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September 15, 2009

Subject: Modeled Outflow to Achieve Protective Water Levels

Ms Brown:

In our March 5, 2009 letter to you, we detailed a scope of work for two analyses related to our recent report on groundwater levels to protect against seawater intrusion and store water offshore (HydroMetrics LLC, 2009). The first analysis involves estimating the outflow required to maintain protective water levels at SqCWD's coastal monitoring wells. The estimated outflows are used with published water budget numbers to evaluate the current sustainable yield estimate. This letter report provides the results of the first analysis.

The second analysis in the scope is to estimate rates and depths of seawater intrusion in the Aromas area based on water quality data from Aromas area monitoring wells. As noted in our scope letter, we know of no instances where this has been attempted with the type of data available to us; and we have yet to develop a satisfactory approach to perform this analysis. Meanwhile, the USGS is finalizing a groundwater model of the Pajaro Valley which extends as far north as the Country Club well in SqCWD's service area. This model includes a water budget that can estimate current rates of seawater intrusion. This model, when available, may be the most effective tool for estimating current rates of seawater intrusion. Based on your guidance, we have documented the first analysis in this letter, and will re-assess the approach to the second analysis after reviewing and evaluating results from the USGS' Pajaro Valley model.

BACKGROUND: CURRENT PUMPING GOALS AND SUSTAINABLE YIELD ESTIMATE

The purpose of the analysis documented here is to evaluate the sufficiency of SqCWD's current pumping goal of 4,800 acre-feet per year based on sustainable yield estimates from *Technical Memorandum 2: Conceptual Hydrogeologic Model* (Johnson et al., 2004). It is important to note that Johnson et al. defined this amount as the upper limit on SqCWD's sustainable production. Johnson et al. stated that SqCWD's sustainable production may be somewhat less than 3,000 acre-feet per year in the Purisima area and is probably somewhat less than 1,800 acre-feet per year in the Aromas area. Although acknowledged as potentially too high, the 4,800 acre-foot per year pumping goal was a good interim goal when SqCWD's pumping was clearly exceeding sustainable yield. As SqCWD's pumping has declined to this pumping goal, it has become necessary to develop more refined sustainable yield estimates. This analysis evaluates the possibility that the yield is somewhat lower than the upper limit presented by Johnson et al. This analysis uses modeled estimates of the ocean outflow required to maintain protective water levels, combined with deep recharge estimates from Johnson et al., to evaluate sustainable yield.

The estimates of deep groundwater recharge are developed by Johnson et al. for each watershed in the Soquel-Aptos Basin (Figure 1). The watershed estimates are then grouped to estimate the total recharge for the Purisima and Aromas areas. Table 1 shows the estimated deep recharge in acre-feet per year from precipitation by watershed and is adapted from Table 5-11 in Johnson et al. These estimates are based on long-term averages, which are appropriate given long travel times between precipitation and deep aquifers, and are consistent with the long-term averages that the protective water levels represent. Sustainable yield should not be affected by short-term deviations from average recharge such as short-term drought. Sustainable yield would be affected by long-term changes in average recharge.

Two other important estimates from Johnson et al. used in this exercise are the consumptive use factor and estimate of non-SqCWD pumping. The consumptive use factor accounts for the amount of pumped water that is returned to recharge. Johnson et al. estimated a consumptive use factor of 85% for both the Purisima and Aromas areas. This means that 15% of total pumping returns to the groundwater basin, and should not be counted as an extraction in the water balance calculation.

Figure 1: Watersheds and Coastal Monitoring Wells

Johnson et al. estimated non-SqCWD pumping as 3,130 acre-feet per year in the Purisima area and 1,400 acre-feet per year in the Aromas area. For the purposes of estimating SqCWD's pumping goal as a portion of the sustainable yield, it is assumed that these estimates are adequate and non-SqCWD pumping does not change in the future.

Table 1: Study Area Watersheds and Estimated Average Deep Recharge

Watershed	Drainage Area in Study Area (mi^2)	Estimated Deep Recharge from Precipitation (afy)
Branciforte Creek	3.6	346
Between Branciforte and Soquel Creeks upstream of Hwy 1 (includes Arana and Rodeo Gulch)	5.9	699
Hwy 1 to Coast (West)	7.9	864
Soquel Creek	13.6	1,600
Between Soquel and Aptos Creeks upstream of Hwy 1 (includes Porter Gulch)	3.5	382
Aptos Creek	8.7	1,223
Valencia Creek (90%)	8.2	1,020
Purisima study area	**51**	**6,100**
Valencia Creek (10%)	0.9	113
Harkins Slough and South to Hwy 1	7.6	2,070
Hwy 1 to Coast (East)	5.2	709
Aromas study area	**14**	**2,900**

ESTIMATING OUTFLOWS TO OCEAN FROM CROSS-SECTIONAL MODELS

The estimated ocean outflows are based on model results documented in *Groundwater Levels to Protect against Seawater Intrusion and Store Freshwater Offshore* (HydroMetrics LLC, 2009). Two potential groundwater levels were presented in the HydroMetrics 2009 report: protective levels and target levels. We focus on the outflows needed to maintain protective levels in this analysis, because those levels are more representative of the freshwater basin being in balance with the ocean and more appropriate for estimating sustainable yield.

In order to calculate outflows from cross-sectional models, we need to define the width that each cross-sectional model represents. Figure 2 shows the midpoints between each of SqCWD's coastal monitoring wells. The width of aquifer represented by each cross-sectional model is defined by the distance between the midpoints. On the western end of the basin, the midpoint between well clusters SC-1 and SC-3 is mirrored on the southwest side of well cluster SC-1 to define the width of the SC-1 well cluster cross-sectional model. On the southeastern end of the basin, the SC-A4 cross-sectional model represents only the area from well cluster SC-A4 northward to the midpoint between well clusters SC-A3 and SC-A4. Table 2 shows the widths represented by each coastal monitoring well's cross-sectional model.

Table 2: Cross-Sectional Model Widths and Distribution of Protective Outflows to Ocean

Coastal Monitoring Well	Cross-Sectional Width (feet)	Protective Outflows (afy) by Percentile		
		30	**70**	**90**
SC-1	3,924	25	50	75
SC-3	4,157	75	125	225
SC-5	4,391	125	200	300
SC-9	3,976	125	250	275
SC-8	4,959	75	150	175
Purisima		**425**	**775**	**1,050**
SC-A1	5,010	600	750	850
SC-A8	3,818	900	1,950	2,300
SC-A2	4,011	350	1,075	1,225
SC-A3	5,257	175	1,200	1,350
SC-A4	3,232	325	1,050	1,200
Aromas		**2,350**	**6,025**	**6,925**

As discussed in our 2009 report, each cross-sectional model was run with 100 reasonable parameter sets of aquifer and aquitard conductivities. The results from each of the 100 runs were analyzed to calculate the amount of freshwater outflow needed to maintain protective groundwater levels. The compilation of all 100 outflow estimates provides a reasonable distribution of outflows required to maintain protective water levels at any monitoring well cluster. Table 2 shows the 30th, 70th, and 90th percentile of protective outflows for each coastal monitoring well cluster. The 70th percentile of the protective water level

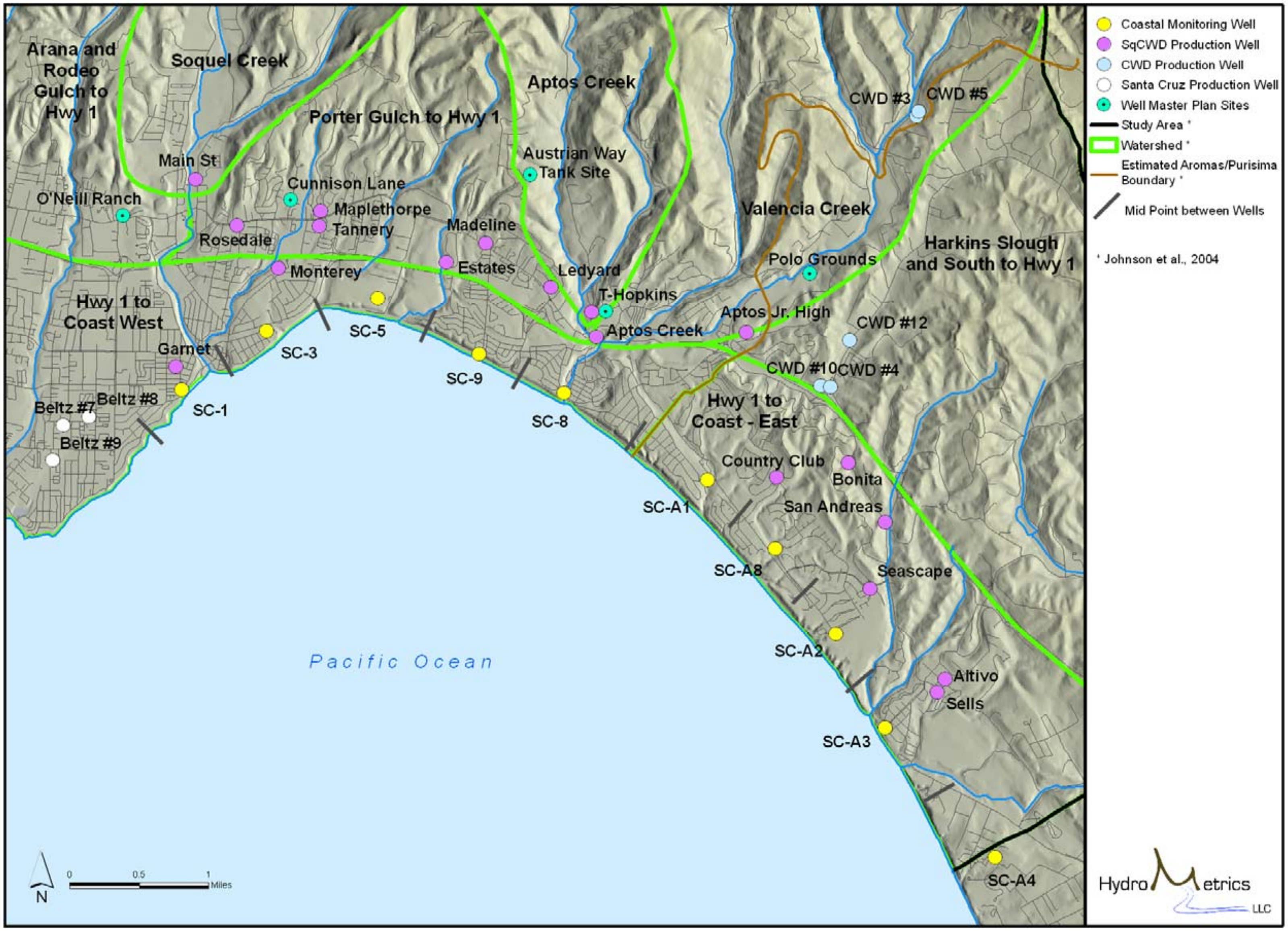

Figure 2: Cross-sectional Widths of Coastal Monitoring Well Models

distribution was recommended as the protective water level for each coastal monitoring well. Likewise, the 70th percentile outflows shown on Table 2 is a conservative estimate of the amount of outflow needed to protect the basin against seawater intrusion. The wide distribution of protective outflows reflects the uncertainty inherent in using these models to update the sustainable yield estimate. This uncertainty arises from the lack of geologic or water level data in the offshore aquifers that are being modeled. This uncertainty will be reduced as water level response to SqCWD's planned reduction and redistribution in pumping is monitored.

The protective outflows to the ocean in the Aromas area are much higher than the protective outflows in the Purisima area. This is a result of the higher horizontal hydraulic conductivities in the Aromas Red Sands and Purisima F unit in the Aromas area. The horizontal conductivities in the Aromas area range between 2 and 50 feet per day, while horizontal conductivities in the Purisima area range between 1 and 18 feet per day. More than half of the Aromas area model runs have protective outflows that exceed the estimated deep recharge from precipitation for the area of 2,900 acre-feet per year. This indicates that the upper estimates of Aromas horizontal conductivities may be too high to represent average values and/or the estimated deep recharge in the Aromas area is too low.

The estimated protective outflows are used to update the existing sustainable yield estimates by subtracting the outflows for the Purisima and Aromas areas from the deep recharge estimated in Johnson et al. to calculate total sustainable consumptive use for the areas. The consumptive use is adjusted by the consumptive use factor to calculate total sustainable pumping. Then, estimates of non-SqCWD pumping are subtracted to estimate SqCWD's portion of the sustainable yield.

A geographic issue arises when attempting to subtract outflows from Johnson et al.'s recharge estimates. SqCWD does not have coastal monitoring wells west of monitoring well cluster SC-1 (Figure 1). Therefore, recharge near Pleasure Point does not end up as outflow in any of the cross-sectional models. The recharge near Pleasure Point is removed from our sustainable yield calculations by subtracting all recharge west of the SC-1 model boundary. The recharges for the watersheds are reduced based on those areas, as shown in Table 3.

Table 3: Watershed Areas West of SC-1 Model Removed from Recharge Estimate

Watershed	Drainage Area West of SC-1 Model (mi^2)	Estimated Deep Recharge from Precipitation (afy)
Branciforte Creek	0.1	10
Between Branciforte and Soquel Creeks upstream of Hwy 1 (includes Arana and Rodeo Gulch)	0.7	85
Hwy 1 to Coast (West)	5.0	545
Removed from Purisima study area	**5.8**	**640**
Purisima recharge used with cross-sectional model outflows	47	5,500

Table 4 shows the sustainable yield calculation for the Purisima area by modeled outflow percentile. The calculation conservatively subtracts all of the City of Santa Cruz's assumed pumping of 575 acre-feet per year[1], 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. Table 4 shows that SqCWD's share of sustainable yield is at least several hundred acre-feet per year less than the current pumping goal of 3,000 acre-feet per year.

Table 4: Purisima Water Balance by Outflow Percentile

Sustainable Yield Component	Modeled Outflow Percentile		
	30	**70**	**90**
Purisima recharge from precipitation (afy)	5,500	5,500	5,500
Modeled Protective Outflows to Ocean (afy)	425	775	1,050
Total Consumptive Use (afy)	5,075	4,725	4,450
Consumptive Use Factor	0.85	0.85	0.85
Total Sustainable Pumping (afy)	5,970	5,560	5,235
Non-SqCWD Pumping	3,130	3,130	3,130
SqCWD Share of Purisima Yield (afy)	**2,840**	**2,430**	**2,105**

[1] This amount was assumed by Johnson et al. based on historical pumping amounts. The City is planning to pump 645 acre-feet per year in non-drought years and 1,290 acre-feet per year in drought years.

Table 5 shows the sustainable yield calculation for the Aromas area by the modeled outflow percentage. Table 5 shows that many model runs estimate that no consumptive use is available in the Aromas area. As discussed above, the range of hydraulic conductivities used for the Aromas may be too high. Also, the recharge estimate included in Johnson et al. may be too low. It is possible that more of the Harkins Slough area recharges the Aromas area as opposed to flowing to Pajaro Valley. Another possibility is that Aromas area wells receive more recharge from the Valencia Creek watershed, but this would reduce the estimated yield of the Purisima area. Even with these possibilities, it is likely that SqCWD's share of the Aromas sustainable yield is at least hundreds of acre-feet per year below the current pumping goal of 1,800 acre-feet per year. This conclusion that SqCWD's assumed sustainable yield of 1,800 acre-feet per year exceeds recharge in most years, resulting in coastal inflow of groundwater and potentially related seawater intrusion, is consistent with preliminary results from the Pajaro Valley Model developed by the U.S. Geological Survey.

Table 5: Aromas Water Balance by Outflow Percentile

<table>
<tr><th rowspan="2">Sustainable Yield Component</th><th colspan="3">Modeled Outflow Percentile</th></tr>
<tr><th>30</th><th>70</th><th>90</th></tr>
<tr><td>Aromas recharge from precipitation (afy)</td><td>2,900</td><td>2,900</td><td>2,900</td></tr>
<tr><td>Modeled Protective Outflows to Ocean (afy)</td><td>2,350</td><td>6,025</td><td>6,925</td></tr>
<tr><td>Total Consumptive Use (afy)</td><td>550</td><td>-3,125</td><td>-4,025</td></tr>
<tr><td>Consumptive Use Factor</td><td>0.85</td><td>0.85</td><td>0.85</td></tr>
<tr><td>Total Sustainable Pumping (afy)</td><td>645</td><td rowspan="3" colspan="2"><0</td></tr>
<tr><td>Non-SqCWD Pumping</td><td>1,400</td></tr>
<tr><td>SqCWD Share of Aromas Yield (afy)</td><td>-755</td></tr>
</table>

ANALYSIS QUALIFICATIONS AND LIMITATIONS

The estimates of ocean outflow were developed at the watershed scale. A full evaluation of sustainable yield requires more detailed estimates of recharge in the basin, including temporal and spatial distribution. The ability of SqCWD to maintain protective water levels at all coastal monitoring wells depends on the distribution of pumping at SqCWD's existing and proposed wells in addition to the total pumping amount. A groundwater model is required to evaluate in advance whether any specific pumping distribution will maintain protective levels. SqCWD can also use adaptive management to observe whether a pumping distribution maintains protective levels.

The limitations of this analysis are demonstrated by issues related to dividing yield between the Purisima and Aromas areas. The recharge areas providing water to the Aromas area are poorly defined. The boundary between the Purisima area and Aromas area is typically based on estimates of the Purisima-Aromas surface contact; resulting in Johnson et al. (2004) estimating that only 10% of the Valencia Creek watershed provides recharge for the Aromas area. In the Aromas area, however, the B-level monitoring wells used to establish protective elevations are typically screened in the Purisima F unit. Well SC-A1B, in particular, is in the lower portion of the Purisima F unit. Because the Purisima F unit is exposed in much of the Valencia Creek watershed, it is likely that more than the estimated 10% of Valencia Creek watershed recharge provides outflow to the Aromas area B-level monitoring wells.

Also, dividing pumping between the Purisima area and Aromas area is not necessarily straightforward. Wells such as the Aptos Jr. High and Polo Grounds well are near the boundary used to divide the Valencia Creek watershed. Even though pumping at those wells likely has more water level effects in the Aromas area, pumping from these wells should be included in the Purisima area total due to the large percentage of the watershed assigned to the Purisima.

This analysis only relates to outflows required to maintain protective water levels. Water levels at all coastal monitoring wells have been below protective elevations since well construction. SqCWD will need to reduce pumping below the sustainable yield estimate to raise water levels to protective levels. This analysis is unable to evaluate how the basin will recover for different pumping amounts. An evaluation of recovery, including the duration needed for recovery, requires development of a groundwater model.

CONCLUSIONS

Based on the analyses presented above, revised sustainable yield goals would seem to be approximately 2,500 acre-feet per year in the Purisima area and 0 acre-feet per year in the Aromas area. Estimating SqCWD's share of sustainable yield in the Purisima area as 2,500 acre-feet per year is reasonable, however, based on the uncertainty in the calculation, we do not recommend revising the sustainable yield estimate in the Aromas area to zero.

After reviewing the USGS model of Pajaro Valley, it may become necessary to adopt a modified concept of sustainable yield for the Aromas area. There is little offshore storage in the Aromas area, and groundwater use appears to be close to, or exceeding, annual recharge. Because recharge in the Aromas area is either extracted by other pumpers or discharged to the ocean within a short number of years, the idea of long term yield may not be viable. The amount of pumping available to SqCWD in the Aromas area may need to be based on recent precipitation.

Our calculations show that current pumping goals for the Purisima area and Aromas area are at least hundreds of acre-feet per year too high to protect the basin against seawater intrusion after the basin recovers to protective elevations. Given this conclusion, SqCWD should use conservation and supplemental supply when available to reduce pumping and monitor recovery. Effects on coastal monitoring wells of redistributing pumping inland as included in the Well Master Plan should also be monitored. With these data, as well as more detailed estimates of recharge and the possible construction of a numerical model, better predictions of what pumping reductions are required for recovering and maintaining protective levels can be developed. We would be glad to discuss with you how we would undertake such studies. Please contact us if you have any questions.

Sincerely,

Cameron Tana

Derrik Williams
HydroMetrics LLC

REFERENCES

HydroMetrics LLC. 2009. *Groundwater levels to protect against seawater intrusion and store water offshore*, 48 p., January.

Johnson, N.M., D. Williams, E.B. Yates, and G. Thrupp, 2004, *Groundwater assessment of alternative conjunctive use scenarios- draft technical memorandum 2: hydrogeologic conceptual model*, Soquel Creek Water District, September,