Water Year 2016
Seawater Intrusion Analysis Report
Seaside Basin, Monterey County
California

Prepared for:
Seaside Basin Watermaster

December 2016

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_3	carbonate
FO	Fort Ord
HCO_3	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

CONVERSIONS

1 acre-foot = 325,851 gallons

1 mg/L ≈ 1 part per million

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EXECUTIVE SUMMARY

This annual report addresses the potential for, and extent of, seawater intrusion in the Seaside Groundwater Basin. 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.

Up until this water year, all of the monitoring data from the existing monitoring and production wells in the Seaside Basin have indicated that seawater intrusion has not occurred. This year for the first time there is conflicting data from two of the Watermaster's sentinel wells. Some of the data are suggestive of the initial onset of seawater intrusion, while other data indicate seawater intrusion is not occurring.

The data which are suggestive of the initial onset of seawater intrusion is described in the bulleted items below. It is important to note that all of these data are based on the same two discrete groundwater quality samples taken from wells SBWM-2 (1,470 ft depth) and SBWM-4 (900 ft depth).

- Water samples for sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) experienced a shift in water chemistry that plots closer to seawater on Piper diagrams than historical samples.
- Stiff diagrams for sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) show a chloride spike somewhat similar to Stiff diagrams of seawater intruded wells in the Salinas Valley.
- July 2016 chloride concentrations in sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) are at 178 and 284 mg/L respectively. This is an increase of 112 mg/L for sentinel well SBWM-2 (1,470 ft) over the past water year and 26 mg/L for sentinel well SBWM-4 (900 ft) from February 2016 to July 2016.
- The sodium/chloride molar ratios of both SBWM-2 (1,470 ft) and SBWM-4 (900 ft) have dropped, but are not below 0.86.
- Groundwater elevations in sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) are at historical lows.
- Maps of chloride concentrations for the deep aquifer show chlorides increasing towards the coast.

Data which are indicative of seawater intrusion not occurring is 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 does not show changes indicative of seawater intrusion.
- Other than the sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) samples, no other monitoring or production wells in the basin have water quality that is indicative of seawater intrusion.

Because of the conflicting data no conclusions with regard to the initial onset of seawater intrusion can be drawn at this time. Verification resampling, as contained in the Recommendations section of this report, will be necessary in order to reach a conclusion.

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

- Northern Coastal subarea groundwater levels in the deep aquifer remain below sea level (Figure 29 and Figure 31). The 4th quarter deep aquifer groundwater levels along the coast are in some cases greater than 30 feet below sea level and are at historical lows.
- Groundwater levels remain below protective elevations in all deep target monitoring wells (MSC deep, PCA-W, 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.
- Groundwater production in the Seaside Groundwater Basin for Water Year 2016 was 2,913.5 acre-feet, which is 848.5 acre-feet less than Water Year 2015. This amount is less than the Court-mandated operating yield of 3,920 acre-feet per year that is required between October 1, 2014 and September 30, 2017, and the current safe yield of 3,000 acre-feet. Although pumping in Water Year 2016 was below the current safe yield, many groundwater elevations in deep monitoring wells continue to decline. It seems likely that the long-term effects of pumping over the safe yield and the dry climatic conditions of the past five years have a greater impact on groundwater levels than one year of reduced pumping,

Due to its long distance from the coast, seawater intrusion is not an issue of concern in the Laguna Seca subarea. However, groundwater levels in the Laguna Seca subarea are continuing to decline at the same rate since 2001 despite triennial reductions in allowable pumping. The shallow groundwater levels are declining at a rate of approximately 0.6 feet per year, while the deep groundwater levels in the eastern portion of the subarea are declining at a much faster rate of between two and three feet per year. 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.

Based on the findings of this report, the following recommendations should be implemented to continue to monitor and track potential seawater intrusion, and to verify recent results in sentinel wells SBWM-2 and SBWM-4.

1. **Verification Water Quality Sampling and Analysis for Sentinel Well SBWM-2, Sentinel Well SBWM-4, and the Ord Terrace Shallow Monitoring Well**

   Analysis of two samples, one from sentinel well SBWM-2 (1,470 ft) and one from SBWM-4 (900 ft), provided data that are in conflict with other types of data from these wells and from other wells in the vicinity in terms of drawing any conclusions regarding seawater intrusion. Additionally, increasing chlorides have been observed at the Ord Terrace Shallow well; although other geochemical evidence suggests this may not be incipient seawater intrusion. In accordance with the Watermaster's Seawater Intrusion Response Plan (SIRP), these wells should be resampled immediately to determine if the data from these two samples are valid, or whether the July 2016 samples experienced analytical errors or were not representative samples. Re-sampling should include the full suite of major cations and anions, which will allow all of the indicators used in this SIAR to be verified. Laboratory analyses should be conducted with an expedited turnaround time.

2. **Potentially Analyze Additional Water Quality Constituents for Seawater Intrusion**

   Depending on the results of the verification sampling, the Watermaster may wish to begin to regularly analyze additional water quality constituents: iodide, bromide, boron, and barium in wells that indicate incipient seawater intrusion.

3. **Increase Water Quality Sampling and Analysis for Sentinel Well SBWM-2**

Currently sentinel wells SBWM-1 and SBWM-4 are sampled twice a year, in the 2nd and 4th quarters. If verification sampling shows the sentinel well SBWM-2 has elevated chloride concentrations, at the very least this well should be sampled twice a year, in the 2nd and 4th quarters.

4. **Potentially Increase Water Quality Sampling and Analysis for Sentinel Well SBWM-2 and SBWM-4**

   Depending on the results of verification sampling, the Watermaster may wish to increase the sampling frequency of SBWM-2 and SBWM-4 to more frequently than twice a year. If indeed the chloride concentrations at these wells are increasing rapidly, monthly sampling may be needed.

5. **Potentially Implement Follow up Actions Outlined in the Seawater Intrusion Response Plan**
   If verification sampling indicates that incipient seawater intrusion is occurring along the coast, additional actions that are outlined in the SIRP will need to be implemented. These actions need not be implemented if verification sampling does not indicate incipient seawater intrusion.

6. **Install a Data Logger in the monitoring well, PCA West Shallow**
   The PCA West Shallow well is a coastal monitoring well that is an important part of the monitoring system for the basin and is one of the wells used to monitor protective groundwater elevations. Because of limited access to this well site, groundwater levels were not measured this water year. A dedicated logger, like that installed in PCA West Deep, at this well will continuously record groundwater levels much more reliably.

7. **Continue to Document Declining Groundwater Levels in the Laguna Seca Subarea**
   Although this recommendation is not one that is related to seawater intrusion because of the inland location of the wells, it is important for the sustainability of the groundwater basin. The state of groundwater levels in monitoring wells in the Laguna Seca subarea needs to be reported at least annually to the Watermaster. The current rate of decline, particularly in the eastern portion of the subarea, is not acceptable. For the sustainability of the subarea, the Watermaster should consider options in the next water year to address the situation.

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 tenth 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.

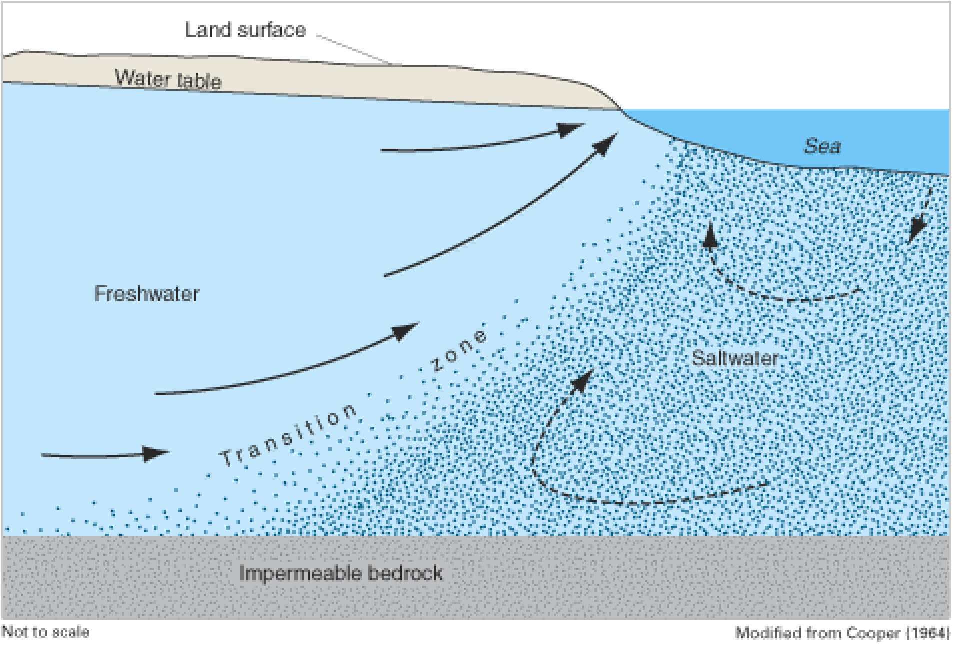


Figure 1: Seawater Wedge in a Simple Coastal Aquifer (from Barlow, 2003)

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.

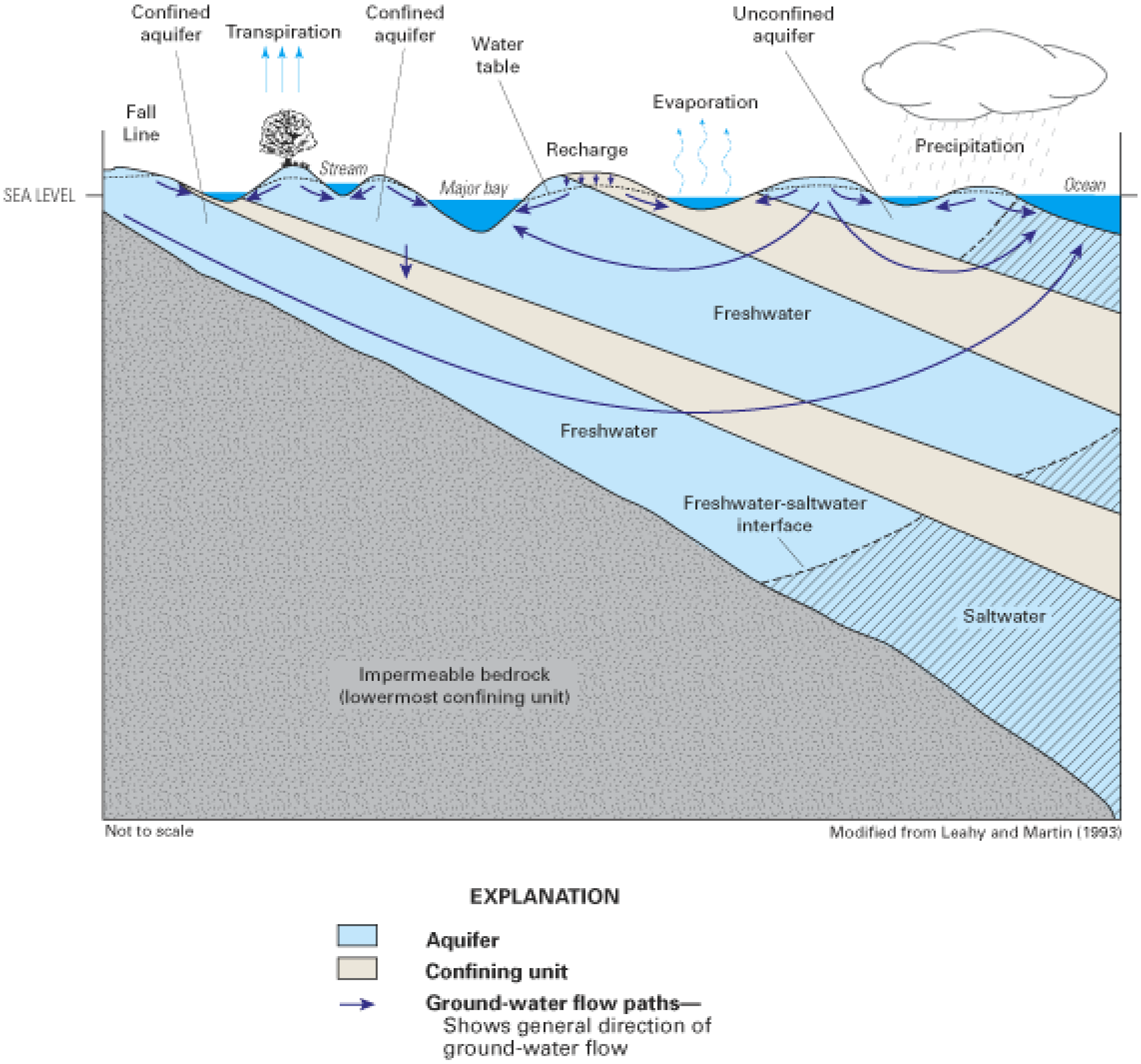


Figure 2: Seawater Wedge in a Layered Coastal Aquifer (from Barlow, 2003)

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.

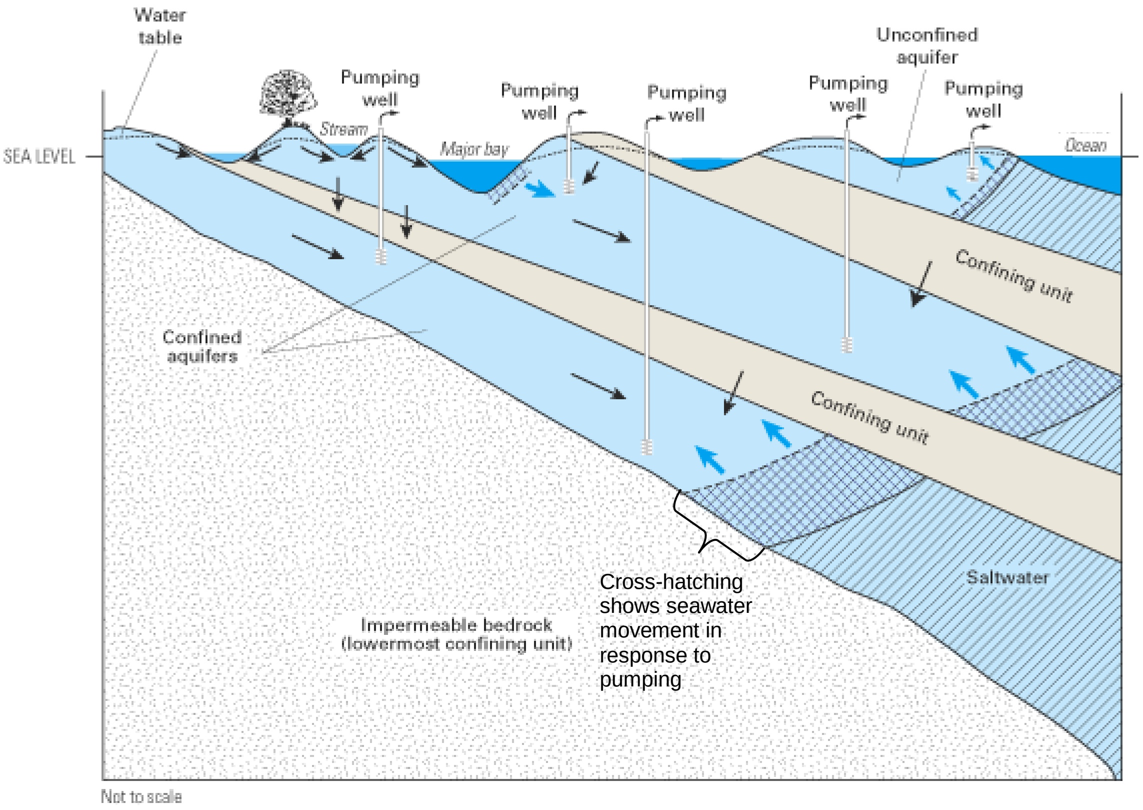
GROUNDWATER PUMPING AND SEAWATER INTRUSION

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.



Cross-hatching shows seawater movement in response to pumping

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 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 16.

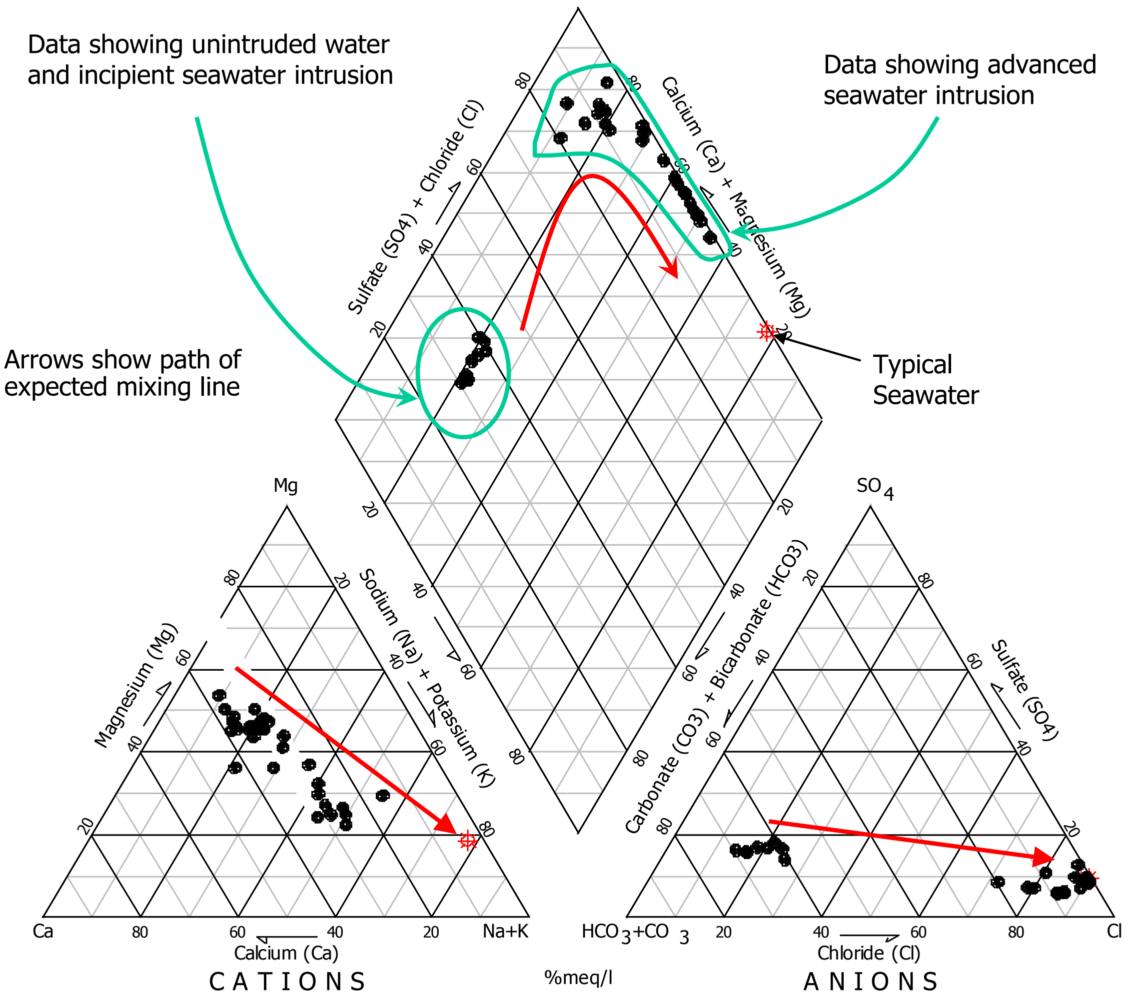


Figure 4: Piper Diagram for Groundwater in Pajaro Valley (Data source: PVWMA)

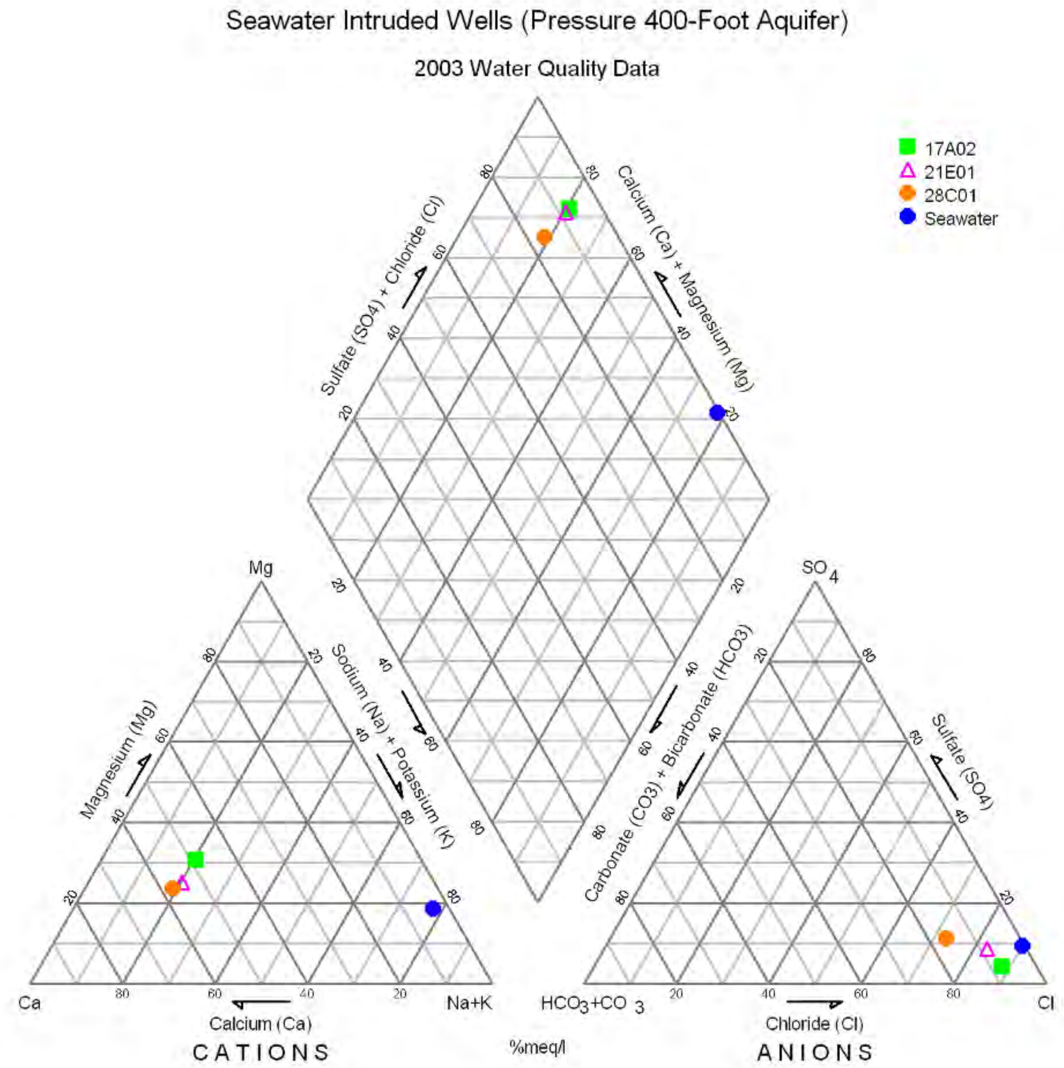


Figure 5: Piper Diagram for Groundwater in Salinas Valley (Source: MCWRA)

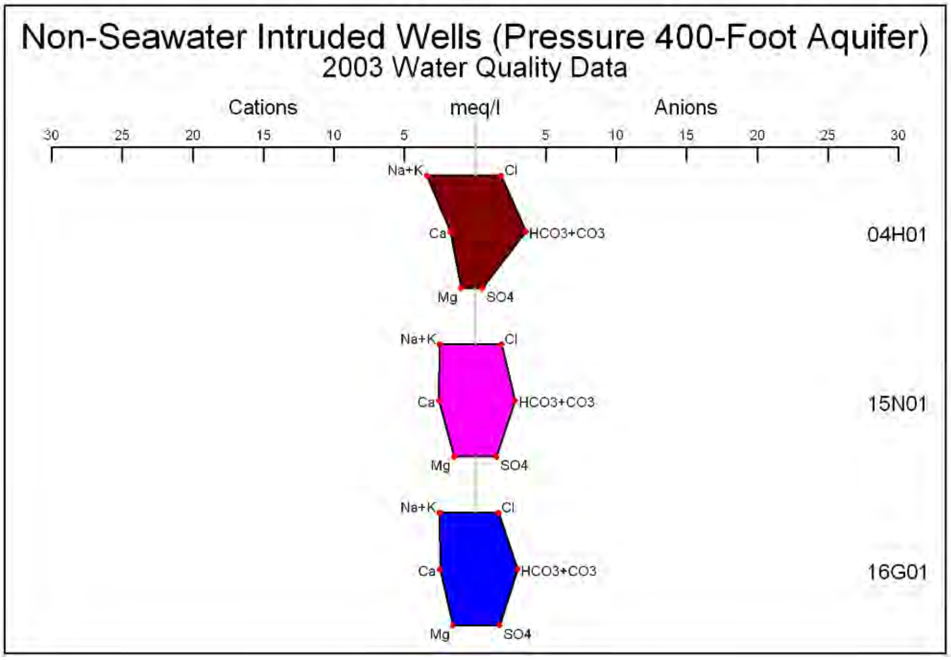


Figure 6: Stiff Diagrams from Salinas Valley Wells without Seawater Intrusion
(Source: MWCRA)

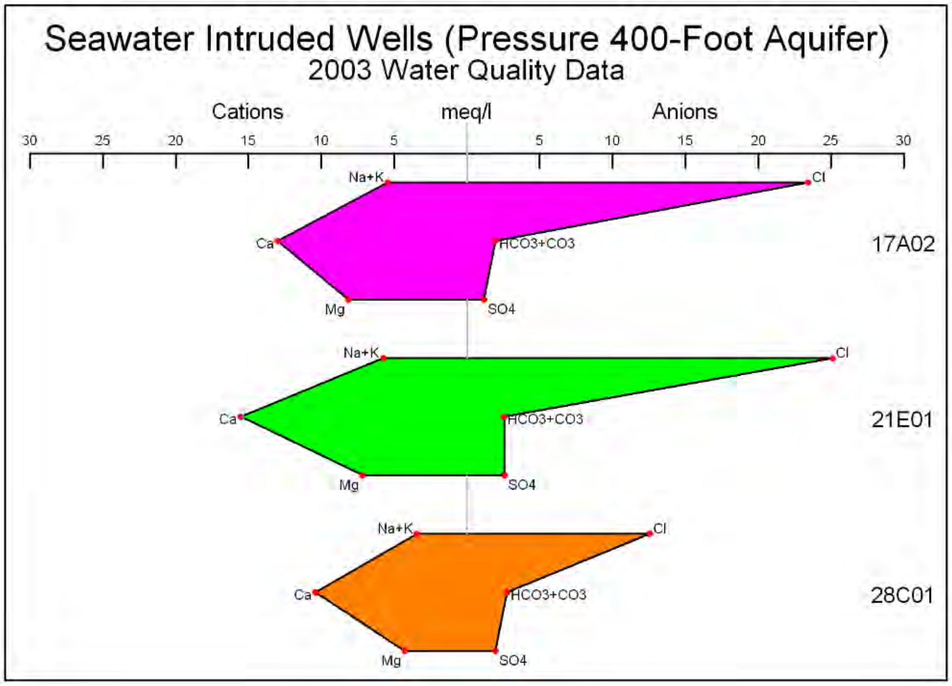


Figure 7: Stiff Diagrams from Salinas Valley Wells with Seawater Intrusion
(Source: MWCRA)

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.

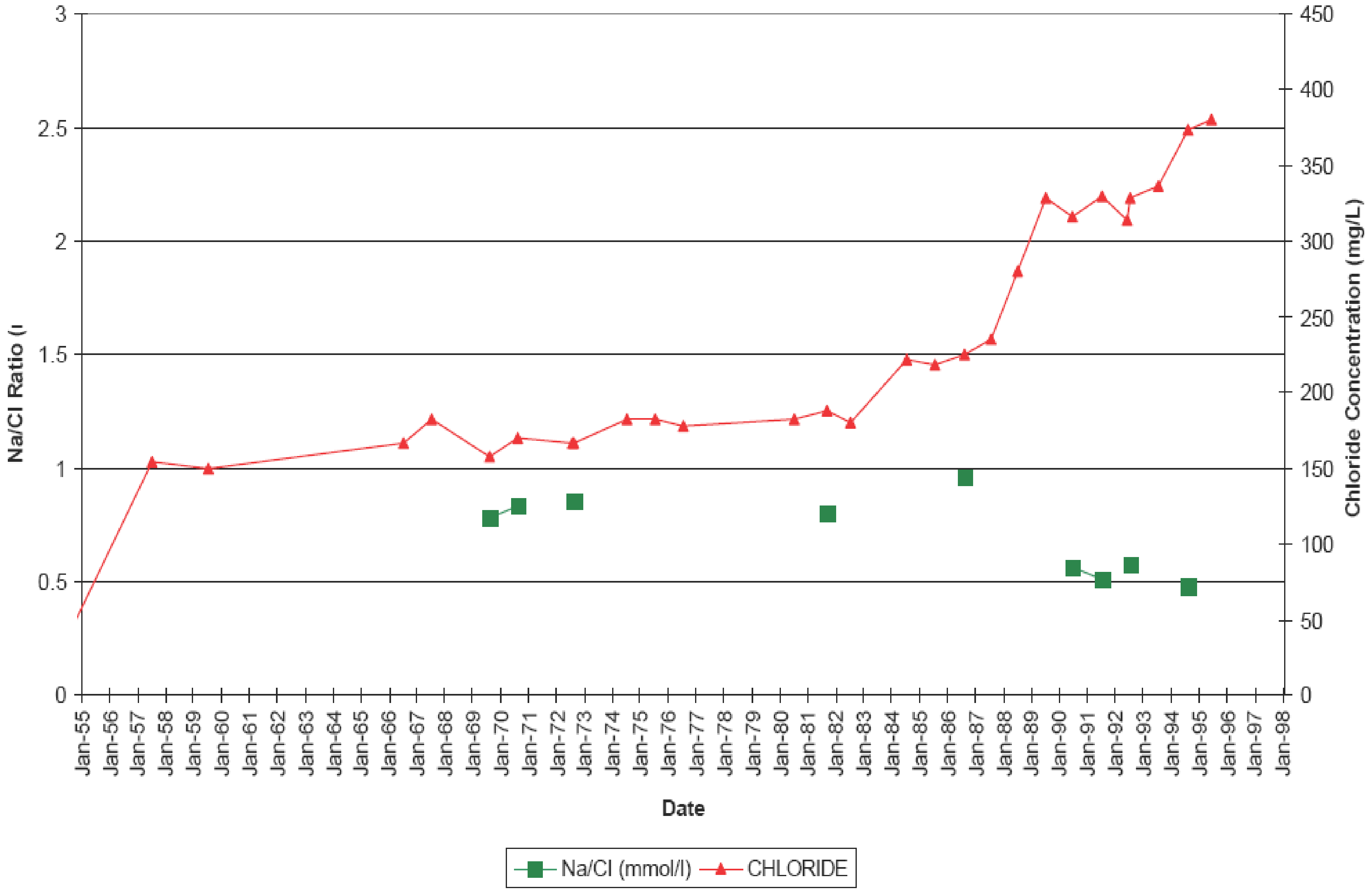


Figure 8: Historical Chloride Concentrations and Sodium/Chloride Ratios for a Well in Salinas Valley Showing Incipient Intrusion (Source: MCWRA)

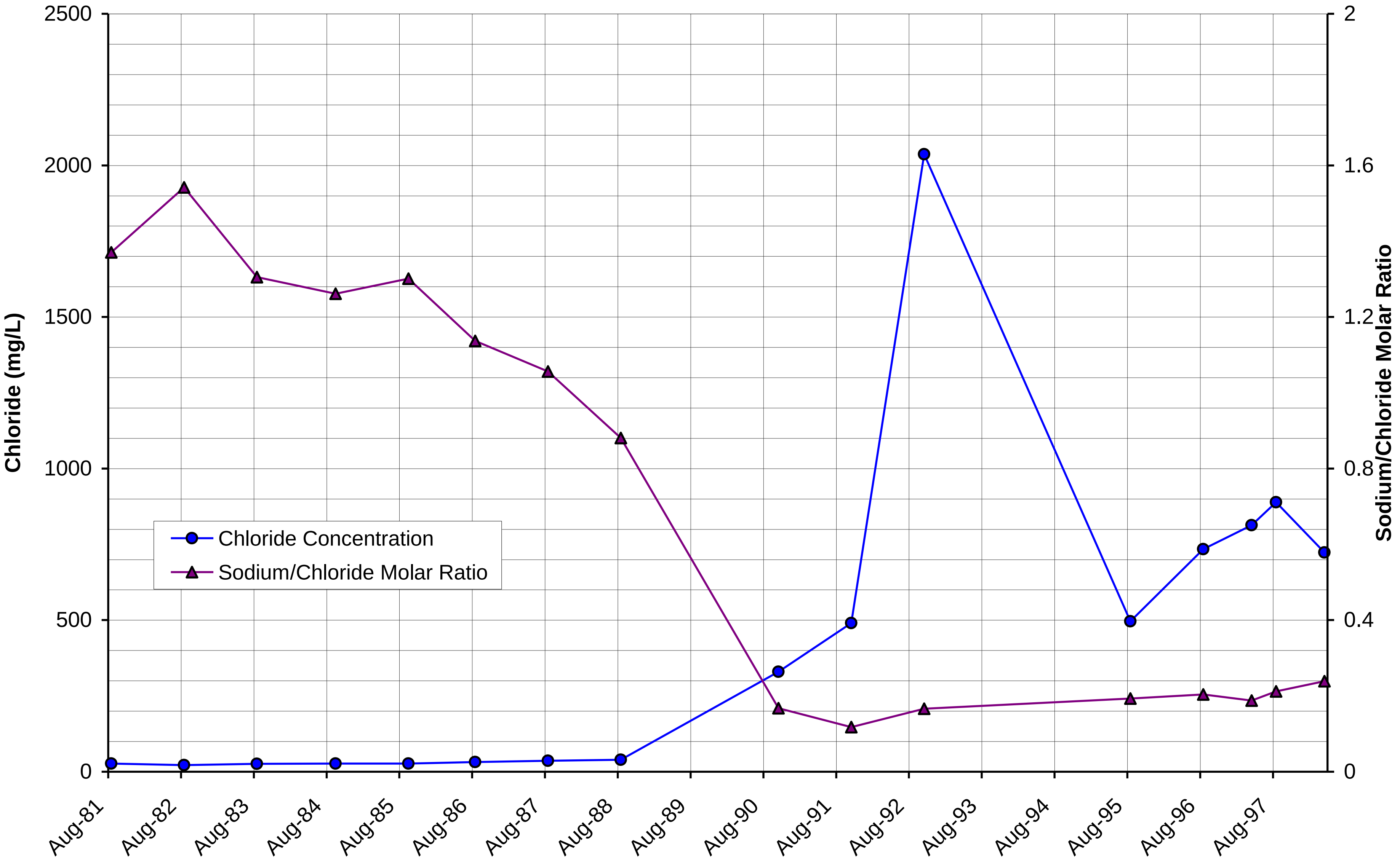


Figure 9: Historical Chloride Concentrations and Sodium/Chloride Ratios for a Well in Pajaro Valley Showing Incipient Intrusion (Data source: PVWMA)

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), this report includes a number of approaches to evaluate seawater intrusion. Data for the 2nd quarter of Water Year 2016 (sampled and measured January-March 2015) and 4th quarter of Water Year 2016 (sampled and measured July-September 2015) 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 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 were 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 Deep Aquifer.

CATION/ANION RATIOS

For Water Year 2016, 16 monitoring wells and 15 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 16 monitoring wells, four are the deep sentinel wells installed by the Watermaster in 2007. Eleven monitoring wells used in this analysis represent one or both well pairs from the MPWMD monitoring well network and two are observation wells (Figure 10). MPWMD uses the deep monitoring well at Seaside Middle School for ASR reporting purposes to the Regional Water Quality Control Board; if there has been no injection during the year, no water quality sample is collected. This year, a sample was collected in June.

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.

SECOND QUARTER WATER YEAR 2016 (JANUARY-MARCH 2016)

A Piper diagram displaying analyses from nine monitoring wells in the Seaside Groundwater Basin for the 2nd quarter Water Year 2016 (January-March 2016) is shown on Figure 11. Analyses from only nine wells are shown because most of the monitoring well pairs, and all but one production well, 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 show their chemical nature 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[1].

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[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.

Stiff diagrams for the monitoring wells sampled during the 2nd quarter of Water Year 2016 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. However, sentinel well SBWM-4 (900 ft)'s Stiff diagram does have a very different shape to that observed historically. The rest of the shapes of the Stiff diagrams for the paired monitoring wells in the Northern subarea are similar to the shapes of the 4th quarter 2015 and earlier data.

FOURTH QUARTER WATER YEAR 2016 (JULY-SEPTEMBER 2016)

Piper diagrams displaying groundwater quality data from 16 monitoring wells and 15 production wells in the Seaside Groundwater Basin for the 4th quarter of Water Year 2016 (July-September 2016) 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, 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 4th quarter Water Year 2015 and the 2nd quarter of Water Year 2016. This groundwater is generally of a sodium-chloride/sodium-bicarbonate type and is not impacted by seawater.

The deepest samples from sentinel wells SBWM-1 (1,470 ft) and SBWM-4 (900 ft), however, show a significant change from other wells and their own historical results. The most recent samples from these two wells plot closer to where seawater typically plots than the other samples (Figure 16). Appendix A's Figure A-16 and Figure A-20 show the historical piper diagrams for sentinel wells SBWM-1 (1,470 ft) and SBWM-4 (900 ft), respectively. These two Piper diagrams show that the most recent sample from these two wells plot closer to where seawater typically plots than previous samples.

Figure 17 presents a Piper diagram for 4th quarter groundwater samples from production wells. The production wells plot in roughly the same location on the Piper diagram as the 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 16 monitoring wells sampled during the 4th quarter of Water Year 2016 are shown in the right column on Figure 12 through Figure 15. With the exception of sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft), the shapes of the Stiff diagrams for the paired monitoring wells are similar to the shapes of the Stiff diagrams from previous years. Stiff diagrams for sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) both have a large spike in sodium and chloride in the 4th quarter (Figure 14 and Figure 15, respectively). Although this shape is not exactly the same as Stiff diagrams in the seawater intruded part of the Salinas Valley (Figure 7), the increase in the chloride ion is significant and resampling for all anions and cations should be carried out as soon as possible.

Stiff diagrams for the 15 production wells sampled during the 4th quarter of Water Year 2016 are shown in the right column on Figure 18 through Figure 20. These production well Stiff diagrams show no significant changes from the shapes observed in the 2nd quarter of Water Year 2016, the 4th quarter of Water Year 2015, 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.

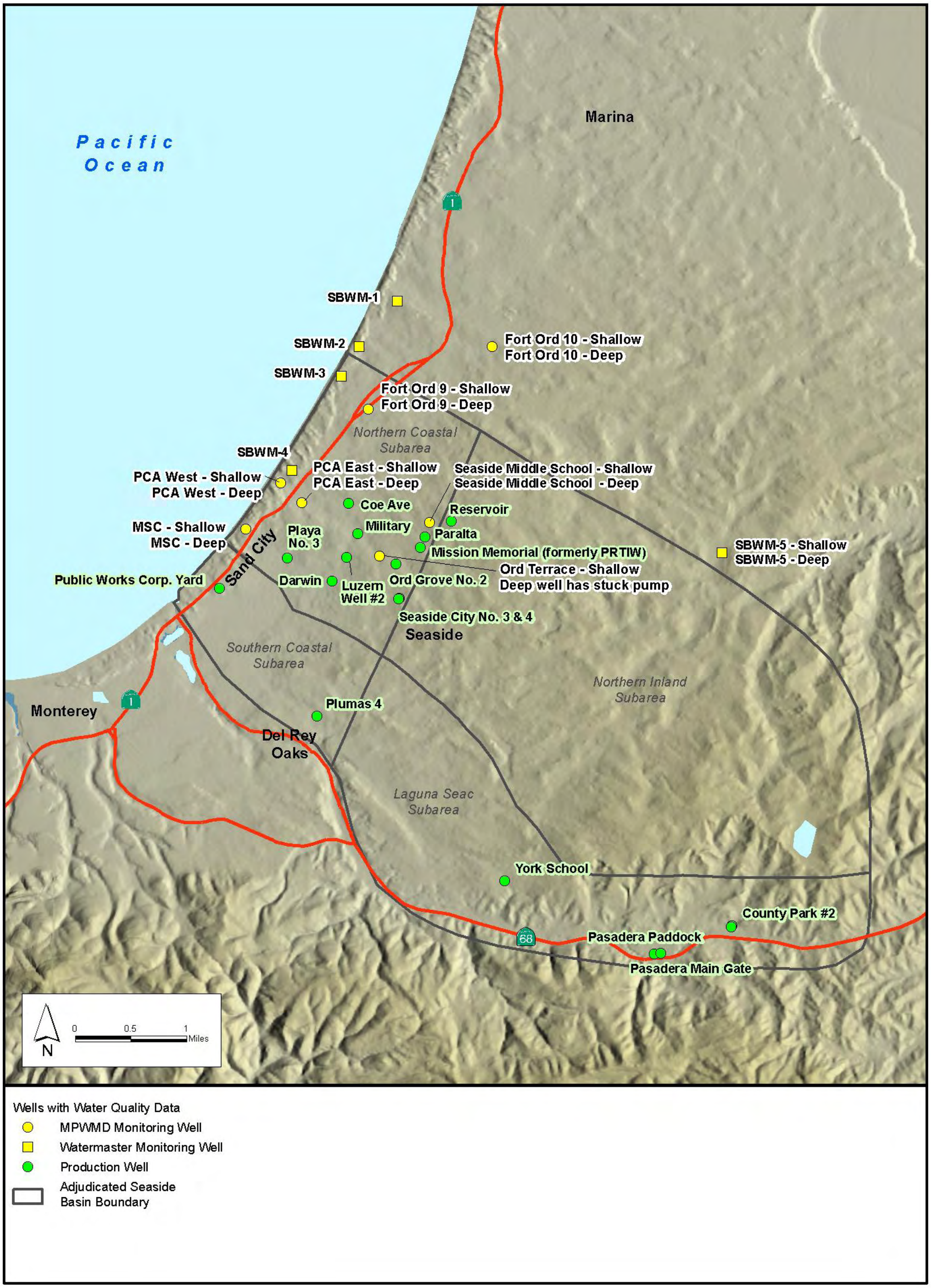


Figure 10: Wells Used for Seawater Intrusion Analyses

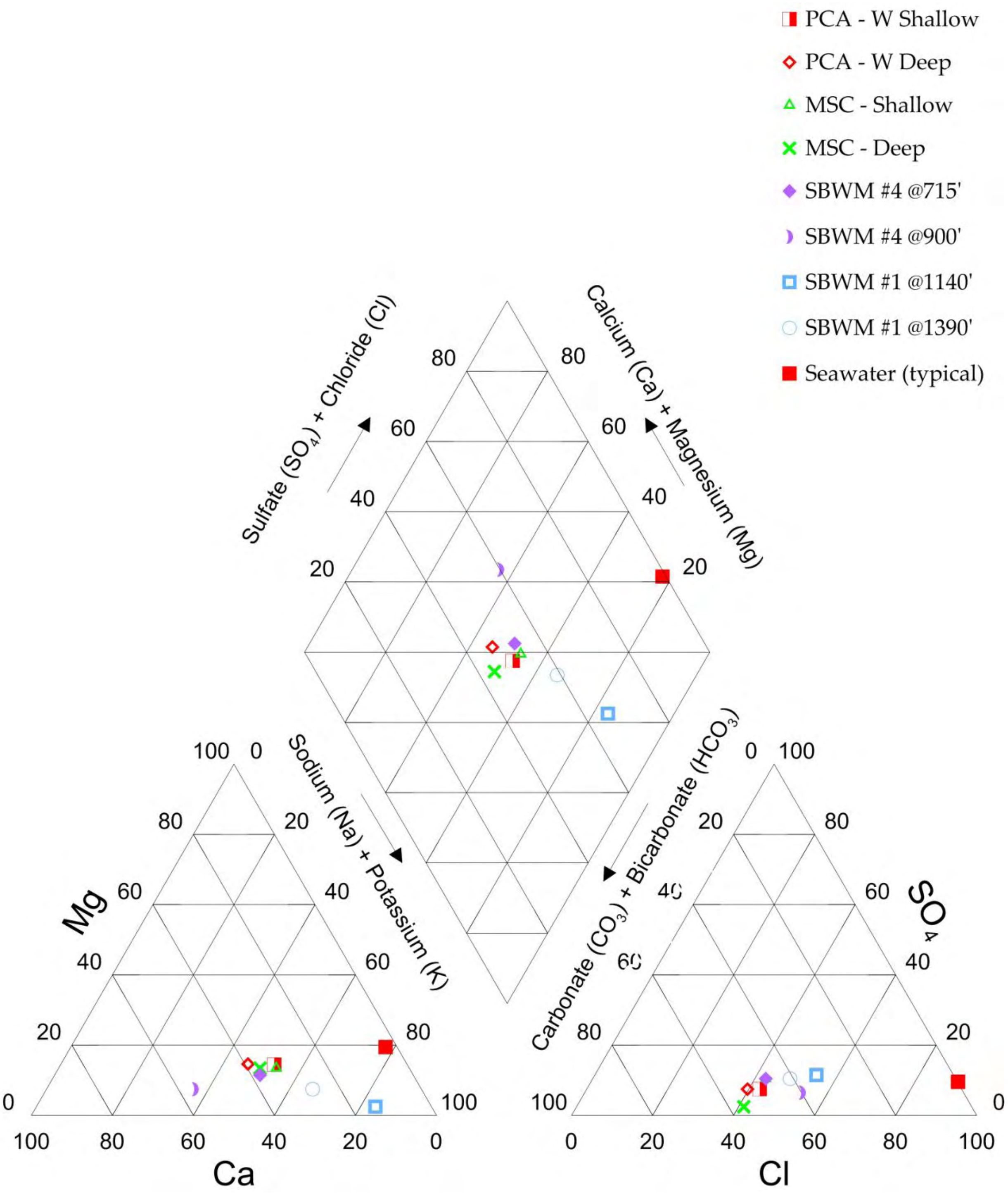


Figure 11: Piper Diagram for Seaside Groundwater Basin Monitoring Wells, 2nd Quarter Water Year 2016 (January-March 2016)
(Data source: Watermaster)

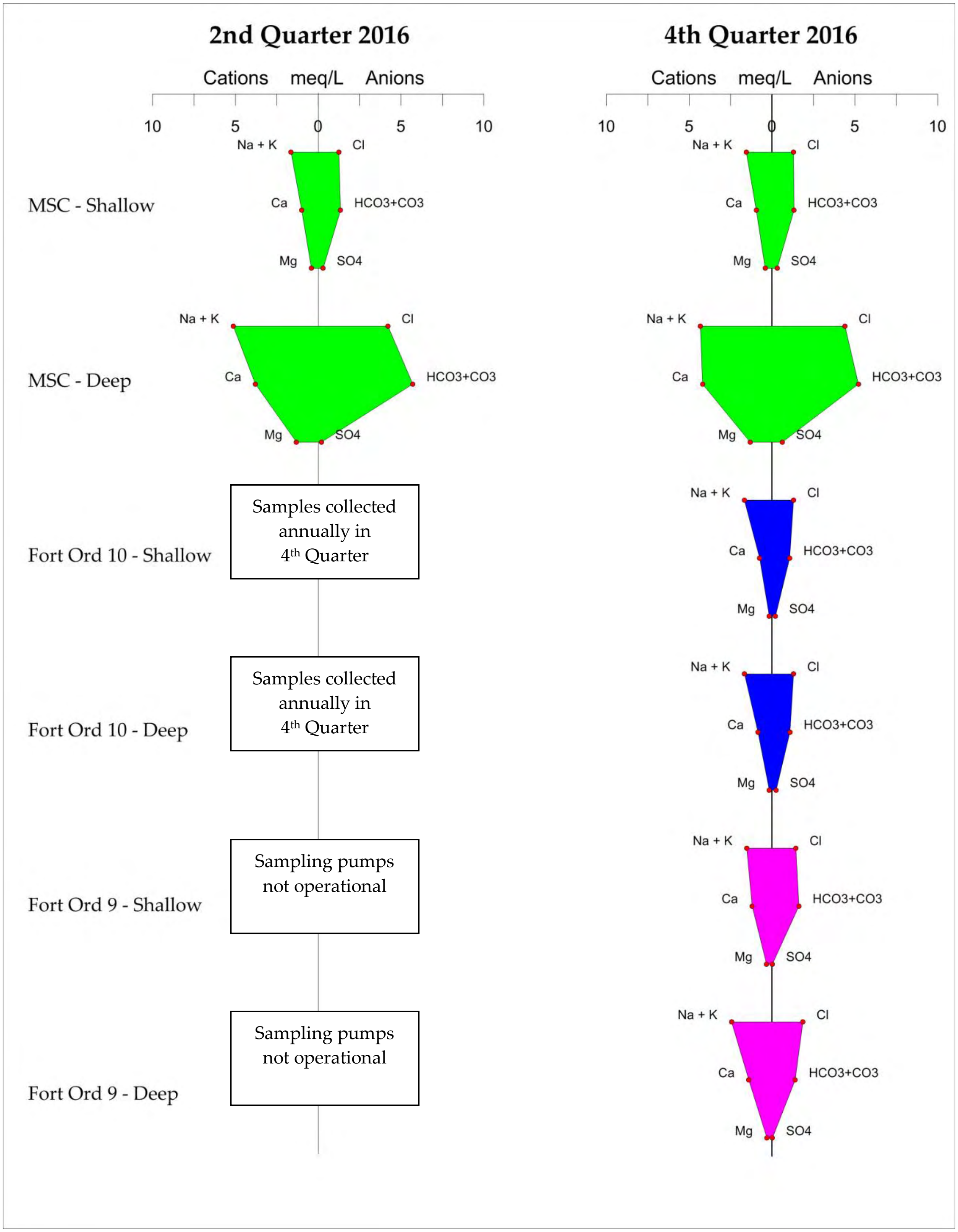
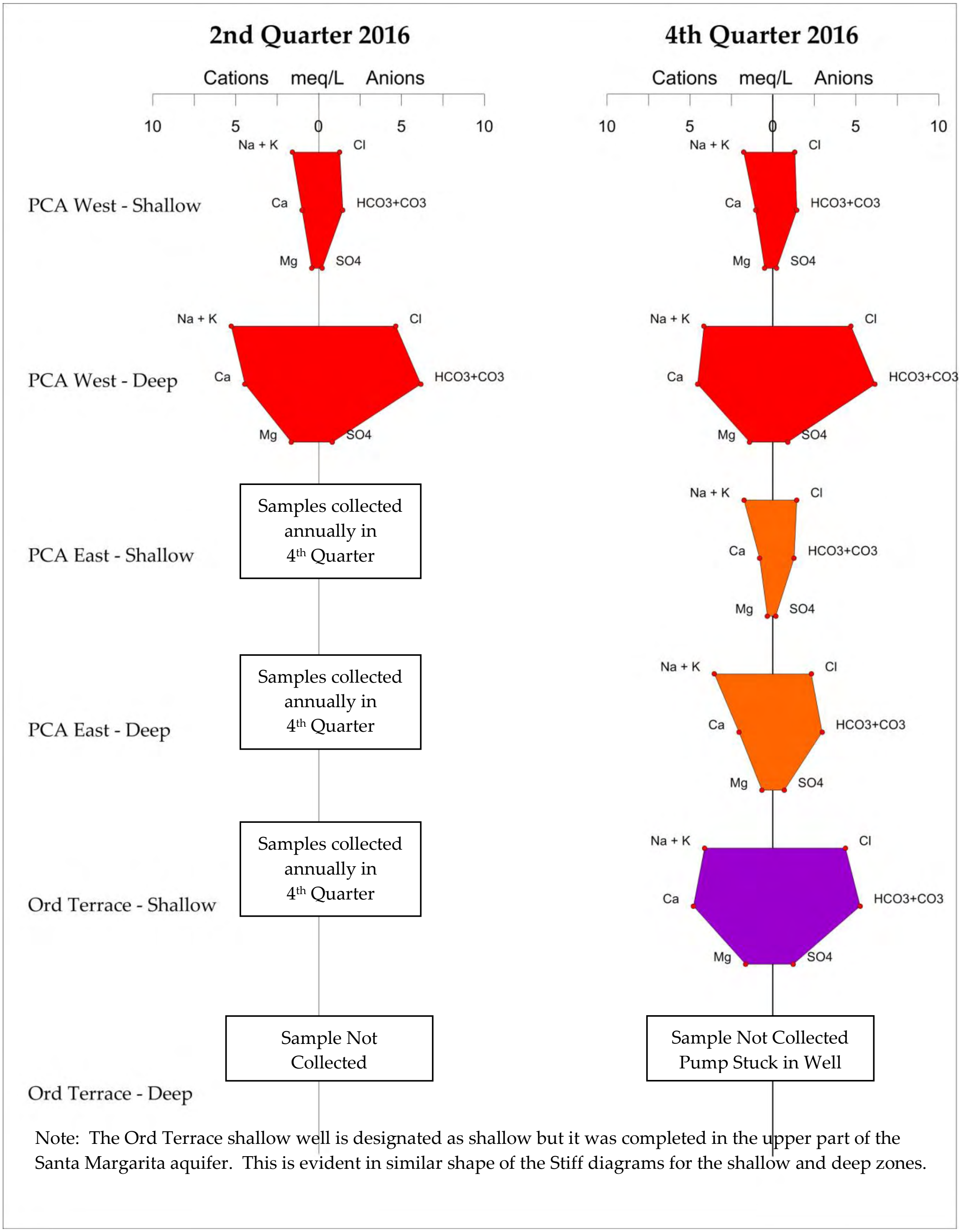

2nd Quarter 2016
4th Quarter 2016
Cations meq/L Anions
10 5 0 5 10
Na + K
Cl
Ca
HCO3+CO3
Mg
SO4
MSC - Shallow
MSC - Deep
Fort Ord 10 - Shallow
Fort Ord 10 - Deep
Fort Ord 9 - Shallow
Fort Ord 9 - Deep
Samples collected annually in 4th Quarter
Sampling pumps not operational

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



Note: The Ord Terrace shallow well is designated as shallow but it was completed in the upper part of the Santa Margarita aquifer. This is evident in similar shape of the Stiff diagrams for the shallow and deep zones.

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

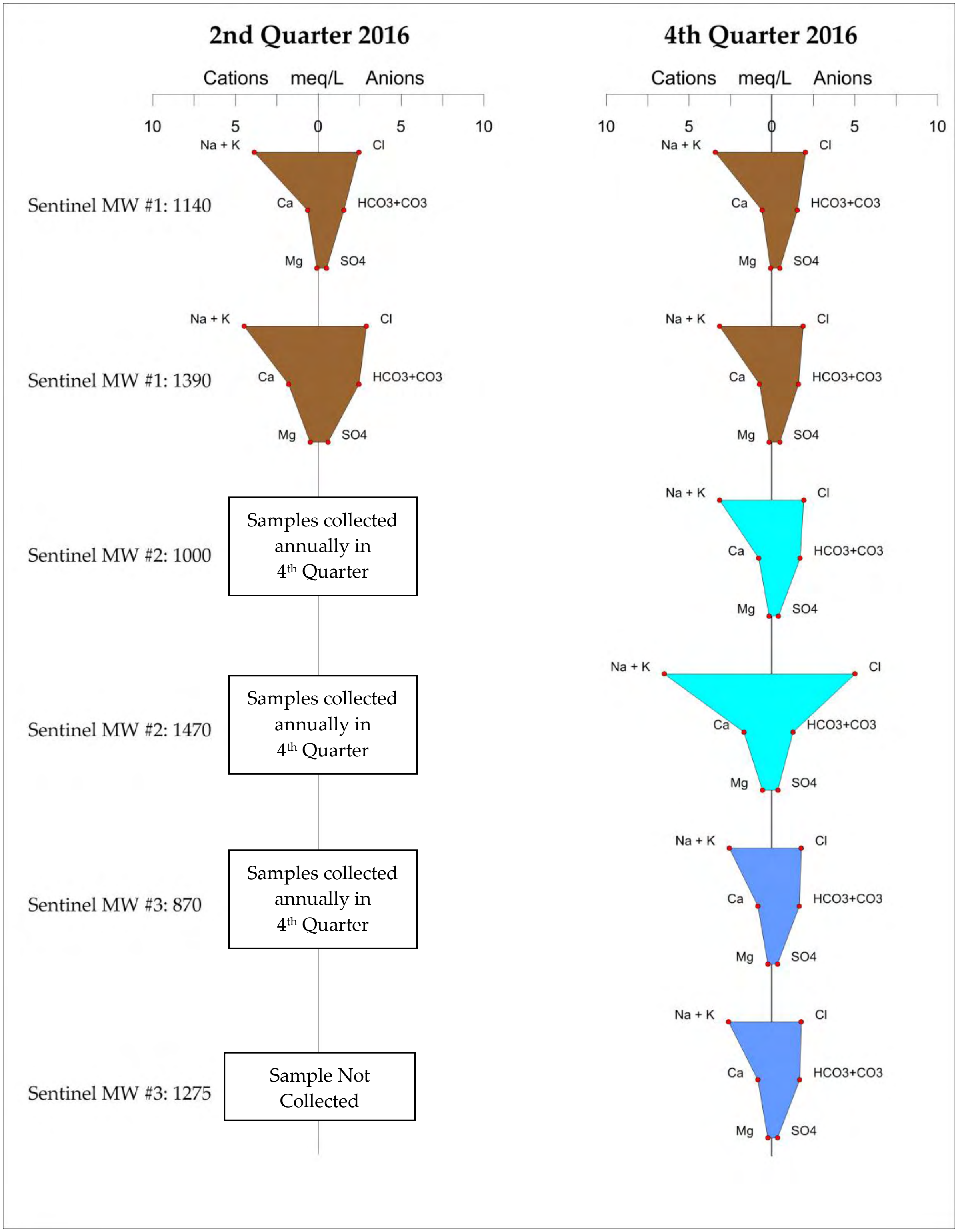


Figure 14: Stiff Diagrams for Watermaster Sentinel Wells 1 - 3 (Data source: Watermaster)

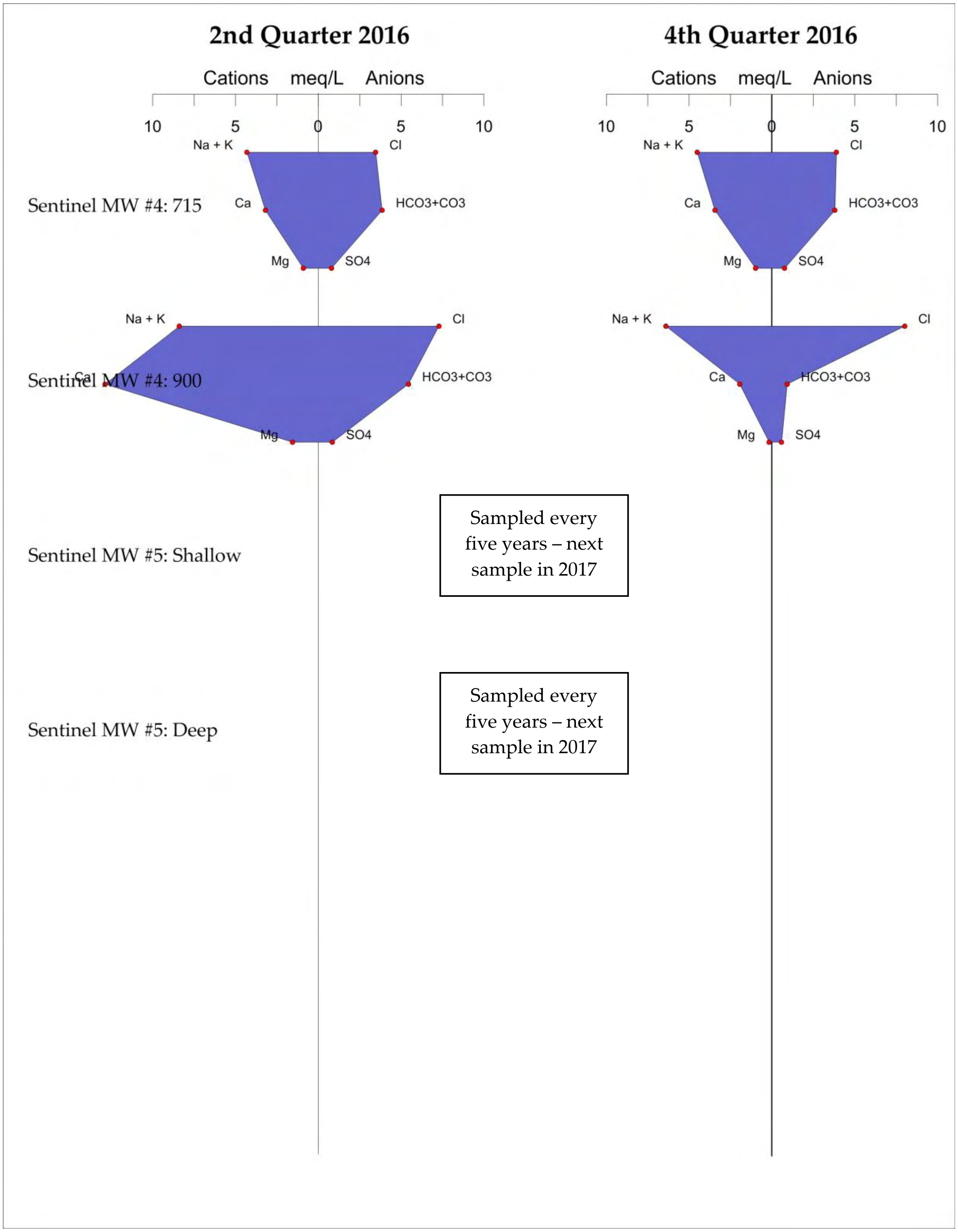
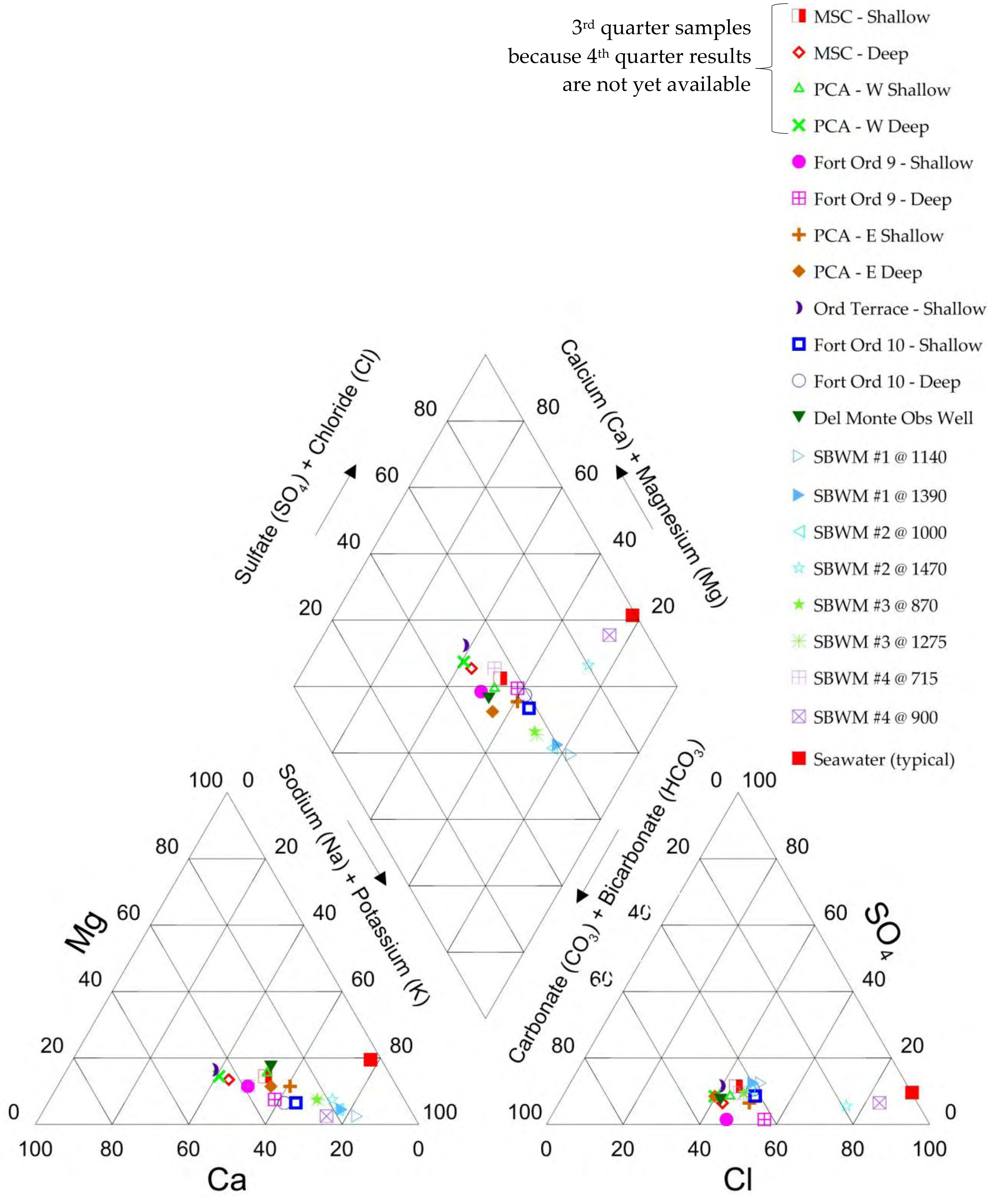


Figure 15: Stiff Diagrams for Watermaster Sentinel Wells 4 and 5
(Data source: Watermaster and MPWMD)



3rd quarter samples because 4th quarter results are not yet available

Figure 16: Piper Diagram for Seaside Groundwater Basin Monitoring Wells, 4th Quarter Water Year 2016 (July- September 2016)
(Data source: Watermaster)

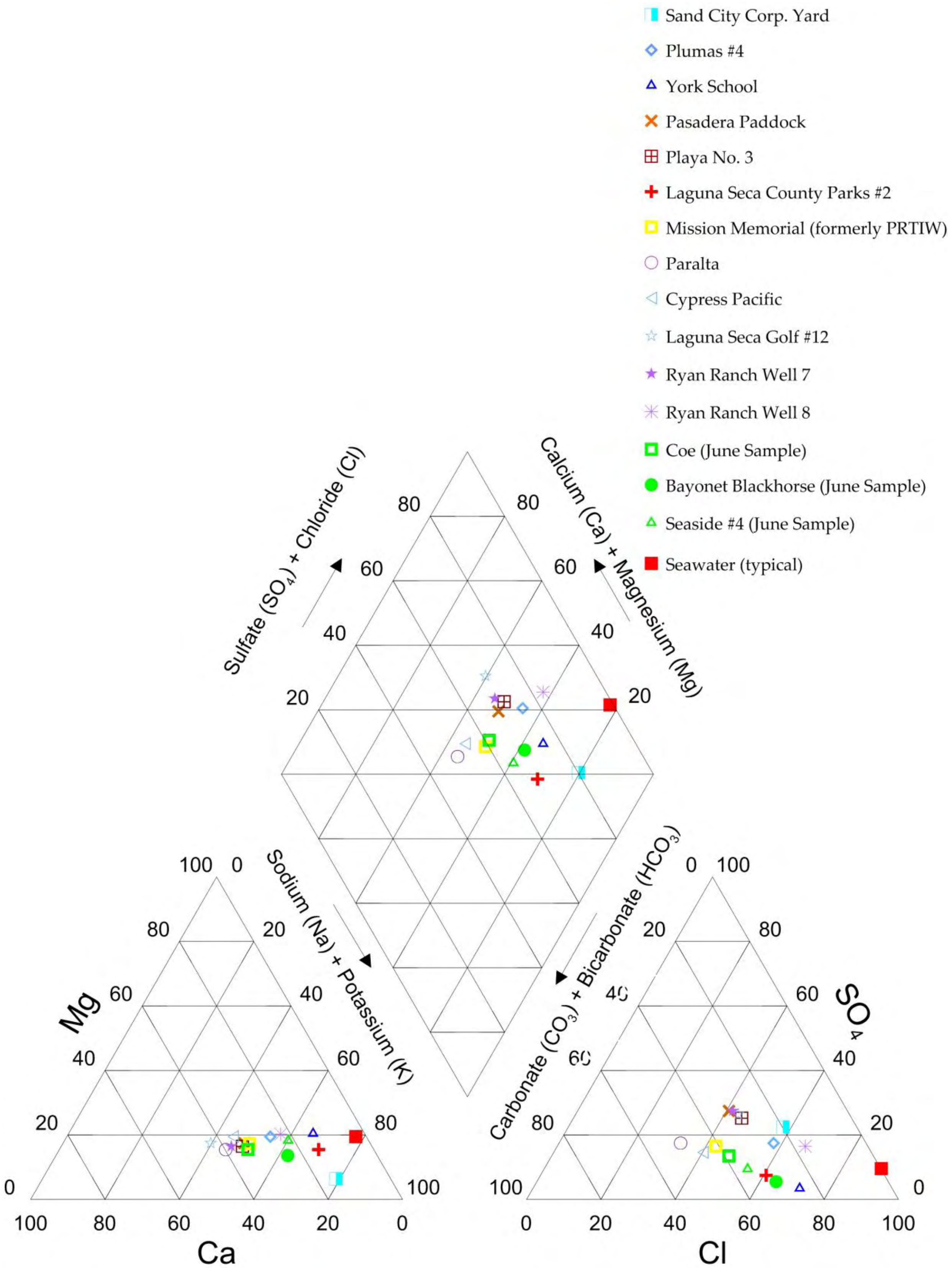


Figure 17: Piper Diagram for Seaside Groundwater Basin Production Wells, 4th Quarter Water

Year 2016 (July-September 2016)
(Data source: Watermaster)

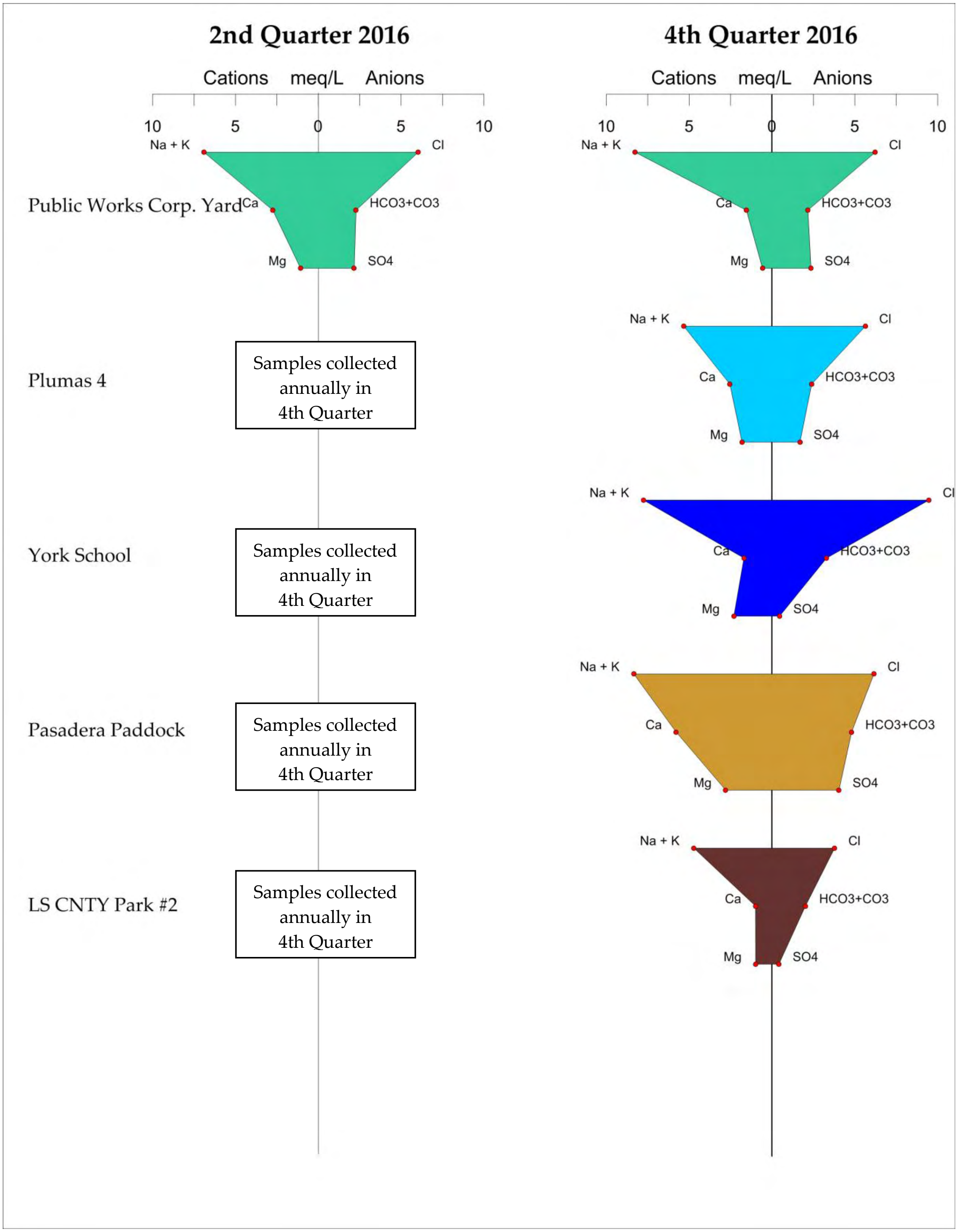


Figure 18: Stiff Diagrams for Southern Coastal and Inland Subarea Production Wells (Data source: Watermaster)

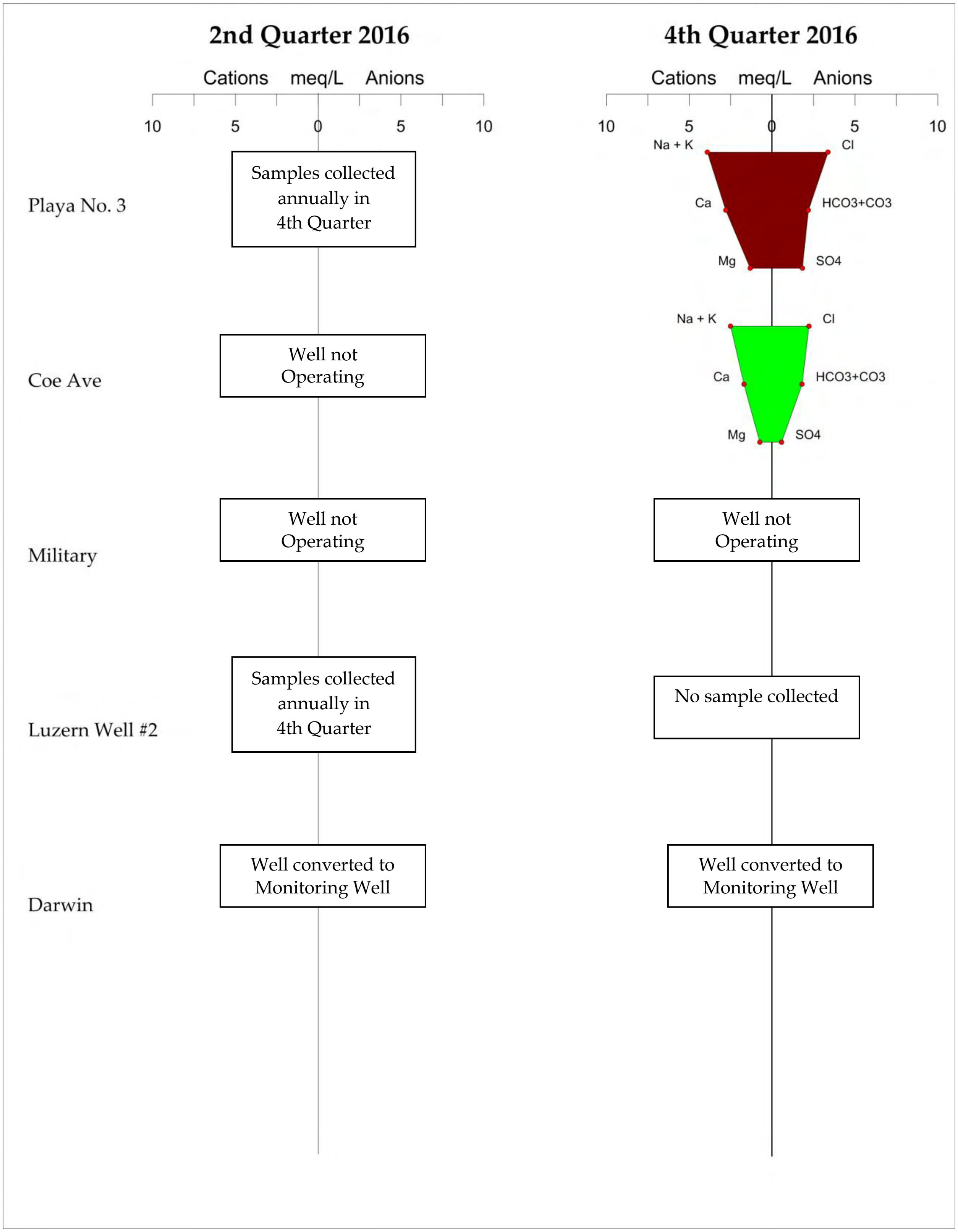


Figure 19: Stiff Diagrams for Northern Coastal Subarea Production Wells #1
(Data source: Watermaster)

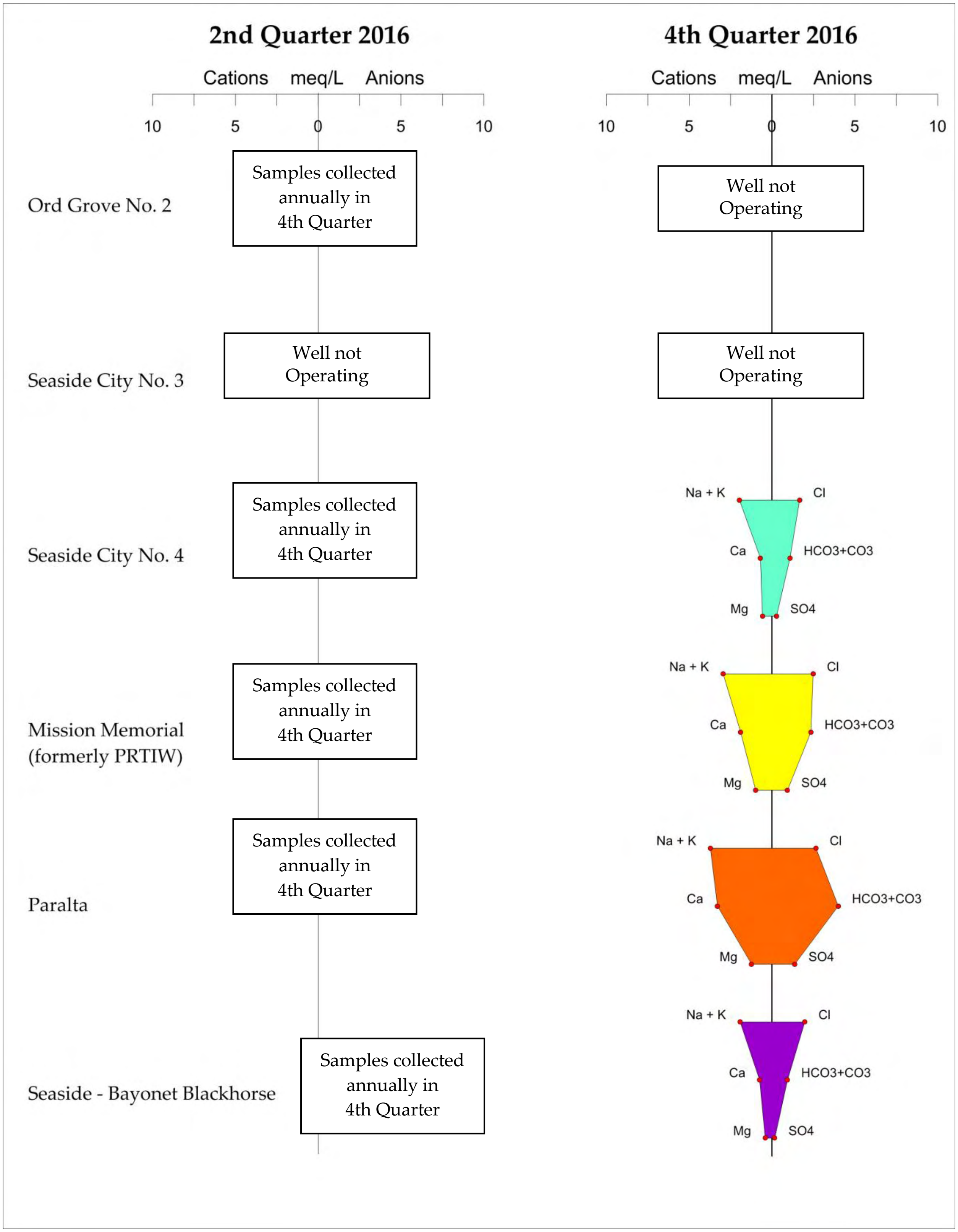


Figure 20: Stiff Diagrams for Northern Coastal Subarea Production Wells #2
(Data source: Watermaster)

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.

This year there are three monitoring wells that have chloride concentration increases of greater than 20 mg/L. These are the most significant chloride increases observed since monitoring and reporting of coastal water quality began. The wells are:

- The deep (1,470 ft) Sentinel well SBWM-2 chloride concentration increased from 66 mg/L in Water Year 2015 to 178 mg/L in Water Year 2016 (Appendix B: Figure B-16).
- The Ord Terrace shallow well continued its increasing trend that was observed last year; and increased an additional 43 mg/L in Water Year 2016 (Appendix B: Figure B-5).
- The deep (900 ft sample) sentinel well SBWM-4 chloride concentrations increased 26 mg/L over the period from the 2nd quarter (February) to the 4th quarter (July) L (Appendix B: Figure B-20).

Trends for the rest of 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. These wells are located north of the Seaside Groundwater Basin and are inland of SBWM-1 and SBWM-2 (Figure 10).

The increasing chloride trends in the SBWM-2 (1,470 ft), Ord Terrace shallow, and SBWM-4 (900 ft) monitoring wells suggests that verification sampling of these wells needs to take place as soon as possible. The cation and anion analysis of these three wells, however, indicates that only the two sentinel wells are showing water quality that is evolving towards seawater based on their most recent samples. Although the Ord Terrace shallow well has had an increase in chloride concentrations, its cations and anions do not suggest a seawater influence.

The higher than previous chloride concentrations of SBWM-2 (1,470 ft) and SBWM-4 (900 ft) along with cation/anion ratios are of concern and resampling should be performed as soon as possible to determine if the data from these samples are valid.

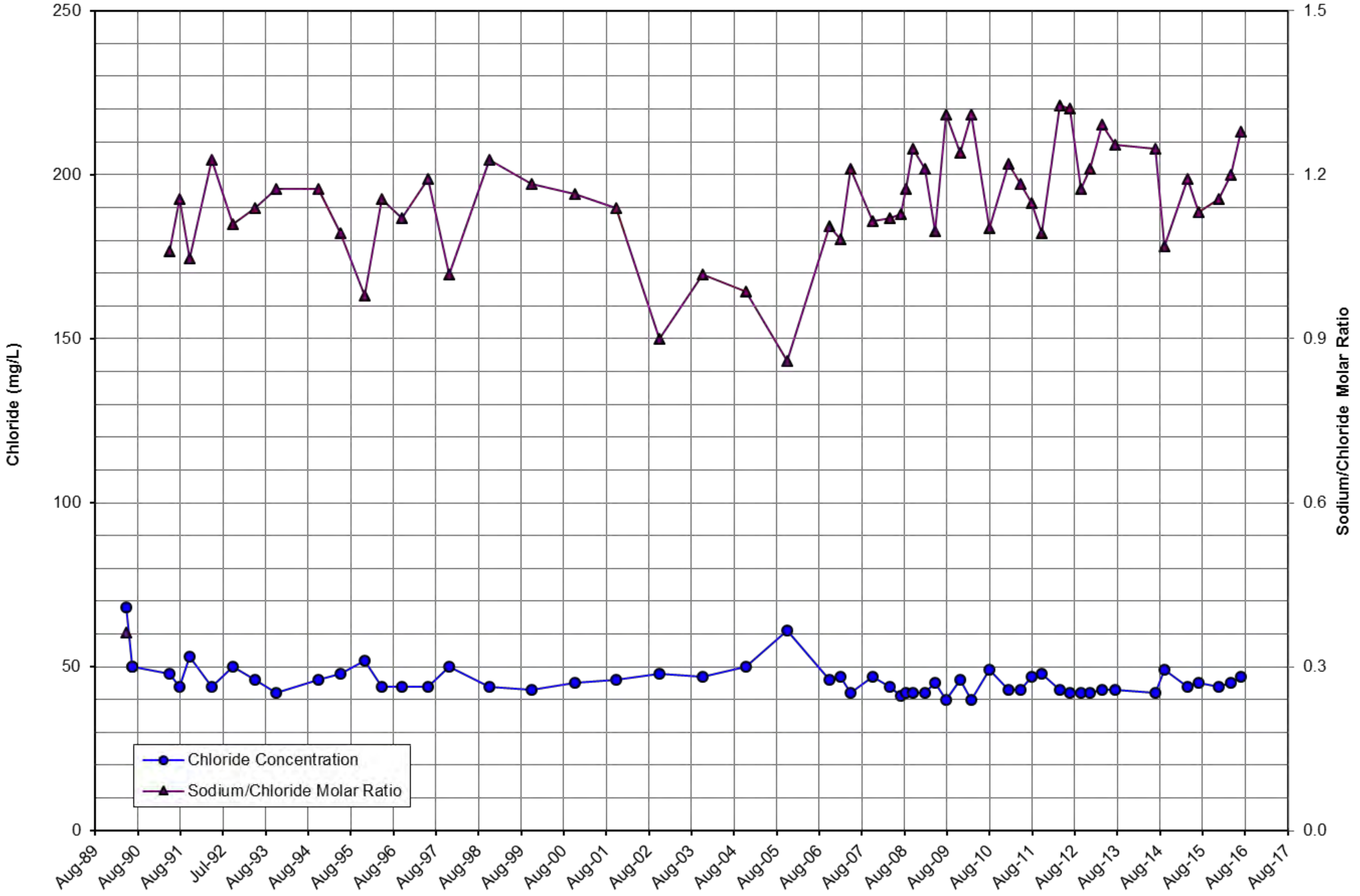


Figure 21: Historical Chloride and Sodium/Chloride Molar Ratios, Shallow PCA West Well

CHLORIDE CONCENTRATION MAPS

FOURTH QUARTER WATER YEAR 2015 (JULY-SEPTEMBER 2015)

Fourth quarter Water Year 2016 chloride concentrations were mapped using data from July through September 2016. The maps for the shallow and deep zones are included on Figure 22 and Figure 23 respectively.

The shallow zone 4th quarter Water Year 2016 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 the previous water year.

For the data available in the shallow zone, chloride concentrations near the coast 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 4th quarter Water Year 2016 chloride concentration map is shown on Figure 23. 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 have historically ranged between 63 mg/L and 260 mg/L, however, this year SBWM-2 (1,470 ft) has a concentration of 178 mg/L, which is an 112 mg/L increase. Additionally, as discussed above, SBWM-4 (900 ft) and Ord Terrace shallow monitoring wells have had significant chloride increases over the past year. These three wells are highlighted on Figure 23 with a different well symbol.

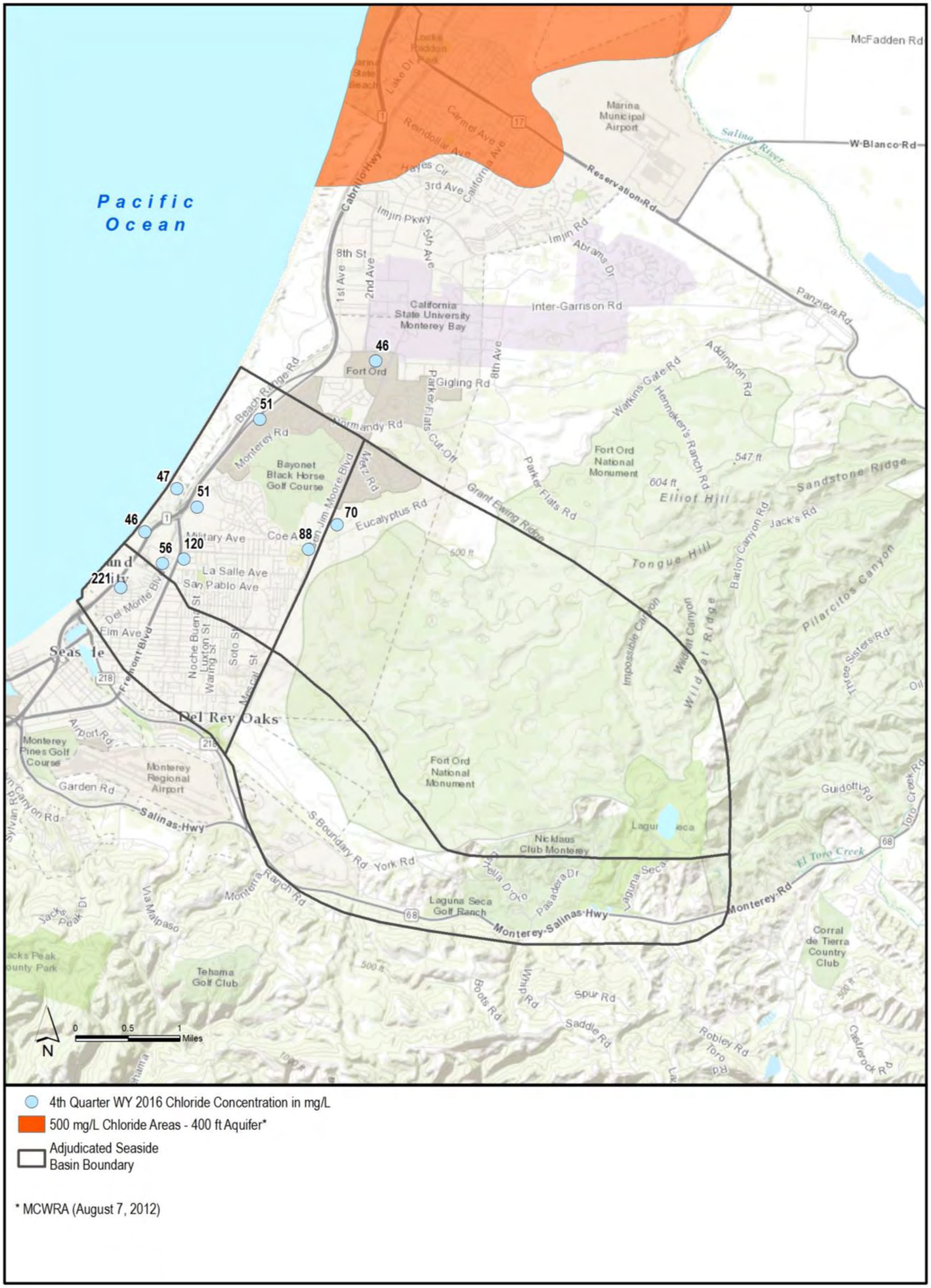


Figure 22: Shallow Zone Chloride Concentration Map – 4th Quarter WY 2016

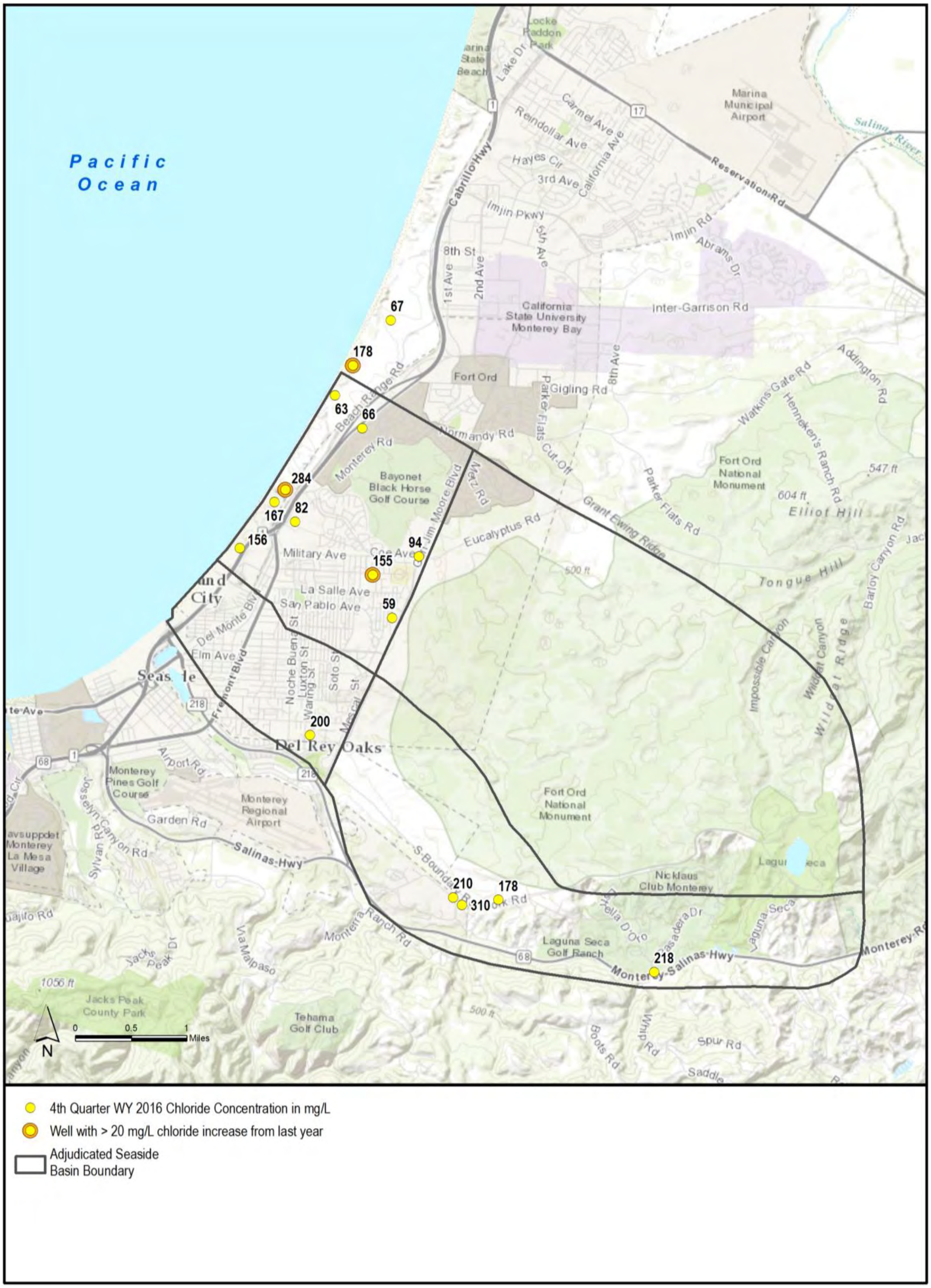


Figure 23: Deep Zone Chloride Concentration Map – 4th Quarter WY 2016

SODIUM/CHLORIDE MOLAR RATIOS

Chemographs showing sodium/chloride molar ratios over time are plotted for each of the 16 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 2016 Piper and Stiff diagrams because data are not available, are also included for completeness. An example plot displaying ratios for the shallow PCA West well is shown on Figure 21. The complete set of chemographs is included in Appendix B.

Most of the sodium/chloride molar ratios remained constant or increased over the past year. However, sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900), and the Ord Terrace shallow monitoring well had decreasing sodium/chloride molar ratios, corresponding with increased chloride over the past water year. Of the three wells of concern this year, none have sodium/chloride molar ratios that are 0.86 or less. The rest of the wells, including Ord Terrace shallow and Sand City Public Works Corp Yard production well have ratios consistently above 0.9 and no sustained decreasing trends.

Verification sampling of the SBWM-2 (1,470 ft), Ord Terrace shallow, and SBWM-4 (900 ft) monitoring wells needs to take place before it can be stated whether the sodium/chloride molar ratios indicate incipient seawater intrusion may be occurring in the Seaside Groundwater Basin.

ELECTRIC INDUCTION LOGS

Two induction logging events took place in the sentinel wells during Water Year 2016. As in most previous years, the first logging event was conducted in January, and the second event took place in July. Pacific Surveys conducted the logging, and have done so since August 2014. Figure 24 represents the new baseline (August 2014) from which to compare the 2015 and 2016 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 μmhos/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 to the deeper aquifers where production wells extract groundwater. This includes sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) which have shown increased chloride concentrations and decreasing sodium/chloride molar ratios. A visual evaluation of the induction logs do not indicate any seawater intrusion into these deeper aquifers.

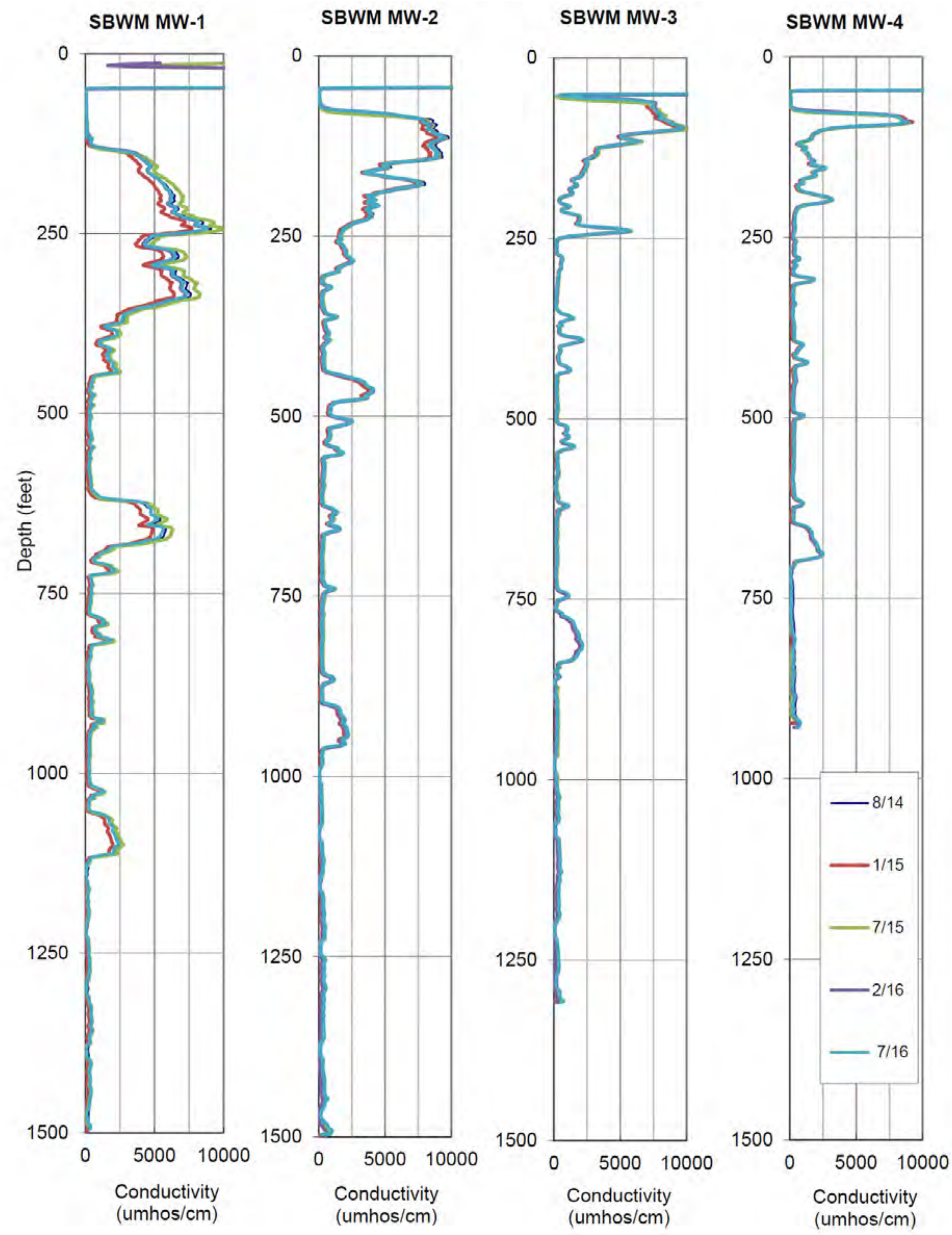


Figure 24: Sentinel Well Induction Log

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. In the deep zone, 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, with levels stabilizing again over Water Years 2015 and 2016. 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 2016, the winter high in PCA-East Deep increased to a level last seen in 2009. 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.

Hydrographs for the sentinel wells have been added this year to the SIAR in an effort to provide more supporting information about the potential seawater intrusion in the deepest samples of wells SBWM-2 and SBWM-4 (Figure 26). The groundwater elevations on this chart are collected using dataloggers 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 clearly show that the wells are at their lowest levels since they were installed. Groundwater in sentinel well SBWM-2 has dropped 12 feet since 2007, and groundwater in well SBWM-4 has dropped 10 feet since 2007. Groundwater in the more inland well, PCA-East Deep, has only dropped about 5 feet over the same period. However, it is the groundwater elevations along the coast which will be responsible for initially inducing seawater intrusion. Sentinel well SBWM-3 is one of the wells selected to be a target protective elevation location as described in the section on Protective Groundwater Elevation on page 60. Sentinel well SBWM-3's groundwater elevations have always been below protective elevations. Sentinel well SBWM-1's groundwater elevations are currently very similar to the elevations in sentinel well SBWM-3. There was a significant drop in groundwater levels in sentinel well SBWM-2 during Water Year 2011 that caused its water levels to drop lower than those in wells SBWM-1 and SBWM-3. Since that time it has always had the lowest groundwater elevations of the sentinel wells.

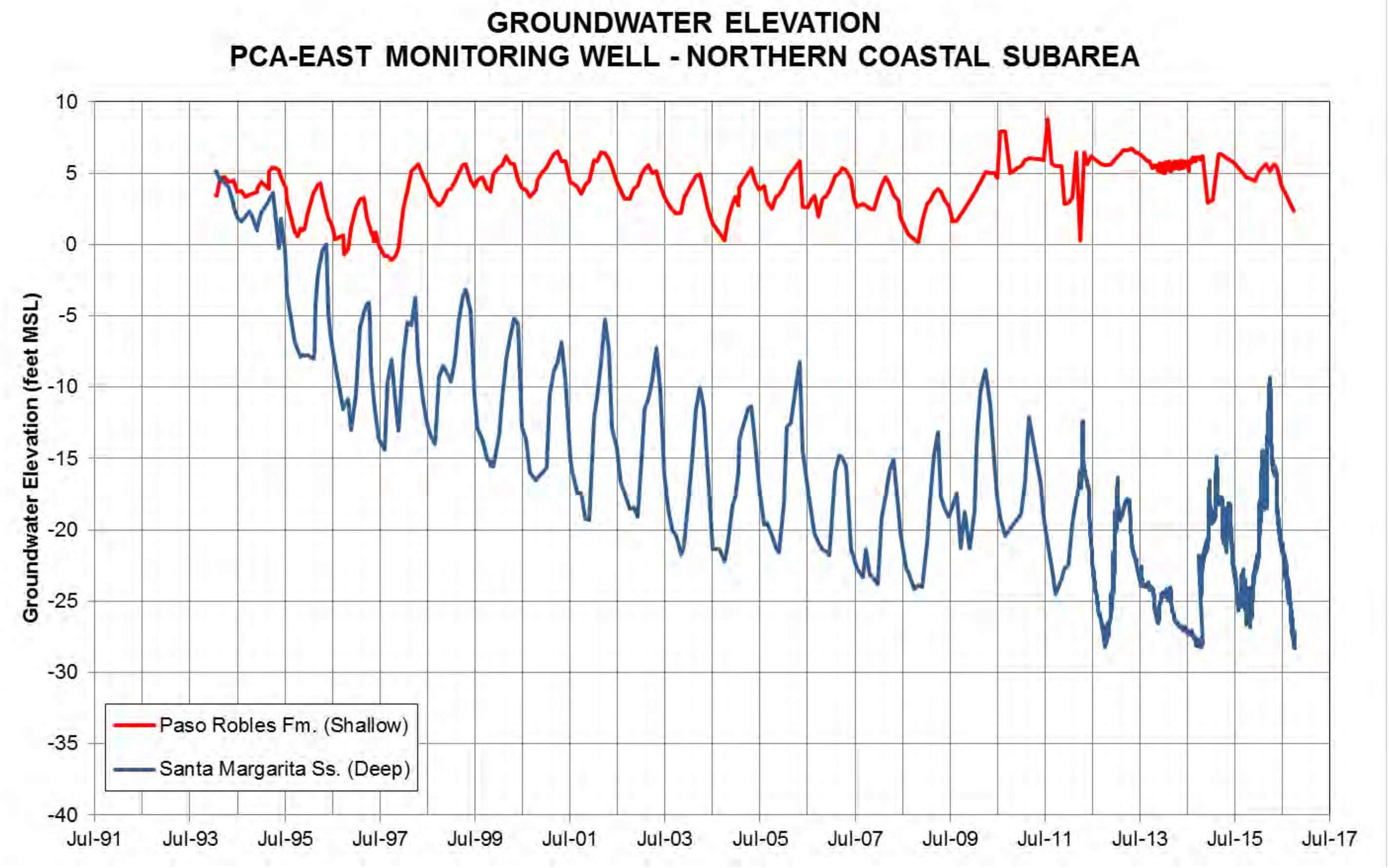
In the shallow zone, 2016 groundwater levels have declined more than in the recent past which has generally seen more stable levels (Figure 25). This is likely due to the increased pumping in CAW's shallow wells while Ord Grove 2 production well was being rehabilitated. Seasonal level increases seen 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 have continued to remain stable over time.

LAGUNA SECA SUBAREA

Although wells in the Laguna Seca subarea are far enough from the coast to not induce seawater intrusion, there is concern that since 2001 this area has experienced an ongoing decline in groundwater levels that is not being improved upon by triennial pumping reductions due to influences of groundwater pumping east of the Seaside Basin (HydroMetrics WRI, 2016). Figure 27 shows in the eastern portion of the subarea that shallow groundwater levels have been declining at approximately 0.6 feet per year, and deep groundwater levels have been declining at between two and three feet per year. There is an indication from 2016 levels that these declines have slowed down slightly over the past year. Declines in the western portion of the subarea are also occurring but on the order of one to two feet per year.



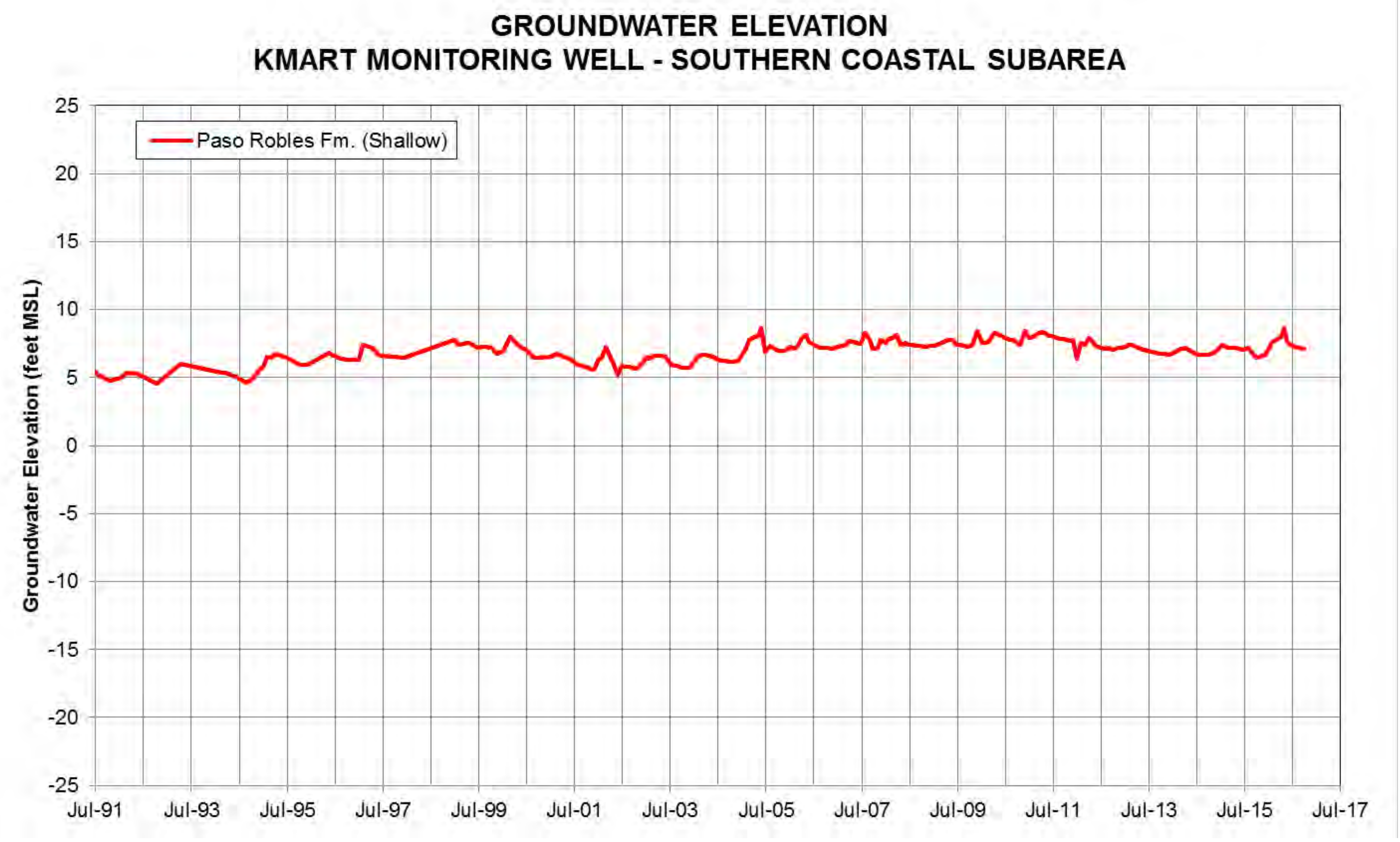


Figure 25: Example Hydrographs (Source: Watermaster)

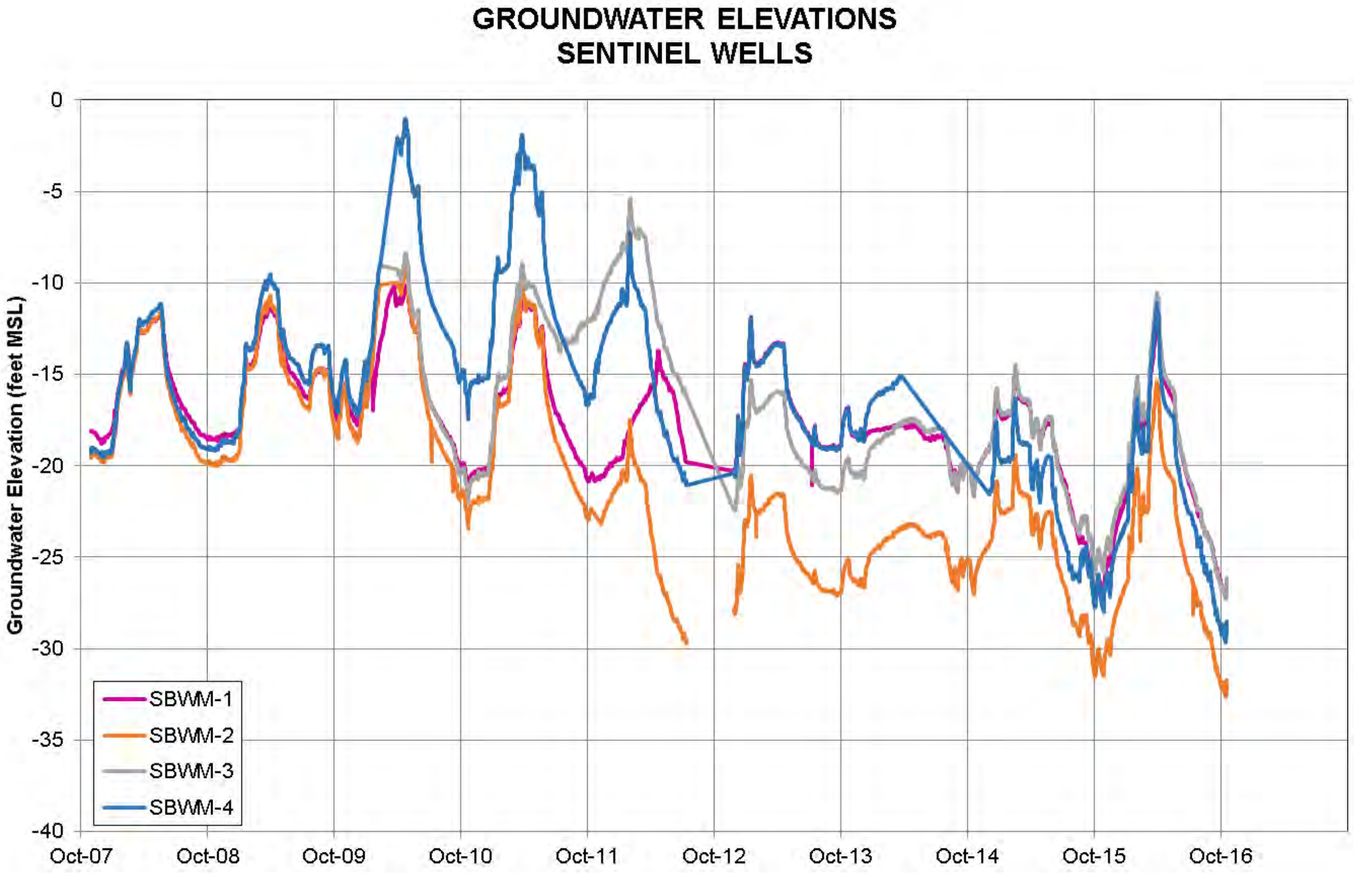


Figure 26: Sentinel Well Hydrographs

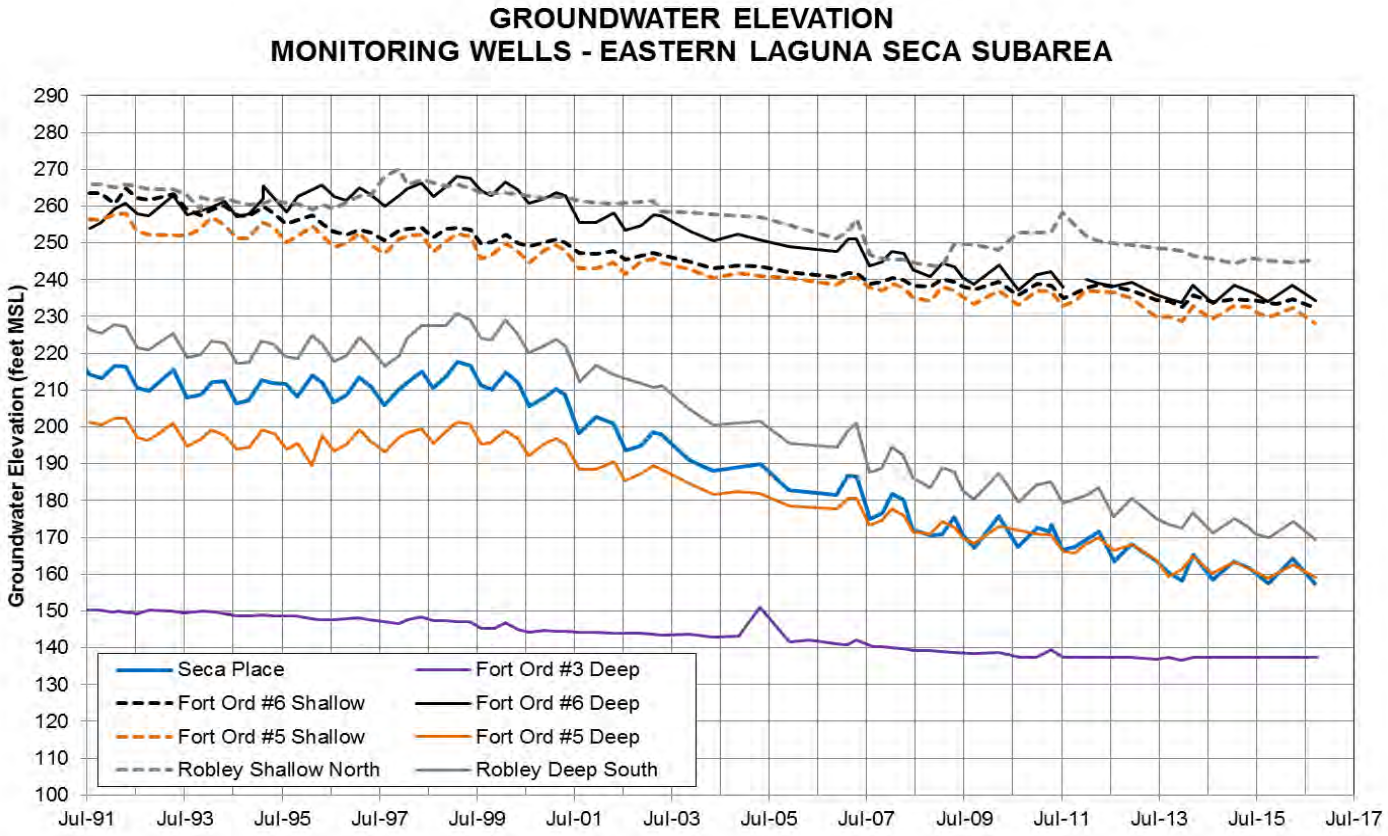


Figure 27: Eastern Laguna Seca Subarea Hydrographs

GROUNDWATER ELEVATION MAPS

SECOND QUARTER WATER YEAR 2016 (JANUARY-MARCH 2016)

Groundwater level maps for the shallow and deep aquifer zones for the 2nd quarter of Water Year 2016 are shown on Figure 28 and Figure 29, respectively.

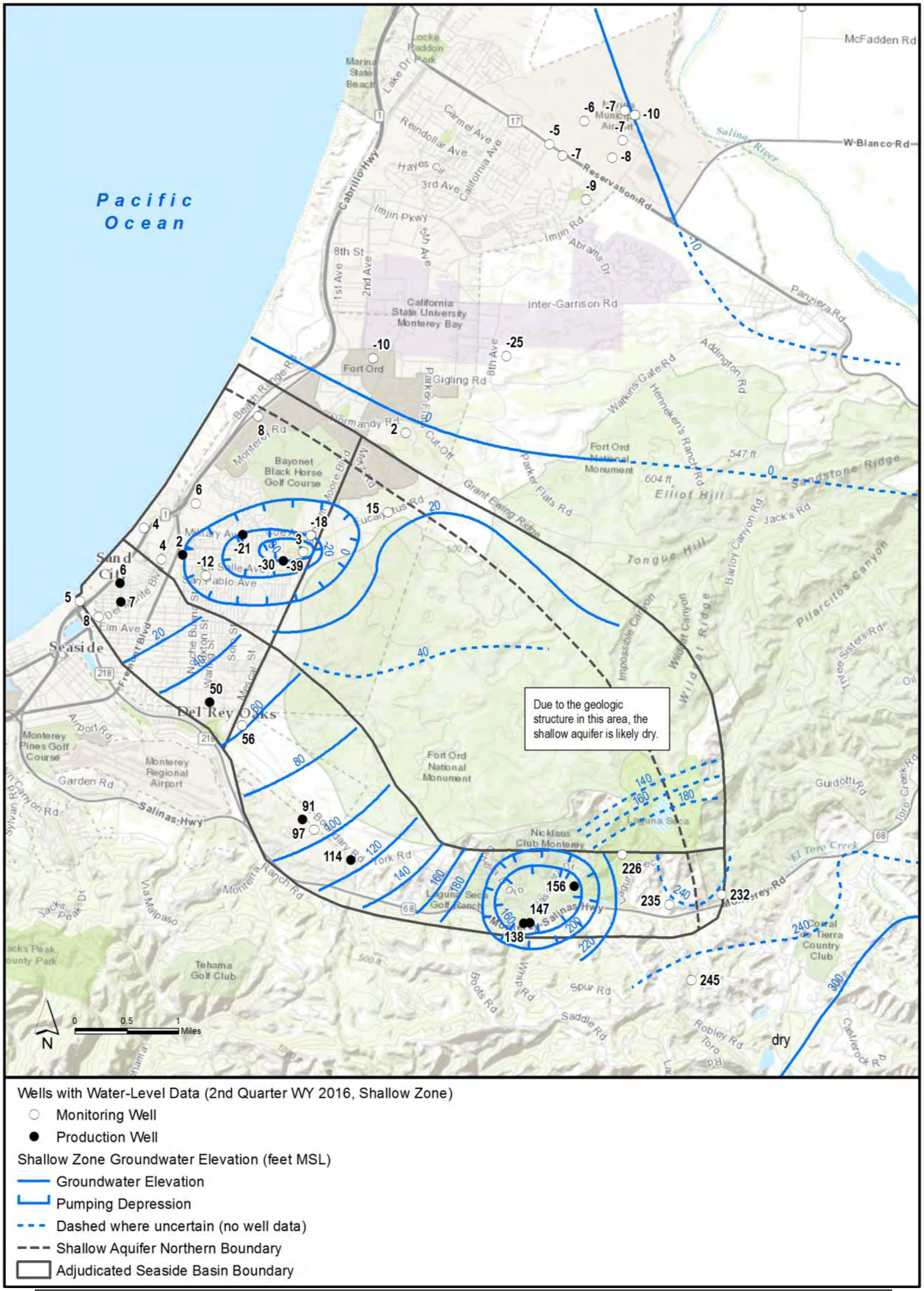
The shallow aquifer does not show seasonal fluctuations to the same extent as the deep aquifer. The groundwater level contours for Water Year 2016 remains essentially the same along the coast in the Northern Coastal subarea, with the exception of the coastal pumping depression which increased very slightly due to more pumping from CAW's shallow wells to make up for the reduced pumping from their Ord Grove 2 well. Groundwater levels remained fairly 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 28). It should be noted that the monitoring well PCA West shallow has limited access which prevented levels being collected this year. It is recommended that the monitoring well have a data logger installed to ensure groundwater levels are reliably recorded at this important location near the coast.

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 variations. Groundwater elevations along the coast in the 2nd quarter are one to two feet lower than the same quarter last year. The pumping depression in the Northern Coastal subarea remained of similar extent but was not as deep as in previous years likely because Ord Grove 2 pumped much less than it usually does (Figure 29). The small pumping depression caused by the Laguna Seca golf course wells is the same as last year because we have no groundwater level data to use in contouring in this area. It appears that in the Laguna Seca subarea, groundwater levels stabilized slightly thereby slowing the decline of two to three feet observed historically.

FOURTH QUARTER WATER YEAR 2016 (JULY-SEPTEMBER 2016)

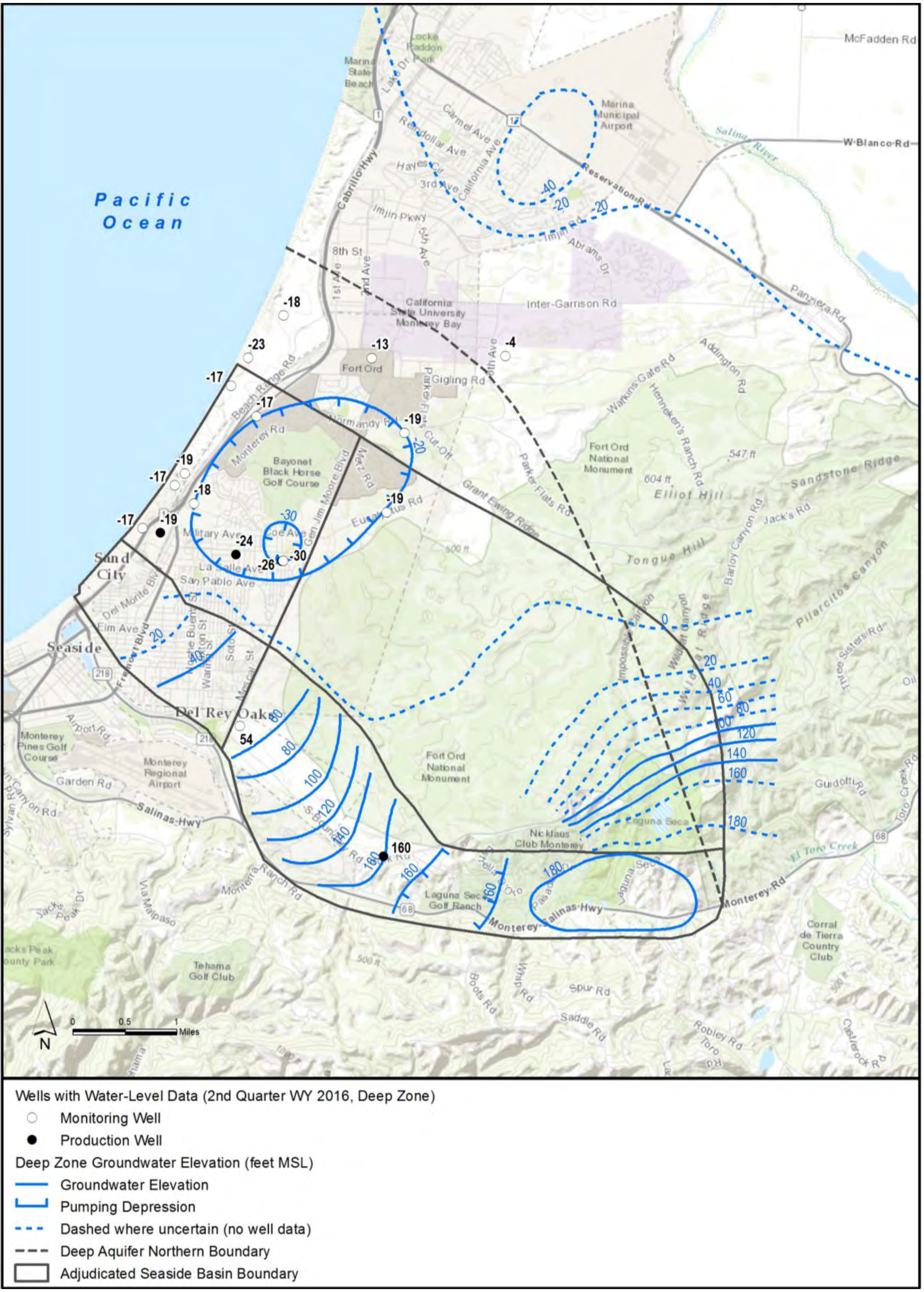
Groundwater elevation maps for the shallow and deep aquifer zones for the 4th quarter of Water Year 2016 are shown on Figure 30 and Figure 31, respectively. The contours for the shallow aquifer show that levels are one to two feet lower than last water year in the Northern Coastal subarea. The pumping depression in the Northern Coastal subarea is very slightly larger in extent that last water year, while the pumping depression in the Laguna Seca subarea remained of similar extent and depth to last water year (Figure 30).

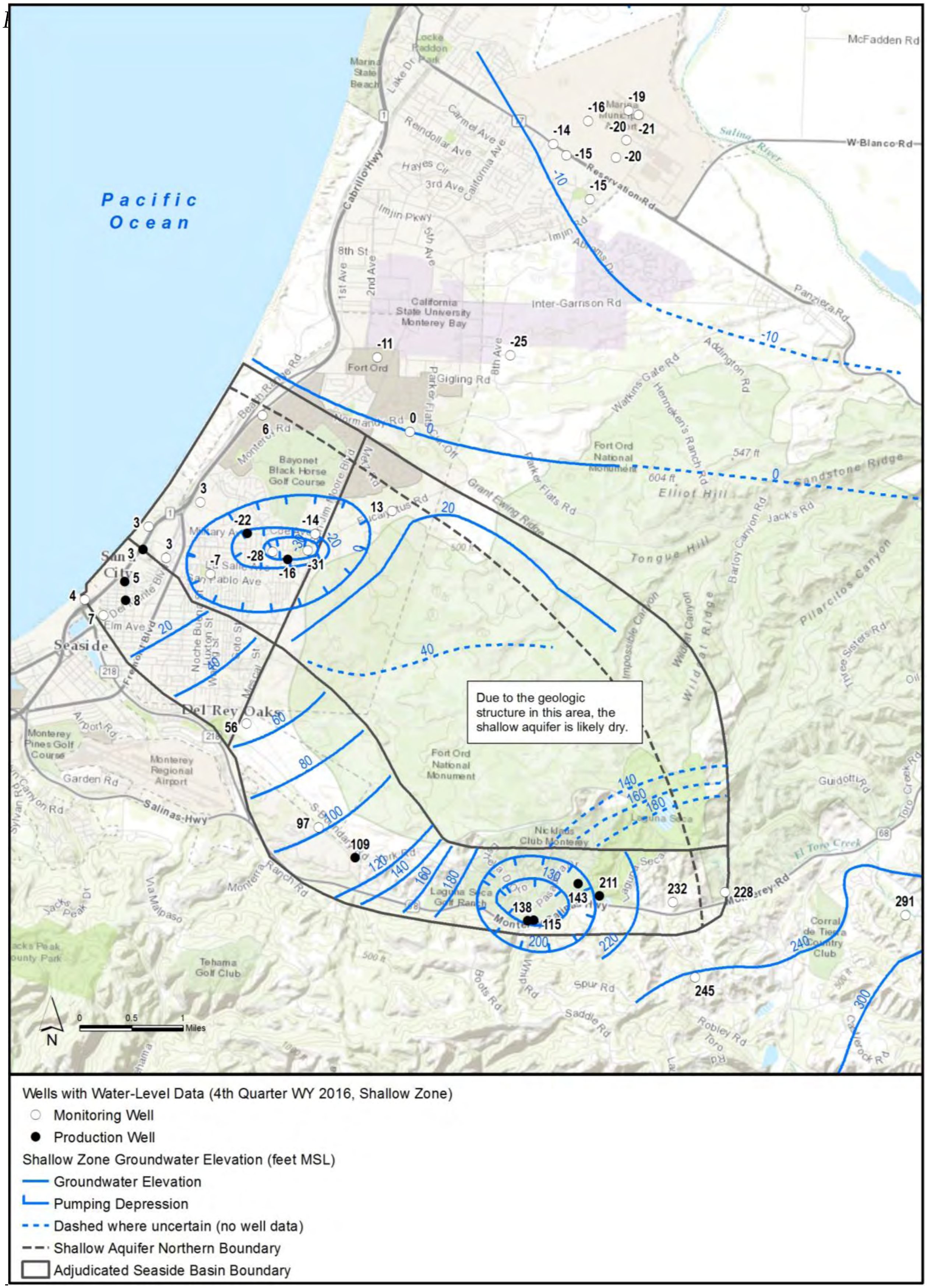
The deep aquifer pumping depression around CAW's main production wells in the Northern Coastal subarea increased in extent for the second year in a row. Figure 31 shows the -20 foot contour (below sea level) is now edging closer to the deep aquifer northern boundary. Supporting the findings above of historical low groundwater levels in the sentinel wells, all the coastal wells have declined three to four feet over the past year. The deepest portion of the Northern Coastal subarea pumping depression (deeper than 40 feet below sea level) moved slightly due to Ord Grove 2 not being online. The Laguna Seca subarea pumping depression around the Laguna Seca golf course wells remained similar to last water year (Figure 31). The eastern portion of the Laguna Seca subarea experienced more stable groundwater levels compared to the last few years.



Due to the geologic structure in this area, the shallow aquifer is likely dry.

F


Pacific Ocean
Marina State Beach
Locke Paddon Park
Marina Municipal Airport
McFadden Rd
W Blanco Rd
Salinas River
Reservation Rd
Imjin Pkwy
California State University Monterey Bay
Inter-Garrison Rd
Fort Ord
Gigling Rd
Bayonet Black Horse Golf Course
Fort Ord National Monument
Elliot Hill
Sandstone Ridge
Tongue Hill
Pilarcitos Canyon
Sand City
Seaside
Del Rey Oaks
Monterey Pines Golf Course
Monterey Regional Airport
Salinas Hwy
Laguna Seca
Nicklaus Club Monterey
Laguna Seca Golf Ranch
Monterey Rd
El Toro Creek
Corral de Tierra Country Club
Tehama Golf Club
Jacks Peak County Park
-40
-20
-18
-23
-13
-4
-17
-19
-24
-26
-30
54
160
0
20
40
60
80
100
120
140
180
0
0.5
1
Miles
N
Wells with Water-Level Data (2nd Quarter WY 2016, 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


Pacific Ocean
Due to the geologic structure in this area, the shallow aquifer is likely dry.
-19
-16
-20
-21
-14
-15
-20
-15
-10
-11
-25
0
6
3
3
3
3
5
8
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-16
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13
56
97
109
138
115
143
211
232
228
245
291
20
40
60
80
100
120
130
140
160
180
200
220
240
300
Marina State Beach
Marina Municipal Airport
California State University Monterey Bay
Fort Ord
Bayonet Black Horse Golf Course
Fort Ord National Monument
Elliot Hill
Tongue Hill
Sand City
Seaside
Del Rey Oaks
Monterey Pines Golf Course
Monterey Regional Airport
Laguna Seca Golf Ranch
Laguna Seca
Nicklaus Club Monterey
Corral de Tierra Country Club
Tehama Golf Club
Salinas River
El Toro Creek
Reservation Rd
Imjin Rd
Inter-Garrison Rd
Gigling Rd
Normandy Rd
General Jim Moore Blvd
Eucalyptus Rd
Grant Ewing Ridge
Parker Flats Rd
Fremont Blvd
Salinas Hwy
Monterey Rd
S Boundary Rd
York Rd
Monterra Ranch Rd
Pilarcitos Canyon
Sandstone Ridge
Wild at Ridge
N
0
0.5
1
Miles
Wells with Water-Level Data (4th Quarter WY 2016, Shallow Zone)
○ Monitoring Well
● Production Well
Shallow Zone Groundwater Elevation (feet MSL)
Groundwater Elevation
Pumping Depression
Dashed where uncertain (no well data)
Shallow Aquifer Northern Boundary
Adjudicated Seaside Basin Boundary

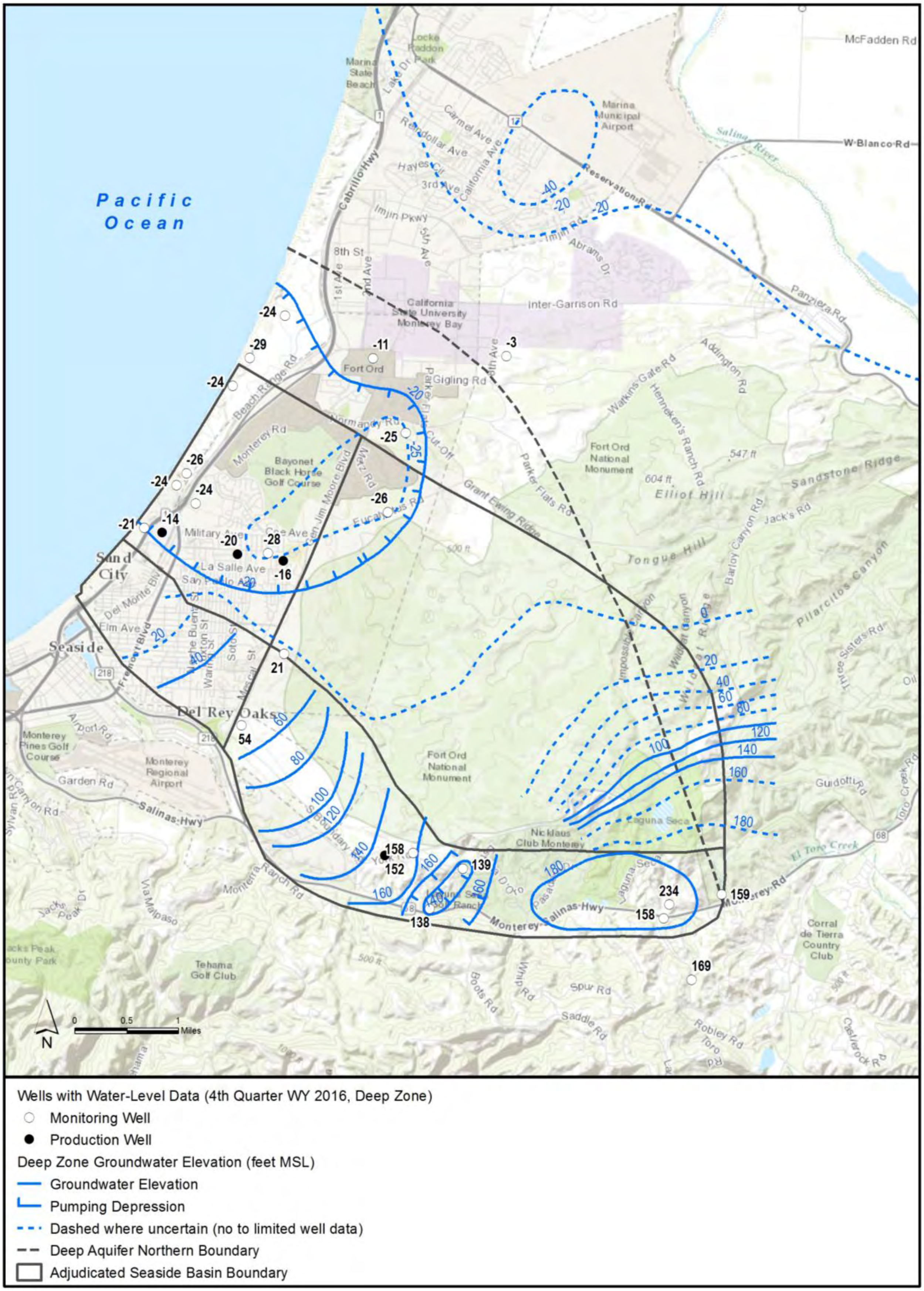


Figure 31: Deep Zone Water Elevation Map – 4th Quarter WY 2016 (July/August 2016)

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.

Net pumping by Watermaster producers in Water Year 2016 was 2,913.5 acre-feet, which is 848.5 acre-feet less than Water Year 2015 and well below the court-ordered amount. Water Year 2016's pumping was the least pumped since the adjudication decision. It is also, for the first time, below the basin's judicially set safe yield of 3,000 acre-feet. Net pumping is the amount pumped after the aquifer storage and recovery 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 2016, 699 acre-feet of injection took place, and 610 acre-feet of injected water was recovered.

The blue charts on Figure 33 reflect the actual or gross amounts pumped from each well, and the green chart reflects the amount of water injected. The pumping distribution this year was slightly different from previous years. The Ord Grove 2 well was offline for rehabilitation during part of Water Year 2016, and was therefore pumped less than normal. To compensate for the Ord Grove 2 well being offline, the Santa Margarita recovery well and the Paralta well were pumped more than in previous years.

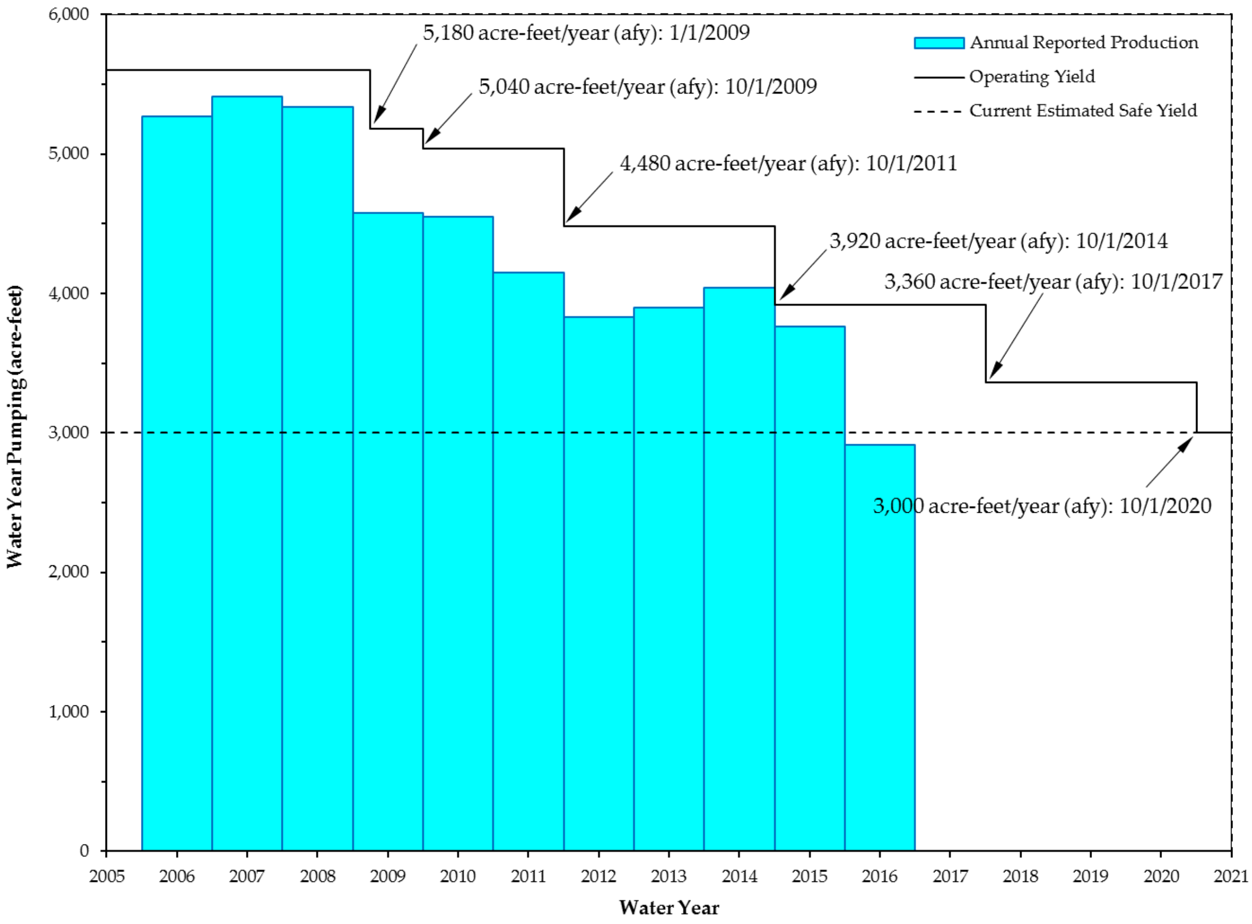
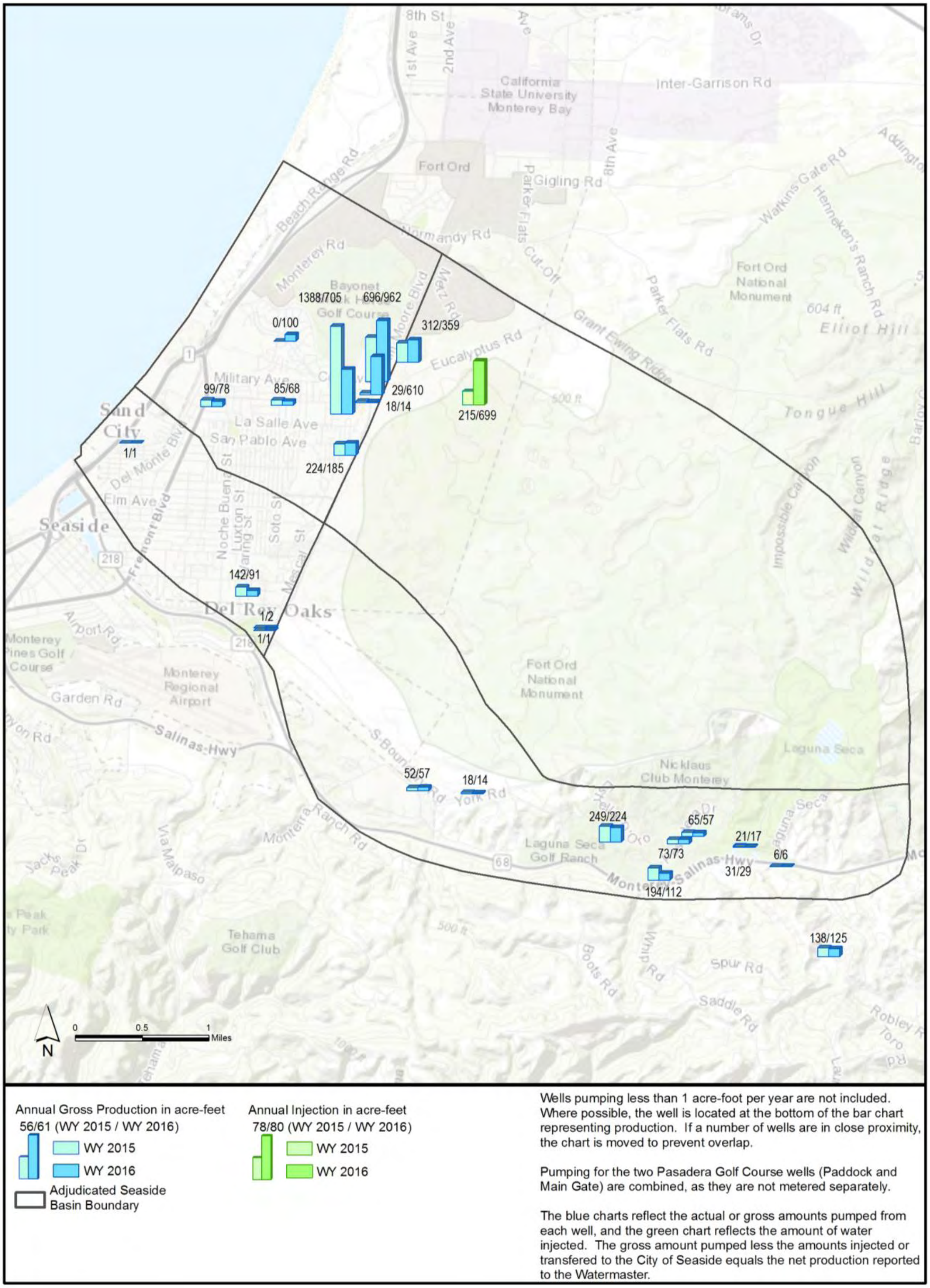


Figure 32: Annual Reported Groundwater Production and Operating Yield for Watermaster Producers



Wells pumping less than 1 acre-foot per year are not included. Where possible, the well is located at the bottom of the bar chart representing production. If a number of wells are in close proximity, the chart is moved to prevent overlap.

Pumping for the two Pasadera Golf Course wells (Paddock and Main Gate) are combined, as they are not metered separately.

The blue charts reflect the actual or gross amounts pumped from each well, and the green chart reflects the amount of water injected. The gross amount pumped less the amounts injected or transfered to the City of Seaside equals the net production reported to the Watermaster.

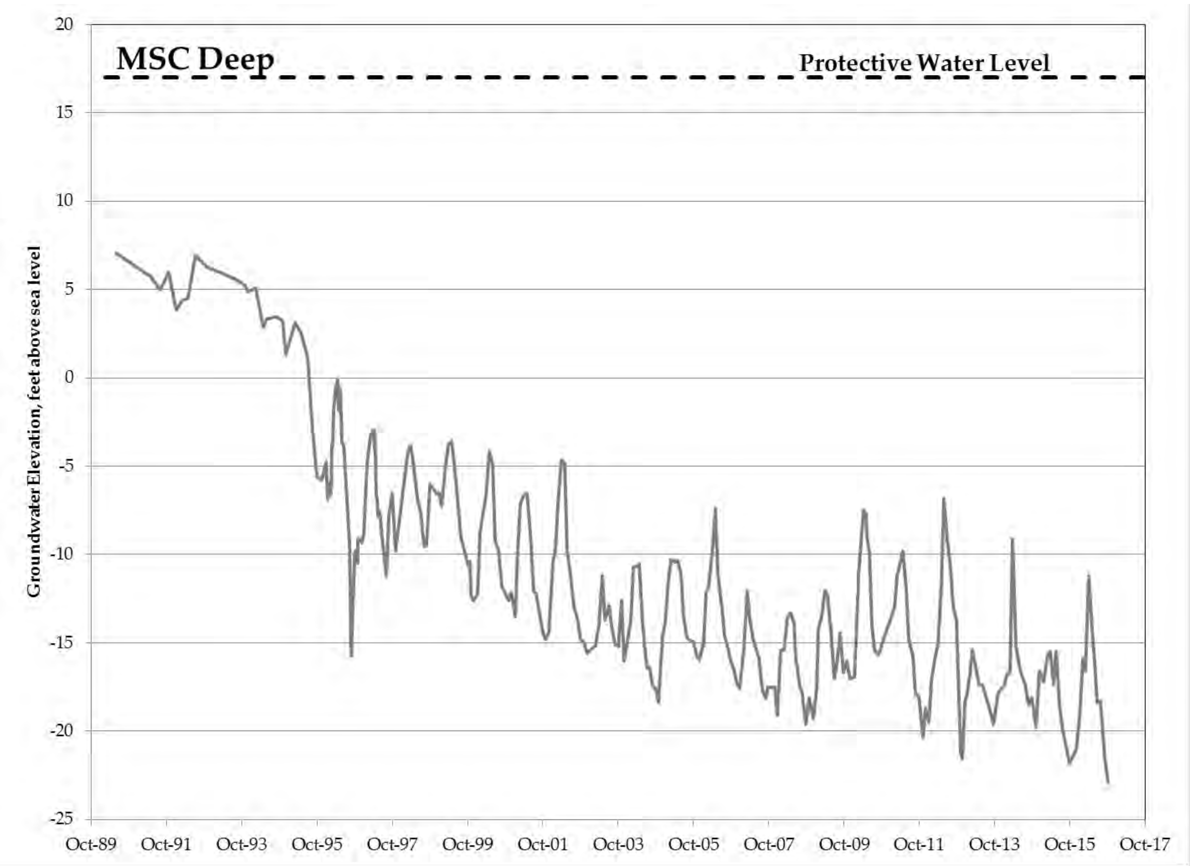
PROTECTIVE GROUNDWATER ELEVATIONS

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 34 through Figure 37 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. In Water Year 2016, access to PCA-W shallow was limited and thus no groundwater elevation data could be collected at this well. It is recommended that a data logger, like that in PCA-W deep, be installed to ensure groundwater elevation data can be collected at this well.



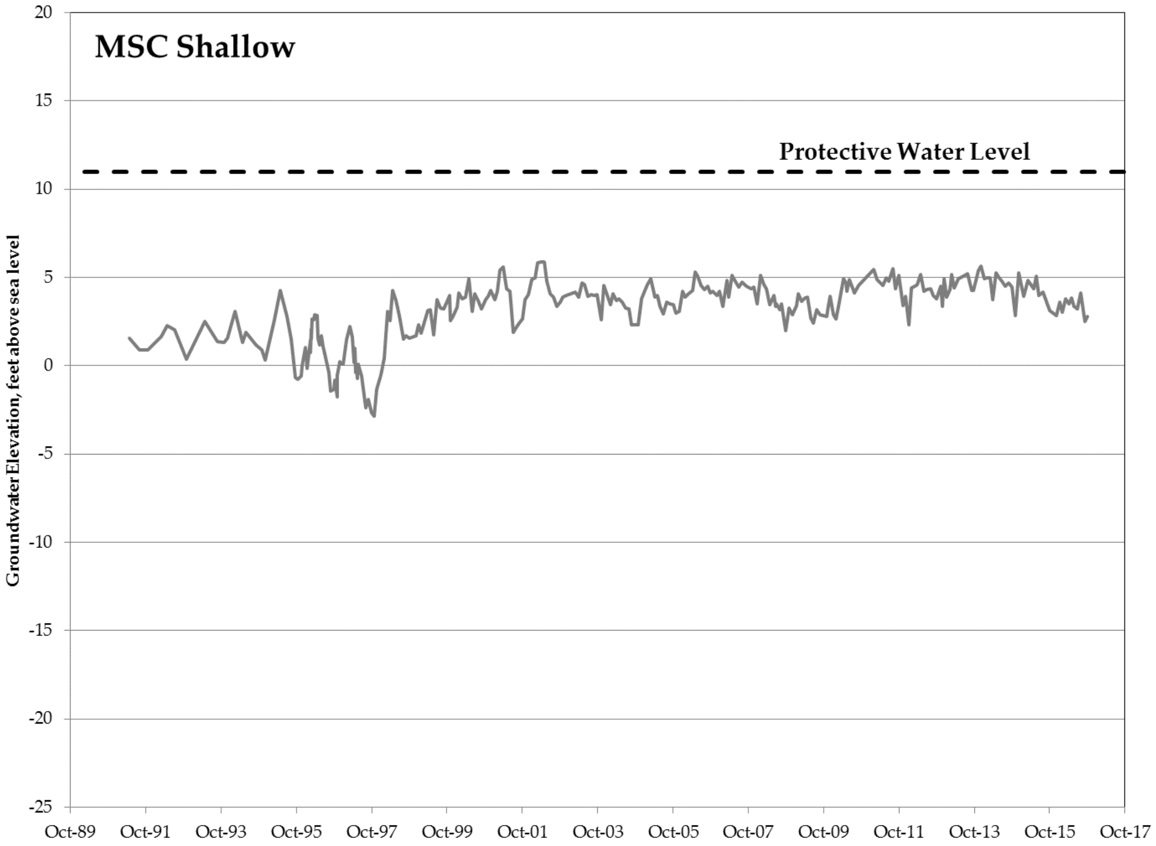
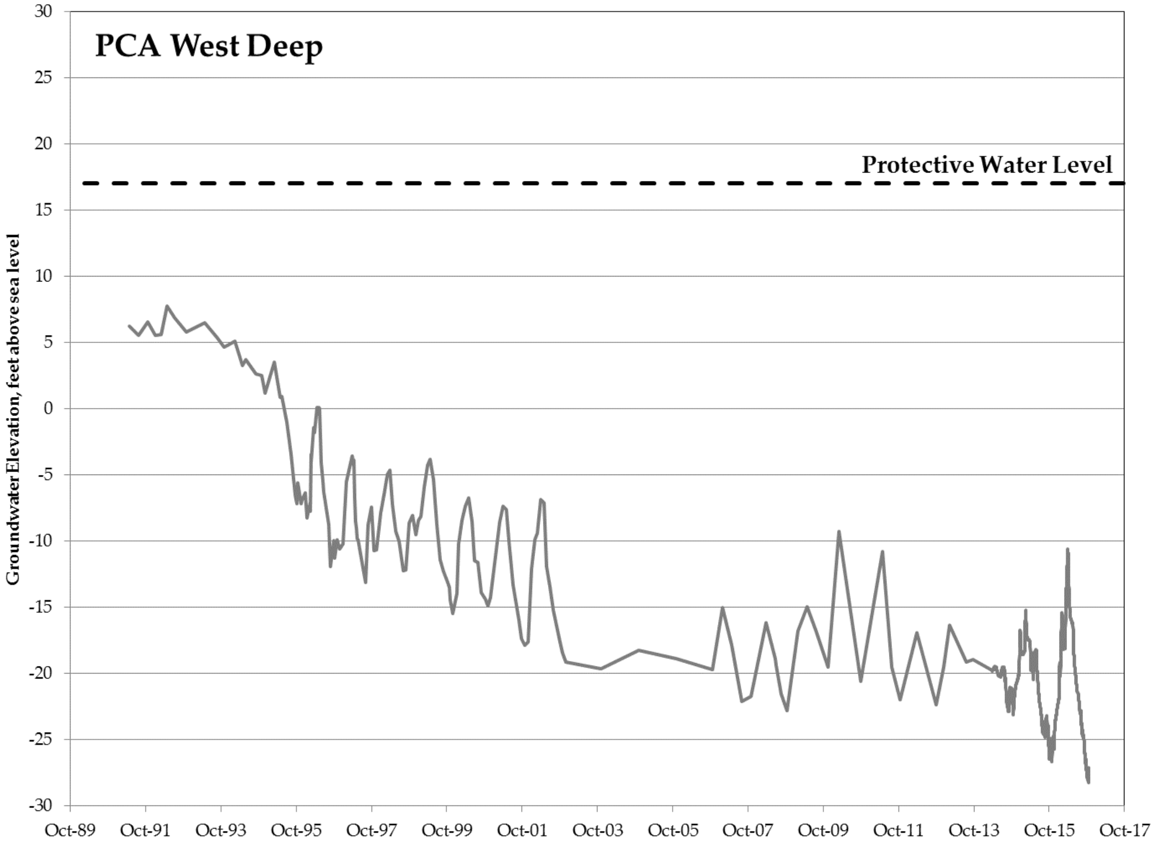
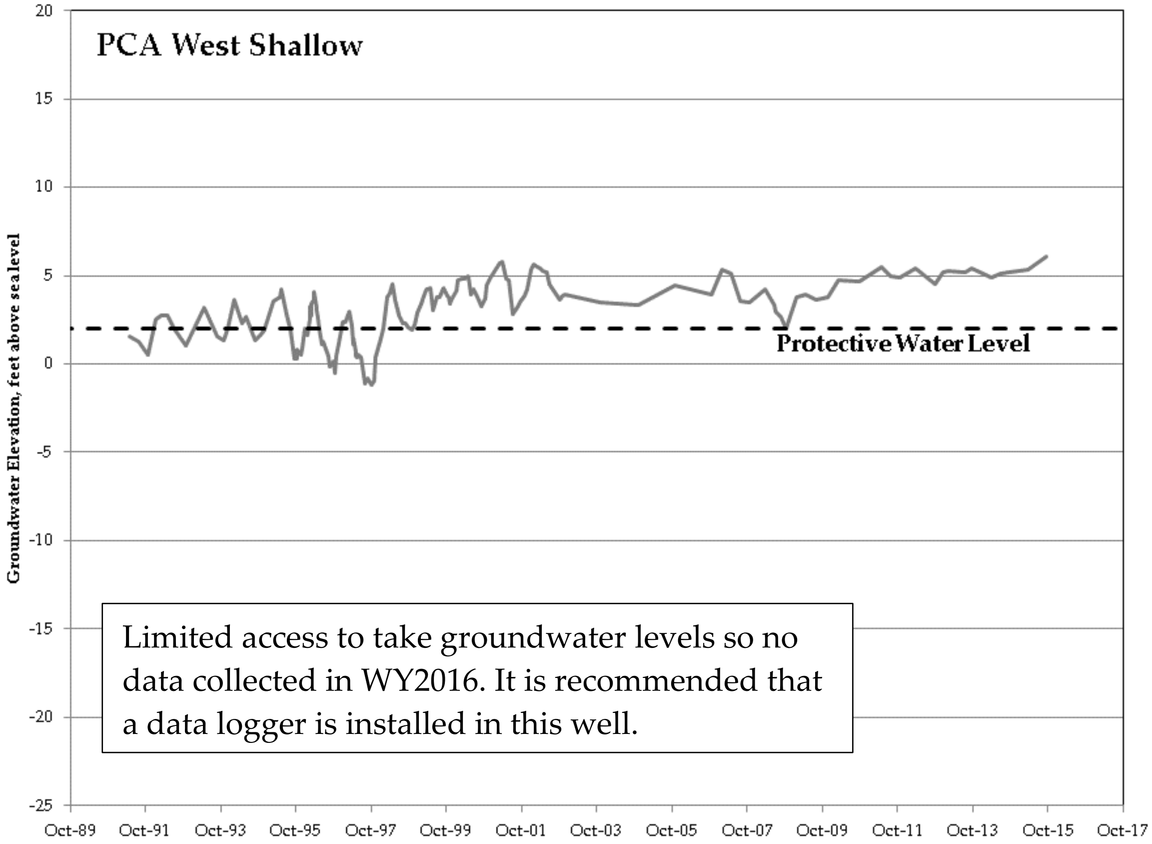


Figure 34: MSC Deep and Shallow Groundwater and Protective Elevations





Limited access to take groundwater levels so no data collected in WY2016. It is recommended that a data logger is installed in this well.

Figure 35: PCA West Deep and Shallow Groundwater and Protective Elevations

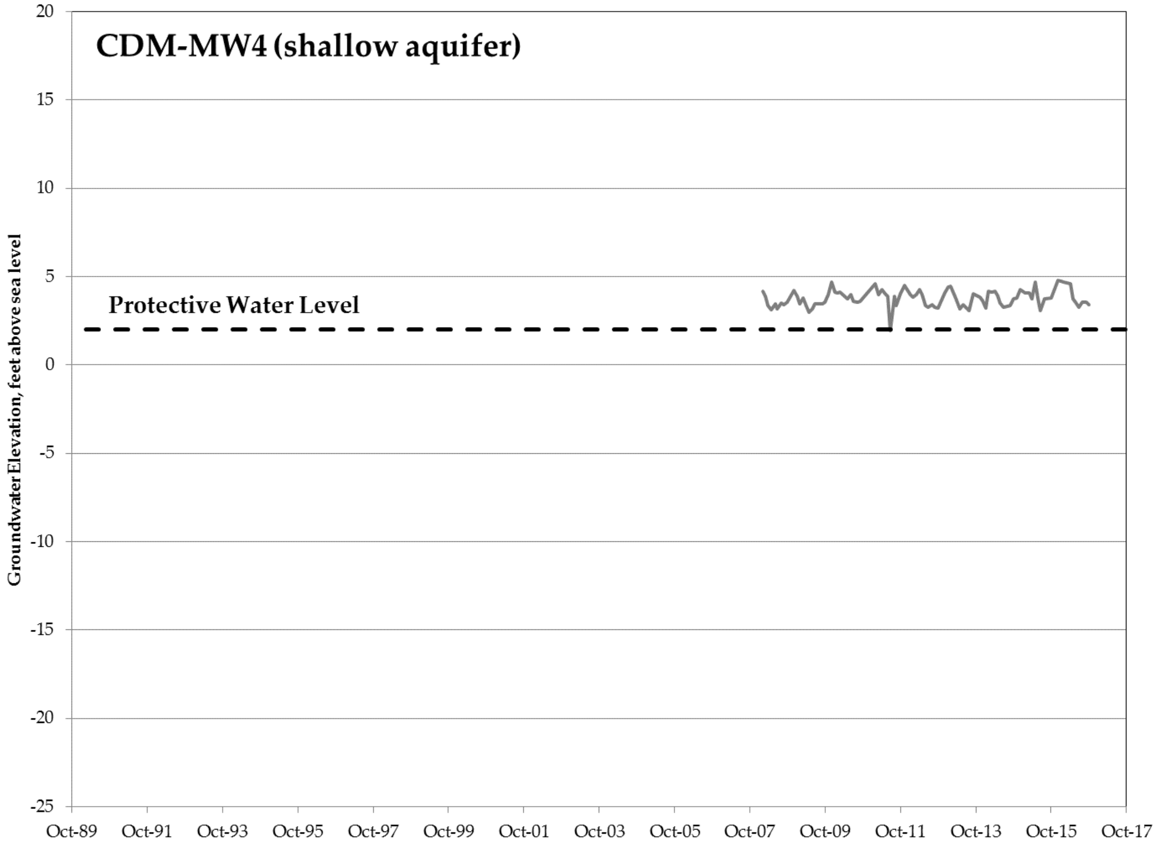


Figure 36: CDM-MW4 Groundwater and Protective Elevations

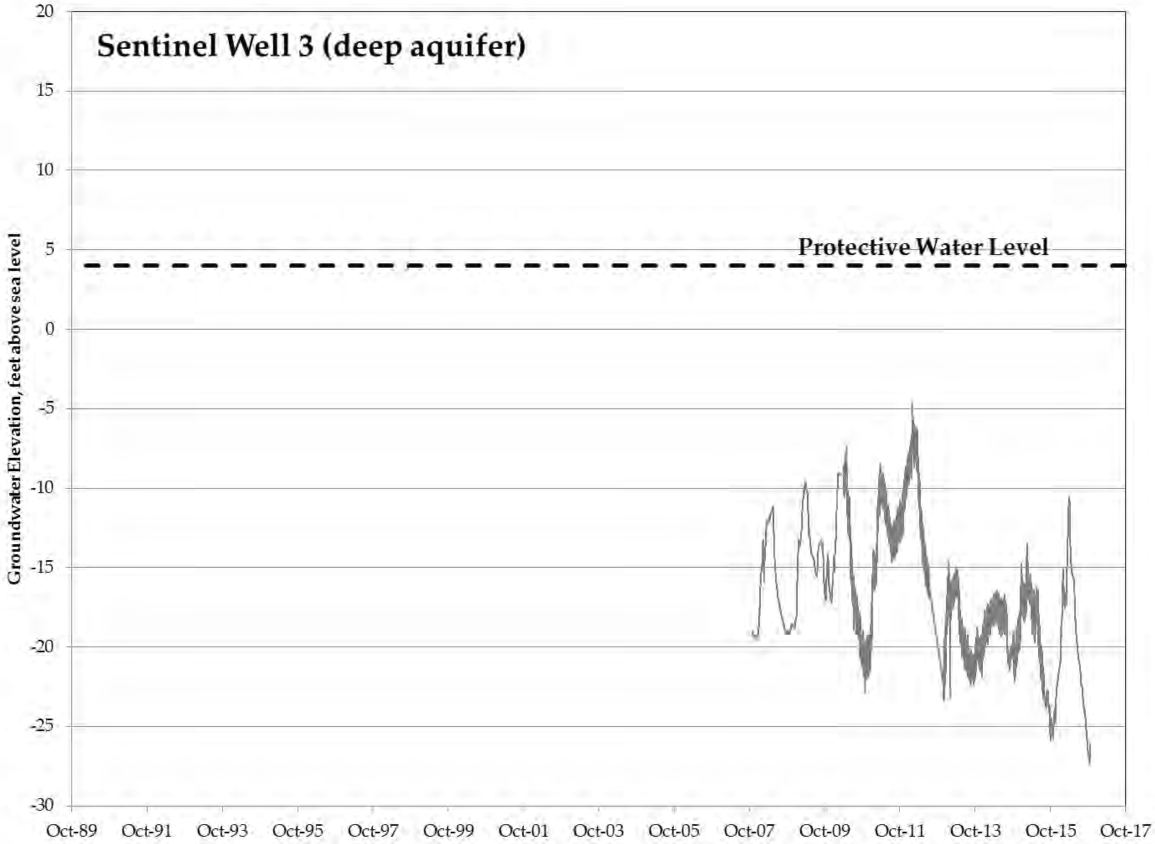


Figure 37: Sentinel Well 3 Groundwater and Protective Elevations

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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. This year for the first time there is conflicting data from two of the Watermaster's sentinel wells. Some of the data are suggestive of the initial onset of seawater intrusion, while other data indicate seawater intrusion is not occurring.

The data which are suggestive of the initial onset of seawater intrusion is described in the bulleted items below. It is important to note that all of these data are based on the same two discrete groundwater quality samples taken from wells SBWM-2 (1,470 ft depth) and SBWM-4 (900 ft depth).

- Water samples for sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) experienced a shift in water chemistry that plots closer to seawater on Piper diagrams than historical samples.
- Stiff diagrams for sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) show a chloride spike somewhat similar to Stiff diagrams of seawater intruded wells in the Salinas Valley.
- July 2016 chloride concentrations in sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) are at 178 and 284 mg/L respectively. This is an increase of 112 mg/L for sentinel well SBWM-2 (1,470 ft) over the past water year and 26 mg/L for sentinel well SBWM-4 (900 ft) from February 2016 to July 2016.
- The sodium/chloride molar ratios of both SBWM-2 (1,470 ft) and SBWM-4 (900 ft) have dropped, but are not below 0.86.
- Groundwater elevations in sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) are at historical lows.
- Maps of chloride concentrations for the deep aquifer show chlorides increasing towards the coast.

Data which are indicative of seawater intrusion not occurring is 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 does not show changes indicative of seawater intrusion.
- Other than the sentinel wells SBWM-2 (1,470 ft) and SBWM-4 (900 ft) samples, no other monitoring or production wells in the basin have water quality that is indicative of seawater intrusion.

Because of the conflicting data no conclusions with regard to the initial onset of seawater intrusion can be drawn at this time. Verification resampling, as contained in the Recommendations section of this report, will be necessary in order to reach a conclusion.

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

- Northern Coastal subarea groundwater levels in the deep aquifer remain below sea level (Figure 29 and Figure 31). The 4th quarter deep aquifer groundwater levels along the coast are in some cases greater than 30 feet below sea level and are at historical lows.
- Groundwater levels remain below protective elevations in all deep target monitoring wells (MSC deep, PCA-W, 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.
- Groundwater production in the Seaside Groundwater Basin for Water Year 2016 was 2,913.5 acre-feet, which is 848.5 acre-feet less than Water Year 2015. This amount is less than the Court-mandated operating yield of 3,920 acre-feet per year that is required between October 1, 2014 and September 30, 2017, and the current safe yield of 3,000 acre-feet. Although pumping in Water Year 2016 was below the current safe yield, many groundwater elevations in deep monitoring wells continue to decline. It seems likely that the long-term effects of pumping over the safe yield and the dry climatic conditions of the past five years have a greater impact on groundwater levels than one year of reduced pumping,

Due to its long distance from the coast, seawater intrusion is not an issue of concern in the Laguna Seca subarea. However, groundwater levels in the Laguna Seca subarea are continuing to decline at the same rate since 2001 despite triennial reductions in allowable pumping. The shallow groundwater levels are declining at a rate of approximately 0.6 feet per year, while the deep groundwater levels in the eastern portion of the subarea are declining at a much faster rate of between two and three feet per year. 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.

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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.

VERIFICATION WATER QUALITY SAMPLING AND ANALYSIS FOR SENTINEL WELL SBWM-2, SENTINEL WELL SBWM-4, AND THE ORD TERRACE SHALLOW MONITORING WELL

Analysis of two samples, one from sentinel well SBWM-2 (1,470 ft) and one from SBWM-4 (900 ft), provided data that are in conflict with other types of data from these wells and from other wells in the vicinity in terms of drawing any conclusions regarding seawater intrusion. Additionally, increasing chlorides have been observed at the Ord Terrace Shallow well; although other geochemical evidence suggests this may not be incipient seawater intrusion. In accordance with the Watermaster's Seawater Intrusion Response Plan (SIRP), these wells should be resampled immediately to determine if the data from these two samples are valid, or whether the July 2016 samples experienced analytical errors or were not representative samples. Re-sampling should include the full suite of major cations and anions, which will allow all of the indicators used in this SIAR to be verified. Laboratory analyses should be conducted with an expedited turnaround time.

POTENTIALLY ANALYZE ADDITIONAL WATER QUALITY CONSTITUENTS FOR SEAWATER INTRUSION

Depending on the results of the verification sampling, the Watermaster may wish to begin to regularly analyze additional water quality constituents: iodide, bromide, boron, and barium in wells that indicate incipient seawater intrusion.

INCREASE WATER QUALITY SAMPLING AND ANALYSIS FOR SENTINEL WELL SBWM-2

Depending on the results of verification sampling, the Watermaster may wish to increase the sampling frequency of SBWM-2 and SBWM-4 to more frequently than twice a year. If indeed the chloride concentrations at these wells are increasing rapidly, monthly sampling may be needed.

POTENTIALLY INCREASE WATER QUALITY MONITORING AND ANALYSIS FOR SENTINEL WELL SBWM-2 AND SBWM-4

Depending on the results of verification sampling, the Watermaster may wish to increase the sampling frequency of SBWM-2 and SBWM-4 to more frequently than twice a year. If indeed the chloride concentrations at these wells are increasing rapidly, monthly sampling may be needed.

POTENTIALLY IMPLEMENT FOLLOW UP ACTIONS OUTLINED IN THE SEAWATER INTRUSION RESPONSE PLAN

If verification sampling indicates that incipient seawater intrusion is occurring along the coast, additional actions that are outlined in the SIRP will need to be implemented. These actions need not be implemented if verification sampling does not indicate incipient seawater intrusion.

INSTALL A DATA LOGGER IN THE MONITORING WELL, PCA WEST SHALLOW

The PCA West Shallow well is a coastal monitoring well that is an important part of the monitoring system for the basin and is one of the wells used to monitor protective groundwater elevations. Because of limited access to this well site, groundwater levels were not measured this water year. A dedicated logger, like that installed in PCA West Deep, at this well will continuously record groundwater levels much more reliably.

CONTINUE TO DOCUMENT DECLINING GROUNDWATER LEVELS IN THE LAGUNA SECA SUBAREA AS DONE SINCE WATER YEAR 2015

Although this recommendation is not one that is related to seawater intrusion because of the inland location of the wells, it is important for the sustainability of the groundwater basin. The state of groundwater levels in monitoring wells in the Laguna Seca subarea needs to be reported at least annually to the Watermaster. The current rate of decline, particularly in the eastern portion of the subarea, is not acceptable. For the sustainability of the subarea, the Watermaster should reconsider options in the next water year to address the situation.

SECTION 6
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APPENDIX A: PIPER DIAGRAMS FOR INDIVIDUAL WELLS

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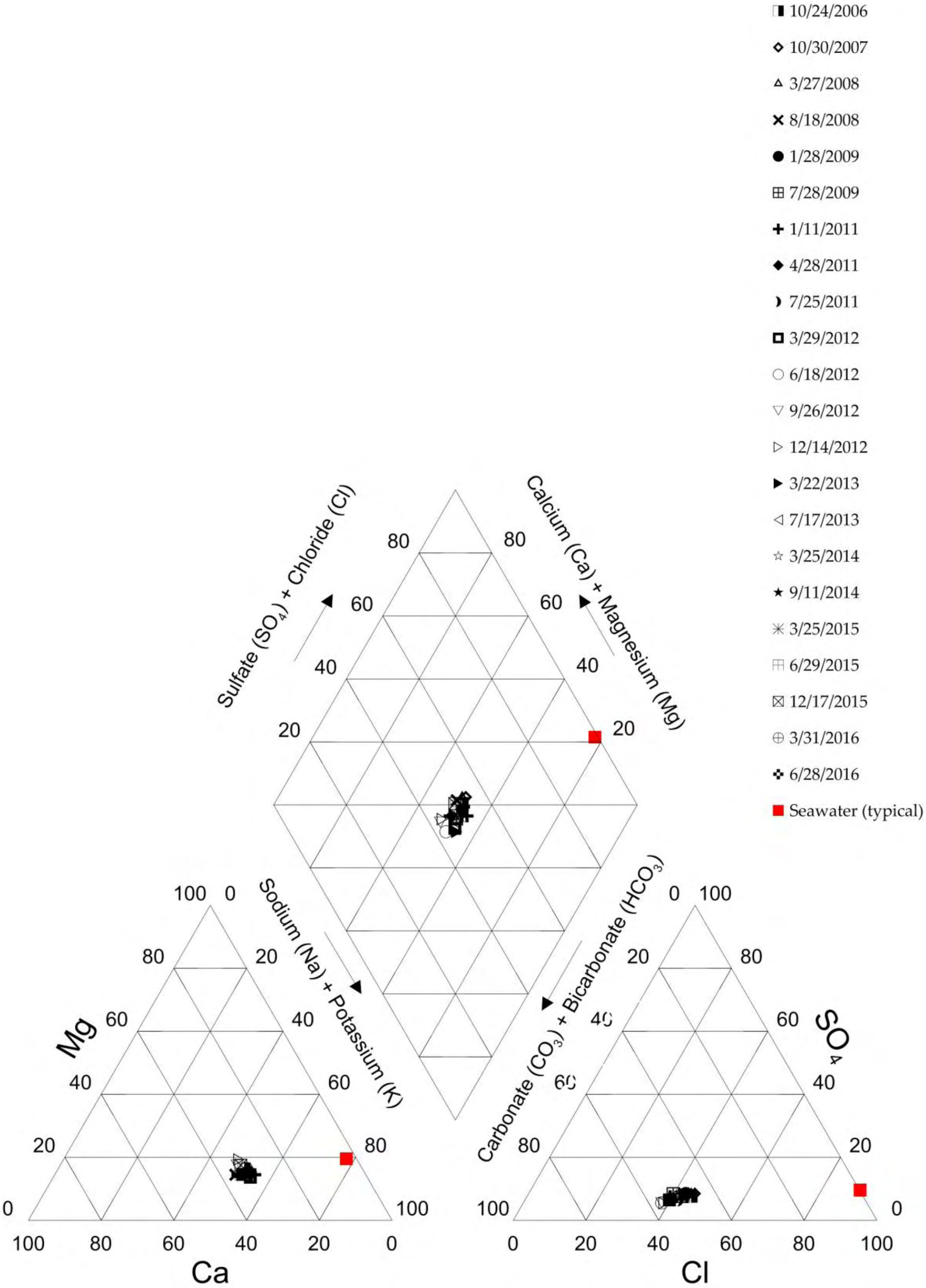

Figure A-1: Piper Diagram of PCA West Shallow

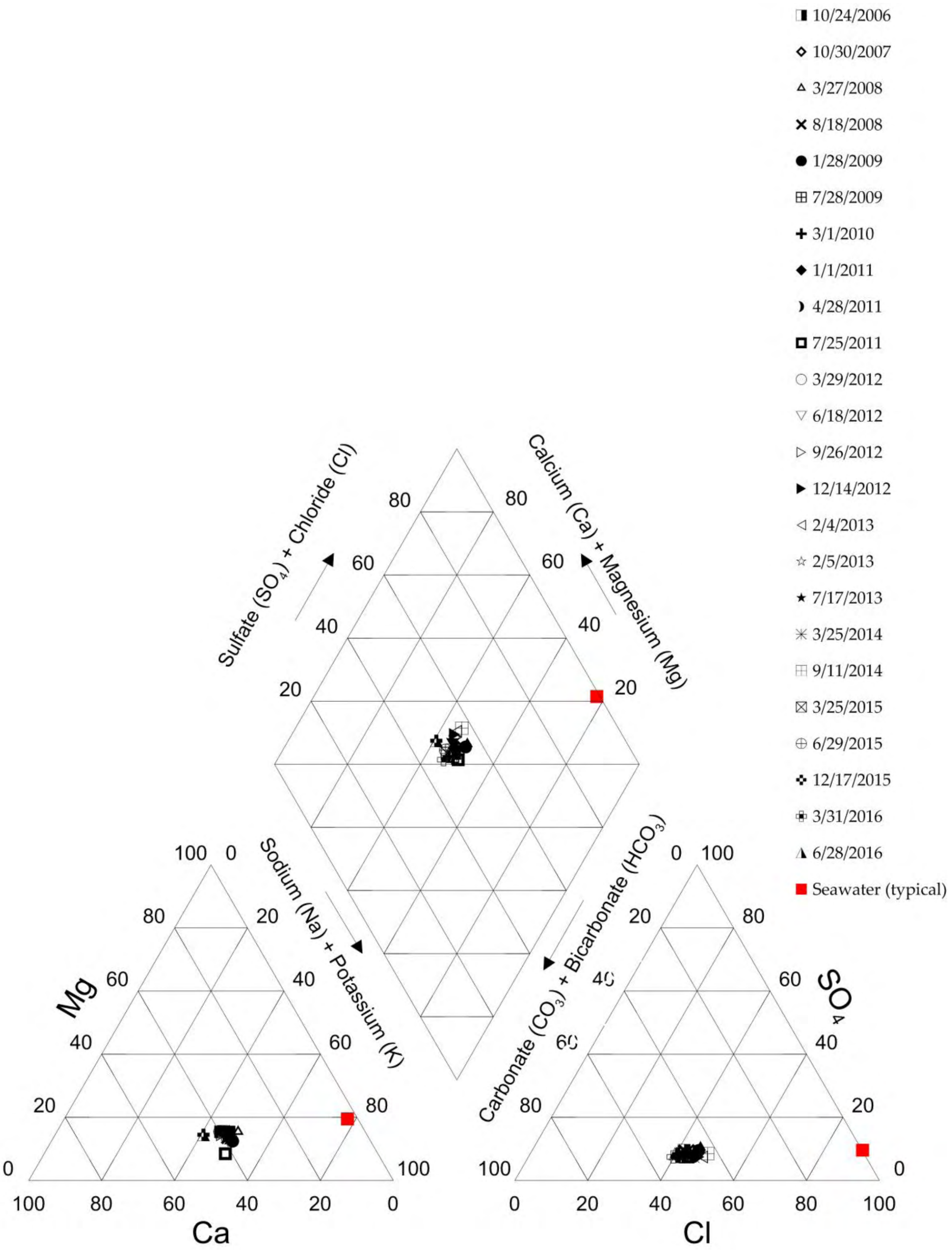

Figure A-2: Piper Diagram of PCA West Deep

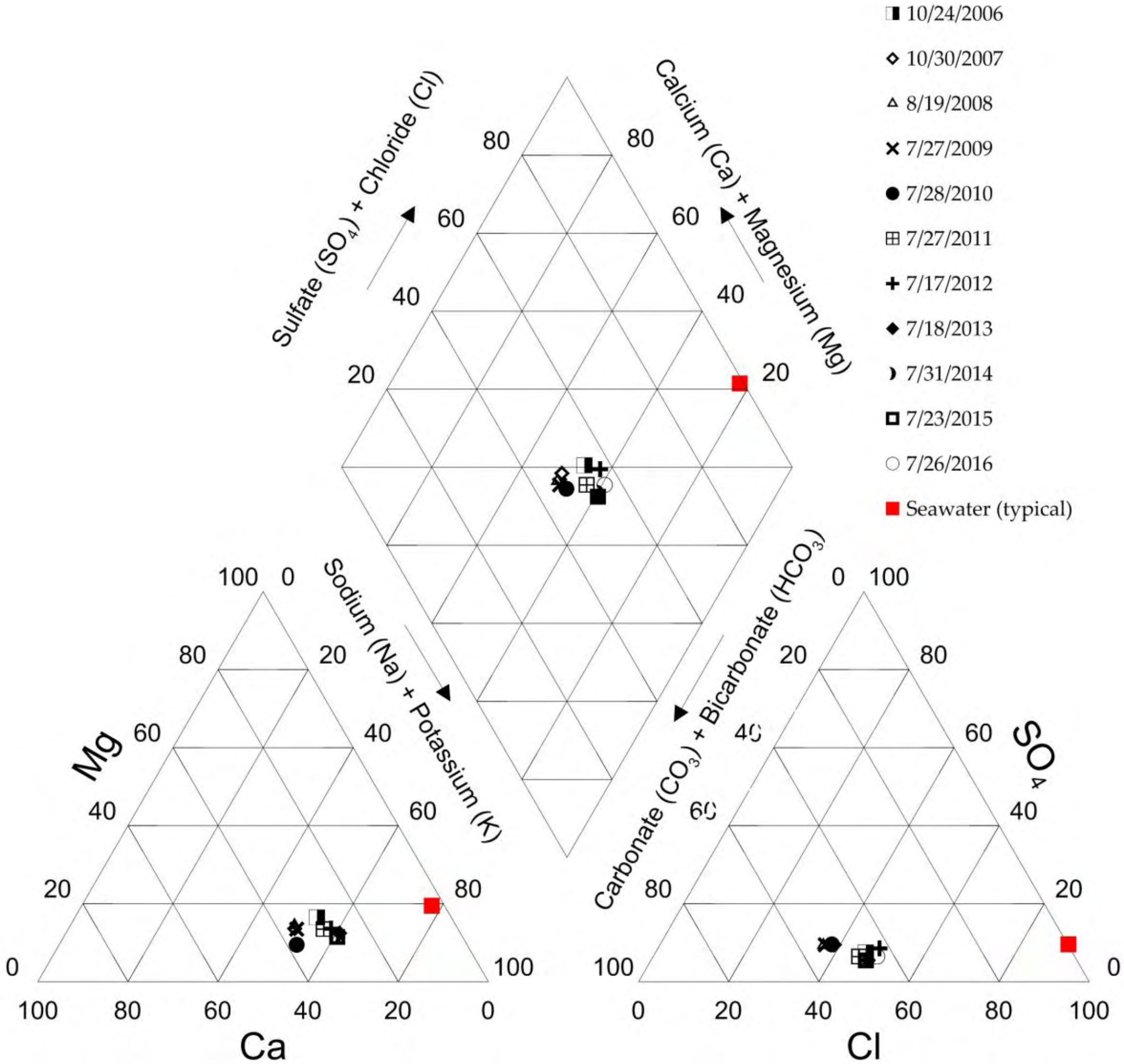

Figure A-3: Piper Diagram of PCA East Deep

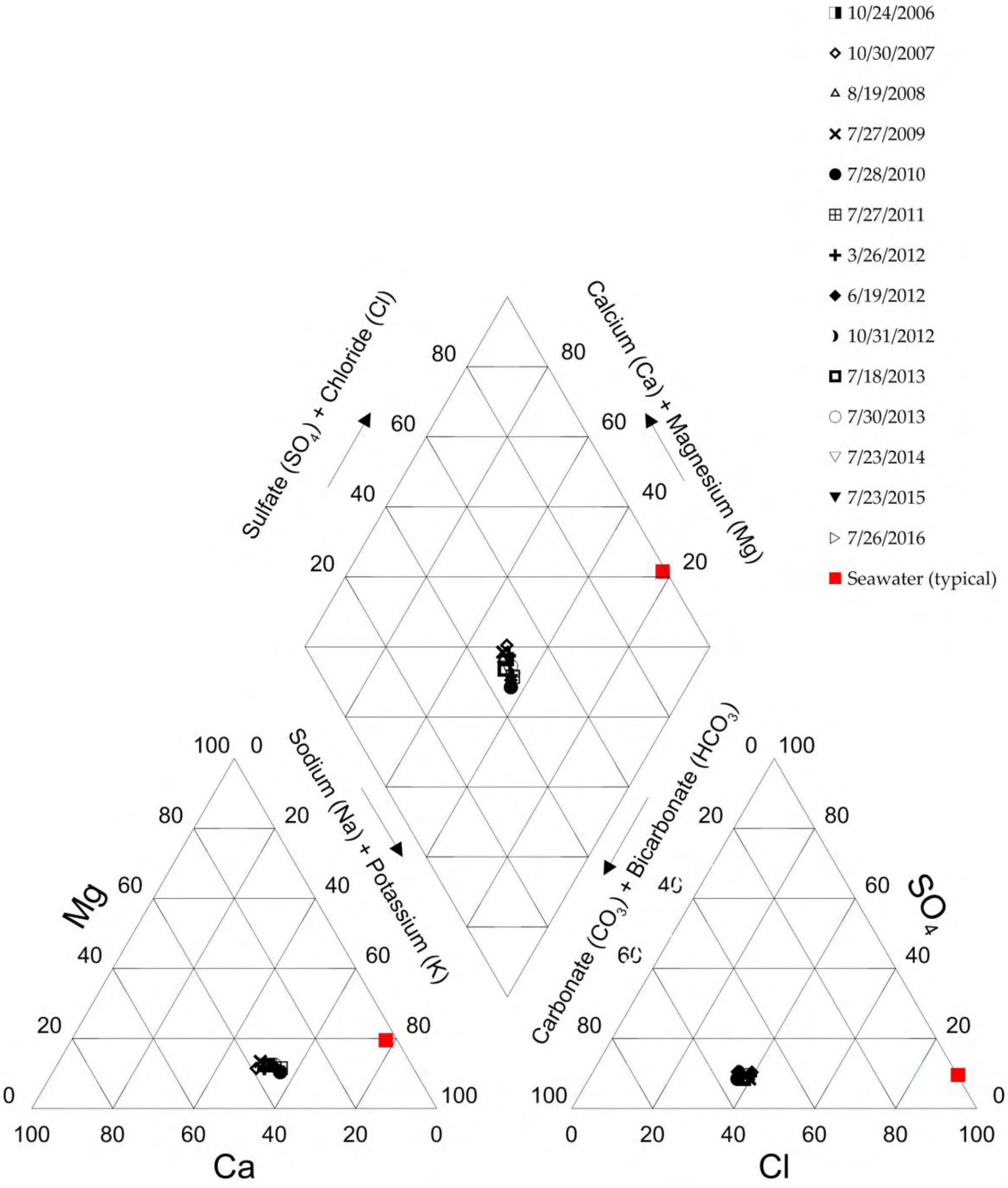

Figure A-4: Piper Diagram of PCA East Deep

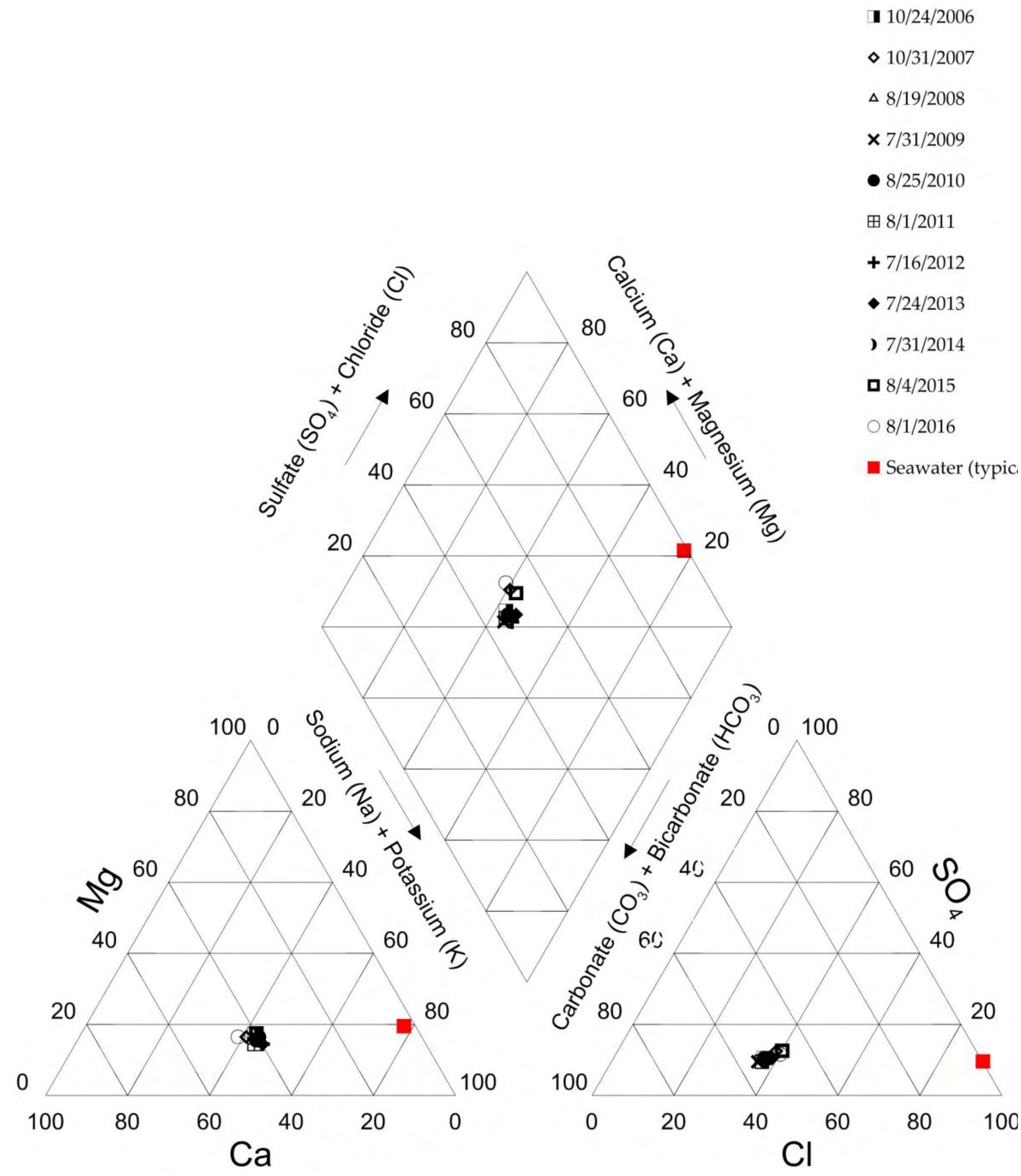

Figure A-5: Piper Diagram of Ord Terrace Shallow

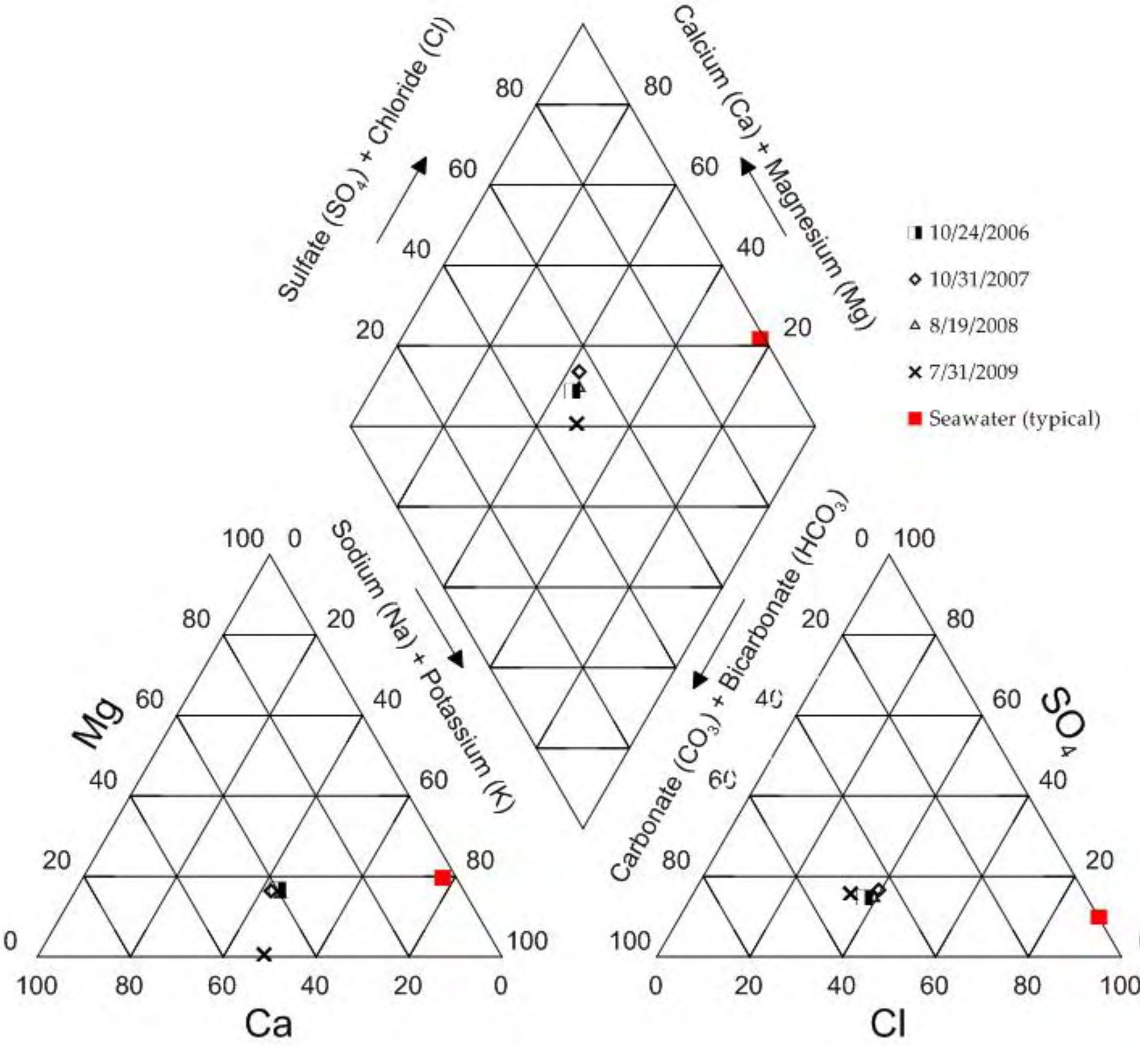

Figure A-6: Piper Diagram of Ord Terrace Deep

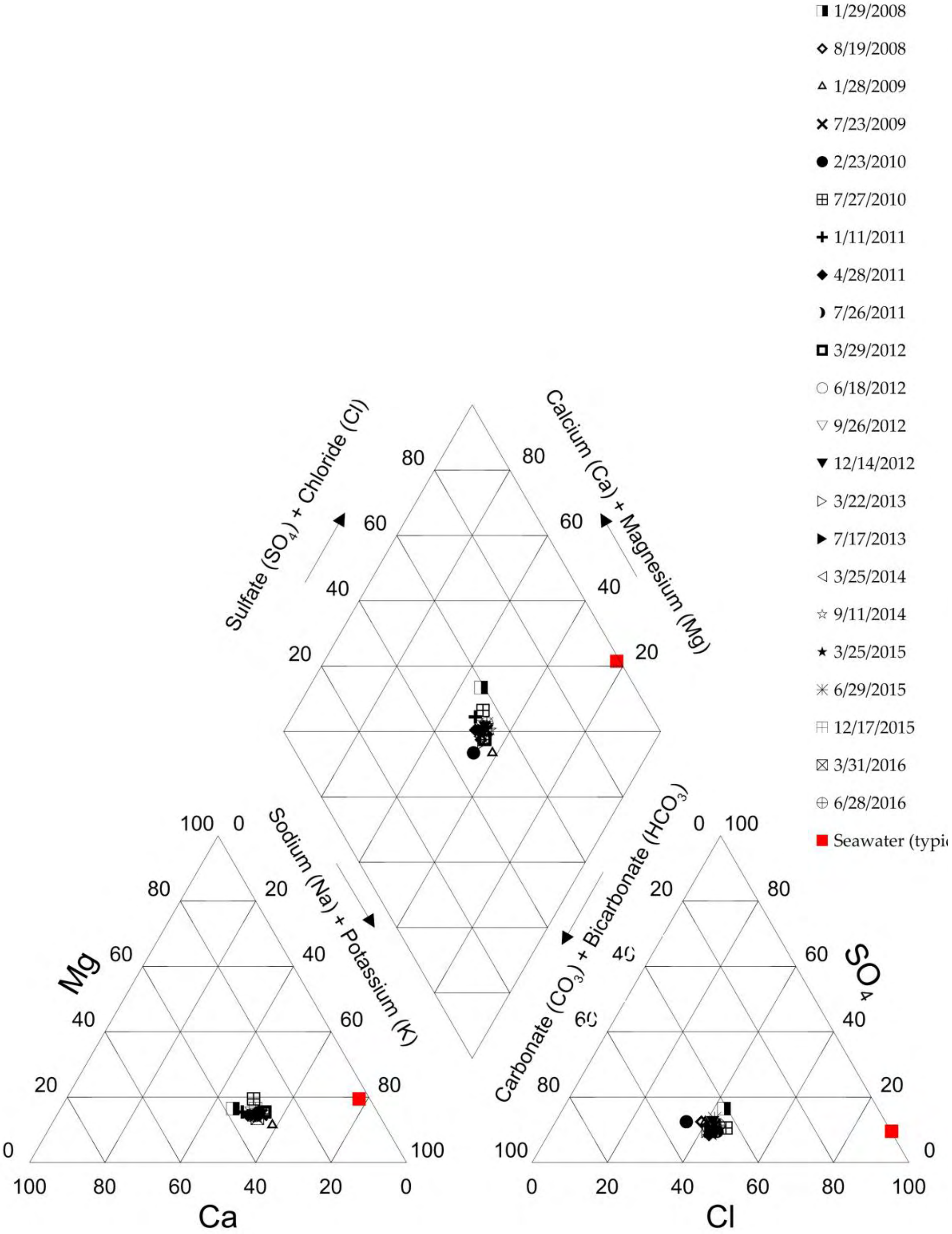

Figure A-7: Piper Diagram of MSC Shallow

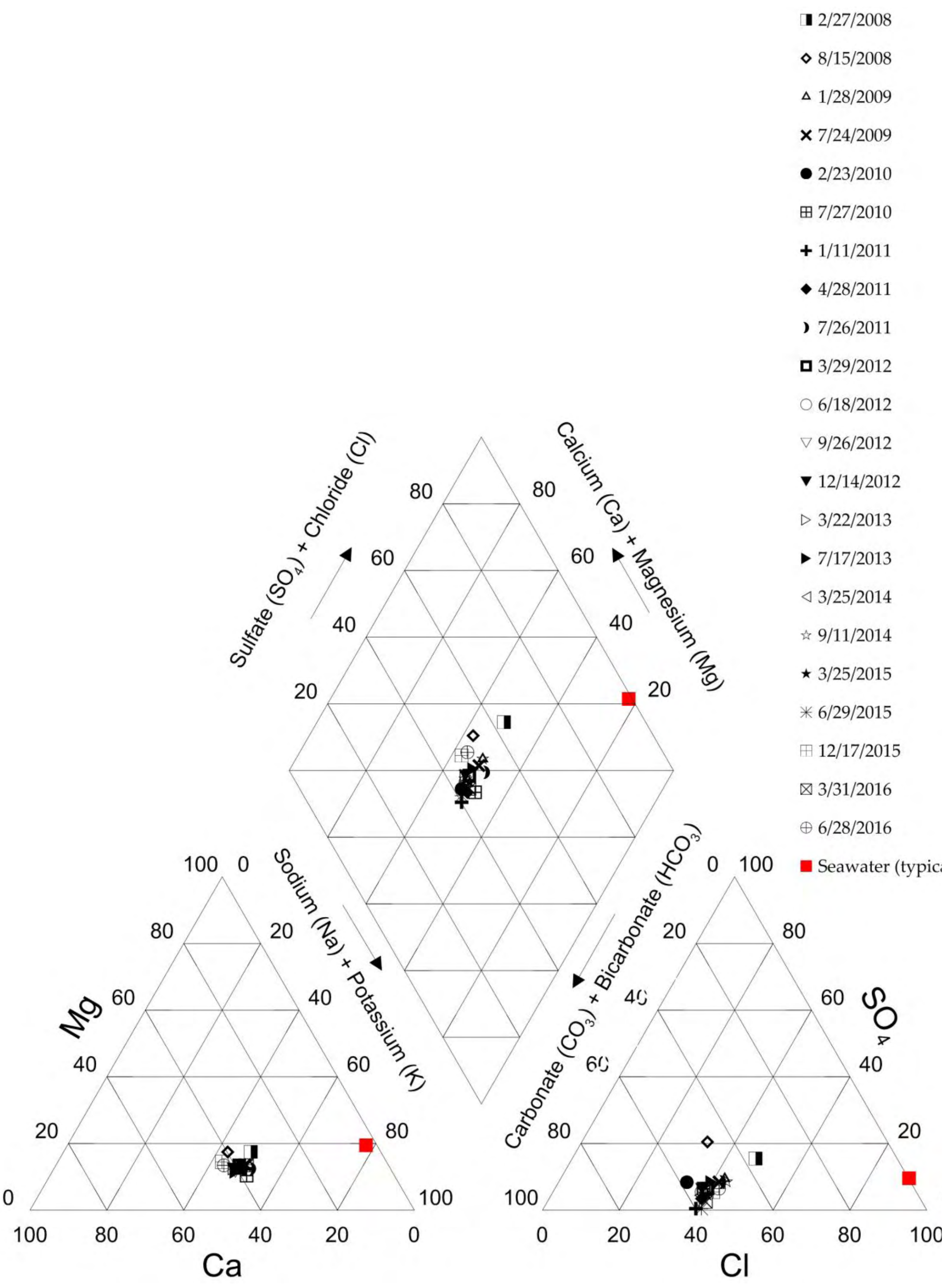

Figure A-8: Piper Diagram of MSC Deep

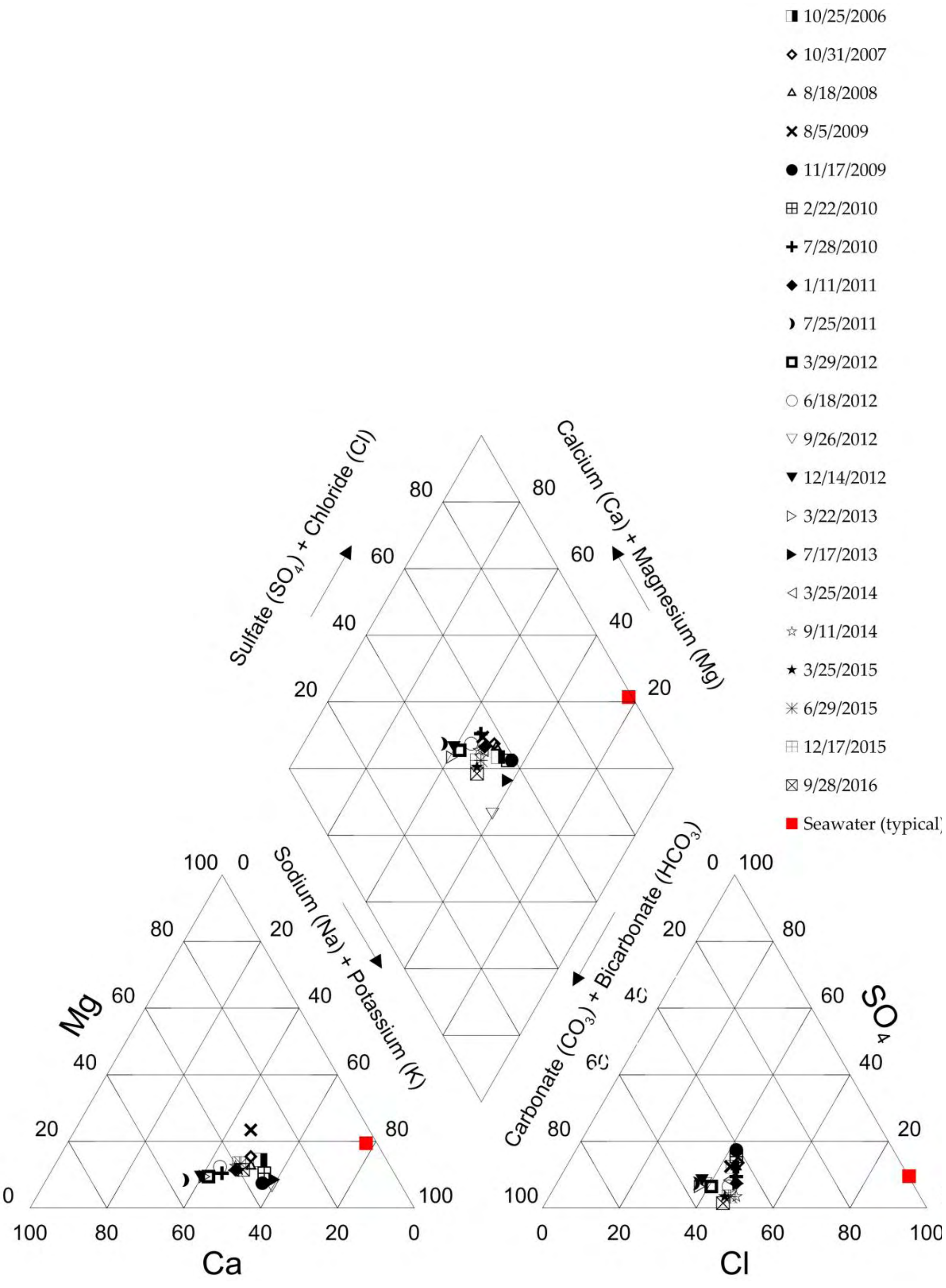

Figure A-9: Piper Diagram of Fort Ord 9 Shallow

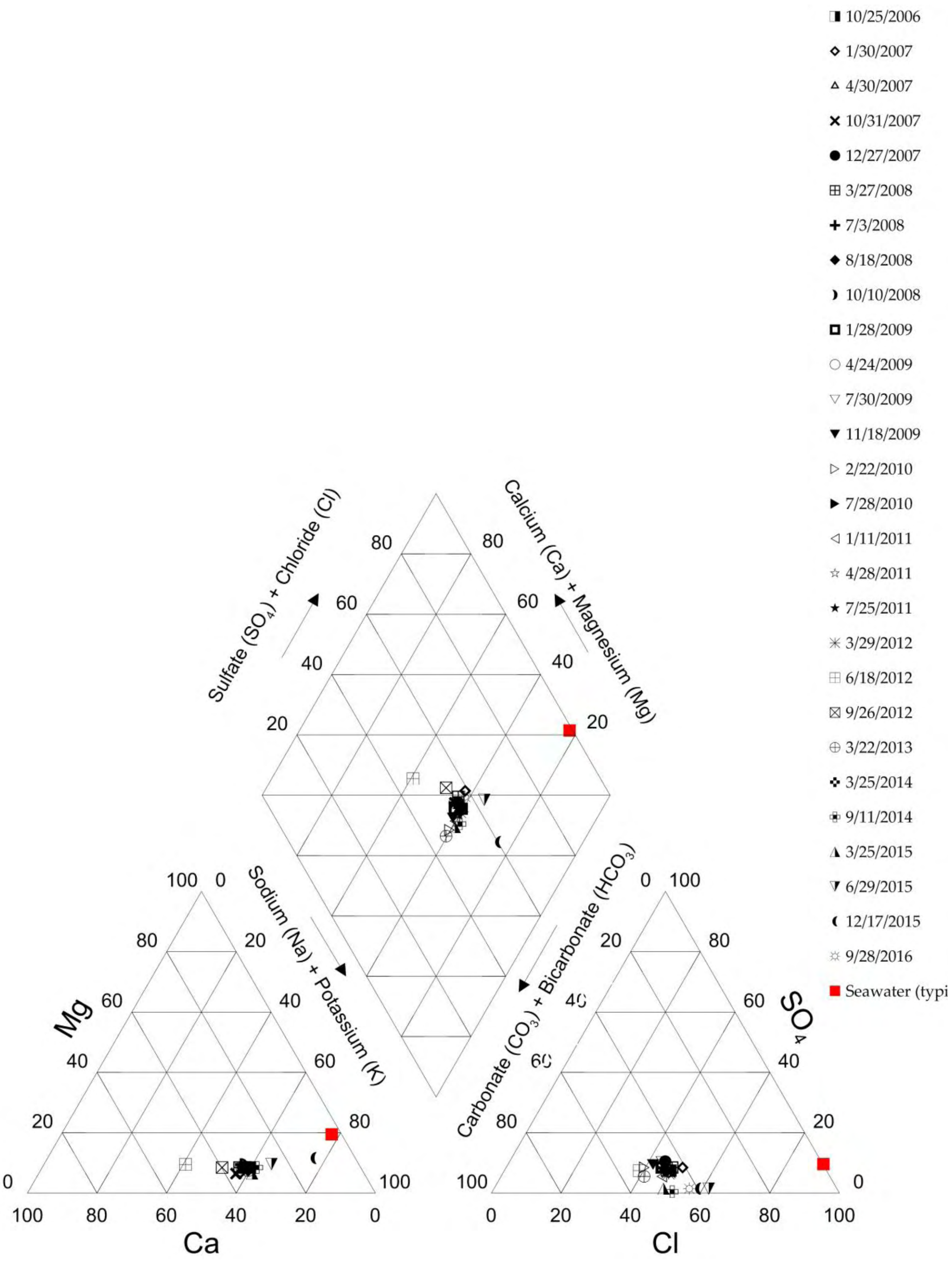

Figure A-10: Piper Diagram of Fort Ord 9 Deep

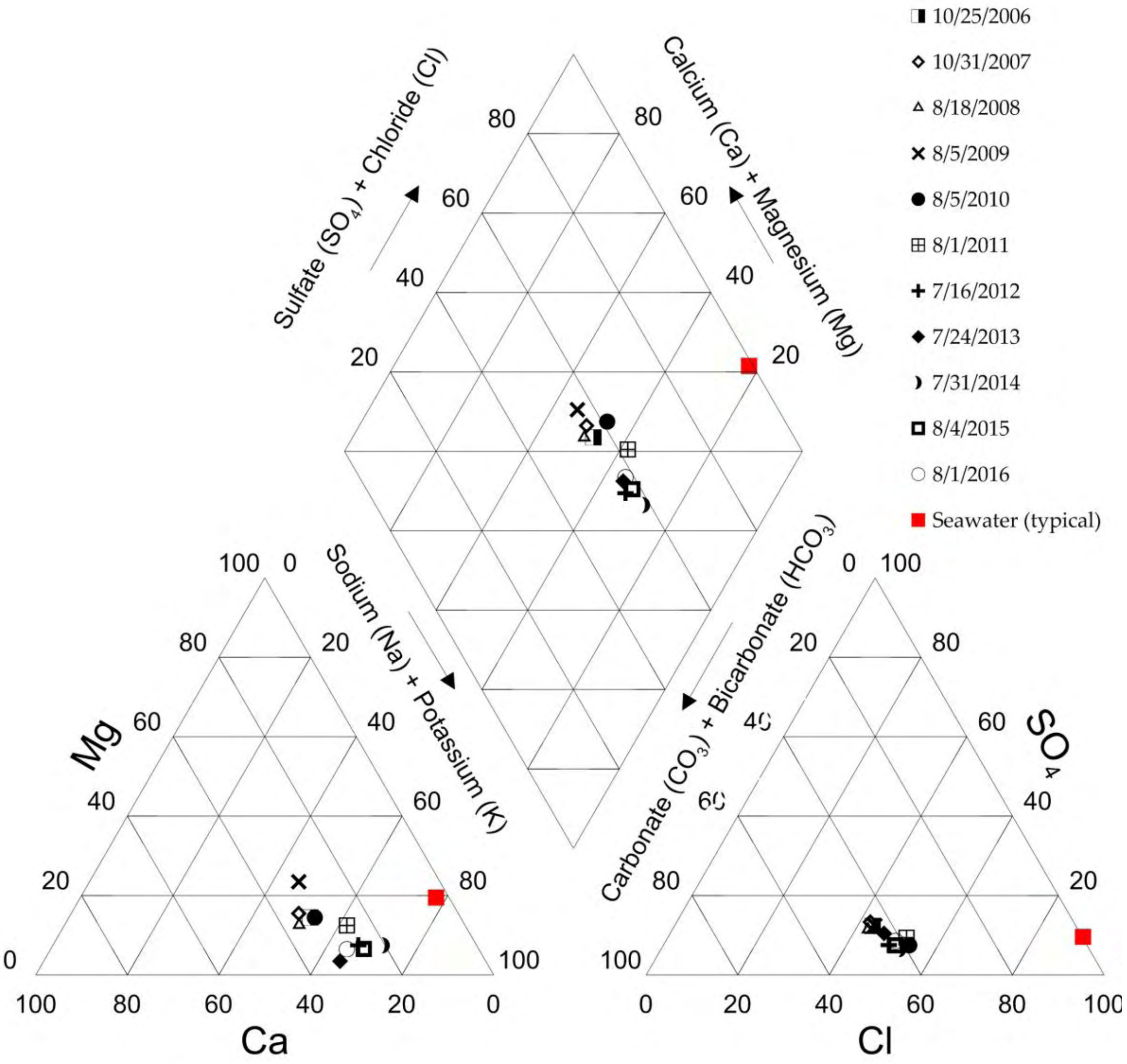

Figure A-11: Piper Diagram of Fort Ord 10 Shallow

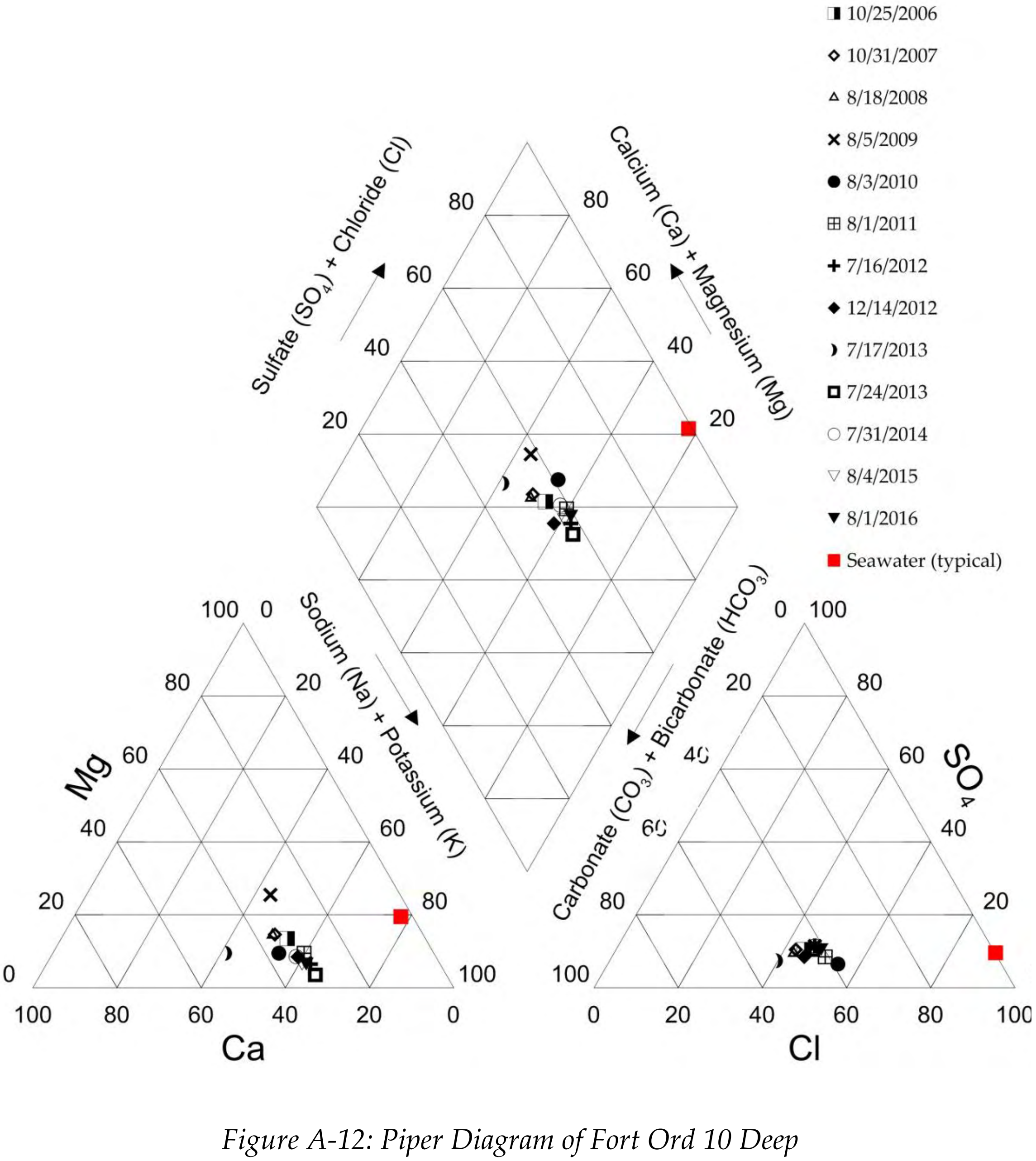

Figure A-12: Piper Diagram of Fort Ord 10 Deep

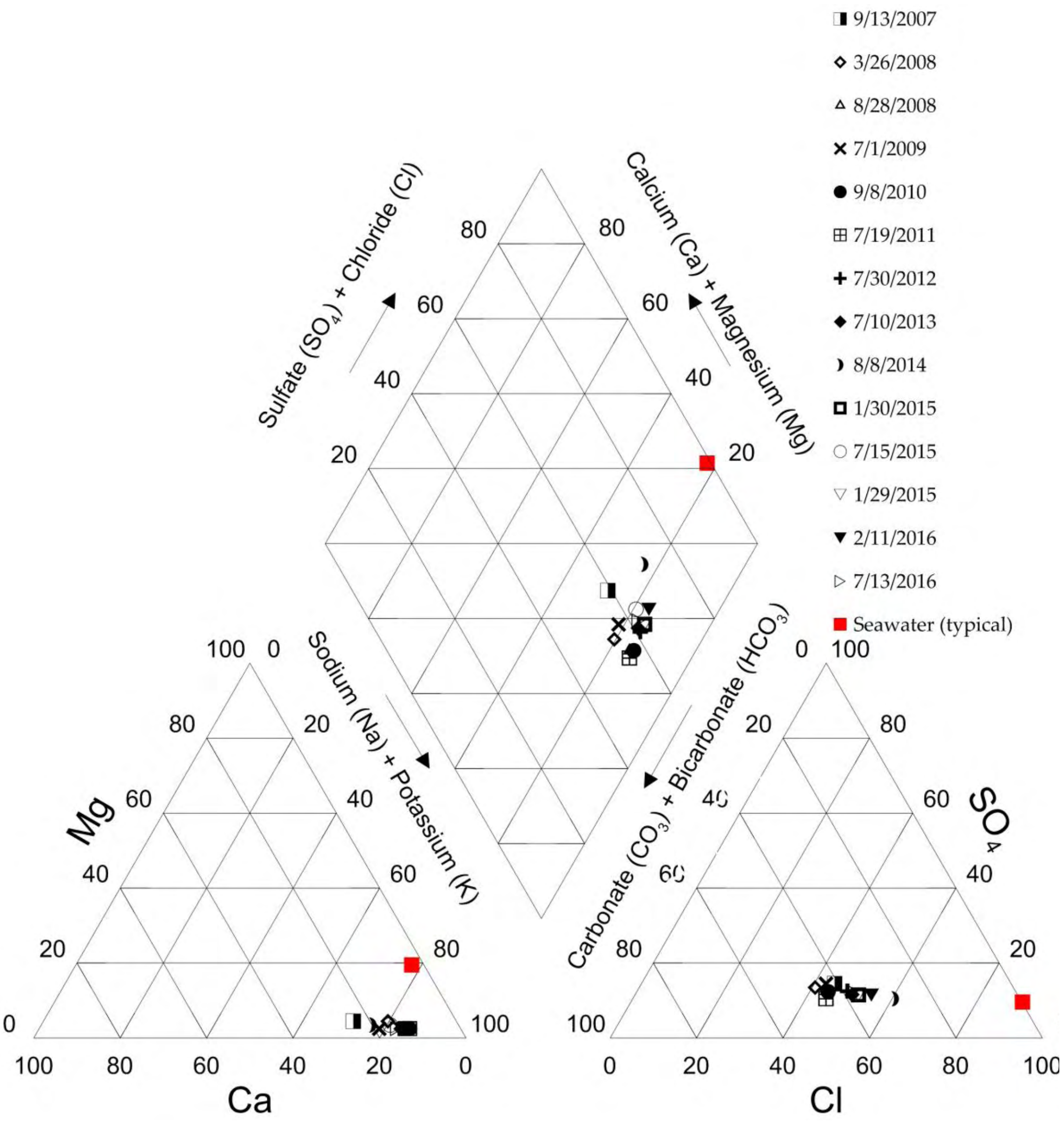

Figure A-13: Piper Diagram of SBWM-1 1,140 ft sample

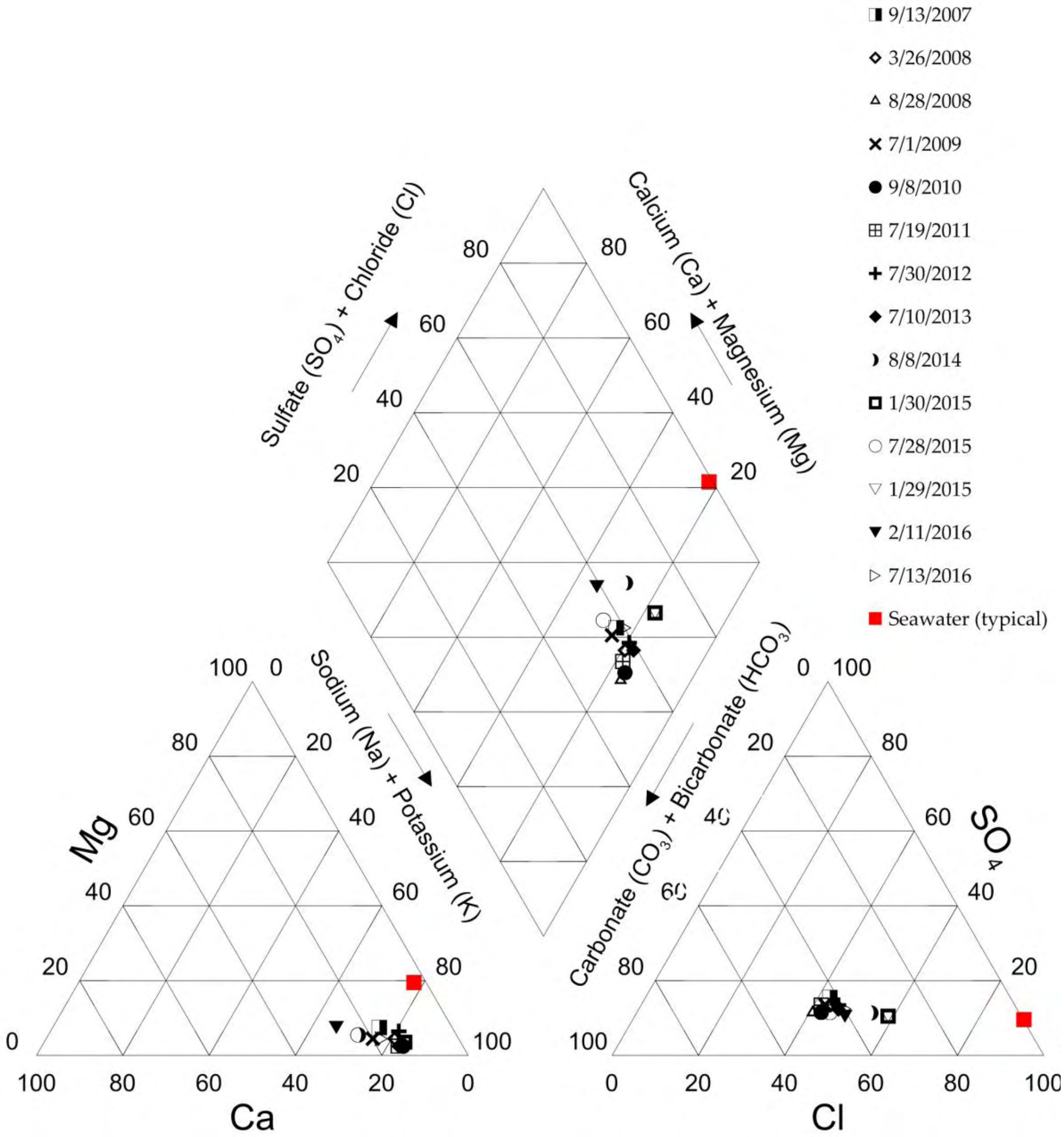

Figure A-14: Piper Diagram of SBWM-1 1,390 ft sample

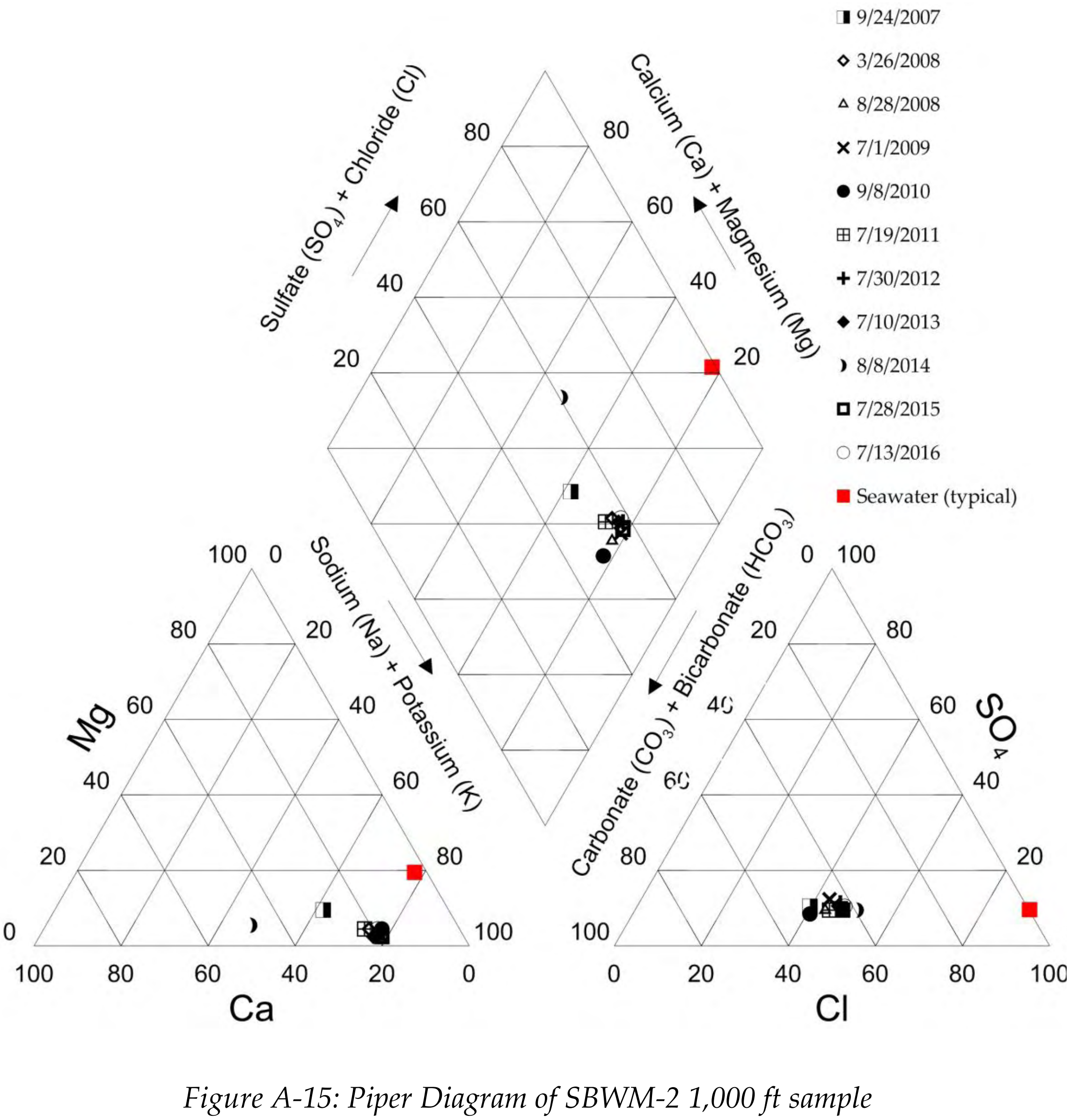

Figure A-15: Piper Diagram of SBWM-2 1,000 ft sample

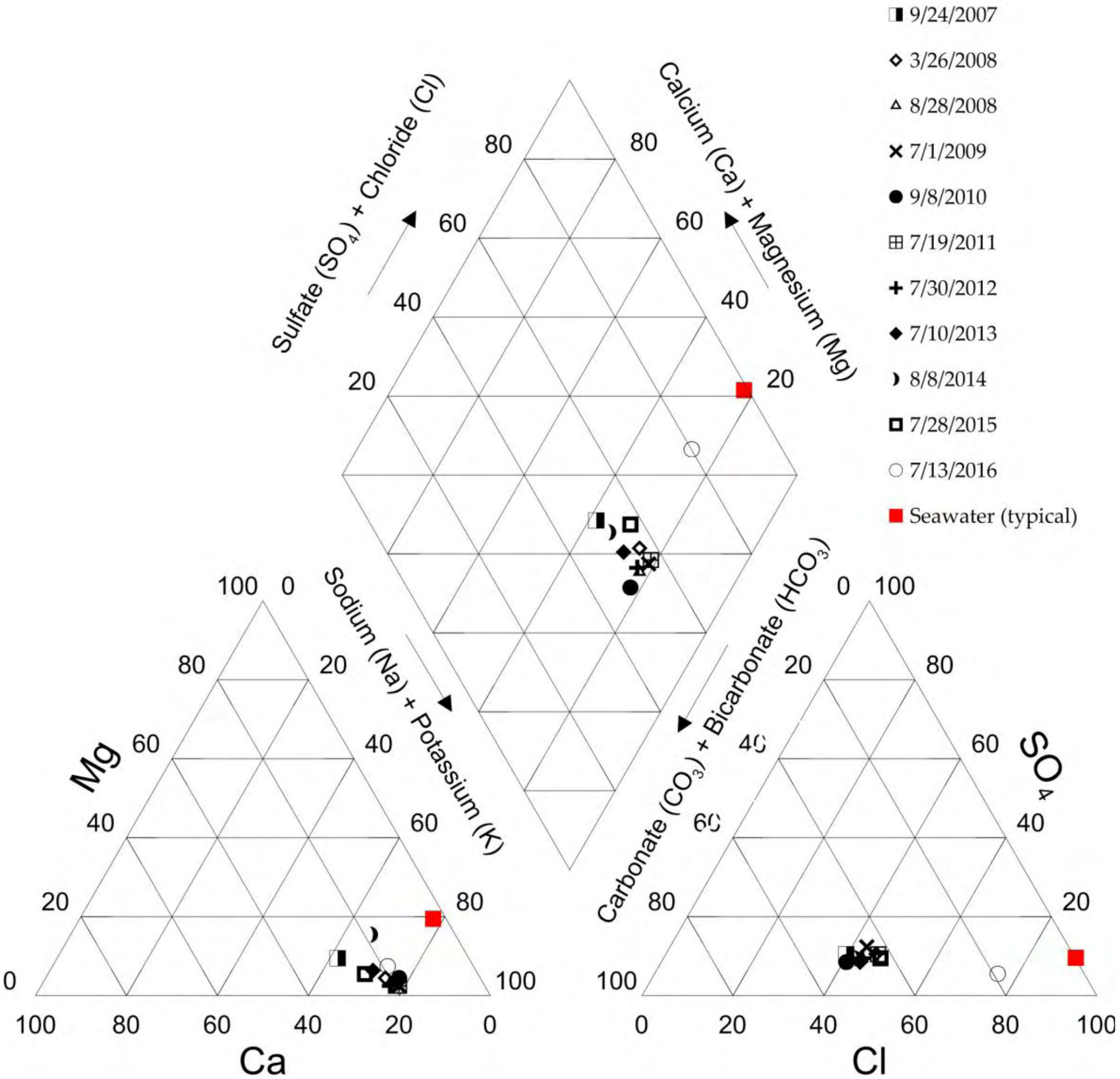

Figure A-16: Piper Diagram of SBWM-2 1,470 ft sample

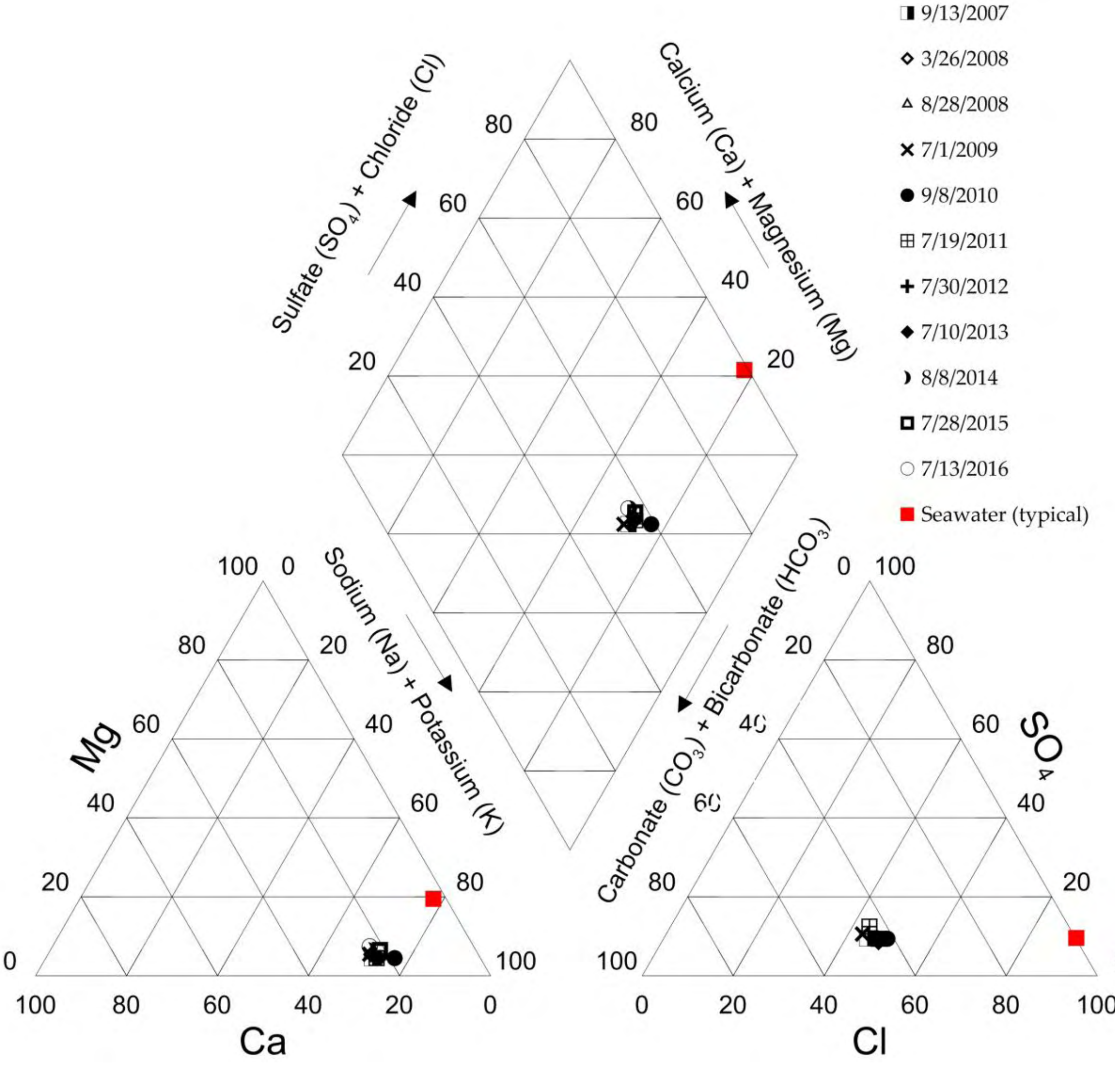

Figure A-17: Piper Diagram of SBWM-3 870 ft sample

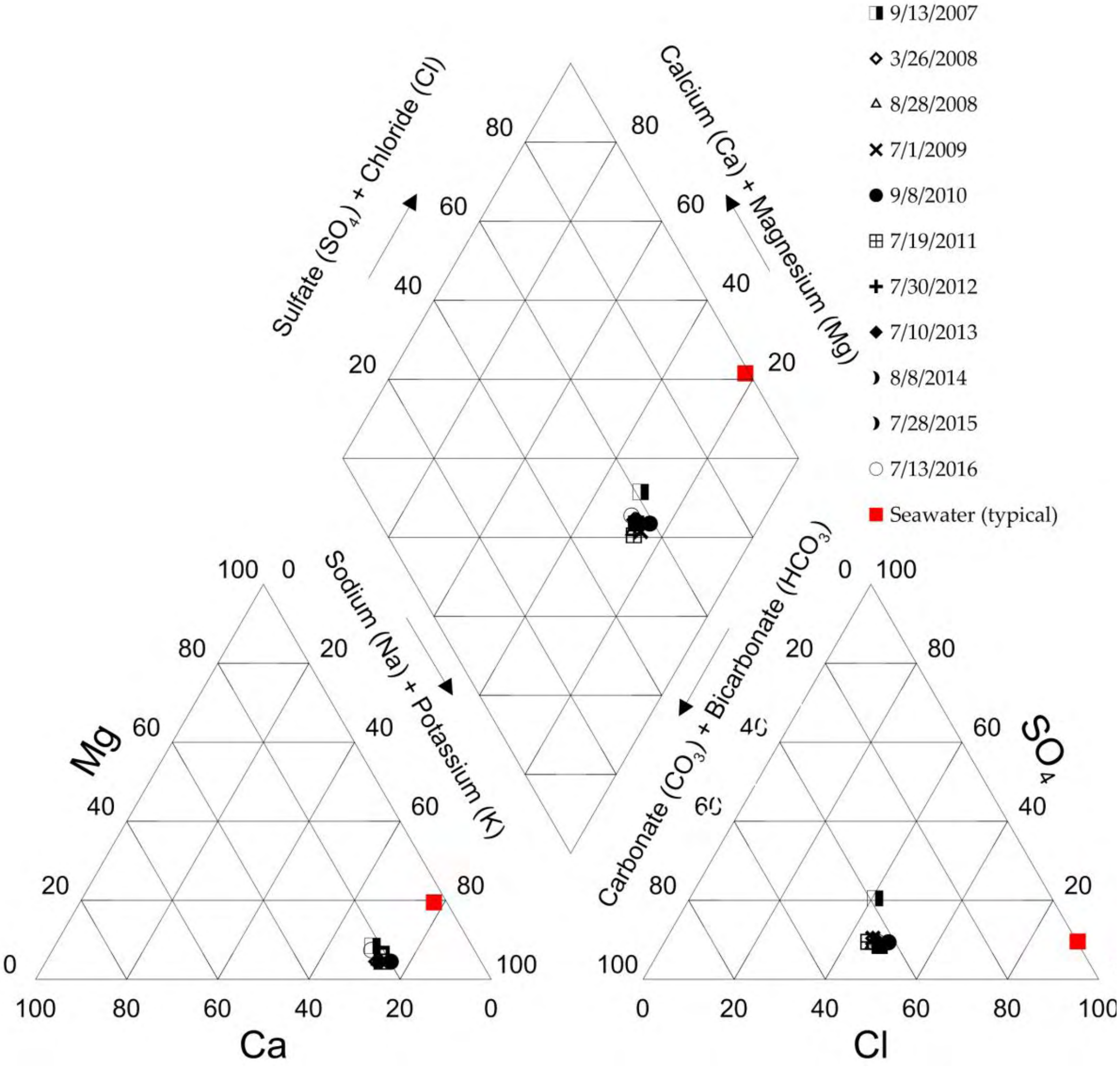

Figure A-18: Piper Diagram of SBWM-3 1,275 ft sample

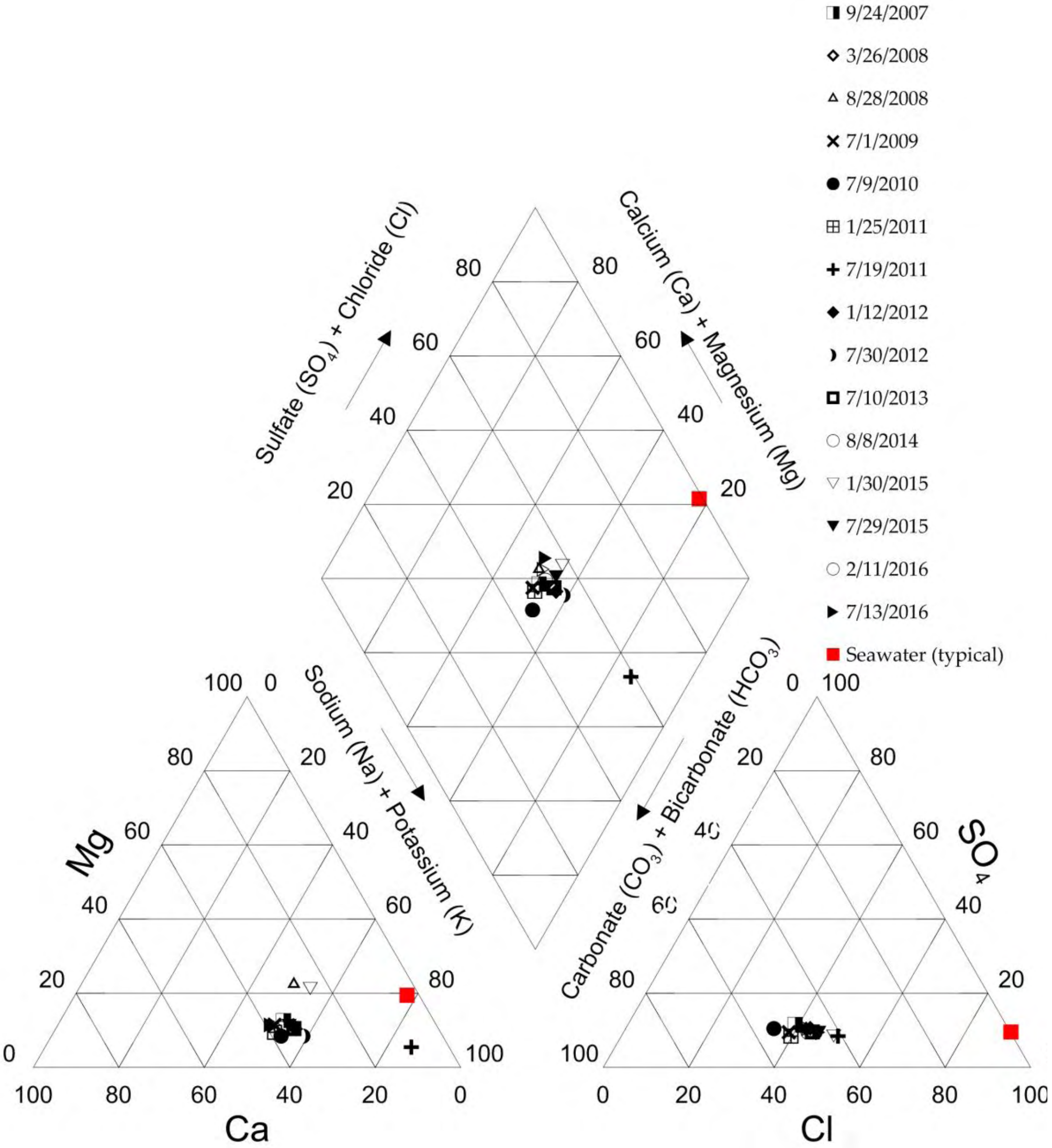

Figure A-19: Piper Diagram of SBWM-4 715 ft sample

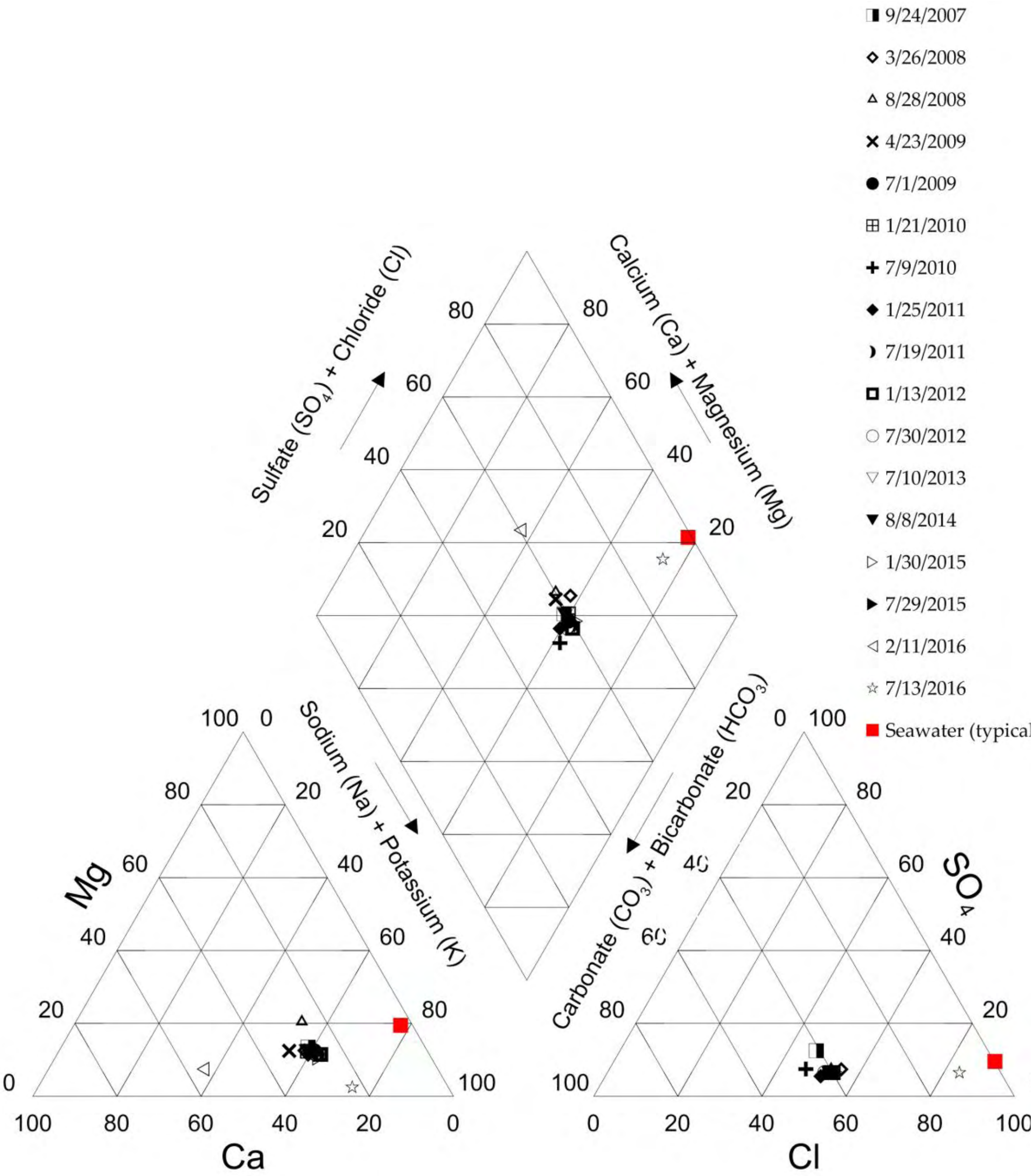

Figure A-20: Piper Diagram of SBWM-4 900 ft sample

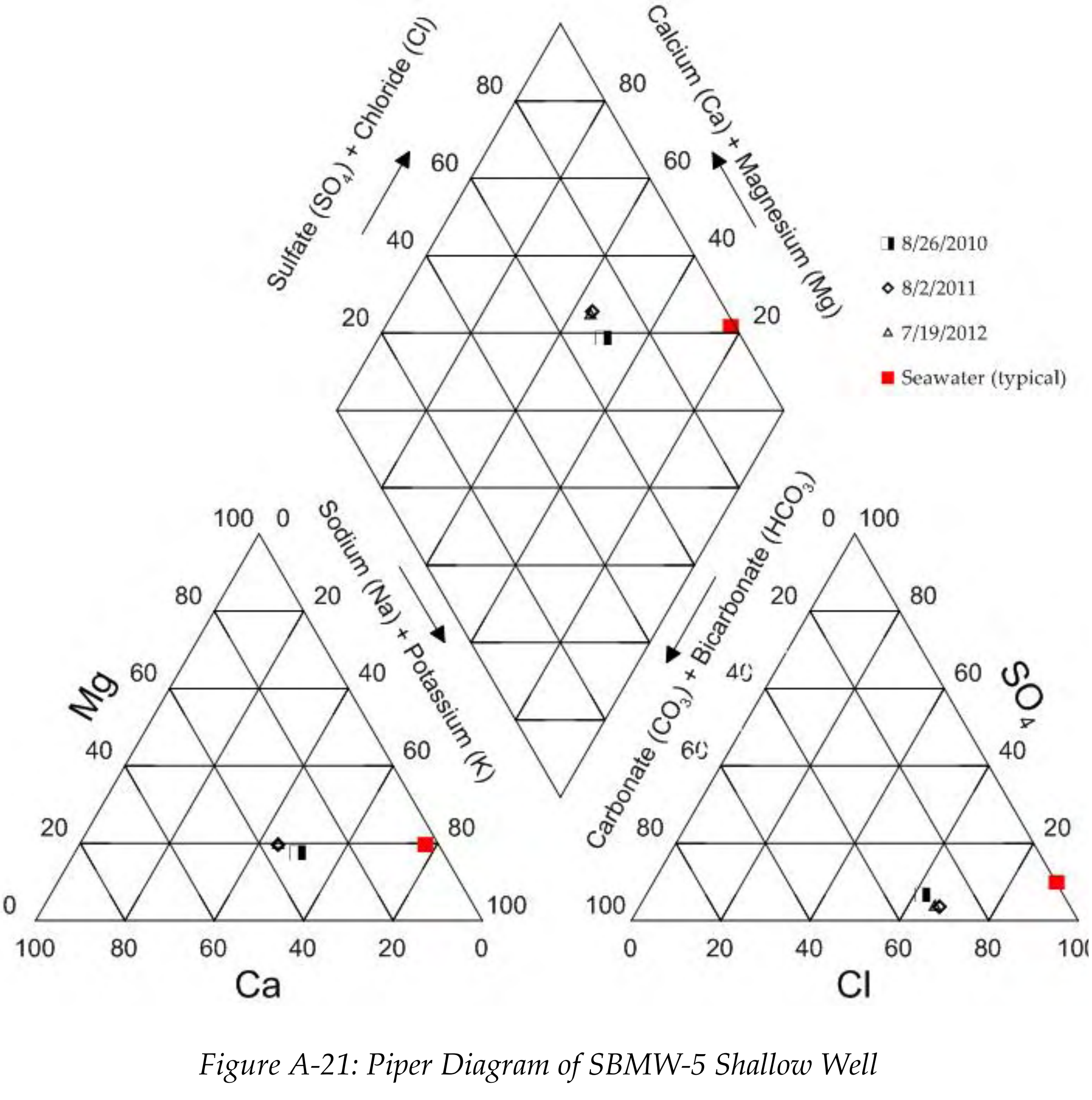

Figure A-21: Piper Diagram of SBMW-5 Shallow Well

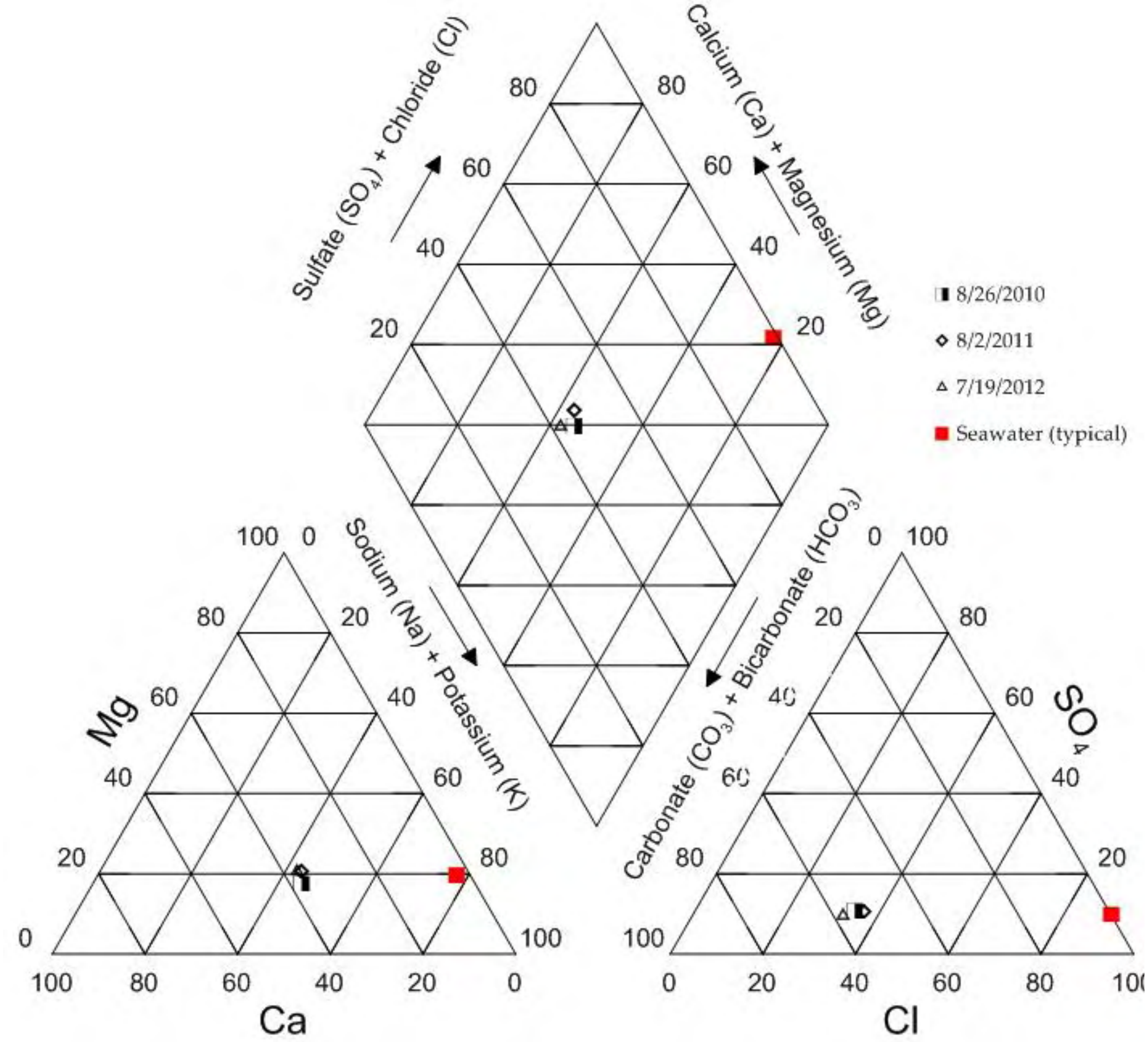

Figure A-22: Piper Diagram of SBMW-5 Deep Well

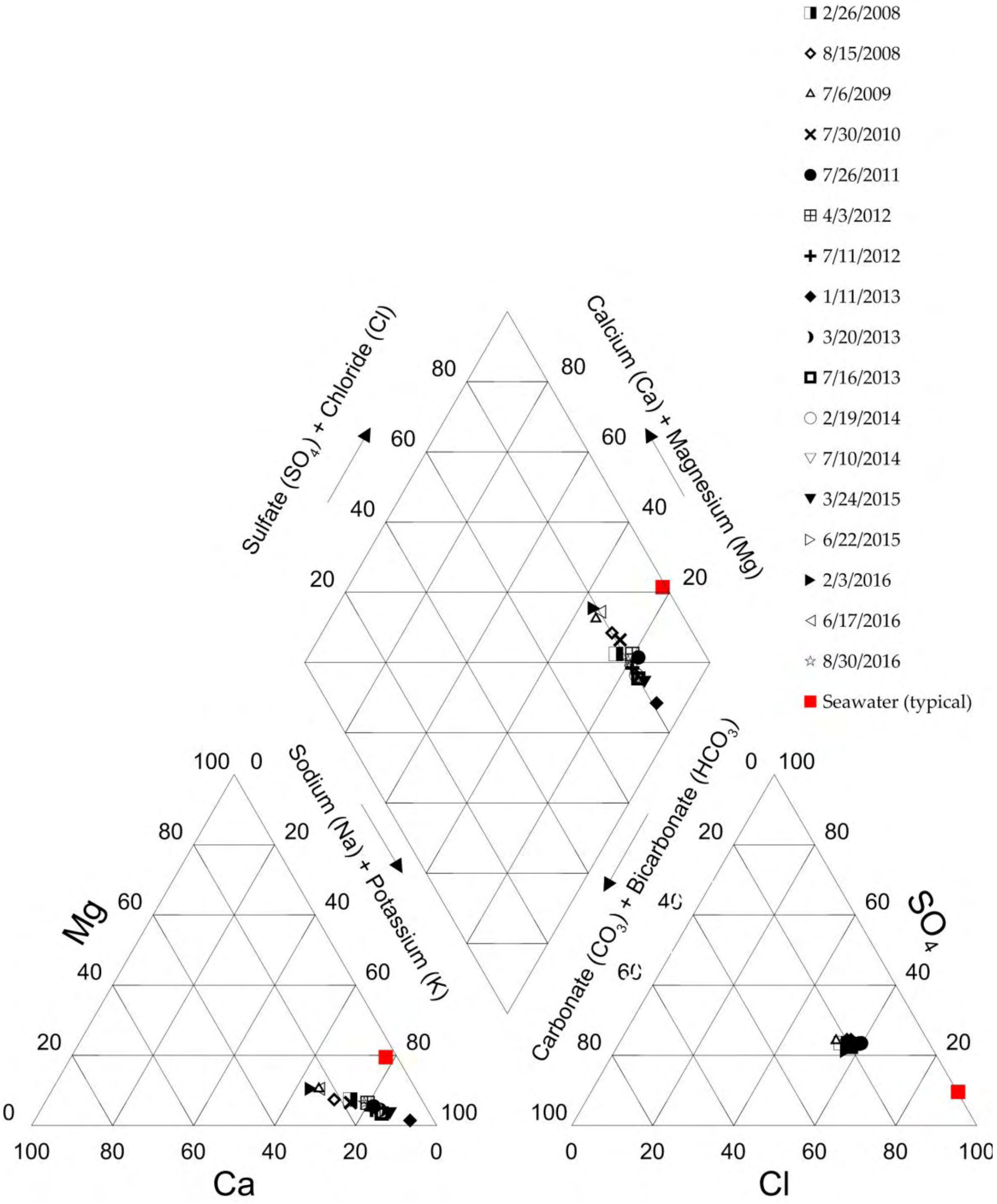

Figure A-23: Piper Diagram of Public Works Corp. Yard Production Well

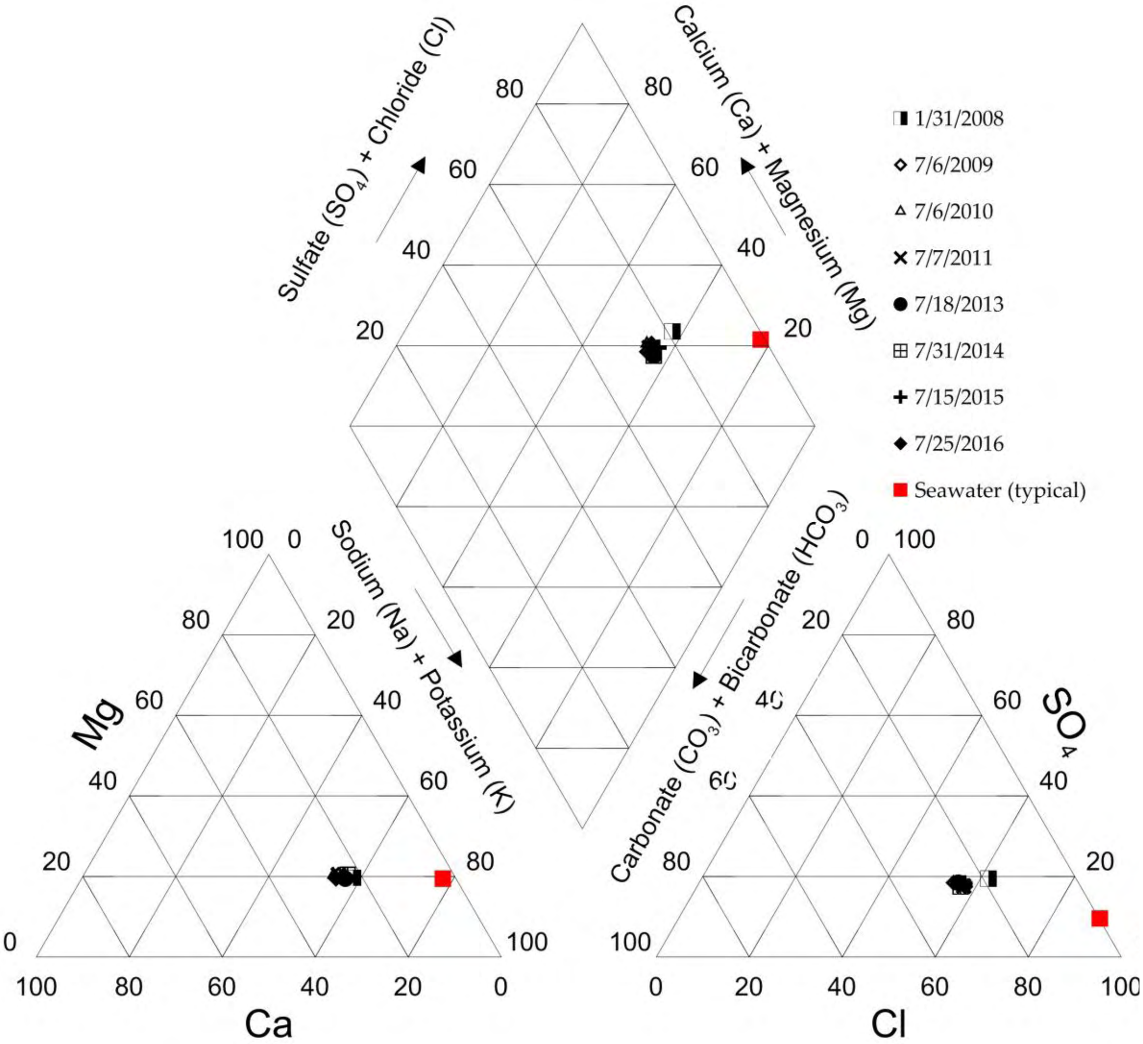

Figure A-24: Piper Diagram of Plumas 4 Production Well

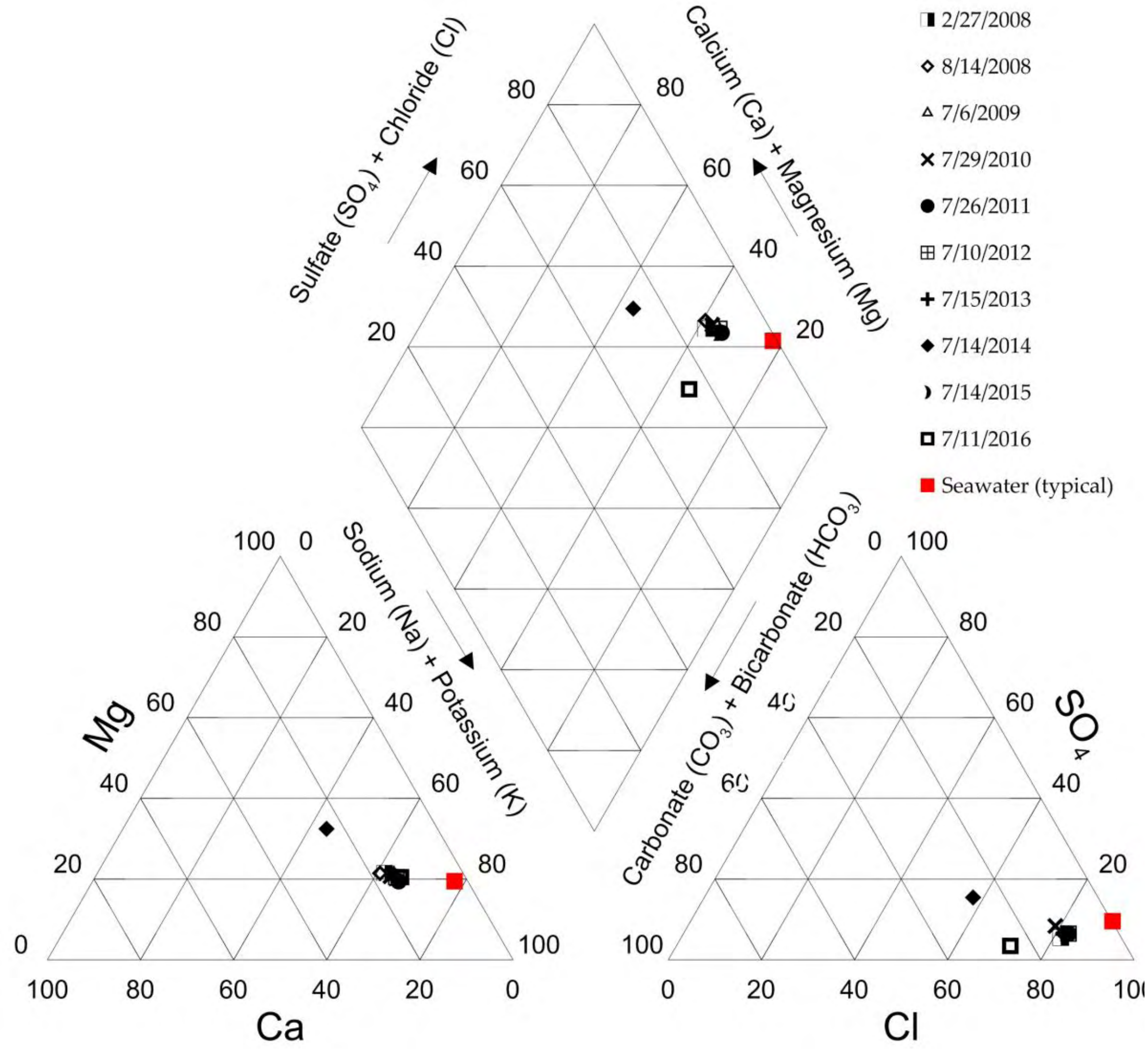

Figure A-25: Piper Diagram of York School Production Well

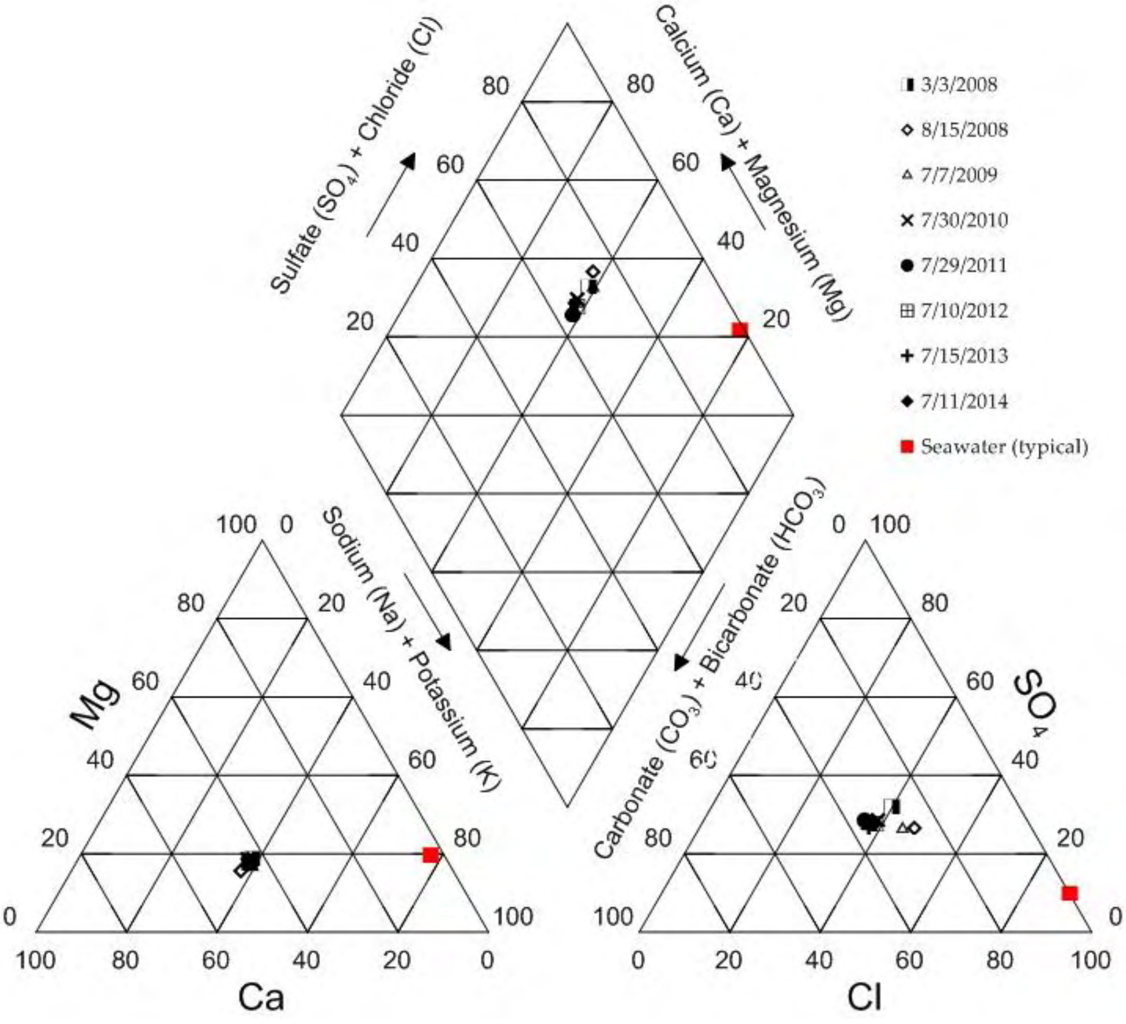

Figure A-26: Piper Diagram of Pasadera Main Gate Production Well

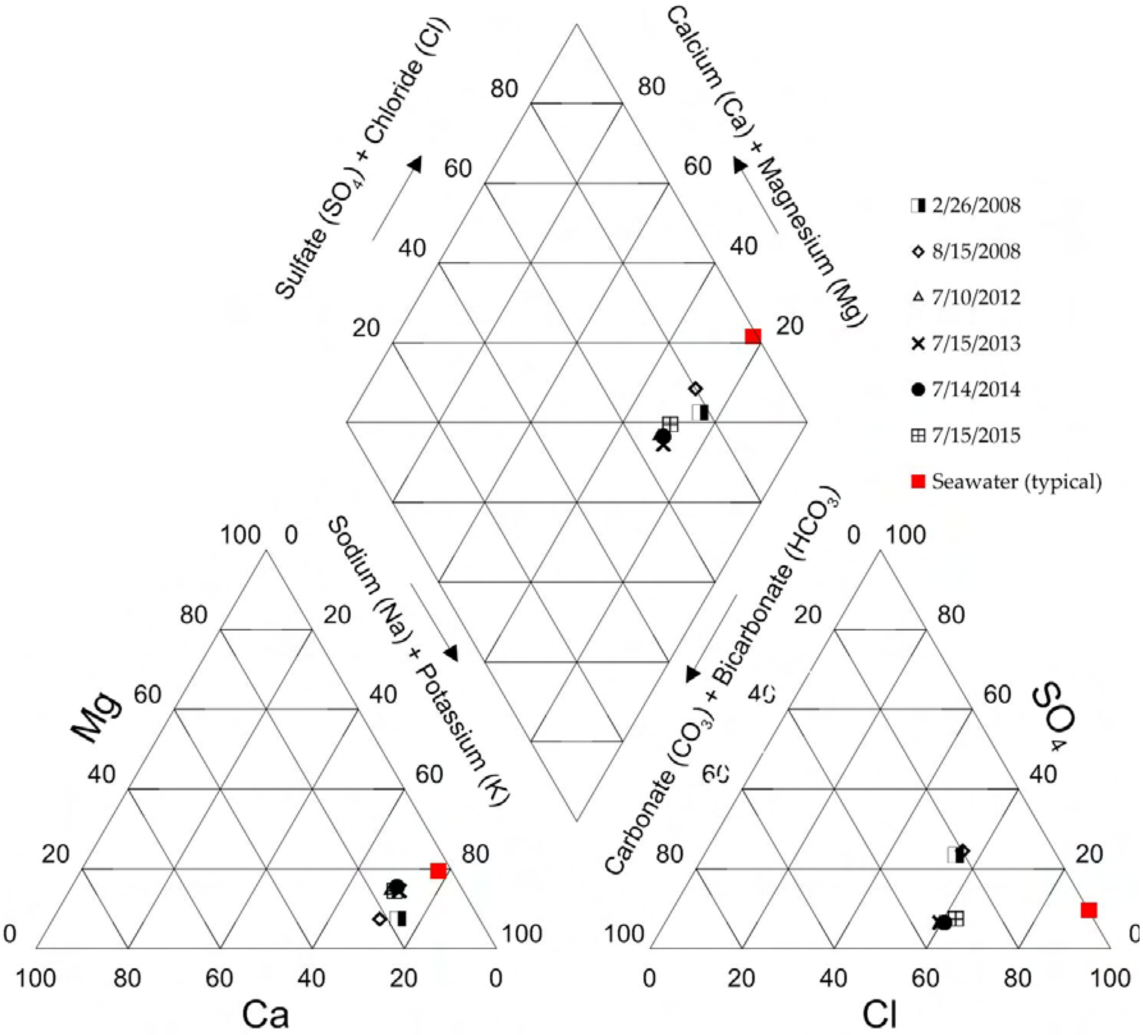

Figure A-27: Piper Diagram of LS County Park #1 Production Well

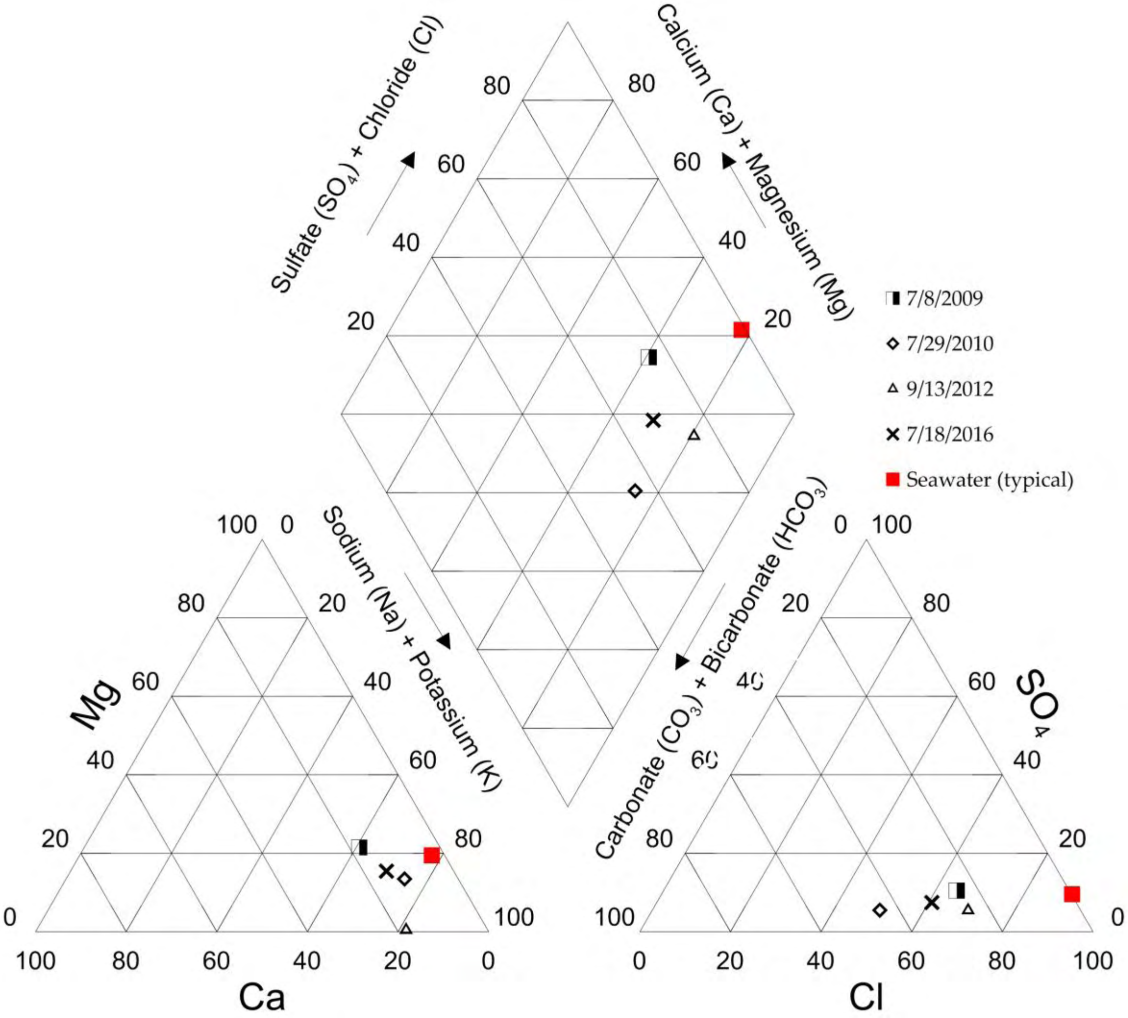

Figure A-28: Piper Diagram of LS County Park #2 Production Well

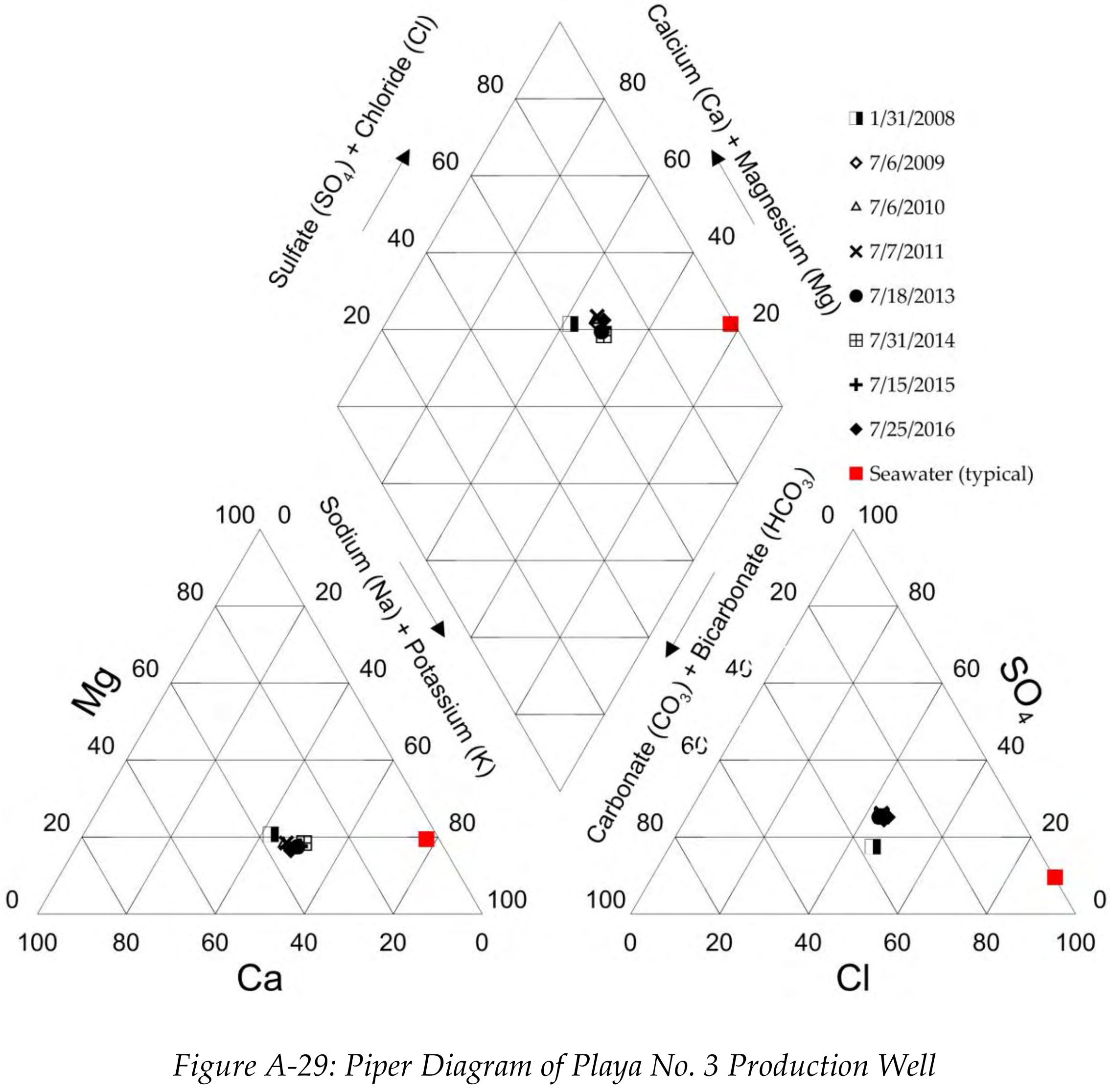

Figure A-29: Piper Diagram of Playa No. 3 Production Well

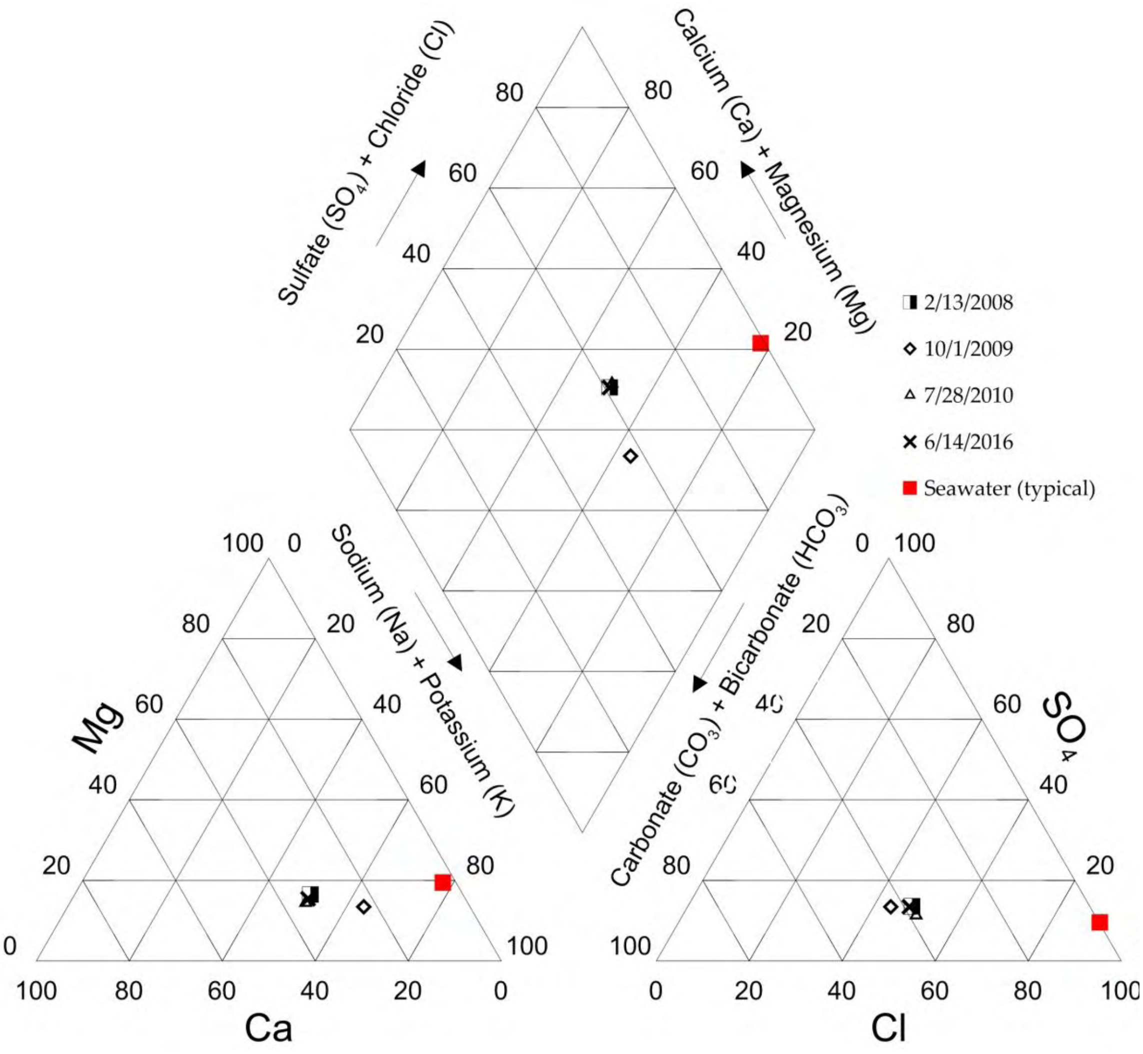

Figure A-30: Piper Diagram of Coe Ave. Production Well

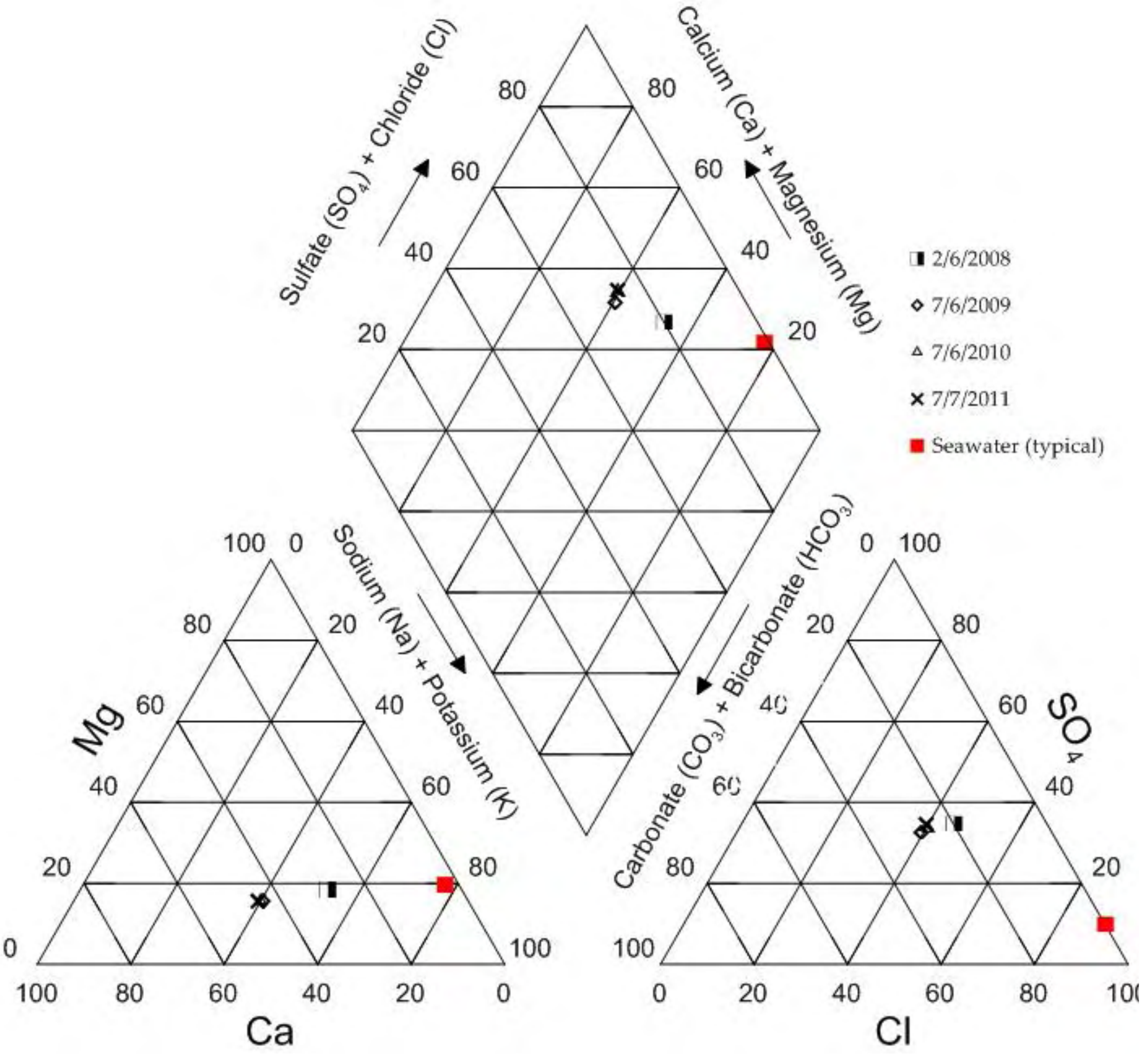

Figure A-31: Piper Diagram of Military Production Well

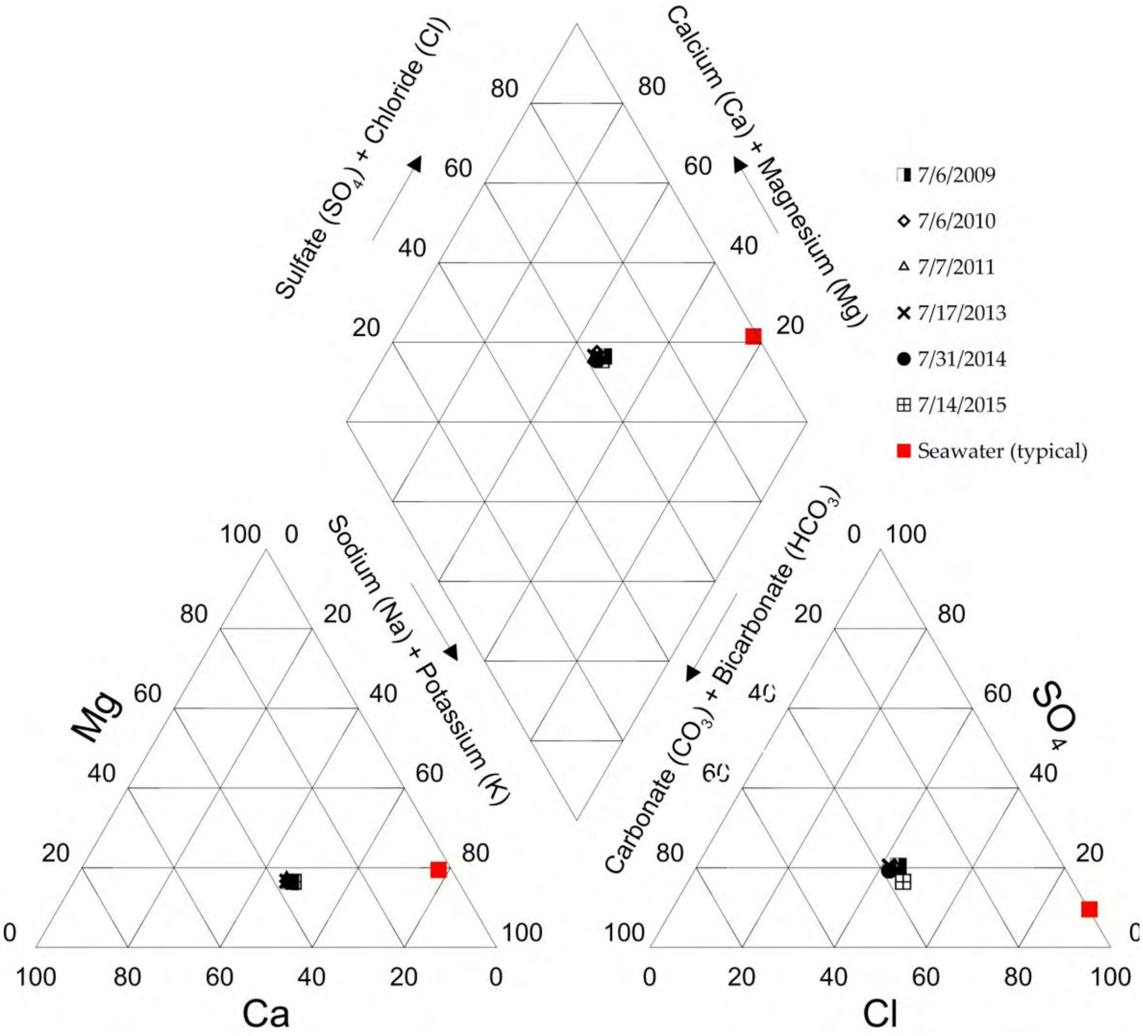

Figure A-32: Piper Diagram of Luzern #2 Production Well

Figure A-33: Piper Diagram of Darwin Production Well

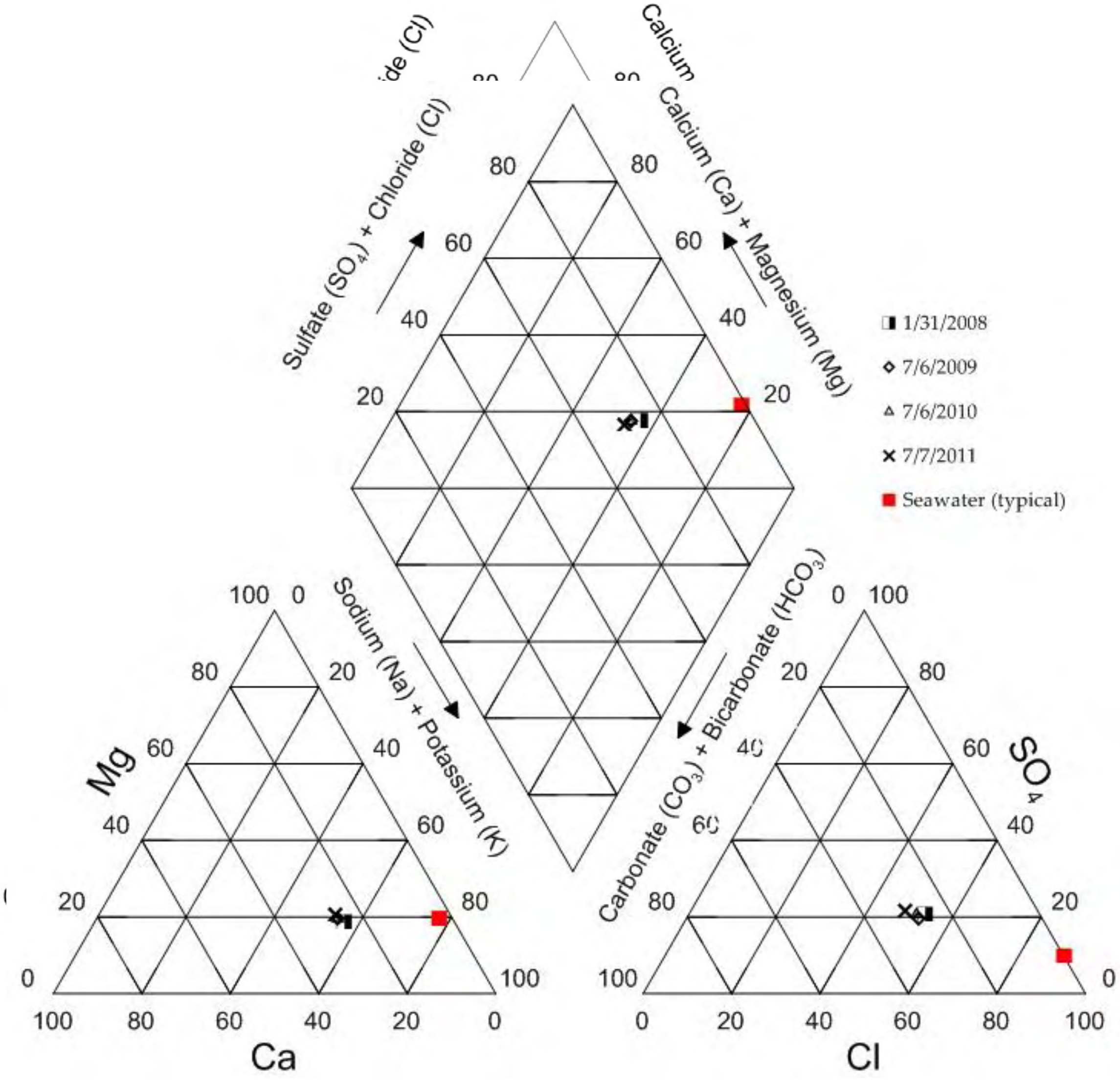

Figure A-34: Piper Diagram of Ord Grove No. 2 Production Well

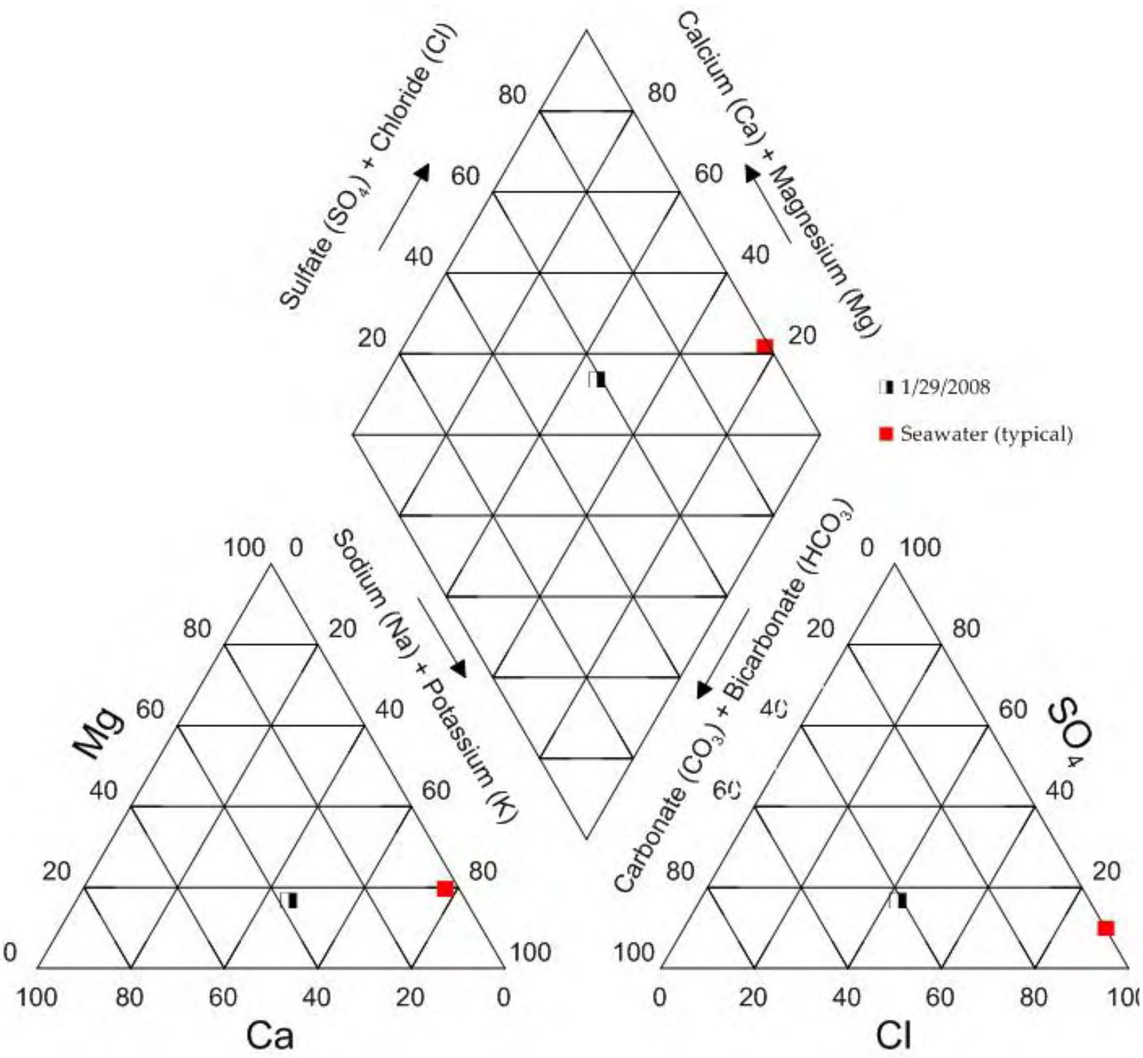

Figure A-35: Piper Diagram of Seaside City No. 3 Production Well

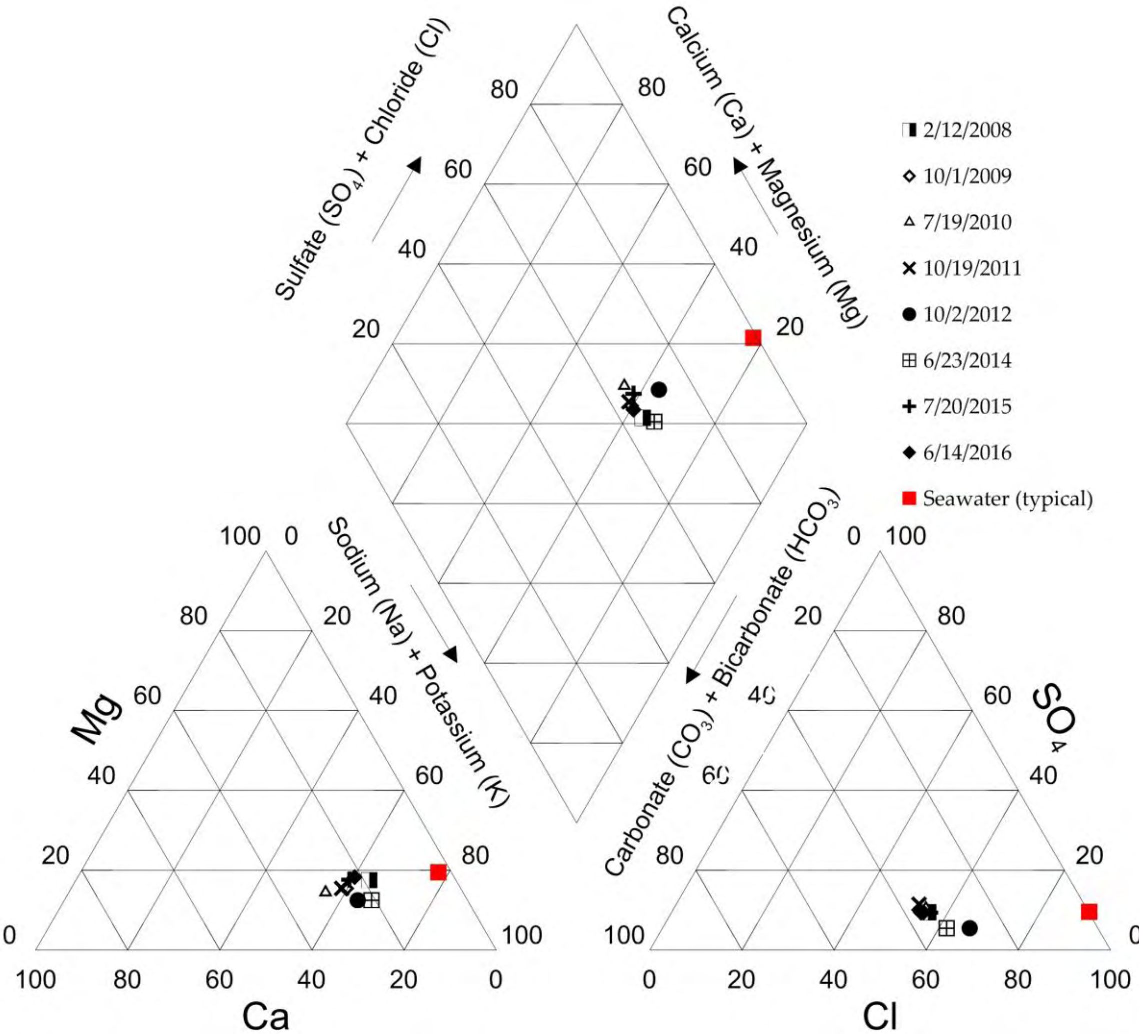

Figure A-36: Piper Diagram of Seaside City No. 4 Production Well

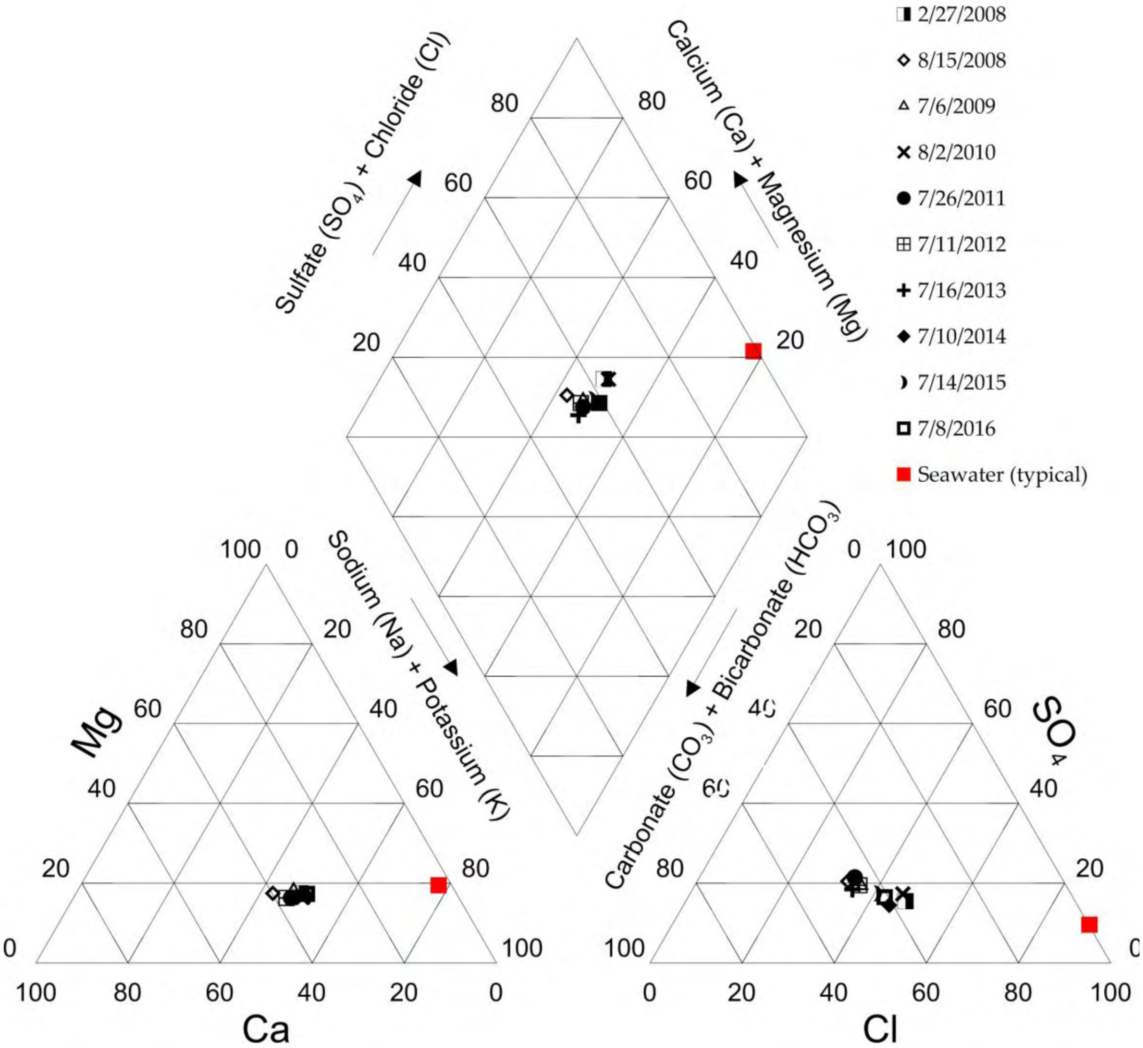

Figure A-37: Piper Diagram of Mission Memorial (formerly PRTIW)

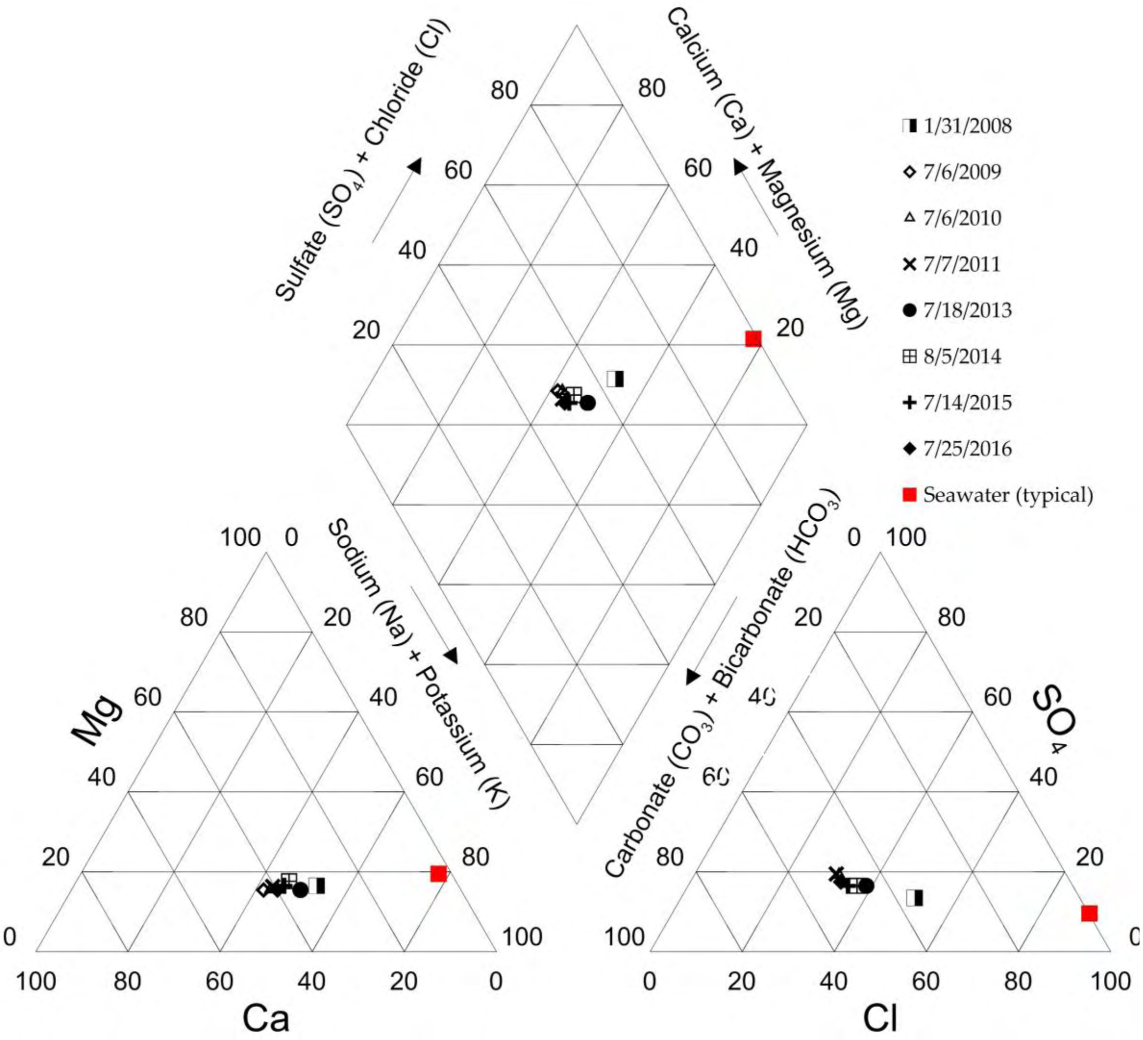

Figure A-38: Piper Diagram of Paralta Production Well

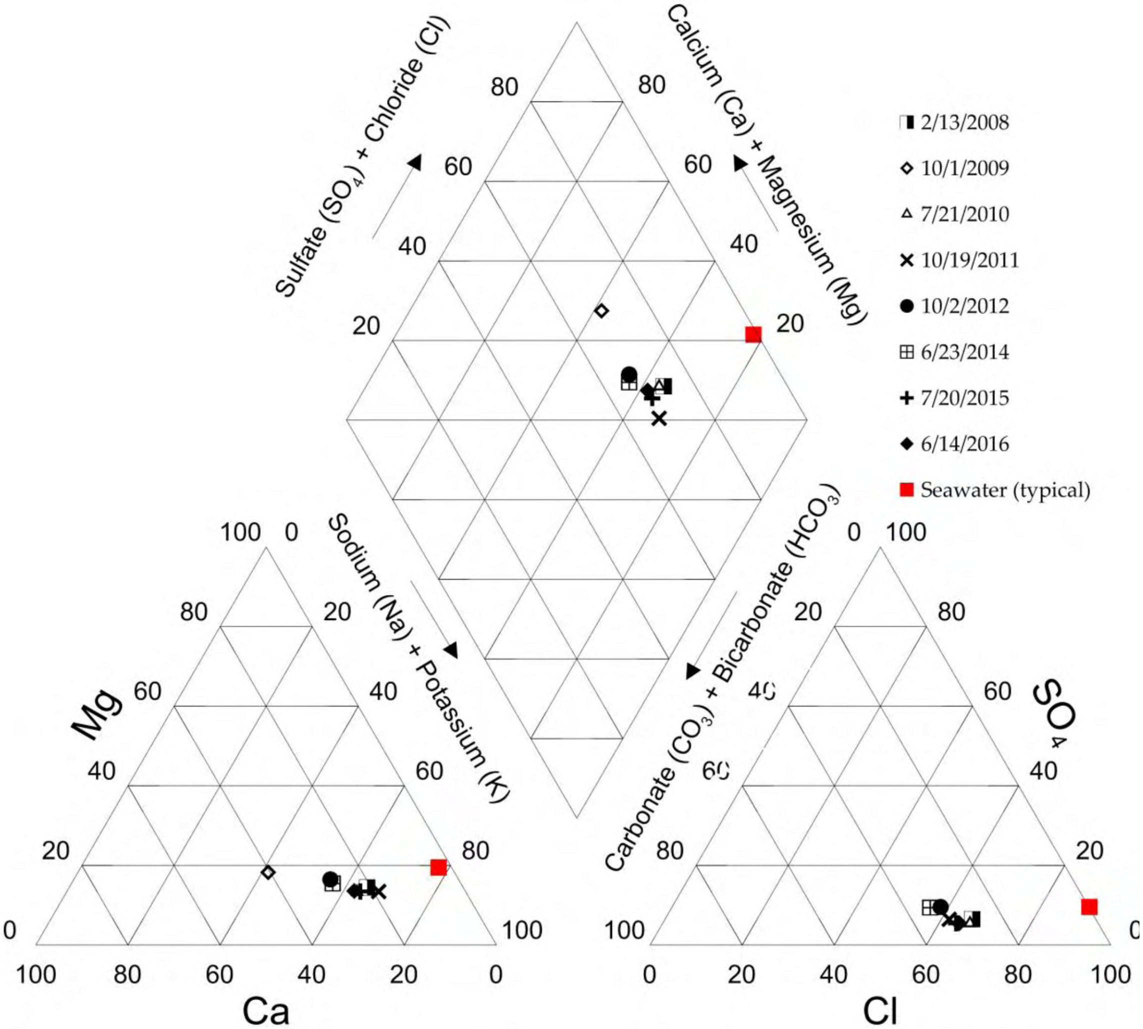

Figure A-39: Piper Diagram of Reservoir (Bayonet Blackhourse) Production Well

APPENDIX B: CHLORIDE AND SODIUM/CHLORIDE MOLAR RATIO GRAPHS

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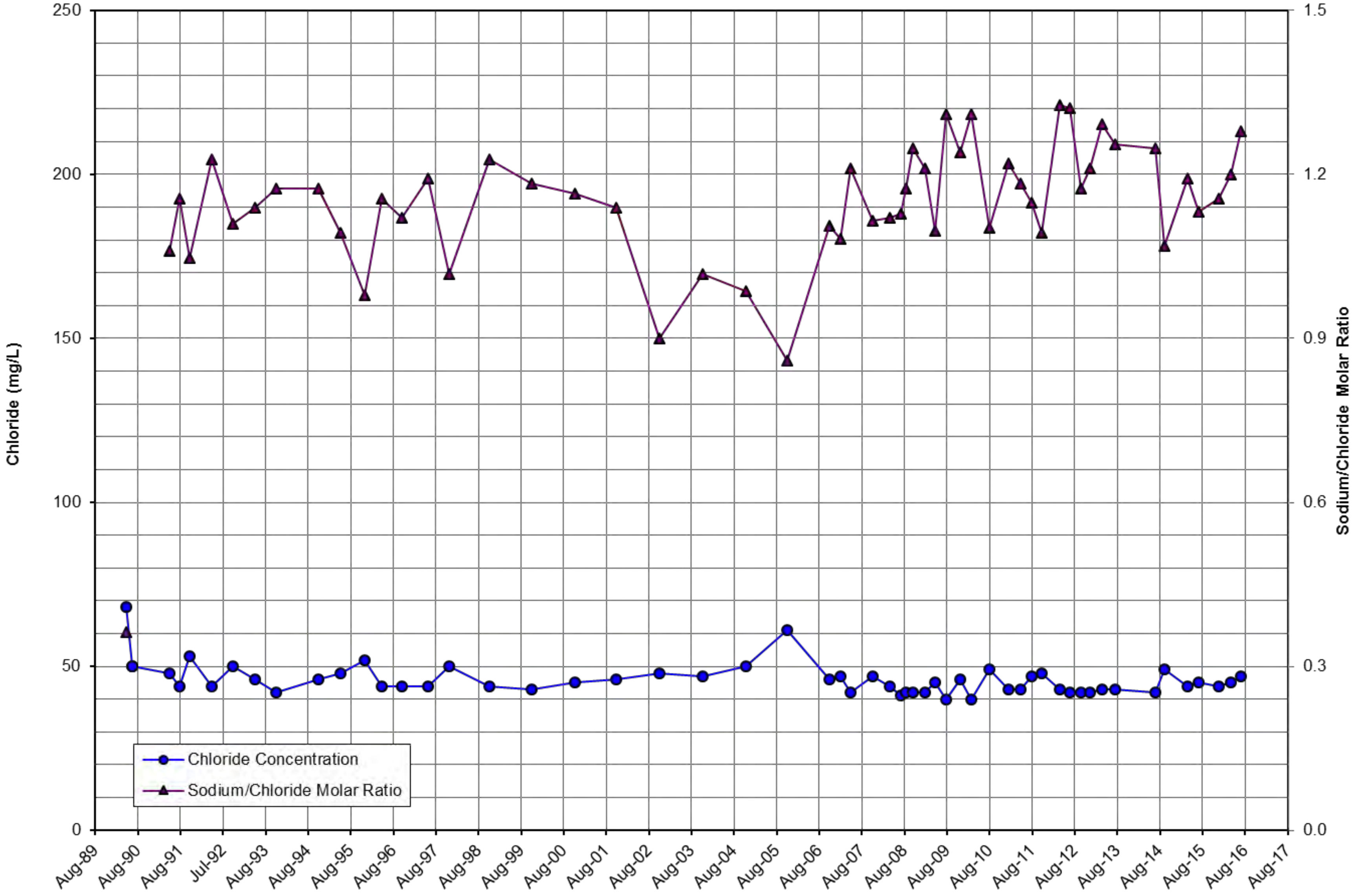

Figure B-1: PCA West Shallow Well Chemograph

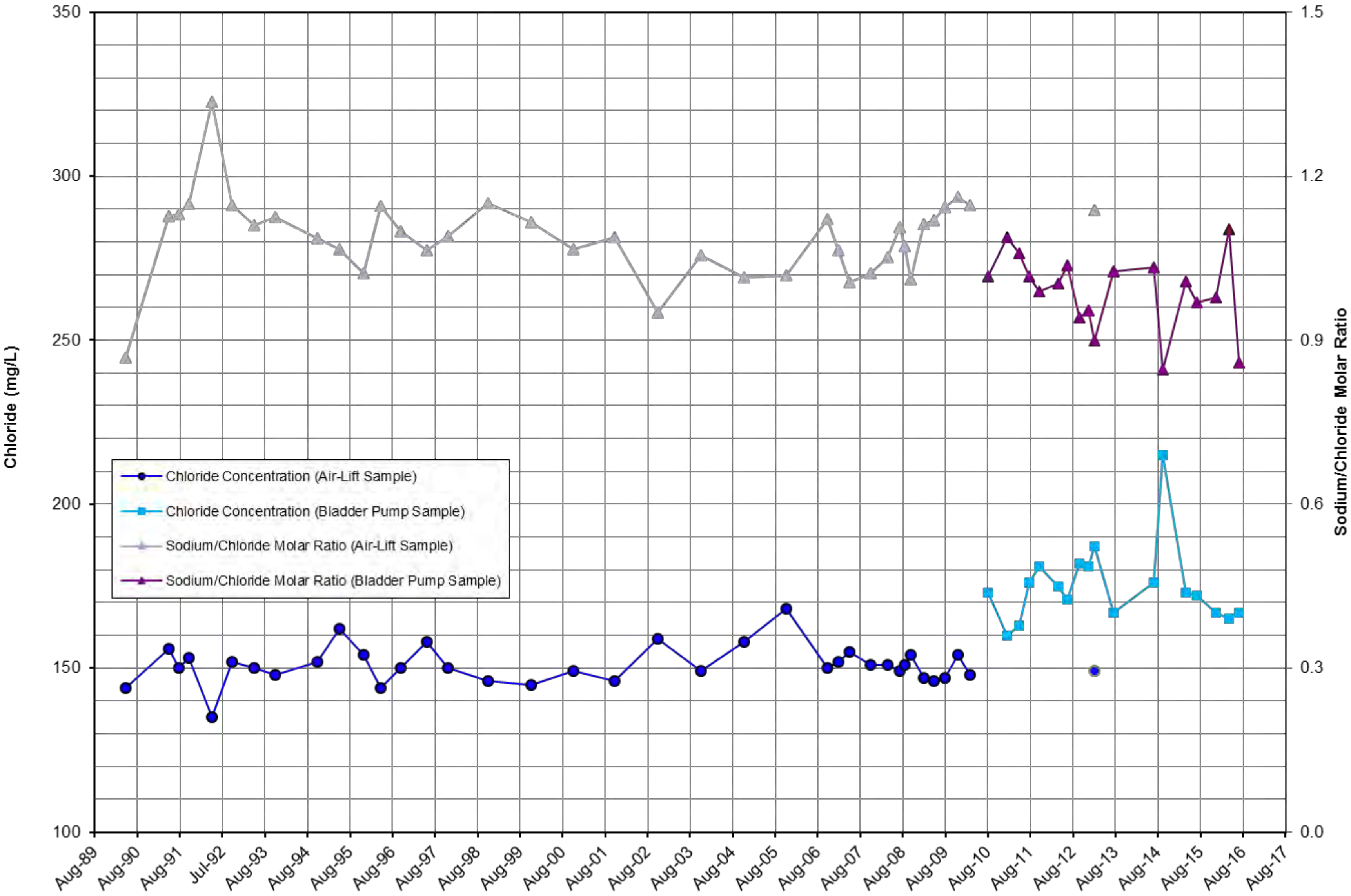

Figure B-2: PCA West Deep Well Chemograph

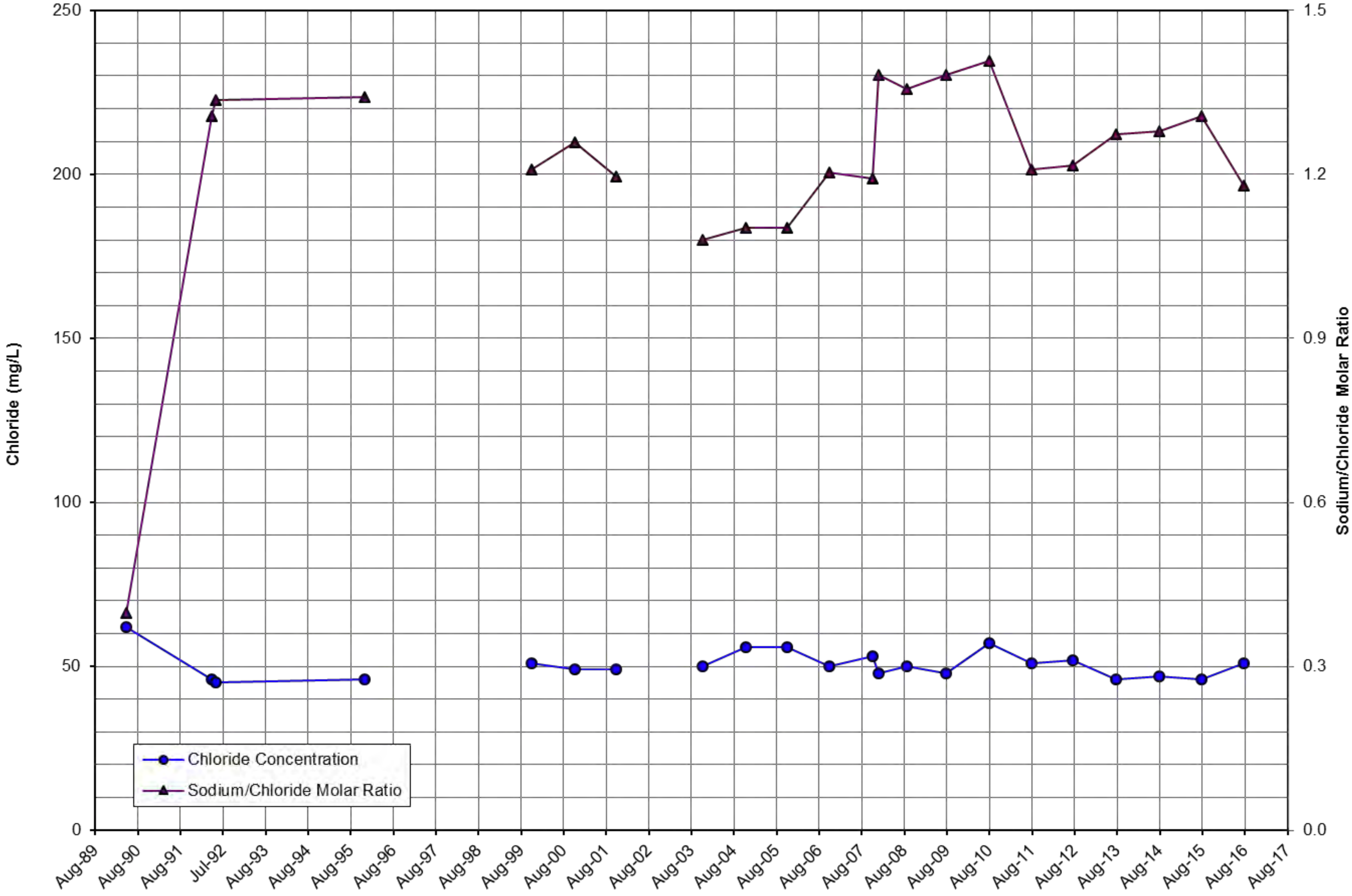

Figure B-3: PCA East Shallow Well Chemograph

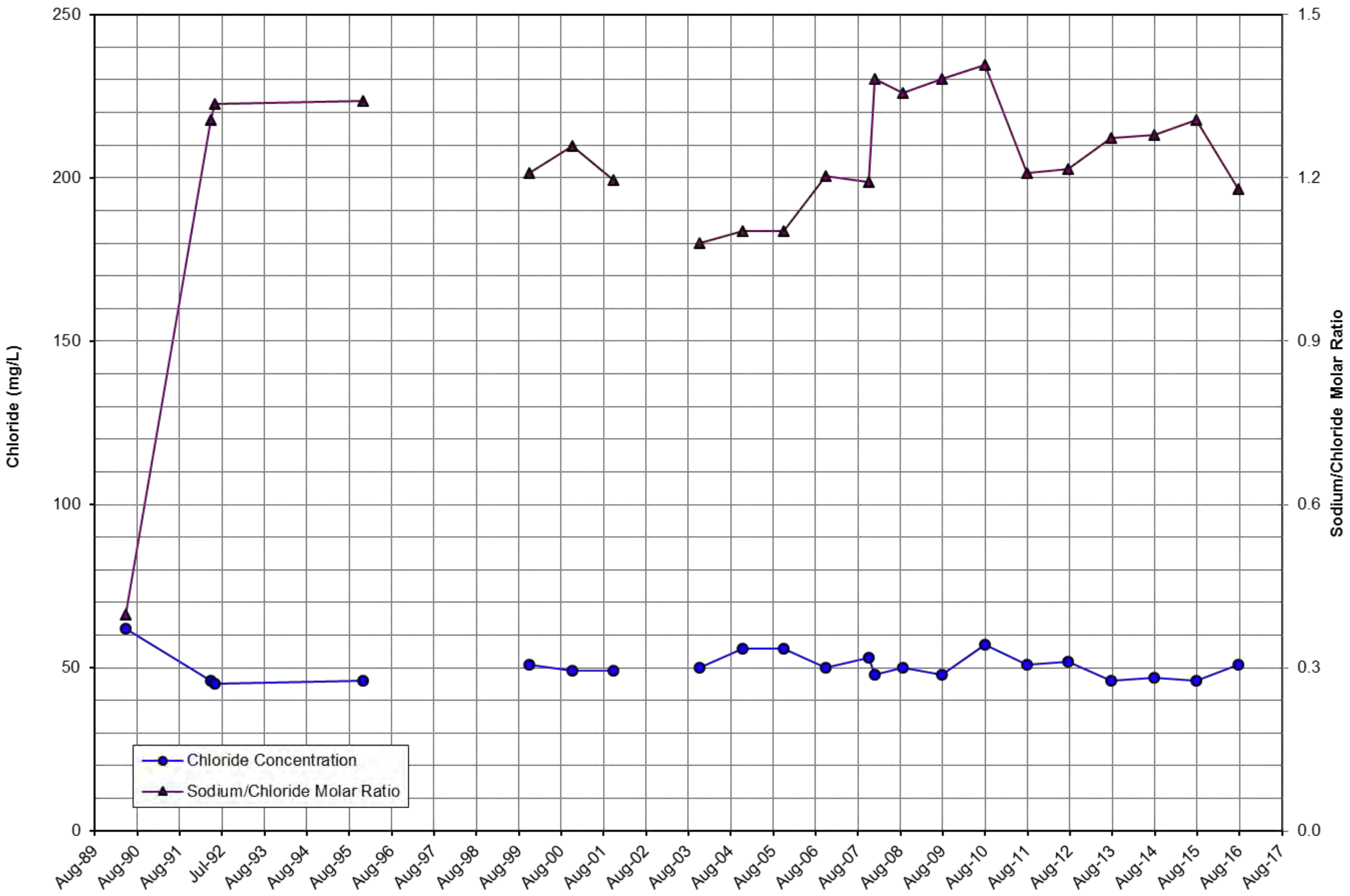

Figure B-4: PCA East Deep Well Chemograph

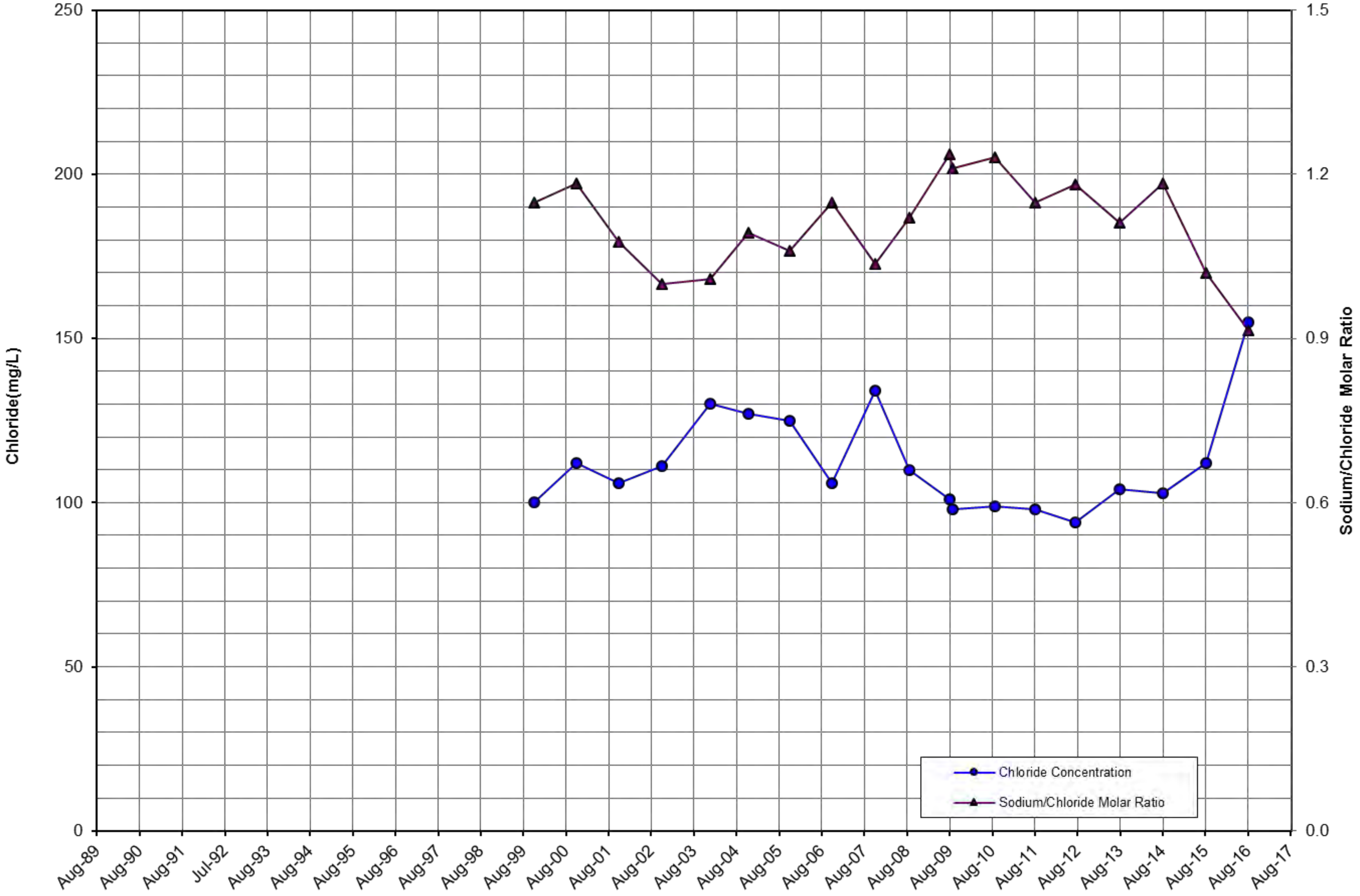

Figure B-5: Ord Terrace Shallow Well Chemograph

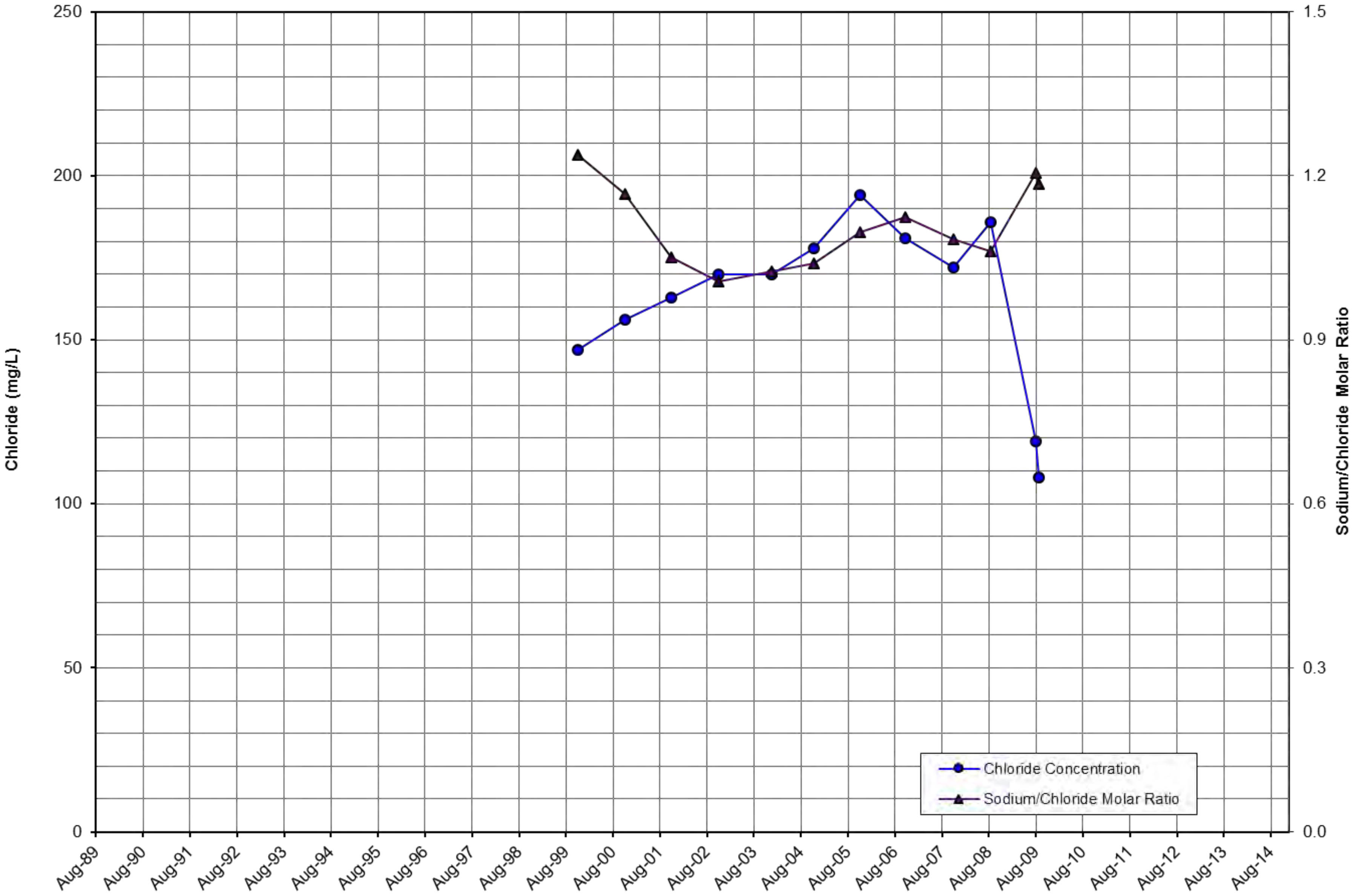

Figure B-6: Ord Terrace Deep Well Chemograph

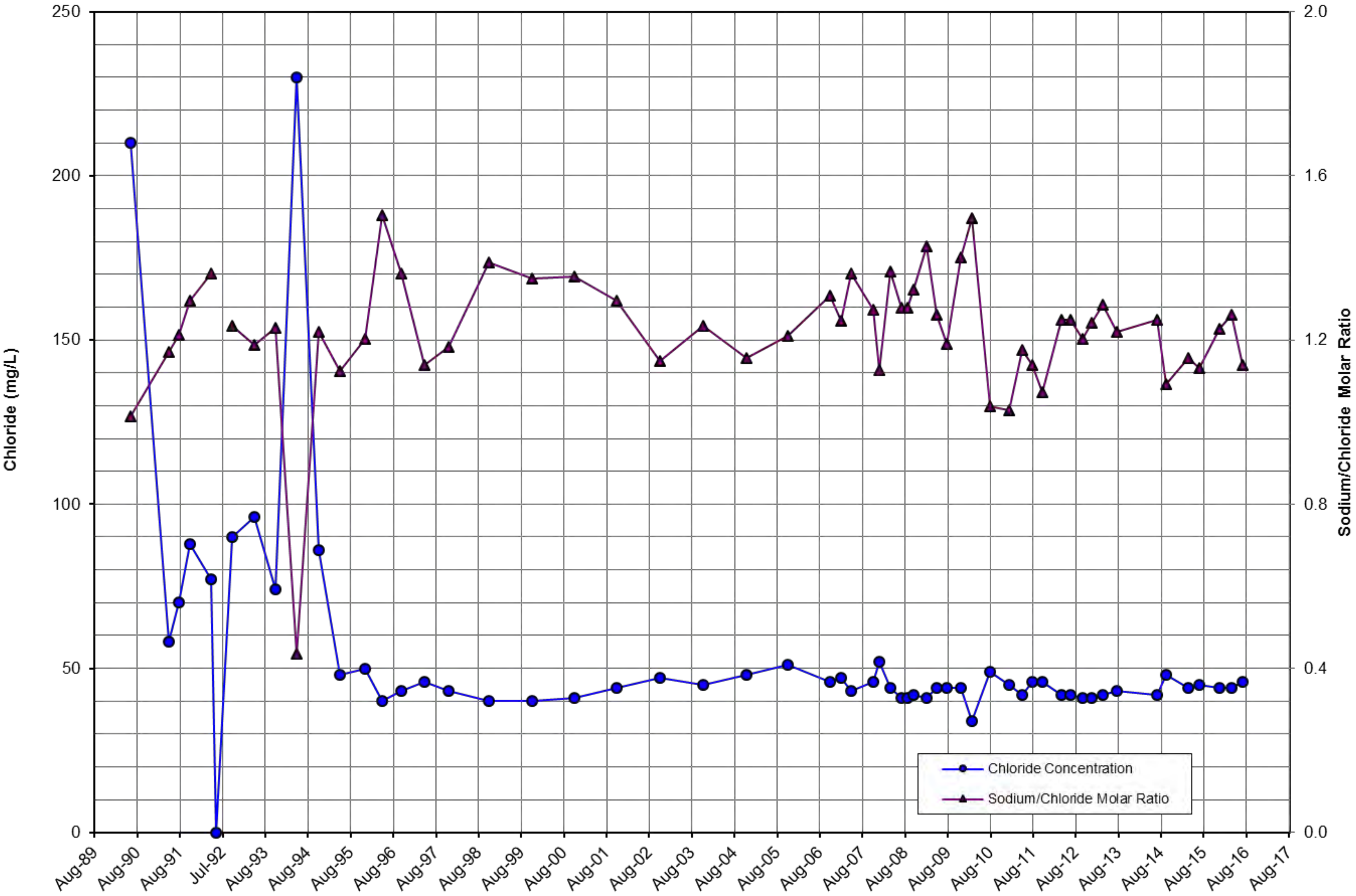

Figure B-7: MSC Shallow Well Chemograph

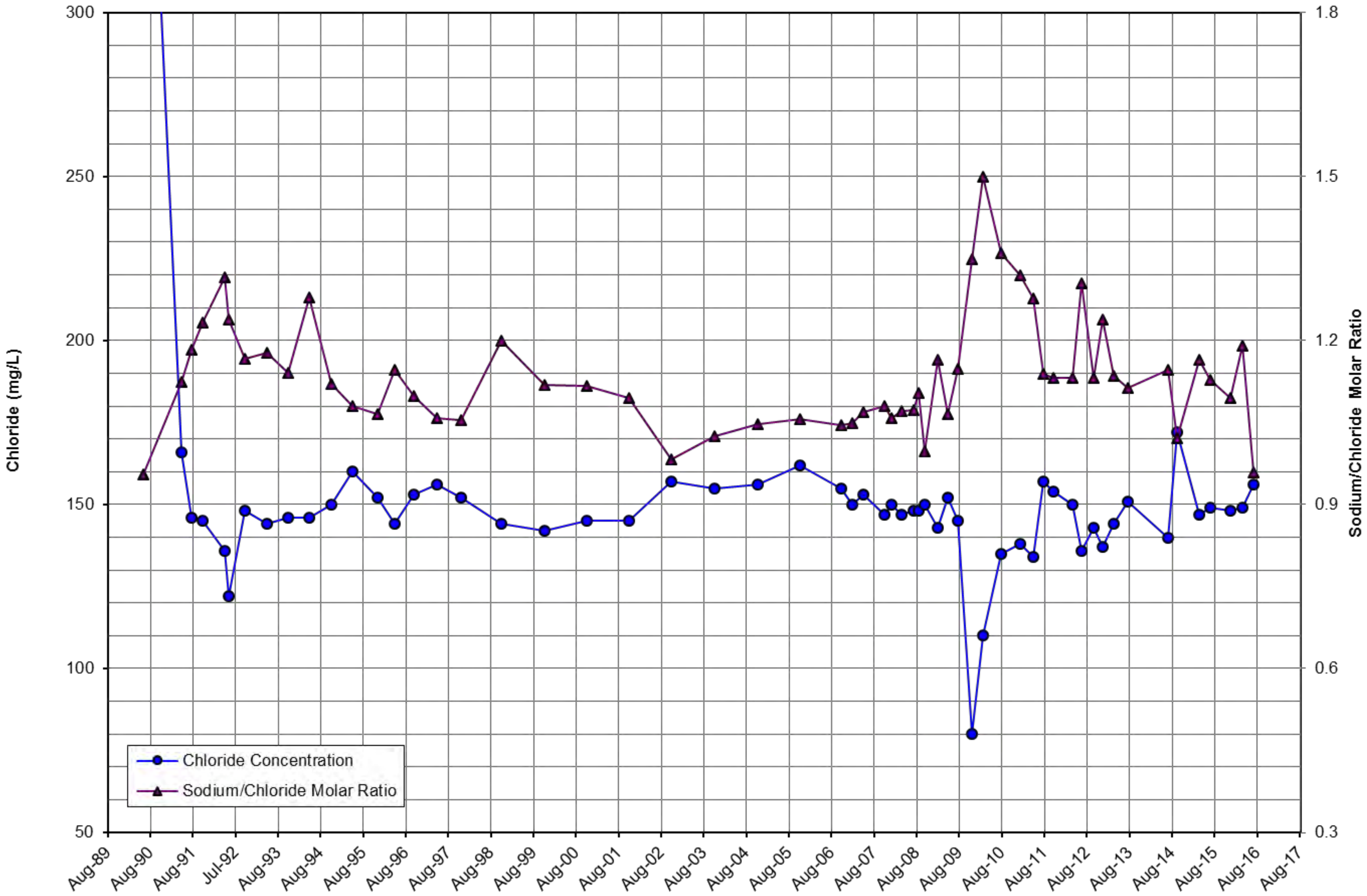

Figure B-8: MSC Deep Well Chemograph

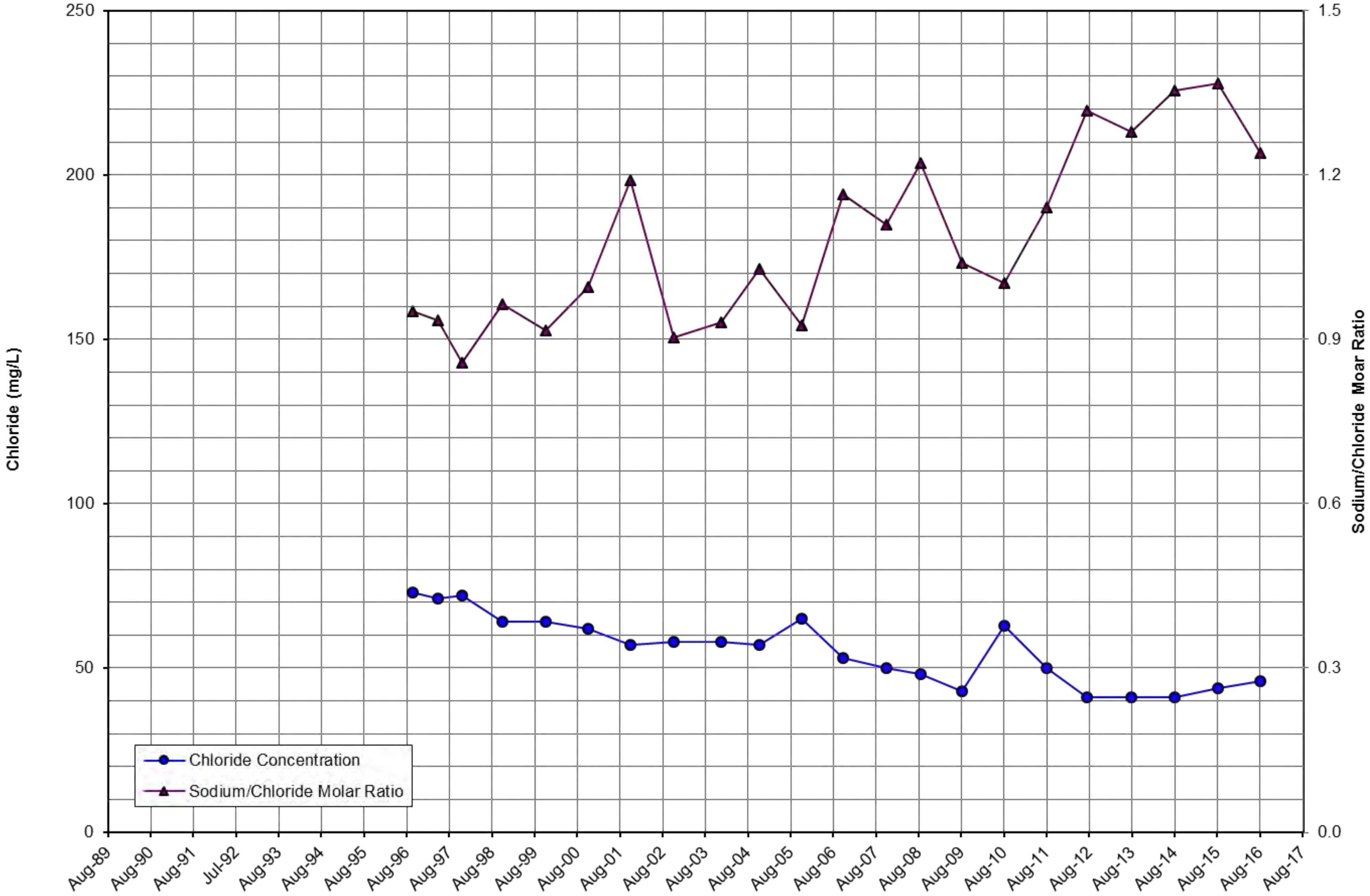

Figure B-9: Fort Ord 10 Shallow Well Chemograph

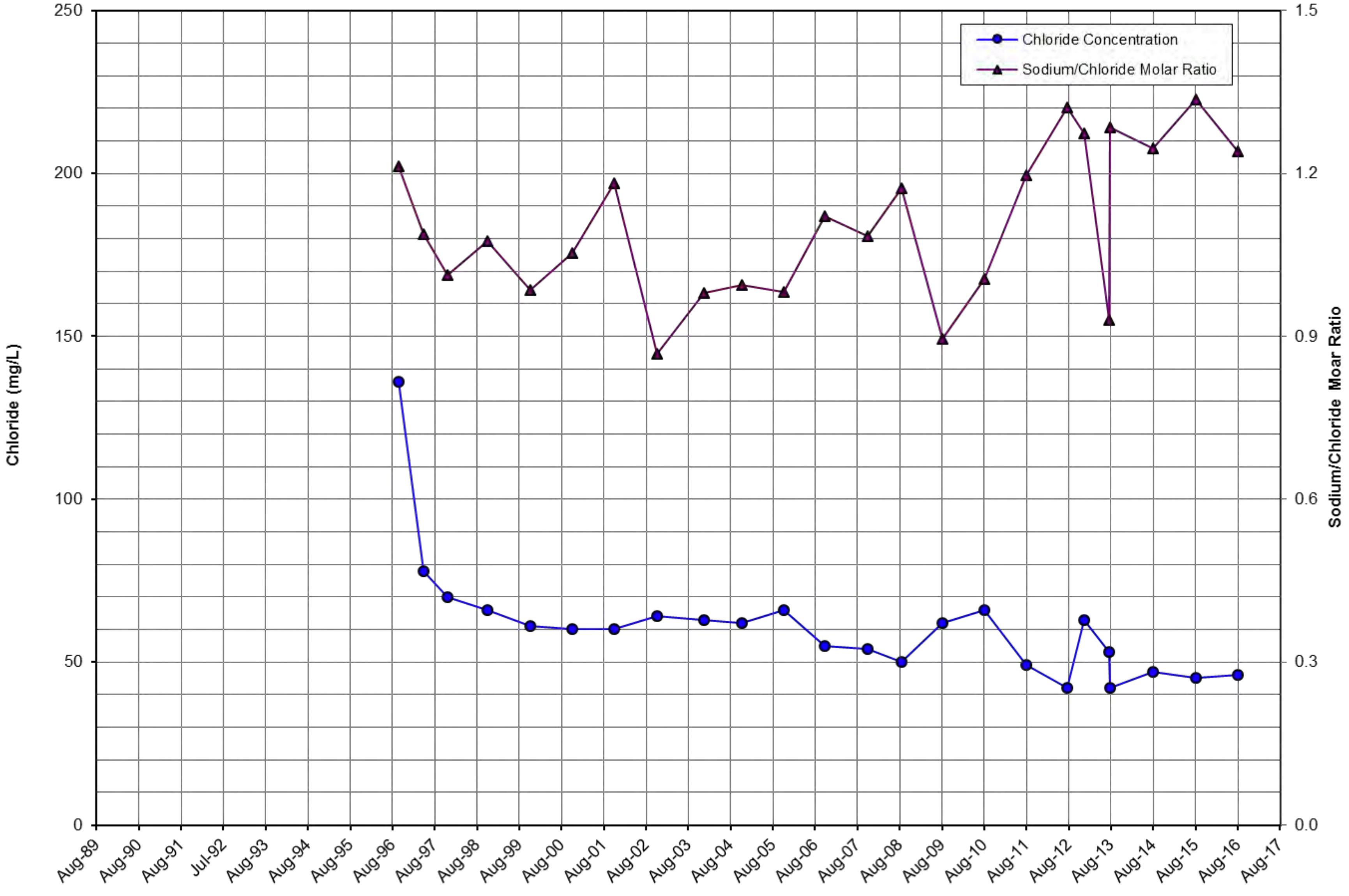

Figure B-10: Fort Ord 10 Deep Well Chemograph

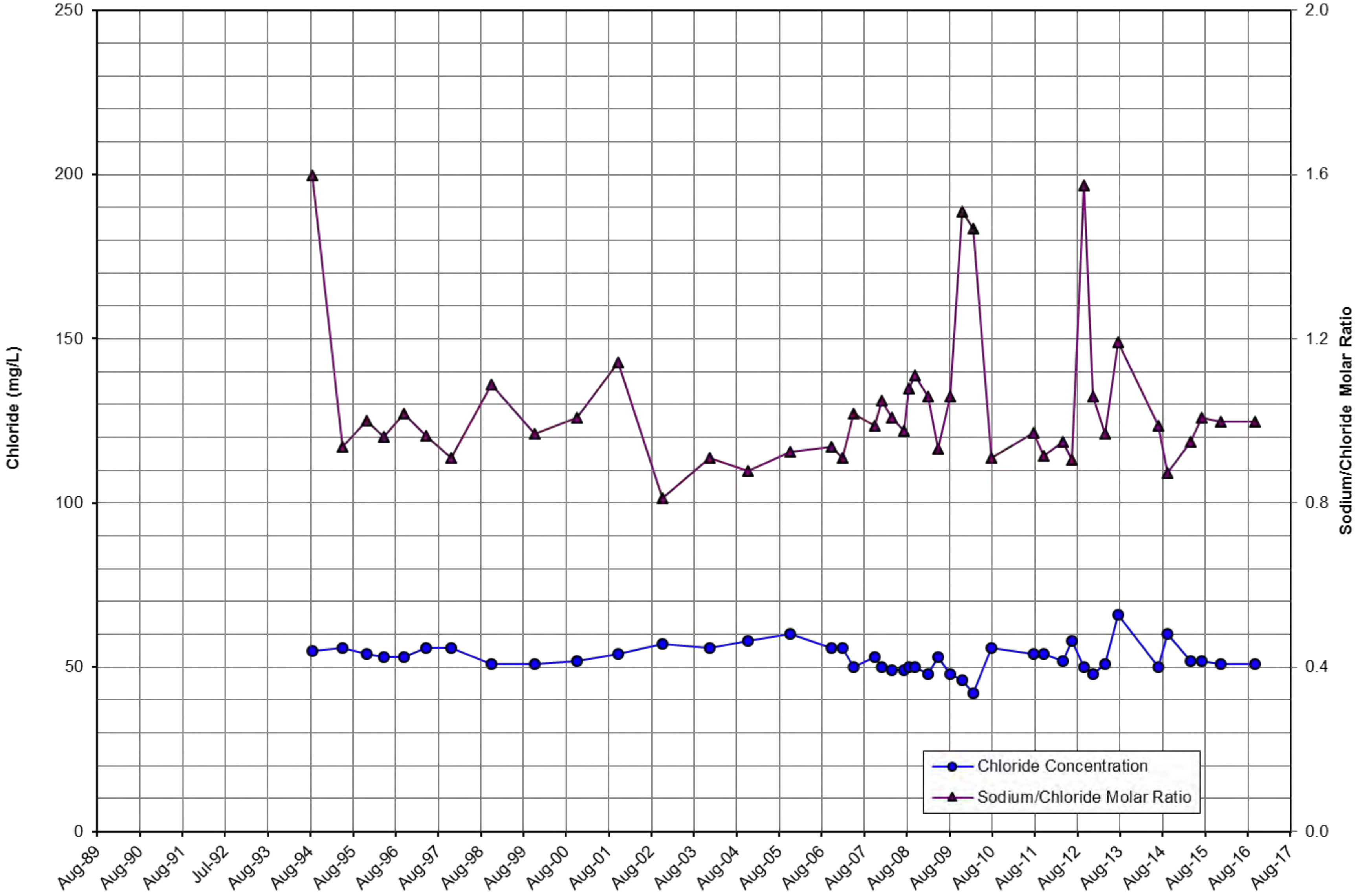

Figure B-11: Fort Ord 9 Shallow Well Chemograph

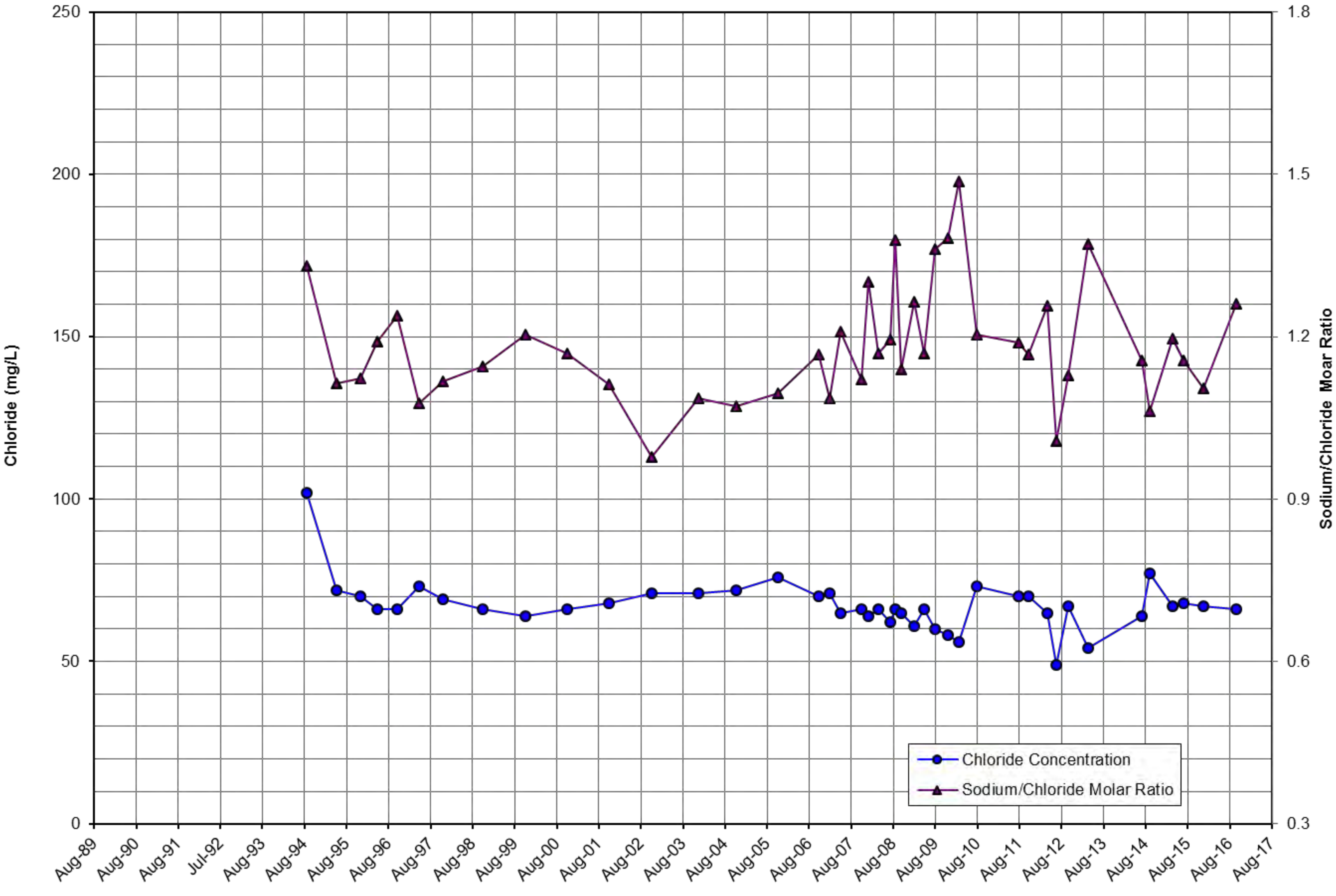

Figure B-12: Fort Ord 9 Deep Well Chemograph

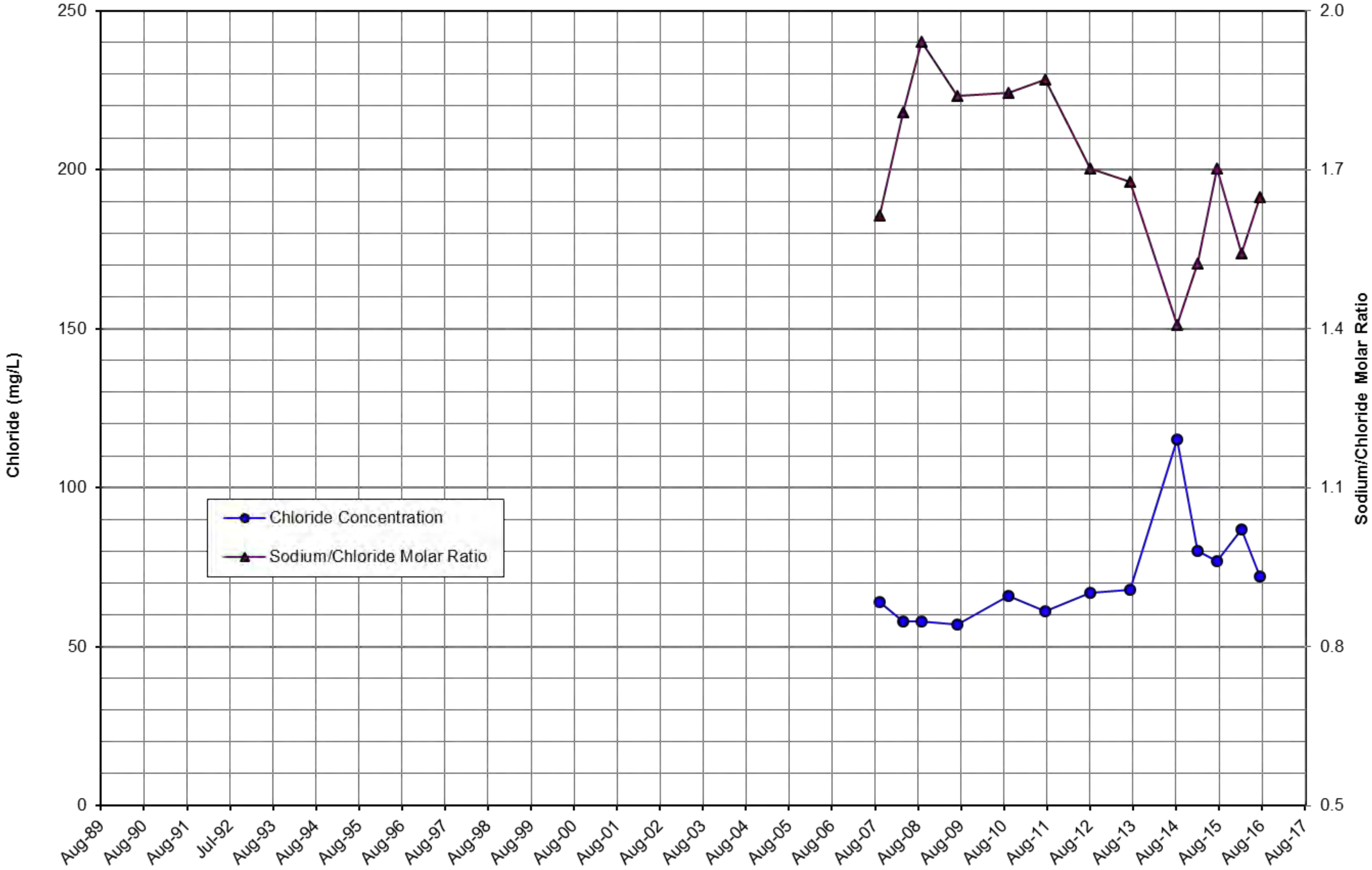

Figure B-13: SBWM-1: 1,140 foot depth sample Chemograph

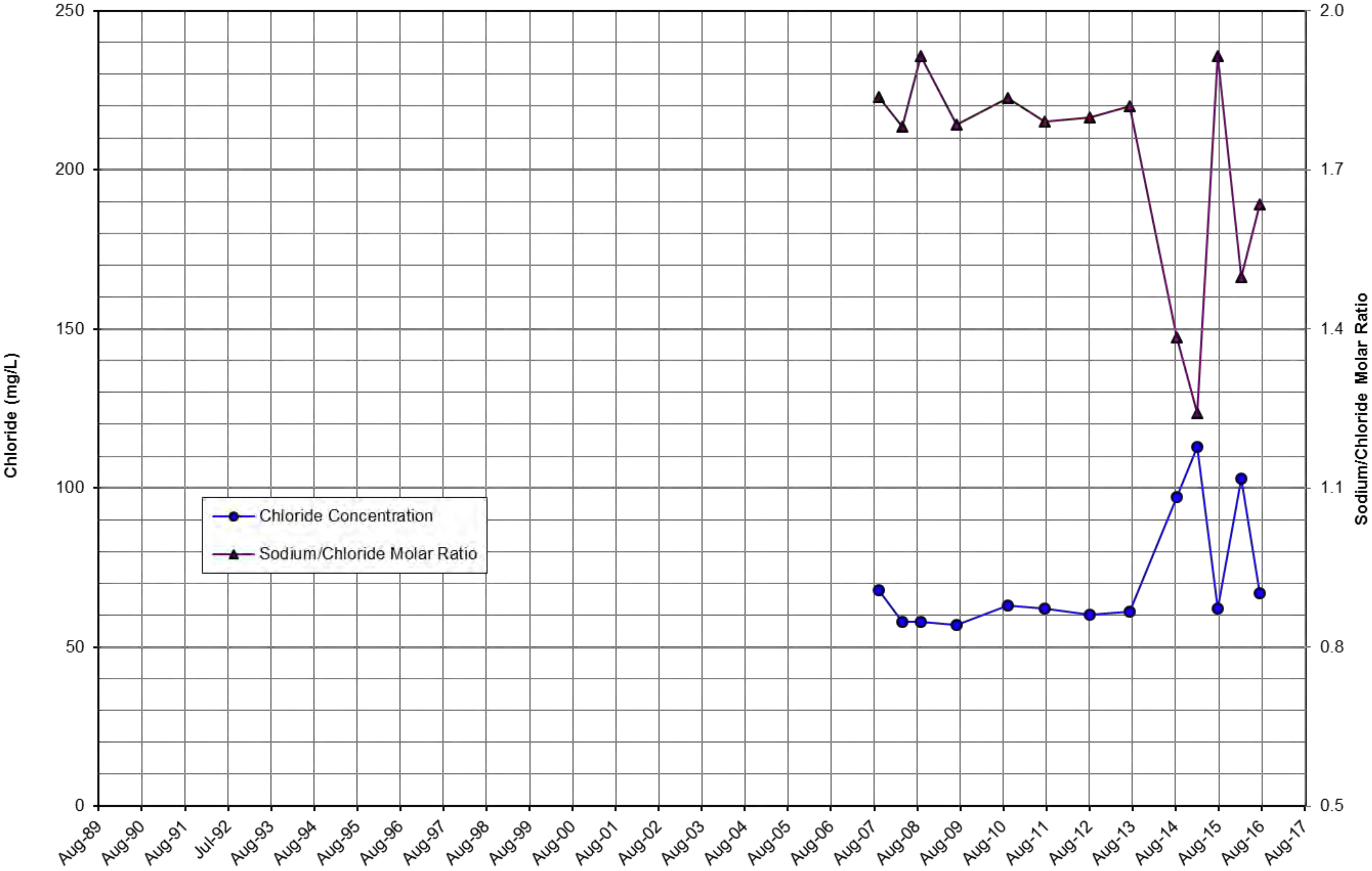

Figure B-14: SBWM-1: 1,390 foot depth sample Chemograph

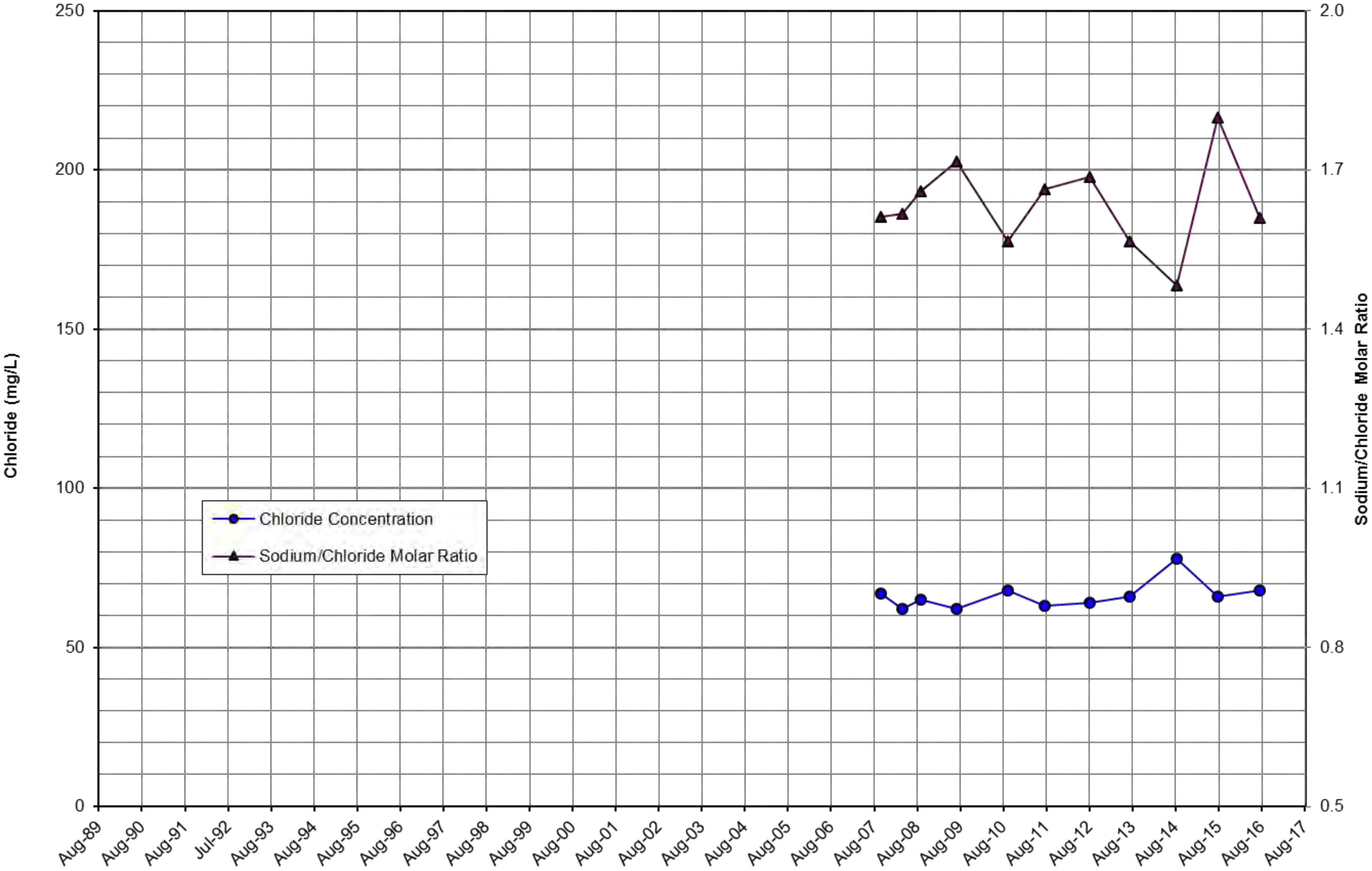

Figure B-15: SBWM-2: 1,000 foot depth sample Chemograph

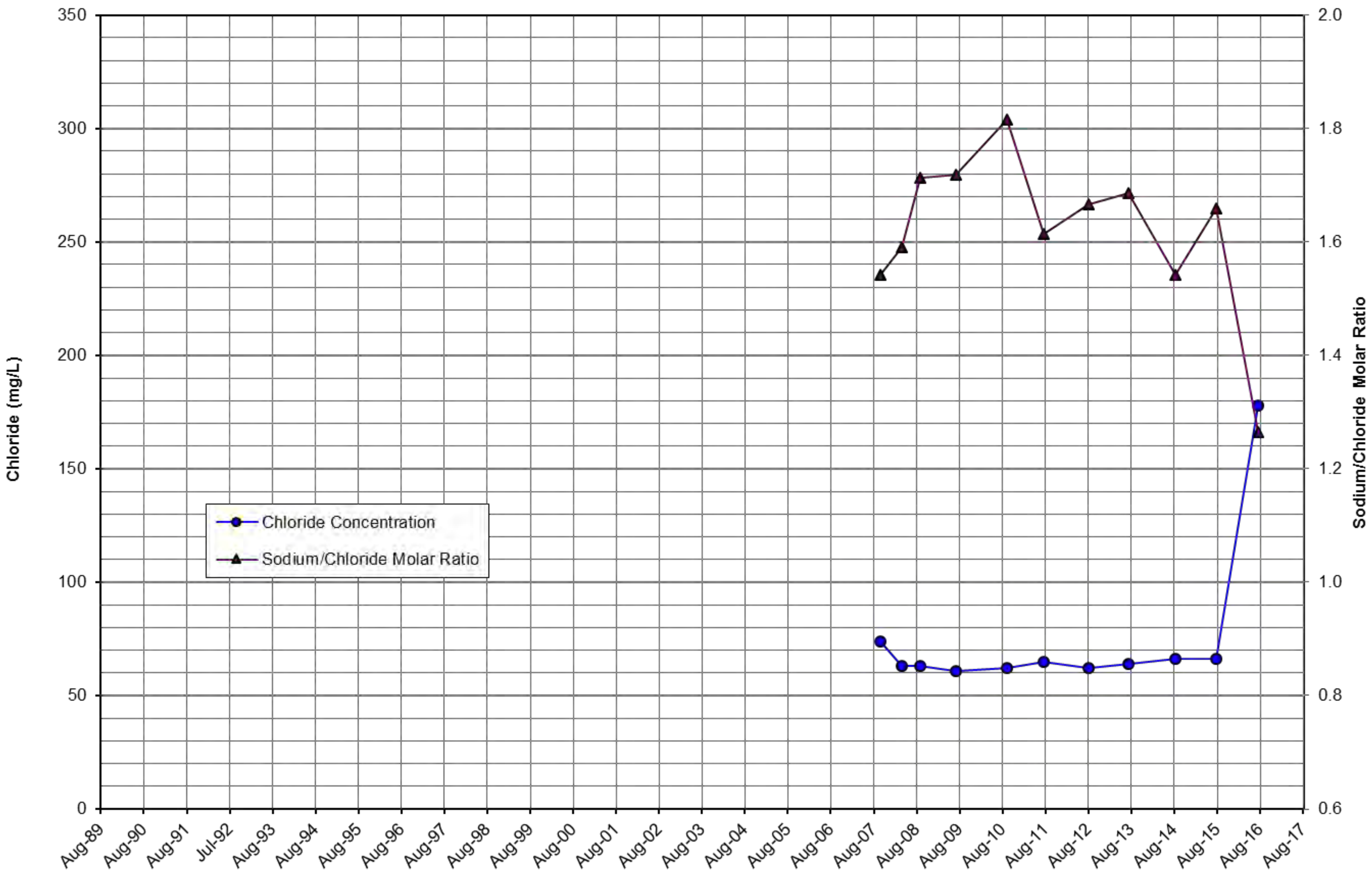

Figure B-16: SBWM-2: 1,470 foot depth sample Chemograph

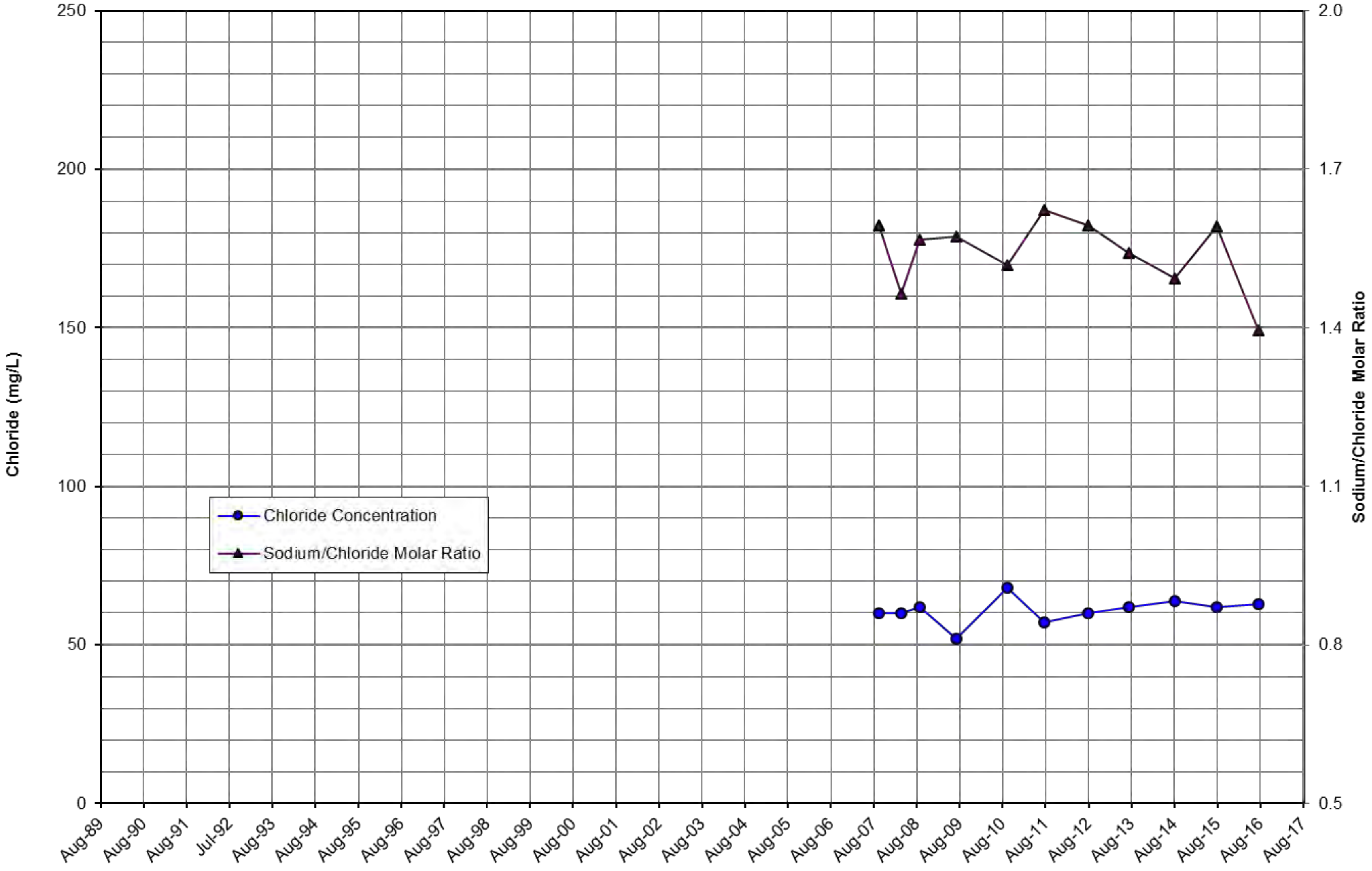

Figure B-17: SBWM-3: 870 foot depth sample Chemograph

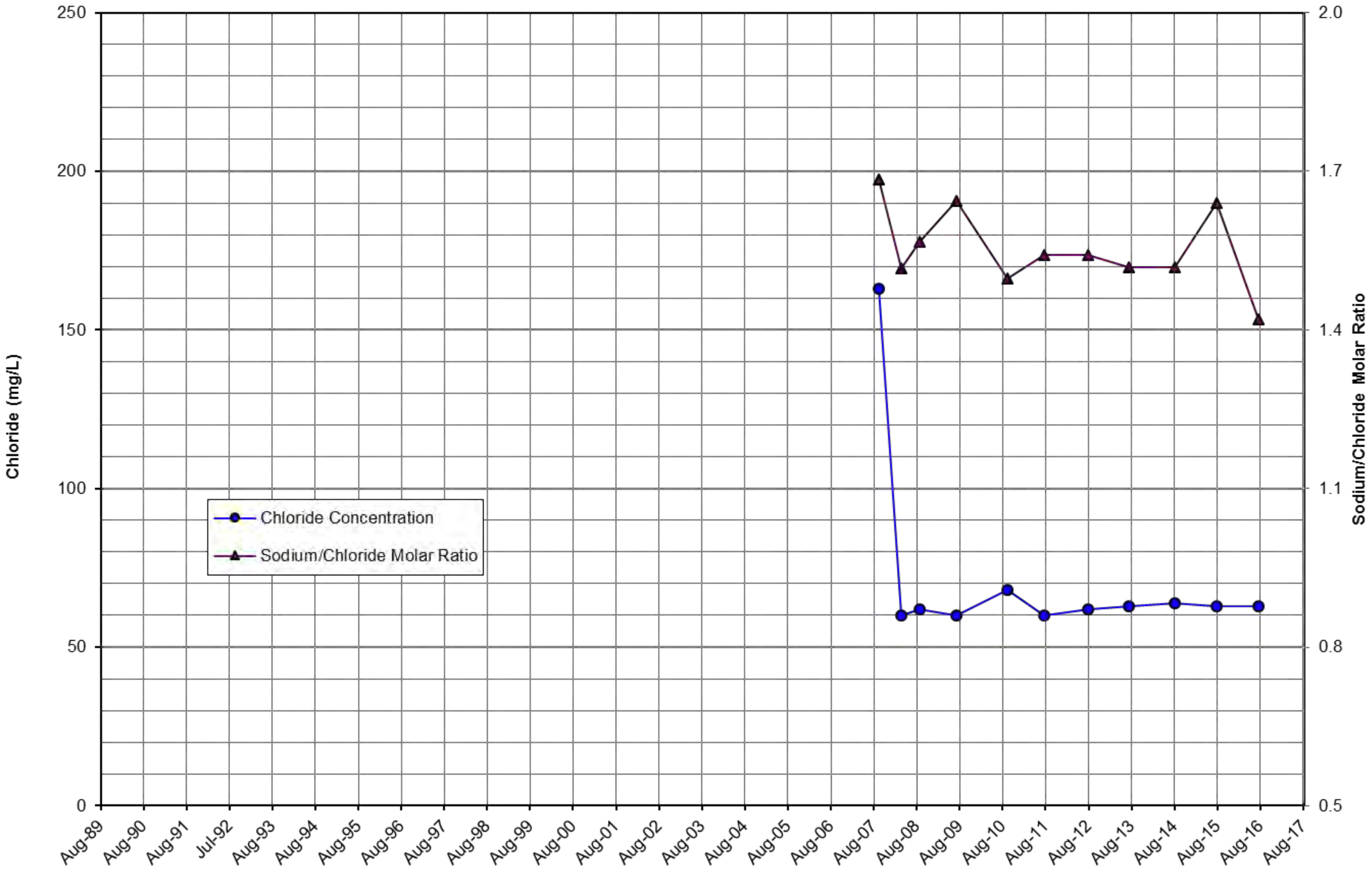

Figure B-18: SBWM-3: 1,275 foot depth sample Chemograph

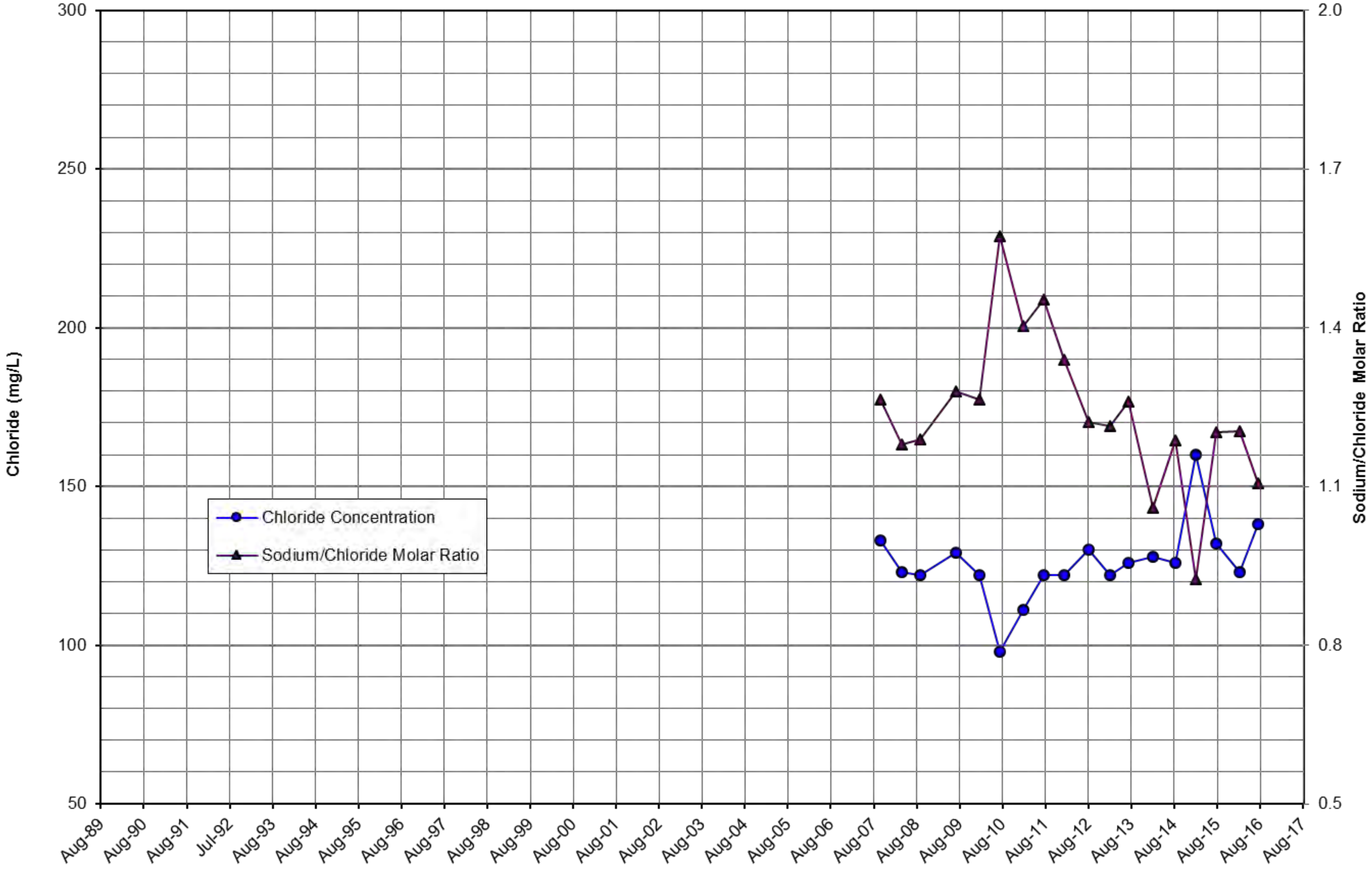

Figure B-19: SBWM-4: 715 foot depth sample Chemograph

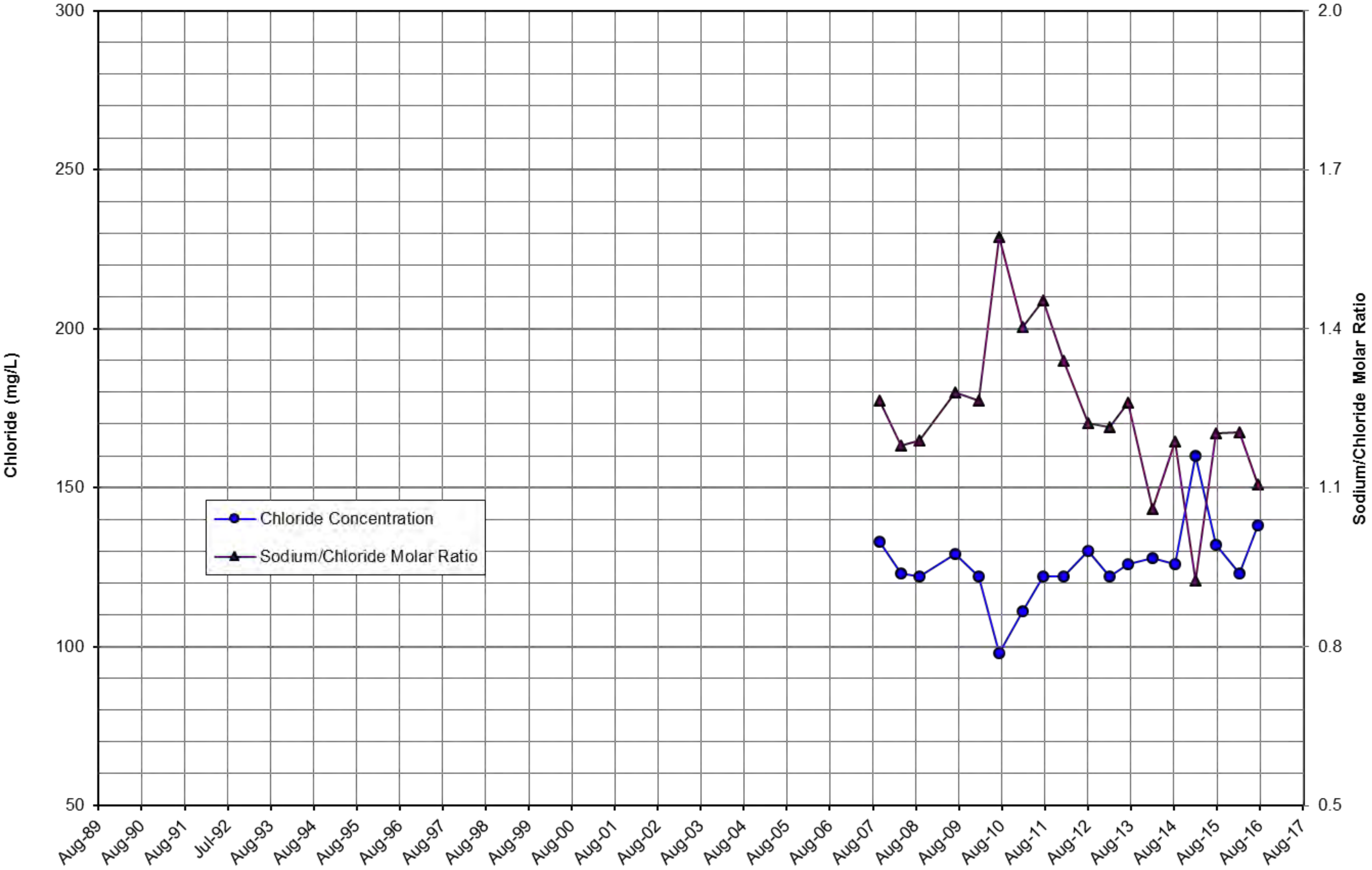

Figure B-20: SBWM-4: 900 foot depth sample Chemograph

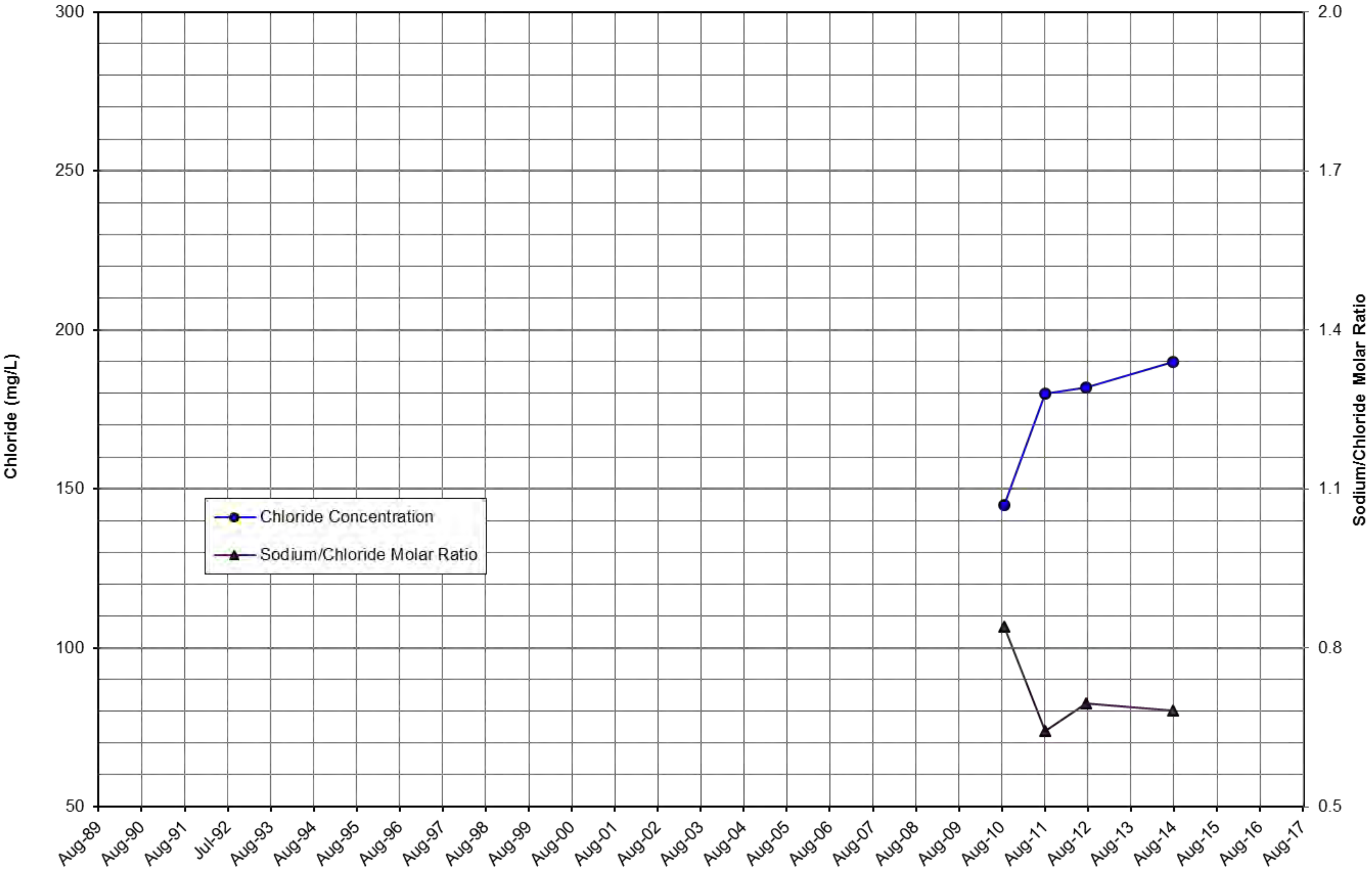

Figure B-21: SBWM-5: Shallow Well Chemograph

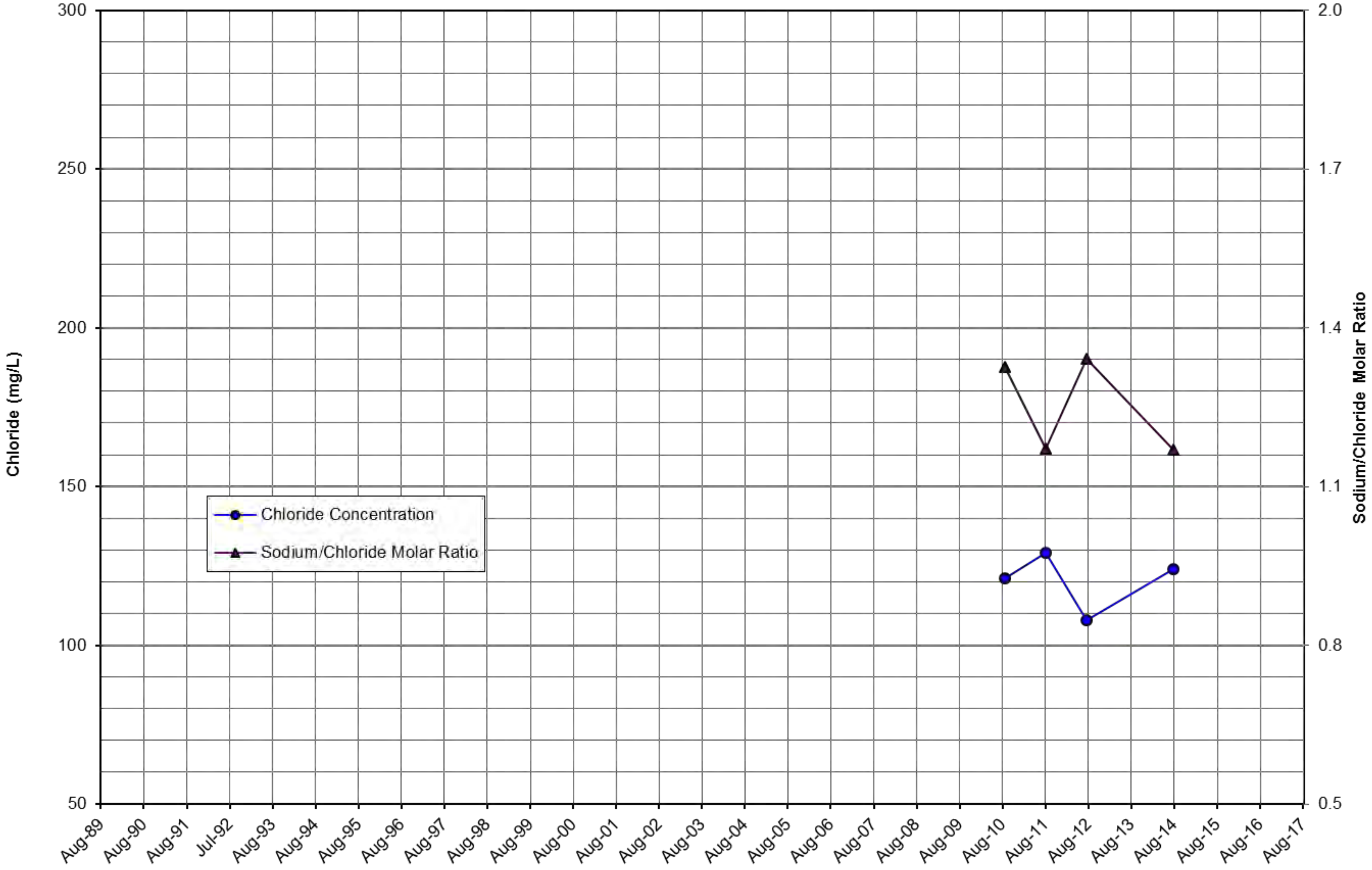

Figure B-22: SBWM-5: Deep Well Chemograph

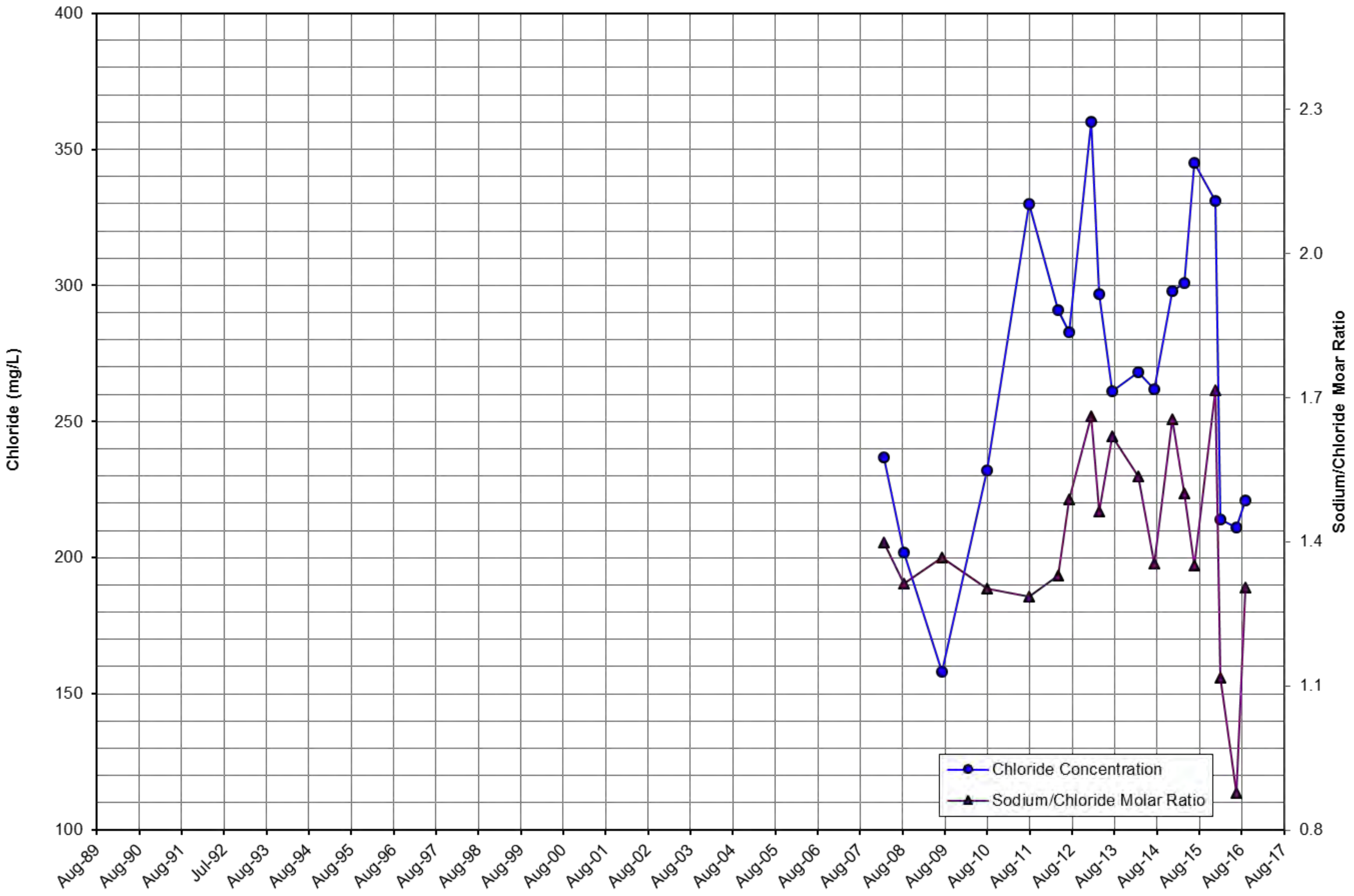

Figure B-23: Sand City Public Works Corp Yard Production Well