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TECHNICAL MEMORANDUM

To:	Rex Vaughn Cedar Lake Improvement Board	**Date:**	March 10, 2023
From:	Mark Kieser, Senior Scientist John Jacobson, PE, Senior Engineer Mike Foster, Environmental Engineer Kieser & Associates, LLC	**cc:**	Files

RE: **Findings for 2022 Cedar Lake Groundwater/Surface Water Level Monitoring**

This memorandum presents 2022 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 2022 on behalf of the Cedar Lake Improvement Board (CLIB). The purpose of the long-term monitoring program is to best understand critical needs and relevant influences on water levels in Cedar Lake.

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. Expanded water level control efforts have been implemented in the Cedar Lake watershed since 2017 including the construction of the wetland enhancement berm, the implementation of the Sherman Creek instream grade structures in 2019, and the reconstruction of the lake outlet in 2020. A summary of each water level control measure is provided in this memorandum.

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 throughout the monitoring period suggest low-flow groundwater is likely the culprit of the continual trickle exiting through the lake outlet structure. 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.

This technical memorandum presents findings of these water level conditions observed in Cedar Lake and its watershed in 2022 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 2022 water level monitoring added three new piezometers and totaled 32 level loggers in operation around the Cedar Lake from April to November. The location and addresses of the sites of the level loggers are provided in Figure 1.

The combination of surface water stations, shallow piezometers, and deep piezometers allow 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 2022 to calculate estimates of surface water flows into Cedar Lake. Level loggers were also deployed in the three instream stilling wells in Sherman Creek to further understand the impacts of the instream grade structures on creek water levels and discharges. Two additional instream level loggers were deployed in Jones Ditch in 2022. An additional logger was also deployed upstream within the wetland complex that contributes surface flows to Jones Ditch. These additional loggers in Jones Ditch watershed will further define the Jones Ditch contribution in 2023.

The 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 substantially underestimated the true inflow volumes occurring over the March-November monitoring period. In 2021, the equation was modified to more accurately quantify flow data which suggest Jones Ditch, under certain conditions, contributes more surface water to Cedar Lake than Sherman Creek. This discovery has significant implications for future engineering designs and management efforts. The three additional instream level loggers in Jones Ditch and the connected wetland implemented in 2022 are expected to provide further insight into the interactions between the surface water and groundwater in and along the northwest corner of Cedar Lake. The surface flow equations from Jones Ditch will continue to be refined with the additional data provided by additional loggers and any field measures taken during site visits.

All 32 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 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. The three additional loggers in Jones Ditch and an additional one near the Timberlakes property on the northeast side of Cedar Lake were purchased in 2022. The lifespan of 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.

2022 Precipitation and Water Level Data

Precipitation Analysis:

Historic summer precipitation totals for the Cedar Lake area are presented in Figure 2. These data represent 2022 summer precipitation information available from the Cedar Lake volunteer rain gauge. Rain 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. From 2016 to 2020, rainfall data used for reporting were triangulated from these weather stations and the near-lake rain gauge due to malfunctions associated with the aging volunteer equipment. Available rainfall data from 1998 to 2022 (minus 2006 when there were no local functioning rain gauges) reflect a 24-year summer average (June-September) of 11.94 inches of rainfall.

In 2022, monthly total precipitation in June, July, and September fell below the respective 24-year average for each month. August exceeded the 24-year precipitation average (3.10 inches) and totaled 3.99 inches. July monthly precipitation totaled 1.80 inches, the lowest since 2012; September precipitation totaled only 0.73 inches, the lowest reading since 2004. The resulting summer precipitation total was 9.00 inches, a below-average reading indicative of a dry summer season.

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 24-year summer precipitation average. Cedar Lake precipitation in 2022 exceeded this critical threshold of lake-elevation drop only in August. 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 2022 Cedar Lake water elevation from March to November with daily precipitation data recorded from the Cedar Lake volunteer rain gauge to visualize the importance of precipitation on lake elevation. Lake elevations above 607.20 ft (one-foot below the legal lake limit) have been historically identified as "desirable conditions." If the lake's elevation exceeds 608.20, flow over the Cedar Lake outlet weir would occur along with a proportionate drop in lake elevation.

High spring discharge from Sherman and Jones Ditch resulting from snowpack melt and precipitation induced a lake level elevation above the outlet (608.2 ft) from early spring through early summer. As a result, Cedar Lake lost approximately 1.69 Mgal of surface water through the lake outlet between April 5 to June 17, 2022. Low summer precipitation resulted in elevations below the Cedar Lake outlet for the remainder of the summer. The lake elevation fell below the minimum desirable threshold (607.2) on September 4 before it eventually reached the 2022 summer minimum of 606.64 on September 30. Lake level continued to fluctuate until reaching the lowest elevation recorded during the 2022 monitoring period of 606.54 ft on October 27.

Cedar Lake's mid- to late-summer levels remain highly dependent on summer precipitation to maintain desirable conditions. Low precipitation in the critical summer months (June and July) of 2022 exacerbated the continual drop in lake level. Despite low summer precipitation, Cedar Lake remained above the desirable threshold until mid- to late-September near the end of the recreation season. Though clearly sub-optimal for recreational conditions, such improvements in lake level despite low precipitation underscores the effectiveness of water retention efforts implemented in the watershed.

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. Site visits during 2022 confirmed the continuous stream exiting through the north side of the outlet structure that has been observed since the construction of the new outlet. K&A field staff continue to periodically collect measurements of the velocity and channel area of the outlet structure, as well as downstream channel to understand the discharge of water flowing through the outlet structure during non-wet weather/weir overflow conditions. Flow rate from the outlet structure continues to be low and likely with what can reasonably be described as negligible impacts on the lake level. Discharge data and calculated equivalent drops in Cedar Lake water elevations are presented in Table 2. The average outflow over the past two years since March of 2021 has been approximately 70,000 GPD or 0.0002 ft/day in equivalent lake level. Evaporation and discharge (leakage) to groundwater across the entirety of the lake's 1,050-acre surface area remain the leading causes of water losses from Cedar Lake during critical summer months.

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 2022 had returned to 2016 levels of 607.59 ft. Notably, total summer precipitation in 2022 was over 3 inches less than in 2016, and yet had an identical average lake level. This relationship is evidence of the effectiveness of the implemented watershed improvements aiding less rapid water level losses within Cedar Lake. Furthermore, a continuous 17-year trend of increasing average summer lake elevation despite a declining trend in precipitation suggests successful implementation of water retention efforts.

Groundwater Levels and Gradients

The 2022 groundwater elevation data from the groundwater monitoring Sites 1-12, "West Kings", and "LWSPC" 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) continue to record groundwater elevations below Cedar Lake levels. With this gradient present throughout the summer, eastward groundwater movement serves as a continual loss from the Cedar Lake watershed. This output 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 report groundwater gradients consistent the movement of groundwater away from Cedar Lake towards the southeast.

Site 3 (Figure 7) tracks the movement of shallow groundwater towards or away from Cedar Lake throughout the summer. The loss of shallow groundwater towards Phelan Creek and eventually into Van Etten Lake represents water loss from Cedar Lake. Beginning in April of 2022, shallow groundwater intermittently moved either towards or away from Cedar Lake while deep groundwater moved towards Phelan Creek. By mid-May, both deep and shallow groundwater started to consistently move away from Cedar Lake. However, intermittent storm events and decreasing lake elevation induced some shallow groundwater to flow towards Cedar Lake throughout the remainder of the monitoring period. Low lake level in late-September induced flow of deep and shallow groundwater towards Cedar Lake. Prior to the wetland berm construction and instream Sherman Creek grade structures, groundwater consistently moved away from Cedar Lake. Since their construction, area groundwater conditions have periodically shown much greater contributions to Cedar Lake than consistent losses. This is a net benefit to maintaining Cedar Lake water levels.

Prior to 2021, shallow groundwater at Site 6 (Figure 10) experienced intermittent flow patterns under dry or wet conditions like Site 3. In 2021 and 2022, groundwater consistently moved towards Cedar Lake due to low lake level and increased groundwater elevation. This relatively novel pattern of recurrent groundwater movement towards Cedar Lake reflects the low summer precipitation observed in 2021 and 2022 as well as an increase in the groundwater elevation due to the 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 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. Low lake elevation in 2021 induced flow towards Cedar Lake from Site 12 for the entire monitoring period. This flow pattern increased in 2022 and showed a marked improvement in groundwater flow toward Cedar Lake. The groundwater elevation at Site 12 was 2 feet above lake level and remained flowing toward the lake all summer, although reduced to an elevation difference of one foot by September.

Site 7 and Site 12 also show an increase of groundwater elevation in the spring of 1 to 1.5 feet over the July elevations. This primarily is due to the enhancements (berm and instream grade structures) to allow the groundwater to be recharged in the spring. This phenomenon was not evident prior to 2017 and the berm installation.

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. High groundwater elevation recorded by the West Kings piezometer until mid-June suggests groundwater had flowed towards the King's Corner culvert and eventually out of the Cedar Lake watershed in the early summer of 2022. By mid-June, increasing evapotranspiration in the Sherman Creek wetland influenced the groundwater elevation at the wetland berm and the West Kings culvert to fall below the King's Corner elevation. As such, the previous groundwater flow had reversed and remained within the Cedar Lake watershed for the remainder of the monitoring period.

Groundwater elevations at the LWSPC station from April to mid-September were below the Cedar Lake elevation. As such, groundwater would expectedly flow westward away from Cedar Lake during this timeframe. Water losses and low precipitation in the fall induced a lake elevation lower than the LWSPC groundwater elevation. All level loggers in the King's Corner area are presented together in Figure 19.

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 represent Site 2 and Site 7 level logger data from the 2022 monitoring period, respectively. Both shallow and deep groundwater at Sites 2 and 7 suggest a continual flow of deep and shallow groundwater to Cedar Lake throughout the summer.

2022 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 608.20 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. Four loggers stationed near each instream grade structure and the Sherman Creek culvert provide surface water flow data for Sherman Creek in 2022.

Surface water discharge rates and total volumes associated with the full 2022 monitoring period at Jones Ditch, Sherman Creek, Cedar Lake outlet, and the King's Corner culvert are presented in Figures 20, 21, 22, and 23, 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 24.

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 more accurately quantify the increased flow through the larger diameter culvert. In September of 2022, two (2) additional loggers placed upstream and downstream of the culvert are expected to further calibrate the discharge equation for future monitoring.

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 or outflow volumes for surface water stations from May-September 2014-2022 for comparison. From May 1 to September 30, 2022, Jones Ditch and Sherman Creek inflows into Cedar Lake totaled 287.76 and 147.43 million gallons (Mgal), respectively.

Since 2020, Sherman Creek has contributed a decreasing volume of cumulative discharge to Cedar Lake throughout the recreational season. Despite a more cumulative precipitation falling in 2020 than 2022, the cumulative discharge in 2022 was nearly over 200 Mgal lower than in 2020. This disparity highlights the importance of early-season snowpack melt that influences high discharge in the Spring. Moreover, this relationship underscores the engineering implications of the instream grade structures and their importance in increasing the timeframe of high discharge conditions into early June. Limited snowpack, and low precipitation throughout the summer induced the lowest Sherman Creek cumulative summer discharge since 2014. Rain events throughout the summer temporarily increased lake level, but increasing evapotranspiration in the connected wetland complex led to Sherman Creek becoming dry in early July.

Jones Ditch cumulative summer discharge had regressed from the all-time high observed in 2021 (799 Mgal) to 287 Mgal in 2022. Drier conditions in 2022 are likely the source of this reduction. The cumulative discharge from Jones Ditch was approximately two times larger than the

Sherman Creek discharge in the same period as shown in Figures 20 and 21. Flatter conditions in the Jones Ditch wetland generally allow precipitation to runoff rather than being infiltrated as 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, 0.145 Mgal discharged through the outlet from Cedar Lake. This cumulative discharge had exited Cedar Lake between April 4, 2022 and June 17, 2022. For the remainder of the monitoring period, no surface water was lost through the outlet. However, a continuous trickle of groundwater was observed exiting the lake outlet during several monitoring events throughout the year.

The outflow volume that exited the Cedar Lake watershed through the King's Corner culvert during the May-September period totaled 0.156 Mgal. This volume is nearly identical to amount observed in 2021 and represents a new all-time low since monitoring of this outflow began. 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 snow-melt 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 cumulative loss through King's Corner culvert in 2022 represents a 99.53% reduction relative to pre-berm annual averages. 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 2022 remained lower than the historic average. 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, snow pack and spring precipitation are the biggest factors in Sherman Creek contributions. Drier than normal conditions in 2022 likely resulted in the low Sherman Creek discharge.

Instream grade structures extended the high discharge period into June. Figure 25 presents the surface/groundwater elevations at each of the Sherman Creek stations. Notably, data from the Sherman Creek 100 ft instream well are not available as data were compromised with a malfunctioning logger. Nonetheless, 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 several loggers within Sherman Creek and the connected wetland.

Figure 26 illustrates the 2022 water elevations at the wetland berm monitoring station positioned at the upstream side of the berm spillway compared to lake levels. 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 2022 monitoring season at the wetland berm spillway to outflows at King's Corner Culvert and inflows to Cedar Lake via Sherman Creek.

The 0.145 Mgal that spilled through the wetland berm April 4 through May 30 from was largely from moderate precipitation events following high surface water and groundwater elevation from spring snowmelt. King's Culvert lost 0.156 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. Increasing evapotranspiration and low precipitation after May 30 induced a water budget in favor of infiltration, and 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 as shown in Figure 29. This discharge distribution was observed in 2022. Dry conditions in June and July eventually led to Sherman Creek drying up by mid-July. 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.

Conclusions and Recommendations

Despite lower precipitation in 2022, improvements in water retention continue to prove effective in limiting outflows from the watershed. Water retention improvements are reflected in the limited outflows through King's Corner culvert (0.156 Mgal), among the lowest recorded since 2014. Jones Ditch continues to supply an increased amount of discharge following the culvert replacement in 2018. 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. The additional lake level piezometers placed in Jones Ditch will further augment the current discharge-stage relationship and work to more accurately quantify incoming flows from Jones Ditch. These efforts are expected to guide any future action in augmenting Jones Ditch in effort to improve Cedar Lake water levels throughout the summer recreation months.

Precipitation, spring snow melt, and evaporation remain as the three dominant factors that influence the Cedar Lake elevation throughout the summer. For the second year in a row, the average lake level has been below the historic average. In the early stages of hydrologic monitoring in the mid-to-late 2000s, Cedar Lake had been under a dry period followed by a wetter period from 2008-2011. Low precipitation in two of the past three years may indicate a pattern emerging of oscillating dry and wet periods for the watershed. While lake level has been improving despite declining or stagnant precipitation totals, drier conditions in the future may require additional management. Planning and coordination by the CLIB and K&A will continue to monitor emerging trends within the watershed and implement engineering design as needed. As such, the continuation of the hydrology monitoring program is recommended in 2023.

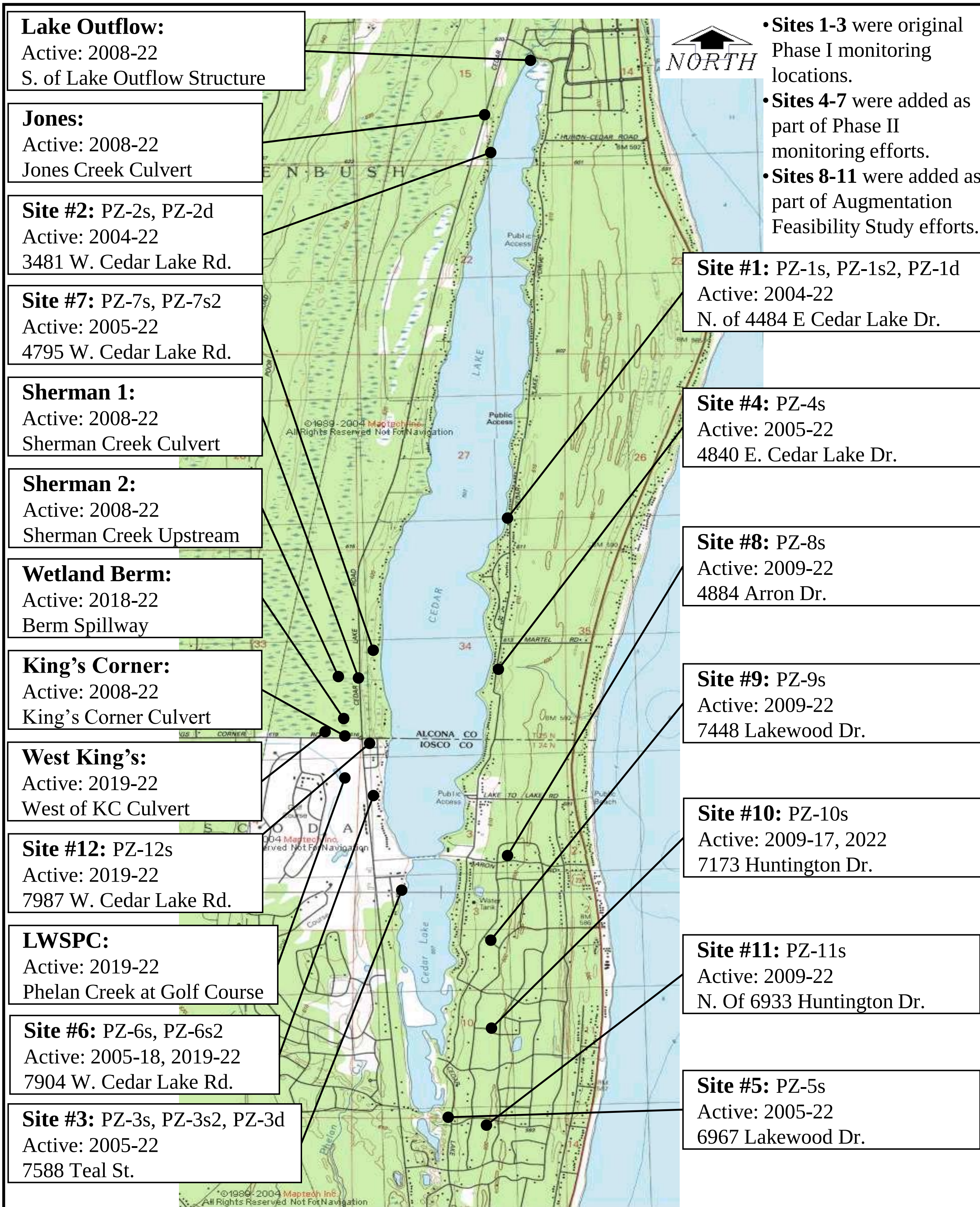
The continued collection of data will be used to identify:

1) Additional hydraulic improvements for both Sherman Creek and Jones Ditch areas including the maintenance of the railroad culverts to increase watershed flows;

2) Further calibration of the Jones Ditch discharge equation with new piezometer data along with wetland topographic data to determine volume control options for surface and groundwater flow enhancements.

3) Redeployment of some ground water piezometers to the northeast gap to verify groundwater losses along the northeast shoreline.

2022 Cedar Lake Hydrology Report: List of Tables and Figures.



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Map of 2022 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 2022

Piezometer ID #	LL Manufactured Year	LL Age (yrs)	Predicted LL Lifespan (yrs)	Predicted Year of LL "Age-Out"	Status
Wetland Berm	2017	5	10	2027	*New (Added site in 2017)*
PZ-02s	2017	5	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)*
Sherman 50'	2019	2	10	2029	*New (Added site in 2019)*
Sherman 100'	2019	2	10	2029	*New (Added site in 2019)*
Sherman 150'	2019	2	10	2029	*New (Added site in 2019)*
PZ-01s	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-01s2	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-01d	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-02d	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-03s	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-03s2	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-03d	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-04s	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-04s Barlog (backup)	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-07s	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-07s2	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-10s	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
Jones Creek	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-05s	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-08s	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-09s	2019	2	10	2030	*New, replaced "Aged-Out" logger in 2020*
PZ-11s	2019	2	10	2030	*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

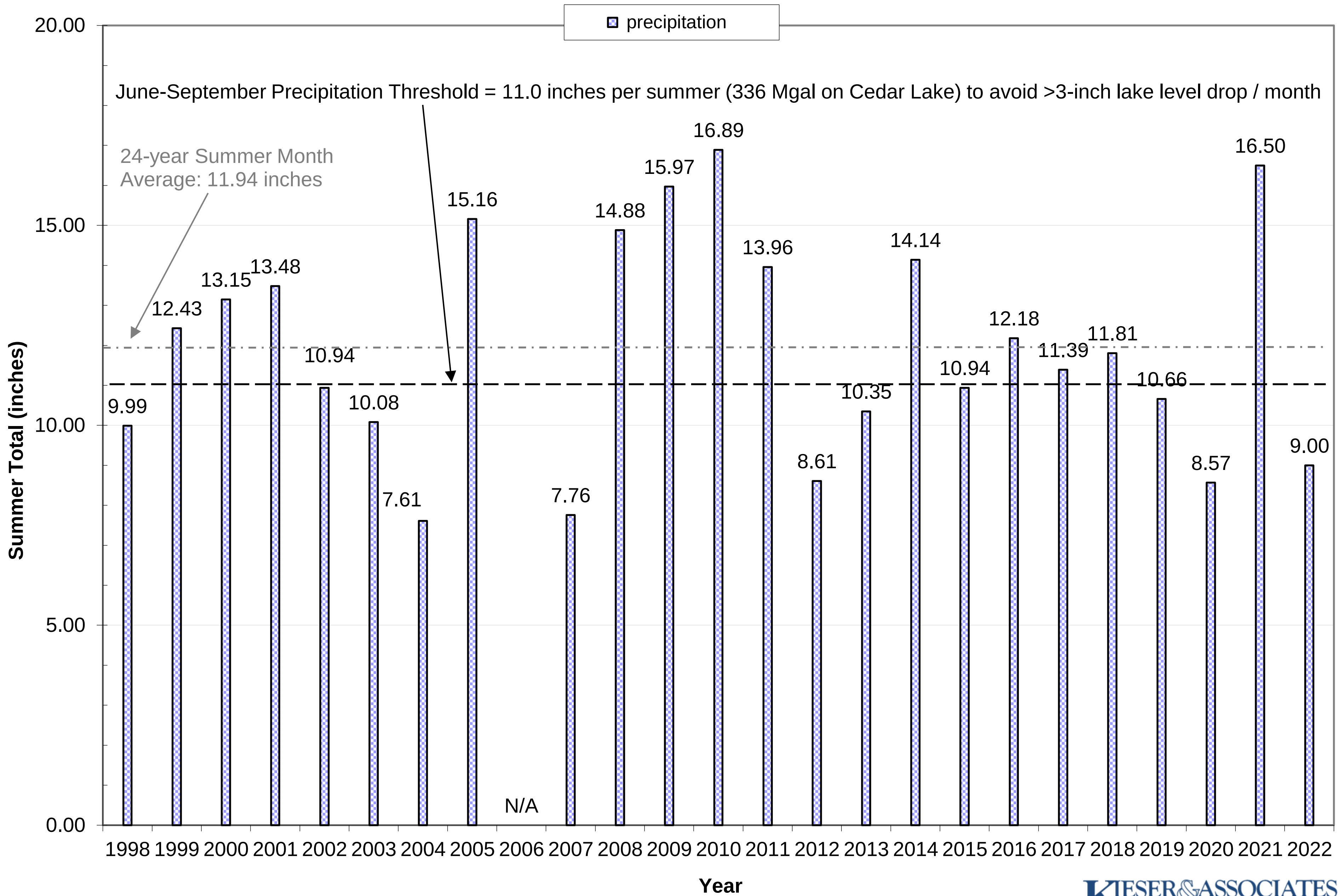

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Figure 3. 2022 Cedar Lake Water Elevation and Measured Rainfall

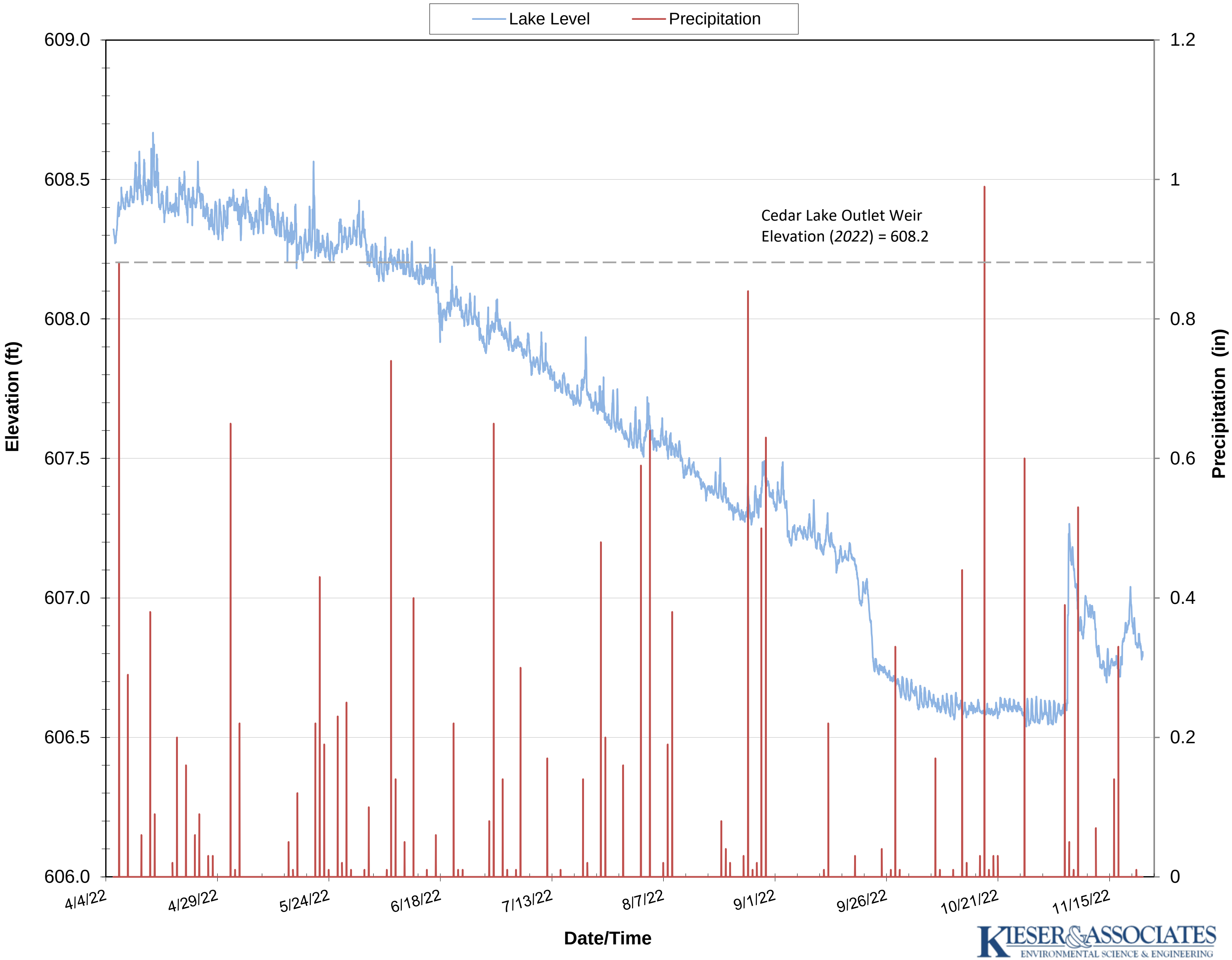

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Table 2. 2022 Cedar Lake Outlet field measurements & estimated elevation drop

Date	Outlet Discharge (GPD)	30' Downstream Discharge (GPD)	Equivalent Elevation Loss (ft/day)
3/19/2021	48,695	48,321	0.00014
6/16/2021	35,545	40,724	0.00012
8/24/2021	33,466	58,568	0.00017
11/17/2021	90,973	107,850	0.00031
4/4/2022 **	1,516,585	931,170	0.00265
7/14/2022	69,970	56,010	0.00016
9/21/2022	37,161	107,281	0.00031
Average *:	52,635	69,792	0.00020

Notes: * Averages do not include the 4/4/2022 data as that data included weir overflow at the structure

** Approximate 1.5 cfs flow across structure, approxiamte to Spicer Flow Curve

Table 3. Comparison of Surface Water Volumes from May 1 to Sep 30, 2014 to 2022.

Site	Volume (Mgal)								
	2014	2015	2016	2017	2018	2019	2020	2021	2022
Sherman Creek (inflow to CL)	136.04	190.929	198.126	449.441	328.134	446.753	359.857	195.171	147.428
Jones Creek (inflow to CL)	64.817	21.587	17.964	59.784*	75.712	654.691	177.250	799.967	287.755
Cedar Lake Outlet (outflow from CL)	13.003	109.5	0.162**	26.123**	51.975	143.156	21.560	0.000	0.145
Kings Corner (outflow away from CL)	32.208	46.862	17.049	38.053	4.384	10.161	21.819	0.158	0.156

*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.

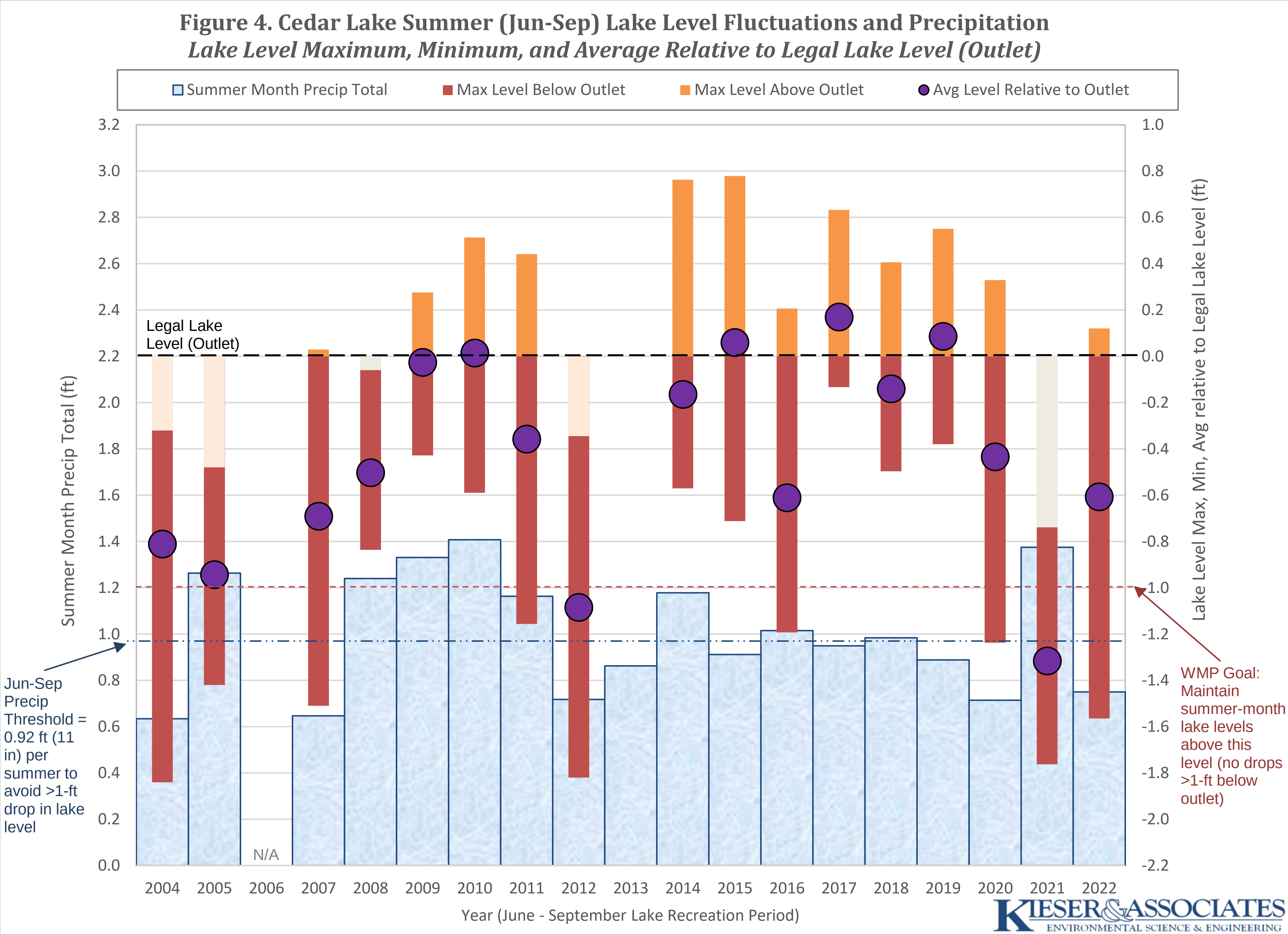

Figure 4. Cedar Lake Summer (Jun-Sep) Lake Level Fluctuations and Precipitation
Lake Level Maximum, Minimum, and Average Relative to Legal Lake Level (Outlet)
Summer Month Precip Total
Max Level Below Outlet
Max Level Above Outlet
Avg Level Relative to Outlet
Summer Month Precip Total (ft)
Lake Level Max, Min, Avg relative to Legal Lake Level (ft)
Legal Lake Level (Outlet)
N/A
Jun-Sep Precip Threshold = 0.92 ft (11 in) per summer to avoid >1-ft drop in lake level
WMP Goal: Maintain summer-month lake levels above this level (no drops >1-ft below outlet)
3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0
1.0 0.8 0.6 0.4 0.2 0.0 -0.2 -0.4 -0.6 -0.8 -1.0 -1.2 -1.4 -1.6 -1.8 -2.0 -2.2
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022
Year (June - September Lake Recreation Period)

Figure 5. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 1)

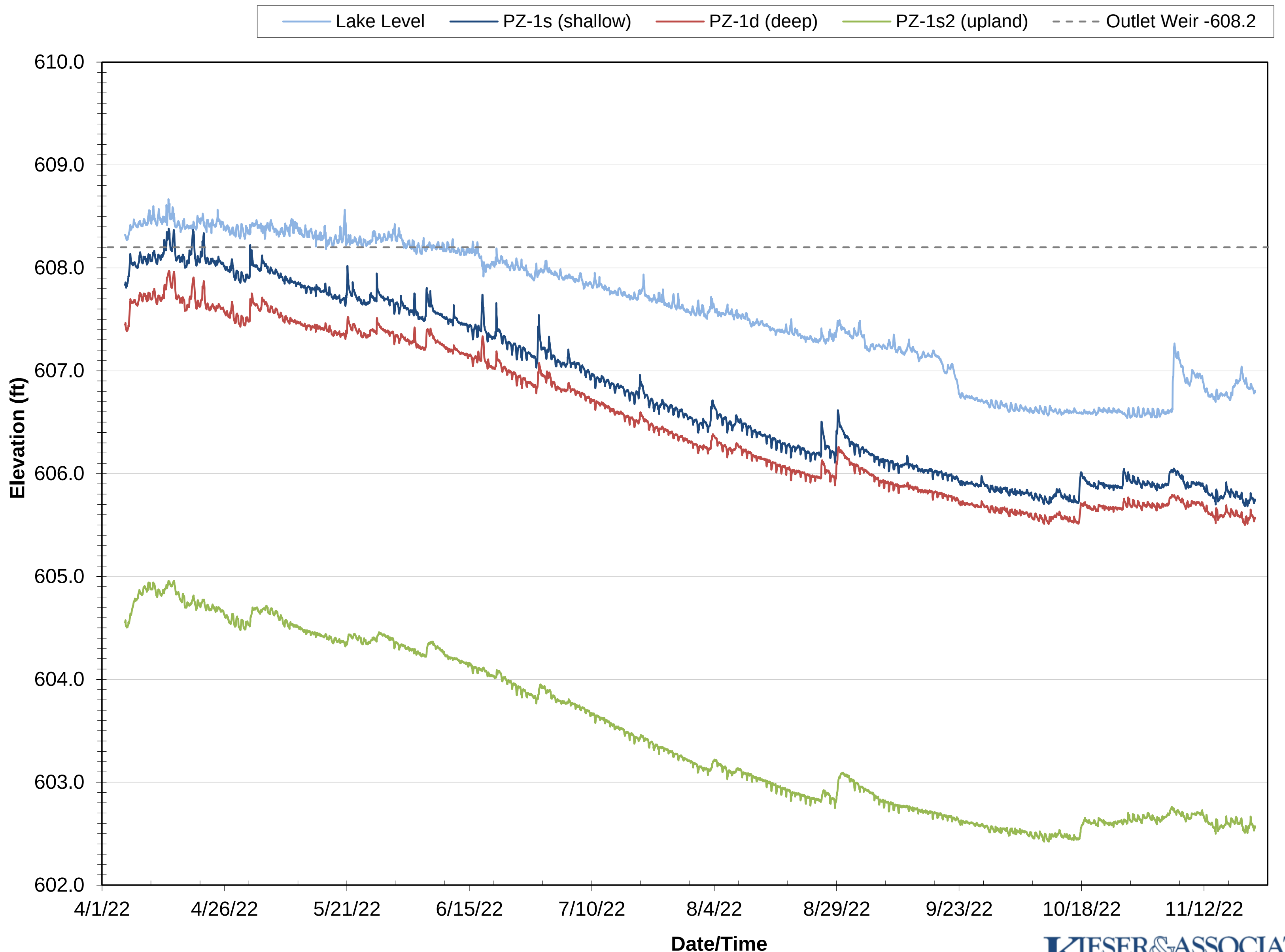

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Figure 6. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 2)

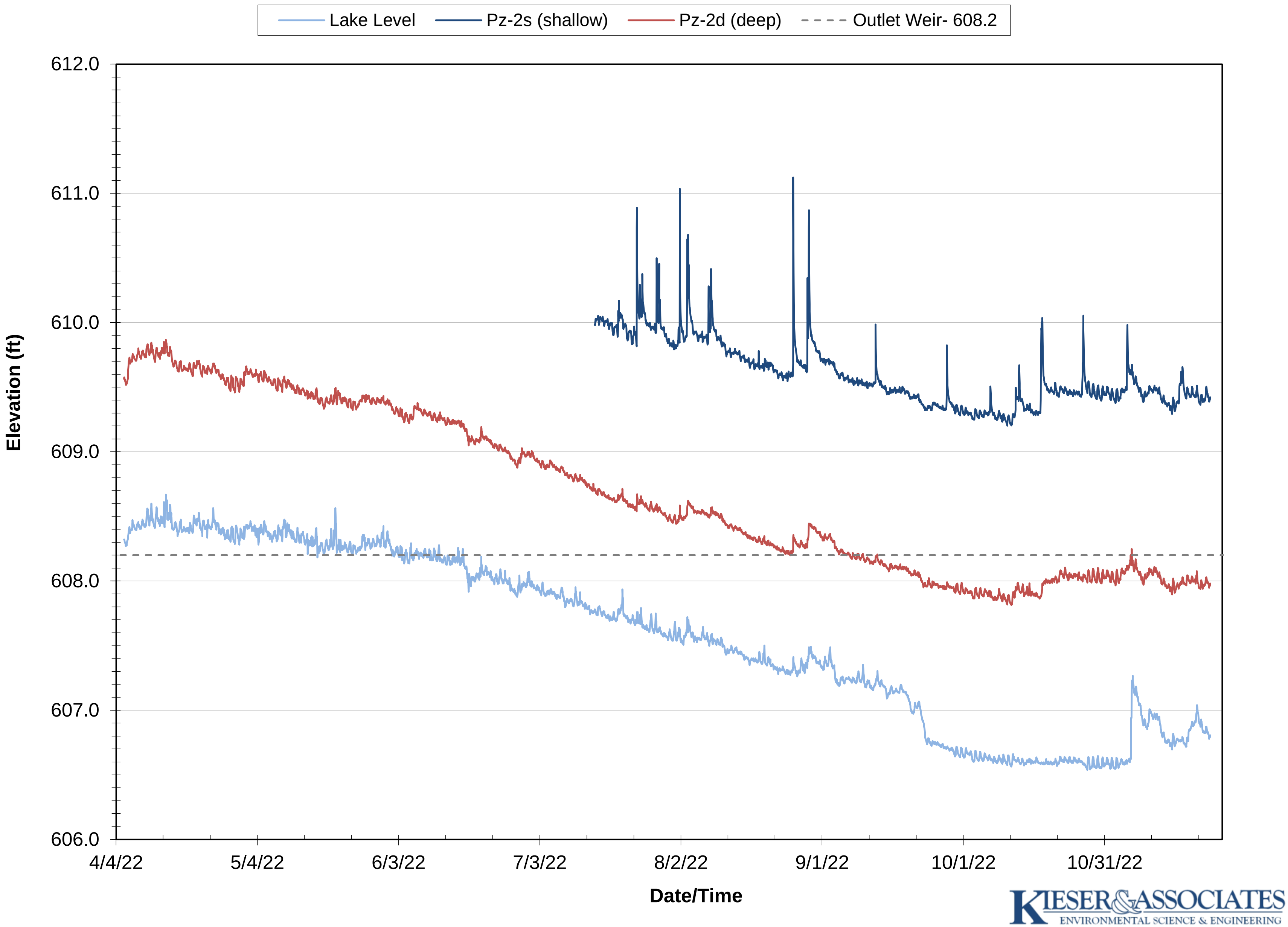

Figure 7. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 3)

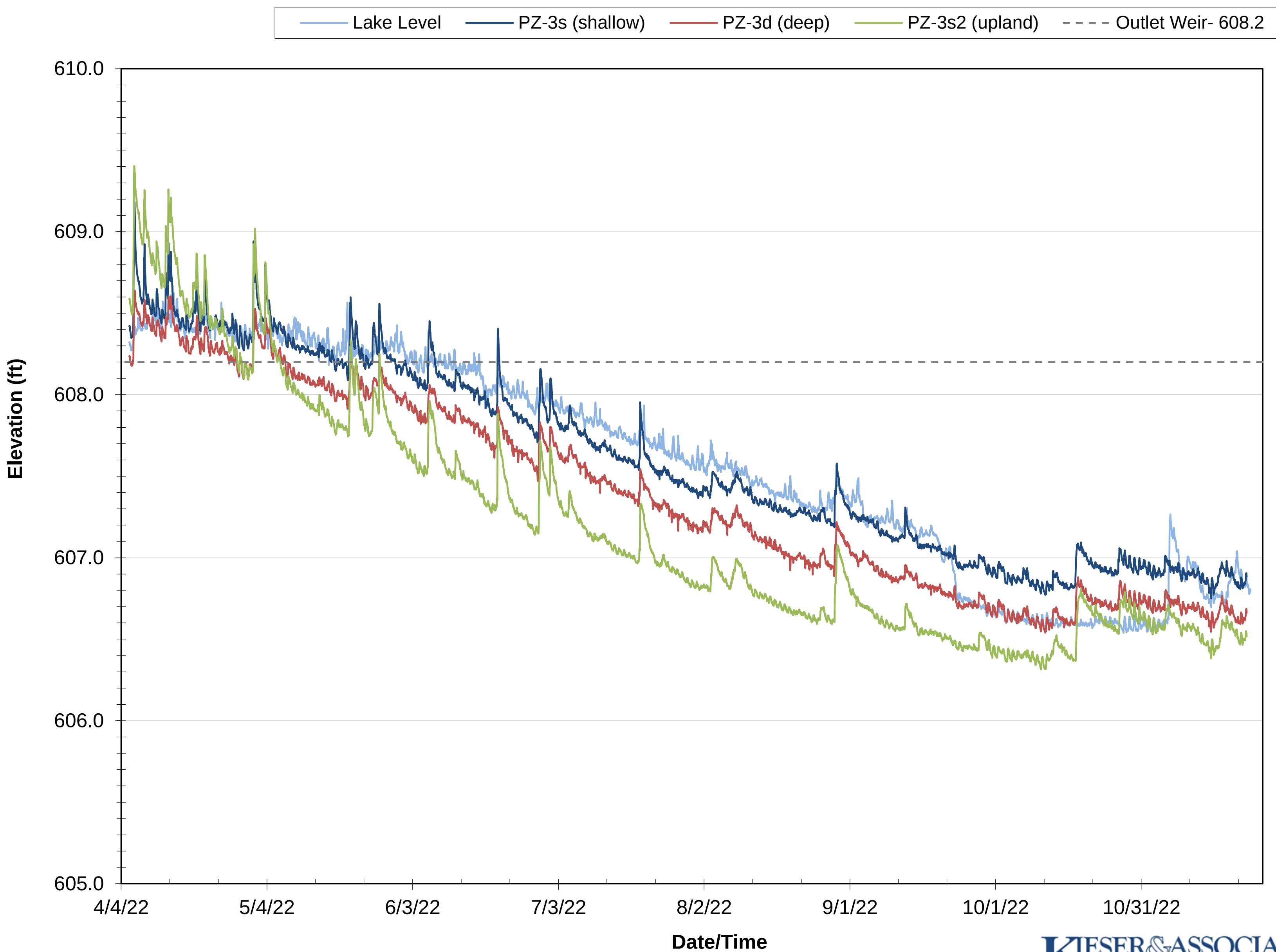

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Figure 8. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 4)

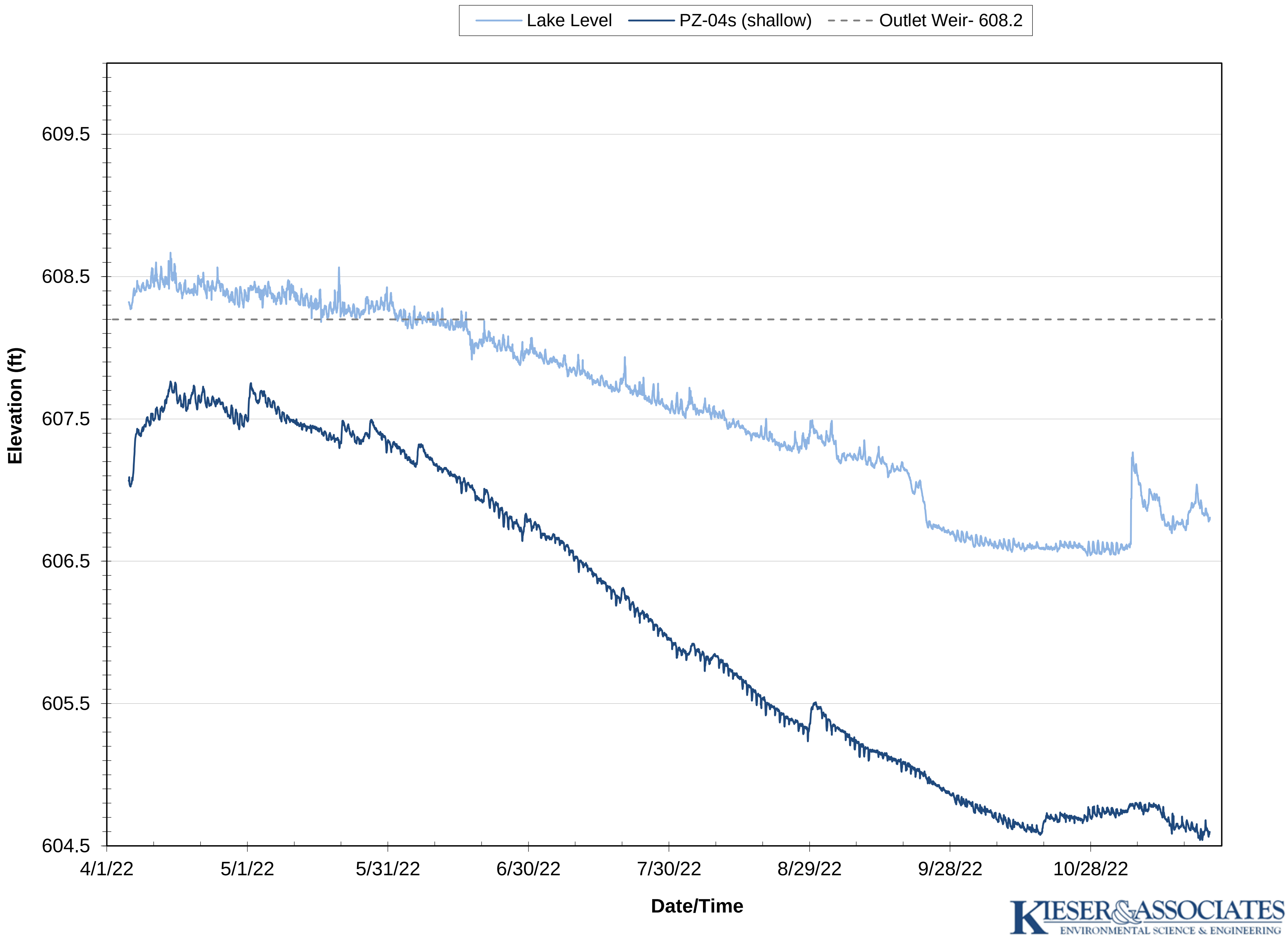

Figure 9. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 5)

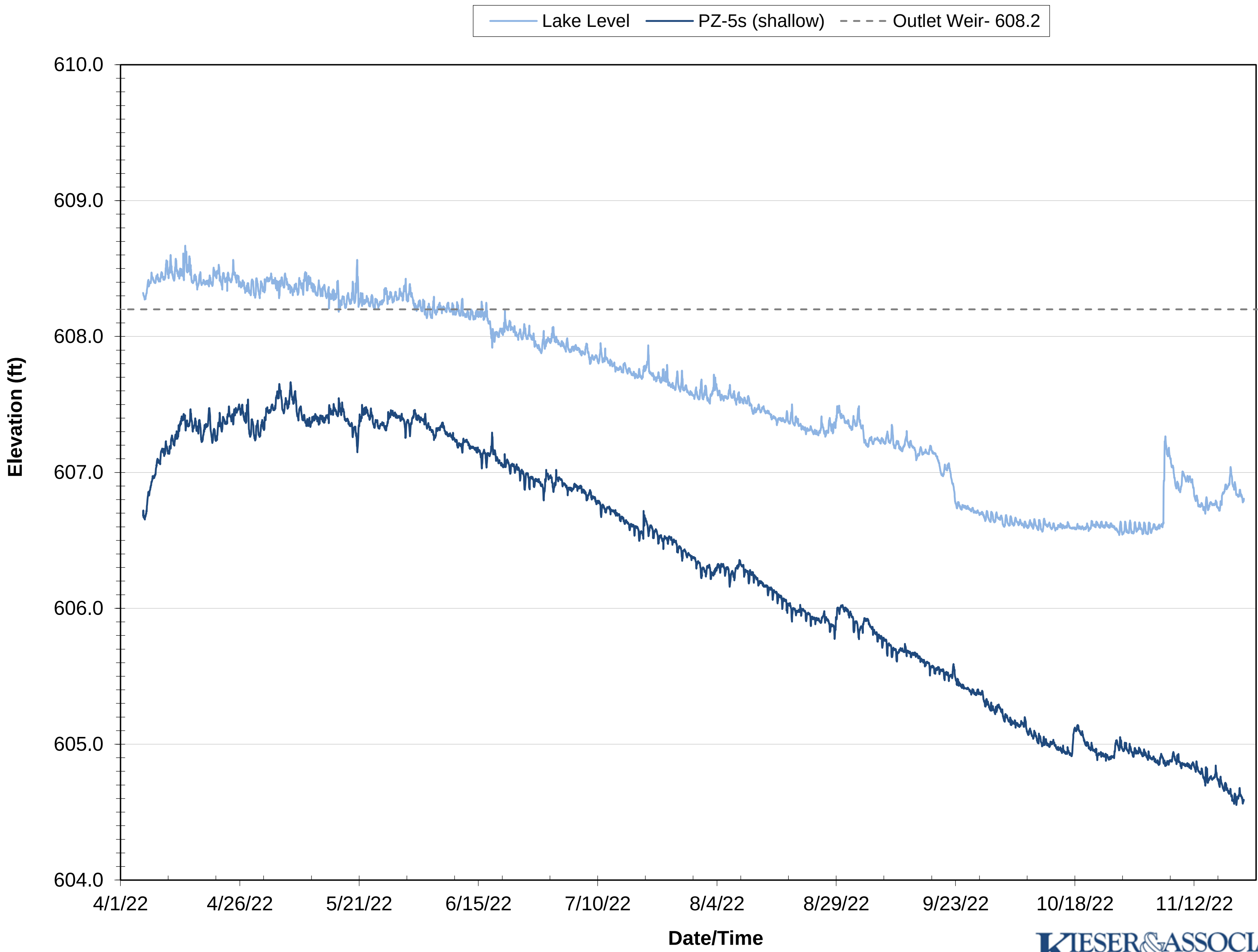

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Figure 10. 2022 Cedar Lake Groundwater / Surface Water Elevations
(Site 6 - *New Location, 2019*)

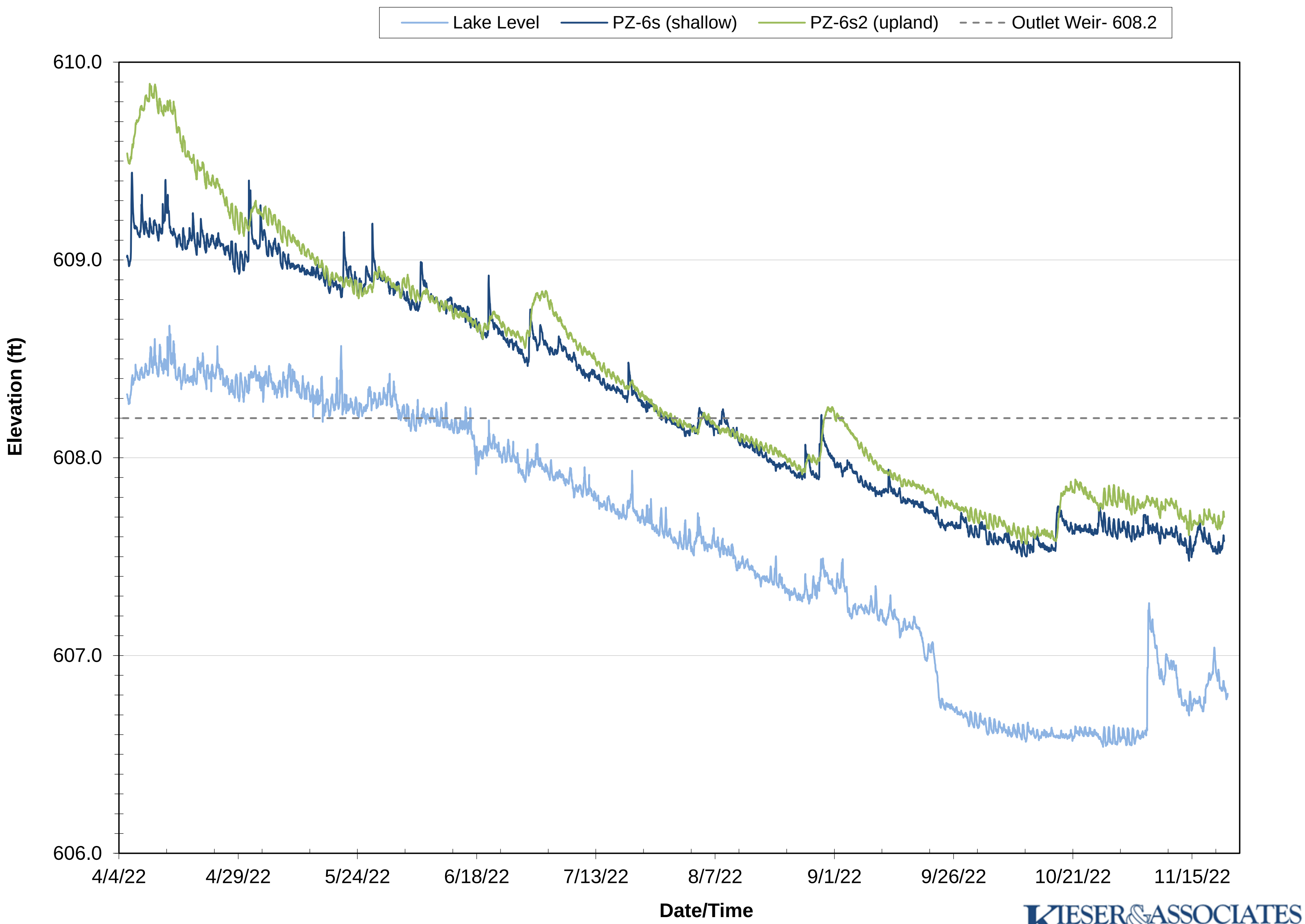

Figure 11. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 7)

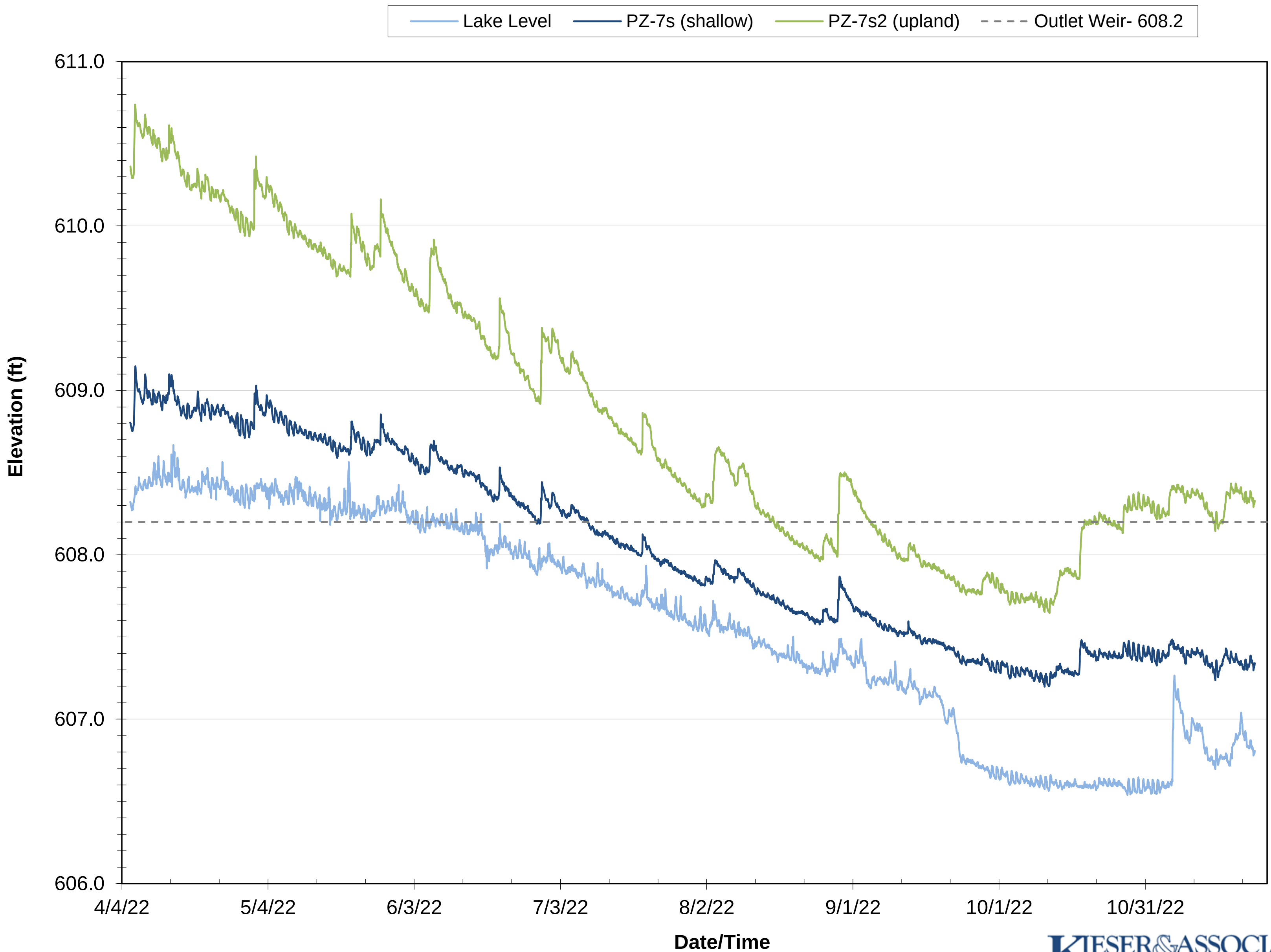

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Figure 12. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 8)

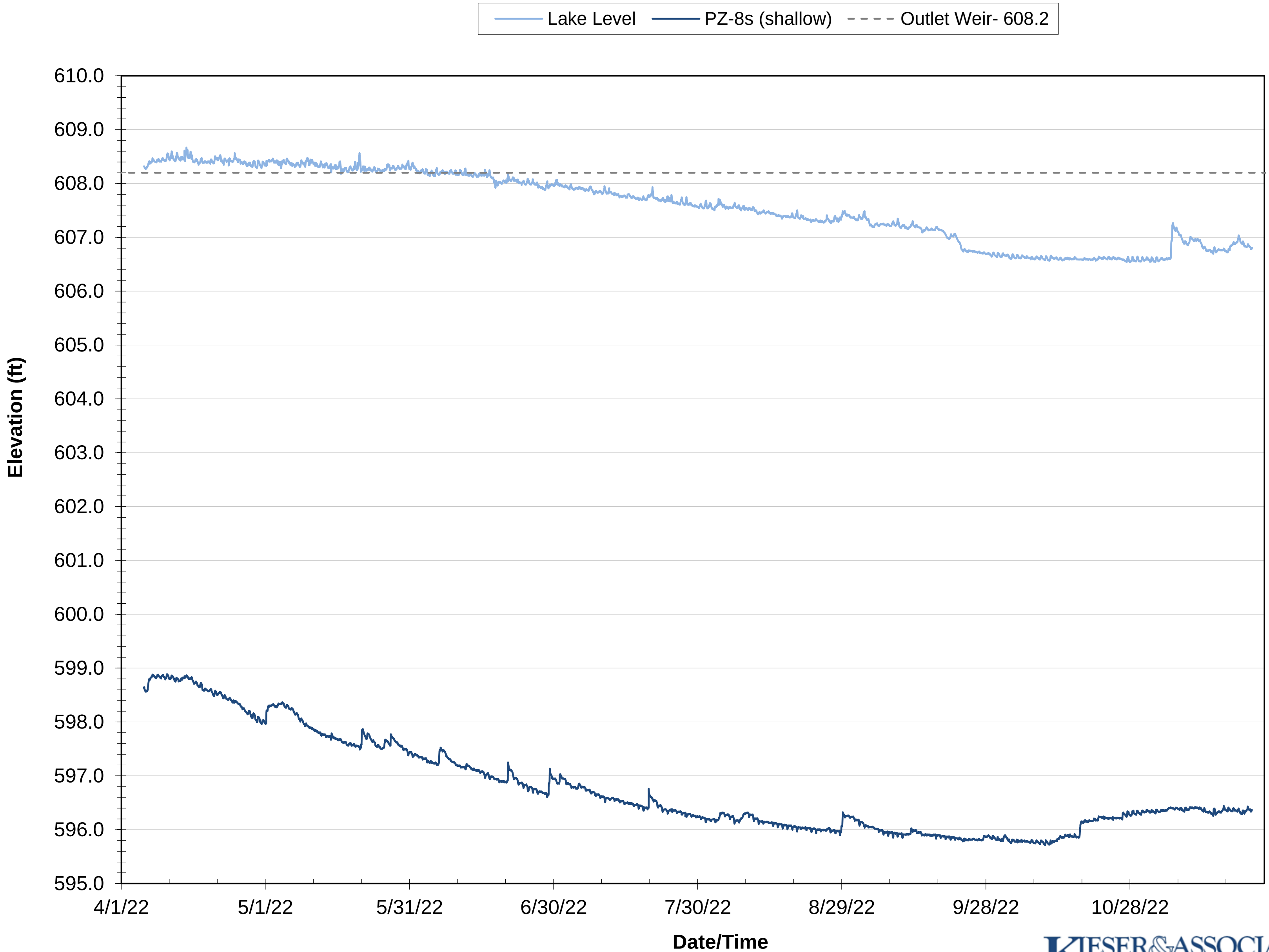

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Figure 13. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 9)

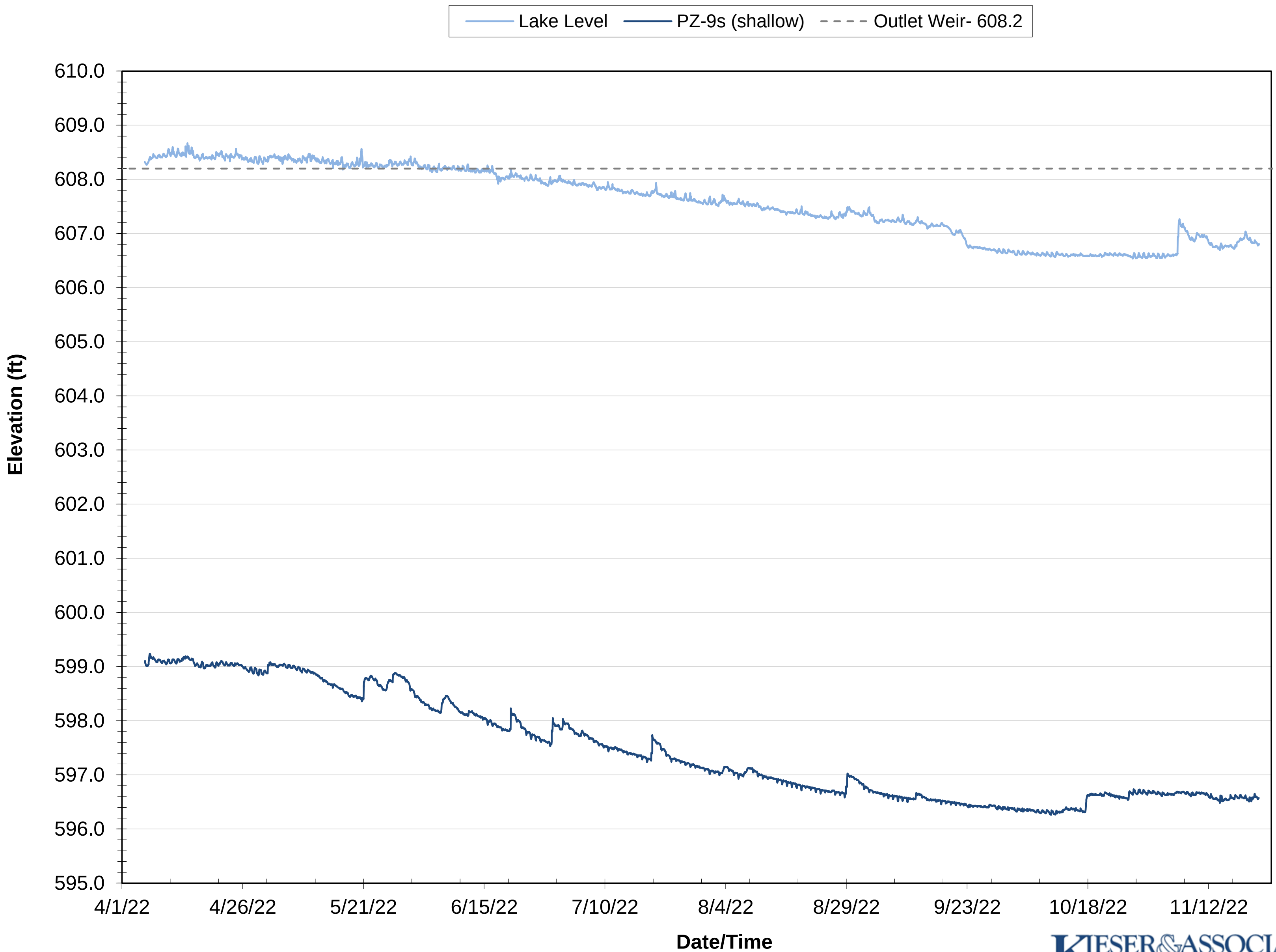

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Figure 14. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 10)

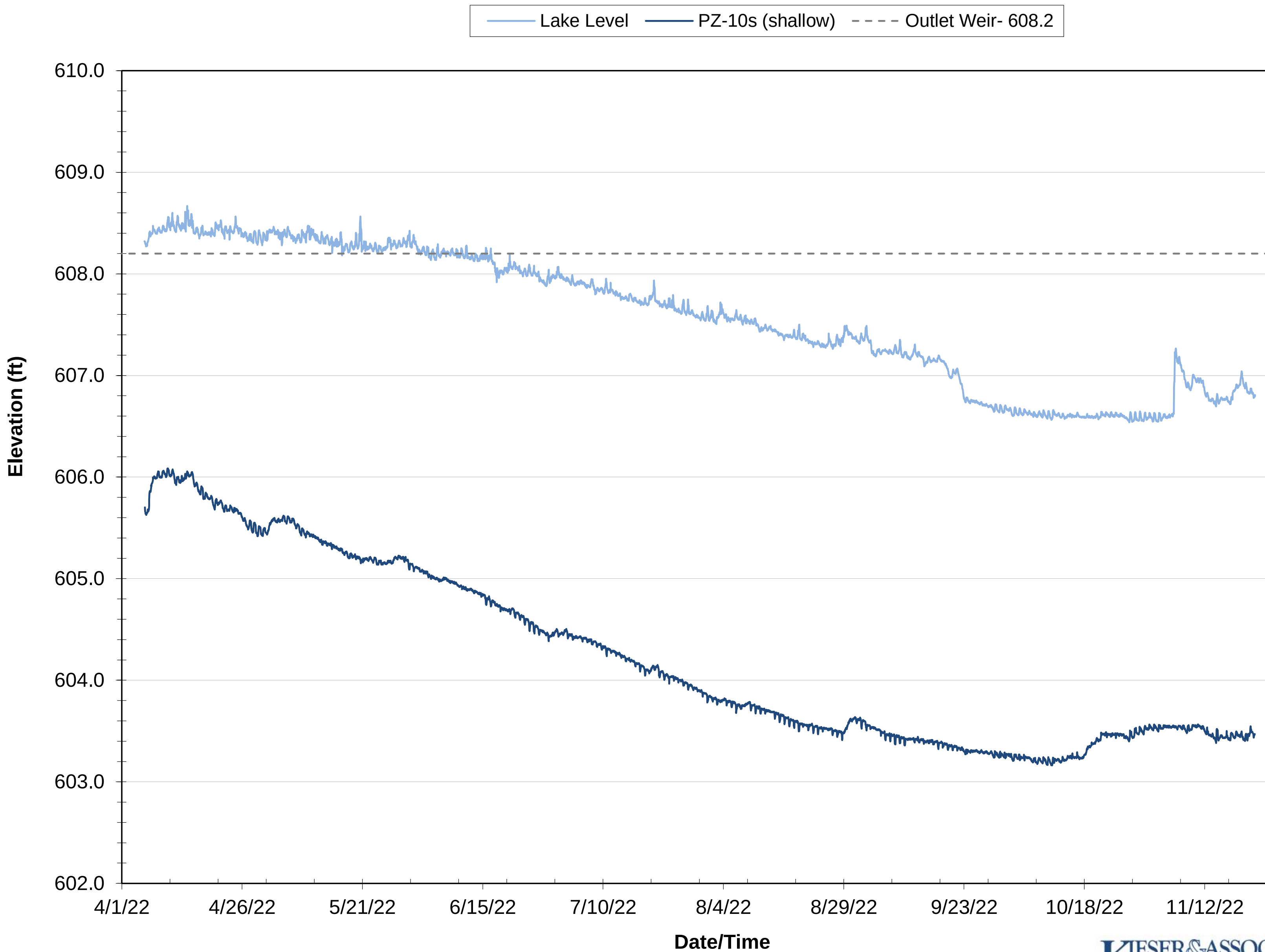

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Figure 15. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 11)

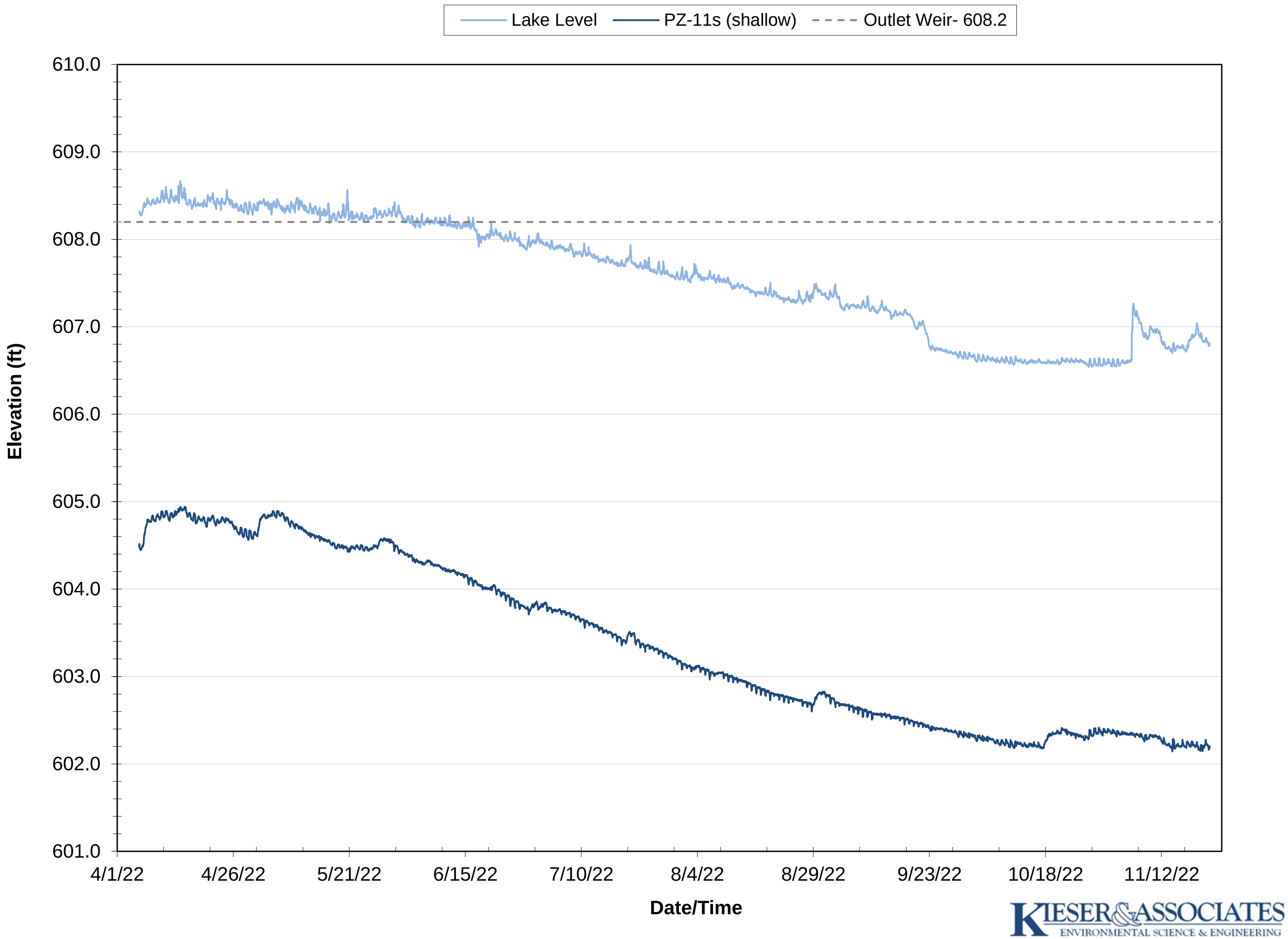

Figure 16. 2022 Cedar Lake Groundwater / Surface Water Elevations (Site 12)

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Figure 17. 2022 Cedar Lake Groundwater / Surface Water Elevations (West Kings)

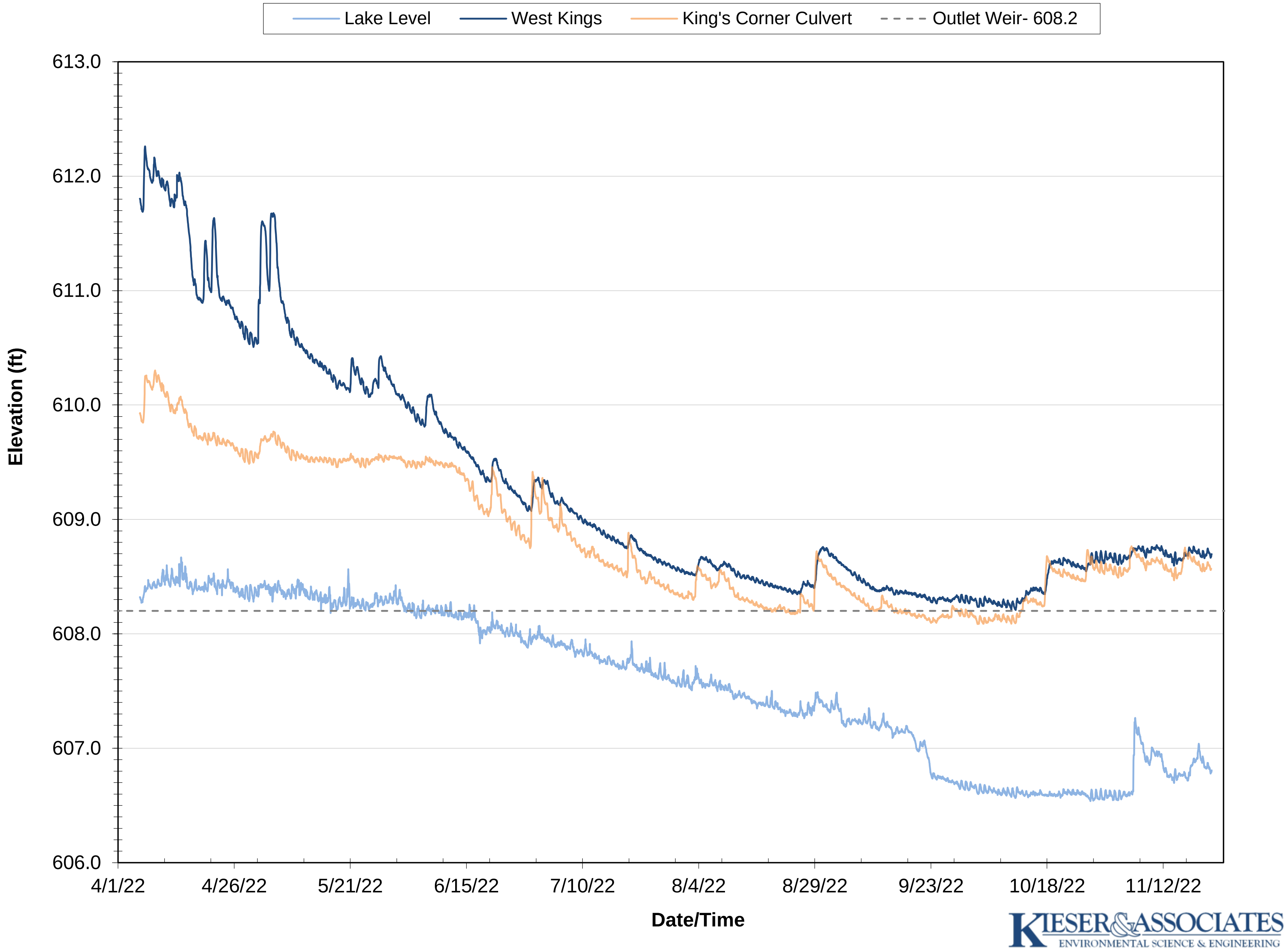

Figure 18. 2022 Cedar Lake Groundwater / Surface Water Elevations (Lakewood Shores Phelan Creek: LWSPC)

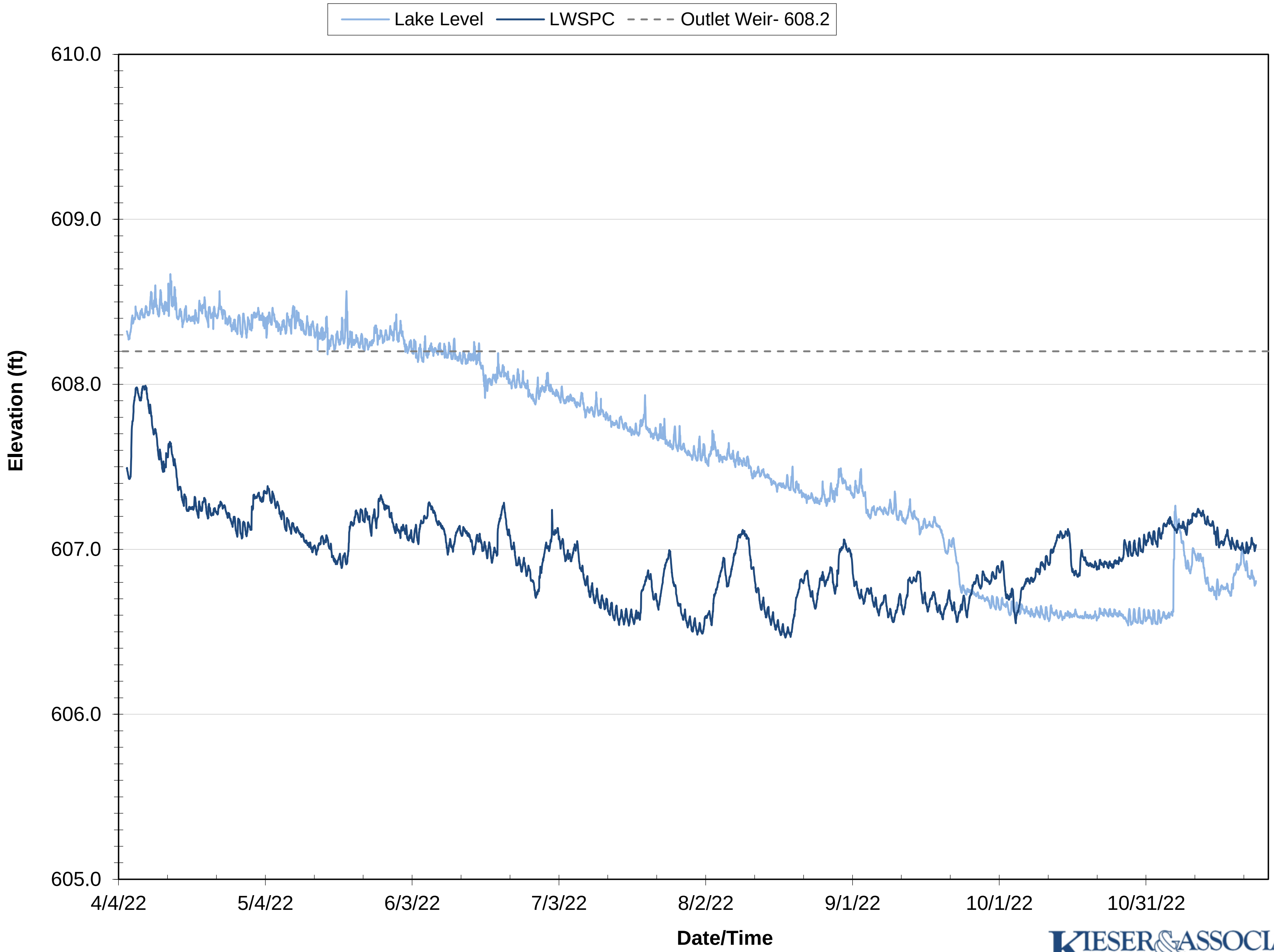

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Figure 19. 2022 Cedar Lake Groundwater / Surface Water Elevations
(King's Corner Area Loggers)

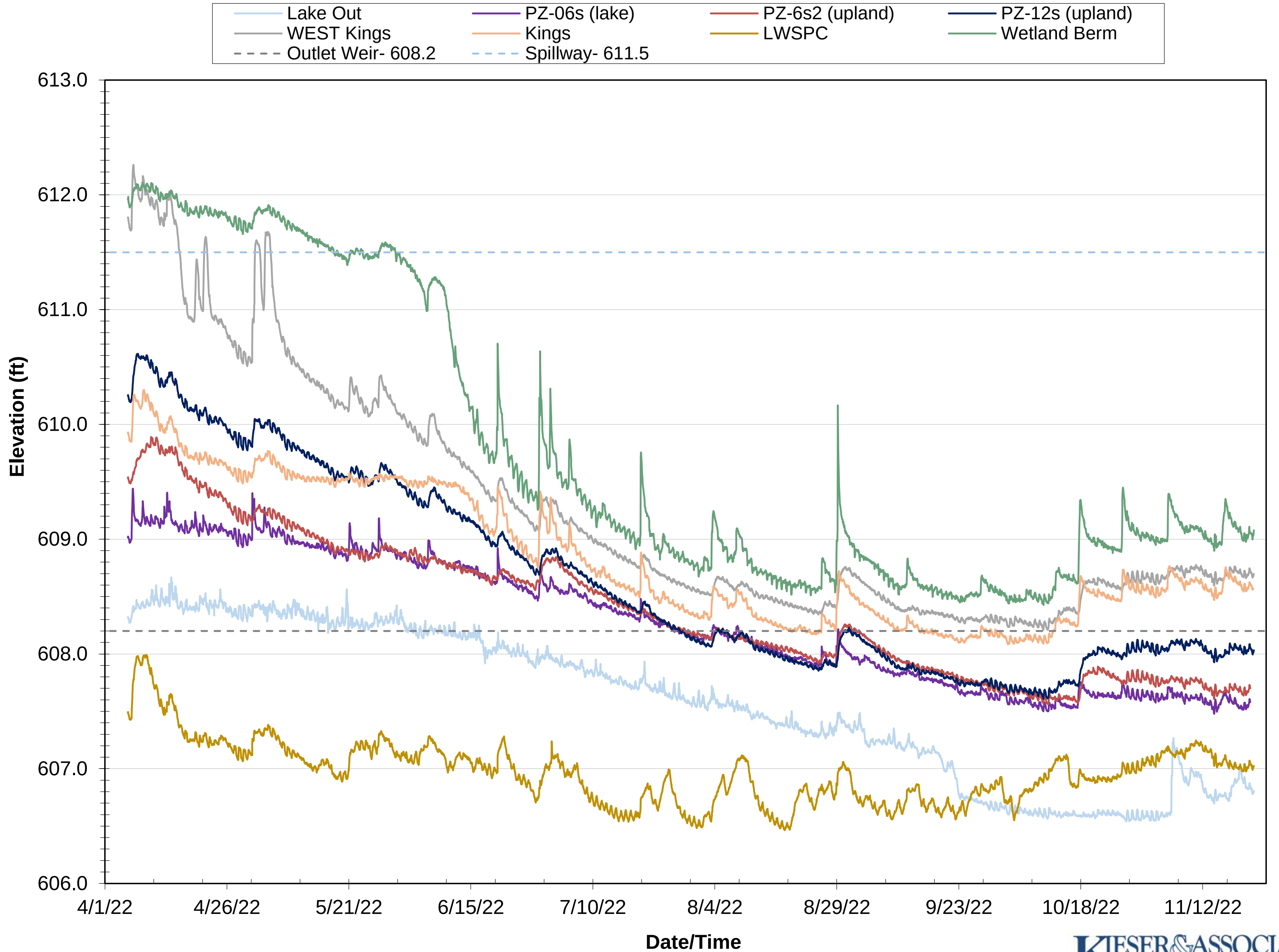

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Figure 20. 2022 Estimated Jones Creek Flows

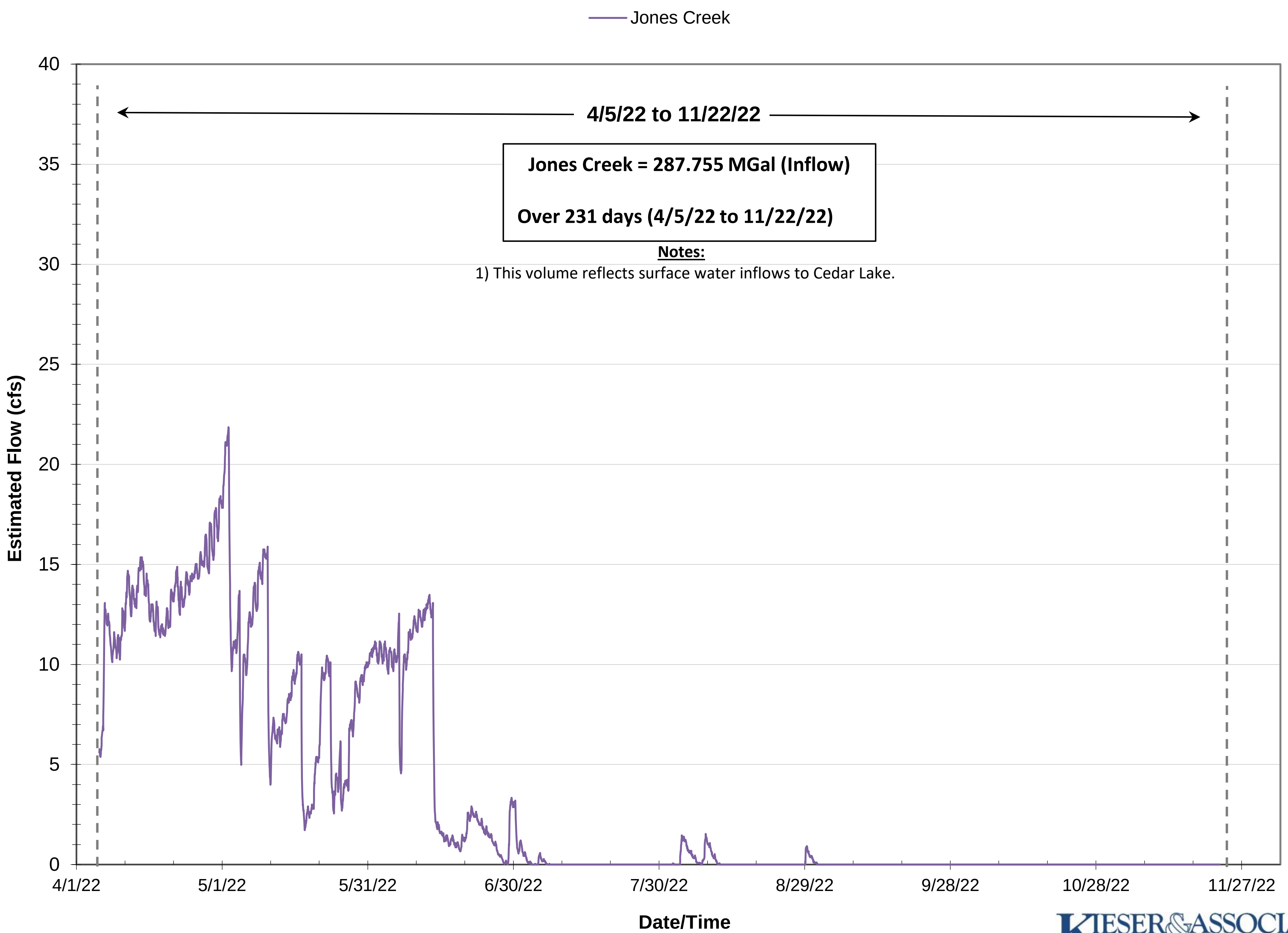

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Figure 21. 2022 Estimated Sherman Creek Flows

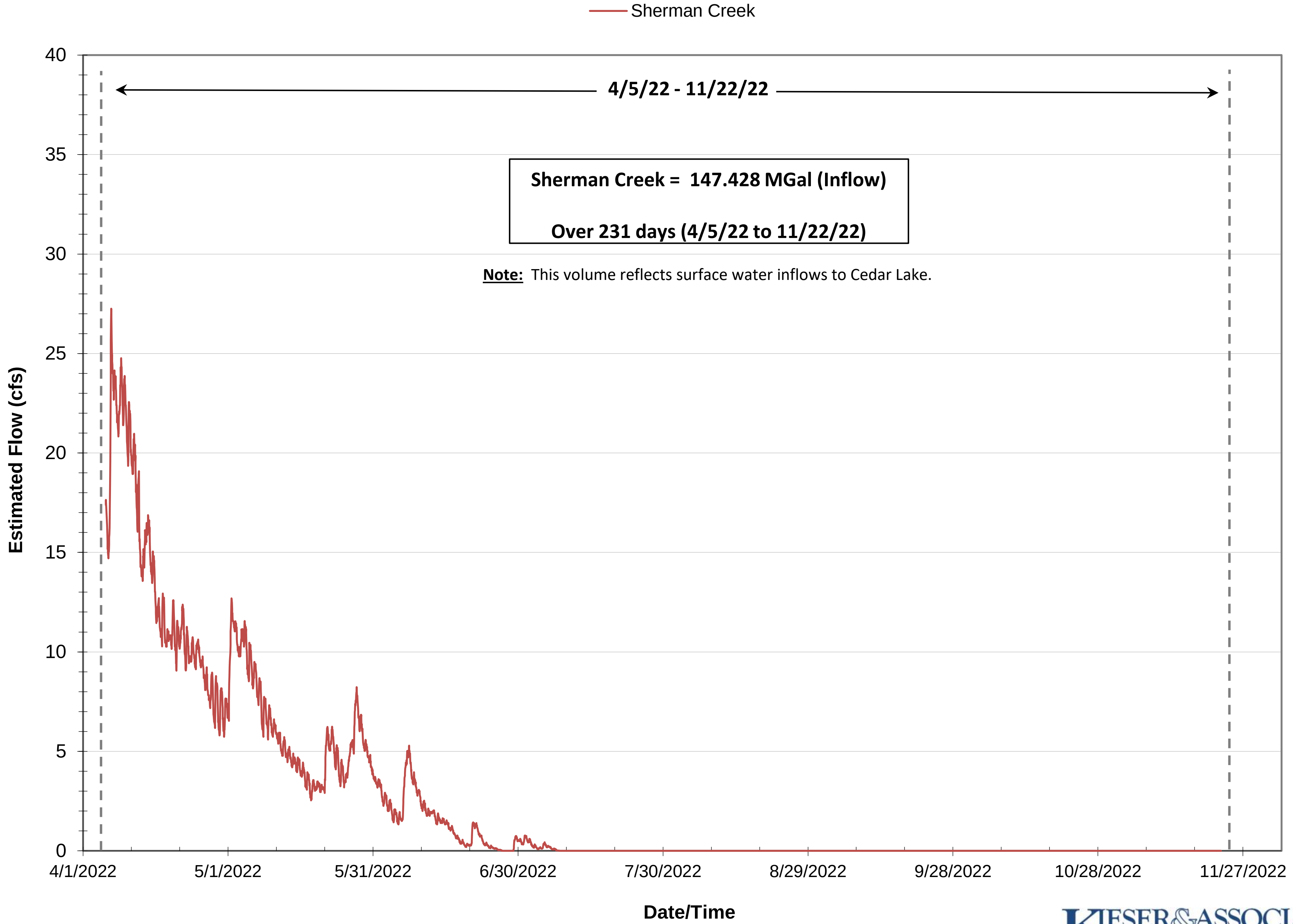

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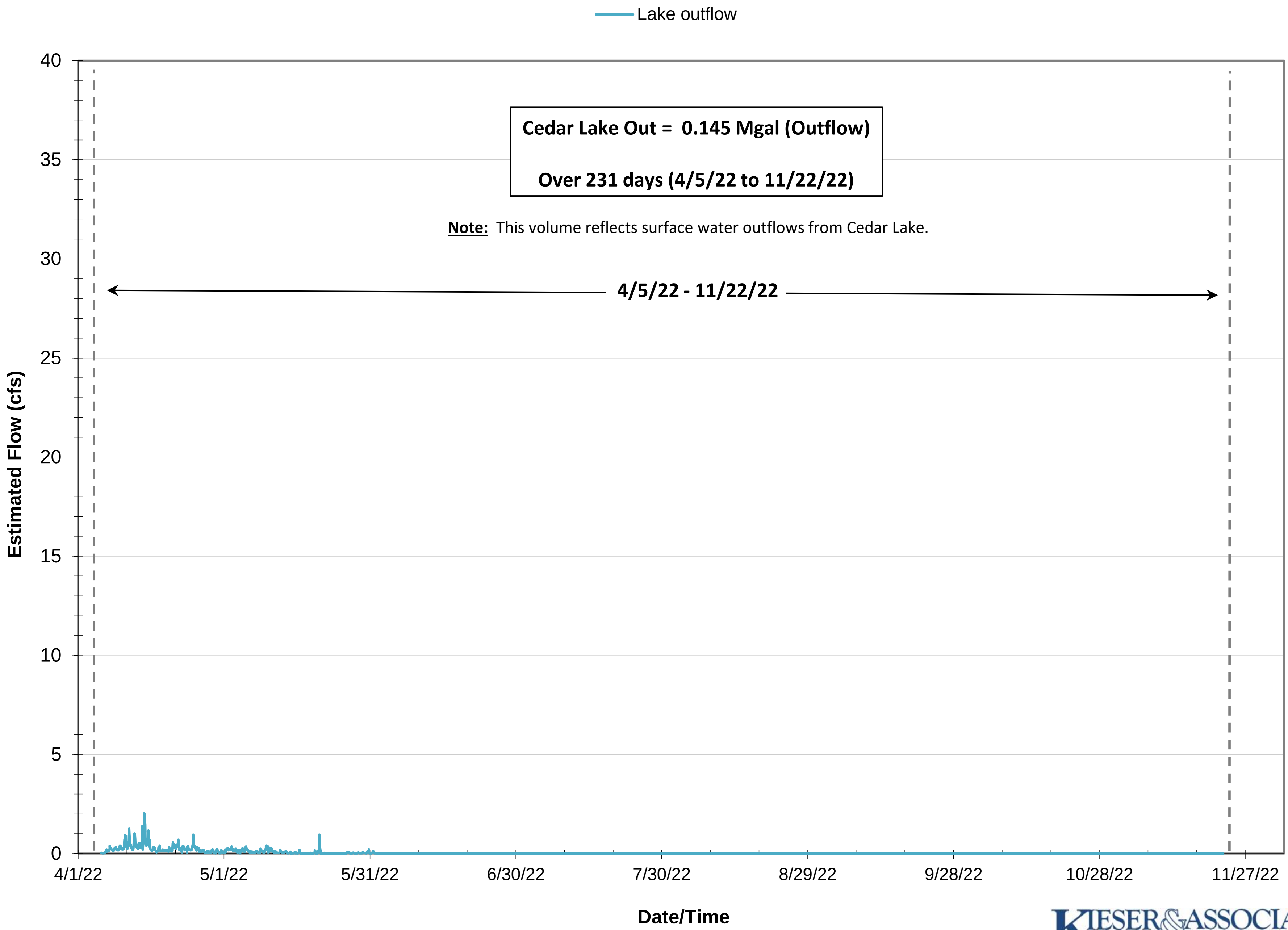
Figure 22. 2022 Estimated Cedar Lake Outflows



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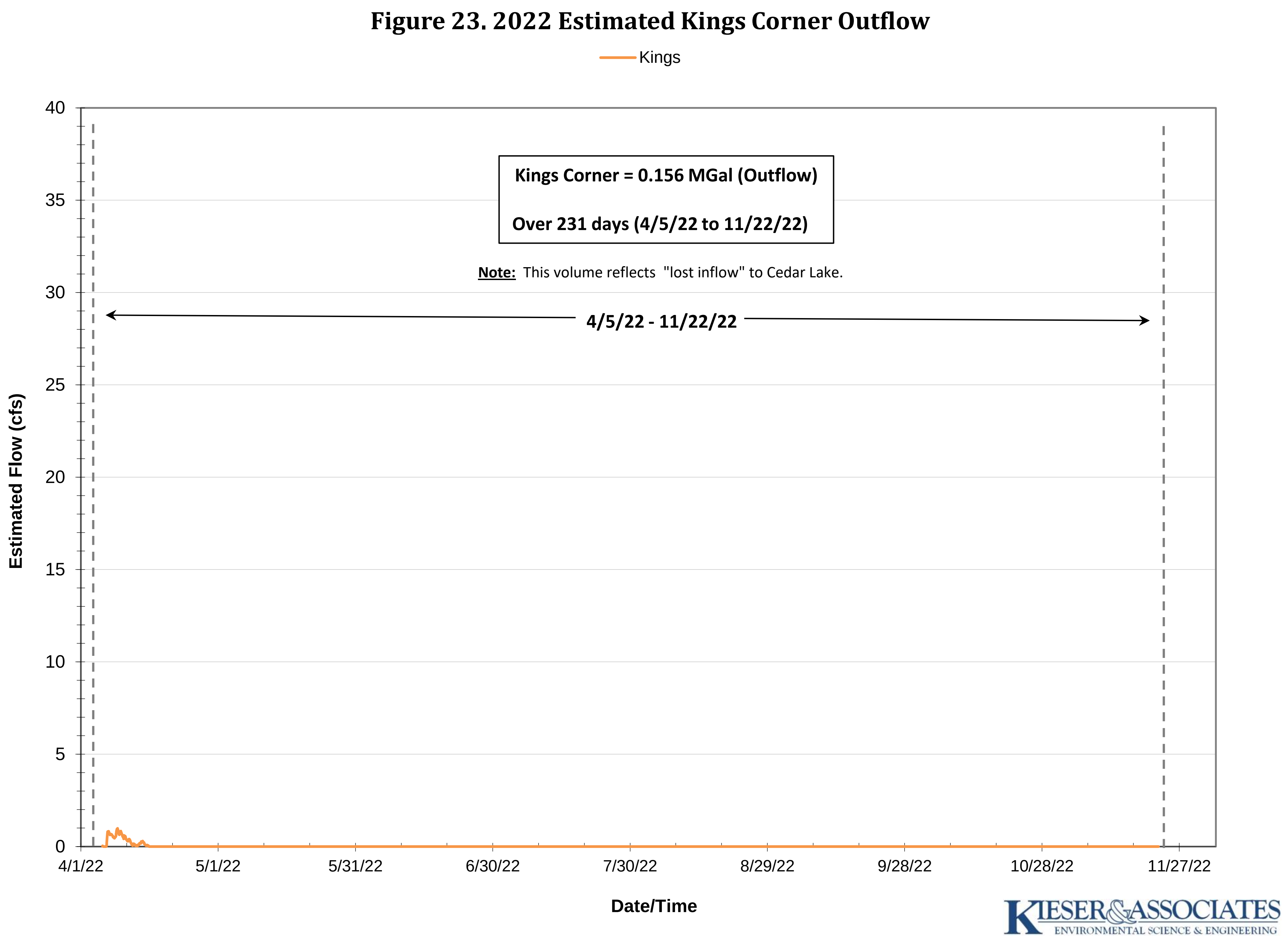
Figure 23. 2022 Estimated Kings Corner Outflow
Kings
Kings Corner = 0.156 MGal (Outflow)
Over 231 days (4/5/22 to 11/22/22)
Note: This volume reflects "lost inflow" to Cedar Lake.
4/5/22 - 11/22/22
Estimated Flow (cfs)
40
35
30
25
20
15
10
5
0
4/1/22
5/1/22
5/31/22
6/30/22
7/30/22
8/29/22
9/28/22
10/28/22
11/27/22
Date/Time
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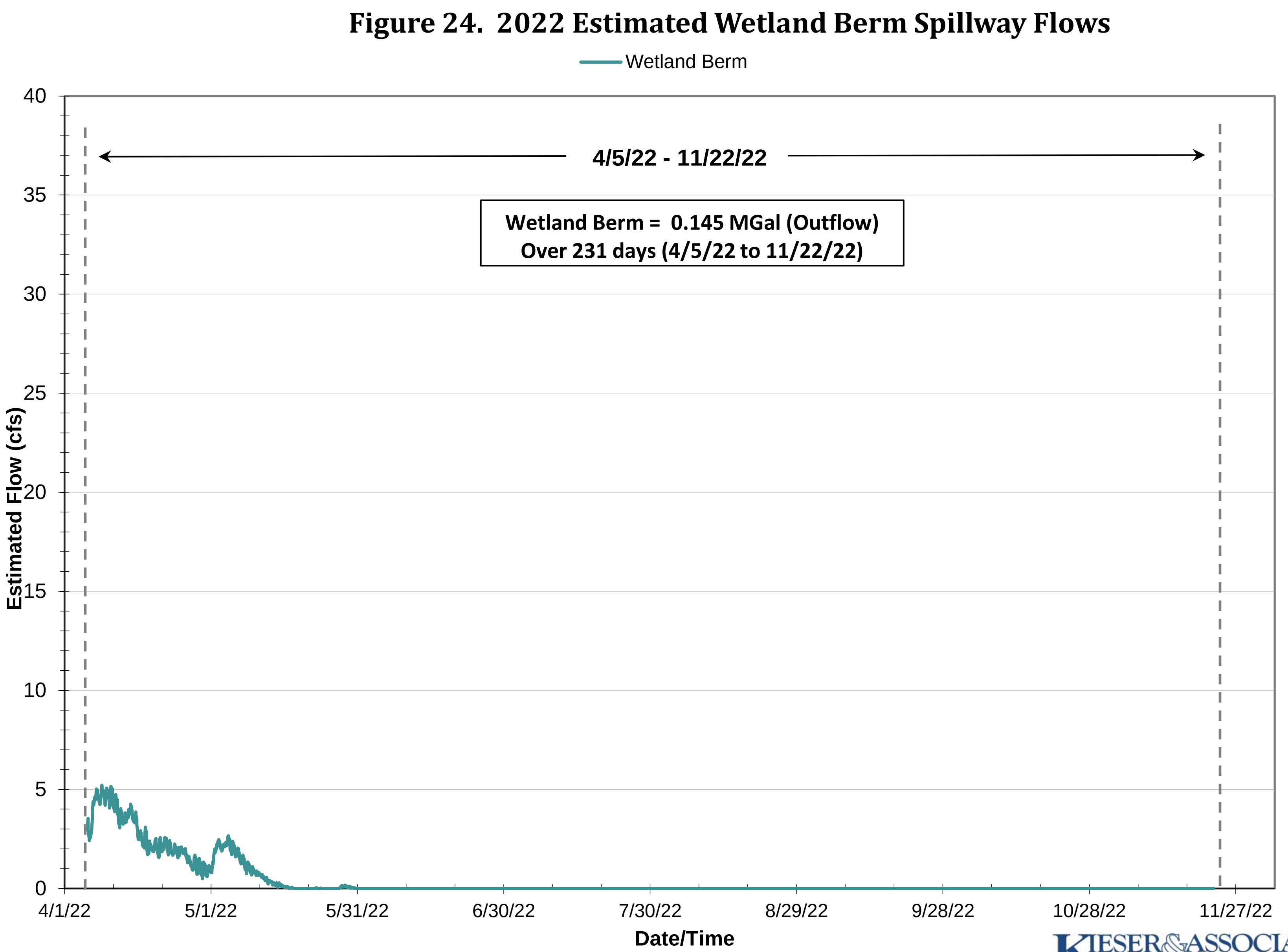
Figure 24. 2022 Estimated Wetland Berm Spillway Flows
Wetland Berm
4/5/22 - 11/22/22
Wetland Berm = 0.145 MGal (Outflow)
Over 231 days (4/5/22 to 11/22/22)
Estimated Flow (cfs)
40
35
30
25
20
15
10
5
0
4/1/22
5/1/22
5/31/22
6/30/22
7/30/22
8/29/22
9/28/22
10/28/22
11/27/22
Date/Time

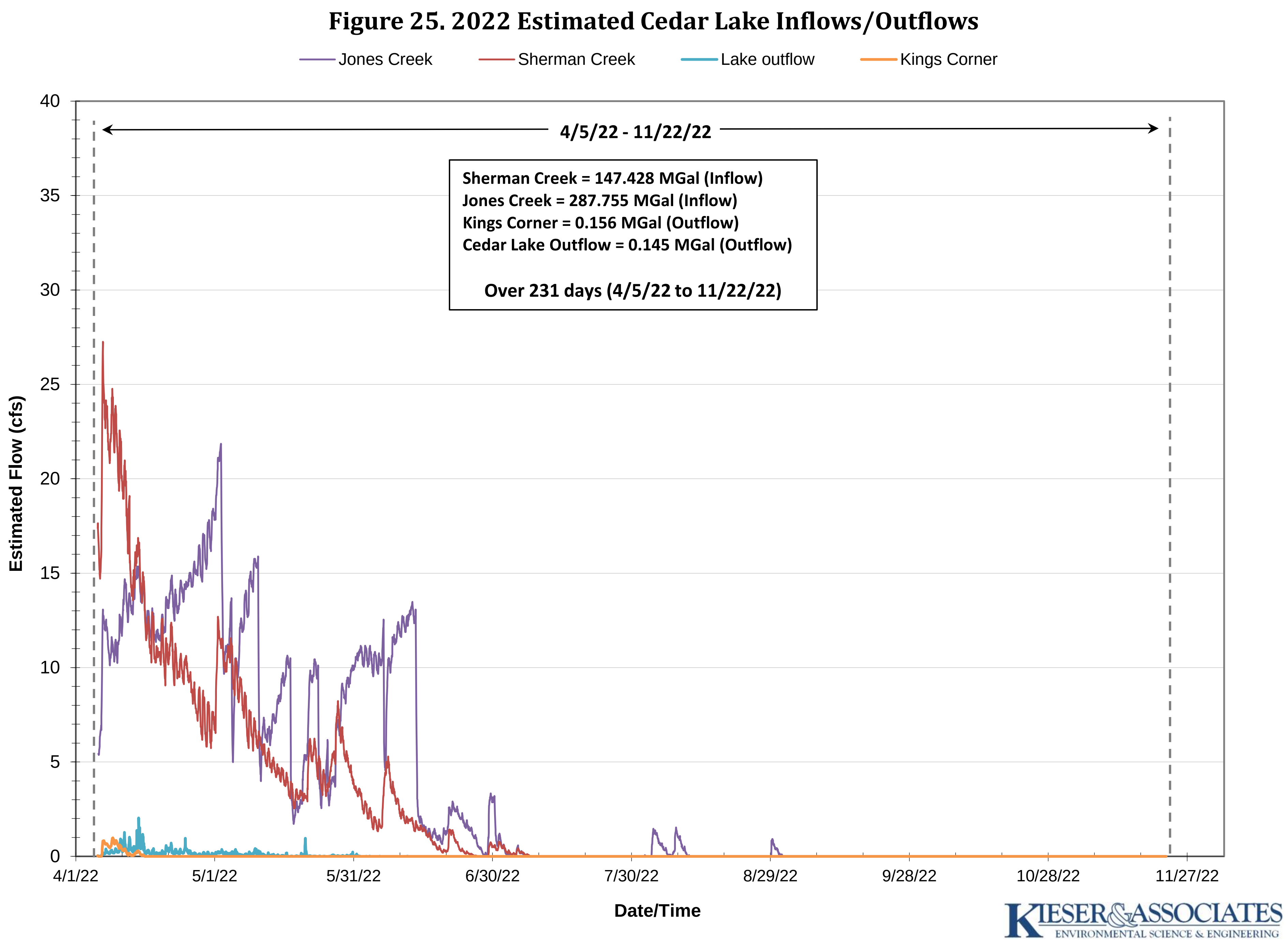
Figure 25. 2022 Estimated Cedar Lake Inflows/Outflows
Jones Creek
Sherman Creek
Lake outflow
Kings Corner
4/5/22 - 11/22/22
Sherman Creek = 147.428 MGal (Inflow)
Jones Creek = 287.755 MGal (Inflow)
Kings Corner = 0.156 MGal (Outflow)
Cedar Lake Outflow = 0.145 MGal (Outflow)
Over 231 days (4/5/22 to 11/22/22)
Estimated Flow (cfs)
0
5
10
15
20
25
30
35
40
4/1/22
5/1/22
5/31/22
6/30/22
7/30/22
8/29/22
9/28/22
10/28/22
11/27/22
Date/Time
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Figure 26. 2022 Cedar Lake Groundwater / Surface Water Elevations (Wetland Berm)

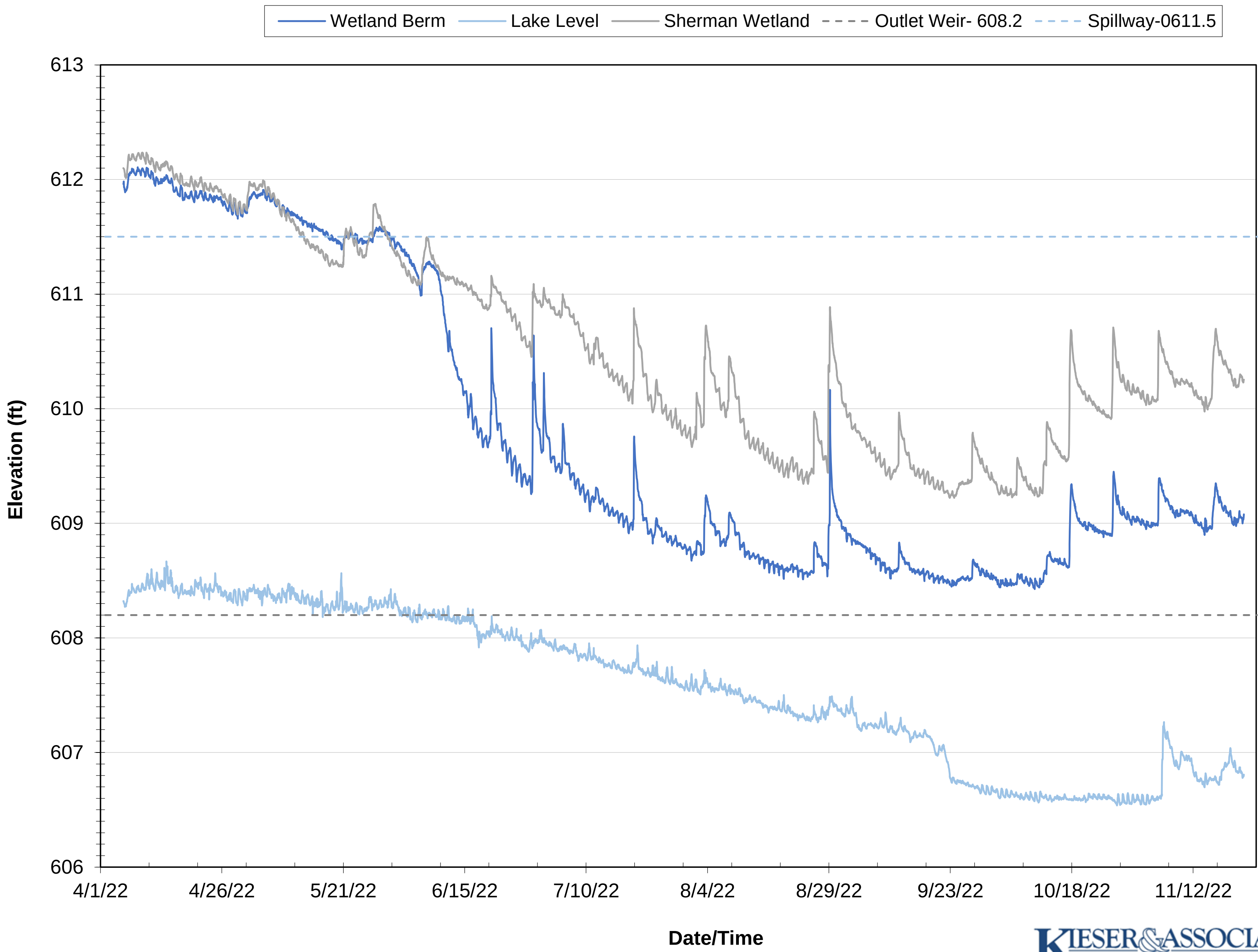

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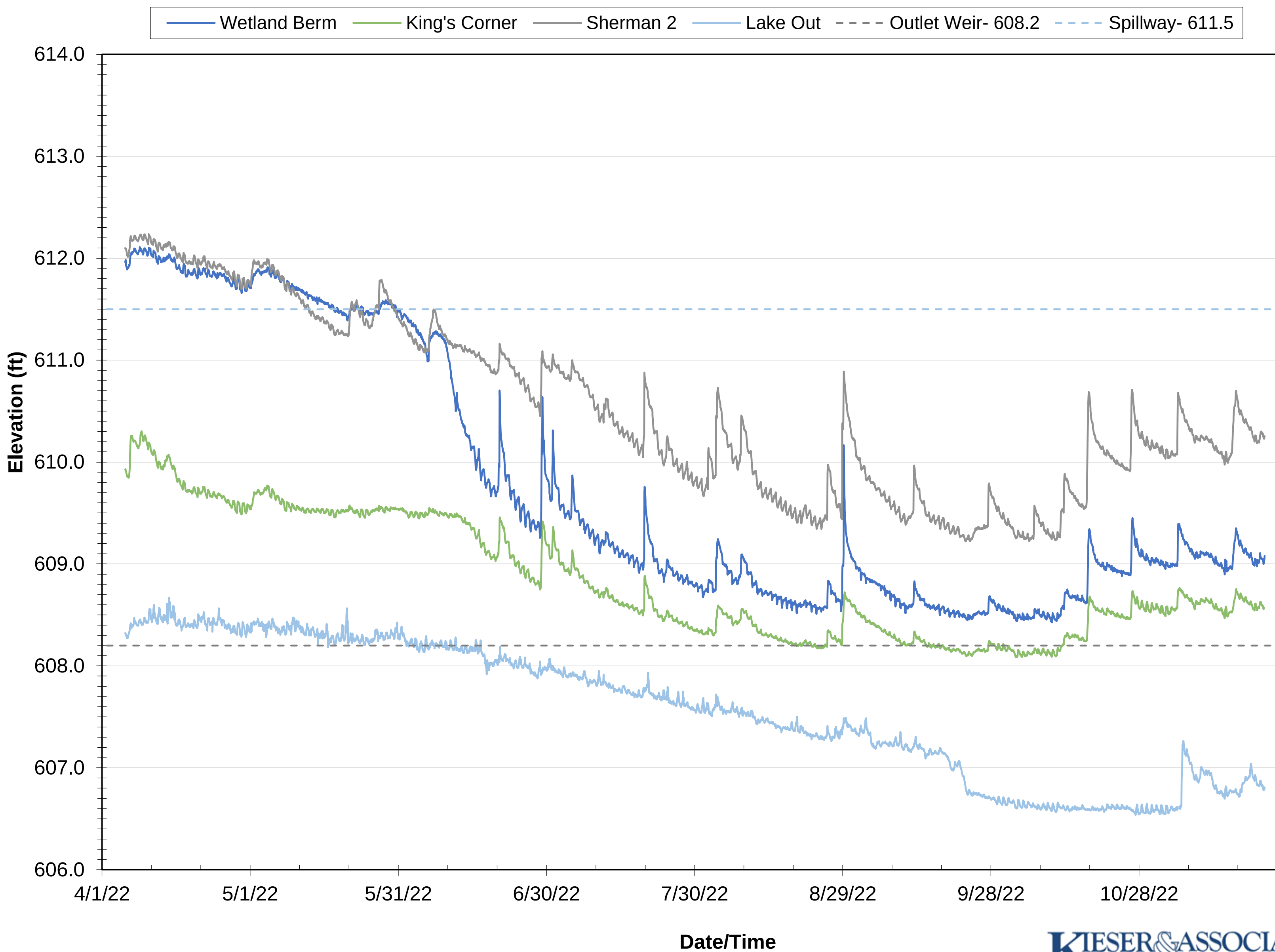
Figure 27. 2022 Cedar Lake Groundwater / Surface Water Elevations (Wetland Berm, King's Corner, and Sherman 2)



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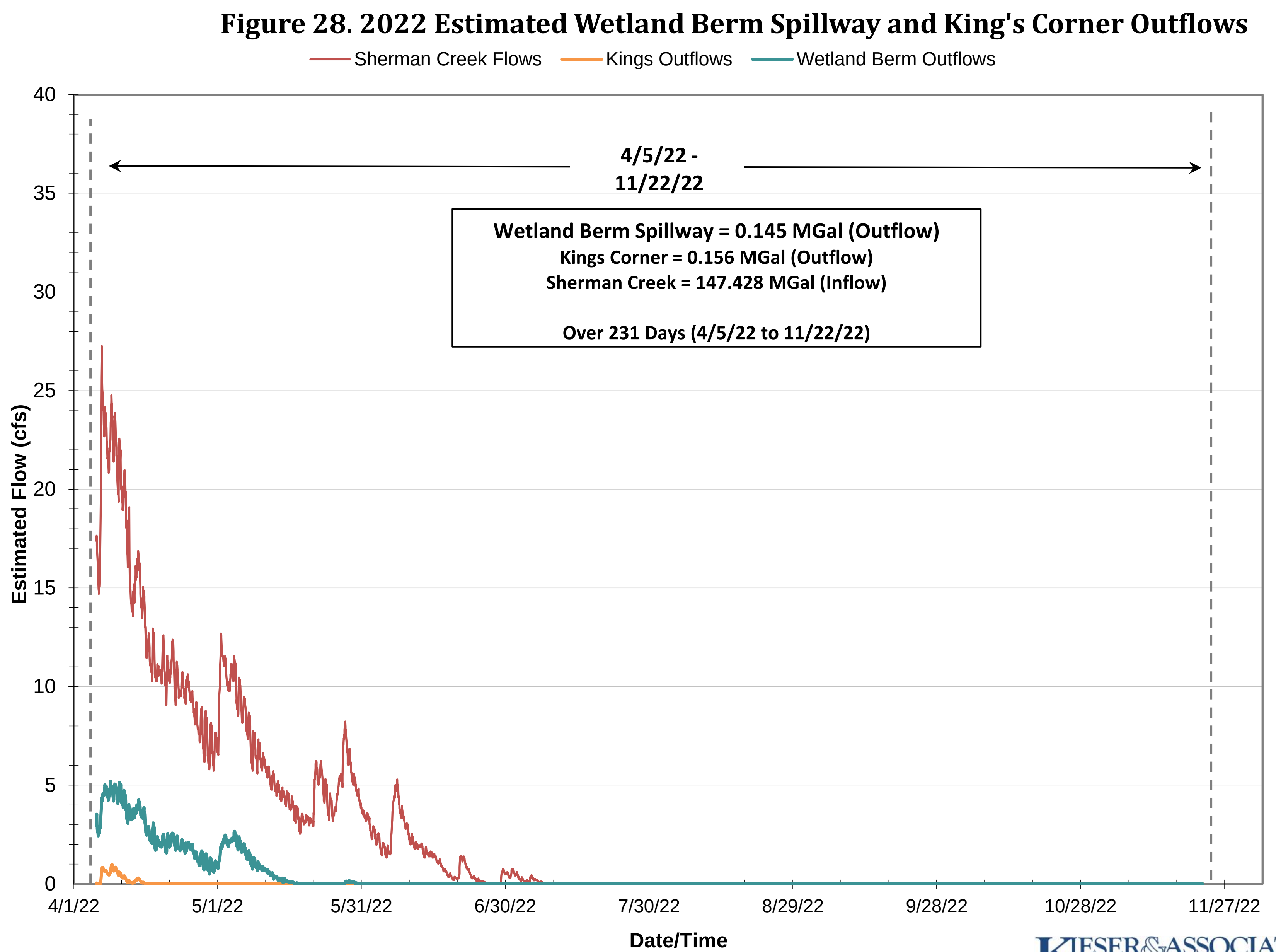

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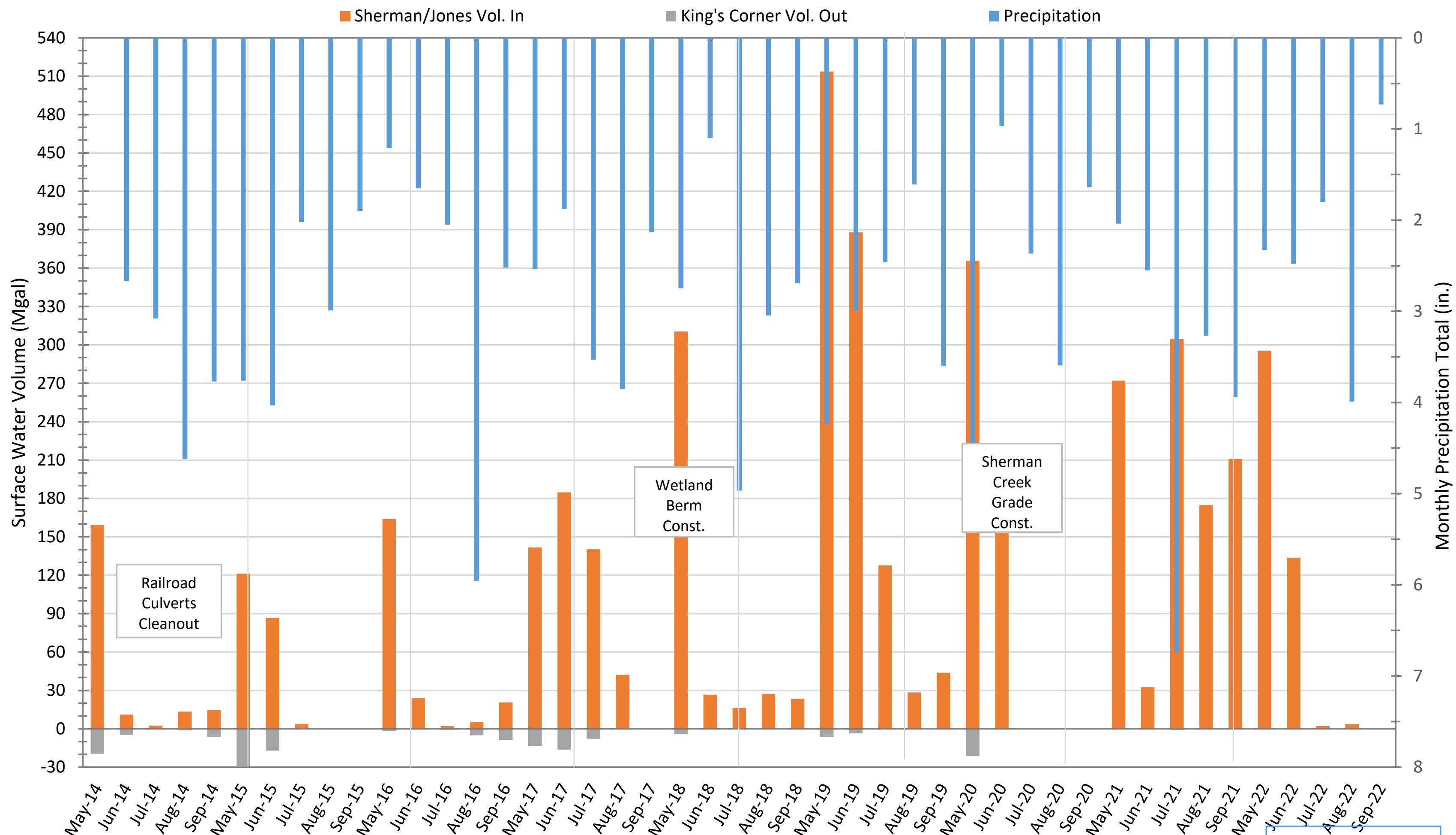
Figure 29. May-Sep, 2014-22: Precipitation, Sherman/Jones Creeks Combined Surface Water Volume into Cedar Lake, and King's Corner Surface Water Volume Away from Cedar Lake



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

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

2016 May-Sep:
Precip: 13.39 in.
Inflow Vol.: 216.1 Mgal
King's Vol. Out: 17.1 Mgal

2017 May-Sep:
Precip: 13.93 in.
Inflow Vol.: 509.2 Mgal
King's Vol. Out: 38.1 Mgal

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

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

2020 May-Sep:
Precip: 13.08 in.
Inflow Vol.: 383.5 Mgal
King's Vol. Out: 21.8 Mgal

2021 May-Sep:
Precip: 18.54 in.
Inflow Vol.: 995.138 Mgal
King's Vol. Out: 0.158 Mgal

2022 May-Sep:
Precip: 11.33 in.
Inflow Vol: *435.18 Mgal*
King's Vol. Out: *0.156 Mgal*