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TECHNICAL MEMORANDUM

To:	Bob Jaques, Seaside Watermaster Program Manager
From:	Georgina King and Derrik Williams
Date:	February 21, 2017
Subject:	Seaside Groundwater Basin Analysis of Wells Sampled in December 2016

1. Executive Summary

Three Sentinel Wells and one monitoring well were sampled in December 2016. Each Sentinel Well was sampled at two depths and the Ord Terrace Well was sampled at only one depth. Three of these wells (Sentinel Well #2 (SBWM-2) at the 1,470 foot depth, Sentinel Well #4 (SBWM-4) at the 900 foot depth, and Ord Terrace Shallow well) were being resampled to verify anomalous results from samples collected in July 2016. Sentinel Well #1 was included in the sampling event to complete the suite of wells that are normally sampled in January. The December sampling event effectively replaced the normal January event.

Of the seven groundwater quality samples analyzed, SBWM-1 (1,140 ft), SBWM-2 (1,000 ft), and SBWM-4 (715 ft) results were within the range of normal historical values. Results from samples with observed anomalies in either the July 2016 or December 2016 samples are summarized below.

- Well SBWM-1 (1,390 ft): Based on the well's piper diagram, and shape of its stiff diagram, the increased chloride concentration in December 2016 is not indicative of incipient seawater intrusion This well has experienced fluctuating chloride concentrations since 2014 with higher chloride concentrations being observed in winter samples and lower concentrations in summer samples. Prior to 2014, its chloride concentrations were fairly stable. The induction log at the deeper depths of well SBWM-1 show no clear evidence of increased salinity over time.

- Well SBWM-2 (1,470 ft): The chloride concentration in December 2016 returned to within the range of historical concentrations. The well's piper and stiff diagrams both indicate that the anions and cations from the December 2016 sample returned to within their pre-July 2016 range. The high chlorides and anomalous sodium/chloride ratios observed in the July, 2016 sample may have been due to seasonal fluctuations, similar to what is observed in well SBWM-1 (1,390 ft). The induction logs for this well shows increased conductivity in the July 2016 log at the 1,470 foot depth which corroborates the higher chloride concentration on that date and rules out sampling/laboratory error for this sample.

- Well SBWM-4 (900 ft): The chloride concentration in December 2016 is higher than historical concentrations, with the exception of the July 2016 sample. The well's piper and stiff diagrams show that its anions and cations have returned to within the range of pre-July 2016 conditions. The anomalous anion and cation distribution observed in July 2016 may have been due to seasonal fluctuations, similar to what is observed in well SBWM-1 (1,390 ft). This well has the highest chloride elevations of all the coastal monitoring wells and appears to have an increasing chloride trend. The electrical conductivity logs for this well are very similar over time, indicating there has been no major increase in salinity in the aquifer at the 900 foot depth

- Ord Terrace Shallow well chloride concentrations have declined to within the range of historical concentrations. Its piper and stiff diagrams, and inland location do not suggest a seawater source.

None of the samples definitively indicate incipient seawater intrusion. However, variations in groundwater quality from samples collected over the last year from wells SBWM-1 and SBWM-4 warrant increased vigilance regarding potential changes to the Basin's groundwater quality in the vicinity of the Sentinel Wells. There may be some seasonal changes in groundwater quality in the deepest portions of the aquifer that could be related to seasonal groundwater elevation changes. If this is true and groundwater elevations continue to decline, larger fluctuations might be seen in the fall when groundwater levels are at their lowest.

The sources of increasing and fluctuating chlorides in wells SBWM-1 and SBWM-4 are unclear. Potential sources may include natural groundwater quality variations, upwelling or upconing of saline water in wells in response to declining groundwater levels, seawater intrusion, or downward leakage of shallow, poor quality groundwater. Regardless of the source, the coincidence of record low groundwater elevations in the basin with increasing and fluctuating chlorides may indicate that the chronically low groundwater elevations have triggered the fluctuations being observed.

Recommendations on future work and monitoring include:

1. Continue to sample SBWM-1 and SBWM-4 twice a year.
2. SBWM-2 should be resampled at the end of summer in 2017 and based on those results a decision should be made as to whether it should be sampled twice a year on an ongoing basis.
3. To determine if groundwater quality samples reflect the influence of fluctuating groundwater elevations, it is recommended that samples in the future be collected in the last week of September for the 4th quarter samples and in the first week of March for the 2nd quarter samples.
4. Prepare a work plan that will direct an effort towards identifying the source of fluctuating chloride concentrations. The work plan should outline the types of analyses and data to be used in identifying the chloride source. If the source of fluctuating chlorides is understood, it will help in developing management actions to prevent the higher concentrations increasing to the point that they cause groundwater degradation.
5. Conduct downhole conductivity and temperature profiles within each of the Sentinel Wells during the next sampling event. This tool measures the conductivity within the well, as opposed to induction logging which measures conductivity within the adjacent sediments. This technique may help identify if upwelling is occurring.
6. Continue the process that has recently been implemented to review water quality results as soon as they are received, rather than waiting until they are used to prepare the annual Seawater Intrusion Analysis Report. This will enable action to be taken, including reanalysis of samples, if appropriate, immediately instead of at the end of the year when the data have historically been analyzed.
7. Continue conducting all groundwater quality sampling and analysis conducted in accordance with standard quality assurance and quality control procedures. This includes submitting field blanks and duplicates samples to the laboratory once every couple of years.

2. Background

The 2016 Seawater Intrusion Analysis Report (SIAR) reported on groundwater samples obtained during July 2016 that contained several anomalous chloride concentrations and other anion and cations concentrations. These anomalous results triggered resampling of those wells with the anomalies. The wells with the increased chlorides were:

- Sentinel Well #2 (SBWM-2) at the 1,470 ft depth,
- Sentinel Well #4 (SBWM-4) at the 900 ft depth, and
- Ord Terrace Shallow well.

The Technical Advisory Committee (TAC) approved the SIAR recommendation to resample those wells as soon as possible to verify the water quality. The Ord Terrace Shallow well was resampled on December 5, 2016 by Monterey Peninsula Water Management District; and the sentinel wells were resampled by Martin Feeney on December 14, 2016.

The December samples effectively replace the samples that were scheduled to be collected in January 2017. Samples were analyzed by Monterey Bay Analytical Services (MBAS), which is the laboratory that has historically analyzed the Seaside Basin groundwater samples. Duplicate samples of the sentinel wells were sent to the Monterey County laboratory for general minerals analysis. Samples were not collected for Sentinel Well 3 (SBWM-3) which is only sampled in July of each year. No duplicate samples for the Ord Terrace Shallow well were analyzed.

3. Laboratory Results

Table 1 summarizes the results obtained from both MBAS and Monterey County laboratories. The analyses in the following section of this memorandum are based on the MBAS results to maintain consistency with previous years' reports.

With one exception, the results from duplicate samples analyzed by Monterey County were close to those results from MBAS; and there were no results that would indicate MBAS laboratory error. Some differences in the cations and anions are to be expected, but overall the results were similar. The exception is the SBWM-1 (1,390 ft) duplicate sample from the Monterey County laboratory which has higher chloride, sodium, specific conductivity than the MBAS sample. The concentrations of these constituents collected at the well's 1,140 foot depth did not have as great a difference.

Table 1: Summary of Laboratory Results

Well	Constituent	MBAS Result	Monterey County Result	Units
SBWM 1 at 1,140 ft **Sampled 12/14/2016**	Calcium	12	9.1	mg/L
	Chloride	74	72	mg/L
	Fluoride	0.2	-	mg/L
	Hardness (as CaCO3)	34	-	mg/L
	Bicarbonate (as HCO3-)	89	-	mg/L
	Potassium	3.3	2.5	mg/L
	Langlier Index, 60°C	0.56	-	
	Magnesium	1.0	0.3	mg/L
	Manganese, Total	21	-	µg/L
	Sodium	73	80	mg/L
	Nitrate as NO3	ND	ND	mg/L
	pH (Laboratory)	8.5	7.9	pH (H)
	Specific Conductance (E.C)	457	443	µmhos/cm
	Total Diss. Solids	254	-	mg/L
	Sulfate	22	25	mg/L
	QC Anion-Cation Balance	-1	-	%
	QC Ratio TDS/SEC	0.56	-	
	o-Phosphate-P, Dissolved	ND	-	mg/L
	Langlier Index, 15°C	-0.04	-	
	Alkalinity, Total (as CaCO3)	73	75	mg/L
	Iron	1359	-	µg/L
	Nitrite as NO2-N	0.1	-	mg/L
	QC Anion Sum x 100	88%	-	%
	QC Cation Sum x 100	86%	-	%
	Hydroxide	ND	-	mg/L
	Carbonate as CaCO3	ND	-	mg/L
	Bromide	0.2	-	mg/L
	Barium, Total	26	-	µg/L
	Iron, Dissolved	ND	-	µg/L
	Manganese, Dissolved	ND	-	µg/L
	Boron	0.09	-	mg/L
	Iodide	28	-	µg/L

ND = Not Detected

Well	Constituent	MBAS Result	Monterey County Result	Units
SBWM 1 at 1,390 ft Sampled 12/14/2016	Calcium	29	27	mg/L
	Chloride	152	201	mg/L
	Fluoride	0.2	-	mg/L
	Hardness (as CaCO3)	81	-	mg/L
	Bicarbonate (as HCO3-)	83	-	mg/L
	Potassium	5.3	4.2	mg/L
	Langlier Index, 60°C	0.97	-	
	Magnesium	2.0	0.3	mg/L
	Manganese, Total	58		µg/L
	Sodium	109	149	mg/L
	Nitrate as NO3	ND	ND	mg/L
	pH (Laboratory)	8.6	7.6	pH (H)
	Specific Conductance (E.C)	706	889	µmhos/cm
	Total Diss. Solids	383	-	mg/L
	Sulfate	29	35	mg/L
	QC Anion-Cation Balance	2	-	%
	QC Ratio TDS/SEC	0.54	-	
	o-Phosphate-P, Dissolved	ND	-	mg/L
	Langlier Index, 15°C	0.38	-	
	Alkalinity, Total (as CaCO3)	68	74	mg/L
	Iron	6400	-	µg/L
	Nitrite as NO2-N	ND	-	mg/L
	QC Anion Sum x 100	89%	-	%
	QC Cation Sum x 100	92%	-	%
	Hydroxide	ND	-	mg/L
	Carbonate as CaCO3	ND	-	mg/L
	Bromide	0.4	-	mg/L
	Barium, Total	72	-	µg/L
	Iron, Dissolved	40	-	µg/L
	Manganese, Dissolved	ND	-	µg/L
	Boron	0.09	-	mg/L
	Iodide	30	-	µg/L

ND = Not Detected

Well	Constituent	MBAS Result	Monterey County Result	Units
SBWM 2 at 1,000 ft Sampled 12/14/2016	Calcium	16	14	mg/L
	Chloride	67	66	mg/L
	Fluoride	0.2	-	mg/L
	Hardness (as CaCO3)	48	-	mg/L
	Bicarbonate (as HCO3-)	99	-	mg/L
	Potassium	3.3	2.8	mg/L
	Langlier Index, 60°C	0.64	-	
	Magnesium	2.0	0.7	mg/L
	Manganese, Total	36	-	µg/L
	Sodium	61	69	mg/L
	Nitrate as NO3	ND	ND	mg/L
	pH (Laboratory)	8.4	8.2	pH (H)
	Specific Conductance (E.C)	432	417	µmhos/cm
	Total Diss. Solids	234	-	mg/L
	Sulfate	17	19	mg/L
	QC Anion-Cation Balance	-2	-2	%
	QC Ratio TDS/SEC	0.54	-	
	o-Phosphate-P, Dissolved	ND	-	mg/L
	Langlier Index, 15°C	0.04	-	
	Alkalinity, Total (as CaCO3)	81	86	mg/L
	Iron	6585	-	µg/L
	Nitrite as NO2-N	0.2	-	mg/L
	QC Anion Sum x 100	89%	-	%
	QC Cation Sum x 100	86%	-	%
	Hydroxide	ND	-	mg/L
	Carbonate as CaCO3	ND	-	mg/L
	Bromide	0.2	-	mg/L
	Barium, Total	40	-	µg/L
	Iron, Dissolved	34	-	µg/L
	Manganese, Dissolved	ND	-	µg/L
	Boron	0.08	-	mg/L
	Iodide	32	-	µg/L

ND = Not Detected

Well	Constituent	MBAS Result	Monterey County Result	Units
SBWM 2 at 1,470 ft Sampled 12/14/2016	Calcium	18	18	mg/L
	Chloride	66	65	mg/L
	Fluoride	0.2	-	mg/L
	Hardness (as CaCO3)	53	-	mg/L
	Bicarbonate (as HCO3-)	100	-	mg/L
	Potassium	3.4	3.0	mg/L
	Langlier Index, 60°C	0.69	-	
	Magnesium	2.0	1.0	mg/L
	Manganese, Total	47	-	µg/L
	Sodium	60	69	mg/L
	Nitrate as NO3	ND	ND	mg/L
	pH (Laboratory)	8.4	7.9	pH (H)
	Specific Conductance (E.C)	431	419	µmhos/cm
	Total Diss. Solids	234	-	mg/L
	Sulfate	18	18	mg/L
	QC Anion-Cation Balance	-2	1	%
	QC Ratio TDS/SEC	0.54	-	
	o-Phosphate-P, Dissolved	ND	-	mg/L
	Langlier Index, 15°C	0.10	-	
	Alkalinity, Total (as CaCO3)	82	89	mg/L
	Iron	5448	-	µg/L
	Nitrite as NO2-N	0.2	-	mg/L
	QC Anion Sum x 100	90%	-	%
	QC Cation Sum x 100	87%	-	%
	Hydroxide	ND	-	mg/L
	Carbonate as CaCO3	ND	-	mg/L
	Bromide	0.2	-	mg/L
	Barium, Total	50	-	µg/L
	Iron, Dissolved	77	-	µg/L
	Manganese, Dissolved	ND	-	µg/L
	Boron	0.08	-	mg/L
	Iodide	34	-	µg/L

ND = Not Detected

Well	Constituent	MBAS Result	Monterey County Result	Units
SBWM 4 at 715 ft Sampled 12/14/2016	Calcium	78	69	mg/L
	Chloride	139	135	mg/L
	Fluoride	0.2	-	mg/L
	Hardness (as CaCO3)	232	-	mg/L
	Bicarbonate (as HCO3-)	224	-	mg/L
	Potassium	8.5	7.5	mg/L
	Langlier Index, 60°C	0.62	-	
	Magnesium	9.0	9.4	mg/L
	Manganese, Total	133	-	µg/L
	Sodium	91	103	mg/L
	Nitrate as NO3	ND	ND	mg/L
	pH (Laboratory)	7.4	7.5	pH (H)
	Specific Conductance (E.C)	866	866	µmhos/cm
	Total Diss. Solids	503	-	mg/L
	Sulfate	37	36	mg/L
	QC Anion-Cation Balance	3	2	%
	QC Ratio TDS/SEC	0.58	-	
	o-Phosphate-P, Dissolved	ND	-	mg/L
	Langlier Index, 15°C	0.02	-	
	Alkalinity, Total (as CaCO3)	184	195	mg/L
	Iron	12,985	-	µg/L
	Nitrite as NO2-N	0.2	-	mg/L
	QC Anion Sum x 100	97%	-	%
	QC Cation Sum x 100	102%	-	%
	Hydroxide	ND	-	mg/L
	Carbonate as CaCO3	ND	-	mg/L
	Bromide	0.4	-	mg/L
	Barium, Total	133	-	µg/L
	Iron, Dissolved	29	-	µg/L
	Manganese, Dissolved	27	-	µg/L
	Boron	0.10	-	mg/L
	Iodide	50	-	µg/L

ND = Not Detected

Well	Constituent	MBAS Result	Monterey County Result	Units
SBWM 4 at 900 ft **Sampled 12/14/2016**	Calcium	86	83	mg/L
	Chloride	274	259	mg/L
	Fluoride	0.2	-	mg/L
	Hardness (as CaCO3)	297	-	mg/L
	Bicarbonate (as HCO3-)	340	-	mg/L
	Potassium	8.6	8.1	mg/L
	Langlier Index, 60°C	0.79	-	
	Magnesium	20	18	mg/L
	Manganese, Total	140	-	µg/L
	Sodium	172	189	mg/L
	Nitrate as NO3	ND	ND	mg/L
	pH (Laboratory)	7.4	7.6	pH (H)
	Specific Conductance (E.C)	1,427	1,430	µmhos/cm
	Total Diss. Solids	806	-	mg/L
	Sulfate	40	50	mg/L
	QC Anion-Cation Balance	-2	0	%
	QC Ratio TDS/SEC	0.56	-	
	o-Phosphate-P, Dissolved	ND	-	mg/L
	Langlier Index, 15°C	0.20	-	
	Alkalinity, Total (as CaCO3)	279	284	mg/L
	Iron	4215	-	µg/L
	Nitrite as NO2-N	0.2	-	mg/L
	QC Anion Sum x 100	99%	-	%
	QC Cation Sum x 100	96%	-	%
	Hydroxide	ND	-	mg/L
	Carbonate as CaCO3	ND	-	mg/L
	Bromide	0.8	-	mg/L
	Barium, Total	347	-	µg/L
	Iron, Dissolved	37	-	µg/L
	Manganese, Dissolved	72	-	µg/L
	Boron	0.31	-	mg/L
	Iodide	65	-	µg/L

ND = Not Detected

Well	Constituent	MBAS Result	Units
Ord Terrace Shallow **Sampled 12/14/2016**	Calcium	64	mg/L
	Chloride	114	mg/L
	Fluoride	0.2	mg/L
	Hardness (as CaCO3)	217	mg/L
	Bicarbonate (as HCO3-)	249	mg/L
	Potassium	3.7	mg/L
	Langlier Index, 60°C	--	
	Magnesium	14	mg/L
	Manganese, Total	87	µg/L
	Sodium	66	mg/L
	Nitrate as NO3	6	mg/L
	pH (Laboratory)	7.6	pH (H)
	Specific Conductance (E.C)	868	µmhos/cm
	Total Diss. Solids	506	mg/L
	Sulfate	43	mg/L
	QC Anion-Cation Balance	-6	%
	QC Ratio TDS/SEC	0.58	
	o-Phosphate-P, Dissolved	ND	mg/L
	Langlier Index, 15°C	--	
	Alkalinity, Total (as CaCO3)	204	mg/L
	Iron	106	µg/L
	Nitrite as NO2-N	0.2	mg/L
	QC Anion Sum x 100	95%	%
	QC Cation Sum x 100	84%	%
	Hydroxide	--	mg/L
	Carbonate as CaCO3	ND	mg/L
	Bromide	0.3	mg/L
	Barium, Total	51	µg/L
	Iron, Dissolved	ND	µg/L
	Manganese, Dissolved	ND	µg/L
	Boron	0.07	mg/L

ND = Not Detected

4. WATER QUALITY ANALYSIS

The analyses used to examine the water quality data collected in December 2016 are the same as those used in the SIAR: chloride concentrations over time, sodium/chloride ratios, and piper and stiff diagrams.

Groundwater quality results for the following wells were within the range of normal historical values, and are therefore not discussed further in this memorandum:

- Well SBWM-1 (1,140 ft),
- Well SBWM-2 (1,000 ft), and
- Well SBWM-4 (715 ft).

The analysis in this memorandum focuses on those wells with observed anomalies in either the July 2016 or December 2016 samples:

- Well SBWM-1 (1,390 ft),
- Well SBWM-2 (1,470 ft),
- Well SBWM-4 (900 ft), and
- Ord Terrace Shallow.

4.1. Chloride Concentrations and Sodium/Chloride Ratios

Figures 1 through 4 update the chloride concentration and sodium/chloride ratio charts from the 2016 SIAR with the December 2016 sample results, and include chloride trend lines. In summary, the charts show:

- Well SBWM-1 (1,390 ft) had a 85 mg/L chloride increase since July 2016 and its overall chloride concentrations are increasing. The increasing chloride trend (grey trend line) observed in this well is more pronounced because of seasonal fluctuations where the winter concentrations tend to be higher than summer concentrations. There is a slight, but inconsequential, increasing trend if the high winter concentrations are excluded (> 70 mg/L, black trend line). The sodium/chloride ratio is well above the ratio of 0.86, below which other investigators have proposed as an indicator of seawater intrusion.
- Well SBWM-2 (1,470 ft) chloride concentrations declined in December to less than 70 mg/L, back to within the range of historical concentrations. The overall chloride trend is virtually flat if the July 2016 sample is excluded. The

sodium/chloride ratio is well above the ratio of 0.86, below which other investigators have proposed as an indicator of seawater intrusion.

- Well SBWM-4 (900 ft) chloride concentrations are slightly less than in July 2016 but still higher than historical values. The overall chloride trend at this depth in the well is increasing over the period of record and increasing at a higher rate since January 2012. The sodium/chloride ratio has increased from less than 0.86 in July 2016 to above 1 in December 2016.
- Ord Terrace Shallow well chloride concentrations have declined to 114 mg/L, which is within the range of historical concentrations. There is a very slight increasing chloride trend over the period of record. The sodium/chloride ratio is between 0.86 and 0.9.

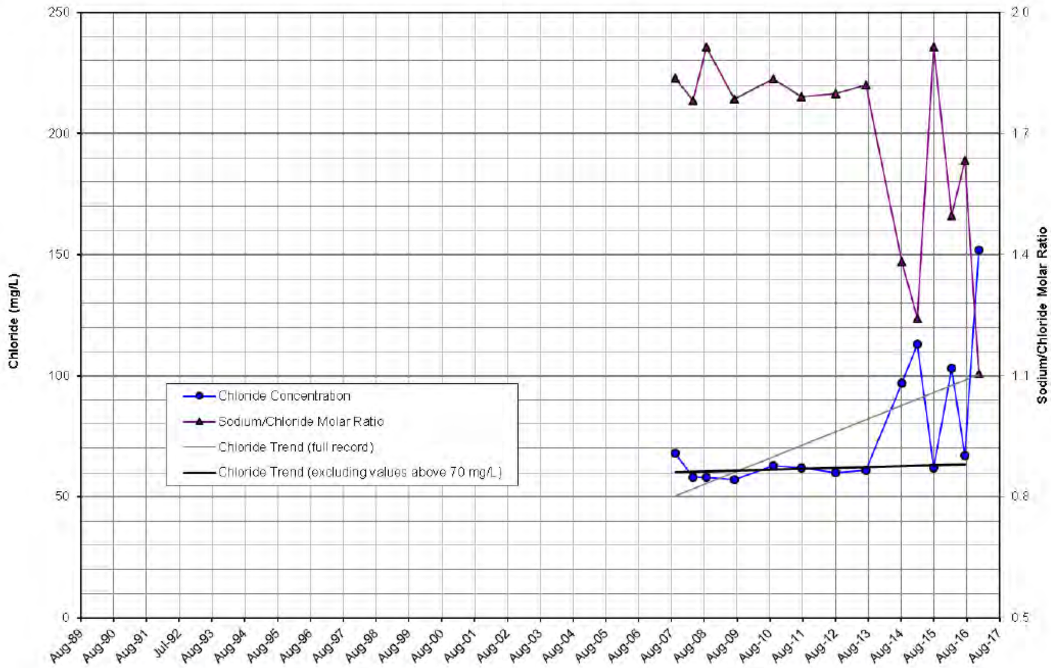

Figure 1: SBWM-1 (1,390 ft) Chloride Concentrations and Sodium/Chloride Ratios

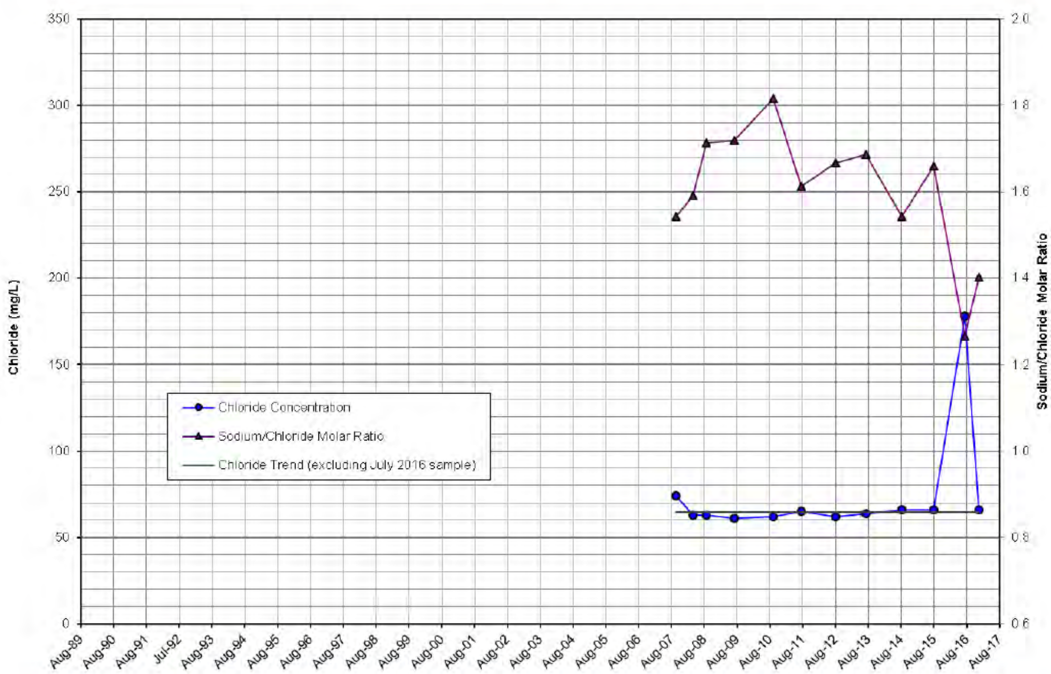

Figure 2: SBWM-2 (1,470 ft) Chloride Concentrations and Sodium/Chloride Ratios

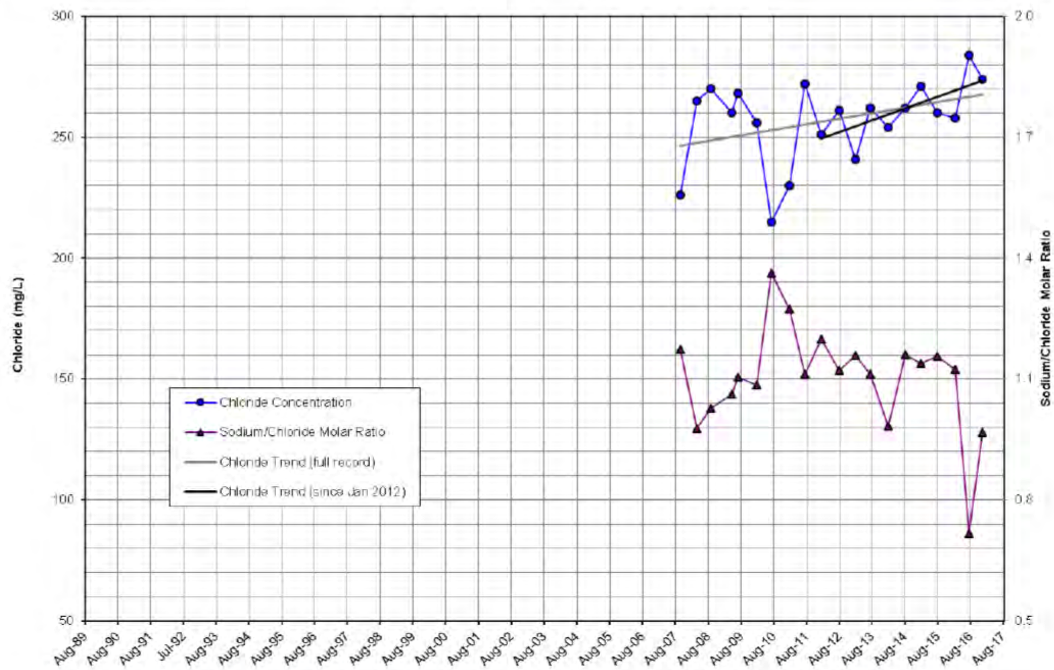

Figure 3: SBWM-4 (900 ft) Chloride Concentrations and Sodium/Chloride Ratios

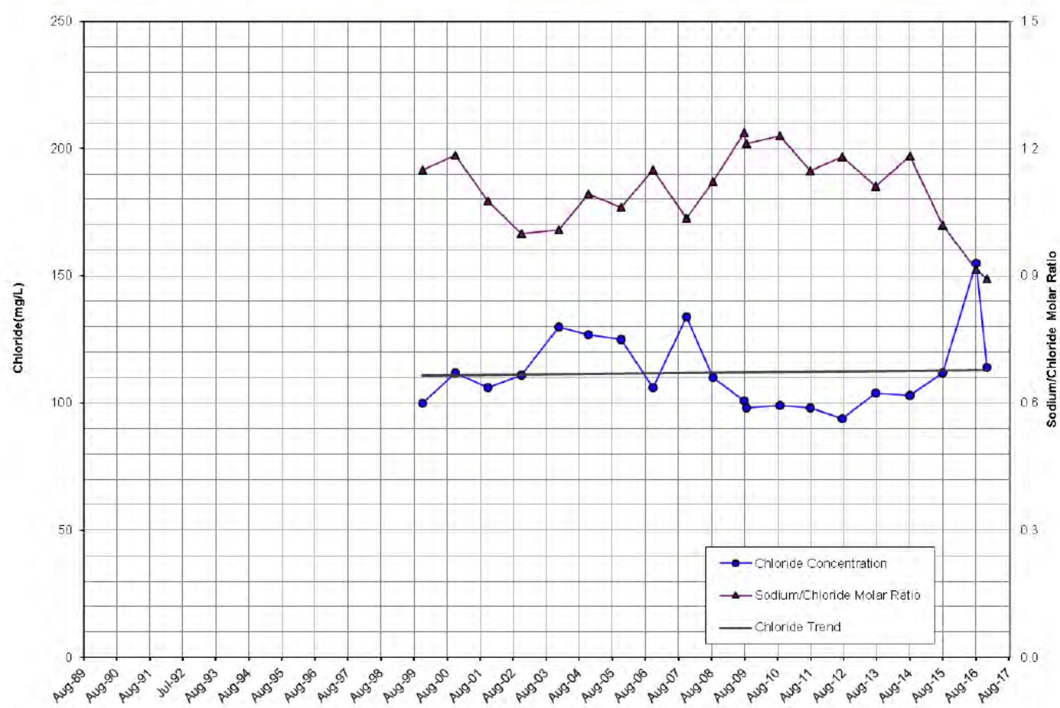

Figure 4: Ord Terrace Shallow Chloride Concentrations and Sodium/Chloride Ratios

4.2. Anion and Cation Analyses

4.2.1. Piper Diagrams

Piper diagrams for the four wells with anomalous data are shown on Figures 5 through 8. In summary the Piper diagrams show:

- Well SBWM-1 (1,390 ft)'s groundwater quality is generally of a sodium-chloride-bicarbonate type (Figure 5). The sample for December 2016, shown with the green solid triangle, has slightly increased calcium cations compared to the majority of the data points. Chloride anions increased such that the water type can be classified as more strongly sodium-chloride in character. The data points on the piper diagram show no consistent trend over time but rather appear to exhibit fluctuations.

- Well SBWM-2 (1,470 ft)'s groundwater quality is generally of a sodium-chloride-bicarbonate type (Figure 6). The sample for December 2016, shown with the green open triangle, plots within its historical cluster of data points. This is in contrast with the July 2016 sample, shown with the open circle, which had no apparent change in cations compared to historical values but a large increase in chloride anions with correspond decrease in bicarbonate anions. The data points on the piper diagram show no consistent trend over time but rather appear to exhibit fluctuations.

- Well SBWM-4 (900 ft)'s groundwater quality is generally of a sodium-chloride type (Figure 7). The sample for December 2016, shown with the green solid star, plots within its historical cluster of data points. This is in contrast with the July 2016 sample, shown with the open star symbol, which exhibits a more strongly sodium-chloride character than usual. The data points on the piper diagram show no consistent trend over time but rather appear to exhibit fluctuations.

- Ord Terrace Shallow well's groundwater quality is generally of a calcium-bicarbonate type (Figure 8). The sample for December 2016, shown with the green open triangle, plots within its historical cluster of data points. The data points on the piper diagram show no trend over time.

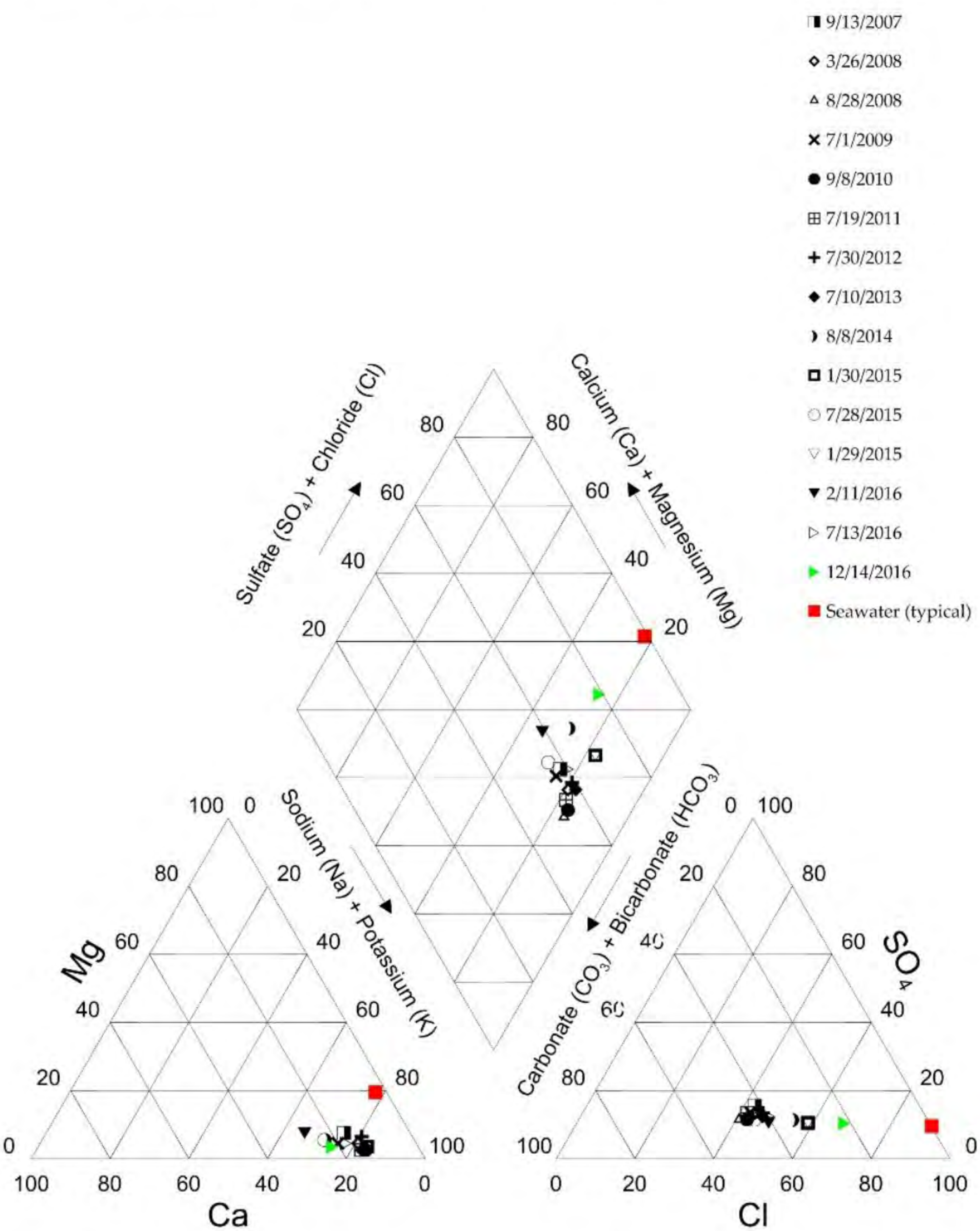

Figure 5: Piper Diagram for SBWM-1 (1,390 ft)

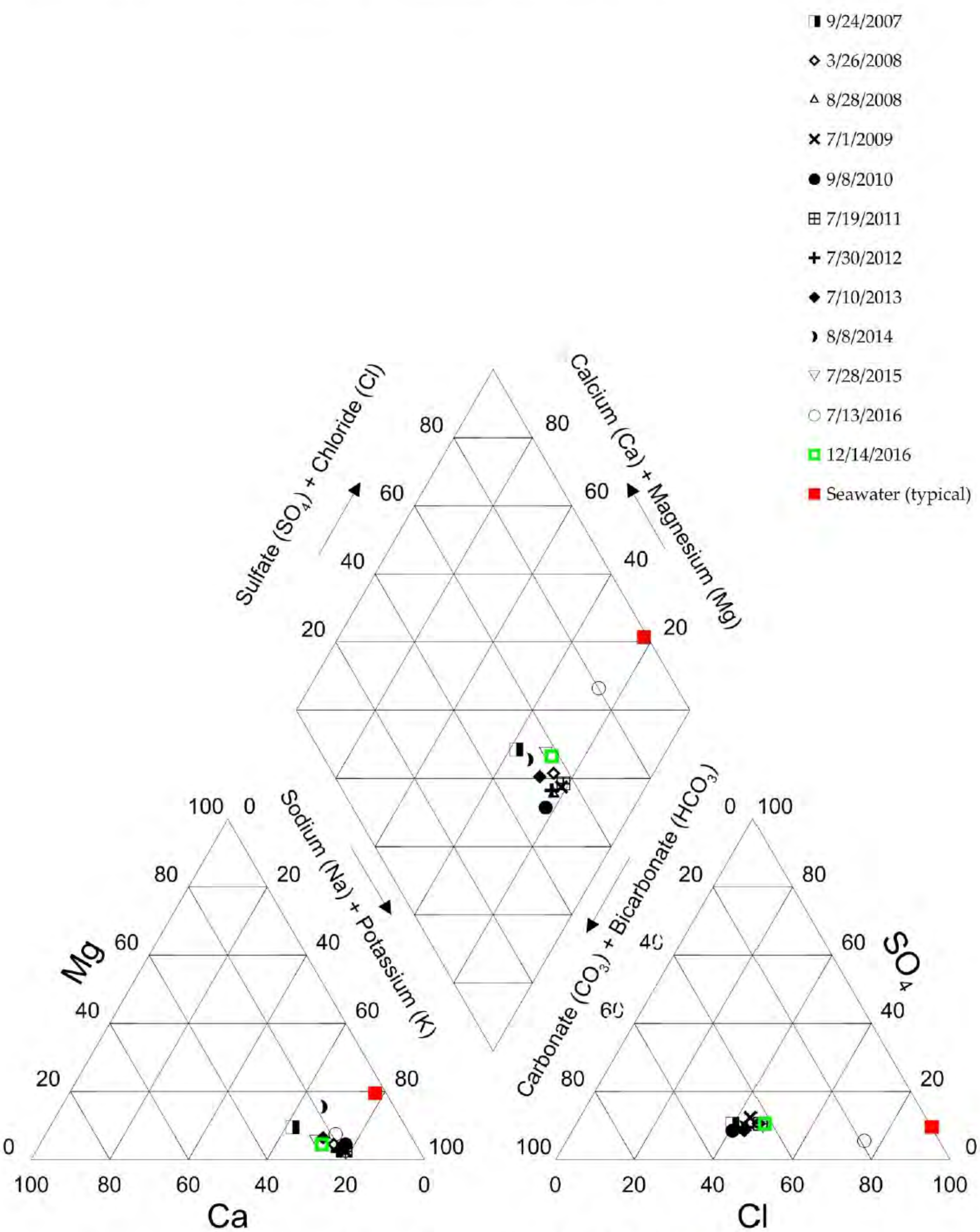

Figure 6: Piper Diagram for SBWM-2 (1,470 ft)

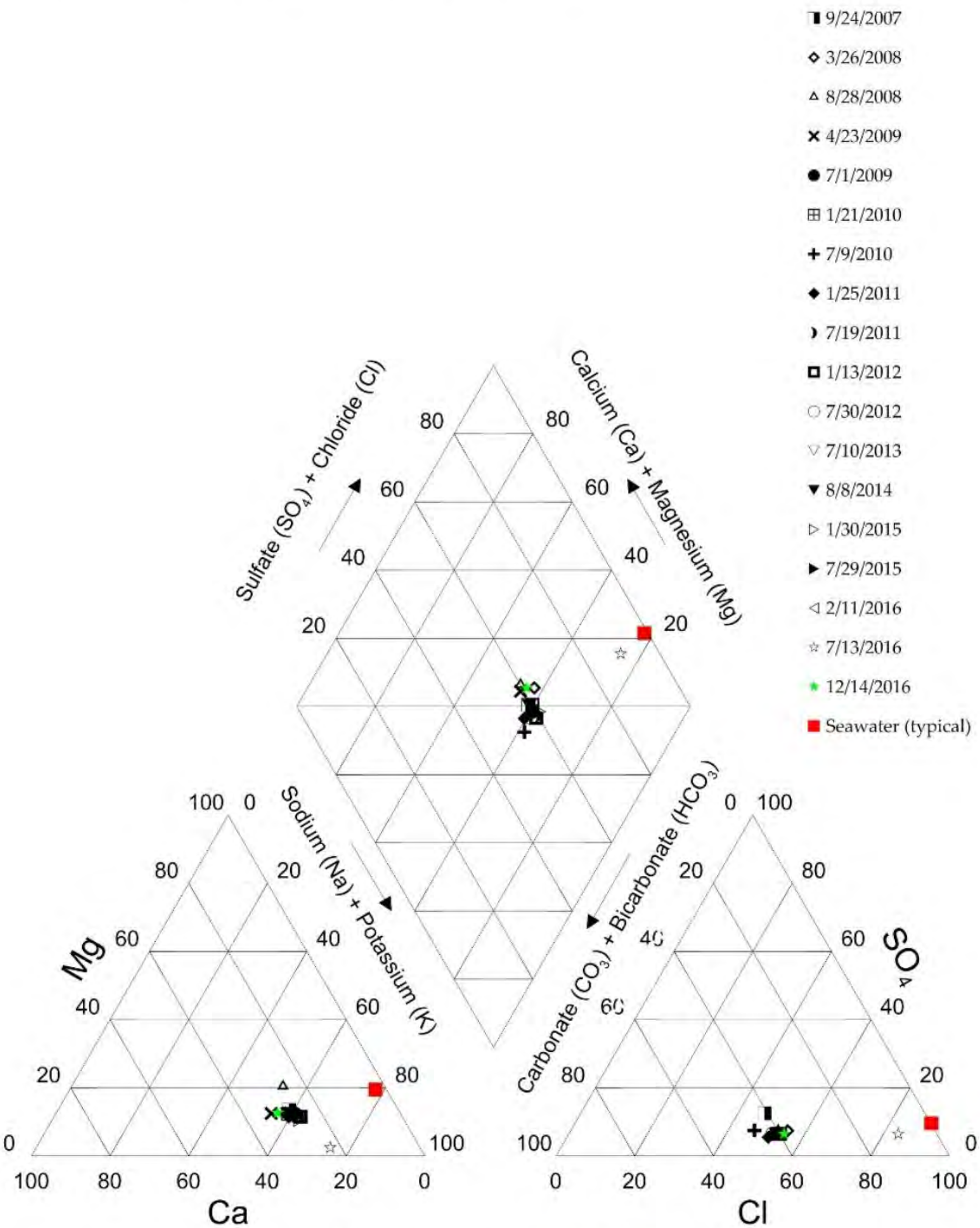

Figure 7: Piper Diagram for SBWM-4 (900 ft)

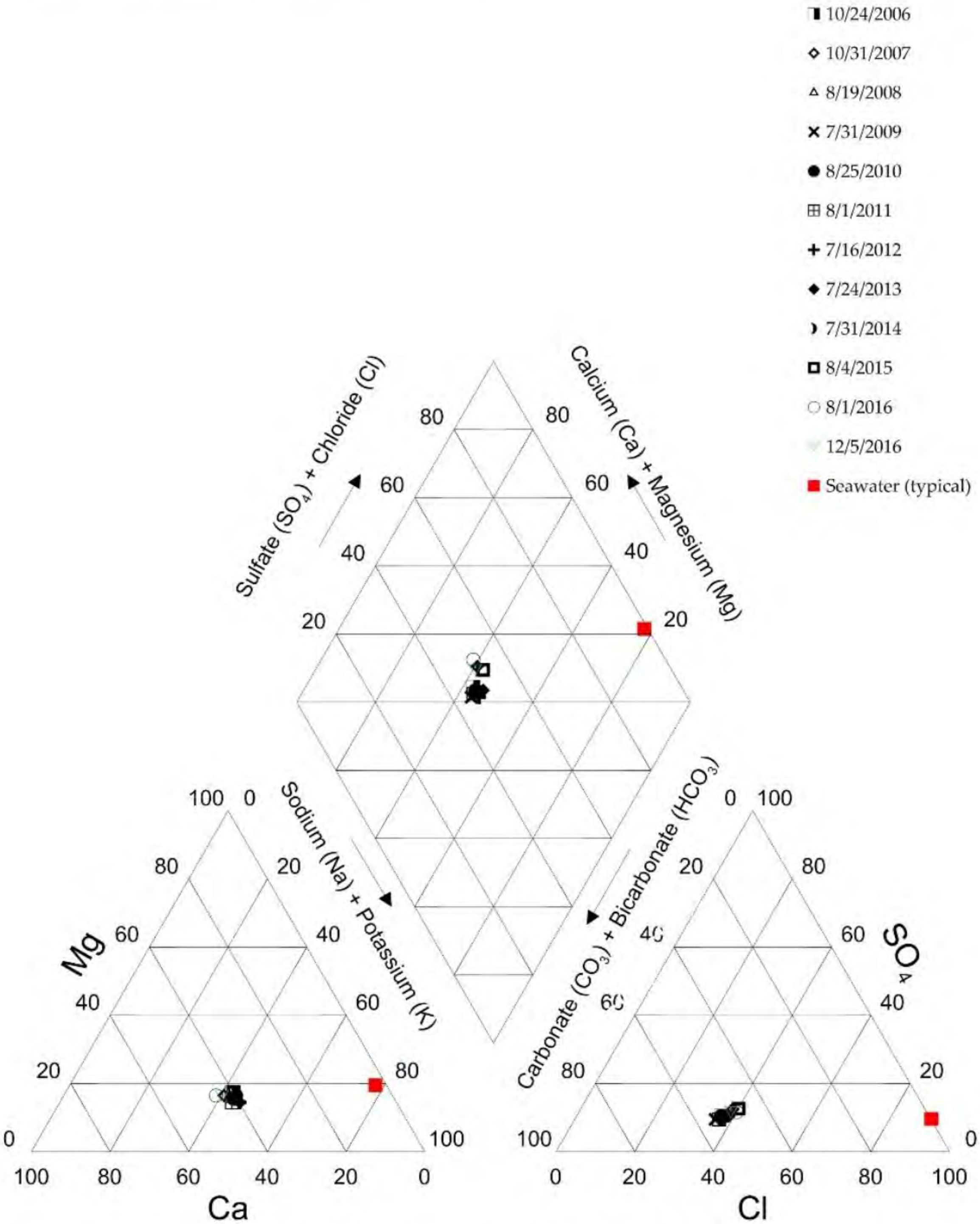

Figure 8: Piper Diagram for Ord Terrace Shallow

In the Pajaro Valley to the north, the evolution of groundwater quality from fresh to seawater intruded followed the paths indicated with red arrows on the piper diagram shown on Figure 9. In the Pajaro Valley, unintruded groundwater was of a calcium-bicarbonate type. During the initial phase of seawater intrusion in the Pajaro Valley, the dominant chemical change in groundwater was an increase in chloride concentrations, as evidenced by the plotted samples moving up towards the peak of the diamond in Figure 9. The expected increase in sodium concentrations only occurs later, as evidenced by the later samples moving down and to the right of the diamond in Figure 9. Groundwater samples from the Pajaro Valley did not exhibit an immediate sodium increase during the initial phase of seawater intrusion because of an ion exchange reaction in which sodium in the groundwater replaces the calcium on the clays; effectively taking sodium out of the groundwater and replacing it with calcium.

The groundwater quality evolution shown in Figure 9 is what we expect to see for any groundwater that is initially of a calcium-bicarbonate type. For wells starting off as a sodium-bicarbonate or sodium-chloride-bicarbonate water type, including wells SBWM-1, SBWM-2 and SBWM-4, it is unclear what the expected chemical evolution of groundwater will look like as seawater advances. To date, we have found no other examples of clearly documented seawater intrusion in these types of groundwater from which to examine whether calcium enrichment occurs or not in sodium-rich waters.

Sentinel Wells SBWM 1, 2 and 3 are completed in the Purisima Formation and have chloride concentrations that are typical of groundwater from that formation (Feeney, 2007). They also share a similar sodium-chloride-bicarbonate chemical character. Sentinel Well SBWM-4 is completed in the Santa Margarita Sandstone and has a different groundwater quality than the three sentinel wells completed in the Purisima Formation. Well SBWM4 has higher chloride concentrations and a stronger sodium-chloride character, which is consistent with wells completed in the Santa Margarita Sandstone (Feeney, 2007).

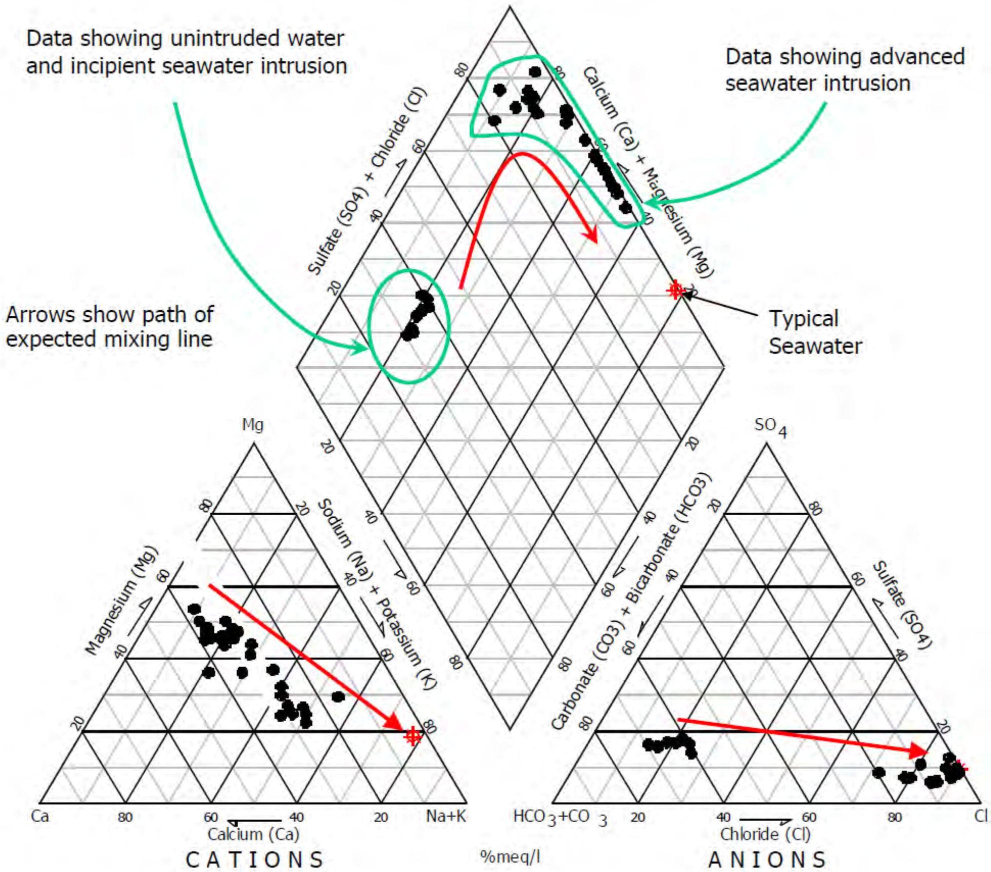

Figure 9: Piper Diagram for Groundwater in Pajaro Valley (Data source: PVWMA)

4.2.2. Stiff Diagrams

Stiff diagrams for SBWM-1 (1,470ft), SBWM-2 (1,390 ft), SBWM-4 (900 ft), and Ord Terrace Shallow are shown on Figures 10 and 11. Stiff diagrams for 2015 and 2016 are included to provide context, and show change over a two year period. All of the well's stiff diagrams for the December 2016 sample, except well SBWM-1 (1,390 ft)'s, are similar to historical diagrams before July 2016. Sentinel well SBWM-1 (1,390 ft)'s stiff diagram has a slightly different shape from previous years, but the shape of the stiff diagrams have varied over time for this well.

The stiff diagrams demonstrating what a seawater intruded sample might look like are provided on Figure 12. Comparing the stiff diagrams on Figure 10 and Figure 11 with Figure 12 reveals that none of the December sample's stiff diagrams are indicative of seawater intrusion, which is characterized on the stiff diagram as having calcium enrichment and a chloride spike. The stiff diagrams in Figure 12 came from locations where the native, unintruded groundwater was a calcium-bicarbonate type. It is unclear what the stiff diagrams of incipient seawater intrusion look like for areas where the native groundwater is of sodium-chloride or sodium-chloride-bicarbonate types.

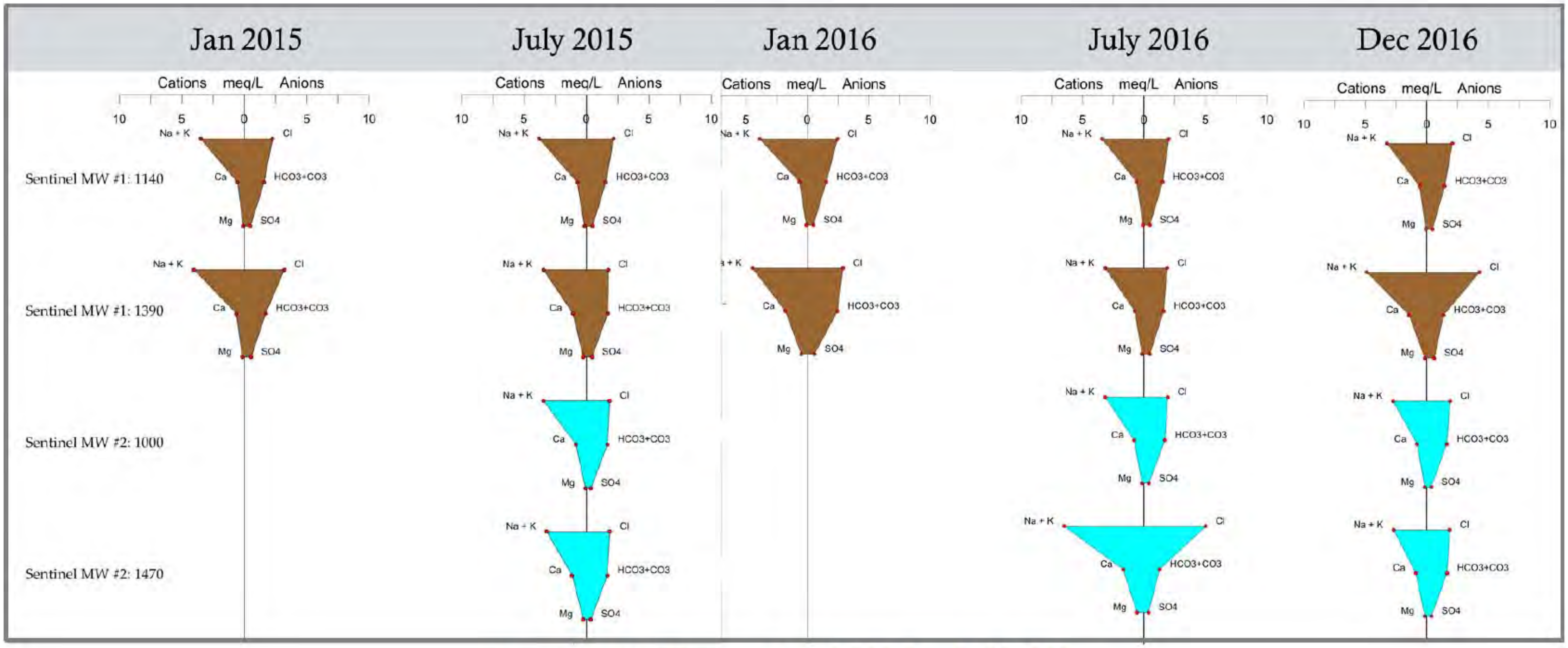

Figure 10: Stiff Diagram for SBWM-1 and SBWM-2

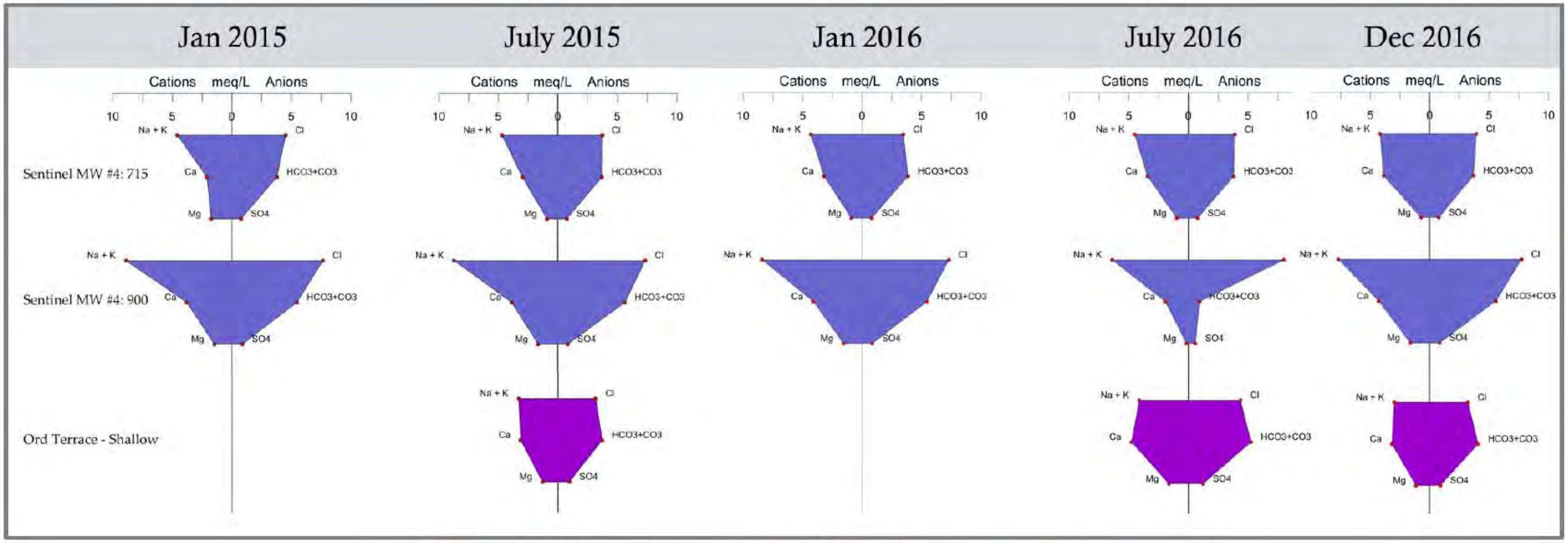

Figure 11: Stiff Diagram for SBWM-4 and Ord Terrace Shallow

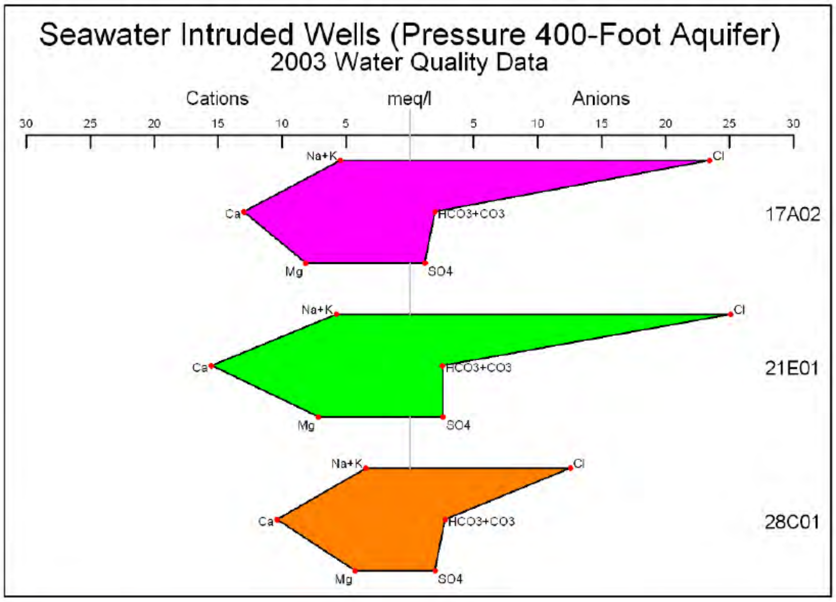

Figure 12: Stiff Diagrams from Salinas Valley Wells with Seawater Intrusion (Source: MWCRA)

5. Discussion of Results

5.1. Well SBWM-1 (1,390 ft)

Based on the piper diagram (Figure 6), and shape of the stiff diagram (Figure 10), the increased chloride concentration in the December 2016 sample is not clearly indicative of incipient seawater intrusion This well has experienced fluctuating chloride concentrations since 2014 (Figure 1) with higher chloride concentrations being observed in winter and lower concentrations in summer. Prior to 2014, its chloride concentrations were fairly stable. It is possible the observed chloride fluctuations are being controlled by seasonal groundwater elevation fluctuations, and that may or may not be attributable to seawater intrusion. This is discussed in more detail in Section 5.5. However, the increasing trend of chloride and significant drop in sodium/chloride ratios that indicated seawater intrusion was occurring in the nearby Salinas and Pajaro valley are not apparent.

5.2. Well SBWM-2 (1,470 ft)

The December 2016 sample, the chloride concentration in SBWM-2 (1,470 ft) returned to within the range of historical concentrations of less than 70 mg/L, following a reading of over 150 mg/L in the July 2016 sample. The piper (Figure 6) and stiff diagrams (Figure

10) both indicate that the anions and cations from the December 2016 sample returned to within their pre-July 2016 range. The high chlorides and anomalous sodium/chloride ratios observed in the July, 2016 sample may have been due to seasonal fluctuations, similar to what is observed in SBWM-1; or may have been the result of sampling/laboratory error. Continued monitoring of this well will determine whether seasonal fluctuations are responsible for the elevated chloride concentration observed in July 2016.

5.3. Well SBWM-4 (900 ft)

The 274 mg/L chloride concentration in SBWM-4 (900 ft) from December 2016 is above historical concentrations prior to July 2016 concentrations, but slightly lower than the July 2016 concentration of 284 mg/L (Figure 3). The piper (Figure 7) and stiff (Figure 11) diagrams for this well show that the anions and cations have returned to within the range of pre-July 2016 conditions. The anomalous anion and cation distribution observed in the July 2016 sample may have been due to seasonal fluctuations, similar to what is observed in well SBWM-1. This well has the highest chloride elevations of all the coastal monitoring wells and appears to have an increasing chloride trend (Figure 3).

5.4. Ord Terrace Shallow Well

The chloride concentration measured in the Ord Terrace Shallow well in December, 2016, returned to within its historical range of concentrations of less than 120 mg/L. In the 2016 SIAR, this well was ruled out as being potentially impacted by seawater because of its inland location, and because its piper and stiff diagrams did not indicate a seawater source of its anions and cations. The piper and stiff diagrams on Figure 7 and Figure 11, respectively, support this observation.

5.5. Trends and Fluctuations

The Seaside Basin Watermaster Seawater Intrusion Response Plan (SIRP) (HydroMetrics WRI, 2009) points out that:

> *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.*

Most of the coastal wells have low chloride concentrations and trends are difficult to identify at those low concentrations because the trends can be masked by natural variations in groundwater quality. However, we are starting to see an increasing trend in the well with the highest coastal chloride concentrations: SBWM-4.

The chloride fluctuations observed more recently in well SBWM-1 (1,390 ft) appear to be seasonal, with samples collected in January/February having higher concentrations than samples collected in July/August. It is apparent from groundwater level hydrographs of the coastal monitoring wells (Figure 13) that the current sampling periods do not correspond with seasonal low and high groundwater levels. Both sampling periods occur midway between the seasonal fluctuation in groundwater levels that occurs in response to groundwater pumping. It may be possible to identify the relationship between chloride concentrations and seasonal changes in groundwater elevations if samples were collected when the extreme low and high groundwater levels were occurring. However, this relationship likely results from a complex interplay of hydrogeologic structure and stratigraphy, pumping location, and seawater interface location.

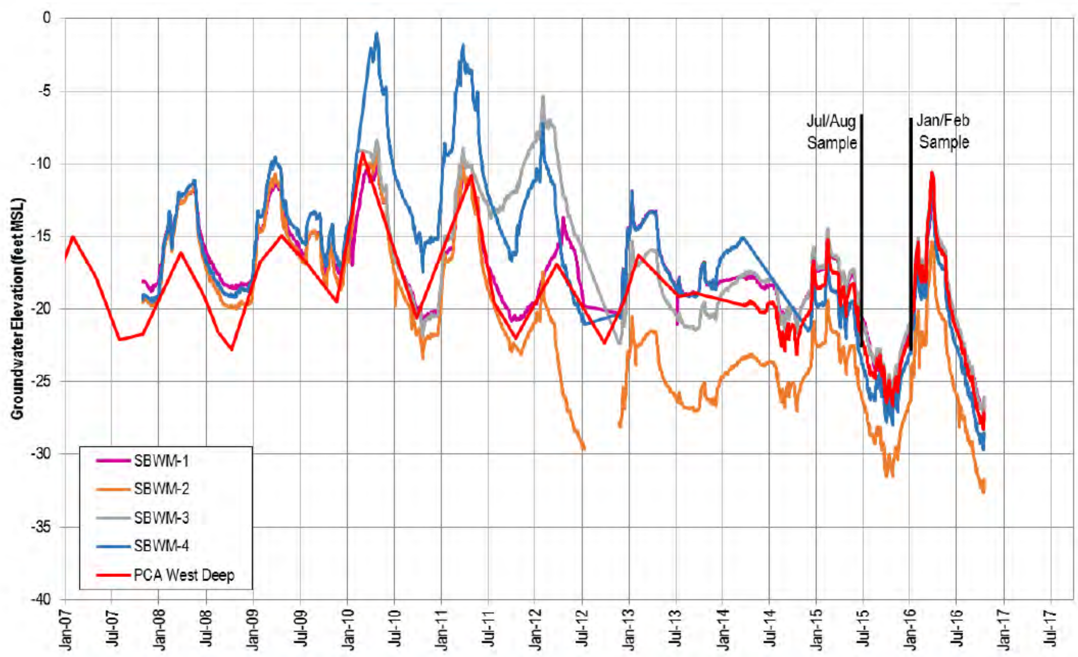

Figure 13: Hydrograph for Sentinel Wells and Monitoring Well PCA West Deep

An increasing chloride trend may underlie the seasonal fluctuations as evidenced by the slight increasing chloride trend even when the seasonal high concentrations are excluded from the trend line (Figure 1). If water quality is changing in response to seasonal groundwater elevation fluctuations, larger groundwater quality impacts may be seen in future fall months as groundwater levels continue to decline in the basin.

The types of analyses for the annual SIAR and this memorandum do not identify the source of the increased salinity or fluctuations. Potential sources of salinity may include natural groundwater quality variations, upwelling or upconing of saline water in wells in response to declining groundwater levels, seawater intrusion, or downward leakage of shallow, poor quality groundwater.

In the Seaside Basin, declining groundwater levels may be causing upwelling of saline water from the Monterey Formation which underlies the Santa Margarita Formation. This saline water, known as connate water, was trapped in the sediment pore spaces at the time of deposition and is known to cause increased salinity. For example, groundwater in the Laguna Seca subarea is more saline than the rest of the Seaside Basin due to the Monterey Formation.

Poorer quality water from shallow depths, migrating down the outside of the well casing is not likely a source of higher chloride concentrations in the sentinel wells because they are constructed with concrete/bentonite seals in the annular space between the formation and well casing that extend from the surface to at least 620 feet down. Mixing of poorer quality water within the well is also not considered a source of higher chlorides. Each sentinel well is sampled at two different depths. The samples taken from shallower depths do not have the same high chloride concentrations as those taken from deeper depths; so there is no apparent water mixing within the well.

The source of fluctuating chloride concentrations at the deeper depths of the sentinel wells should be investigated so that management options to protect the basin can be appropriately developed. For example, managing salinity from upwelling may require lower protective groundwater elevations than incipient seawater intrusion will require.

6. Electric Induction Logging

Induction logging measures the fluid conductivity up to a distance of three feet away from the well, within the formation adjacent to the well being logged. If conductivity increases relative to a baseline value over time, it indicates increased salinity. A 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 logs are run in the sentinel wells because they are deep wells screened at select depths. The induction logs provide qualitative salinity information throughout the entire well depth, including unscreened areas of the well. The groundwater grab samples taken within the screened intervals only provide groundwater quality at that particular screened depth.

Figure 14 through Figure 16 shows the initial induction logs for the entire length of wells SBWM-1, SBWM-2 and SBWM-4 when they were installed (blue), and for all induction logs run by Pacific Surveys since 2014. Welenco performed the logging between 2007 and 2013 but due to a different tool used by Pacific Survey, a new baseline was established in August 2014. To improve readability of the lower portion of the wells, Figure 17 and Figure 18 provide a zoomed in view with the logs overlain on one another.

The induction logs for well SBWM-1 shows there has been an increase in the shallow seawater intrusion zone above 450 feet depth since the well was constructed in 2007 (Figure 14). This intrusion was evident at the time SBWM-1 was constructed (HydroMetrics WRI, 2016). The deeper depths of well SBWM-1 show no clear evidence of increased salinity over time, although seasonal fluctuations are observed in the clays (zones with lower resistivity); summer conductivites (July 2015 and July 2016) plot close together and the conductivites in winter are more varied (Figure 17).

The induction logs for well SBWM-2 shows that there has been an increase in the shallow seawater intrusion zone above 300 feet depth since the well was constructed in 2007 (Figure 15). The logs show seasonal fluctuations in the clays (zones with lower resistivity), with similar conductivites in January 2015 and February 2016, and increased conductivites in summer (August 2014, July 2015 and July 2016) (Figure 17). At a depth of 1,470 feet within the screened sandy part of the aquifer (higher resistivity), the July 2016 conductivity is higher than all previous conductivities, except the initial log in 2007 (Figure 17). This might corroborate the higher chloride concentration observed in the July 2016 sample and rule out sampling/laboratory error for this sample.

At the 900 foot depth in well SBWM-4, it is difficult to see changes in conductivity because most of the logs plot too close together (Figure 18). These similar conductivities indicate that there has been no major increase in salinity at this depth. The seasonal fluctuations observed in SBWM-1 and SBWM-2 are not obvious in this well.

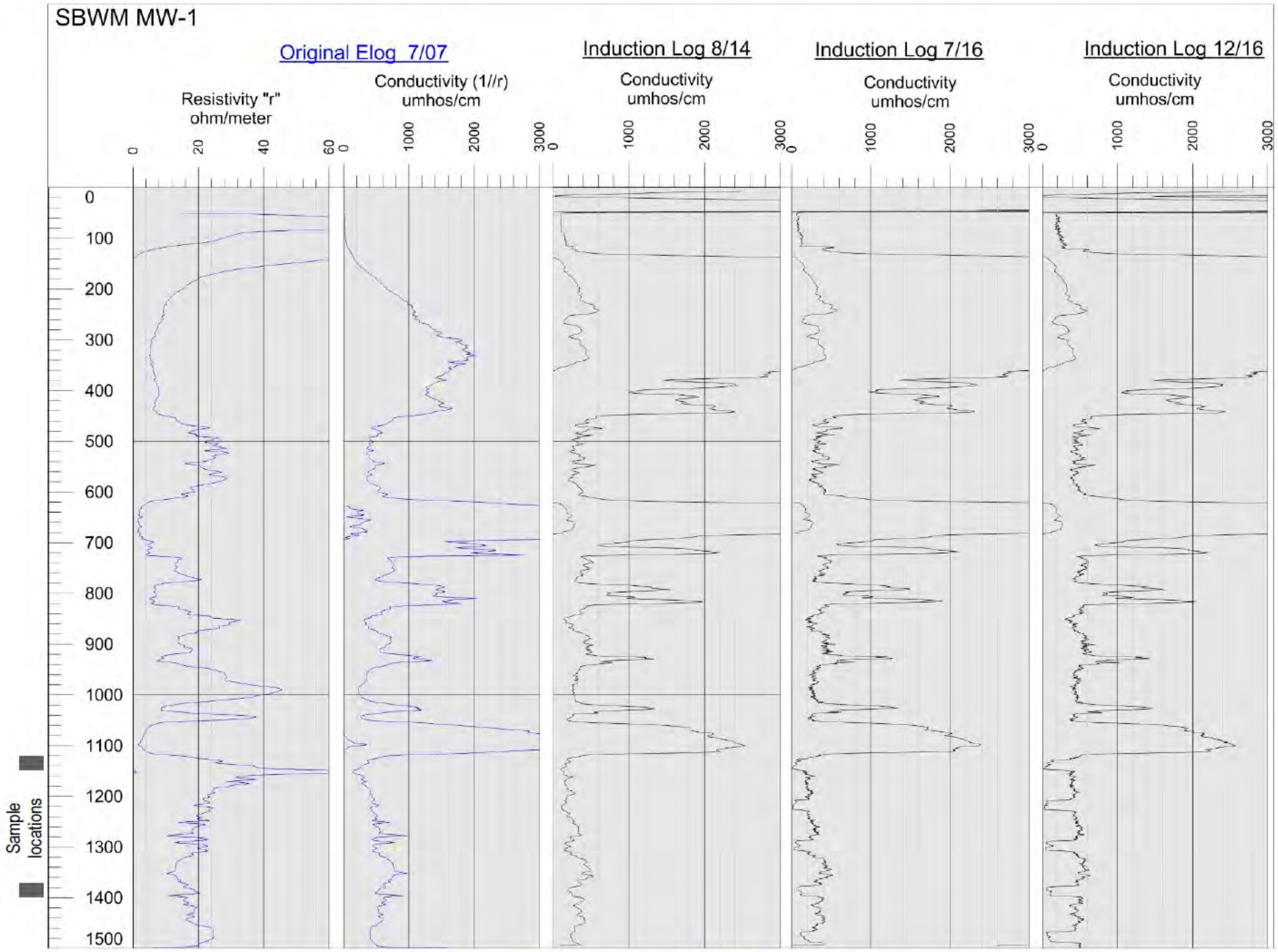

Figure 14: Sentinel Well 1 Induction Logs

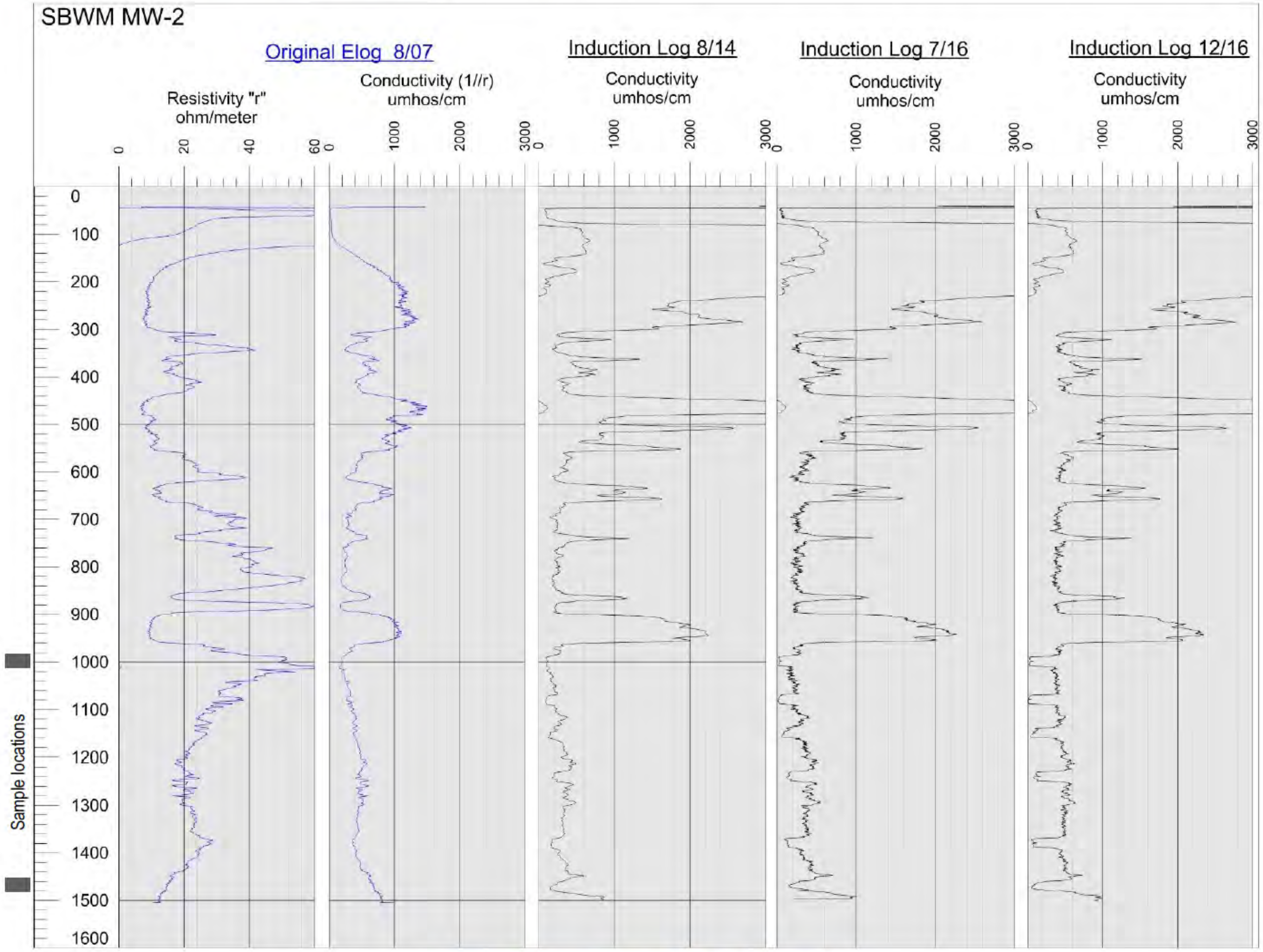

Figure 15: Sentinel Well 2 Induction Logs

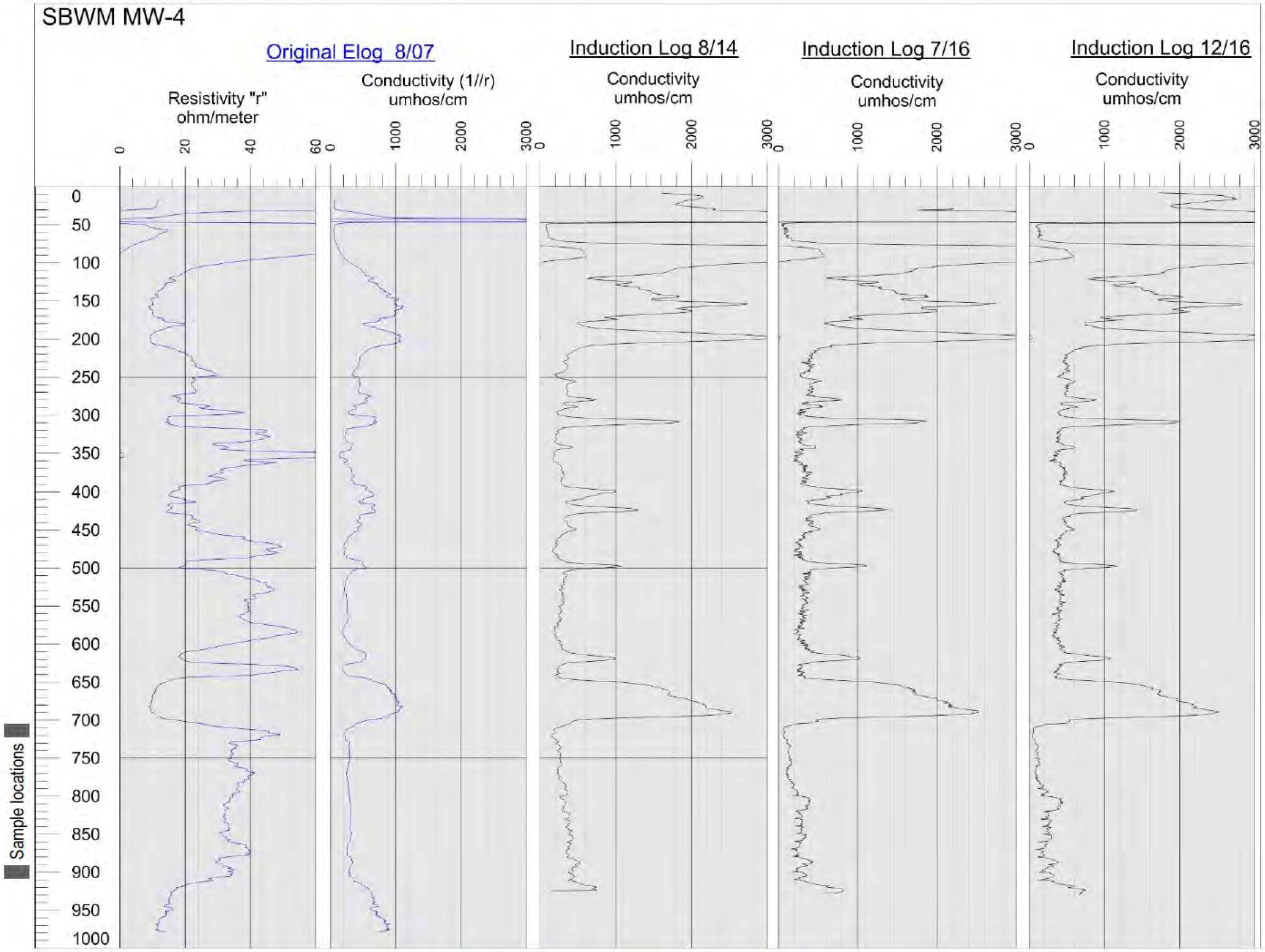

Figure 16: Sentinel Well 4 Induction Logs

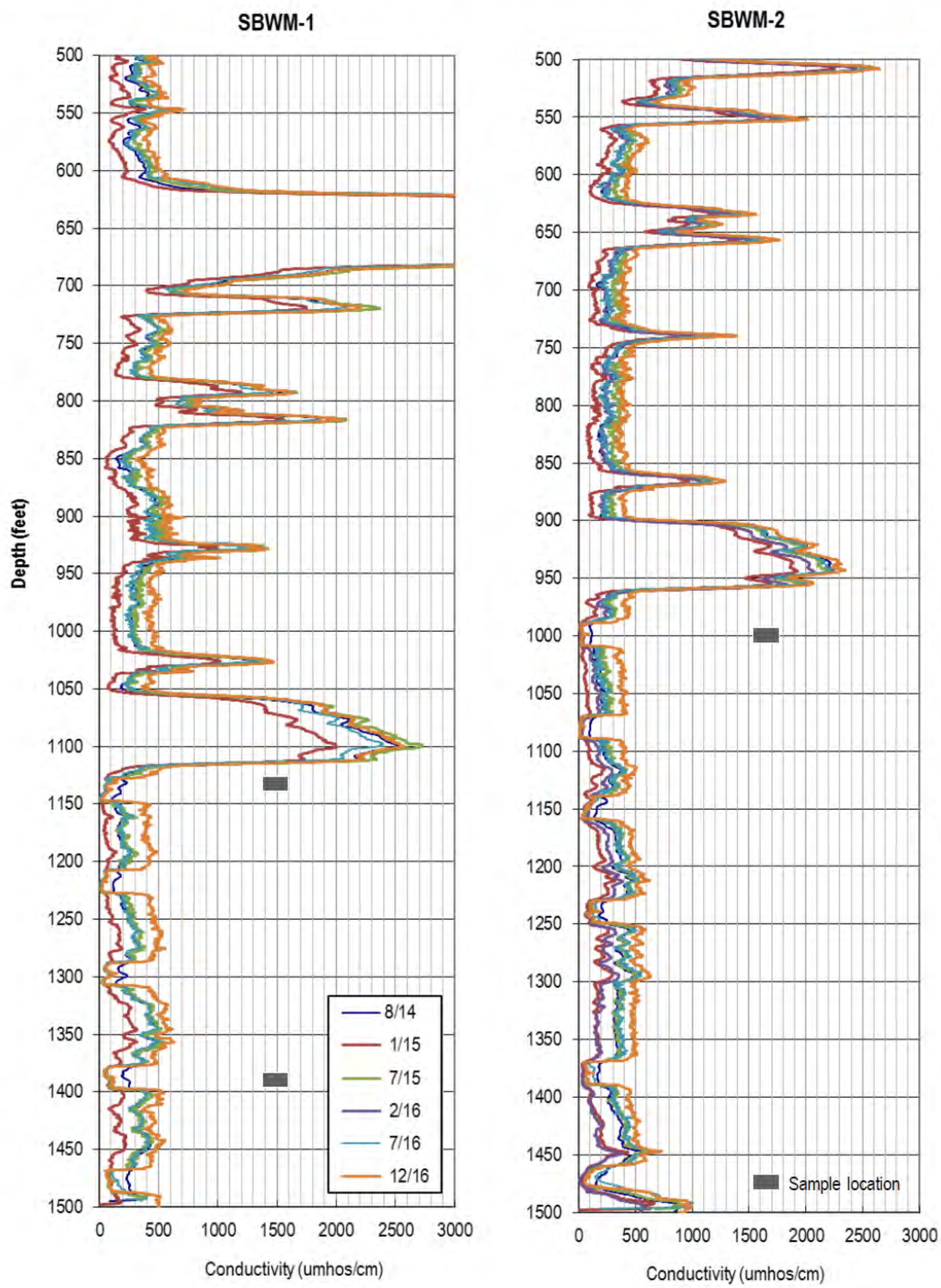

Figure 17: Induction Logs of Lowest 500 feet of Sentinel Wells 1 and 2

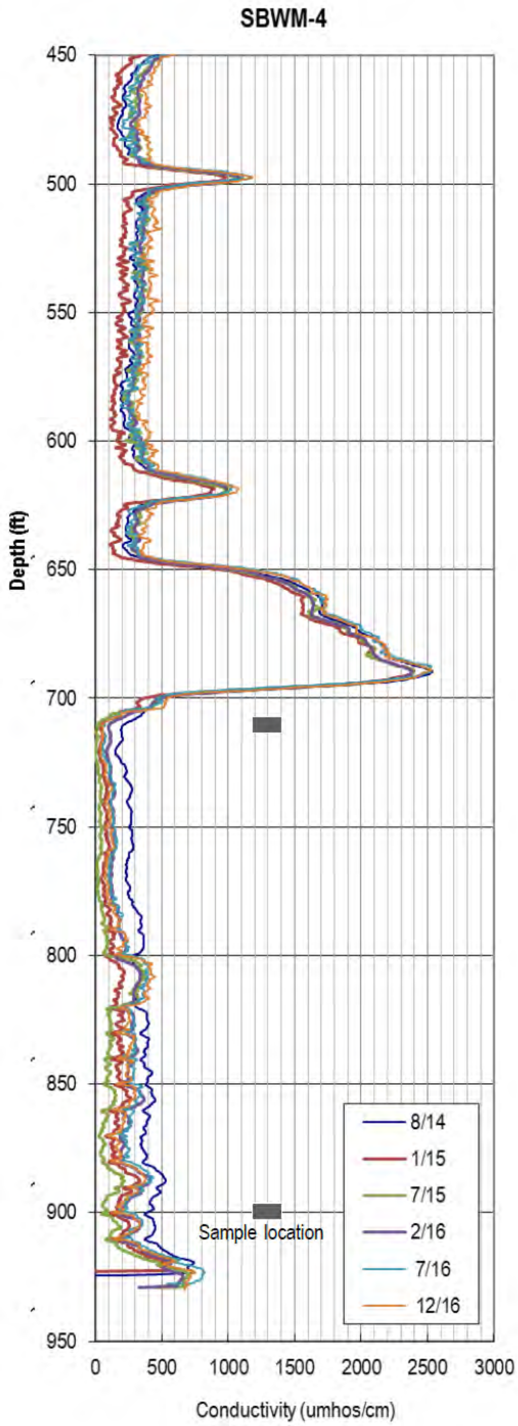

Figure 18: Induction Logs of Lowest 500 feet of Sentinel Well 4

7. CONCLUSIONS

1. None of the samples definitively indicate incipient seawater intrusion. However, variations in groundwater quality from samples collected over the last year from wells SBWM-1 and SBWM-4 necessitate continued vigilance and caution regarding potential changes to the Basin's groundwater quality.

2. Chloride concentrations at well SBWM-1 (1,390 ft) increased in December 2016 but the stiff diagram does not indicate that the anions and cations are much different from previous years. There is a very slight increasing chloride trend in this well.

3. Water quality at both well SBWM-2 (1,470 ft) and well SBWM-4 (900 ft) returned to within the range of historical groundwater quality observed in previous years.

4. Sentinel well SBWM- 4 (900 ft) has the highest coastal chloride concentrations and does appear to show an increasing chloride trend of approximately 5 mg/L per year since 2012. Although, this rate of increase is not significant, any increasing trend should continue to be monitored.

5. Monitoring well Ord Terrance Shallow chloride concentrations returned to the historic range. Its anions and cations both currently and historically do not indicate seawater chemistry.

6. There could possibly be some seasonal effects on groundwater quality in the deepest portions of the aquifer that may be related to seasonal groundwater elevation changes. If this is true and groundwater elevations continue to decline, larger impacts might be seen in the fall when groundwater levels are at their lowest.

7. The sources of increasing and fluctuating chlorides in wells SBWM-1 and SBWM-4 are unclear. Further investigation may provide evidence for the chloride source. Regardless of the source, the increasing and fluctuating chlorides likely result from chronically low groundwater levels.

8. Poorer quality water from shallow depths, migrating down the outside of the well casing is not likely a source of higher chloride concentrations in the sentinel wells because they are constructed with deep concrete/bentonite seals. Mixing of poorer quality water within the well is also not considered a source of higher chlorides at the deeper sample depths of the sentinel wells because the samples taken above the deepest samples do not have the same higher chloride concentrations.

9. While there is no evidence that errors occurred in the July 2016 sampling event, errors in collection, labeling, handling, and/or laboratory analyses of water

quality samples is always a possibility in complex sampling events such as these. Consequently, the possibly of such errors cannot be ruled out. Reanalysis of samples, and resampling as soon as possible when anomalous results are obtained will verify such concentrations.

8. Recommendations

1. Continue to sample SBWM-1 and SBWM-4 twice a year.
2. SBWM-2 should be resampled at the end of summer in 2017 and based on those results a decision should be made as to whether it should be sampled twice a year on an ongoing basis.
3. To determine if groundwater quality samples reflect the influence of fluctuating groundwater elevations, it is recommended that samples in the future be collected in the last week of September for the 4th quarter samples and in the first week of March for the 2nd quarter samples.
4. Prepare a work plan that will direct an effort towards identifying the source of fluctuating chloride concentrations. The work plan should outline the types of analyses and data to be used in identifying the chloride source. If the source of fluctuating chlorides is understood, it will help in developing management actions to prevent the higher concentrations increasing to the point that they cause groundwater degradation.
5. Conduct downhole conductivity and temperature profiles within each of the Sentinel Wells during the next sampling event. This tool measures the conductivity within the well, as opposed to induction logging which measures conductivity within the adjacent sediments. This technique may help identify if upwelling is occurring.
6. Continue the process that has recently been implemented to review water quality results as soon as they are received, rather than waiting until they are used to prepare the annual Seawater Intrusion Analysis Report. This will enable action to be taken, including reanalysis of samples, if appropriate, immediately instead of at the end of the year when the data have historically been analyzed.
7. Continue conducting all groundwater quality sampling and analysis conducted in accordance with standard quality assurance and quality control procedures. This includes submitting field blanks and duplicates samples to the laboratory once every couple of years.

9. References

Feeney, M.B., 2007. *Seaside Groundwater Basin Watermaster - Seawater sentinel wells project, summary of operations*, prepared for the Seaside Groundwater Basin Watermaster, October 2007.

HydroMetrics LLC, 2009. *Seawater intrusion response plan, Seaside basin, Monterey County, California*, prepared for the Seaside Groundwater Basin Watermaster, February 2009.

HydroMetrics Water Resources Inc., 2014. *Water year 2016 seawater intrusion analysis report*, prepared for the Seaside Groundwater Basin Watermaster, December 2016.