Corrosivity

Because sulfate-resistant cement would be used in areas with highly corrosive soils, no adverse impacts from corrosive soils would be expected.

Soils that Uniquely Support Threatened or Endangered Plant Species

As with the Proposed Action, there would be no adverse impacts expected in the Alternative R gas pipeline corridor. The Alternative T gas pipeline corridor may cross exposures of the nutrient-poor calcareous soils that uniquely support the Arizona cliffrose. If these areas are not avoided, significant impacts may result.

Alterations in Stormwater Runoff

Alterations in stormwater runoff would be as described for the proposed pipeline, and no significant impacts would be expected.

No-Action Alternative

If the Proposed Action were not constructed there would be no impact on soils within the Big Sandy basin associated with the proposed Project. The groundwater production and monitoring wells and associated access roads and well pads completed on private land that were used to identify and test the lower aquifer would remain.

3.3.2.6 Mitigation and Residual Impacts

If adopted, the following measures would be implemented to avoid or reduce significant impacts:

- If corridor segment T5 is selected, the nutrient-poor calcareous soils derived from the Tertiary limestone lakebed deposits would be avoided.

If this measure is adopted, no residual impacts would remain.

3.4 GROUNDWATER

This section describes the affected environment and environmental consequences with regard to groundwater resources. Supporting information for this section is provided in Appendices D, E, and F.

3.4.1 Affected Environment

The following sections describe current groundwater conditions in the vicinity of the Proposed Action. The description of current conditions provides a baseline for the assessment of impacts and environmental consequences.

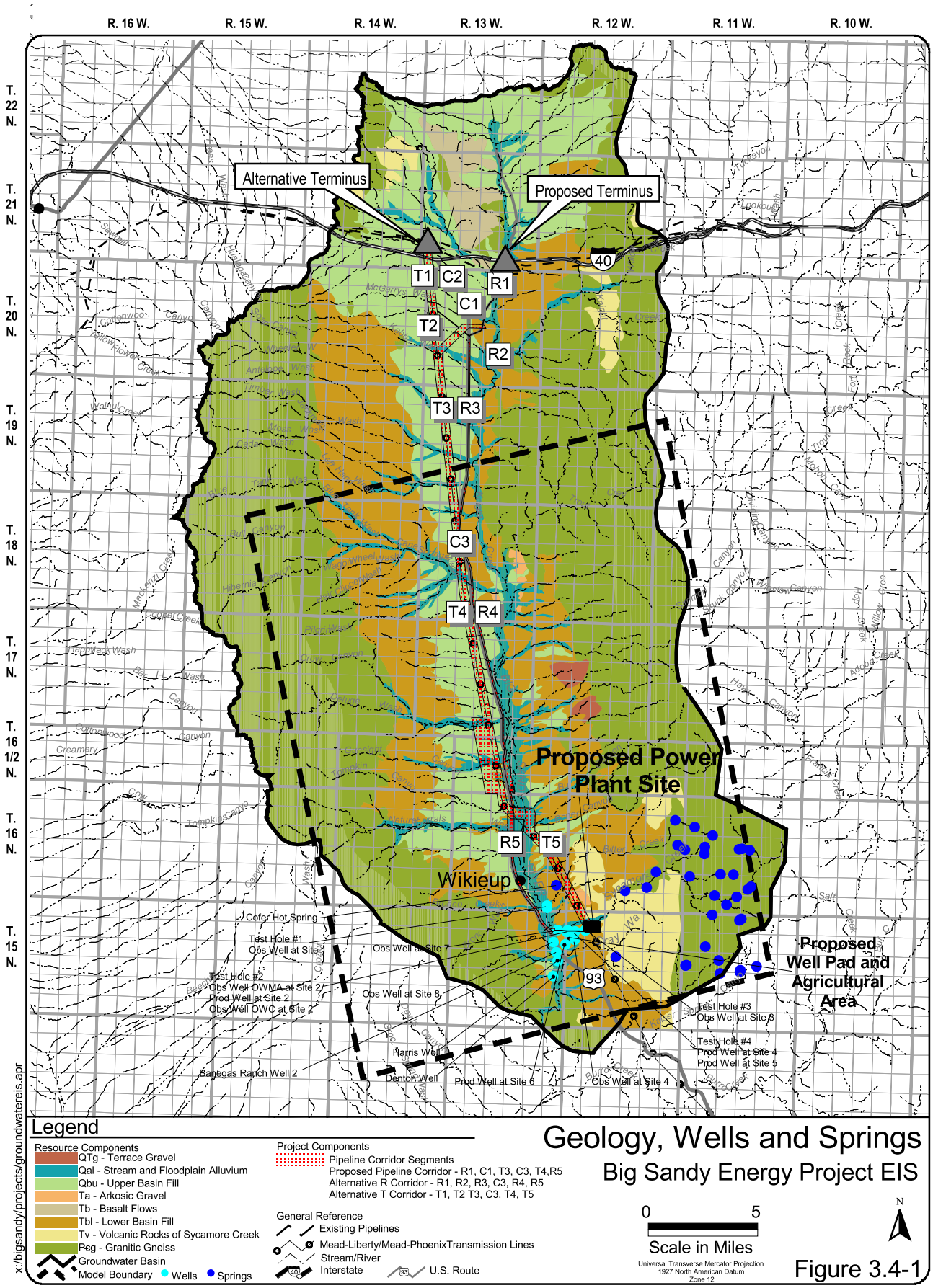
3.4.1.1 Region of Influence

The region of influence for assessing impacts on groundwater includes all aquifers within the southern portion of the Big Sandy groundwater basin that potentially could be impacted by groundwater pumping to supply the proposed Project, or by discharge of pollutants from the evaporation pond or any other activities related to the Proposed Action.

3.4.1.2 Existing Conditions

Hydrogeologic Setting

The proposed power plant site, ancillary facilities, and gas pipeline corridors are located within the Big Sandy basin, a north-south trending alluvial groundwater basin that covers an area of approximately 800 square miles (Figure 3.4-1). The Big Sandy basin is located within the Basin and Range structural and physiographic province, a region of the southwestern United States characterized by alluvial basins and fault block mountain ranges. The basin is bounded by the Hualapai Mountains on the west and southwest, the Aquarius Cliffs and Aquarius Mountains on the east, the Cottonwood Mountains on the northeast, and the Peacock Mountains on the northwest (Davidson 1973).



Geology, Wells and Springs

Big Sandy Energy Project EIS

Figure 3.4-1

The mountains that surround the basin are, for the most part, composed of Precambrian granitic and metamorphic rocks. These older, relatively impermeable rocks are overlain by Tertiary volcanic rocks in several locations in the northern part of the basin. Tertiary volcanic rocks crop out in the vicinity of the Aquarius Cliffs and form the southeastern boundary of the basin. These volcanic rocks are believed to represent the surface expression of the volcanic aquifer that would be developed to supply water for the proposed Project (refer to Figure 3.4-1).

The basin-fill sediments consist mainly of alluvial fan and lacustrine deposits, overlain by stream channel and floodplain deposits of the Big Sandy River (Davidson 1973). The basin-fill deposits have been generally subdivided into upper basin fill and lower basin fill, and are further defined in this section, for the southern portion of the basin, in the section titled Hydrogeologic Units.

Groundwater and Surface Water Flow

Groundwater within the Big Sandy basin originates as natural precipitation, which supplies water to the aquifer through recharge in stream channels and along the mountain fronts. A small amount of groundwater enters the basin as groundwater underflow from the Hackberry Sub-Area to the north (Remick 1981). Groundwater flows from the mountains toward the center of the basin, then south parallel to the Big Sandy River (Cady 1981; Davidson 1973; Figure 3.4-2). Depth to groundwater ranges from near ground surface along the lower reaches of the Big Sandy River, to more than 500 feet in the northern part of the basin (Cady 1981). Groundwater exits the basin as subflow in the Big Sandy River alluvium at Granite Gorge, approximately 4 miles south-southeast of the proposed power plant site.

North of Wikieup, the Big Sandy River is ephemeral, flowing only in response to direct precipitation; the river becomes perennial in the vicinity of Wikieup (refer to Figure 3.4-5). This phenomenon may be due to the presence of the lacustrine deposit, or "lakebed clay," which occurs only in the southernmost part of the basin (refer to the section titled "Hydrogeologic Units"). The lacustrine deposit, which functions as an aquitard, may force groundwater to the surface, where it provides base flow to the river. There is anecdotal evidence that perennial flow in the river disappears and becomes subflow in the alluvium south of Banegas Ranch. Perennial flow reappears at a marsh near the southern boundary of the basin, and continues south through Granite Gorge. The non-perennial reach of the Big Sandy River between Banegas Ranch and Granite Gorge has not been formally documented in the field, and may represent an intermittent reach, where the river flows during certain times of the year.

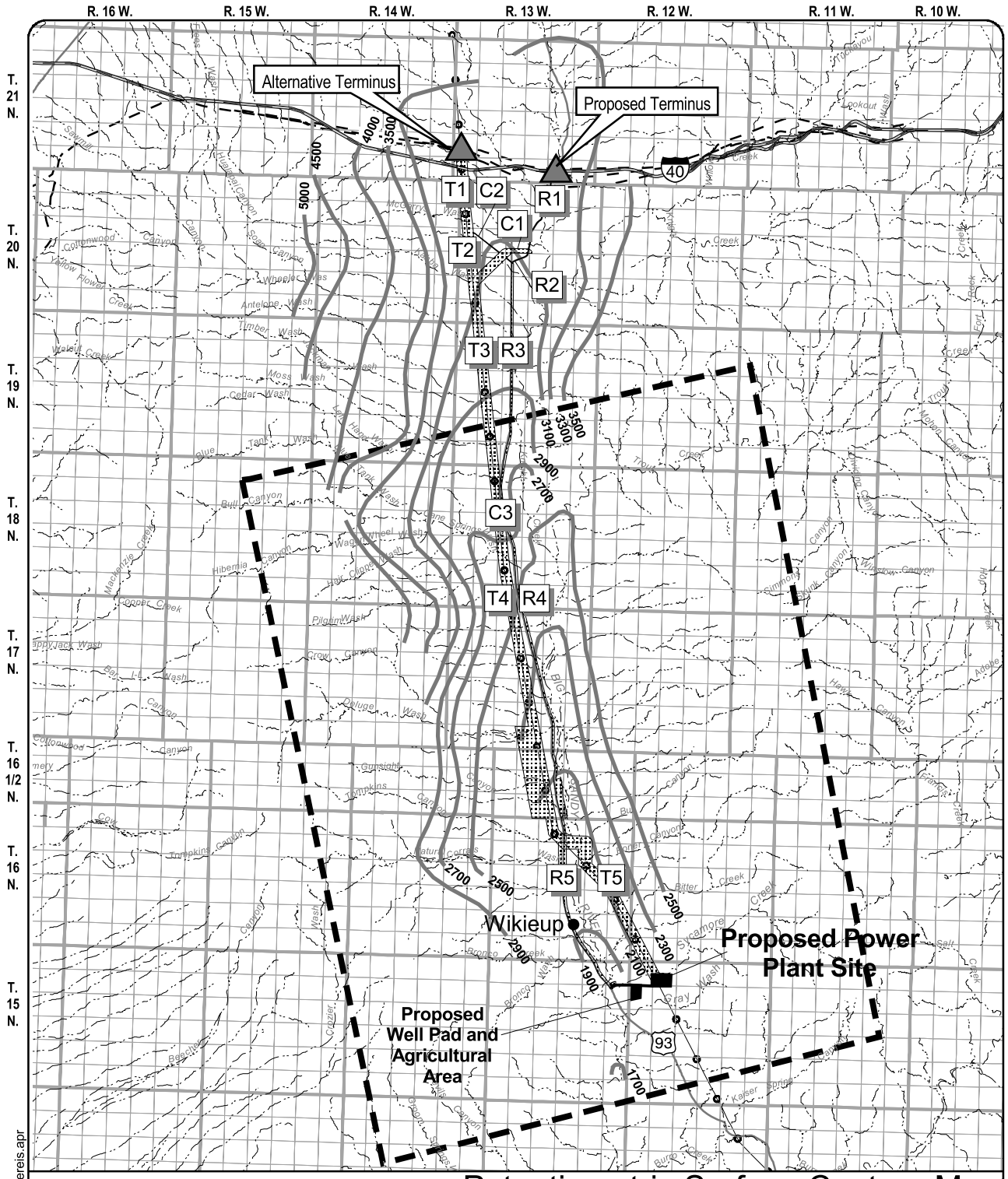
Water Budget

A water budget for the Big Sandy basin was developed to evaluate the relative significance of various sources of groundwater inflow and outflow under current conditions, and to assist in developing a conceptual model of the basin. The water budget is presented in detail in the *Big Sandy Energy Project Groundwater Technical Report* provided in Appendix F, and is summarized in Table 3.4-1.

Sources of Inflow

Sources of inflow (recharge) to the Big Sandy basin can be classified as either incidental recharge or natural 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* (U.S. Geological Survey [USGS] 2000). The total estimated annual recharge from agricultural irrigation, livestock watering, and domestic use in 1990 was 112 acre-feet (ac-ft), or 0.4 percent of the total basin inflow. Natural recharge includes mountain front recharge, stream channel recharge, recharge from direct

TABLE 3.4-1 WATER BUDGET			
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.



Legend

Resource Components
- Water Level Measured between 1959-1970 (ft msl)
- Model Boundary

Project Components
- Pipeline Corridor Segments
- Proposed Pipeline Corridor - R1, C1, T3, C3, T4,R5
- Alternative R Corridor - R1, R2, R3, C3, R4, R5
- Alternative T Corridor - T1, T2 T3, C3, T4, T5

General Reference
- Existing Pipelines
- Mead-Liberty/Mead-PhoenixTransmission Lines
- Stream/River
- Interstate
- U.S. Route

Potentiometric Surface Contour Map of the Upper Aquifer (1959-1970)

Big Sandy Energy Project EIS

0 5
Scale in Miles

Universal Transverse Mercator Projection
1927 North American Datum
Zone 12

N

Figure 3.4-2

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precipitation, and groundwater underflow from the Hackberry Sub-Area. Natural recharge is 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, assuming the basin is currently in steady state (inflow = outflow). The calculated value for natural recharge obtained using this approach is 26,194 ac-ft per year (ac-ft/yr), or 99.6 percent of total basin inflow.

Sources of Outflow

Sources of outflow (discharge) include groundwater pumpage, evapotranspiration, evaporation and evapotranspiration at the marsh south of Banegas Ranch, Cofer Hot Spring flow, consumptive use of surface water for irrigation, and outflow at Granite Gorge.

Groundwater pumpage includes pumping 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). The total estimated annual pumpage in 1990 was 2,263 ac-ft, or 8.6 percent of the total basin outflow. Most of the groundwater pumped (2,005 ac-ft) was used to supply water to the Phelps Dodge Bagdad Mine. All of the groundwater currently pumped in the basin is withdrawn from the upper aquifer (refer to the Hydrogeologic Units section below), or from shallow flow systems disconnected from the main valley groundwater flow, with most of the wells located in the floodplain of the Big Sandy River.

Evapotranspiration for this water budget refers solely to water use by riparian vegetation. 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 in the vicinity and south of Wikieup. The riparian vegetation is primarily a mix of mesquite and saltcedar, with small amounts of cottonwood.

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, and applying an average consumptive use factor based on the relative percentages of riparian plant types. 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.

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.

The amount of water discharged from Cofer Hot Spring was estimated to be 290 ac-ft/yr, or about 1.1 percent of the total basin outflow.

Surface water for agricultural irrigation is supplied to 53 acres of farmland on the Banegas Ranch from the perennial reach of the Big Sandy River through an upstream diversion structure. The land has been used to grow a 50:50 mixture of alfalfa and bermuda grass and fruit and nut trees. The annual consumptive use of surface water for irrigation at the 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 enumerated because their water consumption is minimal.

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 Summary

The water budget for the Big Sandy basin is presented in Table 3.4-1. The water budget was balanced assuming that the basin currently is in steady state, and that there is no change in storage. This assumption is supported by water level data from six water level "index wells" measured by the Arizona Department of Water Resources (ADWR) annually. The water level data from these wells, which originate from as early as 1944, show no long-term changes in water level elevations (ADWR 2000).

The principal observations that can be made based on the water budget are as follows:

- The largest source of inflow to the basin is natural recharge.
- The largest source of outflow from the basin is evapotranspiration.
- The water budget presented in this section is for current conditions, and is based on the assumption that the basin is in steady state. Groundwater pumping at the maximum rate to support the Proposed Action (3,000 gpm) would result in a groundwater overdraft of approximately 4,850 ac-ft/yr.

Hydrogeologic Units

Subsurface lithologic data obtained from groundwater exploration drilling on the Project site (Caithness 2000a, 2000b), and from earlier uranium exploration drilling by the U.S. Department of Energy (DOE) (Lease 1981), indicate that there are five hydrogeologic units in the southernmost part of the Big Sandy basin. In ascending order, these five units are as follows:

- arkosic gravel unit
- volcanic lower aquifer, which is confined by an overlying aquitard and is under a substantial amount of artesian pressure
- middle aquifer composed of conglomerate (lower basin fill) and which is also confined
- lacustrine deposit (also known as the "lakebed clay" portion of the lower basin fill) which serves as an aquitard to the middle aquifer
- upper aquifer (upper basin fill) which includes the recent alluvial deposits of the Big Sandy River

Detailed lithologic descriptions of these units are provided by the lithologic logs in the geology and water resources reports submitted by Caithness (2000a, 2000b).

Although almost all of the subsurface data are concentrated in the vicinity of the proposed power plant site, the areal extents of these units were extrapolated using subsurface lithologic data from six deep exploration wells logged by

DOE (Lease 1981). Figure 3.4-3 shows the estimated areal extent of the lacustrine deposit and the volcanic lower aquifer. The spatial relationships among the five hydrogeologic units and the granitic bedrock are depicted on Figure 3.4-4, and are further depicted and discussed in the groundwater technical report in Appendix F (URS 2001).

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 (refer to Figure 3.4-1). 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 (refer to Figure 3.4-1). The middle aquifer probably grades laterally into other units throughout the basin.

The areal extent and thickness of the lower aquifer are not known, although estimates of its extent and thickness have been made through evaluation of subsurface data. This volcanic unit is connected to the volcanic mass that composes the southern portion of the Aquarius Cliffs, which appears to be the source of the volcanic material and is restricted to the southernmost portion of the Big Sandy basin (refer to Figure 3.4-1). 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.

Groundwater Quality

Groundwater in the upper aquifer and spring water within the Big Sandy basin generally are of good chemical quality, based on data published by ADWR (Cady 1981). Although total dissolved solids (TDS) concentrations in water samples from wells and springs range from approximately 280 to as high as 1,800 milligrams per liter (mg/L), TDS concentrations in almost all wells in the basin are less than 500 mg/L.

Fluoride concentrations in water samples from upper aquifer wells and springs range from approximately 0.2 to 20.0 mg/L; however, most fluoride concentrations are less than the Arizona numeric aquifer water quality standard (AWQS) of 4.0 mg/L. With the exception of fluoride, there are no known chemical constituents present at concentrations above numeric AWQS (Cady 1981).

Groundwater analytical results from well OW4, completed in the lower aquifer, indicate a TDS concentration of 746 mg/L. Concentrations of all chemical constituents, with the exception of arsenic and fluoride, were below numeric AWQS (Caithness 2000b).

Proposed Groundwater Development

Caithness intends to supply water for the power plant and other uses by developing the groundwater resources of the volcanic lower aquifer. Until Caithness began exploring the development potential of this aquifer, its identity as a discrete aquifer had not been recognized and its groundwater production potential was unknown. As of this date, no production wells other than those developed by Caithness have been completed in the lower aquifer.

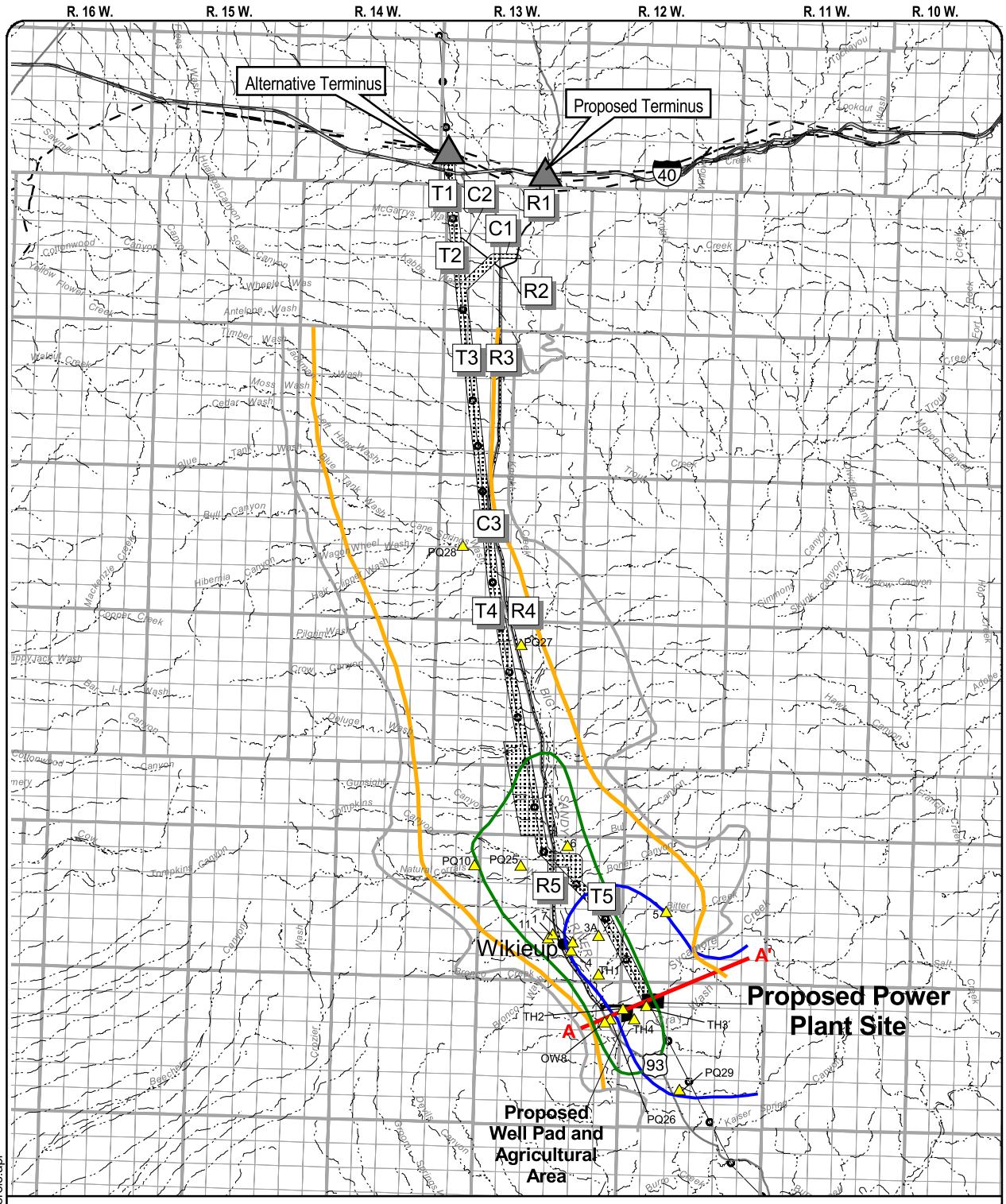
Caithness has installed one groundwater production well and three observation wells in the lower aquifer, one observation well in the middle aquifer, and three observation wells in the upper aquifer. Current plans call for the installation of three additional production wells in the lower aquifer to provide a maximum of 3,000 gallons per minute (gpm) (4,850 acre-feet per year) to supply the proposed power plant. Well locations in the vicinity of the proposed power plant site are shown on Figure 3.4-5 and are listed in Table 3.4-2.

- One lower aquifer production well completed to date (PW-2) has a shut-in pressure of 39 pounds per square inch (psi), which is equivalent to approximately 100 feet of pressure head.

TABLE 3.4-2
WELLS IN THE VICINITY OF THE PROPOSED POWER PLANT SITE

Well ID	Well Site	Well Location	Well Type	Aquifer	Depth (ft)	Screened Interval (ft)	Casing Diameter (in)	Water Level (ft bgs)	Flow/ Pressure (gpm/psi)
Upper Aquifer Wells									
OW1	Site 1	(B-16-13) 36ccc	PZ	U	150	20 – 150	5	12	
OW7	Site 7	(B-15-13) 1ccc	PZ	U	190	20 – 190	3	Dry	
OW8	Site 8	(B-15-13) 12caa	PZ	U	150	90 – 150	5	64	
Banegas Well	---	(B-15-13) 13abc	PR	U	105	85 – 105		20	
Harris Well	---	(B-15-13) 13dbb	PR	U	<200	Unknown	8	40	
Denton Well	---	(B-15-13) 24bdd	PR	U	100	Unknown		42	
Salazar Well	**---**	**(B-16-13) 35dda**	PR	U					
Middle Aquifer Wells									
OWMA2	Site 2	(B-15-12) 7bbb	PZ	M	730	540 - 693	3	85	
Lower Aquifer Wells									
PW2	Site 2	(B-15-12) 7bbb	PR	L	1,500	1,120 - 1,488	20	Flowing	
OW2	Site 2	(B-15-12) 7bbb	PZ	L	1,600				
OW3	Site 3	(B-15-12) 5ccc	PZ	L	1,200	578 - 1,180	12	16	
OW4	Site 4	(B-15-12) 7bdd	PZ	L	1,500	1,070 - 1,500	3	Flowing	125/29
Lower Aquifer Wells (Planned)									
PW4	Site 4	(B-15-12) 7bdd	PR	L	1,600	1,400 - 1,600	20	Flowing	
PW5	Site 5	(B-15-12) 7baa	PR	L	1,500	1,100 - 1,500	20	Flowing	
PW6	Site 6	(B-15-12) 7ccc	PR	L	1,500	1,100 - 1,500	20	Flowing	
Exploration Test Holes									
Test Hole #1	Site 1	(B-16-13) 36cbc	EX	M	700	None	None	Plugged	
Test Hole #2	Site 2	(B-15-12) 7bbb	EX	L	1,155	None	None	Plugged	125/NA
Test Hole #3	Site 3	(B-15-12) 5ccc	EX	M	780	None	None	Plugged	
Test Hole #4	Site 4	(B-15-12) 7bdd	EX	M	1,200	None	None	Plugged	140/NA

U = Upper Aquifer PR = Production Well
M = Middle Aquifer PZ = Piezometer
L = Lower Aquifer EX = Exploration Test Hole
NF = Non-flowing Water Table



Legend

Resource Components

- A — A' Geologic Cross Section
- Boring
- Lakebed Clays
- Volcanic Aquifer
- Arkosic Gravels
- Model Boundary

Project Components

- Pipeline Corridor Segments
  - Proposed Pipeline Corridor - R1, C1, T3, C3, T4,R5
  - Alternative R Corridor - R1, R2, R3, C3, R4, R5
  - Alternative T Corridor - T1, T2 T3, C3, T4, T5

General Reference

- Existing Pipelines
- Mead-Liberty/Mead-PhoenixTransmission Lines
- Stream/River
- Interstate
- U.S. Route

Extent of Geologic Units and Cross Section Locations

Big Sandy Energy Project EIS

0 5

Scale in Miles

Universal Transverse Mercator Projection
1927 North American Datum
Zone 12

N

Figure 3.4-3

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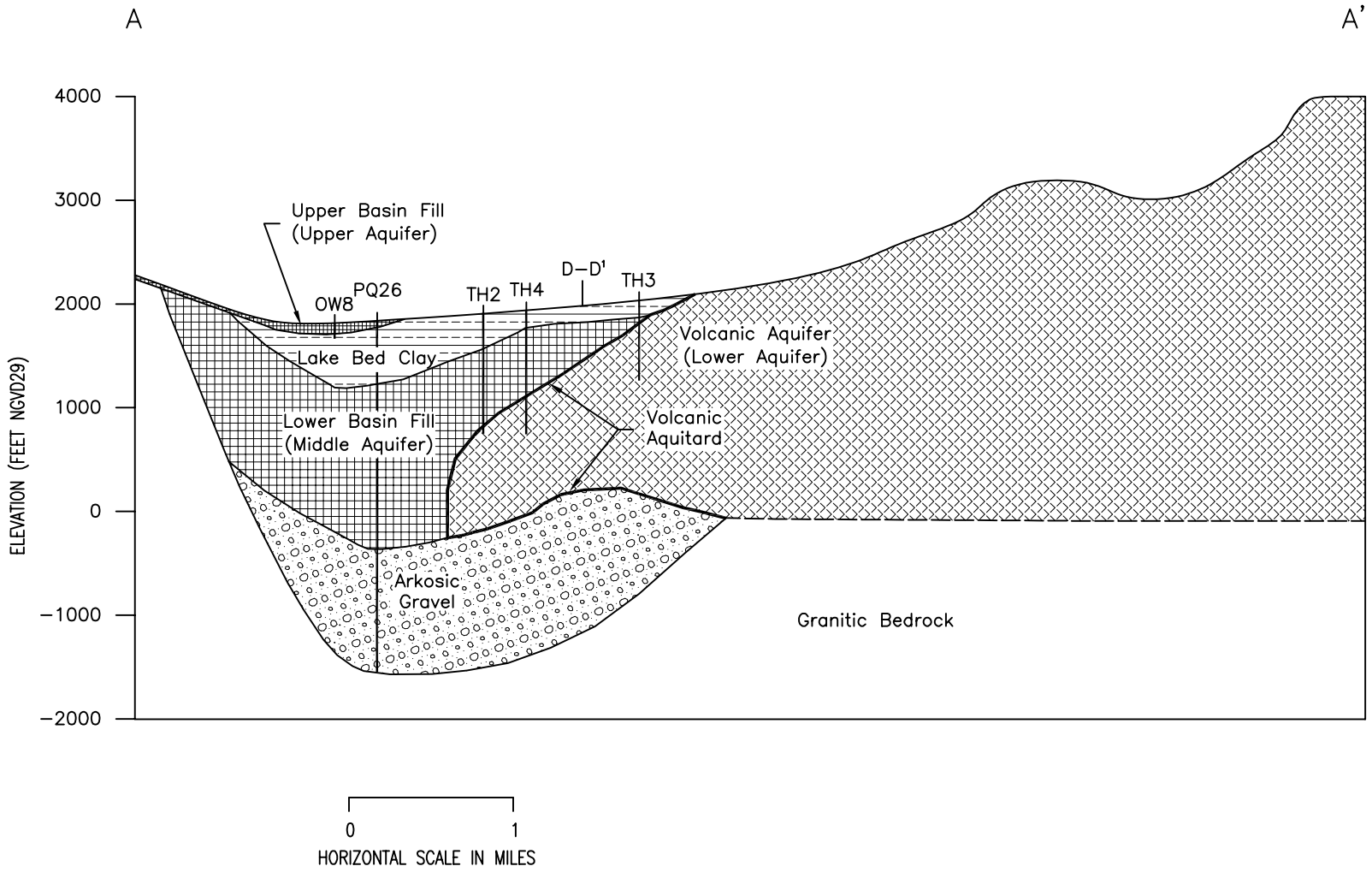
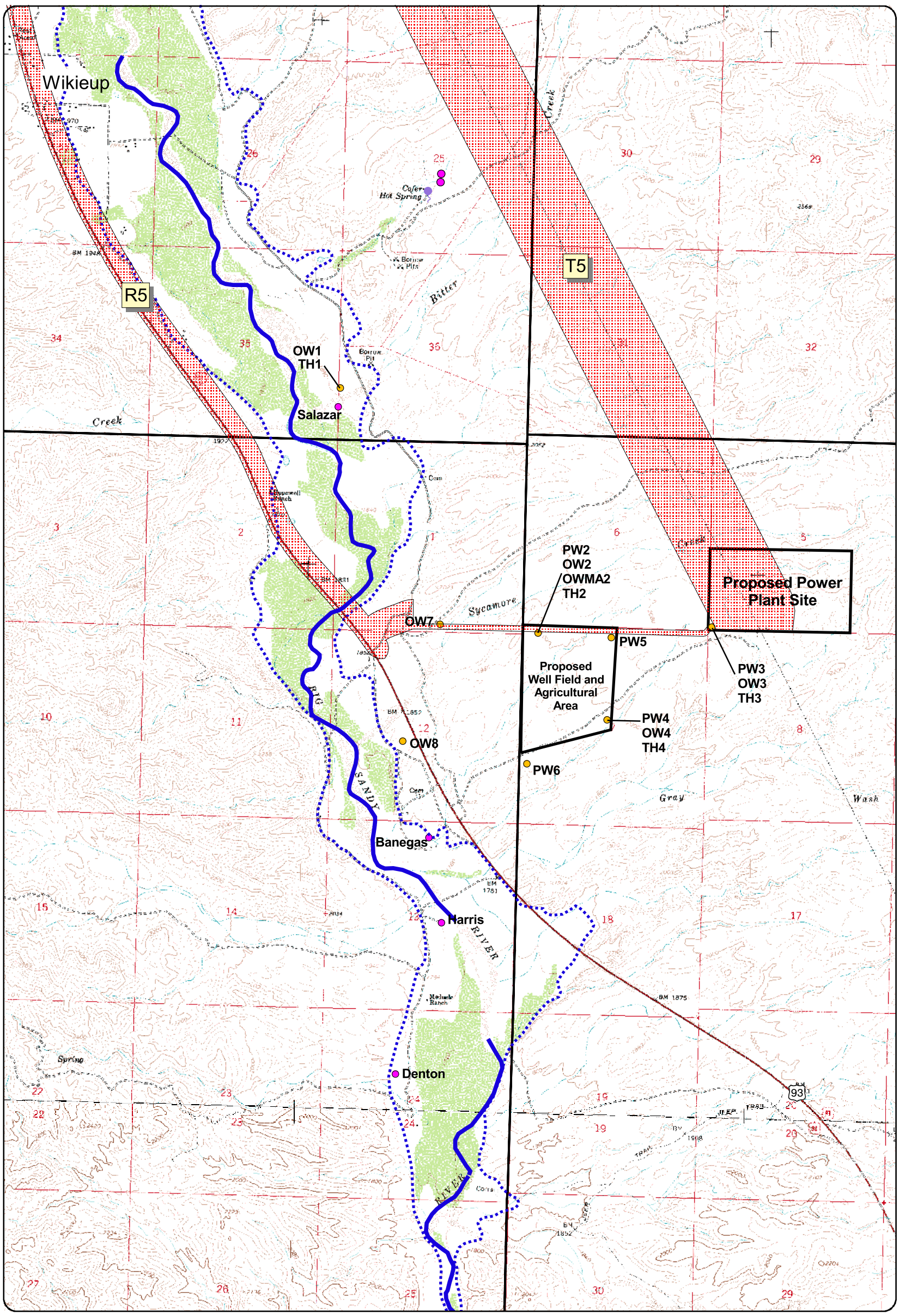


Geologic Cross Section
A - A'

Big Sandy Energy Project EIS

Figure 3.4-4



Legend

Resource Components
- Wells and Test Holes Completed by Caithness
- Other Wells
- Springs
- Approximate Limit of Big Sandy River Alluvium
- Approximate Extent of Perennial Flow in the Big Sandy River Under Base-Flow conditions

Project Components
- Pipeline Corridor Segments
  - Proposed Pipeline Corridor - R1, C1, T3, C3, T4,R5
  - Alternative R Corridor - R1, R2, R3, C3, R4, R5
  - Alternative T Corridor - T1, T2 T3, C3, T4, T5

0 0.5 1
Scale in Miles

Universal Transverse Mercator Projection
1927 North American Datum
Zone 12

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Wells in the Vicinity of the Project Site

Big Sandy Energy Project EIS

Figure 3.4-5

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The well flows artesian at 760 gpm, and is capable of producing groundwater at approximately 2,100 gpm. Available information suggests that the lower aquifer is at least 500 feet thick in the vicinity of the proposed power plant site (Caithness 2000) and has an estimated areal extent of 25 to 80 square miles (Appendix D).

3.4.2 Environmental Consequences

The following sections outline the environmental issues related to groundwater, significance criteria used to assess impacts, and methodology and conclusions of the impact assessment. Also described are various mitigation measures that may be considered if ongoing groundwater level monitoring indicates that groundwater pumping to supply the Project is significantly impacting groundwater levels in the upper aquifer, or the quantity of water discharged from springs.

3.4.2.1 Identification of Issues

The following is a list of identified issues that relate to groundwater. These identified issues form the basis for the assessment of potential impacts:

- Potential impacts on groundwater levels in the upper aquifer sufficient to impact users of groundwater in the upper aquifer.
- Potential impacts on groundwater levels in the upper aquifer sufficient to impact surface water flow in the Big Sandy River (also refer to Section 3.5).
- Potential impacts on the quantity of water discharged from springs and seeps.

Potential impacts on groundwater quality due to discharge of pollutants to the vadose zone from the evaporation pond or any other activities related to the Proposed Action.

3.4.2.2 Significance Criteria

Listed below are the significance criteria that have been established for the identified issues. Impacts would be considered significant if they would result in the following:

- Groundwater pumping of the lower aquifer to supply the Project would result in additional drawdown greater than 10 feet over any 5-year period in a neighboring well of record in the upper aquifer. The significance of 10 feet over 5 years is based on ADWR well spacing requirements.
- Groundwater pumping of the lower aquifer to supply the Project would result in any reduction of surface water flows in the Big Sandy River (also refer to Section 3.5, Surface Water).
- Groundwater pumping of the lower aquifer to supply the Project would result in any reduction in the quantity of water discharged from springs and seeps.
- Discharge of pollutants to the vadose zone from the evaporation pond or any other activities related to the Proposed Action would result in substantial degradation of groundwater quality.

3.4.2.3 Impact Assessment Methods

The impact assessment methods for this Project were developed by the Big Sandy EIS hydrology team (see inset). An effort was made to achieve consensus among the team members during the development of the impact assessment methods and at every ensuing stage of the Project.

The following tasks were performed to assess potential impacts on groundwater resources within the region of influence:

- Data Compilation and Evaluation – Available information was compiled and evaluated related to the hydrogeology and

groundwater resources of the Big Sandy basin, with emphasis on the southern portion of the basin and the proposed groundwater production wellfield. This task included review of all relevant reports prepared by the proponent and its consultants. The objectives of this task were to independently evaluate and verify the accuracy and comprehensiveness of information provided by the proponent, and, where necessary, supplement this information. As part of this process, numerous meetings and conference calls were held among the various Project participants to discuss the ongoing data evaluation, field activities, and groundwater modeling.

- Aquifer Testing – An 11-day, constant-discharge aquifer test of one of the planned groundwater production wells (PW2) was performed by Caithness to obtain data on the hydraulic properties and sustainable yield of the lower aquifer, and to observe any impacts on groundwater levels in wells completed in the upper and middle aquifers. Aquifer test methods and preliminary results are described in the Caithness water resources report (Caithness 2000). Aquifer test data and results are discussed in detail in a subsequent report based on an independent review of the data (David Schafer & Associates 2000). A copy of this independent report is provided in Appendix D. Aquifer test methods and results are summarized in this section.

- Stable Isotope Sampling and Analysis – Twelve samples of groundwater and spring water were collected from various sources and analyzed for stable isotopes of oxygen and hydrogen. Stable isotope sampling and analysis methods and results are summarized in this section, and are described in detail in two URS technical memoranda provided in Appendix E (URS 2000a; 2000b).

Big Sandy EIS Hydrology Team

The Big Sandy EIS hydrology team was an ad hoc working group of hydrologists and other resource specialists that was assembled at the beginning of the Project at the direction of BLM and Western. The team consisted of representatives from the various cooperating agencies and their consultants, as well as from Caithness and its consultants. The team included participants from BLM, Western, USFWS, ADWR, the Hualapai Tribe, URS Corporation, David Schafer & Associates, Caithness, Greystone Consultants, and Manera, Inc.

The purpose of the hydrology team was to provide peer review of ongoing work by Caithness, and to develop a scope of work and provide peer review for the impact assessment. This process consisted of an initial team meeting in July 2000, during which the proposed impact assessment methods were developed, followed by numerous conference calls over the following eight months to review the progress at various stages.

The hydrology team initially Caithness' proposed plan for the 11-day aquifer test, then reviewed the aquifer test results and report. The team reviewed the approach proposed for isotope sampling and analysis, and the results of the study. The team also developed an overall approach for the development of the groundwater flow model, then reviewed the results of the model analysis throughout the modeling process. An effort was made to achieve consensus among the team members during the review of Caithness' scope of work, development of the impact assessment methods, and analysis of the data.

- Groundwater Modeling – A groundwater flow model of the southern portion of the Big Sandy basin was developed as part of the groundwater resources assessment. The purpose of the modeling effort was to create an understandable and technically sound groundwater flow model adequate for use in evaluating the long-term potential impact of the proposed Project on the groundwater and surface water resources of the Big Sandy basin. The USGS model MODFLOW, as embedded in Visual MODFLOW®, was used for the analysis. The groundwater flow

model is described in detail in the groundwater technical report in Appendix F (URS 2001), and is summarized in this section. The results of the model analysis are presented as part of the impact assessment (Section 3.4.2.5).

- Impact Assessment – The groundwater modeling results were used to assess potential direct, indirect, and cumulative impacts on groundwater levels in the upper and middle aquifers, and on the quantity of water discharged from springs and seeps. The proposed evaporation ponds and other potentially discharging activities were reviewed to assess the potential impacts on groundwater quality. Particular consideration was given to the identified issues, and the significance criteria described in Section 3.4.2.2 were used to assess whether significant impacts potentially could occur.

Aquifer Testing

An 11-day, constant-discharge aquifer test was performed on production well PW2 to characterize the hydraulic properties of the aquifer, assess its suitability as a source of water for the proposed power plant, and evaluate the hydraulic connection between the lower, middle, and upper aquifers. The results of the test were used to assist in the development of the groundwater flow model. The test was designed and conducted by Caithness, with the concurrence of the EIS hydrology team.

A detailed description of the aquifer test, and an initial evaluation of the aquifer test data, were included in the Caithness water resources report (Caithness 2000b). A complete analysis of the data was performed by David Schafer & Associates and was presented in a subsequent report (David Schafer & Associates 2000; Appendix D).

Aquifer testing initially consisted of a step-drawdown test. The test was performed at four discrete pumping rates, beginning with the artesian flow rate of 760 gpm, and followed by increasing flow rates of 1,204, 1,800, and 2,100 gpm, respectively. Based on the results of the step-discharge test, a pumping rate of 2,000 gpm was selected for the constant-discharge test.

The constant-discharge aquifer test was initiated on September 11, 2000, and continued for approximately 11 days. The initial pumping rate of 2,000 gpm declined to about 1,950 gpm by the end of the test, for an average pumping rate of 1,960 gpm. After cessation of pumping, water level recovery was monitored for approximately 10 days.

Water levels were measured in the pumping well (PW2) and the three lower aquifer observation wells (OW2, OW3, and OW4). Water levels also were measured in the middle aquifer observation well (OWMA2), and five wells completed in the upper aquifer (OW1, OW7, OW8, Banegas, and Harris). Well locations are shown on Figure 3.4-5.

The results of the constant-discharge test are summarized as follows:

- The water level in the pumping well declined 150.2 feet during pumping, and recovered to within 95 percent of static conditions within the first few minutes of recovery.

- Total drawdowns in the three lower aquifer observation wells were similar, ranging from 7.3 feet in the nearest well (OW2) to 6.8 feet in the most distant well (OW3).

- All three lower aquifer observation wells recovered slowly during the recovery period, and never recovered to more than 85 percent of static conditions during the 10-day recovery period.

- No changes were measured in the water levels in the middle and upper aquifer

observation wells in response to pumping of the lower aquifer during the test.

- There was a measurable decrease in the flow rate of Cofer Hot Spring during the test, indicating that this spring is hydraulically connected to the lower aquifer.

The following conclusions were drawn from the analysis of the constant-discharge aquifer test data (David Schafer & Associates 2000):

- The aquifer response to pumping exhibited the characteristics of both a porous medium and a fractured rock aquifer.

- The aquifer response was consistent with either a highly transmissive, porous medium, or a fractured aquifer with highly transmissive fractures and moderately transmissive blocks.

- Most of the pumping response reflected the effects of aquifer boundaries.

- The hydraulic response suggests an aquifer with an area of about 25 to 80 square miles.

- Linear drawdown response during pumping indicated that the cone of depression was fully developed throughout the extent of the aquifer.

- The data suggest that the lower aquifer is hydraulically separated from the middle and upper aquifers.

- The data suggest that if the arkosic gravel is laterally extensive, it is hydraulically separated from the lower aquifer.

- The aquifer test results are limited in that it was not feasible to run the test for a length of time sufficient to simulate operating conditions. In spite of this limitation, the aquifer test was critical in providing estimates of aquifer transmissivity and storativity for the groundwater flow model, confirming the extent of the volcanic aquifer, and refining the conceptual model of the southern portion of the Big Sandy basin.

Stable Isotope Sampling and Analysis

As part of the groundwater resource evaluation, samples of groundwater and spring water were collected from various sources and analyzed for stable isotopes of oxygen and hydrogen. The objectives of stable isotope sampling and analysis were to accomplish the following:

- assess the source(s) of recharge to the lower aquifer

- evaluate whether the upper, middle, and lower aquifers have distinct isotopic signatures, and are thus hydraulically disconnected

The stable isotopic composition of water (surface water or groundwater) depends on the characteristics of the water's source area and the effects of physical processes such as evaporation and mixing with other waters. If the aquifers in the Big Sandy basin (upper, middle, and lower) have different recharge sources and are hydraulically disconnected, it is conceivable that they would have different stable isotopic compositions. In addition, stable isotopes can be used to identify the recharge area for an aquifer. The information gained from stable isotope analysis was valuable to the assessment of impacts on groundwater resources because it contributed to the understanding of the basin hydrogeology and assisted in the development of the conceptual groundwater model.

Sample Locations

Groundwater samples were collected from five wells, including two upper aquifer wells (OW-7 and OW-8), one middle aquifer well (OWMA-2), and two lower aquifer wells (PW-2 and OW-4). Samples also were collected from Cofer Hot Spring, a seep along Sycamore Creek, three

springs in the Aquarius Cliffs (Arrowweed, Deer, and Halo), and two springs in the Hualapai Mountains (Wild Cow and Chappo). Thus, a total of five groundwater samples and seven spring water samples were collected and analyzed for oxygen and hydrogen stable isotopes.

Results and Conclusions

Complete results of stable isotope sampling and analysis, including data and graphs, are presented in two technical memoranda provided in Appendix E (URS 2000a; 2000b).

The primary conclusions drawn from the analysis are as follows:

- The Aquarius Cliffs to the east of the proposed power plant site are likely the primary recharge source to the lower aquifer. This conclusion was made based on the similar stable isotopic compositions of the lower aquifer groundwater samples and the samples collected from springs located in the Aquarius Cliffs. This conclusion also was supported by the dissimilar isotopic compositions of the lower aquifer groundwater samples and those collected from springs located in the Hualapai Mountains.

- The upper, middle, and lower aquifers generally have distinguishable stable isotopic compositions. This suggests that they may have distinguishable recharge sources and supports conclusions made from test hole drilling and aquifer testing that the aquifers are hydraulically disconnected.

- The lower aquifer is the source for Cofer Hot Spring. This conclusion was made based on similar stable isotopic compositions of the lower aquifer groundwater samples and Cofer Hot Spring, and supports findings from aquifer testing.

Groundwater Modeling

A groundwater flow model of the southern portion of the Big Sandy basin was developed to provide a technically defensible tool for use in evaluating the long-term potential impacts of the Proposed Action on the groundwater and surface water resources of the Big Sandy basin. The groundwater flow model was based on the conceptual model of the area developed during the data evaluation, and was constructed using the USGS model MODFLOW, as embedded in Visual MODFLOW®.

The groundwater flow model was developed by URS with the concurrence of the EIS hydrology team. A detailed description of the model, including development, calibration, sensitivity analyses, and results of model simulations, is provided in the groundwater technical report in Appendix F (URS 2001). The groundwater model in summarized in this section.

Model Development

A three-dimensional, finite-difference groundwater flow model was constructed to represent the pumping and potentially impacted layers. The model domain encompasses the southern half of the Big Sandy basin as far south as Granite Gorge, and is defined on the east and west by the granite outcrops. The model domain extends from ground surface to the deepest part of the basin fill, 5,000 feet below ground surface.

The geology was simplified into the following seven-layer framework:

- upper basin fill (upper aquifer)
- lakebed clay (lacustrine deposit)
- lower basin fill (middle aquifer)
- aquitard above the volcanic aquifer
- volcanic (lower) aquifer

- aquitard below the volcanic aquifer
- arkosic gravel

The layers all overlie essentially impermeable granitic bedrock.

The model domain and boundary conditions are shown on Figure 3.4-6. The model grid consists of 62 columns, 85 rows, and seven layers, and covers an area of about 466 square miles. Recharge is distributed along the mountain fronts, and as infiltration in the permeable volcanic outcrops of the Aquarius Cliffs (Figure 3.4-7). Evapotranspiration was distributed by vegetation type along the Big Sandy River, with an assumed extinction depth of 50 feet; the locations of the pumping wells are those proposed by Caithness (Figure 3.4-8). The model boundary conditions include the following:

- no-flow boundaries at the margins of the basin and either side of Granite Gorge
- constant-head boundary at the northern edge of the model representing inflow of recharge from the northern part of the valley
- wall boundary around the outside edge of the volcanic aquifer to maintain artesian pressures in the aquifer
- drain at Cofer Hot Spring representing connection via a fault to the volcanic aquifer
- general head boundary at the marsh near the Denton well representing evaporative losses to surface water and groundwater
- general head boundary at Granite Gorge representing subsurface outflow via the gorge.

The following three additional simplifying assumptions were used in the model analysis:

- An aquitard exists as a skin around the volcanic aquifer. This assumption is consistent with the aquitard and artesian heads observed in the wells, and with the results of the aquifer test which indicate that the volcanic aquifer is hydraulically isolated from the middle and upper aquifers.
- The volcanic aquifer was assumed to be a uniform porous medium. This assumption was tested by analyzing long-term pumping data using both a porous medium model and a block and fracture model. The results of the analyses were almost identical.
- A uniform pumping rate was applied at the four proposed pumping well locations.

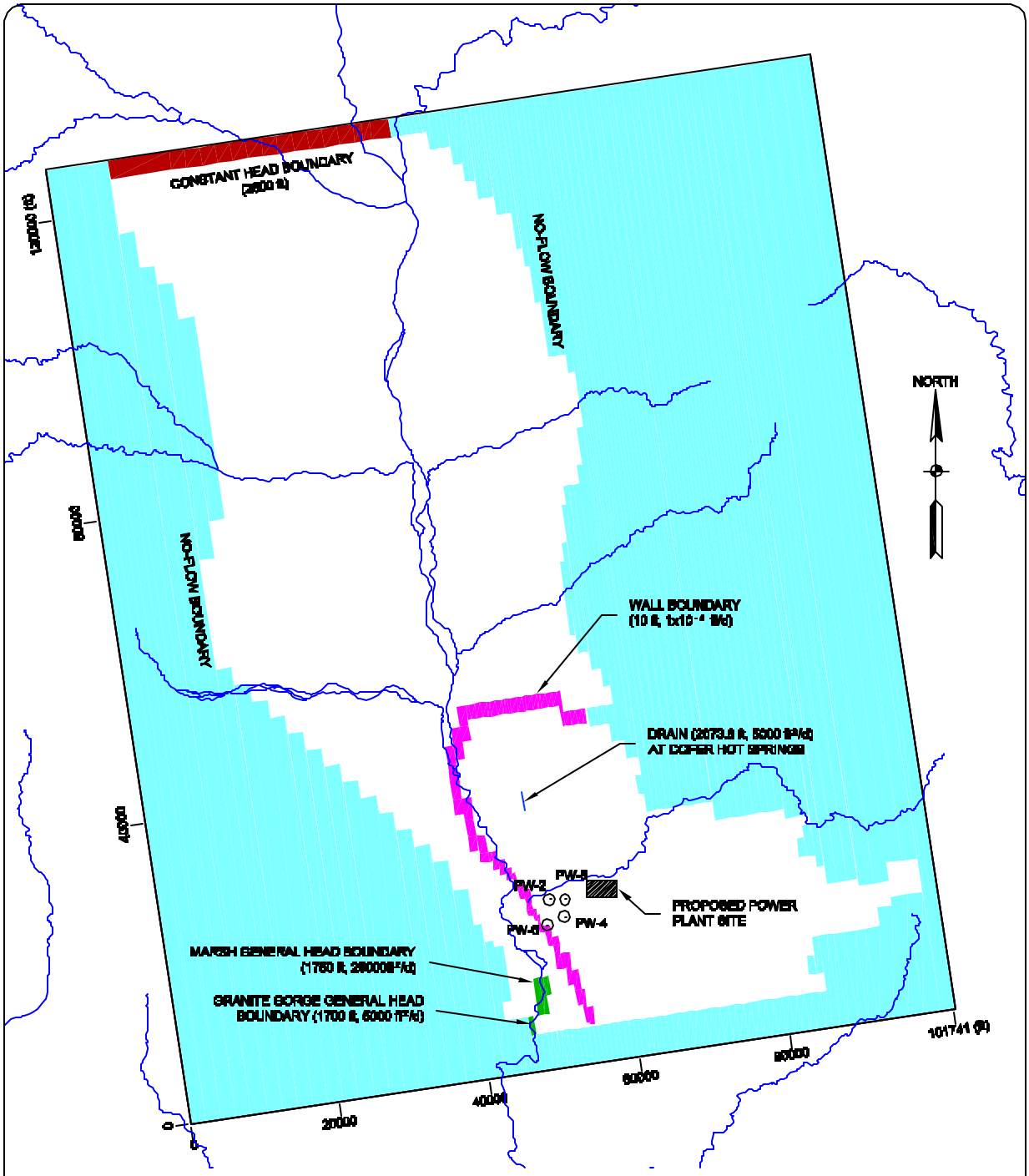
Model Calibration

Model calibration typically consists of the following steps:

- specify calibration criteria and protocol
- modify model assumptions and/or uncertain input data to obtain a realistic simulation
- evaluate the model predictions versus observations
- examine “calibrated” model output and evaluate the results

Steady State Calibration

The model was first calibrated to steady state conditions, followed by transient calibration. Steady state calibration was achieved by varying the hydraulic conductivities of the hydrogeologic units within reported ranges, and varying the infiltration rates such that the sum of the recharge was equivalent to about 5 percent of the precipitation rate, in a set of more than 50 test calculations. The mean error between predicted and observed heads was used to assess each subsequent run, and the best calibrated run



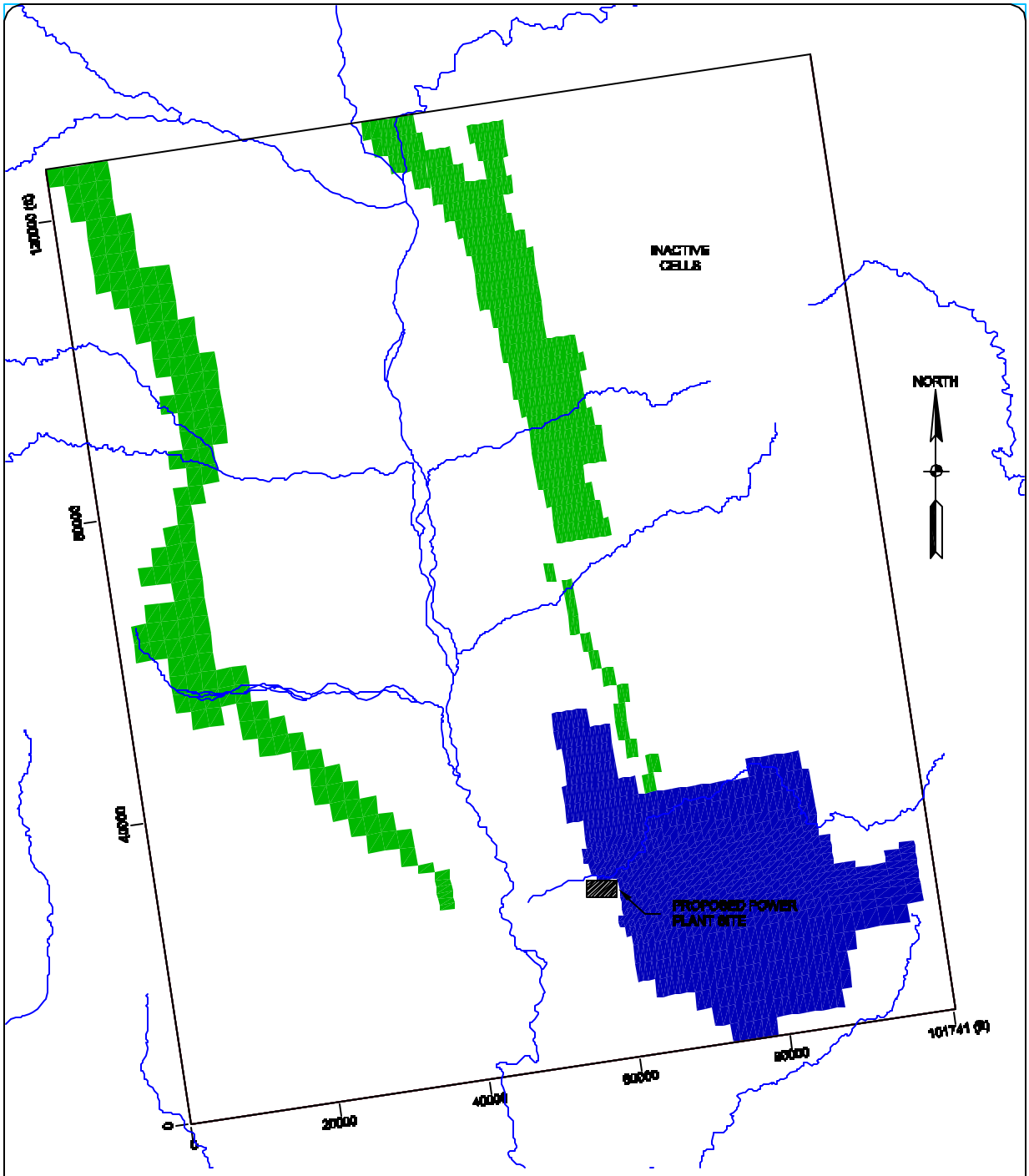
Model Domain and
Boundary Conditions

0 2 4
Scale in Miles

Big Sandy Energy Project EIS

Figure 3.4-6

X:BigSandy/Cad/eis/fig3.4-6.dwg



Legend

Recharge Rate

1.35 inches/year
(in Volcanic Aquifer Outcrop)

7.7 inches/year
(Mountain front recharge)

0 2 4
Scale in Miles

Distribution of Recharge

Big Sandy Energy Project EIS

Figure 3.4-7

X:BigSandy/Cad/eis/fig3.4-7.dwg