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**RESULTS OF DRILLING AND TESTING
BIG BEAR VALLEY GROUND WATER EXPLORATION PROGRAM**

CONTENTS

1.0	EXECUTIVE SUMMARY	1
2.0	INTRODUCTION.....	5
2.1	Background	5
2.2	Purpose and Scope.....	5
2.3	Test Borehole/Monitoring Well Locations	6
3.0	GEOHYDROLOGIC SETTING.....	7
3.1	Geology.....	7
3.1.1	Bedrock Complex	8
3.1.2	Alluvium.....	8
3.2	Ground Water Occurrence and Flow	9
3.3	Ground Water Quality	9
4.0	DRILLING, TESTING, AND MONITORING WELL INSTALLATION	11
4.1	Borehole Drilling and Soil Sampling	11
4.2	Video Logging.....	12
4.3	Geophysical Logging.....	12

4.4	Monitoring Well Construction	12
4.4.1	Casing and Screen	13
4.4.2	Filter Pack and Annular Seal	13
4.4.3	Surface Completion.....	14
4.4.4	Development	14
4.4.5	Aquifer Testing	14
4.4.6	Analysis of Constant Rate Pumping Test Data.....	15
4.4.6.1	Theis Equation	16
4.4.6.2	Jacob’s Straight-Line (Modified Theis Non-Equilibrium) Method.....	17
4.4.7	Water Quality Sampling	18
5.0	FINDINGS.....	19
5.1	Cherokee Site	19
5.1.1	Borehole Lithology	19
5.1.2	Aquifer Testing Results.....	19
5.1.3	Ground Water Quality.....	20
5.2	Magnolia Site	22
5.2.1	Borehole Lithology	22
5.2.2	Aquifer Testing Results.....	22
5.2.3	Ground Water Quality.....	23
6.0	CONCLUSIONS AND RECOMMENDATIONS.....	26
6.1	Cherokee Site	26
6.1.1	Conclusions From Drilling and Testing Of The Cherokee Borehole	26
6.1.2	Recommendations for the Cherokee Site	27
6.2	Magnolia Site	28
6.2.1	Conclusions From Drilling and Testing At The Magnolia Site.....	28
6.2.2	Recommendations for the Magnolia Site	30

7.0	REFERENCES.....	31
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FIGURES, APPENDICES

FIGURES

No.	Description
1	General Location of 2004 Test Drilling Sites
2	Location of Cherokee Test Borehole
3	Location of Magnolia Monitoring Well
4	Geologic Setting – Big Bear Lake and Baldwin Lake Watersheds
5	Magnolia Monitoring Well Technical Cross Section
6	Step Drawdown Test – Cherokee Borehole
7	Constant Rate Pumping Test – Cherokee Borehole
8	Trilinear Diagram – Water Quality Data for Cherokee Site
9	Step Drawdown Test – BBDWP Magnolia Monitoring Well
10	24-Hour Constant Rate Pumping Test – BBDWP Magnolia Monitoring Well
11	Trilinear Diagram – Water Quality for Magnolia Site

APPENDICES

Ltr.	Description
A	Lithologic Logs
B	Geophysical Borehole Logs
C	Water Quality Laboratory Reports
D	Pumping Test Data – Cherokee Borehole
E	Pumping Test Data – Magnolia Monitoring Well

RESULTS OF DRILLING AND TESTING

BIG BEAR VALLEY GROUND WATER EXPLORATION PROGRAM – 2004

1.0 EXECUTIVE SUMMARY

As part of an ongoing evaluation of potential production well sites within the service area of the City of Big Bear Lake Department of Water and Power (BBDWP), GEOSCIENCE conducted detailed test drilling investigations of two (2) sites within the Big Bear Lake and Baldwin Lake watersheds. The purpose of the test drilling program was to collect detailed, site-specific geohydrologic data (including lithology, ground water quality, and ground water yield) at sites within the Big Bear Lake and Baldwin Lake watersheds that would enable a more informed evaluation of their ground water production potential. The first site is located near Cherokee Avenue in the Fawnskin area of the Grout Creek Hydrologic Subunit (Cherokee Site¹). The second site is located near the corner of Magnolia and Sunset Lane in the Sugarloaf area (Magnolia Site).

¹ Test drilling locations were named based on the primary street adjacent to the site.

Summary of Borehole and Monitoring Well Details

Borehole/Monitoring Well Name	Borehole Depth [ft bgs]	Casing Depth [ft bgs]	Casing Diameter [inches]	Screened Interval [ft bgs]	Depth to Ground Water [ft bgs]
Cherokee	605	N/A ¹	N/A ¹	N/A ¹	17 ^{2,3}
Magnolia	1,140	720	4 Inch Sch. 40	300-700	292 ³

¹ Not Applicable.

² Depth to ground water measured in the open borehole.

³ Depth to ground water was measured on 22-Nov-04 (Cherokee Borehole) and 7-Feb-05 (Magnolia Monitoring Well) prior to the beginning of the constant rate pumping tests.

The Cherokee Borehole was drilled and tested between 11-Nov-04 and 24-Nov-04 using an air rotary/casing hammer drilling rig operated by WDC Exploration and Wells of Montclair California (WDC). Drilling of the borehole included installation of a 10-inch outside diameter (O.D.) steel casing from ground surface to 56 feet below ground surface (ft bgs), approximately 3 ft into granitic bedrock. Below this depth the borehole was drilled to approximately 605 ft bgs using an 8-inch diameter bit. Upon reaching the total depth of the borehole, a directional video survey was conducted to determine bedrock fracture orientation and borehole stability. From this survey, the borehole was determined to be stable and subsequent pumping tests were conducted in the unlined borehole.

The Magnolia borehole/monitoring well was drilled and tested by WDC between 30-Nov-04 and 8-Feb-05. Drilling was conducted in two passes using the direct mud rotary drilling method. The first borehole pass was drilled to a total depth of 1,140 ft bgs using an 8-inch diameter bit. The borehole was enlarged to 12 ¼-inch diameter to a total depth of 730 ft bgs during the second pass and subsequently completed as a 4-inch diameter monitoring well with perforations between 300 and 700 ft bgs. Upon completion, the Magnolia monitoring well was developed through a process of airlifting, swabbing and pumping.

The primary aquifer system that is available for municipal supply at the Cherokee Site occurs within the fractured granitic bedrock, which was encountered approximately 53 ft bgs during drilling of the Cherokee Borehole. Notable fractures were observed in the borehole video log at depths of approximately 170, 245 to 247, 260, 274, 410 to 412, 419 to 420, 423 to 424, 460 to 461, and 578 to 579 ft bgs. Ground water discharge during drilling of the borehole increased substantially at a depth of approximately 460 ft bgs and steadily increased with drilling depth. Few open fractures were observed below a depth of approximately 579 ft bgs in the video log. The total depth of the borehole is 605 ft bgs.

Based on the borehole and geophysical log data collected from the borehole at the Magnolia Site, the most promising aquifer material beneath the site occurs between the ground water surface (located approximately 290 ft bgs) and approximately 700 ft bgs. Aquifer sediments in this interval consist primarily of sand and gravel with only minor amounts of silt. Silt and clay content substantially increases below 700 ft bgs with only a few thin potentially permeable layers identified on the geophysical resistivity log below this depth. Dense bedrock was encountered at a depth of approximately 1,120 ft bgs. Given the fine-grained nature of the sediments between 700 ft and bedrock, it is unlikely that they would yield significant quantities of water to a well perforated through them. Based on the data collected from the borehole and geophysical logs, it was decided to construct the Magnolia Monitoring Well with perforations within the aquifer sediments between 300 and 700 ft bgs.

Aquifer pumping tests were conducted in both the uncased Cherokee Borehole and the Magnolia Monitoring Well to assess potential well yield at each site. Tests included both step draw down and constant rate pumping tests. The pumping tests at the Cherokee Site were conducted within the unlined 8-inch diameter borehole. The pumping tests at the Magnolia Site were conducted within the 4-inch diameter monitoring well. Following aquifer testing water quality samples were collected from both sites and submitted to a State of California certified laboratory for water quality analysis including general mineral, general physical, and selected inorganic analysis.

The data collected from the drilling and testing of the Cherokee Borehole indicates that this site is a good candidate for a future production well in the Grout Creek Subunit. Pumping tests within the Cherokee Borehole show that the aquifer system within the fractured bedrock at this site can sustain yields of 60 gpm for approximately 46.5 hours with 197 ft of drawdown. The specific capacity of the 8-inch diameter borehole at the end of the pumping test was 0.3 gpm/ft. The instantaneous discharge rate of the Cherokee Borehole is higher than any other well constructed within the granitic bedrock in the Grout Creek Subunit to date. The water quality of the ground water produced from the Cherokee Borehole during the pumping test is very good and would be suitable for municipal supply although high pH values measured in the pumped water should be confirmed through future testing.

The data collected from the drilling and testing of the Magnolia Monitoring Well indicates that this site is also a good candidate for a future production well. Pumping test parameters of transmissivity and specific capacity show that the aquifer will yield a significant quantity of water to a well constructed through them. Analysis of ground water quality samples, which included the principal constituents of concern for the Big Bear Valley (fluoride, arsenic, manganese, iron, etc.) showed no detections exceeding regulatory standards. Based on the pumping test data, a well at the Magnolia Site would be expected to have a higher yield than many of the other existing wells in the BBDWP system and is considered a favorable production well site.

2.0 INTRODUCTION

2.1 Background

As part of an ongoing evaluation of potential production well sites within the BBDWP's service area, GEOSCIENCE conducted detailed test drilling investigations of two (2) sites within the Big Bear Lake and Baldwin Lake watersheds (see Figure 1). The first site, designated as the Cherokee Site, is located in the Grout Creek Hydrologic Subunit in the town of Fawnskin (see Figure 2). The second site, designated as the Magnolia Site, is located in the West Baldwin Hydrologic Subunit in the town of Sugarloaf (see Figure 3).

2.2 Purpose and Scope

The purpose of the test drilling program was to collect detailed, site-specific geohydrologic data (including lithology, ground water quality, and ground water yield) at sites within the Big Bear Lake and Baldwin Lake watersheds that would enable a more informed evaluation of their ground water production potential. Data collected during the test drilling program included detailed lithologic descriptions from samples collected every 5 ft during drilling, water quality and yield, and geophysical/video logs. A monitoring well was constructed at the Magnolia Site.

The purpose of this report is to summarize the results of the drilling and testing of the two test boreholes and provide construction details for the monitoring well. Included in this report are:

- A description of the drilling, sampling, and testing program,
- Summaries of the lithologic, water quality, and aquifer yield data,
- Lithologic and geophysical logs for each borehole,
- As-built diagram for the Magnolia monitoring well,
- Water quality laboratory reports, and
- Recommended sites for future production wells.

2.3 Test Borehole/Monitoring Well Locations

The test boreholes/monitoring wells are located as shown on Figures 2 and 3 and described as follows:

- Cherokee (Grout Creek Subunit) – Located on private property adjacent to Cherokee Street approximately 50 ft south of Highway 38 (see Figure 2).
- Magnolia (West Baldwin Subunit) – Located on Magnolia Lane between Sunset Lane and Wabash Avenue (see Figure 3).

3.0 GEOHYDROLOGIC SETTING

Big Bear Valley is located within the San Bernardino Mountains of the eastern Transverse Ranges Geomorphic Province of Southern California (see Figure 1). The valley has been divided into two major watersheds: Big Bear Lake watershed at the west end of the valley and Baldwin Lake watershed at the east end of the valley (see Figure 1). The Big Bear Lake watershed has been further subdivided into seven Hydrologic Subunits: Gray's Landing, Grout Creek, North Shore, Division, Rathbone, Village, and Mill Creek. The Baldwin Lake watershed has been subdivided into four Hydrologic Subunits: Van Dusen, West Baldwin, East Baldwin, and Erwin. The subunits are delineated based on surface water drainage divides.

3.1 Geology

The San Bernardino Mountains formed as a result of uplift along a complex system of faults, including the San Andreas Fault System, which separates the San Bernardino Mountains from the neighboring San Gabriel Mountains to the west. The San Bernardino Mountains consist primarily of Mesozoic granitic intrusive rocks with lesser amounts of Precambrian and Late Paleozoic metamorphic rock (see Figure 4).

Faulting is a key aspect of the geologic history of the Big Bear Valley and numerous known and postulated faults have been identified in the area. Sadler (1982) identified numerous faults through surface geological mapping (see Figure 4). Additional faults likely exist that have not been previously mapped because they are concealed by alluvium. Evaluation of air photos and topographic maps show linear topographic features that trend in a northwest/southeast direction throughout the valley (e.g. Grout Creek and Van Dusen Canyon). These features may be fault-related.

Criteria for siting the Cherokee Borehole included consideration of its proximity to the linear topographic low that defines the Grout Creek drainage. If this feature were fault-related, a zone of fractured bedrock could occur on either side of the fault that may be permeable enough to yield ground water to a well constructed within it. The Cherokee Borehole was sited approximately 100 ft from the Grout Creek drainage in an attempt to explore any potential fracture zones that could occur in this area.

3.1.1 Bedrock Complex

Precambrian bedrock in the Big Bear Lake area consists predominantly of Baldwin Gneiss and Late Precambrian quartzite, referred to as the Saragossa Quartzite, outcrops of which are located in the Lake Williams area of the Erwin Subunit. Paleozoic rocks consist of Cambrian and uppermost Precambrian meta-sedimentary rocks comprised of crystalline limestone and marble. These rocks outcrop in the Bertha Ridge area northwest of Big Bear City Airport, in the Bear Mountain Ski area (formerly known as the Gold Mine Ski area) southwest of Moonridge, and northeast of Baldwin Lake (see Figure 4). Mesozoic intrusive rocks in the area are comprised primarily of quartz monzonite and quartz diorite and can be found to the south, southwest, west, and northwest of Big Bear Lake, including the area around the Cherokee Borehole site in the Grout Creek Subunit.

3.1.2 Alluvium

Alluvial deposits in the Big Bear Valley area include three general groups: Pleistocene to Recent Lake and Meadow deposits (Qal), Pleistocene to Recent alluvium and colluvium (Qaa), and Pleistocene Older surficial deposits (Qof). Most of the ground water produced for municipal supply in the Big Bear Valley is from the Qaa and Qof sediments.

3.2 Ground Water Occurrence and Flow

Ground water in the Big Bear Lake and Baldwin Lake watersheds generally occurs in the unconsolidated alluvial deposits on the lower slopes of the surrounding mountains and in the valley and in the secondary porosity features (i.e. cracks and fissures) in the bedrock. Ground water flows by gravity drainage from areas of high elevation (the mountain slopes) into areas of low elevation, ultimately collecting in the sediments beneath Big Bear Lake and Baldwin Lake.

Ground water within the alluvium occurs at depths ranging from less than 10 ft bgs near Big Bear and Baldwin Lakes to more than 350 ft bgs in the southern portions of the Division and West Baldwin subunits. Recharge to the ground water occurs from deep percolation of runoff within individual drainages during periods of extended runoff, near the contact between the bedrock and alluvium and, to a lesser extent, as percolation of precipitation directly on the alluvium.

3.3 Ground Water Quality

Ground water quality in the Big Bear Valley area varies from hydrologic subunit to hydrologic subunit and with depth in the aquifer system. In general, total dissolved solids (TDS) concentrations in ground water from municipal wells range from approximately 95 milligrams per liter (mg/L) in the Northshore wells (Grout Creek Subunit) to approximately 400 mg/L in the Sand Canyon well (Rathbone Subunit). The highest TDS concentrations (700 mg/L) have been detected in the Mill Creek Subunit as part of an investigation done by GEOSCIENCE (2004). With a few exceptions, the TDS concentrations generally decrease with depth in the aquifer system, suggesting possible degradation of shallow ground water from overlying land use.

Ground water quality constituents that have been detected above regulatory requirements in the Big Bear Valley include naturally occurring fluoride, iron, manganese, and arsenic. Fluoride has

been detected throughout the Big Bear Valley and, in some cases, concentrations exceed the maximum contaminant level (MCL) for this constituent (2 mg/L). Fluoride concentrations are generally higher in the deepest portions of the aquifer system. Iron and manganese have also been detected throughout the Big Bear Valley with concentrations exceeding their respective MCLs in wells in the Village Subunit, northern Division Subunit (Division wells), and East Baldwin Subunit. Arsenic concentrations in excess of the proposed MCL (10 micrograms per liter; µg/L) have been detected in the deepest portions of the aquifer system in the Mill Creek Subunit in the vicinity of the Canvasback monitoring well.

4.0 DRILLING, TESTING, AND MONITORING WELL INSTALLATION

The two boreholes were drilled and tested by WDC Exploration and Wells of Montclair, California. Drilling began on November 11, 2004 at the Cherokee Site and was completed on February 8, 2005 at the Magnolia Site. A summary of boreholes and monitoring well details is shown in the following table:

Summary of Borehole and Monitoring Well Details

Borehole/Monitoring Well Name	Borehole Depth [ft bgs]	Casing Depth [ft bgs]	Casing Diameter [inches]	Screened Interval [ft bgs]	Depth to Ground Water [ft bgs]
Cherokee	605	N/A ¹	N/A ¹	N/A ¹	17 ^{2,3}
Magnolia	1,140	720	4 Inch Sch. 40	300-700	292 ³

¹ Not Applicable.

² Depth to ground water measured in the open borehole.

³ Depth to ground water was measured on 22-Nov-04 (Cherokee Borehole) and 7-Feb-05 (Magnolia Monitoring Well) prior to the beginning of the constant rate pumping tests.

4.1 Borehole Drilling and Soil Sampling

Two different drilling methods were employed for the drilling of the Cherokee and Magnolia boreholes. At the Cherokee Site, an 8-inch diameter air hammer bit was used for drilling in the granitic bedrock encountered below approximately 53 ft bgs. The Magnolia borehole was drilled using the direct mud rotary method with an 8-inch diameter mill tooth bit. At both sites, formation samples were collected at 5 ft intervals, placed in plastic Ziploc[®] bags, and properly labeled with the client name, borehole designation, and depth interval from which the soil sample

was collected. The lithologic composition of each sample was logged in the field in accordance with the Unified Soil Classification System (USBR 5005-86). Detailed lithologic logs for each borehole are contained in Appendix A.

4.2 Video Logging

Upon reaching the final depth of 605 ft bgs at the Cherokee Site, Welenco, Inc. of Bakersfield, California conducted a downhole directional video survey to assess the degree of bedrock fracturing and fracture orientation within the borehole. The video survey also provided an indication of the plumbness and stability of the borehole for accommodating a pump for testing.

4.3 Geophysical Logging

At the Magnolia Site, Pacific Surveys of Claremont, California obtained geophysical logs from the initial 1,140 ft deep exploratory borehole. The following sets of geophysical logs were run:

- (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.

Copies of the geophysical logs for the borehole are provided in Appendix B.

4.4 Monitoring Well Construction

Upon completion and analysis of the borehole lithologic and geophysical logs, the BBDWP approved construction of a monitoring well at the Magnolia Site to enable aquifer testing and

provide ongoing ground water level monitoring in an area with no previous monitoring wells. A technical cross section of the well as constructed is shown on Figure 5.

The borehole at the Cherokee Site was not completed as a well because the video log indicated the borehole walls were sufficiently stable to accommodate a test pump without the need for a casing liner. Furthermore, GEOSCIENCE recommended that any future production well at this site be constructed by modifying (i.e. enlarging) the original borehole to ensure that the ground water yield would be similar in the production well as the test borehole. Completion of the test borehole as a monitoring well would necessitate locating the production well away from the original drilling location with a corresponding risk of missing the original fracture system supplying water to the test borehole.

4.4.1 Casing and Screen

Casing and screen used in the construction of the Magnolia Monitoring Well consisted of 4-inch diameter Schedule 40 mild steel (see Figure 5). The casing and screen was installed within the 12 ¼-inch diameter reamed borehole to a total depth of 720 ft bgs. The perforated interval of the well casing extended from 300 to 700 ft bgs and consisted of 0.050-inch vertical mill slots. The lowermost portion of the casing string was constructed with a 20 ft blank section of casing fitted with an end cap to serve as sediment traps below the screened interval.

4.4.2 Filter Pack and Annular Seal

The annular space between the well perforations and borehole wall of the Magnolia Monitoring Well was backfilled with a filter pack consisting of Tacna Sand and Gravel 8 x 20 sand (see Figure 5). Filter pack sand was placed in the annulus from the total depth to approximately 200 ft bgs (100 ft above the top of the perforated interval) by pumping through a tremie pipe

using clear water and/or thinned drilling fluid as a circulating medium. The remaining annulus was backfilled with an annular seal, consisting of cement slurry, which was pumped through a tremie pipe from the top of the uppermost filter pack (200 ft bgs) to the ground surface.

4.4.3 Surface Completion

The Magnolia Monitoring Well was completed with a 12-inch diameter, traffic rated flush mounted well box with a lockable cover (see Figure 5). The protective cover was cemented into place around the well.

4.4.4 Development

The Magnolia Monitoring Well was initially developed by open-ended airlifting to remove any suspended material. The perforated portions of the well were then swabbed while airlifting to remove any colloidal and fine-grained sediments from within the well, filter pack, and near well zone. After swabbing and airlifting the entire screened portion of the well, a dispersing agent (NW220) was added to the well to assist in breaking down and removing drilling mud from the well and near-well zone. Final development was conducted using both a 3-inch diameter submersible pump, and later, a 4-inch submersible pump operating at approximately 6 and 30 gallons per minute (gpm), respectively. A total of 7,392 gallons of ground water was removed from the well during development.

4.4.5 Aquifer Testing

Upon the completion of monitoring well development at the Magnolia Site and upon completion of the video logging at the Cherokee Site, aquifer tests were performed at both sites. The aquifer tests consisted of a variable rate (step) pumping test and a constant rate pumping test at each site.

The step pumping test involves pumping the well/borehole at three progressively increasing pumping rates to assess an optimum pumping rate for the constant rate test and determine the efficiency of the well. Constant rate tests were conducted in the Cherokee Borehole and Magnolia Monitoring Well to assess potential well yield and facilitate collection of representative ground water samples for water quality analysis. The field procedure for all pumping tests followed the American Society for Testing and Materials (ASTM, 1994), Standard Test Method D 4050.

During pumping tests, the pumping ground water level, discharge rate, and sand content of the pumping well/borehole were closely monitored. Ground water levels were measured in the pumping well/borehole at regular intervals using a manual electric well sounder. The discharge rate was monitored using an inline instantaneous flow meter with a sensitivity of 0.1 gpm.

4.4.6 Analysis of Constant Rate Pumping Test Data

In general, 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. Assumptions inherent in the equations used to evaluate the data include:

- 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.

4.4.6.1 Theis Equation

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”:

$$s(r, t) = \frac{114.6Q}{T} W(u) \quad \text{“Theis Equation”} \quad (1)$$

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 = $1.87 \times r^2 \times S / (T \times t)$

4.4.6.2 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:

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

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:

$$T = \frac{264Q}{\Delta s} \quad (3)$$

where:

Q = Pumping rate, [gpm]

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

Storativity can be calculated as:

$$S = \frac{0.3Tt_0}{r^2} \quad (4)$$

where:

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

4.4.7 Water Quality Sampling

Upon the completion of aquifer testing, ground water samples were collected from each site and submitted to E. S. Babcock & Sons, Inc., (a state-certified laboratory) for analysis. Samples collected from the Cherokee Borehole were analyzed for a full Title 22 suite. Samples from the Magnolia Monitoring Well were analyzed for general physical, general minerals and selected inorganic constituents (i.e. fluoride, arsenic, iron and manganese). Each sample was collected at the end of each wells respective constant rate test when the turbidity was measured to be less than or equal to 5 NTU. Laboratory reports of the ground water quality analyses are presented in Appendix C.

5.0 FINDINGS

5.1 Cherokee Site

5.1.1 Borehole Lithology

The lithology of the Cherokee Borehole consisted of a relatively thin upper layer of unconsolidated alluvium underlain by consolidated granitic bedrock. Alluvial sediments encountered during the first 53 ft of drilling consisted primarily of sand and gravel which is younger alluvium associated with stream deposition from Grout Creek, located approximately 100 ft west of the borehole site (see lithologic log in Appendix A). Consolidated granitic bedrock was encountered at approximately 53 ft bgs. Little weathering was noted in the upper portions of the bedrock. Notable fractures were observed in the borehole video log at depths of approximately 170, 245 to 247, 260, 274, 410 to 412, 419 to 420, 423 to 424, 460 to 461, and 578 to 579 ft bgs. Ground water yield generally increased with depth during drilling of the borehole but the largest and most productive fracture system was encountered at approximately 460 ft bgs.

5.1.2 Aquifer Testing Results

The step drawdown test for the Cherokee Borehole was conducted on 19-Nov-04 using average discharge rates of 35 gpm, 51 gpm, and 67 gpm (see Figure 6). The static ground water level was approximately 18 ft bgs prior to the start of pumping. Maximum drawdown during the test was approximately 174 ft bgs. From the step drawdown data, it was decided to conduct the constant rate pumping test at 60 gpm. At this pumping rate, the specific capacity of the well is 0.3 gpm/ft.

A 46.5-hour constant rate pumping test was conducted from 22-Nov-04 to 24-Nov-04 at an average discharge rate of 59.8 gpm. Evaluation of the pumping test data using Jacob's straight-line interpretation (see Figure 7) shows an aquifer transmissivity of approximately 220 gallons per day per foot (gpd/ft). A boundary condition was noted from the pumping test data at 1,110 minutes into the test. The sudden drop in ground water levels at that time reflects the intersection of the pumping cone of depression with an impermeable boundary and is a common occurrence in fractured bedrock aquifer systems. Data collected during the pumping test are provided in Appendix D.

Results of testing showed that after 46.5 hours of continuous pumping at approximately 60 gpm, the total drawdown was approximately 197 ft with a transmissivity value of approximately 220 gpd/ft. The long term drawdown (i.e. one year of continuous pumping at approximately 60 gpm) is estimated to be approximately 358 feet. The data from the pumping test shows that a well at this location can sustain a pumping rate of 60 gpm on a long-term basis.

5.1.3 Ground Water Quality

Ground water samples were collected at the end of the 46.5-hour constant rate test in the Cherokee Borehole and submitted to E. S. Babcock & Sons, Inc., of Riverside, California, a State of California certified laboratory, for water quality analysis. Laboratory water quality reports are provided in Appendix C. The following table summarizes water quality test results for selected constituents from the Cherokee Borehole:

Selected Laboratory Water Quality Results Cherokee Borehole

		46.5-hr Constant Rate Test	MCL or Action Level
Apparent Color (Unfiltered)	[color units]	< 3	15 ²
Odor Threshold @ 60°C	[TON]	< 1	3 ²
pH	[std. units]	9.3	6.5-8.5 ²
Arsenic	[µg/L]	4.3	50 ^{1,3}
Fluoride	[mg/L]	0.8	2.0 ¹
Iron	[µg/L]	< 20	300 ²
Manganese	[µg/L]	< 10	50 ²
Calcium	[mg/L]	1.0	NA
Magnesium	[mg/L]	< 1	NA
Sodium	[mg/L]	67	NA
Potassium	[mg/L]	< 1	NA
Carbonate	[mg/L]	41	NA
Bicarbonate	[mg/L]	88	NA
Sulfate	[mg/L]	4.3	250 ²
Chloride	[mg/L]	5.2	250 ²
Nitrate (as N)	[mg/L]	< 0.2	10 ¹
Total Dissolved Solids, TDS	[mg/L]	190	500-1,000 ¹

Shaded cells indicate constituents that are above present or impending MCLs.

¹ California Department of Health Services (DHS) Primary Maximum Contaminant Levels (MCL).

² California DHS Secondary Maximum Contaminant Levels.

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

Figure 8 is a trilinear diagram showing water quality results from samples collected at the end of the 46.5-hour constant rate pumping test conducted within the Cherokee Borehole. Ground water chemistry from water quality testing at the Cherokee Borehole is of sodium bicarbonate type with a strong sodium component. The TDS concentration of ground water collected during

the constant rate test was 190 mg/L. Although the pH level (9.3) exceeds regulatory standards for drinking water, all other constituents were below their respective State of California DHS maximum contaminant levels (MCLs). The high pH levels at this location will be verified in the completed production well. In the event that the high pH is confirmed, it can be mitigated by blending with water from other BBDWP production wells.

5.2 Magnolia Site

5.2.1 Borehole Lithology

The lithology of the borehole drilled for the Magnolia Monitoring Well consisted of a relatively thick sequence of unconsolidated older alluvium underlain by metamorphic bedrock. Alluvial sediments encountered during drilling consisted primarily of sand and gravel, with clayey sand layers below approximately 700 ft bgs. Geophysical logs show reduced resistivity values (suggesting lower permeability sediments) between 590 and 700 ft bgs and even lower resistivity values below 700 ft bgs. Metamorphic quartzite bedrock was encountered at a depth of approximately 1,120 ft bgs.

5.2.2 Aquifer Testing Results

The step drawdown test for the Magnolia Monitoring Well was conducted on 4-Feb-05 using average discharge rates of 11 gpm, 20 gpm, and 31 gpm (see Figure 9). The static ground water level was 290.53 ft bgs prior to the start of pumping. Maximum drawdown during the test was approximately 9 ft bgs. From the step drawdown data, it was decided to conduct the constant rate pumping test at 30 gpm (see Figure 10).

A 24-hour constant rate pumping test was conducted on 7-Feb-05 and 8-Feb-05 at an average discharge rate of 30 gpm. Evaluation of the pumping test data using Jacob's straight-line

interpretation (see Figure 10) shows an aquifer transmissivity of approximately 13,200 gpd/ft. Some variations in pumping ground water levels were noted during the later portions of the test, which are likely a result of ground water pumping interference from other wells in the area. Data collected during the pumping test are provided in Appendix E.

Results of testing showed that after 24 hours of continuous pumping at approximately 30 gpm, the total drawdown was approximately 8 ft with a specific capacity of approximately 3.75 gpm/ft. The data from the pumping test shows that the aquifer between 300 and 700 ft bgs at this location can yield significant quantities of water to a well perforated through it. The 30 gpm discharge rate from the pumping test was the maximum rate the 4-inch diameter monitoring well could accommodate given the relatively deep static ground water level (290 ft bgs) and did not reflect limitations of the aquifer to yield ground water. A larger diameter production well (e.g. 12-inch diameter) at this site would be able to accommodate a larger pump and produce a higher discharge rate. At a specific capacity of 3.75 gpm/ft, a 12-inch diameter well at this location could sustain a pumping rate of 100 gpm with only 27 ft of drawdown.

5.2.3 Ground Water Quality

Ground water samples were collected at the end of the 24 hour constant rate test in the Cherokee borehole and submitted to E. S. Babcock & Sons, Inc., of Riverside, California, a State of California certified laboratory, for water quality analysis. Laboratory water quality reports are provided in Appendix C. The following table summarizes water quality test results for selected constituents from the Magnolia Monitoring Well:

Selected Laboratory Water Quality Results Of Monitoring Well Samples Magnolia Site

		24-hr Constant Rate Test	MCL or Action Level
Apparent Color (Unfiltered)	[color units]	3.0	15 ²
Odor Threshold @ 60°C	[TON]	< 1.0	3 ²
pH	[std. units]	7.8	6.5-8.5 ²
Arsenic	[µg/L]	< 2.0	50 ^{1,3}
Fluoride	[mg/L]	< 0.1	2.0 ¹
Iron	[µg/L]	240	300 ²
Manganese	[µg/L]	47	50 ²
Calcium	[mg/L]	56	NA
Magnesium	[mg/L]	11	NA
Sodium	[mg/L]	12	NA
Potassium	[mg/L]	1.0	NA
Carbonate	[mg/L]	< 3.0	NA
Bicarbonate	[mg/L]	260	NA
Sulfate	[mg/L]	3.5	250 ²
Chloride	[mg/L]	3.4	250 ²
Nitrate (as N)	[mg/L]	< 0.20	10 ¹
Total Dissolved Solids, TDS	[mg/L]	270	500-1,000 ¹

¹ California Department of Health Services (DHS) Primary Maximum Contaminant Levels (MCL).

² California DHS Secondary Maximum Contaminant Levels.

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

Figure 11 is a trilinear diagram showing water quality results from samples collected at the end of the 24-hour constant rate pumping test conducted on the Magnolia Monitoring Well. Ground water chemistry from water quality testing is of calcium bicarbonate type. The TDS

concentration of ground water collected at the end of the pumping test was 270 mg/L. Although manganese and iron concentrations were relatively high, they may be a result of the turbidity of the sample and not representative of the true ground water concentration. In any case, concentrations of constituents analyzed were below their respective California DHS MCLs.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Evaluation of the findings of the drilling and testing of the Cherokee and Magnolia sites has resulted in the following conclusions and recommendations:

6.1 Cherokee Site

6.1.1 Conclusions From Drilling and Testing Of The Cherokee Borehole

The primary aquifer system that is available for municipal supply at the Cherokee Site occurs within the fractured granitic bedrock, which was encountered approximately 53 ft bgs during drilling of the Cherokee Borehole. Notable fractures were observed in the borehole video log at depths of approximately 170, 245 to 247, 260, 274, 410 to 412, 419 to 420, 423 to 424, 460 to 461, and 578 to 579 ft bgs. Ground water discharge during drilling of the borehole increased substantially at a depth of approximately 460 ft bgs and steadily increased with drilling depth. Few open fractures were observed below a depth of approximately 579 ft bgs in the video log. The total depth of the borehole is 605 ft bgs.

The upper alluvial aquifer system would not be available for municipal supply at the Cherokee Site because any well constructed at the site would have to be designed with a minimum 50-ft sanitary seal to comply with California DHS requirements for municipal supply wells. Furthermore, proximity of the site to an existing storm drain manhole would likely require a sanitary seal deeper than the standard 50-ft requirement.

Pumping tests within the Cherokee Borehole show that the aquifer system within the fractured bedrock at this site can sustain yields of 60 gpm for approximately 46.5 hours with 197 ft of drawdown. The specific capacity of the 8-inch diameter borehole at the end of the pumping test

was 0.3 gpm/ft. The instantaneous discharge rate of the Cherokee Borehole is higher than any other well constructed within the granitic bedrock in the Grout Creek Subunit to date.

The water quality of the ground water produced from the Cherokee Borehole during the pumping test is very good and would be suitable for municipal supply. The only constituent detected above regulatory standards was pH, which should be confirmed through future testing, as described in Section 6.1.2 below.

6.1.2 Recommendations for the Cherokee Site

Based on the findings and conclusions developed from analysis of the data collected during drilling and testing of the Cherokee Borehole, GEOSCIENCE recommends the following regarding this site:

- Given the relatively high aquifer yield obtained from the pumping test in the 8-inch diameter Cherokee Borehole, it is recommended to complete this borehole as a municipal supply well;
- To avoid the risk of missing the fractures encountered within the Cherokee Borehole, it is recommended to construct the production well within the same borehole that has been drilled and tested;
- As seen in the downhole video log, many of the fracture intervals in the borehole are significantly large with loose rock fragments that could come loose and fall in on a permanent pump installed within the borehole. Based on this observation, it is recommended to line the future borehole with a well casing that is perforated in the interval of producing fractures;
- Pumping tests show that a well at the Cherokee Borehole site could produce as much as 60 gpm. The current 8-inch diameter borehole is not large enough to

accommodate a well casing of sufficient diameter to provide space for a pump and associated monitoring equipment to produce 60 gpm. During well construction, it is recommended to enlarge the original 8-inch diameter borehole to 12 ¼-inch diameter and install a 10-inch diameter casing liner to accommodate a future pump and related equipment. A filter pack would not be necessary.

- Prior to enlarging the existing 8-inch diameter borehole, it is recommended to conduct an alignment survey in the existing borehole to ensure that it is sufficiently straight and plumb to conduct further work.
- Although the pH of the ground water produced from the Cherokee Borehole was higher than regulatory standards, the value should be confirmed in the final well. In the event that the pH in the final well is also high, the pH can be lowered through blending with water from other BBDWP wells in the Fawnskin area.

6.2 Magnolia Site

6.2.1 Conclusions From Drilling and Testing At The Magnolia Site

Based on the borehole and geophysical log data collected from the borehole at the Magnolia Site, the most promising aquifer material beneath the site occurs between the ground water surface (located approximately 290 ft bgs) and approximately 700 ft bgs. Aquifer sediments in this interval consist primarily of sand and gravel with only minor amounts of silt. Silt and clay content substantially increases below 700 ft bgs with only a few thin potentially permeable layers identified on the geophysical resistivity log below this depth. Dense bedrock was encountered at a depth of approximately 1,120 ft bgs. Given the fine-grained nature of the sediments between 700 ft and bedrock, it is unlikely that they would yield significant quantities of water to a well perforated through them. Based on the data collected from the borehole and geophysical logs, it

was decided to construct the Magnolia Monitoring Well with perforations within the aquifer sediments between 300 and 700 ft bgs.

Pumping tests within the Magnolia Monitoring Well show that the aquifer system between 300 and 700 ft bgs is relatively permeable. The 4-inch diameter monitoring well was pumped at a rate of 30 gpm for 24 hrs with approximately 8 ft of drawdown. This was the maximum pumping rate possible given the small size of the well and the relatively deep ground water level (approximately 290 ft bgs). The corresponding specific capacity of 3.75 gpm/ft is relatively high compared to other production wells within the BBDWP service area. Furthermore, the transmissivity estimated from the pumping test on the Magnolia Monitoring Well (approximately 13,200 gpd/ft) is similar to that estimated from a pumping test previously conducted for the Maple Well (approximately 10,000 gpd/ft), located approximately 1,800 ft to the east of the Magnolia Site. The Maple Well is capable of producing approximately 500 gpm.

The data collected from the drilling and testing of the Magnolia Monitoring Well indicates that this site is a good candidate for a future production well. Pumping test parameters of transmissivity and specific capacity show that the aquifer will yield a significant quantity of water to a well constructed through them. Analysis of ground water quality samples, which included the principal constituents of concern for the Big Bear Valley (fluoride, arsenic, manganese, iron, etc.) showed no detections exceeding regulatory standards. The expected production of a municipal well at the Magnolia Site would likely be lower than that of the Maple Well to the east because the thickness of aquifer sediments at the Magnolia Site is approximately 250 ft less than that described for the Maple Well. Nonetheless, a well at the Magnolia Site would likely have a higher yield than many of the other existing wells in the BBDWP system and is a favorable production well site.

6.2.2 Recommendations for the Magnolia Site

Based on the findings and conclusions developed from analysis of the data collected during drilling and testing of the Magnolia Monitoring Well, GEOSCIENCE recommends the following regarding this site:

- Given the relatively high aquifer yield obtained from the pumping test in the 4-inch diameter Magnolia Monitoring Well, it is recommended to construct a municipal supply well at this site;
- If possible, the production well should be within 50 ft from the newly constructed monitoring well;
- It is recommended to conduct isolated aquifer zone testing in the pilot borehole for the production well to confirm the production yield and water quality of the aquifer system at the exact production well location. One of the isolated zones to be considered for testing could be one of the thin sand layers below 700 ft bgs, to see if they would contribute water to a well perforated through them.
- The monitoring well constructed at the Magnolia Site will provide a means for the future collection of ground water level and quality data that will greatly assist the BBDWP in assessing the condition of the ground water basin in the Big Bear Valley area. Given this, it is recommended that this monitoring well be incorporated into the ground water monitoring and management plan that has been developed for the BBDWP service area (GEOSCIENCE, 2003).

7.0 REFERENCES

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