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April 3, 2012

Subject: Revised Protective Groundwater Elevations and Outflows for Aromas Area and Updated Water Balance for Soquel-Aptos Groundwater Basin

Ms Brown:

Our January 2009 report documented cross-sectional SEAWAT-2000 models used to estimate groundwater elevations at Soquel Creek Water District's (SqCWD) coastal monitoring wells that protect the basin from seawater intrusion (HydroMetrics LLC, 2009a). A subsequent letter on September 15 included the range of modeled coastal outflows that protect the basin from seawater intrusion after groundwater levels recover to protective elevations (HydroMetrics LLC, 2009b). The outflows needed to protect the Aromas area were incorporated into a water balance developed by Johnson et al. (2004) in an attempt to develop a post-recovery pumping yield for SqCWD in the Aromas area. The letter showed that it is unlikely that the Aromas area can be completely protected to the coast.

This letter report revises the protective groundwater elevations and coastal outflows for the Aromas area, based on protecting the basin at the coastal monitoring wells. The Johnson et al. (2004) water balance calculations for both the Aromas and Purisima areas are updated using the revised coastal outflows and other recently revised estimates for recharge and flows from the Aromas area to the Pajaro Valley. The updated Johnson et al. (2004) water balance is used to calculate SqCWD's post-recovery pumping yields for the Aromas and Purisima areas based on estimates of non-SqCWD consumptive use and return flow in the SqCWD service area.

## REVISED PROTECTION LOCATIONS FOR THE AROMAS AREA

The original protective elevations for the Aromas area were based on keeping the freshwater-saltwater interface at the coastline, at an elevation where the interface was historically observed in coastal monitoring wells. The interface was historically observed between the A and B screens in coastal monitoring wells, SC-A2, SC-A3, SC-A4, and SC-A8; which are located from 200 to 1,550 feet inland from the coast. Defining the protective location at the coastline results in a protective interface substantially below the well screens and the historic interface. Figure 1 shows an example of the original protective elevation; simulated by the yellow dot. This protective elevation is at the coastline, at an elevation between the SC-A2A and SC-A2B well screens. The modeled seawater-freshwater interface is slanted similar to the dashed line on Figure 1 so the interface is significantly below monitoring well SC-A2A using this protective elevation.

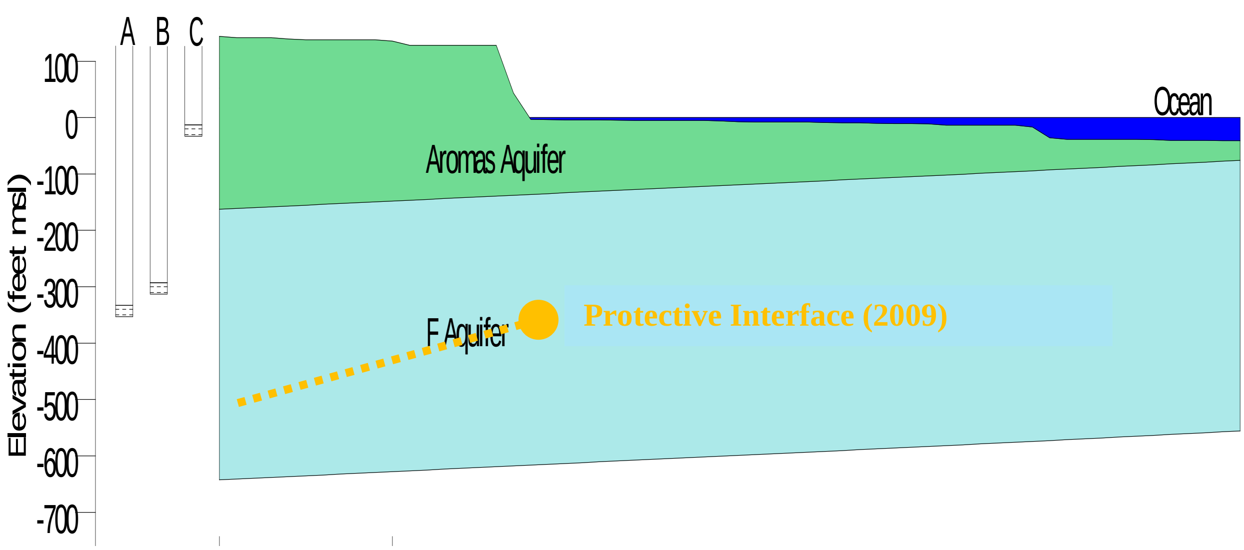


*Figure 1. Example of Protective Interface Modeled in 2009 (SC-A2)*

At its workshop on August 9, 2011, the Board of Directors decided to change the protective elevation location in the Aromas area to maintain the current interface location. The revised protective elevations are the heads at all but one of the SC-A coastal monitoring wells that will keep the interface within the A and B screen interval (Figure 2). The protective location for the SC-A1 well cluster is below the A screen because the interface has not been observed there. Storing water offshore from the Aromas area is no longer a goal.

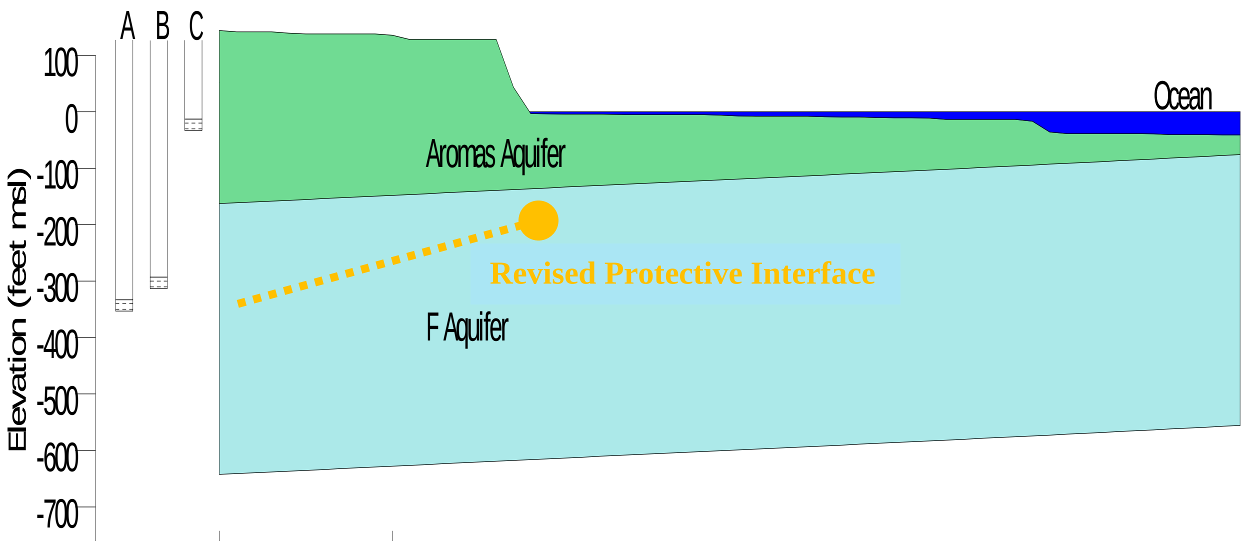


*Figure 2. Example of Revised Protective Interface (SC-A2)*

## IDENTIFYING THE PROTECTIVE INTERFACE IN THE AROMAS AREA

The existing interface at each of the coastal monitoring well clusters is defined by chloride concentrations in the A screen and B screen (Table 1). The interface at the SC-A1 well cluster has not been detected so the protective location is established below well SC-A1A. The protective elevations are the heads at the coastal monitoring wells that maintain the existing chloride concentrations in the A and B screens.

As described in the January 2009 report, protective elevations were estimated using the USGS code SEAWAT 2000. Although the model simulates a sharp interface, there is a transition zone due to numerical dispersion that approximates the brackish concentrations observed in the A and B screens. For each simulation, the concentrations at the bottom of the A and B screens were evaluated. In some cases, the head that maintains the interface at the A screen is different than the head that maintains the interface at the B screen. In this case, the higher of the two heads is considered the protective elevation.

*Table 1. Approximate Existing Chloride Concentrations for Defining Interface Location at Aromas Coastal Monitoring Wells*

| Well | A screen | | B screen | |
|---|---|---|---|---|
| | **Bottom Elevation (feet msl)** | **Chloride Concentration (mg/L)** | **Bottom Elevation (feet msl)** | **Chloride Concentration (mg/L)** |
| SC-A1 | -455 | <250 | -330 | <250 |
| SC-A8 | -408 | 7,000 | -318 | <250 |
| SC-A2 | -353 | 13,000 | -313 | 310 |
| SC-A3 | -207 | 18,000 | -167 | 3,000 |
| SC-A4 | -354 | 8,000 | -314 | <250 |

## REVISED PROTECTIVE ELEVATIONS IN THE AROMAS AREA

As discussed in the January 2009 report, the cross-sectional model for each coastal monitoring well was run with 100 reasonable parameter sets of aquifer and aquitard conductivities. This results in a range of 100 protective elevations. Table 2 shows the revised distribution of protective elevations for Aromas monitoring wells by percentile.

*Table 2. Distribution of Protective Elevations at Aromas Monitoring Wells (feet msl)*

| Percentile | SC-A1 | SC-A8 | SC-A2 | SC-A3 | SC-A4 |
|---|---|---|---|---|---|
| 50 | 2 | 5 | 2 | 2 | 2 |
| ***70*** | ***3*** | ***6*** | ***3*** | ***3*** | ***3*** |
| 80 | 3 | 6 | 3 | 3 | 3 |
| 90 | 5 | 6 | 3 | 4 | 3 |
| 100 | 5 | 7 | 3 | 4 | 4 |

The January 2009 report suggested using the 70$^{th}$ percentile to establish the protective elevation. This elevation is protective for at least 70% of the cross-sectional model runs. SqCWD has adopted the 70$^{th}$ percentile elevations as protective elevations. For the revised protective locations, we still recommend using the 70$^{th}$ percentile elevation as the management objective. This recommendation can be modified in the future; if the interface continues to move inland when the groundwater elevation objective is achieved over consecutive years, the protective elevation can be revised upward.

## COMPARING OBSERVED GROUNDWATER LEVELS TO PROTECTIVE ELEVATIONS IN THE AROMAS AREA

In the most recent Annual Report and Review (HydroMetrics WRI, 2011a), observed groundwater levels at the B screens of the Aromas coastal monitoring wells were compared to protective elevations. The new protective elevations are selected to maintain the interface in both the A and B screens. Therefore, observed groundwater levels in both screens should be compared to protective elevations.

Measured groundwater levels must be adjusted to account for salinity before they are compared to protective elevations. The protective groundwater elevation estimated by SEAWAT-2000 is the freshwater equivalent head (Langevin and others, 2003). The freshwater equivalent head for groundwater with a substantial amount of salinity is higher than the observed groundwater levels due to the higher density of saline water. Attachment 1 documents the saltwater adjustments for the Aromas monitoring wells, and shows hydrographs with freshwater equivalent heads.

Hydrographs in Attachment 1 compare historical observations to protective elevations. The hydrographs show that freshwater equivalent heads in the A screens of the SC-A2, SC-A3, and SC-A4 wells have been below protective elevations; and recovery at these wells is required to protect this part of the basin. The chemographs in Attachment 1 show the long-term rise in salinity at these wells. The hydrographs show freshwater equivalent heads at SC-A1 and SC-A8 have been above protective elevations. The chemographs for SC-A1 show no seawater intrusion at that location and no increase in salinity at SC-A8 since its 2007 installation.

## REVISED PROTECTIVE OUTFLOWS IN THE AROMAS AREA

The freshwater outflows at the coast simulated by the cross-sectional models are evaluated using the same method as for our September 2009 letter (HydroMetrics LLC, 2009b). Cross-sectional outflows are multiplied by the width each cross-sectional model represents as defined by the midpoints between wells and the study area boundary (Figure 3). The protective outflow for each of the 100 parameter sets is the outflow that is required to maintain the protective elevation for that set. . Groundwater levels in the wells must recover to the protective elevation, however, before the identified outflow is protective. Summarizing the results of all parameter sets provides a range of 100 protective outflows. Table 3 shows the revised distribution of protective coastal outflows for Aromas monitoring wells by percentile.

*Table 3. Distribution of Protective Coastal Outflows at Aromas Monitoring Wells (acre-feet per year)*

| Percentile | SC-A1 | SC-A8 | SC-A2 | SC-A3 | SC-A4 | Aromas |
|---|---|---|---|---|---|---|
| 50 | 50 | 475 | 100 | 350 | 50 | 1,025 |
| ***70*** | ***75*** | ***725*** | ***250*** | ***775*** | ***125*** | ***1,950*** |
| 80 | 100 | 800 | 275 | 875 | 150 | 2,200 |
| 90 | 150 | 900 | 275 | 1000 | 175 | 2,500 |
| 100 | 225 | 1050 | 300 | 1375 | 250 | 3,200 |
| **Cross-Sectional Width** | 5,010 | 3,818 | 4,011 | 5,257 | 3,232 | |

As with the protective elevations, we recommend that the 70th percentile of protective outflows be used for establishing post-recovery pumping yields as planning guidelines. These goals are meant to maintain protection of the Aromas and Purisima areas from seawater intrusion after groundwater levels recover to protective elevations. However, unlike groundwater elevations, it will be difficult to measure and quantify the coastal outflows in the field, especially given the uncertainties in other components of the water balance. Pumping yields should be updated based on how pumping affects groundwater levels during and after recovery to protective elevations.

## NEW WATER BALANCE INFORMATION

HydroMetrics LLC's September 2009 letter used the protective outflows in water balance calculations for the Purisima and Aromas areas to estimate SqCWD's post-recovery pumping yields to protect the basin from seawater intrusion after groundwater levels recover to protective elevations. New information about components of the water balance has become available since 2009. The PRMS recharge model (HydroMetrics WRI, 2011b) provides recharge estimates for both the Purisima and Aromas areas, which are applied to the water balance.


*Figure 3: Cross-Sectional Widths of Coastal Monitoring Well Models*

There are several methods available to estimate flows between the Aromas area and Pajaro Valley. Estimates extracted from the Pajaro Valley Hydrologic Model (US Geological Survey, unpublished) and Central Water District DWSAP model (Johnson, 2009) were evaluated for inclusion in the water balance. Johnson et al. (2004) used the estimated gradient from a groundwater level contour map to estimate flow from the Aromas area to the Pajaro Valley. This general approach is applied to groundwater level contour maps from multiple years to provide an estimate for the water balance.

**PRMS RECHARGE MODEL ESTIMATE FOR AROMAS**

The PRMS recharge model estimated average annual recharge in the Aromas Red Sands outcrop portion of the Johnson et al. (2004) study area (Figure 4) to be 4,200 acre-feet per year between Water Years 1984 and 2009 (HydroMetrics WRI, 2011). This total includes 1,600 acre-feet per year from the east bank of the Valencia Creek watershed. The September 2009 report estimated annual Aromas area recharge of 2,900 acre-feet per year, based on an estimate in Johnson et al. (2004). The Johnson et al. estimate only included 10% (113 acre-feet per year) of the Valencia Creek watershed with the Aromas recharge. The updated water balance will incorporate the result from the PRMS model, which is calibrated and uses mapped outcrop areas for the Aromas.

Both the Aptos Jr. High well and the Polo Grounds well are in the east bank of the Valencia Creek Watershed. Because the east bank of the Valencia Creek watershed is included with the Aromas area recharge estimates, we include pumping from the Aptos Jr. High and the Polo Grounds production wells as part of SqCWD's pumping in the Aromas area.

**PRMS RECHARGE MODEL ESTIMATE FOR PURISIMA**

The PRMS recharge model estimated average annual recharge in the Purisima Formation outcrop portion of the Johnson et al. (2004) study area (Figure 4) to be 6,600 acre-feet per year between Water Years 1984 and 2009 (HydroMetrics WRI, 2011). The September 2009 report estimated annual Purisima Formation recharge of 6,100 acre-feet per year based on data in Johnson et al. (2004). The PRMS recharge study report corrected the Johnson et al. calculation to 7,000 acre-feet. The PRMS recharge model includes the west bank of the Valencia Creek watershed in the Purisima, while the Johnson et al. calculation includes 90% of the Valencia watershed in its Purisima estimate. The updated water balance will

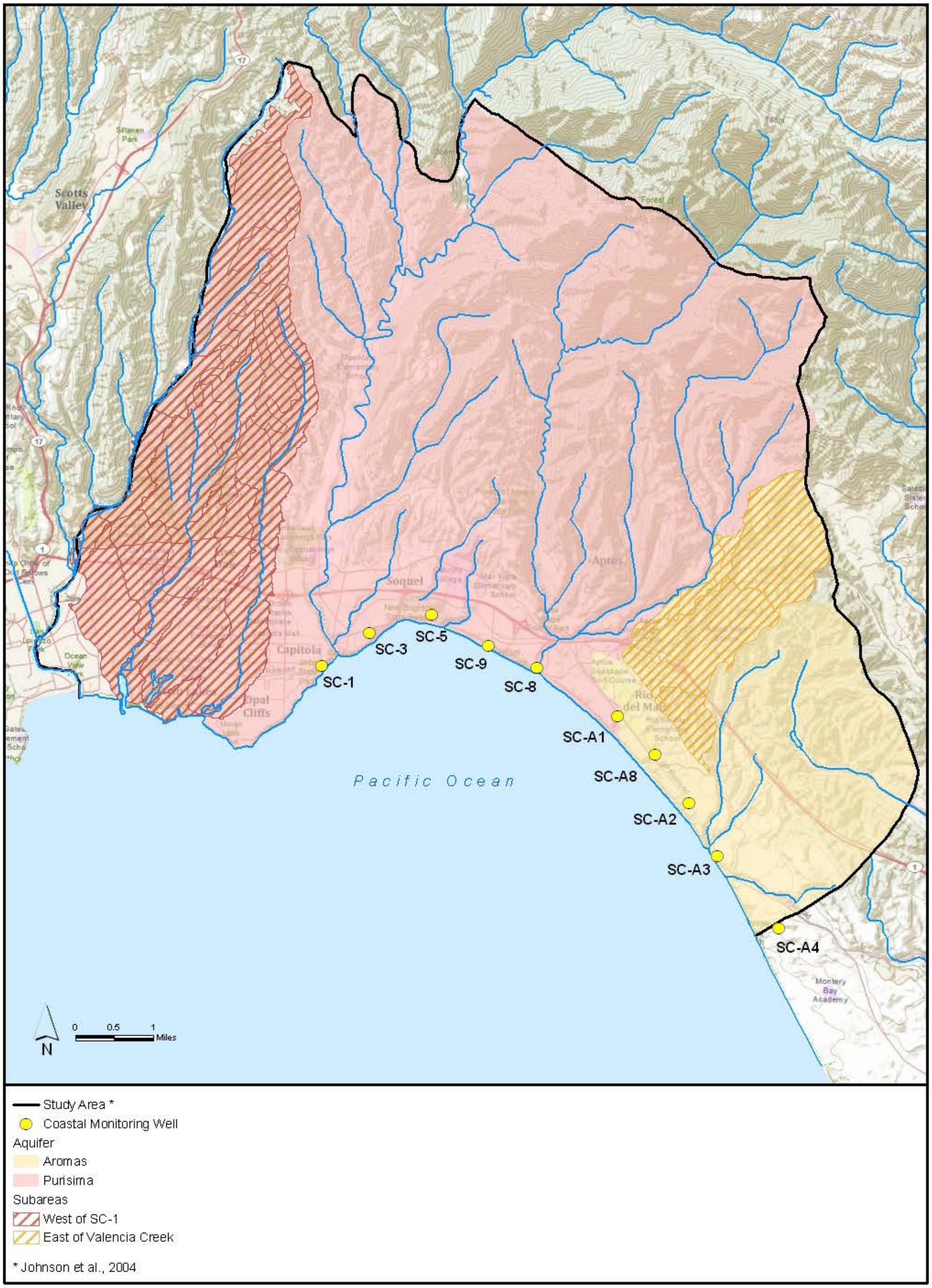


*Figure 4. Aromas and Purisima Outcrop Areas in PRMS Recharge Model*

incorporate the result from the PRMS model, which is calibrated and uses mapped outcrop areas for the Purisima.

As in the September 2009 report, a geographic issue arises when using Purisima recharge estimates. SqCWD does not have coastal monitoring wells west of monitoring well cluster SC-1 (Figure 4). The PRMS recharge model estimates average recharge for the area west of the SC-1 cross-sectional model boundary as 1,200 acre-feet per year. This amount is subtracted from the recharge estimate for the Purisima outcrop area; leaving an estimated recharge of 5,400 acre-feet per year for the Purisima area water balance.

## PAJARO VALLEY HYDROLOGIC MODEL'S AROMAS AREA WATER BUDGET

The U.S. Geological Survey has developed a MODFLOW model for the Pajaro Valley. The final report documenting the Pajaro Valley Hydrologic Model (PVHM) has not been published. HydroMetrics WRI has obtained a draft version of the model, and has used it to evaluate the simulated water budget for the area overlapping the Johnson et al. (2004) study area in the Aromas (blue Water Budget Zone 1 in Figure 5). Table 4 shows the annual average water budget components for the PVHM simulation of Water Years 1969 through 2009. Both the water budget components for the PVHM from ground surface to the bottom of the Aromas Red Sands, and the water budget components for the entire model thickness including the Purisima Formation are shown. The water budget components excluding the Purisima are more similar to what was presented to the Board at its August 9 workshop. However, it is more appropriate to evaluate the entire model thickness because SqCWD's Aromas area production wells are screened in the Purisima Formation as well as the Aromas Red Sands, and the existing interface is located in the Purisima.

The PVHM's estimated recharge of 937 acre-feet per year is substantially less than the approximately 2,500 acre-feet per year estimated by the PRMS recharge model. However, the PVHM model estimates average total freshwater inflows to the Aromas area (Zone 1) as approximately 3,400 acre-feet per year. The total inflow into the Aromas area is much greater in the PVHM than the recharge from the PRMS model. As a result, overall outflow in the PVHM is greater, and suggests that components such as net outflow to the Pajaro Valley should not be combined with PRMS recharge estimates in an update of the Johnson et al. (2004) water balance.

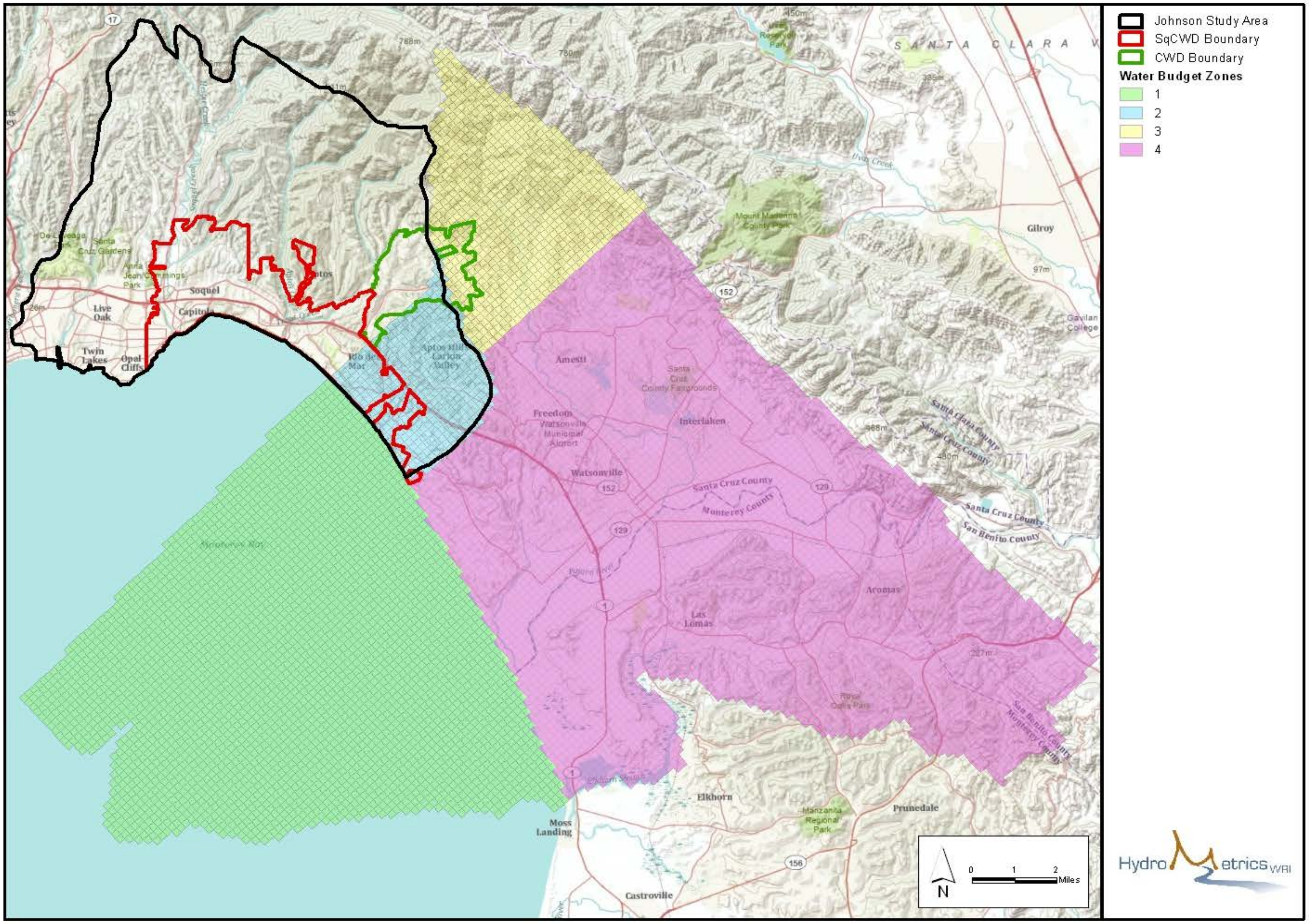


*Figure 5. Pajaro Valley Hydrologic Model Water Budget Zones*

*Table 4. Annual Average Water Budget Components for Aromas Area Simulated by Pajaro Valley Hydrologic Model*

| **Water Budget Component** | **Annual Average Flow (acre-feet per year)** | |
|---|---|---|
| | **Ground Surface to Bottom of Aromas** | **Entire Model Thickness, Including Purisima** |
| Inflows | | |
| Recharge Inflow to Zone 1 | 937 | 937 |
| Net Western Boundary Inflow to Zone 1 | 1,005 | 2,137 |
| Net Northern Hills Inflow from Zone 3 to Zone 1 | 649 | 329 |
| Offshore Inflow from Zone 2 to Zone 1 | 363 | 512 |
| Outflows | | |
| Offshore Outflow from Zone 1 to Zone 2 | 204 | 297 |
| Net Outflow to Pajaro Valley from Zone 1 to Zone 4 | 1,196 | 1,854 |

Despite the large amount of inflow estimated by the PVHM for the area, the average offshore outflow estimated by PVHM is less than the 1,950 acre-feet per year suggested as the protective outflow for the Aromas area. This is consistent with the general understanding that the area is in overdraft and offshore outflow needs to be increased to protect the area from further intrusion.

Directly using a groundwater model such as PVHM to evaluate pumping yield is also possible. However, additional calibration of the PVHM in the Aromas area would be necessary to apply the model for this purpose. Calibration of the PVHM in the Aromas area was not a priority in its development; the primary use of the model is to evaluate groundwater management activities in the Pajaro Valley.

The annual flows simulated by the PVHM do not substantially change in the years since Pajaro Valley Water Management Agency initiated the Harkins Slough Aquifer Storage and Recovery Project (started 2001). The PVHM only simulates several months of the Watsonville Area Water Recycling Project (started April 2009) so the effect of that project has not been identified in the model results.

## CENTRAL WATER DISTRICT DWSAP MODEL WATER BUDGET

Johnson (2009) developed a steady-state MODFLOW model for Central Water District (CWD) to estimate capture zones, as part of the Drinking Water Source Assessments (DWSAP) for CWD's wells. One of Johnson's recommendations for further work was to analyze the simulated water budget, specifically outflows to the Pajaro Valley and the ocean. CWD provided HydroMetrics WRI with the model to perform this analysis. We approximated similar water budget zones in the CWD model (Figure 6) to those used for PVHM (Figure 5) and analyzed the budget for the Aromas area (blue zone in Figure 6). Table 5 shows the annual average water budget components for CWD DWSAP steady-state simulation.

The CWD DWSAP model's estimate for the Aromas area recharge is slightly less than the 2,500 acre-feet estimated by the PRMS recharge model, but overall inflow is substantially higher. As a result, overall outflow is greater and suggests that components such as net outflow to the Pajaro Valley should not be combined with PRMS recharge in an update of the Johnson et al. (2004) water balance.

The CWD DWSAP model estimates that all flow at the ocean is outflow. The model generally simulates heads at coastal monitoring wells that are higher than historical observations. More accurate calibration at the coast was not necessary for using the model to develop capture zones at the CWD production wells. Johnson (2009) recommends a more quantitative calibration as an area of further improvement. Such an effort would be necessary to use the CWD DWSAP model to evaluate pumping yield.

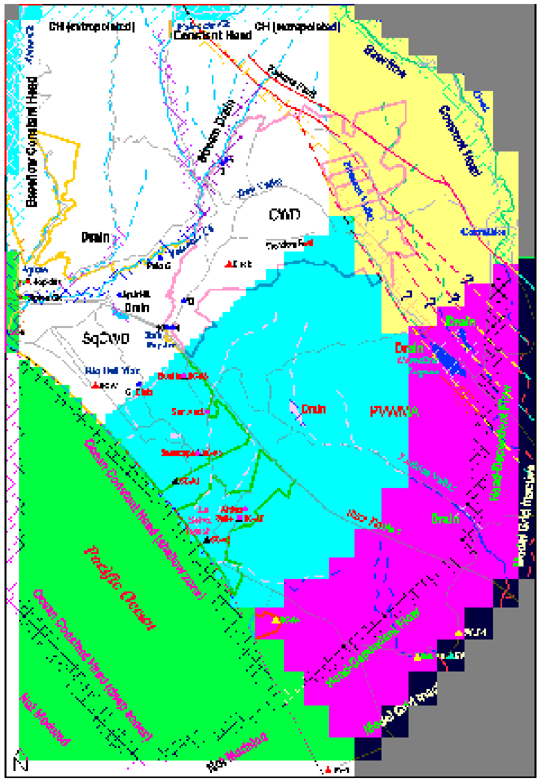


*Figure 6. Central Water District DWSAP Model Water Budget Zones*

*Table 5. Annual Average Water Budget Components for Aromas Area Simulated by Central Water District DWSAP Model*

| **Water Budget Component** | **Annual Average Flow (acre-feet per year)** |
|---|---|
| Inflows | |
| Recharge Inflow to Blue Zone | 1,974 |
| Net Western Inflow from White Zone to Blue Zone | 1,475 |
| Net Northern Inflow from Yellow Zone to Blue Zone | 745 |
| Offshore Inflow from Green Zone/Ocean Constant Heads to Blue Zone | 0 |
| Outflows | |
| Offshore Outflow from Blue Zone to Green Zone/Ocean Constant Heads | 954 |
| Net Outflow to Pajaro Valley from Blue Zone to Violet Zone | 1,669 |

## USING GROUNDWATER LEVEL CONTOUR MAPS TO ESTIMATE FLOW TO PAJARO VALLEY

Johnson et al. (2004) estimated outflow to the Pajaro Valley based on an autumn 1991 groundwater level contour map (Luhdorff and Scalmanini, 1996). Johnson et al. concluded that the map shows a gradient (i) of approximately 3 x $10^{-4}$ feet/feet from the Aromas area to the Pajaro Valley. Using the maximum transmissivity (T) of 10,000 $ft^2$ per day and a flow width (W) of 20,000 feet, Johnson et al. estimated the outflow as 500 acre-feet per year using the Darcy's Law equation Q= T x W x i. Johnson et al. assumed that drought conditions similar to 1991 would occur once every five years; and therefore adopted a long-term average outflow to the Pajaro Valley of 100 acre-feet per year.

In order to refine this estimate, we used the same equation to calculate flow across the boundary between the Aromas area and Pajaro Valley based on groundwater level contour maps produced by the Pajaro Valley Water Management Agency (PVWMA) for its annual reports (PVWMA, 1993, 2007, 2009, 2010, 2011). However, the method for calculating the gradient across the boundary is different from Johnson et al. (2004). PVWMA provided Geographic Information System (GIS) shapefiles for autumn 1992, 2006, 2008, 2009, and 2010 contour maps. This allowed us to estimate the gradient from the Aromas area to the Pajaro Valley for these maps using ArcGIS Spatial Analyst software with the following steps:

1. Interpolated the contours to a 100 meter grid of groundwater elevations.
2. For each grid cell, calculated the magnitude and direction of the groundwater gradient.
3. For each grid cell intersecting the boundary, calculated the direction of the boundary at that cell.
4. For each grid cell intersected by the boundary between the Aromas area and the Pajaro Valley, used trigonometry to calculate the component of the groundwater gradient that is perpendicular to the direction of the boundary at the cell. We used the component of the gradient perpendicular to the boundary instead of the full gradient magnitude because the length of the boundary defines the aquifer width, W. Figure 7 shows the results of this calculation for the 1992 contour map (blue indicates flow to Pajaro Valley and green indicates flow to the Aromas area).

5. Averaged the components of the gradients perpendicular to the boundary for all cells along the boundary to obtain the average groundwater gradient perpendicular to the boundary.

The contour maps for 2006 and 2010 with the results of the calculation in step 4 are provided as Attachment 2. The calculation was not completed for the 2008 and 2009 contour maps, which are also included in Attachment 2. The contour map for 2008 shows a pattern of flow inconsistent with the other maps and maps for the Aromas area in the Soquel-Aptos Annual Review and Report (HydroMetrics WRI, 2011a). The contour map for 2009 shows three contours equaling zero across the boundary, which represent a flat gradient along the boundary that could not be accurately interpolated.

The calculated gradients (i) for the 1992, 2006, and 2010 contour maps are shown in Table 6. Using the range of transmissivities (T) for the Aromas Red Sands of 1,200 – 10,000 $ft^2$ per day (Johnson et al., 2004) and the boundary length (W) of 16,354 feet using the equation $Q = T \times W \times i$, flow from the Aromas area to the Pajaro Valley is estimated and shown in Table 6.

The estimated gradient and flow for the drought year 1992 is higher than the Johnson et al. (2004) estimates for the drought year 1991. These two years occur at the end of the 1987-1992 drought; and therefore these contour maps do not represent typical flow patterns.

The 2006 and 2010 contour maps represent more typical flow patterns and show relatively flat gradients across the basin boundary. The 2009 contour map also shows a flat gradient at the basin boundary, in a year representing the end of a relatively dry period.

The gradient across the basin boundary will increase as SqCWD raises coastal water levels to prevent seawater intrusion. This will increase the flow from the Soquel-Aptos basin into Pajaro Valley. To estimate this increased flow, we modified the typical flow patterns of 2006 and 2010 by adding a protective 3-foot groundwater elevation contour at the coastal monitoring wells SC-A2, SC-A3, and SC-A4. The resulting estimated gradients are shown in Table 6. The modified contour map for 2010 is shown in Figure 8 with the gradient calculation along the boundary between the Aromas area and Pajaro Valley (blue indicates flow to Pajaro Valley and green indicates flow to the Aromas area). Attachment 2 includes the modified contour map for 2006.

*Table 6. Groundwater Level Gradient and Estimated Flow from Aromas Area to Pajaro Valley Calculated from PVWMA Contour Maps*

| Year | Gradient ft/ft | Flow Based on Minimum Transmissivity acre feet per year | Flow Based on Maximum Transmissivity acre feet per year | Annual Rainfall Compared to Average |
|---|---|---|---|---|
| 1992 | $1.2 \times 10^{-3}$ | 200 | 1700 | 6th Consecutive Year Below Average |
| 2006 | $-2.8 \times 10^{-4}$ | -50 | -380 | 2nd Consecutive Year Above Average |
| 2006 with recovery | $-2.3 \times 10^{-4}$ | -40 | -310 | |
| 2008 | Pattern of flow inconsistent with other maps | | | 2nd Consecutive Year Below Average |
| 2009 | Flat gradient along boundary could not be accurately interpolated | | | 3rd Consecutive Year Below Average |
| 2010 | $1.4 \times 10^{-4}$ | 20 | 190 | 1st Year Above Average After 3 Years Below Average |
| 2010 with recovery | $2.7 \times 10^{-4}$ | 40 | 370 | |

Based on the revised 2006 contours, groundwater continues to flow from Pajaro Valley towards the Aromas area. Based on the revised 2010 contours, however, groundwater flow increases from the Aromas area towards Pajaro Valley. For the water balance, we conservatively use the maximum flow of 370 acre-feet per year towards Pajaro Valley based on 2010 contours, as modified with protective elevations at the Aromas coastal monitoring wells.

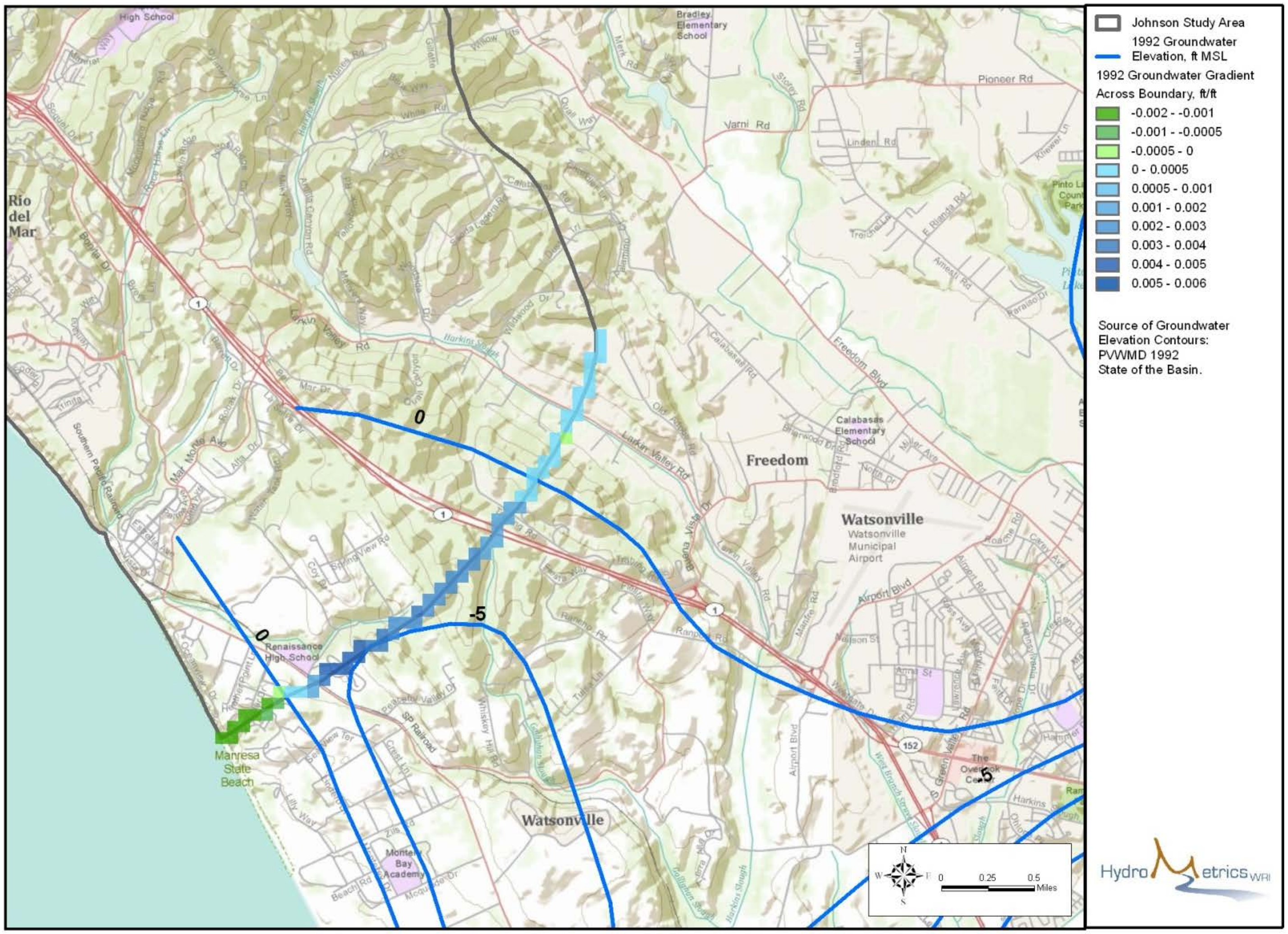


*Figure 7. Components of Groundwater Level Gradient Perpendicular to Boundary between Aromas Area to Pajaro Valley Based on 1992 PVWMA Contour Map*

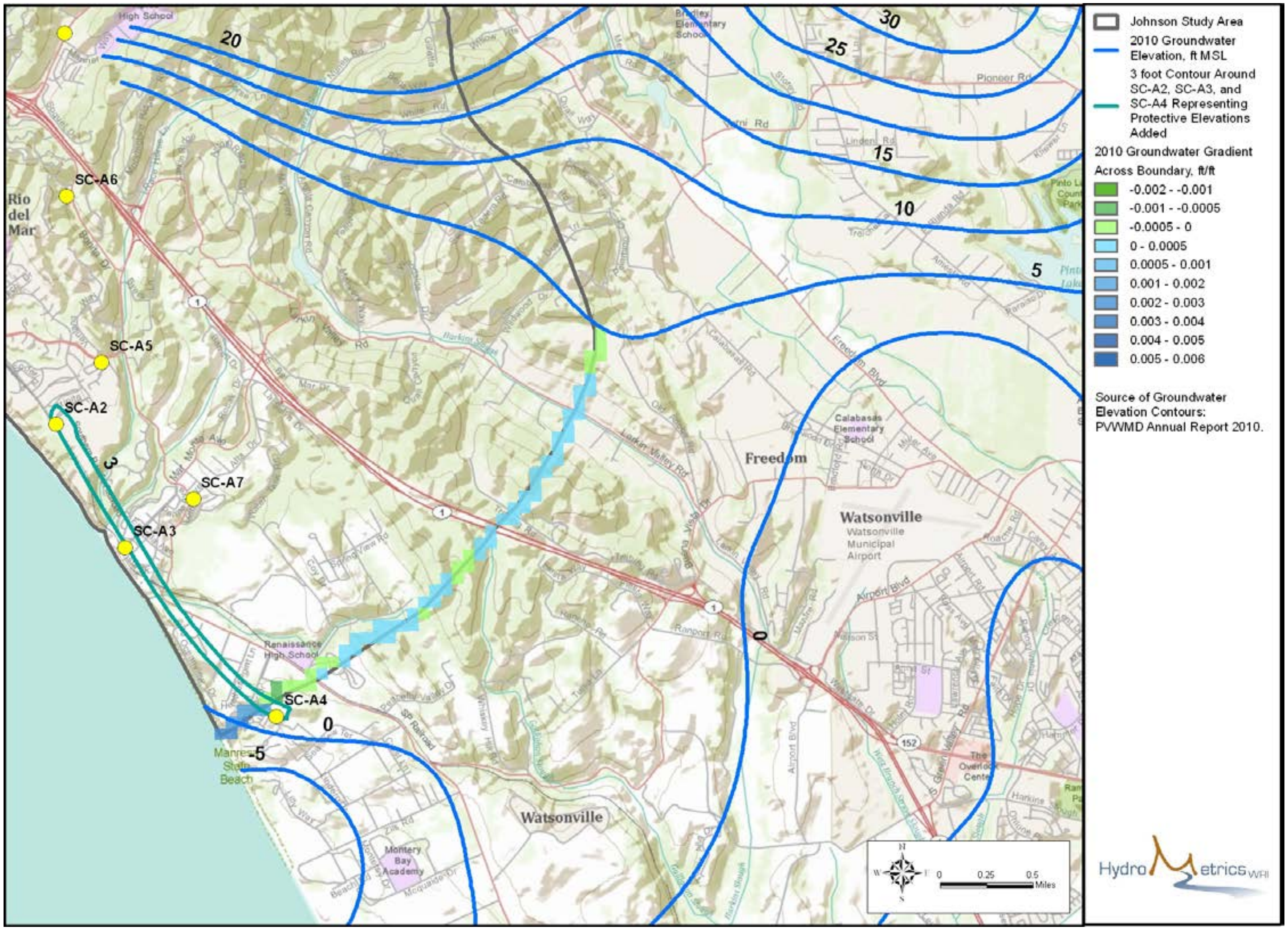


*Figure 8. Components of Groundwater Level Gradient Perpendicular to Boundary between Aromas Area to Pajaro Valley Based on 2010 PVWMA Contour Map Modified with Protective Elevations at Aromas Area Coastal Monitoring Wells*

## UPDATE OF JOHNSON ET AL. (2004) WATER BALANCE

Johnson et al. (2004) used water balance calculations to estimate SqCWD's share of the Soquel-Aptos Basin sustainable yield. We have updated these calculations to calculate SqCWD post-recovery pumping yields in a number of ways, as shown in Table 7.

*Table 7. Water Balance Calculation of SqCWD Post-Recovery Pumping Yield*

| Water Balance Component | Calculation |
|---|---|
| Recharge from precipitation | From PRMS Recharge Model |
| Protective Outflow to Ocean | From SEAWAT-2000 cross-sectional models |
| Flow to Pajaro Valley | From evaluation of PVWMA Annual Report contour maps |
| Total Water Available for Consumptive Use | Recharge MINUS Protective Outflow to Ocean MINUS Flow to Pajaro Valley |
| Non-SqCWD Consumptive Use | From Johnson et al. (2004) Table 5-7; with a revised estimate for Cabrillo College consumptive use based on Cabrillo College pumping in 2009 (HydroMetrics, 2011a) |
| Total Water Available for SqCWD Consumptive Use | Total Water Available for Consumptive Use MINUS Non-SqCWD Consumptive Use |
| SqCWD Return Flow Percentage | Johnson et al. (2004) Table 5-7 accounting for SqCWD parcels on septic systems |
| SqCWD Post-Recovery Pumping Yield | Total Water Available for SqCWD Consumptive Use DIVIDED BY (1 MINUS SqCWD Return Flow Percentage) |

The non-SqCWD consumptive use is calculated differently than what is documented in HydroMetrics LLC's September 15, 2009 letter. In the previous calculations, a single consumptive use factor (1 – return flow percentage) was used to estimate both non-SqCWD and SqCWD consumptive use. In the updated water balance, non-SqCWD consumptive use is calculated separately and subtracted from total available consumptive use to calculate total water available for SqCWD consumptive use. Return flow percentages specific to SqCWD for the Aromas and Purisima areas are used to calculate SqCWD's post-recovery pumping yields. Table 8 shows the calculation of non-SqCWD consumptive use in the Aromas area and the Purisima area.

*Table 8. Non-SqCWD Consumptive Use*

| | Aromas | Purisima |
|---|---|---|
| Non-SqCWD Groundwater Extraction; excluding Cabrillo College (afy) | 1,403 | 2,668 |
| Non-SqCWD Return Flow Percentage excluding Cabrillo College | 46% | 29% |
| Non-SqCWD Consumptive Use (afy) excluding Cabrillo College | 754 | 1,905 |
| Cabrillo College Groundwater Extraction in 2009 (afy) | N/A | 95 |
| Cabrillo College Return Flow Percentage from Johnson et al. (2004) | N/A | 8.5% |
| Cabrillo College Consumptive Use (afy) | N/A | 87 |
| Non-SqCWD Consumptive Use (afy) | 754 | 1,992 |

Note: Aromas area groundwater use is not adjusted for 2007 estimate of Polo Grounds Park water use because Polo Grounds well planned for conversion to SqCWD use.

Johnson et al. (2004) assumed that there is no septic system use in the SqCWD service area and the return flow of indoor use is 0%. SqCWD provided a map of parcels not connected to the sewer system and assumed to have a septic system. We calculated the percentage of parcels on septic in the SqCWD service area overlying the Purisima and Aromas (Figure 9). Based on these percentages along with the assumptions in Johnson et al. (2004) for return flow and water usage, we calculated the current return flow percentages for SqCWD in the Purisima and Aromas areas as shown in Table 9.

*Table 9. SqCWD Return Flow Percentages in Purisima and Aromas Areas Based on Percentage of Parcels on Septic Systems*

| | Aromas | Purisima |
|---|---|---|
| SqCWD Parcels on Septic Systems | 1,483 | 729 |
| Total SqCWD Parcels | 4,957 | 13,242 |
| SqCWD Percentage on Septic Systems | 30% | 6% |
| Return Flow for Indoor Use on Septic (Johnson et al., 2004) | 75% | 75% |
| Return Flow for Indoor Use on Sewer (Johnson et al., 2004) | 0% | 0% |
| Average Return Flow for SqCWD Indoor Use | 22% | 4% |
| SqCWD Indoor Use Percentage (Johnson et al., 2004) | 70% | 70% |
| Return Flow for SqCWD Outdoor Use (Johnson et al., 2004) | 20% | 20% |
| Current SqCWD Return Flow Accounting for Septic Use | 22% | 9% |

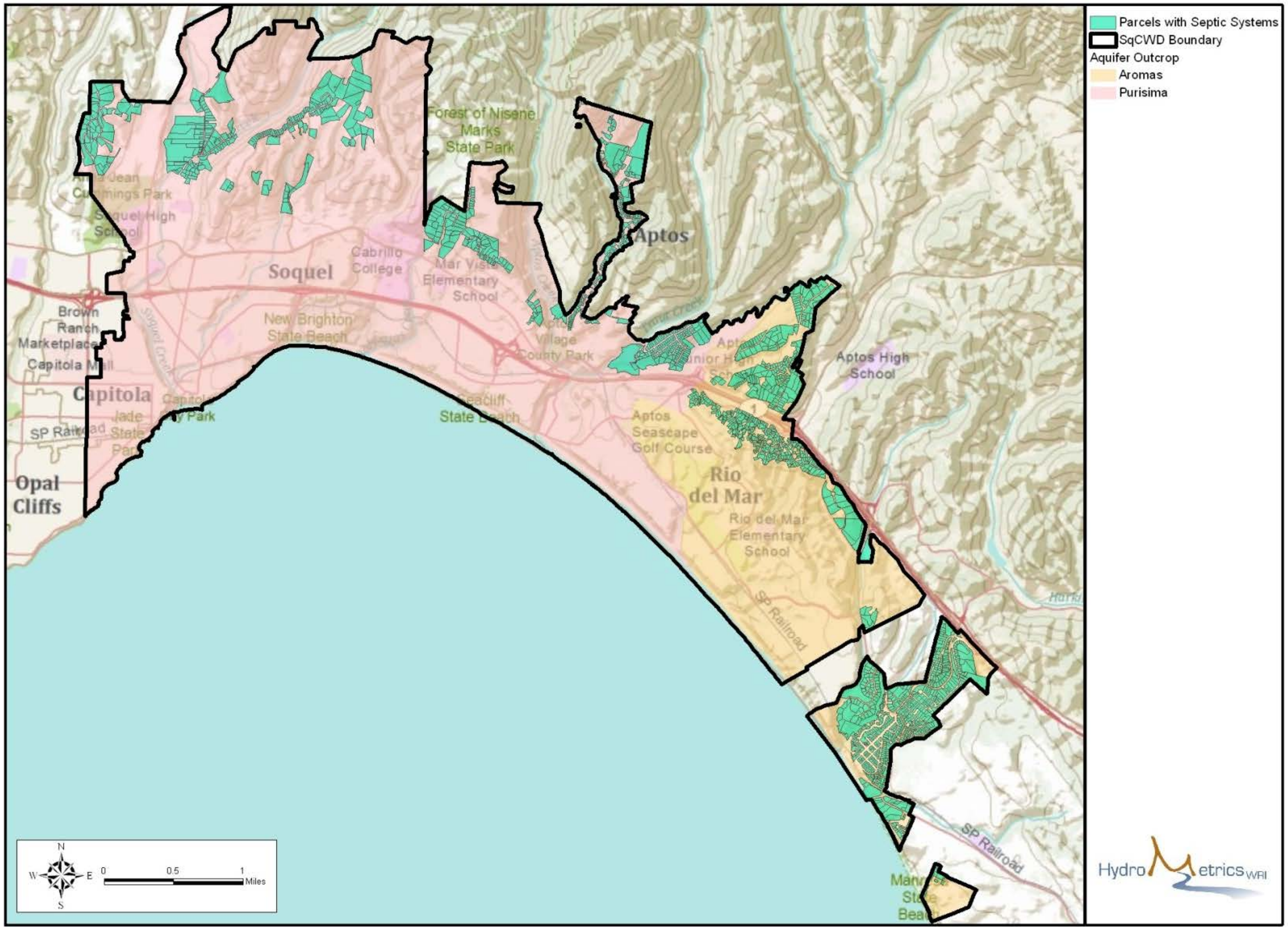


*Figure 9. Parcels on Septic Systems in SqCWD Service Area*

Although return flow percentages accounting for septic system use is representative of current and historical conditions, future return flow percentages may change if septic system use changes. SqCWD's Board of Directors has indicated that it intends to encourage the conversion from septic systems to sewer for water quality purposes. Therefore, the Board does not want to include return flow from septic systems in planning available water supply. We provide water balance calculations assuming no return flow from septic systems in the SqCWD area in Table 10 for the Aromas area and in Table 11 for the Purisima area, which reduces the post-recovery pumping yield for SqCWD.

Table 10 and Table 11 show updated water balance calculations for different percentiles of protective outflow for the Aromas area and for the Purisima area.

*Table 10. Aromas Area Water Balance Calculation of SqCWD Post-Recovery Pumping Yield*

| **Water Balance Component** | **Protective Outflow Percentile** | | |
|---|---|---|---|
| | **50** | **70** | **90** |
| Aromas area recharge from precipitation (afy) | 4,200 | 4,200 | 4,200 |
| Modeled Protective Outflows to Ocean (afy) | 1,025 | 1,950 | 2,500 |
| Flow to Pajaro Valley | 370 | 370 | 370 |
| Total Water Available for Consumptive Use (afy) | 2,805 | 1,880 | 1,330 |
| Non-SqCWD Consumptive Use (afy) | 754 | 754 | 754 |
| Total Water Available for SqCWD's Consumptive Use (afy) | 2,051 | 1,126 | 576 |
| Current SqCWD Return Flow Percentage | 22% | 22% | 22% |
| **SqCWD Post-Recovery Pumping Yield for the Aromas area Accounting for Septic Systems in SqCWD Area (afy)** | **2,620** | **1,440** | **740** |
| Planned SqCWD Return Flow Percentage | 6% | 6% | 6% |
| **SqCWD Post-Recovery Pumping Yield for the Aromas area Assuming No Septic Systems in SqCWD Area (afy)** | **2,180** | **1,200** | **610** |

In addition to the range of uncertainty represented by the protective outflow percentiles, there is uncertainty to each of the other water balance components. The uncertainty of the recharge estimates related to evapotranspiration estimates has been quantified as +/- 5% or approximately +/- 500 acre-feet per year for the Basin. The above contour map gradient estimates show that uncertainty of the flow from the Aromas area to the Pajaro Valley is in the range of a few hundred acre-feet per year.

There are also a number of uncertainties that have not been quantified. Water balance estimates above with uncertainties that have not been quantified include non-SqCWD consumptive use and SqCWD return flow percentage. Another uncertainty that has not been quantified is stream-aquifer interaction. Habitat requirements for baseflow could affect available yield. Groundwater flows between the Purisima and Aromas, between aquifer layers, and into the District are also not quantified.

The water balance for the $50^{th}$ percentile of protective outflows in the Aromas area results in a post-recovery pumping yield that is greater than historical pumping; and is therefore not protective. This may be a result of the $50^{th}$ percentile of protective outflows not being representative of aquifer conditions, errors in the estimates for other water balance components or some combination. The Johnson et al. (2004) estimates of the upper limits for post-recovery pumping yield of 1,800 acre-feet per year in the Aromas area and 3,000 acre-feet per year in the Purisima area can still be considered upper limits, as those values are below both the $50^{th}$ percentile estimates based on current return flow percentages and the average pumping since the early 1980s. For a lower limit on the post-recovery pumping yield reflecting overall uncertainty, we recommend using the estimate represented by the $90^{th}$ percentile of protective outflows. The resulting range in the supply shortage from SqCWD's maximum projected demand of approximately 4,450 acre-feet per year (SqCWD, 2011) is -350 to 1,340 acre-feet per year.

*Table 11. Purisima Area Water Balance Calculation of SqCWD Post-Recovery Pumping Yield*

| Water Balance Component | Protective Outflow Percentile | | |
|---|---|---|---|
| | 50 | 70 | 90 |
| Purisima Area recharge from precipitation (afy) | 5,400 | 5,400 | 5,400 |
| Modeled Protective Outflows to Ocean (afy) | 600 | 775 | 1,050 |
| Total Water Available for Consumptive Use (afy) | 4,800 | 4,625 | 4,350 |
| Non-SqCWD Consumptive Use (afy)[1] | 1,992 | 1,992 | 1,992 |
| Total Water Available for SqCWD's Consumptive Use (afy) | 2,808 | 2,633 | 2,358 |
| Current SqCWD Return Flow Percentage | 9% | 9% | 9% |
| **SqCWD Post-Recovery Pumping Yield for the Purisima Area Accounting for Septic Systems in SqCWD Area(afy)** | **3,080** | **2,890** | **2,590** |
| Planned SqCWD Return Flow Percentage | 6% | 6% | 6% |
| **SqCWD Post-Recovery Pumping Yield for the Purisima Area Assuming No Septic Systems in the SqCWD Area (afy)** | **2,990** | **2,800** | **2,500** |

These water balance calculations based on the 70th percentile of outflows provide planning-level guidelines for estimating the amount of water SqCWD can pump from the Soquel-Aptos Basin after groundwater levels recover to protective elevations. The calculations rely on estimates such as non-SqCWD consumptive use and flow to Pajaro Valley that have uncertainty, and may change over time.

After implementing pumping plans based on the post-recovery yields, SqCWD should continue to adapt its basin management based on how observed coastal groundwater levels compare with protective elevations and observed salinity concentrations. Maintaining groundwater levels at protective elevations will

[1] The calculation conservatively subtracts all of the City of Santa Cruz's assumed consumptive use of 540 acre-feet per year, even though some of the recharge for its production wells may come from the area west of the SC-1 model that has been removed from the calculation. The City is planning to pump up to 520 acre-feet per year in non-critically dry years and up to 645 acre-feet per year in critically dry years.

depend on the distribution of pumping, not just the overall pumping amount. The amount of the post-recovery yields that can be safely pumped by SqCWD's existing and planned wells is a major unknown factor that requires adaptive management.

## COMPARING POST-RECOVERY PUMPING YIELDS TO HISTORICAL SQCWD PUMPING

Figure 10 compares the SqCWD's post-recovery pumping yields using the 70th percentile of protective outflows based on current return flow percentages, to measured SqCWD pumping since 1966. Pumping in the Aromas area has exceeded 1,440 acre-feet per year from 1983 to 2010, but dropped below 1,440 acre-feet in 2011. The accumulated pumping deficit for the Aromas area since 1983 totals 11,500 acre-feet. Pumping in the Purisima area exceeded 2,890 acre-feet per year from 1980 to 2008, but dropped below 2,890 acre-feet per year in the last three years (2009-2011) of historically low pumping. The accumulated pumping deficit in the Purisima area since 1979 totals 10,100 acre-feet.

Figure 10 also shows SqCWD's post-recovery pumping yields based on the 90th percentile of protective outflows based on current return flow percentages. Comparing this value to historical pumping data shows that recent pumping remains above this lower limit for SqCWD's post-recovery pumping yield. Combined Aromas and Purisima pumping has exceeded 3,300 acre-feet since 1975. Since then, the accumulated pumping deficit based on this lower limit estimate for a post-recovery pumping yield exceeds 55,000 acre-feet.

As discussed in the Annual Report and Review for Water Year 2010 (HydroMetrics WRI, 2011a), groundwater elevation recovery has been observed in Purisima area coastal monitoring wells due to the decreased pumping in 2009 and 2010 and this has continued in 2011, but the historically low pumping average of 4,170 acre-feet per year over the last three years may be at least partially due to factors that are not sustainable. These factors include a weak economy and weather conditions.

The recently observed groundwater elevation recovery in the Purisima area does not confirm that recent pumping is below post-recovery pumping yields. The protective outflows are based on maintaining protective elevations which have not yet been achieved.

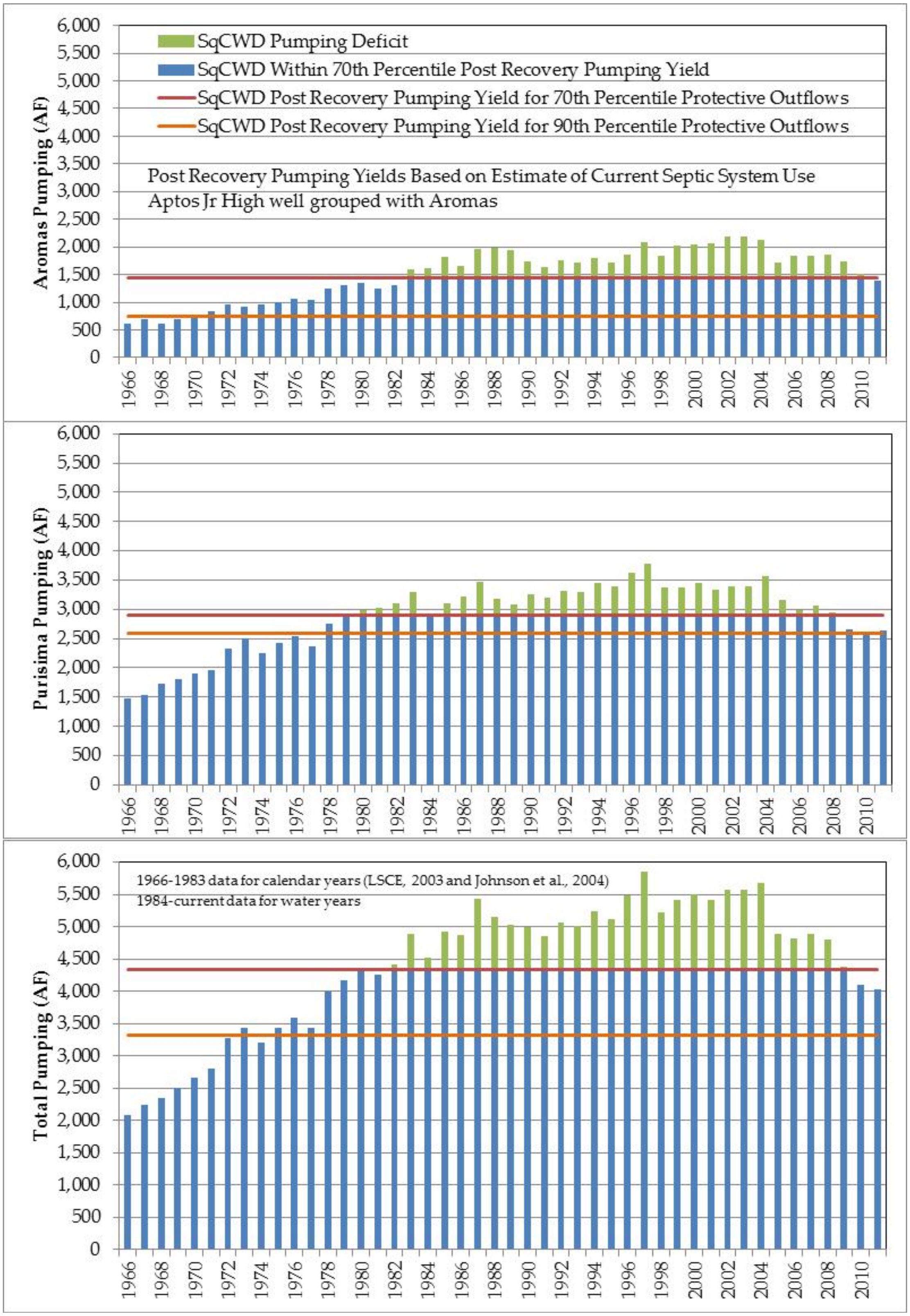


*Figure 10. SqCWD Historical Pumping and SqCWD Post-Recovery Pumping Yields Based on 70th Percentile of Protective Outflows*

## RECOVERY OBJECTIVES

The post-recovery pumping yields are based on estimated outflows needed to maintain protective elevations. Pumping at these yields will not be protective until recovery is achieved. To recover the Soquel-Aptos Basin, pumping will need to be maintained below the post-recovery pumping yields until protective groundwater elevations are achieved. SqCWD can maximize recovery by maximizing the supplemental supply. Based on a potential non-drought supplemental supply of 2.5 million gallons per day, SqCWD could reduce its groundwater pumping to approximately 1,650 acre-feet per year from its maximum projected demand of approximately 4,450 acre-feet per year (SqCWD, 2011). Maximizing supplemental supply will minimize recovery time. Based on the potential drought scenario in which SqCWD is provided the equivalent of 2.5 million gallons per day of supplemental supply over 5 months, SqCWD could still limit its pumping to approximately 2,900 acre-feet per year by declaring a drought curtailment that achieves 15% demand reduction from May to October. Based on this scenario, pumping 2,900 acre-feet per year is the minimum recovery goal that can be achieved in all years. This goal is approximately 210 acre-feet per year below the lower limit for SqCWD's post-recovery pumping yield based on the 90th percentile of protective outflows. SqCWD can set a higher recovery goal but this will result in longer recovery times. For any goal, SqCWD will need to monitor recovery to assess whether recovery is occurring in the time frame desired.

## RECOVERY TIMEFRAME

The combined accumulated pumping deficit of 21,600 acre-feet calculated above provides context for the length of time SqCWD would have to pump below the combined post-recovery pumping yield in order to recover the basin. If SqCWD pumps 2,900 acre-feet per year, the accumulated deficit would be reduced by 1,100 acre-feet per year and the deficit would be eliminated in 20 years assuming planned return flow percentages (no septic in SqCWD area). The time to eliminate the accumulated deficit can be considered an upper limit on the recovery time if SqCWD pumping of 4,000 acre-feet per year protects the Basin from seawater intrusion, assuming a redistribution of pumping that safely pumps the yield. Table 12 shows the estimated times to eliminate the accumulated deficit for different annual pumping levels.

If SqCWD's pumping is protective at an amount lower or higher than 4,000 acre-feet per year, the upper limit on the recovery time would increase or decrease, respectively. For example, based on the 90th percentile of protective outflows, pumping 2,900 acre-feet per year would reduce the accumulated deficit 210 acre-feet per year assuming planned return flow percentages. The deficit of 55,000 acre-feet based on the 90th percentile of protective outflows would be eliminated in approximately 270 years. Table 12 shows the uncertainty of estimated times to eliminate the accumulated deficit for different annual pumping levels.

*Table 12. Durations to Eliminate Accumulated Pumping Deficit*

| Annual SqCWD Pumping (acre-feet) | Duration Based on Post-Recovery Yield for 70th Percentile Protective Outflow (years) | Uncertainty Based on Post-Recovery Yield for 50th and 90th Percentile Protective Outflows (years) |
|---|---|---|
| 2,500 | 14 | 4 - 90 |
| 2,700 | 17 | 4 - 140 |
| 2,900 | 20 | 4 - 270 |
| 3,300 | 30 | 5 - Never |
| 3,700 | 70 | 7 - Never |

Measurable basin recovery is defined by groundwater levels rising to protective elevations; the time needed to eliminate the accumulated deficit does not predict how long it will take for water levels to observe this recovery. Additional tools and information are required to provide a more refined estimate of recovery time. These tools must accurately show the influence of pumping from SqCWD's municipal wells on coastal groundwater elevations. The cross-sectional models developed for estimating protective elevations do not include the influence of any SqCWD pumping.

Simple analysis of historical groundwater elevation data is inadequate for estimating recovery times. One difficulty is that coastal monitoring wells were installed in the mid-1980s, some years after pumping began to exceed the estimate of SqCWD's post-recovery pumping yield. In addition, groundwater levels at most of the coastal monitoring wells have been below protective elevations since installation, therefore there is no historical estimate of the conditions under which coastal groundwater elevations were protective of seawater intrusion. Other components of the water balance such as non-SqCWD consumptive use may have also changed over the time period.

We evaluated the possibility of using statistical relationships between pumping and groundwater levels from Dr. Raquel Prado's recent analysis (Prado and O'Connor, 2011) to estimate recovery time. However, the only coastal monitoring well with a constant relationship between groundwater elevation and pumping is monitoring well SC-1. Groundwater elevations in other monitoring wells have relationships with pumping that change over time and therefore are not appropriate for estimating long-term effects (Prado, 2011).

To provide a more refined estimate of recovery time, a basin-wide groundwater model is required. This modeling should be undertaken if SqCWD needs a better estimate of recovery time than the time needed to eliminate the accumulated deficit.

## CONCLUSION

This evaluation provides SqCWD with guidelines to plan future overall pumping. SqCWD will need to continue its monitoring programs to assess whether management objectives are being met and adapt accordingly. It also remains important to implement other elements of the Groundwater Management Plan (SqCWD and CWD, 2007) such as the Well Master Plan (ESA, 2010), which will redistribute pumping inland.

Please let us know if you have any questions.

Sincerely,

Cameron Tana

Derrik Williams
HydroMetrics Water Resources Inc.

Attachment 1. Calculation of Equivalent Freshwater Heads, Chemographs, and Hydrographs

Attachment 2. Contour Maps for Evaluating Flow from Aromas Area to Pajaro Valley

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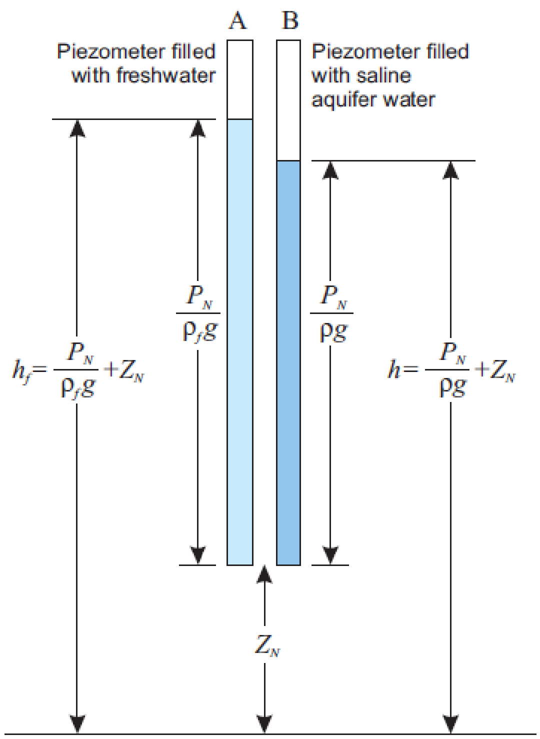
# ATTACHMENT 1: CALCULATION OF FRESHWATER EQUIVALENT HEADS, HYDROGRAPHS AND CHEMOGRAPHS

Measured groundwater levels must be adjusted to account for salinity before they are compared to protective elevations. The protective groundwater elevation estimated by SEAWAT-2000 is the freshwater equivalent head (Langevin and others, 2003). The freshwater equivalent head for groundwater with a substantial amount of salinity is higher than the observed groundwater levels due to the higher density of saline water. The following figure reproduced from the SEAWAT users manual (Guo and Langevin, 2002) illustrates this. The pressures in the two piezometers are equivalent because the higher density of the saline aquifer water column makes up for the lower groundwater elevation.




EXPLANATION

$h_f$ Equivalent freshwater head [L]

$h$ Head [L]

$P_N$ Pressure [$ML^{-1}T^{-2}$]

$\rho_f$ Density of freshwater [$ML^{-3}$]

$\rho$ Density of saline aquifer water [$ML^{-3}$]

$g$ Acceleration due to gravity [$LT^{-2}$]

$Z_N$ Elevation [L]

NOTE: L = length, M = mass, T = time

In the Aromas area coastal monitoring wells, the water column above any point is a mixture of freshwater and saline water. To represent the mixture of fresh and saline water, we use the chloride concentrations measured in the A and B screens. The density for the interval of the water column in each of the screens ($\Delta_A$ and $\Delta_B$ is the interval length in equations below) is based on the chloride concentration in each screen. The density for the interval between the two screens ($\Delta_{AB}$ is the interval length in equations below) is based on the average of the A and B screen intervals. The density for the interval above the B screen is assumed to be the freshwater density.

Therefore, the calculation of pressure, $P_N$, at the bottom of the A screen is:

$$P_N = g(\rho_A \Delta_A + \rho_{AB} \Delta_{AB} + \rho_B \Delta_B + \rho_f \Delta_f)$$

By recognizing that the freshwater interval above the top of the B screen is:

$$\Delta_f = h - \Delta_A - \Delta_{AB} - \Delta_B - Z_N$$

, the equivalent freshwater head at the bottom of the A screen is calculated as:

$$h_f = h - \frac{\rho_A \Delta_A + \rho_{AB} \Delta_{AB} + \rho_B \Delta_B}{\rho_f} - (\Delta_A + \Delta_{AB} + \Delta_B)$$

Only water in the B screen and overlying freshwater creates pressure at the bottom of the screen so the equivalent freshwater head at the bottom of the B screen is calculated as:

$$h_f = h - \frac{\rho_B \Delta_B}{\rho_f} - \Delta_B$$

These equivalent fresh heads are plotted in grey on the following hydrographs where they can be distinguished from measured groundwater levels (all A screen wells except for SC-A1A) and can be compared to the dotted line representing the recommended protective elevations.

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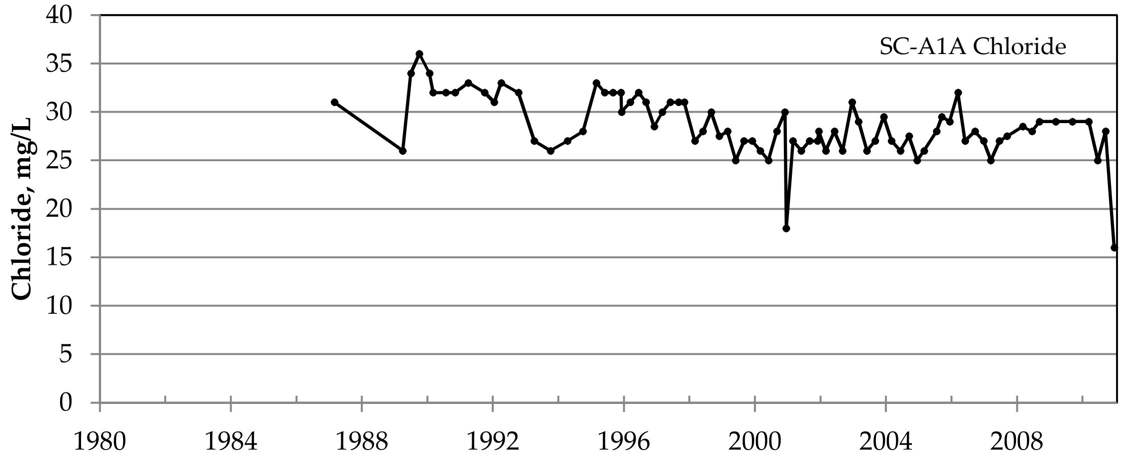
SC-A1A Chloride
Chloride, mg/L
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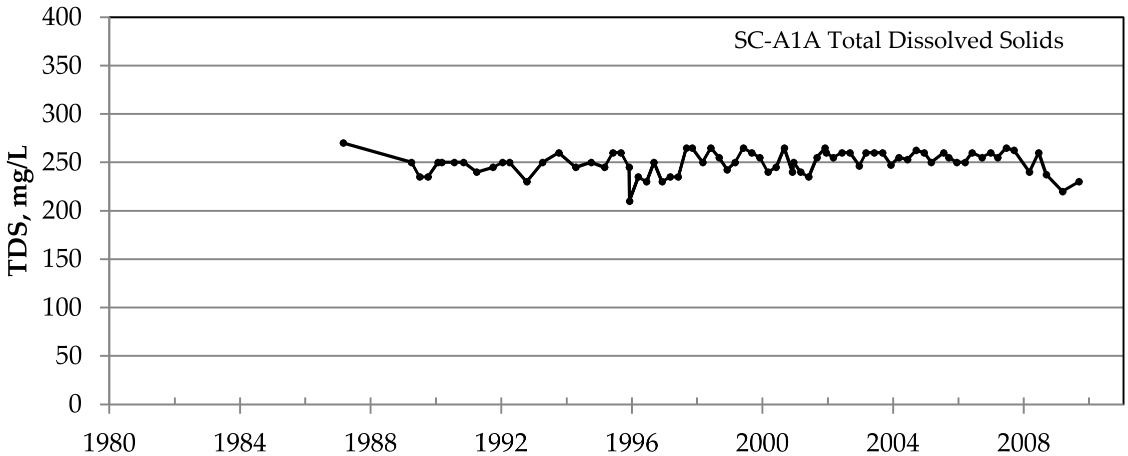
2004
2008


SC-A1A Total Dissolved Solids
TDS, mg/L
400
350
300
250
200
150
100
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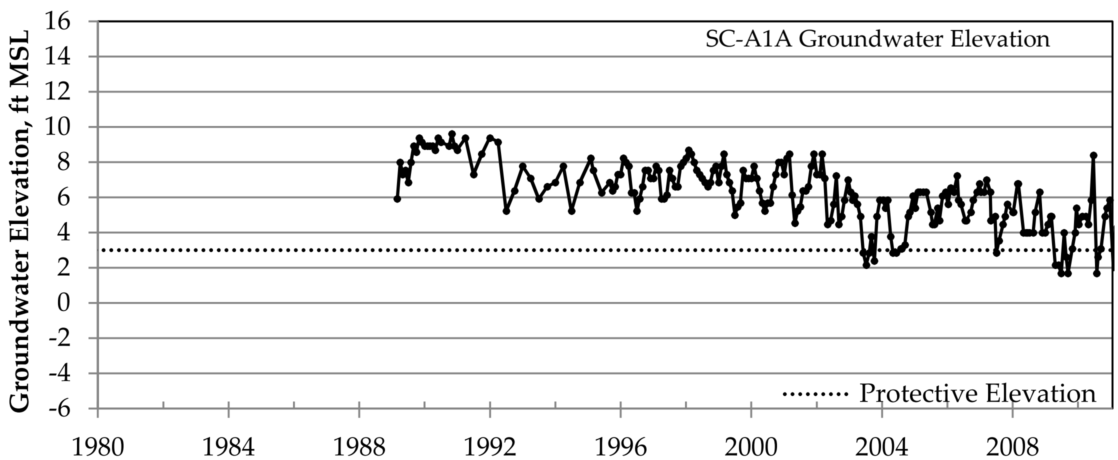
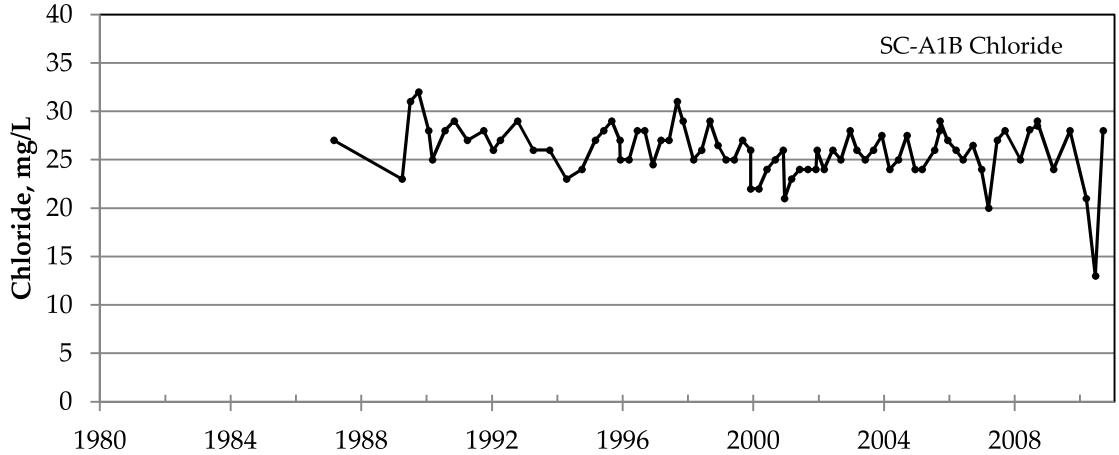
2000
2004
2008


SC-A1A Groundwater Elevation
Groundwater Elevation, ft MSL
16
14
12
10
8
6
4
2
0
-2
-4
-6
Protective Elevation
1980
1984
1988
1992
1996
2000
2004
2008


SC-A1B Chloride
Chloride, mg/L
40
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30
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20
15
10
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1980
1984
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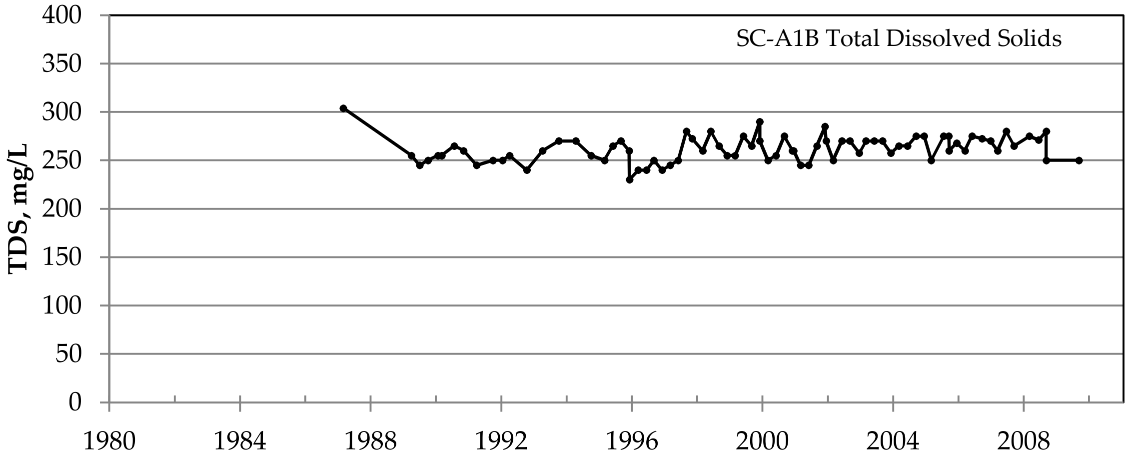
SC-A1B Total Dissolved Solids
TDS, mg/L
400
350
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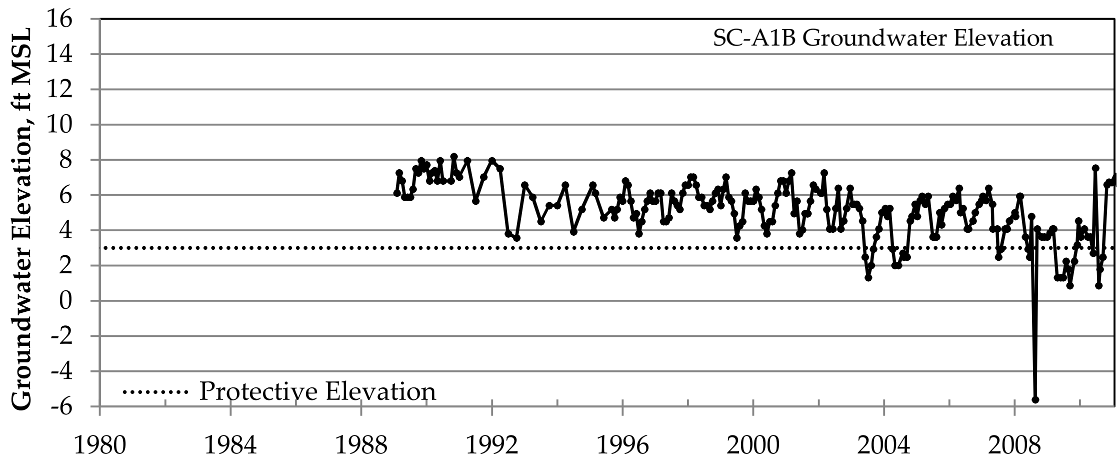
SC-A1B Groundwater Elevation
Groundwater Elevation, ft MSL
Protective Elevation
16
14
12
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-6
1980
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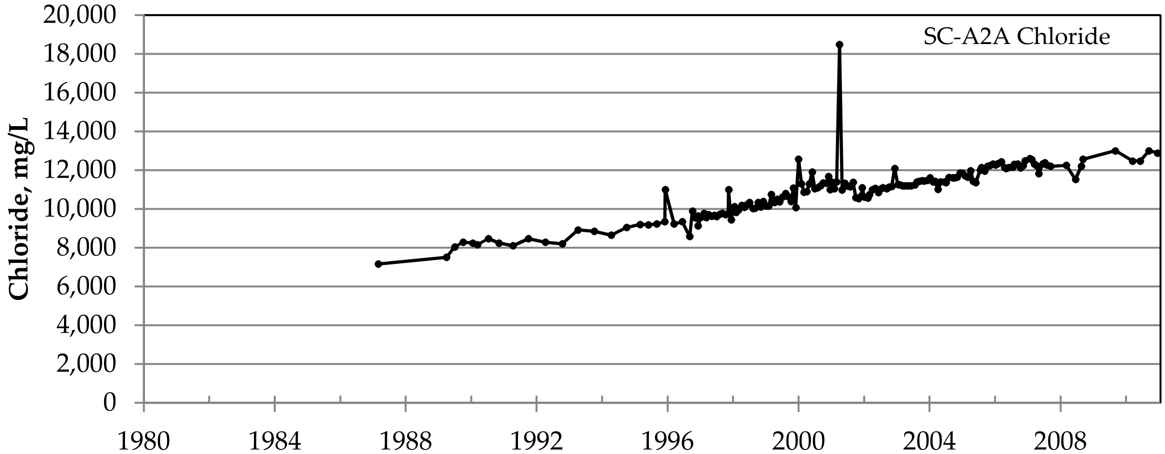
SC-A2A Chloride
Chloride, mg/L
20,000
18,000
16,000
14,000
12,000
10,000
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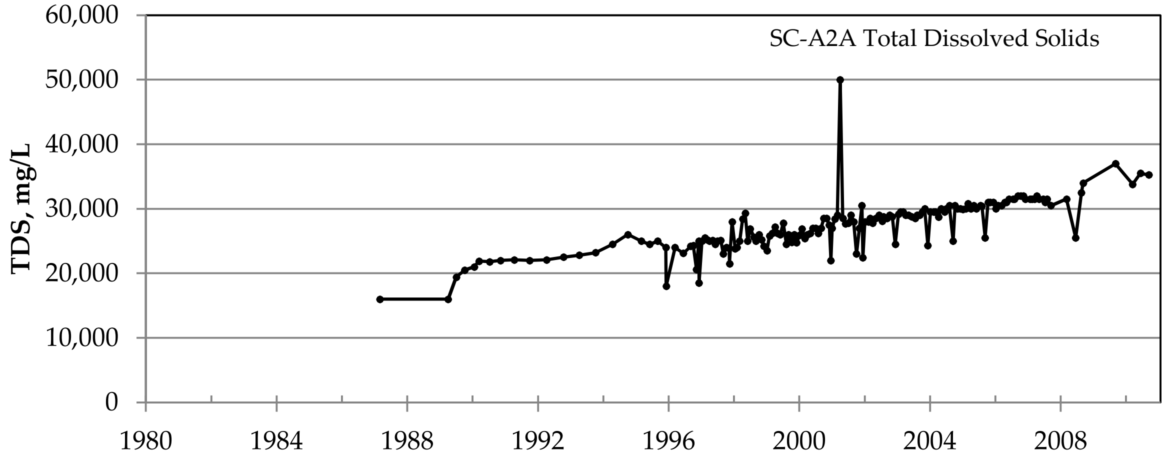
1992
1996
2000
2004
2008


SC-A2A Total Dissolved Solids
TDS, mg/L
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10,000
0
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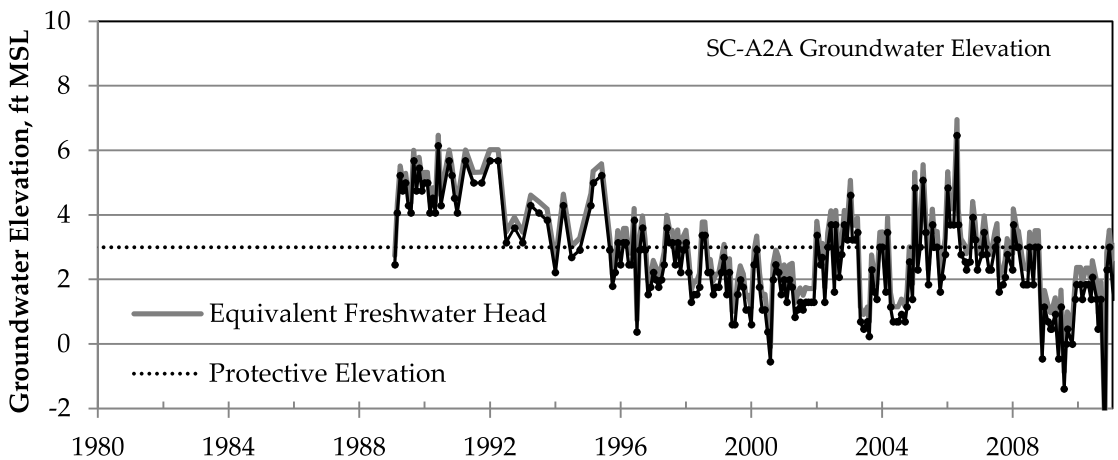
SC-A2A Groundwater Elevation
Groundwater Elevation, ft MSL
Equivalent Freshwater Head
Protective Elevation
10
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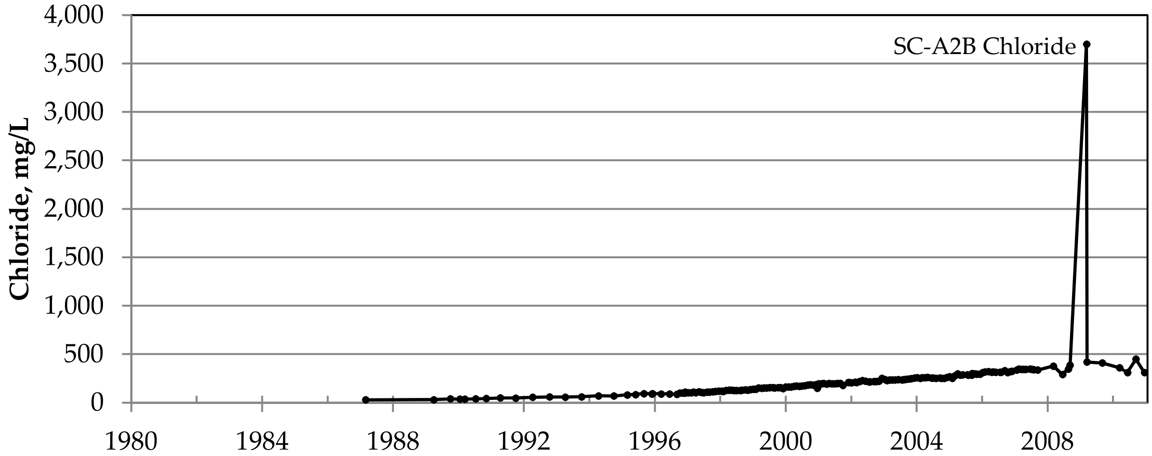
SC-A2B Chloride
Chloride, mg/L
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2,000
1,500
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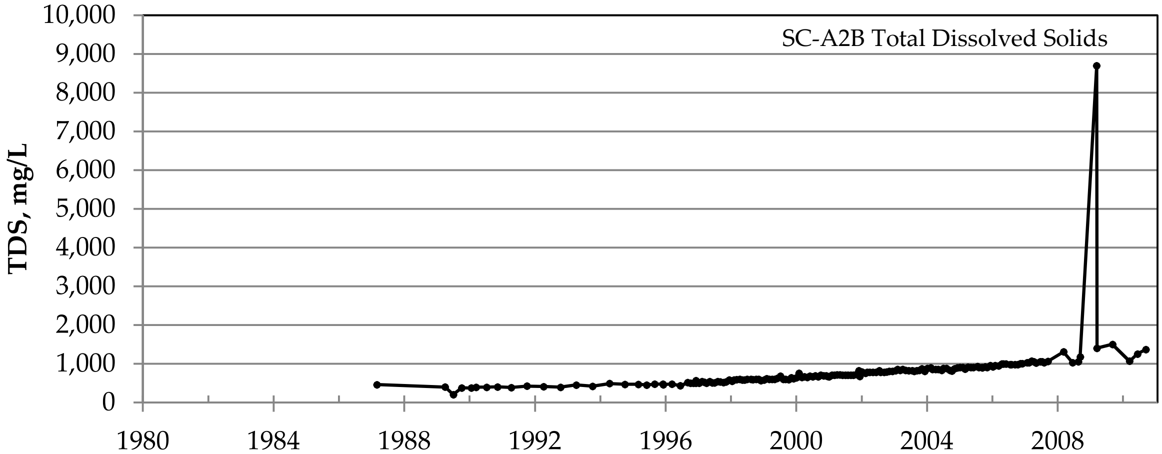
SC-A2B Total Dissolved Solids
TDS, mg/L
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9,000
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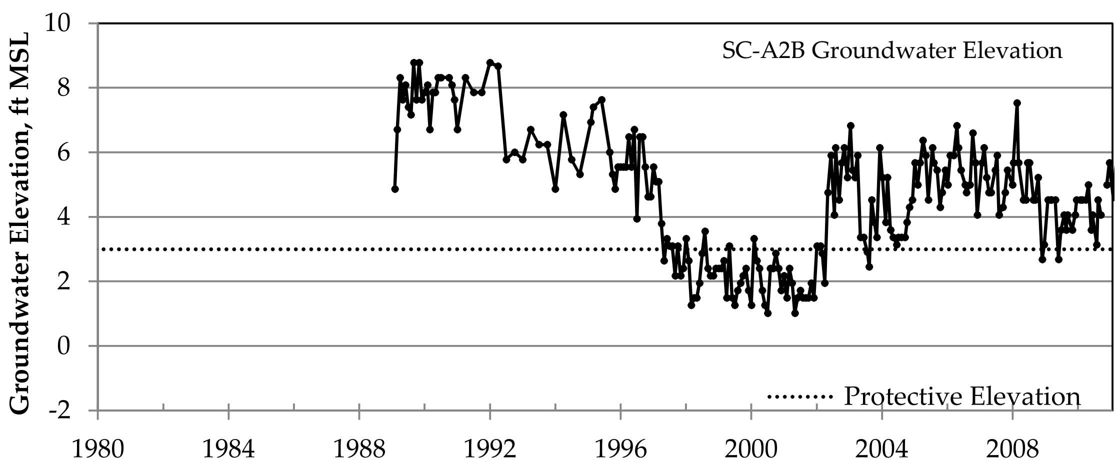
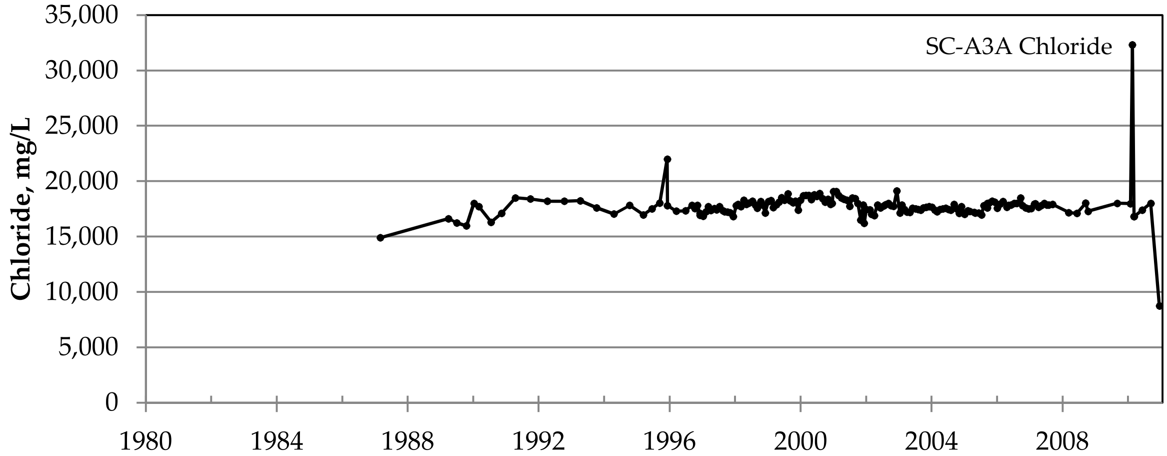

SC-A2B Groundwater Elevation
Groundwater Elevation, ft MSL
10
8
6
4
2
0
-2
Protective Elevation
1980
1984
1988
1992
1996
2000
2004
2008


SC-A3A Chloride
Chloride, mg/L
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1980
1984
1988
1992
1996
2000
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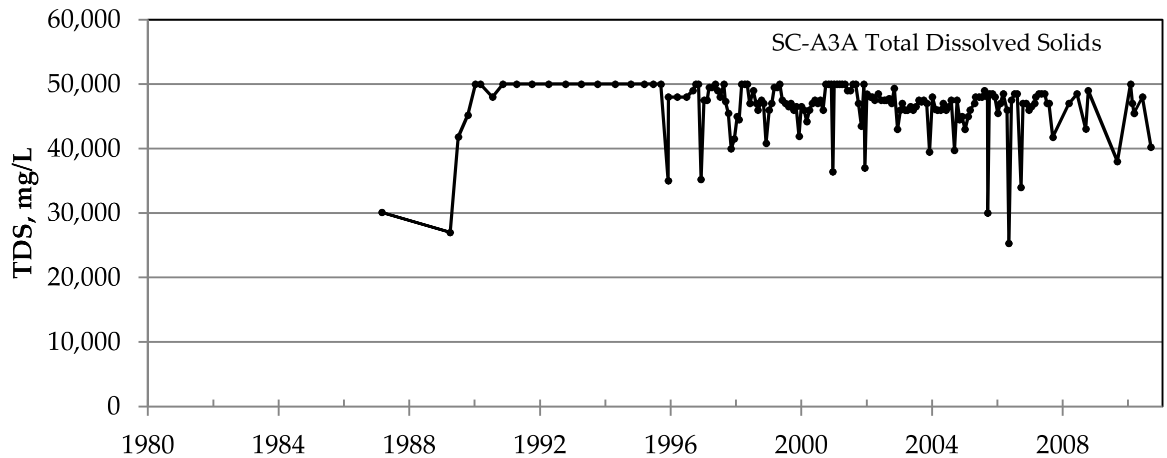
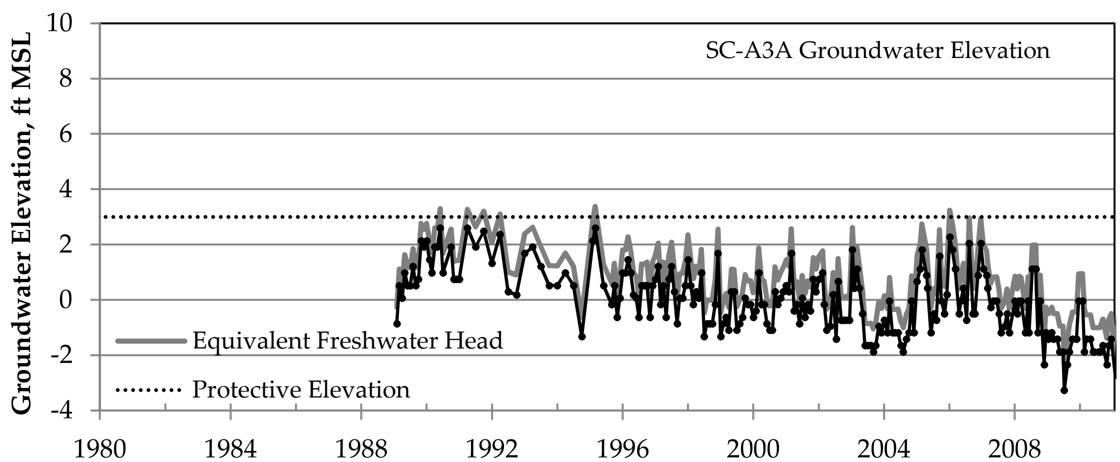
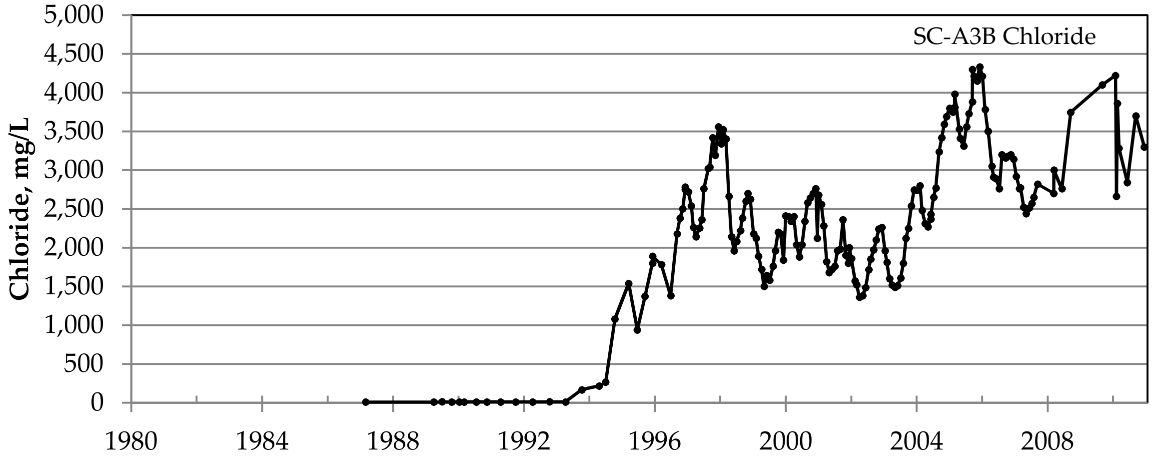
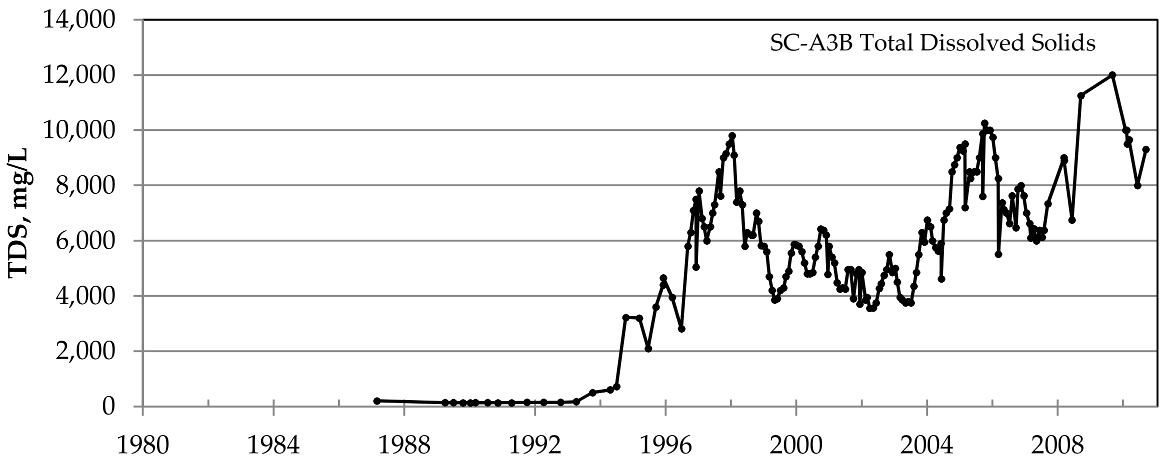
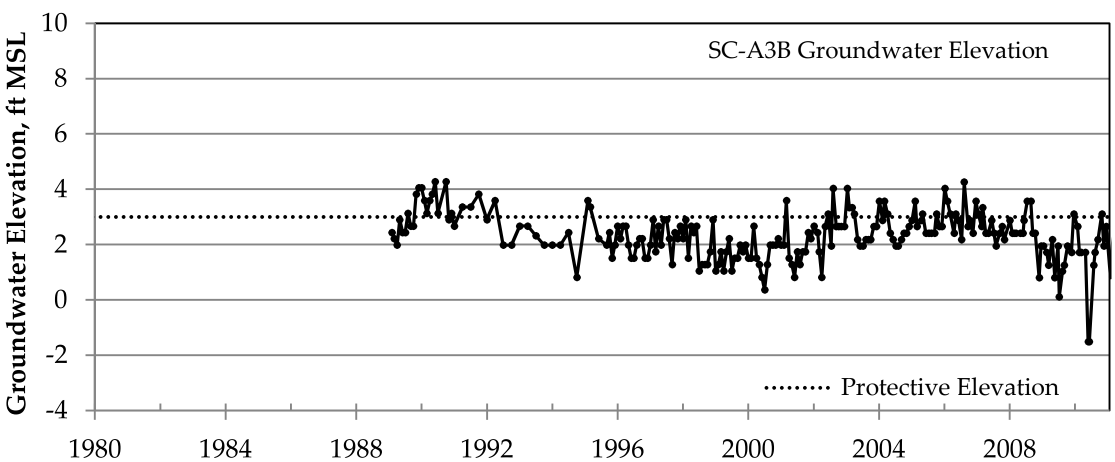
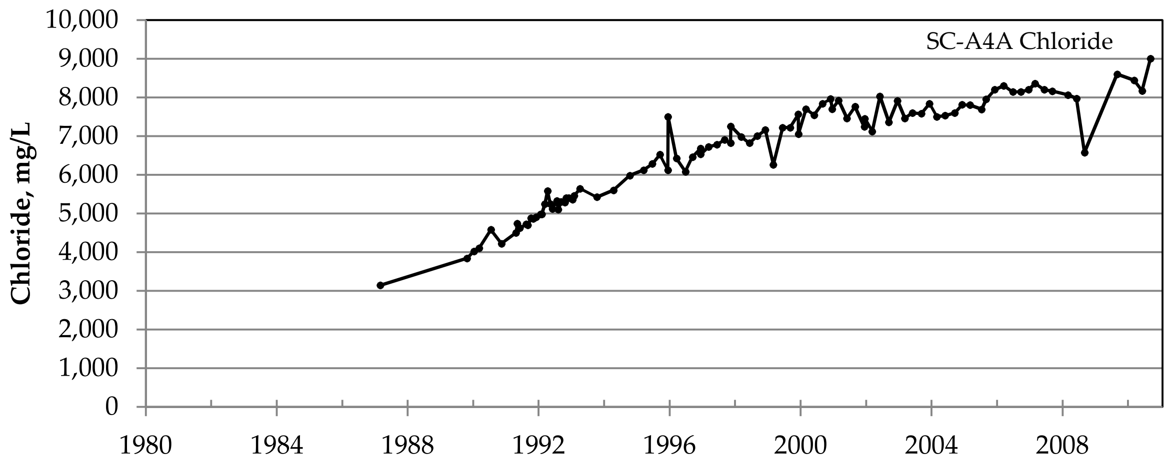

SC-A3A Total Dissolved Solids
TDS, mg/L
60,000
50,000
40,000
30,000
20,000
10,000
0
1980
1984
1988
1992
1996
2000
2004
2008

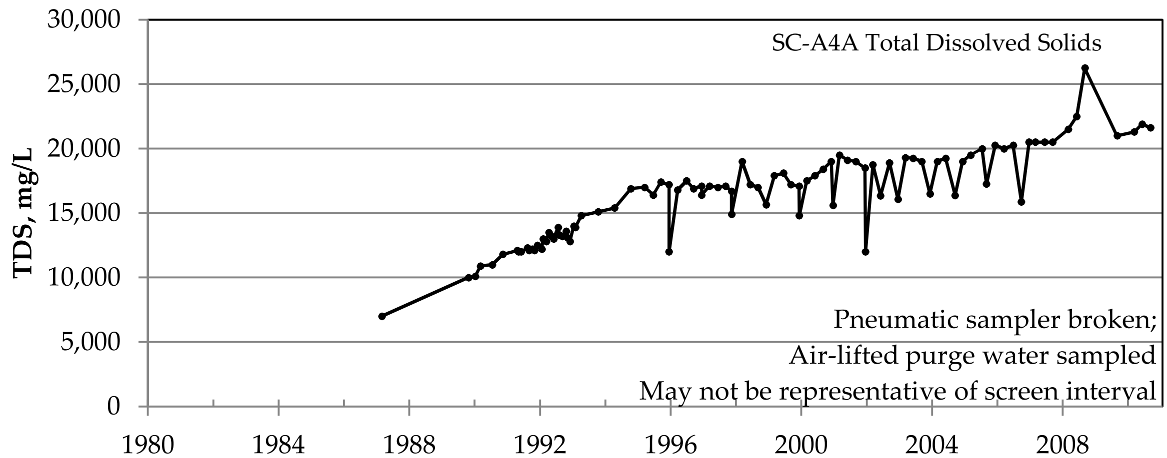

SC-A3A Groundwater Elevation
Groundwater Elevation, ft MSL
10
8
6
4
2
0
-2
-4
Equivalent Freshwater Head
Protective Elevation
1980
1984
1988
1992
1996
2000
2004
2008

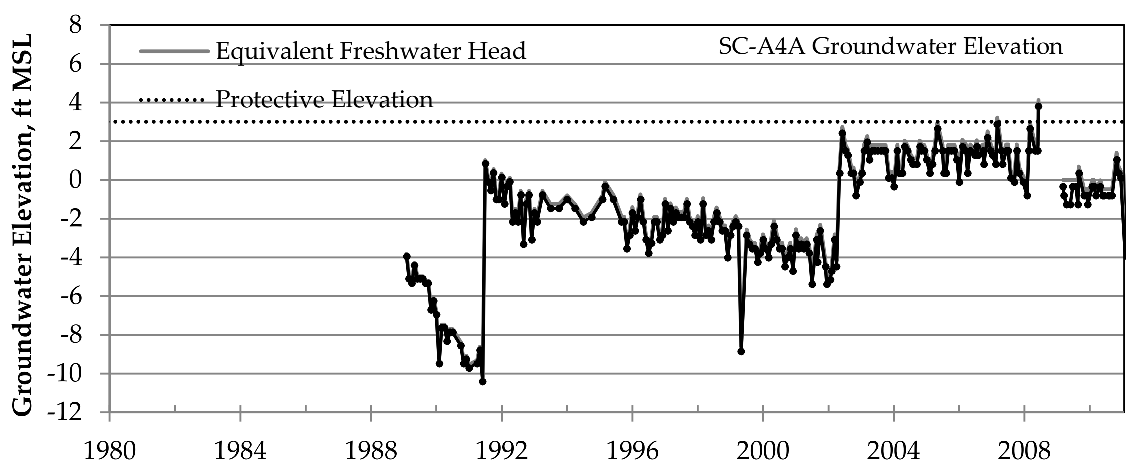

SC-A3B Chloride
Chloride, mg/L
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1980
1984
1988
1992
1996
2000
2004
2008

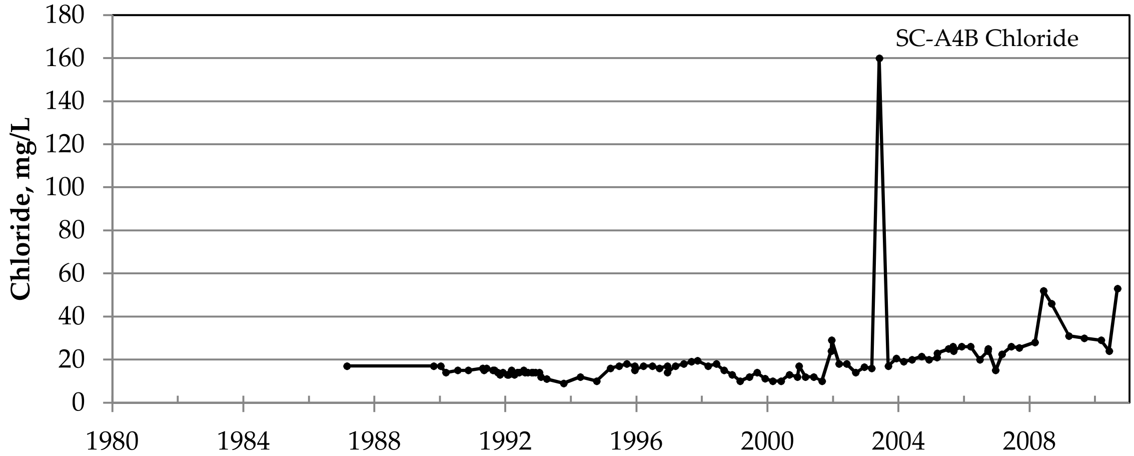

SC-A3B Total Dissolved Solids
TDS, mg/L
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1980
1984
1988
1992
1996
2000
2004
2008

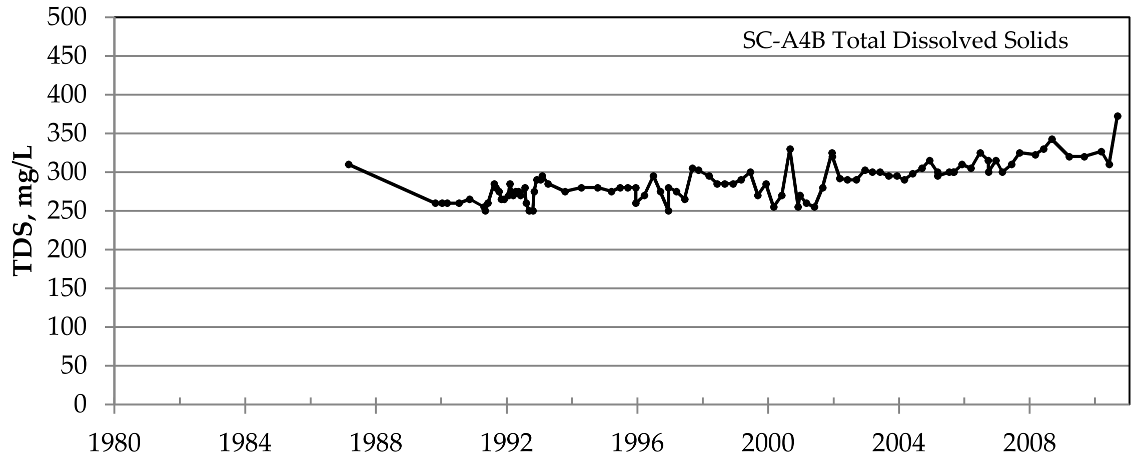

SC-A3B Groundwater Elevation
Groundwater Elevation, ft MSL
Protective Elevation
10
8
6
4
2
0
-2
-4
1980
1984
1988
1992
1996
2000
2004
2008

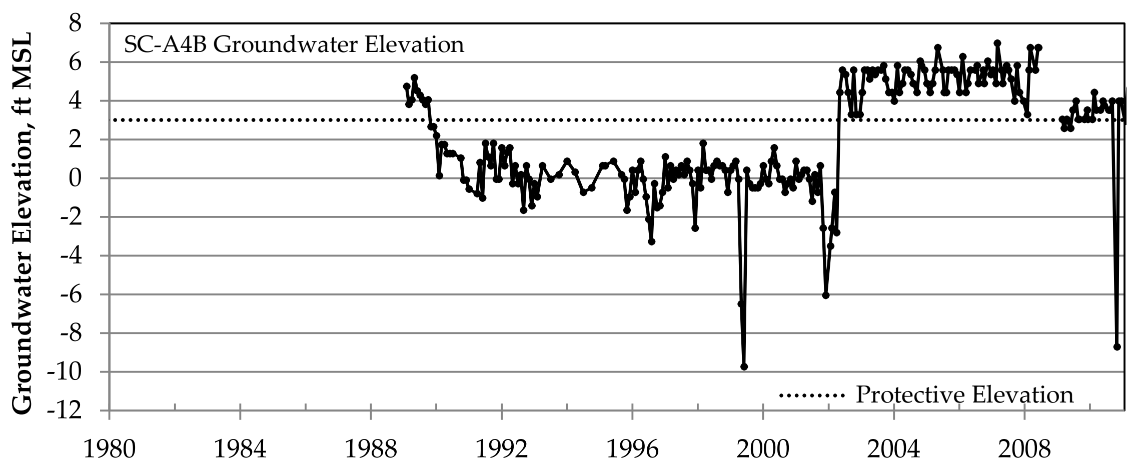

SC-A4A Chloride
Chloride, mg/L
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1980
1984
1988
1992
1996
2000
2004
2008

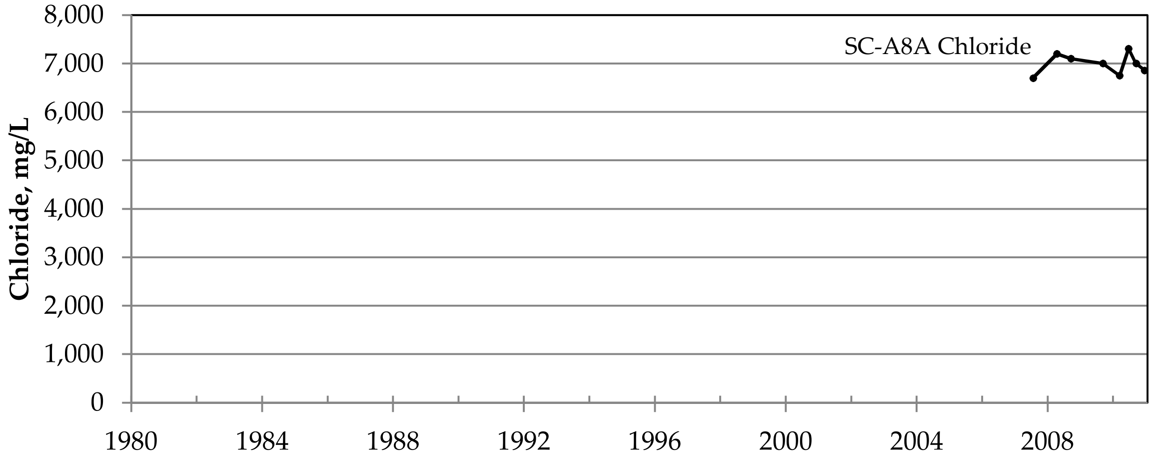

SC-A4A Total Dissolved Solids
TDS, mg/L
30,000
25,000
20,000
15,000
10,000
5,000
0
Pneumatic sampler broken;
Air-lifted purge water sampled
May not be representative of screen interval
1980
1984
1988
1992
1996
2000
2004
2008

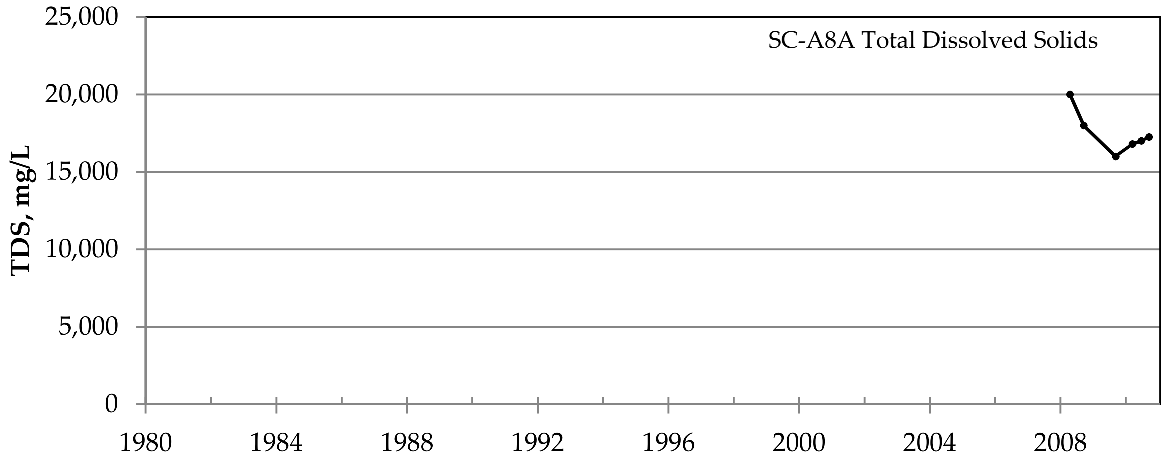

Equivalent Freshwater Head
Protective Elevation
SC-A4A Groundwater Elevation
Groundwater Elevation, ft MSL
8
6
4
2
0
-2
-4
-6
-8
-10
-12
1980
1984
1988
1992
1996
2000
2004
2008

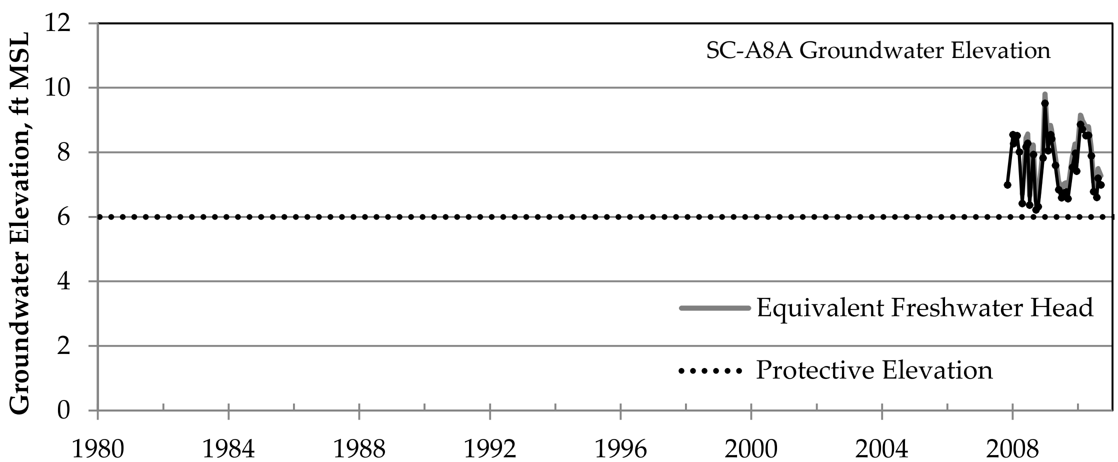

SC-A4B Chloride
Chloride, mg/L
180
160
140
120
100
80
60
40
20
0
1980
1984
1988
1992
1996
2000
2004
2008

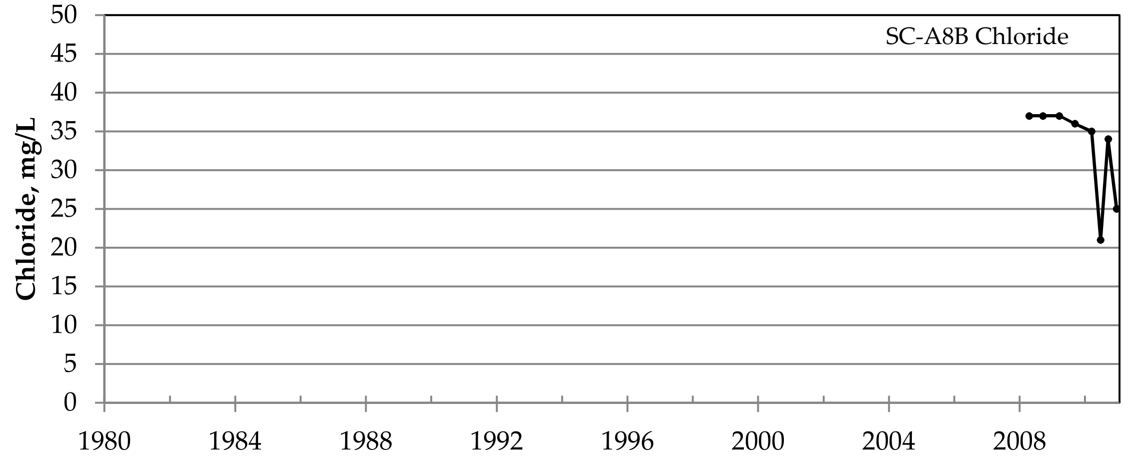

SC-A4B Total Dissolved Solids
TDS, mg/L
500
450
400
350
300
250
200
150
100
50
0
1980
1984
1988
1992
1996
2000
2004
2008

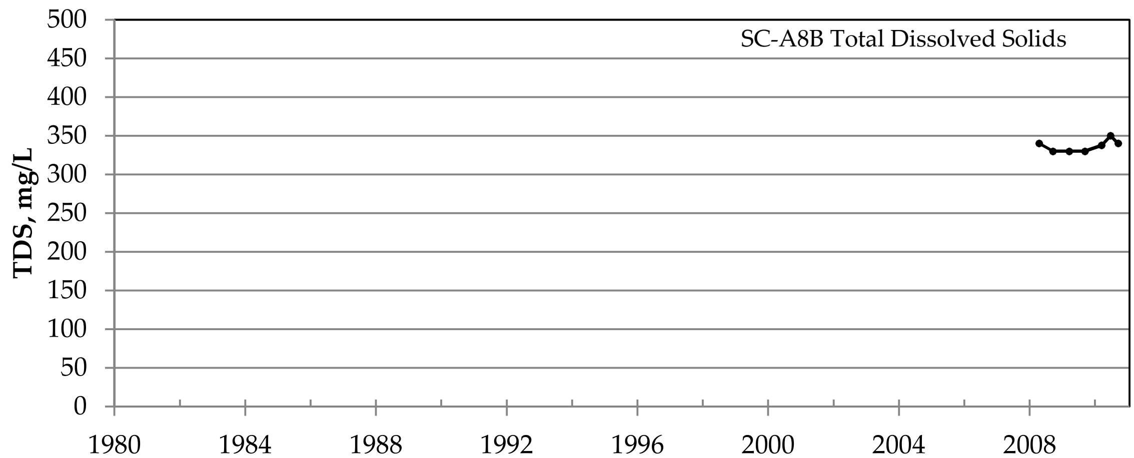

SC-A4B Groundwater Elevation
Groundwater Elevation, ft MSL
8
6
4
2
0
-2
-4
-6
-8
-10
-12
1980
1984
1988
1992
1996
2000
2004
2008
Protective Elevation

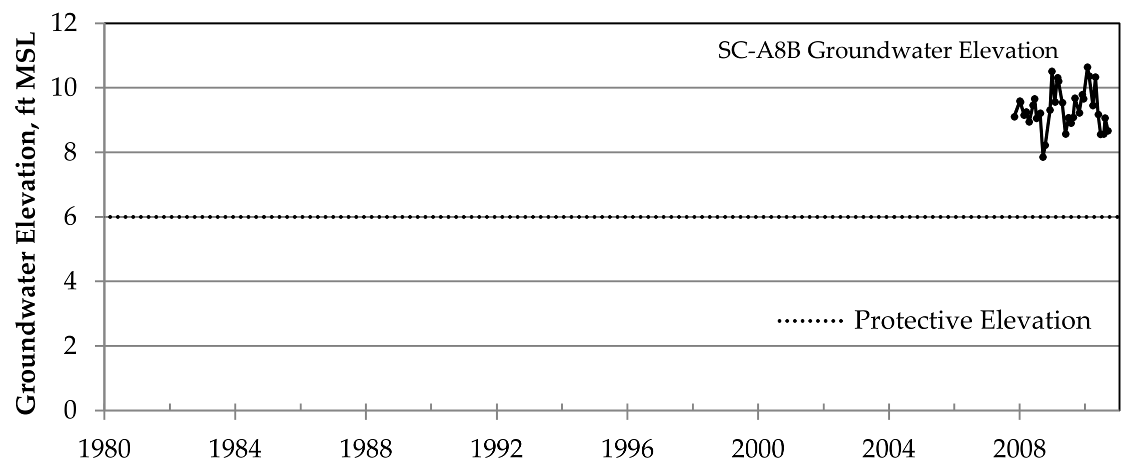

SC-A8A Chloride
Chloride, mg/L
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1980
1984
1988
1992
1996
2000
2004
2008


SC-A8A Total Dissolved Solids
TDS, mg/L
25,000
20,000
15,000
10,000
5,000
0
1980
1984
1988
1992
1996
2000
2004
2008


SC-A8A Groundwater Elevation
Groundwater Elevation, ft MSL
12
10
8
6
4
2
0
Equivalent Freshwater Head
Protective Elevation
1980
1984
1988
1992
1996
2000
2004
2008

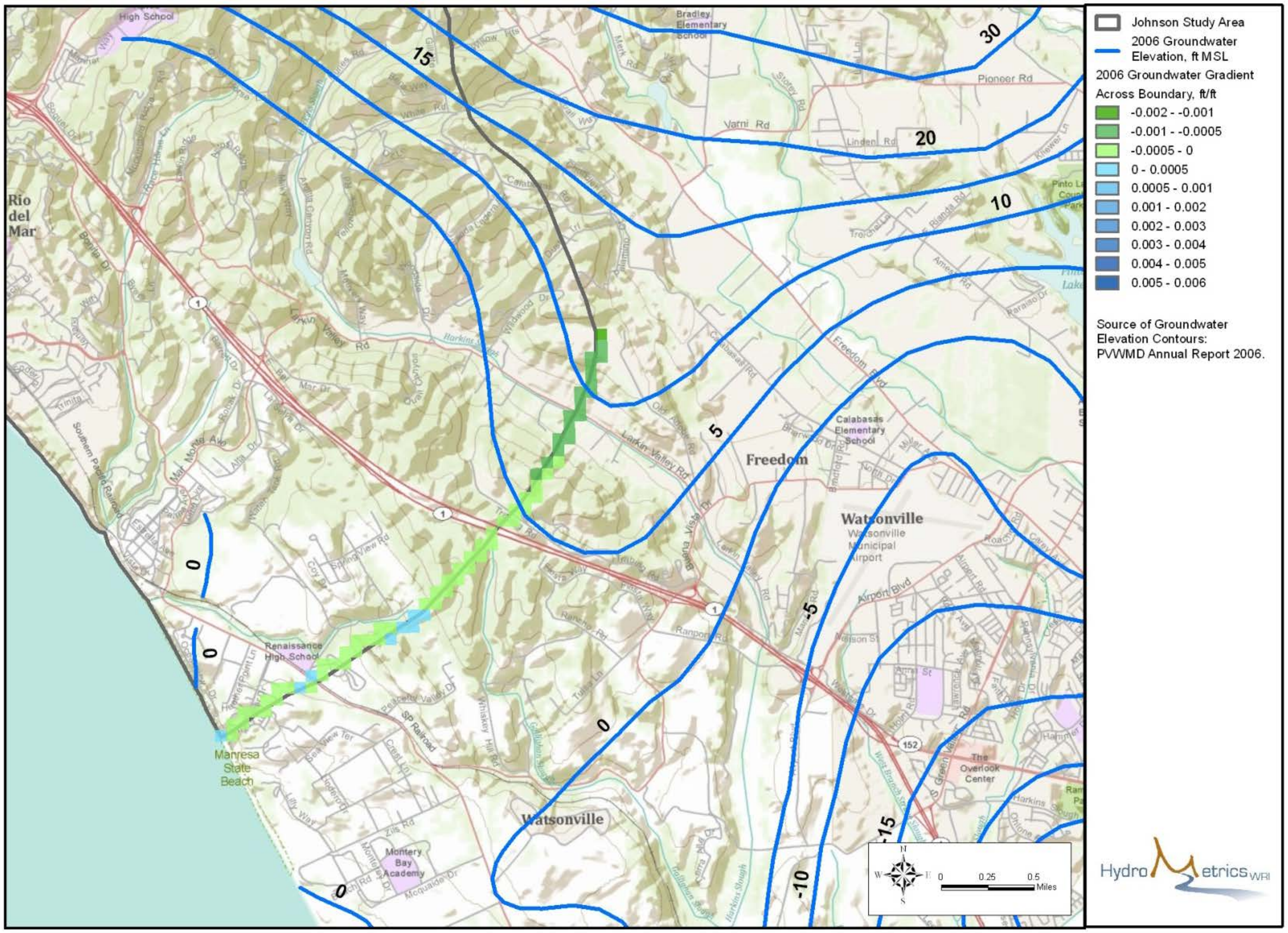

SC-A8B Chloride
Chloride, mg/L
50
45
40
35
30
25
20
15
10
5
0
1980
1984
1988
1992
1996
2000
2004
2008


SC-A8B Total Dissolved Solids
TDS, mg/L
500
450
400
350
300
250
200
150
100
50
0
1980
1984
1988
1992
1996
2000
2004
2008

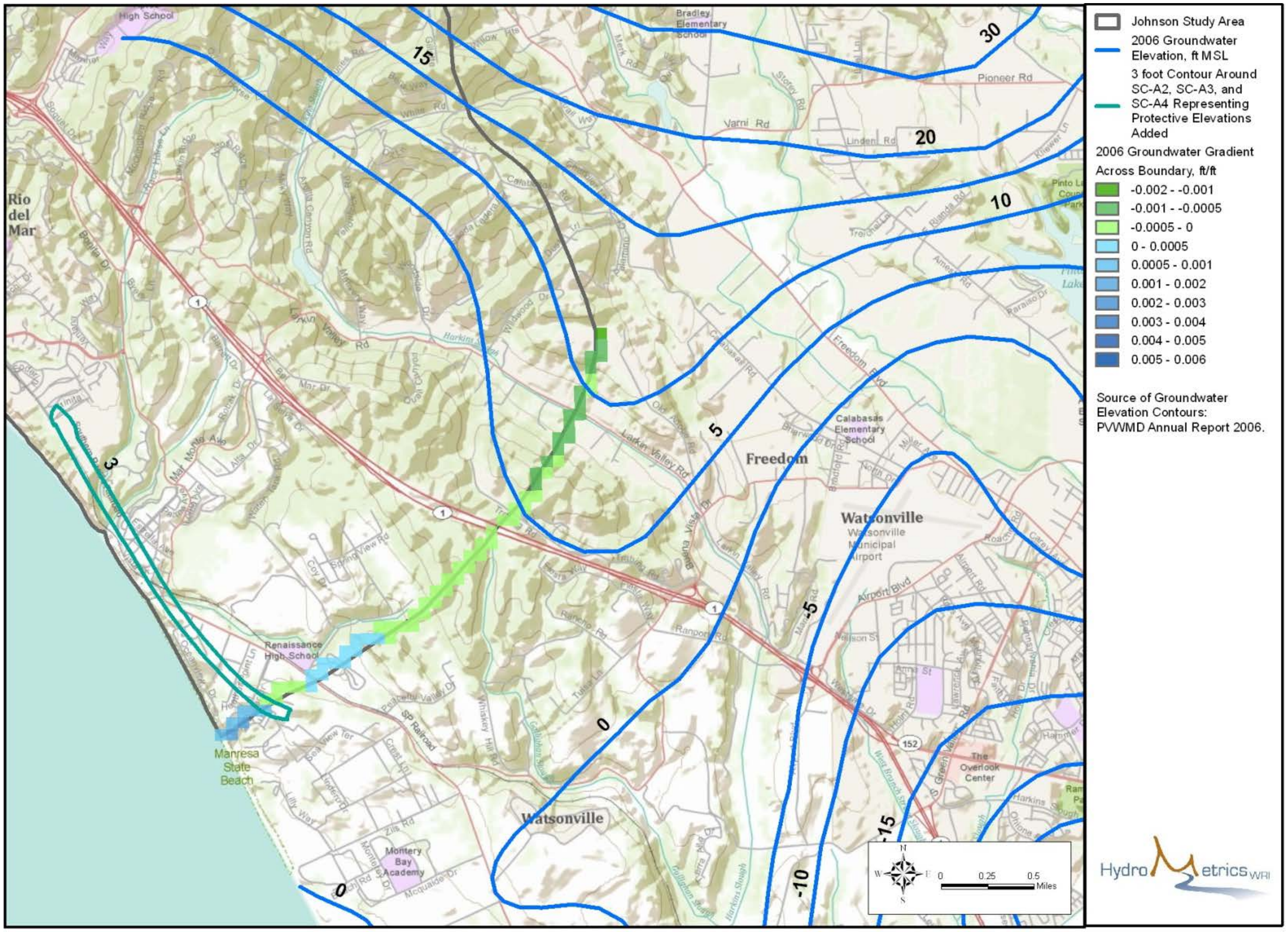

SC-A8B Groundwater Elevation
Groundwater Elevation, ft MSL
Protective Elevation
12
10
8
6
4
2
0
1980
1984
1988
1992
1996
2000
2004
2008

# ATTACHMENT 2:

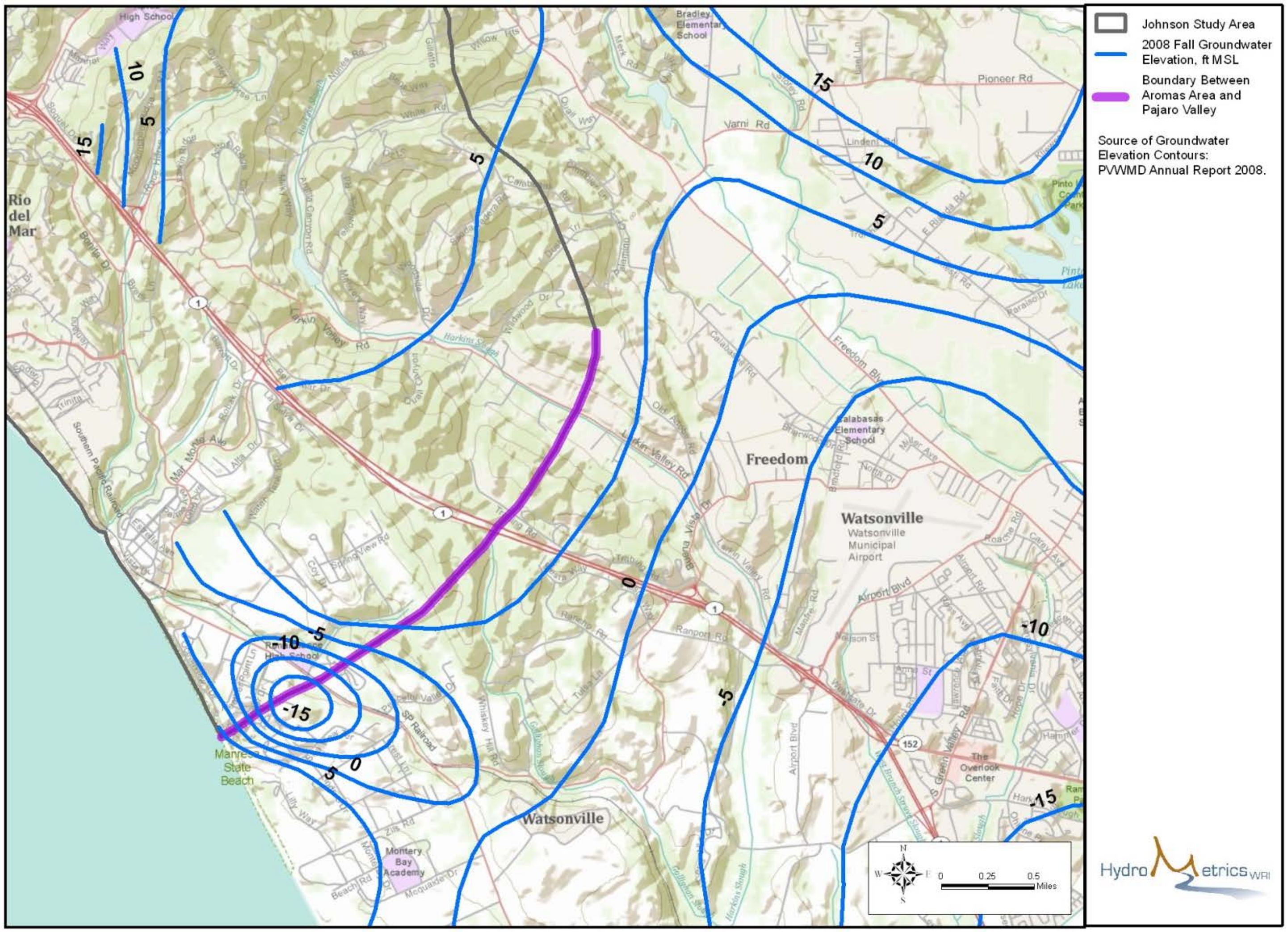
# CONTOUR MAPS FOR EVALUATING FLOW FROM AROMAS AREA TO PAJARO VALLEY


Johnson Study Area
2006 Groundwater Elevation, ft MSL
2006 Groundwater Gradient Across Boundary, ft/ft
-0.002 - -0.001
-0.001 - -0.0005
-0.0005 - 0
0 - 0.0005
0.0005 - 0.001
0.001 - 0.002
0.002 - 0.003
0.003 - 0.004
0.004 - 0.005
0.005 - 0.006
Source of Groundwater Elevation Contours: PVWMD Annual Report 2006.
HydroMetrics WRI
Freedom
Watsonville
Watsonville Municipal Airport
Manresa State Beach
Renaissance High School
Calabasas Elementary School
Bradley Elementary School
Monterey Bay Academy
The Overlook Center
Rio del Mar
0 0.25 0.5 Miles

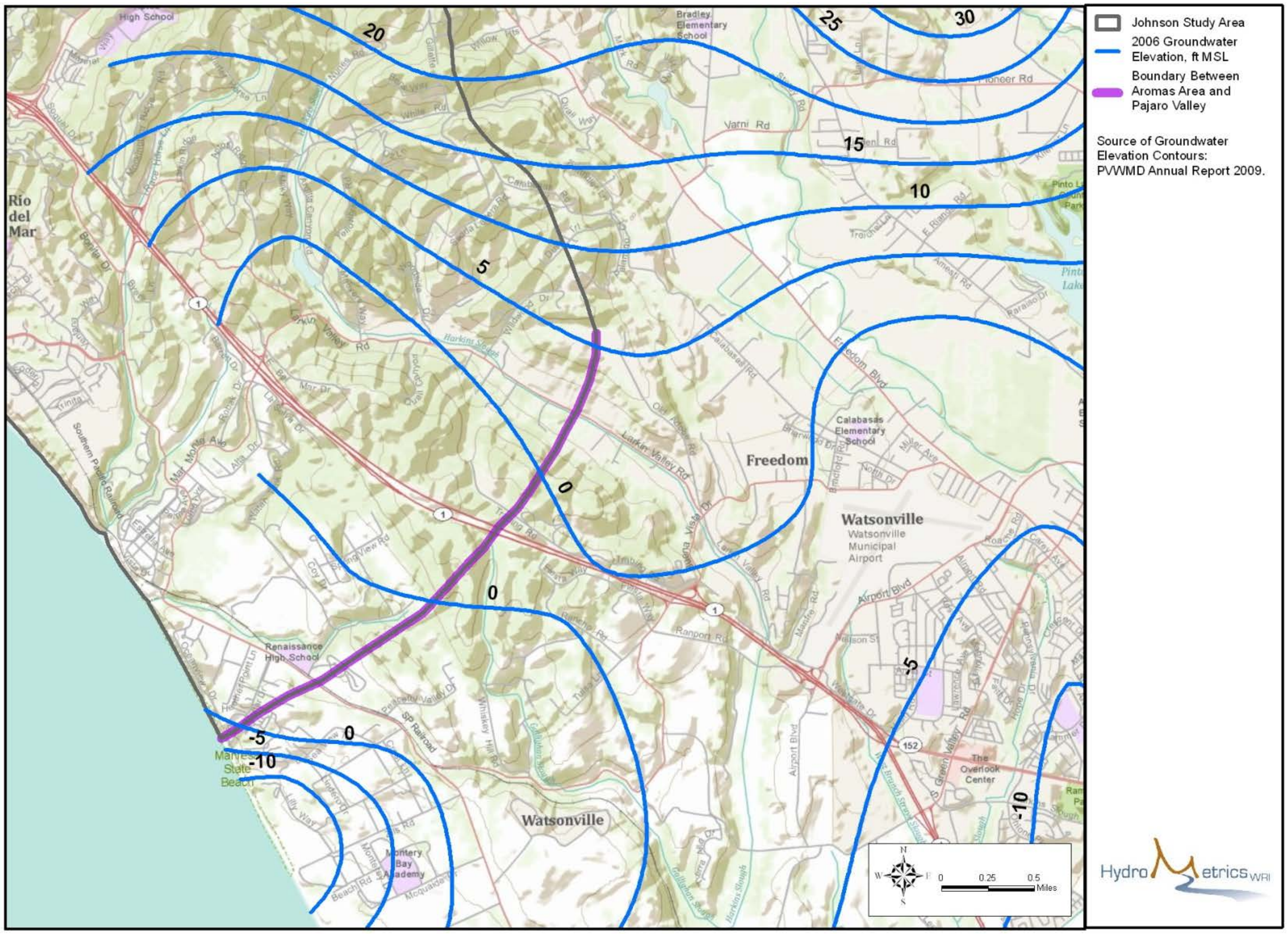
2006



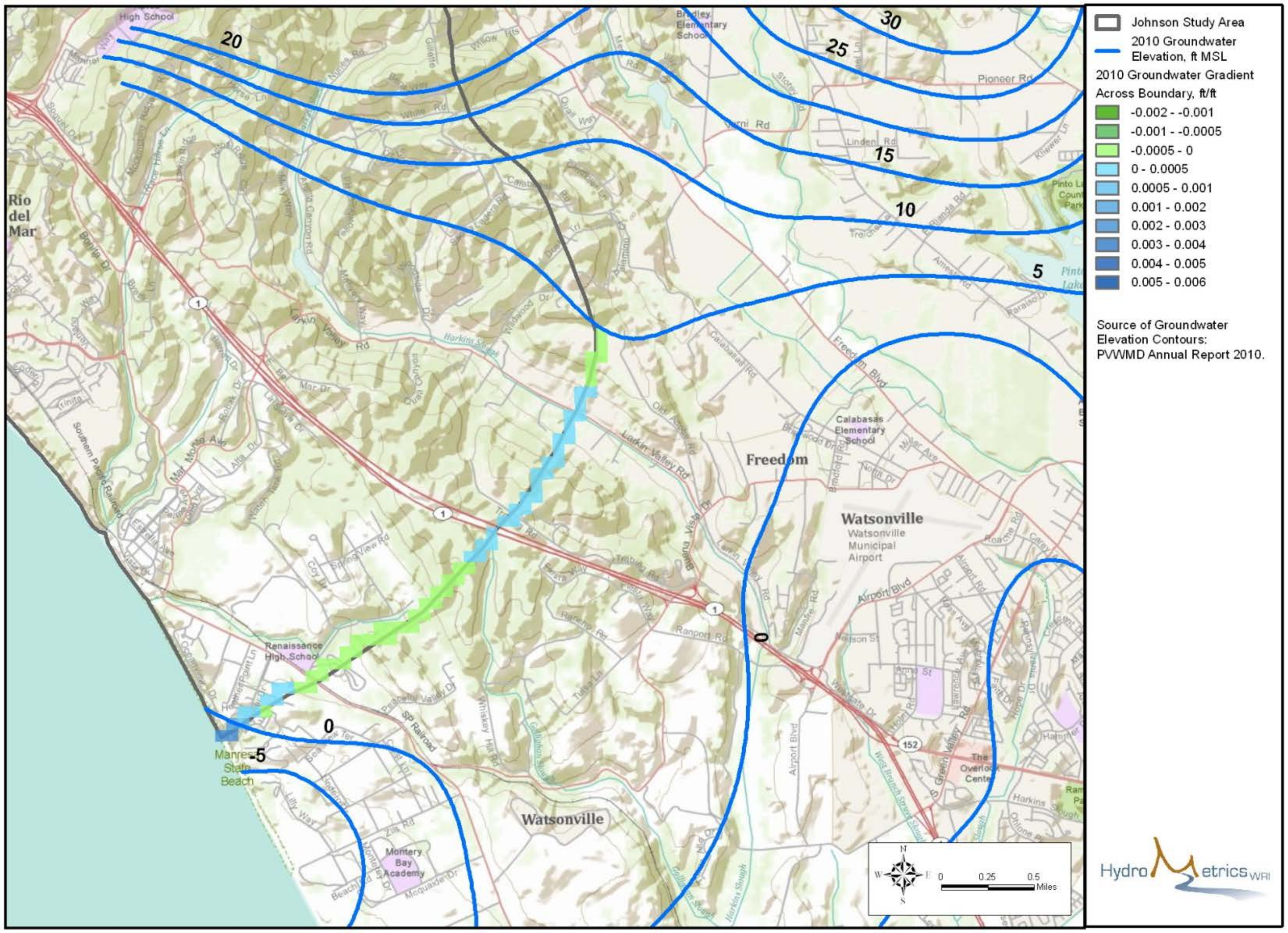

2006 - 3ft contour added


Johnson Study Area
2008 Fall Groundwater Elevation, ft MSL
Boundary Between Aromas Area and Pajaro Valley
Source of Groundwater Elevation Contours: PVWMD Annual Report 2008.
Freedom
Watsonville
Watsonville Municipal Airport
Rio del Mar
Manresa State Beach
HydroMetrics WRI
0 0.25 0.5 Miles
15
10
5
0
-5
-10
-15

2008


Johnson Study Area
2006 Groundwater Elevation, ft MSL
Boundary Between Aromas Area and Pajaro Valley
Source of Groundwater Elevation Contours: PVWMD Annual Report 2009.
HydroMetrics WRI
Freedom
Watsonville
Watsonville Municipal Airport
Rio del Mar
30
25
20
15
10
5
0
-5
-10
0 0.25 0.5 Miles

2009


Johnson Study Area
2010 Groundwater Elevation, ft MSL
2010 Groundwater Gradient Across Boundary, ft/ft
-0.002 - -0.001
-0.001 - -0.0005
-0.0005 - 0
0 - 0.0005
0.0005 - 0.001
0.001 - 0.002
0.002 - 0.003
0.003 - 0.004
0.004 - 0.005
0.005 - 0.006
Source of Groundwater Elevation Contours:
PVWMD Annual Report 2010.
HydroMetrics WRI
30
25
20
15
10
5
0
-5
Rio del Mar
Freedom
Watsonville
Watsonville Municipal Airport
Manresa State Beach
Renaissance High School
Calabasas Elementary School
Monterey Bay Academy
0 0.25 0.5 Miles

2010