

Water Well Aquifer Study

Prepared for:

City of San Clemente

910 Calle Negocio, Suite 100
San Clemente, California 92673
Contact: David Rebensdorf, PE

Prepared by:

DUDEK

605 Third Street
Encinitas, California 92024
Contact: Steven Stuart, PE

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EXECUTIVE SUMMARY

The City of San Clemente asked Dudek to evaluate whether the salinity observed in Well 6 and Well 8 is stable or increasing, what the source of the salinity is, and make recommendations about the operation of the wells in the future. To answer these questions, Dudek conducted flow, temperature, and fluid conductivity surveys in the wells, and collected a variety of depth discrete samples for analysis of inorganic constituents.

Based on analysis of that work, we have concluded that Well 6 water quality is stable and consistent with the salinity observed in the well in 1958 when it was constructed. There is no indication of seawater intrusion or even incipient seawater intrusion at this time. The City should feel free to continue production at previous rates.

With respect to Well 8, we have concluded that the salinity of water produced by the well increased as cumulative production increased and that there may be evidence of incipient seawater intrusion in the deeper portion of the well and also at the bottom of the upper screened interval. Fluid conductivity profiling under pumping conditions indicates that poorer quality water enters the deeper portion of the well. We recommend that the City seal off the deeper screened intervals to minimize production of this poorer quality water. We also recommend that the City redevelop the upper screen interval to increase production from this zone that has better water quality. We further recommend a production rate of 400 GPM and continuous monitoring of conductivity for one year. If after a year of pumping, the water quality in Well 8 remains stable and water level monitoring indicates that there is no response to the pumping in the deeper section of Well 5, the pumping rate could be gradually increased until there is a response in Well 5 or until water quality declines.

We also recommend rehabilitating Well 5 to separate the upper portion of the well screened in the terrace deposits and the lower portion screened in the Capistrano Formation. Following rehabilitation, Well 5 should be monitored continuously for signs of further seawater intrusion in response to production from Well 8.

INTRODUCTION

The City of San Clemente (the City) operates two water supply wells, Well 6 and Well 8, located near the San Clemente Golf Club (Figure 1). Water produced by these wells augments the City's water supply to its residents. Well 6 was taken offline in June 2010 due to a loss of production as a result of iron oxide formation (Water Systems Engineering, Inc., 2009). Well 8 was taken offline in January 2012 to complete a backwash improvement project and was kept out of service until the completion of this study to identify the source of increase chloride and total dissolved solids (TDS) concentrations. The City retained the services of Dudek to investigate these wells and provide recommendations to improve their respective water quality and performance so that the City could bring them back online.

This report includes our assessment of Wells 6 and 8 after conducting fluid temperature and electrical resistivity surveys under static and dynamic conditions, and a review of historical water quality data and results of water samples collected in late 2013 from each well. Depth-discrete samples were collected from Well 8 to enhance our understanding of the nature of water entering the well from the two screen intervals. Historical water quality data for Well 5 and the Calafia observation well were also evaluated to assess whether conditions at Wells 6 and 8, which are farther inland, were the result of seawater intrusion or saline formational water.

The report concludes with recommendations to continue production from the wells, to instrument the wells to monitor water levels and electrical conductivity to enhance the City's understanding of water quality issues at the wells, and for actions that the City may take to improve the water quality and production from Well 8.

1.0 BACKGROUND

1.1 Geology

The southern part of San Clemente consists of Quaternary marine terrace deposits underlain by the Tertiary San Mateo Formation and Capistrano Formation (Tan, 1999; Figure 2). The marine terrace deposits are characterized as predominantly fine to coarse sand and gravel (JMM, 1973). The California Department of Mines and Geology characterized the terrace deposits as silty sand with clay and gravel. The San Mateo Formation, which underlies the terrace deposits, consists of marine sands and conglomerates deposited during Pliocene time (JMM, 1973). The Capistrano Formation, which underlies the San Mateo Formation, consists of interbedded sandstone and shale zones (JMM, 1973). The Capistrano Formation is approximately 1,700 feet thick.

The Cristianitos Fault is a north-south trending fault located approximately 8,000 feet northwest of the San Clemente Wells. Uplifting on the eastern side of the fault has brought older formations in contact with the younger Capistrano Formation in the west. This movement

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probably led to the dipping of the Capistrano Formation, which was noted to dip 8 to 10 degrees to the north (JMM, 1973).

Montgomery Engineers posited a fault that ran north-south between former Well 3 (located near Well 8) and Well 6. This fault was inferred based on different water quality between the wells and limited or no hydraulic connection between the wells during aquifer testing. The California Division of Mines and Geology, however, does not map a fault in this area (Tan, 1999). The difference in water quality and the limited hydraulic connection between the wells may be due to the fact that Well 6 was screened in the lower zone A of the Capistrano Formation and Well 3 was screened in the overlying zones B and C of the Capistrano Formation. Further discussion about groundwater in the Capistrano Formation is addressed in Section 2.2.

In addition to the dipping beds caused by regional faulting, the geology in the southern area of San Clemente is further complicated by nested submarine-fan channels in the Capistrano Formation (Walker, 1975). These nested channels are described as turbidite-filled channels, which means these submarine-fan channels were filled with sediment deposited under density flow from an underwater avalanche. The turbidite-filled submarine channels at San Clemente (which are exposed at San Clemente State Beach) are laterally nested one alongside another that trend southwest to northwest.

1.2 Hydrogeology

The San Clemente Groundwater Basin is located in the southern section of the San Clemente Hydrologic Area, which is within the San Juan Hydrologic Unit (RWQCB, 1994). Boyle Engineering noted that the “turbidite facies and sandstone lens within the Capistrano Formation” are conducive to groundwater production (Boyle, 1987). The interbedded sandstone layers in the Capistrano Formation were designated as aquifer zones A, B, C and D “in respective distance from the ocean” (JMM, 1973). In the vicinity of the City of San Clemente wells, zone A corresponds to the deepest aquifer, which is overlain by zones B, C, and D, respectively (Figure 3). Overlying the Capistrano Formation is the San Clemente Basin alluvium and terrace deposits.

The terrace deposits are in direct hydraulic connection with the ocean and are subject to seawater intrusion (JMM, 1973). The aquifers in the Capistrano Formation are interbedded with shalestone and have isolated the Capistrano Formation from direct hydraulic connection with the ocean. As will be seen when comparing the water quality at Well 5 and the Calafia well, zone A of the Capistrano Formation produces the best quality water. The terrace deposits and, possibly, zone C of the Capistrano Formation, are impacted by seawater intrusion.

2.0 WELL 6

Well 6 was constructed in July 1958. It is located off of Avenue Santa Margarita on the southern edge of the municipal golf course. The City reported that upgrades were made to the well head, pumps, motors and electrical system in 2002 (City of San Clemente, 2012). Since 2002, however, the flow rate in the well had steadily declined to an average rate of 230 GPM by June 2010. The well went offline in June 2010.

2.1 Construction

The well boring was drilled to a depth of 938 feet below ground surface (feet bgs). Land surface elevation is 212.70 feet above mean sea level (MSL). The bottom of the well casing was set at 938 feet bgs and was constructed with a nominal 14-inch diameter mild steel casing. The well casing was perforated with louvers from 754 to 920 feet bgs. The well draws water from zone A of the Capistrano Formation (JMM, 1973).

2.2 Previous Well Inspections and Surveys

A well assessment by Water Systems Engineering (WSE) in 2009 concluded that an accumulation of iron oxide, biomass, and formation sediments was the cause for declining production at Well 6 (WSE, 2009). An analysis of water samples collected from the well indicated “elevated” levels of TDS, alkalinity and hardness. There were also “elevated” levels of manganese and re-suspended iron, which indicated the presence of iron oxidizing bacteria that was most likely the source of biofouling of the well screen. WSE also noted “elevated” silica concentrations that may derive from formational water and “elevated” chloride and sodium concentrations that may indicate brackish or seawater. However, as will be discussed in Section 7.0, water quality at this well has remained consistent since 1958 and there is no indication of degradation over time.

A video survey of the well in November 2010 indicated that the louvers beginning at the top of the well screen at 757 feet bgs were “barely discernible” (GTC, 2010). The louvers from 757 feet bgs to 903 feet bgs were characterized as 70% to 100% plugged and the casing contained minor to abundant iron oxide scale and microbiological growth.

Well rehabilitation occurred in February 2011 with wire-brushing of the well screen by Bakersfield Well and Pump. A video survey 7 hours after the wire-brushing indicated that the wire-brushing was effective in removing mineral scale and biofilm and that the casing contained no defects such as pitting, corrosion, or holes (GTC, 2011). General Pump, under the direction of Geotechnical Consultants (GTC), continued the well rehabilitation with more mechanical and chemical cleaning. After this round of cleaning, the City observed an increase in sand content in the discharge (City of San Clemente, 2012). A video inspection in April 2011 showed “multiple enlarged perfs and holes in casing” (Pacific Surveys, 2012b).

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Consequently, in September 2012, the City installed a 12.5-inch stainless steel casing to line the inside of the original 14-inch diameter mild steel casing. A 10-inch diameter stainless steel wire-wrap screen with 0.050-inch slots was set from 747 to 917 feet bgs (Figure 4).

2.3 Well Production

Well 6 produced 366 AFY (avg. of 227 GPM) to 702 AFY (avg. of 435 GPM) between 1959 and 1970 (Boyle, 1987). The City reported that Well 6 had been a “steady producer for the City at a flow rate of approximately 400 gallons per minute” (City of San Clemente, 2012). Daily production data from January 2009 to September 2009 indicated that the well averaged 340 GPM, but production followed a declining trend (Figure 5). The well operated intermittently in 2010 at an average rate of 240 GPM until it was taken offline in June 2010.

2.4 Historical Water Quality

Water quality at Well 6 has remained consistent since its installation in 1958 (Table 1). For instance, the TDS concentration in the late 1950s and early 1960s ranged from 350 mg/L to 549 mg/L compared to 405 to 440 mg/L in August 2013 (Figure 6). Chloride in the late 1950s and early 1960s ranged from 72 mg/L to 77 mg/L compared to 68 to 74 mg/L in August 2013. There were minor fluctuations in the major ions but no marked change in water quality from 1958 to 2013.

2.5 2013 Fluid Conductivity and Temperature Surveys

Dudek contracted the services of Pacific Surveys to run continuous fluid temperature and resistivity logs under static and dynamic (i.e. pumping) conditions at Well 6 on August 16, 2013. A temporary submersible pump was installed by General Pump on August 1, 2013. Water pumped from the well during the dynamic surveys was discharged to the City’s holding pond located near Well 8.

The static water level at Well 6 on August 16, 2013 was 195 feet bgs. One static survey was conducted from top to bottom followed by three dynamic surveys (Appendix A). The fluid resistivity measurements (in units of ohm-meters) were converted to temperature-compensated fluid conductivity values (in units of microSiemens per centimeter, uS/cm) by multiplying the inverse of the resistivity values by 10,000. Fluid conductivity was compensated to 25°C.

2.5.1 Natural Geothermal Gradient

The temperature surveys conducted under static conditions were compared to the natural geothermal gradient to gauge whether there was vertical groundwater flow in the well under static conditions. A global average natural geothermal gradient is 30°C/kilometer, or 0.009°C/ft, meaning the groundwater temperature increases 30°C for every kilometer vertically downward from land surface. A natural geothermal gradient of 0.012°C/ft was observed at the Seal Beach

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Naval Yard near the Newport-Inglewood fault zone (Higgins, 1984). The geology underlying the Seal Beach Naval Yard is similar to San Clemente in that bedrock is overlain by alternating beds of shalestone and sandstone of Tertiary age. The geothermal gradient of 0.012°C/ft was assumed for San Clemente based on comparable geology and proximity to Seal Beach.

2.5.2 Static Survey

2.5.2.1 Temperature

The temperature increased from approximately 22 °C at the static water level at 195 feet to 26.41 °C at the top of the screen at 747 feet bgs, or approximately 4.4 °C (Figure 7). This yields a rate of temperature increase of approximately 0.008 °C/foot, consistent with the global average. The temperature at the bottom of the screen at 915 feet bgs was 26.68 °C. The rate of temperature increase was only 0.002 °C/ft. This slope was less than the natural geothermal gradient of 0.012 °C/ft, which indicated that groundwater moves down through the screen interval under static conditions. Colder formational water enters at the upper portion of the well screen and flows down, thereby, creating a more uniform temperature profile throughout the well screen interval.

2.5.2.2 Fluid Conductivity

The fluid conductivity during static conditions increased from 722 uS/cm at the top of the well screen to 731 uS/cm at the bottom of the well screen. Conductivity was fairly uniform throughout the well screen interval (Figure 7).

2.5.3 Dynamic Surveys

At the conclusion of the static survey with the temperature/resistivity probe at the bottom of the well, the temporary submersible pump was turned on at 11:40 a.m. on August 16, 2013. The pumping rate was approximately 200 GPM. The well pumped for 30 minutes before starting the first dynamic survey by lifting the temp/resistivity probe from the bottom of the well. A second dynamic survey was conducted after the well had pumped for 70 minutes. A third dynamic survey run was conducted 3.75 hours, or 225 minutes, after pumping started.

2.5.3.1 Temperature

The temperature profiles for all three dynamic surveys showed higher temperatures than the static temperature, indicating that deeper water (i.e. warmer water) was pulled into the well when pumped (Figure 7). The surveys also showed an increasing trend in temperature the longer the well pumped. The average temperatures over the screen interval for dynamic surveys 1, 2, and 3 were 26.87 °C, 26.95 °C, and 27.00 °C, respectively.

2.5.3.2 Fluid Conductivity

The first two dynamic surveys showed similar fluid conductivity profiles over the screen interval. The exception was a slightly lower conductivity in the lower 30 feet of the well screen during the second dynamic survey approximately 40 minutes after the first run (70 minutes after pumping started). Conductivity averaged approximately 720 uS/cm for each survey (Figure 7).

An overall increase in conductivity (average 741 uS/cm) was measured during the third dynamic survey (Figure 7). There was a marked increase in conductivity at the lower 20 feet of well screen, which averaged 771 uS/cm. The increase in TDS 3.75 hours after pumping started indicated that, under static conditions, water with lower TDS moved down from the upper screen interval to the lower screen interval and out into the deeper formation. This lower TDS water was pumped out of the deeper formation after 3.75 hours of pumping, which was then followed by poorer water quality. However, the contribution of lower TDS water from the rest of the well diluted the higher TDS water from the bottom such that the difference in conductivity at the top of the well screen was only 11 uS/cm between 0.5 hour and 3.75 hours after pumping started.

The changes in fluid conductivity over the course of the first few hours of pumping are the result of downward vertical flow in the well during static conditions (i.e. when the well is idle) prior to pumping. This represents a short-term condition of the well during the initial hours of pumping; whereas, for the long-term, water quality data collected since 1958 indicates that the well maintains an average TDS concentration of approximately 500 mg/L (i.e. 759 uS/cm) over extended periods of pumping (Table 1).

2.5.4 2013 Flow Meter Survey

A flow meter survey was conducted between dynamic surveys 2 and 3 at approximately 2.5 hours after pumping started. The well pumped an average 200 GPM during the flow meter survey.

The lower depth interval from 880 to 900 feet bgs contributed 12% of the total flow to the well (Figure 7). The average TDS at this depth was 771 uS/cm; therefore, the TDS of the remaining 88% of the water entering the well had an average TDS of 734 uS/cm. Approximately 25% of the total production of Well 6 enters the well between 790 and 800 feet bgs. This interval may indicate a more permeable zone and probably corresponds with the better quality water (i.e. lower TDS) that enters the well during static conditions.

2.6 2013 Water Quality

2.6.1 Sequential Samples

A series of nine water quality samples were collected at the wellhead from August 16 to 19, 2013. The first sample was collected 2 minutes after the well started pumping at 11:40 a.m.

Subsequent samples were collected intermittently over the next 75 hours. The samples were analyzed for major ions, total dissolved silica, TDS, and metals (Table 1, Appendix B).

The results indicated that, with the exception of a slight increase in the divalent cations (calcium and magnesium) and a slight decrease in sodium and bicarbonate, there was little change over the 75-hour period. Neither chloride nor TDS concentrations changed notably (<2%), though the manganese concentration increased from 0.05 mg/L to 0.14 mg/L over the three days.

Further discussion of water quality at Well 6 in 2013 is provided in Section 7.0.

3.0 WELL 8

3.1 Borehole and Geophysical Logs

Well 8 was constructed by Best Drilling and Pump in October 2008. A 17.5-inch diameter pilot borehole was drilled from September 3 to 12, 2008 using mud rotary to a depth of 842 feet bgs. A borehole geophysical electric log (e-log) was run on September 12, 2008 (Pacific Surveys, 2008). The e-log included a spontaneous potential (SP) log, short-normal and long-normal resistivity logs, a natural gamma radiation log, and a guard log. The high resistivity measurements (>70 ohm-meters) on the long-normal resistivity log were recorded from 456 to 623 feet bgs and from 667 to 776 feet bgs (Figure 8). The lithology characterized in the borehole log for these two depth intervals was predominantly sandstone (fine to coarse sand) with trace gravel and intermittent lenses of claystone (e.g. clay with silt and fine sand) that ranged in thickness from 0.5 to 18 feet (GTC, 2008a).

The highest electrical resistivity was 113.6 ohm-meters at 586 feet bgs, which was characterized as conglomeratic sandstone with coarse sand and small gravel. This peak occurred in an interval of high resistivity (>90 ohm-meters) measured by the long-normal log from 543 to 608 feet bgs (Figure 8). The second highest resistivity peak was 108 ohm-meters at 736 feet, which was characterized between conglomeratic sandstone with coarse sand and gravelly sandstone. This peak occurred in an interval of high resistivity (>90 ohm-meters) measured by the long-normal log from 714 to 751 feet bgs.

3.2 Well Construction

Well 8 was constructed by Best Drilling and Pump in October 2008 (Figure 9). The well was constructed with stainless steel casing. Two well screens were set at:

- 450 – 600 feet bgs (upper screen): 12-inch diameter stainless steel wire-wrap screen with 0.085-inch slots.
- 670 – 750 feet bgs (lower screen): 12-inch diameter stainless steel wire-wrap screen with 0.085-inch slots.

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These two screen intervals corresponded with the depth intervals where the highest resistivity measurements were recorded. The bottom 45 feet of the upper well screen included the interval where the highest resistivity of 113.6 ohm-meters was measured at 586 feet bgs in the conglomeratic sandstone with coarse sand and gravel. The bottom 35 feet of the lower well screen included the interval where the second highest resistivity peak was measured.

A section of stainless steel blank casing was set between the two well screens from 600 to 670 feet bgs. The annular space between the borehole wall and the casing was filled with 6 x 9 Colorado silica sand from 425 to 795 feet bgs. No annular seal was set between the two well screens.

Dudek projected the location and depth of Well 8 on the B-B' geologic cross-section included in the James Montgomery report. The upper well screen appears to be set in zone C of the Capistrano Formation. The lower screen appears to be set in zone B of the Capistrano Formation. The blank casing separating the two screens appears to be set in the low permeable shalestone separating zones B and C (Figure 10).

3.3 Well Development

A 12-inch diameter line-shaft turbine pump was temporarily set at 400 feet with the bowls extending to 408 feet bgs for well development and conducting step drawdown and constant rate aquifer tests (GTC, 2008b). This setting placed the bowls 42 feet above the upper well screen.

Geotechnical Consultants, Inc. (GTC), of Lake Forest, California, reported that well development was conducted using a pump-and-surge method, which involves pumping water from the well and then shutting off the pump to let the water in the column pipe fall back into the well casing. This pump-and-surge process was repeated numerous times over four days and totaled 28 hours. As will be discussed later when reviewing the flow meter survey, this development may have only been effective in the upper portion of the upper screen.

3.4 Aquifer Testing

A 12-hour step test and a 24-hour constant rate aquifer test were conducted after well development (GTC, 2008b). The 12-hour step test, conducted on October 24, included four 3-hour steps with pumping rates (and maximum drawdowns) of 618 GPM (48 feet max. drawdown), 797 GPM (64 feet), 1024 GPM (83 feet), and 1188 GPM (99 feet). The specific capacities for each step were 12.9 GPM/ft, 12.4 GPM/ft, 12.3 GPM/ft, and 12.0 GPM/ft.

The 24-hour constant rate aquifer test was conducted from October 27 to 28 at 795 GPM. The drawdown was 68.4 feet at the end of the test. No other wells were monitored during the

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constant-rate aquifer test. No aquifer characteristics were estimated with the drawdown data collected during the constant-rate aquifer test.

GTC concluded that “Well No. 8 is capable of sustained production at a rate of 800 GPM and maybe higher. Production at 800 GPM would be less susceptible to seasonal or long term drought water level fluctuations” (GTC, 2008).

On August 7, 2013, Well 8 was pumped at a rate of 600 GPM for 3.5 hours while conducting the fluid conductivity and temperature surveys. Analysis of the drawdown data from that time indicates that the transmissivity of the aquifer in the vicinity of Well 8 is approximately 1,100 ft²/day and the hydraulic conductivity is 5 ft/day. It should be noted that a longer period of pumping will yield greater confidence in the estimates of transmissivity and hydraulic conductivity.

To evaluate the extent to which Well 8 captures water to the west, the stagnation point for Well 8 was estimated using the method developed by Javandel and Tsang (Javandel and Tsang, 1986). The stagnation point represents the distance downgradient of a pumping well beyond which water is not captured by the well. Using a value for hydraulic conductivity of 4.5 feet/day based on drawdown during pumping in 2013, the stagnation point for Well 8 pumping at 737 GPM (average historical production rate) was estimated at approximately 3,800 feet west of the well, or approximately the distance west to the Calafia Well. At a pumping rate of 400 GPM, the stagnation point is estimated to be 2,000 feet west of Well 8, or approximately the distance to Well 5. It should be noted that these estimates are based on an assumed hydraulic gradient between Well 8 and the ocean.

3.5 Historical Production

Well 8 came online on October 19, 2009. The well averaged approximately 737 GPM during its operation from October 2009 to January 2012. The well went offline on January 18, 2012. It produced a total 1,460 acre-feet from October 2009 to January 2012 (Figure 11).

3.5.1 2008 Flow Meter Survey

A flow meter survey (i.e. spinner survey) was conducted on November 5, 2008 by Pacific Surveys. The well produced 800 GPM during the survey. The lower well screen contributed 18% (148 GPM) to the total flow from the well. The bottom 50 feet of the upper well screen (from 550 to 600 feet bgs), which included the interval with the highest measured electrical resistivity in the e-log, contributed an additional 19% to the total flow, giving a total contribution of 37% (300 GPM) from the well that included the two coarsest-grain zones of the aquifer. The top 100 feet of the Upper Screen contributed 63% to the total flow from the well. This interval was

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characterized as predominantly sandstone (fine to very coarse sand, locally cemented) with intermittent thin lenses of claystone.

It appears that the bottom 50 feet of the upper well screen and the lower well screen were not developed by the pump-and-surge method because production from these two zones, which appeared to be the most permeable zones based on the e-log and lithologic log, only contributed 37% to the total flow. It appears that the pump-and-surge method was only effective in developing the top 100 feet of the upper well screen and had minimal effect in developing the lower screen sections.

3.5.2 2012 Flow Meter Survey

A second flow meter survey was conducted in February 2012 (Figure 8). The well produced 800 GPM during this survey. The flow meter survey showed that the lower well screen contributed 17% to the total flow from the well. The bottom 50 feet of the Upper Screen (from 550 to 600 feet bgs) contributed an additional 18% to the total flow, giving a total contribution of 35% from the two most permeable zones of the aquifer. The top 100 feet of the Upper Screen contributed 65% to the total flow from the well.

The 2012 flow meter survey was similar to the 2008 flow meter survey in that the most permeable zones produced approximately 35% of the total flow from the well. It does not appear that the 2.25 years of pumping from 2009 to 2012 had further developed the lower screen sections and improved production from the bottom 50 feet of the upper well screen and the lower well screen.

3.5.3 2012 Video Survey

A video survey of the well casing was conducted on February 1, 2012. The video inspection revealed that the upper screen was free of debris, mineral scale, and biofouling. The lower screen was described as having localized zones of bio and/or sediment accumulation on the perforations that appeared to increase with depth (Pacific Surveys, 2012a).

The well was inspected with the pump off during the camera down-run. The pump was started at 750 GPM for 23 minutes before beginning the up-run video survey. Minor turbidity at the bottom of the well cleared a few minutes after the start of pumping. The video inspection during the up survey revealed no unusual sand, color, or air entrainment while the well was pumped.

3.6 Historical Water Quality

Water quality samples were collected at the wellhead before, during and after the well produced water from October 19, 2009 to January 18, 2012 (Table 2). TDS and chloride concentrations increased from 703 mg/L and 154 mg/L in July 2009 to 890 mg/L and 261 mg/L, respectively, in

February 2012 (Figure 11). The well was idled on January 18, 2012 and subsequent concentrations declined to levels comparable to what were observed before the well came online (Figure 11). Similar trends were observed for sodium, calcium, magnesium, and sulfate.

The February 2012 samples were collected two weeks after the well went offline (after pumping for 2.25 years). It appears that, while pumping, Well 8 captured higher TDS and chloride water from the west (i.e. downgradient) that was impacted by seawater intrusion. The water quality improved (i.e. lower TDS and chloride) when pumping stopped as upgradient water from the east moved into the area of the well.

3.6.1 Depth-Discrete Samples

Depth-discrete water quality samples were collected on October 28, 2008 soon after development and aquifer testing were completed. The depth-discrete samples were collected at 670 feet bgs (at the top of the lower well screen), 545 feet bgs (55 feet above the bottom of the upper well screen), and at 490 feet bgs (40 below the top of the upper well screen).

Ion concentration results from the analytical laboratory were adjusted to account for the contribution of flow at each particular depth (i.e. mass balance calculation). For example, the TDS concentration for water collected at the top of the lower screen (i.e. 670 feet bgs) was equivalent to the analytical laboratory result of 660 mg/L. The TDS concentration for the next sample collected at 545 feet bgs, which the laboratory measured at 642 mg/L, included the 660 mg/L from the lower screen plus the concentration from water entering the well between 600 and 545 feet bgs. Therefore, for the water at 545 feet bgs in the well to have a TDS concentration of 642 mg/L, the TDS concentration of the water entering the well between 600 and 545 feet bgs must be 627 mg/L (Table 3). The TDS concentration of water in the interval from 545 to 600 feet bgs was adjusted from 642 mg/L to 627 mg/L; the interval from 490 to 545 feet bgs was adjusted from 662 mg/L to 685 mg/L.

A second round of depth-discrete sampling was conducted on February 1, 2012, which occurred two weeks after the well was idled on January 18. Water quality samples were collected from the same depths that were sampled in 2008. TDS concentrations were higher at all depths. For instance, at 670 feet bgs TDS increased from 660 to 1,080 mg/L; at 545 feet bgs TDS increased from 627 to 1,189 mg/L; and at 490 feet bgs TDS increased from 685 to 807 mg/L (Table 3). The TDS in the discharge at the wellhead was 890 mg/L. This was an increase from the 703 mg/L measured at the wellhead in July 7, 2009 (Table 2).

Both the laboratory and adjusted concentrations for major ions in February 2012 indicated anion-cation ratios beyond the normal range ($\pm 5\%$), which is usually due to laboratory error or to the presence of ions not considered. If not due to laboratory error, then the possible candidates for this anomaly include the presence of organic acids or anions adsorbed to suspended solids, both

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of which could be related to the elevated turbidity and TSS observed in this well (see Section 3.8.1).

3.6.2 Sequential Samples

Three sequential water quality samples were collected at Well 8 on December 4, 2012. The samples were collected at the start of pumping and then approximately 2 and 4 hours after pumping began (Table 2). Very little change in either TDS or the composition of its contributing ions was observed between the three samples. However, there was a two-fold increase in iron concentration over the sampling period. An increase in iron concentration with time could indicate more reduced water entering the well from the formation over the sampling period. If so, the more soluble ferrous iron might be present at higher concentrations; however, this hypothesis cannot be confirmed based on the existing data.

3.6.3 Production Test

The City conducted a test in June 2011 to evaluate whether the TDS concentration would decline with a lower production rate. Prior to reducing the production rate, the TDS in the discharge was 908 mg/L on June 3, 2011. The City reduced the production rate from 750 GPM to approximately 400 GPM on June 20. As a result of reducing the production rate, the estimated distance to the stagnation point decreased from approximately 3,800 feet west of the well, or approximately the distance west to the Calafia Well, to 2,000 feet west of Well 8, or approximately the distance to Well 5.

A sample collected immediately after production was reduced had a TDS concentration at 900 mg/L. Subsequent samples collected over the next 11 days had TDS concentrations that ranged from 870 to 896 mg/L (Figure 12). The lowest value of 870 mg/L was measured two days after the pumping rate was reduced. The reduction in the pumping rate did not have a marked effect in reducing the TDS concentration over the span of 11 days.

3.7 2013 Fluid Conductivity and Temperature Surveys

Dudek contracted the services of Pacific Surveys to run continuous fluid temperature and resistivity logs under static and dynamic (i.e. pumping) conditions. As was done at Well 6, the fluid resistivity measurements were converted to temperature-compensated fluid conductivity values in units of microSiemens per centimeter.

Fluid conductivity and temperature surveys were conducted at this well on August 7, 2013 and on November 14, 2013 (Appendix A). Well 8 went offline on January 18, 2012, so the August 7 survey was conducted 567 days after it was idled (with the exception of a couple days when the well was operated for maintenance reasons). The November 14 survey was performed when

depth-discrete samples were collected to enhance our understanding of the chemistry of water entering the well at discrete depths.

Static surveys were only performed on August 7, 2013. Dynamic surveys were performed on August 7 and November 14, 2013. Pumping was started 25 hours before the surveys on November 14 to draw water from a farther distance to the well than what was surveyed in August.

3.7.1 Static Surveys

3.7.1.1 Temperature

Two surveys were performed under static conditions on August 7, 2013. The temperature at the top of the upper screen averaged 24.52°C between the two runs, and averaged 26.03°C at 570 feet bgs (30 feet above the bottom of the upper screen), resulting in an increasing temperature trend of 0.013°C/ft (Figure 8). This slope was comparable to the estimated natural geothermal gradient of 0.012°C/ft for this region. At 570 feet bgs, the static temperature profile became more vertical with depth. The temperature gradient from 570 feet bgs to the bottom of the lower screen at 750 feet bgs was 0.003°C/ft. It appears that, under static conditions, water from the permeable zone between 570 and 600 feet bgs enters the well and moves down to the lower screen.

3.7.1.2 Fluid Conductivity

The static fluid conductivity surveys showed a general declining trend in conductivity from the top of the upper screen to 580 feet bgs (Figure 8). It appears that the water entering the well from the permeable zone between 570 and 600 feet bgs is better quality (i.e. lower TDS) than the water above. The downward movement of water from that zone to the lower screen creates a uniform and vertical fluid conductivity profile. The difference in conductivity from 570 to 740 feet bgs for both static surveys was 16 uS/cm and 3 uS/cm, respectively. The bottom 5 feet of the well showed a marked increase in conductivity, which may result from sediment accumulation at the bottom of the well.

3.7.2 August 2013 Dynamic Surveys

The turbine pump at Well 8 was turned on at the conclusion of the static surveys on August 7, 2013. The average pumping rate was 600 GPM. The first dynamic survey was performed 50 minutes after pumping started. The second survey was performed 2 hours, 50 minutes after pumping started.

3.7.2.1 Temperature

The two surveys showed an increase in temperature in the upper screen between the static and dynamic surveys, which indicated that warmer water from the lower screen was pulled into the

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well (Figure 8). The average temperature of the two dynamic runs was 25.48°C, which was approximately 1°C higher than the average temperature between the two static runs (24.52°C).

The temperature increase between the two dynamic surveys also indicated that the colder water that flowed down from the upper screen and out into the deeper formations under static conditions was pumped out and replaced by deeper, warmer water.

3.7.2.2 Fluid Conductivity

The fluid conductivity profiles indicated the following:

1. the lower screen contributes the poorest quality water (the peak conductivity in the second dynamic survey was 1,742 uS/cm);
2. the permeable zone at 570 to 600 feet bgs contributes better quality water (the lowest conductivity in the second dynamic survey was 1,376 uS/cm); and
3. the increase in conductivity in the second dynamic survey, particularly in the lower screen, indicated the initial removal of better quality water that originally flowed from the upper screen to the lower screen under static conditions and the subsequent influx of poorer quality water from the lower screen (Figure 8).

3.7.3 November 2013 Dynamic Surveys

The turbine pump at Well 8 was turned on 25 hours before the first dynamic survey on November 14, 2013. The average pumping rate was 300 GPM during the 25-hour period. The pumping rate was increased to an average 600 GPM after the first dynamic survey because conductivity was generally 300 to 400 uS/cm lower than the conductivity measured during the surveys performed on August 7. The well pumped at 600 GPM for 1.5 hours before performing the second dynamic survey in November.

3.7.3.1 Temperature

The temperature profiles for the November surveys were similar to the dynamic surveys in August, except the temperature was, on average, 0.2°C less than the temperature measured in August. The November temperature profiles, when compared to the static temperature profiles measured in August, continued to show warmer, deeper water moving into the well from the lower screen (Figure 8).

3.7.3.2 Fluid Conductivity

As noted earlier, conductivity in November was generally 300 to 400 uS/cm lower than the conductivity measured in August. This may be a result of the longer pumping period and greater

volume of water pumped from the well compared to the volume pumped in August. The November conductivity profiles still show the poorest water quality entering the well at the lower screen and the better quality water entering at the permeable zone from 570 to 600 feet bgs (Figure 8).

What was not evident during the August surveys, however, was the entrance of poor quality water at the bottom of the upper screen right at the top of the blank at 600 feet bgs. A spike in conductivity was measured at 598 feet bgs, but quickly decreased as better quality water entered the upper screen from the permeable zone at 570 to 600 feet bgs. It is possible that this indicates that poor quality water from the interval opposite the blank casing between the two well screens enters the annular space and flows through the filter pack and enters the well at the bottom of the upper screen. It is also possible that this spike indicates that there is poor quality water between 595 and 600 feet bgs.

3.8 2013 Water Quality

A series of depth-discrete samples and two samples from the wellhead were collected on November 14, 2013. The samples were analyzed at Sierra Analytical Labs of Laguna Hills, California for concentrations of common ions, metals, dissolved silica, TDS, total suspended solids (TSS), volatile suspended solids (VSS), and turbidity. The samples were also analyzed for concentrations of bromide and iodide, which are potential markers for seawater intrusion (Appendix B). No water quality samples were collected in August.

Iodide was not detected above the analytical detection limit of 0.5 mg/L, while bromide was present above the detection limit in half of the samples at 0.5 to 0.7 mg/L. Specifically, the ratio of chloride to bromide or iodide can serve as an indicator of the source of saline water. The Cl/Br ratio for modern seawater is 655 (calculated on a molar basis), and all ratios calculated for the Well 8 samples were well above that value (720 to 910), which could indicate the leaching of halite and/or gypsum-rich formations rather than modern seawater (Sonney and Vuataz 2010).

3.8.1 Depth-Discrete Samples

A total of 11 samples were collected from Well 8 on the afternoon of November 14, 2013. Two wellhead samples and 9 depth-discrete samples were collected at 5 depths within the well casing. Both filtered and unfiltered samples were analyzed to investigate the apparent correlation between elevated TDS and turbidity in depth-discrete groundwater samples collected in February 2012. The 2013 chemistry results, as well as those from sampling events other than February 2012, indicate no correlation between TDS and turbidity. The February 2012 results produced anomalous cation-anion ratios that were discussed in Section 3.6.1.

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While there were minor differences in TDS between filtered and unfiltered samples, the most significant difference was the composition of total suspended solids (TSS) among the unfiltered samples (Table 3). All of the TSS at the three deepest depths (≥ 595 feet bgs) was due to volatile suspended solids (VSS), which represent a combustible fraction of TSS that is normally attributed to particulate organic matter (Figure 13). Previously observed biofouling at former wells (e.g., Well 7) suggests that microbial biomass may be a source of the VSS because no organic compounds were detected during the analysis of volatile and semi-volatile priority pollutants. The increase in VSS as a function of depth may suggest that microbial fouling of the well screen or filter pack is greater in the deepest portions of the well.

By contrast, the majority of TSS at the shallower depths may have been dominated by inorganic matter such as fine-grained aquifer solids. The relatively low turbidity and high TSS of water from 555 to 595 feet bgs suggests that VSS may contribute disproportionately to the turbidity in Well 8. Shallow samples (≤ 595 feet bgs) produced water of better quality than did deeper samples as measured by chloride and TDS concentrations.

Further discussion of water quality at Well 8 in 2013 is provided in Section 7.0.

4.0 WELL 5

Well 5 was constructed in 1956. It is located off of Avenue Santa Margarita on the southern edge of the municipal golf course. The well boring was drilled to a depth of 498 feet bgs.

4.1 Well Construction

The well was constructed with 16-inch diameter mild steel casing. It appears that the well was screened from approximately 70 to 320 feet MSL based on information provided in the 1973 Montgomery report. The report states that the well “appears to have been completed in both the terrace deposits and in aquifer zone C in the Capistrano Formation” (JMM, 1973).

The well head was inspected on September 12, 2013 with City staff. There are two 4-inch diameter steel casings set within the 16-inch diameter mild steel casing. One casing is set deeper than the other, but it is not known to what depths these two casings extend. According to City staff, a packer was set in the well to separate the “upper” and “lower” zones. Presumably, the deeper 4-inch casing extended past the packer to the lower zone and the other 4-inch casing terminated above the packer in the upper zone.

It is not known to what depth the packer was set or what kind (pneumatic or water-filled) and size of packer was installed. The monthly “City of San Clemente Well Water Chloride Monitoring” logs for 1994 indicated that the packer was installed in October 1994. The City has not serviced the packer since it was installed. Water level measurements in the 4-inch diameter

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casings on September 17, 2013 were both measured at 153 feet deep, indicating that the packer may no longer be separating the upper and lower zones of the well.

The two 4-inch diameter casings are each fitted with a smaller 1.5-inch diameter casing inside. To collect water samples, the City connected an air compressor to the 1.5-inch casings and pressurized the line to move water up the annular space between the 1.5 and 4-inch casings. The City's last attempt to collect samples (2012) failed in that no water came to surface. The City pressurized the lower zone casing and blew off the cap to the upper zone casing, further indicating that the packer is not separating the two zones.

4.2 Production

The well initially pumped over 1,000 GPM, but was no longer used for City purposes after 1958 due to seawater intrusion. "Long-term production from Well 5 exceeded recharge and storage in the terrace deposits with the result that sea water migrated inland through the terrace aquifer causing the well to become increasingly saline" (JMM, 1973). Seawater intrusion to Well 5 was inferred from an increase in chloride concentration from 119 to 598 mg/L in April 1958 that coincided with the aforementioned pumping.

4.3 Historical Water Quality

Before the packer was set in the well to separate the upper and lower zones, the chloride concentrations in the upper and lower zones averaged 790 mg/L and 873 mg/L, respectively. After the packer was set in October 1994, the chloride concentrations in the upper and lower zones averaged 940 mg/L and 2,450 mg/L, respectively. The poorer water quality in the lower zone, represented by a higher chloride concentration, may have been from zone C of the Capistrano Formation (Figure 3). The terrace deposits (upper zone) may have produced the better quality water.

In addition to the chloride data reported for Well 5, a more complete set of major ions is available from sampling events conducted in June and September 2011. The latter datasets include chloride and TDS concentrations as high as 940 and 2,440 mg/L, respectively; however, these wellhead samples appear to be a mixture of waters from the terrace deposits and zone C of the Capistrano Formation. The chloride maxima of 2,920 mg/L detected from the lower interval (Capistrano Formation) in July 2001 suggests that TDS concentrations may be several-fold greater than those measured either in the upper interval (terrace deposits) or in a mixture of waters from the two intervals. Historical chloride concentrations for Well 5 are plotted on Figure 14.

5.0 CALAFIA WELL

The Calafia observation well was constructed in February 1958. It is located approximately 1,000 feet inland from the shoreline on Avenida Calafia. The well was installed to monitor for sea water intrusion. The well boring was drilled to a depth of 965 feet bgs.

5.1 Construction

Two well casings were installed: an outer 14-inch diameter casing that was perforated from 75 to 360 feet bgs (set in the terrace deposits) and an inner 8-inch diameter casing perforated from 822 to 935 feet bgs (set in zone A of the Capistrano Formation). The two casings were isolated by a cement seal (JMM, 1973).

5.2 Historical Water Quality

Both the deep and shallow Calafia wells were sampled between April 1958 and September 1963, with an extended set of ions and physical properties analyzed from the latter date. Whereas the inorganic chemistry data indicated that groundwater from the shallow well, which was screened in the terrace deposits, was impacted by seawater intrusion (i.e., TDS exceeded 20,000 mg/L), the deep well in zone A of the Capistrano Formation had relatively good water quality (i.e. TDS of 438 mg/L) and an ionic composition uncharacteristic of modern seawater.

Chloride concentrations in the range of 180 to 360 mg/L were detected in groundwater from the deep Calafia well between September 1999 and January 2003, bracketing the maximum chloride concentration of 237 mg/L detected during the 1958 to 1963 period (Figure 14). A complete set of recent data for major inorganic ions are not available for the deep Calafia well; hence, indicators of saline water intrusion or other subtle water quality changes cannot be evaluated.

6.0 WATER QUALITY DISCUSSION

6.1 Relative Ion Composition

In addition to the absolute concentrations of TDS and chloride, relative concentrations of the other major anions and cations comprising TDS are often useful in assessing various aspects of water quality degradation, including the formations contributing saline water, the influence of well design and operation, and the probable sources of the saline water. Trilinear diagrams showing the relative proportions of the three major anions (Cl , SO_4 and HCO_3) in the wellhead discharge for Wells 5, 6, and 8 and the Calafia shallow and deep wells are presented in Figure 15. The wells are plotted according to the percent contribution of each anion as expressed in the units of milliequivalents per liter (meq/L), which takes into account both electric charge and molecular weight.

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Generally, groundwater impacted by a saline source, whether modern seawater or other sources of saline water present in the aquifer, will show an increasing dominance of chloride relative to sulfate and bicarbonate. As expected, the shallow Calafia well plots alongside modern seawater, while the other wells plot nearer the center of the triangle (Figure 15). The 2011 samples from Well 5, which represent a mixture of the upper and lower zones, plot closest to the shallow Calafia well. Given the aforementioned difference in water quality between the two zones, a discrete sample from the lower zone of Well 5 might plot closer to the shallow Calafia well. Well 8 is more chloride-dominant than Well 6 or the deep Calafia well, which both show proportionally greater contributions of sulfate and/or bicarbonate in their respective water.

Among the Well 8 plots, the February 2012 water quality sample showed the greatest chloride impact compared to other samples (Figure 15). The February 2012 sample was collected two weeks after the well went offline (after pumping for 2.25 years). It appears that, while pumping, Well 8 captured higher TDS and chloride water from the west (i.e. downgradient) that was impacted by seawater intrusion. The water quality improved (i.e. lower TDS and chloride) when pumping stopped as upgradient water from the east moved into the area of the well (Figure 16).

A trilinear diagram showing the relative proportions of the three major anions (Cl , SO_4 and HCO_3) for three depth-discrete sampling events at Well 8 in October 2008, February 2012 and November 2013 are presented in Figure 17. Well depths plotted from the October 2008 event are closely grouped and indicate less chloride-dominated water compared to later samples collected after the well came online in October 2009. Data from the November 2013 event indicate that deeper intervals (≥ 595 feet bgs) are potentially impacted by saline water to a greater extent than the shallower intervals (< 595 feet bgs), as represented by a greater proportion of chloride (Table 3 and Figure 16).

Figure 18 is a trilinear plot showing the relative proportions of the three major cations (Ca , Mg and Na) for the same wells plotted on Figure 15. Whereas sodium is the predominant cation in seawater, the relationship between potential seawater intrusion and relative ion composition in groundwater is more complex for cations than anions due to the exchange of the cations on negatively-charged surfaces of the aquifer solids. As saline water migrates into freshwater aquifers, small anions, such as chloride, migrate unretarded and mix with freshwater ahead of the main seawater plume. Sodium follows close behind chloride, and due to its high concentration, often exchanges with calcium and magnesium adsorbed to the aquifer solids. The term “incipient seawater” applies to this leading portion of a saline plume that is characterized by elevated concentrations of chloride, calcium, and magnesium relative to sodium, bicarbonate, and sulfate. Upon arrival of the main saline plume, the cation composition of the impacted water changes such that sodium predominates and magnesium surpasses calcium.

Whereas the Calafia shallow well displays the most sodium-dominated water (i.e. impacted by seawater), the remainder of the wells plot nearer the center of the triangle (Figure 18). Although Well 8 groundwater consistently contains chloride and TDS concentrations higher than those at Well 6, the cation compositions of samples from Well 8 are less sodium rich than that of samples from Well 6 and the Calafia deep well. In fact, the February 2012 sample from Well 8 (containing the highest TDS and chloride concentrations) is the least sodium rich of the samples plotted, perhaps reflecting the capture of incipient seawater (or saline water) west of its location. A relatively greater contribution of calcium and magnesium to the cation composition results from the exchange of sodium on the aquifer solids.

The two Well 5 samples from 2011 plot nearest those from Well 6 and Calafia deep, which is not indicative of incipient seawater. Based on the anion data, the Well 5 cation plot could be indicative of actual seawater or other highly saline water. In other words, one or both of the zones intercepted by Well 5 may have already moved beyond the incipient seawater stage, and is now displaying an increased proportion of sodium as occurs when an actual seawater front reaches a well (e.g., the shallow Calafia well).

6.2 Ion Concentration Ratios

Comparing the ratios among major anions and cations comprising the TDS of groundwater is frequently used to infer the origin of or potential impacts to groundwater. Figure 19 includes six pie diagrams showing the composition of seven major anions and cations comprising the TDS in various samples. Anions appear on the left side of the diagram, while cations appear on the right. Well 6 and the deep Calafia well represent groundwater from Zone A of the Capistrano Formation, which does not appear to be impacted by saline water. By contrast, the shallow Calafia well is impacted by seawater as indicated by its TDS concentration, dominance of chloride and sodium, absence of bicarbonate, and high magnesium-to-calcium ratio. For purposes of comparison, a pie diagram for modern seawater is shown beside the diagram of the shallow Calafia well.

The Well 5 sample is dominated by chloride and sodium; however, the TDS concentration and magnesium-to-calcium ratio are lower than those in the shallow Calafia well and bicarbonate comprises a greater portion of the anions. Well 5 may be impacted by saline formation water or modern seawater; however, the sample contains water from two formations and it is not known if one or both may be impacted or how much of the sample is contributed by each. Moreover, the anion-cation balance is skewed in the Well 5 sample, indicating other potential anomalies.

The Well 8 sample contains chloride as the major anion, but has a sizable bicarbonate contribution, and contains calcium as the major cation. As previously discussed, these factors suggest incipient seawater may be present.

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Table 4 presents molar ratios for some of the major ions that have been identified in the scientific literature as indicators of incipient seawater. Na/Cl ratios less than 0.86 are indicative of incipient seawater as are Cl/HCO₃ ratios above 1.3 (Jones et al. 1999, Korfali & Jurdi 2010). These values are not absolute and can vary depending on the chemistry of freshwater that is impacted and on the source of the saline water. Moreover, ratios shift as the ionic strength of the intruding saline water increases or as the main seawater plume arrives. Nevertheless, these two reported ratio values provide a general indication, along with an elevated Mg+Ca/Na ratio, of incipient seawater. Similar to bicarbonate, silica is present at very low concentrations in seawater and, therefore, declining concentrations in groundwater sometime serve as an early indicator of saline water intrusion.

The ratios shown in Table 4 suggest that water from Well 6 and the deep Calafia well are not indicative of incipient seawater.

Well 8 displays characteristic indicators of incipient seawater from both the February 2012 and November 2013 wellhead sampling events, even though TDS and chloride concentrations were almost 2-fold lower during the latter event. Depth-discrete samples from Well 8 during November 2013 indicate that the three deeper intervals (595'-675', 675'-740', and 740'-750') display much stronger markers of incipient seawater than do shallower ones (555'-595' and 450'-555') (Table 3). In fact, the 595 to 675 feet bgs depth interval in Well 8 shows a possible impact by seawater, as well as an anomalous anion-cation ratio similar to that observed in the February 2012 sampling event.

Well 5 displays inconsistent indicators of incipient seawater, perhaps because one or both of the groundwater zones have been impacted by seawater. In particular, the combination of low Na/Cl and Mg+Ca/Na ratios and a highly elevated Cl/HCO₃ ratio suggests that a seawater or saline water front has already reached Well 5.

It should be noted that discerning seawater intrusion in groundwater with chloride concentrations less than 1,000 mg/L is complicated by spatial and temporal variations in groundwater chemistry, by interactions between the water and aquifer solids, and by the miniscule fraction of seawater required to induce chemical changes (Jones et al. 1999, Richter & Kreitler 1993). Given the background concentrations of chloride at this site, a concentration of 1,000 mg/L corresponds to a contribution of less than 5% seawater. As the fraction of saline water mixed with freshwater in an aquifer increases, additional molar ratios (e.g., Cl/Br, Cl/I, Mg/Ca) and isotope analyses (e.g., boron, strontium, oxygen, hydrogen) may be used to differentiate modern seawater from ancient and formational sources of saline water (e.g., Anders et al. 2013).

6.3 Stable Isotopes

The depth-discrete water samples collected from Well 8 in November 2013 were also analyzed for the ratios of the stable isotopes of oxygen ($^{18}\text{O}/^{16}\text{O}$) and hydrogen ($^2\text{H}/^1\text{H}$ or deuterium(D)/ ^1H). These ratios, expressed in per mil (‰) as $\delta^{18}\text{O}$ and δD , can be used to identify the primary source of recharge to groundwater produced at Well 8. The three most likely sources of recharge are 1) local, coastal precipitation, 2) precipitation from farther inland that has traveled west through the aquifer to Well 8, and 3) imported municipal water used to irrigate property in the vicinity of Well 8.

Precipitation typically falls along the Global Meteoritic Water Line (GWML, Craig, 1961). The GWML represents a global average relationship between the two stable isotopes in precipitation. Where the isotope ratios for precipitation fall along the GWML vary depending on where rainfall occurred. Coastal rainfall in Southern California typically has values in the area of -5.3 for $\delta^{18}\text{O}$ and -38 for δD (Anders et al. 2013, Williams and Rodini, 1997). As the air mass moves farther inland, then subsequent rainfall will be depleted in the heavier isotopes and the values shift to more negative values (Figure 20). Water that is imported to Southern California from the San Francisco Delta or from the Colorado River, which originated from precipitation in mountain ranges farther inland, has values that are shifted more negative to -9.5 for $\delta^{18}\text{O}$ and -78 for δD (Bowen et al. 2007, Williams and Rodini 1997). Seawater is approximately 0 for both $\delta^{18}\text{O}$ and δD .

The Well 8 flow-adjusted ratios of $\delta^{18}\text{O}$ and δD ranged from -6.45 and -5.52 to -38.29 and -31.31, respectively. These values cluster around the GMWL and are typical of coastal southern California precipitation (Figure 20). Therefore, local coastal precipitation is the likely source of recharge to groundwater produced at Well 8 as opposed to inland precipitation or imported municipal water.

Because the $\delta^{18}\text{O}$ and δD of seawater is approximately 0 per mil, the incursion of seawater into a fresh groundwater aquifer will shift the ratios of $\delta^{18}\text{O}$ and δD to higher (less negative) values (e.g. Anders et al. 2013, Hanson 2003). Groundwater from the 555 to 595 feet bgs interval has the lowest (more negative) $\delta^{18}\text{O}$ and second lowest δD values. This water, therefore, shows the least evidence of impact from incipient seawater. The depth intervals with the highest (least negative) isotope ratios (those below 595 feet.) correspond to those that are the most saline and exhibit the strongest markers of incipient seawater based on relative ion composition and concentration ratios as discussed in Sections 6.1 and 6.2.

7.0 CONCLUSIONS

The major conclusions from the water quality analyses include the following:

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- Current and historical data from Well 6 suggests it is a consistent producer of relatively good quality water that is not impacted by saline water. The deep Calafia well is screened in the same Zone A of the Capistrano Formation and appears to be of similar water quality, but there are fewer data to assess its performance over time. Neither well exhibits ion ratios or analyte concentrations that are indicative of saline water intrusion, even as chloride and TDS levels have varied slightly over time.
- The salinity of water produced from Well 8 increased as it was pumped from 2009 to 2012. Chloride increased by approximately 70%. It appears that, while pumping, Well 8 captured higher TDS and chloride water from the west (i.e. downgradient) that was impacted by seawater intrusion. The water quality improved (i.e. lower TDS and chloride) when pumping stopped as upgradient water from the east moved into the area of the well.

Relatively recent data from Well 8 suggest the presence of incipient seawater or the initial stages of intrusion by formational saline water. Ion ratios indicative of incipient seawater (especially in the deepest intervals) have persisted even though concentrations of TDS and chloride varied as much as two-fold. The best water quality is generally found at depths between 555 and 595 feet bgs and the worst in the lower screen interval. However, it appears that extended periods of groundwater production have caused the water quality to decline even at the 555 to 595 interval. The source of the incipient saline water is currently unknown.

- Current and historical data from Well 5 is difficult to assess because the relative contribution of water from two distinct formations, which apparently produce waters of different quality, is uncertain. Historical and recent analyses of wellhead samples indicate that saline water intrusion has occurred; however, chemical characterization of water sampled from the affected formation, rather than from a mixed sample, would be required to assess the source. Given the location and depth of Well 5, a better understanding of the water quality at discrete depths with additional depth-discrete sampling could provide information pertinent to the future performance of Well 8.

8.0 RECOMMENDATIONS

8.1 Well 6

Based on the water quality data collected from 1958 to 2013, we recommend that Well 6 requires no improvements and can be brought back online in its current configuration. The historical water chemistry indicates that water quality is stable and we do not expect further degradation of water produced from this well.

8.2 Well 8

8.2.1 Lower Well Screen

We recommend that the pumping rate in Well 8 be reduced to 400 GPM in an effort to minimize the capture of poorer quality groundwater located to the west of the well. The estimated stagnation point at 400 GPM is approximately 2,000 feet west of Well 8 as opposed to 3,800 feet when it pumped at an average 737 GPM. If after a year of pumping, the water quality in Well 8 remains stable and water level monitoring indicates that there is no response to the pumping in the deeper section of Well 5, the pumping rate could be gradually increased until there is a response in Well 5 or until water quality declines.

We also recommend sealing the lower well screen to eliminate poorer water quality originating from this depth from entering the well. There are three options to consider when sealing the lower well screen:

1. Install a bentonite grout from the bottom of the well to approximately 35 feet into the blank casing above the lower well screen. Set a mechanical plug at the top of the grout. This may be considered a temporary seal in that it could be removed should the City seek to produce water from this lower interval in the future. This may be the case should water quality produced from the upper well screen continue to degrade due to seawater intrusion and the City elects to run the discharge through a R.O. system. This temporary plug will allow the City to increase production from this well (after developing the lower well screen) if a R.O. system is required to treat the groundwater.
2. The second option is to set a permanent seal using cement. The cement will be set from the bottom of the well to approximately 35 feet into the blank casing above the lower well screen. Should the quality of water produced from the upper well screen stabilize and not degrade further, then there will be no need to run water through a R.O. system.
3. A third option would be to cement the lower screen, up into the blank section as in option 1 and then place a swedge covering the bottom 7 feet of the upper screen to minimize the entry of the poor quality water observed at 595-600 feet bgs in both the fluid conductivity surveys and the depth discrete sample.

8.2.2 Re-Development and Disinfection

We recommend that the City, after sealing off the lower screen and prior to re-installing the turbine pump, re-develop the lower portion of the upper screen because it was not fully developed after the well was built in 2008. The more permeable zone of the upper screen appears to be from 570 to 595 feet bgs based on the e-log and lithologic log. The best water quality comes from this zone.

We recommend that Well 8 be disinfected because the well has been idle since January 2012.

8.2.3 Continuous Monitoring of Electrical Conductivity

We understand that the City has obtained an electrical conductivity sensor that will be installed in the discharge line at the wellhead. We recommend measuring and recording electrical conductivity values at a frequency of one measurement per 12 hours beginning when the well is back online and pumping at 400 GPM. An adjustment to the pumping rate may be made after one year of monitoring water quality and water levels at this well, Well 5 and the Calafia well.

8.3 Well 5

We recommend rehabilitating Well 5 to separate the upper portion of the well screened in the terrace deposits and the lower portion screened in the Capistrano Formation. This includes retrieving and inspecting the packer previously set in the well. If the packer is in good condition and serviceable, then we recommend re-setting it; otherwise, we recommend setting a new packer. Following rehabilitation, depth-discrete samples should be collected from the portion of the screen in the terrace deposits and from the portion of the screen in the Capistrano Formation. These samples should be analyzed for common ions, metals, dissolved silica, TDS, total suspended solids (TSS), volatile suspended solids (VSS), and turbidity. Well 5 should be monitored continuously for signs of further seawater intrusion in response to production from Well 8.

We recommend that dedicated pressure transducers equipped to measure electrical conductivity be set in the upper and lower portions of the well screen to continuously measure and record water levels and conductivity. This information may be used to assess water quality conditions west of Wells 6 and 8 and potential influences of pumping at these wells.

8.4 Calafia Deep Well

We recommend that a dedicated pressure transducer equipped to measure electrical conductivity be set in this well to monitor water levels and salinity in zone A of the Capistrano Formation. This information will be used in conjunction with data from Well 5 to assess the potential impacts of pumping from Wells 6 and 8.

9.0 REFERENCES

- Anders, R., G. Mendez, K. Futa, W. Danskin. A geochemical approach to determine sources and movement of saline groundwater in a coastal aquifer. *Ground Water* doi: 10.1111/gwat.12108 (2013).
- Bowen, G.J. et al., 2007. Stable isotope ratios of tap water in the contiguous United States. *Water Resources Research* **43** doi:10.1029/2006WR005186
- Boyle, 1987. City of San Clemente Groundwater Supply and Management Study. Boyle Engineering Corporation. September 11.
- City of San Clemente, 2012. Agenda Report for San Clemente City council Meeting. June 19.
- Craig, H., 1961. Isotopic variations in meteoric waters. *Science* **133** 1702-1703
- Geotechnical Consultants, Inc., 2008a. Mud Log for City of San Clemente Well 8. September 12.
- Geotechnical Consultants, Inc., 2008b. Memorandum to Vernon Weisman; Dennis Phinney of Psomas, Inc. *Preliminary Pumping Test Results, City of San Clemente Well No. 8*. October 29.
- Geotechnical Consultants, Inc., 2010. Memorandum to Greg Deist, City of San Clemente. *Well No. 6 Video Survey Review and Comments Regarding Well Rehabilitation*. November 17.
- Geotechnical Consultants, Inc., 2011. Memorandum to Greg Deist, City of San Clemente. *Well No. 6 Video Survey Review and Well Rehabilitation Discussion*. February 24.
- Hanson, R.T., 2003. Geohydrologic Framework of Recharge and Seawater Intrusion in the Pajaro Valley, Santa Cruz and Monterey Counties, California. U.S. Geological Survey, Water Resources Investigations Report 03-4096.
- Higgins, C. T., 1984. *Geothermal Energy at Long Beach Naval Shipyard and Naval Station and at Seal Beach Naval Weapons Station, California*. California Department of Conservation, Division of Mines and Geology. Open File Report 84-32 SAC.
- James M. Montgomery, 1973. City of San Clemente Development and Treatment of Ground Water Resources. James M. Montgomery Consulting Engineers, Inc. February 14.
- Jones, B., A. Vengosh, E. Rosenthal, Y. Yechieli. Geochemical Investigations. *In: Seawater Intrusion in Coastal Aquifers*; Kluwer Academic Publishers, Dordrecht, Netherlands (1999): 51.

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- Korfali, S.I., M. Jurdi. Deterioration of coastal water aquifers: causes and impacts. *European Water* 29 (2010): 3.
- Pacific Surveys, 2008. Electric Log, Laterolog, and Gamma Ray for San Clemente Well #8. September 12.
- Pacific Surveys, 2012a. Video Survey Report for San Clemente Well #8. February 1.
- Pacific Surveys, 2012b. Video Survey Report for San Clemente Well #6. April 6.
- Regional Water Quality Control Board San Diego Region, 1994. *Water Quality Control Plan for the San Diego Basin*. State
- Sonney, R., F.D. Vuataz. Use of Cl/Br ratios to decipher the origin of dissolved mineral components in deep fluids from the Alps and neighboring areas. In: *Proceedings of the World Geothermal Congress 2010*, Bali, Indonesia.
- Tan, 1999. Geologic Map of the San Clemente 7.5' Quadrangle, Orange and San Diego Counties, California. California Division of Mines and Geology.
- Walker, R. G., 1975. *Nested Submarine-Fan Channels in the Capistrano Formation, San Clemente, California*. Geological Society of America Bulletin, v. 86, p. 915-924. July.
- Water Systems Engineering, 2009. *City of San Clemente Well 6 Well Rehabilitation Recommendations WSE Lab Report No. 18229*. Water Systems Engineering, Inc. Letter to Kevin Lussier, City of San Clemente. September 3.
- Williams, A.E. and Rodini, D.P.1997. Regional isotope effects and application to hydrologic investigations in southwestern California. *Water Resources Research* **33**(7), 1721-1729

Note: Copies of all references are included in Appendix C.