1.0 EXECUTIVE SUMMARY

The Big Sandy groundwater basin covers an area of approximately 800 square miles in northwestern Arizona. The only inflow to the basin is infiltration from precipitation, primarily along the mountain fronts and stream channels. The primary outflows are to evapotranspiration via riparian vegetation along the river channel, and a small amount of subsurface outflow at Granite Gorge at the southern end of the basin. Current consumptive groundwater uses include small-volume irrigation and public supply wells in the southern part of the basin and pumping in the north to supply the Phelps Dodge Bagdad mine.

The purpose of the groundwater model analysis is to create an understandable and technically sound groundwater flow model adequate for use in evaluating the long-term potential impact of the proposed Big Sandy Energy Project on the groundwater and surface water resources of the Big Sandy basin. The model analysis was prepared for, and conducted under the direction of, the Western Area Power Administration (Western) and Bureau of Land Management (BLM), Kingman Field Office, for their use in preparing the environmental impact statement (EIS) for the Big Sandy Energy Project. The U.S. Geological Survey's (USGS) model MODFLOW, as embedded in Visual MODFLOW, was used for this analysis.

Ongoing peer review of model input data, assumptions, calibration, and predictions was provided throughout the project by URS Denver modeling group staff, URS Phoenix project management staff, EIS preparation staff, and the following team of hydrologists and other resource specialists (hydrology team) drawn from cooperating agencies and their consultants, and project proponent staff and their consultants:

Andrew Hautzinger, U.S. Fish and Wildlife Service
Annette Morgan, Hualapai Tribe
Bob Orr, Western
Cisney Havatone, Hualapai Tribe
Cortney Brand, URS Corporation
Dale Mason, Arizona Department of Water Resources
Dave Carr, URS Corporation
David Schafer, David Schafer & Associates
Don Bay, Hualapai Tribe, Office of Natural Resources
Greg Beatty, U.S. Fish and Wildlife Service
Gwen Knadel, URS Corporation
Joanna Moreno, URS Corporation

Lin Fehlmann, BLM
Marc Sydnor, Greystone Consultants
Paul Manera, Manera Inc.
Paul Summers, BLM

The hydrology team conferred more than 10 times during the course of the modeling work. Modeling plans, framework, assumptions, input data, calibration results, predictive cases, sensitivity cases, and results were discussed and revised in response to these meetings. At several points in this report references are made to points of discussion from this group. This report was reviewed by the members of the hydrology team prior to submittal. Data sources included 12 months of field investigations by the project proponent, including installation of eight monitor wells in multiple aquifers, four geologic test holes, aquifer testing, monitoring of water levels and spring flow rates, isotope sampling, vegetation mapping, and water balance preparation. Other basin-specific data included an assessment of the basin water resources by USGS (Davidson 1973), spring mapping and Big Sandy River flow measurements by the BLM, geologic and water level information from the Arizona Department of Water Resources (ADWR) well database, and river flow data from the USGS.

Subsurface lithologic data obtained from drilling at the Caithness Big Sandy site, and logs from U.S. Department of Energy (DOE) wells (Lease 1981), indicate that there are five hydrogeologic units in the southernmost part of the basin: (1) arkosic gravel at depth beneath most of the basin, (2) a volcanic lower aquifer which is confined and under a substantial amount of artesian pressure; (3) a middle aquifer composed of conglomerate (lower basin fill) that is also confined; (4) a lacustrine (lakebed clay) deposit that serves as an aquitard, and (5) an upper aquifer that includes the recent alluvial deposits of the Big Sandy River (upper basin fill). The volcanic aquifer pressures are maintained by an aquitard surrounding the aquifer. Although almost all of the subsurface data are concentrated in the vicinity of the site, the areal extents of these units were extrapolated using subsurface lithologic data from six deep exploration wells logged by DOE (Lease 1981).

The geology of the site was simplified into a seven-layer framework for the purpose of modeling analyses. In descending order, the layers are as follows:

- upper basin fill (upper aquifer)
- lakebed clays (where present)
- lower basin fill (middle aquifer)
- aquitard above volcanic aquifer

- volcanic (lower)aquifer
- aquitard below volcanic aquifer
- arkosic gravel

The layers all overlie essentially impermeable granitic gneiss.

Current conditions were used to calibrate the model. Groundwater levels, basin-wide flow balance, spring discharge rates, river discharge rates, and responses to pumping were used to assess the validity of the calibration. A transient calibration was undertaken using the aquifer pumping test data. Predicted drawdowns during pumping and recovery phases of the pumping test were used to evaluate the model.

The following uncertain input parameters key to the analysis of impacts were identified in hydrology team meetings:

- aquitard hydraulic properties
- specific yield of volcanic aquifer
- extent of volcanic aquifer near Granite Gorge

In addition, four other parameters were tested when they were found to affect predicted impacts:

- the effect of assuming different lateral extents for the lakebed clay unit
- the effect of assuming a larger longitudinal extent of lakebed clay
- the effect of different recharge rates into the volcanic aquifer (1.35 to 1.85 in/yr)
- the effect of a three-fold smaller assumed evaporation rate at the marsh.

The base case of the groundwater model predicts that, as a result of 40 years of pumping groundwater at the maximum proposed annual pumping rate of 3,000 gpm, the maximum groundwater level drawdown from the project would be 85 ft in the lower (volcanic) aquifer, less than 4 ft in the middle aquifer, and less than 0.5 ft in the upper aquiferThe predicted area of drawdown in the upper aquifer is in the vicinity of the Denton well and Banegas Ranch well No. 2. The base-case model also predicts:

- approximately 1 percent (12 gpm or 19 ac-ft/yr) reduction in the flow out of the Big Sandy basin at Granite Gorge

- approximately 0.2 percent (17 gpm or 27 ac-ft/yr) reduction in outflow as evapotranspiration
- approximately 2.5 percent (142 gpm or 229 ac-ft/yr) reduction in outflow at the marsh near the Denton well as a result of 40 years of pumping

These flow reductions add to a predicted maximum drop in flow rates to the river alluvium of approximately 0.5 percent (171 gpm or 275 ac-ft/yr).

For each of the sensitivity analysis groundwater model runs, a different model parameter (such as specific yield or hydraulic conductivity) was altered. Most of the sensitivity analyses produced results that were consistent with the aquifer test results and an acceptable model calibration, but some did not, and these cases were judged to be unrealistic. Of all of those model run cases that were consistent with the aquifer test results and observed heads at the site, and therefore judged to be feasible, one run showed a maximum predicted groundwater level drawdown in the upper aquifer from the project (after 40 years of pumping groundwater at the same maximum proposed annual pumping rate of 3,000 gpm) was approximately 85 ft in the volcanic (lower) aquifer, 12 ft in the middle aquifer, and less than 1 ft in the upper aquifer. For this worst case, the model also predicted:

- approximately 2 percent (23 gpm or 37 ac-ft/yr) reduction in the flow of water out of the Big Sandy basin at Granite Gorge
- approximately 0.3 percent (33 gpm or 53 ac-ft/yr) reduction in outflow from evapotranspiration
- approximately 5 percent (315 gpm or 508 ac-ft/yr) reduction in outflow at the marsh near the Denton well as a result of 40 years of pumping

These flow reductions add to a predicted maximum drop in flow rates to the river alluvium of approximately 1 percent (371 gpm or 598 ac-ft/yr).

The minimum (best case) predicted groundwater level drawdown from the project was approximately 65 ft in the lower (volcanic) aquifer, less than 0.5 ft in the middle aquifer, and less than 0.1 ft in the upper aquifer, with no reduction in the flow of water out of the Big Sandy basin at Granite Gorge as a result of 40 years of pumping.

The predicted drawdowns in the upper aquifer, and flow reductions, are predicted to be mitigated by water replenishment that matches in volume, timing, and duration the predicted drops in flow rates to the marsh near the Denton well and Granite Gorge.

The volcanic aquifer is predicted to take about 130 years for 90 percent recovery to pre-pumping heads. Observed heads in the volcanic aquifer during actual pumping will demonstrate which of the predicted cases best represents reality, and the corresponding likely water replenishment volumes required for mitigation .

2.0 INTRODUCTION

2.1 GENERAL SETTING

The Big Sandy groundwater basin covers an area of approximately 800 square miles in northwestern Arizona (Figure 1). The basin trends roughly north-south and is surrounded by the Peacock and Hualapai mountains on the northwest and southwest, and Cottonwood Cliffs and Aquarius Mountains on the northeast and southeast, respectively.

The mountains are primarily granitic and the central part of the basin contains as much as 2,000 ft of sedimentary rocks. Three hydrologic units occur in the valley: (1) the upper basin fill including streambed alluvium (upper aquifer), (2) the lower basin fill, confined where overlain by lakebed clay (middle aquifer), and (3) a largely confined volcanic unit (lower aquifer) present in the southwestern part of the basin.

The only inflow to the basin is infiltration from precipitation, primarily along the mountain fronts and stream channels. The primary outflows are to evapotranspiration via riparian vegetation along the river channel, evaporation and evapotranspiration at the marsh near the south end of the valley, a small amount of agriculture, and outflow at Granite Gorge at the southern end of the basin. Current consumptive groundwater uses include small-volume irrigation and public supply wells in the southern part of the basin and pumping in the north to supply the Phelps Dodge Bagdad mine. Current consumptive use of surface water is a small amount diverted for agriculture.

2.2 GROUNDWATER MODELING OBJECTIVES

The purpose of the groundwater model analysis was to create an understandable and technically sound groundwater flow model adequate for use in evaluating the long-term potential impact of the proposed Big Sandy Energy Project on the groundwater and surface water resources of the Big Sandy basin.

The overall objectives of the modeling analysis were as follows:

- Analyze existing groundwater conditions in terms of the following:
  - recharge/discharge flow patterns under steady conditions
  - simulation of the aquifer pumping test to evaluate model performance

- Analyze future groundwater conditions as follows:
  - recharge/discharge flow patterns under plant pumping conditions
  - impacts on water levels and flow rates resulting from plant pumping
  - sensitivity of model results to variations in key uncertain model inputs

- Provide input to a protective groundwater monitoring and water augmentation program.

The U.S. Geological Survey's (USGS) model MODFLOW, as embedded in Visual MODFLOW, was used for this analysis.

2.3 QUALITY ASSURANCE AND PEER REVIEW

The model analysis was prepared for, and conducted under the direction of, the Western Area Power Administration (Western) and the Bureau of Land Management (BLM), Kingman Field Office, for their use in preparing the environmental impact statement (EIS) for the Big Sandy Energy Project. Ongoing peer review of model input data, assumptions, calibration, and predictions was provided throughout the project by URS Denver modeling group staff, URS Phoenix project management staff, EIS preparation staff, and the following team of hydrologists and other resource specialists (hydrology team) drawn from cooperating agencies and their consultants, and project proponent staff and their consultants:

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Dale Mason, Arizona Department of Water Resources
Dave Carr, URS Corporation
David Schafer, David Schafer & Associates
Don Bay, Hualapai Tribe, Office of Natural Resources
Greg Beatty, U.S. Fish and Wildlife Service
Gwen Knadel, URS Corporation
Joanna Moreno, URS Corporation
Lin Fehlmann, BLM
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Paul Manera, Manera Inc.
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The hydrology team conferred more than 10 times during the course of the modeling work. Modeling plans, framework, assumptions, input data, calibration results, predictive cases, sensitivity cases, and results were discussed and revised in response to these meetings. At several points in this report references are made to points of discussion from this group. This report was reviewed by several members of the hydrology team prior to submittal.

Groundwater modeling protocols have been attempted to be established in documents such as American Society for Testing and Materials (ASTM) standards D 5447-93, D 18.21.92.09, D5490-93, E 978-84, D 5610-94, D 5609-94, and U.S. Environmental Protection Agency (EPA 1992). These documents have not been widely accepted, or used as industry standard practice. They were used as checklists for this analysis.

3.0 TECHNICAL APPROACH

3.1 DATA SOURCES

Data sources included 12 months of field investigations by the project proponent, including installation of eight monitor wells in multiple aquifers, four geologic test holes, aquifer testing, monitoring of water levels and spring flow rates, isotope sampling, vegetation mapping, and water balance preparation. Other basin-specific data included an assessment of the basin water resources by USGS (Davidson 1973), spring mapping and Big Sandy River flow measurements by BLM, geologic and water level information from the Arizona Department of Water Resources (ADWR) well database, and river flow data from USGS. In addition, many references (some listed in Section 6.0 and others referenced in other documents related to this project) were also used in understanding and defining flow patterns, volumes, and behavior in the Big Sandy basin. Specific references are cited at the point where the data are used in the present report.

3.2 CONCEPTUAL MODEL

The purpose of this section is to summarize the conceptual model (data and assumptions) that form the basis of the Big Sandy model and its conclusions. The parts of the conceptual model described here follow the list provided in EPA's assessment framework for groundwater model applications (EPA 1992). The main topics covered are the hydrogeologic system (including aquifer system, hydrologic boundaries, and hydraulic properties), sources and sinks, water balance, data gaps, and boundary conditions. The model construction section summarizes data supplied to the model and boundary conditions.

Hydrogeologic System

The Big Sandy basin covers an area of approximately 800 square miles in southeastern Mohave County, Arizona (Figure 1). Groundwater within the basin originates as natural precipitation, which supplies water to the regional aquifer through recharge in stream channels and along the mountain fronts. In general, groundwater flows from the mountains toward the center of the basin, then south parallel to the Big Sandy River (Cady 1981; Davidson 1973;). Details of groundwater sources and sinks are given in the water budget (Section 3.2.3).

North of Wikieup, the Big Sandy River is ephemeral, flowing only in response to direct precipitation. Near Wikieup, the river becomes perennial for approximately 6 miles before disappearing underground about 1.5 miles upstream of Granite Gorge. This perennial reach may be due in part to the presence of a lacustrine deposit, or "lakebed clay," that occurs in the southernmost part of the basin. The lacustrine deposit, which is believed to function as an aquitard, may force groundwater to the surface, where it provides base flow to the river. Perennial flow reappears near the southern boundary of the basin, at the end of the marsh, and continues south through Granite Gorge. Groundwater also exits the basin as underflow in the Big Sandy River channel at Granite Gorge.

During the field program, the project proponent identified a very shallow clay layer within the perennial segment of the river (Manera 2000). It has been postulated by the project proponent that this clay layer may also provide a mechanism for sustaining perennial flow in the river, and hydraulically separating surface flow from groundwater.

Aquifer System. Subsurface lithologic data obtained from drilling at the proposed power plant site, and logs from U.S. Department of Energy (DOE) wells (Lease 1981), indicate that there are five hydrogeologic units in the southernmost part of the basin: (1) arkosic gravel at depth beneath most of the basin, (2) a volcanic lower aquifer (also referred to as the volcanic aquifer), which is confined and under a substantial amount of artesian pressure; (3) a middle aquifer composed of conglomerate (lower basin fill) and which is also confined; (4) a lacustrine deposit (lakebed clay) which serves as an aquitard to the middle aquifer, and (5) an upper aquifer which includes the recent alluvial deposits of the Big Sandy River (upper basin fill). The volcanic aquifer pressures are maintained by an aquitard surrounding the aquifer. Although almost all of the subsurface data are concentrated in the vicinity of the power plant site, the areal extents of these units were extrapolated using subsurface lithologic data from the six deep exploration wells logged by DOE (Lease 1981).

The water-bearing portion of the upper aquifer forms a narrow band along the floodplain of the Big Sandy River, and spans the entire length of the basin. The lacustrine deposit crops out along the banks of the Big Sandy River in the southernmost part of the basin but disappears into the subsurface north of Wikieup, where it is thought to grade into coarser-grained basin-fill deposits (Figure 2). The middle aquifer is probably laterally connected with other units throughout the basin.

The extent and depth of the lower aquifer is not precisely known; however, because this volcanic unit is connected to the volcanic mass that composes the southern portion of the Aquarius Mountains, which appears to be the source of the volcanic material, it is inferred to be restricted to the southern portion of the Big Sandy basin. The arkosic gravel is also not well-defined due to a lack of subsurface data, but is believed to be present beneath most of the lower aquifer.

The results of isotope testing of waters from the upper and lower aquifers and springs in the Aquarius Mountains as well as the Hualapai Mountains to the north indicated that the lower aquifer is hydraulically connected to, and receives recharge mainly from, the Aquarius Mountain volcanics to the east. The upper aquifer was shown to receive part of its recharge from a higher elevation source, such as the Hualapai Mountains and/or Cottonwood Mountains at the northern end of the Big Sandy basin.

Hydraulic Boundaries. Hydraulic boundaries include the surface water divides on the east, north, and west sides of the basin, and the hydraulic barrier created by a volcanic plug blocking the southern part of the basin. The boundaries of the groundwater system fall inside these hydraulic divides; the edge of the continuously saturated zone generally coincides with the margins of the basin where mountain front recharge sustains groundwater flow.

Hydraulic Properties. Hydraulic properties for most of the hydraulic units were based on aquifer tests in the alluvium, and well yields in the other units (Davidson 1973). Hydraulic properties for the lower (volcanic) aquifer were based on the results of the aquifer test of that unit performed by the project proponent (David Schafer & Associates 2001). Literature data were used to supplement field measurements. In addition, model calibration to observed heads, the aquifer pumping test, and the derived water balance for the basin were used to revise some hydraulic properties.

Details of the hydraulic property ranges, their sources, and the values supplied to the model are provided in Section 3.4.2.

Sources and Sinks

Sources and sinks to groundwater are described below and quantified in the water budget (Section 3.2.3).

INFLOW

Sources of inflow (recharge) to the Big Sandy basin can be classified as either incidental (anthropogenic) recharge or natural recharge.

Incidental Recharge

Sources of incidental recharge to the Big Sandy basin include agricultural irrigation, livestock watering, and domestic use. Estimates of incidental recharge for these three sources were obtained from the Big Sandy 1990 Water Use Report (USGS 2000).

Agricultural Irrigation. USGS derived recharge from agricultural irrigation by estimating groundwater withdrawals and surface water diversions for agricultural use, and subtracting the total consumptive use. The total consumptive use was derived from the total irrigated acreage and the average consumptive use based on the types of crops grown. The total estimated annual recharge from agricultural irrigation is 22 acre-feet, or 0.1 percent of total basin inflow.

Livestock Watering. Recharge from watering of livestock was derived by estimating groundwater withdrawals and surface water diversions to supply livestock tanks (typically earthen impoundments and subtracting the total consumptive use. The total consumptive use presumably includes evaporation and livestock use. The total estimated annual recharge from livestock watering is 45 ac-ft, or 0.2 percent of total basin inflow.

Domestic Use. Recharge from domestic use was derived using groundwater withdrawals from both public and private wells, and subtracting the total consumptive use. The total consumptive use was derived from the total population of the Big Sandy area, and an average per capita consumptive use factor. The total estimated annual recharge from domestic use is 45 ac-ft, or 0.2 percent of total basin inflow. It is assumed that most of the unused water is recharged through septic systems.

Natural Recharge

Natural recharge in an alluvial basin includes mountain front recharge, stream channel recharge, and recharge from direct precipitation. For this water budget, groundwater underflow entering the Big Sandy basin from the Hackberry Sub-Area to the north (Remick 1981) also was included as natural recharge. Of the two general categories of recharge, natural recharge is always the most difficult to estimate due to the infeasibility of making direct measurements, and the wide range of estimates obtained using various analytical methods (Wilson et. al. 1980). Because of this, natural recharge was not estimated using empirical methods, but rather, was calculated to balance the water budget. The calculated value for natural recharge obtained using this approach is 26,194 acre-feet per year (ac-ft/yr), or about 99.6 percent of total basin inflow.

To substantiate this calculated value, an approximate estimate of natural recharge was made using the Maxey-Eakin method, which assumes that the total percentage of precipitation that is recharged increases with precipitation (Wilson et. al. 1980, p. 4-35). The normal annual precipitation in the Big Sandy area ranges from 10 to 14 inches (Davidson 1973). Assuming an annual average precipitation of 12 inches (1 foot) and a total basin area of 700 square miles (448,000 acres), the total annual precipitation would be about 448,000 ac-ft. According to the Maxey-Eakin method, approximately 5 percent (22,400 ac-ft) of this volume would be recharged

(Wilson et. al. 1980, p. 4-36). This value compares favorably with the 26,194 ac-ft value obtained from the water budget calculation.

OUTFLOW

Sources of outflow (discharge) include groundwater pumpage, evapotranspiration, evaporation and evapotranspiration at the marsh near the Denton well, Cofer Hot Spring Flow, consumptive use of surface water for irrigation, and outflow at Granite Gorge.

Groundwater Pumpage

Sources of groundwater pumpage include pumpage for agricultural irrigation, livestock watering, domestic use, and mining. Estimates of groundwater pumpage for these four sources were obtained from the Big Sandy 1990 Water Use Report (USGS 2000).

Agricultural Irrigation. Pumpage estimates for agricultural irrigation were derived by USGS from electrical power company records. Kilowatt hours were converted to gallons per minute (gpm) pumped based on the depth to groundwater and an average pump efficiency. The total estimated pumpage to support agricultural irrigation is 34 ac-ft, or 0.1 percent of total basin outflow.

Livestock Watering. Pumpage estimates for livestock watering irrigation were derived from electrical power company records, using the same method employed to estimate agricultural irrigation pumpage. The total estimated pumpage to support livestock watering is 123 ac-ft, or 0.5 percent of total basin outflow.

Domestic Use. Pumpage estimates for public (municipal supply) wells were obtained from water company delivery records. For privately owned wells, pumpage was estimated based on the estimated population that receives water from domestic wells, and an average per capita total water use factor. The total estimated pumpage for domestic use is 101 ac-ft, or 0.4 percent of total basin outflow.

Mining. This category of pumpage refers solely to groundwater pumped to supply the Phelps Dodge Bagdad mine, located approximately 20 miles east-southeast of the Big Sandy basin. The pumpage estimate for the Bagdad mine was derived by USGS based on the amount of copper produced in 1990, and a water consumption factor for the mine based on the methods used to extract copper from the ore. The total estimated pumpage for the Bagdad Mine in 1990 is 2,005 ac-ft, or 7.6 percent of total basin outflow.

Evapotranspiration

Evapotranspiration for this water budget refers solely to water use by riparian vegetation (phreatophytes). Evapotranspiration estimates in the water budget developed by Davidson (1973) were updated by obtaining the total riparian acreage from a geographic information system (GIS) land use cover, if available, and applying an average consumptive use factor based on the relative percentages of riparian plant types. Areas of dense riparian vegetation occur along the Big Sandy River, Deluge Wash, and Cane Springs Wash. The density of riparian vegetation is greatest along the Big Sandy River, particularly along the perennial reach of the river in the vicinity and south of Wikieup. The riparian vegetation is primarily a mix of mesquite and saltcedar with small sections of cottonwood. Davidson's evapotranspiration estimates were developed by compiling areas of riparian vegetation from topographic maps based on aerial photographs, and field-checking each area. Vegetation density was estimated from aerial photographs taken in 1954. The total area covered by riparian vegetation, adjusted to 100 percent density, was estimated to be 4,600 acres. Assuming a consumptive use factor of 4 ft per year, the loss of water to evapotranspiration is estimated to be 18,400 ac-ft/yr (Davidson 1973, p. 36), or 70.0 percent of total basin outflow. These evapotranspiration estimates were updated for the southern half of the basin based on recent vegetation mapping, and literature for consumptive use.

Evaporation and Evapotranspiration at Marsh Near Denton Well

The marsh at the southern end of the basin, about 1 mile upstream from Granite Gorge, creates outflow from the basin through evaporation, evapotranspiration and surface flow to the downstream perennial reach of the Big Sandy River. The area of the marsh is estimated to be 335 acres based on the extent of vegetation shown on the USGS quadrangle of the area, then given an evaporation rate of about 95 inches/year (Trauger 1972) and a crop coefficient of 1.12 based on a 50/50 mixture of reed swamp and shallow standing water (FAO website 2001) the calculated outflow at the marsh is 3,053 ac-ft/y or 11.6 percent of the total basin outflow.

Cofer Hot Spring Flow

The flow rate at Cofer Hot Spring was measured at 176 gpm, or 290 ac-ft/yr (Caithness 2000), or 1.1 percent of total basin outflow. Flow rates at other springs in the area, which amount to less than 7 gpm,were later determined to be flowing in perched flow systems separate from the valley aquifers, and therefore were not accounted for in the basin water budget.

Consumptive Use of Surface Water for Irrigation

Surface water for agricultural irrigation is supplied to the Banegas Ranch from the Big Sandy River through an upstream diversion structure. The annual consumptive use and evaporative loss of surface water due to agricultural operations at Banegas Ranch is estimated to be 300 ac-ft/yr, or 1.1 percent of the total basin outflow. Surface water diversions for other parcels of agricultural land in the basin have not been identified.

Outflow at Granite Gorge

The total volume of water that exits the basin as outflow at Granite Gorge includes groundwater underflow in the river alluvium and surface water flow in the Big Sandy River. The amount of groundwater leaving the Big Sandy basin as underflow at Granite Gorge was estimated by Davidson (1973) to be approximately 800 ac-ft/yr, assuming a hydraulic conductivity of 1,000 ft per day, a saturated cross-sectional area of 9,000 square ft, and a hydraulic gradient of 0.01 feet per foot (ft/ft). Perennial flow in the Big Sandy River at the northern end of Granite Gorge has not been measured. However, the BLM has measured flows in the river about 1 mile downstream of the northern end of the gorge. The average annual flow of the Big Sandy River, based on the BLM measurements, is 3,280 ac-ft/yr. These flow measurements may include storm flows as well as base flow.

The estimated range of outflow at Granite Gorge for the water budget, based on the Big Sandy flow measurements downstream of the gorge and the underflow estimates made by the USGS, was the average value of 2,000 ac-ft/yr , or about 7.6 percent of the basin outflow.

Water Budget

This section presents a water budget for the Big Sandy basin for current conditions. The water budget (inflow – outflow +/- change in storage = 0) has been developed to evaluate the relative significance of various sources of groundwater recharge and discharge, and to assist in developing a conceptual hydrogeologic model of the basin. The water budget also is the initial step in the construction of the groundwater flow model of the site. The water budget is summarized in Table 1.

All of the data used to develop the water budget were obtained from publicly available sources. The water budget developed by Davidson (1973) for the Big Sandy basin was used as a starting point for the current water budget. Although the information used by Davidson to develop that water budget is now 30 years old, Davidson's values for one component, underflow at Granite Gorge, was incorporated into the current water budget. Data for incidental recharge and groundwater pumping were obtained from the USGS Internet site (USGS 2000).

Change in groundwater storage was evaluated by reviewing water level data from several index wells in the Big Sandy basin. Index wells are wells with long periods of record that typically are measured annually by ADWR or USGS. A review of water level data from these wells revealed no long-term changes in water level elevations, only short-term fluctuations. Based on the results of this review, it was concluded that there is no long-term change in storage in the basin.

The water budget for the Big Sandy basin presented in this report indicates that the two largest components of the water budget, natural recharge and evapotranspiration, probably are the most uncertain. Natural recharge estimates derived using one or more accepted methods probably would not yield conclusive results. The water budget also indicates that the Phelps Dodge Bagdad mine, as expected, is by far the largest groundwater user in the basin. The water budget could be improved by obtaining current estimates of mine pumpage.

Data Gaps

The following data gaps were identified when creating the conceptual model:

- recharge rate into the volcanic outcrop area
- specific yield of the volcanic aquifer
- hydraulic properties of the aquitard units
- extent of the volcanic aquifer near Granite Gorge

Each of these data gaps was discussed in hydrology team meetings. Relevant parts of the discussions are reported below.

Recharge Rate Into Volcanic Outcrop

The estimated recharge rate into the volcanics was discussed in a hydrology team meeting prior to modeling analyses. A quote from the meeting minutes follows:

The 10 percent recharge value suggested by the water resources report (Caithness, 2000) is only for direct precipitation on highly fractured basalt of the recharge area. No other recharge was considered. Flow out of Cofer Hot Spring (initially reported by Caithness to be 350 gpm) constitutes almost half of the 865 gpm proposed recharge. The water presently issuing from Cofer Hot Spring is being used by the property owner. Other area springs mapped and measured by BLM have a total flow of less than 25 gpm. Where the remainder of the recharged water goes is not known.

As a result of various analyses and measurements, the following issues raised in the hydrology team meeting were subsequently resolved:

(1) The flow out of Cofer Hot Spring was measured by Paul Manera of Manera, Inc. and was estimated to be 176 gpm.

(2) The recharge rates basin-wide were estimated to be 5 percent of precipitation based on application of the Maxey-Eakin method for the appropriate elevation. This rate of recharge agreed well with the water budget for the basin (Section 3.2.3). This recharge is distributed unevenly over the basin. The greatest recharge occurs along the mountain fronts as a result of runoff from the uplands. In addition, a higher than average fraction of recharge is expected in the area of the volcanic outcrop, which is fractured and at a higher elevation than the surrounding terrain. Volcanic outcrop recharge rates varying from 0.75 to 1.85 inches per year (in/yr) (6 to 15 percent of precipitation) were tested in the model. The water recharging the volcanic outcrop is believed to discharge via Cofer Hot Spring and into the aquifers surrounding the volcanic aquifer. The distribution of this discharge is unknown and was modeled as a function of the predicted head differences and assumed hydraulic conductivities of the adjacent layers. These hydraulic properties were varied in the model sensitivity analyses (Section 3.6).

TABLE 1
BIG SANDY BASIN WATER BUDGET FOR CURRENT CONDITIONS

Water Budget Component	Annual Volume (ac-ft/yr)	Percent of Total Inflow/ Outflow	Source of Data/Comments
Inflow			
Incidental Recharge			Source: Big Sandy 1990 Water Use Report (USGS Web Site).
Agricultural Irrigation	22	0.1	Includes conveyance losses and infiltration.
Livestock Watering	45	0.2	Stock pond infiltration.
Domestic Use	45	0.2	Recharge primarily from septic systems.
Subtotal Incidental Recharge	112	0.4	
Natural Recharge	26,194	99.6	Calculated balance of inflow (assuming no change in storage).
Total Inflow	**26,306**	100.0	
Outflow			
Groundwater Pumpage			Source: Big Sandy 1990 Water Use Report (USGS Web Site).
Agricultural Irrigation	34	0.1	Estimated from electrical power company records.
Livestock Watering	123	0.5	Estimated from electrical power company records.
Domestic Use	101	0.4	Public pumpage from delivery records, private pumpage from gpcd
Mining	2,005	7.6	Phelps Dodge Bagdad Mine, based on mine production.
Subtotal Groundwater Pumpage	2,263	8.6	
Evapotranspiration	18,400	70.0	Davidson 1973, p. 36, based on 4 ft/yr x 4,600 acres (8,500 – 16,300 ac-ft/yr in southern half of basin, based on updated acreages and vegetation types).
Evaporation and Evapotranspiration at Marsh Near Denton Well	3,053	11.6	335 ac vegetation area (USGS Quad. Map)
Cofer Hot Spring Flow	290	1.1	Caithness (2000)
Consumptive Use of Surface Water for Irrigation	300	1.1	Based on the consumptive use and evaporative losses due to agricultural operations at Banegas Ranch.
Outflow at Granite Gorge	2,000	7.6	Outflow may range from 800 ac-ft/yr (Davidson 1973, p. 37) to 3,280 ac-ft/yr (BLM measurement at site B1, segment C, below Granite Gorge)
Total Outflow	**26,306**	100.0	
Change in Storage	**0**		No change in storage, based on analysis of long-term water level data.

Specific Yield of the Volcanic Aquifer

Specific yield data for the lower (volcanic) aquifer could not be derived from the aquifer pumping test. Literature data for fractured or vesicular basalt, bracketing the observed hydraulic conductivity of about 50 ft per day (ft/d) from the aquifer pumping test, gave the following ranges of values:

- Singhal and Gupta (2000): 10 to 17 percent porosity for hydraulic conductivities ranging from 2.8 x 10^{-4} to 283 ft/d

- Trauger (1972): 4 to 9 percent specific yield (5 to 10 percent porosity) for hydraulic conductivities ranging from 5 to 500 ft/d

During a hydrology team meeting, Paul Manera of Manera, Inc. mentioned that the volcanic aquifer cores were somewhat vesicular and somewhat fractured and showed deposition of malachite, evidence of well-connected fractures. He also concluded that specific yields were likely to be in the range of 8 to 13 percent.

It was concluded and agreed that a range of 7 to 15 percent specific yield for the volcanic aquifer would be modeled, with a best-estimate value of 11 percent.

Hydraulic Properties of the Aquitard Units

Hydraulic conductivities of the aquitards were discussed during a hydrology meeting and a range of 1 x 10^{-4} to 1 x 10^{-6} ft/d was agreed to be tested in the model.

Extent of Volcanic Aquifer Near Granite Gorge

The extent of the volcanic aquifer in the vicinity of Granite Gorge was discussed in a hydrology team meeting. The potential installation of a middle aquifer monitor well was discussed, as follows:

- Paul Summers (BLM) inquired about the feasibility of installing a monitor well in the middle aquifer near Granite Gorge to determine leakage from lower aquifer into the middle aquifer. The borehole would also provide lithologic data.

- Potential problems with this include: (1) distance from the pumping well (4 miles) may preclude relevance to assessing impacts from pumping, (2) the high cost ($55,000 to $60,000 for an 800-ft well and, $10,000 to $15,000 for road construction), and (3) major disturbance from road construction. In addition, it is not known whether the middle aquifer is present close to the gorge.

- The middle aquifer well will be monitored during the pump test to determine leakage. If no leakage is indicated, then there will be no need for a well at Granite Gorge.

- Consensus opinion is that installation of a southern well would be of questionable value prior to the aquifer test.

- The results of the aquifer test will indicate the amount of leakage (if any) between the middle and lower aquifers. The isotopic data may also show if there is leakage.

- Any leakage (K values) found during the pump test will be applied to the entire aquifer during impact evaluation. Sensitivity runs (changing leakage rates) can be performed to model connectivity.

The issues detailed below were discussed in a subsequent hydrology team meeting. Meeting notes are as follows:

Questions had been raised regarding underflow that may be present at Granite Gorge and leakage from the lower aquifer at that point. There is no evidence to suggest that a special zone of vertical conductivity exists at the gorge. Any impacts the pumping of the lower aquifer might have would be evident near the site first. The distribution of the underflow at the gorge is not known. There is no riparian vegetation in the gorge, and that section of the river is not a gaining reach. Estimated underflow is based on Davidson's report and is assumed to be in the upper basin fill. Lakebed clays that act as the upper aquitard coarsen towards the east and west margins of the basin; they may also coarsen at the gorge. The lower aquitard seems to be volcanic clay that may be the weathered surface of the volcanic flow, and likely does not coarsen in the vicinity of the gorge.

Discharge from the lower aquifer currently appears to be to the middle aquifer and from springs. There is no surface water flow through the gorge.[1] Evidence points to a uniform vertical

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[1] This comment reflects the meeting notes. Our current understanding is that a perennial reach of the Big Sandy River does exist through Granite Gorge. This change in understanding does not affect the conclusion that no unusually conductive zone exists between the volcanic aquifer and the mouth of the gorge.