Groundwater Flow Model Calibration

BMI Upper and Lower Ponds Area

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Prepared for:

Daniel B. Stephens & Associates, Inc.

6020 Academy NE, Suite 100 • Albuquerque, New Mexico 87109

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. 11/12/09)
Daniel B. Stephens & Associates, Inc.

Individuals Who Provided Technical Input to this Document

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

John J. Dodge, P.G.
Daniel B. Stephens & Associates, Inc.

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1. Introduction and Objectives

This document is an interim report regarding groundwater flow model calibration, prepared to detail the methods used in model development and model calibration, as well as the statistical results of model calibration, for the groundwater flow model developed for the BMI Upper and Lower Ponds area at the Basic Remediation Company (BRC) Eastside property (Site). Figure 1 illustrates major site features. The domain of the model, referred to as the BRC Eastside groundwater model, encompasses the BMI Upper and Lower Ponds area at the Site as well as adjacent parcels (Figure 2). The BRC Eastside groundwater model was completed in accordance with the *Groundwater Modeling Work Plan [modeling work plan] for BMI Upper and Lower Ponds Area,* prepared by Daniel B. Stephens & Associates, Inc. (DBS&A), dated November 8, 2006 (DBS&A, 2006).

The input parameters for the numerical groundwater flow model (sources and sinks) were previously presented to BRC and the Nevada Division of Environmental Protection (NDEP) in the *Revised Technical Memorandum: Sources/Sinks and Input Parameters for Groundwater Flow Model, BMI Common Areas, Eastside Area* dated April 30, 2008 (DBS&A, 2008a) (water balance technical memorandum). This technical memorandum presented the methodology and the preliminary calculations, estimates, and information sources and references that were used to develop values for groundwater inflows (sources) and groundwater outflows (sinks) in three scenarios:

- Historical scenario (c. 1968)
- Current scenario (2007)
- Future scenario

The water balance technical memorandum also presented the methodology used in parameter estimation and the preliminary values for each input parameter that was used in the model. The source/sink estimates were, in part, further refined during model development as additional information was obtained regarding off-site properties and Site conditions.

As stated in the work plan, the intended purpose of the modeling effort is as follows:

- Evaluate future groundwater flow conditions at the Site assuming a variety of possible future changes at the land surface, such as development of the Site (e.g., roads, houses) and the removal of phreatophytes (salt cedar [*Tamarisk*]). Of particular importance is the evaluation of the potential for groundwater to rise in the future to a point where it may be near or can potentially intersect the land surface.

- Estimate the impacts to the groundwater flow field attributable to past groundwater mounding beneath the Upper and Lower Ponds and sources of groundwater recharge.

- Evaluate the current and future transport and discharge of dissolved contaminants in groundwater from the Site to the Las Vegas Wash, either directly or indirectly. This also includes evaluation of the potential effects that a rising water table may have on future contaminant transport, including remobilization of contaminants that potentially exist in the vadose zone beneath source areas, and evaluation of contaminant mass flux to the upper unconfined water-bearing zone through leaching of contaminants in the vadose zone due to recharge.

Once the flow model is appropriately calibrated to historical and current conditions (i.e., upon NDEP approval of this report), the model will be used to simulate future conditions. Solute transport will be simulated separately once current and future scenarios are completed. This model calibration report provides an update on work completed to date so that DBS&A, BRC, and NDEP can plan for the upcoming predictive simulations in the future scenario. A final modeling report will be prepared upon completion of the predictive simulations.

2. Background Geology and Hydrogeology

This section provides a brief overview of Site hydrogeology. More detailed descriptions of Site hydrogeology can be found in BRC et al. (2004, Appendix F).

Groundwater at the Site occurs in three primary water-bearing units (Figure 3). The first water occurrence is the upper unconfined water-bearing zone (UUWBZ), which typically occurs in alluvial sands and gravels of Quaternary age that are generally referred to as the Quaternary alluvium (Qal). In some locations, the water table is first encountered in the Upper Muddy Creek formation (UMCf), a lithologic unit comprised mostly of silts and clays that underlies the Qal. The UMCf is a lacustrine deposit of Tertiary age. The UUWBZ is also referred to as the "alluvial aquifer" (Aa), whether or not the water table first occurs in the Qal or the UMCf.

The second water-bearing unit underlying the UUWBZ is confined water that occurs in the UMCf at locations and depths where the sand content is somewhat higher (intermediate water-bearing zone). These sandy lenses are typically thin water-bearing lenses encountered sporadically during drilling and sampling at the site. The sand lenses occur within the generally finer matrix of the UMCf that extends downward from the Qal/UMCf interface. Groundwater observed in intermediate-zone sand lenses of the UMCf is typically confined, and water levels measured in monitoring wells rise above the level at which water from this zone is first observed during drilling.

A third groundwater-bearing zone has been identified on the Site during the 2004 field investigation of the Site (BRC et al., 2004). This confined water-bearing zone was identified as the deep water-bearing zone (DWBZ) and was observed to occur reasonably continuously across the Site within a depth range of approximately 350 to 400 feet below ground surface (ft bgs).

Additional deep monitoring wells were installed on the Site in 2008 that confirmed the presence of this DWBZ. Water in the DWBZ is under pressure, and monitoring well water levels rise up to hundreds of feet higher than the depth at which the water-bearing zone is first encountered. DWBZ wells have been relatively poor producers of water, with observed post-bailing well recharge rates in the nominal range of 1 gallon per minute (gpm).

3. Model Construction

This section presents the details of model construction, which involves the implementation of the hydrogeologic conceptual model into a numerical model of groundwater flow, including development of the model grid and active model domain extent and assignment of appropriate boundary conditions for the top, bottom, and sides of the model domain, including assignment of aquifer hydraulic properties (e.g., hydraulic conductivity) and “internal” boundary conditions such as infiltration and evapotranspiration. These tasks are described in Sections 3.1 and 3.2.

As documented by DBS&A (2008a), the MODFLOW-SURFACT computer code developed by HydroGeoLogic, Inc. of Herndon, Virginia was applied to conduct the groundwater flow simulations. MODFLOW-SURFACT is an upgraded, proprietary version of the USGS MODFLOW code that can be commercially purchased. The code includes all of the functionality of the standard MODFLOW software developed by the U.S. Geological Survey (USGS), but also includes a number of added capabilities and advanced algorithms that are useful for simulating groundwater flow beneath the Site. MODFLOW-SURFACT has been used by numerous governmental and private entities since 1996.

3.1 Grid Design

The model domain was uniformly divided into grid cells 209 feet on a side, which leads to model cells approximately 1 acre in area (Figure 2). This cell size is sufficiently small to implement characteristic site features in reasonable detail and is also sufficiently small to meet typical Peclet number criteria for solute transport simulations (DBS&A, 2006).

In the vertical dimension two model layers were used. Model layer 1 represents the alluvial sediments and model layer 2 represents the upper portion of the UMCf. The top of model layer 1, therefore, is the land surface, and the bottom of model layer 1 (top of model layer 2) is the elevation of the Qal-UMCf contact determined for the center of each cell based on the map provided in the water balance technical memorandum (DBS&A, 2008a). The bottom of model layer 2 was set to be 50 feet below the base of model layer 1. Model layer 1 is specified as unconfined, while model layer 2 is specified as variable type (confined or unconfined). Note that model layer 1 does not necessarily correspond directly to the UUWBZ described above, and model layer 2 does not necessarily correspond directly to the intermediate water-bearing zone, although the prescribed layers will be analogous with the zone terminology at many locations.

3.2 Boundary Conditions

This section presents the boundary conditions applied to the top, bottom, and sides of the model domain.

3.2.1 Lateral (Side) Boundary Conditions

The lateral model boundary conditions applied for model layers 1 and 2 (Figures 4 and 5, respectively) are a combination of prescribed groundwater flux and prescribed hydraulic head. Groundwater inflow is prescribed along the portions of the model domain where the contoured hydraulic head maps or observation well information indicate that inflow would occur to the model domain (DBS&A, 2008a). Where no boundary condition type is indicated, a no-flow boundary (prescribed groundwater flux of zero) is applied. These boundary segments generally coincide with a groundwater flow pathline or, in the case of model layer 1, with locations where the Qal is dry. Note that some lateral boundary conditions in model layer 1 differ between the current and historical scenarios (Figure 4), but the lateral boundary conditions applied in model layer 2 are the same (Figure 5).

The northern boundary of model layer 1 was simulated as a third-type boundary condition using the General Head Boundary Package of MODFLOW-SURFACT (Figure 4). This is generally an outflow boundary, although locally there is limited inflow of water that again exits the model domain in the vicinity of the boundary. The boundary head was estimated to be the head in Las Vegas Wash, and the conductance was estimated based on the approximate distance from the boundary cell to the center of the wash, a hydraulic conductivity of wash sediments of 485 feet per day (ft/d) (McGinley and Associates, 2003) and a saturated thickness of 40 feet. Table 1 summarizes the general head boundary parameters for model layer 1.

The northern boundary of model layer 2 is a prescribed head boundary, where the prescribed head was estimated based on a hydraulic head contour map for the upper portion of the UMCf (Figure 6). Figure 5 also illustrates the location of general head boundary cells used for the base of model layer 2, which is described in detail in Section 3.2.3.

3.2.2 Top Boundary Conditions

The top of the model domain (top of model layer 1) is prescribed as the land surface elevation determined for the center point of each model cell. During the simulations, the top model boundary is actually the simulated location of the water table. Boundary conditions applied to the top of the model include inflow from recharge, discharge due to evapotranspiration, and direct discharge of groundwater at seeps where the water table intersects the land surface. Each of these boundary types is discussed below.

Recharge from precipitation and ponds is prescribed using the Recharge Package of MODFLOW-SURFACT, which requires that a recharge rate, location, and associated time period be prescribed. Initial estimates of recharge from various sources were adjusted during the model calibration process (Section 4).

Evapotranspiration from phreatophytes (e.g., salt cedar) is simulated using the Evapotranspiration Package of MODFLOW-SURFACT. The Evapotranspiration Package requires input of a maximum evapotranspiration rate and an extinction depth, which is the depth below land surface below which it is assumed that evapotranspiration does not occur. Simulated evapotranspiration occurs at the maximum rate when the simulated water level is at land surface, and the simulated rate of evapotranspiration decreases linearly to zero at the extinction depth.

Evapotranspiration input parameters were estimated based on a technical memorandum prepared by Dr. Dale Devitt of the University of Nevada Las Vegas, who provides estimates of evapotranspiration from various stands of salt cedar at the Site (Devitt, 2006). Although the estimates incorporate depth to groundwater and plant-specific considerations, such as age and stand density; a standard formula for rate of evapotranspiration as a function of water table depth (which is needed for input to the model) or other factors is not provided. The maximum evapotranspiration rate of 119 centimeters per year (cm/yr) was estimated by Devitt (2006) for a stand of salt cedar at the north end of the Site near Las Vegas Wash where the depth to groundwater was only 5 to 10 feet. At four other locations where estimated depths to groundwater ranged from 20 to 55 feet, Devitt (2006) estimated evapotranspiration rates of 38 to 75 cm/yr. Based on this information, a maximum evapotranspiration rate of 125 cm/yr was applied, and the extinction depth was set to the average depth of the Qal for each zone of evapotranspiration considered in the model. Evapotranspiration zones applied in the calibrated model are discussed in Section 4.1.1.

Discharge to seeps at the land surface is simulated using the Drain Package in MODFLOW-SURFACT. Application of the Drain Package requires specification of the drain elevation, which was set to the land surface at the appropriate model cells where seepage was known or expected to occur. In addition, drain conductance must be prescribed. The drain conductance is a function of the permeability of the aquifer materials in the vicinity of the drain, the geometry of the primary groundwater flow paths in the vicinity of the drain, and the cell size. Drain conductance was calculated assuming a 25-foot vertical distance and a vertical hydraulic conductivity of 0.3 ft/d.

3.2.3 Bottom Boundary Condition

The bottom boundary of the groundwater model (bottom of model layer 2) was simulated as a third-type boundary condition using the General Head Boundary Package. This type of boundary is one where the simulated groundwater flow across the boundary is a function of the difference in hydraulic head between the shallow UMCf represented as model layer 2 (approximately the upper 50 feet of the UMCf) and the DWBZ in the UMCf that nominally occurs at about 350 to 400 ft bgs at the Site (Figure 3). Available information indicates that the direction of hydraulic gradient between the deep and shallow zones of the UMCf is generally upward in the southern and central portions of the site and generally downward in the region north of the spray wheel and south-southeast of the northern rapid infiltration basins (RIBs) (Figure 1).

Figure 7 provides the contour map used to determine the hydraulic head in the DWBZ of the UMCf for the bottom general head boundary. The conductance term was estimated based on the vertical distance between the bottom of model layer 2 and the DWBZ of the UMCf (approximately 300 feet) and the estimated vertical hydraulic conductivity of the UMCf of 0.002 ft/d used in the modeling.

3.3 Simulation Time Periods

Two time periods were considered for model calibration (DBS&A, 2006):

- The *current* period simulation is representative of recent hydrologic conditions; for this simulation period, 2007 observed data were applied for model calibration.

- The *historical* period simulation is approximately representative of the mid- to late 1960s.

3.4 Density-Dependent Flow

Density-dependent groundwater flow was not considered explicitly in the simulations. However, the effects of density on observed hydraulic head were calculated for 31 site wells by DBS&A (2008b). The calculation considered 10 wells within the shallow zone (primarily Qal), 11 wells within the intermediate zone (upper part of the UMCf), and 10 wells within the DWBZ (lower UMCf). For most of these wells, multiple (4 to 5) measurements of hydraulic head and total dissolved solids (TDS) concentration were available.

For the shallow zone wells, the observed TDS concentrations ranged from 1,990 milligrams per liter (mg/L) at well AA-07 to 47,600 mg/L (well MCF-06C), with most TDS values in the 2,000- to 6,000-mg/L range. The calculated difference between observed hydraulic head and equivalent fresh water hydraulic head (hydraulic head corrected for density effects) is several hundredths of a foot or less at each of these wells, including MCF-06C. The differences are small due to the small water column thickness and relatively low TDS values. Clearly, the effects of groundwater density on groundwater flow are insignificant for the shallow zone (which is generally equivalent to layer 1 in the groundwater model).

For the intermediate zone wells, the observed TDS concentrations ranged from 620 mg/L at well MCF-2B to 74,400 mg/L at well MCF-16B. The calculated difference between observed hydraulic head and equivalent fresh water hydraulic head generally ranges from zero to several tenths of a foot or less. At well MCF-6B, which has observed TDS concentrations of approximately 39,000 mg/L, the difference between observed hydraulic head and equivalent fresh water hydraulic head is less than 1 foot. At well MCF-8B, which has observed TDS concentrations of approximately 27,000 mg/L the difference between observed hydraulic head and equivalent fresh water hydraulic head is about 2.4 feet. Well MCF-16B is the only intermediate zone well that exhibits a significant difference between observed and equivalent fresh water hydraulic head (about 13 feet). This well has observed TDS concentrations of about 70,000 to 74,000 mg/L and is completed substantially deeper than other intermediate zone wells. The bottom of the screen in well MCF-16B is 314 feet, whereas the bottom of the screen in the other intermediate zone wells ranges from 77 to 175 feet. Given these observations, density-dependent effects on groundwater flow in the intermediate zone (generally equivalent to layer 2 in the groundwater model) are believed to be insignificant.

For the deep zone wells, the observed TDS concentrations ranged from 492 mg/L at well MCF-2A to 205,000 mg/L at well MCF-6A. The calculated difference between observed hydraulic head and equivalent fresh water hydraulic head at most wells generally ranges from very small to several feet or less. However, the calculated equivalent fresh water heads in wells MCF-06A, MCF-07, and MCF-16A, all of which have high TDS concentrations, are about 47, 40, and 22 feet higher, respectively, than the observed hydraulic head. These wells are generally located in the vicinity of the northern site boundary and east-southeast of the City of Henderson (CoH) northern RIBs. During model calibration, observed hydraulic heads were used to assign DWBZ hydraulic heads because:

- The observed and calculated equivalent fresh water hydraulic heads are not significantly different at most wells.

- The extent of high-TDS water at depth is not sufficiently delineated to warrant detailed consideration in the model.

Because the assignment of model layer 2 boundary heads (DWBZ hydraulic heads) may be significantly affected by groundwater density in some areas, a sensitivity analysis was run on the bottom boundary flux (Section 5), and based on the results of this analysis, the exchange of groundwater across the bottom of the model domain is not a highly sensitive model parameter.

4. Model Calibration

Model calibration was conducted for both the current and historical time periods, although most of the calibration effort was spent on the current time period, because the amount of observed available data for 2007 was far greater. The results of model calibration for each time period are presented in Sections 4.1 and 4.2. Input parameters that do not vary with time, such as aquifer hydraulic conductivity, are the same in both the current and historical period calibrated models.

Model calibration results are presented in terms of several statistical measures, including mean-absolute error (MAE), mean error (ME), and root-mean-squared error (RMSE). These terms are defined as follows:

$$MAE = \frac{1}{n} \sum_{i=1}^{n} Abs \left(h_{obs} - h_{sim} \right)$$

$$ME = \frac{1}{n} \sum_{i=1}^{n} \left(h_{obs} - h_{sim} \right)$$

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} \left(h_{obs} - h_{sim} \right)^2 \right]^{0.5}$$

where n = number of water level observations

h_{obs} = observed water level

h_{sim} = simulated water level

Abs = absolute value

The primary goal of model calibration is to reduce the value of each of these statistics to the extent possible, using model input values consistent with observed data or realistic estimates. The observed values in the above equations are often referred to as calibration targets.

The ME is a simple average of the residual between observed and simulated water levels, and therefore, positive values will offset negative values. A positive value of ME indicates that, on average, simulated hydraulic heads are lower than observed hydraulic heads, while a negative value indicates the opposite.

MAE is similar to the ME, with the important distinction that the sum of the absolute values of the residuals is calculated, thereby eliminating the offset that occurs by adding positive and negative values. The MAE, therefore, is always positive and represents the average difference between observed and simulated hydraulic head values.

The RMSE is a third commonly applied model calibration statistic computed in groundwater modeling. The RMSE is similar to the MAE, although negative values of the residual between observed and simulated hydraulic heads are eliminated by squaring the difference, and then the square root of the sum is determined prior to computing the average. This approach is analogous to the computation of the variance that would be conducted for a linear regression.

Measures of model calibration such as the MAE and the RMSE are often evaluated in terms of their magnitude relative to the total head loss across the hydrogeologic system (e.g., Anderson and Woessner, 1992). A common informal modeling guideline is that the RMSE should be less than 10 percent of the observed hydraulic head drop that occurs across the model domain.

4.1 Current Period Model Calibration

The model was calibrated to current (2007) conditions by adjusting the hydraulic conductivity and recharge resulting from the various sources. All model inputs were maintained to be within reasonable ranges as determined by the water balance technical memorandum (DBS&A, 2008a), unless additional data or analysis warrants adjustments outside the ranges. Model calibration was conducted primarily through the traditional trial and error approach, although application of the so-called “automated” parameter estimation approach was attempted early in the model calibration process using the PEST code (Watermark Numerical Computing, 2004). The calibrated model input parameters and the results of the current period model calibration are provided in Sections 4.1.1 and 4.1.2.

4.1.1 Model Input Parameters

The primary model calibration parameters were model layer 1 hydraulic conductivity and recharge. Field data and previous studies indicate that within the Qal, hydraulic conductivity tends to be substantially greater in the paleochannel areas than in the interchannel areas. Figure 8 is a plot of the model grid superimposed on the base of Qal (model layer 1) surface. Various paleochannel areas, discussed in detail in previous reports, are evident in the figure. Figure 9 presents the corresponding hydraulic conductivity field applied for model layer 1 as determined through model calibration, as well as the available observed hydraulic conductivity values or range of values determined from field testing. Table 2 lists the sources of the hydraulic conductivity data provided in Figure 9.

As indicated in Figure 9, significantly greater hydraulic conductivity is applied within the paleochannel areas relative to interchannel areas. Across most of the east side of the model domain, a paleochannel hydraulic conductivity of 100 ft/d is applied and an interchannel hydraulic conductivity of 10 ft/d is applied. The interchannel value is supported by existing field data. The paleochannel value of 100 ft/d is slightly higher than the highest observed value of 85 ft/d, but that value was not measured in the central portion of the channel. Alternative model runs using a paleochannel hydraulic conductivity of 80 ft/d in this area provided reasonable, although slightly worse, model calibration statistics. A paleochannel hydraulic conductivity of 300 ft/d is applied in the vicinity of the CoH northern RIBs (Figures 1 and 9). This value is consistent with aquifer test data west of this paleochannel and is necessary to avoid an unreasonable amount of simulated mounding of groundwater in the vicinity of the RIBs.

A paleochannel hydraulic conductivity of 300 ft/d is also applied on the west side of the model domain, where observed data range from 227 to 1,020 ft/d. Paleochannel hydraulic conductivity values in this area are substantially higher than those observed at aquifer test locations to the east. In addition, the applied interchannel hydraulic conductivity of 30 ft/d is higher than in the east (Figure 9). Although the one known observed interchannel data point is 3 ft/d, several data points just outside the model domain west of Pabco Road and north of Boulder Highway indicate a hydraulic conductivity of about 20 ft/d. A previous modeling effort that included a portion of this region used 50 ft/d for a portion of these sediments (NDEP, 2005). As discussed in Section 5, the interchannel hydraulic conductivity in this area is a highly sensitive model input parameter, and significant reduction in the current value (e.g., from 30 ft/d to 10 ft/d) would lead to an unacceptable model calibration.

Two UMCf wells representative of the upper portion of the UMCf, included in the model as layer 2, were slug tested (Kleinfelder, 2007a). Well MCF-03B, screened from 60 to 80 feet below top of casing (ft btoc), had an estimated hydraulic conductivity of 0.18 ft/d. Well MCF-06C, screened from 44 to 59 ft btoc, had an estimated hydraulic conductivity of 1.5 ft/d. Based on model calibration and the predominant fine-grained nature of the UMCf, a uniform value of 0.2 ft/d was used for the horizontal hydraulic conductivity of model layer 2.

Assigned lateral groundwater inflow to both model layers 1 and 2 was adjusted during the model calibration process in conjunction with changes in hydraulic conductivity. This approach maintains a consistent groundwater flow estimate at the boundary.

The vertical hydraulic conductivity of model layer 1 was set to one-tenth of the horizontal hydraulic conductivity value. The vertical hydraulic conductivity of model layer 2 was set to a constant value of 0.002 ft/d, or one-hundredth of the horizontal value, to represent the expected vertical anisotropy of the fine-grained UMCf sediments.

Figure 10 presents the calibrated recharge used in the model for the current period scenario. There are 6 distinct zones of recharge that are expected to have different values attributable to differences in land use. The lowest recharge rate of 0.066 inches per year (in/yr) is assigned to developed areas, while the highest recharge rate of 291.3 in/yr is assigned to the CoH northern RIBs.

Recharge was assigned to the CoH northern RIBs and the Birding Preserve using information supplied by the City. The average reported inflow to the northern RIBs for 2005 and 2006 is 1.59 million gallons per day (mgd), while the average reported inflow to the Birding Preserve for the same period is 1.6 mgd. The average inflow for 2005 and 2006 was selected because these two years immediately precede the early 2007 calibration time period. The area of each facility as implemented in the model (Figure 10) was computed, and an evaporative loss of 0.44 mgd and 0.92 mgd for the RIBs and the Birding Preserve, respectively, was assumed based on a pan evaporation rate of 110.7 in/yr measured at the Boulder station (Shevenell, 1996).

Although water was sent to the CoH southern RIBs during December 2006 through April 2007, recharge from this facility was not included in the model because of the limited time period of application. Since the model assumes steady-state conditions, the implicit assumption is that any applied recharge value or other stress is active for a sufficient period of time that steady- or quasi-steady-state conditions are achieved. The steady-state model is not appropriate, therefore, for implementation of short-term changes in hydrologic stresses, such as those that occurred at the CoH southern RIBs. Prior to this last application of water to the CoH southern RIBs, the amount of water sent to the RIBs was zero or extremely small for a 19-month period (May 2005 through November 2006), and after April 2007, no additional water has been sent to the southern RIBs, and the pipe connection to the southern RIBs was severed by the CoH in March 2008.

Recharge assigned to the Tuscany golf course (4.33 in/yr) is the only value that is outside the estimated range provided in the water balance technical memorandum (DBS&A, 2008a). The range of potential recharge values provided by DBS&A (2008a) for the golf course is believed to be too low, but the value applied in the BRC Eastside model is believed to be reasonable. Although the amount of water applied to the golf course is not known, it would be reasonable to expect that at least 24 inches or more of irrigation would be required over the course of the year based on typical water use in other arid areas. If this were the case, the simulated recharge would amount to about 18 percent of the applied water. If the applied water is greater (which is likely), then the percentage would be less.

The assigned evapotranspiration zones are illustrated in Figure 11. The zones differ only in the extinction depth, which is set to be the approximate average depth to the base of alluvium. As discussed in Section 3.2.2, the maximum evapotranspiration rate that would occur if the water table were at the land surface is 125 cm/yr, or 0.011 ft/d. The simulated evapotranspiration rate decreases linearly between 0.011 ft/d at the land surface to zero at the extinction depth. The actual rate of evapotranspiration depends upon where the simulated water level falls within this range, and it can vary on a cell-to-cell basis.

4.1.2 Calibration Results

Observed 2007 water levels used for model layer 1 calibration are illustrated in Figure 12, and a plot of simulated versus observed model layer water levels for the current period model calibration is provided in Figure 13. Figure 13 illustrates a good agreement between simulated and observed water levels, with an MAE of 5.7 feet, an RMSE of 7.1 feet, and an RMSE divided by the range in observed water levels of 3 percent. In addition, the ME is 0.4 foot, indicating that, on average, simulated water levels are only very slightly lower than observed water levels. A complete listing of model calibration statistics is provided in Table 3, and observation well characteristics and model calibration results are listed in Table 4.

Figure 14 illustrates the simulated model layer 1 hydraulic head field. As illustrated in the figure, significant portions of the model layer 1 are simulated as dry. At these locations, the simulated water table lies below the base of model layer 1 and is in model layer 2, the upper portion of the UMCf. Observation wells indicating dry Qal conditions are indicated on the figure, and there is a good correspondence between observed and simulated dry Qal zones.

Observed 2007 water levels used for model layer 2 calibration are illustrated in Figure 15, and a plot of simulated versus observed model layer water levels for the current period model calibration is provided in Figure 16. Significantly fewer calibration points are available for model layer 2 as compared to model layer 1. Figure 17 illustrates the simulated model layer 2 hydraulic head field.

Figure 16 illustrates a good agreement between simulated and observed water levels, with an MAE of 7.4 feet, an RMSE of 11.7 feet, and an RMSE divided by the range in observed water levels of 5 percent. In addition, the ME is –4.5 feet, indicating that, on average, simulated water levels are slightly higher than observed water levels. If the point with the greatest difference—well BEC-9, with a residual of 45.7 feet—is removed from the calculation, the RMSE would be 7.8 feet. Well BEC-9 occurs just north of the Spray Wheel in the Upper Ponds area (Figure 1). Available depth and screen information was reviewed for this well, and at this time there is no reason to suspect that the hydraulic head observed in this well is anomalous. Additional calibration statistics for model layer 2 are provided in Table 3.

The current period simulation mass balance and the estimated range of values provided in the water balance technical memorandum (DBS&A, 2008a) are summarized in Table 5. As indicated in the table, the largest simulated sources of inflow are from lateral groundwater inflow to the Qal and seepage at the CoH northern RIBs and the Birding Preserve, followed by upward flow from the DWBZ of the UMCf. Although AMPAC well injection is also significant, this term represents a transfer of water from one place to another within model layer 1. The largest simulated sources of outflow are lateral outflow from the Qal to Las Vegas Wash and Tronox and AMPAC pumping for groundwater remediation. The simulated mass balance error is very low, about 0.01 percent.

Review of Table 5 indicates that, where a range of potential values was estimated for a water budget component, simulated values fall within the range except for recharge from Tuscany golf course irrigation (Section 4.1.1). Simulated values for the combined seepage from the CoH northern RIBs and the Birding Preserve and Tronox pumping at the Athens Road well field are different than the estimated value, although a range in estimated values was not determined for the water balance technical memorandum (DBS&A, 2008a). The combined seepage from the CoH northern RIBs and Birding Preserve is about 50 percent of value estimated by DBS&A (2008a), although as explained above, infiltration values were calculated directly from CoH data that were not available when the previous estimate was made. Simulated seepage from the TIMET ponds is sufficiently close to the estimated value to be considered essentially the same.

Tronox pumping at the Athens Road well field is about 86 percent of the estimated value. Higher Tronox pumping values could not be simulated in the model without dewatering model layer 1 at the pumping locations. Similarly, the simulated AMPAC pumping is about 50 percent of the estimated value (AMPAC, 2007), due to the formation of dry cells if higher pumping rates are applied. First attempts at simulating AMPAC pumping led to even smaller pumping amounts, until the base elevation of model layer 1 was adjusted (decreased) at the pumping well locations based on information provided by GeoSyntec Consultants (2005). The need for some degree of reduction in pumping rates to make them sustainable in the model seems reasonable because the model assumes steady-state conditions and the extraction well fields may not yet be at steady state.

Figure 18 illustrates the simulated direction of groundwater flow between model layers 1 and 2. Although variable, groundwater flow is predominantly upward from model layer 2 (upper portion of the UMCf) to model layer 1 (Qal). The simulated direction of groundwater flow is downward from model layer 1 to model layer 2 beneath zones of significant recharge, such as the Birding Preserve, the CoH northern RIBs and the Tuscany golf course.

Figure 19 illustrates the simulated direction of groundwater flow across the bottom of the model domain (bottom of model layer 2). The simulated direction of groundwater flow is primarily due to the direction of hydraulic gradient indicated in the shallow and deep UMCf hydraulic head maps (Figures 6 and 7, respectively). Simulated groundwater flow is primarily upward from the deep UMCf to the shallow UMCf in the west, south, and south-central portions of the model domain and primarily downward from the shallow UMCf to the deep UMCf in the north-central and northeastern portions of the model domain.

4.2 Historical Period Model Calibration

Model calibration to the historical period was not as detailed as that conducted for the current period because water level measurements and other information for the historical time period (mid- to late 1960s) are generally lacking. The historical period simulation consisted of adjusting model recharge in an attempt to generally match observed groundwater outflow conditions believed to be captured in a series of aerial photographs from the mid- to late 1960s.

Figure 20 illustrates the model grid and a 1968 aerial photograph of the Site. The dark region along and extending from the northern boundary of the Upper Ponds is believed to be one of groundwater outflow. The dark regions within the southern portion of the Upper Ponds area are believed to illustrate fluids in the ponds that are evaporating and infiltrating at the time that the photograph was taken. Since one of the purposes of the groundwater flow model is to evaluate potential changes in the water table in the future, and more specifically to evaluate whether the water table may intersect land surface, the modeling work plan (DBS&A, 2006) calls for consideration of this historical period to the extent possible.

Figure 21 represents the calibrated historical model recharge values applied, which are all within the ranges estimated in the water balance technical memorandum (DBS&A, 2008a). Recharge to various sources was adjusted in an attempt to approximate the extent of groundwater outflow cells believed to be represented by the dark area identified in Figure 19. The model area where groundwater outflow is simulated to occur is illustrated in Figure 22. Comparison of Figure 22 with Figure 20 illustrates a reasonable correspondence between observed and simulated conditions, particularly given the general absence of hard data and observations for the historical simulation period. Note that several additional zones of groundwater outflow are indicated by the model that are not evident in the aerial photograph. The extent of these zones would be reduced or eliminated if prescribed boundary inflow were reduced. Reduction of the inflow is probably appropriate due to the general nature of the historical water level map used to make the inflow estimates (DBS&A 2008a); however, boundary adjustments were not made of the historical period simulation.

The historical period simulation mass balance is provided in Table 6. As with the current period simulation, the mass balance error for the historical period simulation is a very small fraction of a percent. The major sources of inflow for the historical period simulation are lateral inflow within the Qal (model layer 1), seepage along the various ditches (primarily the Alpha and Beta ditches), and seepage from the Upper and Lower Ponds. Simulated recharge from the Upper and Lower Ponds is about 8 percent of that estimated by DBS&A (2008a) based on Westphal and Nork (1972). As illustrated in Section 5, application of infiltration rates on the order of those estimated by Westphal and Nork (1972) leads to numerous flooded cells (cells where the simulated water level is above land surface) throughout the model domain. In order to simulate substantially higher infiltration rates for the Upper and Lower Ponds, the hydraulic conductivity used for model layer 1 would have to be much greater, which would be inconsistent with existing aquifer test data.

The major sources of outflow are lateral groundwater outflow from the Qal to the Las Vegas Wash sediments, downward vertical leakage to the deep UMCf, outflow from the Tronox Seep, and evapotranspiration from phreatophytes. The outflow from evapotranspiration for the historical simulation is nearly three times the simulated value for the current period simulation due to the higher simulated water levels and the corresponding increase in evapotranspiration rate. Outflow from the Tronox seep was simulated as a pumping well, since the simulated water table for the historical scenario does not intersect land surface at the seep location.

Due to the general lack of historical data on aquifer and groundwater flow conditions, the results of the historical period model calibration should be considered in a qualitative, rather than a quantitative manner.

5. Sensitivity Analysis

Sensitivity analysis is the process of changing selected model input parameters within reasonable ranges to evaluate the effects of changing the parameter(s) on simulation results. Model input parameters that have a significant (large) effect on model output are called “sensitive” parameters, while input parameters that have little or no influence on simulation results when they are changed are called “insensitive” parameters. Sensitivity analysis was conducted for the current period model for a variety of input parameters, and for the historical period model for recharge rates only.

Sensitivity analysis was conducted using the current period simulation for 13 model input parameters, listed below in approximate order of most sensitive (greatest change to simulation results) to least sensitive (smallest change to simulation results). The input parameters listed near the end of the ranking have only a minor effect on model calibration results.

- Horizontal hydraulic conductivity of the western paleochannels (calibrated value of 300 ft/d [Figure 9])
- Recharge from CoH northern RIBs
- Horizontal hydraulic conductivity of the paleochannel beneath and north of the CoH northern RIBs (calibrated value of 300 ft/d [Figure 9])
- Horizontal hydraulic conductivity of the western interchannel areas (calibrated value of 30 ft/d [Figure 9])
- Horizontal hydraulic conductivity of the eastern (Upper Ponds area) paleochannels (calibrated value of 100 ft/d [Figure 9])
- Recharge from precipitation in undeveloped areas
- Recharge at the CoH Birding Preserve

- General head boundary conductance for bottom of model layer 2 (affects inflow to or outflow from the UMCf DWBZ)
- Horizontal hydraulic conductivity of the eastern interchannel areas (calibrated value of 10 ft/d [Figure 9])
- Horizontal hydraulic conductivity of model layer 2 (calibrated value of 0.2 ft/d)
- TIMET pond seepage
- Maximum evapotranspiration rate
- Recharge from precipitation in developed areas

The results of the sensitivity analysis are provided graphically in Figure 23. As illustrated by the figure, the first five input parameters listed above are those that most significantly affect model calibration, with the horizontal hydraulic conductivity of the various zones and recharge at the CoH northern RIBs clearly being the most sensitive input parameters. The effects of increasing the western paleochannel hydraulic conductivity are not plotted because the change in the sum of squares is too high, in part because increasing this input parameter (without increasing recharge or boundary inflow) leads to numerous dry cells.

Due to a lack of observed data for the historical simulation period, the sensitivity analysis conducted was limited to adjustments in recharge. The historical period simulation recharge applied is on the low end of potential values identified in the water balance technical memorandum (DBS&A, 2008a). For the sensitivity analysis, simulated recharge for each source (Figure 24) was increased by factors of 2 and 10. As illustrated in Figure 24, increasing the specified recharge leads to a significantly greater area of simulated seepage at the land surface.

6. Summary and Conclusions

The BRC Eastside groundwater model was developed based on standard modeling practice in accordance with the proposed work plan (DBS&A, 2006) as amended with the concurrence of NDEP. The model has been successfully calibrated to two periods of different hydrologic conditions, called the current and historical periods. The groundwater flow field for each period is assumed to be at steady state. The current period calibration is representative of early 2007 conditions, while the historical period calibration is believed to be approximately representative of the late 1960s. Most of the model calibration effort and simulation analysis was spent on the current period calibration because a far greater amount of observed data is available relative to the historical time period. Based on the results provided in this report, and recognizing the complexity of the groundwater flow system and the uncertainty of various model inputs, BRC believes that the groundwater model has been suitably calibrated to observed hydrologic conditions and is therefore an appropriate tool for conducting predictive simulations. BRC requests NDEP concurrence and approval of this calibration.

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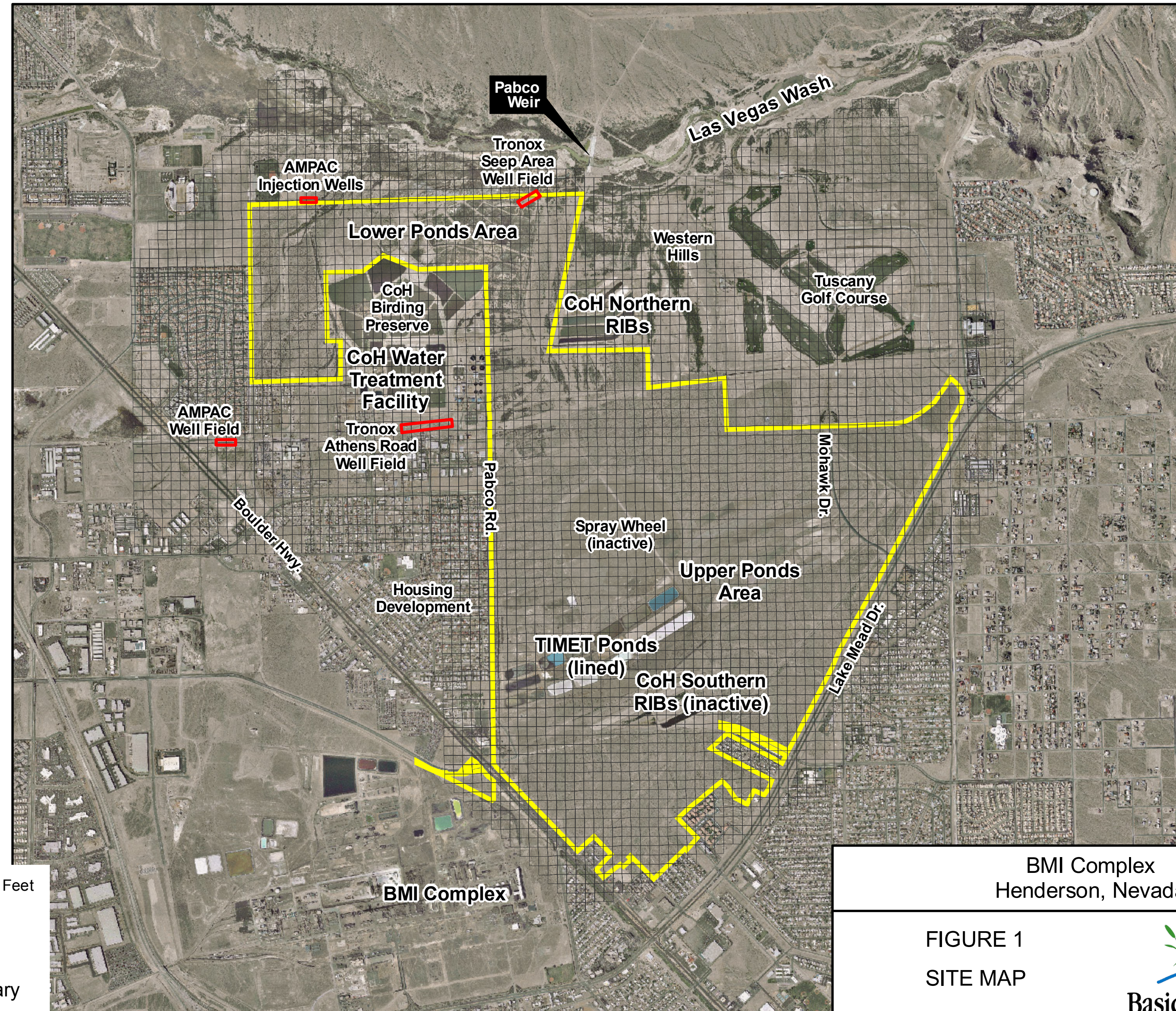
Figures

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG01_SITE_MAP.MXD 800201



Explanation

Site boundary

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 1

SITE MAP

Basic Remediation COMPANY

Prepared by: DBS&A GJ

Date 11/4/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG01_SITE_MAP.MXD 800201

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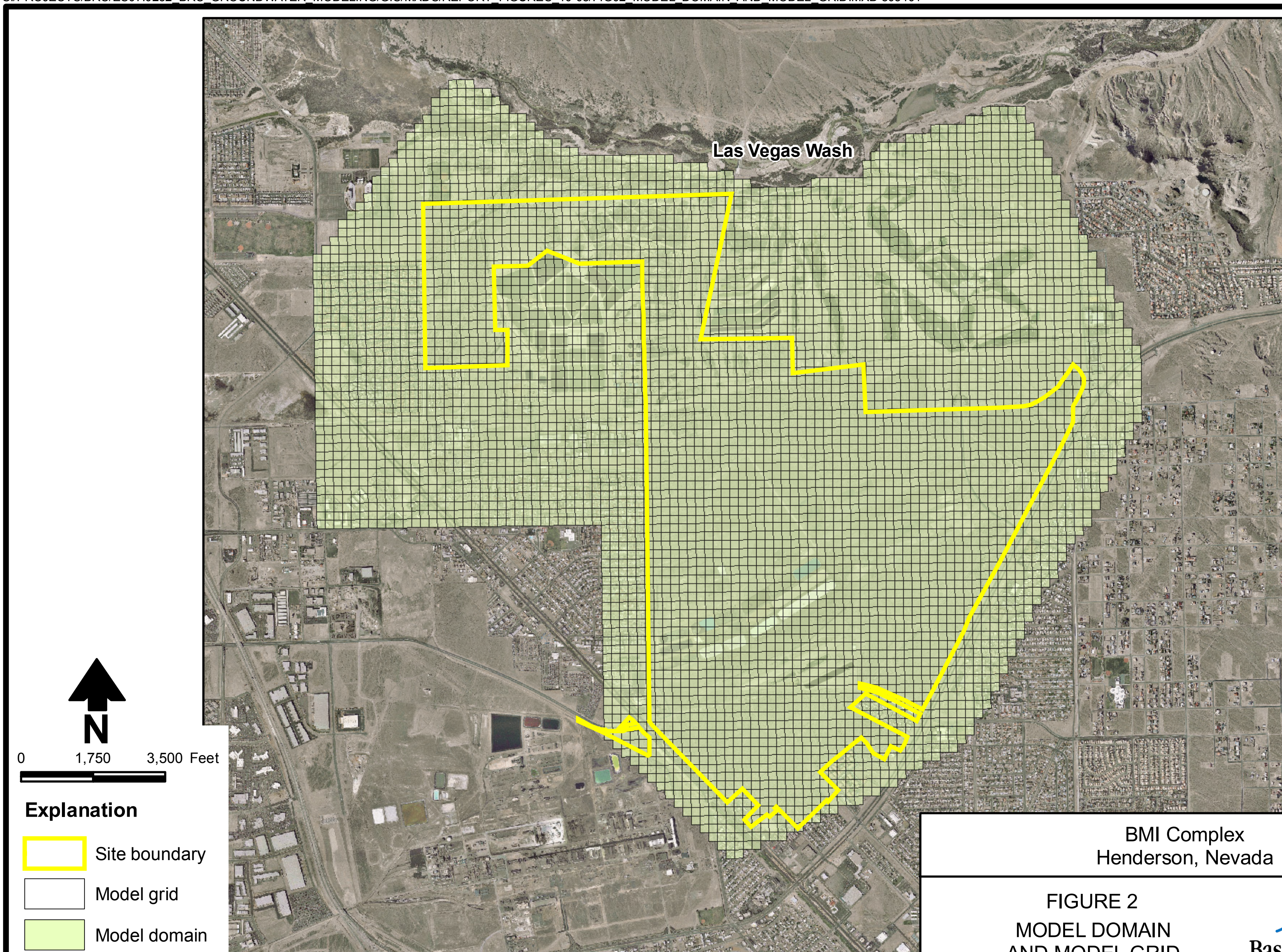
Figure 1

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG02_MODEL_DOMAIN_AND_MODEL_GRID.MXD 803101



Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 2
MODEL DOMAIN
AND MODEL GRID

Basic Remediation COMPANY

Prepared by: DBS&A GJ

Date 10/16/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG02_MODEL_DOMAIN_AND_MODEL_GRID.MXD 803101

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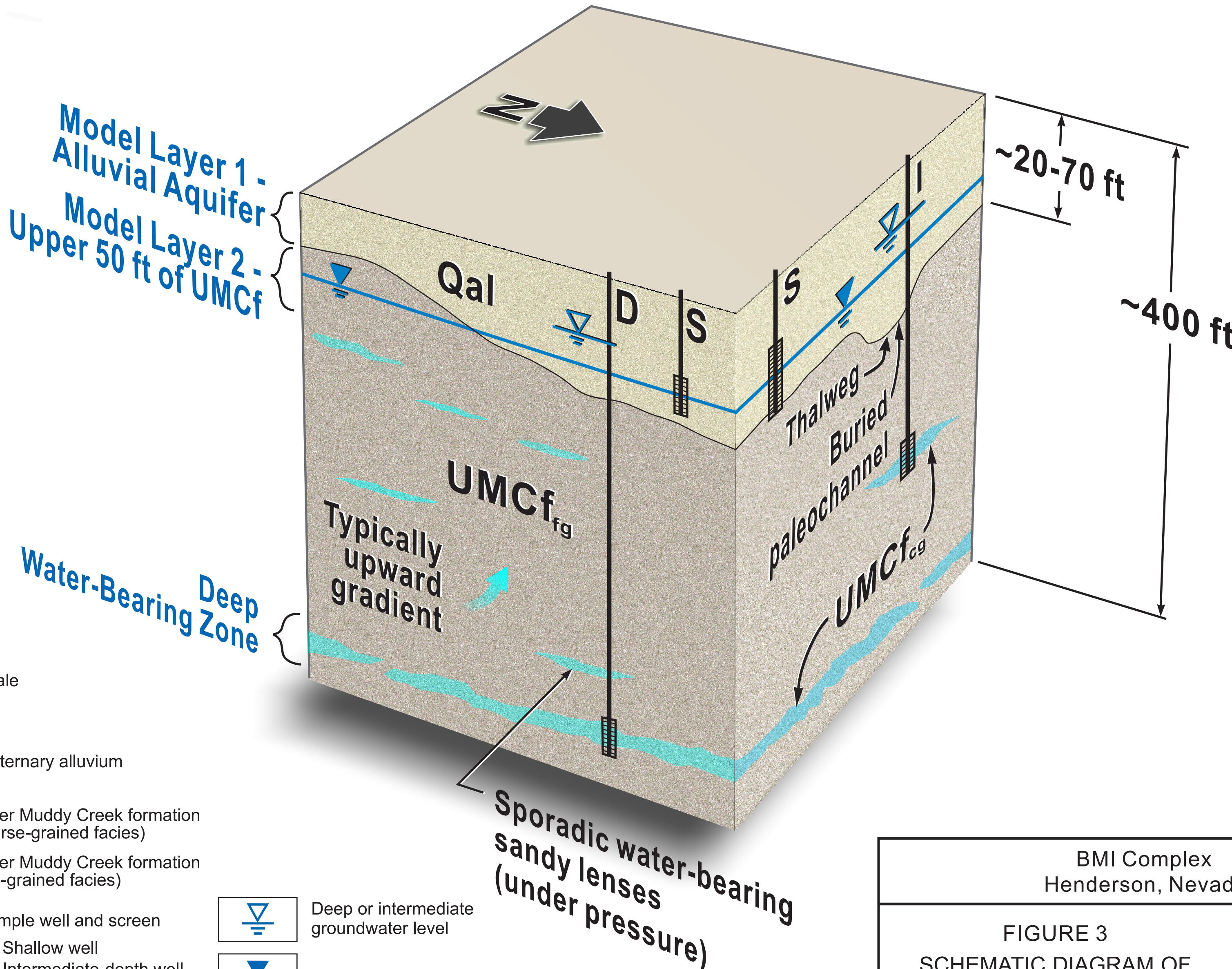
Figure 2

S:\PROJECTS\BRC\ES07.0252_BRC_GROUNDWATER_MODELING\VR_DRAWINGS\FIG03_SCHEM_DIAG_WATER-BEARING_ZONES_MODEL_LAYERS.CDR



Note: Not to scale

Explanation

Qal	Quaternary alluvium
$UMCf_{cg}$	Upper Muddy Creek formation (coarse-grained facies)
$UMCf_{fg}$	Upper Muddy Creek formation (fine-grained facies)
	Example well and screen **S** = Shallow well **I** = Intermediate-depth well **D** = Deep well
	Deep or intermediate groundwater level
	Shallow groundwater level

BMI Complex
Henderson, Nevada

FIGURE 3
SCHEMATIC DIAGRAM OF WATER-BEARING ZONES AND MODEL LAYERS

Basic Remediation COMPANY

Prepared by: DBS&A MNW
Date 10/16/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/VDR_DRAWINGS\FIG03_SCHEM_DIAG_WATER-BEARING_ZONES_MODEL_LAYERS.CDR_

Figure 3

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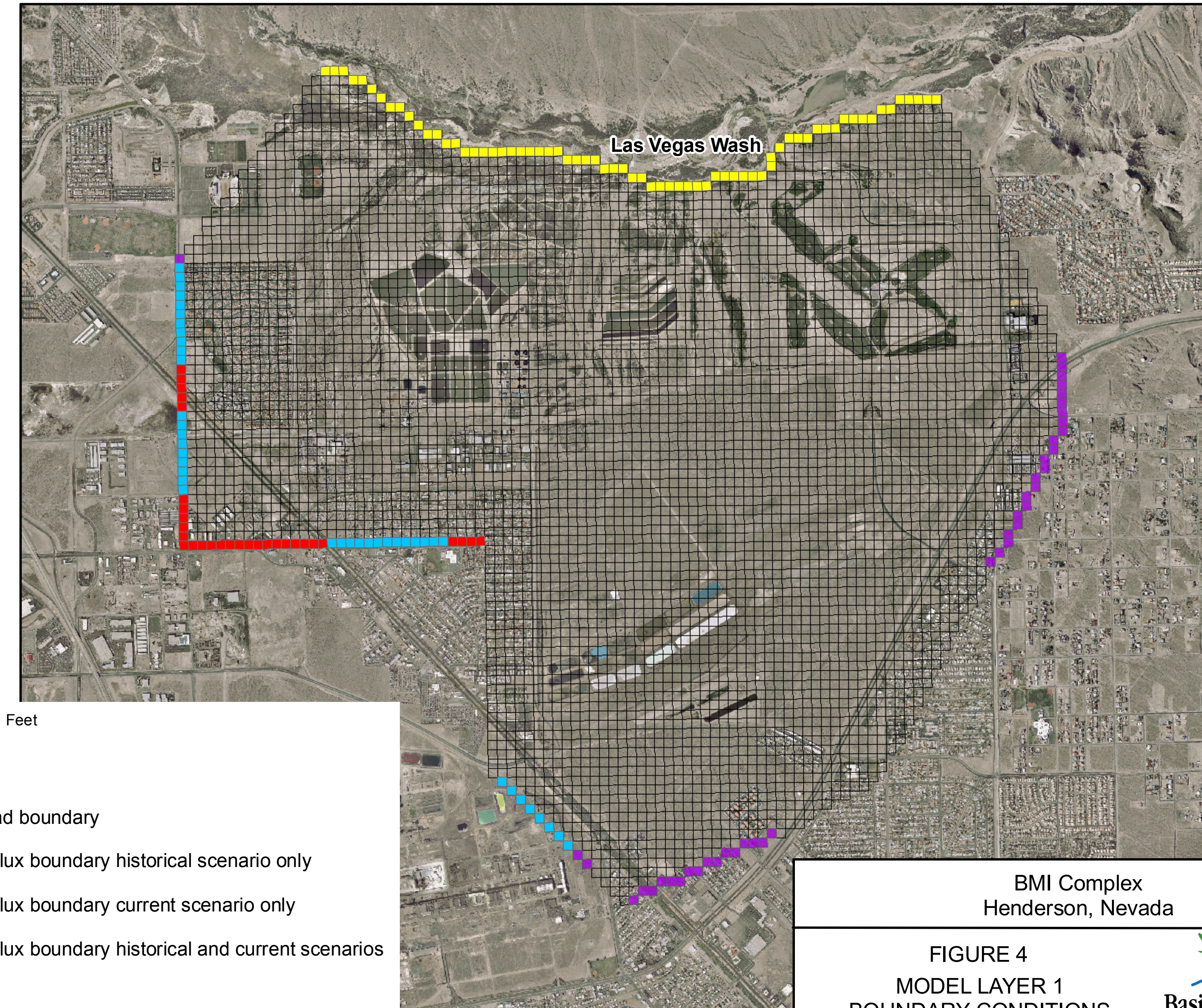
S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG04_MODEL_LAYER_1_BOUNDARY_COND.MXD 806101



N

0 1,750 3,500 Feet

Explanation

- General head boundary
- Prescribed flux boundary historical scenario only
- Prescribed flux boundary current scenario only
- Prescribed flux boundary historical and current scenarios
- Model grid

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 4
MODEL LAYER 1
BOUNDARY CONDITIONS

Basic Remediation COMPANY

Prepared by: DBS&A GJ

Date 11/4/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG04_MODEL_LAYER_1_BOUNDARY_COND.MXD 803101

Figure 4

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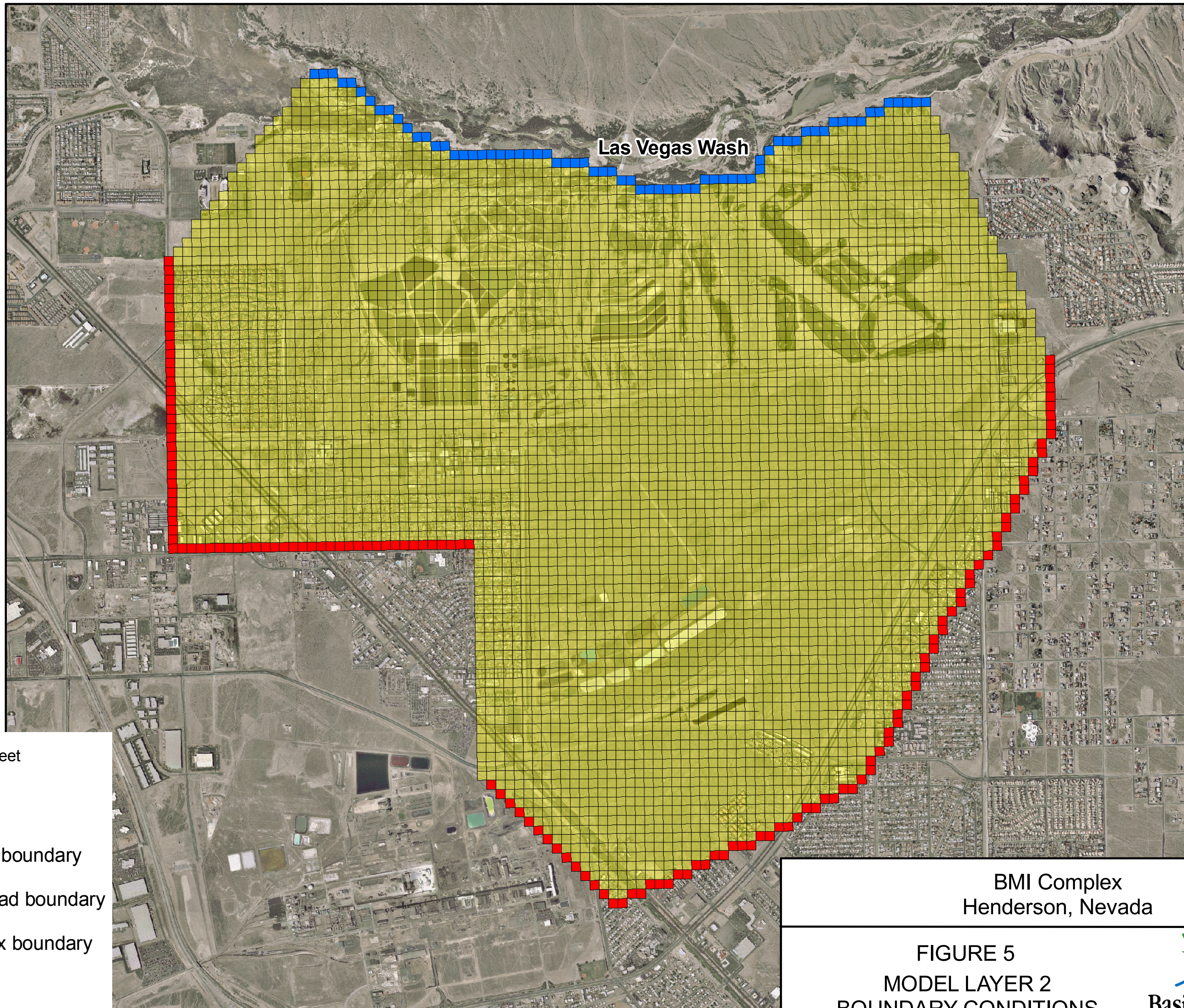
S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG05_MODEL_LAYER_2_BOUNDARY_COND.MXD 806101



N

0 1,750 3,500 Feet

Explanation

- General head boundary
- Prescribed head boundary
- Prescribed flux boundary
- Model grid

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 5
MODEL LAYER 2
BOUNDARY CONDITIONS

Basic Remediation
COMPANY

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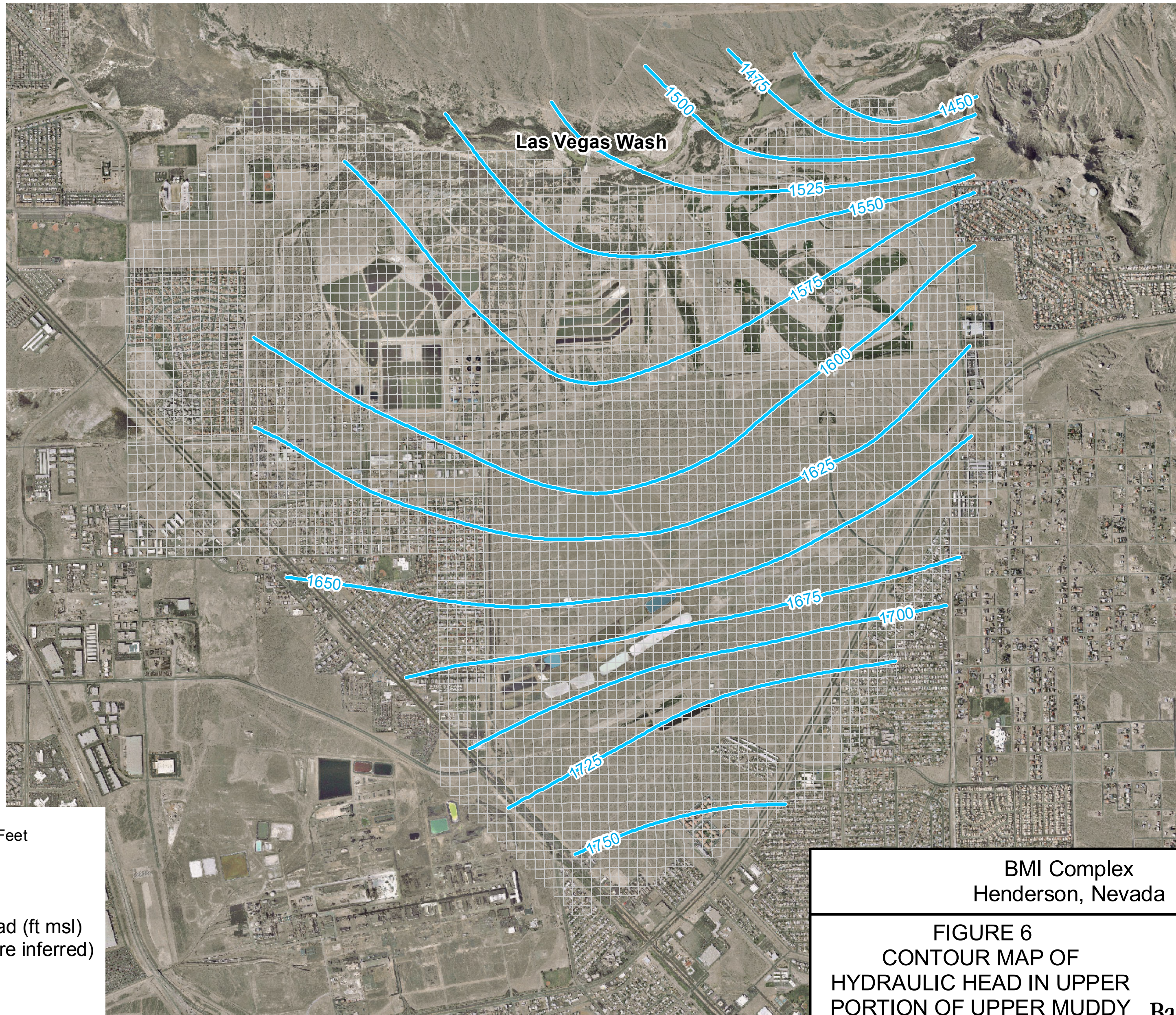
Figure 5



N

0 1,750 3,500 Feet

Explanation

Hydraulic head (ft msl) (dashed where inferred)

Model grid

Sources: 1. MWH, June 2006 data
2. Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 6
CONTOUR MAP OF HYDRAULIC HEAD IN UPPER PORTION OF UPPER MUDDY CREEK FORMATION

Basic Remediation COMPANY

Prepared by: DBS&A	GJ	Date 10/16/08	S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG06_CONTOUR_MAP_HYD_HEAD_LOWER_MUDDY_CREEK_FRM.MXD 806101

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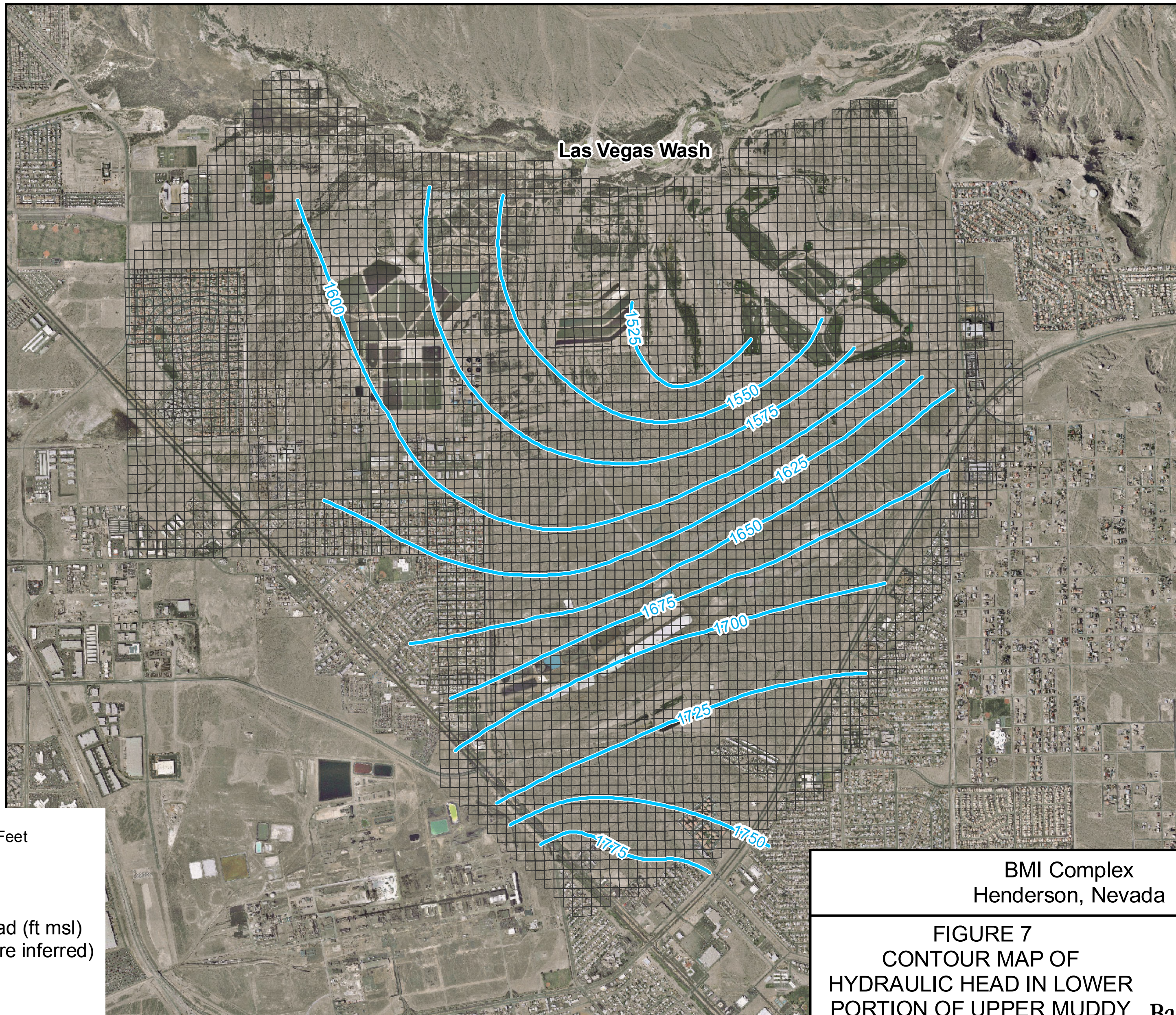

N

0 1,750 3,500 Feet

Explanation

Hydraulic head (ft msl) (dashed where inferred)

Model grid

Sources: 1. MWH, June 2006 data
2. Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 7
CONTOUR MAP OF HYDRAULIC HEAD IN LOWER PORTION OF UPPER MUDDY CREEK FORMATION

Basic Remediation COMPANY

Prepared by:		Date	
DBS&A	GJ	10/16/08	S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG07_CONTOUR_MAP_HYD_HEAD_LOWER_MUDDY_CREEK_FRM.MXD 806101

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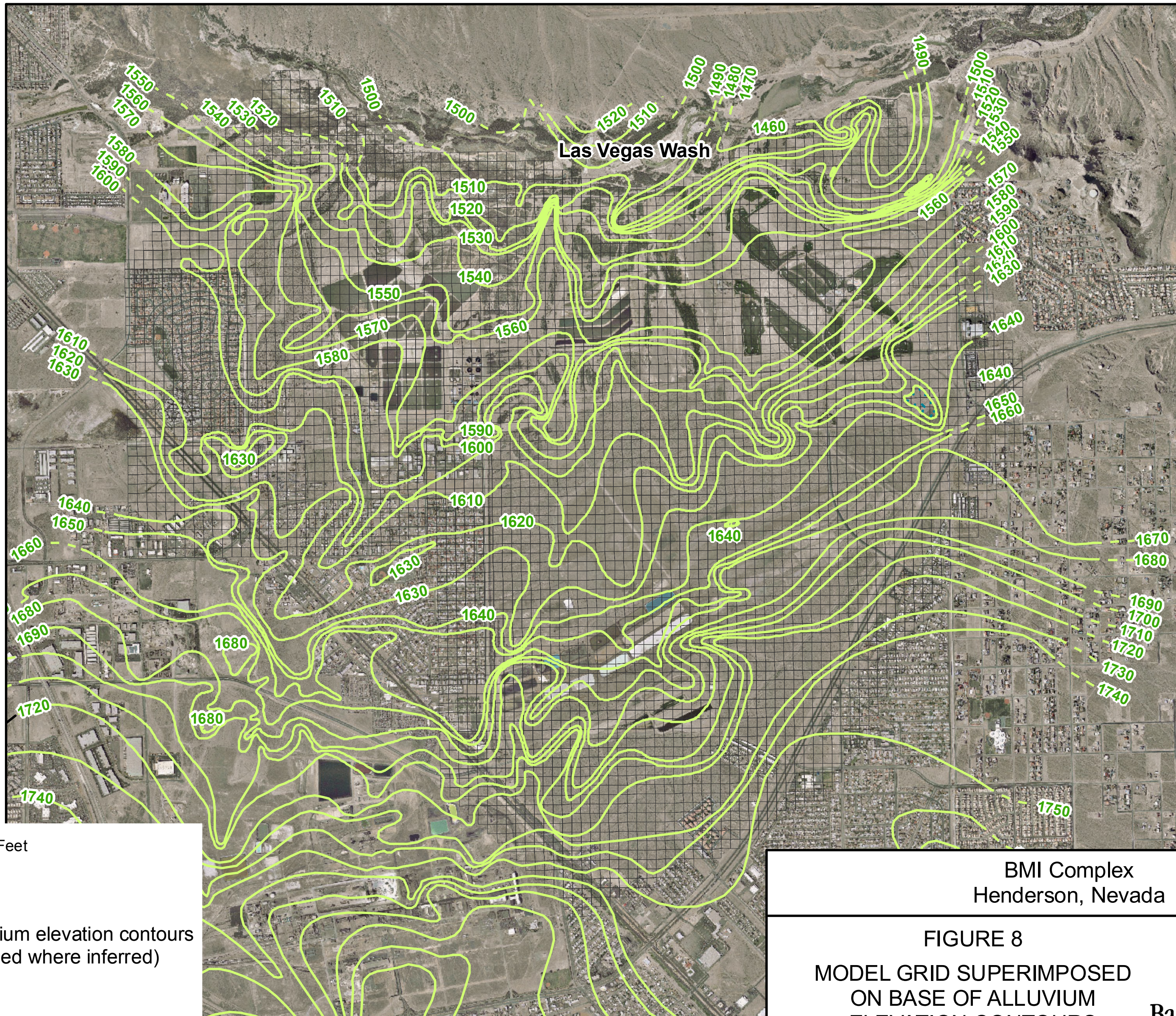
Figure 7

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG08_MODEL_GRID_SUPERIMPOSED_ON_BASE_ALLUVIUM_ELEV_CONT.MXD 806101



N

0 1,750 3,500 Feet

Explanation

Base of alluvium elevation contours (ft msl) (dashed where inferred)

Model grid

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 8

MODEL GRID SUPERIMPOSED ON BASE OF ALLUVIUM ELEVATION CONTOURS

Basic Remediation
COMPANY

Prepared by:		Date	
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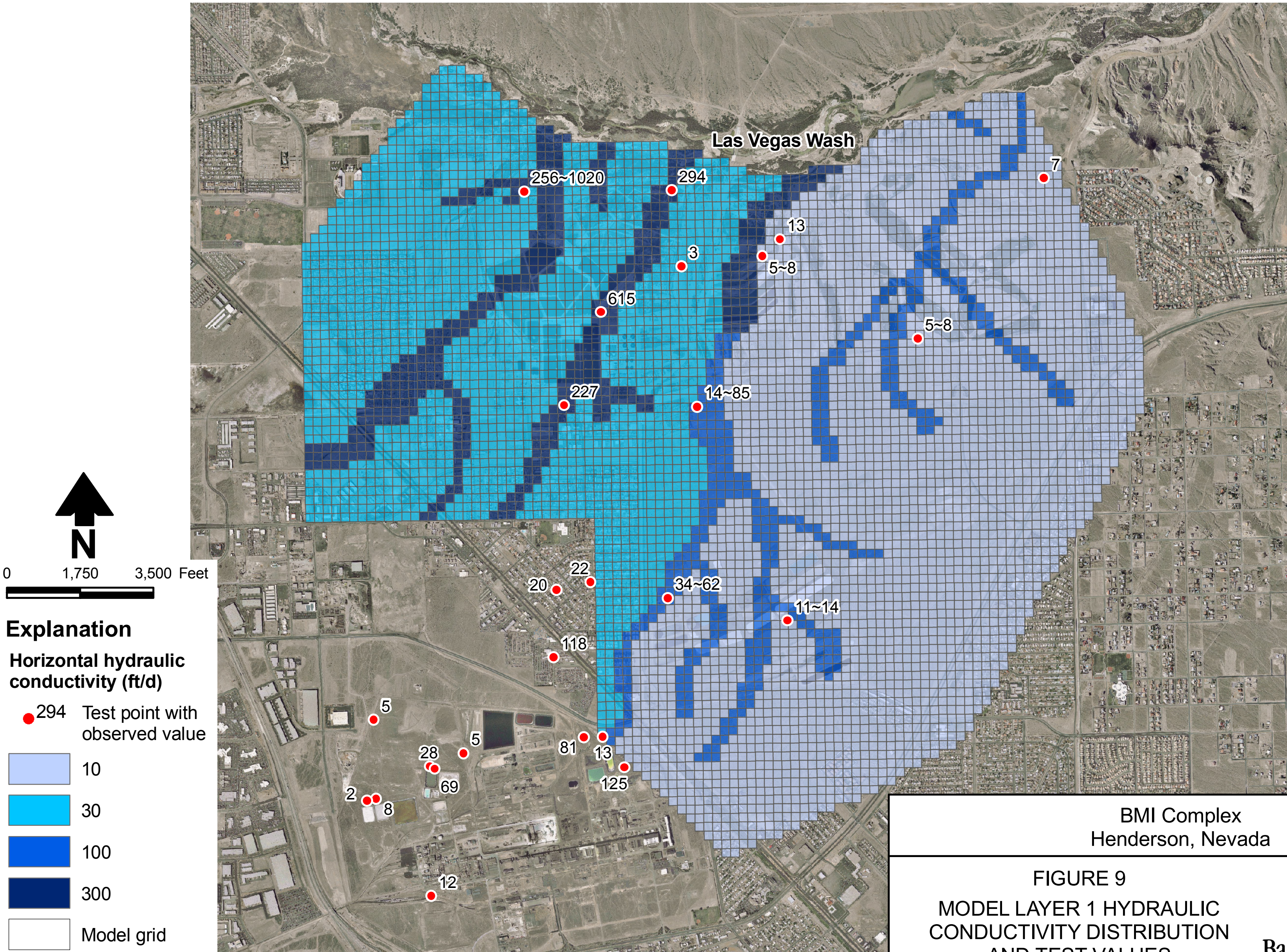
Figure 8

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG09_MODEL_LAYER_1_HYDRAULIC_COND_DIST_AND_TEST_VALUES.MXD 806101



Explanation

Horizontal hydraulic conductivity (ft/d)

294 Test point with observed value

10

30

100

300

Model grid

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 9

MODEL LAYER 1 HYDRAULIC CONDUCTIVITY DISTRIBUTION AND TEST VALUES

Basic Remediation COMPANY

Prepared by: DBS&A GJ

Date 10/16/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG09_MODEL_LAYER_1_HYDRAULIC_COND_DIST_AND_TEST_VALUES.MXD 803101

Figure 9

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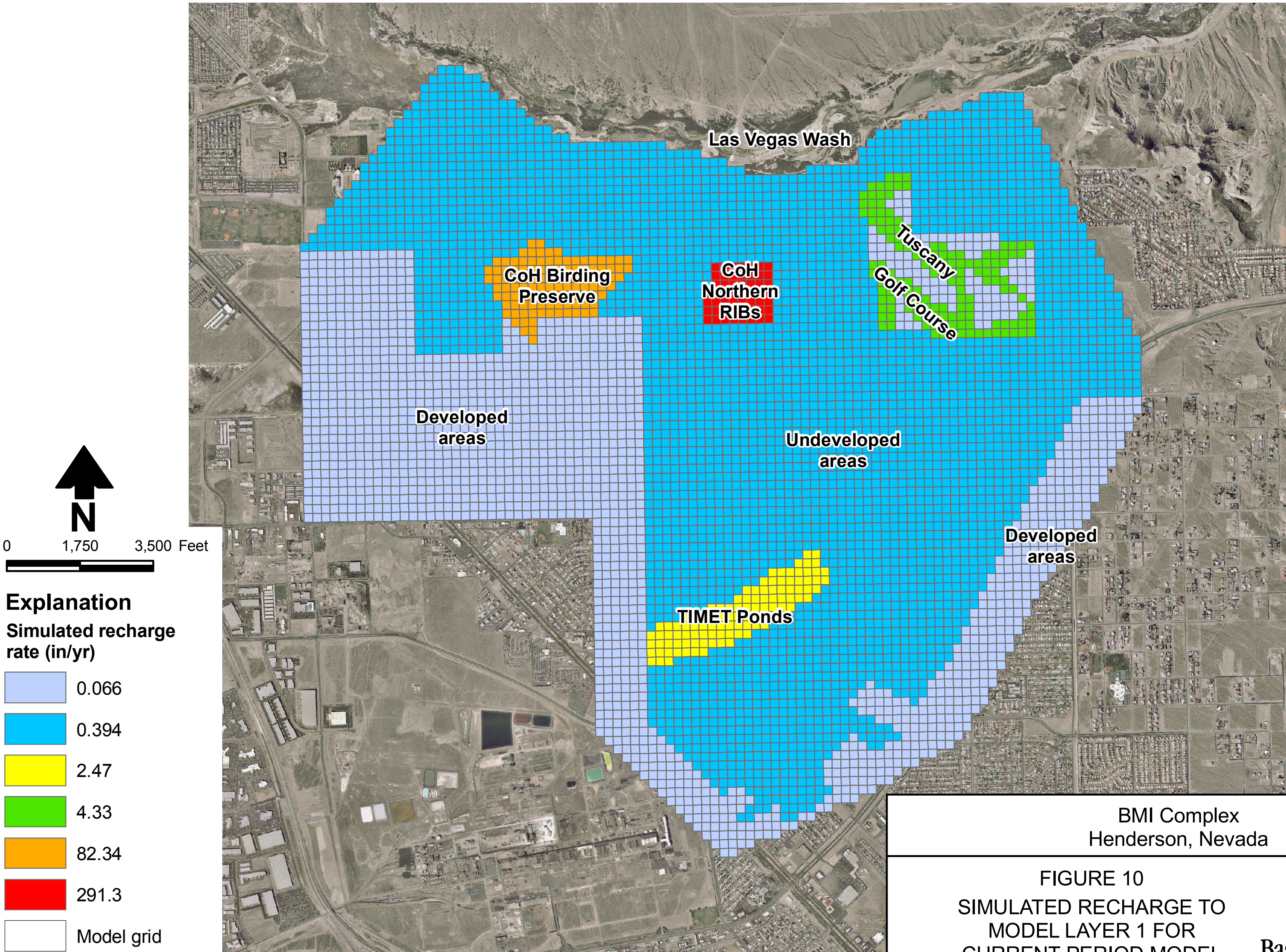
S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG10_SIM_RECHARGE_MODEL_LAYER_1_CURRENT_PERIOD_MODEL.MXD 807101



Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 10
SIMULATED RECHARGE TO MODEL LAYER 1 FOR CURRENT PERIOD MODEL

Basic Remediation Company

Prepared by: DBS&A GJ

Date 10/17/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG10_SIM_RECHARGE_MODEL_LAYER_1_CURRENT_PERIOD_MODEL.MXD 807101

Figure 10

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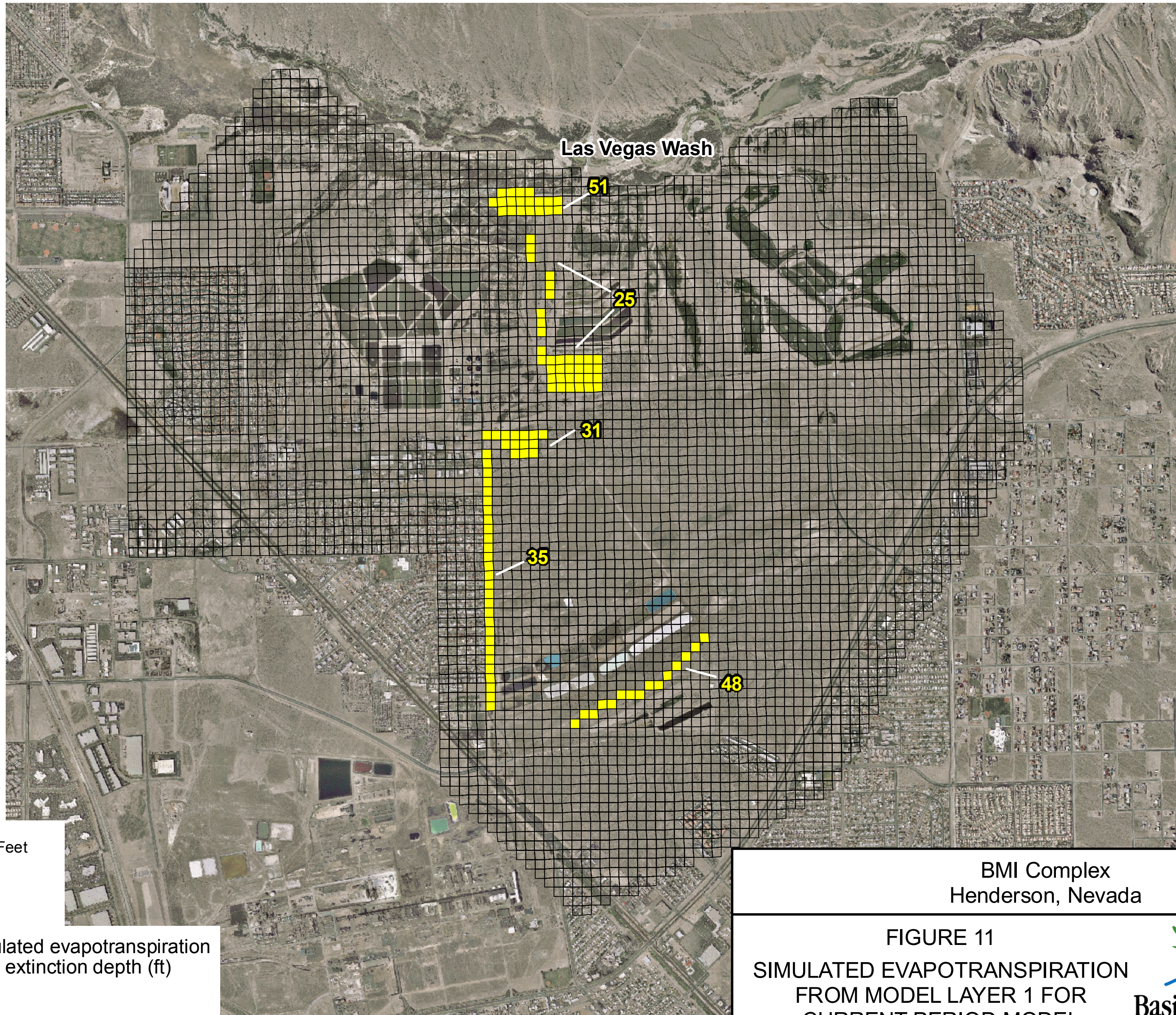
S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG11_SIM_EVAPOTRANS_MODEL_LAYER_1_CURRENT_PERIOD_MODEL.MXD 806101



N

0 1,750 3,500 Feet

Explanation

51 Zone of simulated evapotranspiration with average extinction depth (ft)

Model grid

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 11
SIMULATED EVAPOTRANSPIRATION FROM MODEL LAYER 1 FOR CURRENT PERIOD MODEL

Basic Remediation COMPANY

Prepared by: DBS&A GJ

Date 10/17/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG11_SIM_EVAPOTRANS_MODEL_LAYER_1_CURRENT_PERIOD_MODEL.MXD 805101

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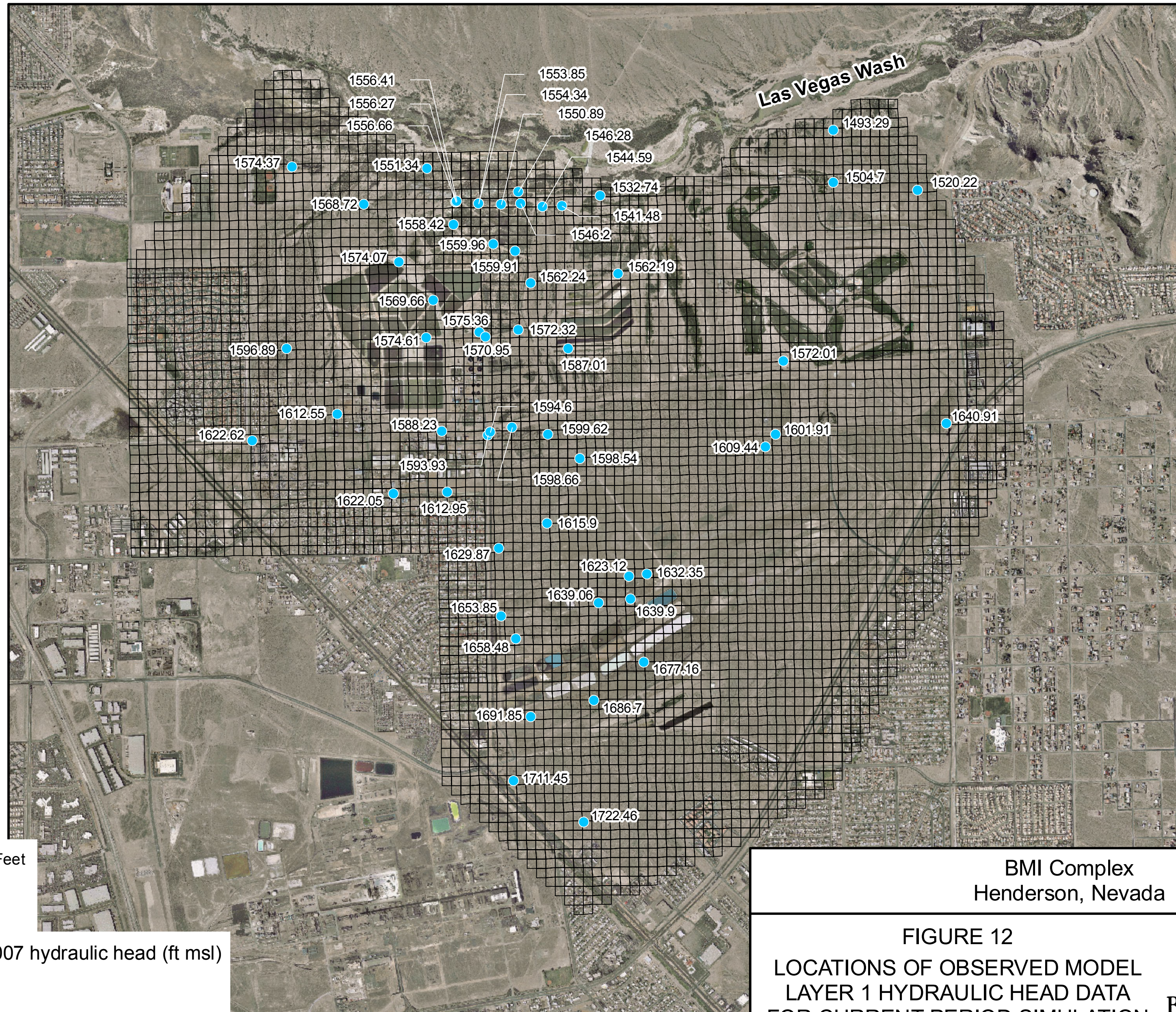
Figure 11



N

0 1,750 3,500 Feet

Explanation

Observed 2007 hydraulic head (ft msl)

Model grid

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 12

LOCATIONS OF OBSERVED MODEL LAYER 1 HYDRAULIC HEAD DATA FOR CURRENT PERIOD SIMULATION

Basic Remediation COMPANY

Prepared by: DBS&A GJ

Date 11/3/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG12_LOC_OBSERVED_MODEL_LAYER_1_HYD_HEAD_CUR_PER_SIM.MXD 804101

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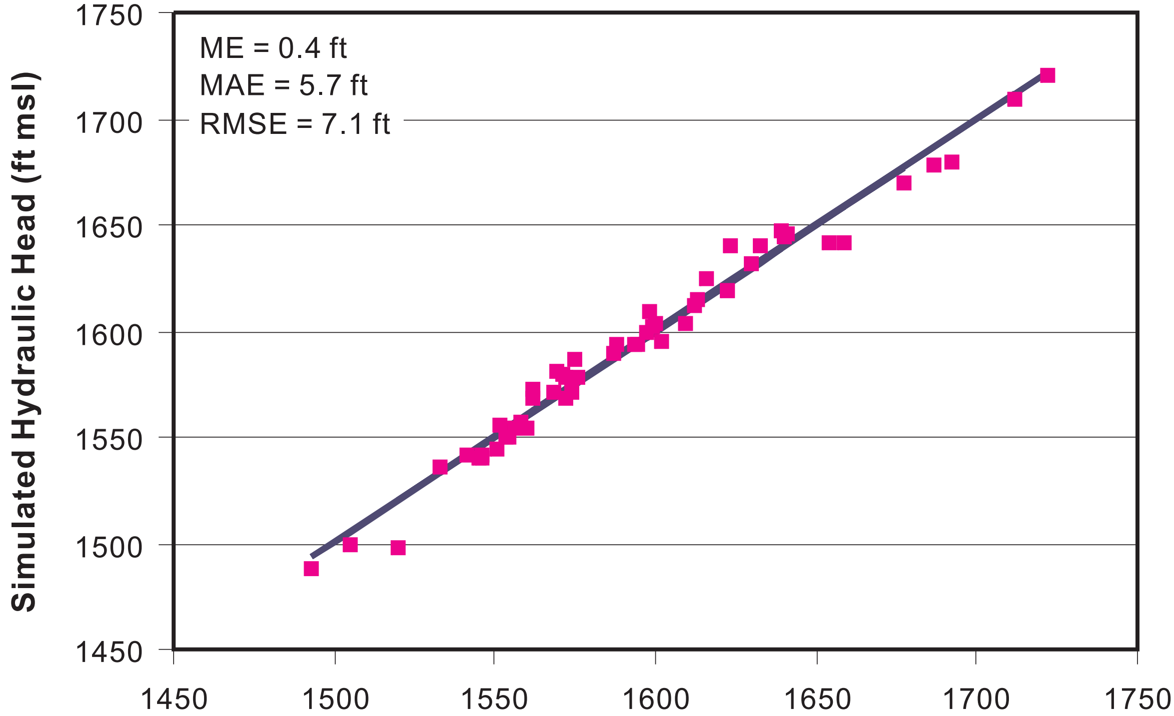

BMI Complex
Henderson, Nevada

FIGURE13
SIMULATED VERSUS
OBSERVED HYDRAULIC HEADS
FOR MODEL LAYER 1 FOR
CURRENT PERIOD SIMULATION

Basic Remediation COMPANY

Prepared by: DBS&A MNW

Date 11/3/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/VDR_DRAWINGS\FIG13_SIM_VS_OBSER_MOD_LAYER_1_CUR_PER_SIM.CDR

S:\PROJECTS\BRC\ES07.0252_BRC_GROUNDWATER_MODELING/VDR_DRAWINGS\FIG13_SIM_VS_OBSER_MOD_LAYER_1_CUR_PER_SIM.CDR

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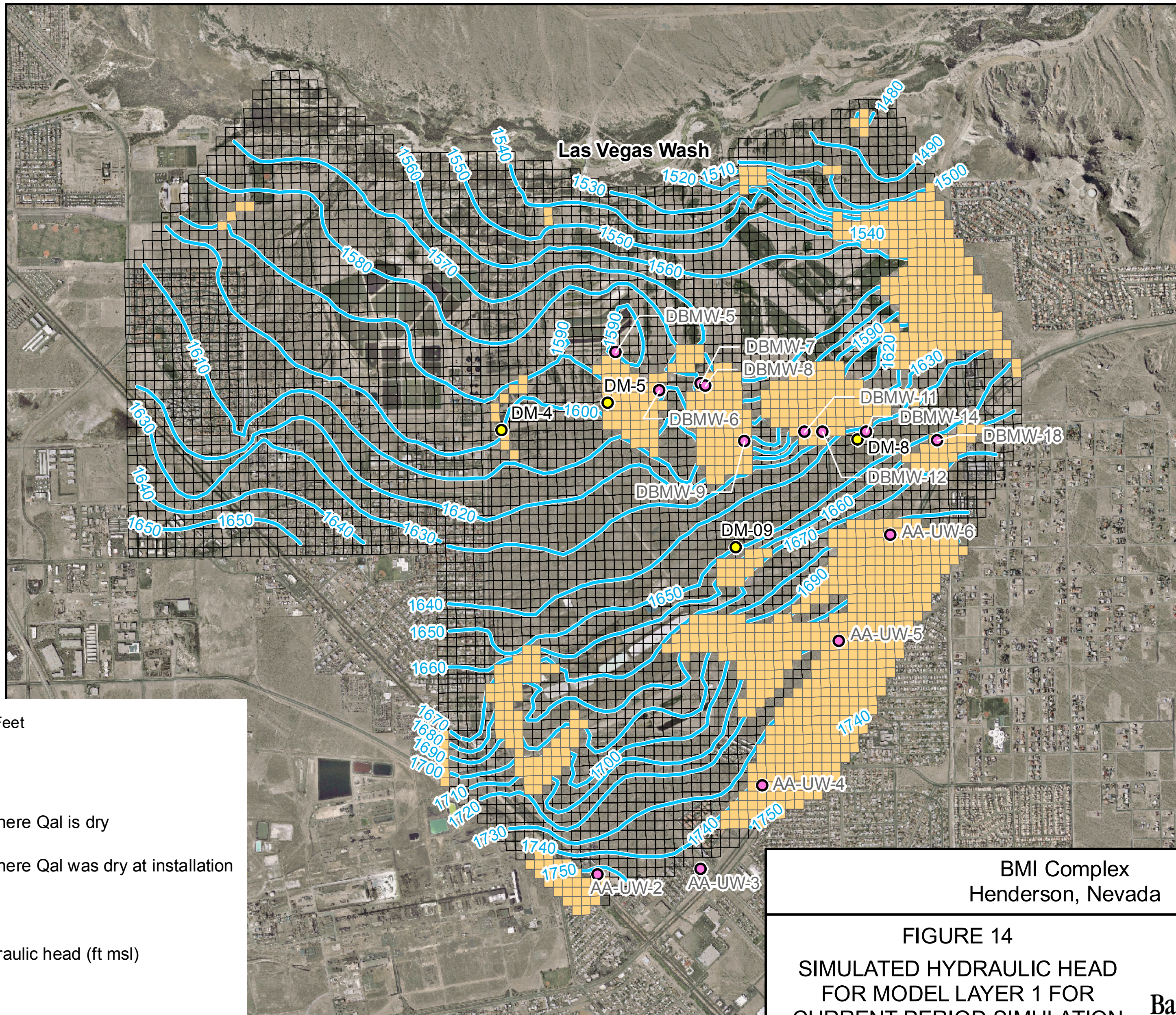
S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG11_SIM_HYD_HEAD_MODEL_LAYER_1_CUR_PER_SIM.MXD 804101



Explanation

- Monitor well where Qal is dry
- Monitor well where Qal was dry at installation
- Dry cells
- Simulated hydraulic head (ft msl)
- Model grid

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 14

SIMULATED HYDRAULIC HEAD FOR MODEL LAYER 1 FOR CURRENT PERIOD SIMULATION

Basic Remediation Company

Prepared by:		Date	
DBS&A	GJ	11/3/08	S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG14_SIM_HYD_HEAD_MODEL_LAYER_1_CUR_PER_SIM.MXD 804101

Figure 14

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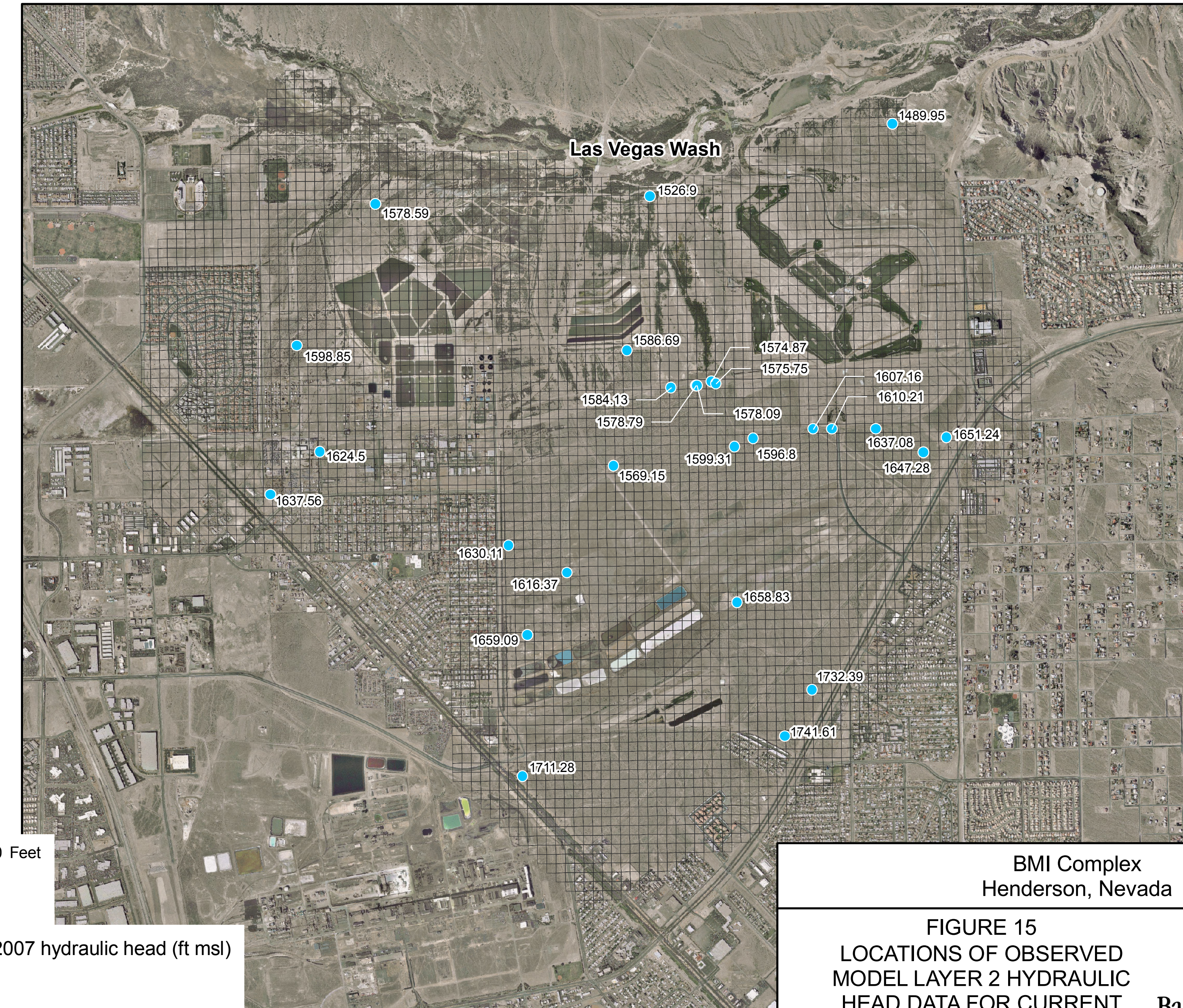
S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG15_LOC_OBSER_MODEL_LAYER_2_HYD_HEAD_DATA_CUR_PER_SIM.MXD 806101



N

0 1,750 3,500 Feet

Explanation

Observed 2007 hydraulic head (ft msl)

Model grid

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 15
LOCATIONS OF OBSERVED
MODEL LAYER 2 HYDRAULIC
HEAD DATA FOR CURRENT
PERIOD SIMULATION

Basic Remediation
COMPANY

Prepared by:		Date	
DBS&A	GJ	11/3/08	S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG15_LOC_OBSER_MODEL_LAYER_2_HYD_HEAD_DATA_CUR_PER_SIM.MXD 804101

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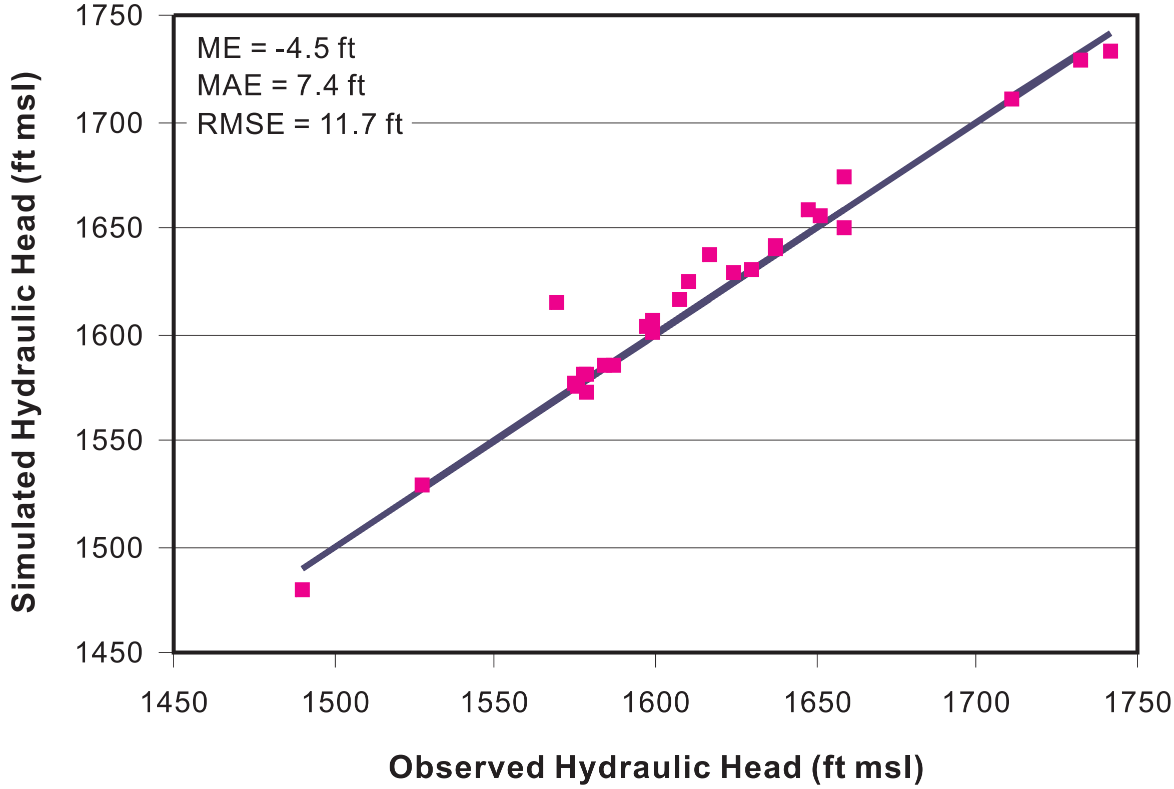
JN ES07.0252

Figure 15



BMI Complex
Henderson, Nevada

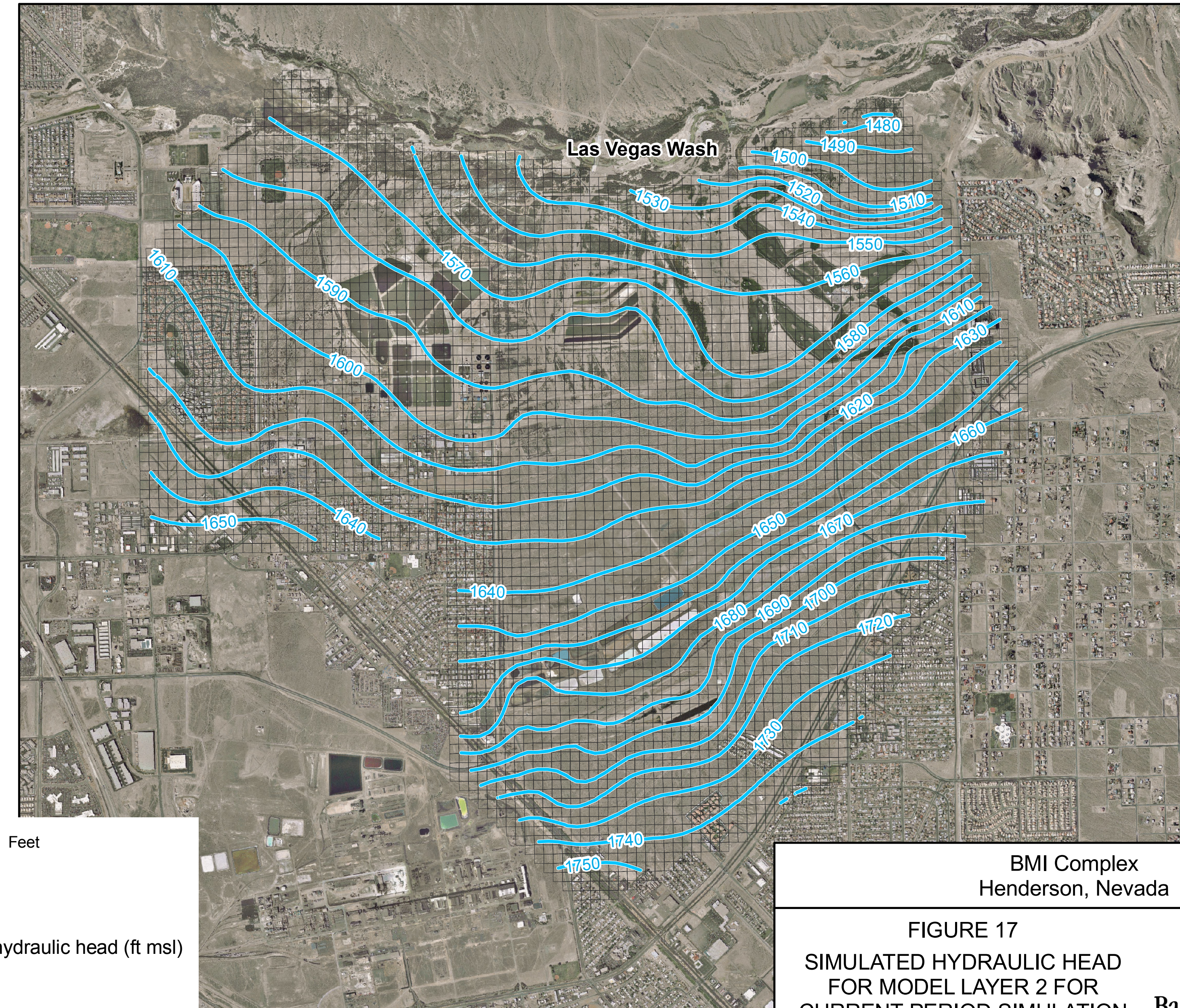
FIGURE16
SIMULATED VERSUS
OBSERVED HYDRAULIC HEADS
FOR MODEL LAYER 2 FOR
CURRENT PERIOD SIMULATION

Basic Remediation COMPANY

Prepared by: DBS&A MNW	Date 11/3/08	S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/VDR_DRAWINGS\FIG16_SIM_VS_OBSER_MOD_LAYER_2_CUR_PER_SIM.CDR

S:\PROJECTS\BRC\ES07.0252_BRC_GROUNDWATER_MODELING/VDR_DRAWINGS\FIG16_SIM_VS_OBSER_MOD_LAYER_2_CUR_PER_SIM.CDR

Daniel B. Stephens & Associates, Inc.
JN ES07.0252



Explanation

Simulated hydraulic head (ft msl)

Model grid

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 17

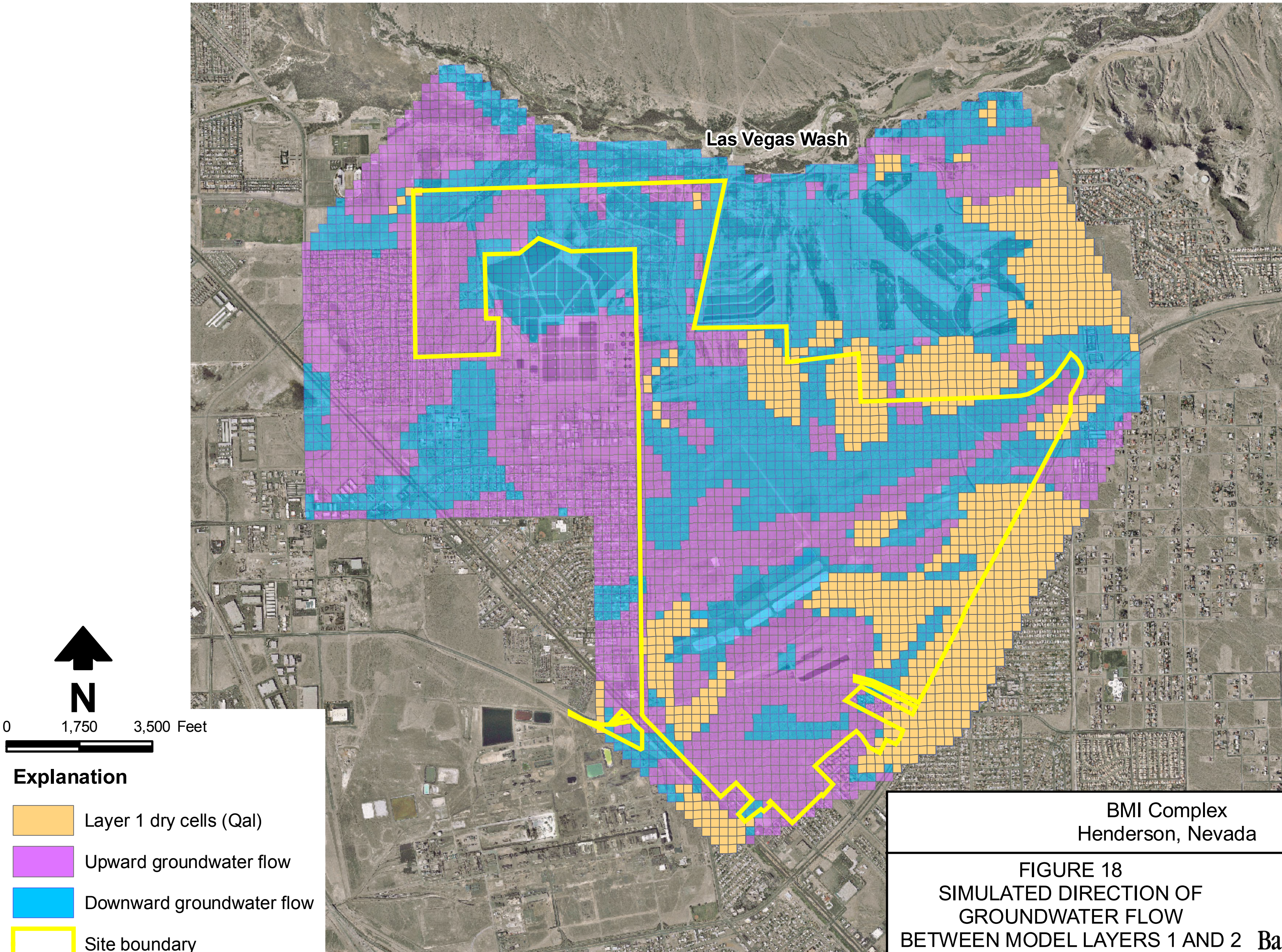
SIMULATED HYDRAULIC HEAD FOR MODEL LAYER 2 FOR CURRENT PERIOD SIMULATION

Basic Remediation COMPANY

Prepared by:		Date	
DBS&A	GJ	10/16/08	S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08_FIG17_SIM_HYD_HEAD_MODEL_LAYER_2_CUR_PER_SIM.MXD 804101

Daniel B. Stephens & Associates, Inc.
JN ES07.0252

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG18_SIM_DIR_GW_FLOW_MOD_LAYERS_1-2.MXD 800201



Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 18
SIMULATED DIRECTION OF
GROUNDWATER FLOW
BETWEEN MODEL LAYERS 1 AND 2
FOR CURRENT PERIOD SIMULATION

Basic Remediation
COMPANY

Prepared by: DBS&A GJ

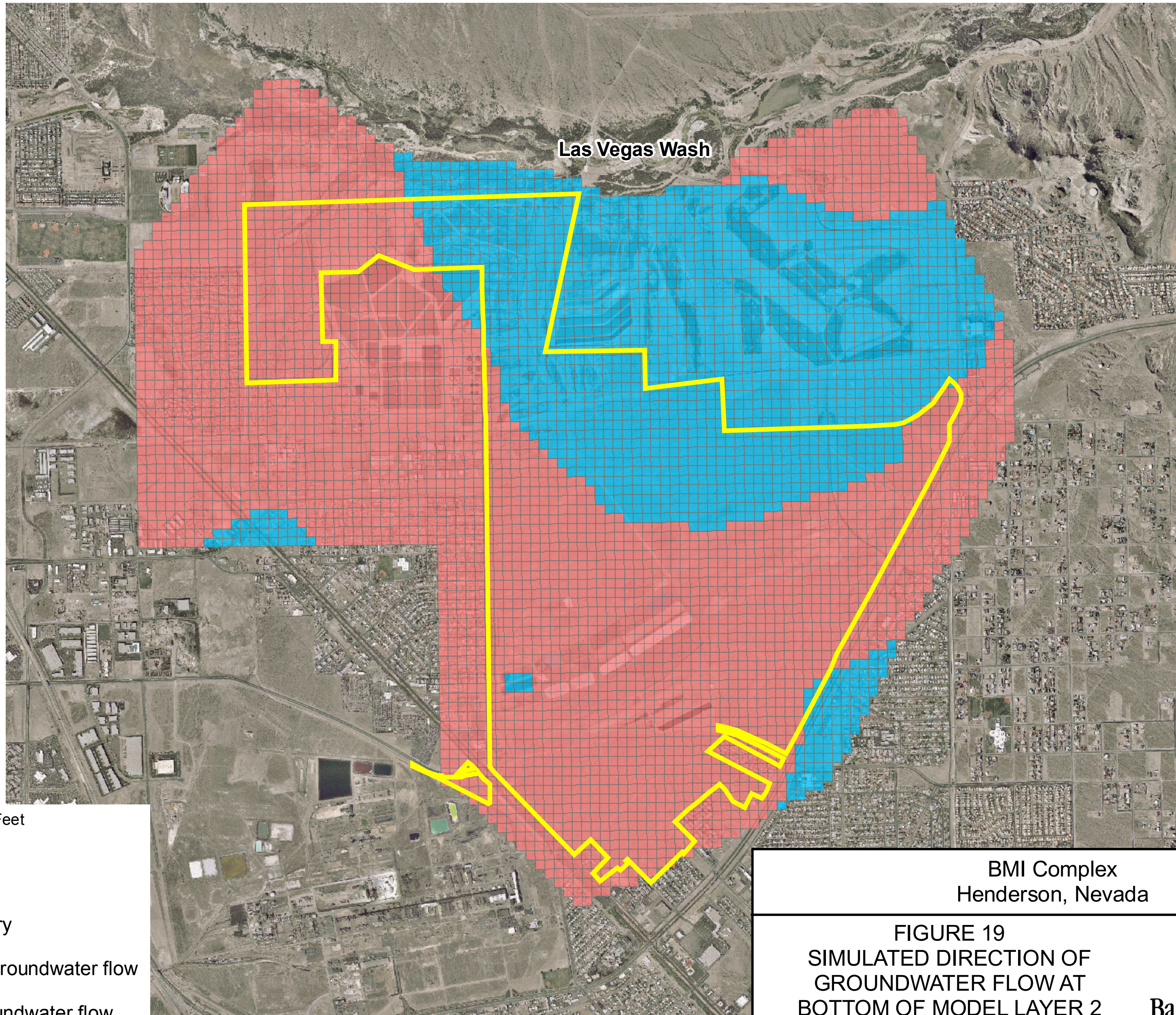
Date 11/3/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG18_SIM_DIR_GW_FLOW_MOD_LAYERS_1-2.MXD 800201

Daniel B. Stephens & Associates, Inc.
JN ES07.0252

Figure 18

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG19_SIM_DIR_GW_FLOW_BOT_LAYER_2.MXD 800201



N

0 1,750 3,500 Feet

Explanation

- Site boundary
- Downward groundwater flow
- Upward groundwater flow

Source: Aerial photograph, April 2004

BMI Complex
Henderson, Nevada

FIGURE 19
SIMULATED DIRECTION OF
GROUNDWATER FLOW AT
BOTTOM OF MODEL LAYER 2
FOR CURRENT PERIOD SIMULATION

Basic Remediation
COMPANY

Prepared by: DBS&A GJ

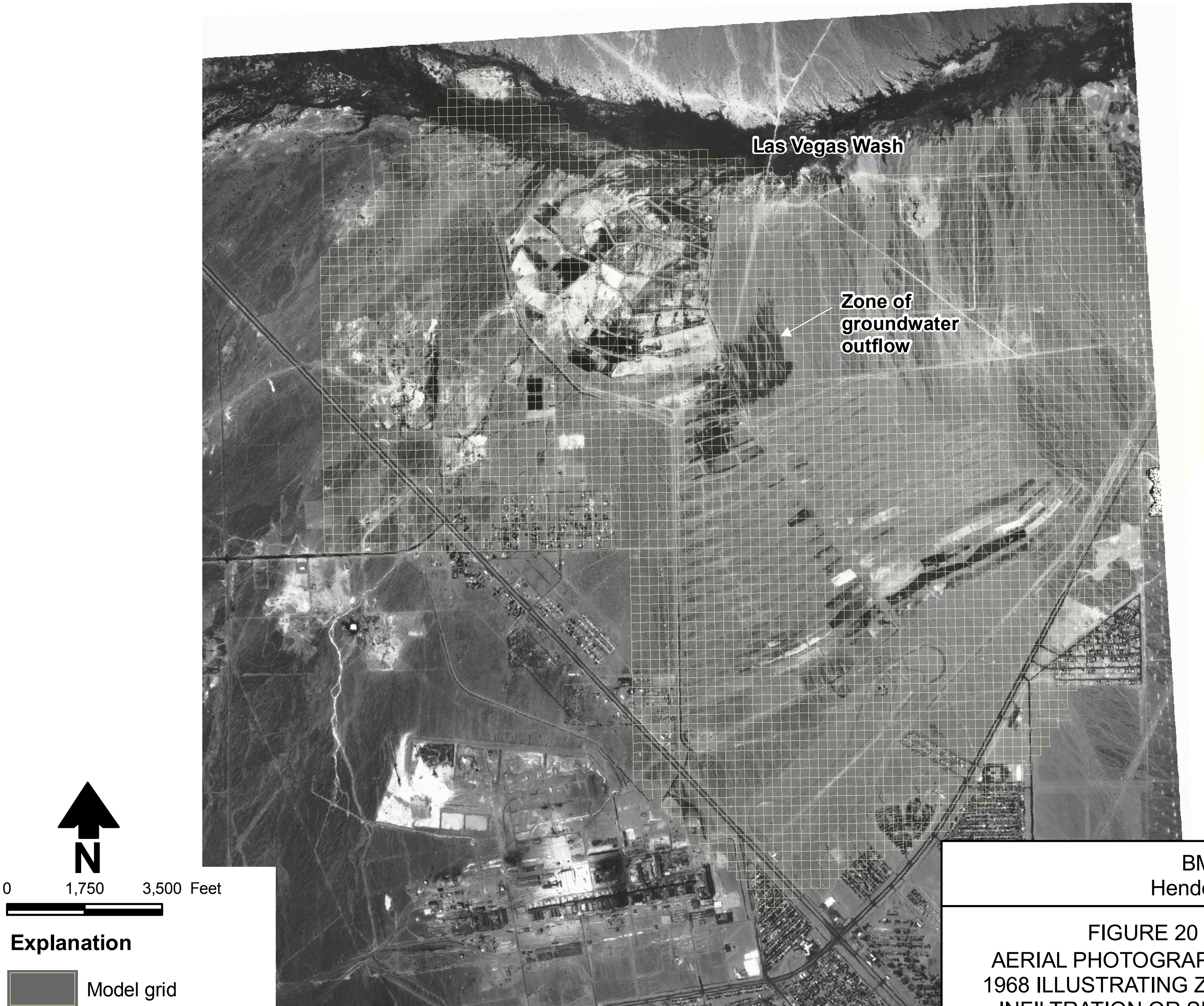
Date 11/4/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG19_SIM_DIR_GW_FLOW_MOD_BOT LAYER 2.MXD 800201

Daniel B. Stephens & Associates, Inc.
JN ES07.0252

Figure 19

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG20_AERIAL_PHOTO_1968_ZONES_OF_INFILTRATION_SEEPAGE.MXD 803101



Source: Aerial photograph, 1968

BMI Complex
Henderson, Nevada

FIGURE 20
AERIAL PHOTOGRAPH AS OF 1968 ILLUSTRATING ZONES OF INFILTRATION OR SEEPAGE

Basic Remediation COMPANY

Prepared by:		Date	
DBS&A	GJ	10/14/08	S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG19_AERIAL_PHOTO_1968_ZONES_OF_INFILTRATION_SEEPAGE.MXD 803101

Figure 20

Daniel B. Stephens & Associates, Inc.
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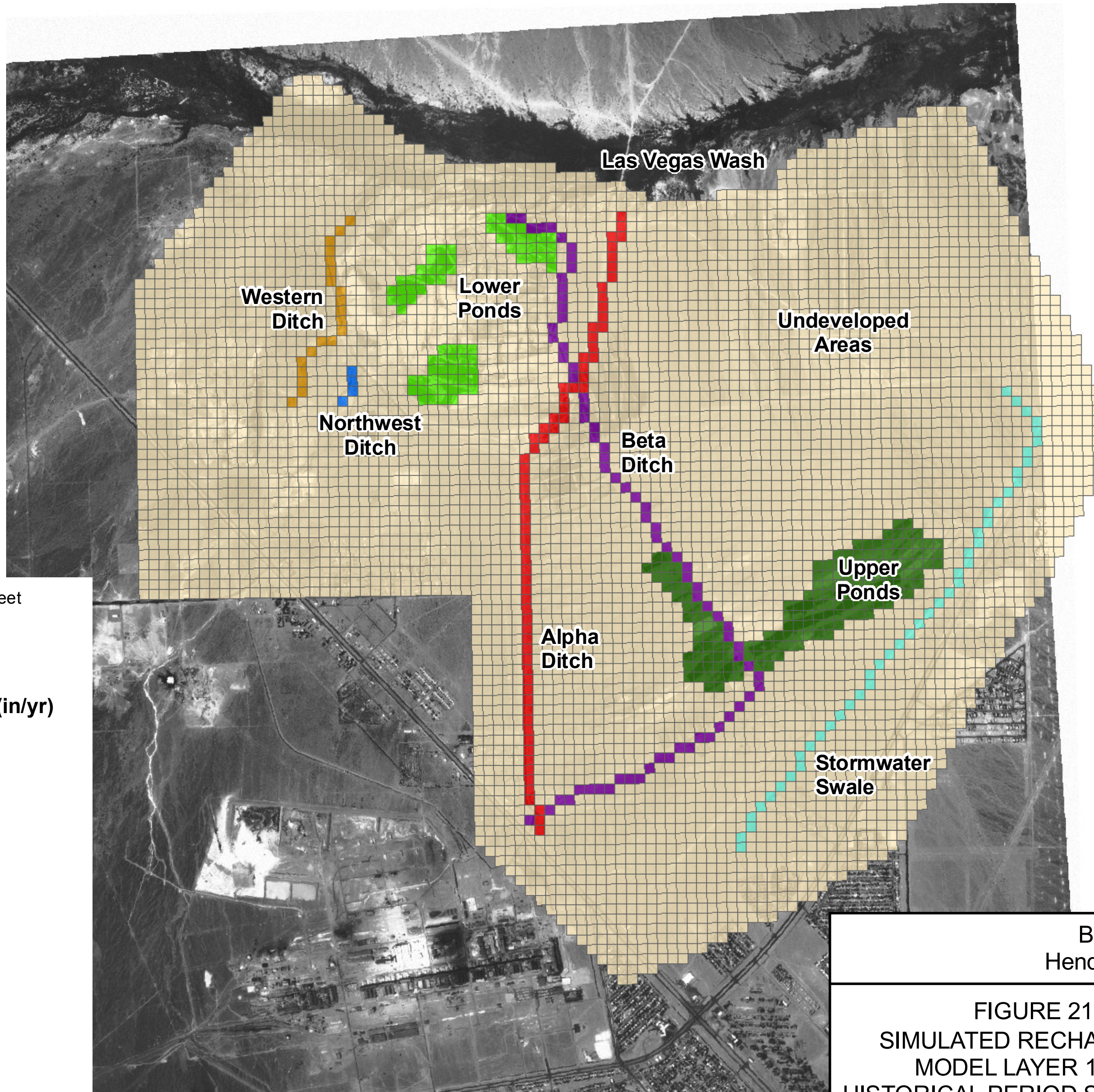
S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG20_SIM_RECHARGE_MODEL_LAYER_1_HIST_PERIOD_MODEL.MXD 800201



N

0 1,750 3,500 Feet

Explanation

Historical recharge (in/yr)

- 0.394
- 13.97
- 14.45
- 21.9
- 41.96
- 48.18
- 87.6
- 105.1
- Model grid

Source: Aerial photograph, 1968

BMI Complex
Henderson, Nevada

FIGURE 21
SIMULATED RECHARGE TO MODEL LAYER 1 FOR HISTORICAL PERIOD SIMULATION

Basic Remediation COMPANY

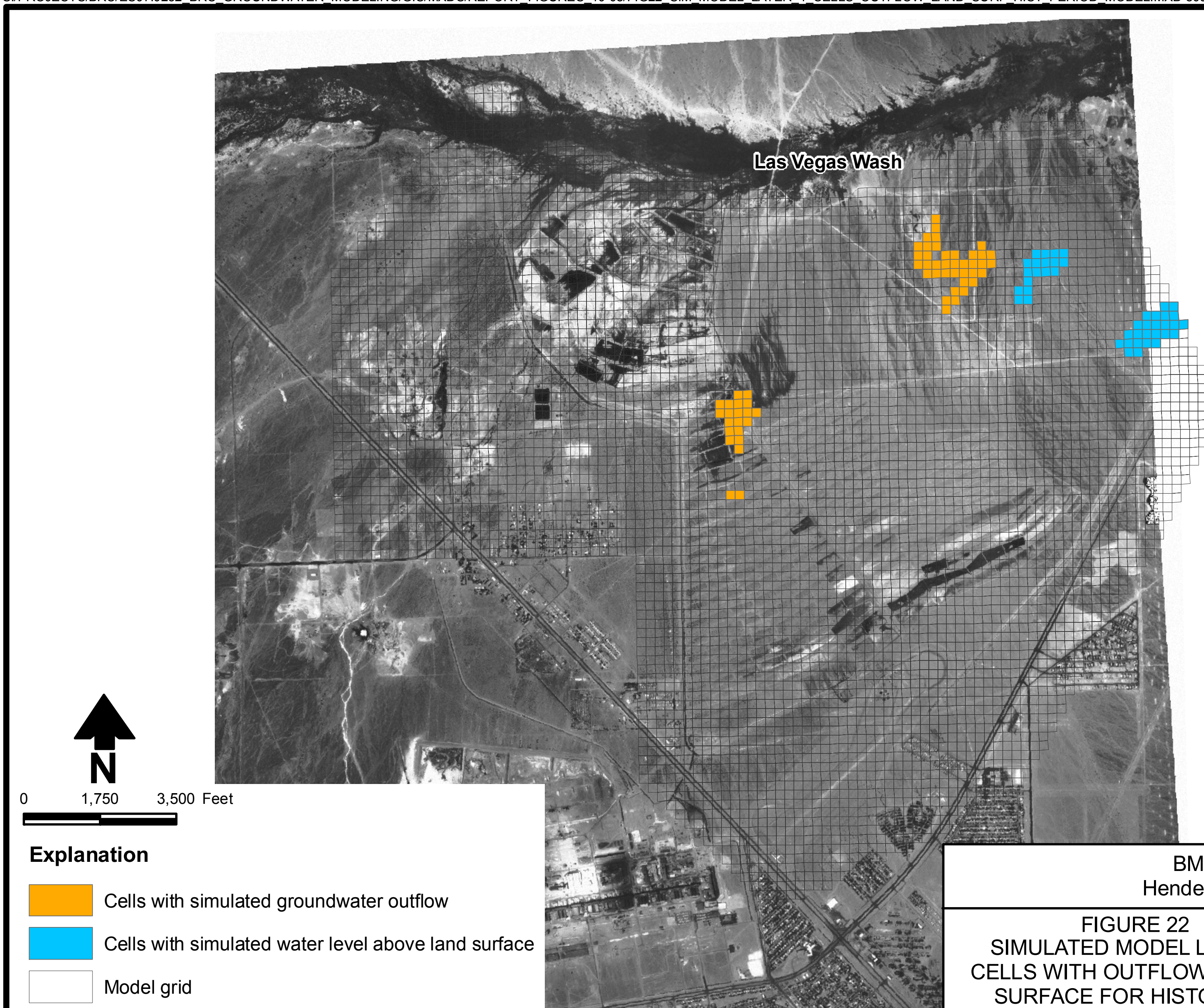
Prepared by: DBS&A GJ

Date 11/4/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG20_SIM_RECHARGE_MODEL_LAYER_1_HIST_PERIOD_MODEL.MXD 804101

Daniel B. Stephens & Associates, Inc.
JN ES07.0252

Figure 21



Explanation

- Cells with simulated groundwater outflow
- Cells with simulated water level above land surface
- Model grid

Source: Aerial photograph, 1968

BMI Complex
Henderson, Nevada

FIGURE 22
SIMULATED MODEL LAYER 1
CELLS WITH OUTFLOW AT LAND
SURFACE FOR HISTORICAL
PERIOD SIMULATION

Basic Remediation
COMPANY

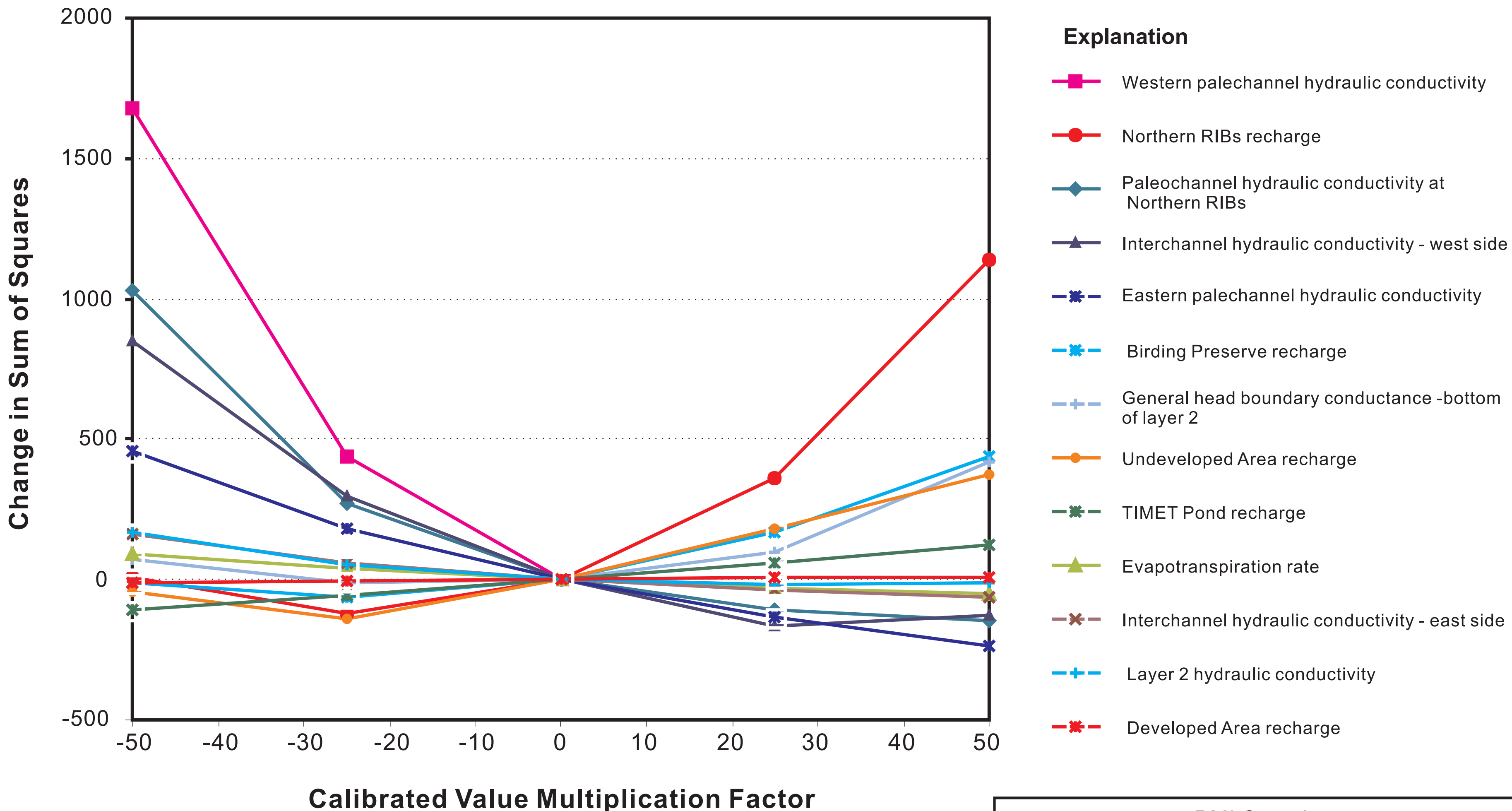
Prepared by: DBS&A GJ

Date 11/4/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG21_SIM_MODEL_LAYER_1_CELLS_OUTFLOW_LAND_SURF_HIST_PERIOD_MODEL.MXD 804101

Daniel B. Stephens & Associates, Inc.
JN ES07.0252

S:\PROJECTS\BRC\ES07.0252_BRC_GROUNDWATER_MODELING\VR_DRAWINGS\FIG23_SUM_CURR_PER_SENSITIVITY_ANALYSIS.CDR



BMI Complex
Henderson, Nevada

FIGURE 23
SUMMARY OF CURRENT PERIOD MODEL SENSITIVITY ANALYSIS

Basic Remediation COMPANY

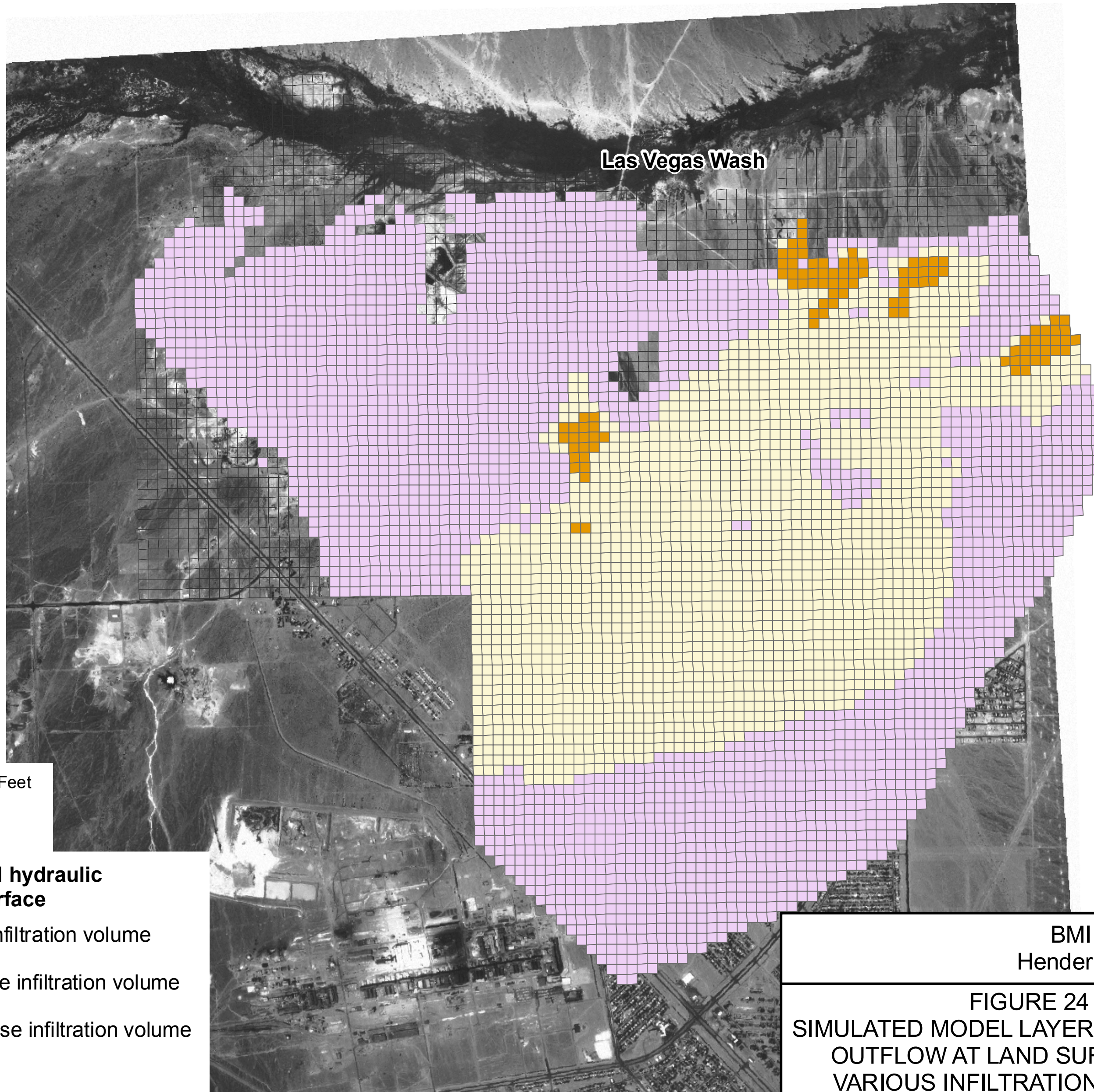
Prepared by: DBS&A MNW

Date 11/4/08

S:\PROJECTS\BRC\ES07.0252_BRC_GROUNDWATER_MODELING\VR_DRAWINGS\FIG22_SUM_CURR_PER_SENSITIVITY_ANALYSIS.CDR

Daniel B. Stephens & Associates, Inc.
JN ES07.0252

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG24_SIM_MODEL_LAYER_1_CELLS_OUTFLOW_LAND_SURF_VAR_INFIL_VOL_HIST_PER_MOD.MXD 800201



Explanation

Cells with simulated hydraulic head above land surface

- Base case infiltration volume
- 2X base case infiltration volume
- 10X base case infiltration volume
- Model grid

Source: Aerial photograph, 1968

BMI Complex
Henderson, Nevada

FIGURE 24
SIMULATED MODEL LAYER 1 CELLS WITH OUTFLOW AT LAND SURFACE FOR VARIOUS INFILTRATION VOLUMES IN HISTORICAL PERIOD MODEL

Basic Remediation COMPANY

Prepared by: DBS&A GJ

Date 11/4/08

S:/PROJECTS/BRC/ES07.0252_BRC_GROUNDWATER_MODELING/GIS/MXDS/REPORT_FIGURES_10-08/FIG23_SIM_MODEL_LAYER_1_CELLS_OUTFLOW_LAND_SURF_VAR_INFIL_VOL_HIST_PER_MOD.MXD 804101

Daniel B. Stephens & Associates, Inc.
JN ES07.0252

Figure 24

Tables

Table 1. General Head Boundary Parameters for Model Layer 1
Page 1 of 2

Row	Column	Head (ft)	Cell Width (ft)	Saturated Thickness (ft)	Distance To Las Vegas Wash (ft)	Hydraulic Conductivity of Las Vegas Wash (ft/d)
4	17	1,565.77	209	40	290.90	485
4	18	1,565.70	209	40	287.55	485
4	19	1,565.58	209	40	248.92	485
5	20	1,565.39	209	40	509.12	485
5	21	1,565.29	209	40	514.83	485
6	22	1,564.91	209	40	527.88	485
7	23	1,564.49	209	40	613.07	485
8	24	1,563.39	209	40	670.43	485
8	25	1,562.79	209	40	490.29	485
9	26	1,561.74	209	40	504.04	485
10	27	1,559.90	209	40	514.99	485
11	28	1,558.40	209	40	581.45	485
11	29	1,557.90	209	40	455.36	485
12	30	1,557.60	209	40	615.26	485
12	31	1,556.10	209	40	617.66	485
13	32	1,555.30	209	40	571.44	485
13	33	1,553.80	209	40	470.35	485
13	34	1,551.57	209	40	315.77	485
13	35	1,550.00	209	40	369.85	485
13	36	1,549.60	209	40	540.02	485
13	37	1,547.70	209	40	483.60	485
13	38	1,545.97	209	40	409.71	485
13	39	1,544.07	209	40	459.36	485
13	40	1,542.25	209	40	450.02	485
13	41	1,541.40	209	40	353.06	485
13	42	1,540.02	209	40	331.90	485
14	43	1,537.80	209	40	792.68	485
14	44	1,537.40	209	40	757.75	485
14	45	1,537.10	209	40	405.47	485
14	46	1,536.86	209	40	374.45	485
15	47	1,535.40	209	40	615.59	485
15	48	1,534.40	209	40	478.22	485
15	49	1,533.55	209	40	263.22	485
16	50	1,532.15	209	40	443.55	485
16	51	1,530.98	209	40	375.69	485

ft/d = Feet per day

Table 1. General Head Boundary Parameters for Model Layer 1

Row	Column	Head (ft)	Cell Width (ft)	Saturated Thickness (ft)	Distance To Las Vegas Wash (ft)	Hydraulic Conductivity of Las Vegas Wash (ft/d)
17	52	1,530.80	209	40	683.19	485
17	53	1,528.30	209	40	728.65	485
17	54	1,526.10	209	40	762.11	485
17	55	1,525.77	209	40	785.04	485
17	56	1,524.30	209	40	733.05	485
17	57	1,523.10	209	40	580.53	485
17	58	1,521.90	209	40	623.86	485
16	59	1,521.10	209	40	487.01	485
16	60	1,520.40	209	40	643.96	485
16	61	1,520.10	209	40	904.36	485
16	62	1,519.60	209	40	1,515.46	485
16	63	1,518.10	209	40	1,495.81	485
16	64	1,517.30	209	40	1,270.21	485
14	65	1,502.06	209	40	1,061.74	485
15	65	1,504.90	209	40	837.81	485
13	66	1,498.90	209	40	658.89	485
12	67	1,497.20	209	40	463.60	485
12	68	1,496.70	209	40	453.00	485
12	69	1,495.80	209	40	581.45	485
11	70	1,494.00	209	40	513.94	485
11	71	1,493.42	209	40	741.71	485
11	72	1,492.60	209	40	833.61	485
10	73	1,490.40	209	40	657.48	485
10	74	1,490.10	209	40	713.24	485
10	75	1,489.00	209	40	731.83	485
10	76	1,488.60	209	40	655.25	485
9	77	1,485.90	209	40	451.62	485
9	78	1,484.90	209	40	520.34	485
8	79	1,480.10	209	40	472.03	485
8	80	1,478.90	209	40	549.01	485
8	81	1,478.40	209	40	574.10	485
8	82	1,478.40	209	40	613.90	485
8	83	1,477.90	209	40	682.32	485

ft/d = Feet per day

Table 2. Observed Hydraulic Conductivity Source Data

Point ID	Well ID	Hydraulic Conductivity (ft/d)	Source
1	CP-1	12	Secor Revised Montrose Facility Report
2	PC-70	227	Kerr-McGee (2001)
3	PC-100	294	Kerr-McGee (2001)
4	PC-90	615	Kerr-McGee (2001)
5	AA-07	5-8	Kleinfelder (2007a)
6	AA-08	256-1020	Kleinfelder (2007a)
7	AA-09	34-62	Kleinfelder (2007a)
8	AA-13	11-14	Kleinfelder (2007a)
9	AA-20	14-85	Kleinfelder (2007a)
10	AA-22	5-8	Kleinfelder (2007a)
11	AA-23R	13	Kleinfelder (2007b)
12	AA-26	7	Kleinfelder (2007b)
13	DBMW-19	3	Kleinfelder (2007b)
14	CLD1R	81	TIMET (2006)
15	CLD3R	13	TIMET (2006)
16	J2D2R2	125	TIMET (2006)
17	PC54	118	TIMET (2006)
18	PC65	20	TIMET (2006)
19	PC67	22	TIMET (2006)
20	AA-BW-7A	5	Kleinfelder (2008)
21	AA-BW-8A	28	Kleinfelder (2008)
22	AA-BW-1A	5	Kleinfelder (2008)
23	B-14R	69	Kleinfelder (2008)
24	B-17	8	Kleinfelder (2008)
25	B-18	2	Kleinfelder (2008)

ft/d = Feet per day

Table 3. Model Calibration Statistics for Current Period Simulation

Statistic Index	Layer 1	Layer 2
Mean error (ME)	0.4	–4.5
Mean absolute error (MAE)	5.7	7.4
Root mean squared error (RMSE)	7.1	11.7
Minimum residual	–16.7	–45.7
Maximum residual	22.2	11.0
Range in target values	229.2	254.9
RMSE/range in target values	0.03	0.05

Table 4. Well Characteristics and Calibration Results

Well Name	TOC Elevation (ft msl)	Screen Depth (ft btoc)		Elevation of Qal - UMCf Contact	Bottom of Model Layer for Cell in Which Well Resides	Water Level (ft msl)		Residual (ft)	Well Located in Simulated Dry Cell?
		Top	Bottom			Observed	Simulated		
Model layer 1									
AA-01	1757.13	31	51	1706.93	1705	1,711.45	1,709.07	2.38	N
AA-07	1612.70	31	51	1558.62	1559	1,572.01	1,568.11	3.90	N
AA-08	1580.82	6	36	1525.46	1529	1,568.72	1,570.95	–2.23	N
AA-09	1695.87	34	69	1624.11	1629	1,658.48	1,641.63	16.85	N
AA-10	1615.12	13	43	1569.04	1560	1,596.89	1,599.58	–2.69	N
AA-11	1660.05	11	31	1630.50	1630	1,629.87	1,631.06	–1.19	N
AA-13	1724.69	42	62	1664.37	1666	1,677.16	1,669.22	7.94	N
AA-14	1701.05	36	61	1640.07	1640	1,639.90	1,644.64	–4.74	N
AA-15	1658.13	20	40	1619.46	1618	1,615.90	1,624.89	–8.99	N
AA-18	1669.00	49	69	1603.60	1606	1,609.44	1,603.55	5.89	N
AA-19	1642.32	24	44	1601.34	1602	1,598.54	1,609.00	–10.46	N
AA-20	1628.49	13	33	1569.07	1581	1,599.62	1,603.32	–3.70	N
AA-21	1584.20	9	39	1544.13	1544	1,574.37	1,570.97	3.40	N
AA-22	1581.53	13	33	1548.88	1548	1,562.19	1,572.12	–9.93	N
AA-26	1566.67	38	58	1513.95	1475	1,520.22	1,498.00	22.22	N
AA-27	1789.43	64	84	1705.53	1718	1,722.46	1,720.47	1.99	N
BEC-4	1681.34 [a]	25	40	1645.35	1640	1,653.85	1,641.63	12.22	N
DBMW1	1626.46	21	51	1583.74	1591	1,593.93	1,593.01	0.92	N
DBMW10	1663.96	56	76	—	1591	1,601.91	1,595.28	6.63	N

[a] Assumed to be the same as the reference point elevation
[b] Survey data (elevation) are uncertain

TOC = Top of casing
ft msl = Feet above mean sea level
ft btoc = Feet below top of casing

Qal = Quaternary alluvium
UMCf = Upper Muddy Creek formation
— = Information not available

Table 4. Well Characteristics and Calibration Results

Well Name	TOC Elevation (ft msl)	Screen Depth (ft btoc)		Elevation of Qal - UMCf Contact	Bottom of Model Layer for Cell in Which Well Resides	Water Level (ft msl)		Residual (ft)	Well Located in Simulated Dry Cell?
		Top	Bottom			Observed	Simulated		
Model layer 1 (cont.)									
DBMW17	1712.38	55	75	1645.61	1636	1,640.91	1,645.54	–4.63	N
DBMW19	1583.40	17	42	1550.41	1554	1,562.24	1,568.49	–6.25	N
DBMW2	1627.00	33	53	1580.66	1591	1,594.60	1,593.47	1.13	N
DBMW3	1625.86	21	41	1591.95	1594	1,598.66	1,601.95	–3.29	N
DBMW4	1605.81	23	43	1577.98	1574	1,587.01	1,589.73	–2.72	N
DM1	1727.21 [b]	30	55	—	1675	1,686.70	1,677.74	8.96	N
HMW16	1622.10	8	23	—	1605	1,612.55	1,611.72	0.83	N
HMW9	1543.60	10	20	—	1512	1,532.74	1,535.26	–2.52	N
MW04	1522.98	—	30	—	1494	1,504.70	1,499.92	4.78	N
MW13	1530.31	—	48	—	1457	1,493.29	1,488.43	4.86	N
PC1	1599.13	14.7	29.7	1568.13	1558	1,575.36	1,578.26	–2.90	N
PC103	1597.02	9	29	1570.49	1572	1,574.61	1,586.02	–11.41	N
PC104	1596.68	10	35	1561.68	1560	1,569.66	1,581.14	–11.48	N
PC108	1584.96 [a]	9.7	44.7	1539.81	1539	1,574.07	1,577.15	–3.08	N
PC12	1616.94	14.8	29.8	1587.50	1578	1,588.23	1,593.48	–5.25	N
PC2	1593.79 [a]	14	29	1566.07	1560	1,570.95	1,578.92	–7.97	N
PC24	1633.95	15	30	1605.95	1608	1,612.95	1,615.04	–2.09	N
PC4	1597.13 [a]	17.7	42.7	1556.92	1562	1,572.32	1,578.50	–6.18	N
PC50	1634.48	11.8	41.8	1599.48	1601	1,622.05	1,619.69	2.36	N

[a] Assumed to be the same as the reference point elevation
[b] Survey data (elevation) are uncertain

TOC = Top of casing
ft msl = Feet above mean sea level
ft btoc = Feet below top of casing

Qal = Quaternary alluvium
UMCf = Upper Muddy Creek formation
— = Information not available

Table 4. Well Characteristics and Calibration Results

Well Name	TOC Elevation (ft msl)	Screen Depth (ft btoc)		Elevation of Qal - UMCf Contact	Bottom of Model Layer for Cell in Which Well Resides	Water Level (ft msl)		Residual (ft)	Well Located in Simulated Dry Cell?
		Top	Bottom			Observed	Simulated		
Model layer 1 (cont.)									
PC56	1568.99 [a]	48.0	54.8	1514.25	1531	1,559.96	1,554.40	5.56	N
PC58	1568.29 [a]	7.8	32.8	1533.96	1528	1,559.91	1,554.85	5.06	N
PC62	1568.45 [a]	7.6	37.6	1530.83	1530	1,558.42	1,556.83	1.59	N
PC76	1564.51 [a]	15	20	1509.10	1508	1,551.34	1,555.47	–4.13	N
PC79	1564.33	34.5	44.5	1519.16	1521	1,556.66	1,553.96	2.70	N
PC80	1564.07	19.5	29.5	1519.31	1521	1,556.27	1,553.90	2.37	N
PC81	1564.03	9.5	14.5	1519.03	1521	1,556.41	1,553.83	2.58	N
PC82	1559.44 [a]	47	57	1503.31	1505	1,553.85	1,549.65	4.20	N
PC83	1559.47	20.5	30.5	1503.32	1505	1,554.34	1,549.54	4.80	N
PC86	1554.08 [a]	17.5	27.5	1506.85	1503	1,550.89	1,544.89	6.00	N
PC90	1550.90 [a]	4.5	14.5	1499.46	1500	1,546.20	1,541.60	4.60	N
PC92	1552.12 [a]	11.5	21.5	1512.05	1509	1,544.59	1,540.47	4.12	N
PC94	1548.84 [a]	9.5	19.5	1508.95	1517	1,541.48	1,541.18	0.30	N
PC95	1550.61	24.5	34.5	1507.62	1500	1,546.28	1,540.61	5.67	N
POD4	1690.01 [a]	47	52	1636.01	1631	1,632.35	1,640.73	–8.38	N
POD7	1690.92 [a]	48	53	1639.42	1634	1,639.06	1,646.48	–7.42	N
POD8	1691.33	42.5	72.5	1617.16	1618	1,623.12	1,639.83	–16.71	N
POU3	1728.51	35	65	1670	1676	1,691.85	1,679.28	12.57	N
PZ13	—	—	—	—	1627	1,622.62	1,619.05	3.57	N

[a] Assumed to be the same as the reference point elevation
[b] Survey data (elevation) are uncertain

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UMCf = Upper Muddy Creek formation
— = Information not available

Table 4. Well Characteristics and Calibration Results

Well Name	TOC Elevation (ft msl)	Screen Depth (ft btoc)		Elevation of Qal - UMCf Contact	Bottom of Model Layer for Cell in Which Well Resides	Water Level (ft msl)		Residual (ft)	Well Located in Simulated Dry Cell?
		Top	Bottom			Observed	Simulated		
Model layer 2									
BEC-6	1725.52 [a]	65	80	1670.52	1626	1,658.83	1,673.87	–15.04	N
BEC-9	1617.74 [a]	44	59	1611.24	1560	1,569.15	1,614.87	–45.72	N
BEC-10	1657.39 [a]	73	88	1629.39	1579	1,599.31	1,606.86	–7.55	N
DBMW5	1609.65	18	38	1594.55	1591	1,586.69	1,585.68	1.01	N
DBMW6	1632.63	32	52	1590.64	1589	1,584.13	1,585.39	–1.26	N
DBMW7	1631.73	53	73	1587.65	1586	1,574.87	1,576.45	–1.58	N
DBMW8	1632.05	49	69	1581.95	1585	1,575.75	1,575.91	–0.16	N
DBMW9	1659.92	56	76	1616.83	1613	1,596.80	1,603.14	–6.34	N
DBMW11	1667.96	45	75	1626.46	1630	1,607.16	1,616.74	–9.58	N
DBMW12	1669.68	49	79	1636.71	1635	1,610.21	1,625.11	–14.90	N
DBMW14	1675.96	38	68	1645.84	1643	1,637.08	1,639.54	–2.46	N
DBMW18	1717.15	48	68	1667.11	1656	1,651.24	1,655.85	–4.61	N
HMW8	—	21	41	—	1428	1,526.90	1,529.27	–2.37	N
HMWWT-6	1774.04	36	51	1744	1682	1,732.39	1,729.46	2.93	N
MCF-01B	1756.28	55	85	1701.45	1655	1,711.28	1,710.72	0.56	N
MCF-03B	1785.72	60	80	1743.46	1687	1,741.61	1,733.78	7.83	N
MCF-06B	1633.18	67	82	1587.40	1538	1,578.79	1,581.56	–2.77	N
MCF-06C	1633.12	44	59	1587.42	1538	1,578.09	1,581.52	–3.43	N
MCF-08B	1581.19	120.1	140.1	1525.43	1479	1,578.59	1,572.12	6.47	N

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Table 4. Well Characteristics and Calibration Results

Well Name	TOC Elevation (ft msl)	Screen Depth (ft btoc)		Elevation of Qal - UMCf Contact	Bottom of Model Layer for Cell in Which Well Resides	Water Level (ft msl)		Residual (ft)	Well Located in Simulated Dry Cell?
		Top	Bottom			Observed	Simulated		
Model layer 2 (cont.)									
MCF-09B	1696.23	112	132	1623.00	1579	1,659.09	1,649.60	9.49	N
MCF-10B	1615.35	84	104	1568.88	1521	1,598.85	1,601.24	–2.39	N
MCF-11	1659.95	93.5	103.5	1625.75	1580	1,630.11	1,630.95	–0.84	N
MCF-12C	1715.27	155	175	1661.53	1615	1,647.28	1,658.18	–10.90	N
MW-01	1526.5	—	—	—	1417	1,489.95	1,478.92	11.03	N
POD2	1673.94	45	65	1623.94	1624	1,616.37	1,636.94	–20.57	N
TWC-126	1650.60	126	146	—	1581	1,637.56	1,641.92	–4.36	N
TWE107	1634.00	107	127	1612	1564	1,624.50	1,628.31	–3.81	N

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Table 5. Current Period Simulation Mass Balance and Estimated Range of Inputs

Inflow/Outflow	Minimum Value	Maximum Value	Average Value	Simulated Value
Groundwater Inflows/Sources (ft^3/d)				
Lateral groundwater inflow-Qal	105	68,443	34,274	123,464
Lateral groundwater inflow-UMCf	2,722	22,686	12,704	2,981
City effluent pond seepage (RIBs plus Birding Preserve)	414,720	414,720	414,720	245,285
TIMET pond seepage	2,609	2,609	2,609	2,591
Recharge from precipitation/storm flow	277	13,844	7,060	13,421
Inflow from deep UMCf (upward vertical leakage)	399	4,868,983	2,434,691	15,282
Seepage from developed areas	253	1,265	759	1,105
Tuscany golf course irrigation return flow	18	89	53	6,184
AMPAC injection wells [a]	47,163	47,163	47,163	47,163
Total inflow	421,103	5,392,639	2,906,871	457,476
Groundwater Outflows/Sinks (ft^3/d)				
Lateral groundwater outflow-Qal	382	2,782,305	1,391,343	294,023
Lateral groundwater outflow-UMCf	1,794	14,952	8,373	4,603
Outflow to deep UMCf (downward vertical leakage)	209	2,546,439	1,273,324	14,005
Tronox seep pumping	62,208	129,600	95,904	62,208
Tronox pumping at Athens Road well field	50,112	50,112	50,112	43,254
AMPAC pumping [a]	44,467	44,467	44,467	22,908
Phreatophyte evapotranspiration	15,117	47,339	31,228	16,522
Total outflow	129,821	5,570,747	2,850,284	457,523

[a] Estimated value from AMPAC (2007)

ft^3/d = Cubic feet per day
Qal = Quaternary alluvium
UMCf = Upper Tertiary Muddy Creek formation
RIB = Rapid infiltration basin

Table 6. Historical Period Simulation Mass Balance and Estimated Range of Inputs

Inflow/Outflow	Minimum Value	Maximum Value	Average Value	Simulated Value
Groundwater Inflows/Sources (ft^3/d)				
Lateral groundwater inflow-Qal	734	194,157	97,446	68,922
Lateral groundwater inflow-UMCf	2,759	22,992	12,876	3,025
Ditch seepage				
Alpha	17	104,160	52,088	61,153
Beta	21	133,920	66,971	75,481
Western	9	55,800	27,904	2,787
Northwestern	5	33,480	16,743	1,674
Stormwater swale	21	133,920	66,971	6,631
Upper and Lower Ponds	1,162,080	1,162,080	1,162,080	96,098
Recharge from precipitation/storm flow	277	13,844	7,060	20,069
Inflow from deep UMCf (upward vertical leakage)	319	3,895,187	1,947,753	11,575
Total inflow	1,166,243	5,749,540	3,457,891	347,415
Groundwater Outflows/Sinks (ft^3/d)				
Lateral groundwater outflow-Qal	356	2,590,720	1,295,538	191,292
Lateral groundwater outflow-UMCf	6	47,206	23,606	4,753
Outflow to deep UMCf (downward vertical leakage)	333	4,069,821	2,035,077	30,931
Tronox seep outflow	57,888	57,888	57,888	57,888
Seeps to north of Upper Ponds area (visible on 1968 aerial photograph)	176,931	176,931	176,931	9,668
Other simulated seeps	—	—	—	15,594
Phreatophyte evapotranspiration	3,779	11,835	7,807	37,286
Total outflow	239,294	6,954,401	3,596,847	347,412

ft^3/d = Cubic feet per day
Qal = Quaternary alluvium
UMCf = Upper Tertiary Muddy Creek formation
— = Not calculated for water balance technical memorandum (DBS&A, 2008a)