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TECHNICAL MEMORANDUM

To:	Cedar Lake Improvement Board	**Date:**	March 12, 2019
From:	Mark Kieser, K&A Josh Kieser, K&A	**cc:**	Doug Pullman, Aquest

RE: **Findings for 2018 Cedar Lake Groundwater/Surface Water Level Monitoring**

This memorandum presents 2018 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 2018 on behalf of the Lake Board. The purpose of the long-term monitoring program is to best understand critical needs and relevant influences on water levels in Cedar Lake. These are becoming particularly important as lake level management activities are now under way.

Desirable summer month water levels in Cedar Lake are a function of both rainfall and management strategies designed to support water level maintenance in dry summer months. These management strategies, as defined in the approved Cedar Lake Watershed Management Plan (WMP), relate to ongoing efforts to bolster water retention in the northwest cedar swamp throughout the year. Water control management efforts to date have included railroad culvert cleanouts in 2014 and the construction of a wetland enhancement berm in 2017 to retain water levels in the cedar swamp. The latter effort serves to reduce out-of-watershed losses through King's Corner Culvert.

Other potential future management strategies per the WMP include improving Sherman Creek and Jones Creek water retention using instream grade structure controls, and utilizing deep groundwater withdrawal augmentation wells. Use of augmentation wells may not prove viable in the near-term given recently discovered groundwater contamination in the area related to the common fire-retardant chemical known as PFAS. In 2018, the Cedar Lake Improvement Board (CLIB) otherwise began the design and permitting process toward implementing instream grade structure controls within Sherman Creek. Water level data being collected for Cedar Lake are vital to assessing, understanding, and cost-effectively pursuing appropriate water level control options in a phased manner.

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

Program Background

A volunteer water level monitoring program was initially developed at select groundwater and surface water monitoring sites around Cedar Lake in 2004. Since then, water level monitoring efforts have expanded to include additional critical areas using automated water level logger equipment in lieu of intermittent volunteer measurements. The 2018 water level monitoring program included 23 level loggers located around the lake, as shown on the map in Figure 1. Consistent with previous years, a combination of surface water stations along with shallow and deep groundwater stations were monitored to document surface/groundwater interactions and their influence on Cedar Lake water levels. Sherman Creek, Jones Creek, and the King's Corner road culvert were likewise included in the 2018 monitoring program to assist with calculating estimates of surface water flows into Cedar Lake. Also included were flows through the new wetland berm just upstream of the King's Corner culvert.

K&A has also included, herein, several updates to previously reported data with updated graphs compiled in Appendix A. These principally relate to 2016 hydrology whereby lake levels were highly influenced by the presence of a beaver dam at the north end of the lake that severely restricted outflows. This restriction contributed to substantial shoreline damage due to high winter water levels and harsh winter ice-cover conditions.

In late April of 2018, K&A reinstalled the Jones Creek monitoring station that was previously removed in September 2017 in anticipation of a culvert replacement as part of the Alcona County Road Commission project along West Cedar Lake Road. K&A staff also recalculated flow equations for Jones Creek surface flows in 2018 based on the invert elevation and as-built dimensions provided by the Road Commission, of the newly installed 48-inch culvert. The surface flow equations will continue to be refined with manual measurements in future monitoring seasons.

K&A additionally installed a new water level monitoring station in April 2018 at the wetland berm north of the King's Corner culvert to measure surface and groundwater elevations at the berm spillway. The wetland berm was constructed in fall of 2017 as part of the ongoing efforts to retain water levels in the cedar swamp. The wetland berm was designed with a stone-laden spillway meant to overflow at an elevation of 611.0 feet so as not to permanently alter historic high-water levels. Initial construction of the wetland berm placed the spillway approximately 0.86 feet higher than designed. Heavy spring rains and snowmelt therefore caused a breach at the berm's east end, causing minor erosion. The berm spillway was reconstructed in July 2018 to better match the engineering specifications, and resurveyed in November 2018 to ensure that adequate corrections had been made. The new wetland berm monitoring station will help to provide important information regarding water retention improvements in the northwest cedar swamp. K&A converted the 2018 water elevation measurements to estimated surface water flows based on the final as-built elevations of the corrected wetland berm spillway.

One level logger, PZ-10s, was not installed in 2018 due to a technical malfunction of the ten-year old logger which the manufacturer was unable to correct. The logger manufacturer suggests ten years to be the predicted lifespan of the level loggers. Additionally, evaluation of precipitation data, collected using a more than ten-year old rain gauge at Cedar Lake and submitted by Rex

Vaughn, showed significant errors compared to nearby weather stations and past rainfall records. This report therefore relies on average rainfall data for 2018 triangulated from three nearby weather stations. These data issues highlight the need to replace aging level logger and rain gauge equipment as well as the importance of phasing out other equipment currently in danger of "aging out". Table 1 illustrates the age and predicted lifespan of the Cedar Lake level loggers.

2018 Precipitation and Water Level Data

Precipitation Comparison

Historic summer precipitation totals for the Cedar Lake area are presented in Figure 2. These data represent triangulated average 2018 precipitation data available from: Harrisville 2 NNE (USC00203628), East Tawas (USC00202423), and Glennie 2 SE (USC00203188), as well as historic rain gauge data from a Cedar Lake rain gauge monitored by volunteers. Available rainfall data from 1998 to 2018 (minus 2006 when there were no local functioning rain gauges) reflect a 20-year summer average (June-September) of 12.09 inches of rainfall. The observed 2018 data are just below-average for rainfall, totaling 11.81 inches during these summer months.

Notably, April 2018 experienced above-average rainfall of 4.12 inches, as well as approximately 17 inches of snowfall. This late-spring snowfall delayed the installation of the groundwater level loggers until the end of April 2018. October 2018 also experienced above-average rainfall of 5.67 inches. The previous summer of 2017 similarly exhibited just below-average summer precipitation amounting to 11.39 inches with above-average precipitation (6.57 in) occurring in April 2017. Rainfall in 2016 was average, while 2015 was below-average and 2014 was above-average. Summer precipitation in the years 2012-2013 was recorded below-average while in 2008-2011, summer precipitation was above-average.

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

Cedar Lake Water Levels

The 2018 Cedar Lake water levels were plotted with April-November recorded rainfall to illustrate lake level response to precipitation (Figure 3). As illustrated in Figure 3, the local precipitation has a direct impact on Cedar Lake water levels with observed responses corresponding to local rain events. The 2018 level logger data collected near the Cedar Lake outflow structures fluctuated within a maximum of 11 inches above and 6 inches below the northern lake outflow structure elevations.

Cedar Lake remained above the legal lake level with outflow conditions occurring from the beginning of the monitoring season to early July. Consistent with the target rainfall threshold data plotted on Figure 2 (i.e., 11 inches per summer season), Figure 3 shows that in 2018 Cedar Lake water levels steadily declined from April to July, after heavy spring rains and snowmelt. Lake levels dropped to within 0.3 feet below the legal lake level from July to mid-September. This drop corresponded with low precipitation levels of 1.1 inches in June. While Cedar Lake levels rose and fell in response to several significant rainfall events during the summer months of 2018, lake levels remained just-below the legal lake level from mid-July to mid-October. The most notable drop, within 0.5 feet below the legal lake level, occurred from mid-September to mid-October. Lake levels returned to the legal lake level in response to heavy rainfall in October and remained above the legal lake level through the end of the monitoring period.

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

In previous years, particularly 2016, a beaver dam has inhibited lake outflow volumes and also affected lake levels. The presence of the beaver dam upstream of the Cedar Lake outlet structures during the 2016 monitoring season, for example, significantly affected lake levels. Water levels downstream of the beaver dam at the lake outlet were significantly lower than in-lake levels upstream of the beaver dam. Appendix A of this report re-illustrates 2016 water elevations at the Cedar Lake outlet that have been re-plotted with updated lake outlet flows and volumes to more accurately reflect the effect of the beaver dam. Original graphics from 2016 showed lake level elevations behind the dam, not necessarily reflecting the actual volume of water leaving the lake. The dam was mechanically removed in October 2017 and therefore did not affect lake levels in 2018. Evidence of renewed beaver activity, however, was noted in late fall of 2018, occurring atop the outflow structures. This could impact 2019 lake levels if left unaddressed.

Groundwater Levels and Gradients

The 2018 groundwater level data from the nearshore groundwater monitoring Sites 1-7 are graphically illustrated along with Cedar Lake water levels in Figures 4-10. Sites 1, 3, 4, 5 and 6 (Figures 4, 6, 7, 8, and 9, respectively) are in areas where shallow groundwater is typically moving away from Cedar Lake, as reflected in the 2018 piezometer water levels that were generally below the lake water level. To further confirm this assertion, K&A conducted an additional evaluation of monthly average groundwater gradients for the 2016-18 monitoring seasons at Sites 3, 5, and 6. Figures 14.1-14.9 illustrate this analysis and affirm that shallow groundwater is typically moving away from the lake. A few exceptions, however, occurred at Site 6 (west side of Cedar Lake), when shallow groundwater flowed toward the lake during periods with heavy rainfall.

Figures 14.1-14.9 utilize historic data from Sites 3 and 6. These data sets were cross-checked for accuracy and noted in 2018 to have been plotted incorrectly in previous reports. Appendix A therefore contains updated, notated groundwater elevations graphs for Sites 3 and 6.

Sites 2 and 7 (Figures 5 and 10, respectively) are located in areas where shallow groundwater is consistently moving toward the lake, with piezometer groundwater levels near or above those measured in the lake. Site 2, located nearest the wetland complex northwest of the lake, signifies why this area is an important groundwater source to the lake and further emphasizes the importance of wetland protection in this critical area. Sites 8, 9, and 11 (Figures 11, 12, and 13, respectively) document conditions beyond the lake, toward the southeast, within an area of Lakewood Shores that is well-drained. Water level data for these sites continue to confirm shallow groundwater loss towards Lake Huron with increasing distance from the lake.

2018 Estimated Surface Flows

Introduction to Surface Flows

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

A major water retention effort to reduce water losses through the King's Corner culvert began in fall 2017 with the construction of a wetland enhancement berm on the newly acquired Lake Board property, parallel to King's Corner Road. The berm is designed to retain water in the cedar swamp which contributes inflows to Cedar Lake via Sherman Creek. Construction of the berm began on August 28 and was completed by October 20, 2017. A groundwater monitoring station was installed at the upstream side of the berm spillway in April 2018 to measure the efficacy of the berm at retaining water in the cedar swamp and decreasing water losses through King's Corner culvert. These data are discussed further in this section.

The two Cedar Lake outflow structures at the north end of the lake discharge to Lake Huron once water levels exceed the legal lake level. Figures 15, 16, 17, and 18 illustrate calculated surface water inflows and outflows including estimated volumes associated with the 2018 monitoring season at the Jones Creek, Sherman Creek, Cedar Lake Out, and King's Corner stations, respectively. All flow monitoring data are derived from water level stage-discharge relationships specific to each location. Table 2 presents estimated inflow or outflow volumes for each station from 2014-2018 for comparison. Estimated flow data and volumes for the 2018 monitoring season from these critical locations were combined and plotted together in Figure 19. Surface water volume data originally reported in 2016 and 2017 were also reevaluated in 2018 and these updates are reflected in Table 2.

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 throughout the summer recreational months. During the 153-day period from May 1 to September 30, 2018, the Jones Creek and Sherman Creek monitoring data reveal inflows of 10.1 and 328.1 million gallons (Mgal), respectively into Cedar Lake (refer to Figure 19). The 2018 inflow volumes were less in both Sherman Creek and Jones Creek than in 2017 (an above average precipitation year), but higher overall than inflows during the same months for each year 2014-2016 (refer to Table 2). Figures 15 and 16 illustrate Jones Creek and Sherman Creek flows throughout this monitoring period.

Measured outflow volumes leaving Cedar Lake at the north outlet structures totaled approximately 52.0 Mgal during this same time period. Discernable 2018 lake outflows occurred in spring and late-fall as shown in Figure 17. The 2018 outflow volumes were greater than 2016 and 2017 outflow volumes which were affected by the presence of a beaver dam prior to fall of 2017. Overall, the 2018 outflow volumes were greater than 2014 outflows but lower than 2015 outflow volumes (refer to Table 2).

Figure 18 summarizes observed flows associated with the King's Corner culvert location for the entire 2018 monitoring season. The plotted flows from the 2018 monitoring period reflect a total discharge volume of 10.1 Mgal over 200 days. During the shorter May 1 to September 30, 2018 recreational season, an estimated 4.4 Mgal flowed out of the Cedar Lake watershed via the King's Corner road culvert. Surface water outflows at King's Corner in 2018 measured approximately 34 Mgal less than in 2017 and significantly less than outflow volumes during the same months in each year 2014-2016 (refer to Table 2). The maximum observed high water elevation at the King's Corner culvert in 2018 was 610.65. Since 2009, this location has had an average high-water elevation of 611.13 and a maximum observed elevation of 612.86. The lower elevations here, despite generally average precipitation in 2018, are attributable to the wetland berm as was intended by design.

Surface Water Retention Design Implications

Comparing historic volume losses from King's Corner culvert demonstrates how the wetland enhancement berm constructed on the Lake Board property is mitigating water losses from this historic diversion out of the basin. The wetland berm monitoring station installed on April 30, 2018, now provides important information regarding water retention improvements in the northwest cedar swamp. Water elevations and flows through the new 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. These should also continue to improve lake inflow volumes through Sherman Creek and increase localized groundwater contributions with the next implementation phase of instream grade structures within Sherman Creek.

Figure 20 illustrates the 2018 water elevations at the wetland berm monitoring station positioned at the upstream side of the berm spillway compared to lake levels. Figure 21 compares water elevations at the wetland berm spillway, the King's Corner culvert, and the "Sherman Creek 2" monitoring station, located in the cedar swamp upstream of the Sherman Creek culvert. Figure 22 compares surface water flows and volumes for the 2018 monitoring season at the wetland berm spillway to outflows at King's Corner Culvert and inflows to Cedar Lake via Sherman Creek. From May 1 through the end of September 2018, approximately 20.2 Mgal of surface water flowed through the wetland berm spillway while only 4.4 Mgal was lost via King's Corner culvert as graphically depicted in Figure 22, all largely in the Spring under high groundwater conditions. Approximately 20% of the water leaving the wetland berm left through the culvert; for the remainder, it is assumed this water infiltrated to shallow groundwater or, under high flows, out of a second King's Corner Road culvert to the west. Figure 22 also illustrates how substantial berm flows in October and November (almost 110 Mgal) where largely retained in the groundwater where only 10% of these flows exited through King's Corner culvert. This would be expected, as illustrated in Figure 21, due to the depressed groundwater table at this time of year and its ability to store these additional volumes.

Notably, the 2011 Cedar Lake Augmentation Feasibility Study suggested that the volume required to offset a 1-month lake level drop of 3-inches in Cedar Lake equates to approximately 91 Mgal per month (of inflow and direct rainfall), totaling 364 Mgal over the four-month summer season. The study assesses potential water control implementation options and their feasibility related to multiple indicators including cost, total available volume, and other restrictions. The 2018 level logger data suggest that, in the spring-summer months May-September since 2014, volumes contributed to Cedar Lake via Sherman and Jones Creek have increased significantly (refer to Figure 23). Inflow volumes during these months from 2014-2016 averaged 209.1 Mgal, while inflow volumes in 2018 were estimated at 338.3 Mgal, a comparative increase of 128.5 Mgal into Cedar Lake. Meanwhile, surface water volume losses through King's Corner culvert have significantly lessened, from an average May to September loss of 33.5 Mgal from 2014-2017 to an estimated 4.4 Mgal during 2018.

Comparing these findings to the aforementioned 364 Mgal 4-month season total calculated in 2011 to offset lake level drops in dry years shows that the improvements to wetland connectivity and water retention may offset any immediate need to pursue other, potentially costlier management options such as augmentation wells. Figure 23 illustrates this analysis by comparing 2014-2018 May 1 to September 30 monthly rainfall totals with monthly combined total volumes contributed to Cedar Lake via Sherman and Jones Creeks and volumes lost from the Cedar Lake watershed via King's Corner culvert.

Conclusions and Recommendations

Data from 2018 lake level monitoring study continue to demonstrate how Cedar Lake first and foremost responds quite directly to prevailing summer month rainfall amounts. Lake levels for 2018 appear to have been within the WMP desired levels; this largely being a function of rainfall only slightly below the observed historic average for June through September, but also water flow and retention improvements in the northwest cedar swamp. Lake outflow data and lake levels still suggest that 2018 lake levels were adequate for targeted summer conditions.

The 2018 data also demonstrate an overall decrease in the volume of water lost through the King's Corner culvert, in spite of comparable precipitation in past years. The wetland berm was completed and active during the 2018 monitoring period and likely accounts for the decreased losses from King's Corner. Comparisons of 2017 and 2018 precipitation and outflow losses demonstrate these improvements in wetland water retention as a result of the berm.

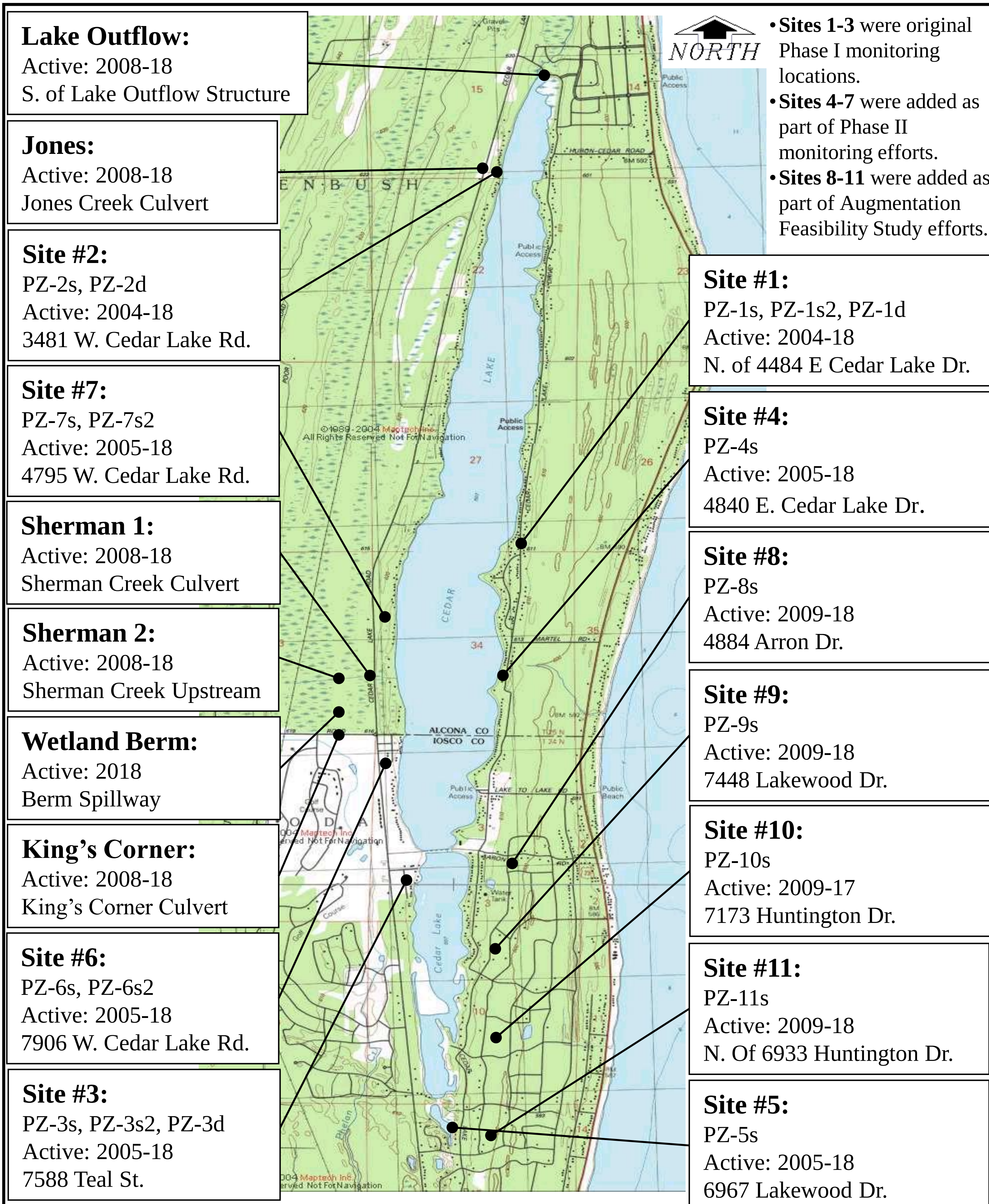
Figure 23 demonstrates the overall increase in surface water volume entering Cedar Lake through Sherman and Jones Creeks during summer months since 2014. These watershed improvements may prove to mitigate any immediate need to pursue deep groundwater withdrawal augmentation wells as outlined in the WMP and feasibility study. Moreover, the proposed instream grade structures for Sherman Creek may ultimately provide the naturalized solution to mitigate long-term concerns of future lake level drops during dry summers. This would also benefit the ecology of the lake by protecting important springtime fish-spawning habitat. As noted earlier, issues of PFAS groundwater contamination also raise a cautionary concern with deeper groundwater pumping for lake level augmentation.

Based on 2018 observations and the noted importance of scientifically valid water level data for making informed watershed management decisions, K&A recommends the Cedar Lake monitoring program be continued during the 2019 calendar year. Additional statistical analyses to further understand long-term trends and relationships is also recommended for the 2019 calendar year. Future data will be used to further evaluate: 1) potential Sherman Creek instream grade control structure improvements within the Lake Board-acquired properties surrounding the creek, 2) quantified improvements on wetland water level retention resulting from the newly constructed wetland berm, including identifying future maintenance needs, 3) ongoing improvements and future maintenance needs associated with the 2014 culvert flow repair efforts conducted by the railroad in the northwest cedar swamp area, and 4) other important watershed issues related to the movement of shallow groundwater in the Cedar Lake watershed.

Continuing the monitoring program will necessitate the acquisition of several new water level loggers in 2019 to replace those in danger of "aging out" (see Table 1). The possibility of continuously monitoring water levels through the winter months at select monitoring sites could also be a driver for the acquisition of updated logger technology. Additionally, a new rain gauge will need to be acquired in 2019 to continue volunteer precipitation monitoring at Cedar Lake. These considerations will be vital to maintaining a comprehensive and unbroken historic water level record.

If you have any questions regarding the information provided within this technical memorandum, please do not hesitate to contact our office at (269) 344-7117.

2018 Cedar Lake Hydrology Report: List of Tables, Figures, and Appendices



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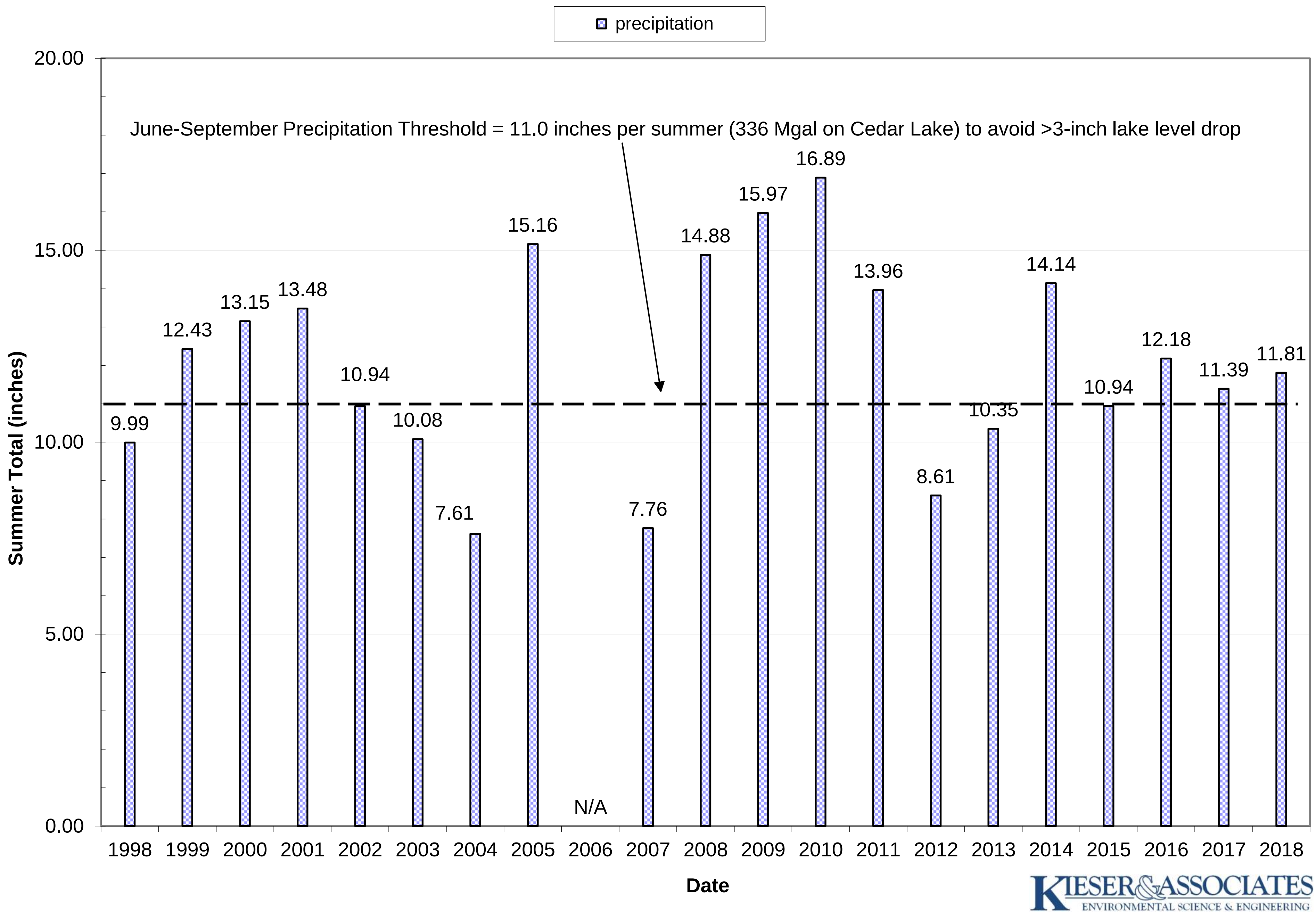
Map of groundwater and surface water elevation monitoring sites with piezometers & level loggers, located around the perimeter of Cedar Lake.

FIGURE 1

Table 1. Cedar Lake Heron DipperLog Level Loggers' (LL) Status, Jan 2019

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

Figure 2. Summer (Jun - Sept) Precipitation Totals for Cedar Lake
(Precipitation Source: Harrisville, MI, CO-OP Station #203628,
Alcona County Cedar Lake Rain Gauge,
Oscoda, MI Oscoda Wurtsmith Airport Station #14808, Iosco County)



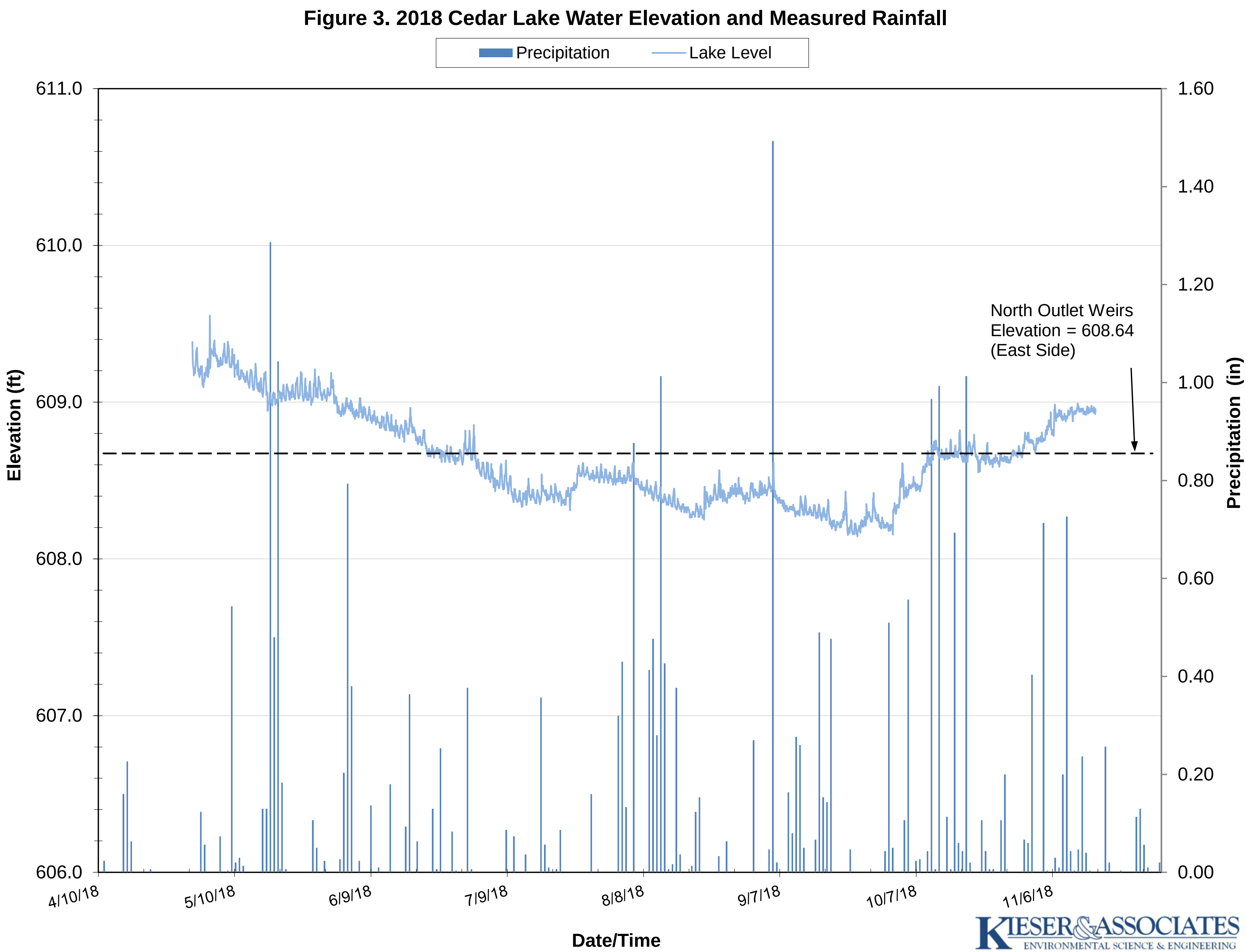


Figure 3. 2018 Cedar Lake Water Elevation and Measured Rainfall
Precipitation
Lake Level
611.0
610.0
609.0
608.0
607.0
606.0
Elevation (ft)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Precipitation (in)
North Outlet Weirs
Elevation = 608.64
(East Side)
4/10/18
5/10/18
6/9/18
7/9/18
8/8/18
9/7/18
10/7/18
11/6/18
Date/Time
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Figure 4. 2018 Cedar Lake Groundwater / Surface Water Elevations (Site 1)

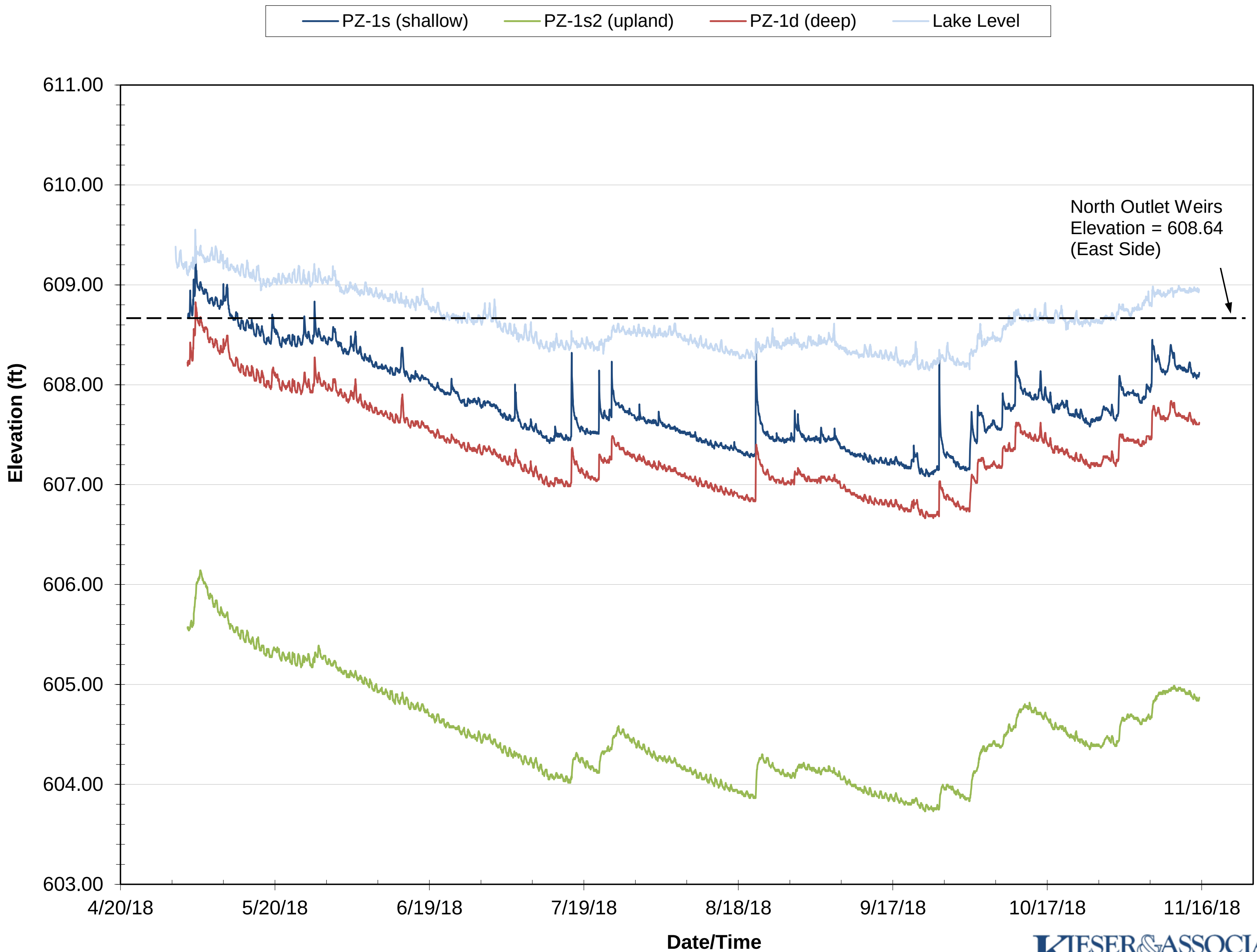

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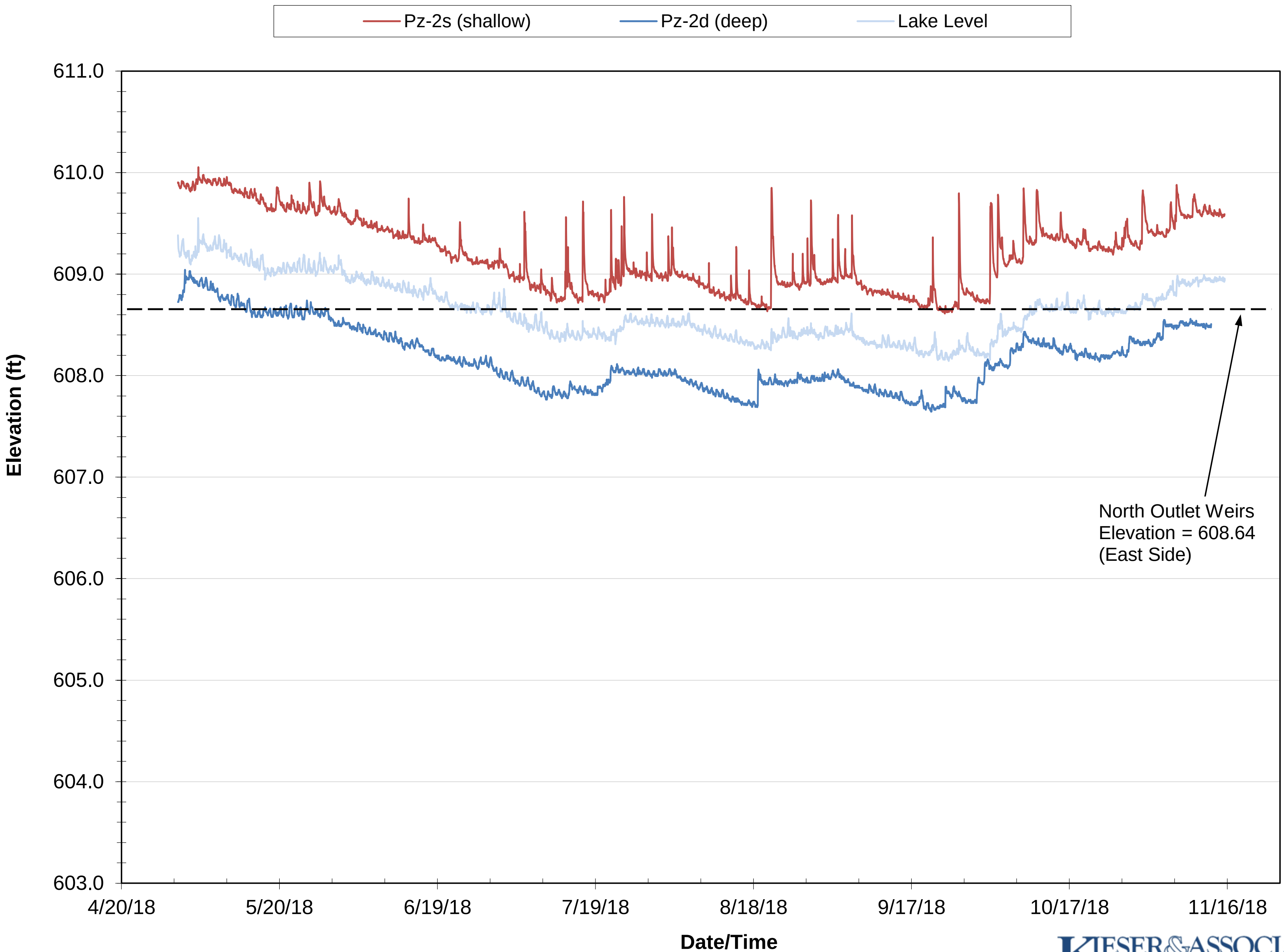
Figure 5. 2018 Cedar Lake Groundwater / Surface Water Elevations (Site 2)



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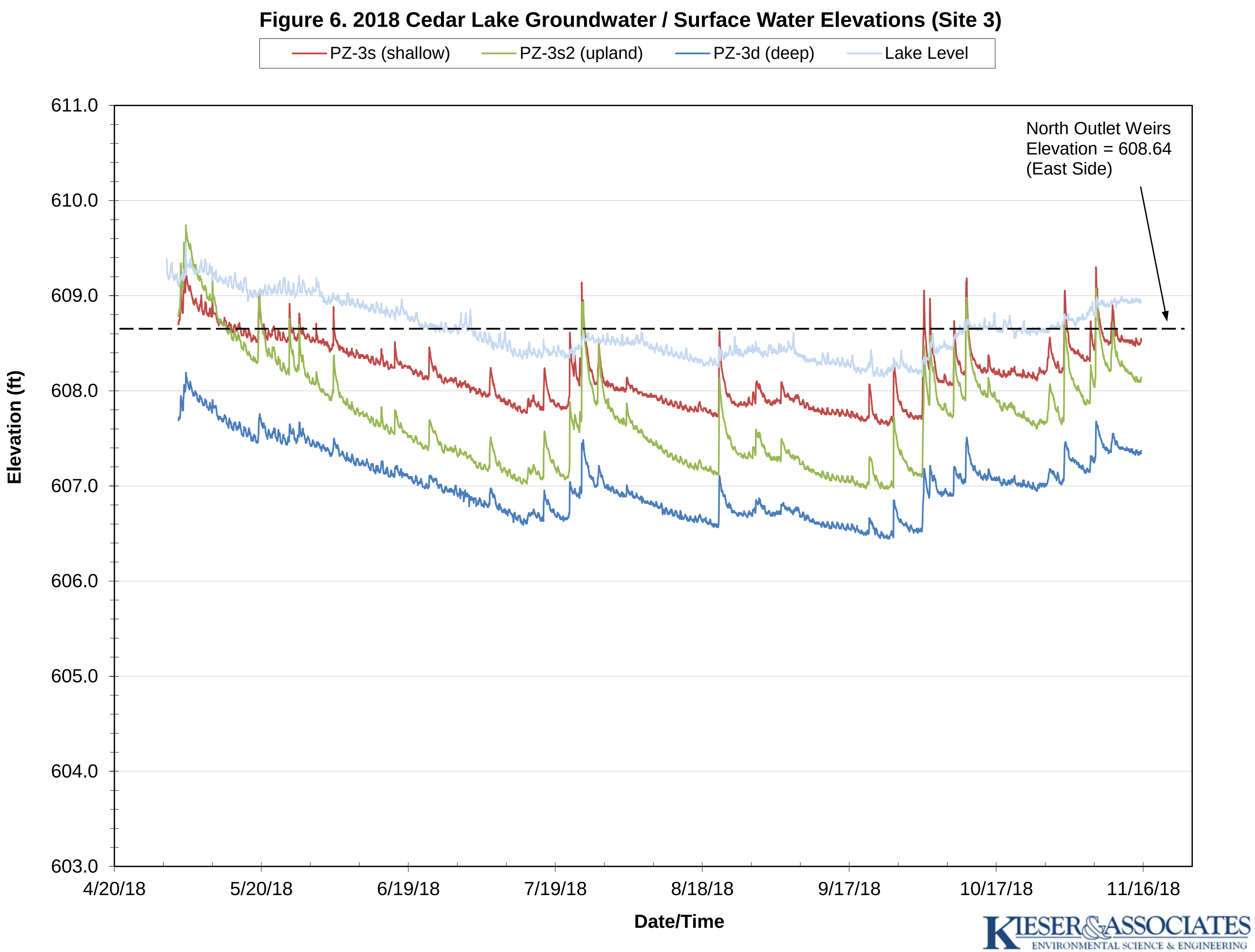

Figure 6. 2018 Cedar Lake Groundwater / Surface Water Elevations (Site 3)
PZ-3s (shallow)
PZ-3s2 (upland)
PZ-3d (deep)
Lake Level
North Outlet Weirs
Elevation = 608.64
(East Side)
Elevation (ft)
611.0
610.0
609.0
608.0
607.0
606.0
605.0
604.0
603.0
4/20/18
5/20/18
6/19/18
7/19/18
8/18/18
9/17/18
10/17/18
11/16/18
Date/Time
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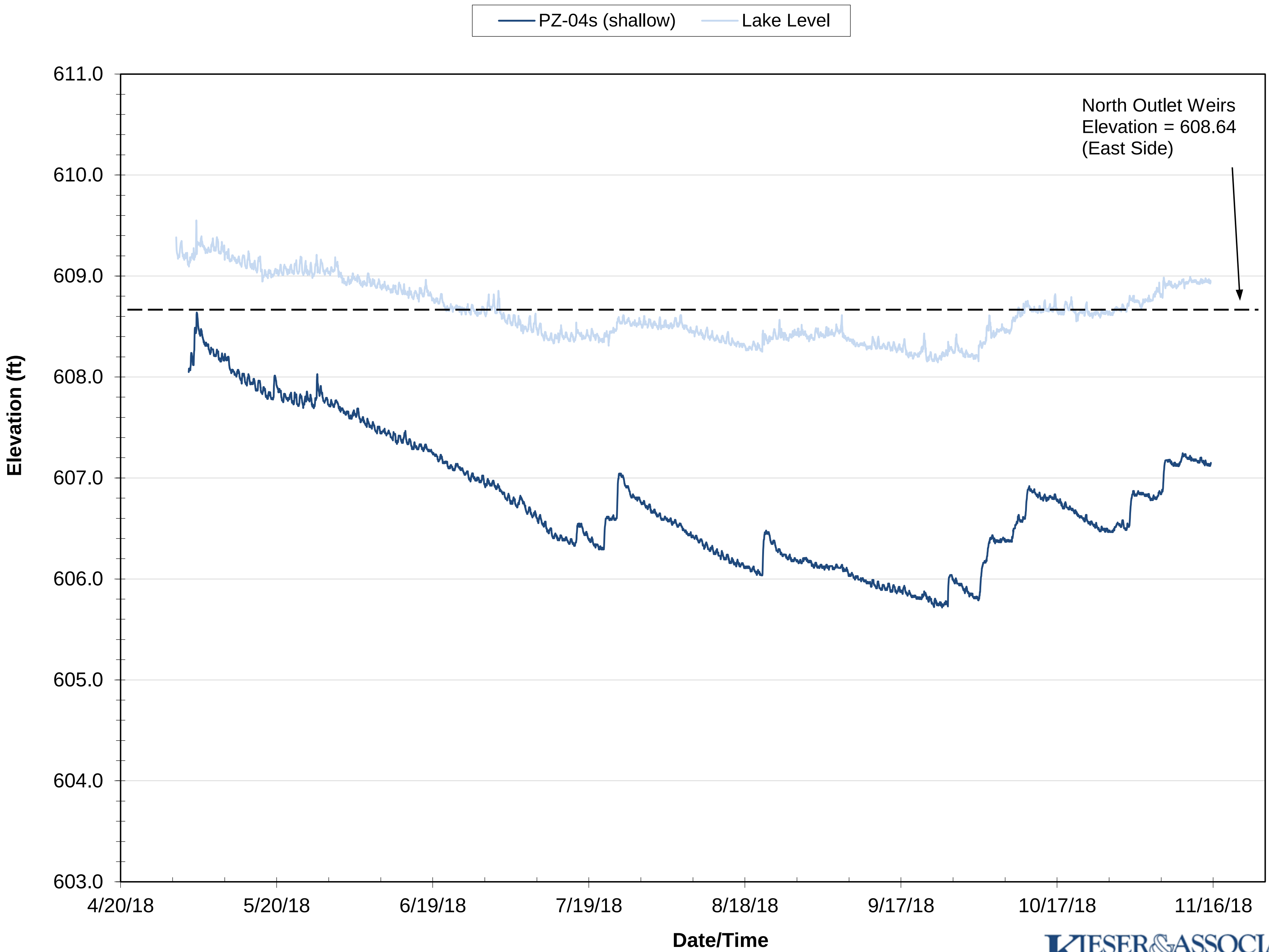
Figure 7. 2018 Cedar Lake Groundwater / Surface Water Elevations (Site 4)



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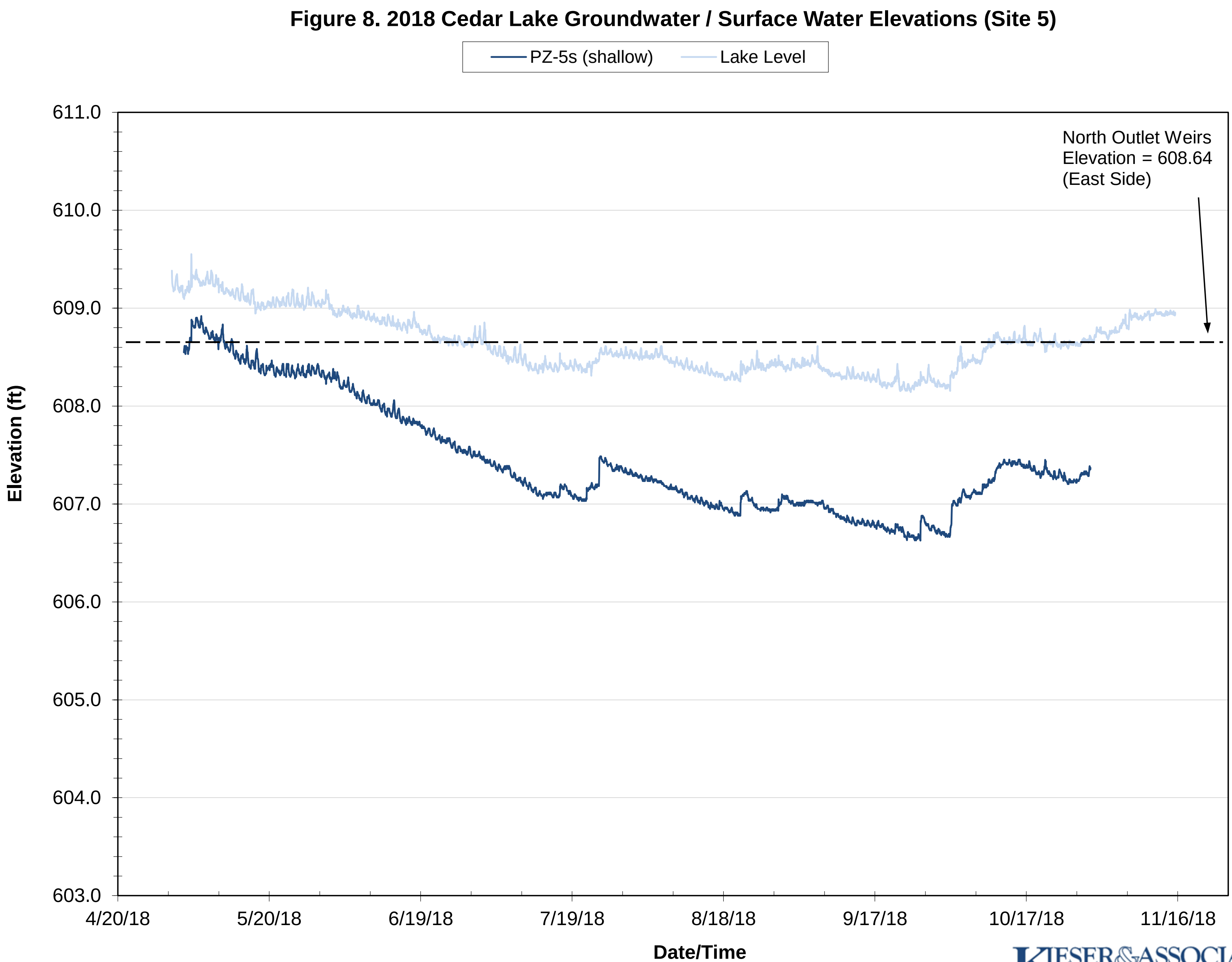

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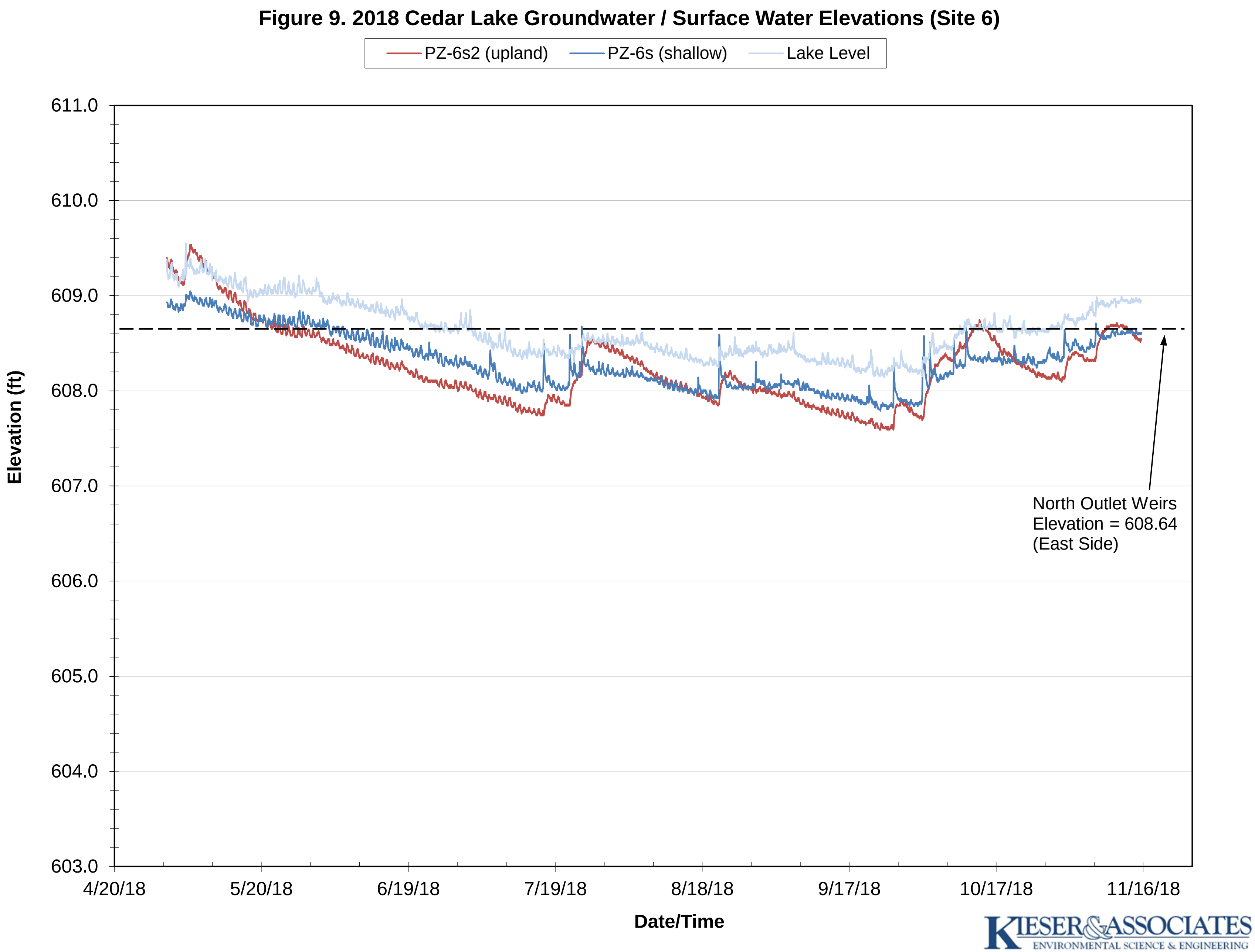
Figure 9. 2018 Cedar Lake Groundwater / Surface Water Elevations (Site 6)
PZ-6s2 (upland)
PZ-6s (shallow)
Lake Level
611.0
610.0
609.0
608.0
607.0
606.0
605.0
604.0
603.0
Elevation (ft)
4/20/18
5/20/18
6/19/18
7/19/18
8/18/18
9/17/18
10/17/18
11/16/18
Date/Time
North Outlet Weirs
Elevation = 608.64
(East Side)
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Figure 10. 2018 Cedar Lake Groundwater / Surface Water Elevations (Site 7)

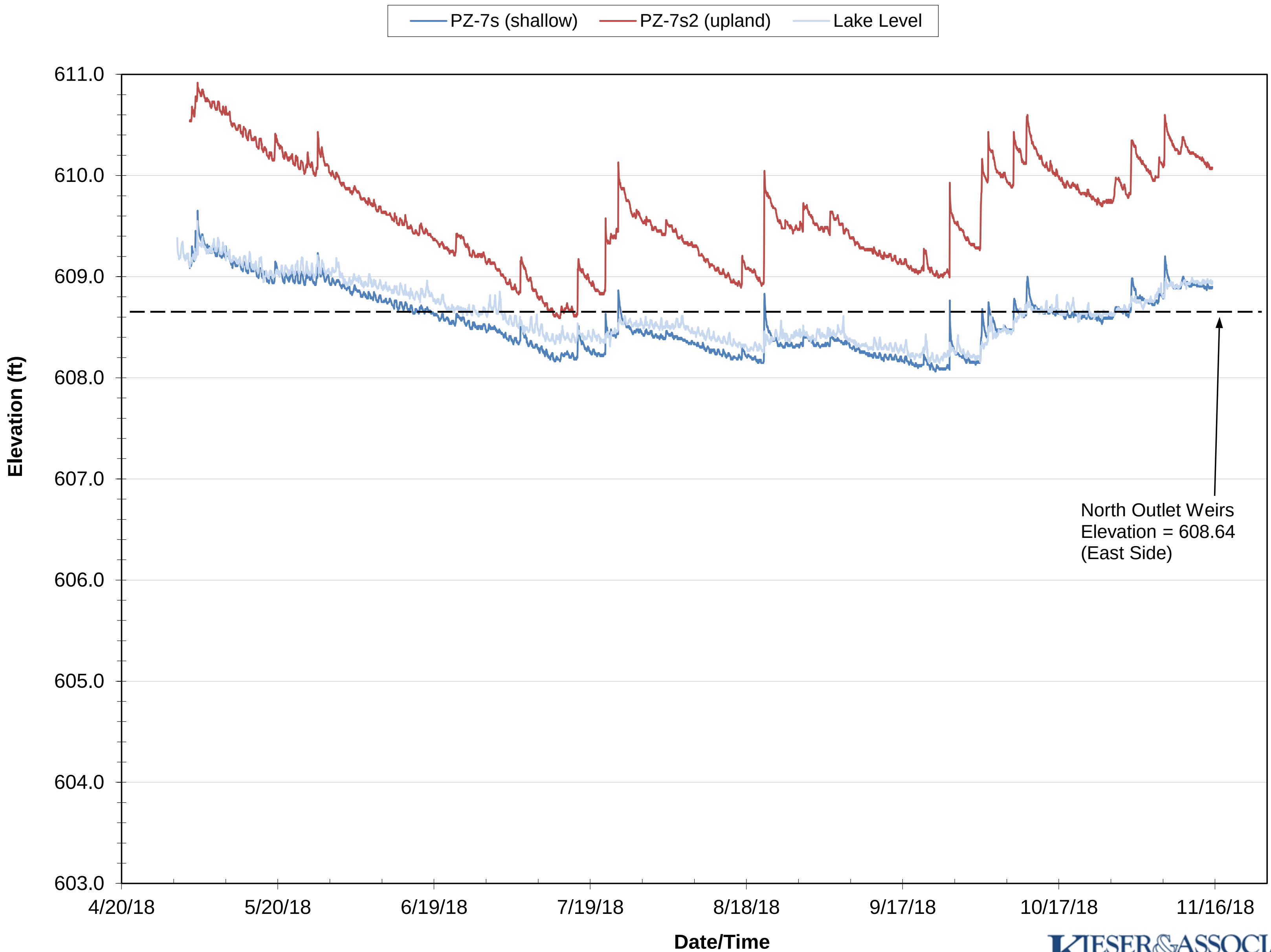

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Figure 11. 2018 Cedar Lake Groundwater / Surface Water Elevations (Site 8)

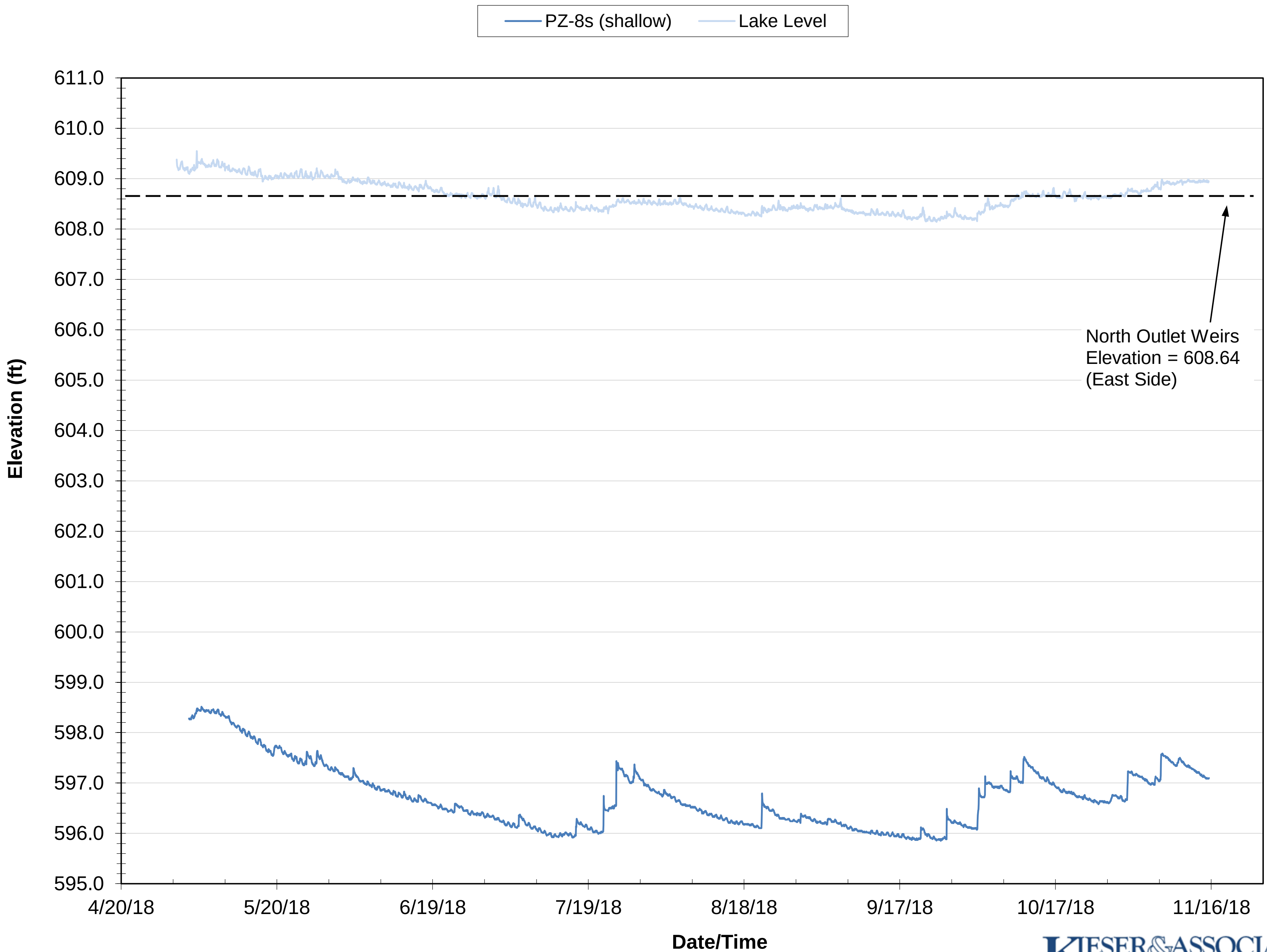

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Figure 12. 2018 Cedar Lake Groundwater / Surface Water Elevations (Site 9)

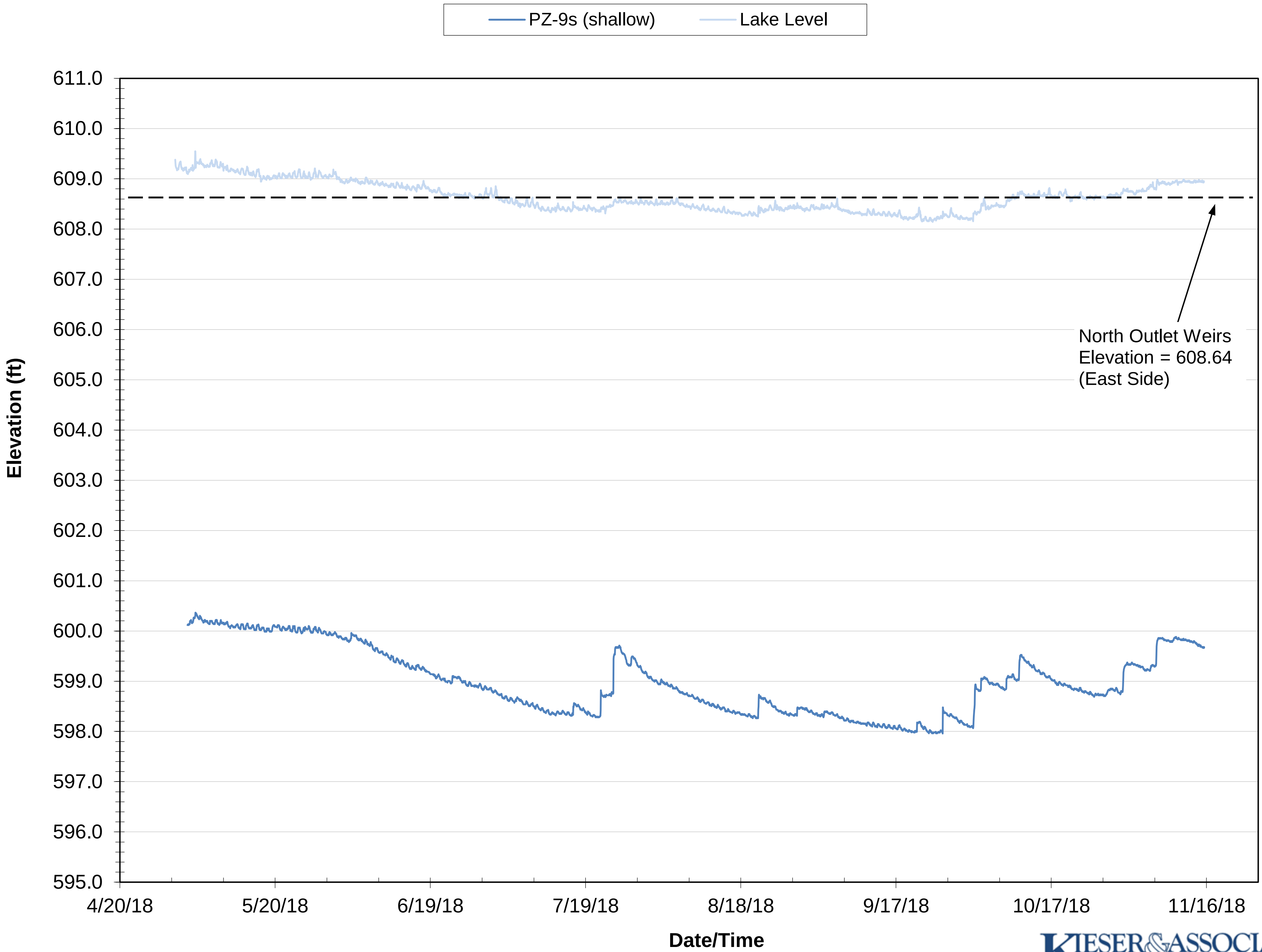

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Figure 13. 2018 Cedar Lake Groundwater / Surface Water Elevations (Site 11)

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Figure 14.1: 2016 Monthly Average Groundwater Gradients
Site #3 (Southwest Side of Cedar Lake)

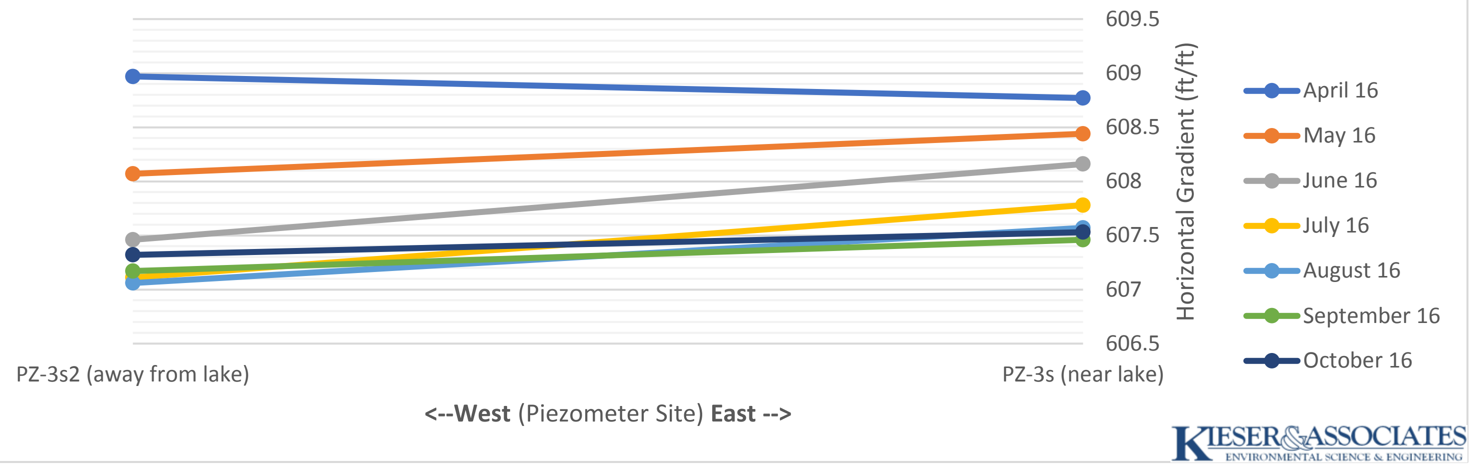


Figure 14.2: 2017 Monthly Average Groundwater Gradients
Site #3 (Southwest Side of Cedar Lake)

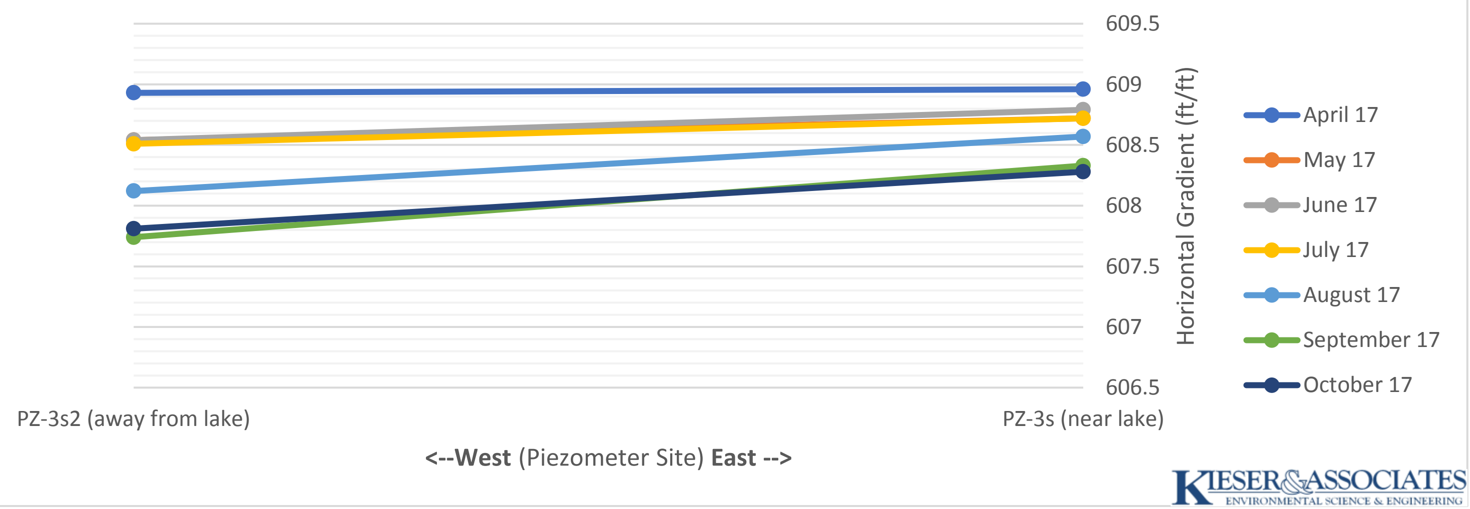
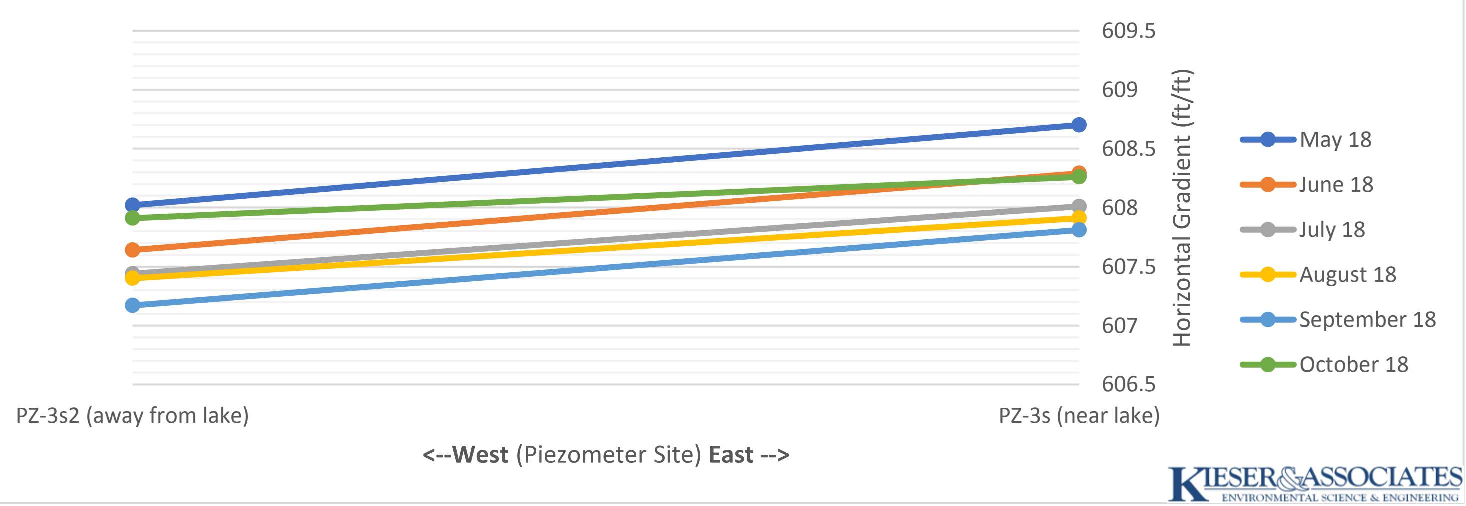


Figure 14.3: 2018 Monthly Average Groundwater Gradients)
Site #3 (Southwest Side of Cedar Lake)



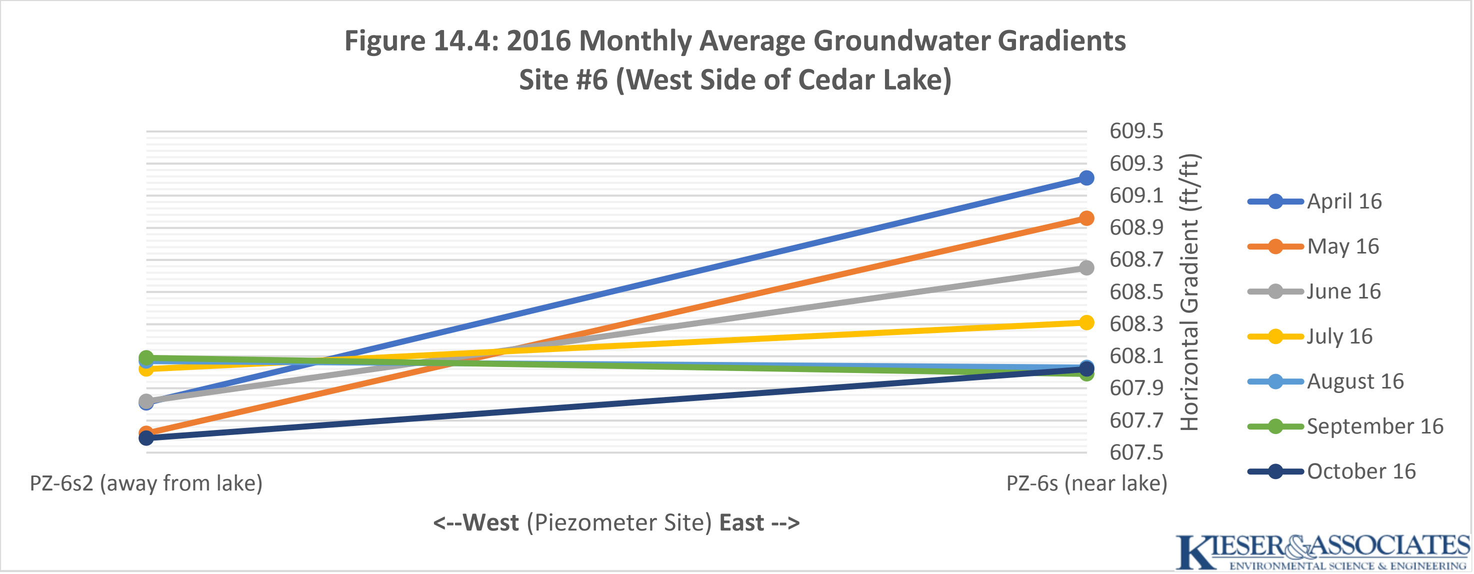


Figure 14.4: 2016 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
609.5
609.3
609.1
608.9
608.7
608.5
608.3
608.1
607.9
607.7
607.5
Horizontal Gradient (ft/ft)
April 16
May 16
June 16
July 16
August 16
September 16
October 16
PZ-6s2 (away from lake)
PZ-6s (near lake)
<--West (Piezometer Site) East -->
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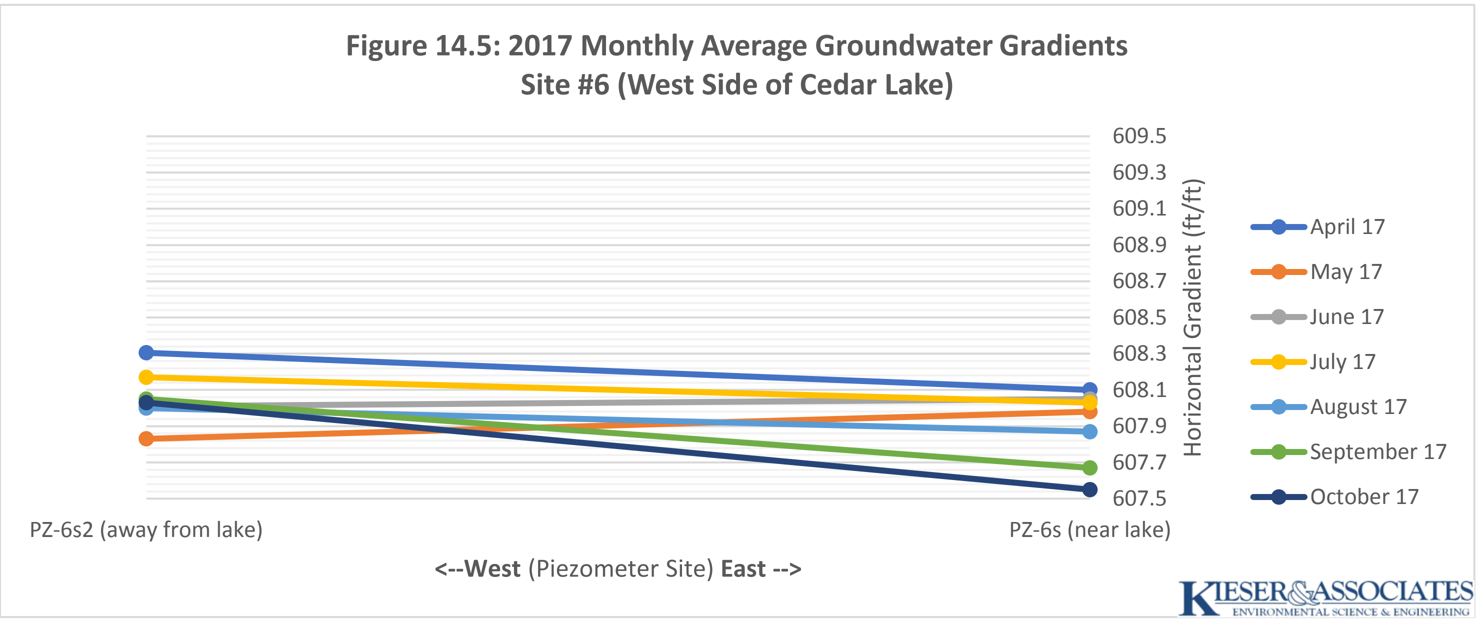

Figure 14.5: 2017 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
609.5
609.3
609.1
608.9
608.7
608.5
608.3
608.1
607.9
607.7
607.5
Horizontal Gradient (ft/ft)
April 17
May 17
June 17
July 17
August 17
September 17
October 17
PZ-6s2 (away from lake)
PZ-6s (near lake)
<--West (Piezometer Site) East -->
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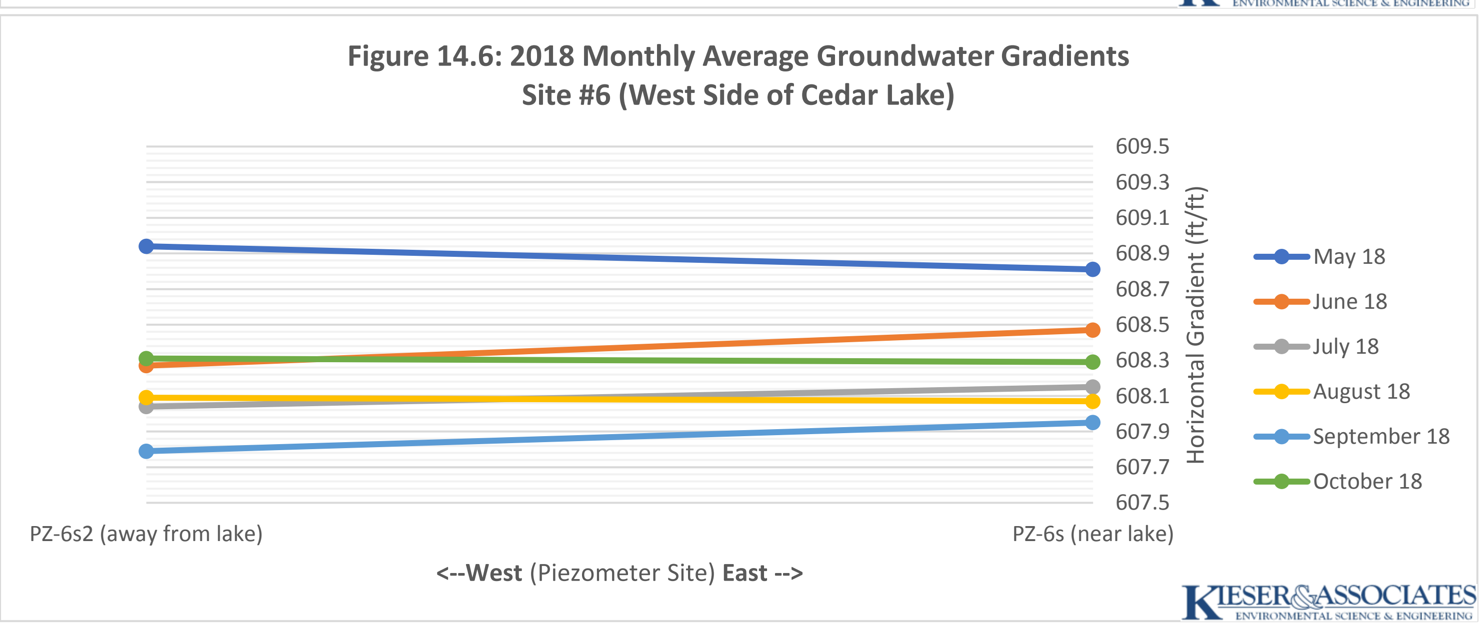

Figure 14.6: 2018 Monthly Average Groundwater Gradients
Site #6 (West Side of Cedar Lake)
609.5
609.3
609.1
608.9
608.7
608.5
608.3
608.1
607.9
607.7
607.5
Horizontal Gradient (ft/ft)
May 18
June 18
July 18
August 18
September 18
October 18
PZ-6s2 (away from lake)
PZ-6s (near lake)
<--West (Piezometer Site) East -->
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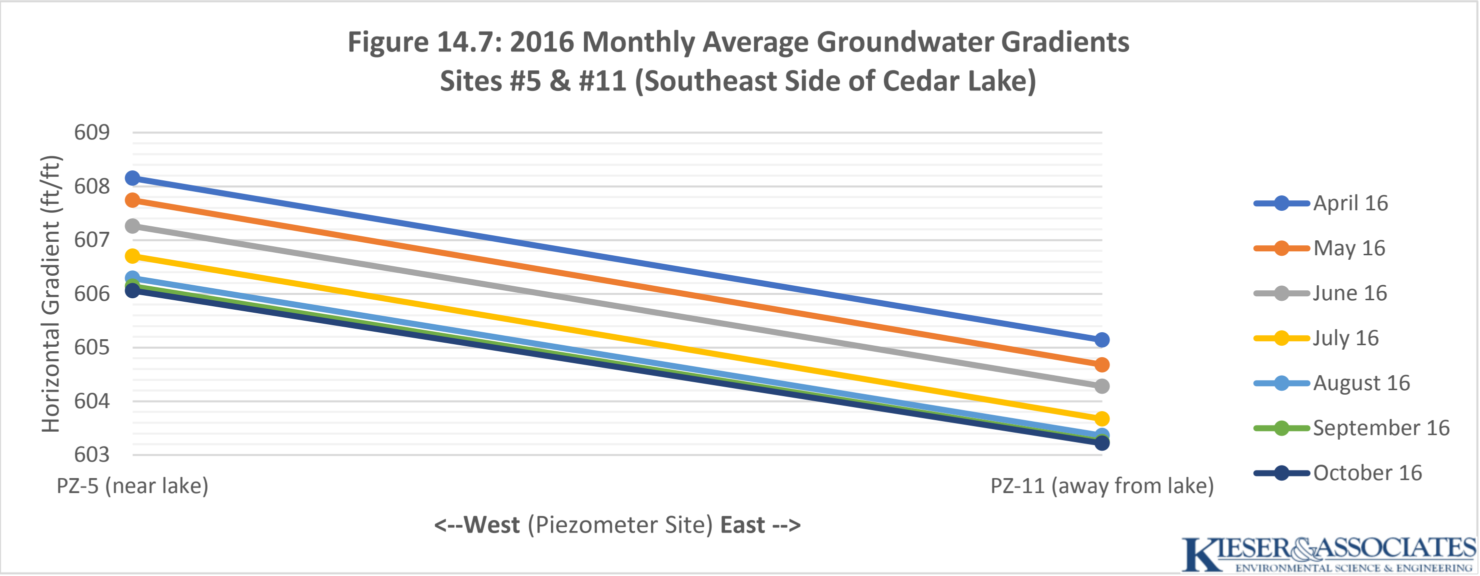
Figure 14.7: 2016 Monthly Average Groundwater Gradients
Sites #5 & #11 (Southeast Side of Cedar Lake)
Horizontal Gradient (ft/ft)
609
608
607
606
605
604
603
PZ-5 (near lake)
PZ-11 (away from lake)
<--West (Piezometer Site) East -->
April 16
May 16
June 16
July 16
August 16
September 16
October 16
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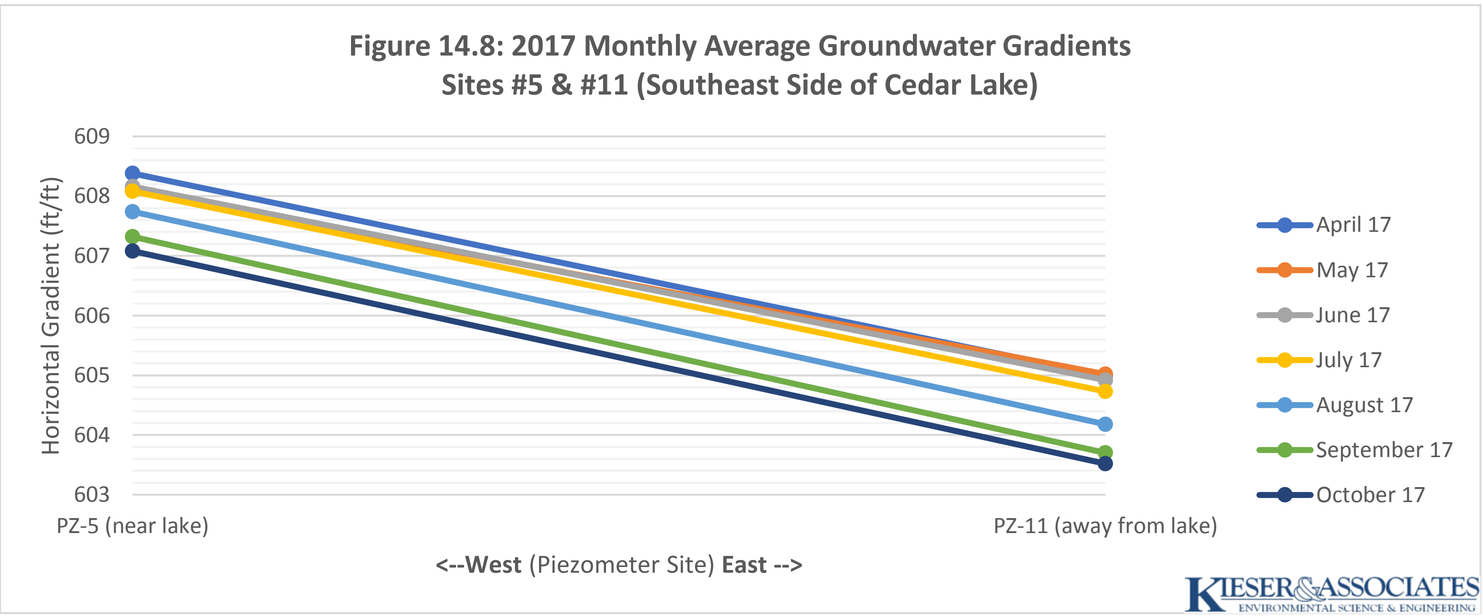
Figure 14.8: 2017 Monthly Average Groundwater Gradients
Sites #5 & #11 (Southeast Side of Cedar Lake)
Horizontal Gradient (ft/ft)
609
608
607
606
605
604
603
PZ-5 (near lake)
PZ-11 (away from lake)
<--West (Piezometer Site) East -->
April 17
May 17
June 17
July 17
August 17
September 17
October 17
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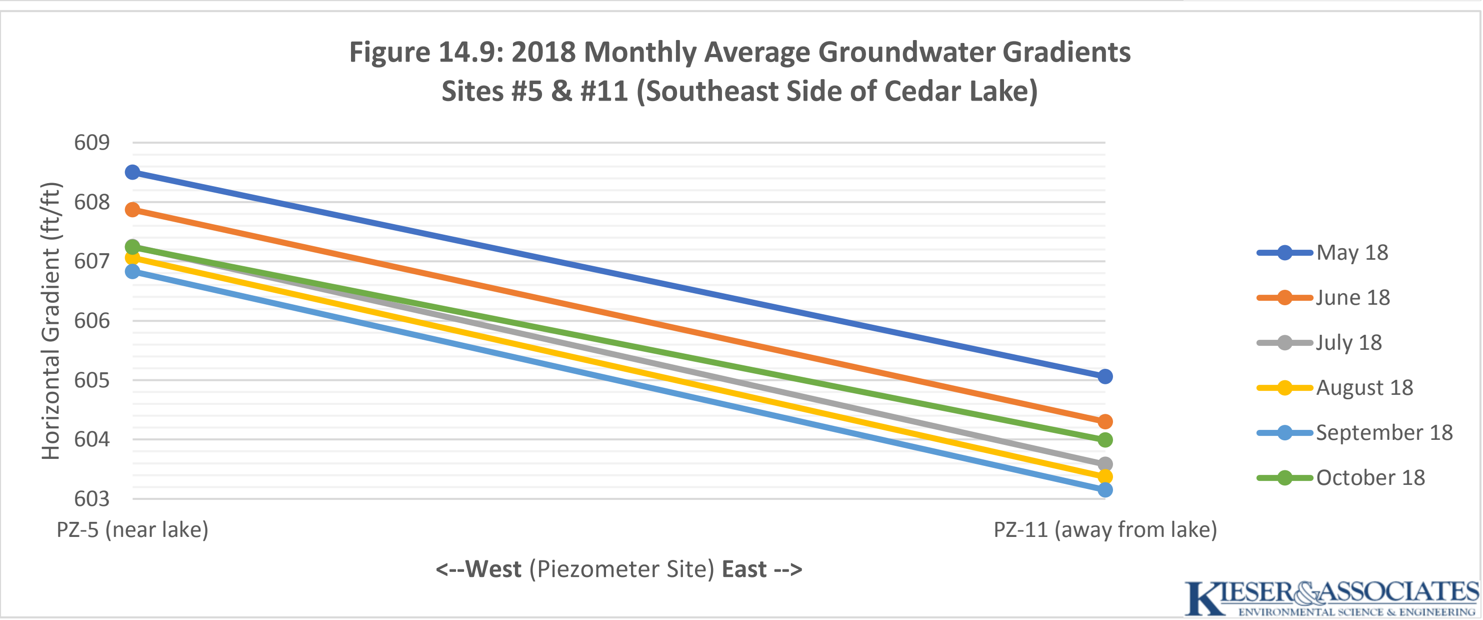
Figure 14.9: 2018 Monthly Average Groundwater Gradients
Sites #5 & #11 (Southeast Side of Cedar Lake)
Horizontal Gradient (ft/ft)
609
608
607
606
605
604
603
PZ-5 (near lake)
PZ-11 (away from lake)
<--West (Piezometer Site) East -->
May 18
June 18
July 18
August 18
September 18
October 18
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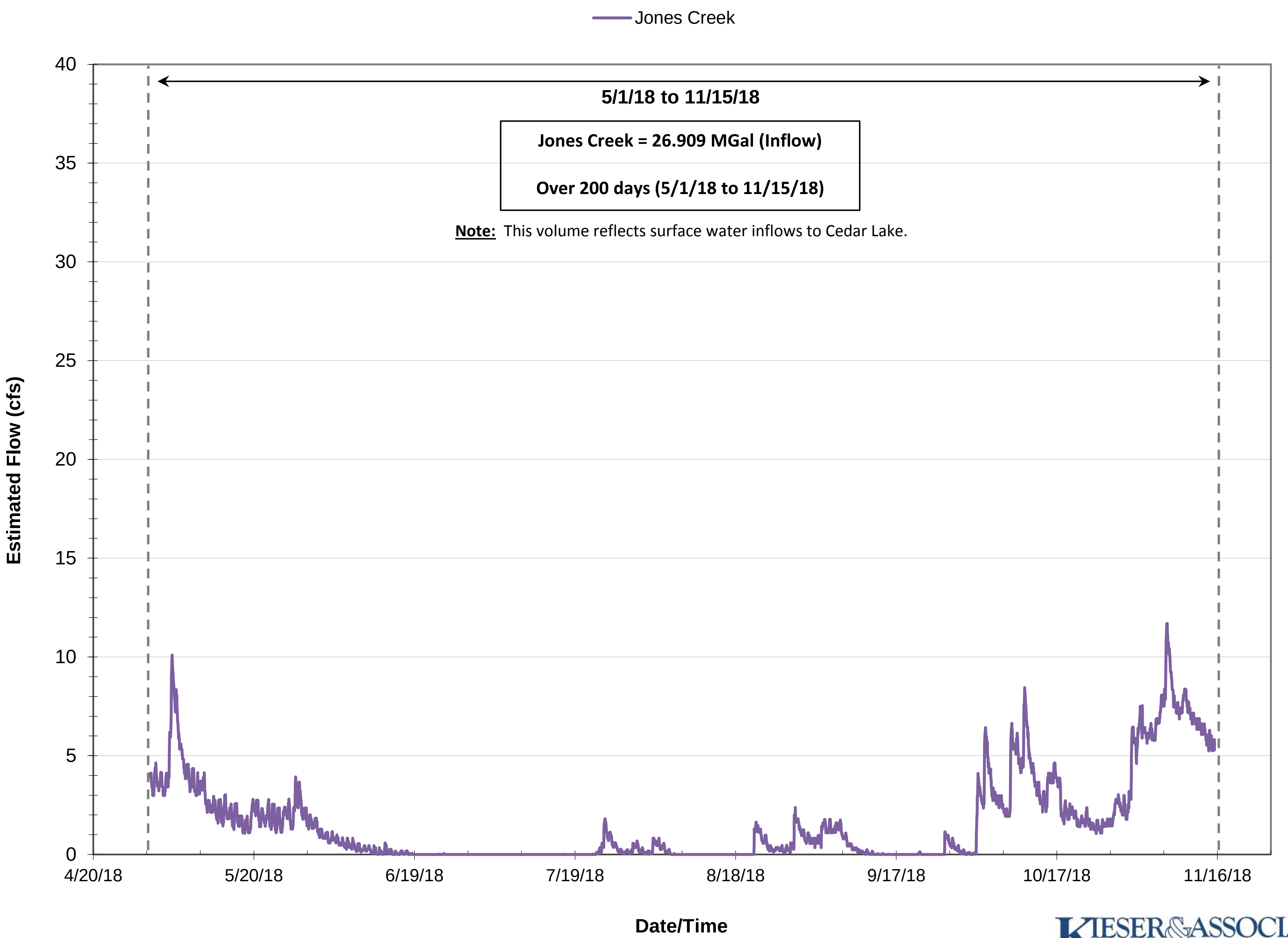
Figure 15. 2018 Estimated Jones Creek Flows



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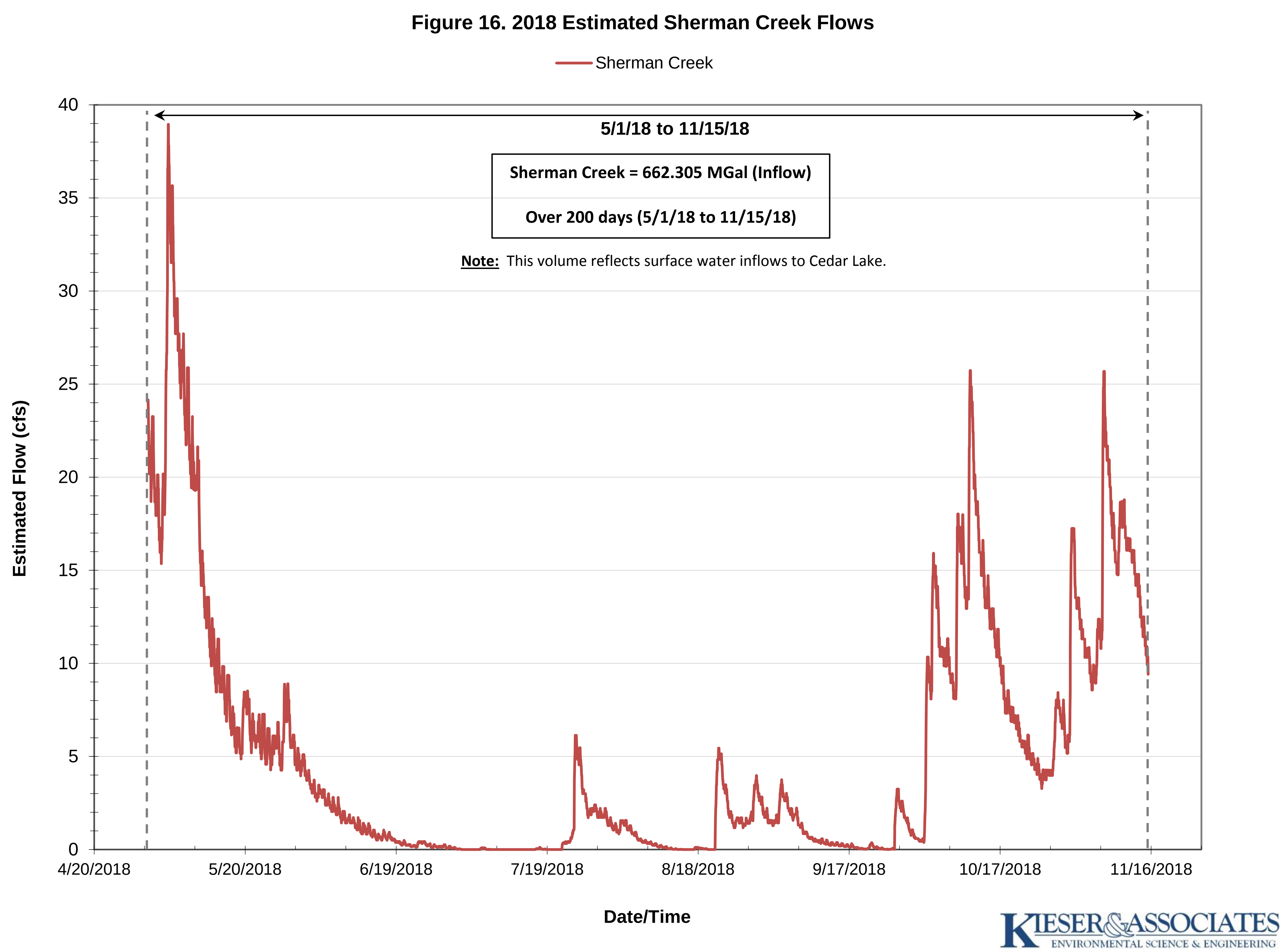

Figure 16. 2018 Estimated Sherman Creek Flows
Sherman Creek
5/1/18 to 11/15/18
Sherman Creek = 662.305 MGal (Inflow)
Over 200 days (5/1/18 to 11/15/18)
Note: This volume reflects surface water inflows to Cedar Lake.
Estimated Flow (cfs)
40
35
30
25
20
15
10
5
0
4/20/2018
5/20/2018
6/19/2018
7/19/2018
8/18/2018
9/17/2018
10/17/2018
11/16/2018
Date/Time
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Figure 17. 2018 Estimated Cedar Lake Outflows

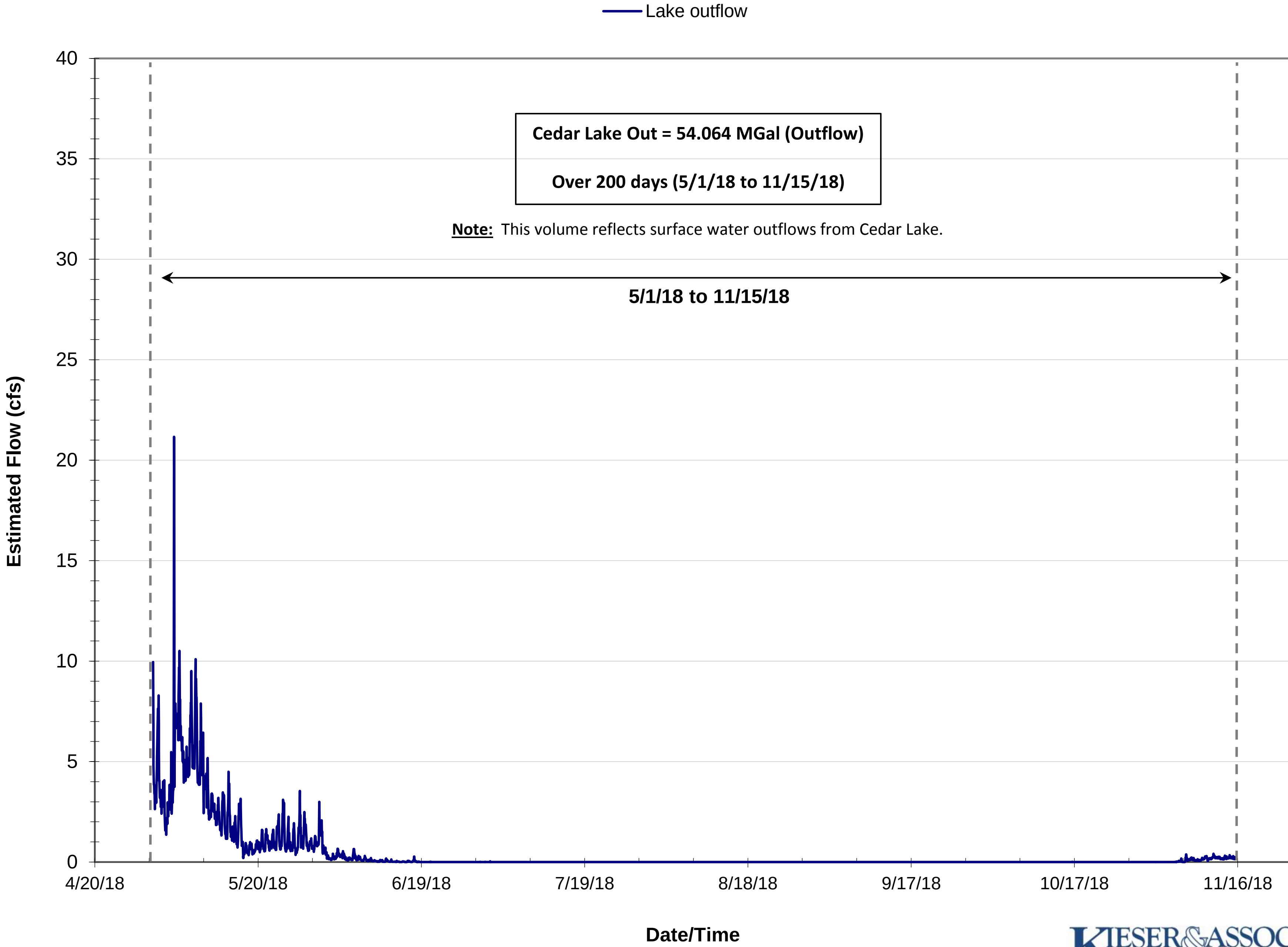

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Figure 18. 2018 Estimated Kings Corner Outflow

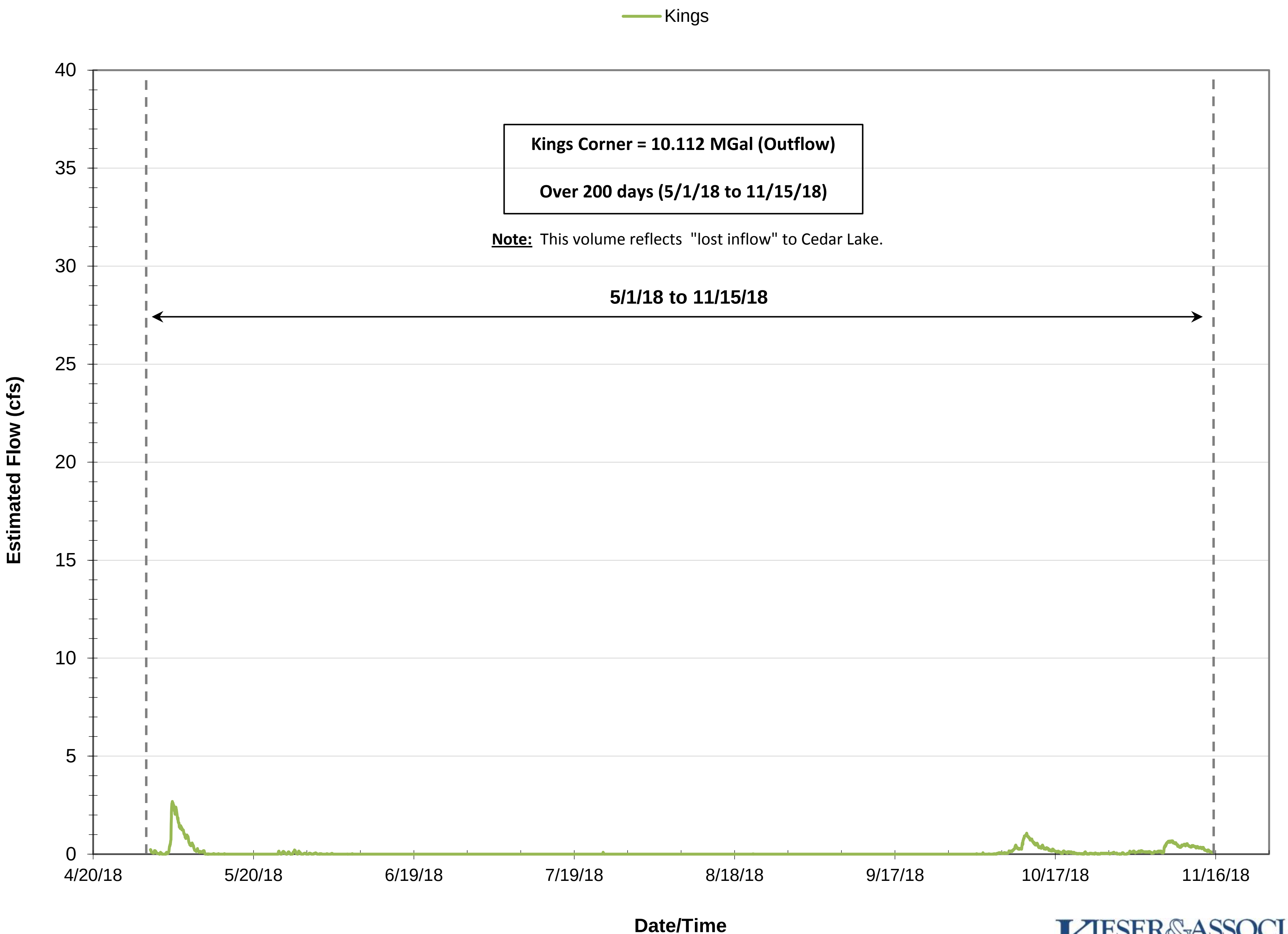

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Figure 19. 2018 Estimated Cedar Lake Inflows/Outflows

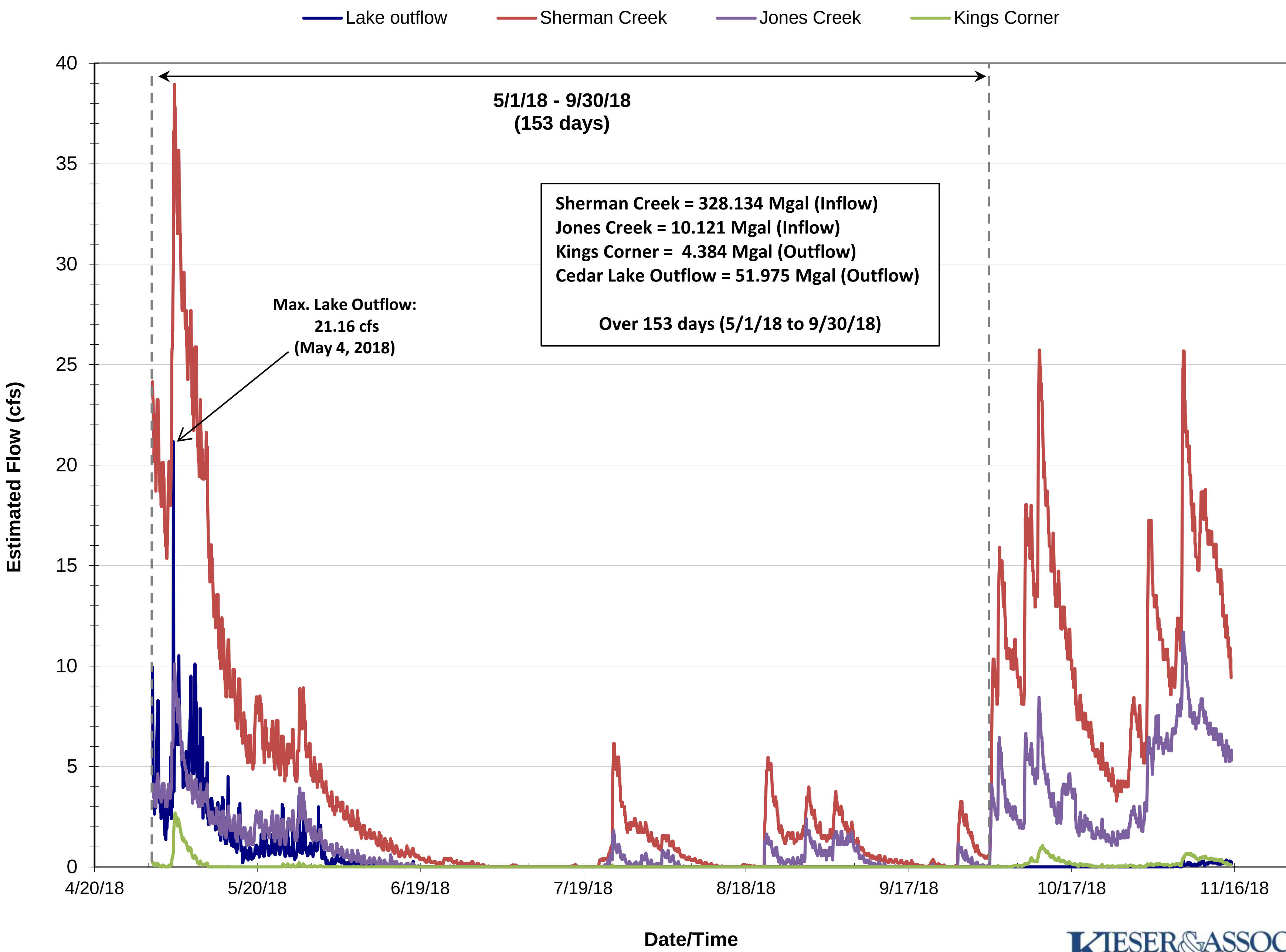

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Figure 20. 2018 Cedar Lake Groundwater / Surface Water Elevations (Wetland Berm)

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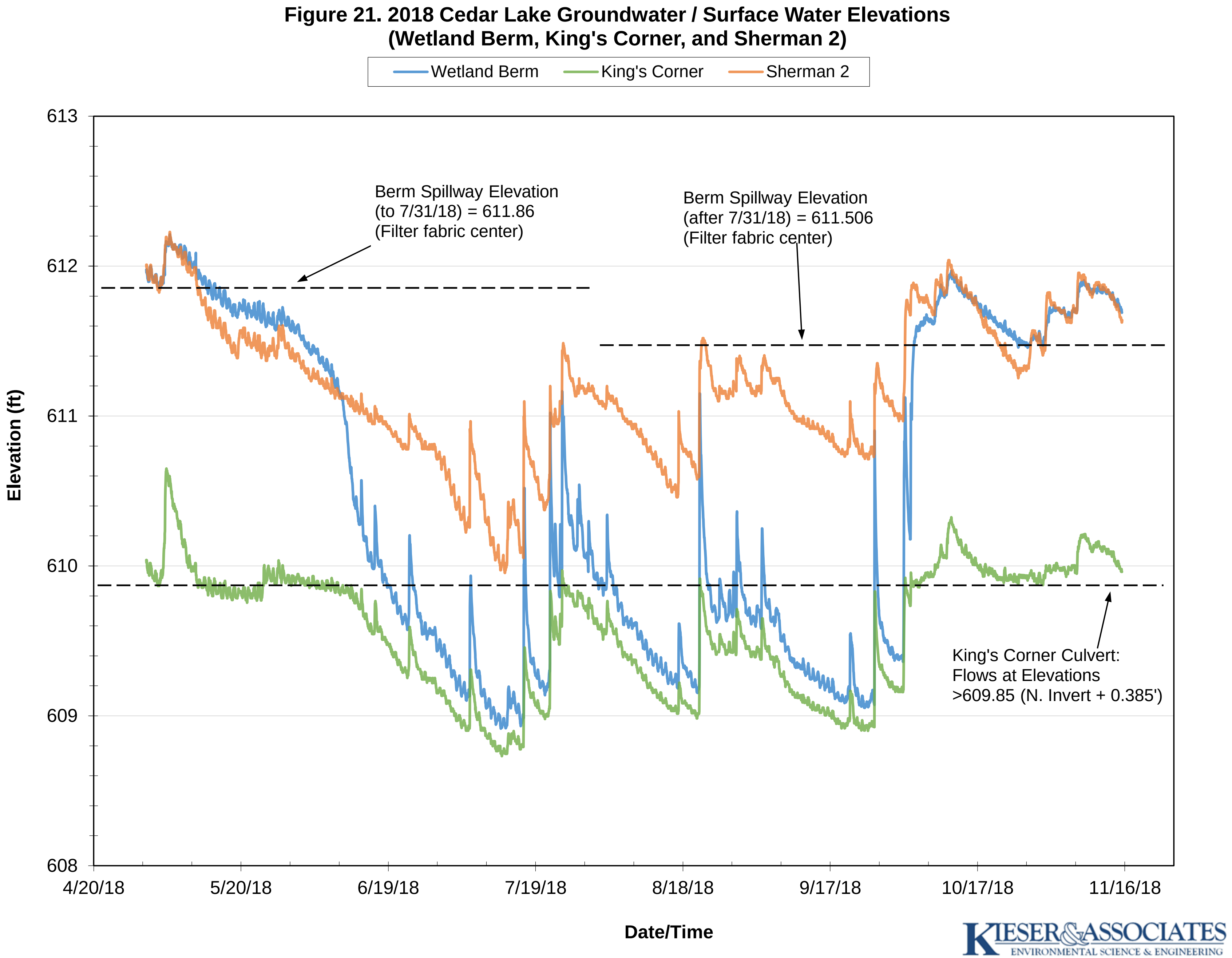
Figure 21. 2018 Cedar Lake Groundwater / Surface Water Elevations
(Wetland Berm, King's Corner, and Sherman 2)
Wetland Berm
King's Corner
Sherman 2
Elevation (ft)
613
612
611
610
609
608
4/20/18
5/20/18
6/19/18
7/19/18
8/18/18
9/17/18
10/17/18
11/16/18
Date/Time
Berm Spillway Elevation (to 7/31/18) = 611.86 (Filter fabric center)
Berm Spillway Elevation (after 7/31/18) = 611.506 (Filter fabric center)
King's Corner Culvert: Flows at Elevations >609.85 (N. Invert + 0.385')
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Figure 22. 2018 Estimated Wetland Berm Spillway and King's Corner Outflows

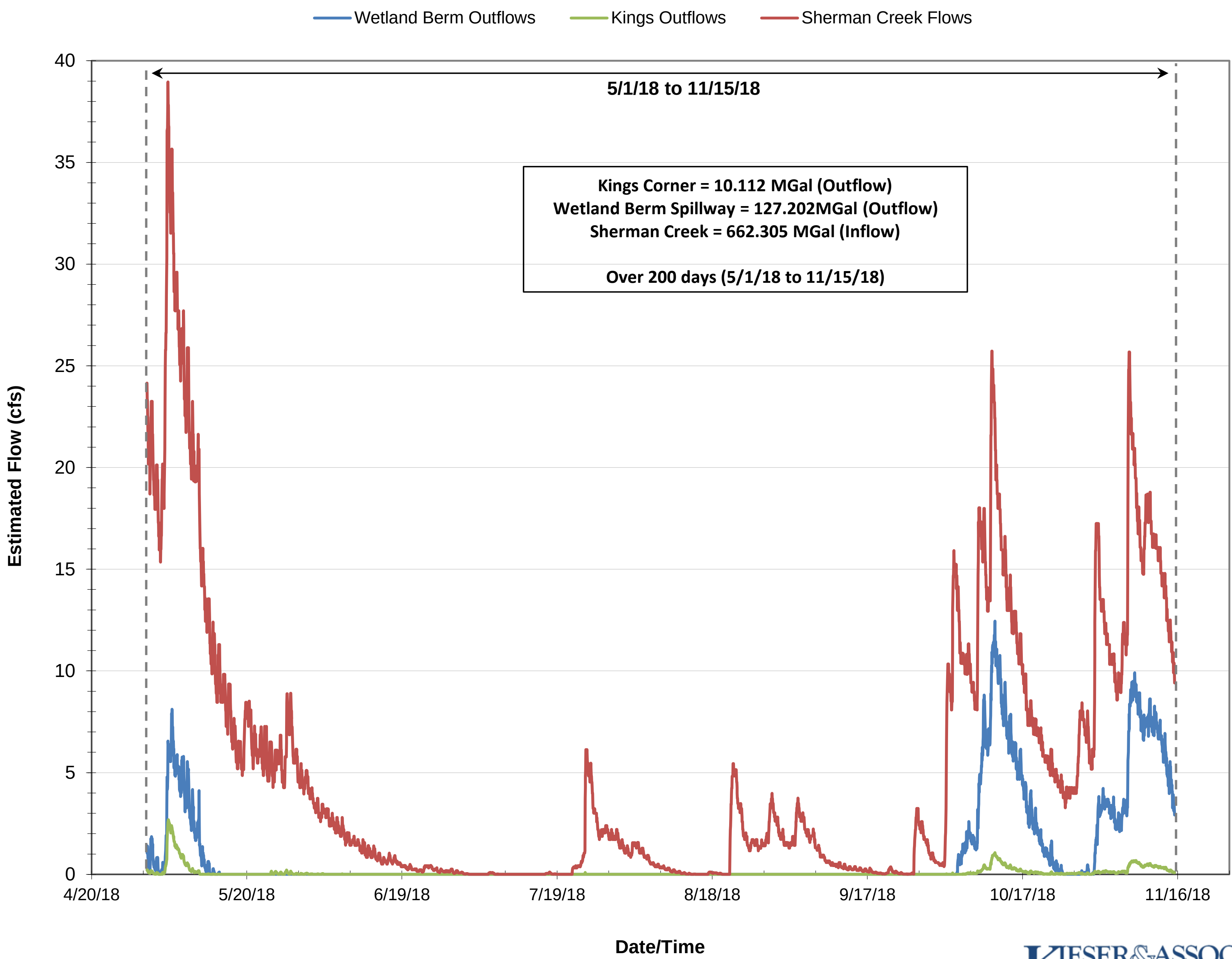

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Table 2. Comparison of Surface Water Volumes, (May 1 to Sep 30), 2014 to 2018.

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

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

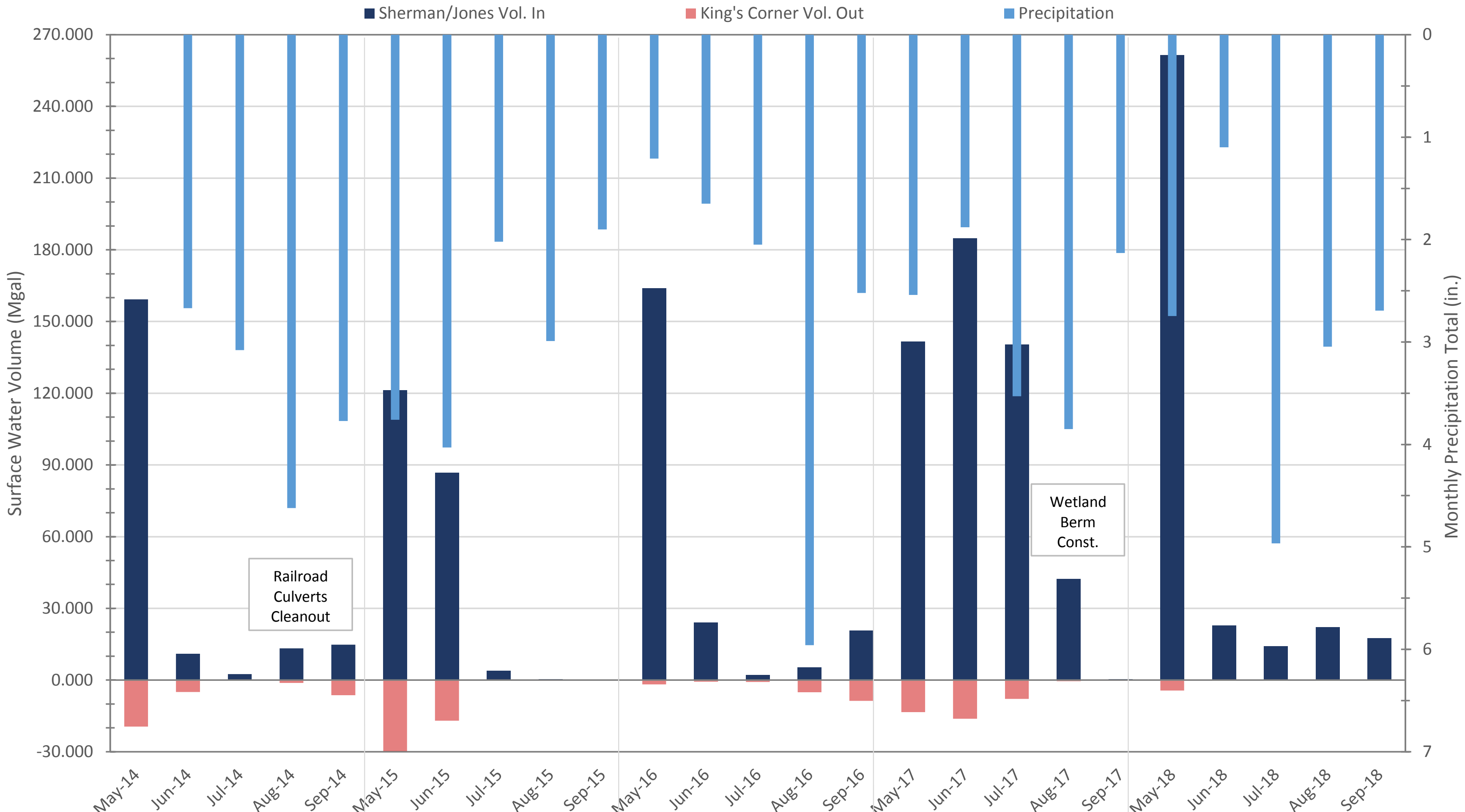
[1]Lake Outlet 2016 volume previously calculated at 1,049 Mgal updated to reflect the affect of a beaver dam, mechanically removed in fall 2017.

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

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

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

Figure 23. May-Sep, 2014-18 : Precipitation, Sherman/Jones Creeks Combined Surface Water Volume into Cedar Lake, and King's Corner Surface Water Volume Away from Cedar Lake



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

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

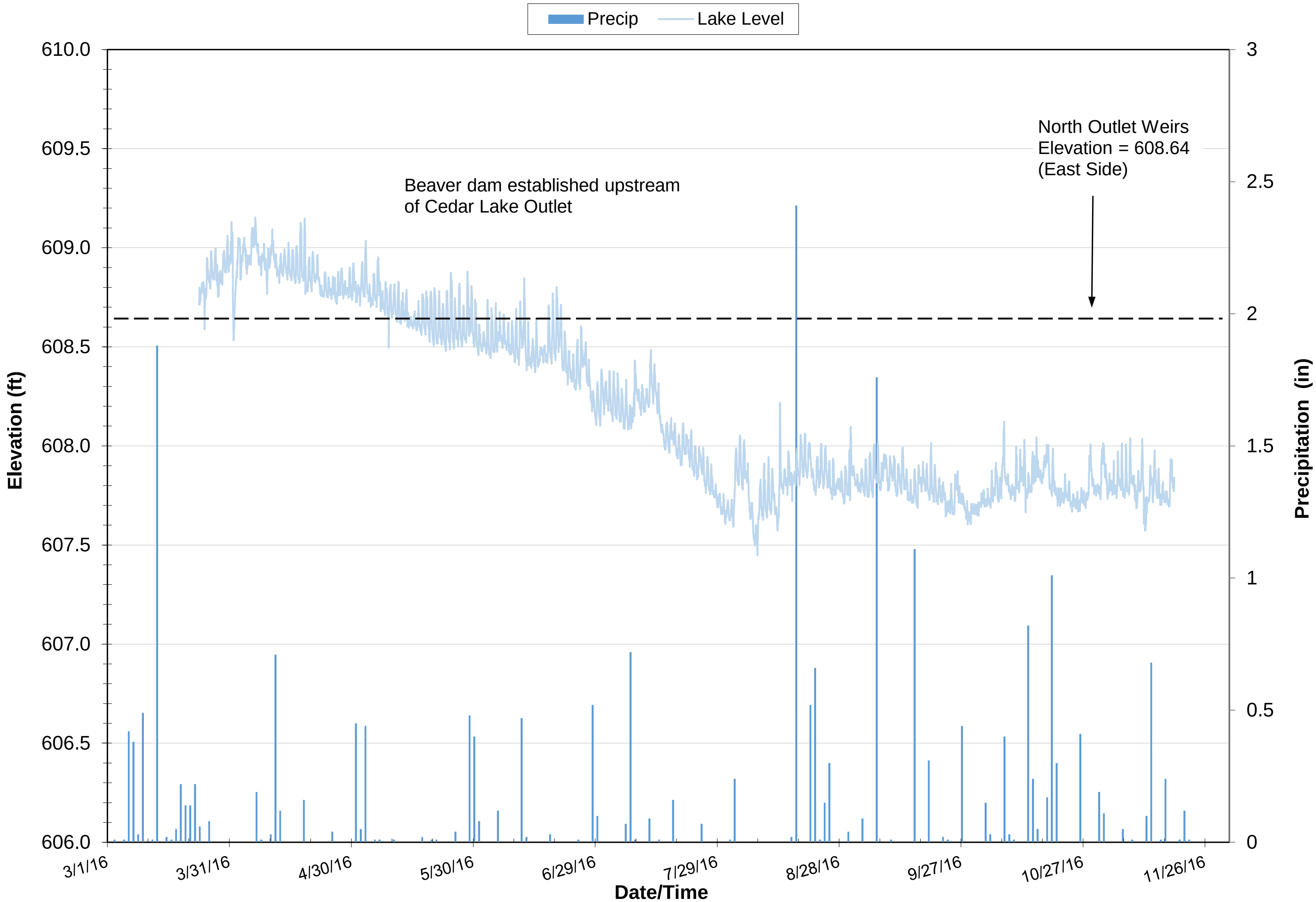
* **2016 May-September:**
Precipitation: 13.39 in.
Inflow Volume: 216.1 Mgal
King's Vol. Out: 17.1 Mgal

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

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

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

Appendix A.1. Updated 2016 Cedar Lake Water Elevation and Measured Rainfall



Note: This updated graph represents water elevation conditions for 2016 at the Cedar Lake Outlet. Elevations plotted in 2016 attempted to represent in-lake conditions above the beaver dam, which was established immediately upstream of the Lake Out level logger. Lake level readings here are used to update calculated outflows for 2016. The beaver dam caused a significant elevation drop at the Outlet, as observed here.

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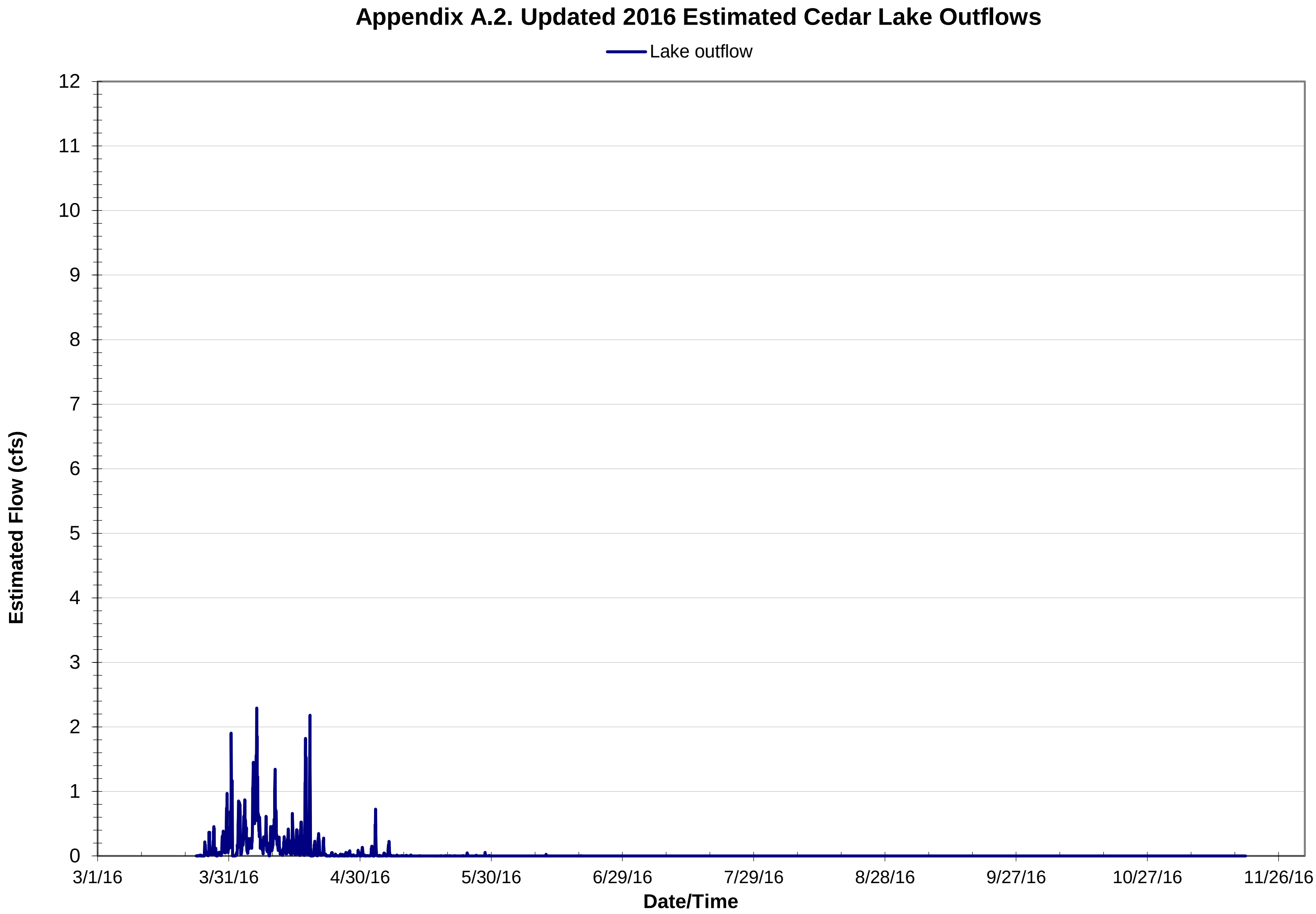

Note: This updated graph represents estimated surface water outflows for 2016 at the Cedar Lake Outlet, per Appendix Figure A.1.

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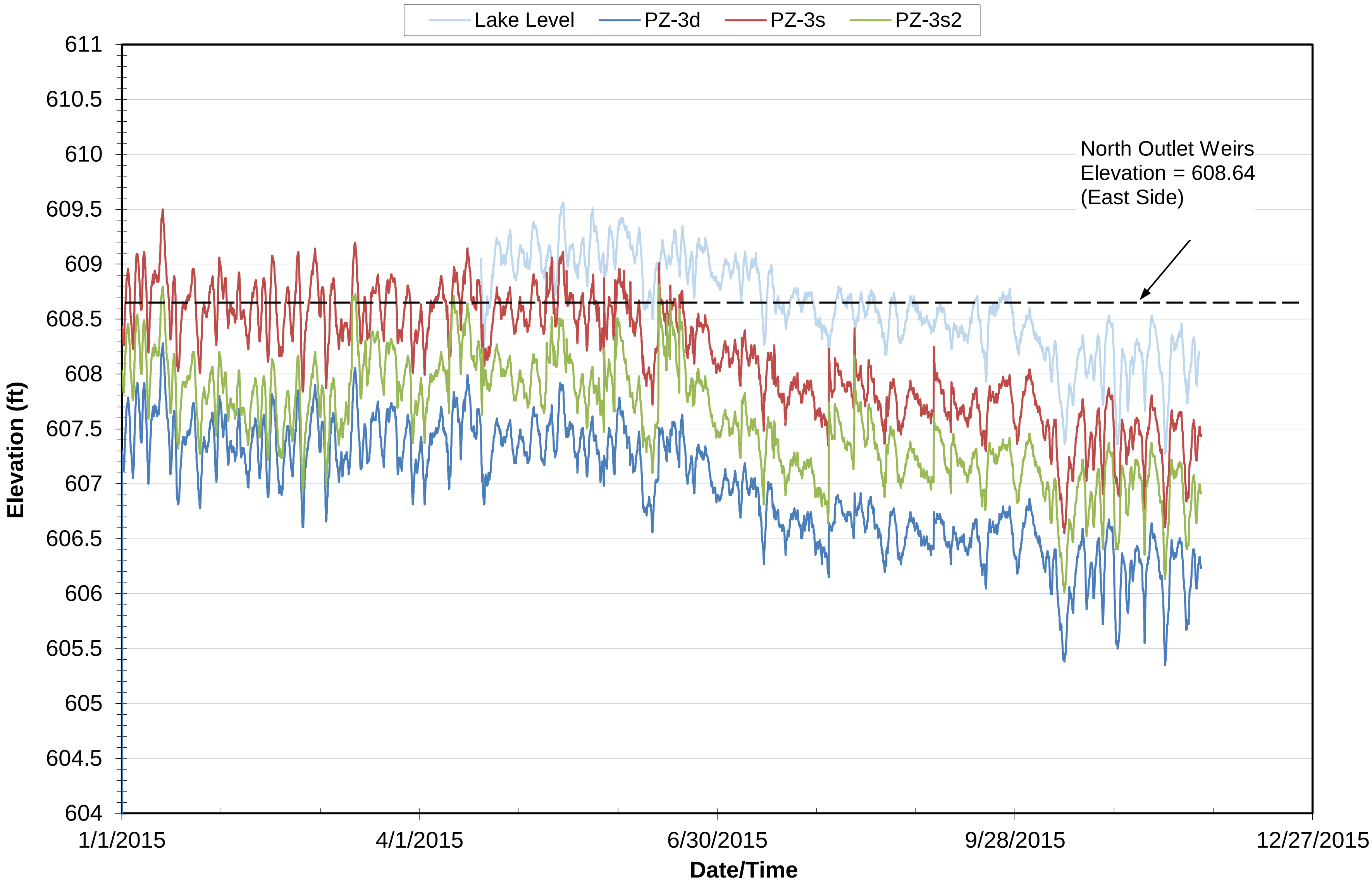
Appendix A.3. Updated 2015 Cedar Lake Groundwater /Surface Water Elevations (Site 3)



Note: This graph presents updated 2015 Site 3 water elevations, which were previously reported using the incorrect top of casing elevations.

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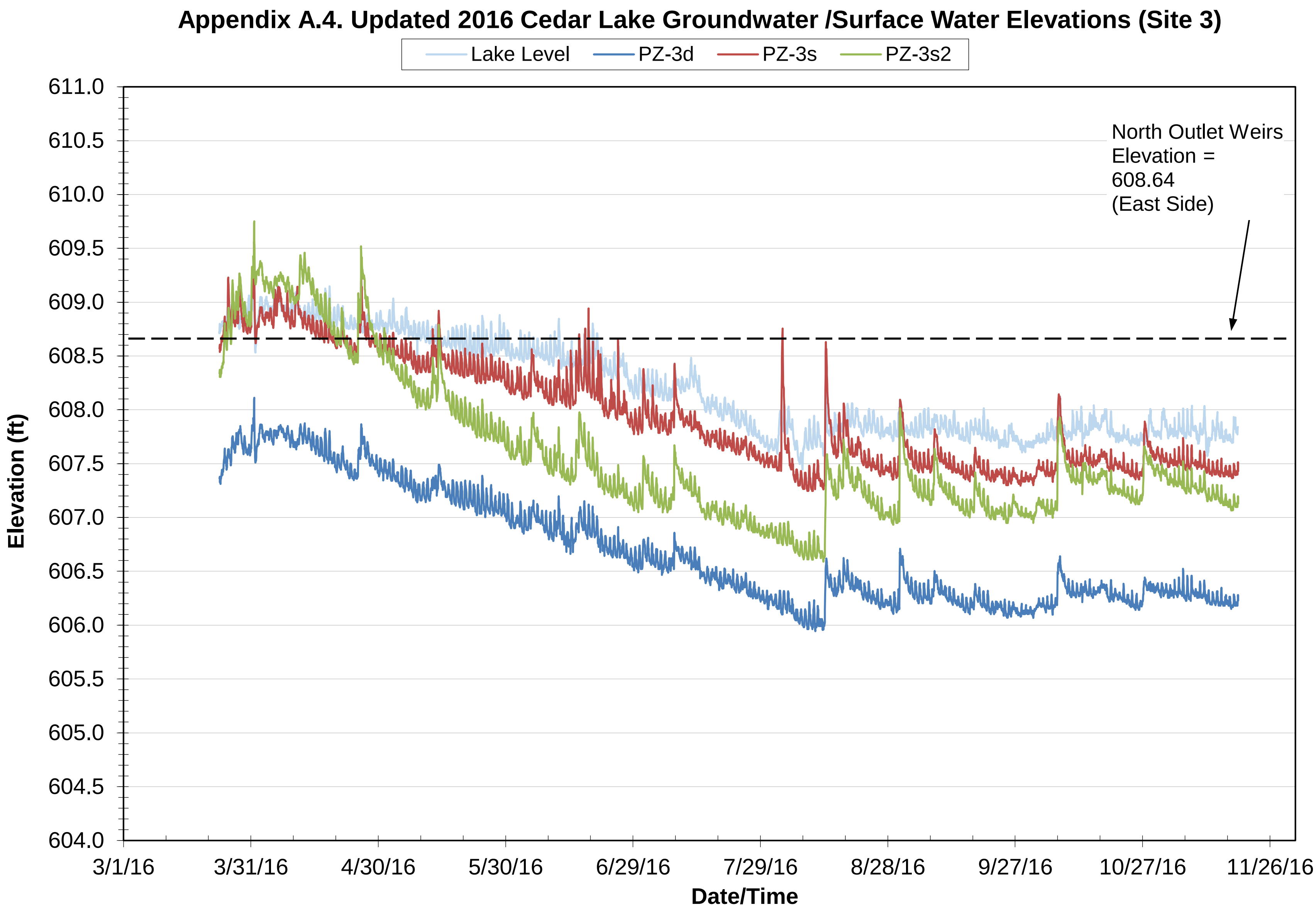

Note: This graph presents updated 2016 Site 3 water elevations, which were previously reported using the incorrect top of casing elevations.

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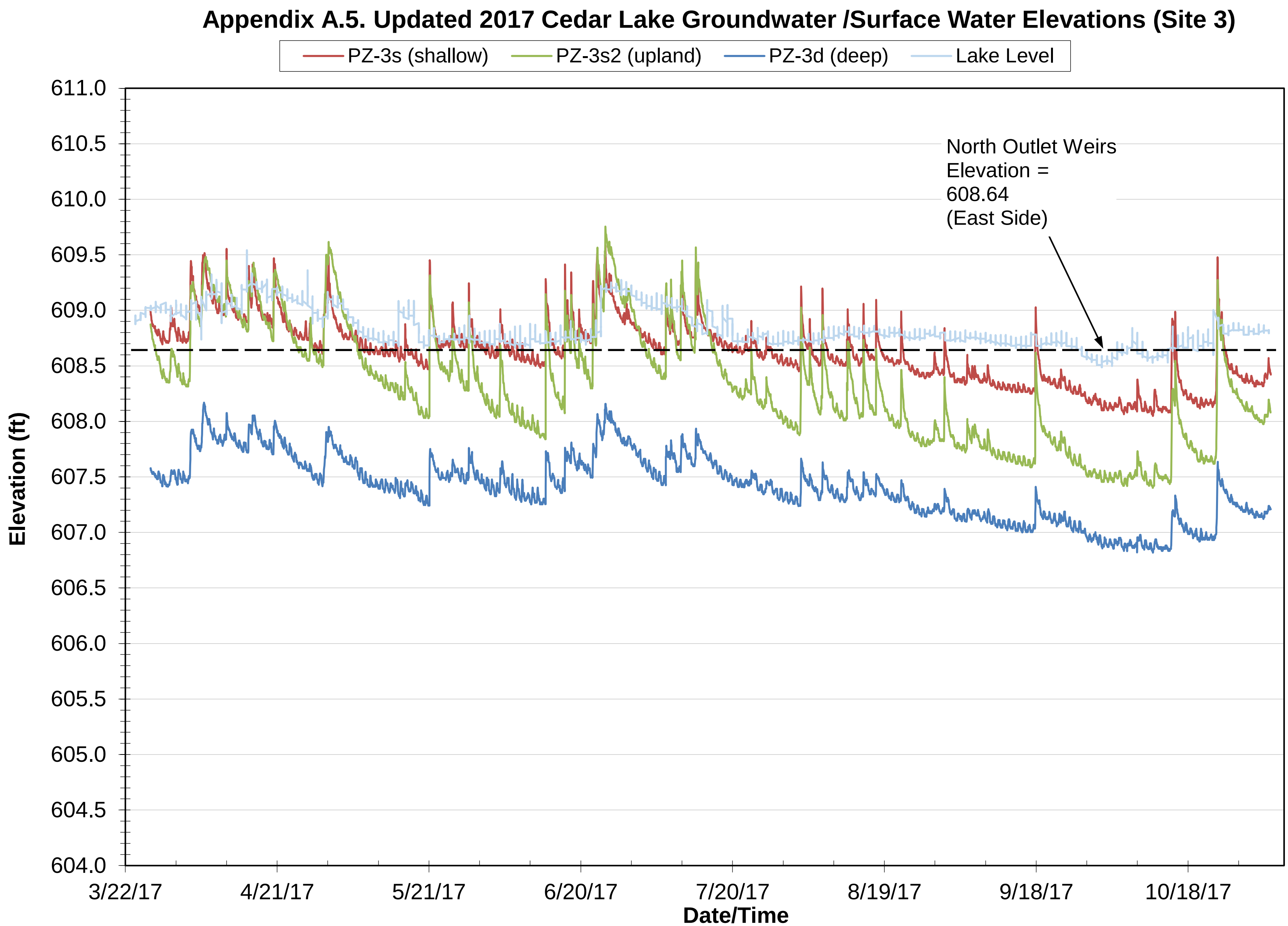

Note: This graph presents updated 2017 Site 3 water elevations, which were previously reported using the incorrect top of casing elevations.

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Appendix A.6. Updated 2016 Cedar Lake Groundwater /Surface Water Elevations (Site 6)

Note: This graph presents updated 2016 Site 6 water elevations, which were previously plotted and reported incorrectly.

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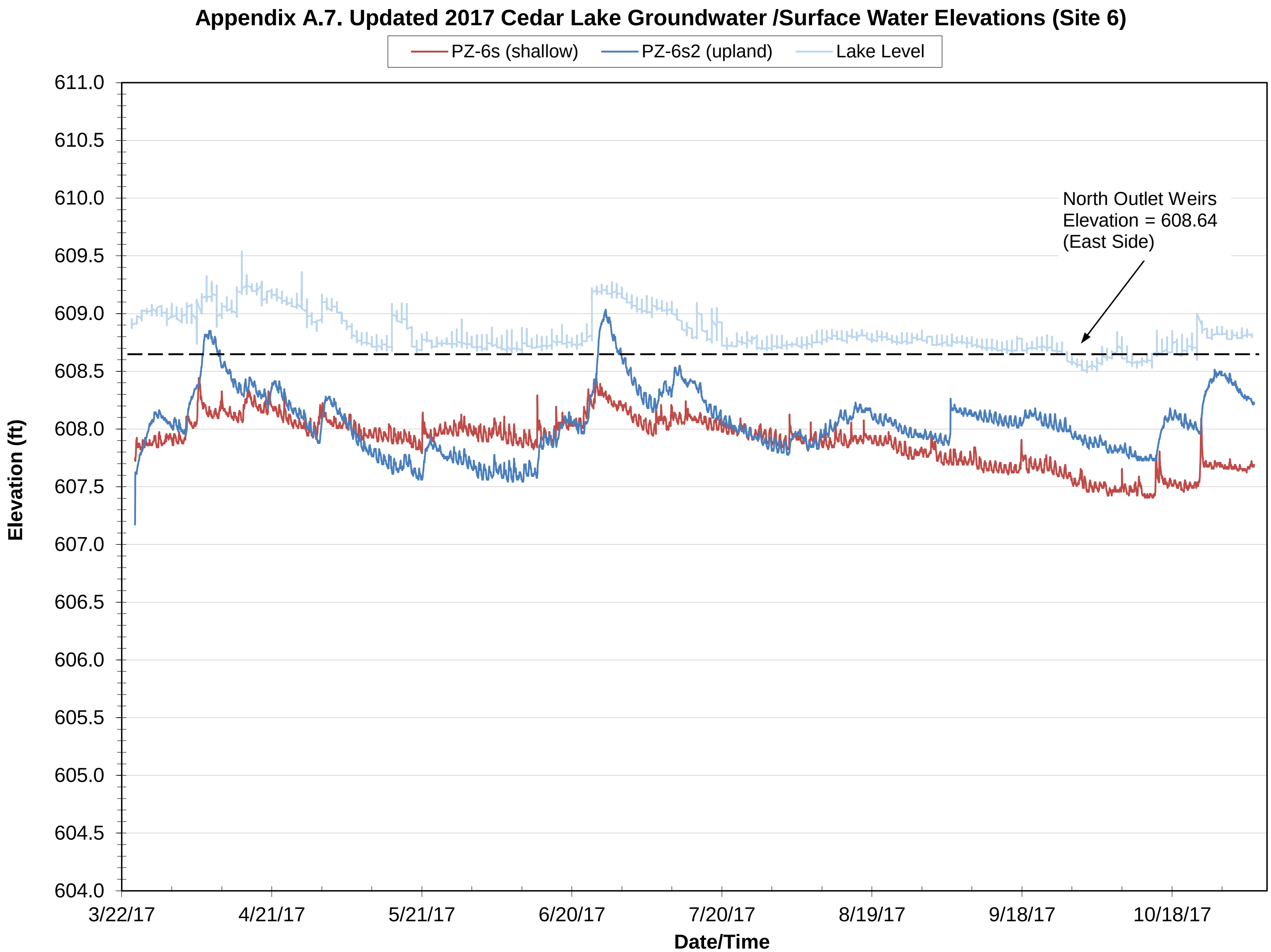

Note: This graph presents updated 2017 Site 6 water elevations, which were previously plotted and reported incorrectly.

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