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BIG BEAR CITY COMMUNITY SERVICES DISTRICT
WELL 10 (BOOSTER STATION SITE)
RESULTS OF DRILLING, CONSTRUCTION, DEVELOPMENT AND TESTING

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**BIG BEAR CITY COMMUNITY SERVICES DISTRICT
WELL 10 (BOOSTER STATION SITE)
RESULTS OF DRILLING, CONSTRUCTION, DEVELOPMENT AND TESTING**

1.0 EXECUTIVE SUMMARY

A new municipal water supply well was recently completed for Big Bear City Community Services District (BBCCSD) in Big Bear City, San Bernardino County, California (see Figure 1). The new well, named Well 10, is located at 201 Maple Lane in Big Bear City, San Bernardino County, California. The pilot borehole was drilled as an exploratory borehole (BH-3) in which zone testing was performed to evaluate water quality and quantity prior to making the decision to complete the well.

Well 10 was drilled using the reverse circulation rotary drilling method, by Bakersfield Well & Pump Company of Bakersfield, California. During January 2003, a 36-inch diameter conductor borehole was drilled to a depth of approximately 53 ft using a screw auger rig. The 26-inch outside diameter (OD) surface conductor casing was installed to 53 ft below ground surface (bgs) and cemented in place from the ground surface to a depth of 53 ft bgs. The 17 1/2-inch diameter pilot borehole was drilled to a total depth of 634 ft bgs but was later reamed to a depth of 654 ft bgs. Alluvial materials penetrated during pilot borehole drilling consisted primarily of varying amounts of broken cobbles, fine- to coarse-grained gravel, fine- to coarse-grained sand and interbedded layers of silt and clay. Physical borehole logs were then conducted in the open pilot borehole by Welenco, Inc. of Bakersfield, California and four isolated aquifer zone tests were performed. The pilot borehole was backfilled and the drilling rig was moved to another site while the results of the zone testing were evaluated.

Weathered granodiorite bedrock was encountered during the drilling of the pilot borehole at a depth of 585 ft bgs with more competent bedrock encountered at 629 ft bgs.

After reaching the total depth of the pilot borehole, four zones were selected and tested before determining if the borehole would be completed as a well. Selection of these zones was based upon examination of the formation samples and analysis of the geophysical borehole logs. Ground water samples were collected from Zone 1 (593 to 613 ft bgs), Zone 2 (462 to 482 ft bgs), Zone 3 (272 to 292 ft bgs), and Zone 4 (190 to 210 ft bgs). Water samples were submitted to Clinical Laboratory of San Bernardino, Inc. (located in Grand Terrace, California) for general physical and general mineral analyses.

It was recommended that Well 10 be completed as a production well. During late June 2003, the drilling rig returned to the Booster Station Site. The borehole was reamed to a diameter of 22 inches from 53 to 654 ft bgs and was completed to a total depth of 640 ft bgs using 12 1/4-inch inside diameter (ID) copper-bearing steel casing and horizontal louvered well screen. Well screen consisting of 12 1/4-inch ID by 1/4-inch wall copper-bearing steel Ful-Flo horizontal louvers with 0.070-inch openings was installed from 195 to 295 ft bgs, and from 545 to 620 ft bgs. Blank well casing consisting of 12 1/4-inch ID by 1/4-inch wall copper-bearing steel was installed from ground surface to 195 ft bgs, and from 295 to 545 ft bgs, and from 620 to 640 ft bgs. An end plate consisting of 12 1/4-inch ID copper-bearing steel was welded to the lowermost blank section. A total of 175 ft of well screen and 465 ft of blank casing were installed, for a total well completion depth of 640 ft bgs.

A custom blend of Tacna Sand and Gravel (Yuma, Arizona) 1/4 in. x 16 filter pack material was installed from 654 to 96 ft bgs in the annular space between the 22-inch diameter borehole and the 12 1/4-inch ID well casing. An annular seal consisting of a 10.5 sack sand cement mixture was pumped through a tremie pipe from a depth of 96 ft bgs to the ground surface, and acts as a deep sanitary seal for the well.

Based on pumping tests, the recommended discharge rate for the well is approximately 100 gallons per minute (gpm). Short-term pumping of this well (i.e. one day of *continuous* pumping) is expected to result in approximately 35 ft of drawdown and a specific capacity of approximately 3 gpm per foot of drawdown (gpm/ft). Long-term pumping of this well (extrapolated to one year of *continuous* pumping) was estimated to result in 50 ft of drawdown.

Calculations using the information obtained from the step drawdown and 24-hour constant rate pumping tests indicate a well efficiency of 85 percent and an aquifer transmissivity of approximately 4,680 gallons per day per foot (gpd/ft).

Based on the information collected during the pumping tests, the recommended discharge rate and pump setting for Well 10 are as follows:

Recommended Pump Design - Well 10 (Booster Station Site)

Parameters	Short Term (1 day)	Long Term (1 year)¹
Design Pumping Rate	100 gpm	100 gpm
Pump Setting	316 ft bgs	316 ft bgs
Design Well Efficiency	85 percent	NA
Static Water Level Depth	156 ft bgs	156 ft bgs
Design Drawdown	35 ft	50 ft
Regional Decline in Static Water Level	50 ft	50 ft
Total Lift to Surface (Including regional decline in static water level)	241 ft	256 ft

¹Extrapolated using water level recovery data from the constant rate pumping test.

At the end of the 24-hour constant rate pumping test (conducted at an average discharge rate of 101 gpm), water samples were collected from the completed well by GEOSCIENCE personnel for Title 22 water quality analysis. Clinical Laboratory of San Bernardino, Inc. performed these analyses. The laboratory reported a total dissolved solids (TDS) value of 220 milligrams per liter (mg/L). This concentration is well below the California Department of Health Services (DHS)

recommended drinking water standard of 500 mg/L. All other constituents had concentrations below their specified maximum contaminant levels (MCLs).

A flowmeter (or “spinner”) survey was not conducted as the pump was near the bottom of the well and did not allow sufficient room to perform the test.

Welenco, Inc. conducted an alignment survey on August 21, 2003 to measure the verticality of the well. Results showed a deviation at 320 ft bgs (the recommended pump setting is 316 ft bgs) of 2.0 inches in the North-South plane and 3.0 inches in the East-West plane. However, the maximum deviation in the North-South plane was 13.5 inches, occurs at 640 ft bgs, and the maximum deviation on the East-West plane was 5.8 inches occurs at a depth of 640 ft bgs, both within the allowable limits per the technical specifications of 6 inches per 100 ft of depth.

Welenco, Inc. completed a video log of the post-construction condition of the well on August 21, 2003 to serve as a permanent record of the construction details and condition of the well following development and testing. The video survey showed the well casing and screen to be clean and in good condition and had no structural flaws or defects. The water column was slightly murky above the screened intervals, and some sediment was observed upon the edges of the louvers. The sediment accumulation at the bottom of the well was insignificant.

2.0 INTRODUCTION

2.1 Background

A new municipal water supply well was recently completed for BBCCSD in Big Bear City, San Bernardino County, California (see Figure 1). The pilot borehole was drilled as an exploratory borehole (BH-3) in which zone testing was performed to evaluate water quality and quantity prior to making the decision to complete the well. The new well, named Well 10, is located at 201 Maple Lane, approximately 1,150 ft south of State Highway 38 (Big Bear Boulevard) and 440 ft west of Maple Lane in Big Bear City, an unincorporated community in San Bernardino County, California.

2.2 Purpose and Scope

This report provides comprehensive details and results of the drilling, construction, and testing procedures for Well 10. Included in this report is a final well design with completion details and recommendations for the optimum discharge rate and pump setting, as well as water quality data collected from individual aquifer zones and the completed well.

2.3 General Geohydrology of the Well Site

Well 10 is located in the West Baldwin Hydrologic Subunit of the Big Bear Valley Ground Water Basin. This area is structurally situated at the eastern end of Big Bear Valley within the San Bernardino Mountains of the eastern Transverse Ranges Geomorphic Province of Southern California. Ground water in the Big Bear Valley generally occurs in the unconsolidated alluvial deposits on the lower slopes of the surrounding mountains and in the valleys. Three major formations occur in the Big Bear area: lacustrine deposits, Recent alluvium, and Older alluvium.

Lacustrine (lake bed) deposits are present in the vicinity of the well site and consist primarily of interbedded non-organic and organic-rich clay and very thin sand and gravel layers. The clay does not transmit appreciable amounts of water and serves as a confining layer for the underlying alluvial sediments. The Recent alluvium is found in the shallow subsurface zones and consists primarily of more permeable sediments (sand and gravel), with minor interbedded lenses of silt and clay. The Older alluvium consists of sand, gravel, and clay, with locally interbedded lenses of silt; and is found underlying the Recent alluvium.

Granodiorite bedrock was encountered during the drilling of the pilot borehole at a depth of 629 ft bgs with weathered bedrock material first encountered at 585 ft bgs. During final testing, the depth of the static water level in Well 10 was measured at approximately 156 ft bgs.

3.0 WELL CONSTRUCTION

The drilling contractor for Well 10 was Bakersfield Well & Pump Company of Bakersfield, California. Drilling and construction of the well began on January 28, 2003, with the installation of the conductor casing. Pilot borehole drilling and zone testing were performed during January and February 2003. On February 28, 2003, the borehole was backfilled to the conductor casing and the drilling rig was moved to another site while the collected data was analyzed before GEOSCIENCE recommended completion as a production well. Following recommendation to complete the well, the drilling rig returned to the site during late June 2003 and began the reaming pass. Development and testing was completed on August 12, 2003. Development and testing was completed on August 10, 2003. The chronology of construction is summarized in Appendix A.

3.1 Conductor Casing Installation and Pilot Borehole Drilling

A 36-inch diameter conductor borehole was drilled to a depth of 53 ft bgs using a bucket auger rig. The 26-inch OD by 5/16-inch wall steel conductor casing was installed to 53 ft bgs and cemented in place from ground surface to a depth of 53 ft. Below the bottom of the conductor casing, a 17 1/2-inch diameter pilot hole was drilled using a reverse circulation rotary drilling rig. Drilling of the pilot borehole began on February 3, 2003, and was advanced to a final depth of 634 ft by February 12, 2003 and was later reamed to a depth of 654 ft bgs. Figure 2 shows a technical cross section of the well as it was constructed, and Table 1 summarizes the well construction details and materials.

Formation materials encountered during pilot borehole drilling consisted primarily of varying amounts of broken cobbles, fine- to coarse-grained gravel, fine- to coarse-grained sand and interbedded layers of silt and clay. Granodiorite bedrock was encountered during the drilling of

the pilot borehole at a depth of 629 ft bgs. A detailed lithologic log of the pilot borehole is found in Appendix B of this report.

3.2 Geophysical Borehole Logging and Aquifer Zone Testing

Upon reaching the final depth of the 17 1/2-inch diameter pilot borehole at 634 ft bgs, fluids in the borehole were circulated for an adequate amount of time so that borehole stability could be verified before removing the drilling string. A suite of geophysical borehole logs were then run by Welenco, Inc. on February 12, 2003 and included the following:

- (1) 16-inch and 64-inch normal resistivity with point resistance;
- (2) Spontaneous potential (SP);
- (3) Focused guard resistivity (Laterolog);
- (4) Acoustic (sonic); and
- (5) Gamma ray.

Welenco, Inc. ran a caliper log of the reamed borehole on July 9, 2003 prior to installation of the well casing and screen. Appendix C contains the geophysical borehole logs including the caliper survey.

A flowmeter (or “spinner”) survey was not conducted as the pump had been placed midway in the well and would not allow sufficient room to allow the flowmeter to pass in order to perform the test.

3.3 Aquifer Zone Testing for Yield and Water Quality

Four zones were selected and tested before determining the final well design (selection of screened intervals, slot size and filter pack). The selection of these zones was based upon examination of the formation samples and analysis of the geophysical borehole logs. Ground water samples were collected from Zone 1 (593 to 613 ft), Zone 2 (462 to 482 ft), Zone 3 (272 to 292 ft), and Zone 4 (190 to 210 ft) and submitted to a laboratory for water quality analyses including general physical and general mineral properties. Clinical Laboratory of San Bernardino, Inc. performed analysis of the water quality samples. The purpose of isolated zone testing is to determine both yield and water quality from the potential completion interval(s) before determining the final design of the well.

3.3.1 Aquifer Zone Testing Procedure

Prior to isolated aquifer zone testing, the open 17 1/2-inch diameter pilot borehole was backfilled with gravel and bentonite to the bottom of each zone to be tested. A 20-ft section of perforated (mill-slotted) pipe was attached to the drill string and inserted in the pilot borehole within the target zone to be tested. Filter pack material was then added to the annular space between the 17 1/2-inch diameter borehole and the zone test tool (perforated pipe), until the tool was covered by at least 10 ft of material. A second bentonite seal was placed to isolate the zone from the rest of the borehole. The bentonite seals were allowed to hydrate for a specified amount of time before airlifting of the isolated zone began.

The isolated zone was initially developed by airlifting the “temporary well” until the fluid being discharged remained acceptably clean and clear, and the integrity of the seal had been verified.¹

¹ Verification of the seal for zone testing is determined when water levels occurring in the annulus remain stable and predictable (allowing for losses to the formation above the top seal), and is different than the water level measured inside the zone testing tools (i.e. the drill pipe), whether the zone is being actively pumped, or is at rest.

If the seal was determined to not be holding, more bentonite and/or cuttings were added to the annulus and were allowed to hydrate before continuing development. Airlifting was followed by pumping to further clarify each zone.

Once the water being pumped from each isolated zone was observed to be acceptably clean and clear, and it was determined that the seal was holding, the temporary well was pumped continuously for several hours. This additional pumping was to ensure that only formation water from the isolated zone was being produced, and that the water was uncontaminated by the fluids used during drilling. During this time, periodic measurements were made of field water quality parameters (including turbidity) water levels and rates of discharge.

At the end of continuous pumping, samples were collected from Zones 1, 3 and 4 for water quality analysis. The water quality samples were then delivered to Clinical Laboratory of San Bernardino, Inc., for water quality analyses. Zone 2 was not sampled due to low flow.

The isolated aquifer zone test procedure is summarized below:

1. The 17 1/2-inch pilot borehole was backfilled to approximately 10 feet below the zone to be tested. A bentonite seal was placed on top of the backfill material.
2. A 20-foot long mill-slotted section of pipe was placed opposite the zone to be tested.
3. Filter pack material was placed in the annular space between the perforated tool and the borehole, to approximately 10 ft above the top of the tool.
4. Ten feet of bentonite material was placed on top of the filter pack material to complete the zone isolation process, and was allowed to hydrate.
5. The temporary well was developed by airlifting, and the integrity of the seal was verified.

6. Following development by airlifting, the isolated zone was pumped using a submersible pump for several hours at rates ranging from approximately 15 to 65 gpm.
7. Water levels and discharge rates were measured and recorded periodically. Water samples were collected to determine the water chemistry for each zone tested.

3.3.2 Results of the Aquifer Zone Testing

Water quality analyses were performed for Zones 1, 3 and 4 and included general mineral and general physical properties. Zone 2 water levels and field parameters were not collected as they were not representative of true aquifer conditions. The zone appeared to be “drying up” during airlifting and pumping, and was not able to produce significant amounts of water.

Clinical Laboratory of San Bernardino, Inc. performed the water quality analyses. Results show that the TDS concentrations for Zones 1, 3 and 4 ranged from 140 to 230 mg/L, well below the recommended secondary Maximum Contaminant Level (MCL) of 500 mg/L. The concentration of fluoride in the ground water sampled from Zone 1 was 2.5 mg/L (above the MCL of 2.0 mg/L). The concentration of iron in the ground water sample from Zone 1 was 1.0 mg/L (above the MCL of 0.3 mg/L). The pH of ground water sampled from Zone 1 was 9.1 (outside the MCL range of 6.5 to 8.5). The apparent color (unfiltered) of ground water sampled from Zone 1 was 30 color units (above the MCL of 15 color units). All other water quality results from isolated aquifer zone testing were below their respective MCLs. Well 10 was completed including Zone 1 as the total flow from all zones would result in an acceptable water blend.

A summary of selected water quality results is presented in the following table:

Aquifer Zone Testing Results
Water Quality Analytical Data

		Zone				MCL or Action Level
		1	2	3	4	
Depth Interval	[ft]	593-613	462-482	272-292	190-210	
Arsenic	[µg/L]	< 2.0	NS	< 2.0	< 2.0	50 ^{1,3}
Fluoride	[mg/L]	2.5	NS	< 0.10	< 0.10	2.0 ¹
Iron	[µg/L]	1,000	NS	150	< 100	300 ²
Manganese	[µg/L]	< 20	NS	< 20	< 20	50 ²
Nitrate (as NO ₃)	[mg/L]	< 2	NS	< 2	< 2	45 ¹
Total Dissolved Solids (TDS)	[mg/L]	140	NS	200	230	500-1,000 ²
Apparent Color (Unfiltered)	[color units]	30	NS	15	< 3	15 ²
Lab Turbidity	[NTU]	17.4	NS	3.19	0.6	5.0 ²
Odor Threshold @ 60°C	[TON]	1	NS	1	1	3 ²
pH	[std. units]	9.1	NS	7.6	7.6	6.5-8.5 ²

Shaded cells indicate constituents that are above the present MCLs.

ND signifies that the analyte was not detected or that the analyte concentration was below the detection limit of the analytical method.

NS signifies that no sample was collected.

¹ California DHS Primary MCL.

² California DHS Secondary MCL.

³ In January 2006 the MCL for arsenic will be reduced to 0.010 mg/L (10 µg/L).

3.4 Casing and Screen Design

Welenco, Inc. ran a caliper log in the 22-inch diameter borehole, which had been reamed from a depth of 53 to 654 ft bgs. The caliper log was performed before installing the casing, screen, filter pack, and annular seals to determine the borehole condition and volume. The well was completed with the bottom of the well casing placed at 640 ft bgs.

The casing and screen materials consist of Roscoe Moss Manufacturing Company 12 1/4-inch ID by 1/4-inch wall copper-bearing steel (ASTM A-139) Ful-Flo horizontal louvered well screen (0.070-inch openings). The screened intervals were placed from 195 to 295 ft bgs and 545 to 620 ft bgs. Blank copper-bearing steel casing was installed from ground surface to 195 ft bgs, from 295 to 545 ft bgs and from 620 to 640 ft bgs. An end plate consisting of 1/4-inch thick copper-bearing steel was welded to the lowermost blank section (see Figure 2 and Table 1).

3.5 Filter Pack and Annular Seal

Formation samples from nine intervals between 200 and 620 ft bgs (within the recommended screened interval) were selected for mechanical grading analysis (see Figure 3). The filter pack was designed using a pack-aquifer ratio of 4 to 10 times the finest aquifer and Terzaghi criteria (see Table 2). The mean grain diameter (i.e. the 50 percent passing size) of the aquifer materials ranged from 0.23 mm to 1.0 mm. Uniformity coefficients² of aquifer materials ranged from approximately 8 to 23 (well graded or poorly sorted materials).

A custom blend of Tacna Sand and Gravel (Yuma, Arizona) 1/4 in. x 16 filter pack material was installed from 654 to 96 ft bgs within the annular space between the 22-inch diameter borehole and the 12 1/4-inch ID well casing (see Figure 3). An annular seal consisting of a 10.5-sack sand cement mixture was pumped through a tremie pipe from a depth of 96 ft bgs to the ground surface, and acts as a deep sanitary seal for the well. The recommended design for the Tacna Sand and Gravel 1/4 in. x 16 Custom Blend Filter Pack is shown in the following table:

² The uniformity coefficient is defined as the 60% passing grain size (d_{60}) divided by the 10% passing grain size (d_{10}). The lower the value of the uniformity coefficient, the more uniform the grading. Similarly, the larger the value, the less uniform the grading of the material.

Mechanical Grading Analysis – As Designed Filter Pack - Well 10 (Booster Station Site)

U.S. Standard Sieve Size	Opening [in.]	Opening [mm]	Cumulative Percent Passing
3/8"	0.375	9.53	100
1/4"	0.250	6.35	95
4	0.187	4.75	85
8	0.094	2.38	48
10	0.079	2.00	30
12	0.066	1.68	17
16	0.047	1.19	9
20	0.033	0.84	5
30	0.023	0.59	2

One 3-inch diameter schedule 40 steel gravel feed pipe was installed in the annulus to a depth of 110 ft to allow for future addition of filter pack material to the annulus. A 2-inch diameter schedule 40 steel sounding tube was welded to the outside of the well casing at a depth of 194 ft. The sounding tube will be used to collect water level measurements while the pump is in the well.

3.6 Well Development

Well 10 was initially developed using a combination airlifting and swabbing tool to consolidate the filter pack after placement, and to remove colloidal and fine-grained sediments from within the well, filter pack, and near-well zone. Ten-foot intervals were swabbed and airlifted simultaneously until relatively clean water was discharged. A total of approximately 72 hours were ultimately spent airlifting and swabbing the screened sections of the well.

Final development was conducted using a vertical turbine test pump from July 31 to August 7, 2003. The pump bowls were set at 316 ft bgs. Final development consisted of pumping the well at a steady discharge rate until the sand concentration reached a minimum threshold of less than 10 parts per million (ppm). At that point, the well was “surged” repeatedly

at increasing rates as long as the sand content remained low. A 5 ppm threshold was maintained throughout the final day of development. The contractor's notes taken during the well development process are contained in Appendix D.

During development, the discharge rate was measured using an in-line propeller meter and water level measurements were collected using an electric wireline water level indicator while the sand concentration was measured using a centrifugal Rossum Sand Tester. When the specific capacity (discharge rate divided by drawdown) approached a maximum, and the turbidity and sand concentration approached a minimum and remained stable, well development was considered complete.

During development pumping, a maximum short-term discharge rate of approximately 200 gpm was achieved, although most of the development time was conducted at much lower rates. A total of approximately 63 hours were spent on final development by pumping.

3.7 Spinner (Flowmeter) Survey

A flowmeter (or "spinner") survey was not conducted as the pump was located midway down the well and would not permit a flowmeter tool to pass.

3.8 Plumbness and Alignment Survey

Welenco, Inc. of Bakersfield, California conducted a plumbness and alignment survey on August 21, 2003 to measure the verticality of the well. Results showed a deviation at 320 ft bgs (the recommended pump setting is 316 ft bgs) of 2.0 inches in the North-South plane and 3.0 inches in the East-West plane. The results of the deviation survey indicate that the verticality of the well is within the limits defined by the technical specifications (6 inches per 100 ft of depth). The maximum deviation in the North-South plane was 13.5 inches occurring at

640 ft bgs, and the maximum deviation on the East-West plane was 5.8 inches occurring at a depth of 640 ft bgs. The complete results of the alignment survey are shown on Table 3, and are shown graphically in Figure 4.

3.9 Downhole Video Survey

Welenco, Inc. completed a video log of the post-construction condition of the well on August 21, 2003 to serve as a permanent record of the construction details and condition of the well following development and testing. The video survey showed the well casing and screen to be clean and in good condition. The water column was slightly murky and some sediment was observed upon the edges of the louvers. Sediment build-up at the bottom of the well was insignificant.

3.10 Well Completion Report

Appendix E contains a copy of the Well Completion Report that was filed by Bakersfield Well & Pump Company with the State of California Department of Water Resources upon the completion of Well 10 (Booster Station Site).

4.0 PUMPING TEST ANALYSIS PROCEDURES AND RESULTS

4.1 Data Collection

After development pumping, two separate pumping tests were conducted. A step drawdown test was performed to determine specific capacity and well efficiency relationships. Following the step drawdown test, a 24-hour constant rate pumping test was conducted. The constant rate pumping test was followed by four hours of recovery measurements.

During both tests the pumping water level, discharge rate, and sand content were closely monitored (see Appendix F). The field procedure for these tests followed the American Society for Testing and Materials (ASTM, 1994, standard test method D 4050).

4.2 Basic Assumptions Used in Analysis of Pumping Test Data

The purpose of a pumping test is to obtain field data, which when substituted into an equation or set of equations, will yield estimates of well and aquifer properties. As certain assumptions have been used to derive these equations, it is important to observe or control these factors during the test. These assumptions and conditions are:

- The aquifer material is assumed to consist of porous media, with flow velocities being laminar and obeying Darcy's law.
- The aquifer is considered to be homogeneous, isotropic, of infinite aerial extent, and of constant thickness throughout.
- Water is released from (or added to) internal aquifer storage instantaneously upon change in water level.

- No storage occurs in the semi-confining layers of leaky aquifers.
- The storage in the well is negligible.
- The pumping well penetrates the entire aquifer and receives water from the entire thickness by horizontal flow.
- The slope of the water table or piezometric surface is assumed to be flat during the test with no natural (or other) recharge occurring, which would affect test results.
- The pumping rate is assumed constant during the entire time period of pumping during a constant-rate test, and constant during each discharge step in a variable-rate test.

4.3 Pumping Test Data Analysis Methods

4.3.1 Step Drawdown Test Method

The purpose of the step drawdown test is to determine formation losses, well losses, and well efficiency; all necessary in determining the final pump design. In an actively pumping well, the total drawdown in the well is composed of both laminar and turbulent head loss components. Laminar losses generally occur away from the borehole (where approach velocities are low), while turbulent losses are confined to the area in and around the immediate vicinity of the well screen and within the well borehole.

The total drawdown in a pumping well may be expressed as:

$$s_w = BQ + CQ^2 \quad \text{“Drawdown In A Pumping Well”} \quad (1)$$

where:

$$\begin{aligned} s_w &= \text{Total drawdown measured in the well, [ft]} \\ B &= \text{Formation or aquifer loss coefficient, [ft/gpm]} \\ Q &= \text{Discharge rate of the well, [gpm]} \\ C &= \text{Well loss coefficient, [ft/gpm}^2\text{]} \end{aligned}$$

The first and second terms in equation (1) are referred to as formation, or aquifer loss³ (BQ) and well loss⁴ (CQ²), respectively. Formation (i.e. aquifer) loss and well loss coefficients are determined from the step drawdown test. The test procedure involves pumping the well at multiple (at least three) discharge rates with each "step" being a fraction of the maximum discharge. Analysis of the step drawdown data requires plotting the "specific drawdown" (s_w/Q) for each step against discharge rate. The formation loss coefficient (B) is the y-intercept of the best-fit straight line through the specific drawdown data points. The slope of the line is equal to the well loss coefficient (C).

Well Efficiency (E) is defined as the ratio of the formation (i.e. aquifer) loss component (BQ) to the total drawdown measured in the well (s_w) and is expressed as a percent:

$$E = 100 \frac{BQ}{s_w} = \frac{100}{1 + CQ/B} \quad \text{“Well Efficiency”} \quad (2)$$

³ Aquifer loss is the head loss measured at the interface between the aquifer and the filter pack. The magnitude of the aquifer loss can be found from consideration of radial flow into the well and can be calculated, for example, using Jacob's equation.

⁴ Well losses are turbulent flow losses which are head losses associated with the entrance of water into and through the well screen as well as those losses incurred as the flow moves axially towards the pump intake. These losses vary as the square of the velocity.

where:

- E = Well Efficiency, [percent]
- B = Formation or aquifer loss coefficient, [ft/gpm]
- Q = Discharge rate of the well, [gpm]
- s_w = Total drawdown measured in the well, [ft]
- C = Well loss coefficient, [ft/gpm²]

4.3.2 Constant Rate Test Method

Calculation of aquifer parameters from pumping test data is based on analytical solutions of the basic differential equation of ground water flow that can be derived from fundamental laws of physics. One of the most widely used solutions of this equation for non-steady radial flow to wells is the “Theis Equation”:

$$s(r, t) = \frac{114.6Q}{T} W(u) \quad \text{“Theis Equation”} \quad (3)$$

where:

- s(r,t) = Drawdown in the vicinity of an artesian well, [ft]
- r = Distance from pumping well, [ft]
- Q = Discharge rate of pumping well, [gpm]
- T = Transmissivity of aquifer, [gpd/ft]
- W(u) = “Well function of Theis”
- u = $1.87 \times r^2 \times S / (T \times t)$

where:

- S = Storativity, [fraction]
- t = Time after pumping started, [days]

4.3.2.1 Jacob's Straight-Line (Modified Theis Non-Equilibrium) Method

According to Jacob (1950), for small values of “u” ($u < 0.05$), the Theis equation may be approximated by Jacob's equation:

$$s(r, t) = \frac{264Q}{T} \log \left(\frac{0.3 T t}{r^2 S} \right) \quad \text{“Jacob's Equation”} \quad (4)$$

Jacob's equation is valid for use for most hydrogeologic problems of practical interest, is easier to use than the Theis equation, and involves a simple graphical procedure to calculate transmissivity and storativity. This method (D 4105) is summarized by ASTM (1994).

Transmissivity (T, in gpd/ft) can be calculated as:

$$T = \frac{264Q}{\Delta s} \quad (5)$$

where:

Q = Pumping rate, [gpm]

Δs = Change in drawdown over one log cycle of time, [ft]

Storativity can be calculated as:

$$S = \frac{0.3 T t_0}{r^2} \quad (6)$$

where:

T = Transmissivity, [gpd/ft]

t_0 = Time at the zero-drawdown intercept, [days]

r = Radial distance from the pumping well, [ft]

4.4 Pumping Test Data Analysis and Results

4.4.1 Step Drawdown Pumping Test

A step drawdown test was performed on August 8, 2003 at average discharge rates of 98 gpm, 127 gpm, and 151 gpm. The static water level at the beginning of the test was approximately 157 ft bgs. Figure 5 is a plot of the step drawdown test data and shows the time-drawdown curve for each step. The specific drawdown for each step is shown in the following table:

Step m	Discharge Rate Q_m [gpm]	Incremental Drawdown Δs_m [ft]	Drawdown ¹ s_m [ft]	Specific Drawdown $(s/Q)_m$ [ft/gpm]
1	98	22.58	22.58	0.2304
2	127	7.61	30.19	0.2377
3	151	7.43	37.62	0.2491

¹Drawdown at 1,440 minutes after the start of each step.

The specific drawdown plot (see Figure 6) shows the relationship between specific drawdown (s/Q) and the discharge rate (Q). The testing showed a formation loss coefficient (B) of 0.19523 ft/gpm and a well loss coefficient (C) of 0.00035 ft/gpm².

The specific capacity and well efficiency diagram (see Figure 7) shows estimated drawdown and well efficiency. Estimated drawdown and well efficiency may also be calculated from equations (1) and (2) described above in Section 4.3.1 Step Drawdown Test Method. At a design discharge rate of 100 gpm, the specific capacity of Well 10 is approximately 4 gpm/ft; with a well efficiency of approximately 85 percent.

4.4.2 Constant Rate Pumping Test

Following recovery from the step drawdown test, a 24-hour constant rate pumping test was conducted on August 11 and 12, 2003 (see Figure 8). The static water level at the start of the test was approximately 156 ft bgs, and the average discharge rate was 101 gpm. Water level drawdown in Well 10 was 5.7 ft of drawdown per log cycle. The Jacob's straight-line method was used to analyze the time-drawdown data with results showing an aquifer transmissivity of approximately 4,680 gpd/ft (see Figure 8).

5.0 DESIGN DISCHARGE RATE, TOTAL LIFT AND PUMP SETTING

A maximum pumping rate of 100 gpm is recommended for Well 10. At this rate, short-term pumping of the well (i.e. one day of *continuous* pumping) is expected to result in 35 ft of drawdown with a total lift to land surface of 241 ft (which also includes regional decline in static water level). The long-term drawdown (extrapolated to one year of *continuous* pumping) was estimated to be 50 ft with a total lift to ground surface of 256 ft (which also includes regional decline in static water level). At a discharge rate of 100 gpm, the specific capacity of Well 10 will be approximately 3 gpm/ft (extrapolated from constant rate test data) with a well efficiency of 85 percent (see Figure 7).

It is recommended that the pump bowls be set at a depth of 316 ft bgs, which is located in the blank casing between the two sections of horizontal louvered well screen (195 to 295 ft bgs, and 545 to 620 ft bgs).

The following table summarizes the recommended pump design:

Recommended Pump Design -Well 10 (Booster Station Site)

Parameters	Short Term (1 day)	Long Term (1 year) ¹
Design Pumping Rate	100 gpm	100 gpm
Pump Setting	316 ft bgs	316 ft bgs
Design Well Efficiency	85 percent	NA
Static Water Level Depth	156 ft bgs	156 ft bgs
Design Drawdown	35 ft	50 ft
Regional Decline in Static Water Level	50 ft	50 ft
Total Lift to Surface (Including regional decline in static water level)	241 ft	256 ft

¹Extrapolated using water level recovery data from the constant rate pumping test.

6.0 GROUND WATER QUALITY

Water samples were collected August 12, 2003 at the end of the 24-hour constant rate pumping test and submitted to Clinical Laboratory of San Bernardino Inc., for Title 22 analysis. The results of the Title 22 analysis, as well as water quality results from the aquifer zone testing are presented on Figure 9 and in Appendix G.

The total dissolved solids (TDS) value of the sample collected from the completed well was 220 mg/L. This concentration is well below the California EPA recommended drinking water standard of 500 mg/L. Fluoride and iron were not detected in the completed well. All other constituents were reported below their specified MCLs.

The results of the water quality analyses are summarized in the following table:

Completed Well Title 22 Water Quality Analytical Data

		Analysis Result	Drinking Water Standards
Arsenic	[µg/L]	< 2.0	50 ^{1,3}
Fluoride (Total)	[mg/L]	< 0.10	2.0 ¹
Iron	[µg/L]	< 100	300 ²
Manganese	[µg/L]	< 20	50 ²
Nitrate (as NO ₃)	[mg/L]	< 2.0	45 ¹
Total Dissolved Solids (TDS)	[mg/L]	220	500 - 1,000 ²
Volatile Organic Chemicals (EPA Method 524.2)	[µg/L]	ND	Varies with Compound
Apparent Color (Unfiltered)	[color unit]	< 3	15 ²
Odor Threshold @ 60°C	[TON]	1	3 ²
pH	[std. units]	7.7	6.5 - 8.5 ²

ND signifies that the analyte was not detected or that the analyte concentration was below the detection limit of the analytical method.

¹ California DHS Primary MCL.

² California DHS Secondary MCL

³ In January 2006 the MCL for arsenic will be reduced to 10 µg/L.

7.0 REFERENCES

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