

**Well 9 (Greenway Park Site)
Results of Drilling, Construction,
Development and Testing**

Big Bear City Community Services District

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WELL 9 (GREENWAY PARK SITE)
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**BIG BEAR CITY COMMUNITY SERVICES DISTRICT
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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 9, is located 850 feet (ft) north of State Highway 38 and 170 ft east of Greenway Drive in Big Bear City, an unincorporated community in San Bernardino County, California. The pilot borehole of Well 9 was drilled as an exploratory borehole (BH-1) in which zone testing was performed to evaluate water quality and quantity prior to making the decision to complete the well.

Well 9 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 50 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 bgs. The 17 1/2-inch diameter pilot borehole was drilled to a total depth of 1,190 ft bgs. Alluvial materials penetrated during pilot borehole drilling consisted primarily of varying amounts of fine- to coarse-grained gravel, fine- to coarse-grained sand, and interbedded layers of silt and clay. Weathered bedrock may have been encountered during the drilling of the pilot borehole at a depth of 1,190 ft bgs. Geophysical borehole logs were then run in the open pilot borehole by Welenco, Inc. of Bakersfield, California and four isolated aquifer zone tests were performed. Selection of the intervals for isolated aquifer zone testing was based upon examination of the formation samples

and analysis of the geophysical borehole logs. During isolated aquifer zone testing, water samples were collected and submitted to Clinical Laboratory of San Bernardino, Inc. (located in Grand Terrace, California) for general physical and general mineral analyses. The pilot borehole was then backfilled to the conductor casing (from the top of Zone 1 to 50 ft bgs) using filter pack material, before moving the drilling rig to another site while the results of the zone testing were being evaluated.

During late May 2003, the drilling rig returned to the Greenway Park Site. The pilot borehole (that had been backfilled) was cleaned out before being reamed to a diameter of 22 inches from 50 to 556 ft bgs. Well 9 was completed to a total depth of 536 ft bgs using 12 1/4-inch inside diameter (ID) copper-bearing steel casing and horizontal louvered well screen. (A total of 634 ft of the 17 1/2-inch diameter pilot hole (from 556 to 1,190 ft bgs) was backfilled with materials placed during zone testing.) Well screen consisting of 12 1/4-inch ID by 1/4-inch wall copper-bearing steel Ful-Flo horizontal louvers with 0.060-inch openings was installed from 200 to 362 ft bgs, and from 470 to 516 ft bgs. Blank well casing consisting of 12 1/4-inch ID by 1/4-inch wall copper-bearing steel was installed from the ground surface to 200 ft bgs, from 362 to 470 ft bgs, and from 516 to 536 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 208 ft of well screen and 328 ft of blank casing were installed, for a total well depth of 536 ft.

A custom blend of Tacna Sand and Gravel (Yuma, Arizona) 1/4 inch x 16 filter pack material was installed from 556 to 103 ft bgs in the annular space between the 22-inch diameter borehole and the 12 1/4-inch ID well casing. A layer of fine sand was installed on top of the filter pack material from 103 to 100 ft bgs to prevent cement from invading the top of the filter pack. An annular seal consisting of a 10.5-sack sand-cement mixture was pumped through a tremie pipe from a depth of 100 ft bgs to the ground surface, and acts as a deep annular seal for the well.

Based on pumping tests, the recommended discharge rate for the well is approximately 180 gallons per minute (gpm). Short-term pumping of this well (i.e. one day of *continuous*

pumping) is expected to result in approximately 76 ft of drawdown and a specific capacity of approximately 2 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 138 ft of drawdown.

Calculations using the information obtained from the step drawdown and 24-hour constant rate pumping tests indicate a well efficiency of 70 percent. Calculations using the recovery data indicate an aquifer transmissivity of approximately 1,960 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 9 are as follows:

Recommended Pump Design – Well 9 (Greenway Park Site)

Parameters	Short-term (1 day)	Long-term (1 year)¹
Design Pumping Rate	180 gpm	180 gpm
Pump Setting	380 ft bgs	380 ft bgs
Design Well Efficiency	70 Percent	N/A
Static Water Level Depth	81 ft bgs	81 ft bgs
Design Drawdown	76 ft	138 ft
Regional Decline in Static Water Level	50 ft	50 ft
Total Lift to Surface (Including regional decline in static water level)	207 ft	269 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 208 gpm), water samples were collected from the completed well by GEOSCIENCE personnel for Title 22 water quality analysis. Clinical Laboratory of San Bernardino, Inc., located in Grand Terrace, California, performed these analyses. The laboratory reported a total dissolved solids (TDS) value of 180 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. The

fluoride concentration in the completed well was 0.68 mg/L, which is well below the California DHS Primary Maximum Contaminant Level (MCL) of 2.0 mg/L.

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 July 24, 2003 to measure the verticality of the well. Results showed a deviation at 380 ft bgs (i.e., the recommended pump setting) of 2.4 inches in the North-South plane and 8.9 inches in the East-West plane. The maximum deviation in the North-South plane was 2.9 inches, occurring at 300 ft bgs, and the maximum deviation on the East-West plane was 16.3 inches occurring at a depth of 536 ft bgs, both within the allowable limits per the technical specifications of 6 inches per 100 ft.

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, and some sediment was observed upon the edges of the louvers. The sediment build-up 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-1) 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 9, is located 850 ft north of State Highway 38 and 170 ft east of Greenway Drive 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 9. 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 9 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 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; it is found underlying the Recent alluvium.

Weathered bedrock may have been encountered during the drilling of the pilot borehole at a depth of 1,190 ft bgs; however, the geophysical borehole logs did not indicate competent bedrock. During final testing, the depth of the static water level in Well 9 was measured at approximately 81 ft bgs.

3.0 WELL CONSTRUCTION

The drilling contractor for Well 9 was Bakersfield Well & Pump Company of Bakersfield, California. Drilling and construction of the well began on January 29, 2003, with the installation of the conductor casing. Pilot borehole drilling and isolated aquifer zone testing were performed during March and April 2003. On April 29, 2003, the borehole was backfilled to the conductor casing and the drilling rig was moved to another site. Following recommendation to complete the well, the drilling rig returned to the site during late May 2003 and began the reaming pass. Development and testing was completed on July 9, 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 bgs using a bucket auger drilling rig. The 26-inch OD by 5/16-inch wall steel conductor casing was installed to 50 ft bgs and was 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 March 11, 2003, and advanced to a final depth of 1,190 ft by March 21, 2003.

Formation materials encountered during pilot borehole drilling consisted primarily of varying amounts of fine- to coarse-grained gravel, fine- to coarse-grained sand, and interbedded layers of silt and clay. Weathered bedrock may have been encountered during the drilling of the pilot borehole at a depth of 1,190 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 1,190 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 was then run by Welenco, Inc. on March 21, 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 June 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 intake of the pump had been placed near the bottom of the well and would not allow sufficient room 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 (930 to 950 ft), Zone 2 (699 to 719 ft), Zone 3 (310 to 330 ft), and Zone 4 (200 to 220 ft) and submitted to a laboratory for water quality analyses including general physical and general mineral properties. Clinical Laboratory of San Bernardino, Inc., located in Grand Terrace, California performed the 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 If the seal was determined not to 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.

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 are 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.

Isolated Aquifer Zone Testing Results
Discharge and Geochemical Parameters Measured at the Time of Sampling

Zone No.	Depth of Zone [ft, bgs]	Static Ground Water Level [ft, bgs]	Pumping Ground Water Level [ft, bgs]	Average Discharge Rate [gpm]	Field TDS [mg/L]	Field pH [units]	Field Water Temp. [°C]
1	930-950	38.0*	267.2	50	210	8.2	19.5
2	699-719	82	328.1	37	130	8.9	18.5
3	310-330	74.8	172.6	50	130	8.2	14.5
4	200-220	68	132.7	50	170	7.6	14.5

* The static water level in Zone 1 may not be the true static water level as a large volume of water was injected during construction of the zone test.

At the end of continuous pumping, samples were collected from Zones 2, 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.

The isolated aquifer zone test procedure is summarized below:

1. The 17 1/2-inch diameter pilot borehole was backfilled to approximately 10 ft below the zone to be tested. A bentonite seal was placed on top of the backfill material.
2. A 20-ft 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 ft 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, each isolated zone was pumped using a submersible pump for several hours at rates ranging from approximately 37 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 Zones 1, 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 TDS concentrations for Zones 1, 2, 3 and 4 ranged from 140 to 250 mg/L, well below the recommended secondary MCL of 500 mg/L. The concentration of fluoride in the ground water sampled from Zones 1 and 2 was 7.0 mg/L and 3.2 mg/L, respectively (well above the MCL of 2.0 mg/L), while Zones 3 and 4 had concentrations of 1.2 and 0.48 mg/L, respectively. The concentration of iron in the ground water sample from Zone 2 was 0.64 mg/L (above the MCL of 0.3 mg/L), while the concentration of iron in Zones 1, 3 and 4 ranged from below the detection level (0.1 mg/L) to 0.19 mg/L. Therefore, it was recommended that the well be completed above Zone 2 to avoid zones with high fluoride. All other water quality results from isolated aquifer zone testing were below their respective MCLs.

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

Water Quality Results from Isolated Aquifer Zone Testing

		Zone				MCL or Action Level
		1	2	3	4	
Depth Interval	[ft]	930-950	699-719	310-330	200-220	
Arsenic	[µg/L]	< 2.0	6.1	< 2.0	< 2.0	50 ^{1,3}
Fluoride	[mg/L]	7.0	3.2	1.2	0.48	2.0 ¹
Iron	[µg/L]	< 100	640	190	< 100	300 ²
Manganese	[µg/L]	< 20	36	< 20	< 20	50 ²
Nitrate (as NO ₃)	[mg/L]	< 2	< 2	2.1	< 2	45 ¹
Total Dissolved Solids (TDS)	[mg/L]	250	150	140	190	500-1,000 ²
Apparent Color (Unfiltered)	[color units]	< 3	< 3	< 3	< 3	15 ²
Lab Turbidity	[NTU]	0.1	0.1	0.2	0.4	NA
Odor Threshold @ 60°C	[TON]	1	1	1	1	3 ²
pH	[std. units]	8.0	8.6	8.2	7.8	6.5-8.5 ²

Shaded cells indicate constituents that are above the current MCLs.

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 50 to 556 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 536 ft bgs.

The casing and screen materials consisted 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 (0.060-inch openings). The screened intervals were placed from 200 to 362 ft bgs, and 470 to 516 ft bgs. Blank copper-bearing steel casing was installed from ground surface to 200 ft bgs, from 362 to 470 ft bgs, and from 516 to 536 ft bgs. An end plate consisting of

1/4-inch thick copper-bearing steel was welded to the lowermost blank section. Figure 2 shows a technical cross section of the well as it was constructed, and Table 1 summarizes the well construction details and materials.

3.5 Filter Pack and Annular Seal

Formation samples from six intervals between 250 and 510 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 0.13 mm to 0.8 mm. Uniformity coefficients² of aquifer materials ranged from approximately 5 to 15 (well graded materials).

A custom blend of Tacna Sand and Gravel (Yuma, Arizona) 1/4 inch x 16 filter pack material was installed from 556 to 103 ft bgs within the annular space between the 22-inch diameter borehole and the 12 1/4-inch ID well casing (see Figure 3). A layer of fine sand was installed on top of the filter pack material from 103 to 100 ft bgs to prevent cement from invading into the top of the filter pack. An annular seal consisting of a 10.5-sack sand cement mixture was pumped through a tremie pipe from a depth of 100 ft bgs to the ground surface, and acts as a deep annular seal for the well. The recommended design for the Tacna Sand and Gravel 1/4 inch 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.

**1/4 inch x 16 Filter Pack Design
Well 9 (Greenway Park Site)**

U.S. Standard Sieve Size	Opening [inches]	Opening [mm]	Cumulative Percent Passing
3/8 inch	0.375	9.53	100
1/4 inch	0.250	6.35	97
4	0.187	4.75	88
8	0.094	2.38	48
10	0.079	2.00	34
12	0.066	1.68	23
16	0.047	1.19	13
20	0.033	0.84	7
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 196 ft. The sounding tube will be used to collect water level measurements while the pump is in the well.

3.6 Well Development

Well 9 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-ft 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 lineshaft test pump from June 24 to July 1, 2003. The pump bowls were set at 380 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 shown 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. Well development was considered complete when the specific capacity (discharge rate divided by drawdown) approached a maximum and the turbidity and sand concentration approached a minimum and remained stable.

During development pumping, a maximum short-term discharge rate of approximately 600 gpm was achieved, although most of the development time was conducted at much lower rates. A total of approximately 60 hours were spent on final development by pumping.

3.7 Spinner (Flowmeter) Survey

A flowmeter (or “spinner”) survey was not conducted as the pump intake was located near the bottom of the well and would not permit a flowmeter tool to pass.

3.8 Alignment Survey

Welenco, Inc. of Bakersfield, California conducted a plumbness and alignment survey on July 24, 2003 to measure the verticality of the well. Results showed a deviation at 380 ft bgs (i.e., the recommended pump setting) of 2.4 inches in the North-South plane and 8.9 inches in the East-West plane (see Figure 4 and Table 3). 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 2.9 inches occurring at 300 ft bgs, and the maximum deviation on the East-West plane was 16.3 inches occurring at a depth of 536 ft bgs. The complete results of the alignment survey are shown in Table 3, and are shown graphically on 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. Although 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 9.

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 July 2, 2003 to determine specific capacity and well efficiency relationships. Following the step drawdown test, a 24-hour constant rate pumping test was conducted on July 7 and July 8, 2003 to obtain data from which to calculate aquifer transmissivity. The constant rate pumping test was followed by recovery measurements on July 8 and July 9, 2003.

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 are 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:

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

where:

$$E = \text{Well Efficiency, [Percent]}$$

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 with the square of the velocity.

- 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 for Well 9

4.4.1 Step Drawdown Pumping Test

A step drawdown test was performed on July 2, 2003 at average discharge rates of 183 gpm, 246 gpm and 322 gpm. The static water level at the beginning of the test was approximately 94 ft bgs. Figure 5 is a chart showing the step drawdown test data with a 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	183	50.66	50.66	0.2768
2	246	26.59	77.25	0.3140
3	322	30.69	107.94	0.3352

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

The specific drawdown chart (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 0.2047 ft/gpm and a well loss coefficient (C) of 0.0004152 ft/gpm².

The specific capacity and well efficiency chart (see Figure 7) shows estimated formation and well losses and well efficiency based on the step drawdown data. 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 180 gpm, the specific capacity of Well 9 is approximately 2 gpm/ft. Design drawdown at 180 gpm was extrapolated from the constant rate pumping test, which was ran at 208 gpm.

The design drawdown (at 180 gpm) is estimated to be 76 ft. This was calculated by extrapolating the drawdown trend line (to remove the influence of fluctuations in the discharge rate during testing) and using the ratio of the design discharge rate to the actual discharge rate measured during the constant rate pumping test⁵.

4.4.2 Constant Rate Pumping Test

Following recovery from the step drawdown test, a 24-hour constant rate pumping test was conducted on June 7, 8, and 9, 2003 (see Figure 8). The static water level at the start of the test was approximately 81 ft bgs, and the average discharge rate was 208 gpm. Water level drawdown in Well 9 was 27 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 2,030 gpd/ft (see Figure 8). Following completion of the 24-hour constant rate pumping test, recovering ground water levels were recorded for approximately 24 hours and these data were analyzed to show an aquifer transmissivity of approximately 1,960 gpd/ft (see Figure 9).

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

Summary of Aquifer Testing – Well 9 (Greenway Park Site)

Method	Transmissivity [gpd/ft]
Jacob's Straight Line Time-Drawdown	2,030
Jacob's Straight Line Time-Drawdown Applied to Recovery	1,960

⁵ The design drawdown at 180 gpm was calculated using the following equation: $88 \text{ ft} \times (180 \text{ gpm} / 208 \text{ gpm}) = 76 \text{ ft}$.

5.0 DESIGN DISCHARGE RATE, TOTAL LIFT AND PUMP SETTING

A maximum pumping rate of 180 gpm is recommended for Well 9. At this rate, short-term pumping of the well (i.e. one day of *continuous* pumping) is expected to result in 76 ft of drawdown with a total lift to land surface of 207 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 138 ft with a total lift to ground surface of 269 ft (which also includes regional decline in static water level). At a discharge rate of 180 gpm, the specific capacity of Well 9 will be approximately 2 gpm/ft. Design drawdown at 180 gpm was extrapolated from the constant rate pumping test, which was run at 208 gpm (See Section 4.4.1, Step Drawdown Pumping Test).

It is recommended that the pump bowls be set at a depth of 380 ft bgs, which is located in the blank casing between the two sections of horizontal louvered well screen (200 to 362 ft bgs, and 470 to 516 ft bgs).

The following table summarizes the recommended pump design:

Recommended Pump Design – Well 9 (Greenway Park Site)

Parameters	Short-term (1 day)	Long-term (1 year)*
Design Pumping Rate	180 gpm	180 gpm
Pump Setting	380 ft bgs	380 ft bgs
Design Well Efficiency	70 Percent	NA
Static Water Level Depth	81 ft bgs	81 ft bgs
Design Drawdown	76 ft	138 ft
Regional Decline in Static Water Level	50 ft	50 ft
Total Lift to Surface Including regional decline in static water level)	207 ft	269 ft

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

6.0 GROUND WATER QUALITY

Water samples were collected on July 8, 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 results from the isolated aquifer zone testing are presented on Figure 10 and in Appendix G.

The TDS value of the sample collected from the completed well was 180 mg/L. This concentration is well below the California Environmental Protection Agency (EPA) recommended drinking water standard of 500 mg/L. Fluoride was detected in the completed well at a concentration of 0.68 mg/L, which is below the California DHS Primary MCL of 2.0 mg/L. 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

		Analytical Result	Drinking Water Standards
Arsenic	[µg/L]	< 2.0	50 ^{1,3}
Fluoride (Total)	[mg/L]	0.68	2.0 ¹
Iron	[µg/L]	< 100	300 ²
Manganese	[µg/L]	< 20	50 ²
Nitrate (as NO₃)	[mg/L]	< 2.0	45 ¹
Total Dissolved Solids, TDS	[mg/L]	180	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]	7.5	6.5 - 8.5 ²

ND signifies that the constituent was not detected or the 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 0.010 mg/L (10 µg/L).

7.0 REFERENCES

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Jacob, C. E., 1950. Engineering Hydraulics. J. Wiley and Sons, New York.