Revised Aquifer Testing Work Plan
BMI Common Area Eastside
Henderson, Nevada

Submitted to:

January 9, 2007

NDEP Nevada Division of Environmental Protection
protecting the future for generations

Prepared for:

Basic Remediation Company

Daniel B. Stephens & Associates, Inc.
6020 Academy NE, Suite 100 • Albuquerque, New Mexico 87109

Daniel B. Stephens & Associates, Inc.

Responsible CEM for this Project

I hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been provided in a manner consistent with the current standards of the profession and, to the best of my knowledge, comply with all applicable federal, state, and local statutes, regulations, and ordinances.

Stephen J. Cullen, Ph.D., C.E.M. (No. 1839, Exp. 11/12/07)
Daniel B. Stephens & Associates, Inc.

Individuals Who Provided Technical Input to this Document

T. Neil Blandford, P.G.
Daniel B. Stephens & Associates, Inc.

Other Reviewers

I have reviewed this document for quality control purposes.

Konnie W. Andrews, Technical Editor
Daniel B. Stephens & Associates, Inc.

Table of Contents

Section **Page**

List of Figures

Figure

List of Tables

Table

List of Appendices

Appendix

Revised Aquifer Testing Work Plan
BMI Common Area Eastside
Henderson, Nevada

1. Introduction

On behalf of Basic Remediation Company (BRC), Daniel B. Stephens & Associates, Inc. (DBS&A) has prepared this work plan for implementation of an aquifer testing program at the BMI Common Area Eastside (the Site). BRC proposes to complete multiple aquifer tests (pumping tests and slug tests) to provide Site-specific data for use in the development of a groundwater flow model (DBS&A, 2006). This work plan is an updated version of the work plan dated November 9, 2006. Comments on the previous version of the work plan were provided by the Nevada Division of Environmental Protection (NDEP) in a letter dated December 18, 2006. BRC's responses to NDEP's comments are provided in Appendix A.

In the Groundwater Modeling Work Plan, DBS&A identified hydraulic conductivity (K) and the storage coefficient (S) as two sensitive input parameters that could be improved through the collection of Site-specific data. These Site-specific parameters will be obtained as a result of this field investigation. In addition, data will be collected that will allow a qualitative assessment of the hydraulic connection, if any, between water bearing zones at the Site. An attempt will also be made to use soil cores to obtain a measured estimate of the anisotropy ratio (ratio of vertical to horizontal hydraulic conductivity) at the Site.

The proposed aquifer testing program includes step-drawdown, constant-rate, and slug tests to be performed at shallow monitoring wells. The rationale for the proposed well locations and test type are based on the following factors:

- The location of wells relative to dissolved contaminant plumes
- The location of wells relative to paleochannels
- The height of the water column in a well
- The monitoring well construction details

- The anticipated well yield

Groundwater wells that contain a sufficient water column and intersect permeable water-bearing materials will be tested using 8- to 24-hour constant-rate pumping tests, if sustainable. Groundwater wells that contain sufficient water and intersect low-permeability materials will be tested using the slug method. Finally, core samples will also be used to estimate the hydraulic parameters of unsaturated materials using laboratory measurements. Hydraulic testing of cores is proposed at selected locations where the Quaternary alluvium is not saturated or has very little saturation—rendering aquifer tests infeasible.

This work plan is organized into the following sections:

- Section 2 - Background
- Section 3 - Technical Approach
- Section 4 - Scope of Work

2. Background

2.1 Site Setting

The study area is located near the BMI Industrial Complex, in Clark County, Nevada, approximately 13 miles southeast of Las Vegas and 2 miles northeast of City of Henderson's downtown (Figure 1). Over the past 65 years, numerous private and public entities have owned, leased, or operated facilities on the original 5,000 acres, engaging in a wide range of commercial and other activities, including the manufacture of chemicals and metals. Historically, a network of ditches, canals, flumes, and unlined ponds were used for the disposal of aqueous waste from the original magnesium plant and, later, other industrial plants and the municipality adjacent to it. The Site as described herein encompasses approximately 2,287 acres of the original 5,000-acre deed referred to as the Eastside Area (Figure 2).

Surface water flows can occur for brief periods of time during periodic precipitation events and can drain to the Las Vegas Wash via ditches. Groundwater seeps have been historically observed at various locations beyond the northern portions of the Site close to the Las Vegas Wash. An evaluation of historical aerial photographs indicates that seeps have appeared in association with past effluent conveyance into the ponds and with infiltration of municipal wastewater at the northern of the two municipal rapid infiltration basins (RIBs). The locations of the RIBs are shown on Figure 2.

2.2 Geology

The depositional environment of the various strata encountered beneath the Site has been characterized by numerous borings installed during previous investigations. The Site is located on alluvial fan sediments, with a surface that slopes to the north-northeast at a gradient of approximately 0.02 towards the Las Vegas Wash. The uppermost two geologic formations encountered at the Site are the focus of this work plan. The uppermost unit is composed of relatively coarse-grained Quaternary alluvial sediments. The alluvial sediments are underlain by lacustrine sediments known as the Muddy Creek Formation (TMCf). For the most part, the lacustrine TMCf is comprised of silts and clays, although a coarser facies was noted in the southwest portion of the site as described in Section 2.2.2. Each of these geologic units is described below.

2.2.1 Quaternary Alluvium

The uppermost strata beneath the Site consist primarily of alluvial sands and gravels of Quaternary age (Carlsen et al., 1991), and are mapped and referred to as Qal. The alluvial fan deposits are composed of volcanic materials that were shed from various nearby mountains, which then coalesced in the Las Vegas Valley. The Qal is typically on the order of 50 feet thick at the Site, with a maximum thickness of 65 feet noted to the southwest of the Southern RIBs. The variations of the thickness of the Qal are, in part, a result of the non-uniform contact between the Qal and the underlying TMCf. The Qal is not present in localized areas of the northernmost portion of the Site, where it was removed as a result of previous gravel mining. Such areas where excavation has occurred previously (such as the Weston Hills development) have since been backfilled to allow for residential development.

Whereas the original surface of the Qal prior to development was a nominally planar surface that, as a whole, dipped gently to the north, the contact between the Qal and the underlying TMCf is not a planar surface. The unconformity between these two geologic units is a result of uplift and erosion of the TMCf prior to the deposition of the alluvial sediments that comprise the Qal. As the TMCf was eroded, broad channels were incised into its surface and were subsequently filled with the alluvium, resulting in the development of several paleochannels of varying depths and width. BRC et al. (2006) have interpreted that two paleochannels originating to the east and west of the Southern RIBs join at the southern end of the former location of the historic spray wheel to form one paleochannel that runs north beneath the Northern RIBs and then northeasterly to the Las Vegas Wash. As indicated by the borelog data, the structural surface of the TMCf also exhibits a topographic gradient to the north-northeast. However, the TMCf topography does not appear to be deeply incised enough such that the current flow of groundwater is controlled by “paleochannel” features. The degree to which these paleochannels act as preferential pathway(s) for groundwater flow and contaminant migration is presently uncertain and is most likely a function of the amount and location of groundwater present. Proposed testing discussed in Sections 3 and 4 is intended to assist with evaluation of this data gap.

Figure 3 is a structure contour of the top of the TMCf (base of the Qal) based on the evaluation of geophysical surveys and logs as later refined by the interpretation of more than 500 boring logs. The figure details the irregular nature of the topographic surface of the TMCf, as well as the presence of the three dominant paleochannels that trend north-northeast toward the Las Vegas Wash. As depicted in Figure 3, the data demonstrate that two of the three paleochannels originate from off-site in the southern portion of the study area and then extend generally northward to the Site's Western Hook and No-Build sub-areas. BRC understands that work is ongoing by TIMET regarding the occurrence of any paleochannels in the southwest portion of the Site. As this information becomes available, the conceptual site model will be revised as necessary.

2.2.2 Upper Muddy Creek Formation

The TMCf underlies much of the Las Vegas Valley and is more than 2,000 feet thick in places. At the Site, this unit is encountered beneath the Qal, where an unconformity separates the two geologic units. The depth to the top of the TMCf ranges from approximately 27 feet below ground surface (bgs) at well MCF-11 to a depth of approximately 65 feet bgs southwest of the Southern RIBs. The TMCf at the Site was encountered to the maximum explored depth of 430 feet bgs. The TMCf is typically fine-grained (sandy silt and clayey silt), although thin layers (interbeds or "stringers") with increased sand content are encountered sporadically.

A coarser-grained facies of the TMCf occurs off-site and in the southwest portion of the study area (at well MCF-27, for example). The proportion of coarser-grained sediments in the upper portion of the TMCf decreases to the north beneath the Site. This more permeable TMCf facies is interpreted as being caused by an influx of slightly coarser alluvial deposits into the older lacustrine depositional environment. One possible ramification of the presence of these coarser TMCf sediments near the southwestern border of the Site is that they may serve as a potential pathway for chemicals to migrate into the TMCf.

2.3 Hydrogeology

Two distinct water-bearing zones have been observed in the upper 400 feet of the subsurface at the Site:

- An upper, unconfined water-bearing zone primarily within the Qal, referred to herein as the alluvial aquifer (Aa)
- A deep (approximately 400 feet), confined water-bearing zone that occurs in a sandier depth interval within the silts of the deeper TMCf, referred to herein as the Deep Zone

The Aa and Deep Zone are separated by hundreds of feet of fine-grained materials of the upper TMCf. In addition, thin saturated interbeds composed of sandier materials were also encountered during drilling within the upper TMCf. These sporadically encountered saturated interbeds, referred to as the Middle Zone, generally occur at depths about 50 feet or greater beneath the base of the alluvium, but above the Deep Zone.

2.3.1 Alluvial Aquifer

The Aa is the shallowest water-bearing zone encountered beneath the Site. Water in the Aa is unconfined and tends to occur in the Qal. In the eastern portion of the Site, however, groundwater is first encountered in the shallowest portion of the fine-grained sediments of the Upper Muddy Creek Formation, within 5 to 10 feet beneath the contact between the Qal and the TMCf. The depth from the surface to first groundwater at the Site ranges from 14 to 48 feet bgs.

The water surface in the Aa generally follows topography, with the water surface sloping towards the Las Vegas Wash. Figure 4 presents the water surface elevation of the Aa at the Site and its vicinity in the summer of 2004. Groundwater in the Aa flows in a northerly direction at a nominal gradient of 0.017. As indicated by flow arrows on the figure, the direction of Aa groundwater flow beneath the Site varies from northwest to northeast. Infiltration of water beneath the northern RIBs appears to cause groundwater to flow around the western and eastern sides of the resulting groundwater mound.

Groundwater monitoring wells completed in the Aa generally have low production, as indicated by recovery rates of less than 5 gallons per minute (gpm) observed during the development of the wells in 2004 (Appendix B). One notable exception is a shallow-zone well on the west side of the first eight rows of Upper Ponds, AA-09, that recovered at a rate of 52 gpm during 2004. Because of the high recovery rate at this well, AA-09 is proposed to be included in the aquifer testing program. After well AA-09, the next 2 most productive wells installed in the Aa were wells AA-08 and AA-15, which had approximate recharge rates of 6.3 and 3.9 gpm, respectively. The observed recharge rates of the remaining 14 Aa wells range from 0.1 to 2.0 gpm.

Observed water levels in the Aa at the Site have dropped significantly between 2004 and the present. This decline in water levels coincides with the May 2005 cessation of use of both the Southern RIBs and the TIMET ponds. Because the Southern RIBs were designed to deliver water into the subsurface, and the TIMET ponds were lined to prevent infiltration, it is most likely that the observed water level drop was caused primarily by cessation of infiltration at the Southern RIBs. However, some seepage from the TIMET ponds may also have occurred. It is noted that cessation of use of the Southern RIBs by the City of Henderson is not permanent until the City's wastewater reclamation facility expansion is completed sometime in 2008. Therefore, resumption of use of the Southern RIBs is possible, though unlikely, between now and 2008. BRC will continue to monitor the Southern RIBs.

Historical water level data for the Site are included in Appendix B. Note that the April and July 2006 data from recent groundwater monitoring events are preliminary and have not yet been approved by the NDEP. Therefore, a potentiometric map based on these data has not been prepared. These data sets will be formally submitted by BRC to the NDEP separately as part of quarterly monitoring reports. The observed water level drop in the Aa wells has created constraints on the types of Aa aquifer tests that are feasible at the Site. This issue is addressed below.

2.3.2 Deep Water-Bearing Zone

The Deep Zone is encountered between 335 and 395 feet bgs, within the fine-grained portion of the TMCf. This water-bearing interval is of variable thickness, occurring in lenses of sandier silts of up to 5 feet in thickness. Groundwater in the Deep Zone is confined. Static water levels in Deep Zone wells are tens to hundreds of feet higher than the elevations at which the water was encountered during drilling. Water levels at the Site in Deep Zone wells have not shown appreciable changes from 2004 to 2006.

It is BRC's hypothesis, based on Site investigations to date and the geologic setting of the area, that groundwater in the Deep Zone is not hydraulically connected to the Aa situated above it at the Site. BRC recognizes that NDEP does not agree with this hypothesis, but rather believes that a direct hydraulic connection might exist between the Aa and groundwater in the Deep Zone. Site data indicate that groundwater from the Deep Zone does not contact the Las Vegas Wash, or its sediments, immediately north of the Site. To the east of the Site, Bell and Smith (1980) have identified faulting, which may provide a pathway of hydraulic connectivity between Deep Zone groundwater and the Las Vegas Wash. Testing proposed in Section 4 will generate data to help test the various hypotheses and evaluate whether the Aa and Deep Zone may be hydraulically connected.

2.3.3 Upper Portion of the Upper Muddy Creek Formation

Between the Aa and the Deep Zone, several hundred feet of dry to moist, fine-textured silts to silty clays are encountered. The upper portion of the TMCf also contains sporadic, thin, sandier layers, most of which are saturated and under pressure. These lenses are depicted on cross section Z-Z', the location of which is shown on Figure 5. Cross section Z-Z' is presented as Figure 6. Note that because the thickness of the sporadic saturated sandier lenses encountered in the TMCf was typically very thin (from less than 1 to approximately 3 feet), the thickness of these lenses has been exaggerated in Figure 6 for clarity. Within the silty TMCf, these saturated lenses were encountered in sediments where an increase in sand content to approximately 30 to 40 percent was observed. Groundwater in these lenses was found at depths ranging from as shallow as 55 feet bgs to as deep as 315 feet bgs. Due to their sporadic nature, the hydraulic connectivity of these lenses to each other and/or with the Aa and Deep Zone is not known.

3. Technical Approach

The goal of this investigation is to obtain data that characterize the hydraulic parameters of the geologic materials that form the water-bearing zones at the Site, with primary emphasis on the Aa and the upper portion of the Upper Muddy Creek Formation. Pumping tests are proposed at wells that intersect permeable portions of the Aa where this water-bearing zone is sufficiently thick. Pumping tests are proposed only where it appears that the water-bearing zone can be sufficiently stressed to sustain a reasonable pumping rate (several gallons per minute) for a significant period of time (e.g., at least 8 hours). Proposed pumping tests include step-drawdown tests and 8- to 24-hour constant-rate tests. At wells that do not intersect permeable portions of the Aa and where the water thickness is sufficient, slug tests will be performed. At two locations, AA-08 and AA-026, the saturated thickness of the Qal is significant (40 to 60 feet), but the existing monitor wells are screened only across the water table. At these locations, BRC proposes to construct a fully penetrating 4-inch-diameter extraction well adjacent to the existing monitor well, along with two new observation wells that fully penetrate the full saturated thickness of the Qal. The new production well will be pumped to conduct the aquifer test, and the existing monitor well and two new observation wells will be used to observe drawdown. Finally, hydraulic testing of cores is proposed at several locations where the alluvium is not saturated or has very little saturation, and where pumping or slug testing is not feasible. Table 1 summarizes the aquifer testing program.

Water level measurements collected at the Site during July 2006 revealed that water levels have declined significantly since the monitoring event conducted in the summer of 2004. For example, the water level in well AA-14 declined approximately 24 feet during this period. The proposed aquifer testing outlined in Table 1 was developed based on current observations. BRC has two additional quarterly groundwater monitoring events scheduled. In the event that water levels in wells completed in the Qal rise significantly in the future, BRC will consult with NDEP and conduct additional aquifer testing as needed.

The approach used to design the proposed pumping tests, slug tests, and laboratory hydraulic testing of selected geologic materials is presented below in Sections 3.1, 3.2, and 3.3, respectively.

3.1 Slug Testing

Slug tests will be conducted on all wells identified in Table 1 (eight total). The purpose of these tests is to better define hydraulic properties within the Aa and the uppermost TMCf for use in the groundwater model and or utilization during other quantitative analytical computations, such as groundwater mounding calculations. While four of these wells are scheduled for slug tests only (AA-13, AA-22, MCF-03B, and MCF-16C), four additional wells (AA-07, AA-09, AA-20, and MCF-06C), will also have pumping tests performed if the wells recover sufficiently during the slug tests to suggest that an aquifer test is likely to be successful. Slug tests will be repeated at least two times. If the results from the first two tests are not essentially the same, a third test will be conducted.

3.2 Pumping Test Design

Pumping tests are proposed at wells AA-07, AA-08, AA-09, AA-20, AA-026, and MCF-06C. These wells were selected based on their location across the site and the observed available water column. Due to the limited saturated thickness observed at most Aa well locations, sustainability of pumping during a pumping test is a significant concern. As noted above and as outlined in detail at the end of this section, proposed slug testing at wells AA-07, AA-09, AA-20, and MCF-06C will be used to determine if a pumping test appears feasible. In addition, in an effort to assess whether the proposed test wells could sustain pumping at rates adequate for conducting pumping tests for periods of 8 to 24 hours, the AQTESOLV software developed by HydroSOLVE, Inc. (2002) was applied. This software was used to predict how much pumpage the proposed test wells might be able to sustain, and to estimate the how much drawdown would likely occur. Based on the well-development estimates of the Aa permeability and the inspection of well boring logs, hydraulic conductivities values (K) of 1, 10 and 100 feet per day (ft/d) were used for the evaluation runs performed. Transmissivities were assumed using these ranges of K values and the saturated thickness at each well based on the July 2006 water level data. Note that new pumping wells will be drilled for the aquifer testing adjacent to AA-08 and AA-026; based on current data, sustainable production is not anticipated to be an issue at these two locations. Appropriate pumping rates for these two new wells will be determined based on well development information collected in the field.

3.2.1 Approach to Determining Feasibility of Pumping Tests.

Based on the results of the AQTESOLV runs, the following approach was developed to determine whether a pumping test is feasible at wells AA-07, AA-09, AA-20, and MCF-06C:

1. If the slug test indicates that the hydraulic conductivity of the Aa is less than 10 feet per day (ft/d), the well will not be tested using pumping-type tests. Preliminary evaluations using available hydrogeologic data suggest that while well AA-09 is a good candidate for a constant-rate pumping test, wells AA-07, AA-20 and MCF-06C may not be.

2. If the slug tests at wells AA-07, AA-09, AA-20, and MCF-06C indicate that the hydraulic conductivity of the Aa is more than 10 ft/d, then a step-drawdown test will be conducted.

3. If the step-drawdown test indicates that the well can sustain a pumping rate of at least 1.5 gpm for at least 24 hours, then the well will be further considered as a candidate for a constant-rate pumping test.

4. If the step-drawdown test indicates that the well cannot sustain a pumping rate of at least 1.5 gpm for at least 24 hours, then the well will not be considered as a candidate for a constant-rate pumping test.

Performance of a slug test at the proposed pumping test wells will allow for comparison of aquifer parameters obtained from the slug test and pumping test methods if a pumping test is actually conducted at one or more locations.

3.2.2 Observation Wells

There is no accepted standard for the number of observation wells required during a constant-rate pumping test. Standard references indicate that a single observation well is sufficient to determine aquifer transmissivity and storage coefficient, although the more observation wells that can be employed the better. Excerpts from several standard references that discuss this point are provided below:

1. Kruseman and de Ridder (1990, p.32) “The question of how many piezometers to place depends on the amount of information needed, and especially on its required degree of

accuracy, but also on the funds available for the test. Although it will be shown in later chapters that drawdown data from the well itself or from one single piezometer often permit the calculation of an aquifer's hydraulic characteristics, it is nevertheless always best to have as many piezometers as conditions permit. Three, at least, are recommended."

2. Todd and Mays (2005, p. 164) "Average values of S and T can be obtained in the vicinity of the pumped well by measuring in one or more observation wells the change in drawdown with time under the influence of a constant pumping rate."

3. Driscoll (1986, p. 548) "The appropriate number of observation wells depends on the amount of information desired and upon the funds available for the test program. The data obtained by measuring the drawdown at a single location outside the pumped well permit calculation of the average hydraulic conductivity, transmissivity and storage coefficient of the aquifer. If two or more observation wells are placed at different distances, the test data can be analyzed by studying both the time-drawdown and distance-drawdown relationships. Using both these analytical methods provides greater assurance that the calculated transmissivity and storage coefficient values are correct. It is usually advantageous to have as many observation wells as conditions allow because the hydraulic conductivity may vary in one or more directions away from the pumping well. Observation wells placed in a circle around the pumping well will reveal this trend."

DBS&A proposes the following approach to installation of monitor wells specifically for aquifer testing.

Group 1: Wells AA-08 and AA-26. Significant Qal saturated thickness (40 to 60 feet) exists at these wells, and we do not anticipate that sustained pumping at a reasonable rate will be a problem. Consequently, we expect to be able to stress a greater volume of aquifer at these locations than at other potential pumping test locations (Group 2, below). At the AA-08 and AA-26 locations, a new 4-inch extraction well will be drilled. In addition, two new, fully penetrating 2-inch-diameter observation wells will be constructed. One new observation well will be in line with the existing monitor well (i.e., either AA-08 or AA-26), and the other new monitor well will be at approximately 90 degrees, or cross-gradient from the other monitor well line. At both locations, the existing monitor wells (AA-08 and AA-26) are partially penetrating, and therefore these wells will be the farthest from the newly constructed extraction wells to minimize partial penetration effects. If possible, these wells will be about 75 feet from the new extraction wells, which is approximately 1.5 times the approximate aquifer thickness of 50 feet.

Group 2: Wells AA-07, AA-09, AA-20 and MCF-06C. Pumping tests are proposed at these wells if it is determined that sufficient pumping can be sustained for a significant period of time, according to the procedure outlined in Section 3.2.1. If it appears feasible to conduct an aquifer test at one or more of these four locations, we anticipate that the volume of aquifer tested will be small due to the limited saturated thickness of the Qal. If it is determined that aquifer tests can be performed at any of these wells, BRC proposes to install one adjacent, fully penetrating monitoring well in the Qal. Due to the small volume of aquifer that can be tested at these locations because of the limited saturated thickness, it is BRC's belief that multiple observation wells are not warranted. The new observation wells (if any are installed) will likely be very close (e.g., 10 feet) to the proposed pumping well.

3.3 Laboratory Hydraulic Testing

In addition to the aquifer testing described above, hydraulic testing of cores is proposed at several locations where the alluvium is not saturated (or has very little saturation) and where significant infiltration of waste water may have occurred historically based on aerial photographs. Hydraulic testing of sediment cores is proposed for three locations within the east side of the Upper Ponds area as illustrated in Figure 7.

3.4 Evaluation of Connectivity Between Site Water-Bearing Zones

Tracer tests and other means to quantify the connectivity between the Aa (the upper water-bearing zone), the Middle Zone, and the Deep Zone have been considered. As previously reported to NDEP, BRC has conducted the following activities to evaluate the connectivity between the two referenced zones:

- 2004 investigations

- Advanced 13 exploratory borings to a depth of approximately 400 feet bgs.
- Conducted geophysical logging of 13 borings to a depth of approximately 400 feet bgs.
- Collected continuous core soil samples from 3 of the 400-foot mud-rotary borings (locations 1, 4, and 6) and from all of the boreholes drilled with the rotary sonic drilling method (18 locations).
- Drilled 50 boreholes at 27 locations throughout the Site; 13 locations were drilled with mud rotary, 5 locations were drilled with hollow-stem auger, and 18 locations were drilled with rotary sonic drilling methods.
- Collected 94 saturated soil samples and 12 in-situ groundwater samples from the various water-bearing zones at the Site for fast turnaround analysis of perchlorate using U.S. Environmental Protection Agency (EPA) method 314.0.
- Installed 44 groundwater monitor wells, including 8 wells in the Qal and 27 wells in the Upper Muddy Creek Formation, 11 of which were screened below 335 feet bgs.
- Collected water level measurements in 44 monitor wells; samples were subsequently collected from the wells for water quality analyses of the chemicals on the Site-related chemical (SRC) list.

- Activities conducted since 2004
  - Submitted a report of groundwater monitoring for the first quarter of 2006 (06Q1), including water elevations reported for 104 wells and water sample chemical analytic results for 53 wells.
  - Collected data for the second quarter of 2006 (06Q2), including water elevations reported for 105 wells and water sample chemical analytic results for 56 wells; report is being prepared.

The use of tracers to assess the connectivity of the three water-bearing zones has also been considered. Conservative chemical or isotopic tracers can be used to demonstrate connectivity and provide a means for estimating groundwater flux. These tracers are applied as a pulse at some locations (e.g., a monitor well), and groundwater flow transports the tracer to some point downgradient from the point of introduction, where it is collected in a sampling device such as a well. The time differential is observed between the time of application and the time of sample collection at the downgradient sampling location. Applied tracers provide groundwater flux and travel time estimates at a point scale that may or may not apply to larger scales. Commonly used tracers include bromide, tritium (^3H), and visible dyes. Organic dyes are generally used to evaluate preferential flow and would not be appropriate for use in the low-recharge wells of the Site's Middle Zone. Although tritium (^3H) is the most conservative of all tracers, its use as an applied tracer is not appropriate because of environmental protection concerns. Bromide or sulfur hexafluoride, however, would be chemically appropriate for use at the Site.

DBS&A does not believe that the use of tracer testing to directly assess the connectivity of the three water-bearing zones, or even the connectivity of the Upper Muddy Creek Formation with groundwater in the alluvium is practical for two main reasons:

- The travel time for a conservative tracer introduced in the upper portion of the Upper Muddy Creek Formation to migrate upward into the alluvium where it could potentially be observed in a monitor well is at least on the order of several years, and quite possibly much longer.

- Due to what are expected to be heterogeneous and unidentified specific flow paths for tracer migration, appropriate target sampling location(s) are, to a large extent, unknowable.

We do believe that some investigation regarding the potential for using historical tracers at the Site is warranted. Each of these topics is discussed in more detail below.

The following calculation is presented to illustrate what DBS&A believes is the main problem with using tracer injection to evaluate saturated zone connectivity at the Site. The 2004 groundwater well measurement data indicated that vertical hydraulic gradients were upward at most locations, downward in some, and ranged in magnitude from approximately 0.018 to 0.180. Assuming, for the sake of discussion, that the increased sand content of the Middle Zone lenses has an overall hydraulic conductivity of 1 x 10^{-4} centimeters per second (cm/s) and an effective porosity of 30 percent, the average groundwater velocity can be estimated using Darcy's Law:

$$v = \frac{Ki}{n_e}$$

where v = average groundwater pore velocity (cm/s)

K = saturated hydraulic conductivity (cm/s)

i = gradient (unitless, L/L)

n_e = effective porosity (unitless, L^3/L^3)

Using a gradient of 0.018, the calculated average pore velocity would be:

$$v = 6 \times 10^{-6} \text{ cm/s} = 0.017 \text{ ft/d}$$

Using this average pore velocity, it would take a conservative tracer about 5 years to travel 30 feet in the vertical direction. Although other assumed values could be applied in the time of travel calculation, DBS&A believes that the main constraint will be the average hydraulic conductivity of the intervening materials between the tracer release point and the target reception point. The 1 x10^{-4} cm/s value was selected to be on the expected high end of possibilities, and the actual hydraulic conductivity may be lower, perhaps by 10 to 100 times. Furthermore, the sporadic nature of the TMCf sand lenses indicates that a straight-line path is not realistic and that the path is tortuous and longer, possibly much longer, than accounted for in the analysis above (i.e., the actual flow path is not likely to be 30 feet). This would make the tracer travel time even longer. Although it is theoretically possible to reduce expected tracer travel times by inducing a higher hydraulic gradient by pumping or injection, DBS&A does not believe that this approach is appropriate because there is a significant likelihood that flow pathways would be opened where none existed prior to creation of the induced gradient. The results of such a study would therefore not be representative of the flow regime observed at the site.

In addition to the travel time problem, insufficient data are currently available (and are not likely to be reasonably attainable) to characterize the location, if any, of the point of intersection and the area of intersection of the Middle Zone sand lenses with either the overlying Aa or the underlying Deep Zone. Therefore, it is not possible to confidently identify the proper location for a monitor well to capture the tracer as it discharges from the Middle Zone into either the Aa or the Deep Zone.

Use of historical tracers may have application at the BMI Site. Historical tracers result from human activities or events in the past, such as contaminant spills or atmospheric nuclear testing (^{3}H and ^{36}Cl).

Known industrial chemical contaminants at the Site from previous operational activities, such as perchlorate and tetrachloroethylene, will be evaluated, together with groundwater elevation data, to provide qualitative evidence of connectivity, or lack thereof, between the three Site water-bearing zones. Total dissolved solids (TDS) distribution will also be evaluated. However, uncertainties with respect to source location, concentration, timing of chemical release, and the non-conservative behavior of some chemicals will make it difficult to use this information to quantify the connectivity in terms of groundwater flow between water-bearing zones.

The presence of an event marker, such as bomb tritium, in groundwater can provide evidence that a component of that water recharged during a particular time period. Because of tritium's short half-life, the use of bomb tritium as a hydrologic tracer is relatively temporary. In the southern hemisphere, the bomb pulse has already decayed to within 15 tritium units of natural background; in the northern hemisphere, bomb tritium will be difficult to detect in 10 to 20 years (Bentley et al., 1986). Tritium content in precipitation in North America since the advent of atmospheric bomb testing in 1952 reached an atmospheric high in approximately 1963, diminishing significantly to the present atmospheric levels. Before significant amounts of tritium were injected into the atmosphere through nuclear activities, precipitation had a natural background of around 5 tritium units (TU). The Santa Maria, California station is one of the longest-running tritium monitoring stations in the U.S. and is located about 400 miles west-southwest of Las Vegas. At Santa Maria, peak atmospheric tritium concentrations of about 1,300 TU were recorded from 1962 through early 1964 and diminished to less than 400 TU in late 1964. Today, atmospheric background levels in the northern hemisphere are between about 5 and 30 TU (IAEA/WMO, 1998). Another reference, the Illinois Environmental Protection Agency (1997), reports that the naturally occurring tritium level in pre-bomb precipitation is estimated at 5 to 10 TU, and that the actual tritium content varies widely with location.

BRC proposes that, at the time of the fourth quarterly monitoring event, a one-time sampling and analysis of tritium from monitor wells in the three water-bearing zones be completed. A subsample of monitor wells will be selected such that wells will be sampled at the southern, middle, and northern portions of the Site vicinity between the Las Vegas Wash and the southern boundary of the Site property. This sampling is exploratory in nature, and it is expected that the results of this sampling will be used to determine if the age of the water in the three water-bearing zones can be differentiated on the basis of the tritium content. For example, if the results of samples from the Deep Zone wells in the northern portion of the sampled area indicate that tritium levels are at or near pre-bomb tritium levels, while tritium levels in the Aa indicate, as is expected, that the water is of more recent age, it would be interpreted that little connectivity is indicated between the Deep Zone and the Aa.

Stable isotopes will also be sampled to facilitate evaluation of the connectivity between the three water-bearing zones. An isotope is a variation of an element produced by differences in the number of neutrons in the nucleus of the element; hence, isotopes of an element have different masses. The two stable, or non-radioactive, isotopes of hydrogen (^{1}H and ^{2}H, or deuterium [D]) and the three stable isotopes of oxygen (^{16}O, ^{17}O, and ^{18}O) form part of the water molecule, and analyses of their concentrations in groundwater can be used to trace movement of water in the subsurface. It is well established that the isotopic composition of precipitation at a particular location will vary seasonally and with individual storms. The isotopic composition of precipitation will also vary among locations depending upon climate and elevation. Nevertheless, the composition of all precipitation generally falls on a straight line of a plot of δD versus $\delta^{18}O$ (where δ is the relative difference of the isotopic ratios in precipitation versus standard mean ocean water [SMOW], expressed in parts per thousand). This line is called the meteoric water line (MWL).

The stable isotope concentration of the precipitation can be modified subsequent to infiltration; this signature of the soil water reveals origin of the water. Evaporation of soil water leads to a fractionation of the stable isotopes D and ^{18}O. When water evaporates, the heavier atoms tend to remain behind in the liquid phase, thus leading to an enrichment in the concentration of the heavier isotopes in the residual liquid, and lighter isotopes fractionate into the vapor phase. At the time of the fourth quarterly monitoring event, BRC proposes to collect groundwater samples from the three water-bearing zones for isotopic analysis. This proposed sampling will be exploratory in nature, and it is expected that the results will be used to determine if the isotopic character of the water in the three water-bearing zones can be differentiated on the basis of their isotopic signature, and thus provide a means to assess the connectivity between the three site water-bearing zones.

BRC will plot the MWL, a linear regression of the values of unevaporated precipitation collected worldwide. Water collected from the same wells sampled for tritium will be analyzed for isotopes of hydrogen and oxygen. The results of the sample analyses will be plotted with the unevaporated precipitation waters. It is anticipated that evaporated waters will plot on lines that lie to the right of the unevaporated waters. Waters subjected to increasing evaporation will lie increasingly to the right of the MWL. The proximity of a water's isotopic value relative to the MWL is proportional to the extent of evaporation or isotopic enrichment. For example, if water from Deep Zone wells has undergone a high degree of isotopic enrichment while those of the Middle Zone and Aa have not, different isotopic character and a lack of significant hydraulic connectivity should be indicated.

4. Scope of Work

To address the goals of the testing and evaluation program, 10 interrelated tasks are proposed:

- Task 1: Planning and coordination
- Task 2: Determine suitability of existing cores for laboratory use
- Task 3: Determine short-term water level fluctuations
- Task 4: Obtain core samples for laboratory analysis (if needed)
- Task 5: Construct extraction and observation wells
- Task 6: Conduct slug testing
- Task 7: Conduct step-drawdown tests
- Task 8: Conduct constant-rate pumping tests
- Task 9: Analyze testing data
- Task 10: Prepare report

Two field events will be implemented to complete the investigation:

- Field event 1: Tasks 3, 4, 5, 6, and 7
- Field event 2: Task 8

The tasks included in the proposed hydrogeologic investigation are described in greater detail in Sections 4.1 through 4.10.

4.1 Task 1: Planning and Coordination

During Task 1, DBS&A will:

- Coordinate with BRC and others as needed for access to the groundwater monitoring wells.

- Coordinate rental of data loggers, pressure transducers, and other materials needed to perform the proposed tasks.

- Arrange for preparation of the pumping wells. This includes the removal of existing low-flow sampling pumps and the installation of higher capacity pumps, valves, flow meters, discharge pipe, and "stilling tubes." The stilling tube will help prevent the pump's electrical wires and discharge line from causing the cables of water level measuring devices to become tangled in the well as these are lowered and raised during the test. A stilling tube consists of an open small-diameter PVC pipe that is lowered into the well to a depth that extends past the pump and then securely attached to the well. A measuring point is then established and its height above the existing measuring point determined. An added benefit of using a stilling tube is that it eliminates any potential effects that might be caused by turbulence in the well due to pumping, as well as those that might be caused by water cascading into the well.

- Coordinate the rental of generators to run the pump used in the pumping tests. Having continuous power for the pump for the duration of the test is crucial for the success of the test. If interruptions occur early in the test, it may be necessary to stop the test and allow the aquifer to recover prior to restarting the test. A backup generator will be obtained in case there is a disruption late in the pumping period of each test.

- Coordinate wastewater disposal after proper testing.

4.2 Task 2: Determine Suitability of Existing Cores for Laboratory Use

Hydraulic testing of cores is proposed at three locations where the alluvium is not saturated beneath regions of historical infiltration (Figure 7). BRC has a substantial archive of undisturbed soil cores that were collected during the hydrogeologic investigation conducted on the Eastside Area in 2004. Most of these cores where collected using a rotary sonic drill rig; as such, the cores may be suited for laboratory testing.

BRC will investigate the viability of using these undisturbed, archived cores to obtain representative measurements of hydraulic conductivity. In addition to vertical permeability, the feasibility of subcoring the archived cores will be evaluated to determine if horizontal hydraulic conductivity can be directly measured. The results of particle distribution analysis will be used to estimate hydraulic conductivity. If utilization of the archived cores proves infeasible for the intended purpose, BRC will perform Task 4 (Section 4.4).

4.3 Task 3: Determine Short-Term Water Level Fluctuations

Groundwater elevations are known to fluctuate at the Site. As discussed previously, water levels at some locations dropped more than 20 feet between 2004 and 2006. However, water levels observed during April/May 2006 and July 2006 are generally consistent. For the purposes of aquifer test analysis, characterization of short-term water level changes is also of interest, as these can potentially impact the quality of drawdown data collected during pumping tests. Short-term changes in water levels (caused by factors other than pumping at the test well) create "noise" that may reduce the discernable signal, especially when total drawdown may be on the order of several tenths of a foot (at observation wells) or late in the pumping period when the rate of drawdown decreases (at all wells).

These short-term fluctuations may affect the interpretation of water level data obtained during the pumping test. Therefore, pre-test water level fluctuations need to be sufficiently characterized prior to performing the proposed constant-rate pumping tests so that appropriate data filtering can occur if warranted.

In addition to providing data needed to properly design the proposed pumping tests, DBS&A proposes to install data loggers in one series of nested wells completed in the Aa, and in the shallow and deep zones of the TMCf. These two sets of water levels will be used to qualitatively evaluate whether the shallow and deep water-bearing zones are hydraulically connected (i.e., short-term changes in water levels in both zones mimic each other). This evaluation is limited, but useful in that it can suggest whether the two zones are or are not hydraulically connected, but does not provide data that can characterize the nature of a connection, if one is suspected.

In addition to monitoring water levels, the existing weather station at the BMI Complex will be used to measure any rainfall and to log atmospheric pressure fluctuations in order to factor the effect of barometric pressure on water level fluctuations in monitoring wells completed in confined groundwater zones. The data loggers will be installed in wells MC-06A, MC-06B, and

MC-06C as soon as DBS&A personnel arrive at the Site and will be programmed to measure water levels at 15-minute intervals as Tasks 3 through 5 are being completed. Data loggers will be downloaded and removed from the wells at the end of Task 5.

4.4 Task 4: Obtain Core Samples for Laboratory Analysis (if needed)

If it is determined during Task 2 that existing cores generated during the 2004 investigation are not suited for the laboratory determination of hydraulic parameters, new samples will be collected at the Site during this task. DBS&A proposes to use a rotary sonic rig to collect undisturbed 3-inch-diameter core samples of the alluvium and upper portion of the TMCf using a split-spoon sampler. Samples will be collected at approximately 5-foot intervals beginning at the land surface and continuing approximately 10 feet into the TMCf. The proposed samples will be collected from the same area identified in Section 4.2. These samples will be shipped to DBS&A's hydrologic testing laboratory in Albuquerque, New Mexico for analysis.

4.5 Task 5: Construction of Pumping and Observation Wells

Two 4-inch extraction wells, one near AA-08 and one near AA-026, will be constructed in order to obtain hydraulic properties at these locations. The new wells will serve as the extraction wells at these locations, while the existing wells will serve as observation wells. Although specific well locations will be determined based on screening runs using AQTESOLV, it is anticipated that the pumping wells will be drilled approximately 50 to 75 feet from the existing monitoring wells, in an approximate upgradient or downgradient direction, depending on well-site availability. Each production well will be screened across the entire Qal saturated thickness, which is anticipated to be about 40 and 60 feet at AA-08 and AA-026, respectively, based on water levels measured in July 2006.

In addition to the pumping wells discussed above, two new 2-inch diameter observation wells that fully penetrate the saturated portion of the Qal will be constructed near AA-08 and near AA-026 (four wells total). At each location, one new observation well will be located between the new extraction well and the existing observation well (i.e., either AA-08 or AA-26), and a second observation well will be located at a 90-degree angle relative to this imaginary line (approximately cross-gradient).

If it is determined through the approach outlined in Section 3.2 that a pumping test can be conducted at AA-07, AA-09, AA-20, or MCF-06C, a single 2-inch diameter observation well that fully penetrates the saturated portion of the Qal will be installed adjacent to the pumping well to be used for the test. This approach could lead to the installation of up to four additional observation wells for use during aquifer testing. The radial distance from the pumping well to any new observation wells will be determined based on AQTESOLV screening runs.

All of the new wells will be drilled and installed using a hollow-stem auger drilling rig in accordance with the BRC Standard Operating Procedures (FSSOP) SOP-1 (MWH, 2006).

4.6 Task 6: Conduct Slug Testing

A slug test is an in-situ, single-well testing method that is commonly used to estimate the hydraulic conductivity of an aquifer or water-bearing zone. DBS&A does not propose to perform slug tests in any wells that have less than about 5 feet of water because sufficient water will not be able to be instantaneously removed from the well using a slug. Slug tests will be performed in accordance with DBS&A standard operating procedures (SOPs) that address the performance of the slug test and making automated water level measurements (Appendix C). Upon approval of this work plan by the NDEP, BRC will include the SOPs that describe these field procedures in the field sampling standard operating procedure (FSSOP) document.

As discussed in Section 3.1, four potential pumping test wells will be slug tested to evaluate permeability and for comparison with later pumping test results, if conducted. In addition, wells AA-13 and AA-22, which have a limited water column, will also be slug tested to provide additional coverage within the Aa. Wells completed in the TMCf produce little water, but generally contain a sufficient water column to be considered as good candidates for slug testing. BRC therefore proposes to test wells MCF-03B and MCF-16B using the slug testing method.

4.7 Task 7: Conduct Step-Drawdown Tests

Step-drawdown tests are single-well tests used to obtain information on well yield, well efficiency, and the specific capacity of the well. Step-drawdown tests will be performed in accordance with the DBS&A standard operating procedure (Appendix C). Step-drawdown tests will be performed at well AA-07, AA-09, AA-20, and MCF-06C if possible, following Task 4. At locations AA-08 and AA-026, the step-drawdown tests will be conducted on the newly constructed pumping wells. The test data will be analyzed using AQTESOLV (see Section 4.8 for additional details) to allow a suitable pumping rate to be determined for the proposed constant-rate pumping tests. The step-drawdown data will also be analyzed to determine well efficiency.

Prior to performing the test, a pump, valves, instantaneous and totalizing flow meters, stilling tube, and discharge line will be installed at the pumping well. The pump will be installed near the base of the well so that the well may eventually be completely evacuated. Three to four steps will be performed at increasingly higher pumping rates; the magnitude of each step rate will ultimately be determined in the field based on the water level response. Following the step test, the transducer will be left in the well to record the rate of water level recovery.

Proposed pumping rates for each step were chosen based on previous experience at sites with similar hydrogeology, as well as through some simple, preliminary AQTESOLV runs. Because well AA-09 produced significant water during well development, it will be pumped at a much higher rate than low-producing wells (e.g., AA-20 or MCF-06C). The proposed pumping rate for each “step” at wells AA-07, AA-09, AA-20, and MCF-06C is presented in Table 2. Appropriate pumping rates for the step tests at the new wells installed adjacent to AA-08 and AA-26 will be determined based on well development information collected when these wells are drilled.

The proposed pumping rates are estimated based on approximate analysis of well development and purging data. Therefore, it is likely that the rates shown in Table 2 for steps 2 through 4 may need to be adjusted; such a decision will be made in the field based on the response of the aquifer to pumping. The pumping rate will be chosen so that the rates are roughly proportional to each other and the last step causes the well to go dry. To avoid generating excessively large volumes of groundwater, the maximum proposed pumping rate will be 100 gpm.

During each step, the well will be pumped without interruption for approximately 90 to 120 minutes. If the water level in the well stabilizes (changing less than 0.02 foot per hour), the pumping level will be increased and a new step started. During the pumping and recovery periods of the test, water levels in the well will be closely monitored, both manually and using data loggers and pressure transducers. When pumping ceases, the water level in the well will be closely monitored until the well has recovered to 90 percent of its original water level.

Based on these data, the degree of hydraulic connection between each proposed test well and the surrounding aquifer materials will be qualitatively evaluated and the need to redevelop the well will be assessed. If the well needs to be redeveloped, this task will occur on the day following the step-drawdown test. During and immediately after the redevelopment, water levels will be monitored to confirm that they will recover sufficiently to allow a second step-drawdown test to be performed the day following the well redevelopment.

All groundwater generated during the test will be stored on-site in BRC's 5,000-gallon tank pending proper disposal after sampling. Additional storage capacity will be acquired on a temporary basis if needed.

4.8 Task 8: Conduct Constant-Rate Pumping Tests

DBS&A proposes to perform the pumping tests in a single field effort. Pumping tests will be performed in accordance with the DBS&A standard operating procedure (Appendix C). Owing to the large distances between the wells, it is not likely that pumping tests at any of the proposed locations will induce drawdown at the other proposed aquifer test locations. Prior to the initiation of the aquifer pumping tests, transducers will be installed in the pumping and observation wells as outlined in Table 1.

The first test will be performed at the AA-09 location followed by the AA-07, AA-26, AA-08, AA-20, and MCF-06C locations. Note that this proposed order may have to be adjusted, as dictated by field conditions or logistical considerations. The same general procedure will be used to test all of the wells. The constant-rate pumping test will be conducted in three phases: (1) collection of pre-test water level and weather station data, (2) the pumping period, and (3) the recovery period. Each of these phases is discussed below.

4.8.1 Pre-Test Data Collection Period

Collecting data to characterize the pre- and post-test water levels is essential for successful analysis of the test data (Driscoll, 1986). The pre-test water level data provide the basis for correcting test data to account for ongoing regional water level fluctuations that may be influenced by factors such as precipitation or changes in barometric pressure.

The local pre-test groundwater level fluctuations will be determined using data loggers/ pressure transducers installed in all observation wells associated with a given constant-rate test. The period of pre-test data collection will be one week. Barometric pressure data will be collected to correct for the effect of barometric changes on observed water levels, if needed. The barometric pressure data will also be used to evaluate whether changes in Deep Zone water levels (if observed) can be attributed to pumping or not.

4.8.2 Pumping Period

All watches and data logger clocks used by the field personnel to record the time of depth-to-water measurements will be synchronized. Two persons will be on-site during the test to manually monitor water levels in the wells, to monitor the pumping rate and adjust the valves to maintain as constant a pumping rate as possible, to collect groundwater samples for field and laboratory analysis, and to verify that the data loggers are operating properly (measuring water levels, the pumping rate, precipitation, and barometric pressure).

Immediately before pumping begins, static water levels in all wells being monitored during the test will be recorded. Once pumping begins, water levels in wells being monitored using data loggers will also be measured manually to the extent practical in case of data logger failure and to provide quality assurance/quality control (QA/QC) of the test data.

There are no firm rules regarding the time frame for measuring water levels at wells used during a pumping test. It is important that measurements in observation wells occur often enough and soon enough after pumping begins to avoid missing the initial drawdown in each well. As time since pumping started increases, less frequent measurements are needed to adequately define the water level response curve. DBS&A will follow the ASTM guidelines (ASTM, 1996) to monitor the water level changes at the Site. Expected measurement frequencies are provided in Table 3.

At the start of the test, the pumping rate will be brought up to the designated rate as quickly as possible. The valves used to control the pumping rate will have been preset the day before the start of pumping. Attaining and maintaining the desired pumping rate will require diligence from the field crew as they monitor and adjust the discharge rate. During the initial hour of the test, well discharge at the pumping well will be monitored and recorded as often as is practical.

The discharge will not be allowed to vary more than ±5 percent from the design rate, although some random short-term variations in the discharge rate will likely occur and are acceptable if the average discharge does not vary by more than ±5 percent (ASTM, 1996).

Groundwater samples will be collected from the pumping well for field analyses. Specific conductance, dissolved oxygen, temperature, and pH of groundwater being discharged from the pumping well will be measured in the field every 2 hours.

As pumping proceeds, the drawdown data will be plotted on semi-log paper to monitor the status and effectiveness of the test. Plotting the data may also allow the field staff to identify erroneous data, which is especially important when data loggers are being used to collect water level data. Finally, the plots of drawdown will indicate when enough data for a solution have been collected, indicating that the pumping period may be stopped.

The anticipated length of the test at well AA-09 is expected to be 8 to 24 hours, while an 8-hour test is anticipated at wells AA-07, AA-20, and MCF-06C. The tests at wells AA-08 and AA-026 are expected to last 24 to 72 hours. Pumping will continue until the drawdown has stabilized, or the collected data are adequate to define the shape of the drawdown curve and permit the desired parameters to be calculated. Following the stabilization of drawdown, pumping may be continued to investigate the potential presence of local hydraulic boundaries (e.g., the effect of paleochannels or of laterally limited permeable units). The decision of how long to pump the well will be made as the test is being performed and will depend on the response of the aquifer to the pumping stress.

4.8.3 Recovery Period

As soon as the pumping stops, water level recovery will be measured in the same manner as drawdown measurements. These measurements will be collected until water levels have recovered to 90 percent of their pre-test levels. Water levels, barometric pressure, and rainfall will be monitored for three to seven days after pumping stops; these data will provide the basis for the use of any corrections that may be identified as necessary using the pre-test data.

4.8.4 Investigation-Derived Waste Management

All extracted water will be containerized on-site and will be transported to an approved disposal facility, depending on test data.

4.9 Task 9: Analyze Testing Data

The pumping test data will be analyzed as described in the following subsections.

4.9.1 Data Compilation

Data recorded by the data loggers will be downloaded from field computers, and manually collected measurements will be entered into spreadsheets. To analyze drawdown data, DBS&A will use the AQTESOLV (Version 3.50) software program developed by HydroSOLVE, Inc. (2002). AQTESOLV provides an option to analyze data from multiple observations simultaneously, yielding a single set of hydraulic parameter estimates that are consistent with data from all observation wells over the entire test period (pumping and recovery). The analysis entails an automatic least squares fit of the drawdown data to a set of theoretical curves corresponding to the various observation wells. The curves are based on mathematical expressions developed by various authors to fit a variety of hydrogeologic conditions. To obtain meaningful results, the analyst must select curves that are appropriate to the circumstances of the test.

4.9.2 Data Analysis

The data analysis task includes the calculation of drawdown and groundwater elevations and corrections of the raw data to account for external influences such as changes in barometric pressure or nearby pumpage. The tasks that will be performed include:

- Calculation of drawdown using measured changes in water levels from static conditions

- Calculation of groundwater elevations for multiple-well comparison of pumping influences

- Correction of drawdown data to account for any influence(s) due to nearby pumpage (not expected to occur), precipitation, barometric influences, or other regional factors

- Preparation of maps that illustrate the plan view of drawdown

- Analysis of the well data using the AQTESOLV program, most likely using the Theis, and/or Cooper-Jacob solutions, which are the most widely accepted solutions

- Manual analysis of distance-drawdown based on the drawdown data

These analyses will allow the transmissivity, hydraulic conductivity, specific storage, and storativity of the aquifer to be calculated. These data, used in conjunction with data collected from the core samples, will result in development of a more accurate constraint on specific yield.

4.10 Task 10: Prepare Report

A draft report will be prepared and submitted to the NDEP that details the following:

- Methodologies used along with photographic documentation
- Discussion of results
- Site plan illustrating pumping and observation well locations
- Waste management procedures and manifests
- Raw data, including calculation sheets, software output, and laboratory reports
- An analysis of the connectivity of the three Site water-bearing zones, based only on an evaluation of recent groundwater well elevation and water quality sample data

A final report will be produced once comments on the draft report are received from the NDEP.

4.11 Schedule

BRC anticipates that the field work described in this work plan can be initiated four to six weeks after work plan approval, subject to availability of appropriate subcontractors for drilling and pump and generator setup and removal. It is anticipated that the field testing described in this work plan can be accomplished in five weeks. Data analysis and reporting can be accomplished in an additional four weeks, with a final report submitted to NDEP at that time.

References

American Society for Testing and Materials (ASTM). 1996. *Standard field test method (field procedure) for withdrawal and injection well test for determining hydraulic properties of aquifer systems*.

BRC, Environmental Resources Management (ERM), Montgomery Watson Harza (MWH), and Daniel B. Stephens & Associates, Inc. (DBS&A). 2006. *BRC closure plan, BMI Common Areas, Clark County, Nevada*. August 2006.

Bell, J.W. and E.I. Smith. 1980. *Geologic map of the Henderson Quadrangle, Nevada*. Nevada Bureau of Mines and Geology Map 67.

Bentley, H.W., F.M. Phillips, and S.N. Davis. 1986. ^{36}Cl in the terrestrial environment. pp. 422-475 *in* Fritz, P. and J.C. Fones (eds.), *Handbook of environmental isotope geochemistry*. Elsevier Science, New York.

Carlsen, C.L., R.C. Lunnis, and D.E. Prudie. 1991. *Changes in water levels and water quality in shallow groundwater, Pittman-Henderson Area, Clark County, Nevada, resulting from diversion of industrial cooling water from ditch to pipeline in 1985*. U.S. Geological Survey Water-Resources Investigation Report 89-4093. Carson City, Nevada.

Daniel B. Stephens & Associates, Inc. (DBS&A). 2006. *Groundwater modeling work plan for BMI Upper and Lower Ponds area*. Prepared for Basic Remediation Company. November 8, 2006.

Driscoll, F.G. 1986. *Ground water and wells*. 2nd ed. Johnson Division, St. Paul, Minnesota.

HydroSOLVE, Inc. 2002. *User's guide: AQTESOLV for Windows*. December 4, 2002. Reston, Virginia.

International Atomic Energy Agency (IAEA)/World Meteorological Organization (WMO). 1998. *Global network of isotopes in precipitation*. The GNIP Database.

Illinois Environmental Protection Agency. 1997. *Use of tritium in assessing aquifer vulnerability*. October 1997. Available at <http://www.epa.state.il.us/watr/tritium.html>.

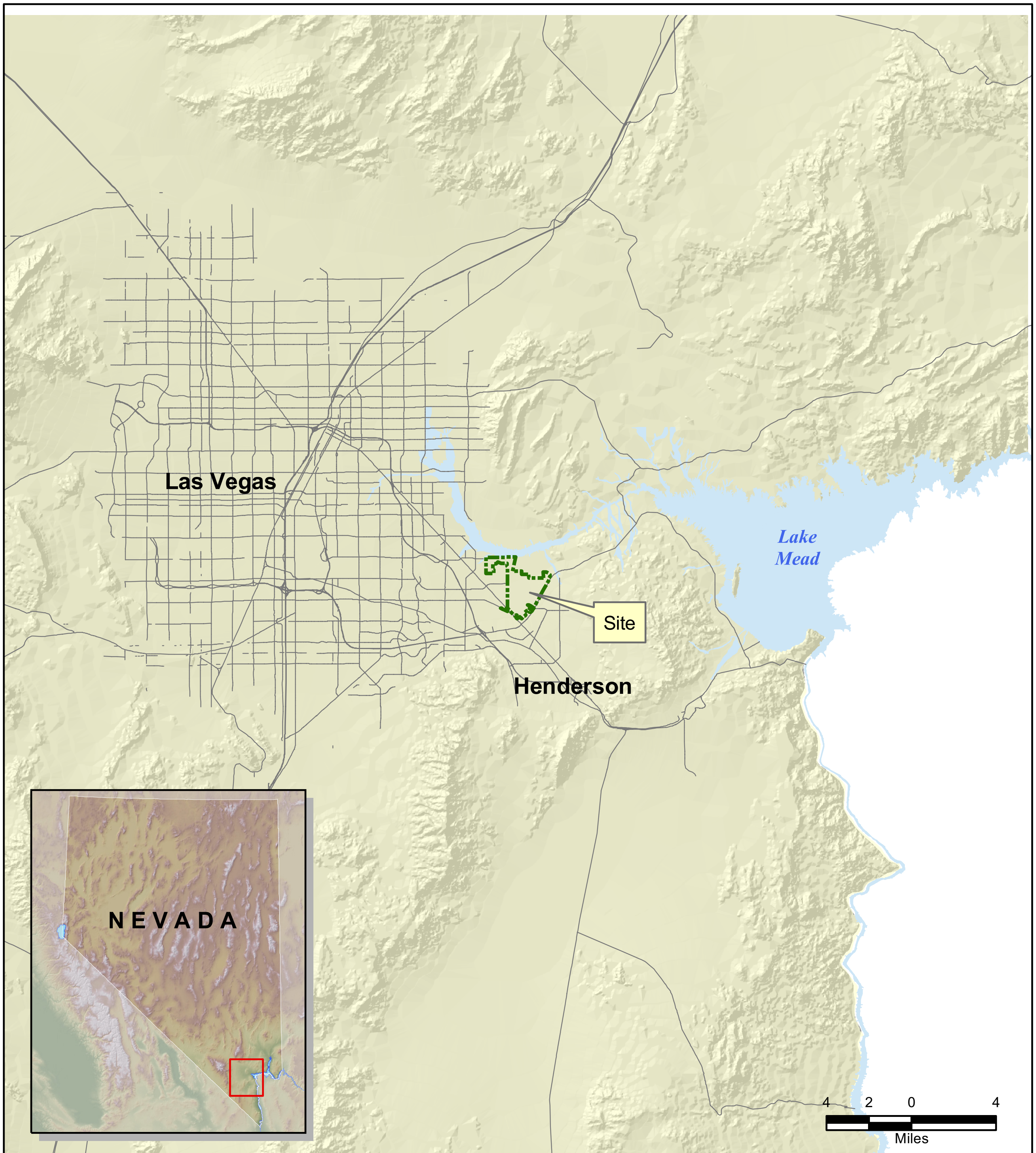
Kruseman, G.P. and N.A. de Ridder (with assistance from J.M. Verweij). 1990. *Analysis and evaluation of pumping test data*. 2nd ed. Publication 47, International Institute for Land Reclamation and Improvement, The Netherlands.

MWH Americas, Inc. (MWH). 2006. *BRC field sampling and standard operating procedures, BMI Common Areas, Clark County, Nevada*. Prepared for Basic Remediation Company, Henderson, Nevada. May 2006.

Todd, D.K. and L.W. Mays. 2005. *Groundwater hydrology*. 3rd ed. John Wiley & Sons, Inc.

U.S. Environmental Protection Agency (U.S. EPA). 1993. *Suggested operating procedures for aquifer pumping tests.*

Figures



BMI Common Areas (Eastside)
Henderson, Nevada

FIGURE 1

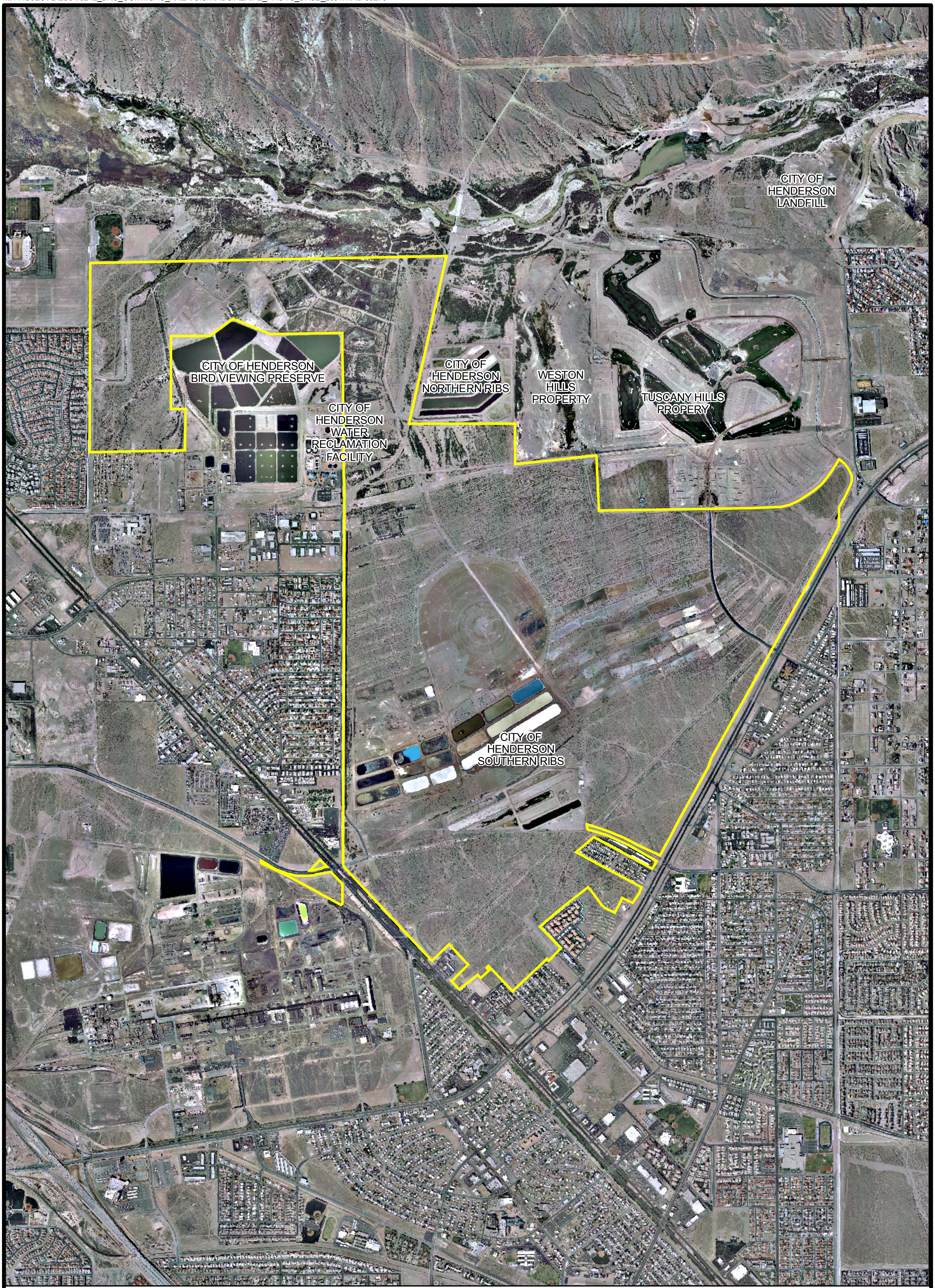
SITE LOCATION

Basic Remediation COMPANY

Prepared by: MWH MKJ	Date 10/14/04	JOB No. 3850357 FILE: GIS/BRC/FIGURE1-1.MXD

M:\PROJECTS\ES04.0212_BRC_COMMONS_AREA\VR_DRAWINGS\WORKPLAN_SITE_LOCATION_FIGURE_1_09_06_06.PDF

M:/PROJECTS/ES04.0212_BRC_COMMONS_AREA/GIS/MXDS/AERIAL_PHOTO_BASE_2004.MXD 602//9



N

0 2,000 Feet

Explanation

Site boundary

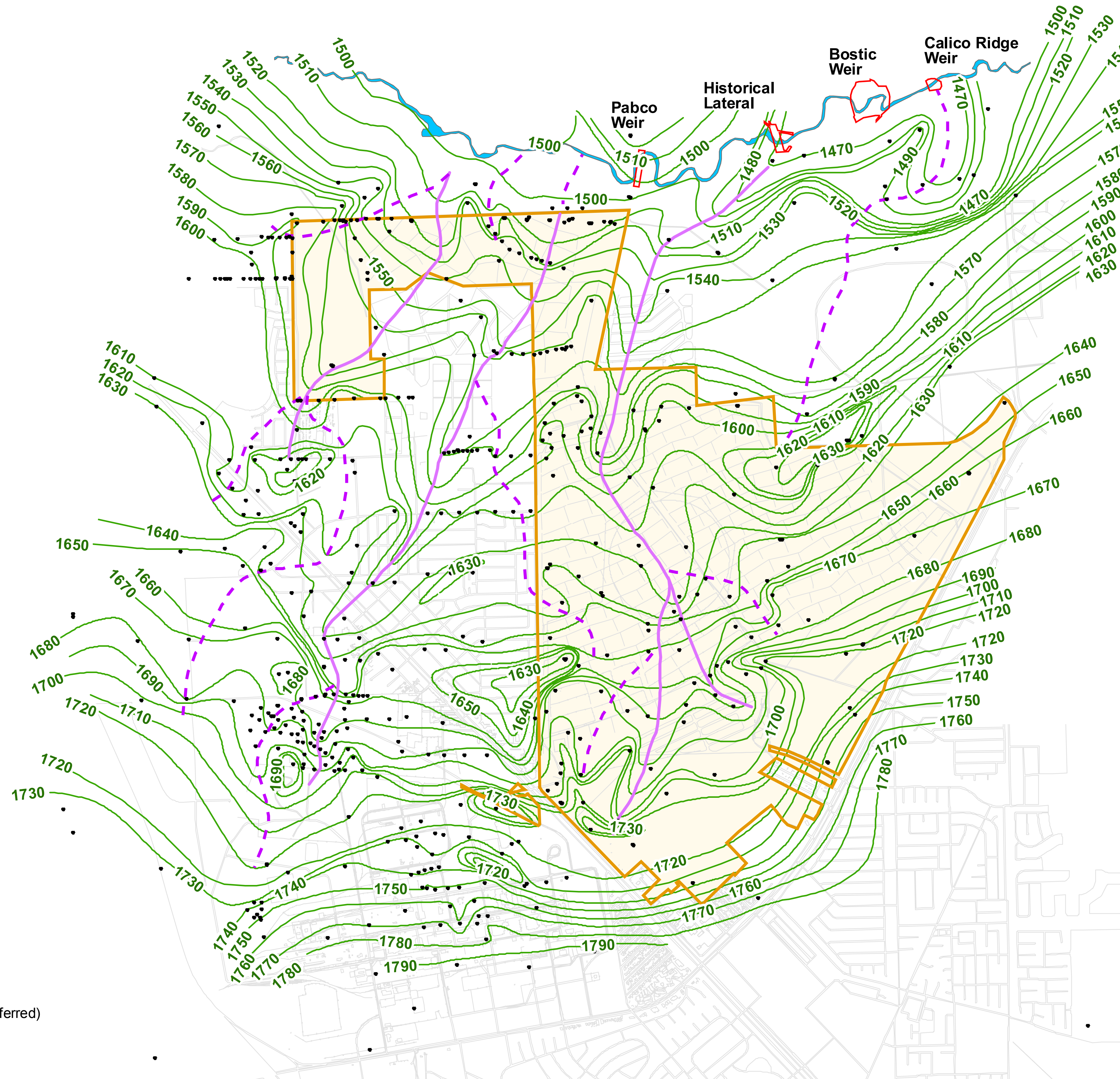
BMI Common Areas (Eastside)
Henderson, Nevada

FIGURE 2
AERIAL PHOTOGRAPH
SEPTEMBER 2003

Basic Remediation COMPANY

Prepared by: DWR (DBS&A)

Date: 09-08-06



Note:
Although work is ongoing to further delineate the paleochannels, the channels depicted are thought to be the primary subsurface features.

N

0 1,250 2,500 Feet

- Site
- Data point used in contouring
- Muddy Creek contour
- Paleochannels (dashed where inferred)

S:/PROJECTS/BRC/ES04.0212_BRC_COMMONS_AREA/GIS/MXDS/TOP_MUDDY_CREEK_11-6-06_11X17.MXD

Daniel B. Stephens & Associates, Inc.

BMI Common Areas (Eastside)
Henderson, Nevada

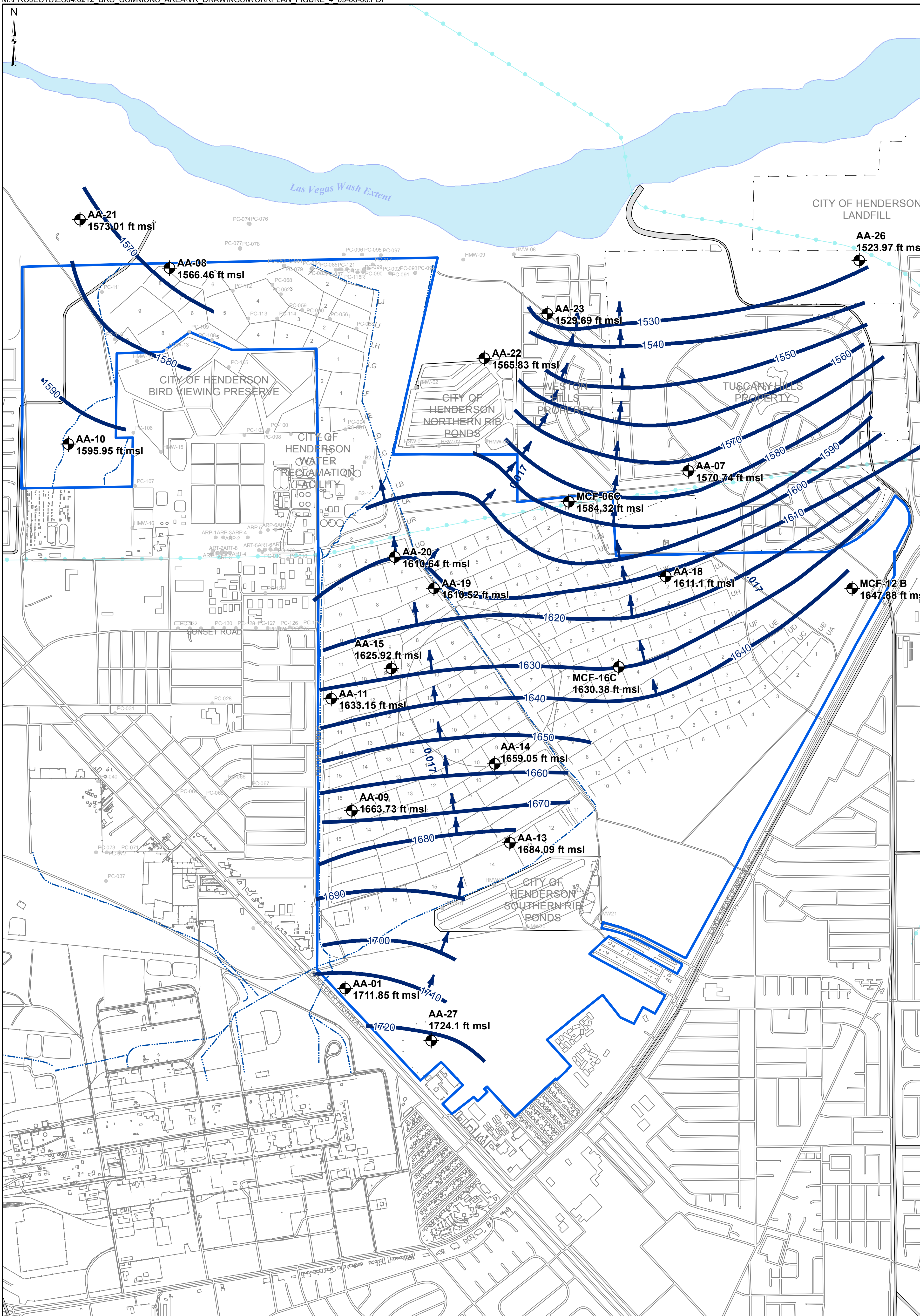
FIGURE 3

TOPOGRAPHIC SURFACE OF THE MUDDY CREEK FORMATION

Basic Remediation Company

Prepared by: DWR & TNB (DBS&A) Date: 11-07-06

M:\PROJECTS\ES04.0212_BRC_COMMONS_AREA\VR_DRAWINGS\WORKPLAN_FIGURE_4_09-06-06.PDF



Site Boundary

Ditches

Flood Conveyance Channels

Laterals

ft msl = feet above mean sea level

Monitoring Well Location

Water Level Contour (Contour Interval = 10 ft)

Direction of GW flow indicated by GW elevation contours

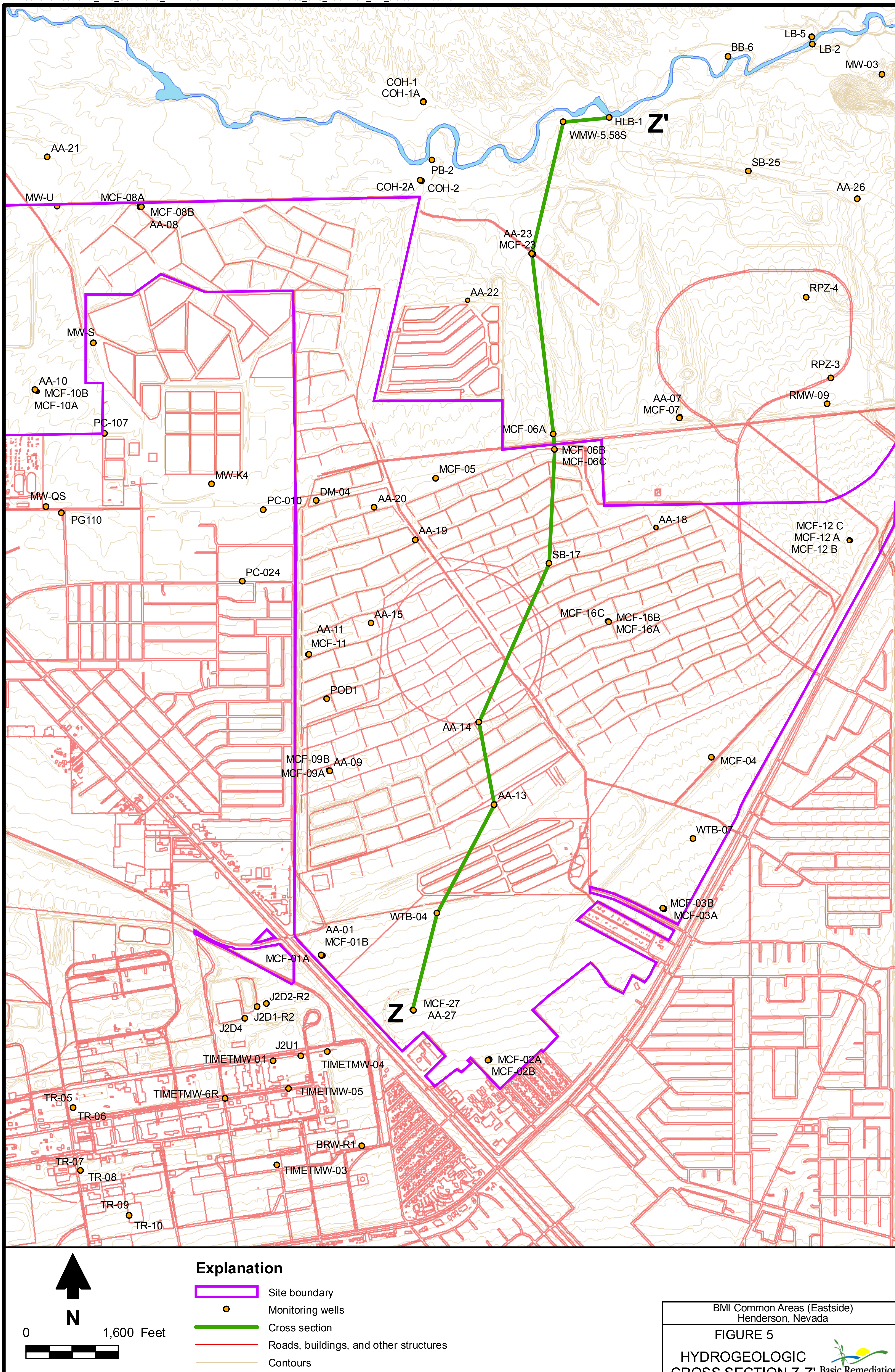
BMI Common Areas (Eastside)
Henderson, Nevada

FIGURE 4
ALLUVIAL AQUIFER (Aa) GROUNDWATER ELEVATIONS

Basic Remediation COMPANY

Prepared by:	Date	JOB No. 1881425
MWH MKJ	09/08/06	FILE: GIS/BRC/FIGURE_4-5.MXD

M:/PROJECTS/ES04.0212_BRC_COMMONS_AREA/GIS/MXDS/WORK PLAN/CROSS_SEC_LOCATION_Z-Z'_9-6-06.MXD 602//9



Explanation

- Site boundary
- Monitoring wells
- Cross section
- Roads, buildings, and other structures
- Contours
- Las Vegas wash

Daniel B. Stephens & Associates, Inc.

BMI Common Areas (Eastside)
Henderson, Nevada

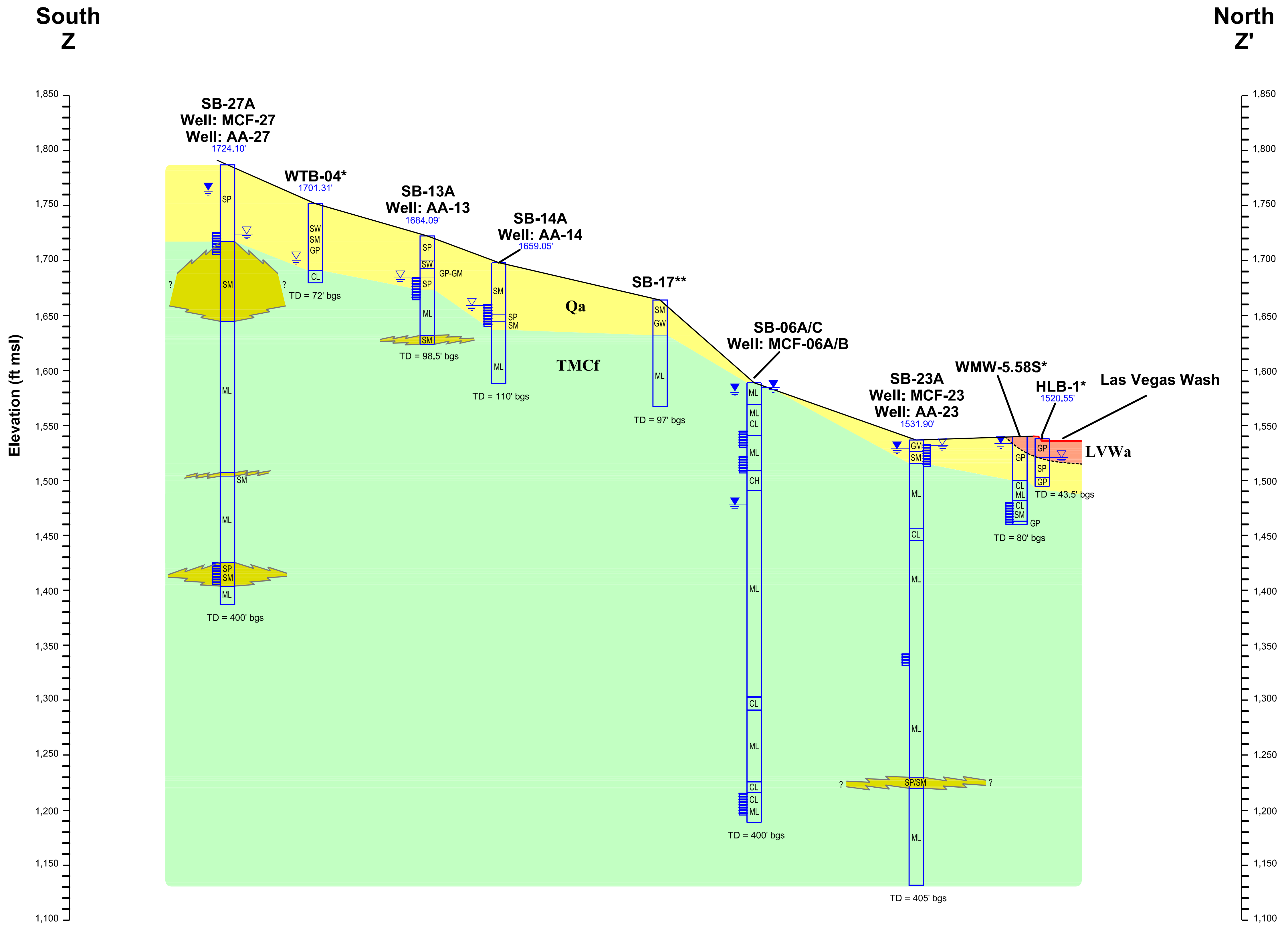
FIGURE 5

HYDROGEOLOGIC CROSS SECTION Z-Z' LOCATION MAP

Basic Remediation Company

Prepared by: DWR (DBS&A)

Date: 09-08-06



Explanation

CH	High plasticity clay
CL	Low plasticity clay
ML	Low plasticity silt
SM	Silty sand
SP	Poorly graded sand
SW	Well-graded sand
GM	Silty gravel
GP	Poorly graded gravel
GW	Well graded gravel
	Well & well screen
	Water level for wells completed in Qa
	Water level for wells completed in TMCf
1724.1	Groundwater elevation for Qa
Qa	Quaternary alluvium
TMCf	Tertiary Muddy Creek Formation
LVWa	Las Vegas Wash Alluvial sediments
	Coarse-grained facies change
	Dashed where contact inferred

0 — 2000 ft

20X vertical exaggeration

Note: Groundwater elevations measured in July 2004

* Groundwater elevations in these wells were not measured contemporaneously with the other wells

** No well was installed at the SB-17 location because groundwater was not encountered

T:\VDR\0-VDR-PROJECTS\00-ENV_SERVICES\ES04_0212\ES04_0212_22F_Z-Z.DWG

Daniel B. Stephens & Associates, Inc.

BMI Common Areas (Eastside)
Henderson, Nevada

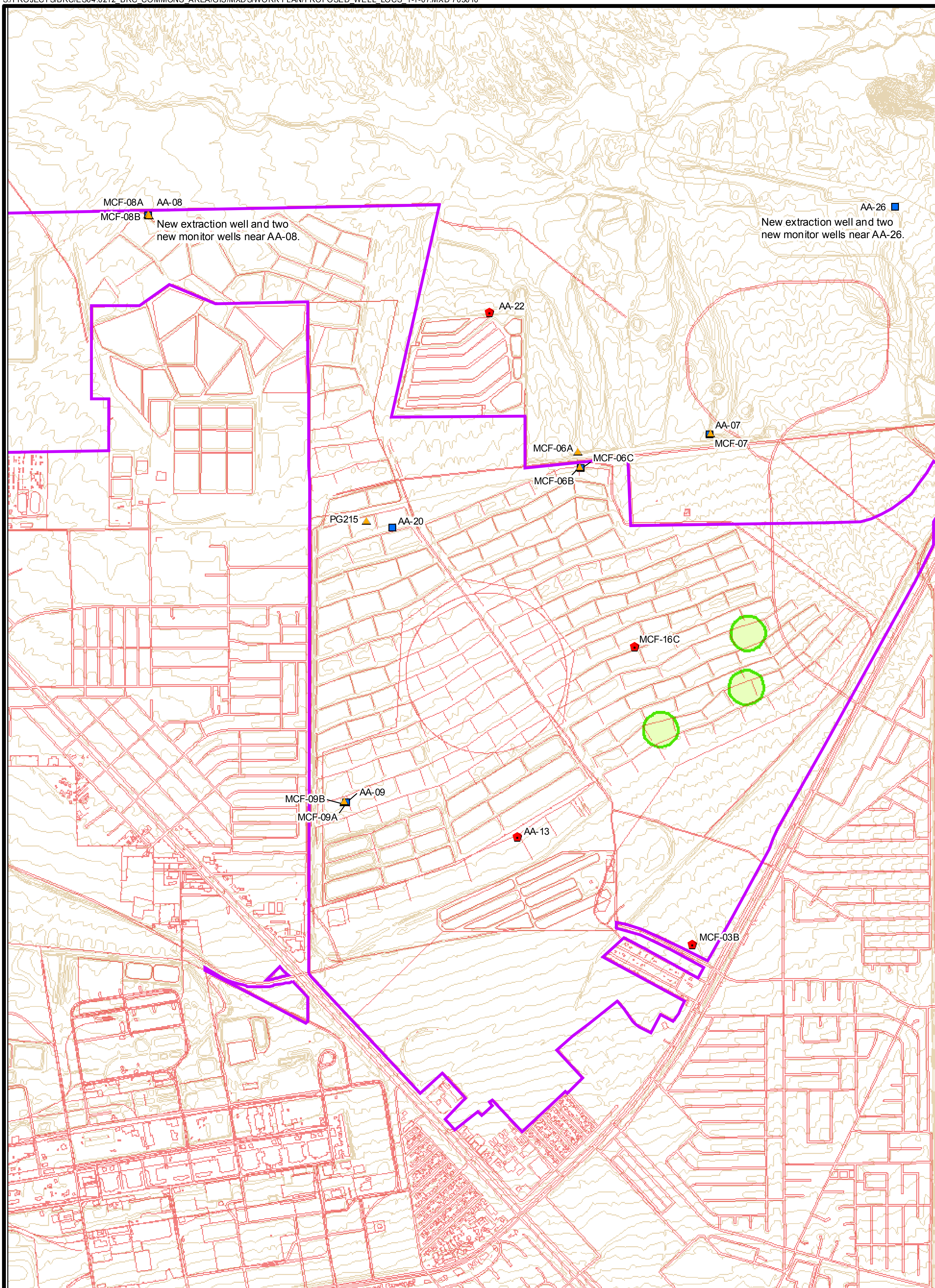
FIGURE 6

HYDROGEOLOGIC CROSS SECTION Z-Z'

Basic Remediation Company

Prepared by: DWR (DBS&A) Date: 09-08-06

S:/PROJECTS/BRC/ES04.0212_BRC_COMMONS_AREA/GIS/MXDS/WORK PLAN/PROPOSED_WELL_LOCS_1-1-07.MXD 705010



N

0 1,500 Feet

Explanation

- Proposed well for slug test
- Proposed pumping well for aquifer test
- Proposed observation well for pumping test
- Site boundary
- Proposed zone for laboratory core analysis of alluvial sediments

BMI Common Areas (Eastside)
Henderson, Nevada

FIGURE 7

PROPOSED TEST WELLS

Prepared by: DWR (DBS&A)

Date: 09-08-06

Daniel B. Stephens & Associates, Inc.

Tables

Table 1. Summary of Aquifer Testing Program

Wells Included in Testing Program	Observation Wells
AA-13 (slug test only)	NA
AA-22 (slug test only)	NA
MCF-03B (slug test only)	NA
MCF-16C (slug test only)[1,2]	NA
AA-09 (slug and pump test)[2]	MCF-09A
	MCF-09B
AA-20 (slug and pump test)[2]	PG 215
MCF-06C (slug and pump test)[2]	MCF-06A
	MCF-06B
AA-07 (slug and pump test)[2]	MCF-07
New pumping well at AA-08 (pump test)	AA-08, MCF-08A, MCF-08B and two new observation wells screened across the saturated portion of the Qal
New pumping well at AA-26 (pump test)	AA-26 and two new observation wells screened across the saturated portion of the Qal

NA = Not applicable
[1] This well is screened across Qal sediments
[2] One observation well screened across the Qal will be constructed if a pump test is performed

Table 2. Proposed Step-Drawdown Test Pumping Rates

Step	Pumping Rate (gallons per minute)			
	AA-07	AA-09	AA-20	MCF-06C
1	0.5	25	0.5	0.5
2	1.0	50	1.0	1.0
3	1.5	75	1.5	1.5
4	2.0	100	2.0	2.0

Table 3. Recommended Measurement Time Intervals

Elapsed Time	Measurement Frequency
0 to 3 minutes	Every 30 seconds
3 to 15 minutes	Every minute
15 to 60 minutes	Every 5 minutes
60 to 120 minutes	Every 10 minutes
2 to 8 hours (or shutdown)	Every 30 minutes
8 hours to shut down	Every 4 hours

Appendix A

Responses to Comments

Appendix A1

Responses to NDEP Comments on BRC's Aquifer Testing Work Plan dated November 9, 2006

Responses to NDEP Comments on BRC's Aquifer Testing Work Plan
BMI Common Area Eastside, Henderson, Nevada dated November 9, 2006

1. Response-to-comments (RTC) Letter, the NDEP has the following comments:
   a) In the future, please include the RTC letter as an appendix to the subject document.
   b) RTC 12, it is not clear to the NDEP how the inclusion of an additional 520 data points has resulted in a reduction in the level of detail regarding the locations of paleochannels. It appears to the NDEP that BRC has added data points but has not utilized all available data points for the development of the figure which presents the paleochannels. The NDEP requests that BRC develop and submit a large map which posts all data used to develop the paleochannel map. This map should include the contouring that BRC has used for its interpretation of the location of the paleochannels.

Response: In the future all RTC letters will be included in the appendix to the subject document. The large map requested will be submitted, under separate cover, along with this RTC and update to the Aquifer Testing Work Plan. The statement that the data that were used to create the map includes "an additional 520 data points" needs clarification. It is correct to state that the inclusion of the additional data brings the total up to approximately 520 data points. The most recently incorporated data represents approximately 150 additional data points. All of the data available to BRC (including data obtained pursuant to requests made of other entities) were used to generate the topographic contours of the surface of the structural contact between the Qa and the TMCf. No detail or data was omitted, and all of the data points were used in the constructing the topographic contour map. This matter was also discussed at the last (November 17, 2006) All Companies meeting.

2. Section 1, page 1, 2nd paragraph, please clarify that the modeling "report" referred to is actually the Groundwater Modeling Work Plan.

Response: The clarification has been made.

3. Section 2.2.2, page 5, 1st paragraph, BRC states "One possible ramification of the presence of these coarser TMCf sediments near the southwestern border of the Site is that they may serve as a potential pathway for chemicals to migrate into the TMCf." Please remove all hypotheses regarding potential contaminant sources because this document is an aquifer test work plan and not a report of findings from an investigation.

Response: The referenced comment is in the background section of the work plan, which is provided as an overview and context of site geology and hydrogeology as currently understood and also highlights some key issues that BRC believes are important for consideration as part of the Aquifer Testing Work Plan. For this reason, BRC respectfully believes that the statement should remain.

4. Section 2.3.2, page 7, 2nd paragraph, BRC state "It is BRC's hypothesis, based on Site investigations to date and the geologic setting of the area, that groundwater in the Deep Zone is not hydraulically connected to the Aa situated above it at the Site. BRC recognizes that NDEP does not agree with this hypothesis, but rather believes that a direct hydraulic connection might exist between the Aa and groundwater in the Deep Zone." Please remove all hypotheses

regarding potential contaminant sources because this document is an aquifer test work plan and not a report of findings from an investigation.

Response: BRC respectfully believes that this statement provides context and useful information regarding the purpose of some of the testing proposed in the Aquifer Testing Work Plan, and therefore should remain.

5. Sections 3, 3.1, and 3.2, general comment, these sections need to be reviewed and re-written by BRC for clarity and consistency within the document. Some examples are provided below.

Response: These sections have been reviewed and re-written where necessary.

6. Section 3, page 8, 2nd paragraph, please remove this paragraph as it appears to add confusion and does not clarify the discussion in the previous paragraph.

Response: This section has been edited to address this comment. The point that observed water levels in some Aa wells have declined significantly since monitoring began is an important observation that potentially affects aquifer testing activities described in the work plan. Discussion of this issue, therefore, is retained in Section 3.0.

7. Section 3.1, page 9, the first sentence in this section references eight wells, however the latter sentence references nine wells as shown in quotations. "While four of these wells are scheduled for slug tests only (AA-13, AA-22, MCF-3B, and MCF-16B), five additional wells (AA-07, AA-08, AA-09, AA-20, and MCF-06C)…" Please clarify what is intended.

Response: In the second clause of the sentence reproduced in this comment, well AA-08 should not have been listed and it has been omitted. This clause has been edited to read "four" additional wells, which are AA-07, A-09, AA-20 and MCF-06C. In addition, in the first clause of the sentence reproduced in the above comment, the well listed as MCF-16B should actually be MCF-16C (which has the same location, but a shallower screen); this edit has also been incorporated in the work plan. Please note that well MCF-16C is actually screened across the Aa at this location.

8. Section 3.2, page 9, BRC states "Pumping tests are proposed at wells AA-07, AA-08, AA-09, AA-20, AA-026, and MCF-06A." , however, BRC stated in Section 3.1 that these wells will have aquifer tests only if recovery data indicate that an aquifer test would be successful. Please clarify what is intended.

Response: Additional language has been added to this section to further clarify this point. The approach that BRC proposes is provided in the items numbered 1 through 4 at the end of Section 3.2.1.

9. Section 3.2, pages 9 and 10, please clarify that the planned tests will be conducted for a period of 8- to 24-hours.

Response: The clarification has been made.

10. Section 3.3, page 10, it is not clear to the NDEP how BRC selected the locations for hydraulic testing of the cores. All of the locations that are selected on Figure 7 are located in the "Upper Eight Rows" sub-area and these results may not be representative of conditions in other areas of the Site. This issue should be discussed in the final report.

Response: The first sentence of Section 3.3 provides BRC's rationale for the selected locations. It reads, in part, "... hydraulic testing of cores is proposed at several locations where the alluvium is not saturated ... and where significant infiltration of waste water may have occurred historically based on aerial photographs." The proposed locations meet both of these criteria.

11. Section 4, general comment, it is also important for BRC to research and note regional issues that may affect the various hydraulic tests. Examples are discussed as follows: regional pumping or injection of drinking water; infiltration of waste water at the City of Henderson RIBs; localized dewatering operations due to construction in the vicinity of the Site; and seasonally dependent activities (for example, watering at nearby golf courses will be reduced in the colder months).

Response: Comment noted.

12. Section 4.3, page 19, BRC notes that a weather station will be installed. A weather station already exists at the BMI Complex and it is likely not necessary to install another one.

Response: Comment noted and appropriate edits made.

13. Section 4.4, page 20, BRC indicates that hydrologic testing of the soil cores will be performed by DBS&A. It is suggested that BRC consider utilizing an independent, third-party laboratory to perform this analysis.

Response: While noting NDEP's comment, BRC respectfully believes that this is not necessary. The DBS&A Hydrologic Testing Laboratory is a nationally recognized, highly respected laboratory that specializes in the determination of vadose zone hydraulic parameters and soil and sediment properties. The laboratory has been in operation for over 20 years, follows all applicable ASTM standards and protocols, and is currently certified by the AASHTO Materials Reference Laboratory (AMRL) and United States Army Corps of Engineers (USACE) to accept and analyze samples. The laboratory has been audited by multiple national laboratories (such as Los Alamos National Laboratory and the Idaho National Engineering and Environmental Laboratory) and serves as a certified calibration laboratory for contractors at Yucca Mountain. The laboratory is independent in that it is located in a separate facility and has staff dedicated solely to the operation of that facility in accordance with designated procedures and protocols. ASTM, AASHTO and other testing methods used to generate laboratory reports are standard for the industry. Finally, laboratory testing results are not interpreted by laboratory personnel nor do they constitute a professional or expert opinion.

14. Section 4.5, page 20, BRC indicates that a production well will be installed adjacent an existing well and that the existing well will be used as the observation well. In general, one observation well is not adequate for completion of an aquifer test. Please refer to Analysis and Evaluation of Pumping Test Data (Kruseman and deRidder, 1991). Please note that if three or more observation wells are installed then distance-drawdown methodology may also be used to

analyze the aquifer tests. Comparison of aquifer hydraulic parameters calculated by several different methods will increase the confidence in the test results and hence will increase confidence in BRC's groundwater model.

Response: BRC agrees that, as a general matter, the more observation wells the better. However, as the below references indicate, there is no accepted standard for the number of observation wells required, and it is commonly accepted that a single observation well is sufficient to determine transmissivity and storage coefficient. Observations in the pumping well itself are often sufficient to estimate transmissivity (the storage coefficient cannot be determined from a single well test). Some text on this topic from several standard references is provided below for context regarding our proposed approach (emphasis added):

1) Kruseman and de Ridder (1990, p.32) "The question of how many piezometers to place depends on the amount of information needed, and especially on its required degree of accuracy, but also on the funds available for the test. Although it will be shown in later chapters that ***drawdown data from the well itself or from one single piezometer often permit the calculation of an aquifer's hydraulic characteristics****, it is nevertheless always best to have as many piezometers as conditions permit. Three, at least, are recommended."*

2) Todd and Mays (2005, p. 164) "Average values of S and T can be obtained in the vicinity of the pumped well by measuring in ***one or more observation wells*** *the change in drawdown with time under the influence of a constant pumping rate."*

3) Driscoll (1986, p. 548) "The appropriate number of observation wells depends on the amount of information desired and upon the funds available for the test program. The ***data obtained by measuring the drawdown at a single location outside the pumped well permit calculation of the average hydraulic conductivity, transmissivity and storage coefficient of the aquifer****. If two or more observation wells are placed at different distances, the test data can be analyzed by studying both the time-drawdown and distance-drawdown relationships. Using both these analytical methods provides greater assurance that the calculated transmissivity and storage coefficient values are correct. It is usually advantageous to have as many observation wells as conditions allow because the hydraulic conductivity may vary in one or more directions away from the pumping well. Observation wells placed in a circle around the pumping well will reveal this trend."*

With due consideration of the purpose of the aquifer testing and the fact that the proposed tests will be the first aquifer tests conducted by BRC, we propose the following approach to installation of monitor wells specifically for aquifer testing. The work plan has been amended to reflect this methodology.

Group 1: Wells AA-08 and AA-26. *Significant Qa saturated thickness (40-60 feet) exists at these wells, and we do not anticipate that sustained pumping at a reasonable rate will be a problem. Consequently, we expect to be able to stress a greater volume of aquifer at these locations than at other potential pumping test locations (Group 2, below). At the AA-08 and AA-26 locations, a new 4-inch extraction well will be drilled as discussed in the work plan. In addition, two new, fully penetrating 2-inch diameter observation wells will be constructed. One new observation well will be in line with the existing monitor well (i.e., either AA-08 or AA-26), and the other new monitor well will be at approximately 90 degrees, or cross-gradient from the other monitor well line. At both locations, the existing monitor wells (AA-08 and AA-26) are partially penetrating, and therefore these wells will be the* *farthest from the newly constructed extraction wells to minimize partial penetration effects. If possible, these wells will be about 75 feet from the new extraction wells, which is approximately 1.5 times the approximate aquifer thickness of 50 feet.*

Group 2: Wells AA-07, AA-09, AA-20 and MCF-06C*. Pumping tests are proposed at these wells if it is determined that sufficient pumping can be sustained for a significant period of time, according to the procedure outlined in the four numbered steps in Section 3.2.1 of the revised work plan. If it appears feasible to conduct an aquifer test at one or more of these four locations, we anticipate that the volume of aquifer tested will be small due to the limited saturated thickness of the Qa. If it is determined that aquifer tests can be performed at any of these wells, BRC proposes to install one adjacent, fully penetrating monitoring well in the Qa. Due to the small volume of aquifer that can be tested at these locations because of the limited saturated thickness, it is BRC's belief that multiple observation wells are not warranted. The new observation wells (if any are installed) will likely be very close (e.g., 10 feet) to the proposed pumping well.*

15. Section 4.5, page 20, BRC indicates that the production wells will be screened across the entire Aa saturated thickness. Please clarify if this includes the saturated portion of the Upper Muddy Creek Formation. This comprises the first water bearing zone and is the understanding of the NDEP based upon the discussion included in Section 2.3.1.

Response: The wells will be installed across the saturated portion of the alluvium only. This is the appropriate approach to determine hydraulic parameters for this hydrogeologic unit. If the wells were completed across multiple hydrogeologic units and an aquifer test was performed, it would not be possible to determine discrete hydraulic properties for each unit. Hydraulic properties for the upper portion of the Upper Muddy Creek Formation will be determined through slug testing at two locations (MCF-03B and MCF-06C),with possible follow-on aquifer testing at MCF-06C as described in Sections 3.1 and 3.2 of the work plan. Note that although slug testing is also proposed at well MCF-16C, this well is actually screened across alluvium sediments, rather than the Upper Muddy Creek Formation (see response to Comment No. 7), and test results will therefore be indicative of the saturated portion of the alluvium at that location.

16. Section 4.7, page 21, BRC indicates that step-drawdown tests will be completed at wells AA-08 and AA-026, however, these wells are not shown on Figure 7. Please clarify what is intended.

Response: The figure has been updated to include these wells.

17. Section 4.8, page 23, BRC states "Although it is not likely that these observation wells will show a response to the pumping, these additional data will provide confirmation." Please explain what these wells will provide confirmation of.

Response: This section has been clarified in the work plan. The point of the sentence was that, although BRC does not anticipate drawdown to occur in the particular observation wells referred to, measuring the water level in these wells during the pumping test would confirm the amount of drawdown that actually occurs, even if it is zero.

18. Figure 3, the NDEP will not provide additional comments on this figure at this time. NDEP's lack of comment on this Figure does not indicate concurrence.

Response: Comment noted.

19. Figure 4, the NDEP has commented several times on Figures similar to this in previous letters. It is not clear to the NDEP why BRC has chosen to present a sub-set of the available water level data (neither the City of Henderson nor Tronox Aa wells are included to draw contours). If BRC is representing that this is the most comprehensive depiction of water levels at the Site additional monitoring wells will need to be installed.

Response: This figure is provided to illustrate observed groundwater elevations and the direction of groundwater flow in the vicinity of wells proposed for aquifer testing. Water level information from adjacent sites was not used because it was not available in final form (i.e., appropriately quality assurance and quality control checks had not been made) at the time that this figure was constructed. Regardless, the adjacent site data would not change the observed information at the BRC wells, nor would it change any methods, approaches or procedures proposed in the Aquifer Test Work Plan. Adjacent data will be provided in the report containing results derived from implementing the Work Plan.

20. Appendix B, Standard Operating Procedures, Section 6.2.3.1, page 3 of 7, BRC state "A submersible pump can also be used to rapidly remove water from the test well. If using a pump, it will need to remove a sufficient volume of water from the test well in a matter of seconds; in addition, a check valve should be used to ensure that water in the discharge line does not flow back into the well once the pump is shut off." Strike the word "should" (italics added for reference) and insert "will". Please note that if a check valve is not installed above the pump then backflow will likely render water recovery data meaningless.

Response: Edit made and comment noted.

Appendix A2

Responses to NDEP Comments on BRC's Aquifer Testing Work Plan dated September 11, 2006

Responses to NDEP Comments on BRC's Aquifer Testing Work Plan
BMI Common Area Eastside, Henderson, Nevada dated September 11, 2006

1. General comment, overall the NDEP was pleased with the quality and content of the workplan. Some modifications are required as discussed below.

Response: Comment acknowledged.

2. General comment, in general the work plan is not adequately referenced. The NDEP prefers original references; the EPA 1993 reference, *Suggested Operating Procedures for Aquifer Pumping Test* is not adequate for technical scope in a work plan. The references at the end of *Suggested Operating Procedures for Aquifer Pumping Test* are a good start for original sources. Please address this in future submittals.

Response: Comment acknowledged. Additional original references have been added in the revised work plan.

3. General comment, once finalized, please provide stand alone copies of the Standard Operating procedures in Appendix B for inclusion in BRC's FSP/SOP document.

Response: BRC will include the Appendix B SOPs in the stand-alone BRC FSSOP once this work plan is finalized.

4. Section 2.3, page 6, 3rd paragraph, please note that it is the understanding of the NDEP that the Southern RIBs have not yet been taken out of service. While it may be true that the RIBs have not been used it is not clear to the NDEP that the RIBs may never be used again.

Response: The work plan has been corrected to reflect this comment.

5. Section 2.3.2, page 7, 2nd paragraph, BRC's *2004 Hydrogeologic Characterization Summary BMI Upper and Lower Ponds and Ditches, Henderson , Nevada* report contains perchlorate in groundwater data that does not support the hypothesis discussed in this paragraph. The NDEP would argue that if a site related chemical is found in the deep water-bearing zone, then hydraulic connection exists until BRC proves otherwise. The NDEP has provided numerous comments to this effect in previous submittals.

Response: BRC acknowledges NDEP's alternative interpretation of the data, and it has been noted in the revised work plan.

6. Section 2.3.2, page 7, 2nd paragraph, please discuss if BRC has considered tracer tests or other means of quantifying the connectivity between the Deep Zone and the alluvial aquifer or the Middle Zone.

Response: A section has been added to the Technical Approach section of the workplan, entitled "Evaluation of Connectivity between Site Water Bearing Zones" to address this comment and Comment 7 below.

7. Section 2.3.3, page 7, 3rd paragraph, please discuss if BRC has considered tracer tests or other means of quantifying the connectivity between the Middle Zone and the alluvial aquifer or the Deep Zone.

Response: See response to Comment 6

8. Section 3.1, pages 8 and 9, NDEP requests that all slug tests be repeated no less than three times in each well location.

Response: Per discussions with the NDEP after this comment was received, BRC will repeat the slug tests at least two times. If the results from the first two tests are not essentially the same, then a third test will be conducted.

9. Section 3.2, page 9, 1st bullet. "f the slug test indicates…" should be "If…"

Response: The edit has been made.

10. Section 4.3, page13, 2nd full paragraph. Please note that it is the position of the NDEP that arbitrarily taking measurements such as water levels and comparing them for a qualitative evaluation of hydraulic connectivity will neither demonstrate connectivity nor disprove connectivity. Qualitatively evaluating more than one or more parameter(s) will not provide proof of connectivity or lack thereof.

Response: BRC acknowledges NDEP's comment. We do believe, however, that observation of water levels during the same time period for different hydrogeologic zones will likely provide useful information, and is one potential (although qualitative, and not the only) line of evidence that may assist with interpretation of connectivity between various groundwater units at the Site when considered in addition to other data and observations.

11. It is the belief of the NDEP that there should be a section 4.10 which contains a proposed schedule/timeline for implementation of the work plan.

Response: BRC has included a proposed schedule/timeline for implementation of the work plan in the revised work plan.

12. Figure 3, Topographic Surface of the Muddy Creek Formation, compared to Figure 8-1 Paleochannels from BRC's *2004 Hydrogeologic Characterization Summary BMI Upper and Lower Ponds and Ditches, Henderson , Nevada* shows significantly less detail. Please provide an explanation of the decreasing level of detail. Also to be noted, this Figure contains significantly less detail than a similar Figure developed by Kerr-McGee titled "Plate 3 Structure Map on Top of the Muddy Creek Formation" dated July 15, 1998. If BRC is uncertain regarding the location

of the paleochannels it is suggested that the paleochannels be presented as dashed lines. Additional investigative and intrusive work should be completed to address this data gap.

Response: BRC understands that the NDEP reference to "significantly less detail" refers to the reduction in the number of paleochannels identified on the figure. BRC has provided a revised figure in the revised work plan that delineates additional possible paleochannels locations as requested by NDEP. The referenced Kerr-McGee map was based on less data (less than 300 data points) than the referenced map produced by BRC (approximately 520 data points).

13. Figure 7, it appears that there are not sufficient observation wells for the pumping tests proposed at any of the locations to enable BRC to calculate storativity. Please justify the need for or lack of need for calculation of aquifer storativity.

Response: We anticipate estimation of a storativity from aquifer test results at wells AA-08 and AA-026, where new pumping wells are proposed and we expect to be able to sustain significant pumping for a significant period of time (see below). Based on review of the first and second quarterly groundwater monitoring data, we do not believe that the other selected test wells can be pumped at a reasonable, constant rate for a significant period of time, and therefore we have not proposed to install monitor wells at these locations. Because storativity is an aquifer parameter that is generally not highly variable, we believe that estimation of this parameter at two locations is sufficient.

14. Appendix B, Section 6.2.3.1 Causing the Water Level Change, pg 3 of 7, 1st paragraph of section, next to last line. "…a check valve *should* be used…" needs to be changed to "…a check valve *will* be used…"

Response: The indicated change has been made.

Additional Comment. In its October 20, 2006 letter to BRC, NDEP addressed a geographic area underlain by groundwater as follows:

a. Bound on the north by the Las Vegas Wash as described in the Phase 3 Settlement Agreement and Administrative Order on Consent.
b. Approximately bound on the west by the Lower Ponds and City of Henderson WRF. This is delineated by the location of well PG-214.
c. Approximately bound on the east by the extents of the model domain as defined by BRC in the *Groundwater Modeling Work Plan for BMI Upper and Lower Ponds Area* dated August 17, 2006.
d. Approximately bound on the south by the northern portion of the Upper Ponds.

In reference to that area of interest, NDEP made the following comment:

> "Complete aquifer tests (including observation wells) associated with the area of interest. It appears that the *Aquifer Testing Work Plan* dated September 11, 2006 did not include tests in wells AA-07, AA-26 and AA-08 but could have. It appears that these locations meet the criteria that BRC has developed for the selection of locations to conduct tests."

Response: The work plan has been revised to include aquifer testing at locations AA-07, AA-026, and AA-08. New extraction wells that fully penetrate the aquifer are proposed at locations AA-08 and AA-026, and the existing wells are proposed as monitor wells for the aquifer test.

Appendix B

Historical Well Information

Appendix B1

Water Level Data

Table B-1. Water Level Data

Well ID	Top of Casing Elevation (ft - amsl)	Date Measured	Measured Depth to Water (ft- btoc)	Water Level (ft - amsl)	Measured Depth to Well Base (ft- btoc)	Water Column (ft)
BRC WELLS (2004, HGI)						
AA-01	1757.13	07/14/04	45.28	1711.85	51.50	6.22
	1757.13	4/18/2006	44.78	1712.35	51.5	6.72
	1757.13	7/27/2006	45.44	1711.69	51.50	6.06
MCF-01A	1756.61	07/25/04	36.40	1720.21	~350.00	323.60
	1756.61	4/18/2006	33.10	1723.51	NM	322.35
	1756.61	7/27/2006	30.00	1726.61	355.45	325.45
MCF-01B	1756.28	07/23/04	44.70	1711.58	88.50	43.90
	1756.28	4/18/2006	44.12	1712.16	86.2	42.08
	1756.28	7/27/2006	44.78	1711.50	86.20	41.42
MCF-02A	1818.42	07/14/04	47.00	1771.42	375.00	328.00
	1818.42	4/18/2006	43.31	1775.11	377.9	334.59
	1818.42	7/27/2006	42.62	1775.80	377.90	335.28
MCF-02B	1819.38	07/24/04	65.43	1753.95	~240.00	174.54
	1819.38	4/20/2006	62.13	1757.25	237.4	175.27
	1819.38	7/27/2006	61.98	1757.40	237.40	175.42
MCF-03A	1784.06	7/13/2004	50.16	1733.90	376.00	325.84
	1784.06	4/20/2006	47.33	1736.73	375	327.67
	1784.06	7/27/2006	46.94	1737.12	387.75	340.81
MCF-03B	1785.72	07/23/04	44.20	1741.52	82.17	38.00
	1785.72	4/20/2006	43.70	1742.02	80.15	36.45
	1785.72	7/27/2006	43.92	1741.80	80.15	36.23
MCF-04	1750.42	07/12/04	37.10	1713.32	400.00	362.90
	1750.42	4/20/2006	34.90	1715.52	402.3	367.40
	1750.42	7/27/2006	34.60	1715.82	367.65	333.05
MCF-05	1627.37	7/25/2004	60.10	1567.27	~220.00	159.90
	1627.37	4/20/2006	47.91	1579.46	233.4	185.49
	1627.37	7/26/2006	48.37	1579.00	233.40	185.03
MCF-06A	1590.69	7/18/2004	113.02	1477.67	393.00	279.98
	1590.69	4/20/2006	71.31	1519.38	396.8	325.49
	1590.69	7/27/2006	81.15	1509.54	396.00	314.85
MCF-06B	1633.18	07/25/04	51.85	1581.33	87.25	35.40
	1633.18	4/20/2006	52.00	1581.18	85.23	33.23
	1633.18	7/26/2006	52.93	1580.25	85.23	32.30
MFC-06C	1633.12	07/25/04	48.80	1584.32	64.42	15.60
	1633.12	4/20/2006	52.49	1580.63	62.42	9.93
	1633.12	7/26/2006	53.74	1579.38	62.42	8.68
AA-07	1612.70	7/23/2004	41.59	1571.11	52.80	10.91
	1612.70	5/24/2006	40.60	1572.10	51.20	10.60
	1612.70	7/27/2006	40.65	1572.05	51.00	10.35
MCF-07	1612.63	7/24/2004	88.30	1524.33	~371.00	282.70
	1612.63	5/24/2006	ND	NM	57.50	NA
	1612.63	8/30/2006	89.59	1523.04	370.00	280.41
AA-08	1580.82	4/21/2006	13.13	1567.69	36.64	23.51
	1580.82	7/26/2006	15.35	1565.47	36.65	21.30
MCF-08A	1581.24	07/17/04	0.00	1581.24	371.50	371.50
	1581.24	4/21/2006	5 P.S.I.	0.00	NM	NA
	1581.24	7/26/2006	NA	NA	371.50	NA

Table B-1. Water Level Data

Well ID	Top of Casing Elevation (ft - amsl)	Date Measured	Measured Depth to Water (ft- btoc)	Water Level (ft - amsl)	Measured Depth to Well Base (ft- btoc)	Water Column (ft)
MCF-08B	1581.19	07/18/04	3.35	1577.84	139.00	135.65
	1581.19	4/21/2006	2.76	1578.43	139.30	136.54
	1581.19	7/26/2006	4.30	1576.89	139.30	135.00
AA-09	1695.87	07/20/04	32.50	1663.37	71.40	38.90
	1695.87	4/20/2006	36.71	1659.16	69.00	32.29
	1695.87	7/26/2006	37.23	1658.64	69.00	31.77
MCF-09A	1695.77	07/18/04	37.95	1657.82	280.00	242.05
	1695.77	4/20/2006	38.41	1657.36	286.70	248.29
	1695.77	7/26/2006	38.57	1657.20	286.70	248.13
MCF-09B	1696.23	07/20/04	32.10	1664.13	132.30	100.20
	1696.23	4/20/2006	36.09	1660.14	130.40	94.31
	1696.23	7/26/2006	36.84	1659.39	94.23	57.39
AA-10	1615.12	07/20/04	19.40	1595.72	45.00	25.60
	1615.12	4/21/2006	19.08	1596.04	42.85	23.77
	1615.12	7/27/2006	18.15	1596.97	42.85	24.70
MCF-10A	1615.86	07/21/04	102.90	1512.96	384.60	281.70
	1615.86	4/21/2006	Artesian	0.00	386.70	386.70
	1615.86	7/27/2006	14.30	1601.56	386.60	372.30
MCF-10B	1615.35	07/21/04	17.90	1597.45	109.30	91.40
	1615.35	4/21/2006	17.43	1597.92	107.31	89.88
	1615.35	7/27/2006	17.27	1598.08	107.31	90.04
AA-11	1660.05	07/26/04	26.90	1633.15	33.60	6.60
	1660.05	4/20/2006	29.43	1630.62	31.40	1.97
	1660.05	7/26/2006	30.09	1629.96		1.31
MCF-11	1659.95	07/26/04	26.70	1633.25	107.90	81.05
	1659.95	4/20/2006	29.13	1630.82	106.00	76.87
	1659.95	7/26/2006	29.83	1630.12	105.80	75.97
MCF-12 A	1716.16	7/22/2004	58.10	1658.06	~370	311.90
	1716.16	4/27/2006	55.13	1661.03	371.20	316.07
	1716.16	7/27/2006	54.95	1661.21	371.20	316.25
MCF-12 B	1714.88	7/21/2004	67.00	1647.88	86.60	19.60
	1714.88	4/27/2006	65.80	1649.08	84.32	18.52
	1714.88	7/27/2006	66.55	1648.33	84.20	17.65
MCF-12 C	1715.27	07/21/04	67.71	1647.56	175.00	107.29
	1715.27	4/27/2006	66.59	1648.68	117.44	50.85
	1715.27	7/27/2006	67.30	1647.97	175.32	108.02
AA-13	1724.69	07/14/04	40.60	1684.09	62.90	22.30
	1724.69	4/20/2006	56.95	1667.74	62.71	5.76
	1724.69	7/26/2006	57.37	1667.32	62.71	5.34
AA-14	1701.05	7/16/2004	42.00	1659.05	67.25	25.75
	1701.05	4/21/2006	64.42	1636.63	65.25	0.83
	1701.05	7/26/2006	64.83	1636.22		0.42
AA-15	1658.13	7/17/2004	32.21	1625.92	44.70	12.49
	1658.13	4/20/2006	42.31	1615.82	42.55	0.24
	1658.13	7/26/2006	42.28	1615.85		0.27
MCF-16A	1691.66	07/23/04	49.55	1642.11	~385.00	335.45
	1691.66	4/20/2006	47.82	1643.84	385.80	337.98
	1691.66	7/26/2006	48.04	1643.62	393.94	345.90

Well ID	Top of Casing Elevation (ft - amsl)	Date Measured	Measured Depth to Water (ft- btoc)	Water Level (ft - amsl)	Measured Depth to Well Base (ft- btoc)	Water Column (ft)
MCF-16B	1692.26	07/23/04	53.80	1638.46	~315.00	251.20
	1692.26	4/20/2006	65.71	1626.55	312.00	246.29
	1692.26	7/26/2006	65.15	1627.11	312.00	246.85
MCF-16C	1691.98	07/23/04	61.60	1630.38	80.20	18.60
	1691.98	4/20/2006	65.75	1626.23	78.2	12.45
	1691.98	7/26/2006	66.10	1625.88	81.86	15.76
AA-18	1669.00	07/22/04	57.90	1611.10	71.60	13.70
	1669.00	4/21/2006	59.64	1609.36	69.53	9.89
	1669.00	7/27/2006	59.62	1609.38	69.53	9.91
AA-19	1642.32	07/22/04	31.80	1610.52	46.70	14.90
	1642.32	4/20/2006	38.64	1603.68	44.55	5.91
	1642.32	7/26/2006	41.30	1601.02	44.55	3.25
AA-20	1628.49	07/22/04	17.85	1610.64	35.00	17.15
	1628.49	4/20/2006	24.02	1604.47	32.88	8.86
	1628.49	7/26/2006	26.53	1601.96	33.00	6.47
AA-21	1584.20	07/25/04	11.19	1573.01	39.00	27.81
	1584.20	4/21/2006	9.80	1574.40	40.37	30.57
	1584.20	7/26/2006	12.43	1571.77	41.11	28.68
AA-22	1581.53	07/16/04	15.70	1565.83	36.50	20.80
	1581.53	4/24/2006	14.97	1566.56	33.91	18.94
	1581.53	7/27/2006	12.09	1569.44	33.95	21.86
AA-23	1566.67	07/16/04	6.85	1559.82	26.35	19.50
	1566.67	07/20/04	42.73	1523.94	56.50	13.77
AA-26	1566.67	4/24/2006	42.95	1523.72	54.47	11.52
	1566.67	7/27/2006	42.68	1523.99	54.47	11.79
AA-27	1789.43	07/15/04	65.28	1724.15	84.20	18.92
	1789.43	4/19/2006	65.85	1723.58	84.15	18.30
	1789.43	7/26/2006	66.77	1722.66	84.15	17.38
MCF-27	1789.38	7/26/2004	23.00	1766.38	~385.00	362.00
	1789.38	4/20/2006	15.88	1773.50	384.80	368.92
	1789.38	7/26/2006	15.10	1774.28	384.80	369.70
TIMET WELLS (On BMI Property - Need to Cut locks and Install BRC Locks)						
DM-1	1727.21	4/24/2006	43.43	1683.78	54.65	11.22
	1727.21	7/31/2006	44.23	1682.98	54.51	10.28
POU3	1728.51	4/24/2006	35.15	1693.36	67.19	32.04
	1728.51	7/27/2006	35.88	1692.63	67.15	31.27
POD2	1673.94	4/24/2006	54.05	1619.89	64.45	10.40
	1673.94	7/27/2006	56.21	1617.73	64.41	8.20
POD8	1691.33	4/24/2006	65.56	1625.77	75.30	9.74
	1691.33	7/27/2006	66.54	1624.79	75.17	8.63
BEC-4	1681.34	4/24/2006	27.16	1654.18	39.60	12.44
	1681.34	7/27/2006	28.03	1653.31	39.61	11.58
POD-4	1690.01	4/24/2006	56.15	1633.86	59.10	2.95
	1690.01	7/27/2006	57.81	1632.20	59.10	1.29
POD-7	1690.92	4/24/2006	52.00	1638.92	54.86	2.86
	1690.92	7/27/2006	52.00	1638.92	54.84	2.84

Well ID	Top of Casing Elevation (ft - amsl)	Date Measured	Measured Depth to Water (ft- btoc)	Water Level (ft - amsl)	Measured Depth to Well Base (ft- btoc)	Water Column (ft)
UPPER PONDS WELLS (On BMI Property - Need to Cut locks and Install BRC Locks)						
BEC-6	1725.52	4/24/2006	65.62	1659.90	80.75	15.13
	1725.52	7/27/2006	66.28	1659.24	85.70	19.42
BEC-9	1617.74	4/24/2006	44.23	1573.51	58.90	14.67
	1617.74	7/27/2006	46.76	1570.98	58.71	11.95
BEC-10	1657.39	4/24/2006	56.55	1600.84	89.08	32.53
	1657.39	7/27/2006	57.30	1600.09	88.90	31.60
DM-4	1621.02	4/24/2006	Dry	Dry	19.83	0.00
	1621.02	7/27/2006	Dry	NA	19.85	0.00
DM-5	1623.90	4/24/2006	22.78	1601.12	23.65	0.00
	1623.90	7/27/2006	Dry	NA	23.51	0.00
DM-7B	INA	4/24/2006	Dry	Dry	48.15	0.00
	INA	7/27/2006	Dry	NA	48.00	0.00
DM-8	INA	4/27/2006	Dry	Dry	39.90	0.00
	INA	7/27/2006	Dry	NA	39.76	0.00
DM-9	INA	4/24/2006	Dry	Dry	61.21	0.00
	INA	7/27/2006	Dry	NA	61.11	0.00
HMWWT-4	INA	5/26/2006	44.86	NA	50.00	5.14
	INA	7/27/2006	45.44	NA	50.00	4.56
HMWWT-6	1774.04	4/24/2006	41.67	1732.37	50.60	8.93
	1774.04	7/27/2006	41.81	1732.23	51.30	9.49
HMWWT-8	1766.00	NA	NM	NM	NM	NA
	1766.00	7/27/2006	NM	NA	NM	NA
LOWER PONDS WELLS (BMI Property - For Wells PC-1, PC-2, PC-4 Notify Richard Leger @702-241-7309 for access).						
PC-1	1599.13	4/25/2006	23.43	1575.70	27.36	3.93
	1599.13	7/27/2006	25.17	1573.96	27.25	2.08
PC-2	1593.79	4/25/2006	22.16	1571.63	33.19	11.03
	1593.79	7/27/2006	24.78	1569.01	33.20	8.42
PC-4	1597.13	4/25/2006	24.09	1573.04	43.26	19.17
	1597.13	7/27/2006	25.82	1571.31	43.25	17.43
PC-56	1568.99	4/25/2006	10.77	1558.22	54.26	43.49
	1568.99	7/26/2006	12.69	1556.30	63.56	50.87
PC-58	1568.29	4/25/2006	9.86	1558.43	28.60	18.74
	1568.29	7/26/2006	11.88	1556.41	25.50	13.62
PC-62	1568.45	NA	NM	NM	NM	NA
	1568.45	7/26/2006	13.01	1555.44	32.27	19.26
PC-76	1564.51	4/25/2006	13.67	1550.84	22.20	8.53
	1564.51	7/26/2006	14.31	1550.20	22.20	7.89
PC-79	1564.33	4/25/2006	8.91	1555.42	44.50	35.59
	1564.33	7/26/2006	11.38	1552.95	44.94	33.56
PC-80	1564.07	4/25/2006	9.07	1555.00	28.94	19.87
	1564.07	7/26/2006	11.55	1552.52	28.81	17.26
PC-81	1564.03	4/25/2006	8.88	1555.15	15.11	6.23
	1564.03	7/26/2006	11.43	1552.60	14.85	3.42
PC-82	1559.44	4/25/2006	7.14	1552.30	58.28	51.14
	1559.44	7/26/2006	9.46	1549.98	65.30	55.84

Table B-1. Water Level Data

Well ID	Top of Casing Elevation (ft - amsl)	Date Measured	Measured Depth to Water (ft- btoc)	Water Level (ft - amsl)	Measured Depth to Well Base (ft- btoc)	Water Column (ft)
PC-83	1559.47	4/25/2006	6.45	1553.02	33.71	27.26
	1559.47	7/26/2006	8.07	1551.40	31.79	23.72
PC-84	1559.14	NA	NA	NA	NM	NA
	1559.14	NA	NM	NA	NM	NA
PC-86	1554.08	4/25/2006	4.73	1549.35	26.56	21.83
	1554.08	7/26/2006	6.50	1547.58	27.64	21.14
PC-88	1550.91	NA	NA	NA	NM	NA
	1550.91	7/26/2006	7.83	1543.08	47.42	39.59
PC-89	1550.53	4/25/2006	Dry	Dry	2.31	0.00
	1550.53	NA	NM	NA	NM	NA
PC-90	1550.90	4/25/2006	6.23	1544.67	26.35	20.12
	1550.90	7/26/2006	7.66	1543.24	13.26	5.60
PC-92	1552.12	5/31/2006	9.57	1542.55	21.51	11.94
	1552.12	7/26/2006	10.6	1541.52	21.31	10.71
PC-94	1548.84	4/25/2006	8.49	1540.35	19.57	11.08
	1548.84	7/26/2006	10.08	1538.76	19.57	9.49
PC-95	1550.61	4/25/2006	5.57	1545.04	35.02	29.45
	1550.61	7/26/2006	7.00	1543.61	35.05	28.05
PC-108	1584.96	4/25/2006	12.68	1572.28	41.74	29.06
	1584.96	7/26/2006	12.14	1572.82	40.52	28.38
PITTMAN AREA (Non-BMI Property - Wells PC-12, -19, -103 through PC-107 contact Richard Leger @ 702-241-7309 with City of Henderson for access).						
PC-10	1619.59	NA	NA	NA	NM	NA
	1619.59	NA	NM	NA	NM	NA
PC-12	1616.94	4/25/2006	27.40	1589.54	29.85	2.45
	1616.94	7/26/2006	28.28	1588.66	29.75	1.47
PC-19	1618.07	4/25/2006	NA	NA	NM	NA
	1618.07	NA	NM	NA	NM	NA
PC-21	1722.20	4/25/2006	26.68	1695.52	36.88	10.20
	1722.20	NA	NM	NA	NM	NA
PC-24	1633.95	4/25/2006	20.83	1613.12	29.74	8.91
	1633.95	7/26/2006	23.62	1610.33	32.91	9.29
PC-28	1651.17	4/25/2006	11.75	1639.42	19.80	8.05
	1651.17	7/26/2006	11.82	1639.35	19.60	7.78
PC-31	1658.13	4/25/2006	11.23	1646.90	47.25	36.02
	1658.13	7/26/2006	11.49	1646.64	46.85	35.36
PC-40	1677.05	4/25/2006	23.08	1653.97	57.67	34.59
	1677.05	7/26/2006	NM	NA	NM	NA
PC-50	1634.48	4/25/2006	12.69	1621.79	38.63	25.94
	1634.48	7/26/2006	19.52	1614.96	46.42	26.90
PC-54	1704.40	4/25/2006	15.15	1689.25	27.59	12.44
	1704.40	7/26/2006	15.21	1689.19	47.65	32.44
PC-64	1675.51	4/25/2006	6.81	1668.70	18.43	11.62
	1675.51	7/26/2006	7	1668.51	18.14	11.14
PC-67	1674.38	4/25/2006	10.61	1663.77	36.00	25.39
	1674.38	7/26/2006	11.91	1662.47	34.40	22.49
PC-103	1597.02	4/25/2006	23.75	1573.27	30.49	6.74
	1597.02	7/26/2006	23.05	1573.97	30.34	7.29

Well ID	Top of Casing Elevation (ft - amsl)	Date Measured	Measured Depth to Water (ft- btoc)	Water Level (ft - amsl)	Measured Depth to Well Base (ft- btoc)	Water Column (ft)
PC-104	1596.68	4/25/2006	28.96	1567.72	33.35	4.39
	1596.68	7/26/2006	28.4	1568.28	30.25	1.85
PC-105	1591.27		NA	NA	NA	NA
	1591.27			1591.27		NA
PC-106	1602.10	5/31/2006	4.81	1597.29	29.32	24.51
	1602.10	7/26/2006	3.24	1598.86	29.00	25.76
PC-107	1617.19	4/25/2006	NA	NA	NA	NA
	1617.19			1617.19		NA
AMPAC WELLS (Non-BMI Property - Special Wrench Needed to access wells - Call Dane Grimshaw at (702) 699-4147 for access)						
TWE-107	1634.00	4/28/2006	9.71	1624.29	127.80	118.09
	1634.00	7/26/2006	9.98	1624.02	127.66	117.68
HMW-16	1622.10	4/28/2006	Dry	Dry	9.89	0.00
	1622.10	7/26/2006	10.04	1612.06	22.98	12.94
PZ-13	1639.20	4/28/2006	Dry	Dry	17.26	0.00
	1639.20	7/26/2006	Dry	NA	19.08	0.00
TWC-126	1650.60	4/28/2006	13.64	1636.96	144.60	130.96
	1650.60	7/26/2006	13.84	1636.76	145.37	131.53
TWI	1653.30	4/28/2006	NA	NA	NA	NA
	1653.30	7/27/2006	13.25	1640.05	19.02	5.77
CITY OF HENDERSON NORTHERN RIB PONDS (Well was not locked and just off of access road)						
HMW-09	1543.60	4/24/2006	17.26	1526.34	42.06	24.80
	1543.60	7/26/2006	12.96	1530.64	46.00	33.04
CITY OF HENDERSON LANDFILL (Well construction details needed - Need to contact Robert Carrington with CoH @702-267-1307 for front gate and well keys).						
MW-01	INA	4/24/2006	75.56	NA	108.60	33.04
	INA	7/27/2006	36.32	NA	43.41	7.09
MW-03	INA	5/10/2006	36.48	NA	67.45	30.97
	INA	7/27/2006	36.49	NA	67.33	30.84
MW-15	INA	4/24/2006	95.47	NA	110.85	15.38
	INA	7/27/2006	95.66	NA	110.65	14.99
BUREAU OF LAND MANAGEMENT (Well construction details needed - Access needed)						
HMW-08	1545.30	4/24/2006	17.26	1528.04	42.06	24.80
	1545.30		18.00	1527.30	41.56	23.56
W02	INA	NA	NA	NA	NA	NA
	INA			NA		NA
SOUTHERN NEVADA WATER AGENCY (Well construction details needed - Contact Eric Dano @ 702-822-3365 with SNWA for well keys and access).						
COH-1	INA	4/28/2006	16.82	NA	168.95	152.13
	INA	7/31/2006	16.72	NA	168.95	152.23
COH-1A	INA	4/28/2006	17.60	NA	18.82	1.22
	INA	7/27/2006	Dry	NA	17.11	0.00
WMWS.58SS	INA	4/28/2006	8.69	NA	21.25	12.56
	INA	7/31/2006	8.72	NA	21.95	13.23
WMWS.58SI	INA	4/28/2006	7.33	NA	41.60	34.27
	INA	7/31/2006	7.31	NA	41.12	33.81

Well ID	Top of Casing Elevation (ft - amsl)	Date Measured	Measured Depth to Water (ft- btoc)	Water Level (ft - amsl)	Measured Depth to Well Base (ft- btoc)	Water Column (ft)
WMWS.58SD	INA	4/28/2006	8.51	NA	79.58	71.07
	INA	7/31/2006	8.44	NA	79.59	71.15

NOTES:

ID - Identification

btoc - beneath top of casing

bgs - Below ground surface

amsl - Above mean sea level

*** Survey Data (elevation) is uncertain**

NA - Not applicable

~ The Reference Point Elevation on Table 4-4 Monitoring Well Network Evaluation Summary, Hydrogeologic Characterization Workplan was assumed to be the same as the Top of Casing Elevation given on this table.

INA - Information not available on Table 4-4 Monitoring Well Network Evaluation Summary, Hydrogeologic Characterization Workplan.

Appendix B2

Well Development Summary

Table B-2. Well Development Summary

Well Identification	Well Construction Completion Date	Development Completion Date	Well Screen Interval (ft - btoc)	Static Water Level (ft - btoc)	Purge Method	Total Volume Purged (gallons)	Average Purge Rate (gpm)	Approximate Recharge Rate (gpm)	Comments/Observations
AA-01	2/25/2004	4/8/2004	29-49	45.10	Bailer	7	NM	0.1	Well bailed dry; developed over 2 days; turbidity remained overrange (>999 NTU) at end of development
MCF-01A	5/21/2004	6/9/2004	335-355	301.10	Pump/Bailer	420	15.0	NM	Very slow recovery; developed over 2 days; turbidity remained overrange (>999 NTU) at end of development
MCF-01B	5/22/2004	6/7/2004	55-85	42.40	Pump/Bailer	264	1.5	0.3	
MCF-02A	3/8/2004	3/24/2004	360-380	48.20	Pump/Bailer	513	2.0	0.7	Well pumped dry; developed over 2 days; turbidity remained overrange (>999 NTU) at end of development
MCF-02B	6/4/2004	7/8/2004	215-235	67.55	Pump/Bailer	148	variable	0.02	Very slow recovery
MCF-03A	2/14/2004	2/25/2004	364-384	51.35	Pump/Bailer	910.8	6.3	2.0	
MCF-03B	6/7/2004	7/9/2004	57-77	44.00	Pump/Bailer	36	NM	0.1	Well pumped dry; developed over 2 days
MCF-04	2/20/2004	2/26/2004	379-399	36.51	Pump/Bailer	580	5.0	0.7	Turbidity remained overrange (>999 NTU) at end of development
MCF-05	7/14/2004	7/17/2004	221-231	67.30	Pump/Bailer	128	10.0	0.5	Water quality meter malfunctioning
MCF-06A	3/9/2004	4/16/2004	373.5-393.5	27.42	Bailer	390	NM	0.02	Well bailed dry; very slow recovery; developed over 6 days
MCF-06B	7/12/2004	7/16/2004	67-82	42.60	Pump/Bailer	55	2.0	0.04	Very slow recovery; water quality meter malfunctioning; well bailed dry
MCF-06C	7/13/2004	7/15/2004	44-59	48.95	Pump/Bailer	100	2.0	1.5	
AA-07	5/9/2004	6/8/2004	30-50	11.40	Pump/Bailer	128	0.5	0.2	Developed over 2 days
MCF-07	4/15/2004	4/16/2004	350-370	9.47	Pump/Bailer	309	2.0	0.1	Developed over 2 days; turbidity remained overrange (>999 NTU) at end of development
AA-08	5/23/2004	6/7/2004	5-35	14.00	Pump/Bailer	211	1.0	6.3	Developed over 2 days
MCF-08A	3/19/2004	4/7/2004	350-370	-17.1	Pump/Bailer	268	2.0	0.3	Artesian well; Gauge on cap read 7.5 psi prior to development (water level equivalent to approximately -17.1 ft. btoc)
MCF-08B	5/23/2004	6/9/2004	107.5-137.5	10.60	Bailer	357	NM	1.5	Developed over 3 days; turbidity remained overrange (>999NTU) at the end of development; well bailed dry
AA-09	6/9/2004	7/7/2004	30-65	32.41	Pump/Bailer	185	7.0	52.0	
MCF-09A	4/17/2004	4/18/2004	270-290	28.48	Bailer	198	NM	0.1	Developed over 2 days; turbidity remained overrange (>999NTU) at the end of development
MCF-09B	6/18/2004	7/7/2004	105-125	32.80	Pump/Bailer	115	1.0	1.6	
AA-10	6/16/2004	7/9/2004	10-40	19.21	Pump/Bailer	96	2.0	2.6	Well pumped dry
MCF-10A	4/8/2004	4/14/2004	365-385	2.80	Pump/Bailer	249	2.0	0.1	Turbidity remained overrange (>999 NTU) at end of development
MCF-10B	6/17/2004	7/9/2004	84-104	17.48	Pump/Bailer	156	1.0	0.1	Well bailed dry
AA-11	4/1/2004	4/15/2004	9-29	27.21	Bailer	108	NM	0.3	Abundant mud; jetted with treated water; well bailed dry; developed over 3 days; turbidity remained overrange (>999 NTU) at end of development
MCF-11	7/2/2004	7/13/2004	93.5-103.5	27.82	Pump/Bailer	313	1.5	0.4	Developed over 2 days; well pumped dry
MCF-12A	4/4/2004	4/8/2004	349.5-369.5	42.55	Pump/Bailer	216	2.0	0.1	
MCF-12B	4/22/2004	6/5/2004	64-84	66.70	Bailer	90.5	NM	0.4	Developed over 2 days
MCF-12C	4/24/2004	6/11/2004	155-175	112.50	Pump/Bailer	240	20.0	NM	Developed over 3 days, well pumped dry
AA-13	6/10/2004	7/11/2004	38-58	40.50	Pump/Bailer	98	1.5	1.9	Well pumped dry
AA-14	6/16/2004	7/12/2004	33-58	41.85	Pump/Bailer	248	1.5	1.0	

Table B-2. Well Development Summary

Well Identification	Well Construction Completion Date	Development Completion Date	Well Screen Interval (ft - btoc)	Static Water Level (ft - btoc)	Purge Method	Total Volume Purged (gallons)	Average Purge Rate (gpm)	Approximate Recharge Rate (gpm)	Comments/Observations
AA-15	6/20/2004	7/12/2004	20-40	32.21	Pump/Bailer	128	1.0	3.9	
MCF-16A	3/24/2004	4/6/2004	364.5-384.5	29.68	Pump/Bailer	179	2.0	1.0	
MCF-16B	6/3/2004	6/11/2004	283.7-313.7	245.70	Pump/Bailer	500	20.0	0.1	Developed over 3 days, turbidity remained overrange (>999 NTU) at end of development; well pumped dry
MCF-16C	6/5/2004	6/11/2004	53-73	62.00	Bailer	65	NM	0.1	Developed over 3 days, turbidity remained overrange (>999 NTU) at end of development
AA-18	6/23/2004	7/10/2004	44.5-64.5	59.40	Pump/Bailer	165	NM	0.1	
AA-19	7/10/2004	7/15/2004	22-42	32.00	Pump/Bailer	76	0.8	1.0	
AA-20	7/11/2004	7/15/2004	10-30	17.91	Pump/Bailer	108	0.8	1.2	Well bailed dry
AA-21	4/1/2004	4/7/2004	9-39	9.50	Bailer	125	NM	0.7	
AA-22	4/2/2004	4/8/2004	11-31	16.18	Bailer	113	NM	1.5	Turbidity remained overrange (>999 NTU) at end of development
AA-23	5/9/2004	6/6/2004	4-24	7.90	Pump/Bailer	99	1.0	2.0	
MCF-23	5/8/2004	6/9/2004	195-205	9.20	Pump/Bailer	410	20.0	1.0	Developed over 4 days, well pumped dry
AA-26	7/15/2004	7/17/2004	32-52	42.70	Pump/Bailer	62	0.5	1.0	Well bailed dry
AA-27	7/7/2004	7/13/2004	61.5-81.5	59.45	Pump/Bailer	150	1.0	0.5	
MCF-27	7/6/2004	7/14/2004	361.5-381.5	25.90	Pump/Bailer	465	1.0	1.0	Developed over 2 days

NOTES:

Equipment used for development includes Horiba U-22 water quality meter and Heron Dipper-T water level meter; pumped with Grundfos 3-inch submersible pump.

gpm - Gallons per minute
ft. - btoc - Feet below top of casing
NTU - Nephelometric turbidity units
2 - Measurement may not be static, re-measure level at later date after well completely equilibrates
NM - Not measured
> - Greater than value indicated
psi - Pounds per square inch

Appendix C

Standard Operating Procedures

6. Aquifer Hydraulic Testing

This section provides standard operating procedures (SOPs) and standard operating guidelines (SOGs) for the conduct of aquifer hydraulic testing in the field. The characterization of a groundwater system is a critically important step in solving aquifer problems. Determining accurate estimates of aquifer hydraulic characteristics is dependent on the availability of reliable data from hydraulic tests.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

The scope of the guidelines described in this section includes the following:

6.1 Groundwater Level Measurement

6.2 Slug Testing

6.3 Aquifer Pumping Test

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

6.1 Groundwater Level Measurement

The purpose of this standard operating procedure (SOP) is to provide DBS&A personnel with the information necessary to collect accurate water level data from groundwater wells. Water level measurements provide the fundamental data needed to determine aquifer characteristics; therefore, it is crucial that the appropriate methods are used to meet the data requirements of an aquifer investigation.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

Several methods are available for determining the depth to water (DTW); this SOP briefly describes methods used to measure water levels manually and automatically with data loggers equipped with pressure transducers. This information is intended to help DBS&A personnel determine the appropriate equipment to collect water levels for background trend analysis and aquifer tests.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

6.1.1 Procedures

Immediately following well construction (see Section 4.1), a measuring point (MP) shall be established and clearly labeled "MP" with a permanent marker at the top of the casing. The designated MP shall be located at a point that is unlikely to change in elevation during the life of the well. This mark will prevent repeated surveys to determine the reference elevation of the measuring point. If the MP does change, it shall be clearly re-marked and referenced to the original elevation, or a new survey will be necessary. Water levels will be measured in accordance with ASTM D 4750-87 (reapproved 1993), Standard Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well).

The DTW shall be recorded on the Water Level Measurements form included as Attachment 6.1-1 (DBS&A Form 120). In addition, the following information shall be recorded on the form: the person making the measurement, the measuring device, the surveyed point from which the measurement is made, the time of day (military time), the date, the wellhead condition, and any MP changes. Groundwater level data may also be recorded in the field log and on other applicable DBS&A forms, including but not limited to those used for water sampling and drilling/soils logging.

The following subsections describe the most commonly used techniques for obtaining water level data in the field.

6.1.1.1 Electric Sounders

Electrical sounders operate by completing an electric circuit when the probe contacts the water, thus providing a measure of the depth to water. When the circuit is completed, a light, buzzer, or ammeter needle indicates that the probe is in contact with the water surface. The probe is connected to a graduated tape, usually made from plastic and fiberglass. Batteries supply the necessary current through electrical wires contained in the graduated tape. Electrical sounders measure depths to within 0.01 foot.

Electrical sounders are most often used to measure groundwater levels on DBS&A projects. The major advantage of electrical sounders is that measurements can be made rapidly and accurately without removing the probe from the well. Field personnel should position themselves near the MP so the DTW can be read at eye level. A second confirmatory reading should be performed before the electrical tape is withdrawn from the well. The length of the electrical line shall be calibrated annually with an engineer's tape by the DBS&A Environmental Equipment Coordinator. Information from these calibrations shall be kept at the DBS&A equipment supply facility.

Potential disadvantages of the electrical sounder devices include (1) the expense of an accurate sounder, (2) inaccurate measurements that may be made due to stretching or kinking of the tape, (3) electrical shorts caused by broken or corroded wires, (4) false readings due to cascading water, (5) snagging the sounder tip on pump columns and cables, or (6) incomplete circuits due to low concentrations of total dissolved solids in the water.

6.1.1.2 Automated Water Level Measurements

The most economic method to collect water level data over an extended period of time (ranging from days to months) is to set up a continuous data recorder capable of making many measurements automatically. Driscoll (1986) discusses the application and installation of such systems in detail. The most common recorders store the data electronically for future retrieval, while other methods may produce a graphical chart. Continuous water level records are useful for determining daily and seasonal fluctuations that result from recharge and discharge periods, short-term changes in atmospheric pressure, evapotranspiration, tidal stresses, or during aquifer tests when field personnel may not be available to collect all the necessary data. The following paragraphs briefly review equipment used with continuous recorders to measure water levels.

Electronic data loggers equipped with pressure transducers are commonly used and are useful for collecting large quantities of water level data rapidly during labor-intensive aquifer tests. DBS&A owns various electronic data logging systems that can be programmed to collect data on arithmetic and logarithmic time scales. Measurements are accurate to approximately 0.01 foot, depending on the type of pressure transducers used.

Mechanical data collection systems can also be used to collect a continuous record of water levels in a well. This type of system typically uses a tape or cable passing over a pulley with a float attached to one end and a counterweight attached to the other. The float rises and falls with changes in water levels in a well, and a graphic or electronic recorder records or stores the data. Float sensors work best in large diameter wells (4-inches or greater). The greatest disadvantage of this method is the potential for the float to stick to the side of the well casing or to jump the pulley, which results in a "stair stepping" record or no record at all. Measurements are accurate to 0.1 foot or greater depending on the precision of the recorder and pulley calibration.

6.1.1.3 Airline Bubblers

Airline bubblers are commonly used by the U.S. Geological Survey for measuring stream stage and water levels in wells. A small diameter airline is inserted into the well to a depth below the anticipated water level in the well. The line is injected with pressurized air to force all water from the line, and the air pressure that develops in the line after the air injection is recorded. The resulting pressure in the airline is proportional to the distance between the elevation of the bottom of the airline and the water level in the well. Depending on the setup used, measurements are accurate to within approximately 0.01 foot.

6.1.1.4 Steel Tape

Graduated steel tapes provide accurate measurements to within approximately 0.01 foot for depths of 100 feet or less. The rigidity of the tape allows it to hang straight in the well. Steel tapes should generally not be used when many measurements must be made in rapid succession, such as during aquifer testing. Measurement with a steel tape is relatively time consuming.

When a steel tape is used, the lower 2 to 3 feet are wiped dry and coated with carpenter's chalk or water finding paste before the tape is lowered into the well to the estimated DTW. The tape should be held on a foot marker at the wellhead MP. After the tape is removed, the wetted end is read and subtracted from the previous reading; the difference is the actual depth to water. If tape graduations are greater than 0.1 foot apart, a separate engineering tape or scale shall be used to accurately determine the wetted end measurement.

The main disadvantage of the steel tape method is that the approximate DTW must be known prior to the measurement. In addition, interferences such as cascading water, smearing, and/or evaporation may compromise the accuracy of the wetted-end measurement. However, steel tapes are relatively inexpensive and generally more durable than electrical instruments for measuring water levels.

Attachment

6.1-1. Water Level Measurements (DBS&A Form 120)

References

American Society for Testing and Materials (ASTM). 1993. *Standard test method for determining subsurface liquid levels in a borehole or monitoring well (observation well)*. Standard D 4750-87 (reapproved 1993). Philadelphia, Pennsylvania.

American Society for Testing and Materials (ASTM). 1995. *Standard practice for design and installation of ground water monitoring wells in aquifers*. Standard D 5092-90 (reapproved 1995). Philadelphia, Pennsylvania.

Driscoll, F.G. 1986. *Groundwater and wells*. Johnson Division. St. Paul, Minnesota.

Water Level Measurements

Daniel B. Stephens & Associates, Inc.

Project Name__________ Measurement Date__________

Project Number__________ Field Staff__________

Measuring Points and Datum Used__________

Observations__________

Well Number	Time	Elevation of Measuring Point (feet, mean sea level)	Depth Below Measuring Point (feet)	Water Level Elevation (feet, mean sea level)

Signature__________ Date__________

DBS&A Form No. 120 1/99

6.2 Slug Testing

This section describes guidelines for performing and analyzing aquifer slug tests. A slug test is an in-situ single-well testing method that is commonly used to estimate the hydraulic conductivity of an aquifer or water-bearing unit.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

6.2.1 Significance and Use

The field procedure for performing a slug test involves creating a sudden change in the water level in a well and measuring the resulting water-level response. Typically, the water level change is induced by the sudden removal or addition of a known volume of water to the well. However, the well can also be stressed by using a mechanical slug, or by simulating the injection or withdrawal of a slug of water using changes in air pressure within the well casing.

Regardless of the method used to stress the well, water levels are closely monitored prior to and during the slug test to determine how rapidly the water level in the well returns to the static (pre-test) level. The analysis of the data generated by the test allows the horizontal hydraulic conductivity (K) of the water-bearing zone to be estimated.

The main advantages of performing slug tests over a pumping test are that (Bouwer, 1978; ASTM D 4044 96, 1997b):

1. The testing can be performed in a short time.
2. Slug tests do not require the disposal of large quantities of water (especially important at contaminated sites).
3. No observation wells are required.
4. Slug tests can be performed in aquifer materials of lower hydraulic conductivity than generally considered suitable for hydraulic testing with pumping tests.
5. Slug tests can be performed at a well where there is interference from other wells, or where there are other disturbances that conflict with the basic conditions of a pumping test.

The disadvantages of the technique are that:

1. The applied stress is small and the test results therefore only reflect conditions that occur in the immediate vicinity of the well. Therefore, results are influenced by near-well conditions such as the gravel pack, poor well development, and skin effects.

2. The storativity (S) cannot normally be evaluated.

The procedures described are in accordance with the ASTM document Standard Test Method (Field Procedure) for Instantaneous Change in Head (Slug) for Determining Hydraulic Properties of Aquifers (ASTM D 4044-96, 1997b). Additional references which may be helpful in planning and performing slug tests are Aquifer Hydraulics - A Comprehensive Guide to Hydrogeologic Data Analysis (Batu, 1998) and Applied Hydrogeology (Fetter, 1994).

The three main tasks required in order to successfully perform and analyze a slug test are described below. These include the following:

1. Review available hydrogeologic information (Section 6.2.2)

2. Perform the slug test (Section 6.2.3)

3. Analyze the test data (Section 6.2.4)

6.2.2 Review Hydrogeologic Information

The reliability of any determination of hydraulic properties depends on the conformance of the hydrogeologic site characteristics to the assumptions of the test method. Therefore, a conceptual understanding of the hydrogeology of the site needs to be determined prior to performing the test (ASTM D 4043-96, 1997a).

Available site data (well construction details, geologic logs and cross sections, groundwater elevation maps, etc.) will be reviewed to evaluate whether:

1. The aquifer is confined or unconfined

2. The well fully or partially penetrates the aquifer

3. The well screen (or open hole) is completely saturated, or whether it intersects the water table

4. The water-bearing zone is extremely permeable

Based on known site conditions and the nature of the problem being addressed, wells that are best suited for testing will be selected. This information will also be used to ensure that the test procedures will create a sufficient stress to yield data that will define a strong signal (water-level response curve) with little associated noise.

6.2.3 Performing a Slug Test

Slug tests may be categorized as rising head tests and falling head tests. Both tests are conducted by causing a sudden change in the water level in a well, and collecting sufficient water-level measurements prior to and during the test to properly define the resultant water-level response curve. The procedures used to stress the well and to collect water-level measurements are described below in Sections 6.2.3.1 and 6.2.3.2, respectively. The procedure used to test the well will be recorded in the site field book.

6.2.3.1 Causing the Water Level Change

If a well is installed with a screen that intersects the water table (the screen or open hole is not fully saturated), then only the rising head test should be performed. For a rising head test, the water level in a well is lowered, and the water level recovery is subsequently measured and recorded until the water level has recovered to approximately 95% of the static water level or more. The bailer should be of sufficient size to ensure an adequate water-level response; although there is no fixed requirement for the magnitude of the change in water level, a change ranging from 1 to 3 feet will typically be sufficient to allow the response curve to be defined. A submersible pump can also be used to rapidly remove water from the test well. If using a pump, it will need to remove a sufficient volume of water from the test well in a matter of seconds; in addition, a check valve will be used to ensure that water in the discharge line does not flow back into the well once the pump is shut off.

To perform a falling head test, the water level in the well is raised and the water level change in the well is monitored. This method is best suited for wells installed in confined aquifers; however, it can be used to test wells in unconfined aquifers if the screen is located at least several feet below the water table surface.

The following methods can be used to cause a water level change in a test well:

- Water Slug: Inject or withdraw water of a known quantity into or out of the well. A bailer is commonly used to remove water from a well by lowering the bailer below the water level in the well and then rapidly removing it.

- Mechanical Slug: Inject (or withdraw) a mechanical slug (constructed of nonporous material with a density greater than water) below (or above) the water level. The water level in the well will then rise or fall an amount equal to the volume of the mechanical slug.

- Release Vacuum or Pressure: Simulates the injection or withdrawal of a slug of water by the release of a vacuum or pressure on a tightly capped well. Before the release, the vacuum or pressure is held constant to establish a static water level.

6.2.3.2 Water-Level Measurements

The method used to measure water levels will depend on how water is injected or removed from the well, as well as on the anticipated response of the well (how rapidly the well recovers). In most cases, water levels will be measured both manually (using an electronic water level probe) and automatically (using an electronic data logger and pressure transducer). Water levels will be measured as described in Section 6.1. Depth-to-water measurements collected during the slug test will be recorded in the site field book. If needed, these can later be transferred to the DBS&A Slug Test Measurements form (No. 124), included as Attachment 6.2-1.

Prior to the test, the depth to water in the well should be measured several times to determine whether the water level in the well is being significantly affected by stresses unrelated to the proposed test. If only small water level fluctuations are known to occur at a site, then only two pre-test water levels need to be collected immediately prior to the start of the test to establish the static water level. If a trend in water levels prior to the test is observed, a sufficient number of pre-test water levels should be collected to establish the trend.

Following the start of the test, the water-level response to the change in the water level in the well will be measured. The required frequency of water-level measurements will depend on the hydraulic conductivity of the material being tested. Initially, the water-level measurements should be collected as rapidly as possible until the water level in the well has recovered to approximately 60 to 80 percent of the static level; this is especially important when the water-bearing materials are very permeable. It may be easier and more accurate to measure the time at which the water level reaches a specified depth, especially if the recovery rate is rapid. However, if the tested material has a low permeability (such as a silty fine sand, silt or clay), the recovery rate in the well will most likely be very slow (less than 0.01 to 0.05 feet per minute), so water levels will not need to be collected as rapidly. As the test proceeds, the length of time between measurements can increase. The person performing the test will use their judgement to determine how often the depth to water should be measured.

Since the methods of data analysis are curve-fitting techniques, it is essential that the water levels be measured frequently enough to define the water-level response curve. If the water level change is very rapid, a data logger equipped with a pressure transducer should be used. The data logger should be programmed to the logarithmic sampling rate to ensure that initially rapid changes in water level are recorded. If using a data logger, sufficient manual measurements should be collected during the test to confirm the integrity of the logger data. Depth-to-water measurements should be collected until the water level recovers to 90 to 95 percent of the pretest water level, or 60 minutes has passed since the start of the test. If the water level has still not recovered significantly following 60 minutes, data collection can probably stop. However, prior to ceasing the test, a graph of the water levels versus time should be prepared to evaluate whether additional data collection is warranted, and the decision to continue or stop the test will then be made.

Graphs of data collected during each test will be prepared in the field to evaluate the quality of the data, thereby confirming that the well has been successfully tested. If time allows, a second test should be performed at each test well to increase the confidence level of the resultant data.

6.2.4 Data Analysis

Several methods can be used to analyze the water level data generated during a slug test. Which method to use will depend on the type of aquifer being tested, as well as the construction of the well. This section does not describe the steps that need to be performed to analyze the test data, but is intended to present a brief description of which method is best suited for analyzing test data generated at a site. Three of the commonly used methods are briefly described below.

6.2.4.1 Bouwer and Rice Method

This is probably the most commonly used method to analyze slug test data for both rising head and falling head tests. The method can be applied for a falling head test provided that the static water level is above the screened or open section of the borehole. If the screen or open hole intersects the water table surface, then rising head test data must be used. This method can be used to analyze data generated on tests performed on open boreholes or screened wells that are fully or partially penetrating. Although the method was originally developed for unconfined aquifers, it can also be used for confined aquifers if the top of the screen is “some distance” below the top of the confining layer (Fetter, 1994).

References describing the procedure used to calculate the hydraulic conductivity of a water-bearing zone include the original publication by Bouwer and Rice (1976); an update to the method published by Bouwer (1989); and descriptions of the method presented in hydrogeology textbooks (Fetter, 1994; Batu, 1998; Kruseman and de Ridder, 1994). Some of the critical aspects with regard to the applicability of the method are discussed by Bouwer (1989) and Batu (1998). The computer program AQTESOLV for Windows (HydroSolve, Inc.) can be used to analyze slug test data using the Bouwer and Rice Method, which greatly facilitates the analysis of the data.

6.2.4.2 Hvorslev Method

This method can be used to analyze data for both rising and falling head tests on partially penetrating wells; however, the well screen must be located below the water table (i.e., the screen and gravel pack must be completely saturated). This method can be used to analyze data generated on tests performed on confined and unconfined aquifers (Batu, 1998).

References describing the procedure used to calculate the hydraulic conductivity of a water-bearing zone include the original publication by Hvorslev (1951), and descriptions of the method presented in hydrogeology textbooks (Fetter, 1994; Batu, 1998). The computer program AQTESOLV for Windows (HydroSolve, Inc.) can be used to analyze slug test data using the Hvorslev Method, which greatly facilitates the analysis of the data.

6.2.4.3 Cooper, Bredehoeft, and Papadopulos Method

This method can be only be used to analyze data for falling head tests performed on wells installed in either confined or unconfined aquifers (Batu, 1998). This method can be used to analyze data generated on tests performed on open boreholes or screened wells, but it assumes that the well is fully penetrating.

References describing the procedure used to calculate the hydraulic conductivity of a water-bearing zone include the original publication by Cooper et al. (1967), and descriptions of the method presented in hydrogeology textbooks (Fetter, 1994; Batu, 1998). The computer program AQTESOLV for Windows (HydroSolve, Inc.) can be used to analyze slug test data using the Cooper, Bredehoeft, and Papadopulos Method, but only for confined aquifers, which greatly facilitates the analysis of the data.

Attachment

6.2-1. Slug Test Measurements (DBS&A Form No. 124)

References

American Society for Testing and Materials (ASTM). 1997a. *Standard guide for selection of aquifer test method in determining hydraulic properties by well techniques*. ASTM D 4043-96, West Conshohocken, Pennsylvania.

American Society for Testing and Materials (ASTM). 1997b. *Standard test method (field procedure) for instantaneous change in head (slug) tests for determining hydraulic properties of aquifiers* [sic]. ASTM D 4044-96, West Conshohocken, Pennsylvania.

Batu, V. 1998. *Aquifer hydraulics: A comprehensive guide to hydrogeologic data analysis*. John Wiley & Sons, Inc., New York.

Bouwer, H., and R.C. Rice. 1976. *A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells*. Water Resources Research 12(3):423-428.

Bouwer, H. 1978. *Groundwater hydrology*. McGraw-Hill Book Company, New York.

Bouwer, H. 1989. *The Bouwer and Rice slug test — An update*. Ground Water 27(3):304-309.

Cooper, H.H., Jr., J.D. Bredehoeft, and I.S. Papadopulos. 1967. *Response of a finite-diameter well to an instantaneous charge of water*. Water Resources Research 3(1):263-269.

Fetter, C.W. 1994. *Applied hydrogeology, Third edition*. Macmillan College Publishing Company, New York.

Hvorslev, M.J. 1951. *Time lag and soil permeability in groundwater observations*. Bulletin No. 36, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. 49p.

HydroSolve, Inc. *AQTESOLVE for Windows* (www.aqtesolve.com).

Kruseman, G.P., and N.A. de Ridder. 1994. *Analysis and evaluation of pumping test data, Second edition*. Publication 47, International Institute of Land Reclamation and Improvement, Wageningen, The Netherlands.

DANIEL B. STEPHENS & ASSOCIATES, INC.

Slug Test Measurements

Project Name ______________________ Test Date ______________

Project Number ______________ Field Staff ______________________

Well Number and Datum Used ______________________

Slug Type (material, volume, etc.) ______________________

Observations ______________________

Time	Depth Below Measuring Point (feet)	Change in Water Level (feet)

Signature ______________________ Date ______________

DBS&A Form No. 124 8/93

6.3 Aquifer Pumping Test

This section provides standard operating guidelines (SOGs) for conducting aquifer pumping tests in the field using groundwater wells. The characterization of a groundwater system is a critically important first step in solving aquifer problems (Batu, 1998). A pumping test is performed by pumping groundwater from a well and measuring resultant water level changes to determine the hydraulic characteristics of an aquifer and/or lower-permeability aquitards (if present or desired). A pumping test is the most reliable type of aquifer test that is commonly conducted during groundwater investigations (EPA, 1993).

Although the primary purpose of this SOG is to describe the tasks needed to successfully perform constant-rate pumping tests, a brief description of two other commonly-used testing procedures (specific capacity tests and step-drawdown tests) is also presented.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

6.3.1 Procedures

An aquifer pumping test is a controlled field test conducted by imposing a stress (pumping from a well) on an aquifer and determining the aquifer's response to that stress by measuring the changes in the potentiometric (unconfined) or piezometric (confined) surface. The recovery of the water level surface once the stress on the aquifer is relieved will also be measured during a pumping test. Aquifer pumping tests are conducted to determine aquifer hydraulic characteristics, such as aquifer transmissivity, hydraulic conductivity, storage, well yield, and specific capacity. Depending on the test configuration and the reliability of the collected data, aquifer pumping tests may also be used to determine the location of hydrologic boundaries or to determine the impact of pumping on surface waters.

Several types of tests are commonly performed depending on the objectives of the investigation; these include specific capacity tests, step-drawdown tests, and constant-rate pumping tests.

6.3.1.1 Specific Capacity Test

The specific capacity of a well is defined as the ratio of its discharge to its total drawdown (typical units are gallons per minute per foot of drawdown); this value typically decreases with the length of time a well is pumped. A specific capacity test is a single-well test that is typically performed at water supply wells in order to estimate the yield of a well. The specific capacity of a well is its yield per unit of drawdown, after a given time has elapsed. During this test, the flow from the well may vary by as much as 50 percent as drawdown in the well progressively increases.

6.3.1.2 Step-Drawdown Test

A step-drawdown test is also a single-well test performed at a pumping well. The test was developed to examine the performance of wells having turbulent flow (Driscoll, 1986), as it allows the efficiency and yield of a well to be evaluated. When performing a step-drawdown test, it is good practice to use a pump that has sufficient capacity to remove all of the water from a well. The test consists of pumping a well at a constant rate for specified time period (a "step", whose duration typically ranges from 60 to 120 minutes) and to measure the resultant drawdown in the well until the drawdown in the well stabilizes. Typically, three to four steps are performed at increasing higher pumping rates. The test data is used to obtain information on the well and aquifer's ability to produce water, and/or the degree of hydraulic interconnection between the open portion of the well and the surrounding saturated material.

A step-drawdown test should typically be performed at a well that is going to be used as the pumping well in a constant-rate pumping test. This is especially true when testing formations that produce little water, since it will be important to produce the maximum stress (the greatest amount of drawdown) without permitting the well to go dry prior to the end of the proposed pumping period. Data generated during a step-drawdown test can potentially be used to:

- Estimate the overall transmissivity of an aquifer
- Evaluate whether nearby observation wells will adequately characterize the cone of depression caused by a proposed constant-rate test
- Identify the depth(s) of significant water-producing zones intersected by the well open interval, although this applies primarily to fractured bedrock aquifers
- Confirm that a newly installed well has been properly developed, or determine whether an existing well may need to be redeveloped

6.3.1.3 Constant-Rate Pumping Test

A constant-rate pumping test is performed by withdrawing water at a constant rate from (or applying a known stress to) an aquifer of known or assumed dimensions, and observing the temporal changes in water levels in the pumping and observation wells. Depending on the type and quality of the test data, and the method used to analyze the resulting data, the primary hydraulic characteristics that may be estimated include:

- Transmissivity (T)
- Coefficient of storage (S)
- Specific yield (S_y)
- Horizontal and vertical hydraulic conductivity (K_h and K_v, respectively)
- Leakage from or through adjacent confining layer(s)

In addition, it may be possible to determine the location and type of aquifer boundaries (e.g., barrier or constant-head boundaries) if appropriate monitoring points are used and sufficient data are collected.

The main advantages of performing a constant-rate pumping test (versus a slug test or a single-well test) are that:

- The test monitors the hydraulic response over a larger portion of an aquifer and therefore can generate data that may provide better estimates of aquifer hydraulic characteristics.
- The storativity and/or specific storage of an aquifer may be determined.
- The hydraulic interconnection between different water-producing zones (separated by lower-permeability zones) may be evaluated.
- Leakage from or through confining layer(s) below or above an aquifer may be assessed.

The disadvantages of the technique are that:

- The tests are costly to design and perform.
- New wells may need to be installed to properly monitor the response to pumping.
- If elevated pumping rates need to be used at contaminated sites, disposal of contaminated groundwater may be expensive.

The procedures described are in accordance with the ASTM document Standard Guide for Selection of Aquifer Test Method in Determining Hydraulic properties by Well Techniques (ASTM D 4043-96) and Standard Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems (ASTM D 4050-96). Additional references which may be helpful in planning and performing aquifer tests are Suggested Operating Procedures for Pumping Tests (EPA, 1993), Groundwater and Wells (Driscoll, 1986), and Applied Hydrogeology (Fetter, 1994).

The main tasks required to successfully perform a constant-rate pumping test are described below; these include the following:

- Review hydrogeologic information (Section 6.3.1.4)
- Pumping well design (Section 6.3.1.5)
- Pumping test design (Section 6.3.1.6)
- Antecedent data collection (Section 6.3.1.7)
- Pumping period (Section 6.3.1.8)
- Recovery period (Section 6.3.1.9)
- Precautions (Section 6.3.1.10)
- Data analysis (Section 6.3.1.11)

This SOG does not describe how data generated during an aquifer pumping test may be analyzed.

6.3.1.4 Review Hydrogeologic Information

The first task of any aquifer test is to determine which type of aquifer will be tested and which data analysis method will be used. The reliability of any determination of hydraulic properties depends on the conformance of the hydrogeologic site characteristics to the assumptions of the test method (EPA, 1993). Available information on the aquifer and the site should therefore be collected and reviewed; this information will provide the basis for the development of a conceptual model of the site and test design. Existing data on the aquifer and related geologic and hydrologic units should be collected and analyzed to assess the following:

- Geologic characteristics of the subsurface (i.e., lithologic, stratigraphic and structural features that may influence the flow of groundwater)
- Aquifer type (confined versus unconfined)
- Location and type of aquifer boundaries
- Confining bed thicknesses and lateral extent (if present)
- Surface water features
- Information on wells located near the test area (e.g., water supply, observation or monitoring wells)
- Data on the groundwater flow system (e.g., estimates of the aquifer transmissivity, thickness, and horizontal and vertical hydraulic gradients; the presence and effect of lower-permeability zones)
- And other pertinent data

Based on known site conditions and the nature of the problem being addressed, pumping and observation wells that are best suited for testing will be selected. Trial calculations of well drawdown using estimated values of aquifer transmissivity should be performed. The results of these calculations may be used to confirm that sufficient observation wells are located at appropriate distances from the pumping well so that water level fluctuations measured during the test will generate good quality data that defines a strong signal (water-level response curve) with little associated noise.

6.3.1.5 Pumping Well Design

There are six principal elements that need to be evaluated during the design of the pumping facility (EPA, 1993):

1. Well construction and setup
2. Water-level measurement access
3. Reliable power source
4. Pump selection
5. Discharge control and measurement equipment
6. Water disposal

Each of these elements is briefly described below.

6.3.1.5.1 Well Construction and Setup. The construction details of the pumping well should be reviewed to determine its diameter, depth, and all intervals that are open to the aquifer. Information on how the well was installed and developed should be reviewed. Available data that demonstrates that the well was properly developed should be collected and reviewed, since data collected from a poorly-developed well may not be representative of the aquifer.

For example, head losses at a pumping well that are associated with the entry of water from the aquifer may be significant if the well is poorly constructed or if the well is in poor hydraulic connection with the aquifer (e.g., the well screen is plugged). If this is suspected, a step-drawdown test should be performed at the well to obtain an estimate of well entry losses and determine whether the well should be redeveloped (EPA, 1993). If a well is redeveloped, a second step-drawdown test should be performed to confirm the well redevelopment has been effective.

6.3.1.5.2 Water-Level Measurement Access. One must be able to measure the water level in the pumping well before, during and after pumping. Typically, water levels will be measured using electric sounders and data loggers equipped with pressure transducers.

The installation of a “stilling tube” is often warranted at a pumping well since the presence of the pump, electric wires, and the discharge line often causes water-level-measuring devices to become tangled in the well. A stilling tube consists of an open small-diameter PVC pipe that is lowered into the well to a depth that extends past the pump, and is securely attached to the well. A measuring point is then established and its height above the existing measuring point determined. Once installed, water levels at the well can be measured (using pressure transducers and electric sounders) inside the stilling tube. Two added benefits of using a stilling tube are that it eliminates potential effects that may be caused by turbulence in the well due to pumping, as well as those potentially caused by cascading water.

In cases where a pump is isolated by a packer to limit production to a certain portion of an open hole, a transducer system should be used to monitor pumping hydraulic heads.

6.3.1.5.3 Reliable Power Source and Pump Selection. Having continuous power for the pump for the duration of the test is crucial for the success of the test. If interruptions occur, it may be necessary to stop the test and allow the aquifer to recover prior to restarting the test. Depending on the proposed location and duration of a test, it may be warranted to consider having the local power company provide a power drop to supply a reliable source of power for the pump. This is especially true if the test is long (for example, a 30- to 60-day aquifer stress test performed in a residential neighborhood where the use of a generator might cause undue disruption). When using a gasoline or diesel powered generator, it is prudent to have a backup generator.

The pump should be sized to ensure that the desired pumping rate can be maintained throughout the duration of the pumping period. To obtain good data during the recovery period, a check valve should be installed at the base of the pump column pipe in the pumping well. This will prevent the backflow of water from the discharge line into the well when pumping ceases and the recovery period begins.

6.3.1.5.4 Discharge Control and Measurement Equipment. Control of the pumping rate requires an accurate means of measuring the pumping rate, and a convenient means of adjusting the rate to keep it as constant as possible. It is critical that the pump discharge be closely monitored throughout the test. An instantaneous flow meter should be used to monitor the pumping rate, and a second measurement method should be used to confirm the accuracy of the primary measurement device as well as providing a backup means of monitoring the discharge from the well (such as the use of a calibrated bucket and stopwatch or the use of orifice plates equipped with a manometer). The discharge should be measured frequently at the beginning of the test (every few minutes), and the discharge rate should be adjusted as needed to maintain as constant a pumping rate as possible. When the discharge becomes more stable, reduce the frequency of adjustments and check the discharge less frequently (hourly checks should be sufficient). The method used to monitor the flow should have an accuracy of at least plus or minus 2 percent. The accuracy and precision of the method(s) used to monitor the flow rate are important since the flow rate during the test should not be allowed to vary by more than 5 to 10 percent.

If the proposed pumping rate is less than 10 gallons per minute (gpm), the flow rate can typically beadjusted using a rheostatic control on the electric pump or a valve installed in the discharge line to create back pressure and control the discharge rate. The use of both of these controls will greatly facilitate making minor adjustments to the pumping rate. Most higher-yield pumps used to pump groundwater at rates of approximately 20 gpm and greater will most likely be controlled solely using valves installed on the discharge line. At elevated pumping rates (50 to over 500 gpm), the use of a gate valve as the primary means of rate adjustment is recommended since ball valves often tend to open as the test proceeds. The installation of a second “fine adjustment” valve is recommended at higher pumping rates, where a smaller diameter bypass pipe valve can facilitate small adjustments to the pumping rate.

If groundwater samples are to be collected during the pumping period of the test, a separate valve should be installed on the discharge line as close to the well casing as practicable.

6.3.1.5.5 Water Disposal. Water generated during the test should either be temporarily stored during the testing period, or may be discharged if the discharge point is located far enough away to ensure that water discharged will not be able to recharge the portion of the aquifer that is being tested. This may require that piping be installed to transport the pumped water a considerable distance from the test site. If the water being pumped is contaminated, the water may need to be stored in temporary on-site storage containers (i.e., steel storage tank). It may be necessary to obtain permits for the on-site storage and final disposal of contaminated fluids.

6.3.1.6 Pumping Test Design

The conceptual understanding of the site hydrogeology forms the basis for the design of the aquifer testing method(s). It is important that the geometry of the aquifer, location and depth of pumping and observation wells, and the pumping period correspond to the mathematical model which will be used to analyze the data (EPA, 1993). The hydraulic properties that can be determined from a test depend on the instrumentation of the field test, knowledge of the aquifer system being investigated, and the conformance of the site’s hydrogeology to the assumptions of the test method. Most test methods allow the hydraulic conductivity and storage coefficient of an aquifer to be determined. However, some test methods may allow other hydraulic parameters to be estimated, such as vertical and horizontal anisotropy, aquifer discontinuities, vertical hydraulic conductivity of confining beds, specific storage, etc.

Information on existing wells should be reviewed to identify suitable candidates for monitoring the aquifer response to pumping. If a well has not been recently used, it should be field tested to confirm it will be suitable for monitoring the aquifer response. Such a test may be performed by injecting or withdrawing water from a well and measuring the subsequent water level changes to identify wells that should be redeveloped, replaced, or dropped from consideration in favor of another available well. The type and number of observation wells needed to monitor the aquifer response to pumping depends on the information that needs to be determined from the test data. Depending on the type of information which is wanted, additional observation wells may need to be installed. The diameter of the observation wells only needs to be large enough to permit accurate and rapid measurements of water levels. A 2-inch diameter well is usually fine, although these small diameter wells are often difficult to develop properly.

Each site needs to be evaluated independently to determine appropriate distances for the placement of observation wells, since certain hydraulic conditions may warrant the use of closer or more distant wells. If aquifer boundaries are suspected, observation wells should be located in a manner which will identify the location and effect of the boundaries. Furthermore, if aquifer anisotropy is suspected, wells may be located in a pattern based on the suspected or known anisotropic conditions at the site.

Prior to beginning data collection, a schedule should be created for each well that contains a timetable for required water level measurements. Field data sheets should be used to record critical data (e.g., depth-to-water measurements) for the pumping well and the observation wells being monitored during the test (Attachments 6.3-1 and 6.3-2).

6.3.1.7 Antecedent Data Collection

Collecting data to characterize the pre-test water levels is essential if the analysis of the test data is to be completed successfully (EPA, 1993). The antecedent water level data provide the basis for correcting test data to account for on-going regional water level changes or fluctuations caused by short-term changes in atmospheric pressure. If possible, water levels in key off-site wells near the site should also be measured to identify off-site pumping which may affect the test results. As a general rule, water levels in the pumping and key observation wells may be collected every 15 minutes for 3 to 7 days prior to the start of pumping to establish a baseline for the test. These data are generally collected using data loggers equipped with pressure transducers; manual measurements of the depth to water should be performed to confirm the loggers are functioning properly. Well caps should be vented or removed during the entire testing period to ensure that water levels in the well are in equilibrium with atmospheric pressure.

In addition to collecting water level data (at wells and nearby surface water bodies), precipitation and barometric pressure should be monitored and data collected. Atmospheric pressure data, when analyzed with the water level data collected during the antecedent period, may be used to correct water levels for the effect of short-term atmospheric pressure changes. The atmospheric pressure data should be collected at the same times as the water level data (as this greatly facilitates the subsequent analysis of an aquifer’s barometric efficiency).

Nearby pumping activities that may occur near the site should be identified and characterized, if possible; pump on-off times should be recorded, and their discharge rates determined. Significant effects caused by off-site pumping can often be removed from the test data if the on-off times of these wells are monitored during the test.

6.3.1.8 Pumping Period

Prior to the start of pumping, all watches and data logger clocks used by the field personnel to record the time of depth-to-water measurements shall be synchronized. Immediately before pumping is to begin, static water levels in all wells being monitored during the test shall be recorded. If possible, dedicated water-level-measuring devices should be used at each well being monitored during the test, and these should be lowered into each well 30 to 60 minutes prior to the start of the test. Data loggers being used to collect on-site data should be programmed to collect data on a logarithmic schedule. Water levels in wells where levels are being monitored using data loggers should also be measured manually in case of data logger failure and to provide proper quality assurance/quality control (QA/QC) of the test data. If drawdown is expected in an observation well soon after pumping begins, and the well is not equipped with a data logger, an observer should be stationed at each well to record water levels for the first two or three hours of the test (EPA, 1993). If numerous observation wells are being used to monitor a test, using data loggers will reduce manpower needs.

There are no firm rules regarding the time frame for measuring water levels at wells used during a pumping test. However, measurements are performed much more frequently at the start of a test. Measurements in observation wells should occur often enough, and soon enough, after pumping begins to avoid missing the initial drawdown in each well. The actual timing of the start of drawdown at a well will vary depending on the aquifer, the distance from the pumping well, and the pumping rate used during the test. Estimates for the timing of drawdown at observation wells should be made during the planning stages (Section 6.3.4) using estimated aquifer parameters and the proposed pumping rate.

Frequent measurements during early times are needed to define the drawdown curve; this is especially important to accurately determine the storativity of an aquifer. As time since pumping started increases, the logarithmic time scale used to analyze the data dictates that less frequent measurements are needed to adequately define the curve, since most data analysis techniques involve plotting the drawdown versus the log of the time passed since pumping began. A minimum of ten measurements should be collected during each log interval.

When data loggers are used to monitor water levels at a site, the maximum logging interval is typically set to 15 minutes. The EPA maximum recommended time intervals for water-level measurements are listed below (Table 6.3-1, 1993):

Table 6.3-1. EPA Maximum Recommended Time Intervals for Water-Level Measurements

Elapsed Time	Measurement Frequency
0 to 3 minutes	every 30 seconds
3 to 15 minutes	every minute
15 to 60 minutes	every 5 minutes
60 to 120 minutes	every 10 minutes
2 to 10 hours	every 30 minutes
10 to 48 hours	every 4 hours
48 hours to shut down	every 24 hours

It is important when starting the test to bring the pumping rate to the chosen rate as quickly as possible. At the immediate start of the test, attaining and maintaining the desired pumping rate will require diligence from the field crew as they monitor and adjust the discharge rate. If using valves to control the discharge rate, it is advantageous to have these at a pre-set position known to create the desired rate; the valves should be set well in advance of the start of the test to ensure the disturbance caused by pumping at the well will not impact the test data. This setting of the valve position can be done during the antecedent period, preferable 24 to 48 hours prior to the start of the pumping period.

How frequently the discharge needs to be monitored and adjusted during a test depends on the pump, well, aquifer, and power characteristics (EPA, 1993). During the initial hour of the test, well discharge at the pumping well should be monitored and recorded as often as practical. The date and time of adjustments made to the discharge rate should be noted, and the pre-adjustment and post-adjustment pumping rates recorded. The EPA (1993) recommends that the discharge should never be allowed to vary more that plus or minus 5 percent, since the variation of the discharge rate has a large effect on permeability estimates calculated using data collected during the test. However, it is important to note that some random short-term variations in the discharge rate may be acceptable if the average discharge does not vary by more than plus or minus 5 percent.

The length of the pumping period depends on the following:

- Objectives of the test
- Type of aquifer
- Location of suspected boundaries
- Degree of accuracy need to establish the storage coefficient and transmissivity
- Rate of pumping

The pumping period should continue until the data are adequate to define the shape of the drawdown curve and permit the desired hydraulic parameters to be calculated. This may require that pumping continue for a significant period after the rate of water level change becomes small, especially when the location of boundaries or the effects of delayed yield are of interest. Typically, the pumping period of a test performed on a confined aquifer may be 24 to 48 hours long, whereas a test performed on an unconfined aquifer may be 48 to 96 hours long. The anticipated length of the pumping period should be estimated based on the data needs and using the estimated site hydraulic parameters and conceptual model.

Plotting the drawdown data on semi-log paper during the test is essential for monitoring the status and effectiveness of the test. Plotting the data may also allow the field staff to identify erroneous data, which is especially important if data loggers are being used to collect data. Finally, the plots of drawdown will indicate when enough data for a solution has been collected.

6.3.1.9 Recovery Period

Recovery measurements should be made in the same manner and frequency as drawdown measurements made during the pumping period. These measurements should be collected until water levels have recovered to 95 percent of their pretest levels. If possible, water levels at selected wells and the barometric pressure should be monitored for three to seven days after pumping stops; these data will bolster the use of any corrections which may be identified using the antecedent data.

6.3.1.10 Precautions

- All depth-to-water measurements need to be performed using the same measuring points. If the location of a measuring point needs to be changed during a test, the time of the change shall be recorded and any change in the elevation of the point determined.

- The exact time of each depth-to-water measurement will be recorded regardless of the prescribed time interval.

- Comments describing all actions performed as testing is performed may be valuable when analyzing the data. It is very important to note any problems or events that may affect the quality of test data.

- If several water-level measurement devices are used during the test, they should be calibrated to each other by simultaneously measuring the water level in single well during the antecedent or late in the recovery period.

- If water levels are changing very rapidly (typically only in the pumping well when pumping first starts or ceases), it is easier to set the water-level measuring device immediately above or below the level of the water in the well and then record the exact time at which that the level occurs.

6.3.1.11 Data Analysis

This document is not intended to be an overview of aquifer test analytical methods. Numerous solutions are available to determine aquifer hydrogeologic parameters; the method selected depends on the type of aquifer and the type of test. Aquifer Hydraulics: A Comprehensive Guide to Hydrogeologic Data Analysis (Batu, 1998) describes many analytical methods which can be used to analyze aquifer testing data for various hydrogeologic settings. The computer program AQTESOLV for Windows (HydroSolve, Inc.) is a powerful program that greatly facilitates the analysis of data using some of the more commonly used solutions. Other useful references include Kruseman and de Ritter (1994), Dawson and Istok (1991), Driscoll (1986), and Domenico and Schwartz (1990).

Attachments

6.3-1. Pumping Test Data Sheet, Pumping Well

6.3-2. Pumping Test Data Sheet, Observation Well

References

American Society for Testing and Materials (ASTM). 2001a. *ASTM standards relating to environmental site characterization*. ASTM Publication Code Number (PCN) 03-418297-38. August 1997.

American Society for Testing and Materials (ASTM). 2001b. *Standard guide for selection of aquifer test method in determining hydraulic properties by well techniques* (ASTM D 4043-96).

American Society for Testing and Materials (ASTM). 2001c. *Standard test method (field procedure) for withdrawal and injection well tests for determining hydraulic properties of aquifer systems* (ASTM D 4050-96).

Batu, V. 1998. *Aquifer hydraulics: A comprehensive guide to hydrogeologic data analysis*. John Wiley & Sons, Inc., New York.

Dawson, K.J., and J.D. Istok. 1991. *Aquifer testing, design and analysis of pumping and slug tests*. Lewis Publishers, Inc., Chelsea, Michigan.

Domenico, P.A., and F.W. Schwartz. 1990, *Physical and chemical hydrogeology*. John W. Wiley & Sons, Inc., New York, NY.

Driscoll, F.G. 1986. *Groundwater and wells, Second edition*. Johnson Filtration Systems, Inc., St. Paul, Minnesota.

Fetter, C.W. 1994. *Applied hydrogeology, Third edition*. Macmillan College Publishing Company, New York.

Kruseman, G.P., and N.A. de Ridder. 1994. Analysis *and evaluation of pumping test data, Second edition*. Publication 47, International Institute of Land Reclamation and Improvement, Wageningen, The Netherlands.

U.S. Environmental Protection Agency (EPA). 1993. *Suggested operating procedures for aquifer pumping tests*. Ground Water Issue, EPA/540/S-93/503. February.

Daniel B. Stephens & Associates, Inc.

Pumping Test Data Sheet

Sheet ___ of ___

Project Name: ______________________________ Pumping Well: ____________________

Date	Time	Rate (gpm)	Depth to Water (ft)	Elapsed Time (min)	Drawdown (feet)	Comments

P:\SOPs\13-Field\Bill's\13-6-3 Attach_2004.doc

Pumping Test Data Sheet

Daniel B. Stephens & Associates, Inc.

Sheet ___ of ___

Project Name: ______________________________ Observation Well: ____________________

Date	Time	Depth to Water (ft)	Elapsed Time (min)	Drawdown (feet)	Comments

P:\SOPs\13-Field\Bill's\13-6-3 Attach_2004.doc