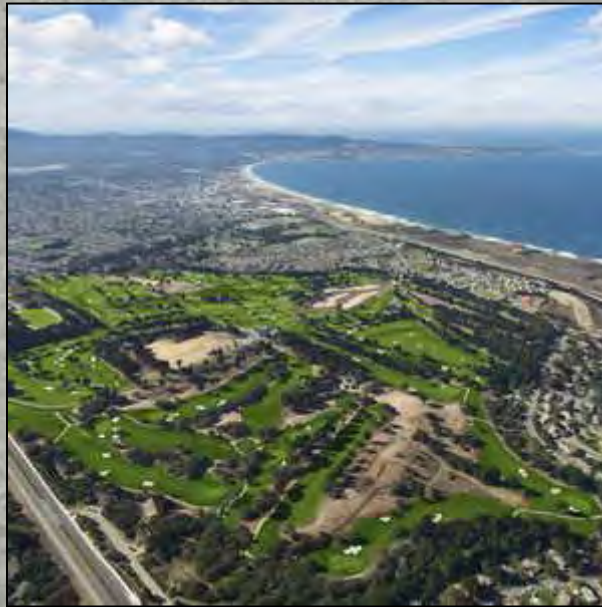


# Water Year 2017 Seawater Intrusion Analysis Report Seaside Basin, Monterey County California

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*Prepared for:  
Seaside Basin Watermaster*

**December 2017**



*Prepared by:*





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## ABBREVIATIONS

amsl .....	above mean sea level
ASR.....	aquifer storage and recovery
bgs .....	below ground surface
Ca.....	calcium
CAW.....	California American Water
Cl.....	chloride
CO <sub>3</sub> .....	carbonate
FO .....	Fort Ord
HCO <sub>3</sub> .....	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 <sub>4</sub> .....	sulfate
TAC .....	Technical Advisory Committee
WY .....	Water Year

## CONVERSIONS

1 acre-foot = 325,851 gallons

1 mg/L  $\approx$  1 part per million

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## 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 2017 and prior, no seawater intrusion has historically been or is currently observed in existing monitoring and production wells in the Seaside Groundwater Basin. It should be noted that although seawater intrusion has not been observed in the hydrogeologic data collected, there have been some chloride anomalies observed over the past two water years in some of the Sentinel Wells.

In September 2017, Sentinel Well SBWM-2's deep sample at 1,470 feet had a chloride concentration of 292 mg/L, which is the highest chloride measured in any of the coastal wells. Verification sampling is not necessary as the concentration was effectively verified using downhole electrical conductivity profiling, which uses an instrument to measure the conductivity of the water within the well casing. The September 2017 chloride concentration is a 226 mg/L increase from the December 2016 concentration of 66 mg/L. The previous 4<sup>th</sup> quarter sample was also elevated at 178 mg/L. These past three results

indicate that chloride concentrations are fluctuating over 100 mg/L within each of the past two water years. After last year's concentration fluctuation possible sources of the salinity contributing to the observed increases were postulated to include natural groundwater quality variations, upwelling or upconing of underlying saline formation water from the Monterey Formation in response to declining groundwater levels, or very early seawater intrusion (HydroMetrics WRI, 2017). However, from evaluation of the downhole electrical conductivity profiling of all four Sentinel Wells (Feeney, 2017) and their long-term electric induction logs, it appears the groundwater samples collected using the low flow sampler is 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 therefore not considered representative of the aquifer and should not be used in further seawater intrusion analysis.

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

- Maps of chloride concentrations for the shallow aquifer do not show chlorides increasing towards the coast.
- Induction logging data at the coastal Sentinel Wells do not show large changes over time that are indicative of seawater intrusion in the deep aquifer.
- None of the Stiff diagrams for monitoring and production wells show the characteristic chloride spike that typically indicates seawater intrusion in Stiff diagrams.
- None of the Piper diagrams for monitoring and production wells show the typical evolution of water chemistry from freshwater to seawater.

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

- Even though Water Year 2017 was an above average rainfall year with increased groundwater elevations, and basin pumping was very slightly above the current safe yield of 3,000 acre-feet per year, Northern Coastal subarea groundwater levels in the deep aquifer remain below sea level (Figure 30 and Figure 32). The 4<sup>th</sup> quarter deep aquifer groundwater levels along the coast, in most locations, are at elevations greater than 20 feet below sea level.
- Groundwater levels remain below protective elevations in all deep monitoring wells used for protective groundwater elevation monitoring (MSC deep, PCA-W deep, and Sentinel Well SBWM-3). Two of the three shallow wells' groundwater

levels are above protective elevations: PCA-W shallow and CDM-MW4. The MSC shallow well remains below protective elevations.

Due to its far 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 been declining at rates of 0.6 feet per year in the shallow aquifers, and between two and three feet per year in the deep aquifers. These declines have occurred since 2001, despite triennial reductions in allowable pumping. The cause of this decline is due in part to the safe yield of the subarea being incorrect and in part due to the influence of wells to the east of the groundwater basin. The rate of decline in groundwater levels in the western portion of the subarea is between one and two feet per year. There is an indication, however, from 2016 and 2017 groundwater levels that the rate in decline has stabilized over the past couple years.

Based on the findings of this report, the following recommendations should be implemented to monitor and track potential seawater intrusion.

**1. 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.

**2. Discontinue Sampling Water Quality in the Four Sentinel Wells but Continue Induction Logging Twice a Year**

Due to the finding that the water quality samples being extracted from the Sentinel Wells are not representative of the aquifer, it is recommended that sampling the wells with the low flow sampler is discontinued. The depth of the wells and the small 3-inch diameter of the wells limit sampling techniques that can be applied cost-effectively to extract a representative sample. The Sentinel Wells were designed for the purpose of electric induction logging, and therefore should continue to be induction logged twice a year.

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## SECTION 1

# 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.

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## SECTION 2

# 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.

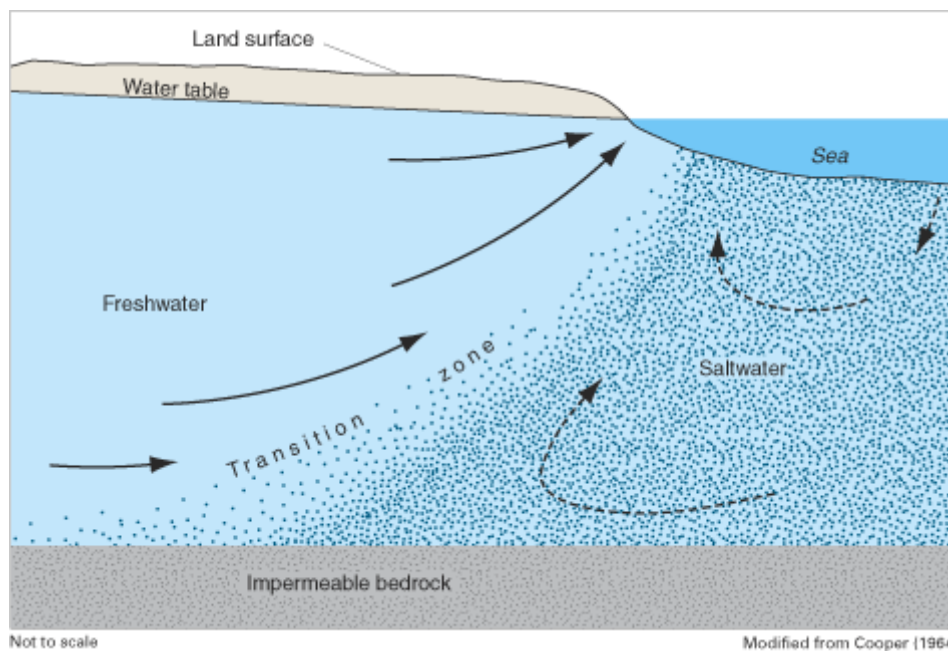
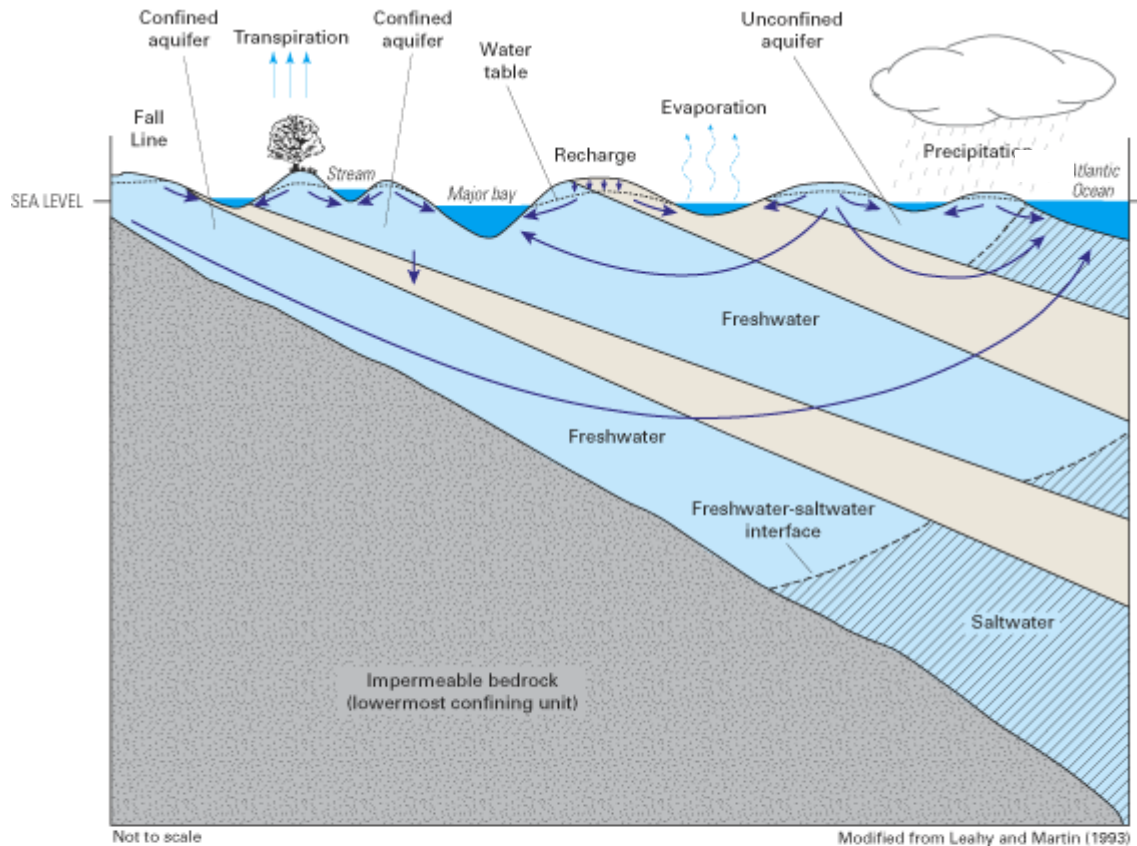


Figure 1: Seawater Wedge in a Simple Coastal Aquifer (from Barlow, 2003)

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.



- EXPLANATION**
- Aquifer**
  - Confining unit**
  - Ground-water flow paths—**  
Shows general direction of ground-water flow

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.

## 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.

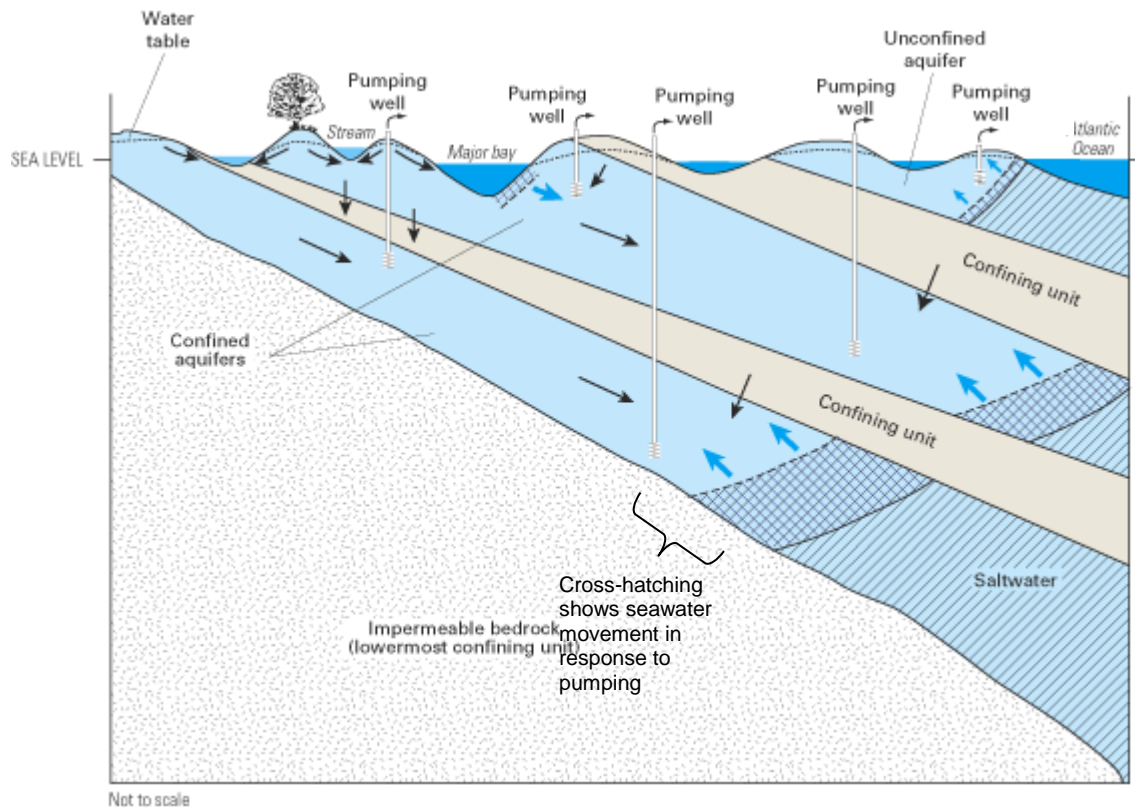


Figure 3: Interface Migration in Response to Groundwater Pumping  
(from Barlow, 2003)

## 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.

## 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 is 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 16.

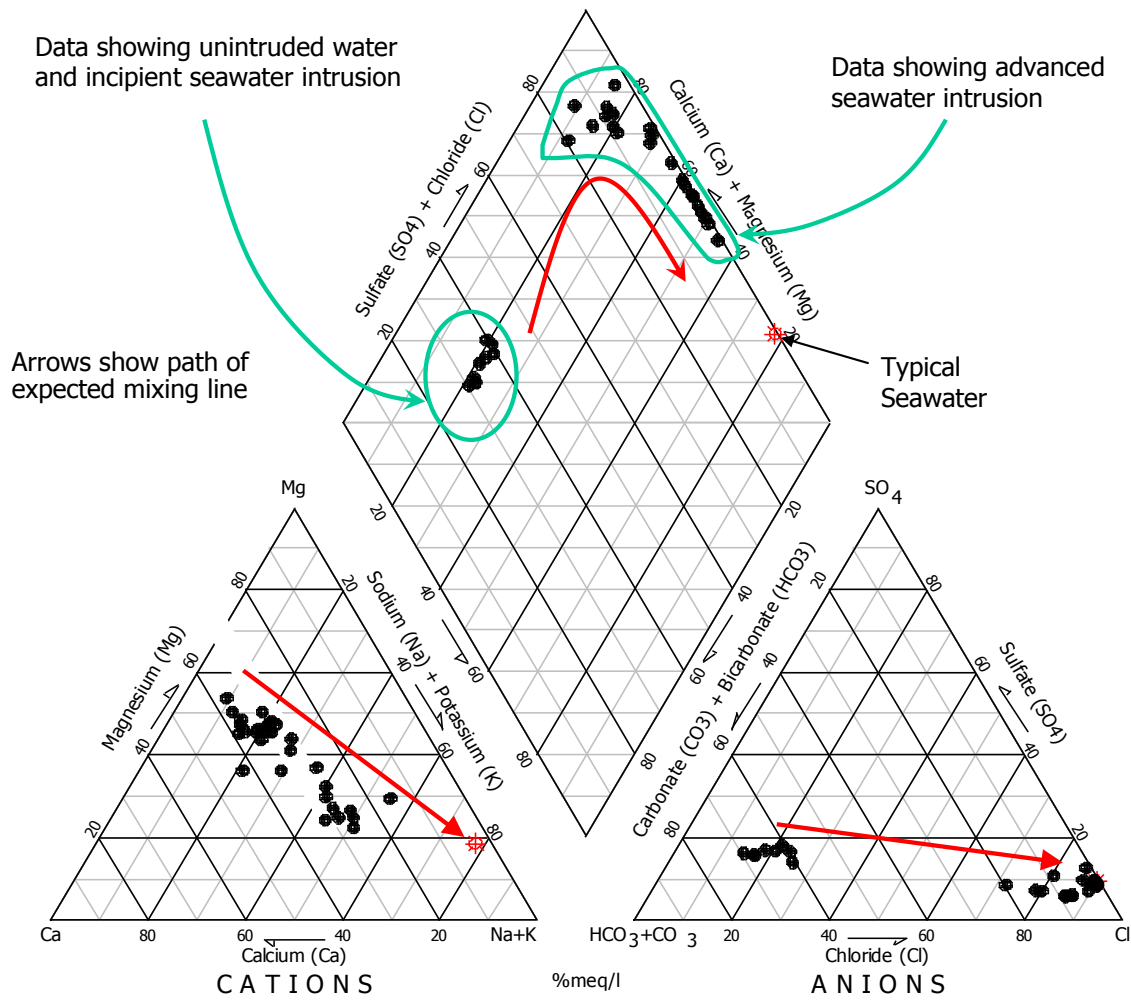


Figure 4: Piper Diagram for Groundwater in Pajaro Valley  
(Data source: PVWMA)

Seawater Intruded Wells (Pressure 400-Foot Aquifer)

2003 Water Quality Data

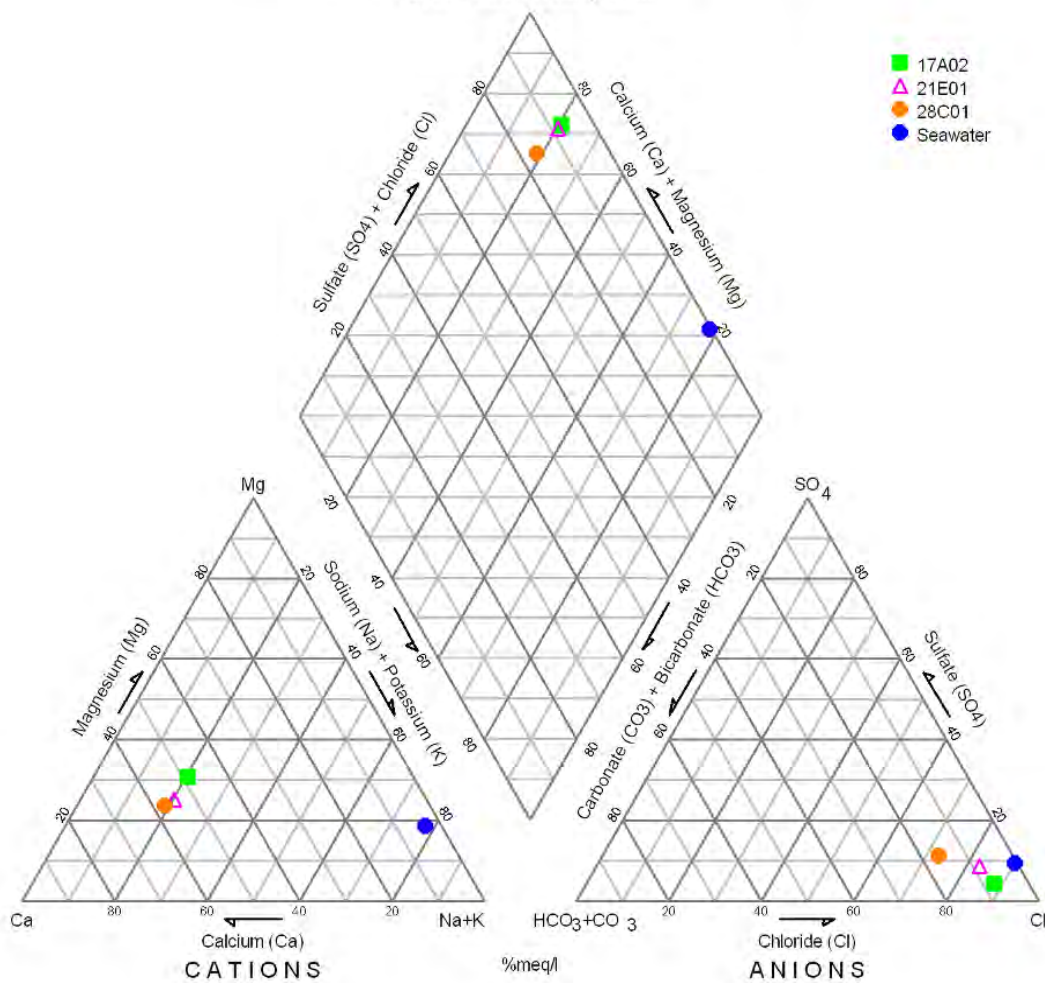


Figure 5: Piper Diagram for Groundwater in Salinas Valley  
(Source: MCWRA)

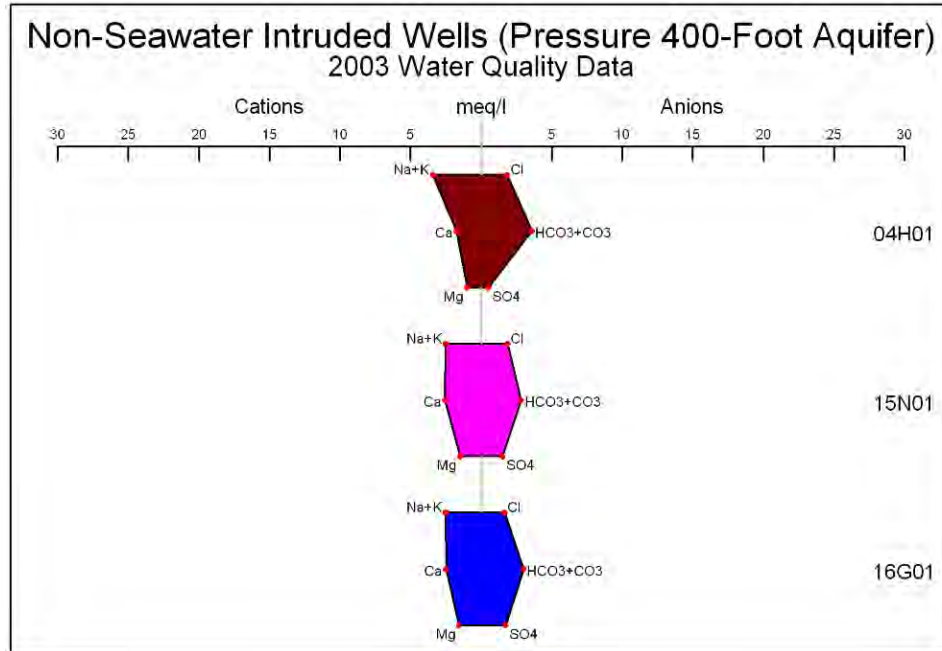


Figure 6: Stiff Diagrams from Salinas Valley Wells without Seawater Intrusion  
(Source: MWCRA)

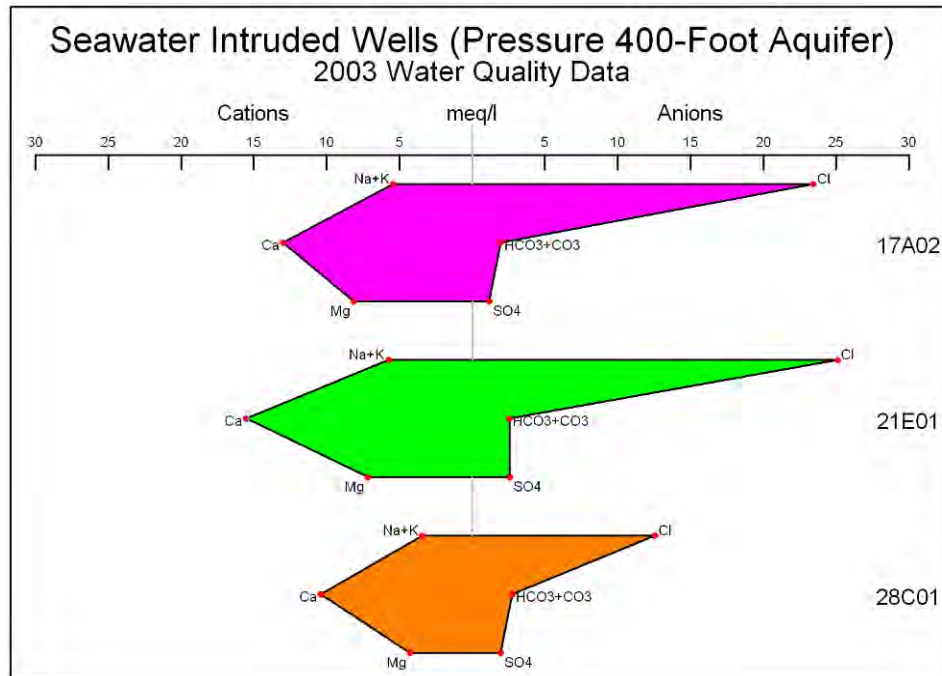


Figure 7: Stiff Diagrams from Salinas Valley Wells with Seawater Intrusion  
(Source: MWCRA)

## 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.

## 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.

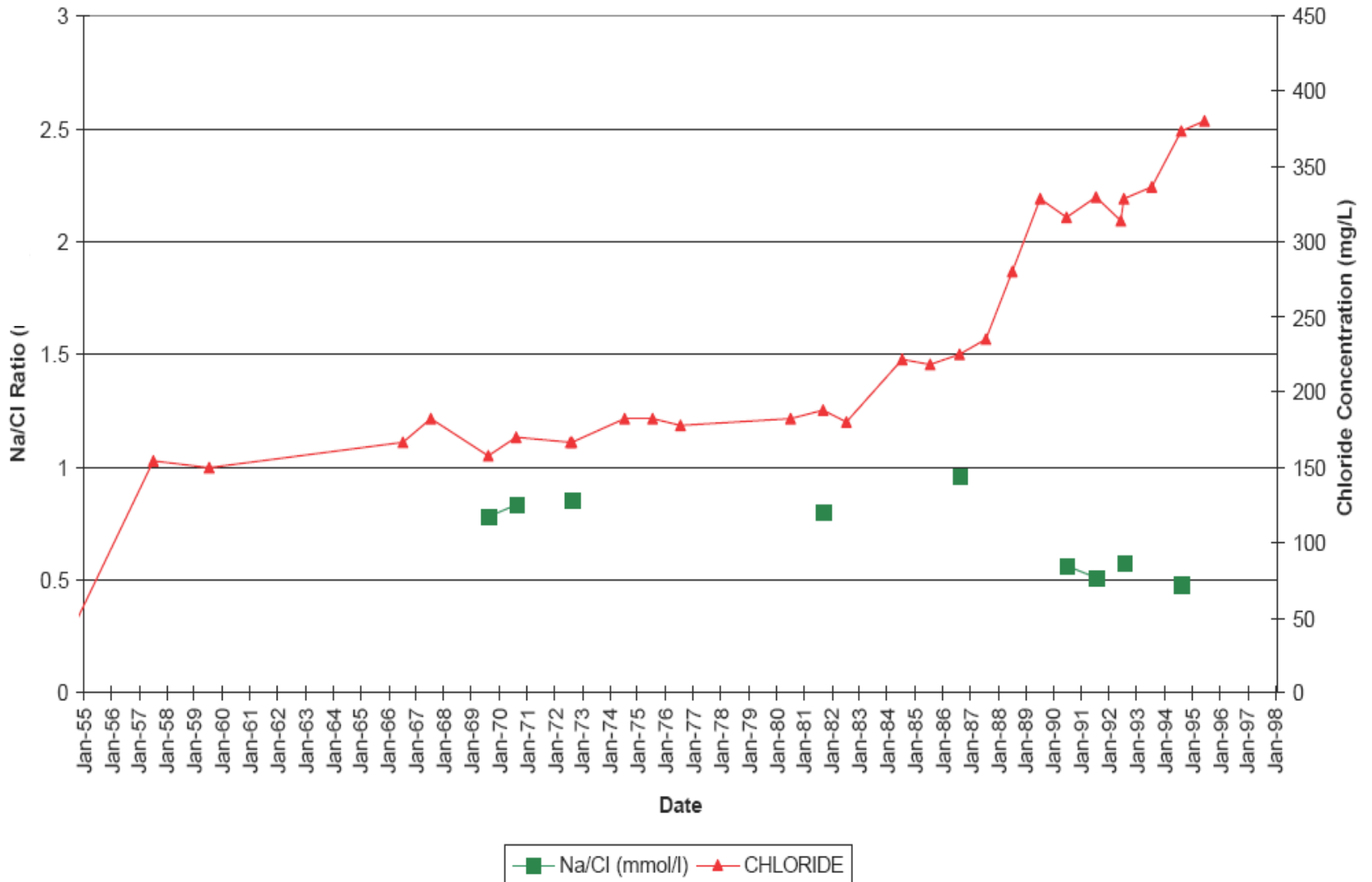


Figure 8: Historical Chloride Concentrations and Sodium/Chloride Ratios for a Well in Salinas Valley Showing Incipient Intrusion (Source: MCWRA)

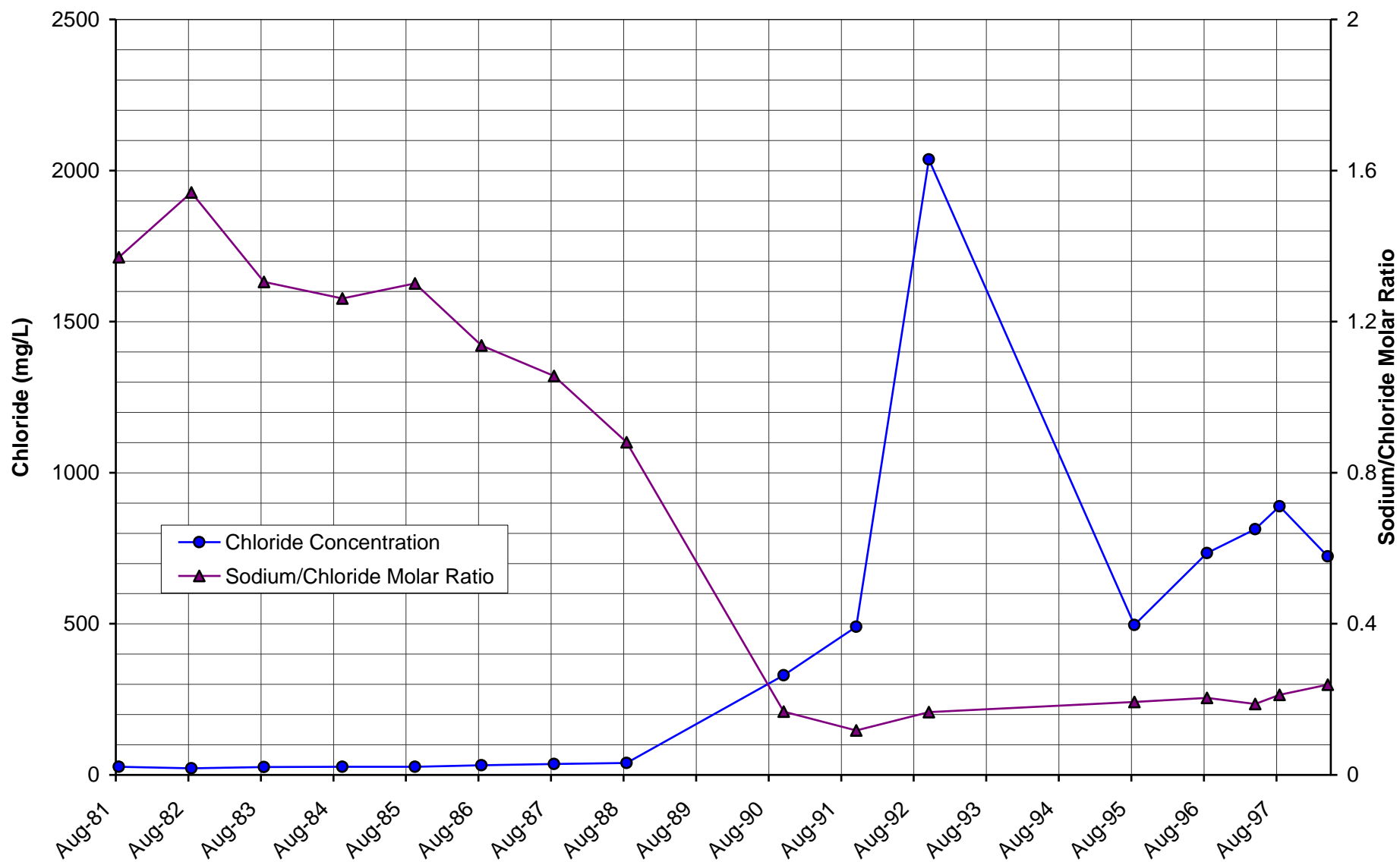


Figure 9: Historical Chloride Concentrations and Sodium/Chloride Ratios for a Well in Pajaro Valley Showing Incipient Intrusion (Data source: PVWMA)

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.

## **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.

## **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.

## 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.

## SECTION 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.

## 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), this report includes a number of approaches to evaluate seawater intrusion. Data for the 2<sup>nd</sup> quarter of Water Year 2017 (sampled and measured January-March 2016) and 4<sup>th</sup> quarter of Water Year 2017 (sampled and measured July-September 2017) were analyzed and mapped to show the spatial distribution of groundwater quality and groundwater elevations. In addition to spatial mapping, historical data were graphed to assess geochemical trends. Data from the 2<sup>nd</sup> quarter represents conditions during the wet time of the year; data from the 4<sup>th</sup> quarter represents conditions during the dry time of the year. In some cases when samples or measurements were not collected strictly within the 2<sup>nd</sup> or 4<sup>th</sup> 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 Deep Aquifer.

## CATION/ANION RATIOS

For Water Year 2017, 18 monitoring wells and 16 production wells were used for geochemical trend analyses. The locations of all monitoring and production wells used in the SIAR analysis over the years are shown on Figure 10. Some of the production wells are not included in the analysis this year because they have not been pumped during the year. Of the 18 monitoring wells, four are the deep Sentinel Wells installed by the Watermaster in 2007. Thirteen 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 4<sup>th</sup> quarter. Where samples are not available for analysis, the text and figures indicate as such.

### SECOND QUARTER WATER YEAR 2017 (JANUARY-MARCH 2017)

A Piper diagram displaying analyses from nine monitoring wells in the Seaside Groundwater Basin for the 2<sup>nd</sup> quarter Water Year 2017 (January-March 2017) is shown on Figure 11. Analyses from only nine wells are shown because most of the monitoring well pairs are not sampled during this quarter; they are only sampled annually in the 4<sup>th</sup> quarter. Appendix A includes individual Piper diagrams for each well to show 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 the water from both the deep and shallow well pairs straddle the sodium-chloride and sodium-bicarbonate type water<sup>1</sup>. Sentinel Well SBWM-1 has a slightly different anion/cation composition from the other monitoring wells, but its individual Piper diagram in

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<sup>1</sup> 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.

Appendix A: Figures A-13 and A-14 shows that historically, this is typical of groundwater from the well.

Stiff diagrams for the monitoring wells sampled during the 2<sup>nd</sup> quarter of Water Year 2017 are shown in the left column on Figure 12 through Figure 15. The Stiff diagrams are coded to match the colors and symbols on the Piper diagram. None of the Stiff diagrams show the high chloride spike shown on Figure 7 that indicates seawater intrusion.

#### **FOURTH QUARTER WATER YEAR 2017 (JULY-SEPTEMBER 2017)**

Piper diagrams displaying groundwater quality data from 18 monitoring wells and 16 production wells in the Seaside Groundwater Basin for the 4<sup>th</sup> quarter of Water Year 2017 (July-September 2017) are shown on Figure 16 and Figure 17, respectively. Appendix A includes individual Piper diagrams for each well to show trends over time.

Except for Sentinel Wells SBWM-1 through SBWM-4 which are deeper than most monitoring wells in the basin,

Figure 16 shows water quality data for the monitoring wells clustering generally in a single area on the Piper diagram, which is a pattern similar to that observed during the 4<sup>th</sup> quarter of Water Year 2016 and the 2<sup>nd</sup> quarter of Water Year 2017. This groundwater is generally of a sodium-chloride/sodium-bicarbonate type and is not impacted by seawater.

Figure 17 presents a Piper diagram for 4<sup>th</sup> quarter groundwater samples from production wells. The production wells plot in roughly the same location on the Piper diagram as the majority of monitoring wells on

Figure 16. 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. These wells can be 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-23). 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 18 monitoring wells sampled during the 4<sup>th</sup> quarter of Water Year 2017 are shown in the right column on Figure 12 through Figure 15. With the exception of Sentinel Well SBWM-2 (1,470 ft), 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. The 4<sup>th</sup> quarter Stiff diagram for Sentinel Well SBWM-2 (1,470 ft) has a shape different from its 2<sup>nd</sup> quarter sample and similar to Water Year 2016's 4<sup>th</sup> quarter sample.

Stiff diagrams for the 16 production wells sampled during the 4<sup>th</sup> quarter of Water Year 2017 are shown in the right column on Figure 18 through Figure 20. These production well Stiff diagrams show no significant changes from the shapes were observed in the 4<sup>th</sup> quarter of Water Year 2016 or 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.

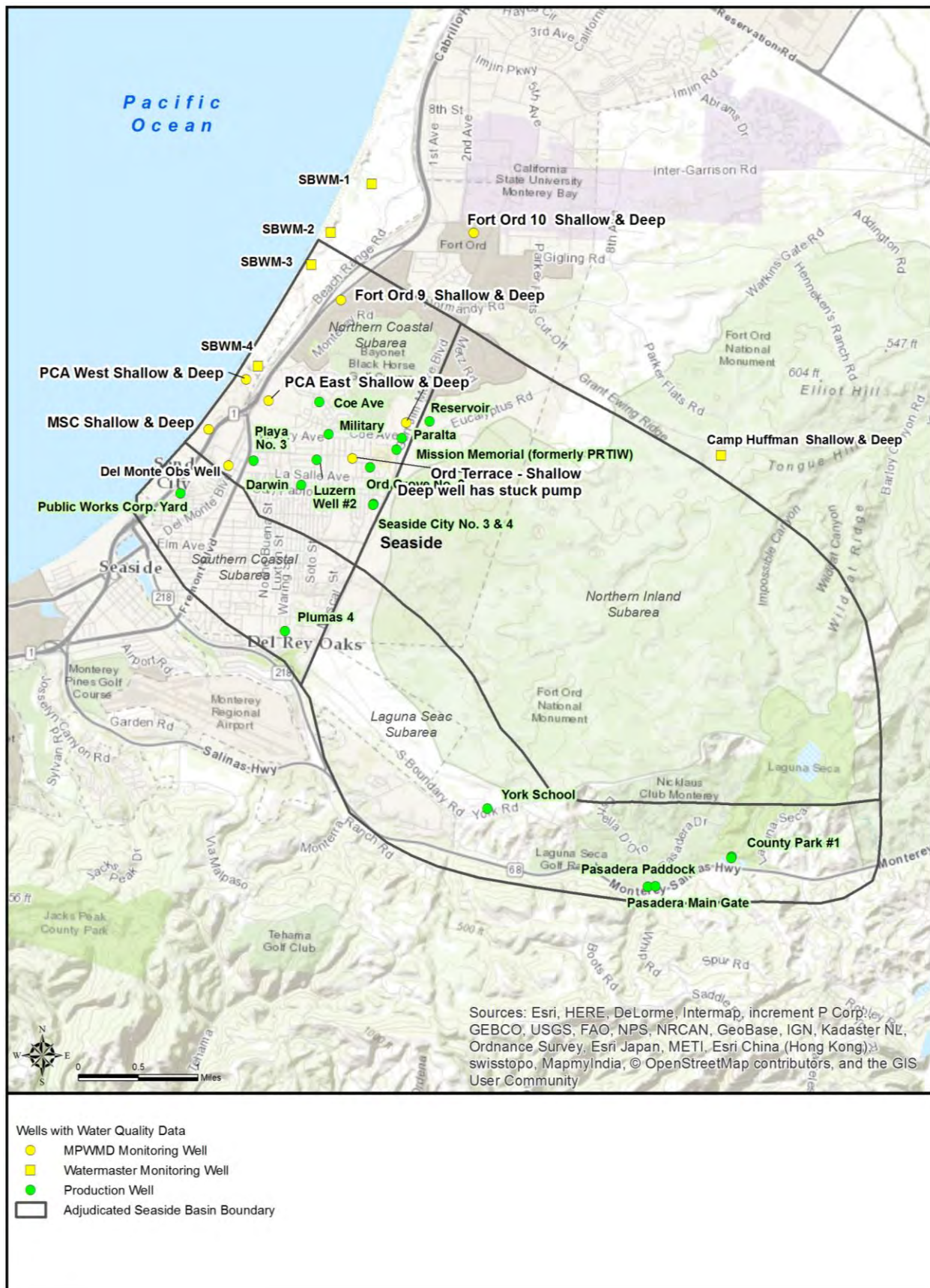


Figure 10: Wells Used for Seawater Intrusion Analyses

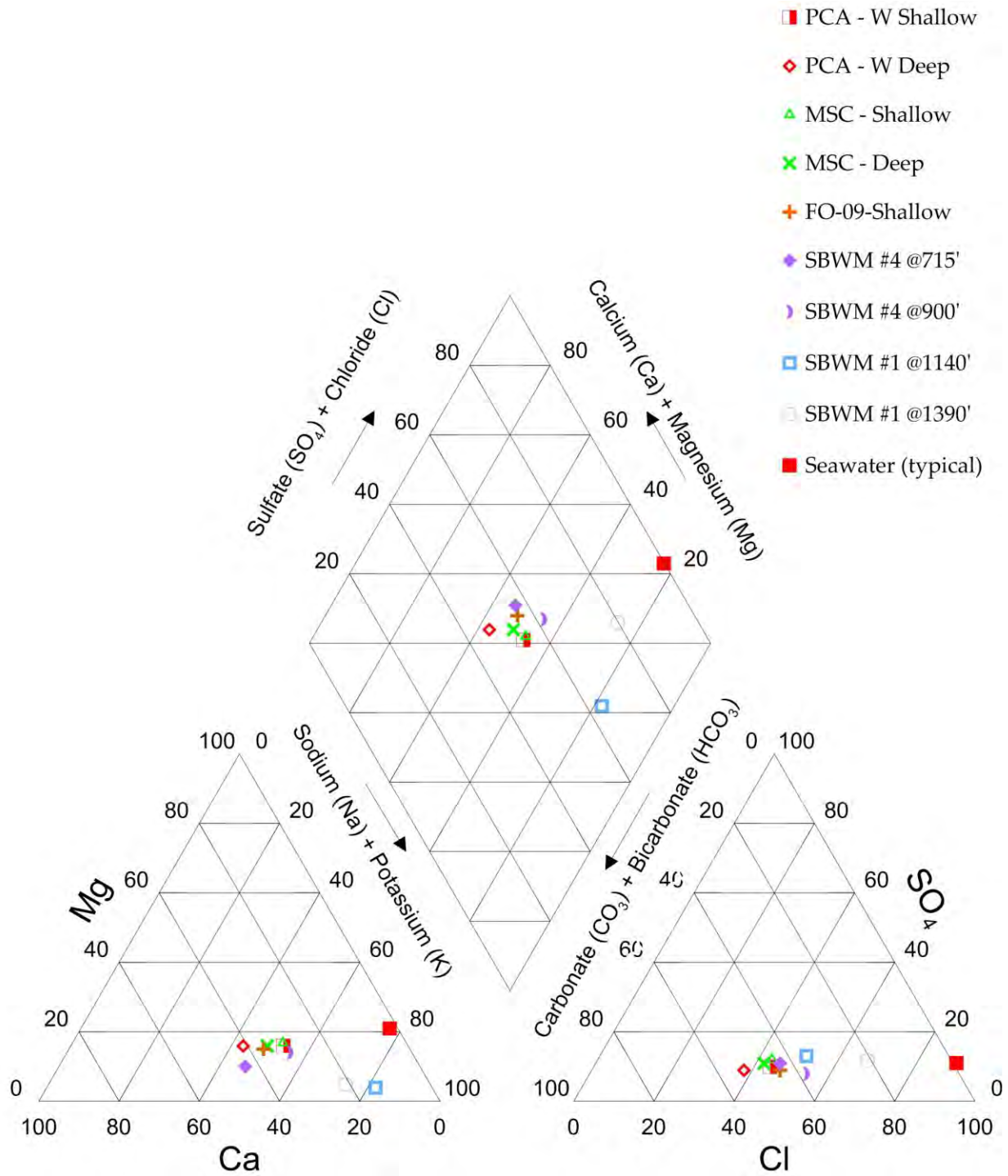


Figure 11: Piper Diagram for Seaside Groundwater Basin Monitoring Wells, 2<sup>nd</sup> Quarter Water Year 2017 (January-March 2017)  
 (Data source: Watermaster)

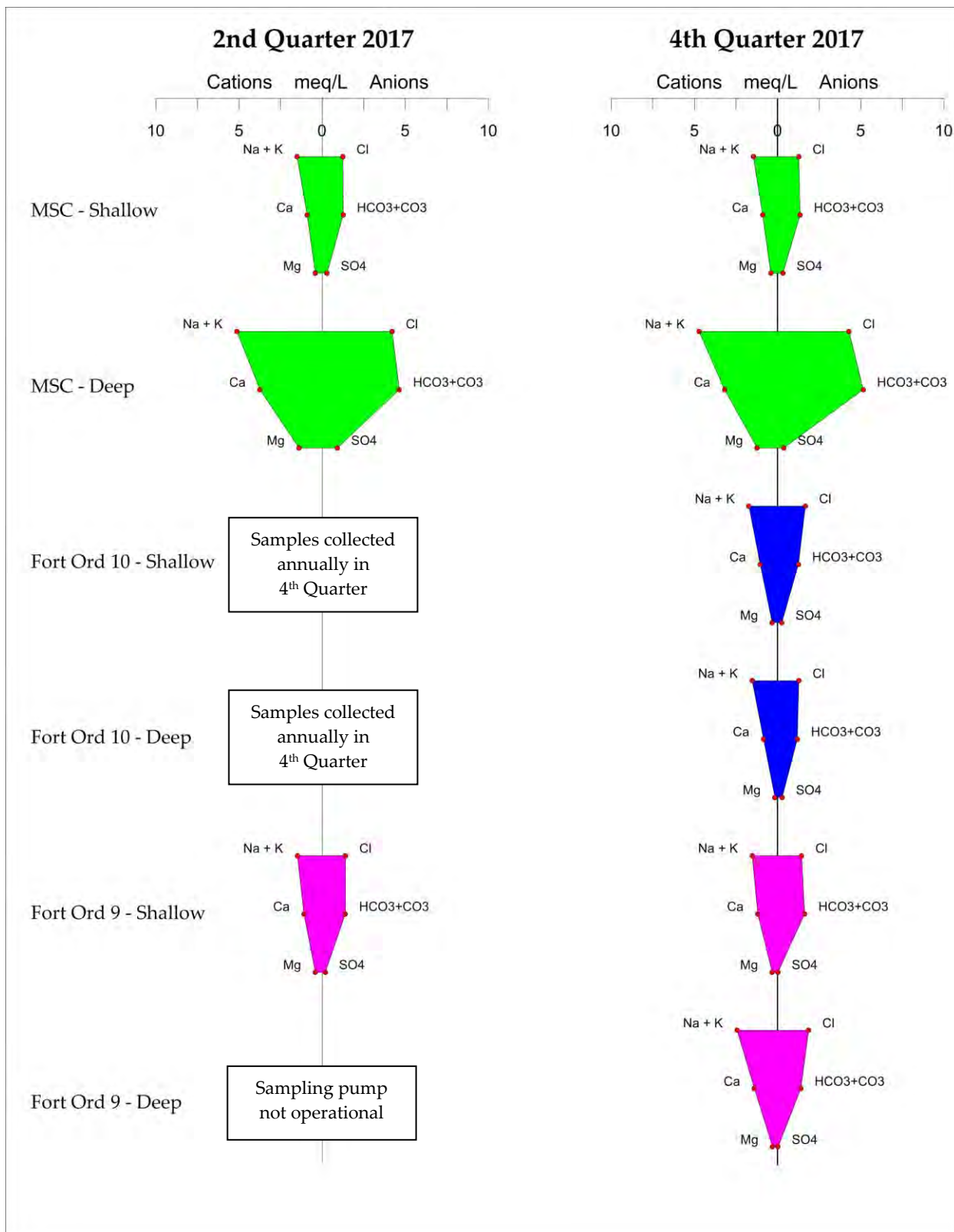


Figure 12: Stiff Diagrams for MSC, Fort Ord 9, and Fort Ord 10 Wells  
(Data source: Watermaster)

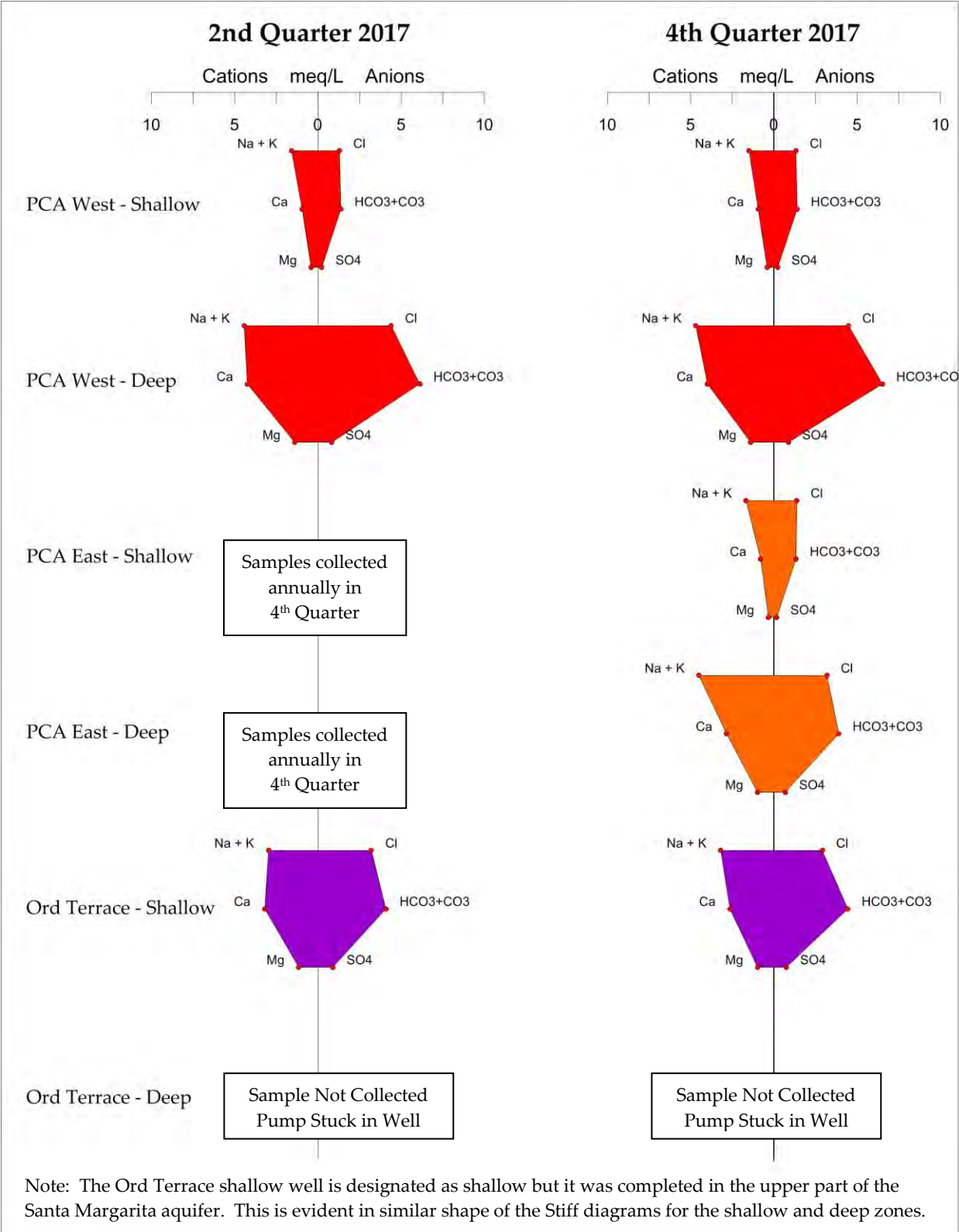


Figure 13: Stiff Diagrams for PCA West, PCA East, and Ord Terrace Wells  
(Data source: Watermaster)

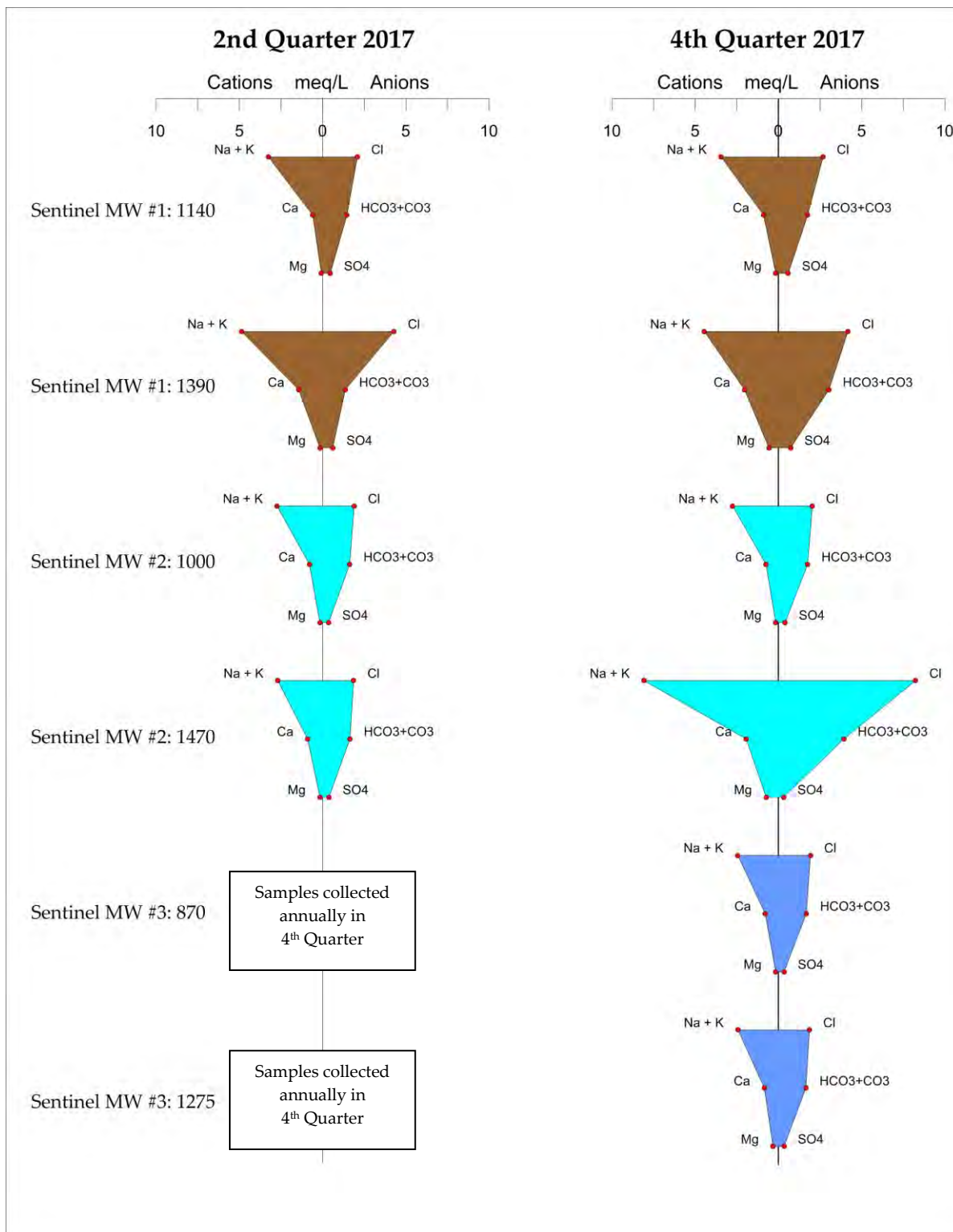


Figure 14: Stiff Diagrams for Watermaster Sentinel Wells 1 - 3 (Data source: Watermaster)

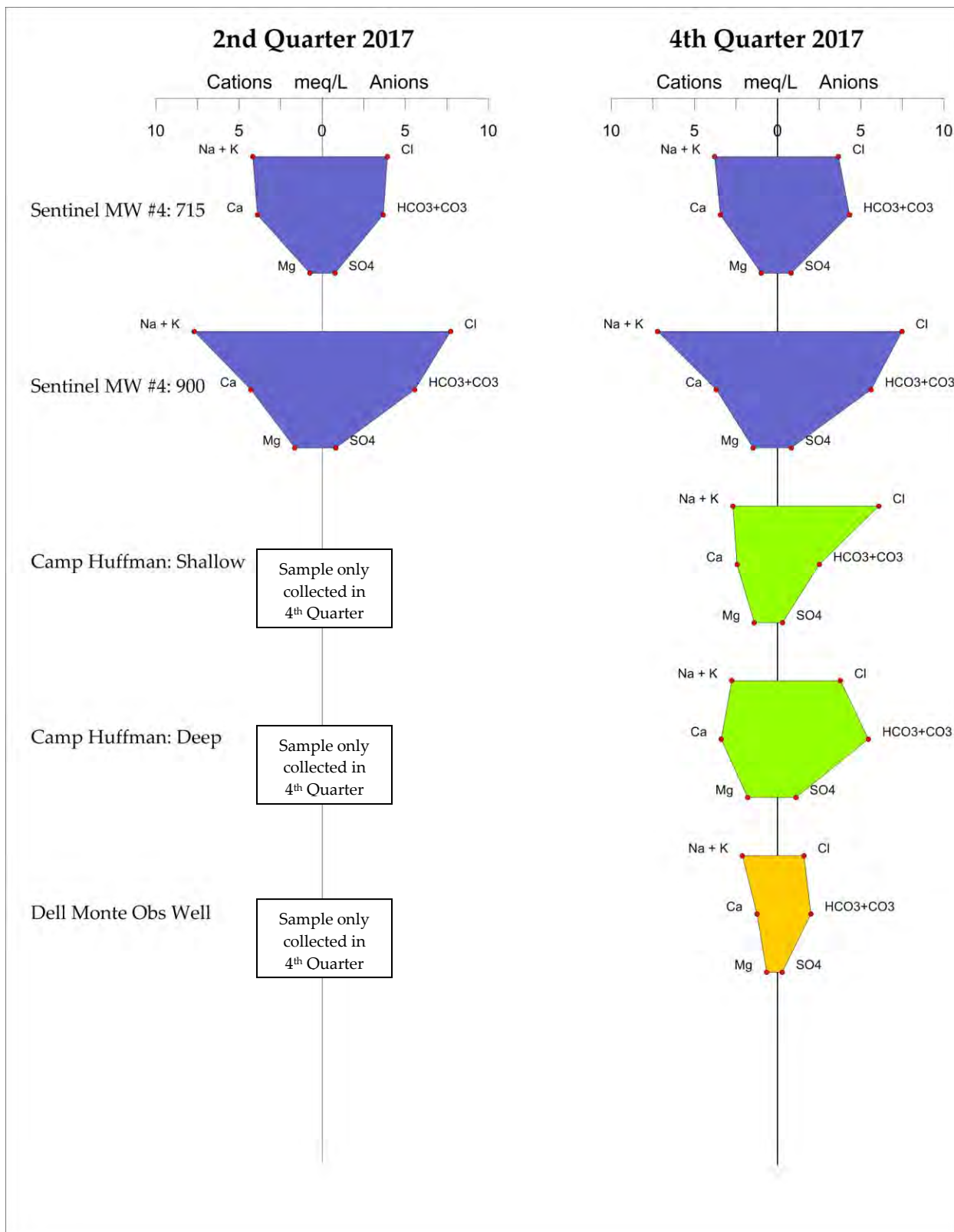


Figure 15: Stiff Diagrams for Watermaster Sentinel Well 4, Camp Huffman, and Del Monte (Data source: Watermaster and MPWMD)

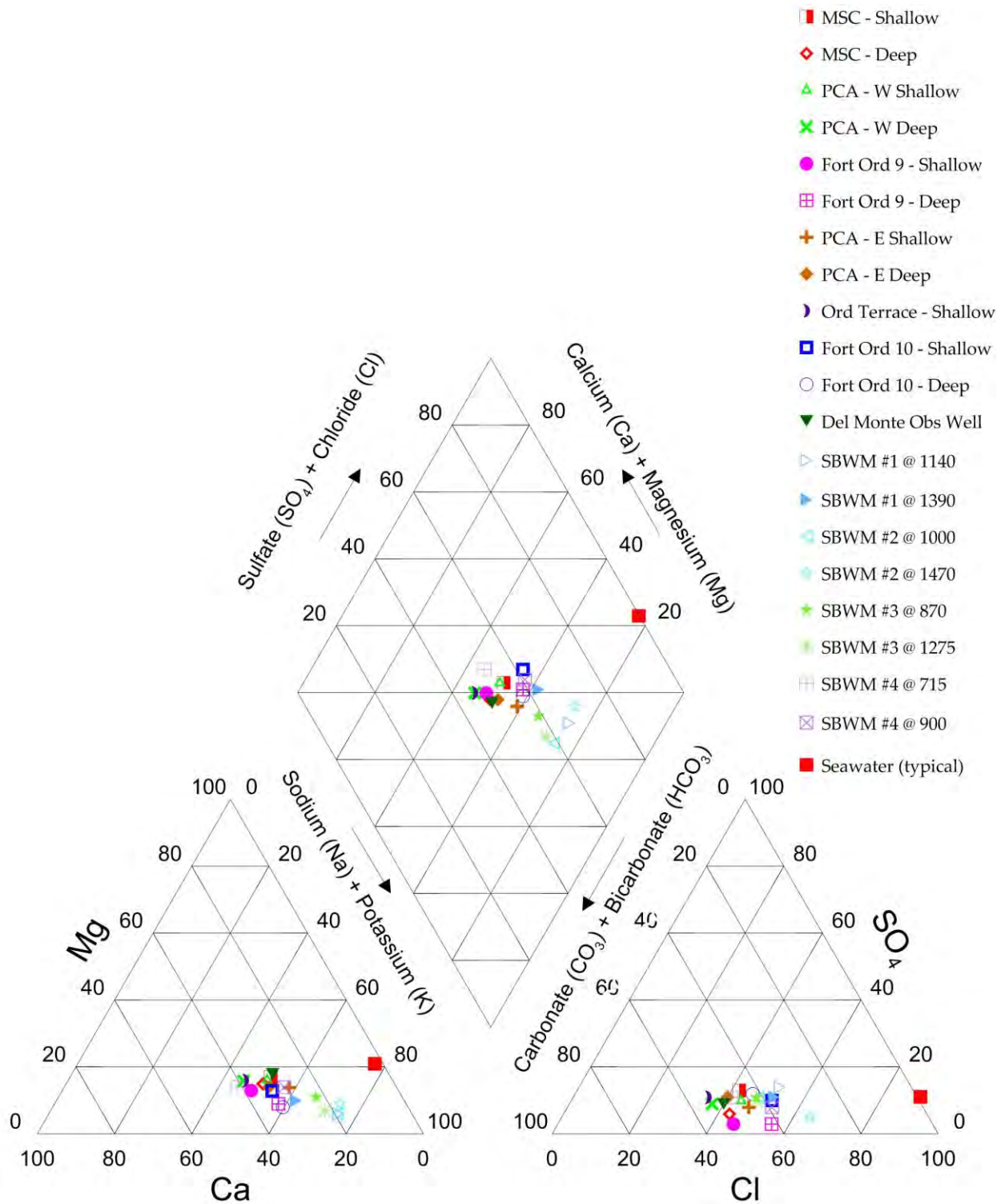


Figure 16: Piper Diagram for Seaside Groundwater Basin Monitoring Wells, 4<sup>th</sup> Quarter Water Year 2017 (July- September 2017)  
(Data source: Watermaster)

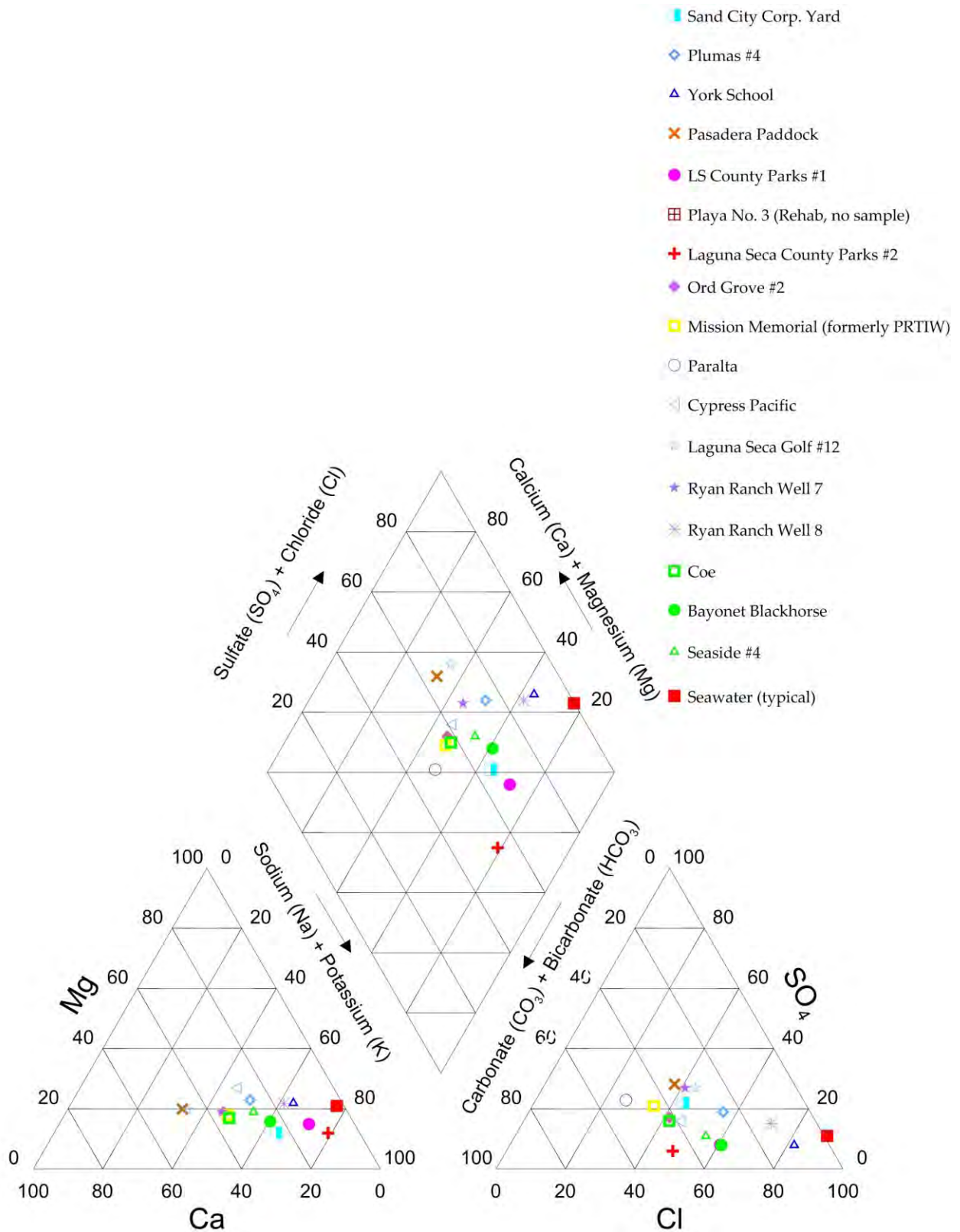
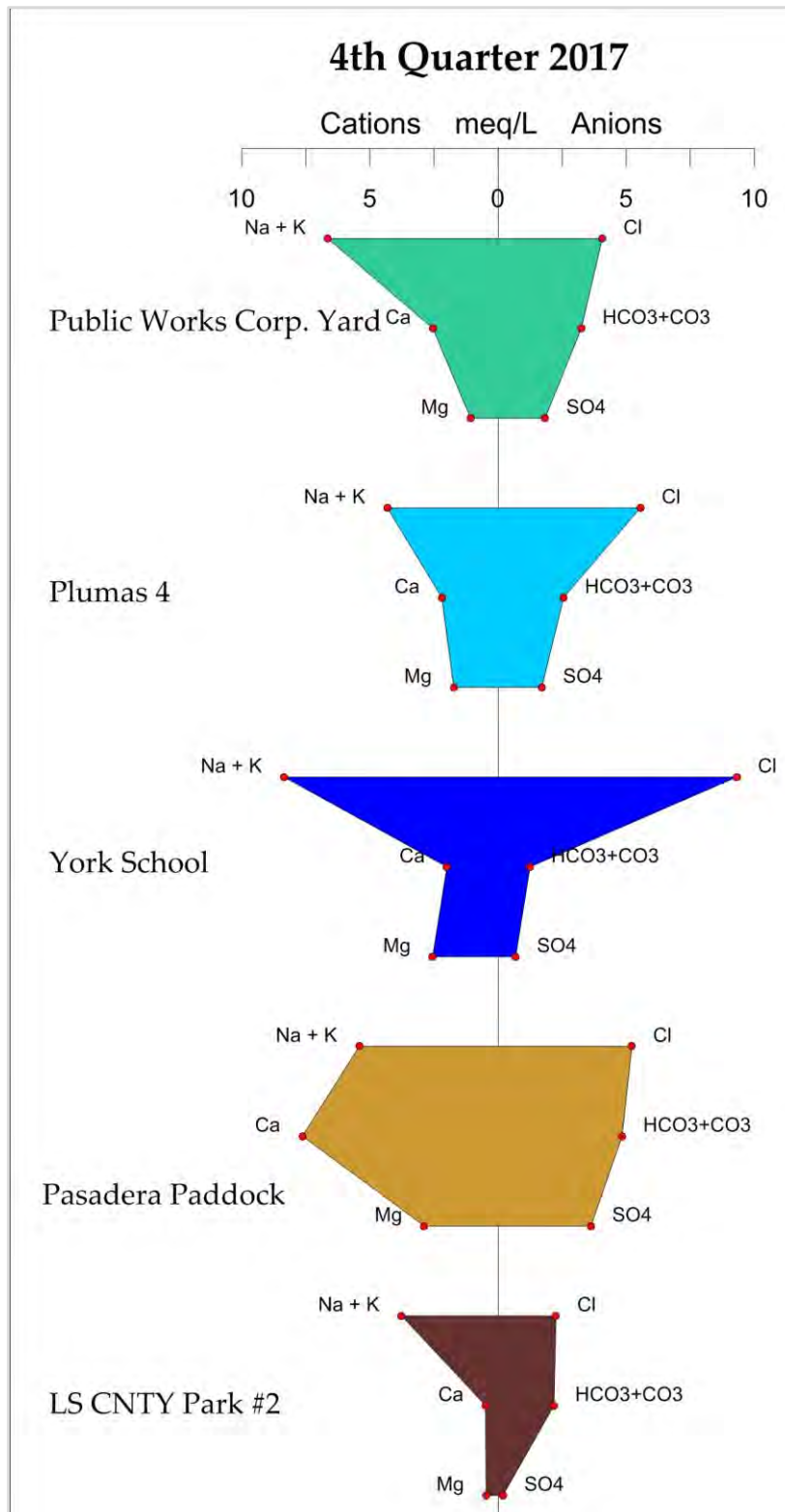
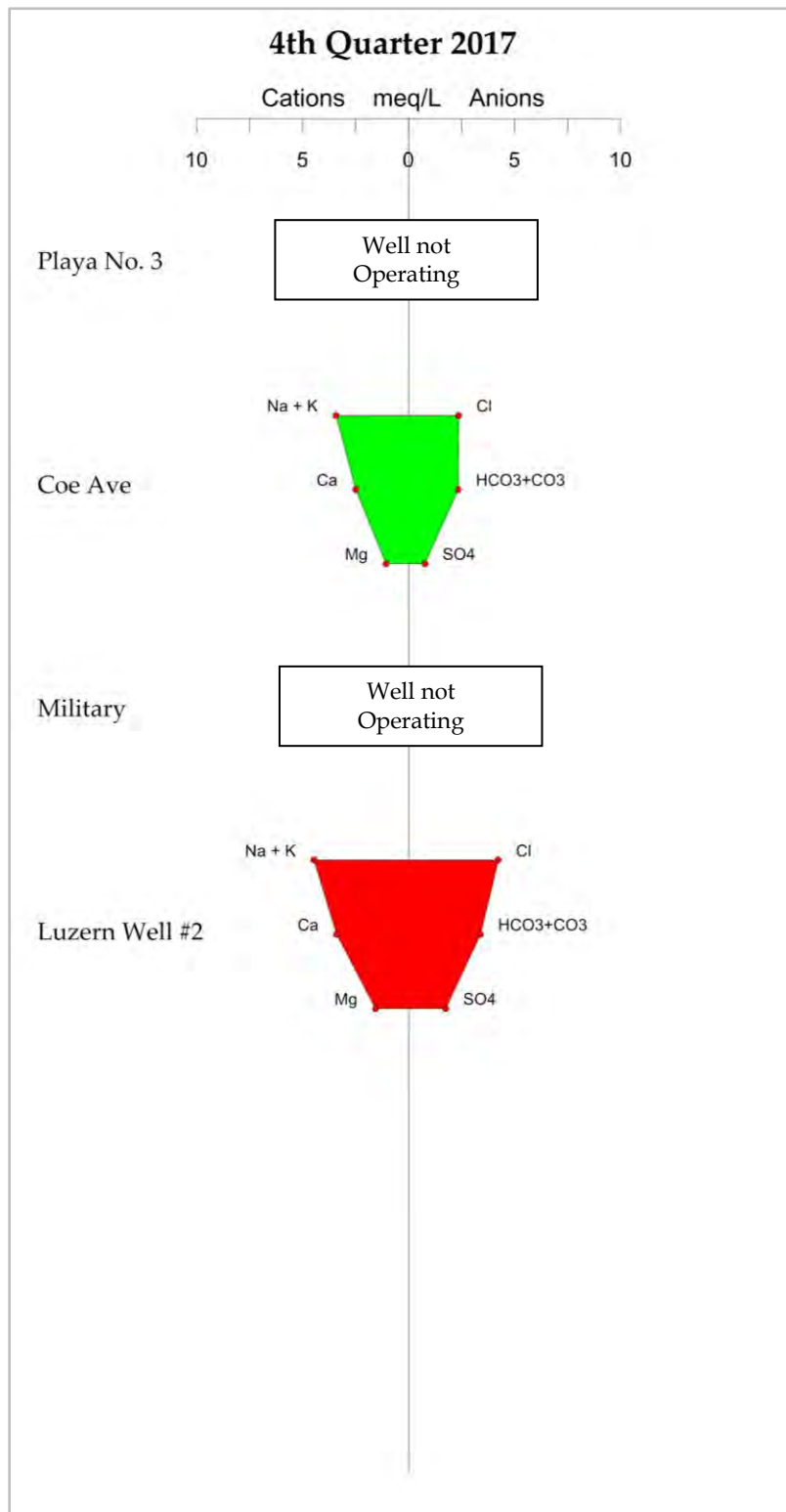


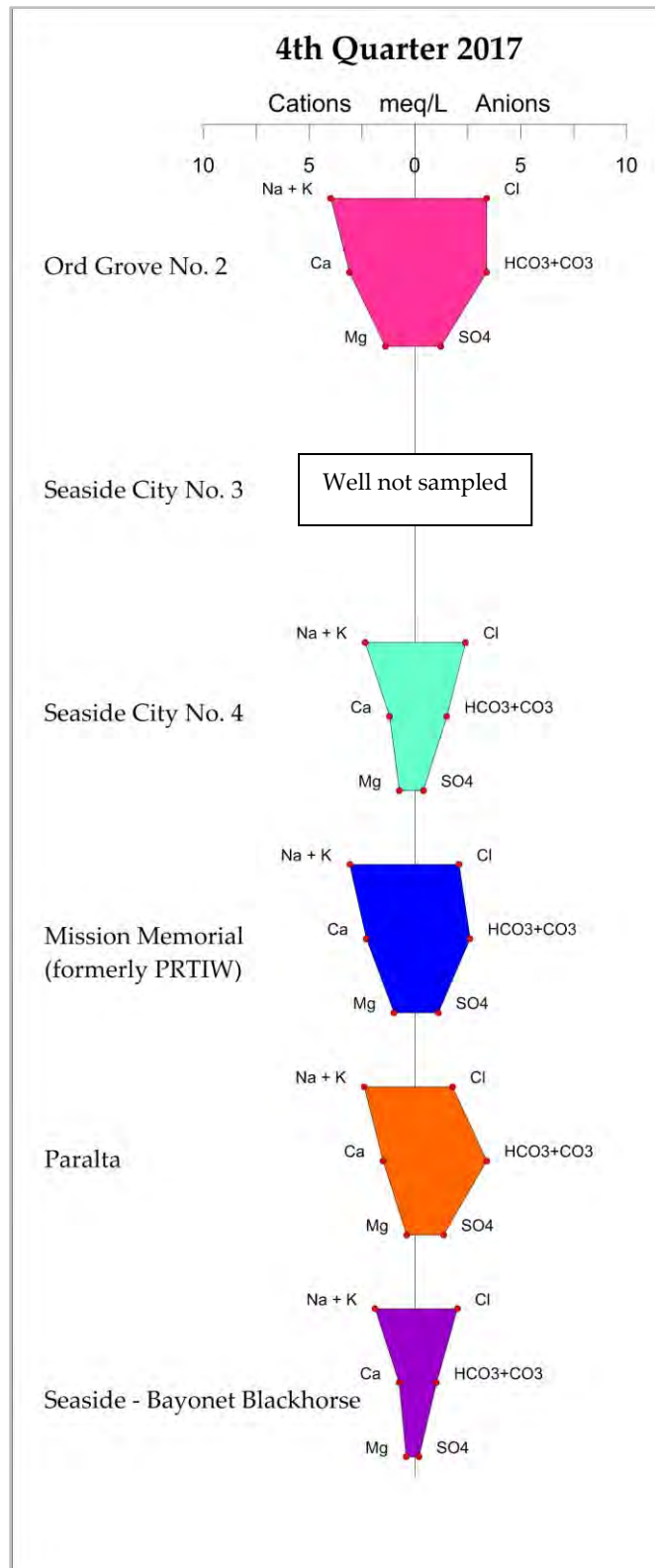
Figure 17: Piper Diagram for Seaside Groundwater Basin Production Wells, 4<sup>th</sup> Quarter Water Year 2017 (July-September 2017)  
(Data source: Watermaster)



*Figure 18: Stiff Diagrams for Southern Coastal and Inland Subarea Production Wells  
(Data source: Watermaster)*



*Figure 19: Stiff Diagrams for Northern Coastal Subarea Production Wells #1  
(Data source: Watermaster)*



*Figure 20: Stiff Diagrams for Northern Coastal Subarea Production Wells #2  
(Data source: Watermaster)*

# CHLORIDE CONCENTRATIONS

## TRENDS

Chemographs showing chloride concentrations over time are plotted for each of the MPWMD and Watermaster monitoring wells shown on the Piper and Stiff diagrams. 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.

In September 2017, Sentinel Well SBWM-2's deep sample at 1,470 feet had a chloride concentration of 292 mg/L, which is the highest chloride measured in any of the coastal wells. The September 2017 chloride concentration is a 226 mg/L increase from the December 2016 concentration of 66 mg/L. The previous 4<sup>th</sup> quarter sample was also elevated at 178 mg/L. These past three results indicate that chloride concentrations are fluctuating over 100 mg/L within each of the past two water years.

Usually, verification sampling would be recommended for Sentinel Well SBWM-2 (1,470 ft) because of the higher than usual concentration. However, the result was effectively verified by a downhole fluid resistivity profile, which uses an instrument to measure the conductivity of the water within the well casing. Downhole resistivity profiles were run all four Sentinel Wells in August 2017 (Feeney, 2017). The results of the profiling indicated that all the depth-specific laboratory analyzed groundwater electrical conductivities from both shallow and deep sampling locations within each well compared closely with the downhole resistivities converted to electrical conductivities (Feeney, 2017).

As discussed in a technical memorandum summarizing resampling of select wells in December 2016 (HydroMetrics WRI, 2017), the mechanism causing this fluctuation is not yet understood, but were postulated to possibly include natural groundwater quality variations, upwelling or upconing of underlying saline formation water from the Monterey Formation in response to declining groundwater levels, or very early seawater intrusion. However, from evaluation of the downhole electrical conductivity profiling of all four Sentinel Wells (Feeney, 2017) and their long-term electric induction logs, it appears the groundwater samples collected using the low flow sampler is 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 therefore not considered representative of the aquifer and should not be used in further seawater intrusion analysis.

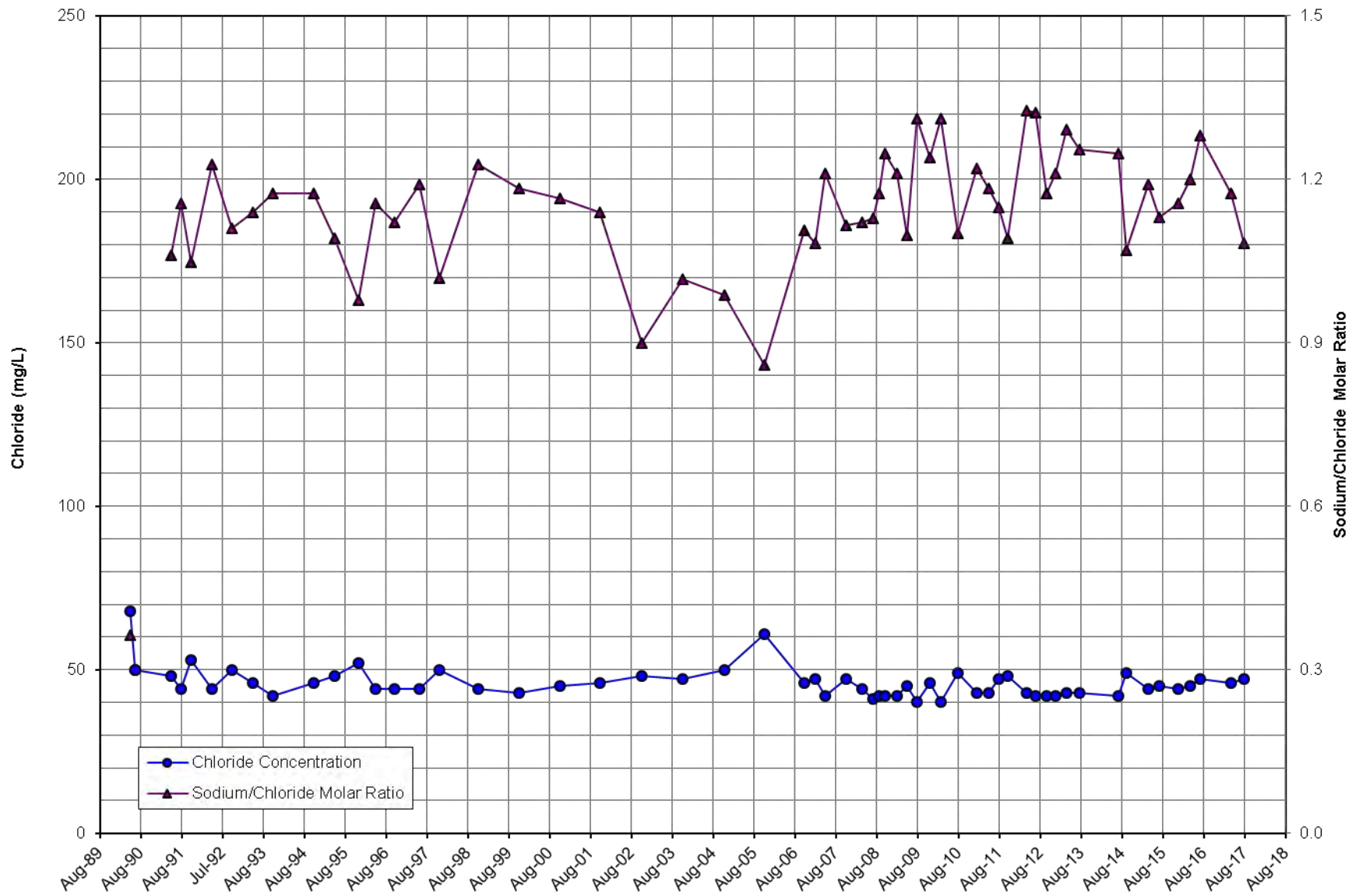


Figure 21: Historical Chloride and Sodium/Chloride Molar Ratios, Shallow PCA West Well

Chloride trends for the coastal monitoring wells remain stable, or fluctuate within a historical tolerance. One monitoring well pair, FO-10 Shallow and Deep are the only wells with long-term decreasing chloride trends. This monitoring well pair is located north of the Seaside Groundwater Basin and is inland of SBWM-1 and SBWM-2 (Figure 10).

## CHLORIDE CONCENTRATION MAPS

### *FOURTH QUARTER WATER YEAR 2017 (JULY-SEPTEMBER 2017)*

Fourth quarter Water Year 2017 chloride concentrations were mapped using data from August and September 2017. The maps for the shallow and deep zones are included on Figure 22 and Figure 23, respectively.

The shallow zone 4<sup>th</sup> quarter Water Year 2017 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 wells having consistently shown higher chloride concentrations. 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, and has historically had the highest concentration of all shallow wells (Appendix B: Figure B-23). However, this year its chloride concentration remained less than 230 mg/L for the second consecutive year. 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 4<sup>th</sup> quarter Water Year 2017 chloride concentration map is shown on Figure 23. Chloride concentrations for the Sentinel Wells are not shown on this map because it has been determined that the samples analyzed 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 63 mg/L and 160 mg/L.

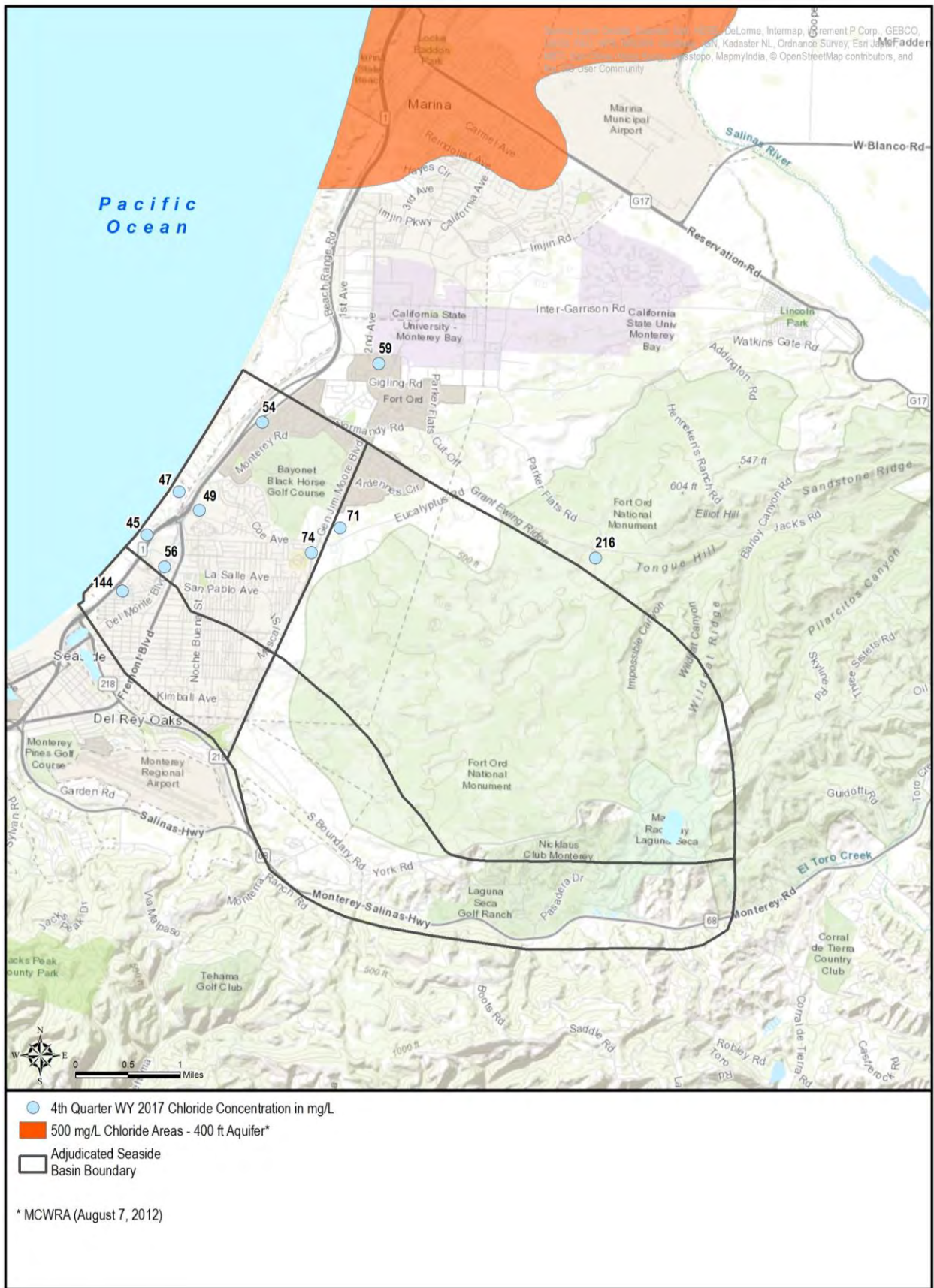


Figure 22: Shallow Zone Chloride Concentration Map – 4<sup>th</sup> Quarter WY 2017

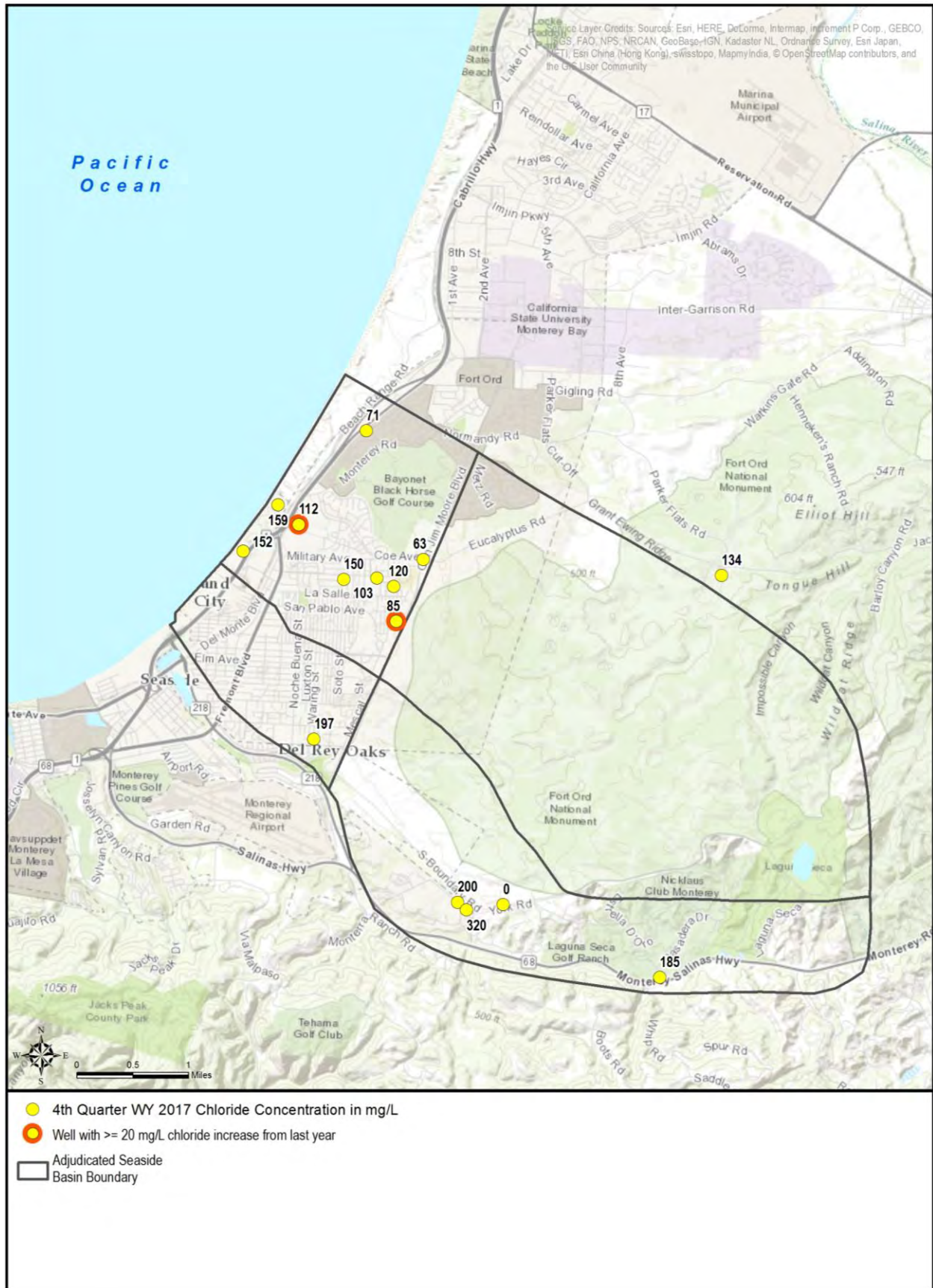


Figure 23: Deep Zone Chloride Concentration Map – 4<sup>th</sup> Quarter WY 2017

The City of Seaside Well 4 and monitoring well PCA-East Deep have a chloride concentration increase of greater than 20 mg/L over last year. Although their concentration increases are greater than 20 mg/L, these same concentrations have been observed historically. The City of Seaside Well 4 and PCA-East Deep are highlighted on Figure 23 with a different well symbol to the other wells.

## SODIUM/CHLORIDE MOLAR RATIOS

Chemographs showing long-term sodium/chloride molar ratios over time are plotted for 16 of the 18 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 2017 Piper and Stiff diagrams because data are not available, 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 water quality data is not representative of the aquifer.

## ELECTRIC INDUCTION LOGS

Two induction logging events took place in all four Sentinel Wells during Water Year 2017. The first logging event was conducted in December 2016, and the second event took place in August 2017. Pacific Surveys conducted the logging, and have done so since August 2014. Figure 24 represents the new baseline (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  $\mu$ 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.”*

The salinity changes shown on Figure 24 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.

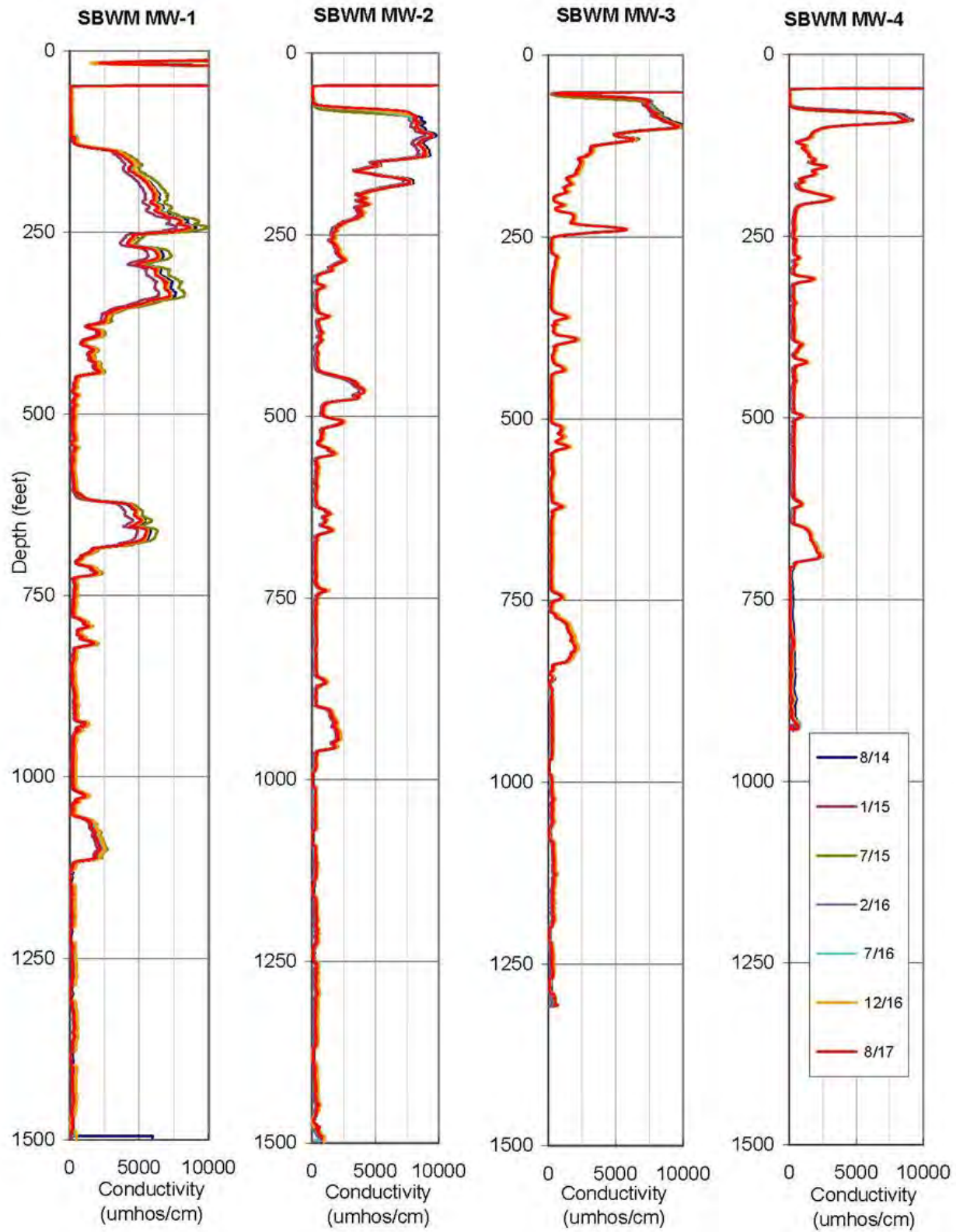


Figure 24: Sentinel Well Induction Log

## 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 level of seawater intrusion unless groundwater levels increase.

### 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 25.

#### *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. This hydrograph shows the effect of production from the nearby CAW production wells on groundwater levels in the deep zone (Figure 25). In the deep zone, although there was a good amount of recovery, groundwater levels continue to be well below sea level.

The hydrograph peaks and lows are strongly influenced by pumping and/or injection occurring in the area east of the monitoring well. Other influences such as tides which can cause up to a one foot fluctuation in the deep completion of PCA-East also need to be 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 25 shows an overall decline in groundwater levels until 2009, levels more or less stabilize the next two years, and then from 2011 to 2014 have experienced a continual decline associated with a period of below average rainfall, with levels stabilizing again over Water Years 2015 and 2016, and recovering in Water Year 2017. The start of the overall decline in groundwater levels in the deep completion of PCA-East corresponds with the shift in CAW'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. 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 26 includes hydrographs of groundwater elevations for the four coastal deep Sentinel Wells. The 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 show that groundwater elevations over winter and spring were the highest in Water Year 2017 than they have been since the wells were installed in 2007. The summer low elevations are only higher than the previous two years and not higher than year prior to 2015. For Water Year 2017, there is 20-25 feet of groundwater recovery along the coast from December 2016 through May 2017 and just over 15 feet of decline again in the summer, which is similar to the summer decrease observed in Water Year 2016. The greater than average Water Year 2017 rainfall appears to have stopped the ongoing declining groundwater elevations that have taken place since 2010. Unless there is another above average rainfall year, it is expected that groundwater elevations will decline once again.

In the shallow zone, Water Year 2017 end of summer groundwater levels are a few feet higher than levels observed in Water Year 2016 (Figure 25). Seasonal level increases seen in the data are usually related to reduced wintertime production in the shallow aquifer, 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.

### *SOUTHERN COASTAL SUBAREA*

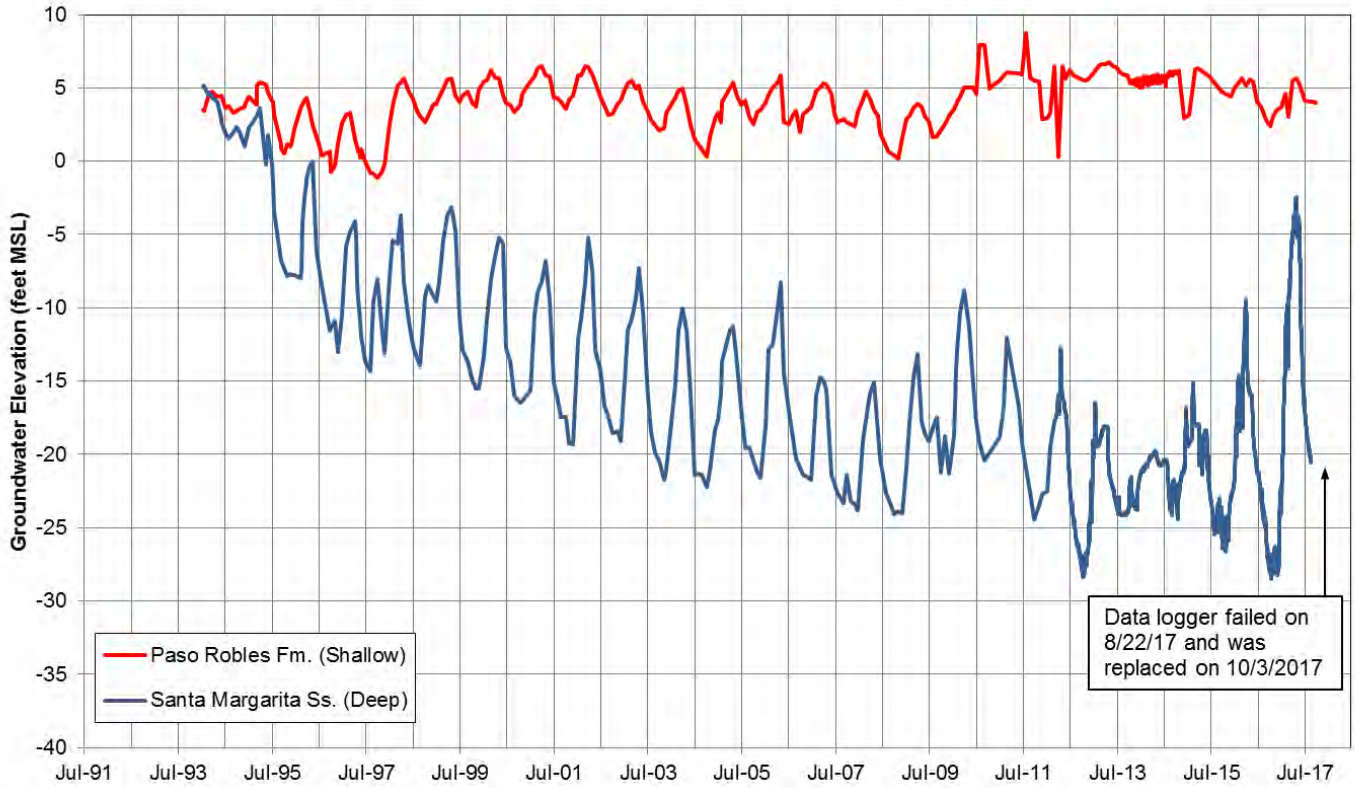
In the Southern Coastal subarea, the KMART monitoring well is representative of groundwater levels near the coast (Figure 25). The hydrograph shows that groundwater elevations have always been above sea level and continue to remain fairly stable over time. It is noticeable that over the period of drought (Water Years 2012 – 2015) in California, there was a slight decline in shown groundwater level, which has since recovered to pre-drought levels.

### *LAGUNA SECA SUBAREA*

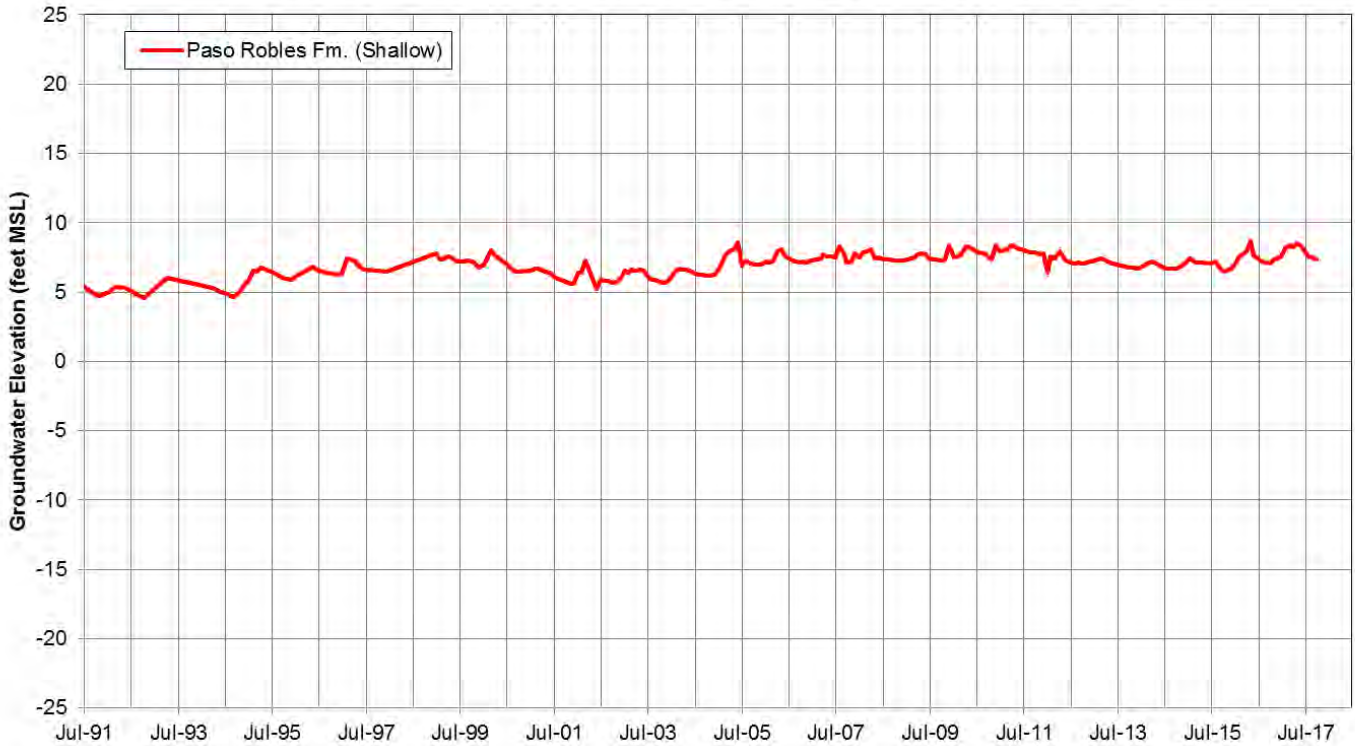
Although wells in the Laguna Seca subarea are far enough from the coast not to induce seawater intrusion, there is concern that since 2001 this area has experienced an ongoing decline in groundwater levels that is not being halted or improved upon by triennial pumping reductions. It is believed this is occurring due to influences of groundwater

pumping east of the Seaside Basin boundary (HydroMetrics WRI, 2016). Figure 27 shows in the eastern portion of the subarea that between 2001 and 2015, shallow groundwater levels declined at a rate of approximately 0.6 feet per year, and deep groundwater levels declined at between two and three feet per year. Figure 28 shows the location of the hydrographs on Figure 27. There is an indication from 2016 and 2017 groundwater levels that the rate in declines has stabilized over the past couple years. Declines in the western portion of the subarea are also occurring but on the order of one to two feet per year.

**GROUNDWATER ELEVATION  
PCA-EAST MONITORING WELL - NORTHERN COASTAL SUBAREA**



**GROUNDWATER ELEVATION  
K MART MONITORING WELL - SOUTHERN COASTAL SUBAREA**



*Figure 25: Example Hydrographs (Source: Watermaster)*

### GROUNDWATER ELEVATIONS SENTINEL WELLS

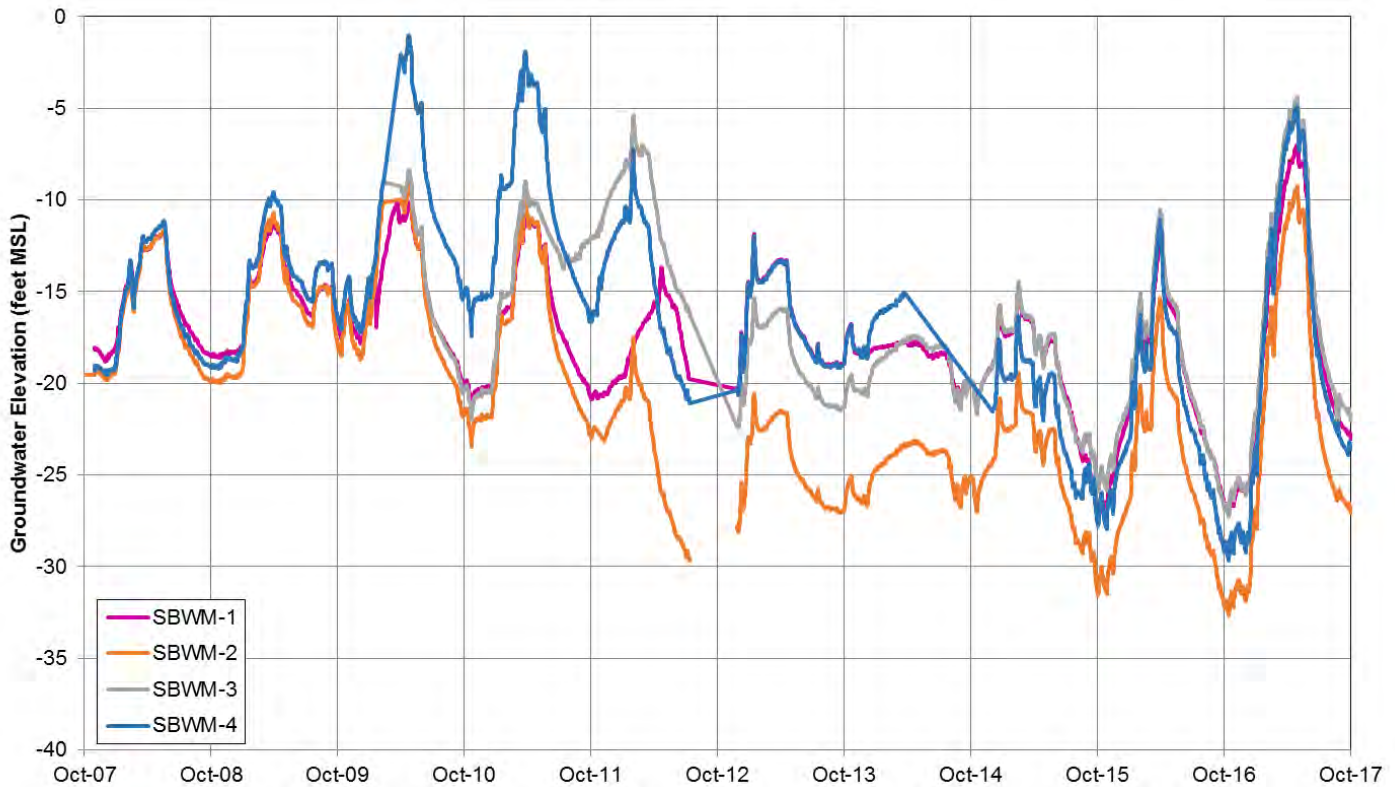


Figure 26: Sentinel Well Hydrographs

### GROUNDWATER ELEVATION MONITORING WELLS - EASTERN LAGUNA SECA SUBAREA

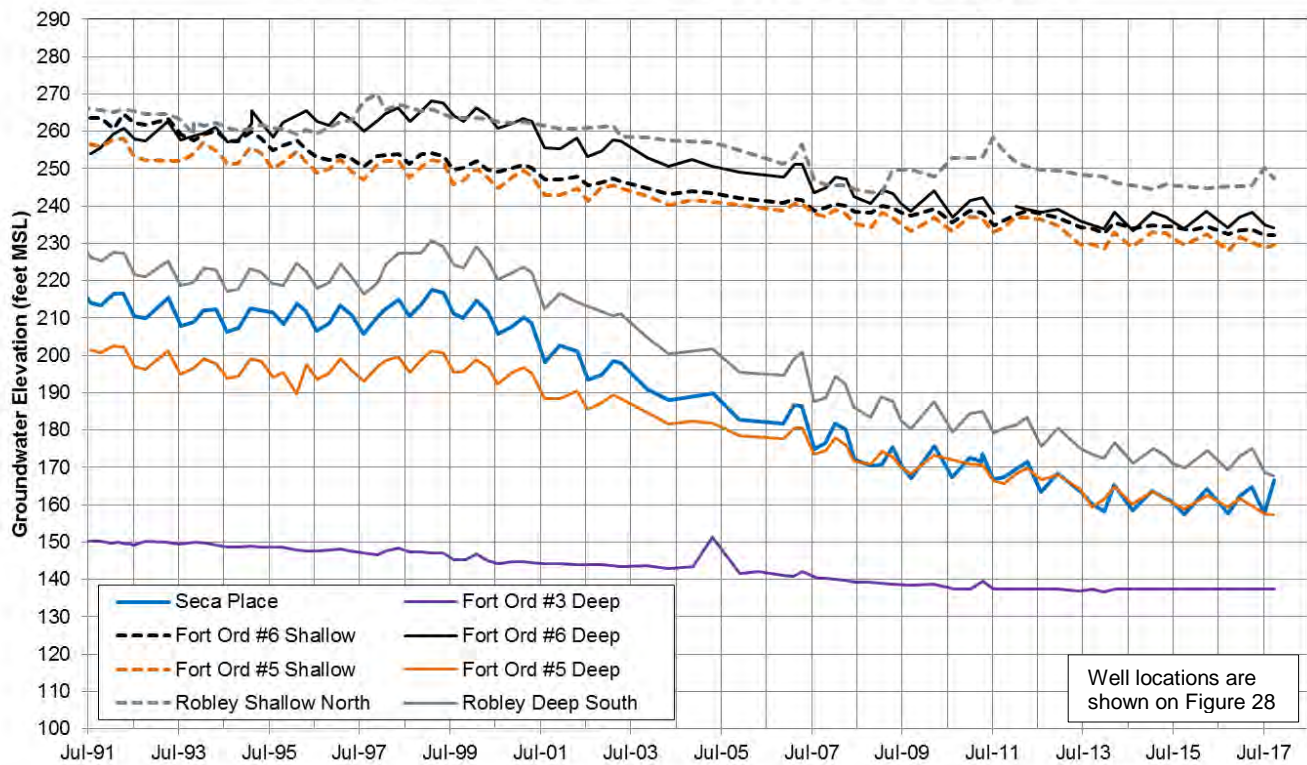


Figure 27: Eastern Laguna Seca Subarea Hydrographs

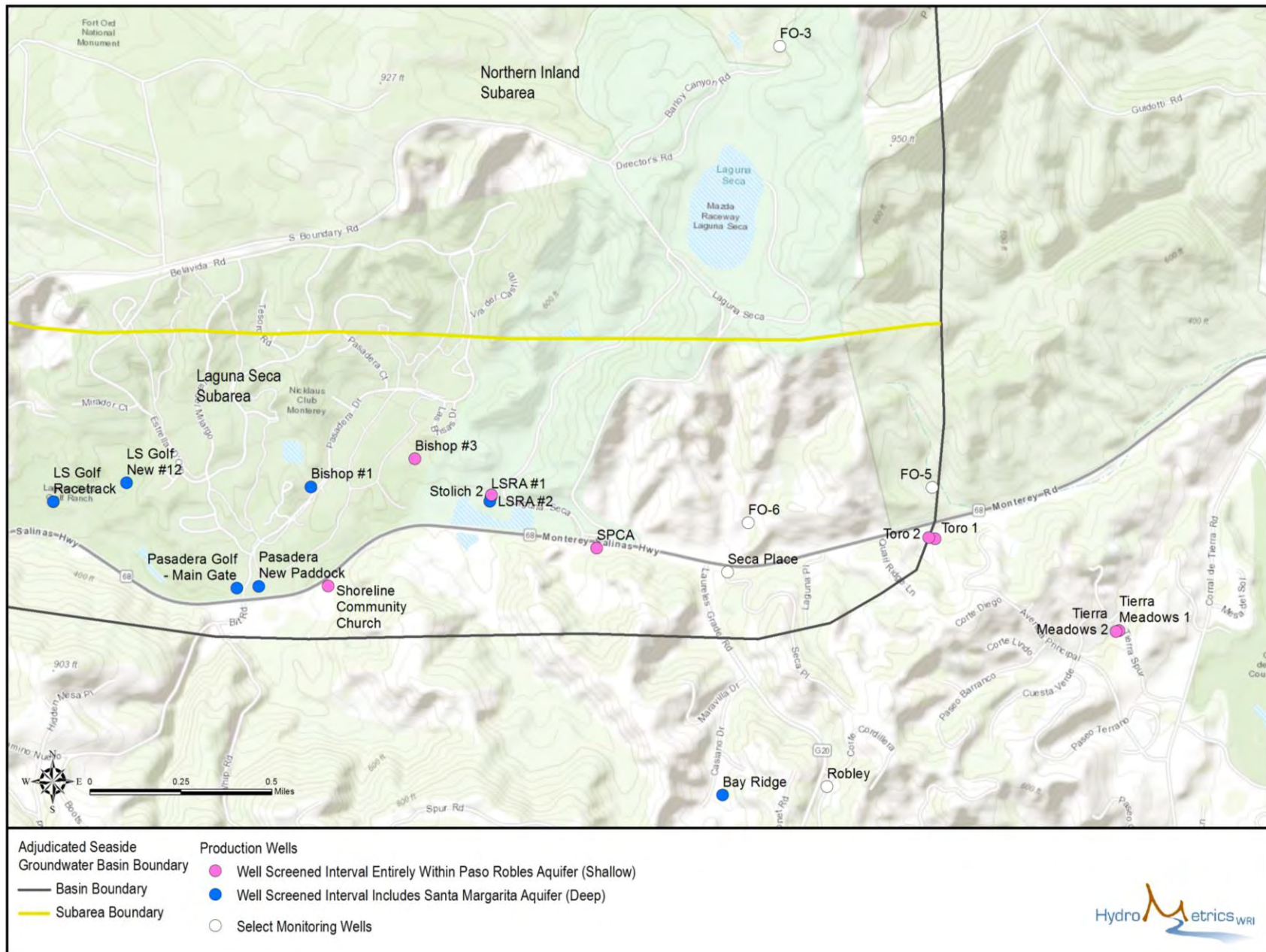


Figure 28: Eastern Laguna Seca Subarea Wells

## GROUNDWATER ELEVATION MAPS

### *SECOND QUARTER WATER YEAR 2017 (JANUARY-MARCH 2017)*

Groundwater level maps for the shallow and deep aquifer zones for the 2<sup>nd</sup> quarter of Water Year 2017 are shown on Figure 29 and Figure 30, 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 2017 remain essentially the same as Water Year 2016 along the coast in the Northern Coastal subarea, with the exception of the coastal pumping depression which decreased slightly from Water Year 2016. Groundwater levels remained stable in the western portion of the Laguna Seca subarea and the Laguna Seca subarea pumping depression remained similar in extent to last water year. In the eastern part of the Northern Inland subarea, an area of the shallow aquifer has been indicated to be potentially dry due to geologic structural control (Figure 29).

Second quarter groundwater levels in the deep aquifer, particularly along the coast, are usually higher than 4<sup>th</sup> quarter groundwater levels by up to six to seven feet due to seasonal variations. In Water Year 2017, groundwater elevations along the coast in the 2<sup>nd</sup> quarter are 10 to 15 feet higher than the same quarter last year. The pumping depression in the Northern Coastal subarea is smaller in extent than Water Year 2016 (Figure 30). The small pumping depression caused by the Laguna Seca golf course wells continues as in previous years. As pointed out from Laguna Seca hydrographs on Figure 27, groundwater levels in the Laguna Seca subarea have stabilized thereby slowing the decline of two to three feet observed historically.

### *FOURTH QUARTER WATER YEAR 2017 (JULY-SEPTEMBER 2017)*

Groundwater elevation maps for the shallow and deep aquifer zones for the 4<sup>th</sup> quarter of Water Year 2016 are shown on Figure 31 and Figure 32, respectively. The contours for the shallow aquifer along the coast show that groundwater levels are essentially the same as last water year in the Northern Coastal subarea. The pumping depression in the Northern Coastal subarea is very slightly larger in extent than last water year, while the pumping depression in the Laguna Seca subarea had a very slight reduction in size compared to last water year (Figure 31).

The deep aquifer pumping depression around CAW's main production wells in the Northern Coastal subarea decreased slightly in extent from Water Year 2016 (Figure 32).

The depression is not as deep in the northern portion of the subarea as it was in Water Year, although the deepest part of the pumping depression centered around CAW's Ord Grove 2 and Paralta wells (Figure 32), is deeper than last year because the elevations posted on the map and used for contouring are pumping levels as static levels were not available. Supporting the higher 4<sup>th</sup> quarter groundwater levels in the Sentinel Wells, all the coastal wells have increased groundwater elevations of two to three feet over the past year. This is much less than the 2<sup>nd</sup> quarter change in elevation of 10 to 15 feet over last year. The Laguna Seca subarea pumping depression around the Laguna Seca golf course wells remained similar to last water year (Figure 32). The eastern portion of the Laguna Seca subarea is experiencing more stable groundwater levels compared to the last few years.

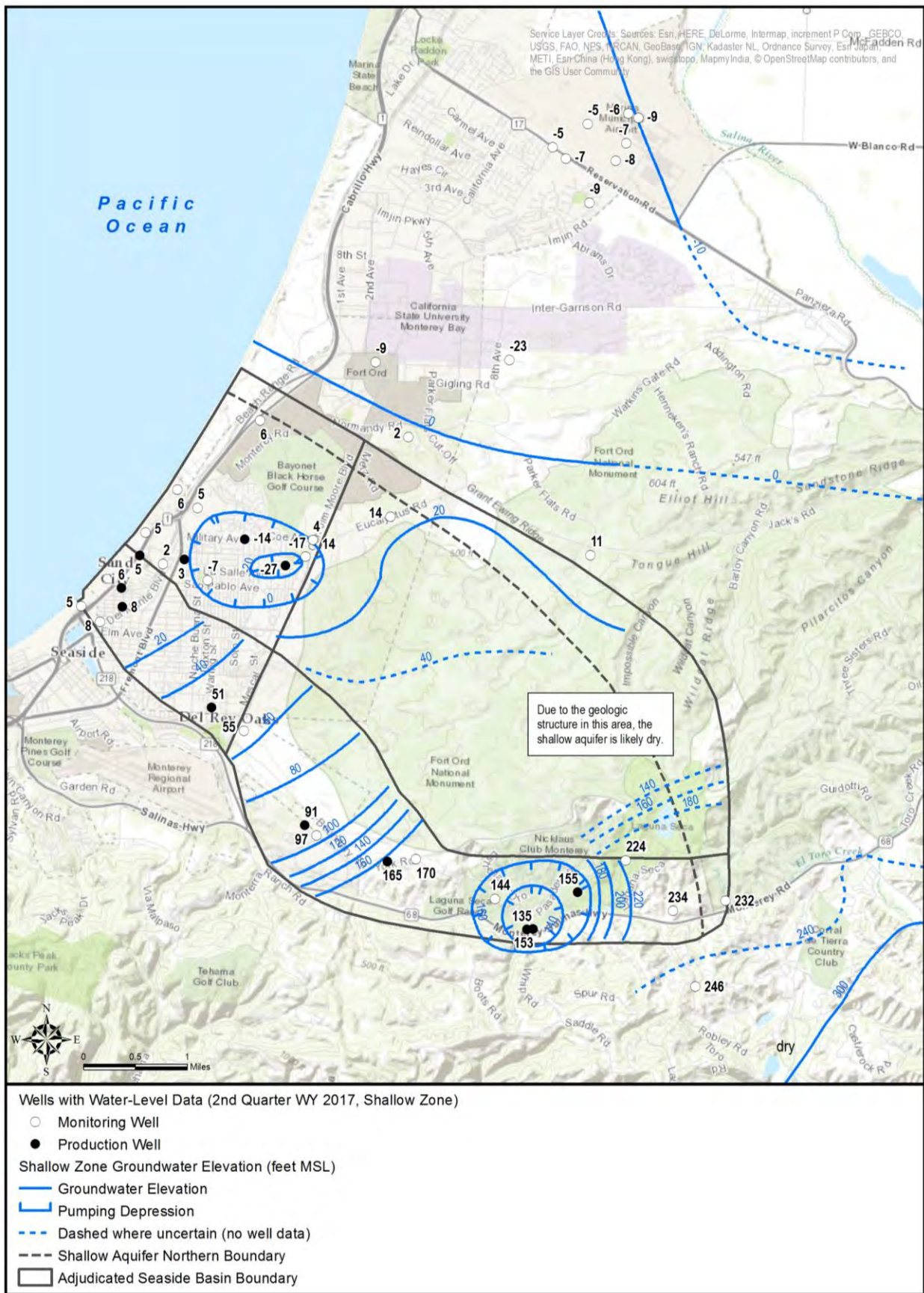
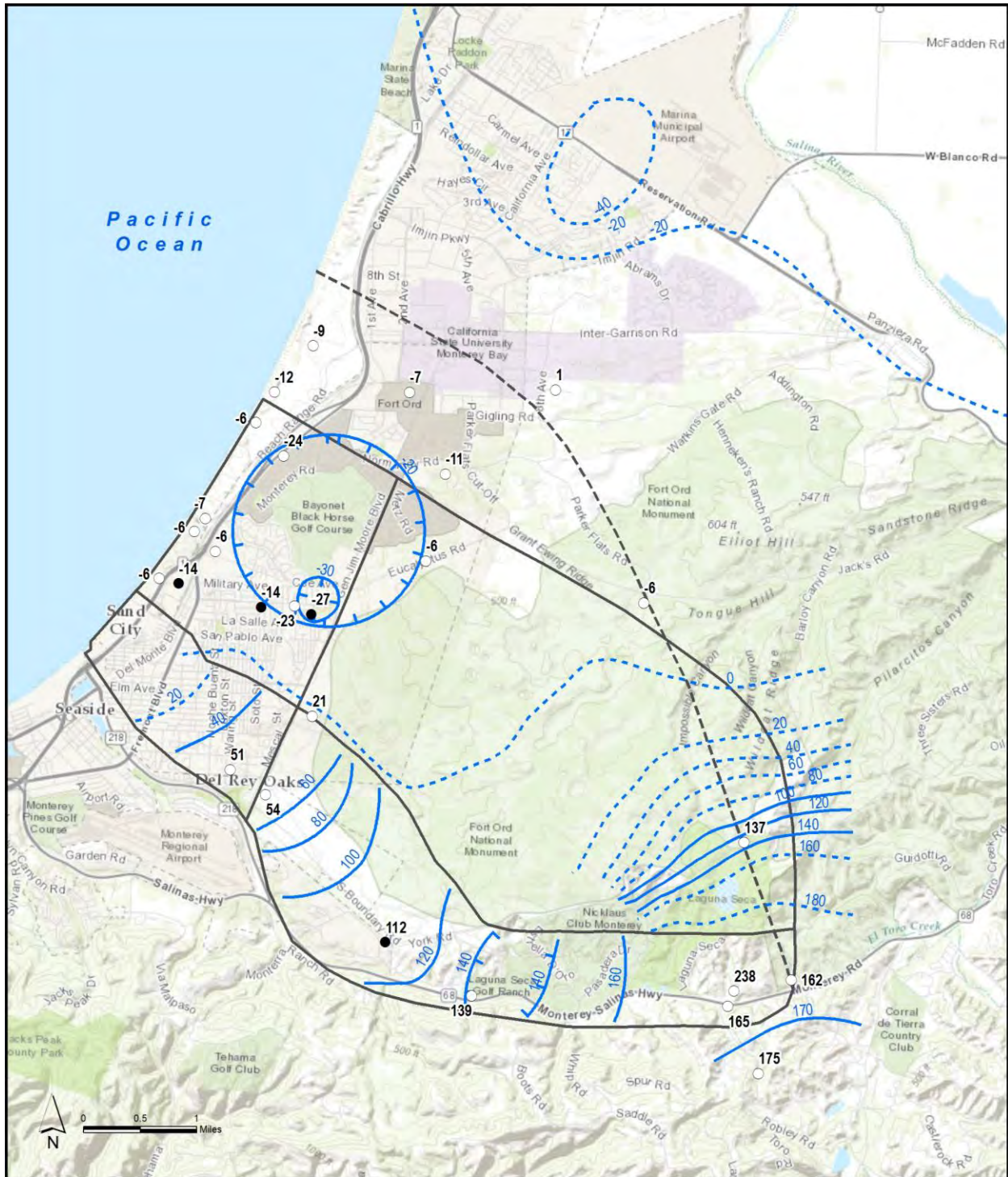


Figure 29: Shallow Zone Water Elevation Map – 2<sup>nd</sup> Quarter WY 2017 (January-March 2017)



**Wells with Water-Level Data (2nd Quarter WY 2017, Deep Zone)**

- Monitoring Well
  - Production Well
- Deep Zone Groundwater Elevation (feet MSL)**
- Groundwater Elevation
  - Pumping Depression
  - - - Dashed where uncertain (no well data)
  - - - Deep Aquifer Northern Boundary
  - ▭ Adjudicated Seaside Basin Boundary

Figure 30: Deep Zone Water Elevation Map – 2<sup>nd</sup> Quarter WY 2017 (January-March 2017)

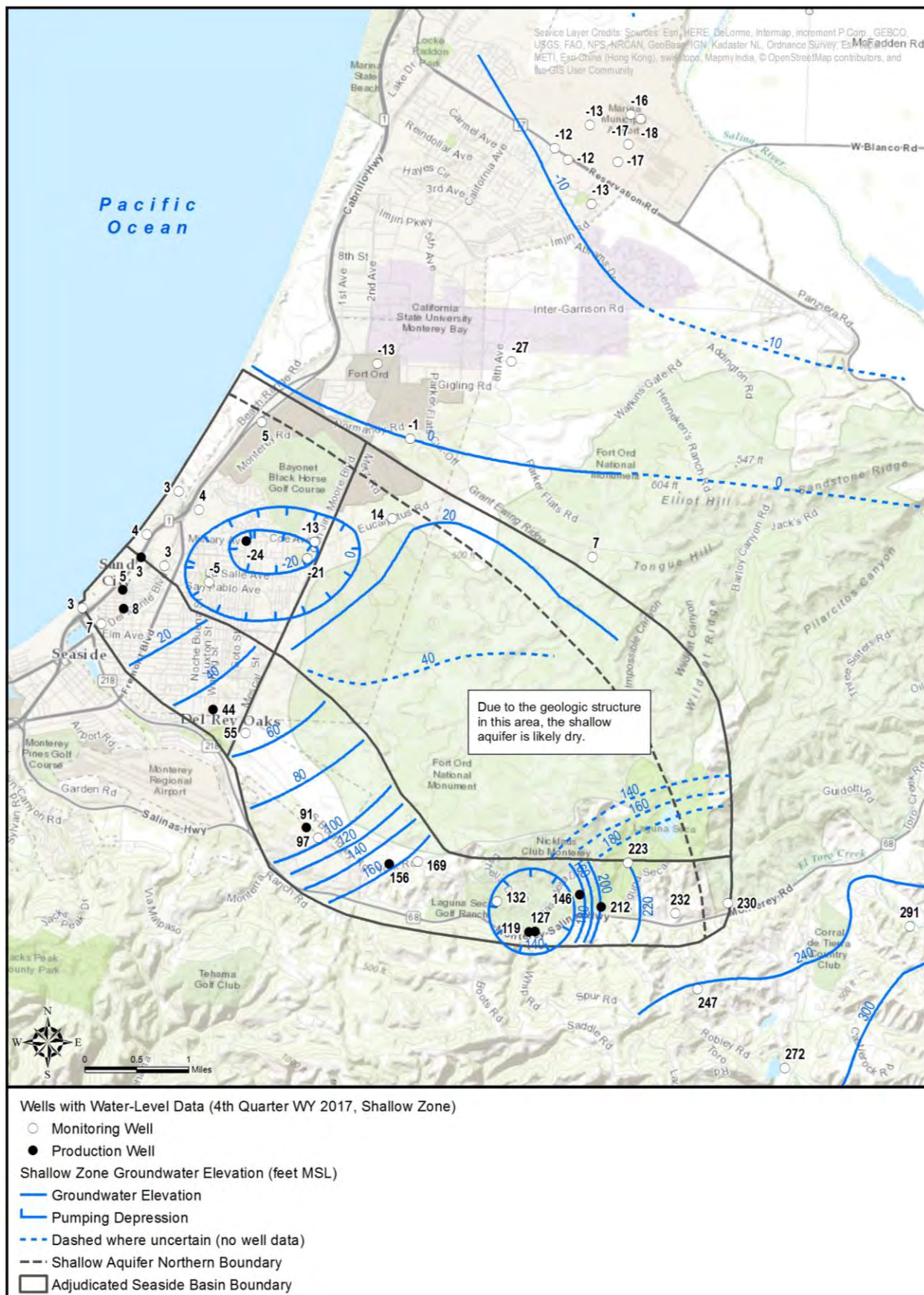


Figure 31: Shallow Zone Water Elevation Map – 4<sup>th</sup> Quarter WY 2017 (August/September 2017)

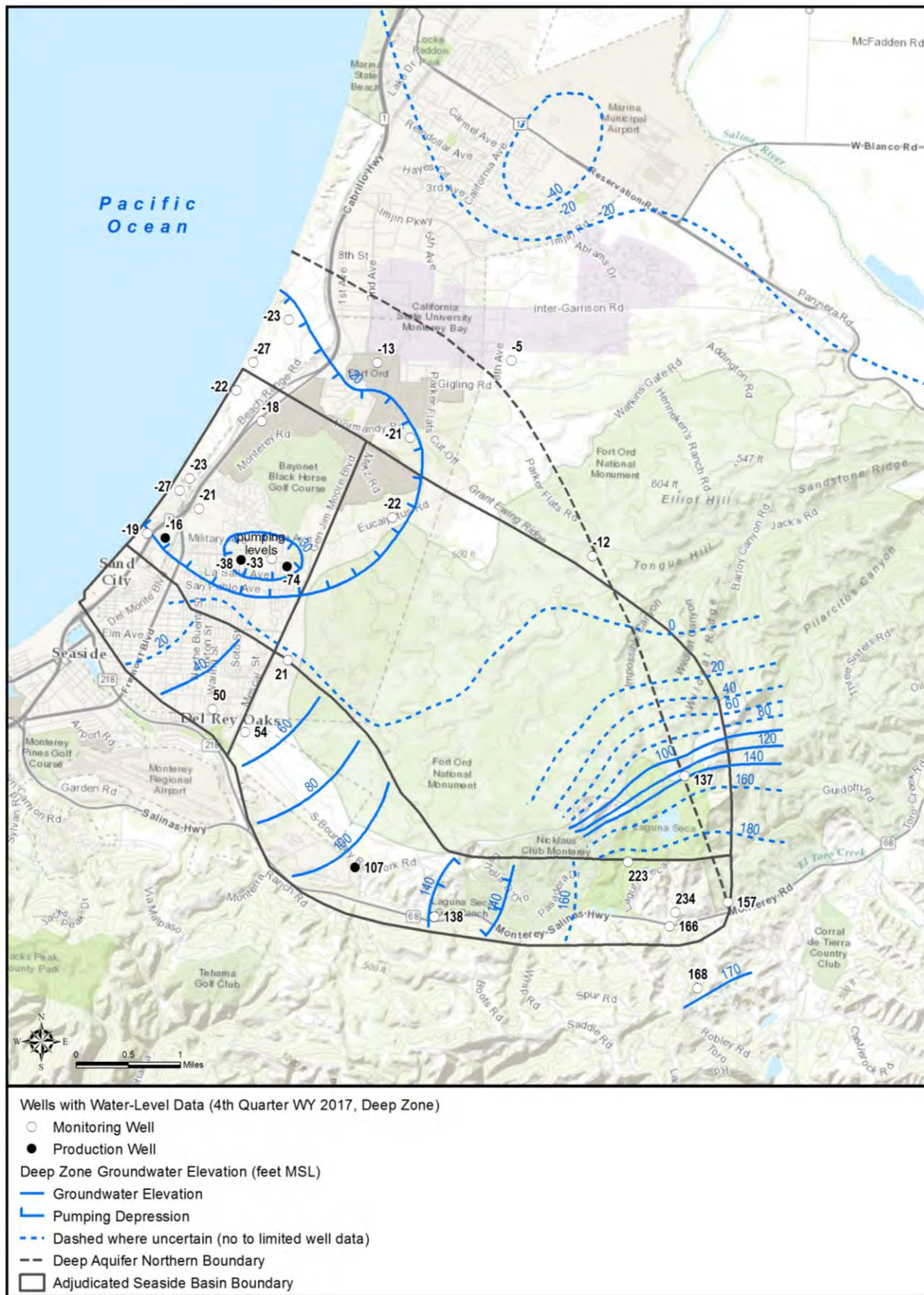


Figure 32: Deep Zone Water Elevation Map – 4<sup>th</sup> Quarter WY 2017 (August/September 2017)

## 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 2017 was 4,550.7 acre-feet, which includes recovery of 1,501.3 acre-feet of aquifer storage and recovery (ASR) water. The net or native groundwater pumping is the amount pumped after the ASR program is taken into account. This means that in years where there is water injected and recovered, more water is actually pumped from CAW's wells to recover water injected the previous operational year. In Water Year 2017, 2,345 acre-feet of injection took place, and 1,501.3 acre-feet of injected water was recovered. The net or native groundwater production is therefore 3,049.4 acre-feet, which is very slightly above the court-ordered operating yield for Water Year 2017 (Figure 33). The net or native groundwater produced from the basin in Water Year 2017 was 745 acre-feet more than in Water Year 2016.

The blue charts on Figure 34 reflect the actual or gross amounts pumped from each well, and the green chart reflects the amount of water injected at the ASR well. Similar to years prior to Water Year 2016, the majority of pumping in the basin occurs at CAW's Ord Grove No. 2 and Paralta wells.

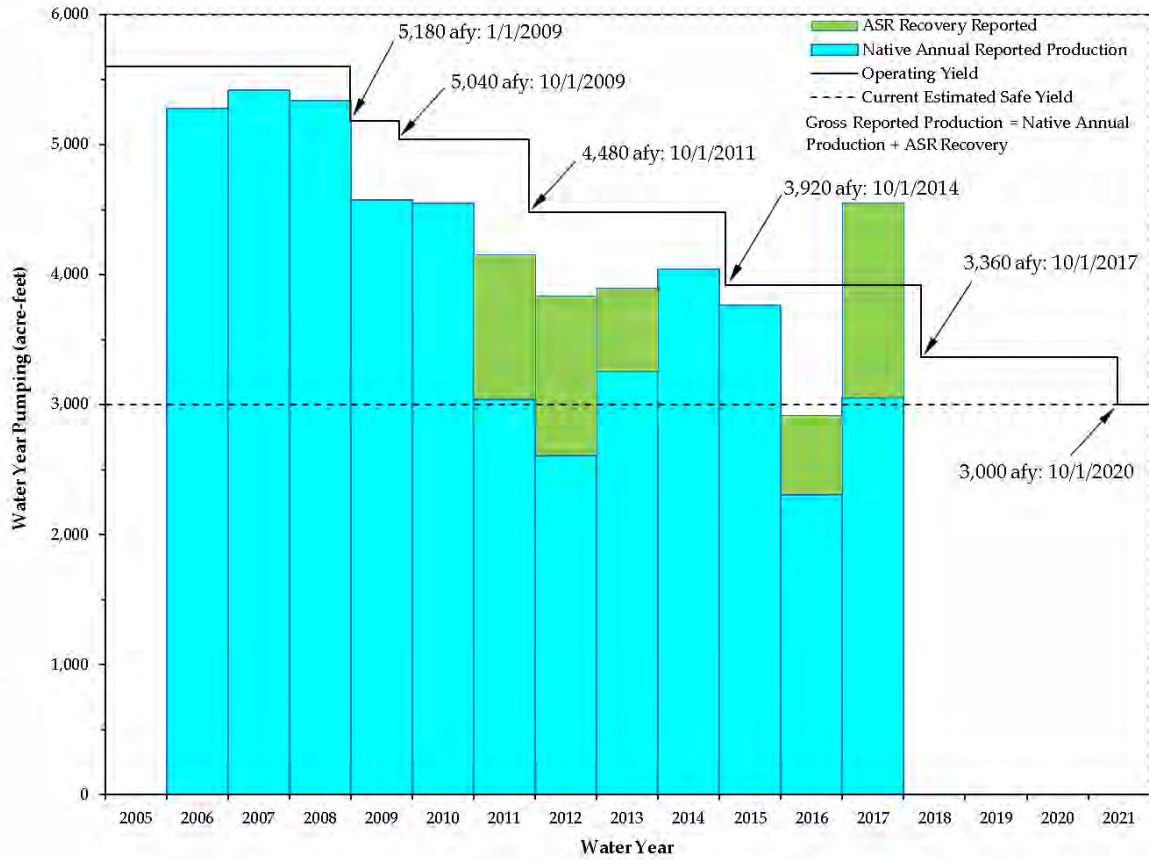


Figure 33: Annual Reported Groundwater Production and Operating Yield for Watermaster Producers

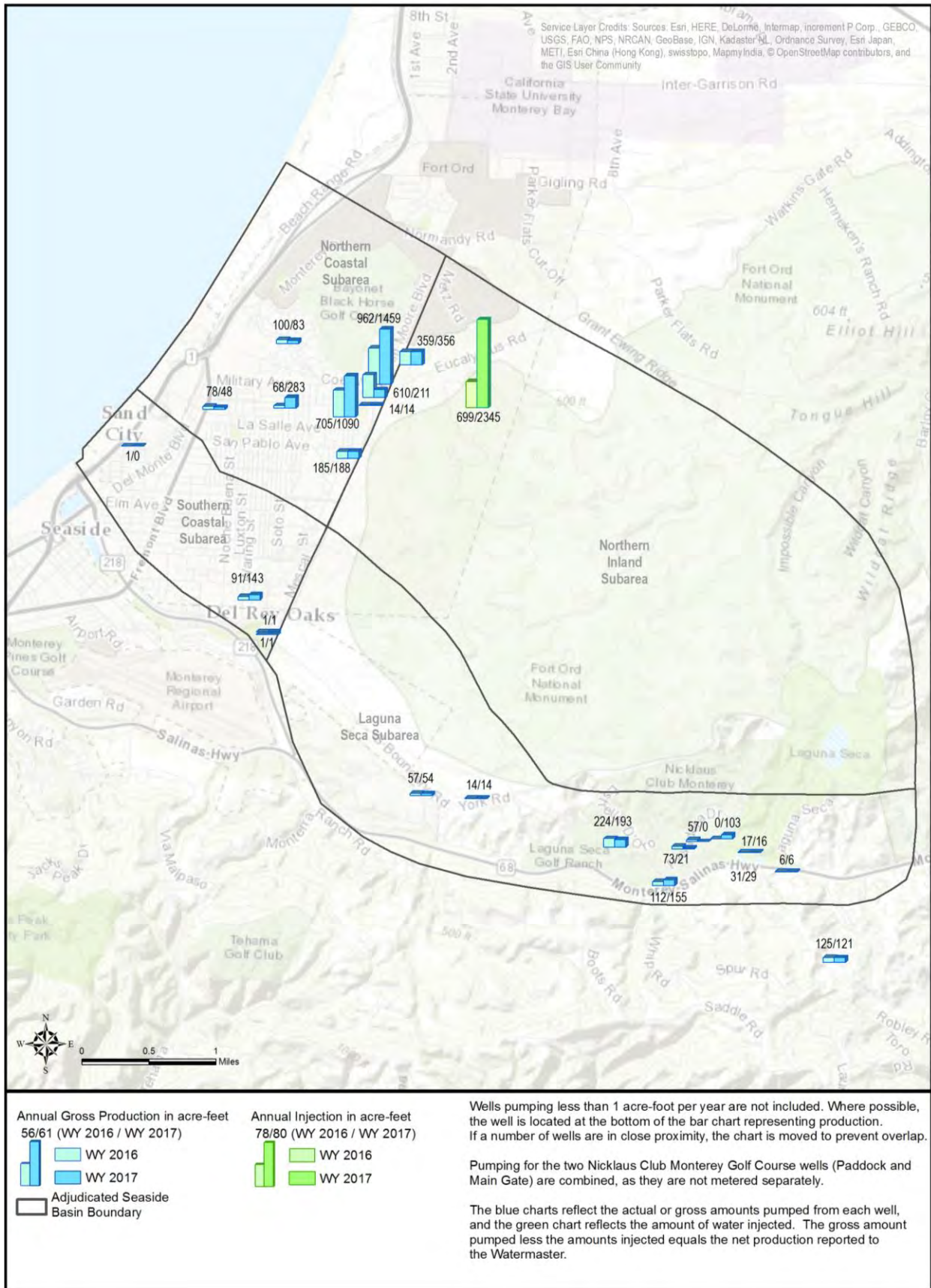


Figure 34: Watermaster Producers' Pumping Distribution for Water Years 2016 and 2017

## 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). 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. 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).

*Table 1: Summary of Protective Elevation Monitoring Locations*

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

Figure 35 through Figure 38 show the historical groundwater elevations at each of the target protective elevation locations. 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 are above protective elevations: the PCA-W shallow well and the CDM-MW4 well. The MSC shallow well is the only shallow target well with levels below its protective elevation.

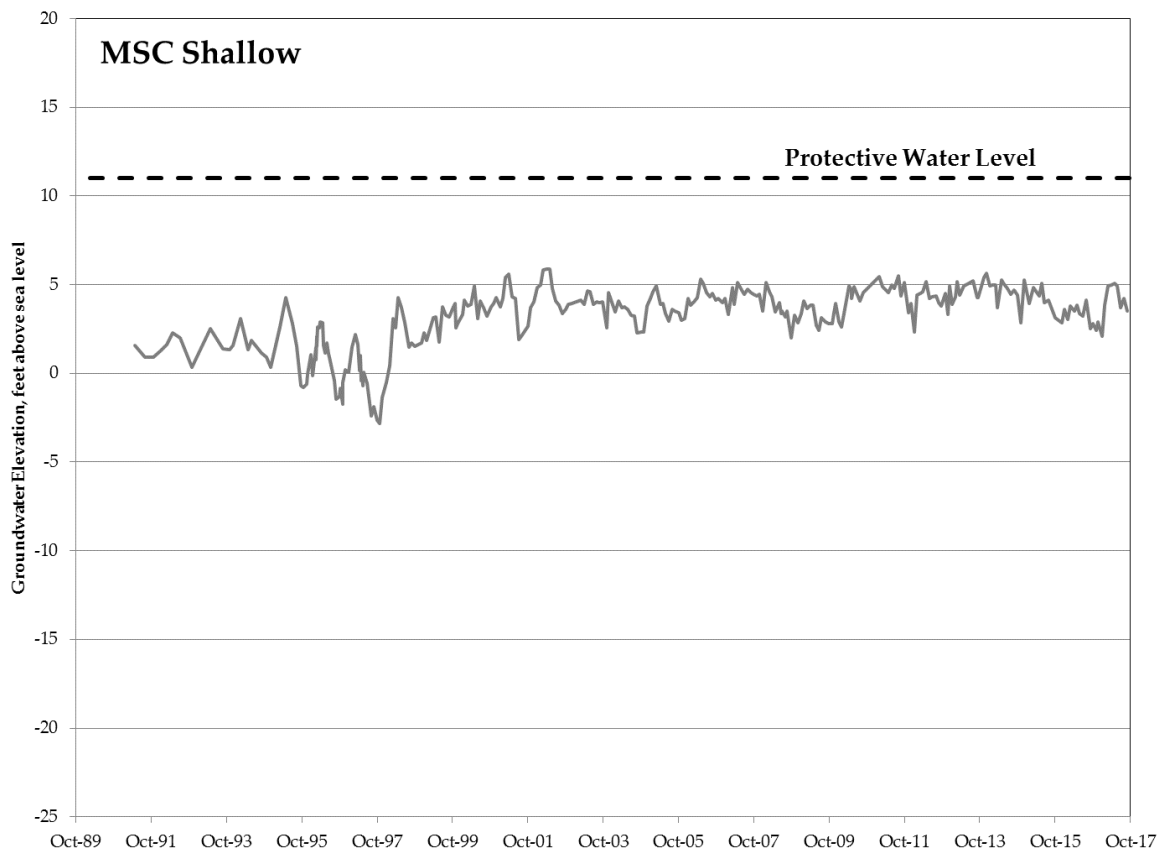
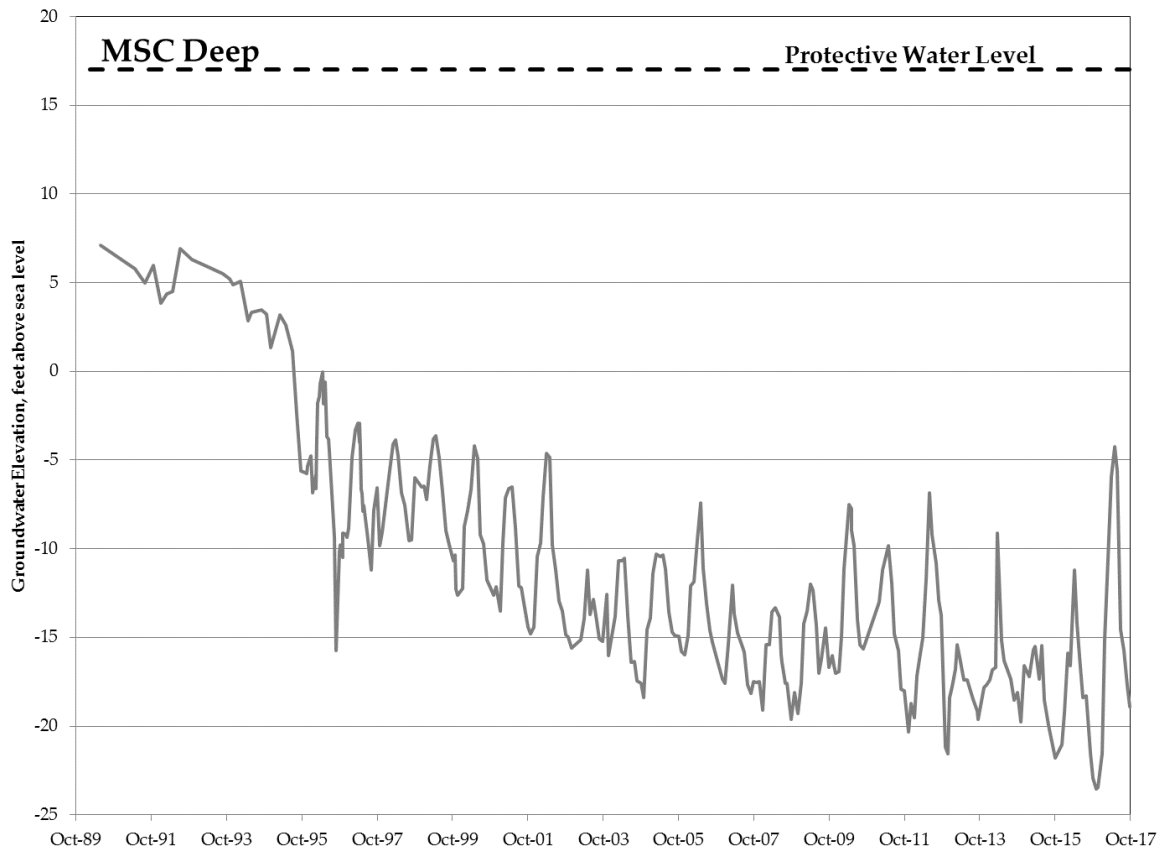


Figure 35: MSC Deep and Shallow Groundwater and Protective Elevations

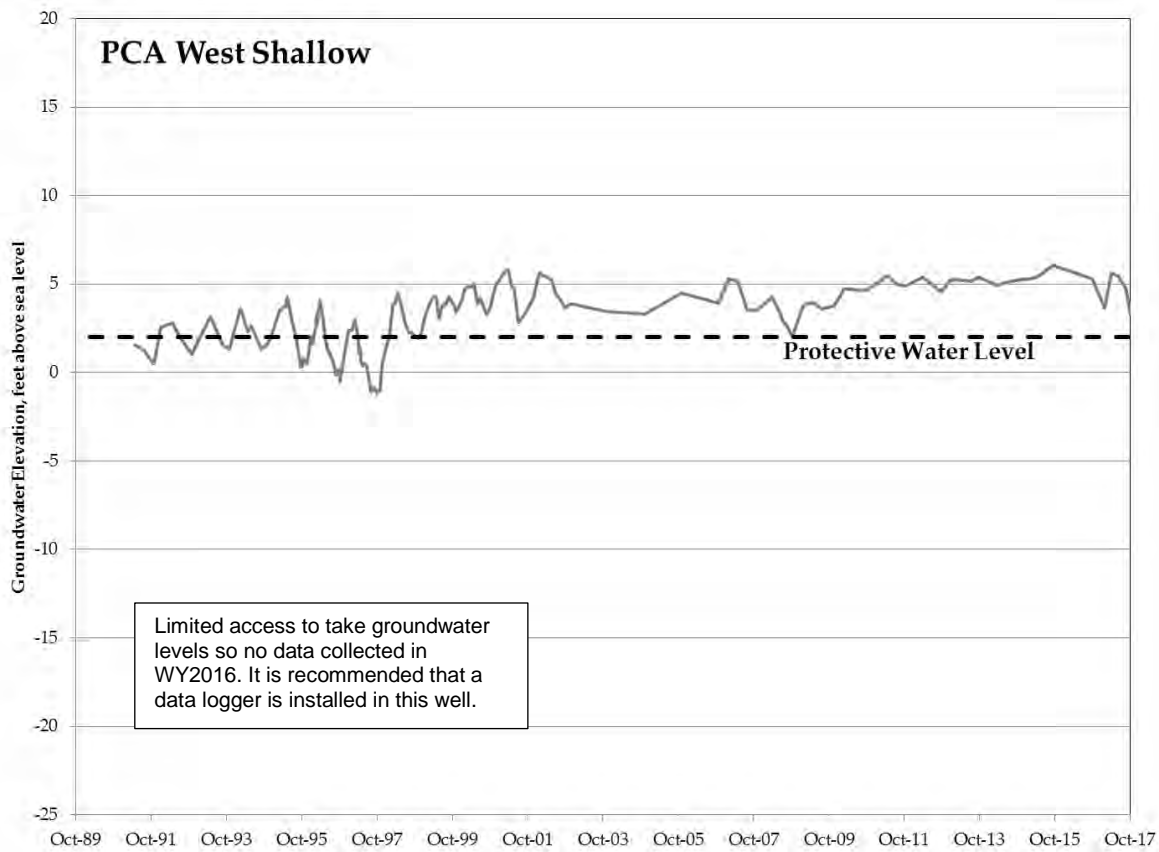
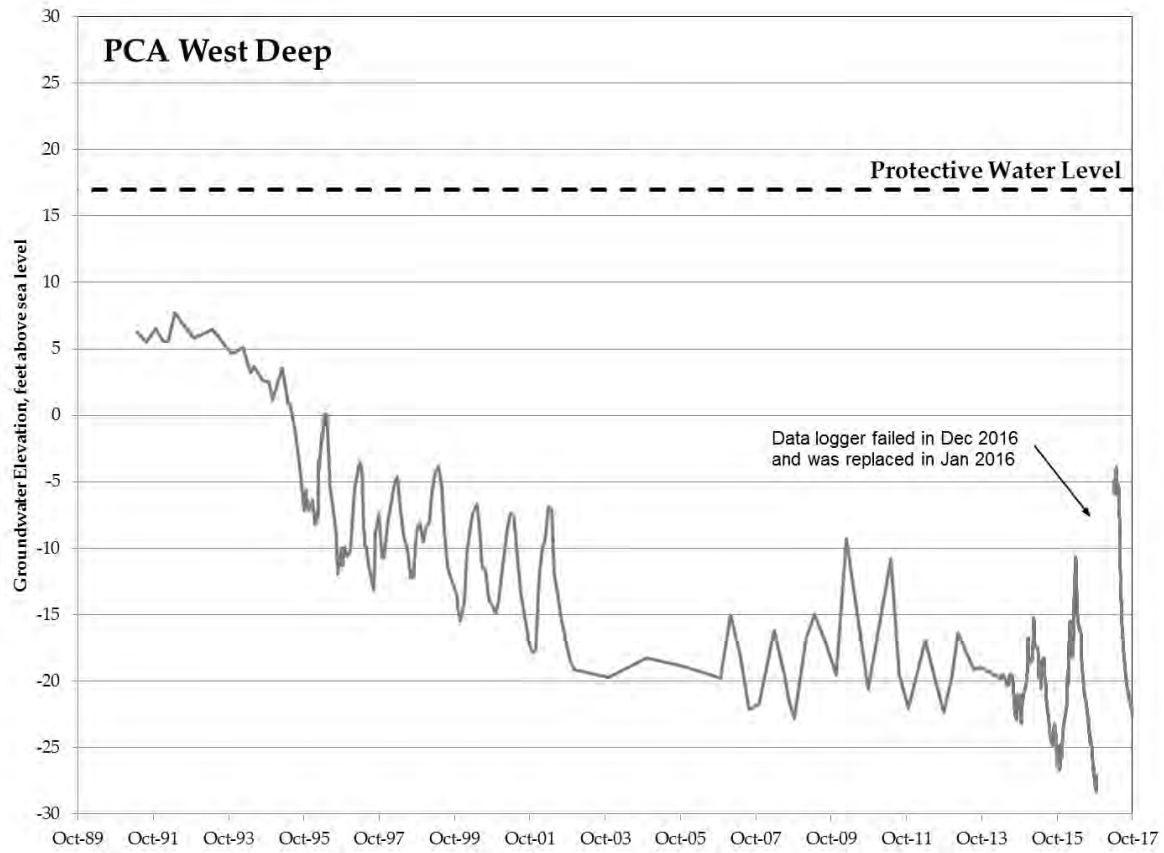


Figure 36: PCA West Deep and Shallow Groundwater and Protective Elevations

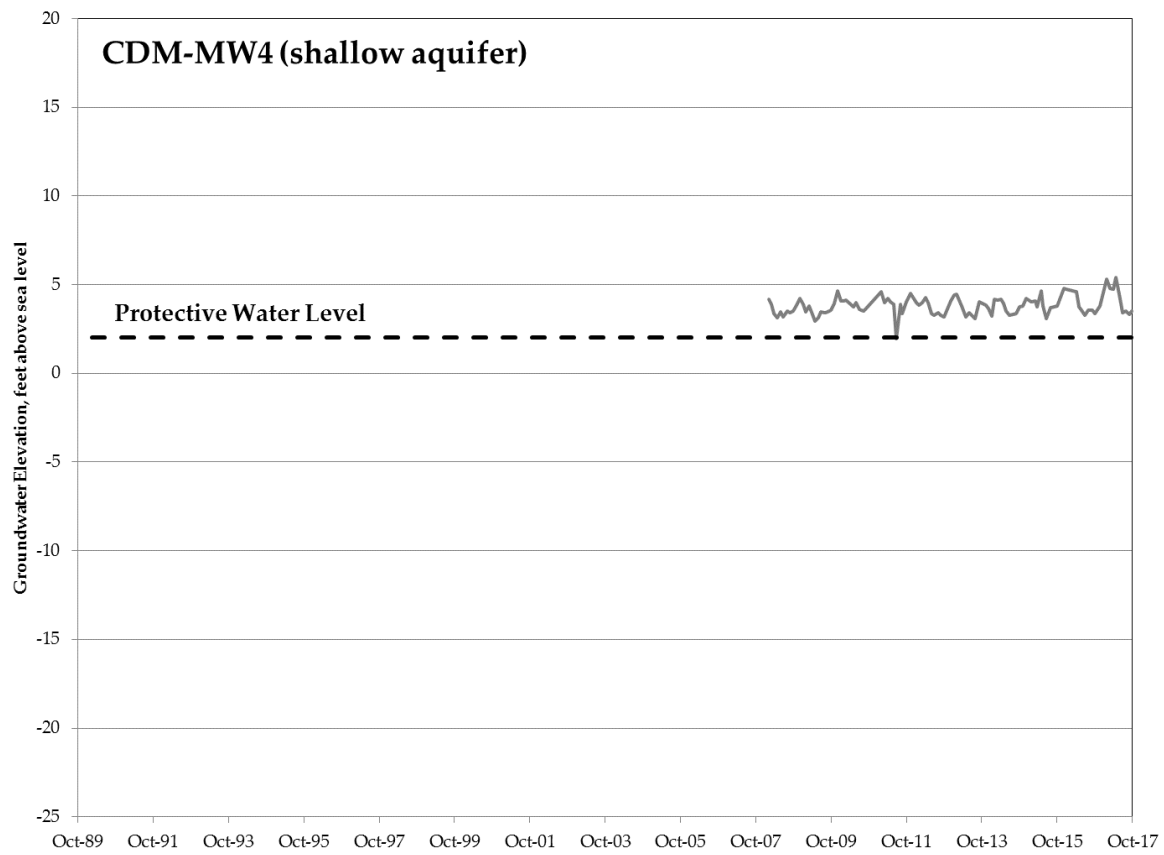


Figure 37: CDM-MW4 Groundwater and Protective Elevations

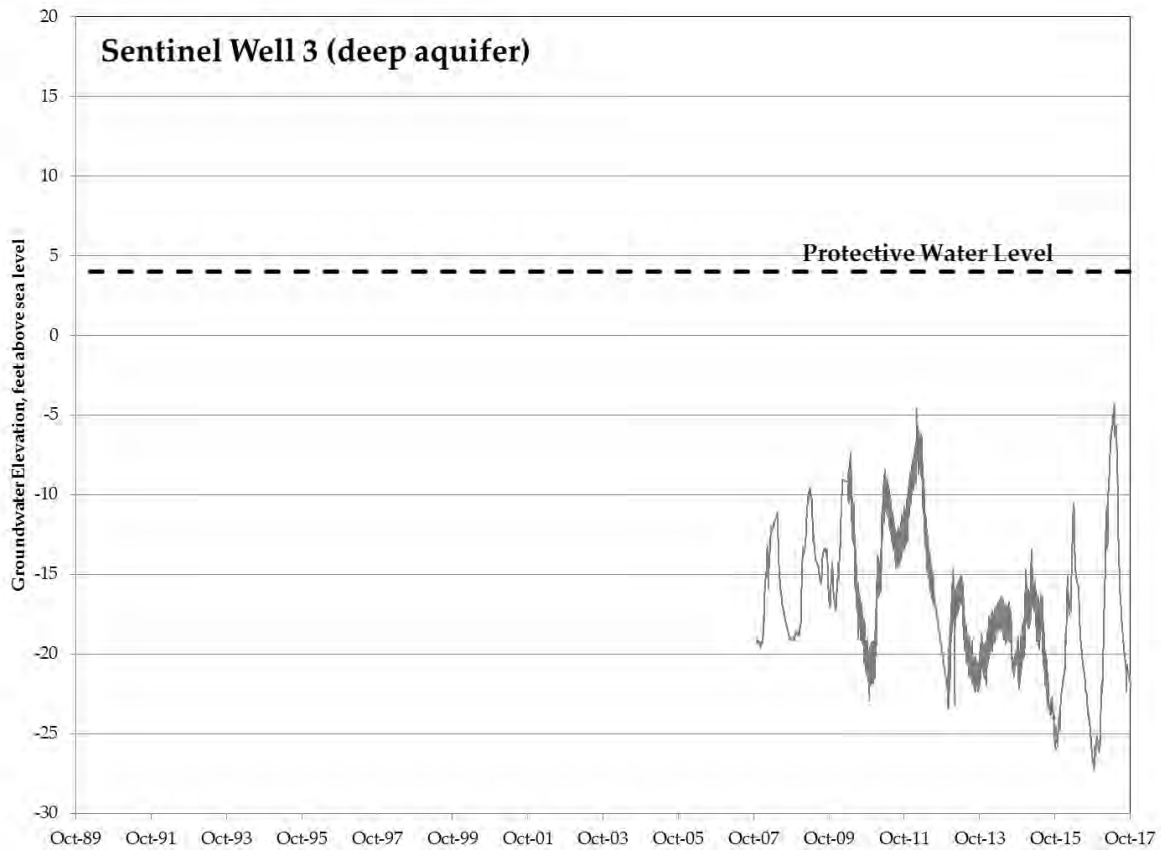


Figure 38: Sentinel Well 3 Groundwater and Protective Elevations

## SECTION 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.

No seawater intrusion has historically been or is currently observed in existing monitoring and production wells in the Seaside Groundwater Basin, as demonstrated by the different analyses that are used to investigate evidence of seawater intrusion. It should be noted that although seawater intrusion has not been observed in the hydrogeologic data collected, there have been some chloride anomalies observed over the past two water years in some of the Sentinel Wells. Notably, there have been some elevated chlorides above baseline concentrations in the two northernmost Sentinel Wells, located just north of the adjudicated Seaside Basin. In September 2017, Sentinel Well SBWM-2's deep sample at 1,470 feet had a chloride concentration of 292 mg/L, which is the highest chloride measured in any of the coastal wells. Verification sampling is not necessary as the concentration was effectively verified using downhole electrical conductivity profiling, which uses an instrument to measure the conductivity of the water within the well casing. The September 2017 chloride concentration is a 226 mg/L increase from the December 2016 concentration of 66 mg/L. The previous 4<sup>th</sup> quarter sample was also elevated at 178 mg/L. These past three results indicate that chloride concentrations are fluctuating over 100 mg/L within each of the past two water years in Sentinel Well SBWM-2 (1,470 ft).

After last year's concentration fluctuation in Sentinel Well SBWM-2, possible sources of the salinity contributing to the observed increases were postulated to include natural groundwater quality variations, upwelling or upconing of underlying saline formation water from the Monterey Formation in response to declining groundwater levels, or very early seawater intrusion (HydroMetrics WRI, 2017). However, from evaluation of the downhole electrical conductivity profiling of all four Sentinel Wells (Feeney, 2017) and their long-term electric induction logs, it appears the groundwater samples collected using the low flow sampler is 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 therefore not considered representative of the aquifer and should not be used in further seawater intrusion analysis.

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

- Maps of chloride concentrations for the shallow aquifer do not show chlorides increasing towards the coast.
- Induction logging data at the coastal Sentinel Wells do not show large changes over time that are indicative of seawater intrusion. deep aquifer
- None of the Stiff diagrams for monitoring and production wells show the characteristic chloride spike that typically indicates seawater intrusion in Stiff diagrams.
- None of the Piper diagrams for monitoring and production wells show the typical evolution of water chemistry from freshwater to seawater.

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

- Even though Water Year 2017 was an above average rainfall year and basin pumping was very slightly above the current safe yield of 3,000 acre-feet per year, Northern Coastal subarea groundwater levels in the deep aquifer remain below sea level (Figure 30 and Figure 32). The 4<sup>th</sup> quarter deep aquifer groundwater levels along the coast, in most locations, are at elevations greater than 20 feet below sea level.
- Groundwater levels remain below protective elevations in all deep target monitoring wells (MSC deep, PCA-W deep, and Sentinel Well SBWM-3). Two of the three shallow wells' groundwater levels are above protective elevations: PCA-W shallow and CDM-MW4. The MSC shallow well remains below protective elevations.

Due to its far 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 been declining at rates of 0.6 feet per year in the shallow aquifers, and between two and three feet per year in the deep aquifers. These declines have occurred since 2001, despite triennial reductions in allowable pumping. The cause of this decline is due in part to the safe yield of the subarea being incorrect and in part due to the influence of wells to the east of the groundwater basin. The rate of decline in groundwater levels in the western portion of the subarea is between one and two feet per year. There is an indication, however, from 2016 and 2017 groundwater levels that the rate in decline has stabilized over the past couple years.

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## SECTION 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.

### **DISCONTINUE SAMPLING WATER QUALITY IN THE FOUR SENTINEL WELLS BUT CONTINUE INDUCTION LOGGING TWICE A YEAR**

Due to the finding that the water quality samples being extracted from the Sentinel Wells are not representative of the aquifer, it is recommended that sampling the wells with the low flow sampler is discontinued. The depth of the wells and the small 3-inch diameter of the wells limit sampling techniques that can be applied cost-effectively to extract a representative sample. The Sentinel Wells were designed for the purpose of electric induction logging, and therefore should continue to be induction logged twice a year.

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## SECTION 6

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## **APPENDIX A: PIPER DIAGRAMS FOR INDIVIDUAL WELLS**

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- Figure A-2: Piper Diagram of PCA West Deep
- Figure A-3: Piper Diagram of PCA East Shallow
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- Figure A-5: Piper Diagram of Ord Terrace Shallow
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- 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
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- 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
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- Figure A-24: Piper Diagram of Ord Grove No. 2 Production Well
- Figure A-25: Piper Diagram of Seaside City No. 3 Production Well
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- Figure A-27: Piper Diagram of Mission Memorial (formerly PRTIW)
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- Figure A-29: Piper Diagram of Reservoir (Bayonet Blackhorse) Production Well

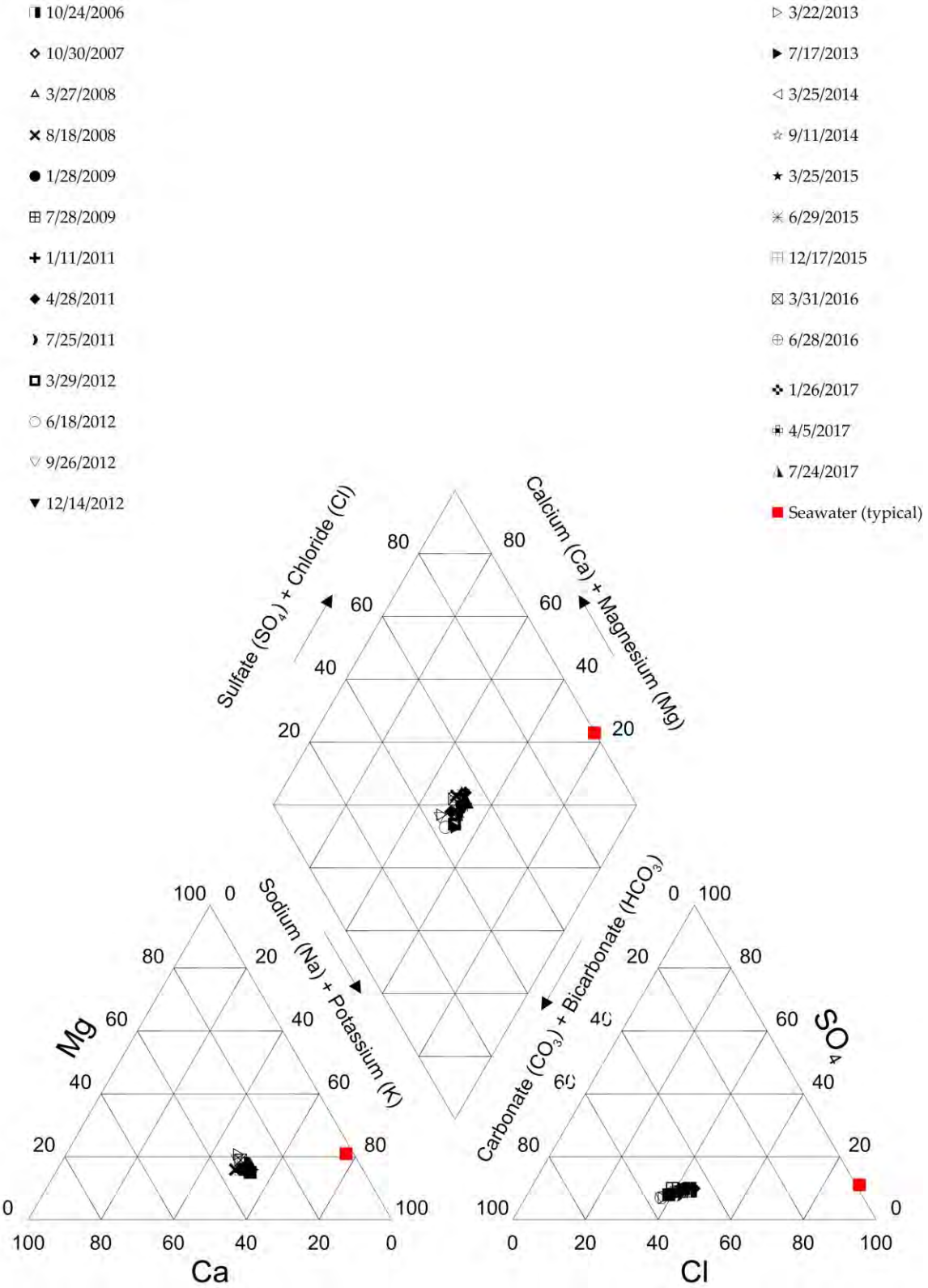


Figure A-1: Piper Diagram of PCA West Shallow

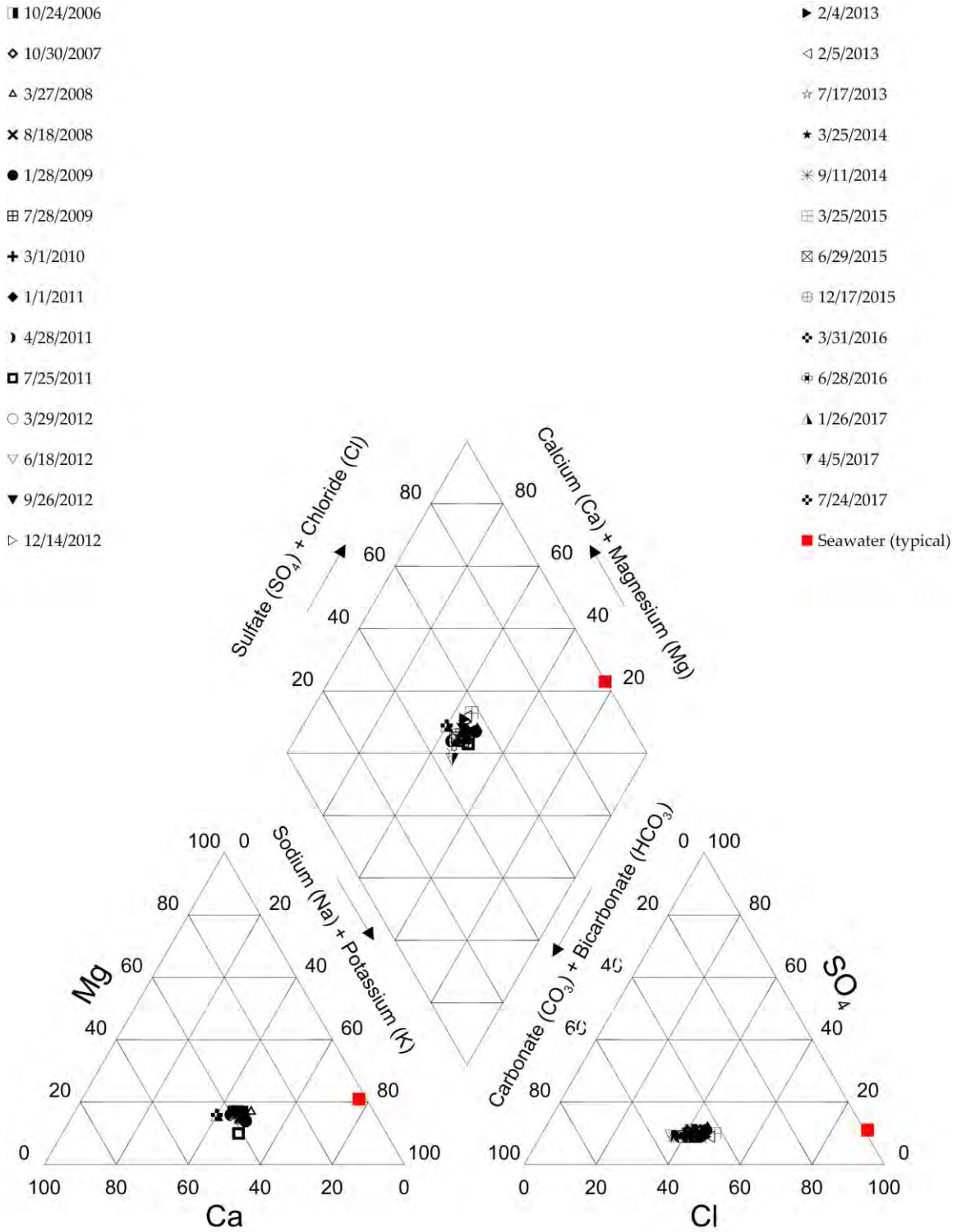


Figure A-2: Piper Diagram of PCA West Deep

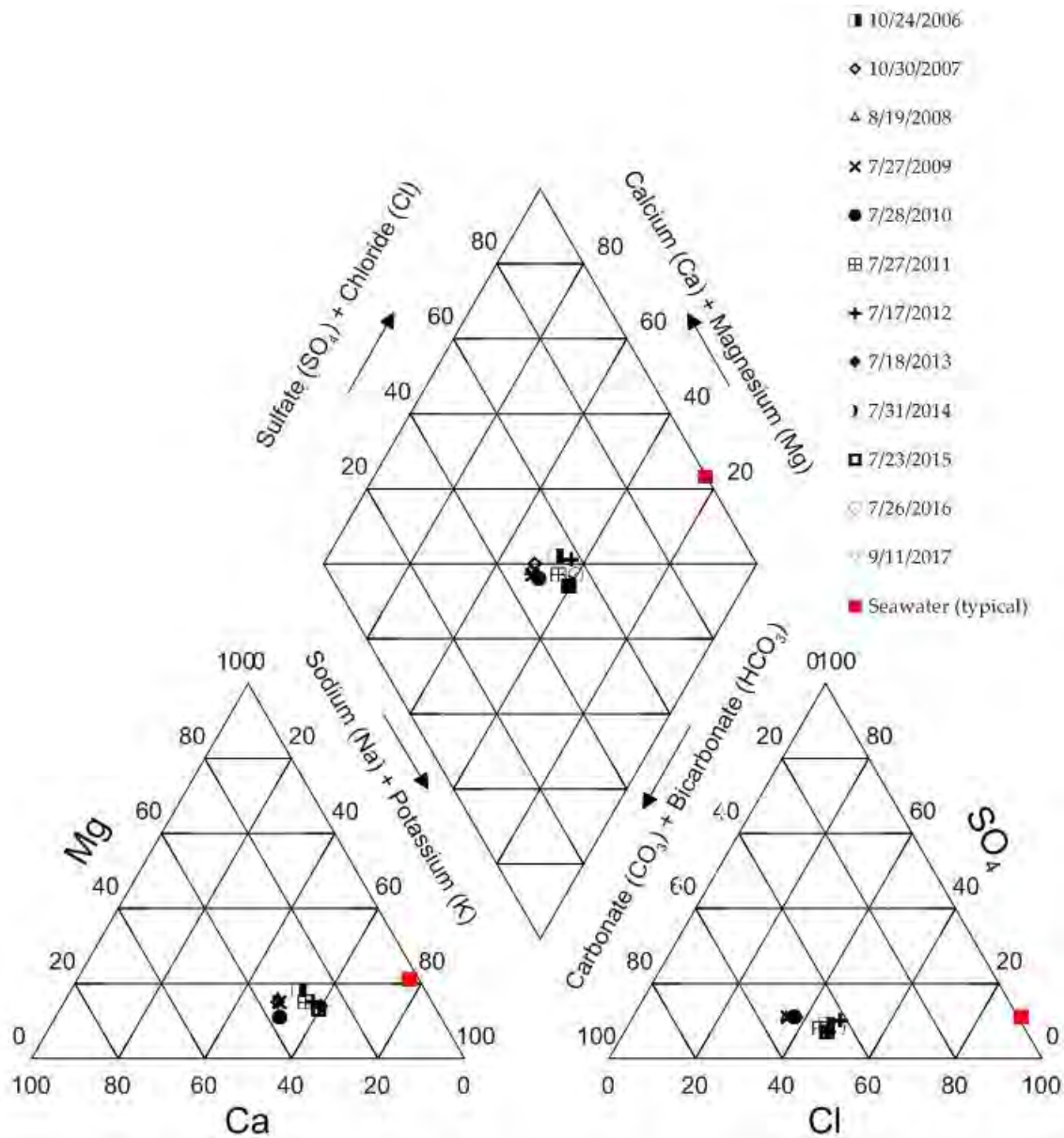


Figure A-3: Piper Diagram of PCA East Shallow

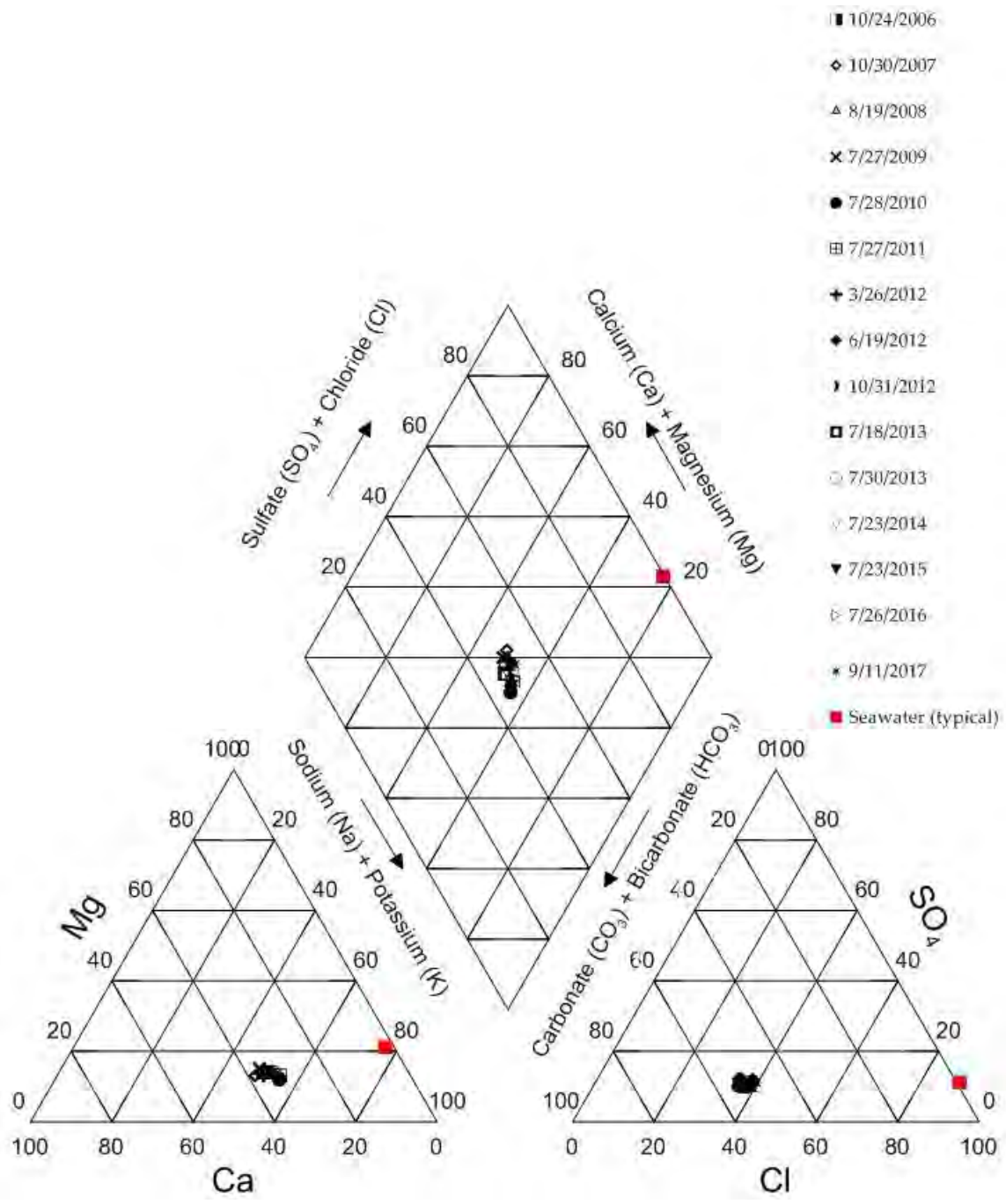


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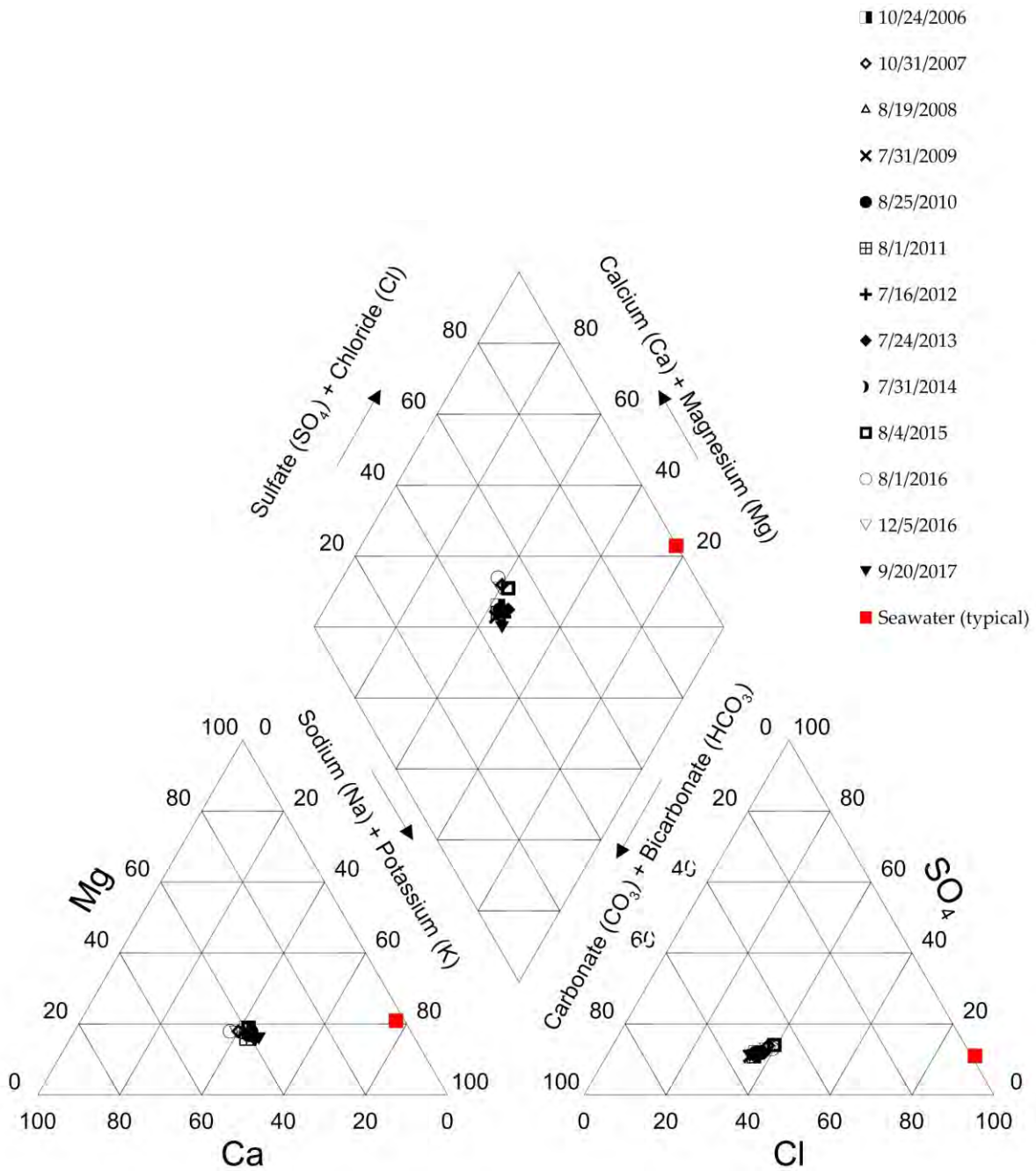


Figure A-5: Piper Diagram of Ord Terrace Shallow

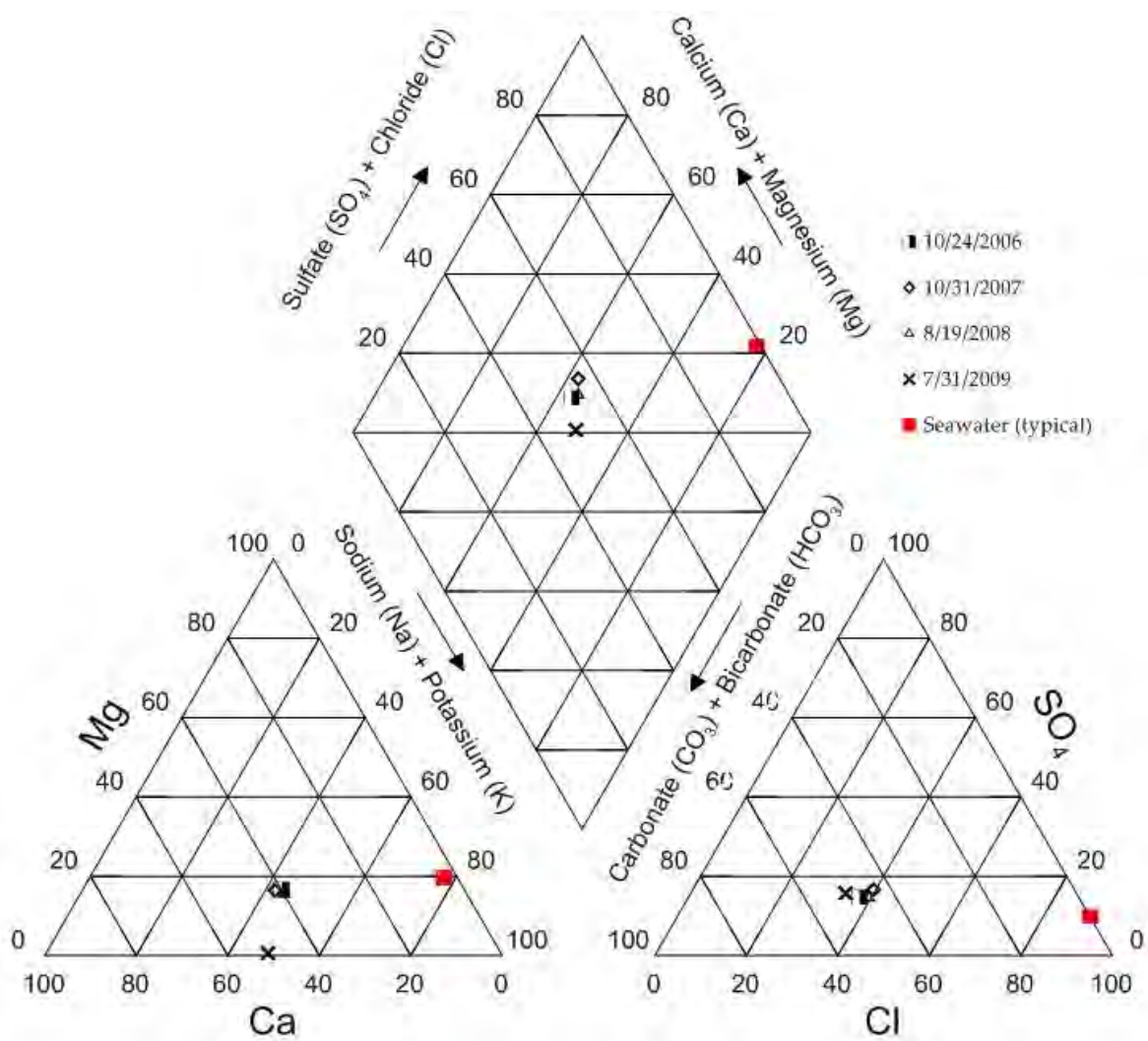


Figure A-6: Piper Diagram of Ord Terrace Deep

- 1/29/2008
- ◇ 8/19/2008
- △ 1/28/2009
- × 7/23/2009
- 2/23/2010
- ▣ 7/27/2010
- + 1/11/2011
- ◆ 4/28/2011
- ⤵ 7/26/2011
- ▣ 3/29/2012
- 6/18/2012
- ▽ 9/26/2012
- ▼ 12/14/2012

- ▷ 3/22/2013
- ▶ 7/17/2013
- ◁ 3/25/2014
- ☆ 9/11/2014
- ★ 3/25/2015
- ✱ 6/29/2015
- ⊞ 12/17/2015
- ⊠ 3/31/2016
- ⊕ 6/28/2016
- ❖ 1/26/2017
- ⊞ 4/5/2017
- ▲ 7/24/2017
- Seawater (typical)

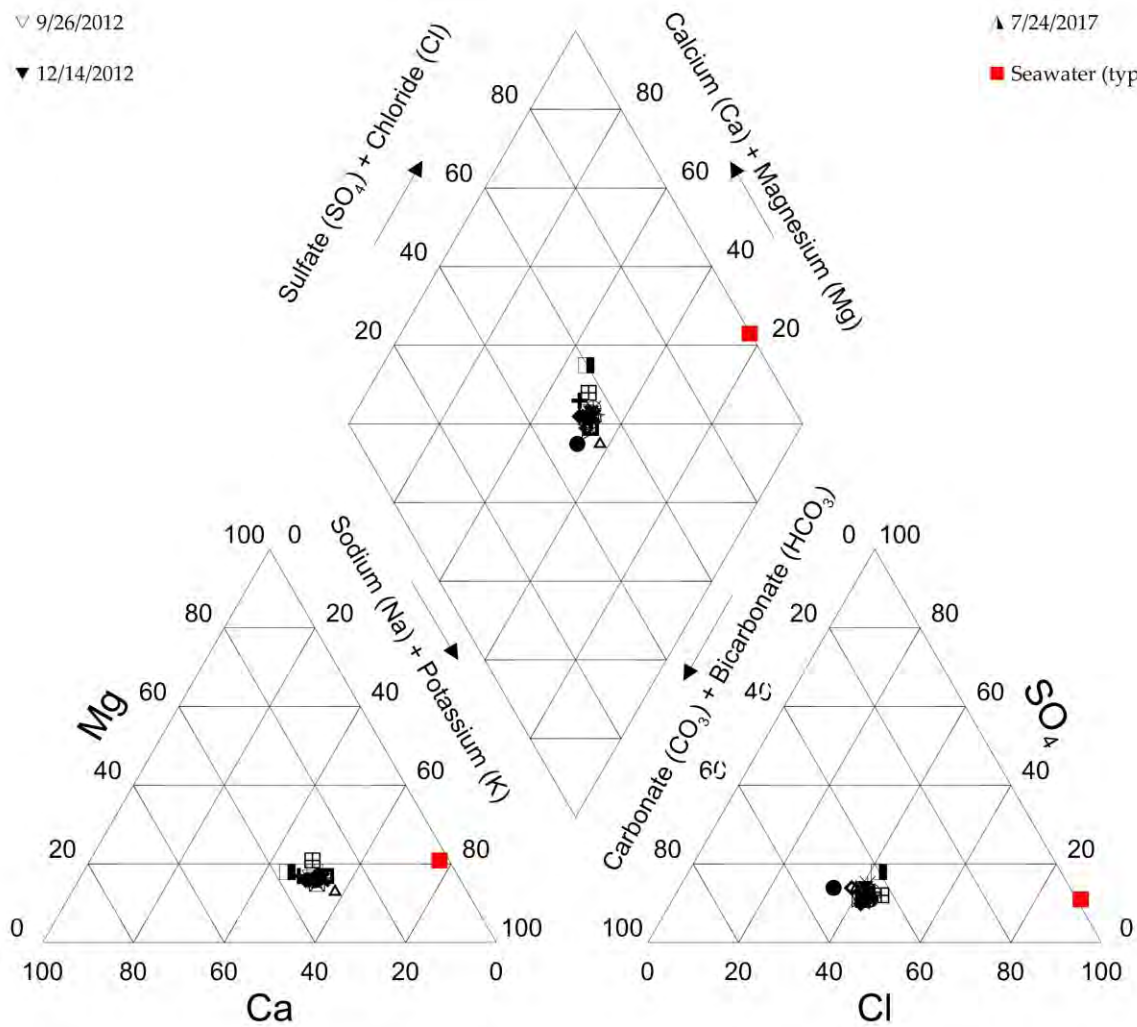


Figure A-7: Piper Diagram of MSC Shallow

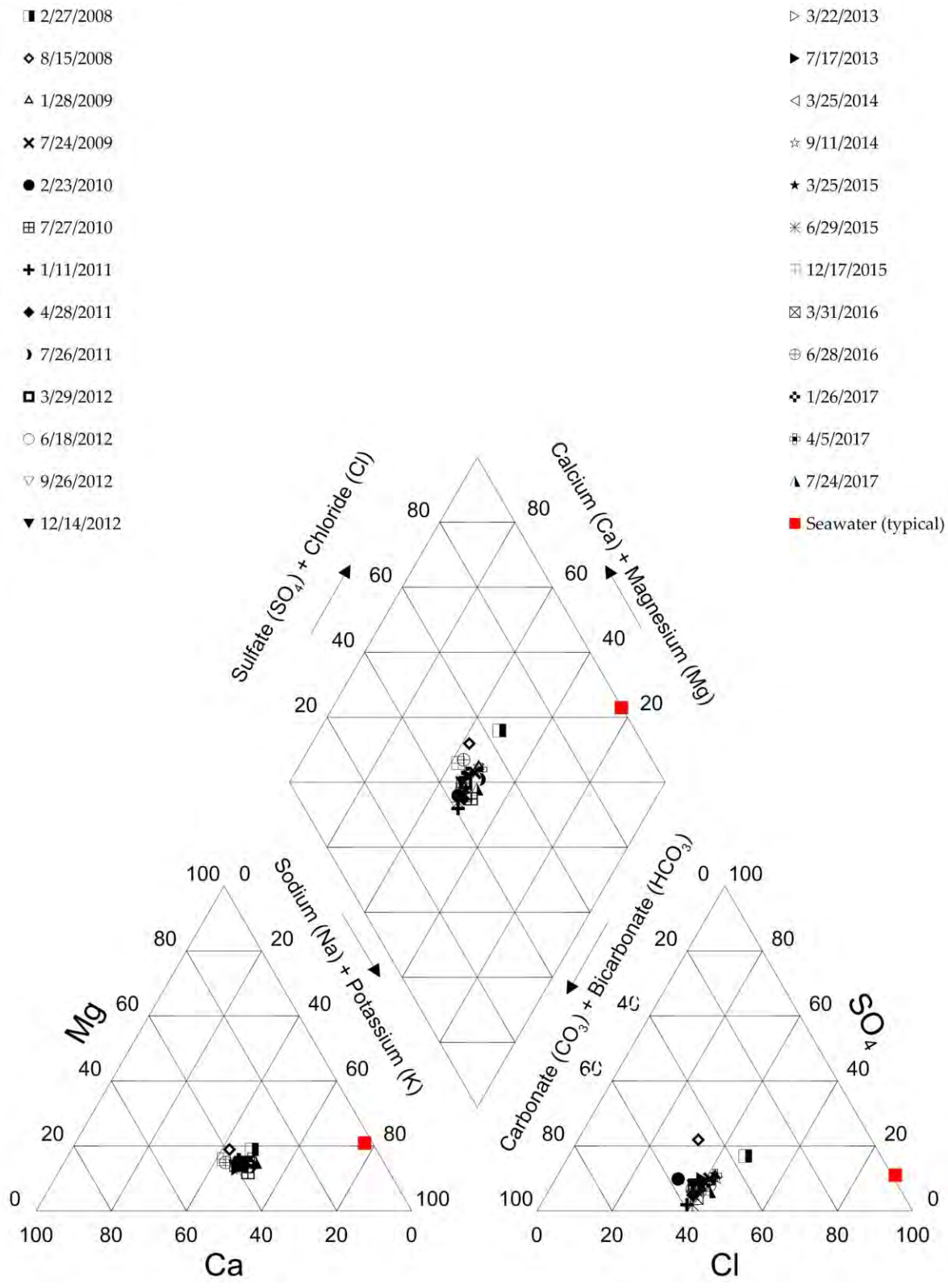


Figure A-8: Piper Diagram of MSC Deep

- 10/25/2006
- ◇ 10/31/2007
- △ 8/18/2008
- ✕ 8/5/2009
- 11/17/2009
- ▣ 2/22/2010
- + 7/28/2010
- ◆ 1/11/2011
- ) 7/25/2011
- ▣ 3/29/2012
- 6/18/2012
- ▽ 9/26/2012
- ▼ 12/14/2012
- ▷ 3/22/2013
- ▶ 7/17/2013
- ◁ 3/25/2014
- ☆ 9/11/2014
- ★ 3/25/2015
- ✱ 6/29/2015
- ⊞ 12/17/2015
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- Seawater (typical)

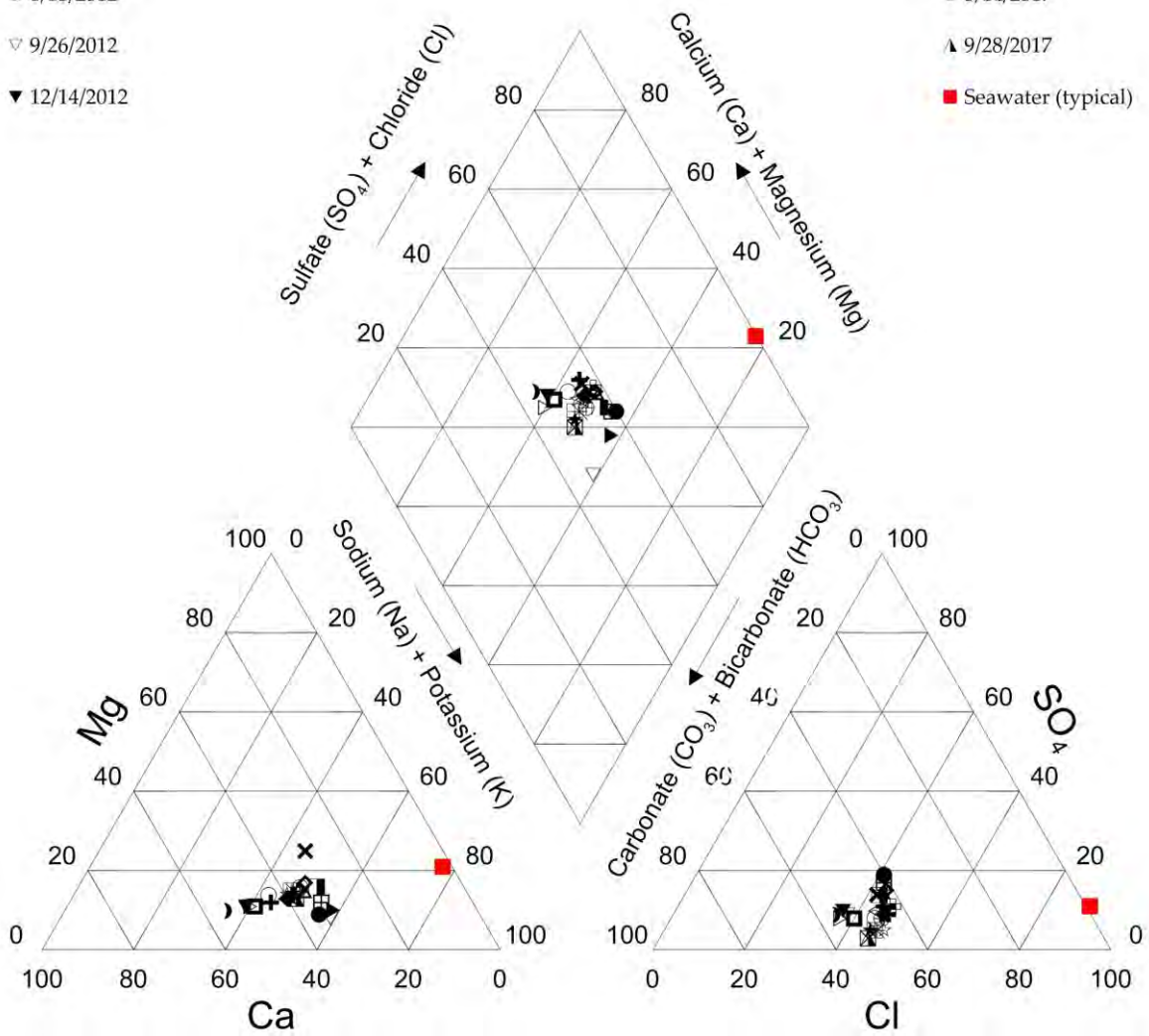


Figure A-9: Piper Diagram of Fort Ord 9 Shallow

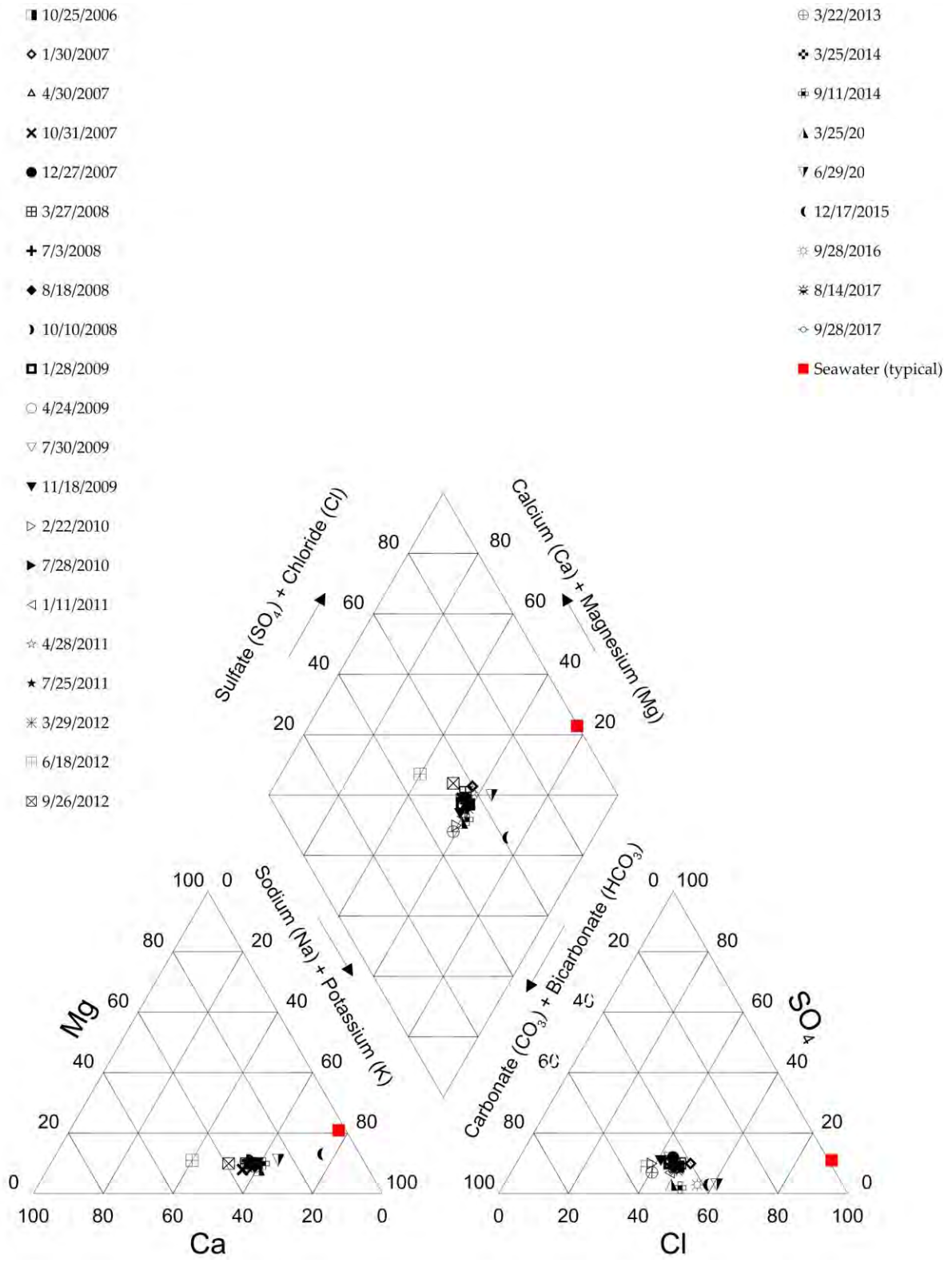


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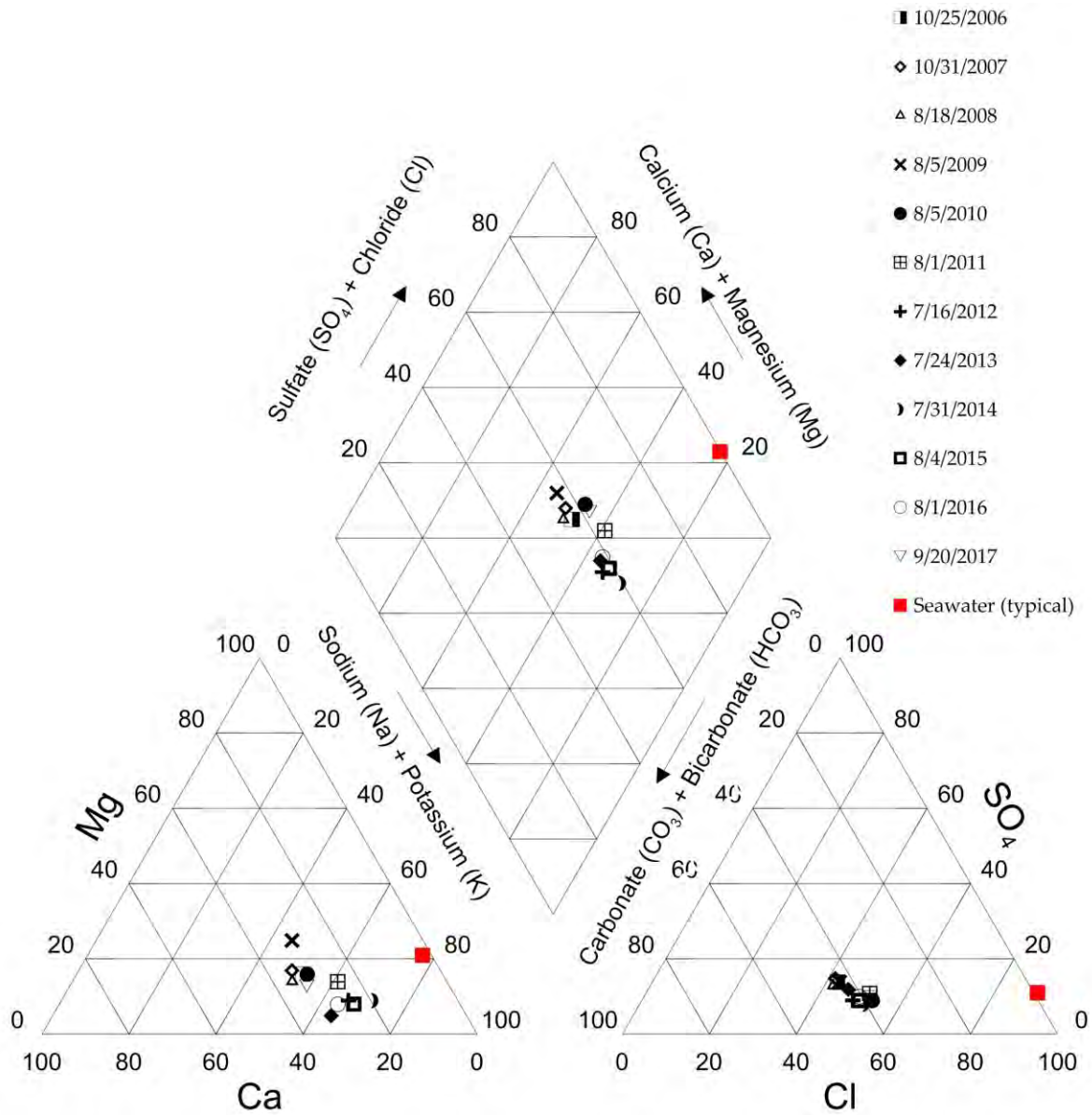


Figure A-11: Piper Diagram of Fort Ord 10 Shallow

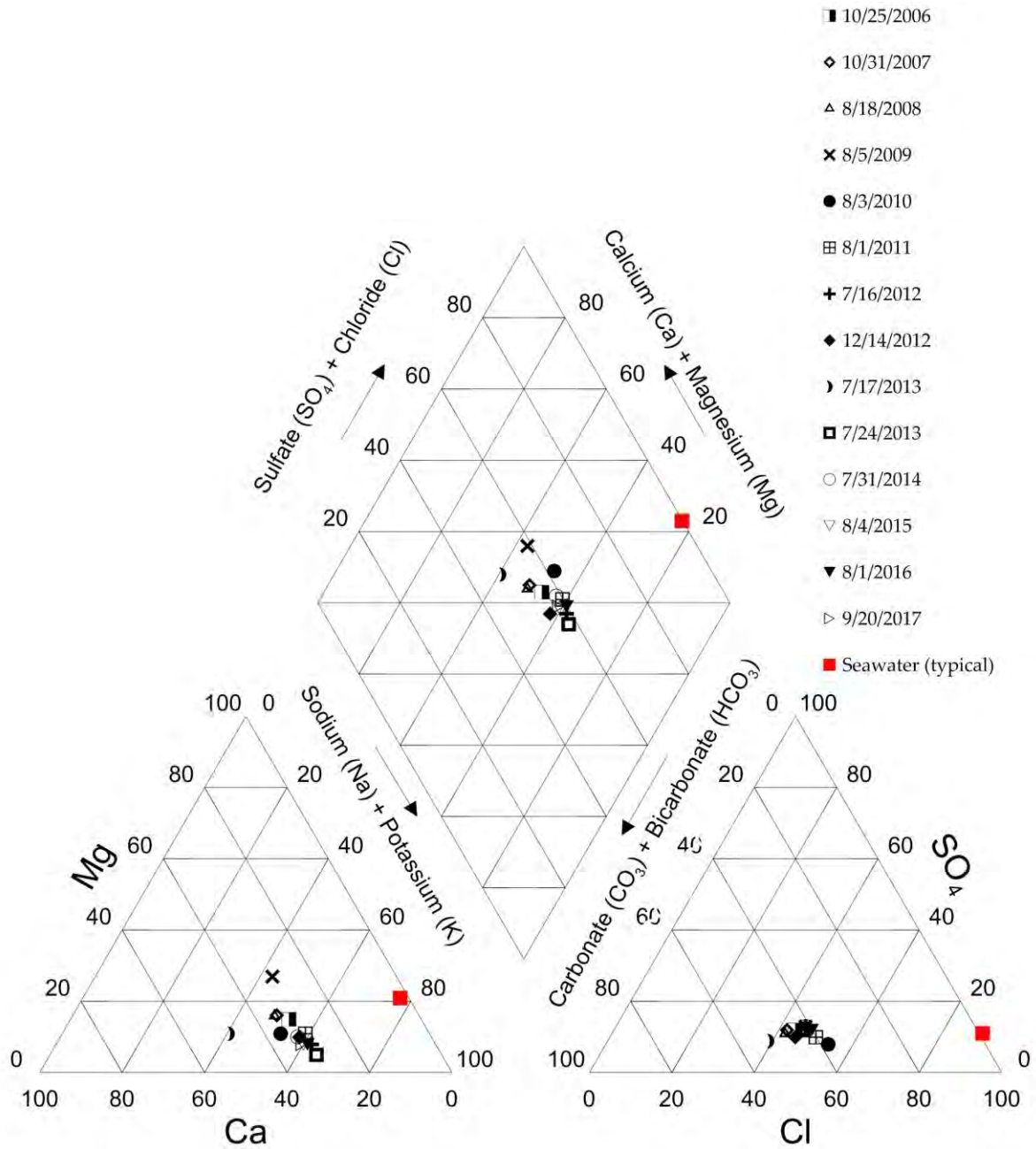


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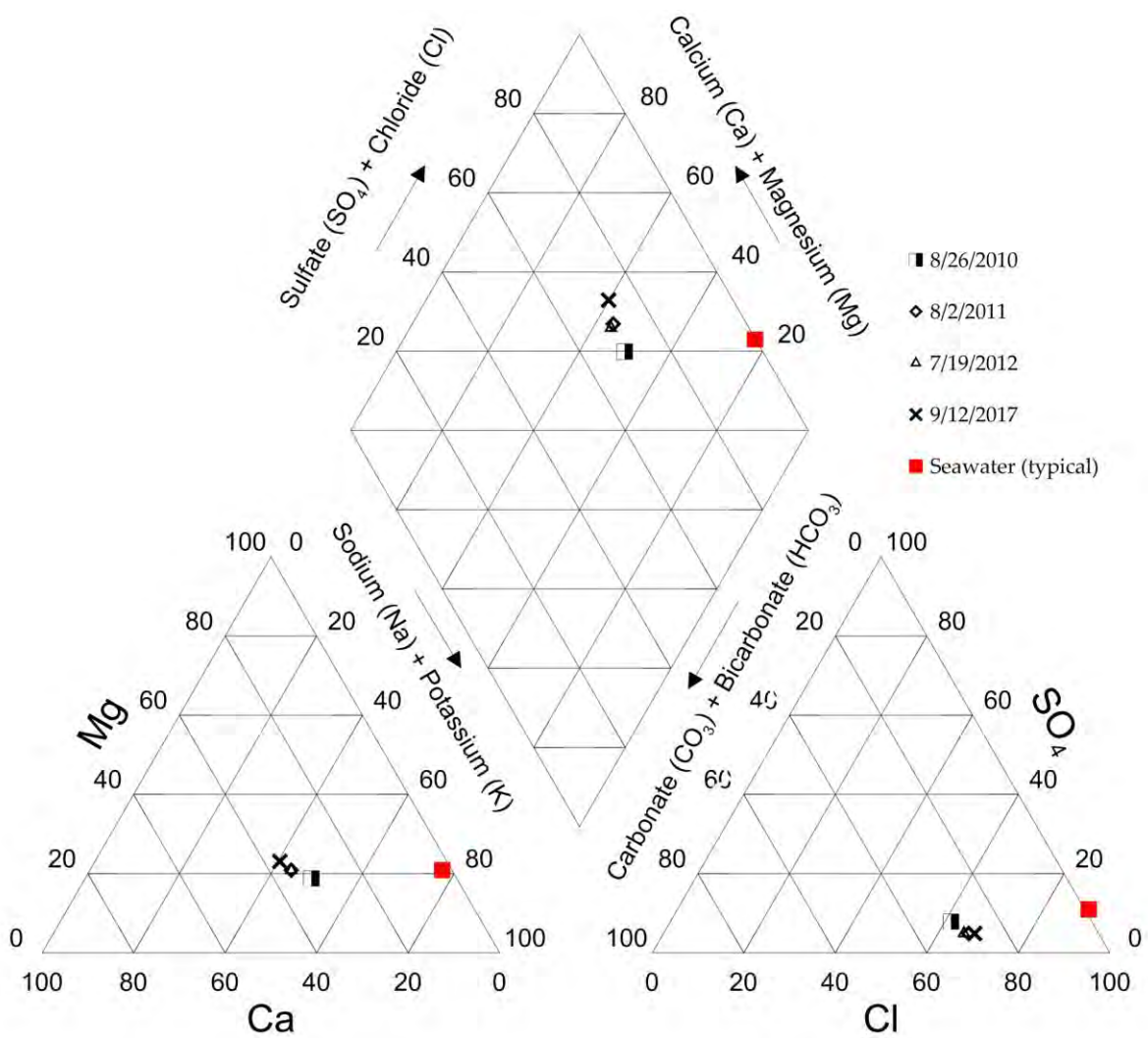


Figure A-13: Piper Diagram of Camp Huffman Shallow Well

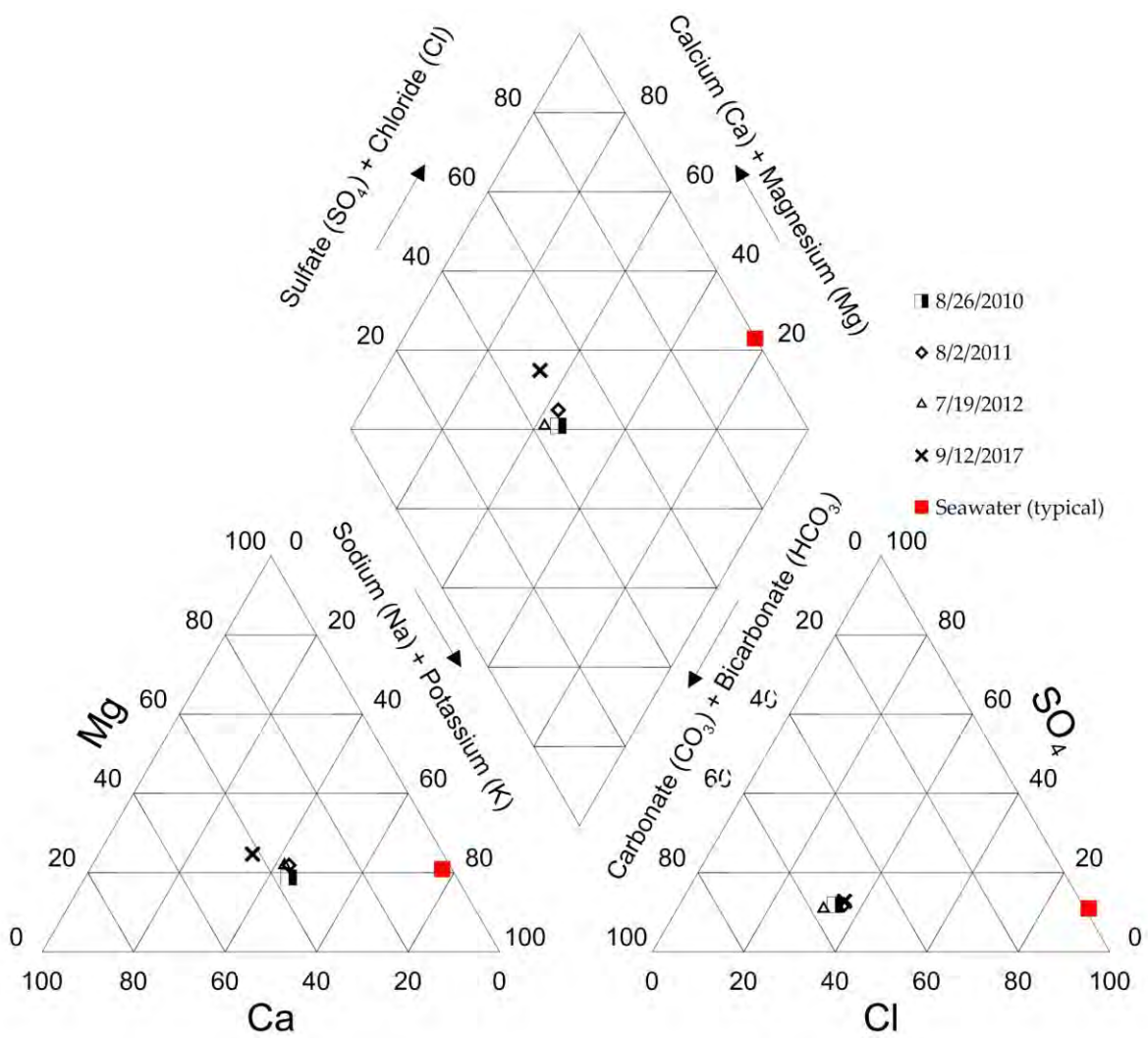


Figure A-14: Piper Diagram of Camp Huffman Deep Well

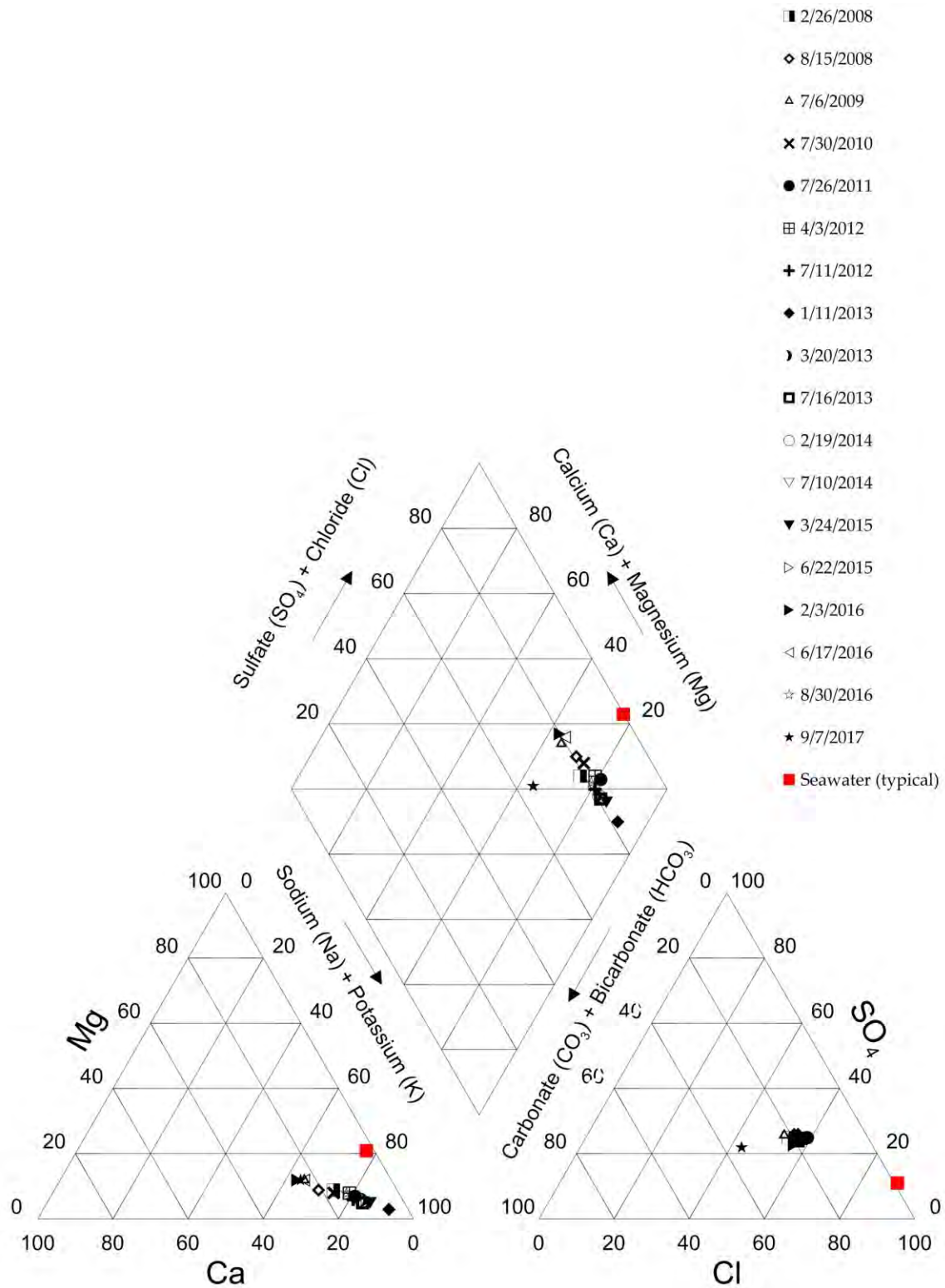


Figure A-15: Piper Diagram of Public Works Corp. Yard Production Well

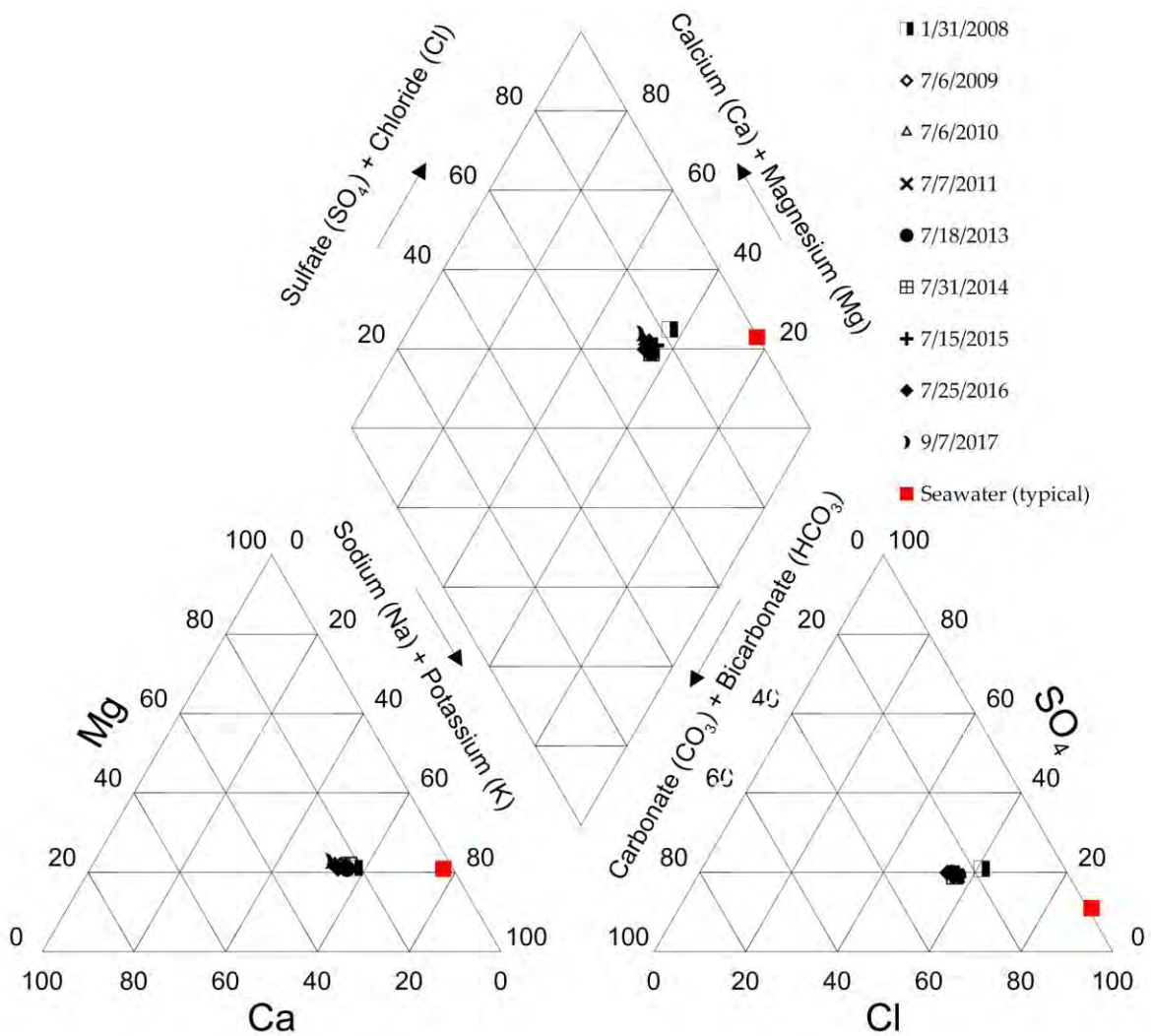


Figure A-16: Piper Diagram of Plumas 4 Production Well

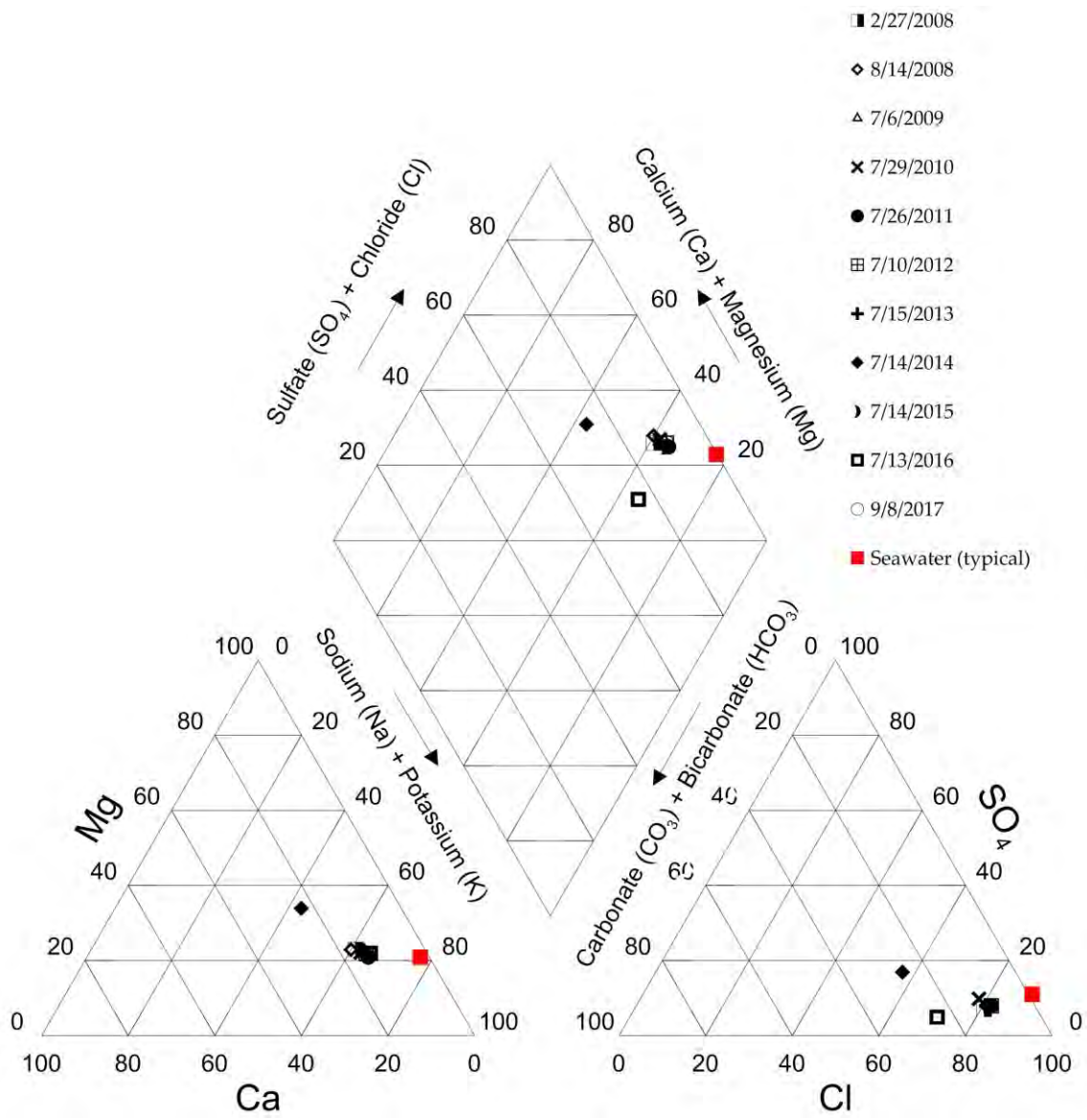


Figure A-17: Piper Diagram of York School Production Well

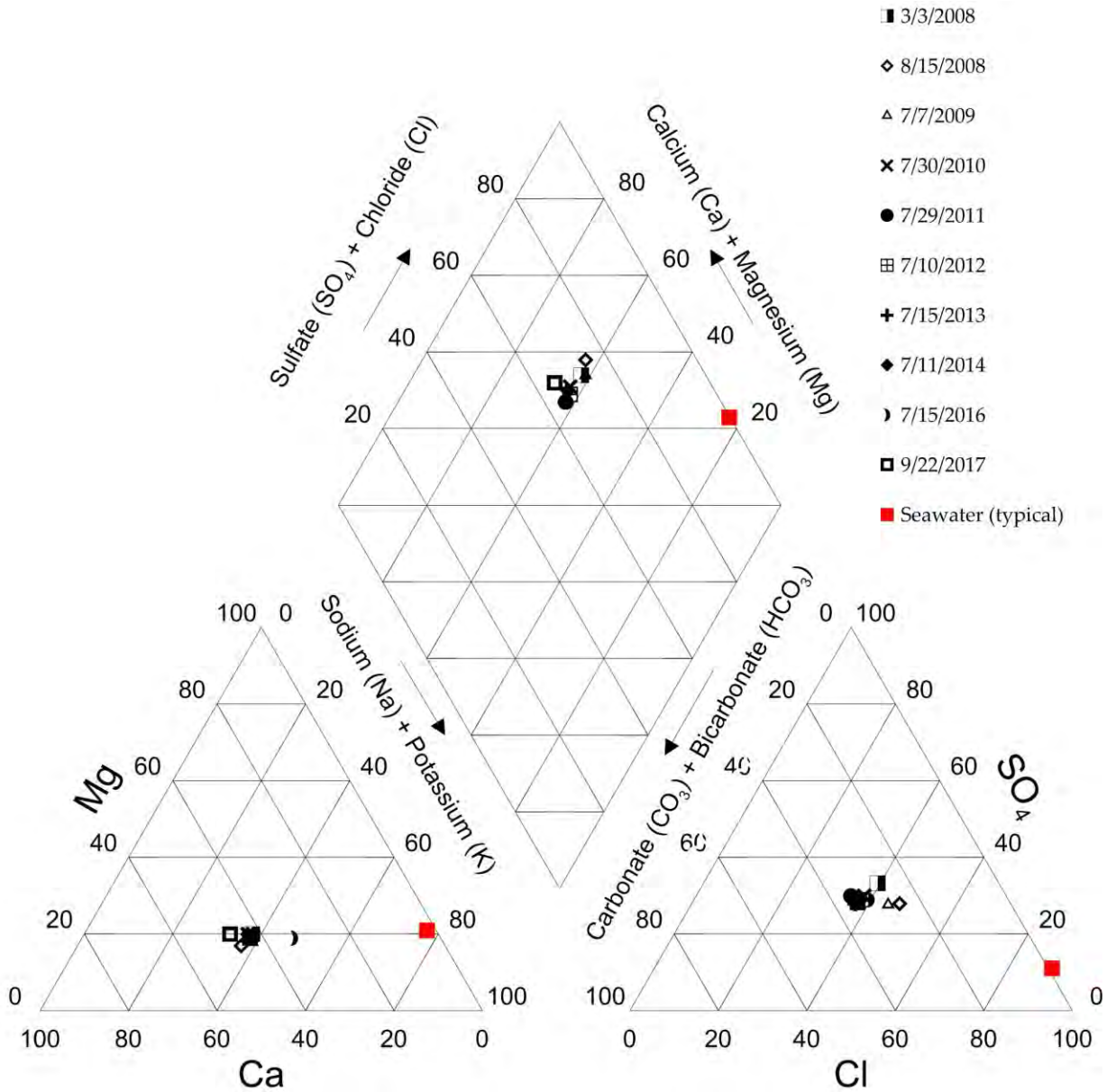


Figure A-18: Piper Diagram of Pasadera Main Gate Production Well

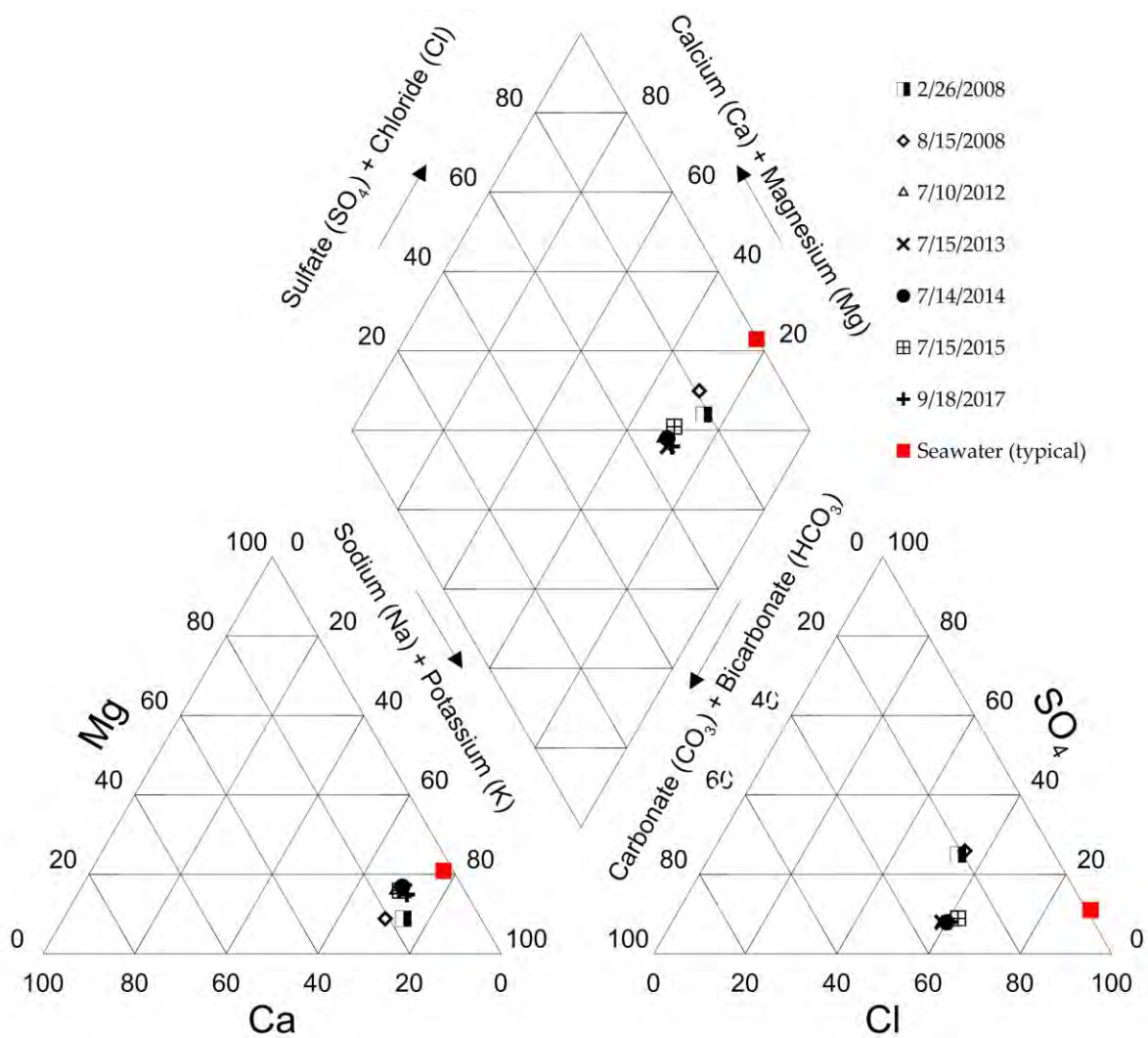


Figure A-19: Piper Diagram of LS County Park #1 Production Well

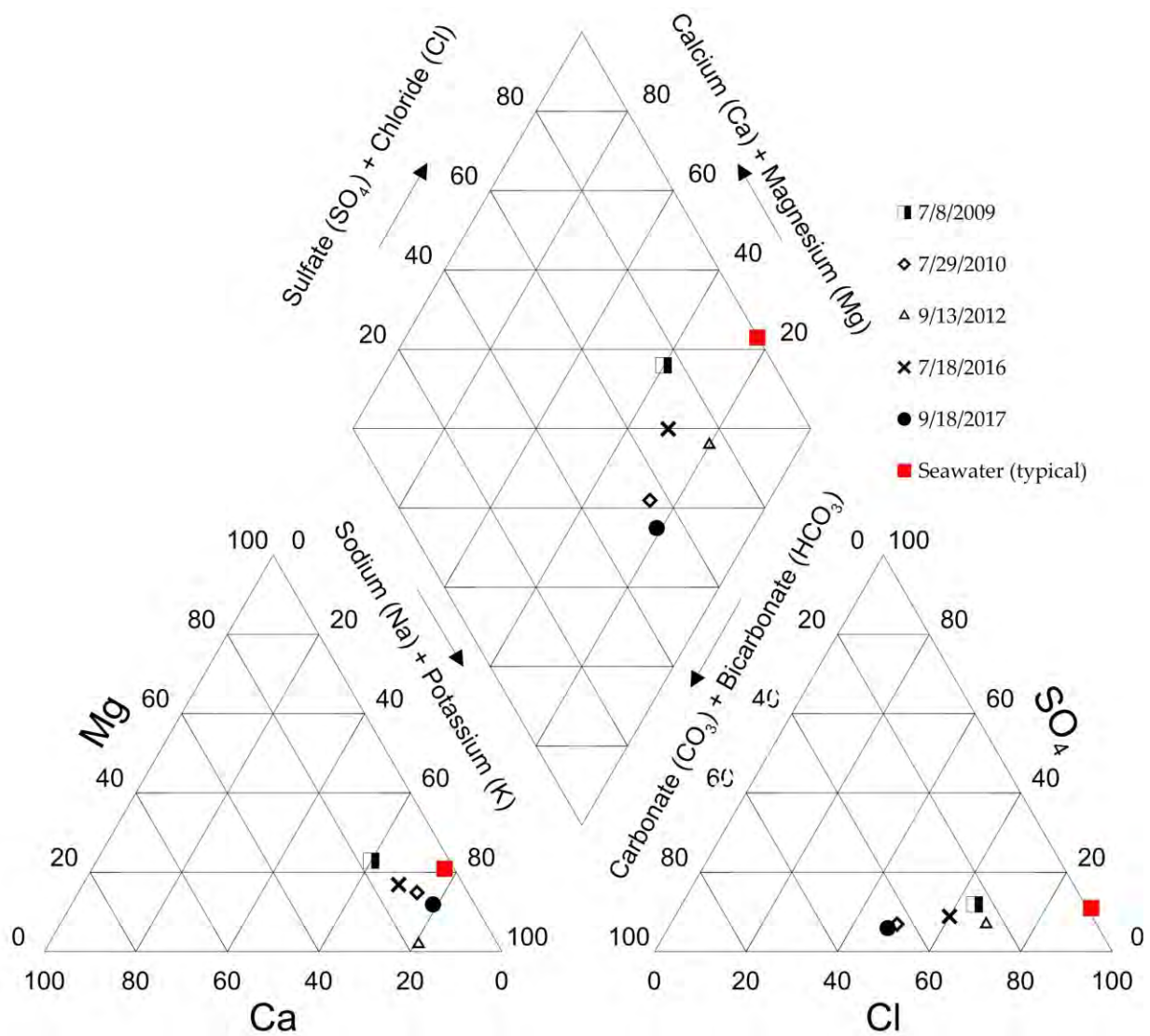


Figure A-20: Piper Diagram of LS County Park #2 Production Well

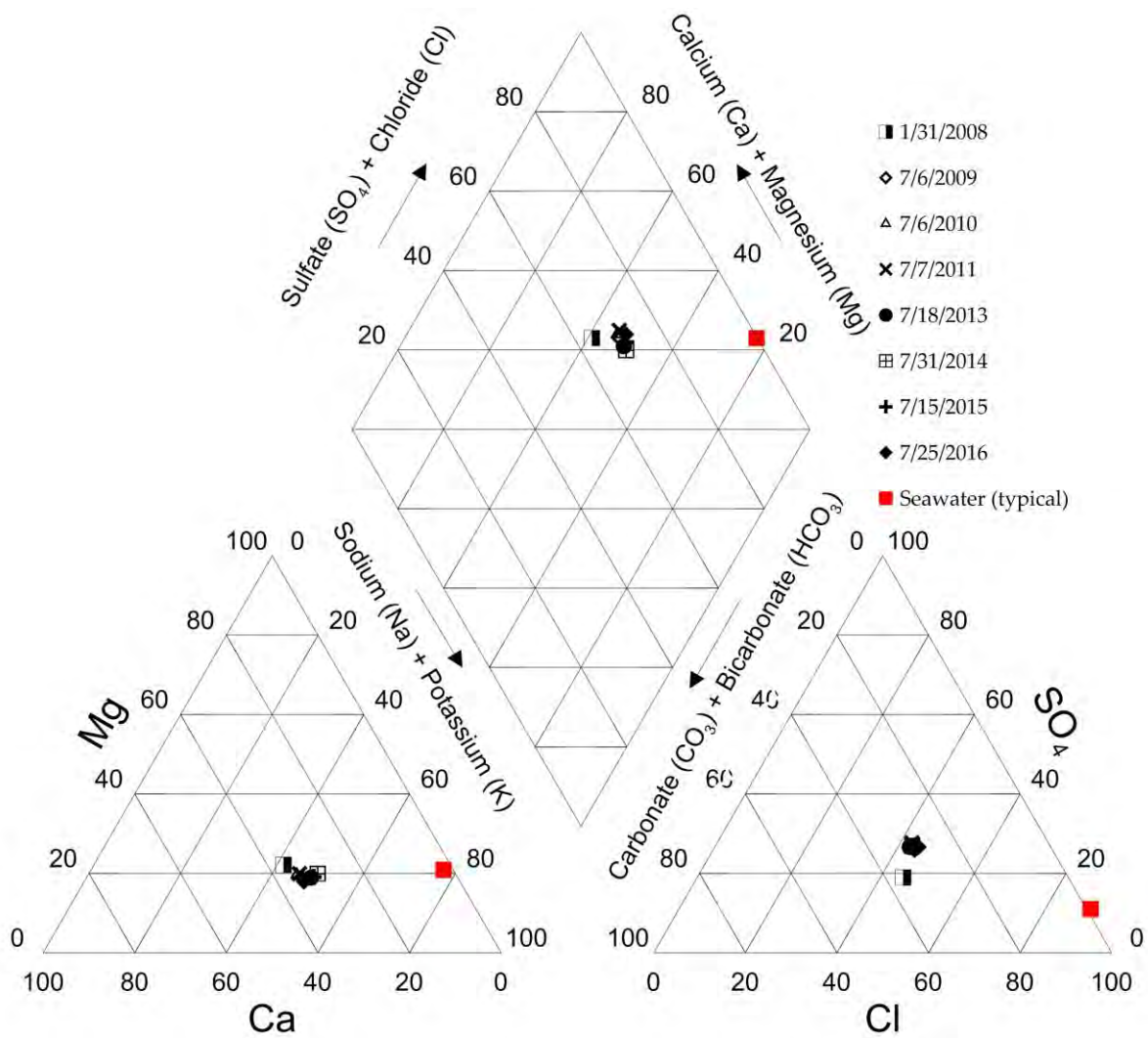


Figure A-21: Piper Diagram of Playa No. 3 Production Well

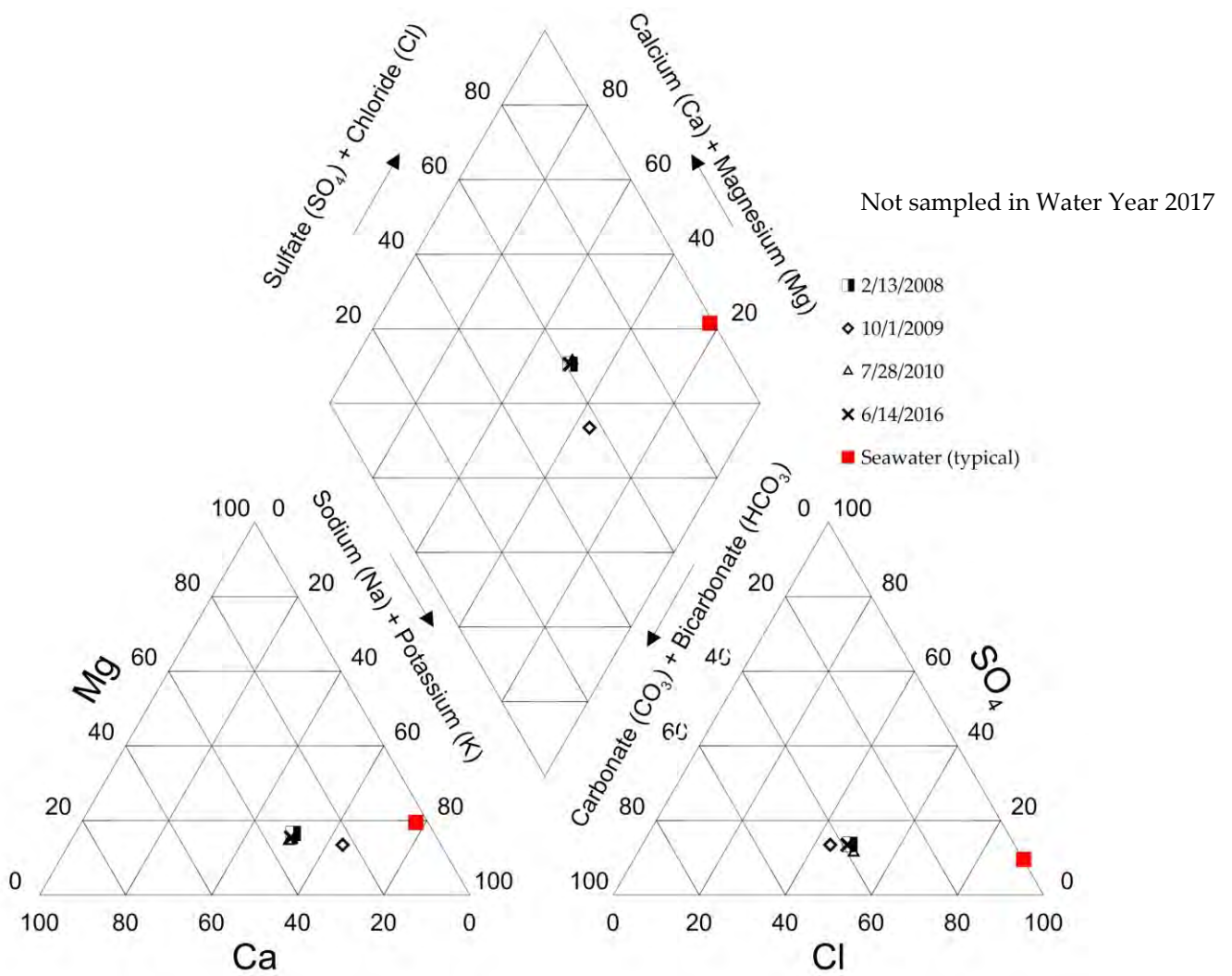


Figure A-22: Piper Diagram of Coe Ave. Production Well

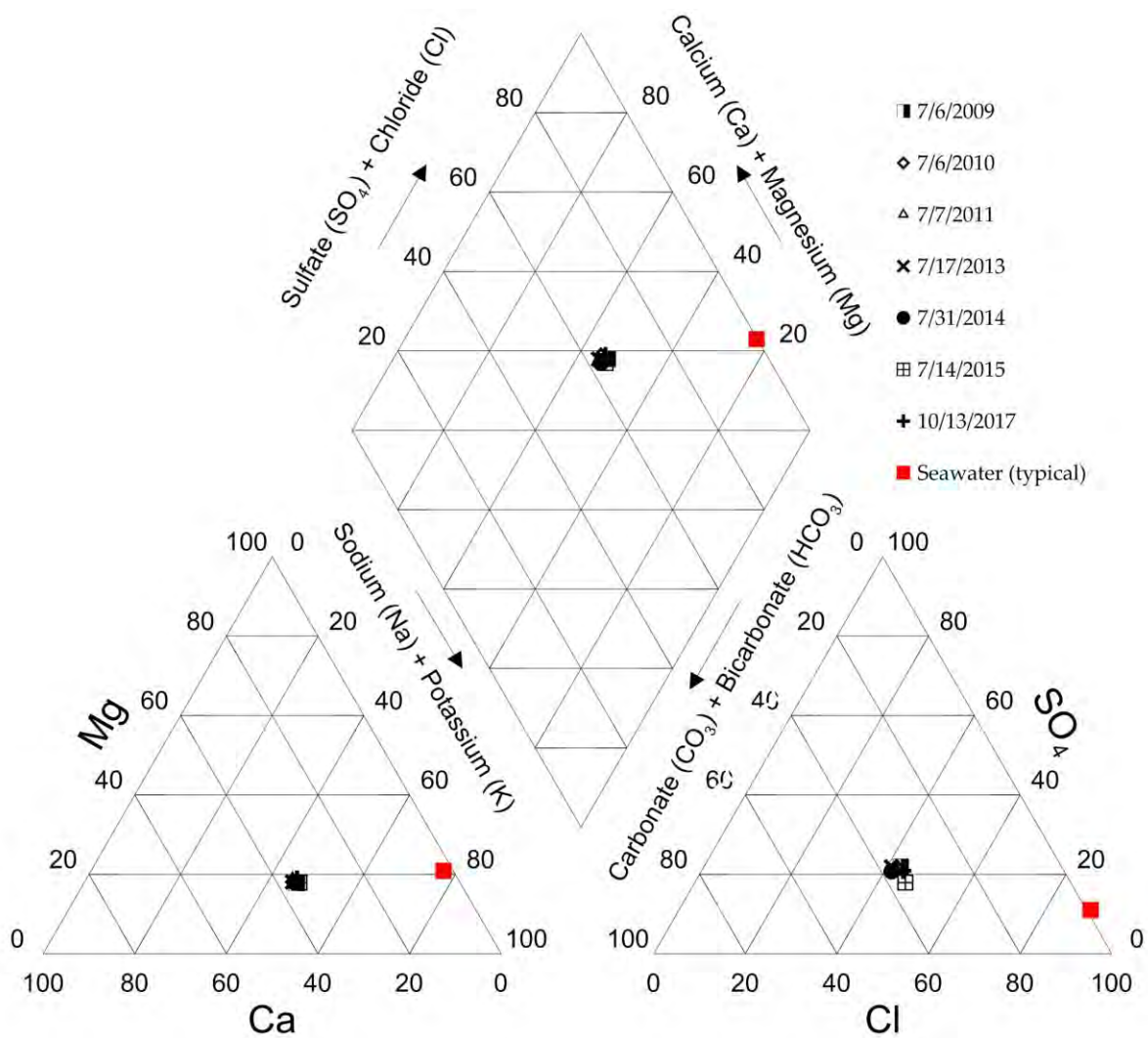


Figure A-23: Piper Diagram of Luzern #2 Production Well

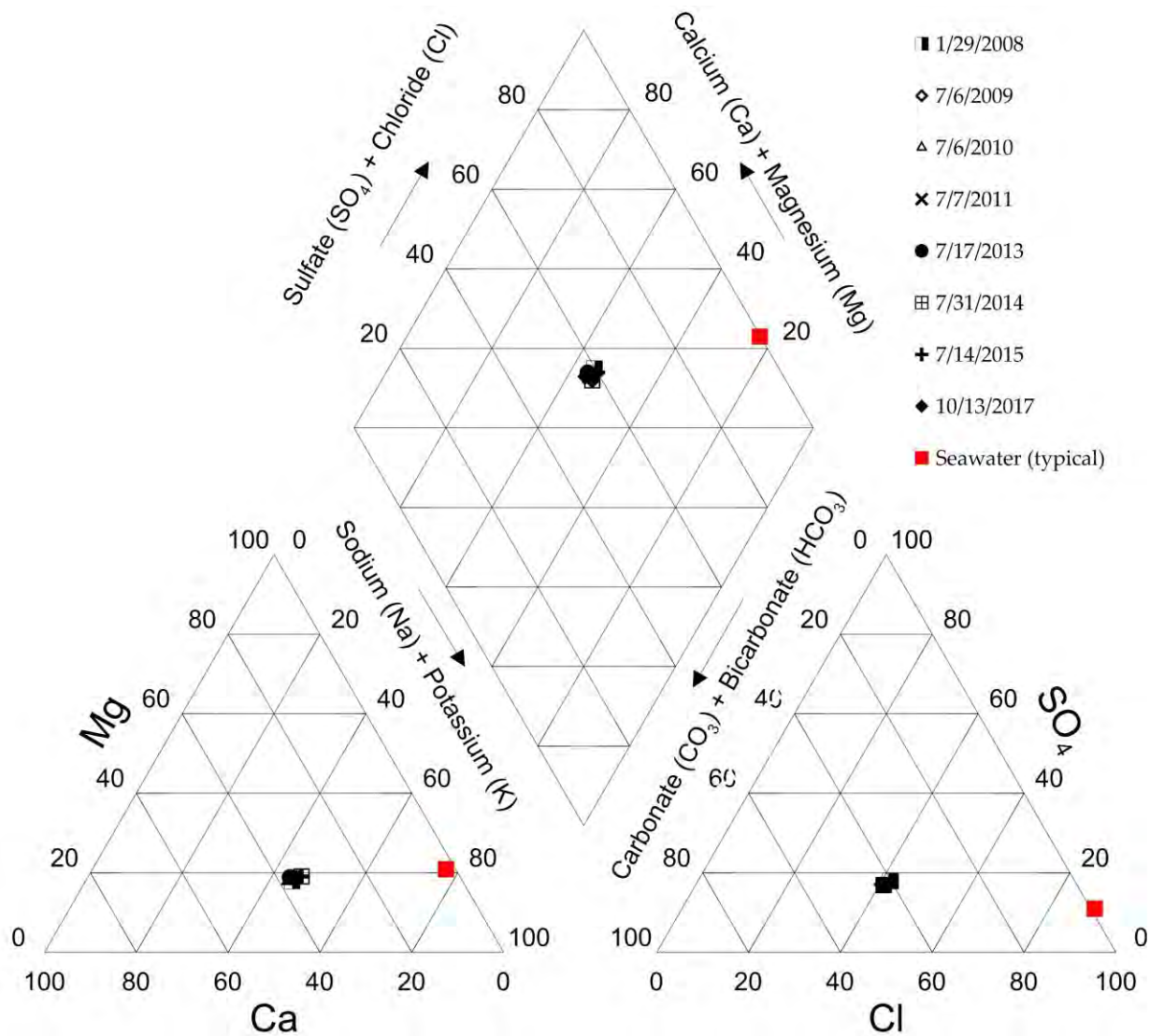


Figure A-24: Piper Diagram of Ord Grove No. 2 Production Well

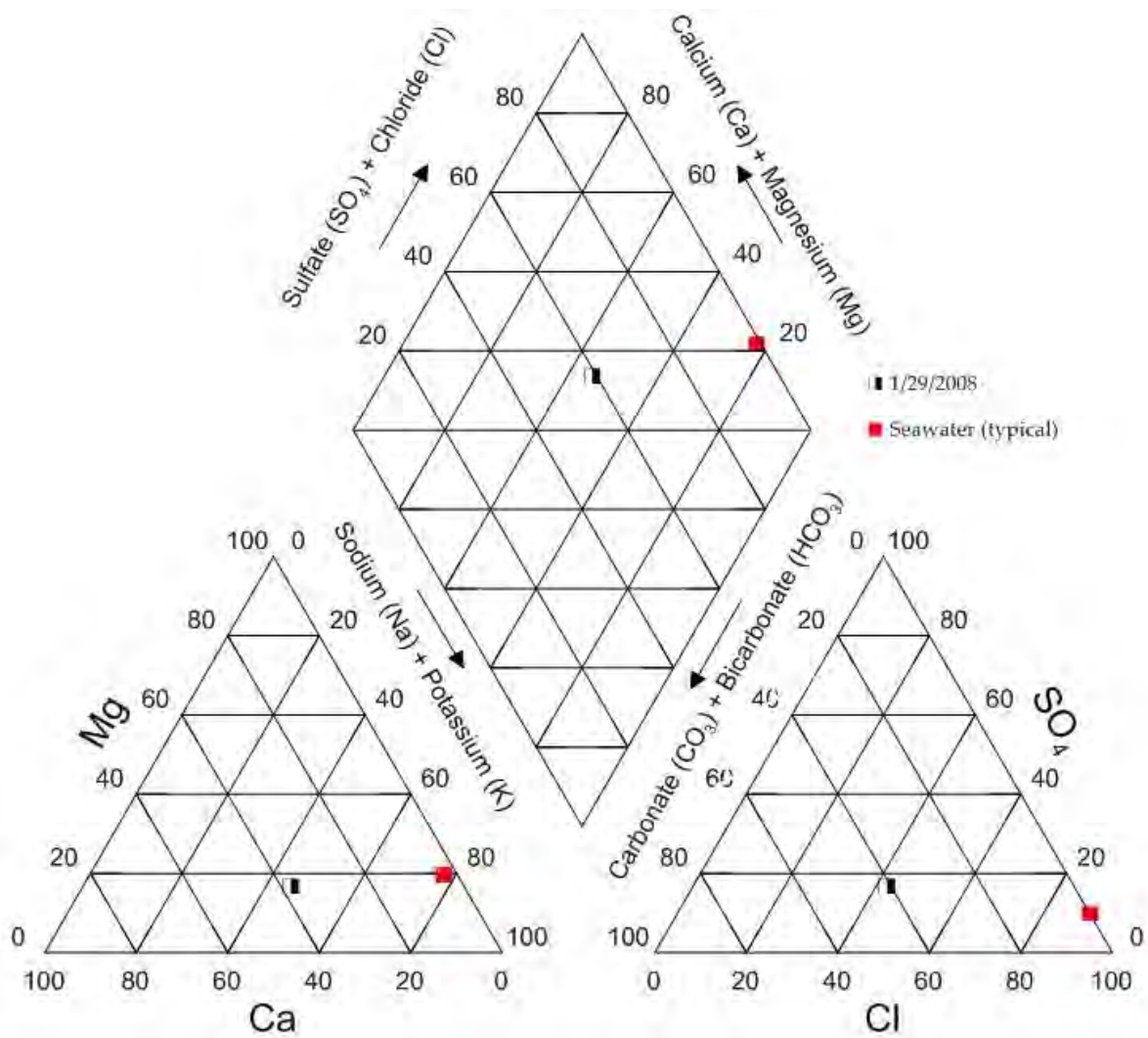


Figure A-25: Piper Diagram of Seaside City No. 3 Production Well

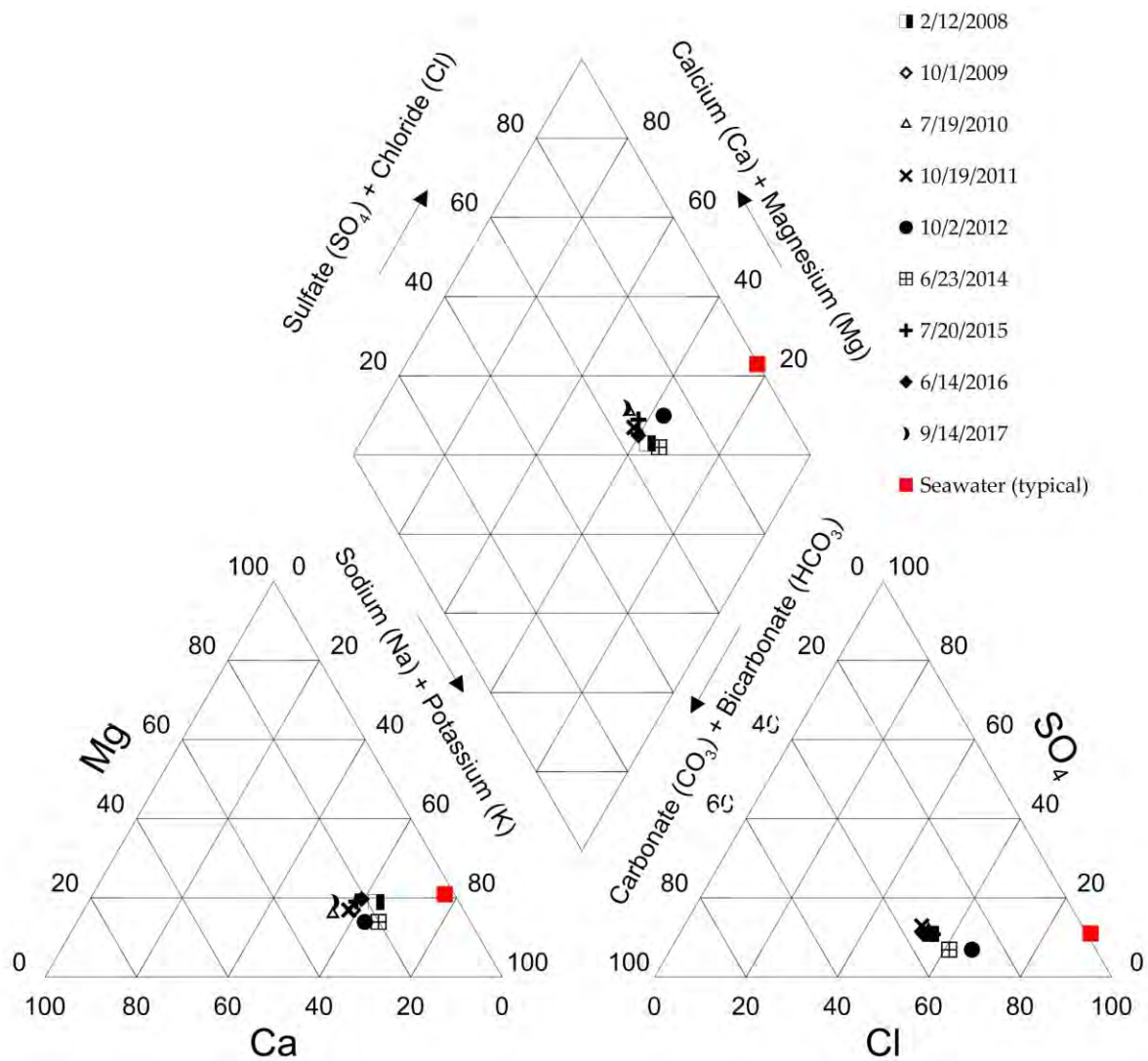


Figure A-26: Piper Diagram of Seaside City No. 4 Production Well

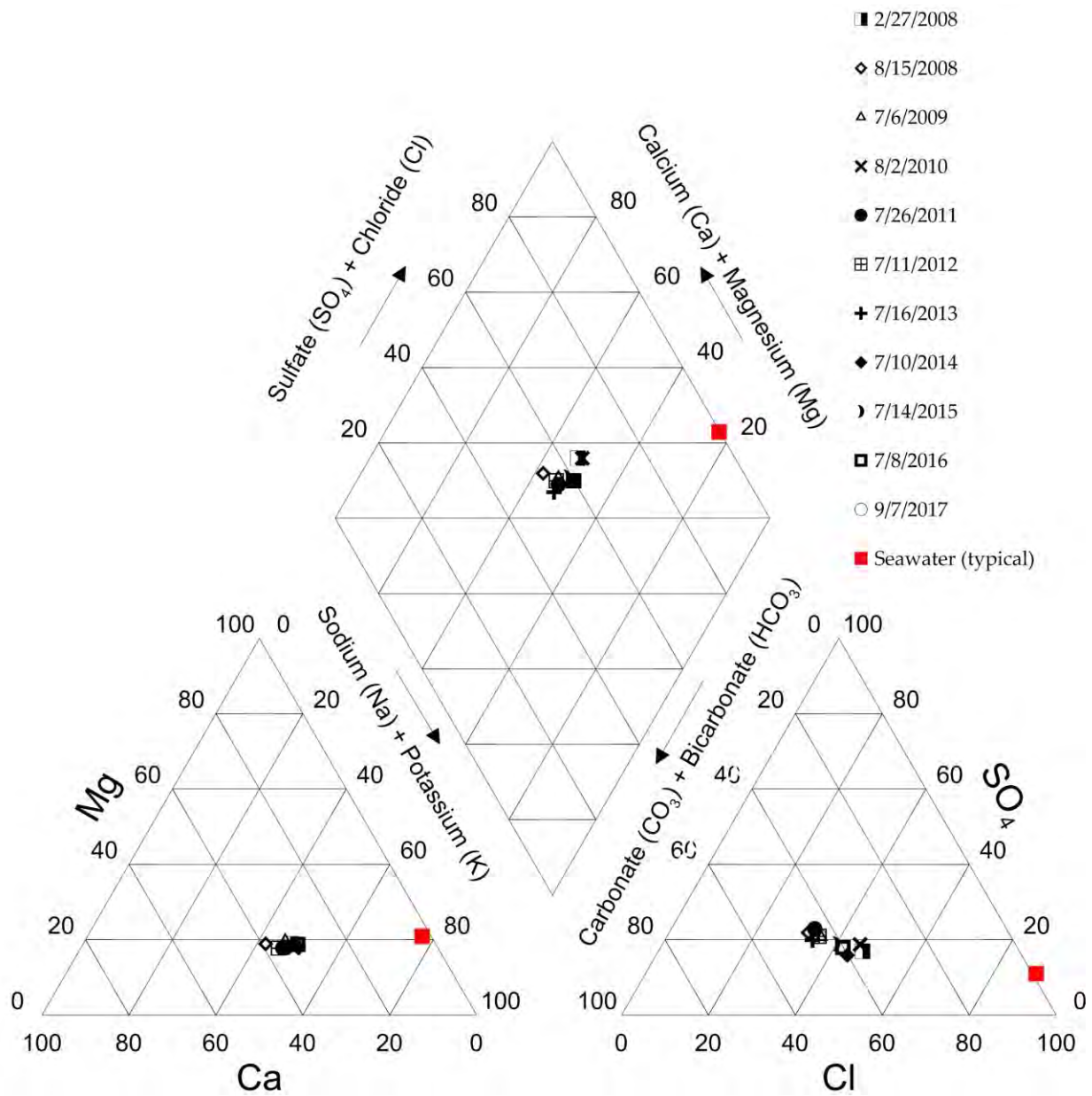


Figure A-27: Piper Diagram of Mission Memorial (formerly PRTIW)

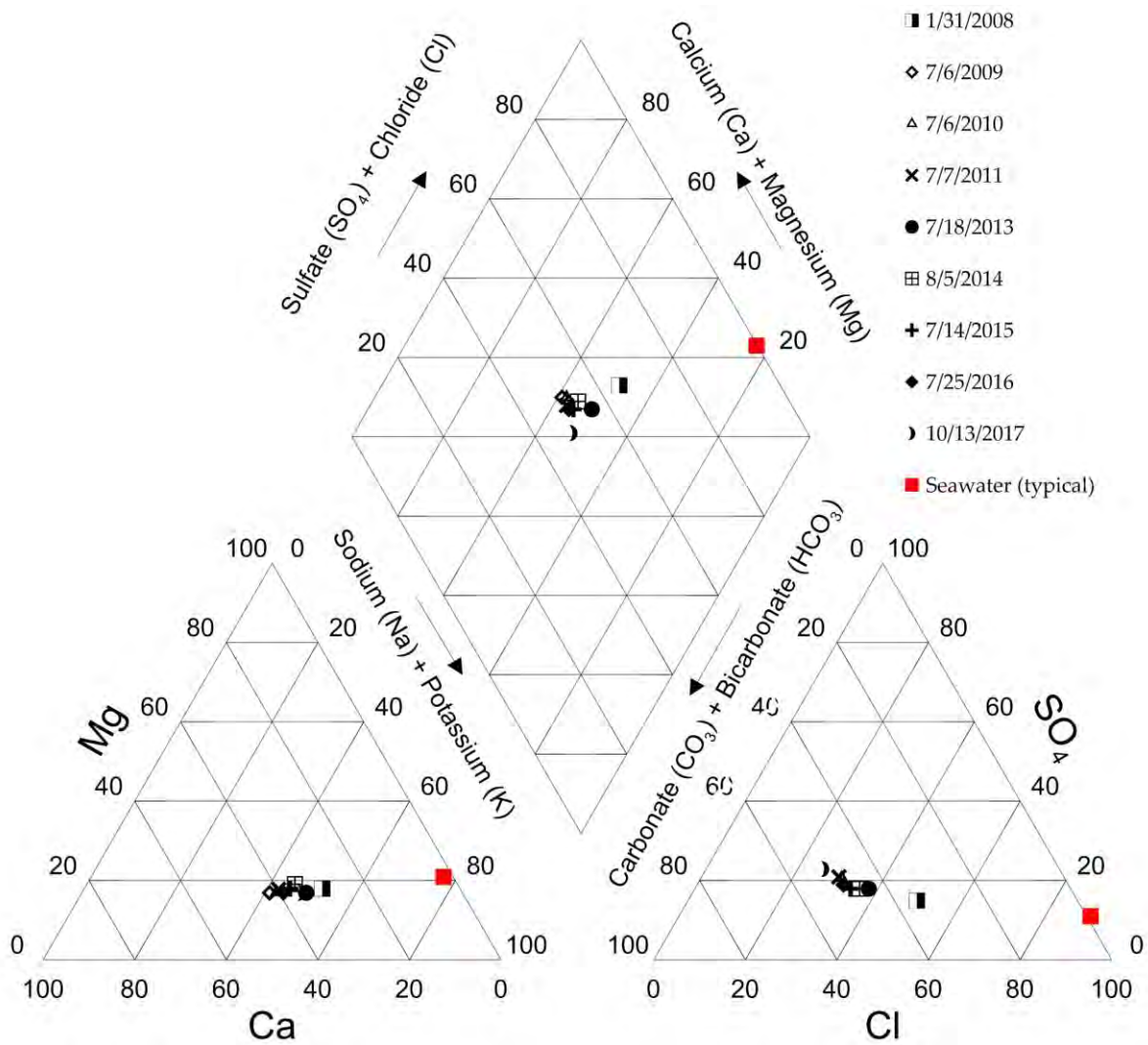


Figure A-28: Piper Diagram of Paralta Production Well

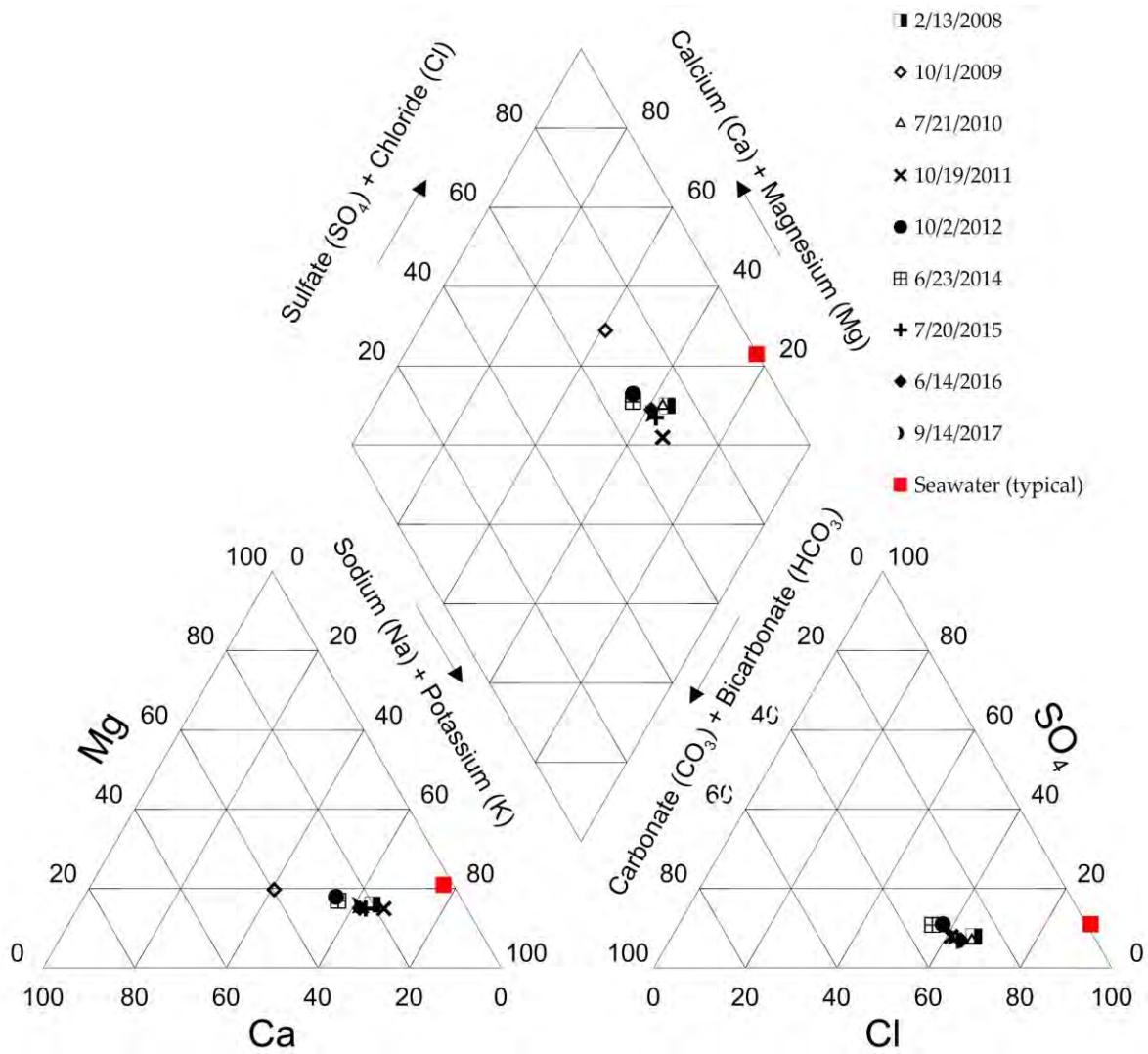


Figure A-29: Piper Diagram of Reservoir (Bayonet Blackhorse) Production Well

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## **APPENDIX B: CHLORIDE AND SODIUM/CHLORIDE MOLAR RATIO GRAPHS**

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- Figure B-12: Fort Ord 9 Deep Well Chemograph
- Figure B-13: Sand City Public Works Corp Yard Production Well

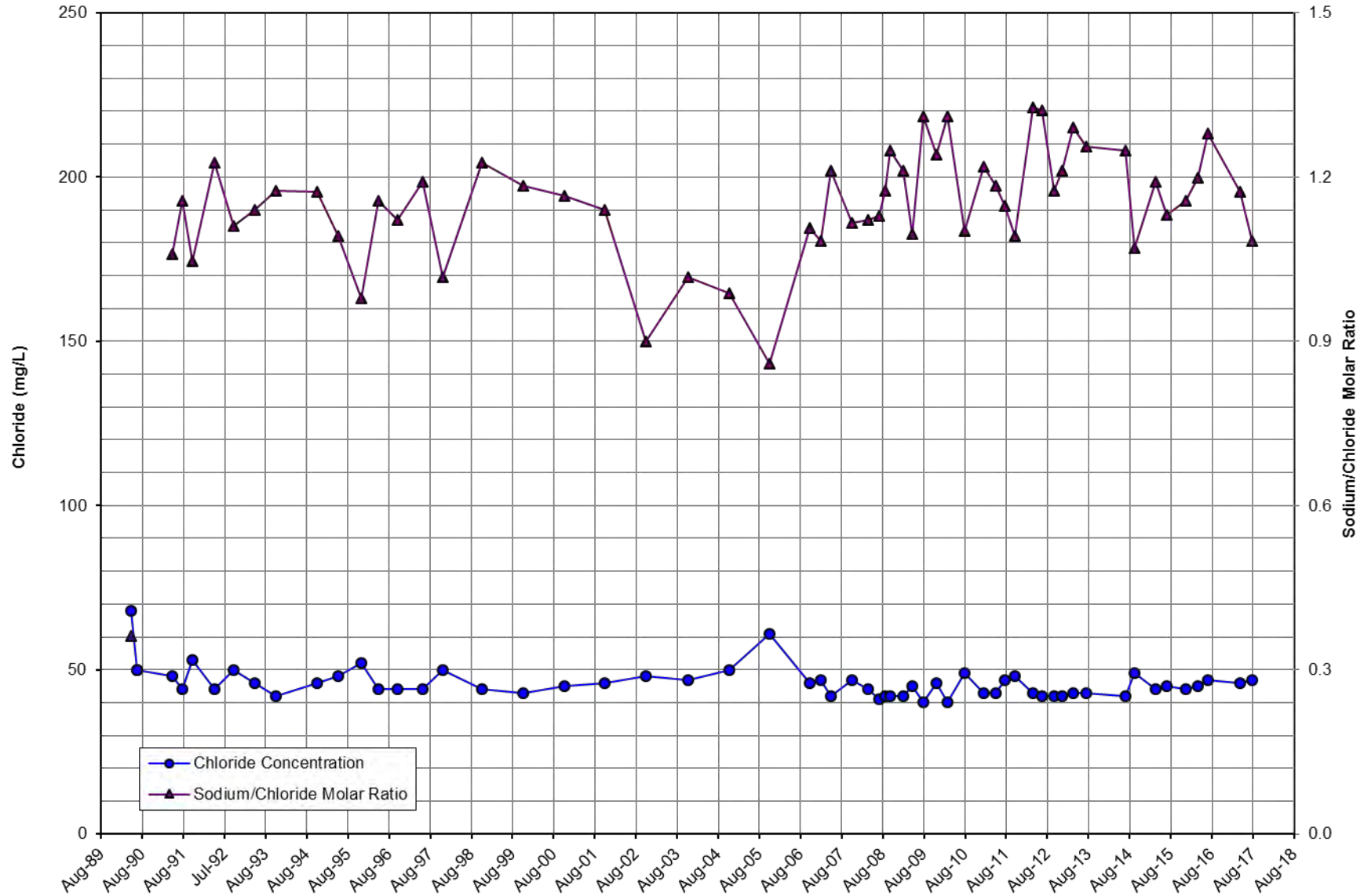


Figure B-1: PCA West Shallow Well Chemograph

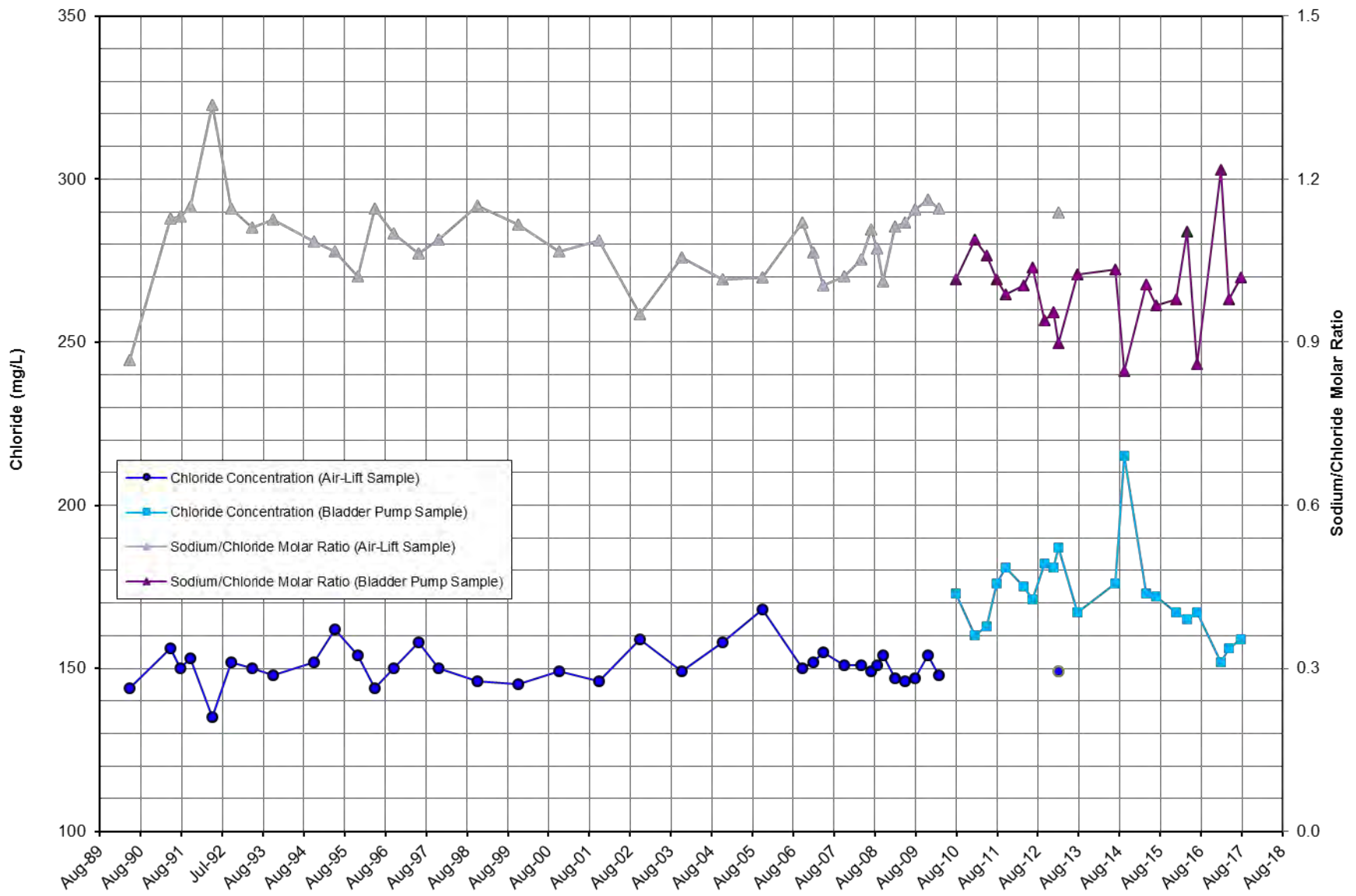


Figure B-2: PCA West Deep Well Chemograph

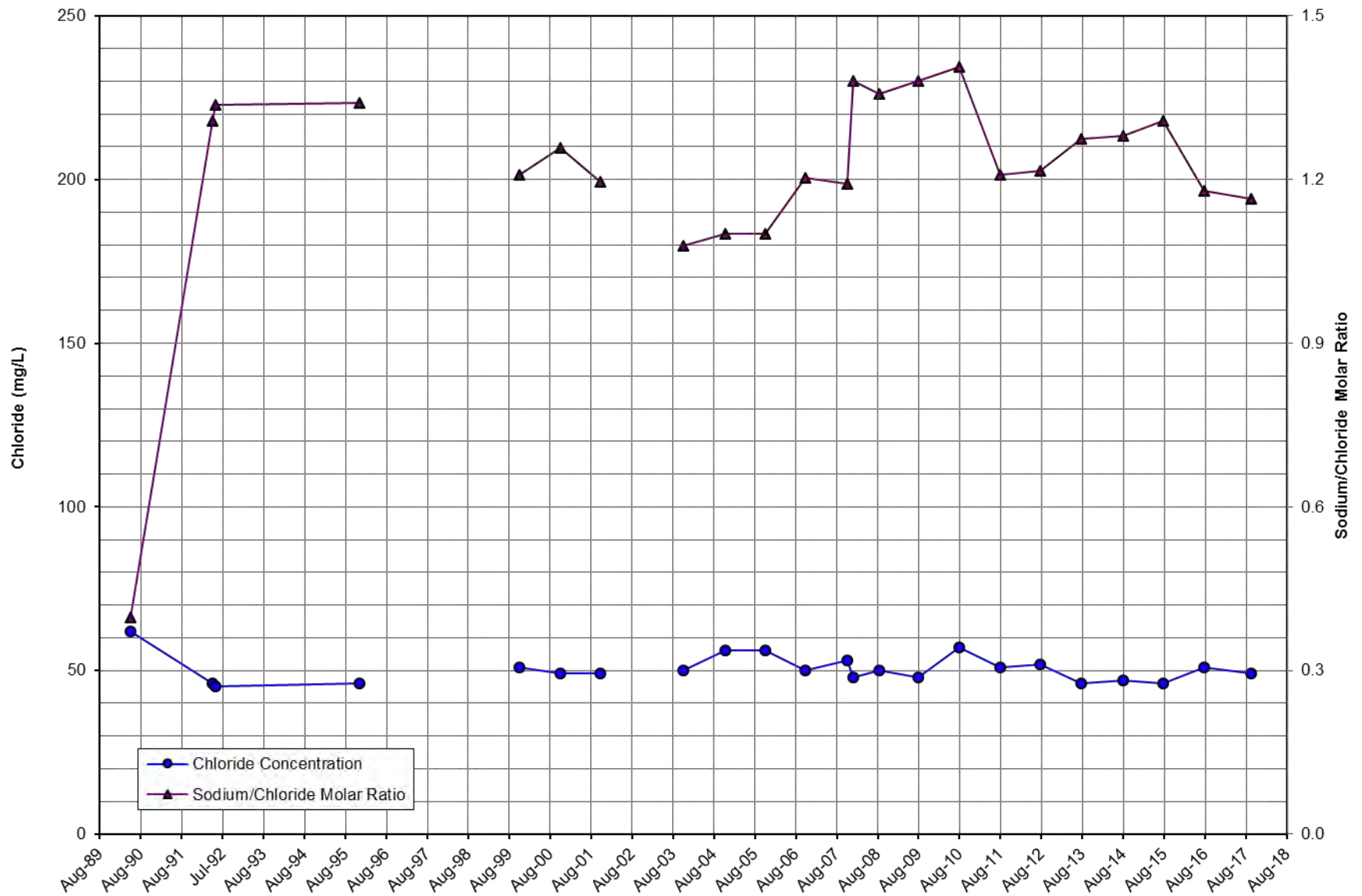


Figure B-3: PCA East Shallow Well Chemograph

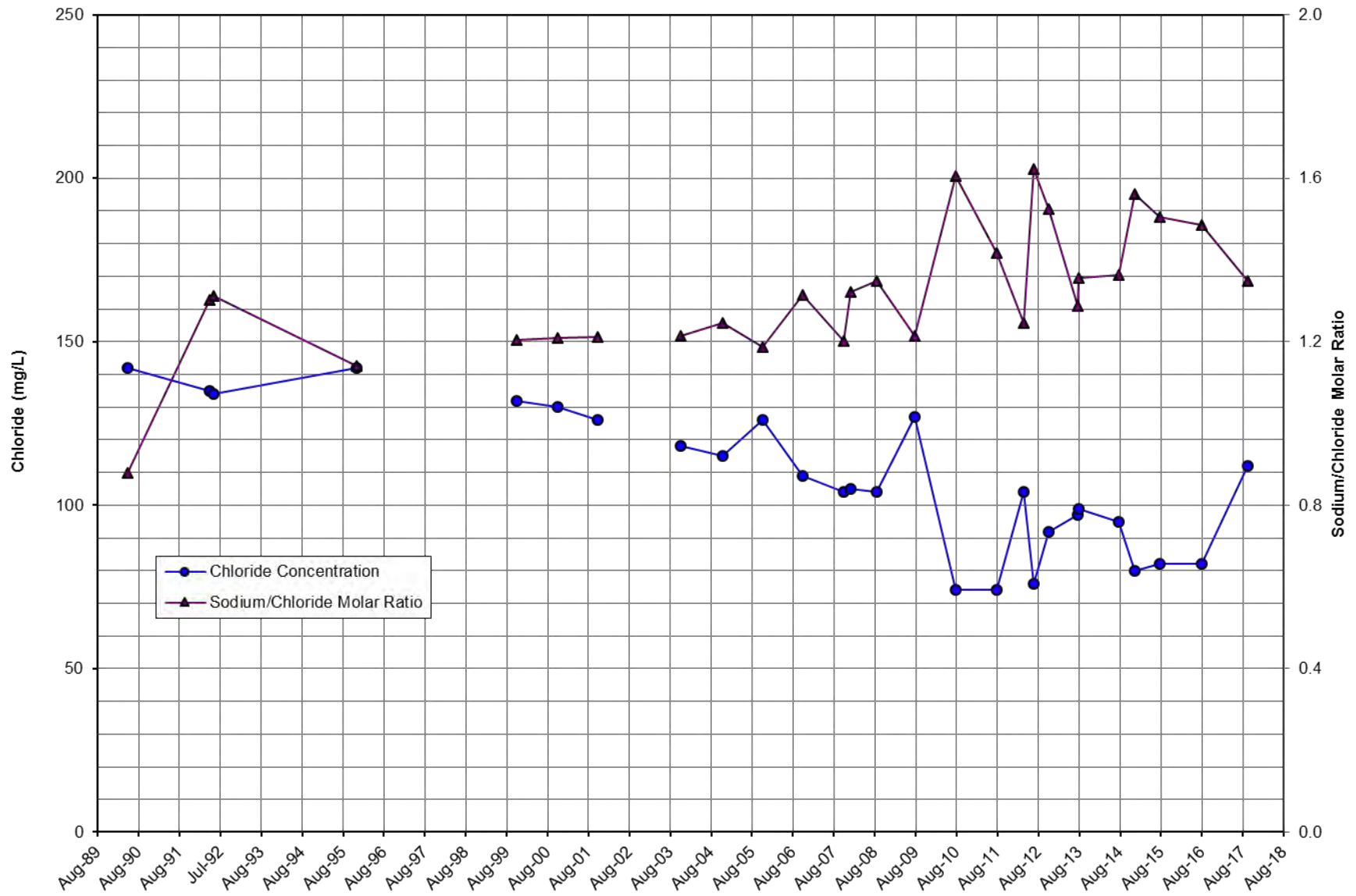


Figure B-4: PCA East Deep Well Chemograph

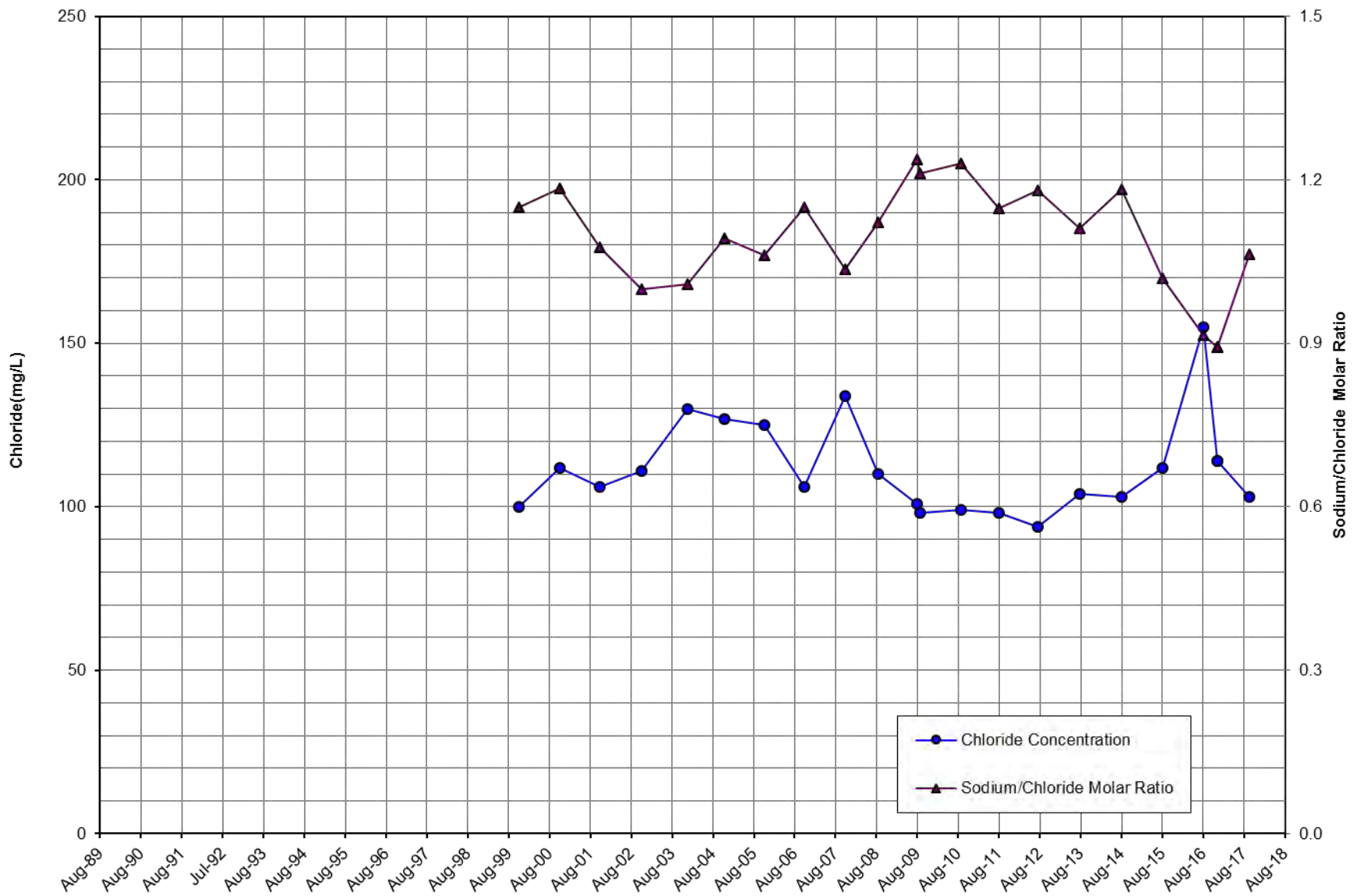


Figure B-5: Ord Terrace Shallow Well Chemograph

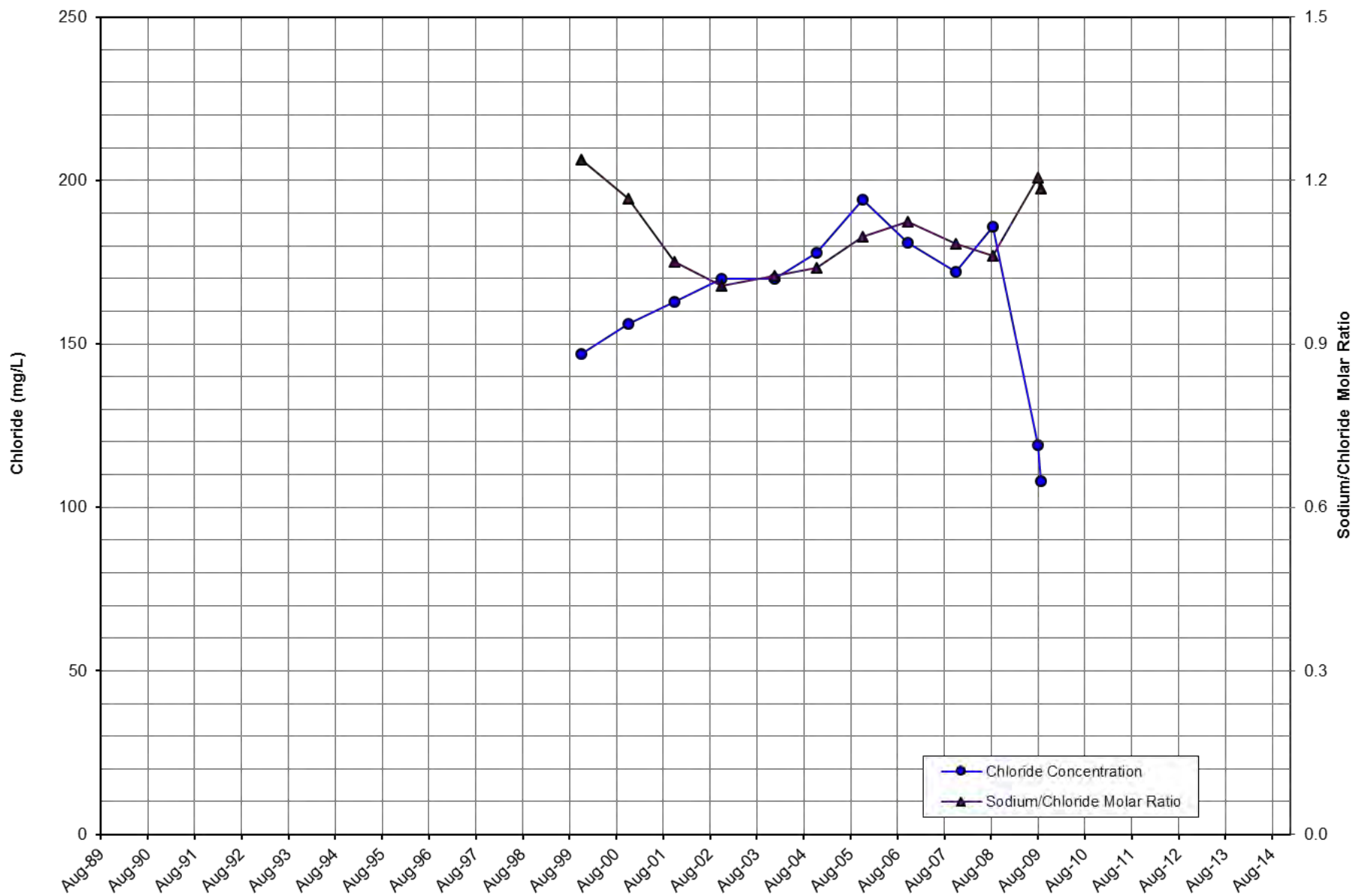


Figure B-6: Ord Terrace Deep Well Chemograph

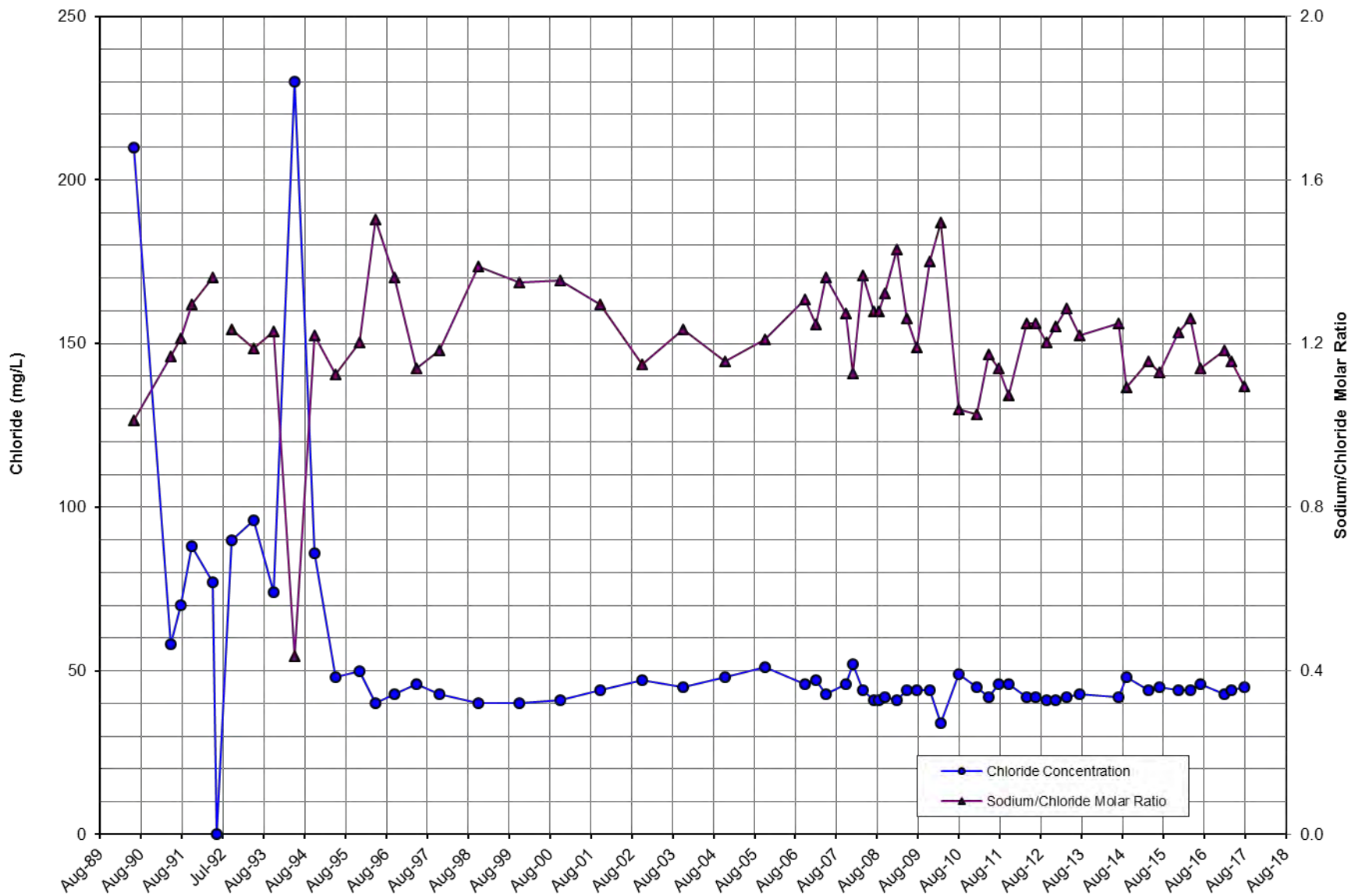


Figure B-7: MSC Shallow Well Chemograph

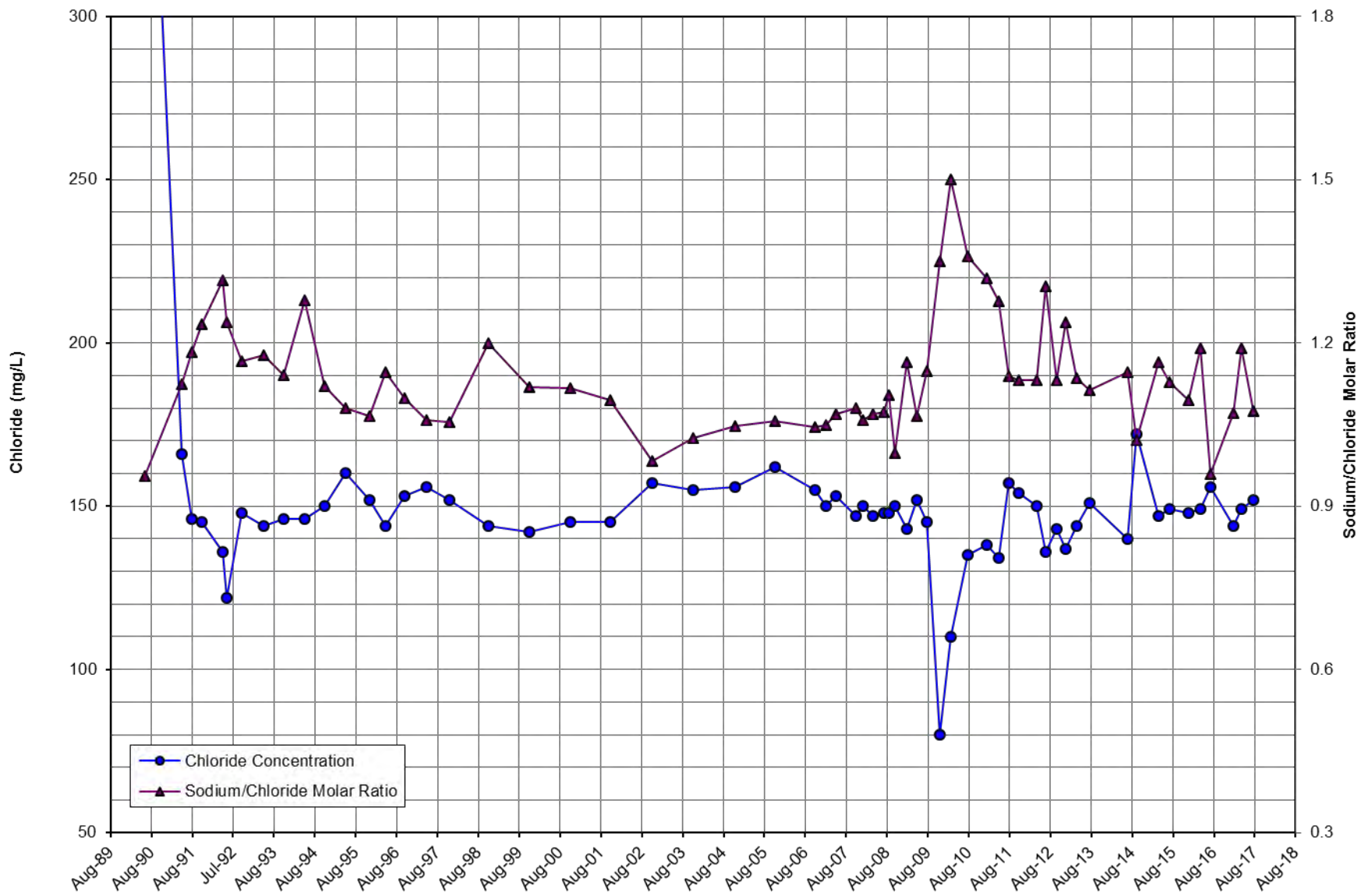


Figure B-8: MSC Deep Well Chemograph

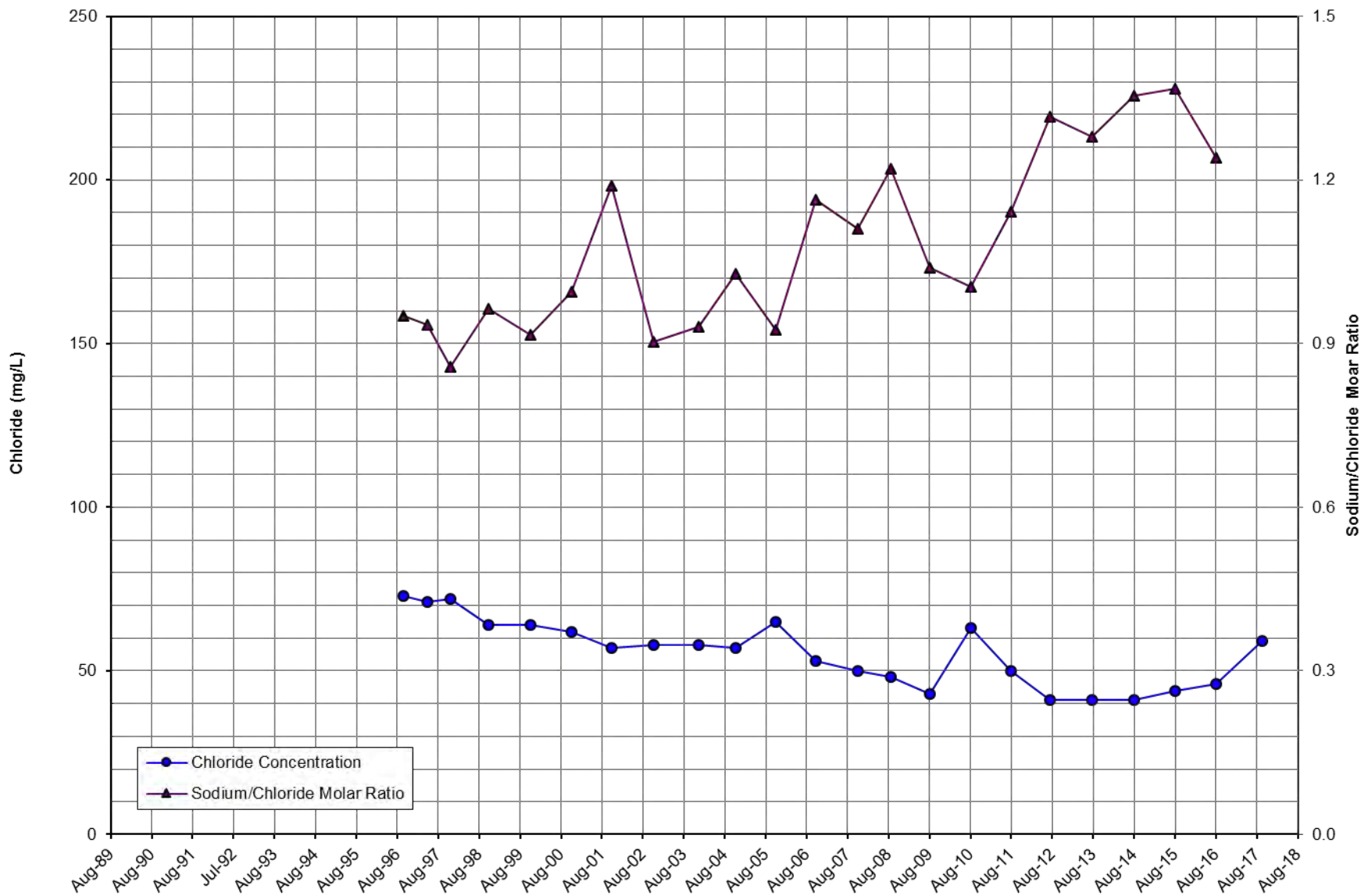


Figure B-9: Fort Ord 10 Shallow Well Chemograph

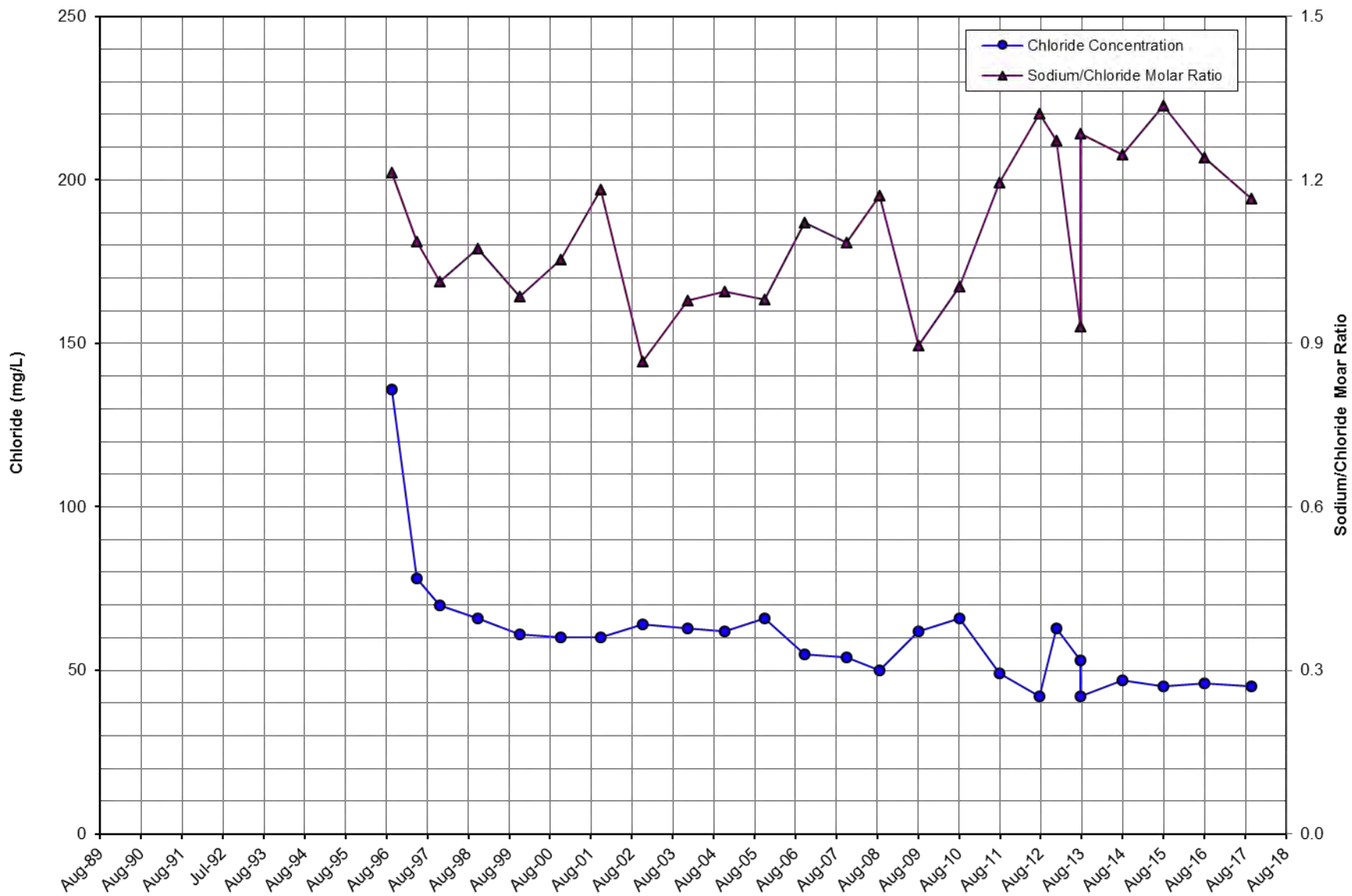


Figure B-10: Fort Ord 10 Deep Well Chemograph

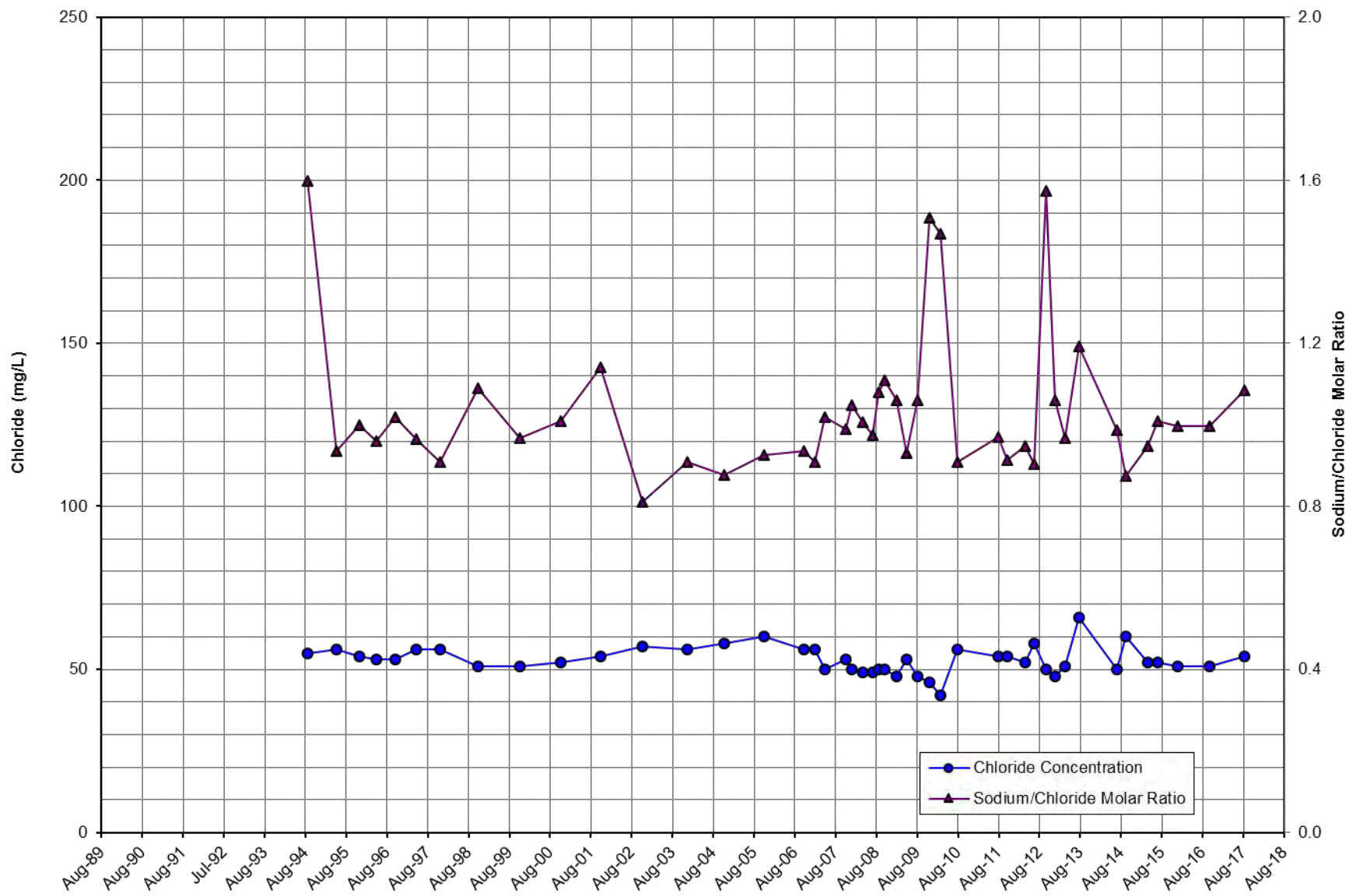


Figure B-11: Fort Ord 9 Shallow Well Chemograph

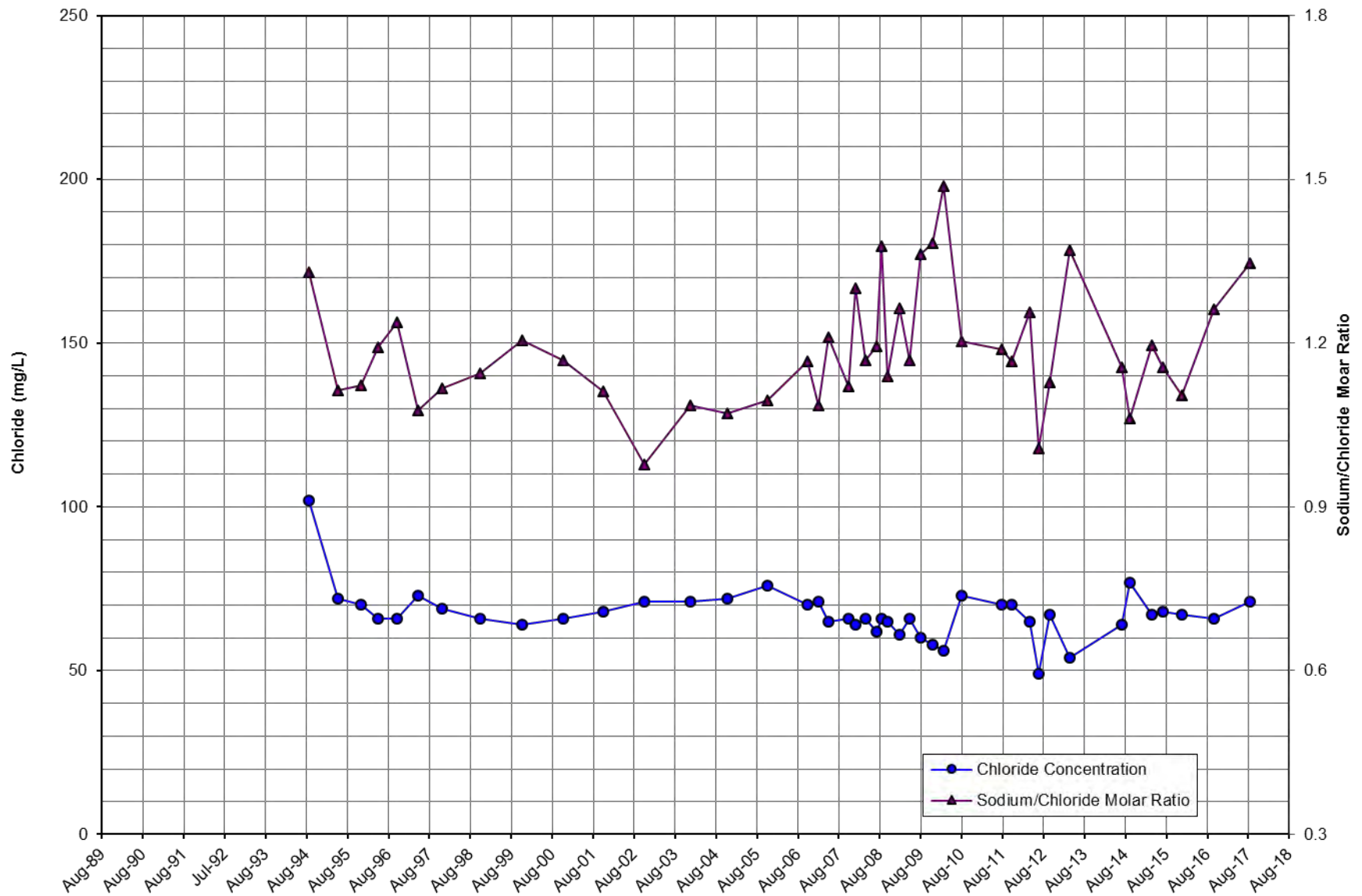


Figure B-12: Fort Ord 9 Deep Well Chemograph

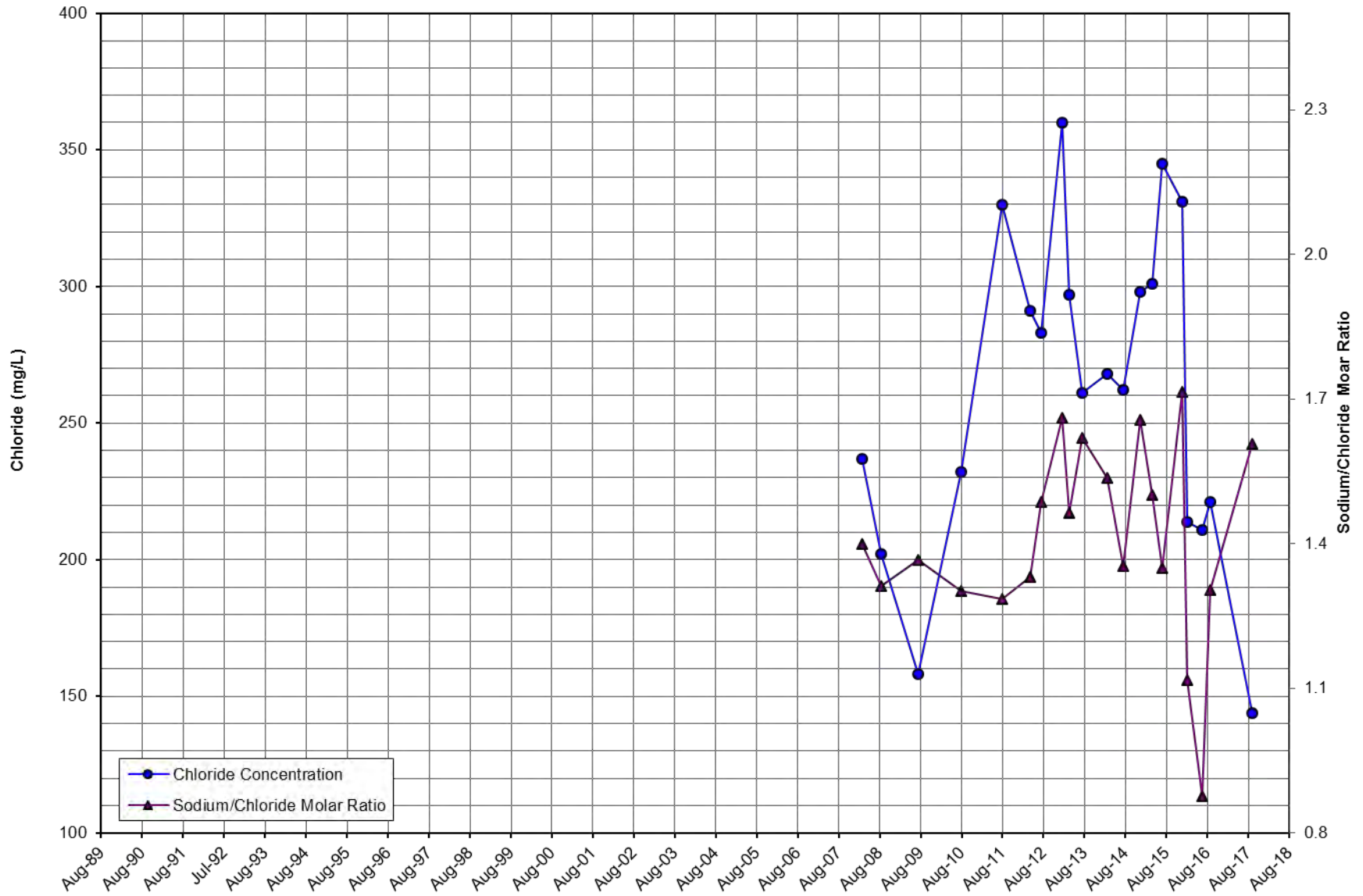


Figure B-13: Sand City Public Works Corp Yard Production Well