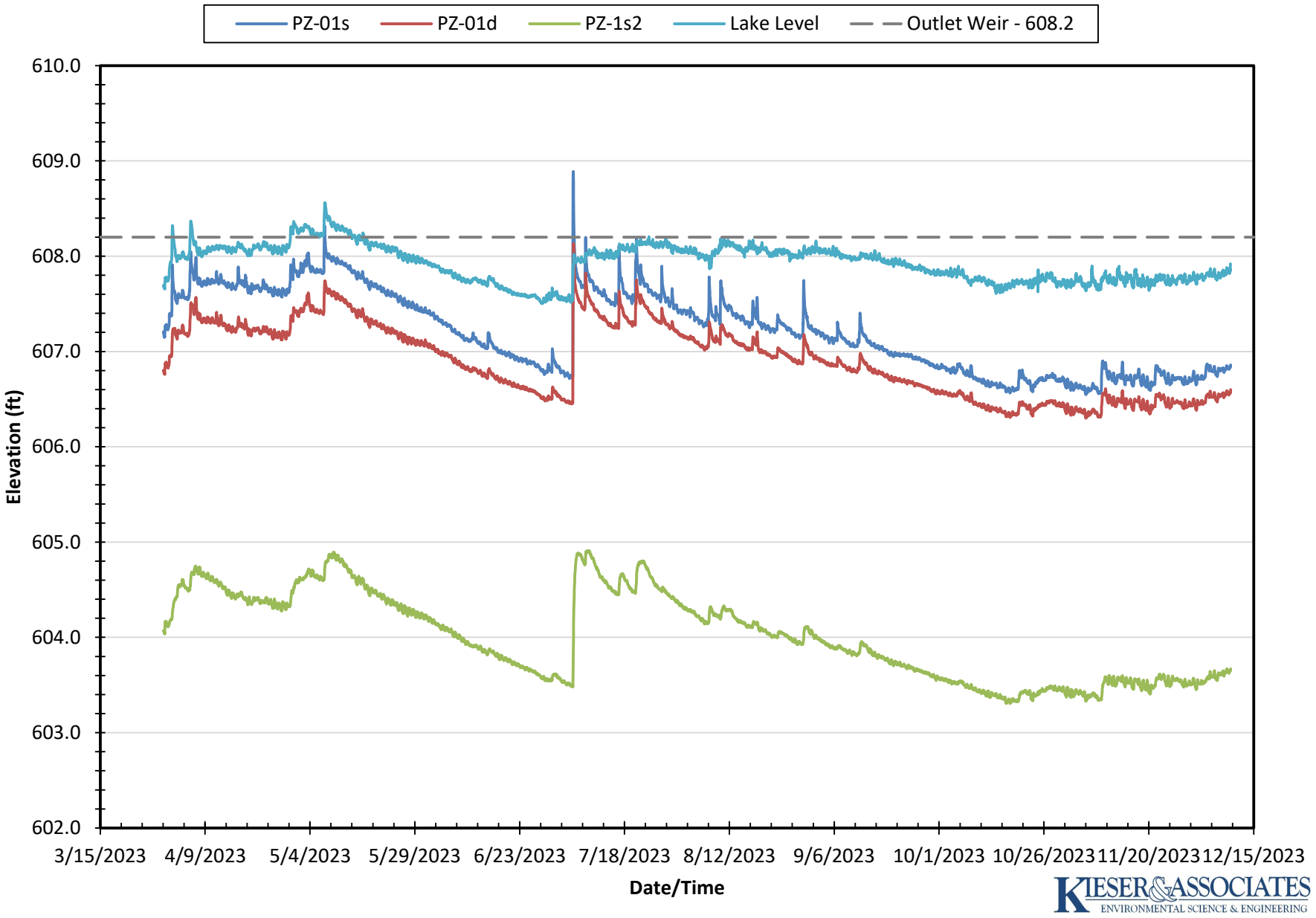

Figure 6. 2023 Cedar Lake Groundwater / Surface Water Elevations (Site 2)

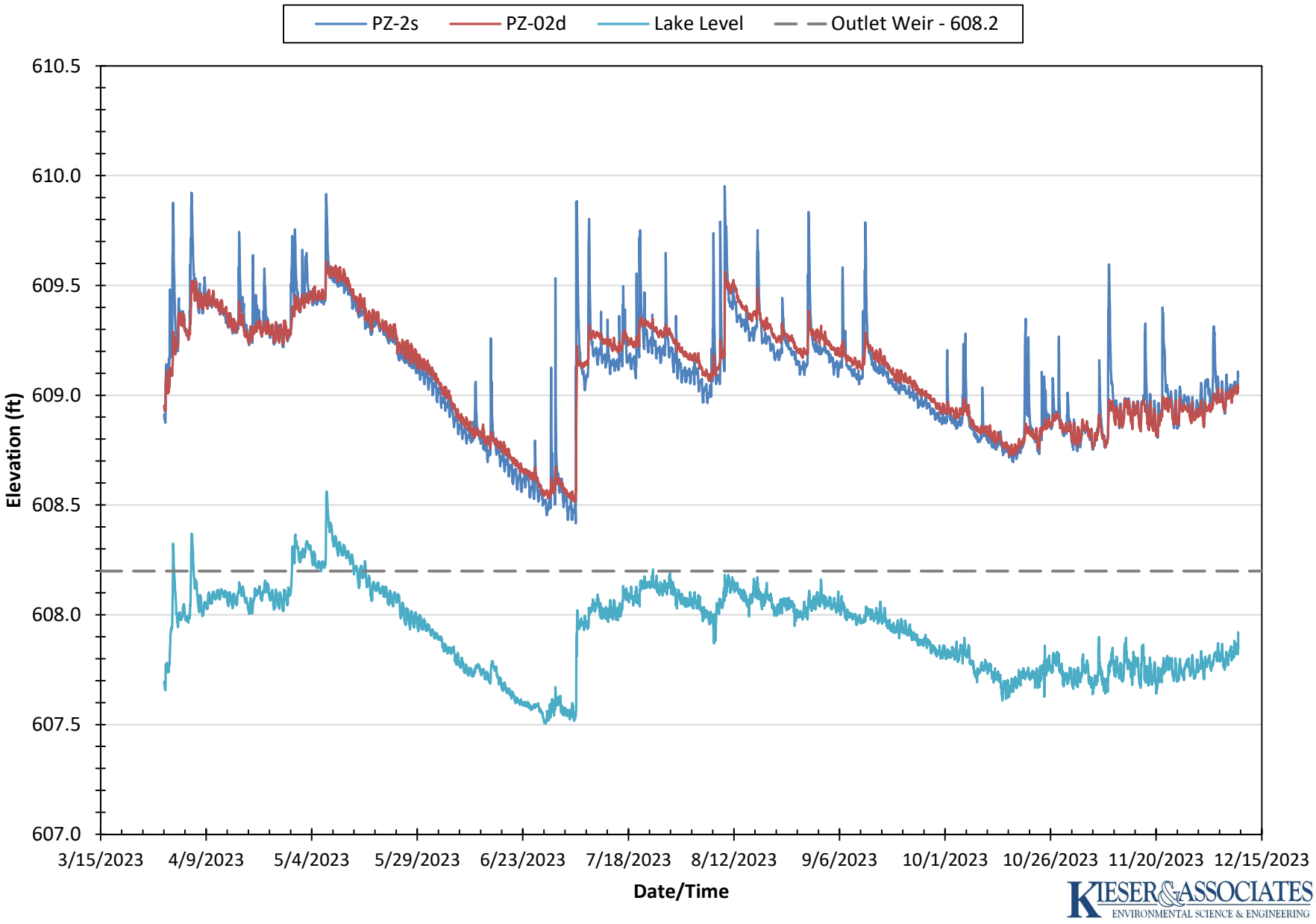

Figure 7. 2023 Cedar Lake Groundwater / Surface Water Elevations (Site 3)

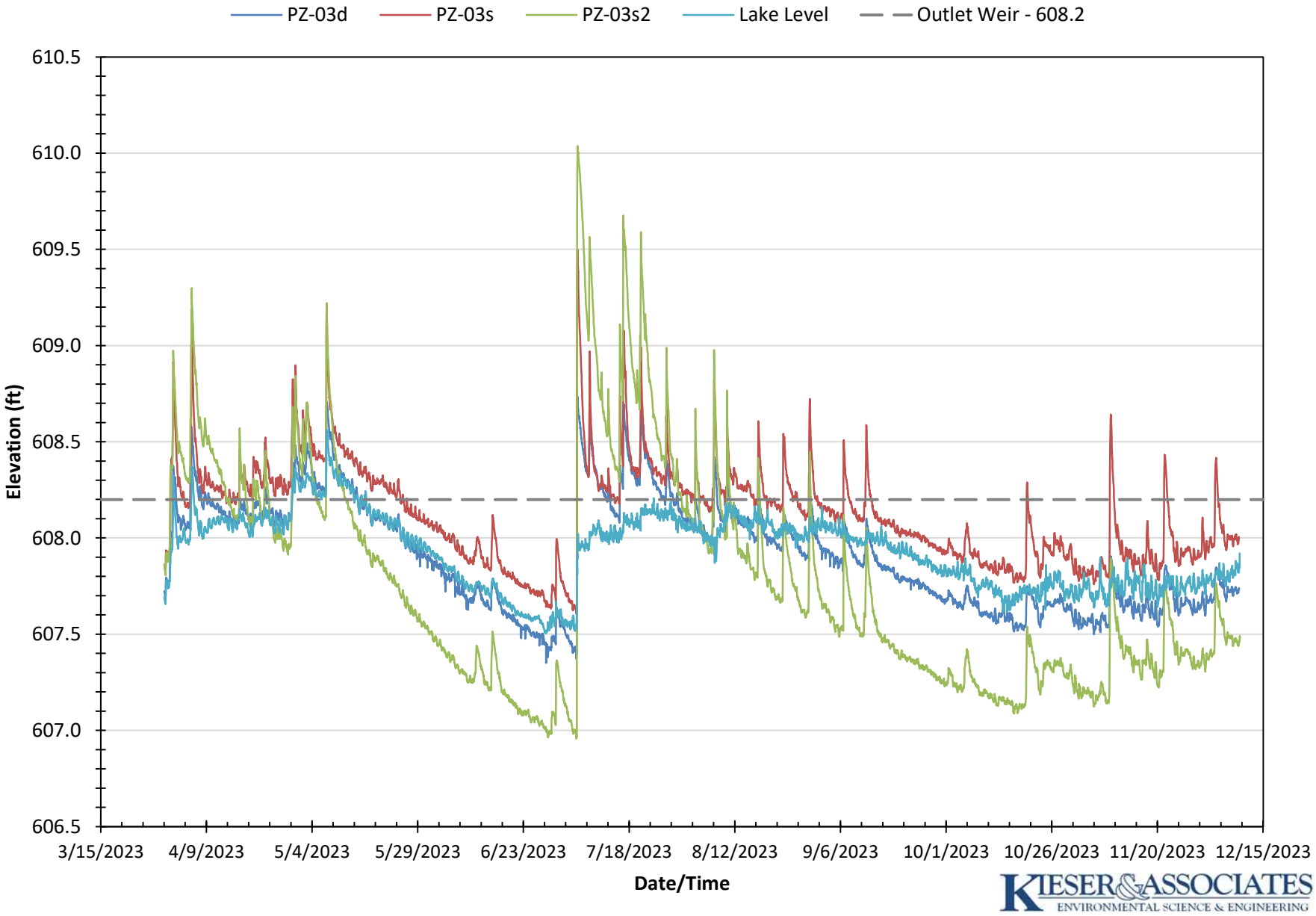

Figure 8. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 4)

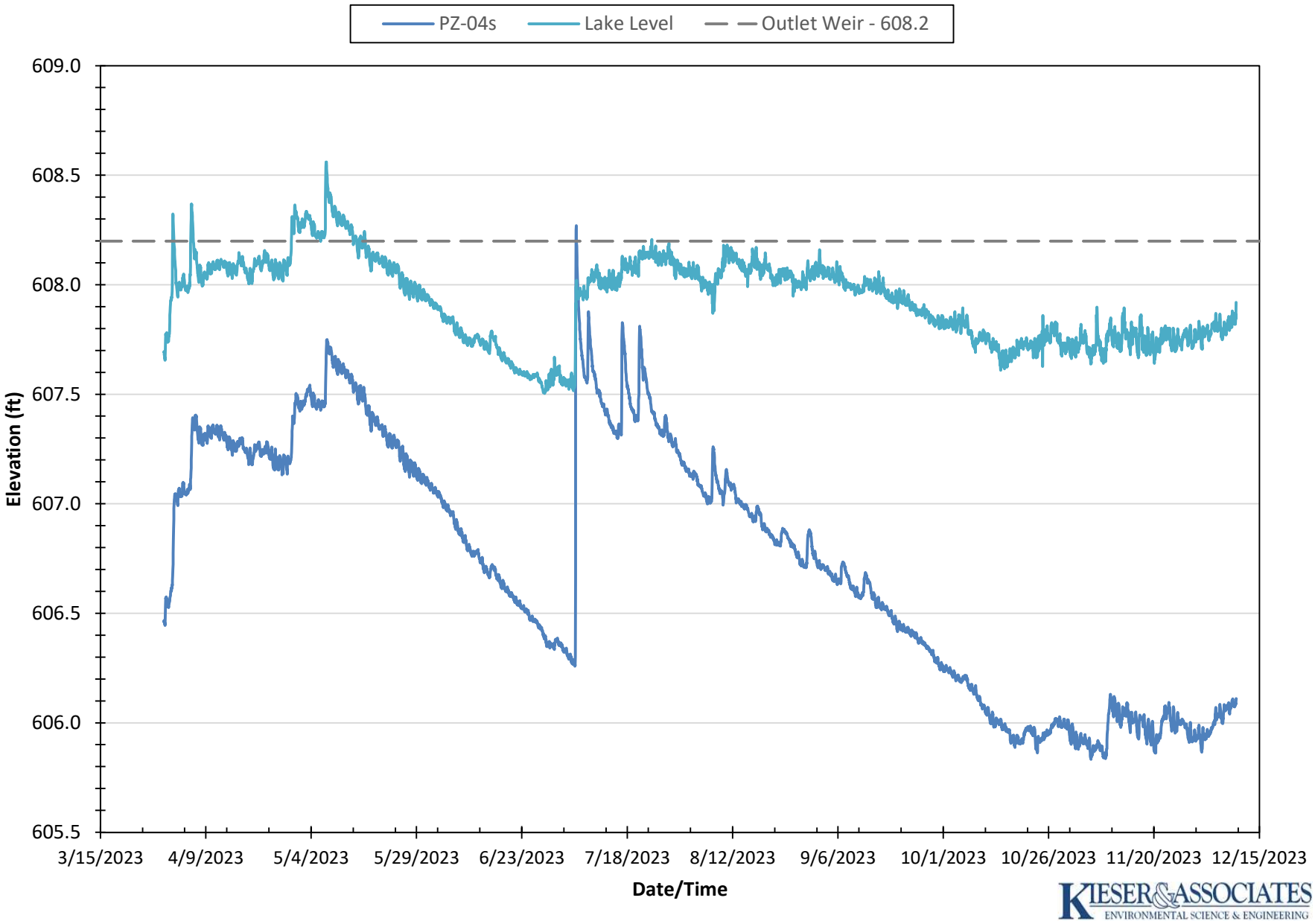

Figure 9. 2023 Cedar Lake Groundwater / Surface Water Elevations (Site 5)

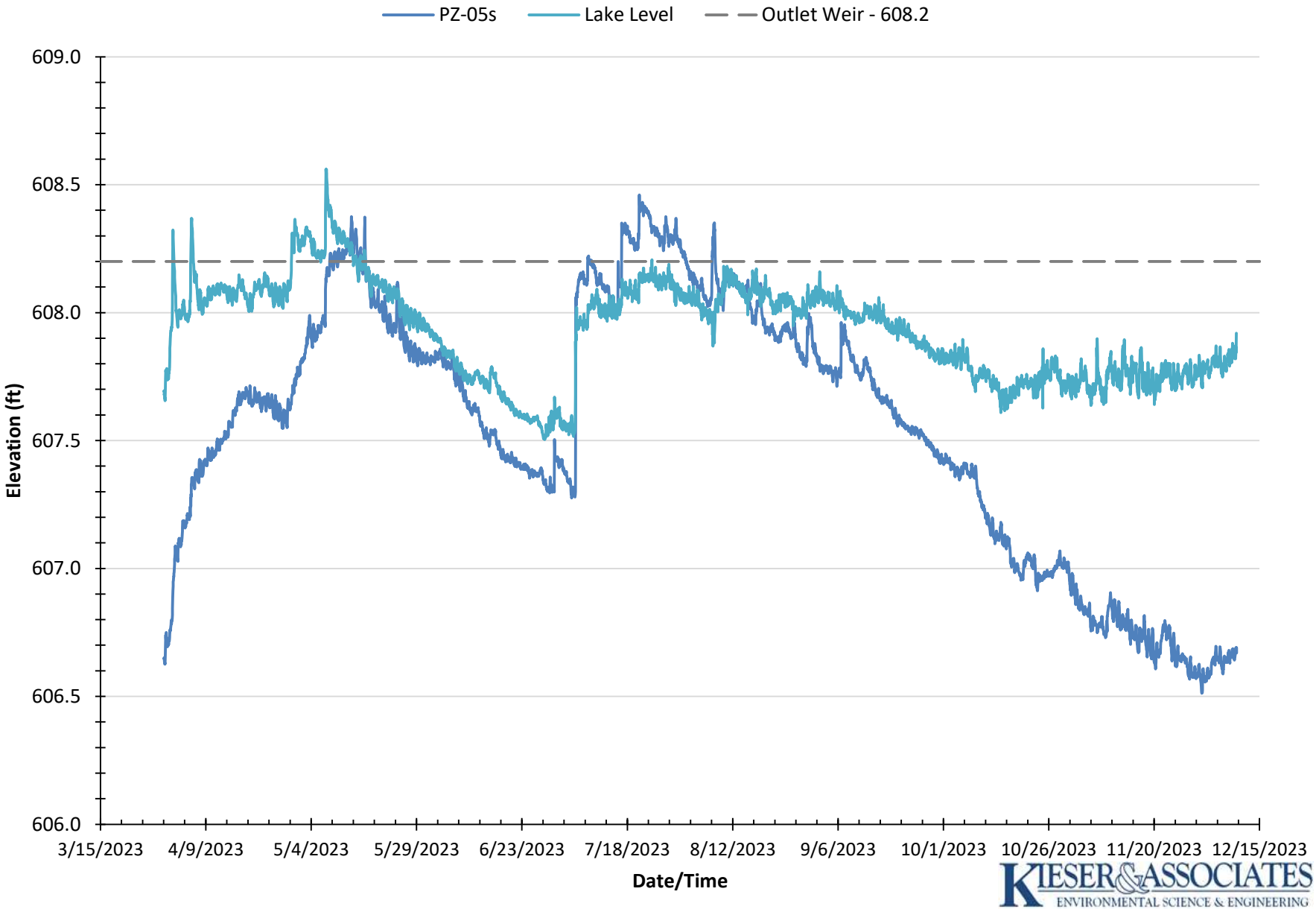

Figure 10. 2023 Cedar Lake Groundwater / Surface Water Elevation
(Site 6 - *New Location, 2019*)

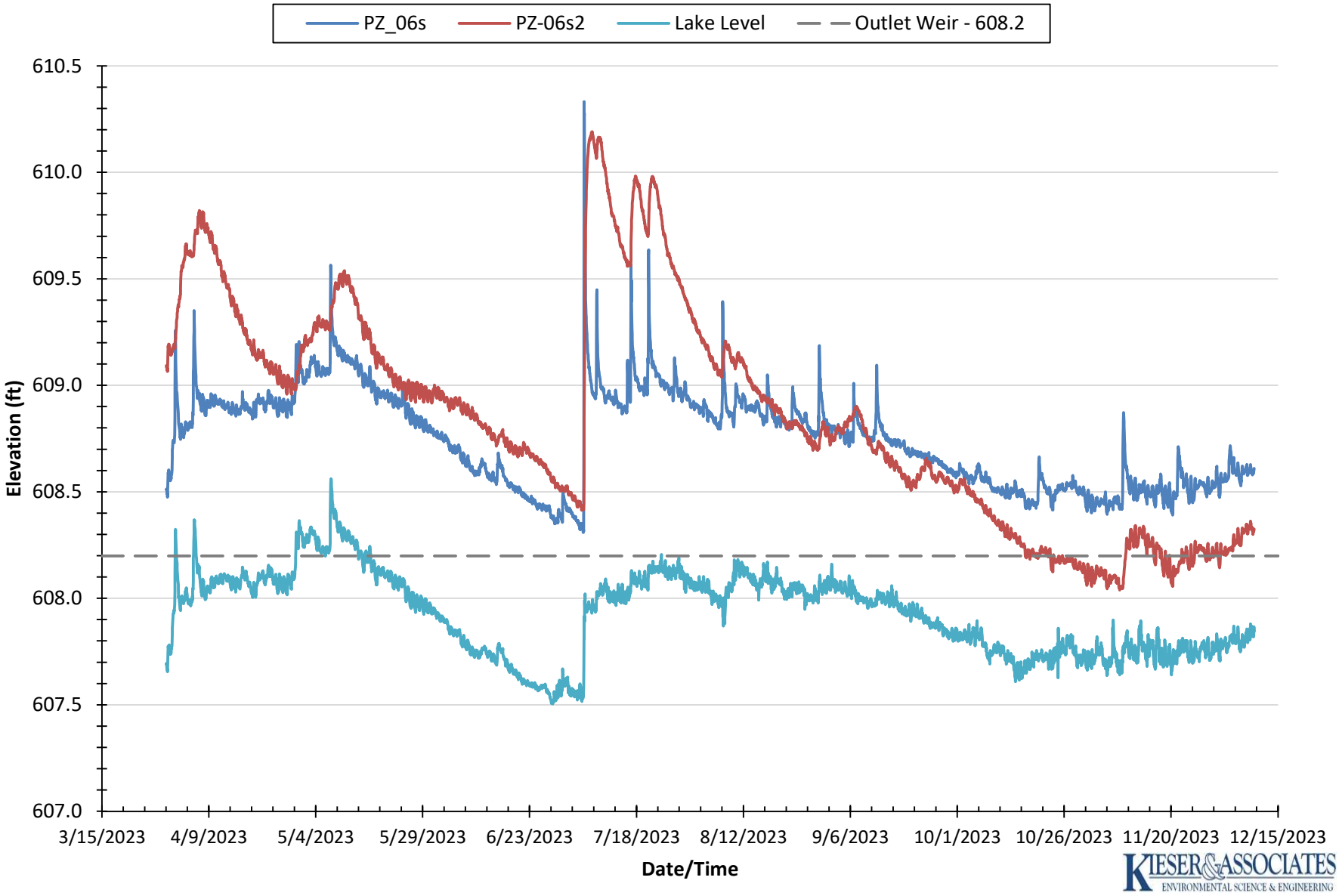

Figure 11. 2023 Cedar Lake Groundwater / Surface Water Elevations (Site 7)

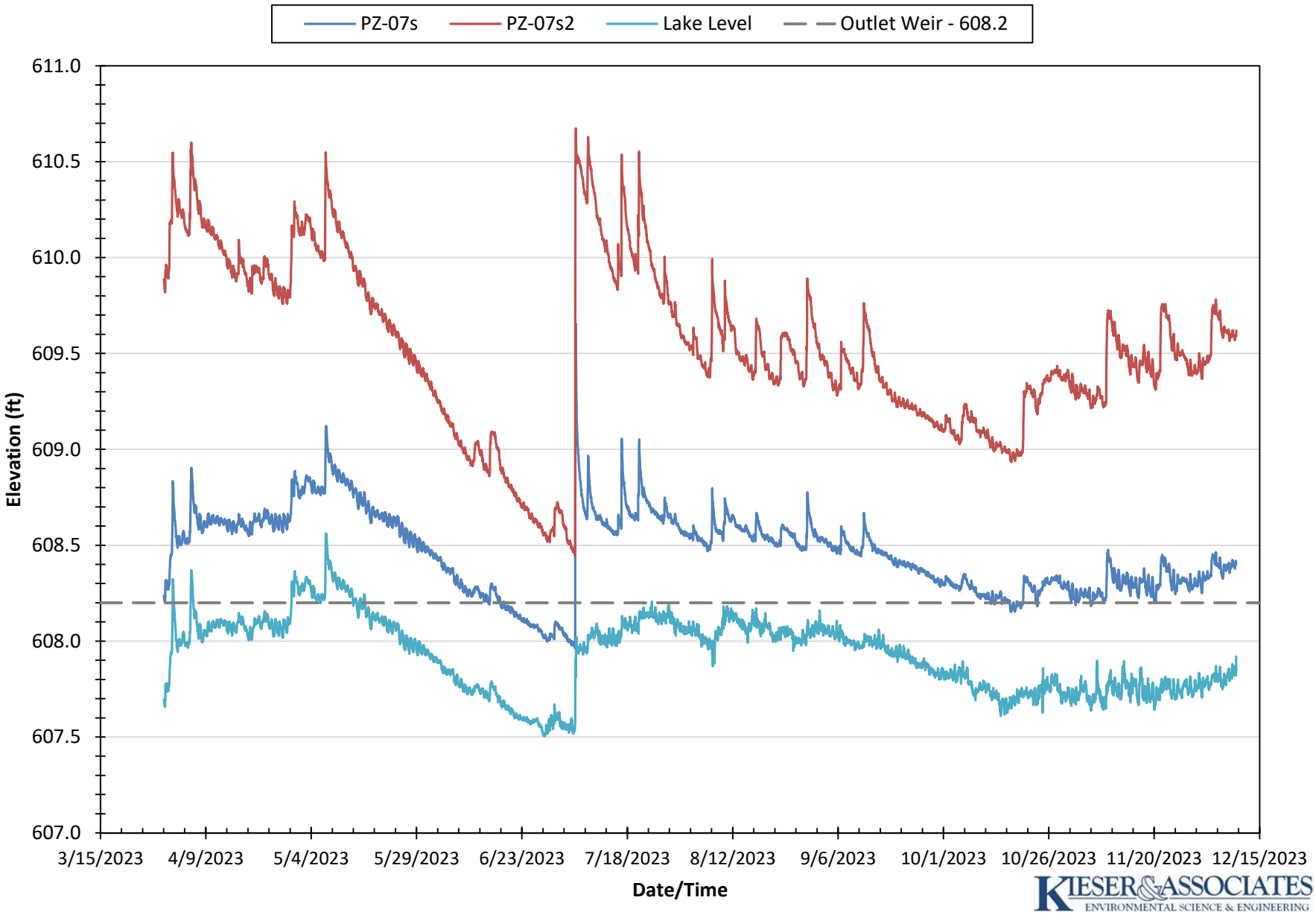

Figure 12. 2023 Cedar Lake Groundwater / Surface Water Elevations (Site 8)

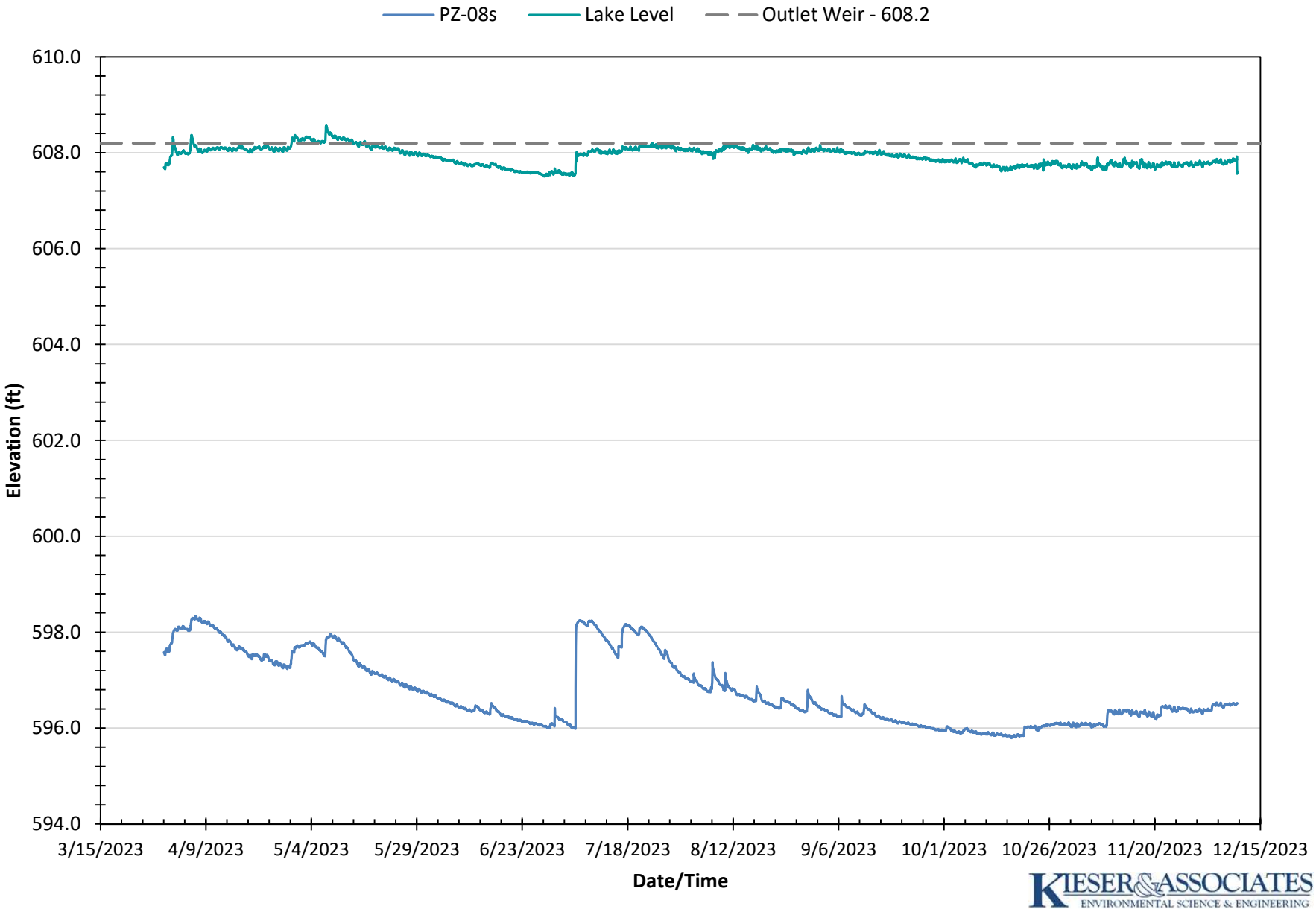

Figure 13. 2023 Cedar Lake Groundwater / Surface Water Elevations (Site 9)

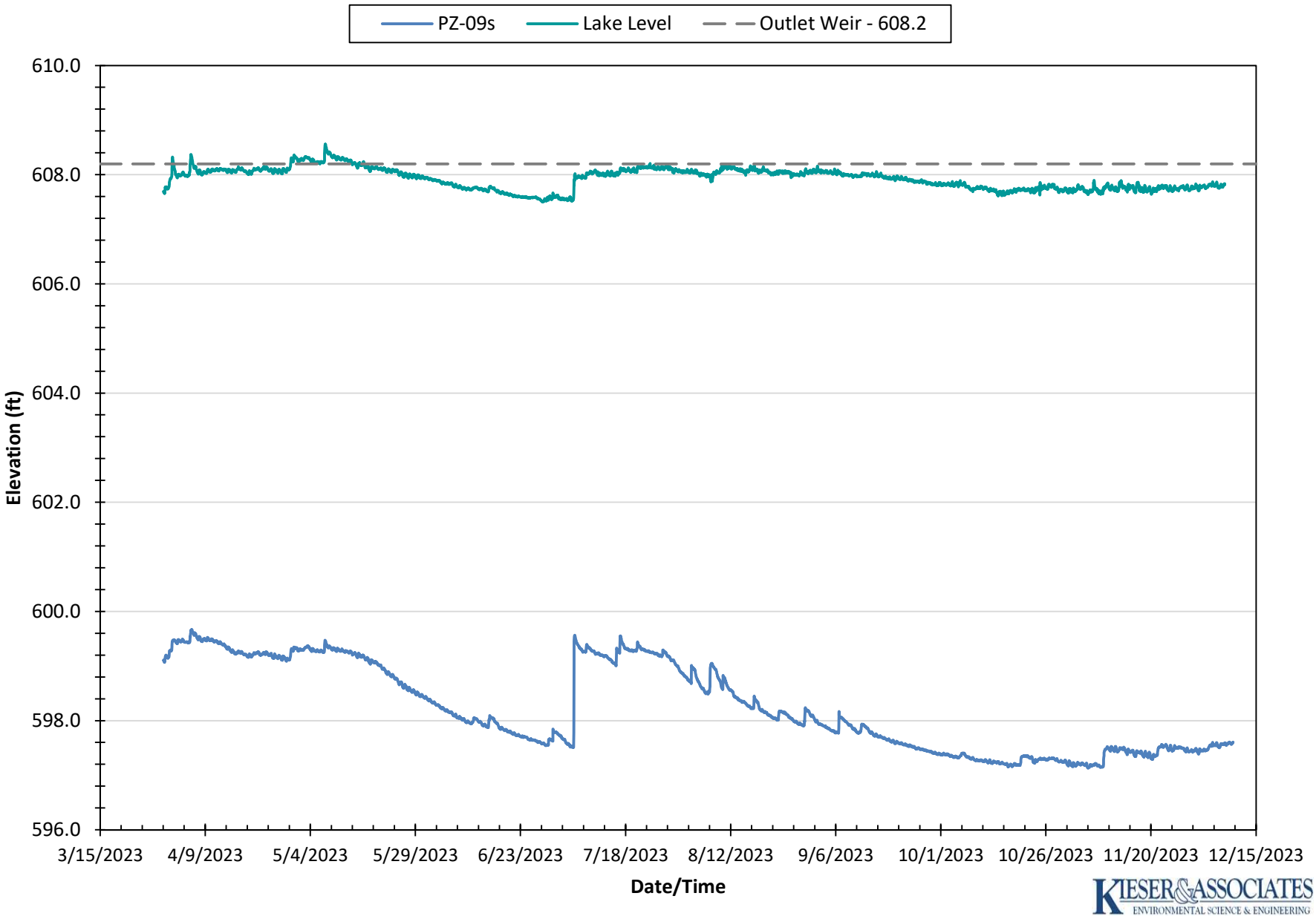

Figure 14. 2023 Cedar Lake Groundwater / Surface Water Elevations (Site 10)

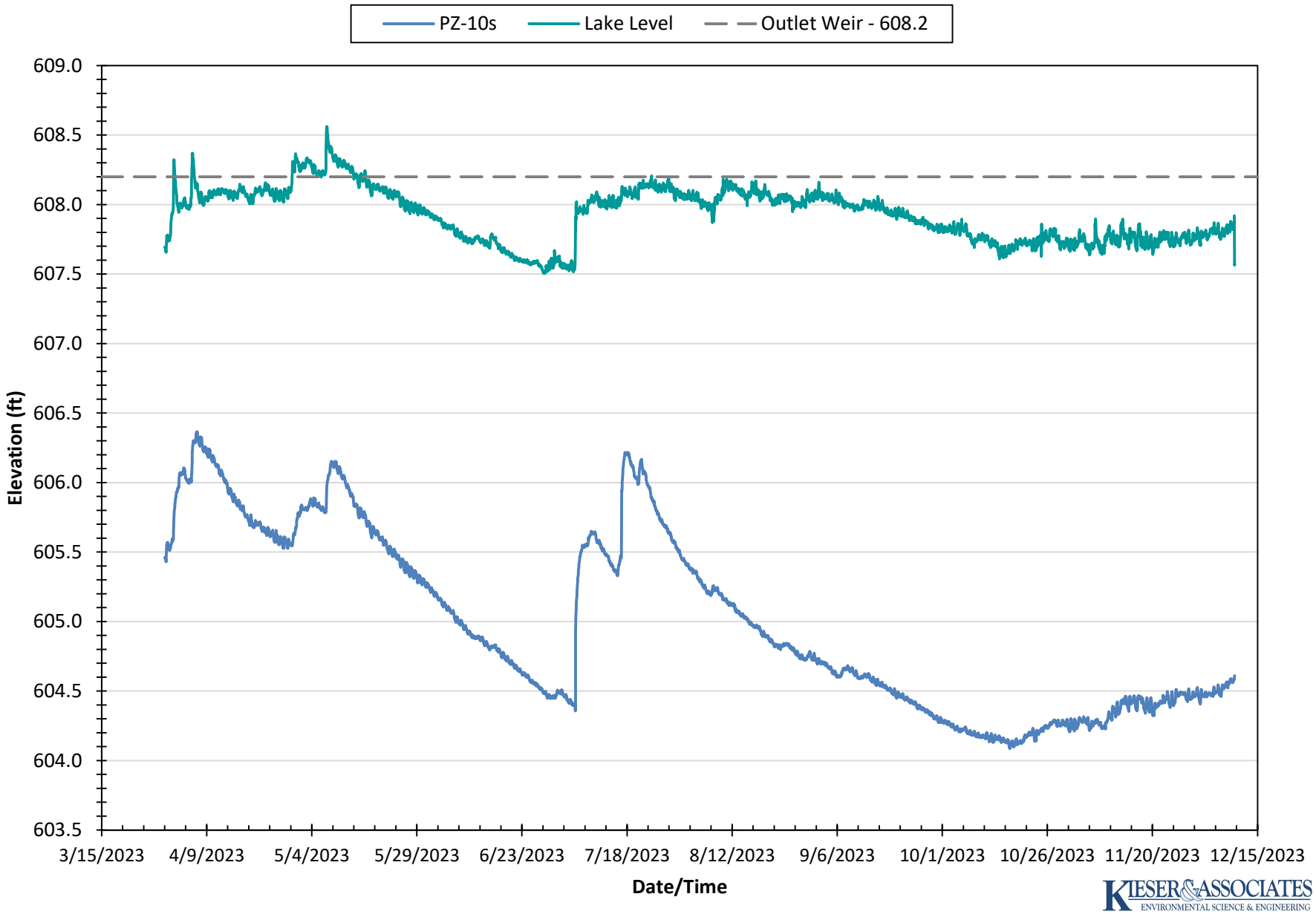

Figure 15. 2023 Cedar Lake Groundwater / SurfaceWater Elevations (Site 11)

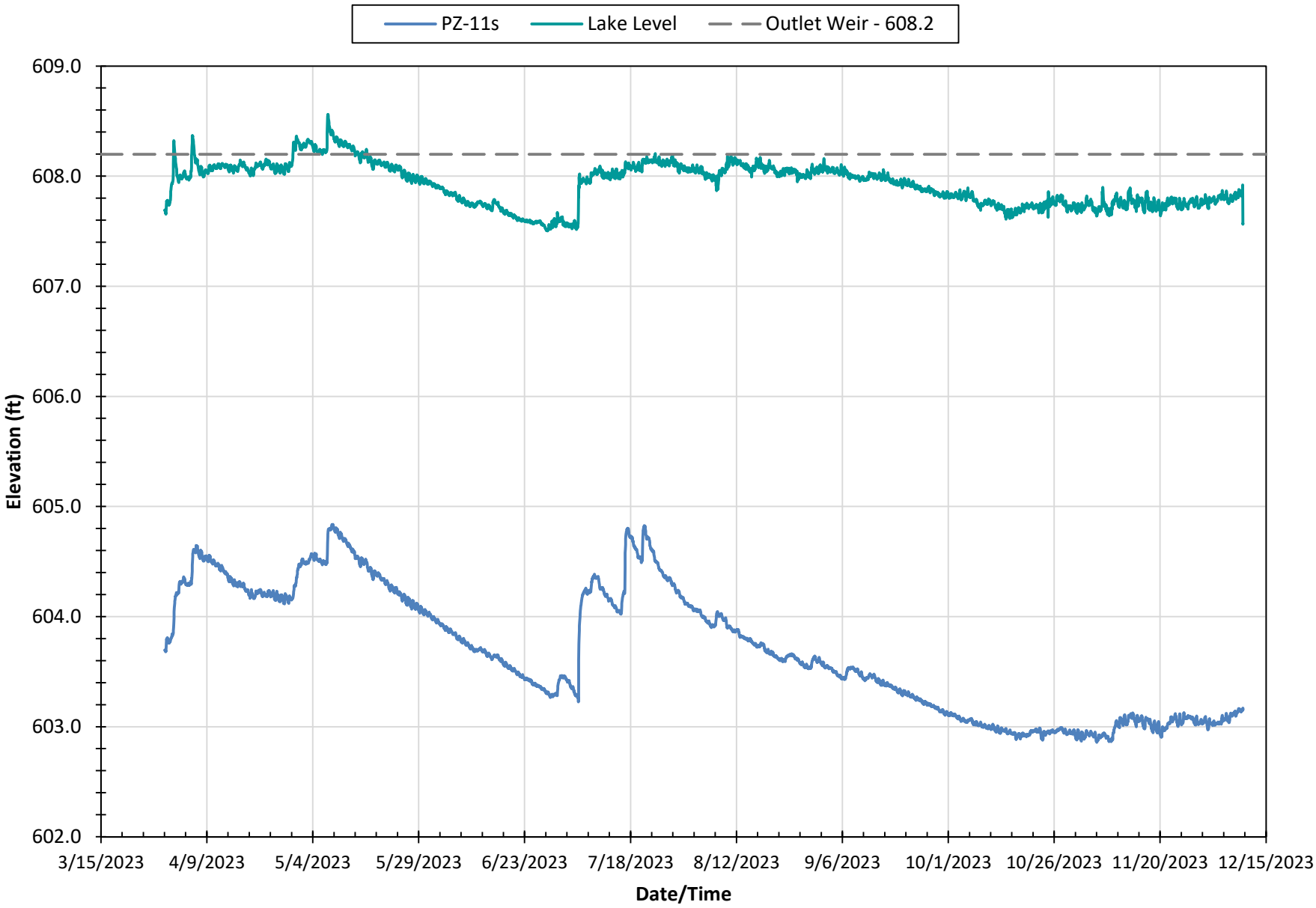

Figure 16. 2023 Cedar Lake Groundwater / Surface Water Elevations (Site 12)

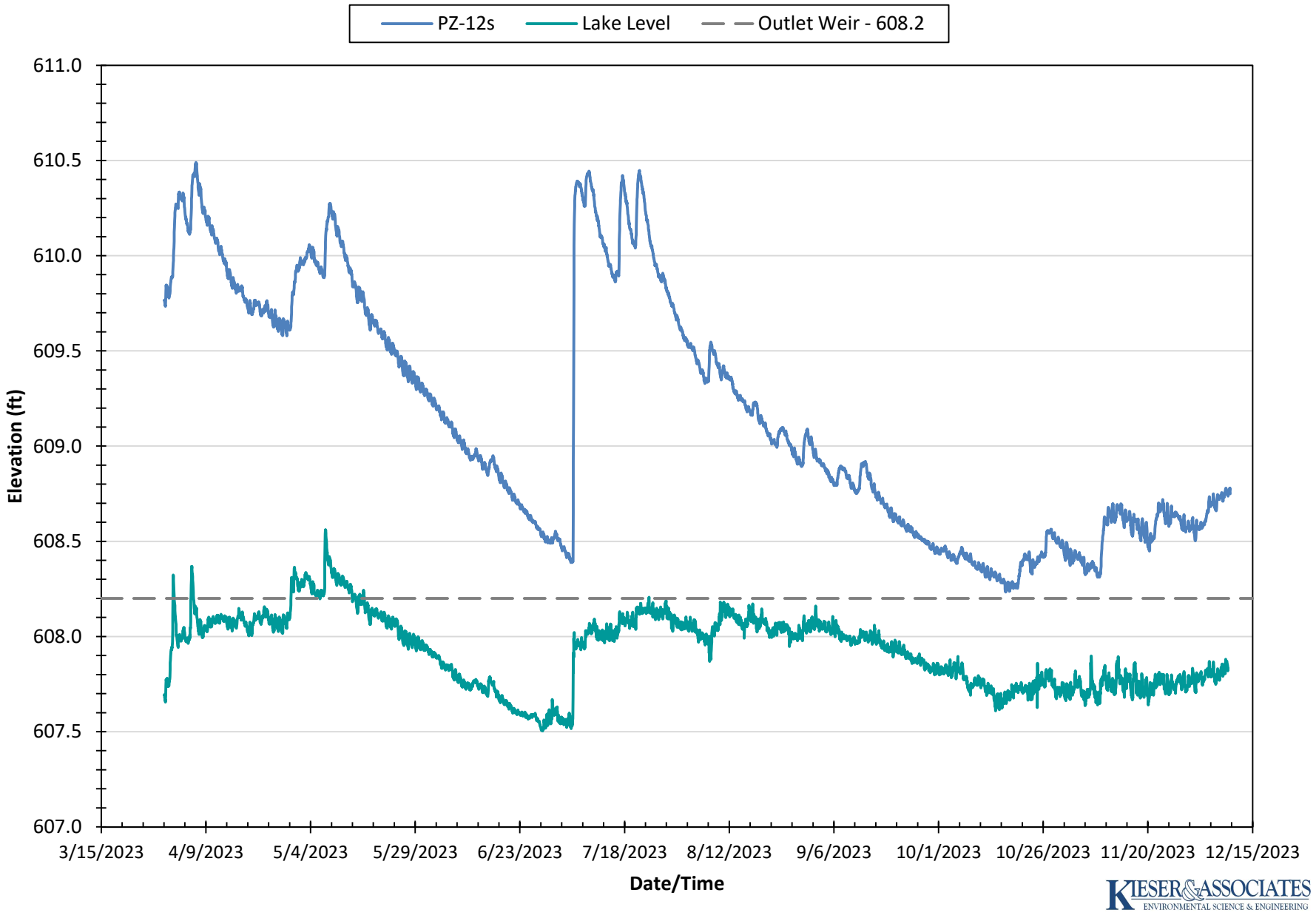

Figure 17. 2023 Cedar Lake Groundwater / Surface Water Elevations (TL Lake 2)

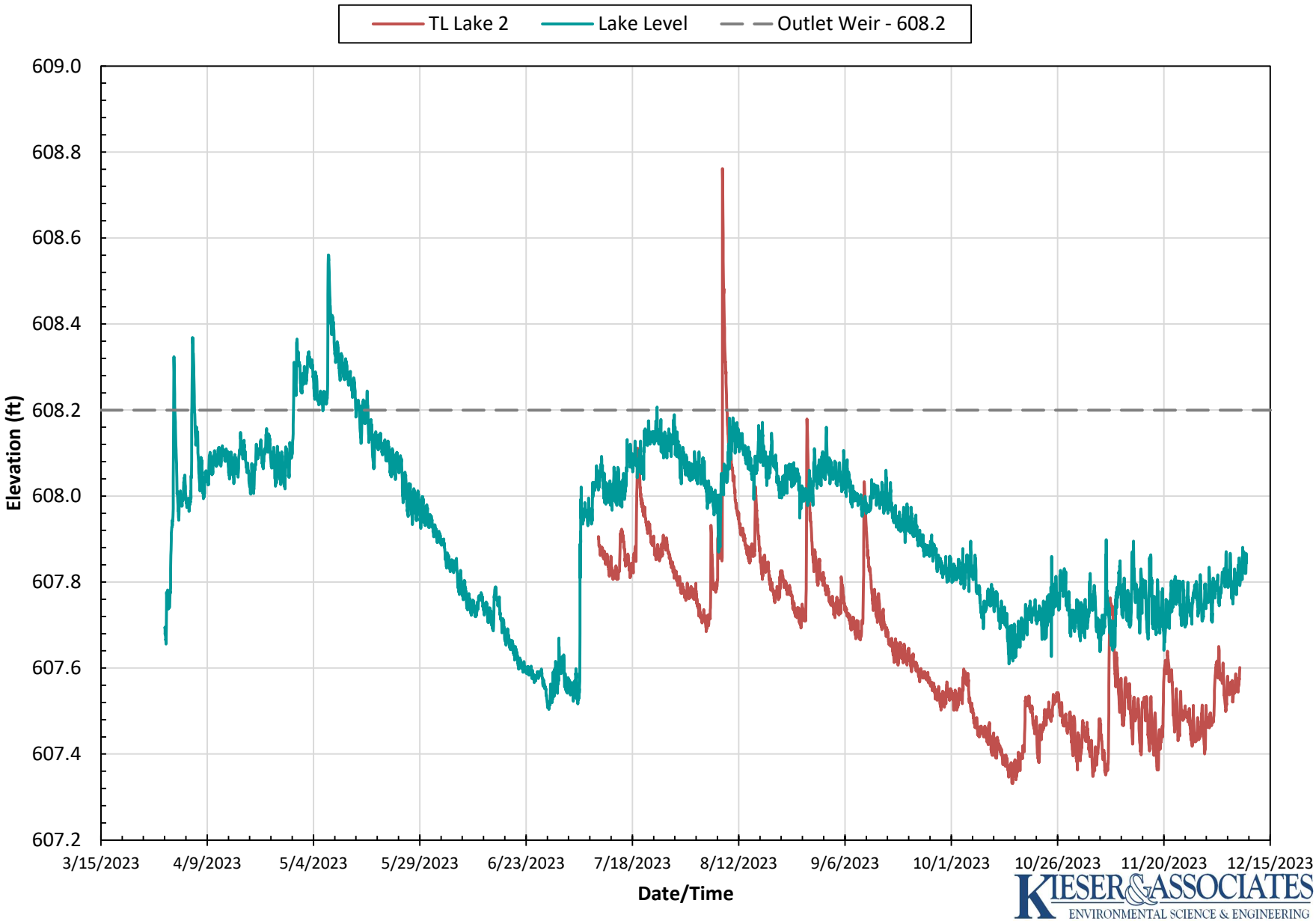

Figure 18. 2023 Cedar Lake Groundwater / Surface Water Elevations (TL Road)

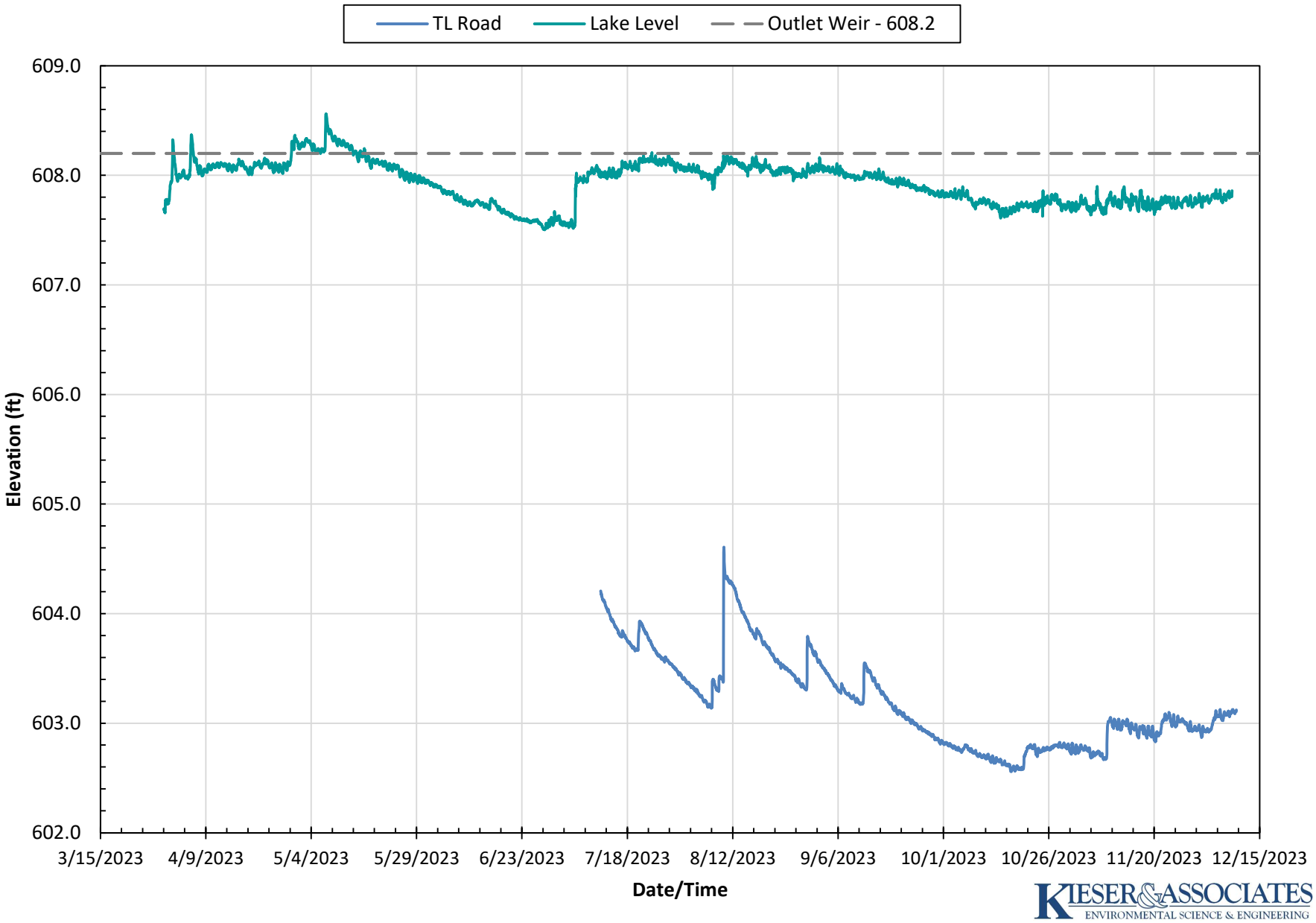

Figure 19. 2023 Cedar Lake Groundwater / Surface Water Elevations (King's Corner Area Loggers)

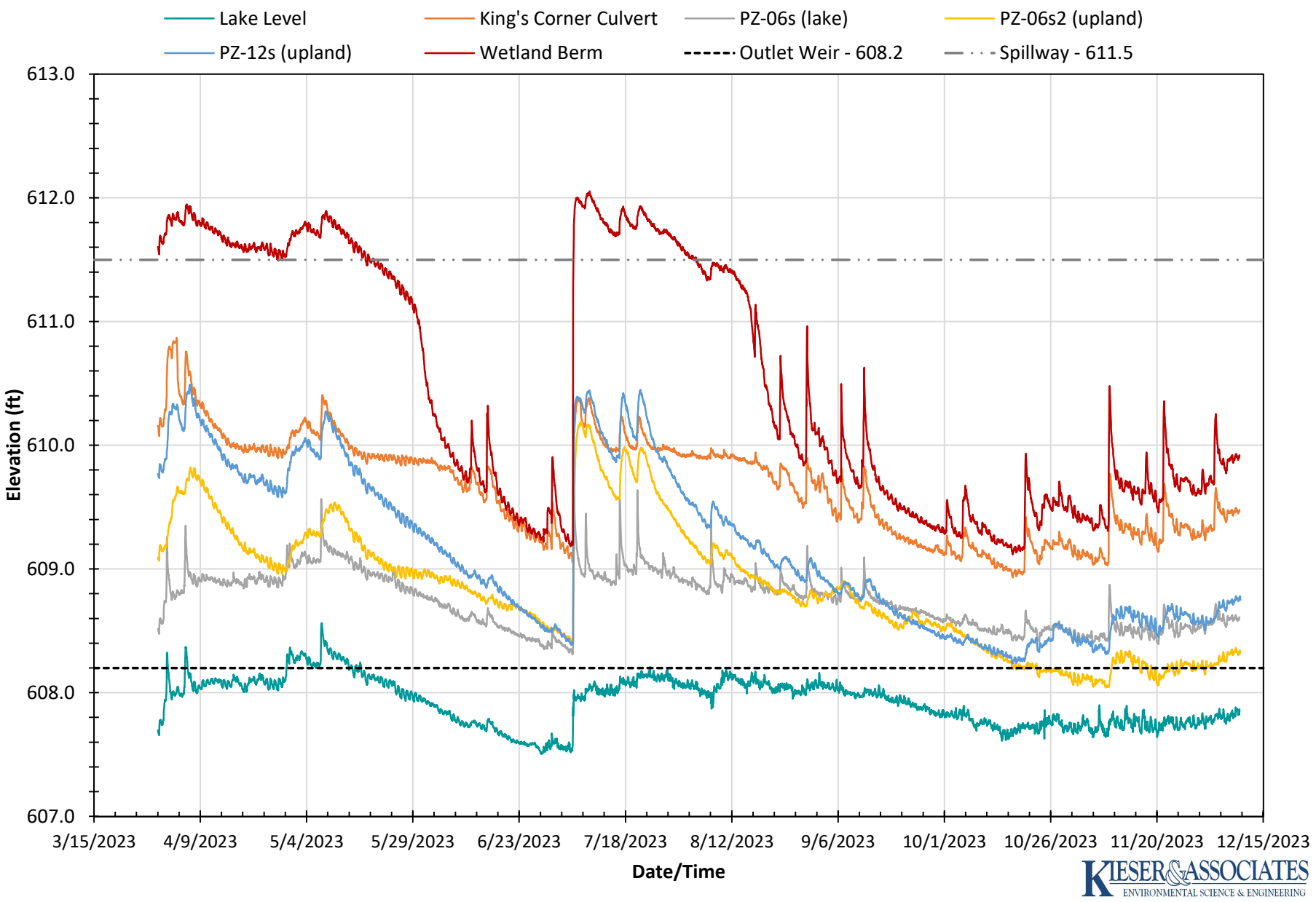

Figure 20. 2023 Jones Ditch Groundwater / Surface Water Elevations

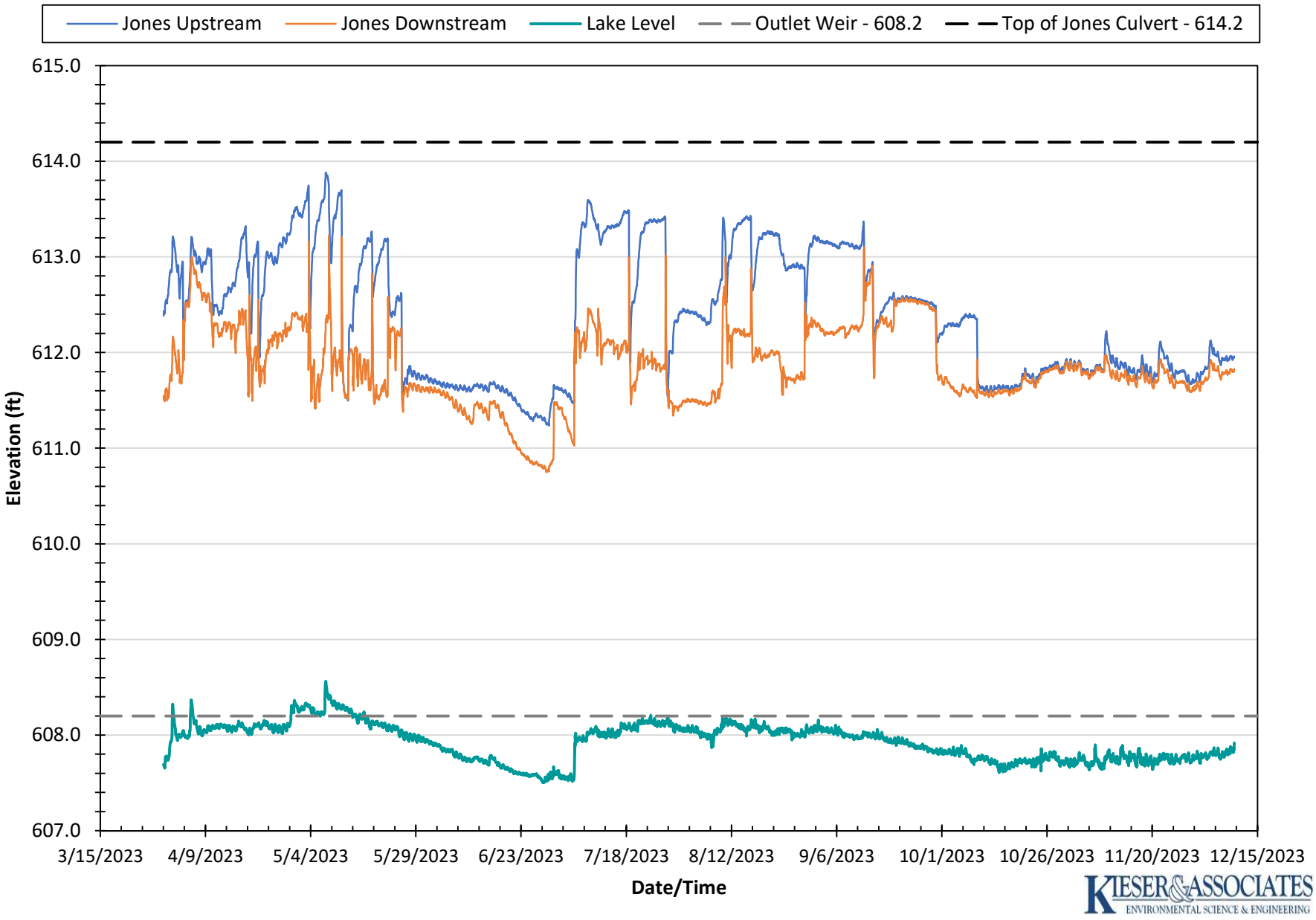

Figure 21. 2023 Estimated Jones Ditch Flows

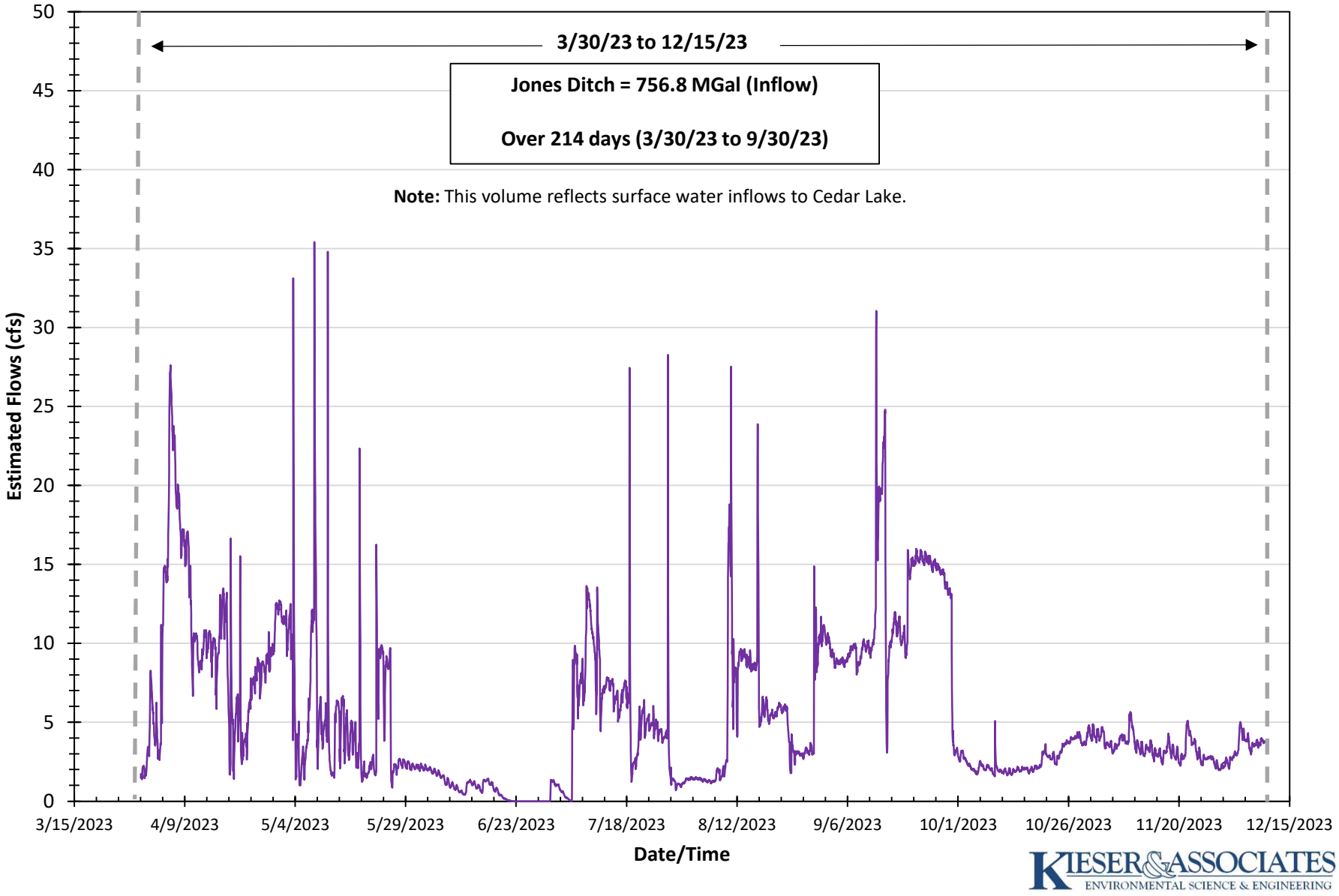

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Figure 22. 2023 Estimated Sherman Creek Flows

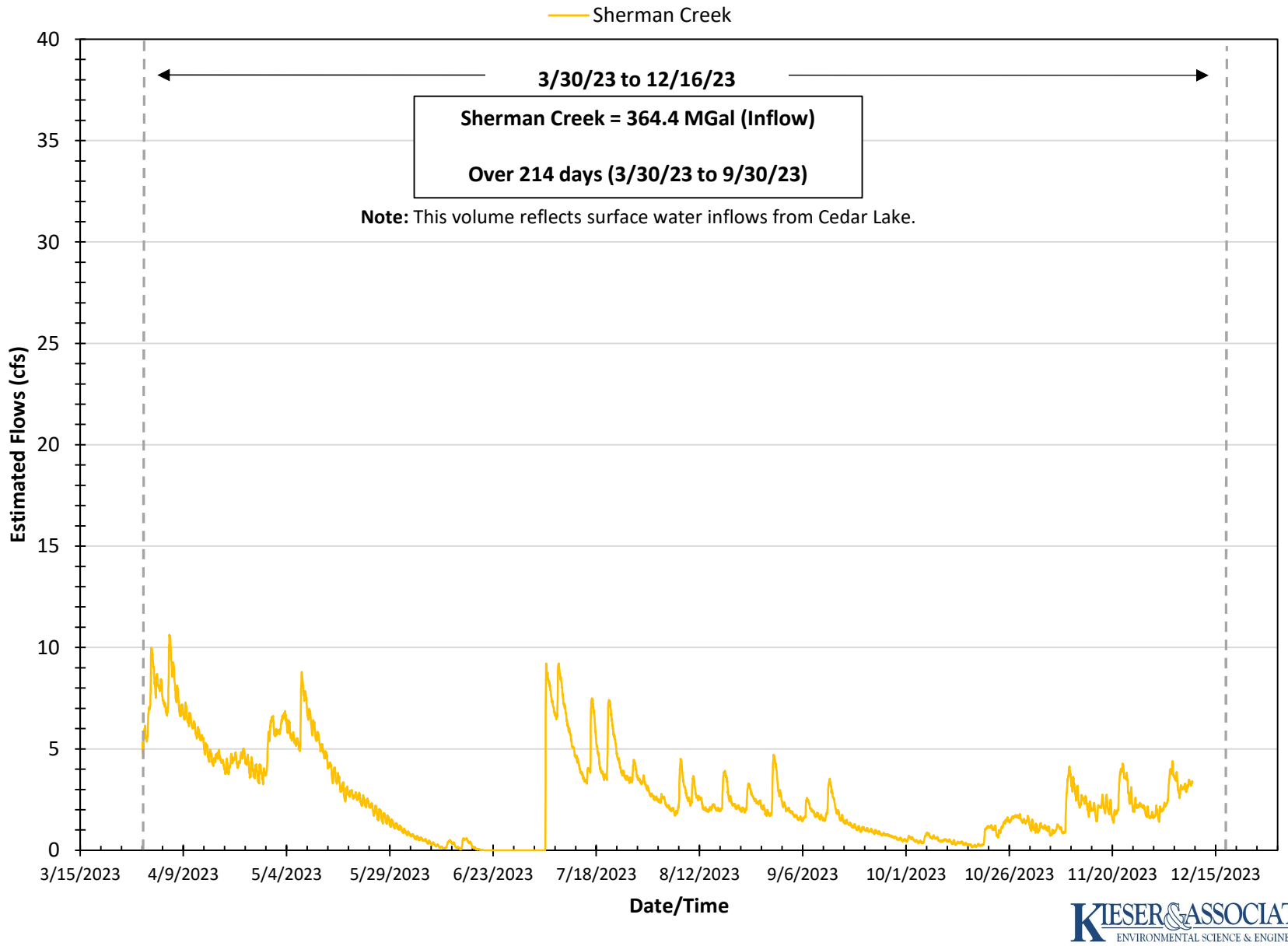

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Figure 23. 2023 Estimated Cedar Lake Outflows

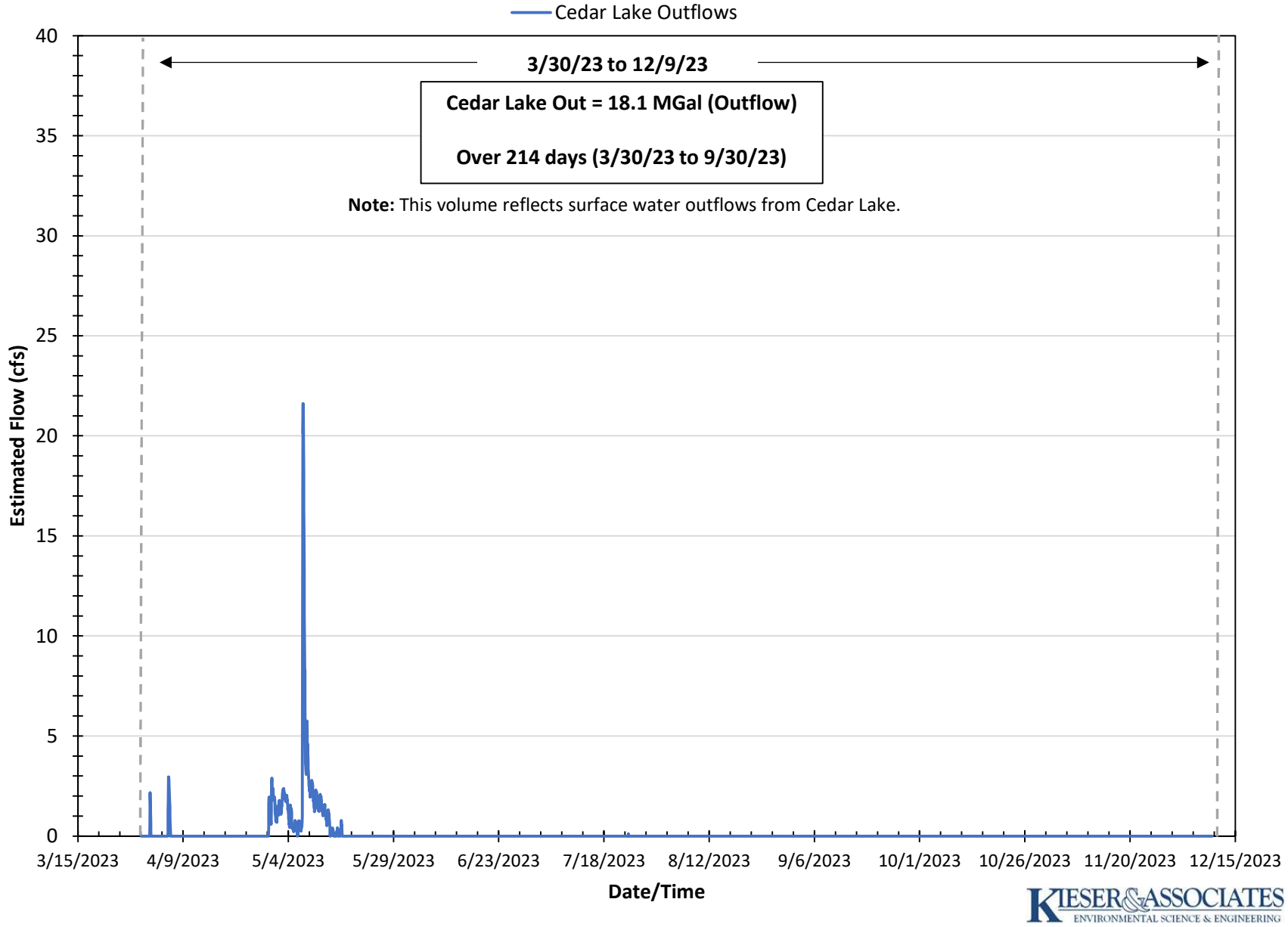

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Figure 24. 2023 Estimated King's Corner Outflow

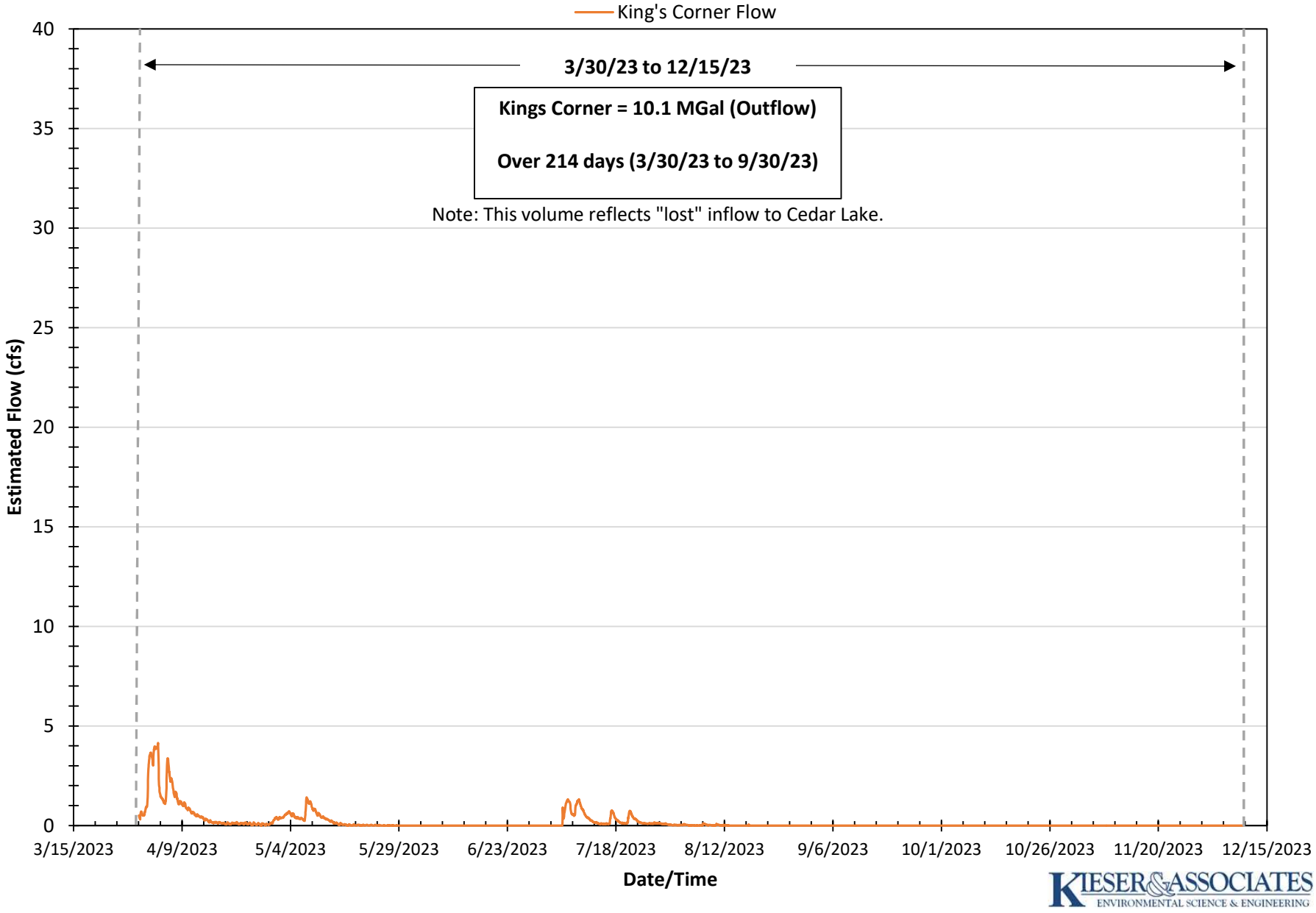


Figure 25. 2023 Estimated Wetland Berm Spillway Flows

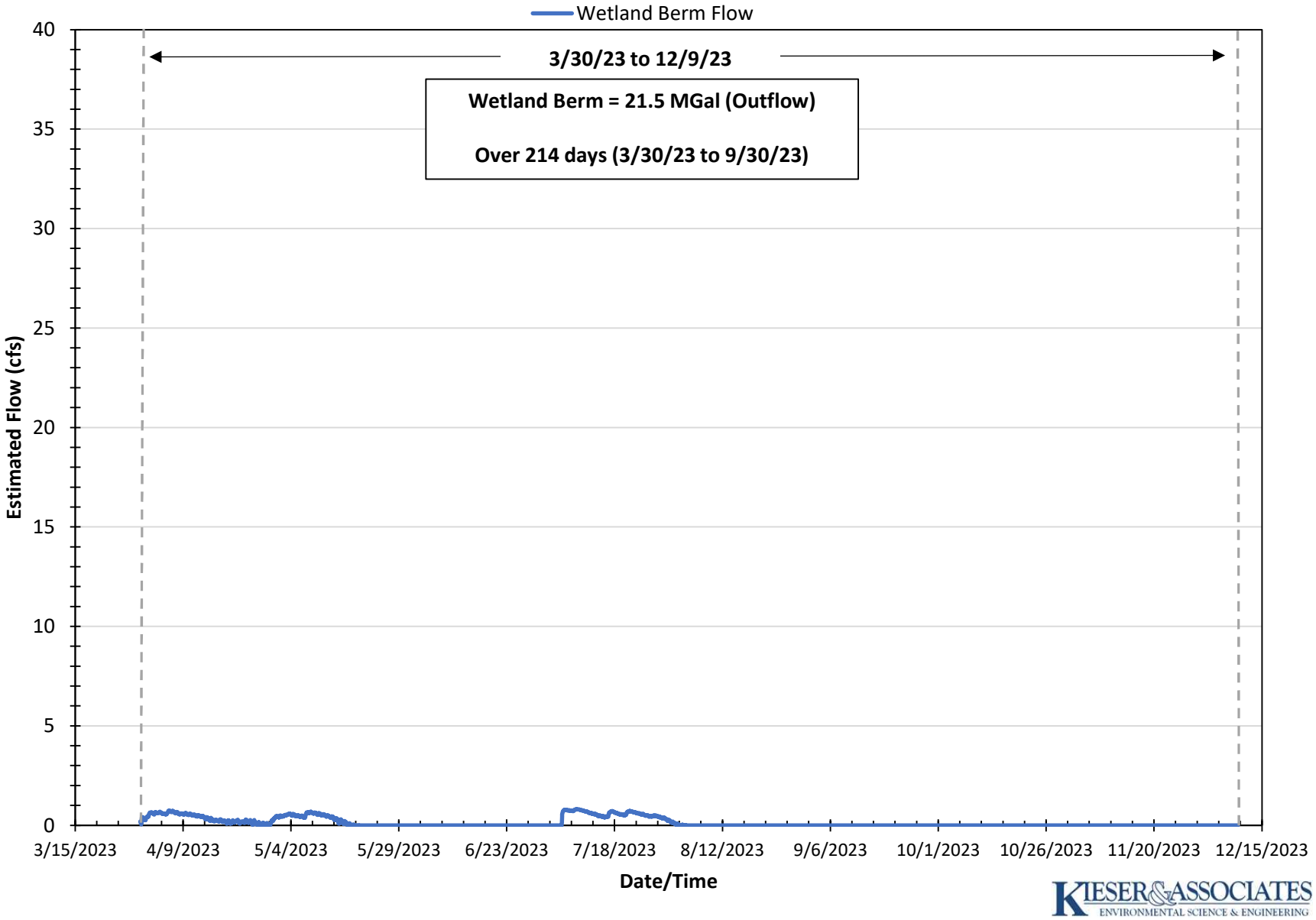


Figure 26. 2023 Estimated Cedar Lake Inflows/Outflows

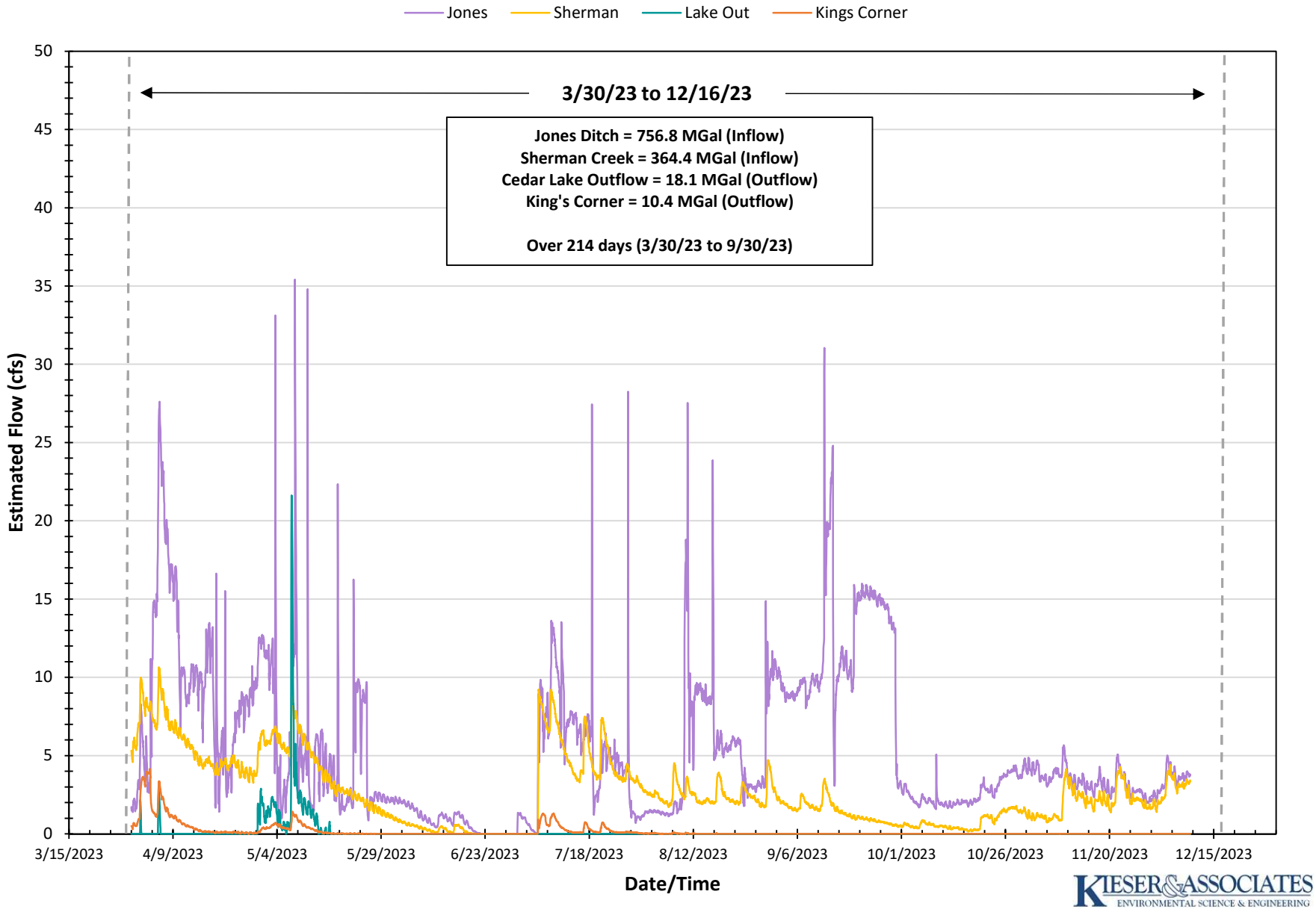


Figure 27. 2023 Sherman Creek Stations: Groundwater / Surface Water Elevations

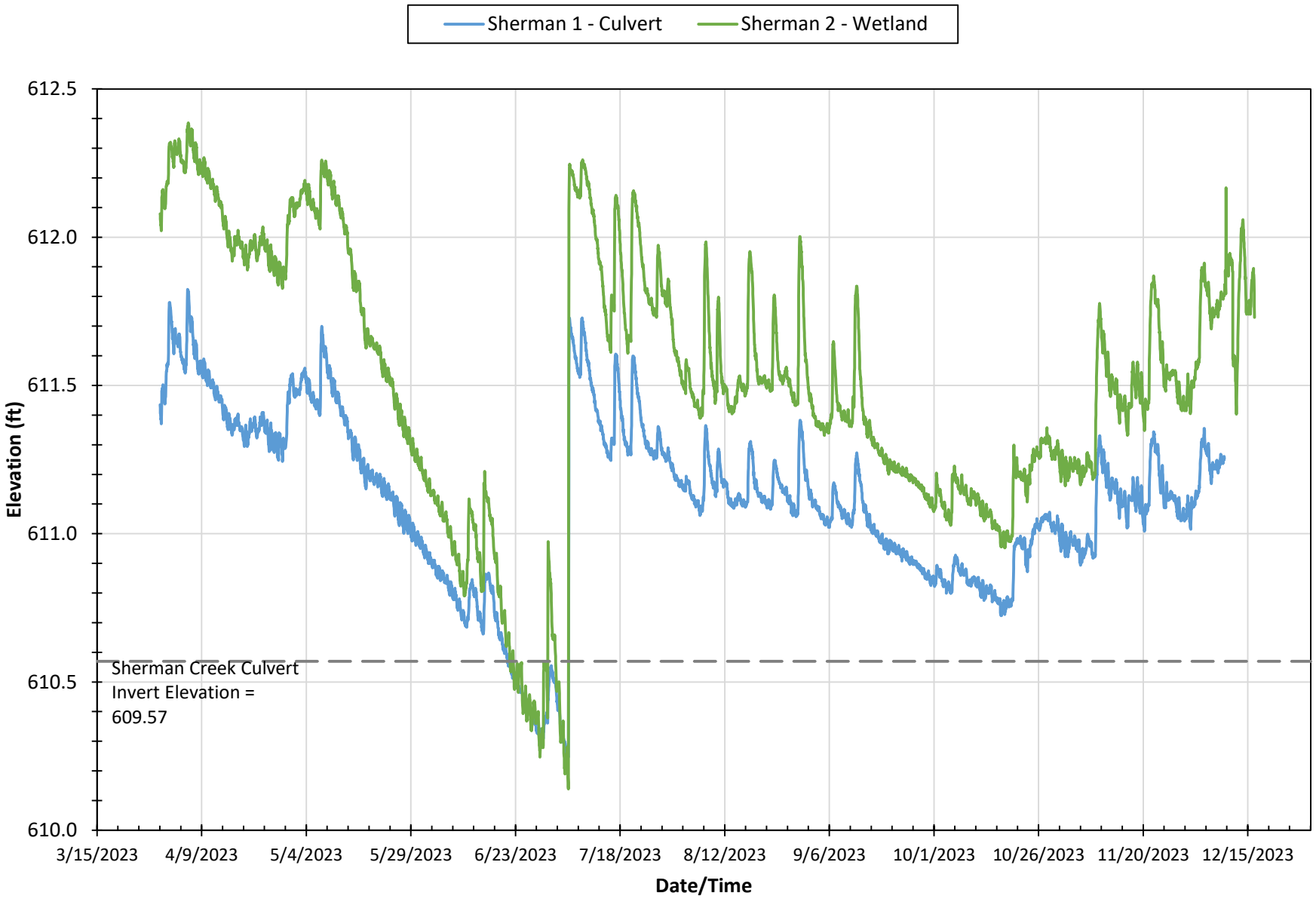


Figure 28. 2023 Cedar Lake Groundwater / Surface Water Elevations (Wetland Berm)

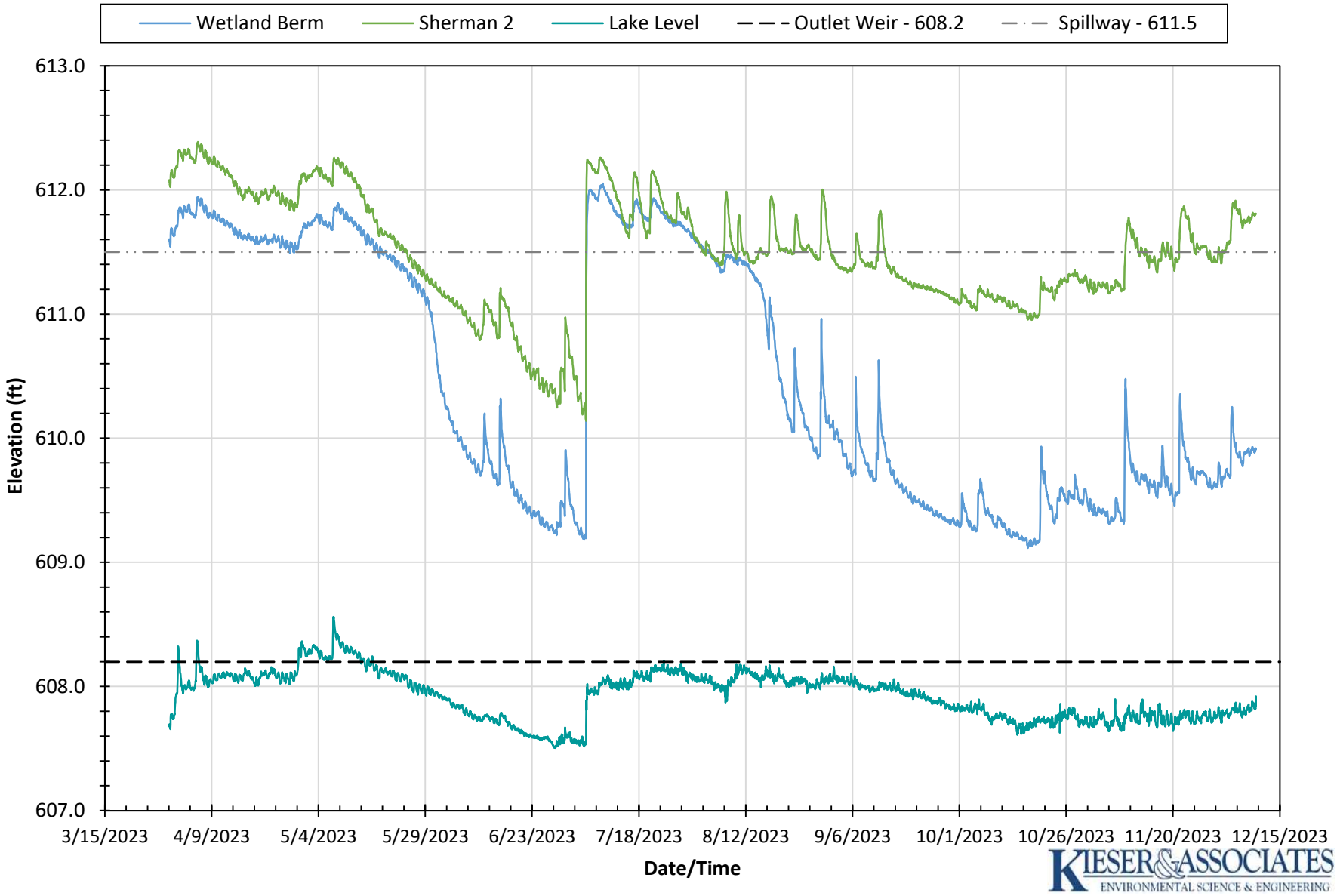


Figure 29. 2023 Cedar Lake Groundwater / Surface Water Elevations (Wetland Berm, King's Corner, and Sherman 2)

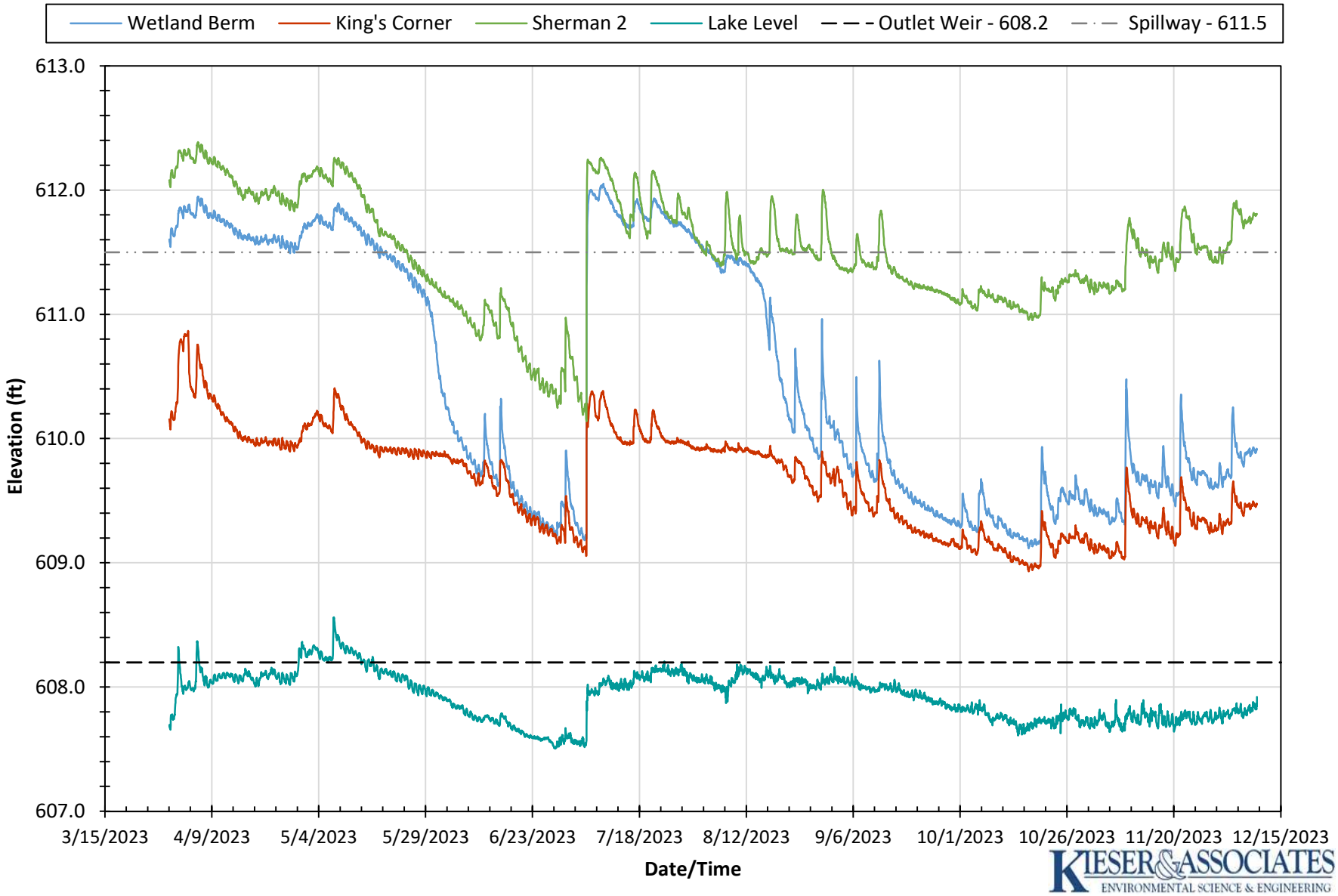
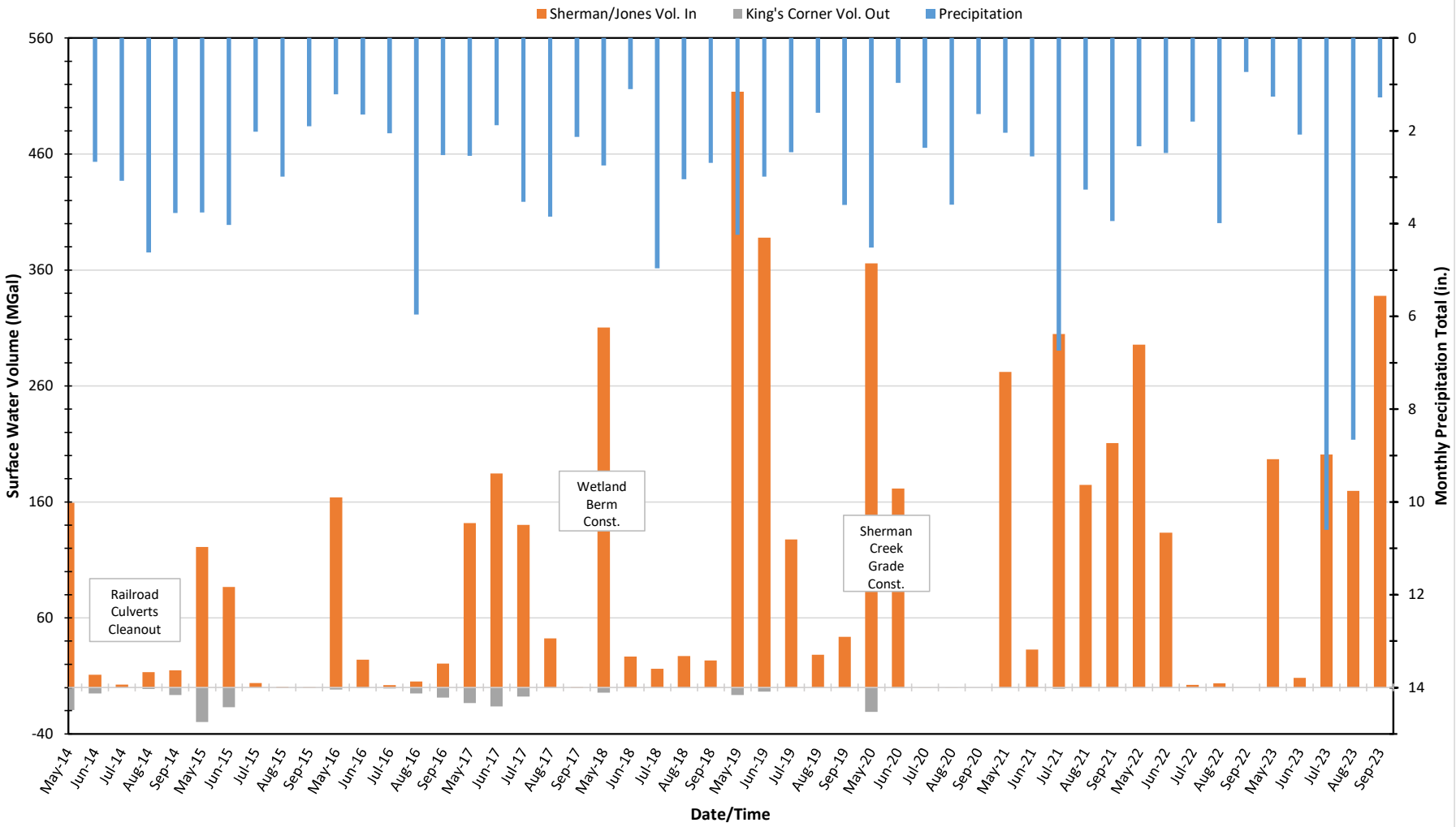


Figure 30. May- Sept, 2014-2023: Precipitation, Sherman/Jones Creek Combined Surface Water Volume into Cedar Lake, and King's Corner Water Volume Away from Cedar Lake



2014 May-Sep:	2015 May-Sep:	2016 May-Sep:	2017 May-Sep:	2018 May-Sep:	2019 May-Sep:	2020 May-Sep:	2021 May-Sep:	2022 May-Sep:	2023 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.	***Precip:*** 11.33 in.	***Precip:*** 23.88 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	***Inflow Vol.:*** 435.18 MGal	***Inflow Vol.:*** 1477.13 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	***King's Vol. Out:*** 0.156 MGal	***King's Vol. Out:*** 10.373 MGal

Table 1. Cedar Lake level loggers 2023 status.

Piezometer ID #	LL Manu-factured Year	LL Age (years)	Predicted LL Lifespan (years)	Predicted Year of LL "Age-Out"	Status
Wetland Berm	2017	6	10	2027	New (Added site in 2017)
PZ-02s	2017	6	10	2027	New, replaced "Aged-Out" logger in 2017
TL Lake 2	2017	6	10	2027	New (Added site in 2023)
Sherman 1(Culvert)	2019	4	10	2029	New, replaced "Aged-Out" logger in 2019
Sherman 2 (Wetland)	2019	4	10	2029	New, replaced "Aged-Out" logger in 2019
Kings Corner	2019	4	10	2029	New, replaced "Aged-Out" logger in 2019
Kings Corner Barlog	2019	4	10	2029	New, replaced "Aged-Out" logger in 2019
Lake Out	2019	4	10	2029	New, replaced "Aged-Out" logger in 2019
PZ-12s	2019	4	10	2029	New (Added site in 2019)
TL Road	2019	4	10	2029	New (Added site in 2023)
PZ-06s	2019	4	10	2029	New (Added site in 2019)
PZ-06s2	2019	4	10	2029	New (Added site in 2019)
PZ-07s2	2019	4	10	2029	New, replaced "Aged-Out" logger in 2020
Jones Creek Upstream	2019	4	10	2029	New, replaced "Aged-Out" logger in 2020
PZ-01s	2020	3	10	2030	New, replaced "Aged-Out" logger in 2020
PZ02d	2020	3	10	2030	New, replaced "Aged-Out" logger in 2020
PZ-03s	2020	3	10	2030	New, replaced "Aged-Out" logger in 2020
PZ-03s2	2020	3	10	2030	New, replaced "Aged-Out" logger in 2020
PZ-03d	2020	3	10	2030	New, replaced "Aged-Out" logger in 2020
PZ-07s	2020	3	10	2030	New, replaced "Aged-Out" logger in 2020
PZ-10s	2020	3	10	2030	New, replaced "Aged-Out" logger in 2020
PZ-09s	2020	3	10	2030	New, replaced "Aged-Out" logger in 2020
PZ-01s2	2021	2	10	2031	New, replaced "Aged-Out" logger in 2020
PZ-01d	2021	2	10	2031	New, replaced "Aged-Out" logger in 2020
PZ-04s	2021	2	10	2031	New, replaced "Aged-Out" logger in 2020
PZ-04s Barlog	2021	2	10	2031	New, replaced "Aged-Out" logger in 2020
PZ-05s	2021	2	10	2031	New, replaced "Aged-Out" logger in 2020
PZ-08s	2021	2	10	2031	New, replaced "Aged-Out" logger in 2020
PZ-11s	2021	2	10	2031	New, replaced "Aged-Out" logger in 2020
Sherman 100'	2022	1	10	2032	New (Added site in 2019)
Jones Creek Downstream	2022	1	10	2032	New (Added site in 2022)

Table 2. Comparison of Surface Water Volumes from May 1 to Sep 30, 2014 to 2023.

Site	Volume (Mgal)									
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Sherman Creek (inflow to CL)	136.0	190.9	198.1	449.4	328.1	446.8	359.9	195.2	147.4	364.4
Jones Ditch (inflow to CL)	64.8	21.6	18.0	59.8*	75.7	654.7	177.3	800.0	287.8	756.8
Cedar Lake Outlet (outflow from CL)	13.0	109.5	0.2**	26.1**	52.0	143.2	21.6	0.0	0.1	18.1
Kings Corner (outflow away from CL)	32.2	46.9	17.0	38.1	4.4	10.2	21.8	0.2	0.2	10.4

*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.