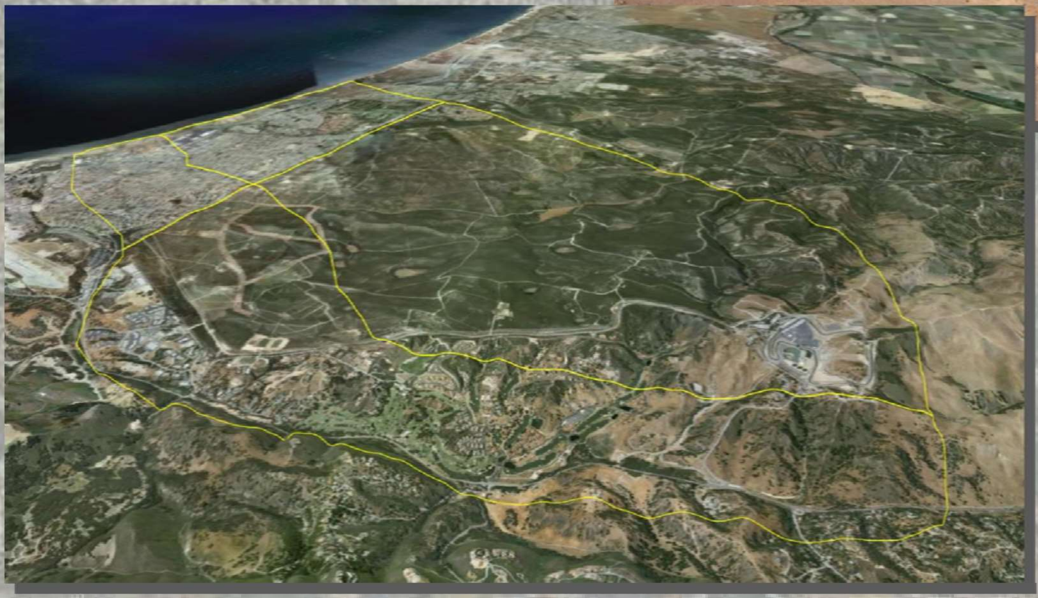
Seawater Intrusion Response Plan
Seaside Basin, Monterey County
California

Prepared for:
Seaside Basin Watermaster

February 2009
With Corrected Version of Table C-4

Prepared by:
HydroMetrics LLC



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ABBREVIATIONS

BMAP	Basin Management Action Plan
CAW	California American Water
mg/L	Milligrams per liter
MPWMD	Monterey Peninsula Water Management District
MPWRS	Monterey Peninsula Water Resources System
MCWRA	Monterey County Water Resources Agency
SBMMP	Seaside Groundwater Basin Monitoring and Management Program
SIRP	Seawater Intrusion Response Plan
TDS	Total dissolved solids

CONVERSIONS

1 acre-foot = 325,851 gallons
1 mg/L ≈ 1 part per million

SECTION 1

BACKGROUND AND PURPOSE

1.1 INTRODUCTION AND PURPOSE

This *Seawater Intrusion Response Plan* (SIRP) is the Seaside Groundwater Basin Watermaster's (Watermaster) contingency plan for responding to seawater intrusion in the Seaside Groundwater Basin, if and when it occurs. This SIRP was developed as part of the Watermaster's implementation of the *Seaside Groundwater Basin Monitoring and Management Program* (SBMMP) (Seaside Groundwater Basin Watermaster, 2006). This document was produced in accordance with the requirements contained in the Amended Decision (California American Water Company v. City of Seaside et al., *Superior Court, County of Monterey, Case Number M66343*, 2007).

The SIRP details both the indicators of seawater intrusion, and a list of recommended actions to be taken if seawater intrusion is observed. Section 2 evaluates consistency with existing documents that may influence the Watermaster's ability to implement this response plan. Section 3 establishes indicators of seawater intrusion and action levels that trigger response measures. Section 4 lists recommended actions that should be implemented if seawater intrusion is observed in the Seaside Groundwater Basin.

It should be noted that the actions detailed in this SIRP will likely have a significant economic impact for both the Watermaster's member agencies and the communities they serve. Foreseeable impacts might include, but are not limited to, the following issues:

- Reduced economic activity due to reduced water available to users,
- Cost of immediate response monitoring for seawater intrusion verification and cost of notification,
- Cost of installing new monitoring wells and/or pumping redistribution, and
- Reduced revenue for water suppliers from water users due to reduced water sales.

No sources of replacement water are identified in this document. Potential sources of replacement water are identified in the Basin Management Action Plan (BMAP) which describes supplemental water supplies and management actions that may be implemented to help prevent seawater intrusion by allowing groundwater levels to recover in the Seaside Groundwater Basin.

1.2 BACKGROUND

Historical and persistent low groundwater elevations caused by pumping in the Seaside Groundwater Basin has led to concerns that seawater intrusion may threaten the coastal subareas' groundwater resources. Previous studies have addressed the potential for, and extent of, seawater intrusion in the Seaside Groundwater Basin. The *Seawater Intrusion Analysis Report, Seaside Groundwater Basin, Monterey County California* (HydroMetrics LLC, 2007 and 2008) provided detailed reviews of seawater intrusion mechanisms, and analyzed historical water quality data for indications of seawater intrusion in the Seaside Groundwater Basin. The geochemical analyses showed that no seawater intrusion has been detected in the Seaside Groundwater Basin, and there is no indication of seawater intrusion into either of the Basin's principal aquifers – the Paso Robles Formation (shallow) or Santa Margarita Sandstone (deep). Although seawater intrusion has not been detected, it is apparent, based on water level and pumping data, that a potential for seawater intrusion in the Seaside Groundwater Basin exists.

In March 2008, the Monterey Peninsula Water Management District (MPWMD) prepared an *Interim Seawater Intrusion Contingency Plan* for the Watermaster. The *Interim Seawater Intrusion Contingency Plan* served as the Watermaster's temporary contingency plan, in anticipation of this current SIRP. This SIRP supersedes the *Interim Seawater Intrusion Contingency Plan*.

SECTION 2

CONSISTENCY WITH OTHER DOCUMENTS

Five documents were reviewed to evaluate consistency of the recommendations in these documents with this SIRP. These five documents include:

- Seaside Basin Amended Decision (California American Water Company v. City of Seaside et al., *Superior Court, County of Monterey, Case Number M66343*, 2007)
  - *Expanded Water Conservation and Standby Rationing Plan* (MPWMD, 1999)
- *Contingency Plan for Seawater Intrusion, Seaside Groundwater Basin* (Bachman, 2005)
- *2007 Seawater Intrusion Analysis Report, Seaside Groundwater Basin* (HydroMetrics LLC, 2007)
- *2008 Seawater Intrusion Analysis Report, Seaside Groundwater Basin* (HydroMetrics LLC, 2008)

The 2007 and 2008 *Seawater Intrusion Analysis Reports* (HydroMetrics LLC, 2007 and 2008) consisted mainly of data analysis, and contained no recommended remedial actions. Therefore these documents were not analyzed further. Each of the other three documents is addressed separately below.

2.1 SEASIDE GROUNDWATER BASIN AMENDED DECISION

The Amended Decision details the legal requirements imposed on the Watermaster as a result of the Seaside Groundwater Basin Adjudication. The requirements in the Amended Decision take precedence over policies or procedures outlined in other reviewed documents.

The Amended Decision included, in part, the requirement to "…develop a plan of action to contain seawater intrusion, should it occur". Additionally, section III(B)(3)(e) of the Amended Decision requires that any pumping reductions be distributed throughout the impacted subarea in a *pro-rata* (proportional) fashion. However, the *Interim Contingency Procedure to Contain Seawater Intrusion* included in Exhibit A to the Amended Decision proposed a pumping reduction methodology that appears to be inconsistent with this *pro-rata* approach. It has therefore been assumed that this SIRP is not bound by section III(B)(3)(e) of the Amended Decision, and instead proposes a pumping reduction plan similar to the one in Exhibit A of the Amended Decision. As such, there is no conflict between this SIRP and Exhibit A of the Amended Decision.

2.2 EXPANDED WATER CONSERVATION AND STANDBY RATIONING PLAN

The regulations imposed by MPWMD's *Expanded Water Conservation and Standby Rationing Plan* (MPWMD, 1999) state that Stage 1 through Stage 7 water conservation and rationing may apply to water distribution system users and water users within the Monterey Peninsula Water Resources System (MPWRS) in response to limited water supply. These stages provide, among other benefits, responses to emergency situations where immediate reductions in water use are necessary to ensure public health, safety or welfare.

The plan authorizes the MPWMD Board of Directors to, from time to time, determine by resolution that any water distribution system or set of water users within the MPWMD area shall be subject to water rationing as provided in the ordinance, based on conservation and reduction percentages. Specifically, Stage 3 water conservation requires a fifteen percent reduction in CAW use. Stage 4 water rationing requires a 15 percent reduction for all water users, while maintaining the provisions of Stage 3 water conservation.

The *Expanded Water Conservation and Standby Rationing Plan* deals only with rationing, and not with groundwater pumping. Because the Watermaster's only authority is pumping regulation, and not end-use regulation, there is no conflict between this SIRP and the *Expanded Water Conservation and Standby Rationing Plan*.

2.3 CONTINGENCY PLAN FOR SEAWATER INTRUSION

This SIRP builds on the *Contingency Plan for Seawater Intrusion, Seaside Basin*, developed by Dr. Steve Bachman (2005). More detailed seawater intrusion indicators have been developed since the *Contingency Plan for Seawater Intrusion* was presented as a deposition exhibit during the adjudication. This SIRP is an update using site-specific geochemical indicators of seawater intrusion. Based on the presence of specific seawater intrusion indicators, various actions, including pumping redistribution and reduction, are defined in this SIRP.

There is no requirement for this SIRP to be consistent with the 2005 *Contingency Plan for Seawater Intrusion, Seaside Basin*, however it was used as a reference document while developing this SIRP.

SECTION 3

SEAWATER INTRUSION INDICATORS AND TRIGGERS

Seawater intrusion must be detected within the Adjudicated boundary of the Seaside Groundwater Basin, and declared by the Watermaster before the response plan can be implemented. This section presents general indicators of seawater intrusion, and discusses how to identify incipient seawater intrusion in the Seaside Groundwater Basin. A group of positive indicators would trigger a contingency action.

This SIRP has adopted the following terminology for identifying and containing seawater intrusion:

Indicator: A chemical characteristic or groundwater level that suggests potential seawater intrusion. No one indicator definitively identifies seawater intrusion.

Trigger: A specific group of indicators that, taken together, can identify seawater intrusion.

Contingency Actions: A series of actions that should be implemented if the triggers indicate seawater intrusion is occurring.

Each indicator of seawater intrusion is addressed separately below. Four seawater intrusion indicators have been developed for the monitoring program including chloride concentrations and trend analysis, sodium/chloride molar ratio trend analysis, cation and anion distributions on Piper and Stiff Diagrams, chloride concentration maps, and groundwater levels.

Chloride concentration is the only indicator with a threshold value or specific numerical target that indicates seawater intrusion. The threshold values are based on historical groundwater monitoring data collected from 12 wells within the Seaside Groundwater Basin (Figure 1). The 12 wells represent six well pairs from the MPWMD monitoring well network.

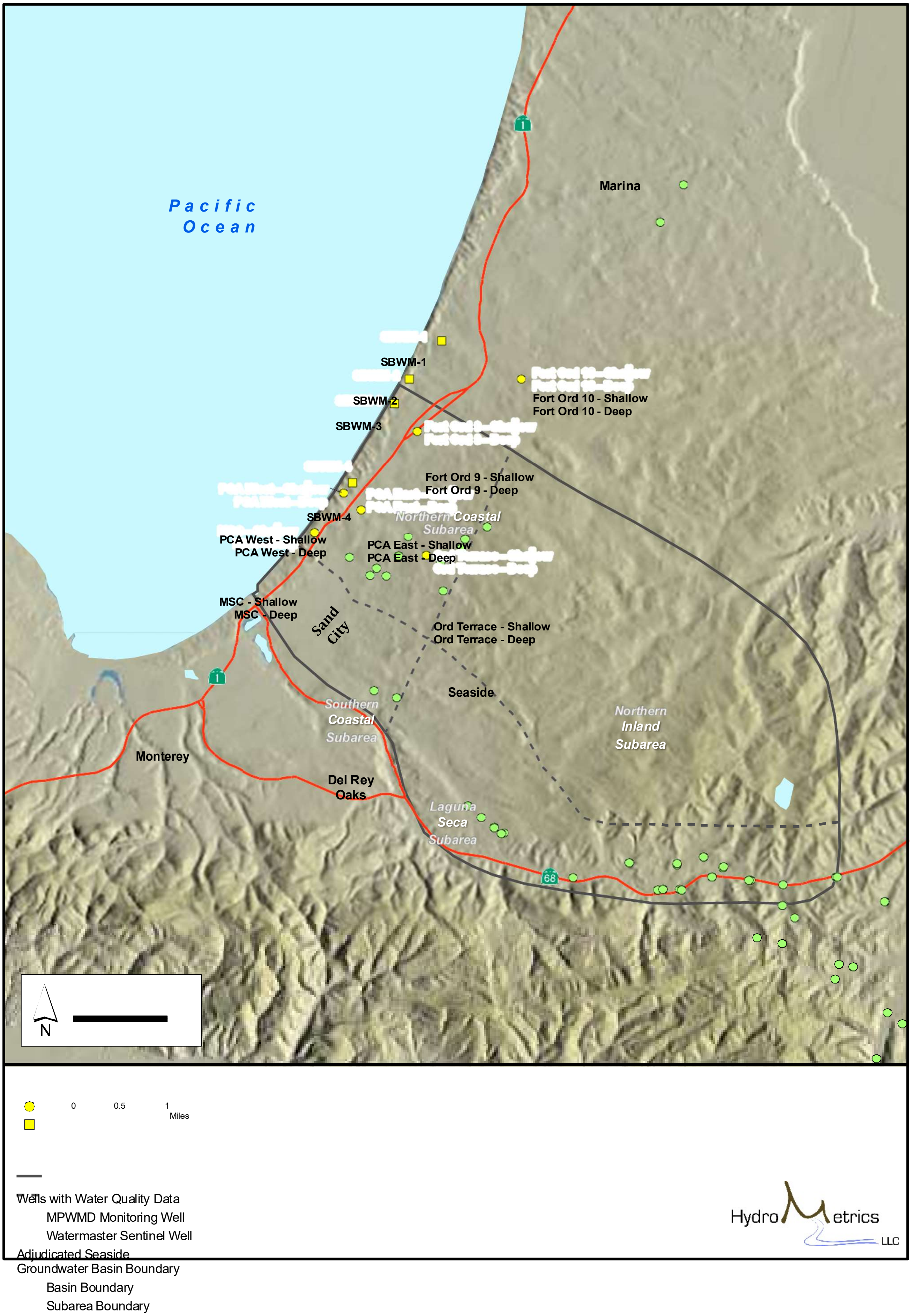
Pacific Ocean
Marina
1
SBWM-1
SBWM-2
SBWM-3
Fort Ord 10 - Shallow
Fort Ord 10 - Deep
Fort Ord 9 - Shallow
Fort Ord 9 - Deep
Northern Coastal Subarea
SBWM-4
PCA West - Shallow
PCA West - Deep
PCA East - Shallow
PCA East - Deep
MSC - Shallow
MSC - Deep
Sand City
Ord Terrace - Shallow
Ord Terrace - Deep
Seaside
Northern Inland Subarea
Southern Coastal Subarea
Monterey
Del Rey Oaks
Laguna Seca Subarea
68
N
0
0.5
1
Miles
Wells with Water Quality Data
MPWMD Monitoring Well
Watermaster Sentinel Well
Adjudicated Seaside Groundwater Basin Boundary
Basin Boundary
Subarea Boundary
HydroMetrics LLC

Figure 1: Wells with Adequate Historical Water Quality Data

3.1 INDICATORS OF SEAWATER INTRUSION

Seawater intrusion is generally identified through chemical analyses of groundwater. No one analysis definitively identifies seawater intrusion. However, by looking at various analyses and through statistical evaluation of historical data, it can be ascertained when fresh groundwater is beginning to mix with seawater. Common geochemical indicators of seawater intrusion are discussed and site-specific data are presented in the following sections. A detailed review of geochemical characteristics indicative of seawater intrusion is provided in the *Seawater Intrusion Analysis Report* (Hydrometrics LLC, 2008). Section 2 of the *Seawater Intrusion Analysis Report* (2008) is provided as Appendix A to this report.

The 12 monitoring wells with historical geochemical data that were statistically analyzed in this Section are shown on Table 1. Data collected prior to the release of the Adjudication Decision in March 2006 were analyzed to provide a baseline chemical characterization of the Seaside Groundwater Basin. Where possible, analyses are separated by depth zone. Two depth zones were 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 to the Santa Margarita Sandstone where it exists in the Seaside Groundwater Basin. This deep zone is roughly at the same depth as the Salinas Valley Deep Aquifer.

Some production wells in the Seaside Groundwater Basin are screened across multiple depth zones, and the water qualities of these wells reflect a blend from multiple sources. These wells cannot be used for assessing water quality of individual aquifers. Water quality data are, however, collected at these wells; and seawater intrusion indicators should be established for these wells after sufficient data are acquired. Seawater intrusion indicators for wells completed across multiple depth zones should be the least restrictive indicators of all the screened zones. As additional geochemical data are collected through future groundwater monitoring, groundwater quality in these wells should be evaluated to determine site-specific indicators.

INDICATOR 1: INCREASING CHLORIDE CONCENTRATIONS

Unusually high or steadily increasing chloride concentrations are 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. While chloride concentrations are strongly indicative of seawater intrusion, it often takes time for the increasing chloride trend to be recognizable due to the long-term and relatively slow increase in chlorides during seawater intrusion.

HIGH CHLORIDE CONCENTRATIONS

Chloride concentrations significantly greater than historical average concentrations may indicate seawater intrusion. Graphs showing historical chloride concentrations from the 12 analyzed wells are included in Appendix B. Average chloride concentrations at each well are calculated from the historical data available prior to the adoption of the Adjudication Decision in March 2006. Data collected prior to January 1995 are excluded from the calculation of each well's average chloride concentration due to the variable nature of those data. In general, chloride data collected after 1995 fluctuate within a relatively small range compared with data collected prior to 1995. The point at which these large fluctuations stabilize is different for each well; the 1995 cut-off date was chosen for all wells for consistency, although the chloride concentration detected in September 1996 for well FO-10/MPWMD-10 Deep was considered an outlier and was not included in the average chloride concentration calculation.

The graphs in Appendix B also show the calculated chloride threshold values. Chloride concentrations greater than these threshold values may indicate seawater intrusion. The chloride threshold values are statistically derived for each well. For additional information regarding the statistical formulas used to calculate the chloride threshold value, refer to Appendix C.

Table 1 presents the threshold chloride concentrations at individual monitoring wells. The threshold values for wells where historical data are not available are also presented in Table 1. The threshold values for wells in each aquifer without historical data are set to the highest threshold value for any well in that aquifer: 94 milligrams per liter (mg/L) for the Shallow Aquifer (well FO-10/ MPWMD-10 Shallow), and 260 mg/L for the Deep Aquifer (well Ord Terrace Deep). No wells currently show chloride concentrations above the threshold values.

CHLORIDE CONCENTRATION TRENDS

A clear trend of increasing chloride concentrations may indicate seawater intrusion. At low chloride concentrations, trends are often as important as absolute concentrations because of natural variations in groundwater chemistry. Data collected from October 2006 to present were analyzed for increasing trends using the Mann-Kendall statistical approach. The Mann-Kendall test is a statistical test that can be used to show whether chemical concentrations in a monitoring well are increasing, stable or decreasing. The Mann-Kendall Test can be used with a minimum of four consecutive sampling results. For additional information on the Mann-Kendall Test refer to Appendix C. One drawback of the Mann-Kendall test is that it is not valid if chloride concentrations have significant seasonal fluctuations. Appendix C presents the detailed methodology and seasonality test for this evaluation, and discusses additional trend analyses that would be relevant if future monitoring indicates any seasonal correlation.

Table 1 summarizes the results of the statistical trend analysis. Trends on Table 1 are categorized as increasing, decreasing, no trend, or not possible to determine (NP). Table 1 shows that none of the recent data suggest an increasing chloride concentration trend in the monitoring wells.

Table 1: Chloride Threshold Values and Trend Analysis

Primary Aquifer	**Well Location**	**Chloride Threshold Value[a] (mg/L)**	**Statistical Trend**
Paso Robles (shallow)	MSC-Shallow	62	No Trend
	PCA-W Shallow	70	No Trend
	PCA-E (Multiple) Shallow	73	NP
	MPWMD #FO-09-Shallow	67	Decreasing
	MPWMD #FO-09-Deep	85	No Trend
	MPWMD #FO-10-Shallow	94	NP
	MPWMD #FO-10-Deep	93	NP
	Basin Wide[b]	94	
Santa Margarita (deep)	MSC-Deep	182	Decreasing
	PCA-W Deep	186	No Trend
	PCA-E (Multiple) Deep	181	NP
	Ord Terrace-Shallow	185	NP
	Ord Terrace-Deep	260	NP
	Basin Wide[b]	260	

Note: It is suggested to collect at least 8 to 10 observations using these statistical methods.

a Historical maximum chloride concentrations prior to 1995 are not included in the statistical analysis and should not be used when determining acceptable maximum chloride concentrations during future monitoring events.

b Basin wide screening criteria is based on maximum chloride screening criteria.

INDICATOR 2: DECREASING SODIUM/CHLORIDE MOLAR RATIOS

A rapid decline in the molar ratio of sodium to chloride may indicate seawater intrusion. In the early stages of seawater intrusion, sodium often replaces calcium on the aquifer's clay particles through ion exchange before significant chloride increases are observed. This effectively removes sodium from the water, and sodium/chloride molar ratios drop. The ratio of sodium to chloride in groundwater can therefore sometimes be used as an early indicator of seawater intrusion. Sodium/chloride molar ratios can also be used to differentiate between seawater intrusion and other sources of salinity. Jones et al. (1999) suggest that sodium/chloride molar ratios in advance of a seawater intrusion front will be below 0.86 molar ratio.

HISTORICAL SODIUM/CHLORIDE MOLAR RATIOS

Chemographs showing sodium/chloride molar ratios over time are provided in Appendix D. None of these chemographs show the rapid decline in sodium/chloride molar ratios that is indicative of seawater intrusion.

SODIUM/CHLORIDE MOLAR RATIO TREND ANALYSIS

In addition to evaluating increasing chloride concentrations, decreasing sodium/chloride molar ratios are also evaluated using the Mann-Kendall statistical test. Table 2 summarizes the results of the statistical trend analysis. None of the data suggest a downward trend in the sodium/chloride molar ratios.

Table 2: Sodium/Chloride Molar Trend Analysis

Primary Aquifer	**Well Location**	**Mann-Kendall Statistical Trend**
Paso Robles (shallow)	MSC-Shallow	No Trend
	PCA-W Shallow	No Trend
	PCA-E (Multiple) Shallow	NP
	MPWMD #FO-09-Shallow	Increasing
	MPWMD #FO-09-Deep	No Trend
	MPWMD #FO-10-Shallow	NP
	MPWMD #FO-10-Deep	NP
Santa Margarita (deep)	MSC-Deep	No Trend
	PCA-W Deep	No Trend
	PCA-E (Multiple) Deep	NP
	Ord Terrace-Shallow	NP
	Ord Terrace-Deep	NP

Note: It is suggested to collect at least 8 to 10 observations using these statistical methods.

INDICATOR 3: VISUAL INSPECTION OF CATION/ANION RATIOS

Seawater intrusion is often indicated by graphically analyzing shifts in groundwater quality. Two common graphical techniques for these analyses are Piper diagrams and Stiff diagrams.

PIPER DIAGRAMS

Piper diagrams plot the relative abundances of individual cations and anions on two trilinear plots, and their combined distribution is plotted on a 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.

An example Piper Diagram showing changes in molar ratios that are indicative of seawater intrusion is included in Appendix E. The indicator of seawater intrusion using Piper diagrams is the water chemistry trending in the direction of the curved arrow on the example Piper diagram.

Appendix E also displays Piper diagrams based on August 2008 chemical analyses of the 12 monitoring wells and the four sentinel wells in the Seaside Groundwater Basin. Two Piper diagrams are displayed; one for each aquifer. Each well pair is represented with a unique symbol. All 12 monitoring well pairs cluster in a single area on the Piper diagrams. Some of the sentinel wells plot in a slightly different area on the diagrams reflecting a different water chemistry than the monitoring wells. None of the data indicate seawater intrusion.

STIFF DIAGRAMS

Stiff diagrams plot the relative abundances of individual cations and anions on a single graph. Cations are plotted on the left side of the graph, and anions are plotted on the right side of the graph. Waters with similar chemistries will have similar shaped Stiff diagrams.

Example Stiff diagrams from the Salinas Valley are shown in Appendix A. These figures, along with a short description, are included to demonstrate the utility of Stiff diagrams. The indicator of seawater intrusion using Stiff diagrams is a change in the shape of a stiff diagram towards one of the example seawater intruded Stiff diagrams shown on Figure F-1.

Stiff diagrams for the 12 monitoring wells and four sentinel wells are provided in Appendix F. If viewed in color, the stiff diagrams are color coded to match the colors on the Piper diagrams. None of the Stiff diagrams show the high chloride spike shown on Figure F-1 that is indicative of seawater intrusion in the example Stiff diagrams. The Stiff diagrams in Appendix F serve as baseline diagrams for future comparison.

INDICATOR 4: CHLORIDE CONCENTRATION MAPS

In basins experiencing seawater intrusion, chloride concentrations will be highest at the coast. If chloride concentrations have a distribution that can be contoured, annual chloride isoconcentration maps can be generated. This would show whether seawater is migrating in from the coast. As in the case of the 2007 and 2008 *Seawater Intrusion Analysis Reports*, chloride did not show a distribution that could be contoured and thus data were simply plotted on concentration maps. The concentration maps in the 2007 and 2008 *Seawater Intrusion Analysis Reports* did not show any indication of seawater intrusion.

OTHER FACTORS

Groundwater levels alone do not indicate seawater intrusion, but indirectly suggest potential for seawater intrusion. Coastal groundwater levels at or near sea level are not sufficient to repel seawater intrusion. As sea levels rise, coastal groundwater levels must also be allowed to rise to repel seawater intrusion. Groundwater level maps, combined with estimates of recharge and extraction volumes, can be used as a tool for determining the extent of likely seawater intrusion, once it is detected in a given well.

Additional indicators, or revisions to the indicators presented above may be warranted when a larger database is developed containing statistically significant populations of geochemical parameters of interest (i.e., greater than ten sample dates – not including data prior to 1995). Revisions would also be warranted if the revisions to these baseline criteria appear necessary to respond to the new groundwater management strategies of the Watermaster.

3.2 CONTINGENCY PLAN TRIGGERS

The four seawater intrusion indicators listed above are combined to form the triggers that prompt the contingency actions described in Section 4. These triggers have been developed using a combination of quantitative and qualitative indicators described above.

Because no one indicator definitively identifies seawater intrusion, a combination of indicators is necessary to identify intrusion. In order to clearly define seawater intrusion, the following combination of indicators should be used to trigger the actions described in Section 4:

1. Chloride concentrations must be higher than the chloride threshold value shown on Table 1.
2. Sodium/chloride molar ratios must show a rapid drop, and be below the 0.86 molar ratio.
3. At least one of the following four trends or qualitative indicators must be apparent:
    a. The Mann-Kendall statistical trend for chloride concentrations is increasing.
    b. Evolution of seawater mixing is observed in Piper diagram(s).

c. Change of Stiff diagram(s) shape from baseline conditions featuring prominent high chloride spike.
d. Concentration maps indicate increasing chloride concentrations near the coast.

SECTION 4

SEAWATER INTRUSION CONTINGENCY ACTIONS

It is not possible to halt and reverse seawater intrusion unless supplemental supplies are available. Until these supplies are secured, the Watermaster should implement containment strategies to reduce the magnitude and extent of seawater intrusion, if it is observed. By containing seawater intrusion, the Watermaster will: (1) help preserve productive use of the Seaside Groundwater Basin; and (2) facilitate the restoration of the Seaside Groundwater Basin water quality by limiting the extent and spread of the intrusion. The purpose of this section of the SIRP is to develop a containment strategy and actions that can be implemented in the event that seawater intrusion is observed in the Seaside Groundwater Basin.

4.1 GEOGRAPHIC AREA COVERED BY CONTINGENCY ACTIONS

The contingency actions described in Section 4.2 are only triggered by seawater intrusion occurring inside the Seaside Groundwater Basin boundary as illustrated on Figure 1. Some wells monitored by the Watermaster, such as the FO-10 shallow and deep wells, may be located outside the Seaside Groundwater Basin boundary. Seawater intrusion observed at wells outside the adjudicated boundary should not necessarily trigger the actions listed in Section 4.2, but should trigger a review of the data by the Watermaster to assess necessary actions to prevent Material Injury to the Seaside Groundwater Basin.

4.2 ACTIONS ADDRESSING OBSERVED SEAWATER INTRUSION

The specific actions that should be implemented if seawater intrusion is detected, as defined by the triggers in Section 3.2, are as follows.

ACTION 1: VERIFICATION

Wells with water quality indicative of seawater intrusion shall be re-sampled as soon as possible. The re-sampling should include the full suite of major cations and anions, which will allow all of the indicators listed in Section 3 to be verified. Laboratory analyses should be conducted with an expedited turnaround time. If re-sampling these wells verifies the presence of seawater intrusion in the Seaside Groundwater Basin, Actions 2 through 5 should be implemented.

ACTION 2: DECLARATION OF SEAWATER INTRUSION

If the verification confirms that seawater intrusion has occurred within the Seaside Groundwater Basin, the Watermaster shall issue a Declaration of Seawater Intrusion within 15 calendar days of verification.

ACTION 3: NOTIFICATION

Within 10 calendar days following the Watermaster's Declaration of Seawater Intrusion, all groundwater producers in the Seaside Groundwater Basin, MPWMD, and all other interested entities within the Seaside Groundwater Basin shall be formally notified. The Watermaster shall notify all parties that the SIRP contingency actions have been triggered, and will identify the well(s) that triggered the SIRP contingency actions.

ACTION 4: PUMPING REDISTRIBUTION PLAN

The pumping redistribution plan is designed to contain observed seawater intrusion, and to protect production wells until a supplemental water supply is obtained. The pumping redistribution plan consists of the following eight activities that will be implemented. Many of these activities should be applied iteratively.

- **Discontinue or substantially reduce pumping the Impacted Well(s).** If seawater intrusion has been declared for a production well, pumping at this well shall be discontinued or substantially reduced as soon as possible, but no longer than 30 calendar days after the Declaration of Seawater Intrusion. If seawater intrusion has been declared for only monitoring wells, this activity is unnecessary.

All of the following activities shall be initiated within 90 calendar days after the Declaration of Seawater Intrusion:

- **Identify At Risk Well(s) where seawater intrusion might occur.** At Risk Wells are production wells that have the potential to become impacted by seawater intrusion based on their proximity to the Impacted Well(s), local groundwater gradients, and other conditions.

- **Identify and/or install additional monitoring wells.** The Watermaster will evaluate the benefit of installing additional groundwater monitoring wells to evaluate the movement of seawater intrusion towards the At Risk Well(s). If this evaluation concludes that monitoring wells should be installed, the Watermaster will pursue installation of these wells with due diligence.

- **Estimate the groundwater conditions that protect production wells.** The Watermaster shall estimate the maximum acceptable groundwater gradient between the Impacted Well(s) and the At Risk Well(s) that prevents seawater intrusion from reaching the At Risk Wells before a supplemental supply is obtained, currently estimated to be 2015. The Watermaster should further estimate the expected total dissolved solids (TDS) and chloride concentrations over time that might be observed at existing or new monitoring wells under this maximum groundwater gradient.

- **Identify and evaluate production wells' influence on observed seawater intrusion**. All production wells in the Seaside Groundwater Basin shall be evaluated and ranked for their influence on the groundwater gradients that are causing seawater intrusion and migration. The Watermaster shall estimate one or more recommended pumping scenarios that will achieve the maximum acceptable gradient between Impacted and At Risk well(s).

- **Increase monitoring frequency**. The Watermaster should increase the monitoring frequency of the Impacted Well(s), monitoring wells, and At Risk Well(s) to evaluate the progress of the seawater intrusion. Groundwater elevations at these wells should be measured monthly, and groundwater samples should be collected from these wells and analyzed monthly for major cations and anions. The groundwater gradient should be analyzed every month to confirm that the pumping reduction is having the planned effect.

- **Re-evaluate the Operating Yield.** In accordance with the Amended Decision, the Watermaster should re-evaluate the Operating Yield to prevent further Material Injury.

The following activity shall be initiated within 90 calendar days of the Water master Board adopting recommendations from the previous activities:

- **Modify pumping to achieve the desired groundwater gradient**. Groundwater pumping at the most influential production wells should be modified to achieve the groundwater gradient calculated above.

ACTION 5: FOCUS SUPPLEMENTAL SUPPLIES TO HALT AND REVERSE SEAWATER INTRUSION

When a supplemental water supply becomes available for Seaside Groundwater Basin replenishment, the Watermaster will seek to have the supplemental water used strategically to protect the Seaside Groundwater Basin from further seawater intrusion, and to restore the Basin to pre-seawater intruded conditions. Supplemental supplies should be used to both offset pumping that causes the observed seawater intrusion, and to raise groundwater levels to reverse seawater intrusion.

SECTION 5
REFERENCES

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APPENDIX A:
OVERVIEW OF SEAWATER INTRUSION
2008 SEAWATER INTRUSION ANALYSIS REPORT, (SECTION 2)

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.

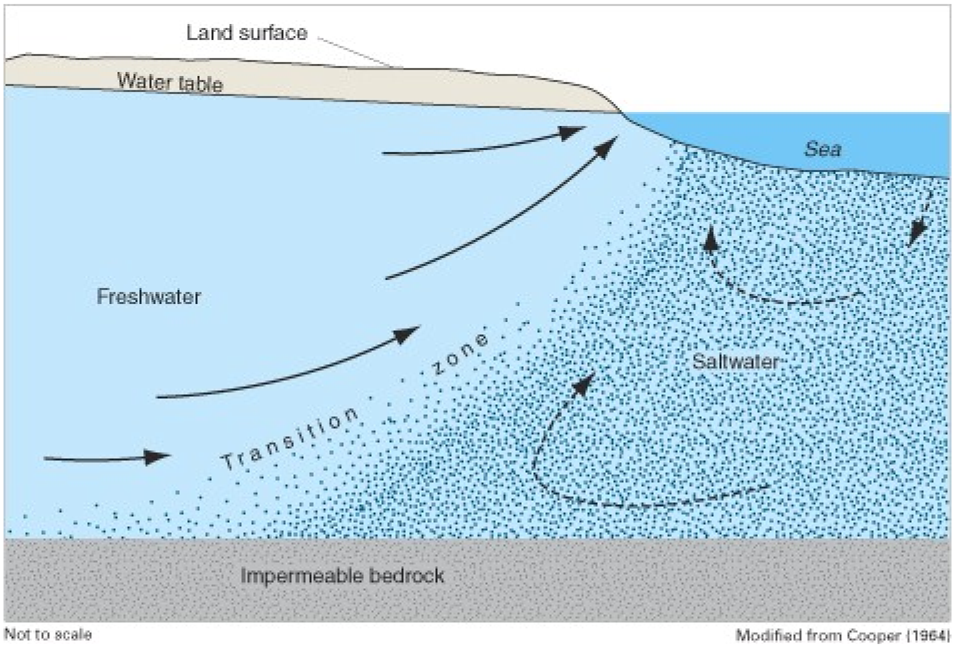

Figure 1: Seawater Wedge in a Simple Coastal Aquifer (from Barlow, 2003)

In more complex, layered groundwater systems, the location of the seawater/freshwater interface may vary among the different aquifers. Such a situation is illustrated in 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 the each aquifer, the aquifer hydraulic conductivities, and the vertical conductivity of the inter-layered confining units.

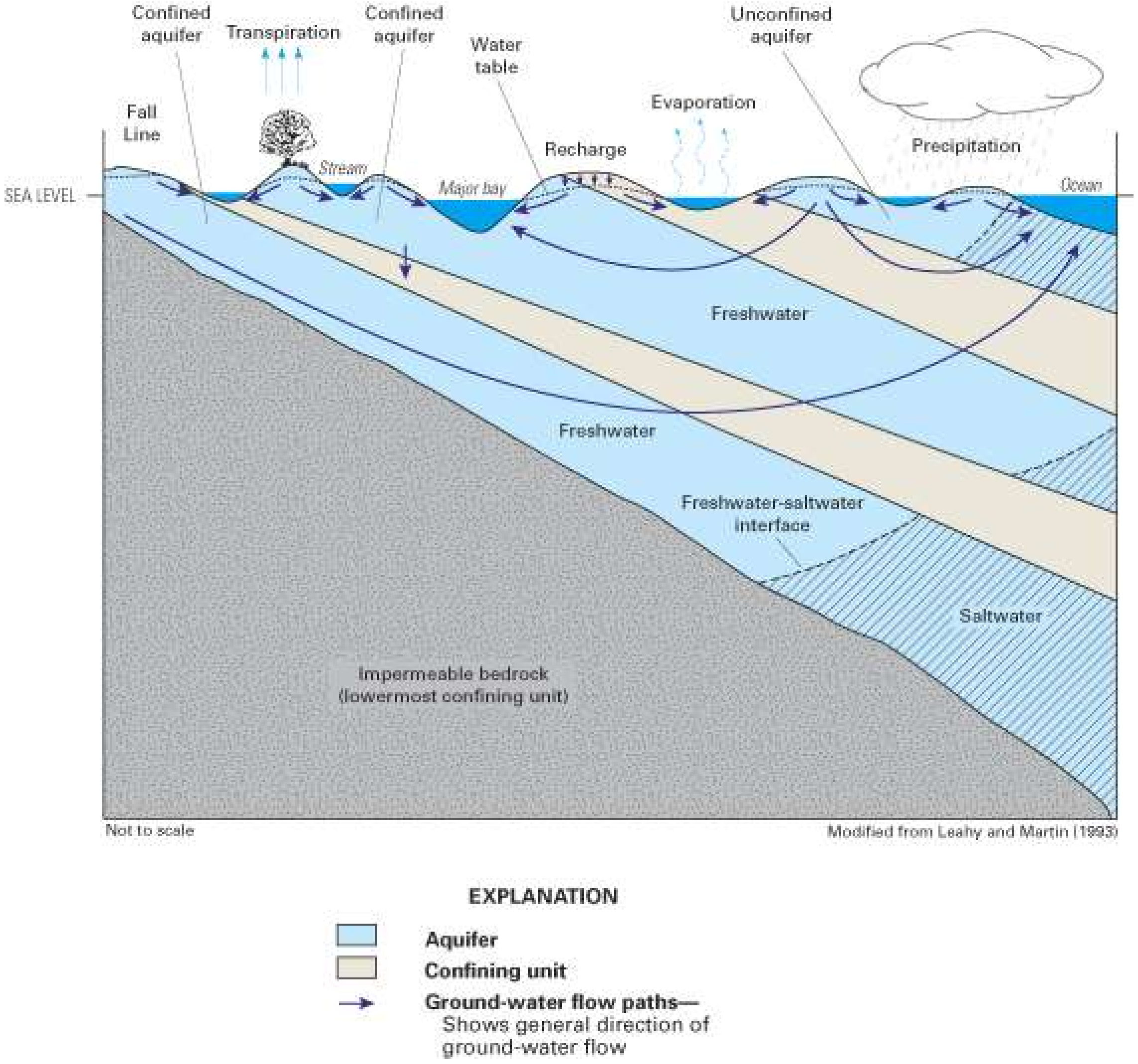

Figure 2: Seawater Wedge in a Layered Coastal Aquifer (from Barlow, 2003)

Figure 2 shows that under non-pumping conditions, the seawater interface in confined units is often 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.

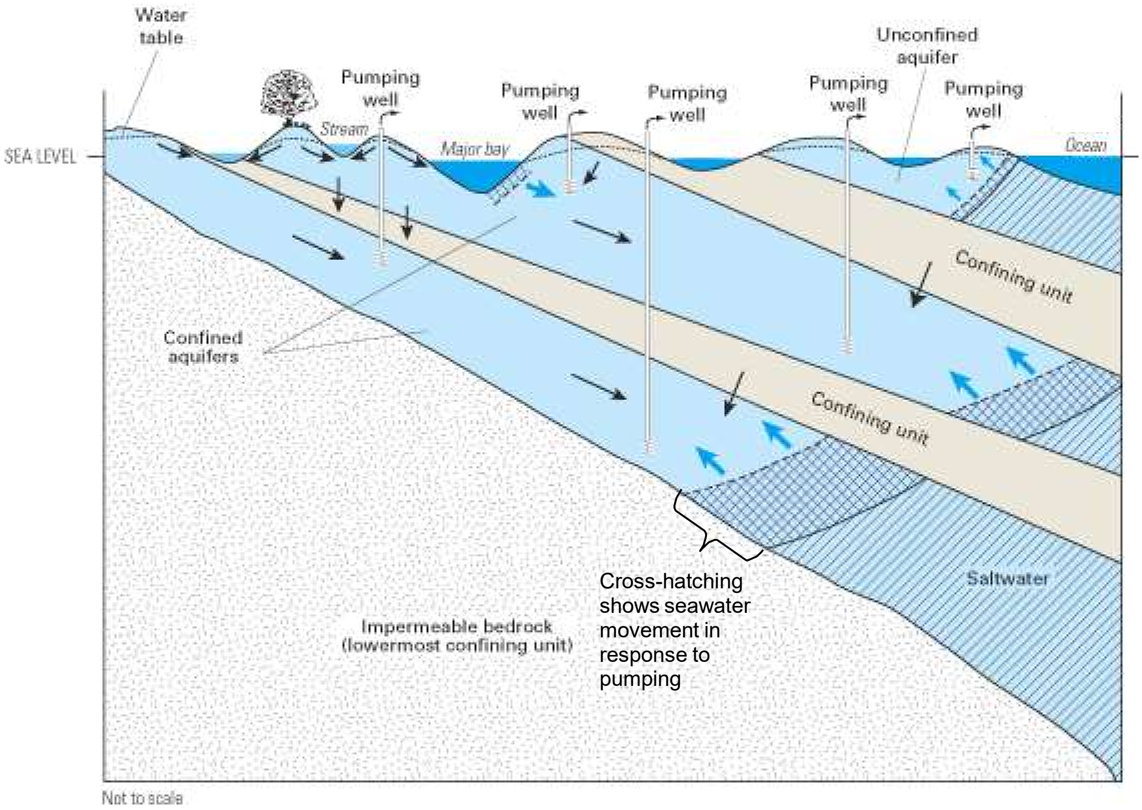

Figure 3: Interface Migration in Response to Groundwater Pumping (from Barlow, 2003)

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.

INDICATORS OF SEAWATER INTRUSION

Seawater intrusion is generally identified through chemical analyses of groundwater. Low groundwater levels 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. Mixing trends between groundwater and seawater are more easily defined when chloride concentrations exceed 1,000 milligrams per liter (mg/L). This is due to the dominance of natural variation in fresh water chemistry at chloride concentrations below 1,000 mg/L (Richter and Kreitler, 1993). Chloride concentrations greater than 1,000 mg/L are clearly indicative of seawater intrusion in the local aquifers.

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 in 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 in 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 in 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 similar shapes in 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 in 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 the adsorption of calcium on the aquifer material.

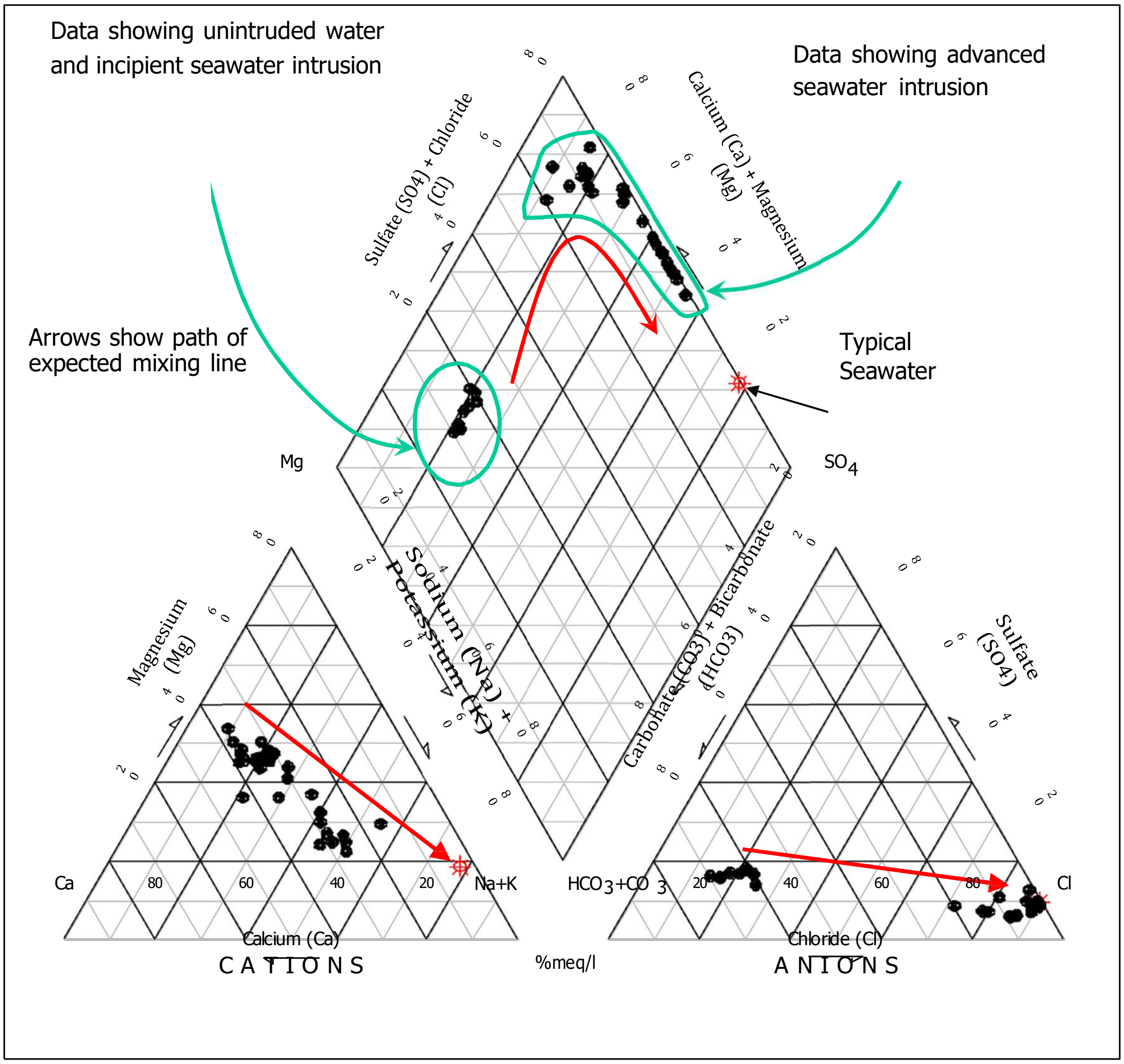

Figure 4: Piper Diagram for Groundwater in Pajaro Valley
(Data source: PVWMA)

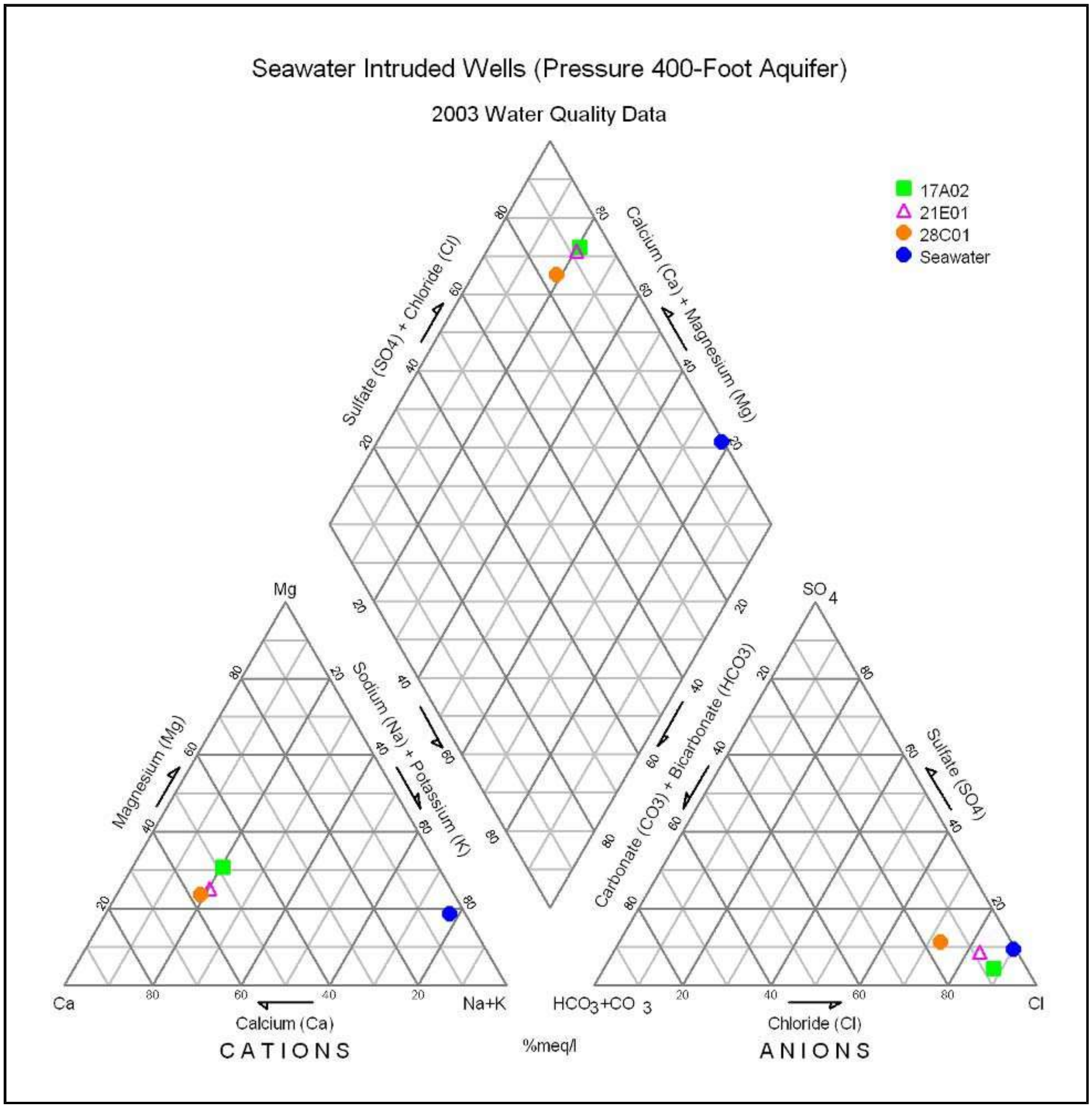

Figure 5: Piper Diagram for Groundwater in Salinas Valley
(Source: MCWRA)

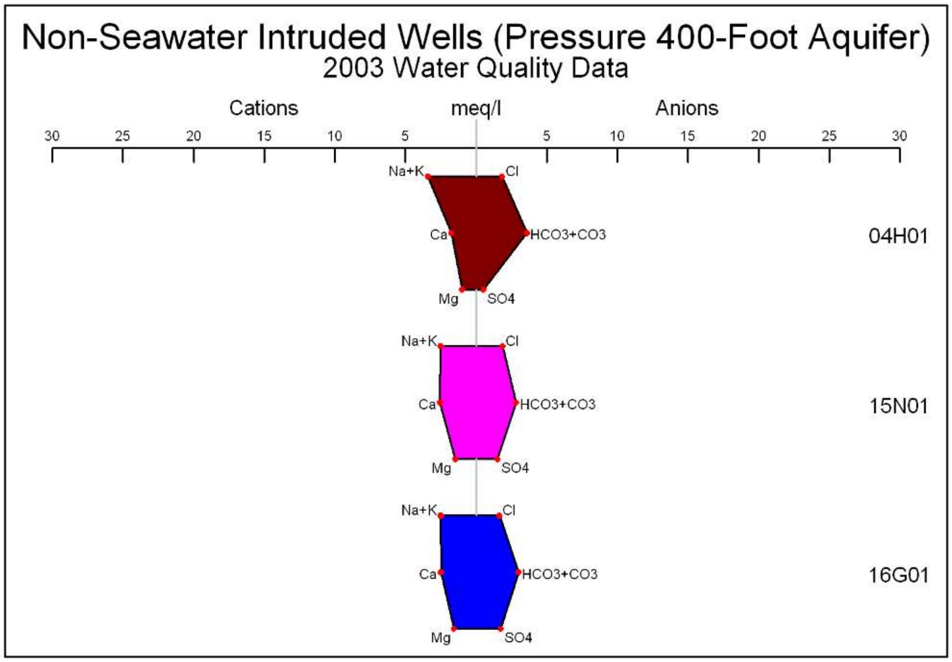

Figure 6: Stiff Diagrams from Salinas Valley Wells without Seawater Intrusion (Source: MWCRA)

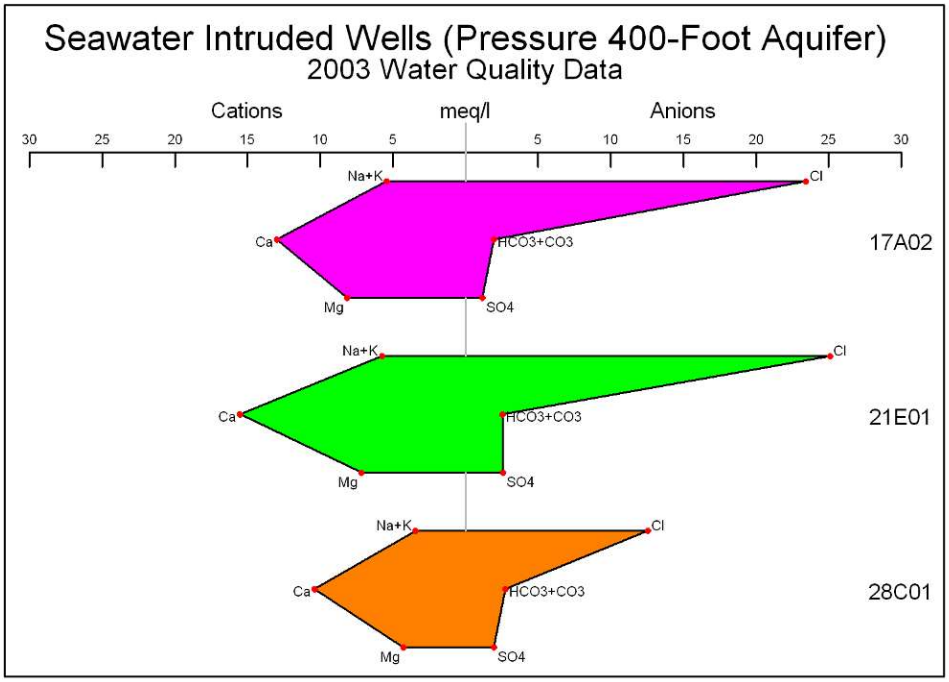

Figure 7: Stiff Diagrams from Salinas Valley Wells with Seawater Intrusion (Source: MWCRA)

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 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 in 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 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 1.86 (molar ratio). This distinguishes seawater intrusion from domestic waste water, which typically has sodium/chloride ratios above 1.

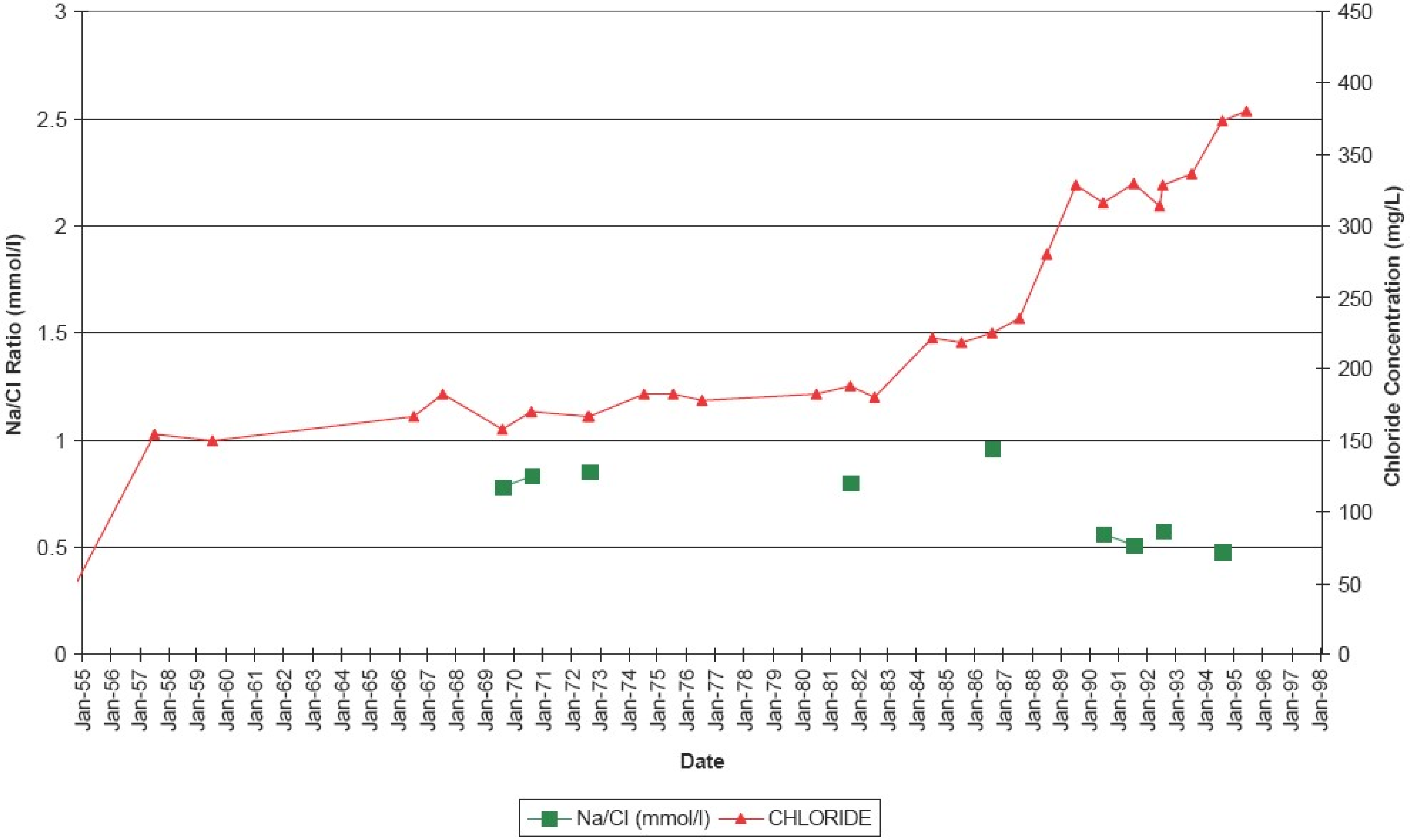

Figure 8: Historical Chloride Concentrations and Sodium/Chloride Ratios for a Well in Salinas Valley Showing Incipient Intrusion (Source: MCWRA)

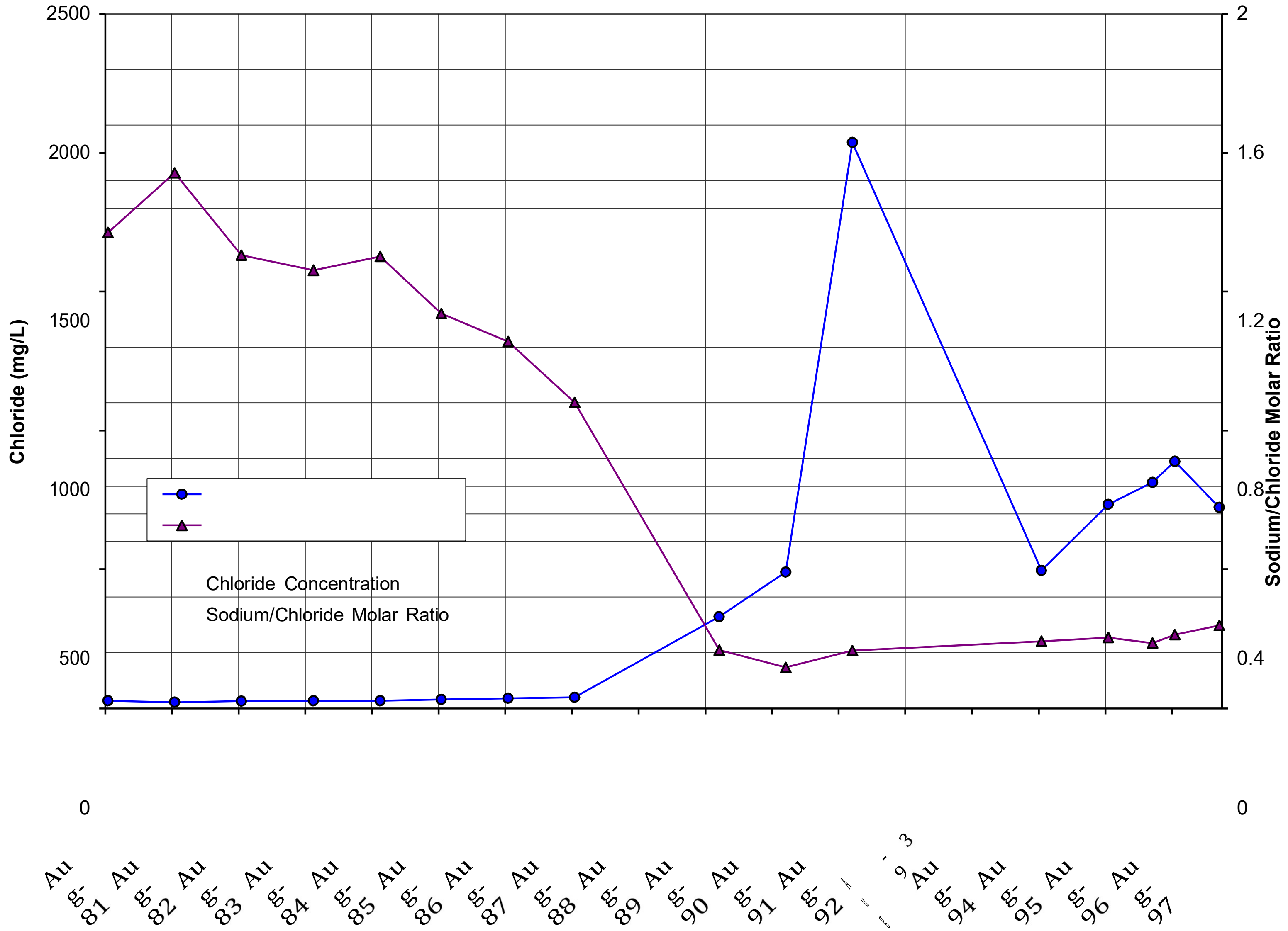

Figure 9: Historical Chloride Concentrations and Sodium/Chloride Ratios for a Well in Pajaro Valley Showing Incipient Intrusion

(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. Wells that are completed with PVC casing and screen do not interfere with the method.

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

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 data exist for the minor constituents such as iodide and barium; and only limited historical data exist for bromide and boron.

APPENDIX B:
HISTORICAL CHLORIDE CONCENTRATION GRAPHS

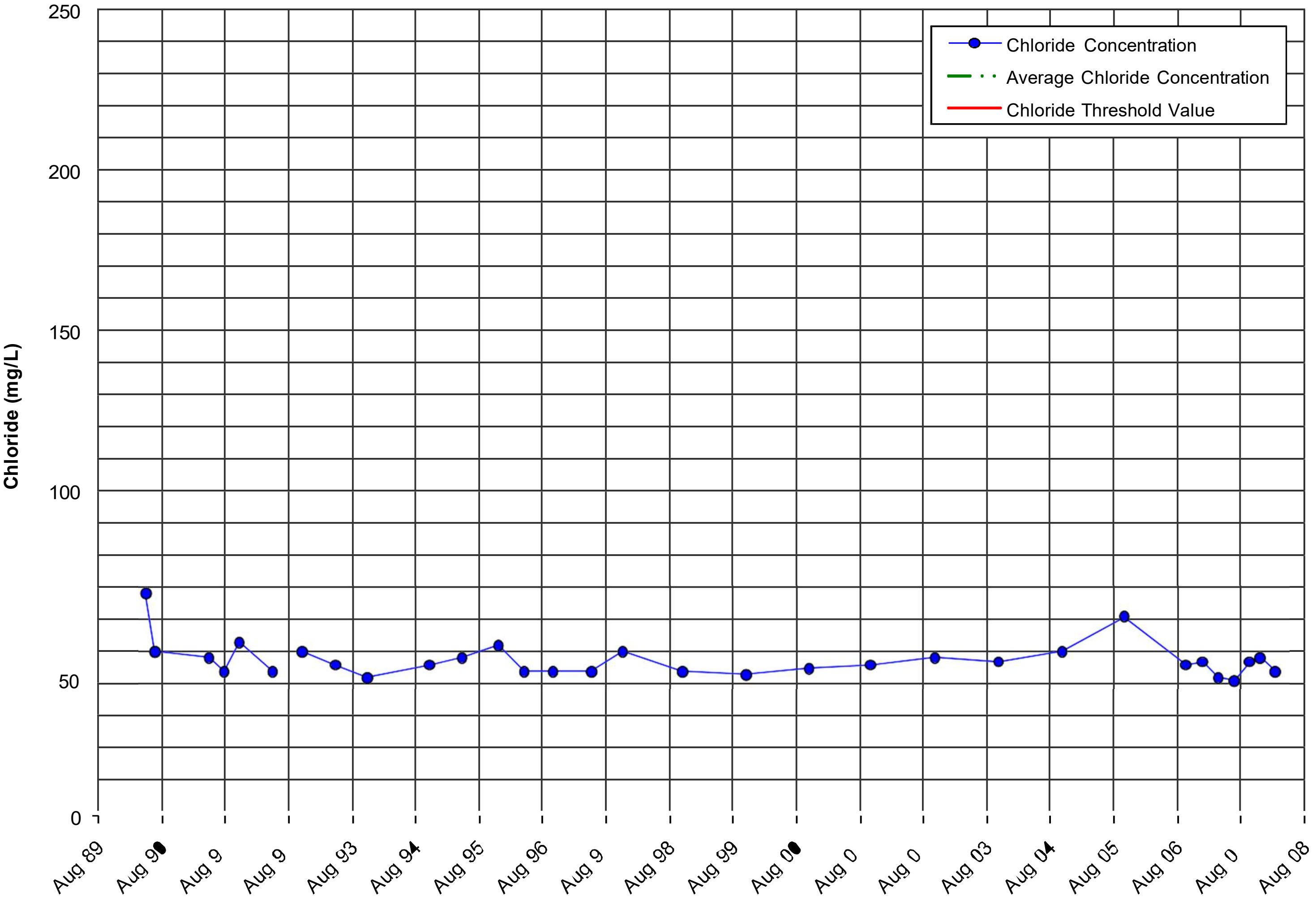

Figure B-1: PCA West Shallow Well

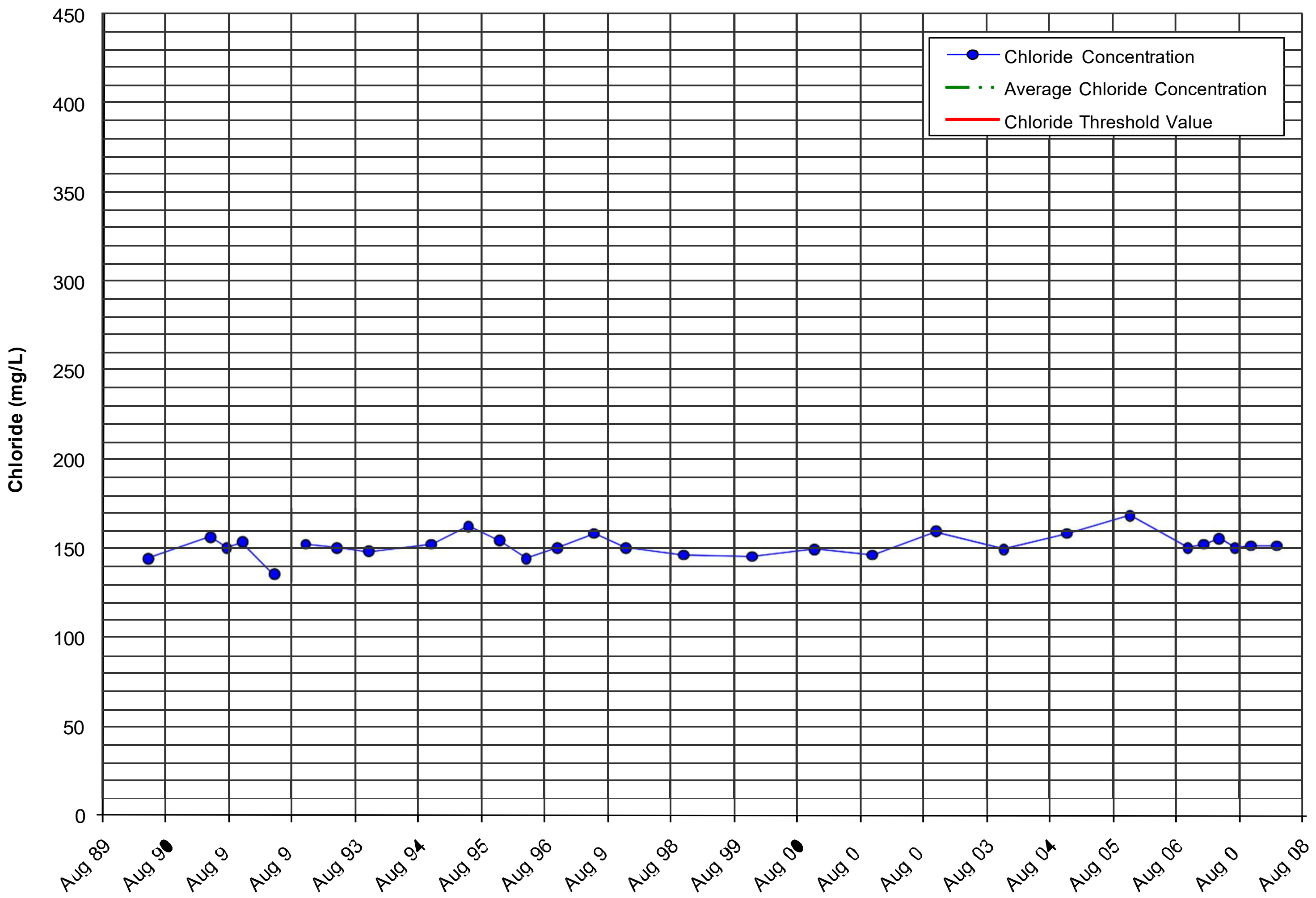

Figure B-2: PCA West Deep Well

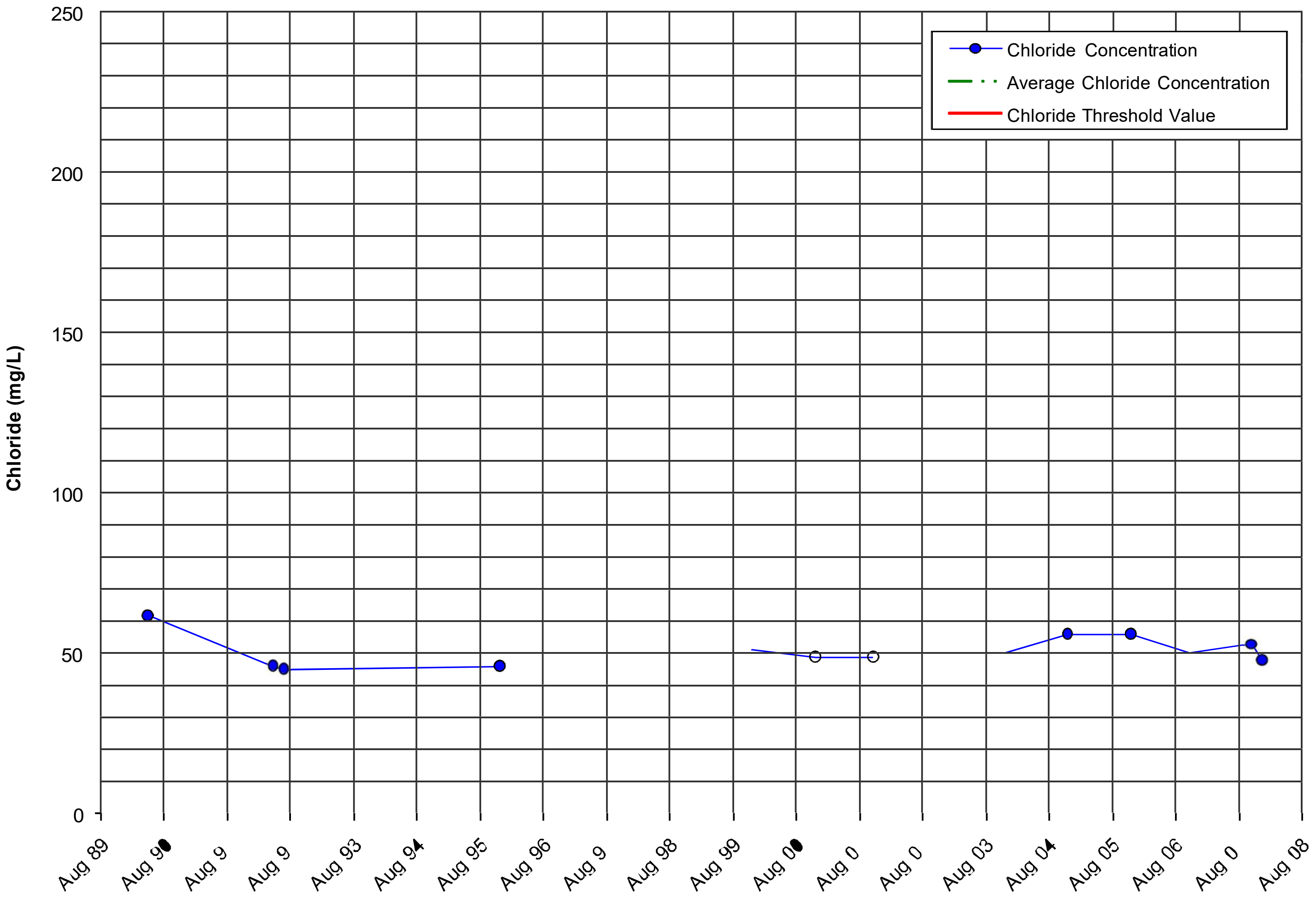

Figure B-3: PCA East Shallow Well

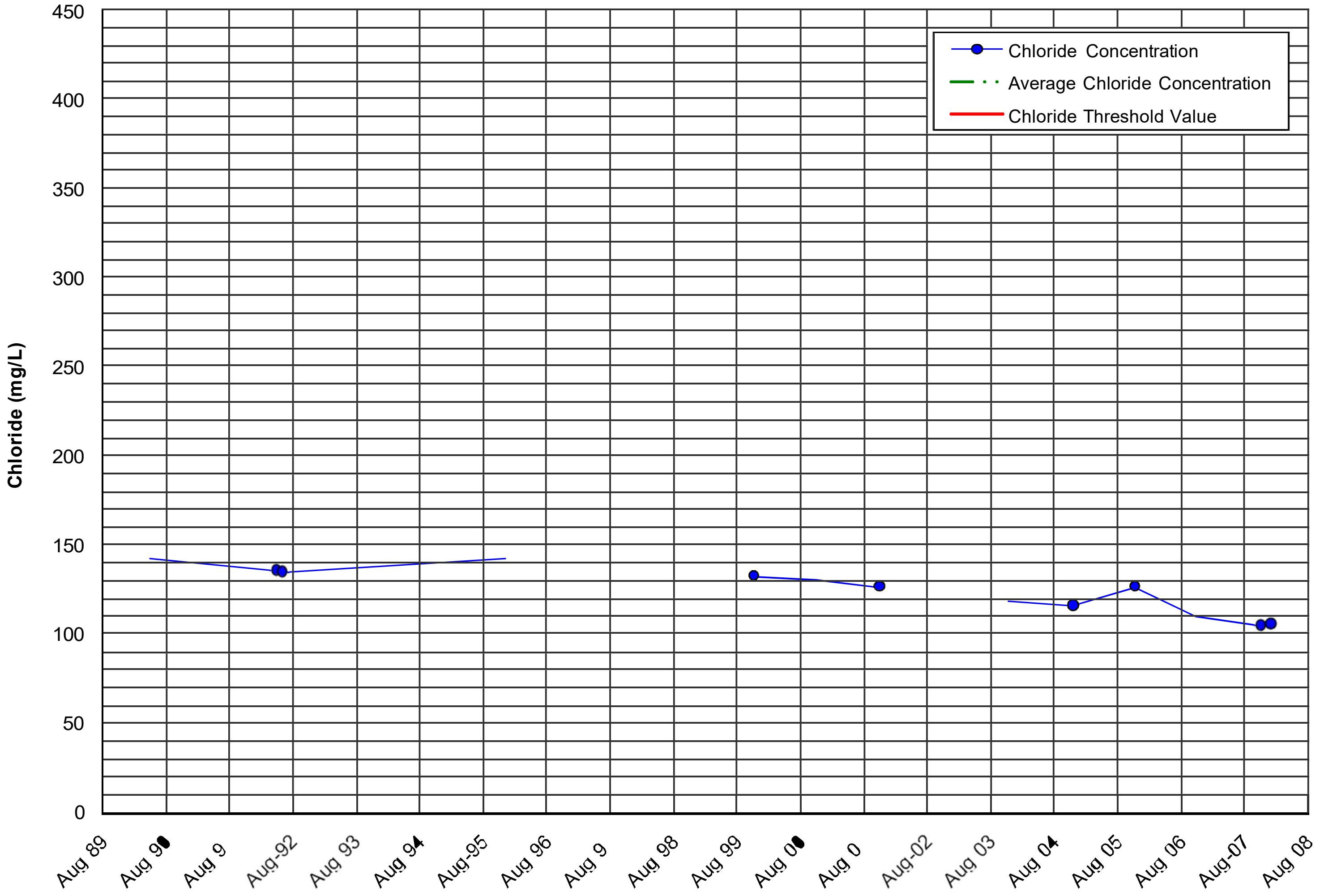

Figure B-4: PCA East Deep Well

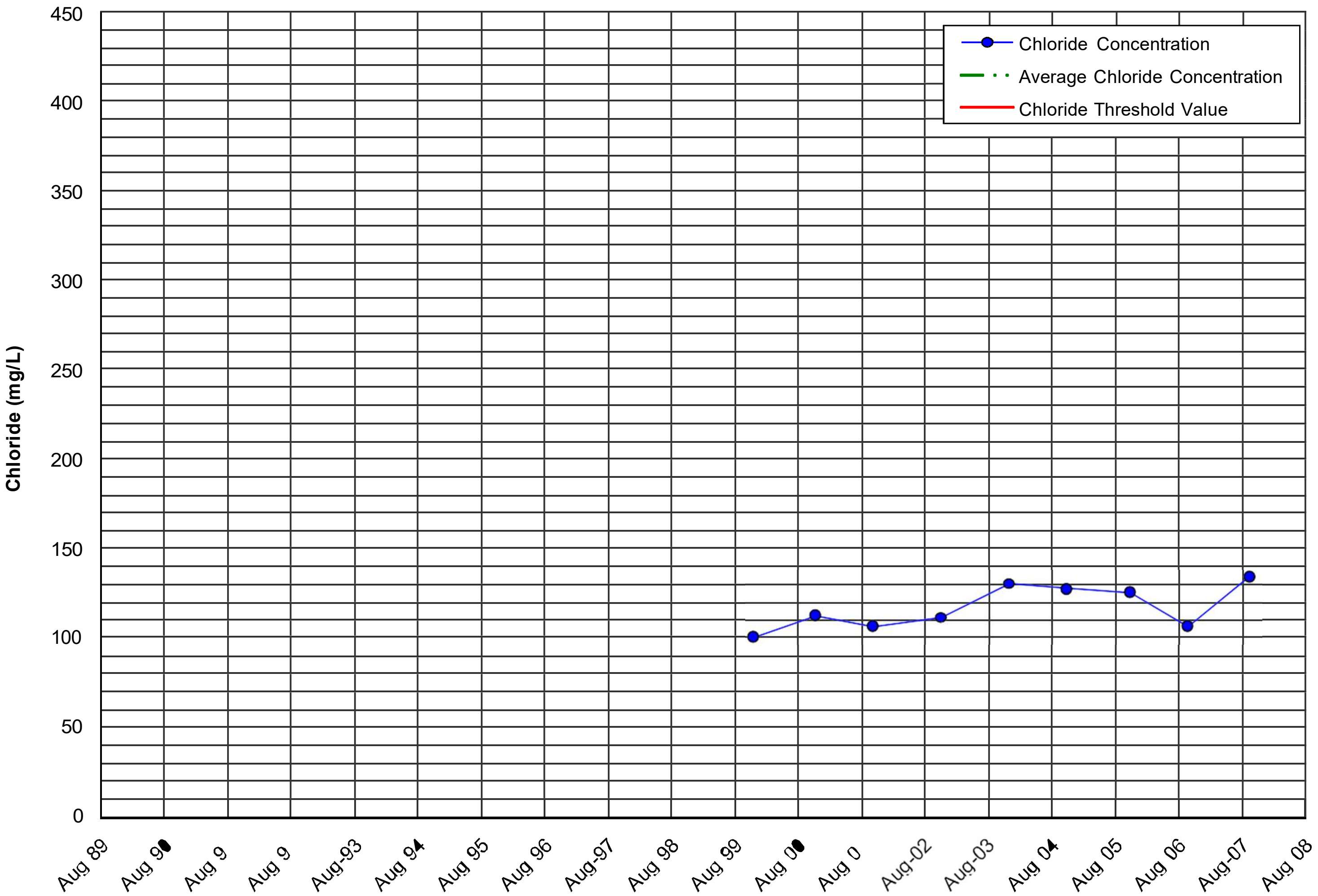

Figure B-5: Ord Terrace Shallow Well

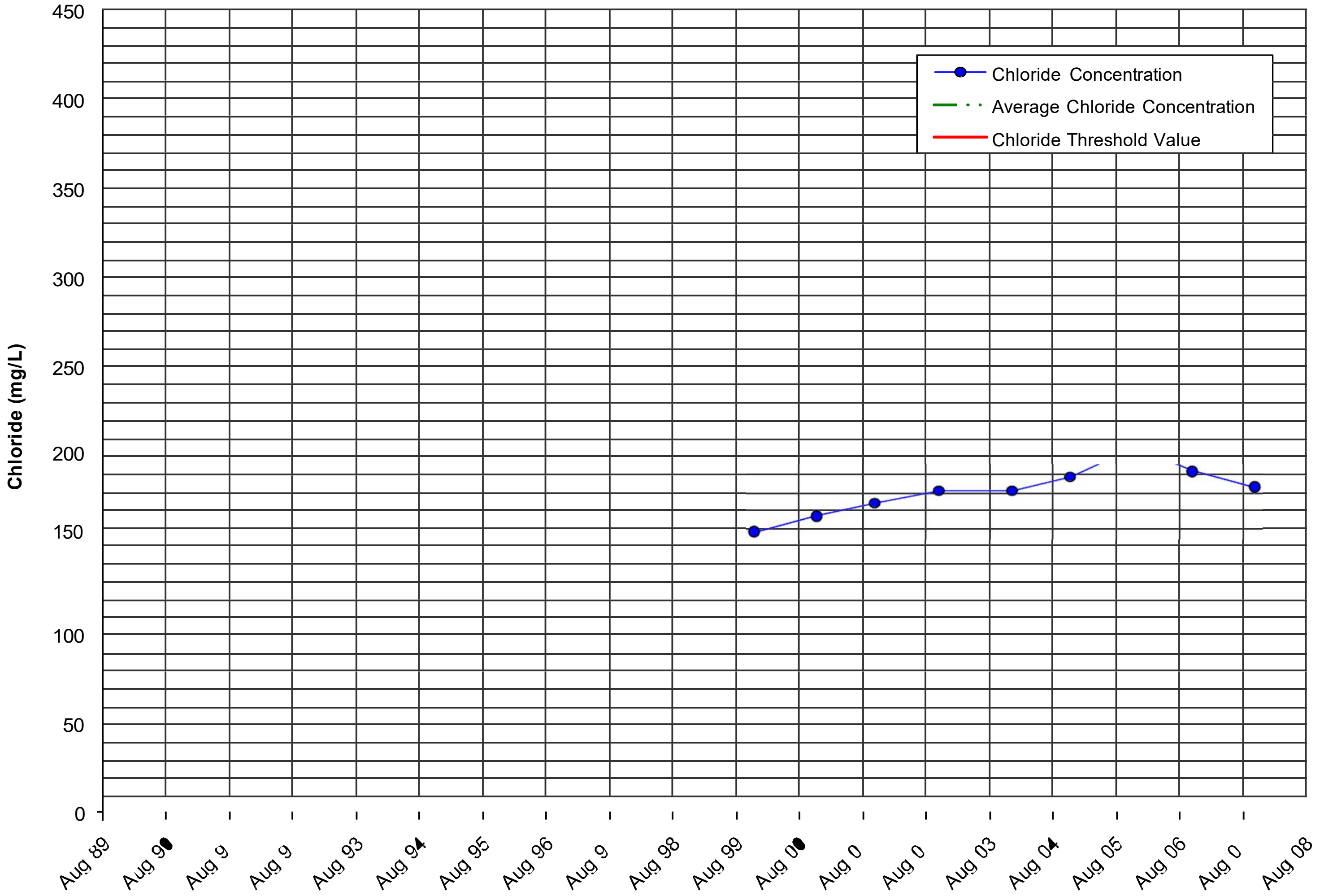

Figure B-6: Ord Terrace Deep Well

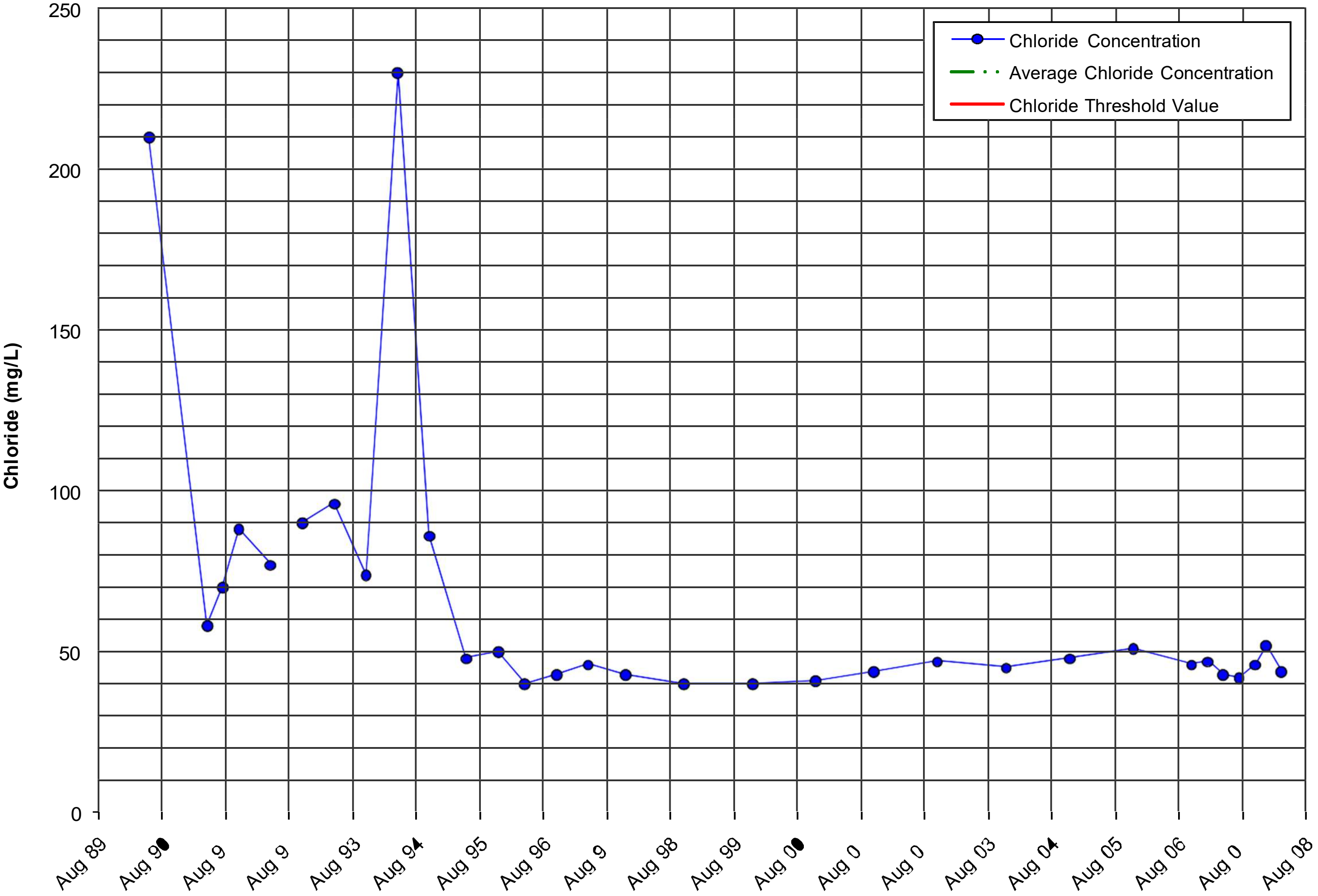

Figure B-7: MSC Shallow Well

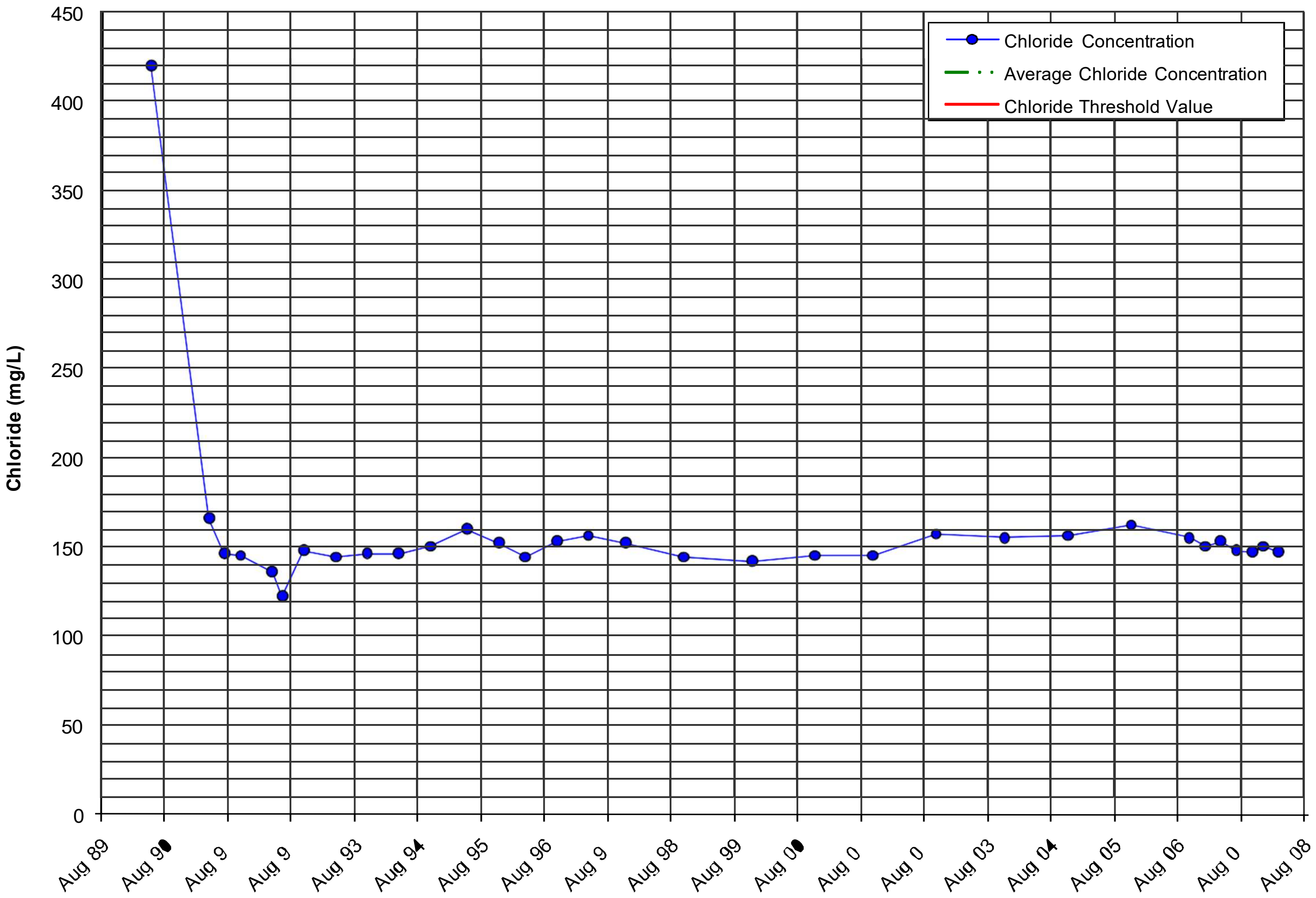

Figure B-8: MSC Deep Well

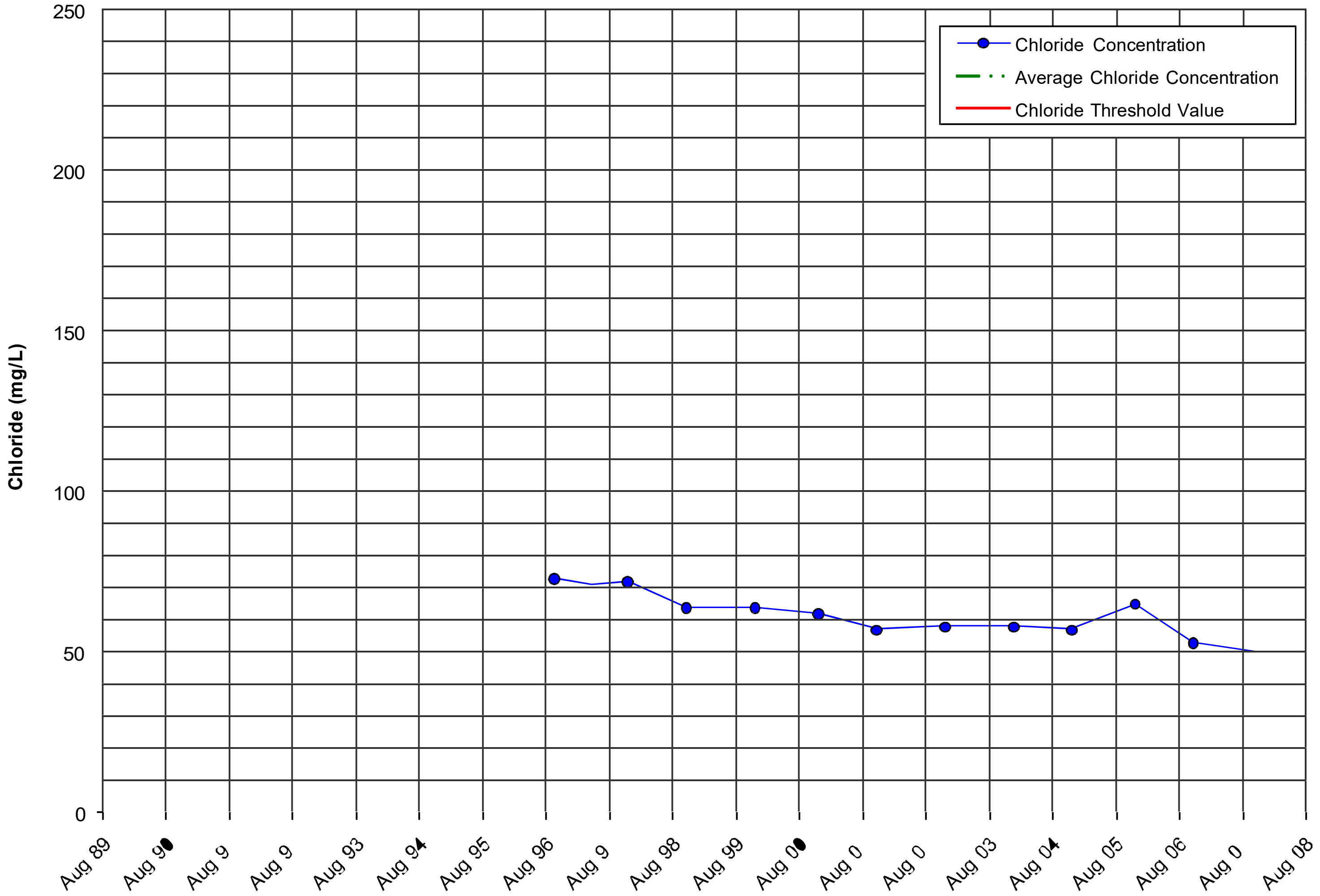

Figure B-9: Fort Ord 10 Shallow Well

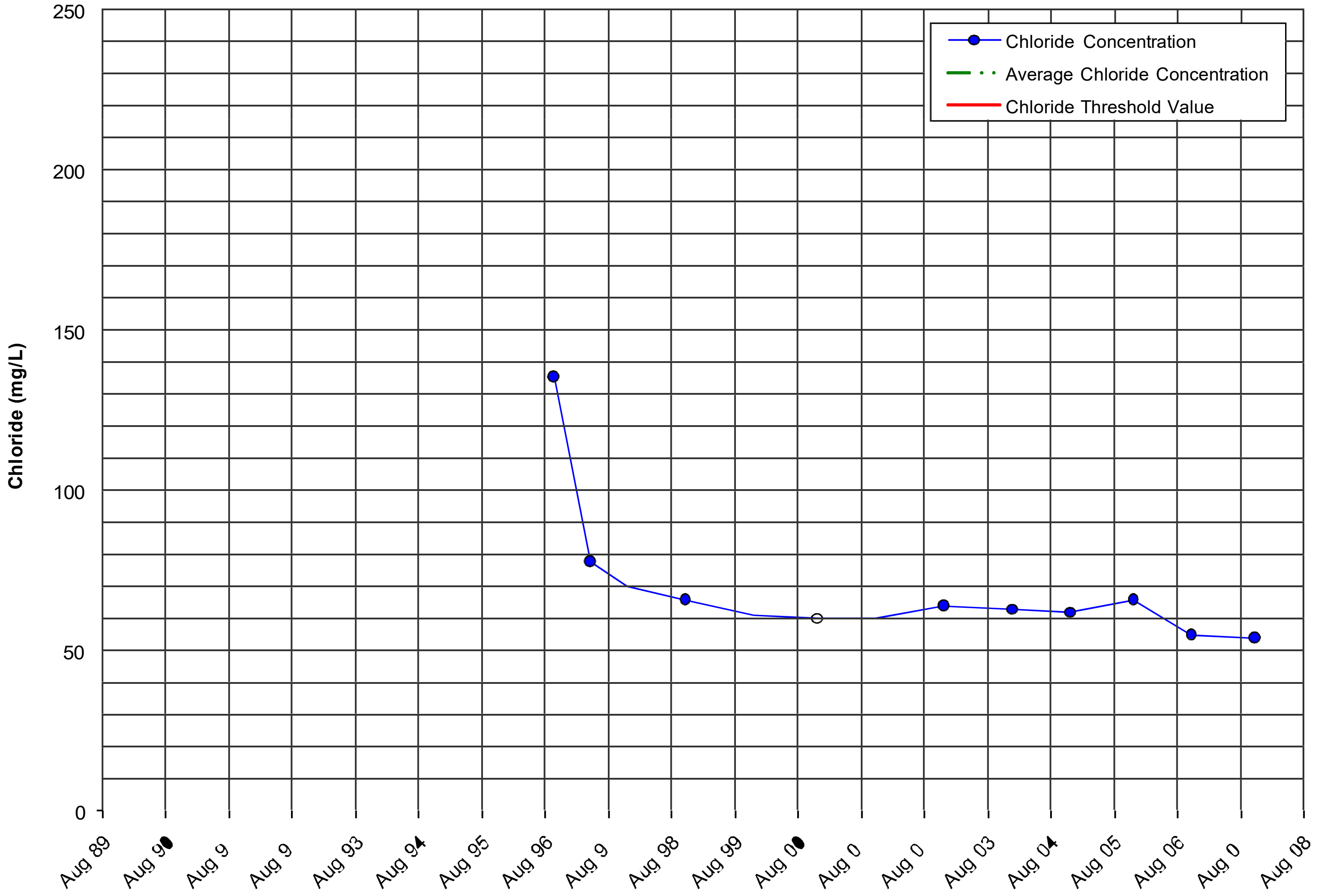

Figure B-10: Fort Ord 10 Deep Well

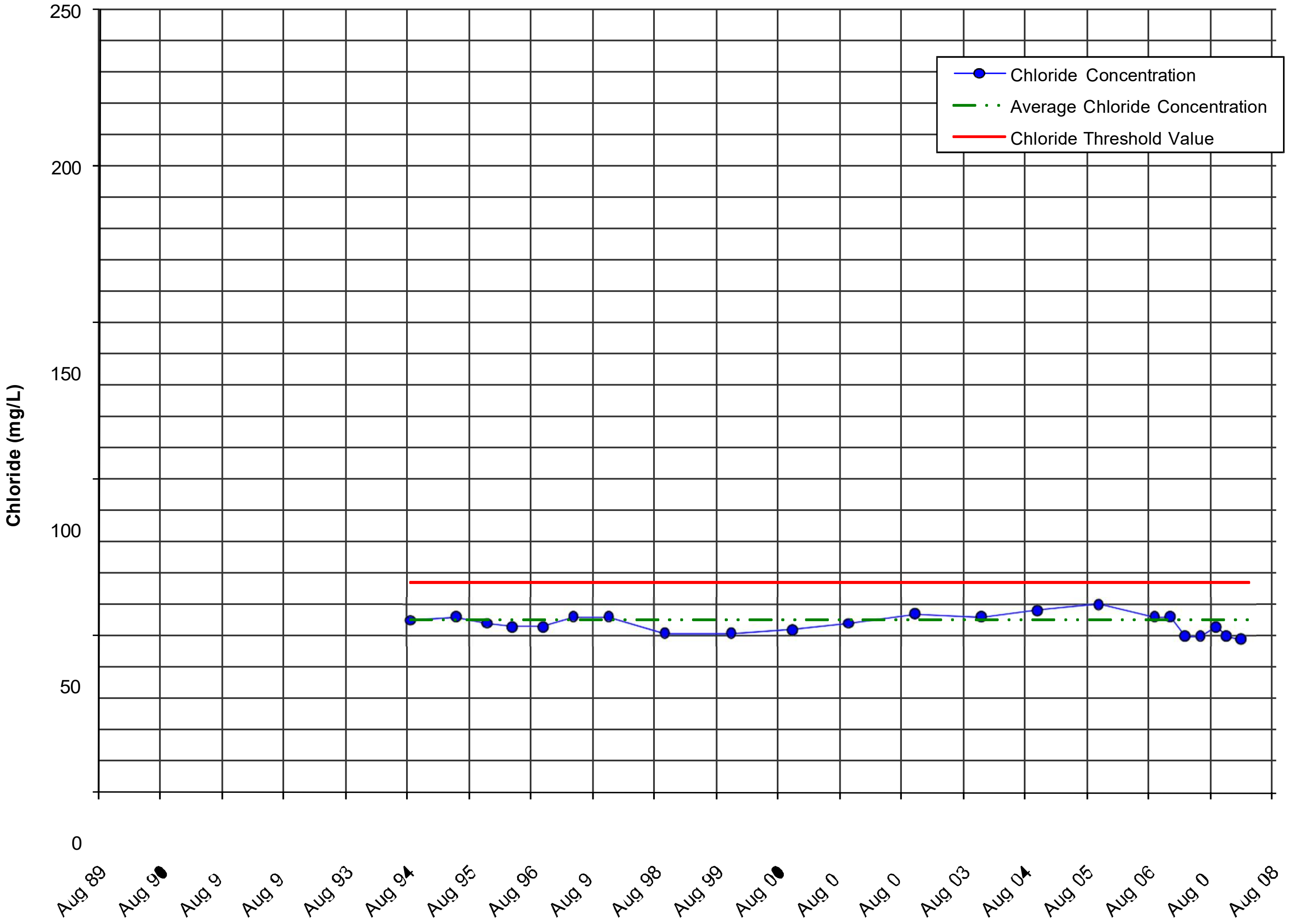

Figure B-11: Fort Ord 9 Shallow Well

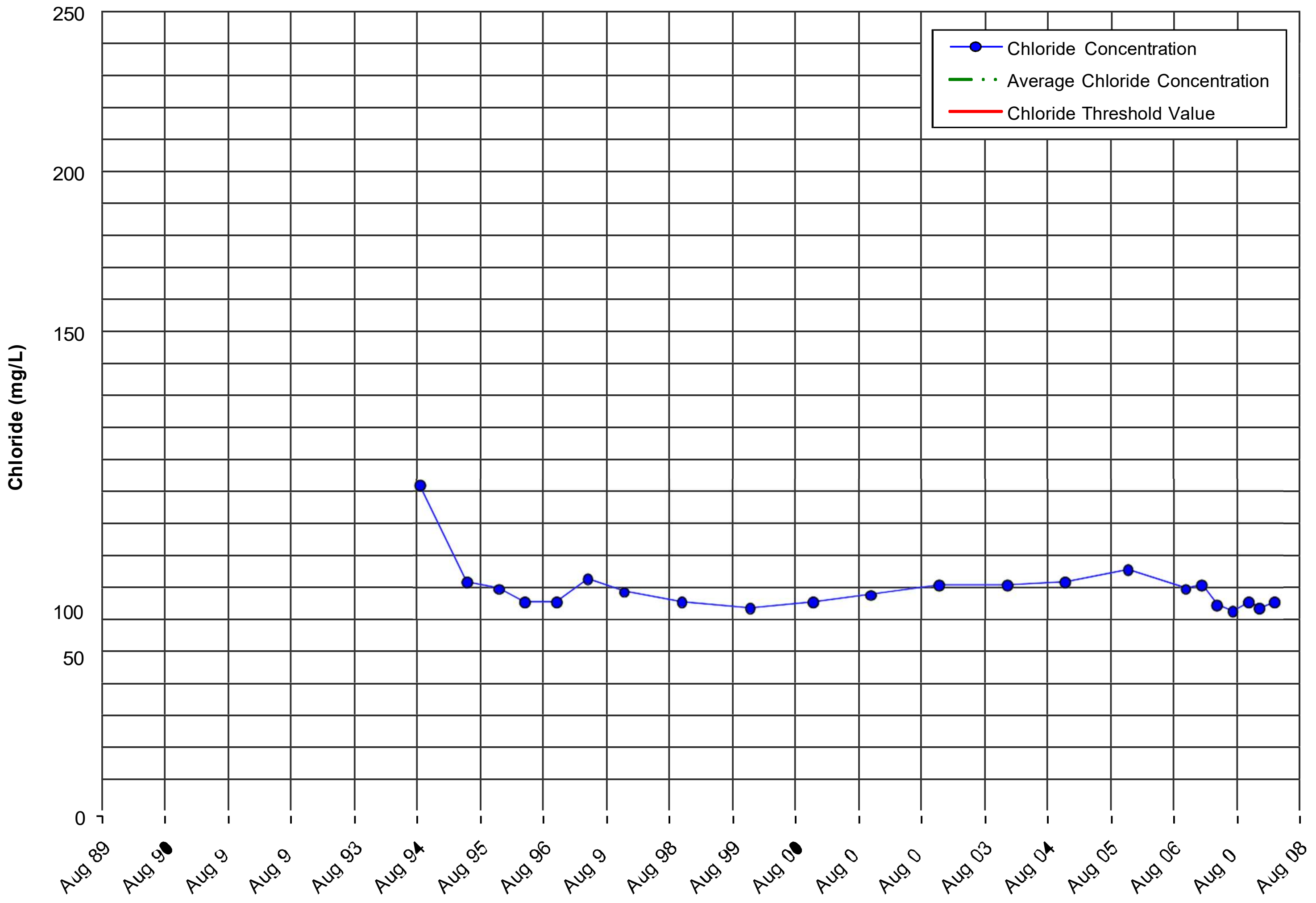

Figure B-12: Fort Ord 9 Deep Well

APPENDIX C:
STATISTICAL TREND ANALYSIS

STATISTICAL TREND ANALYSES

DEVELOPMENT OF CHLORIDE THRESHOLD VALUES

Historical data were analyzed to develop representative background concentrations of chloride and to determine a reasonable chloride threshold value. Background chloride concentrations are estimated as the average chloride concentration at each well, calculated from the historical data available. The chloride threshold value is the background chloride concentration plus an acceptable tolerance interval multiplied by the standard deviation that ensures that 99% of the population of chloride measurements collected and evaluated would not exceed the chloride threshold value. This approach assures that the variability observed over time is incorporated into the final chloride threshold value used for identifying seawater intrusion at individual wells. The accuracy of this approach for determining a true average chloride concentration and upper confidence interval depends on the accuracy of the assumption that the data display a normal distribution of chloride concentrations.

STATISTICAL APPROACH

The most powerful test for normality is the Shapiro-Wilk W test (US EPA, 2006). This test is difficult to compute by hand, but many statistical programs have been developed that calculate the statistical distribution such as the EPA program ProUCL (US EPA, 2007) which is available to download at *http://www.epa.gov/esd/tsc/software.htm*.

The formula to determine the average chloride concentrations is as follows:

$$[Cl^-]_{average} = \frac{\sum_{i=1}^{n}[Cl^-]_i}{n}$$

The standard deviation is calculated as:

$$[Cl^-]_S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left([Cl^-]_i - [Cl^-]_{average}\right)^2}$$

Where *n* equals the number of samples in the data set, *i* represents one of the *n* chloride concentrations being evaluated, and *SD* stands for *standard deviation*.

The tolerance interval is determined using the criteria that with a 95% tolerance limit, 99.9% of the population of chloride concentrations observed will be below a specific value. The following formula is used to determine the tolerance interval:

$$k_1 = \frac{z_{1-p} + \sqrt{z^2 - ab}}{a}, \quad a = 1 - \frac{z_{1-\alpha}^2}{2 \bullet (n-1)} \quad \text{and } b = z_{1-}^2 - \frac{z_{1-\alpha}^2}{n}$$

Where z_{1-p} is obtained from a statistical look up table; to include 99.9% of the population, z_{1-p} is equal to 3.08. And the value to establish the 95% tolerance limit (obtained from the same statistical look up table), $z_{1-\alpha}$ is approximately 1.645. The final chloride threshold limit is the average chloride concentration plus the tolerance interval multiplied by the standard deviation, as follows:

$$[Cl^-]_{threshold} = [Cl^-]_{average} + (k_1 \bullet [Cl^-]_{SD})$$

A summary of the statistical distribution for the twelve data sets evaluated, the average chloride concentrations, tolerance intervals, and final chloride threshold values are provided in Table C-1.

Statistical approaches that require an assumption to be made with regard to population distributions fall into a branch of statistics referred to as parametric statistics. Parametric tests will have more power than a nonparametric counterpart if the assumptions are met (US EPA, 2006). However, the distributional assumptions are often strict or undesirable for the parametric tests and deviations can lead to misleading results (US EPA, 2006). In this case, the assumption regarding normal distribution is met by 11 of the 12 datasets analyzed indicating that this approach will generally predict representative average values for chloride concentrations at specific wells within the Seaside Basin.

Table C-1: Summary of Statistical Information for Chloride Threshold Values

Well Location	Number of Observations	Statistical Distribution at 5% Significance	Average Chloride Concentration (mg/L)	Standard Deviation (mg/L)	K_1 Multiplier	Chloride Threshold Value (mg/L)
Paso Robles Formation						
MSC-Shallow	14	Normal	45	3.75	4.64	62
PCA-W Shallow	14	Normal	48	4.75	4.64	70
PCA-E (Multiple) Shallow	7*	Normal	51	3.74	5.99	73
MPWMD #FO-09-Shallow	14	Normal	55	2.67	4.64	67
MPWMD #FO-09-Deep	14	Normal	69	3.43	4.64	85
MPWMD #FO-10-Shallow	11	Normal	64	6.07	4.98	94
MPWMD #FO-10-Deep	10	Not Normal	65	5.54	5.14	93
Santa Margarita Formation						
MSC-Deep	14	Normal	152	6.54	4.64	182
PCA-W Deep	14	Normal	153	7.26	4.64	186
PCA-E (Multiple) Deep	7*	Normal	127	9.00	5.99	181
Ord Terrace-Shallow	7*	Normal	116	11.51	5.99	185
Ord Terrace-Deep	7*	Normal	168	15.24	5.99	260

NOTES:

* = It is suggested to collect at least 8 to 10 observations using these statistical methods.

a = Historical maximum chloride concentrations prior to 1995 are not included in the statistical analysis and should not be used when determining acceptable maximum chloride concentrations during future monitoring events.

b = Basin wide screening criteria is based on maximum chloride threshold value.

EXAMPLE CALCULATION

An electronic data file has been compiled that includes the statistical computations for the twelve wells analyzed for the Seaside Basin Seawater Intrusion Response Plan (SIRP). The following example is taken from monitoring well FO-9 Shallow to further illustrate the use of the statistical calculations used to develop the chloride threshold values. Between January 1995 and March 2006 there are 14 data points for chloride concentration available for monitoring well FO-9 Shallow. In order, those concentrations are as follows: 56, 54, 53, 53, 56, 56, 51, 51, 52, 54, 57, 56, 58, and 60. Using this data set, the average chloride concentration is calculated as follows:

$$[Cl^-]_{average} = \frac{56 + 54 + 53 + 53 + 56 + 56 + 51 + 51 + 52 + 54 + 57 + 56 + 58 + 60}{14}$$

$$[Cl^-]_{average} = 54.79$$

The standard deviation is calculated as follows:

$$[Cl^-]_S = \sqrt{\frac{1}{14 - 1} \bullet \left((56 - 54.79)^2 + (54 - 54.79)^2 + (53 - 54.79)^2 + \ldots + (60 - 54.79)^2\right)}$$

$$[Cl^-]_{SD} = 2.67$$

And the tolerance limit is calculated as follows:

$$a = 1 - \frac{1.645^2}{2 \bullet (14 - 1)} = 0.8959 \text{ and } b = 3.08^2 - \frac{1.645^2}{14} = 9.293\text{, and}$$

$$k_1 = \frac{3.08 + \sqrt{3.08^2 - 0.8959 \bullet 9.293}}{0.8959} = 4.64$$

The final chloride threshold value for monitoring well FO-9 Shallow is:

$$[Cl^-]_{threshold} = 54.79 + (4.64 \bullet 2.67) = 67.18$$

Please note that because these calculations are performed in an excel program, all decimal places are carried throughout each equation and rounded to the appropriate significant figure upon completion. Therefore, there may be slight differences in final chloride threshold values if rounding occurs before the final calculation is complete.

STATISTICAL TREND ANALYSES

Nonparametric methods are often referred to as distribution free methods because they do not rely on assumptions that the data are drawn from a given probability distribution. The Mann-Kendall statistical test is a nonparametric statistical method that can be used to show whether chemical concentrations detected in a groundwater monitoring well are increasing, stable, or decreasing. This provides a reliable approach for the trend analysis because as seawater intrusion may occur at a given monitored location, there is no assumption that those data follow a specific distribution while seawater mixes with the ambient groundwater to produce changes in the overall geochemistry.

The test involves computing a statistic *S*, which is the difference between the number of pairwise differences that are positive minus the number that are negative. If *S* is a large positive value, then there is evidence of an increasing trend in the data. If *S* is a large negative value, then there is evidence of a decreasing trend in the data. The Mann-Kendall statistical approach is based solely on calculations of the sign and does not take into account the magnitudes of the differences. It is a robust statistical test as it is insensitive to outliers. The test should be conducted on wells where data were collected at equal time intervals, such as quarterly or semiannually monitored data.

It is important to note that there are different calculation approaches for the Mann-Kendall Test dependent on sample size. The following provides an example of the Mann-Kendall Trend test for a population of up to 10 data points.

Table C-2: Example Mann-Kendall Statistical Test for FO-9 Shallow

Time Data	1 $[Cl^-]_{1=56}$	2 $[Cl^-]_{2=56}$	3 $[Cl^-]_{3=50}$	4 $[Cl^-]_{4=50}$	5 $[Cl^-]_{5=53}$	6 $[Cl^-]_{6=50}$	7 $[Cl^-]_{7=49}$	No. of increases	No. of decreases
$[Cl^-]_{1=56}$		nc	-	-	-	-	-	0	5
$[Cl^-]_{2=56}$			-	-	-	-	-	0	5
$[Cl^-]_{3=50}$				nc	+	nc	-	1	1
$[Cl^-]_{4=50}$					+	nc	-	1	1
$[Cl^-]_{5=53}$						-	-	0	2
$[Cl^-]_{6=50}$							-	0	1
$[Cl^-]_{7=49}$									
								2	15

Statistical Test:

1) S = 2-15 = -13
2) Look up critical values for the sample size of 7 at 0.10 and 0.20 significance levels.
   a. At 0.10 significance level, the critical value is 11.
   b. At 0.20 significance level, the critical value is 7.
3) Look up the probabilities for the sample size of 7.
   a. The probability for a sample size of 7 is 0.035.

4) Because -13 is less than 11 and less than 7, and the probability is less than the significance level, the data appear to have a decreasing trend at both the 90% and 80% confidence level.

The Mann-Kendall statistical test conducted for the SIRP was done so using a spreadsheet developed by the State of Wisconsin, Department of Natural Resources, Form 4400-215, which can be downloaded from *http://dnr.wi.gov/org/aw/rr/archives/pub_index.html#TECHNICAL-GR*. This form has been through a quality assurance and quality control process, and is equipped with the appropriate statistical lookup references for the critical values needed to complete the test. A compilation of the files developed for this test is included in the electronic data file attached to this document. A summary of the Mann-Kendall statistical trend analysis for chloride concentrations is provided in Table C-3.

Table C-3: Mann-Kendall Test Summary for Chloride Concentrations and Sodium Chloride Molar Ratios

Well Location	Chloride Trend	Chloride Stability Test [1]	Sodium/Chloride Trend	Sodium/Chloride Stability Test [1]
Paso Robles Formation				
MSC-Shallow	No Trend	Stable	No Trend	Stable
PCA-W Shallow	No Trend	Stable	No Trend	NA[2]
PCA-E (Multiple) Shallow	NP	NA	NP	NA
MPWMD #FO-09-Shallow	Decreasing	NA	Increasing	NA
MPWMD #FO-09-Deep	No Trend	Stable	No Trend	NA[2]
MPWMD #FO-10-Shallow	NP	NA	NP	NA
MPWMD #FO-10-Deep	NP	NA	NP	NA
Santa Margarita Formation				
MSC-Deep	Decreasing	NA	No Trend	NA[2]
PCA-W Deep	No Trend	Stable	No Trend	Stable
PCA-E (Multiple) Deep	NP	NA	NP	NA
Ord Terrace-Shallow	NP	NA	NP	NA
Ord Terrace-Deep	NP	NA	NP	NA

NOTES:

Trend analyses reported at the 90% confidence interval.

[1] Stability assessment given when no statistical trend is apparent at the 80% confidence level

[2] Increasing trend at the 80% confidence interval

NA = not applicable

NP = not possible; data not collected on a quarterly or semiannual schedule since October 2006.

The Mann-Kendall Test can be used with a minimum of four rounds of sampling results; however, the Mann-Kendall Test is not valid for data that exhibit seasonal behavior. Please note that there are limited data available that were collected on a quarterly or semi-annual basis making it difficult to completely verify the assumption of seasonality.

To test the data for seasonality, an evaluation of groundwater levels and chloride concentrations was conducted. If chloride concentrations change as water levels change, then the data is seasonally affected. Figures C-1 through C-12 illustrates the relationship between chloride concentrations and groundwater elevations in the twelve wells where sufficient data exists to conduct the trend analysis. The overall correlation of water levels and chloride concentrations are roughly correlated in some cases, but overall, there does not appear to be a direct correlation that would clearly indicate a seasonal component. In addition to the visual evaluation of water levels and chloride concentrations in groundwater, a test for a correlation coefficient was conducted using the Pearson’s Correlation Coefficient. In general, data that exhibit a correlation coefficient greater than 0.8 would be considered to have a strong correlation, and values close to zero imply little linear correlation between the water levels and chloride concentrations. Directions for calculating Pearson’s Correlation Coefficient are provided below.

Let $X_1, X_2, \ldots, X_n$ represent the variable for groundwater elevation measurements of n data points and let $[Cl^-]_1, [Cl^-]_2, \ldots [Cl^-]_n$ represent the chloride concentration measurements of the n data points. The Pearson correlation coefficient, r, between X and $[Cl^-]$ is:

$$r = \frac{\sum_{i=1}^{n} X_i [Cl^-]_i - \frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)\left(\sum_{i=1}^{n} [Cl^-]_i\right)}{\sqrt{\left[\sum_{i=1}^{n} X_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2\right] \cdot \left[\sum_{i=1}^{n} [Cl^-]_i^2 - \frac{1}{n}\left(\sum [Cl^-]_i\right)^2\right]}}$$

Historical water elevation and chloride concentration data were evaluated to determine the Pearson’s Correlation Coefficient. As shown in Table C-4, there do not appear to be any wells with a correlation coefficient greater than 0.8 except PAC-E (Multiple) Deep.

Table C-4: Pearson's Correlation Coefficient for Groundwater Elevations and Chloride Concentrations

Well Location	**Primary Aquifer**	**Pearson's Correlation Coefficient**
MSC-Shallow	Paso Robles Formation	0.541
PCA-W Shallow	Paso Robles Formation	0.007
PCA-E (Multiple) Shallow	Paso Robles Formation	0.361
MPWMD #FO-09-Shallow	Paso Robles Formation	0.138
MPWMD #FO-10-Shallow	Paso Robles Formation	0.516
MSC-Deep	Santa Margarita	0.116
PCA-W Deep	Santa Margarita	0.028
PCA-E (Multiple) Deep	Santa Margarita	0.841
Ord Terrace-Shallow	Santa Margarita	0.690
Ord Terrace-Deep	Santa Margarita	0.702
MPWMD #FO-09-Deep	Santa Margarita	0.199
MPWMD #FO-10-Deep	Santa Margarita	0.598

There are multiple statistical approaches to evaluate trends in a given data set. If future groundwater monitoring results indicate a seasonal correlation of chloride over time, other trend analyses may provide more robust results. Specifically, the Mann-Kendall test can be used by only testing data from the seasons with the highest chloride concentrations or the lowest sodium/chloride molar ratios. Other statistical tests that are unaffected by seasonality include the Sen's Slope Estimator or the Mann-Whitney U Test (also referred to as the Wilcoxon Rank Sum Test).

REFERENCES

United States Environmental Protection Agency (US EPA). 2006. *Data Quality Assessments: Statistical Methods for Practitioners (EPA QA/G-9S)*. February 2006.

United States Environmental Protection Agency (US EPA). 2007. *ProUCL Version 4.00.02, User Guide (EPA/600/R-07/038)*. April 2007.

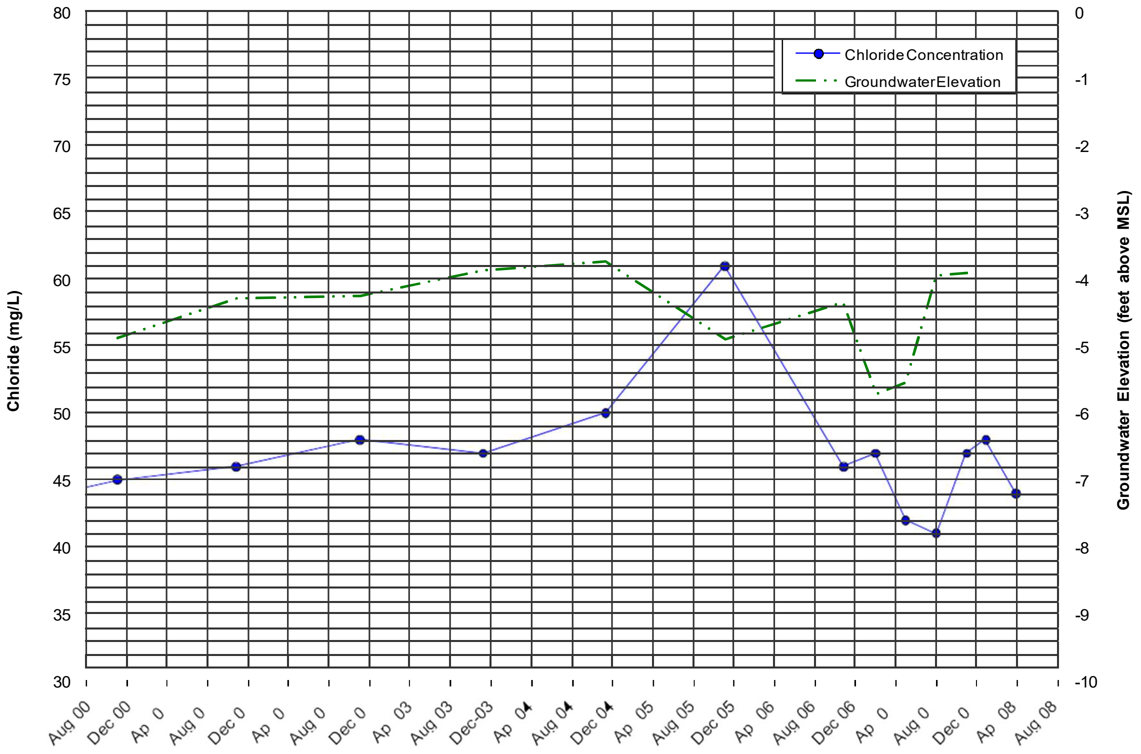

Figure C-1: PCA West Shallow Well

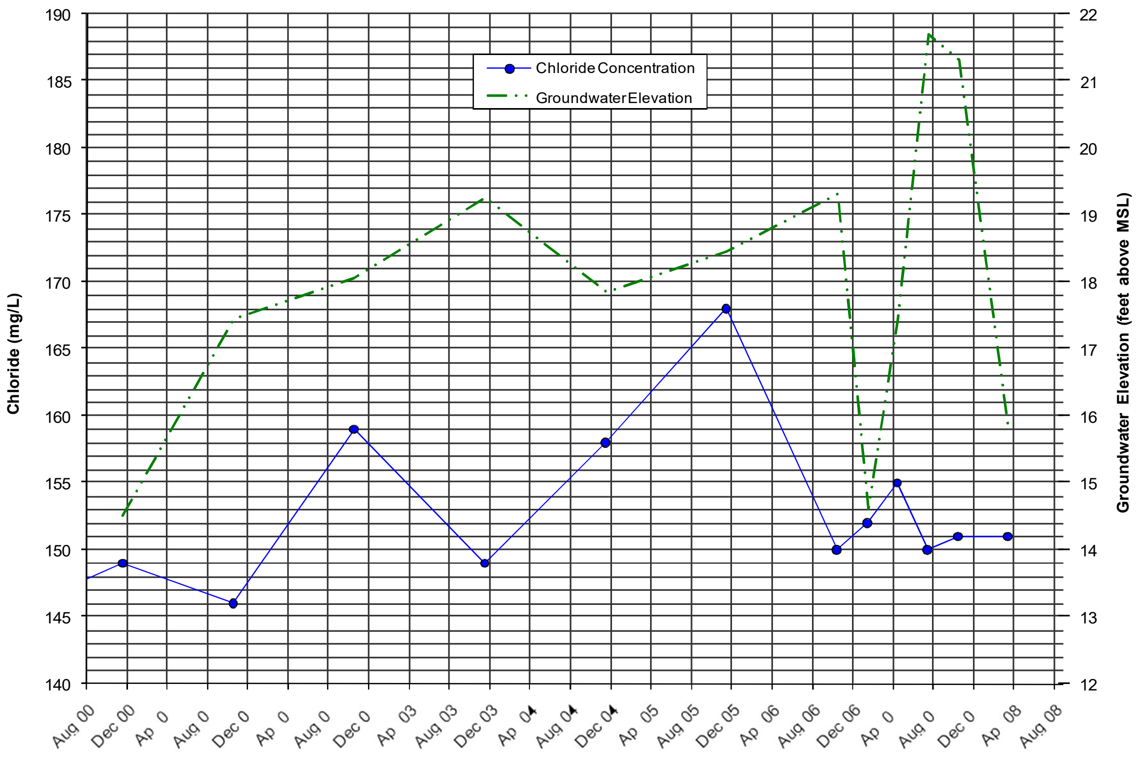

Figure C-2: PCA West Deep Well

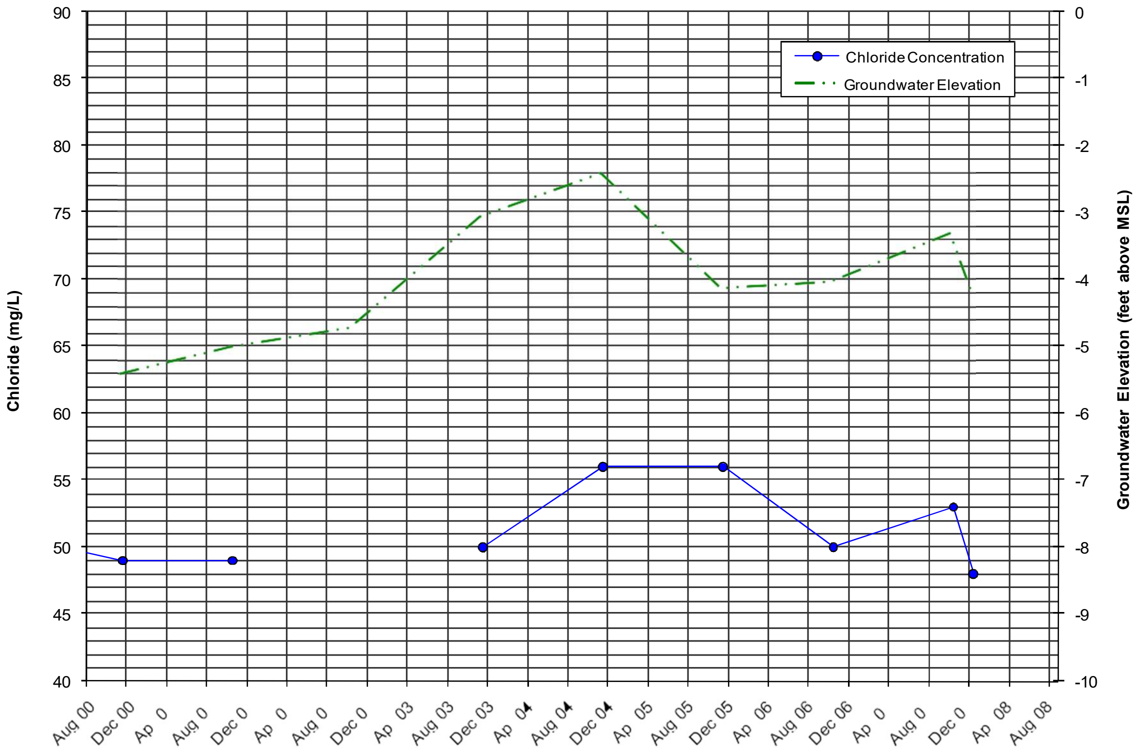

Figure C-3: PCA East Shallow Well

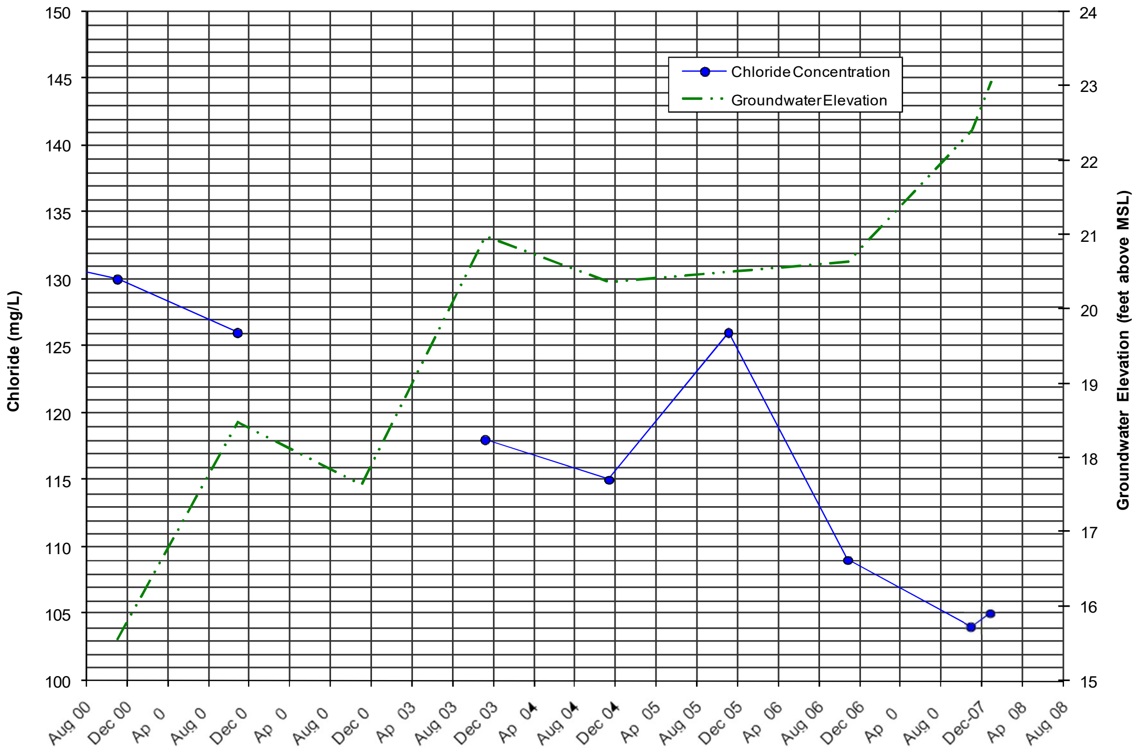

Figure C-4: PCA East Deep Well

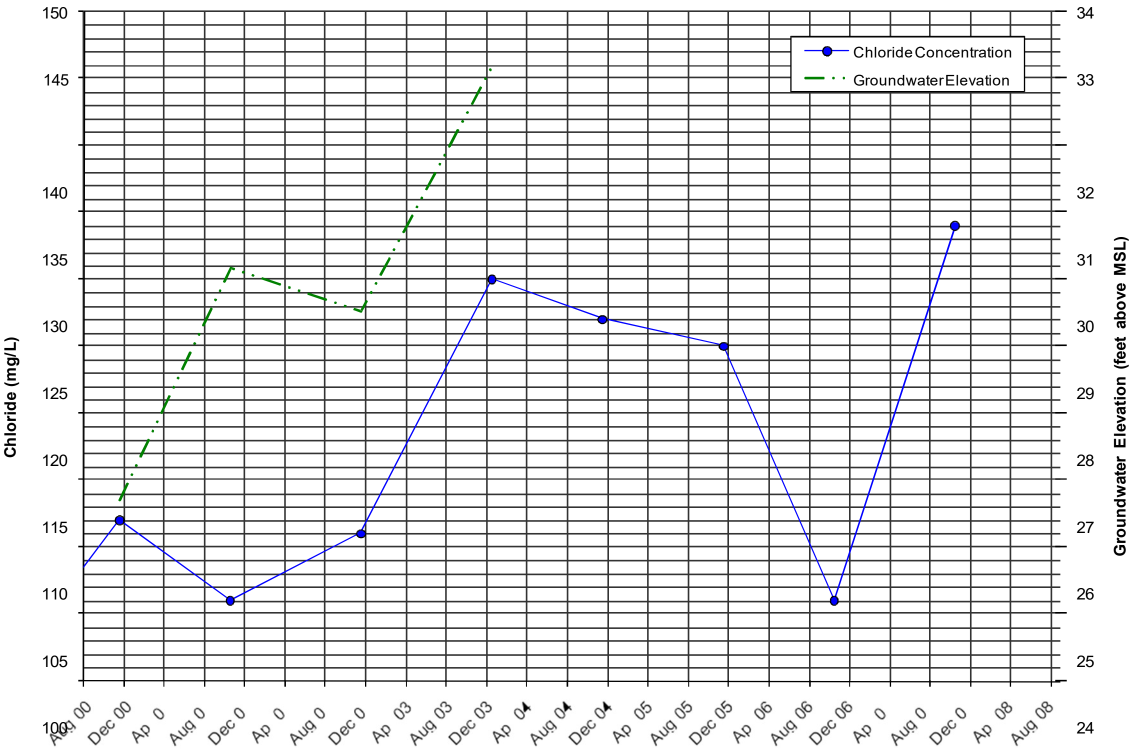

Figure C-5: Ord Terrace Shallow Well

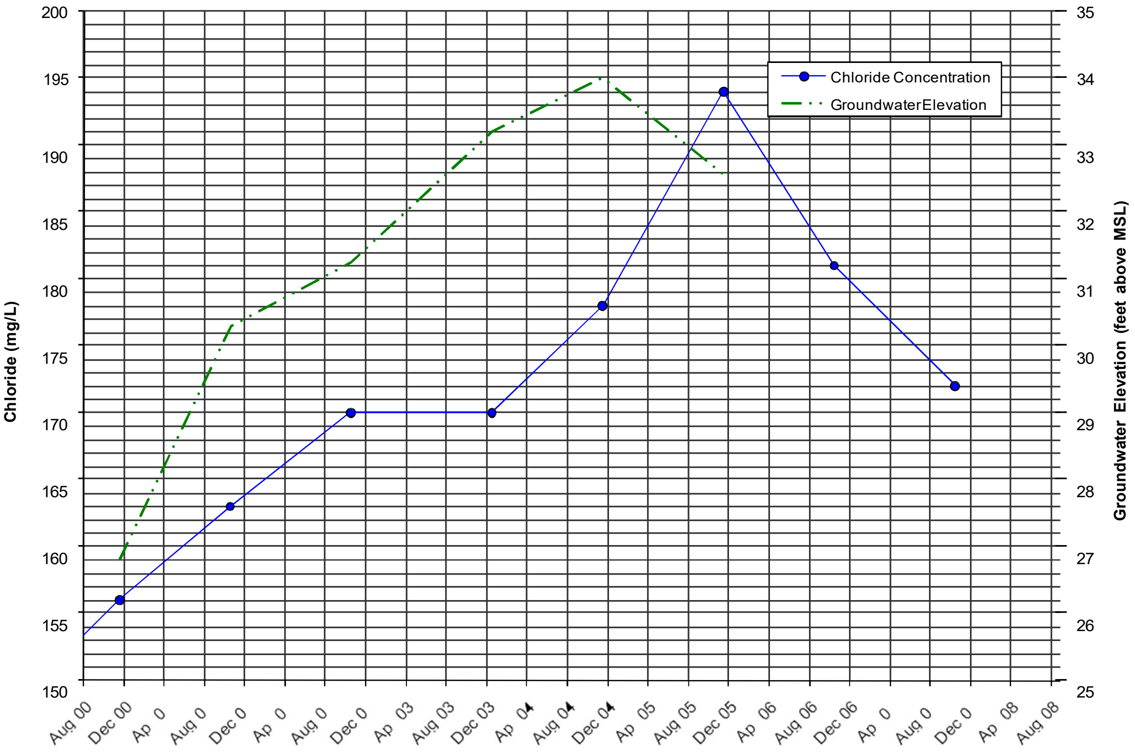

Figure C-6: Ord Terrace Deep Well

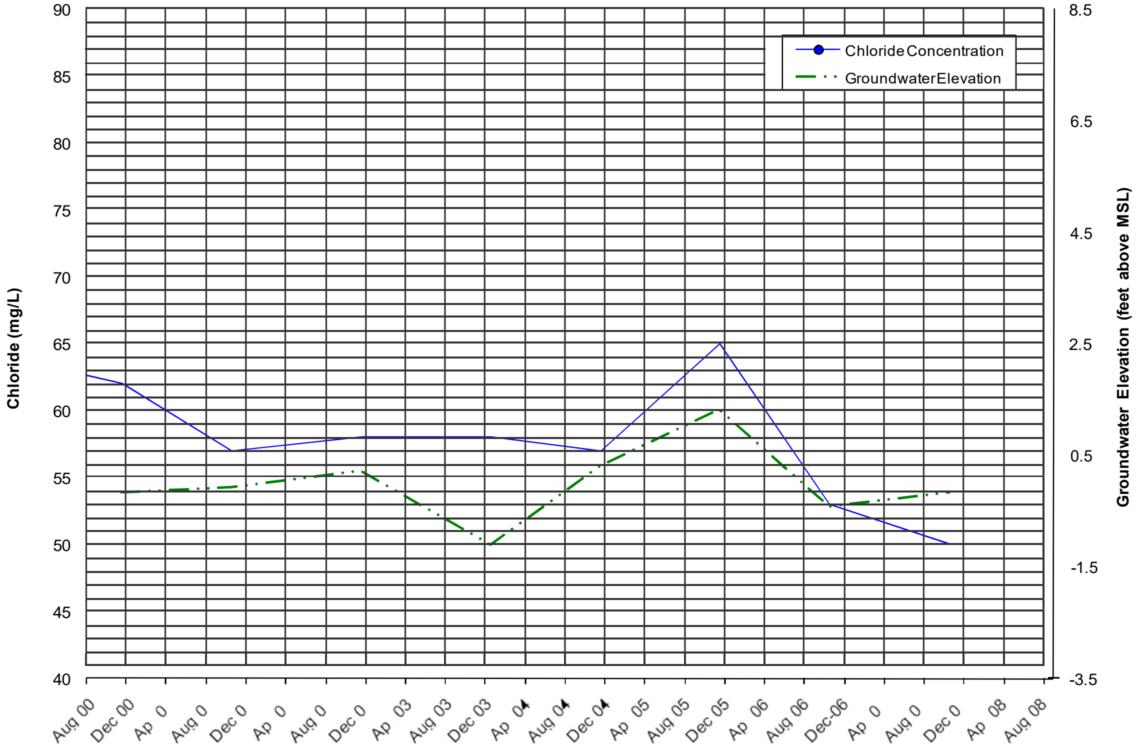

Figure C-7: MSC Shallow Well

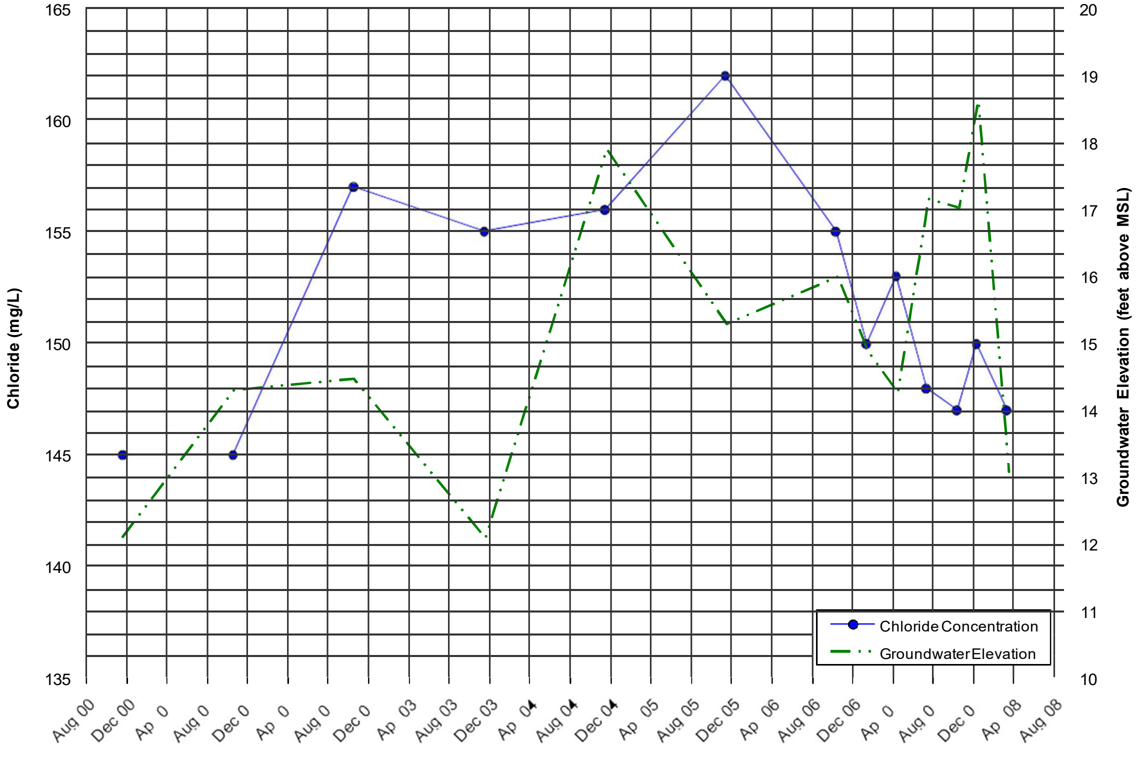

Figure C-8: MSC Deep Well

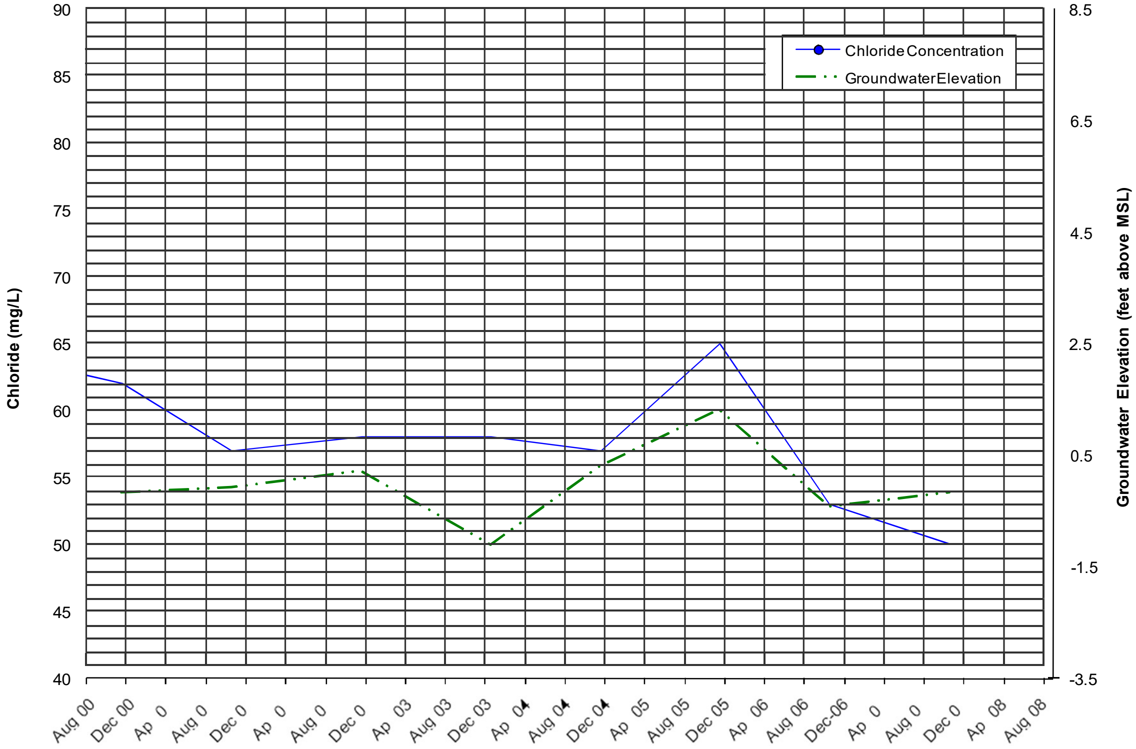

Figure C-9: Fort Ord 10 Shallow Well

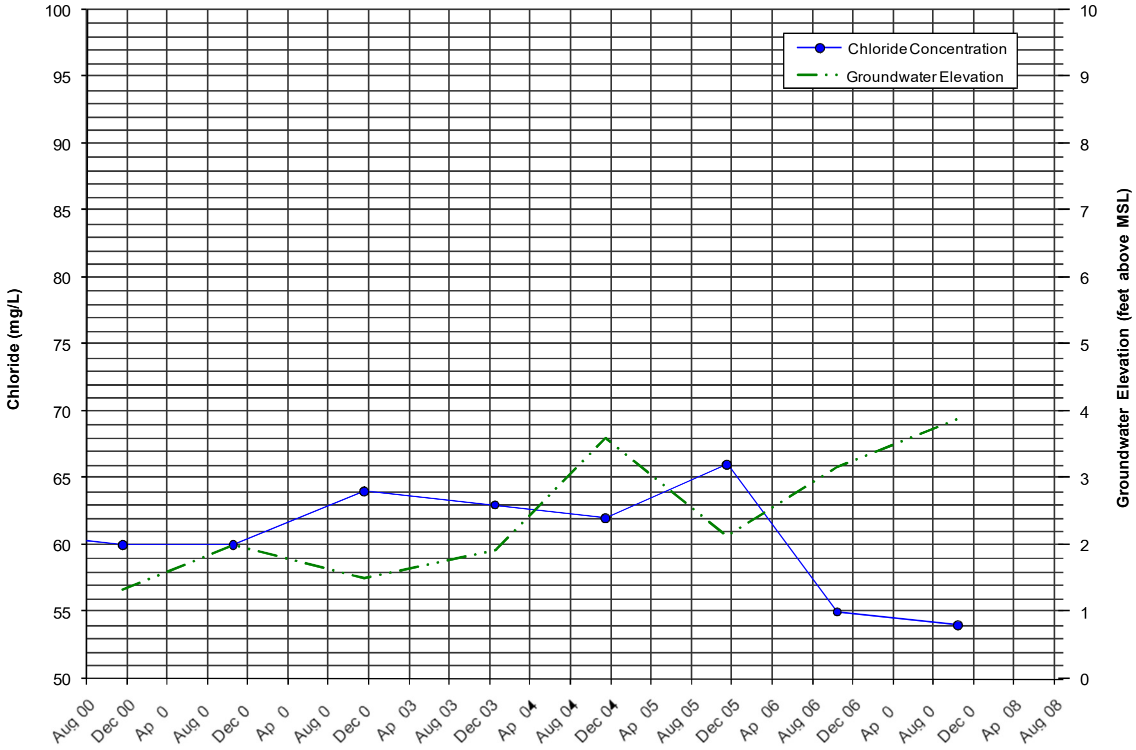

Figure C-10: Fort Ord 10 Deep Well

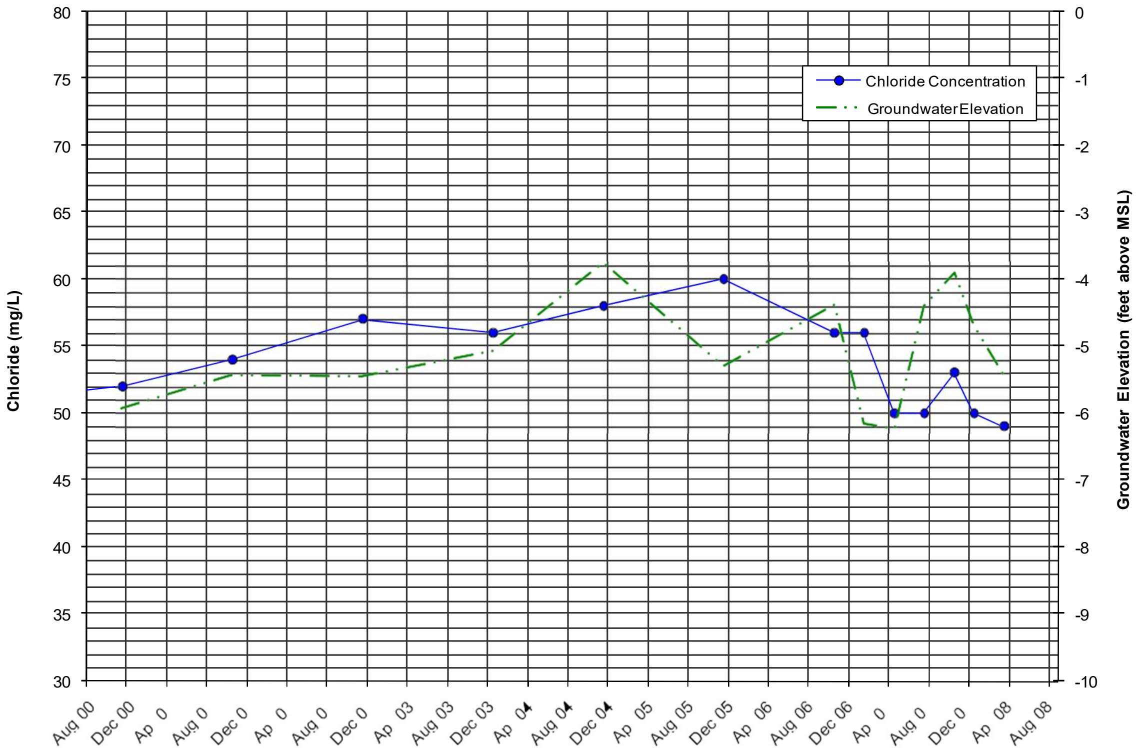

Figure C-11: Fort Ord 9 Shallow Well

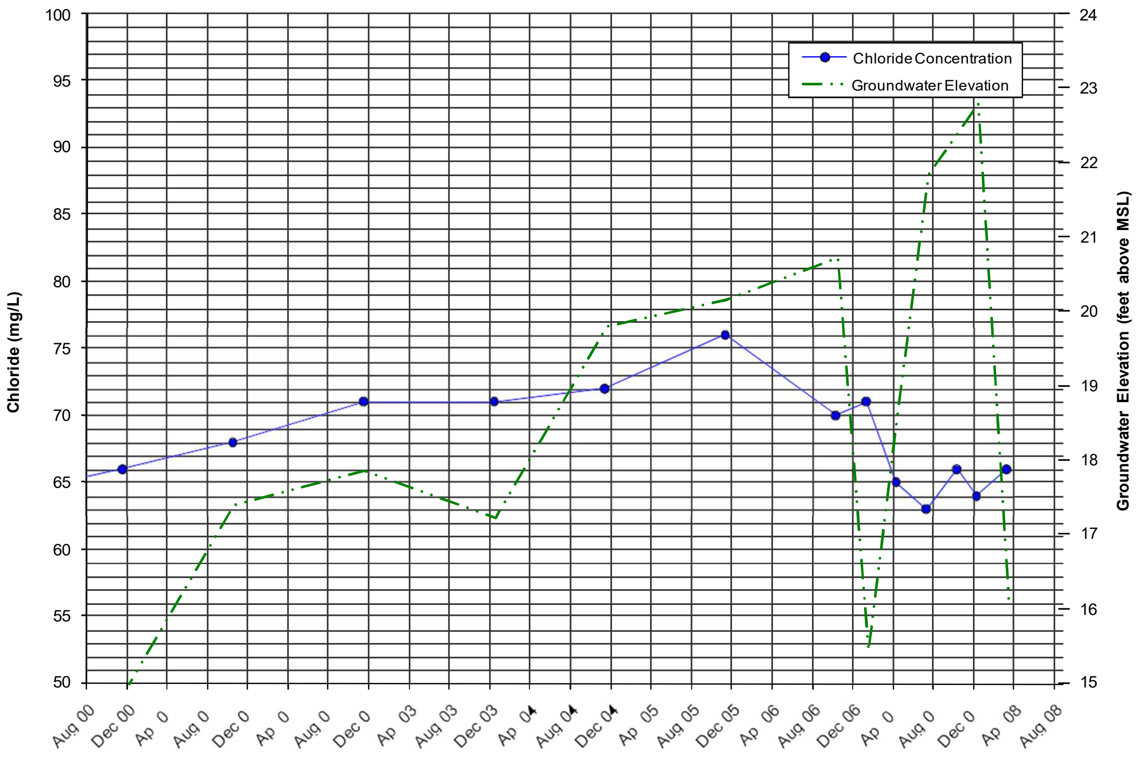

Figure C-12: Fort Ord 9 Deep Well

APPENDIX D:
HISTORICAL SODIUM/CHLORIDE MOLAR RATIO GRAPHS

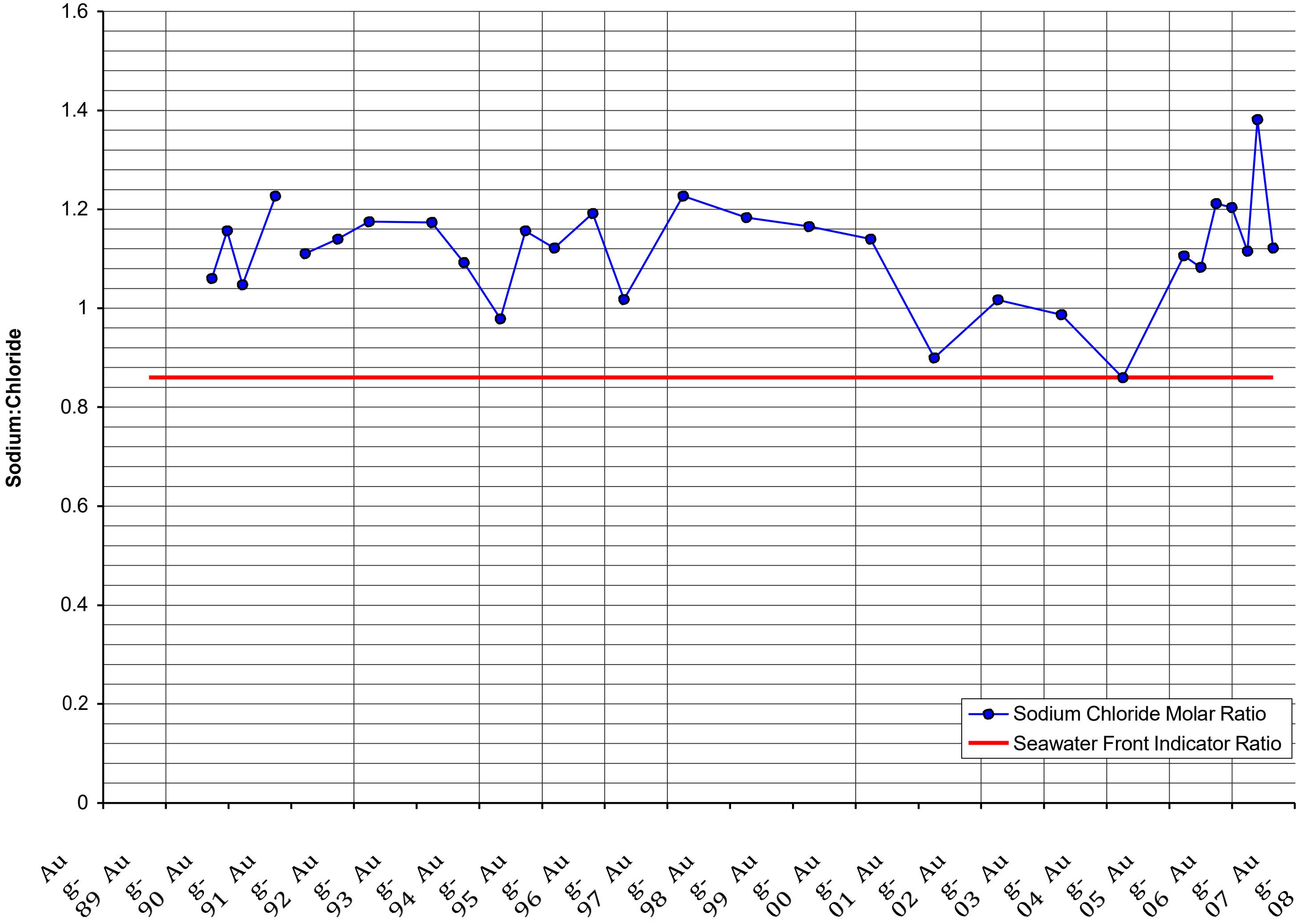

Figure D-1: PCA West Shallow Well

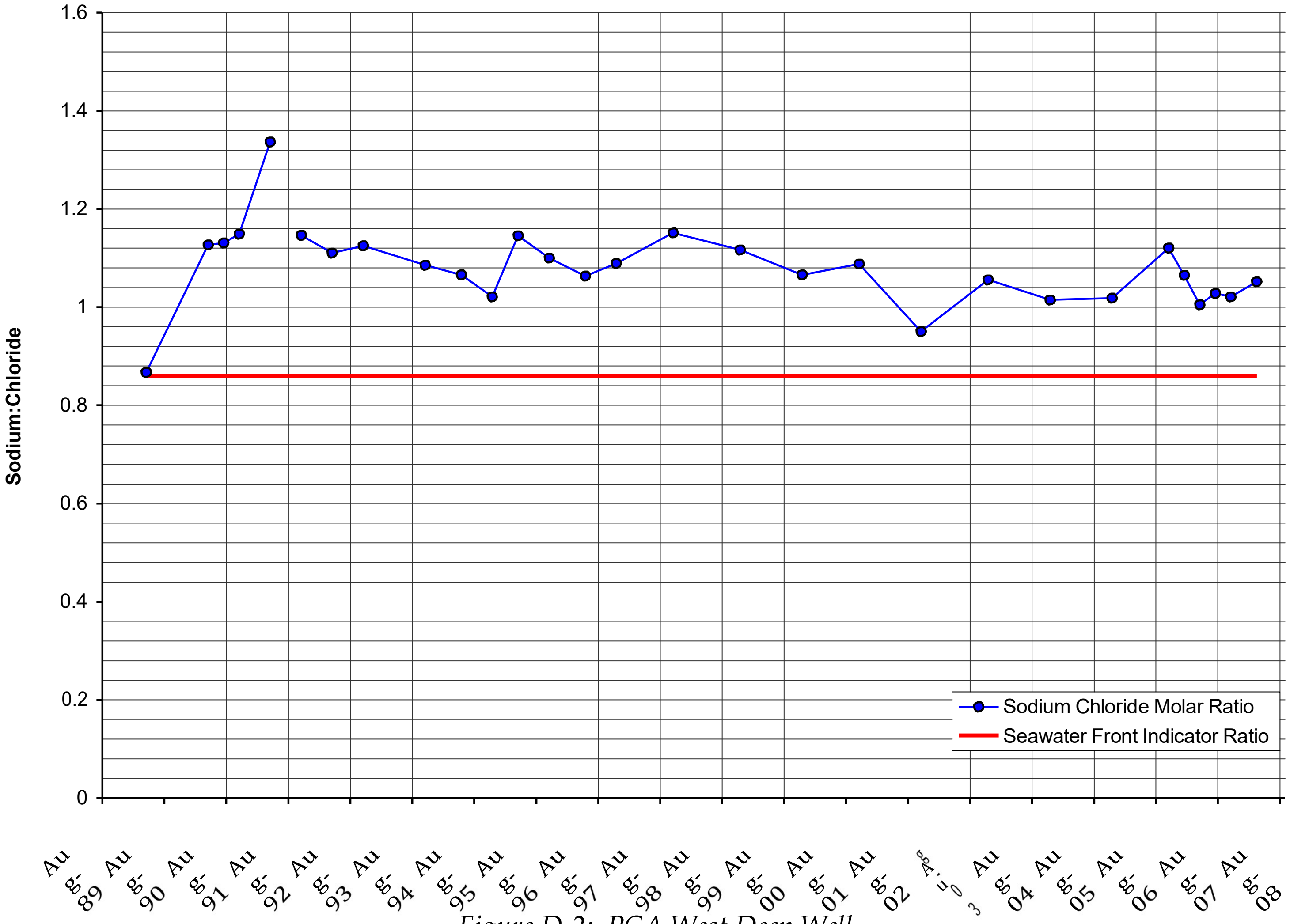

Figure D-2: PCA West Deep Well

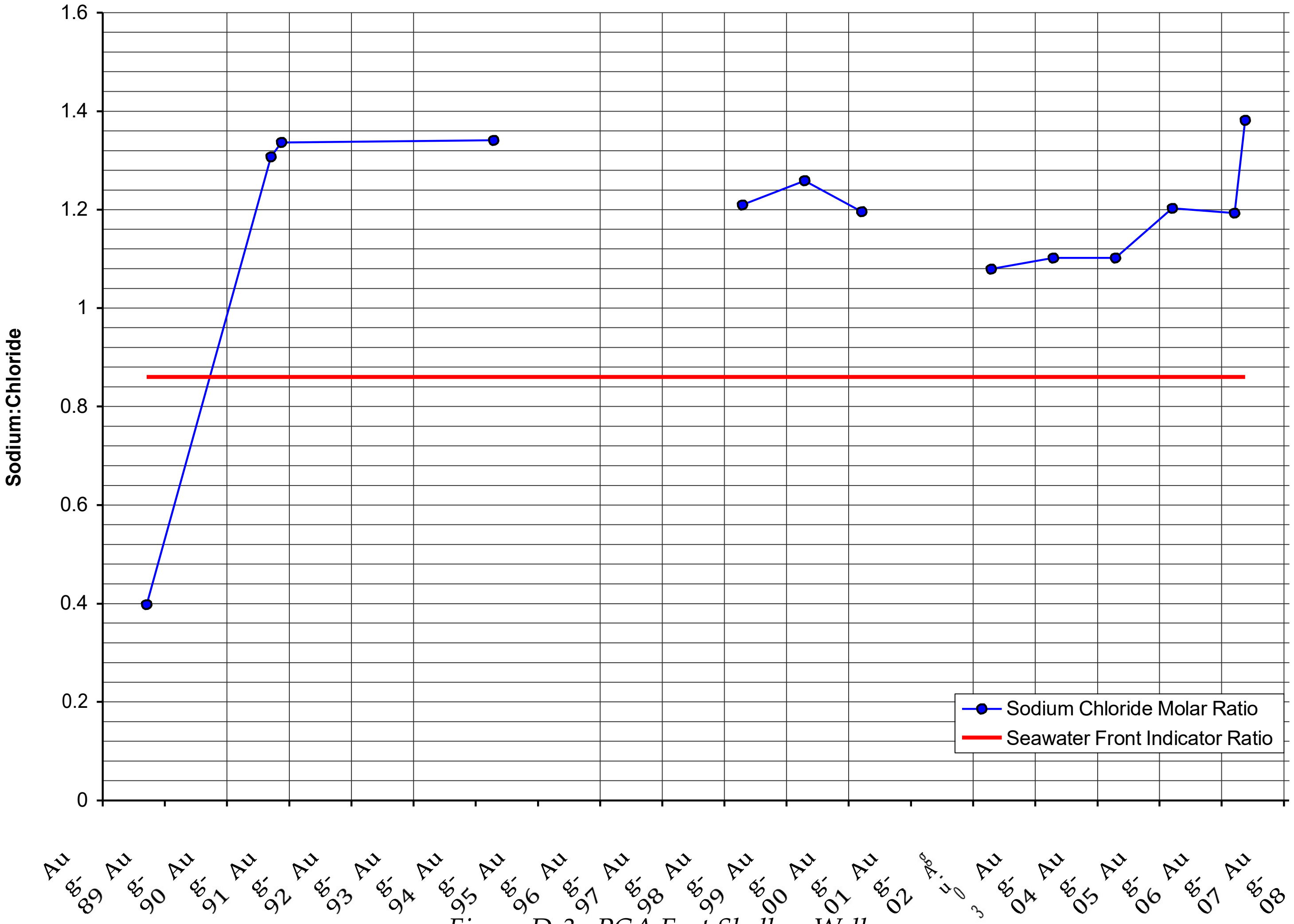

Figure D-3: PCA East Shallow Well

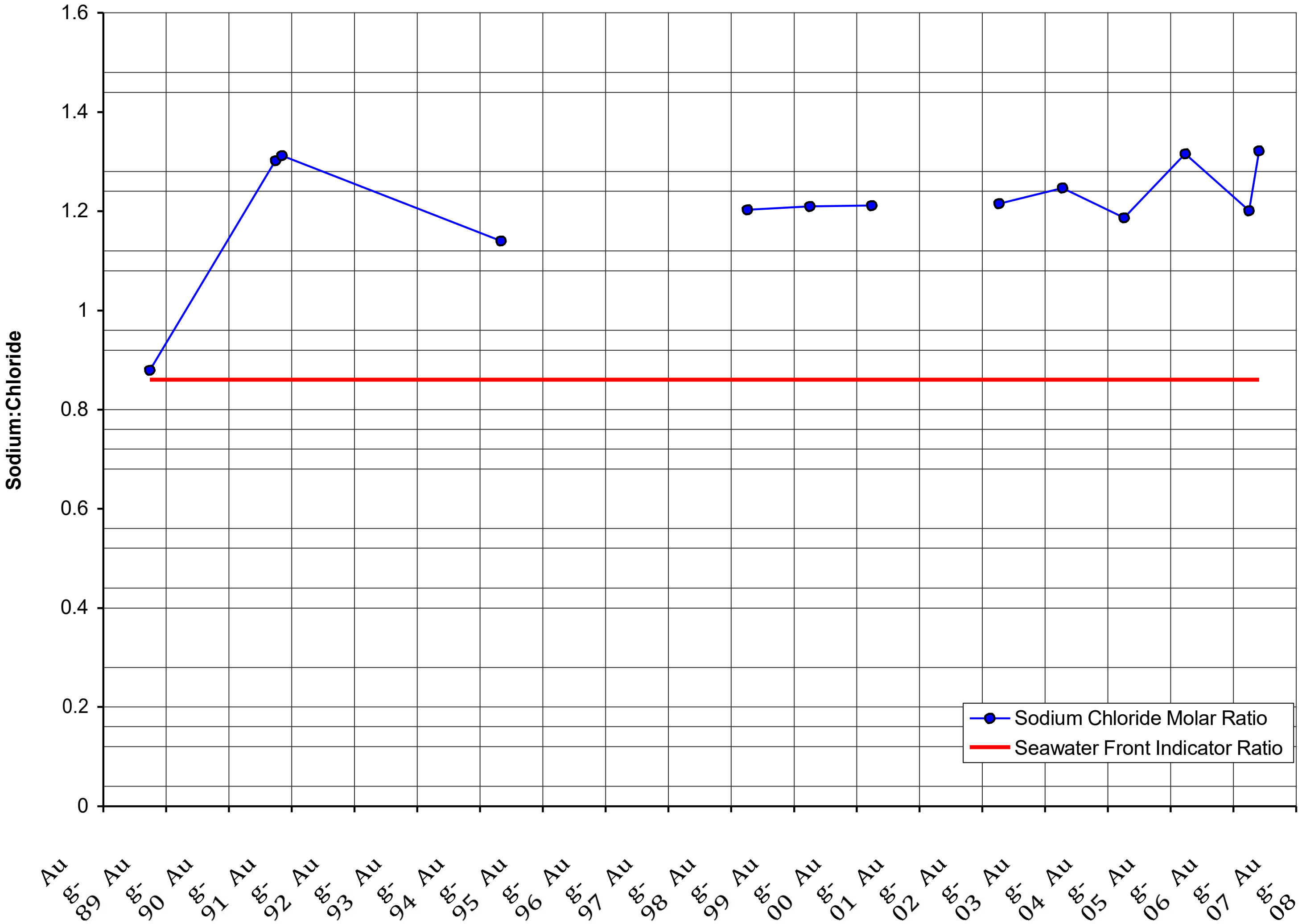

Figure D-4: PCA East Deep Well

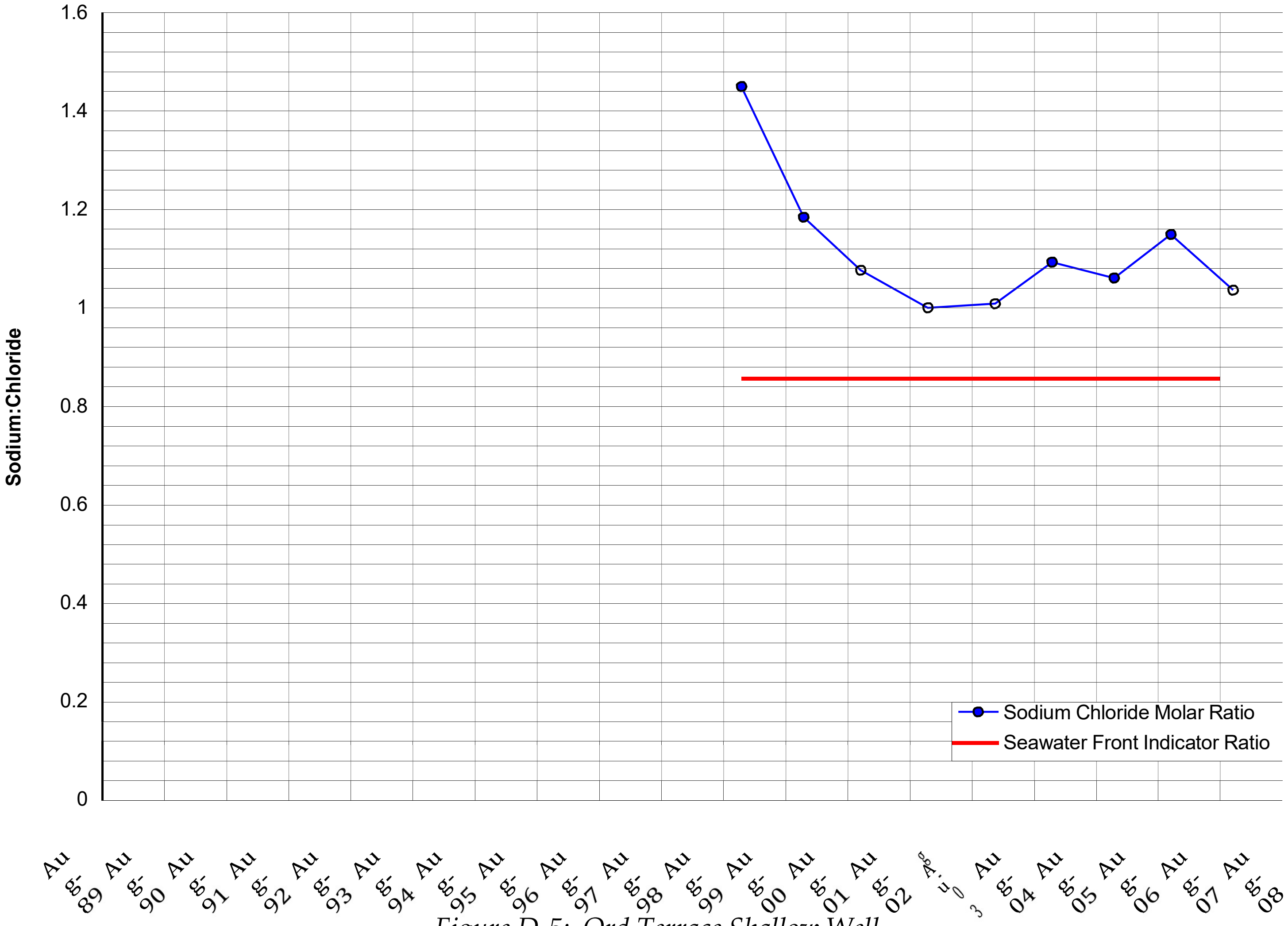

Figure D-5: Ord Terrace Shallow Well

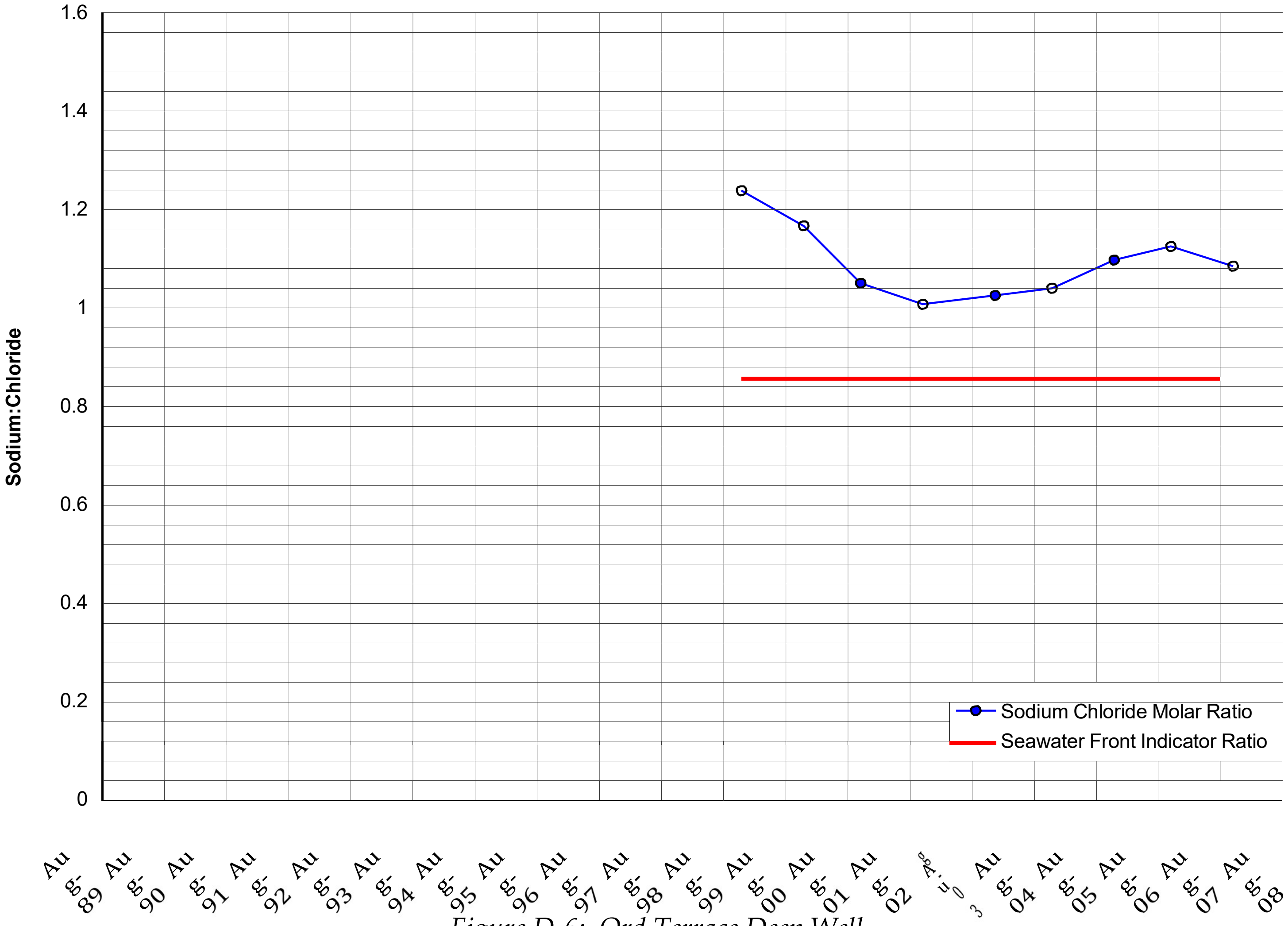

Figure D-6: Ord Terrace Deep Well

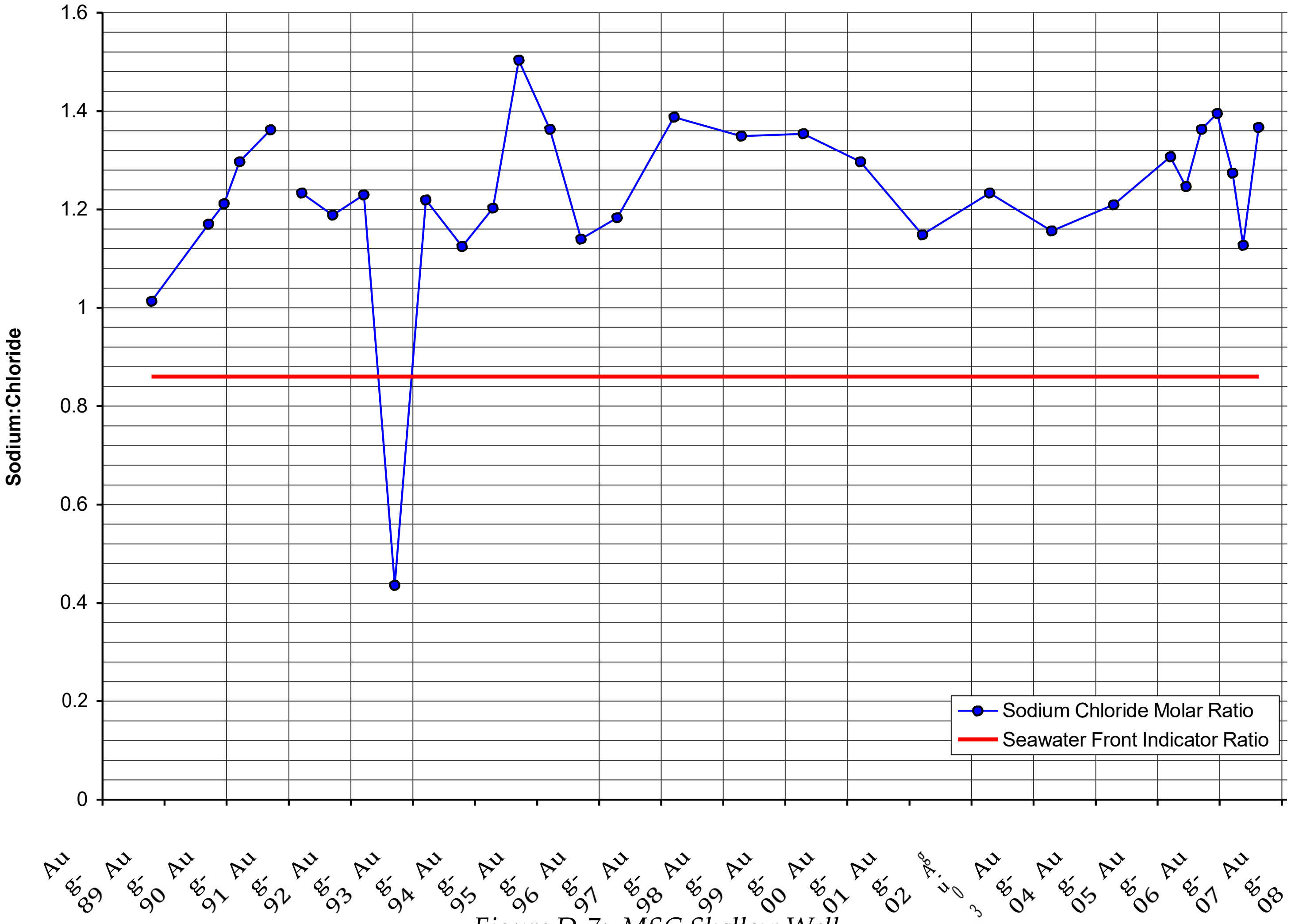

Figure D-7: MSC Shallow Well

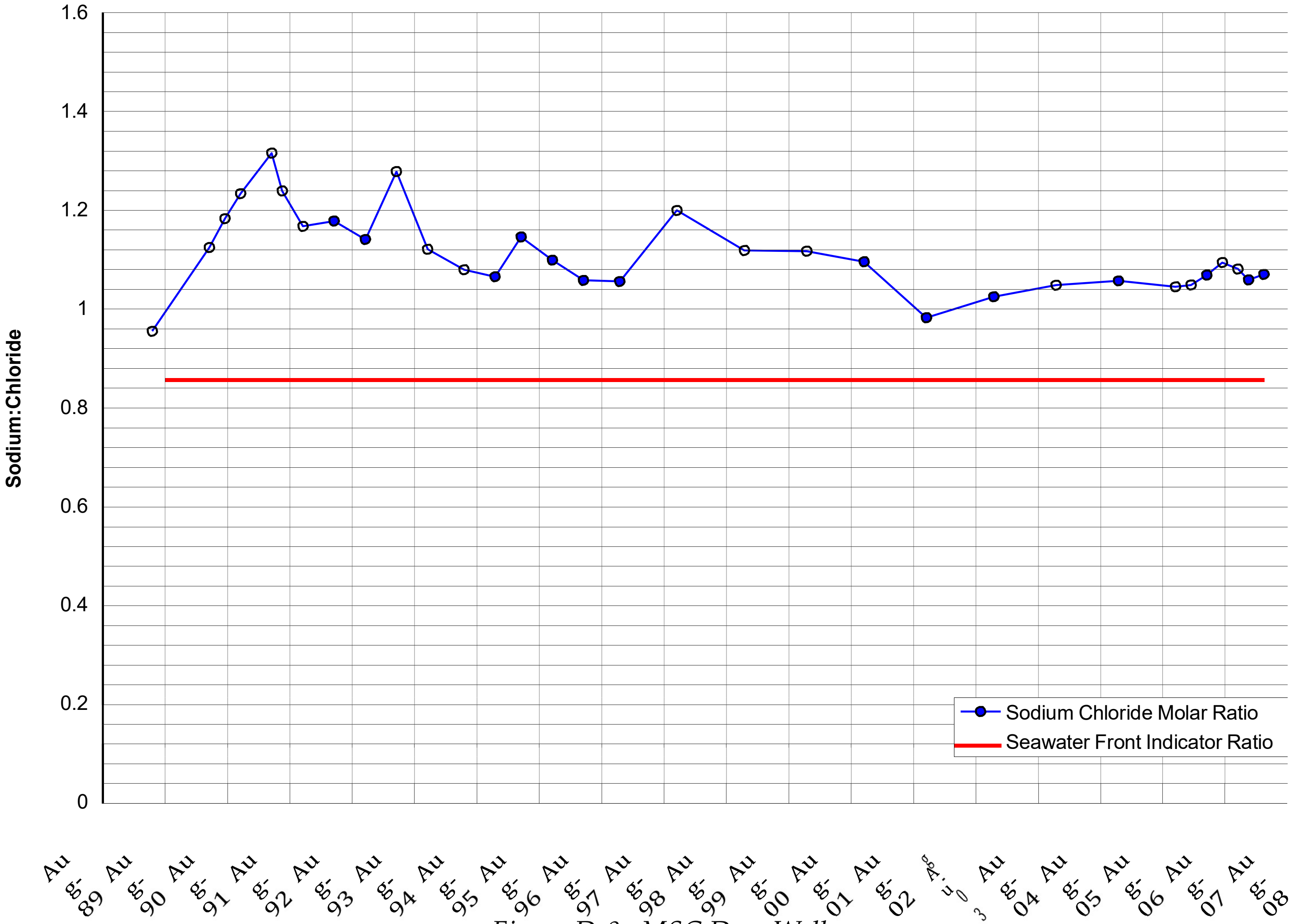

Figure D-8: MSC Deep Well

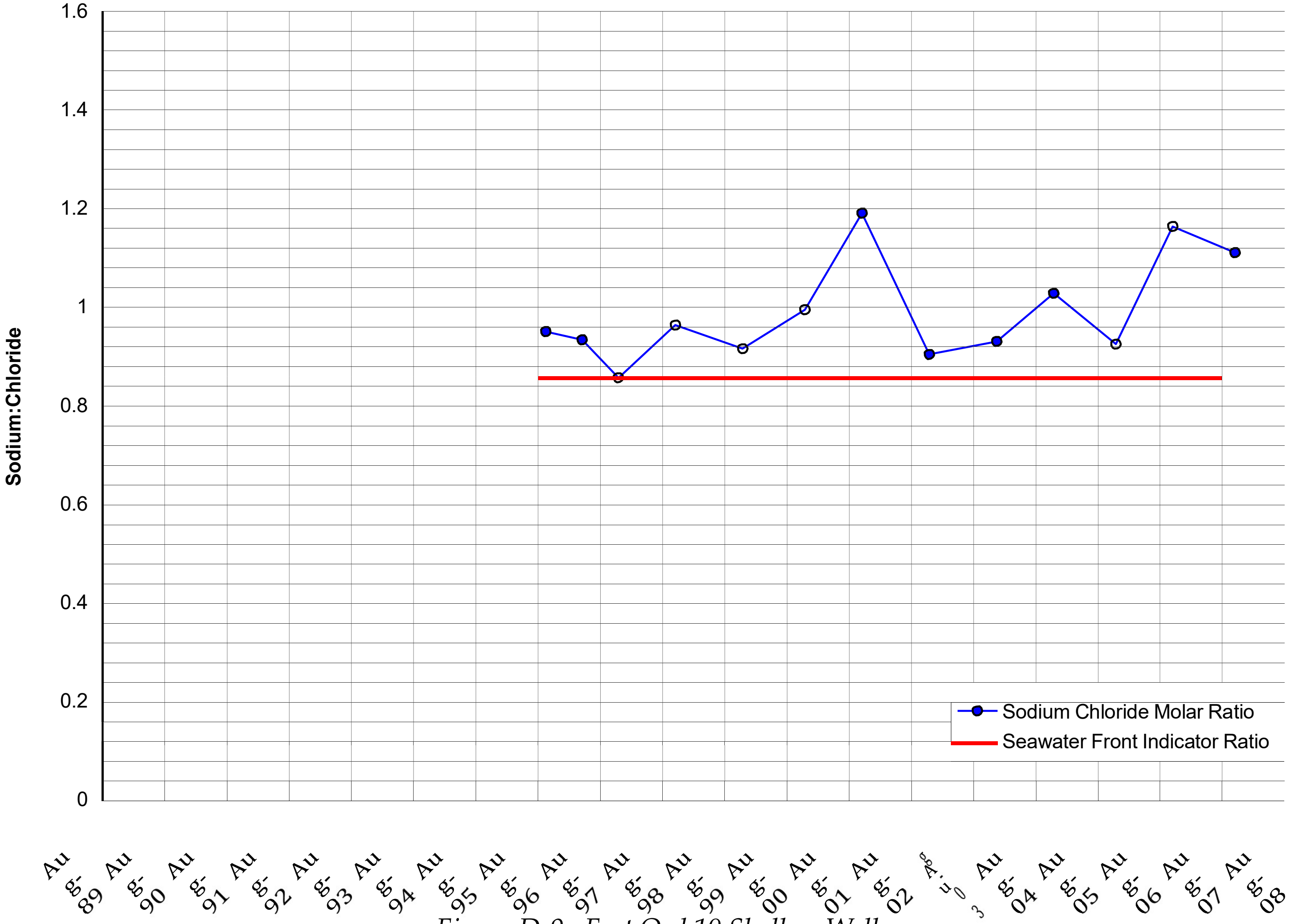

Figure D-9: Fort Ord 10 Shallow Well

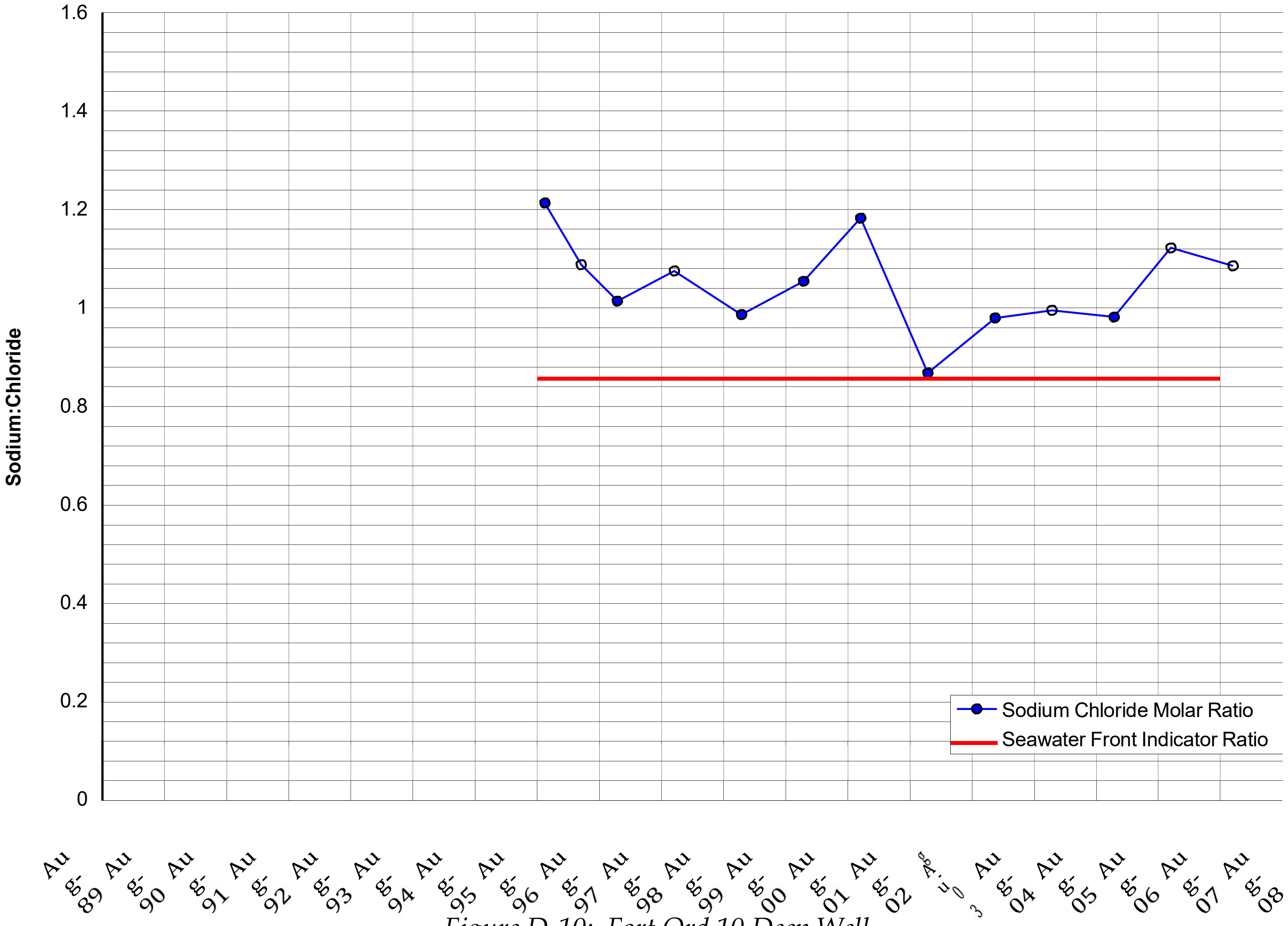

Figure D-10: Fort Ord 10 Deep Well

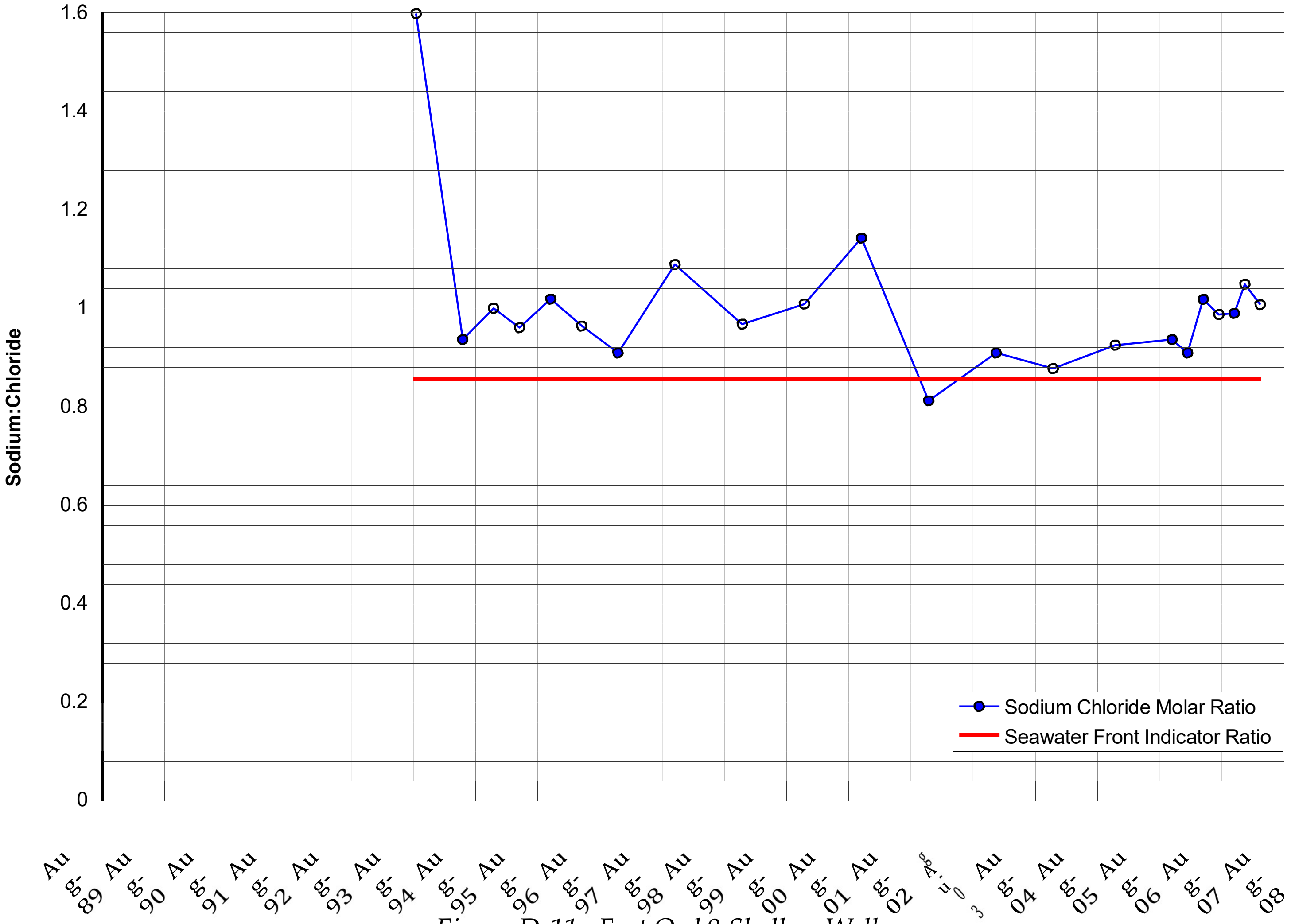

Figure D-11: Fort Ord 9 Shallow Well

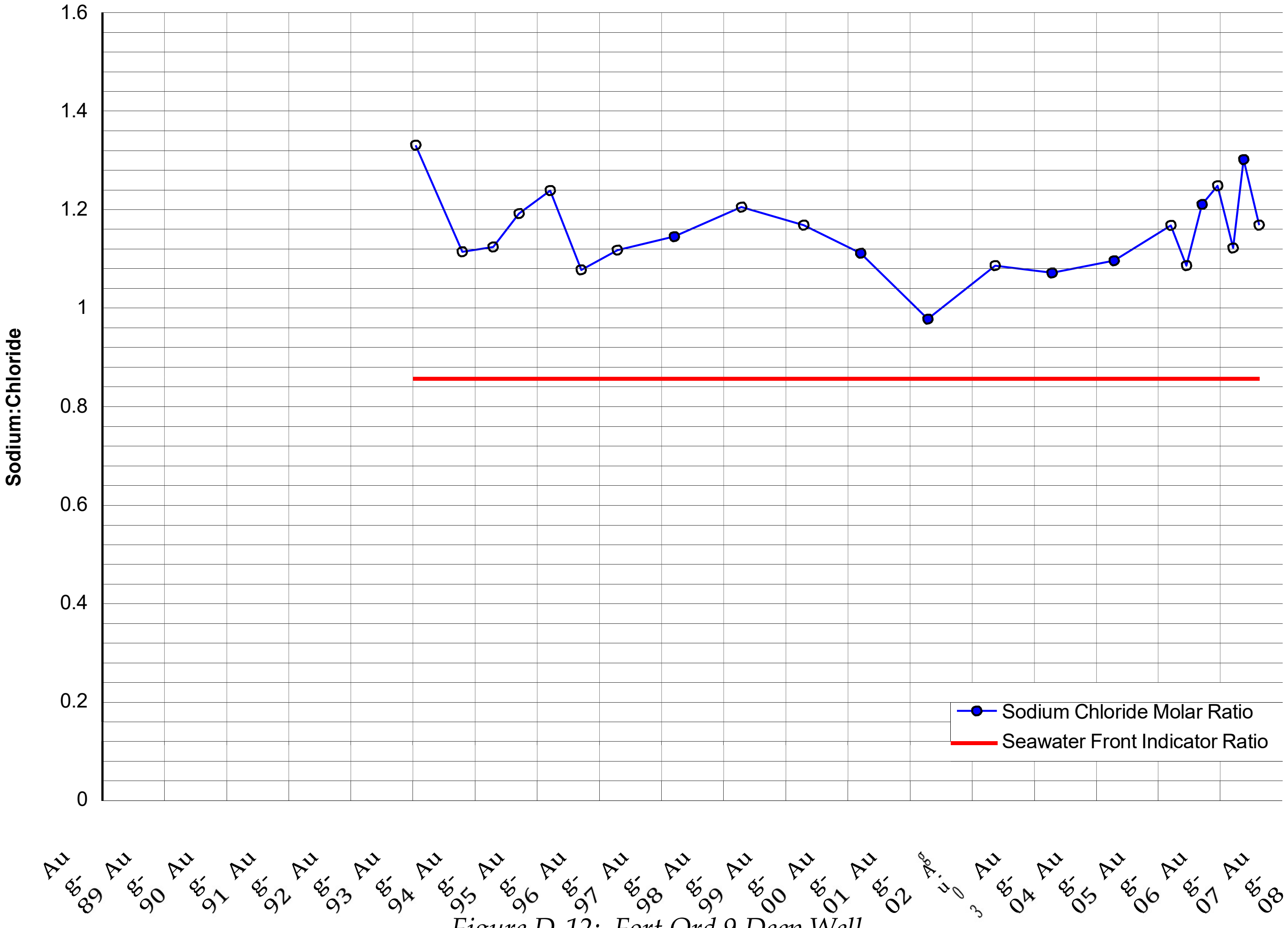

Figure D-12: Fort Ord 9 Deep Well

APPENDIX E:
PIPER DIAGRAM
FOR SEASIDE GROUNDWATER BASIN WELLS

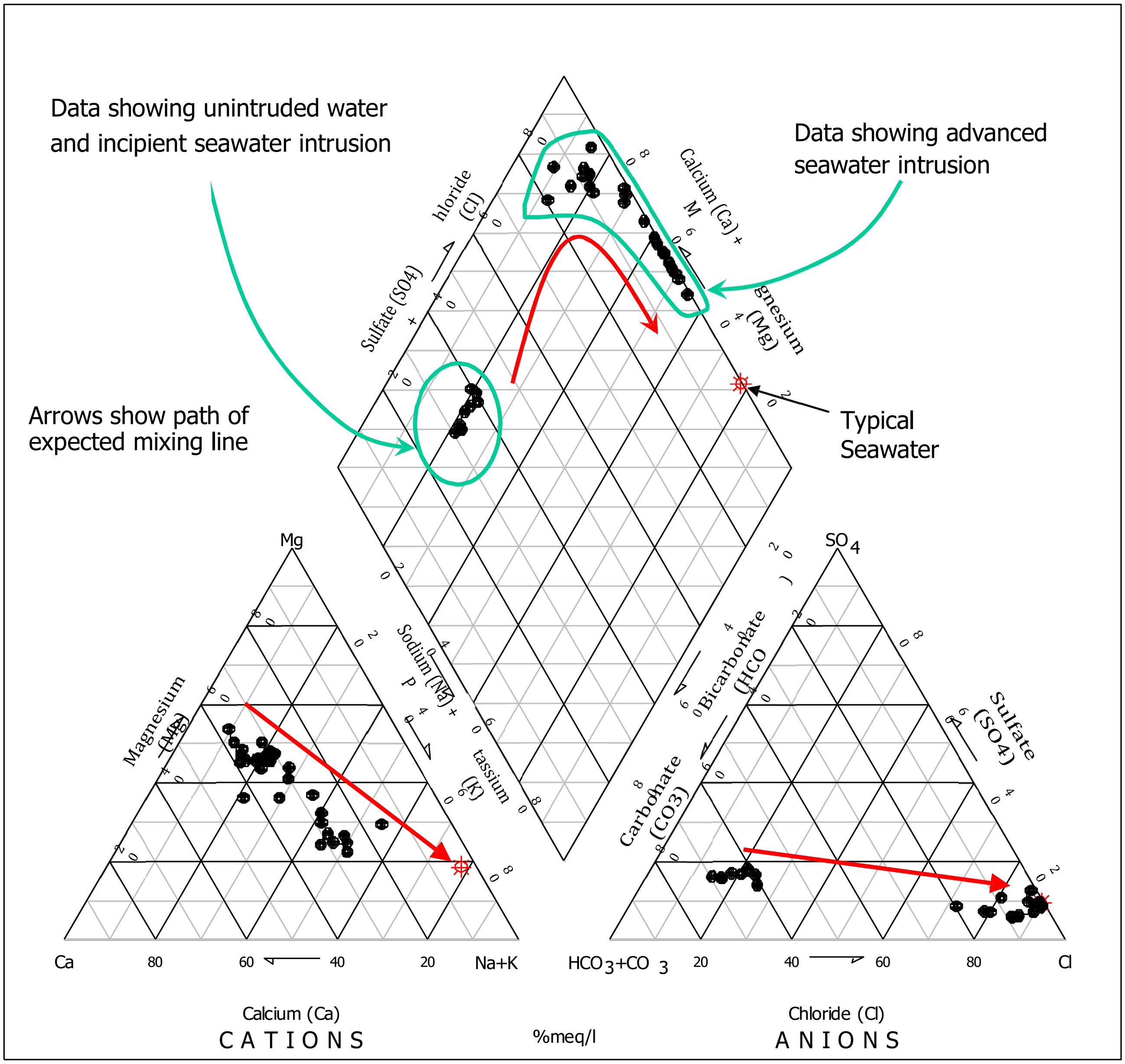

Figure E-1: Example Piper Diagram for Seawater Intrusion, Pajaro Valley (Data source: PVWMA)

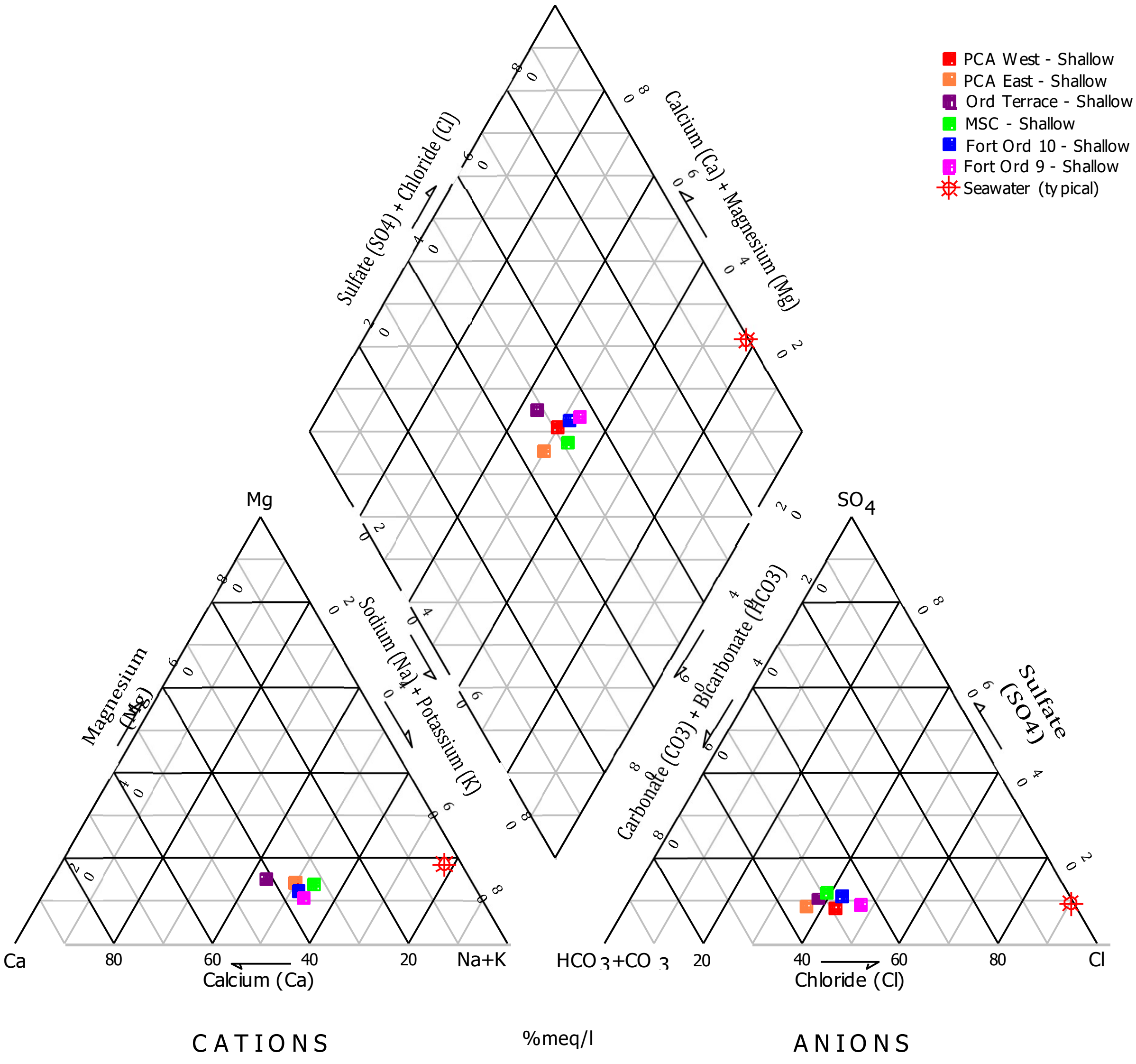

Figure E-2: Piper Diagram for Shallow Zone Seaside Groundwater Basin Monitoring Wells, August 2008
(Data source: MPWMD)

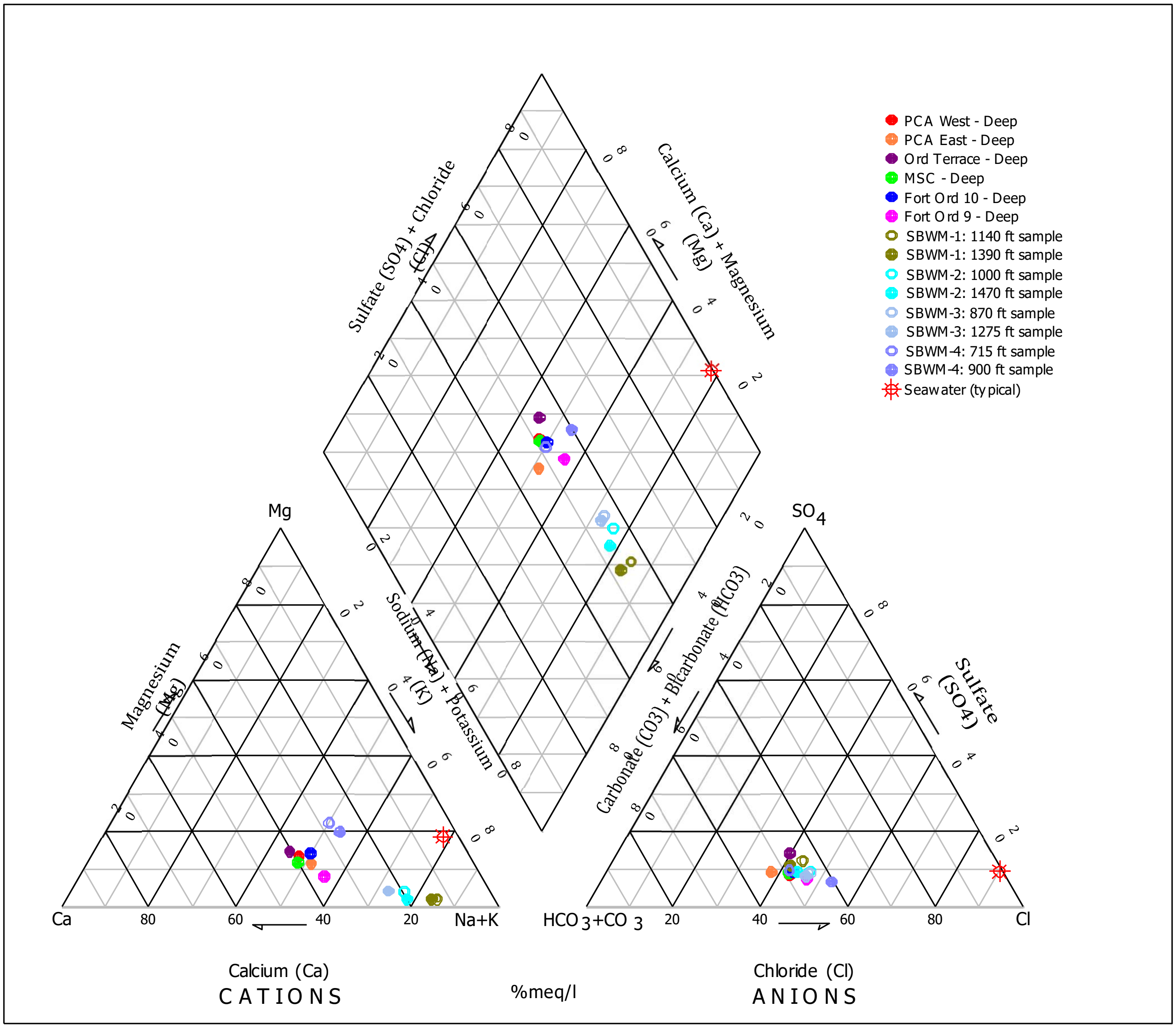

Figure E-3: Piper Diagram for Deep Zone Seaside Groundwater Basin Monitoring Wells, August 2008 (Data source: MPWMD)

APPENDIX F:
STIFF DIAGRAMS
FOR SEASIDE GROUNDWATER BASIN WELLS

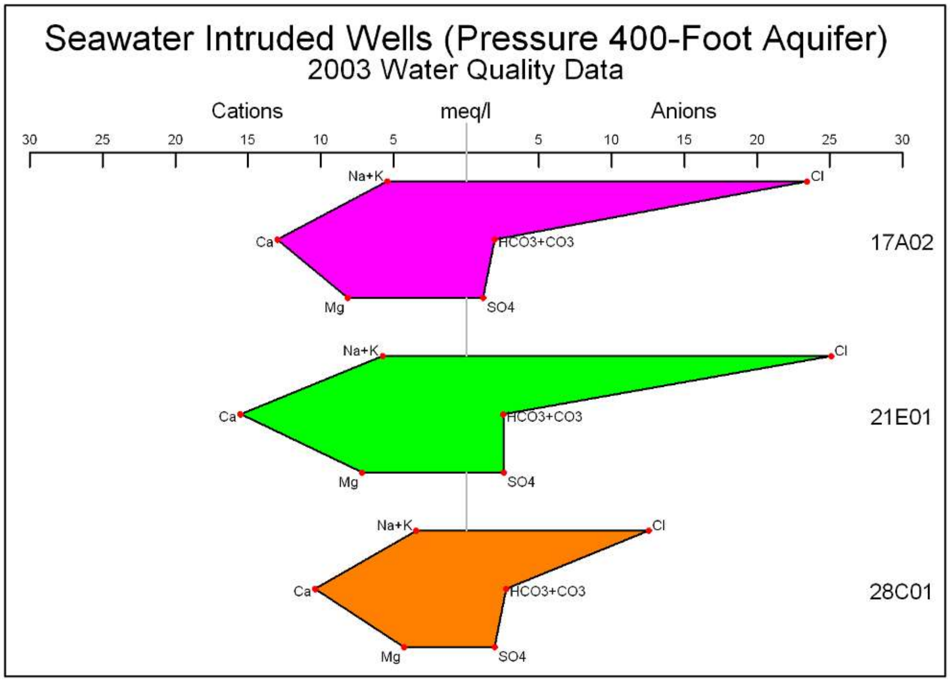

Figure F-1: Example Stiff Diagrams from Salinas Valley Wells showing Typical Seawater Intrusion Shape
(Source: MCWRA)

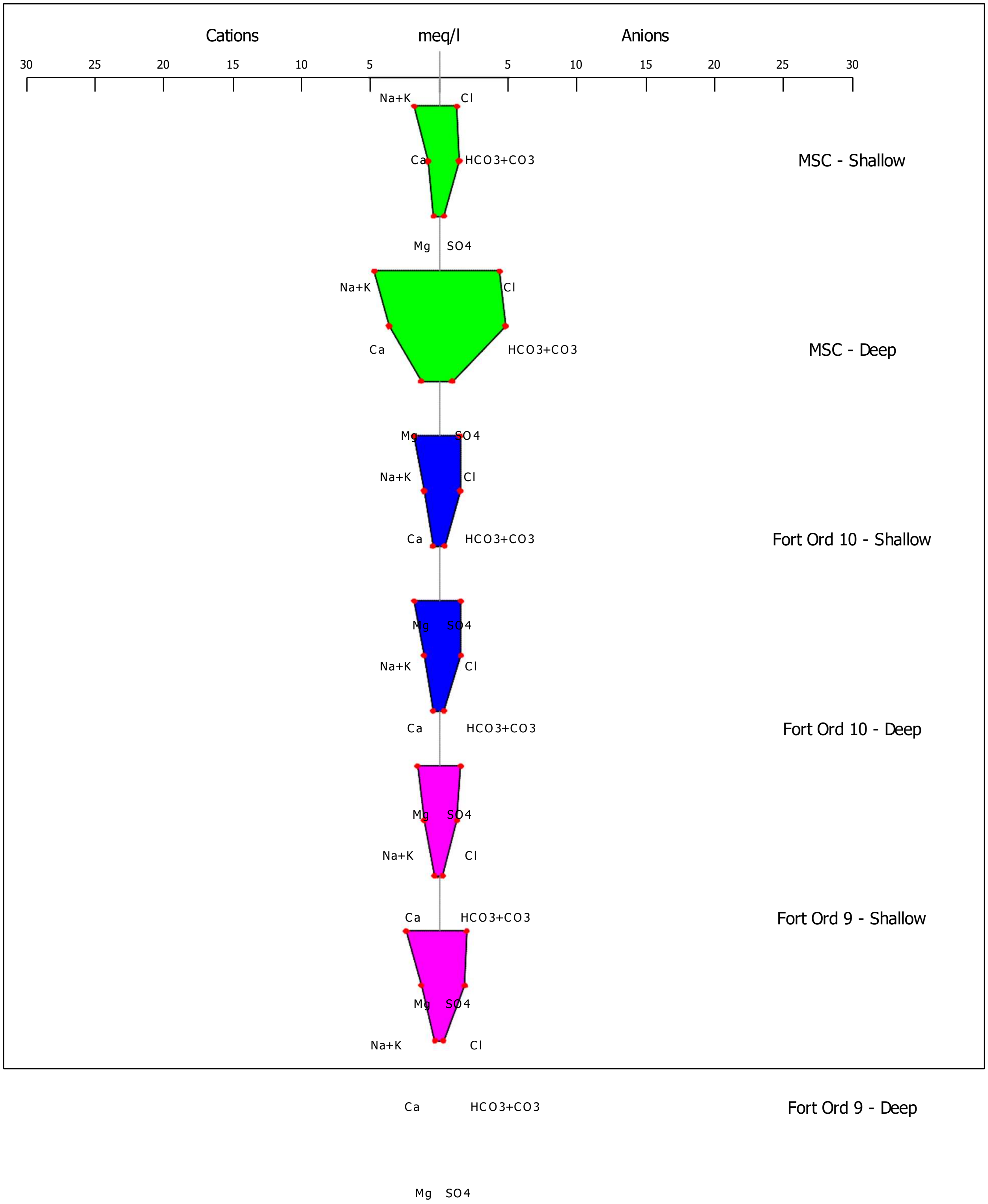

Figure F-2: Stiff Diagrams for Fort Ord 9, Fort Ord 10, and MSC Wells, October 2006 (Data source: Watermaster)

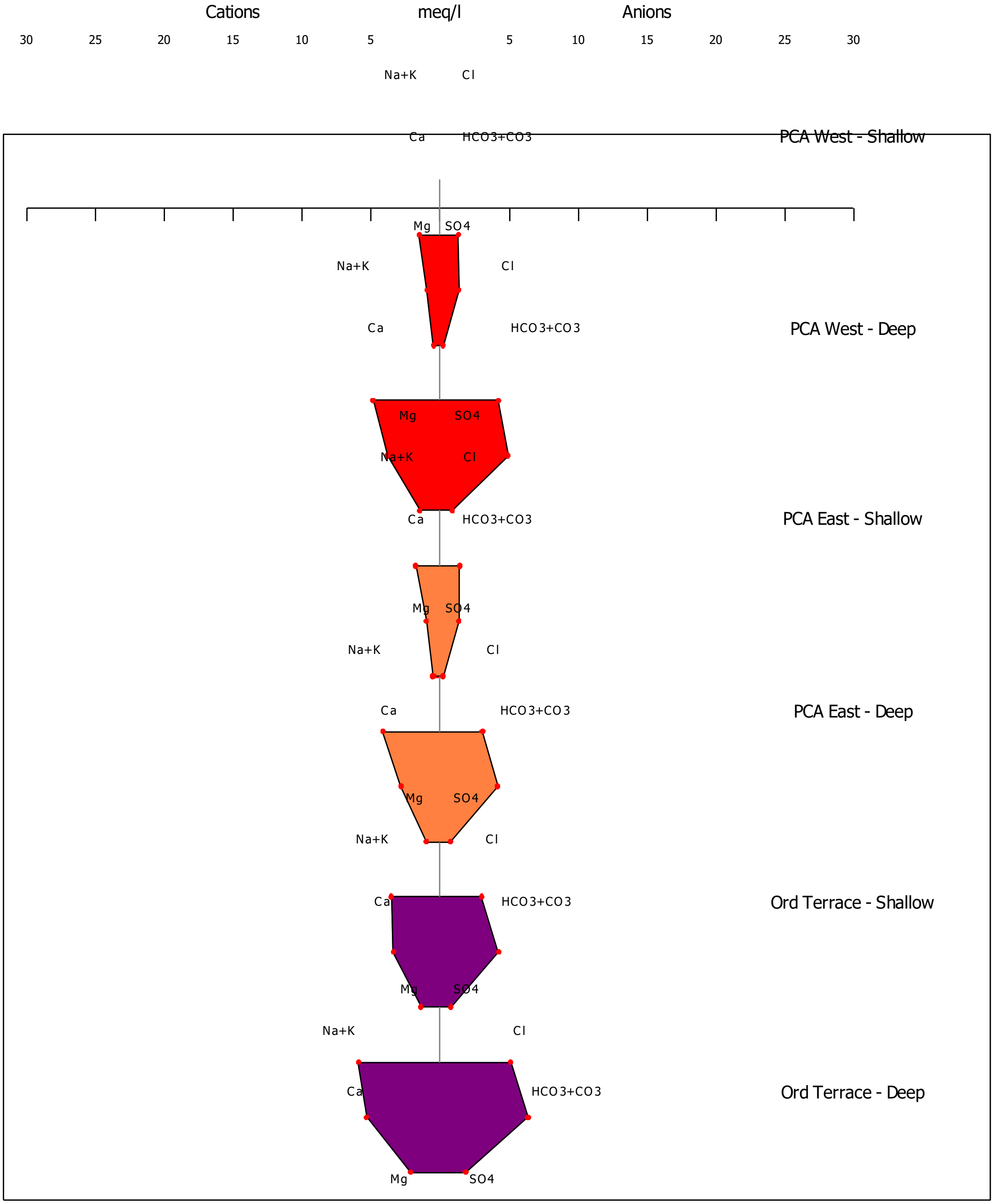

Figure F-3: Stiff Diagrams for PCA West, PCA East, and Ord Terrace Wells, October 2006
(Data source: Watermaster)

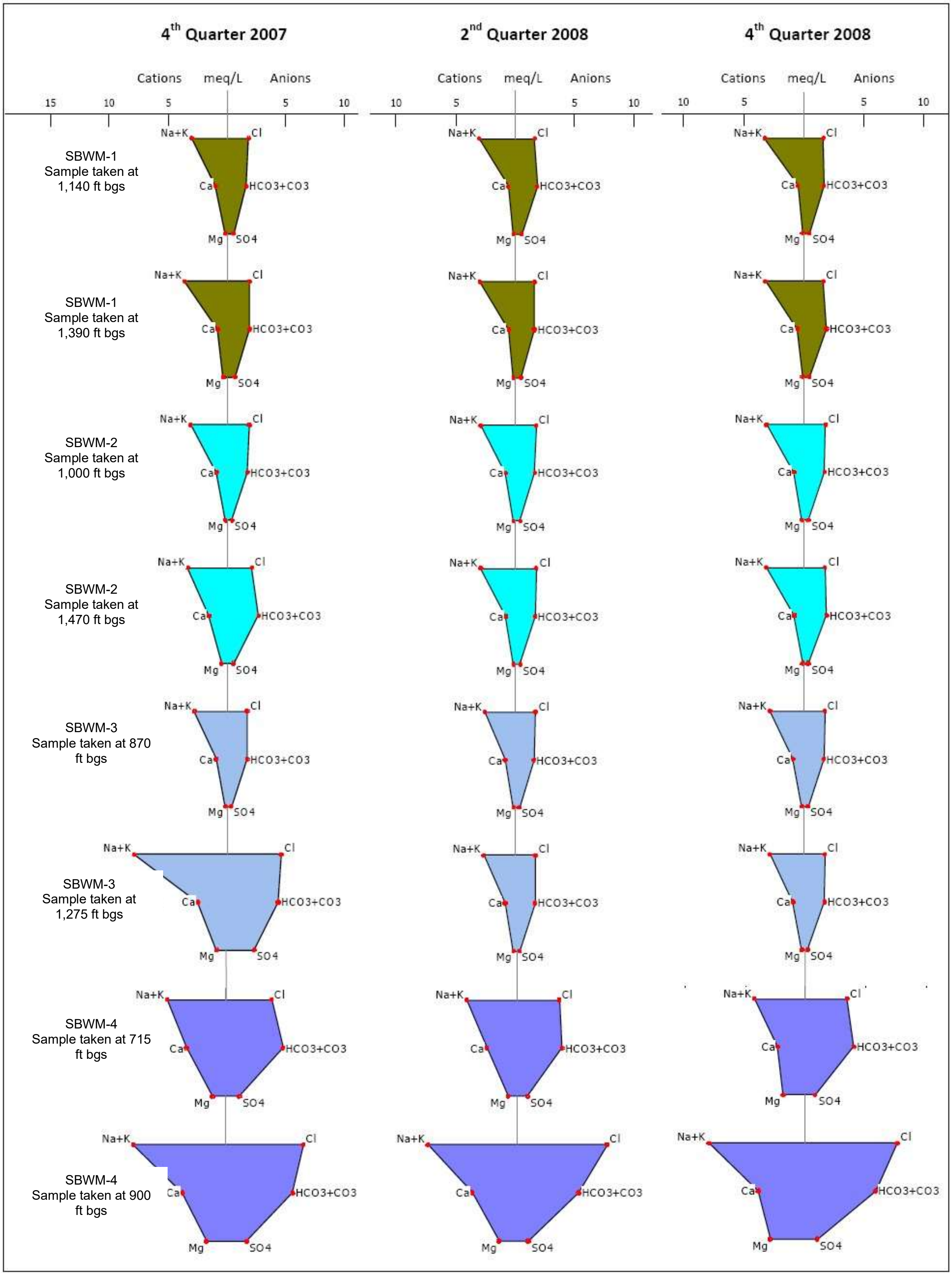

Figure F-4: Stiff Diagrams for Sentinel Wells (Data source: Watermaster)