COMPUTER MODEL INTEGRATION: SALT RIVER VALLEY AND LOWER HASSAYAMPA SUB-BASIN NUMERICAL GROUNDWATER MODELS

Prepared for:
United States Bureau of Reclamation
West Salt River Valley CAP Contractors
(WESTCAPS)
January 29, 2010

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Brown and Caldwell Project #: 136286.400

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3D	three-dimenisonal
ADWR	Arizona Department of Water Resources
AFY	acre-feet per year
BCF	Block Centered Flow package
bls	below land surface
BOR	United States Bureau of Reclamation
BWCDD	Buckeye Water Conservation and Drainage District
CAP	Central Arizona Project
DEM	digital elevation model
ESRV	East Salt River Valley
ET	evapotranspiration
EVS	Environmental Visualization System®
ft/day	feet per day
ft^2/day	square feet per day
GIS	Geographic Information System
GWSI	ADWR's Grounwater Site Inventory Database
Kx	horizontal hydrualic conductivity
Kx:Kz	horizontal to vertical hydraulic conductivity ratio
Kz	vertical hydraulic conductivity
LAU	Lower Alluvial Unit
LHSB	Lower Hassayampa Sub-Basin
LPF	Layer Property Flow package
MAU	Middle Alluvial Unit
QC	quality control
REGID	Registry Identification
ROGR	ADWR's Registry of Groundwater Rights
Sc	storage coefficient
SRV	Salt River Valley
Ss	specific storage
Sy	specific yield
tr	transient data
UAU	Upper Alluvial Unit
USF	underground storage facility
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WESTCAPS Model	WESTCAPS Expansion Groundwater Model
WESTCAPS	West Valley CAP Subcontractors
WSRV	West Salt River Valley

1. PROJECT DESCRIPTION

1.1 Project Background

Identifying water demands and supplies for sustainable growth is critical for the continued development of cities in Arizona. To promote regional water resources planning, the West Valley CAP Subcontractors (WESTCAPS), a coalition of water providers in Western Maricopa County, Arizona, was formed in July 1997. WESTCAPS' mission is to develop workable alternatives for its members that emphasize Central Arizona Project (CAP) utilization and provide customers with a cost effective, sustainable, reliable, and high quality water supply through partnerships and cooperative efforts in regional water resource planning and management. Members of WESTCAPS include: Arizona American Water; City of Avondale; City of El Mirage; City of Goodyear; City of Peoria; City of Surprise; Global Water; and the Town of Buckeye. Planning partners assisting WESTCAPS include the Arizona Department of Water Resources (ADWR) and the United States Bureau of Reclamation (BOR).

WESTCAPS membership understands that groundwater will remain an integral source of supply in the western Salt River Valley (SRV) of central Arizona. A clear understanding of the regional trends in demand and availability of groundwater supplies will be a critical component of future water resources planning efforts. The first numerical groundwater flow model used for planning efforts in the WESTCAPS service areas was the SRV groundwater model, published by ADWR in 1982. This model has been updated several times to include new water demands and pumping rates, but there are geographic limitations to this model in the form of artificial, numerical boundaries, which describe the hydrogeologic connection to the Lower Hassayampa Sub-Basin (LHSB) along the northwestern and southwestern edges of the model domain (Figure 1).

The magnitude of projected groundwater development in the LHSB, located immediately west of the SRV groundwater basin, was the impetus for the creation of a second groundwater model covering the remaining service areas of WESTCAPS members. This groundwater model, termed the Lower Hassayampa Sub-Basin Groundwater Model (or LHSB model) was completed by Brown and Caldwell in 2006 and was subsequently provided to ADWR. This model also shares artificial boundaries with the SRV along its eastern borders (Figure 2). WESTCAPS recognized that the integration and seaming together of these two regional models would provide 1) a significantly improved understanding of groundwater reserves and water level trends in the western Salt River Valley (WSRV), and 2) an improved modeling tool to study and to plan for sustainable groundwater development for water providers in both the WSRV and LHSB.

In 2008, BOR authorized and funded Brown and Caldwell to conduct the initial phase of integration of the SRV and LHSB groundwater flow models as part of WESTCAPS planning work. This report summarizes the initial steps in the integration of these two models, discusses the preliminary findings, and highlights future steps needed to complete the development of the WESTCAPS Expansion Groundwater Model (WESTCAPS model), which will eventually be used to simulate water resources planning scenarios for WESTCAPS members.

1.2 Scope of Work

The Scope of Work presented herein is designed as the first phase of work to develop a spatially expanded regional groundwater flow model that meets the planning needs of WESTCAPS members and builds upon the extensive regional modeling work performed to date in the SRV and the LHSB. The ultimate goal of the project is to develop a single modeling tool that adequately simulates groundwater trends in all WESTCAPS member service areas. However, the work product presented in this report and completed in fulfillment of the Scope of Work should be considered to be the first step in a series that will culminate in the completion, calibration, and release of a groundwater modeling tool that encompasses the entire SRV and LHSB. The work product discussed herein is intended to both advance the development of this expanded model as well as guide future phases of model development and data collection.

1.2.1 Task 1.0 – Review of Updated SRV Model

Brown and Caldwell obtained a copy of the most recent SRV model, publicly released in April 2009, along with associated ADWR databases and Geographic Information System (GIS) data files. A model review was performed emphasizing general hydrogeologic conceptualization, numerical model construction, ADWR's simulation results, and model calibration. Although the entire model was reviewed, emphasis was placed on the model assumptions and results in the WSRV region. Brown and Caldwell developed additional GIS-compatible data sets and maps to support model review. All data provided to Brown and Caldwell was maintained in a GIS-compatible database structure that supports the spatial requirements of the modeling process.

1.2.2 Task 2.0 – Feasibility of Integrating the Updated SRV and LHSB Models

Brown and Caldwell reviewed the feasibility of integrating the updated SRV model and the LHSB model by running simulations with each model over their respective calibration time periods and comparing model results using standard MODFLOW output files and the project GIS. The assessment focused on identifying areas of agreement and variation between the two models with respect to water levels, hydraulic gradients, fluxes, model layering, hydraulic parameterization, and grid orientation in the vicinity of the areas where the domains of both models overlap. Additionally, the baseline simulation timeframe for the LHSB model was expanded to extend through 2006, the end of the baseline calibration simulation time period for the updated SRV groundwater model. This temporal adjustment to the LHSB model facilitated comparison of model simulation results as well as the integration of time-dependent model input data from both models.

1.2.3 Task 3.0 – Model Integration

Results from Tasks 1 and 2 were presented to WESTCAPS members on July 16, 2009 for discussion and decision on whether to proceed with Task 3.0(a) or Task 3.0(b) of the project Scope of Work (Appendix A). The results of the feasibility assessment (Task 2.0) guided the decision to either proceed with Task 3.0(a), digitally integrating the numerical framework and hydrologic stresses contained in the two models to create the framework of the WESTCAPS model, or revert to Task 3.0(b) and expand the model review process to identify specific model variables that would require additional investigation and modification prior to performing test simulations with a fully expanded model.

Following the presentation of the results of Tasks 1.0 and 2.0, WESTCAPS members decided that it was appropriate to proceed with Task 3.0(a). Brown and Caldwell subsequently integrated the numerical framework of both the SRV and LHSB models and performed several test simulations with the newly constructed WESTCAPS model to isolate remaining inconsistencies and identify recommended actions for the successful completion and calibration of the expanded model in the future. This assessment focused on model simulation results within the geographic regions where the pre-existing SRV and LHSB models overlap, but it was also broad enough to encompass the entire modeled region of the WESTCAPS model. This larger scale assessment allowed for the evaluation of overall indicators of model performance, such as regional water level trends and water budget components. Additionally, assessments of simulated water levels, groundwater flow gradients, and water budgets for the updated SRV, LHSB, and preliminary WESTCAPS models were performed.

1.2.4 Phase 4.0 – Documentation and Imagery

A summary of the results of Tasks 1.0 through 3.0 are documented in this report. Additionally, this report includes a discussion of the results of all test simulations that were performed (with all models), recommendations for future model development, and a list of data needs/data gaps identified during the course of the project.

Deliverables for the Scope of Work include: this report, associated model files and GIS-compatible datasets, and a series of three-dimensional (3D) model visualizations and animations constructed using Environmental Visualization System® (EVS) software. The 3D visualizations demonstrate model construction, hydrogeologic conceptualizations, and regional groundwater stresses. Digital copies of all deliverables are included in Appendix Z (DVD in pocket).

2. MODEL REVIEWS

2.1 Previous Modeling Efforts

Previous numerical groundwater modeling efforts in the SRV and LHSB have contributed substantially to the current conceptualization of groundwater resources and provided the framework for development of the preliminary WESTCAPS groundwater model. Studies of note include:

- Long, M.R., M.A. Niccoli, R. Hollander, and J.L. Watts, 1982. *Salt River Valley Cooperative Study Modeling Effort: A Comprehensive Study of Groundwater Conditions of the Salt River Valley Aquifer System and Description of Digital Groundwater Modeling Efforts by the ADWR*. June 1982.
- Corkhill, Edwin F., Steve Correll, Bradley M. Hill, and David A. Carr, 1993. *A Regional Groundwater Flow Model of the Salt River Valley – Phase I, Phoenix Active Management Area, Hydrogeologic Framework and Basic Data Report*. ADWR. Modeling Report No. 6. April, 1993.
- Corell, Steven W., and Edwin F. Corkhill, 1994. *A Regional Groundwater Flow Model of the Salt River Valley – Phase II, Phoenix Active Management Area, Numerical Model, Calibration, and Recommendations*. ADWR. Modeling Report No. 8. March, 1994.
- Bota, Lou, Phil Jahnke, and Dale Mason, 2004. *Technical Memorandum Re: SRV Model Calibration Update 1983 – 2002*. ADWR. December 1, 2004.
- Brown and Caldwell, 2006. *Lower Hassayampa Sub-Basin Hydrologic Study and Computer Model*. Prepared for the Town of Buckeye, Arizona. November 15, 2006.
- Freihoefer, Adam, Dale Mason, Philip Jahnke, Lisa Dubas, and Kade Hutchinson, 2009. *Regional Groundwater Flow Model of the Salt River Valley, Phoenix Active Management Area, Model Update and Calibration*. ADWR. Modeling Report No. 19. April 2009.

All but the 2006 study by Brown and Caldwell focused primarily on the SRV and the SRV groundwater flow model developed by ADWR. The development of the SRV model began in 1982 and has undergone four published updates to refine the model domain, expand the simulation time period, and improve the hydrogeologic conceptualization. The 2006 report by Brown and Caldwell documents the development of a conceptual hydrogeologic model and construction and calibration of a numerical groundwater flow model for the LHSB. The construction of the LHSB model also relied on previous studies and data sets for the neighboring and hydrologically connected SRV groundwater basin.

The publications listed above all provide a thorough description of the development, construction, and appropriate usage of these two modeling tools. The details of these studies will not be reiterated in this report; however, it is recommended that they be referenced and consulted for additional details regarding the work performed for this project.

2.1.1 Salt River Valley Groundwater Model

The SRV model, which has a spatial extent shown on Figure 1, has been maintained and advanced by ADWR since 1982 as a tool in developing comprehensive water management plans. It has undergone several updates since its initial development. The most recent update was released in April 2009 and included an extension of the simulation time frame through 2006, model domain expansion, grid refinement, and geologic and conceptual model refinement (Freihoefer et al., 2009).

The SRV model is a three-layer, finite-difference model based on the United States Geological Survey (USGS) code MODFLOW-2000 (Harbaugh et al., 2000). The active model domain of approximately 2,505 square miles is bounded by the White Tank Mountains to the west, the Superstition Mountains to the east, the Lake Pleasant area to the north, and the Santan Mountains to the south (Figure 1). The three model layers roughly correspond to regional hydrostratigraphic units termed the Upper Alluvial Unit (UAU), Middle Alluvial Unit (MAU), and the Lower Alluvial Unit (LAU) (Corkhill et al., 1993). The April 2009 update included a refinement of the uniform, model grid spacing from 1-mile square cells to 0.5-mile square cells, and a northern expansion of the model domain to cover the regional aquifer in the Lake Pleasant portion of the SRV. Lithologic logs were reviewed by ADWR staff and used to refine the conceptual geologic model, particularly in the WSRV (Freihoefer et al., 2009). The updated SRV model currently simulates from 1983 through 2006 in 24 annual stress periods. Additional detailed information regarding the conceptualization, construction, and historical development of the SRV model can be found in the above-listed references.

2.1.2 Lower Hassayampa Sub-Basin Groundwater Model

The LHSB model was developed by Brown and Caldwell in 2006 as a basin-scale tool for water resources management. Stakeholders involved in the project included landowners in various stages of the development process, the Town of Buckeye, and ADWR. Details on conceptualization, development, calibration, sensitivity, and subsequent predictive simulations are provided in the *Lower Hassayampa Sub-Basin Hydrologic Study and Computer Model* (Brown and Caldwell, 2006). The spatial extent of the active domain for the LHSB model is shown on Figure 2. It comprises an areal extent of approximately 880 square miles, extending from the Palo Verde Hills on the west to the White Tank Mountains on the east, and from the Vulture Mountains in the north to the Buckeye Hills and the Gila Bend Mountains in the south. The calibrated model simulation time period extends from the early 1900s through 2003.

The LHSB model was designed to be compatible with the SRV model (i.e., a three-layer MODFLOW-2000 model aligned with the SRV model grid), and was constructed to facilitate the future integration of its eastern boundaries with the then-current SRV model (Bota et al., 2006). However the 2009 SRV model update included changes to layering geometry, thus the eastern portions of the LHSB do not reflect any new layering refinements by ADWR. Additionally, the LHSB geologic conceptualization in portions of the model domain that overlaps with the SRV model was based on local lithologic logs as well as gravity survey data not used in previous versions of the SRV model. For these reasons, there are some differences in hydrogeologic conceptualization between the two models.

2.2 Importation of the SRV Model

The review of the SRV model included the inspection of model documentation, model files, GIS files, and the successful importation of the source input files. The review focused on the WSRV, which for the purposes of this study is defined as the portion of the SRV model that is west of the Union Hills, Phoenix Mountains, and South Mountain. SRV model documentation stated that the current SRV model simulates conditions more accurately in the eastern SRV (ESRV) than in the WSRV, an important consideration for future work. Additionally, Freihoefer et al. (2009) noted that large geologic data-deficient areas exist in the WSRV, particularly where the SRV groundwater basin connects and overlaps with the LHSB both north and south of the White Tank Mountains.

Brown and Caldwell received the updated SRV model files and geodatabase from ADWR on May 1, 2009 and began importing the source files into the MODFLOW pre- and post-processor, Groundwater Vistas (Environmental Simulations, Inc. [ESI] 2006). All model inputs and parameters underwent a quality control (QC) check to confirm that the data were imported correctly, including wells, recharge values, hydraulic conductivity, stream parameters, boundary conditions, storage, and evapotranspiration (ET). During this initial step, problems were noted with the importation and representation of the constant head, ET, and stream packages. Environmental Simulations subsequently released a patch that corrected these issues (Groundwater Vistas 5.34, Build 1).

After successfully importing and running the SRV model, the simulation results were inspected and compared against the source output files provided by ADWR. Table 2-1 presents a comparison of the simulated water budget components for the end of the final stress period of ADWR's SRV model (December 2006), with the simulation performed by Brown and Caldwell. The close agreement in 2006 water levels between the ADWR simulation and Brown and Caldwell's SRV model import is shown on Figure 3. The agreement between simulated water budget and water levels was deemed sufficient to assume that the SRV model was operating correctly within a standardized, GIS-compatible modeling environment.

Table 2-1. Water Budget Comparison for ADWR and Brown and Caldwell Simulations of the SRV Model

	ADWR SRV Model December 2006 (Stress Period 24)	Brown and Caldwell Import Model December 2006 (Stress Period 24)
	Inflows (AFY)	
Recharge	963,187	963,187
Stream Leakage	106,880	106,880
Storage	80,091	80,091
Wells	14,168	14,168
Constant Head	6,418	6,418
Total	1,170,744	1,170,744
	Outflows (AFY)	
ET	38,994	38,993
Stream Leakage	31,332	31,332
Storage	310,814	310,815
Wells	781,523	781,523
Constant Head	8,088	8,088
Total	1,170,751	1,170,751

AFY = acre-feet per year

2.3 Comparison of the SRV and LHSB Models

A comparison of the numerical model details for each of the groundwater models is presented in Table 2-2 with emphasis placed on the overlapping model areas. The location of both model domains and the overlap areas are shown on Figure 4. Both the LHSB and the SRV models were built using the MODFLOW-2000 code, with a consistent number of layers (and the generalized hydrostratigraphic units that they represent) and the same grid spacing interval. From Table 2-2, it is clear that layer discretization, flow packages, and simulation time periods vary significantly between the two models. Details on the model differences and the approach used to resolve these differences during model integration are discussed in the following sections.

Table 2-2. SRV and LHSB Model Detail Comparison

Model Component	Hassayampa Model	SRV Model
MODFLOW Packages	MODFLOW 2000, Basic, Layer Property Flow, Discretization, Zone, Output Control, Solver, Well, General Head, Stream, Recharge, ET	MODFLOW 2000, Basic, Block Centered Flow, Discretization, Output Control, Solver, Well, Constant Head, Stream, Recharge, ET
Model Projection	UTM, Zone 12, NAD 1927	UTM, Zone 12, HARN 1983
Cell Size	2,640 x 2,640 feet; uniform 0.5-mile cell spacing	2,640 x 2,640 feet; uniform 0.5-mile cell spacing
Layers	Layer 1 (UAU): LAYCON 1 Layer 2 (MAU): LAYCON 3 Layer 3 (LAU): LAYCON 3	Layer 1: LAYCON 1 Layer 2: LAYCON 3 Layer 3: LAYCON 3
Cell Types	Active, No-flow, Flux, Stream, General Head, Constant Head	Active, No-flow, Flux, Stream, Constant Head, Variable Head
Units	Time: Days Length: Feet	Time: Days Length: Feet
Boundary Conditions	General head boundary and specified flux with the WSRV	Constant head boundary and specified flux with the Hassayampa
Simulation Time	1900 through 2003	1983 through 2006
Stress periods	Variable (steady state, 1-year and 10- year); 5 Time steps each; 1.2 multiplier	Annual; 12 Time steps each; 1 and 1.05 multiplier
Solution Method	PCG	GMG or PCG
Hydraulic Conductivity (in overlap area)	Layer 1: 9 to 150 ft/day Layer 2: 1 to 100 ft/day Layer 3: 1 to 40 ft/day	Layer 1: 4 to 85 ft/day Layer 2: 1 to 60 ft/day Layer 3: 0.3 to 34 ft/day
Storage (in overlap area)	Ss Layer 1 = 0.1 to 0.2 ft^{-1} Ss Layer 2 = 1e-6 to 8e-5 ft^{-1} Ss Layer 3 = 1e-6 ft^{-1}	Sc Layer 1 = 0 Sc Layer 2 = 0.005 Sc Layer 3 = 0.005
Specific Yield (in overlap area)	Layer 1 = 0.1 to 0.2 Layer 2 = 0.05 to 0.15 Layer 3 = 0.05 to 0.1	Layer 1 = 0.09 to 0.2 Layer 2 = 0.05 to 0.11 Layer 3 = 0.05 to 0.11

2.3.1 Spatial Discretization and Layering

Both the SRV and LHSB models are discretized into 0.5-mile square cells and three layers with the top of Layer 1 being defined by a USGS digital elevation model of land surface (DEM). However, discrepancies in the elevations of the bottom of the layers in the overlap areas were identified. Using the project GIS, the difference in cell-specific layer elevations was calculated by subtracting SRV model layer bottom elevations from the corresponding values for the LHSB model. Results are summarized in Table 2-3 and presented on Figure 5. Although layering differences are apparent in all layers, the greatest elevation offsets are present at the base of Layer 3, and the greatest degree of agreement occurs along the base of Layer 1. The differences in Layer 3 are thought to be partially caused by variations in the assumed depths to bedrock in the deeper portions of the basins.

As seen on Figure 5, the smallest differences in model layering generally occur along the eastern boundaries of the LHSB model, as it was constructed using the layering information from the previous version of the SRV model. The LHSB model also relied on a 3D gravity model developed specifically for the project. These data were not incorporated into the SRV model but it is understood that an update to the SRV layering is currently being performed by ADWR. Additionally, the largest discrepancies in Layer 3 are found in the southern overlap area, where different geologic conceptualizations of the nature of a localized rock outcrop along the western edge of the overlap area are used. This difference in conceptualization produces significantly shallower depths to bedrock in the SRV model relative to the LHSB model, accounting for the large differences between Layer 3 elevations reflected in Table 2-3. In future phases of work, effort will be required to refine and unify the conceptualization of the hydrostratigraphic layers.

Table 2-3. Layer Elevation Comparison in the Overlap Area

	Range of Layer Elevation Differences* (feet)	Percent of Model Cells within ± 50 feet
North of the White Tank Mountains		
Bottom of Layer 1	-310 to 372	27
Bottom of Layer 2	-494 to 415	24
Bottom of Layer 3	-562 to 1,611	12
South of the White Tank Mountains		
Bottom of Layer 1	-237 to 152	77
Bottom of Layer 2	-728 to 520	22
Bottom of Layer 3	-2,201 to 1,070	15

** Positive value denotes the LHSB as higher than the SRV, and a negative value denotes the LHSB as lower than the SRV.*

The variations in assumed layer bottom elevations produces corresponding differences in total model thickness, which will be addressed during refinement of model layering in future phases of work. Note that each model also has slightly different active domain extents within the overlap areas. The distribution of active cells in the SRV model in the overlap areas is the same for all three layers; however, the LHSB model constrains the lateral extent of active cells in Layer 3. This difference in the spatial extent of model layers was taken into account when assessing elevation differences and was also considered when defining the lateral extent of WESTCAPS model layers in the overlap areas.

2.3.2 Temporal Discretization

Temporally, the two models simulate different time periods: the LHSB model begins in the early 1900s and ends in 2003, whereas the SRV model starts in 1983 and ends in 2006. The LHSB model is calibrated to assume steady state conditions from 1900 to 1930, as well as transient conditions through 2003. The SRV model simulates groundwater conditions from 1983 through 2006 using observed 1982 water levels as initial conditions. For the time period between 1984 and 2003, both models are set up with annual stress periods, meaning that boundary parameters and groundwater fluxes can only change on an annual basis.

2.3.3 Model Boundaries

The model overlap areas have a total areal extent of approximately 250 square miles divided approximately equally between the regions immediately north and south of the White Tank Mountains (Figure 4). Artificial boundaries were used in each model to represent the hydraulic connection to the neighboring basin. These artificial boundaries (shown on Figures 1 and 2) define the eastern and western bounds of the two overlap areas and are set as either constant head, specified flux, or general head boundaries. North of the White Tank Mountains, the SRV model simulates groundwater underflow from the LHSB as specified flux (Figure 1). South of the White Tank Mountains, the connection with the LHSB is simulated as constant head cells, which hold water levels at a set elevation but allow the amount of groundwater flux into or out of the SRV model to change over time. Boundary condition cells used in other regions of the SRV model domain are also shown on Figure 1.

During LHSB model development, simulated groundwater conditions within the SRV model domain were used to define reference heads for the general head boundary conditions (both north and south) to more accurately simulate the connection between the LHSB and the SRV groundwater basins north and south of the White Tank Mountains (Figure 2). This type of boundary condition establishes reference head values a set distance away from the boundary and allows both water levels and groundwater fluxes to vary over time at the LHSB model boundary cells. Boundary condition cells used in other regions of the LHSB model domain more distal to the WSRV are also shown on Figure 2.

2.3.4 Aquifer Hydraulic Properties

Aquifer parameter distributions in the two models were established using two different approaches. The LHSB model used a zoning approach where various regions of the aquifer were assigned consistent hydraulic parameters during calibration based upon spatially correlated hydrogeologic conditions and interpolation (i.e. kriging) of data from field testing. The SRV model used a matrix approach where variations in aquifer properties were applied on a cell by cell basis to optimize agreement with observed water levels. Table 2-4 presents a comparison of hydraulic conductivity values and storage parameters within the overlap areas. Figure 6 shows the spatial distribution of differences in hydraulic conductivities for the two model overlap areas. North of the White Tank Mountains, horizontal hydraulic conductivity (Kx) values from both models are comparable, with slightly lower values observed in the SRV model (note that both models assume horizontal isotropic conditions with Kx = Ky). South of the White Tank Mountains, there are greater differences in estimated Kx values, particularly along the course of the Gila River. In this region, the SRV model hydraulic conductivity estimates are significantly lower than those in the LHSB model, with differences in Kx values as great as 122 feet/day. Vertical anisotropy also differs between the models in Layers 2 and 3, with the SRV having a larger horizontal to vertical hydraulic conductivity ratio (Kx:Kz). The influence of these conductivity values upon groundwater elevations and underflow is discussed in Section 3.3.

The two models also differ in the simulation of anisotropy and storage: the LHSB model uses the Layer Property Flow (LPF) package, whereas the SRV model uses the Block Centered Flow (BCF) package from an older version of MODFLOW. The primary benefit of using the LPF package over the BCF package is the ability to explicitly assign parameters for the degree of vertical anisotropy between model layers. These two packages also differ in the requirements for confined aquifer storage parameters: the BCF package in the SRV model requires use of the storage coefficient parameter and the LPF package in the LHSB model requires the use of specific storage. However, estimated specific yield values (used for unconfined groundwater conditions) were defined in both models and are comparable across all three layers (Table 2-4).

Table 2-4. Aquifer Parameter Comparison in the Overlap Area

	LHSB K_x Range (ft/day)	SRV K_x Range (ft/day)	LHSB K_x:K_z Ratio	SRV K_x:K_z Ratio	LHSB Ss Range (ft^{-1})	SRV Sc Range	LHSB Sy Range	SRV Sy Range
North of the White Tank Mountains								
Layer 1	20 to 25	4 to 24	10:1	10:1	0.1	0	0.1	0.1
Layer 2	3 to 12	1 to 14	10:1	20:1	1e-6 to 5e-5	5e-3	0.07 to 0.1	0.05 to 0.1
Layer 3	3 to 10	0.3 to 9	10:1	12:1	1e-6	5e-3	0.05 to 0.1	0.05 to 0.1
South of the White Tank Mountains								
Layer 1	9 to 150	8 to 85	10:1	10:1	0.1 to 0.2	0	0.1 to 0.2	0.09 to 0.2
Layer 2	1 to 100	2 to 60	10:1	20:1	1e-6 to 8e-5	5e-3	0.05 to 0.15	0.05 to 0.11
Layer 3	1 to 40	3 to 34	10:1 or 8.8:1	12:1	1e-6	5e-3	0.06 to 0.1	0.06 to 0.11

K_x = Horizontal Hydraulic Conductivity
K_z = Vertical Hydraulic Conductivity
LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley
Sc = Storage Coefficient
Ss = Specific Storage
Sy = Specific Yield

2.3.5 Water Budget Components

Groundwater sources and sinks within both models include recharge, ET, groundwater pumping (wells), and leakage into and out of canals and streams. Figures 1 and 2 show the locations of model features that represent these water budget components for both the SRV and LHSB models.

Table 2-5 presents a comparison of the simulated water budget components for both models in 2003 (the end of the calibrated LHSB model simulation period) and for the SRV model in 2006. The overall simulated water budget for the SRV model is approximately 1 million acre-feet per year

(AFY) greater than that for the LHSB model, reflecting both the greater degree of historic and current groundwater development and recharge within the SRV, and the greater spatial extent of the SRV model domain.

Table 2-5. Water Budget Comparison (Full Model Domains)

	LHSB Model (2003)	SRV Model (2003)	SRV Model (2006)
Inflows (AFY)			
Recharge	86,020	975,150	963,187
Stream Leakage	13,246	108,623	106,880
Storage	69,425	269,636	80,091
Constant Head	-	10,426	6,418
General Head	4,808	-	-
Wells	0	14,168	14,168
Total	173,499	1,378,003	1,170,744
Outflows (AFY)			
Constant Head	11,502	6,753	8,088
General Head	13,826	-	-
Wells	122,963	1,087,442	781,523
Evapotranspiration	9,650	33,337	38,993
Stream Leakage	11,933	19,698	31,332
Storage	3,607	230,780	310,815
Total	173,481	1,378,010	1,170,751

AFY = acre-feet per year
LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley

The substantial differences between the various water budget components suggest that care must be taken during development of the WESTCAPS model to ensure that all groundwater sources and sinks are represented correctly in the model input database and numerical model framework. Additionally, the large difference in total simulated water budget between the two groundwater basins reinforces the concern that over time, the substantial groundwater demand and artificial recharge activities within the SRV groundwater basin may not be adequately handled by the artificial boundary conditions currently utilized within the WSRV in both models. There is significant potential for future groundwater trends in the regional SRV groundwater system to impact water budgets and water levels within the LHSB. Likewise, an expansion of groundwater development and recharge within the LHSB model domain is not explicitly considered in the current SRV model, and significant changes to the future estimated LHSB model water budget have been demonstrated to impact the boundaries that the LHSB model uses to simulate the interconnection with the WSRV (Brown and Caldwell, 2006).

Table 2-6 compares ET and recharge parameters for the two models; the spatial distribution of both parameters is presented on Figure 7. Within the overlap areas, variations in the placement and magnitude of ET and recharge between the SRV and LHSB models present a challenge to unifying these water budget components in the WESTCAPS model. ET rates in the overlap areas for the LHSB model were maintained at a single consistent rate and were confined to a narrower zone along the Gila River corridor relative to ET cells in the SRV model. ET rates in the SRV model were spatially variable, and bracketed the LHSB model value. Additionally, the SRV model ET cells have a greater estimated extinction depth, which can significantly impact the water budget by allowing ET to remove larger quantities of groundwater from the model at greater depths.

Table 2-6. Comparison of Recharge and ET in the Overlap Area

	ET 2003 Rate Range (feet/day)	ET Extinction Depth (feet bls)	Recharge 2003 Rate Range (feet/day)
LHSB	0.005	10	1.1e-4 to 0.0041
SRV	4.4e-5 to 0.012	30	1.7e-5 to 0.017

ET = evapotranspiration
bls = below land surface
ft/day = feet per day
LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley

Table 2-7 summarizes the construction and parameterization of the stream package in both models, which, as seen in Table 2-5, comprises a significant portion of both models' groundwater inflows and outflows. The location of stream cells for both models can be seen on Figures 1 and 2, and although there are variations in the placement of individual stream cells in the southern overlap area, there is generally good agreement in the alignment of stream cells along the major river and canal features. Inputs for the stream package in the SRV model do not include all components of the streambed conductance term; therefore, the evaluation of the construction of the stream package was constrained to channel width and the "lumped" streambed conductance parameter, which describes the ease with which water can move between the stream and the underlying groundwater system.

The segments of the stream package representing the Gila River in both models have comparable widths, but the SRV model tends to have estimated streambed conductances lower than those used in the LHSB model. For the stream segments representing the Buckeye Water Conservation and Drainage District (BWCDD) canal, the SRV model assumes twice the channel width and has generally higher streambed conductance values relative to the LHSB model, which allows for greater leakage of water into the underlying aquifer. For the stream segments representing the Hassayampa River, the SRV model assumes a significantly greater width than the LHSB, as well as significantly higher streambed conductance values, again allowing a greater degree of communication with the local groundwater system. These differences in stream package parameterization have significant impact on the simulated water budgets of both models and will need to be addressed, supported, and unified to appropriately simulate the interactions between surface water and groundwater. Additionally, the final construction of the stream package features will need to consider surface water channel conditions and flows in the SRV but outside of the southern overlap area in order to ensure that abrupt fluctuations in simulated surface water flows do not occur in the WESTCAPS model.

Table 2-7. Stream Package Construction Comparison in the Overlap Area						
	Gila River Above Hassayampa Confluence		BWCDD Canal		Hassayampa River	
Streambed Conductance Parameters	*LHSB*	*SRV*	*LHSB*	*SRV*	*LHSB*	*SRV*
Segment Number	1	17 and 20	2	16	3	19
Width (feet)	200	200 to 400 (tr)	10	20	10	200
Length (feet)	2,640	n/a	1,320 to 2,640	n/a	2,640	n/a
Streambed Conductivity (feet/day)	0.5 to 1	n/a	0.2 to 0.5	n/a	0.05 to 0.2	n/a
Streambed Thickness (feet)	5	2 to 10	5	5	5	5
Streambed Conductance (ft^2/day)	52,800 to 105,600	6,552 to 70,453 (tr)	1,056 to 2,640	1,696 to 14,886	264 to 1,056	19,280 to 55,587

BWCDD = Buckeye Water Conservation and Drainage District
ft^2/day = square feet per day
LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley
tr = Transient data
n/a = not applicable

3. INDIVIDUAL MODEL SIMULATIONS

Brown and Caldwell reviewed the feasibility of merging the updated SRV model with the LHSB model by running a simulation with each model through 2006 and comparing model results. This evaluation fulfilled the final requirement of Task 2.0 and provided a means to determine the most logical approach to take regarding the development of the WESTCAPS model structure. This section details the independent simulation of the SRV and LHSB models, the comparison of the results for the model overlap areas, and the subsequent decision to move forward with the task of merging the two models.

3.1 SRV Model Simulation

The updated SRV model simulates conditions through 2006. For this comparison exercise, the SRV model was run without modification and the simulation results for the end of 2006 were exported for comparison with output from the LHSB model.

3.2 LHSB Model Update and Simulation

The original, calibrated LHSB model simulates transient groundwater conditions from the early 1900s through 2003, with the predictive simulation period beginning in 2004. The predictive version of the LHSB model was used for the comparison with the SRV and was updated with available groundwater pumping and recharge data from 2004 through 2006 to facilitate 1) the comparison of simulated water levels and water budgets from each model in the overlap areas, and 2) the development of a complete set of groundwater stresses for the WESTCAPS model through 2006. It is important to note that the general head cells used at the boundaries north and south of the White Tank Mountains from 1900 through 2003 were changed to specified flux boundaries in the predictive LHSB model, beginning in 2004. Although this change did not cause detectable variations in simulated water levels, it did affect how underflow from the LHSB into the WSRV is represented in the water budget.

The following revisions and assumptions were made to the LHSB model for the comparison exercise:

- ET was held constant at the calibrated 2003 rate.
- Natural recharge was held constant at the long-term average rate used in the LHSB model predictive simulations (Brown and Caldwell, 2006).
- Groundwater pumping was updated with reported values from 2004 through 2006 using the Registry of Groundwater Rights (ROGR) database maintained by ADWR.
- Artificial recharge was held constant at the average rates used for the predictive LHSB model simulations (Brown and Caldwell, 2006), with the exception of recharge at the Hieroglyphic Mountains underground storage facility (USF). To be consistent, simulated recharge rates from the SRV model for this facility were incorporated into the LHSB model from 2004 through 2006.
- The specified flux boundaries that represent the LHSB connection with the WSRV groundwater basin were held constant at 2004 rates. (Note: specified flux values along these boundaries were based upon output from the previous version of the SRV model.)

3.3 Evaluation of Results

Water level elevations for 2006 were exported and compared for both models. Cell-specific water level differences were calculated using GIS and reviewed for the model overlap areas. Additionally, simulated groundwater zone budgets for the overlap areas were also exported and evaluated.

3.3.1 Water Level Comparison

Simulated water level contours for 2006 from both the SRV and updated LHSB models are shown on Figure 8 for the model overlap areas in the vicinity of the White Tank Mountains. In general, flow directions and trends are similar for both models. North of the White Tank Mountains, the results from both models reflect a steep groundwater gradient oriented to the southeast, toward the deeper portions of the WSRV basin. South of the White Tank Mountains, both models show groundwater moving southward from the central LHSB toward the Gila River, with groundwater underflow also entering the LHSB model domain from the southwestern SRV under a relatively flat hydraulic gradient.

The principle difference between the simulated water levels from each model is the overall magnitude of groundwater elevations and flow gradients. Near the western boundary of the northern overlap area, significantly higher water levels were simulated in the LHSB model relative to the SRV model, resulting in higher groundwater flow gradients. In the southern overlap area, the SRV model generally exhibits a greater range in water levels to the south and west of the White Tank Mountains. This spatial variation in water levels is largely attributable to the groundwater elevations that are prescribed at the SRV model's southwestern constant head boundary conditions. However, the significant variation between models in the magnitude of water budget components for the southern overlap area may also play a significant role in localized water level differences. This issue is addressed in greater detail in Section 3.3.2.

Figure 9 presents the differences between the simulated water table from the SRV and LHSB models for 2006. These cell-specific head differences were derived from model output that was exported directly into GIS, and were calculated by subtracting the SRV model head values from the LHSB model head values.

North of the White Tank Mountains, simulated water levels from the LHSB groundwater model are consistently higher (from 4 to 185 feet) than those simulated with the SRV model (Figure 9). The best agreement between the two models occurs along the southwest boundary of the northern overlap area. The greatest discrepancy in simulated water levels occurs along the northwestern and southeastern edges of the northern overlap area, coincident with the artificial boundaries for both the SRV and LHSB models, respectively. It is likely that the higher water levels simulated by the LHSB model are attributable to 1) the inclusion of recharge from the upper reaches of the Hassayampa River (causing higher water levels in the LHSB model simulation along the western portion of the northern overlap area), and 2) the inclusion of WSRV groundwater demands and associated drawdown in the SRV model (causing lower water levels in the SRV model simulation along the western portion of the northern overlap area). Given the active domains of both models, neither model is completely capable of accurately simulating the complex interactions and impacts of groundwater demands or recharge occurring beyond its boundaries.

Although water levels from the SRV model in the southern overlap region range from 58 feet above to 29 feet below the water level elevations simulated for the same locations within the LHSB model, SRV model water levels are significantly higher than those from the LHSB model for the majority of the southern overlap area north of the Gila River (Figure 9). The best agreement between simulated water levels occurs along the course of the Gila River, where groundwater elevations are constrained by land surface and leakage from the groundwater system into the river. The greatest discrepancy in simulated water levels occurs in the central portion of the southern model overlap area, adjacent to the constant head boundary cells of the SRV model and coincident with areas of significant agricultural activity. Given the large volume of groundwater pumping, recharge, and stream-aquifer interactions being simulated in the southern overlap area of both models, it is difficult to quantify what numerical or conceptual groundwater components may be causing this discrepancy between simulated water levels. However, it is apparent that for both the northern and southern model overlap areas there are significant differences between the numerical construction and conceptualization of both groundwater models, which will require additional effort to reconcile in future phases of the WESTCAPS groundwater model integration.

Additional simulations were also performed, with both the SRV and updated LHSB models, with a simulation time period that was extended through 2035. All groundwater sources and sinks were held constant at 2006 levels; therefore, the simulation was not deemed valid as a planning tool for future groundwater development. However, a comparison of future simulated water levels from both models over a time period of approximately 25 years beyond present day exhibited a similar spatial pattern in water level differences as those simulated for 2006, indicating that each model's water level bias (relative to each other) persists during predictive simulations.

3.3.2 Water Budget Comparison

A comparison of the simulated, zone water budgets for the northern and southern model overlap areas for both the SRV and LHSB models is presented in Table 3-1. This review was performed in order to evaluate potential causes of simulated water level differences between the SRV and LHSB models, as well as identify components of the model that will require additional investigation, refinement, and analysis. The total simulated water budget for the model overlap area south of the White Tank Mountains is substantially greater than that for the northern model overlap area due to the large amounts of groundwater recharge, pumping, and interactions with surface water features (i.e. canals and the Gila and Hassayampa Rivers).

For the northern model overlap area, both models exhibit similar magnitudes for most water budget components as well as the overall zone water budget, which differs only by 4,500 to 5,000 AFY. The principle difference in water budgets for this area is caused by the nearby artificial boundary conditions. Inflows along the western boundary of the northern overlap area are inside the active domain of the LHSB model and are calculated by the model as a result of surrounding model stresses (such as natural and artificial recharge and pumping) and hydraulic parameters. However, in the SRV model, this boundary is simulated with prescribed flux cells along the model's edge, which are defined at a constant estimated groundwater flow value. Conversely, the eastern boundary of the northern model overlap area is defined in the LHSB model as prescribed flux cells, whereas this same location is within the SRV model domain and thus all groundwater underflow is calculated by the model.

Table 3-1. Water Budget Comparison (Overlap Areas)

	LHSB North of the White Tank Mountains (2006)	SRV North of the White Tank Mountains (2006)	LHSB South of the White Tank Mountains (2006)	SRV South of the White Tank Mountains (2006)
Inflows (AFY)				
Recharge	10,252	10,579	55,418	119,108
Stream Leakage	-	-	19,928	13,477
Storage	4,961	2,687	7,850	1,553
Underflow	Western Boundary 6,399	Western Boundary 3,368*	Western Boundary 14,291 Eastern Boundary 2,691*	Western Boundary 6,400 Eastern Boundary 1,295
Total	21,612	16,634	100,178	141,833
Outflows (AFY)				
Wells (Extraction)	1,054	1,241	73,783	72,446
Evapotranspiration	-	-	10,274	19,644
Stream Leakage	-	-	10,418	15,015
Storage	6,982	7,822	3,701	26,703
Underflow	Eastern Boundary 13,576*	Eastern Boundary 8,002	Western Boundary 2,004	Western Boundary 8,025**
Total	21,612	17,065	100,180	141,833

NOTE: Eastern Boundary and Western Boundary refer to the general geographic edges of the model overlap areas, which correspond to the artificial numerical boundaries of the SRV and LHSB groundwater models.

**Underflow simulated with prescribed flux cells*

***Underflow simulated with constant head cells*

AFY = acre-feet per year

LHSB = Lower Hassayampa Sub-Basin

SRV = Salt River Valley

A comparison of the estimated groundwater underflow values for both models shows that more water is simulated to be moving both into and out of the northern overlap area in the LHSB model than in the SRV model. This agrees with the higher overall groundwater gradient simulated by the LHSB model in this region (Figure 8). Both models estimate that significantly more water is leaving this area than entering it via underflow due to the steepening groundwater gradient approaching the central portions of the WSRV (Figure 8).

This review suggests that the simulation of the northern model overlap area in the WESTCAPS model will likely be significantly influenced by both the higher water levels and Hassayampa River recharge included in the LHSB model, as well as the impacts of groundwater withdrawals within the northern and central portions of the WSRV. Essentially, this would result in a greater range of groundwater elevations and a steeper gradient throughout the northern overlap area. It should be noted that future groundwater development within the LHSB could alter predicted groundwater conditions in the northern portions of the adjacent WSRV. The development of the WESTCAPS model will allow for direct simulation of this interrelationship between groundwater conditions in both basins when the artificial boundary conditions are removed.

In the southern overlap area there is a difference of approximately 40,000 AFY in the total simulated water budget between the LHSB and SRV models. In particular, the SRV model simulates over 60,000 AFY of additional estimated recharge in this area relative to the LHSB model in 2006. The bulk of this recharge is related to extensive agricultural activity in and adjacent to the "waterlogged" area north of the Gila River. The source of water for recharge is derived from imported groundwater and surface water, as well as return flows from groundwater pumping for agriculture (Brown and Caldwell, 2006). Simulated groundwater storage, stream leakage, and ET are also substantially different between the models, in part due to this large discrepancy in the assumed magnitude of recharge.

Underflow values along the western boundary of the southern model overlap area also vary substantially between models. The LHSB model estimates that over twice as much groundwater (or more than 13,500 AFY) enters the southern model overlap area annually via underflow from the central LHSB than the SRV model. Conversely, the SRV model simulates approximately 6,000 AFY more groundwater underflow leaving this area. The correlation between underflow into and out of the southern model overlap area is not as direct as that for the northern overlap area due to the large water budget variations between the two models and the extent of water resource development. However, it is likely that the ability of the LHSB model to directly simulate the impacts of groundwater conditions within the central portions of the LHSB improves the accuracy of the simulation of water budget features within the western portion of the southern overlap area.

The eastern boundary of the southern model overlap area exhibits significantly better agreement in both simulated water levels and water budget components than the western portion of the area. This is likely due to the fact that 1) the LHSB model used water levels and groundwater fluxes from the previous version of the SRV model to define conditions along this eastern boundary, and 2) water levels from both models have flatter gradients and exhibit little change in elevation over the simulation time period.

4. INTEGRATION OF GROUNDWATER MODELS

Following the independent simulation of both models through 2006, the numerical frameworks of both models were seamed together to create the basis for the WESTCAPS model. Integration of the models included joining together the active domains, layering, pumping arrays, and other groundwater sources and sinks. The generation of the WESTCAPS model framework and successful running of a set of preliminary, test simulations satisfies the tasks outlined in Task 3.0(a) of the Scope of Work.

4.1 Feasibility of Model Integration

In general, the comparison of simulated water levels and water budgets from both models, discussed in Section 3.0, suggests that the WESTCAPS model will require future work and study in order to defensibly unify the differing conceptualizations of groundwater conditions both north and south of the White Tank Mountains. However, the evaluation of layering, hydraulic parameters, simulated water levels, and zonal water budgets from both models did not reveal any critical flaws or differences that would prohibit the initial development of the preliminary WESTCAPS model numerical framework.

4.2 Construction of Expanded Model

The integration of the two models included joining together the SRV and LHSB active model domains, adjusting the extents of the layers in the overlap area, converting the SRV model to utilize the LPF package with MODFLOW-2000, and seaming together various groundwater source and sink data including groundwater pumping, recharge, ET, and the stream package. The WESTCAPS model was developed using MODFLOW-2000, an updated, finite-difference, MODFLOW groundwater modeling code (Harbaugh et al., 2000). Groundwater Vistas version 5.34, coupled with ESRI® ArcGIS™ version 9.3.1, was utilized as the pre- and post-processor to condition model input data and view WESTCAPS model output data (ESI, 2006).

4.2.1 Model Discretization and Domain

A new model domain was constructed that covered the full 3D extent of both models. To facilitate the importation of pre-existing model data sets, the locations of active cells in the new WESTCAPS model were precisely aligned with those from both the LHSB and SRV models. The lateral extent of active model cells for the model overlap areas were based upon the LHSB model construction, whereas the remainder of the SRV and LHSB model domains were kept consistent with each model's original construction. The generation of the expanded WESTCAPS model domain also required the removal of the artificial boundary conditions along the edges of the overlap areas. Additionally, all LHSB model files were re-projected into Universal Transverse Mercator (UTM) zone 12N, HARN 1983 to match the current SRV model projection and facilitate the importation of future GIS data developed by ADWR.

4.2.2 Time Frame and Initial Conditions

The WESTCAPS model was designed to simulate the time period from 1983 through 2006, the same time period as the most recent version of the SRV model. This time period was selected to maintain consistency with ADWR's current model data sets and allow for more efficient updates as additional SRV model input data become available. The WESTCAPS model is temporally discretized into 24 annual stress periods, with 12 time steps per year and a multiplier of 1.2.

Initial heads for all layers were directly imported from those contained in the SRV model for areas outside of the LHSB model domain. Simulated head values from the LHSB model for the end of 1982 were imported as initial heads over the full extent of the LHSB model domain. This process is only an interim solution, and it is recommended that future model development include the generation of an interpolated updated initial head data set derived using observed water levels from approximately 1983 throughout the LHSB and WSRV.

4.2.3 Model Layering

Model hydrostratigraphic layering in the overlap areas was constructed by initially selecting one model to take precedence. From discussions with ADWR modeling staff and reviews of both pre-existing models, it was concluded that the layering from the LHSB model in the overlap areas would be more appropriate at present. This decision was made due to the ongoing update of SRV model layering with more recent geologic information. For the remainder of the SRV and LHSB model domains, layer elevations were kept consistent with each model's original construction. This approach does cause some abrupt vertical offsets in layer elevations along the eastern boundaries of the model overlap areas. However, maintaining consistency with one model layering conceptualization allows for rapid update at a later date and avoids the generation of an unverified and non-reviewed layering data set, which would be the result of "smoothing" or "averaging" the elevations of both models. Test simulations also indicated that this approach to layering would allow the model to converge with negligible errors throughout the simulation time period.

4.2.4 Aquifer Hydraulic Properties

To maintain consistency with the LHSB model layer elevations, aquifer hydraulic properties such as hydraulic conductivity, specific yield, and specific storage were also based upon the LHSB model for the overlap areas. For the remainder of the SRV and LHSB model domains, hydraulic parameter distributions and magnitudes were taken from each model's original construction.

The SRV model utilizes the BCF package, which requires the use of storage coefficient (or storativity) as the primary confined unit storage input; however, the LHSB model uses the LPF package, which requires specific storage to be the main confined unit storage input. The decision to run the entire model using the LPF package was made in the early stages of the project, as this would fully integrate the WESTCAPS model into the MODFLOW-2000 numerical framework. This necessitated a conversion from storage coefficient to specific storage over the extent of the SRV model domain, excluding model overlap areas. Specific storage values for Layers 2 and 3 were calculated by dividing the storage coefficient by the thickness of the corresponding layer on a cell-by-cell basis. Resulting specific storage values ranged from 1.0×10^{-6} ft^{-1} to 0.0005 ft^{-1}.

Relative to the LPF package, the BCF package also requires different inputs for the calculation of vertical leakance, a measure of the degree of vertical connection between model layers. To successfully calculate this parameter in the WESTCAPS model, the SRV model hydraulic conductivity dataset was modified to calculate vertical conductance from vertical hydraulic conductivity values (K_z). This approach was also used during development of the LHSB model. To assign vertical hydraulic conductivity values where hydraulic parameters from the SRV model were used, the horizontal to vertical hydraulic conductivity ratios cited by Freihoefer et al. (2009) were applied.

4.2.5 Recharge and Evapotranspiration

Outside of the overlap areas, recharge and ET rates and distributions were kept consistent with the construction of the current SRV and LHSB models. Recharge in the overlap areas was assigned the distribution and rates from the LHSB model with the exception of the Hieroglyphics USF, which is simulated in the SRV model beginning in 2003. Because the magnitude of recharge from this facility is regionally significant and influences groundwater elevations and gradients within the northern WSRV and LHSB, it was incorporated into the recharge array for the WESTCAPS model (Figure 7). ET rates and spatial distribution from the LHSB model were allowed to take precedence in the model overlap areas for the purposes of performing the preliminary simulation (Figure 7).

4.2.6 Stream Package

Parameters from the stream packages for both models were integrated by allowing the stream construction from the LHSB to take precedence in the model overlap areas. The SRV model stream package was truncated at the eastern edge of the overlap area and set to route surface water flows directly to the adjacent, downstream LHSB model stream segments. No further changes were made to the SRV stream package. Segment and routing information for the LHSB portion of the stream were updated accordingly to accept flows from the SRV portion of the stream package. Specified inflows that were previously assigned to represent surface water inflows from the WSRV at the eastern artificial boundary of the LHSB model were removed.

4.2.7 Wells

Pumping information from both models was compiled in a formally developed groundwater demand database and merged into a unified, GIS-compatible pumping dataset. Merging the data from both models preserved the unique well structure of the original files; however, wells with ADWR registry identification numbers that were common to both models were given the location and pumping rates from the LHSB model. The decision to remove duplicate SRV model wells (within the LHSB model domain) from the pumping data was based upon the fact that model layering and hydraulic parameters in the overlap areas are also based upon the LHSB model. Additionally, LHSB model pumping wells are based upon specific locations as recorded by ADWR in their well registry database, unlike SRV model wells, which are assigned locations based upon the nearest model node.

Wells from the SRV model have pumping assigned discretely to each model layer, whereas individual LHSB model wells can have pumping assigned over multiple layers depending upon their screened intervals. Due to this variation, layer-specific pumping in the overlap areas will not agree with the pumping previously developed by ADWR, even though the total estimated pumping is consistent. Additional effort will be required in the future to address these pumping discrepancies.

4.3 Preliminary WESTCAPS Model Simulation

After construction of the WESTCAPS model grid and importation of all model inputs, a series of test simulations was performed to isolate missing data, import errors, model inconsistencies, or significant model output variations from the previous SRV and LHSB simulations. Once these issues were resolved, the model was capable of achieving convergence over the entire simulation time period with negligible numerical mass balance errors. The series of test runs with the WESTCAPS model culminated with a simulation that spanned the baseline model time period from 1983 through 2006. Although the WESTCAPS model has not gone through a formal calibration process and requires additional adjustments to model construction and water budget components, it is useful to compare the results of this preliminary simulation to previous modeling efforts to qualitatively and quantitatively assess the numerical impact of merging the SRV and LHSB models together.

Figure 10 presents a comparison of the simulated 2006 water level contours from the preliminary WESTCAPS model simulation to the water levels simulated separately by the LHSB and SRV models. From visual inspection, there is clearly good agreement between these water levels at a contour interval of 25 feet, and there is excellent agreement in general groundwater flow gradients and overall flow regime. As expected, the WESTCAPS model water levels exhibit greater agreement with the LHSB model water levels in the overlap areas. This is primarily because the model parameters and inputs from the LHSB model took precedence during WESTCAPS model construction. The shifts in model layering and parameterization that occur along the eastern edges of the model overlap areas did not prohibit the WESTCAPS model from producing groundwater conditions similar to those previously simulated by both the SRV and LHSB models. However, the joining of these two model domains did alter simulated groundwater elevations in both overlap areas as well as in the northern and central portion of the WSRV.

Figures 11 and 12 show color flood representations of the differences between simulated water levels from the WESTCAPS model and those from the LHSB model and SRV model, respectively. (Note that the color flood scale on these two maps is not consistent due to the large range in values shown on Figure 12.) All areas represented by light gray indicate a head difference of less than 10 feet between the models. Generally, the WESTCAPS model water levels are within 10 feet of the LHSB and SRV model water levels throughout substantial portions of the model domain (Figures 11 and 12). Those regions that reflect water level differences significantly greater than 10 feet should be the focus of investigations in future phases of work. This includes the model overlap areas north and south of the White Tank Mountains, isolated areas where a single well or recharge zone may need to be verified or corrected (e.g., wells near Palo Verde Nuclear Station, in the southwest LHSB model domain), and potentially regions in the ESRV that may be indicative of model issues with simulating large amounts of recharge over time (Figure 12).

In the waterlogged area (southern overlap zone), water levels in the WESTCAPS model closely match the LHSB model, with water level differences generally within 15 feet (Figure 11). Given the high degree of statistical calibration of the LHSB model in this region (Brown and Caldwell, 2006), this is a positive outcome for the preliminary simulation. For the northern overlap area, the bulk of the water levels in the WESTCAPS model again match closely with the LHSB model. However, WESTCAPS model heads are lower than those simulated with the LHSB model along the periphery of the eastern LHSB boundary, with a maximum difference of more than 40 feet near the mountain fronts (Figure 11).

A comparison of simulated water levels between the WESTCAPS and SRV models in the southern overlap area demonstrates that head values from the WESTCAPS model are significantly lower than those from the SRV model, reaching a maximum difference of approximately 60 feet (Figure 12). However, simulated water levels along the Gila River are almost identical due to the physical constraint of groundwater draining into this surface water feature. The greatest difference in water levels is located south and west of the White Tank Mountains, in a similar distribution to that observed on Figure 9. Once again this difference in water levels is likely attributable to the removal of the constant head boundary conditions from the SRV model and the differences between estimated agricultural recharge and pumping between the models, as discussed in Section 3.3.2.

For the northern overlap area, simulated water levels from the WESTCAPS model are generally higher than those from the SRV model, likely due to the removal of the impacts from the SRV model's artificial, specified flux boundary to the northwest (Figure 12). The water level difference between the two models is more than 180 feet along the northwestern edge of the northern overlap area where recharge from the Hassayampa River occurs in the WESTCAPS model. The difference reaches a maximum of approximately 90 feet along the southeastern edge of the overlap area where a sudden shift in aquifer parameters and model layering occurs between the LHSB and SRV model domains (Section 4.2.3).

The success of the WESTCAPS model preliminary simulation in removing the bias from artificial hydrogeologic boundaries is evidenced in Figures 10 through 12 depicting the differences and similarities in water levels and flow regimes. These results also provide a basis to identify areas for further study in future phases of the project.

5. RECOMMENDATIONS

5.1 Future Model Development

Although the numerical frameworks of the ADWR SRV model and the LHSB model were successfully integrated to create the preliminary WESTCAPS model, several key model integration challenges were identified. The following issues should be addressed during future phases of WESTCAPS model development:

- **Model Layering**: ADWR is currently reviewing geologic information in the overlap areas and updating SRV model layering. Obtaining the updated geologic information and incorporating it into the WESTCAPS model layering will be necessary to fully integrate the various interpretations of regional hydrostratigraphy as well as to refine hydraulic parameters and groundwater sources and sinks during the calibration process. Currently, the WESTCAPS model layering shifts abruptly from the LHSB to the SRV layer contact elevations along the trends of the old artificial boundaries. These layer transition areas will need to be rectified and smoothed during a future model update.
- **Stream package**: Conceptualization of surface hydrology in the southern overlap area differed between the two models, as reflected in the comparison of the stream package parameters (Table 2-7). Differences in stream width and streambed conductance, in addition to additional information regarding ADWR assumptions regarding channel morphology, will need to be reviewed and reconciled with observational data and previous hydrologic studies to resolve these discrepancies.
- **Model Pumping**: A full and comprehensive QC review of the integrated model pumping and newly constructed groundwater demands database needs to be performed. During the merge of digital pumping data, it was noted that a number of wells in the ADWR SRV model lack a registry identification number (REGID). The lack of REGIDs in any of the pre-existing models' pumping input data could allow for double accounting of pumping, as the merge was based largely upon this unique ADWR identifier. The QC process would require obtaining the most up-to-date version of the ROGR database from ADWR, and rigorously reviewing the pumping magnitudes and spatial locations for all groundwater demands. Additionally, an updated, merged pumping dataset should contain all georeferenced well locations (coordinates) instead of the location of the model cell nodes associated with a pumping entity. Tracking, maintaining, updating, and QC of pumping inputs for future modeling efforts will be significantly streamlined once this task is initially performed. Additionally, this task would facilitate the vertical distribution of pumping across regional aquifer units.
- **Hydraulic parameters**: Similar to model layering, aquifer parameters are continuously being updated based on new information from aquifer testing and geologic information. Obtaining this updated information and incorporating it into the WESTCAPS model geodatabase will aid in future model calibration efforts, refine the regional hydrogeologic conceptualization for the WSRV, and provide greater defensibility for assumed model hydraulic parameters. As noted in Section 2.3.4, the SRV and LHSB models spatially

distribute aquifer parameters in different manners (zoning vs. cell by cell). This difference in approaches to parameter distribution would need to be addressed and reconciled to ensure that the estimates are consistent in the transition zones between the SRV and LHSB models. Additionally, a unified approach to hydraulic parameter distribution will greatly facilitate future model updates and refinements. The calculation of specific storage and vertical hydraulic conductivity estimates for the WESTCAPS model should also be reviewed.

- **Recharge and Evapotranspiration**: The distribution and magnitude of groundwater recharge and ET should be reconciled, and to the extent feasible, standardized between the SRV and LHSB models, beginning with an investigation of the recharge in the southern overlap zone near the waterlogged area.
- **Target Water Levels:** A comprehensive data schema and database for observed groundwater elevations should be developed, incorporating data from ADWR's Groundwater Site Inventory (GWSI) database and from water providers within the LHSB and WSRV. This database should be fully compatible with the database structure and content contained within the formal pumping database developed during this project's Scope of Work. The populated water levels in the database will be used as targets for the future transient and steady state WESTCAPS model calibrations, as well as potentially providing a basis for the development of initial conditions for the transient WESTCAPS model (prior to full simulation from steady state conditions).
- **Calibration**: After the above-listed tasks, updates, and reviews are completed, the fully integrated model will require a rigorous calibration process to ensure that it is capable of simulating observed water levels over the full simulation time period. Calibration will focus on the full extent of the model, with emphasis placed on the overlap areas where the bulk of model updates are anticipated to be located.
- **Steady State Simulation:** ADWR is currently in the process of developing an updated steady state simulation for the SRV model that presumably captures conditions circa 1900. A steady state simulation should also be performed with the updated WESTCAPS model in order to qualitatively calibrate it to assumed pre-development conditions. This step in model calibration and refinement should be aided by the work currently being conducted by ADWR, and should incorporate the previous steady state simulation and calibration performed for the LHSB model.
- **Pre-Development through 1982**: The SRV portion of the WESTCAPS model is limited to simulating conditions beginning in 1983. Once a steady state simulation is developed for the SRV model, transient conditions from pre-development through 1982 could be conceptualized and adapted into an expanded simulation time frame. This information should also be incorporated into the WESTCAPS model. This update would synchronize the SRV portion of the WESTCAPS model with the LHSB model timeline. This represents a substantial level of effort as it involves developing model inputs from pre-development (early 1900s) through the beginning of 1983, the current start time of the SRV model. This step will greatly increase the confidence level in results from WESTCAPS model simulations, and is vital for constraining results from predictive simulations. An additional calibration step should be performed to verify the model's ability to simulate this greater range of historic transient conditions. As an interim solution, in lieu of a simulation of pre-development groundwater conditions through 1982, it is recommended that future model development include the generation of an updated initial head data set derived from observed water levels from approximately 1983 throughout the LHSB and WSRV.

5.2 Data Needs

As detailed in Section 5.1, full model integration and subsequent model calibration would require the following data:

- All new geologic/lithologic data in the SRV and LHSB models' overlap areas from ADWR and other local entities for use in the refinement of layering geometry and hydraulic parameters in the WSRV;
- Steady state model files and documentation for the SRV model (once completed);
- Historic model input data for the SRV, currently under development by ADWR;
- New SRV model layering information from ADWR;
- Updated water level information from ADWR's GWSI database and local entities (for model calibration verification);
- Updated well information from the ROGR database maintained by ADWR to update and QC groundwater pumping magnitudes and locations; and
- Updated surface water flow records for all major drainages and canal features within the WSRV and LHSB.

6. REFERENCES

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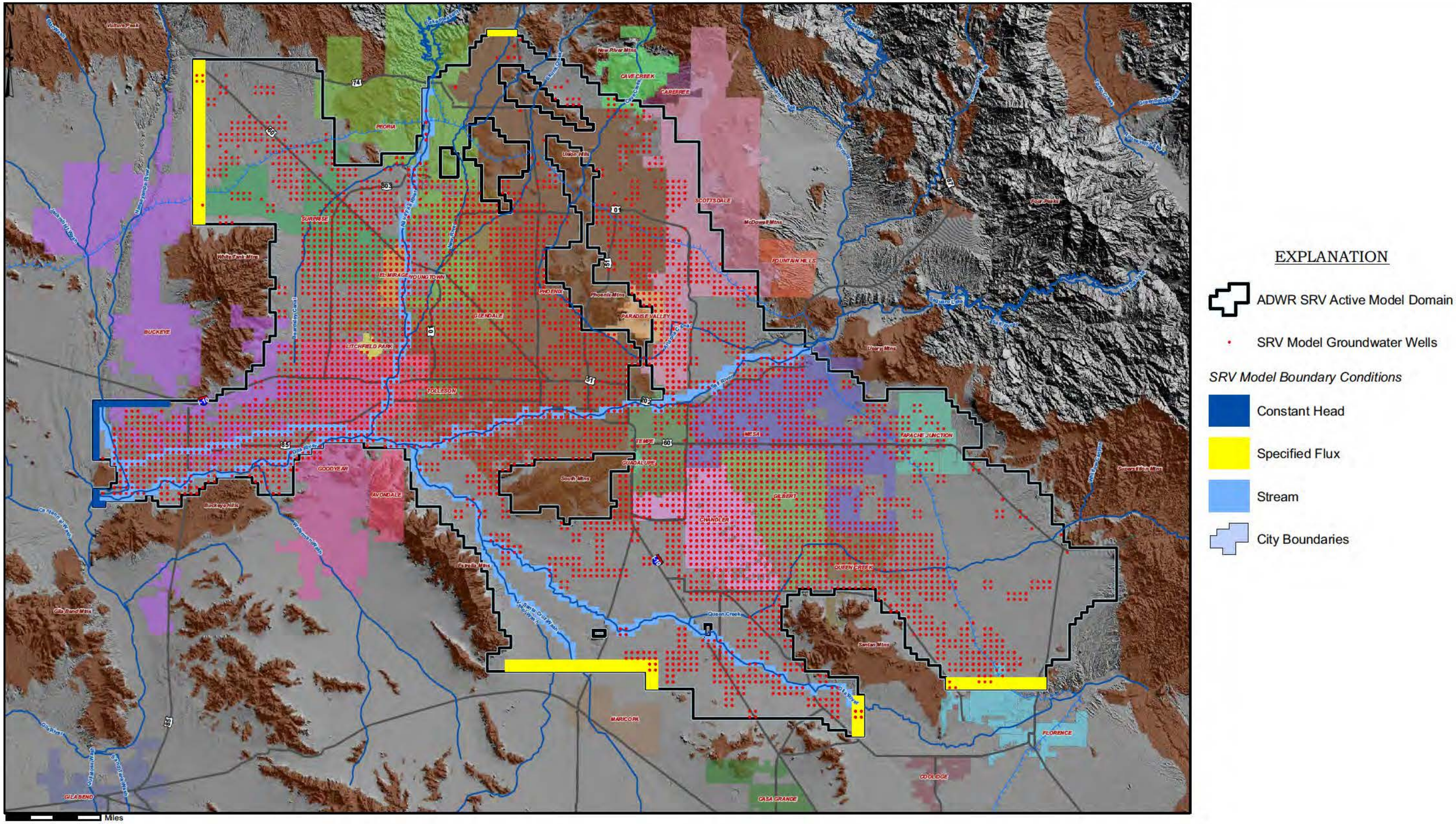
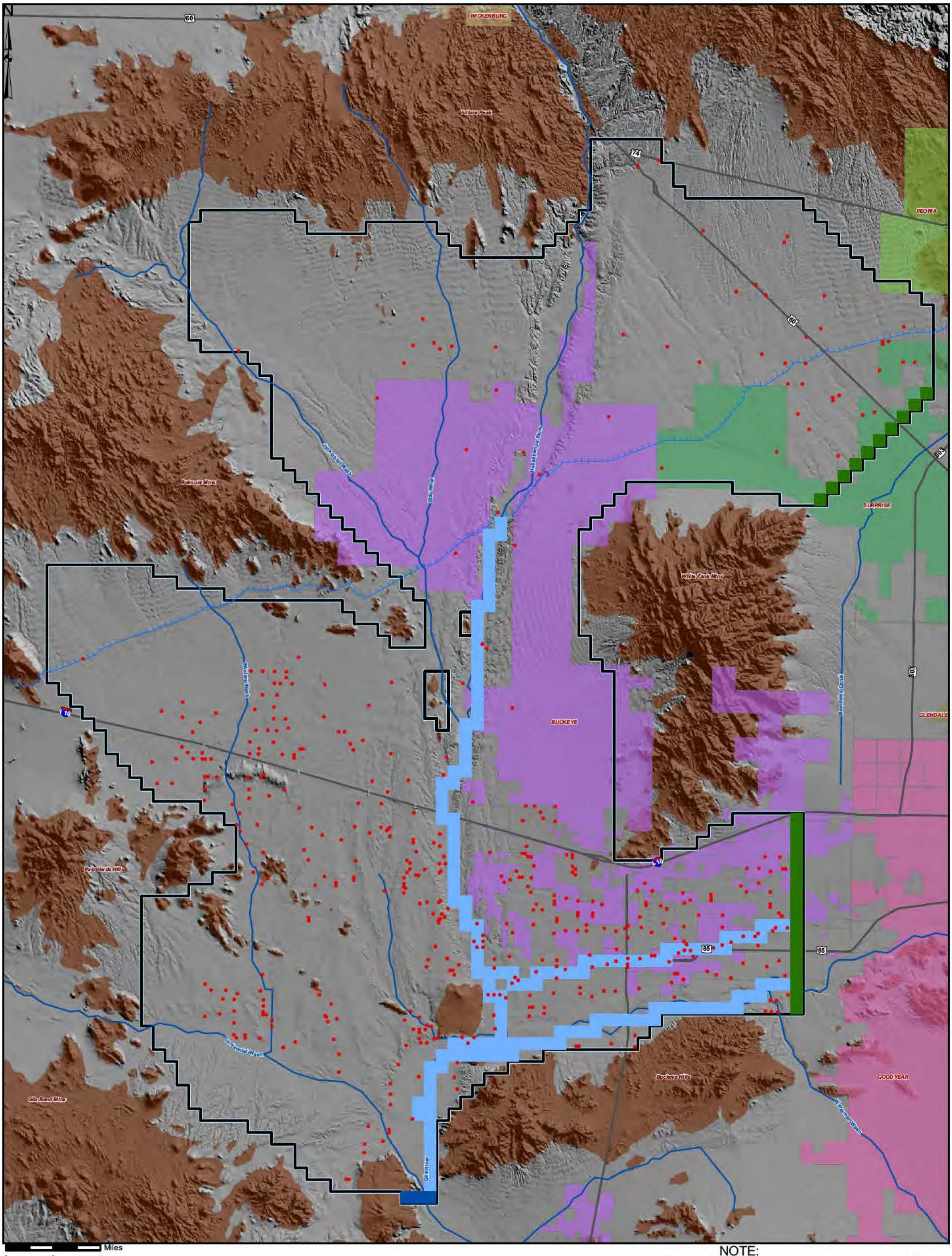


BROWN AND CALDWELL

NOTE:
ADWR = Arizona Department of Water Resources
LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley

Figure 1
ADWR SRV ACTIVE MODEL DOMAIN
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA



NOTE:
LHSB = Lower Hassayampa Sub-Basin

EXPLANATION

LHSB Active Model Domain

LHSB Model Groundwater Wells

LHSB Model Boundary Conditions

Constant Head

General Head Boundary

Stream

City Boundaries

BROWN AND CALDWELL

Figure 2
LHSB ACTIVE MODEL DOMAIN
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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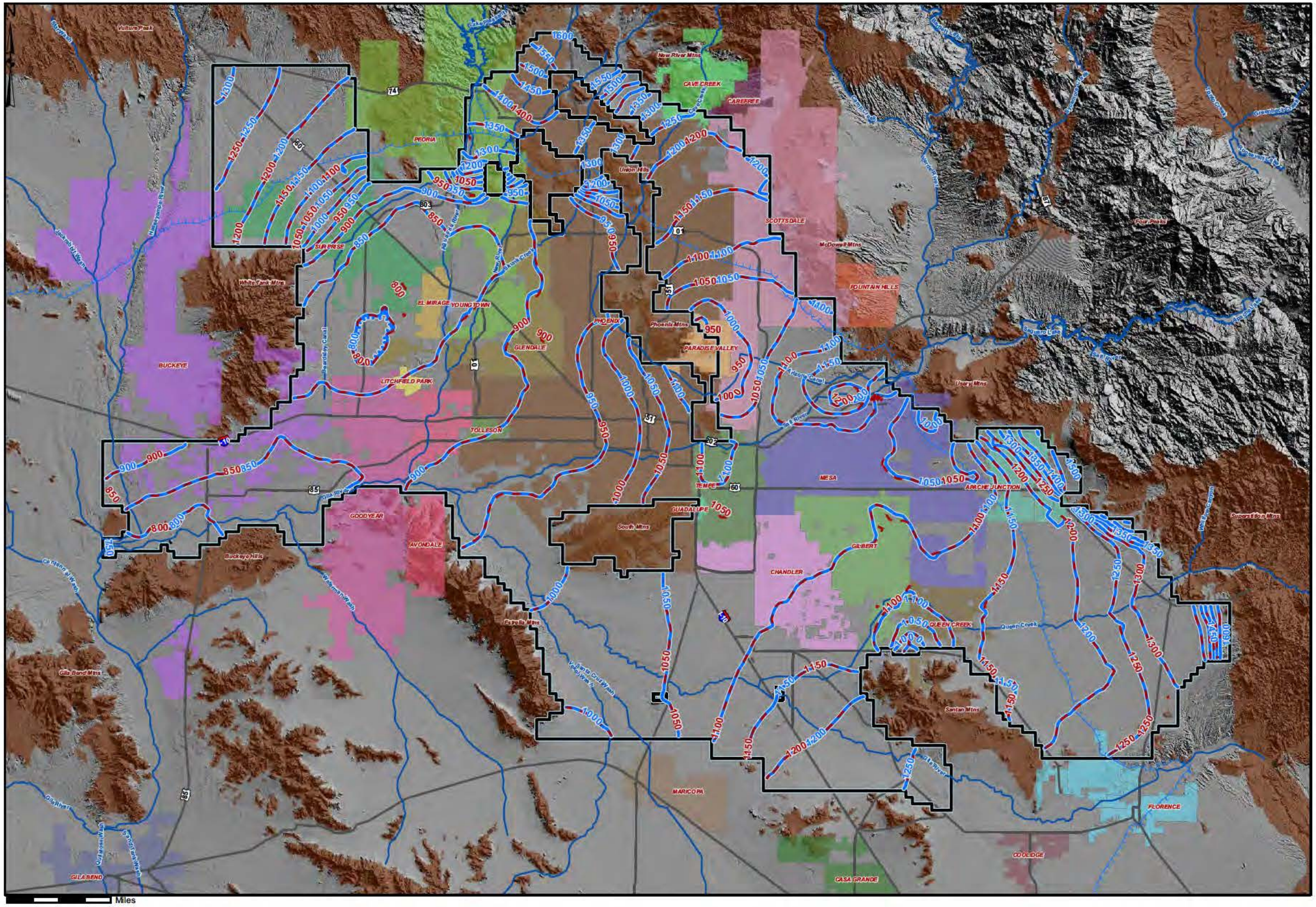

EXPLANATION

- BC Import SRV Model Simulated Water Levels (ft amsl) Contour Interval = 50 ft
- ADWR SRV Model Simulated Water Levels (ft amsl) Contour Interval = 50 ft
- ADWR SRV Active Model Domain
- City Boundaries

NOTE:
2002 water levels provided by ADWR in their SRV geodatabase.
2006 water levels were not provided.

BROWN AND CALDWELL

ADWR = Arizona Department of Water Resources
BC = Brown and Caldwell
SRV = Salt River Valley
ft amsl = feet above mean sea level

Figure 3
2002 SIMULATED WATER LEVEL COMPARISON
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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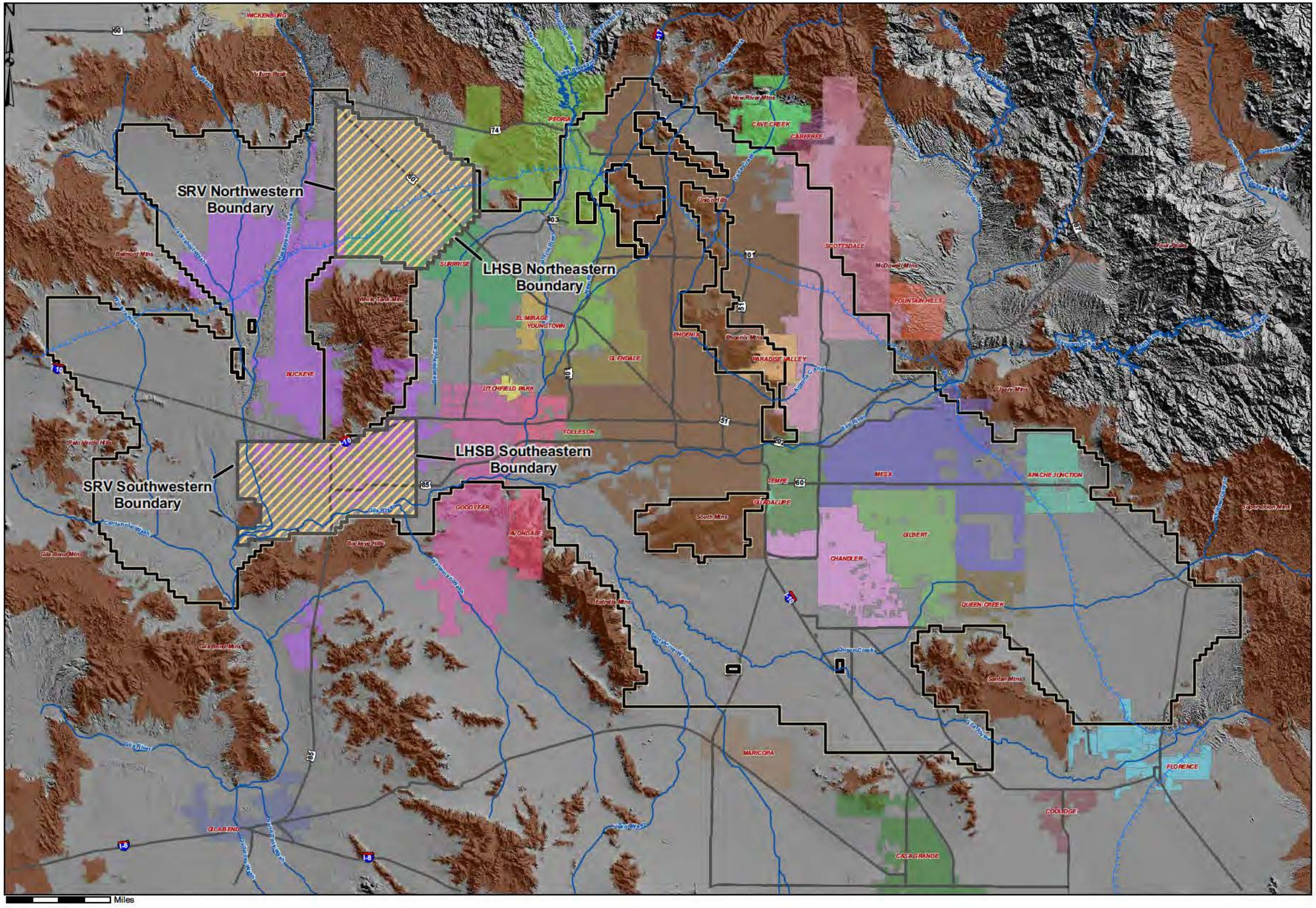

EXPLANATION

Model Overlap Areas

WESTCAPS Active Model Domain

BROWN AND CALDWELL

Figure 4
WESTCAPS ACTIVE MODEL DOMAIN
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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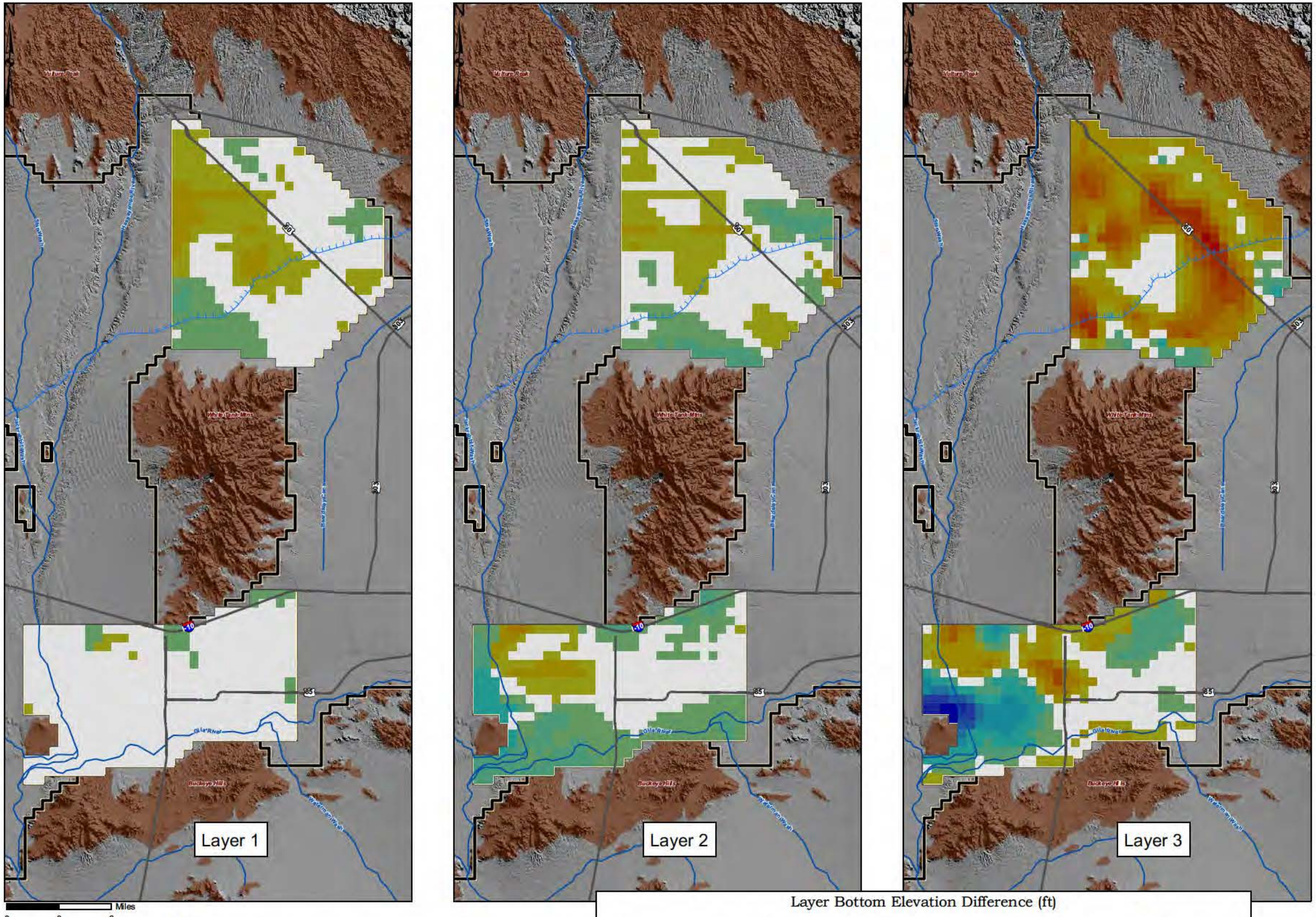

EXPLANATION

Model Overlap Areas

WESTCAPS Active Model Domain

Layer Bottom Elevation Difference (ft)

-2201 - -2000	-1249 - -1000	-249 - -101	251 - 500	1251 - 1500
-1999 - -1750	-999 - -750	-100 - 0	501 - 750	1501 - 1750
-1749 - -1500	-749 - -500	1 - 100	751 - 1000	
-1499 - -1250	-499 - -250	101 - 250	1001 - 1250	

NOTE:
Negative values denote that the LHSB model elevation is lower than the SRV model elevation;
Positive values denote that the LHSB model elevation is higher than the SRV model elevation.

LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley
ft = feet

BROWN AND CALDWELL

Figure 5
LAYER ELEVATION COMPARISON
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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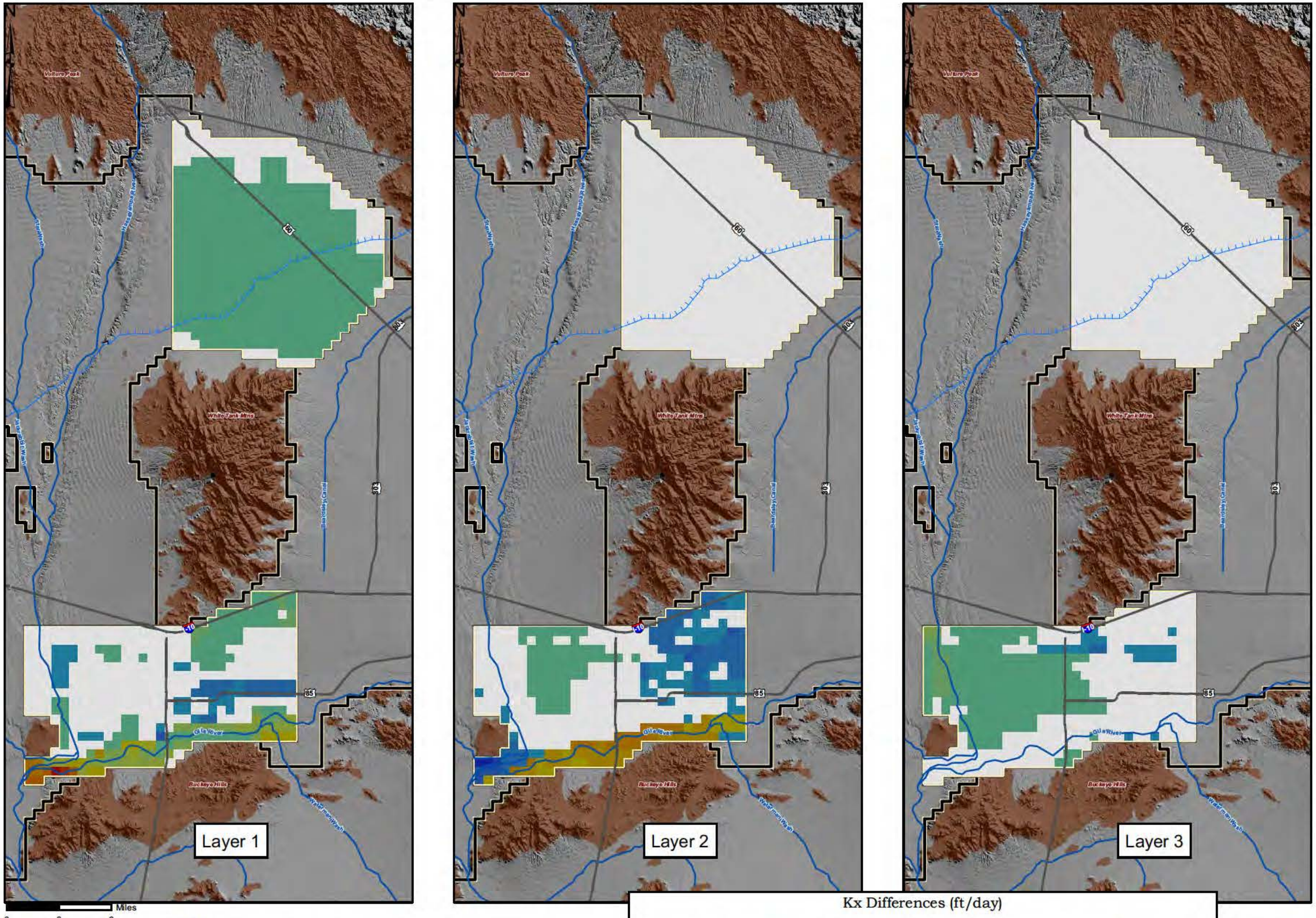

EXPLANATION

Model Overlap Areas

WESTCAPS Active Model Domain

Kx Differences (ft/day)

60 50	19 11	21 30	61 70	101 110
49 40	10 0	31 40	71 80	111 120
39 30	1 10	41 50	81 90	121 130
29 20	11 20	51 60	91 100	

NOTE:
Negative values denote that the LHSB model Kx value is lower than the SRV model Kx value;
Positive values denote that the LHSB model Kx value is higher than the SRV model Kx value.

LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley
ft/day = feet per day

BROWN AND CALDWELL

Figure 6
HYDRAULIC CONDUCTIVITY COMPARISON
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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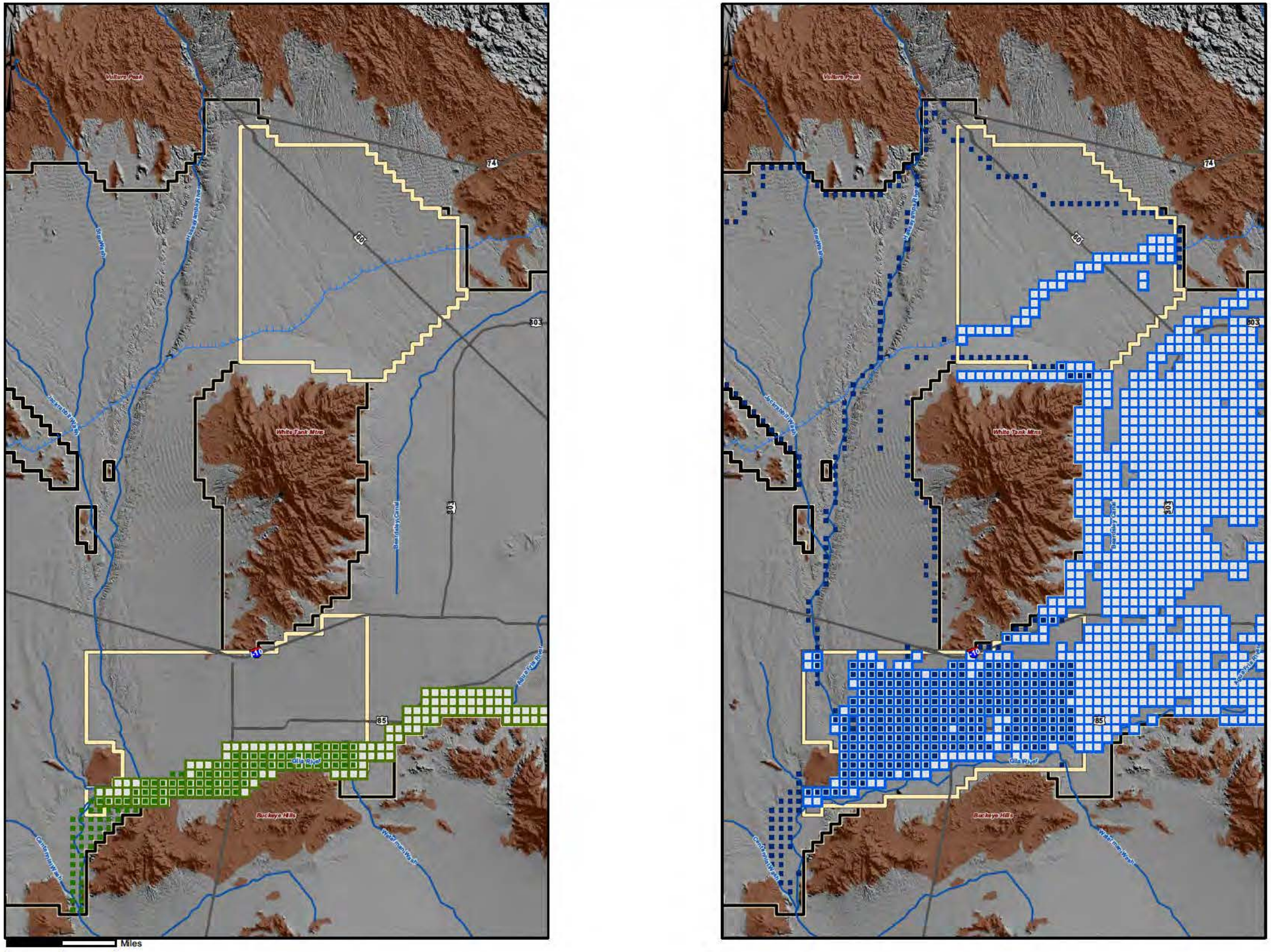

EXPLANATION

- 2006 LHSB Model ET Location
- 2006 SRV Model ET Location
- 2006 LHSB Model Recharge Location
- 2006 SRV Model Recharge Location
- Model Overlap Areas
- WESTCAPS Active Model Domain

BROWN AND CALDWELL

NOTE:
LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley
ET = Evapotranspiration

Figure 7
SPATIAL DISTRIBUTION COMPARISON of ET and RECHARGE
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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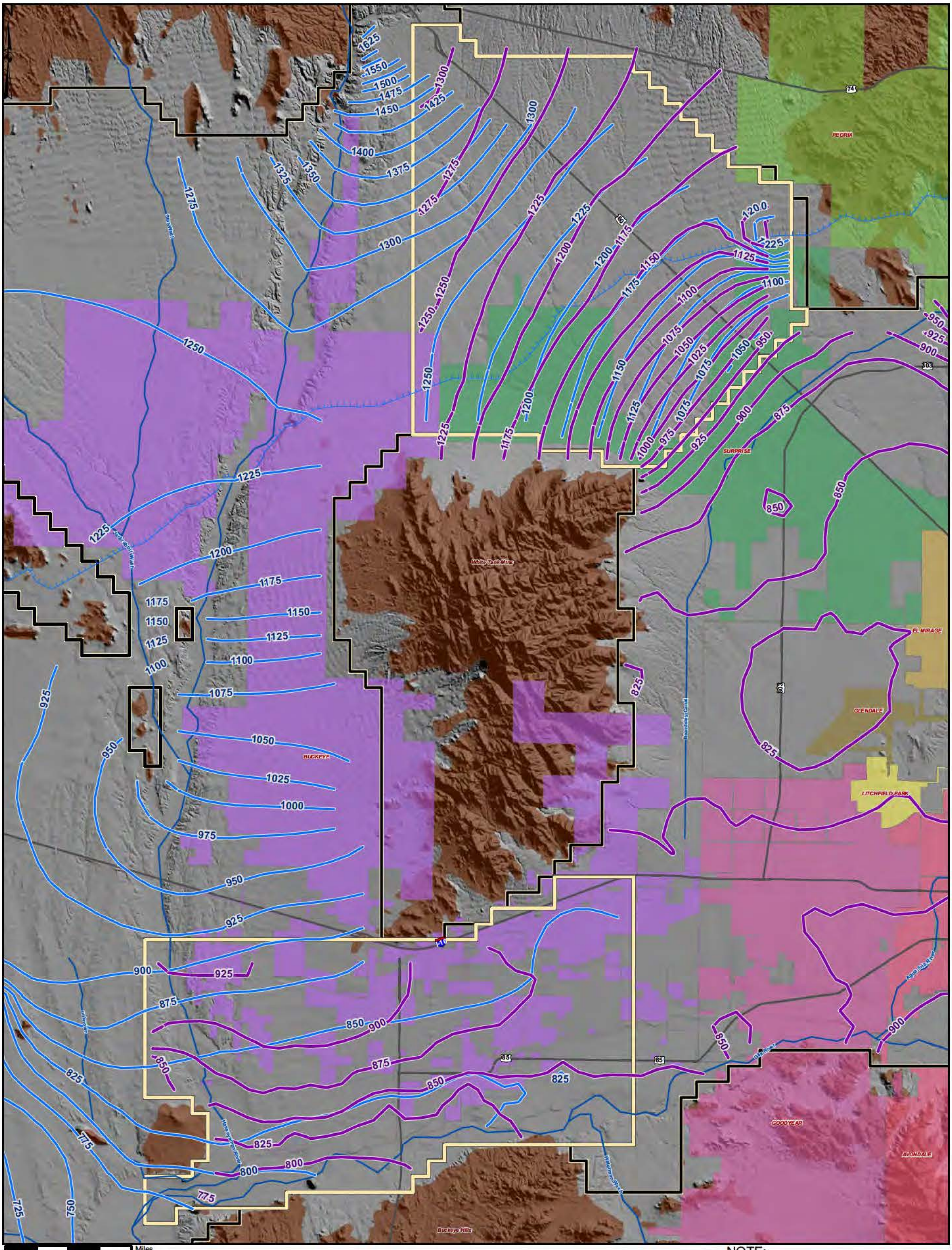

NOTE:
LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley
ft amsl = feet above mean sea level

EXPLANATION

- SRV Model Simulated Water Levels (ft amsl) Contour Interval = 25 ft
- LHSB Model Simulated Water Levels (ft amsl) Contour Interval = 25 ft
- Model Overlap Areas
- WESTCAPS Active Model Domain
- City Boundaries

BROWN AND CALDWELL

Figure 8
2006 SIMULATED WATER LEVEL COMPARISON
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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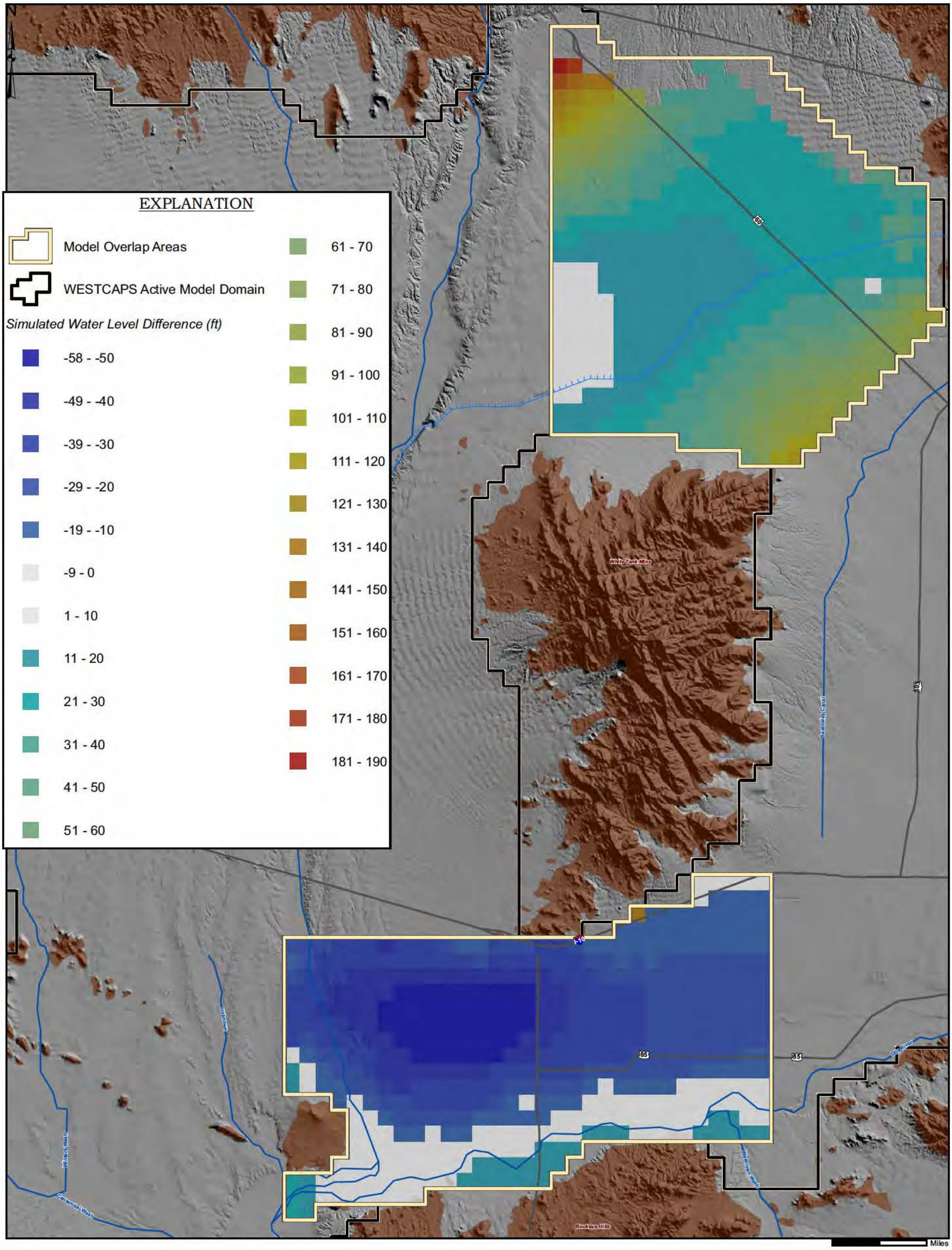

NOTE:
Negative values denote that the
LHSB model simulated water level is lower than the
SRV model simulated water level;
Positive values denote that the
LHSB model simulated water level is higher than the
SRV model simulated water level.

LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley
ft = feet

BROWN AND CALDWELL

Figure 9
2006 SIMULATED WATER LEVEL DIFFERENCE
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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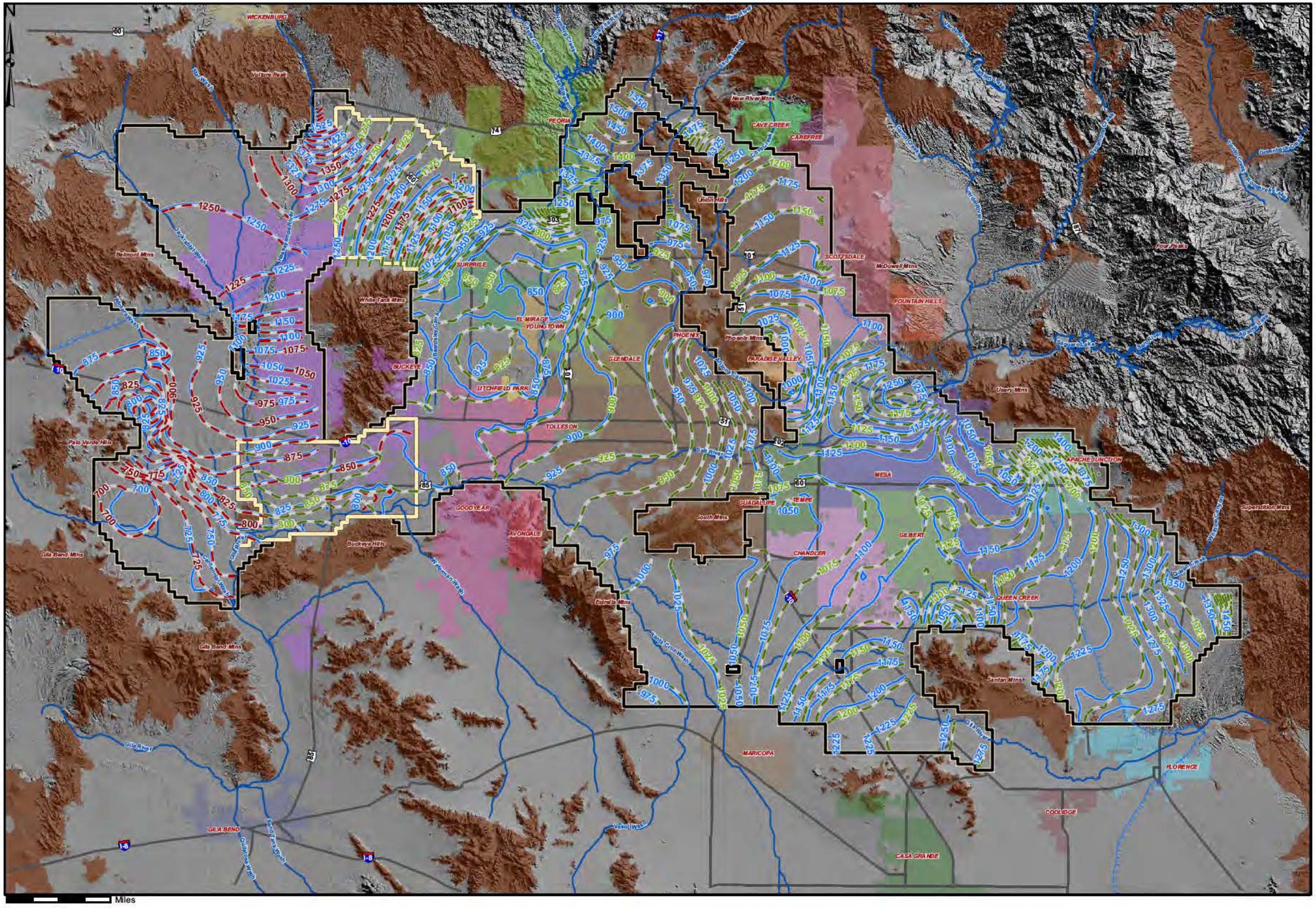

EXPLANATION

- SRV Model Simulated Water Levels (ft amsl) Contour Interval = 25 ft
- LHSB Model Simulated Water Levels (ft amsl) Contour Interval = 25 ft
- WESTCAPS Model Simulated Water Levels (ft amsl) Contour Interval = 25 ft
- Model Overlap Areas
- WESTCAPS Active Model Domain
- City Boundaries

BROWN AND CALDWELL

NOTE:
LHSB = Lower Hassayampa Sub-Basin
SRV = Salt River Valley
ft amsl = feet above mean sea level

Figure 10
WESTCAPS MODEL
2006 SIMULATED WATER LEVEL COMPARISON
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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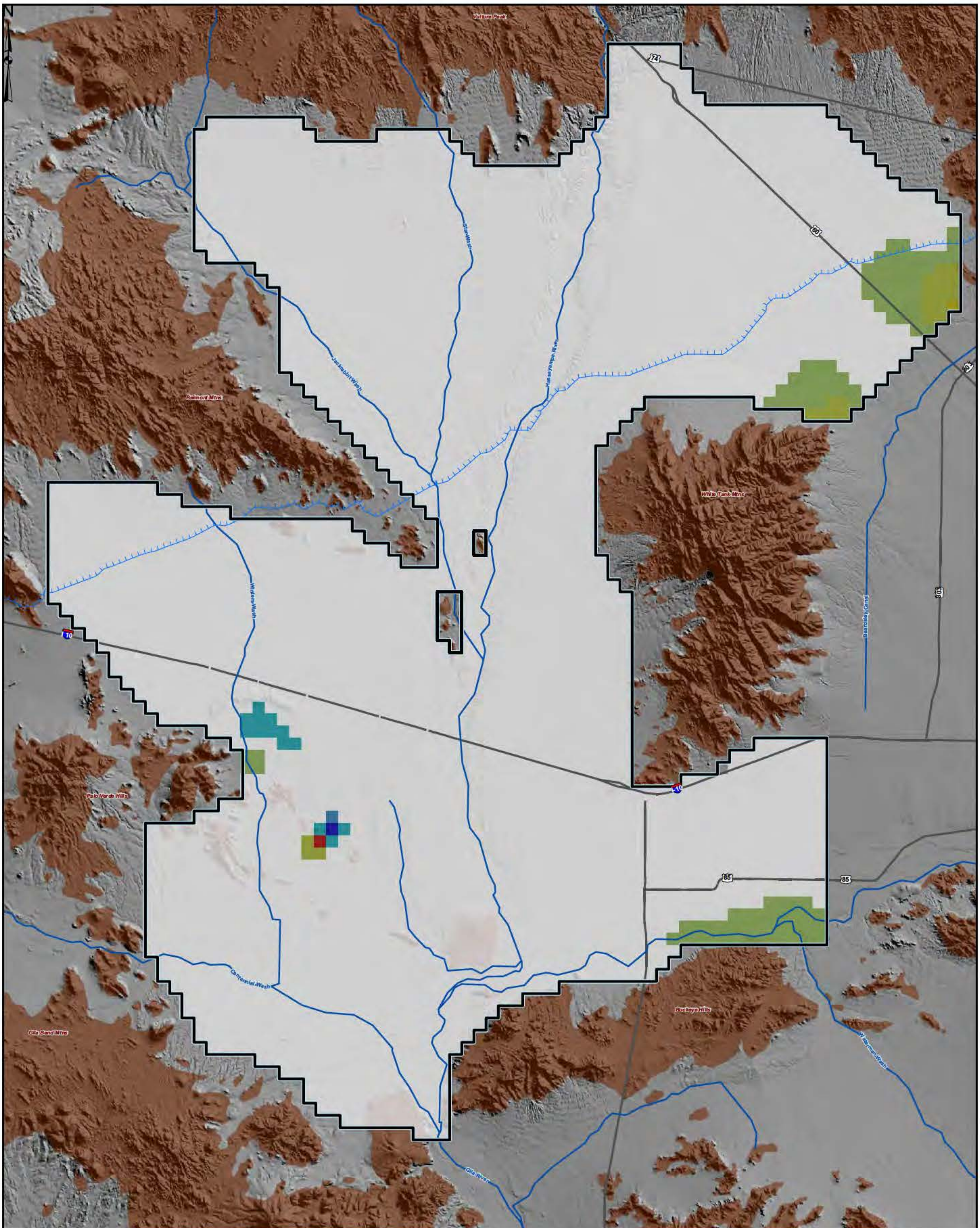

EXPLANATION

LHSB Active Model Domain

Simulated Water Level Difference (ft)

- -95 - -80
- -79 - -60
- -59 - -40
- -39 - -20
- -19 - -10
- -9 - 0
- 1 - 10
- 11 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100
- 101 - 120
- 121 - 140

NOTE:
Negative values denote that the LHSB model simulated water level is lower than the WESTCAPS model simulated water level;
Positive values denote that the LHSB model simulated water level is higher than the WESTCAPS model simulated water level.

LHSB = Lower Hassayampa Sub-Basin
ft = feet

BROWN AND CALDWELL

Figure 11
2006 LHSB MODEL and WESTCAPS MODEL SIMULATED WATER LEVEL DIFFERENCE
WESTCAPS GROUNDWATER MODELING PHASE 1
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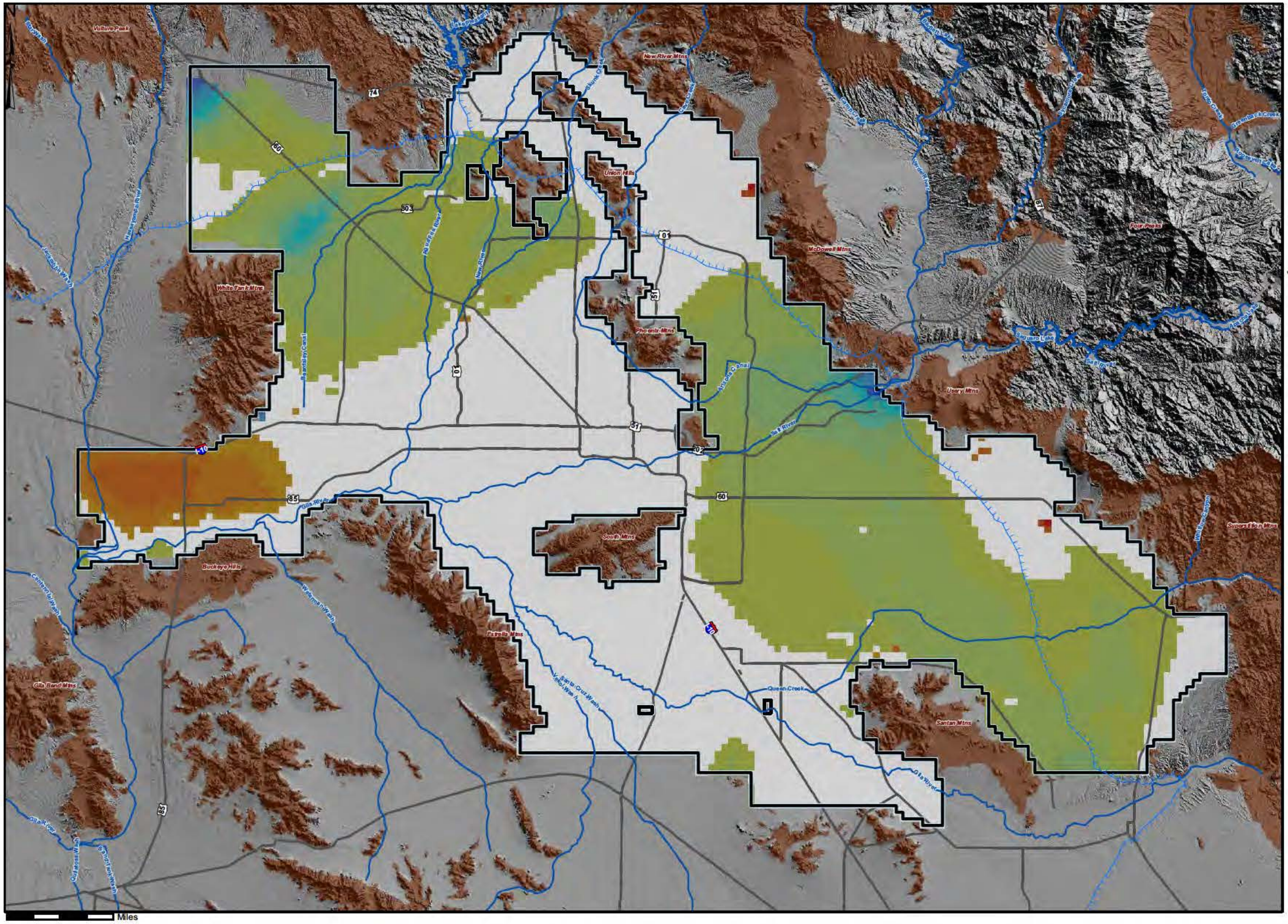

NOTE:
Negative values denote that the SRV model simulated water level is lower than the WESTCAPS model simulated water level;
Positive values denote that the SRV model simulated water level is higher than the WESTCAPS model simulated water level.

ADWR = Arizona Department of Water Resources
SRV = Salt River Valley
ft = feet

BROWN AND CALDWELL

Figure 12
2006 SRV MODEL and WESTCAPS MODEL SIMULATED WATER LEVEL DIFFERENCE
WESTCAPS GROUNDWATER MODELING PHASE 1
U.S. BUREAU OF RECLAMATION, ARIZONA

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APPENDIX A

Scope of Work

TABLE OF CONTENTS

SECTION C -- DESCRIPTIONS AND SPECIFICATIONS

C.1 SCOPE OF WORK (SOW)

Acronyms

3D	Three-Dimensional
ADWR	Arizona Department of Water Resources
CD	Compact Disc
ESI	Environmental Simulations International
ESRV	East Salt River Valley
EVS	Environmental Visualization Systems
GIS	Geographic Information System
LHSB	Lower Hassayampa Sub-Basin
SRV	Salt River Valley
USGS	United States Geological Survey
WESTCAPS	West Valley CAP Contractors
WSRV	West Salt River Valley

Task 1.0 - Obtain and Review ADWR's Updated SRV Model
The lead engineer will obtain ADWR's updated SRV model and any associated databases, and GIS data files. A model review will be performed emphasizing hydrogeologic conceptualization, ADWR's model results, and model calibration statistics. The entire model will be reviewed, however, an emphasis will be placed on the model assumptions and results in the WSRV region. The lead engineer will develop GIS compatible data sets and maps to support model review. Water levels, well information, any provided water quality data, groundwater pumping, and hydrostratigraphy will be maintained in a GIS compatible database structure that will support the spatial requirements of the modeling process.

Per the current performance schedule it is anticipated that you will receive the SRV model two months after the start date of the contract. If you do not receive the SRV model within the two months of the contract start date then a no cost time extension will be issued upon verification of receipt of the SRV model. Upon receipt of the SRV model you will immediately notify the Contracting Officer's Point Of Contact (POC) that you received it by email. The Contracting Officer's POC is William Doyle with email address wadoyle@lc.usbr.gov. The Contracting Officer will be on the cc line of that email. The Contracting Officer is Pete Smolinski with email address psmolinski@lc.usbr.gov.The method of performing the no cost time extension will be by bilateral modification to adjust the ending date.

Task 2.0 - Integration of the Updated SRV and LHSB models
The Engineer will review the feasibility of integrating the updated SRV model and the LHSB model. This review will be facilitated by running simulations with each model separately over the same time period, and model results in the overlapping regions will be compared. The assessment will focus on agreement and variations between the two models in water levels, hydraulic gradients, fluxes, model layering, hydraulic parameterization, and grid orientation and discretization in the vicinity of the overlapping boundaries.
The results of the assessment will determine how the work progresses in the ensuing task. In the event that the two models can be merged without alterations to the existing data bases, then the lead engineer will digitally integrate and merge the two models, creating the Expansion Model, a combined SRV-LHSB tool (see Task 3.0 (a) below). Should the assessment result in an understanding that alterations to the existing data bases are necessary (i.e., the models are not currently amenable to merging together without significant alterations to one or both models), the work will progress using Task 3.0 (b) below.

Task 3.0 (a) - Model Integration Test Run

The lead engineer will perform several test and sensitivity simulations with the Expansion Model to continue to identify any remaining inconsistencies. This assessment will focus on model results within the geographic regions where the models overlap, but will be broad enough to encompass the entire modeled region for evaluation of overall indicators of model performance, such as water budget and regional water level trends. Any adjustments made to model layering and parameters within the model overlap areas will be documented. Additionally, an assessment of water levels and groundwater flow gradients within the Expansion Model domain will be performed. The results of this work will provide the foundation for recommendations regarding proposed future work product and model updates.

Task 3.0 (b) - Necessary Steps Prior to Model Integration, and Model Integration Test Run
Prior to performing test runs of the model, the lead engineer would be required to modify model variables so that independent test runs of each model provide similar results at their common boundaries. This work, which is required prior to integrating and merging the models into the Expansion Model, replaces the effort required to perform the model integration test and sensitivity simulations only which is described in Task 3.0 (a). Only after altering the model parameters and construction details, which will improve the agreement between the results from both models can the lead engineer generate the Expansion Model and begin to perform a set of test simulations with the Expansion Model. Task 3.0 (b) therefore is a modified form of Task 3.0 (a), which focuses primarily on determining how to produce better agreement between simulation results from the updated SRV and LHSB models. The overall work will require that either Task 3.0 (a), or Task 3.0 (b) be accomplished. The primary deliverable from Task 3.0 (b) will be the framework required to successfully and accurately integrate the two models for future phases of work.

Task 4.0 - Documentation and Imagery
The Engineer will provide a final report of the review of the updated SRV model as well as full documentation of any adjustments or refinements that were applied to either the updated SRV or LHSB model to successfully merge the models and develop the Expansion Model. Additionally, the report will include recommendations for future model development and model updates, as well as identification of any data gaps identified during the course of this Scope of Work. All generated databases, GIS compatible files, and model files will be included in electronic formats.
A minimum of three, three-dimensional model visualizations and animations will be constructed using EVS or comparable software, demonstrating model construction, simulations, and any pertinent refinements; these files will also be provided in digital format and demonstrated by the lead Engineer during a presentation.

Performance Schedule

Item No.	Activities/Description	Activity and/or Completion Date
i.	Notifies Reclamation that SRV model has been obtained and begins work on Task 1.0	Upon receipt of the SRV model from ADWR
ii.	Completes Task 1.0	Within 30 calendar days of receipt of the SRV model
iii.	Completes Task 2.0	Within 60 calendar days of receipt of the SRV model
iv.	Completes Task 3.0(a) or Task 3.0 (b)	Within 90 calendar days of receipt of the SRV model
v.	Completes Task 4.0	Within 120 calendar days of receipt of the SRV model
vi.	Final Report Delivery	Within 30 calendar days of the completion of Task 4.0

SECTION G -- CONTRACT ADMINISTRATION DATA

G.1 PAYMENT TRACKING INFORMATION

Payment for supplies/services provided/performed under this purchase order/contract will be made by Electronic Funds Transfer. For assistance in tracking your payment information, Reclamation has entered into an agreement with the U.S. Department of the Treasury's Financial Management Services to make invoice payment remittance information available on the Internet or by e-mail to Reclamation vendors. There is no cost or obligation to use the Payment Advice Internet Delivery (PAID) system. For information on how to register for and access the PAID system, go to http://fms.treas.gov/paid/index.asp

SECTION H -- SPECIAL CONTRACT REQUIREMENTS

H.1 COMPLIANCE WITH SECTION 508 OF THE REHABILITATION ACT OF 1973

The products of this contract must be compliant with Section 508 of the Rehabilitation Act Of 1973 (29 U.S.C. 794(d)) as prescribed by Federal Acquisition Regulation (FAR) Subpart 39.2. The contractor is required to submit documentation verifying compliance.

SECTION I -- CONTRACT CLAUSES

I.1 1452.237-80 SECURITY REQUIREMENT -- INFORMATION TECHNOLOGY/COMPULSORY PROTECTION OF SENSITIVE INFORMATION AND SECURITY ACCESS REQUIREMENTS--BOR OCTOBER 2006

(a) General Security Requirements:

(1) This clause addresses security requirements, including general procedural requirements, information security requirements, contractor employee suitability requirements, identification card requirements, site security requirements, and information technology security requirements. Within this clause, COR means Contracting Officer's Representative. If there is no COR appointed and identified to the Contractor, the term instead will mean the Program Manager or any other authorized individual responsible for technical oversight under the contract. "Work site" means the Government facility, office, construction site, and any other area within the Government office or facility that the Contractor must access to accomplish work under this contract.

(2) The work performed under this contract shall only be accomplished by individuals (in the employment of the Contractor or any subcontractors) whose conduct and behavior is consistent with the efficiency of the Federal Service and the requirements of this contract, and who are acceptable to the CO. If Reclamation finds a Contractor employee to be unsuitable or unfit for his or her assigned duties, the CO will direct the Contractor to remove the individual from the contract and access to the Federal facility at which the contract activities are occurring.

(3) The Contractor's employees governed by this contract may need access to sensitive information and/or may need access to designated Controlled Access Areas (CAAs). The Federal Government (Government) reserves the right, in its sole discretion, to determine suitability of Contractor personnel and deny access to any sensitive information or project specific area to any personnel for any cause.

(4) The Contractor is responsible for informing and ensuring compliance by its employees with any applicable security procedures of the Government facility where work may be performed under this contract.

(5) Any Contractor employee that will have access to a Federally-controlled facility or information system will be required to have a Government-issued identification card consisting of either a Personal Identity Verification (PIV) Card, a temporary identification card, or a visitor badge. During performance of the contract, the Contractor shall keep the COR apprised of any changes in personnel, or changes in personnel access or duration, to ensure that performance is not delayed by compliance with credentialing processes.

(6) A Contractor employee will not be provided access to a Government facility or information system until a Government PIV Card, temporary identification card, or visitor identification badge has been issued to the Contractor employee. For those individuals that will be receiving a PIV Card, the Government may, at its discretion, issue a temporary identification card or visitor identification badge after the background investigation forms have been received and the investigation is initiated.

(7) All Contractor employees shall access the facility via the facility's entry screening system and visibly display the Government-issued PIV Card, temporary identification card, or visitor identification badge at all times. Contractor employees must visibly wear the Government-issued identification card at all times they are on Government facilities. Contractor employees are responsible for the safekeeping of all Government-issued identification cards, whether on-site or off-site. Cards that have been lost, damaged, or stolen must be reported to the COR within 24 hours. The Contractor shall return all identification cards and card keys and any other Government property and information upon completion of performance or when personnel depart permanently or for a period of 7 days or more. The Contractor may be required to turn in access control cards or identification cards on a daily basis.

(8) Misuse or loss of access control or identification cards, or failure to comply with required surrender of such cards may, at Government discretion, result in Contractor personnel being denied access to the work site, at no cost to Government. The Contractor may be charged up to $500 for each occurrence for any required replacement of Government-issued access control or identification cards due to loss or misuse. At the end of contract performance, or when a Contractor employee is no longer working under this contract, the Contractor shall ensure that all access control and identification cards are returned to the COR.

(9) All Contractor personnel, including subcontractor personnel, with access to the work site shall be U.S. citizens or foreign individuals legally residing in, or legally admitted to, the U.S. At the direction of the COR, the Contractor shall provide to the COR, in writing, the name and nationality of all non-U.S. citizens working under this contract. For those individuals with access to the work site, the Contractor shall also provide documentation that the foreign individual is legally residing in, or has been legally admitted to, the U.S.

(10) The Contractor shall report all contacts with entities, individuals, and counsel/representatives (including foreign entities and foreign nationals) who seek in any way to obtain unauthorized access to sensitive information or areas. The Contractor shall report any violations of contract provisions, laws, executive orders, regulations, and guidance to the CO. The Contractor shall report any information raising a doubt as to whether an individual's eligibility for continued employment or access to sensitive information is consistent with the interests of National Security and the Public Trust.

(11) Unsanctioned, negligent, or willful inappropriate action on the part of the Contractor (or its employees) may result in termination of the contract or removal of some Contractor employees from Reclamation facilities at no cost to the Government. These actions include, but are not limited to, exploration of a sensitive system and/or information, introduction of unauthorized and/or malicious software, or failure to follow prescribed access control policies and/or security procedures. Failure to comply with Reclamation policies, procedures, or other published security requirements may result in termination of the contract or removal of some contracted employees from Reclamation buildings and/or facilities at no cost to the Government.

(12) All provisions of this clause shall equally apply to all subcontractors. The Contractor shall incorporate the substance of this clause in all subcontracts.

(13) These security requirements apply to all sections of this Contract including Contract Drawings and other Contract Specifications as applicable. Related documents include other general provisions of Construction or Operations and Maintenance type Contracts, including FAR clauses by reference or as amended by related documents.

(b) Information Security Requirements.

(1) The term "sensitive information" means any information which warrants a degree of protection and administrative control as defined by Reclamation or that meets the criteria for exemption from public disclosure set forth under Sections 552 and 552a of Title 5, United States Code: the Freedom of Information Act and the Privacy Act. Sensitive information is generally categorized as FOR OFFICIAL USE ONLY (FOUO) information, but in some cases may include other unclassified information. (The protection of National Classified information is beyond the scope of this clause. If any work on classified information is required under this contract, it is addressed under other contract clauses.) The Contractor shall protect this type of information from unauthorized release into public domain, or to unauthorized persons, organizations, or subcontractors. Information which, either alone or in aggregate, is deemed sensitive by Reclamation shall be handled and protected in accordance with Reclamation Directives and Standards for Identifying and Safeguarding FOR OFFICIAL USE ONLY (FOUO) Information, which is available at http://www.usbr.gov/recman/DandS html#sle.

(2) Any Government-furnished information/material does not become the property of the Contractor and may be withdrawn at any time. Upon expiration of the contract, all documents released to the Contractor and any material created using data from such documents shall be returned to the COR for final disposition. Only with prior authorization from the CO may the Contractor retain the material. The Contractor or subcontractor shall not disclose or release the materials provided to the Contractor to any individuals of the Contractor's organization not directly engaged in providing services under the contract or that do not have a valid need-to-know. All technical data provided to the Contractor by the Government shall be protected from public or private disclosure in accordance with the markings printed on them. All other information relating to the items to be delivered or the services to be performed under this contract shall not be disclosed by any means without prior approval of the CO. Prohibited dissemination or disclosure includes, but is not limited to: permitting access to such information by foreign nationals or by immigrant aliens who may be employed by the Contractor, publication of technical or scientific papers, advertising, and disclosure to Contractor staff not investigated and deemed acceptable at the appropriate contract/information sensitivity level, or any other proposed public release. The Contractor shall maintain, and furnish upon demand of the CO, records of the names of individuals who have access to sensitive material in its custody. All questions regarding information security, access, and control shall be referred to the COR.

(3) The Contractor shall not release to anyone outside the Contractor's organization any sensitive, or otherwise protected information, regardless of medium in which it is contained (for example, film, tape, document, electronic), pertaining to any part of this contract or any Reclamation program or activity, unless the CO has given prior written approval. This includes, but is not limited to, news releases, marketing promotions, articles, interviews, reports, and any other media releases. Requests for approval shall identify the specific information to be released, the medium to be used, the purpose for the release, and a description of the need-to-

know. The Contractor shall submit its request to the CO before the proposed date for release. Subcontractors shall submit requests for authorization to release through the prime Contractor to the CO.

(4) The Contractor shall notify the COR immediately when known or suspected loss/compromise of sensitive information or other documents, notes, drawings, sketches, reports, photographs, exposed film or similar information which may affect the security interests of Government has occurred. This requirement extends to employees and other personnel working on behalf of the Contractor, and expands responsibility to include prompt reporting of security issues, including observed or subsequently discovered efforts by unauthorized persons to gain unauthorized access to sensitive information.

I.2 52.227-14 RIGHTS IN DATA--GENERAL DECEMBER 2007

(a) Definitions. As used in this clause-

"Computer database" or "database means" a collection of recorded information in a form capable of, and for the purpose of, being stored in, processed, and operated on by a computer. The term does not include computer software.

"Computer software"- (1) Means (i) Computer programs that comprise a series of instructions, rules, routines, or statements, regardless of the media in which recorded, that allow or cause a computer to perform a specific operation or series of operations; and

(ii) Recorded information comprising source code listings, design details, algorithms, processes, flow charts, formulas, and related material that would enable the computer program to be produced, created, or compiled.

(2) Does not include computer databases or computer software documentation.

"Computer software documentation" means owner's manuals, user's manuals, installation instructions, operating instructions, and other similar items, regardless of storage medium, that explain the capabilities of the computer software or provide instructions for using the software.

"Data" means recorded information, regardless of form or the media on which it may be recorded. The term includes technical data and computer software. The term does not include information incidental to contract administration, such as financial, administrative, cost or pricing, or management information.

"Form, fit, and function data" means data relating to items, components, or processes that are sufficient to enable physical and functional interchangeability, and data identifying source, size, configuration, mating and attachment characteristics, functional characteristics, and performance requirements. For computer software it means data identifying source, functional characteristics, and performance requirements but specifically excludes the source code, algorithms, processes, formulas, and flow charts of the software.

"Limited rights" means the rights of the Government in limited rights data as set forth in the Limited Rights Notice of paragraph (g)(3) if included in this clause.

"Limited rights data" means data, other than computer software, that embody trade secrets or are commercial or financial and confidential or privileged, to the extent that such data pertain to items, components, or processes developed at private expense, including minor modifications.

"Restricted computer software" means computer software developed at private expense and that is a trade secret, is commercial or financial and confidential or privileged, or is copyrighted computer software, including minor modifications of the computer software.

"Restricted rights," as used in this clause, means the rights of the Government in restricted computer software, as set forth in a Restricted Rights Notice of paragraph (g) if included in this clause, or as otherwise may be provided in a collateral agreement incorporated in and made part of this contract, including minor modifications of such computer software.

"Technical data" means recorded information (regardless of the form or method of the recording) of a scientific or technical nature (including computer databases and computer software documentation). This term does not include computer software or financial, administrative, cost or pricing, or management data or other information incidental to contract administration. The term includes recorded information of a scientific or technical nature that is included in computer databases (See 41 U.S.C. 403(8)).

"Unlimited rights" means the rights of the Government to use, disclose, reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, in any manner and for any purpose, and to have or permit others to do so.

(b) Allocation of rights. (1) Except as provided in paragraph (c) of this clause, the Government shall have unlimited rights in-

(i) Data first produced in the performance of this contract;

(ii) Form, fit, and function data delivered under this contract;

(iii) Data delivered under this contract (except for restricted computer software) that constitute manuals or instructional and training material for installation, operation, or routine maintenance and repair of items, components, or processes delivered or furnished for use under this contract; and

(iv) All other data delivered under this contract unless provided otherwise for limited rights data or restricted computer software in accordance with paragraph (g) of this clause.

(2) The Contractor shall have the right to-

(i) Assert copyright in data first produced in the performance of this contract to the extent provided in paragraph (c)(1) of this clause;

(ii) Use, release to others, reproduce, distribute, or publish any data first produced or specifically used by the Contractor in the performance of this contract, unless provided otherwise in paragraph (d) of this clause;

(iii) Substantiate the use of, add, or correct limited rights, restricted rights, or copyright notices and to take other appropriate action, in accordance with paragraphs (e) and (f) of this clause; and

(iv) Protect from unauthorized disclosure and use those data that are limited rights data or restricted computer software to the extent provided in paragraph (g) of this clause.

(c) Copyright- (1) Data first produced in the performance of this contract. (i) Unless provided otherwise in paragraph (d) of this clause, the Contractor may, without prior approval of the Contracting Officer, assert copyright in scientific and technical articles based on or containing data first produced in the performance of this contract and published in academic, technical or professional journals, symposia proceedings, or similar works. The prior, express written permission of the Contracting Officer is required to assert copyright in all other data first produced in the performance of this contract.

(ii) When authorized to assert copyright to the data, the Contractor shall affix the applicable copyright notices of 17 U.S.C. 401 or 402, and an acknowledgment of Government sponsorship (including contract number).

(iii) For data other than computer software, the Contractor grants to the Government, and others acting on its behalf, a paid-up, nonexclusive, irrevocable, worldwide license in such copyrighted data to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly by or on behalf of the Government. For computer software, the Contractor grants to the Government, and others acting on its behalf, a paid-up, nonexclusive, irrevocable, worldwide license in such copyrighted computer software to reproduce, prepare derivative works, and perform publicly and display publicly (but not to distribute copies to the public) by or on behalf of the Government.

(2) Data not first produced in the performance of this contract. The Contractor shall not, without the prior written permission of the Contracting Officer, incorporate in data delivered under this contract any data not first produced in the performance of this contract unless the Contractor-

(i) Identifies the data; and

(ii) Grants to the Government, or acquires on its behalf, a license of the same scope as set forth in paragraph (c)(1) of this clause or, if such data are restricted computer software, the Government shall acquire a copyright license as set forth in paragraph (g)(4) of this clause (if included in this contract) or as otherwise provided in a collateral agreement incorporated in or made part of this contract.

(3) Removal of copyright notices. The Government will not remove any authorized copyright notices placed on data pursuant to this paragraph (c), and will include such notices on all reproductions of the data.

(d) Release, publication, and use of data. The Contractor shall have the right to use, release to others, reproduce, distribute, or publish any data first produced or specifically used by the Contractor in the performance of this contract, except-

(1) As prohibited by Federal law or regulation (e.g., export control or national security laws or regulations);

(2) As expressly set forth in this contract; or

(3) If the Contractor receives or is given access to data necessary for the performance of this contract that contain restrictive markings, the Contractor shall treat the data in accordance with such markings unless specifically authorized otherwise in writing by the Contracting Officer.

(e) Unauthorized marking of data. (1) Notwithstanding any other provisions of this contract concerning inspection or acceptance, if any data delivered under this contract are marked with the notices specified in paragraph (g)(3) or (g) (4) if included in this clause, and use of the notices is not authorized by this clause, or if the data bears any other restrictive or limiting markings not authorized by this contract, the Contracting Officer may at any time either return the data to the Contractor, or cancel or ignore the markings. However, pursuant to 41 U.S.C. 253d, the following procedures shall apply prior to canceling or ignoring the markings.

(i) The Contracting Officer will make written inquiry to the Contractor affording the Contractor 60 days from receipt of the inquiry to provide written justification to substantiate the propriety of the markings;

(ii) If the Contractor fails to respond or fails to provide written justification to substantiate the propriety of the markings within the 60-day period (or a longer time approved in writing by the Contracting Officer for good cause shown), the Government shall have the right to cancel or ignore the markings at any time after said period and the data will no longer be made subject to any disclosure prohibitions.

(iii) If the Contractor provides written justification to substantiate the propriety of the markings within the period set in paragraph (e)(1)(i) of this clause, the Contracting Officer will consider such written justification and determine whether or not the markings are to be cancelled or ignored. If the Contracting Officer determines that the markings are authorized, the Contractor will be so notified in writing. If the Contracting Officer determines, with concurrence of the head of the contracting activity, that the markings are not authorized, the Contracting Officer will furnish the Contractor a written determination, which determination will become the final agency decision regarding the appropriateness of the markings unless the Contractor files suit in a court of competent jurisdiction within 90 days of receipt of the Contracting Officer's decision. The Government will continue to abide by the markings under this paragraph (e)(1)(iii) until final resolution of the matter either by the Contracting Officer's determination becoming final (in which instance the Government will thereafter have the right to cancel or ignore the markings at any time and the data will no longer be made subject to any disclosure prohibitions), or by final disposition of the matter by court decision if suit is filed.

(2) The time limits in the procedures set forth in paragraph (e)(1) of this clause may be modified in accordance with agency regulations implementing the Freedom of Information Act (5 U.S.C. 552) if necessary to respond to a request thereunder.

(3) Except to the extent the Government's action occurs as the result of final disposition of the matter by a court of competent jurisdiction, the Contractor is not precluded by paragraph (e) of the clause from bringing a claim, in accordance

with the Disputes clause of this contract, that may arise as the result of the Government removing or ignoring authorized markings on data delivered under this contract.

(f) Omitted or incorrect markings. (1) Data delivered to the Government without any restrictive markings shall be deemed to have been furnished with unlimited rights. The
Government is not liable for the disclosure, use, or reproduction of such data.

(2) If the unmarked data has not been disclosed without restriction outside the Government, the Contractor may request, within 6 months (or a longer time approved by the Contracting Officer in writing for good cause shown) after delivery of the data, permission to have authorized notices placed on the data at the Contractor's expense. The Contracting Officer may agree to do so if the Contractor-

(i) Identifies the data to which the omitted notice is to be applied;

(ii) Demonstrates that the omission of the notice was inadvertent;

(iii) Establishes that the proposed notice is authorized; and

(iv) Acknowledges that the Government has no liability for the disclosure, use, or reproduction of any data made prior to the addition of the notice or resulting from the omission of the notice.

(3) If data has been marked with an incorrect notice, the Contracting Officer may-

(i) Permit correction of the notice at the Contractor's expense if the Contractor identifies the data and demonstrates that the correct notice is authorized; or

(ii) Correct any incorrect notices.

(g) Protection of limited rights data and restricted computer software. (1) The Contractor may withhold from delivery qualifying limited rights data or restricted computer software that are not data identified in paragraphs (b)(1)(i), (ii), and (iii) of this clause. As a condition to this withholding, the Contractor shall-

(i) Identify the data being withheld; and

(ii) Furnish form, fit, and function data instead.

(2) Limited rights data that are formatted as a computer database for delivery to the Government shall be treated as limited rights data and not restricted computer software.

(3) [Reserved]

(h) Subcontracting. The Contractor shall obtain from its subcontractors all data and rights therein necessary to fulfill the Contractor's obligations to the Government under this contract. If a subcontractor refuses to accept terms affording the Government those rights, the Contractor shall promptly notify the Contracting Officer of the refusal and shall not proceed with the subcontract award without authorization in writing from the Contracting Officer.

(i) Relationship to patents or other rights. Nothing contained in this clause shall imply a license to the Government under any patent or be construed as affecting the scope of any license or other right otherwise granted to the Government.

APPENDIX Z

Digital Deliverable (see enclosed Data CD)