

BIG BEAR CITY COMMUNITY SERVICES DISTRICT
WELL 8 (PALOMINO SITE)
RESULTS OF DRILLING, CONSTRUCTION, TESTING AND PUMP DESIGN

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 8, is located 980 feet (ft) north of Shay Road and 140 ft east of Palomino Road in Big Bear City, San Bernardino County, California.

Well 8 was drilled using the reverse circulation drilling method, by Bakersfield Well & Pump Company of Bakersfield, California. A 36-inch diameter conductor borehole was drilled to a depth of 50 feet (ft) using a screw auger rig. The 26-inch outside diameter (OD) surface conductor casing was installed to 50 ft below ground surface (bgs) and cemented in place from the ground surface to a depth of 50 ft. The 17 1/2-inch diameter pilot borehole was drilled to a total depth of 609 ft bgs. Geophysical borehole logs were then run in the open borehole. The borehole was reamed to 24-inches from 50 to 96 ft (to permit adequate space for sounding tube installation), and 22-inches from 96 to 404 ft. Alluvial materials penetrated during drilling consisted primarily of varying amounts of coarse- to fine-grained sand, fine-grained gravel, broken cobbles, and interbedded layers of silt and clay. Quartzite bedrock was encountered during the drilling of the pilot borehole at a depth of 609 ft bgs.

Four zones were selected and tested before determining the final well design (selection of screened intervals, slot size and filter pack). 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 No. 2 (476 to 496 ft), Zone No. 3 (340 to 360 ft), and Zone No. 4 (265 to 285 ft). Water quality analyses including general physical and general

mineral properties were then run on the samples. Zone 1 (547 to 567) was not analyzed due to high fluoride concentrations¹. Clinical Laboratories of San Bernardino, Inc., located in San Bernardino, California performed the water quality analyses.

Well 8 was completed to a total depth of 380 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 louver was installed from 90 to 175 ft, 195 to 245 ft, and 260 to 360 ft. Blank well casing consisting of 12 1/4-inch ID by 1/4-inch wall Copper-bearing steel was installed from ground surface to 90 ft, 175 to 195 ft, 245 to 260 ft, and 360 to 380 ft. A total of 205 ft of the of the 17 1/2-inch diameter pilot hole (404 to 609 ft depth) were backfilled with native material generated during the reaming process. An end cap consisting of 12 1/4-inch ID copper-bearing steel was welded to the lowermost blank section. A total of 235 ft of well screen and 145 ft of blank casing were installed, for a total well depth of 380 ft.

A custom blend of Tacna Sand and Gravel (Yuma, Arizona) 1/4 x 16 filter pack material was installed from 30 to 50 ft depth between the 26-inch OD conductor casing and the 12 1/4-inch blank well casing, from 50 to 96 ft in the 24-inch borehole, and from 96 to 404 ft in the 22-inch borehole. An annular seal consisting of a 10.5 sack cement mixture was pumped through a tremie pipe from 30 ft depth to the ground surface, and acts as a deep sanitary seal for the well.

Pumping tests have established that the designed discharge rate for the well is approximately 550 gpm. Short-term pumping of this well (i.e. one day of *continuous* pumping) is expected to result in approximately 24 ft of drawdown and a specific capacity of approximately 23 gpm/ft. Long-term pumping of this well (extrapolated to one year of *continuous* pumping) was estimated to result in 39 ft of drawdown.

¹ An initial ground water sample collected from Zone No. 1 (547 to 567 ft bgs) and analyzed at the Big Bear Area Regional Wastewater Agency (BBARWA) water quality laboratory indicated an elevated fluoride concentration of 1.1 mg/L.

Calculations using the information obtained from the step drawdown and 24-hour constant rate pumping tests indicate a well efficiency of 69 % and an aquifer transmissivity of approximately 35,900 gpd/ft.

Based on the information collected during the pumping tests, the recommended discharge rate and pump setting for Well 8 are as follows:

Recommended Design - Well 8 (Palomino Site)

Parameters	Short Term (1 day)	Long Term (1 year)*
Design Pumping Rate	550 gpm	550 gpm
Pump Setting	370 ft bgs	370 ft bgs
Design Well Efficiency	69 %	NA
Design Drawdown	24 ft	39 ft
Static Water Level Depth	40 ft bgs	40 ft bgs
Regional Decline in Static Water Level	20 ft	20 ft
Total Lift to Surface (does not include regional decline in static water level)	64 ft	79 ft

* Extrapolated using water level data from the step drawdown and constant rate pumping tests.

At the end of the 24-hour constant rate pumping test (conducted at an average discharge rate of 517 gpm), water samples were collected from the completed well by a GEOSCIENCE employee for Title 22 water quality analysis. Clinical Laboratory of San Bernardino, Inc., located in San Bernardino, California, performed these analyses. The laboratory reported a total dissolved solids (TDS) value of 360 mg/L. This amount is well below the California EPA recommended drinking water standard of 500 mg/L. Fluoride was detected in the completed well at a concentration of 0.64 mg/L. This concentration is also below the California Department of Health Services Primary Maximum Contaminant Level. All other constituents had concentrations below their specified 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. of Bakersfield, California conducted a plumbness and alignment survey on April 4, 2003 to measure the verticality of the well. Results showed a deviation at 370 ft bgs (i.e., the recommended pump setting) of 2.3 inches in the North-South plane and 5.8 inches in the East-West plane (Figure 5). The maximum deviation in the North-South plane was 4.8 inches occurring at 300 ft bgs, and the maximum deviation on the East-West plane was 5.9 inches occurring at a depth of 380 ft bgs. 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).

Welenco, Inc. completed a video log of the post-construction condition of the well on June 30, 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 not murky, and no sediment was observed upon the edges of the louvers, or at the bottom of the well.

2.0 INTRODUCTION

2.1 Background

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 8, is located 980 feet (ft) north of Shay Road and 140 ft east of Palomino Road in Big Bear City, 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 8. 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.

2.3 General Geohydrology of the Well Site

Well 8 is located in the East Baldwin Lake 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 non-organic and organic-rich clay with 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 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.

Quartzite bedrock was encountered during the drilling of the pilot borehole at a depth of 609 ft bgs. During testing, the depth of the static water level in Well 8 was measured at approximately 40 ft bgs.

3.0 WELL CONSTRUCTION

The drilling contractor for BBCCSD's Well 8 was Bakersfield Well & Pump Company of Bakersfield, California. Drilling and construction of the well began on January 29, 2003. Development and testing was completed on June 12, 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 50 ft using a screw auger rig. The 26-inch OD by 5/16-inch wall steel conductor casing was installed to 50 ft bgs and cemented in place from ground surface to a depth of 50 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 April 21, 2003, and was advanced to a final depth of 609 ft by April 28, 2003. 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 fine- to coarse-grained sand, fine- to coarse-grained gravel, broken cobbles, and interbedded layers of silt and clay. Quartzite bedrock was encountered during the drilling of the pilot borehole at a depth of 609 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 a depth of 558 ft bgs in the 17 1/2-inch pilot borehole, it was expected that the well had encountered bedrock due to an extremely slow drilling rate of less than 1/2-foot per

hour, in addition to the presence of broken, angular rock fragments in the sample collection box. As a result, 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 April 24, 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.

A field interpretation of the geophysical borehole logs indicated that bedrock had not been encountered. Therefore, drilling of the 17 1/2-inch pilot borehole was recommenced at 585 ft bgs and the drill bit soon broke through a hard layer with a corresponding increase in drilling rate until the drilling rate again slowed to less than 1/2-foot per hour and quartzite bedrock was encountered at a depth of 609 ft bgs. As lithology encountered did not change significantly, a second geophysical borehole log of the 17 1/2-inch pilot borehole was not conducted. .

Welenco, Inc. ran a caliper log on May 15, 2003 prior to installation of the well casing and screen. Appendix C contains the geophysical borehole logs including the caliper survey.

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). Selection of these zones was based upon examination of the formation samples and analysis of the geophysical logs. 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. Ground water samples were obtained from Zone No. 2 (476 to 496 ft bgs), Zone No. 3 (340 to 360 ft bgs), and Zone No. 4 (265 to 285 ft bgs) for water quality analyses including general physical and general mineral properties. Clinical Laboratories of San Bernardino, Inc., located in San Bernardino, California performed analysis of the water quality samples. An initial analysis of ground water collected from Zone No. 1 (547 to 567 ft bgs) by the BBARWA water quality laboratory indicated an elevated fluoride concentration (1.1 mg/L). In addition, a drawdown of approximately 288 feet at a discharge rate of only 2 to 3 gpm, and high turbidity precluded a complete water quality analysis for this zone by Clinical Laboratories of San Bernardino, Inc.

3.3.1 Aquifer Zone Testing Procedure

Prior to zone testing, the open 17 1/2-inch pilot borehole was backfilled with gravel and bentonite to the bottom of the 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 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 test zone was 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.² If the seal was not holding, more bentonite and/or cuttings were added to the annulus and were allowed to hydrate before continuing development.

² 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.

Once the water airlifted from the zone was observed to be clean and clear, and it was determined that the seal was holding, the temporary well was again airlifted for several additional hours. This additional airlifting 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, water levels and rates of discharge.

At the end of continuous airlifting, samples were collected from each zone for water quality analysis. The water quality samples were then delivered to Clinical Laboratory of San Bernardino, Inc., for water quality analyses. This process was repeated for Zone Nos. 2, 3, and 4.

The 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, each isolated Zone (Nos. 2, 3, and 4) was airlifted for several hours at rates ranging from approximately 40 to 50 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 Zone Nos. 2, 3, and 4 and included General Mineral and General Physical Properties.

Clinical Laboratory of San Bernardino, Inc. performed the water quality analyses. Results show that the total dissolved solids (TDS) concentrations for Zone Nos. 2, 3 and 4 ranged from 80 to 260 milligrams per liter (mg/L), well below the recommended secondary MCL of 500 mg/L. Zone No. 1 was not sampled for a complete laboratory analysis due to low yield, high turbidity, and a high fluoride concentration detected in an initial analysis conducted by the BBARWA water quality laboratory. The concentration of fluoride in the ground water sampled from Zone No. 2 was 4.8 mg/L (above the MCL of 2.0 mg/L). Zone No. 2 also had a high, but acceptable pH of 8.4, slightly within the secondary MCL of 8.5. However, the well was completed above Zone No. 2 to avoid pumping ground water of high fluoride concentration. All other water quality results were below their respective MCLs.

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

Aquifer Zone Testing Results
Water Quality Analytical Data

		Zone Number				MCL or Action Level
		1	2	3	4	
Depth Interval	[ft bgs]	547-567	476-496	340-360	265-285	--
Color (Unfiltered)	[color unit]	NA ¹	<3	<3	<3	15 ²
Odor @ 60°C	[odor unit]	NA	1	1	1	3 ²
pH	[pH unit]	8.1 ³	8.4	7.7	7.3	6.5-8.5 ²
Arsenic	[mg/L]	NA	<0.002	<0.002	<0.002	0.05 ^{4,5}
Fluoride (Total)	[mg/L]	1.1 ⁶	4.8	1.0	0.54	2.0 ⁴
Iron	[mg/L]	NA	<0.1	0.23	<0.1	0.3 ²
Manganese	[mg/L]	NA	0.033	<0.02	<0.02	0.05 ⁴
Nitrate (as NO₃)	[mg/L]	NA	<2	<2	<2	45 ⁴
Total Dissolved Solids (TDS)	[mg/L]	270 ³	260	180	240	500-1,000 ⁴

Note: Shaded cells indicate constituent concentrations that are above the present or impending Maximum Contaminant Levels (MCLs).

¹No samples analyzed due to low yield from zone.

²California Department of Health Services (DHS) Secondary MCLs.

³Result of field analysis.

⁴California Primary MCL.

⁵In January 2006 the MCL for arsenic will be reduced to 0.01 mg/L (10 µg/L).

⁶An initial ground water sample collected from Zone No. 1 and analyzed at the BBARWA water quality laboratory indicated an elevated fluoride concentration of 1.1 mg/L. As a result, an analysis for complete general physical and general mineral properties was not run on Zone No. 1.

3.4 Casing and Screen Design

Welenco, Inc. ran a caliper log in the 24-inch (50 to 96 ft) and the 22-inch (96 to 404 ft) diameter borehole, which had been reamed, to a depth of 404 ft bgs. The caliper log was performed before installing the casing, screen, filter pack, and annular seals. The well was completed with the bottom of the well casing placed at 380 ft bgs.

Roscoe Moss Company 12 1/4-inch ID by 1/4-inch wall copper-bearing steel (ASTM A-139) Ful-Flo horizontal louvered well screen with 1/16-inch (0.0625 inch) openings was placed from 90 to 175 ft, 195 to 245 ft, and 260 to 360 ft bgs. Blank 12 1/4-inch ID by 1/4-inch wall copper-bearing steel casing was placed from ground surface to 90 ft, 175 to 195 ft, 245 to 260, and from 360 to 380 ft bgs. An end plate made of the same material as the casing and screen was welded to the lowermost blank section.

3.5 Filter Pack and Annular Seal

Formation samples from size intervals below 120 ft bgs were selected for mechanical grading analysis (see Figure 3). The filter pack was designed using Terzaghi criteria (see Table 3). The mean grain diameter (i.e. the 50% passing size) of the aquifer materials ranged from 0.15 mm to 1.19 mm. Uniformity coefficients³ of aquifer materials ranged from approximately 5 to 6 (well graded materials).

Tacna Sand and Gravel provided the custom blend 1/4 x 16 filter pack material (see Figure 4). The filter pack was placed into the annular space between the 36-inch (0 to 50 ft), 24-inch (50 to 96 ft), and 22-inch (96 to 404 ft) diameter borehole and the 12 1/4-inch ID casing and screen.

³ 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.

The filter pack material was placed from 30 to 404 ft bgs by pumping through a tremie pipe using clear water as a circulating medium.

One 3-inch diameter schedule 40 steel gravel feed pipe was installed in the annulus to a depth of 35 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 to a depth of 86 ft. The sounding tube will be used to collect water level measurements while the pump is in the well.

An annular seal, consisting of 10.5-sack sand cement slurry, was pumped through a tremie pipe from the top of the filter pack at 30 ft bgs to ground surface.

3.6 Well Development

Well 8 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 well.

Final development was conducted using a vertical turbine test pump from June 3 to June 9, 2003. The pump bowls were set at 370 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 5 parts per million (ppm). The 5 ppm threshold was maintained throughout the final day of development, both when the discharge rate was increased, and when the well was “surged”. The contractor’s notes taken during the well development process are contained in Appendix D.

The discharge rate was measured using an in-line propeller meter. Water level measurements were collected using an electronic sounder. During pumping, 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, well development was considered complete.

During development pumping, a maximum discharge rate of approximately 1,100 gpm was achieved. Short-term specific capacities on the final day ranged from 21.81 to 30.42 gpm per foot of drawdown, depending upon the rate of discharge. A total of approximately 51 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 near the bottom of the well and would not permit a flowmeter tool to pass.

3.8 Plumbness and Alignment Survey

Bakersfield Well and Pump conducted a plumbness and alignment survey on Tuesday July 1, 2003 to measure the verticality of the well. Results showed a deviation at 370 ft bgs (i.e., the recommended pump setting) of 2.31 inches in the North-South plane and 5.79 inches in the East-West plane. The maximum deviation in the North-South plane was 4.79 inches, occurring at 300 ft bgs. The maximum deviation in the East-West plane was 5.93 inches at 380 ft bgs. The results of the deviation survey indicate that the verticality of the well above 370 ft depth is within the limits defined by the technical specifications (6 inches per 100 ft of depth).

The results of the alignment survey are shown on Table 2, and are shown graphically in Figure 5.

3.9 Downhole Video Survey

Welenco, Inc. completed a video log of the post-construction condition of the well on June 30, 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 not murky, and no sediment was observed upon the edges of the louvers, or at the bottom of the well.

3.10 Well Completion Report

Appendix E contains a copy of the Well Completion Report that was filed by Bakersfield Well and Pump Company with the State of California Department of Water Resources upon the completion of Well 8.

4.0 PUMPING TEST ANALYSIS PROCEDURES AND RESULTS

4.1 Data Collection

After development pumping, two separate pumping tests were conducted. First, a step drawdown test was run to determine specific capacity and well efficiency relationships. Then a 24-hour constant rate test was conducted to obtain data from which to calculate aquifer transmissivity.

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 bore.

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:

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

The first and second terms in equation (1) are referred to as formation, or aquifer loss⁴ (BQ) and well loss⁵ (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:

⁴ 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.

⁵ 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.

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

where:

- E = Well Efficiency, [%]
- 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:

$$S = \frac{0.3Tt_0}{r^2} \quad (6)$$

where:

- T = Transmissivity, [gpd/ft]
 t₀ = Time at the zero-drawdown intercept, [days]
 r = Radial distance from the pumping well, [ft]

4.4 Pumping Test Data Analysis and Results for Well 8

4.4.1 Step Drawdown Pumping Test

A step drawdown test was performed on June 10, 2003 at average discharge rates of 325 gpm, 638 gpm, and 950 gpm. The static water level at the beginning of the test was approximately 40 ft bgs. Figure 6 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 s _m [ft]	Specific Drawdown (s/Q) _m [ft/gpm]
1	325	11.90	11.90	0.0366
2	638	17.18	29.08	0.0456
3	950	20.36	49.44	0.0520

The specific drawdown plot (see Figure 7) shows the relationship between specific drawdown (s/Q) and the discharge rate (Q). The testing showed a formation loss coefficient (B) of 0.02949 ft/gpm and a well loss coefficient (C) of 0.00002430 ft/gpm².

The specific capacity and efficiency diagram (see Figure 8) shows estimated drawdown and well efficiency. Estimated drawdown and well efficiency may also be calculated from equations (1) and (2) above.

4.4.2 Constant Rate Pumping Test

Following recovery from the step drawdown test, a 24-hour constant rate pumping test was conducted on Well 8 on June 11 and 12, 2003 (see Figure 9). The static water level at the start of the test was approximately 40 ft bgs, and the average discharge rate was 517 gpm. Water level drawdown in Well 8 was 3.8 ft of drawdown per log cycle. The Jacob's straight-line method was used to analyze the time-drawdown data and results show a transmissivity of approximately 35,900 gpd/ft (see Figure 9).

The following table summarizes the transmissivity and storativity values obtained from the analysis of the constant rate pumping test data:

Summary of Aquifer Testing - Well 8 (Palomino Site)

Well	Methods	Transmissivity [gpd/ft]	Storativity
Well 8 (Palomino Site)	Jacob's Straight Line Time-Drawdown	35,900	NA

5.0 DESIGN DISCHARGE RATE, TOTAL LIFT AND PUMP SETTING

A maximum pumping rate of 550 gpm is recommended for Well 8. At this rate, short-term pumping of the well (i.e. one day of *continuous* pumping) is expected to result in 24 ft of drawdown with a total lift to land surface of 64 ft. The long-term drawdown (extrapolated to one year of *continuous* pumping) was estimated to be 39 ft with a total lift to ground surface of 79 ft. At a discharge rate of 550 gpm, the specific capacity of Well 8 will be approximately 23 gpm/ft with a well efficiency of 69 percent (see Figure 8).

It is recommended that the pump bowls be set at a depth of 370 ft bgs, which is located in the sump (360 to 380 ft bgs).

The following table summarizes the recommended design:

Recommended Design -Well 8

Parameters	Short Term (1 day)	Long Term (1 year)*
Design Pumping Rate	550 gpm	550 gpm
Pump Setting	370 ft bgs	370 ft bgs
Design Well Efficiency	69 %	NA
Design Drawdown	24 ft	39 ft
Static Water Level Depth	40 ft bgs	40 ft bgs
Regional Decline	20 ft	20 ft
Total Lift to Surface	84 ft	99 ft

* Extrapolated using water level data from the step drawdown and constant rate pumping tests.

6.0 GROUND WATER QUALITY

Water samples were collected 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 contained on Figure 10 and in Appendix G.

The total dissolved solids (TDS) value of the sample collected from the completed well was 360 mg/L. This amount is well below the California EPA recommended drinking water standard of 500 mg/L. Fluoride was detected in the completed well at a concentration of 0.64 mg/L. However, this concentration is below the California Department of Health Services Primary Maximum Contaminant Level. All other constituents were reported below their specified MCLs.

The results are summarized in the following table:

Completed Well Title 22 Water Quality Analytical Data

		Analysis Result	Drinking Water Standards
Color	[color unit]	< 3	15 ¹
Odor	[odor unit]	1	3 ¹
Arsenic	[mg/L]	0.0034	0.050 ^{2,3}
Fluoride (Total)	[mg/L]	0.64	2.0 ²
Iron	[mg/L]	0.22	0.3 ¹
Manganese	[mg/L]	0.029	0.05 ¹
Nitrate (as NO ₃)	[mg/L]	<2	45 ²
Total Dissolved Solids, TDS	[mg/L]	360	500-1,000 ¹

¹ California DHS Secondary Maximum Contaminant Levels.

² California Department of Health Services (DHS) Primary Maximum Contaminant Levels.

³ In January 2006 the MCL for arsenic will be reduced to 0.01 mg/L.

7.0 REFERENCES

- American Society for Testing and Materials, 1994. ASTM Standards on Ground Water and Vadose Zone Investigations. 2nd Edition.
- Cooper, H. H., Jr. and Jacob, C. E., 1946. A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History. Transactions, American Geophysical Union, Vol. 27, No. 4.
- Jacob, C. E., 1950. Engineering Hydraulics. J. Wiley and Sons, New York.

THIS REPORT IS RENDERED TO BIG BEAR CITY COMMUNITY SERVICES DISTRICT AS OF THE DATE HEREOF, SOLELY FOR THEIR BENEFIT IN CONNECTION WITH ITS STATED PURPOSE AND MAY NOT BE RELIED ON BY ANY OTHER PERSON OR ENTITY OR BY THEM IN ANY OTHER CONTEXT. ALL CALCULATIONS WERE PERFORMED USING ACCEPTED PROFESSIONAL STANDARDS.

AS DATA IS UPDATED FROM TIME TO TIME, ANY RELIANCE ON THIS REPORT AT A FUTURE DATE SHOULD TAKE INTO ACCOUNT UPDATED DATA.

CONTENTS

1.0	EXECUTIVE SUMMARY.....	1
2.0	INTRODUCTION.....	5
2.1	Background.....	5
2.2	Purpose and Scope	5
2.3	General Geohydrology of the Well Site.....	5
3.0	WELL CONSTRUCTION.....	7
3.1	Conductor Casing Installation and Pilot Borehole Drilling.....	7
3.2	Geophysical Borehole Logging and Aquifer Zone Testing.....	7
3.3	Aquifer Zone Testing for Yield and Water Quality.....	8
3.3.1	Aquifer Zone Testing Procedure	9
3.3.2	Results of the Aquifer Zone Testing	11
3.4	Casing and Screen Design.....	13
3.5	Filter Pack and Annular Seal	13
3.6	Well Development	14
3.7	Spinner (Flowmeter) Survey.....	15
3.8	Plumbness and Alignment Survey	15
3.9	Downhole Video Survey.....	16
3.10	WELL COMPLETION REPORT	16

CONTENTS

(Contents)

4.0	PUMPING TEST ANALYSIS PROCEDURES AND RESULTS.....	17
4.1	Data Collection	17
4.2	Basic Assumptions Used in Analysis of Pumping Test Data	17
4.3	Pumping Test Data Analysis Methods.....	18
4.3.1	Step Drawdown Test Method.....	18
4.3.2	Constant Rate Test Method	20
4.3.2.1	Jacob's Straight-Line (Modified Theis Non-Equilibrium) Method	21
4.4	Pumping Test Data Analysis and Results for Well 8.....	22
4.4.1	Step Drawdown Pumping Test.....	22
4.4.2	Constant Rate Pumping Test.....	23
5.0	DESIGN DISCHARGE RATE, TOTAL LIFT AND PUMP SETTING.....	24
6.0	GROUND WATER QUALITY	25

FIGURES, TABLES, APPENDICES

FIGURES

No.	Description
1	General Location - Well 8 (Palomino Site)
2	Technical Cross Section - Well 8 (Palomino Site)
3	Mechanical Grading Analysis - Composite Plot - Well 8 (Palomino Site)
4	Mechanical Grading Analysis - Tacna Sand and Gravel 1/4 x 16 Filter Pack - Well 8 (Palomino Site)
5	Plumbness and Alignment Survey Plot - Well 8 (Palomino Site)
6	Step Drawdown Test - Well 8 (Palomino Site)
7	Specific Drawdown Plot - Well 8 (Palomino Site)
8	Specific Capacity and Well Efficiency Diagram - Well 8 (Palomino Site)
9	24-Hour Constant Rate Pumping Test - Well 8 (Palomino Site)
10	Trilinear Diagram - Aquifer Zone Test and Completed Water Quality Data - Well 8 (Palomino Site)

TABLES

No.	Description
1	Summary of Well Construction Details - Well 8 (Palomino Site)
2	Plumbness and Alignment Survey Data - Well 8 (Palomino Site)
3	Well Design Parameters and Recommended Filter Pack - Well 8 (Palomino Site)

APPENDICES

No.	Description
A	Chronology of Construction - Well 8 (Palomino Site)
B	Lithologic Log - Well 8 (Palomino Site)
C	Geophysical Borehole Logs - Well 8 (Palomino Site)
D	Contractor's Development Notes - Well 8 (Palomino Site)
E	Well Completion Report - Well 8 (Palomino Site)
F	Pumping Test Data - Well 8 (Palomino Site)
G	Water Quality Data - Well 8 (Palomino Site)