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Seaside Groundwater Basin
2018 Seawater Intrusion Analysis Report

SEASIDE GROUNDWATER BASIN WATERMASTER
MONTEREY COUNTY, CALIFORNIA

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1 EXECUTIVE SUMMARY

This report fulfills part of the annual reporting requirements contained in the Seaside Groundwater Basin Adjudication (California American Water v. City of Seaside, Monterey County Superior Court, Case Number M66343). The annual report addresses the potential for, and extent of, seawater intrusion in the Seaside Groundwater Basin.

Seawater intrusion may occur in basic hydrogeologic conditions as a wedge beneath fresh groundwater, or in more complex hydrogeology with various intrusion interfaces among the different aquifers. Continued pumping in excess of recharge and fresh water inflows, coastal groundwater levels well below sea level, and ongoing seawater intrusion in the nearby Salinas Valley all suggest that seawater intrusion could occur in the Seaside Groundwater Basin.

Seawater intrusion is typically identified through regular chemical analyses of groundwater which can identify geochemical changes in response to seawater intrusion. No single analysis definitively identifies seawater intrusion, however by looking at various analyses we can ascertain when fresh groundwater mixes with seawater. At low chloride concentrations, it is often difficult to identify incipient seawater intrusion. This is due to the natural variation in fresh water chemistry at chloride concentrations below 1,000 milligrams per liter (mg/L). Mixing trends between groundwater and seawater are more easily defined when chloride concentrations exceed 1,000 mg/L. Common geochemical indicators of seawater intrusion are cation and anion ratios, chloride trends, sodium/chloride ratios, and electric induction logging.

Based on an evaluation of geochemical indicators for Water Year 2018 and prior, no seawater intrusion has historically been or is currently observed in existing monitoring and production wells in the Seaside Groundwater Basin.

Data which indicate that seawater intrusion is not occurring are described in the bulleted items below:

- All groundwater samples for Water Year 2018 from depth-discreet monitoring wells plot generally in a single cluster on Piper diagrams, with no water chemistry changes towards seawater.

- Groundwater quality plot on Piper diagrams in some of the production wells is different than the water quality in the monitoring wells. This may be a result of mixed water quality from both shallow and deep zones in which these wells are perforated. None of the production wells' groundwater qualities are indicative of seawater intrusion.

- None of the Stiff diagrams for monitoring and production wells show the characteristic chloride spike that typically indicates seawater intrusion in Stiff diagrams.
- Overall, chloride concentration trends were stable for most monitoring wells, with no increases greater than 10 mg/L.
- Sodium/chloride molar ratios in the monitoring wells remained constant or increased over the past year.
- Maps of chloride concentrations for the shallow aquifer do not show chlorides increasing towards the coast. The deep aquifer maps show that higher chloride concentrations are limited to coastal monitoring wells PCA-West Deep and MSC Deep, but these are not indicative of seawater intrusion.
- Induction logging data at the coastal Sentinel Wells do not show large changes over time that are indicative of seawater intrusion.

The following groundwater level and production data suggest that conditions in the basin continue to provide a potential for seawater intrusion:

- All deep groundwater in the Northern Coastal subarea is below sea level. The 2nd quarter (winter/spring) deep aquifer coastal groundwater levels are more than 12 feet below sea level and the 4th quarter (summer/fall) levels are more than 25 feet below sea level. These are similar to the historic low levels observed in Water Year 2016 at the end of the recent drought.
- Groundwater levels remain below protective elevations in all deep target monitoring wells (MSC deep, PCA-W, and sentinel well SBWM-3). Currently, only one of the three shallow wells' groundwater levels are above protective elevations: CDM-MW4. Since 1997, PCA-W shallow groundwater levels has been above protective elevations but has just fallen below its protective elevation this fall; probably due to increased shallow aquifer production that started in 2015. As observed historically, MSC shallow groundwater levels remains below protective elevations.

Due to its distance from the coast, seawater intrusion is not an issue of concern in the Laguna Seca subarea. However, groundwater levels in the eastern Laguna Seca subarea have historically declined at rates of 0.6 feet per year in the shallow aquifers, and up to four feet per year in the deep aquifers. These declines have occurred since 2001, despite triennial reductions in allowable pumping. The cause of the declines is due in part to the Natural Safe Yield of the subarea being too high and in part due to the influence of wells to the east of the Seaside Basin. Since 2014, however, the rate of decline is less and now appears close to stabilizing.

Native groundwater production in the Seaside Groundwater Basin for Water Year 2018 was 3,363.4 acre-feet, which is 314 acre-feet more than Water Year 2017. This amount is 3.4 acre-feet more than the Decision-ordered Operating Yield of 3,360 acre-feet per year that is required between October 1, 2017 and September 30, 2020.

Based on the findings of this report, there are no specific recommendations that relate to the collection of groundwater data from existing wells used in the seawater intrusion analysis, other than to continue analyzing and reporting on groundwater quality, groundwater levels, and production each year. However, as projects that recharge and recover water into the Basin are implemented, groundwater levels and thus groundwater flow directions will change, and possibly groundwater quality too. It is important that data from new monitoring wells are reported to the Watermaster and taken into consideration in future SIARs.

2 BACKGROUND AND INTRODUCTION

Historical and persistent low groundwater elevations caused by pumping in the Seaside Groundwater Basin have led to concerns that seawater intrusion may threaten the Basin's groundwater resources. This report addresses the potential for, and extent of, seawater intrusion in the Seaside Groundwater Basin. The report first reviews seawater intrusion mechanisms, analyzes historical water quality data for indications of seawater intrusion in the Seaside Groundwater Basin, and finally reaches conclusions on the extent of seawater intrusion and proposes recommendations for continued monitoring.

This report fulfills part of the annual reporting requirements contained in the Seaside Groundwater Basin Adjudication (California American Water v. City of Seaside, Monterey County Superior Court, Case Number M66343). The analyses in this report were developed by HydroMetrics Water Resources Inc. of Oakland, CA, in cooperation with members of the Watermaster Technical Advisory Committee (TAC). Staff from the Monterey County Water Resources Agency (MWCRA) and Monterey Peninsula Water Management District (MPWMD) provided invaluable assistance, data, and review during the preparation of this report.

This report is the eleventh in a series of Seawater Intrusion Analysis Reports (SIAR) which are produced annually by the Watermaster. It builds on the work performed in the preceding SIARs.

2.1 Overview of Seawater Intrusion

Seawater intrusion is a threat to many coastal groundwater basins along the California Coast. It has been observed and documented in a number of groundwater basins in both southern and central California.

In general, groundwater in coastal basins flows from recharge areas in local highlands towards discharge areas along the coast. In most undeveloped coastal groundwater basins there is a net outflow of fresh water into the ocean. Seawater intrusion occurs when the outflow of freshwater ceases and seawater flows into the groundwater basin from the ocean.

In the simplest condition, seawater intrudes as a wedge beneath the fresh groundwater (**Figure 1**). This wedge shape is a result of seawater being denser than freshwater.

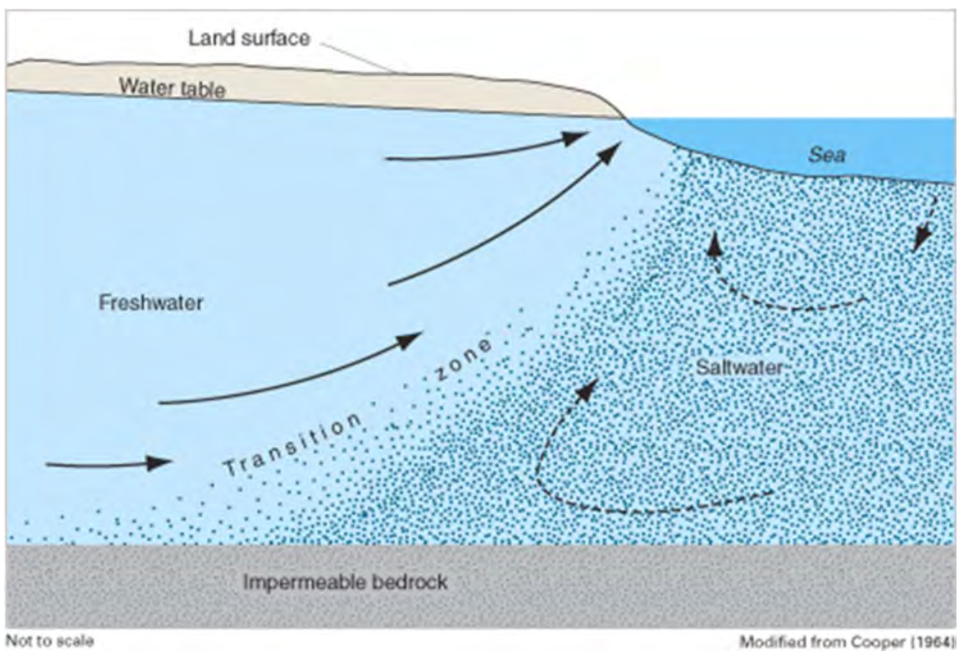


Figure 1. Seawater Wedge in a Simple Coastal Aquifer (from Barlow, 2003)

In more complex, layered groundwater systems, the location of the seawater/freshwater interface may vary among the different aquifers. Such a situation is illustrated on **Figure 2**. **Figure 2** shows a series of aquifers in blue, which transmit water easily. The aquifers are separated by a series of tan aquitards, which transmit water relatively slowly. Each aquifer has a unique rate of outflow to the ocean, and therefore a unique location of the seawater interface. In these more complex situations, the locations of the seawater/freshwater interfaces are a complex function of the horizontal groundwater gradient in each aquifer, the aquifer hydraulic conductivities, and the vertical conductivity of the inter-layer aquitards.

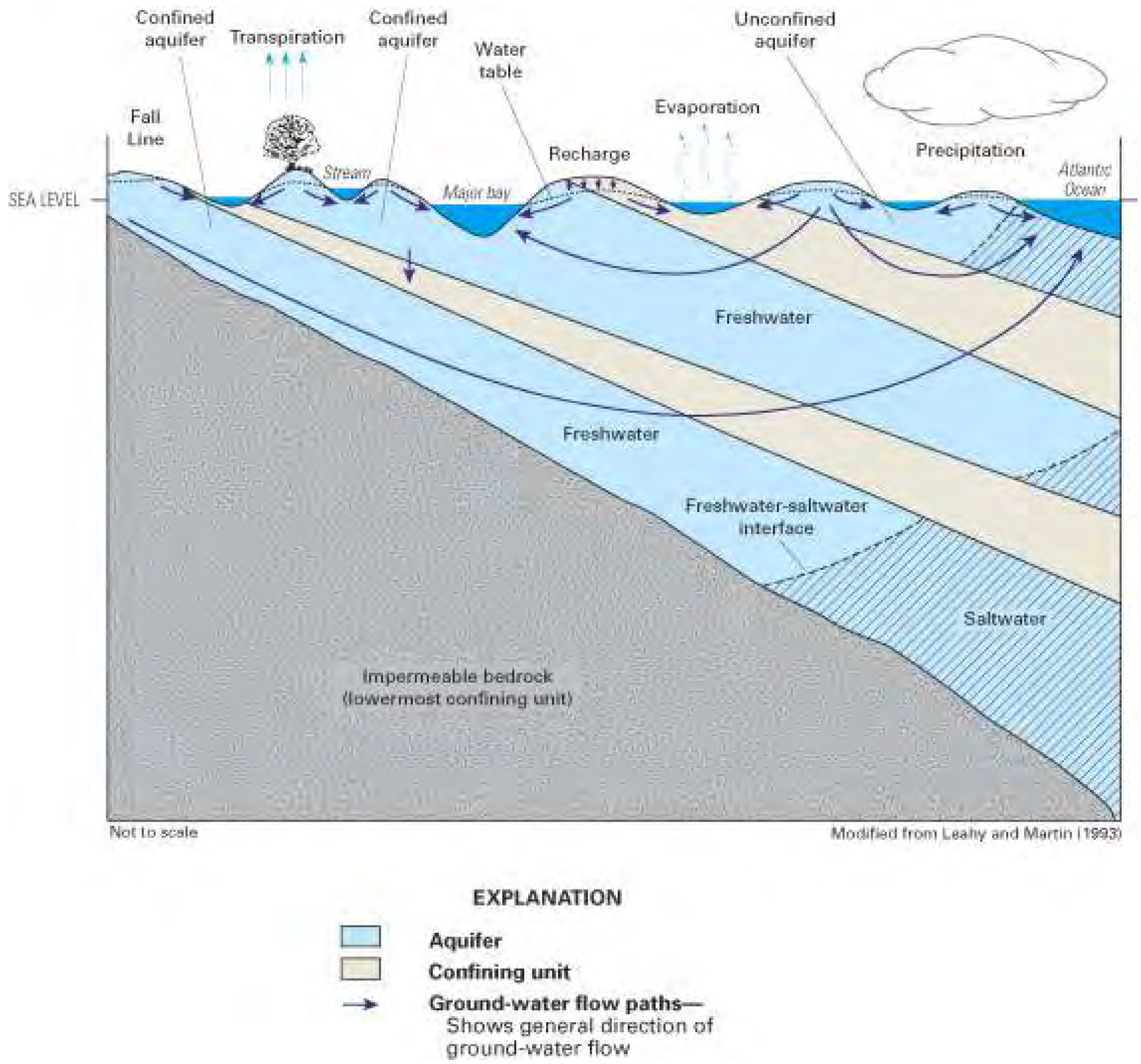


Figure 2. Seawater Wedge in a Layered Coastal Aquifer (from Barlow, 2003)

Figure 2 shows that under non-pumping conditions, the seawater interface in confined units can be located farther offshore than in surficial unconfined aquifers. The fresh water in an unconfined aquifer can flow readily into the ocean, allowing the seawater interface to exist near shore. Fresh water in the lower confined aquifers must seep out slowly through the overlying confining units. The slow seepage rates allow the fresh water to maintain pressure beneath the sea floor, pushing the seawater interface away from the coastline.

2.2 Groundwater Pumping and Seawater Intrusion

Pumping groundwater in a coastal aquifer reduces the amount of water discharging to the ocean. Sufficient pumping can eliminate ocean discharges, either locally or basin-wide, triggering seawater intrusion. The response of the seawater interface to groundwater pumping is manifested in two related ways: upconing and interface migration. Upconing refers to the ability of a pumping well to draw seawater up from below. Upconing only occurs if seawater exists directly below a pumping well. Because no seawater intrusion has been observed in the Seaside Groundwater Basin, upconing cannot occur, and only seawater interface migration will be further addressed in this report.

As mentioned earlier, groundwater pumping reduces the amount of fresh water outflow to the ocean. This allows the interface to migrate shoreward. Substantial pumping can allow the interface to move onshore, potentially impacting municipal wells, private wells, or agricultural wells. **Figure 3** shows a two-dimensional cross section of how the fresh water/seawater interface may migrate in response to pumping.

As can be inferred from **Figure 3**, the degree of interface migration depends on the amount of water pumped from a particular aquifer, as well as the amount of leakage from overlying or underlying aquifers. Groundwater extracted from the lowest aquifer might be replaced by rainfall recharge, by seawater migrating shoreward, or by groundwater leaking from the overlying aquifer.

An additional issue that must be considered with seawater interface migration is the initial location of the seawater interface. An interface that starts far from the shore may take a considerable amount of time, often on the order of decades, to reach any production or monitoring well. Furthermore, the farther the interface is from the pumping well, the more area is available for fresh water to leak from overlying aquifers into the producing aquifer. This slows, or may completely stop, seawater intrusion in the pumped aquifer. Downward leakage, however, removes fresh water from overlying aquifers. This leakage may therefore exacerbate seawater intrusion in the overlying aquifer.

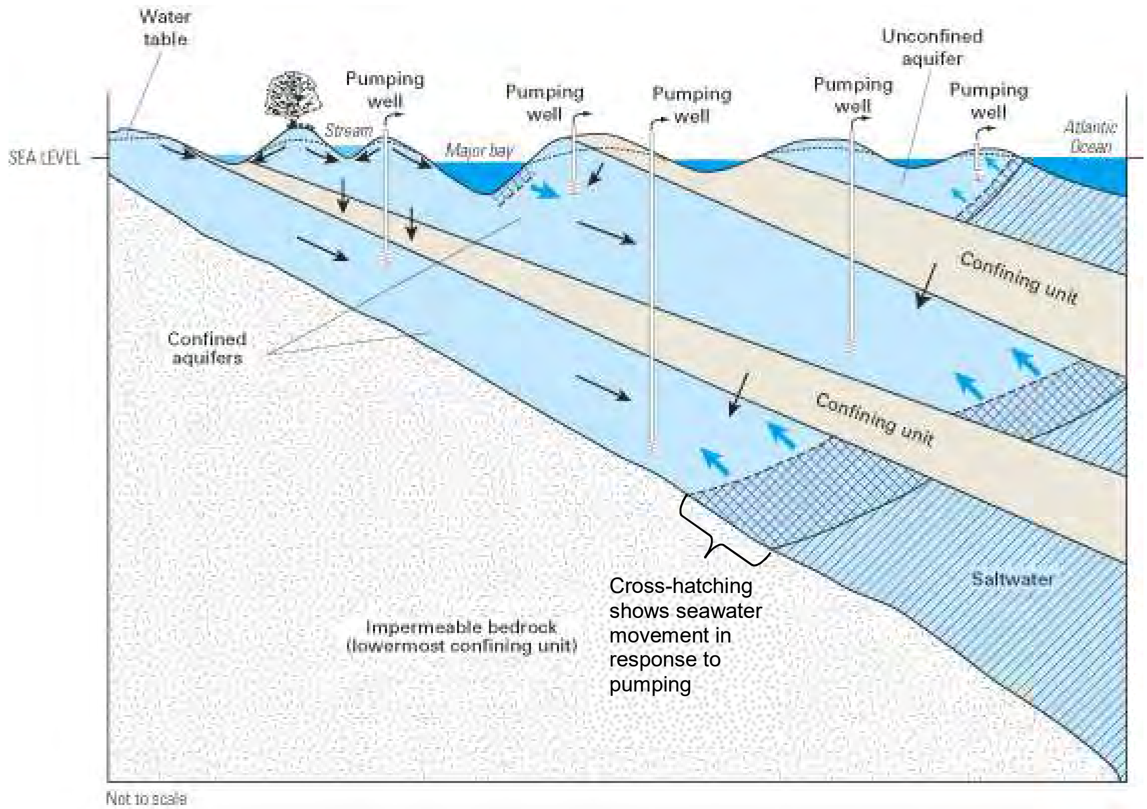


Figure 3. Interface Migration in Response to Groundwater Pumping (from Barlow, 2003)

2.3 Indicators of Seawater Intrusion

Seawater intrusion is generally identified through chemical analyses of groundwater. Groundwater levels below or near sea level indicate an opportunity for seawater intrusion, but the actual seawater intrusion is indicated by various geochemical changes in groundwater.

No single analysis definitively identifies seawater intrusion, however by looking at various analyses we can ascertain when fresh groundwater mixes with seawater. At low chloride concentrations, it is often difficult to identify incipient seawater intrusion. This is due to the natural variation in fresh water chemistry at chloride concentrations below 1,000 milligrams per liter (mg/L) (Richter and Kreitler, 1993). Mixing trends between groundwater and seawater are more easily defined when chloride concentrations exceed 1,000 mg/L

Common geochemical indicators of seawater intrusion are discussed, and example analyses are presented, in the following sections.

2.3.1 Cation/Anion Ratios

Molar ratios of cations and anions can prove distinctive for various groundwater systems. Seawater intrusion is often indicated by graphically analyzing shifts in these molar ratios. Two common graphical techniques for these analyses are Piper diagrams and Stiff diagrams.

Piper Diagrams

Example Piper diagrams are shown for data from the Pajaro Valley and Salinas Valley on **Figure 4** and **Figure 5**, respectively. These figures are included to demonstrate the utility of Piper diagrams, and show how they have been used in nearby basins. These figures are not provided for directly comparing data between basins; groundwater quality trends in one basin will not necessarily correlate with trends in other basins.

On these Piper diagrams, the relative abundances of individual cations and anions are plotted in the left and right triangles, respectively, and their combined distribution is plotted in the central diamond. Waters from similar or related sources will generally plot together. The mixture of two waters will generally plot along a straight line between the two end-member types within the central diamond. The trend towards seawater intrusion, however, often plots along a curved path as shown on **Figure 4**. The red arrows track the evolution of water chemistry from freshwater to seawater. Often only the first, upward leg of this curve is observed, because wells become too saline to use before reaching the downward leg, and sampling is usually discontinued.

Stiff Diagrams

Example Stiff diagrams from the Salinas Valley are shown on **Figure 6** and **Figure 7**. These figures are included to demonstrate the utility of Stiff diagrams, and show how they have been used in nearby basins. On Stiff diagrams, the relative abundances of individual cations are plotted on the left side of the graph, and the relative abundances of anions are plotted on the right side of the graph. Waters with similar chemistries will have similarly shaped Stiff diagrams.

Figure 6 shows Stiff diagrams characteristic of the unintruded portions of the Salinas Valley Pressure 400-Foot Aquifer. By contrast, **Figure 7** shows Stiff diagrams from the intruded portion of the Salinas Valley Pressure 400-Foot Aquifer. The significantly higher chloride levels in the intruded aquifer result in the noticeable spike at the upper right-hand side of the Stiff diagrams on **Figure 7**. This spike is indicative of incipient seawater intrusion.

The Stiff diagrams shown on **Figure 7** are from wells that have acknowledged seawater intrusion, based on multiple lines of evidence. The Stiff diagrams alone are often not sufficient to identify seawater intrusion because there is no standard for Stiff diagram shapes; the diagrams are most useful as a comparative tool, showing the evolution of water chemistry over time and space. The shape of these Stiff diagrams is considered indicative of seawater intrusion in Salinas Valley only because considerable data analyses have shown that locally, Stiff diagrams adopt this shape as seawater encroaches.

The Stiff diagrams of seawater intruded wells shown on **Figure 7** show calcium concentrations greater than sodium concentrations, in spite of the fact that sodium in the dominant cation in seawater. Incipient seawater intrusion is often characterized by increasing calcium and decreasing sodium, due to cation exchange between sodium and calcium on the aquifer material. This concept is discussed further on page 14.

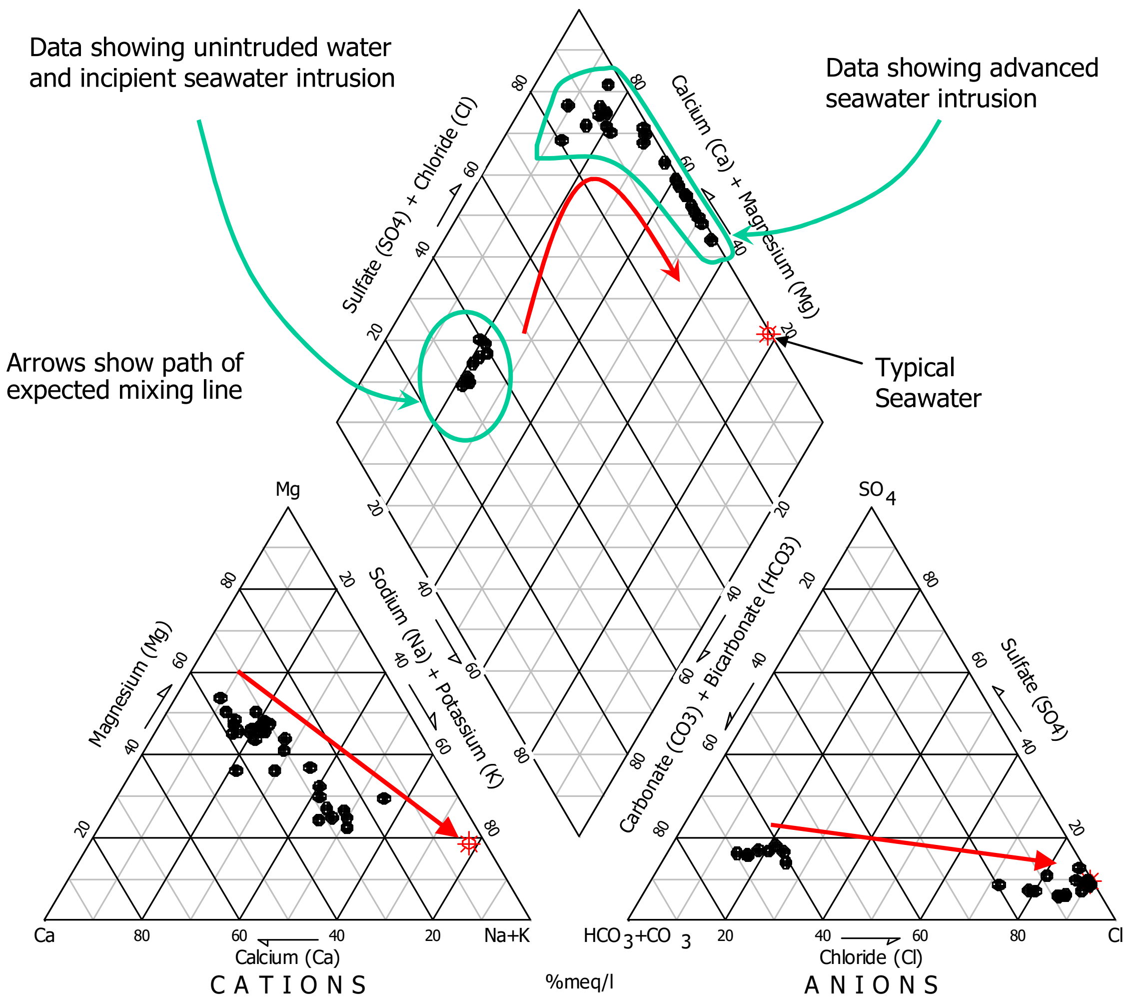


Figure 4. Piper Diagram for Groundwater in Pajaro Valley (Data source: PVWMA)

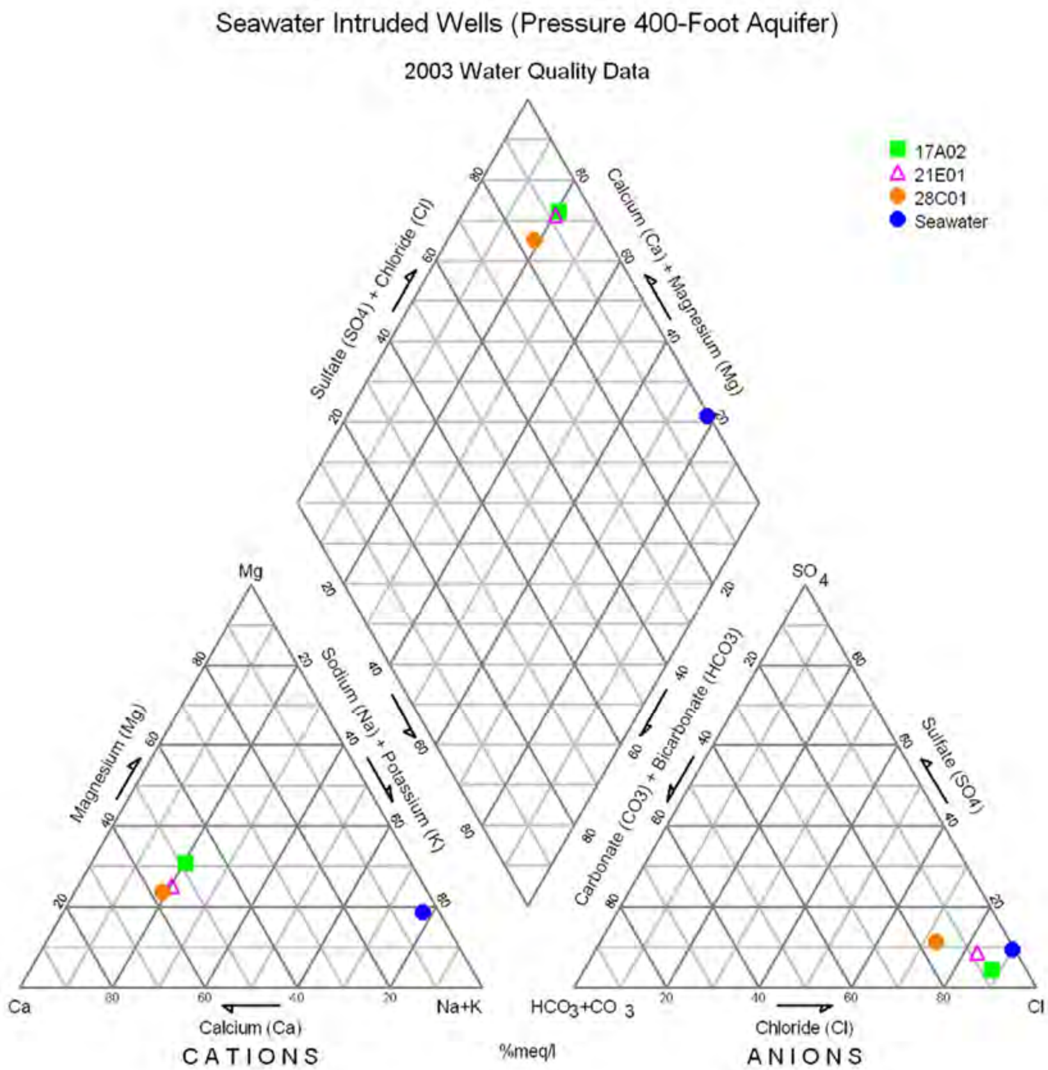


Figure 5. Piper Diagram for Groundwater in Salinas Valley (Source: MCWRA)

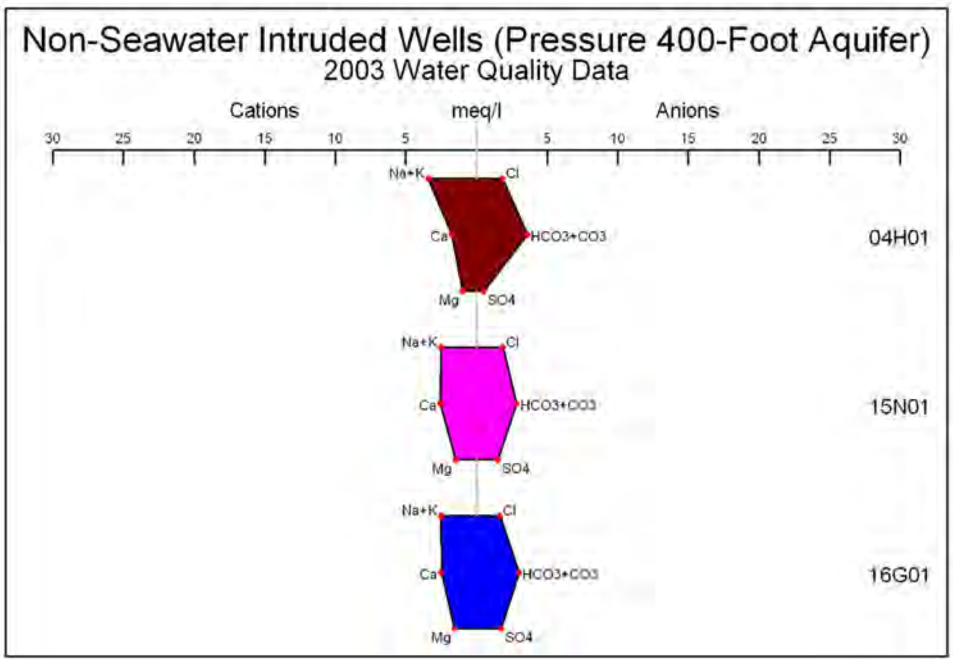


Figure 6. Stiff Diagrams from Salinas Valley Wells without Seawater Intrusion (Source: MWCRA)

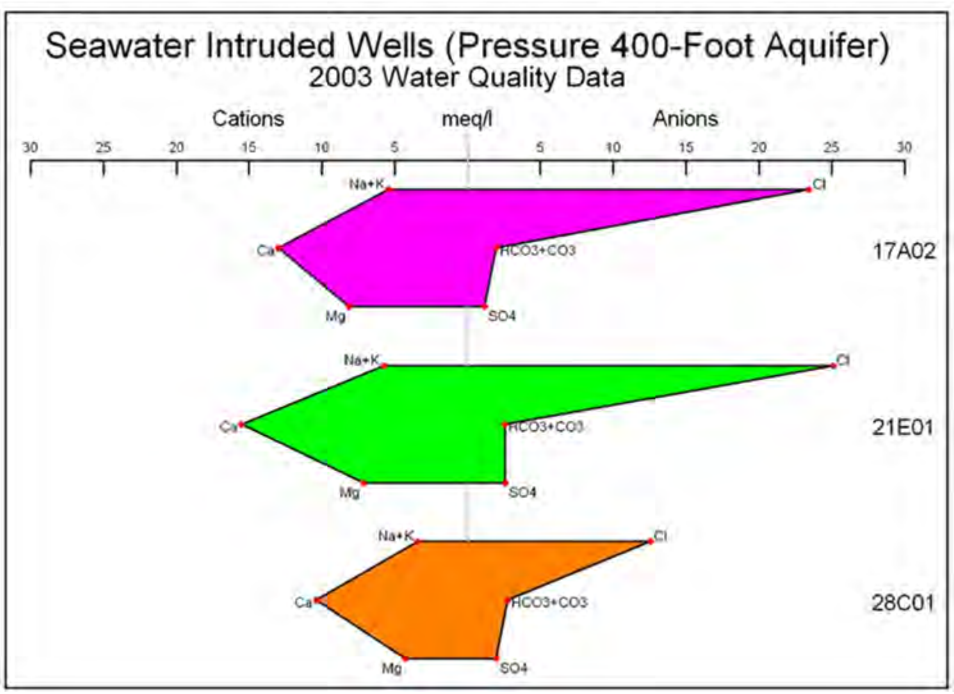


Figure 7. Stiff Diagrams from Salinas Valley Wells with Seawater Intrusion (Source: MWCRA)

2.3.2 Increasing Chloride Concentrations

Seawater is chloride rich, whereas bicarbonate or sulfate are the dominant anions in many groundwater systems. Steadily increasing chloride concentrations over time is the one of the most commonly used indicators of seawater intrusion. At low chloride concentrations, trends are often as important as absolute concentrations because of natural variations in groundwater chemistry. As an example, in 2004 the coastal shallow Pacific Cement Aggregates (PCA) West well had a chloride concentration of 46 mg/L, whereas the much more inland well 2701882-016, located in the Laguna Seca subarea, had a chloride concentration of 225 mg/L. The higher chloride concentration in well 2701882-016 is fairly consistent, showing no increasing trend, and is clearly not an indicator of seawater intrusion.

Example graphs showing historical chloride concentration increases indicative of seawater intrusion are shown on **Figure 8** and **Figure 9**. **Figure 8** graphs steadily increasing chloride concentrations in a shallow well in the Salinas Valley. **Figure 9** graphs increasing chloride concentrations in a well in the Pajaro Valley. Both of these graphs show that the rise in chlorides is a lengthy and persistent process; chloride concentrations began to increase in the representative Salinas Valley well in 1982, and took six years before exceeding the Safe Drinking Water Act secondary drinking water standard of 250 mg/L. This long-term and relatively slow increase in chlorides suggests that while chloride concentrations are strongly indicative of seawater intrusion, it often takes time for the increasing chloride trend to be recognizable.

2.3.3 Sodium/Chloride Molar Ratios

As mentioned earlier in this report, sodium often replaces calcium on the aquifer matrix through ion exchange in advance of the seawater front. This effectively removes sodium from the water, and sodium/chloride ratios drop in advance of the seawater front. This can sometimes be used as an early indicator of seawater intrusion. Sodium/chloride ratios can also be used to differentiate between seawater intrusion and other sources of saltwater. Jones et al. (1999) suggest that sodium/chloride ratios in advance of a seawater intrusion front will be below 0.86 (molar ratio). This distinguishes seawater intrusion from domestic waste water, which typically has sodium/chloride ratios above 1.

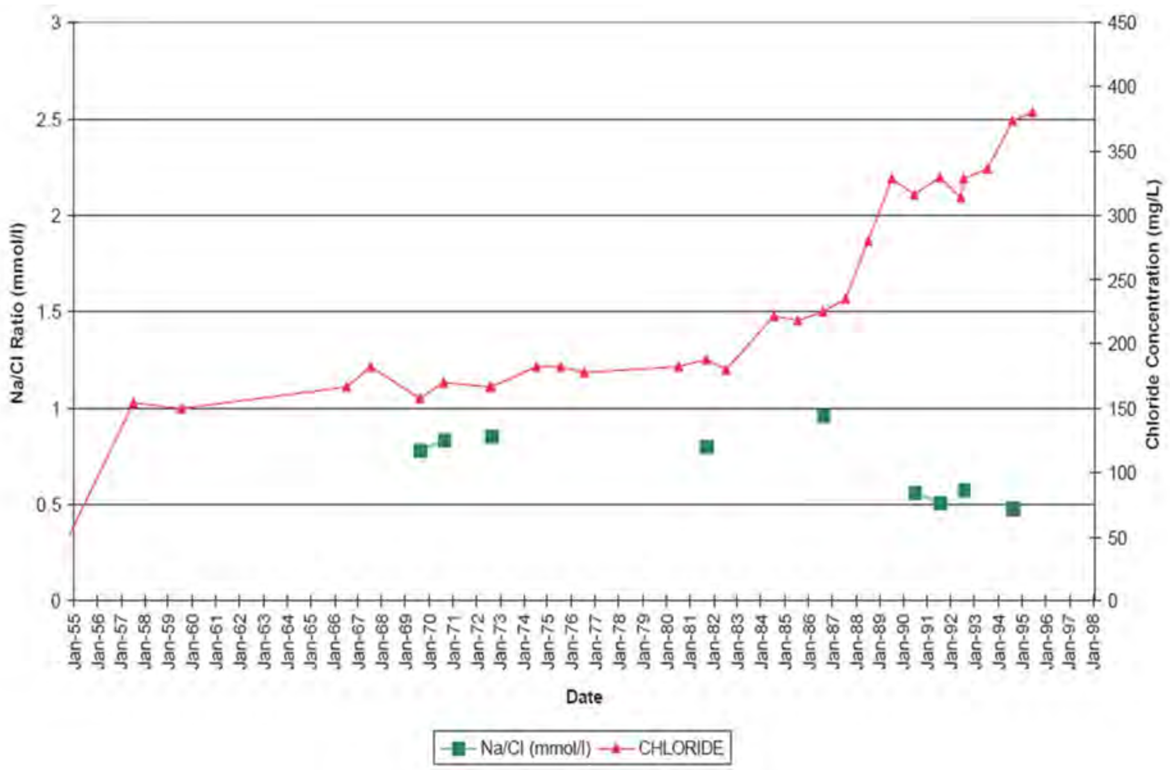


Figure 8. Historical Chloride Concentrations and Sodium/Chloride Ratios for a Well in Salinas Valley Showing Incipient Intrusion (Source: MCWRA)

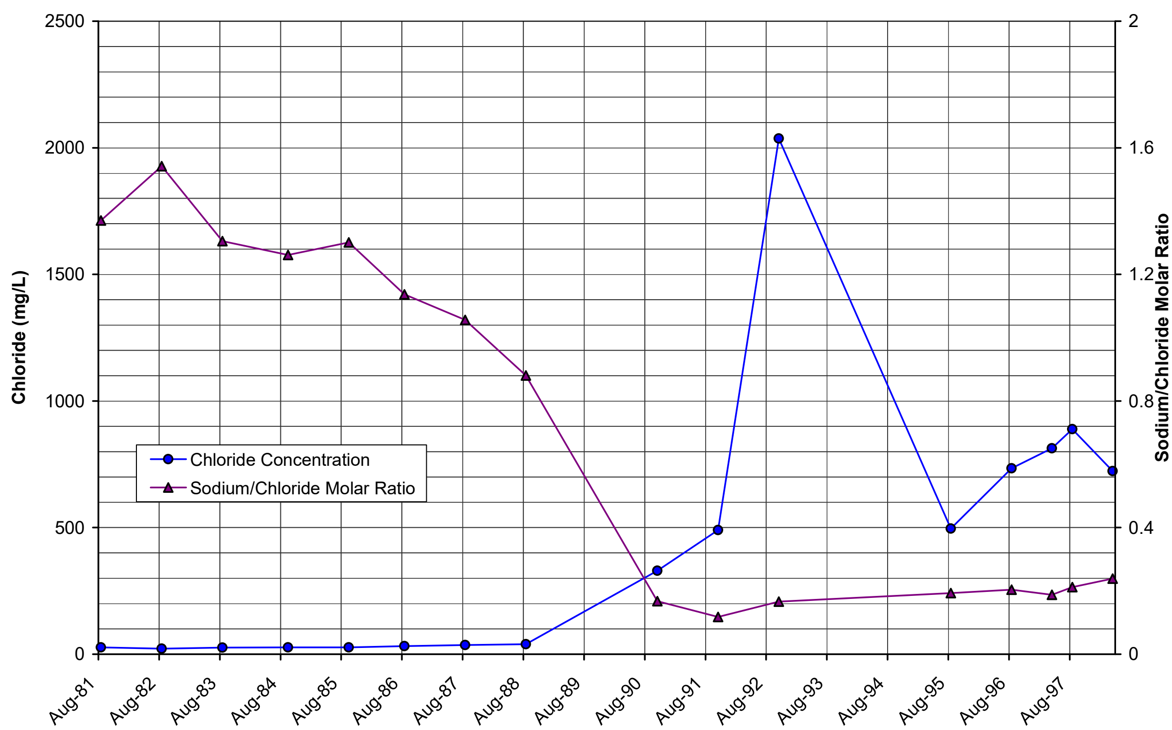


Figure 9. Historical Chloride Concentrations and Sodium/Chloride Ratios for a Well in Pajaro Valley Showing Incipient Intrusion (Data source: PVWMA)

In addition to plotting increasing chloride concentrations, decreasing sodium/chloride ratios are plotted on **Figure 8** and **Figure 9**. The strong correlation between the two indicators of seawater intrusion can be observed on these two figures. The potential utility of sodium/chloride ratios as an early indicator of seawater intrusion is shown on **Figure 9**. This figure shows that by August 1988, chloride concentrations in the Pajaro Valley well had remained relatively constant, yet sodium/chloride ratios were beginning to drop, suggesting incipient seawater intrusion. By September 1990, the rising chloride levels can be clearly correlated to dropping sodium/chloride ratios; definitively associating the high chlorides with seawater intrusion.

2.3.4 Chloride-Bicarbonate Ratios

The ratio of chloride to bicarbonate-plus-carbonate contrasts the relative abundance of the dominant seawater and freshwater anions. As a ratio of concentrations expressed in mg/L, the ratio for seawater exceeds 100 and values for groundwater unaffected by seawater are generally less than 0.3. For groundwater with relatively low total dissolved solids, this ratio provides little benefit over evaluating chloride concentrations alone; and therefore is not used in the current analyses.

2.3.5 Electric Induction Logs

Changes in formation salinity can be measured from within a well using electric induction logging. Induction logging within the well measures the fluid conductivity within the adjacent formation up to a distance of three feet from the well casing. This technique can be used in wells that are completed with PVC casings and screens.

This method can be used as a cost-effective method of detecting seawater intrusion by measuring the electrical conductivity of the formation throughout the depth of the well. If over time, the conductivity increases relative to the baseline value, it could indicate seawater intrusion. One limitation of this method is that it does not provide concentrations of chloride or other ions that contribute to salinity. Therefore, the use of electric induction logs can only be used qualitatively.

Induction logging has been performed on the Watermaster’s coastal Sentinel Wells since their completion in 2007.

2.3.6 Other Indicators

Hem (1989) suggested several other indicators for seawater intrusion, including the concentration ratio of calcium to magnesium (approximately 0.3 in seawater and greater in fresh water); the percentage of sulfate among all ions (approximately 8 percent in seawater and larger in fresh water); and the concentrations of minor constituents such as iodide, bromide, boron, and barium. These other indicators are not used in the current analyses for two reasons:

1. The analyses presented in the following sections overwhelmingly suggest that seawater intrusion has not advanced onshore in the Seaside Groundwater Basin.

2. No historical data exists for the minor constituents such as iodide and barium; and only limited historical data exist for bromide and boron. It should be noted that since 2012, the Watermaster has been analyzing samples from selected coastal monitoring and production wells for iodide, bromide, boron, and barium.

Using the other indicators mentioned above is not necessary in light of there being other methods available for indicating seawater intrusion, as discussed in the preceding sections. Should the other methods start showing seawater intrusion, the minor constituents of iodide, bromide, boron, and/or barium will be included in future water quality analyses so that they can be used as supplemental indicators.

3 SEAWATER INTRUSION IN THE SEASIDE GROUNDWATER BASIN

The geochemical criteria discussed above, along with various maps showing spatial distributions of concentrations, can be used to estimate the presence or lack of seawater intrusion in the Seaside Groundwater Basin. While no single analysis is a definitive indicator of seawater intrusion, the combined weight of all analyses may be instrumental in detecting seawater intrusion.

3.1 Analysis Approach

As was used in previous Seawater Intrusion Analysis Reports (RBF, 2007; HydroMetrics LLC, 2008; HydroMetrics LLC, 2009a; HydroMetrics WRI, 2010; HydroMetrics WRI, 2011; HydroMetrics WRI, 2012a; HydroMetrics WRI, 2013a; HydroMetrics WRI, 2014; HydroMetrics WRI, 2015; HydroMetrics WRI, 2016b; HydroMetrics WRI, 2017b), this SIAR includes a number of approaches to evaluate seawater intrusion. Data for the 2nd quarter of Water Year 2018 (sampled and measured January-March 2018) and 4th quarter of Water Year 2018 (sampled and measured July-September 2018) were analyzed and mapped to show the spatial distribution of groundwater quality and groundwater elevations. In addition to spatial mapping, historical data are graphed to assess geochemical trends. Data from the 2nd quarter represents conditions during the wet time of the year; data from the 4th quarter represents conditions during the dry time of the year. In some cases when samples or measurements are not collected strictly within the 2nd or 4th quarter, the quarter in which they were collected is provided with the data.

Where possible, analyses are separated by depth zone. Two depth zones have been chosen, following the system of Yates et al. (2005). Wells assigned to the shallow depth zone generally correlate to the Paso Robles Formation where it exists. This shallow zone is roughly at the same depth as the Salinas Valley Pressure 400-Foot Aquifer. Wells assigned to the deep zone correlate with the Santa Margarita Sandstone where it exists in the Seaside Groundwater Basin. The deep zone is roughly at the same depth as the Salinas Valley Pressure Deep Aquifers.

3.2 Cation/Anion Ratios

For Water Year 2018, 12 monitoring wells and 15 production wells were used for geochemical trend analyses. Locations of all monitoring and production wells used in the SIAR analysis are shown on **Figure** 10. Some of the production wells that were included in previous years' analysis are not included in the analysis this year because they have not been pumped during the year and thus not sampled. This year there are fewer monitoring wells included in the analysis because the Sentinel Wells are not included. After reevaluation of groundwater quality data from the Sentinel Wells and discussions with the TAC in early 2017, it was concluded that groundwater samples collected using the low flow sampler were more representative of water within the well casing and not from the groundwater in the aquifer surrounding the well. The groundwater quality data collected in the Sentinel Wells is not used in further seawater intrusion analysis.

Eleven monitoring wells used in this analysis represent one or both well pairs from the MPWMD monitoring well network and one is an observation well (**Figure** 10). A well pair comprises two wells drilled in close proximity to one another: one perforated in the shallow zone and the other perforated in the deep zone. Each well pair is represented with a unique color and symbol on Piper and Stiff diagrams. The shallow well of each pair is represented by a filled square on the Piper diagrams; the deep well of each pair is represented by a filled circle on the Piper diagrams.

The production wells included in the analysis are water purveyor wells that are sampled annually for general inorganic minerals per the Seaside Basin Monitoring and Management Program (Seaside Groundwater Basin Watermaster, 2006). The current schedule includes sampling selected coastal monitoring wells quarterly. All other monitoring and production wells are sampled annually during the 4th quarter. Where samples are not available for analysis, the text and figures indicate as such.

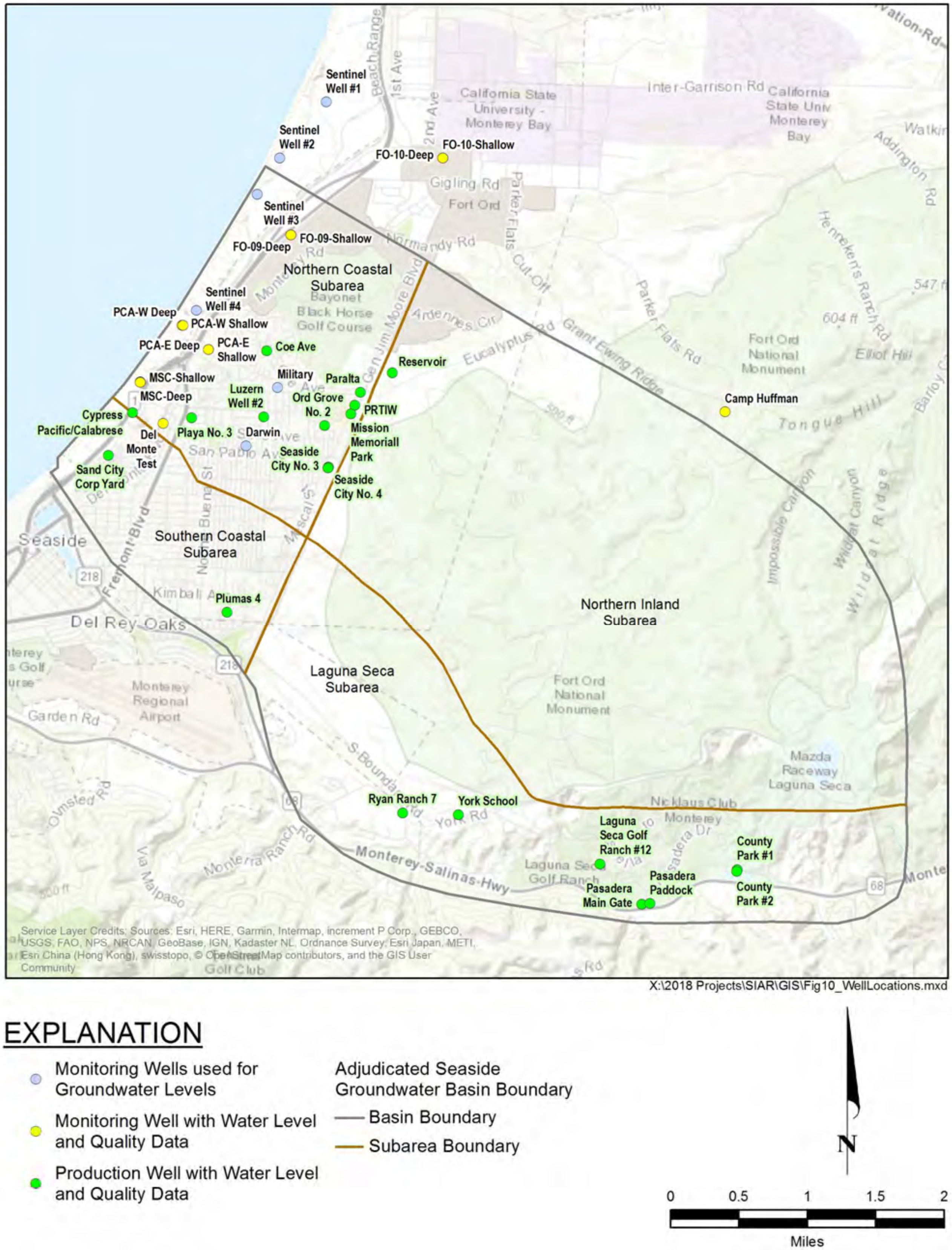


Figure 10. Wells Used for Seawater Intrusion Analyses

3.2.1 Second Quarter Water Year 2018 (January-March 2018)

A Piper diagram displaying analyses from six monitoring wells in the Seaside Groundwater Basin for the 2nd quarter Water Year 2018 (January-March 2018) is shown on **Figure 11**. Analyses from only six wells are shown because the Sentinel Wells are no longer sampled for groundwater quality (only used for induction logging), and most of the monitoring well pairs are not sampled during this quarter; they are only sampled annually in the 4th quarter. Appendix A includes individual Piper diagrams for each well to track their chemistry over time.

The monitoring wells generally cluster in a single area on the Piper diagram that is consistent with previous data. The location on the Piper diagram indicates that groundwater from both the deep and shallow well pairs straddle the sodium-chloride and sodium-bicarbonate type water[1].

Stiff diagrams for the monitoring wells sampled during the 2nd quarter of Water Year 2018 are shown in the left column on **Figure 12** through **Figure 14**. None of the Stiff diagrams show the high chloride spike shown on **Figure 7** that indicates seawater intrusion.

[1] Where the data points fall in the Piper diagram triangle for anions and the triangle for cations determines the type of water. For example, if the points plot in the lower right corner of the anion triangle, the water is classed as chloride type water.

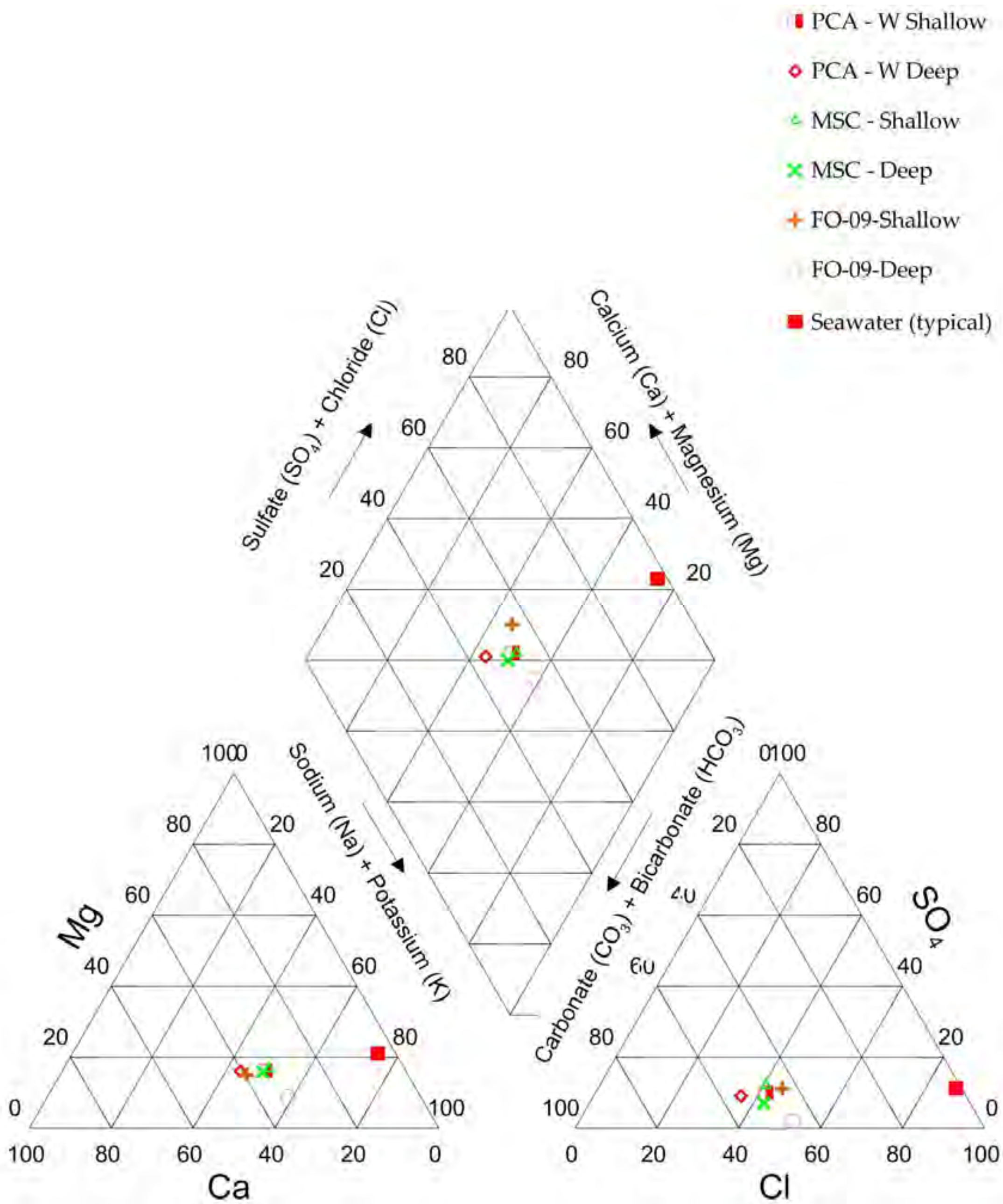


Figure 11. Piper Diagram for Seaside Groundwater Basin Monitoring Wells, 2nd Quarter Water Year 2018 (January-March 2018) (Data source: Watermaster)

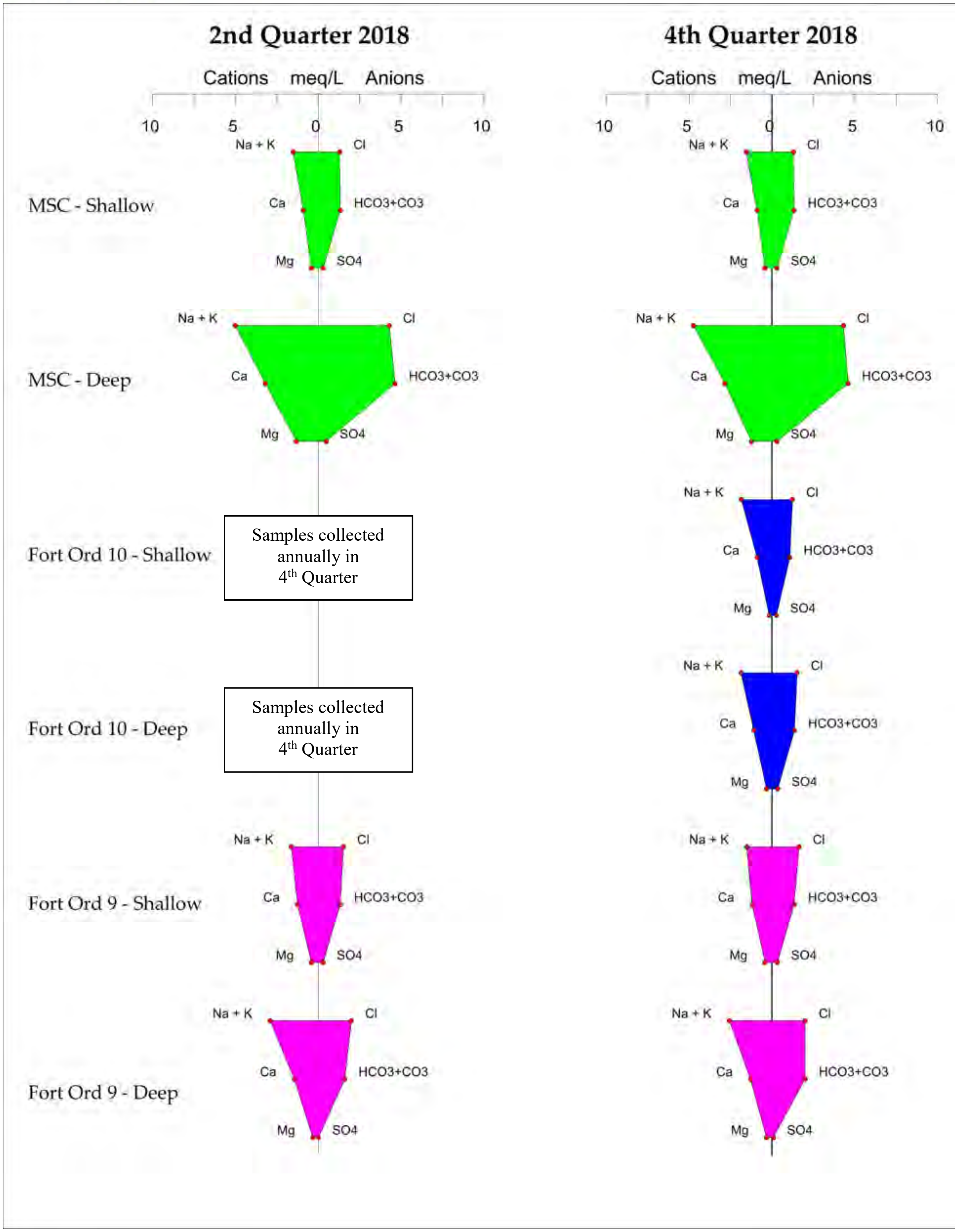


Figure 12. Stiff Diagrams for MSC, Fort Ord 9, and Fort Ord 10 Wells (Data source: Watermaster)

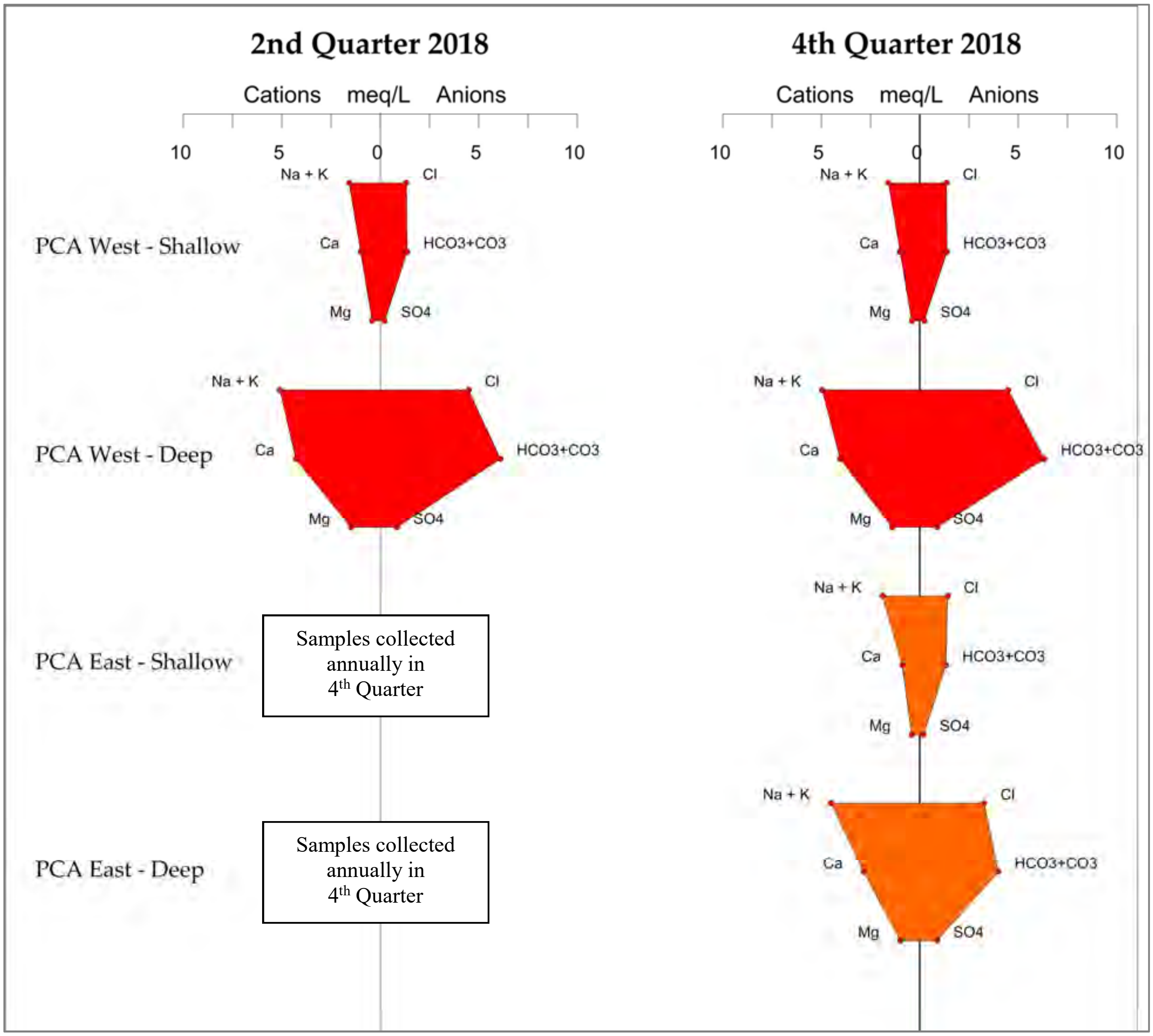


Figure 13. Stiff Diagrams for PCA West and PCA East Wells (Data source: Watermaster)

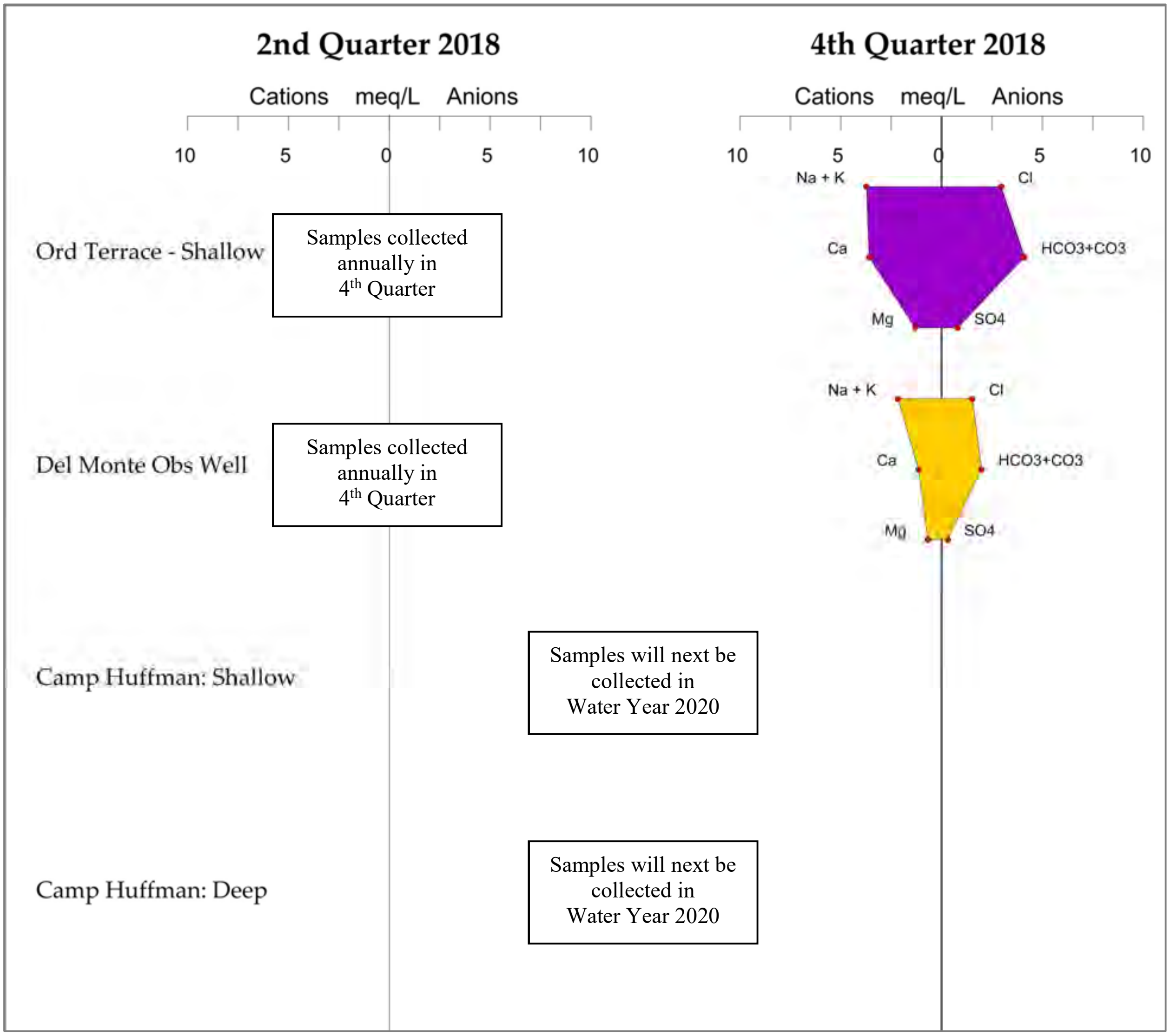


Figure 14. Stiff Diagrams for Watermaster Ord Terrace, Del Monte, and Camp Huffman Wells (Data source: Watermaster and MPWMD)

3.2.2 Fourth Quarter Water Year 2018 (July-September 2018)

Piper diagrams displaying groundwater quality data from 12 monitoring wells and 15 production wells in the Seaside Groundwater Basin for the 4th quarter of Water Year 2018 (July-September 2018) are shown on **Figure 15** and **Figure 16**, respectively. Appendix A includes individual Piper diagrams for each well to show trends over time.

Figure 15 shows groundwater quality data for the monitoring wells clustering generally in a single area on the Piper diagram, which is a pattern similar to that observed in previous SIARs. Groundwater is generally of a sodium-chloride/sodium-bicarbonate type and is not impacted by seawater.

Figure 16 presents a Piper diagram for 4th quarter groundwater from production wells. The production wells plot in roughly the same location on the Piper diagram as the majority of monitoring wells on **Figure 15**. The variation of the plot location on the Piper diagram for production wells is due to higher sulfate and chloride anions than in the monitoring wells. Groundwater from these wells is characterized as sodium-sulfate-chloride type waters. The York School well plots closest to typical seawater on this diagram, however its inland location precludes seawater intrusion as the cause for the observed water chemistry at this well. Overall, the Piper diagrams show no indication of seawater intrusion at any of the production wells.

The Sand City's Public Works Corp Yard production well Piper diagram shows that its cations, namely calcium, sodium, and potassium, vary while the anions remain more stable (Appendix A: Figure A-15). Initially it was thought this well's chemistry was evolving over time; but after multiple years of monitoring, it appears that the relative percentage of cations varies between fixed points and is not evolving in one direction only. The source of this variance is not seawater because it does not follow the pattern depicted on **Figure 4** and **Figure 5**.

Stiff diagrams for the 12 monitoring wells sampled during the 4th quarter of Water Year 2018 are shown in the right column on **Figure 12** through **Figure 14**. The shapes of the Stiff diagrams for the paired monitoring wells are similar to the shapes of the Stiff diagrams for the majority of prior years.

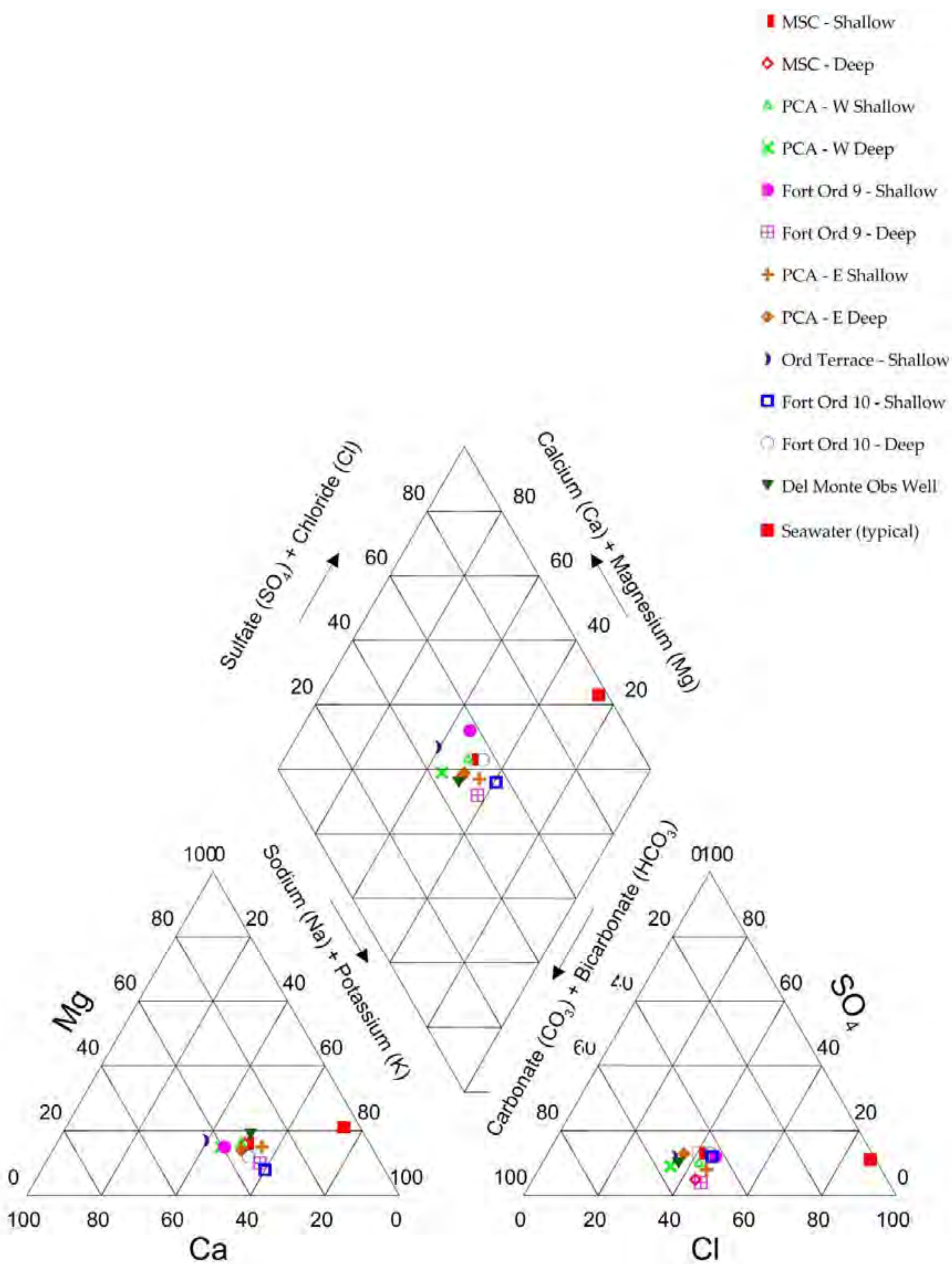


Figure 15: Piper Diagram for Seaside Groundwater Basin Monitoring Wells, 4th Quarter Water Year 2018 (July- September 2018) (Data source: Watermaster)

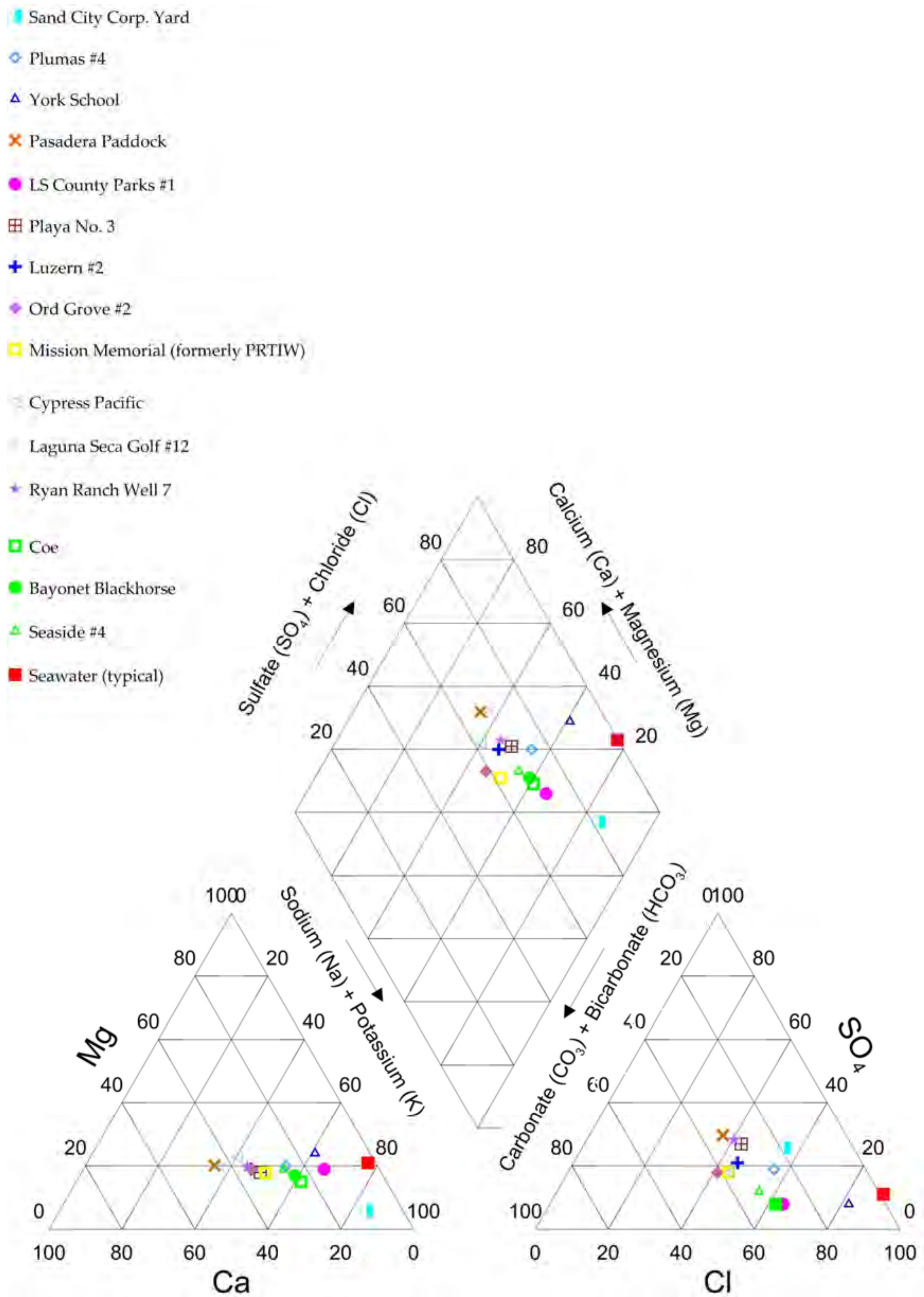


Figure 16: Piper Diagram for Seaside Groundwater Basin Production Wells, 4th Quarter Water Year 2018 (July-September 2018) (Data source: Watermaster)

Stiff diagrams for the 15 production wells sampled during the 4th quarter of Water Year 2018 are shown on **Figure 17** through **Figure 20**. These production well Stiff diagrams show no significant changes from the shapes were observed in previous years. The Pasadera Paddock production well has a Stiff diagram shape that is different from the other wells' chemistry. The cause of this could be localized mineralization. The Laguna Seca subarea is known to have higher salts in groundwater than the rest of the basin due to the underlying Monterey shale which was deposited in a marine environment. None of the Stiff diagrams for production wells show the high chloride spike shown on **Figure 7** that indicates seawater intrusion.

The York School production well, in the Laguna Seca subarea, and Sand City's Public Works Corp Yard production well, in the Southern Coastal subarea both have Stiff diagrams different from most other wells' water quality (**Figure 18**). Although the shapes are different, they do not display the large chloride spike associated with seawater intrusion as shown on **Figure 7**. None of the production wells analyzed using Stiff and Piper diagrams show an indication of seawater intrusion.

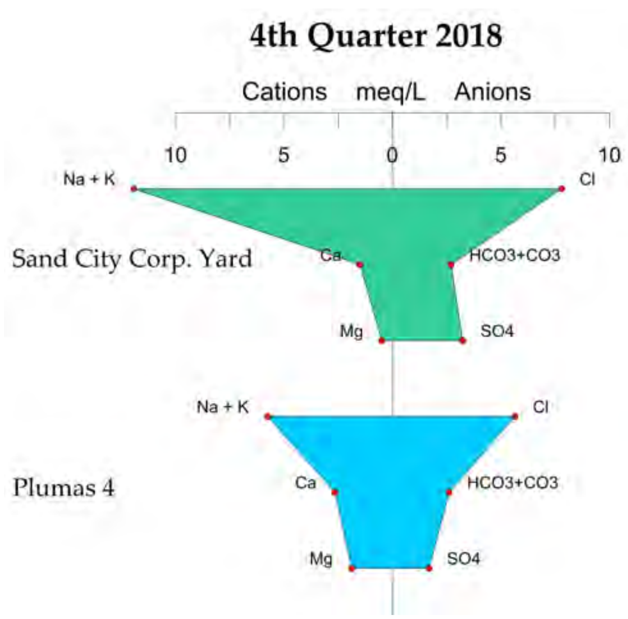


Figure 17. Stiff Diagrams for Southern Coastal Subarea Production Wells (Data source: Watermaster)

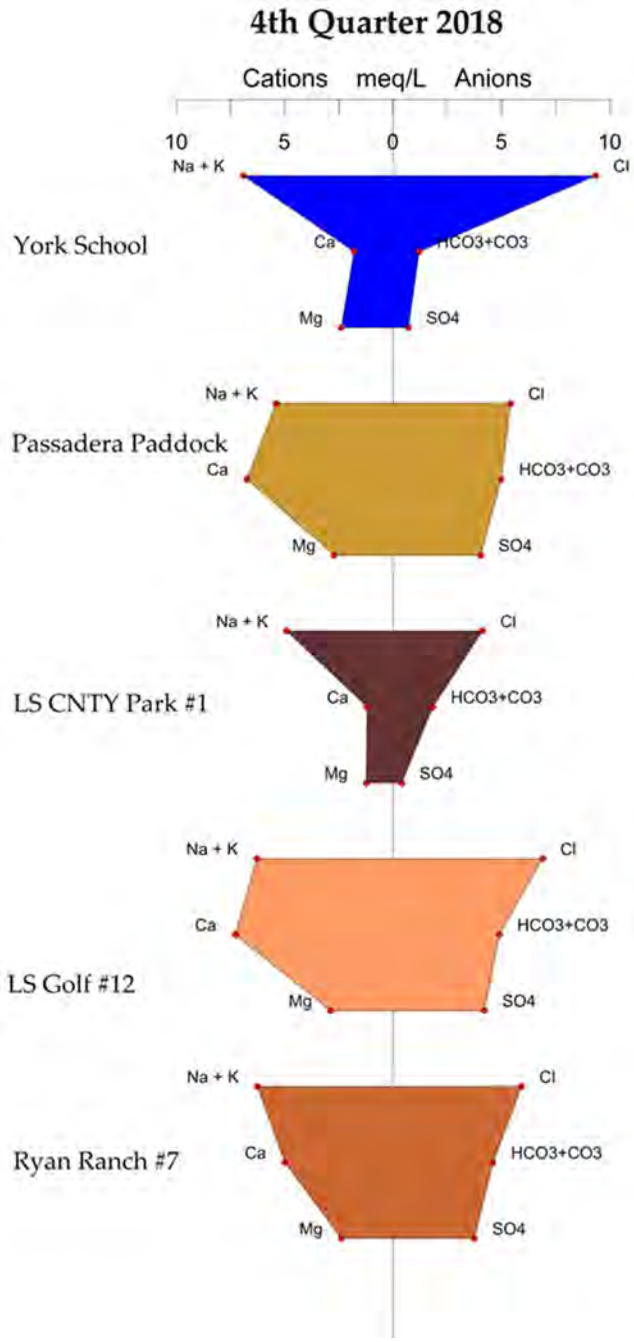


Figure 18. Stiff Diagrams for Laguna Seca Subarea Production Wells (Data source: Watermaster)

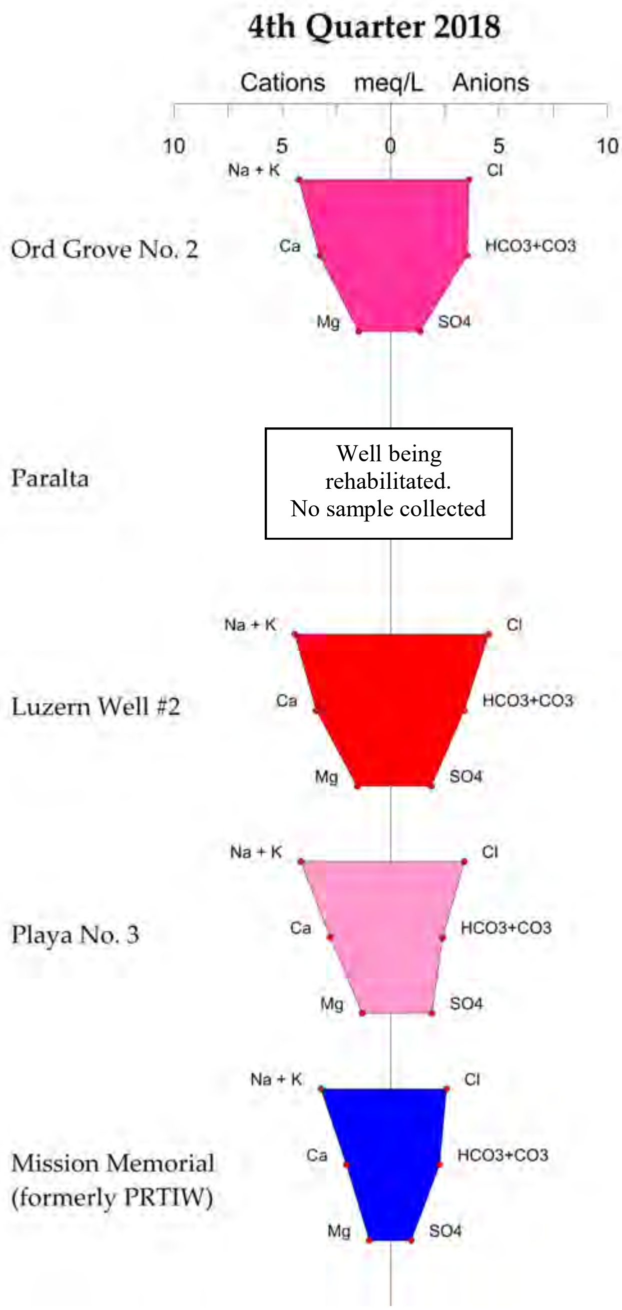


Figure 19. Stiff Diagrams for Northern Coastal Subarea CAWC and Mission Memorial Production Wells (Data source: Watermaster)

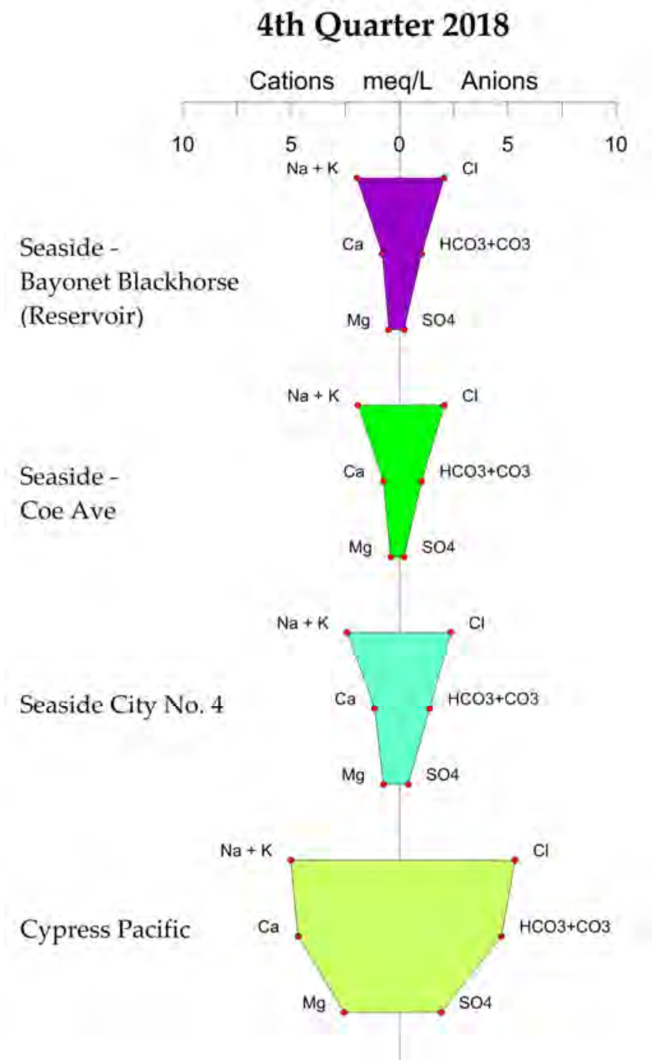


Figure 20. Stiff Diagrams for Northern Coastal Subarea City of Seaside and Cypress Pacific Wells (Data source: Watermaster)

3.3 Chloride Concentrations

3.3.1 Trends

Chemographs showing chloride concentrations over time are plotted for each of the monitoring wells shown on the Piper and Stiff diagrams and one production well. An example plot displaying chloride concentrations for the shallow PCA West well is shown on **Figure 21**. The complete set of chemographs is included in Appendix B. Chloride trends for the monitoring wells remain stable, or fluctuate within a historical tolerance.

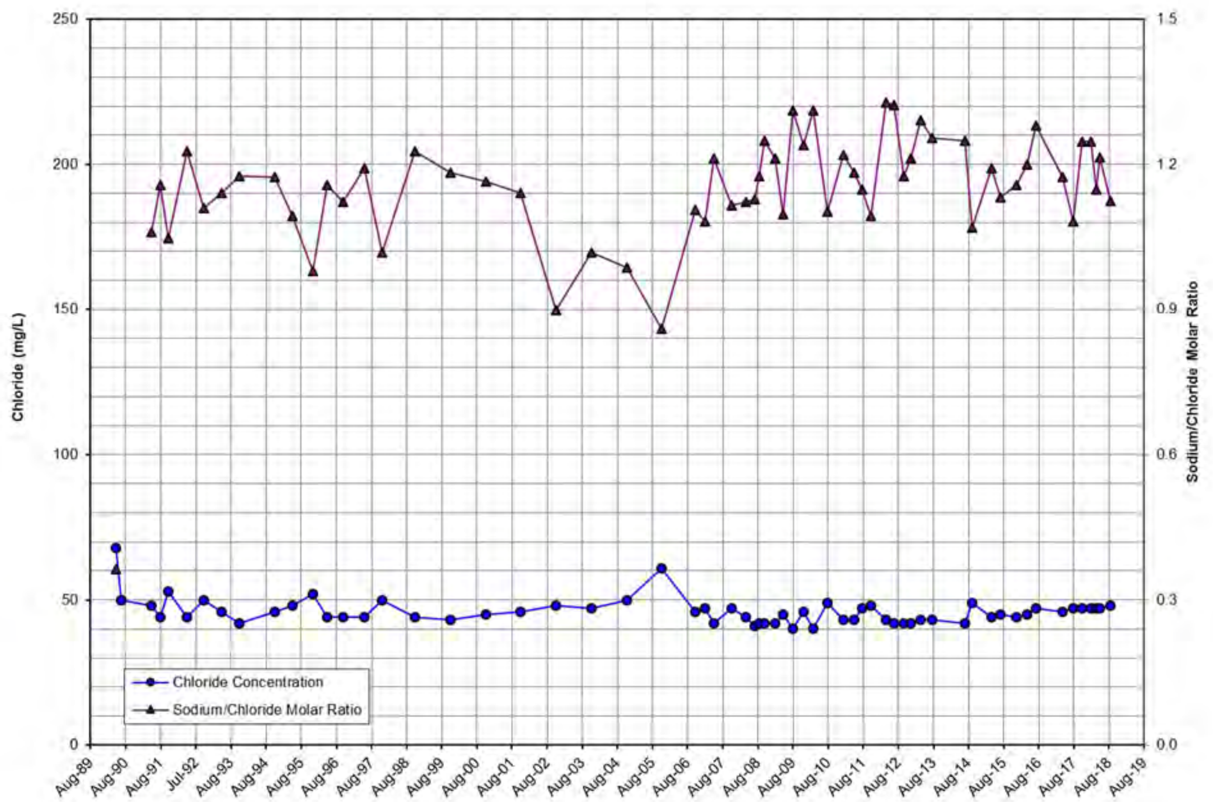


Figure 21. Historical Chloride and Sodium/Chloride Molar Ratios, Shallow PCA West

3.3.2 Chloride Concentration Maps

Fourth Quarter Water Year 2018 (July-September 2018)

Fourth quarter Water Year 2018 chloride concentrations are mapped using data from August and September 2018. The maps for the shallow and deep zones are included on **Figure 22** and **Figure 23**, respectively.

The shallow zone 4th quarter Water Year 2018 chloride concentration map is shown on **Figure 22**. Chloride data from shallow wells are posted on this map but do not show a spatial distribution that can be readily contoured because of large differences in concentrations in close proximity to each other. In general, the shallow chloride concentrations have not varied much from previous water years.

For the data available in the shallow zone, chloride concentrations near the coast continue to average 50 mg/L in the Northern Coastal subarea, with the more inland Northern Coastal subarea wells having slightly higher chloride concentrations that may be due to depositional mineralization differences in the Paso Robles Formation. Based on available data, there is no discernible spatial trend of higher coastal chloride concentrations, and therefore no indication of seawater intrusion within the shallow aquifer. Sand City's Public Works Corp Yard well continues to be the only coastal well in the Southern Coastal subarea with measured chloride data, which has historically had the highest concentration of all shallow coastal monitoring wells (Appendix B: Figure B-13). The Piper and Stiff diagrams, and sodium/chloride molar ratio for the well continue to suggest that the source of high chloride is not seawater.

The deep zone 4th quarter Water Year 2018 chloride concentration map is shown on **Figure 23.** Chloride concentrations for the Sentinel Wells are not shown on this map anymore because it was found that their groundwater samples are not representative of the aquifer. Because the chloride data shows no discernible spatial distribution, with high concentrations in close proximity to low concentrations, the data cannot be readily contoured. Deep zone chloride concentrations near the coast range between 71 mg/L and 159 mg/L.

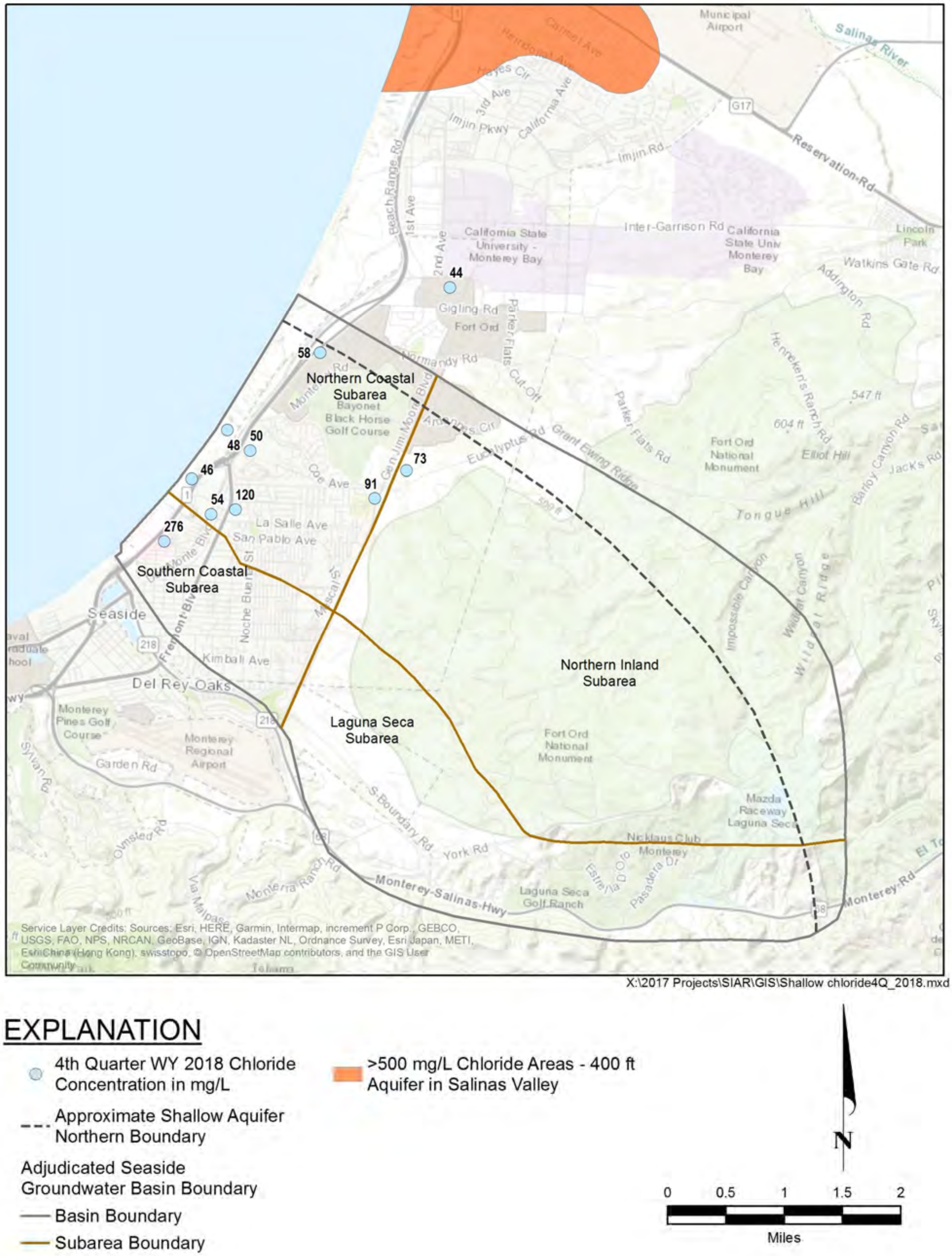


Figure 22. Shallow Zone Chloride Concentration Map – 4th Quarter WY 2018

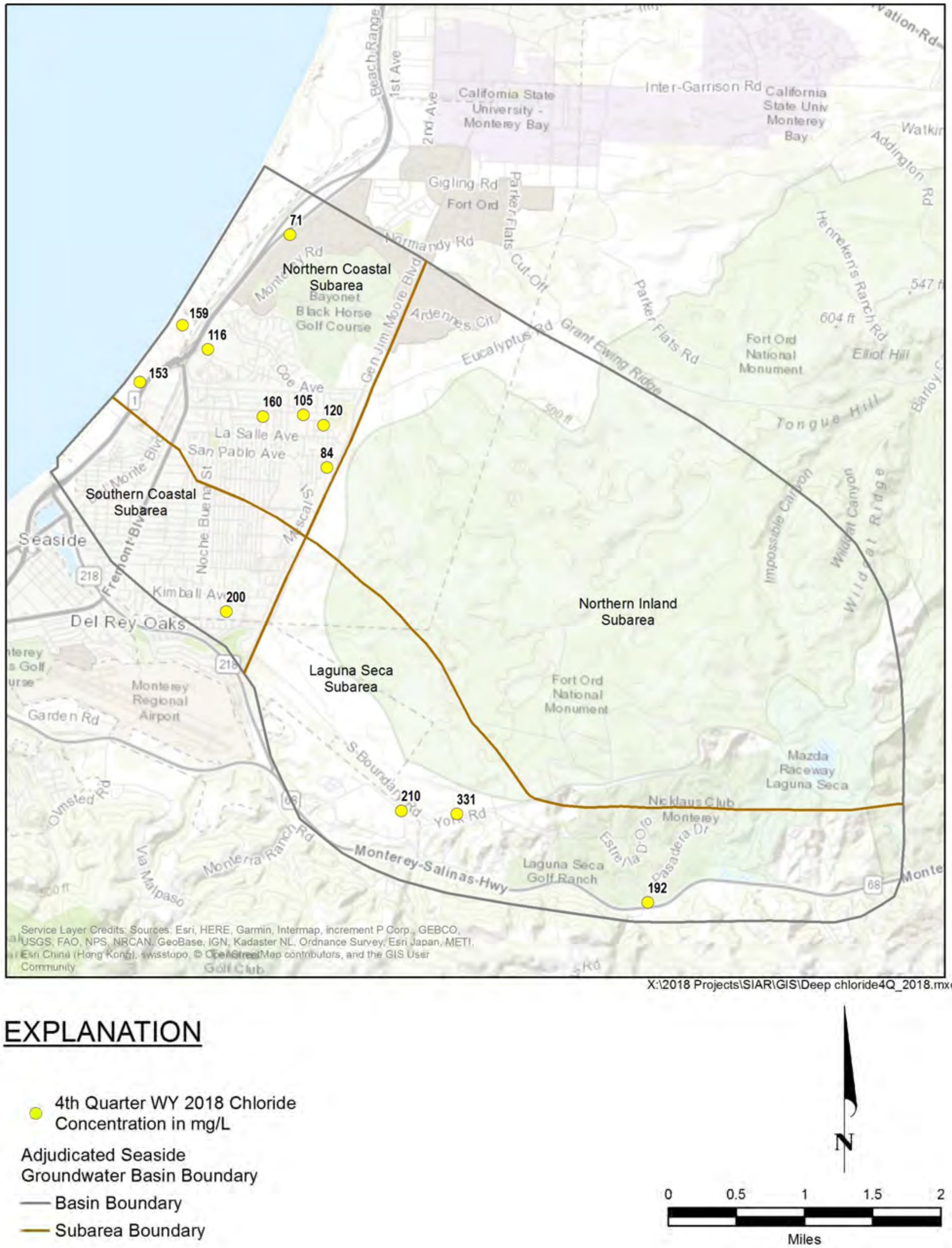


Figure 23. Deep Zone Chloride Concentration Map – 4th Quarter WY 2018

3.4 Sodium/Chloride Molar Ratios

Chemographs showing long-term sodium/chloride molar ratios over time are plotted for all of the 12 monitoring wells shown on the Piper and Stiff diagrams and one production well. Historical chemographs for monitoring wells that are not on the Water Year 2018 Piper and Stiff diagrams because they were not sampled, are also included for completeness. An example plot displaying sodium/chloride molar ratios for the shallow PCA West well are shown on **Figure 21**. The complete set of chemographs is included in Appendix B.

All of the sodium/chloride molar ratios in the monitoring wells remained constant or increased over the past year. Charts for the Sentinel Wells are not included because their groundwater samples are not representative of the aquifer.

3.5 Electric Induction Logs

Two induction logging events took place in the four Sentinel Wells during Water Year 2018. The first logging event was conducted in March 2018, and the second event took place in September 2018. Pacific Surveys conducted the logging, and have done so since August 2014. **Figure 24** through **Figure 27** includes the new baseline (starting in August 2014) from which to compare all subsequent logs.

Feeney (2007) described the original 2007 baseline induction logs for each of the wells as follows:

> *"SBWM-1 — The upper 50 feet of this well shows very high conductivities. This signature is present in all of the wells and is the result of the 50-foot steel conductor casing. However, because the water table is below the conductor casing at all locations, the steel casing does not interfere with data collection within the saturated sediments below. Below the conductor casing in SBWM-1, the sediment materials are dry to a depth of approximately 115 feet. Below this depth, there is approximately 10 feet of sand containing fresh water. Below 125 feet and extending to approximately 350 – 400 feet is sand containing saline water with conductivities measuring as high as 10,000 mhos/cm. This saline water is contained within the Dune /Beach Sand Deposits and the Aromas Sand. Below this depth, conductivities are relatively low with the exception of the thick marine clay between approximately 600 -700 feet. The other conductive zones also correlate with clay zones.*

> *SBWM-2 — As in SBWM-1 there is a thin layer of fresh water overlying a zone of saline water to approximately 130 feet within the Beach/Dune Sands and Aromas Sand. Below this depth, the materials become increasingly clayey, complicating the interpretation. Below this depth, there are no obvious zones of anomalous conductivity; that is, the zones that are more conductive correlate with clay zones.*
>
> *SBWM-3 — In SBWM-3 saline water extends to a depth of approximately 100 feet within the Dune/Beach Sand and Aromas Deposits. Below 100 feet, the materials become clay and conductivities rapidly decline. Again, below the shallow saline water in the sand deposits, all zones of increased conductivity correlate with clay zones.*
>
> *SBWM-4 — As with the other wells, the induction log reveals a thin layer of fresh water overlying saline water with the Dune Sands/Beach Deposits to a depth of approximately 100 feet. Below this depth the materials become clay and there are no additional zones of increased conductivity uncorrelated with clay zones."*

Salinity changes shown on **Figure 24** through **Figure 27** for Sentinel Wells 1 – 4, respectively, are only relative, and do not allow direct measurement of TDS or chloride concentrations in the aquifer. They do, however, provide a means to determine changes in salinity over time. It appears that the salinity in the Dune Sands and Aromas Formation overlaying the main production aquifers fluctuates from season to season; becoming more saline in the summer months when stresses on the aquifer are greatest. As has been the case historically, none of the wells show detectable changes in conductivity to the deeper aquifers where production wells extract groundwater.

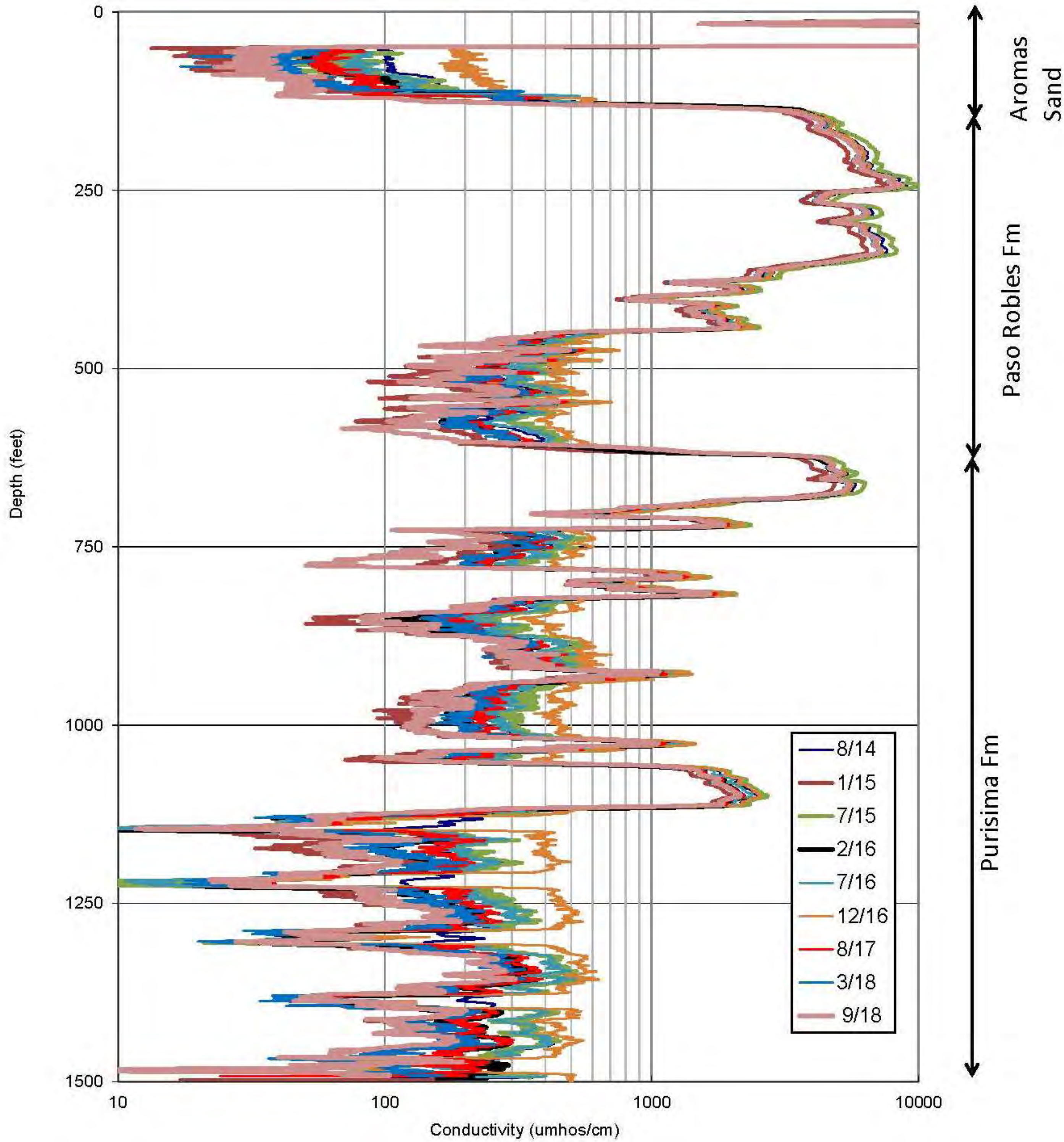


Figure 24. Sentinel Well SBWM MW-1 Induction Log

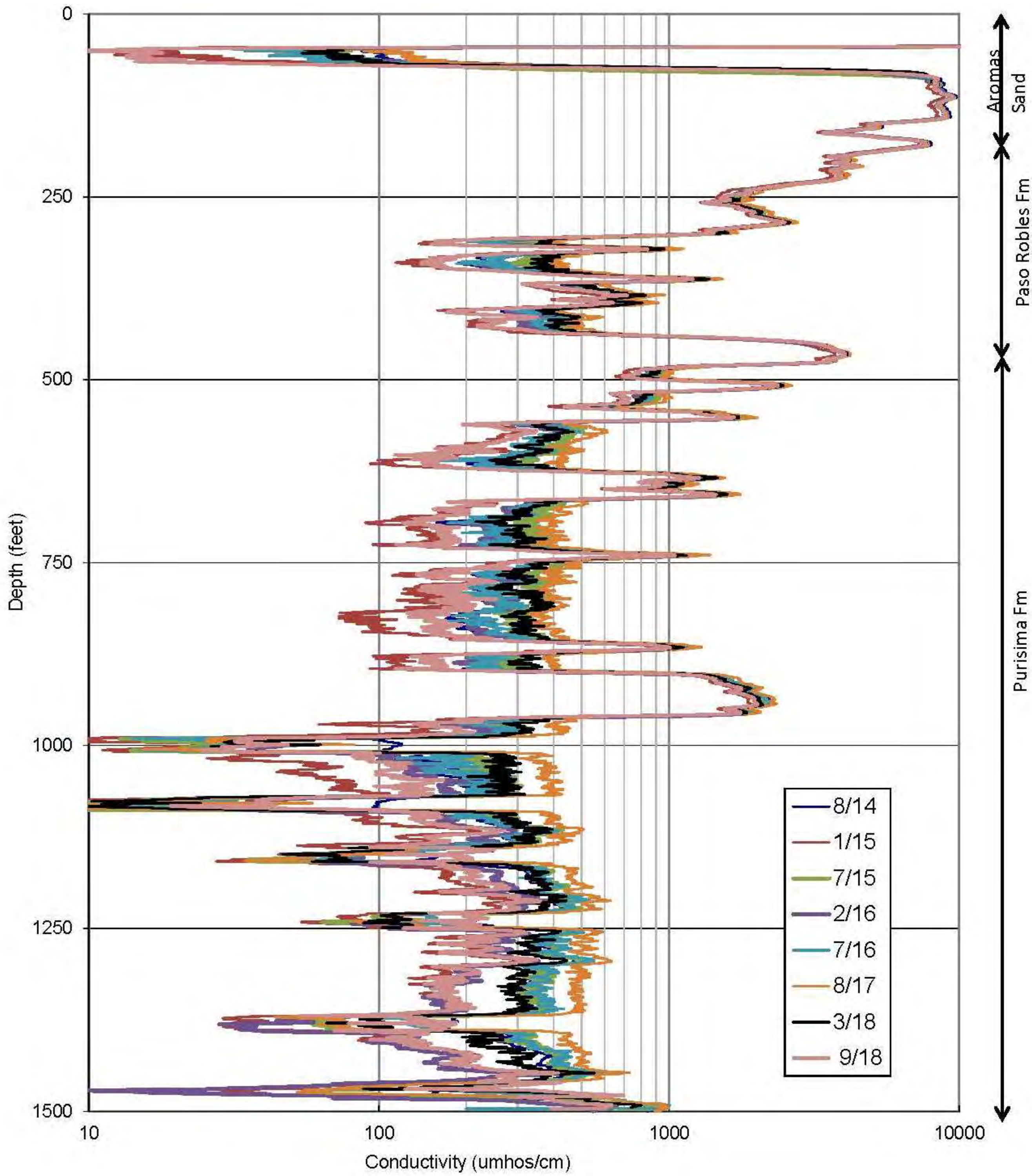


Figure 25. Sentinel Well SBWM MW-2 Induction Log

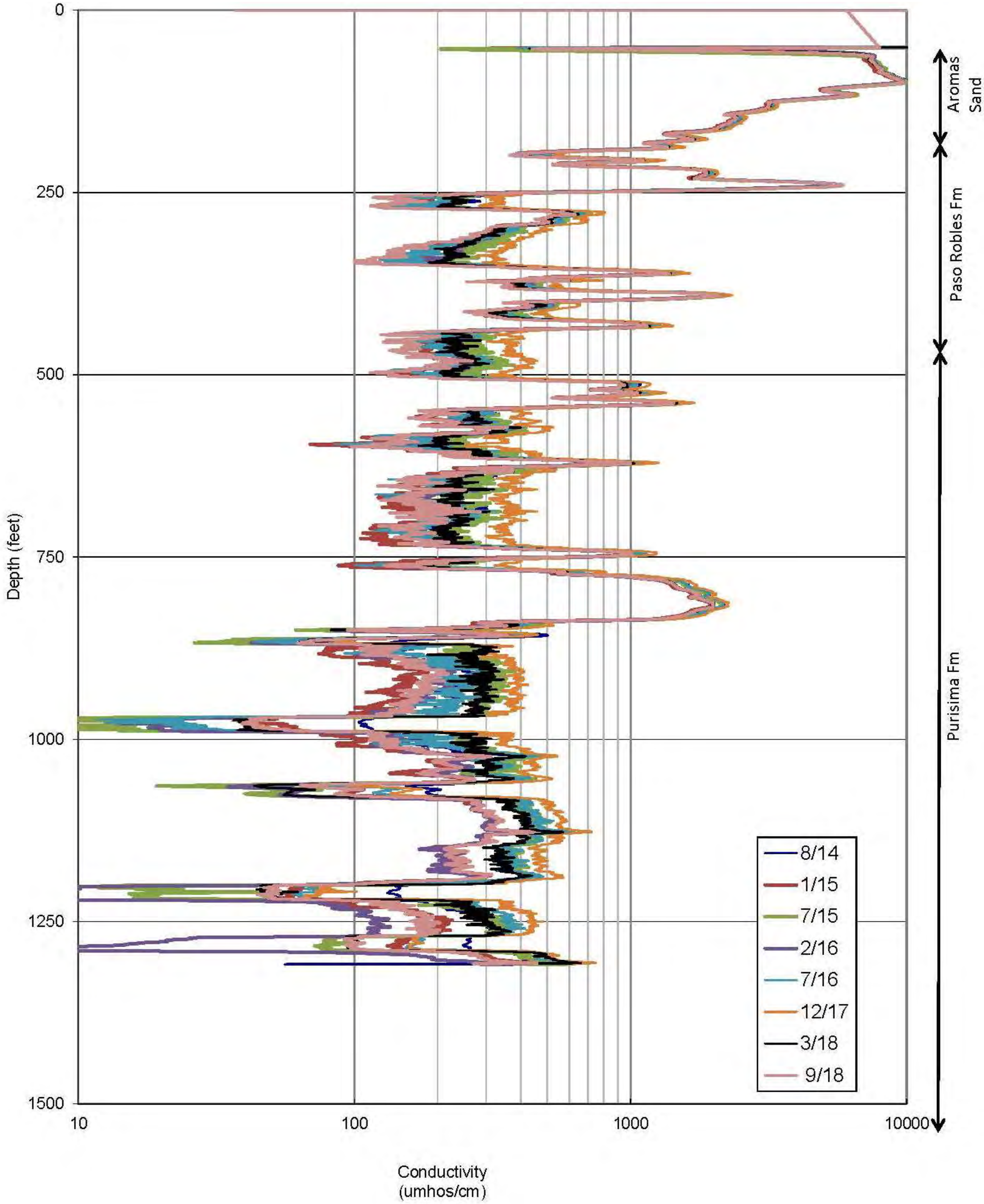


Figure 26. Sentinel Well SBWM MW-3 Induction Log

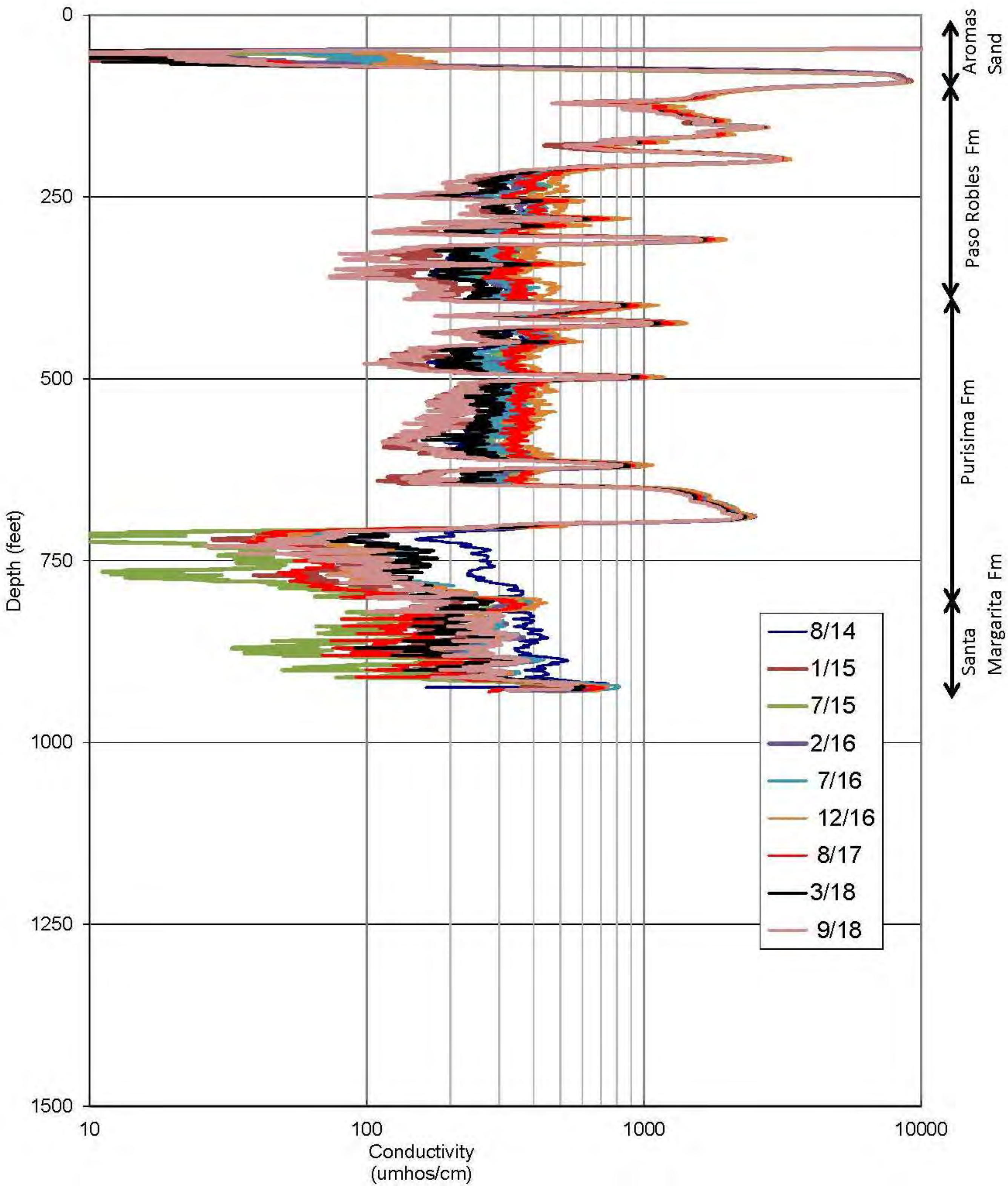


Figure 27. Sentinel Well SBWM MW-4 Induction Log

3.6 Groundwater Levels

Groundwater levels are not direct indicators of seawater intrusion, but indirectly suggest opportunities for seawater intrusion. Coastal groundwater levels at or near sea level are not sufficient to repel seawater intrusion, and will likely allow some amount of seawater intrusion unless groundwater levels increase.

3.6.1 Trends

Groundwater level hydrographs representative of well pairs in the Northern Coastal subarea and one shallow well in the Southern Coastal subarea are shown on **Figure 28**.

Northern Coastal Subarea

Groundwater level data from the PCA-East well are representative of groundwater levels in the Northern Coastal subarea, west of nearby production wells. The hydrograph shows peaks and lows that are strongly influenced by pumping from the nearby California American Water Company (CAWC) production wells on groundwater levels in the deep zone and injection of Carmel River water at the eastern boundary of the subarea **(Figure 28**). Other influences such as tides which can cause up to a one-foot fluctuation in the deep completion of PCA-East are also recognized. Because of all the possible influences on groundwater levels, it is difficult to compare the present year to the previous year directly. What is more important is to look at the long-term trends.

PCA-East Deep on **Figure 28** shows an overall decline in groundwater levels until 2009, levels increase and then more or less stabilize over the next two years, and then from 2011 to 2016 have experienced a continual decline, summer/fall levels slightly higher in Water Year 2017, and a slight decline again in Water Year 2018. The start of the overall decline in groundwater levels in the deep completion of PCA-East corresponds with the shift in CAWC's production from their shallow Paso Robles wells to deeper Santa Margarita wells.

Seasonal fluctuations are noticeable in the winter season when groundwater elevations are at their highest for the year. For Water Year 2017, the winter high in PCA-East Deep increased to a level last seen in 1995, which is 17 feet higher than the lowest winter high level experienced during the recent drought. This is because 2,345 acre-feet of excess Carmel River water was injected as it was a very wet year. Only 530 acre-feet was injected in Water Year 2018 and thus the seasonal high in 2018 is similar to the seasonal high in 2016 when 699 acre-feet was injected.

It is important to note that the Santa Margarita Sandstone has limited connection to the ocean and is highly confined by the layers above it. This means that the amount of recharge entering the Santa Margarita Sandstone is limited and is therefore always susceptible to depletion if more water is pumped than is being recharged.

Figure 29 includes hydrographs of groundwater elevations for the four deep coastal Sentinel Wells. Groundwater elevations on this chart are collected using data loggers in each well that record levels every 30 minutes. The hydrographs show the daily average elevations, thereby smoothing out the more detailed data which are affected by tidal variations. The hydrographs for the Sentinel Wells are similar to the PCA-East deep hydrograph and show that groundwater elevations over winter and spring were the highest in Water Year 2017 because of increased injection. Groundwater levels in Water Year 2018 did not fall to lowest levels experienced in at the end of Water Year 2016, which was at the end of the recent drought.

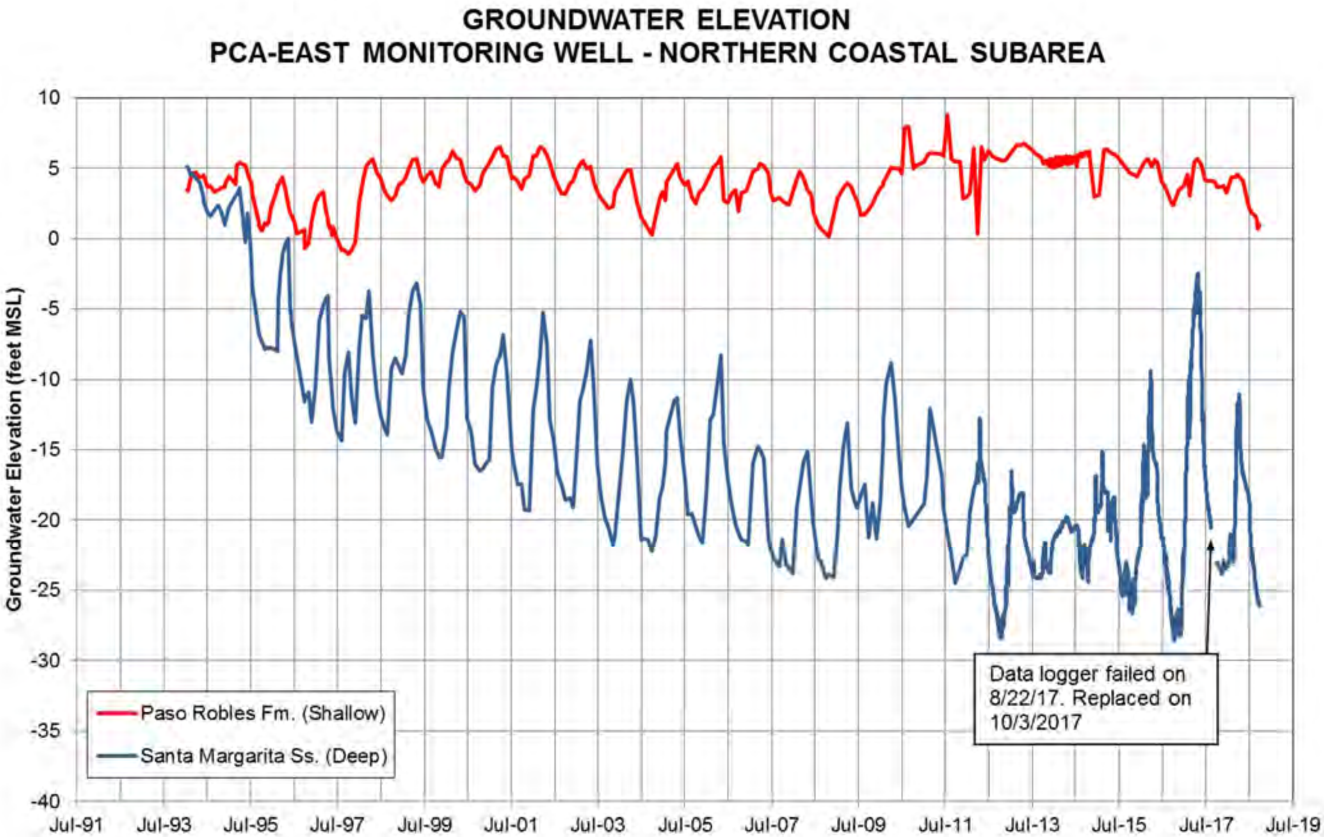
The hydrograph of shallow groundwater levels in PCA-East shows a declining trend since Water Year 2014, where levels have dropped about five feet over the past four years (**Figure 28**). Seasonal level increases in the shallow aquifer are usually related to reduced wintertime production, and increased pumping during summer. Although the shallow seasonal fluctuations correspond with deep zone fluctuations, it is because seasonal pumping occurs in both aquifers, and not because the aquifers are closely connected. It appears that since Water Year 2015, the shallow aquifer is exhibiting greater seasonal fluctuations that corresponds with the recommencement of pumping at the Coe Ave and Black Horse Bayonet golf course irrigation wells after being supplied water by Marina Coast Water District from Water Year 2009 through 2014/2015.

Southern Coastal Subarea

In the Southern Coastal subarea, the KMART monitoring well is representative of groundwater levels near the coast (**Figure 28**). The hydrograph shows that groundwater elevations have always been above sea level and continue to remain fairly stable over time.

Laguna Seca Subarea

Although wells in the Laguna Seca subarea are far enough from the coast not to induce seawater intrusion, there is concern that since 2001 this area has experienced ongoing groundwater level declines that is not being halted or improved upon by triennial pumping reductions. It is believed this is occurring due in part to the Natural Safe Yield of the subarea being too high and in part due to influences of groundwater pumping east of the Seaside Basin boundary (HydroMetrics WRI, 2016). **Figure 30** shows in the eastern portion of the subarea that between 1999 and 2014, shallow groundwater levels declined at a rate of approximately 0.6 feet per year, and deep groundwater levels declined up to four feet per year. Since 2014, the decline is less and appears close to stabilizing. **Figure 31** shows the location of wells with hydrographs on **Figure 30**.



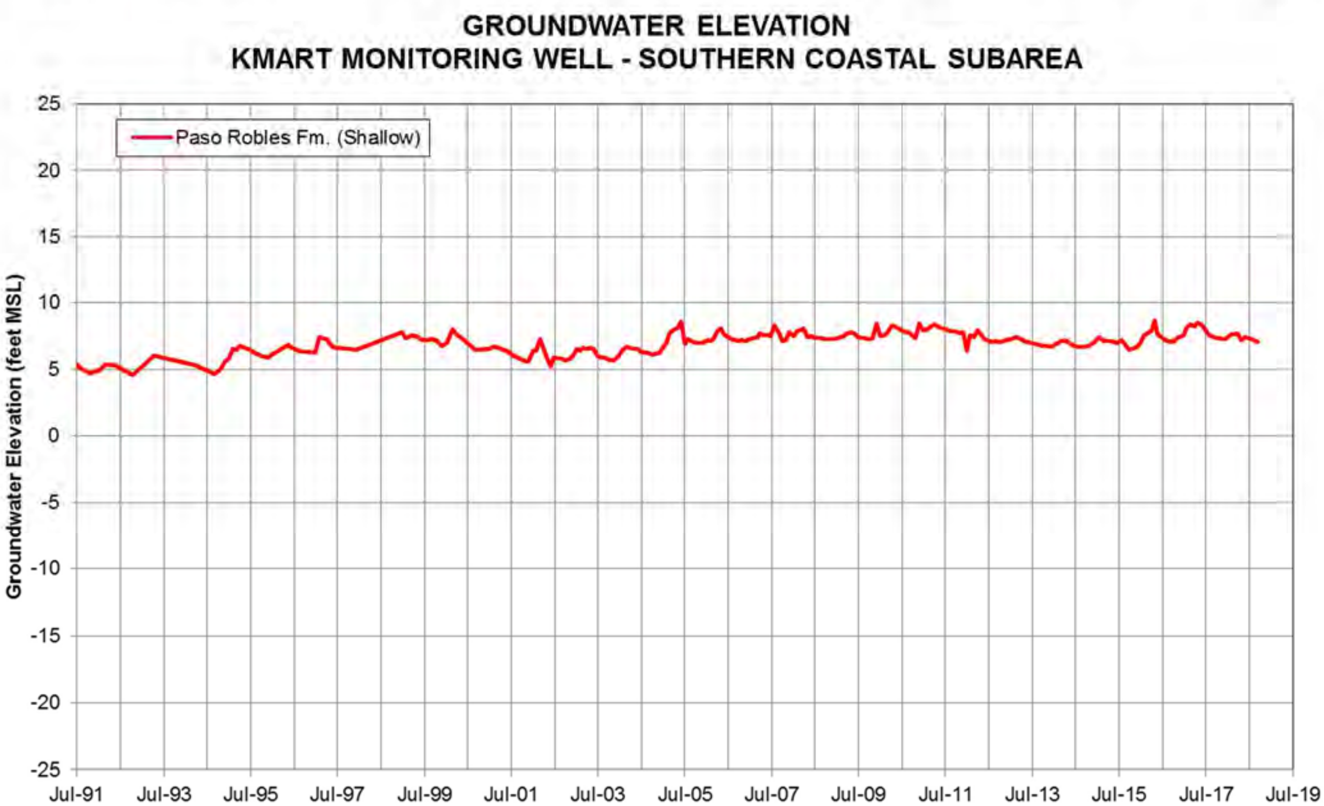


Figure 28. Example Hydrographs (Source: Watermaster)

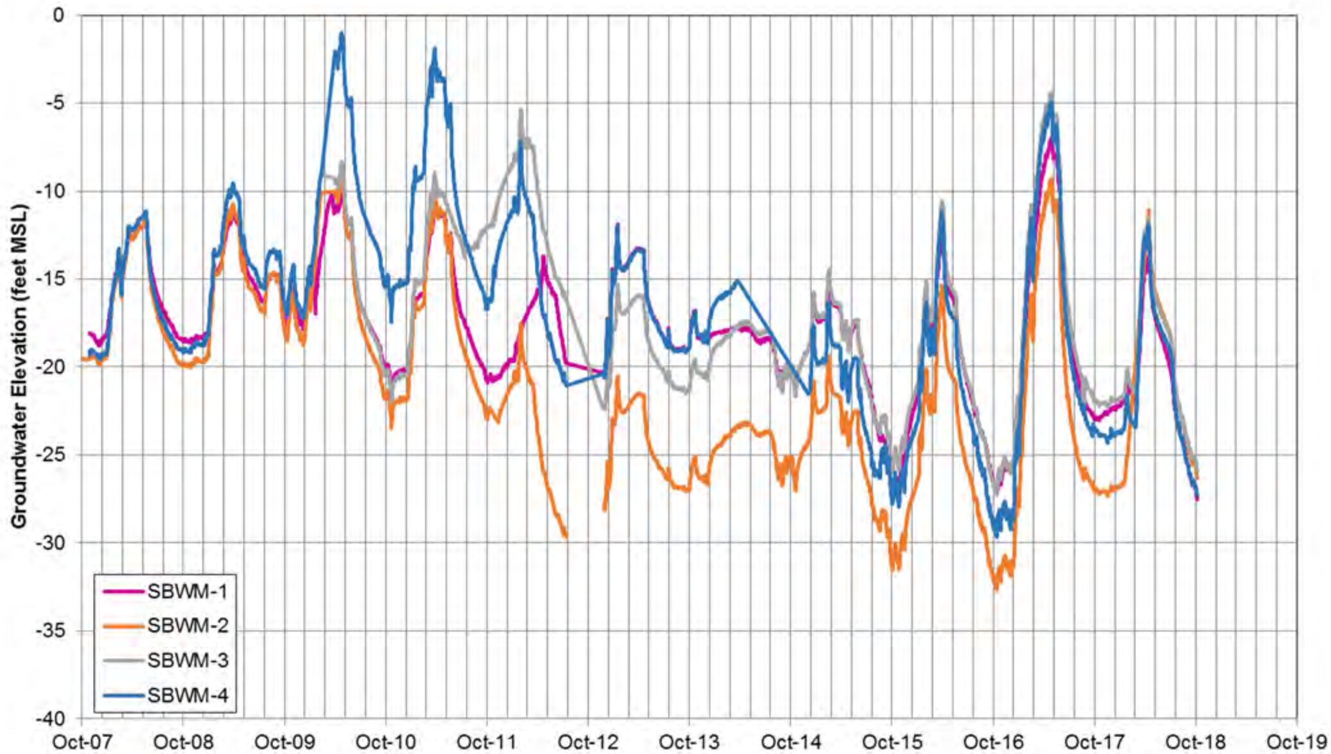


Figure 29. Sentinel Well Hydrographs (Source: Watermaster)

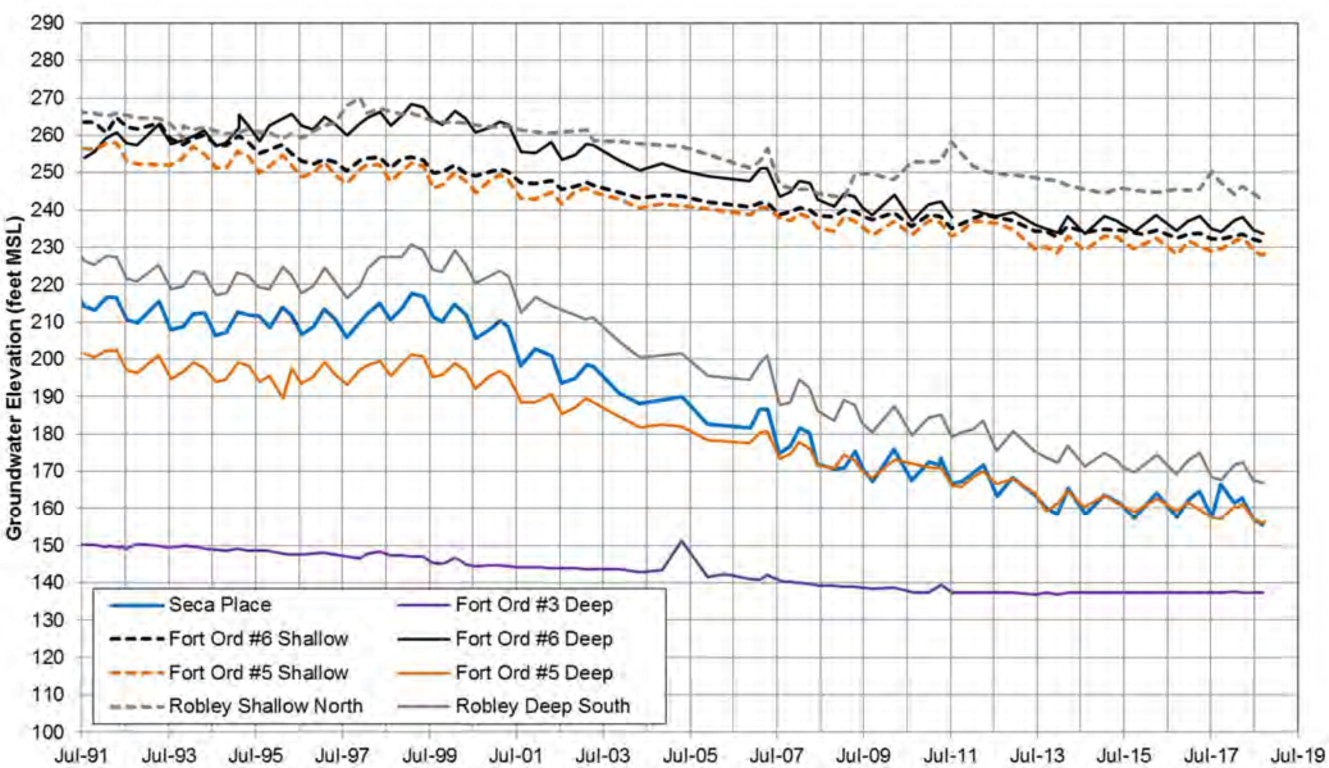


Figure 30. Eastern Laguna Seca Subarea Hydrographs

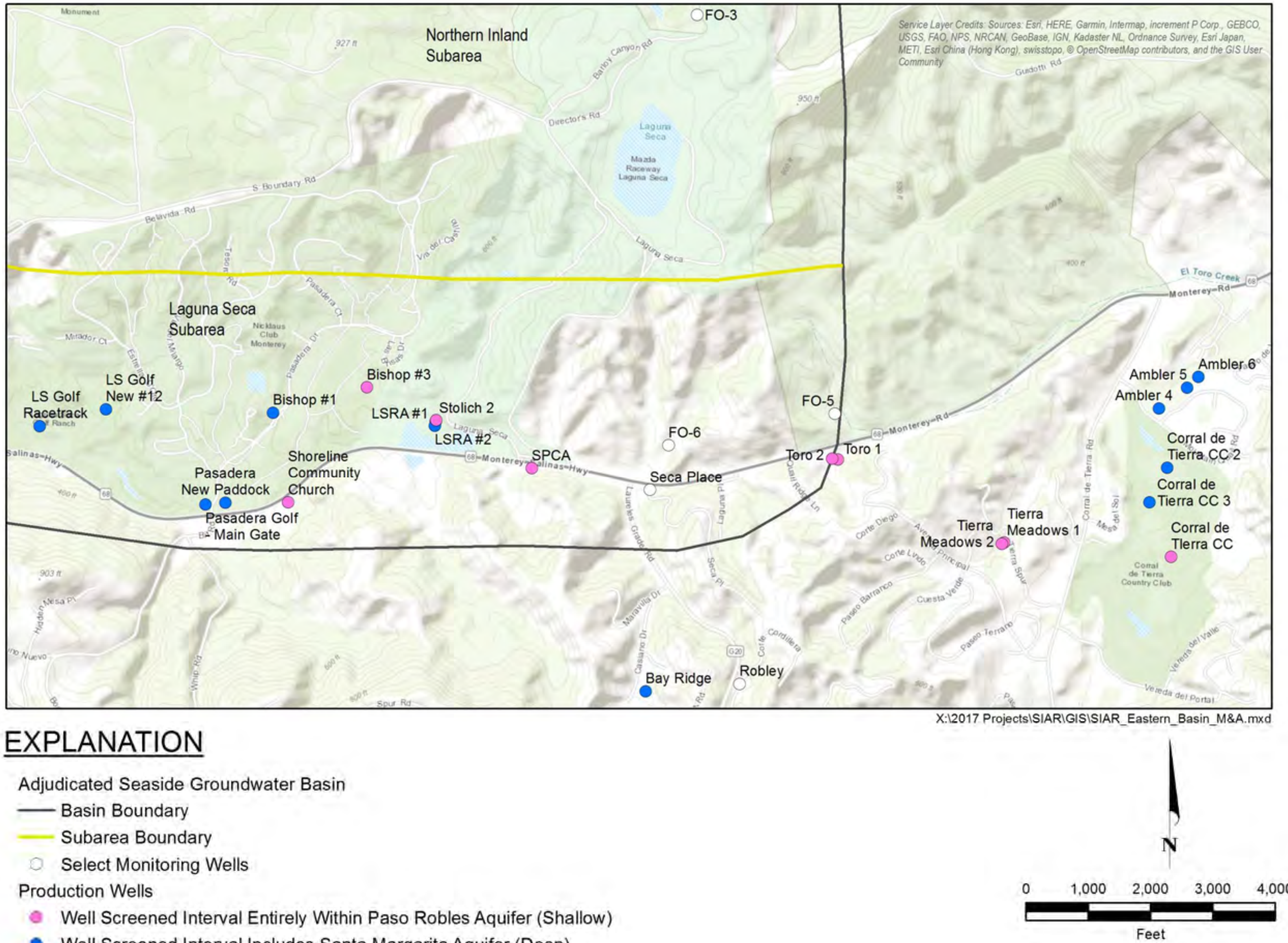


Figure 31: Eastern Laguna Seca Subarea Wells

3.6.2 Groundwater Elevation Maps

Second Quarter Water Year 2018 (January-March 2018)

Groundwater level maps for the shallow and deep aquifer zones for the 2nd quarter of Water Year 2018 are shown on **Figure 32** and **Figure 33**, respectively.

Other than in areas of active groundwater pumping, the shallow aquifer does not show seasonal fluctuations to the same extent as the deep aquifer. The shallow zone groundwater level contours for Water Year 2018 remain essentially the same as Water Year 2016 and 2017 along the coast in the Northern Coastal subarea, with the exception of the coastal pumping depression which increased slightly from Water Year 2017. Groundwater levels remain stable in the western portion of the Laguna Seca subarea, and the Laguna Seca subarea pumping depression remained similar in extent to last two water years. In the eastern portion of the Northern Inland subarea, an area of the shallow aquifer is indicated to be potentially dry due to geologic structural control (**Figure 32**).

Second quarter groundwater levels in the deep aquifer, particularly along the coast, are usually higher than 4th quarter groundwater levels by up to six to seven feet due to seasonal groundwater demand. In Water Year 2017, because of the large volume of Carmel River water injected, groundwater levels at the coast were approximately 10 to 15 feet higher than they normally would be. In Water Year 2018, less injection took place and groundwater elevations dropped from Water Year 2017 levels to elevations similar to those in Water Year 2016. The pumping depression in the Northern Coastal subarea in Water Year 2018 is slightly larger in extent than Water Year 2017 (**Figure 33**).

As pointed out from Laguna Seca subarea hydrographs on **Figure 30**, groundwater levels in the central and eastern Laguna Seca subarea have stabilized and thus the small pumping depression caused by the Laguna Seca Golf Ranch wells remains a similar size to recent years. As the Ryan Ranch wells in the western portion of the Laguna Seca subarea have not pumped since February 2018, groundwater recovery of up to 15 feet was experienced in this area.

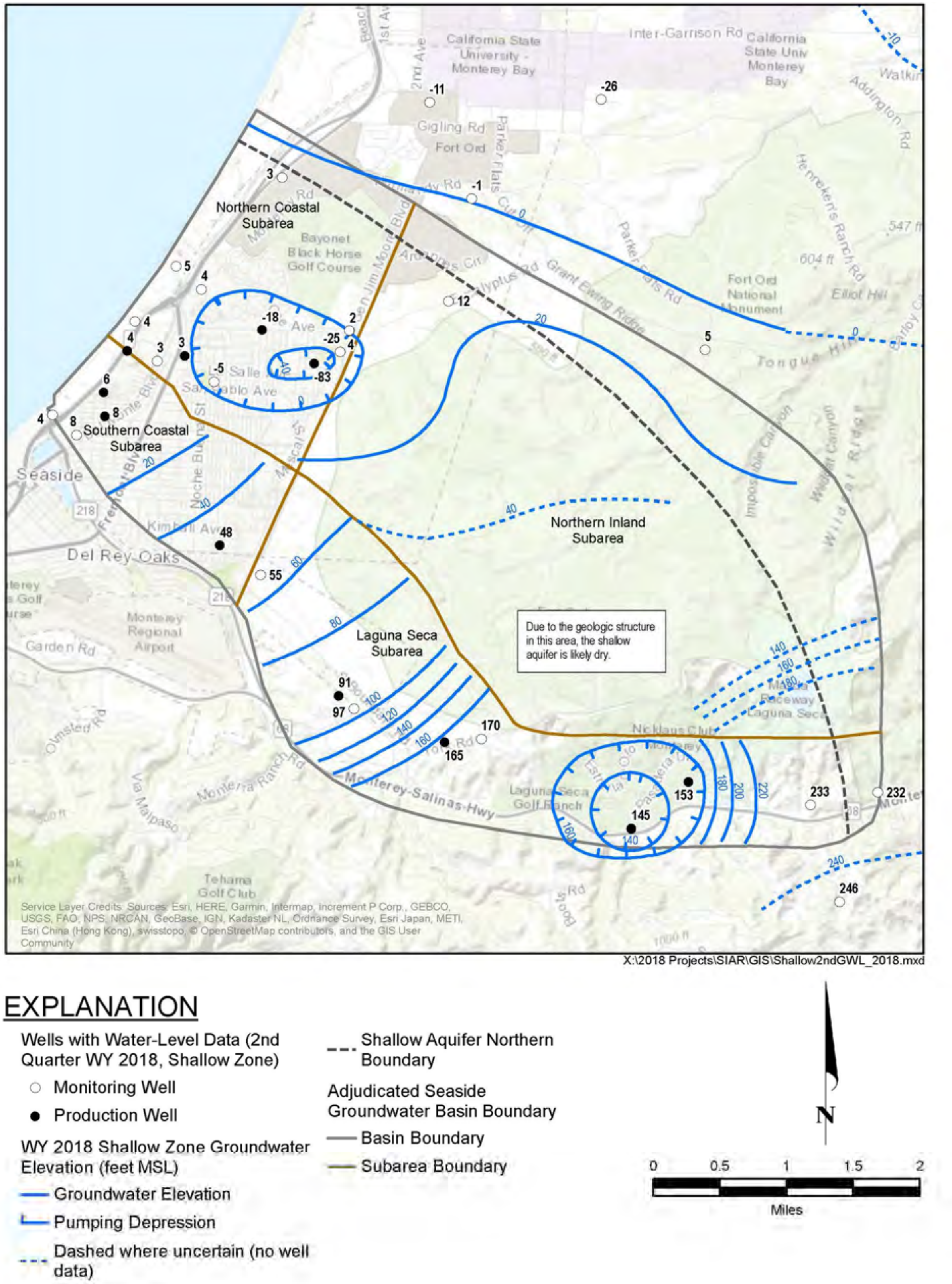


Figure 32. Shallow Zone Water Elevation Map – 2nd Quarter WY 2018 (January-March 2018)

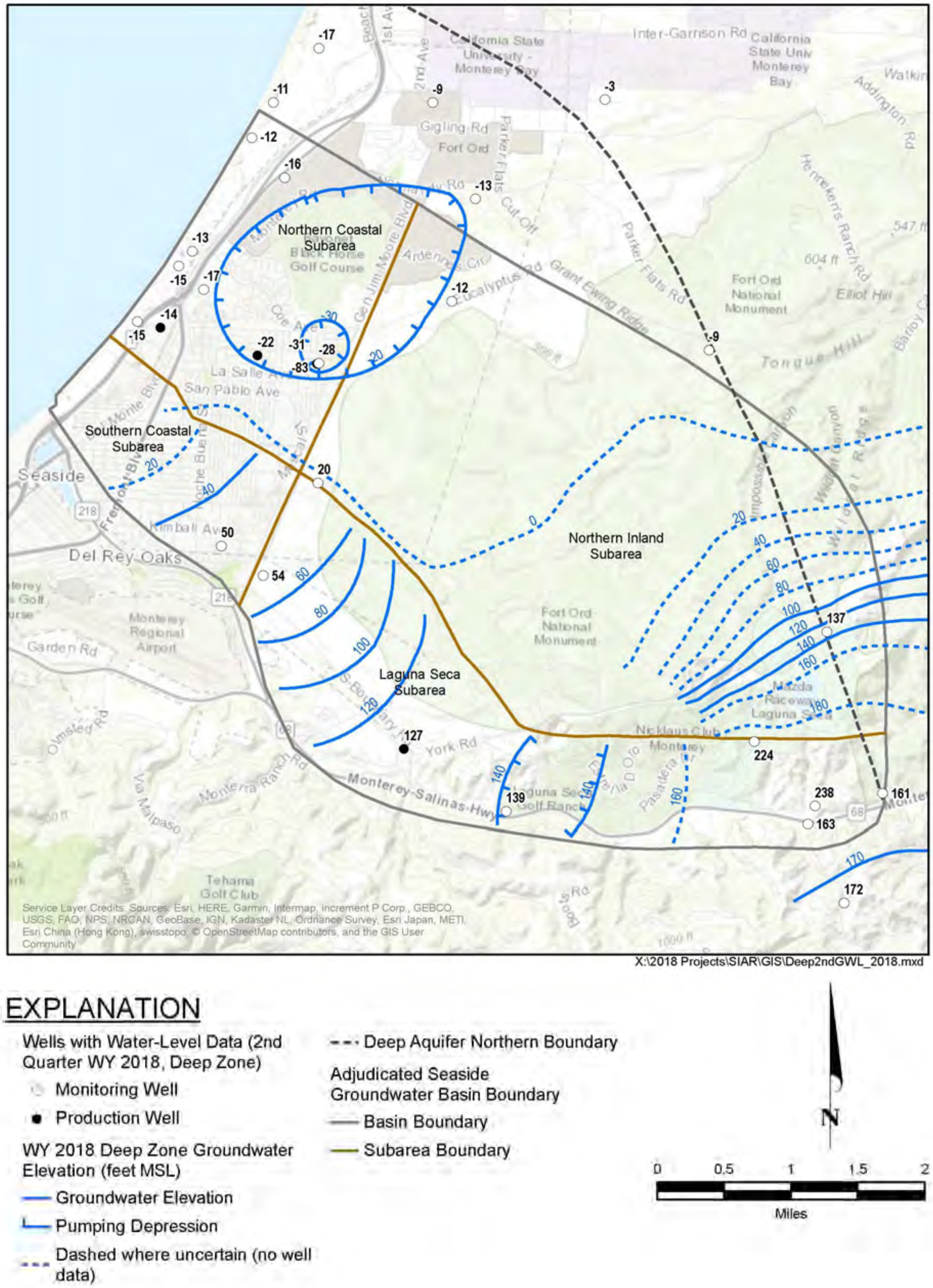


Figure 33. Deep Zone Water Elevation Map – 2nd Quarter WY 2018 (January-March 2018)

Fourth Quarter Water Year 2018 (July-September 2018)

Groundwater elevation maps for the shallow and deep aquifer zones for the 4th quarter of Water Year 2018 are shown on **Figure 34** and **Figure 35,** respectively. The contours for the shallow aquifer along the coast show that groundwater levels declined slightly in the Northern Coastal subarea from the 2nd quarter of Water Year 2017. The pumping depression in the Northern Coastal subarea is slightly larger in extent that last water year, while the pumping depression in the Laguna Seca subarea remained the same size as last water year (**Figure 34**).

The deep aquifer -20 foot elevation pumping depression around the largest producing wells in the Northern Coastal subarea increased slightly in extent from Water Year 2017 (**Figure 35**), likely because less injection (531 acre-feet) took place in the winter than the previous year, and 1,210 acre-feet of water injected during Water Years 2017 and 2018 was recovered during Water Year 2018. At the coast, deep groundwater elevations decreased up to 8 feet. The Laguna Seca subarea pumping depression around the Laguna Seca Golf Ranch wells remained similar to last water year (**Figure 35**). There has been up to 30 feet of groundwater level recovery in the area of the Ryan Ranch wells as a result of them not pumping since February 2018.

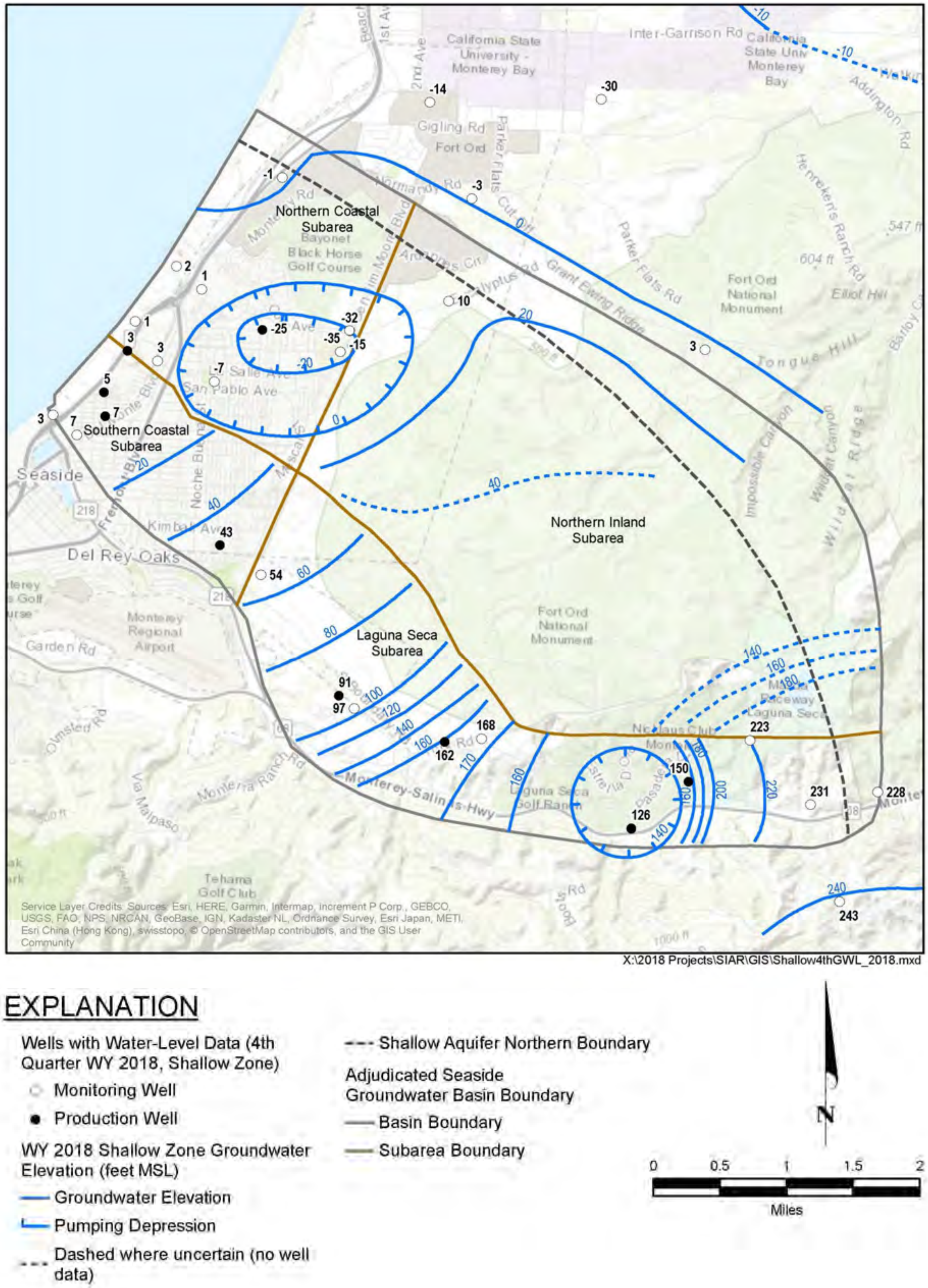


Figure 34. Shallow Zone Water Elevation Map – 4th Quarter WY 2018 (August/September 2018)

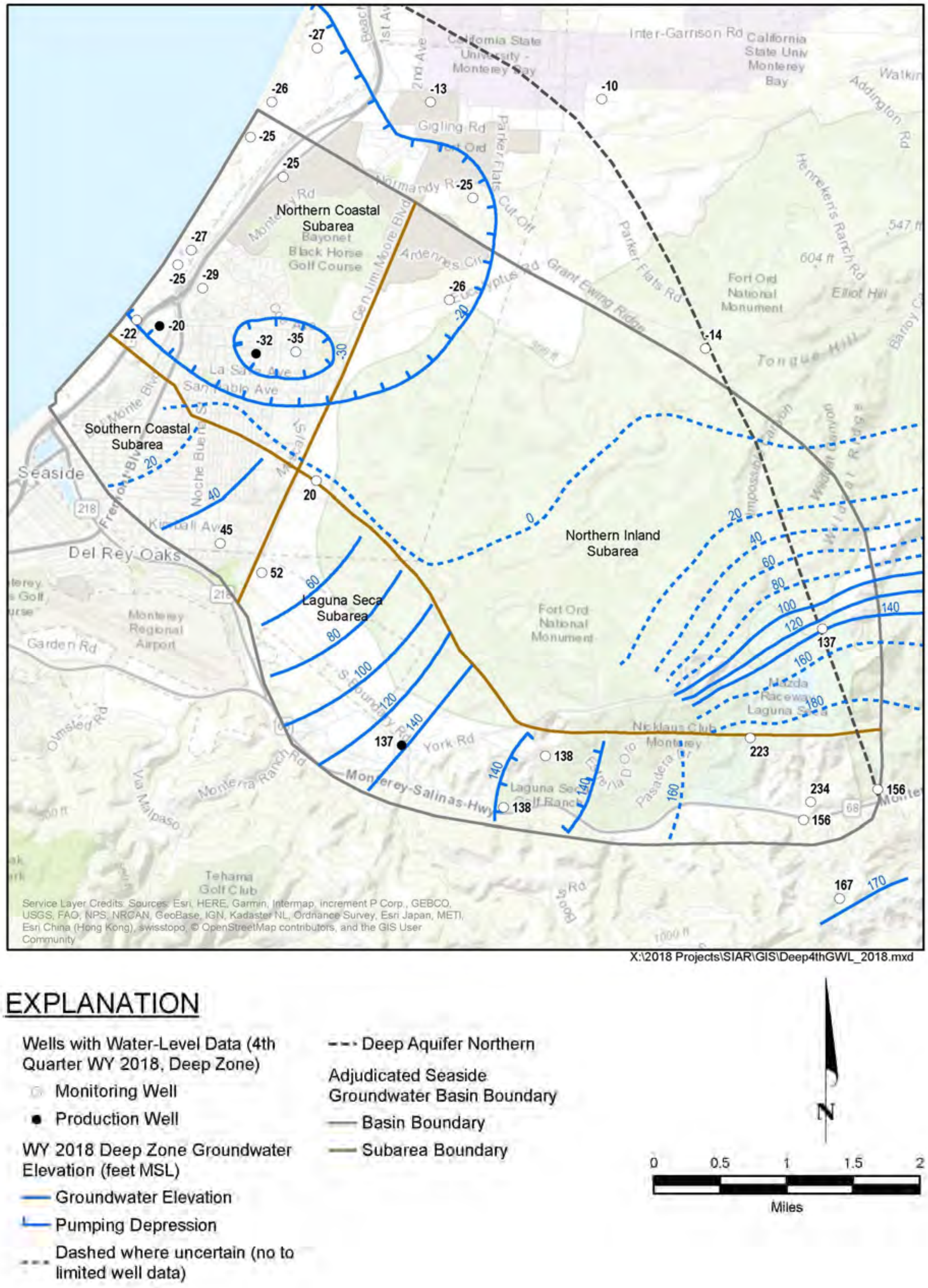


Figure 35. Deep Zone Water Elevation Map – 4th Quarter WY 2018 (August/September 2018)

3.6.3 Protective Groundwater Elevations

Protective groundwater elevations were determined in 2009 using the Seaside Groundwater Basin groundwater flow model and cross-sectional modeling (HydroMetrics LLC, 2009b). A subsequent study in 2013 to revisit and update the protective groundwater elevations concluded that the calibrated parameters in the basin wide model do not indicate that protective elevations should be lowered (HydroMetrics WRI, 2013b). Protective elevations for both the deep and shallow aquifers were established for monitoring well pairs with both a shallow and deep completion. Protective elevations are shown in **Table 1**.

Table 1. Summary of Protective Elevations at Coastal Monitoring Wells

Subarea	Well	Completion	Protective Elevation, Feet above sea level	Currently Above or Below Protective Elevations
Northern Coastal	MSC	Deep	17	below
		Shallow	11	below
	PCA-W	Deep	17	below
		Shallow	2	below
	Sentinel Well 3	Deep	4	below
Southern Coastal	CDM-MW4	Shallow	2	above

Figure 36 through **Figure 39** show the historical groundwater elevations at each of the target protective elevation monitoring wells. Groundwater levels continue to be below protective elevations in all deep target monitoring wells (MSC deep, PCA-West Deep, and Sentinel Well 3). Two of the three shallow wells' groundwater levels have previously been above protective elevations: the PCA-W shallow well and the CDM-MW4 well. However, at the end of this water year, the PCA shallow well groundwater levels fell slightly below protective elevations. It appears the well is exhibiting greater seasonal fluctuations, likely due to the recommencement of pumping in Water Year 2015 from the shallow aquifer at the Coe Ave well after being supplied water by Marina Coast Water District from Water Year 2009 through 2014/2015. Groundwater levels in the MSC shallow well continue to be below the protective elevation.

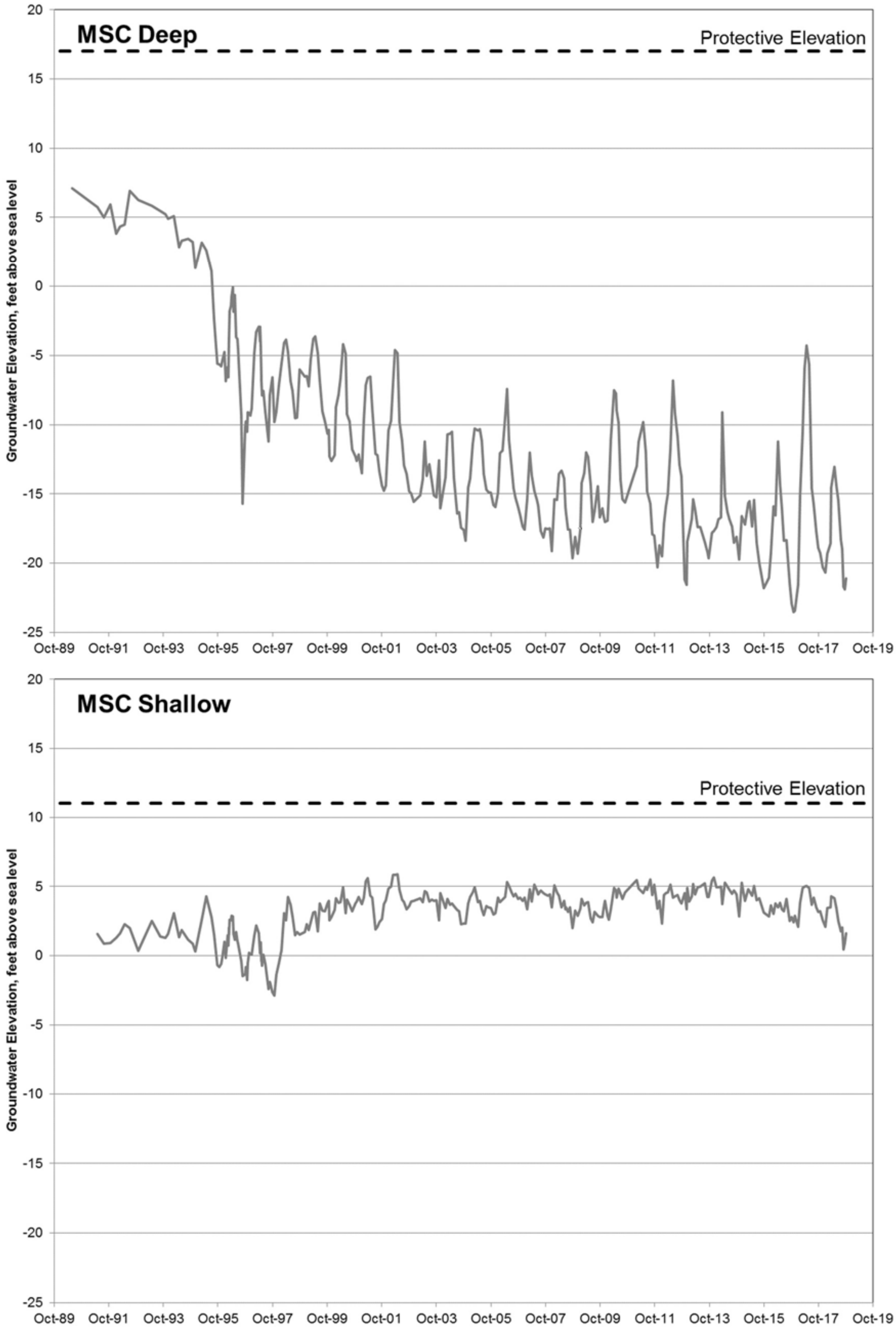
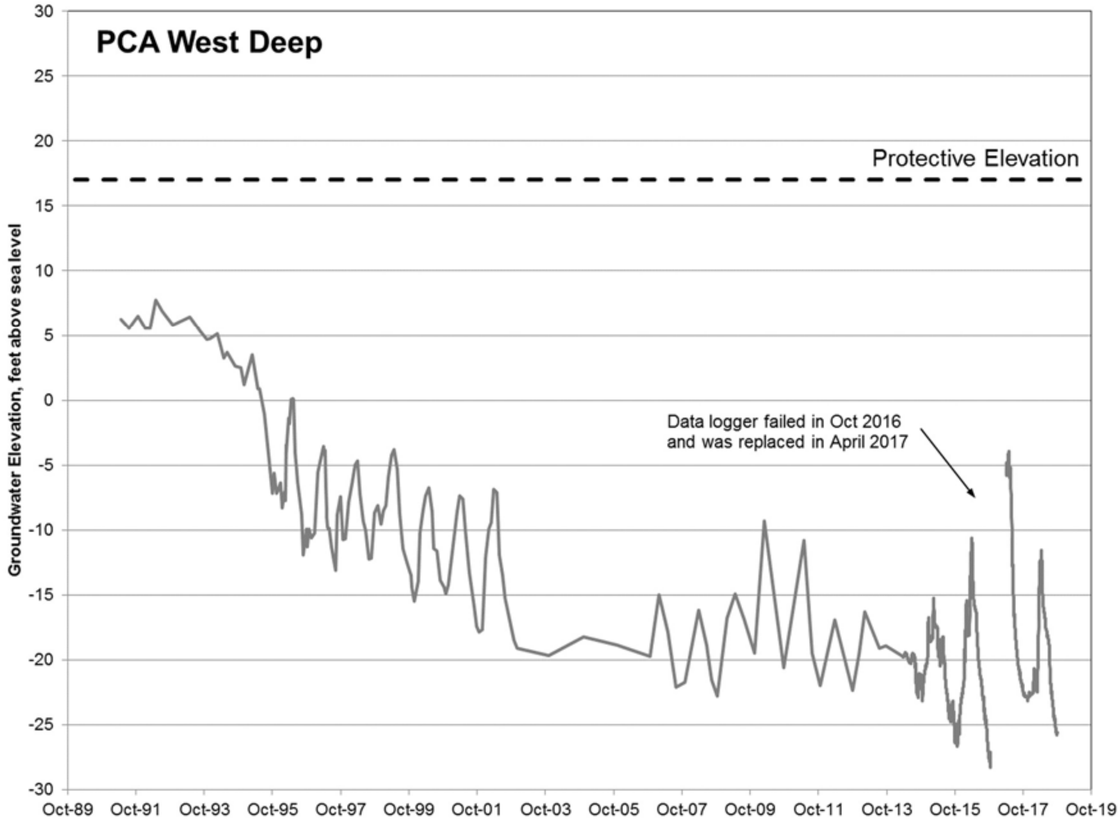


Figure 36. MSC Deep and Shallow Groundwater and Protective Elevations



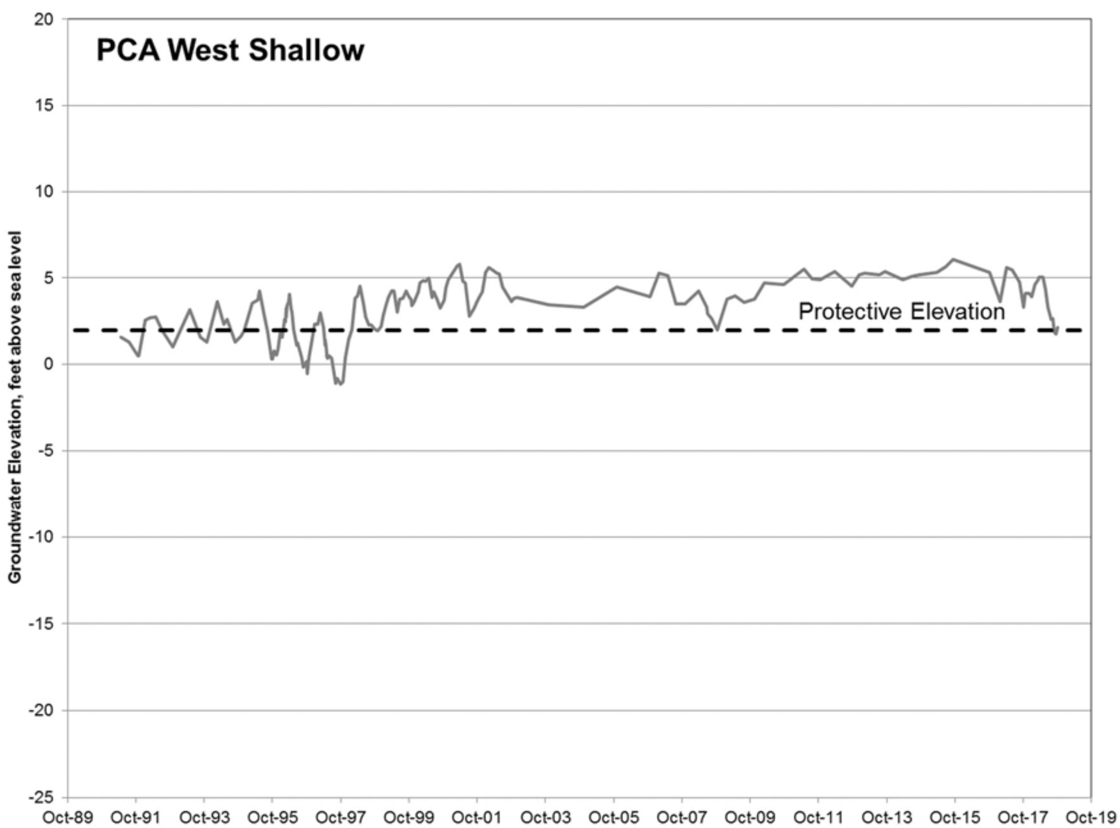


Figure 37. PCA West Deep and Shallow Groundwater and Protective Elevations

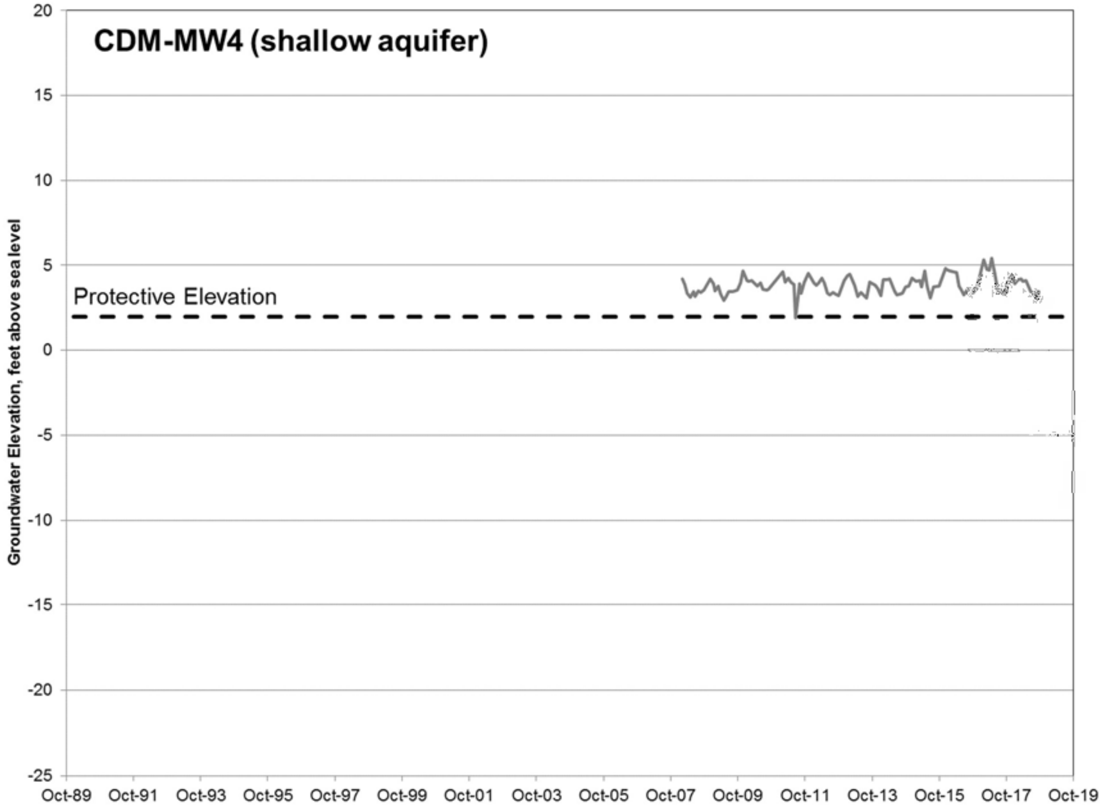


Figure 38. CDM-MW4 Groundwater and Protective Elevations

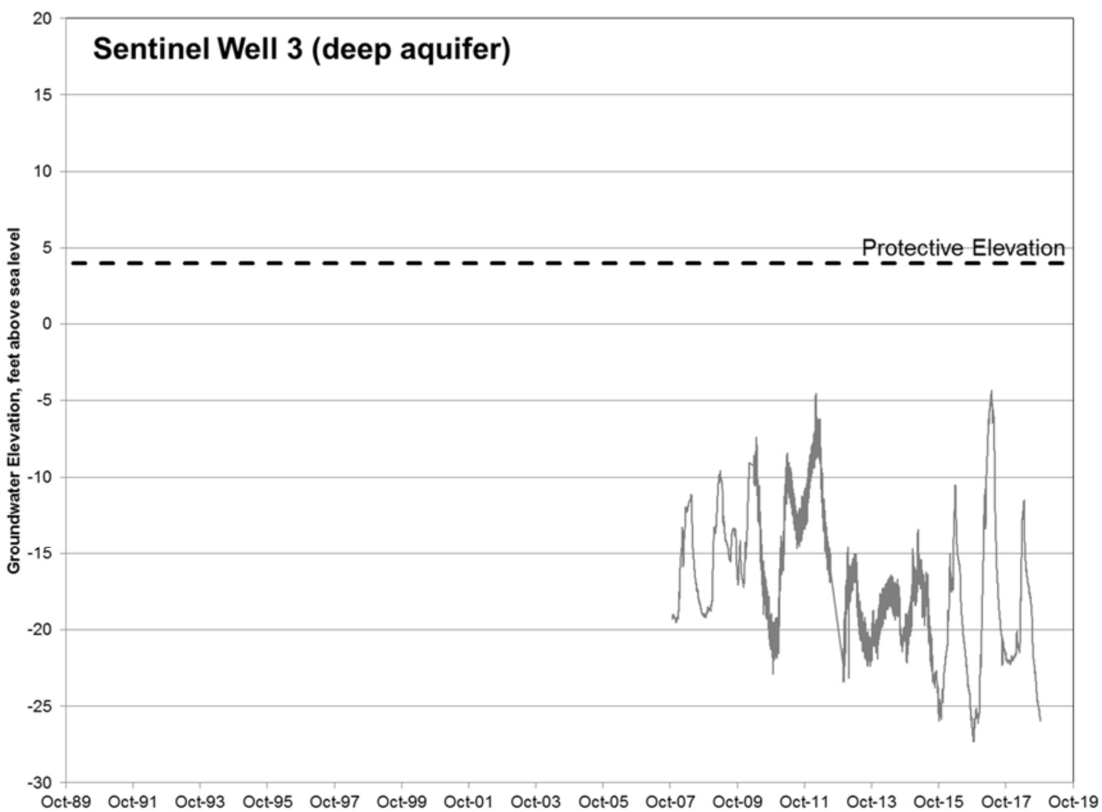


Figure 39. Sentinel Well 3 Groundwater and Protective Elevations

3.7 Groundwater Production

Groundwater pumping in excess of freshwater recharge and subsurface inflow from adjacent areas is the primary cause of seawater intrusion. Mapping pumping volumes gives an indirect indication of the threat of seawater intrusion. Ideally, pumping should be equally distributed throughout a basin, and occur relatively far inland.

Gross pumping by Watermaster producers in Water Year 2018 was 4,572.9 acre-feet, which includes recovery of 1,209.7 acre-feet of aquifer storage and recovery (ASR) water (**Figure 40**). Net or native groundwater pumping is the amount pumped after ASR recovery is taken into account. This means that in years where there is water injected and recovered, more water may be pumped from CAWC's wells to recover water injected the previous operational year. In Water Year 2018, 530.5 acre-feet of injection took place, and 1,209.7 acre-feet of injected water was recovered. The net or native groundwater production is therefore 3,363.2 acre-feet, which is 3.2 acres above the Decision-ordered Operating Yield for Water Year 2018 of 3,360 acre-feet (**Figure 40**). The net or native groundwater produced from the Basin in Water Year 2018 was 314 acre-feet more than in Water Year 2017.

The blue charts on **Figure 41** reflect the actual or gross amounts pumped from each well, and the green chart reflects the amount of water injected at the ASR well. The majority of pumping in the basin occurs at CAWC's Ord Grove No. 2 and Santa Margarita Recovery wells. CAWC's Paralta well was not pumped as much as it usually is as it was undergoing rehabilitation this year.

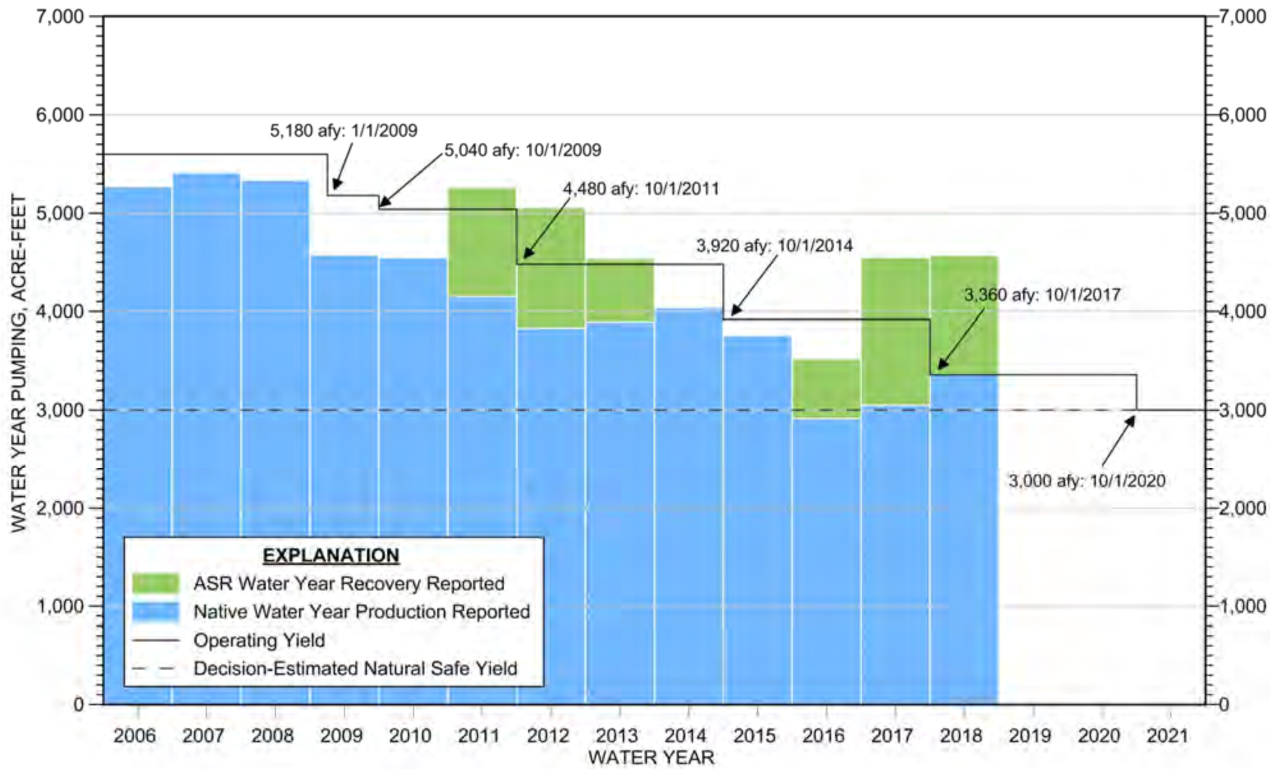


Figure 40. Annual Reported Groundwater Production and Operating Yield for Watermaster Producers

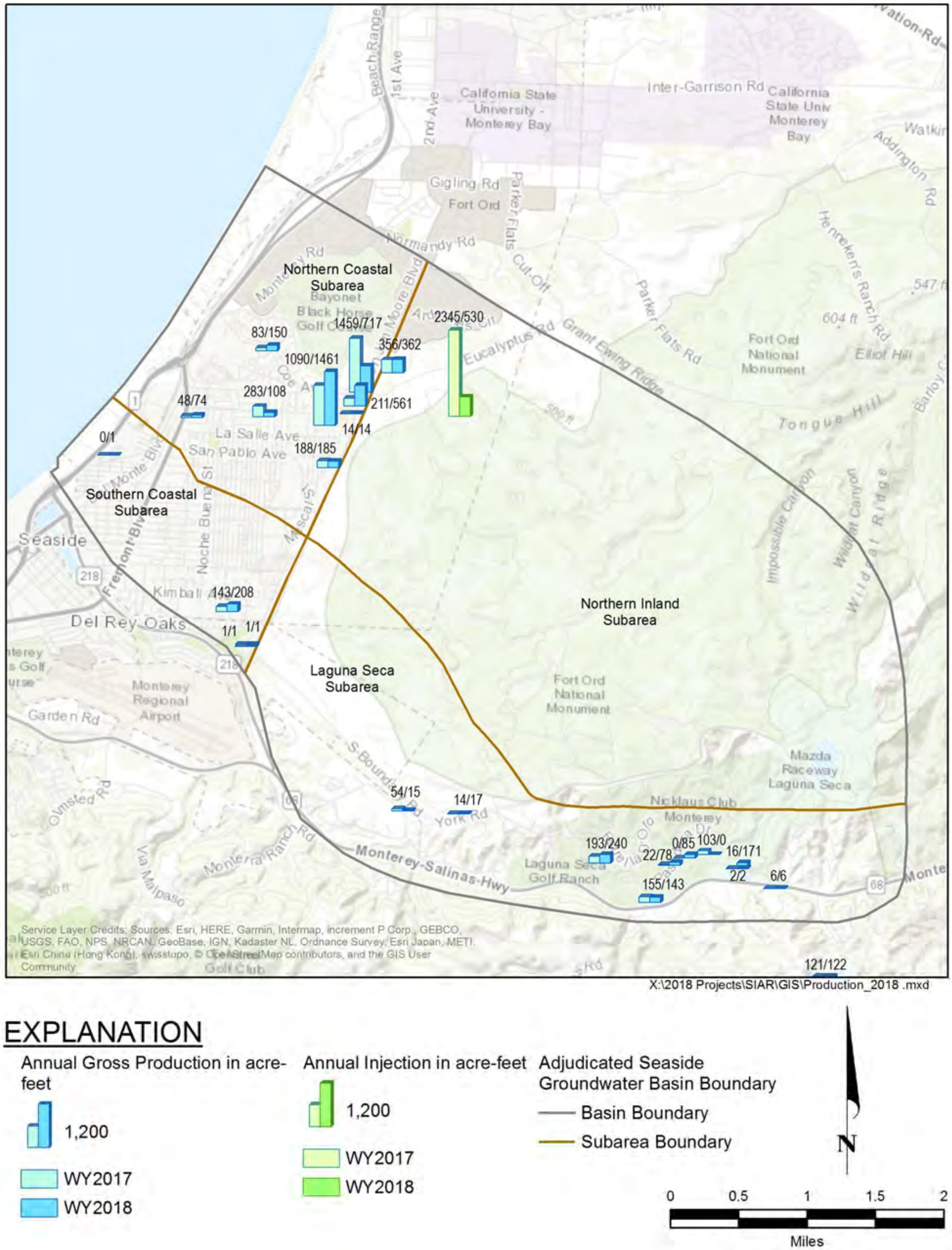


Figure 41. Watermaster Producers' Pumping Distribution for Water Years 2017 and 2018

4 CONCLUSIONS

Groundwater levels below sea level, the cumulative effect of pumping in excess of recharge and fresh water inflows, and ongoing seawater intrusion in the nearby Salinas Valley all suggest that seawater intrusion could occur in the Seaside Groundwater Basin. In spite of these factors, no seawater intrusion has historically been or is currently observed in existing monitoring or production wells in the Seaside Groundwater Basin. This is demonstrated by the different analyses that are used to investigate evidence of seawater intrusion. Analyses which indicate that seawater intrusion is not occurring include:

- All groundwater samples for Water Year 2018 from depth-discreet monitoring wells plot generally in a single cluster on Piper diagrams, with no water chemistry changes towards seawater.
- Groundwater quality plot on Piper diagrams in some of the production wells is different than the water quality in the monitoring wells. This may be a result of mixed water quality from both shallow and deep zones in which these wells are perforated. None of the production wells' groundwater qualities are indicative of seawater intrusion.
- None of the Stiff diagrams for monitoring and production wells show the characteristic chloride spike that typically indicates seawater intrusion in Stiff diagrams.
- Overall, chloride concentration trends were stable for most monitoring wells, with no increases greater than 10 mg/L.
- Sodium/chloride molar ratios in the monitoring wells remained constant or increased over the past year.
- Maps of chloride concentrations for the shallow aquifer do not show chlorides increasing towards the coast. The deep aquifer maps show that higher chloride concentrations are limited to coastal monitoring wells PCA-West Deep and MSC Deep, but these are not indicative of seawater intrusion.
- Induction logging data at the coastal Sentinel Wells do not show large changes over time that are indicative of seawater intrusion.

The following groundwater level and production data suggest that conditions in the basin continue to provide a potential for seawater intrusion:

- All deep groundwater in the Northern Coastal subarea is below sea level. The 2^{nd} quarter (winter/spring) deep aquifer coastal groundwater levels are more than 12 feet below sea level and the 4^{th} quarter (summer/fall) levels are more than 25 feet below sea level. These are similar to the historic low levels observed in Water Year 2016 at the end of the recent drought.

- Groundwater levels remain below protective elevations in all deep target monitoring wells (MSC deep, PCA-W, and sentinel well SBWM-3). Currently, only one of the three shallow wells' groundwater levels are above protective elevations: CDM-MW4. Since 1997, PCA-W shallow groundwater levels has been above protective elevations but has just fallen below its protective elevation this fall; probably due to increased shallow aquifer production that started in 2015. As observed historically, MSC shallow groundwater levels remains below protective elevations.

Other conclusions from the analysis contained in this report are:

- Due to its distance from the coast, seawater intrusion is not an issue of concern in the Laguna Seca subarea. However, groundwater levels in the eastern Laguna Seca subarea have historically declined at rates of 0.6 feet per year in the shallow aquifers, and up to four feet per year in the deep aquifers. These declines have occurred since 2001, despite triennial reductions in allowable pumping. The cause of the declines is due in part to the Natural Safe Yield of the subarea being too high and in part due to the influence of wells to the east of the Seaside Basin. Since 2014, however, the rate of decline is less and now appears close to stabilizing.

- Native groundwater production in the Seaside Groundwater Basin for Water Year 2018 was 3,363.4 acre-feet, which is 314 acre-feet more than Water Year 2017. This amount is 3.4 acre-feet more than the Decision-ordered Operating Yield of 3,360 acre-feet per year that is required between October 1, 2017 and September 30, 2020.

5 RECOMMENDATIONS

The analyses presented previously in this report are based on existing data. While informative, the data are spatially incomplete and temporally sporadic. The following recommendations should be implemented to monitor and track seawater intrusion.

Continue to Analyze and Report on Water Quality Annually

Seawater intrusion is a threat, and data must be analyzed regularly to identify incipient intrusion. Maps, graphs, and analyses similar to what are found in this report should continue to be developed every year.

Include Data from New Monitoring Wells Installed as Part of Recharge Projects

There are a number of projects being implemented or planned in the Seaside Basin that involve recharge and recovery of imported water. It is important that data from new monitoring wells that are part of these projects be reported to the Watermaster and taken into consideration in future SIARs. This is because is it expected that these projects will change groundwater levels in their vicinity and beyond, which in turn changes groundwater flow directions and hydraulic gradients. Being able to determine if the benefits of these projects reduce the threat of seawater intrusion is an added important aspect of the annual reporting.

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7 ACRONYMS & ABBREVIATIONS

amsl ....above mean sea level
ASR................aquifer storage and recovery
bgs ....below ground surface
Ca ....calcium
CAWC............California American Water Company
Cl....................chloride
CO3 ....carbonate
FO ....Fort Ord
HCO3 ....bicarbonate
K.....................potassium
MCWRA ....Monterey County Water Resources Agency
meq/L ....milliequivalent per liter
Mg ....magnesium
mg/L ....milligrams per liter
MPWMD........Monterey Peninsula Water Management District
MSC ....Monterey Sand Company
Na ....sodium
PCA................Pacific Cement Aggregates
PVWMA ....Pajaro Valley Water Management Agency
SBMMP ....Seaside Groundwater Basin Monitoring and Management Program
SO_4 ....sulfate
TAC................Technical Advisory Committee
WY ....Water Year

Appendix A

Piper Diagrams

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Figure A-27: Piper Diagram of Mission Memorial Park

Figure A-28: Piper Diagram of Paralta Production Well

Figure A-29: Piper Diagram of Reservoir (Bayonet Blackhorse) Production Well

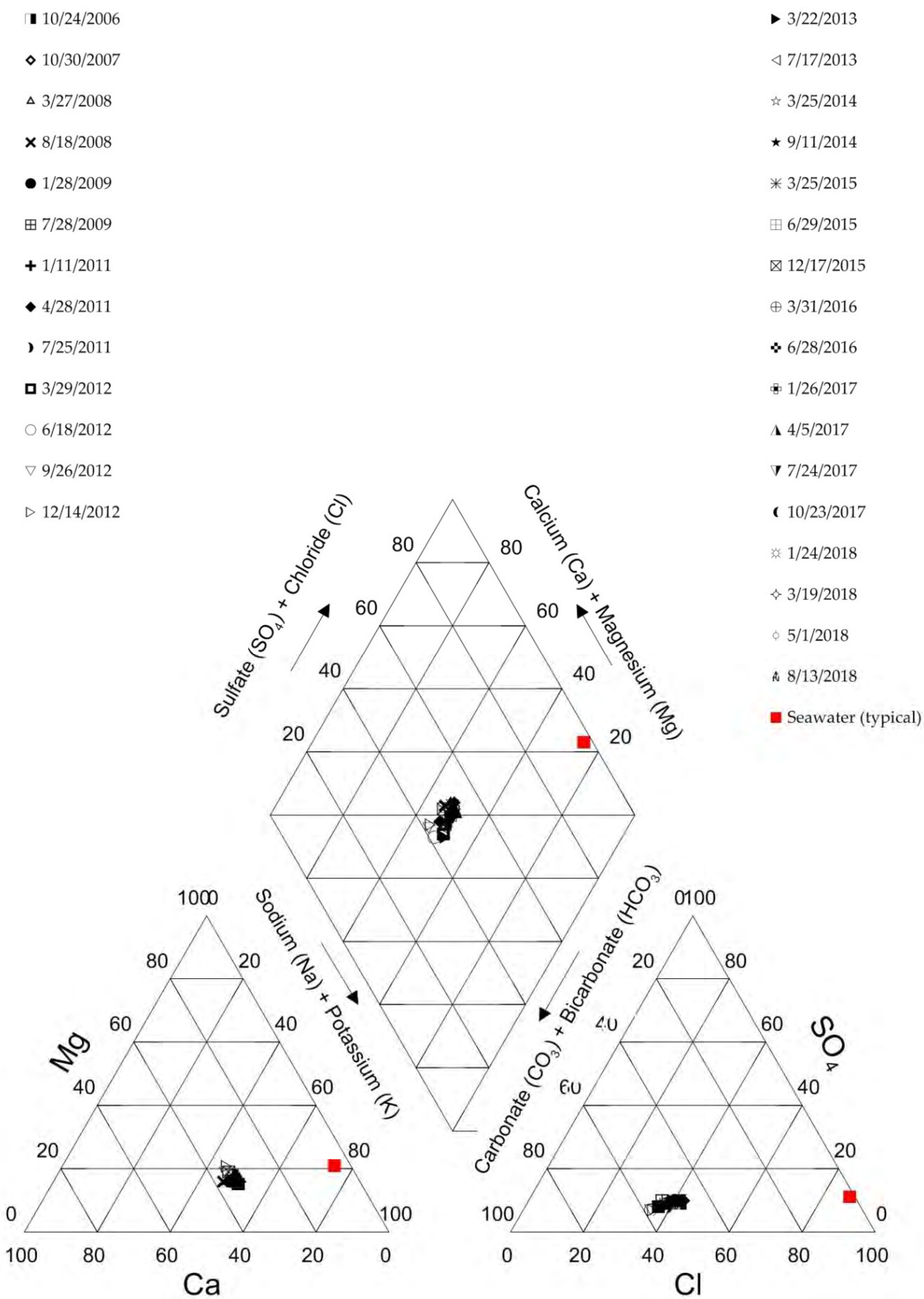

Figure A-1: Piper Diagram of PCA West Shallow

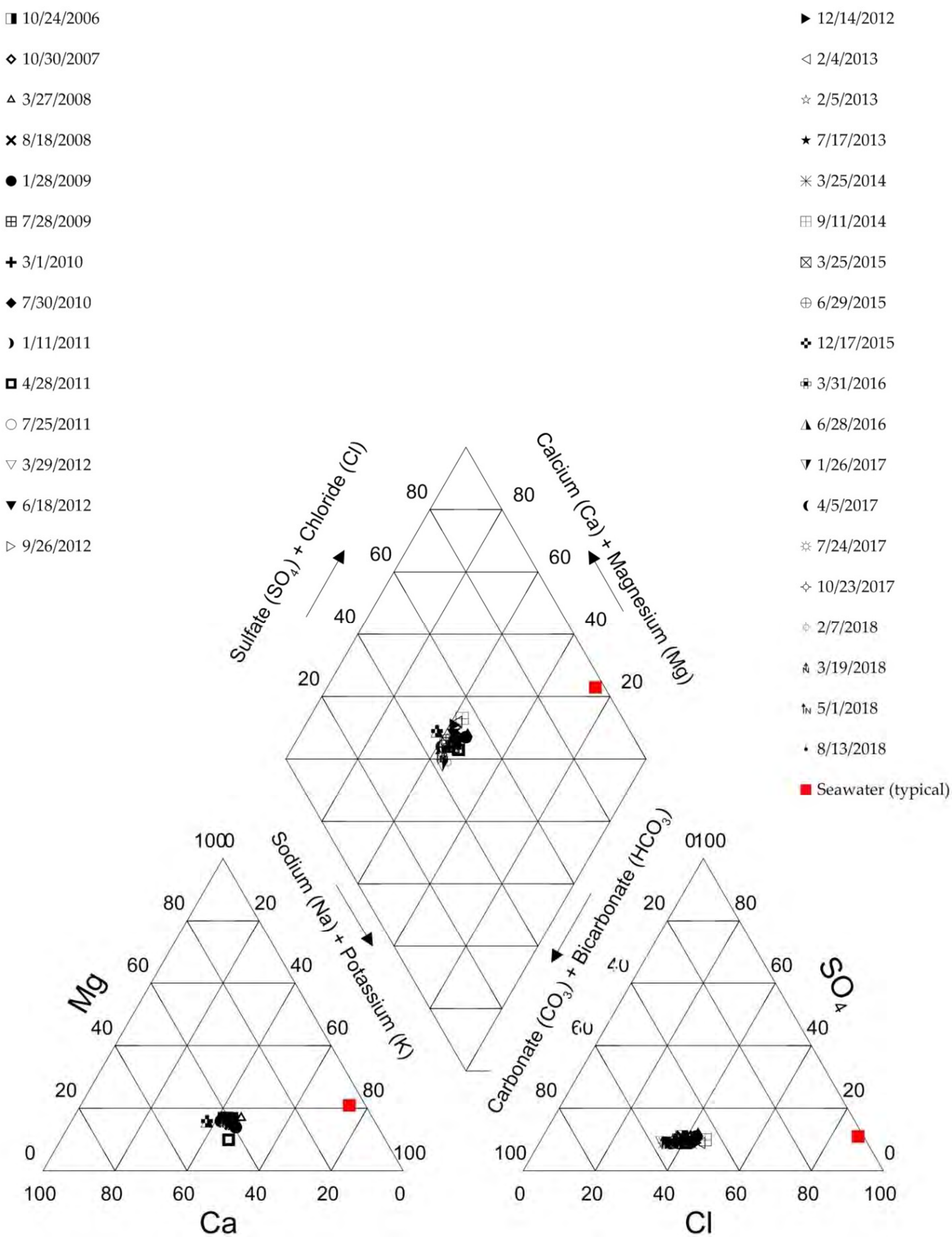

Figure A-2: Piper Diagram of PCA West Deep

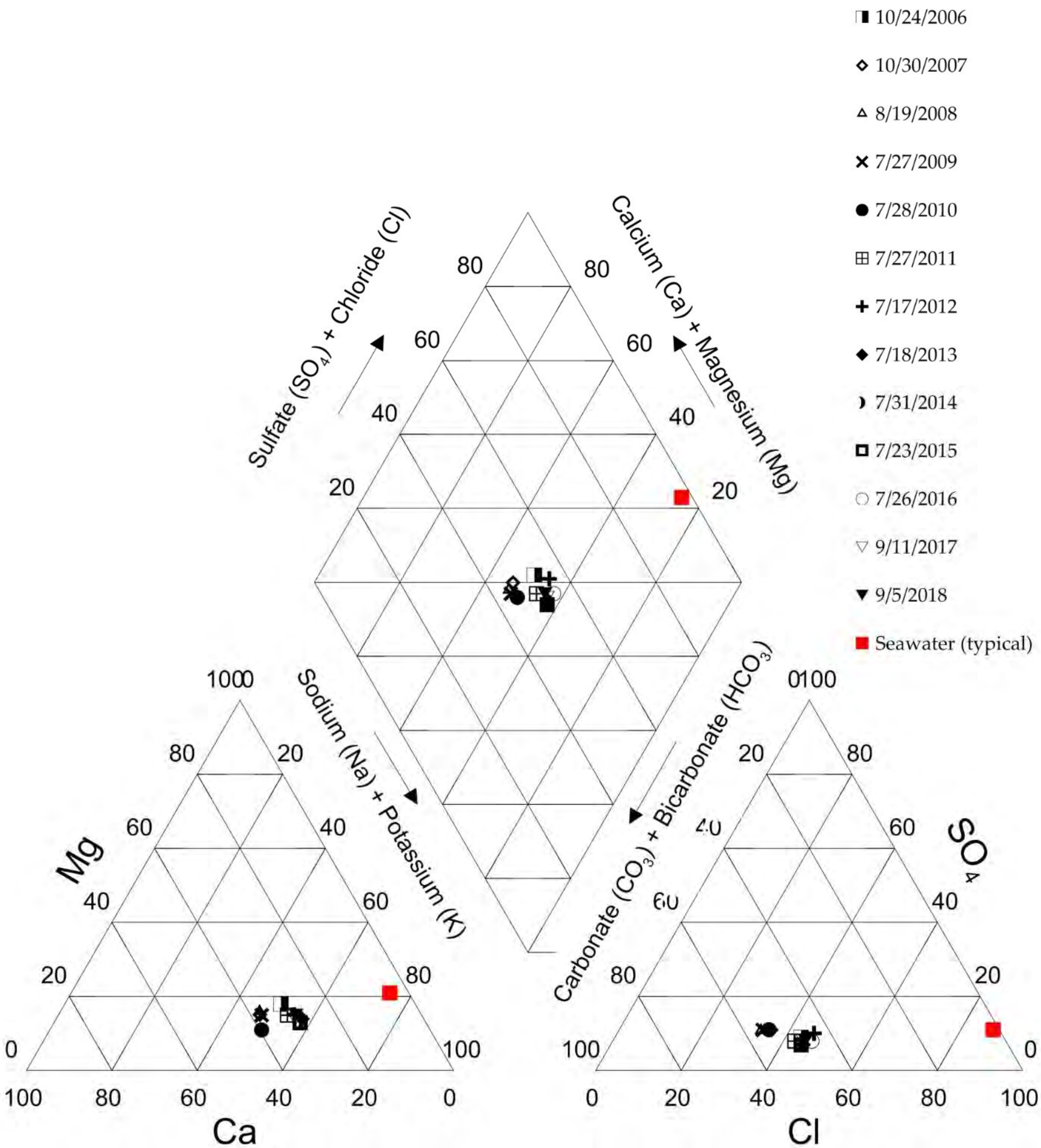

Figure A-3: Piper Diagram of PCA East Shallow

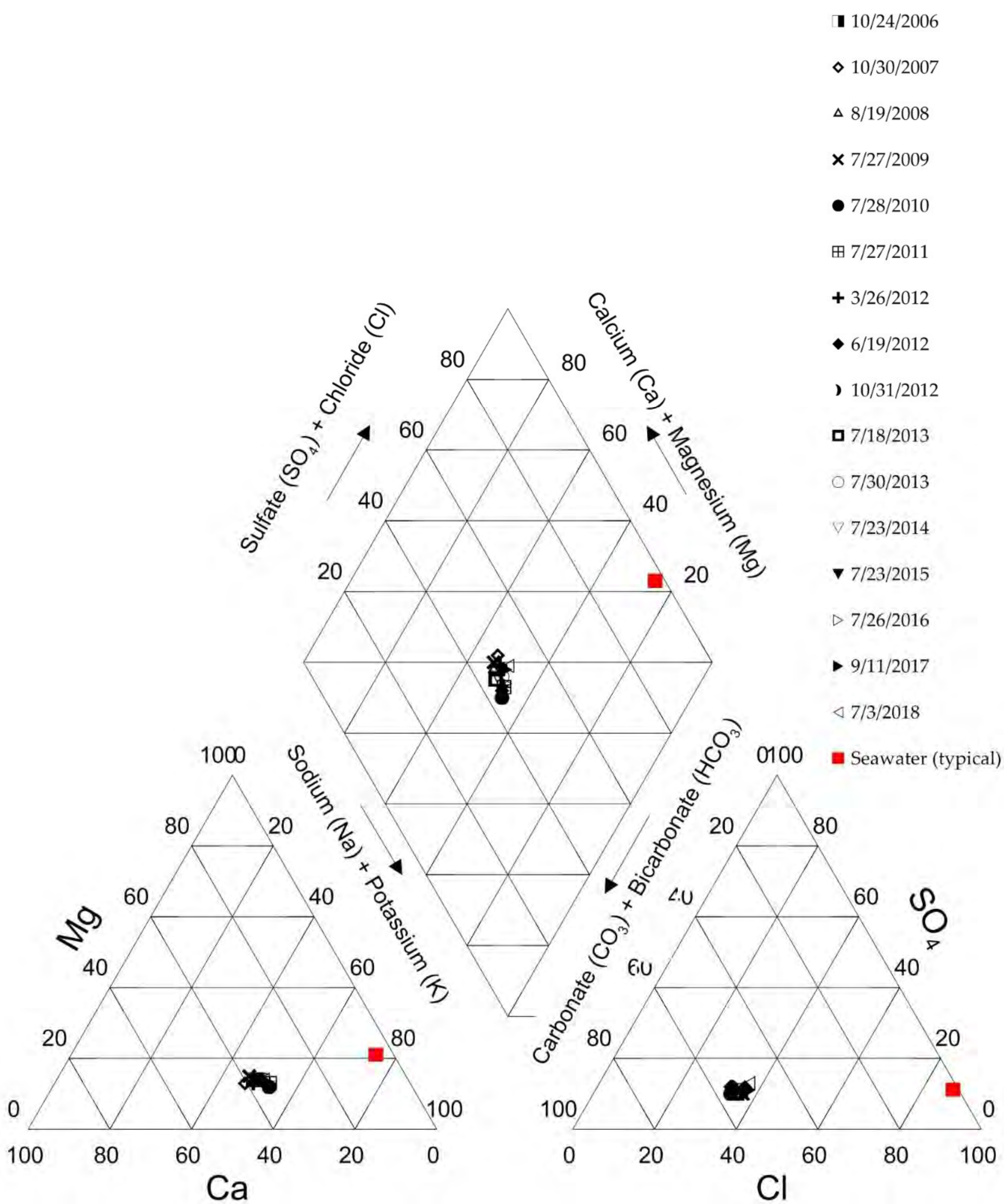

Figure A-4: Piper Diagram of PCA East Deep

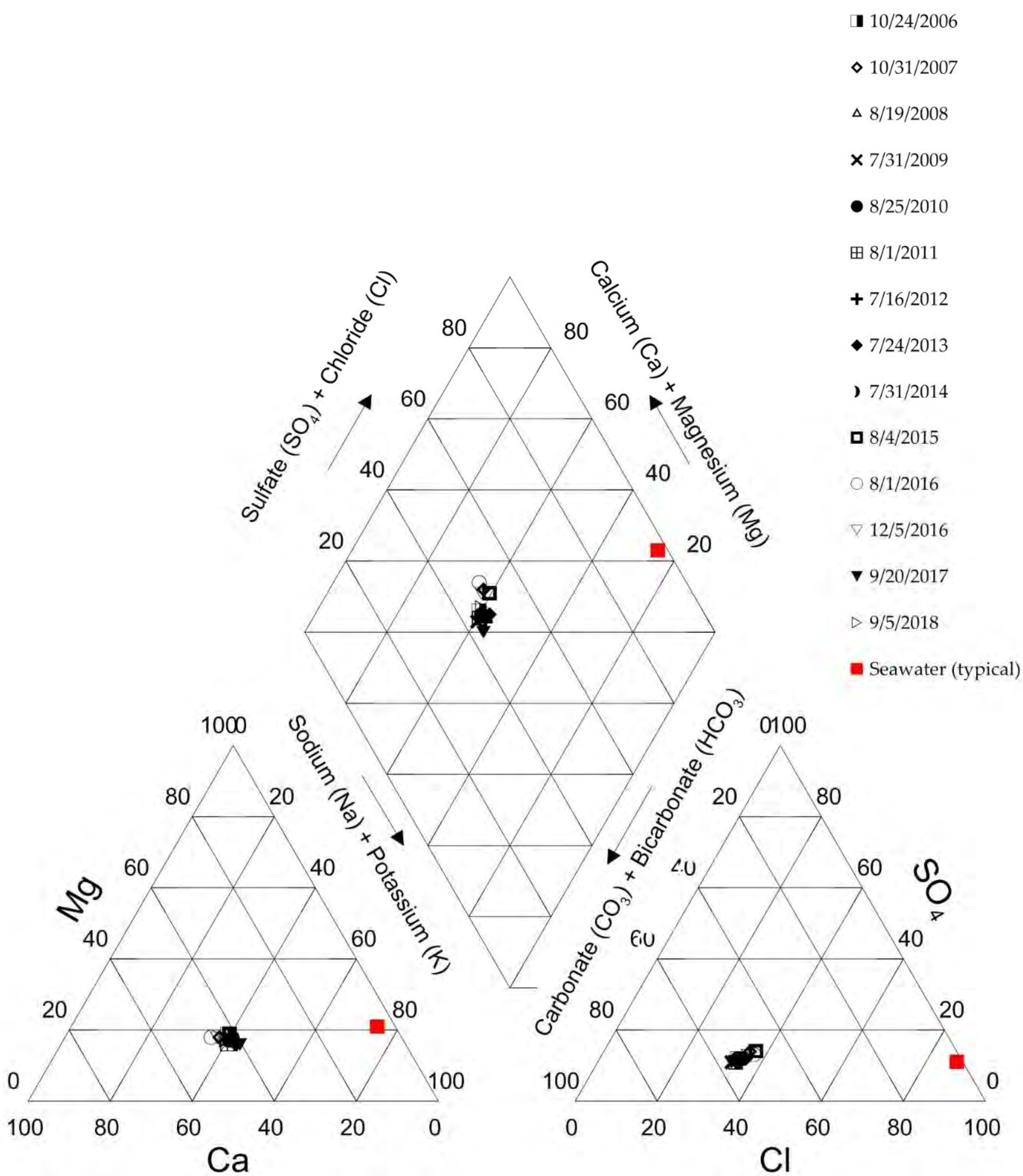

Figure A-5: Piper Diagram of Ord Terrace Shallow

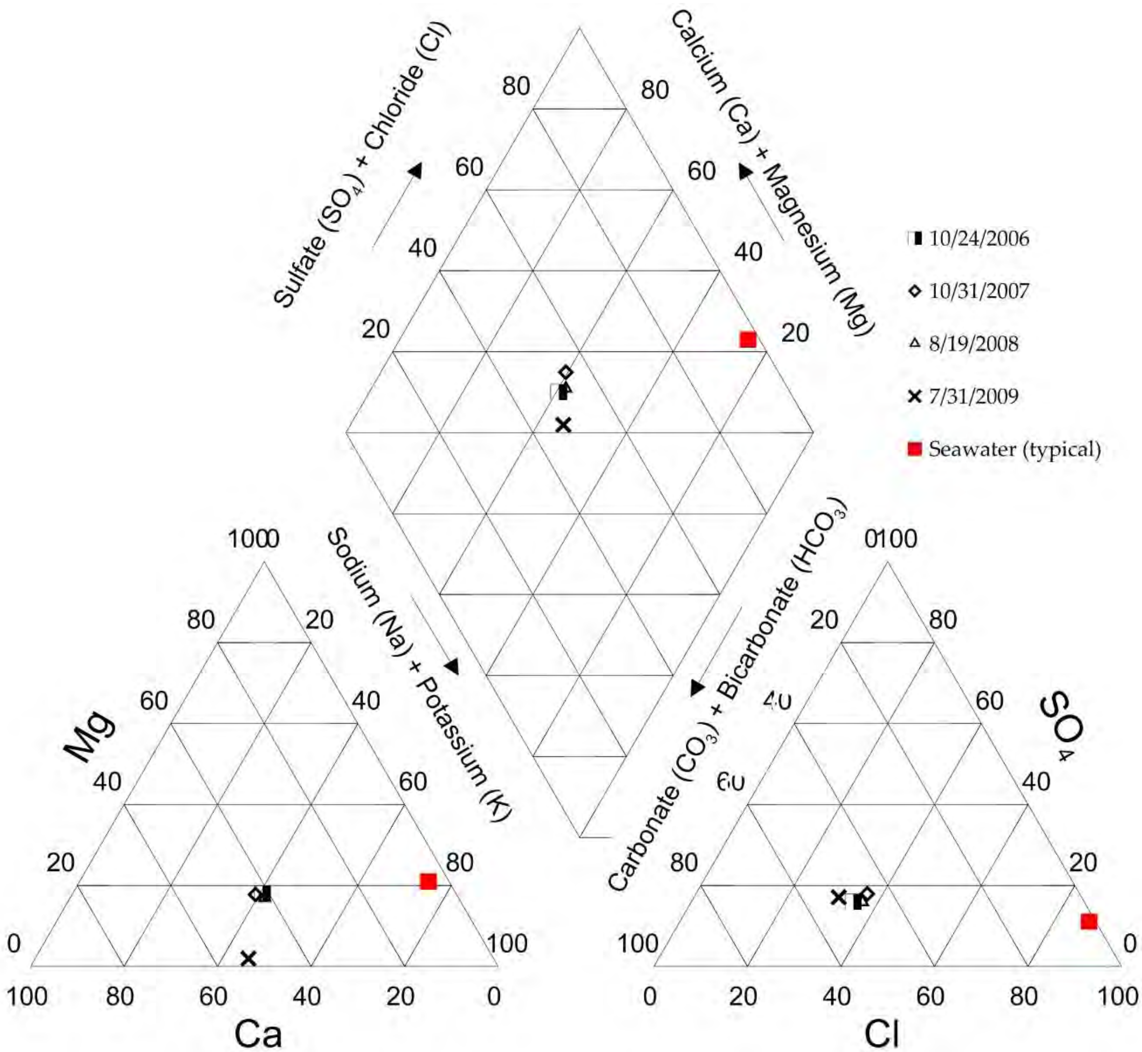

Figure A-6: Piper Diagram of Ord Terrace Deep

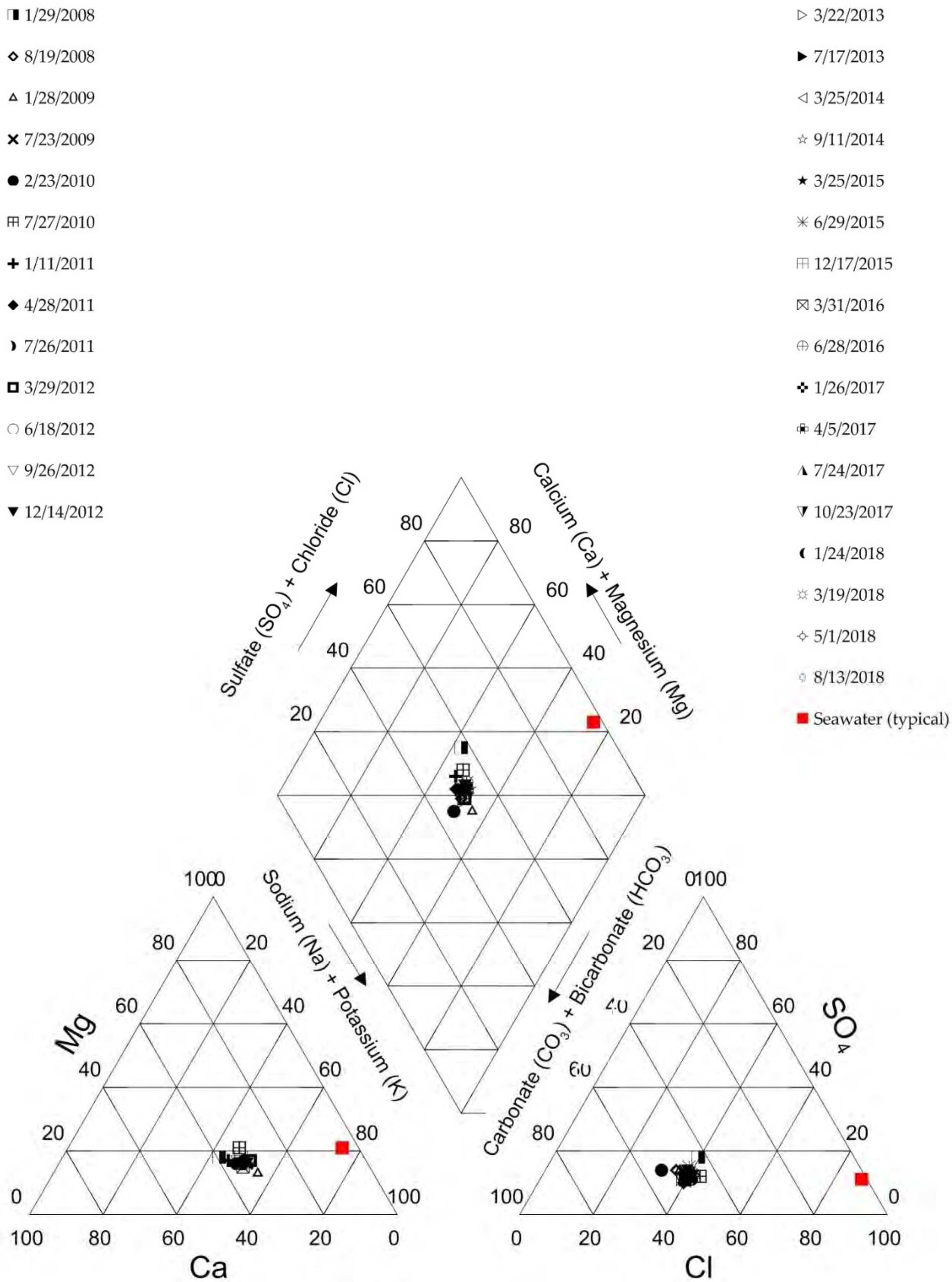

Figure A-7: Piper Diagram of MSC Shallow

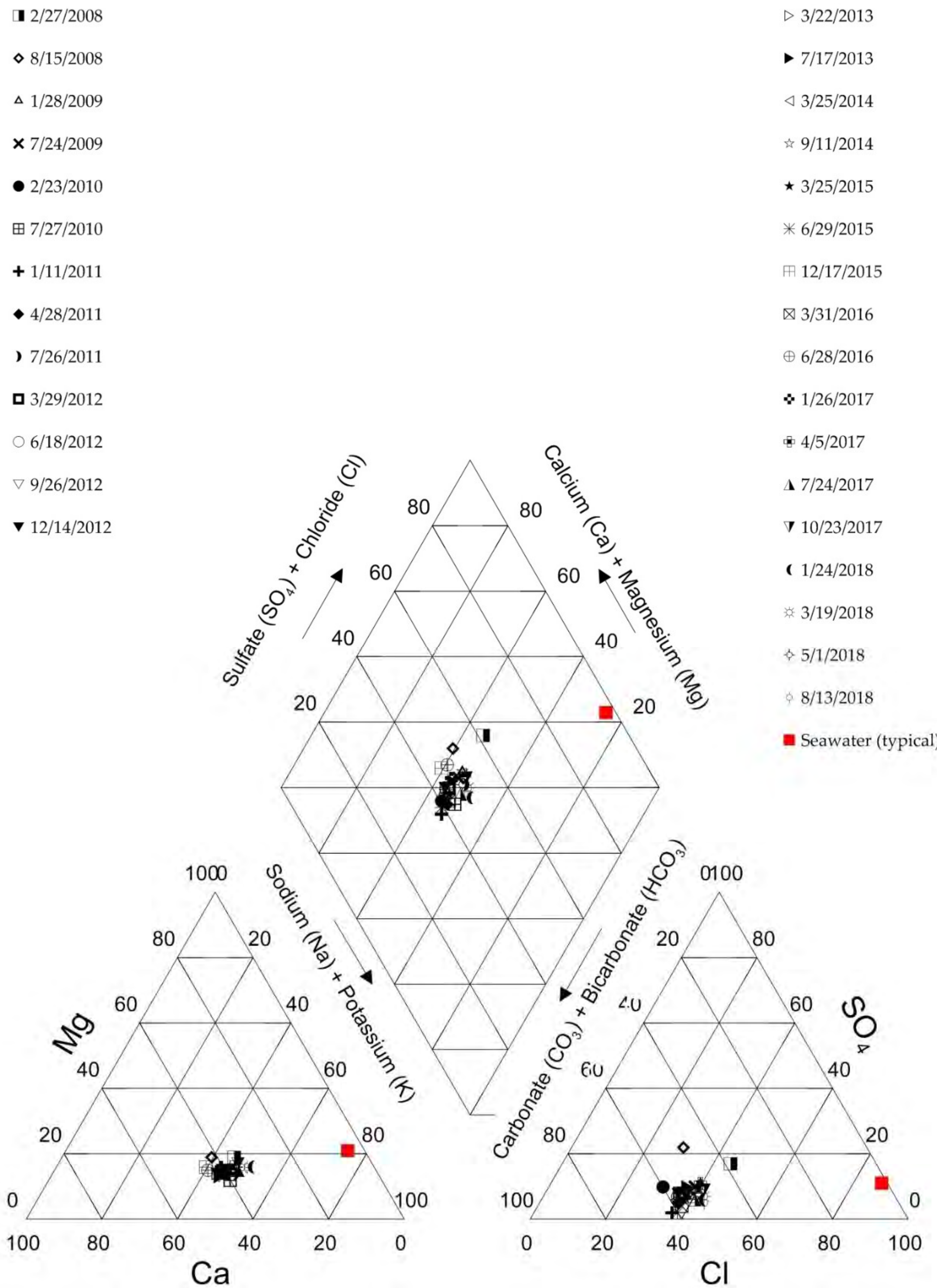

Figure A-8: Piper Diagram of MSC Deep

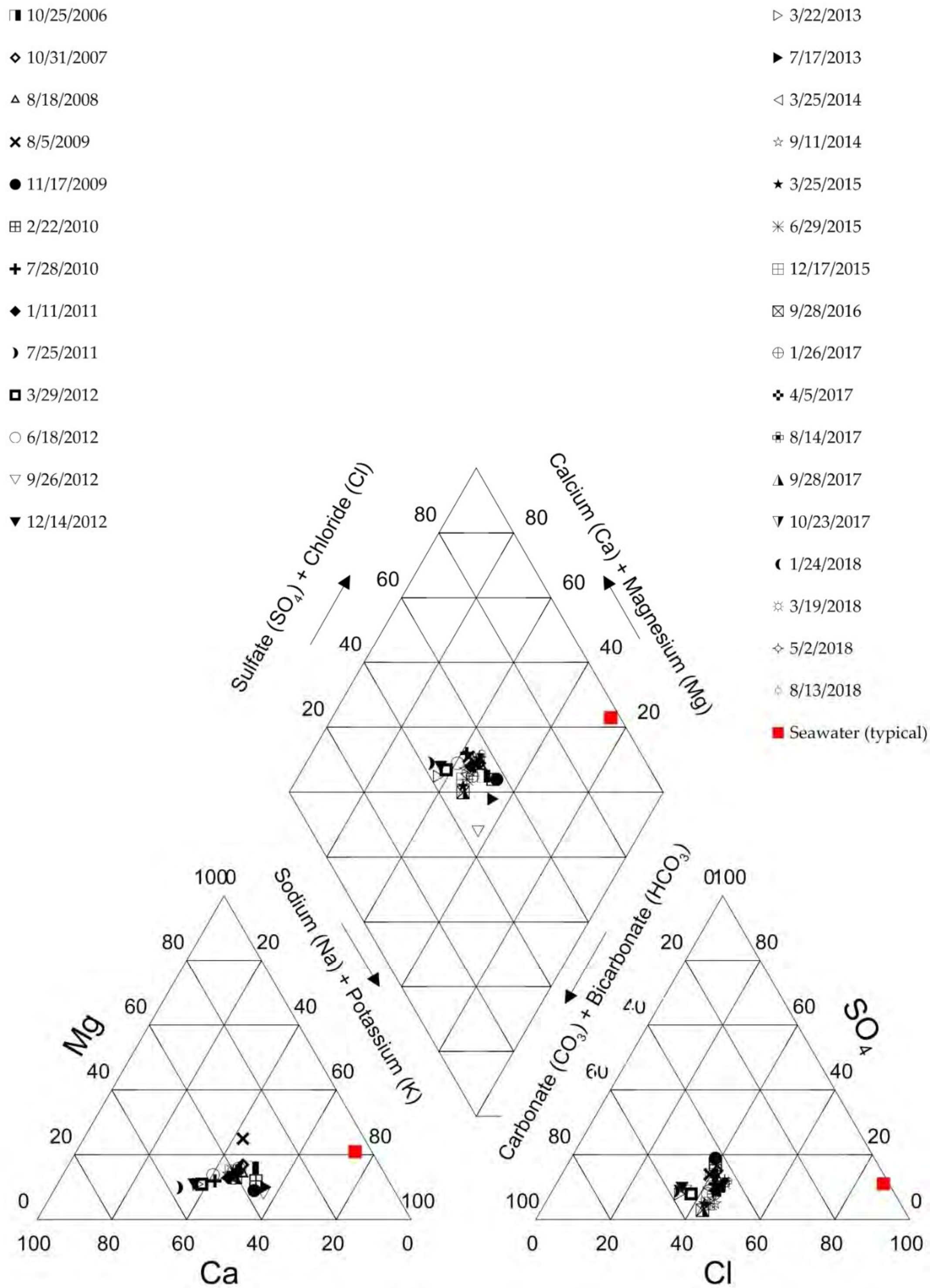

Figure A-9: Piper Diagram of Fort Ord 9 Shallow

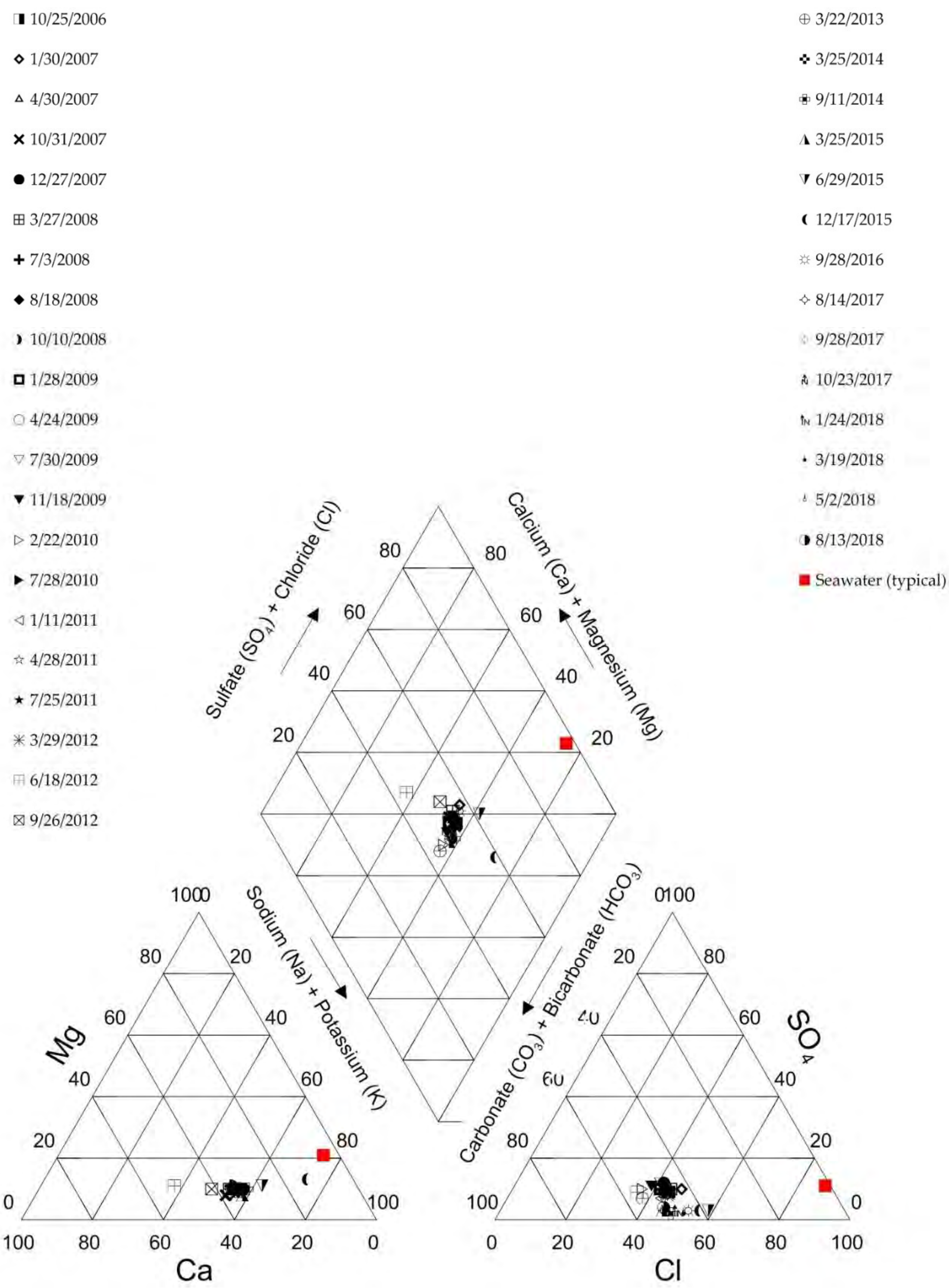

Figure A-10: Piper Diagram of Fort Ord 9 Deep

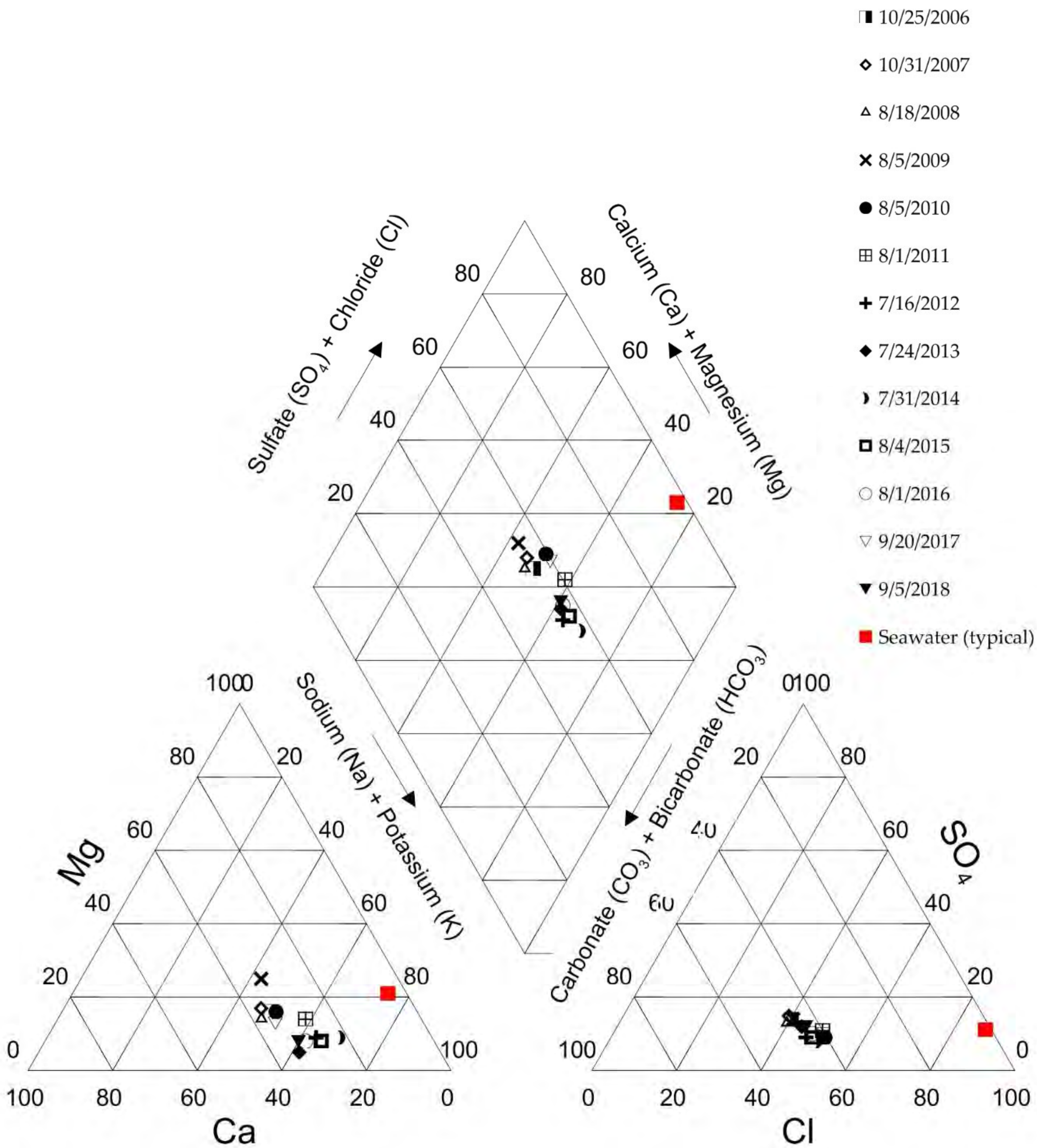

Figure A-11: Piper Diagram of Fort Ord 10 Shallow

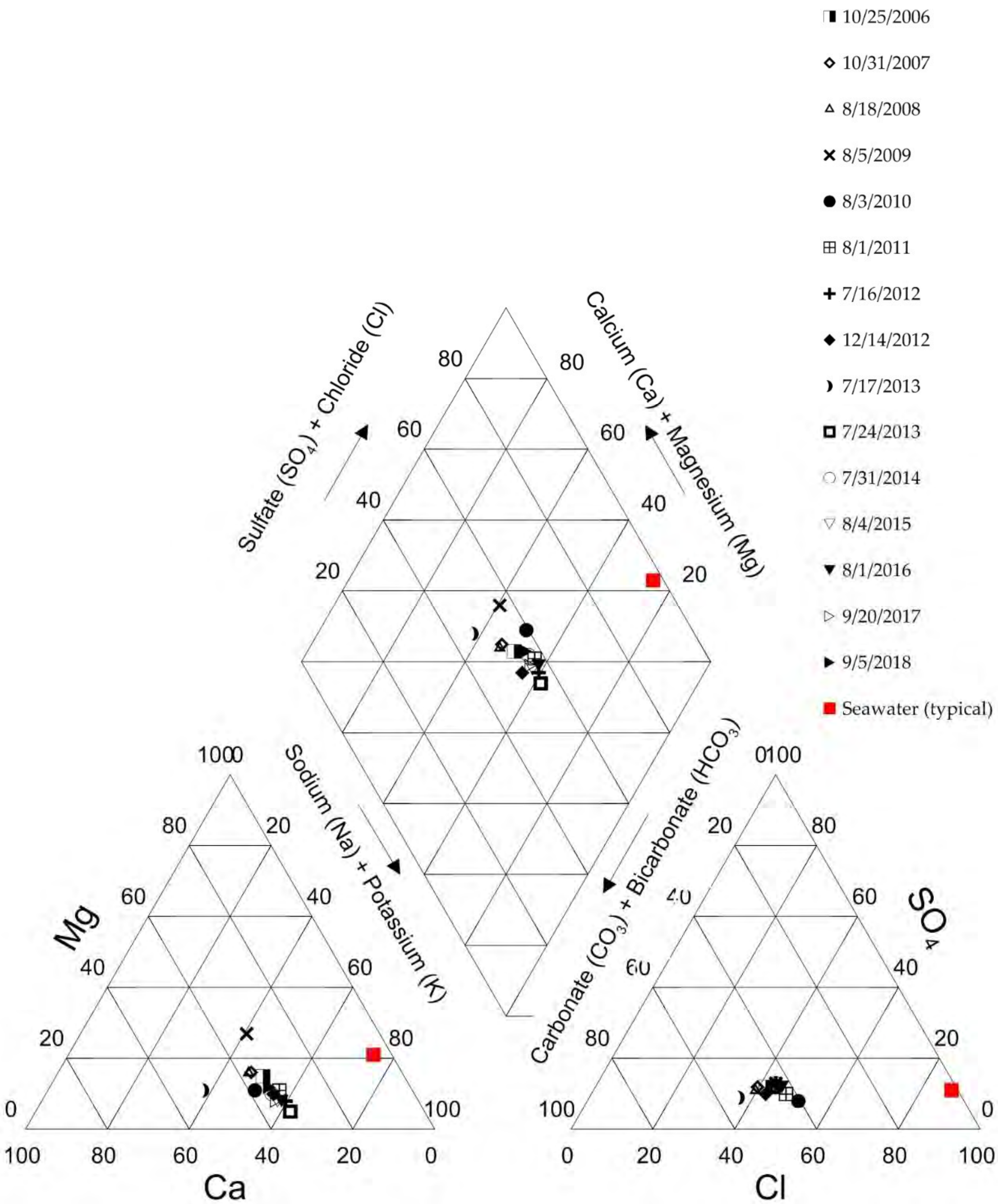

Figure A-12: Piper Diagram of Fort Ord 10 Deep

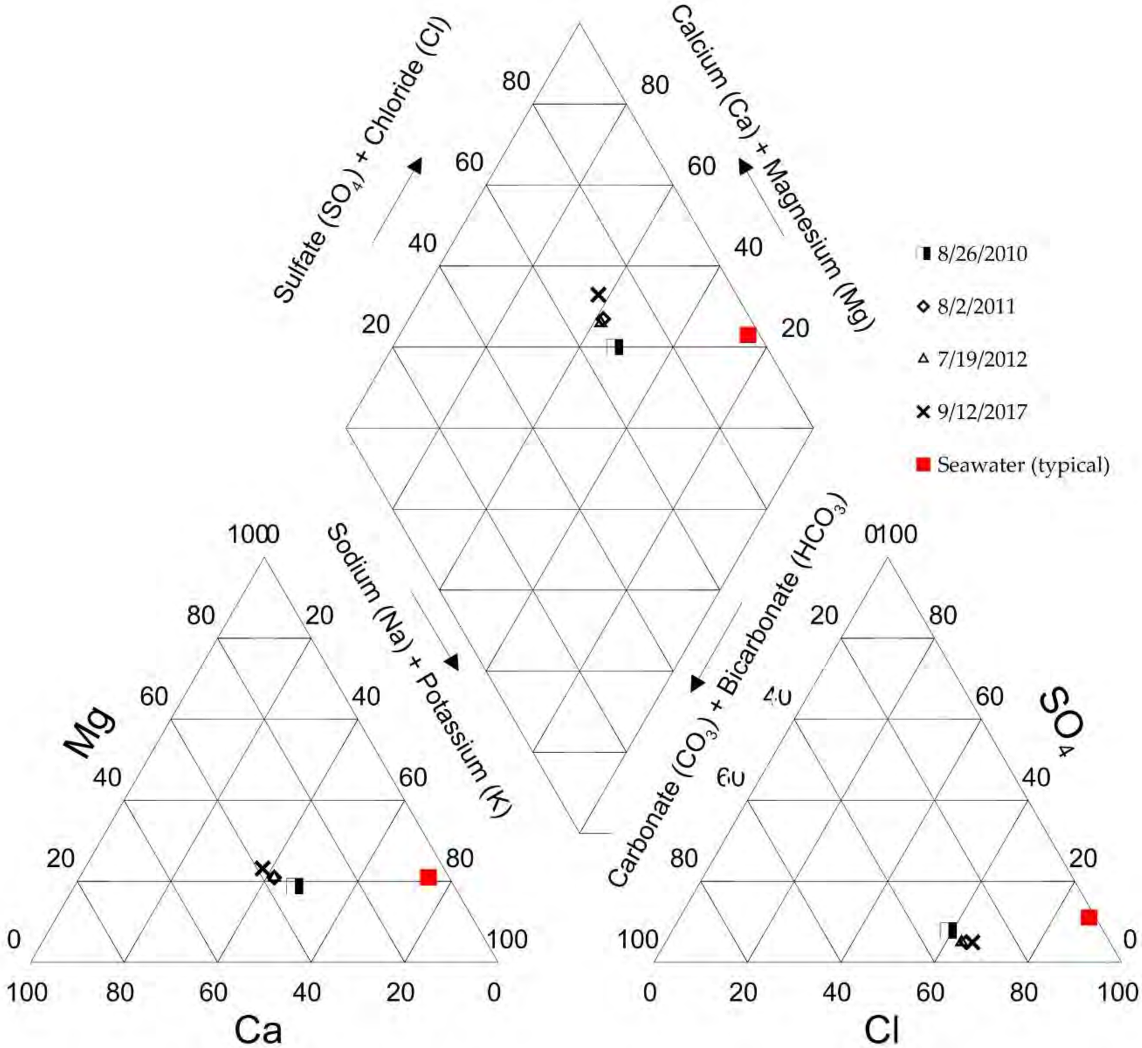

Figure A-13: Piper Diagram of Camp Huffman Shallow Well

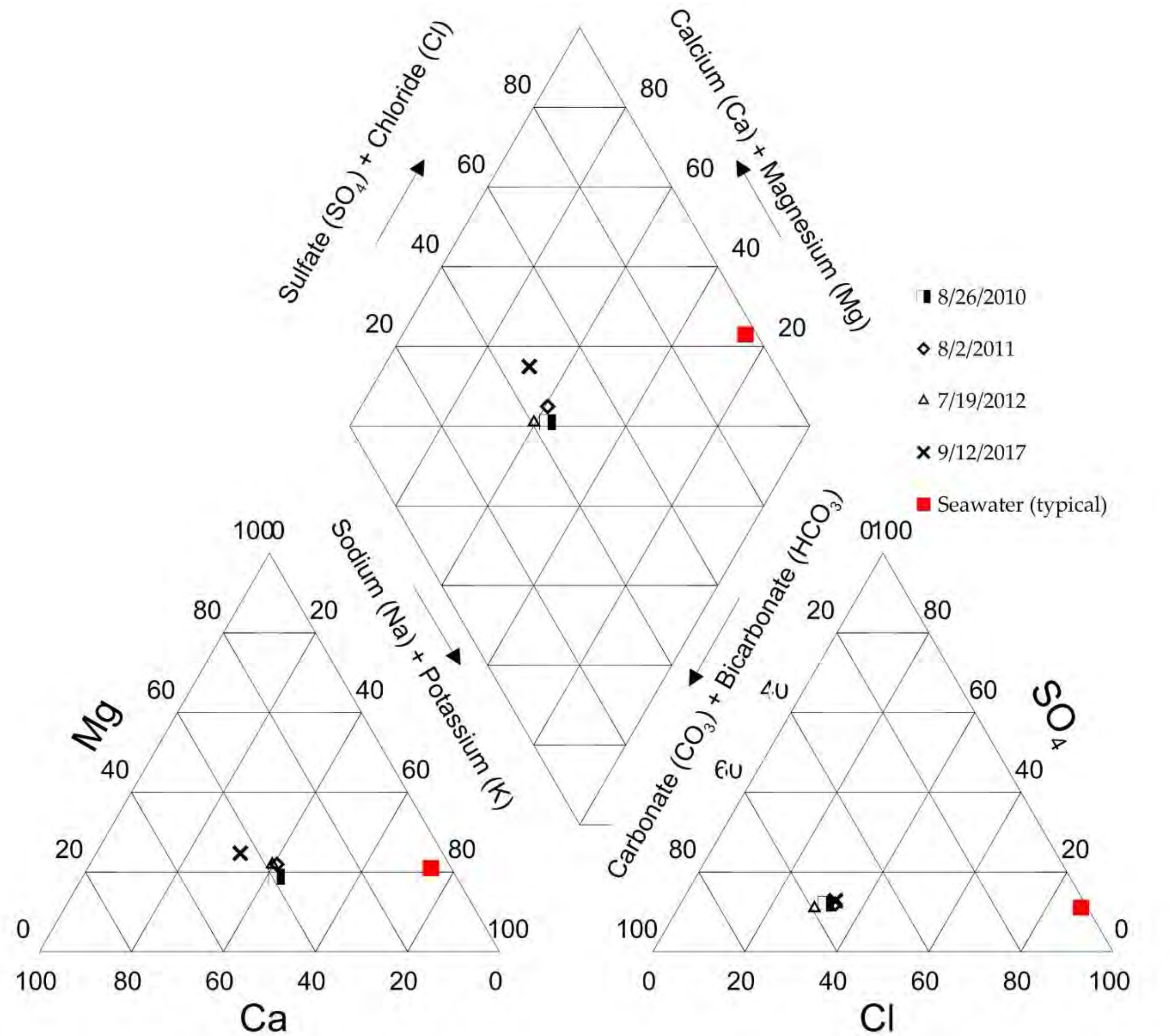

Figure A-14: Piper Diagram of Camp Huffman Deep Well

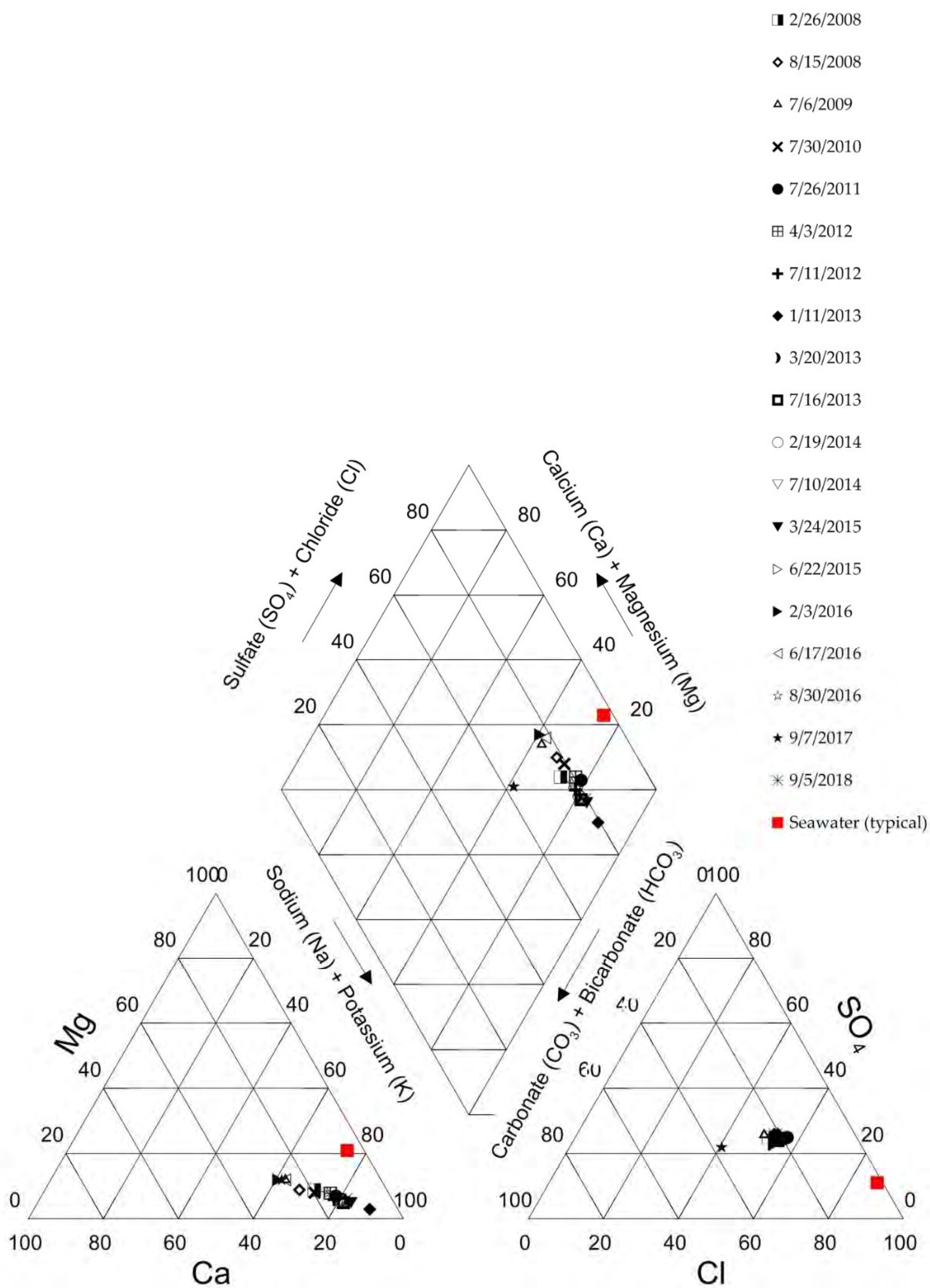

Figure A-15: Piper Diagram of Sand City Corp. Yard Production Well

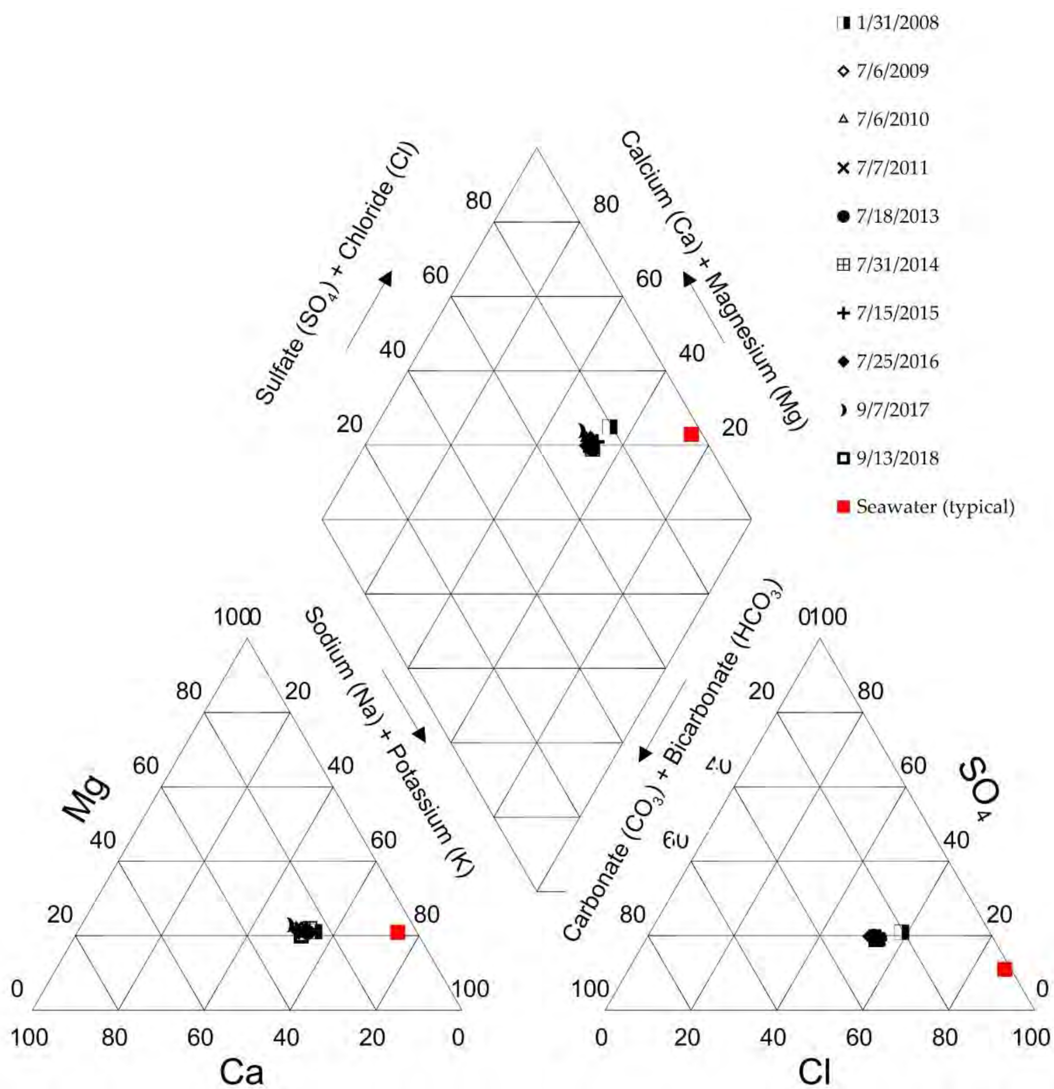

Figure A-16: Piper Diagram of Plumas 4 Production Well

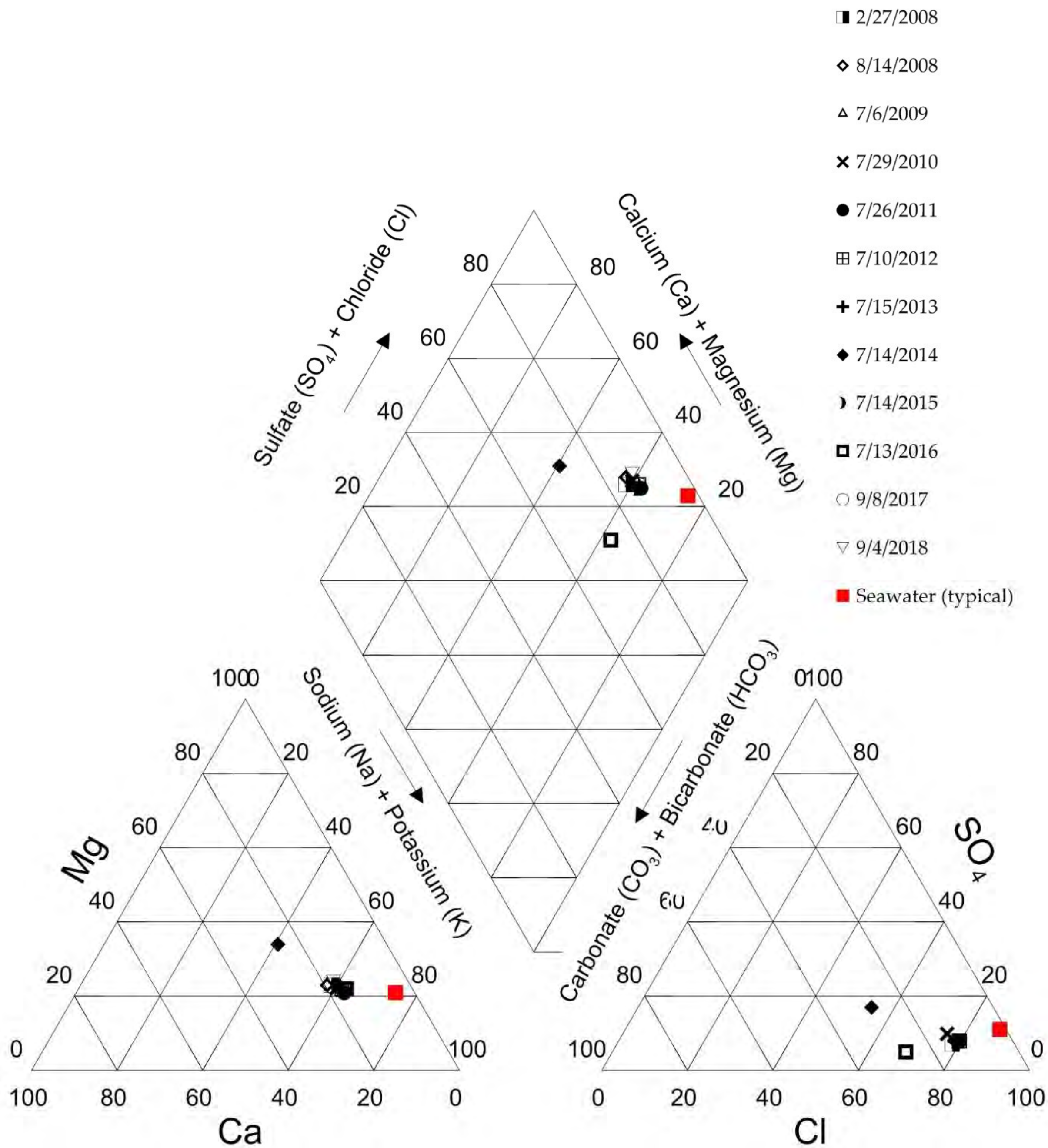

Figure A-17: Piper Diagram of York School Production Well

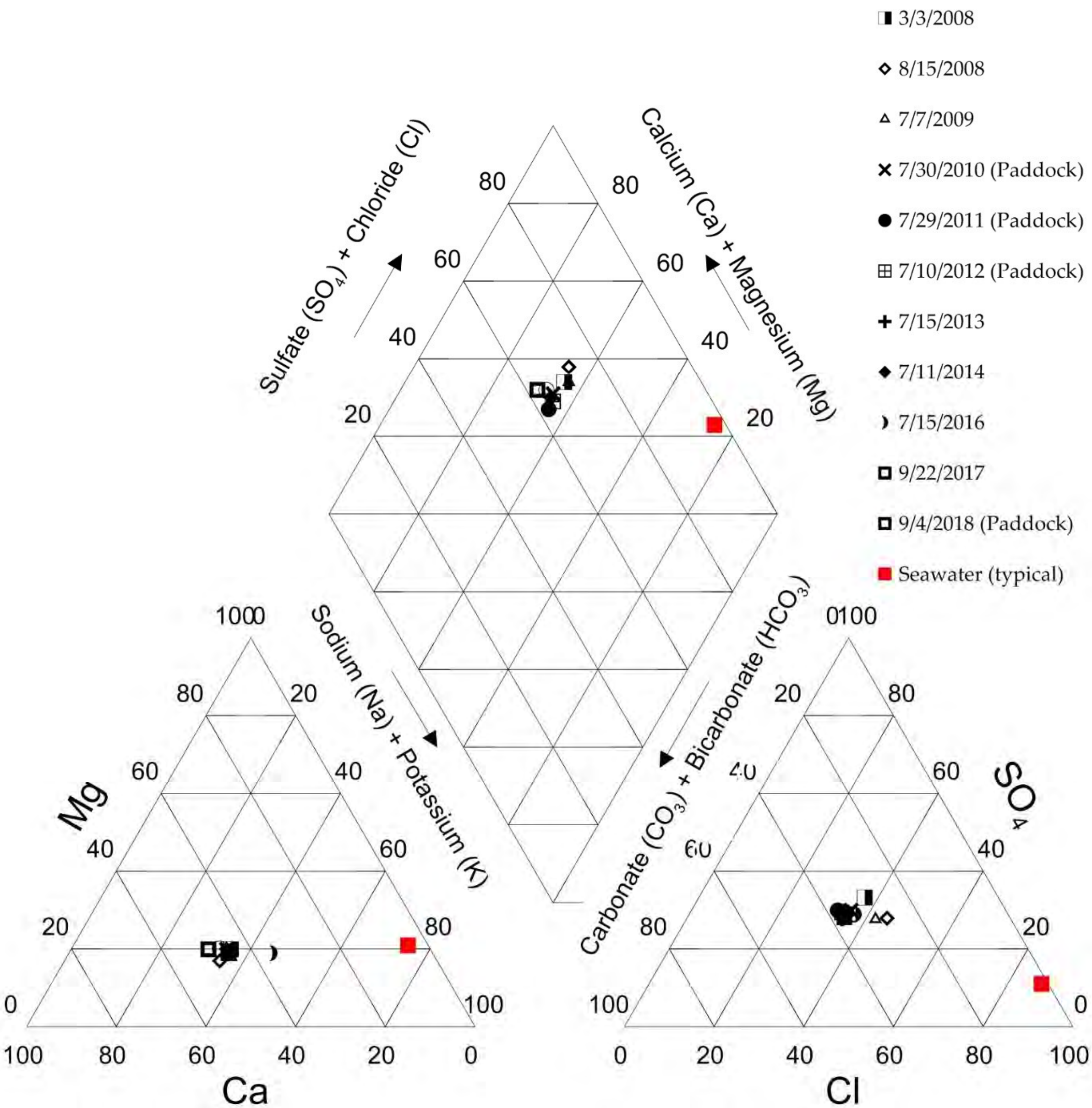

Figure A-18: Piper Diagram of Pasadera Main Gate Production Well

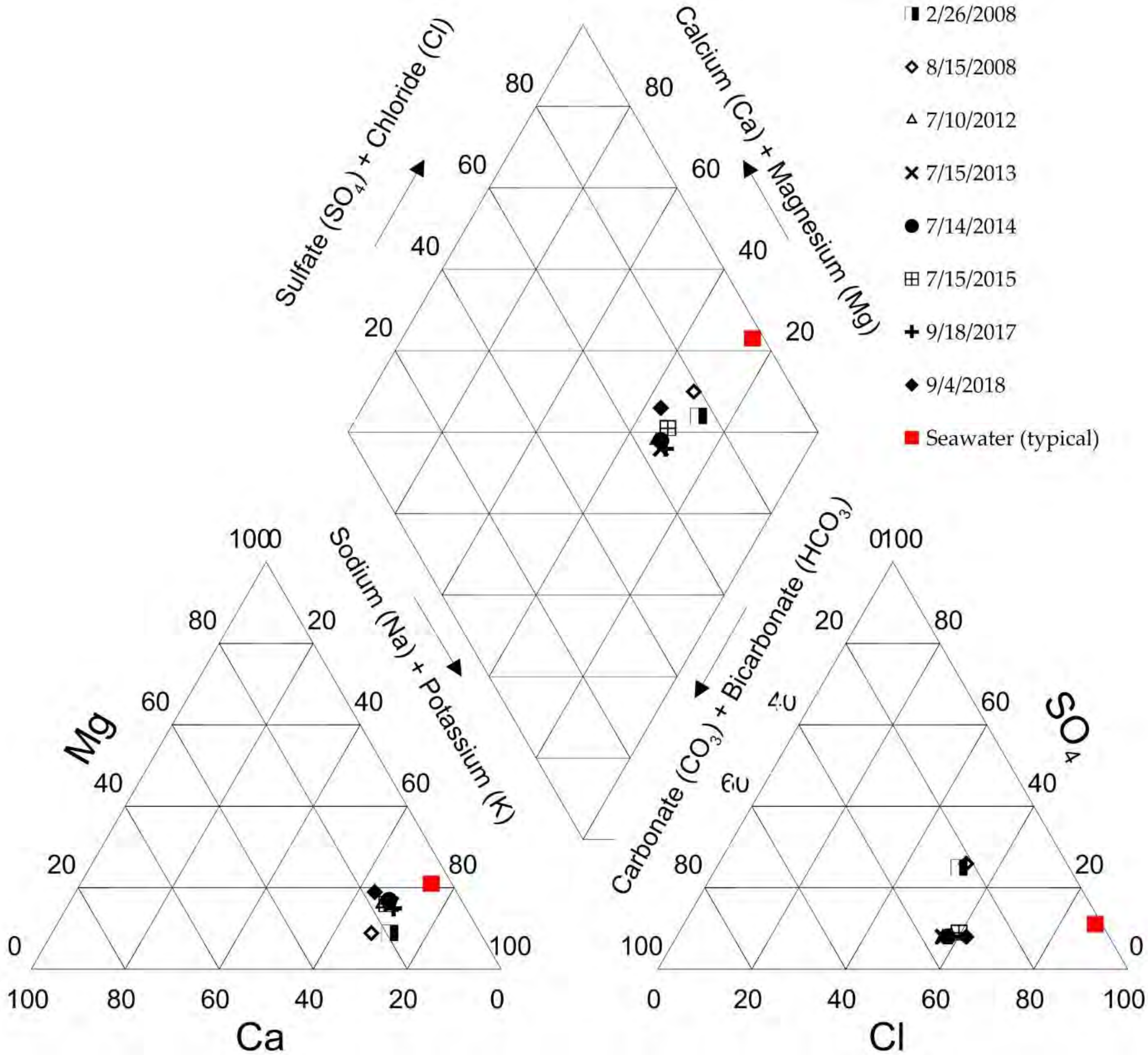

Figure A-19: Piper Diagram of LS County Park #1 Production Well

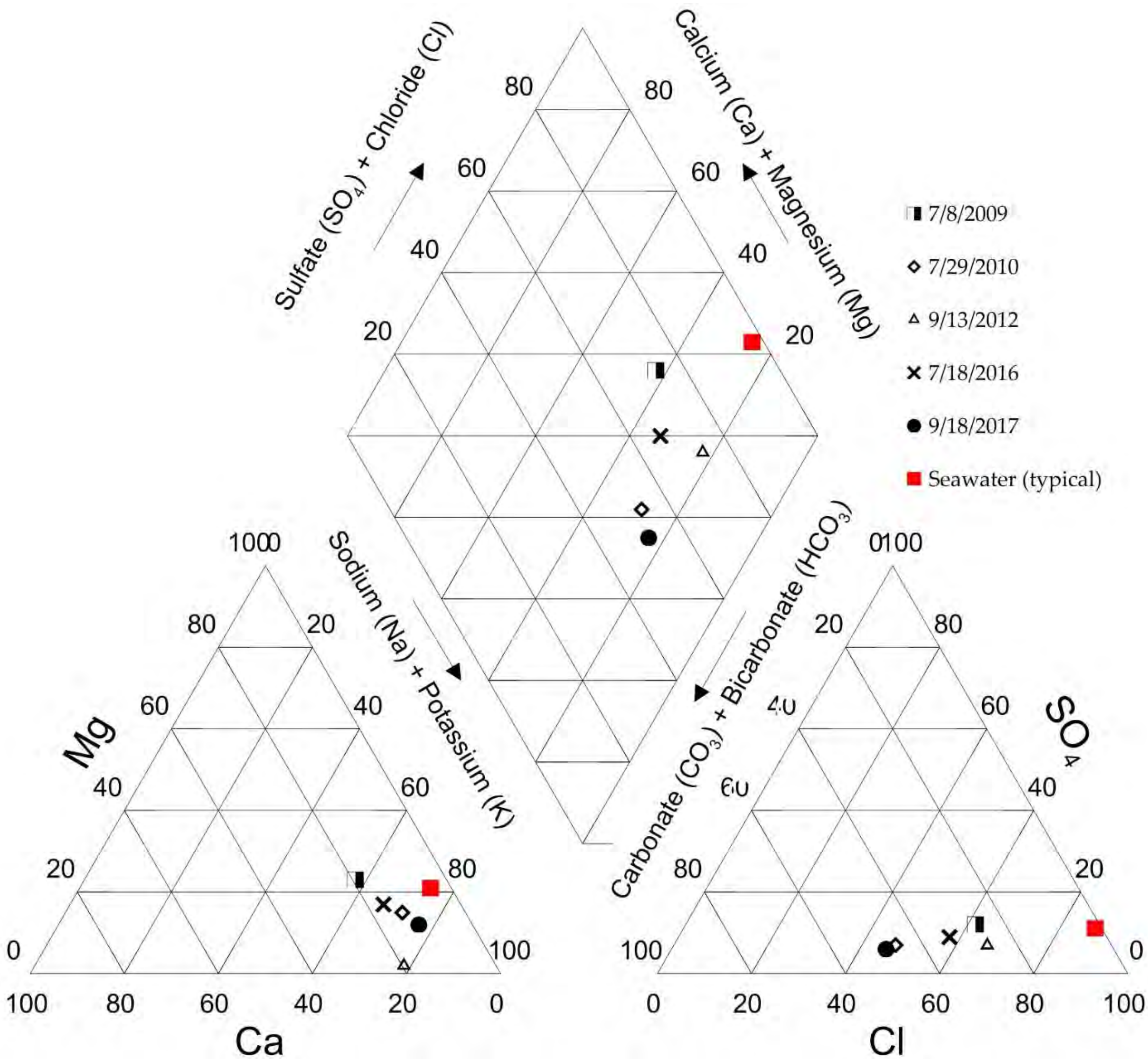

Figure A-20: Piper Diagram of LS County Park #2 Production Well

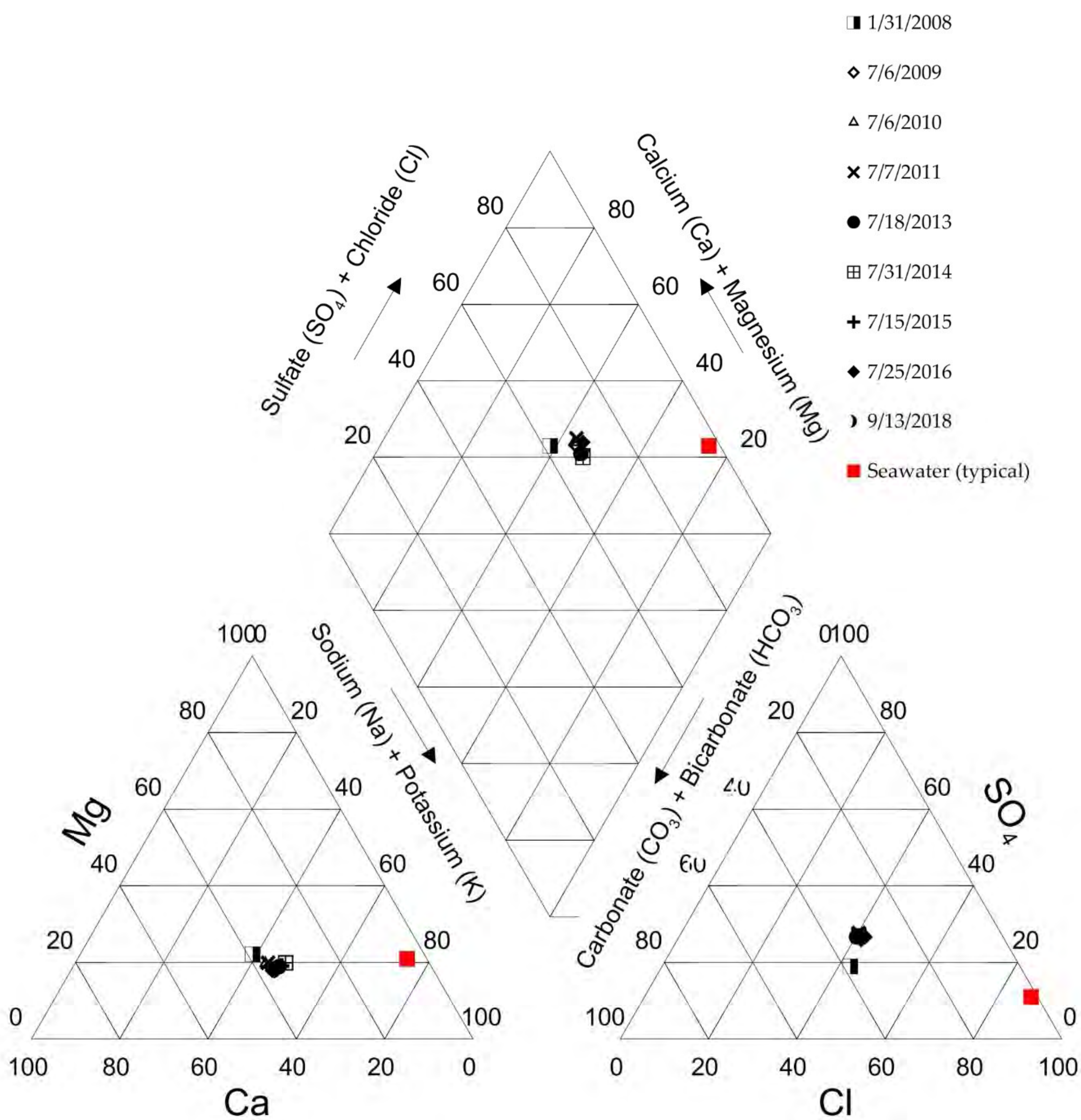

Figure A-21: Piper Diagram of Playa No. 3 Production Well

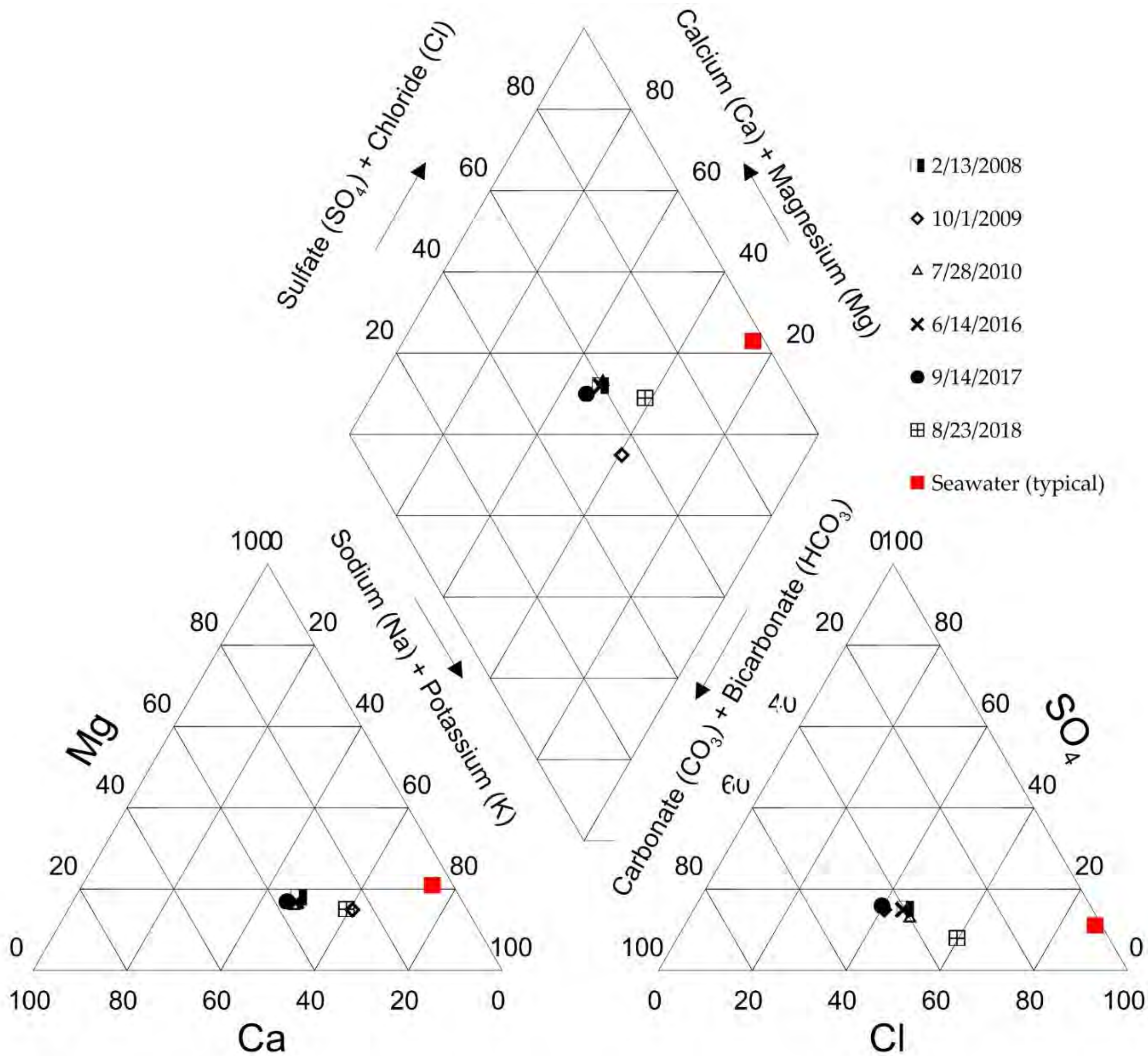

Figure A-22: Piper Diagram of Coe Ave. Production Well

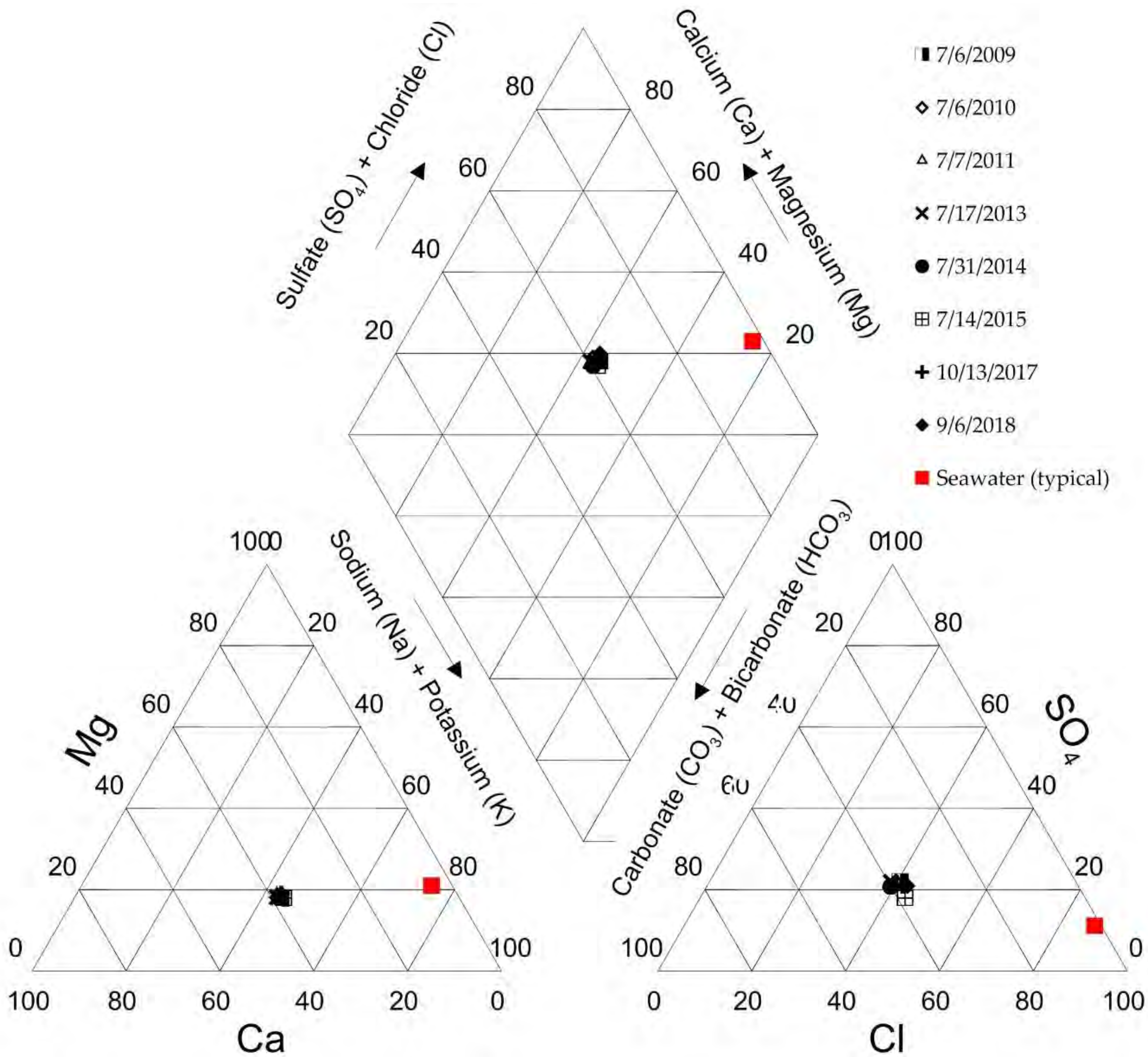

Figure A-23: Piper Diagram of Luzern #2 Production Well

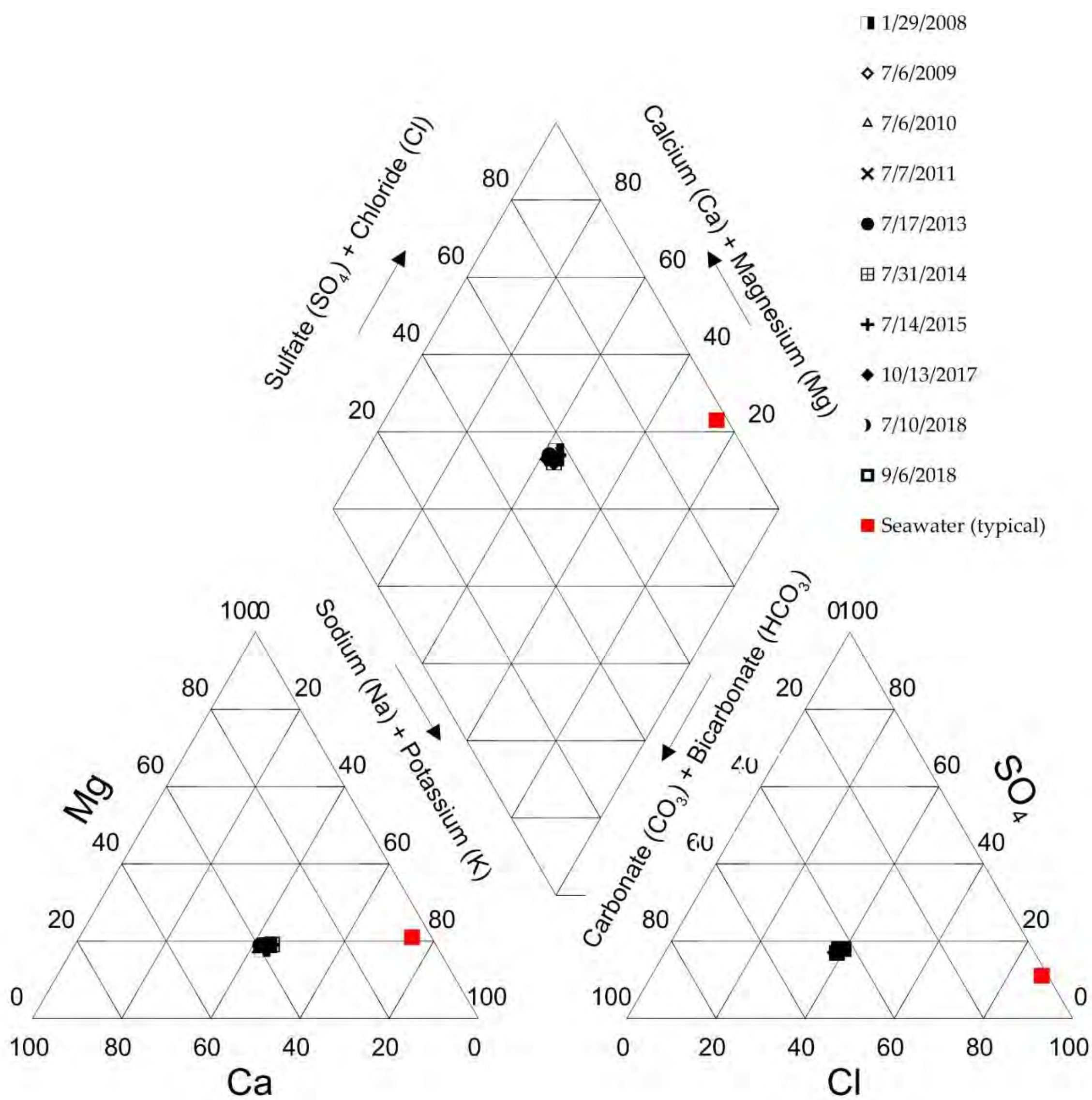

Figure A-24: Piper Diagram of Ord Grove No. 2 Production Well

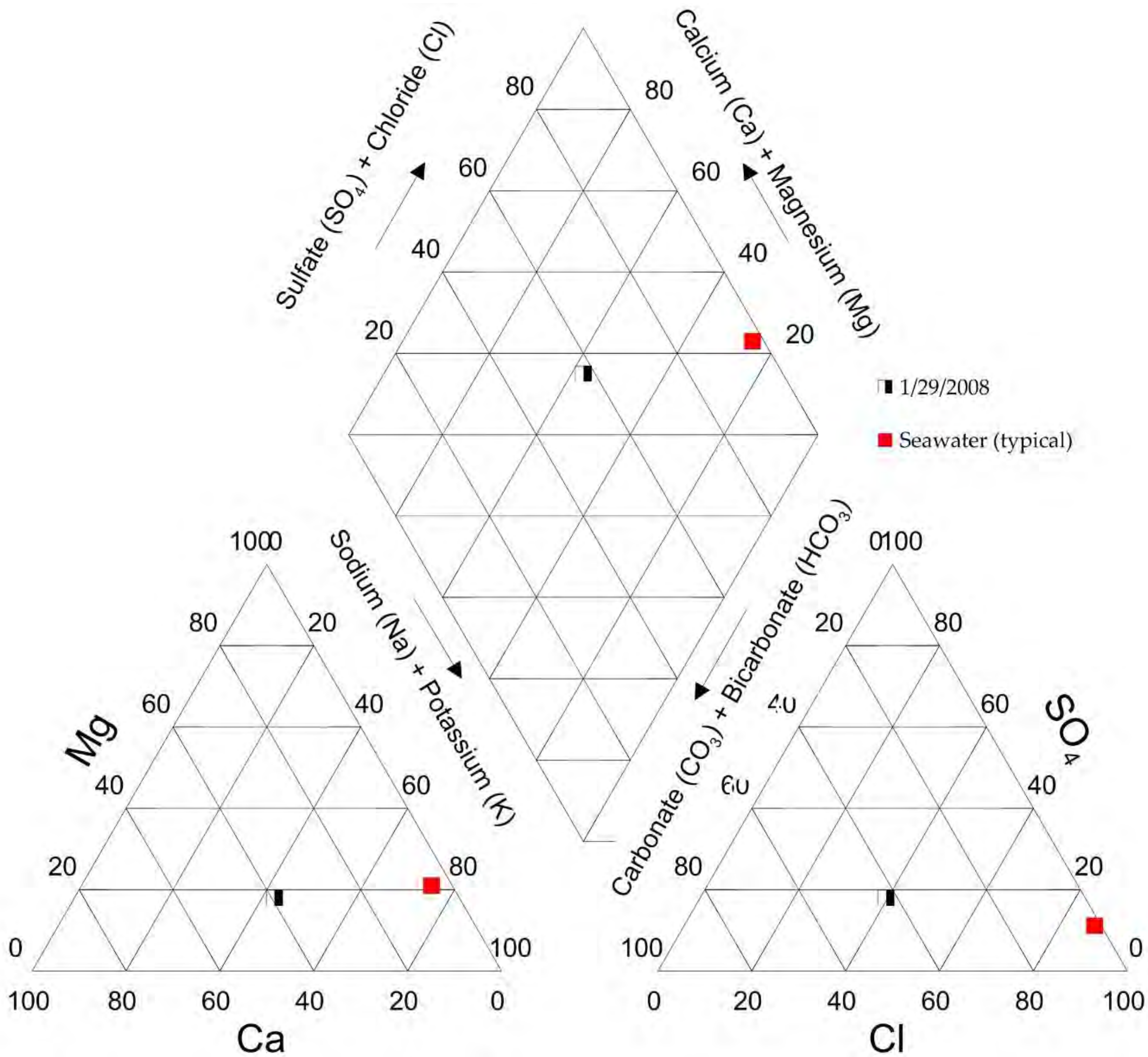

Figure A-25: Piper Diagram of Seaside City No. 3 Production Well

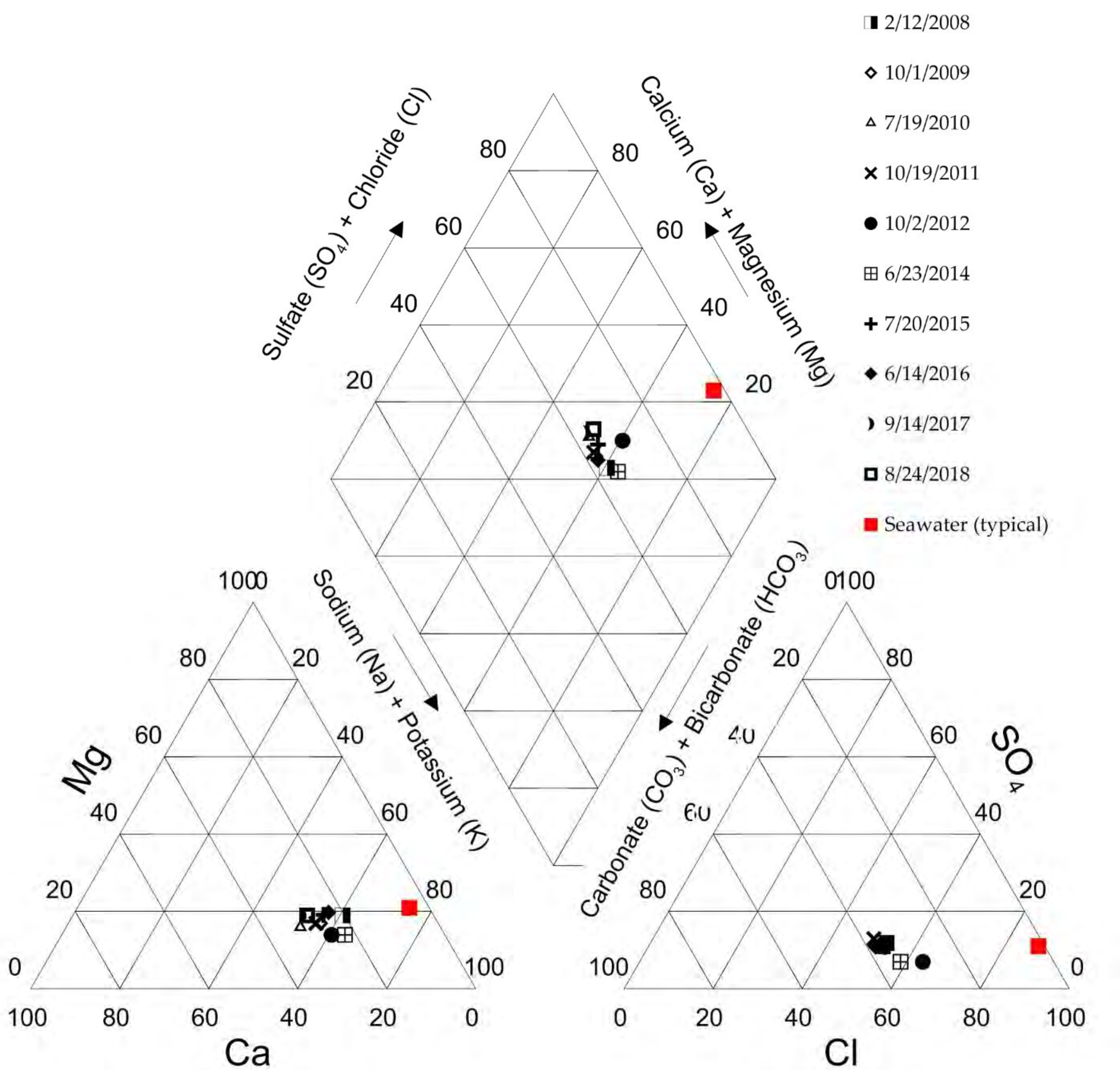

Figure A-26: Piper Diagram of Seaside City No. 4 Production Well

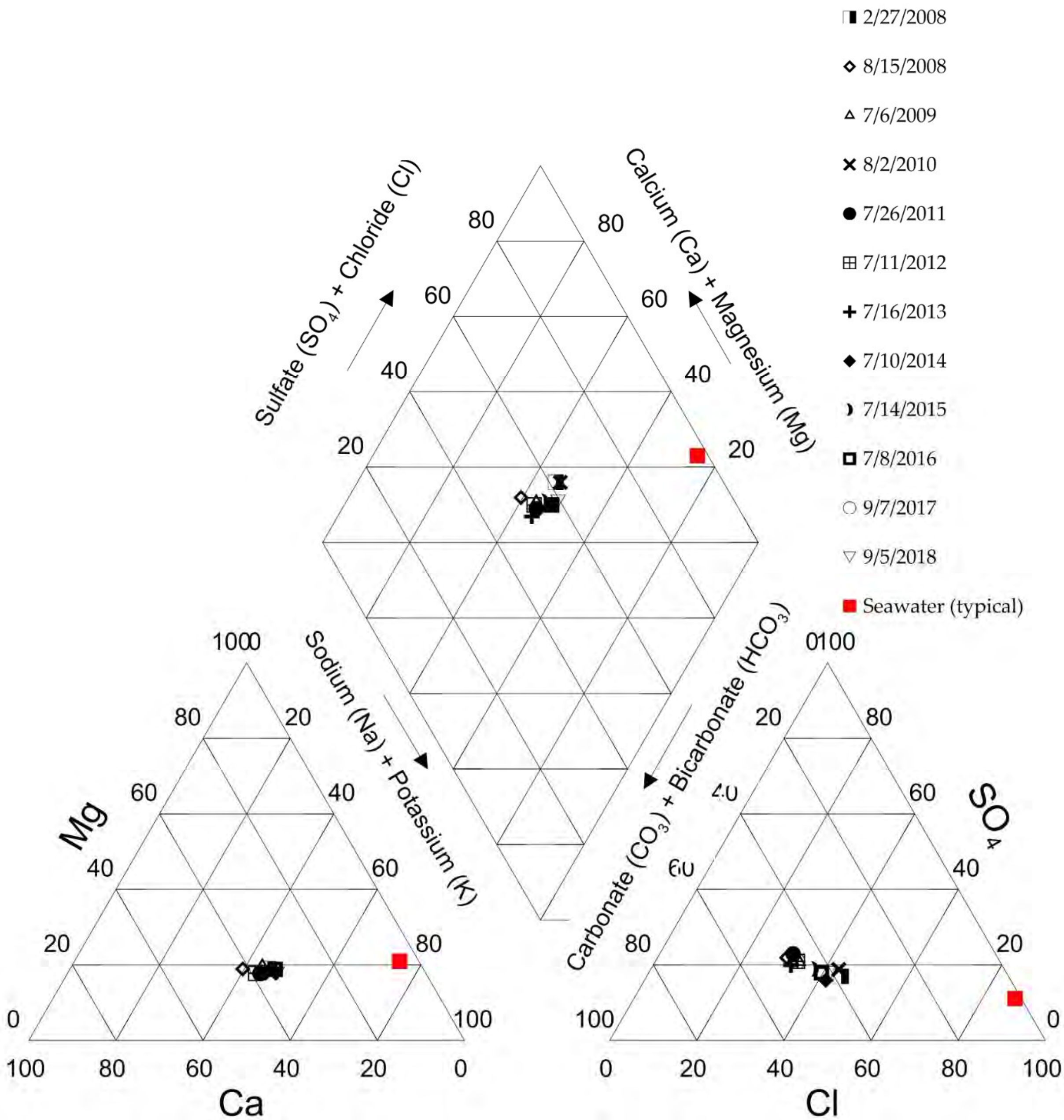

Figure A-27: Piper Diagram of Mission Memorial Park (formerly PRTIW)

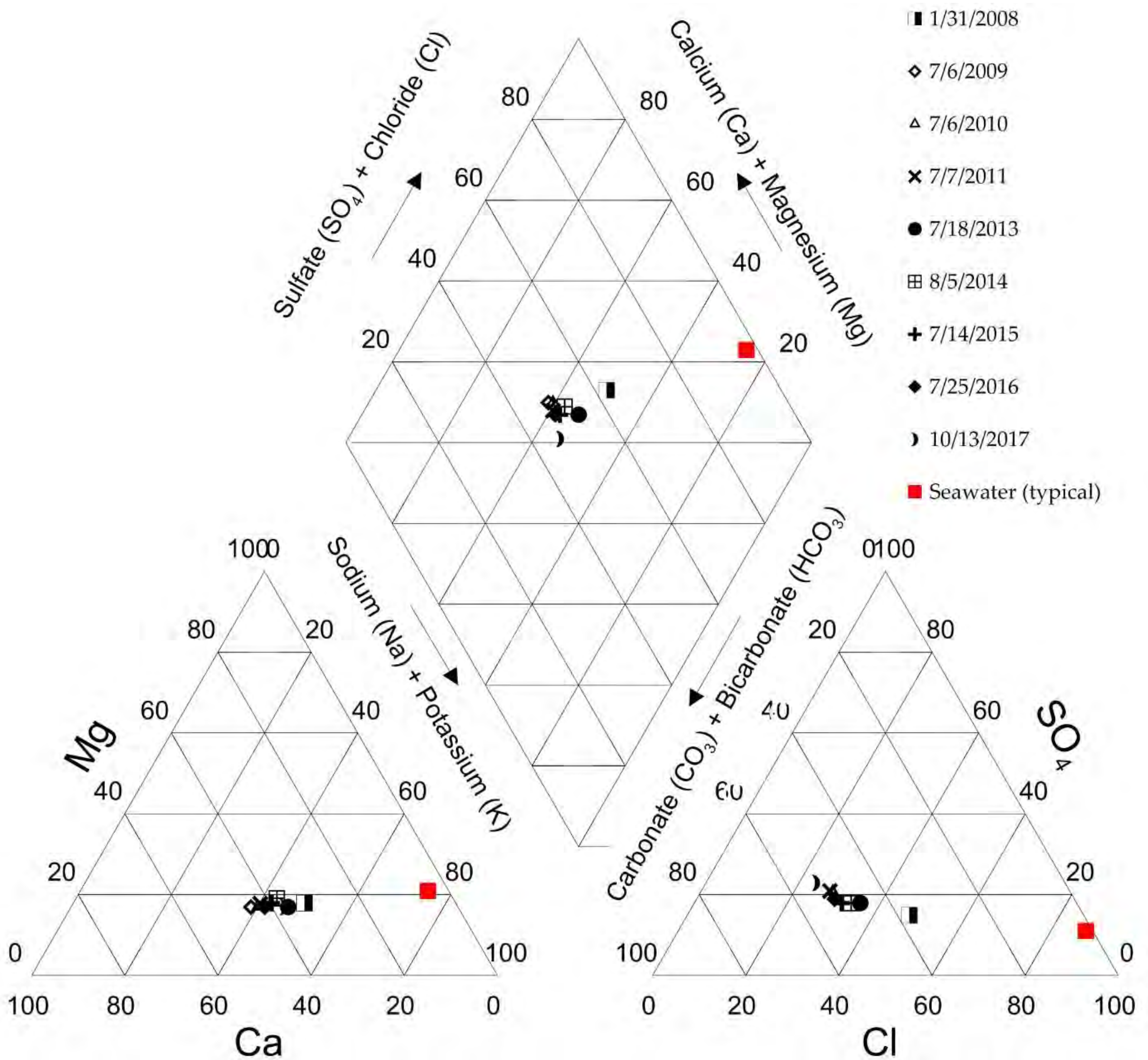

Figure A-28: Piper Diagram of Paralta Production Well

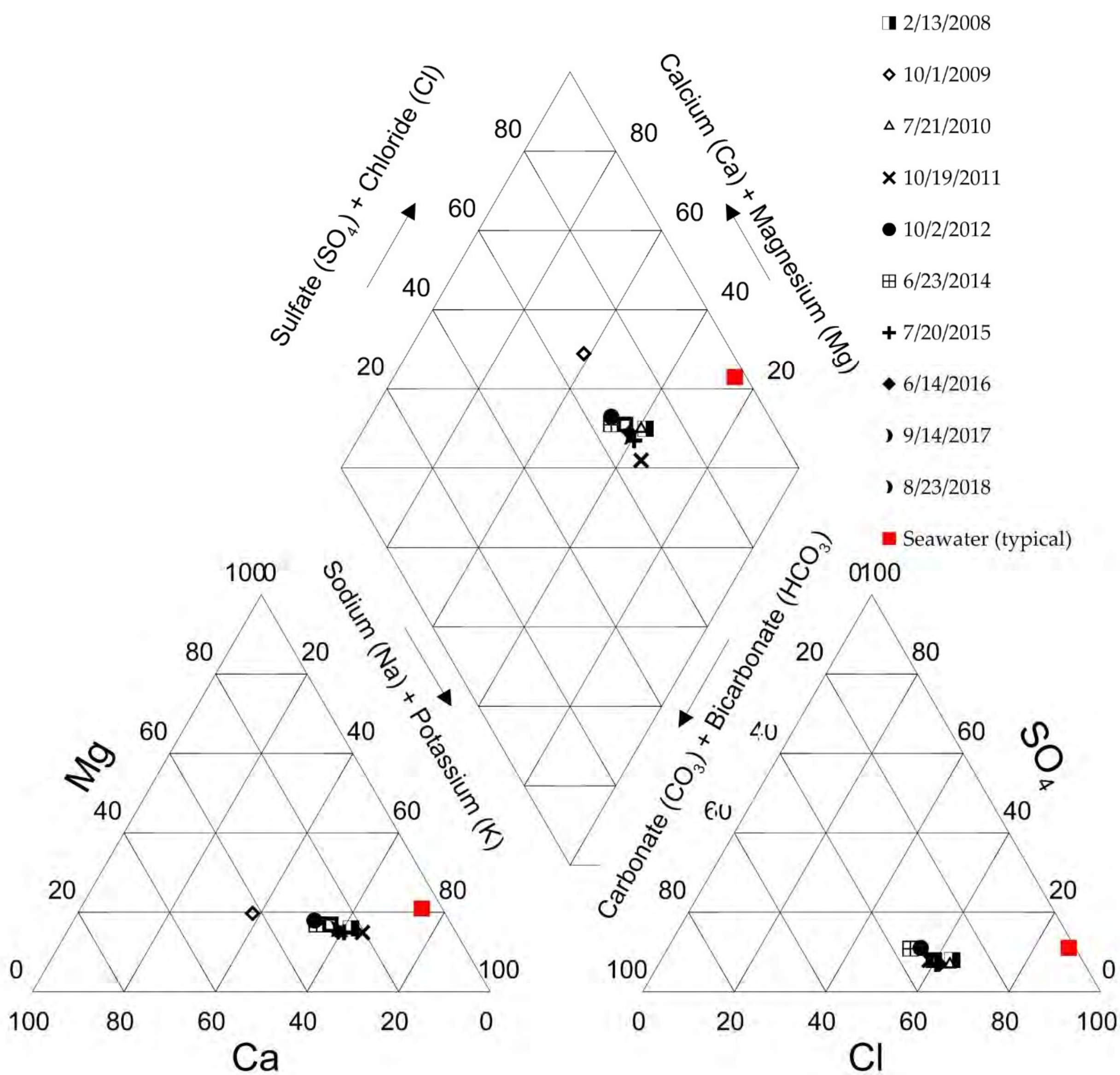

Figure A-29: Piper Diagram of Reservoir (Bayonet Blackhorse) Production Well

Appendix B

Chloride and Sodium/Chloride Molar Ratio Graphs

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Figure B-4: PCA East Deep Well Chemograph

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Figure B-6: Ord Terrace Deep Well Chemograph

Figure B-7: MSC Shallow Well Chemograph

Figure B-8: MSC Deep Well Chemograph

Figure B-9: Fort Ord 10 Shallow Well Chemograph

Figure B-10: Fort Ord 10 Deep Well Chemograph

Figure B-11: Fort Ord 9 Shallow Well Chemograph

Figure B-12: Fort Ord 9 Deep Well Chemograph

Figure B-13: Sand City Public Works Corp Yard Production Well

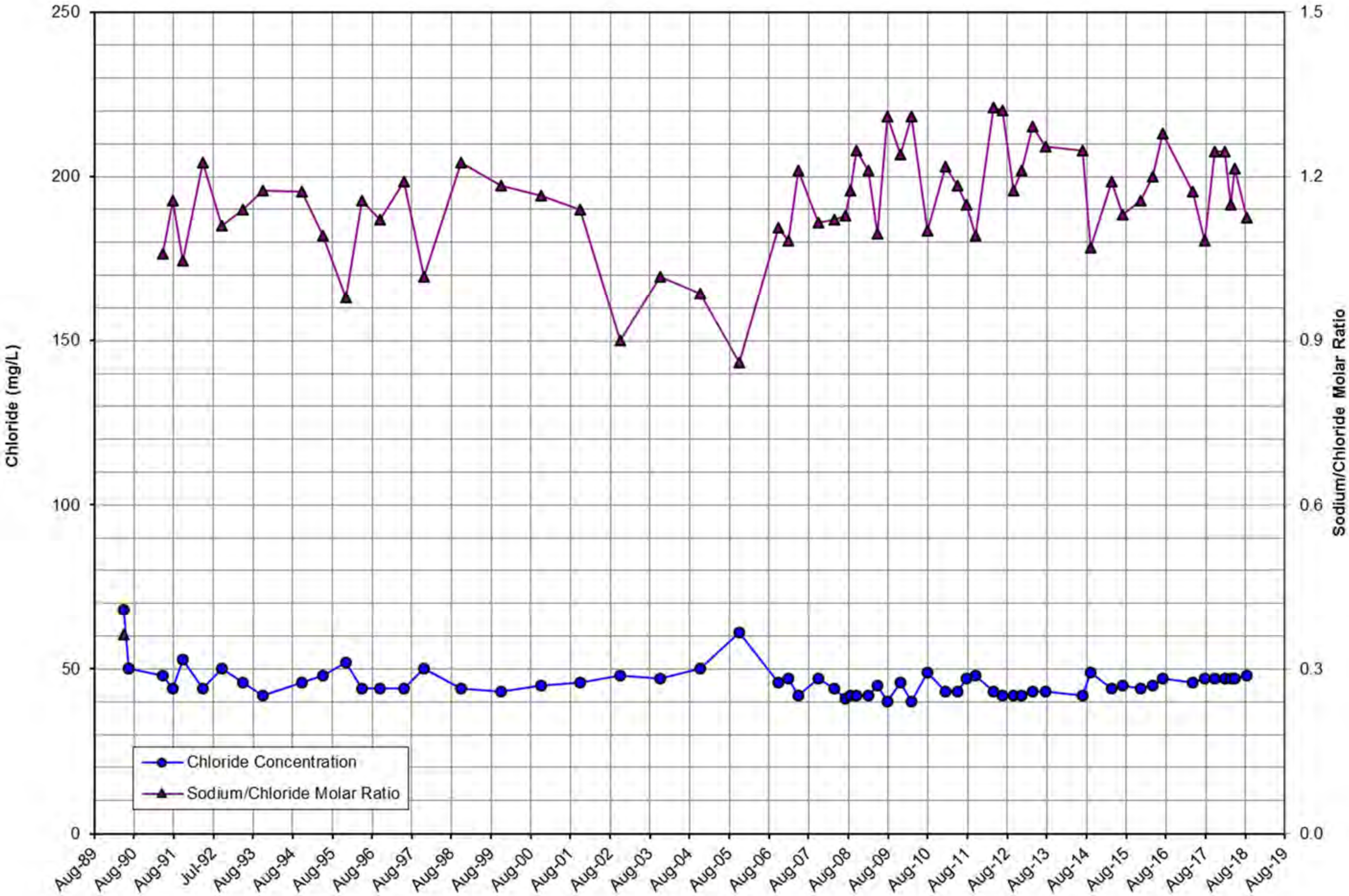

Figure B-1: PCA West Shallow Well Chemograph

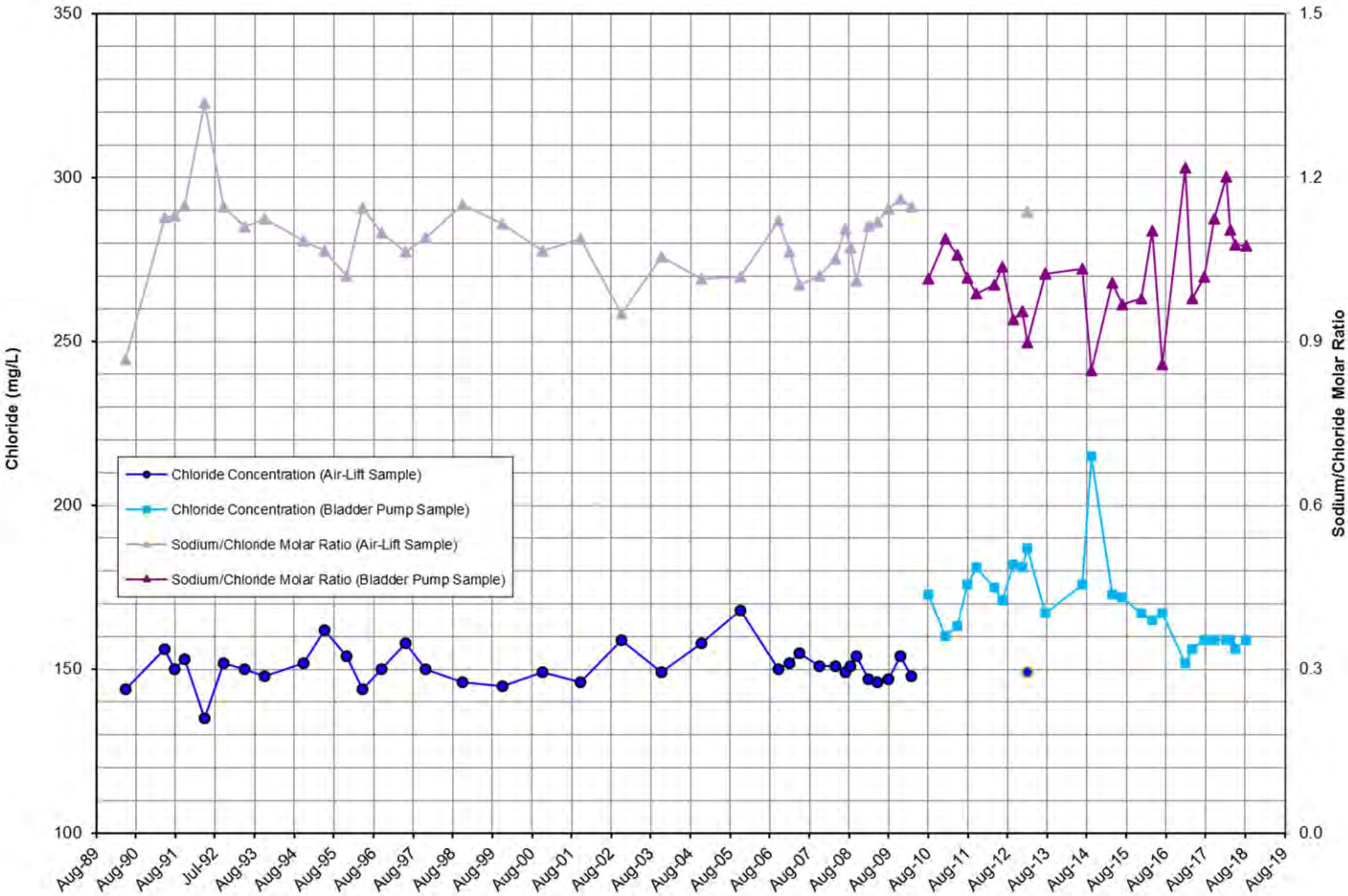

Figure B-2: PCA West Deep Well Chemograph

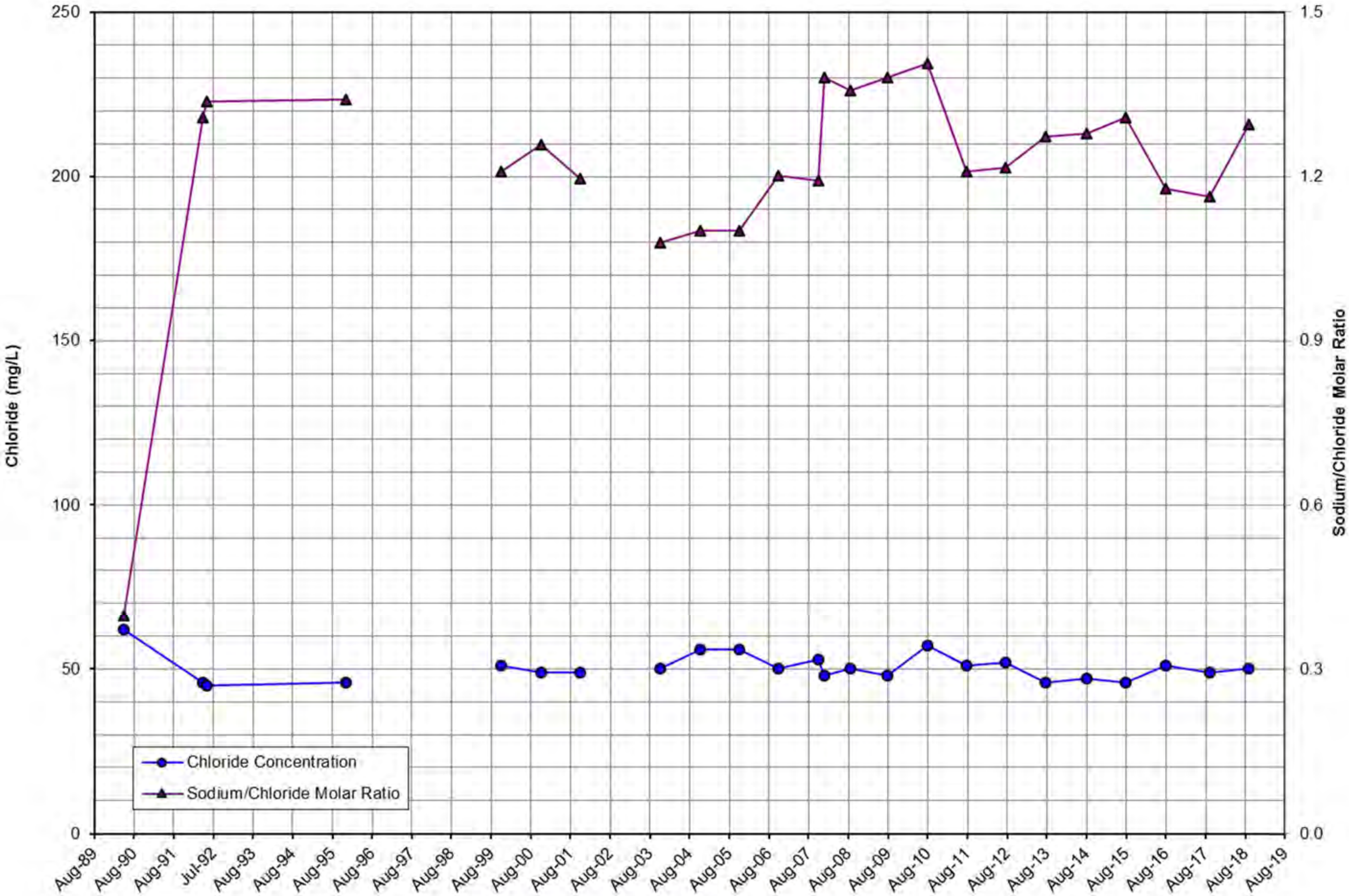

Figure B-3: PCA East Shallow Well Chemograph

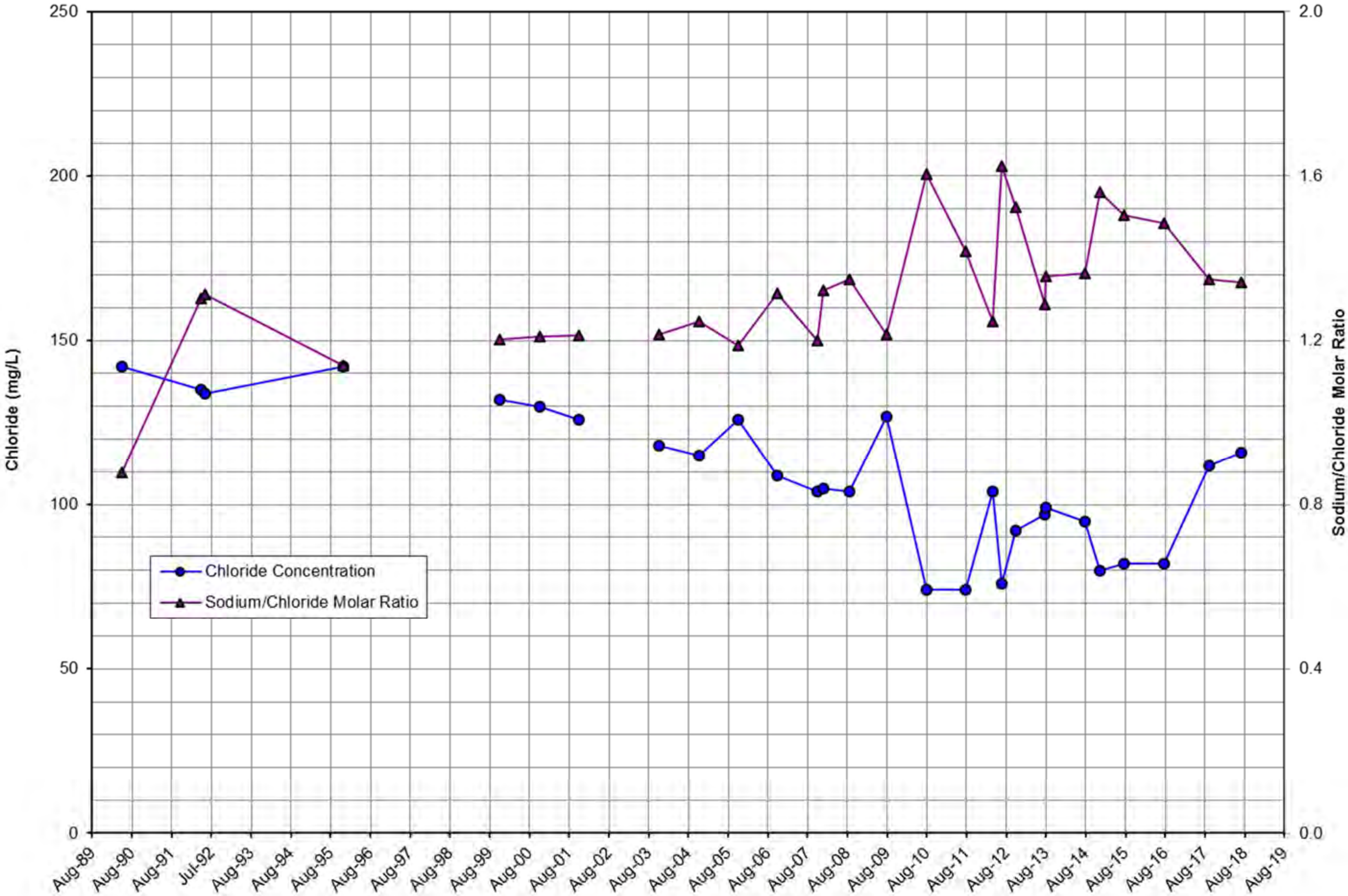

Figure B-4: PCA East Deep Well Chemograph

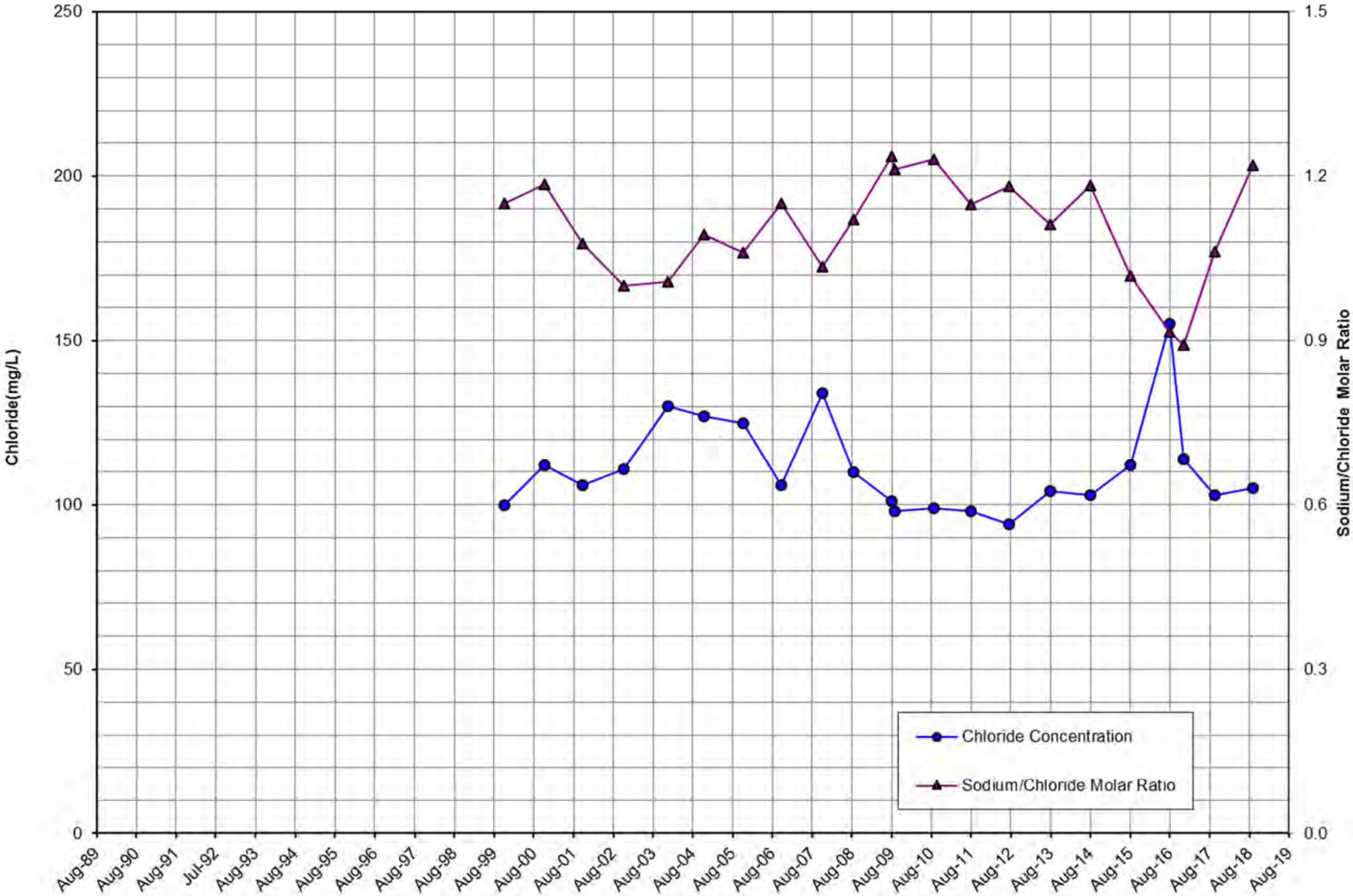

Figure B-5: Ord Terrace Shallow Well Chemograph

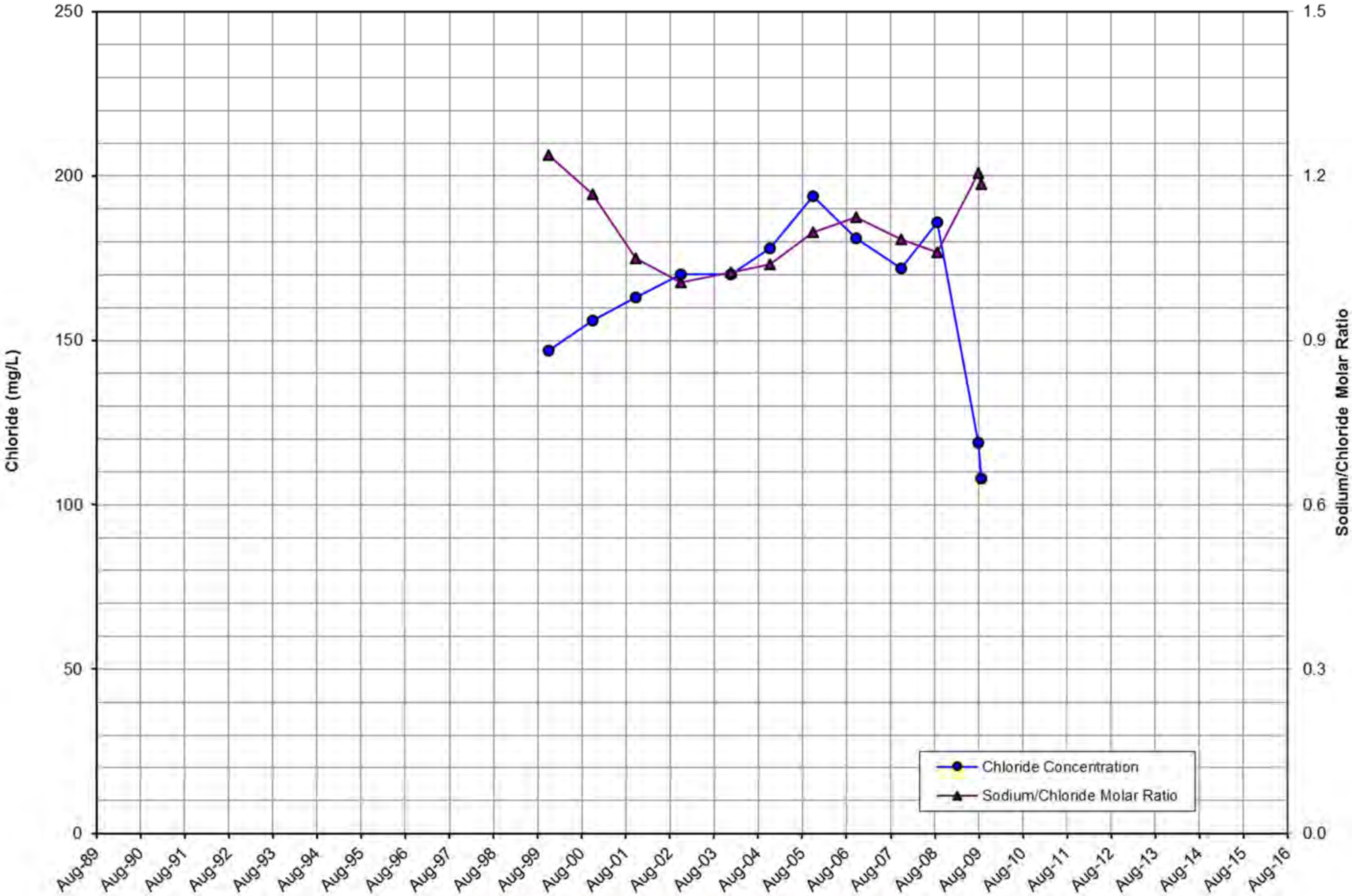

Figure B-6: Ord Terrace Deep Well Chemograph

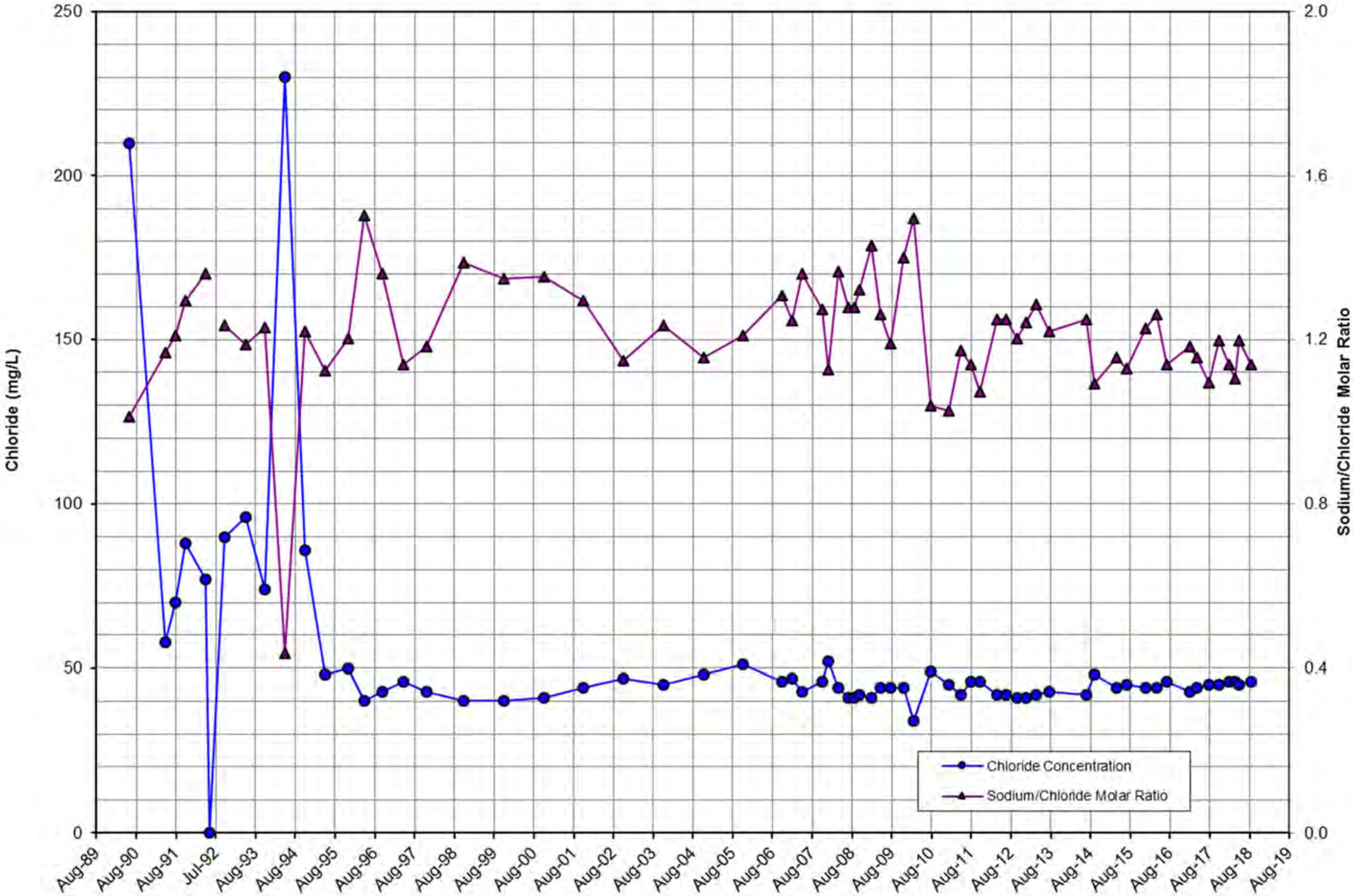

Figure B-7: MSC Shallow Well Chemograph

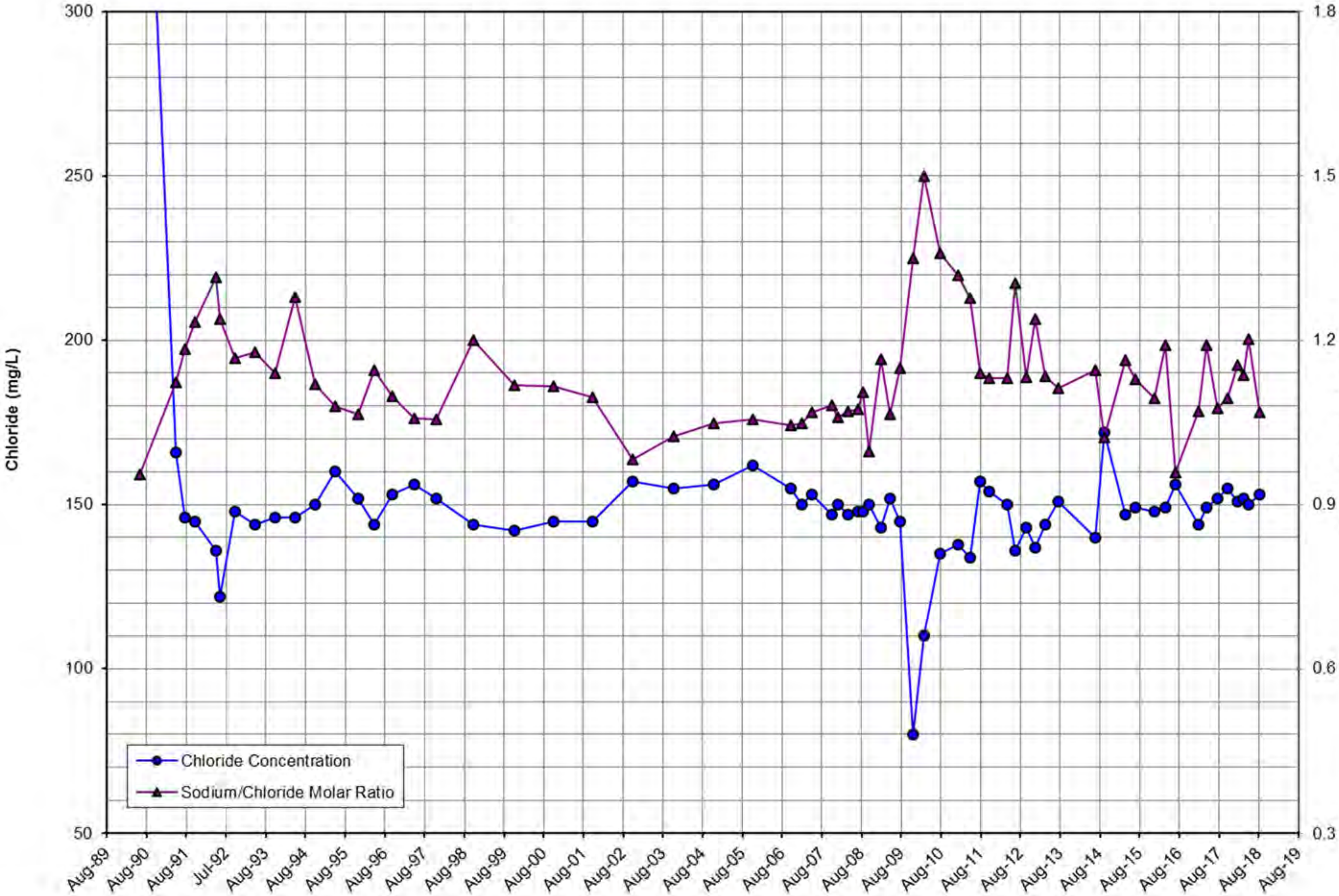

Figure B-8: MSC Deep Well Chemograph

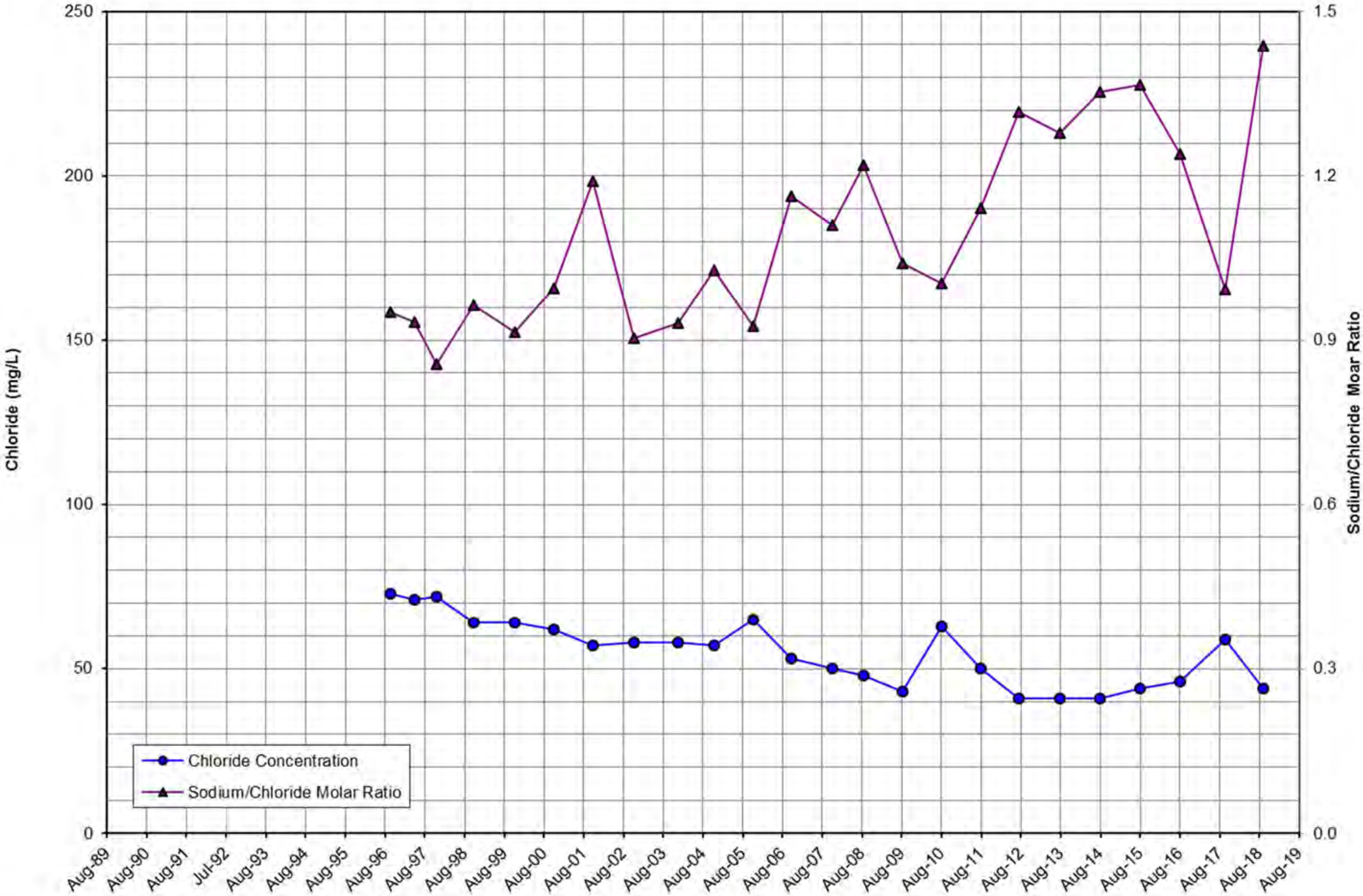

Figure B-9: Fort Ord 10 Shallow Well Chemograph

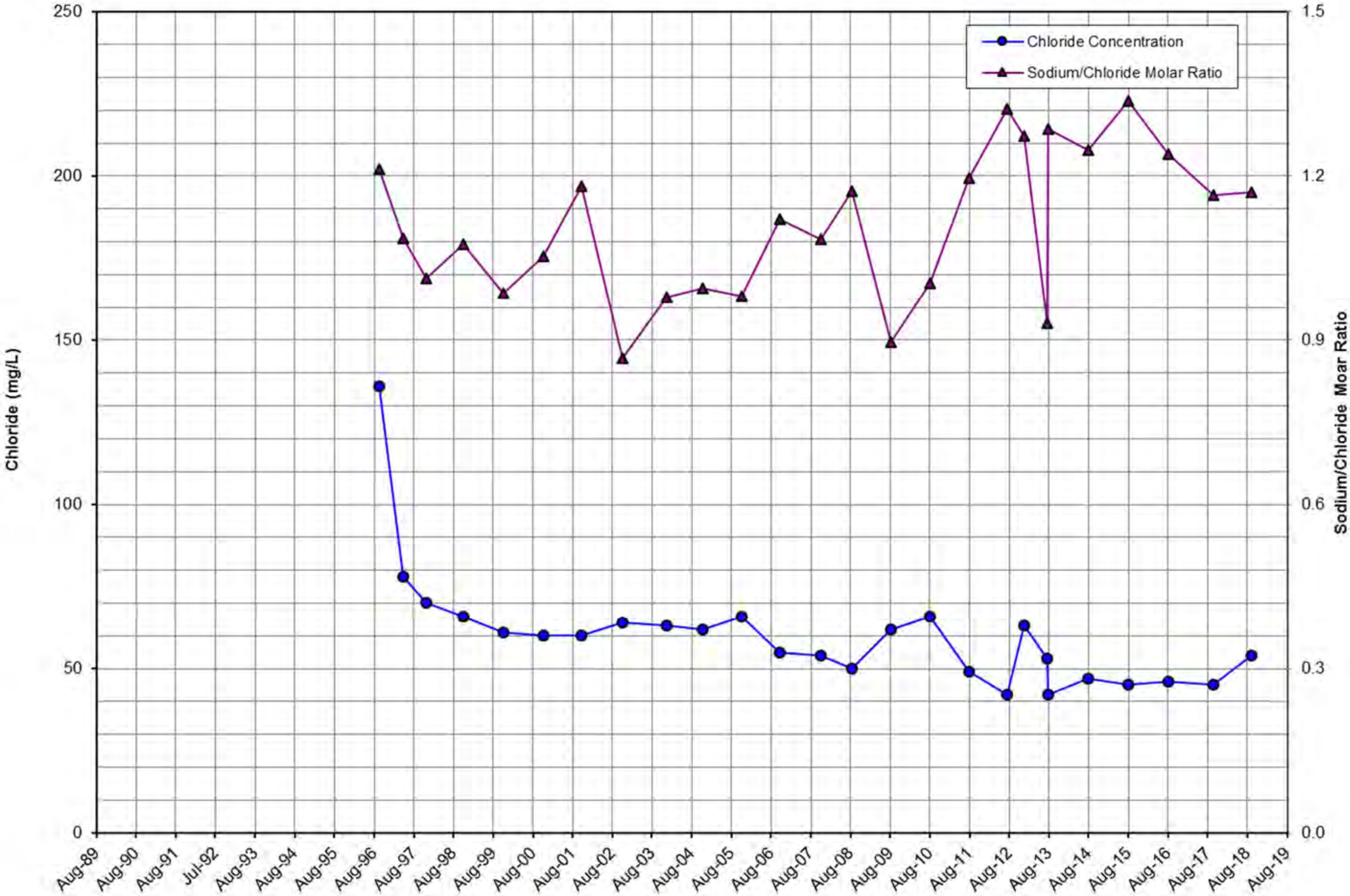

Figure B-10: Fort Ord 10 Deep Well Chemograph

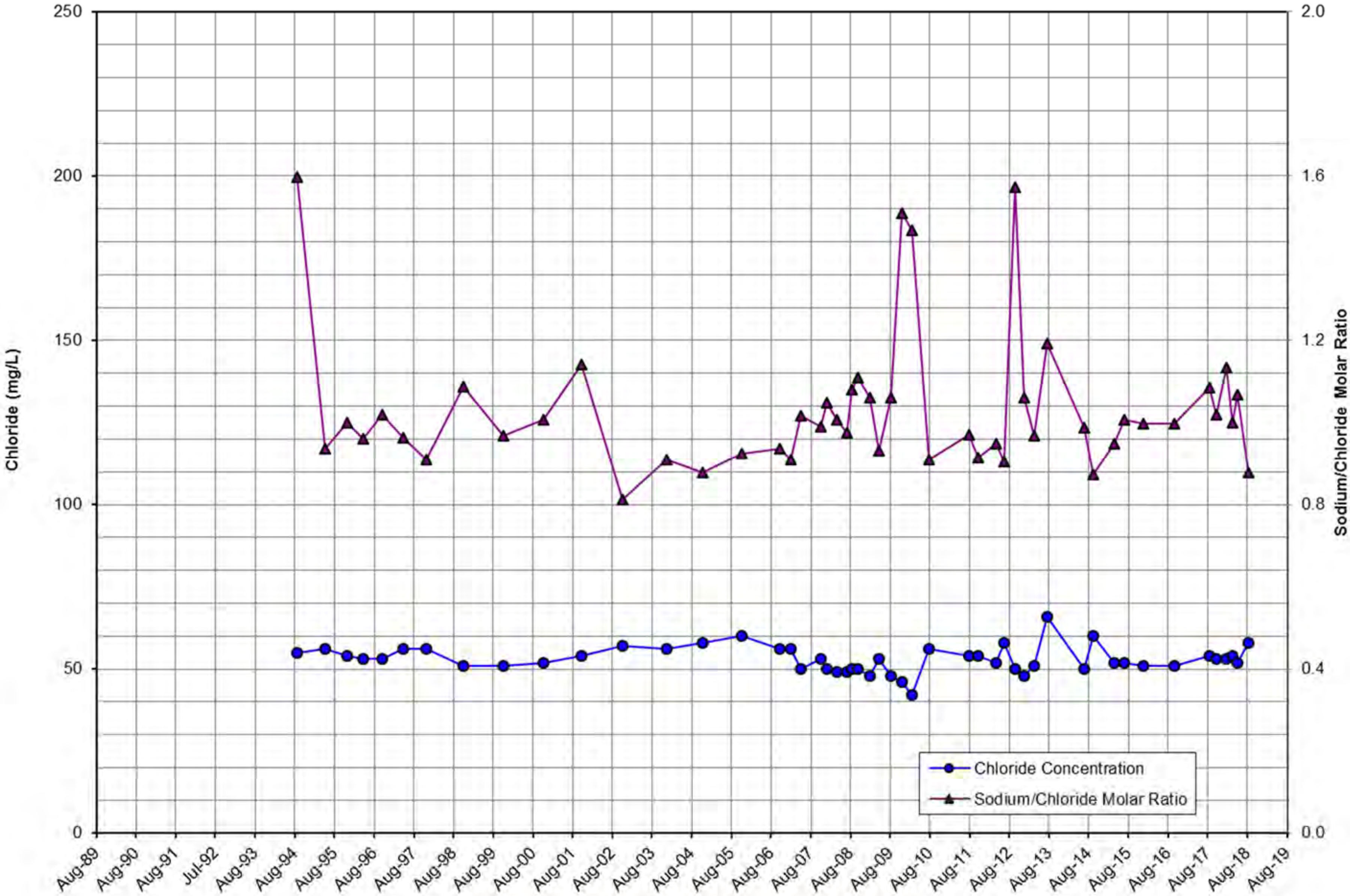

Figure B-11: Fort Ord 9 Shallow Well Chemograph

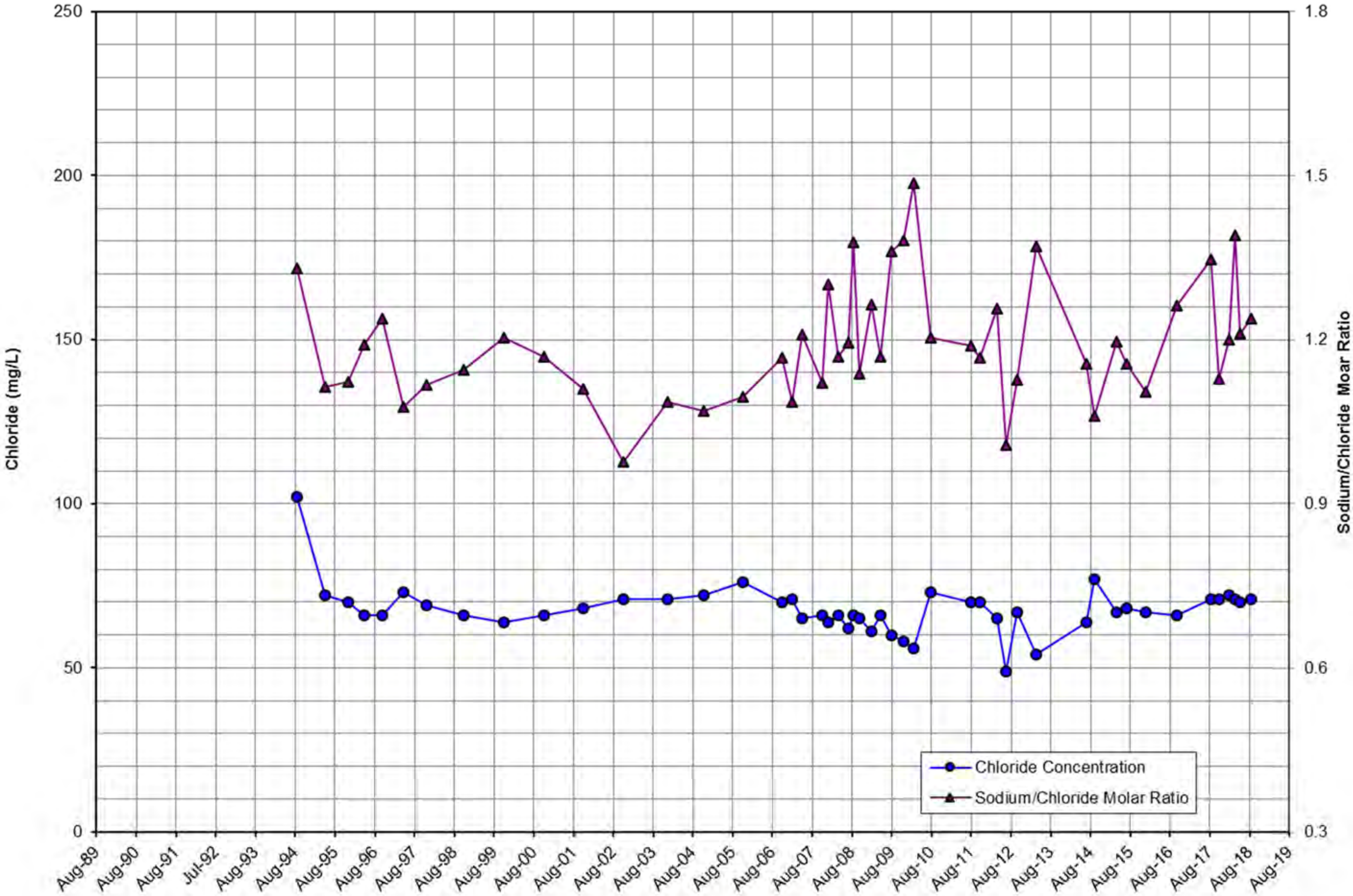

Figure B-12: Fort Ord 9 Deep Well Chemograph

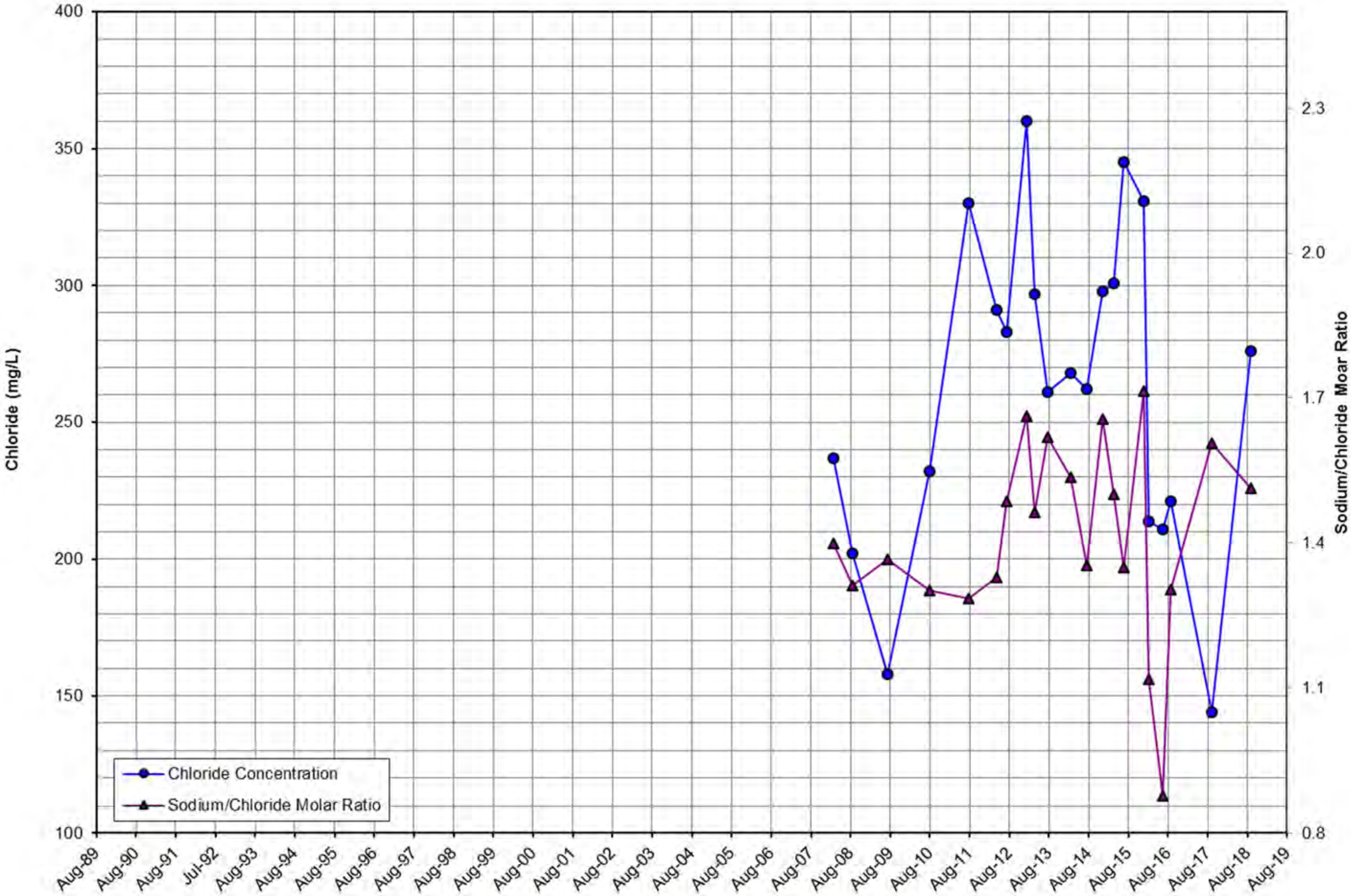

Figure B-13: Sand City Corp Yard Production Well