SAN BERNARDINO BASIN AREA REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT

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Prepared For:

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SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND
SOLUTE TRANSPORT MODEL REPORT

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SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND
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1.0 EXECUTIVE SUMMARY

The San Bernardino Basin Area (SBBA) includes the Bunker Hill and Lytle Groundwater Basins. Approximately 600,000 residents in the SBBA depend upon these underground reservoirs as their primary water source. In the past, water levels in the Pressure Zone (located wholly within the City of San Bernardino and commonly referred to as the Area of Historic High Groundwater) have risen high enough to cause artesian conditions (groundwater rising above land surface). Groundwater levels which are this shallow frequently cause basements to flood (adversely affect the load-bearing capacity of streets), disrupt underground utilities, and may cause "liquefaction" during an earthquake. When liquefaction occurs, the ground no longer provides support to underground utilities or overlying structures, allowing them to sink or to float. In some cases, the foundational supports have been compromised, resulting in buildings toppling over.

The SBBA is also plagued by groundwater contamination plumes. The Newmark Groundwater Contamination Superfund Site cleanup projects are currently underway in the SBBA. A work plan was developed by the Newmark project team (Newmark Team) for the enhancement of a groundwater flow model to support work at this Superfund Site. The purpose was to develop a modeling tool to implement the "institutional controls" as required by the Consent Decree in a fairly focused area around the Muscoy and Newmark plumes. Because the Superfund site represents a relatively small portion of the SBBA, the Newmark Groundwater Flow Model (NGFM) depends upon boundary conditions obtained from the flow model developed for the SBBA (Basin Flow Model) by the USGS. The USGS Basin Flow Model is an integrated streamflow and groundwater model developed for streams and the valley-fill aquifer of the SBBA, including Bunker Hill and Lytle Creek Basins (Danskin, McPherson and Woolfenden, 2006). San Bernardino Valley Municipal Water District (Valley District) is a "cooperator" with the USGS and funded a large portion of the modeling work for purposes of being able to evaluate "cumulative impacts" on the Basin from various existing and proposed projects. These cumulative impacts may, in time, extend basin-wide. Since the conditions in the overall basin will vary, the boundary conditions for the NGFM will also vary. Thus, to operate the NGFM separately would require very close coordination with the USGS Basin Flow Model.

To eliminate the possibility of having inaccurate boundary conditions in the NGFM and to avoid the development of two different models that may not be compatible or defendable, it was agreed by the City of San Bernardino Municipal Water Department (SBMWD) and Valley District that the regional USGS Basin Flow Model would be modified to a detail sufficient to evaluate both Consent Decree issues in and around the Newmark/Muscoy plumes and basin-wide management issues. This refined is named as the Newmark Groundwater Flow Model/Refined Basin Flow Model (NGFM/RBFM). As part of this management strategy, a refinement of the Basin Flow Model was undertaken for Valley District under USEPA Grant X-97957701-1. This approach of having only one model not only eliminated the duplication of effort, but it also ensured that the RBFM still retains the credibility of the original USGS Basin Flow Model. As part of the refinement, the Valley District's Basin Water Quality Model was also refined and was named as Refined Basin Solute Transport Model (RBSTM).

The scope of work for this Project included the following:

- Conducted a comprehensive review and interpretation of existing geohydrologic data that was used to compile input to the refined basin flow and transport models. Data gaps within the SBBA were identified and recommendations for data collection were provided in a technical memorandum (GEOSCIENCE, 2006);
- Provided additional data collected to update datasets of well locations and

construction details, groundwater production, and groundwater quality with respect to preparing input files for the refined models;

- Reviewed the existing USGS Basin Flow Model and Valley District's Basin Water Quality Model, and incorporated the components into the RBFM and RBSTM;

- Characterized the perchloroethene (PCE), trichloroethene (TCE) and perchlorate groundwater contaminant plumes within the SBBA for purposes of developing initial conditions, and for the selection of transport model calibration targets. Water quality data was also provided to AMEC Geomatrix to update Valley District's EQuIS[1] database;

- Refined the basin flow and solute transport models. The refinement included reducing model cell size, increasing the number of model layers, and modifying the length of annual stress periods;

- Conducted a comprehensive review of groundwater barriers locations. This was conducted due to inconsistencies of the locations in the existing dataset;

- One of the major model refinements is the subdivision of model layers. Stantec developed the model layers in the Newmark and Muscoy plume areas using a 3-D lithology model with assistance from Numeric Solutions. In order to be consistent with the approach used by Stantec, GEOSCIENCE expanded the 3-D lithology model to the entire model area with subcontracted assistance from Numeric Solutions;

- Conducted steady-state model calibration and transient model calibration for the RBFM from 1945 to 2000 (Runs 1 through 9), and the RBSTM from 1986 to 2000. The RBFM was also calibrated for the period from 1983 through 2000 with a monthly stress period (Run 10). The RBFM was also verified by extending the transient calibration period to 2006 (Run 11);

1 Environmental Quality Information System (EQuIS) developed for SBVMWD by EarthSoft.

- Conducted sensitivity analysis for the RBFM;
- Simulated various predictive model runs for the Upper Santa Ana River Watershed Integrated Regional Water Management Plan (IRWMP) Baseline Run 1 and conjunctive use scenarios using the RBFM;
- Simulated various predictive model runs for sensitivity to SWP water and local surface water supplies using the RBFM;
- Simulated predictive model run for the Updated Baseline Run (Run 12)[2] using the RBFM and RBSTM;
- Attended peer review meetings to discuss the model refinement and calibration processes;
- Provided peer review for the NGFM report prepared by Stantec; and
- Prepared a model summary report to document the results of all previous tasks.

The following table summarizes the model runs were included in this report.

[2] This run is the updated run for the IRWMP Baseline Run 1 (see Section 5.3.1 for the changes in model assumptions).

Model Runs		Model Time Period	Type of Model
Steady-State Model Calibration		1945	Flow
Transient Model Calibration	**Run 1 through Run 9**	1945 to 2000	Flow
	Run 10	1983 to 2000	Flow
	PCE and TCE Calibration	1984 to 2000	Solute Transport
Model Verification	**Run 11**	2001 to 2006	Flow
Predictive Model Runs	**IRWMP Baseline Run 1 and Conjunctive Use Scenarios**	Model Year: 2006 to 2044 Hydrologic Year: 1962 to 2000	Flow
	Sensitivity to SWP and Local Surface Water Supplies Runs	Model Year: 2006 to 2044 Hydrologic Year: 1962 to 2000	Flow
	Updated Baseline Run (Run 12)	Model Year: 2007 to 2032 Hydrologic Year: 1979 to 2004	Flow and Solute Transport

This report summarizes the tools and methodology used in the refinement of the USGS Basin Flow Model and the Basin Water Quality Model. It also summarizes the results of various IRWMP Baseline Run 1 and conjunctive use scenarios and sensitivity run that were performed using the RBFM. This report also summarizes the results of the Updated Baseline Run (Run 12) simulated using the RBFM and RBSTM.

The refinement process for both the RBFM and RBSTM was a cooperative technical effort involving representatives of the SBMWD and Valley District, their respective consultants at Stantec and GEOSCIENCE, and Mr. Wes Danskin of the USGS. A total of 11 model runs were made for the calibration runs of the RBFM as shown in the following table.

Summary of Transient Calibration Model Runs of RBFM

Model Run	Description
Run 1	USGS Model with Cell Size of 102.5x102.5 feet (without HFB and STR Packages)
Run 2	USGS Model with Cell Size of 102.5x102.5 feet (with HFB and STR Packages)
Run 3	USGS Model with Cell Size of 102.5x102.5 feet and Refinements of HFB and STR Packages
Run 4	USGS Model with Cell Size of 102.5x102.5 feet and Refinements of Well, HFB and STR Packages
Run 5	Two-Layer MODFLOW 2000 with K and b
Run 6	Five-Layer MODFLOW 2000 with Uniform Properties and New Basement
Run 7	Five-Layer MODFLOW 2000 with New Interpretation of Model Layer Elevations
Run 8	Steady State Model Calibration (1945)
Run 9	Annual Transient Model Calibration (1945-2000)
Run 10	Monthly Transient Model Calibration (January 1983 – December 2000)
Run 11	Monthly Model Verification (January 2001 – December 2006)

Note:
HFB is Horizontal-Flow Barrier Package
STR represents Streamflow-Routing Package

GEOSCIENCE made the runs from Run 1 through Run 9. During the process of model Run 1 through Run 9, a comprehensive review of groundwater barriers locations was conducted due to inconsistencies of the locations in the existing dataset. In addition, GEOSCIENCE experienced model numerical instability (i.e., failure to converge). One of the most sensitive model inputs to cause instability is the streamflow-routing package. GEOSCIENCE spent a significant amount of time to develop the package with variations of the number of cells used and streambed conductance.

GEOSCIENCE also assisted Stantec in developing the Streamflow-Routing and Recharge packages and collecting monthly production data for the model Runs 10 and 11.

The original USGS Basin Flow Model covers an area of approximately 524 square miles and is a two-layer finite difference model with a cell size of 820 feet x 820 feet. The RBFM is a five-layered finite difference model and covers the same area as the original USGS Basin Flow Model. Each model cell of the original USGS Basin Flow Model was rediscretized to 64 model cells with a cell size of 102.5 feet x 102.5 feet. The refined model consists of 944 nodes[3] in the north-to-south direction (i-direction) and 1,472 nodes in the west-to-east direction (j-direction), for a total of 6,947,840 nodes.

The RBFM was calibrated appropriately including steady-state model calibration (1945), annual transient model calibration (1945-2000), monthly transient model calibration (January 1983–December 2000), and monthly model verification (January 2001–December 2006). In general, steady-state model calibration is acceptable with a relative error of 7.1% and mean residual of 11.29 feet based on the measured water level in 120 wells in 1945. For the annual transient model calibration (Run 9), historical groundwater level data for 141 wells within the SBBA were compared with model-generated groundwater levels. In general, the pattern of the model-generated and measured levels are similar in that the model appears to capture the long- and short-term temporal trends in groundwater levels in most parts of the basin. The relative error of the model-generated groundwater levels between 1945 and 2000 is approximately 4.6%. Common modeling practice is to consider a good fit between historical and model-predicted data if the relative error is below 10%. The model also provided a good match with the gaged surface runoff within the SBBA. For the monthly transient calibration January 1983 – December 2000 (Run 10), the relative error of water level residuals is approximately 4.3% with an average water level residual of -6.6 feet. For the monthly model validation January 2001 through December 2006 (Run 11), the relative error of water level residuals is approximately 4.6% with an average

3 A model "node" is the center of a model "cell." The model cells are square with a side of 102.5 ft. The network of model cells forms a "grid" or "mesh" covering the entire model area.

water level residual of 3.2 feet. This water level residual statistic indicates that the SBBA RBFM accurately simulates water levels in most of the model area.

The RBSTM was calibrated against the observed PCE and TCE data for the period 1986 through 2000. The model relative error is 7.7% and 3.4% for PCE and TCE concentrations, respectively. It is common modeling practice to consider a relative error of less than 10% to be a good fit. Therefore, these results are considered reasonable.

Based on the results from the predictive model runs for the IRWMP Baseline Run 1 and conjunctive use scenarios, the following conclusions are made:

- In general, the model-generated groundwater flow direction for the IRWMP Baseline Run 1 is similar to historical directions with groundwater flowing west from the SAR and Mill Creek Spreading Grounds, and southeast from the Lytle Creek southeast from the Lytle Creek and Cajon Creek (i.e., flowing to the Pressure Zone area). Groundwater level fluctuations reflect hydrological wet and dry cycles. For example, a change in groundwater level of 50 feet to 100 feet occurs in the Pressure Zone between model years 2027 (equivalent to 1983 – end of a wet year cycle) and 2036 (equivalent to 1992 - end of a dry cycle). Groundwater flow directions and general patterns of fluctuations for the three conjunctive use scenarios (Runs 1A, 1B and 1C) are similar to the Baseline Run 1.

- The lowest groundwater level for the Baseline Run 1 would be approximately 160 feet in the City of Riverside Raub 1 Well, which is above the historical lowest level. Therefore land subsidence potential for this model run is minimal. However, groundwater levels would be an additional 20 to 60 feet lower in this well for model Runs 1A, 1B, and 1C compared to the Baseline Run 1. Depth to groundwater level below the historical low may have subsidence potential. The Basin Management Technical Committee of SBBA plans to monitor land subsidence in their annual Regional Water Management Plan.

- Annual potential liquefaction area as a percentage of the Pressure Zone area ranges from zero in year 2036 (hydrologic year 1992) to 6.0% in year 2030 (hydrologic year 1986) with an annual average of 2.3%. This is significant reduction as compared to the high groundwater conditions in the Pressure Zone occurred in 1984. In 1984, approximately 50% of Pressure Zone area was with depth to water shallower or equal to 50 feet below the land surface. The potential liquefaction area in the Pressure Zone for model Runs 1A and 1B would be similar to the conditions of Baseline Run 1. Run 1C shows elevated potential liquefaction areas in some years with the greatest percentage up to 19.5% in year 2019. In this case, liquefaction potential is higher in both Highland and San Bernardino. Mitigation through additional of pumping of wells or new wells would be needed to lower the groundwater level below 50 feet from land surface. The Basin Management Technical Committee of SBBA plans to review water levels annually in their Regional Water Management Plan.

- Groundwater storage in the SBBA increases 322 acre-ft/yr during the period 2006 through 2044 under Baseline Run 1 conditions. Changes in groundwater storage for all three conjunctive use runs are similar to Baseline Run 1 ranging from a decline of 722 acre-ft/yr for Run 1B to an increase of 726 acre-ft/yr for Run 1A. The patterns of the cumulative changes in groundwater storage for all the four model runs during the period 2006-2044 are similar to the historical period from 1962-2000. At the end of the model simulation in year 2044, the cumulative change in groundwater storage would be negative 200,000 acre-ft, which would be similar to the level at the beginning of the model simulation (i.e., in year 2005). This indicates that the basin is in “balance.”

- For model Runs 1A, 1B and 1C, the additional amounts of artificial recharge compared to Baseline Run 1 are 22,956 acre-ft/yr, 72,924 acre-ft/yr and 114,433 acre-ft/yr, respectively. Due to artificial recharge, the amounts of recharge from gaged streamflow, evapotranspiration, groundwater pumping, underflow and changes in groundwater storage are also changed. The major loss of water for the conjunctive use model runs would be the reduction of recharge from gaged streamflow. These decreases are 781 acre-ft/yr, 11,143 acre-ft/yr and 21,755 acre-ft/yr for model Runs 1A, 1B, and 1C, respectively. This loss is due to a significant increase in artificial recharge at the spreading grounds in the forebay area that would cause higher groundwater levels in the forebay area, thereby preventing some groundwater recharge in the stream channel (i.e., rejected recharge). For purpose of this report, the efficiency of conjunctive use was calculated as the ratio of the amount of additional groundwater pumping to the amount of additional artificial recharge. The efficiency ranges from 77% for model Run 1C to 87% model Run 1A.

- The maximum groundwater pumping during a single year drought was 289,105 acre-ft in 2034 (hydrologic year 1990) for the Baseline Run 1. This was to meet the projected water demands and additional 4.3% increase for a critical year. The additional yield for the conjunctive use would be 40,000 acre-ft, 120,000 acre-ft and 160,000 acre-ft for model Runs 1A, 1B, and 1C, respectively. This additional yield is due to water stored prior to the drought for these conjunctive use scenarios. The conjunctive use scenarios are essentially "put and take" projects. The additional yields (take) require an equivalent amount of net recharge (put) (i.e., amount of recharge minus water losses due to rejected recharge and evapotranspiration). The maximum groundwater pumping during a three-year drought was 838,422 acre-ft in 2032-2034 (hydrologic years 1988-1990) for the Baseline Run 1. This was to meet the projected water demands and additional 4.3% increase in these critical years. The additional yield for the conjunctive use would be 100,000 acre-ft, 320,000 acre-ft and 420,000 acre-ft for model Runs 1A, 1B, and 1C, respectively.

Based on the results from the predictive model runs for sensitivity analysis to the surface water supplies including SWP water and local surface water, the following conclusions were made:

- Groundwater levels would decrease in these runs compared to the IRWMP Baseline Run 1 reflecting the reduction of SWP and local surface water supplies. For example, water levels in the Backyard Well would decrease by 20 ft (95% local surface water supplies) to 50 ft (50% SWP) in year 2044 as compared to the water level under Baseline Run 1 conditions.

- Cases A through D show that reducing the reliability of the SWP and/or local surface water supplies would result in annual declines ranging from 3,773 acre-ft per year to 11,561 acre-ft per year, or 147,100 acre-ft to 450,900 acre-ft over the 39-year base period. In worse case scenario (Case E), the cumulative groundwater storage decline for the entire 39-year study period would be approximately 798,200 acre-ft (20,467 acre-ft/yr). Since the cumulative change in storage is lower than the Baseline Run 1 for each of these cases, specific water management strategies would need to be implemented to make up for the loss in these supplies.

- Although the basin cannot meet demands if the SWP or local supplies are reduced, the model can show the impacts on individual wells. Approximately 76% of the total groundwater pumping in the SBBA comes from 134 wells operated by the major retail water agencies in the SBBA. Modeling results show that water levels in 18% to 20% of the 134 wells (i.e., 24 to 27 wells) would be below the top of the screen interval by more than 50% at the end of multiple drought years under the reduction of SWP or local surface water supplies. This will reduce the pumping capacity of these wells. Under the worst case scenario (Case E) conditions, there would be more than 27 wells with water levels below the top of screen interval by more than 50% at the end of multiple drought years. However, these conditions can be mitigated by water conservation, water recycling projects, increased utilization of storm water and implementation of new conjunctive use projects.

Based on the results from the predicted model run for the Updated Baseline Run (Run 12), the following conclusions are made:

- In general, the model-generated groundwater flow direction and range of water level fluctuations for the Updated Baseline Run (Run 12) are similar to historical directions and IRWMP Baseline Run 1 conditions with groundwater flowing west from the SAR and Mill Creek and southeast from the Lytle Creek and Cajon Creek toward the Pressure Zone area and groundwater level fluctuations reflecting hydrological wet and dry cycles.

- The acreage of the potential liquefaction area is approximately 720 acres and is approximately 4% of total Pressure Zone area of 19,320 acres. The highest percentage was 6.0% in year 2030 (hydrologic year 1986) for the IRWMP Baseline Run 1 and 50% for the historical conditions occurred in 1984.

- Groundwater storage in the SBBA decreases approximately 1,200 acre-ft/yr during the period 2007 through 2032 under the Updated Baseline Run (Run 12) conditions. This is approximately the same as the IRWMP Baseline Run 1 considering the SBBA basin storage of approximately 6,000,000 acre-ft (DWR, 2003). The patterns of the cumulative changes in groundwater storage for the Updated Baseline Run (Run 12) during the period 2007-2032 are similar to the historical period from 1979-2004. At the end of the model simulation in year 2032, the cumulative change in groundwater storage would be negative 257,000 acre-ft, which would be similar to the level at the beginning of the model simulation (i.e., negative 231,000 acre-ft in year 2006). This indicates that the basin is in “balance.”

- The Muscoy PCE plume in model Layer 1 dissipates and moves towards the southeast throughout the entire predictive period (2007 to 2032). The plume in model Layer 2 undergoes very little change (i.e., size and movement) due to the presence of widespread fine-grained sediments. The Newmark and Muscoy PCE plumes in model Layers 3 through 5 dissipate the quickest as a result of increased artificial recharge at spreading basins upgradient of the Newmark plume. These spreading grounds include East Twin and Waterman Spreading Grounds in the northwestern portion of the SBBA. By the end of the predictive run (2032), the overall initial area of the PCE plume (approximately 1,910 acres) is reduced to approximately 670 acres.

- The TCE plume boundary in all five model layers dissipate and move west throughout the entire predictive period from 2007 to 2032. By the end of the predictive run (2032), the overall initial area of the TCE plume (approximately 2,030 acres) is reduced to approximately 260 acres.

- The perchlorate plume boundary in all five model layers dissipates and moves to the west throughout the entire predictive period from 2007 to 2032. The perchlorate plume in model Layer 1 disappears by 2027. By the end of the predictive run (2032), the overall initial area of the perchlorate plume (approximately 7,820 acres) is reduced to approximately 420 acres

Based on the results of the modeling, the following recommendations are made:

- The RBFM uses a constant transmissivity for the model layer 1 in order to handle the “dry” cells and model numerical problems. In reality, the transmissivity in the model layer would vary depending on the saturated thickness and hydraulic conductivity values of the aquifer. The calibrated transmissivity may not represent the real transmissivity during extreme water level conditions (i.e., high and low water level conditions). This may result in an underestimation of the recharge capacity and impacts during significant drought conditions. It is our recommendation to convert the model layer 1 to variable transmissivity using the new MODFLOW version MODFLOW-2005 during future model updates. The MODFLOW-2005 has the capability to handle the “dry” cells and numerical problems encountered from MODFLOW-2000 currently used by the RBFM.

- The recharge from direct precipitation and recharge from local runoff generated by precipitation used for the RBFM model were estimated based on an empirical average. A watershed model approach has been developed and improved significantly in recent years such as Hydrologic Simulation Program – Fortran (HSPF) and Precipitation-Runoff Modeling System (PRMS). These modeling tools will improve not only the quantification of the recharge but also the spatial and temporal distributions of the recharge as a result of changes in land uses. It is our recommendation to consider including the watershed modeling approach during future model updates. Improvement of the determination of recharge from precipitation will enhance the overall water budget quantification and development of conceptual model for salt budgets. An accurate conceptual model for salt budgets will be important for salinity management of the basin.

- The return flow used for the RBFM model was based on an assumption of 30% of the groundwater pumping. The amount of return flow may change due to water use changes. It is our recommendation to reevaluate the return flow based on the types of water use during future model updates. This will also be important components for development of conceptual model for salt budgets.

The SBBA RBFM and RBSTM are useful tools for evaluating water levels and water quality of the aquifer systems as the model calibration exceeds the industry standards. In addition, the confidence in using the model for predictive model runs is increased through the reasonable results from the IRWMP Baseline Run 1 and conjunctive use scenarios, sensitivity model runs to SWP water and local surface water supplies, and the Updated baseline Run (Run 12). However, they are a simplified approximation of a complex hydrogeologic system. The accuracy of the models predictions is highly dependent on the simplifying assumptions used for each model. As an example, simplifications of the estimation mass loading for the contaminants (i.e., PCE, TCE and perchlorate) could have a significant effect on model results. It is anticipated that the models will be updated on a regular basis to improve the accuracy of the model.

2.0 INTRODUCTION

2.1 Background

The San Bernardino Basin Area (SBBA) includes the Bunker Hill and Lytle Groundwater Basins (see Figure 1). Approximately 600,000 residents in the SBBA depend upon these underground reservoirs as their primary water source.

Groundwater in the SBBA generally flows westerly from the Santa Ana River (SAR) and Mill Creek and southeasterly from Lytle Creek and Cajon Creek toward the Pressure Zone area. The San Jacinto Fault generally runs perpendicular to the groundwater flow and acts as a barrier, or underground dam, causing the groundwater "pool" behind the fault to rise toward land surface in the form of high groundwater. The water in this area also rises due to the pressure caused by the water on the outer edges of the basin, which is at a higher elevation. The area defined by this high groundwater condition is located wholly within the City of San Bernardino and is commonly referred to as the Pressure Zone or the Area of Historic High Groundwater (AHHG). In the past, water levels in the AHHG rose high enough to cause artesian conditions (groundwater rising above land surface). Groundwater levels that are this shallow frequently result in the flooding of basements, adversely affect the load-bearing capacity of streets, disrupt underground utilities, and may cause "liquefaction" during an earthquake. Liquefaction occurs when saturated, sandy soil turns into a "quicksand" state during an earthquake. When liquefaction occurs, the ground no longer provides support to underground utilities or overlying structures, allowing them to sink or to float. In some cases, the foundational supports have been compromised, resulting in buildings toppling over.

The SBBA is also plagued by groundwater contamination plumes (see Figure 2). Contaminants have mainly been found within the shallow, unconfined member (from land surface to 75 feet below land surface), the upper water bearing zone member (between 75 feet and 300 feet below land surface) and the middle water bearing member (between 400 feet and 600 feet below land surface). Due to the presence of groundwater contamination and a high salt content, local water agencies deliberately avoid extracting groundwater from the unconfined member (UCM), portions of the upper water bearing member (UWB), and the middle water bearing member (MWB).

The Newmark Groundwater Contamination Superfund Site cleanup projects are currently underway in the SBBA. A work plan was developed by the Newmark project team (Newmark Team) for the enhancement of a groundwater flow model to support work at this Superfund Site. The purpose was to develop a modeling tool to implement the "institutional controls" as required by the Consent Decree in a fairly focused area around the Muscoy and Newmark plumes. Because the Superfund site represents a relatively small portion of the SBBA, the Newmark Groundwater Flow Model (NGFM) depends upon boundary conditions obtained from the flow model developed for the SBBA (Basin Flow Model) by the USGS. The USGS Basin Flow Model is an integrated streamflow and groundwater model developed for streams and the valley-fill aquifer of the SBBA, including Bunker Hill and Lytle Creek Basins (Danskin, McPherson and Woolfenden, 2006). San Bernardino Valley Municipal Water District (Valley District) is a "cooperator" with the USGS and funded a large portion of the modeling work for purposes of being able to evaluate "cumulative impacts" on the Basin from various existing and proposed projects. These cumulative impacts may, in time, extend basin-wide. Since the conditions in the overall basin will vary, the boundary conditions for the NGFM will also vary. Thus, to operate the NGFM separately would require very close coordination with the USGS Basin Flow Model.

To eliminate the possibility of having inaccurate boundary conditions in the NGFM and to avoid the development of two different models that may not be compatible or defendable, it was agreed by the City of San Bernardino Municipal Water Department (SBMWD) and Valley District that the regional USGS Basin Flow Model would be modified to a detail sufficient to evaluate both Consent Decree issues in and around the Newmark/Muscoy plumes and basin-wide management issues. This refined is named as the Newmark Groundwater Flow Model/Refined Basin Flow Model (NGFM/RBFM). As part of this management strategy, a refinement of the Basin Flow Model was undertaken for Valley District under USEPA Grant X-97957701-1. This approach of having only one model not only eliminated duplication of effort, but it ensured that the RBFM still retains the credibility of the original USGS Basin Flow Model. As part of the refinement, the Valley District's Basin Water Quality Model was also refined and was named as Refined Basin Solute Transport Model (RBSTM).

2.2 Purpose and Scope

This report summarizes the tools and methodology used in the refinement of the USGS Basin Flow Model and the Basin Water Quality Model and the results from the refined model calibration runs (Run 1 through Run 11). It also summarizes the results of various predictive model runs including the Upper Santa Ana River Watershed Integrated Regional Water Management Plan (IRWMP) Baseline Run 1 and conjunctive use scenarios, sensitivity to SWP water and local surface water supplies, and the Updated Baseline Run (Run 12).

The scope of work for this Project included the following:

- Conducted a comprehensive review and interpretation of existing geohydrologic data that was used to compile input to the refined basin flow and transport models. Data gaps within the SBBA were identified and recommendations for data collection were provided in a technical memorandum (GEOSCIENCE, 2006);

- Provided additional data collected to update datasets of well locations and construction details, groundwater production, and groundwater quality with respect to preparing input files for the refined models;

- Reviewed the existing USGS Basin Flow Model and Valley District's Basin Water Quality Model, and incorporated the components into the RBFM and RBSTM;

- Characterized the perchloroethene (PCE), trichloroethene (TCE) and perchlorate groundwater contaminant plumes within the SBBA for purposes of developing initial conditions, and for the selection of transport model calibration targets. Water quality data was also provided to AMEC Geomatrix to update Valley District's EQuIS[4] database;

- Refined the basin flow and solute transport models. The refinement included reducing model cell size, increasing the number of model layers, and modifying the length of annual stress periods;

- Conducted a comprehensive review of groundwater barriers locations. This was conducted due to inconsistencies of the locations in the existing dataset;

- One of the major model refinements is the subdivision of model layers. Stantec developed the model layers in the Newmark and Muscoy plume areas using a 3-D lithology model with assistance from Numeric Solutions. In order to be consistent with the approach used by Stantec, GEOSCIENCE expanded the 3-D lithology model to the entire model area with subcontracted assistance from Numeric Solutions;

- Conducted steady-state model calibration and transient model calibration for the RBFM from 1945 to 2000 (Runs 1 through 9), and the RBSTM from 1986 to 2000. The RBFM was also calibrated for the period from 1983 through 2000 with a monthly stress period (Run 10). The RBFM was also verified by extending the transient calibration period to 2006 (Run 11);

- Conducted sensitivity analysis for the RBFM;

- Simulated various predictive model runs for the IRWMP Baseline Run 1 and conjunctive use scenarios using the RBFM;

- Simulated various predictive model runs for sensitivity to SWP water and local surface water supplies using the RBFM;

[4] Environmental Quality Information System (EQuIS) developed for SBVMWD by EarthSoft.

- Simulated predictive model run for the Updated Baseline Run (Run 12)[5] using the RBFM and RBSTM;
- Attended peer review meetings to discuss the model refinement and calibration processes;
- Provided peer review for the NGFM report prepared by Stantec; and
- Prepared a model summary report to document the results of all previous tasks.

The following table summarizes the model runs were included in this report.

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	Sensitivity to SWP and Local Surface Water Supplies Runs	Model Year: 2006 to 2044 Hydrologic Year: 1962 to 2000	Flow
	Updated Baseline Run (Run 12)	Model Year: 2007 to 2032 Hydrologic Year: 1979 to 2004	Flow and Solute Transport

5 This run is the updated run for the IRWMP Baseline Run 1 (see Section 5.3.1 for the changes in model assumptions).

2.3 Previous Investigations

Groundwater flow models have been used successfully in the SBBA over the past two decades. The latest refinement process was a cooperative technical effort involving representatives of SBMWD and Valley District, their respective consultants at Stantec Consulting (Stantec) and GEOSCIENCE, and Mr. Wes Danskin of the USGS. The cooperative effort was initiated to avoid the development of two different models and to develop a model that would be compatible and defendable.

The various groundwater flow models that have formed part of the evolution of the current RBFM include:

1. The first numerical model of the area in 1966-1967 by the Tyson, Weber and Frankel of the California Department of Water Resources (personal communication, Reiter, 2005);

2. A simplified well-response model by the USGS's Durbin (1974), and Durbin and Morgan (1978); and

3. A more complex groundwater flow model by the USGS's Hardt and Hutchinson (1980) developed to simulate aquifer response to natural and artificial recharge and production. It was also used in 1987 by Hardt and Freckleton to predict changes in groundwater levels based on projected recharge and production to the year 2025.

4. The USGS Basin Flow Model prepared by Danskin, et al, 2006. This model formed the basis for the RBFM.

2.4 Cooperation

The refinement process for both the RBFM and RBSTM was a cooperative technical effort involving representatives of the SBMWD and Valley District, their respective consultants at

Stantec and GEOSCIENCE, and Mr. Wes Danskin of the USGS. A total of 11 model runs were made for the calibration runs of the RBFM as shown in the following table.

Summary of Transient Calibration Model Runs of RBFM

Model Run	Description
Run 1	USGS Model with Cell Size of 102.5x102.5 feet (without HFB and STR Packages)
Run 2	USGS Model with Cell Size of 102.5x102.5 feet (with HFB and STR Packages)
Run 3	USGS Model with Cell Size of 102.5x102.5 feet and Refinements of HFB and STR Packages
Run 4	USGS Model with Cell Size of 102.5x102.5 feet and Refinements of Well, HFB and STR Packages
Run 5	Two-Layer MODFLOW 2000 with K and b
Run 6	Five-Layer MODFLOW 2000 with Uniform Properties and New Basement
Run 7	Five-Layer MODFLOW 2000 with New Interpretation of Model Layer Elevations
Run 8	Steady State Model Calibration (1945)
Run 9	Annual Transient Model Calibration (1945-2000)
Run 10	Monthly Transient Model Calibration (January 1983 – December 2000)
Run 11	Monthly Model Verification (January 2001 – December 2006)

Note:
HFB is Horizontal-Flow Barrier Package
STR represents Streamflow-Routing Package

GEOSCIENCE made the runs from Run 1 through Run 9. During the process of model Run 1 through Run 9, a comprehensive review of groundwater barriers locations was conducted due to inconsistencies of the locations in the existing dataset. In addition, GEOSCIENCE experienced model numerical instability (i.e., failure to converge). One of the most sensitive model inputs to cause instability is the streamflow-routing package. GEOSCIENCE spent a significant amount of time to develop the package with variations of the number of cells used and streambed conductance.

GEOSCIENCE also assisted Stantec in developing the Streamflow-Routing and Recharge packages and collecting monthly production data for the model Runs 10 and 11.

2.5 Sources of Data

The following are sources of geohydrologic data that were used to compile input to the RBFM and the refined Solute Transport Model in order to update the models to December 2006.

1. Characterization of Groundwater Contamination in the Area of Historical High Groundwater within the San Bernardino Basin Area. Geomatrix Consultants, October 2004 (funded by a USEPA grant).

2. Valley District EQuIS Database – well locations, well construction, lithology, water quality, groundwater levels (period of record from 1888 – 2006[6]).

3. Valley District Water Resources Database - well locations, well construction, groundwater levels and production (period of record from 1900 – 2006).

4. Western Municipal Water District / San Bernardino Valley Municipal Water District Cooperative Well Measuring Program – fall and spring groundwater levels for approximately 400 wells in the Bunker Hill Basin (period of record from 1993 – 2006).

[6] Not all wells have data that covers the 1929 – 2003 period.

5. San Bernardino Valley Water Conservation District (SBVWCD) – monthly spreading volumes at Santa Ana River and Mill Creek spreading grounds (period of record from 1912 to 2006).

6. Valley District – monthly spreading volumes of imported water (period of record from start of spreading in 1971 to 2006); annual production (period of record from 1945 to 2006).

7. National Climatic Data Center (NCDC) – daily precipitation records for Station 47723 (San Bernardino F S 226) for the period from 1893 – December 2006.

8. USGS – daily streamflow records and groundwater levels (period of record for streamflow is from 1911 – December 2006).

9. California Department of Water Resources (DWR) – groundwater levels up until April 2000.

In addition, monthly pumping data obtained from various water agencies were compiled. The water level, groundwater pumping and water quality data were provided to AMEC Geomatrix to be included in the Valley District's database. Based on the spatial distribution of water quality data points, there are a number of areas where limited or no sampling locations exist. Recommendations were made to AMEC Geomatrix for additional data collection to improve plume characterization.

A detailed list of sources of data used for this study is summarized in Section 8.0.

3.0 REFINED BASIN GROUNDWATER FLOW MODEL

3.1 Three-Dimensional Lithologic Model

In order to refine the USGS Basin Flow Model, a three-dimensional lithologic model was developed. More than 400 water wells with categorical lithology value for intervals in the well bore were obtained and used for the development of the three-dimensional lithology model. These lithology logs were derived from both driller's logs and geophysical logs measured over the last several decades. The lithology log values consisted of the 14 categories recognized within the Unified Soil Classification System (USCS) scale – a scale that approximates grain size distribution, where the larger the category value the larger the grain size.

The first step to developing the lithologic model was the construction of a geological structure model of the basin that includes the position of the crystalline basement rock, the surface elevation, and the faults and barriers responsible for lithologic lateral variations. Crystalline basement positions were estimated using a combination of data including: well-basement intersections, USGS gravity data, and deepest known sediments in the lithology logs.

The basic goal behind the three-dimensional lithologic modeling was to estimate the type of lithology at each cell of a three-dimensional mesh. This mesh is conformal at the base of the sediment package to the crystalline basement and at the top of the model to the surface elevation. Moreover, this property estimation needed to be statistically robust so that one may derive the uncertainty of the estimate at each cell. The lithology-estimation approach used is called geostatistics. Using this geostatistical approach, the variation of the lithologic data in approximately 400 wells was modeled (see insert map of Figures 3 through 12 for well locations). This model was used to guide the estimation of the lithologic property, using an estimation technique known as ordinary kriging, on a mesh comprised of 23 million cells.

This work was carried out using an assortment of geomodeling software. Structural framework modeling was done within EarthVision (www.dgi.com); the geostatistical analysis and estimation were carried out in GoCad (www.earthdecision.com) and Gslib (www.gslib.com). Numeric Solutions produced an EarthVision plug-in to export the stratigraphic model as a series of MODFLOW meshes.

Upon the completion of the three-dimensional lithologic model, it was used to interpret the location of the five model layer boundaries. This was an iterative process whereby geologists interpreted the model layer boundary locations along ten cross-sections extracted from the three-dimensional lithologic model (see Figures 3 through 12). After the model layer boundaries were determined, they were interpolated and then corrected to include a minimum thickness and made to truncate at crystalline basement outcroppings. Lastly, the positions of these boundaries were imposed on meshes used for input to MODFLOW.

3.2 Conceptual Model

The RBFM is an integrated streamflow and groundwater model developed for streams and the valley-fill aquifer of the SBBA. The model consists of five model layers:

- Layer 1 contains the upper confining member and upper water-bearing zone;
- Layer 2 represents the middle confining member;
- Layer 3 consists of the middle water-bearing zone;
- Layer 4 represents the lower confining member; and
- Layer 5 contains the lower water-bearing zone.

Groundwater flow between the five layers is restricted by numerous fine-grained deposits in the alluvium deposits. Near the mountain front, the fine-grained deposits thin to extinction and the five layers act as one. The streams crossing the model area in the aquifers can be both influent (losing water to the aquifer) and effluent (gaining water from the aquifer). The streamflow inflow components are generated from surface runoff originating from rain events as well as water gained from aquifers. The streamflow outflow components include deep percolation to underlying leakage aquifers and flow out of the basin. The primary sources of recharge to the model area include seepage from gaged streams, seepage from ungaged runoff, direct infiltration of precipitation, recharge from local runoff (i.e., runoff originating from precipitation), artificial recharge of imported water, return flow from groundwater pumping, and underflow from adjacent groundwater areas. The primary discharge terms are groundwater extraction, evapotranspiration, and subsurface outflow.

3.3 Model Cells and Layers

The original USGS Basin Flow Model covers an area of approximately 524 square miles and is a two-layer finite difference model with a cell size of 820 feet x 820 feet for a total of 43,424 cells. The RBFM is a five-layered finite difference model and covers the same area as the original USGS Basin Flow Model. Each model cell of the original USGS Basin Flow Model was rediscretized to 64 model cells with a cell size of 102.5 feet x 102.5 feet. The refined model consists of 944 nodes[7] in the north-to-south direction (i-direction) and 1,472 nodes in the west-to-east direction (j-direction), for a total of 6,947,840 nodes (see Figure 13).

3.4 Boundary Conditions

The SBBA is bordered on the northwest by the San Gabriel Mountains, on the northeast by the San Bernardino Mountains, on the southeast by the Crafton Fault, and on the southwest by the San Jacinto Fault (see Figure 14).

The mountainous areas to the northwest and northeast represent impermeable boundaries and were assigned as “no-flow” or “inactive” cells. Groundwater recharge along the mountain front was simulated using MODFLOW’s Well Package. Surface inflow from streams was simulated using MODFLOW’s Streamflow-Routing Package. Unconsolidated or poorly consolidated sediments southeast of the Crafton Fault (Yucaipa Basin and San Timoteo Basin), and southwest of the San Jacinto Fault (Rialto-Colton Basin and Riverside Basin), were also assigned as “no-

[7] A model “node” is the center of a model “cell.” The model cells are square with a side of 102.5 ft. The network of model cells forms a “grid” or “mesh” covering the entire model area.

flow" or "inactive" cells. The underflow recharge or discharge across these faults was simulated using MODFLOW's Well Package.

3.5 Aquifer Parameters

The aquifer parameters used in the RBFM include hydraulic conductivity (from aquifer thickness and transmissivity), vertical hydraulic conductivity, and specific storativity. Since the aforementioned values are related to the lithology of the aquifers, a method was developed to describe the heterogeneity of hydraulic properties using a three-dimensional (3D) lithologic model and a hydraulic parameter multiplier that is discussed below.

3.5.1 Model Layer Elevations

Land surface elevation, as determined from Digital Elevation Models (DEMs) for the 7.5" topographic quadrangles in the model area, were used as the top of model Layer 1. The bottom elevations for each of five model layers were determined based on the 3D lithologic model developed for the SBBA. Figure 15 shows the thickness for each of the five model layers.

3.5.2 Hydraulic Conductivity

The initial horizontal hydraulic conductivity values were estimated based on the 3D lithology model. Extensive groundwater pumping test data collected in the Newmark and Muscoy groundwater extraction network, pumping test data in the regional basin compiled from published documents and the transmissivity values used in the original USGS Basin Flow Model were used to develop the relationship between lithology and hydraulic conductivity. The hydraulic conductivity values were iteratively adjusted by a range of 0.1 to 5 times of the initial estimation during the model calibration to minimize the residuals between the measured and model-generated groundwater levels. The final horizontal hydraulic conductivity values are shown in Figure 16. A 10:1 ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity was used, as determined during the model calibration.

3.5.3 Specific Storativity

The specific storativity values for Model Layer 1 (conceptualized as an unconfined aquifer), were assigned based on the specific yield[8] values (Eckis, 1934) and aquifer thickness. For model Layers 2 through 5, a specific storativity was assigned based a storativity of 0.0001 used by the original USGS Basin Flow Model and the aquifer thickness of each model layer. Figure 17 shows the specific storativity for each of the model layers.

3.5.4 Conductance for Groundwater Barriers

The original USGS Basin Flow Model considers several faults and groundwater barriers to be "partial" barriers to groundwater flow within the aquifer systems of the SBBA. The groundwater barriers were simulated in the model using the Horizontal-Flow-Barrier (HFB) Package and assigning a lower hydraulic characteristic value (the barrier transmissivity divided by the width of the horizontal-flow barrier) to the boundary of the barrier. The spatial rediscretization of the original USGS Basin Flow Model from a uniform cell size of approximately 820 feet x 820 feet to a cell size of approximately 102.5 feet x 102.5 feet requires rediscretization of the HFB Package representing major faults and flow barriers within the model domain. The HFB Package was refined based on fault and barrier locations provided by the USGS. The refined HFB Package includes 6,064 cells (see Figure 18). The initial hydraulic characteristic values were estimated based on the values used in the original USGS Basin Flow Model and adjusted during the model calibration. The final hydraulic characteristic values range from 0.00005 ft/day to 1 ft/day.

3.6 Recharge and Discharge

Recharge and discharge terms (i.e., "flux" terms) in the SBBA were simulated using MODFLOW's Streamflow-Routing Package, Recharge Package, Well Package and

[8] Equivalent to effective porosity or "drainable" porosity.

Evapotranspiration Package. The following table shows recharge and discharge terms and the associated MODFLOW package used by the RBFM.

Recharge and Discharge Terms and Associated MODFLOW Package Used

Recharge and Discharge Flux Used on the RBFM		MODFLOW Package
Recharge	Gaged Streamflow	Streamflow-Routing
	Recharge from Ungaged Mountain Front Runoff	Well
	Imported Water	Well
	Return Flow from Groundwater Pumping	Well
	Underflow	Well
	Infiltration from Direct Precipitation	Recharge
	Recharge from Local Runoff Generated from Precipitation	Recharge
Discharge	Groundwater Pumping	Well
	Evapotranspiration	Evapotranspiration
	Gaged Streamflow	Streamflow-Routing
	Underflow	Well

3.6.1 Streamflow-Routing Package

The Streamflow-Routing Package (STR) was used to simulate the recharge and discharge of the gaged mountain front runoff through interaction between major streams and aquifers of the SBBA. The Streamflow-Routing Package of the original USGS Basin Flow Model was refined to be consistent with cell size of 102.5 feet x 102.5 feet. Each reach (one model cell) of the refined STR1 Package was delineated based on the stream channels shown on the USGS topographic maps. The area used for simulation of interactions between stream and aquifer is fixed and only the conductance of streambed varies according to hydrological conditions. Streamflow was routed down the stream channels, through spreading grounds and past outflow gages near the San Jacinto Fault. A total of 56 “segments” were identified (see Figure 19). A stream segment is defined as the longest portion of a surface watercourse having no tributaries.

Segments 1, 2, 5, 17, 19, 30, 33, 35, 42 and 53 receive surface runoff from the drainage area tributary to each segment. The surface runoff inflow for these segments was based on the annual discharge of each segment's mountain front gage. These gages include:

- Lytle Creek near Fontana (Segment 1),
- Cajon Creek below Lone Pine Creek near Keenbrook (Segment 2),
- Devil Canyon Creek near San Bernardino (Segment 5),
- Waterman Canyon Creek near Arrowhead Springs (Segment 17),
- East Twin Creek near Arrowhead Springs (Segment 19),
- City Creek near Highland (Segment 30),
- Plunge Creek near East Highlands (Segment 33),
- Santa Ana River near Mentone (Segment 35),
- Mill Creek near Yucaipa (Segment 42), and
- San Timoteo Creek near Redlands (Segment 53).

Inflow from surface runoff during the period 1945-2000 for each gage is shown on Figures 20 through 29. Figure 30 shows the total inflow from surface runoff to the SBBA. As shown, during the model calibration period from 1945 to 2000, the total surface water inflow from these gages ranges from 35,900 acre-ft in 1961, to 674,000 acre-ft in 1969 with an annual average of 143,600 acre-ft/yr.

A stream "reach" is defined as the portion of a stream segment that transects a single model grid cell. Model cells containing a portion of a stream across a corner or along an edge were generally included as reaches. Reaches were identified by their "i, j" coordinates and were numbered (by segment) from their upstream to downstream. The top streambed elevation for each reach was determined based on the average surface elevation along the edge of the stream within the reach. The stream stage and the bottom elevation of the streambed were assumed to be five feet above and five feet below the top elevation of the streambed, respectively.

The initial streambed conductance for each reach was derived based on the values used in the original USGS Basin Flow Model. During model calibration, streambed conductance was adjusted by trial-and-error until final calibration was achieved. During “wet” years, an increase in the width of the stream usually occurs due to amounts of streamflow overflowing the stream channels (i.e., historical flow). In addition, the vertical hydraulic conductivity of the streambed increases due to the removal of fine-grained sediments by the high energy of the streamflow. Both of these result in an increase in streambed conductance. In order to account for variations of streambed conductance over time (i.e., due to wet and dry cycles), an adjustment factor was applied to the values for wet years, specifically, 1958, 1967, 1969, 1978, 1979, 1980, 1983, 1993, 1995 and 1998. The adjustment factor has a range from one (unchanged) to five (higher conductance).

3.6.2 Recharge Package

The Recharge Package simulates regionally distributed recharge to the groundwater system as a result of precipitation. This includes infiltration from direct precipitation and recharge from local runoff generated from precipitation. The infiltration from precipitation was assumed to be approximately 1% of the long-term mean annual precipitation and to be constant from year to year (Danskin, et al., 2006). This assumption results in approximately 1,100 acre-ft/yr of infiltration originating from precipitation for the SBBA. Recharge from local runoff generated from precipitation varies each year and was assumed to be 5% of the annual precipitation (Danskin, et al., 2006). During the model calibration period from 1945 to 2000, the recharge from local runoff generated from precipitation in the SBBA ranged from 2,000 acre-ft in 1947, to 11,500 acre-ft in 1983 with an annual average of 5,300 acre-ft/yr (see Figure 31).

The recharge values were areally distributed to each model cell based on the isohyetal map (see Figure 32) representing the spatial variation of long-term average annual precipitation.

3.6.3 Well Package

Input data for the Well Package included the following:

- Recharge from ungaged mountain front runoff;
- Artificial recharge of imported water;
- Groundwater pumping (i.e., extractions);
- Return flow from application of groundwater pumping; and
- Underflow recharge and underflow discharge.

Recharge from ungaged mountain front runoff from the adjacent mountains and small outcrops within the SBBA was estimated based on drainage areas, streamflow in nearby basins, and measured flow in the Santa Ana River (Danskin, et al., 2006). Figure 33 shows the model cells used to simulate recharge of ungaged mountain front runoff in the RBFM. During the model calibration period (1945 to 2000), the recharge from mountain front runoff for the SBBA ranged from 4,000 acre-ft in 1990 to 68,000 acre-ft in 1980 with an annual average of 15,700 acre-ft/yr (see Figure 34).

Artificial recharge of imported water was based on the historically measured imported water delivered to each of the spreading grounds. A recharge rate of 95% of the imported water was used to simulate water that actually recharged the groundwater systems (Danskin, et al., 2006). Figure 35 shows model cells used to simulate artificial recharge of imported water. During the period from 1945 to 2000, artificial recharge of imported water for the SBBA ranged from 0 acre-ft/yr (artificial recharge began in 1972) to 30,400 acre-ft/yr with an annual average of 2,900 acre-ft/yr (see Figure 36).

Groundwater extraction quantities were based on measured data obtained from Steve Mains (Watermaster) and major water agencies in the SBBA. The amount of groundwater pumped from each well was distributed to model Layers 1 through 5 based on the perforated interval and the hydraulic conductivity of adjacent deposits. The proportion of pumping from each well from each layer is a function of the length of the well screen in that layer and the hydraulic conductivity of the layer. Figure 37 shows the distribution of 779 production wells and Figure 38 shows annual groundwater pumping for the period 1945 to 2000. As shown, annual groundwater pumping ranges from 122,900 acre-ft to 238,500 acre-ft with an annual average of 178,100 acre-ft/yr.

For the purposes of the model, return flow from groundwater pumping was assumed to be the quantity of groundwater pumped that returns to the groundwater system as a result of agricultural, domestic, and municipal uses. Return flow was assumed to be 30% of total groundwater pumping except for wells that export groundwater directly out of the SBBA (Danskin, et al., 2006). Previous reports (Hardt and Hutchinson, 1980) estimated that return flow from these sources was equivalent to 30% of the applied water, considering the permeability of the soil and volume of applied water. Wells used for export were assumed to have 0 to 3% (pipe losses) return flow. This is a common engineering estimate of expected leakage from pipes (Danskin, et al., 2006). The return flow was assumed to recharge Layer 1 in the same cell as the pumping wells, assuming that groundwater was applied in the nearby vicinity of the pumping well. As shown in Figure 39, the annual return flow from groundwater pumping ranges from 20,100 acre-ft to 37,000 acre-ft with an annual average of 28,500 acre-ft/yr for the period from 1945 to 2000.

Recharge from underflow to the SBBA occurs across the Crafton Fault. Figure 40 shows the model cells used to simulate this recharge. The amount of annual recharge from underflow ranged from 3,700 acre-ft to 6,700 acre-ft with an annual average of 5,000 acre-ft/yr for the period from 1945 to 2000 (Danskin, et al., 2006) (see Figure 41). Groundwater outflow from the SBBA occurs across the San Jacinto Fault and Barrier E. Figure 40 also shows the model cells used to simulate groundwater outflow. The amount of subsurface outflow ranges from 2,200 acre-ft to 13,400 acre-ft with an annual average of 5,500 acre-ft/yr for the period from 1945 to 2000 (Danskin, et al., 2006) (see Figure 42).

3.6.4 Evapotranspiration Package

The Evapotranspiration Package simulates the effects of plant transpiration and direct evaporation in removing water from the saturated zone. Data on maximum evapotranspiration rate, evapotranspiration surface, and extinction depth are required inputs to the RBFM.

A maximum evapotranspiration rate of 38 inch/yr was used in the USGS Basin Flow Model based on Hardt and Hutchinson (1980). Extinction depth was estimated to be 15 feet (Lee 1912; Robinson 1958; and Sorenson, et al. 1991). Based on the depth to water, the evapotranspiration rate linearly decreased from 100% at the surface to 0% at the extinction depth of 15 feet. Evapotranspiration is assumed to occur whenever the groundwater level is above the extinction depth (Danskin, et al., 2006).

3.7 Model Calibration and Verification

3.7.1 Model Calibration Approach

A step-by-step approach has been developed to systematically modify the USGS Basin Flow Model to meet the goals and purposes of the RBFM modeling project, while still maintaining the basic integrity of the USGS model. This approach allows for benchmarking of the model refinements and continual comparison of groundwater budgets and calibration results with the existing USGS Basin Flow Model.

3.7.2 Steady-State Model Calibration

The steady-state model calibration was performed for 1945 to generate the initial water levels for the transient model calibration. In general, steady-state model calibration is acceptable with a relative error (the standard deviation of the groundwater level residuals[9] divided by the observed

[9] "Residual" = measured – modeled

head range; Zheng and Bennett, 2002) of 7.1% and mean residual of 11.29 feet based on the measured water level in 120 wells in 1945.

3.7.3 Annual Transient Model Calibration (1945-2000)

Annual transient model calibration covers the period from 1945 through 2000. Table 1 summarizes the groundwater budgets and water level residual statistics for these RBFM runs compared to the original USGS Basin Flow Model.

For the annual transient model calibration (Run 9), historical groundwater level data for 141 wells within the SBBA were compared with model-generated groundwater levels. In general, the pattern of the model-generated and measured levels are similar in that the model appears to capture the long- and short-term temporal trends in groundwater levels in most parts of the basin (see Figures 43 and 44). Figure 45 is an “x-y” plot showing comparisons of measured and model-generated groundwater levels. The relative error of the model-generated groundwater levels between 1945 and 2000 is approximately 4.6%. Common modeling practice is to consider a good fit between historical and model-predicted data if the relative error is below 10% (Spitz and Moreno, 1996; and Environmental Simulations, Inc., 1999). The model also provided a good match with the gaged surface runoff within the SBBA (see Figure 46).

3.7.4 Monthly Transient Model Calibration (1983-2000)

A monthly calibration (Run 10) run was carried out for the period January 1983 through December 2000. The pattern of the model-generated and measured levels is also similar in most parts of the basin. The relative error of water level residuals is approximately 4.3% with an average water level residual of -6.6 feet.

3.7.5 Monthly Model Verification (2001-2006)

As an additional validation of the calibration process, the period from January 2001 through December 2006 was withheld from the original model construction. A separate simulation was conducted using this data set to determine how well the calibrated model reproduced future scenarios. The relative error of water level residuals is approximately 4.6% with an average water level residual of 3.2 feet. This water level residual statistic indicates that the SBBA RBFM accurately simulates water levels in most of the model area.

3.8 Model Sensitivity

Sensitivity analysis was performed during the stages of the RBFM calibration by changing one parameter at a time. The following parameters were held constant during the calibration process:

- Proportion of recharge from precipitation;
- Layer thickness;
- Evapotranspiration; and
- Annual groundwater pumping.

During the calibration process, the following parameters were considered for variation using a systematic approach. Sensitivity to individual parameters was assessed during the process:

- Hydraulic conductivity;
- Anisotropy;
- Specific storativity;
- Streambed conductance;
- Recharge from mountain front runoff;
- Imported water recharge;
- Underflow;
- Return flow; and

- Conductance of horizontal flow barriers.

Hydraulic conductivity and streambed conductance were determined to be the most sensitive parameters. The model is moderately sensitive to variations in underflow outflow and locally sensitive to variations in groundwater barrier conductance.

4.0 REFINED BASIN SOLUTE TRANSPORT MODEL

4.1 General Description and Purpose of Model

The purpose of the RBSTM was to evaluate potential impact of the various scenarios on existing plumes and chemical constituents of concern such as PCE, TCE, and perchlorate. Solute transport modeling was carried out using MT3DMS[10], a modular three-dimensional multi-species transport model. The RBSTM requires data from the RBFM (e.g., seepage velocities and flow directions). The flow in and out of each model cell is read by MT3DMS and used to track concentrations of PCE, TCE, and perchlorate advectively and dispersively, applying retardation to the species, if needed. For purposes of this study, the PCE transport model was used to simulate the migration of the Muscoy and Newmark plumes and the TCE transport model was used to simulate the movement of the Norton and Crafton-Redlands plumes.

For PCE and TCE, a linear isotherm equation was used to model the equilibrium-controlled linear sorption processes that occur in the aquifers. The retardation factor is a function of aquifer parameters and the sorption distribution coefficient which may be written as:

$$R = 1 + \frac{\rho_b}{\theta} Kd$$

where:

R	= Retardation Factor,
ρ_b	= Bulk Density of Aquifer Materials, [g/cm^3]
θ	= Effective Porosity,
Kd	= Sorption Distribution Coefficient, [cm^3/g]

10 U.S. Army Corps of Engineers, 1999. MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide.

For perchlorate, the linear isotherm was not used, as the retardation factor for this constituent was assumed to be one.

It was assumed that neither PCE nor TCE degrades significantly in groundwater. If significant degradation does occur, this assumption would result in an overestimation of PCE and TCE contamination.

4.2 Development of Solute Transport Models

In addition to the aquifer parameters used for the RBFM, the RBSTM requires the following data to simulate transport of chemical constituents: effective porosity, longitudinal, transverse, and vertical dispersivities, bulk density of the aquifer material, and the sorption distribution coefficient of each chemical constituent.

The effective porosity values for model Layer 1 were assigned based on specific yield values from USGS Basin Flow Model (Danskin, et al., 2006). These values were estimated based on specific yield values from Eckis (1934). For model Layers 2 through 5, an effective porosity value of 80% of Layer 1 was assigned (see Figure 47) (personal communication, Danskin, 2004). The longitudinal dispersivity value was initially estimated based on the scale of observation (Gelhar et al., 1992) and adjusted during the model calibration. Sorption distribution coefficient can be estimated from the product of the partition coefficient of a compound between water and organic carbon (K_{oc}) and organic carbon content (f_{oc}) of sediments. Since no site data is available for f_{oc}, the sorption distribution coefficients for PCE and TCE were initially estimated based on the typical retardation factors and then adjusted during model calibration.

The following table summarizes the final values for the solute transport model parameters.

Model Parameters		Units	PCE	TCE	Perchlorate
Dispersivity	Longitudinal	[feet]	30	30	30
	Transverse	[feet]	3	3	3
	Vertical	[feet]	0.3	0.3	0.3
Bulk Density		[g/cm^3]	1.9	1.9	-
Sorption Distribution Coefficient		[cm^3/g]	0.0947	0.054	-

Using an average effective porosity of 0.09, which approximates the average porosity in the region of the PCE and TCE plumes, the retardation factors for PCE and TCE were calculated as 3.0 and 2.1, respectively.

4.3 Solute Transport Model Calibration

Solute transport model calibration was performed for PCE and TCE for the period from 1986 to 2000. The RBSTM was calibrated using historical match techniques in which dispersivities, sorption distribution coefficients, and mass loading of continued sources were varied within acceptable limits to best fit the model-generated plumes to observed concentrations at wells. Sources of water quality data used for transport model calibration include CDM, 1996; HSI GeoTrans, 1998; URS, 1997 and 1999; Wildermuth Environmental, Inc., 2000; California DHS, 2003b; and USGS NWISWeb, 2003.

4.3.1 Initial Concentrations

The initial concentrations used to calibrate the PCE and TCE RBSTM were derived from 1986 measured concentrations (see Figures 48 and 49). Due to the limited quantity of measured PCE and TCE data available for 1986, PCE and TCE concentrations measured from 1987 to 1996 were also used.

4.3.2 Sinks and Sources

The MT3DMS transport model required concentrations to be specified for each of the sinks and sources used in the RBFM. The PCE and TCE models required inputs of dissolved contaminants to simulate point sources where the dissolution of adsorbed contaminants continues in source areas. All other sources of recharge identified in the RBFM were considered to contribute no PCE or TCE. All sinks (i.e., areas of discharge) were considered to have the same PCE and TCE concentration as that occurring in the same model cell (i.e., equal to the aquifer concentration).

The amount of contaminant introduced to the model was varied iteratively to match observed concentrations. The PCE input was simulated using mass-loading of dissolved PCE located at the Muscoy Source and the Newmark Source areas. The TCE input was located in the northeastern part of the Norton plume. The concentration of the TCE input was estimated initially based on the observed data in the Norton plume area.

4.3.3 Transient Calibration Results

The model-generated PCE maximum contaminant level (MCL) plume boundaries for selected years in model Layers 1 through 5 are shown in Figures 50 to 54. In general, the model-generated MCL plume boundary closely matches the MCL plume boundary contoured from observed data. The model-generated TCE MCL plume boundaries in model Layers 1 through 5 are shown in Figures 55 to 59. The model-generated migration rate of the TCE plume agrees with the rate estimated from observed data.

In order to evaluate the accuracy of the transport model calibration, PCE and TCE concentrations from the final calibration run were compared to measured data at selected wells (see Figure 60 for PCE and Figure 61 for TCE). In most of the wells, measured and model-generated PCE and TCE concentrations display similar trends. The model underestimates the very high observed concentration and was not able to improve during the model calibration process. This may be explained by model simulates the average concentration of each of the model layer instead of concentration at a particular depth.

Histograms of PCE and TCE residual concentrations (measured concentrations less model-generated concentrations) are shown in Figures 62 and 63, respectively. The histograms show a bell shape with most of the residual concentrations in the range of +/- 5 micrograms per liter (µg/L), indicating an acceptable model calibration. The model relative error[11] is 7.7% and 3.4% for PCE and TCE concentrations, respectively. It is common modeling practice to consider a relative error of less than 10% to be a good fit (Spitz and Moreno, 1996; and Environmental Simulations, Inc., 1999). Therefore, these results are considered reasonable.

[11] Relative error is the standard deviation of the water quality residuals divided by the observed range.

5.0 MODEL PREDICTIVE SCENARIOS

5.1 IRWMP Baseline Run 1 and Conjunctive Use Scenarios

The RBFM was used to simulate the Baseline Run 1 and conjunctive use scenarios of the Upper Santa Ana River IRWMP. The primary purpose of the IRWMP is to assist local agencies with developing tools for optimizing management and the use of the region's water resources while protecting the groundwater basins from water quality degradation and the threat liquefaction. Four model runs were developed and simulated using the RBFM. The following table presents the assumptions for each model run.

Model Assumptions for IRWMP Baseline Run 1 and Conjunctive Use Scenarios

<table>
<tr><th colspan="3">Model Assumptions</th><th>Baseline Run 1*</th><th>Run 1A</th><th>Run 1B</th><th>Run 1C</th></tr>
<tr><td colspan="3">Hydrologic Base Period</td><td colspan="4">1962-2000 (Wet, Dry and Average)</td></tr>
<tr><td colspan="3">Groundwater Pumping</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td rowspan="4">Artificial Recharge</td><td colspan="2">Valley District's Replenishment Obligation</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">Diversion by SBVWCD</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">Diversion by Senior Water Rights Claimants</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">SAR Water Right Applications</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td rowspan="3">Conjunctive Use</td><td rowspan="3">Maximum Annual Additional Yield</td><td>40,000 AF</td><td></td><td>x</td><td></td><td></td></tr>
<tr><td>90,000 AF</td><td></td><td></td><td>x</td><td></td></tr>
<tr><td>140,000 AF</td><td></td><td></td><td></td><td>x</td></tr>
</table>

* This run was updated in June 2009 (see Section 5.3.1 for the changes in model assumptions)

The following sections describe the model assumptions used for the RBFM model runs.

5.1.1 Hydrologic Base Period

A hydrologic base period is the period of time over which elements of the equation of hydrologic equilibrium[12] are evaluated. The time period selected should:

- Be representative of long-term hydrologic conditions;
- Include wet, dry and average years of precipitation;
- Span a 20- to 30-year period (Mann, 1968);
- Have its start and end years preceded by comparatively similar rainfall quantities (DWR, 2002);
- Preferably start and end in a dry period (Mann, 1968). This minimizes any water draining (in transit) through the vadose zone; and
- Include recent cultural conditions (DWR, 2002).

Based on analyses of historical precipitation and streamflow, the 39-year period from October 1961 through September 2000 (water years October 1961-September 1962 through October 1999-September 2000) was selected as the hydrologic base period. This base period covers both wet and dry hydrologic cycles and the average precipitation is approximately the same as the long-term average. For model prediction runs, the hydrologic base period was assumed to represent future conditions for the 39-year period October 2005 through September 2044 (water years October 2005-September 2006 through October 2043-September 2044). Annual stress periods for predictive scenarios duplicated historical hydrologic conditions of the base period.

5.1.2 Groundwater Pumping

Groundwater pumping was determined using the Allocation Model based on future water

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[12] The equation of hydrologic equilibrium is a quantitative statement of the conservation of mass. In groundwater hydrology, it is simply Inflow = Outflow ± Change in Storage. This is also known as a water balance or hydrologic budget.

demands obtained from 2005 Urban Water Management Plans and other sources of information (GEI, SAIC and GEOSCIENCE, 2007). In addition, for critical hydrologic years 1963, 1964, 1965, 1977, 1988, 1989, 1990, and 2000, the water demands were assumed to have a 4.3% increase. Figure 64 shows the projected groundwater pumping estimated for the Baseline Run 1 based on the Allocation Model. During the model period 2006-2044, the groundwater pumping ranges from 193,200 acre-ft in 2010 (hydrologic year 1966) to 289,100 acre-ft in 2034 (hydrologic year 1990) with an average of 249,000 acre-ft/yr.

The pumping value assigned to each well from a particular water agency in a particular year was based on the maximum amount pumped in the recent years multiplied by the ratio of the total projected pumping for that particular water agency in that particular year. The total projected groundwater pumping for each of the water agencies was based on results from the Allocation Model.

5.1.3 Artificial Recharge of SAR Water

Artificial recharge in the SBBA comprises three components:

- Diversion by Senior Water Rights Claimants,
- Diversion by SBVWCD, and
- Diversion by Valley District/Western Santa Ana River Water Right Applications.

Diversions by Senior Water Rights Claimants were estimated based on the Seven Oaks Accord using OPMODEL (GEI, SAIC and GEOSCIENCE, 2007). The amount of spreading in SAR and Airport spreading grounds was estimated by the Allocation Model and was then assigned to the RBFM.

SBVWCD diversions were estimated based on the Valley District/SBVWCD Settlement Agreement using OPMODEL[13]. The amount of spreading in Santa Ana River spreading grounds was estimated by the Allocation Model and was then assigned to the RBFM.

Under the SAR Water Right Applications, Valley District/Western has several options for conveying and distributing SAR water. The water can be put either to direct use, stored in groundwater basins within the Valley District/Western services area for later extraction and use, or conveyed to agencies outside the Valley District/Western service area for their use and returned through exchange. The amount of spreading possible at various spreading grounds was estimated by the Allocation Model and assigned to the RBFM.

5.1.4 Artificial Recharge of Imported Water

The annual replenishment obligation by Valley District using SWP water under the Western Judgment was initially estimated using the Allocation Model as the difference between the Watermaster determined natural safe yield of the SBBA and extractions from the SBBA. The amount of artificial recharge at each spreading ground for each year estimated by the Allocation Model was then assigned to the RBFM using the Recharge Package, assuming a 5% evapotranspiration loss. The final amount of artificial recharge was the result of iterative model runs between Allocation Model and RBFM until there was only a negligible change in groundwater storage. The resultant artificial recharge of SWP water is approximately 32,400 acre-ft/yr.

Figure 65 shows the resultant total amount of artificial recharge of SAR water and SWP water. As shown, for the Baseline Run 1, the artificial recharge ranges from zero acre-ft in years 2021, 2032, and 2034 (hydrologic years 1977, 1988, and 1990) to 155,300 acre-ft in year 2037

13 This assumption has been changed for the Updated Baseline Run (Run 12). The San Bernardino Valley Water Conservation District withdrew their water rights application that they had submitted to the State Water Resources Control Board that was a condition of their settlement agreement with the San Bernardino Valley Municipal Water District. As a result, the Conservation District amounts provided in the settlement agreement no longer apply and the Conservation District's rights continue to be their two seasonal permits of License No. 2831 (January 1 to May 31) and License No. 2832 (October 1 to December 31).

(hydrologic year 1993) with an average of 59,700 acre-ft. The artificial recharge of SWP water accounts for approximately 54% of the total recharge.

5.1.5 Conjunctive Use

Model Runs 1A, 1B, and 1C are conjunctive scenarios involving artificial recharge and groundwater pumping in addition to the Baseline Run 1. The initial amount of recharge and groundwater pumping was developed based on State Water Project (SWP) System hydrology, local hydrology and Sacramento Valley Index Hydrologic Year Type (GEI, SAIC, GEOSCIENCE, 2007). Through iterative model runs between the Allocation Model and RBFM, the area of new spreading grounds, the required number of new groundwater pumping wells, and the final amount of groundwater pumping and artificial recharge were determined. Figure 66 shows the locations of new spreading grounds and new wells for these conjunctive model runs. The final groundwater pumping and artificial recharge for Runs 1A, 1B and 1C are summarized in Figure 64 and Figure 65, respectively. The following table summarizes the new facilities used for the model operation runs.

New Facilities Required Based on Modeling Results

Model Run	New Spreading Grounds	New Wells
Baseline Run 1	None	None
Run 1A	None	20
Run 1B	250 acres	50
Run 1C	480 acres	76

5.1.6 Summary of Groundwater Model Assumptions

The following table summarizes assumptions and sources of RBFM input data that were used for the various model scenarios.

Summary of RBFM Input Data

<table>
<tr><th colspan="3">Description of Model Input Data</th><th>Assumptions and Sources of Data</th></tr>
<tr><td rowspan="9">Inflow Term</td><td rowspan="2">Gaged Mountain Front Runoff</td><td>Release to SAR from the Seven Oaks Dam</td><td>Historical Daily Data</td></tr>
<tr><td>Other Gaged Inflow</td><td>Historical Data (1962-2000)*</td></tr>
<tr><td colspan="2">Artificial Recharge at Spreading Grounds</td><td>Availability of SAR Water and SWP Water</td></tr>
<tr><td colspan="2">Recharge from Underflow</td><td>Extension of Historical Trend*</td></tr>
<tr><td colspan="2">Return Flow from Groundwater Pumping</td><td>Groundwater Pumping Data</td></tr>
<tr><td colspan="2">Recharge from Ungaged Mountain Front Runoff</td><td>Historical Data 1962-2000*</td></tr>
<tr><td colspan="2">Infiltration from Direct Precipitation</td><td>Historical Data 1962-2000*</td></tr>
<tr><td colspan="2">Recharge from Local Runoff Generated by Precipitation</td><td>Historical Data 1962-2000*</td></tr>
<tr><td rowspan="5">Outflow Term</td><td colspan="2">Groundwater Pumping</td><td>Water Demands in 2005 Urban Water Management Plans</td></tr>
<tr><td colspan="2">Evapotranspiration</td><td>Model-Calculated</td></tr>
<tr><td colspan="2">Streamflow Outflow</td><td>Model-Calculated</td></tr>
<tr><td rowspan="2">Groundwater Outflow (i.e., Underflow Discharge)</td><td>Across San Jacinto Fault near SAR area</td><td>Model-Calculated</td></tr>
<tr><td>Across Barrier E</td><td>Extension of Historical Trend*</td></tr>
</table>

* From flow transient model calibration run (1945-2000).

5.1.7 Model Results

5.1.7.1 Groundwater Elevations

Groundwater elevation contours for each of model runs in the years 2027 (highest level, hydrologic year 1983) and 2036 (lowest level, hydrologic year 1992) are shown on Figures 67 through 74. In general, the model-generated groundwater flow direction is similar to historical directions with groundwater flowing west from the SAR and Mill Creek Spreading Grounds, and southeast from the Lytle Creek and Cajon Creek (i.e., flowing to the Pressure Zone area). Groundwater level fluctuations reflect hydrological wet and dry cycles. For example, a change in groundwater level of 50 feet to 100 feet occurs in the Pressure Zone between model years 2027 (equivalent to 1983 – end of a wet year cycle) and 2036 (end of a dry cycle, historical year 1992). Groundwater flow directions and general patterns of fluctuations for the three Project scenarios are similar to the Baseline Run 1.

Hydrographs at selected wells (including 25 index wells of the Seven Oaks Accord and the Backyard Well for the Valley District/Western/Riverside Agreement) for all the four IRWMP model runs are provided in Appendix B. The locations of these wells are shown on Figure 75. These hydrographs show the temporal variations in groundwater levels reflecting the hydrologic conditions, artificial recharge and groundwater pumping assumed for these model operation runs.

Land subsidence due to declining groundwater levels has historically been reported in the SBBA (Lofgren, 1971; Miller and Singer, 1971; and Fife, 1976). Figure 76 shows average annual subsidence in the Pressure Zone ranging from 0.015 feet to 0.04 feet during the period from 1944 to 1956. During the period from 1944 to 1969, at least one foot of subsidence had occurred in the Pressure Zone immediately north of Loma Linda between the San Jacinto and Loma Linda faults (Miller and Singer, 1971). Figure B-11 (in Appendix B) shows the model predicted depth to water for the City of Riverside Raub 1 Well located in the Pressure Zone area. The lowest groundwater level for the Baseline Run 1 would be approximately 160 feet, which is above the historical lowest level. Therefore land subsidence potential for this model run is minimal. However, groundwater levels would be an additional 20 to 60 feet lower in this well for model Runs 1A, 1B, and 1C compared to the Baseline Run 1. Depth to groundwater level below the historical low may have subsidence potential. The Basin Management Technical Committee of SBBA plans to monitor land subsidence in their annual Regional Water Management Plan.

5.1.7.2 Potential Liquefaction Area in the Pressure Zone

Liquefaction typically occurs in recent (Holocene to late Pleistocene) deposits of silt, sand, and gravel. Most liquefaction occurs where the depth to groundwater is shallower than 50 feet; limiting analysis to this depth is traditionally considered adequate for most investigations of liquefaction potential (Martin and Lew, 1999). Soil liquefaction is a major cause of damage during earthquakes. For purposes of this report, areas with depth to groundwater of shallower than 50 feet in the Pressure Zone were quantified for each model operational run.

Areas where depth to groundwater was shallower or equal to 50 feet below the land surface were delineated using the RBFM. Annual potential liquefaction area as a percentage of the Pressure Zone area is shown on Figures 77 through 80 for Baseline Runs 1, 1A, 1B, and 1C, respectively. The percentage ranges from zero in year 2036 (hydrologic year 1992) to 6.0% in year 2030 (hydrologic year 1986) with an annual average of 2.3%. This is a significant reduction when compared to the high groundwater conditions in the Pressure Zone that occurred in 1984. In 1984, approximately 50% of Pressure Zone area had a depth to water shallower or equal to 50 feet below the land surface. Figure 77 also shows the potential liquefaction in year 2030 (year with the greatest potential liquefaction area). As shown, the area is located in the eastern portion of the Pressure Zone near the Santa Ana River and City Creek areas in the vicinity of the City of Highland. The potential liquefaction area in the Pressure Zone for model Runs 1A and 1B would be similar to the conditions of Baseline Run 1 (see Figures 78 and 79). Run 1C shows elevated potential liquefaction areas in some years with the greatest percentage up to 19.5% in year 2019 (hydrologic year 1975, see Figure 80). In this case, liquefaction potential is higher in both Highland and San Bernardino. This was due to artificial recharge occurring in the new spreading grounds in the Pressure Zone area. In these cases, mitigation through additional pumping of wells or new wells would be needed to lower the groundwater level below 50 feet from land surface. The Basin Management Technical Committee of SBBA plans to review water levels annually in their Regional Water Management Plan.

5.1.7.3 Groundwater Budgets

The overall water budgets for each of the model runs were compiled to evaluate the IRWMP Baseline Run 1 and conjunctive use scenarios. The inflow terms for the model include recharge to groundwater from gaged streamflow, artificial recharge, local runoff generated by precipitation, infiltration from direct precipitation, return flow from groundwater pumping, ungaged mountain front runoff and underflow. The outflow terms comprise evapotranspiration, groundwater pumping, and underflow. The difference between the total inflow and total outflow is the change in groundwater storage. Annual groundwater budgets for each scenario are shown in Tables 2 through 5. The average annual groundwater budgets for the period 2006-2044 for each model run are shown in Figure 81 and are also shown in the following table.

Summary of RBFM Run Water Budgets

Flux Terms			Baseline Run 1 [acre-ft/yr]	Run 1A [acre-ft/yr]	Run 1B [acre-ft/yr]	Run 1C [acre-ft/yr]
Inflow	Recharge from Gaged Streamflow		128,489	127,708	117,346	106,734
	Artificial Recharge of SAR Water		27,285	27,285	27,285	27,285
	Artificial Recharge of Imported Water		32,428	55,384	105,352	146,861
	Recharge from Local Runoff Generated by Precipitation		5,491	5,491	5,491	5,491
	Infiltration from Direct Precipitation		1,109	1,109	1,109	1,109
	Return Flow from Groundwater Pumping		46,907	46,907	46,907	46,907
	Recharge from Ungaged Mountain Front Runoff		18,038	18,038	18,038	18,038
	Underflow Recharge		2,819	2,819	2,819	2,819
	Total Inflow		**262,567**	**284,742**	**324,347**	**355,244**
Outflow	Evapotranspiration		10,700	12,822	15,358	15,031
	Groundwater Pumping		248,904	248,904	248,904	248,904
	Groundwater Pumping for Conjunctive Use	40,000 AF	0	19,872	19,872	19,872
		90,000 AF	0	0	38,462	38,462
		140,00 AF	0	0	0	29,487
	Underflow Discharge		2,642	2,417	2,474	2,892
	Total Outflow		**262,245**	**284,016**	**325,070**	**354,648**
Average Annual Change in Groundwater Storage (Total Inflow – Total Outflow)			322	726	-722	596
Cumulative Changes in Groundwater Storage Over the 39-Year Modeling Period			12,600 acre-ft	28,300 acre-ft	-28,300 acre-ft	23,200 acre-ft

As shown in the above table, groundwater storage in the SBBA increases 322 acre-ft/yr during the period 2006 through 2044 under Baseline Run 1 conditions. Changes in groundwater storage for all three conjunctive use runs are similar to Baseline Run 1 ranging from a decline of 722 acre-ft/yr for Run 1B to an increase of 726 acre-ft/yr for Run 1A.

The cumulative changes in groundwater storage for the historical period 1934 through 2005 (calculated based on groundwater levels) and for the IRWMP Baseline Run 1 and conjunctive use scenarios are shown in Figure 82. In general, the patterns of the cumulative changes in groundwater storage for all the four operational model runs during the period 2006-2044 are similar to the historical period from 1962-2000. At the end of the model simulation in year 2044, the cumulative change in groundwater storage would be negative 200,000 acre-ft, which would be similar to the level at the beginning of the model simulation (i.e., in year 2005). This indicates that the basin is in "balance."

5.1.7.4 Efficiency of Conjunctive Use

Based on the water budgets from the model operational runs, the efficiencies of conjunctive use scenarios were evaluated. For model Runs 1A, 1B and 1C, the additional amounts of artificial recharge compared to Baseline Run 1 are 22,956 acre-ft/yr, 72,924 acre-ft/yr and 114,433 acre-ft/yr, respectively. Due to artificial recharge, the amounts of recharge from gaged streamflow, evapotranspiration, groundwater pumping, underflow and changes in groundwater storage are also changed. The following table summarizes these changes compared to the Baseline Run 1.

Summary of Efficiency for Conjunctive Use Scenarios
(Scenarios minus Baseline Run 1)

Flux Term		Run 1A [acre-ft/yr]	Run 1B [acre-ft/yr]	Run 1C [acre-ft/yr]
Inflow	Artificial Recharge	+22,956	+72,924	+114,433
	Recharge from Gaged Streamflow	-781	-11,143	-21,755
	Subtotal	**+22,175**	**+61,781**	**+92,678**
Outflow	Groundwater Pumping	+19,872	+58,334	+87,821
	Evapotranspiration	+2,122	+4,658	+4,331
	Underflow Outflow	-225	-168	+250
	Changes in Groundwater Storage	+404	-1,044	+274
	Subtotal	**+22,173**	**+61,780**	**+92,676**

As shown in the table above, the major loss of water for the conjunctive use model runs would be the reduction of recharge from gaged streamflow. These decreases are 781 acre-ft/yr, 11,143 acre-ft/yr and 21,755 acre-ft/yr for model Runs 1A, 1B, and 1C, respectively. This loss is due to a significant increase in artificial recharge at the spreading grounds in the forebay area that would cause higher groundwater levels in the forebay area, thereby preventing some groundwater recharge in the stream channel[14] (i.e., rejected recharge).

For purpose of this report, the efficiency of conjunctive use was calculated as the ratio of the amount of additional groundwater pumping to the amount of additional artificial recharge. The following table summarizes the results.

[14] When the groundwater level in the aquifer is above the stage of the stream channel, there is no percolation from the stream channel and the groundwater flows from the aquifer to the stream channel.

Summary of Efficiency of Conjunctive Use as a Ratio of the Amount of Additional Groundwater Pumping to the Amount of Additional Artificial Recharge

Terms		Run 1A	Run 1B	Run 1C
[1]	**Average Additional Artificial Recharge [acre-ft/yr]**	22,956	72,924	114,433
[2]	**Average Additional Groundwater Pumping [acre-ft/yr]**	19,872	58,334	87,821
[3] = [1] – [2]	**Water Loss Due to Rejected Recharge and Evapotranspiration and Changes in Underflow Outflow and Storage**	3,084	14,590	26,612
[4] = [2] / [1]	**Efficiency**	**87%**	**80%**	**77%**

The efficiency ranges from 77% for model Run 1C to 87% model Run 1A. These variations are due to the amount of artificial recharge, the locations and areas of new spreading grounds used for artificial recharge, and the number and locations of new wells used for groundwater pumping. For example, model Run 1B has an increase of additional recharge of 46,968 acre-ft/yr (72,924 - 22,956 = 49,968) compared to model Run 1A. The efficiency reduces from 87% to 80% due to the increase in artificial recharge although using additional 30 new wells and additional 250 acres spreading grounds for the expansion of the existing spreading grounds.

5.1.7.5 Additional Yield during the Drought

The maximum additional yields for the conjunctive use during single year drought and three-year drought were summarized in the table below based on the water budgets.

Summary of Additional Yields for Drought Years

Terms	Simulated Drought	Units	Baseline Run 1	Run 1A	Run 1B	Run 1C
Groundwater Pumping	2032 (hydrologic year 1988)	[acre-ft]	271,987	301,987	381,987	421,987
	2033 (hydrologic year 1989)		277,330	307,330	367,330	387,330
	2034 (hydrologic year 1990)		289,105	329,105	409,105	449,105
	Total		838,422	938,422	1,158,422	1,258,422
Maximum Additional Yield	Single Year Drought 2034		None	40,000	120,000	160,000
	3-Year Drought 2032-2034		None	100,000	320,000	420,000
Additional Average Annual Recharge Required		[acre-ft/yr]	None	22,956	72,924	114,433

Single year drought 2034 (hydrologic year 1990)
Three-year drought 2032-2034 (hydrologic years 1988-1990)

As shown in the above table, the maximum groundwater pumping during a single year drought was 289,105 acre-ft in 2034 (hydrologic year 1990) for the Baseline Run 1. This was to meet the projected water demands and additional 4.3% increase for a critical year. The additional yield for the conjunctive use would be 40,000 acre-ft, 120,000 acre-ft and 160,000 acre-ft for model Runs 1A, 1B, and 1C, respectively. This additional yield is due to water stored prior to the drought for these conjunctive use scenarios. The conjunctive use scenarios are essentially "put and take" projects. The additional yields (take) require an equivalent amount of net recharge (put) (i.e., amount of recharge minus water losses due to rejected recharge and evapotranspiration). The amount of average annual additional recharge required for these conjunctive use scenarios were also shown in the above table. The maximum groundwater pumping during a three-year drought was 838,422 acre-ft in 2032-2034 (hydrologic years 1988-1990) for the Baseline Run 1. This was to meet the projected water demands and additional 4.3% increase in these critical years. The additional yield for the conjunctive use would be 100,000 acre-ft, 320,000 acre-ft and 420,000 acre-ft for model Runs 1A, 1B, and 1C, respectively.

5.2 Sensitivity Analysis Model Runs

The RBFM was also used to perform a sensitivity analysis for the surface water supplies including SWP water and local surface water. The purpose of this analysis was to evaluate any impacts due to decreased supplies of local and SWP have on meeting the water needs of the Upper Santa Ana River Watershed and the San Bernardino Basin Area groundwater storage. Reduction of water supplies may result from climate change or other constraints on SWP delivery system.

For Baseline Run 1 of the IRWMP, the long-term reliability of SWP water was assumed to be 78% of the Table A Entitlements (DWR water supply reliability report 2005 (DWR, 2006)). This task analyzes the potential impact of reducing the reliability on both the SWP and local surface water supplies. For this sensitivity analysis, the following cases were analyzed:

Case	SWP 50% Reliable	SWP 60% Reliable	Local Surface Water is reduced to 90%	Local Surface Water is reduced to 95%
A	X			
B		X		
C			X	
D				X
E (worst case)	X		X	

5.2.1 Assumptions for the Sensitivity Model Runs

The assumptions used for this sensitivity analysis are the same as the assumptions used for the Baseline Run 1 (see Section 5.1) except for the inputs involving SWP water and local water such as artificial recharge of SWP and Santa Ana River waters, streamflow inflow, recharge from local runoff generated by precipitation, infiltration from direct precipitation, and recharge from ungaged mountain front runoff. The following table compares the assumptions used for the Baseline Run 1 with the sensitivity model runs (Case A through E.).

Summary of Assumptions for Sensitivity Model Runs

Flux Terms	Baseline Run 1	Case A 50% SWP	Case B 60% SWP	Case C 90% Local Surface Water	Case D 95% Local Surface Water	Case E (Worst Case) 50% SWP 90% Local Surface Water*
Recharge of SWP	78% SWP Water Reliability	50% SWP Water Reliability	60% SWP Water Reliability	Same as Baseline Run 1	Same as Baseline Run 1	50% SWP Water Reliability
Recharge of SAR Water	Historical 1962-2000 Conditions	Same as Baseline Run 1 (78%)	Same as Baseline Run 1 (78%)	90% Precipitation of 1962-2000 Conditions	95% Precipitation of 1962-2000 Conditions	90% Precipitation of 1962-2000 Conditions
Streamflow Inflow	Historical 1962-2000 Conditions	Same as Baseline Run 1 (78%)	Same as Baseline Run 1 (78%)	90% Precipitation of 1962-2000 Conditions	95% Precipitation of 1962-2000 Conditions	90% Precipitation of 1962-2000 Conditions
Recharge from Local Runoff Generated by Precipitation	Historical 1962-2000 Conditions	Same as Baseline Run 1 (78%)	Same as Baseline Run 1 (78%)	90% Precipitation of 1962-2000 Conditions	95% Precipitation of 1962-2000 Conditions	90% Precipitation of 1962-2000 Conditions
Infiltration from Direct Precipitation	Historical 1962-2000 Conditions	Same as Baseline Run 1 (78%)	Same as Baseline Run 1 (78%)	90% Precipitation of 1962-2000 Conditions	95% Precipitation of 1962-2000 Conditions	90% Precipitation of 1962-2000 Conditions
Recharge from Ungaged Mountain Front Runoff	Historical 1962-2000 Conditions	Same as Baseline Run 1 (78%)	Same as Baseline Run 1 (78%)	90% Precipitation of 1962-2000 Conditions	95% Precipitation of 1962-2000 Conditions	90% Precipitation of 1962-2000 Conditions

*Groundwater flow model simulation was not performed for the Case E (Worst Case). The evaluation of the Case E was based on the model results from Baseline Run 1 and Case A through Case D.

5.2.2 Model Results

5.2.2.1 Groundwater Elevations

Hydrographs of selected wells (including 25 index wells of the Seven Oaks Accord and the Backyard Well for the Muni/Western/Riverside Agreement) for the Baseline Run 1 and Case A through Case D are provided in Appendix C. The locations of these wells are shown on Figure 75. These hydrographs show the temporal variations in groundwater levels reflecting the reduction of SWP and local surface water supplies. For example, the water level in the Backyard Well would decrease by 20 ft (95% local surface water supplies) to 50 ft (50% SWP) in year 2044 as compared to the water level under Baseline Run 1 conditions (see C-26 in Appendix C).

5.2.2.2 Groundwater Budgets

A water budget was developed for each case to help evaluate any impact from a reduction in SWP and/or local surface water supply reliability. The "inflow" terms for the model include:

- Recharge to groundwater from gaged streamflow;
- Artificial recharge;
- Local runoff generated by precipitation;
- Infiltration from direct precipitation;
- Return flow from groundwater pumping;
- Ungaged mountain front runoff; and
- Underflow.

The "outflow" terms include:

- Evapotranspiration;
- Groundwater pumping; and
- Underflow across the "Bunker Hill Dike".

The difference between the total inflow and total outflow is the change in groundwater storage. A positive change in storage indicates that the basin increased in volume, while a negative change in storage indicates that the basin decreased in volume. The desired result is to have a "zero" cumulative change in storage over the modeling period, indicating that the basin is in "balance." That is essentially the result that was obtained from the Baseline Run 1. Annual groundwater budgets for model run Case A through D are shown in Tables 6 through 9. The average annual groundwater budgets for the period 2006 to 2044 are shown for each sensitivity run in the following table:

Summary of Annual Average Water Budgets for Baseline Run 1 and Model Sensitivity Runs

Flux Terms		Baseline Run 1	Case A 50% SWP	Case B 60% SWP	Case C 90% Local	Case D 95% Local	Case E (Worst Case) 50% SWP 90% Local*
		[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]
Inflow	Recharge from Gaged Streamflow	128,489	129,321	128,767	120,134	124,687	120,134
	Artificial Recharge	59,713	43,886	50,384	57,550	58,561	43,886
	Recharge from Local Runoff Generated by Precipitation	5,491	5,491	5,491	4,942	5,217	4,942
	Infiltration from Direct Precipitation	1,109	1,109	1,109	998	1,054	998
	Return Flow from Groundwater Pumping	46,907	46,907	46,907	46,907	46,907	46,907
	Recharge from Ungaged Mountain Front Runoff	18,038	18,038	18,038	16,234	17,136	16,234
	Underflow Recharge	2,819	2,819	2,819	2,819	2,819	2,819
	Total Inflow	**262,567**	**247,572**	**253,515**	**249,585**	**256,380**	**235,920**
Outflow	Evapotranspiration	10,700	7,816	8,823	7,286	8,759	5,129
	Groundwater Pumping	248,904	248,904	248,904	248,904	248,904	248,904
	Underflow Discharge	2,642	2,413	2,519	2,354	2,490	2,354
	Total Outflow	**262,245**	**259,133**	**260,246**	**258,544**	**260,154**	**256,387**
Average Annual Change in Groundwater Storage (Total Inflow – Total Outflow)		322	-11,561	-6,731	-8,959	-3,773	-20,467
Cumulative Changes in Groundwater Storage Over Base Period (2006 to 2044)		12,600 acre-ft	-450,900 acre-ft	-262,500 acre-ft	-349,400 acre-ft	-147,100 acre-ft	-798,200 acre-ft

*Groundwater flow model simulation was not performed for the Case E (Worst Case). The model-calculated water budget terms (i.e., recharge from gaged streamflow, evapotranspiration and underflow discharge) of the Case E were calculated based on the model results from Baseline Run 1 and Case A through D.

As shown, groundwater storage in the SBBA increases by approximately 322 acre-ft per year during the period 2006 through 2044 under Baseline Run 1 conditions. However, Cases A through D show that reducing the reliability of the SWP and/or local surface water supplies would result in annual declines ranging from 3,773 acre-ft per year to 11,561 acre-ft per year, or 147,100 acre-ft to 450,900 acre-ft over the 39-year base period (see Figures 83 and 84).

In worse case scenario (Case E), the cumulative groundwater storage decline for the entire 39-year study period would be approximately 797,800 acre-ft (20,457 acre-ft/yr).

To prevent overdraft, the groundwater basin must be operated so that storage at the beginning and the end of the study period will be the same, as is the case with the Baseline Run 1. Since the cumulative change in storage is lower than the Baseline Run 1 for each of these cases, specific water management strategies would need to be implemented to make up for the loss in these supplies.

5.2.2.3 Potential Effect of a Reduction in SWP and/or Local Surface Water Reliability on Groundwater Pumping Reliability during a Multiple Year Drought

As discussed in the previous sections, water levels would decline if SWP and local surface water supplies were reduced. Although the basin cannot meet demands if the SWP or local supplies are reduced, the model can show the potential impacts on individual wells.

Approximately 76% of the total groundwater pumping in the SBBA comes from 134 wells operated by the major retail water agencies in the SBBA. Well screen intervals were obtained for each of these wells. The depth to groundwater predicted by the groundwater flow model for the end of a multiple year drought (2036; the end of multiple drought years, hydrologic year 1992) was then compared to the well screen interval for each of these wells. The model accounts for the difference between the pumping well diameter and the size of the model cell.

In addition to the above adjustment, the model-predicted water levels in the wells were adjusted to include well losses[15] during pumping. The drawdown in the aquifer (right outside the well) was calculated using the Thiem Equation and the well losses were obtained assuming a well efficiency of 70%.

Results show that water levels in 18% to 20% of the 134 wells (i.e., 24 to 27 wells) would be below the top of the screen interval by more than 50% at the end of multiple drought years under the reduction of SWP or local surface water supplies. This condition will reduce the pumping capacity of these wells. The projected groundwater pumping rates for these wells ranges from 30,835 acre-ft to 35,670 acre-ft in 2036. The results for individual major water purveyors are shown in Tables 10, 11, 12, and 13 for the model sensitivity runs Case A through D, respectively. Under the worst case scenario (Case E) conditions, there would be more than 27 wells with water levels below the top of screen interval by more than 50% at the end of multiple drought years. However, these conditions can be mitigated by water conservation, water recycling projects, increased utilization of storm water and implementation of new conjunctive use projects.

5.3 Updated Baseline Run (Run 12)

5.3.1 Model Assumptions for Updated Baseline Run (Run 12)

The RBFM was used to simulate the Updated Baseline Run (Run 12). The RBSTM was also used to simulate PCE, TCE, and perchlorate plumes movement for the Updated Baseline Run (Run 12). The Updated Baseline Run (Run 12) includes the following updates:

- A monthly stress period instead of annual,
- New base period from 1979 through 2004 instead of 1962 through 2000,

[15] Head losses associated with the entrance of water through the well screen and the axial flows toward the pump intake are known as "well losses." These losses are caused by turbulent flow conditions and vary as the square of the velocity.

- Changes in projected groundwater pumping as submitted by some of the retail water agencies during a technical workshop in November 2008,
- DWR report 2007 (DWR, 2007) SWP water availability projection instead of DWR report 2005 (DWR, 2006) SWP water availability projection, and
- SAR diversions by SBVWCD's licensed rights[16] instead of Agreement between SBVWCD and Valley District/Western.

The following table compares the assumptions used for the Updated Baseline Run (Run 12) and IRWMP Baseline Run 1.

16 This is due to the San Bernardino Valley Water Conservation District withdrew their water rights application that they had submitted to the State Water Resources Control Board which was a condition of their settlement agreement with the San Bernardino Valley Municipal Water District. As a result, the Conservation District diversion amounts provided in the settlement agreement no longer apply and Conservation District's rights continue to be their two seasonal permits of License No. 2831 (January 1 to May 31) and License No. 2832 (October 1 to December 31).

Compare Model Assumptions

IRWMP Baseline Run 1 and Updated Baseline Run (Run 12)

Model Assumptions		IRWMP Baseline Run 1	Updated Baseline Run (Run 12)
Hydrologic Base Period		1962-2000 with Annual Stress Period	1979-2004 with Monthly Stress Period
Groundwater Pumping		2005 Urban Water Management Plans	2005 Urban Water Management Plans with 2008 Update
Artificial Recharge	**Valley District's Replenishment Obligation**	Western Judgment (SWP Water Availability Based on DWR Report 2005[1] Projection)	Western Judgment (SWP Water Availability Based on DWR Report 2007[2] Projection)
	Diversion by SBVWCD	Agreement between SBVWCD and Valley District/Western	SBVWCD's Licensed Rights
	Diversion by Senior Water Rights Claimants	Seven Oaks Accord	Seven Oaks Accord
	Valley District/Western	SAR Water Right Applications	SAR Water Right Applications
	SBMWD Recycled Water Recharge	None	Up to 25,500 acre-ft

[1] DWR, 2006.
[2] DWR, 2007.

Based on monthly data availability and analyses of historical precipitation and streamflow, the 26-year period from January 1979 through December 2004 was selected for the hydrologic base period of the Updated Baseline Run (Run 12). This base period covers both wet and dry hydrologic cycles, and the average precipitation and streamflow are approximately the same as the long-term average (see Figures 85 and 86). For model prediction runs, the hydrologic base period was assumed to represent future conditions for the 26-year period January 2007 through December 2032.

Groundwater pumping was updated based on information presented by City of Colton, City of

Redlands, SBMWD, East Valley Water District, and West Valley Water District at the 7-Nov-08 technical workshop. The water agencies also provided more information regarding the location of future wells. Figure 87 shows the projected groundwater pumping estimated for the Updated Baseline Run (Run 12). During the model period 2007-2032, the groundwater pumping ranges from 206,100 acre-ft in 2007 (hydrologic year 1979) to 308,300 acre-ft in 2032 (hydrologic year 2002) with an average of 258,600 acre-ft/yr. This is approximately 9,700 acre-ft/yr more than the groundwater pumping projected for the IRWMP Baseline Run 1.

The final amount of artificial recharge was the result of iterative model runs. Figure 88 shows the resultant total amount of artificial recharge. As shown, for the Updated Baseline Run (Run 12), the artificial recharge ranges from 8,200 acre-ft in year 2016 (hydrologic year 1988) to 144,000 acre-ft in year 2032 (hydrologic year 2004) with an average of 87,700 acre-ft/yr including 48,300 acre-ft/yr of SWP water. The artificial recharge of SWP water accounts for approximately 55% of the total recharge.

5.3.2 Model Results

5.3.2.1 Groundwater Elevations

Groundwater elevation contours for the Updated Baseline Run (Run 12) in the years 2011 (highest level, hydrologic year 1983), 2020 (lowest level, hydrologic year 1992), and 2032 (end of model simulation, hydrologic year 2004) are shown on Figures 89 through 91. In general, the model-generated groundwater flow direction is similar to historical directions and IRWMP Baseline Run 1 conditions with groundwater flowing west from the SAR and Mill Creek and southeast from the Lytle Creek and Cajon Creek toward the Pressure Zone area. Groundwater level fluctuations reflect hydrological wet and dry cycles.

Hydrographs at selected wells (including 25 index wells of the Seven Oaks Accord and the Backyard Well for the Valley District/Western/Riverside Agreement) for all the four model operational runs are provided in Appendix D. The locations of these wells are shown on

Figure 75. These hydrographs show the temporal variations in groundwater levels reflecting the hydrologic conditions, artificial recharge and groundwater pumping assumed for the Updated Baseline Run (Run 12).

5.3.2.2 Potential Liquefaction Area in the Pressure Zone

Areas where depth to groundwater was less than or equal to 50 feet below the land surface were delineated using the RBFM to assess the liquefaction potential. Figure 92 also shows the potential liquefaction in year 2011 (year with the greatest potential liquefaction area). As shown, the acreage of the potential liquefaction area is approximately 720 acres and is approximately 4% of total Pressure Zone area of 19,320 acres. The highest percentage was 6.0% in year 2030 (hydrologic year 1986) for the IRWMP Baseline Run 1 and 50% for the historical conditions that occurred in 1984.

5.3.2.3 Groundwater Budgets

The overall water budgets for the Updated Baseline Run (Run 12) were compiled (see Table 14). The average annual groundwater budgets for the period 2007-2032 for the Updated Baseline Run (Run 12) are shown in Figure 93 and are also shown in the following table.

Summary of Average Annual Water Budgets for Updated Baseline Run (Run 12)

Flux Terms		IRWMP Baseline Run 1 (Average of 2006 to 2044) [acre-ft/yr]	Updated Baseline Run (Run 12) (Average of 2007 to 2032) [acre-ft/yr]
Inflow	Recharge from Gaged Streamflow	128,489	113,208
	Artificial Recharge of SAR Water	27,285	26,813
	Artificial Recharge of Imported Water	32,428	48,279
	Artificial Recharge of Recycled Water	0	12,649
	Recharge from Local Runoff Generated by Precipitation	5,491	5,221
	Infiltration from Direct Precipitation	1,109	1,083
	Return Flow from Groundwater Pumping	46,907	48,807
	Recharge from Ungaged Mountain Front Runoff	18,038	17,171
	Underflow Recharge	2,819	3,667
	Total Inflow	**262,567**	**276,898**
Outflow	Evapotranspiration	10,700	16,856
	Groundwater Pumping	248,904	258,588
	Underflow Discharge	2,642	2,692
	Total Outflow	**262,245**	**278,136**
Average Annual Change in Groundwater Storage (Total Inflow – Total Outflow)		322	-1,238
Cumulative Changes in Groundwater Storage Over the Modeling Period		12,600 acre-ft	-32,188 acre-ft

As shown, groundwater storage in the SBBA decreases approximately 1,200 acre-ft/yr during the period 2007 through 2032 under the Updated Baseline Run (Run 12) conditions. This is approximately the same as the IRWMP Baseline Run 1 considering the SBBA basin storage of approximately 6,000,000 acre-ft (DWR, 2003).

The cumulative changes in groundwater storage for the historical period 1934 through 2006 (calculated based on groundwater levels) and for the Updated Baseline Run (Run 12) 2007-2032 are shown in Figure 94. In general, the patterns of the cumulative changes in groundwater storage for the Updated Baseline Run (Run 12) during the period 2007-2032 are similar to the historical period from 1979-2004. At the end of the model simulation in year 2032, the cumulative change in groundwater storage would be negative 257,000 acre-ft, which would be similar to the level at the beginning of the model simulation (i.e., negative 231,000 in year 2006). This indicates that the basin is in "balance."

5.3.2.4 Model-Predicted PCE, TCE and Perchlorate Concentrations

Initial PCE, TCE and perchlorate concentrations for the Updated Baseline Run (Run 12) are shown in Figures 95 through 97.

Results for the PCE transport model are shown in Figures 98 through 102. These figures show the modeled MCL (5 μg/L) plume boundary of the Newmark-Muscoy PCE plumes for the Updated Baseline Run (Run 12). The Muscoy PCE plume in model Layer 1 dissipates and moves towards the southeast throughout the entire predictive period (2007 to 2032). The plume in model Layer 2 undergoes very little change (i.e., size and movement) due to the presence of widespread fine-grained sediments. The Newmark and Muscoy PCE plumes in model Layers 3 through 5 dissipate the quickest as a result of increased artificial recharge at spreading basins upgradient of the Newmark plume. These spreading grounds include East Twin and Waterman Spreading Grounds in the northwestern portion of the SBBA. By the end of the predictive run (2032), the overall initial area of the PCE plume (approximately 1,910 acres) is reduced to approximately 670 acres.

Results for the TCE transport model are shown in Figures 103 through 107. These figures show the modeled MCL (5 μg/L) plume boundary of the Redlands-Crafton TCE plume for the Updated Baseline Run (Run 12). The TCE plume boundary in all five model layers dissipate and move west throughout the entire predictive period from 2007 to 2032. By the end of the predictive run (2032), the overall initial area of the TCE plume (approximately 2,030 acres) is reduced to approximately 260 acres.

Results for the perchlorate transport model are shown in Figures 108 through 112. These figures show the modeled MCL (6 µg/L) plume boundary for the Updated Baseline Run (Run 12). The perchlorate plume boundary in all five model layers dissipates and moves to the west throughout the entire predictive period from 2007 to 2032. The perchlorate plume in model Layer 1 disappears by 2027. By the end of the predictive run (2032), the overall initial area of the perchlorate plume (approximately 7,820 acres) is reduced to approximately 420 acres.

5.3.2.5 Summary of Model Results

The model results from the Updated Baseline Run (Run 12) are summarized in Table 15. Comparisons between the IRWMP Baseline Run 1 and Updated Baseline Run (Run 12) were also made. In general, the groundwater elevations and basin storage for these two runs are similar. However, the amounts of groundwater pumping and artificial recharge required for each run are different. The amount of groundwater pumping for the Updated Baseline Run (Run 12) was approximately 9,700 acre-ft/yr more than the IRWMP Baseline Run 1 due to the changes in assumptions for future water demands and the sources of water to meet the water demands. The increase of artificial recharge required to maintain a balanced basin storage for the Updated Baseline Run (Run 12) was primarily a result of the changes in groundwater pumping and the hydrologic base period. The IRWMP Baseline Run 1 uses the hydrologic base period from 1962 to 2000, which starts with 16 years (1962 to 1977) of dry and average conditions. During this time period, the basin storage would be low and would be more efficient for artificial recharge. The Updated Baseline Run (Run 12) uses the base period from 1979 through 2004, which starts with a six year wet period. Artificial recharge during this period would have more rejected streamflow recharge (i.e., less recharge) and evapotranspiration. This is evident from the model-calculated streamflow recharge and evapotranspiration shown in Table 15. For the IRWMP Baseline Run 1, the evapotranspiration and streamflow recharge were calculated to be 10,700 acre-ft/yr and 128,500 acre-ft/yr, respectively. For the Updated Baseline Run (Run 12), the evapotranspiration would increase to 16,900 acre-ft/yr and the streamflow recharge would decrease to 113,200 acre-ft/yr. The other changes in model assumptions (see Table 15) also contribute to the differences in the model results, such as the availability of SWP water and time length of stress periods (i.e., annual or monthly).

6.0 CONCLUSIONS AND RECOMMENDATIONS

The USGS Basin Flow Model and Valley District's Water Quality Model have been refined and named as the NGFM/RBFM and RBSTM, respectively. With cooperation from the USGS (Wes Danskin) and the Newmark Project Team[17], the model refinement process was performed successfully.

The RBFM calibration exceeded industry standards, including steady-state model calibration (1945), annual transient model calibration (1945-2000), monthly transient model calibration (January 1983– December 2000), and monthly model verification (January 2001–December 2006). The RBSTM was calibrated against the observed PCE and TCE data for the period 1986 through 2000. Results show that the RBFM and RBSTM model calibration is acceptable both qualitatively and quantitatively.

Based on the results from the predictive model runs for the IRWMP Baseline Run 1 and conjunctive use scenarios, the following conclusions are made:

- In general, the model-generated groundwater flow direction for the IRWMP Baseline Run 1 is similar to historical directions with groundwater flowing west from the SAR and Mill Creek Spreading Grounds, and southeast from Lytle Creek and Cajon Creek (i.e., flowing to the Pressure Zone area). Groundwater level fluctuations reflect hydrological wet and dry cycles. For example, a change in groundwater level of 50 feet to 100 feet occurs in the Pressure Zone between model years 2027 (equivalent to 1983 - end of a wet year cycle) and 2036 (equivalent to 1992 - end of a dry cycle). Groundwater flow directions and general patterns of fluctuations for the three conjunctive use scenarios (Runs 1A, 1B and 1C) are similar to the Baseline Run 1.

- The lowest groundwater level for the Baseline Run 1 would be approximately 160 feet in

[17] The Newmark Project Team comprises Stantec and the SBMWD.

the City of Riverside Raub 1 Well, which is above the historical lowest level. Therefore, land subsidence potential for this model run is minimal. However, groundwater levels would be an additional 20 to 60 feet lower in this well for model Runs 1A, 1B, and 1C compared to the Baseline Run 1. Depth to groundwater level below the historical low may have subsidence potential. The Basin Management Technical Committee of SBBA plans to monitor land subsidence in their annual Regional Water Management Plan.

- Annual potential liquefaction area as a percentage of the Pressure Zone area ranges from zero in year 2036 (hydrologic year 1992) to 6.0% in year 2030 (hydrologic year 1986) with an annual average of 2.3%. This is a significant reduction when compared to the high groundwater conditions that occurred in the Pressure Zone in 1984. In 1984, approximately 50% of the Pressure Zone area had a depth to water less than or equal to 50 feet below the land surface. The potential liquefaction area in the Pressure Zone for model Runs 1A and 1B would be similar to the conditions of Baseline Run 1. Run 1C shows elevated potential liquefaction areas in some years with the greatest percentage up to 19.5% in year 2019. In this case, liquefaction potential is higher in both Highland and San Bernardino. Mitigation through additional pumping of existing or new wells would be needed to lower the groundwater level below 50 feet from land surface. The Basin Management Technical Committee of SBBA plans to review water levels annually in their Regional Water Management Plan.

- Groundwater storage in the SBBA increases 322 acre-ft/yr during the period 2006 through 2044 under Baseline Run 1 conditions. Changes in groundwater storage for all three conjunctive use runs are similar to Baseline Run 1, ranging from a decline of 722 acre-ft/yr for Run 1B to an increase of 726 acre-ft/yr for Run 1A. The patterns of the cumulative changes in groundwater storage for all the four model runs during the period 2006-2044 are similar to the historical period from 1962-2000. At the end of the model simulation in year 2044, the cumulative change in groundwater storage would be negative 200,000 acre-ft, which would be similar to the level at the beginning of the model simulation (i.e., in year 2005). This indicates that the basin is in “balance.”

- For model Runs 1A, 1B and 1C, the additional amounts of artificial recharge compared to Baseline Run 1 are 22,956 acre-ft/yr, 72,924 acre-ft/yr and 114,433 acre-ft/yr, respectively. Due to artificial recharge, the amounts of recharge from gaged streamflow, evapotranspiration, groundwater pumping, underflow and changes in groundwater storage are also changed. The major loss of water for the conjunctive use model runs would be the reduction of recharge from gaged streamflow. These decreases are 781 acre-ft/yr, 11,143 acre-ft/yr and 21,755 acre-ft/yr for model Runs 1A, 1B, and 1C, respectively. This loss is due to a significant increase in artificial recharge at the spreading grounds in the forebay area that would cause higher groundwater levels in the forebay area, thereby preventing some groundwater recharge in the stream channel (i.e., rejected recharge). For purpose of this report, the efficiency of conjunctive use was calculated as the ratio of the amount of additional groundwater pumping to the amount of additional artificial recharge. The efficiency ranges from 77% for model Run 1C to 87% model Run 1A.

- The maximum groundwater pumping during a single year drought was 289,105 acre-ft in 2034 (hydrologic year 1990) for the Baseline Run 1. This was to meet the projected water demands and additional 4.3% increase for a critical year. The additional yield for the conjunctive use would be 40,000 acre-ft, 120,000 acre-ft and 160,000 acre-ft for model Runs 1A, 1B, and 1C, respectively. This additional yield is due to water stored prior to the drought for these conjunctive use scenarios. The conjunctive use scenarios are essentially “put and take” projects. The additional yields (take) require an equivalent amount of net recharge (put) (i.e., amount of recharge minus water losses due to rejected recharge and evapotranspiration). The maximum groundwater pumping during a three-year drought was 838,422 acre-ft in 2032-2034 (hydrologic years 1988-1990) for the Baseline Run 1. This was to meet the projected water demands and additional 4.3% increase in these critical years. The additional yield for the conjunctive use would be

100,000 acre-ft, 320,000 acre-ft and 420,000 acre-ft for model Runs 1A, 1B, and 1C, respectively.

Based on the results from the predictive model runs for sensitivity analysis to the surface water supplies including SWP water and local surface water, the following conclusions were made:

- Groundwater levels would decrease in these runs compared to the IRWMP Baseline Run 1, reflecting the reduction of SWP and local surface water supplies. For example, water levels in the Backyard Well would decrease by 20 ft (95% local surface water supplies) to 50 ft (50% SWP) in year 2044 as compared to the water level under Baseline Run 1 conditions.

- Cases A through D show that reducing the reliability of the SWP and/or local surface water supplies would result in the decline of annual groundwater storage ranging from 3,773 acre-ft per year to 11,561 acre-ft per year, or 147,100 acre-ft to 450,900 acre-ft over the 39-year base period. For the worse case scenario (Case E), the cumulative groundwater storage decline for the entire 39-year study period would be approximately 798,200 acre-ft (20,467 acre-ft/yr). Since the cumulative change in storage is lower than the Baseline Run 1 for each of these cases, specific water management strategies would need to be implemented to make up for the loss in these supplies.

- Although the basin cannot meet demands if the SWP or local supplies are reduced, the model can show the impacts on individual wells. Approximately 76% of the total groundwater pumping in the SBBA comes from 134 wells operated by the major retail water agencies in the SBBA. Modeling results show that water levels in 18% to 20% of the 134 wells (i.e., 24 to 27 wells) would be below the top of the screen interval by more than 50% at the end of multiple drought years under the reduction of SWP or local surface water supplies. This will reduce the pumping capacity of these wells. Under the worst case scenario (Case E) conditions, there would be more than 27 wells with water levels below the top of screen interval by more than 50% at the end of multiple drought years. However, these conditions can be mitigated by water conservation, water recycling projects, increased utilization of storm water and implementation of new conjunctive use projects.

Based on the results from the predicted model run for the Updated Baseline Run (Run 12), the following conclusions are made:

- In general, the model-generated groundwater flow direction and range of water level fluctuations for the Updated Baseline Run (Run 12) are similar to historical directions and IRWMP Baseline Run 1 conditions with groundwater flowing west from the SAR and Mill Creek Spreading Grounds, and southeast from Lytle Creek and Cajon Creek toward the Pressure Zone area. Groundwater level fluctuations reflect hydrological wet and dry cycles.

- The acreage of the potential liquefaction area is approximately 720 acres and is approximately 4% of total Pressure Zone area of 19,320 acres. The highest percentage was 6.0% in year 2030 (hydrologic year 1986) for the IRWMP Baseline Run 1, and 50% for the historical conditions that occurred in 1984.

- Groundwater storage in the SBBA decreases approximately 1,200 acre-ft/yr during the period 2007 through 2032 under the Updated Baseline Run (Run 12) conditions. This is approximately the same as the IRWMP Baseline Run 1 considering the SBBA basin storage of approximately 6,000,000 acre-ft (DWR, 2003). The patterns of the cumulative changes in groundwater storage for the Updated Baseline Run (Run 12) during the period 2007-2032 are similar to the historical period from 1979-2004. At the end of the model simulation in year 2032, the cumulative change in groundwater storage would be negative 257,000 acre-ft, which would be similar to the level at the beginning of the model simulation (i.e., negative 231,000 acre-ft in year 2006). This indicates that the basin is in "balance."

- The Muscoy PCE plume in model Layer 1 dissipates and moves towards the southeast throughout the entire predictive period (2007 to 2032). The plume in model Layer 2 undergoes very little change (i.e., size and movement) due to the presence of widespread fine-grained sediments. The Newmark and Muscoy PCE plumes in model Layers 3 through 5 dissipate the quickest as a result of increased artificial recharge at spreading basins upgradient of the Newmark plume. These spreading grounds include the East Twin and Waterman Spreading Grounds in the northwestern portion of the SBBA. By the end of the predictive run (2032), the overall initial area of the PCE plume (approximately 1,910 acres) is reduced to approximately 670 acres.

- The TCE plume boundary in all five model layers dissipates and move west throughout the entire predictive period from 2007 to 2032. By the end of the predictive run (2032), the overall initial area of the TCE plume (approximately 2,030 acres) is reduced to approximately 260 acres.

- The perchlorate plume boundary in all five model layers dissipates and moves to the west throughout the entire predictive period from 2007 to 2032. The perchlorate plume in model Layer 1 disappears by 2027. By the end of the predictive run (2032), the overall initial area of the perchlorate plume (approximately 7,820 acres) is reduced to approximately 420 acres

Based on the results of the modeling, the following recommendations are made:

- The RBFM uses a constant transmissivity for the model layer 1 in order to handle the "dry" cells and model numerical problems. In reality, the transmissivity in this model layer would vary depending on the saturated thickness and hydraulic conductivity values of the aquifer. The calibrated transmissivity may not represent the real transmissivity during extreme water level conditions (i.e., high and low water level conditions). This may result in an underestimation of the recharge capacity during significant drought conditions. It is our recommendation to convert model layer 1 to a variable transmissivity using the new MODFLOW version MODFLOW-2005 during future model updates. MODFLOW-2005 has the capability to handle the "dry" cells and numerical problems encountered with MODFLOW-2000 that is currently used by the RBFM.

- The recharge from direct precipitation and recharge from local runoff generated by precipitation used for the RBFM model were estimated based on an empirical average. A watershed model approach has been developed and improved significantly in recent years such as Hydrologic Simulation Program – Fortran (HSPF) and Precipitation-Runoff Modeling System (PRMS). These modeling tools will improve not only the quantification of the recharge but also the spatial and temporal distributions of the recharge as a result of changes in land uses. It is our recommendation to consider including the watershed modeling approach during future model updates. Improvement of the determination of recharge from precipitation will enhance the overall water budget quantification and development of a conceptual model for salt budgets. An accurate conceptual model for salt budgets will be important for the salinity management of the basin.

- The return flow used for the RBFM model was based on an assumption of 30% of the groundwater pumping. The amount of return flow may change due to water use changes. It is our recommendation to reevaluate the return flow based on the types of water use during future model updates. This will also be an important component for the development of a conceptual model for salt budgets.

7.0 MODEL LIMITATIONS AND UNCERTAINTY

The SBBA RBFM and RBSTM are useful tools for evaluating water levels and water quality of the aquifer systems as the model calibration exceeds the industry standards. In addition, the confidence in using the model for predictive model runs is increased through the reasonable results from the IRWMP Baseline Run 1 and conjunctive use scenarios, sensitivity model runs to SWP water and local surface water supplies, and the Updated Baseline Run (Run 12). However, they are a simplified approximation of a complex hydrogeologic system. The accuracy of predictions made by the RBFM and RBSTM models are highly dependent on the simplifying assumptions used. As an example, the simplifications of the estimated mass loading for the contaminants (i.e., PCE, TCE and perchlorate) could have a significant effect on the model results. It is anticipated that each model will be updated on a regular basis to improve its accuracy.

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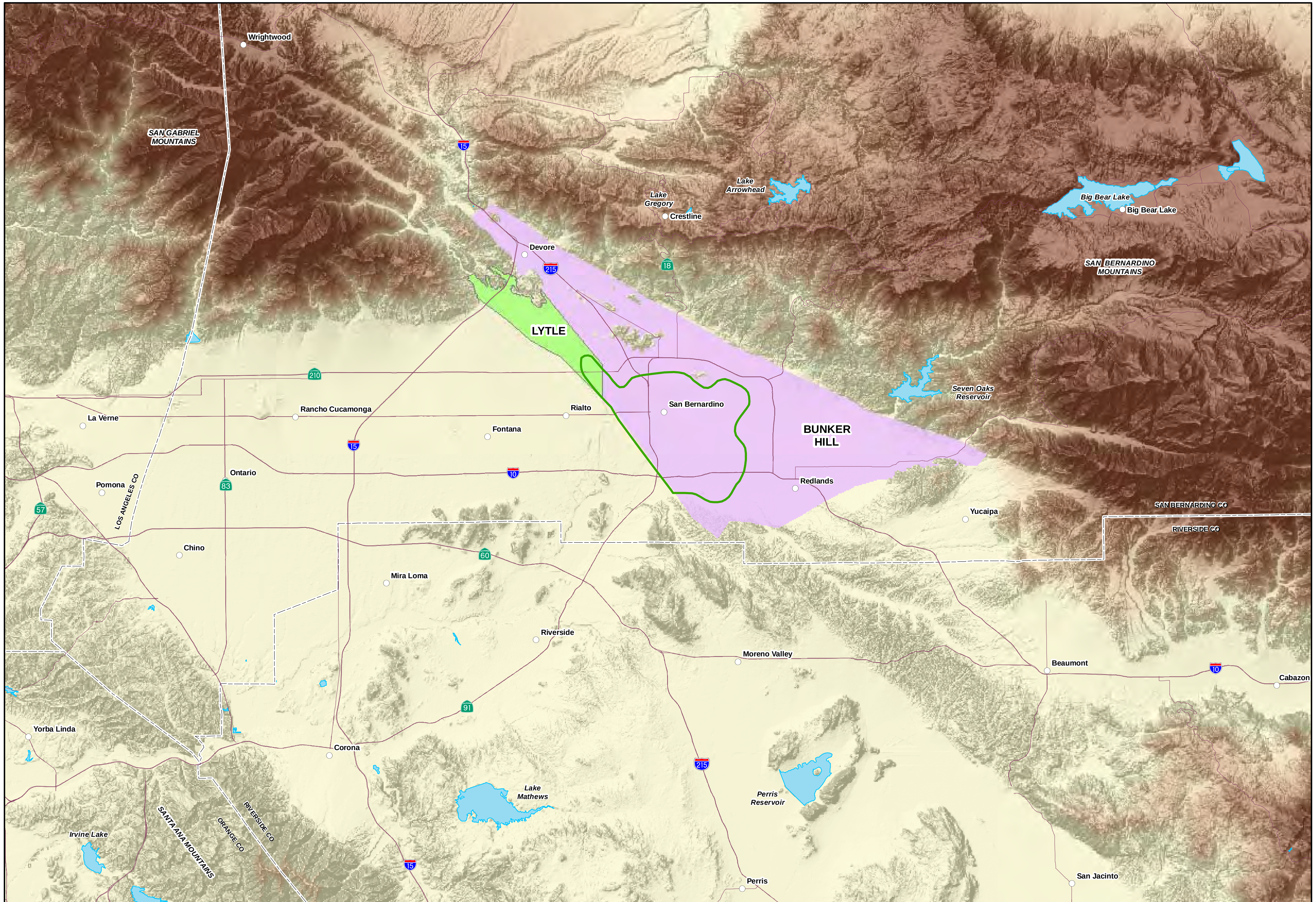
FIGURES

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT

GENERAL PROJECT LOCATION



EXPLANATION

Bunker Hill Groundwater Basin

Lytle Groundwater Basin

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

NORTH

0 5 10 Miles

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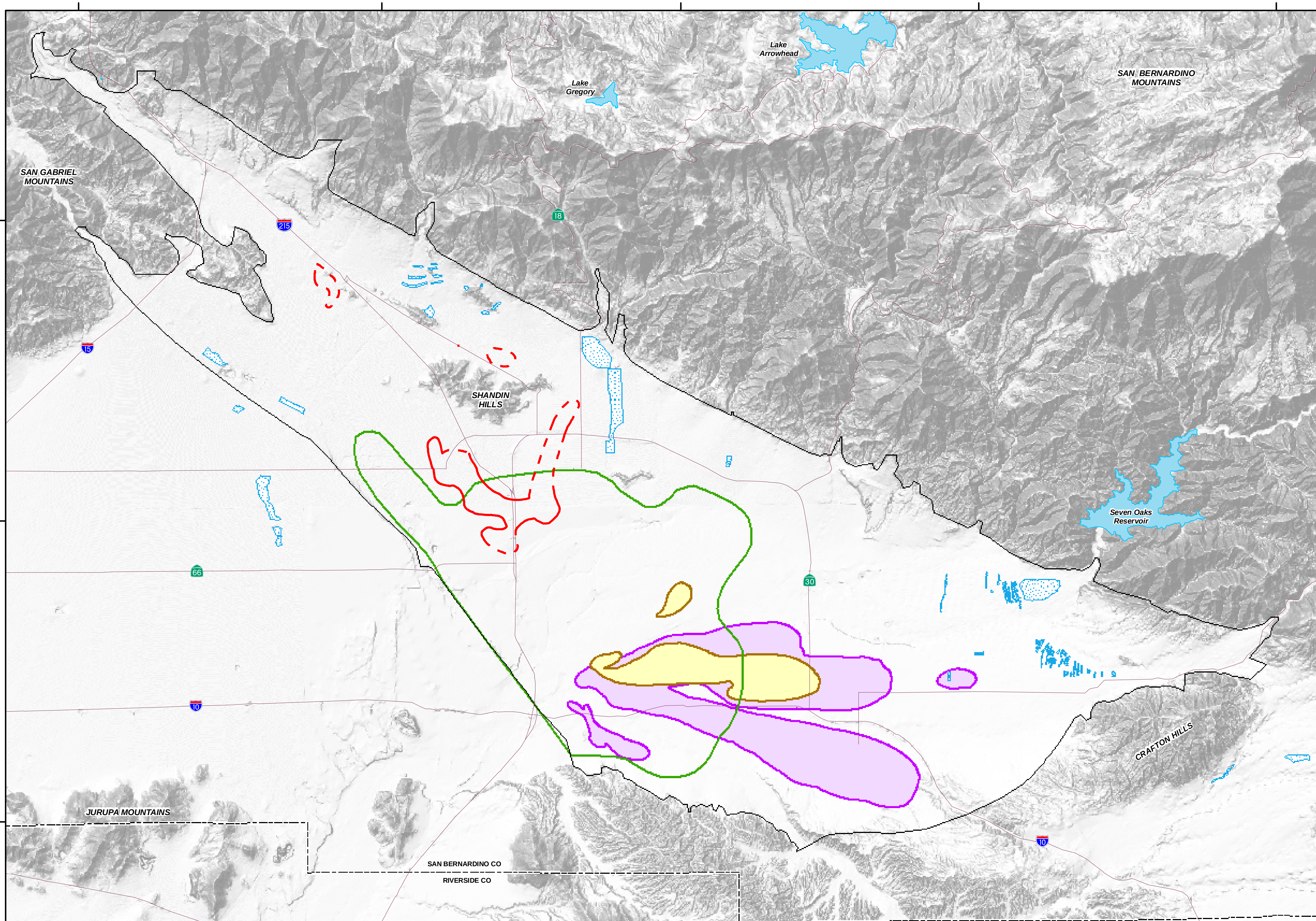
Figure 1

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_1_gen_proj_loc_9-09.mxd

GROUNDWATER CONTAMINANT PLUMES IN THE SBBA



EXPLANATION

- PCE Groundwater Contaminant Plume (5 ug/L) Dashed where less certain (Source: SECOR, 2007.)
- TCE Groundwater Contaminant Plume (5 ug/L) (Source: TetraTech, 2008.)
- Perchlorate Groundwater Contaminant Plume (6 ug/L) (Source: TetraTech, 2008.)
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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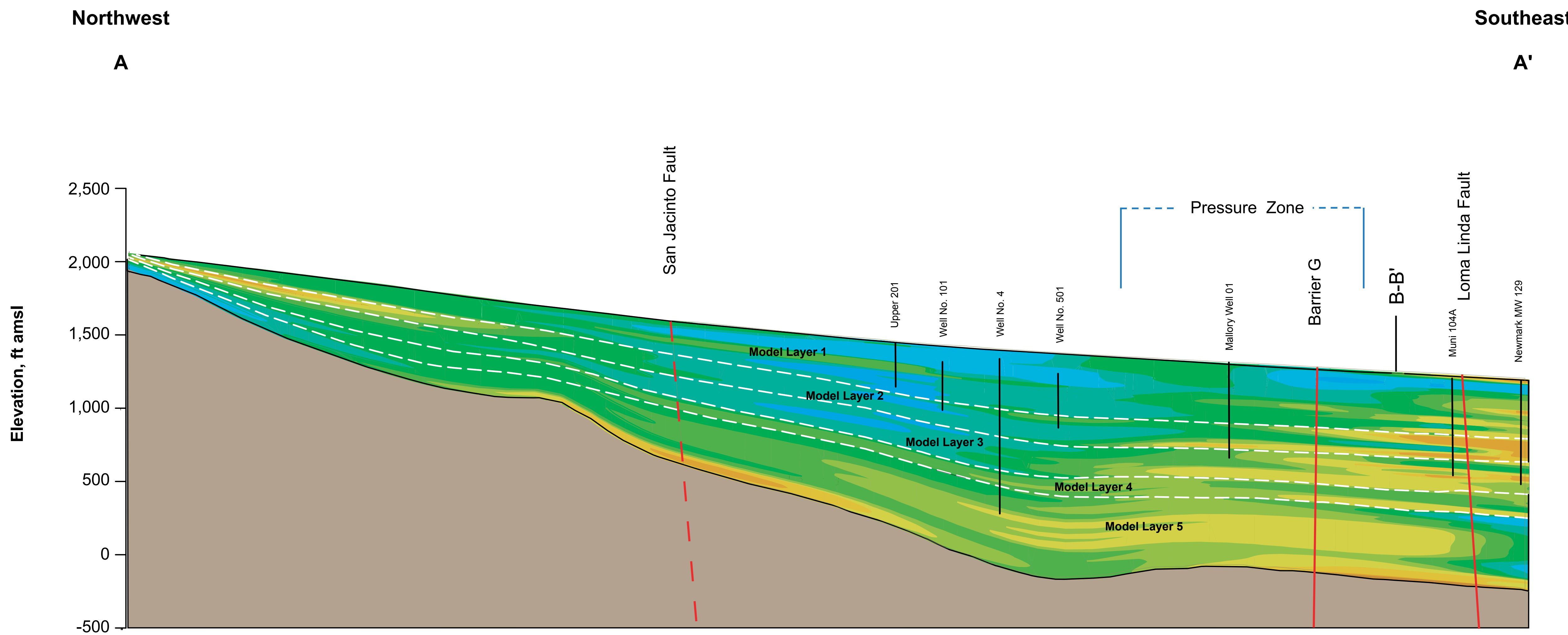
Figure 2



EXPLANATION

Lithology
- Gravel
- Sand
- Silt
- Clay
- Weathered Bedrock
- Bedrock

White Dashed Line — Model Layer Boundary

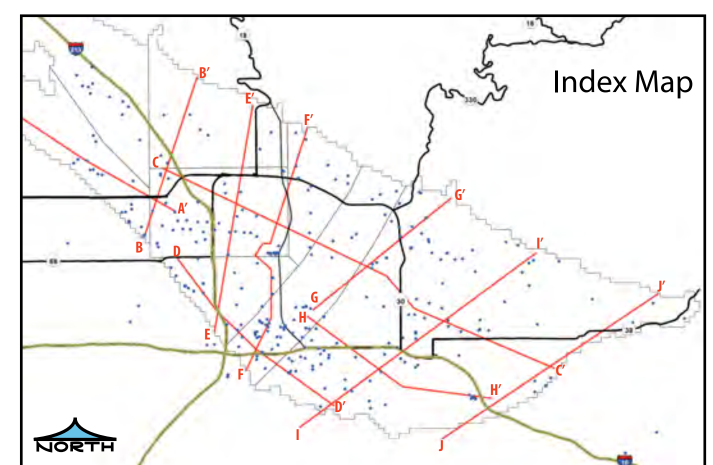
Well Borehole

Fault, dashed where inferred

Pressure Zone

Source of Cross Section:
Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 3,500 7,000

Approximate Scale Feet

Vertical Exaggeration = 2X

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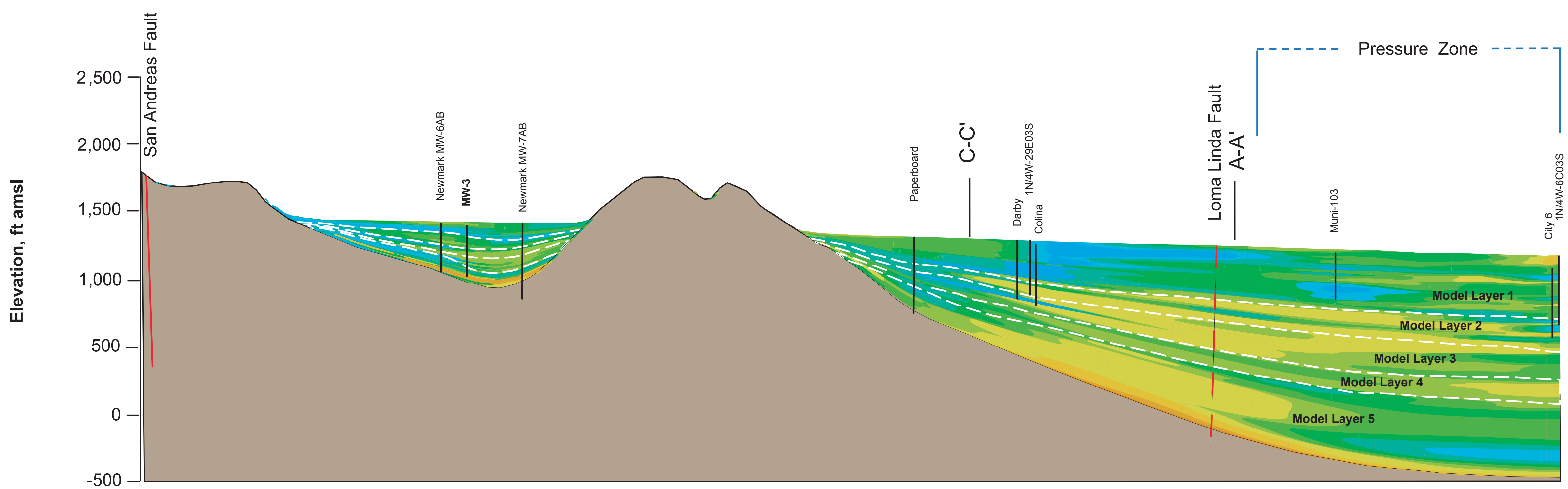
SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

3-DIMENSIONAL LITHOLOGIC MODEL
GEOLOGIC CROSS SECTION FOR A-A'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 3

Projects\San_Bernardino_MUNI\Model_refinement_2005\(31)30_Sep_09_Final_Report\Figures\Figure_3_cross_sec_a-a'.ai



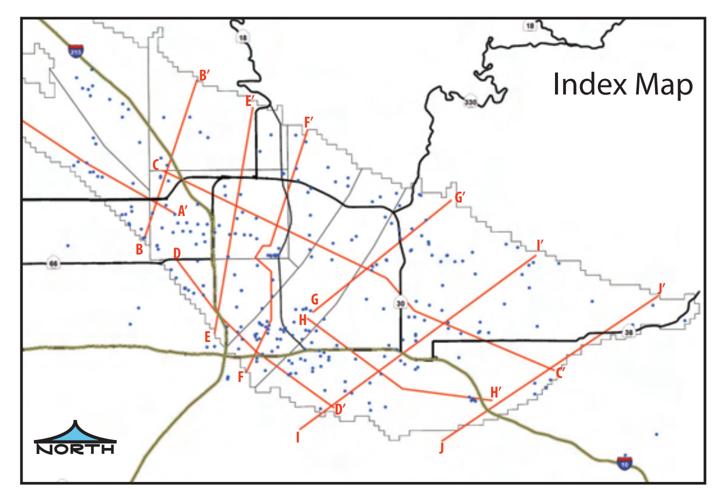
EXPLANATION

Lithology
- Gravel
- Sand
- Silt
- Clay
- Weathered Bedrock
- Bedrock

White Dashed Line — Model Layer Boundary
Well Borehole
Fault, dashed where inferred
Pressure Zone

Source of Cross Section:
Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 2,500 5,000

Approximate Scale Feet
Vertical Exaggeration = 2X

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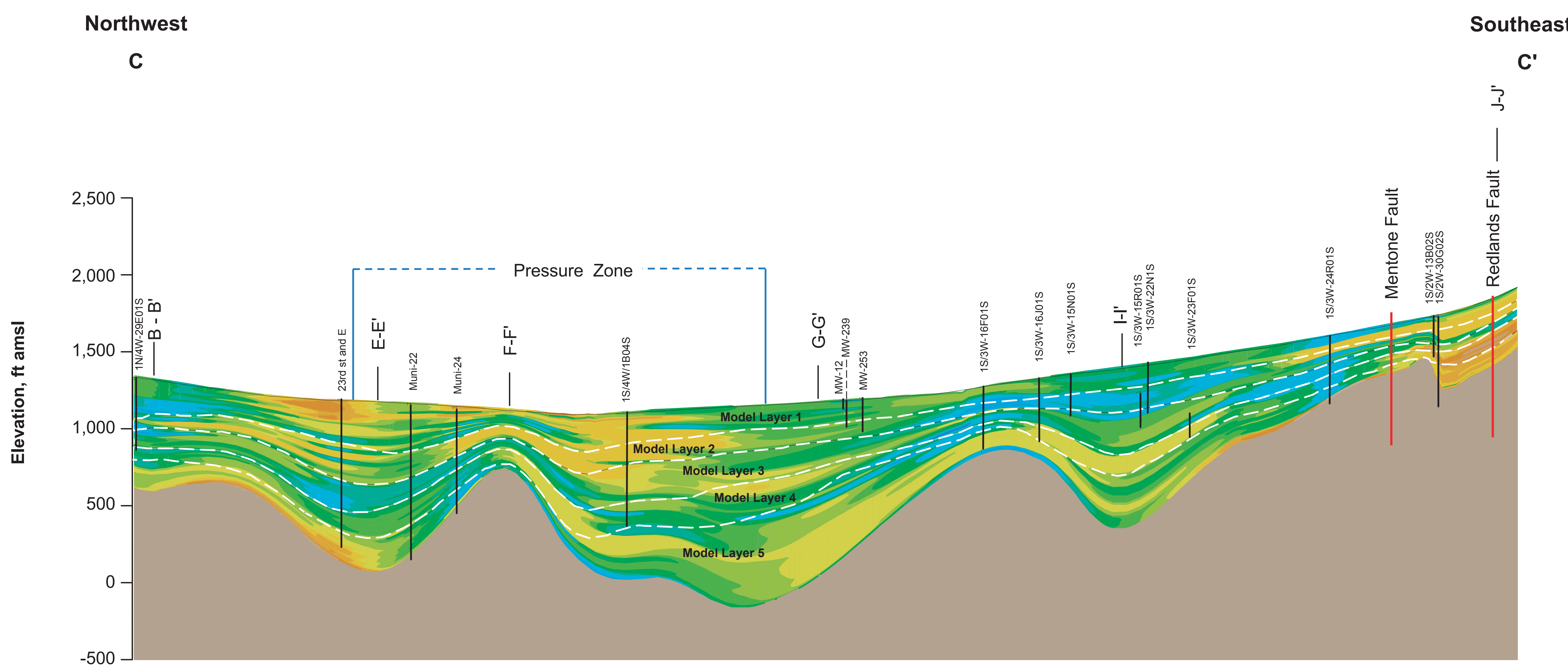
SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

3-DIMENSIONAL LITHOLOGIC MODEL GEOLOGIC CROSS SECTION FOR B-B'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 4

Projects\San_Bernardino_MUNI\Model_refinement_2005\(31)30_Sep_09_Final_Report\Figures\Figure_4_cross_sec_b-b.ai



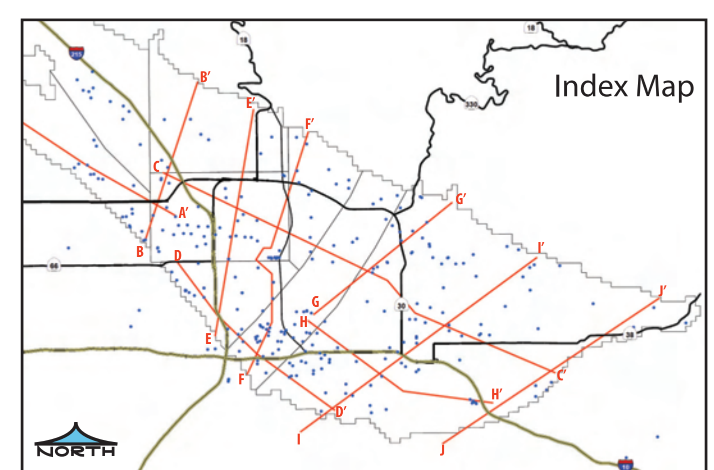
EXPLANATION

Lithology
- Gravel
- Sand
- Silt
- Clay
- Weathered Bedrock
- Bedrock

White Dashed Line — Model Layer Boundary
Well Borehole
Fault
Pressure Zone

Source of Cross Section:
Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 6,500 13,000
Approximate Scale Feet
Vertical Exaggeration = 4x

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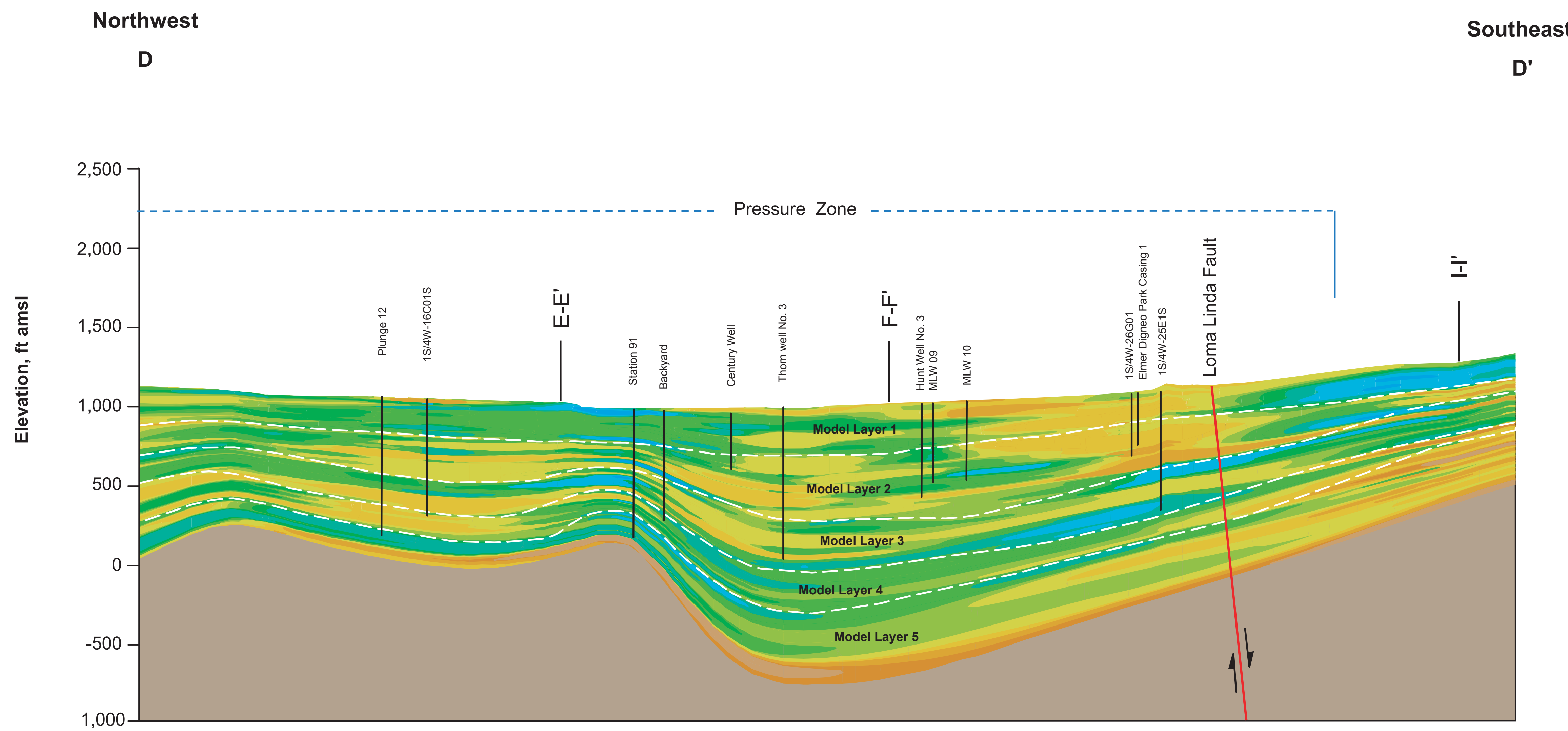
3-DIMENSIONAL LITHOLOGIC MODEL GEOLOGIC CROSS SECTION FOR C-C'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 5



EXPLANATION

Lithology

- Gravel
- Sand
- Silt
- Clay
- Weathered Bedrock
- Bedrock

White Dashed Line — Model Layer Boundary

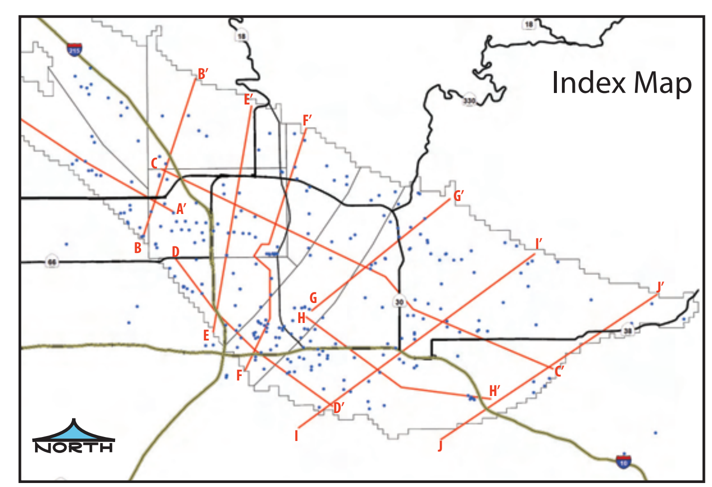
Well Borehole

Fault

Pressure Zone

Source of Cross Section:
Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 3,500 7,000

Approximate Scale Feet

Vertical Exaggeration = 2x

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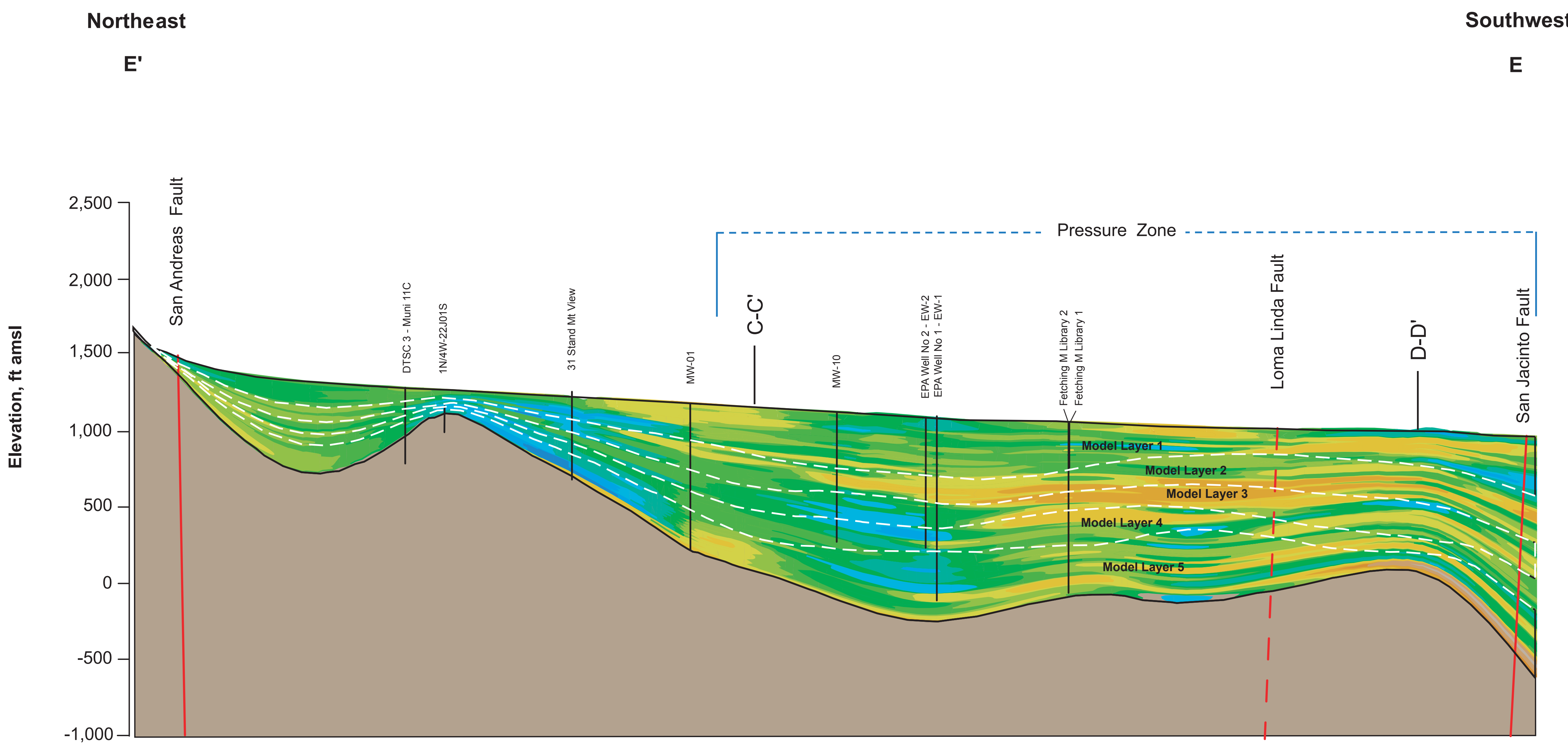
SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

3-DIMENSIONAL LITHOLOGIC MODEL
GEOLOGIC CROSS SECTION FOR D-D'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 6

Projects\San_Bernardino_MUNI\Model_refinement_2005\(31)30_Sep_09_Final_Report\Figures\Figure_6_cross_sec_D-D'.ai



EXPLANATION

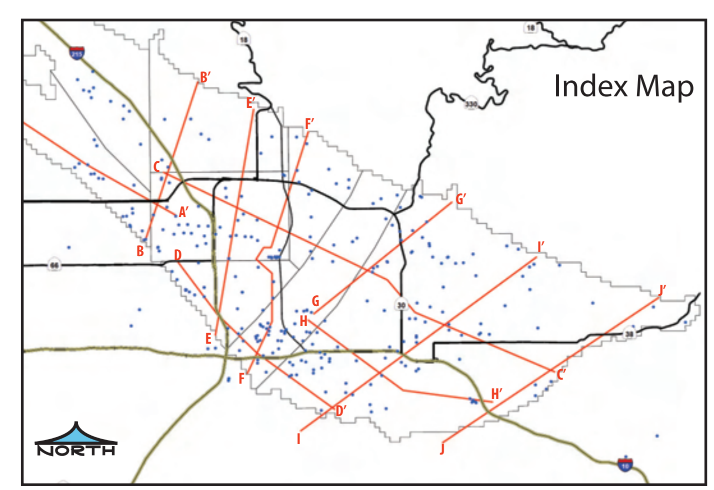
Lithology

- Gravel
- Sand
- Silt
- Clay
- Weathered Bedrock
- Bedrock

White Dashed Line — Model Layer Boundary
Well Borehole
Fault, dashed where inferred
Pressure Zone

Source of Cross Section:
Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 3,500 7,000
Approximate Scale Feet
Vertical Exaggeration = 2x

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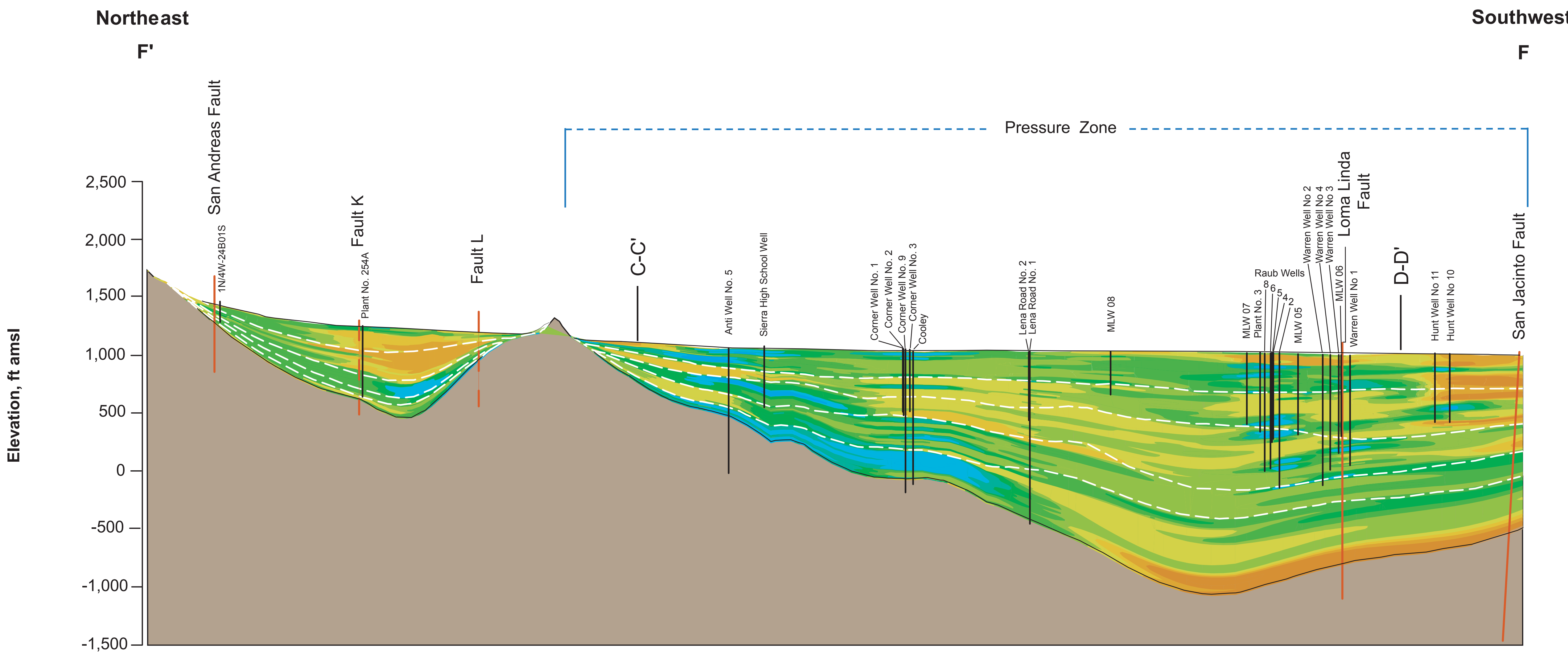
SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

3-DIMENSIONAL LITHOLOGIC MODEL
GEOLOGIC CROSS SECTION FOR E-E'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 7

Projects\San_Bernardino_MUNI\Model_refinement_2005\(31)30_Sep_09_Final_Report\Figures\Figure_7_cross_sec_E-E'.ai



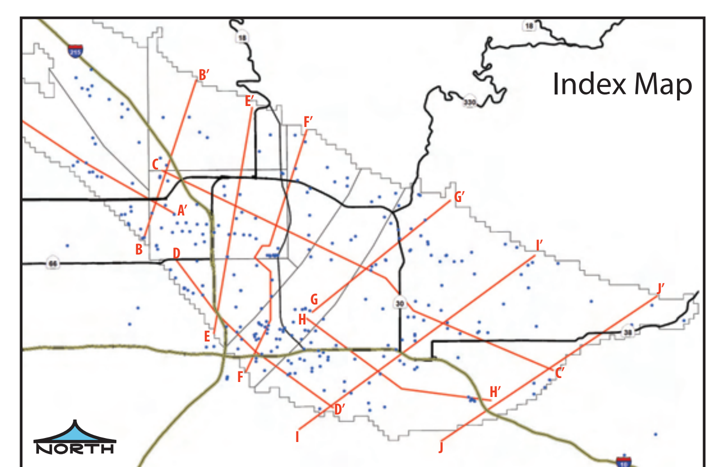
EXPLANATION

Lithology
Gravel
Sand
Silt
Clay
Weathered Bedrock
Bedrock

White Dashed Line — Model Layer Boundary
Well Borehole
Fault, dashed where inferred
Pressure Zone

Source of Cross Section:
Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 4,000 8,000
Approximate Scale Feet
Vertical Exaggeration = 2x

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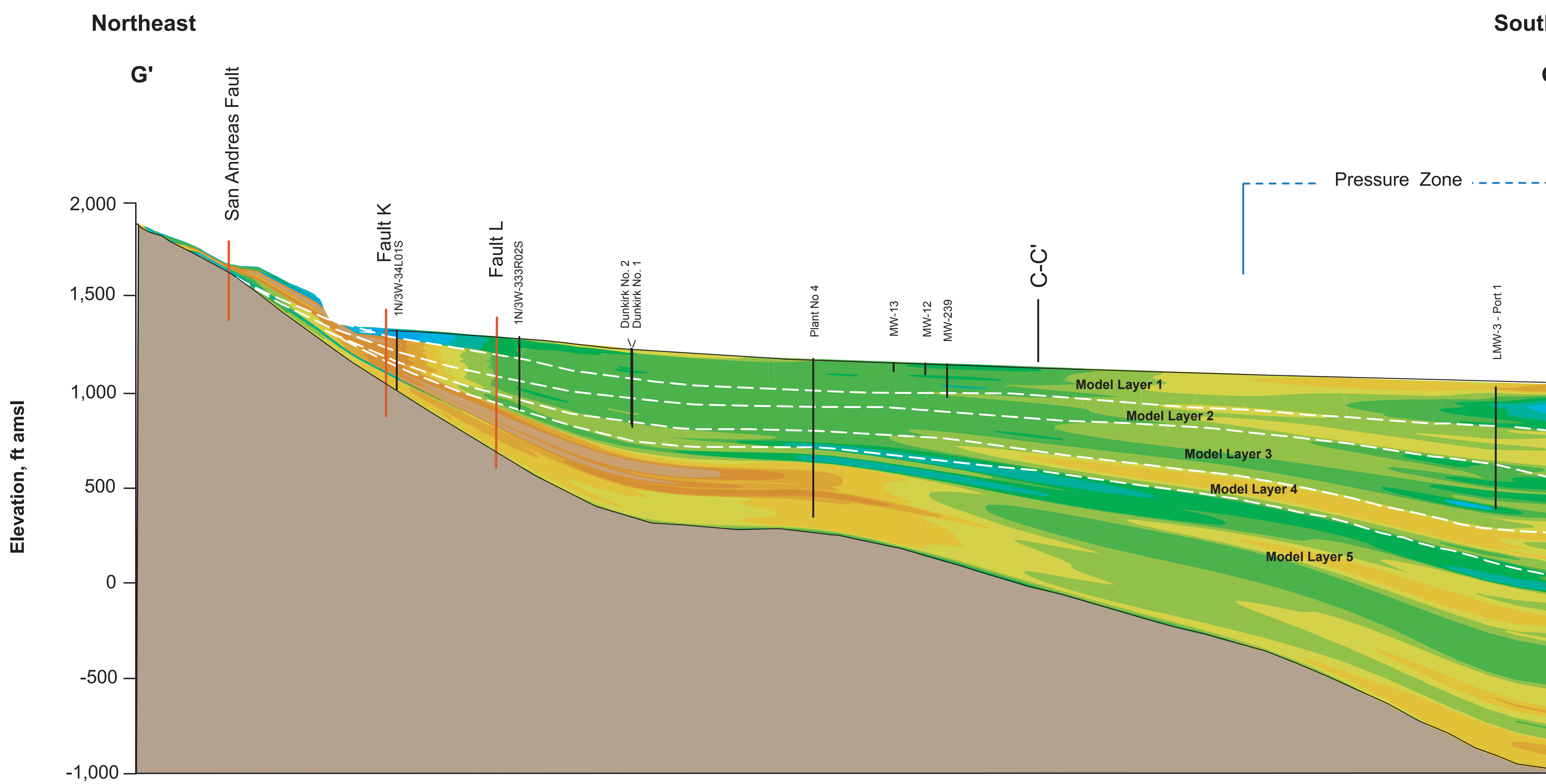
SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

3-DIMENSIONAL LITHOLOGIC MODEL
GEOLOGIC CROSS SECTION FOR F-F'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 8



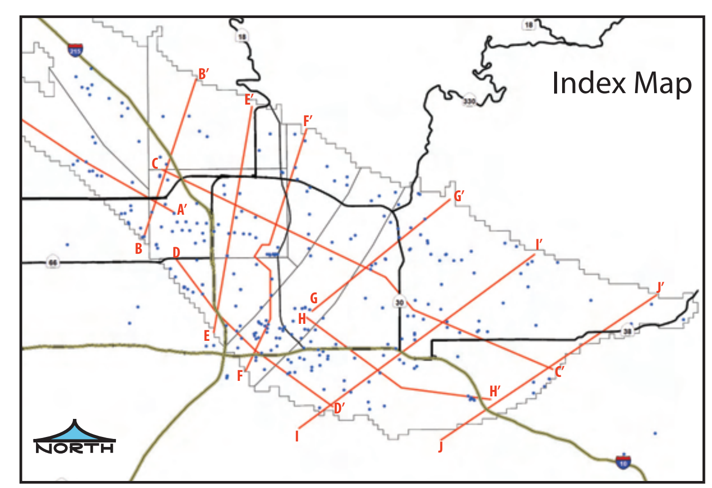
EXPLANATION

Lithology
- Gravel
- Sand
- Silt
- Clay
- Weathered Bedrock
- Bedrock

White Dashed Line — Model Layer Boundary
Well Borehole
Fault
Pressure Zone

Source of Cross Section:
Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 3,000 6,000
Approximate Scale Feet
Vertical Exaggeration = 2x

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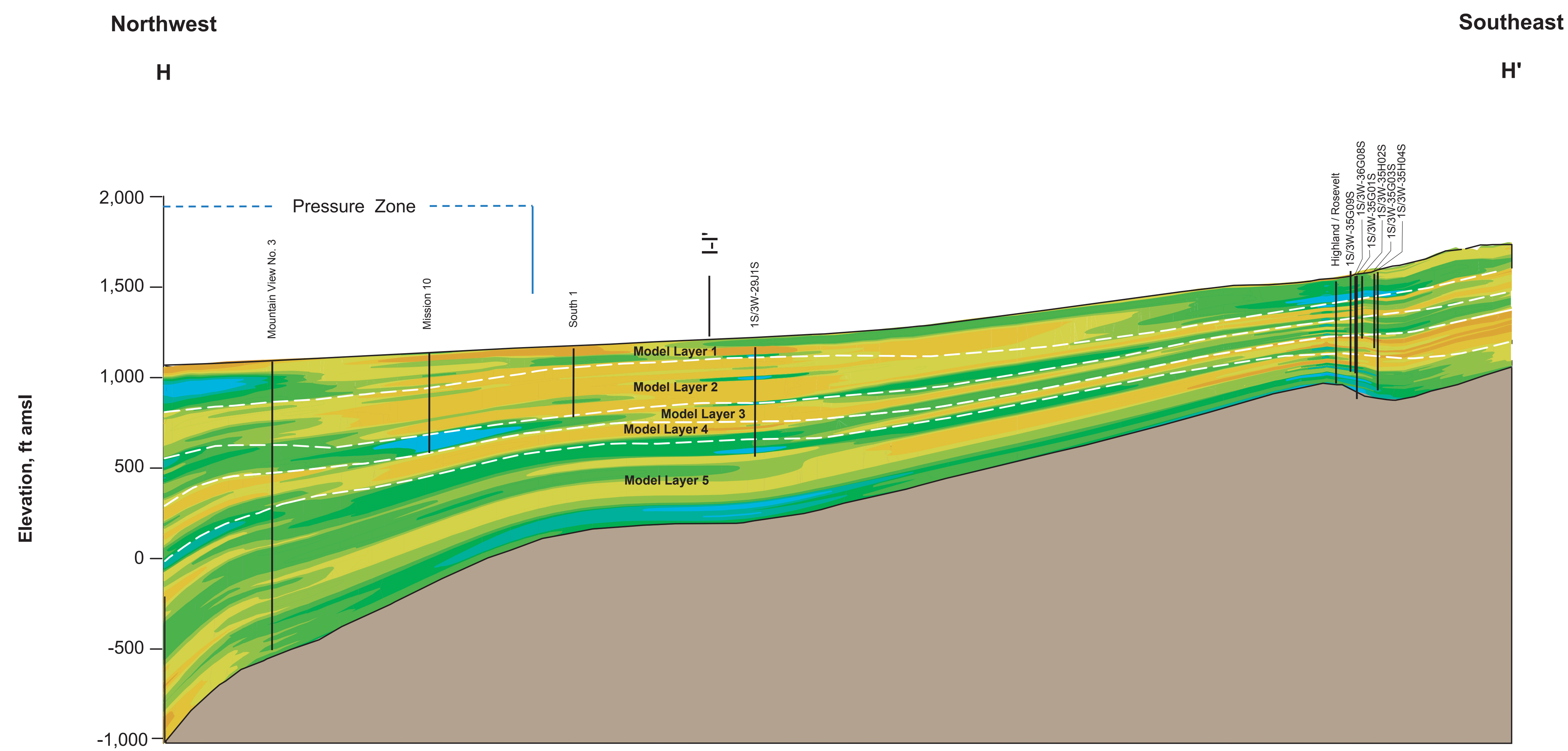
SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

3-DIMENSIONAL LITHOLOGIC MODEL
GEOLOGIC CROSS SECTION FOR G-G'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 9



EXPLANATION

Lithology

- Gravel
- Sand
- Silt
- Clay
- Weathered Bedrock
- Bedrock

White Dashed Line — Model Layer Boundary

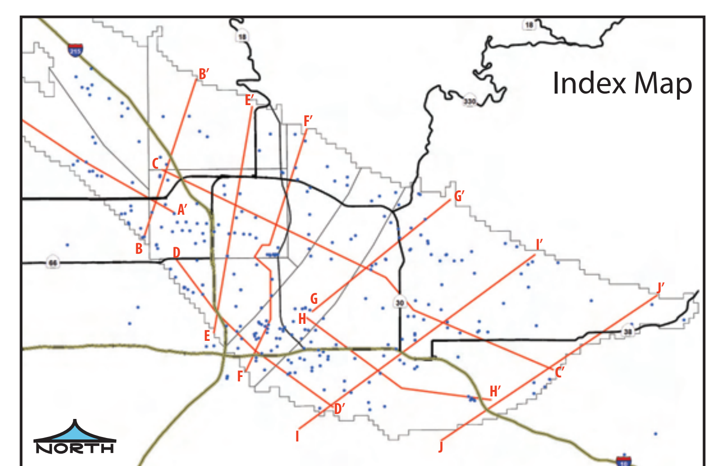
Well Borehole

Fault

Pressure Zone

Source of Cross Section:
Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 3,500 7,000

Approximate Scale Feet

Vertical Exaggeration = 2X

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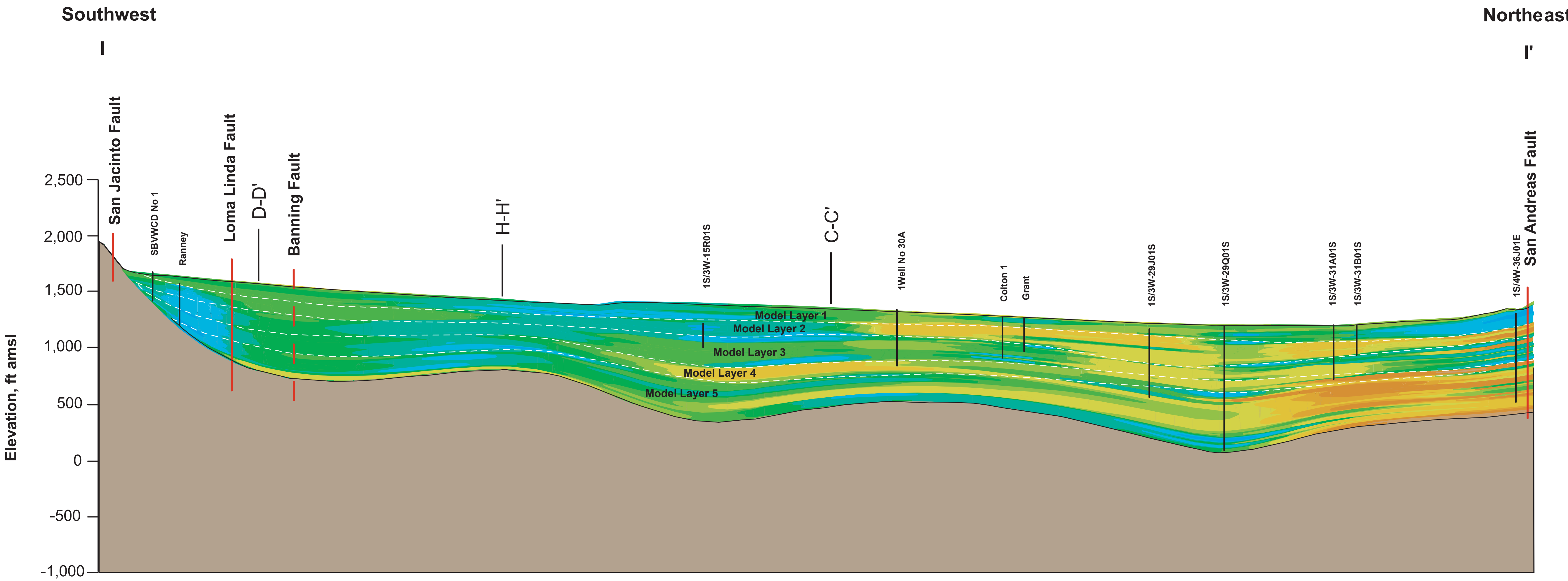
SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

3-DIMENSIONAL LITHOLOGIC MODEL
GEOLOGIC CROSS SECTION FOR H-H'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 10



EXPLANATION

Lithology

- Gravel
- Sand
- Silt
- Clay
- Weathered Bedrock
- Bedrock

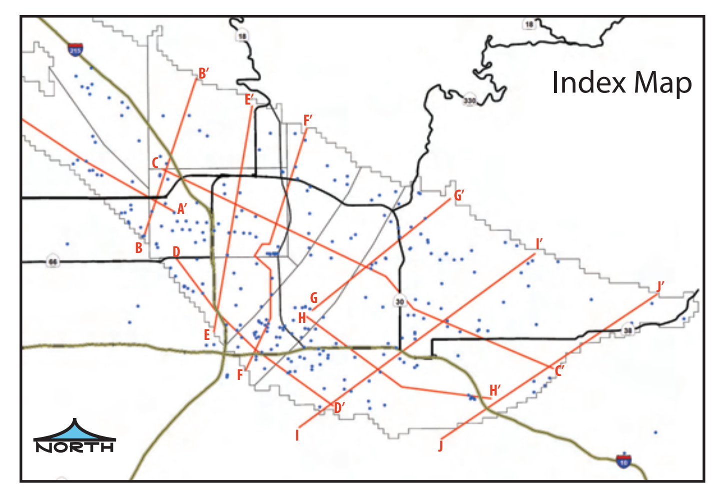
White Dashed Line — Model Layer Boundary

Well Borehole

Fault, dashed where inferred

Source of Cross Section: Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 4,500 9,000

Approximate Scale Feet

Vertical Exaggeration = 2x

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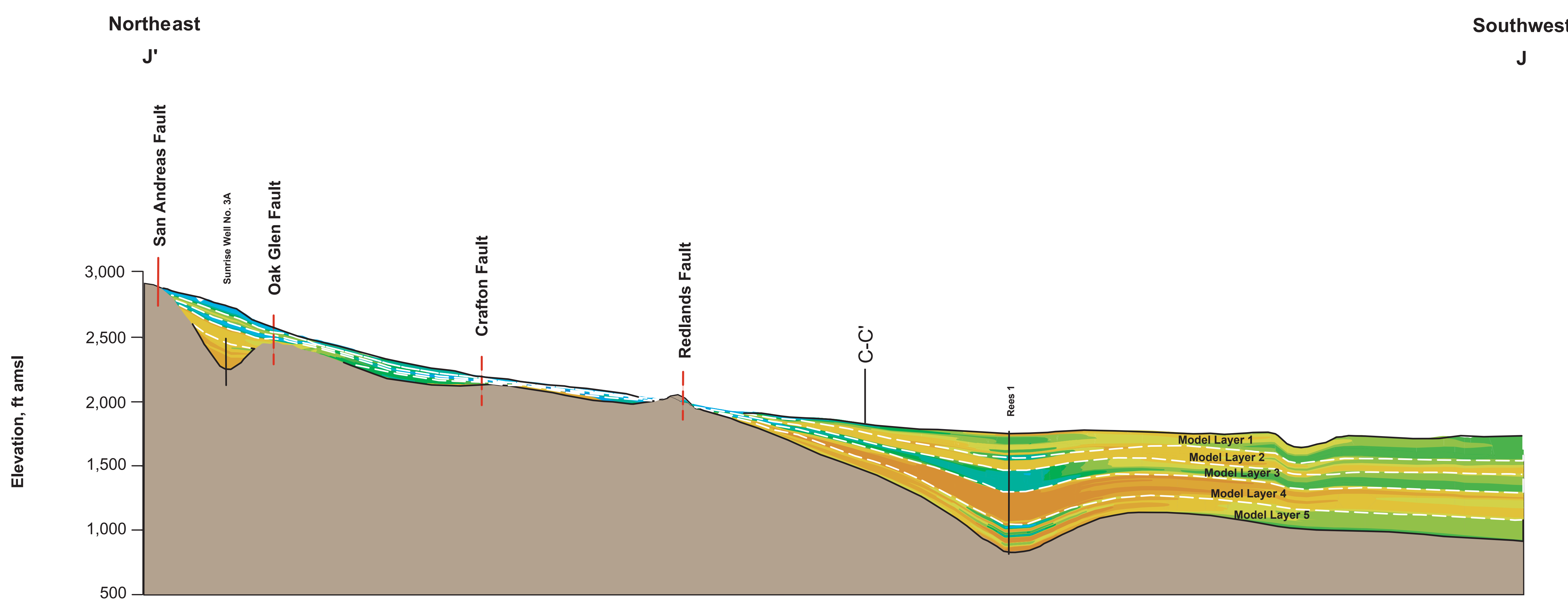
SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

3-DIMENSIONAL LITHOLOGIC MODEL
GEOLOGIC CROSS SECTION FOR I-I'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 11



EXPLANATION

Lithology

- Gravel
- Sand
- Silt
- Clay
- Weathered Bedrock
- Bedrock

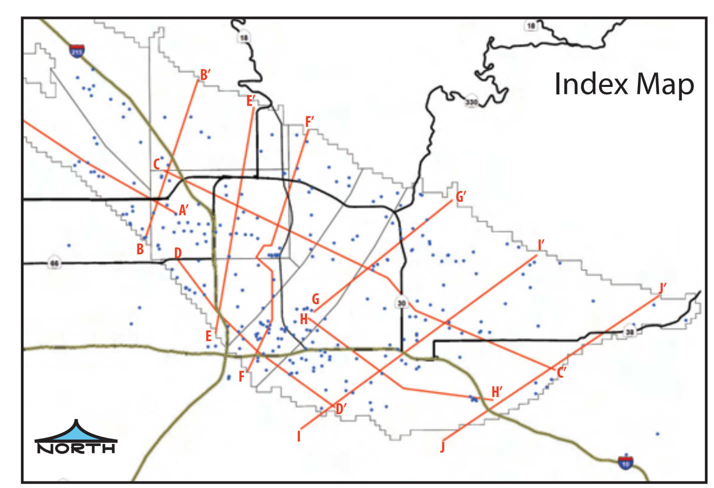
White Dashed Line — Model Layer Boundary

Well Borehole

Fault, dashed where infered

Source of Cross Section:
Numeric Solutions, 2006

Note: Borehole logs of wells shown in the index map were used to construct the 3-dimensional lithologic model.



0 3,500 7,000

Approximate Scale Feet

Vertical Exaggeration = 2X

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SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

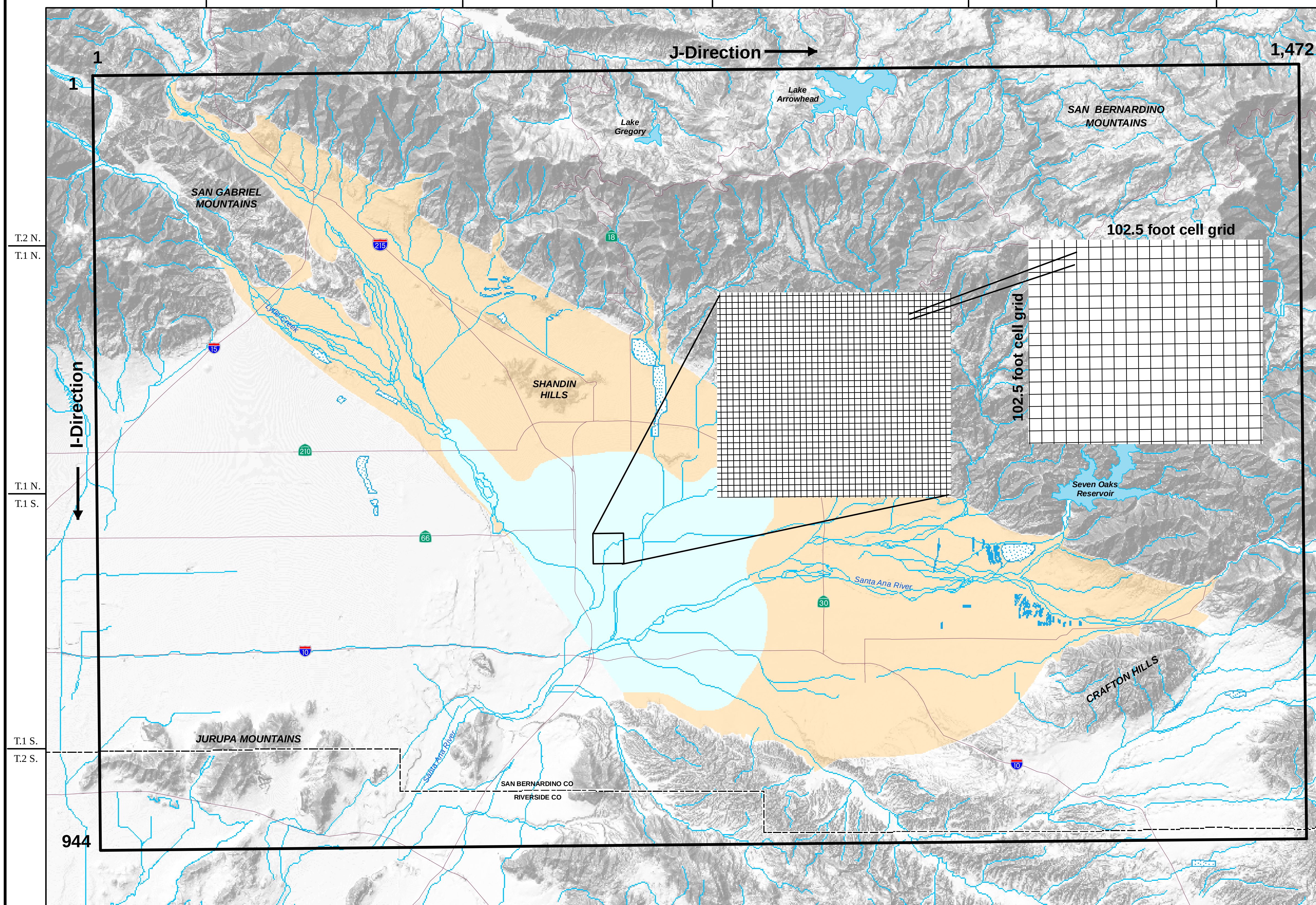
3-DIMENSIONAL LITHOLOGIC MODEL GEOLOGIC CROSS SECTION FOR J-J'

Drawn: LH
Checked: JK
Approved:
Date: 30-Sep-09

Figure 12

Projects\San_Bernardino_MUNI\Model_refinement_2005\(31)30_Sep_09_Final_Report\Figures\Figure_12_cross_sec_j-j.ai

MODEL GRID OF THE REFINED BASIN FLOW MODEL



EXPLANATION

- Model Grid of the Refined Basin Flow Model (102.5 feet by 102.5 feet grid)
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

NORTH

0 2 4 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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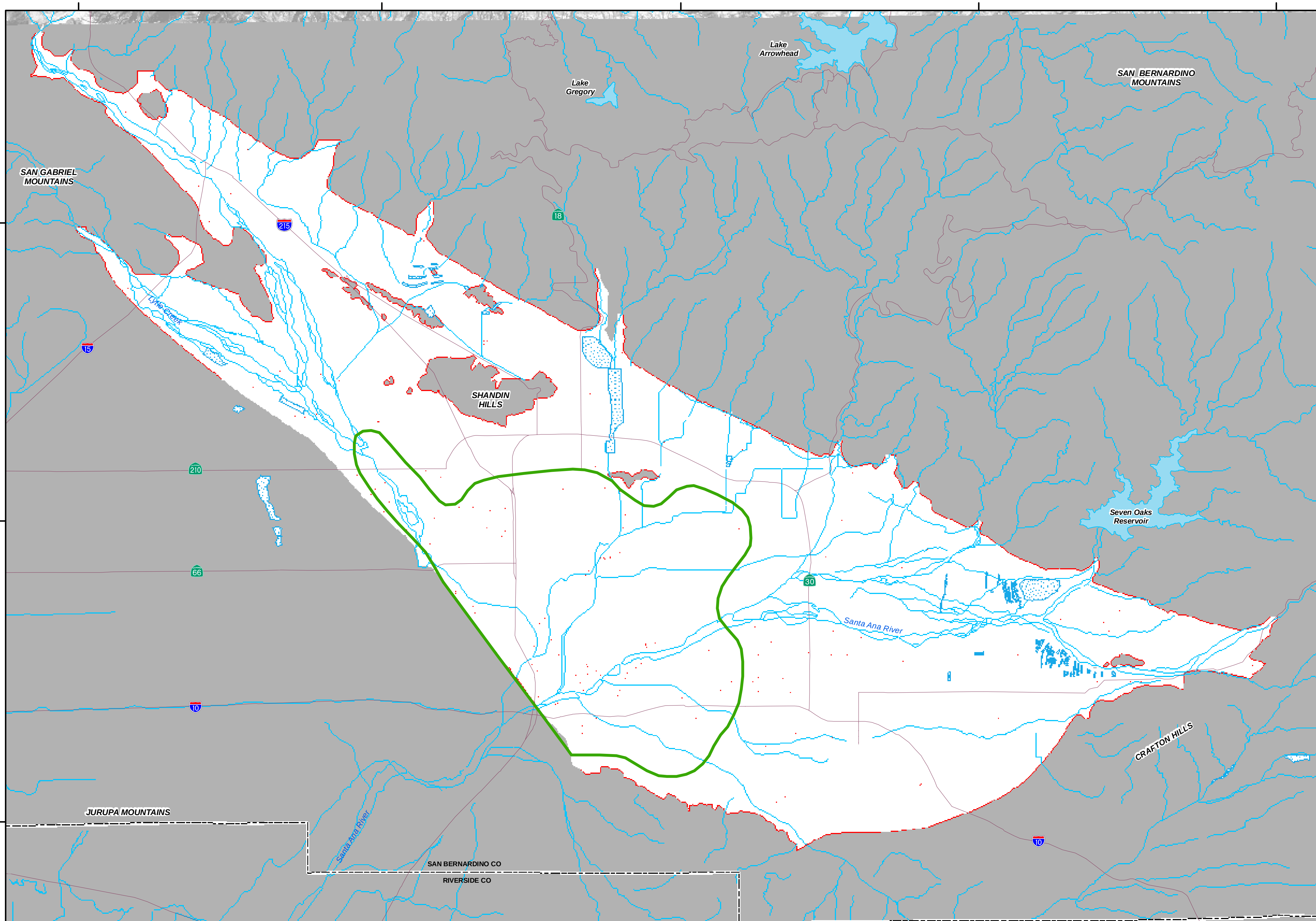
Figure 13

BOUNDARY CONDITIONS OF THE REFINED BASIN FLOW MODEL



EXPLANATION

Boundary Conditions

- Active Model Cell
- No Flow Model Cell
- Recharge from Mountain Front Runoff, Underflow Inflow, Groundwater Pumping and Underflow Outflow
- Spreading Grounds or Basins
- Pressure Zone
- County Boundary

NORTH

0 2 4 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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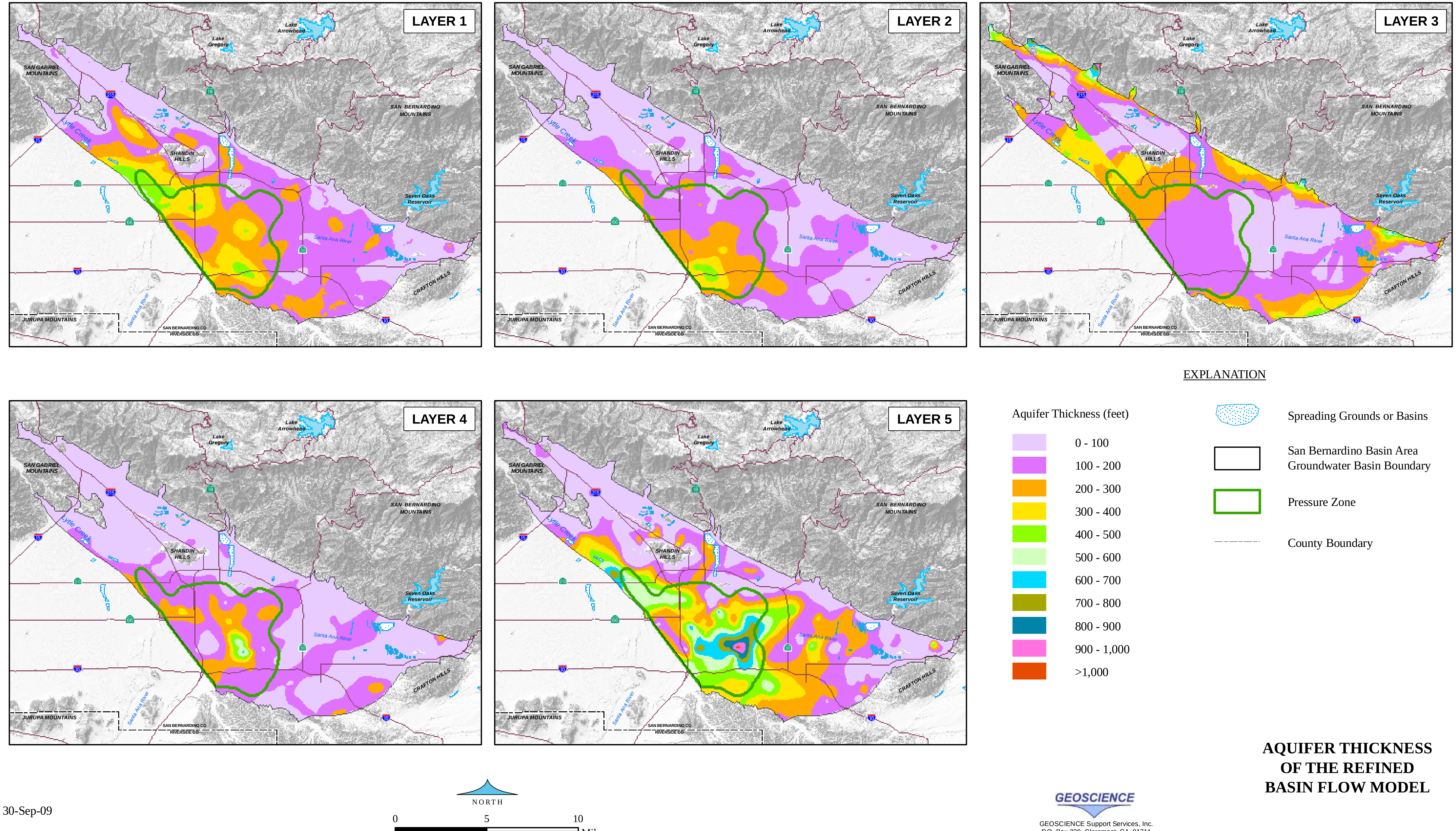
Figure 14

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_14_bndy_cond_9-09.mxd



AQUIFER THICKNESS OF THE REFINED BASIN FLOW MODEL

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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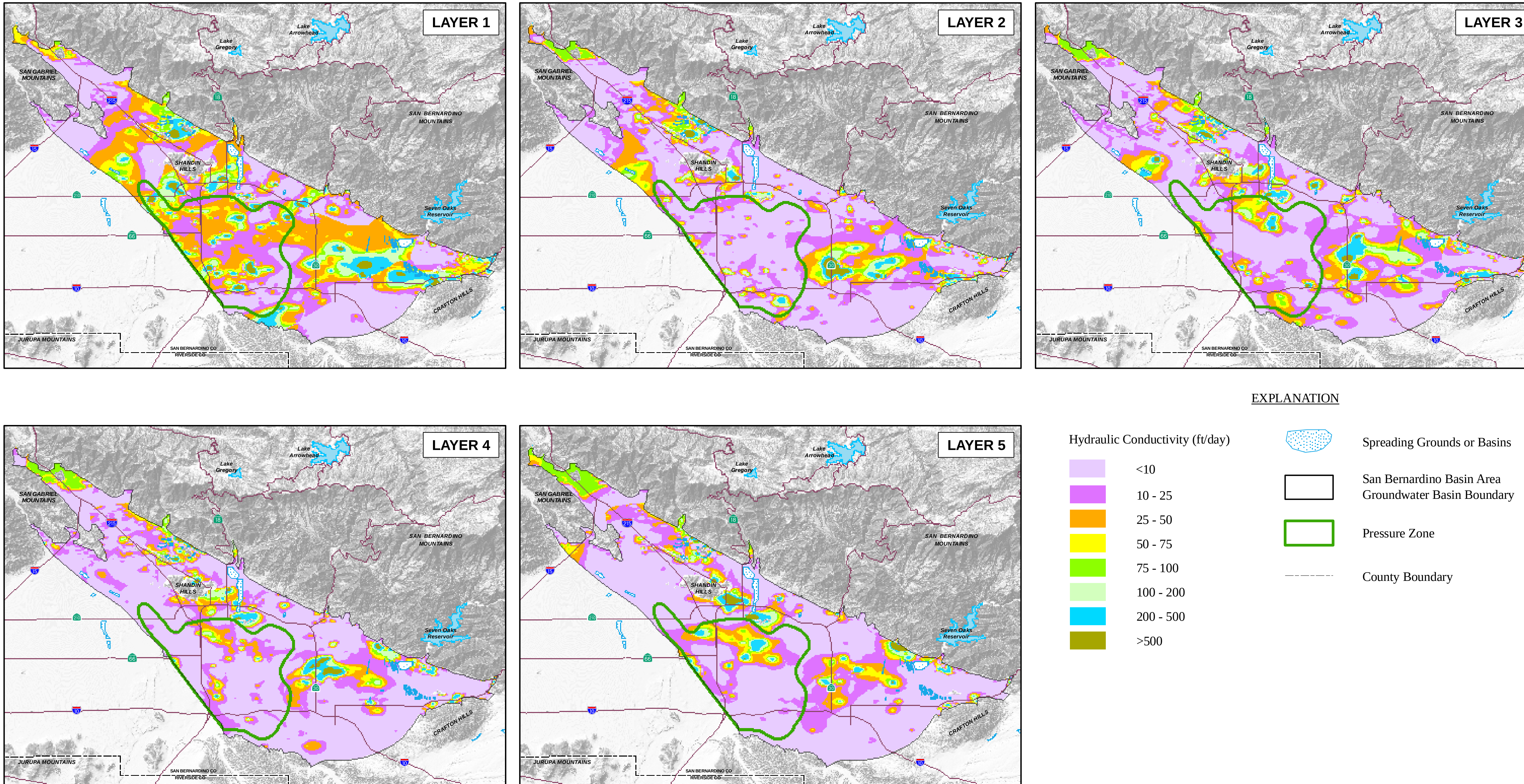
Figure 15

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_15_thickness_9-09.mxd



NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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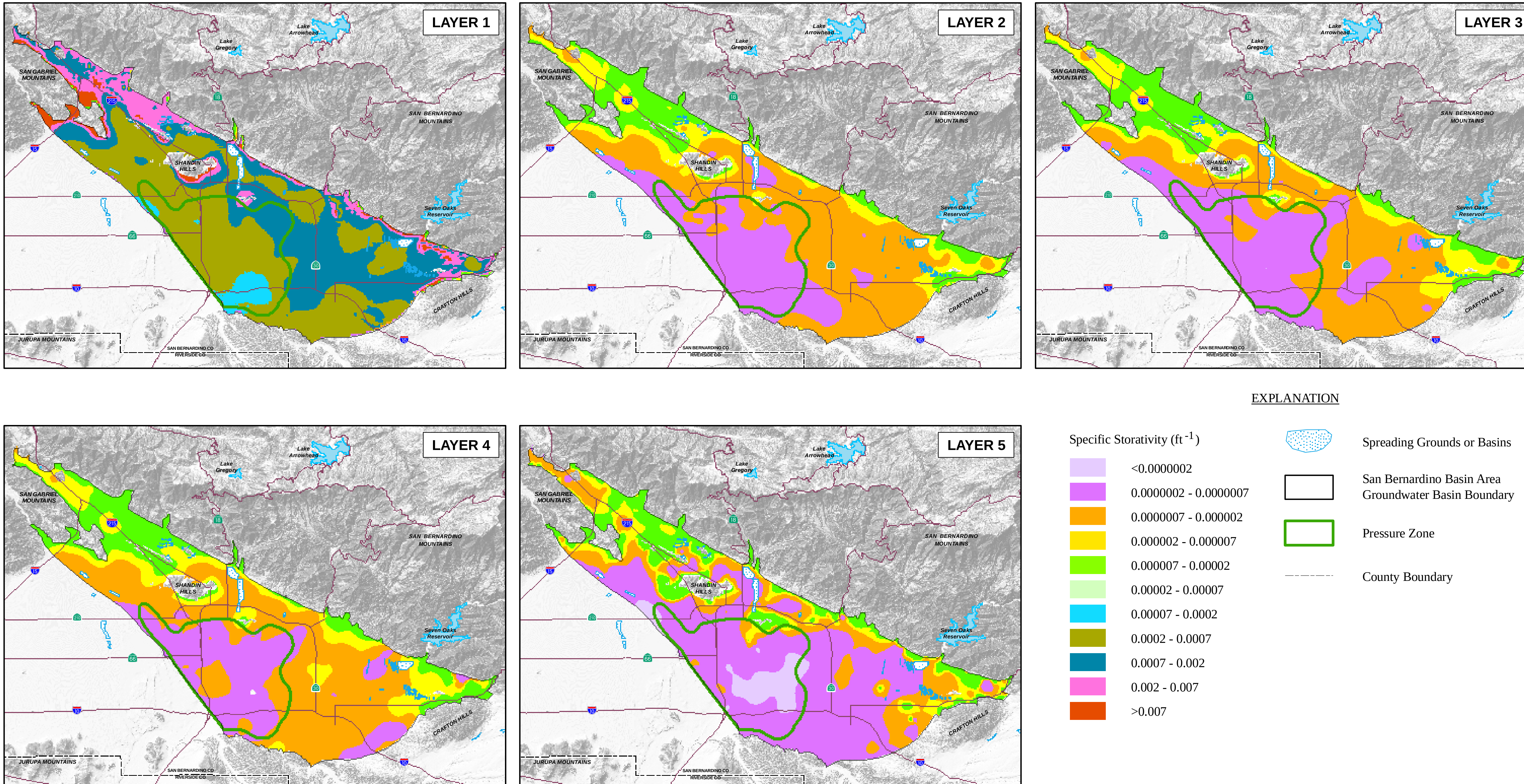
HYDRAULIC CONDUCTIVITY OF THE REFINED BASIN FLOW MODEL

Figure 16

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_16_hy_cond_9-09.mxd



NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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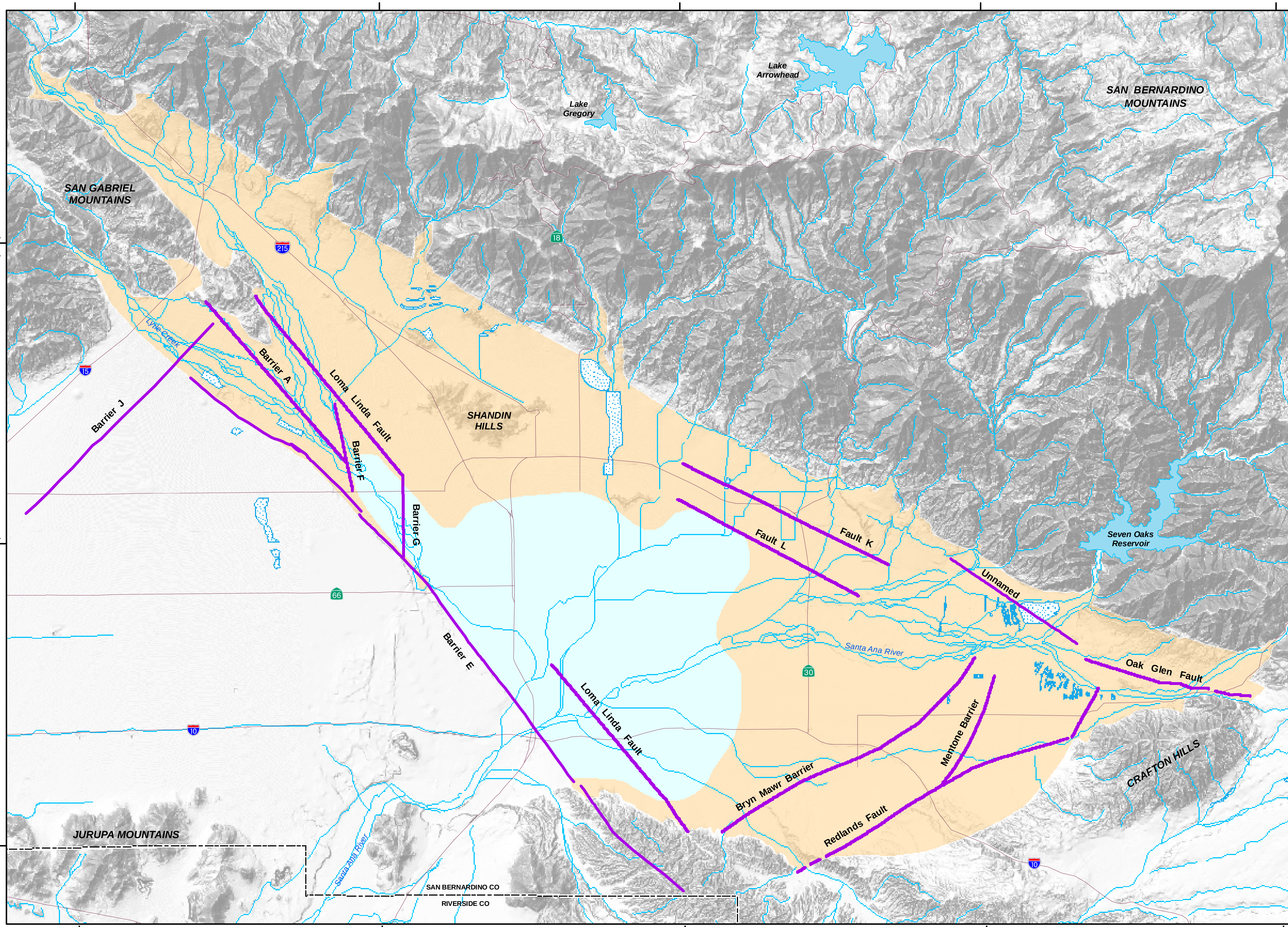
SPECIFIC STORATIVITY OF THE REFINED BASIN FLOW MODEL

Figure 17

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_17_storativity_9-09.mxd

LOCATION OF GROUNDWATER FLOW BARRIERS



EXPLANATION

- Groundwater Flow Barrier
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

NORTH

0 2 4 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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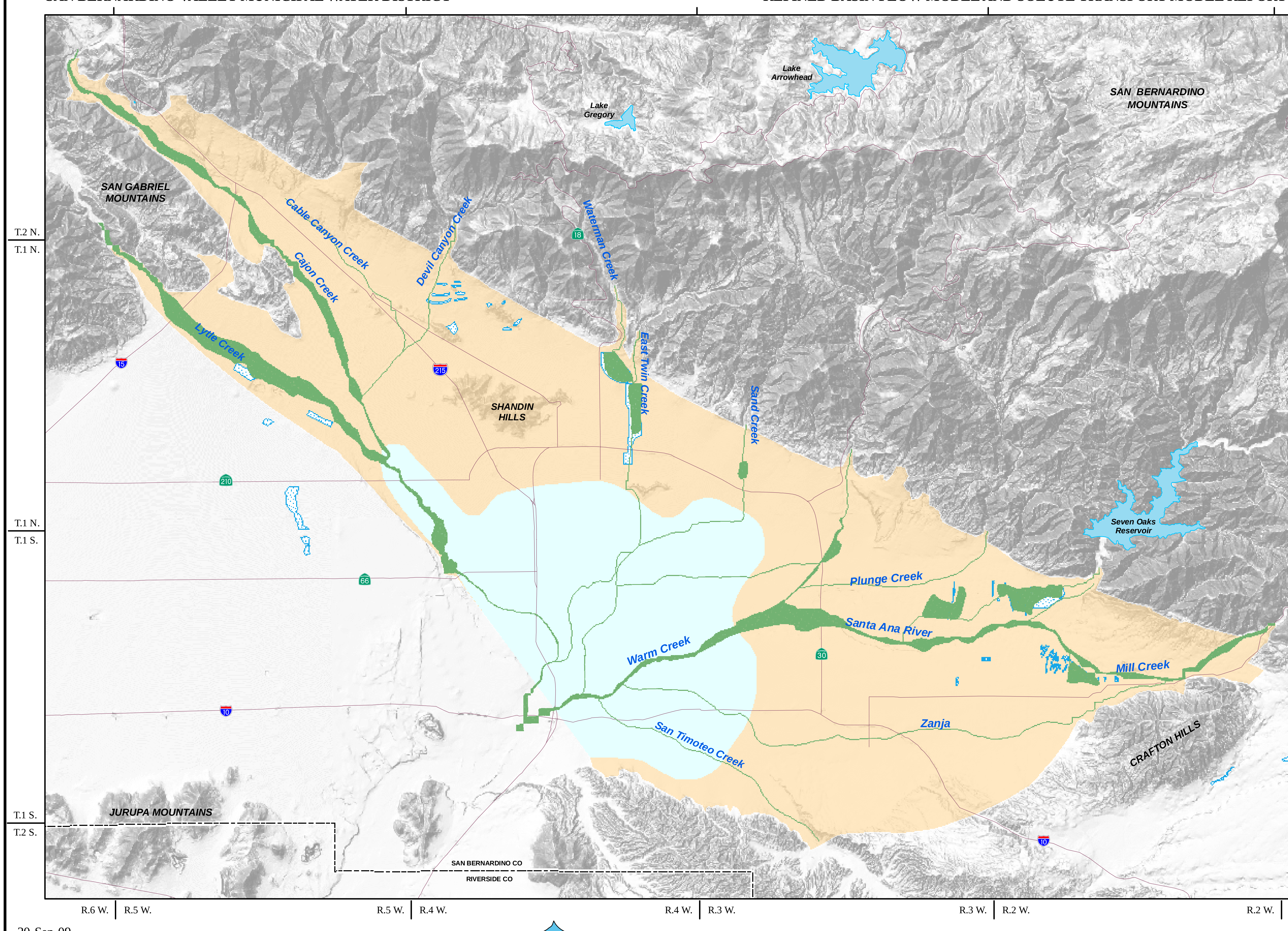
Figure 18

GIS_proj/sbvmwd_refined_flow_transport_model_8-09/0_Fig_18_GW_barriers_8-09.mxd

LOCATION OF STREAM SEGMENTS



EXPLANATION

- Stream Segments
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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Figure 19

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_19_stream_segments_9-09.mxd

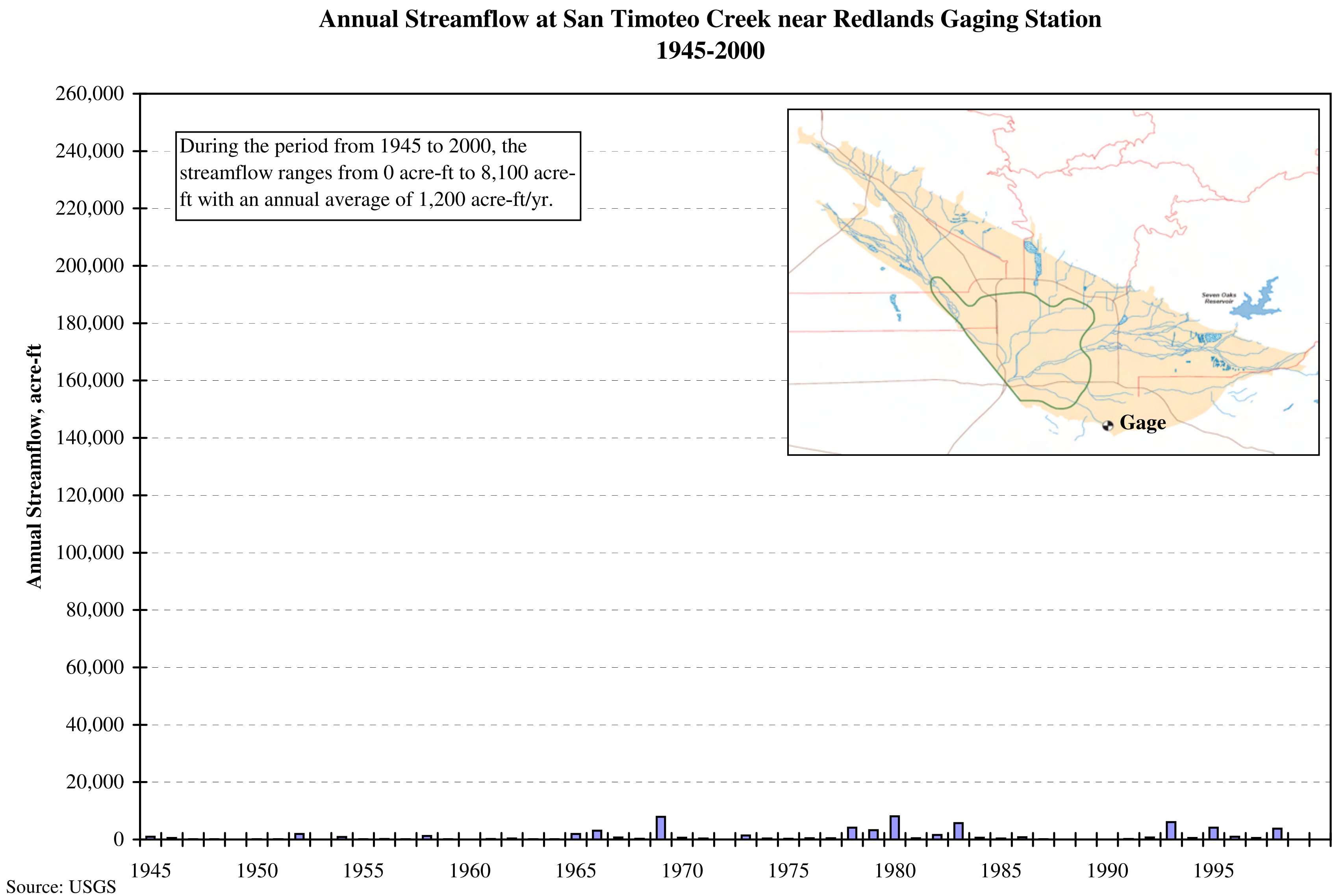
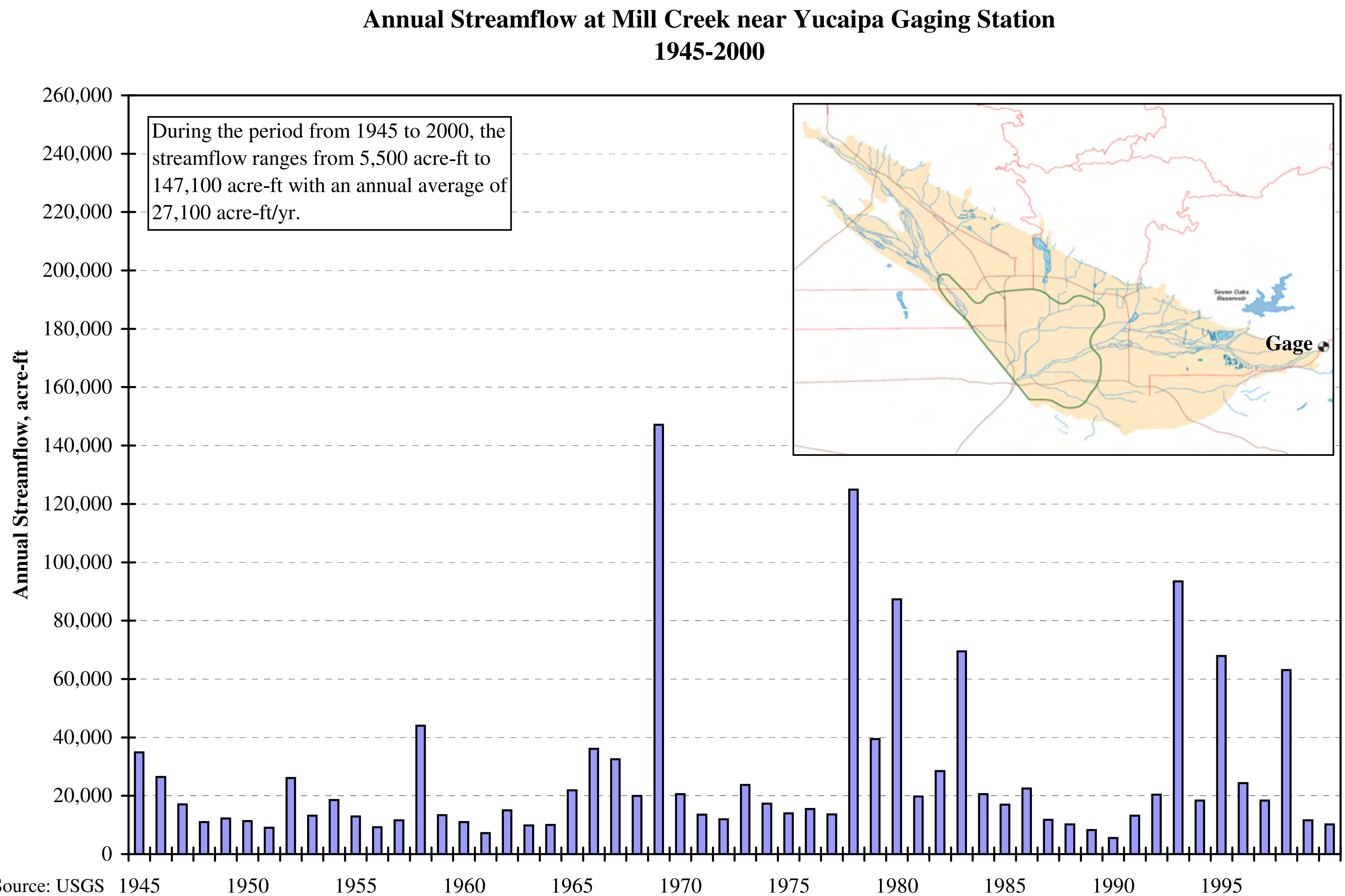

Annual Streamflow at San Timoteo Creek near Redlands Gaging Station
1945-2000
During the period from 1945 to 2000, the streamflow ranges from 0 acre-ft to 8,100 acre-ft with an annual average of 1,200 acre-ft/yr.
Annual Streamflow, acre-ft
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Gage
Source: USGS

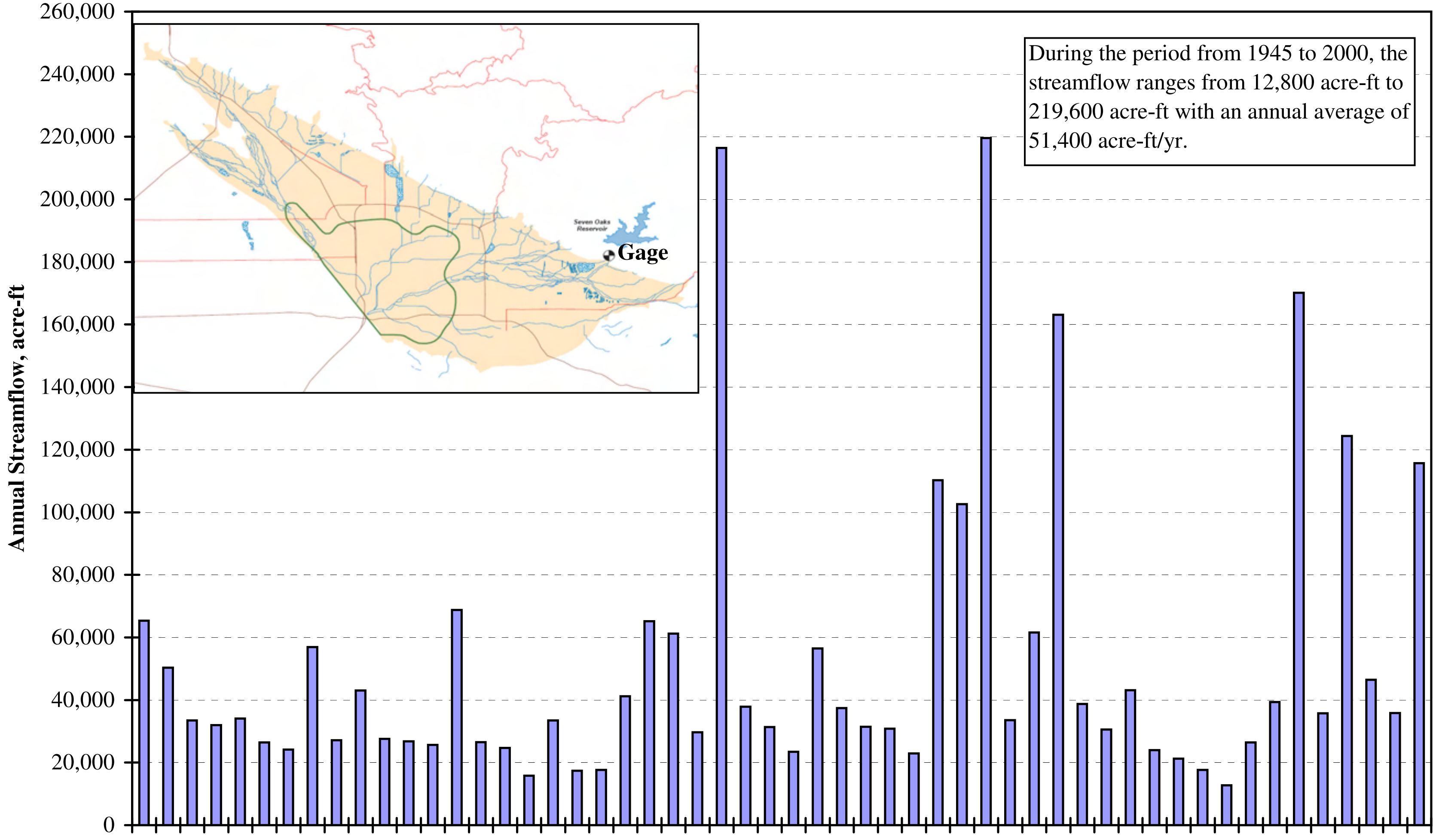
Figure 20



Source: USGS

Figure 21

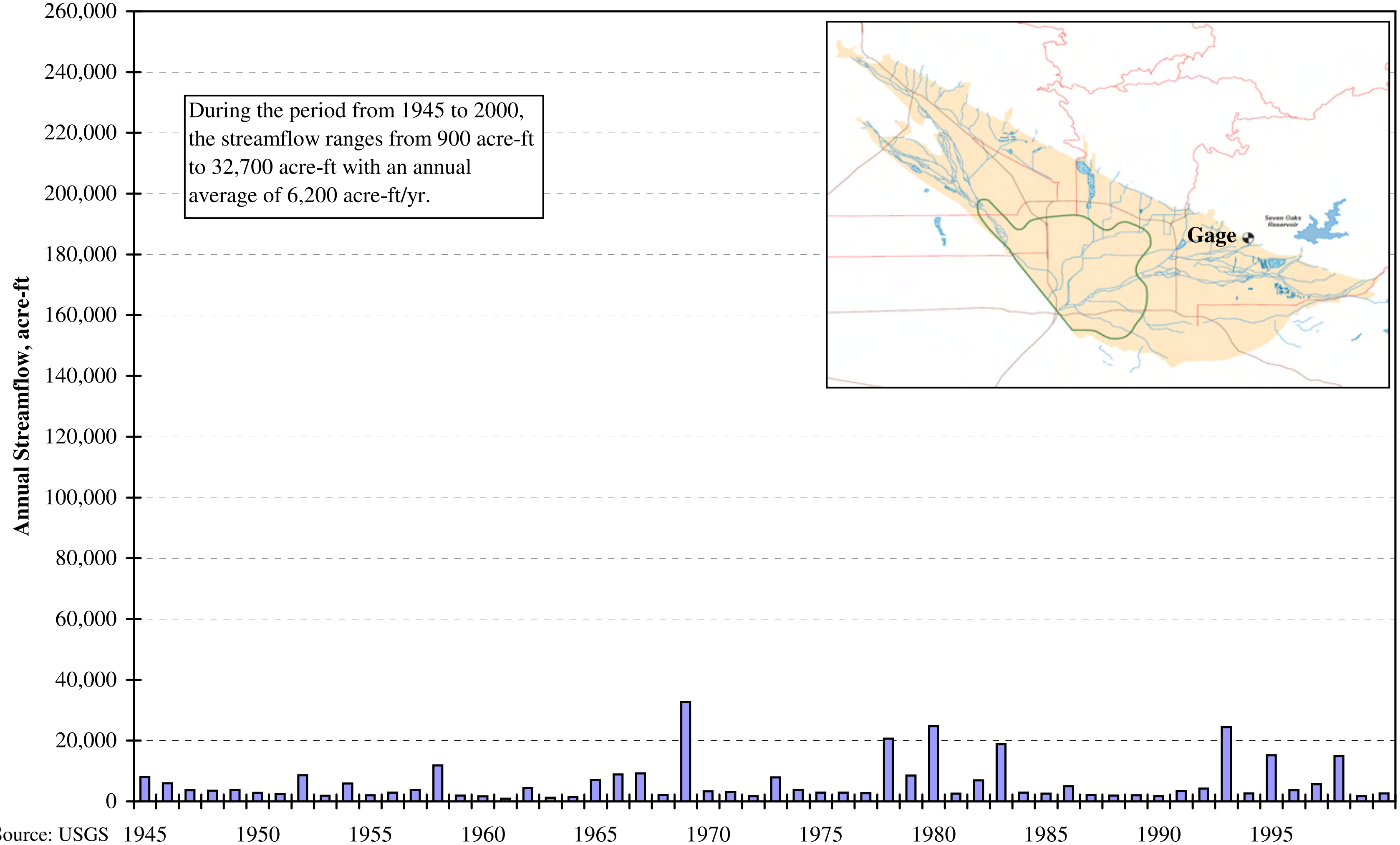
Annual Streamflow at Santa Ana River near Mentone Gaging Station 1945-2000



Source: USGS

Figure 22

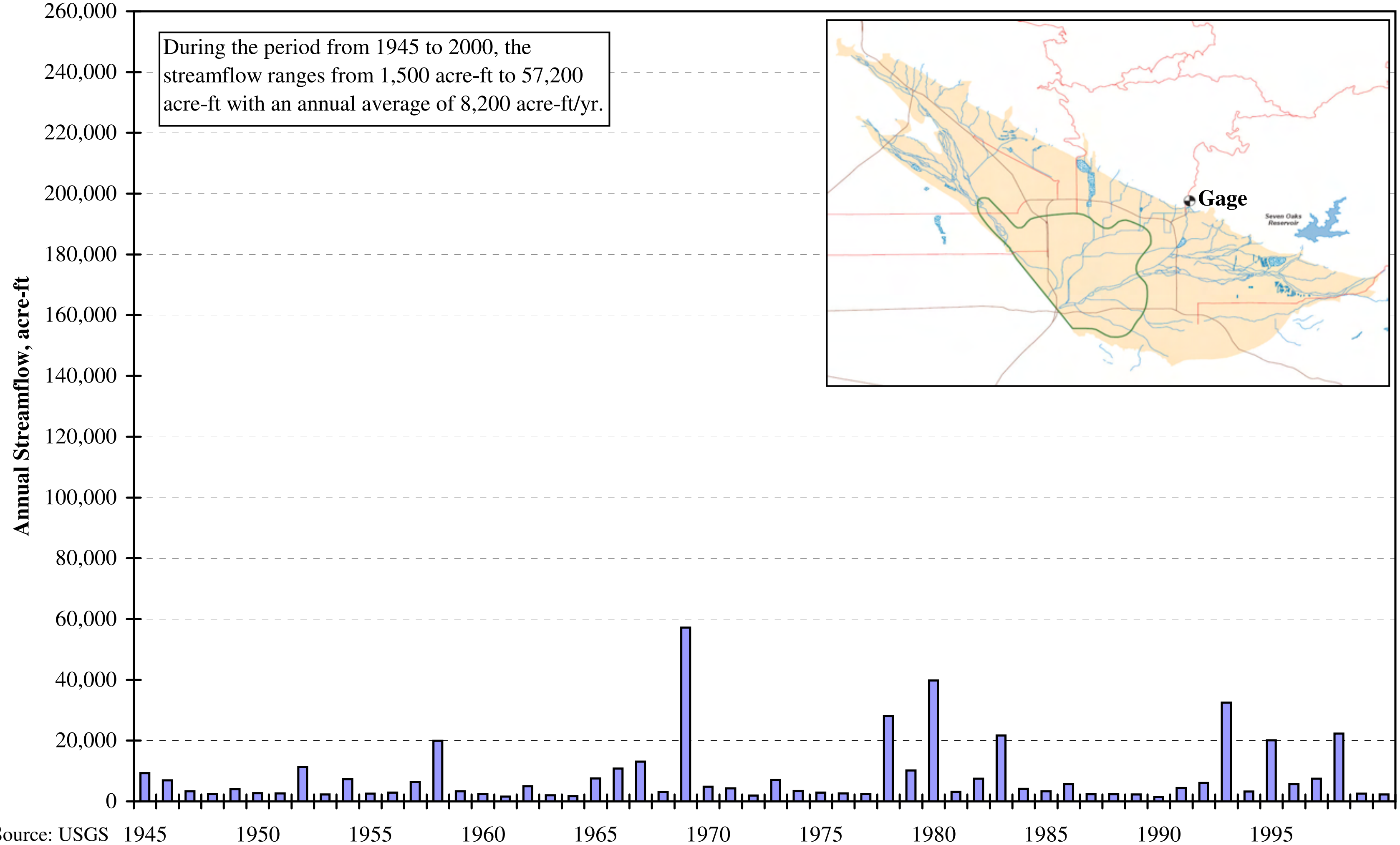
Annual Streamflow at Plunge Creek near East Highlands Gaging Station 1945-2000



Source: USGS

Figure 23

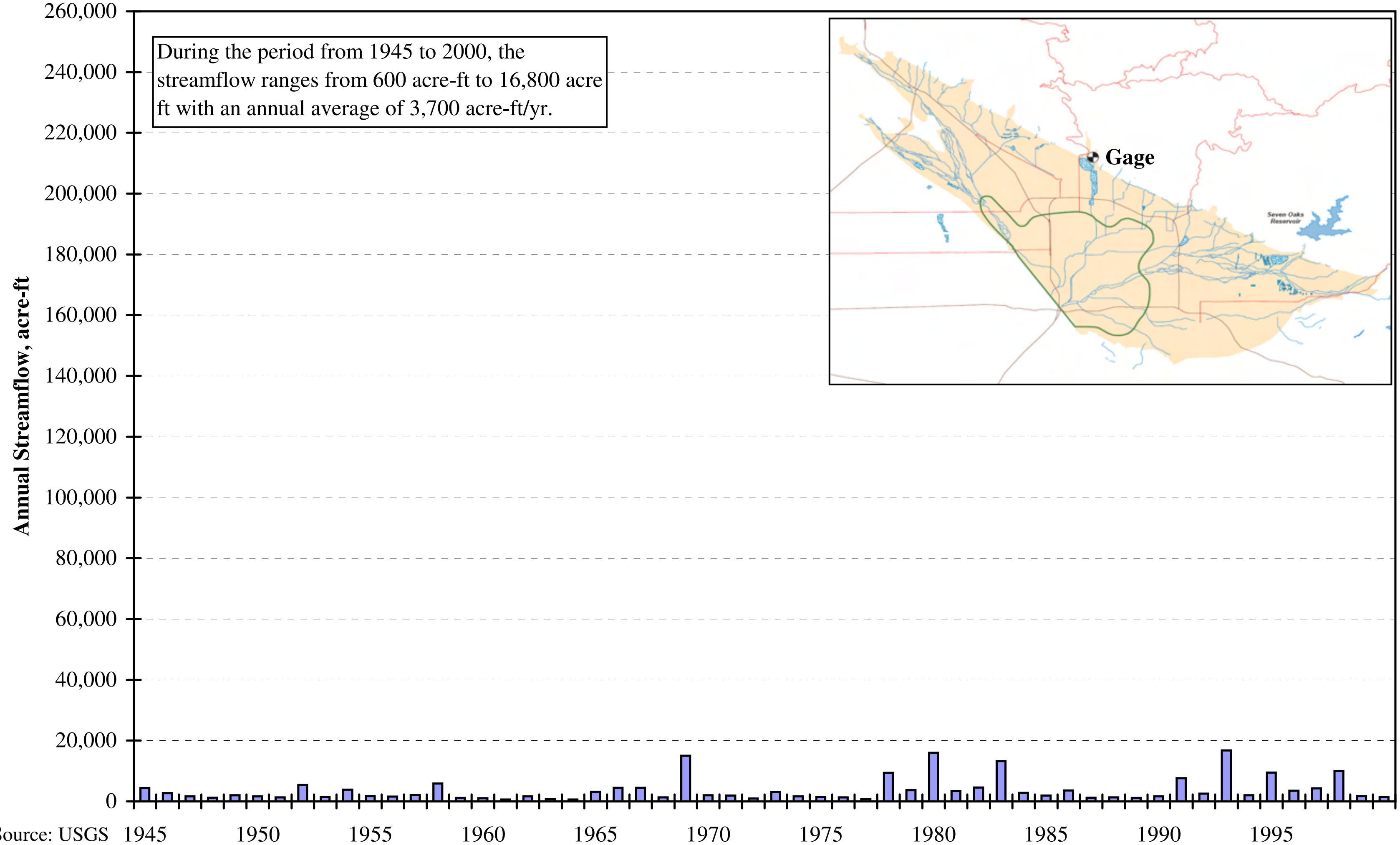
Annual Streamflow at City Creek near Highland Gaging Station
1945-2000



Source: USGS

Figure 24

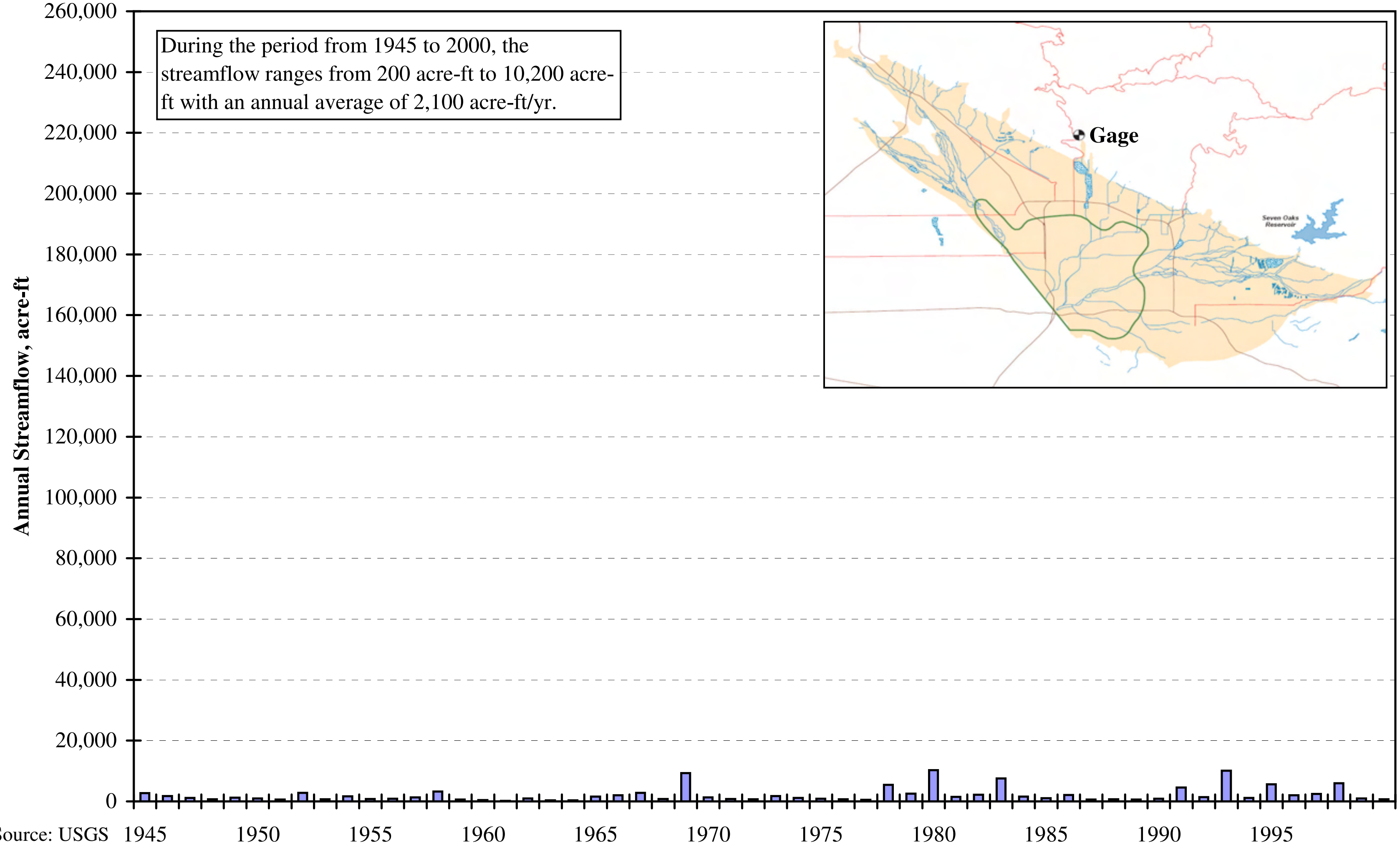
Annual Streamflow at East Twin Creek near Arrowhead Springs Gaging Station
1945-2000



Source: USGS

Figure 25

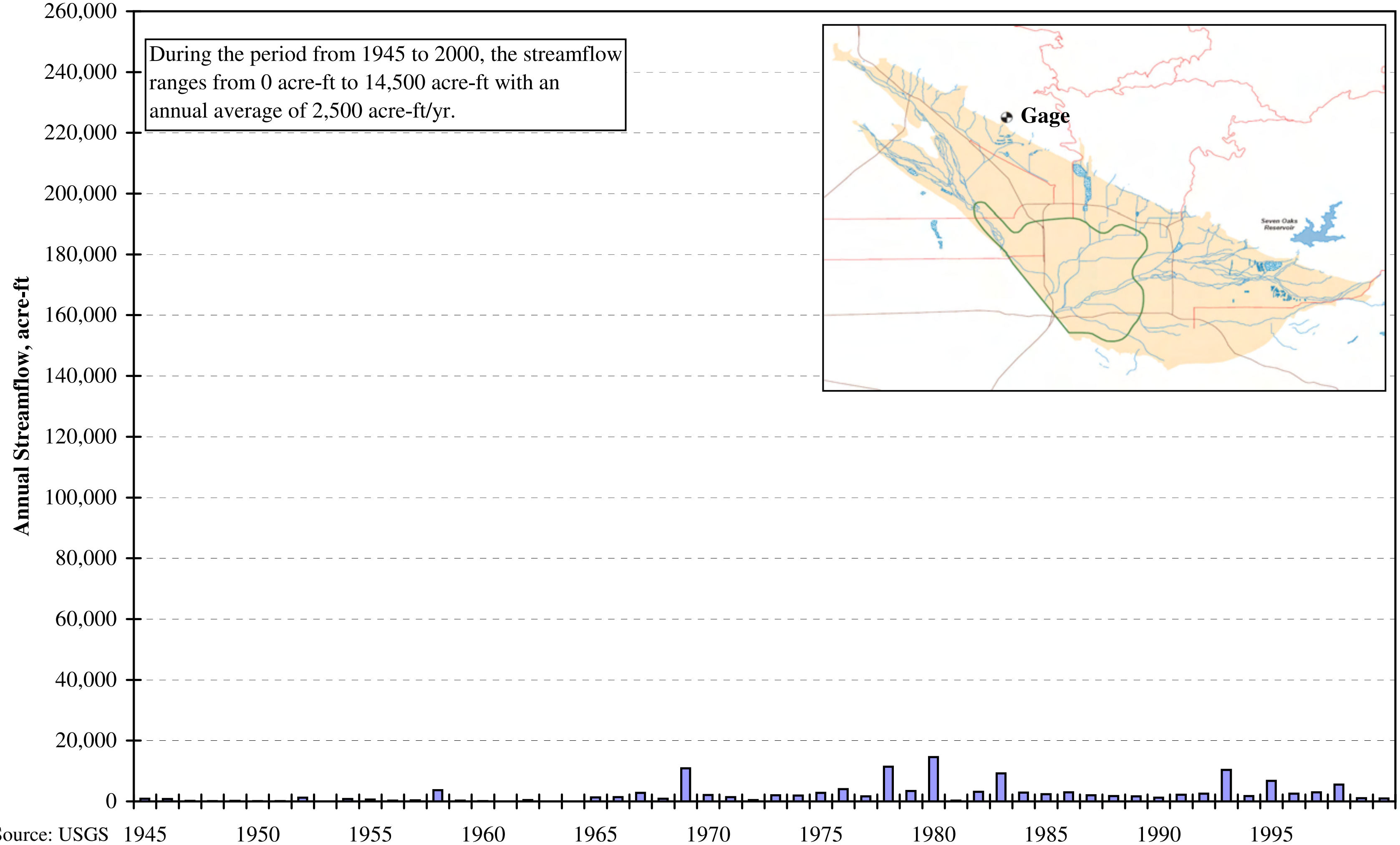
Annual Streamflow at Waterman Canyon Creek near Arrowhead Springs Gaging Station 1945-2000



Source: USGS

Figure 26

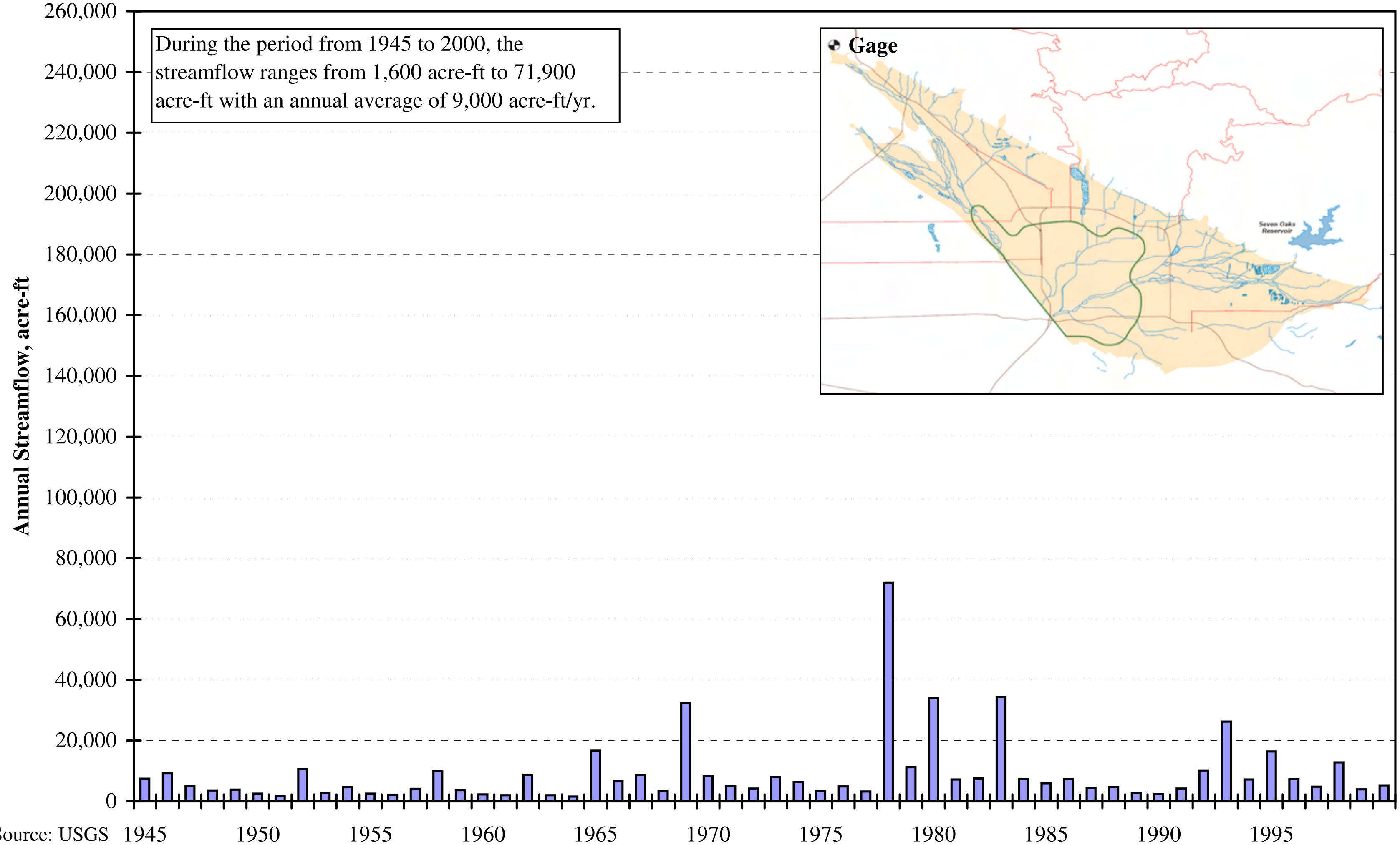
Annual Streamflow at Devil Canyon Creek near San Bernardino Gaging Station 1945-2000



Source: USGS

Figure 27

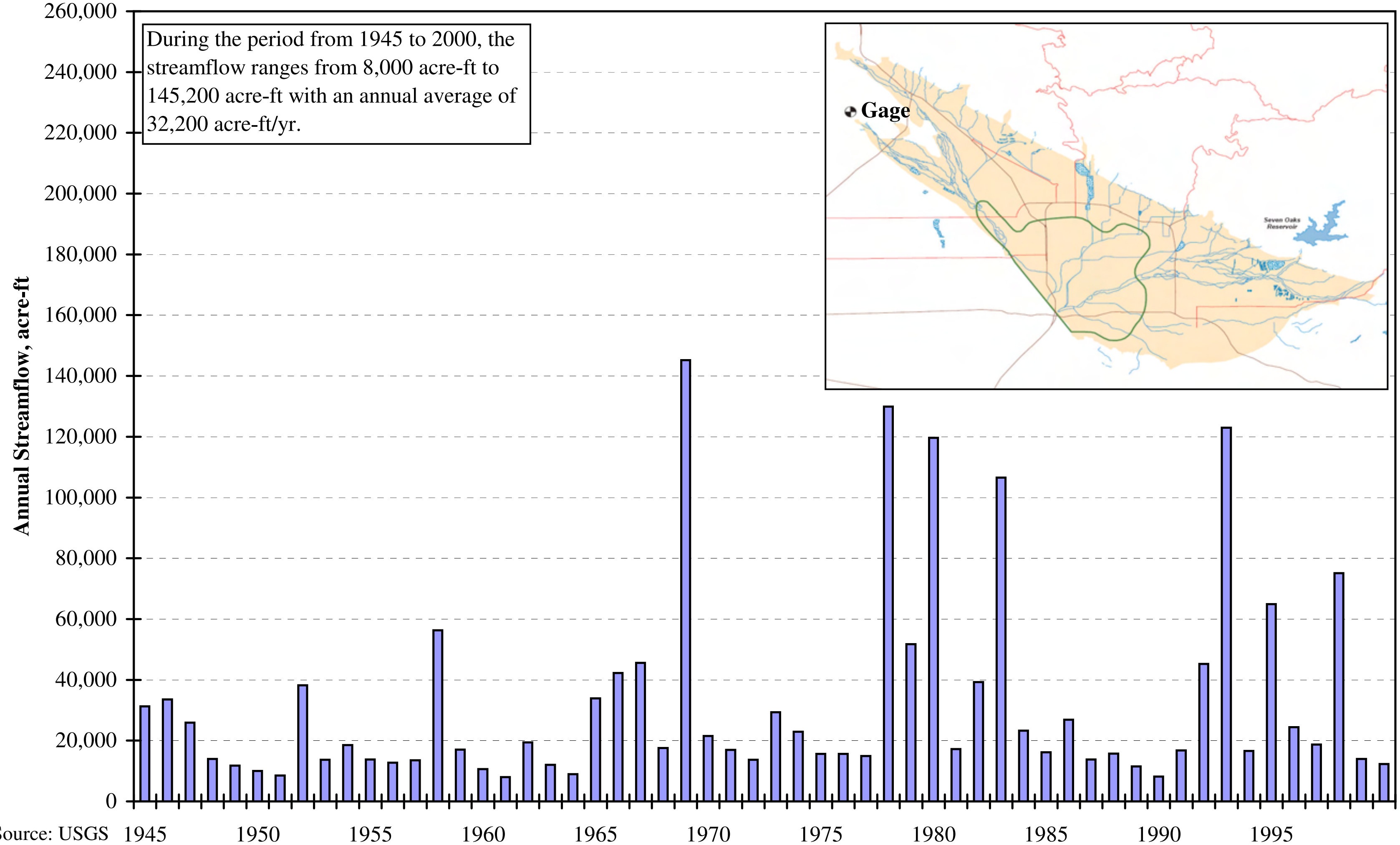
Annual Streamflow at Cajon Creek below Lone Pine Creek near Keenbrook Gaging Station 1945-2000



Source: USGS

Figure 28

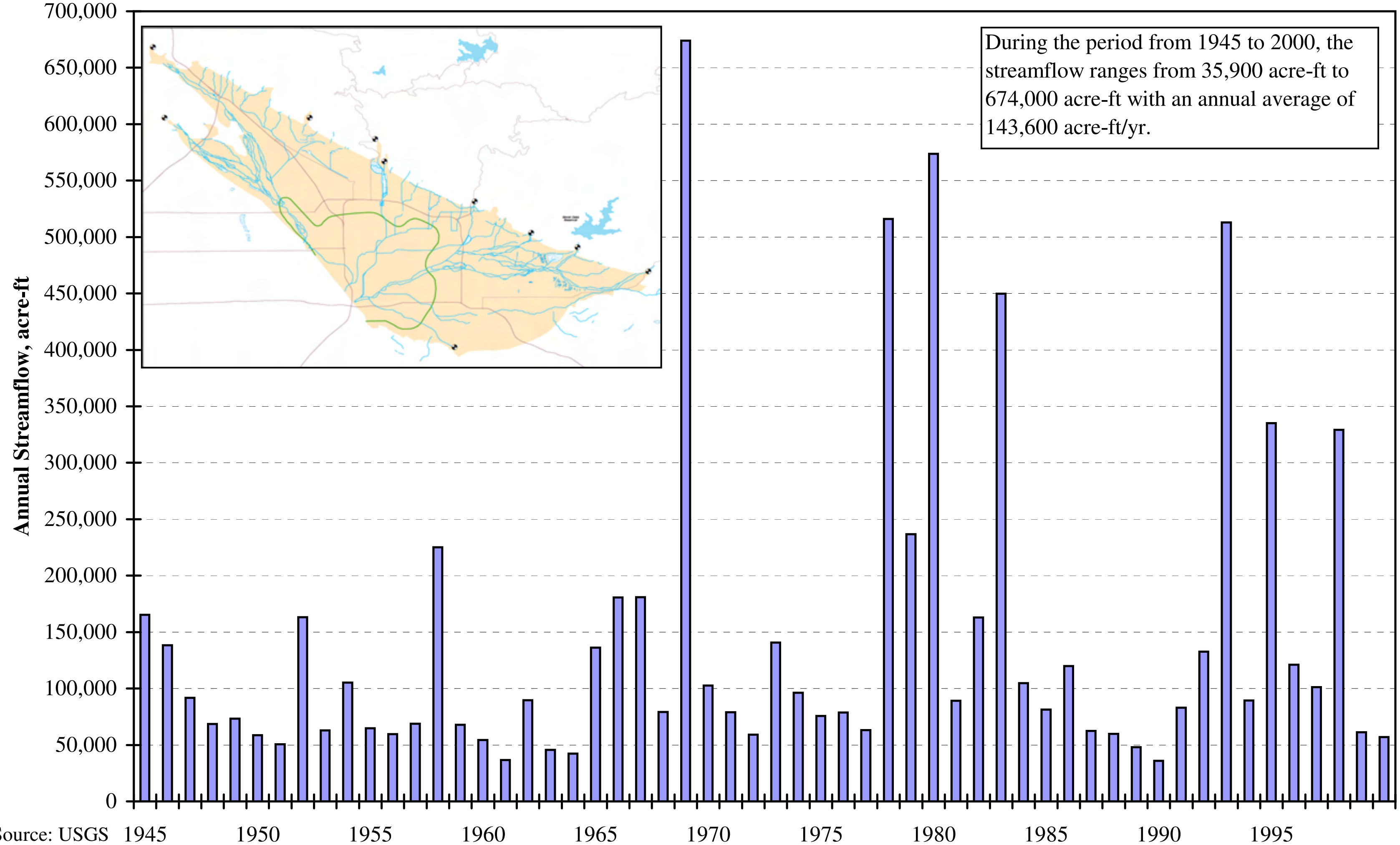
Annual Streamflow at Lytle Creek near Fontana Gaging Station 1945-2000



Source: USGS

Figure 29

Total Annual Streamflow Inflow for the SBBA 1945-2000



Source: USGS

Figure 30

Recharge from Local Runoff Generated by Precipitation for the SBBA 1945-2000

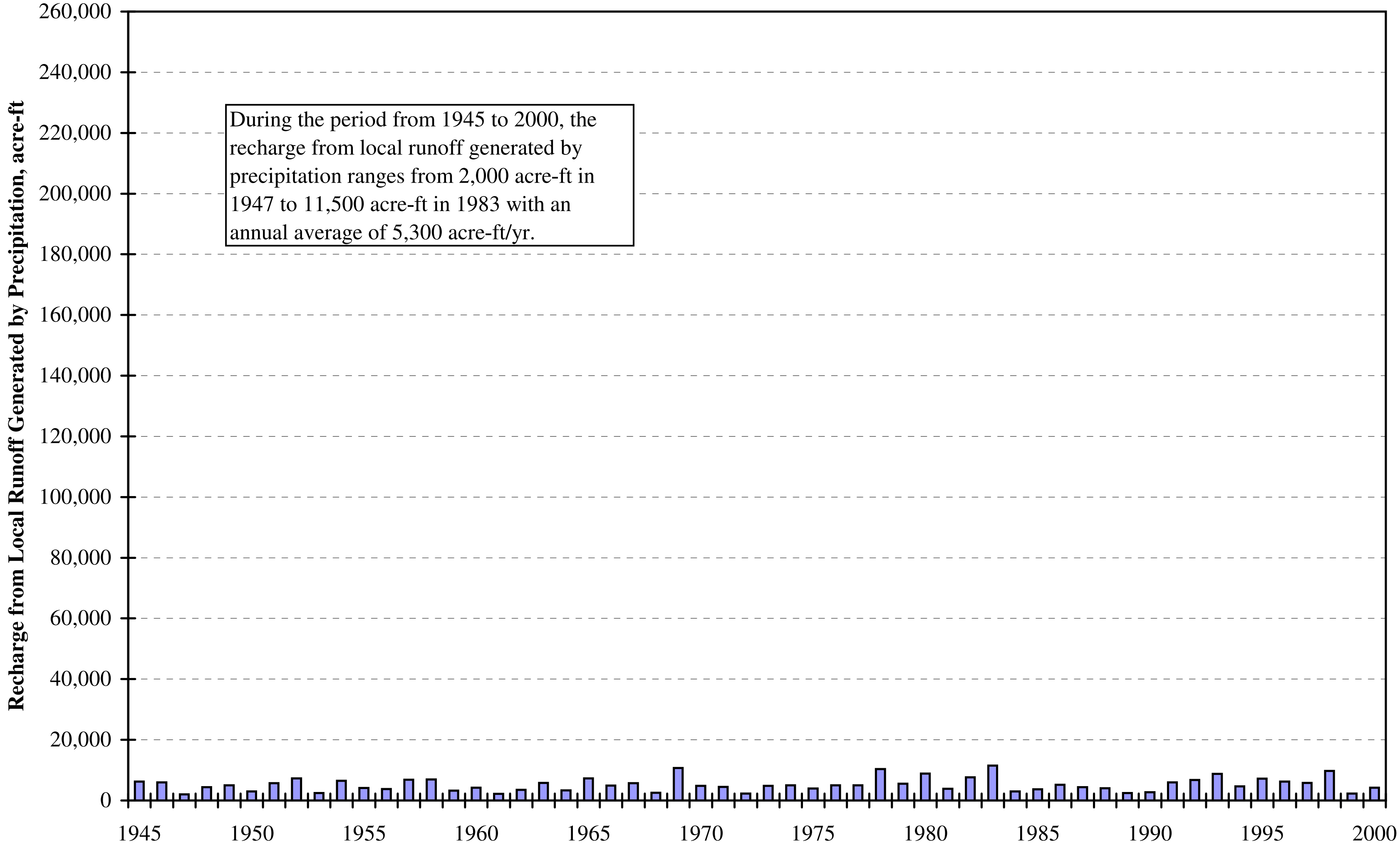
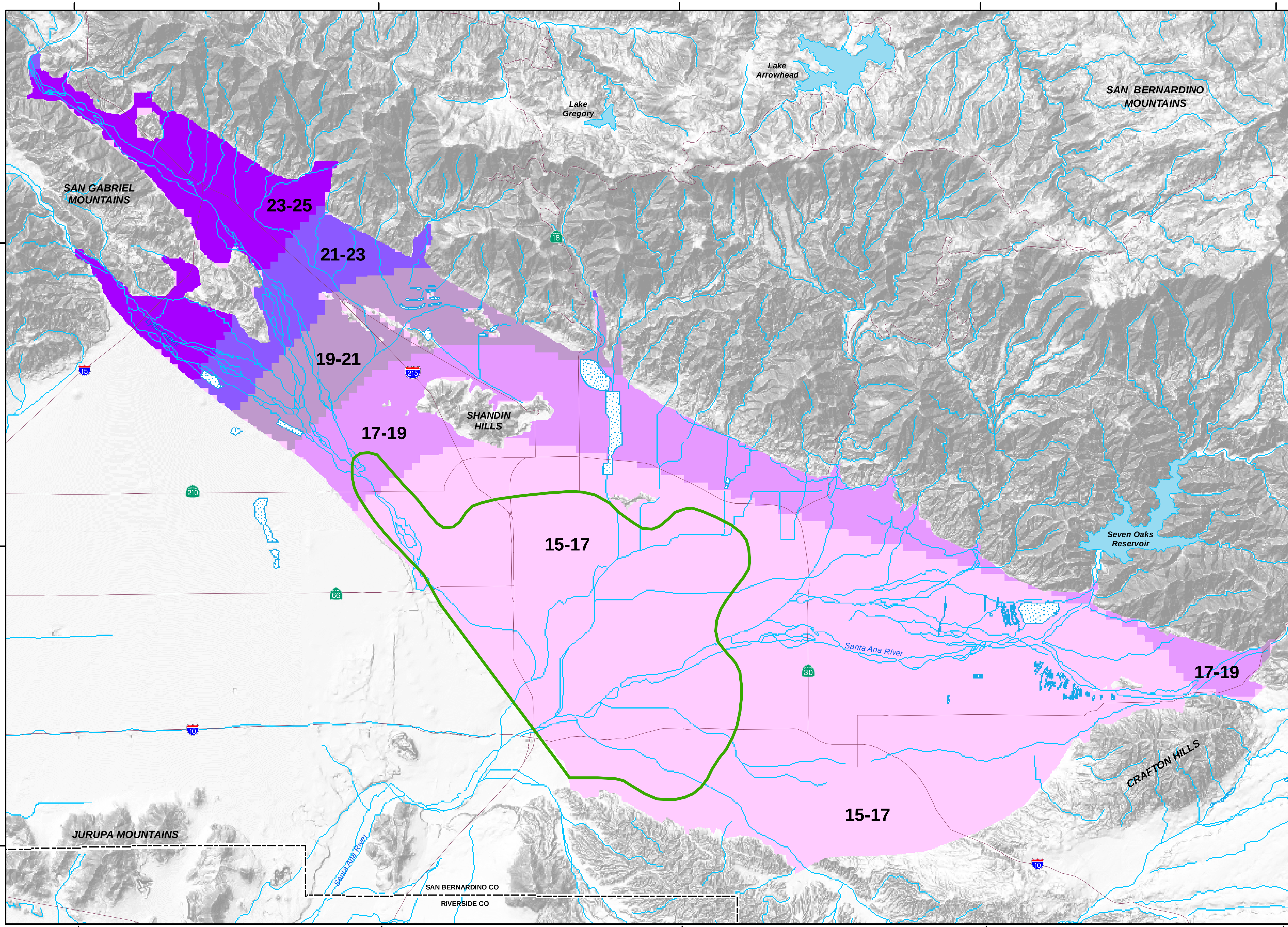


Figure 31



AVERAGE ANNUAL PRECIPITATION FOR THE SBBA

EXPLANATION

Average Annual Precipitation (inches)

- 15 - 17
- 17 - 19
- 19 - 21
- 21 - 23
- 23 - 25

Spreading Grounds or Basins

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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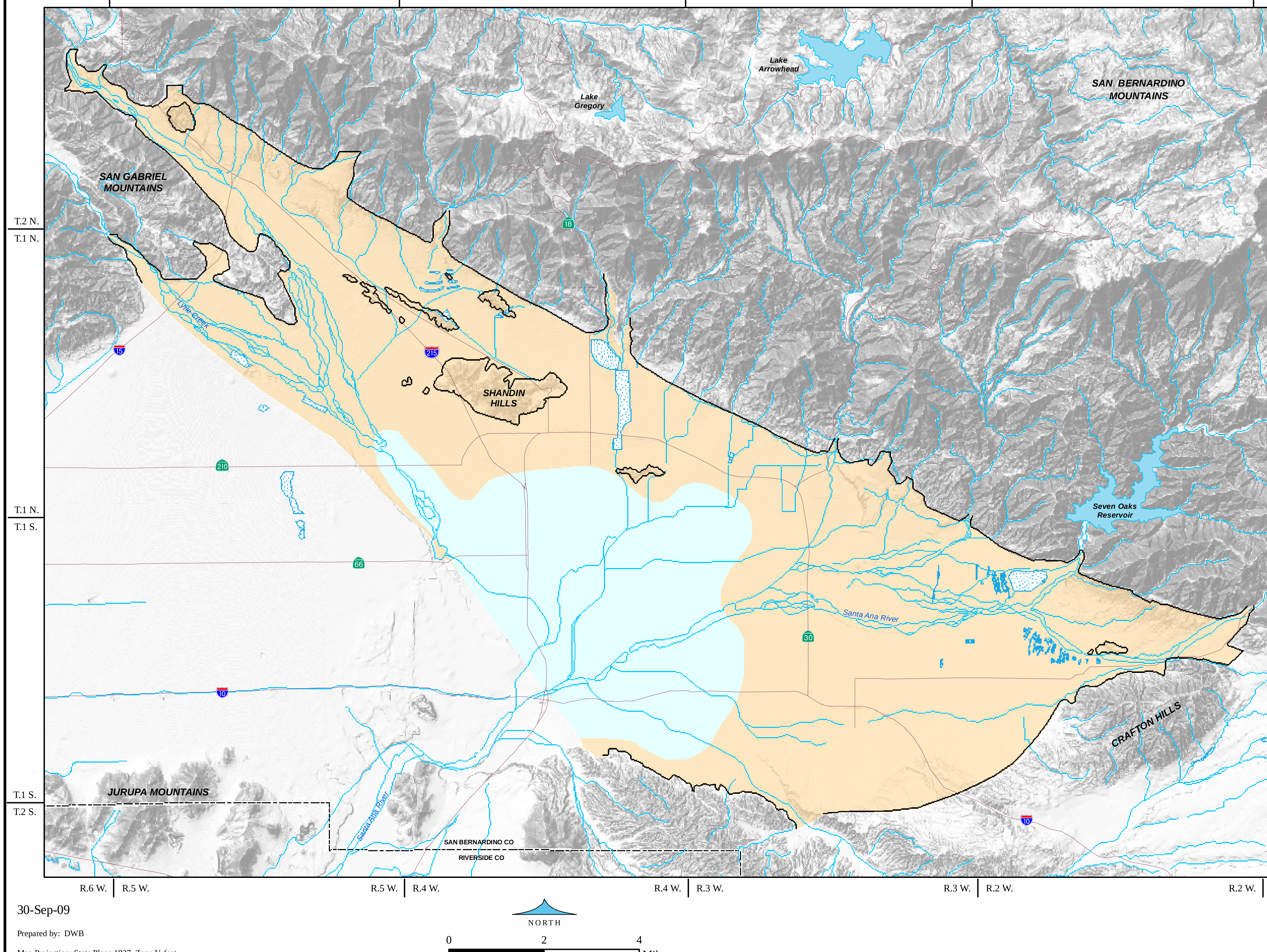
Figure 32

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_32_precip_9-09.mxd

LOCATION OF RECHARGE FROM MOUNTAIN FRONT RUNOFF



EXPLANATION

- Location of Recharge From Mountain Front Runoff
- Spreading Grounds or Basins
- Pressure Zone
- County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1927, Zone V, feet

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Figure 33

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_33_mtn_runoff_9-09.mxd

Annual Recharge from Mountain Front Runoff for the SBBA
1945-2000

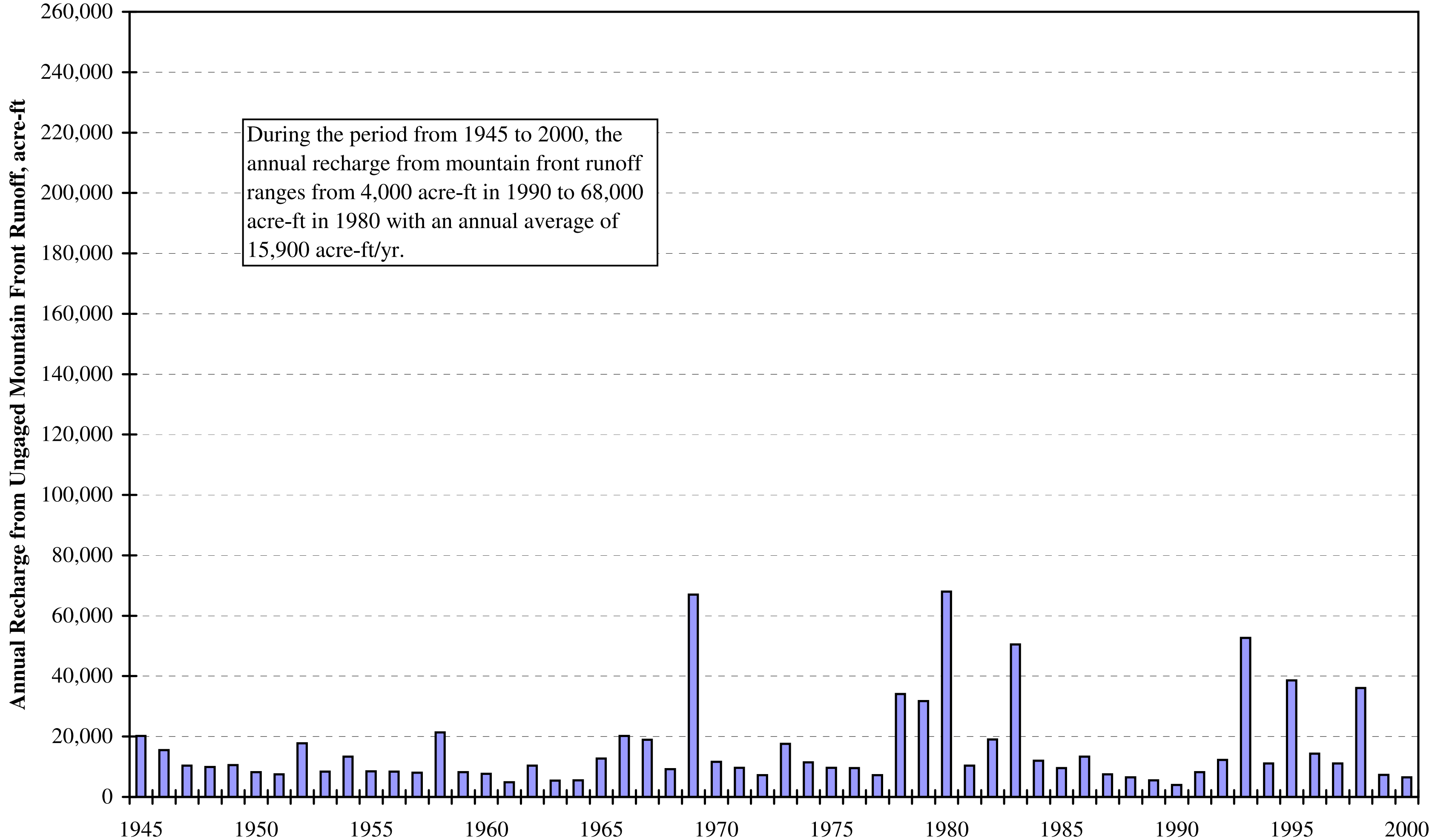
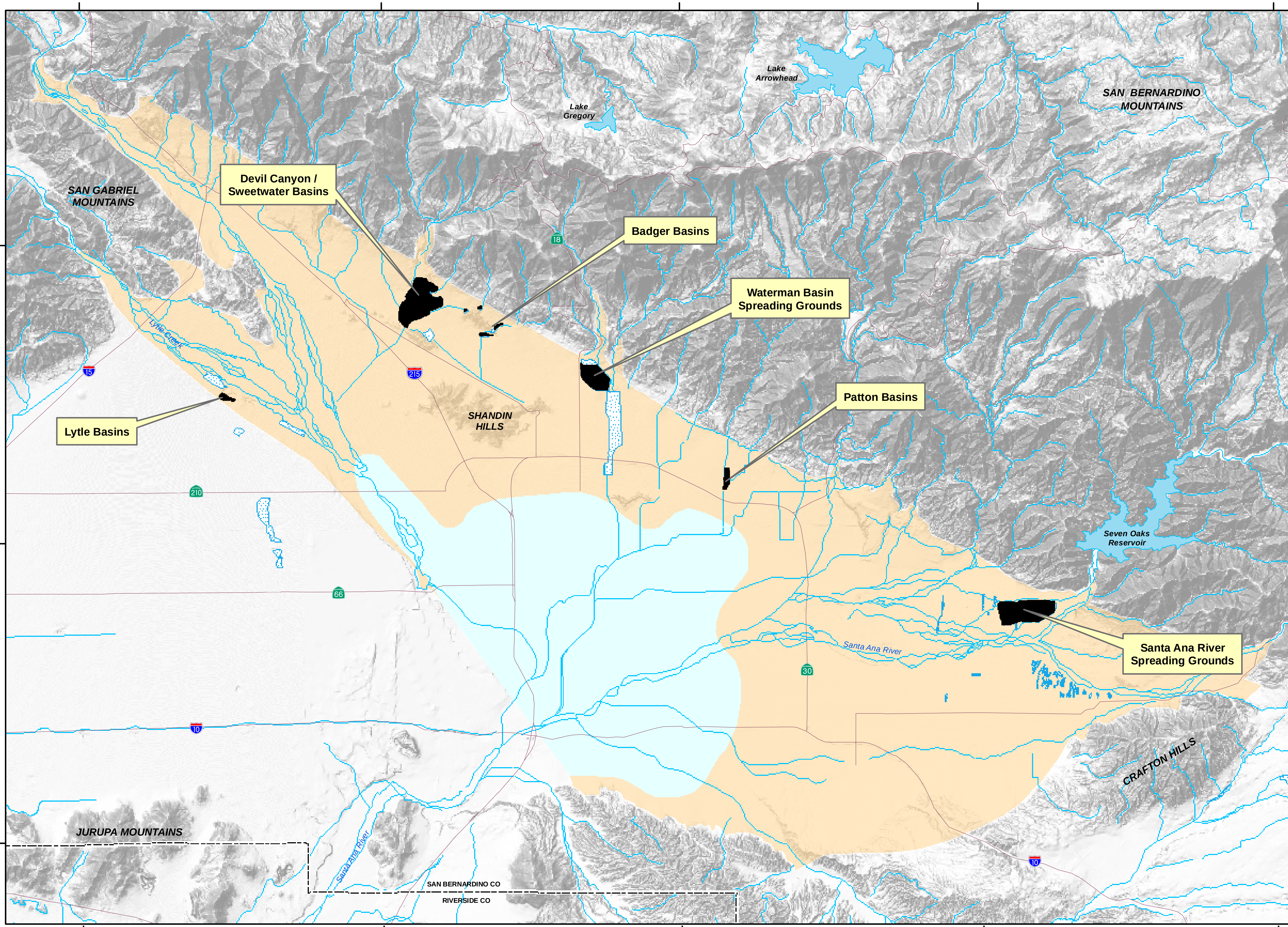


Figure 34

LOCATION OF ARTIFICIAL RECHARGE OF IMPORTED WATER



EXPLANATION

- Locations of Artificial Recharge of Imported Water
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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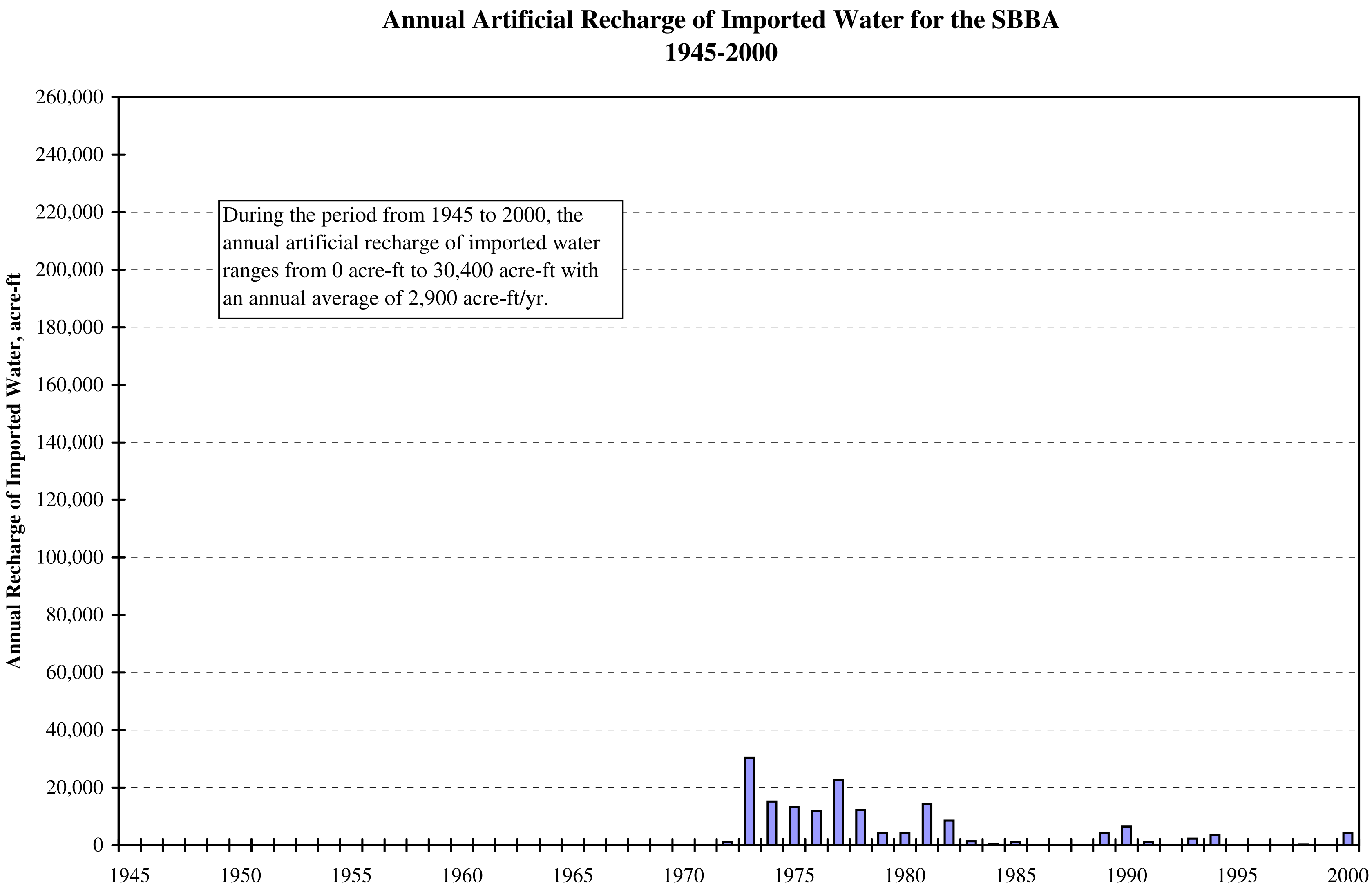
Figure 35

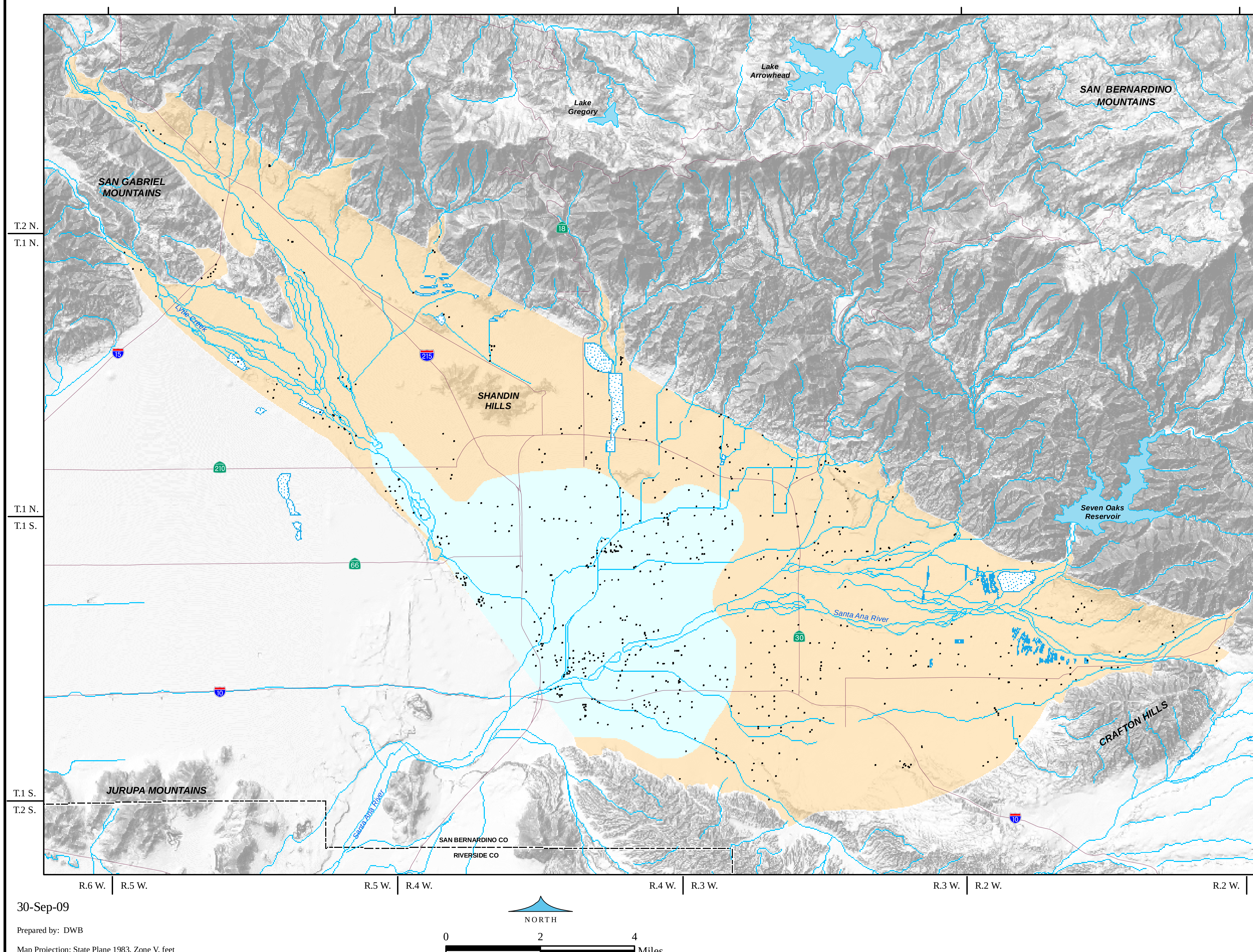
GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_35_imported_9-09.mxd



Source: SBVMWD

Figure 36

LOCATION OF GROUNDWATER PUMPING WELLS



EXPLANATION

- Locations of Groundwater Pumping Wells
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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Figure 37

Annual Groundwater Pumping of the SBBA 1945-2000

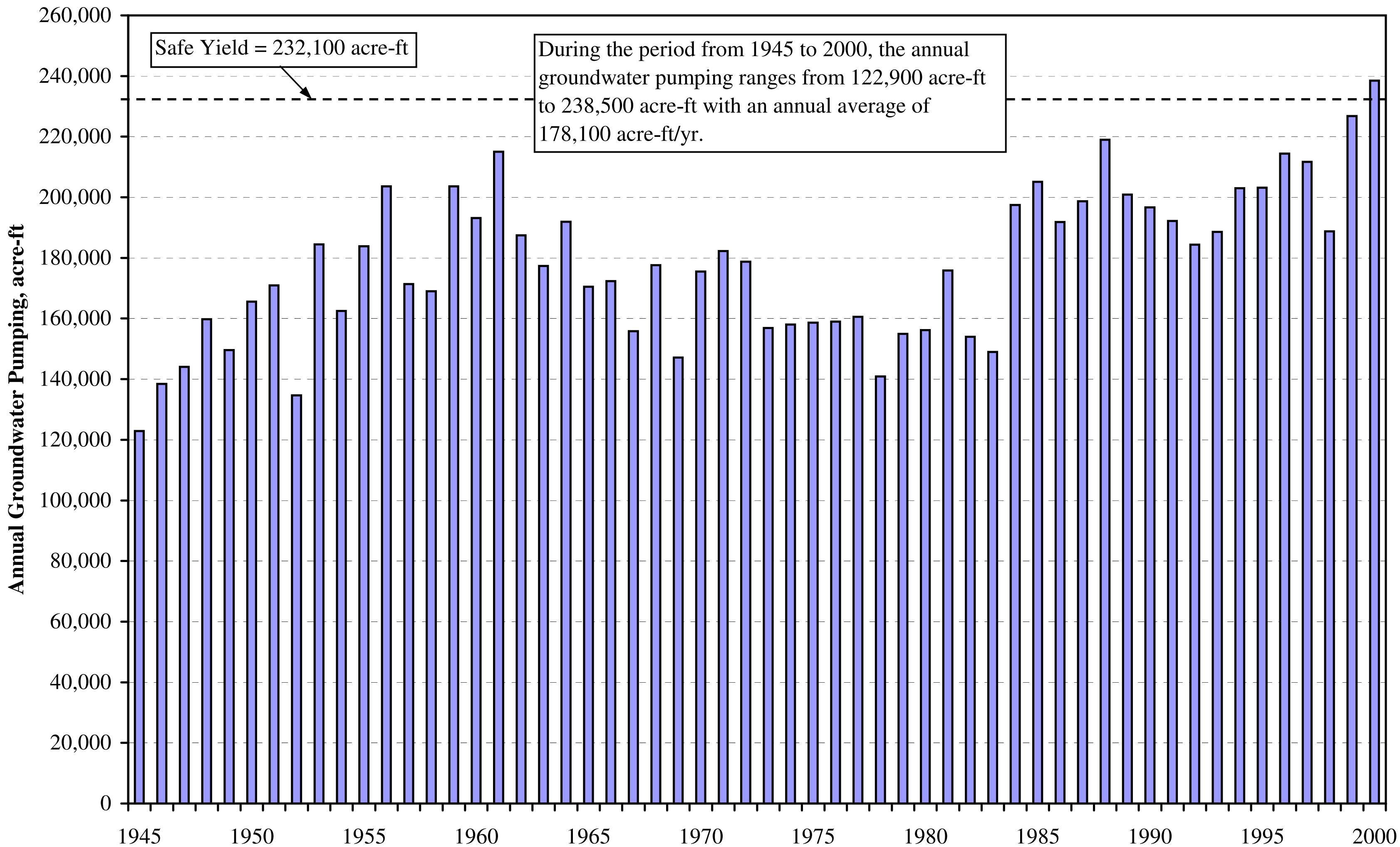


Figure 38

Annual Return Flow from Groundwater Pumping of the SBBA
1945-2000

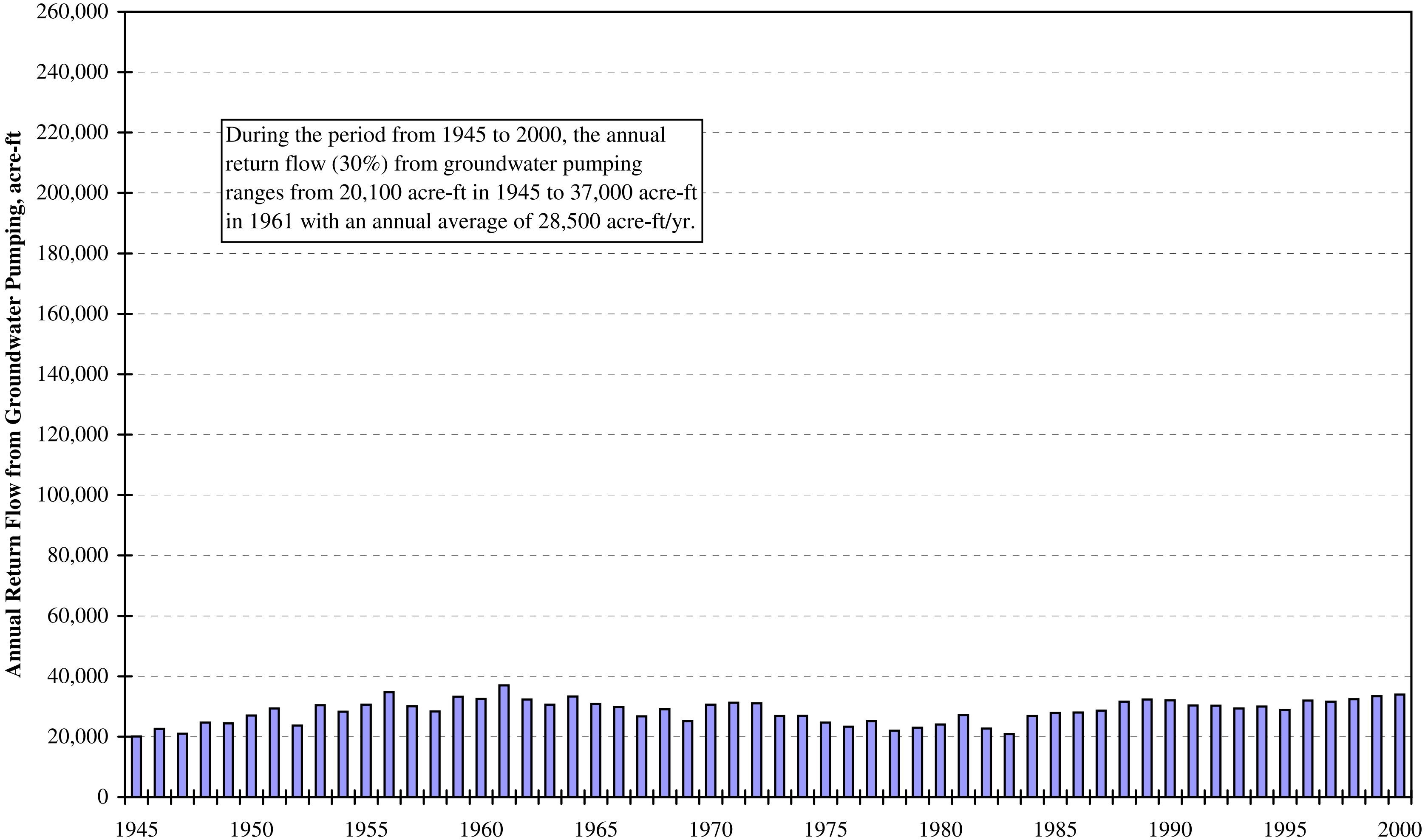
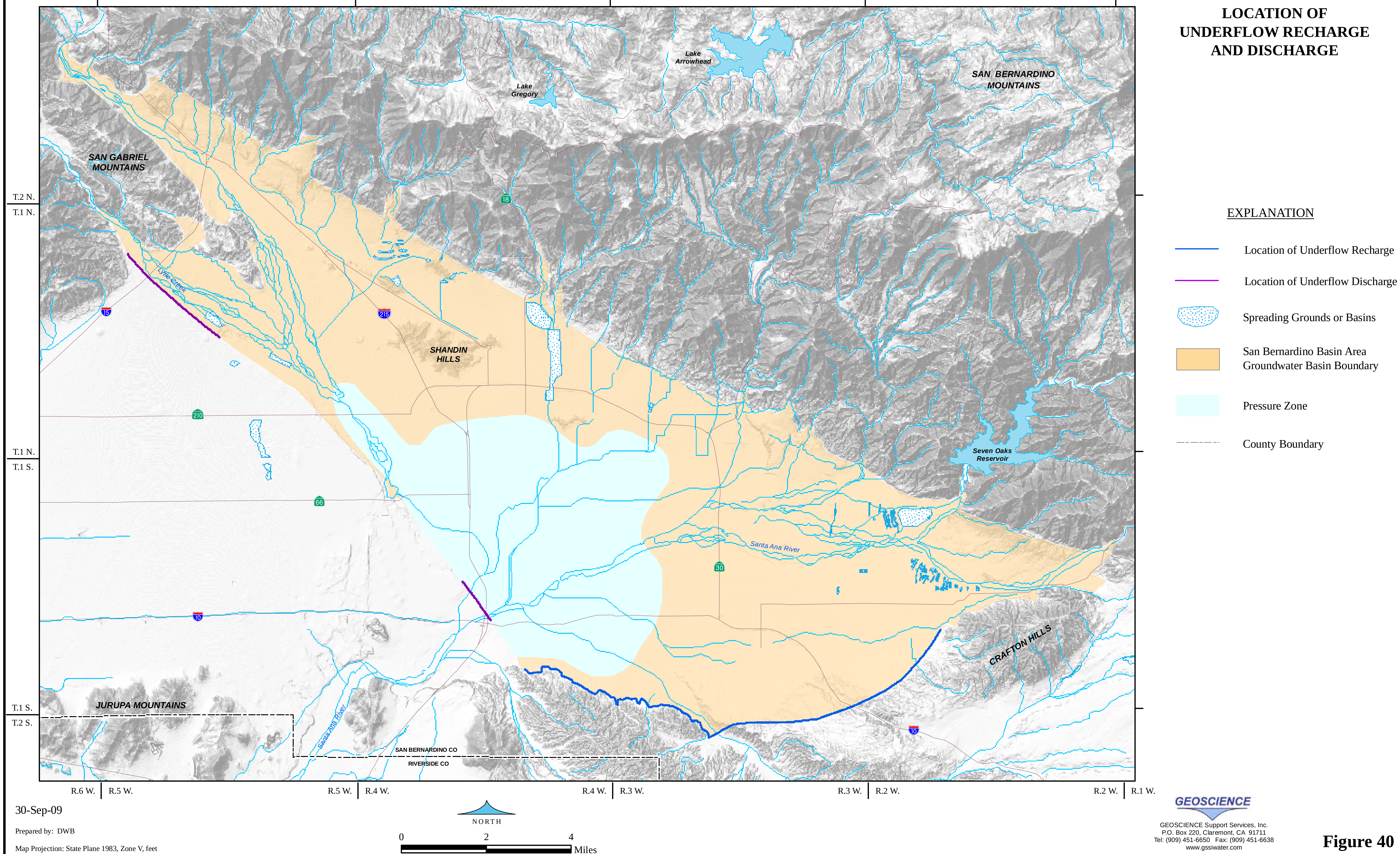


Figure 39

LOCATION OF UNDERFLOW RECHARGE AND DISCHARGE



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Map Projection: State Plane 1983, Zone V, feet

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Figure 40

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_40_underflow_9-09.mxd

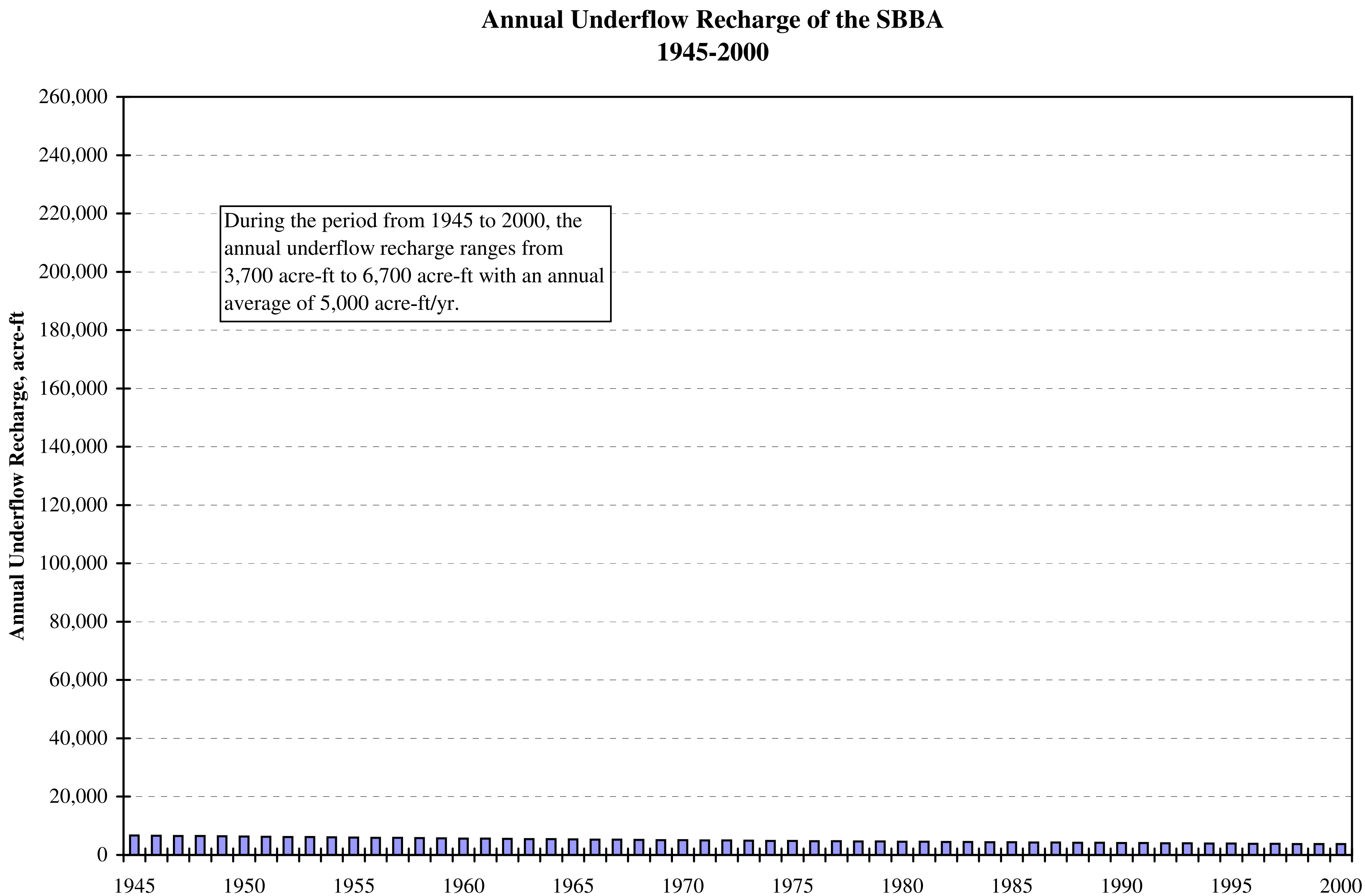

Annual Underflow Recharge of the SBBA
1945-2000
During the period from 1945 to 2000, the annual underflow recharge ranges from 3,700 acre-ft to 6,700 acre-ft with an annual average of 5,000 acre-ft/yr.
Annual Underflow Recharge, acre-ft
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000

Figure 41

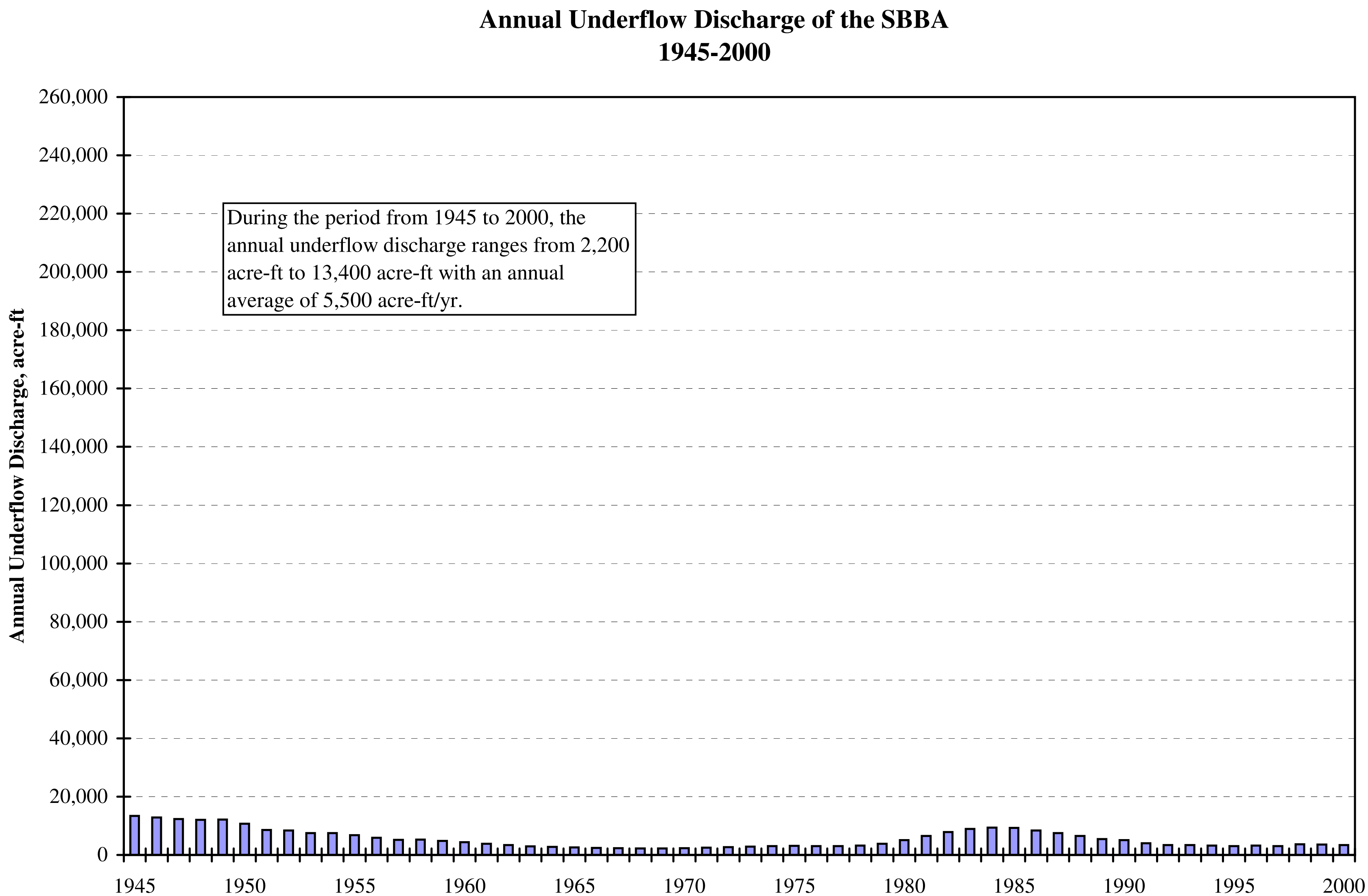
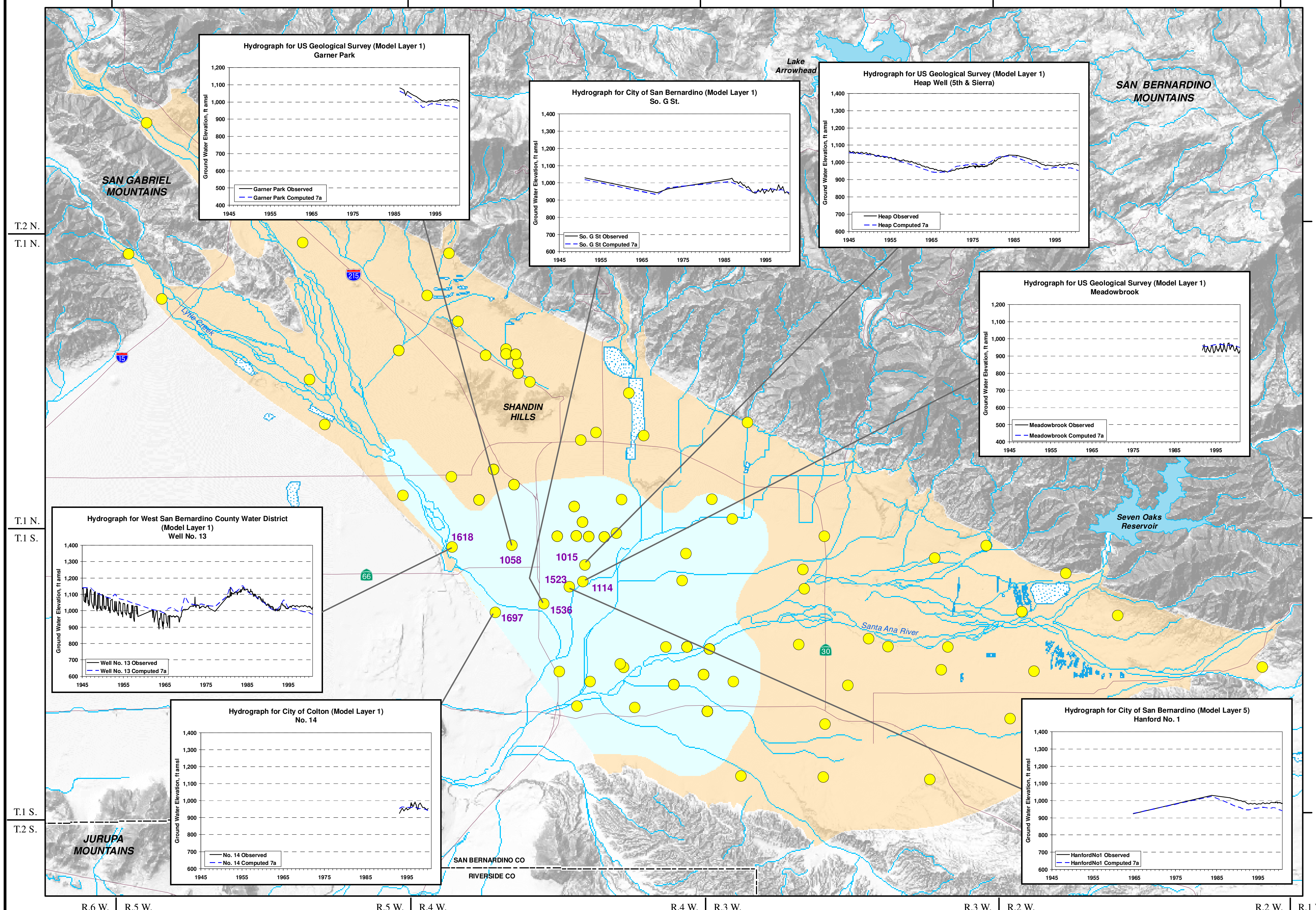

Annual Underflow Discharge of the SBBA
1945-2000
Annual Underflow Discharge, acre-ft
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
During the period from 1945 to 2000, the annual underflow discharge ranges from 2,200 acre-ft to 13,400 acre-ft with an annual average of 5,500 acre-ft/yr.

Figure 42

SELECTED HYDROGRAPHS FOR ANNUAL TRANSIENT MODEL CALIBRATION 1945-2000 (1 OF 2)



EXPLANATION

- 1697 — Selected Wells with Hydrographs
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

Note: The relative error of the model-generated groundwater levels is approximately 4.6%. Common modeling practice is to consider a good fit between historical and model-predicted data if the relative error is below 10%.

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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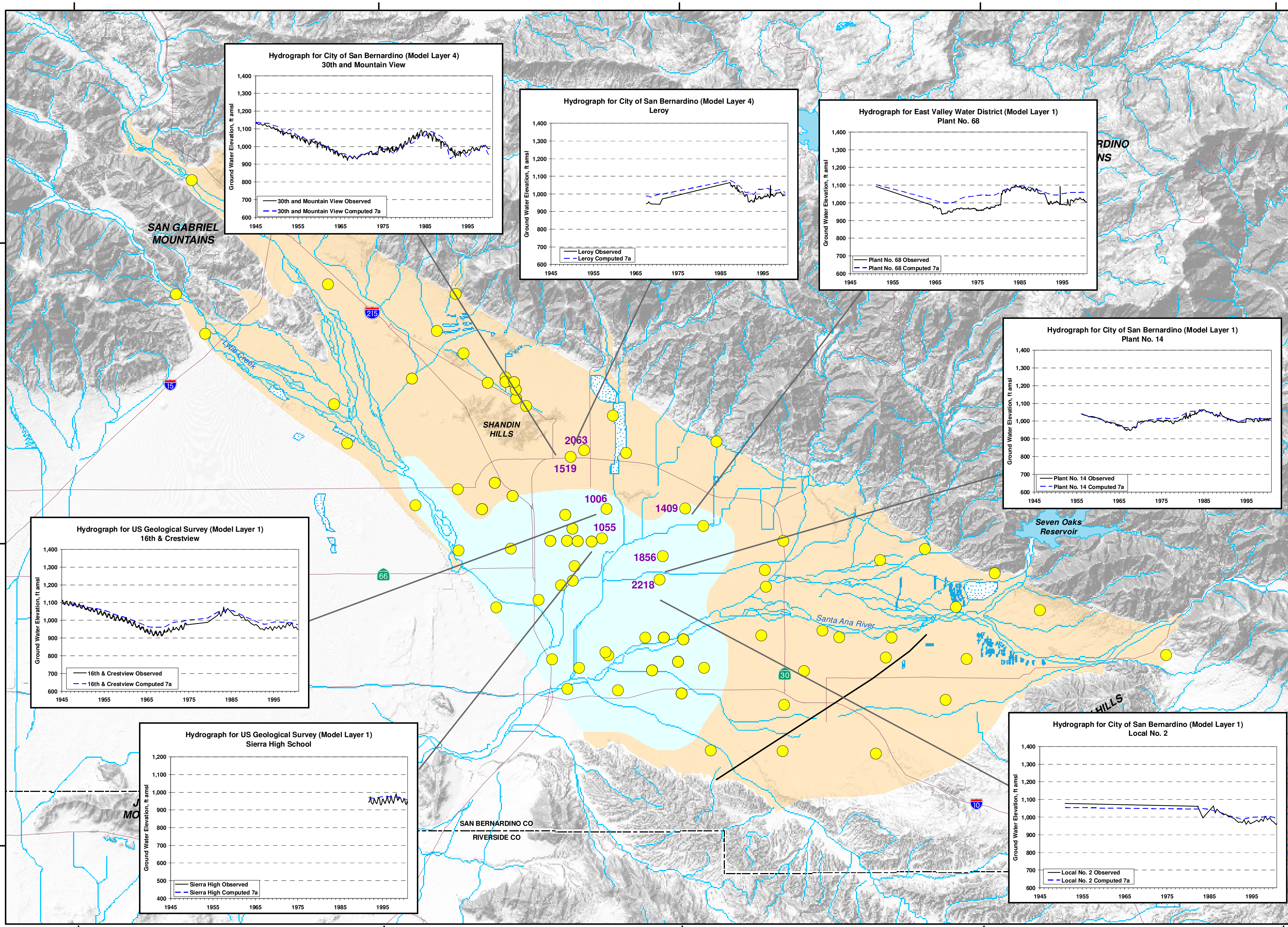
Figure 43

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_43_Hydrograph_1of2_9-09.mxd

SELECTED HYDROGRAPHS FOR ANNUAL TRANSIENT MODEL CALIBRATION 1945-2000 (2 OF 2)



EXPLANATION

1519 Selected Wells with Hydrographs

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

Note: The relative error of the model-generated groundwater levels is approximately 4.6%. Common modeling practice is to consider a good fit between historical and model-predicted data if the relative error is below 10%.

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Prepared by: DWB

Map Projection: State Plane 1927, Zone V, feet

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Figure 44

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_44_Hydrograph_2of2_9-09.mxd

Comparison of Measured and Model-Generated Groundwater Levels for Annual Transient Model Calibration 1945-2000

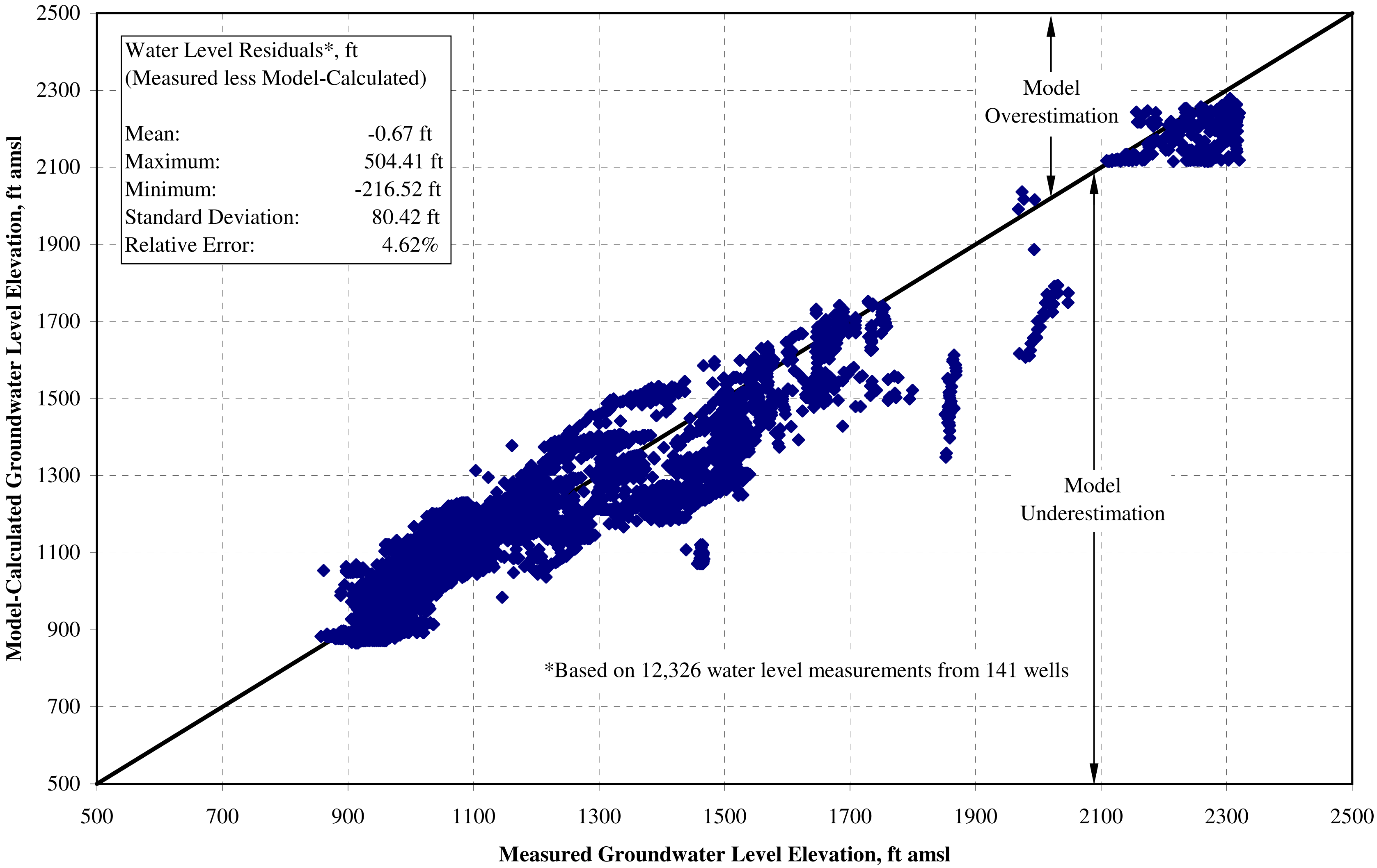


Figure 45

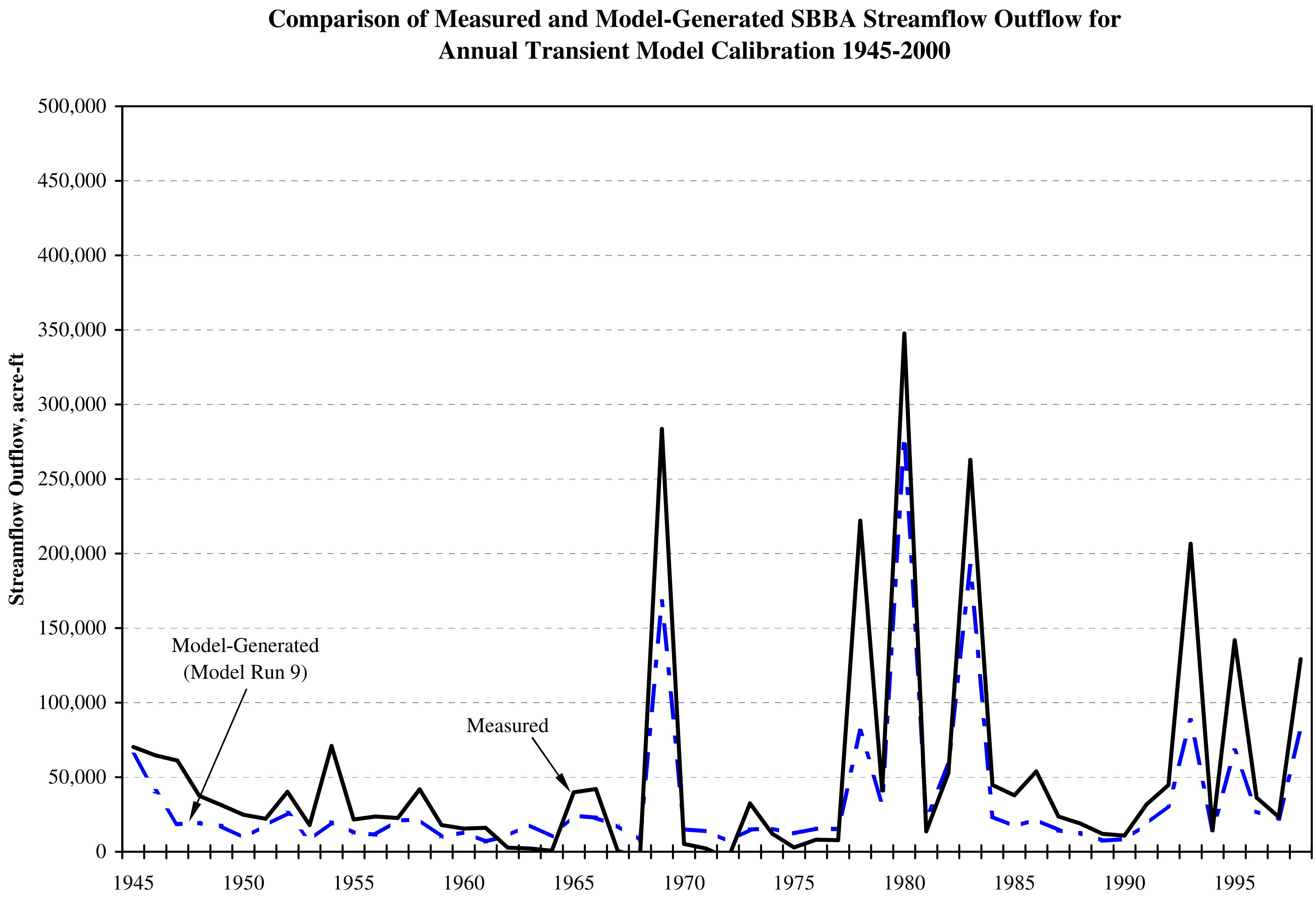
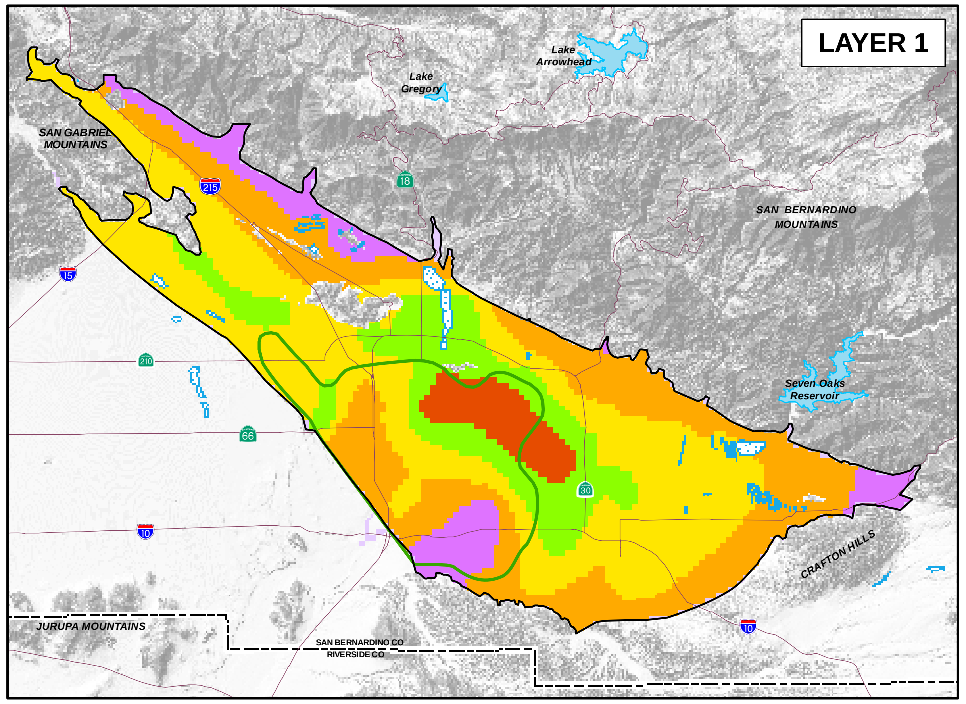
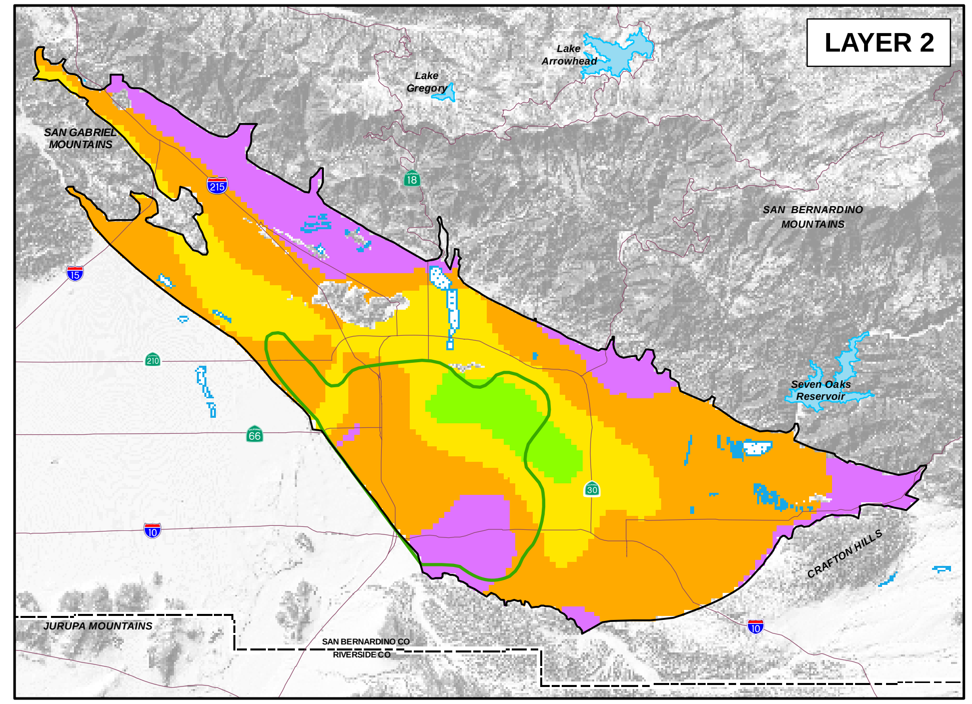
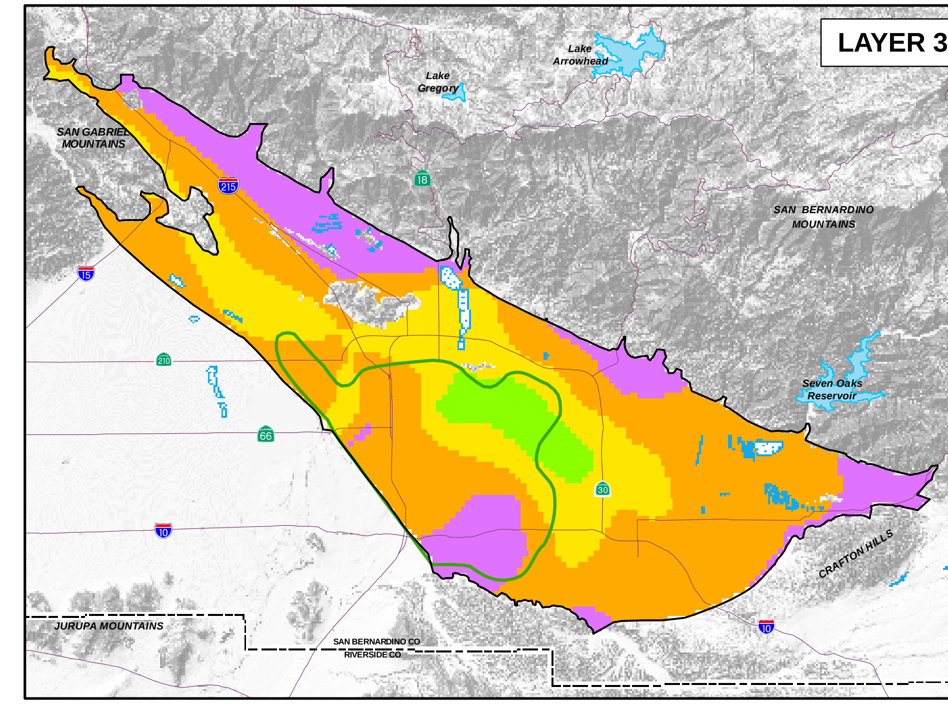
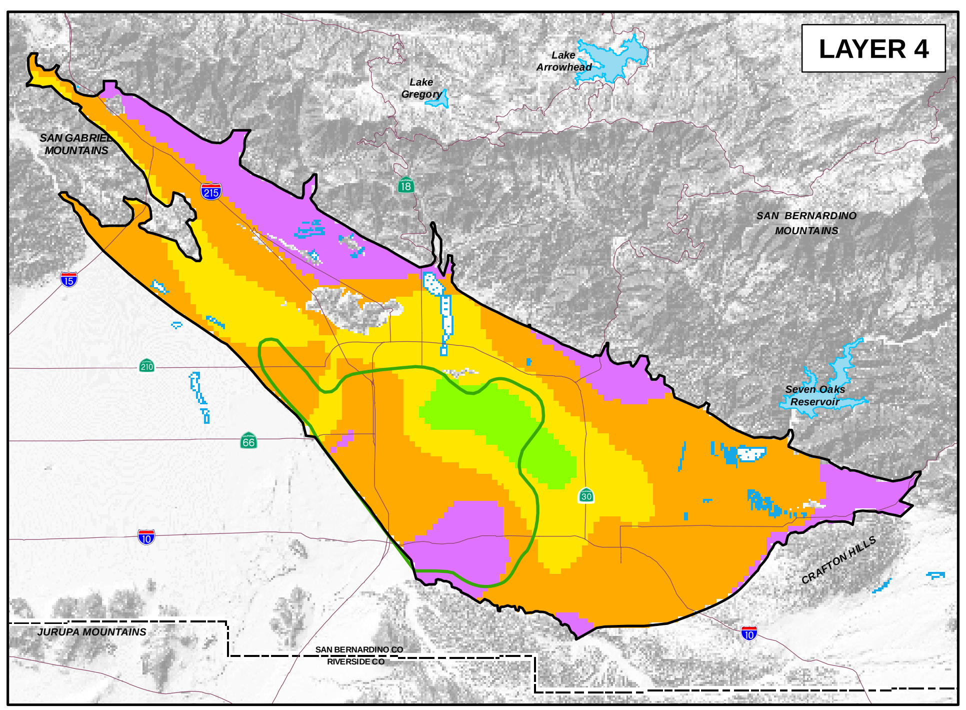

Comparison of Measured and Model-Generated SBBA Streamflow Outflow for
Annual Transient Model Calibration 1945-2000
Streamflow Outflow, acre-ft
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Model-Generated
(Model Run 9)
Measured
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

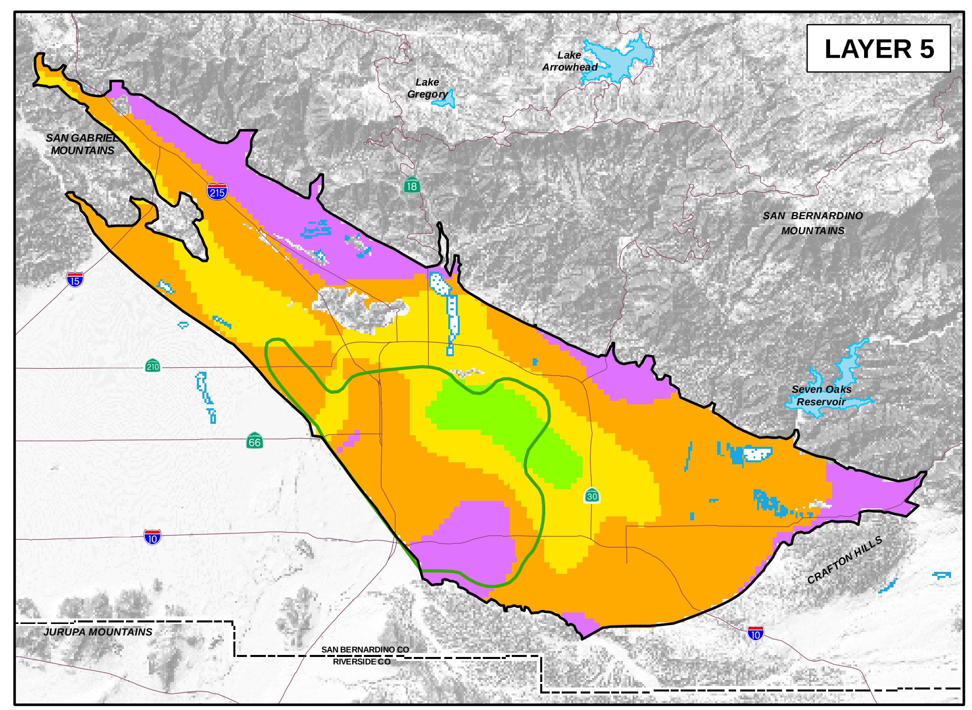
Figure 46











EXPLANATION

Effective Porosity

- <0.03
- 0.03 to 0.06
- 0.06 to 0.09
- 0.09 to 0.12
- 0.12 to 0.15
- >0.15

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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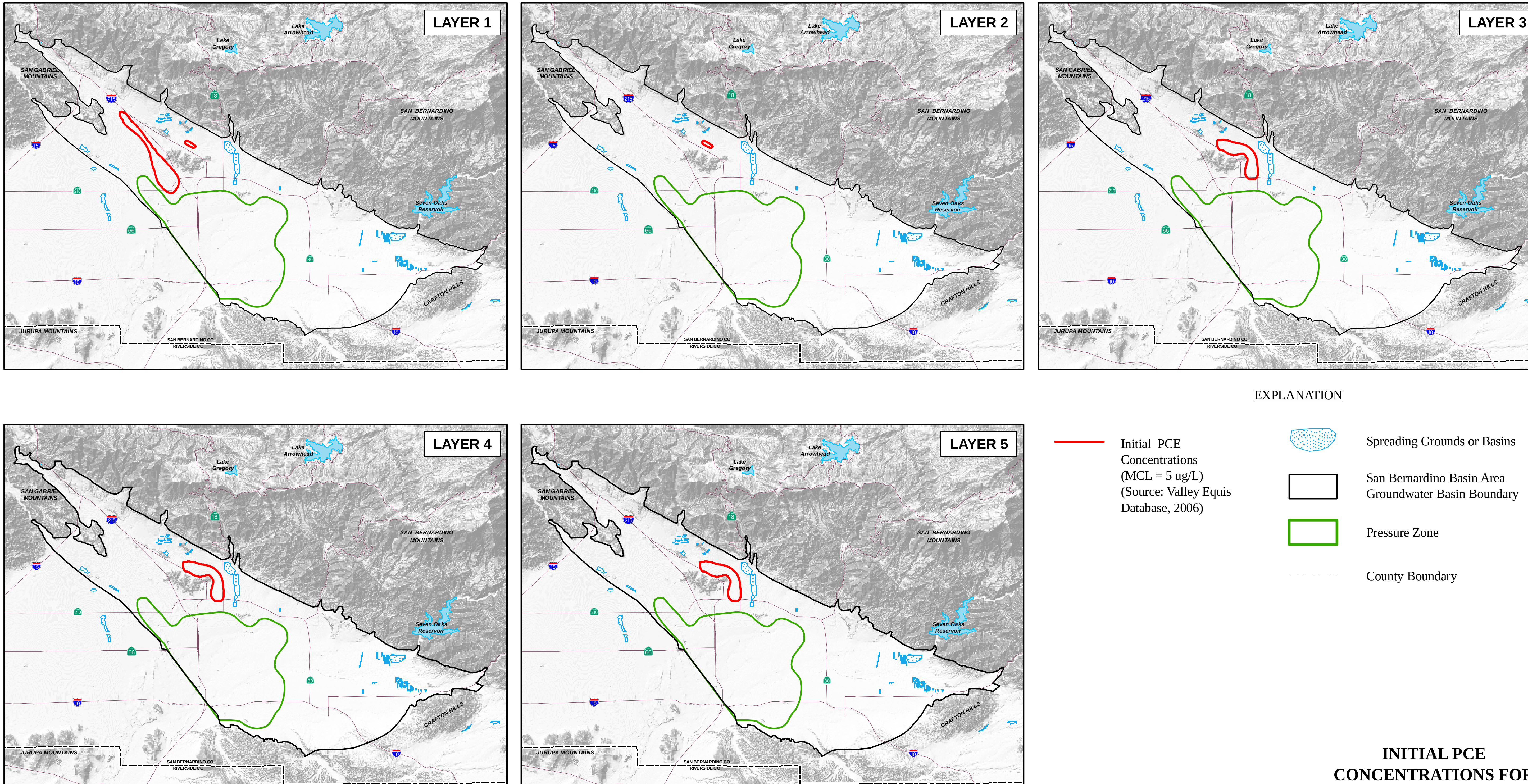
EFFECTIVE POROSITY OF THE REFINED BASIN SOLUTE TRANSPORT MODEL

Figure 47

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_47_effective_porosity_9-09.mxd



EXPLANATION

Initial PCE Concentrations (MCL = 5 ug/L) (Source: Valley Equis Database, 2006)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

INITIAL PCE CONCENTRATIONS FOR REFINED SOLUTE TRANSPORT MODEL CALIBRATION

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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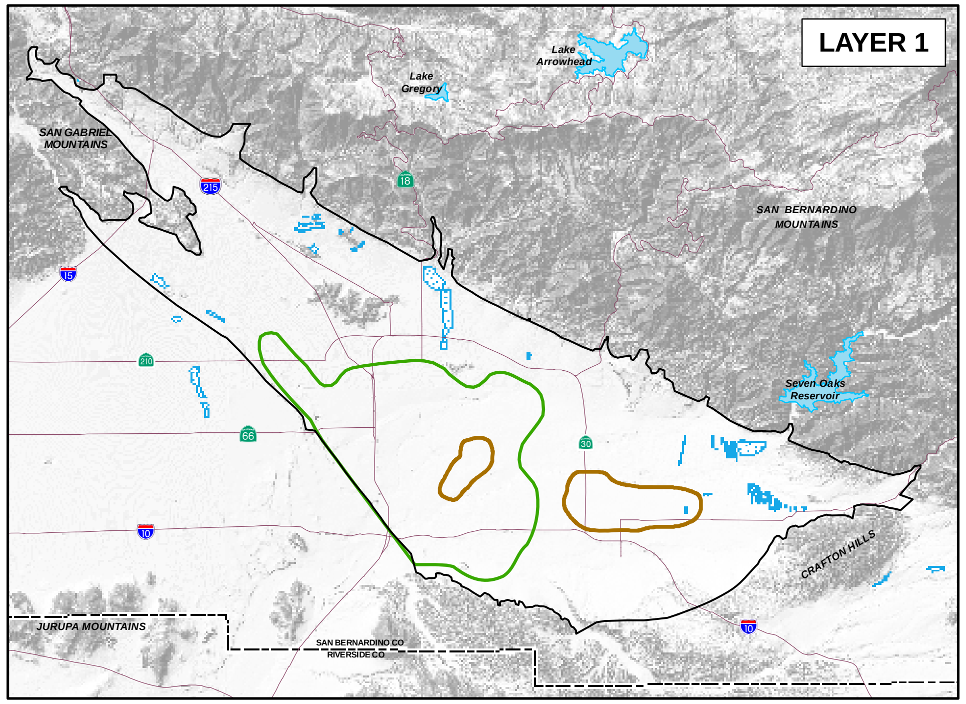
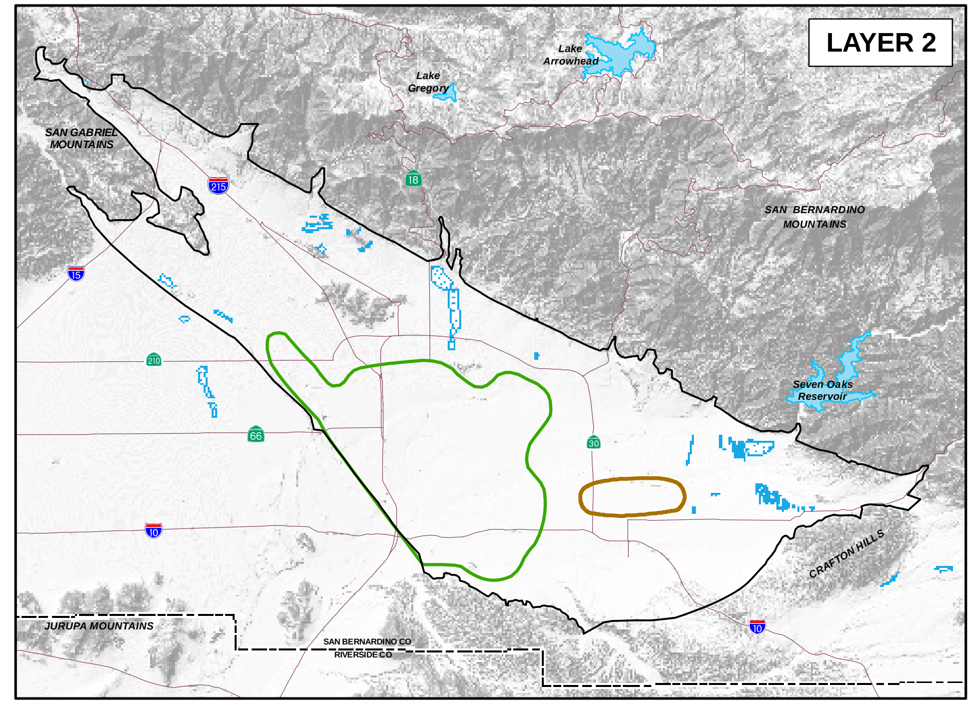
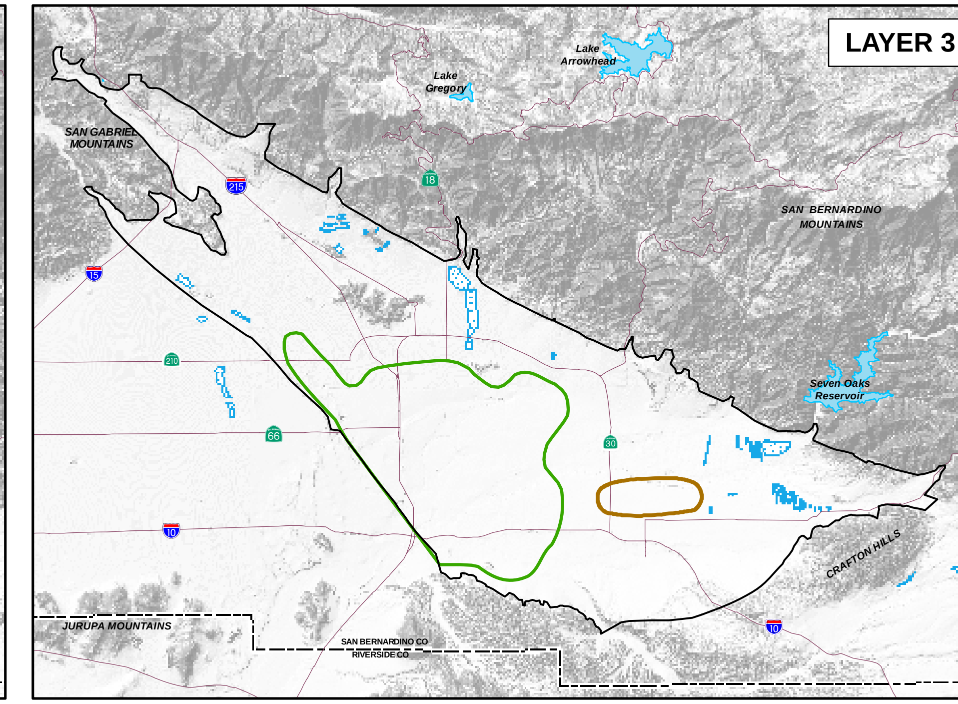
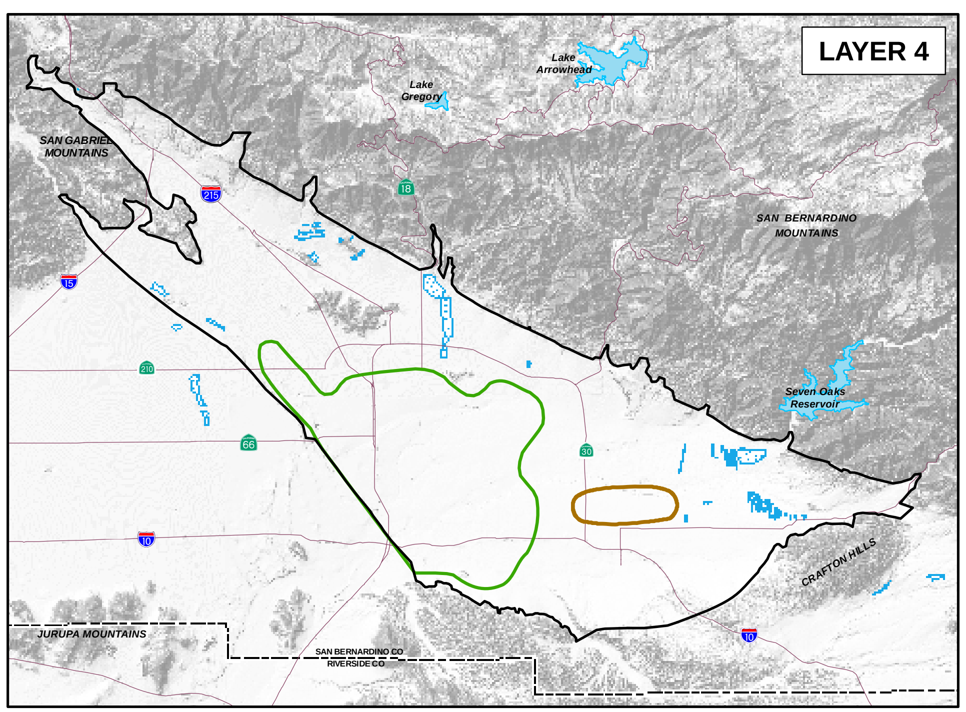
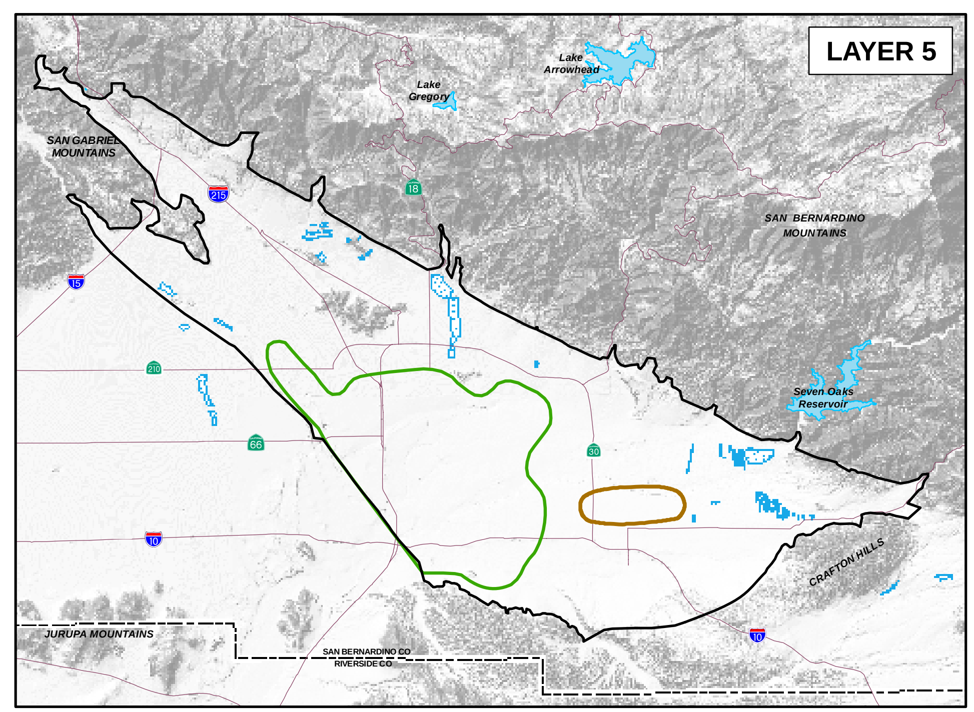
Figure 48











EXPLANATION

Initial TCE Concentrations (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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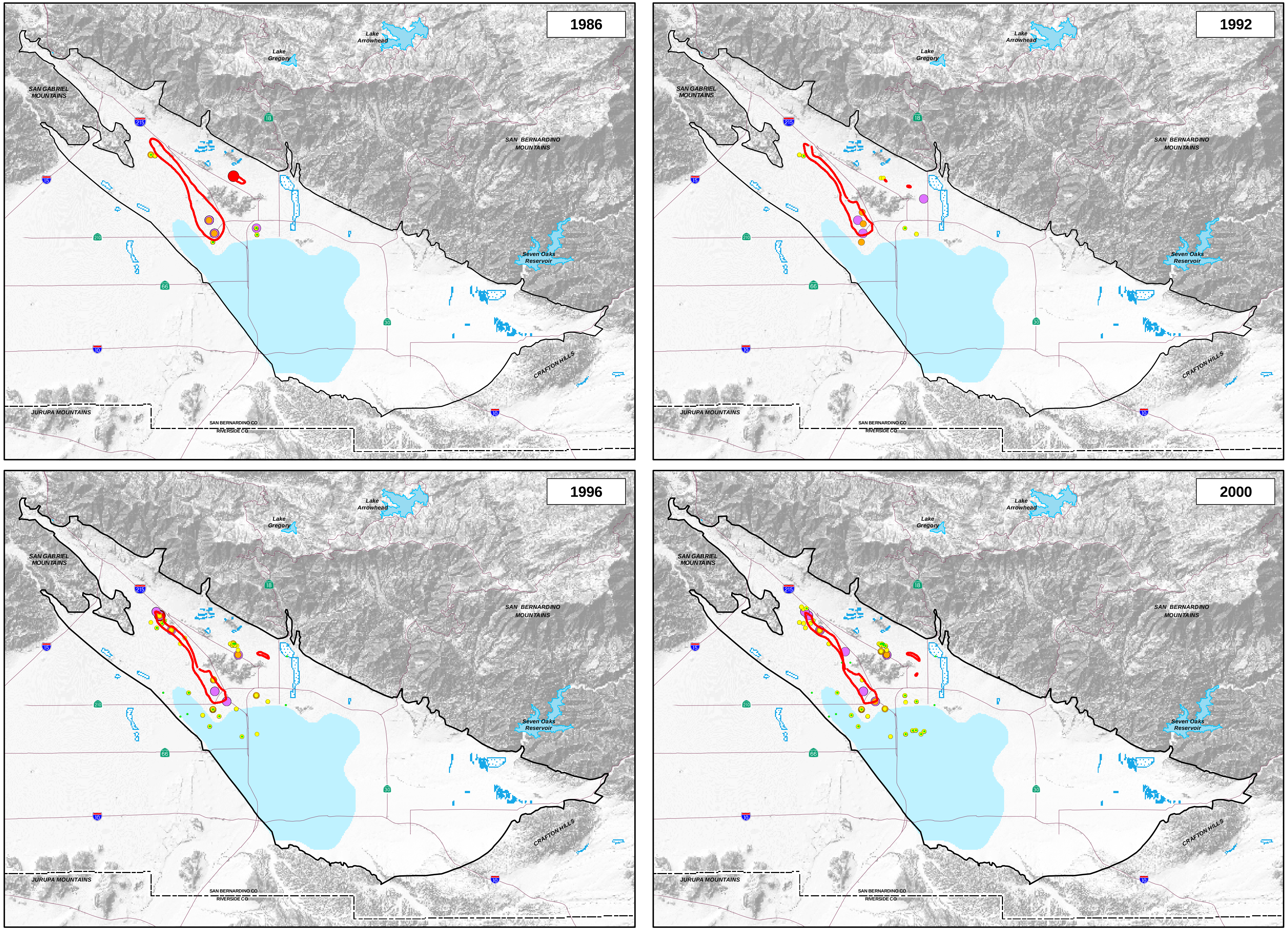
INITIAL TCE CONCENTRATIONS FOR REFINED SOLUTE TRANSPORT MODEL CALIBRATION

Figure 49



MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR PCE - MODEL LAYER 1

EXPLANATION

Measured PCE Concentrations (ug/L)

- 0
- <5
- 5 - 10
- 10 - 50
- >50

Model-Generated PCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

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Figure 50

30-Sep-09 Prepared by: DWB Map Projection: State Plane 1983, Zone V, feet

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_50_PCE_plumes_L1_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT

MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR PCE - MODEL LAYER 2

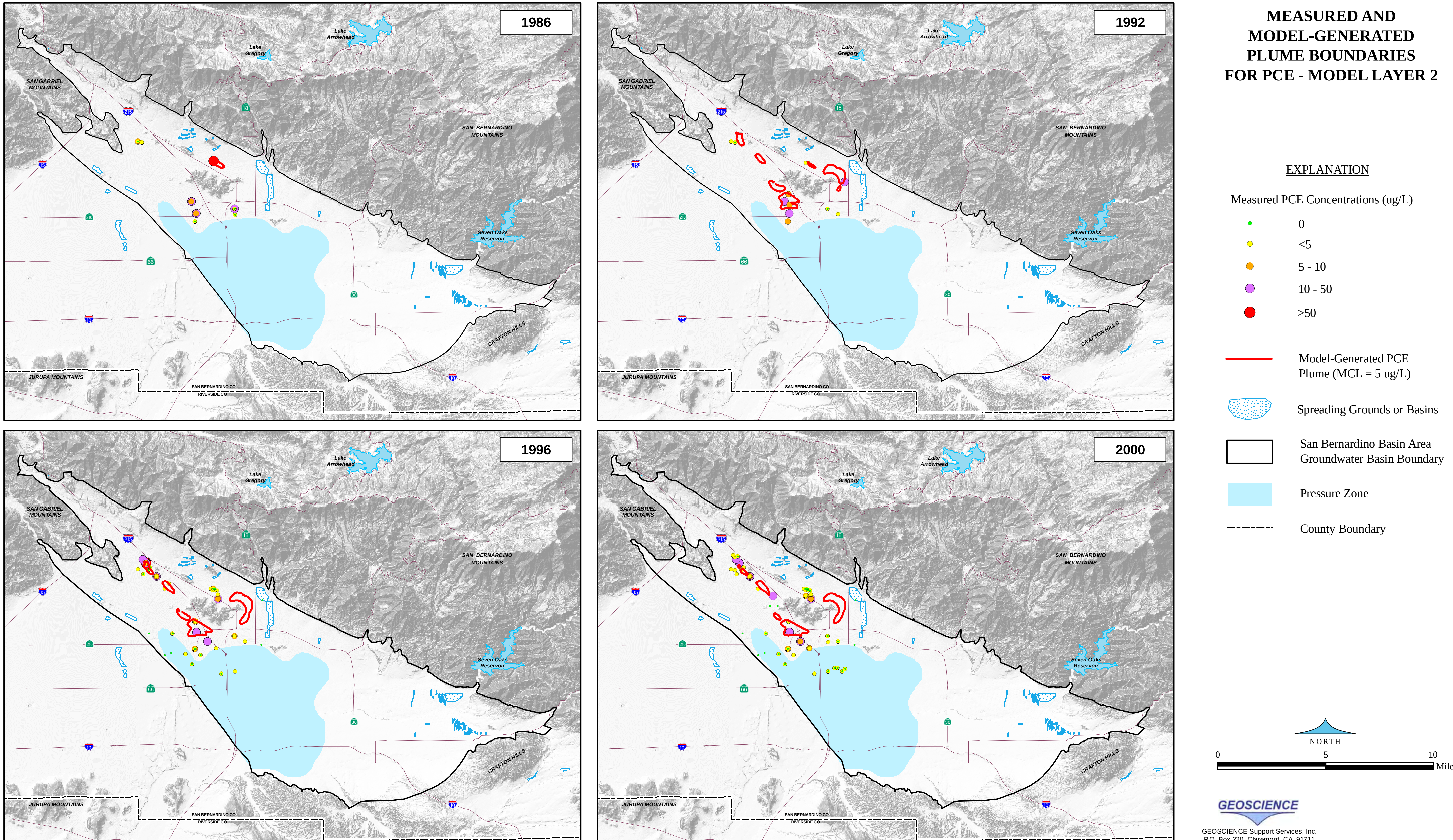

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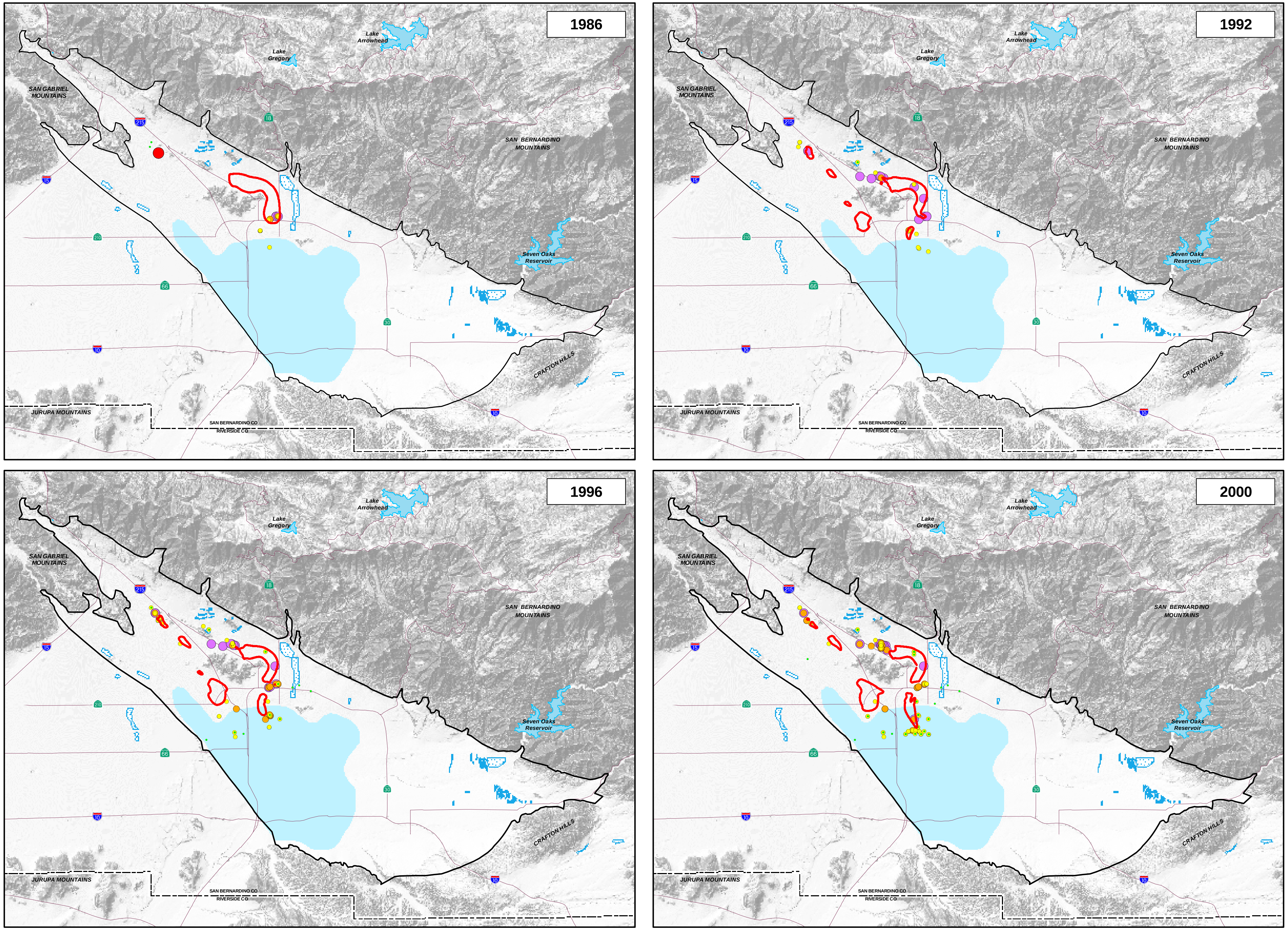
Figure 51

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_51_PCE_plumes_L2_9-09.mxd

MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR PCE - MODEL LAYER 3



EXPLANATION

Measured PCE Concentrations (ug/L)

- 0
- <5
- 5 - 10
- 10 - 50
- >50

Model-Generated PCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

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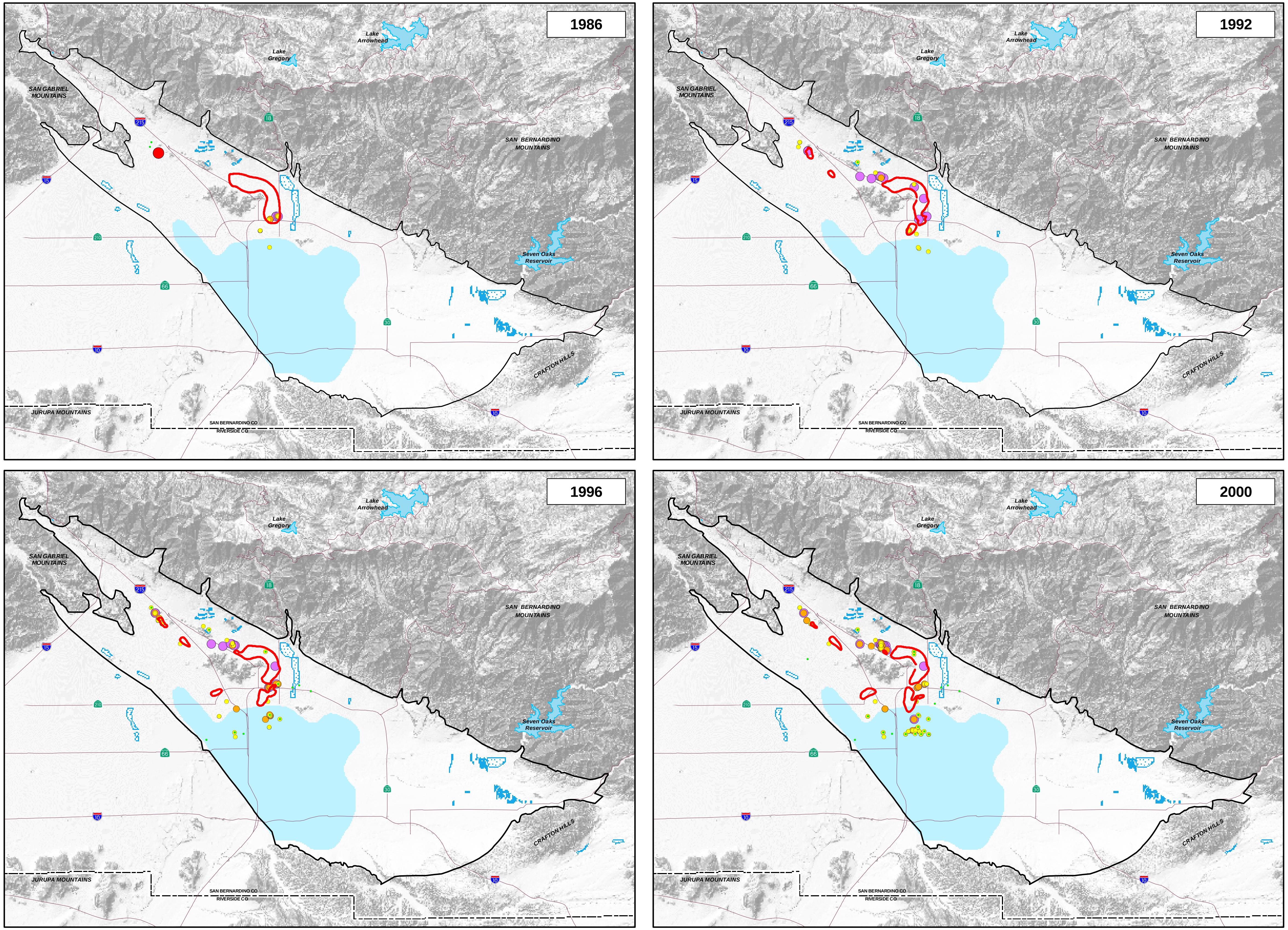
Figure 52

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT

MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR PCE - MODEL LAYER 4



EXPLANATION

Measured PCE Concentrations (ug/L)

- 0
- <5
- 5 - 10
- 10 - 50
- >50

Model-Generated PCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

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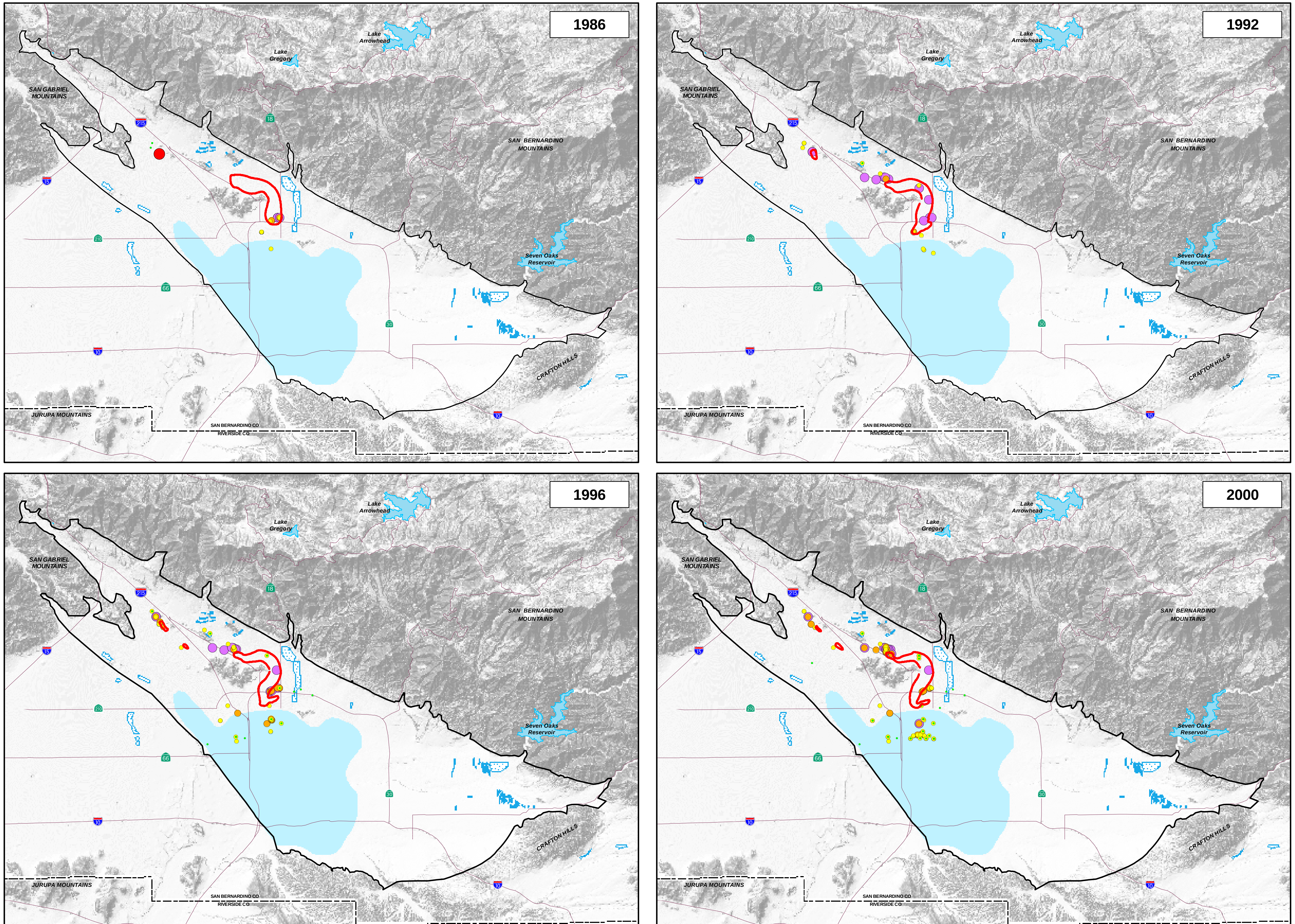
Figure 53

30-Sep-09 Prepared by: DWB Map Projection: State Plane 1983, Zone V, feet

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_53_PCE_plumes_L4_9-09.mxd

MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR PCE - MODEL LAYER 5



EXPLANATION

Measured PCE Concentrations (ug/L)

- 0
- <5
- 5 - 10
- 10 - 50
- >50

Model-Generated PCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

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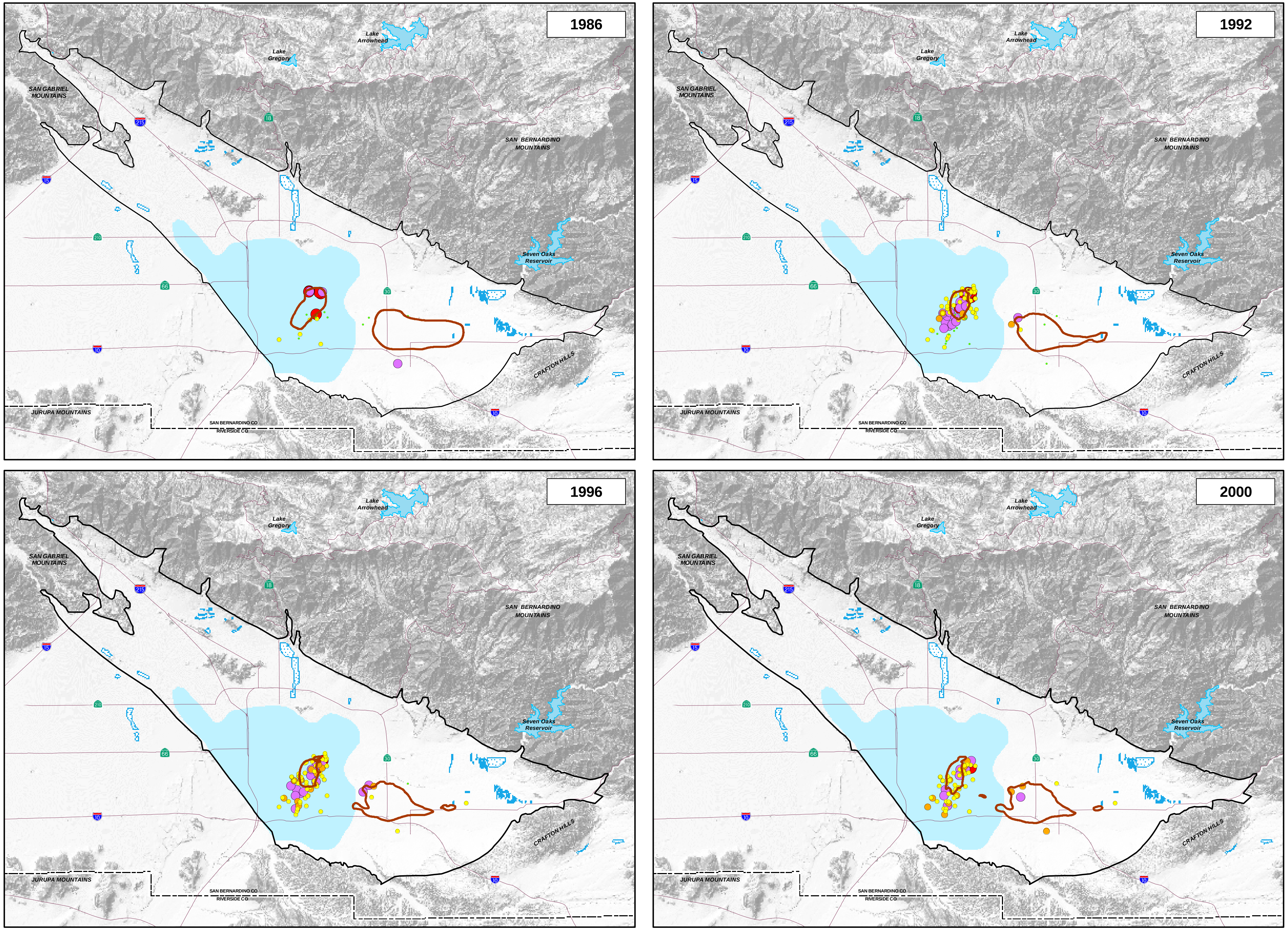
Figure 54

30-Sep-09 Prepared by: DWB Map Projection: State Plane 1983, Zone V, feet

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_54_PCE_plumes_L5_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR TCE - MODEL LAYER 1

EXPLANATION

Measured TCE Concentrations (ug/L)

- 0
- <5
- 5 - 10
- 10 - 50
- >50

Model-Generated TCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

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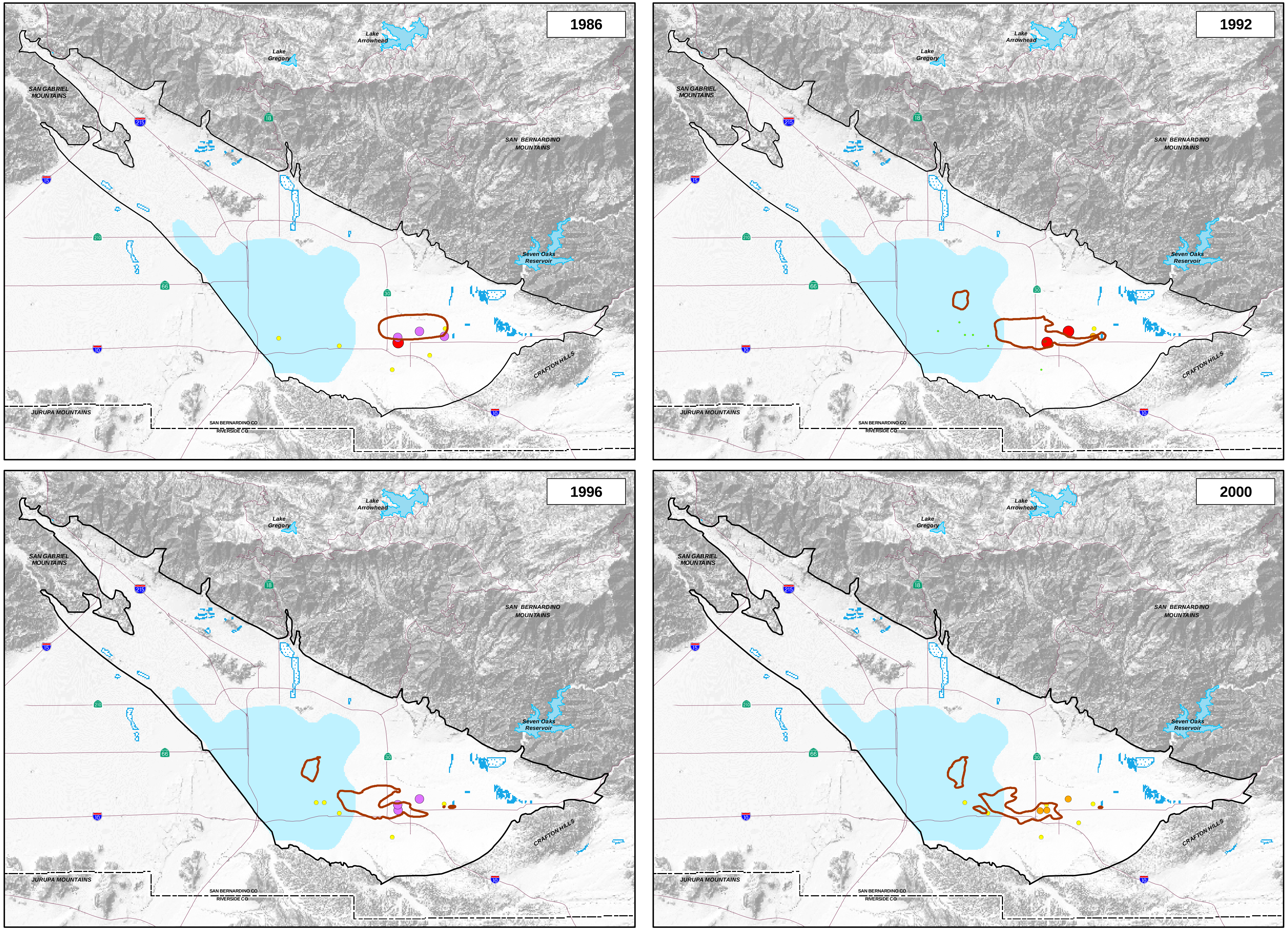
Figure 55

30-Sep-09 Prepared by: DWB Map Projection: State Plane 1983, Zone V, feet

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_55_TCE_plumes_L1_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR TCE - MODEL LAYER 2

EXPLANATION

Measured TCE Concentrations (ug/L)

- 0
- <5
- 5 - 10
- 10 - 50
- >50

Model-Generated TCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

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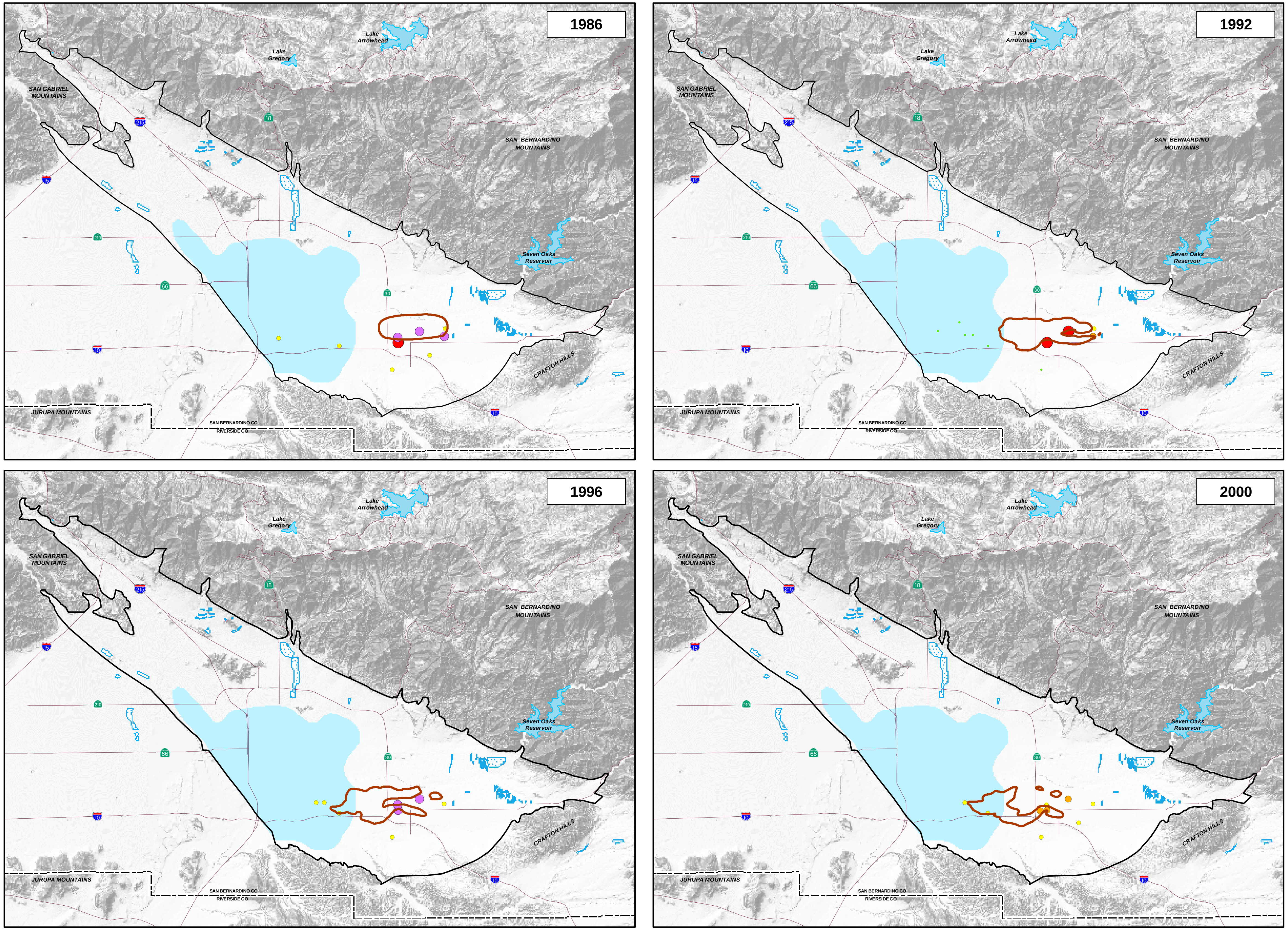
Figure 56

30-Sep-09 Prepared by: DWB Map Projection: State Plane 1983, Zone V, feet

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_56_TCE_plumes_L2_9-09.mxd



MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR TCE - MODEL LAYER 3

EXPLANATION

Measured TCE Concentrations (ug/L)
- 0
- <5
- 5 - 10
- 10 - 50
- >50

Model-Generated TCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

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Figure 57

30-Sep-09 Prepared by: DWB Map Projection: State Plane 1983, Zone V, feet

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_57_TCE_plumes_L3_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT

MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR TCE - MODEL LAYER 4

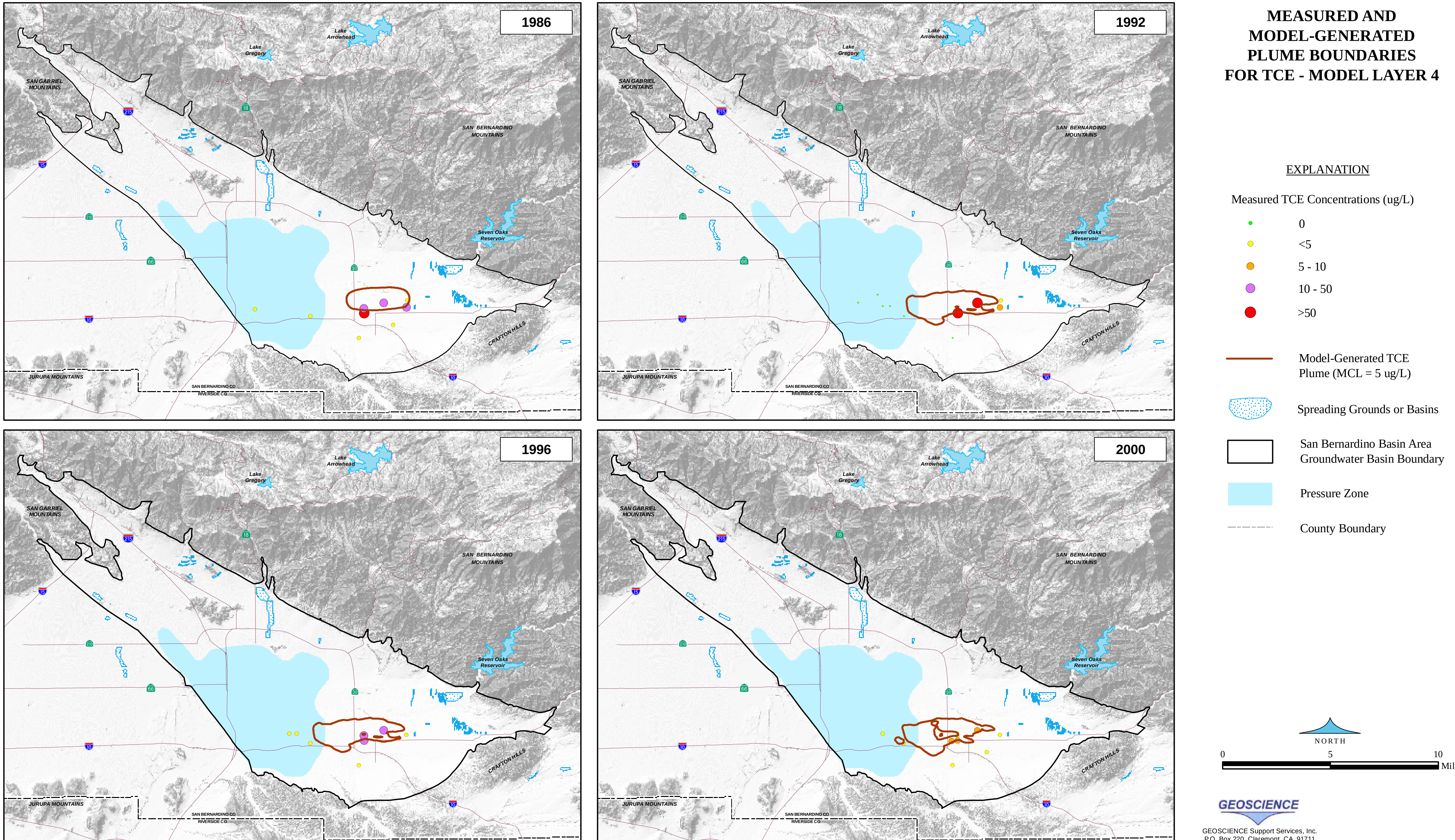

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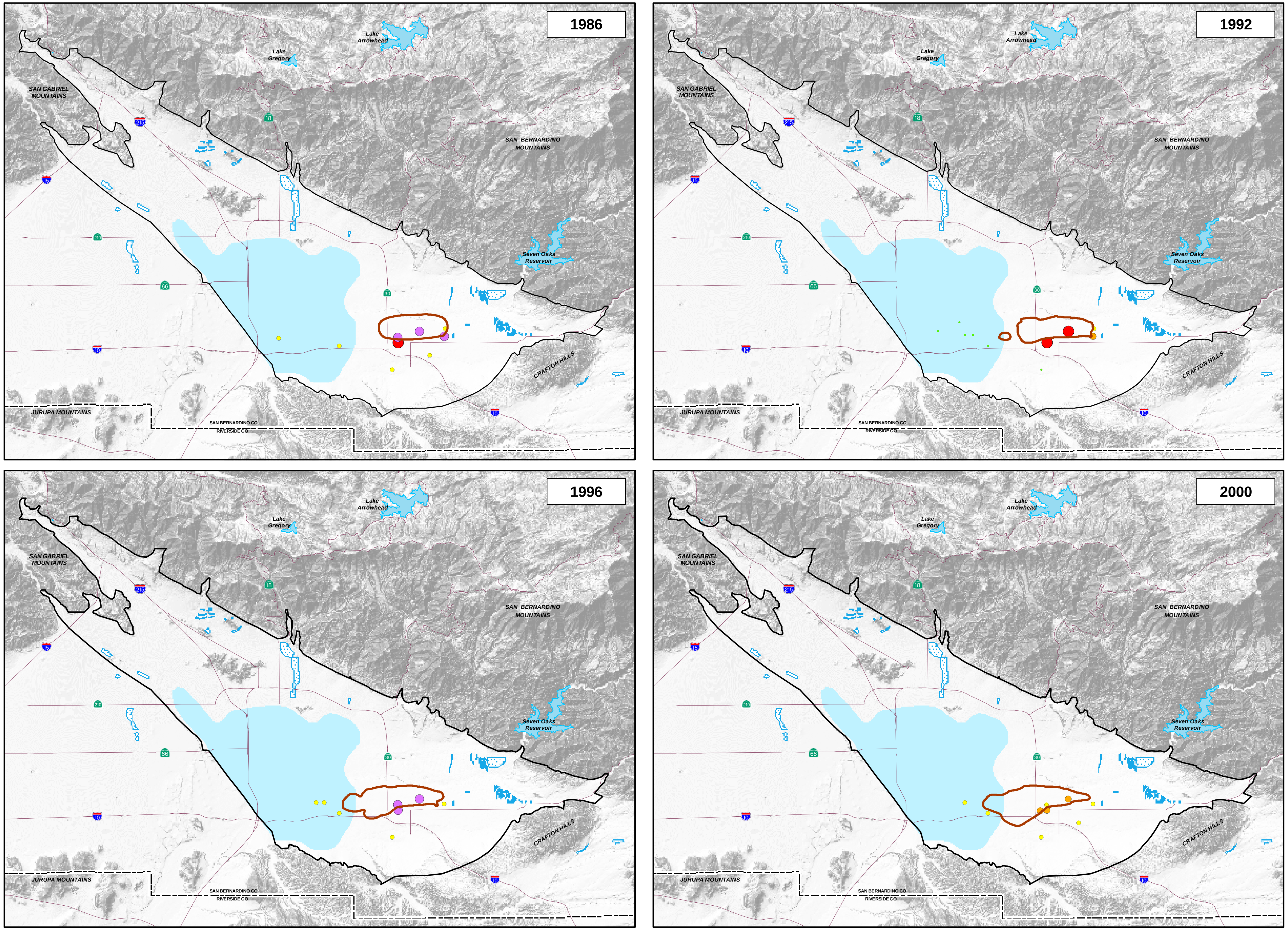
Figure 58

30-Sep-09 Prepared by: DWB Map Projection: State Plane 1983, Zone V, feet

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_58_TCE_plumes_L4_9-09.mxd

MEASURED AND MODEL-GENERATED PLUME BOUNDARIES FOR TCE - MODEL LAYER 5



EXPLANATION

Measured TCE Concentrations (ug/L)

- 0
- <5
- 5 - 10
- 10 - 50
- >50

Model-Generated TCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH

0 5 10 Miles

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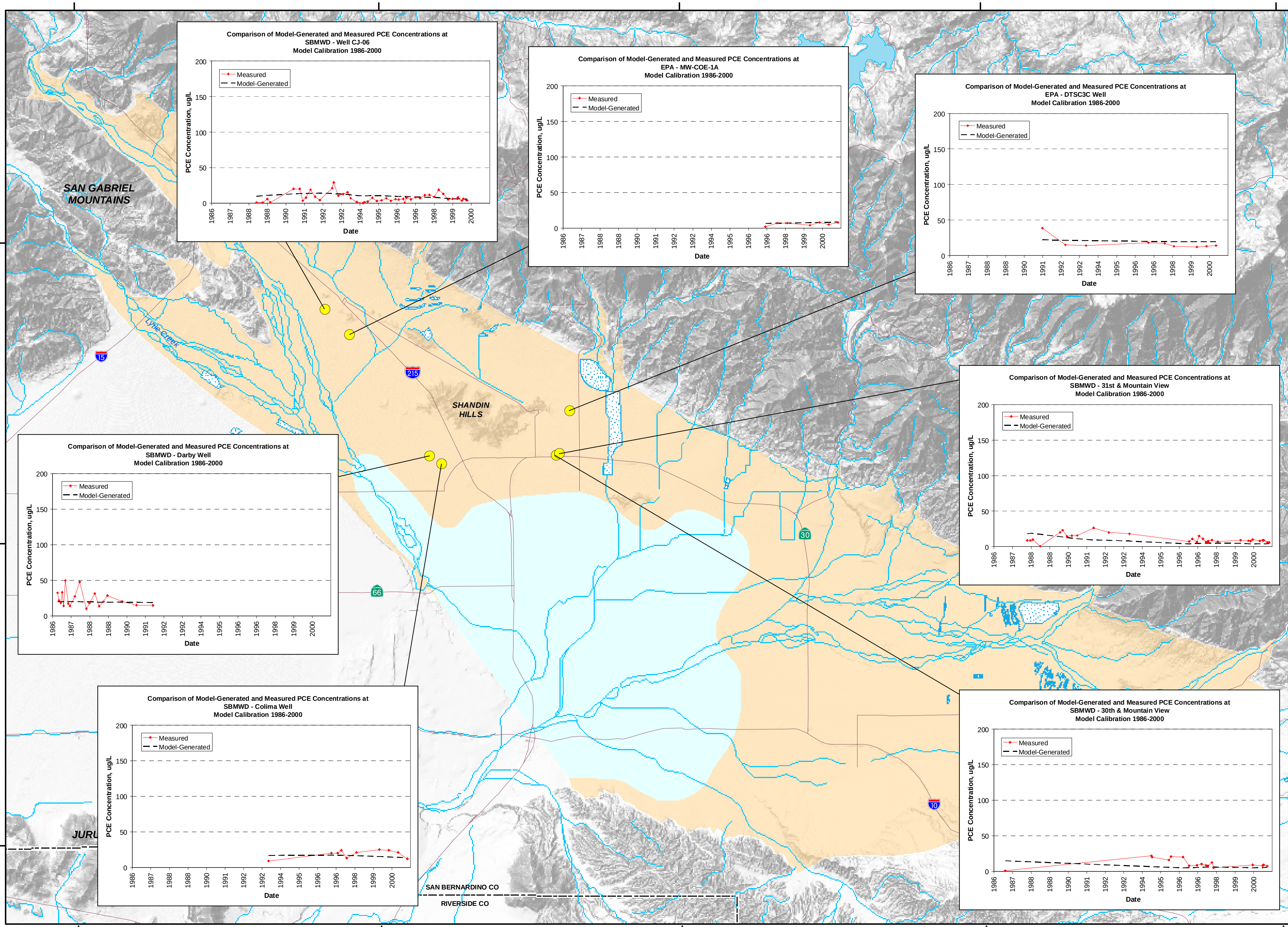
Figure 59

30-Sep-09 Prepared by: DWB Map Projection: State Plane 1983, Zone V, feet

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_59_TCE_plumes_L5_9-09.mxd

MEASURED VERSUS MODEL-GENERATED PCE CONCENTRATIONS AT SELECTED LOCATIONS



EXPLANATION

- Well used for PCE Transient Calibration
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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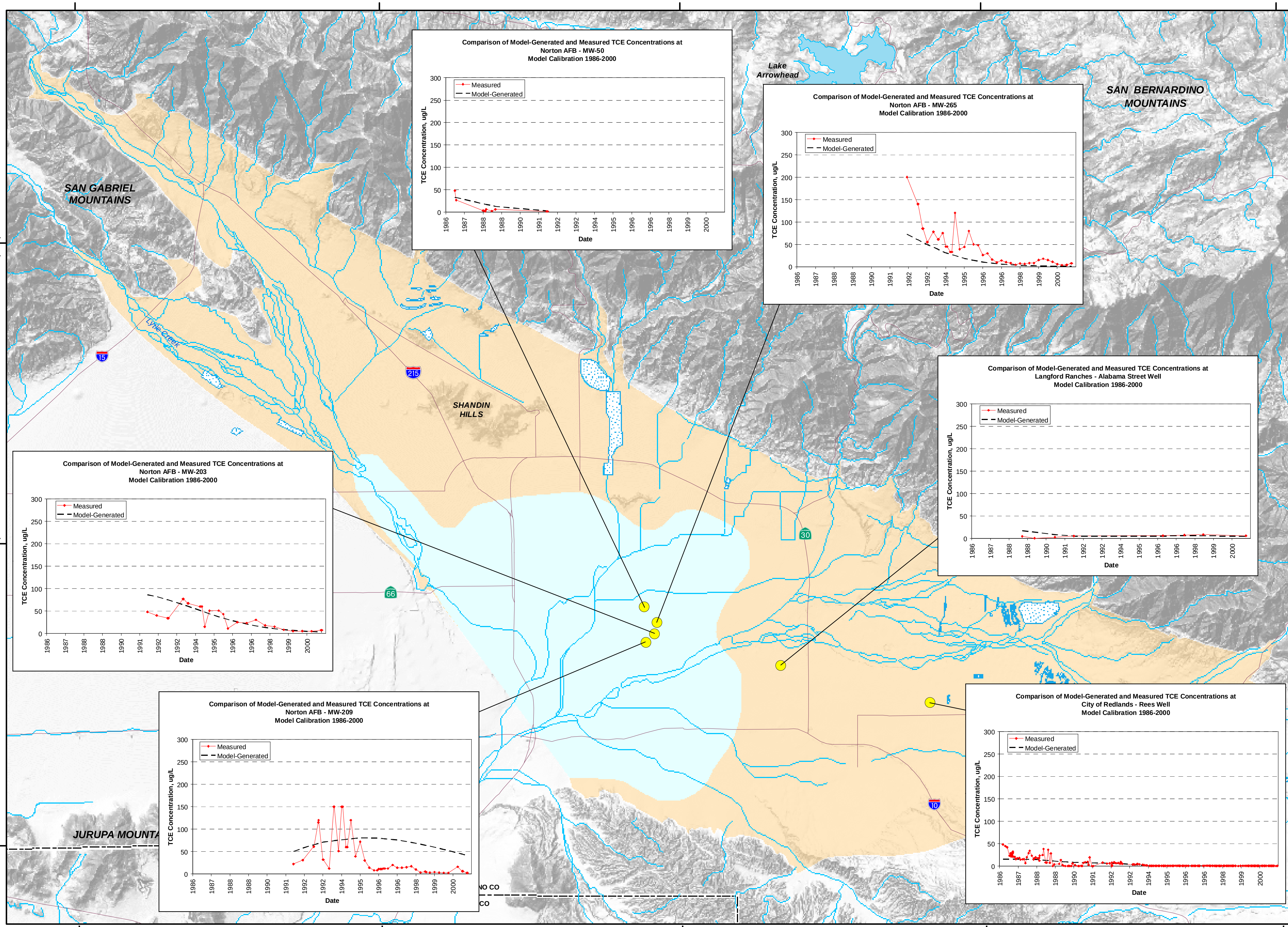
Figure 60

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_60_pce_calibration_9-09.mxd

MEASURED VERSUS MODEL-GENERATED TCE CONCENTRATIONS AT SELECTED LOCATIONS



EXPLANATION

- Well used for TCE Transient Calibration
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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Figure 61

Histogram of PCE Residuals* for Model Calibration - 1986 to 2000

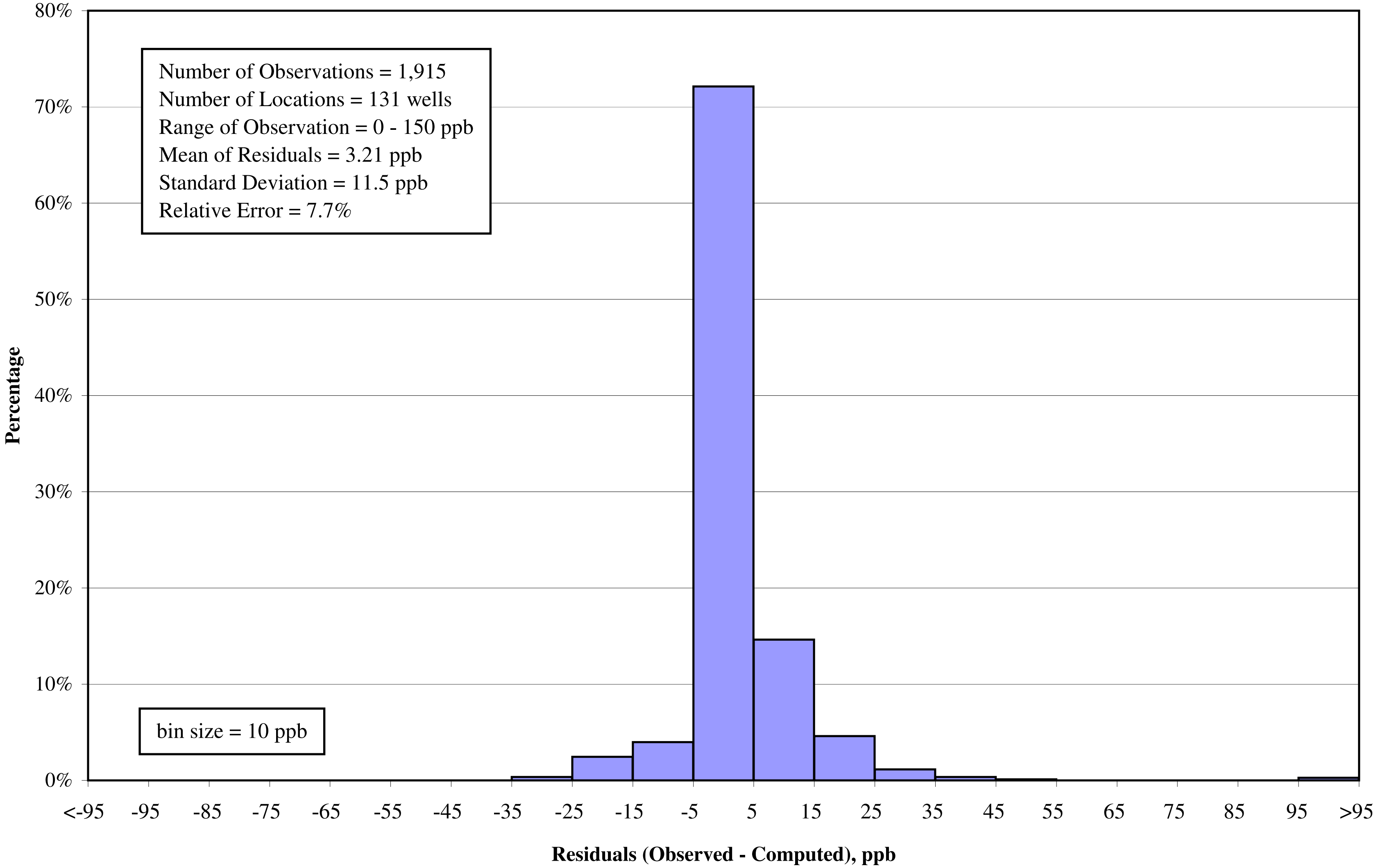


Figure 62

* "Residual" = Measured Data - Modeled Data

Histogram of TCE Residuals* for Model Calibration - 1986 to 2000

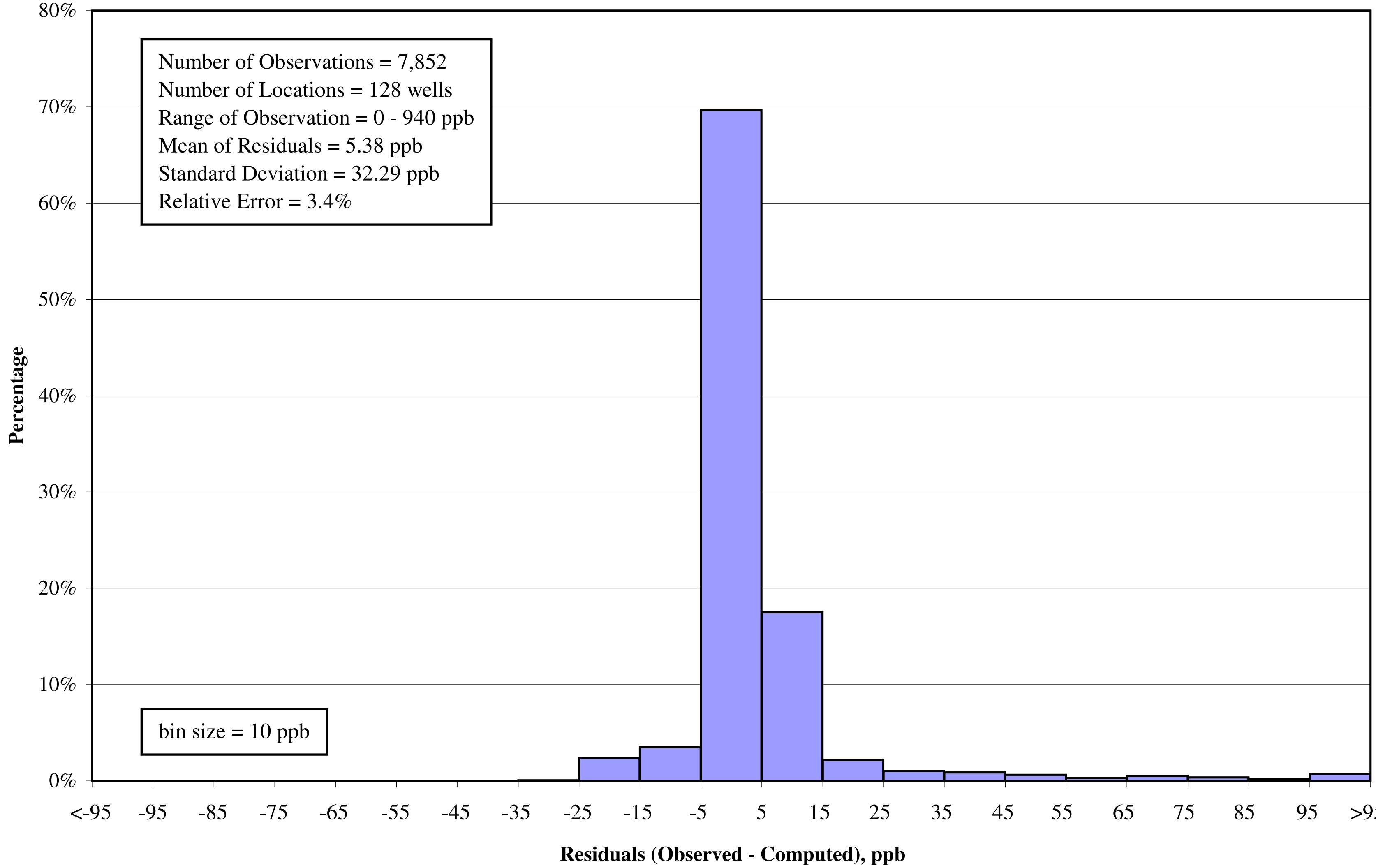


Figure 63

* "Residual" = Measured Data - Modeled Data

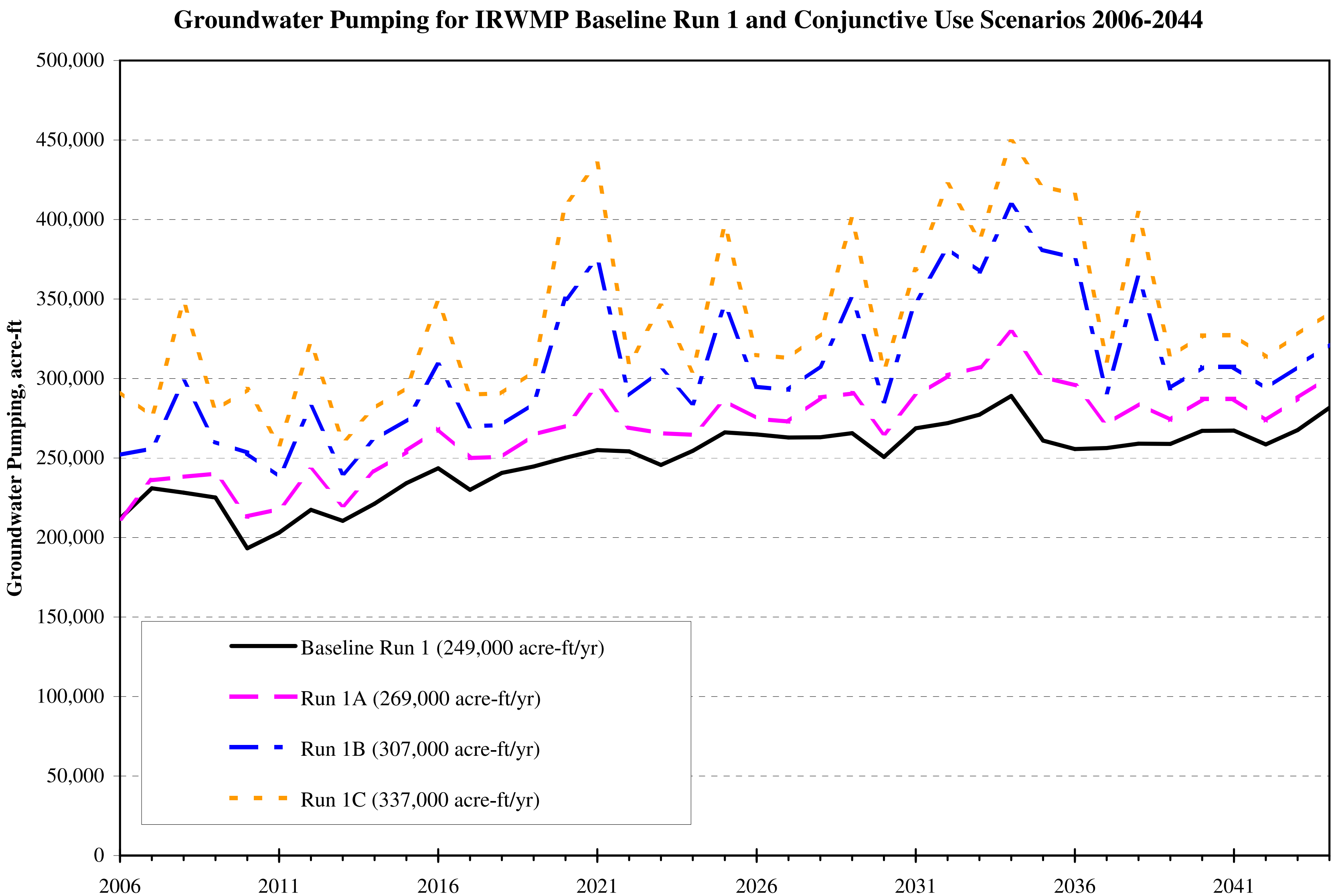

Groundwater Pumping for IRWMP Baseline Run 1 and Conjunctive Use Scenarios 2006-2044
Groundwater Pumping, acre-ft
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1 (249,000 acre-ft/yr)
Run 1A (269,000 acre-ft/yr)
Run 1B (307,000 acre-ft/yr)
Run 1C (337,000 acre-ft/yr)

Figure 64

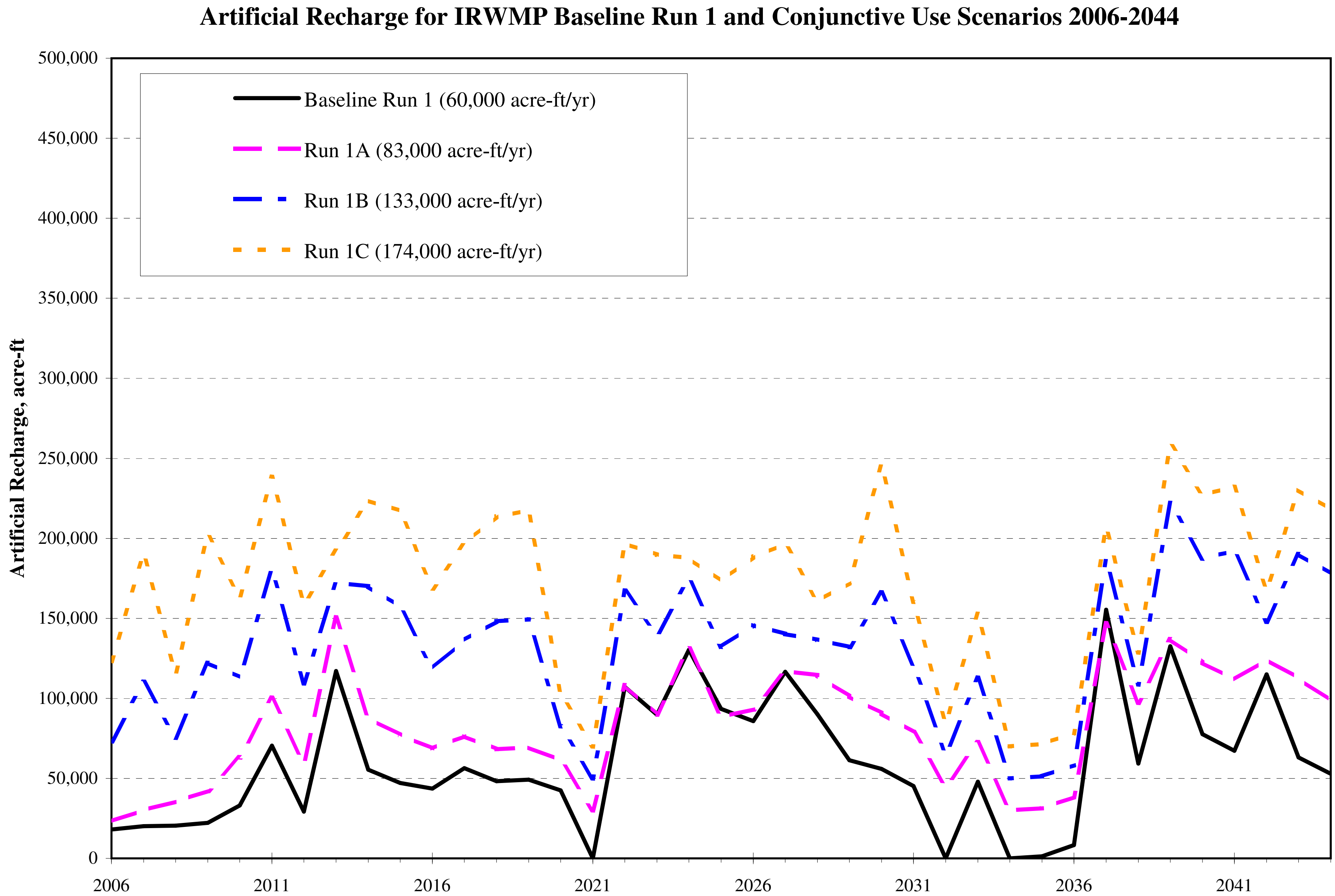
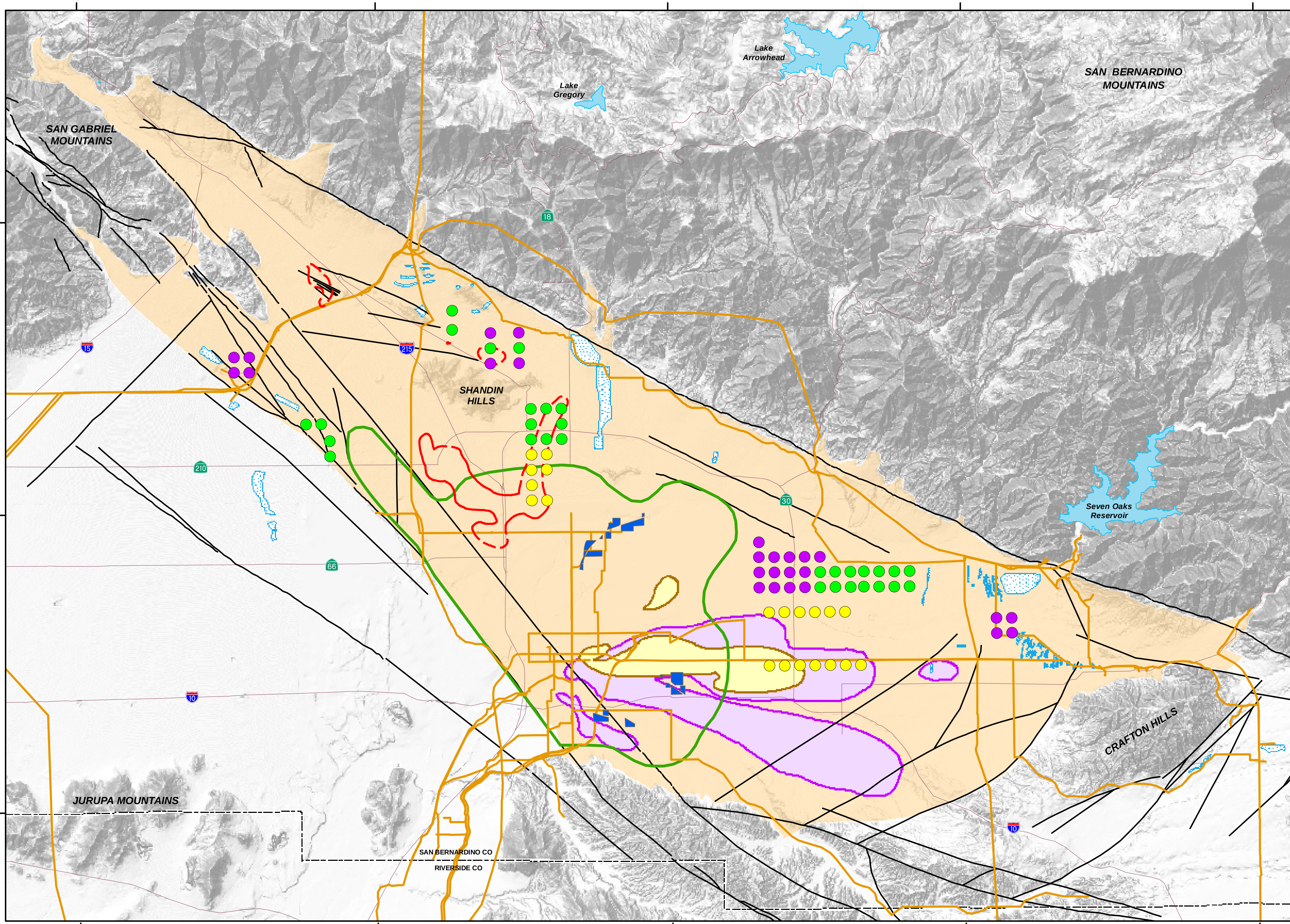

Artificial Recharge for IRWMP Baseline Run 1 and Conjunctive Use Scenarios 2006-2044
Artificial Recharge, acre-ft
Baseline Run 1 (60,000 acre-ft/yr)
Run 1A (83,000 acre-ft/yr)
Run 1B (133,000 acre-ft/yr)
Run 1C (174,000 acre-ft/yr)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
2006
2011
2016
2021
2026
2031
2036
2041

Figure 65

NEW FACILITIES REQUIRED FOR IRWMP CONJUCTIVE USE SCENARIOS



EXPLANATION

- New Wells For Scenarios 1A, 1B and 1C
- New Wells For Scenarios 1B and 1C
- New Wells For Scenario 1C
- New Spreading Grounds For Scenario 1C
- Existing Pipelines
- Fault
- PCE Groundwater Contaminant Plume (5 ug/L) Dashed where less certain (Source: SECOR, 2007.)
- TCE Groundwater Contaminant Plume (5 ug/L) (Source: TetraTech, 2008.)
- Perchlorate Groundwater Contaminant Plume (6 ug/L) (Source: TetraTech, 2008.)
- San Bernardino Basin Area Groundwater Basin Boundary
- Spreading Grounds or Basins
- Pressure Zone
- County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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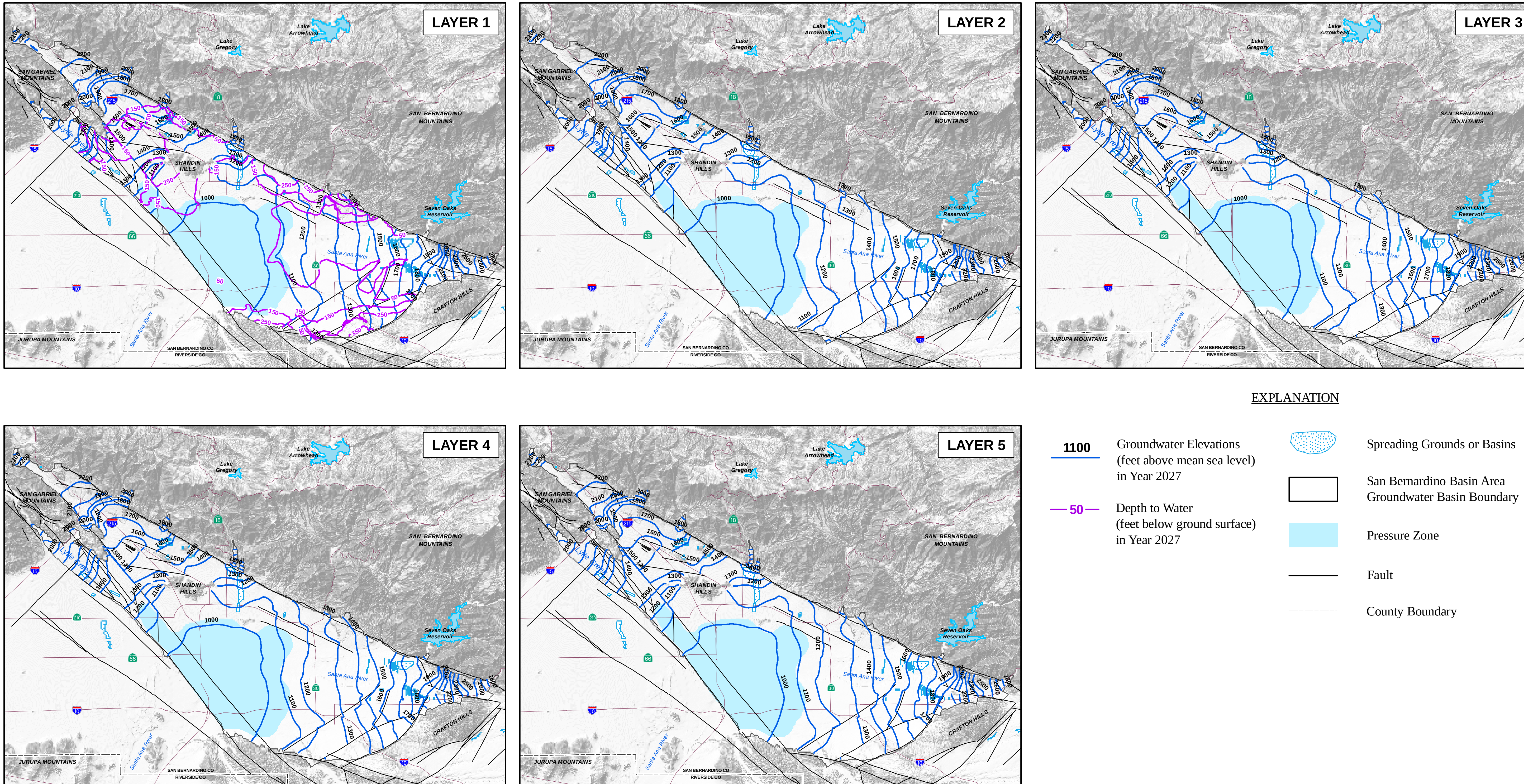
Figure 66

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



GROUNDWATER ELEVATIONS IN YEAR 2027 IRWMP BASELINE RUN 1

NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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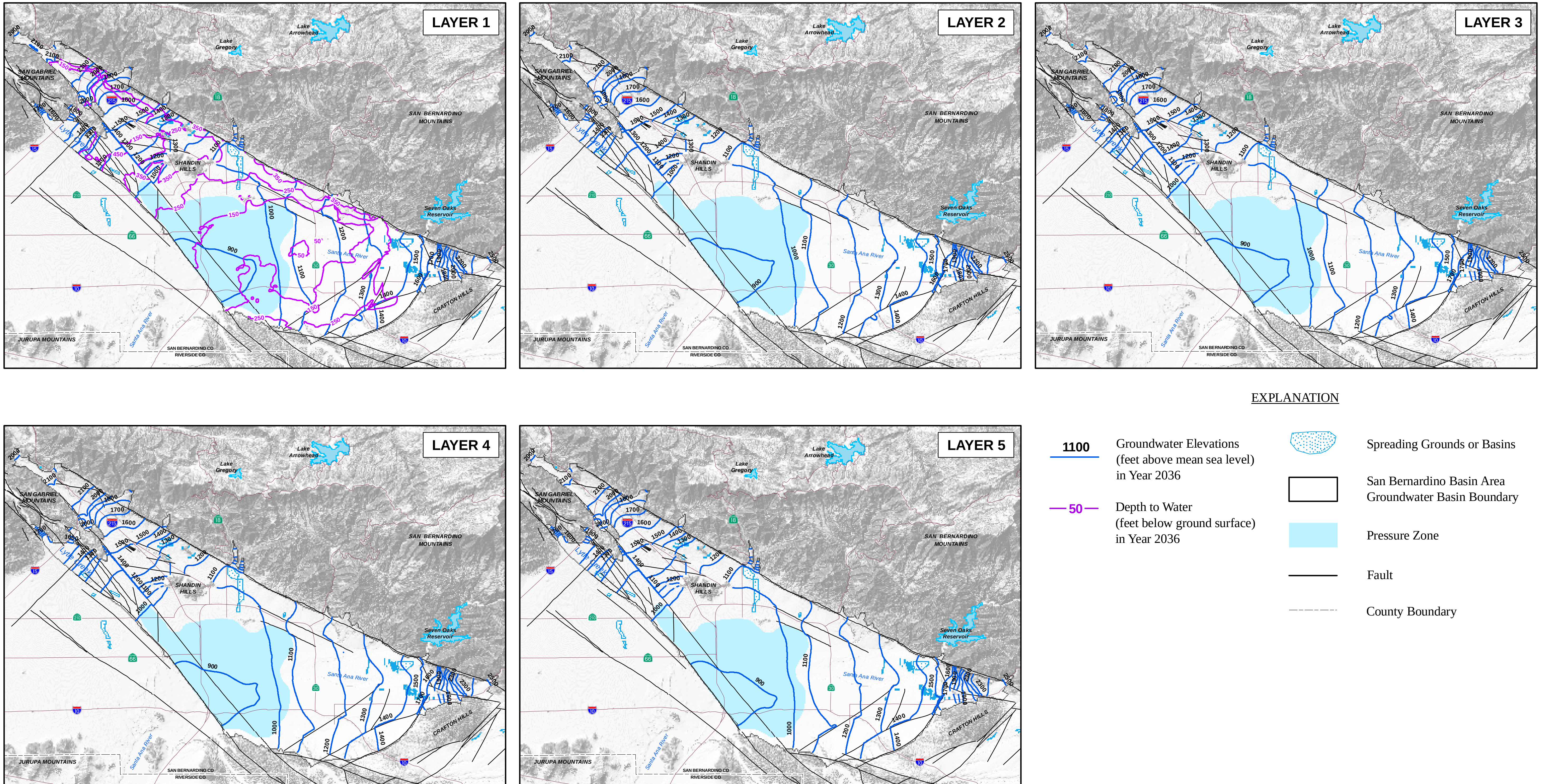
Figure 67

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_67_WL-2027_9-09.mxd



GROUNDWATER ELEVATIONS IN YEAR 2036 IRWMP BASELINE RUN 1

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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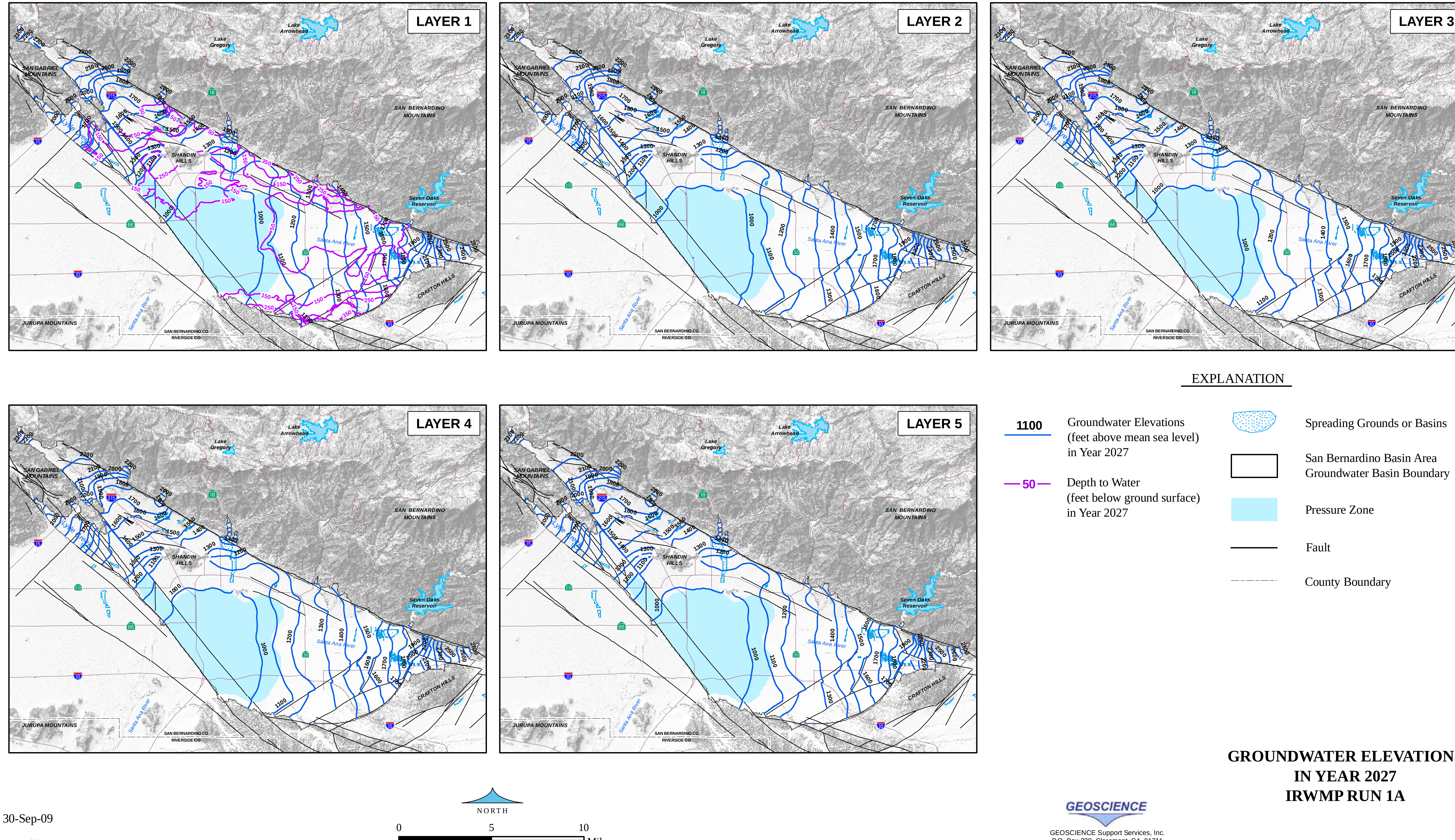
Figure 68

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_68_WL-2036_9-09.mxd



GROUNDWATER ELEVATIONS IN YEAR 2027 IRWMP RUN 1A

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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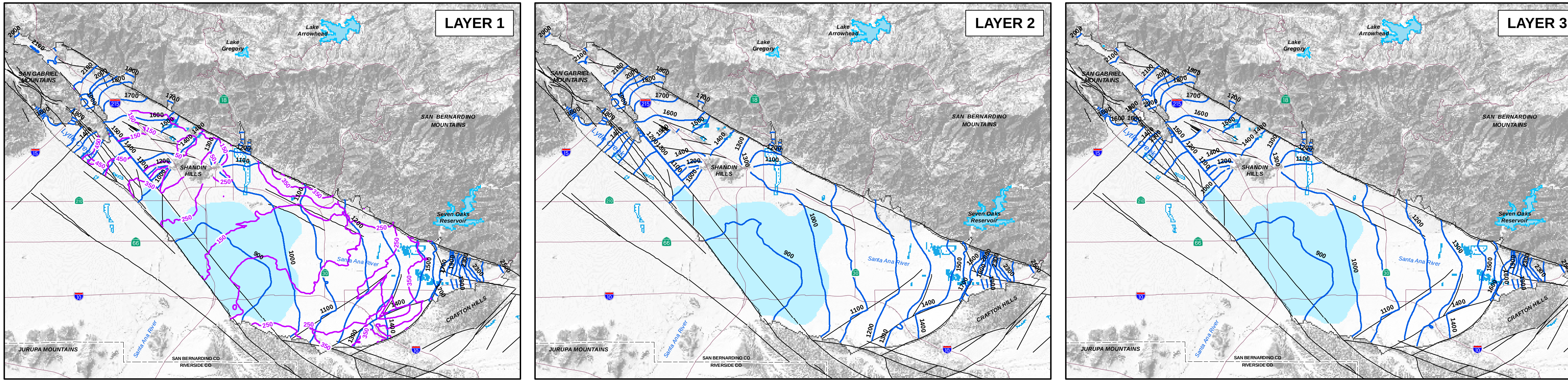
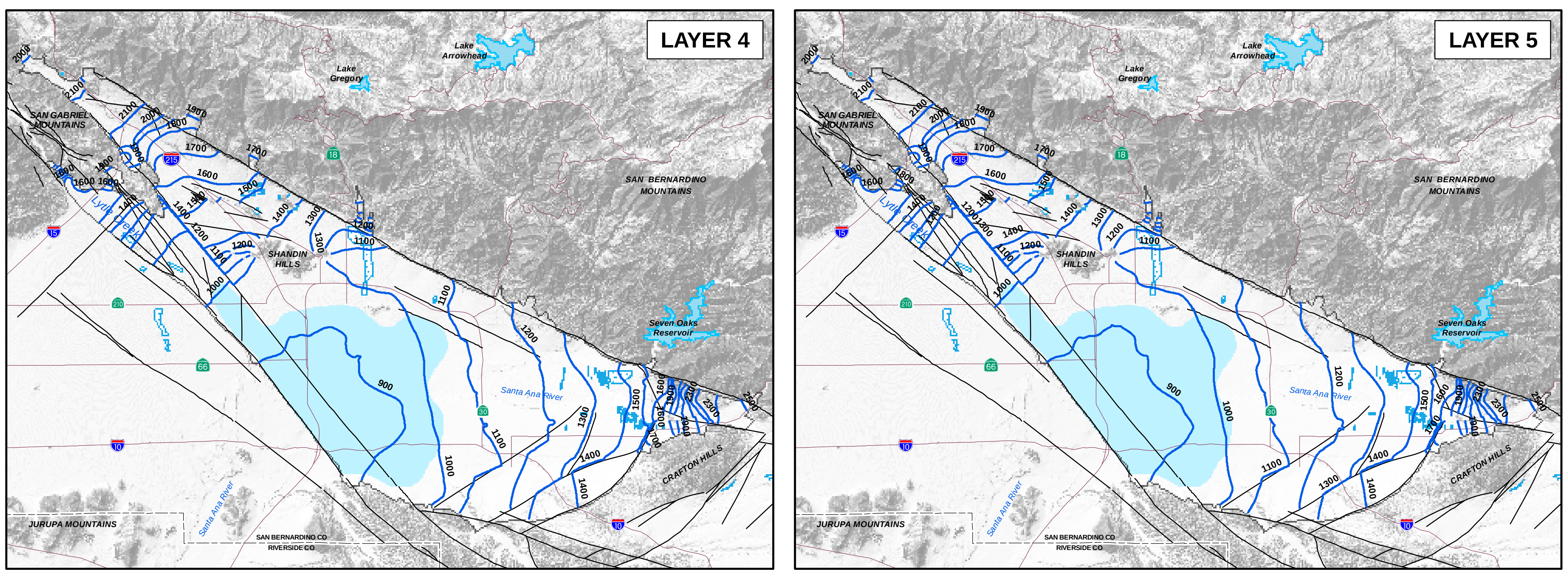
Figure 69

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT





EXPLANATION

1100 Groundwater Elevations (feet above mean sea level) in Year 2036

50 Depth to Water (feet below ground surface) in Year 2036

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

Fault

County Boundary

NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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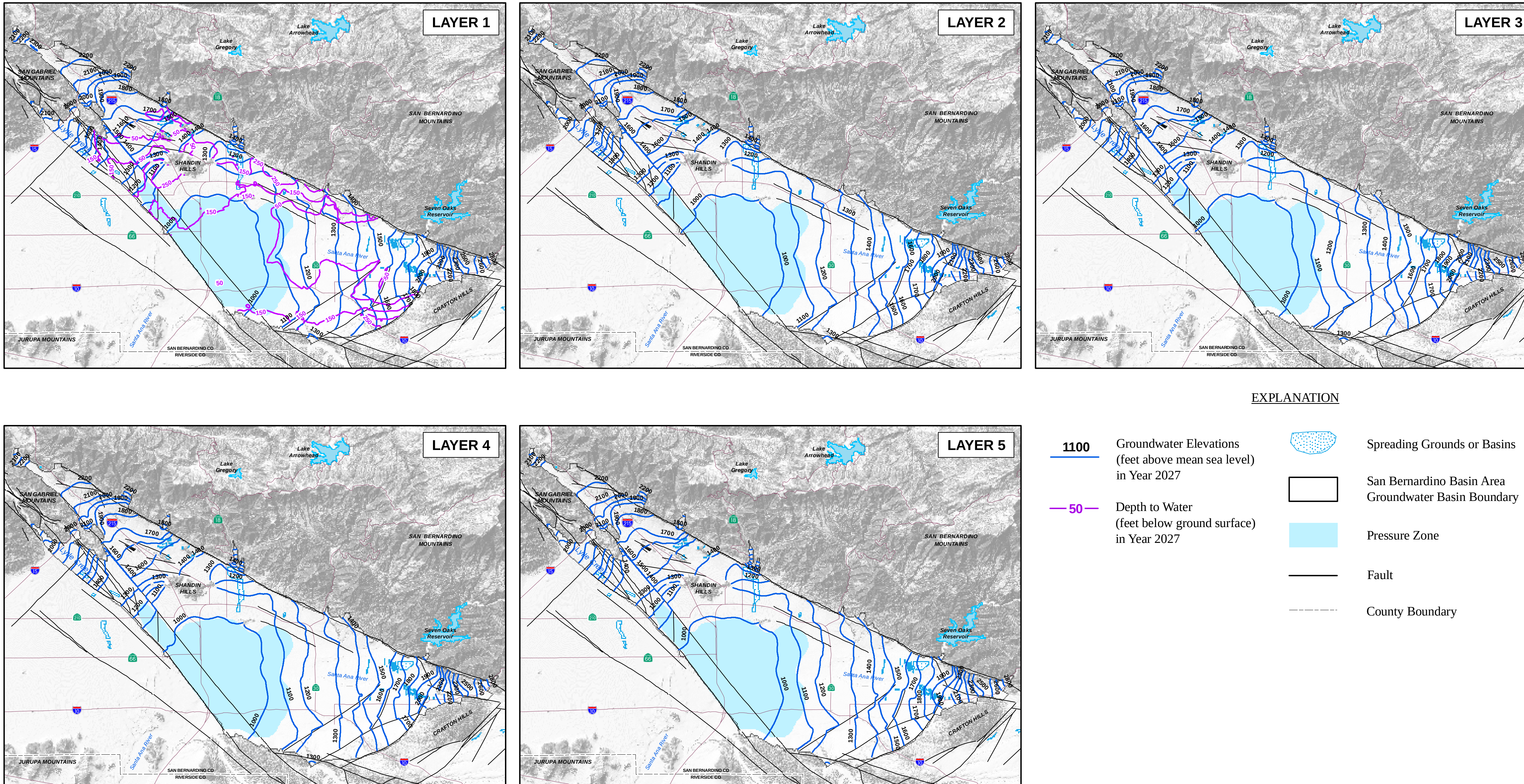
GROUNDWATER ELEVATIONS IN YEAR 2036 IRWMP RUN 1A

Figure 70

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_70_WL-2036_Run1A_9-09.mxd



GROUNDWATER ELEVATIONS IN YEAR 2027 IRWMP RUN 1B

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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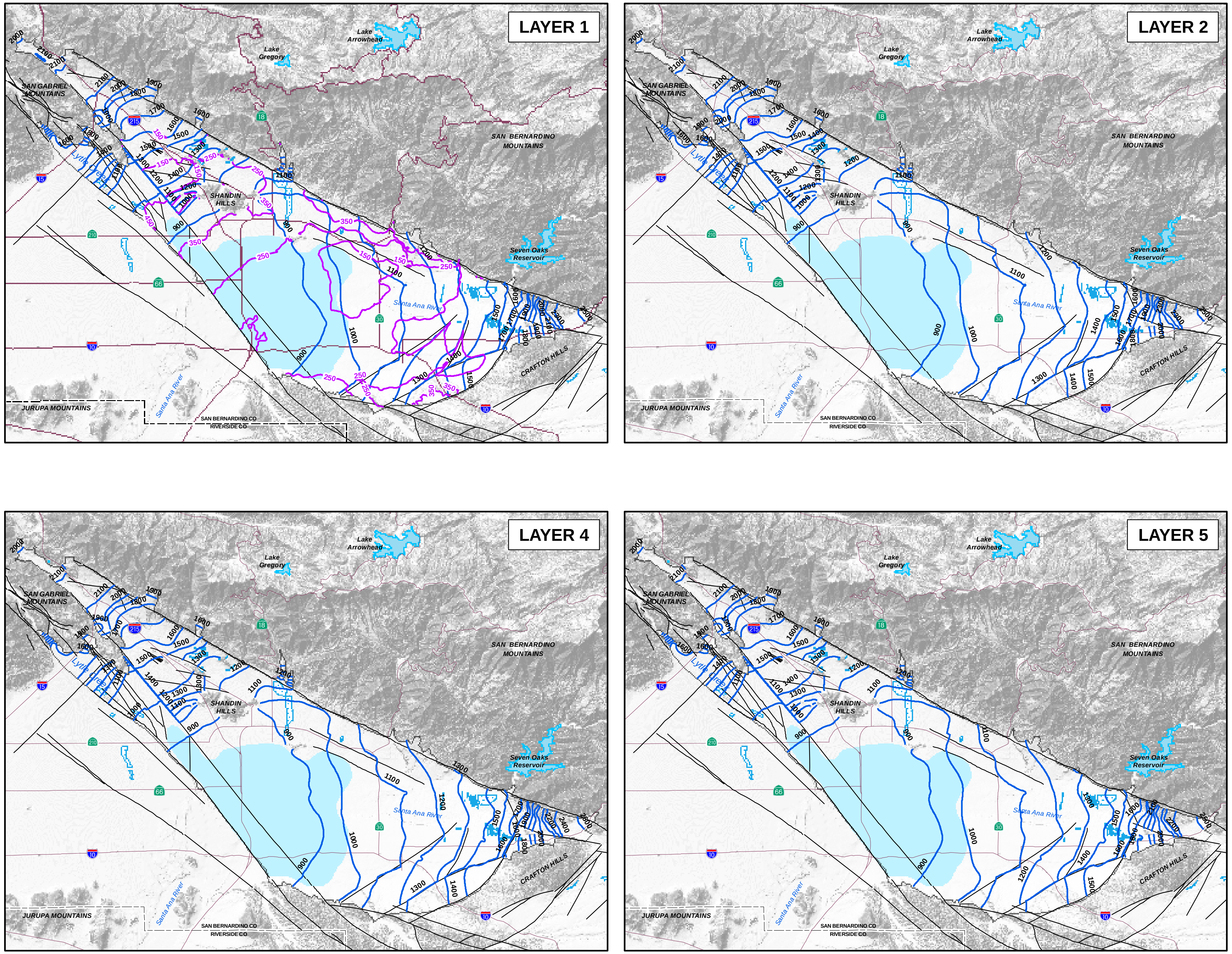
Figure 71

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



EXPLANATION

1100	Groundwater Elevations (feet above mean sea level) in Year 2036
50	Depth to Water (feet below ground surface) in Year 2036
	Spreading Grounds or Basins
	San Bernardino Basin Area Groundwater Basin Boundary
	Pressure Zone
	Fault
	County Boundary

NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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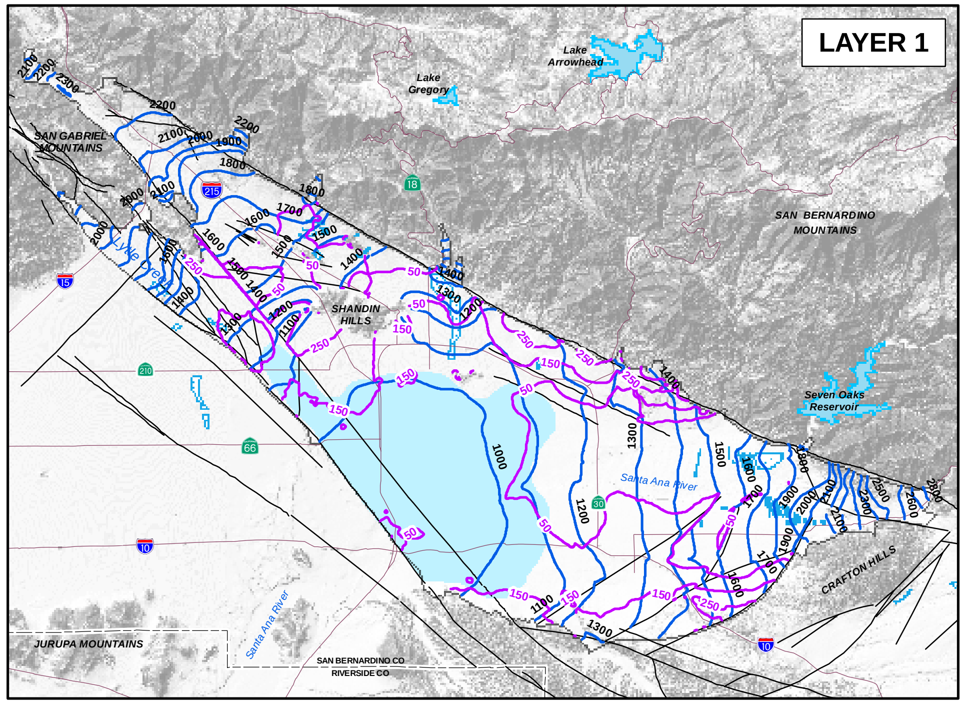
GROUNDWATER ELEVATIONS IN YEAR 2036 IRWMP RUN 1B

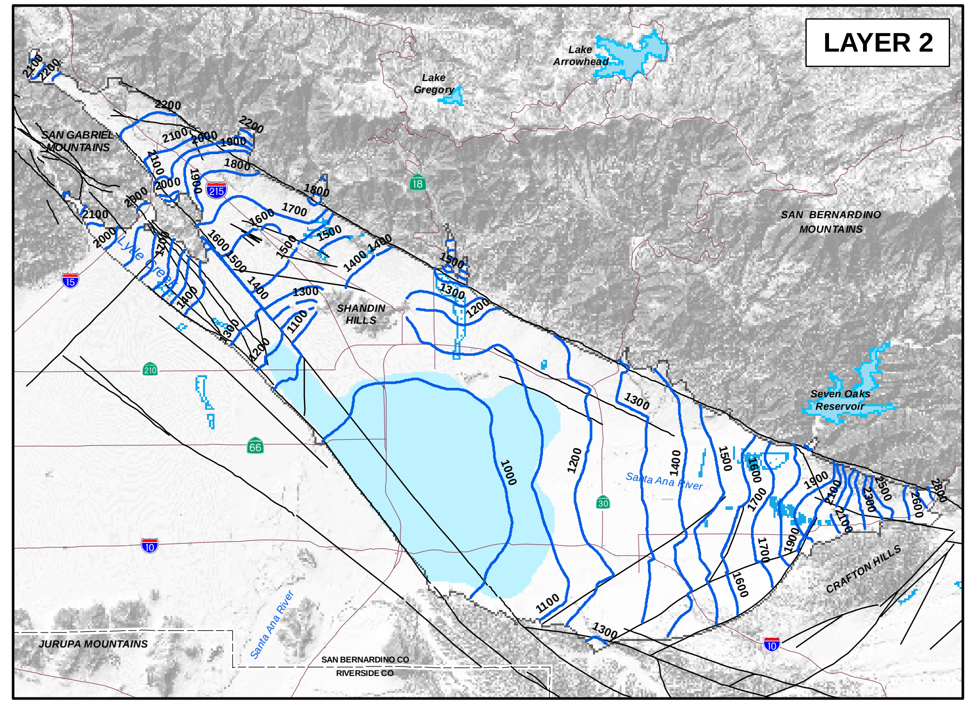
Figure 72

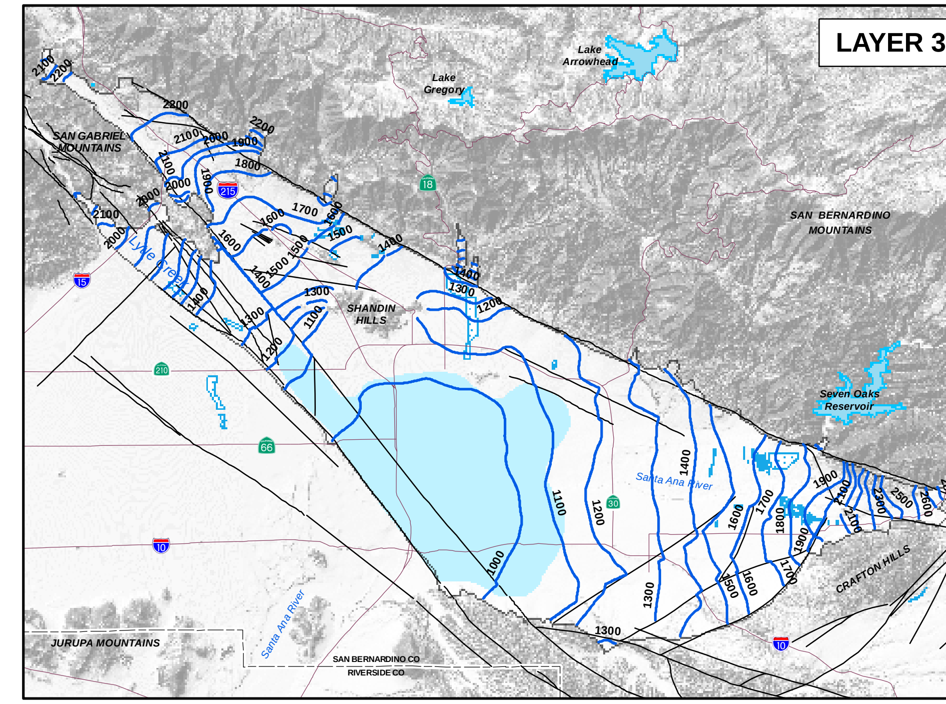
GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_72_WL-2036_Run1B_9-09.mxd

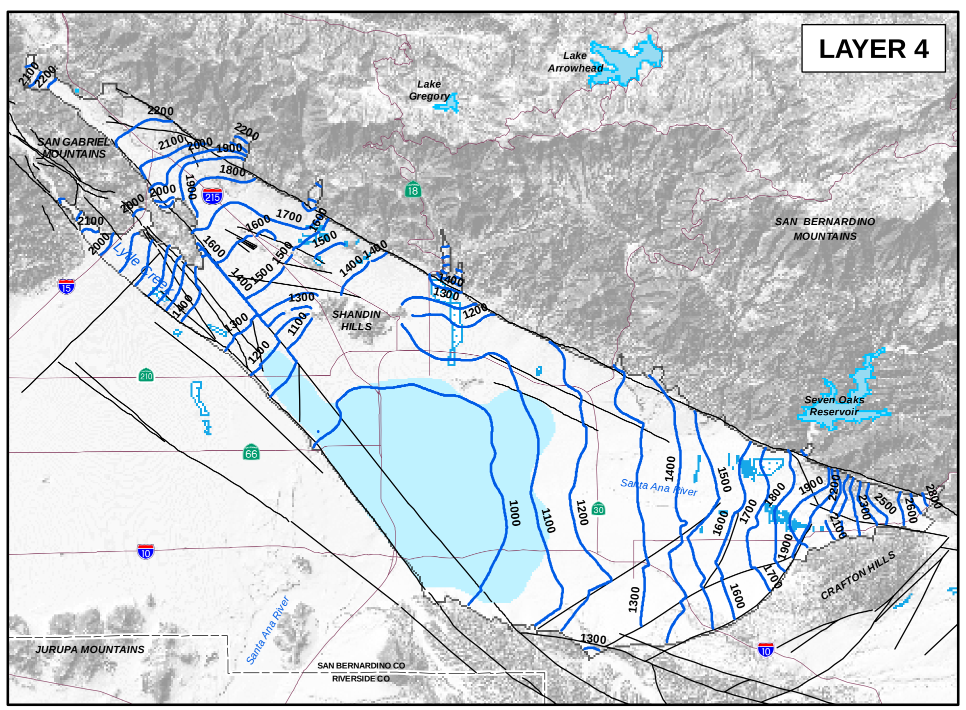
SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

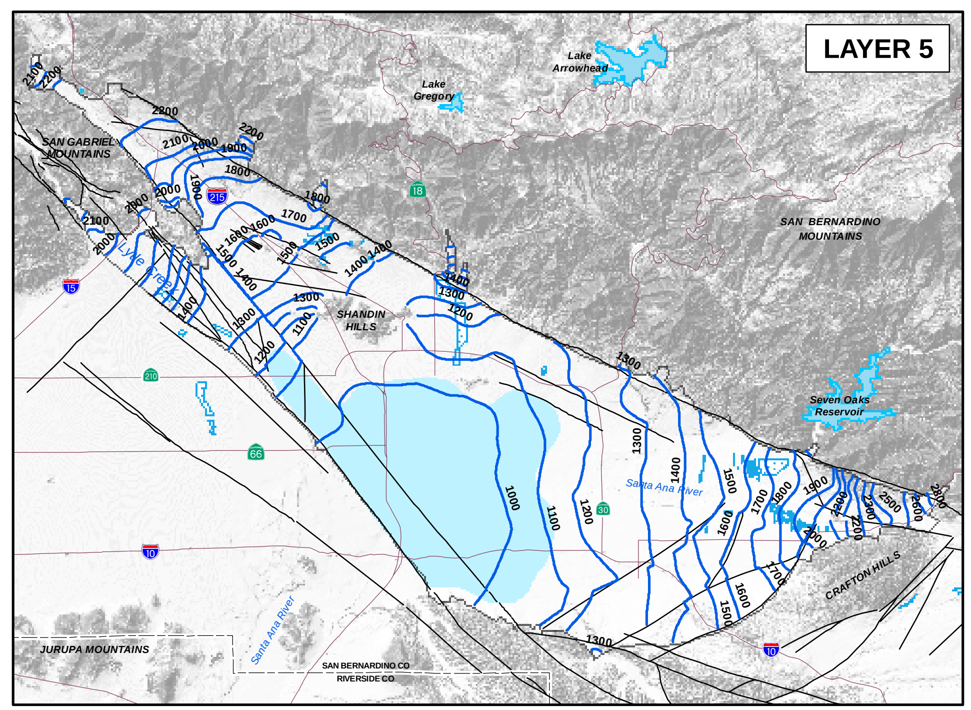
SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT











EXPLANATION

1100 — Groundwater Elevations (feet above mean sea level) in Year 2027

50 — Depth to Water (feet below ground surface) in Year 2027

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

Fault

County Boundary

NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983 Zone V, feet

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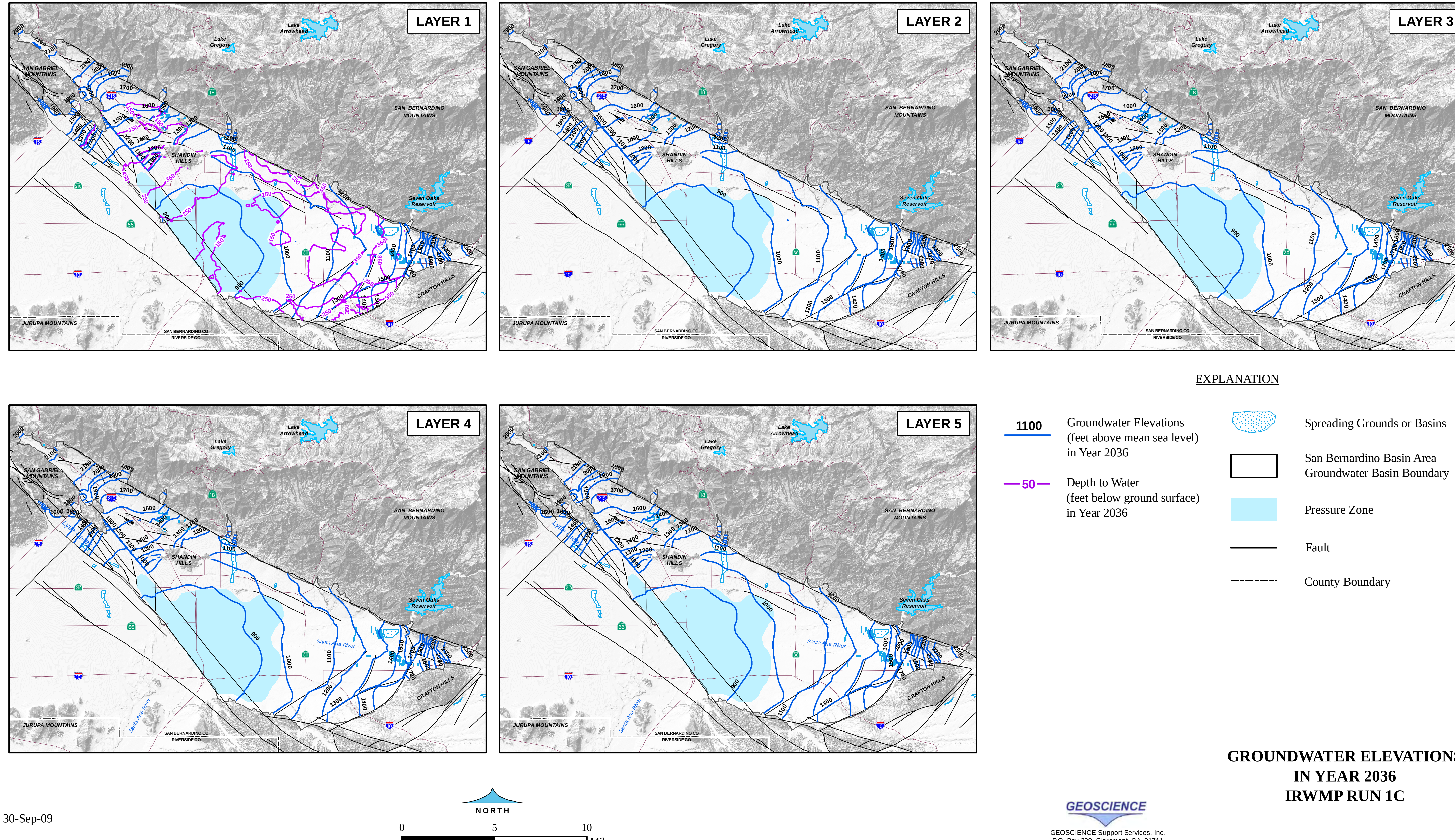
GROUNDWATER ELEVATIONS IN YEAR 2027 IRWMP RUN 1C

Figure 73

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_73_WL-2027_Run1C_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



GROUNDWATER ELEVATIONS IN YEAR 2036 IRWMP RUN 1C

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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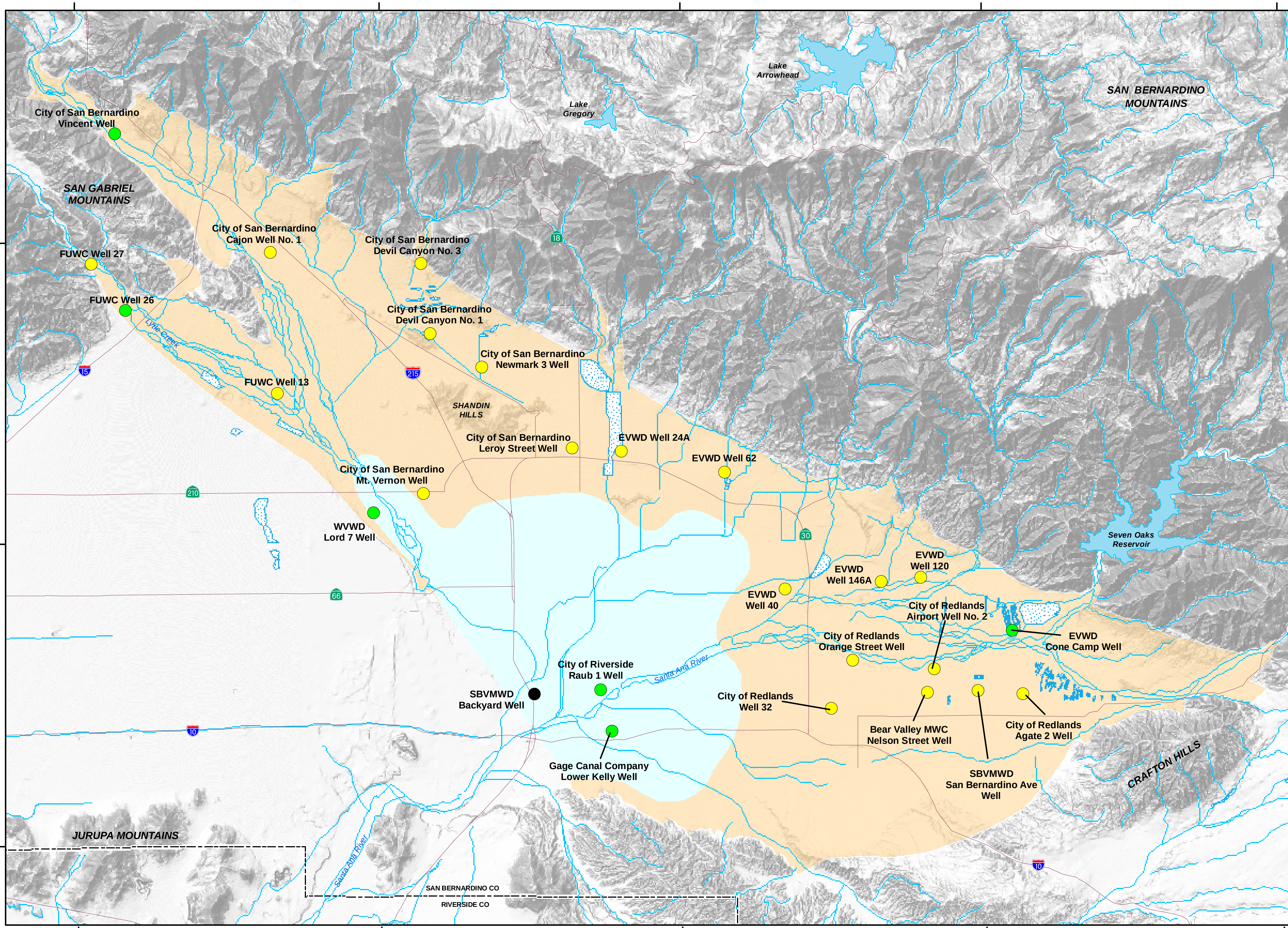
Figure 74

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_74_WL-2036_Run1C_9-09.mxd

IRWMP CONJUNCTIVE USE SCENARIOS LOCATIONS OF WELLS WITH HYDROGRAPHS



EXPLANATION

SBVMWD Backyard Well (black)	Riverside Agreement Well (1 Well)
City of Riverside Raub 1 Well (green)	Seven Oaks Accord Wells (6 Wells)
EVWD Well 40 (yellow)	Riverside Agreement and Seven Oaks Accord Wells (19 Wells)

Bear Valley MWC - Bear Valley Municipal Water Company
EVWD - East Valley Water District
FUWC - Fontana Union Water Company
SBVMWD - San Bernardino Valley Municipal Water District
WVWD - West Valley Water District

Spreading Grounds or Basins
San Bernardino Basin Area Groundwater Basin Boundary
Pressure Zone
County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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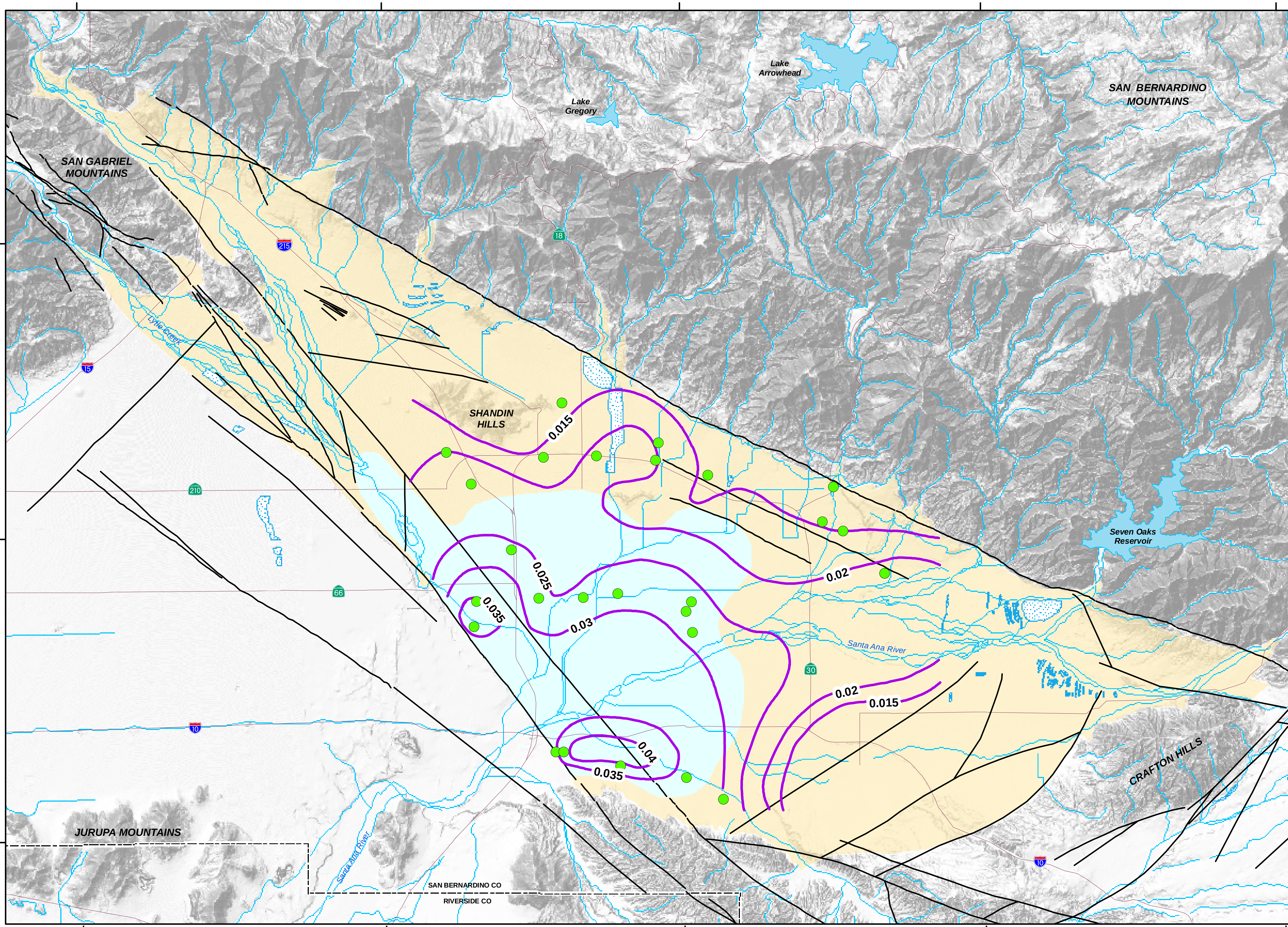
Figure 75

HISTORICAL LAND SUBSIDENCE IN THE SBBA 1944-1956



EXPLANATION

- 0.02 — Line of Average Annual Subsidence (1944-56), in hundredths of a foot (Miller & Singer, 1971)
- Benchmarks (1944-56) (Miller & Singer, 1971)
- San Bernardino Basin Area Groundwater Basin
- Spreading Grounds or Basins
- Pressure Zone
- Fault
- County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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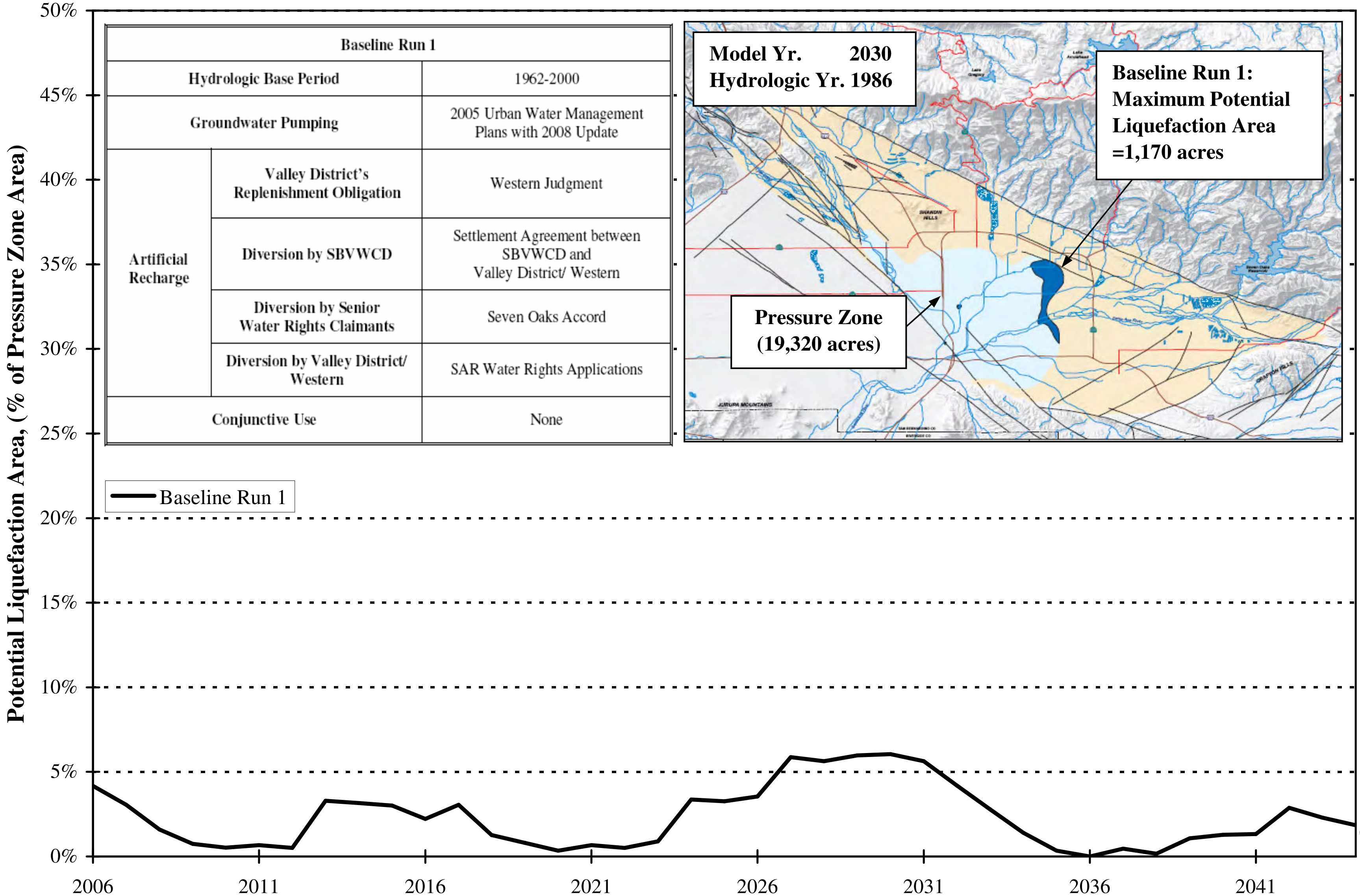
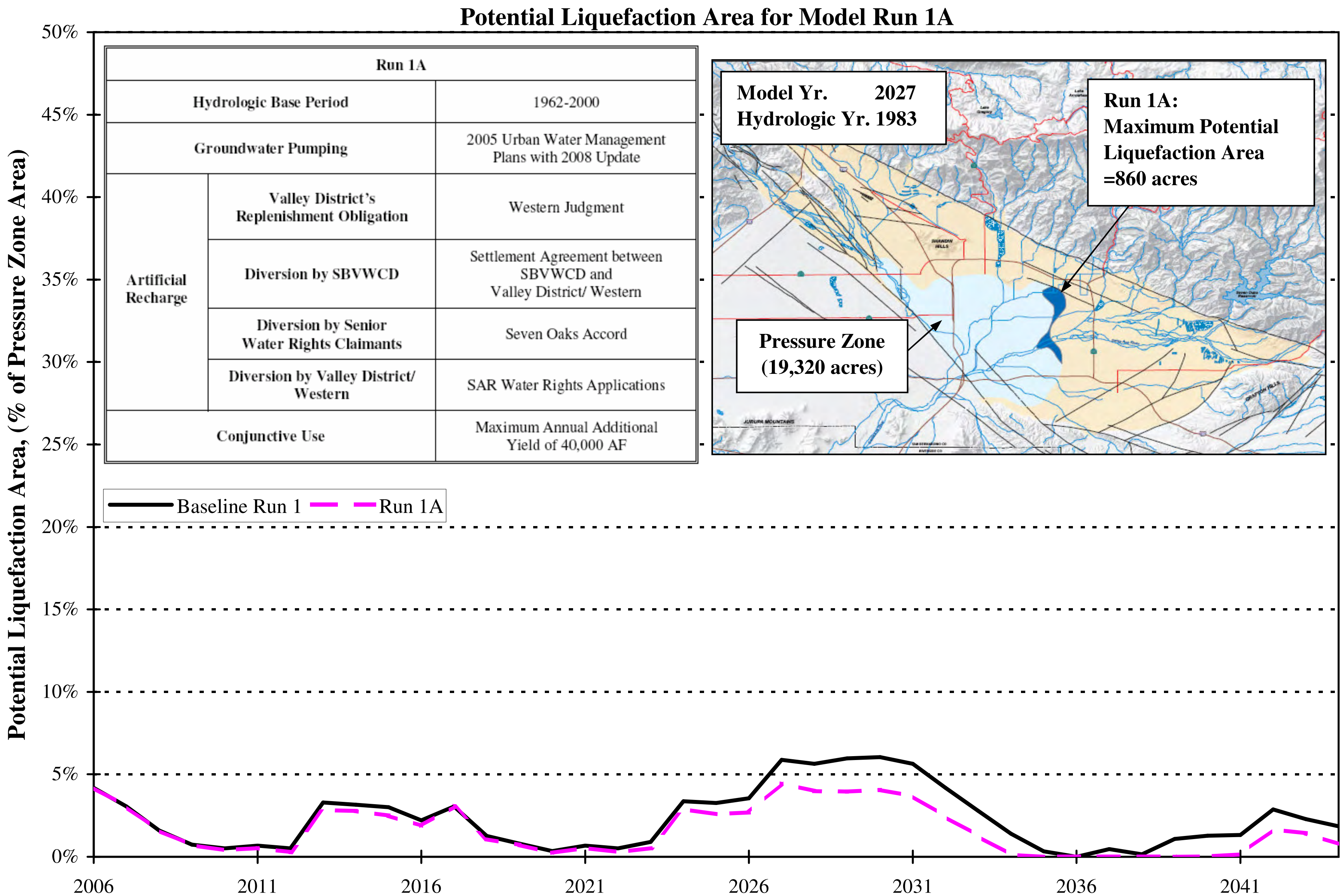
Figure 76

Potential Liquefaction Area for Model Baseline Run 1



Baseline Run 1		
Hydrologic Base Period		1962-2000
Groundwater Pumping		2005 Urban Water Management Plans with 2008 Update
Artificial Recharge	Valley District's Replenishment Obligation	Western Judgment
	Diversion by SBVWCD	Settlement Agreement between SBVWCD and Valley District/ Western
	Diversion by Senior Water Rights Claimants	Seven Oaks Accord
	Diversion by Valley District/ Western	SAR Water Rights Applications
Conjunctive Use		None

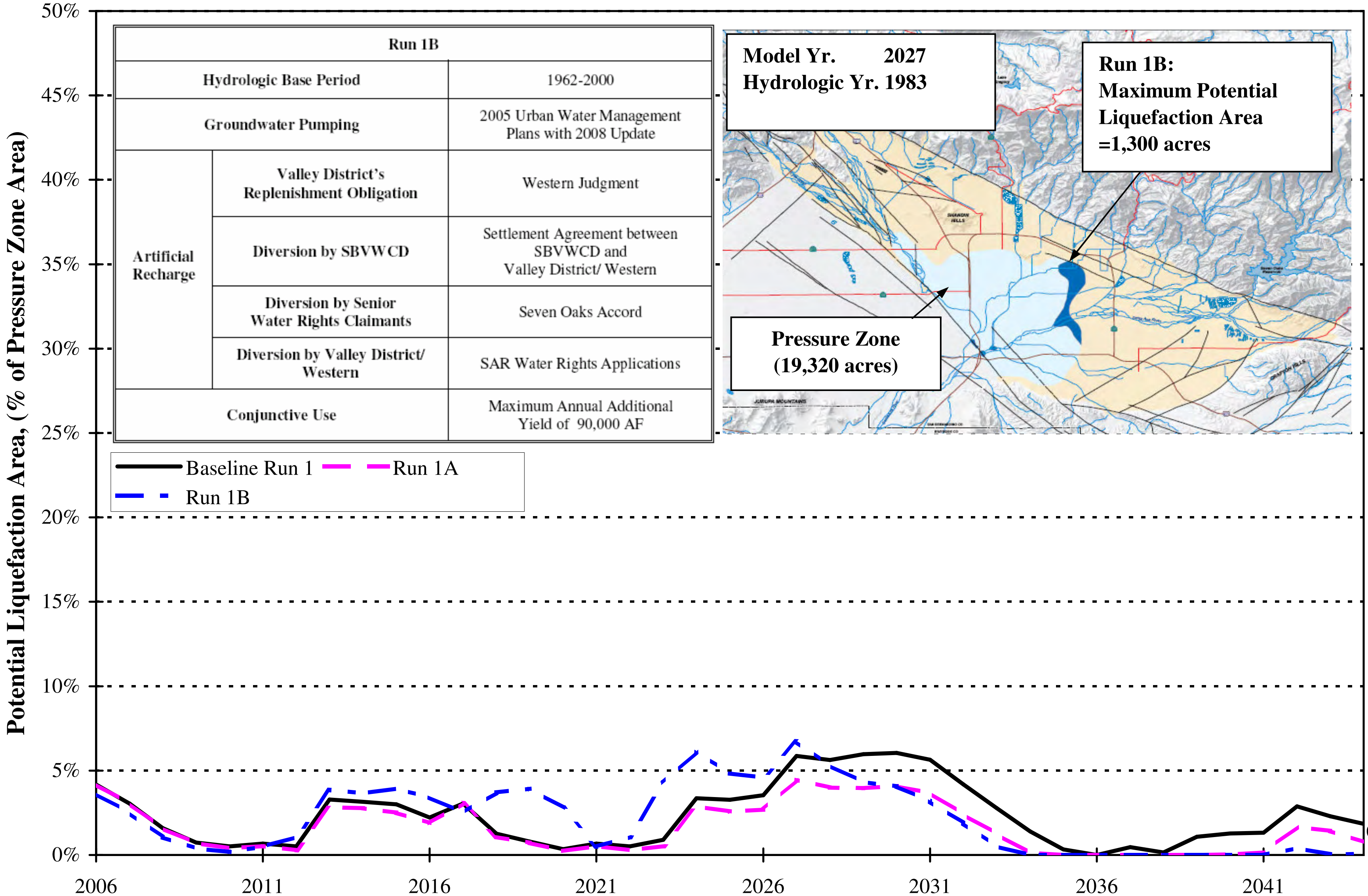
Figure 77



Run 1A		
Hydrologic Base Period		1962-2000
Groundwater Pumping		2005 Urban Water Management Plans with 2008 Update
Artificial Recharge	Valley District's Replenishment Obligation	Western Judgment
	Diversion by SBVWCD	Settlement Agreement between SBVWCD and Valley District/ Western
	Diversion by Senior Water Rights Claimants	Seven Oaks Accord
	Diversion by Valley District/ Western	SAR Water Rights Applications
Conjunctive Use		Maximum Annual Additional Yield of 40,000 AF

Figure 78

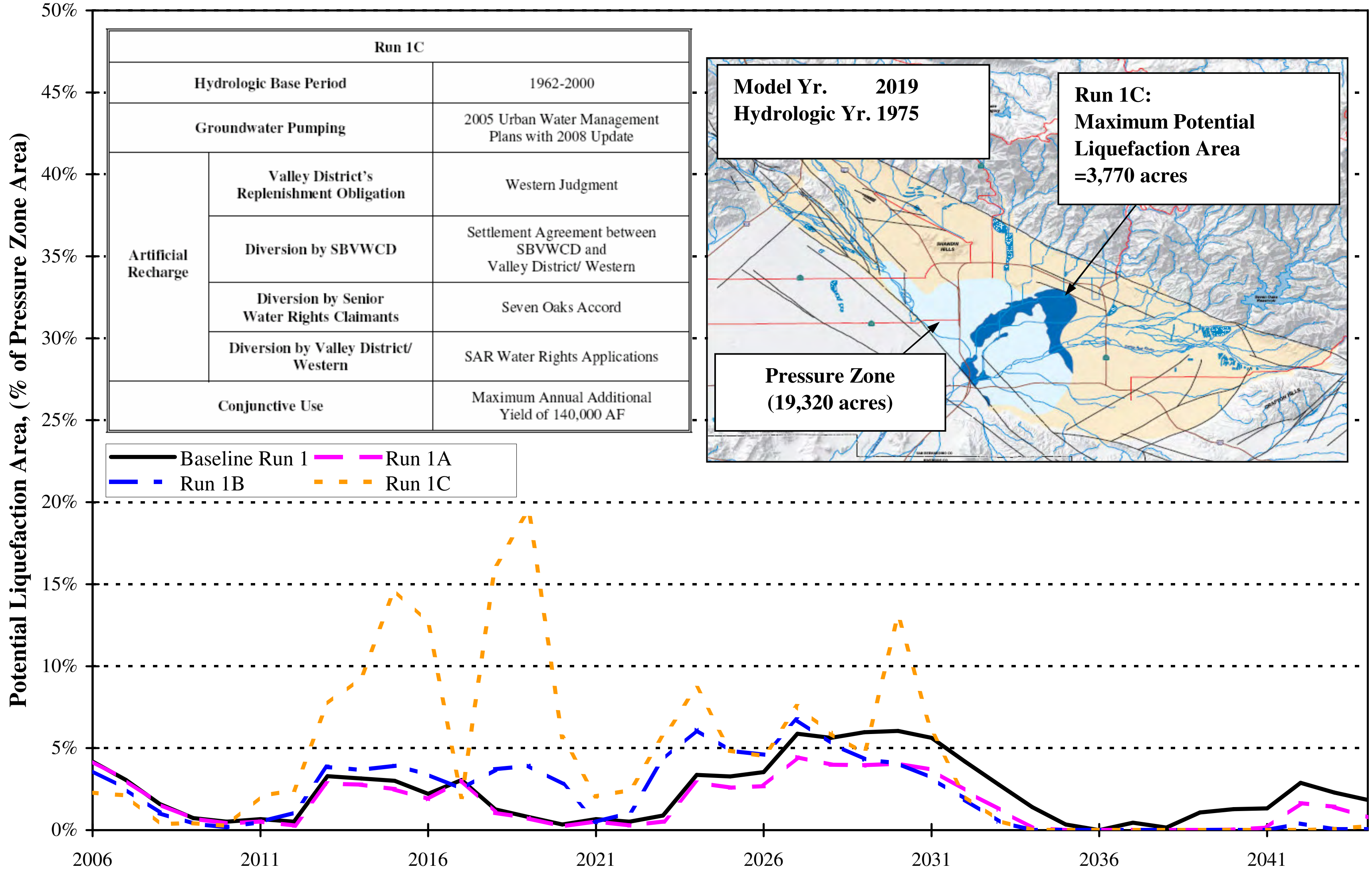
Potential Liquefaction Area for Model Run 1B



Run 1B		
Hydrologic Base Period		1962-2000
Groundwater Pumping		2005 Urban Water Management Plans with 2008 Update
Artificial Recharge	Valley District's Replenishment Obligation	Western Judgment
	Diversion by SBVWCD	Settlement Agreement between SBVWCD and Valley District/ Western
	Diversion by Senior Water Rights Claimants	Seven Oaks Accord
	Diversion by Valley District/ Western	SAR Water Rights Applications
Conjunctive Use		Maximum Annual Additional Yield of 90,000 AF

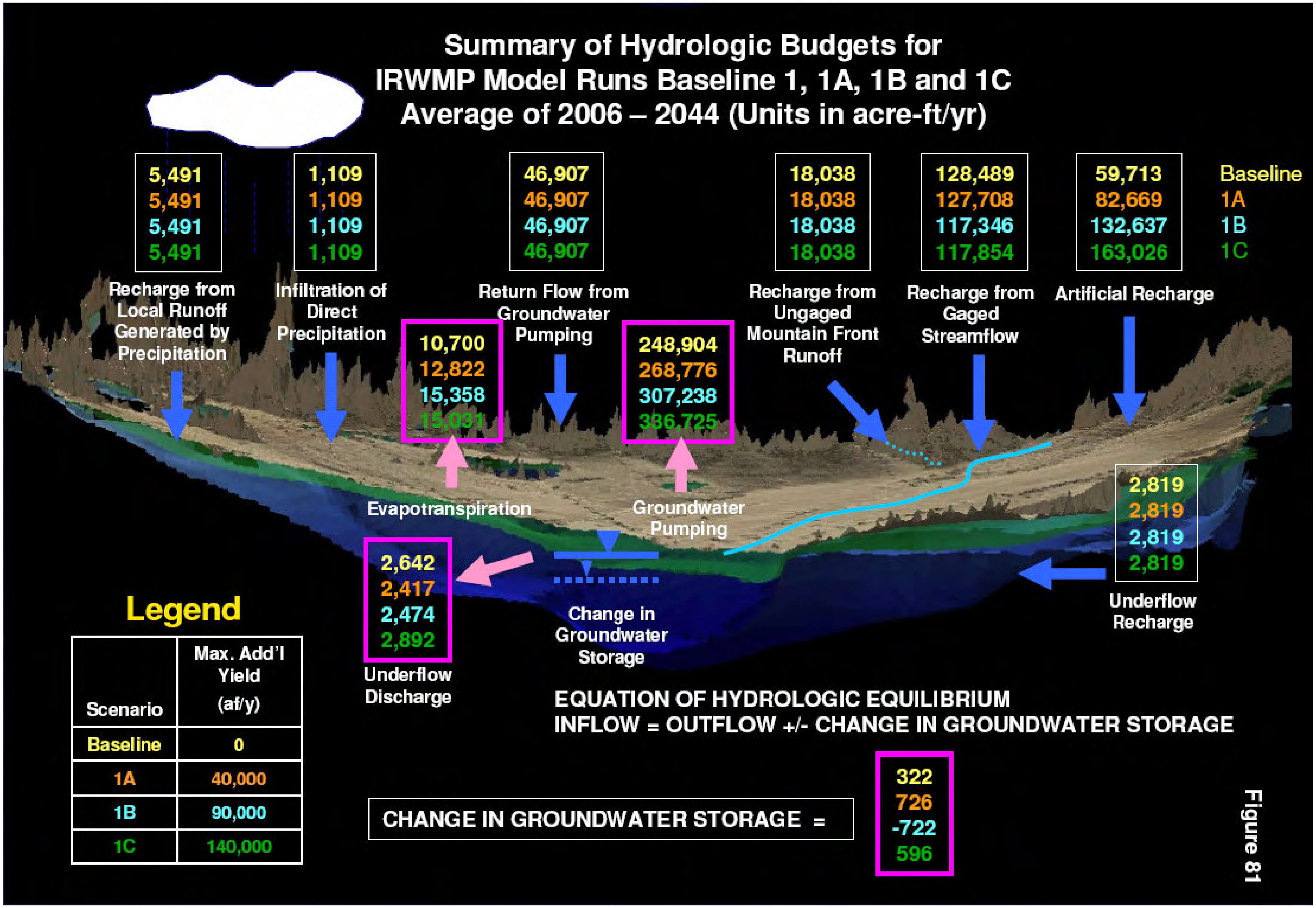
Figure 79

Potential Liquefaction Area for Model Run 1C



Run 1C		
Hydrologic Base Period		1962-2000
Groundwater Pumping		2005 Urban Water Management Plans with 2008 Update
Artificial Recharge	Valley District's Replenishment Obligation	Western Judgment
	Diversion by SBVWCD	Settlement Agreement between SBVWCD and Valley District/ Western
	Diversion by Senior Water Rights Claimants	Seven Oaks Accord
	Diversion by Valley District/ Western	SAR Water Rights Applications
Conjunctive Use		Maximum Annual Additional Yield of 140,000 AF

Figure 80


Summary of Hydrologic Budgets for
IRWMP Model Runs Baseline 1, 1A, 1B and 1C
Average of 2006 – 2044 (Units in acre-ft/yr)
5,491 5,491 5,491 5,491
Recharge from Local Runoff Generated by Precipitation
1,109 1,109 1,109 1,109
Infiltration of Direct Precipitation
46,907 46,907 46,907 46,907
Return Flow from Groundwater Pumping
18,038 18,038 18,038 18,038
Recharge from Ungaged Mountain Front Runoff
128,489 127,708 117,346 117,854
Recharge from Gaged Streamflow
59,713 82,669 132,637 163,026
Artificial Recharge
Baseline
1A
1B
1C
10,700 12,822 15,358 15,031
Evapotranspiration
248,904 268,776 307,238 336,725
Groundwater Pumping
2,819 2,819 2,819 2,819
Underflow Recharge
2,642 2,417 2,474 2,892
Underflow Discharge
Change in Groundwater Storage
Legend
Scenario | Max. Add'l Yield (af/y)
Baseline | 0
1A | 40,000
1B | 90,000
1C | 140,000
EQUATION OF HYDROLOGIC EQUILIBRIUM
INFLOW = OUTFLOW +/- CHANGE IN GROUNDWATER STORAGE
CHANGE IN GROUNDWATER STORAGE =
322 726 -722 596
Figure 81

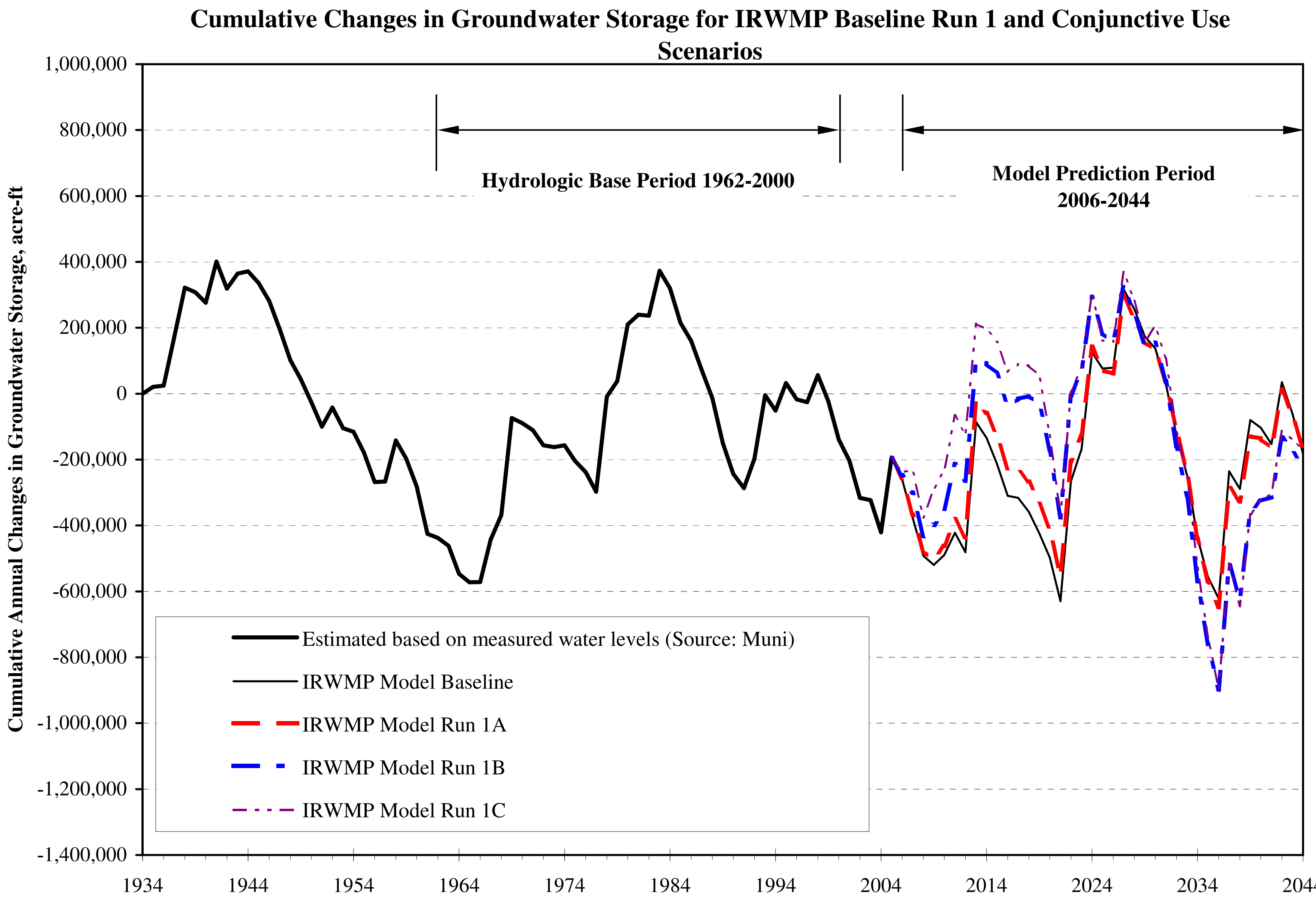

Cumulative Changes in Groundwater Storage for IRWMP Baseline Run 1 and Conjunctive Use Scenarios
Cumulative Annual Changes in Groundwater Storage, acre-ft
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
-400,000
-600,000
-800,000
-1,000,000
-1,200,000
-1,400,000
1934
1944
1954
1964
1974
1984
1994
2004
2014
2024
2034
2044
Hydrologic Base Period 1962-2000
Model Prediction Period 2006-2044
Estimated based on measured water levels (Source: Muni)
IRWMP Model Baseline
IRWMP Model Run 1A
IRWMP Model Run 1B
IRWMP Model Run 1C

Figure 82

Cumulative Changes in Groundwater Storage for Model Sensitivity to Loss of SWP Supply Runs

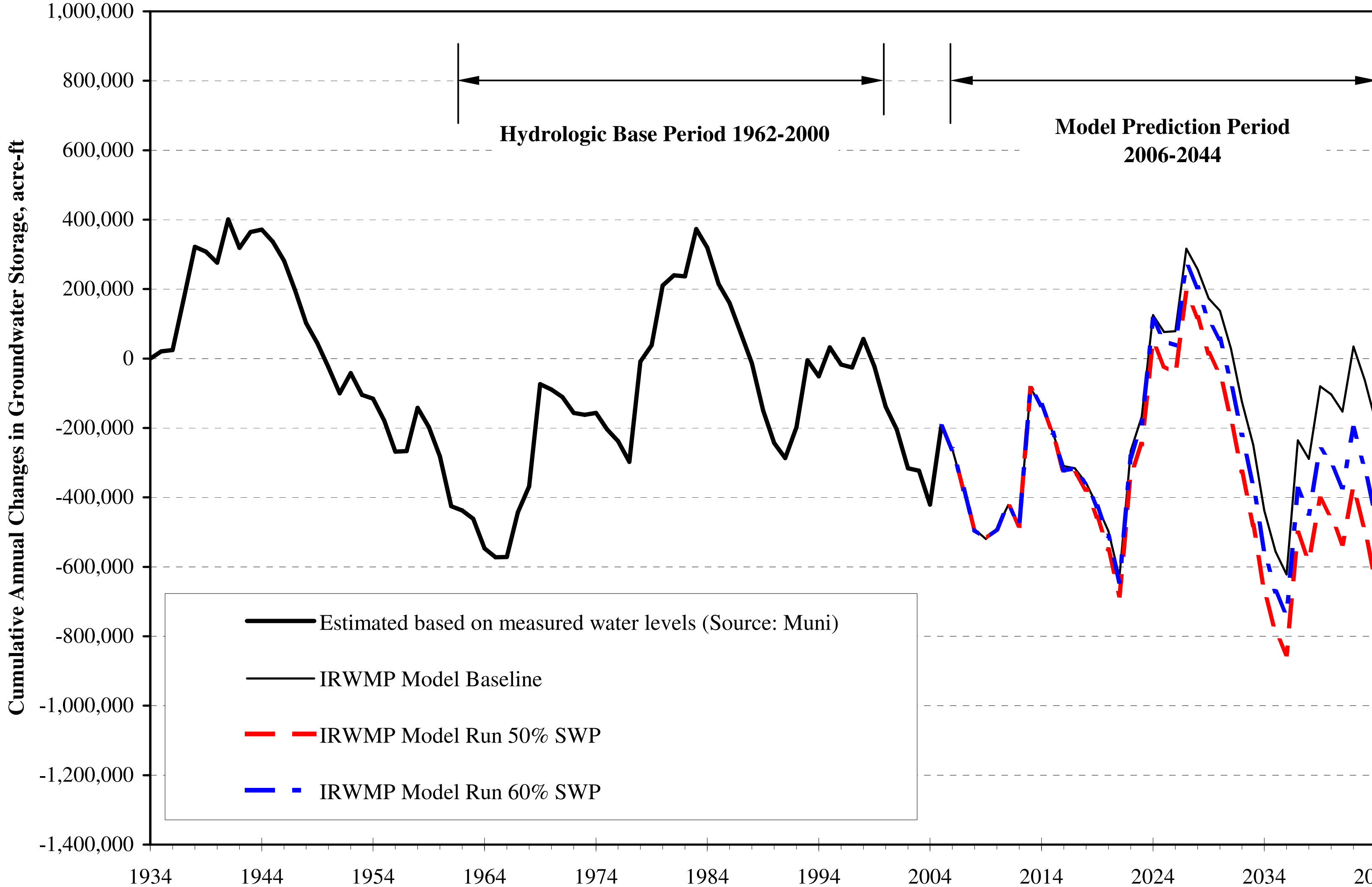


Figure 83

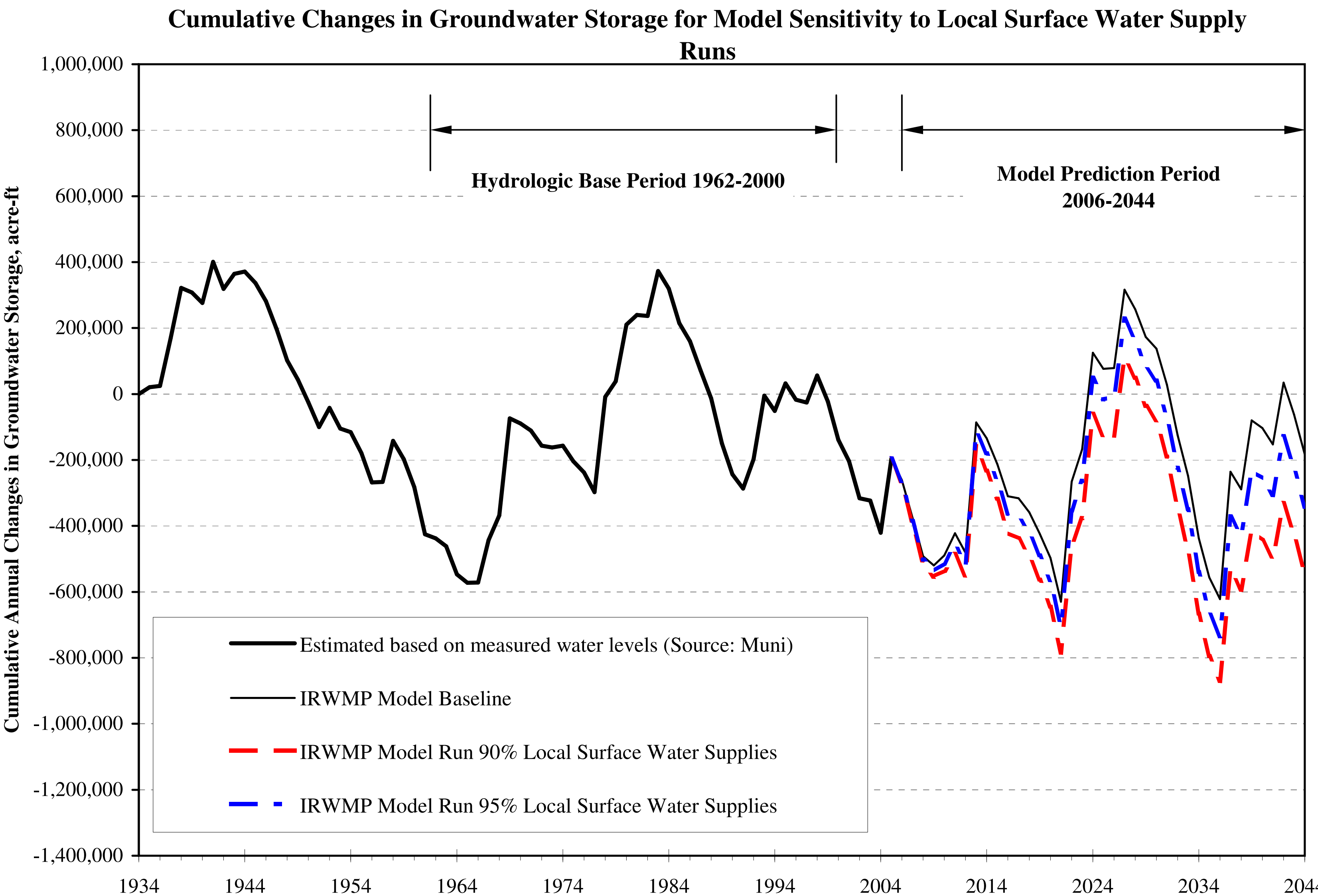
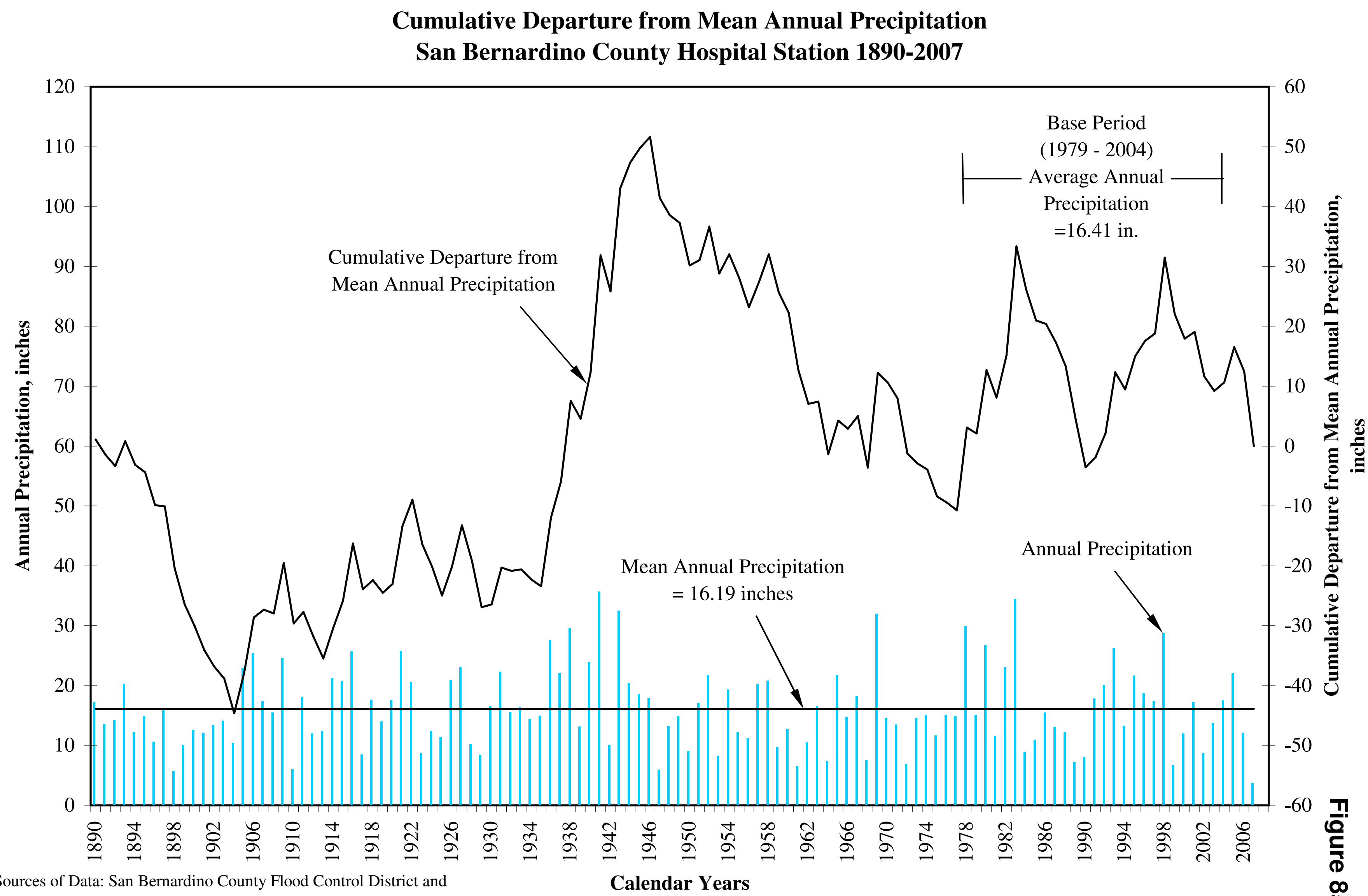
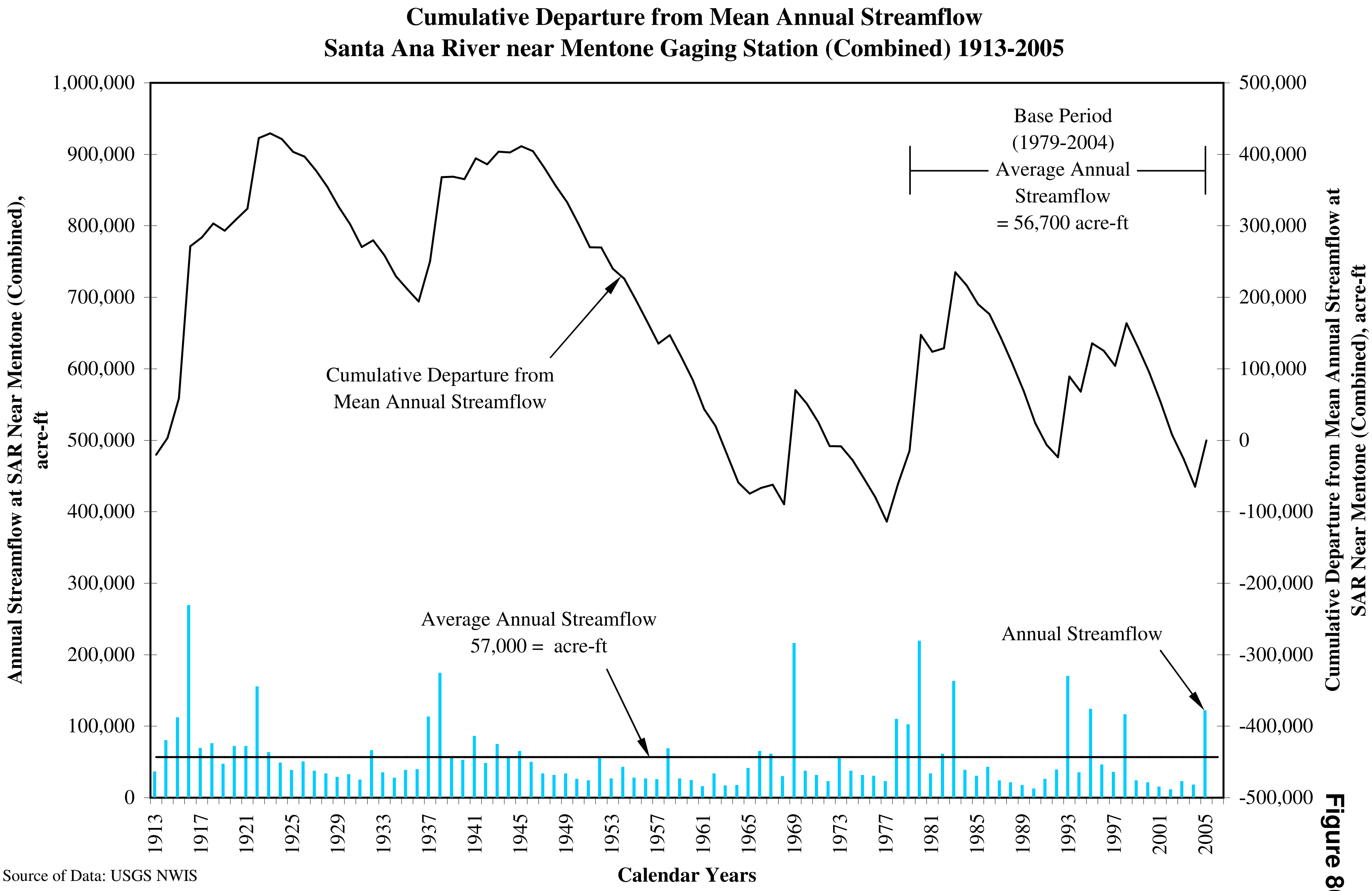

Cumulative Changes in Groundwater Storage for Model Sensitivity to Local Surface Water Supply Runs
Cumulative Annual Changes in Groundwater Storage, acre-ft
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
-400,000
-600,000
-800,000
-1,000,000
-1,200,000
-1,400,000
1934
1944
1954
1964
1974
1984
1994
2004
2014
2024
2034
2044
Hydrologic Base Period 1962-2000
Model Prediction Period 2006-2044
Estimated based on measured water levels (Source: Muni)
IRWMP Model Baseline
IRWMP Model Run 90% Local Surface Water Supplies
IRWMP Model Run 95% Local Surface Water Supplies

Figure 84



Sources of Data: San Bernardino County Flood Control District and Santa Ana River Watermaster Annual Reports

Figure 85



Source of Data: USGS NWIS

Figure 86

Groundwater Pumping for the Updated Baseline Run (Run 12)

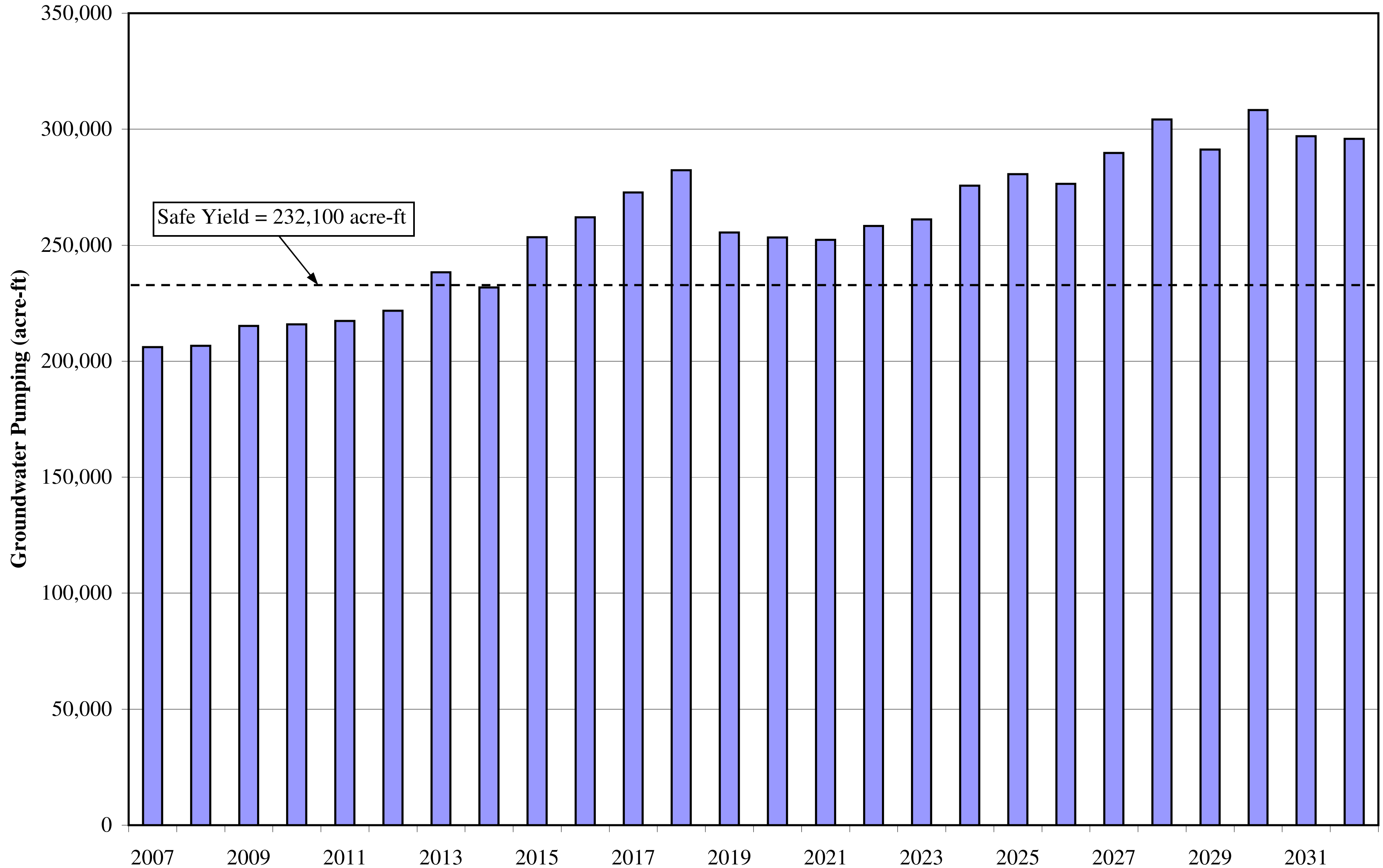


Figure 87

Artificial Recharge for the Updated Baseline Run (Run 12)

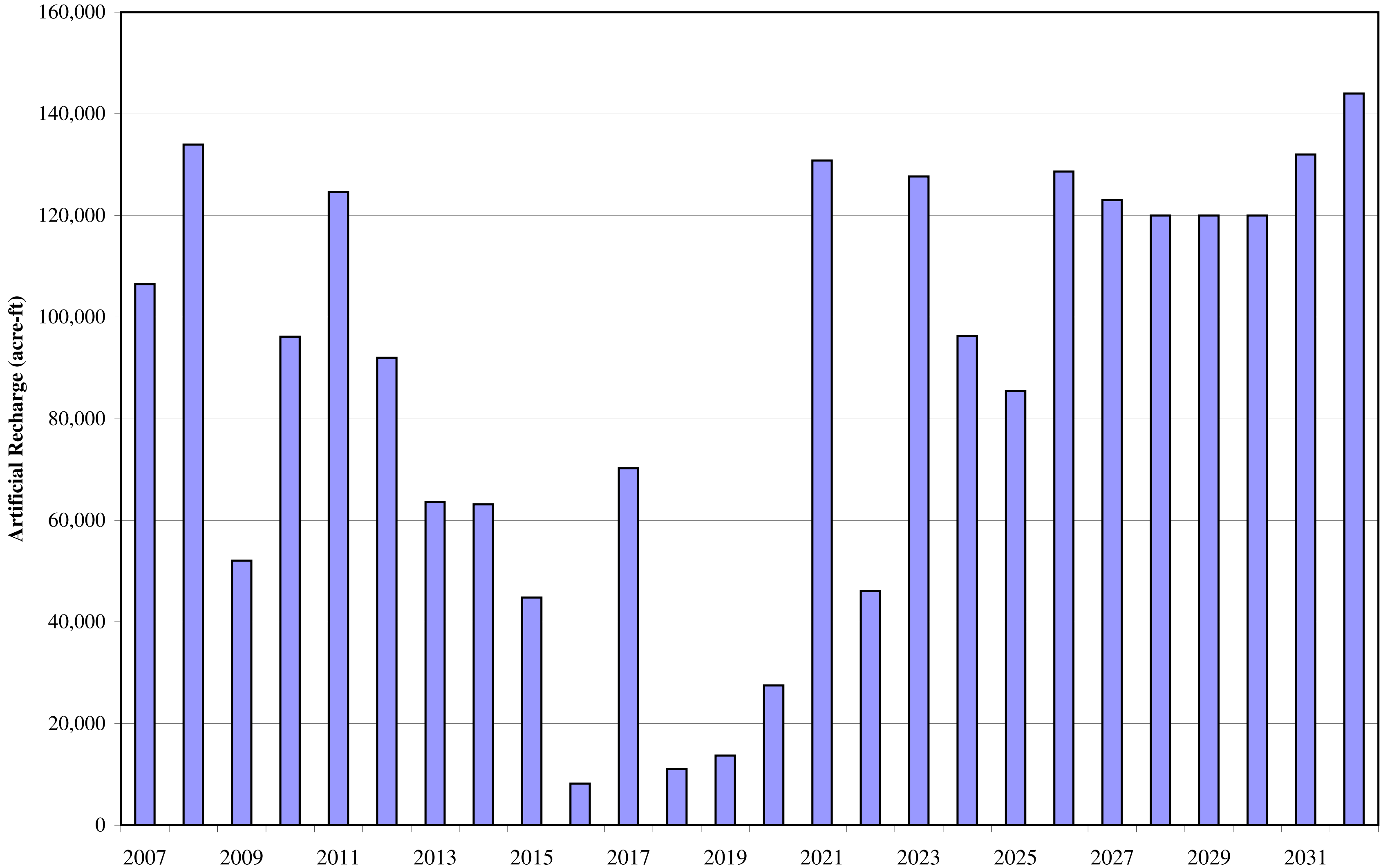
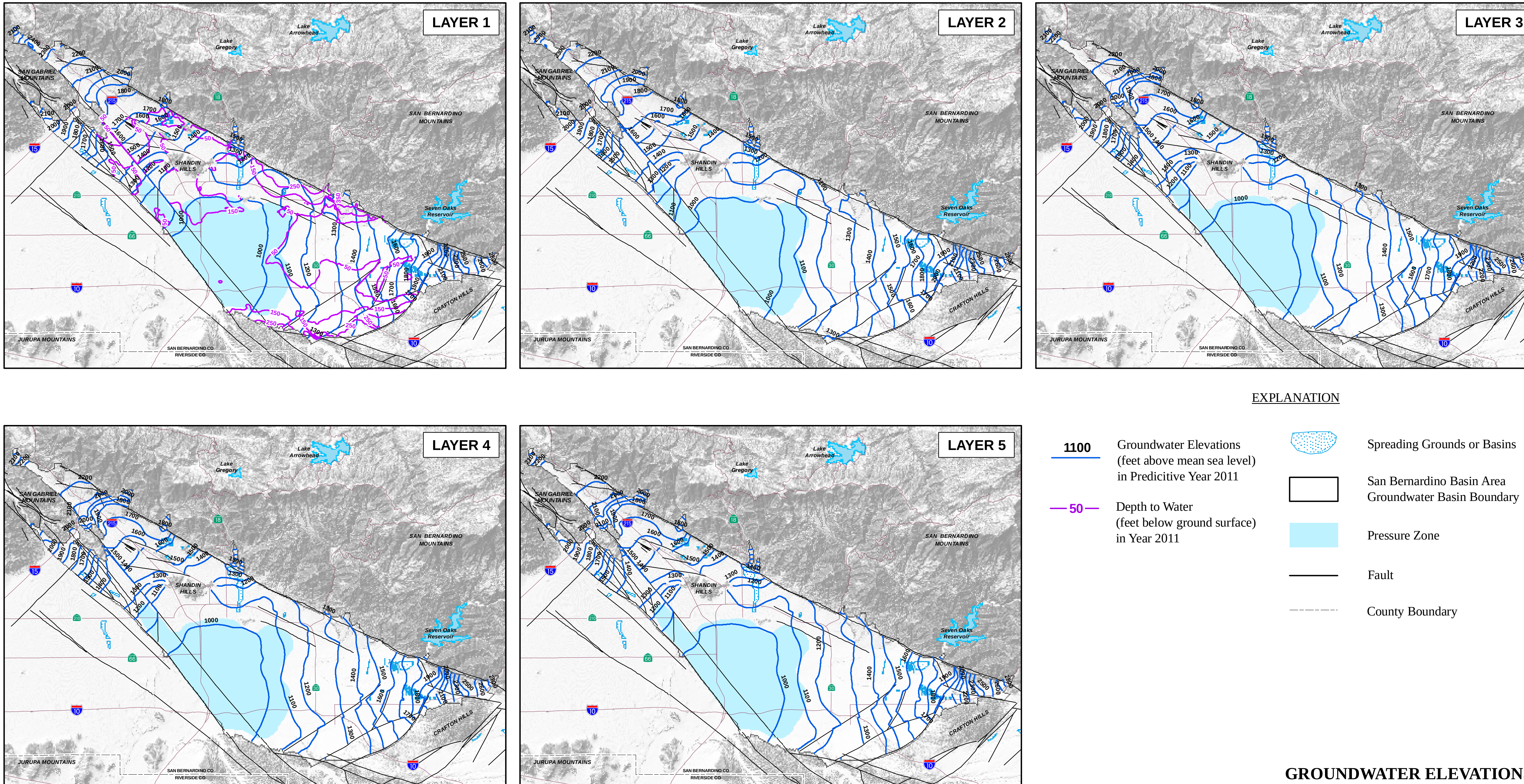


Figure 88



GROUNDWATER ELEVATIONS FOR UPDATED BASELINE PREDICTIVE YEAR 2011 MODEL LAYERS 1 THROUGH 5

NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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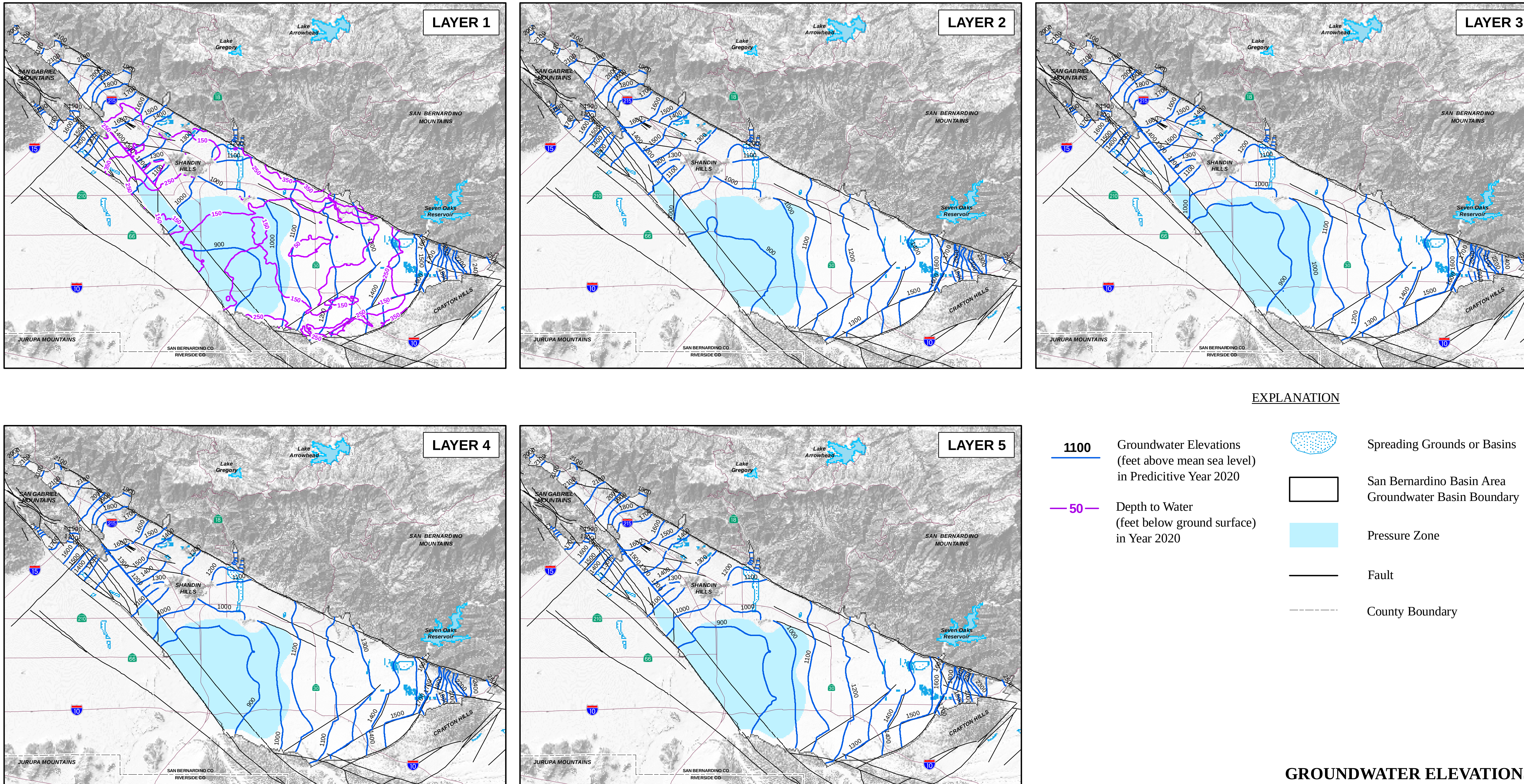
Figure 89

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_89_WL_updated_baseline_2011_9-09.mxd



GROUNDWATER ELEVATIONS FOR UPDATED BASELINE PREDICTIVE YEAR 2020 MODEL LAYERS 1 THROUGH 5

NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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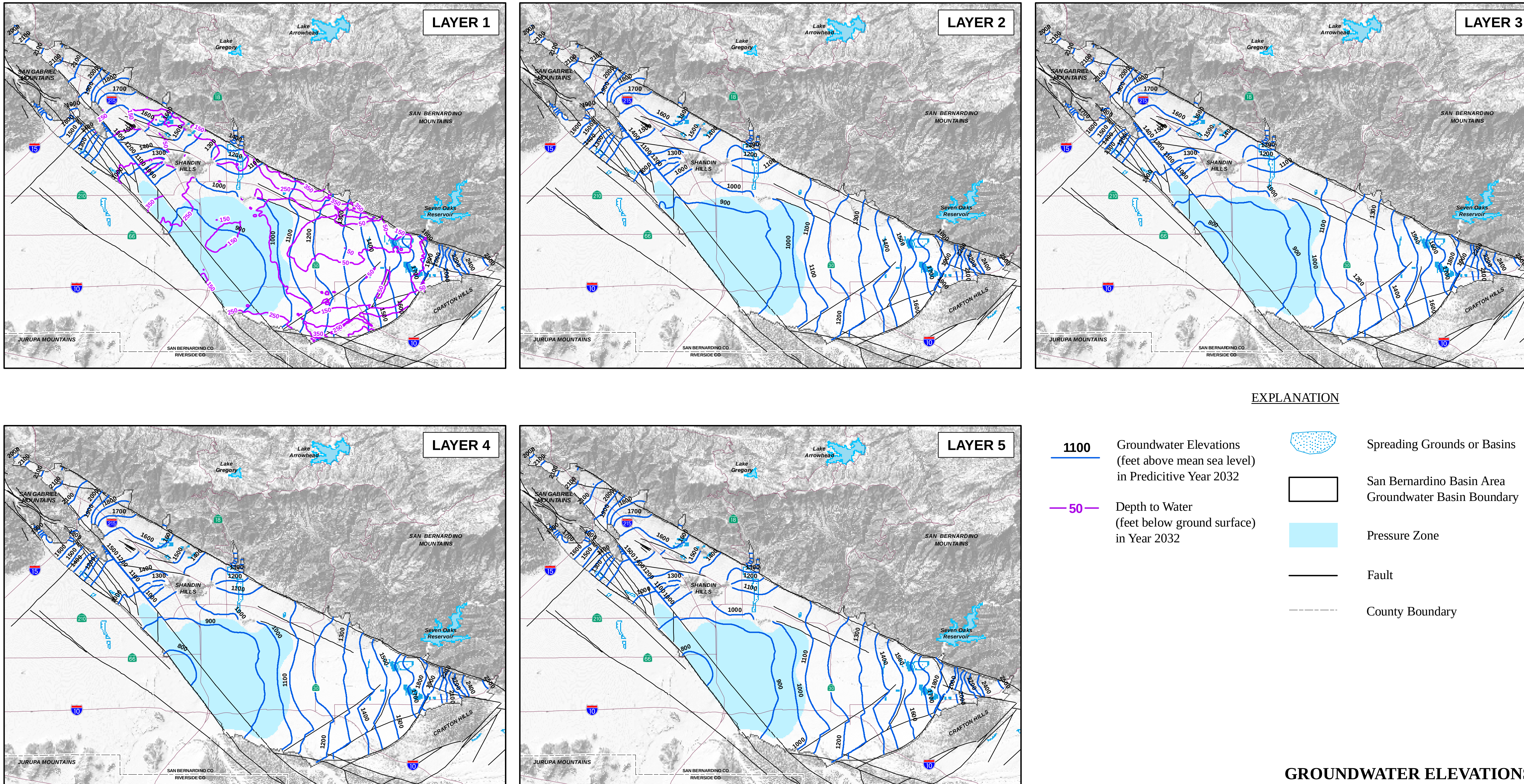
Figure 90

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_90_WL_updated_baseline_2020_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



GROUNDWATER ELEVATIONS FOR UPDATED BASELINE PREDICTIVE YEAR 2032 MODEL LAYERS 1 THROUGH 5

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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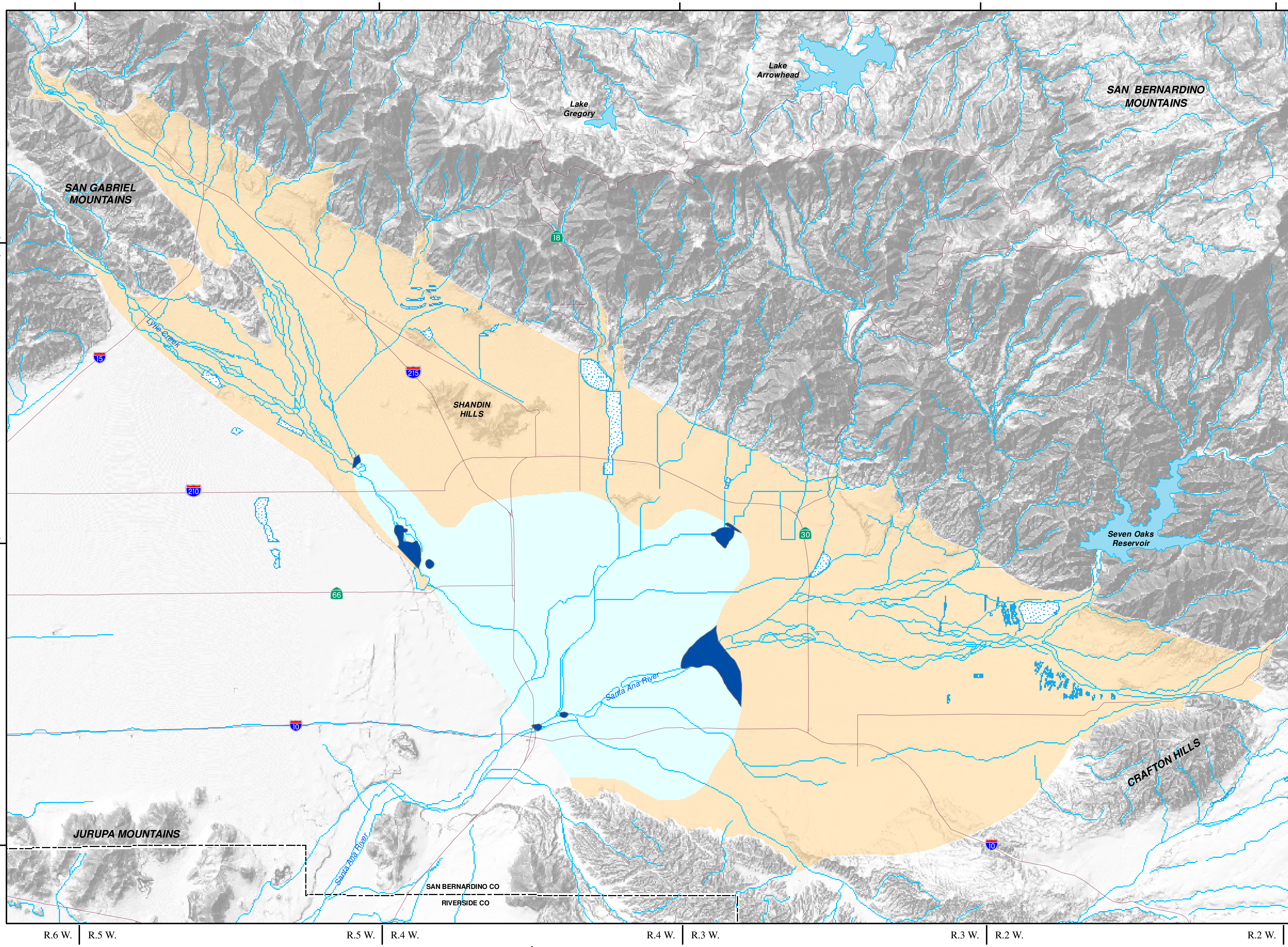
Figure 91

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_91_WL_updated_baseline_2032_9-09.mxd

POTENTIAL LIQUEFACTION AREA IN YEAR 2011 FOR THE UPDATED BASELINE RUN (RUN 12)



EXPLANATION

- Potential Liquefaction Area for the Updated Baseline Run (Run 12)
- Spreading Grounds or Basins
- San Bernardino Basin Area Groundwater Basin Boundary
- Pressure Zone
- County Boundary

Note: The acreage of the potential liquefaction area is approximately 720 acres, and is approximately 4% of the total Pressure Zone area of 19,320 acres.

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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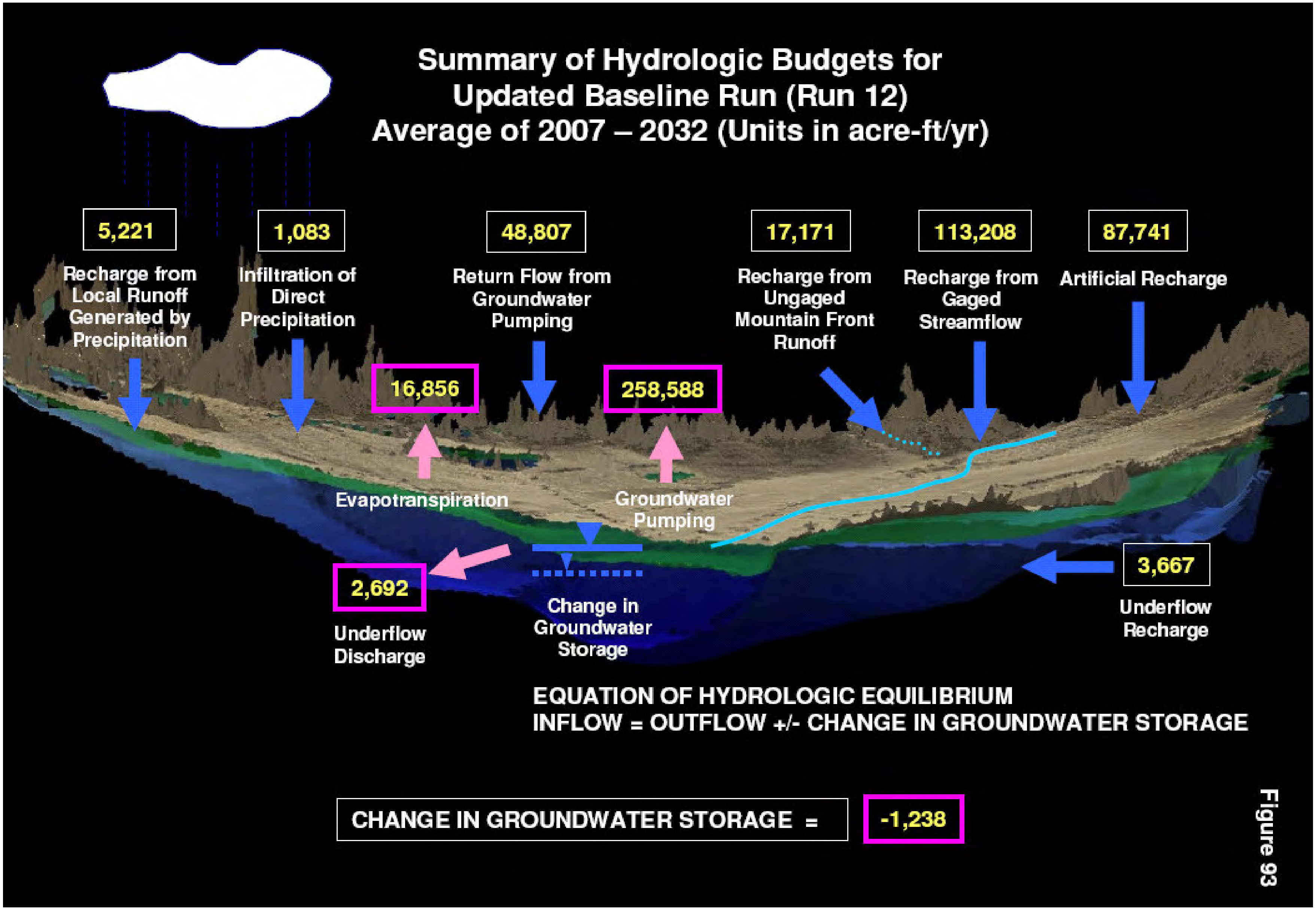
Figure 92

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_92_potential_liquefaction_9-09.mxd


Summary of Hydrologic Budgets for Updated Baseline Run (Run 12) Average of 2007 – 2032 (Units in acre-ft/yr)
5,221
Recharge from Local Runoff Generated by Precipitation
1,083
Infiltration of Direct Precipitation
48,807
Return Flow from Groundwater Pumping
17,171
Recharge from Ungaged Mountain Front Runoff
113,208
Recharge from Gaged Streamflow
87,741
Artificial Recharge
16,856
Evapotranspiration
258,588
Groundwater Pumping
2,692
Underflow Discharge
Change in Groundwater Storage
3,667
Underflow Recharge
EQUATION OF HYDROLOGIC EQUILIBRIUM
INFLOW = OUTFLOW +/- CHANGE IN GROUNDWATER STORAGE
CHANGE IN GROUNDWATER STORAGE =
-1,238
Figure 93

Cumulative Changes in Groundwater Storage for Updated Baseline Run (Run 12)

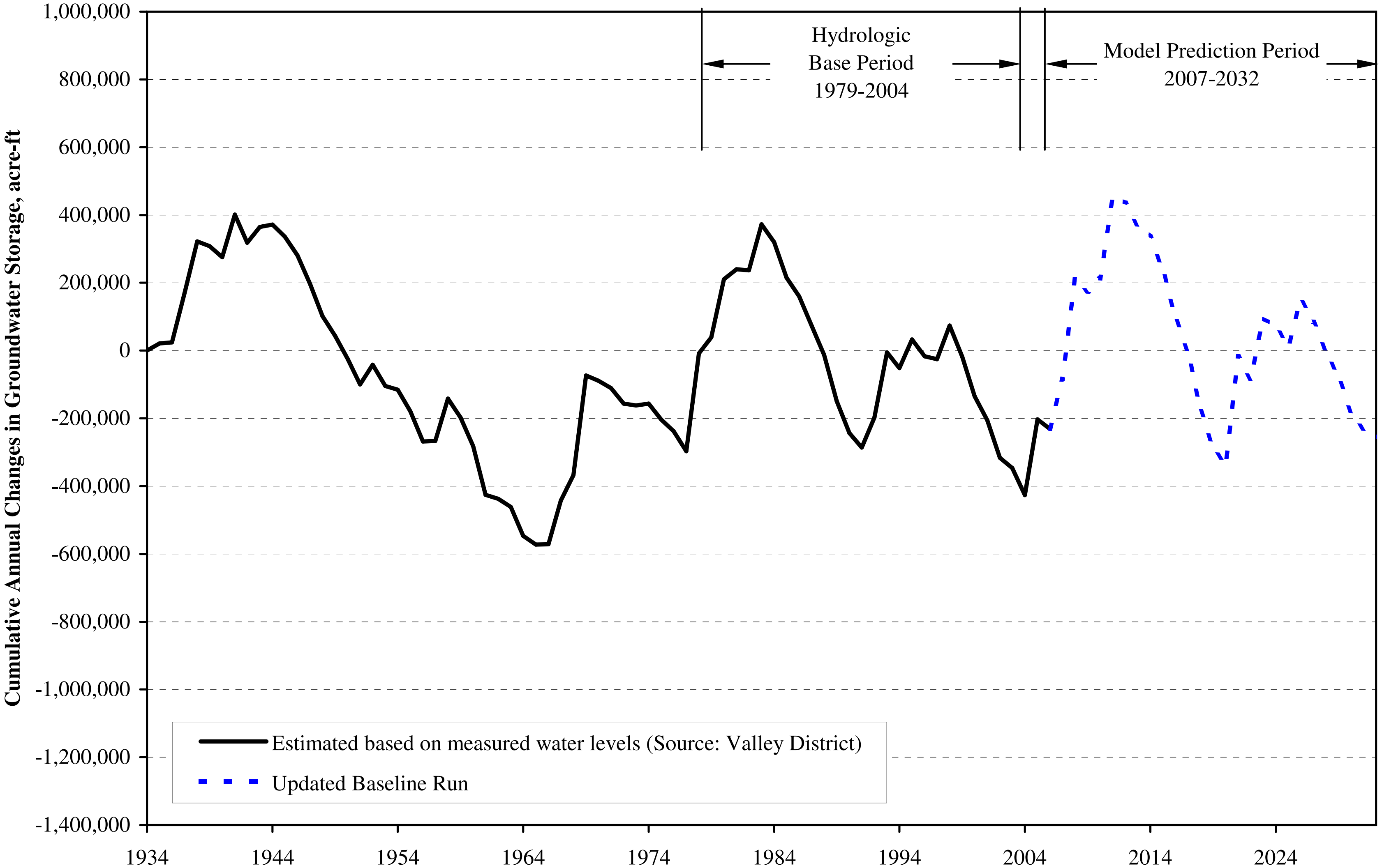
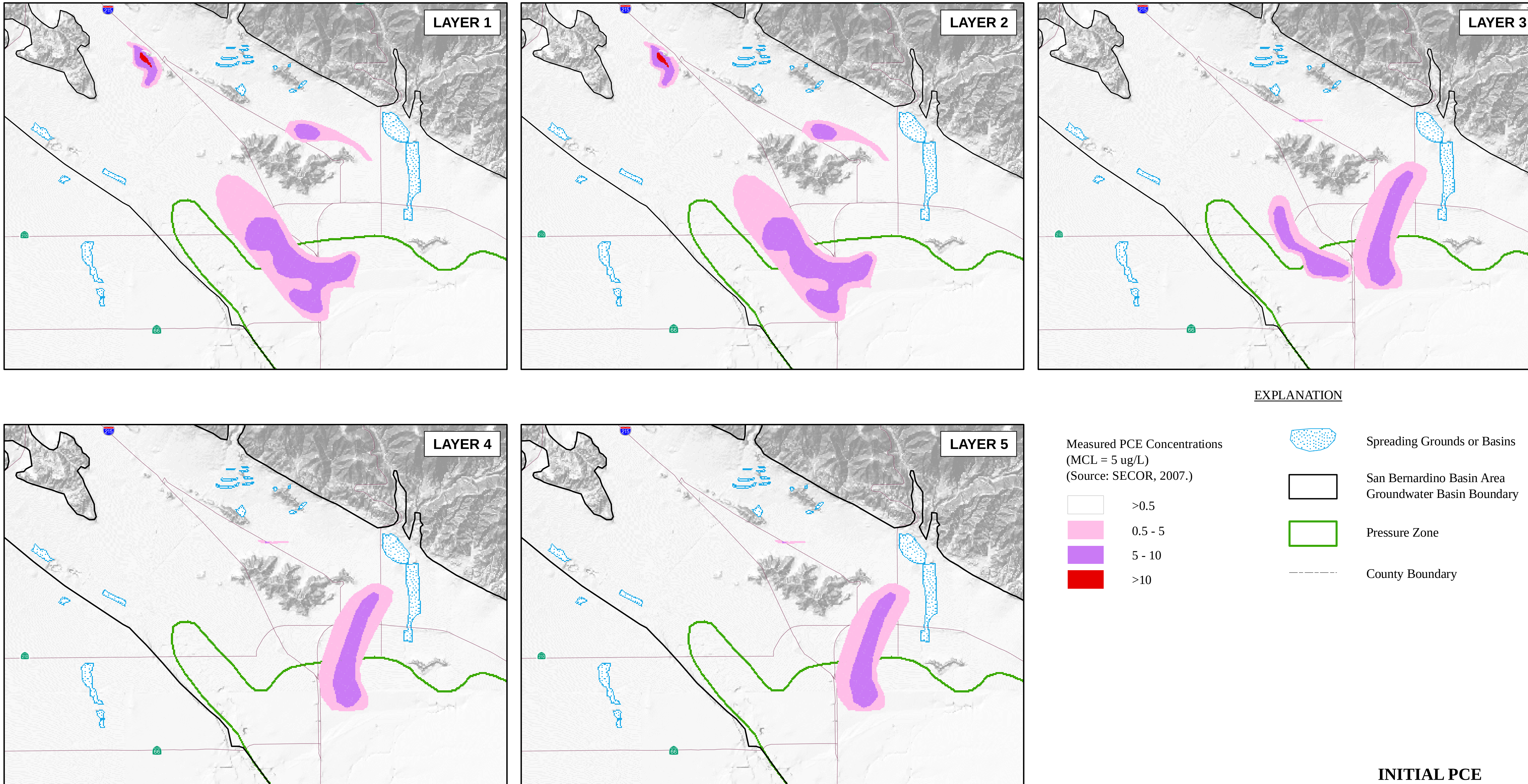


Figure 94

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



INITIAL PCE CONCENTRATIONS FOR UPDATED BASELINE RUN (RUN 12)

NORTH

0 2 4 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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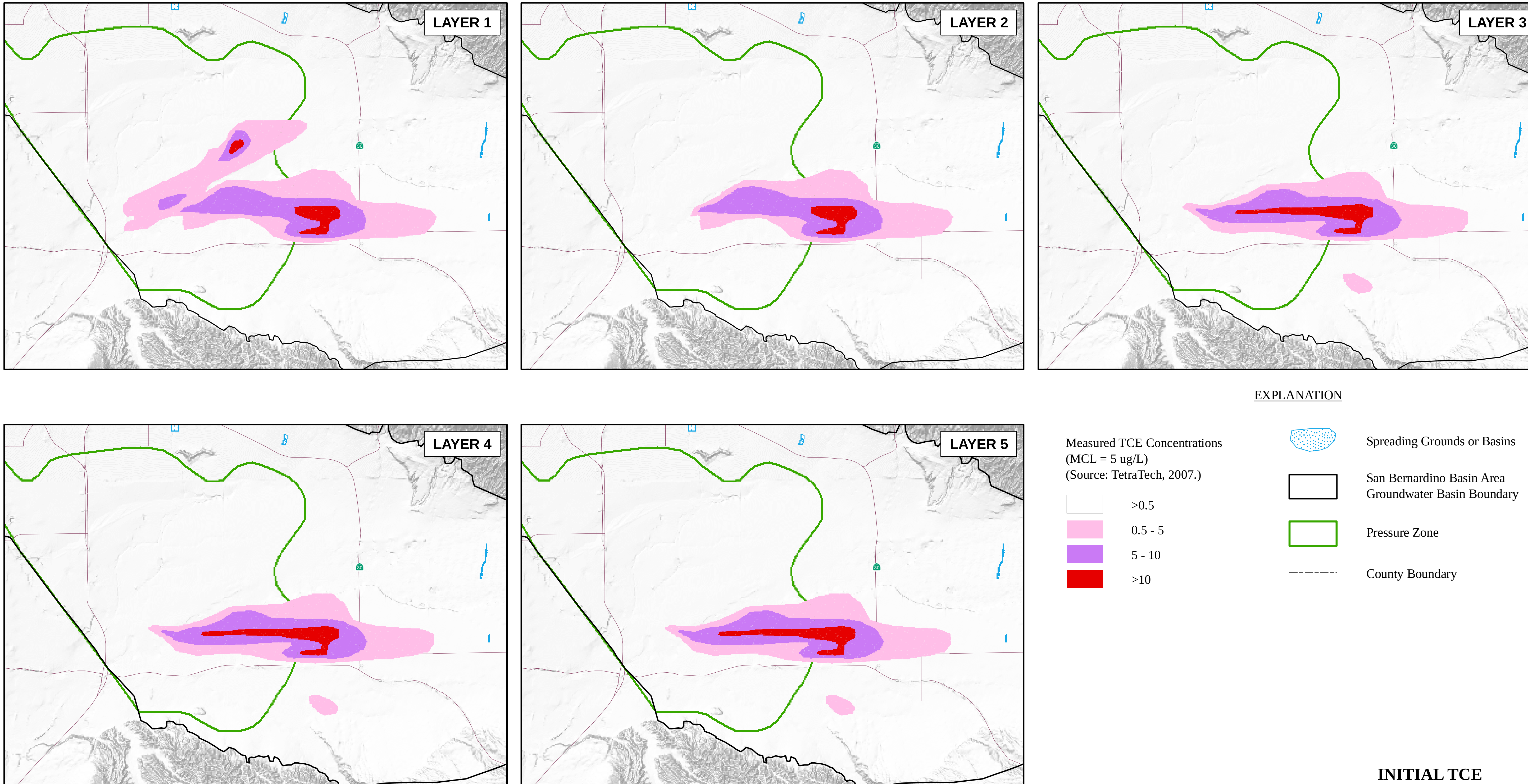
Figure 95

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_95_initial_PCE_update_baseline_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



EXPLANATION

Measured TCE Concentrations
(MCL = 5 ug/L)
(Source: TetraTech, 2007.)

>0.5
0.5 - 5
5 - 10
>10

Spreading Grounds or Basins

San Bernardino Basin Area
Groundwater Basin Boundary

Pressure Zone

County Boundary

NORTH
0 2 4 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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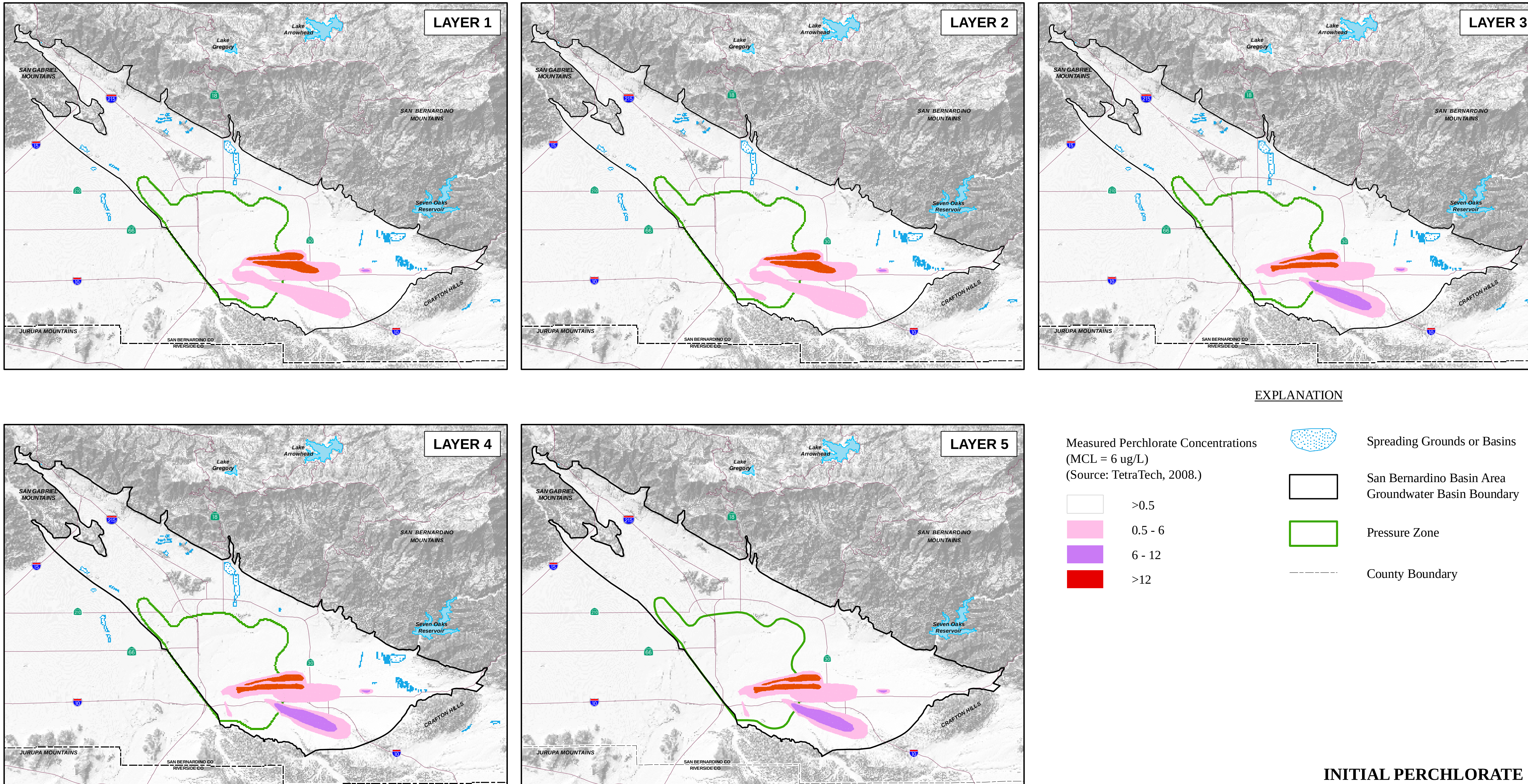
INITIAL TCE CONCENTRATIONS FOR UPDATED BASELINE RUN (RUN 12)

Figure 96

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_96_initial_TCE_update_baseline_9-09.mxd



NORTH

0 5 10 Miles

INITIAL PERCHLORATE CONCENTRATIONS FOR UPDATED BASELINE RUN (RUN 12)

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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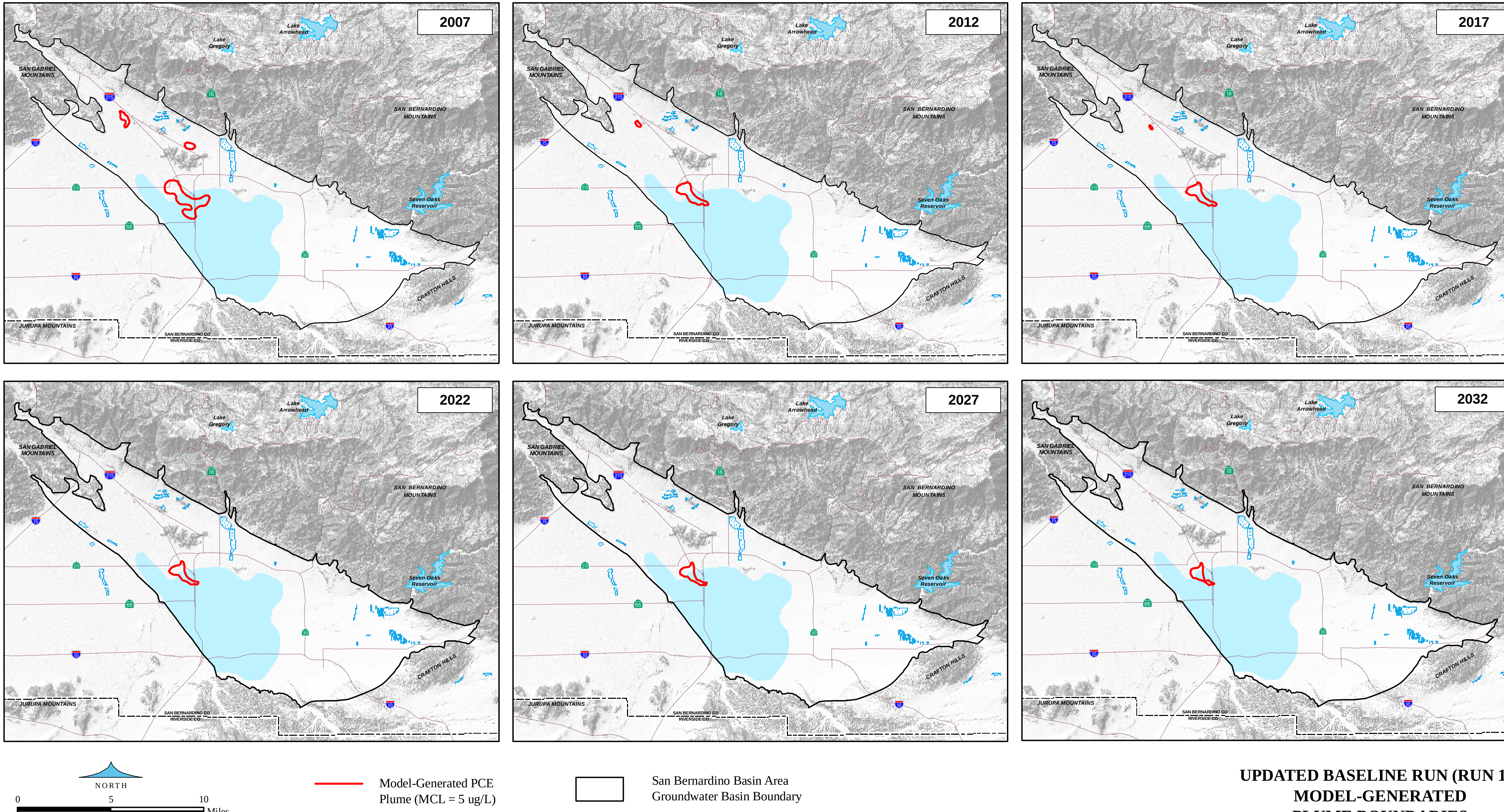
Figure 97

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_97_initial_Perch_update_baseline_9-09.mxd



30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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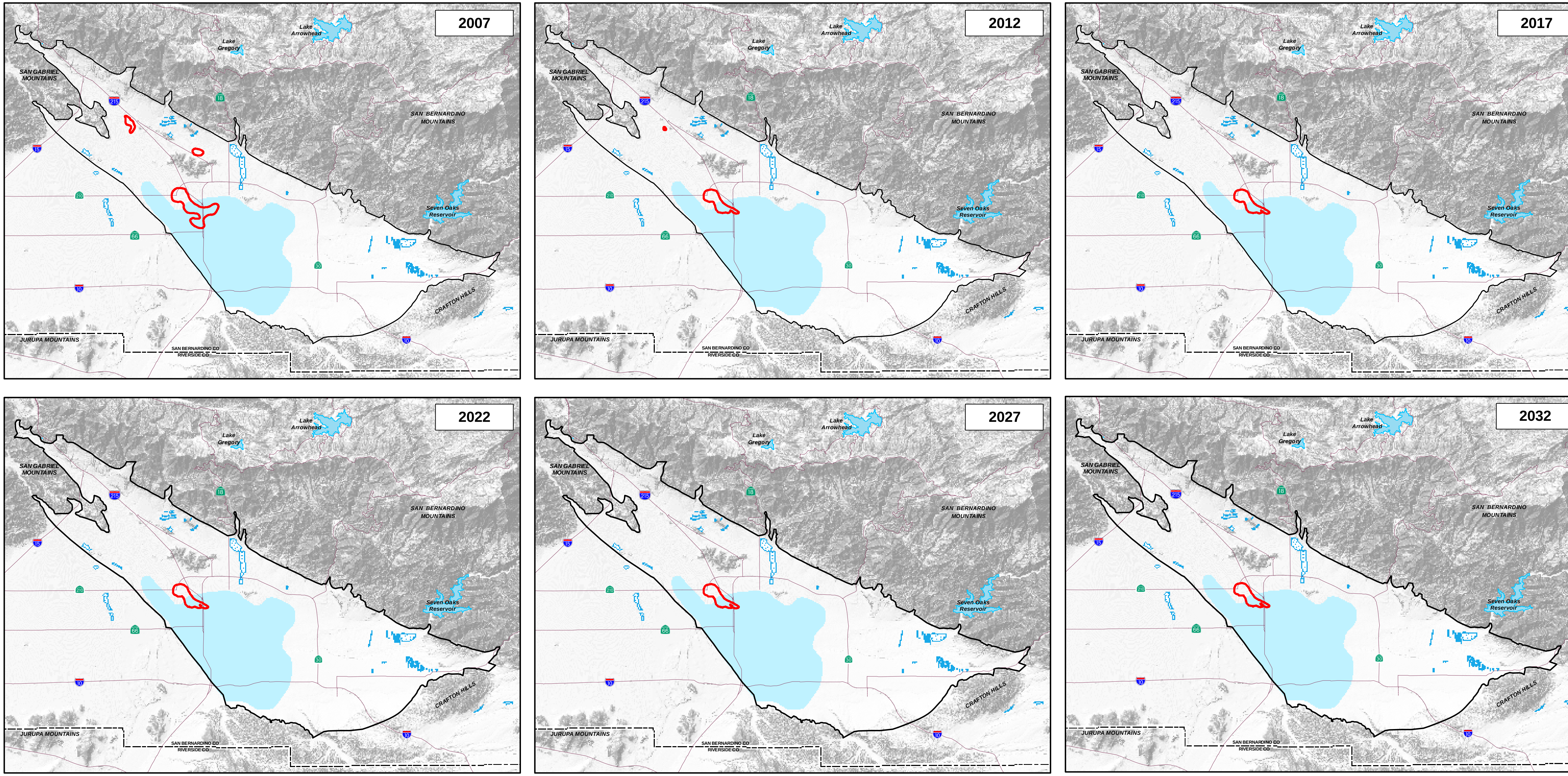
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR PCE - MODEL LAYER 1**

Figure 98

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_98_PCE_plumes_update_baseline_L1_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



NORTH

0 5 10 Miles

Model-Generated PCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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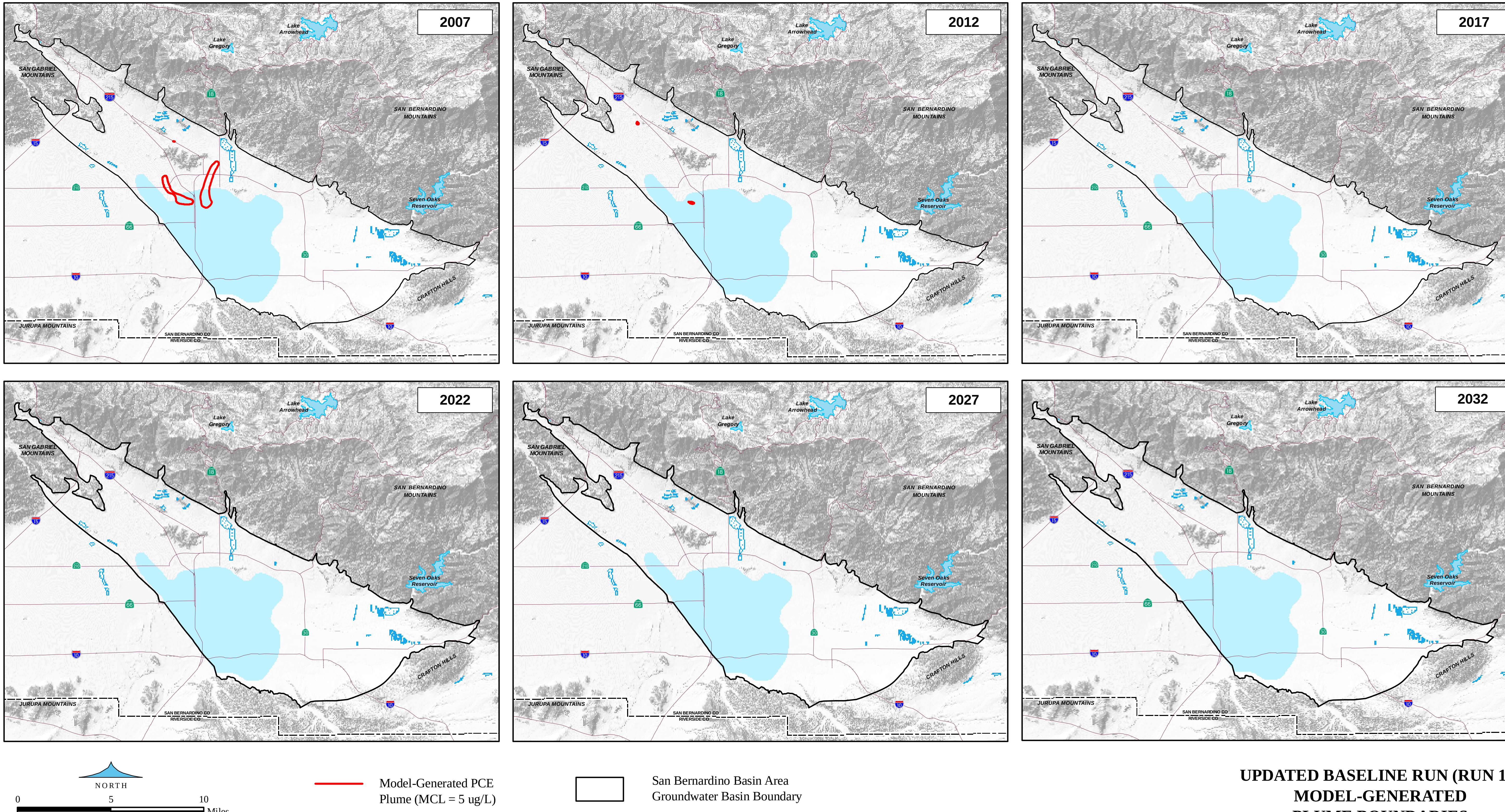
UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR PCE - MODEL LAYER 2

Figure 99

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_99_PCE_plumes_update_baseline_L2_9-09.mxd



30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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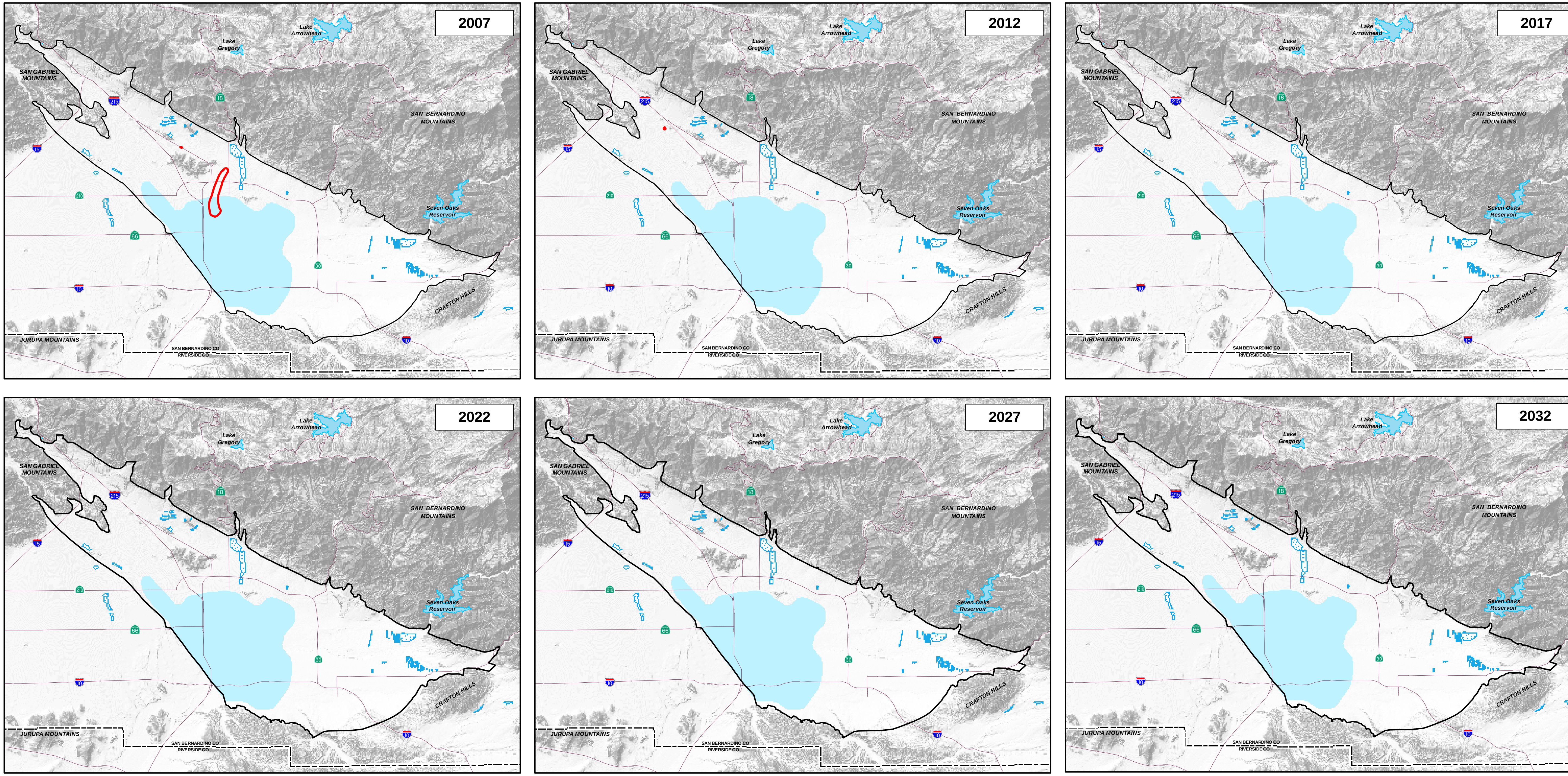
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR PCE - MODEL LAYER 3**

Figure 100

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

Model-Generated PCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

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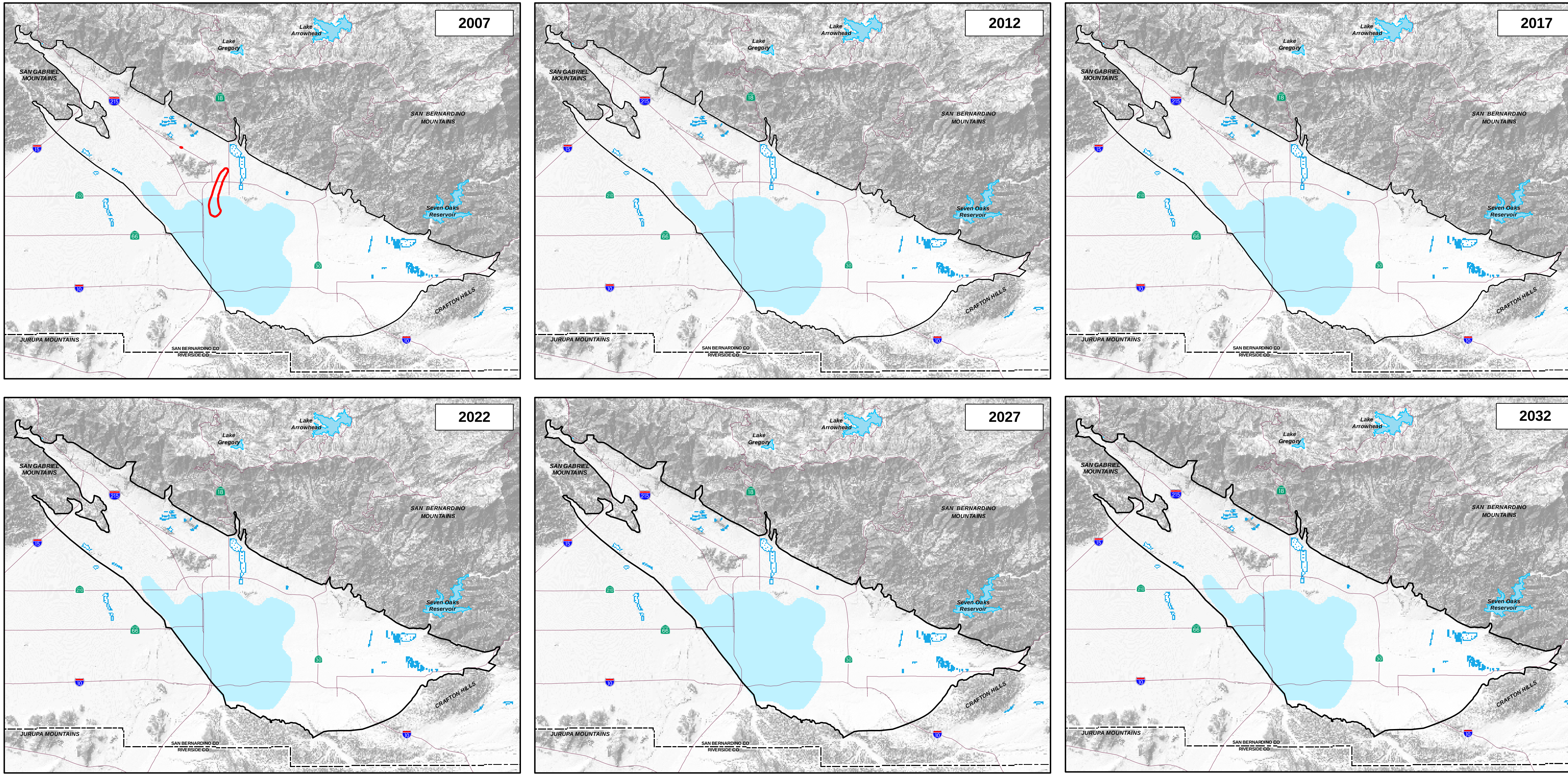
UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR PCE - MODEL LAYER 4

Figure 101

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_101_PCE_plumes_update_baseline_L4_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



NORTH

0 5 10 Miles

Model-Generated PCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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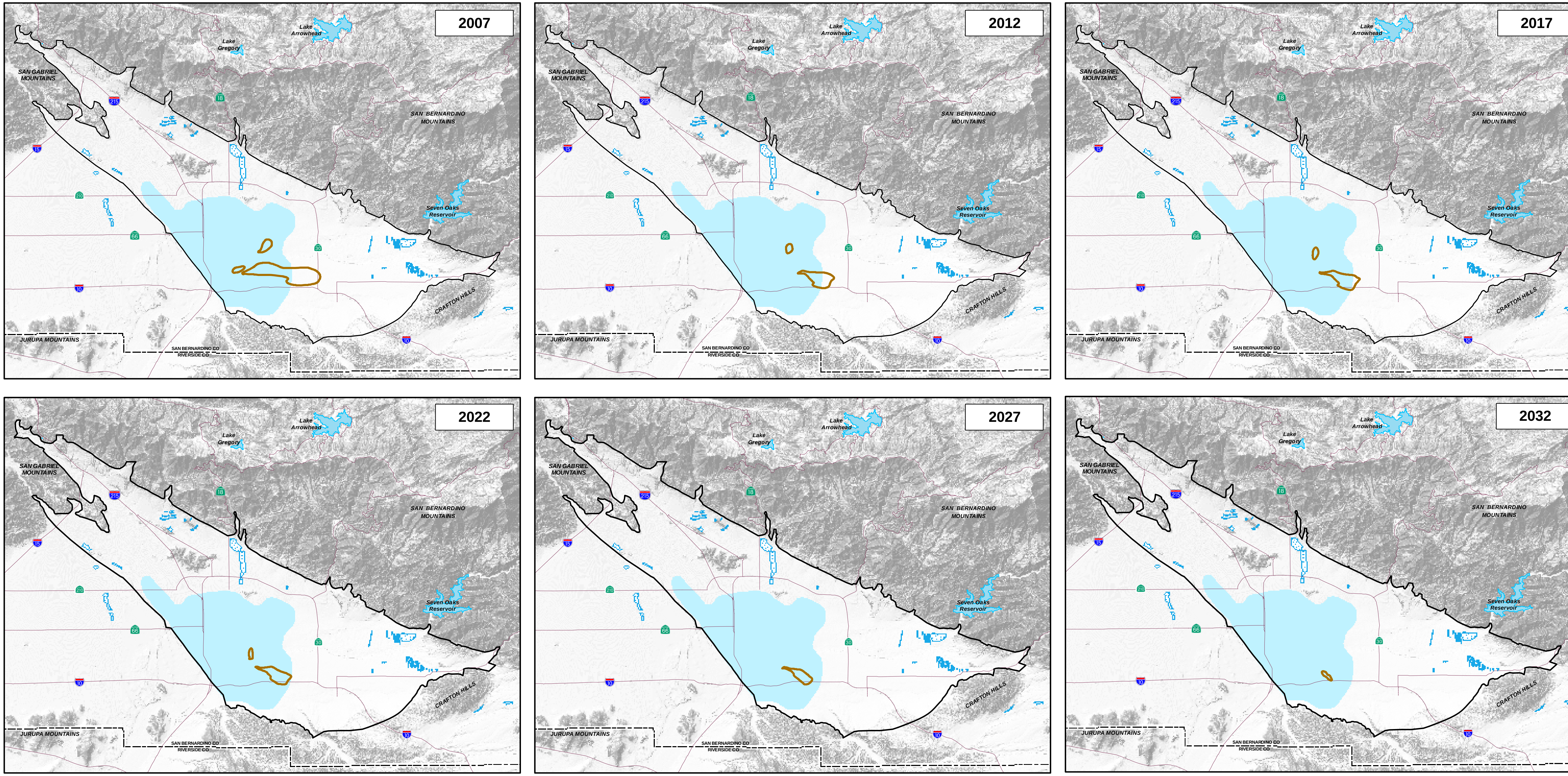
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR PCE - MODEL LAYER 5**

Figure 102

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_1028_PCE_plumes_update_baseline_L5_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



NORTH

0 5 10 Miles

Model-Generated TCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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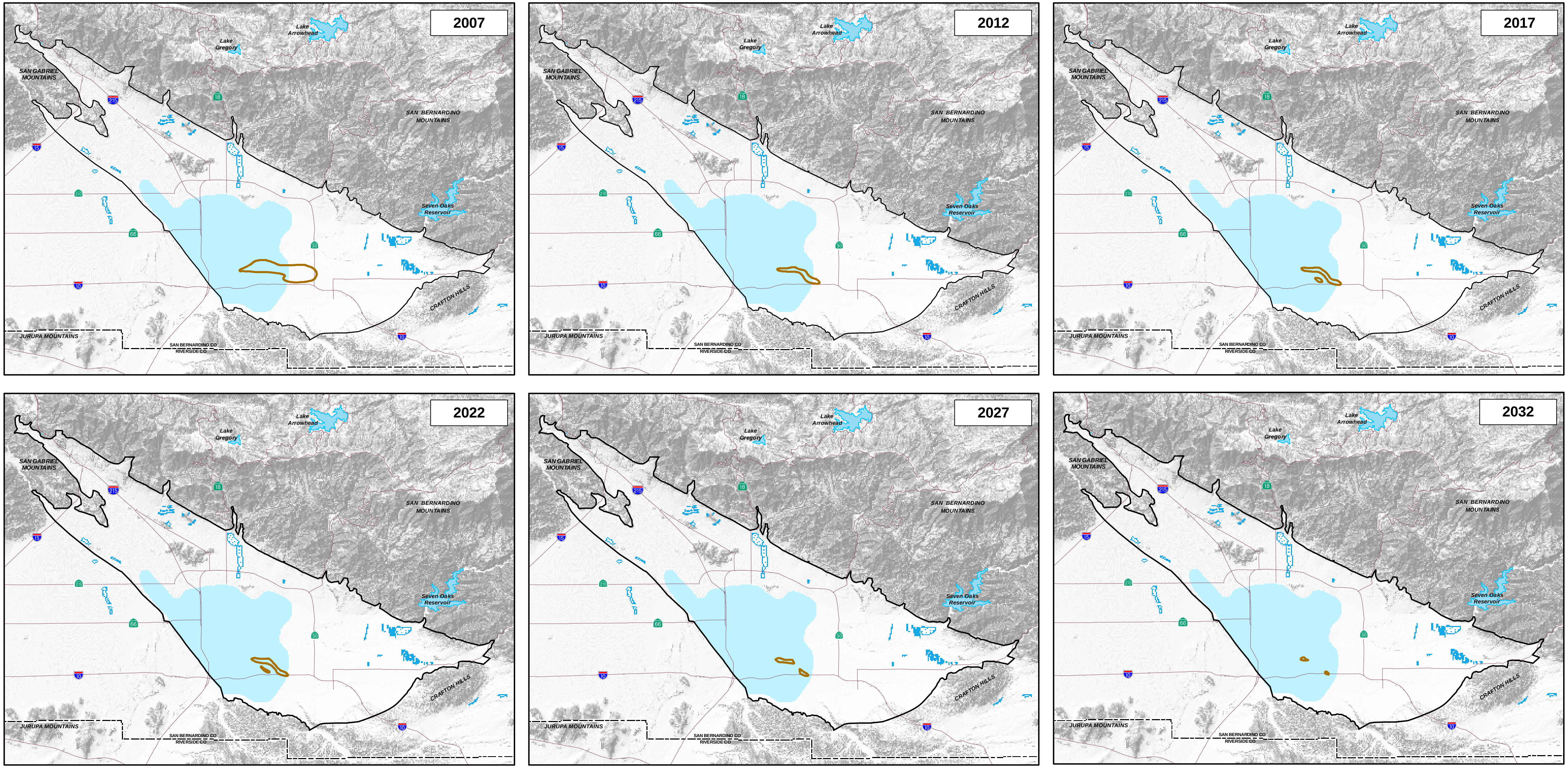
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR TCE - MODEL LAYER 1**

Figure 103

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_103_TCE_plumes_update_baseline_L1_9-09.mxd



NORTH

0 5 10 Miles

Model-Generated TCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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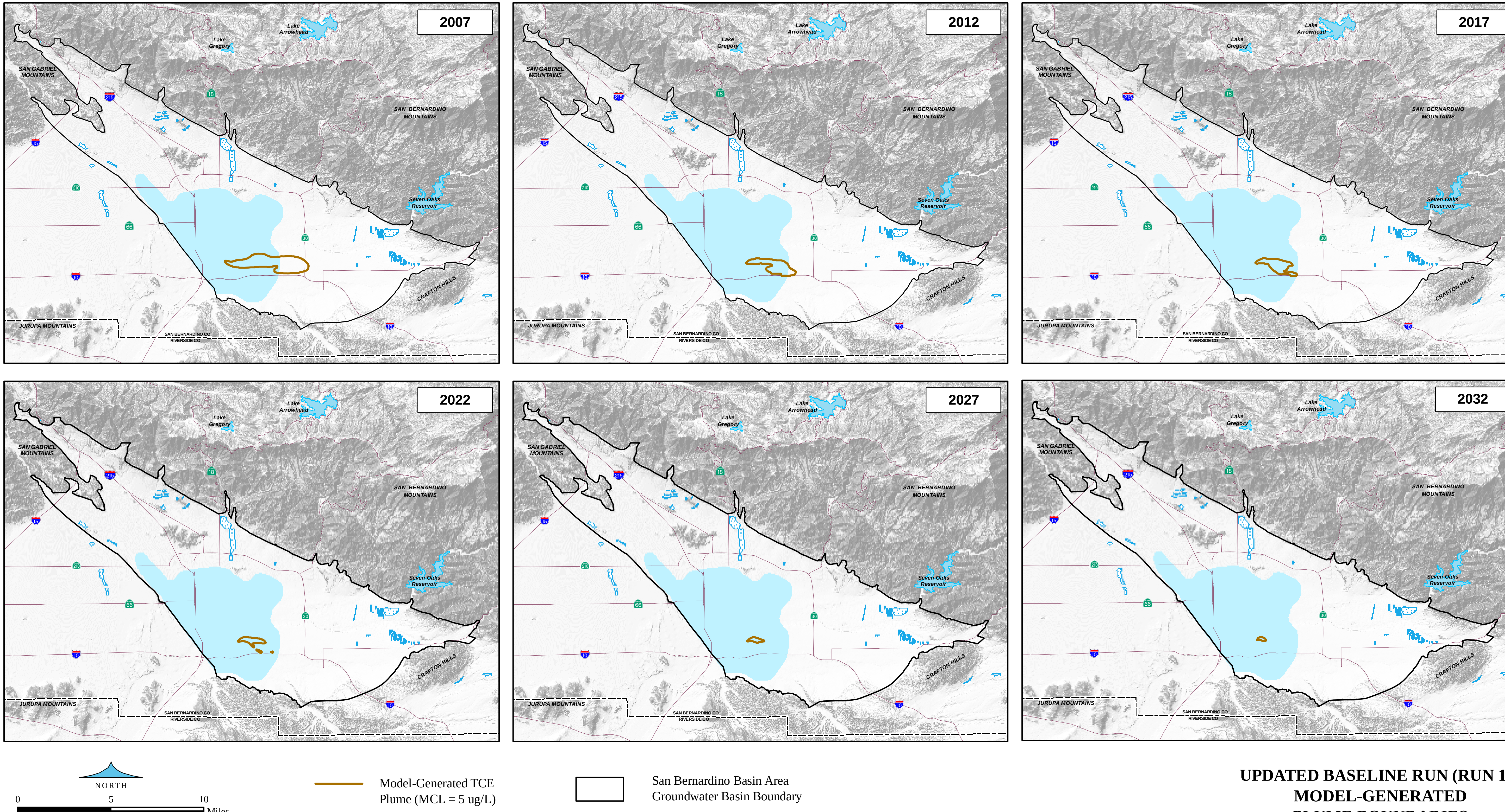
UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR TCE - MODEL LAYER 2

Figure 104

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_104_TCE_plumes_update_baseline_L2_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



30-Sep-09

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Map Projection: State Plane 1983, Zone V, feet

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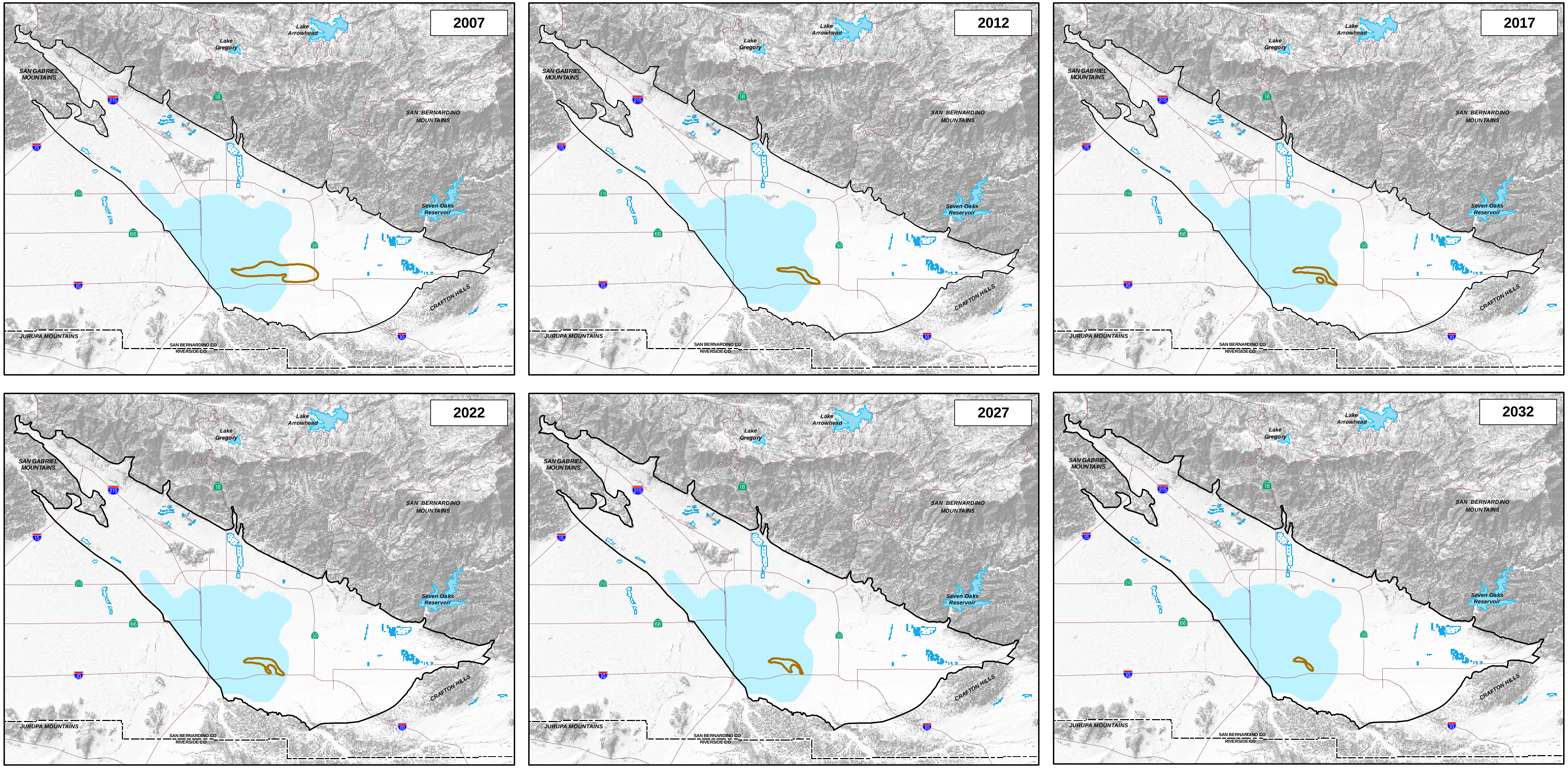
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR TCE - MODEL LAYER 3**

Figure 105

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_105_TCE_plumes_update_baseline_L3_9-09.mxd



NORTH

0 5 10 Miles

Model-Generated TCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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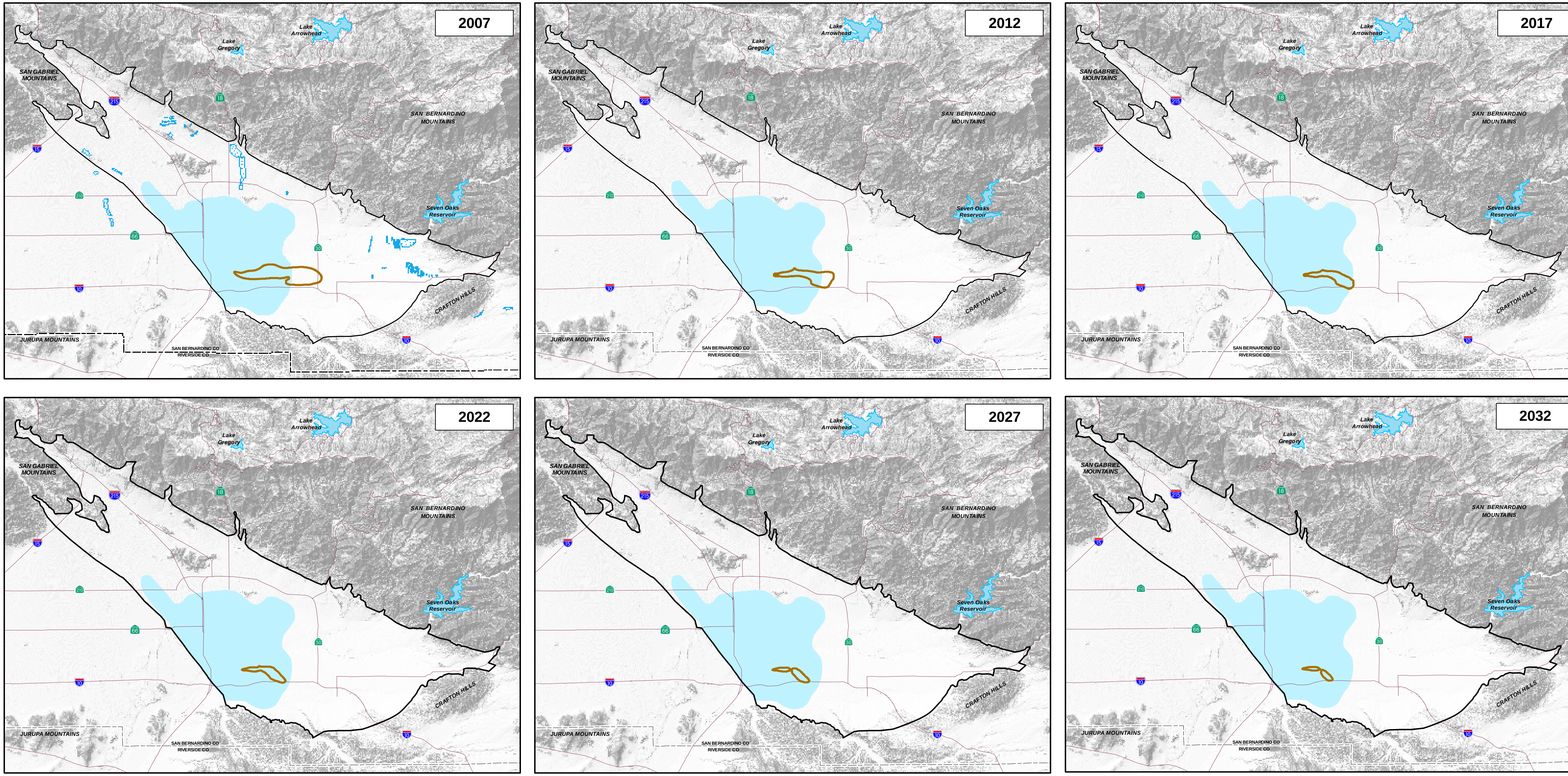
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR TCE - MODEL LAYER 4**

Figure 106

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_106_TCE_plumes_update_baseline_L4_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



NORTH

0 5 10 Miles

Model-Generated TCE Plume (MCL = 5 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

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Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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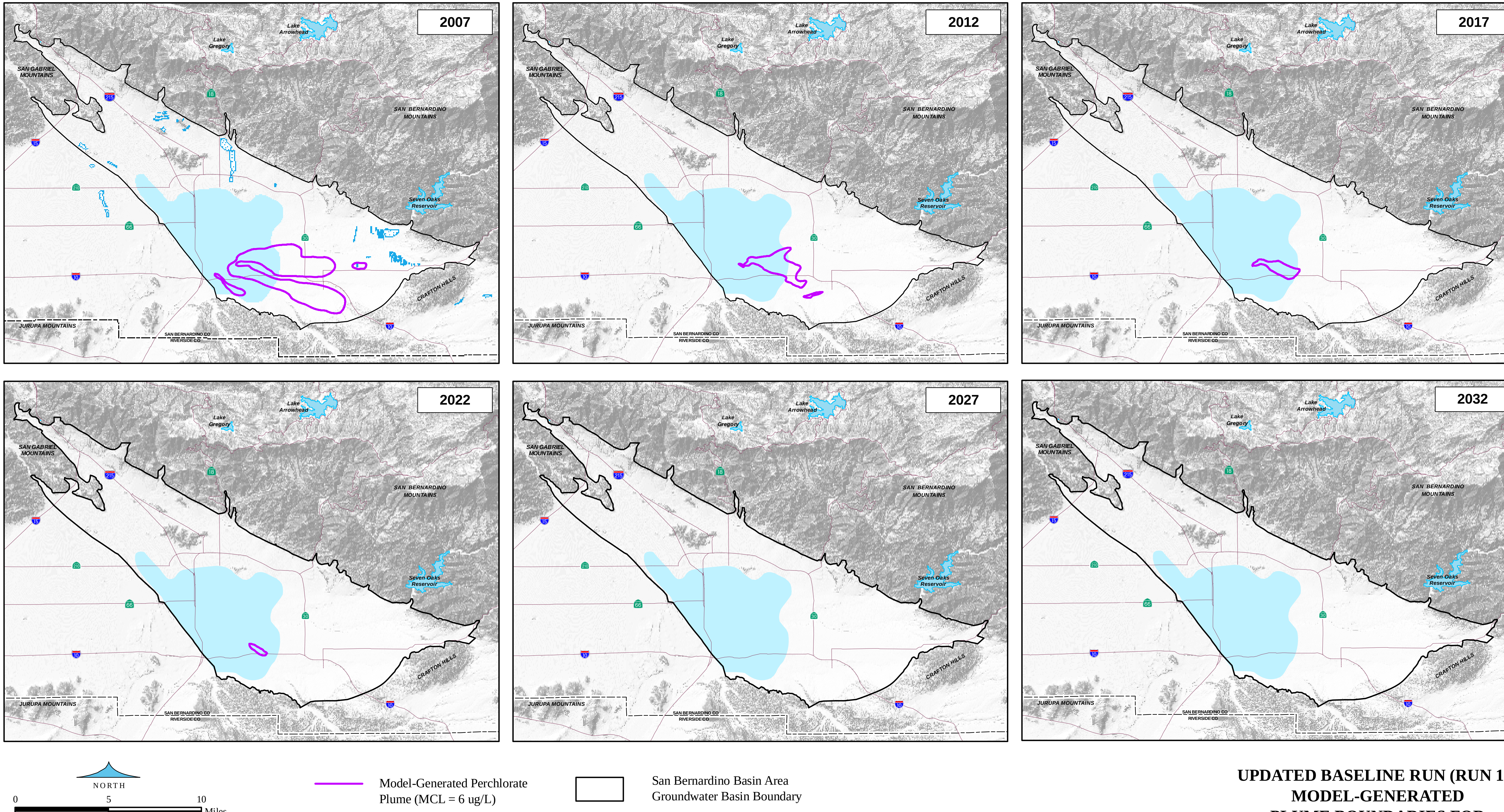
UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES
FOR TCE - MODEL LAYER 5

Figure 107

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_107_TCE_plumes_update_baseline_L5_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



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Map Projection: State Plane 1983, Zone V, feet

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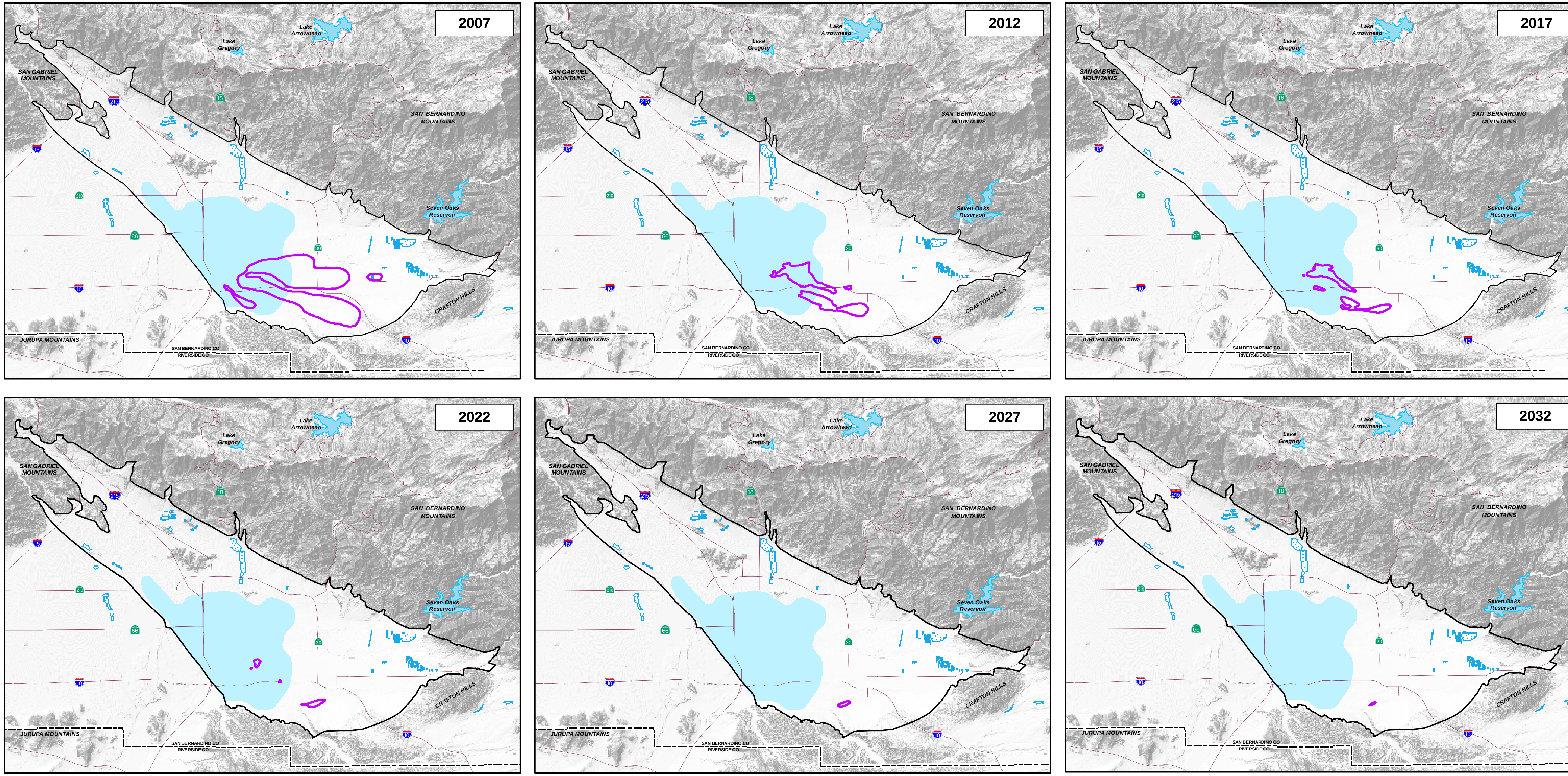
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES FOR
PERCHLORATE - MODEL LAYER 1**

Figure 108

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_108_Perch_plumes_update_baseline_L1_9-09.mxd



NORTH

0 5 10 Miles

Model-Generated Perchlorate Plume (MCL = 6 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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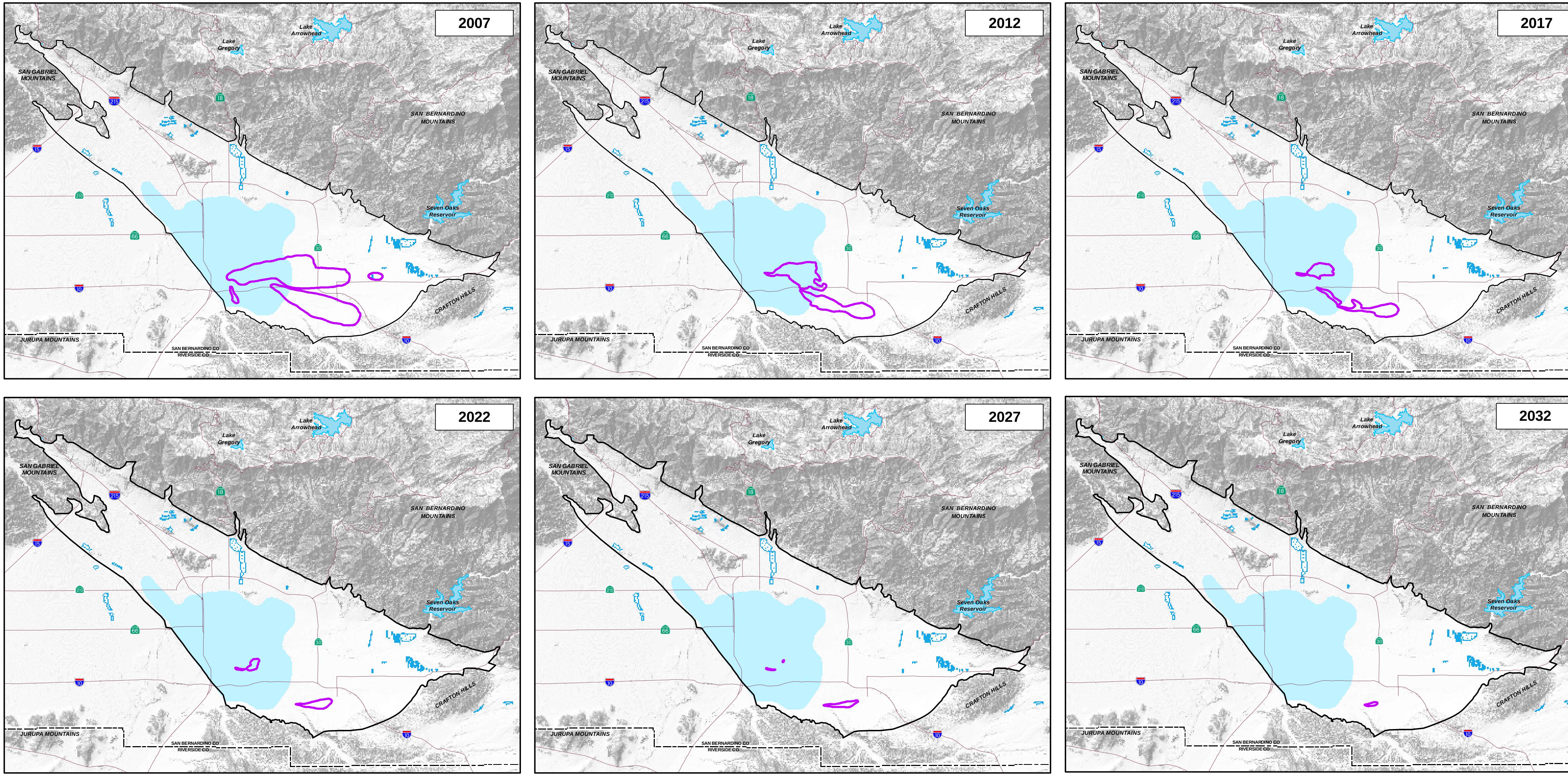
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES FOR
PERCHLORATE - MODEL LAYER 2**

Figure 109

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



NORTH

0 5 10 Miles

Model-Generated Perchlorate Plume (MCL = 6 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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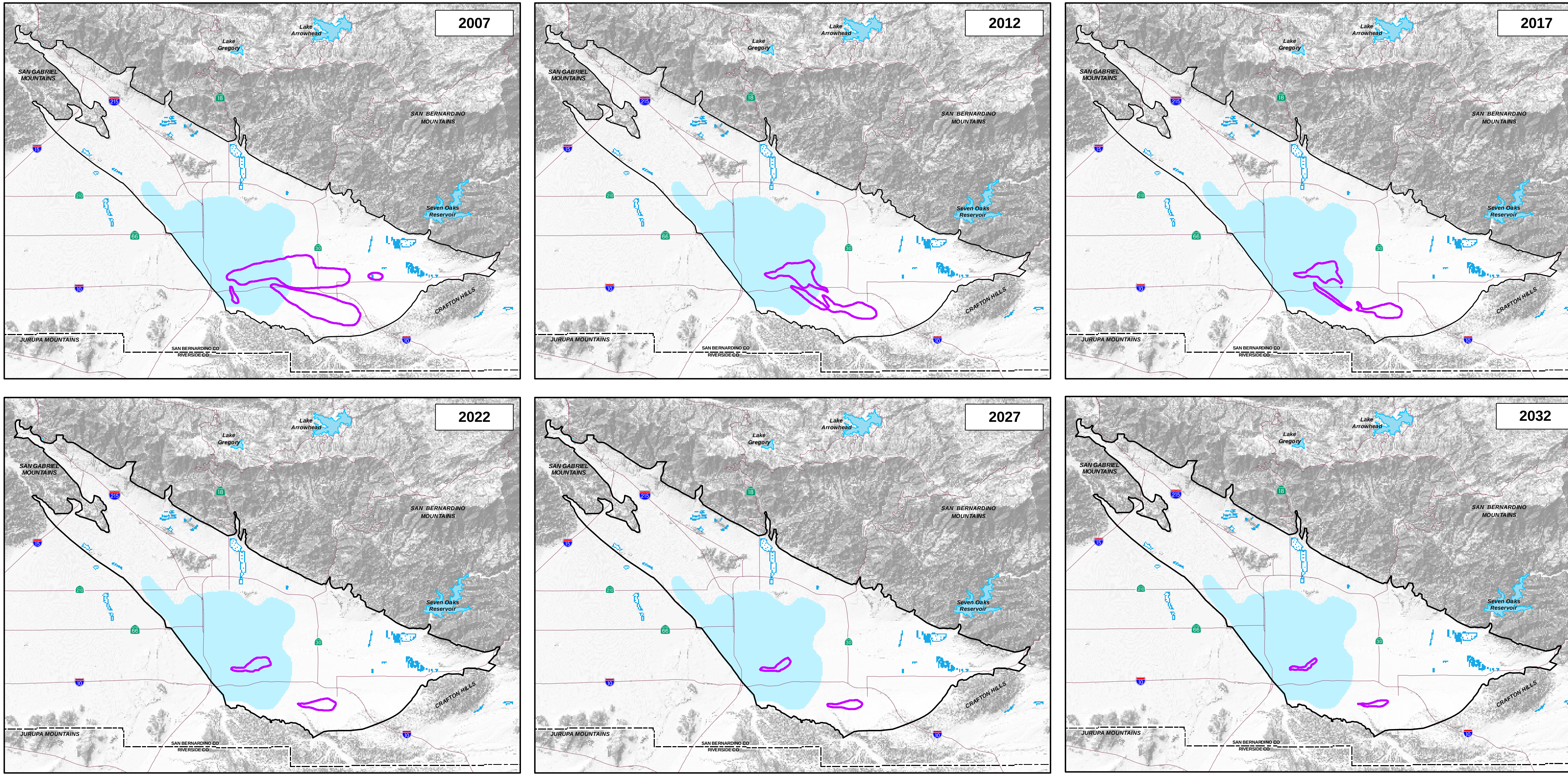
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES FOR
PERCHLORATE - MODEL LAYER 3**

Figure 110

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_110_Perch_plumes_update_baseline_L3_9-09.mxd

SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

SAN BERNARDINO BASIN AREA
REFINED BASIN FLOW MODEL AND SOLUTE TRANSPORT MODEL REPORT



NORTH

0 5 10 Miles

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

Model-Generated Perchlorate Plume (MCL = 6 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

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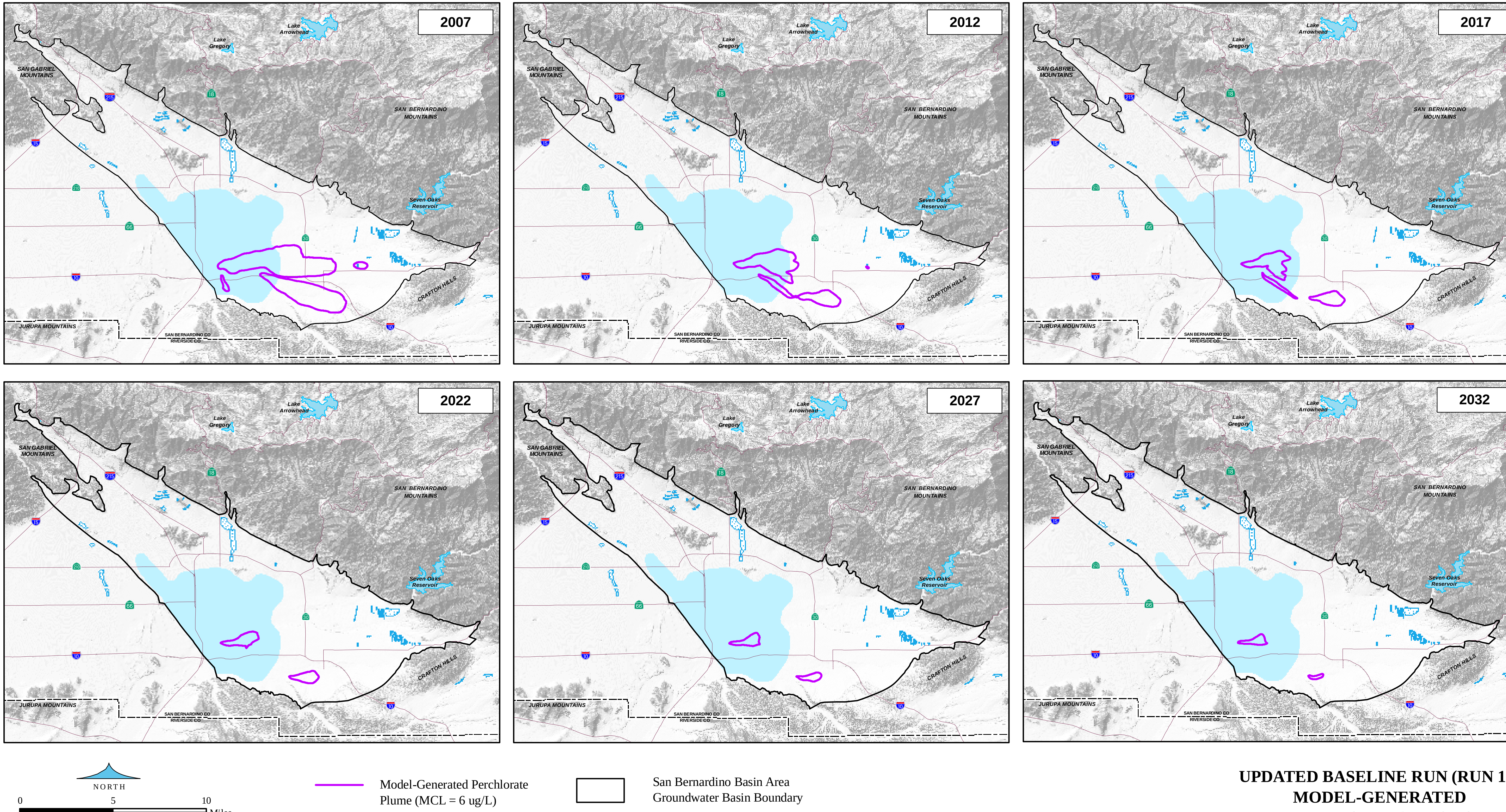
**UPDATED BASELINE RUN (RUN 12)
MODEL-GENERATED
PLUME BOUNDARIES FOR
PERCHLORATE - MODEL LAYER 4**

Figure 111

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_111_Perch_plumes_update_baseline_L4_9-09.mxd



Model-Generated Perchlorate Plume (MCL = 6 ug/L)

Spreading Grounds or Basins

San Bernardino Basin Area Groundwater Basin Boundary

Pressure Zone

County Boundary

30-Sep-09

Prepared by: DWB

Map Projection: State Plane 1983, Zone V, feet

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UPDATED BASELINE RUN (RUN 12) MODEL-GENERATED PLUME BOUNDARIES FOR PERCHLORATE - MODEL LAYER 5

Figure 112

GIS_proj/sbvmwd_refined_flow_transport_model_9-09/0_Fig_111_Perch_plumes_update_baseline_L4_9-09.mxd

TABLES

GEOSCIENCE Support Services, Inc.

Summary of Water Budgets and Water Level Residual Statistics for RBFM Calibration Runs

Model Run	Groundwater Budgets		Water Level Calibration Statistics[3]	
	Average Annual Change in Groundwater Storage[1] [acre-ft/yr]	Global Budget Errors[2]	Mean Residual[4] [ft]	Relative Error of Residual[5]
Original USGS Model	-8,902	0.00%	26.92	4.93%
Run 1	Not Applicable	0.21%	Not Applicable	Not Applicable
Run 2	-9,491	0.29%	24.94	4.93%
Run 3	-8,855	0.08%	24.41	4.96%
Run 4	-9,191	0.08%	25.77	4.86%
Run 5	-8,385	0.26%	19.27	4.89%
Run 6	-8,251	0.16%	18.89	4.94%
Run 7	-12,044	0.20%	-30.51	5.40%
Run 8	Not Applicable	0.42%	11.29	7.10%
Run 9	-10,800	0.00%	-0.67	4.62%

1. A positive sign represents an increase in groundwater storage and a negative sign indicates a decline in groundwater storage.
2. For most groundwater flow problems, global groundwater flow budget errors greater than one percent are unacceptable (Hill, 1990)
3. Runs 1-7 were based on 7,854 measured water level data from 43 wells during the period 1945-2000. Run 8 was based on measured data from 119 wells in 1945. Run 9 was based on 12,326 measured data from 141 wells during the period 1945-2000.
4. Residual = Measured Water Level minus Model-calculated Water Level
5. The relative error is defined as the standard deviation of the water level residuals divided by the observed head range (Zheng and Bennett, 2002). Common modeling practice is to consider a good fit between historical and model predicted data if the relative error is below 10% (Spitz and Moreno, 1996; and Environmental Simulations, Inc., 1999).

Table 1

Table 2

Groundwater Budgets for IRWMP Baseline Run 1 - 2006 to 2044
(in acre-ft)

Water Years	[1] INFLOW: Recharge from Gaged Streamflow	[2] INFLOW: Artificial Recharge	[3] INFLOW: Recharge from Local Runoff Generated by Precipitation	[4] INFLOW: Infiltration from Direct Precipitation	[5] INFLOW: Return Flow from Groundwater Pumping	[6] INFLOW: Recharge from Ungaged Mountain Front Runoff	[7] INFLOW: Underflow Recharge	[8] INFLOW: Total Inflow	[9] OUTFLOW: Evapo-transpiration	[10] OUTFLOW: Groundwater Pumping	[11] OUTFLOW: Groundwater Pumping for Conjunctive Use: 40,000 acre-ft	[12] OUTFLOW: Groundwater Pumping for Conjunctive Use: 90,000 acre-ft	[13] OUTFLOW: Groundwater Pumping for Conjunctive Use: 140,000 acre-ft	[14] OUTFLOW: Underflow Discharge	[15] OUTFLOW: Total Outflow	[16] CHANGE IN GROUNDWATER STORAGE
2006	81,839	18,091	3,524	1,109	38,077	10,336	3,491	156,466	7,853	211,957	0	0	0	2,766	222,575	**-66,109**
2007	45,765	20,146	5,804	1,109	42,436	5,371	3,455	124,086	5,860	230,965	0	0	0	2,636	239,461	**-115,375**
2008	42,612	20,448	3,306	1,109	42,306	5,491	3,420	118,692	3,449	228,153	0	0	0	2,527	234,129	**-115,437**
2009	114,190	22,150	7,266	1,109	41,645	12,708	3,385	202,454	2,357	225,125	0	0	0	2,467	229,949	**-27,495**
2010	131,360	33,101	4,938	1,109	34,161	20,225	3,349	228,243	2,365	193,241	0	0	0	2,444	198,049	**30,194**
2011	142,863	70,352	5,734	1,109	35,932	18,952	3,314	278,255	5,609	203,113	0	0	0	2,412	211,134	**67,121**
2012	79,328	29,171	2,510	1,109	40,436	9,211	3,279	165,044	4,002	217,449	0	0	0	2,378	223,829	**-58,785**
2013	387,002	117,095	10,694	1,109	38,027	67,034	3,243	624,205	16,150	210,486	0	0	0	2,484	229,120	**395,085**
2014	76,495	55,473	4,868	1,109	38,759	11,632	3,208	191,544	15,906	221,288	0	0	0	2,624	239,818	**-48,275**
2015	61,090	47,060	4,504	1,109	41,424	9,645	3,172	168,006	10,333	234,249	0	0	0	2,634	247,216	**-79,211**
2016	54,904	43,630	2,292	1,109	44,242	7,200	3,137	156,515	7,096	243,528	0	0	0	2,596	253,221	**-96,706**
2017	107,351	56,401	4,854	1,109	41,906	17,593	3,102	232,317	5,730	230,010	0	0	0	2,548	238,288	**-5,971**
2018	92,200	48,207	5,038	1,109	45,138	11,497	3,066	206,256	5,470	240,657	0	0	0	2,517	248,643	**-42,388**
2019	72,585	49,265	3,992	1,109	46,491	9,645	3,031	186,118	4,423	244,669	0	0	0	2,486	251,579	**-65,460**
2020	73,425	42,475	5,043	1,109	47,700	9,520	2,996	182,269	3,209	250,182	0	0	0	2,440	255,831	**-73,562**
2021	60,834	0	4,990	1,109	48,681	7,200	2,960	125,776	731	254,986	0	0	0	2,362	258,079	**-132,303**
2022	424,562	107,181	10,317	1,109	48,555	34,125	2,925	628,774	8,479	254,137	0	0	0	2,352	264,969	**363,805**
2023	183,171	89,730	5,507	1,109	47,699	31,769	2,890	361,874	15,426	245,578	0	0	0	2,380	263,384	**98,489**
2024	316,010	130,237	8,890	1,109	48,043	68,000	2,854	575,144	25,299	254,596	0	0	0	2,534	282,429	**292,715**
2025	80,762	93,481	3,852	1,109	49,610	10,336	2,819	241,969	21,761	266,139	0	0	0	2,735	290,636	**-48,666**
2026	123,998	85,809	7,669	1,109	49,767	19,024	2,784	290,160	20,148	264,846	0	0	0	2,838	287,833	**2,327**
2027	301,337	116,633	11,503	1,109	50,031	50,499	2,748	533,861	30,495	262,923	0	0	0	3,093	296,512	**237,350**
2028	77,762	90,086	2,988	1,109	48,779	12,036	2,713	235,474	28,346	263,029	0	0	0	3,405	294,780	**-59,306**
2029	77,147	61,295	3,648	1,109	50,442	9,520	2,678	205,838	20,694	265,622	0	0	0	3,492	289,808	**-83,970**
2030	108,617	55,870	5,196	1,109	48,412	13,361	2,642	235,207	16,696	250,592	0	0	0	3,486	270,773	**-35,567**
2031	62,917	45,207	4,361	1,109	51,674	7,526	2,607	175,401	12,502	268,668	0	0	0	3,398	284,567	**-109,167**
2032	59,255	0	4,076	1,109	53,726	6,501	2,572	127,239	5,307	271,987	0	0	0	3,188	280,481	**-153,242**
2033	46,695	47,948	2,419	1,109	54,696	5,491	2,536	160,895	4,527	277,330	0	0	0	2,932	284,789	**-123,894**
2034	36,273	0	2,741	1,109	57,353	3,994	2,501	103,971	544	289,105	0	0	0	2,715	292,363	**-188,392**
2035	75,560	1,319	5,971	1,109	50,239	8,210	2,466	144,874	266	260,936	0	0	0	2,520	263,722	**-118,848**
2036	111,492	8,295	6,728	1,109	50,262	12,233	2,430	192,549	451	255,612	0	0	0	2,393	258,456	**-65,907**
2037	385,886	155,305	8,798	1,109	47,967	52,706	2,395	654,167	9,172	256,268	0	0	0	2,338	267,779	**386,389**
2038	86,192	59,197	4,640	1,109	49,599	11,089	2,360	214,186	5,743	259,090	0	0	0	2,355	267,188	**-53,002**
2039	253,793	132,481	7,240	1,109	48,557	38,572	2,324	484,075	13,949	258,922	0	0	0	2,355	275,227	**208,848**
2040	109,745	77,571	6,259	1,109	50,535	14,326	2,289	261,835	15,823	267,029	0	0	0	2,377	285,229	**-23,394**
2041	93,770	67,258	5,809	1,109	51,004	11,089	2,254	232,293	12,412	267,185	0	0	0	2,396	281,993	**-49,700**
2042	256,284	114,922	9,704	1,109	49,439	36,070	2,218	469,747	20,938	258,469	0	0	0	2,432	281,839	**187,908**
2043	62,909	63,003	2,276	1,109	51,593	7,281	2,183	190,354	17,515	267,557	0	0	0	2,498	287,570	**-97,216**
2044	53,106	52,931	4,213	1,109	54,021	6,472	2,148	174,000	10,255	281,580	0	0	0	2,492	294,328	**-120,328**
Average	**128,489**	**59,713**	**5,491**	**1,109**	**46,907**	**18,038**	**2,819**	**262,567**	**10,700**	**248,904**	**0**	**0**	**0**	**2,642**	**262,245**	**322**

Note:
[1] Model-Calculated values
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[3] Model input based on historical conditions
[4] Model input based on historical conditions
[5] Model input data from Allocation Model
[6] Model input based on historical conditions
[7] Model input based on historical conditions
[8] = sum of [1] through [7]
[9] Model-Calculated values
[10] Model input data from Allocation Model
[11] Model input data from Allocation Model
[12] Model input data from Allocation Model
[13] Model input data from Allocation Model
[14] Model input based on historical conditions and model-calculated water level in Heap Well
[15] = sum of [9] through [14]
[16] = [8]-[15]

Baseline Run 1		
Hydrologic Base Period		1962-2000
Groundwater Pumping		2005 Urban Water Management Plans with 2008 Update
Artificial Recharge	Valley District's Replenishment Obligation	Western Judgement
	Diversion by SBVWCD	Settlement Agreement between SBVWCD and Valley District/ Western
	Diversion by Senior Water Rights Claimants	Seven Oaks Accord
	Diversion by Valley District/ Western	SAR Water Rights Applications
Conjunctive Use		None

Table 3

Groundwater Budgets for IRWMP Run 1A - 2006 to 2044
(in acre-ft)

Water Years	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]
	INFLOW								OUTFLOW							
	Recharge from Gaged Streamflow	Artificial Recharge	Recharge from Local Runoff Generated by Precipitation	Infiltration from Direct Precipitation	Return Flow from Groundwater Pumping	Recharge from Ungaged Mountain Front Runoff	Underflow Recharge	Total Inflow	Evapo-transpiration	Groundwater Pumping	Groundwater Pumping for Conjunctive Use			Underflow Discharge	Total Outflow	CHANGE IN GROUNDWATER STORAGE
											40,000 acre-ft	90,000 acre-ft	140,000 acre-ft			
2006	81,839	23,091	3,524	1,109	38,077	10,336	3,491	161,466	8,102	211,957	0	0	0	2,616	222,676	**-61,209**
2007	45,765	30,146	5,804	1,109	42,436	5,371	3,455	134,086	6,363	230,965	5,000	0	0	2,481	244,809	**-110,723**
2008	42,612	35,449	3,306	1,109	42,306	5,491	3,420	133,693	4,200	228,153	10,000	0	0	2,394	244,747	**-111,054**
2009	114,190	42,150	7,266	1,109	41,645	12,708	3,385	222,453	3,350	225,125	15,000	0	0	2,374	245,849	**-23,396**
2010	131,361	63,101	4,938	1,109	34,161	20,225	3,349	258,244	3,649	193,241	20,000	0	0	2,340	219,230	**39,014**
2011	142,863	100,351	5,734	1,109	35,932	18,952	3,314	308,255	6,602	203,113	15,000	0	0	2,301	227,016	**81,239**
2012	79,328	59,171	2,510	1,109	40,436	9,211	3,279	195,044	5,068	217,449	25,000	0	0	2,406	249,923	**-54,879**
2013	384,905	150,546	10,694	1,109	38,027	67,034	3,243	655,558	17,590	210,486	10,000	0	0	2,515	240,591	**414,967**
2014	76,567	87,669	4,868	1,109	38,759	11,632	3,208	223,811	17,397	221,288	20,000	0	0	2,512	261,197	**-37,386**
2015	61,090	77,060	4,504	1,109	41,424	9,645	3,172	198,005	11,600	234,249	20,000	0	0	2,450	268,299	**-70,294**
2016	54,903	68,630	2,292	1,109	44,242	7,200	3,137	181,514	8,369	243,528	25,000	0	0	2,410	279,307	**-97,793**
2017	107,350	76,401	4,854	1,109	41,906	17,593	3,102	252,317	6,587	230,010	20,000	0	0	2,386	258,983	**-6,667**
2018	92,200	68,207	5,038	1,109	45,138	11,497	3,066	226,255	6,786	240,657	10,000	0	0	2,344	259,787	**-33,532**
2019	72,585	69,265	3,992	1,109	46,491	9,645	3,031	206,118	5,933	244,669	20,000	0	0	2,302	272,905	**-66,787**
2020	73,426	61,402	5,043	1,109	47,700	9,520	2,996	201,195	4,994	250,182	20,000	0	0	2,250	277,425	**-76,230**
2021	60,835	30,000	4,990	1,109	48,681	7,200	2,960	155,776	2,317	254,986	40,000	0	0	2,245	299,547	**-143,771**
2022	424,232	108,253	10,317	1,109	48,555	34,125	2,925	629,516	8,846	254,137	15,000	0	0	2,262	280,245	**349,271**
2023	183,171	89,730	5,507	1,109	47,699	31,769	2,890	361,873	16,708	245,578	20,000	0	0	2,366	284,653	**77,221**
2024	304,457	131,872	8,890	1,109	48,043	68,000	2,854	565,226	28,091	254,596	10,000	0	0	2,467	295,154	**270,073**
2025	85,624	88,519	3,852	1,109	49,610	10,336	2,819	241,869	25,132	266,139	20,000	0	0	2,520	313,792	**-71,922**
2026	116,048	93,042	7,669	1,109	49,767	19,024	2,784	289,443	21,843	264,846	10,000	0	0	2,681	299,370	**-9,927**
2027	309,460	116,823	11,503	1,109	50,031	50,499	2,748	542,175	31,000	262,923	10,000	0	0	2,823	306,746	**235,429**
2028	68,853	114,500	2,988	1,109	48,779	12,036	2,713	250,979	28,689	263,029	25,000	0	0	2,818	319,536	**-68,558**
2029	77,713	101,295	3,648	1,109	50,442	9,520	2,678	246,404	24,260	265,622	25,000	0	0	2,805	317,687	**-71,283**
2030	106,436	90,643	5,196	1,109	48,412	13,361	2,642	267,799	22,400	250,592	15,000	0	0	2,779	290,771	**-22,971**
2031	62,914	78,921	4,361	1,109	51,674	7,526	2,607	209,112	17,341	268,668	20,000	0	0	2,683	308,691	**-99,579**
2032	59,256	45,000	4,076	1,109	53,726	6,501	2,572	172,240	9,640	271,987	30,000	0	0	2,563	314,190	**-141,950**
2033	46,695	72,558	2,419	1,109	54,696	5,491	2,536	185,505	7,039	277,330	30,000	0	0	2,433	316,802	**-131,297**
2034	36,274	30,000	2,741	1,109	57,353	3,994	2,501	133,971	3,645	289,105	40,000	0	0	2,320	335,070	**-201,098**
2035	75,562	31,319	5,971	1,109	50,239	8,210	2,466	174,875	2,140	260,936	40,000	0	0	2,245	305,321	**-130,447**
2036	111,483	38,295	6,728	1,109	50,262	12,233	2,430	222,540	2,036	255,612	40,000	0	0	2,203	299,851	**-77,311**
2037	385,886	146,963	8,798	1,109	47,967	52,706	2,395	645,825	8,778	256,268	15,000	0	0	2,190	282,236	**363,588**
2038	86,192	97,145	4,640	1,109	49,599	11,089	2,360	252,134	8,234	259,090	25,000	0	0	2,174	294,497	**-42,363**
2039	253,791	136,994	7,240	1,109	48,557	38,572	2,324	488,587	15,412	258,922	15,000	0	0	2,185	291,519	**197,067**
2040	105,581	122,340	6,259	1,109	50,535	14,326	2,289	302,440	19,261	267,029	20,000	0	0	2,201	308,491	**-6,052**
2041	93,770	111,770	5,809	1,109	51,004	11,089	2,254	276,804	17,521	267,185	20,000	0	0	2,218	306,924	**-30,120**
2042	255,298	124,434	9,704	1,109	49,439	36,070	2,218	478,272	25,403	258,469	15,000	0	0	2,262	301,133	**177,139**
2043	56,997	112,515	2,276	1,109	51,593	7,281	2,183	233,954	23,002	267,557	20,000	0	0	2,259	312,818	**-78,864**
2044	53,106	98,520	4,213	1,109	54,021	6,472	2,148	219,589	14,747	281,580	20,000	0	0	2,492	318,819	**-99,230**
Average	**127,708**	**82,669**	**5,491**	**1,109**	**46,907**	**18,038**	**2,819**	**284,742**	**12,822**	**248,904**	**19,872**	**0**	**0**	**2,417**	**284,016**	**726**

Note:
[1] Model-Calculated
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[14] Model input based on historical conditions and model-calculated water level in Heap Well
[15] = sum of [9] through [14]
[16] = [8]-[15]

Baseline Run 1A		
Hydrologic Base Period		1962-2000
Groundwater Pumping		2005 Urban Water Management Plans with 2008 Update
Artificial Recharge	Valley District's Replenishment Obligation	Western Judgement
	Diversion by SBVWCD	Settlement Agreement between SBVWCD and Valley District/ Western
	Diversion by Senior Water Rights Claimants	Seven Oaks Accord
	Diversion by Valley District/ Western	SAR Water Rights Applications
Conjunctive Use		Maximum Annual Additional Yield of 40,000 AF

Table 4

Groundwater Budgets for IRWMP Run 1B - 2006 to 2044
(in acre-ft)

Water Years	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]
	INFLOW								OUTFLOW							
											Groundwater Pumping for Conjunctive Use					
	Recharge from Gaged Streamflow	Artificial Recharge	Recharge from Local Runoff Generated by Precipitation	Infiltration from Direct Precipitation	Return Flow from Groundwater Pumping	Recharge from Ungaged Mountain Front Runoff	Underflow Recharge	Total Inflow	Evapo-transpiration	Groundwater Pumping	40,000 acre-ft	90,000 acre-ft	140,000 acre-ft	Underflow Discharge	Total Outflow	CHANGE IN GROUNDWATER STORAGE
2006	81,839	73,091	3,524	1,109	38,077	10,336	3,491	211,466	9,192	211,957	0	40,000	0	2,751	263,899	**-52,433**
2007	45,764	110,146	5,804	1,109	42,436	5,371	3,455	214,085	8,008	230,965	5,000	20,000	0	2,614	266,587	**-52,502**
2008	42,612	75,449	3,306	1,109	42,306	5,491	3,420	173,693	4,933	228,153	10,000	60,000	0	2,474	305,560	**-131,868**
2009	114,190	122,150	7,266	1,109	41,645	12,708	3,385	302,453	6,392	225,125	15,000	20,000	0	2,395	268,912	**33,541**
2010	131,356	113,101	4,938	1,109	34,161	20,225	3,349	308,240	5,868	193,241	20,000	40,000	0	2,391	261,499	**46,741**
2011	142,861	180,351	5,734	1,109	35,932	18,952	3,314	388,253	10,267	203,113	15,000	20,000	0	2,372	250,752	**137,501**
2012	78,364	109,171	2,510	1,109	40,436	9,211	3,279	244,079	8,958	217,449	25,000	40,000	0	2,355	293,761	**-49,682**
2013	338,705	172,116	10,694	1,109	38,027	67,034	3,243	630,928	24,945	210,486	10,000	20,000	0	2,499	267,930	**362,998**
2014	56,074	170,120	4,868	1,109	38,759	11,632	3,208	285,769	29,256	221,288	20,000	20,000	0	2,666	293,210	**-7,440**
2015	55,980	157,060	4,504	1,109	41,424	9,645	3,172	272,895	26,689	234,249	20,000	20,000	0	2,748	303,686	**-30,791**
2016	54,903	118,630	2,292	1,109	44,242	7,200	3,137	231,514	17,934	243,528	25,000	40,000	0	2,709	329,171	**-97,658**
2017	107,350	136,401	4,854	1,109	41,906	17,593	3,102	312,316	18,304	230,010	20,000	20,000	0	2,679	290,993	**21,323**
2018	89,164	148,207	5,038	1,109	45,138	11,497	3,066	303,219	21,346	240,657	10,000	20,000	0	2,739	294,742	**8,477**
2019	72,565	149,265	3,992	1,109	46,491	9,645	3,031	286,098	20,853	244,669	20,000	20,000	0	2,782	308,304	**-22,206**
2020	73,426	82,475	5,043	1,109	47,700	9,520	2,996	222,269	11,230	250,182	20,000	80,000	0	2,689	364,101	**-141,832**
2021	60,835	50,000	4,990	1,109	48,681	7,200	2,960	175,776	3,276	254,986	40,000	80,000	0	2,487	380,748	**-204,972**
2022	412,385	167,181	10,317	1,109	48,555	34,125	2,925	676,596	14,599	254,137	15,000	20,000	0	2,441	306,178	**370,419**
2023	182,369	139,729	5,507	1,109	47,699	31,769	2,890	411,071	23,927	245,578	20,000	40,000	0	2,528	332,034	**79,037**
2024	237,278	174,931	8,890	1,109	48,043	68,000	2,854	541,106	33,771	254,596	10,000	20,000	0	2,757	321,123	**219,982**
2025	64,594	132,134	3,852	1,109	49,610	10,336	2,819	264,454	24,579	266,139	20,000	60,000	0	2,868	373,586	**-109,132**
2026	66,159	145,808	7,669	1,109	49,767	19,024	2,784	292,320	21,177	264,846	10,000	20,000	0	2,838	318,861	**-26,541**
2027	241,376	140,180	11,503	1,109	50,031	50,499	2,748	497,447	30,272	262,923	10,000	20,000	0	2,903	326,098	**171,349**
2028	46,967	136,540	2,988	1,109	48,779	12,036	2,713	251,132	27,012	263,029	25,000	20,000	0	2,890	337,932	**-86,800**
2029	77,723	132,053	3,648	1,109	50,442	9,520	2,678	277,172	18,942	265,622	25,000	60,000	0	2,749	372,312	**-95,140**
2030	79,732	166,114	5,196	1,109	48,412	13,361	2,642	316,566	20,717	250,592	15,000	20,000	0	2,706	309,014	**7,551**
2031	62,915	120,207	4,361	1,109	51,674	7,526	2,607	250,400	15,524	268,668	20,000	60,000	0	2,649	366,841	**-116,441**
2032	59,255	65,000	4,076	1,109	53,726	6,501	2,572	192,239	6,692	271,987	30,000	80,000	0	2,492	391,171	**-198,932**
2033	46,697	112,948	2,419	1,109	54,696	5,491	2,536	225,897	4,972	277,330	30,000	60,000	0	2,345	374,647	**-148,750**
2034	36,272	50,000	2,741	1,109	57,353	3,994	2,501	153,969	2,896	289,105	40,000	80,000	0	2,218	414,219	**-260,249**
2035	75,557	51,319	5,971	1,109	50,239	8,210	2,466	194,870	2,829	260,936	40,000	80,000	0	2,129	385,894	**-191,024**
2036	111,486	58,295	6,728	1,109	50,262	12,233	2,430	242,542	2,603	255,612	40,000	80,000	0	2,076	380,291	**-137,748**
2037	385,888	186,740	8,798	1,109	47,967	52,706	2,395	685,604	9,571	256,268	15,000	20,000	0	2,054	302,893	**382,711**
2038	86,189	108,572	4,640	1,109	49,599	11,089	2,360	263,557	5,929	259,090	25,000	80,000	0	2,045	372,064	**-108,506**
2039	253,793	221,985	7,240	1,109	48,557	38,572	2,324	573,580	13,654	258,922	15,000	20,000	0	2,038	309,614	**263,966**
2040	96,639	187,253	6,259	1,109	50,535	14,326	2,289	358,411	14,517	267,029	20,000	20,000	0	2,046	323,592	**34,819**
2041	71,534	192,258	5,809	1,109	51,004	11,089	2,254	335,056	14,262	267,185	20,000	20,000	0	2,062	323,508	**11,548**
2042	252,597	147,688	9,704	1,109	49,439	36,070	2,218	498,826	22,985	258,469	15,000	20,000	0	2,079	318,532	**180,294**
2043	34,736	190,234	2,276	1,109	51,593	7,281	2,183	289,412	22,899	267,557	20,000	20,000	0	2,109	332,565	**-43,153**
2044	48,360	177,932	4,213	1,109	54,021	6,472	2,148	294,255	17,176	281,580	20,000	20,000	0	2,130	340,886	**-46,631**
Average	**117,346**	**132,637**	**5,491**	**1,109**	**46,907**	**18,038**	**2,819**	**324,347**	**15,358**	**248,904**	**19,872**	**38,462**	**0**	**2,474**	**325,070**	**-722**

Note:
[1] Model-Calculated
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[14] Model input based on historical conditions and model-calculated water level in Heap Well
[15] = sum of [9] through [14]
[16] = [8]-[15]

Baseline Run 1B		
Hydrologic Base Period		1962-2000
Groundwater Pumping		2005 Urban Water Management Plans with 2008 Update
Artificial Recharge	Valley District's Replenishment Obligation	Western Judgement
	Diversion by SBVWCD	Settlement Agreement between SBVWCD and Valley District/ Western
	Diversion by Senior Water Rights Claimants	Seven Oaks Accord
	Diversion by Valley District/ Western	SAR Water Rights Applications
Conjunctive Use		Maximum Annual Additional Yield of 90,000 AF

Table 5

Groundwater Budgets for IRWMP Run 1C - 2006 to 2044
(in acre-ft)

Water Years	[1] INFLOW: Recharge from Gaged Streamflow	[2] INFLOW: Artificial Recharge	[3] INFLOW: Recharge from Local Runoff Generated by Precipitation	[4] INFLOW: Infiltration from Direct Precipitation	[5] INFLOW: Return Flow from Groundwater Pumping	[6] INFLOW: Recharge from Ungaged Mountain Front Runoff	[7] INFLOW: Underflow Recharge	[8] INFLOW: Total Inflow	[9] OUTFLOW: Evapo-transpiration	[10] OUTFLOW: Groundwater Pumping	[11] OUTFLOW: Groundwater Pumping for Conjunctive Use: 40,000 acre-ft	[12] OUTFLOW: Groundwater Pumping for Conjunctive Use: 90,000 acre-ft	[13] OUTFLOW: Groundwater Pumping for Conjunctive Use: 140,000 acre-ft	[14] OUTFLOW: Underflow Discharge	[15] OUTFLOW: Total Outflow	[16] CHANGE IN GROUNDWATER STORAGE
2006	81,839	123,090	3,524	1,109	38,077	10,336	3,491	261,466	9,640	211,957	0	40,000	40,000	2,770	304,367	**-42,901**
2007	45,763	190,146	5,804	1,109	42,436	5,371	3,455	294,084	9,643	230,965	5,000	20,000	20,000	2,776	288,384	**5,701**
2008	42,612	115,448	3,306	1,109	42,306	5,491	3,420	213,692	6,580	228,153	10,000	60,000	50,000	2,623	357,356	**-143,664**
2009	110,648	202,150	7,266	1,109	41,645	12,708	3,385	378,912	8,105	225,125	15,000	20,000	20,000	2,636	290,866	**88,046**
2010	131,356	163,101	4,938	1,109	34,161	20,225	3,349	358,239	8,433	193,241	20,000	40,000	40,000	2,689	304,363	**53,876**
2011	142,860	238,424	5,734	1,109	35,932	18,952	3,314	446,325	17,123	203,113	15,000	20,000	20,000	2,830	278,066	**168,259**
2012	65,575	159,171	2,510	1,109	40,436	9,211	3,279	281,291	15,017	217,449	25,000	40,000	40,000	2,724	340,190	**-58,899**
2013	317,156	192,116	10,694	1,109	38,027	67,034	3,243	629,379	29,012	210,486	10,000	20,000	20,000	3,112	292,610	**336,769**
2014	16,692	223,572	4,868	1,109	38,759	11,632	3,208	299,839	31,242	221,288	20,000	20,000	20,000	3,687	316,218	**-16,379**
2015	8,721	217,262	4,504	1,109	41,424	9,645	3,172	285,838	25,682	234,249	20,000	20,000	20,000	3,971	323,902	**-38,064**
2016	50,200	168,630	2,292	1,109	44,242	7,200	3,137	276,810	15,672	243,528	25,000	40,000	40,000	3,839	368,039	**-91,229**
2017	68,537	196,401	4,854	1,109	41,906	17,593	3,102	333,503	15,924	230,010	20,000	20,000	20,000	3,812	309,746	**23,758**
2018	27,547	213,739	5,038	1,109	45,138	11,497	3,066	307,135	17,490	240,657	10,000	20,000	20,000	4,028	312,175	**-5,040**
2019	14,673	217,317	3,992	1,109	46,491	9,645	3,031	296,259	16,751	244,669	20,000	20,000	20,000	4,111	325,531	**-29,272**
2020	73,424	102,475	5,043	1,109	47,700	9,520	2,996	242,268	8,297	250,182	20,000	80,000	60,000	3,420	421,899	**-179,632**
2021	60,836	70,000	4,990	1,109	48,681	7,200	2,960	195,777	3,697	254,986	40,000	80,000	60,000	2,862	441,544	**-245,767**
2022	406,529	196,933	10,317	1,109	48,555	34,125	2,925	700,494	13,524	254,137	15,000	20,000	20,000	2,698	325,360	**375,134**
2023	166,223	189,729	5,507	1,109	47,699	31,769	2,890	444,925	22,610	245,578	20,000	40,000	40,000	2,770	370,959	**73,967**
2024	250,042	187,826	8,890	1,109	48,043	68,000	2,854	566,766	33,550	254,596	10,000	20,000	20,000	3,011	341,156	**225,610**
2025	34,427	173,286	3,852	1,109	49,610	10,336	2,819	275,440	19,630	266,139	20,000	60,000	50,000	3,089	418,858	**-143,418**
2026	64,032	188,433	7,669	1,109	49,767	19,024	2,784	332,818	18,267	264,846	10,000	20,000	20,000	3,034	336,147	**-3,329**
2027	246,368	196,433	11,503	1,109	50,031	50,499	2,748	558,692	31,498	262,923	10,000	20,000	20,000	3,179	347,600	**211,092**
2028	42,385	160,764	2,988	1,109	48,779	12,036	2,713	270,775	26,193	263,029	25,000	20,000	20,000	3,272	357,495	**-86,720**
2029	55,663	172,053	3,648	1,109	50,442	9,520	2,678	295,112	14,740	265,622	25,000	60,000	50,000	3,120	418,481	**-123,370**
2030	54,440	246,114	5,196	1,109	48,412	13,361	2,642	371,273	17,420	250,592	15,000	20,000	20,000	3,605	326,617	**44,657**
2031	62,916	160,207	4,361	1,109	51,674	7,526	2,607	290,400	15,097	268,668	20,000	60,000	20,000	3,374	387,139	**-96,738**
2032	59,256	85,000	4,076	1,109	53,726	6,501	2,572	212,240	7,094	271,987	30,000	80,000	40,000	2,934	432,014	**-219,775**
2033	46,697	152,948	2,419	1,109	54,696	5,491	2,536	265,897	7,561	277,330	30,000	60,000	20,000	2,628	397,518	**-131,621**
2034	36,271	70,000	2,741	1,109	57,353	3,994	2,501	173,969	4,080	289,105	40,000	80,000	40,000	2,396	455,581	**-281,612**
2035	75,560	71,319	5,971	1,109	50,239	8,210	2,466	214,873	3,915	260,936	40,000	80,000	40,000	2,233	427,083	**-212,210**
2036	111,486	78,295	6,728	1,109	50,262	12,233	2,430	262,543	3,774	255,612	40,000	80,000	40,000	2,138	421,523	**-158,981**
2037	385,885	206,740	8,798	1,109	47,967	52,706	2,395	705,601	10,813	256,268	15,000	20,000	20,000	2,101	324,181	**381,420**
2038	86,192	128,571	4,640	1,109	49,599	11,089	2,360	283,559	7,052	259,090	25,000	80,000	40,000	2,078	413,220	**-129,661**
2039	253,792	258,626	7,240	1,109	48,557	38,572	2,324	610,220	14,481	258,922	15,000	20,000	20,000	2,096	330,500	**279,721**
2040	82,953	227,254	6,259	1,109	50,535	14,326	2,289	384,726	14,927	267,029	20,000	20,000	20,000	2,145	344,100	**40,625**
2041	61,136	232,259	5,809	1,109	51,004	11,089	2,254	364,659	13,443	267,185	20,000	20,000	20,000	2,193	342,820	**21,840**
2042	256,285	167,692	9,704	1,109	49,439	36,070	2,218	522,518	17,076	258,469	15,000	20,000	20,000	2,170	332,715	**189,803**
2043	27,073	230,234	2,276	1,109	51,593	7,281	2,183	321,749	17,980	267,557	20,000	20,000	20,000	2,275	347,812	**-26,063**
2044	38,567	217,931	4,213	1,109	54,021	6,472	2,148	324,462	13,191	281,580	20,000	20,000	20,000	2,378	357,149	**-32,687**
Average	**106,734**	**174,146**	**5,491**	**1,109**	**46,907**	**18,038**	**2,819**	**355,244**	**15,031**	**248,904**	**19,872**	**38,462**	**29,487**	**2,892**	**354,648**	**596**

Note:
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[14] Model input based on historical conditions and model-calculated water level in Heap Well
[15] = sum of [9] through [14]
[16] = [8]-[15]

Baseline Run 1C		
Hydrologic Base Period		1962-2000
Groundwater Pumping		2005 Urban Water Management Plans with 2008 Update
Artificial Recharge	**Valley District's Replenishment Obligation**	Western Judgement
Artificial Recharge	**Diversion by SBVWCD**	Settlement Agreement between SBVWCD and Valley District/ Western
Artificial Recharge	**Diversion by Senior Water Rights Claimants**	Seven Oaks Accord
Artificial Recharge	**Diversion by Valley District/ Western**	SAR Water Rights Applications
Conjunctive Use		Maximum Annual Additional Yield of 140,000 AF

Groundwater Budgets for IRWMP Scenario of 50% SWP Supply Reliability - 2006 to 2044
(in acre-ft)

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]
	INFLOW								OUTFLOW							
											Groundwater Pumping for Conjunctive Use					
Water Years	**Recharge from Gaged Streamflow**	**Artificial Recharge**	**Recharge from Local Runoff Generated by Precipitation**	**Infiltration from Direct Precipitation**	**Return Flow from Groundwater Pumping**	**Recharge from Ungaged Mountain Front Runoff**	**Underflow Recharge**	**Total Inflow**	**Evapo-transpiration**	**Groundwater Pumping**	**40,000 acre-ft**	**90,000 acre-ft**	**140,000 acre-ft**	**Underflow Discharge**	**Total Outflow**	**CHANGE IN GROUNDWATER STORAGE**
2006	81,839	18,091	3,524	1,109	38,077	10,336	3,491	156,466	7,853	211,957	0	0	0	2,771	222,580	**-66,114**
2007	45,765	20,146	5,804	1,109	42,436	5,371	3,455	124,086	5,860	230,965	0	0	0	2,644	239,470	**-115,384**
2008	42,612	20,448	3,306	1,109	42,306	5,491	3,420	118,692	3,449	228,153	0	0	0	2,536	234,138	**-115,446**
2009	114,190	22,150	7,266	1,109	41,645	12,708	3,385	202,454	2,357	225,125	0	0	0	2,475	229,957	**-27,503**
2010	131,359	33,101	4,938	1,109	34,161	20,225	3,349	228,243	2,365	193,241	0	0	0	2,452	198,057	**30,186**
2011	142,863	70,352	5,734	1,109	35,932	18,952	3,314	278,255	5,608	203,113	0	0	0	2,420	211,141	**67,114**
2012	79,328	29,171	2,510	1,109	40,436	9,211	3,279	165,044	4,001	217,449	0	0	0	2,385	223,835	**-58,791**
2013	387,010	117,095	10,694	1,109	38,027	67,034	3,243	624,212	16,149	210,486	0	0	0	2,493	229,128	**395,084**
2014	76,496	55,473	4,868	1,109	38,759	11,632	3,208	191,544	15,905	221,288	0	0	0	2,636	239,829	**-48,285**
2015	61,090	47,004	4,504	1,109	41,424	9,645	3,172	167,949	10,330	234,249	0	0	0	2,646	247,224	**-79,276**
2016	54,904	22,822	2,292	1,109	44,242	7,200	3,137	135,706	6,054	243,528	0	0	0	2,593	252,175	**-116,469**
2017	107,351	61,409	4,854	1,109	41,906	17,593	3,102	237,324	5,965	230,010	0	0	0	2,519	238,494	**-1,169**
2018	92,200	44,110	5,038	1,109	45,138	11,497	3,066	202,159	5,227	240,657	0	0	0	2,478	248,362	**-46,203**
2019	72,585	35,076	3,992	1,109	46,491	9,645	3,031	171,929	3,657	244,669	0	0	0	2,437	250,764	**-78,835**
2020	73,426	21,005	5,043	1,109	47,700	9,520	2,996	160,799	2,095	250,182	0	0	0	2,374	254,651	**-93,852**
2021	60,834	0	4,990	1,109	48,681	7,200	2,960	125,776	726	254,986	0	0	0	2,290	258,002	**-132,226**
2022	424,570	91,496	10,317	1,109	48,555	34,125	2,925	613,098	7,474	254,137	0	0	0	2,274	263,885	**349,212**
2023	183,172	76,254	5,507	1,109	47,699	31,769	2,890	348,399	13,805	245,578	0	0	0	2,283	261,666	**86,733**
2024	319,554	128,806	8,890	1,109	48,043	68,000	2,854	577,257	24,829	254,596	0	0	0	2,382	281,807	**295,451**
2025	84,286	66,203	3,852	1,109	49,610	10,336	2,819	218,215	19,666	266,139	0	0	0	2,508	288,313	**-70,098**
2026	128,550	54,054	7,669	1,109	49,767	19,024	2,784	262,957	16,486	264,846	0	0	0	2,547	283,879	**-20,922**
2027	312,667	94,034	11,503	1,109	50,031	50,499	2,748	522,592	24,215	262,923	0	0	0	2,668	289,806	**232,786**
2028	86,744	60,025	2,988	1,109	48,779	12,036	2,713	214,395	20,465	263,029	0	0	0	2,814	286,309	**-71,914**
2029	77,638	32,013	3,648	1,109	50,442	9,520	2,678	177,047	13,292	265,622	0	0	0	2,810	281,724	**-104,677**
2030	108,619	27,656	5,196	1,109	48,412	13,361	2,642	206,995	9,631	250,592	0	0	0	2,742	262,965	**-55,970**
2031	62,914	14,017	4,361	1,109	51,674	7,526	2,607	144,207	6,914	268,668	0	0	0	2,637	278,219	**-134,011**
2032	59,256	0	4,076	1,109	53,726	6,501	2,572	127,240	3,393	271,987	0	0	0	2,504	277,883	**-150,644**
2033	46,698	14,808	2,419	1,109	54,696	5,491	2,536	127,758	1,867	277,330	0	0	0	2,379	281,576	**-153,818**
2034	36,274	0	2,741	1,109	57,353	3,994	2,501	103,971	351	289,105	0	0	0	2,273	291,730	**-187,759**
2035	75,559	1,319	5,971	1,109	50,239	8,210	2,466	144,872	244	260,936	0	0	0	2,195	263,375	**-118,503**
2036	111,499	8,295	6,728	1,109	50,262	12,233	2,430	192,556	416	255,612	0	0	0	2,146	258,174	**-65,619**
2037	385,886	116,317	8,798	1,109	47,967	52,706	2,395	615,179	6,673	256,268	0	0	0	2,122	265,063	**350,116**
2038	86,192	29,566	4,640	1,109	49,599	11,089	2,360	184,555	3,360	259,090	0	0	0	2,118	264,568	**-80,013**
2039	253,793	94,613	7,240	1,109	48,557	38,572	2,324	446,207	7,897	258,922	0	0	0	2,106	268,926	**177,281**
2040	109,746	39,703	6,259	1,109	50,535	14,326	2,289	223,967	5,326	267,029	0	0	0	2,100	274,455	**-50,487**
2041	93,769	29,390	5,809	1,109	51,004	11,089	2,254	194,423	3,246	267,185	0	0	0	2,092	272,523	**-78,100**
2042	256,284	77,054	9,704	1,109	49,439	36,070	2,218	431,878	9,422	258,469	0	0	0	2,087	269,977	**161,901**
2043	62,910	25,135	2,276	1,109	51,593	7,281	2,183	152,487	5,694	267,557	0	0	0	2,086	275,337	**-122,850**
2044	53,106	13,352	4,213	1,109	54,021	6,472	2,148	134,421	2,569	281,580	0	0	0	2,074	286,224	**-151,802**
Average	**129,321**	**43,886**	**5,491**	**1,109**	**46,907**	**18,038**	**2,819**	**247,572**	**7,816**	**248,904**	**0**	**0**	**0**	**2,413**	**259,133**	**-11,561**

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Groundwater Budgets for IRWMP Scenario of 60% SWP Supply Reliability - 2006 to 2044
(in acre-ft)

Water Years	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]
	INFLOW								OUTFLOW							
											Groundwater Pumping for Conjunctive Use					
	Recharge from Gaged Streamflow	Artificial Recharge	Recharge from Local Runoff Generated by Precipitation	Infiltration from Direct Precipitation	Return Flow from Groundwater Pumping	Recharge from Ungaged Mountain Front Runoff	Underflow Recharge	Total Inflow	Evapo-transpiration	Groundwater Pumping	40,000 acre-ft	90,000 acre-ft	140,000 acre-ft	Underflow Discharge	Total Outflow	CHANGE IN GROUNDWATER STORAGE
2006	81,839	18,091	3,524	1,109	38,077	10,336	3,491	156,466	7,853	211,957	0	0	0	2,771	222,580	**-66,114**
2007	45,765	20,146	5,804	1,109	42,436	5,371	3,455	124,086	5,860	230,965	0	0	0	2,644	239,470	**-115,384**
2008	42,612	20,448	3,306	1,109	42,306	5,491	3,420	118,692	3,449	228,153	0	0	0	2,536	234,138	**-115,446**
2009	114,190	22,150	7,266	1,109	41,645	12,708	3,385	202,454	2,357	225,125	0	0	0	2,475	229,957	**-27,503**
2010	131,359	33,101	4,938	1,109	34,161	20,225	3,349	228,243	2,365	193,241	0	0	0	2,452	198,057	**30,186**
2011	142,863	70,352	5,734	1,109	35,932	18,952	3,314	278,255	5,608	203,113	0	0	0	2,420	211,141	**67,114**
2012	79,328	29,171	2,510	1,109	40,436	9,211	3,279	165,044	4,001	217,449	0	0	0	2,385	223,835	**-58,791**
2013	387,010	117,095	10,694	1,109	38,027	67,034	3,243	624,212	16,149	210,486	0	0	0	2,493	229,128	**395,084**
2014	76,496	55,473	4,868	1,109	38,759	11,632	3,208	191,544	15,905	221,288	0	0	0	2,636	239,829	**-48,285**
2015	61,091	47,060	4,504	1,109	41,424	9,645	3,172	168,006	10,332	234,249	0	0	0	2,646	247,227	**-79,222**
2016	54,903	30,948	2,292	1,109	44,242	7,200	3,137	143,832	6,461	243,528	0	0	0	2,598	252,587	**-108,756**
2017	107,351	69,084	4,854	1,109	41,906	17,593	3,102	244,999	6,356	230,010	0	0	0	2,537	238,903	**6,097**
2018	92,200	48,207	5,038	1,109	45,138	11,497	3,066	206,256	5,451	240,657	0	0	0	2,508	248,616	**-42,360**
2019	72,585	47,388	3,992	1,109	46,491	9,645	3,031	184,241	4,304	244,669	0	0	0	2,479	251,452	**-67,211**
2020	73,425	30,362	5,043	1,109	47,700	9,520	2,996	170,155	2,587	250,182	0	0	0	2,427	255,196	**-85,041**
2021	60,834	0	4,990	1,109	48,681	7,200	2,960	125,776	729	254,986	0	0	0	2,343	258,058	**-132,282**
2022	424,555	103,070	10,317	1,109	48,555	34,125	2,925	624,656	8,205	254,137	0	0	0	2,330	264,673	**359,983**
2023	183,171	87,458	5,507	1,109	47,699	31,769	2,890	359,602	15,052	245,578	0	0	0	2,353	262,983	**96,618**
2024	314,444	139,271	8,890	1,109	48,043	68,000	2,854	582,612	25,854	254,596	0	0	0	2,494	282,944	**299,668**
2025	81,962	77,530	3,852	1,109	49,610	10,336	2,819	227,218	20,689	266,139	0	0	0	2,676	289,504	**-62,286**
2026	125,662	66,366	7,669	1,109	49,767	19,024	2,784	272,381	17,727	264,846	0	0	0	2,747	285,319	**-12,938**
2027	306,061	105,731	11,503	1,109	50,031	50,499	2,748	527,682	26,506	262,923	0	0	0	2,936	292,365	**235,318**
2028	82,305	72,337	2,988	1,109	48,779	12,036	2,713	222,268	24,277	263,029	0	0	0	3,164	290,471	**-68,203**
2029	77,385	42,232	3,648	1,109	50,442	9,520	2,678	187,013	16,130	265,622	0	0	0	3,188	284,940	**-97,927**
2030	108,617	36,152	5,196	1,109	48,412	13,361	2,642	215,488	11,490	250,592	0	0	0	3,118	265,200	**-49,712**
2031	62,916	23,866	4,361	1,109	51,674	7,526	2,607	154,059	8,280	268,668	0	0	0	2,986	279,933	**-125,875**
2032	59,257	0	4,076	1,109	53,726	6,501	2,572	127,241	4,157	271,987	0	0	0	2,795	278,939	**-151,699**
2033	46,695	25,274	2,419	1,109	54,696	5,491	2,536	138,220	2,875	277,330	0	0	0	2,605	282,809	**-144,589**
2034	36,275	0	2,741	1,109	57,353	3,994	2,501	103,972	409	289,105	0	0	0	2,445	291,959	**-187,987**
2035	75,560	1,319	5,971	1,109	50,239	8,210	2,466	144,873	259	260,936	0	0	0	2,319	263,514	**-118,641**
2036	111,494	8,295	6,728	1,109	50,262	12,233	2,430	192,551	439	255,612	0	0	0	2,241	258,292	**-65,740**
2037	385,887	128,629	8,798	1,109	47,967	52,706	2,395	627,492	7,471	256,268	0	0	0	2,204	265,943	**361,549**
2038	86,192	38,923	4,640	1,109	49,599	11,089	2,360	193,912	3,962	259,090	0	0	0	2,202	265,254	**-71,343**
2039	253,793	106,432	7,240	1,109	48,557	38,572	2,324	458,027	9,759	258,922	0	0	0	2,189	270,870	**187,157**
2040	109,747	51,522	6,259	1,109	50,535	14,326	2,289	235,788	8,892	267,029	0	0	0	2,184	278,105	**-42,317**
2041	93,769	41,210	5,809	1,109	51,004	11,089	2,254	206,243	5,682	267,185	0	0	0	2,177	275,044	**-68,802**
2042	256,286	88,874	9,704	1,109	49,439	36,070	2,218	443,701	13,228	258,469	0	0	0	2,175	273,872	**169,829**
2043	62,908	36,955	2,276	1,109	51,593	7,281	2,183	164,305	8,912	267,557	0	0	0	2,181	278,650	**-114,345**
2044	53,104	24,458	4,213	1,109	54,021	6,472	2,148	145,525	4,092	281,580	0	0	0	2,165	287,838	**-142,313**
Average	**128,767**	**50,384**	**5,491**	**1,109**	**46,907**	**18,038**	**2,819**	**253,515**	**8,823**	**248,904**	**0**	**0**	**0**	**2,519**	**260,246**	**-6,731**

Note:
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[12] Model input data from Allocation Model
[13] Model input data from Allocation Model
[14] Model input based on historical conditions and model-calculated water level in Heap Well
[15] = sum of [9] through [14]
[16] = [8]-[15]

Table 8

Groundwater Budgets for IRWMP Scenario of 90% Local Surface Water Supply - 2006 to 2044
(in acre-ft)

Water Years	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]
	INFLOW								OUTFLOW							
											Groundwater Pumping for Conjunctive Use					
	Recharge from Gaged Streamflow	Artificial Recharge	Recharge from Local Runoff Generated by Precipitation	Infiltration from Direct Precipitation	Return Flow from Groundwater Pumping	Recharge from Ungaged Mountain Front Runoff	Underflow Recharge	Total Inflow	Evapo-transpiration	Groundwater Pumping	40,000 acre-ft	90,000 acre-ft	140,000 acre-ft	Underflow Discharge	Total Outflow	CHANGE IN GROUNDWATER STORAGE
2006	73,655	16,766	3,171	998	38,077	9,302	3,491	145,460	7,625	211,957	0	0	0	2,769	222,351	**-76,891**
2007	41,188	20,146	5,224	998	42,436	4,834	3,455	118,281	5,510	230,965	0	0	0	2,638	239,114	**-120,833**
2008	38,351	20,448	2,976	998	42,306	4,942	3,420	113,440	3,103	228,153	0	0	0	2,526	233,783	**-120,342**
2009	102,771	22,126	6,540	998	41,645	11,437	3,385	188,902	2,067	225,125	0	0	0	2,451	229,643	**-40,741**
2010	121,752	33,037	4,444	998	34,161	18,203	3,349	215,944	1,770	193,241	0	0	0	2,419	197,429	**18,515**
2011	128,973	68,427	5,161	998	35,932	17,057	3,314	259,861	4,212	203,113	0	0	0	2,383	209,707	**50,154**
2012	71,396	29,171	2,259	998	40,436	8,290	3,279	155,828	2,989	217,449	0	0	0	2,344	222,781	**-66,953**
2013	386,111	123,973	9,624	998	38,027	60,331	3,243	622,307	14,086	210,486	0	0	0	2,401	226,973	**395,334**
2014	68,966	34,358	4,381	998	38,759	10,469	3,208	161,138	12,825	221,288	0	0	0	2,495	236,608	**-75,470**
2015	54,982	46,858	4,054	998	41,424	8,680	3,172	160,169	8,659	234,249	0	0	0	2,481	245,389	**-85,220**
2016	49,414	42,814	2,063	998	44,242	6,480	3,137	149,149	5,829	243,528	0	0	0	2,441	251,799	**-102,651**
2017	96,615	55,274	4,369	998	41,906	15,834	3,102	218,099	4,037	230,010	0	0	0	2,394	236,441	**-18,343**
2018	82,980	48,207	4,534	998	45,138	10,348	3,066	195,271	3,876	240,657	0	0	0	2,363	246,896	**-51,625**
2019	65,327	49,265	3,593	998	46,491	8,680	3,031	177,385	3,275	244,669	0	0	0	2,336	250,280	**-72,894**
2020	66,083	42,475	4,538	998	47,700	8,568	2,996	173,359	2,747	250,182	0	0	0	2,299	255,228	**-81,869**
2021	54,751	0	4,491	998	48,681	6,480	2,960	118,363	548	254,986	0	0	0	2,240	257,774	**-139,411**
2022	396,679	100,965	9,285	998	48,555	30,713	2,925	590,120	6,066	254,137	0	0	0	2,216	262,420	**327,700**
2023	165,251	85,848	4,956	998	47,699	28,592	2,890	336,234	8,224	245,578	0	0	0	2,219	256,021	**80,212**
2024	336,906	135,785	8,001	998	48,043	61,200	2,854	593,788	20,105	254,596	0	0	0	2,257	276,957	**316,831**
2025	81,051	68,485	3,467	998	49,610	9,302	2,819	215,733	17,029	266,139	0	0	0	2,337	285,506	**-69,772**
2026	124,452	83,036	6,902	998	49,767	17,121	2,784	285,060	15,014	264,846	0	0	0	2,369	282,229	**2,831**
2027	295,653	118,513	10,353	998	50,031	45,449	2,748	523,746	23,746	262,923	0	0	0	2,439	289,108	**234,638**
2028	84,985	77,826	2,690	998	48,779	10,833	2,713	228,824	21,938	263,029	0	0	0	2,554	287,522	**-58,698**
2029	69,951	61,295	3,283	998	50,442	8,568	2,678	197,215	14,787	265,622	0	0	0	2,599	283,008	**-85,793**
2030	97,754	54,333	4,676	998	48,412	12,025	2,642	220,841	10,066	250,592	0	0	0	2,601	263,259	**-42,418**
2031	56,624	45,207	3,925	998	51,674	6,774	2,607	167,808	7,414	268,668	0	0	0	2,574	278,655	**-110,847**
2032	53,330	0	3,668	998	53,726	5,851	2,572	120,145	2,241	271,987	0	0	0	2,501	276,729	**-156,584**
2033	42,026	47,948	2,177	998	54,696	4,942	2,536	155,324	3,054	277,330	0	0	0	2,402	282,786	**-127,462**
2034	32,648	0	2,467	998	57,353	3,595	2,501	99,561	250	289,105	0	0	0	2,313	291,667	**-192,106**
2035	68,004	213	5,374	998	50,239	7,389	2,466	134,682	109	260,936	0	0	0	2,227	263,272	**-128,590**
2036	103,887	7,418	6,055	998	50,262	11,010	2,430	182,060	269	255,612	0	0	0	2,169	258,050	**-75,990**
2037	347,695	150,615	7,918	998	47,967	47,436	2,395	605,025	7,672	256,268	0	0	0	2,132	266,072	**338,952**
2038	77,573	59,197	4,176	998	49,599	9,980	2,360	203,883	4,599	259,090	0	0	0	2,128	265,817	**-61,934**
2039	228,809	125,571	6,516	998	48,557	34,714	2,324	447,489	8,330	258,922	0	0	0	2,125	269,378	**178,112**
2040	98,771	75,998	5,634	998	50,535	12,894	2,289	247,119	6,080	267,029	0	0	0	2,126	275,234	**-28,116**
2041	84,394	65,791	5,228	998	51,004	9,980	2,254	219,648	4,678	267,185	0	0	0	2,128	273,990	**-54,342**
2042	231,053	111,142	8,734	998	49,439	32,463	2,218	436,048	8,722	258,469	0	0	0	2,133	269,324	**166,724**
2043	56,618	63,003	2,048	998	51,593	6,553	2,183	182,996	6,162	267,557	0	0	0	2,142	275,861	**-92,865**
2044	47,796	52,931	3,792	998	54,021	5,825	2,148	167,511	4,452	281,580	0	0	0	2,138	288,170	**-120,659**
Average	**120,134**	**57,550**	**4,942**	**998**	**46,907**	**16,234**	**2,819**	**249,585**	**7,286**	**248,904**	**0**	**0**	**0**	**2,354**	**258,544**	**-8,959**

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[16] = [8]-[15]

Groundwater Budgets for IRWMP Scenario of 95% Local Surface Water Supply - 2006 to 2044
(in acre-ft)

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]
	INFLOW								OUTFLOW							
											Groundwater Pumping for Conjunctive Use					
Water Years	Recharge from Gaged Streamflow	Artificial Recharge	Recharge from Local Runoff Generated by Precipitation	Infiltration from Direct Precipitation	Return Flow from Groundwater Pumping	Recharge from Ungaged Mountain Front Runoff	Underflow Recharge	Total Inflow	Evapo-transpiration	Groundwater Pumping	40,000 acre-ft	90,000 acre-ft	140,000 acre-ft	Underflow Discharge	Total Outflow	CHANGE IN GROUNDWATER STORAGE
2006	77,747	17,421	3,348	1,054	38,077	9,819	3,491	150,956	7,722	211,957	0	0	0	2,770	222,449	**-71,493**
2007	43,477	20,146	5,514	1,054	42,436	5,102	3,455	121,183	5,673	230,965	0	0	0	2,641	239,279	**-118,095**
2008	40,481	20,448	3,141	1,054	42,306	5,216	3,420	116,066	3,270	228,153	0	0	0	2,531	233,954	**-117,888**
2009	108,480	22,126	6,903	1,054	41,645	12,073	3,385	195,666	2,197	225,125	0	0	0	2,462	229,784	**-34,118**
2010	126,557	33,037	4,691	1,054	34,161	19,214	3,349	222,062	2,014	193,241	0	0	0	2,434	197,689	**24,373**
2011	135,918	67,598	5,447	1,054	35,932	18,004	3,314	267,267	4,701	203,113	0	0	0	2,400	210,214	**57,053**
2012	75,362	29,171	2,384	1,054	40,436	8,751	3,279	160,436	3,417	217,449	0	0	0	2,363	223,229	**-62,792**
2013	389,475	125,717	10,159	1,054	38,027	63,683	3,243	631,357	15,435	210,486	0	0	0	2,455	228,377	**402,981**
2014	72,797	42,205	4,624	1,054	38,759	11,051	3,208	173,697	14,328	221,288	0	0	0	2,583	238,199	**-64,502**
2015	58,036	46,858	4,279	1,054	41,424	9,162	3,172	163,986	9,526	234,249	0	0	0	2,575	246,350	**-82,363**
2016	52,159	43,219	2,178	1,054	44,242	6,840	3,137	152,829	6,508	243,528	0	0	0	2,531	252,568	**-99,739**
2017	101,983	56,401	4,612	1,054	41,906	16,714	3,102	225,771	4,866	230,010	0	0	0	2,479	237,355	**-11,584**
2018	87,590	48,207	4,786	1,054	45,138	10,922	3,066	200,763	4,658	240,657	0	0	0	2,445	247,760	**-46,997**
2019	68,957	49,265	3,793	1,054	46,491	9,162	3,031	181,752	3,748	244,669	0	0	0	2,415	250,832	**-69,080**
2020	69,755	42,475	4,790	1,054	47,700	9,044	2,996	177,814	2,893	250,182	0	0	0	2,371	255,446	**-77,631**
2021	57,793	0	4,741	1,054	48,681	6,840	2,960	122,070	622	254,986	0	0	0	2,302	257,909	**-135,840**
2022	413,431	104,634	9,801	1,054	48,555	32,419	2,925	612,819	6,819	254,137	0	0	0	2,289	263,244	**349,574**
2023	174,211	87,215	5,231	1,054	47,699	30,181	2,890	348,480	10,482	245,578	0	0	0	2,301	258,361	**90,118**
2024	327,369	141,198	8,446	1,054	48,043	64,600	2,854	593,564	23,674	254,596	0	0	0	2,394	280,663	**312,901**
2025	84,691	69,845	3,659	1,054	49,610	9,819	2,819	221,498	19,049	266,139	0	0	0	2,541	287,730	**-66,232**
2026	128,891	84,306	7,286	1,054	49,767	18,073	2,784	292,159	17,715	264,846	0	0	0	2,607	285,168	**6,991**
2027	297,337	120,848	10,928	1,054	50,031	47,974	2,748	530,920	27,417	262,923	0	0	0	2,765	293,105	**237,816**
2028	81,819	78,865	2,839	1,054	48,779	11,435	2,713	227,503	25,222	263,029	0	0	0	2,961	291,212	**-63,709**
2029	73,744	61,295	3,465	1,054	50,442	9,044	2,678	201,721	17,811	265,622	0	0	0	3,019	286,451	**-84,730**
2030	103,186	55,101	4,936	1,054	48,412	12,693	2,642	228,024	13,376	250,592	0	0	0	3,009	266,976	**-38,952**
2031	59,769	45,207	4,143	1,054	51,674	7,150	2,607	171,604	10,021	268,668	0	0	0	2,949	281,638	**-110,035**
2032	56,293	0	3,872	1,054	53,726	6,176	2,572	123,693	3,788	271,987	0	0	0	2,815	278,590	**-154,898**
2033	44,362	47,948	2,298	1,054	54,696	5,216	2,536	158,111	3,649	277,330	0	0	0	2,646	283,625	**-125,514**
2034	34,459	0	2,604	1,054	57,353	3,794	2,501	101,764	323	289,105	0	0	0	2,498	291,926	**-190,162**
2035	71,784	799	5,672	1,054	50,239	7,799	2,466	139,812	160	260,936	0	0	0	2,362	263,458	**-123,646**
2036	107,689	7,758	6,391	1,054	50,262	11,621	2,430	187,205	352	255,612	0	0	0	2,273	258,236	**-71,031**
2037	366,790	153,006	8,358	1,054	47,967	50,071	2,395	629,641	8,270	256,268	0	0	0	2,224	266,762	**362,879**
2038	81,884	59,197	4,408	1,054	49,599	10,535	2,360	209,036	4,799	259,090	0	0	0	2,225	266,114	**-57,078**
2039	241,301	130,281	6,878	1,054	48,557	36,643	2,324	467,037	9,813	258,922	0	0	0	2,223	270,958	**196,079**
2040	104,257	76,783	5,946	1,054	50,535	13,610	2,289	254,474	8,531	267,029	0	0	0	2,229	277,789	**-23,315**
2041	89,081	66,491	5,518	1,054	51,004	10,535	2,254	225,937	6,458	267,185	0	0	0	2,238	275,880	**-49,944**
2042	243,670	112,853	9,219	1,054	49,439	34,267	2,218	452,720	14,102	258,469	0	0	0	2,252	274,823	**177,897**
2043	59,763	63,003	2,162	1,054	51,593	6,917	2,183	186,675	11,545	267,557	0	0	0	2,275	281,377	**-94,703**
2044	50,454	52,931	4,003	1,054	54,021	6,148	2,148	170,759	6,651	281,580	0	0	0	2,273	290,505	**-119,746**
Average	**124,687**	**58,561**	**5,217**	**1,054**	**46,907**	**17,136**	**2,819**	**256,380**	**8,759**	**248,904**	**0**	**0**	**0**	**2,490**	**260,154**	**-3,773**

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Summary of Impact from Changes in Reliability of SWP - 50% Supply

			Water Level Above Top of Screen		Water Level 0-25% Below Top of Screen Interval		Water Level 25-50% Below Top of Screen Interval		Water Level >50% Below Top of Screen Interval	
Owner	**No. of Wells Analyzed**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**
Colton, City of	5	7,229	2	2,244	2	4,041	1	943	0	0
East Valley Water District	19	26,877	16	24,623	2	2,178	0	0	1	76
Fontana W.C.	0	0	0	0	0	0	0	0	0	0
Loma Linda, City of	5	6,314	5	6,314	0	0	0	0	0	0
Marigold Mutual W.C.	0	0	0	0	0	0	0	0	0	0
Muscoy Mutual W.C.	2	1,391	0	0	0	0	0	0	2	1,391
Redlands, City of - Water Utility	9	10,980	3	4,062	2	2,330	0	0	4	4,589
Rialto, City of	1	383	0	0	0	0	0	0	1	383
San Bernardino Municipal Water District	2	3,576	2	3,576	0	0	0	0	0	0
San Bernardino Municipal Water Dept, City of	41	70,394	20	42,865	3	2,425	4	3,658	14	21,447
Terrace Water Co.	1	303	1	303	0	0	0	0	0	0
West Valley Water District	8	11,185	2	4,062	3	4,516	1	533	2	2,074
Riverside Public Utilities	37	52,199	27	35,117	2	1,550	5	9,823	3	5,709
Riverside-Highland W.C.	3	3,576	2	2,626	1	950	0	0	0	0
Meeks and Daley W.C.	1	1,055	1	1,055	0	0	0	0	0	0
Regents of California	0	0	0	0	0	0	0	0	0	0
Totals	134	195,462	81	126,847	15	17,990	11	14,957	27	35,668

Table 10

Summary of Impact from Changes in Reliability of SWP - 60% Supply

			Water Level Above Top of Screen		Water Level 0-25% Below Top of Screen Interval		Water Level 25-50% Below Top of Screen Interval		Water Level >50% Below Top of Screen Interval	
Owner	**No. of Wells Analyzed**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**
Colton, City of	5	7,229	4	6,285	1	943	0	0	0	0
East Valley Water District	19	26,877	16	24,623	2	2,178	0	0	1	76
Fontana W.C.	0	0	0	0	0	0	0	0	0	0
Loma Linda, City of	5	6,314	5	6,314	0	0	0	0	0	0
Marigold Mutual W.C.	0	0	0	0	0	0	0	0	0	0
Muscoy Mutual W.C.	2	1,391	0	0	0	0	0	0	2	1,391
Redlands, City of - Water Utility	9	10,980	3	4,062	2	2,330	0	0	4	4,589
Rialto, City of	1	383	0	0	0	0	0	0	1	383
San Bernardino Municipal Water District	2	3,576	2	3,576	0	0	0	0	0	0
San Bernardino Municipal Water Dept, City of	41	70,394	21	43,087	4	4,197	3	3,864	13	19,246
Terrace Water Co.	1	303	1	303	0	0	0	0	0	0
West Valley Water District	8	11,185	3	5,055	3	4,057	1	1,034	1	1,038
Riverside Public Utilities	37	52,199	27	35,117	4	4,962	3	6,411	3	5,709
Riverside-Highland W.C.	3	3,576	2	2,626	1	950	0	0	0	0
Meeks and Daley W.C.	1	1,055	1	1,055	0	0	0	0	0	0
Regents of California	0	0	0	0	0	0	0	0	0	0
Totals	134	195,462	85	132,104	17	19,618	7	11,309	25	32,432

Table 11

Summary of Impact from Changes in Reliability of Local Surface Water Supply - 90% of Historical

			Water Level Above Top of Screen		Water Level 0-25% Below Top of Screen Interval		Water Level 25-50% Below Top of Screen Interval		Water Level >50% Below Top of Screen Interval	
Owner	No. of Wells Analyzed	Projected Pumping in 2036 [acre-ft]	No. of Wells	Projected Pumping in 2036 [acre-ft]	No. of Wells	Projected Pumping in 2036 [acre-ft]	No. of Wells	Projected Pumping in 2036 [acre-ft]	No. of Wells	Projected Pumping in 2036 [acre-ft]
Colton, City of	5	7,229	2	2,244	2	4,041	1	943	0	0
East Valley Water District	19	26,877	16	24,623	1	982	1	1,196	1	76
Fontana W.C.	0	0	0	0	0	0	0	0	0	0
Loma Linda, City of	5	6,314	5	6,314	0	0	0	0	0	0
Marigold Mutual W.C.	0	0	0	0	0	0	0	0	0	0
Muscoy Mutual W.C.	2	1,391	0	0	0	0	0	0	2	1,391
Redlands, City of - Water Utility	9	10,980	3	4,062	1	2,141	1	188	4	4,589
Rialto, City of	1	383	0	0	0	0	0	0	1	383
San Bernardino Municipal Water District	2	3,576	2	3,576	0	0	0	0	0	0
San Bernardino Municipal Water Dept, City of	41	70,394	21	43,087	4	4,199	2	1,662	14	21,447
Terrace Water Co.	1	303	1	303	0	0	0	0	0	0
West Valley Water District	8	11,185	2	4,062	3	4,516	1	533	2	2,074
Riverside Public Utilities	37	52,199	27	35,117	2	1,550	5	9,821	3	5,711
Riverside-Highland W.C.	3	3,576	2	2,626	1	950	0	0	0	0
Meeks and Daley W.C.	1	1,055	1	1,055	0	0	0	0	0	0
Regents of California	0	0	0	0	0	0	0	0	0	0
Totals	134	195,462	82	127,069	14	18,380	11	14,343	27	35,670

Table 12

Summary of Impact from Changes in Reliability of Local Surface Water Supplpy - 95% of Historical

			Water Level Above Top of Screen		Water Level 0-25% Below Top of Screen Interval		Water Level 25-50% Below Top of Screen Interval		Water Level >50% Below Top of Screen Interval	
Owner	**No. of Wells Analyzed**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**	**No. of Wells**	**Projected Pumping in 2036 [acre-ft]**
Colton, City of	5	7,229	4	6,285	1	943	0	0	0	0
East Valley Water District	19	26,877	16	24,623	1	982	1	1,196	1	76
Fontana W.C.	0	0	0	0	0	0	0	0	0	0
Loma Linda, City of	5	6,314	5	6,314	0	0	0	0	0	0
Marigold Mutual W.C.	0	0	0	0	0	0	0	0	0	0
Muscoy Mutual W.C.	2	1,391	0	0	0	0	0	0	2	1,391
Redlands, City of - Water Utility	9	10,980	3	4,062	1	2,141	1	188	4	4,589
Rialto, City of	1	383	0	0	0	0	0	0	1	383
San Bernardino Municipal Water District	2	3,576	2	3,576	0	0	0	0	0	0
San Bernardino Municipal Water Dept, City of	41	70,394	23	45,096	2	2,193	4	5,458	12	17,647
Terrace Water Co.	1	303	1	303	0	0	0	0	0	0
West Valley Water District	8	11,185	3	5,055	3	4,057	1	1,034	1	1,038
Riverside Public Utilities	37	52,199	27	35,117	4	4,960	3	6,411	3	5,711
Riverside-Highland W.C.	3	3,576	2	2,626	1	950	0	0	0	0
Meeks and Daley W.C.	1	1,055	1	1,055	0	0	0	0	0	0
Regents of California	0	0	0	0	0	0	0	0	0	0
Totals	134	195,462	87	134,113	13	16,227	10	14,287	24	30,835

Table 13

Table 14

Groundwater Budgets for Updated Baseline Run (Run 12) – 2007 to 2032
(in acre-ft)

		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
		INFLOW								OUTFLOW				
Model Year	Hydrologic Year	Recharge from Gaged Streamflow	Artificial Recharge	Recharge from Local Runoff Generated from Precipitation	Infiltration from Direct Precipitation	Return Flow from Groundwater Pumping	Recharge from Ungaged Mountain Front Runoff	Underflow Recharge	Total Inflow	Evapo-transpiration	Groundwater Pumping	Underflow Discharge	Total Outflow	CHANGE IN GROUNDWATER STORAGE
2007	**1979**	181,023	106,486	5,376	1,083	38,194	31,030	3,667	366,858	11,373	206,079	2,413	219,865	**146,993**
2008	**1980**	282,923	133,937	8,680	1,083	38,770	66,632	3,667	535,693	28,923	206,644	2,403	237,970	**297,723**
2009	**1981**	86,405	52,046	3,761	1,083	39,517	10,125	3,667	196,604	18,451	215,193	2,470	236,114	**-39,510**
2010	**1982**	108,673	96,150	7,488	1,083	40,493	18,593	3,667	276,147	19,304	215,930	2,573	237,807	**38,340**
2011	**1983**	263,117	124,636	11,231	1,083	41,248	49,131	3,667	494,114	36,606	217,363	2,692	256,661	**237,453**
2012	**1984**	88,843	91,971	2,918	1,083	41,643	11,637	3,667	241,761	32,931	221,773	2,924	257,628	**-15,866**
2013	**1985**	74,588	63,619	3,561	1,083	44,563	9,235	3,667	200,317	25,240	238,329	3,198	266,768	**-66,450**
2014	**1986**	94,056	63,133	5,073	1,083	43,164	13,106	3,667	223,282	22,221	231,828	3,391	257,440	**-34,158**
2015	**1987**	62,870	44,778	4,258	1,083	48,115	7,249	3,667	172,019	15,509	253,435	3,458	272,402	**-100,382**
2016	**1988**	59,314	8,202	3,980	1,083	50,292	6,389	3,667	132,925	7,399	262,069	3,413	272,882	**-139,956**
2017	**1989**	46,371	70,247	2,362	1,083	51,875	5,388	3,667	180,993	6,550	272,692	3,260	282,502	**-101,510**
2018	**1990**	36,166	10,996	2,676	1,083	55,177	3,866	3,667	113,631	1,357	282,283	3,054	286,694	**-173,063**
2019	**1991**	66,839	13,712	5,829	1,083	48,920	7,958	3,667	148,010	887	255,474	2,870	259,231	**-111,221**
2020	**1992**	104,925	27,482	6,569	1,083	49,845	11,878	3,667	205,450	1,615	253,332	2,716	257,663	**-52,214**
2021	**1993**	342,743	130,812	8,590	1,083	47,561	51,496	3,667	585,952	10,783	252,345	2,612	265,740	**320,212**
2022	**1994**	85,901	46,093	4,530	1,083	49,550	10,829	3,667	201,653	6,361	258,263	2,565	267,189	**-65,536**
2023	**1995**	237,122	127,647	7,069	1,083	48,612	37,558	3,667	462,757	20,327	261,107	2,525	283,959	**178,797**
2024	**1996**	100,322	96,251	6,111	1,083	51,842	14,036	3,667	273,313	18,002	275,637	2,487	296,125	**-22,812**
2025	**1997**	80,067	85,438	5,671	1,083	52,515	10,847	3,667	239,288	16,995	280,685	2,456	300,136	**-60,849**
2026	**1998**	218,584	128,634	9,475	1,083	50,240	35,275	3,667	446,959	30,319	276,413	2,430	309,162	**137,797**
2027	**1999**	62,827	123,007	2,222	1,083	54,663	7,189	3,667	254,658	27,640	289,810	2,418	319,869	**-65,210**
2028	**2000**	53,038	120,000	4,114	1,083	56,575	6,383	3,667	244,860	22,693	304,172	2,400	329,265	**-84,405**
2029	**2001**	48,468	120,000	1,235	1,083	54,735	4,708	3,667	233,896	18,121	291,241	2,364	311,726	**-77,830**
2030	**2002**	31,560	120,000	2,052	1,083	58,526	3,519	3,667	220,407	13,368	308,311	2,328	324,007	**-103,601**
2031	**2003**	58,434	132,000	5,192	1,083	55,408	6,920	3,667	262,704	12,605	296,989	2,297	311,891	**-49,186**
2032	**2004**	68,222	144,000	5,728	1,083	56,939	5,457	3,667	285,096	12,678	295,889	2,264	310,832	**-25,737**
Average		**113,208**	**87,741**	**5,221**	**1,083**	**48,807**	**17,171**	**3,667**	**276,898**	**16,856**	**258,588**	**2,692**	**278,136**	**-1,238**

Note:
[1] Model-Calculated
[2] Model input data from Allocation Model
[3] Model input based on historical conditions
[4] Model input based on historical conditions
[5] Model input data from Allocation Model
[6] Model input based on historical conditions
[7] Model input based on historical conditions
[8] = sum of [1] through [7]
[9] Model-Calculated
[10] Model input data from Allocation Model
[11] Model input based on historical conditions and model-calculated water level in Heap Well
[12] = sum of [9] through [11]
[13] = [8]-[12]

Table 15

Comparisons of Model Assumptions and Results for IRWMP Baseline Run 1 and Updated Baseline Run (Run 12)

Parameters				Units	IRWMP Baseline Run 1	Updated Baseline Run (Run 12)
Model Assumptions	**Hydrologic Base Period**				1962-2000 with Annual Stress Period	1979-2004 with Monthly Stress Period
	Groundwater Pumping				2005 Urban Water Management Plans	2005 Urban Water Management Plans with 2008 Update
	Artificial Recharge		Valley District's Replenishment Obligation		Western Judgment (SWP Water Availability Based on DWR 2005 Projection)	Western Judgment (SWP Water Availability Based on DWR 2007 Projection)
			Diversion by SBVWCD		Settlement Agreement between SBVWCD and Valley District/Western*	SBVWCD's Licensed Rights
			Diversion by Senior Water Rights Claimants		Seven Oaks Accord	Seven Oaks Accord
			Valley District/Western		SAR Water Right Applications	SAR Water Right Applications
			SBMWD Recycled Water Recharge		None	Up to 25,500 acre-ft
Model Results	**Groundwater Elevations**				Flow directions and range of water level fluctuations are similar to the historical conditions	Flow directions and range of water level fluctuations are similar to the historical conditions
	Potential Liquefaction Area in the Pressure Zone				Potential liquefaction area accounts for zero to 6% of the Pressure Zone Area	Potential liquefaction area accounts for zero to 4% of the Pressure Zone area
	Groundwater Budgets	**Inflow**	Recharge from Gaged Streamflow	acre-ft/yr	128,489	113,208
			Artificial Recharge of SAR Water	acre-ft/yr	27,285	26,813
			Artificial Recharge of Imported Water	acre-ft/yr	32,428	48,279
			Artificial Recharge of Recycled Water	acre-ft/yr	0	12,649
			Recharge from Local Runoff Generated by Precipitation	acre-ft/yr	5,491	5,221
			Infiltration from Direct Precipitation	acre-ft/yr	1,109	1,083
			Return Flow from Groundwater Pumping	acre-ft/yr	46,907	48,807
			Recharge from Ungaged Mountain Front Runoff	acre-ft/yr	18,038	17,171
			Underflow Recharge	acre-ft/yr	2,819	3,667
			Total Inflow	acre-ft/yr	**262,567**	**276,898**
		Outflow	Evapotranspiration	acre-ft/yr	10,700	16,856
			Groundwater Pumping	acre-ft/yr	248,904	258,588
			Underflow Discharge	acre-ft/yr	2,642	2,692
			Total Outflow	acre-ft/yr	**262,245**	**278,136**
		Average Annual Change in Groundwater Storage (Total Inflow - Total Outflow)		acre-ft/yr	322	-1,238
		Cumulative Changes in Groundwater Storage Over the Modeling Period		acre-ft	12,600	-32,188
	PCE Plume			acres	Not Modeled	1,910 (initial area) reduced to 670 (end of predictive run 2032)
	TCE Plume			acres	Not Modeled	2,030 (initial area) reduced to 260 (end of predictive run 2032)
	Perchlorate Plume			acres	Not Modeled	7,820 (initial area) reduced to 420 (end of predictive run 2032)

*The San Bernardino Valley Water Conservation District withdrew their water rights application that they had submitted to the State Water Resources Control Board which was a condition of their settlement agreement with the San Bernardino Valley Municipal Water District. As a result, the Conservation District diversion amounts provided in the settlement agreement no longer apply and Conservation District's rights continue to be their two seasonal permits of License No. 2831 (January 1 to May 31) and License No.2832 (October 1 to December 31).

APPENDIX A

Terms and Definitions

GEOSCIENCE Support Services, Inc.

Terms and Definitions

Definition of Terms	Explanation
acre-ft	Acre foot; equivalent to a one acre area covered with water one foot of water.
Alluvium	A geologic term describing beds of sand, gravel, silt and clay deposited by flowing water.
amsl	Above mean sea level.
Anisotropy	The property of being directionally dependent, as opposed to isotropy, which means homogeneity in all directions.
Aquifer	A geologic formation or group of formations which store, transmit and yield significant quantities of water to wells and springs.
Areal Recharge	Areal recharge is the regionally distributed recharge to the groundwater system as a result of precipitation.
Artificial Recharge	Involves surface spreading of water in basins in order to percolate water and recharge the aquifer or direct injection of water into the aquifer through injection wells.
Assimilative Capacity	The capacity of a natural body of water to receive wastewaters or toxic materials without deleterious effects and without damage to aquatic life or humans who consume the water.
Basement Complex	Bedrock below a sedimentary basin that is metamorphic or igneous in origin.
Calibration	Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria.
Conceptual Model	A hypothesis that explains how a hydrogeologic system works. It consists of basic elements such as inflow, outflow, and system geometry.

Definition of Terms	Explanation
Conductance	Fluid conductance is related to the rate at which a unit of material can transmit fluids, and is used mainly in hydrology in relation to river and lake bottoms. It is an application of intrinsic permeability to a unit of material with a defined area and thickness.
Confined Aquifer	A permeable geologic unit located beneath a relatively impermeable unit whose piezometric water level is higher than the confining layer.
Conjunctive Use	Conjunctive use is the coordinated management of surface water and groundwater supplies to maximize the yield of the overall water resource.
Crystalline Basement	Bedrock below a sedimentary basin that is metamorphic or igneous in origin
DEM	Digital Elevation Model.
Dispersivity	An empirical factor which quantifies how contaminants stray from the path of the groundwater which is carrying it.
Drainage Area	An extent of land where water from rain or snowmelt drains downhill into a body of water, such as a river, lake, reservoir, estuary, wetland, sea or ocean.
EarthVision	Software for 3D model building and visualization.
Effective Porosity	A fraction consisting of the void space that forms part of the interconnected flow paths through the medium, per unit volume of porous medium (excluding void space in isolated or dead-end pores). Also known as "specific yield."
Effluent	The outflow of water from a natural body of water, or aquifer.
Evaporation	The process by which water is changed from the liquid or solid state into the gaseous state through the transfer of heat energy.
Evapotranspiration	A term embracing that portion of the precipitation returned to the air through direct evaporation or by transpiration of vegetation.

Definition of Terms	Explanation
Exceedance Probability	Statistical test of a probability exceeding some value.
Extraction	Generally refers to the pumping of ground water from wells.
Fault	A fracture in the earth's crust, with displacement of one side of the fracture with respect to the other.
Flux	Flux is defined as the amount of water that flows through a unit area per unit time.
Forebay	An area of high permeable soils which allow for the deep percolation of surface waters.
Geostatistics	Geostatistics is a branch of geology that deals with the analysis of spatial variance through mathematical models and is applied in disciplines such as, hydrogeology and hydrology.
GoCAD	Geological Object Computer Aided Design.
Groundwater	The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined or semi-confined aquifer.
Groundwater Budget	An accounting of the inflow, outflow, and storage in an aquifer or a drainage basin.
Groundwater Level	The elevation of the water table or other potentiometric surface at a particular location.
Groundwater System	All the components of subsurface materials that relate to water, including Aquifers (confined and unconfined), zones of saturation, and water tables.
Groundwater Table	The upper surface of the saturated zone that determines the water level in a well in an unconfined aquifer.
Gslib	Geostatistical Software Library.

Definition of Terms	Explanation
Head	Also known as hydraulic head or piezometric head is a specific measurement of water pressure above a geodetic datum. It is usually measured as a water surface elevation, expressed in units of length.
HFB	Horizontal Flow Barrier.
Hydraulic Budget	An accounting of the inflow, outflow, and storage in an aquifer or a drainage basin.
Hydraulic Conductivity	The measure of the ability of the soil to transmit fluid, dependent upon both the properties of the soil and those of the fluid.
Infiltration	The process of water entry into the soil surface from rainfall, snowmelt or irrigation, and the subsequent percolation downward through the soil.
Influent	The inflow of water from a natural body of water, or aquifer.
Injection Well	A well used for introducing water into an aquifer.
Isoheytal	A line on a map connecting areas of equal rainfall.
Kriging	Kriging is a group of geostatistical techniques to interpolate the value of a random field (e.g., the elevation) at an unobserved location from observations of its value at nearby locations.
Leaky Aquifer	An aquifer overlaid and/or underlain by a thin semipervious layer through which flow into or out of the aquifer can take place.
Mass Balance	A quantitative statement of the conservation of mass. In groundwater hydrology, it is simply Inflow = Outflow ± Change in Storage. Also known as a water balance or hydrologic budget.
MODFLOW	MODFLOW, a three-dimensional, numerical (finite-difference) ground-water flow model code.
MODPATH	A particle-tracking postprocessor model for MODFLOW.

Definition of Terms	Explanation
Mountain Front Runoff	Recharge to the aquifer due to surface runoff from watersheds that flows over bedrock and infiltrates at the bedrock-alluvium contact at the base of the mountain.
MT3DMS	A modular 3D multi-species transport model for simulation of advection, dispersion, and chemical reactions of contaminants in groundwater systems
PCE	Tetrachloroethylene, or perchloroethylene is a chlorinated hydrocarbon chemical compound.
Perchlorate	Perchlorates are the salts derived from perchloric acid.
Percolation	The vertical migration of water through the soil or alluvium to the ground water table.
Permeability	The capability of soil or other geologic formations to transmit water. The term is used to separate the effects of the medium from those of the fluid on the hydraulic conductivity.
Recharge	Flow to ground water storage from precipitation, infiltration from streams, and other sources of water.
RBFM	Refined Basin Flow Model.
RBSTM	Refined Basin Solute Transport Model
Residual	A residual is a measured quantity minus modeled quantity.
Return Flow	The amount of water that reaches a ground or surface water source after release from the point of use and thus becomes available for further use.
Runoff	That part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers.
Safe Yield	The maximum quantity of water that can be continuously withdrawn from a ground water basin without adverse effects.

Definition of Terms	Explanation
Salinity	Consisting of or containing salts, the most common of which are potassium, sodium, or magnesium in combination with chloride, nitrate, or carbonate.
Saturated Zone	The part of a water bearing layer of rock or soil in which all spaces are filled with water.
SBBA	San Bernardino Basin Area consists of the Bunker Hill and Lytle Creek groundwater basins.
Seepage	The slow movement of ground water from a basin or aquifer to a collection point such as a lake.
Sensitivity Analysis	The study of how the variation (uncertainty) in the output of a mathematical model can be apportioned, qualitatively or quantitatively, to different sources of variation in the input of a model.
Sink	A groundwater modeling flux term that “removes” water or solutes out of the model.
Solute	Any substance that is dissolved in water.
Solute Transport	The movement of dissolved substances in an aquifer.
Solute Transport Model	Mathematical model used to predict the movement of solutes (generally contaminants) in an aquifer through time.
Source	A groundwater modeling flux term that “adds” water or solutes into the model.
Specific Storativity	The volume of water that a unit volume of porous medium releases from or takes into storage per unit change in hydraulic head, while remaining fully saturated.

Specific Yield	The volume that a given aquifer will yield when all the water is allowed to drain out of it under the forces of gravity.
Definition of Terms	Explanation
Spreading Grounds	Basins that are excavated in the existing terrain so that the water can percolate into the soil and recharge aquifers.
Standard Deviation	A measure of the variability or dispersion of a data set. A low standard deviation indicates that the data points tend to be very close to the same value (the mean), while high standard deviation indicates that the data are "spread out" over a large range of values.
Storage	The storage of water in ground water reservoirs.
Storativity	Specific storativity multiplied by the aquifer thickness.
Streamflow Routing	Streamflow routing provides a set of methods for describing and predicting the movement of water from one point to another along a river.
Stress Period	Computational time intervals for a MODFLOW simulation in which the model stresses (inflows and outflows) are constant.
SWP	State Water Project.
TCE	Trichloroethylene or trichloroethene is a chlorinated hydrocarbon chemical compound.
TIN	Total inorganic nitrogen.
Transient Model	A numerical model in which the model stresses (inflows and outflows) and aquifer head vary over time.
Transmissivity	A measure of the ability of an aquifer to transmit water. The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.
Transpiration	The process by which water vapor escapes from a living plant and enters the atmosphere.
Unconfined Aquifer	A permeable geologic unit with the water table forming its upper boundary.

Underflow	Interbasin groundwater movement.
Definition of Terms	Explanation
USCS	Unified Soil Classification System is used to describe the texture and grain size of a soil.
USGS	United States Geological Survey.
Vadose Zone	The subsurface zone between the water table (Zone of Saturation) and the land surface where some of the spaces between the soil particles are filled with air. Also referred to as the Unsaturated Zone.
Vertical Leakance	The vertical flow between aquifer layers modeled in MODFLOW.
Watershed	Also known as drainage basin is an extent of land where water from rain or snow melt drains downhill into a body of water, such as a river, lake, reservoir, estuary, wetland, sea or ocean.

APPENDIX B

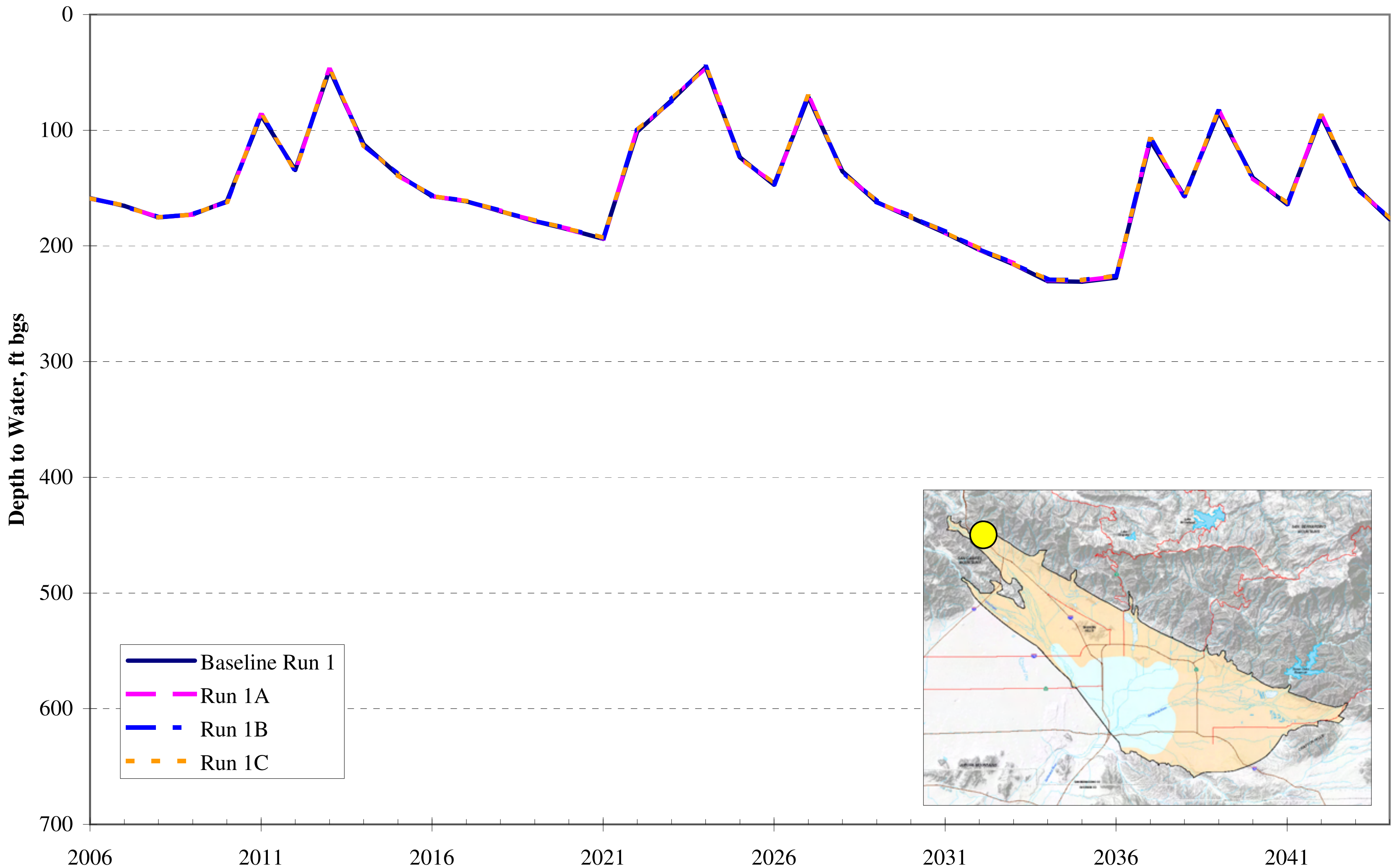
Selected Hydrographs of

IRWMP Baseline Run and

Conjunctive Use Scenarios

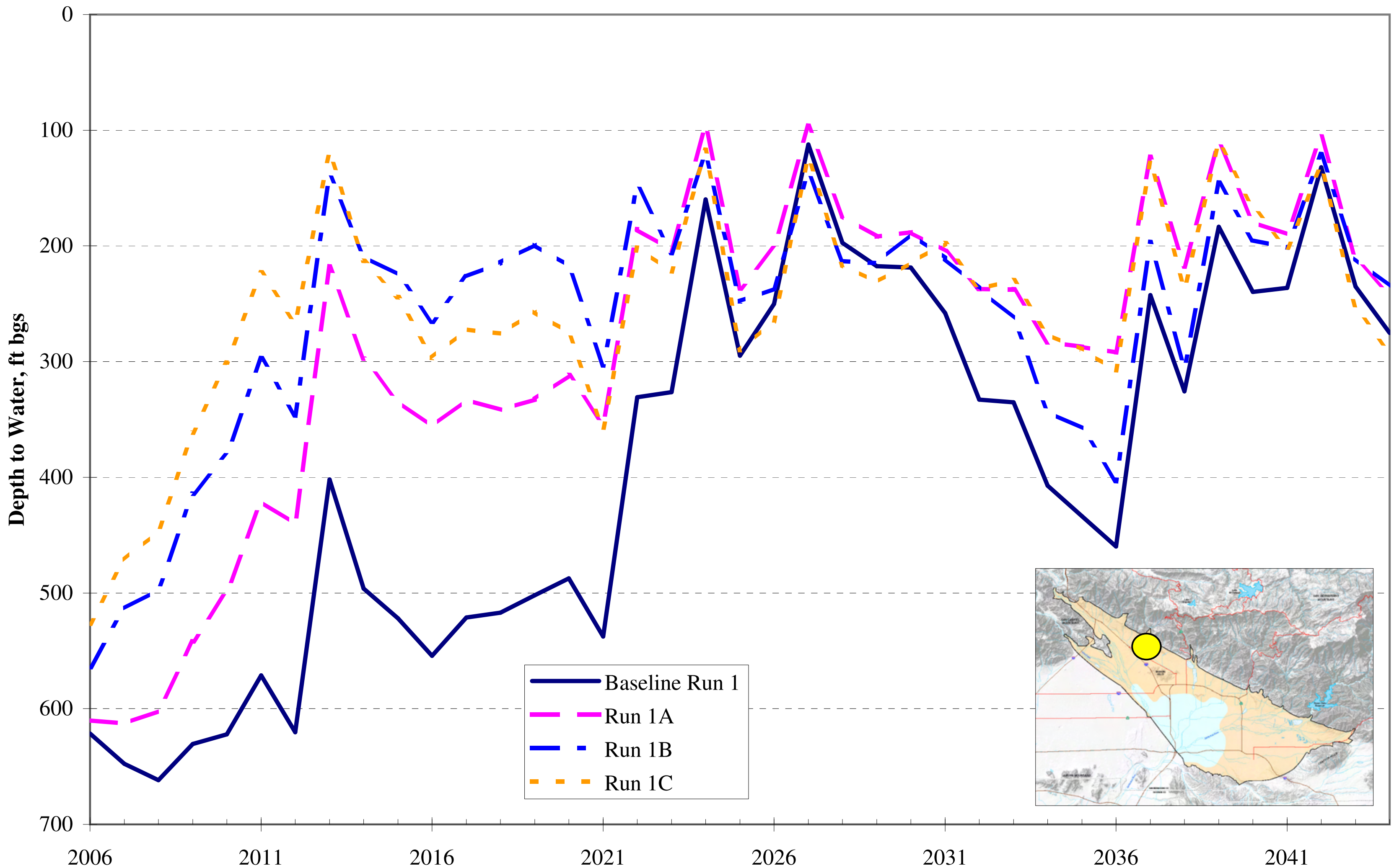
GEOSCIENCE Support Services, Inc.

Depth to Water for City of San Bernardino Vincent Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044



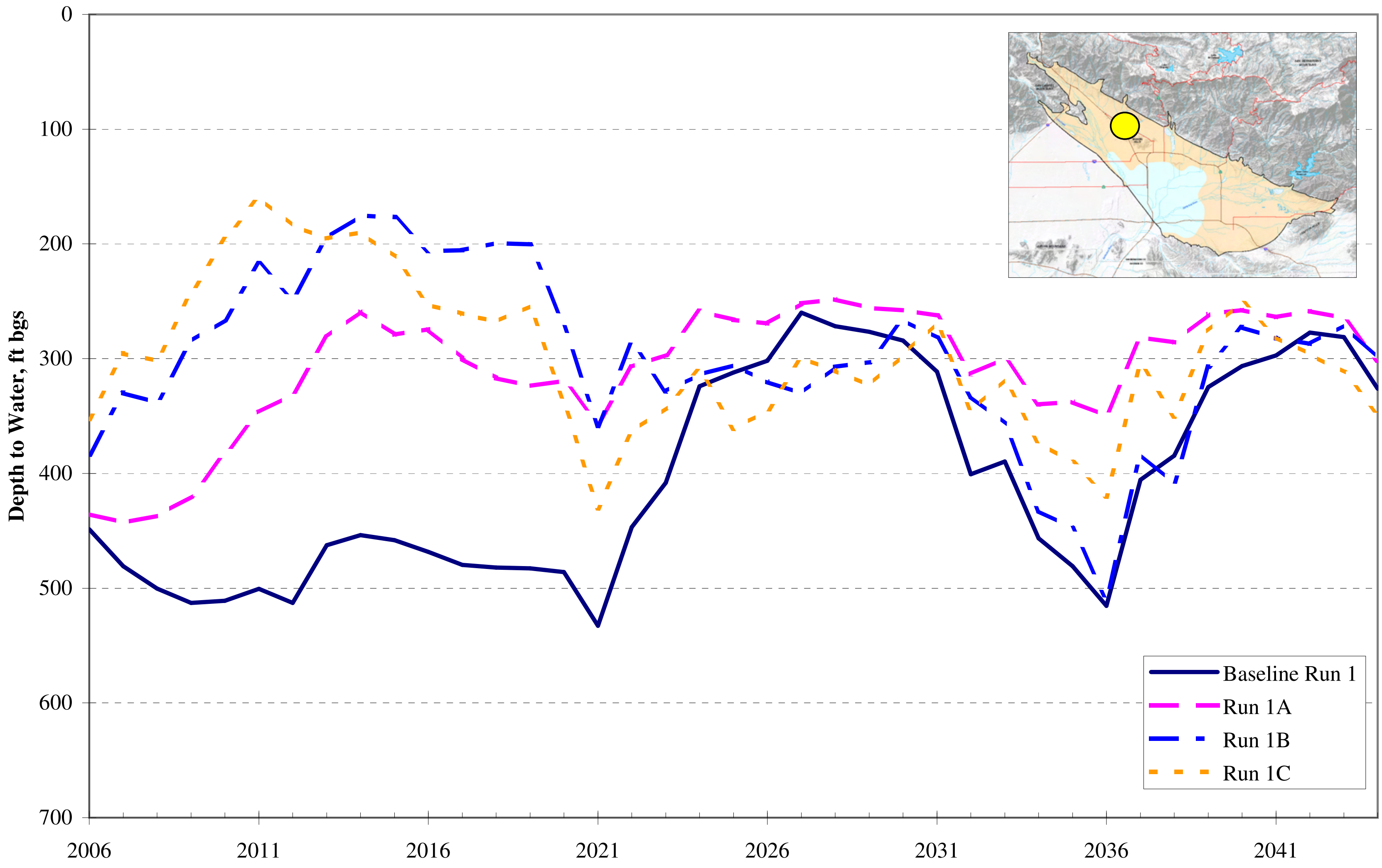
Appendix B

Depth to Water for City of San Bernardino Devil Canyon Well No. 3
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044



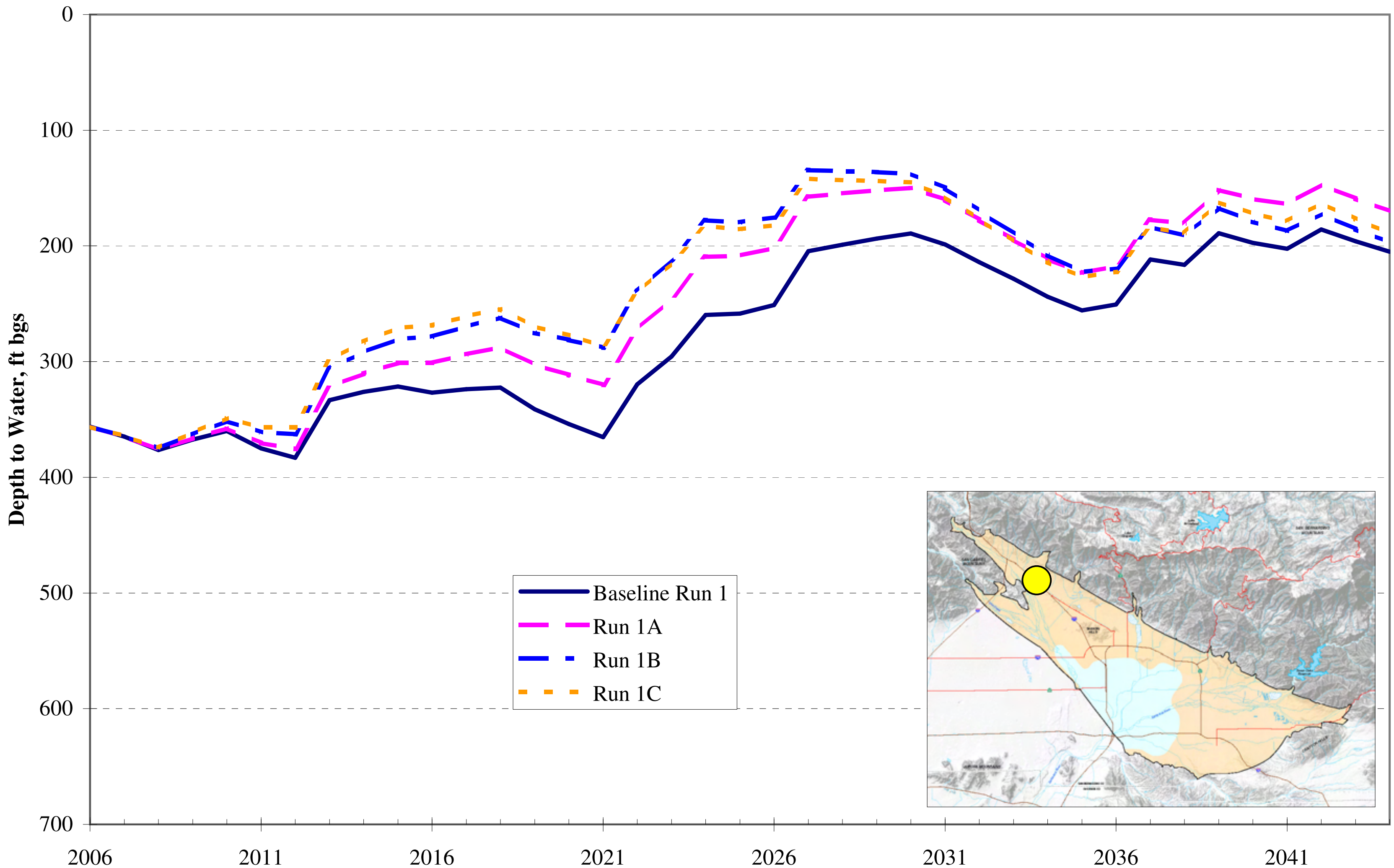
Appendix B

Depth to Water for City of San Bernardino Devil Canyon Well No. 1
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044

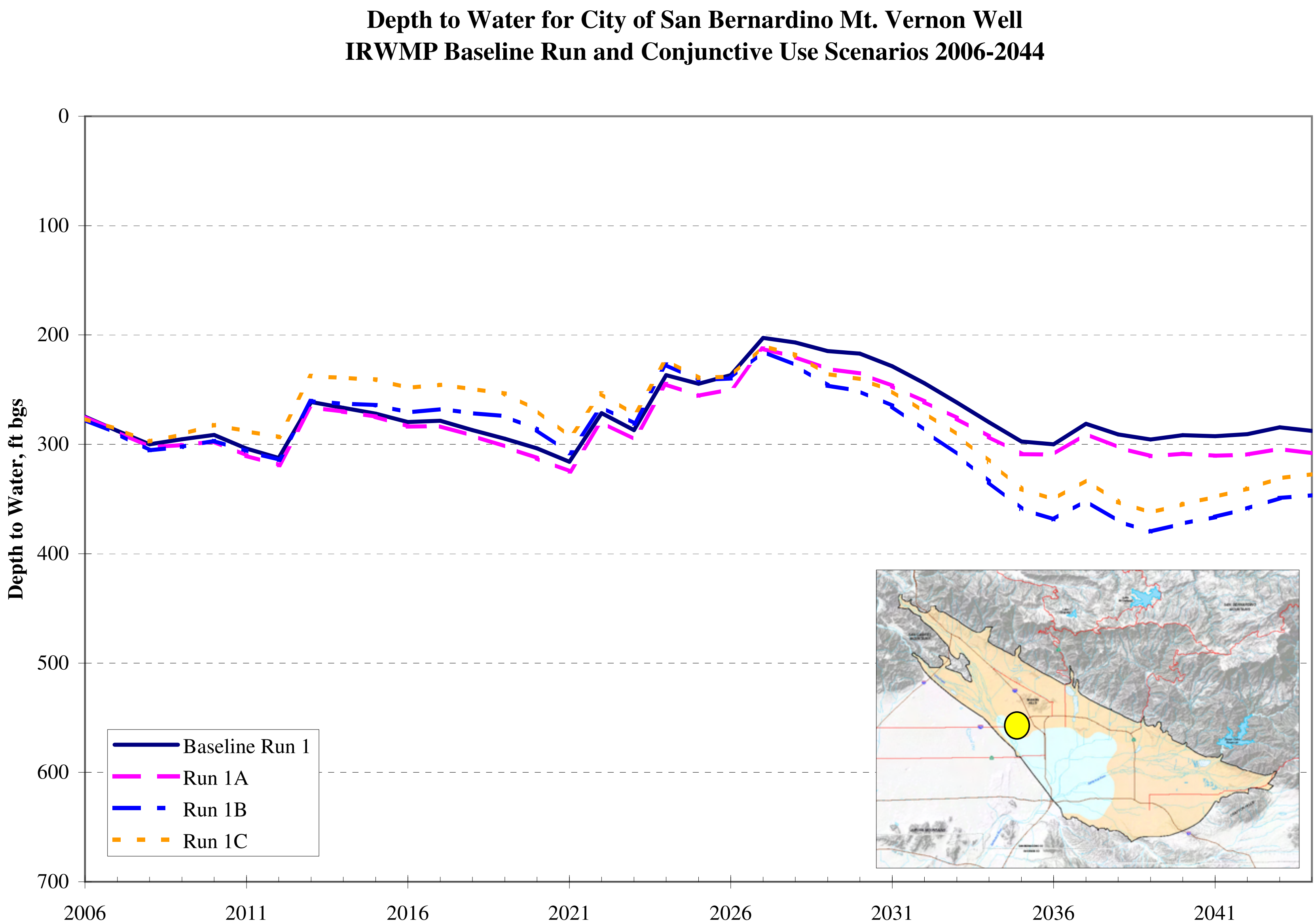


Appendix B

Depth to Water for City of San Bernardino Cajon Well No. 1
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044

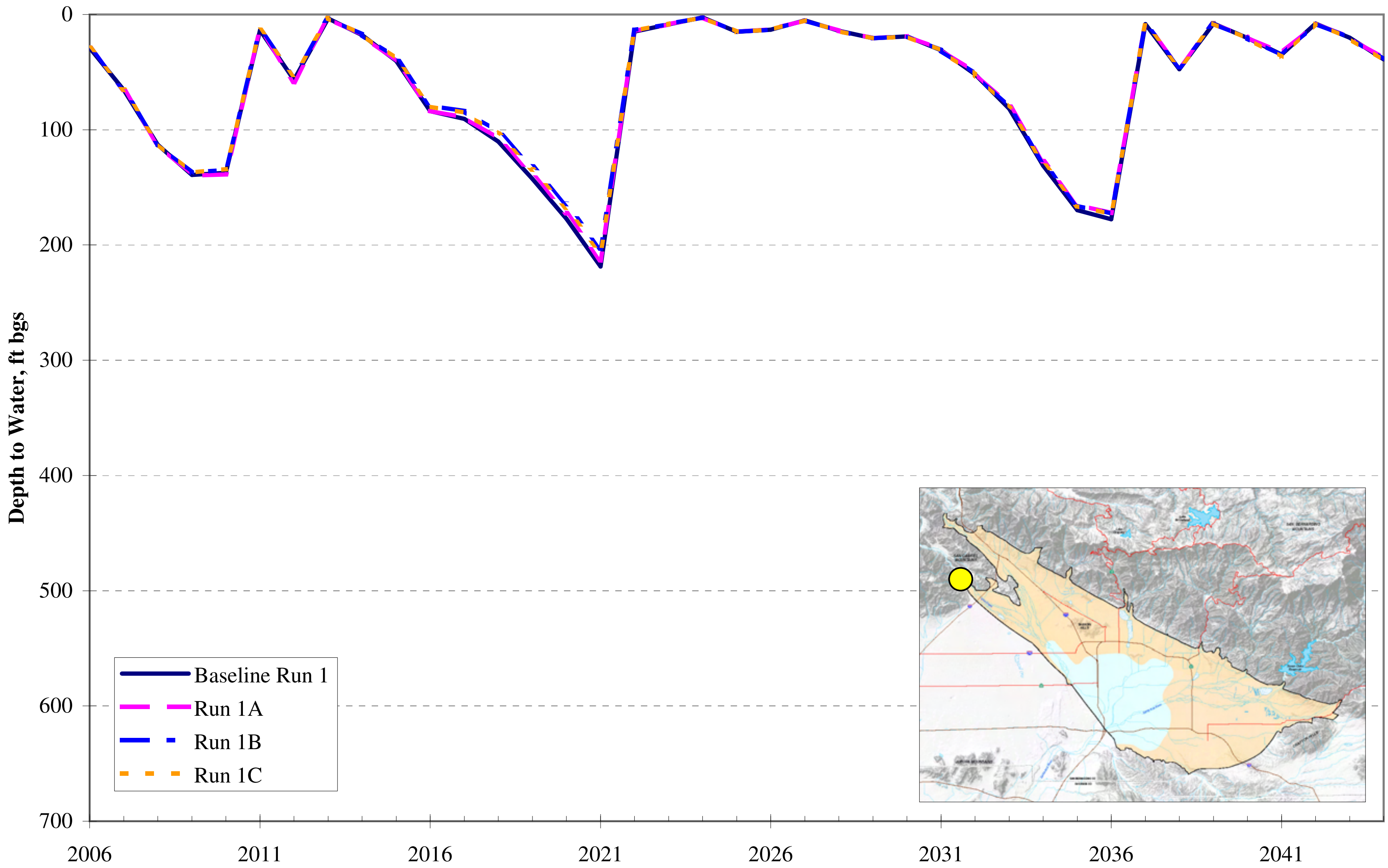


Appendix B

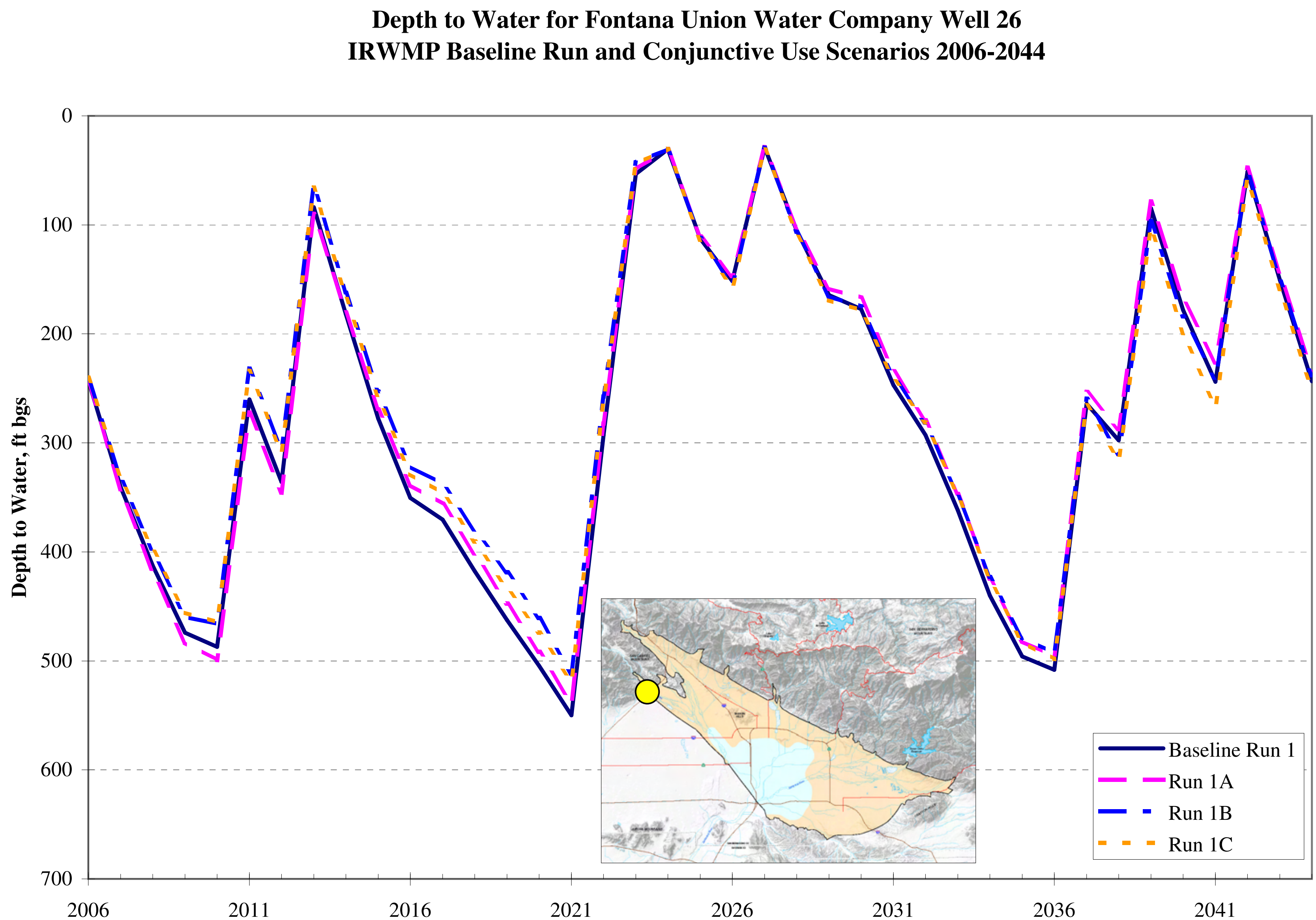

Depth to Water for City of San Bernardino Mt. Vernon Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
Run 1A
Run 1B
Run 1C

Appendix B

Depth to Water for Fontana Union Water Company Well 27
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044

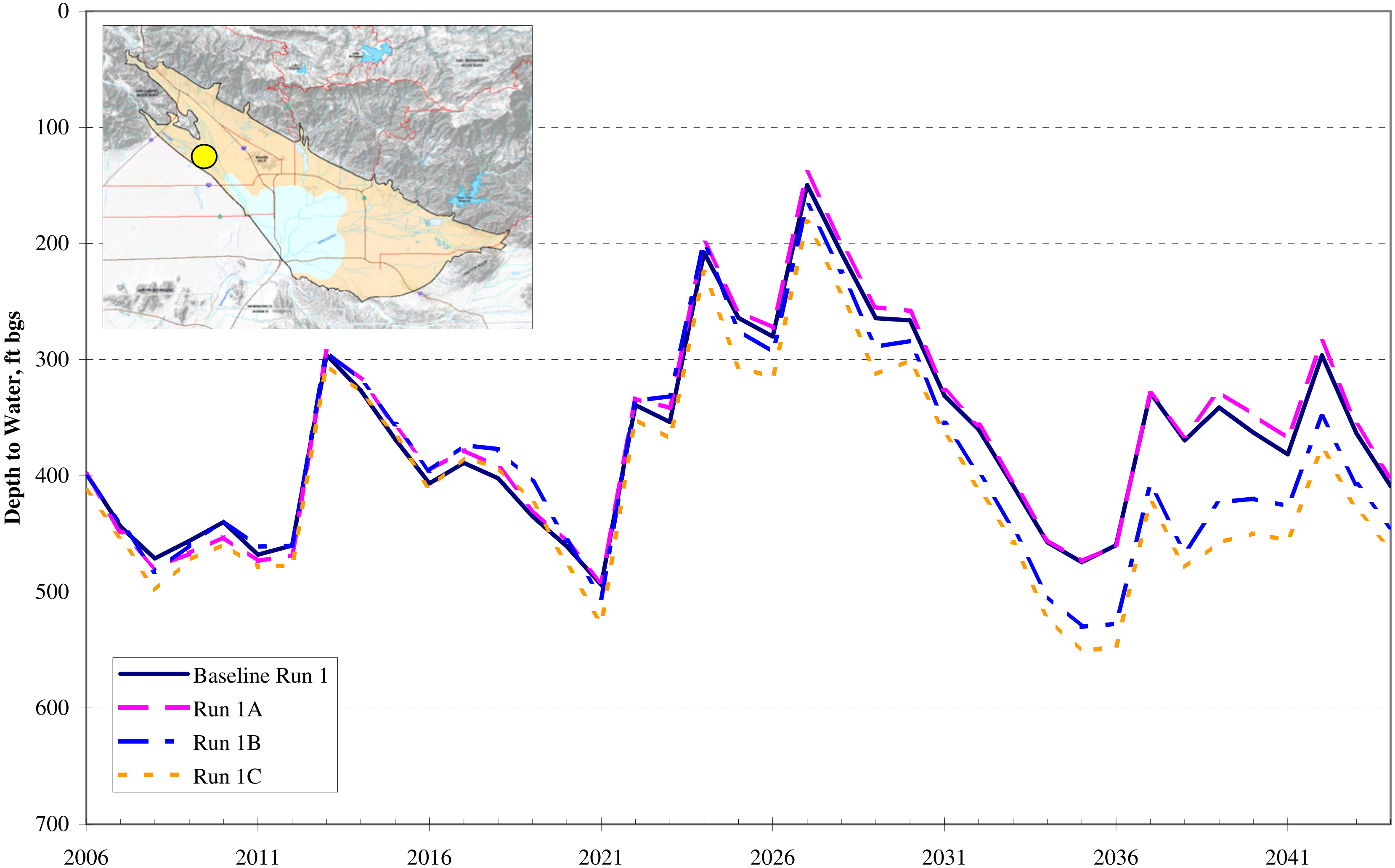


Appendix B

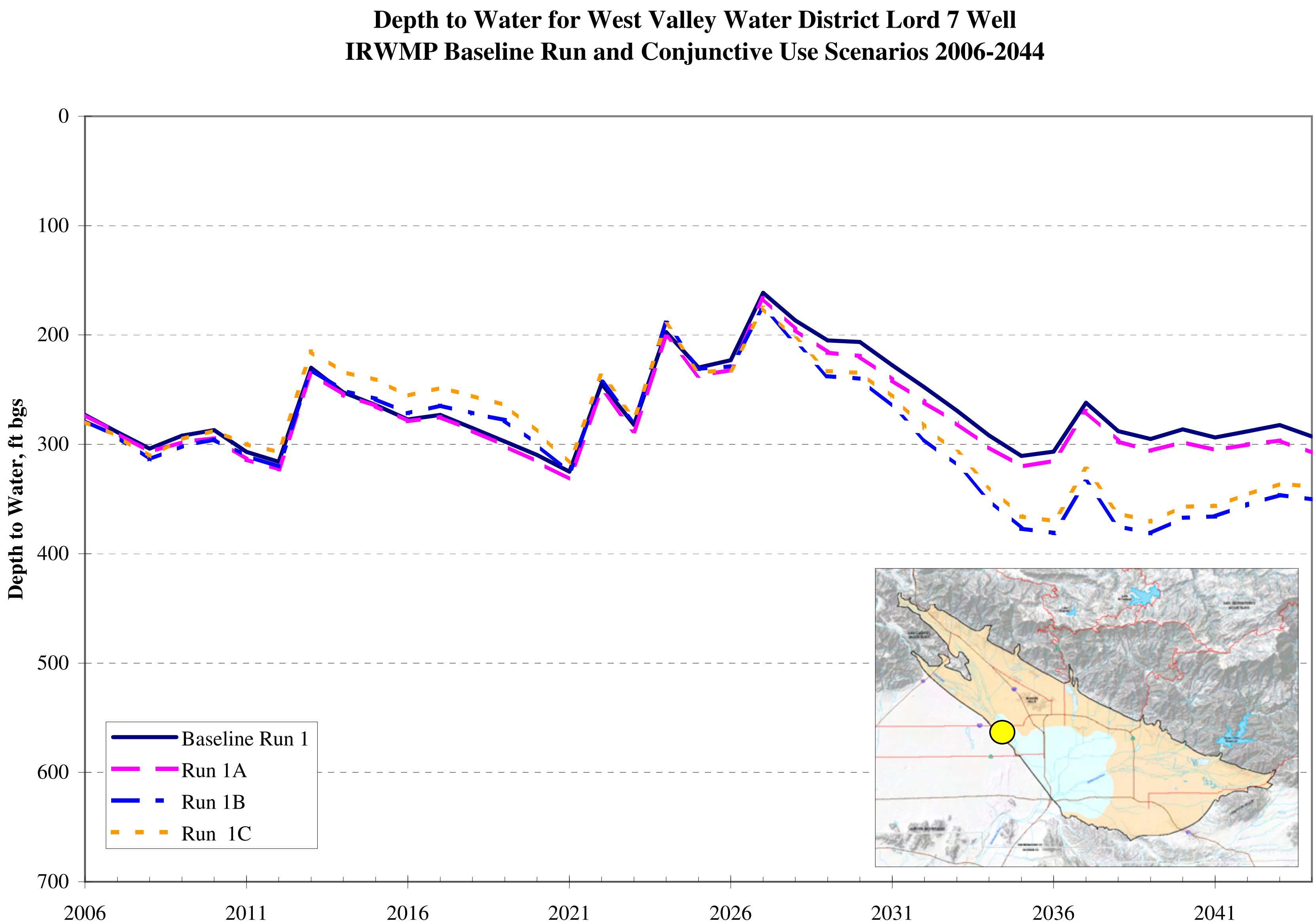

Depth to Water for Fontana Union Water Company Well 26
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
Run 1A
Run 1B
Run 1C

Appendix B

Depth to Water for Fontana Union Water Company Well 13
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044

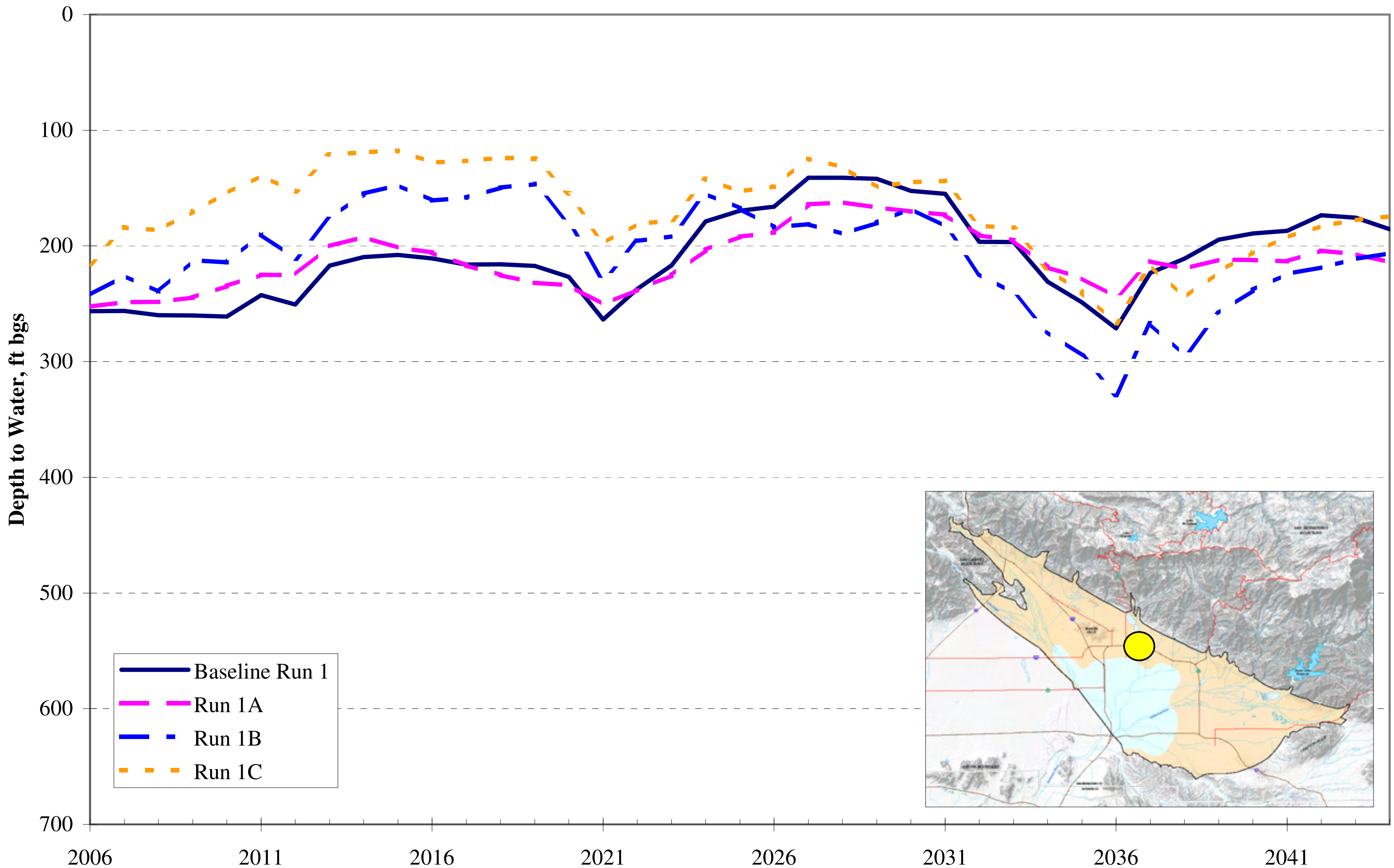


Appendix B

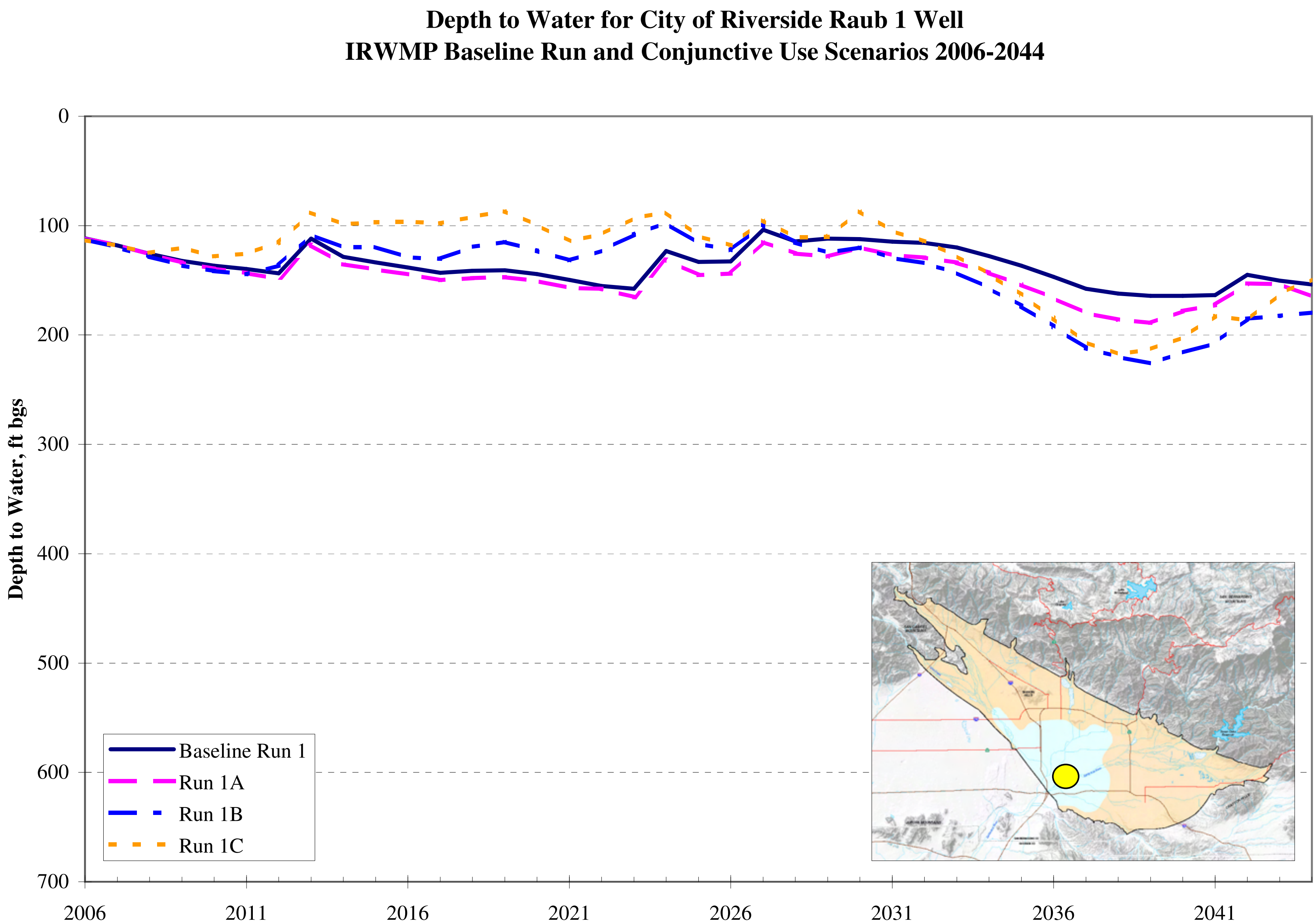

Depth to Water for West Valley Water District Lord 7 Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
Run 1A
Run 1B
Run 1C

Appendix B

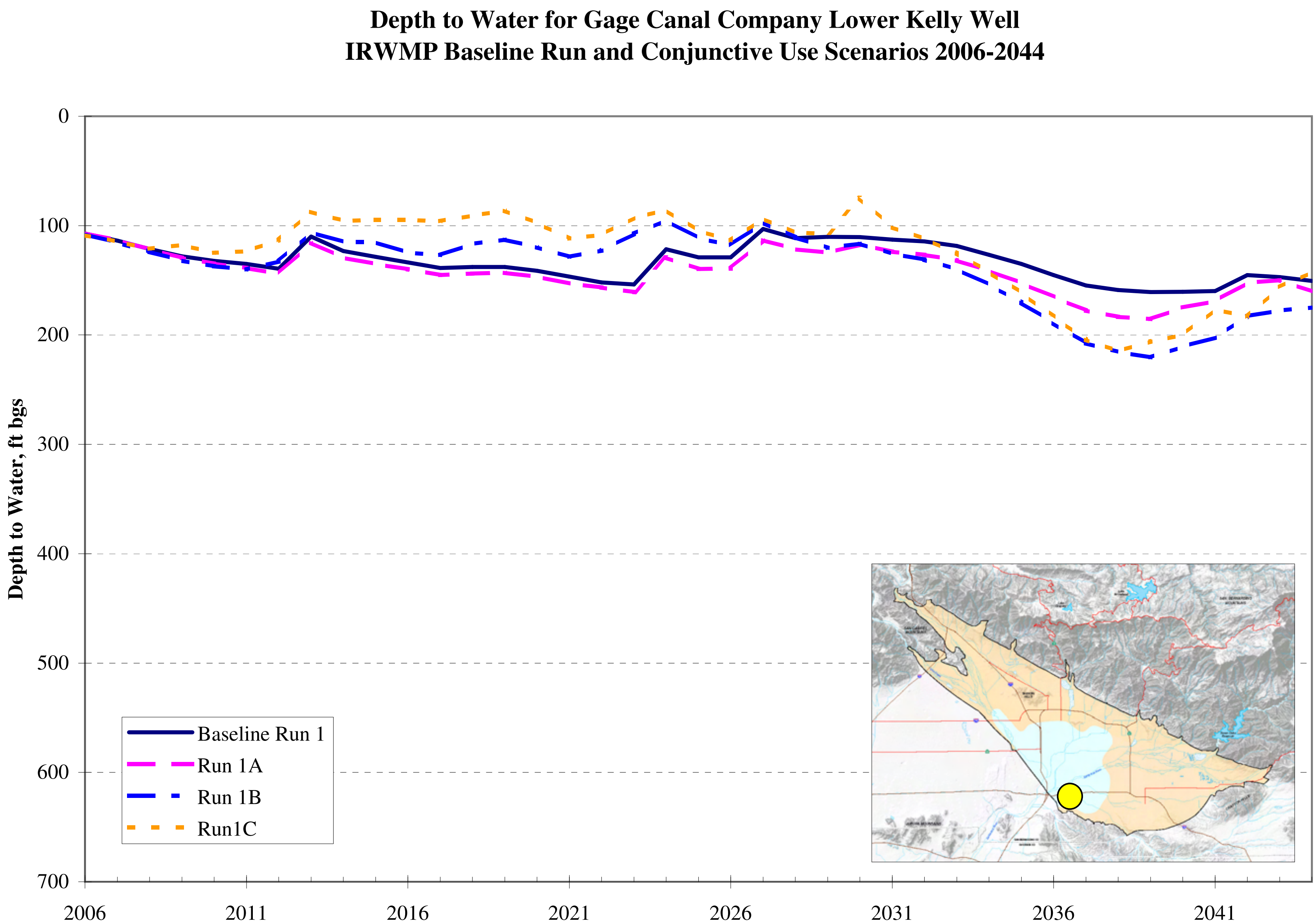
Depth to Water for East Valley Water District Well 24A
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044



Appendix B

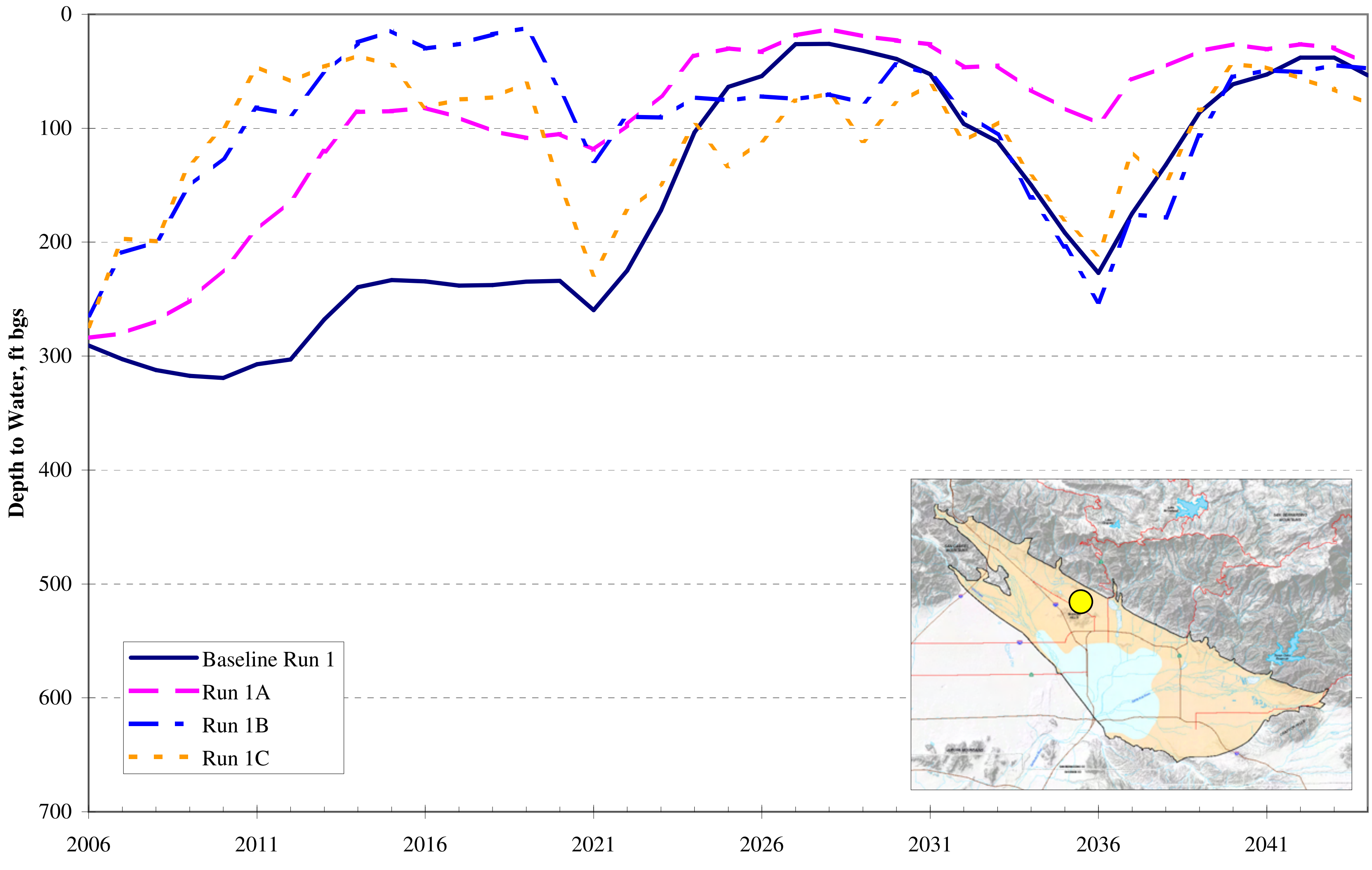

Depth to Water for City of Riverside Raub 1 Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
Run 1A
Run 1B
Run 1C

Appendix B

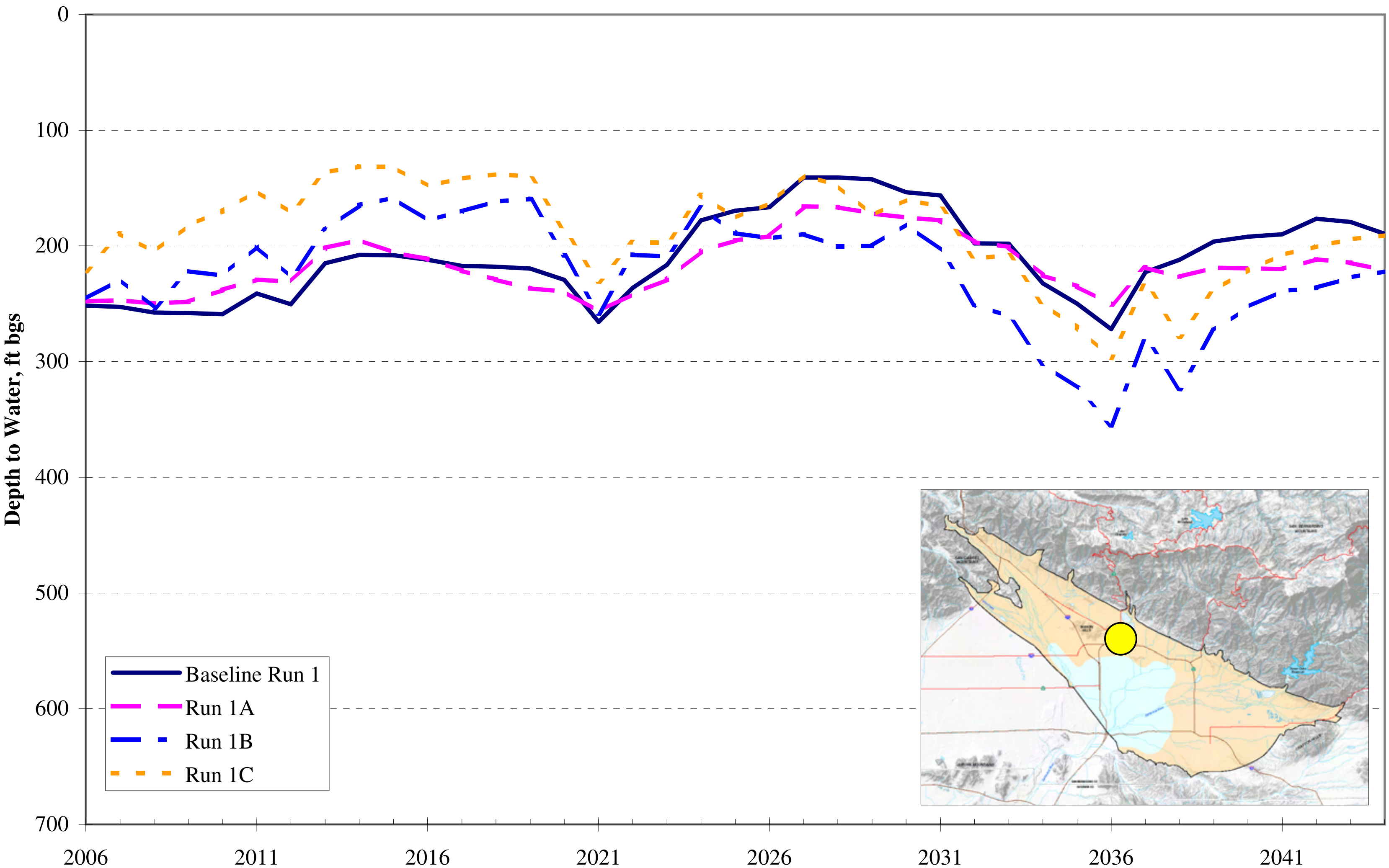

Depth to Water for Gage Canal Company Lower Kelly Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
Run 1A
Run 1B
Run1C

Appendix B

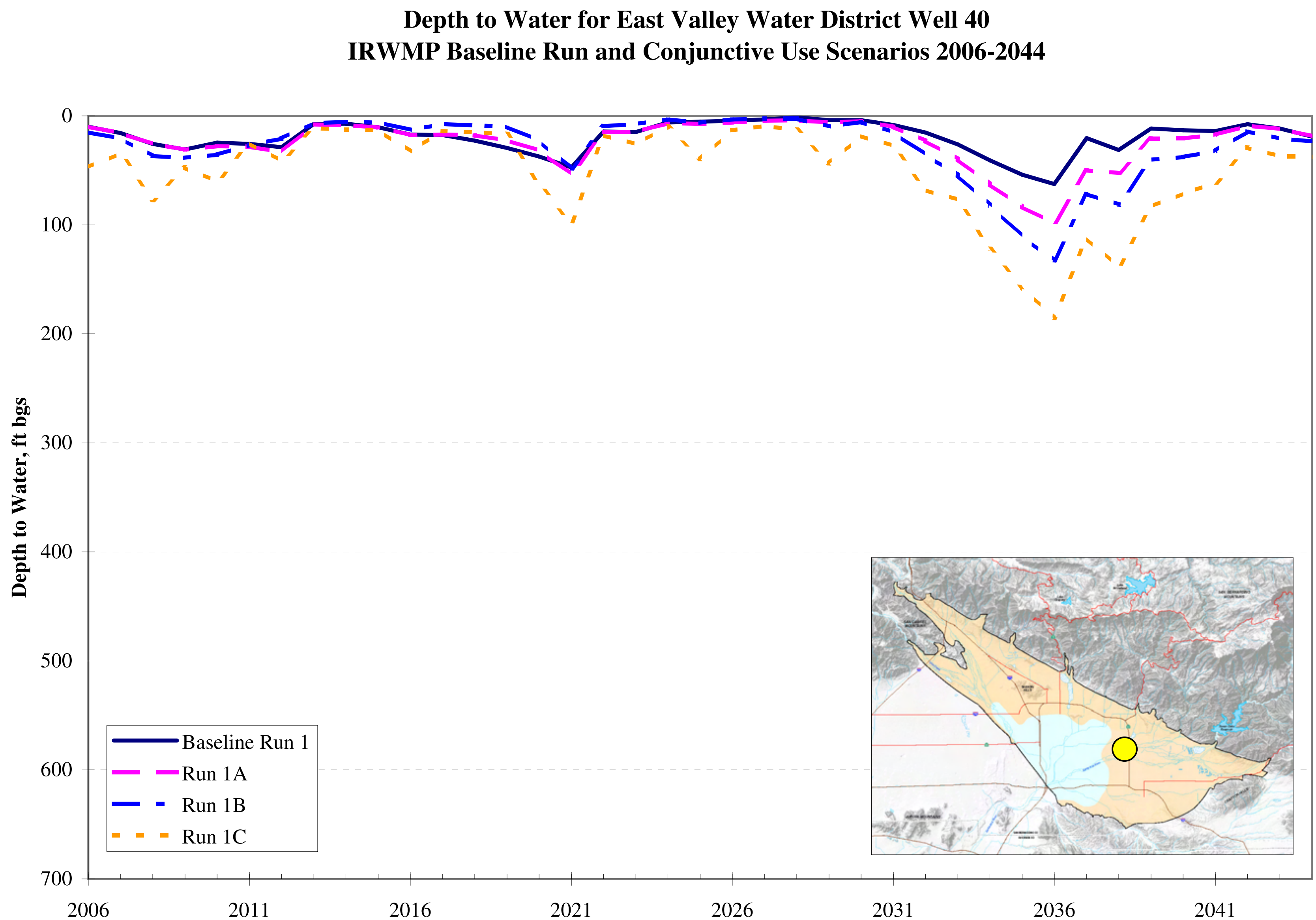
Depth to Water for City of San Bernardino Newmark 3 Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044



Depth to Water for City of San Bernardino Leroy Street Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044

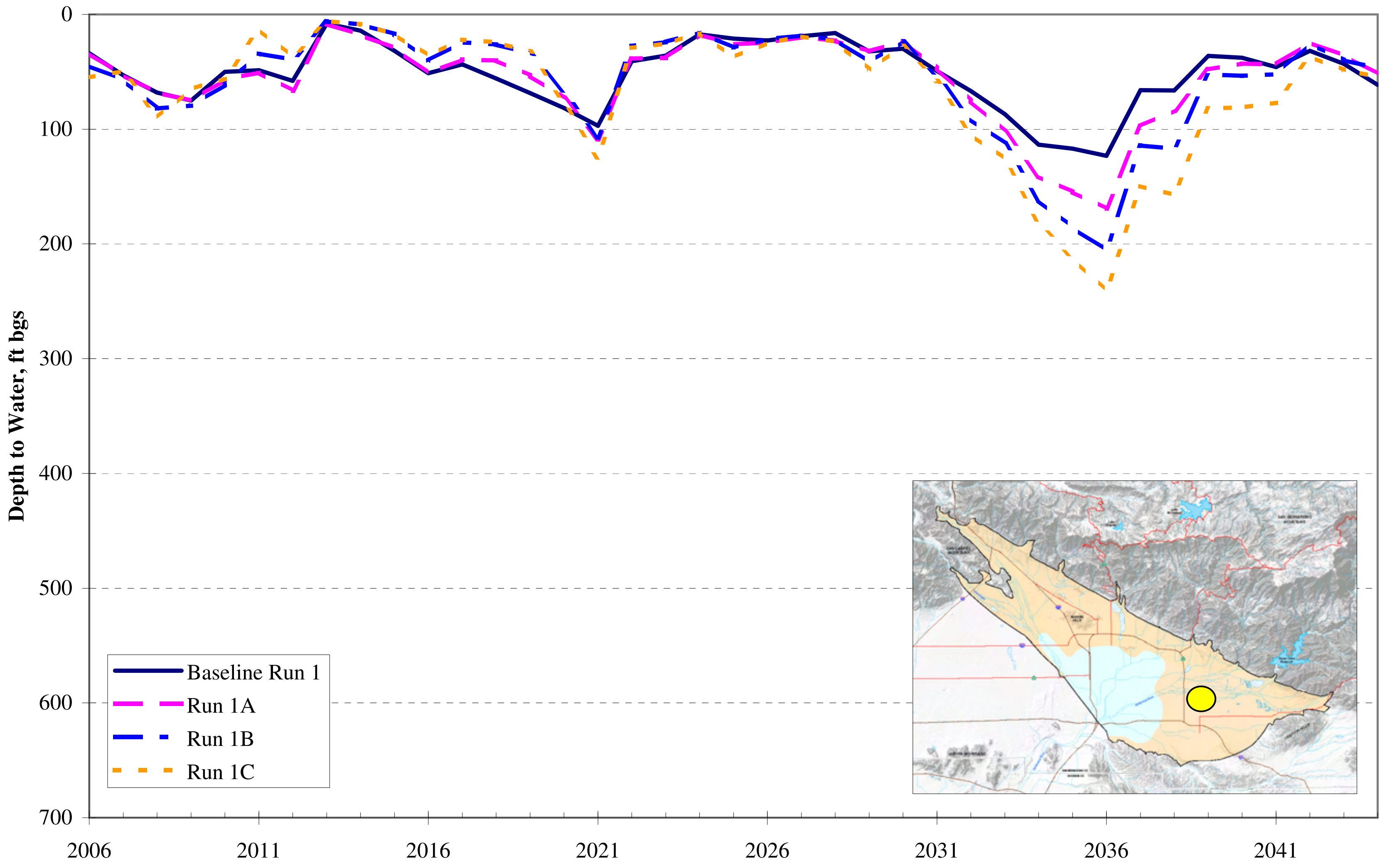


Appendix B


Depth to Water for East Valley Water District Well 40
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
Run 1A
Run 1B
Run 1C

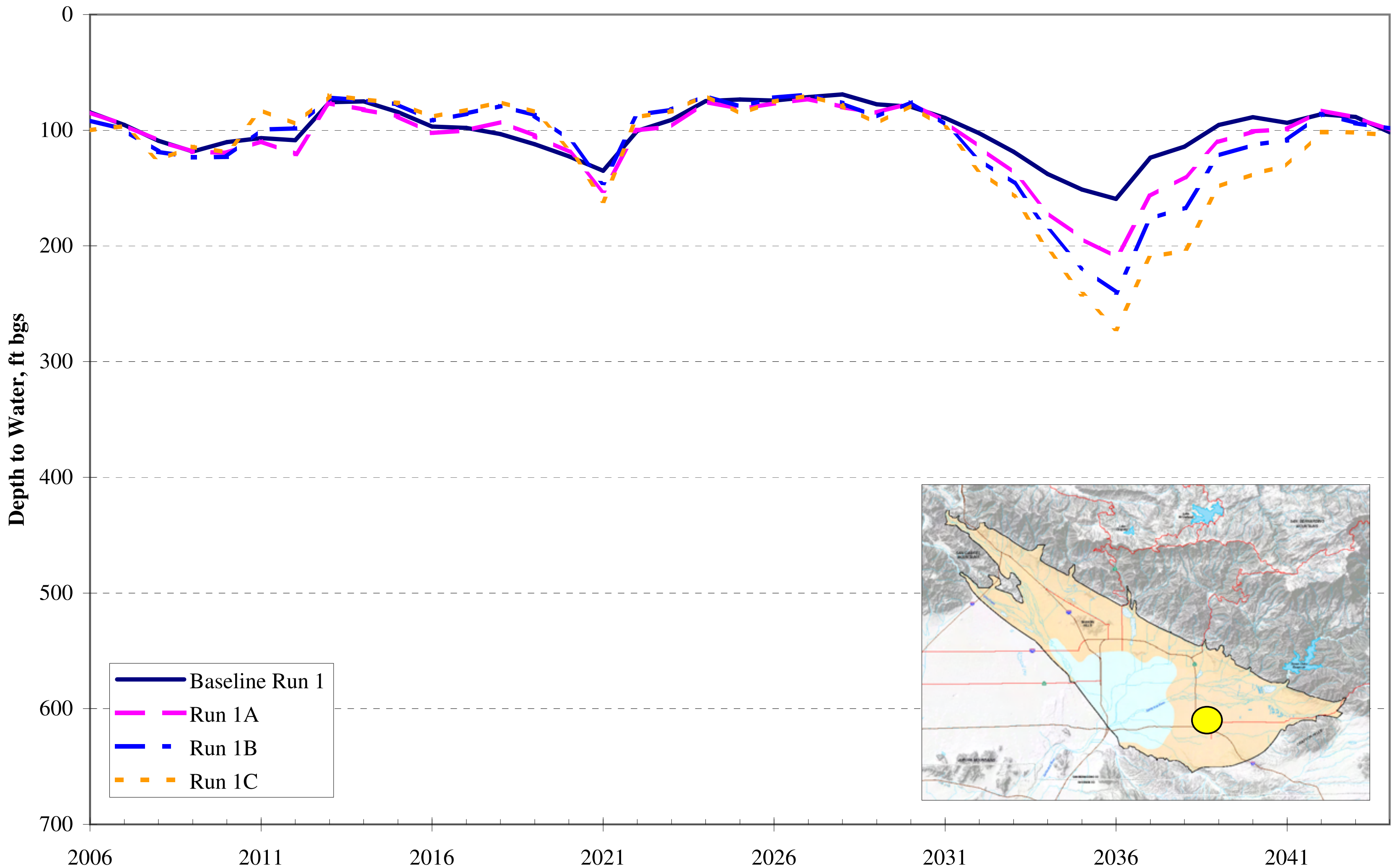
Appendix B

Depth to Water for City of Redlands Orange Street Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044



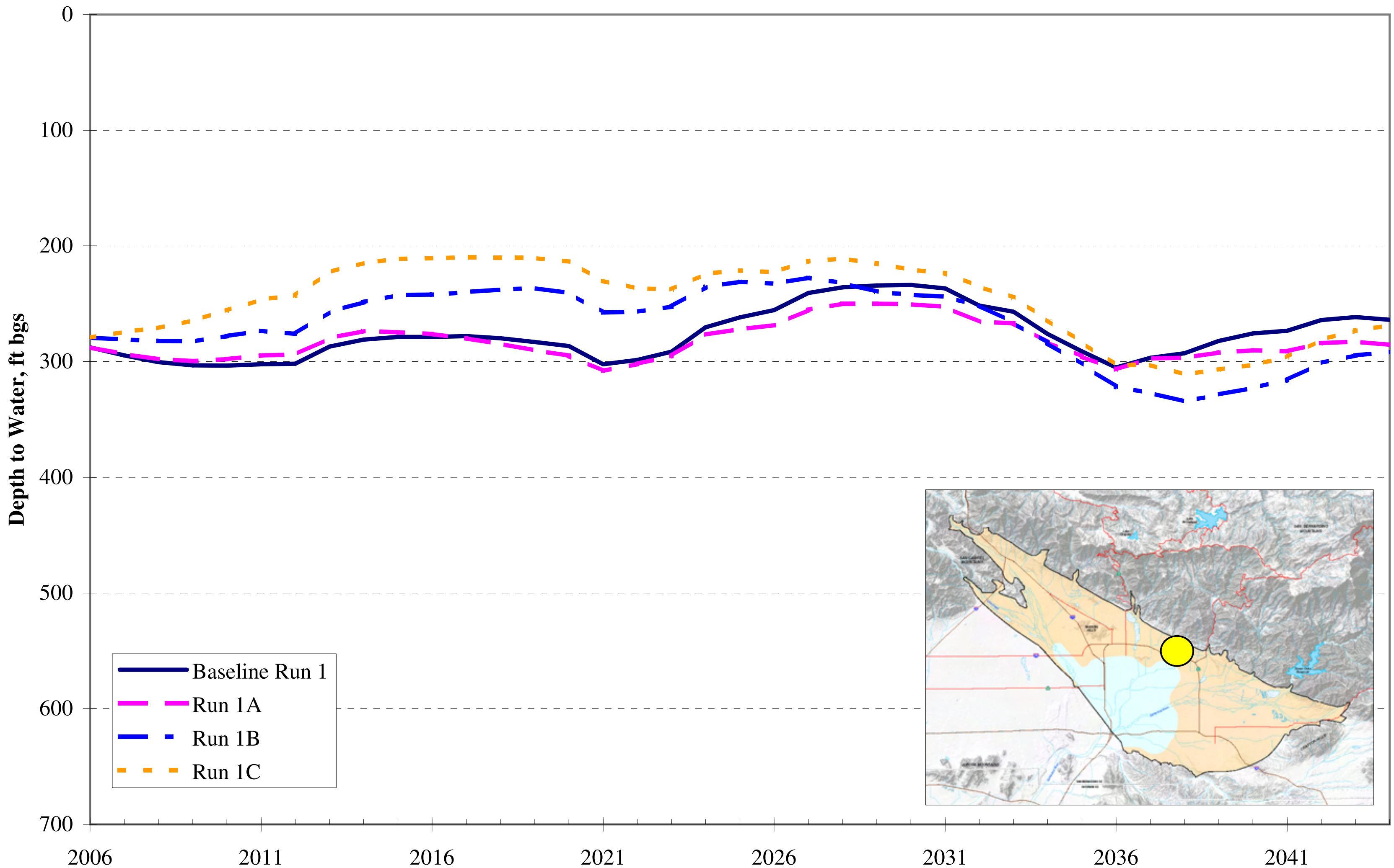
Appendix B

Depth to Water for City of Redlands Well 32
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044



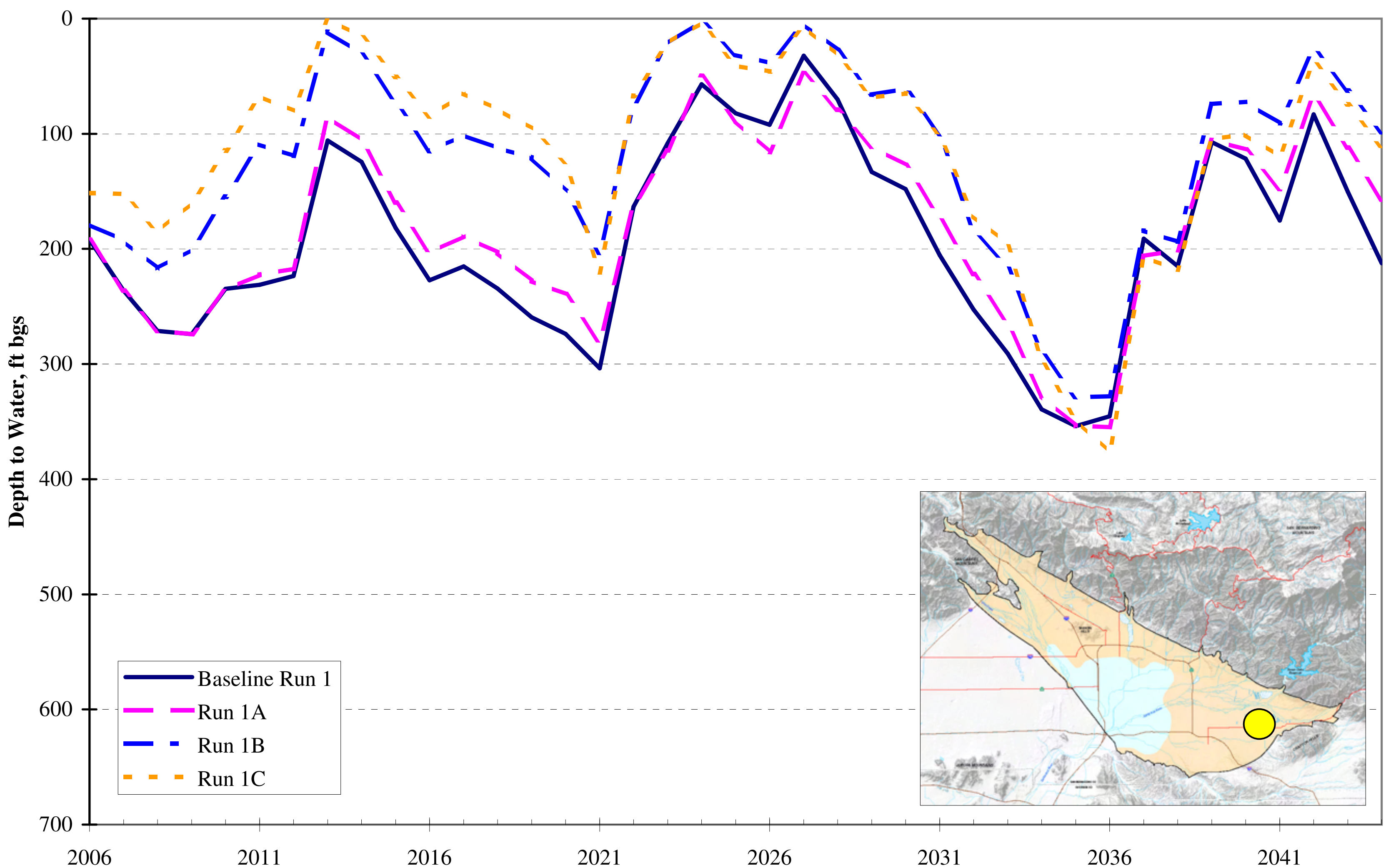
Appendix B

Depth to Water for East Valley Water District Well 62
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044



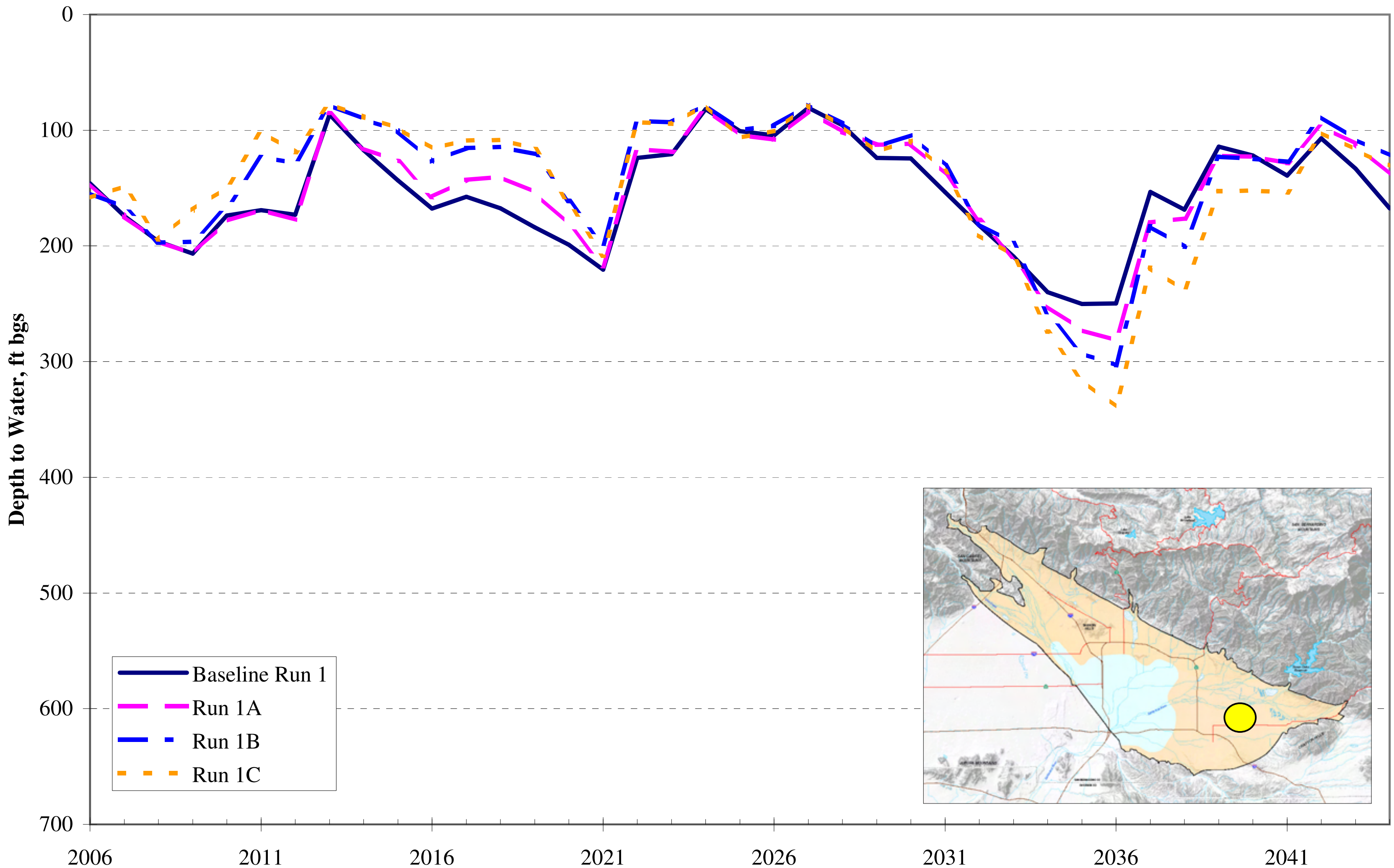
Appendix B

Depth to Water for City of Redlands Agate 2 Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044



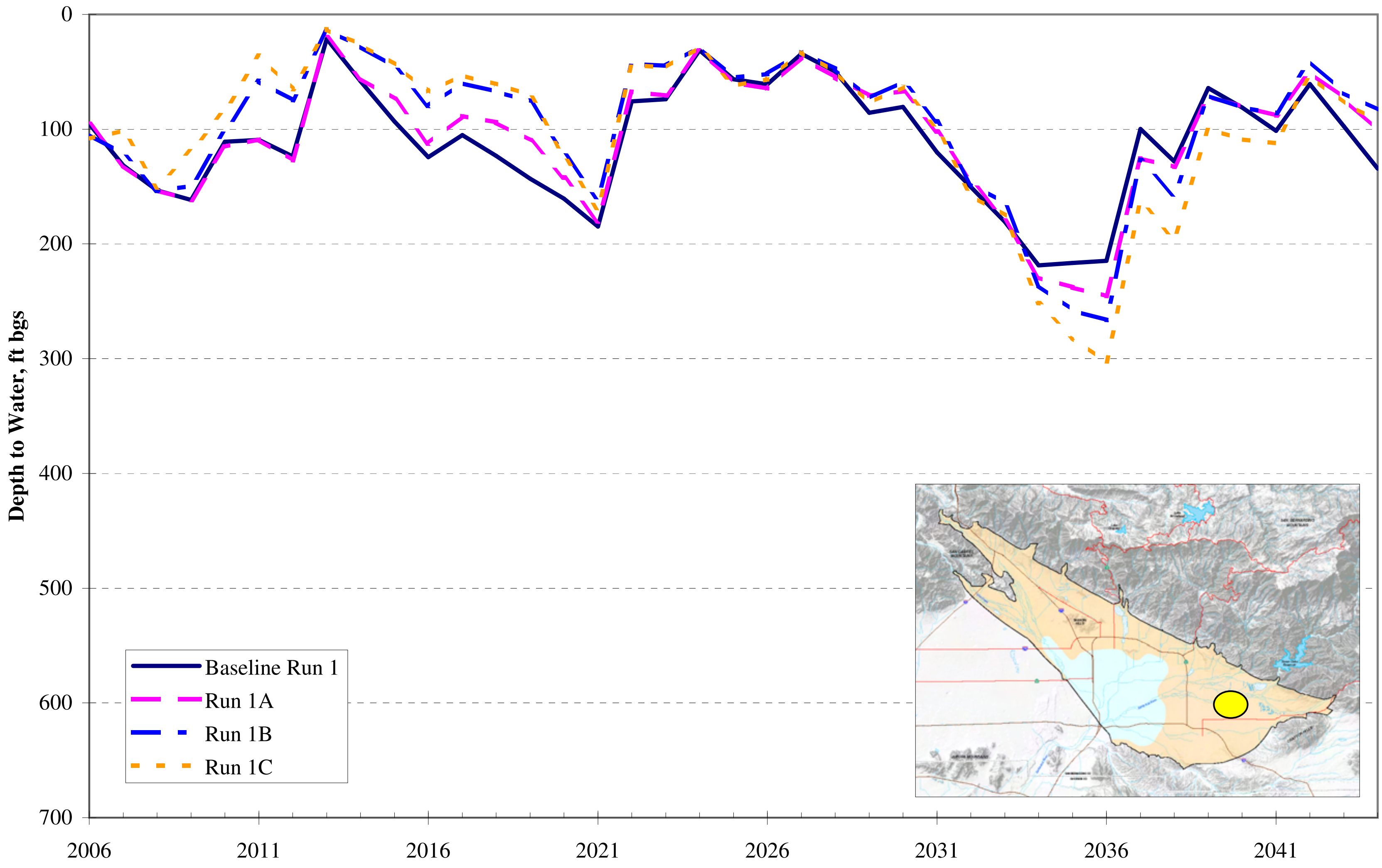
Appendix B

Depth to Water for Bear Valley MWC Nelson Street Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044



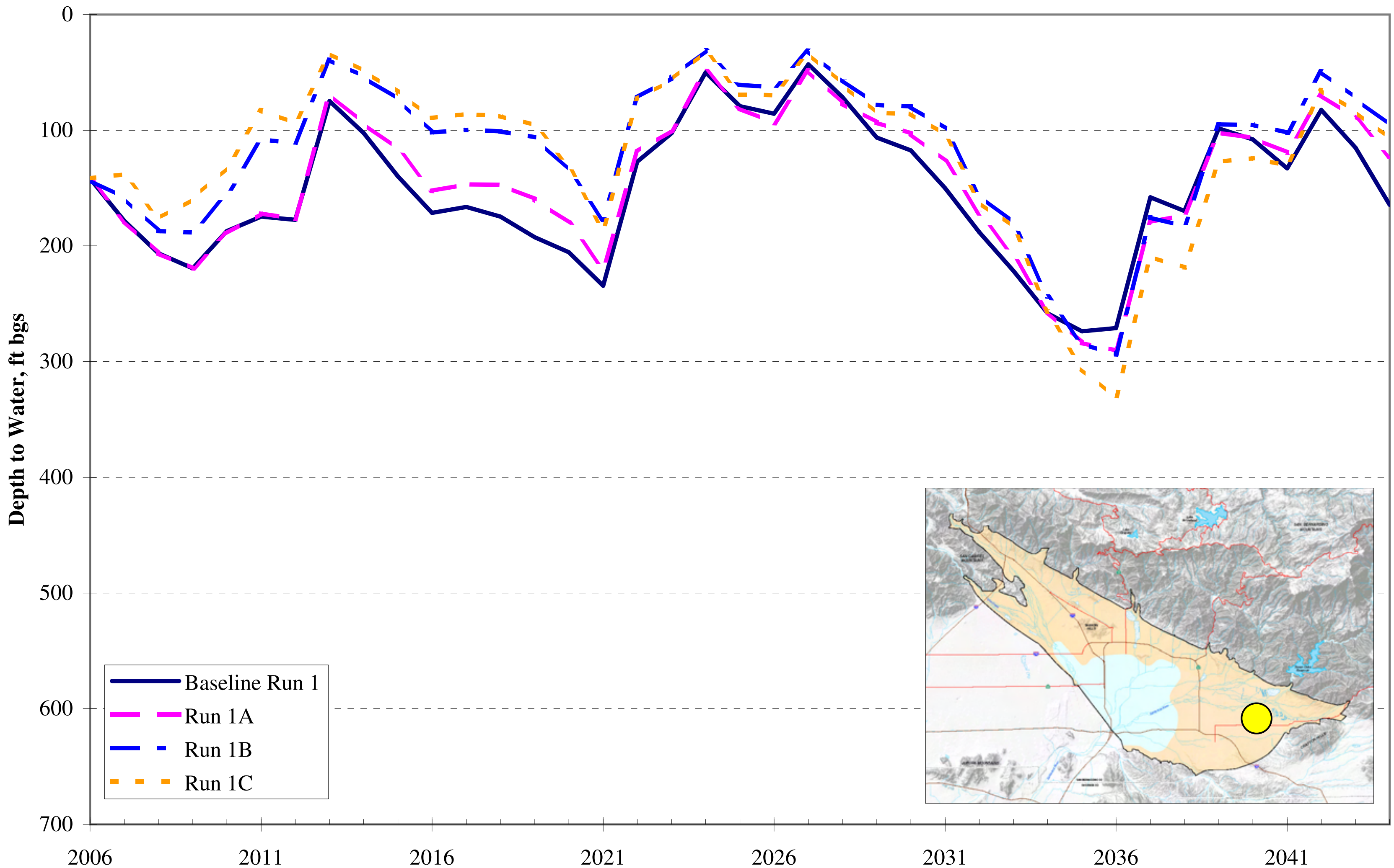
Appendix B

Depth to Water for City of Redlands Airport Well No. 2
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044

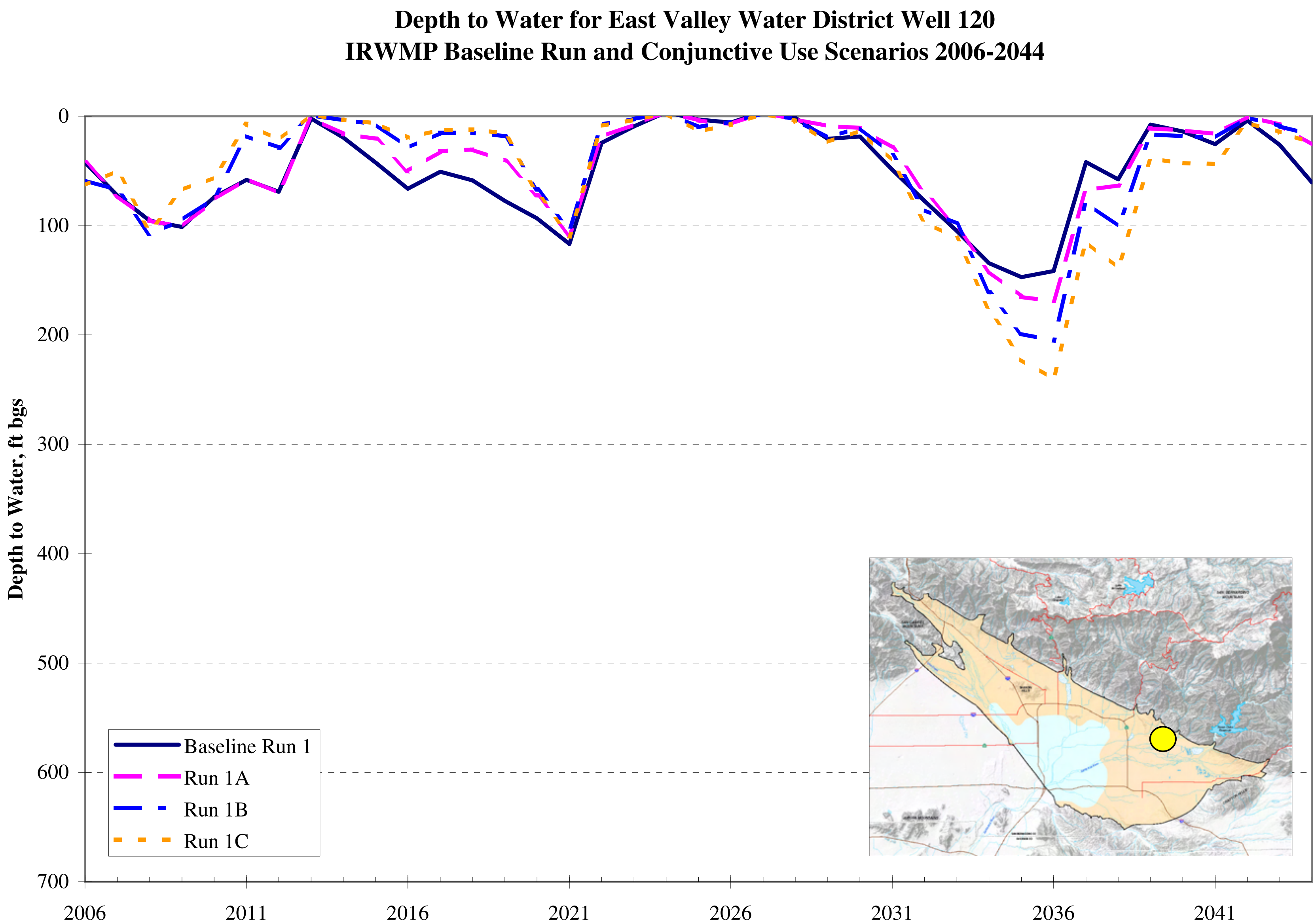


Appendix B

Depth to Water for SBVMWD San Bernardino Ave. Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044

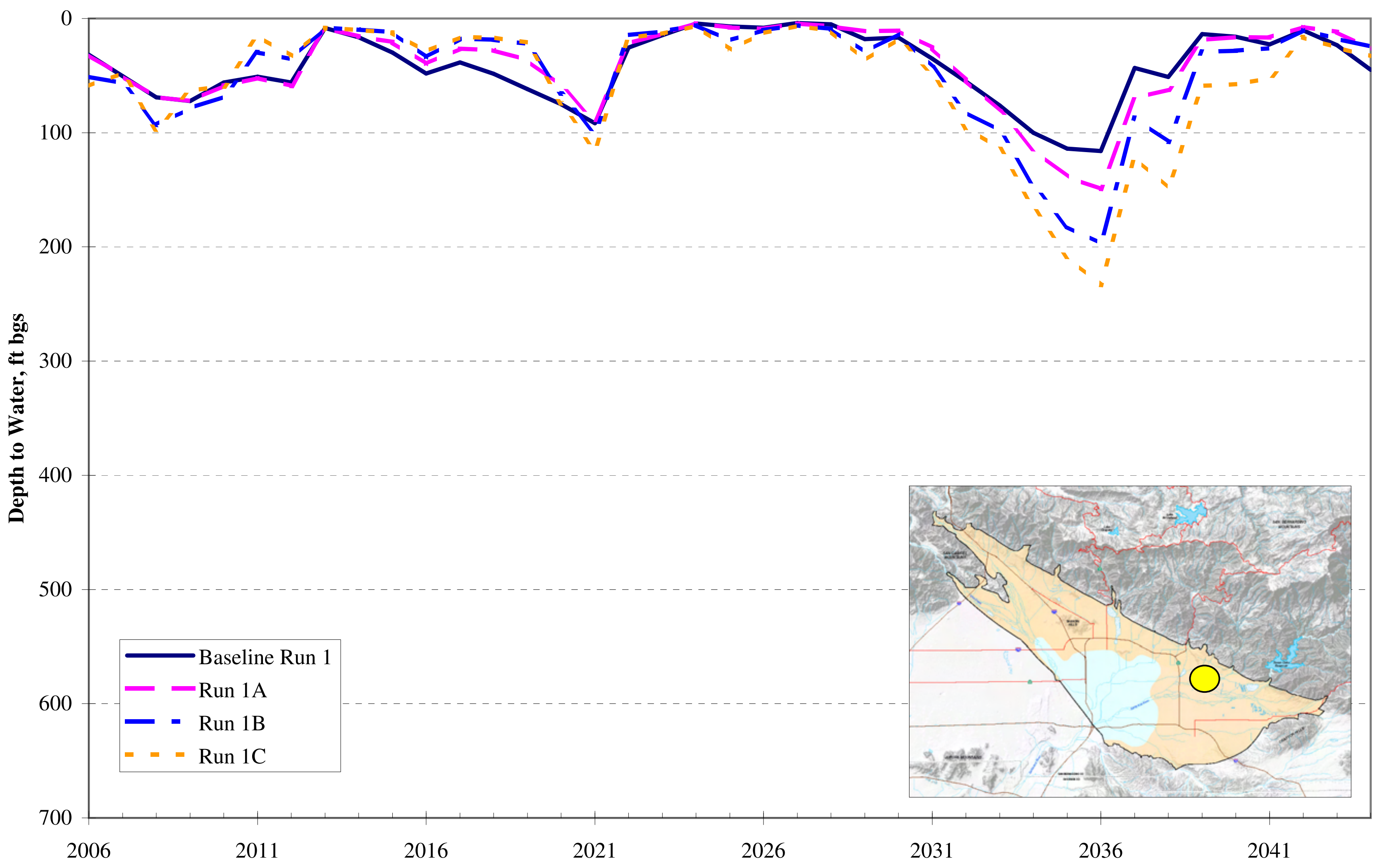


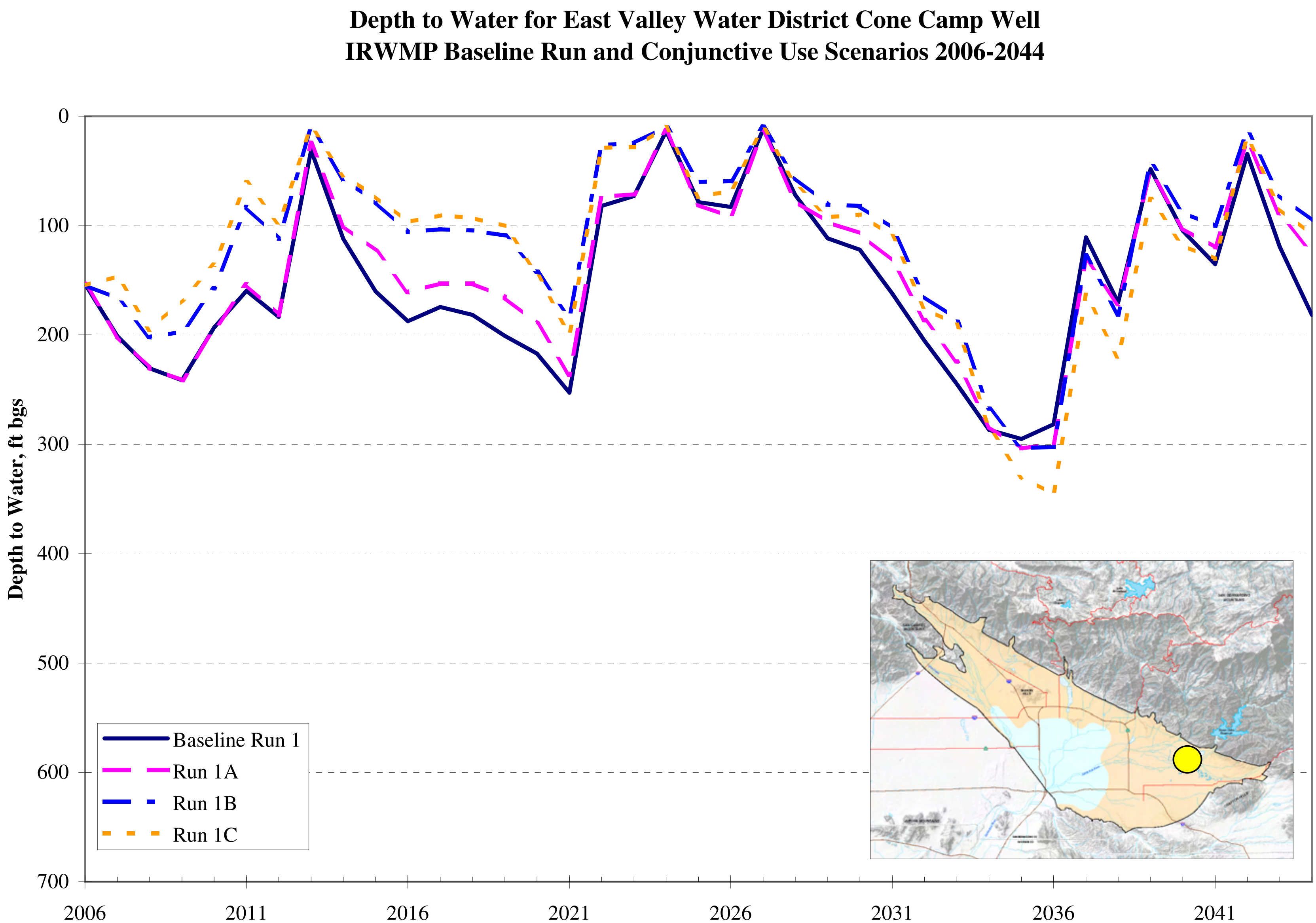
Appendix B


Depth to Water for East Valley Water District Well 120
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
Run 1A
Run 1B
Run 1C

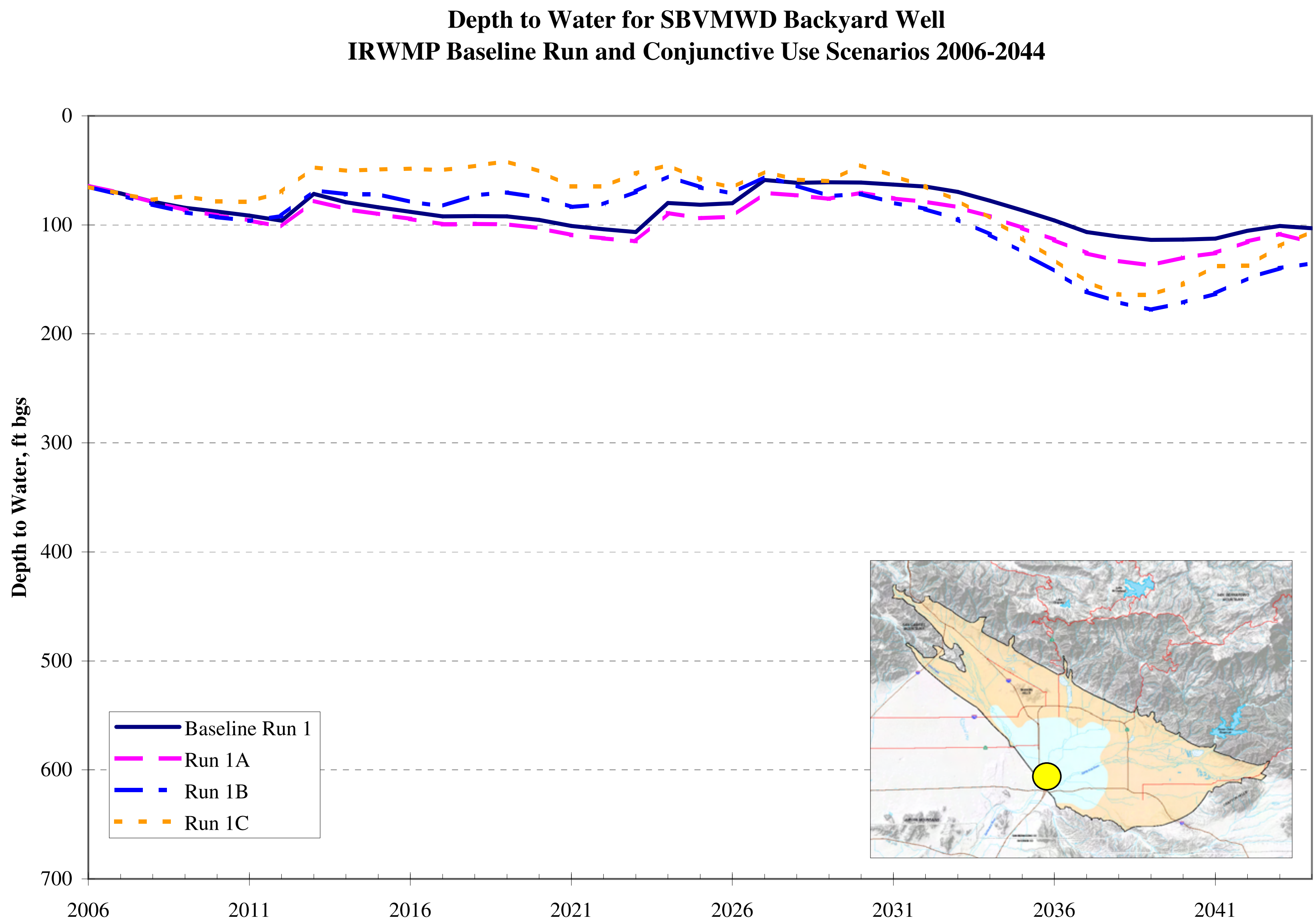
Appendix B

Depth to Water for East Valley Water District Well 146 A
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044




Depth to Water for East Valley Water District Cone Camp Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
Run 1A
Run 1B
Run 1C

Appendix B


Depth to Water for SBVMWD Backyard Well
IRWMP Baseline Run and Conjunctive Use Scenarios 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
Run 1A
Run 1B
Run 1C

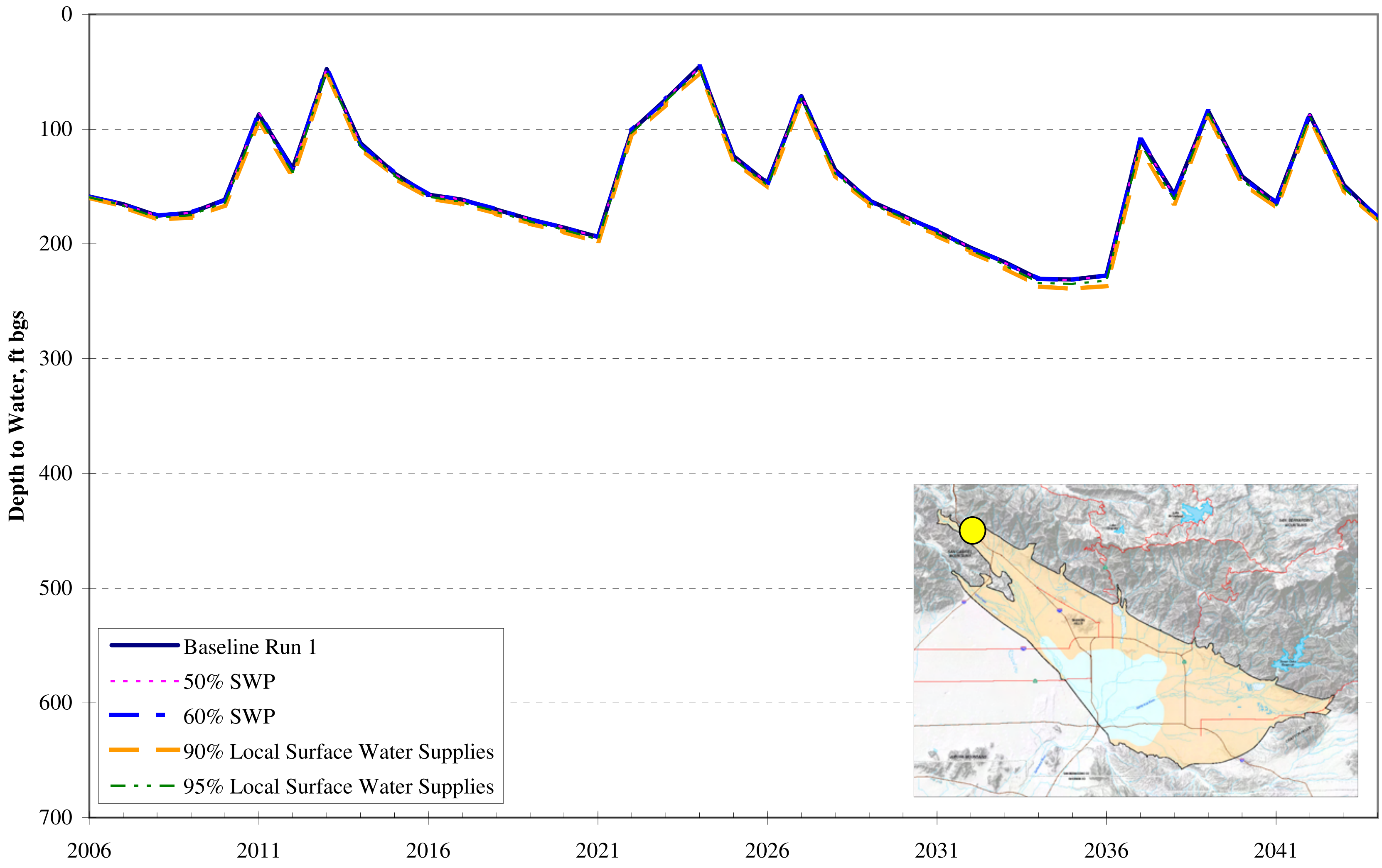
Appendix B

APPENDIX C

Selected Hydrographs of Sensitivity Analysis Model Runs

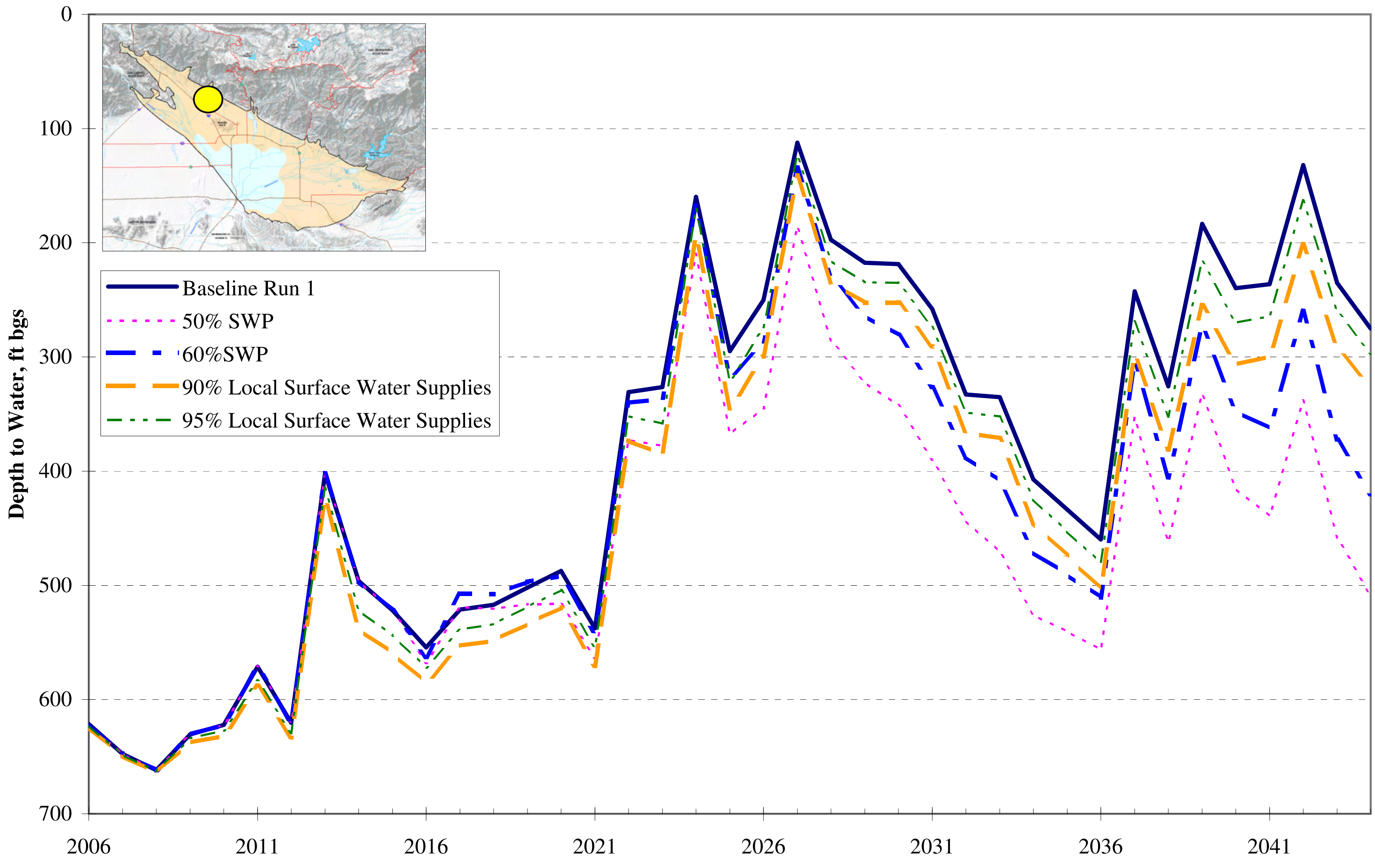
GEOSCIENCE Support Services, Inc.

Depth to Water for City of San Bernardino Vincent Well
Sensitivity Analysis Model Runs 2006-2044



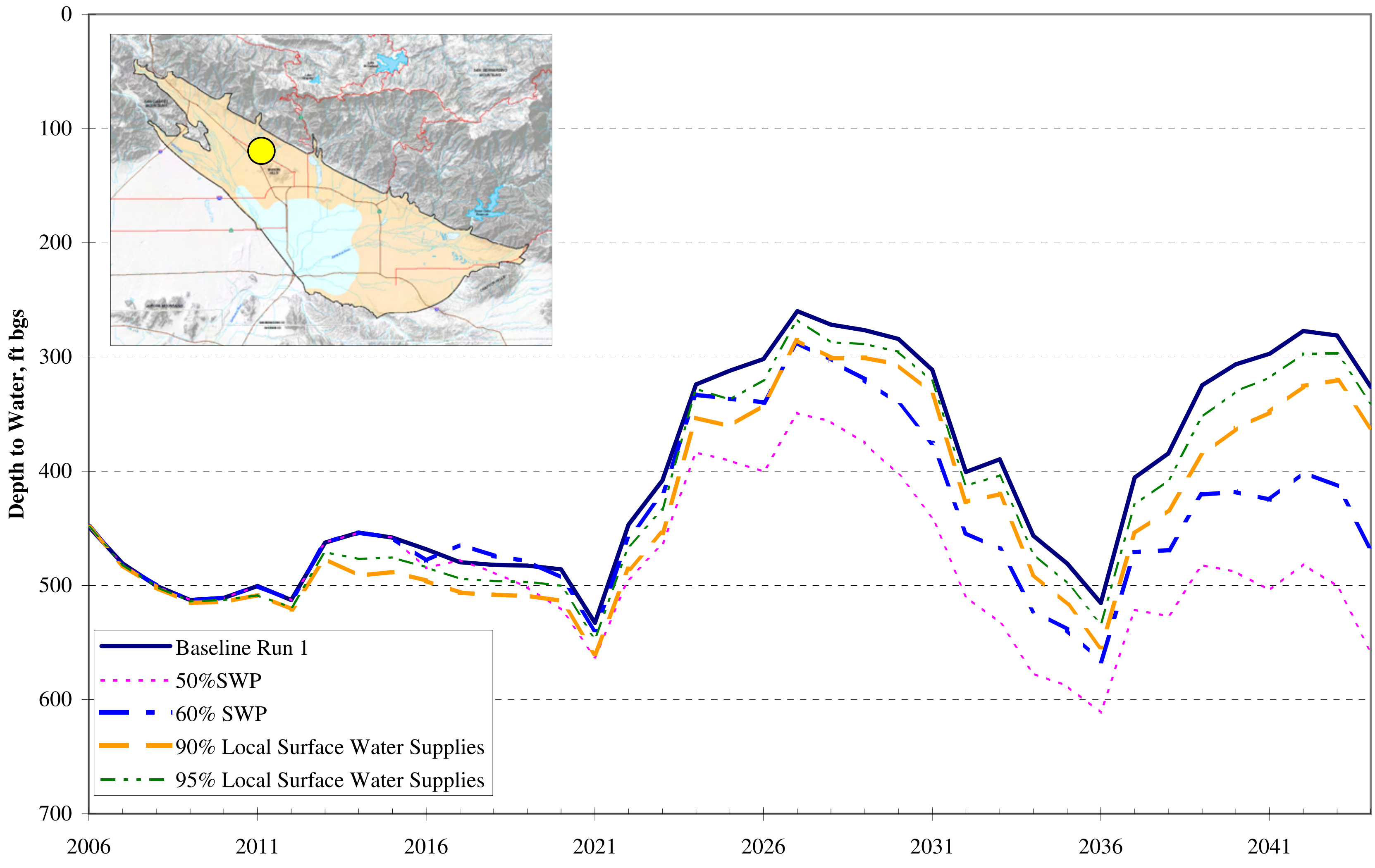
Appendix C

Depth to Water for City of San Bernardino Devil Canyon Well No. 3
Sensitivity Analysis Model Runs 2006-2044



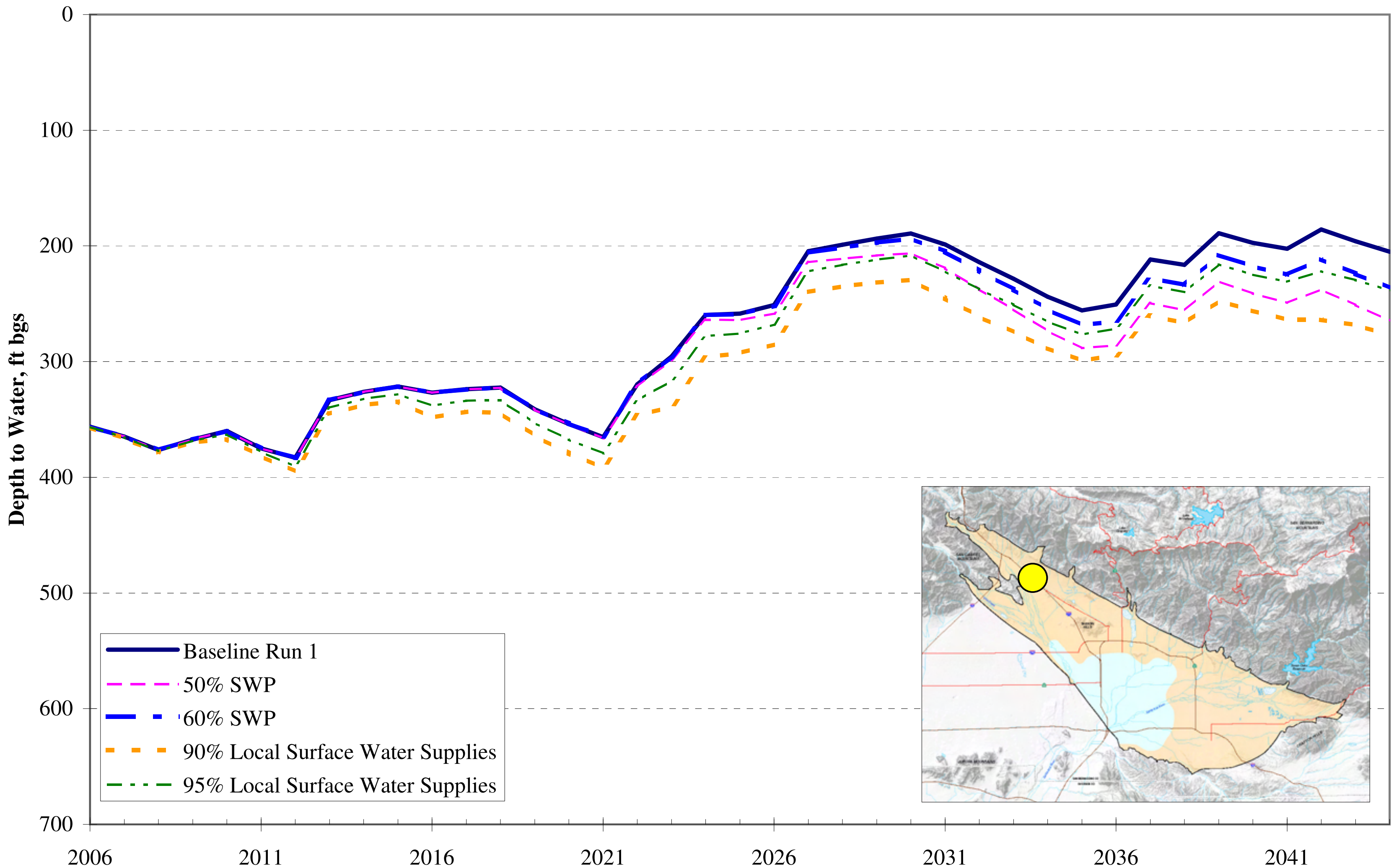
Appendix C

Depth to Water for City of San Bernardino Devil Canyon Well No. 1
Sensitivity Analysis Model Runs 2006-2044



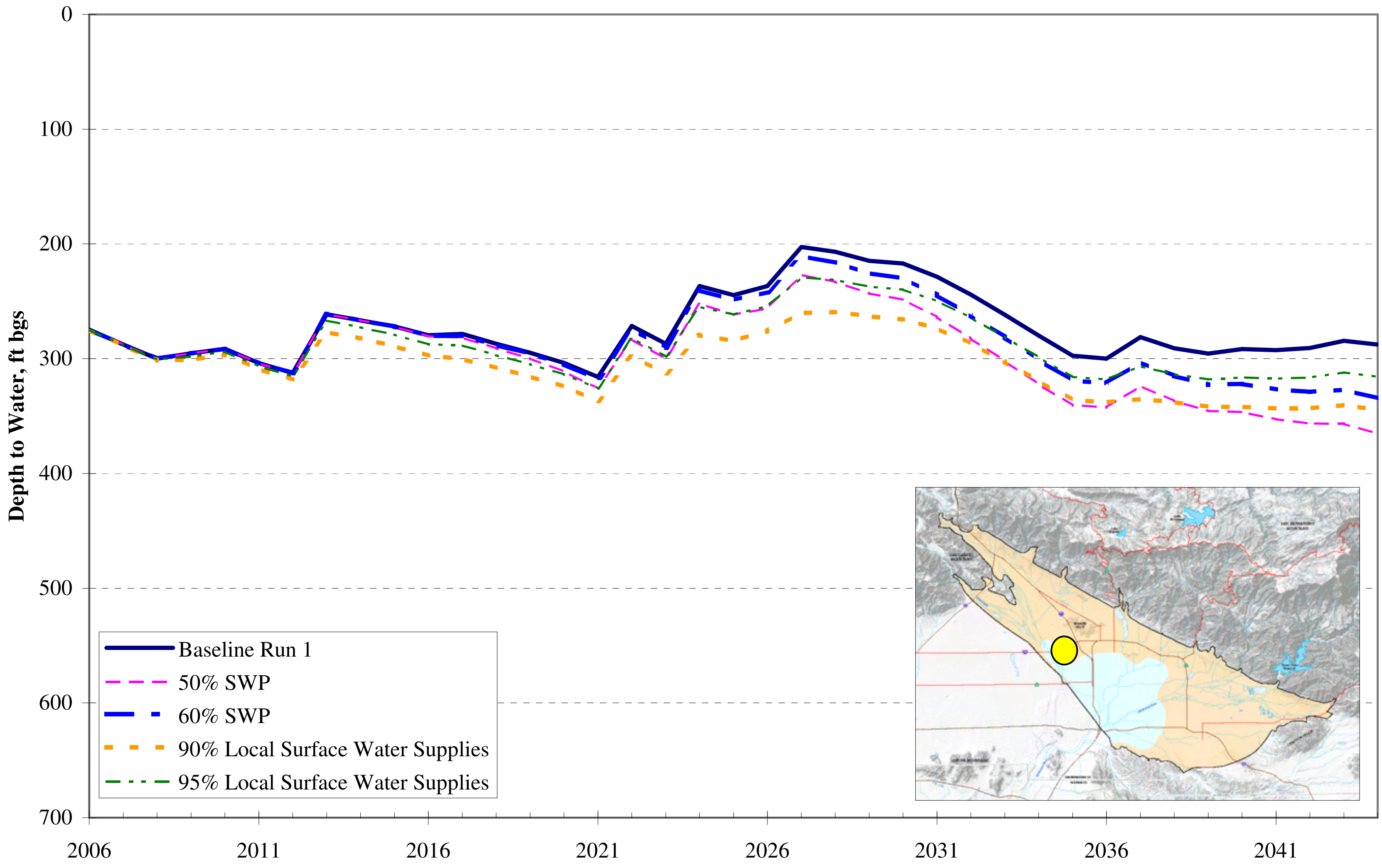
Appendix C

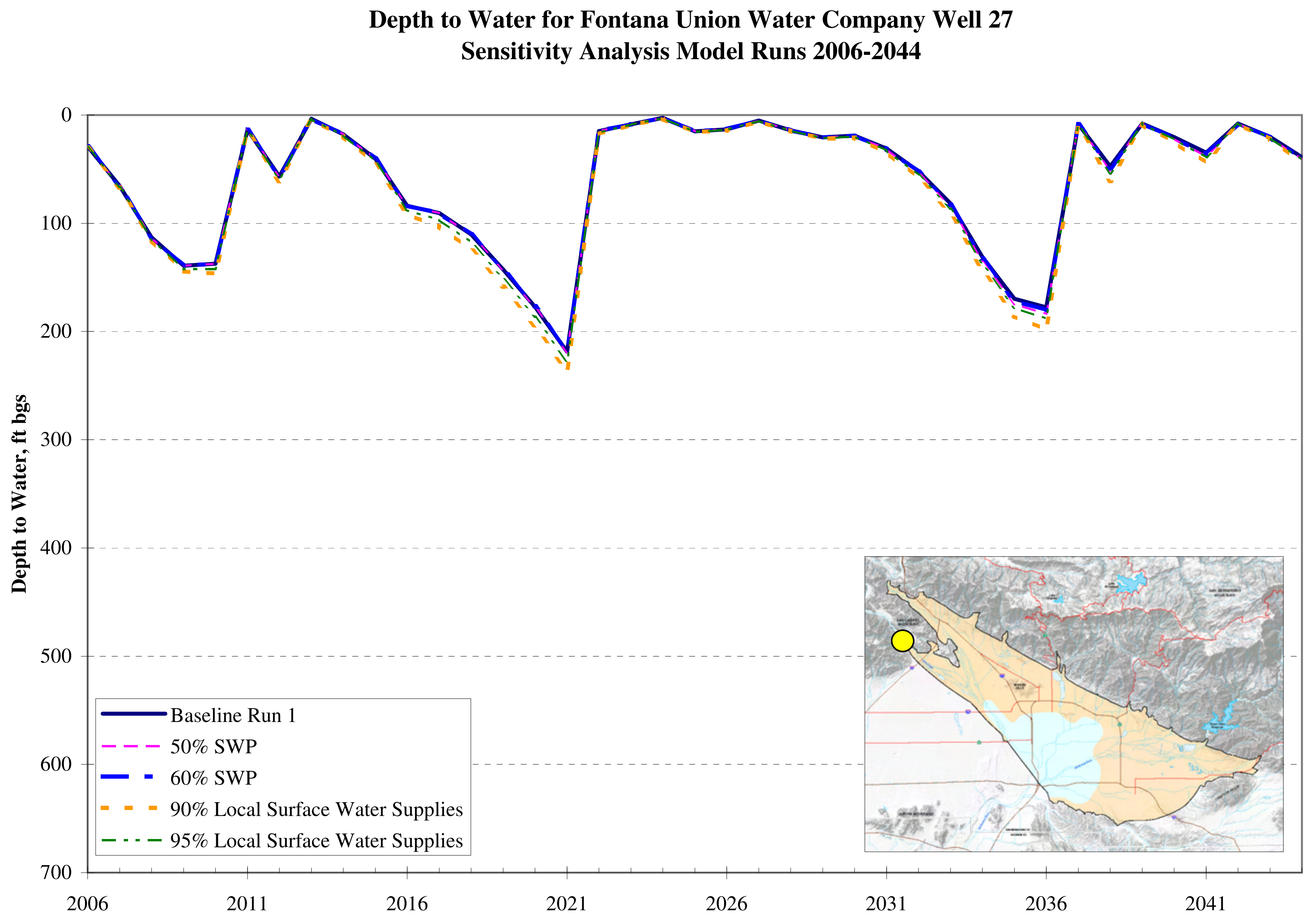
Depth to Water for City of San Bernardino Cajon Well No. 1
Sensitivity Analysis Model Runs 2006-2044



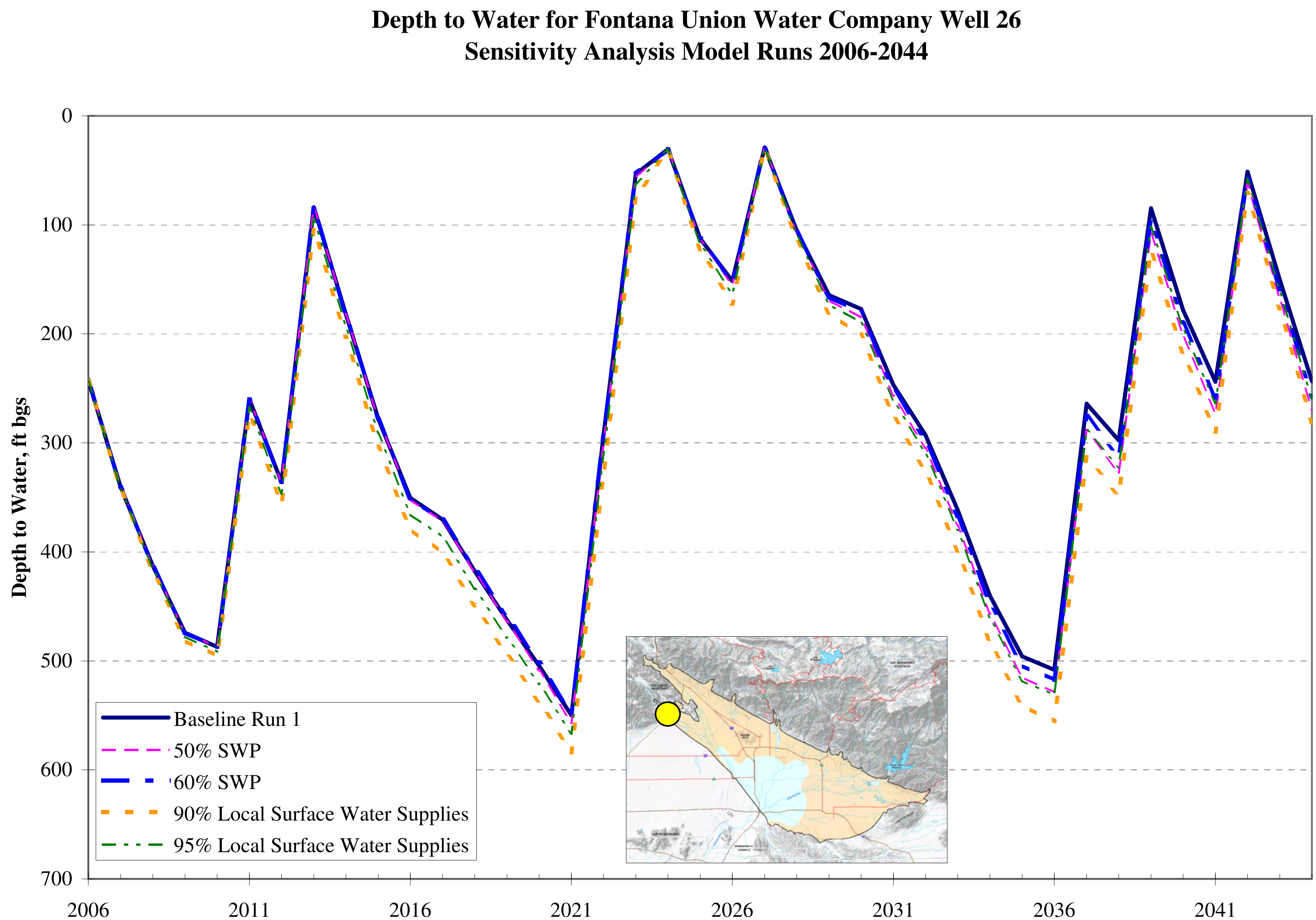
Appendix C

Depth to Water for City of San Bernardino Mt. Vernon Well
Sensitivity Analysis Model Runs 2006-2044



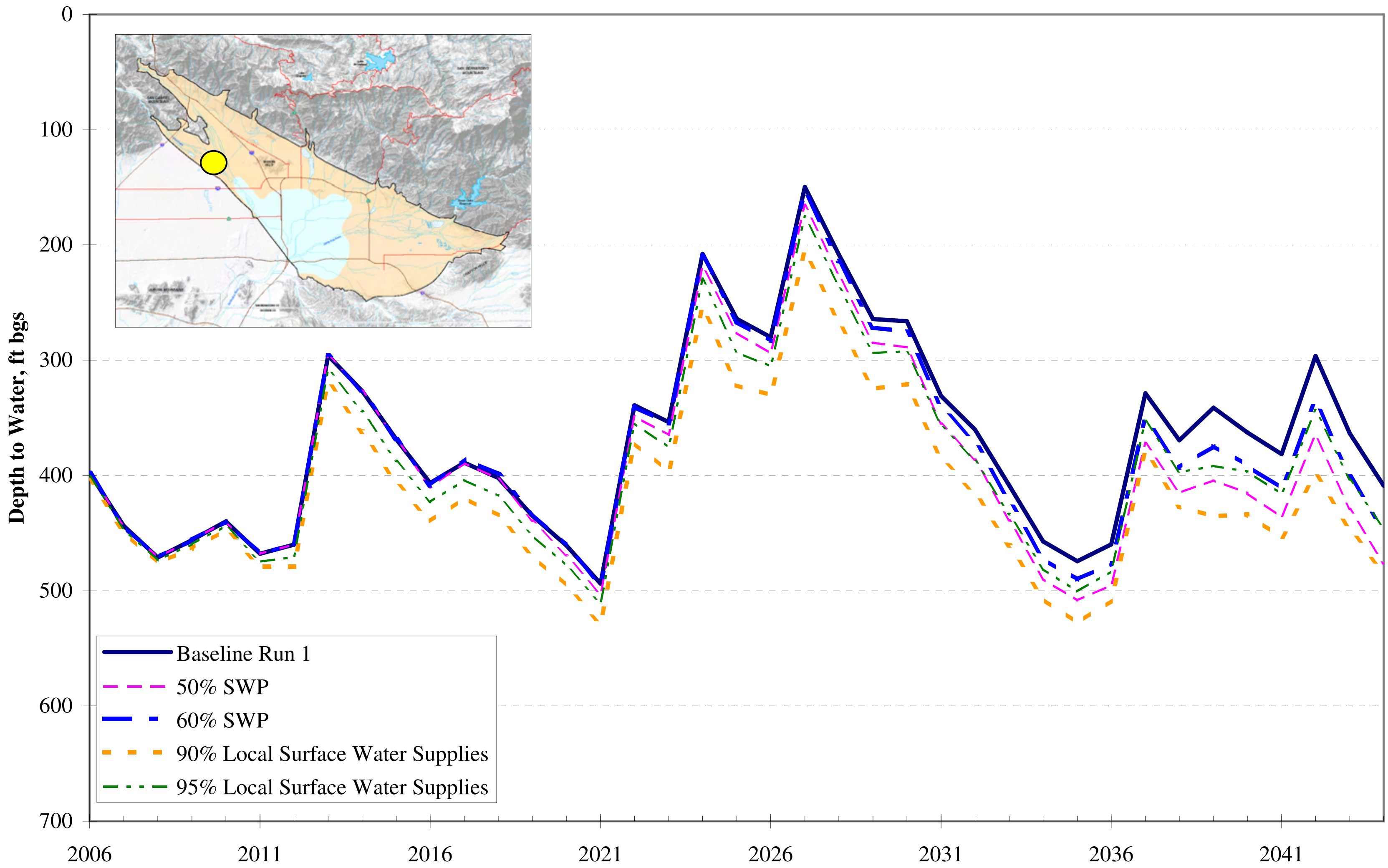

Depth to Water for Fontana Union Water Company Well 27
Sensitivity Analysis Model Runs 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
50% SWP
60% SWP
90% Local Surface Water Supplies
95% Local Surface Water Supplies

Appendix C


Depth to Water for Fontana Union Water Company Well 26
Sensitivity Analysis Model Runs 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
50% SWP
60% SWP
90% Local Surface Water Supplies
95% Local Surface Water Supplies

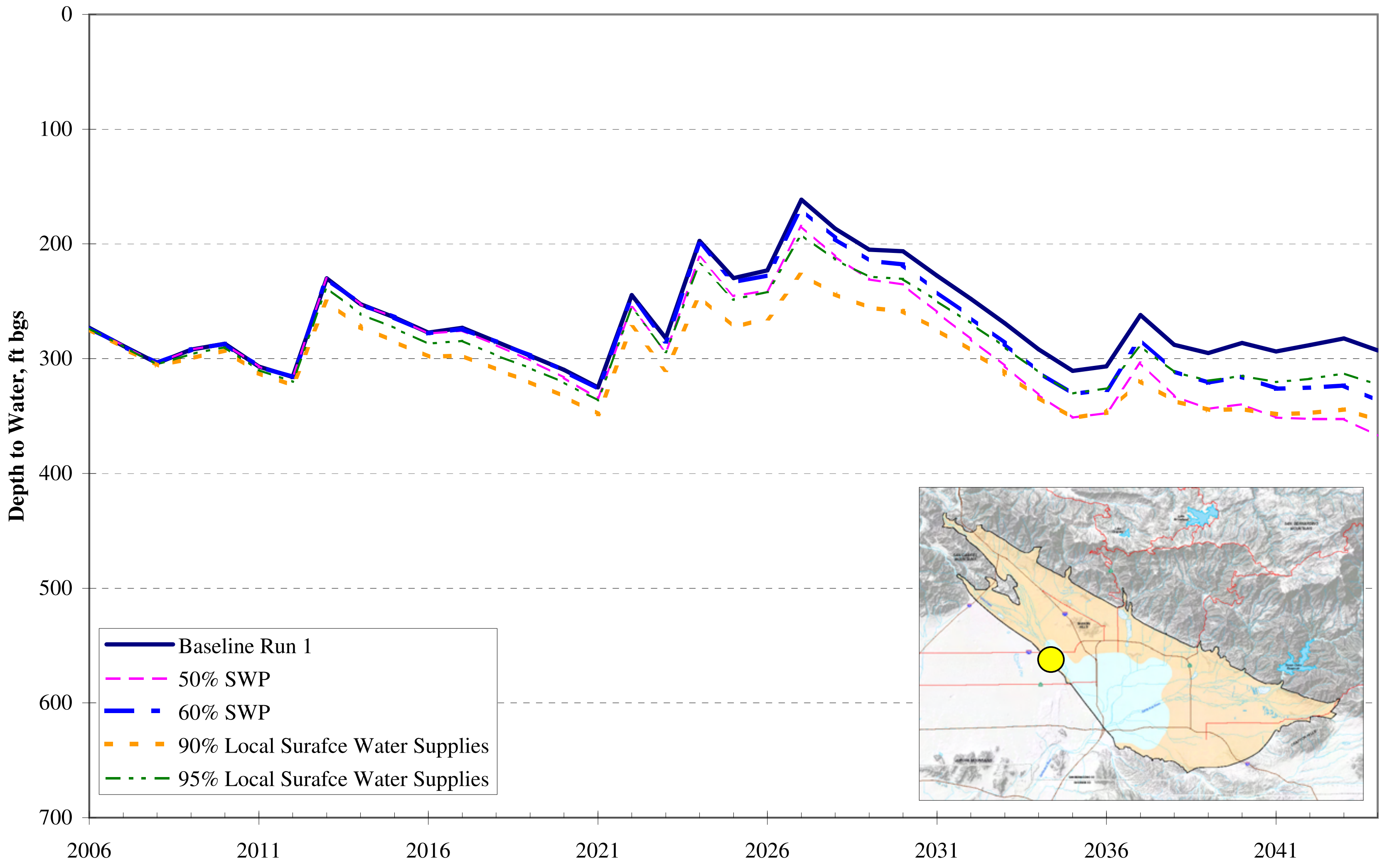
Appendix C

Depth to Water for Fontana Union Water Company Well 13
Sensitivity Analysis Model Runs 2006-2044



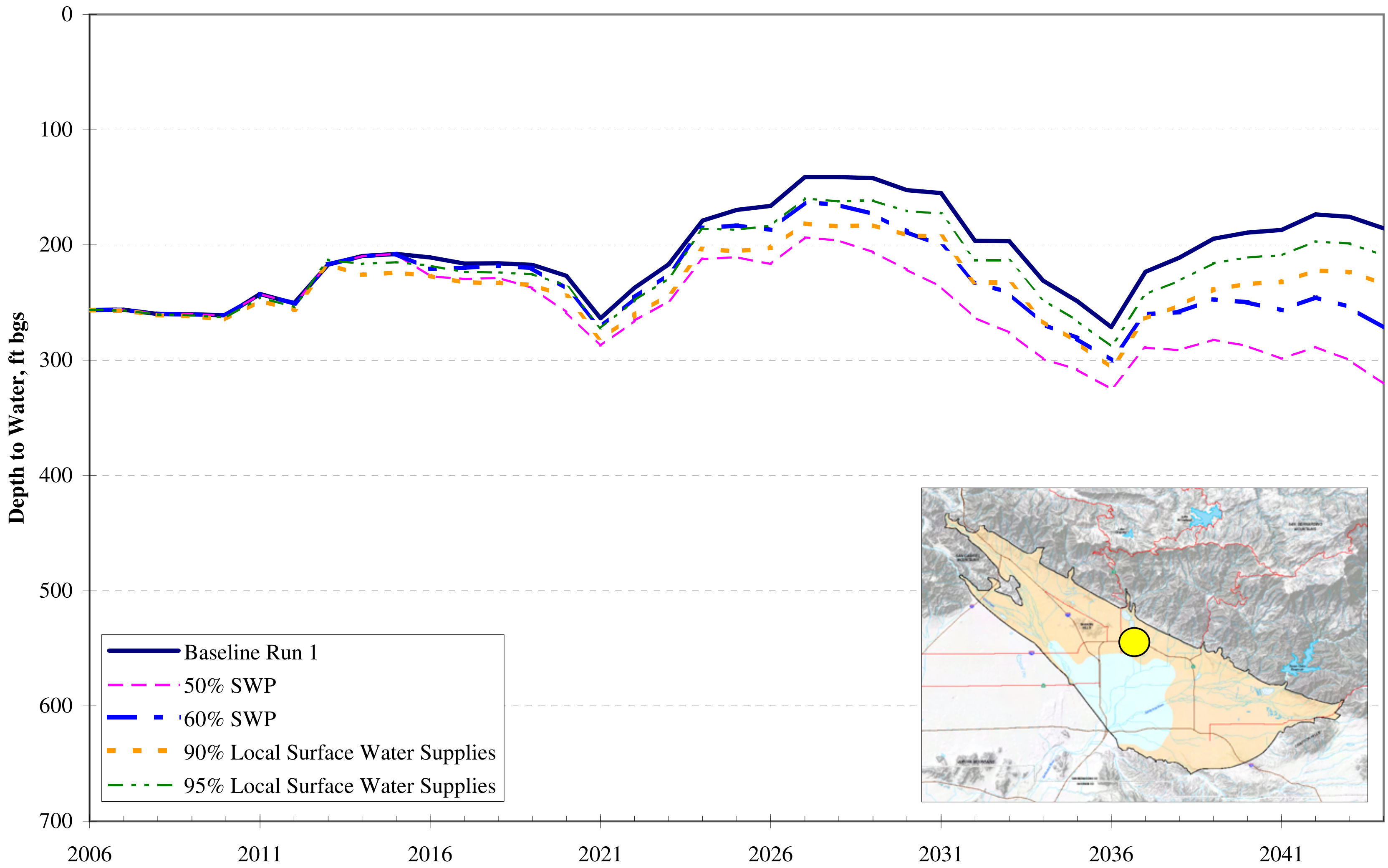
Appendix C

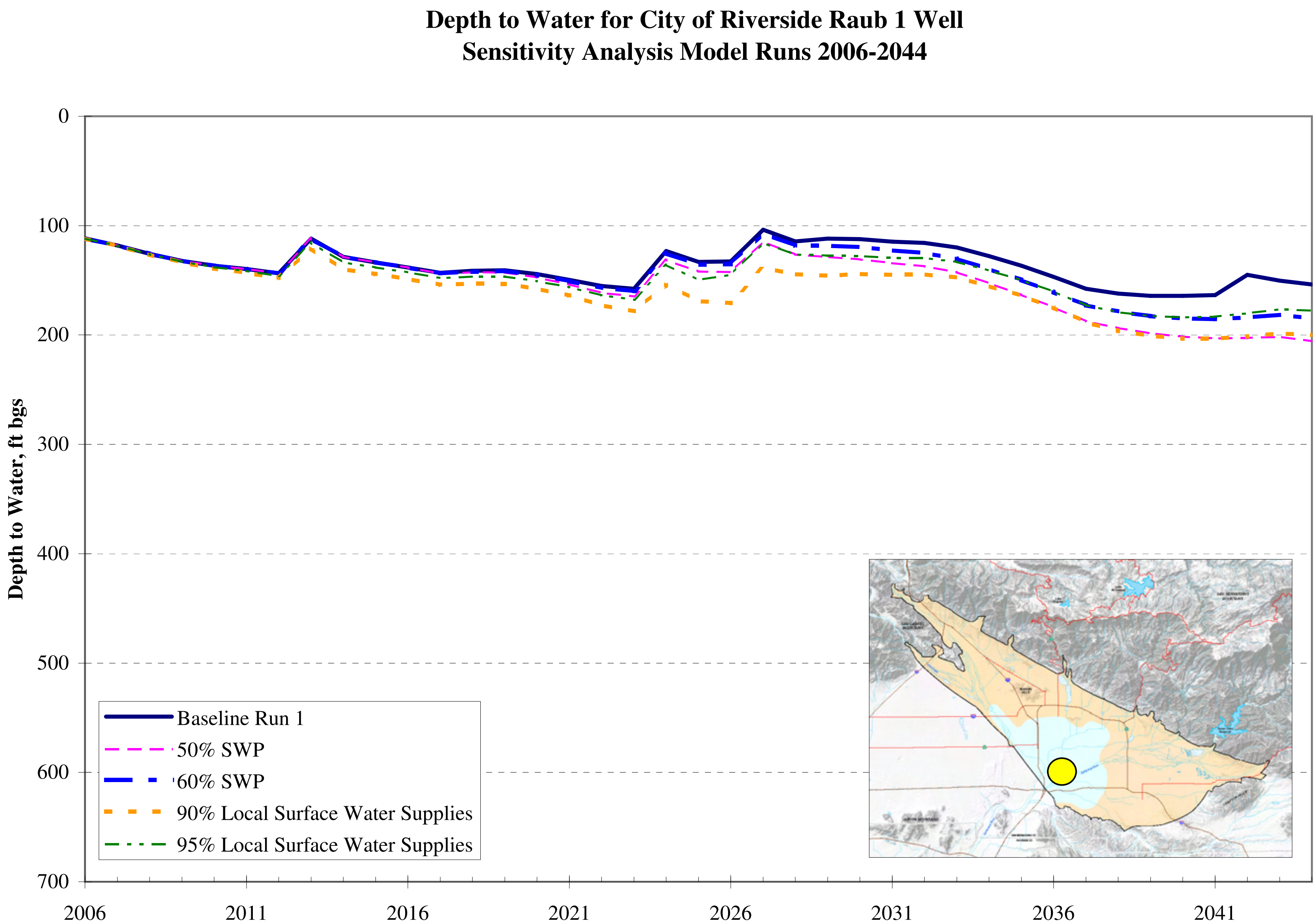
Depth to Water for West Valley Water District Lord 7 Well
Sensitivity Analysis Model Runs 2006-2044



Appendix C

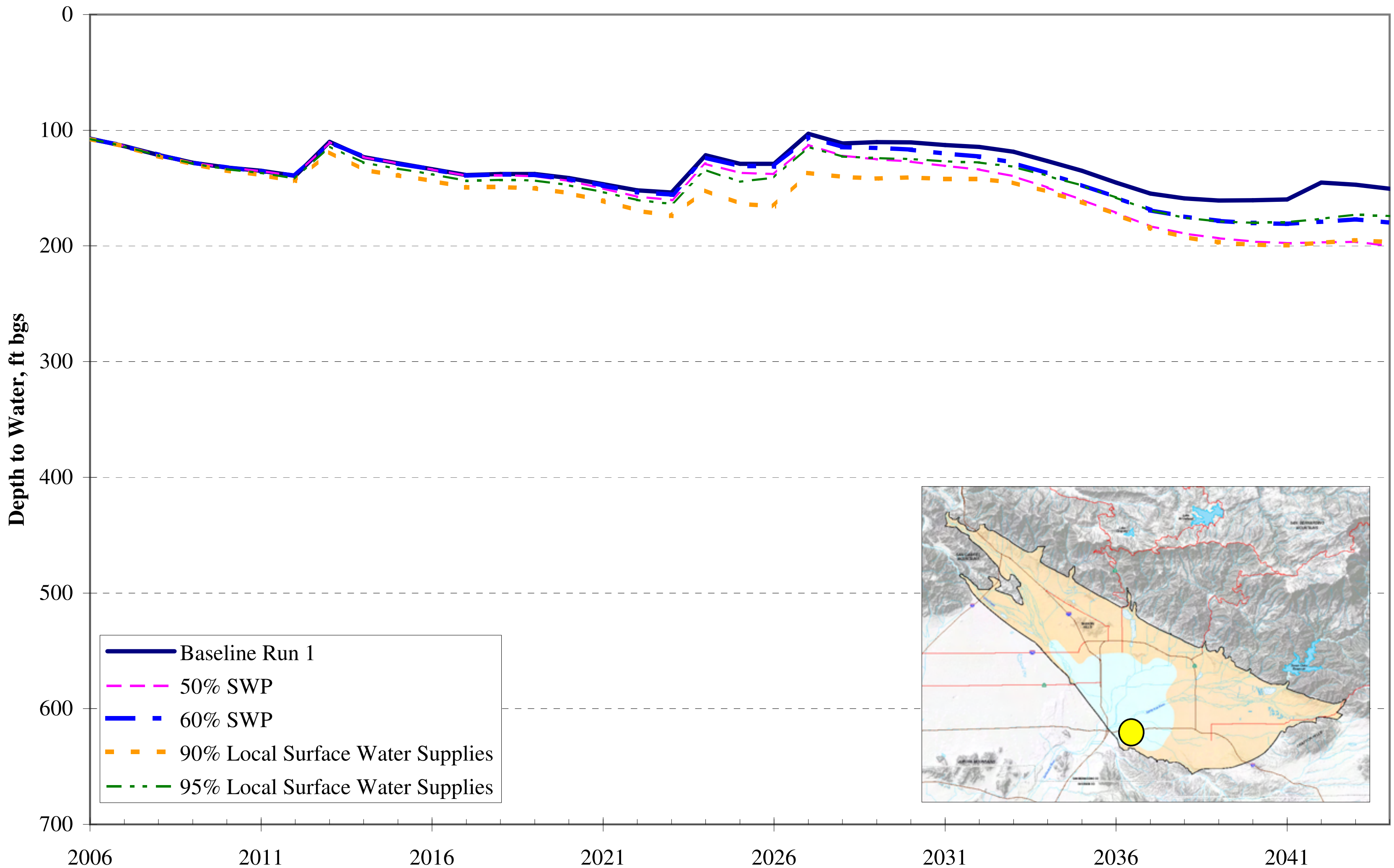
Depth to Water for East Valley Water District Well 24A
Sensitivity Analysis Model Runs 2006-2044



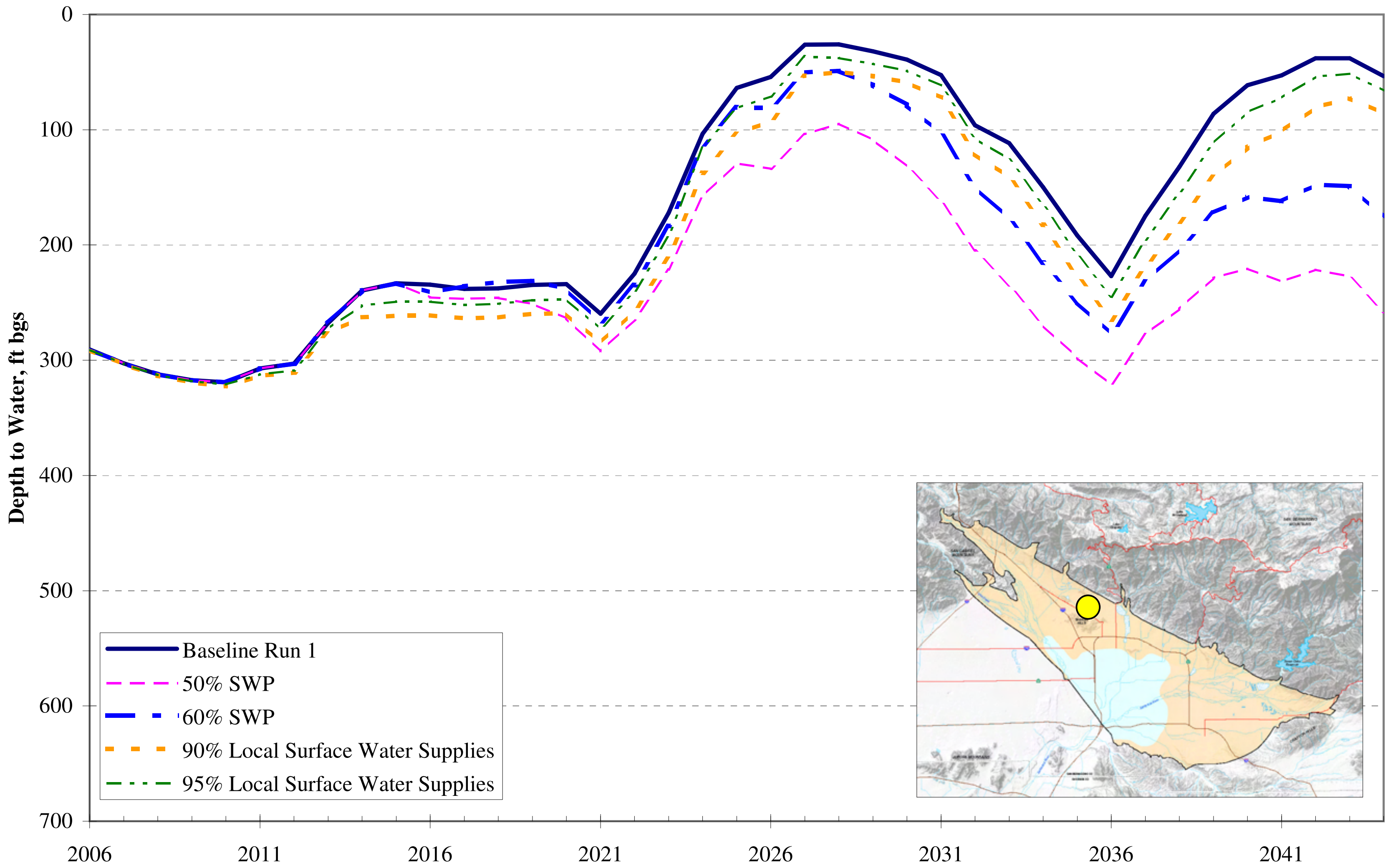

Depth to Water for City of Riverside Raub 1 Well
Sensitivity Analysis Model Runs 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
50% SWP
60% SWP
90% Local Surface Water Supplies
95% Local Surface Water Supplies

Appendix C

Depth to Water for Gage Canal Company Lower Kelly Well
Sensitivity Analysis Model Runs 2006-2044

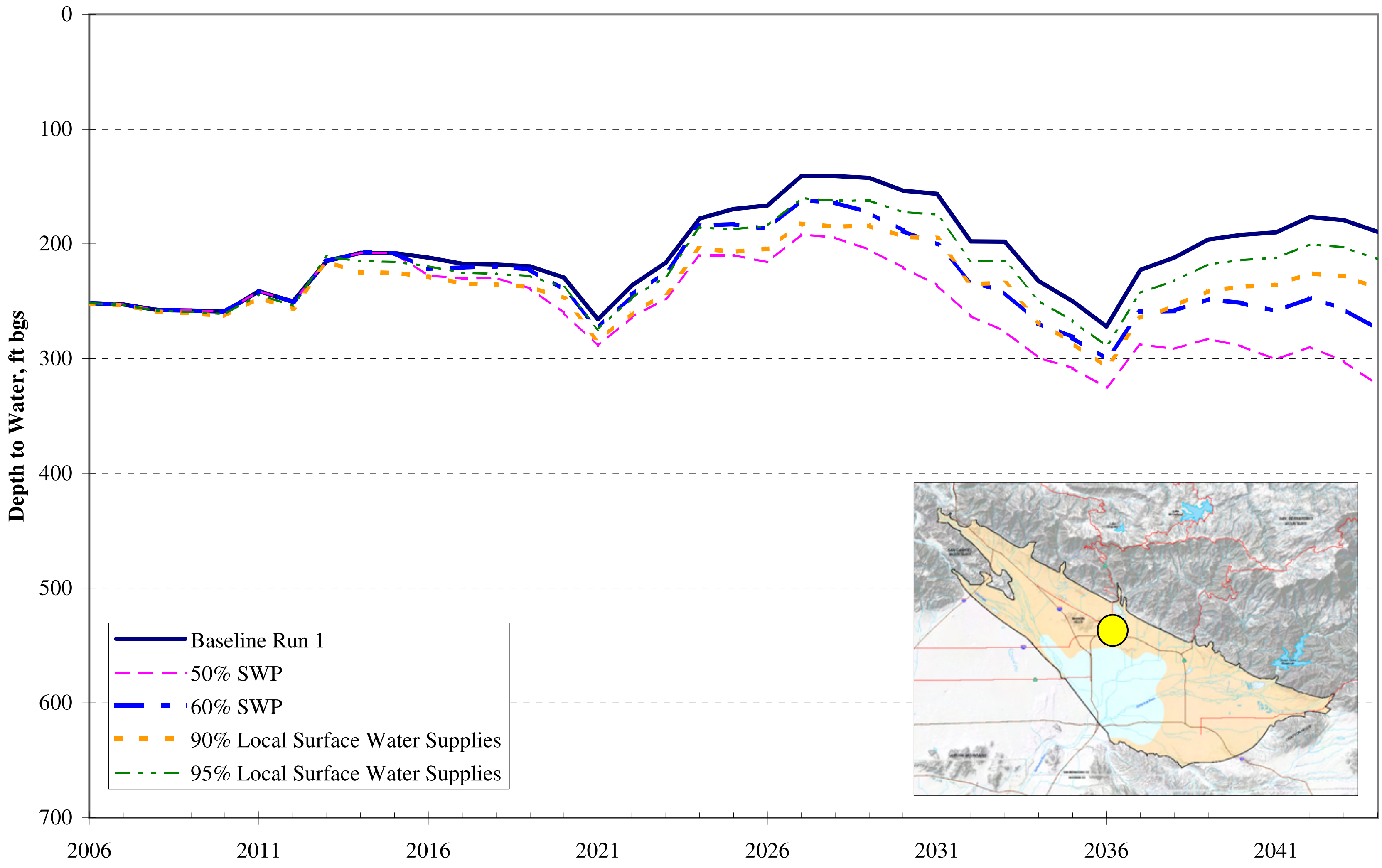


Depth to Water for City of San Bernardino Newmark 3 Well
Sensitivity Analysis Model Runs 2006-2044

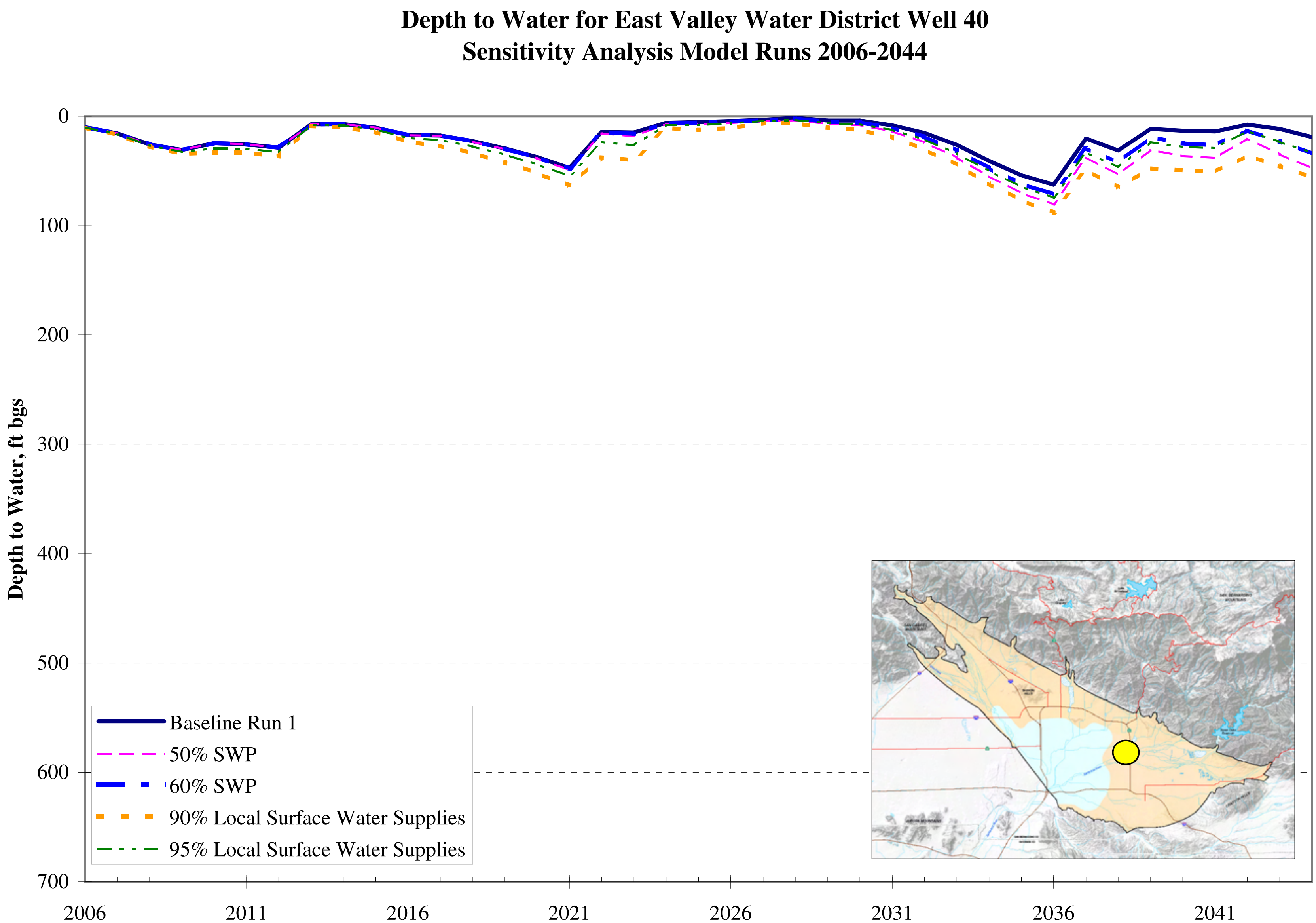


Appendix C

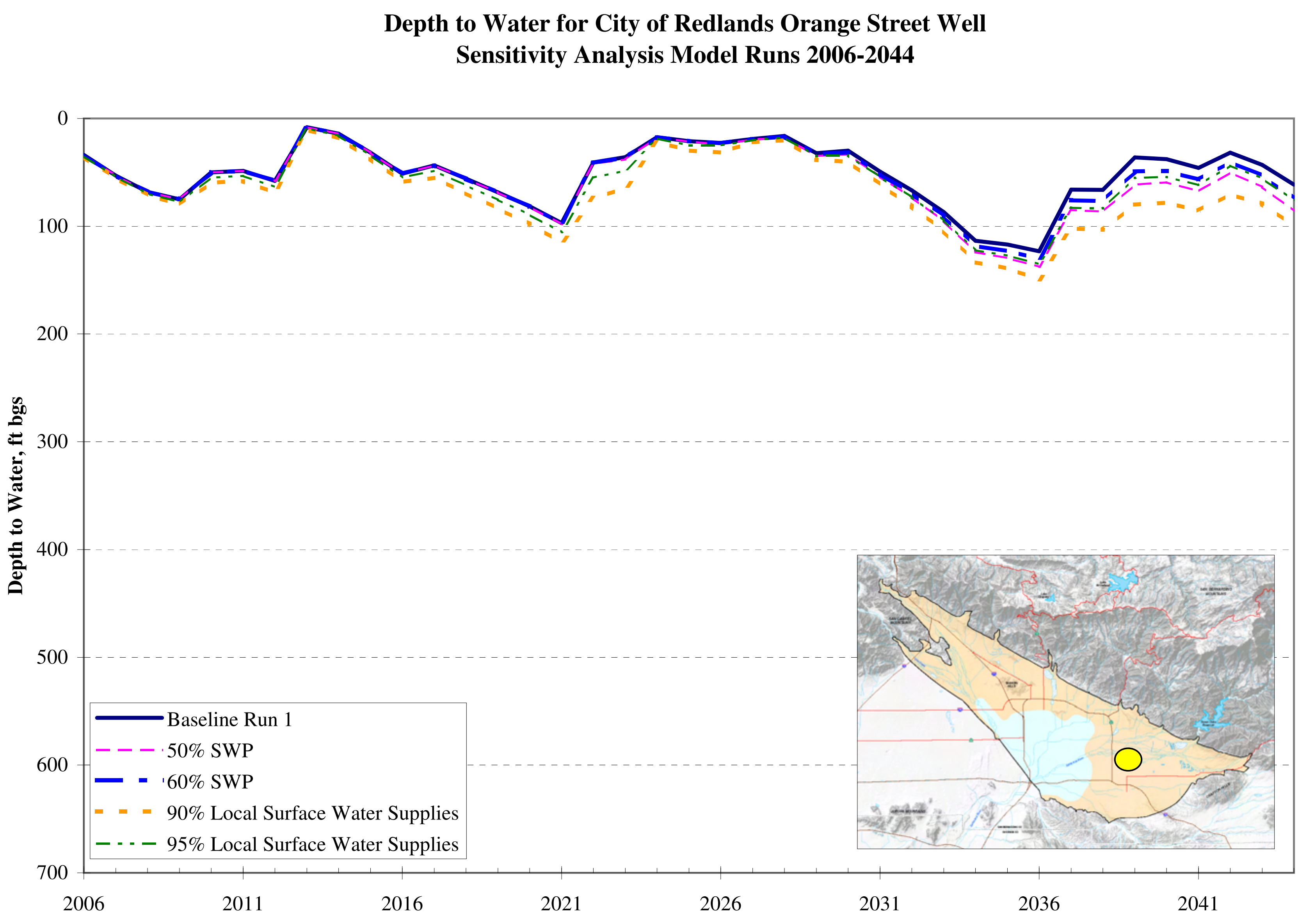
Depth to Water for City of San Bernardino Leroy Street Well
Sensitivity Analysis Model Runs 2006-2044



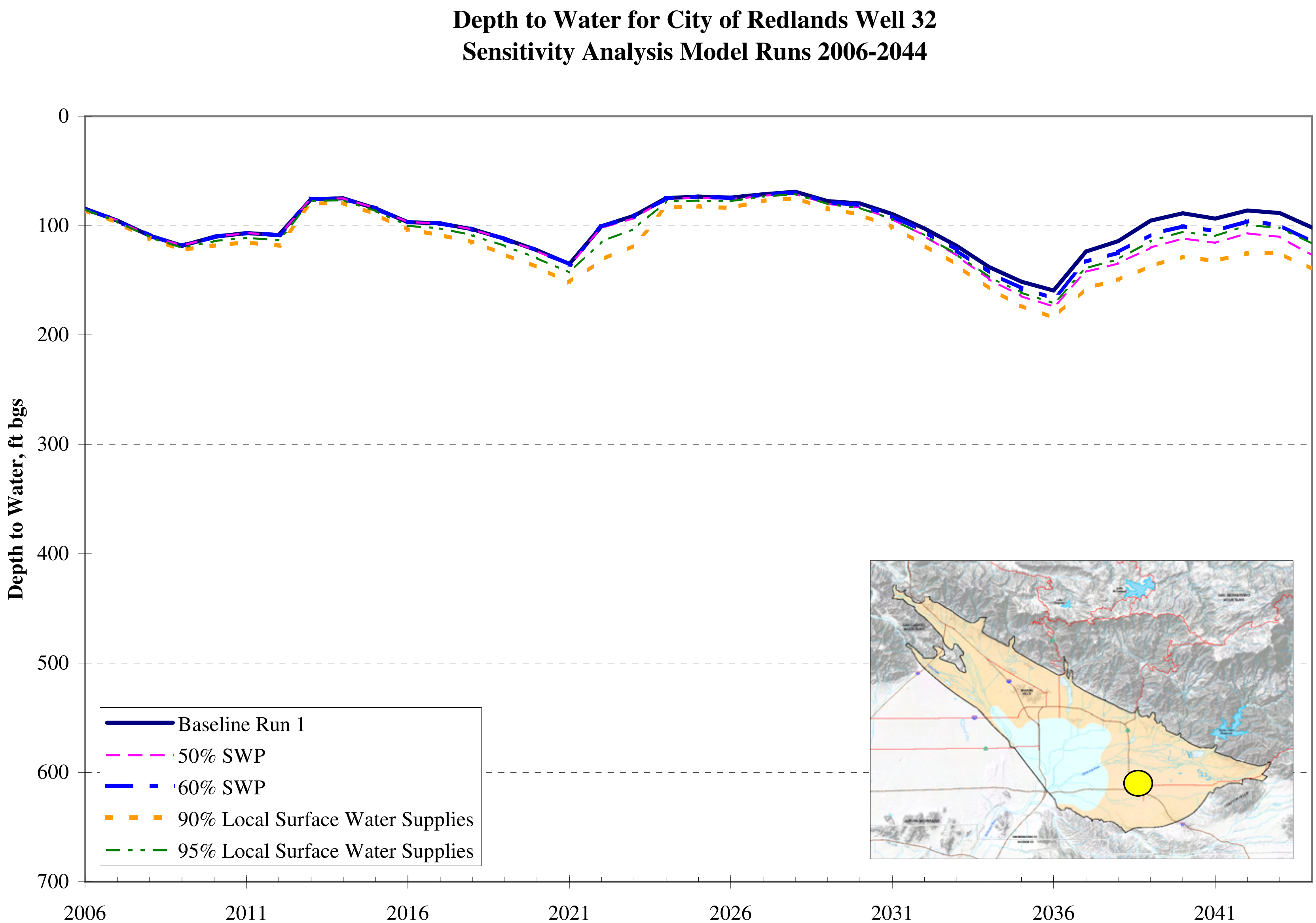
Appendix C


Depth to Water for East Valley Water District Well 40
Sensitivity Analysis Model Runs 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
50% SWP
60% SWP
90% Local Surface Water Supplies
95% Local Surface Water Supplies

Appendix C

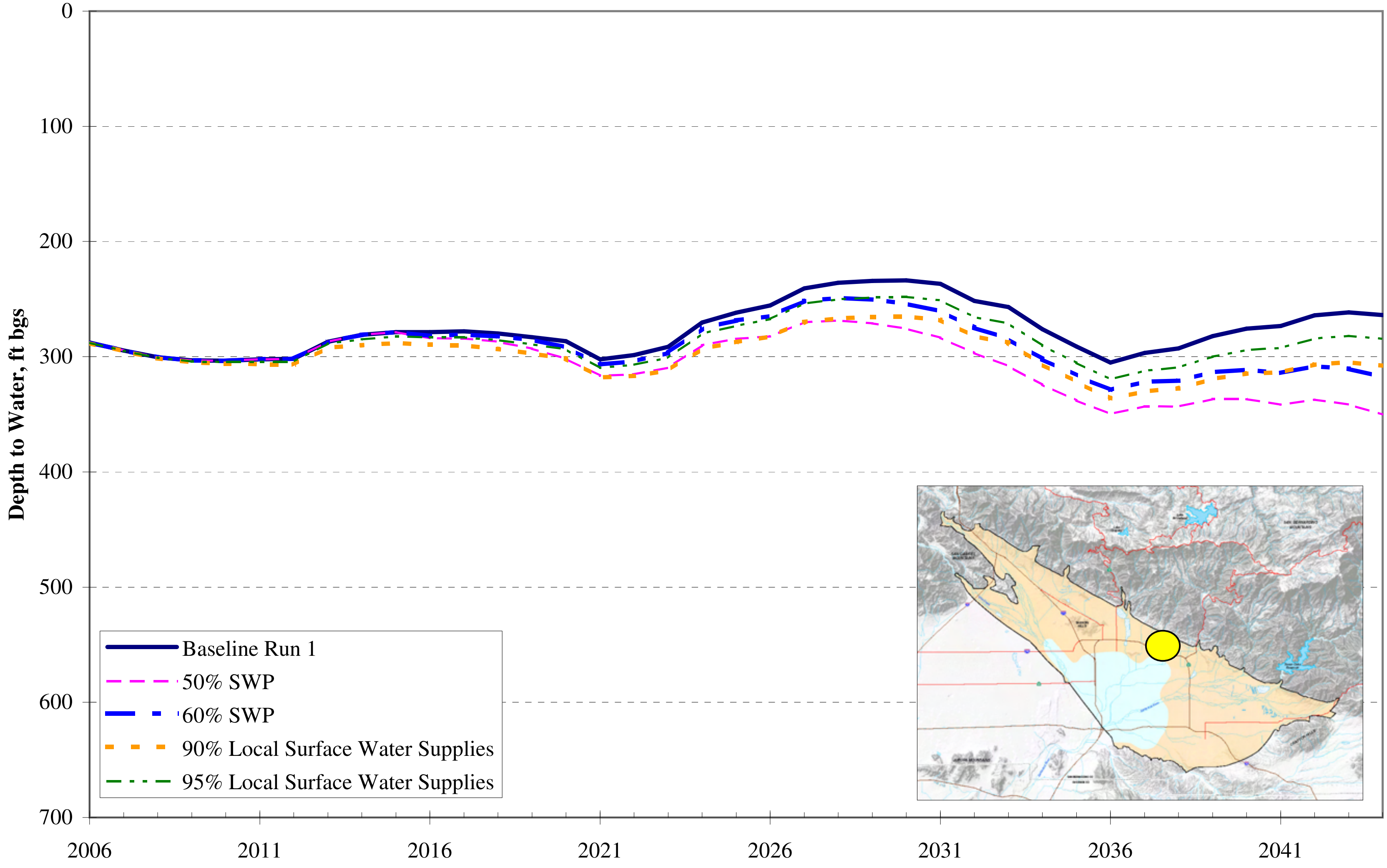

Depth to Water for City of Redlands Orange Street Well
Sensitivity Analysis Model Runs 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
50% SWP
60% SWP
90% Local Surface Water Supplies
95% Local Surface Water Supplies

Appendix C

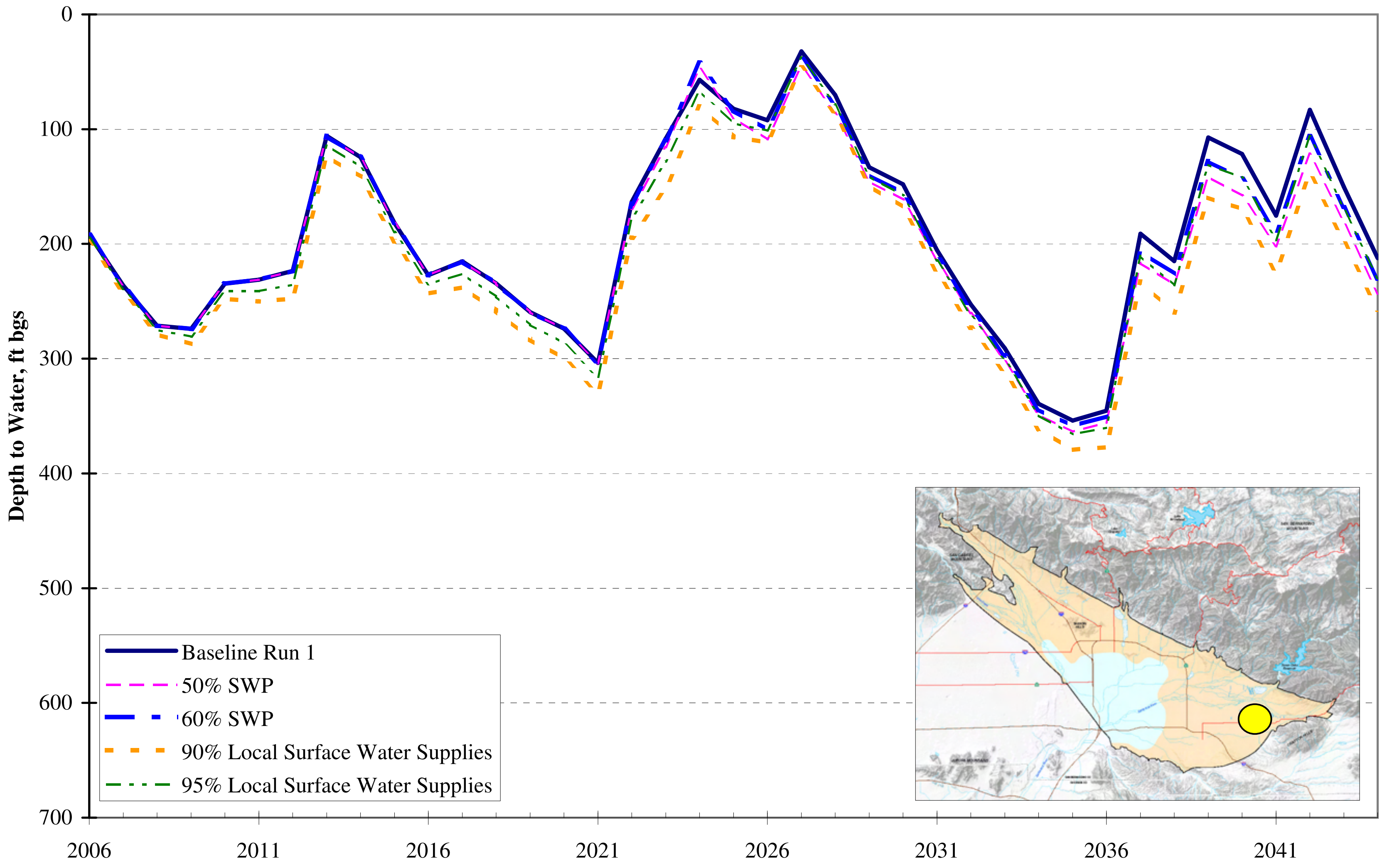

Depth to Water for City of Redlands Well 32
Sensitivity Analysis Model Runs 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
50% SWP
60% SWP
90% Local Surface Water Supplies
95% Local Surface Water Supplies

Appendix C

Depth to Water for East Valley Water District Well 62
Sensitivity Analysis Model Runs 2006-2044

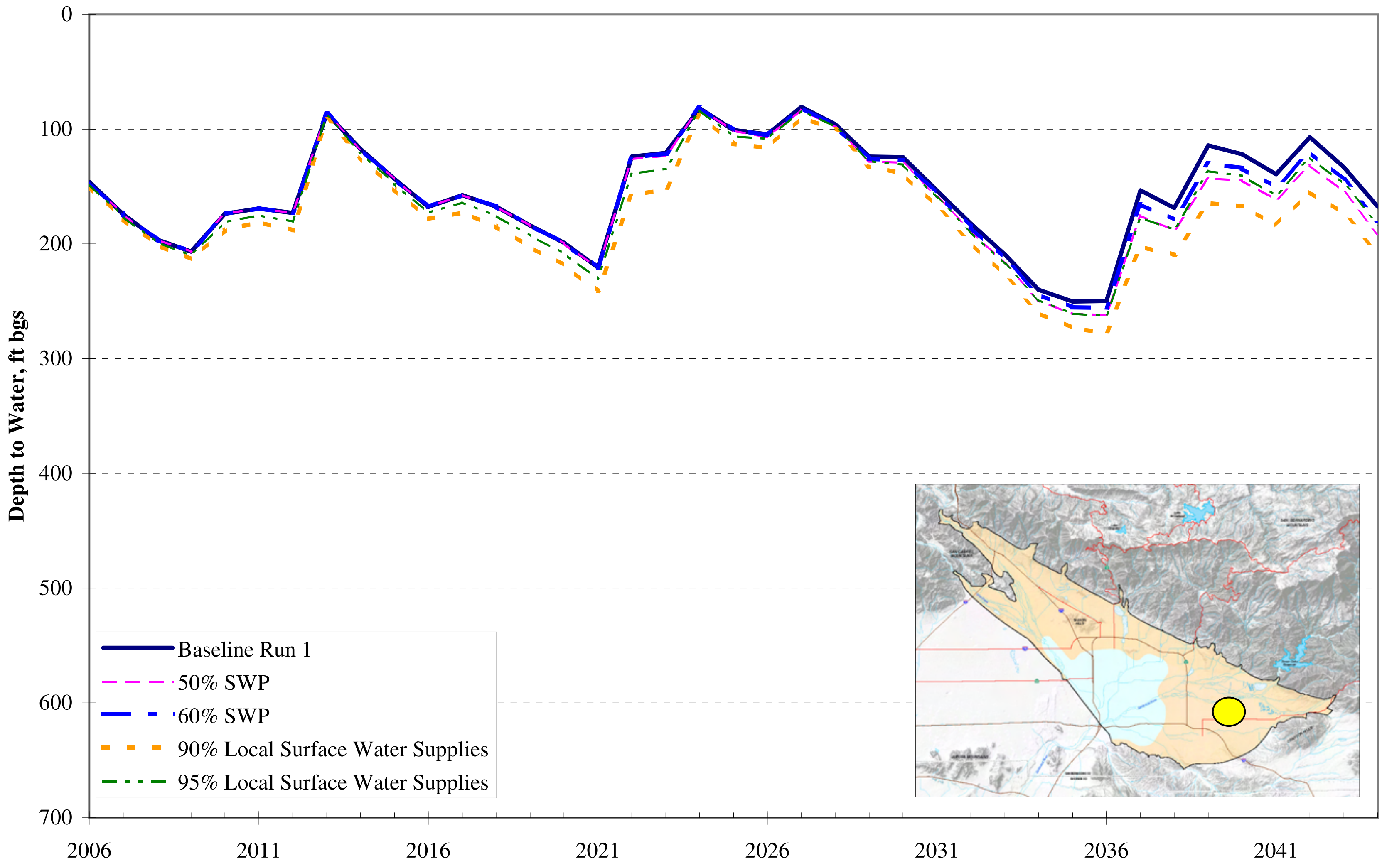


Depth to Water for City of Redlands Agate 2 Well
Sensitivity Analysis Model Runs 2006-2044

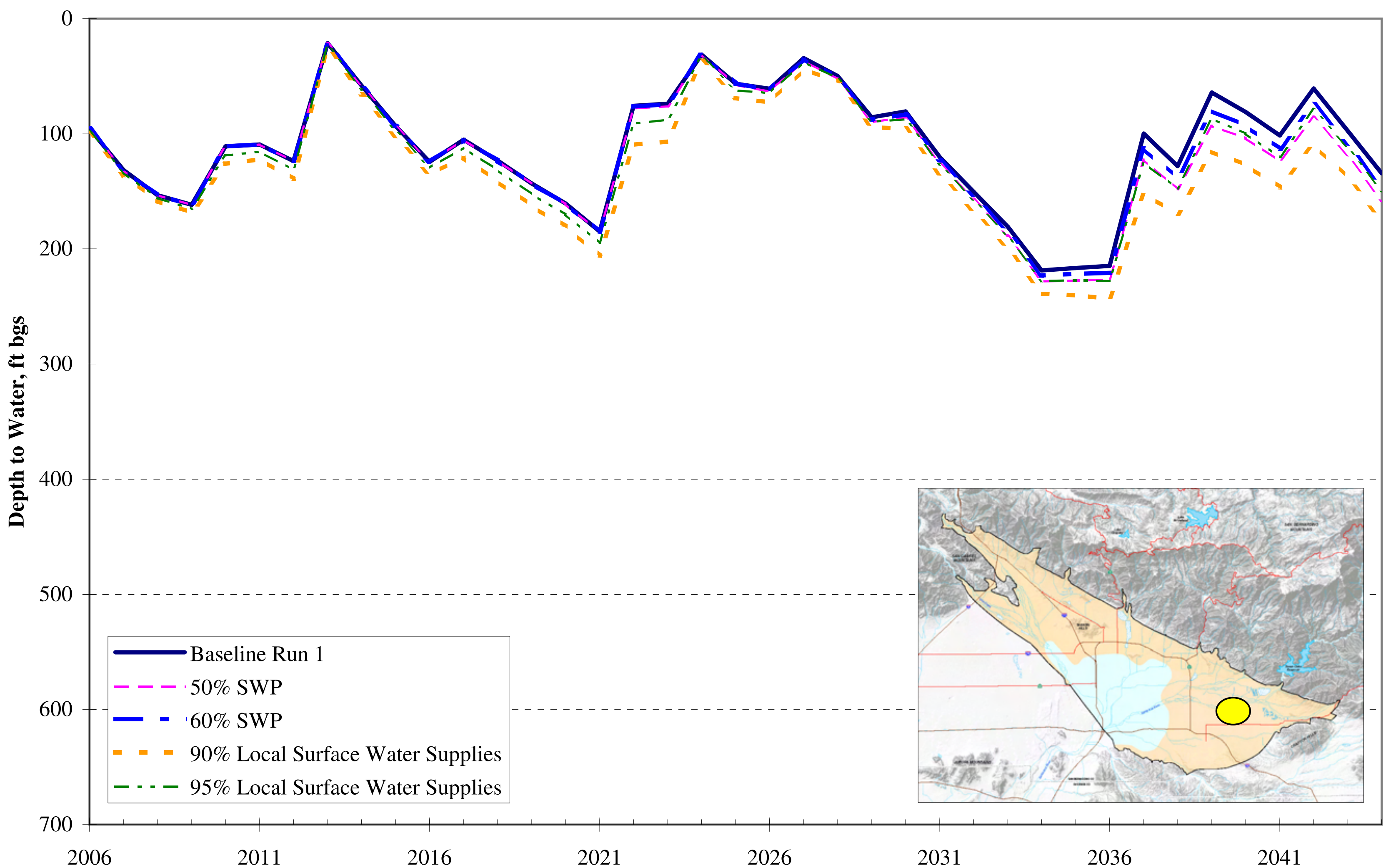


Appendix C

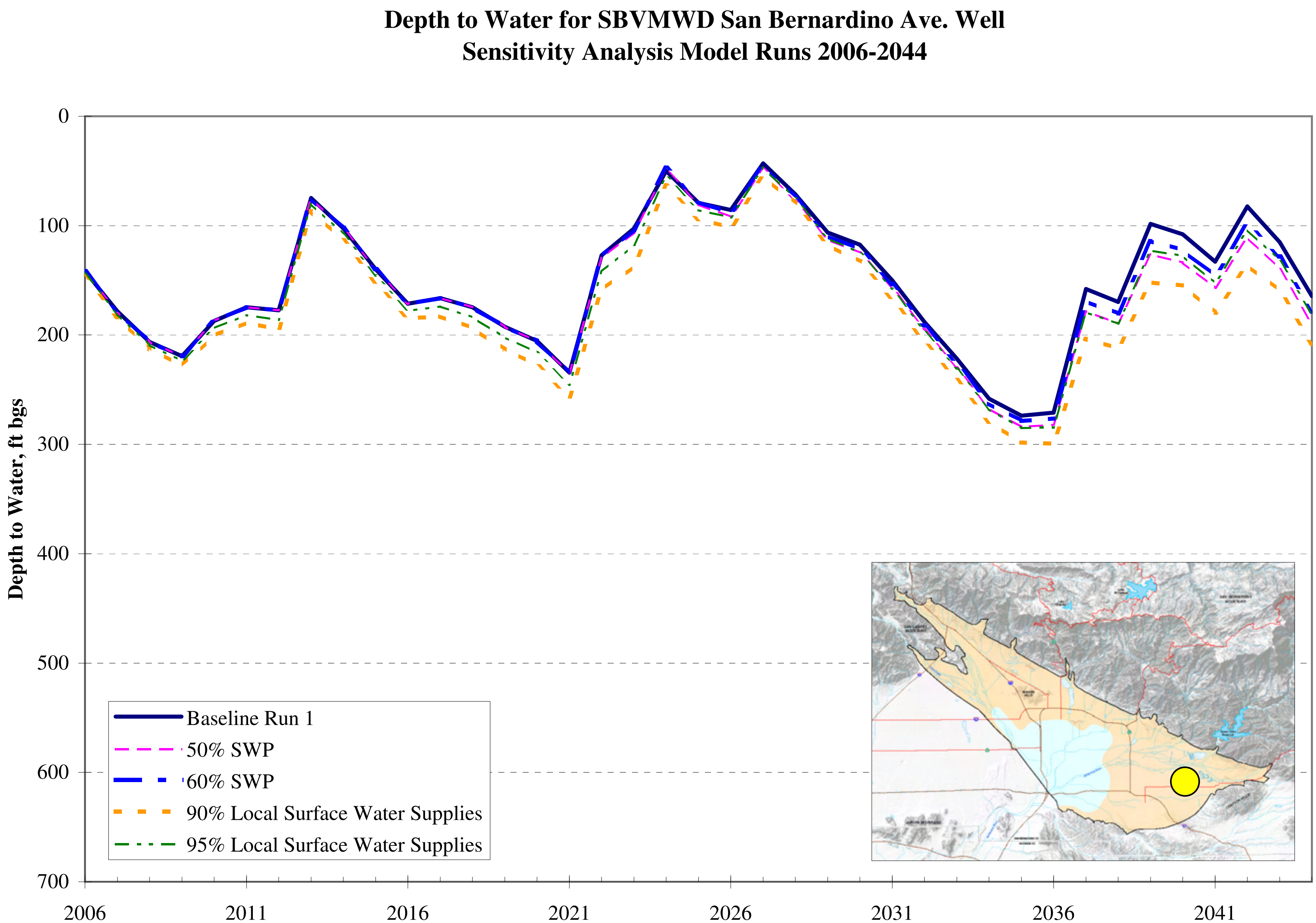
Depth to Water for Bear Valley MWC Nelson Street Well
Sensitivity Analysis Model Runs 2006-2044



Depth to Water for City of Redlands Airport Well No. 2
Sensitivity Analysis Model Runs 2006-2044

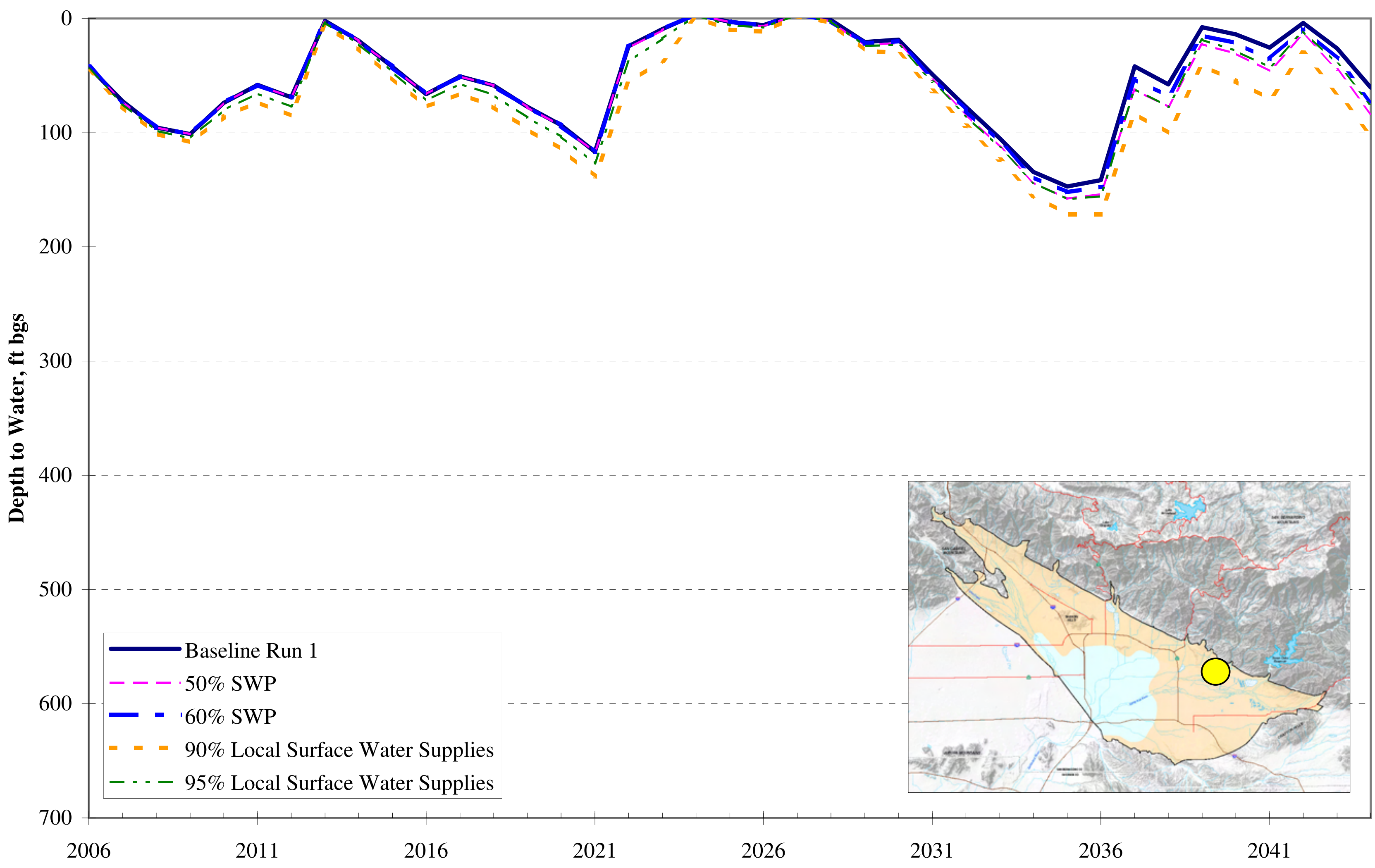


Appendix C


Depth to Water for SBVMWD San Bernardino Ave. Well
Sensitivity Analysis Model Runs 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
50% SWP
60% SWP
90% Local Surface Water Supplies
95% Local Surface Water Supplies

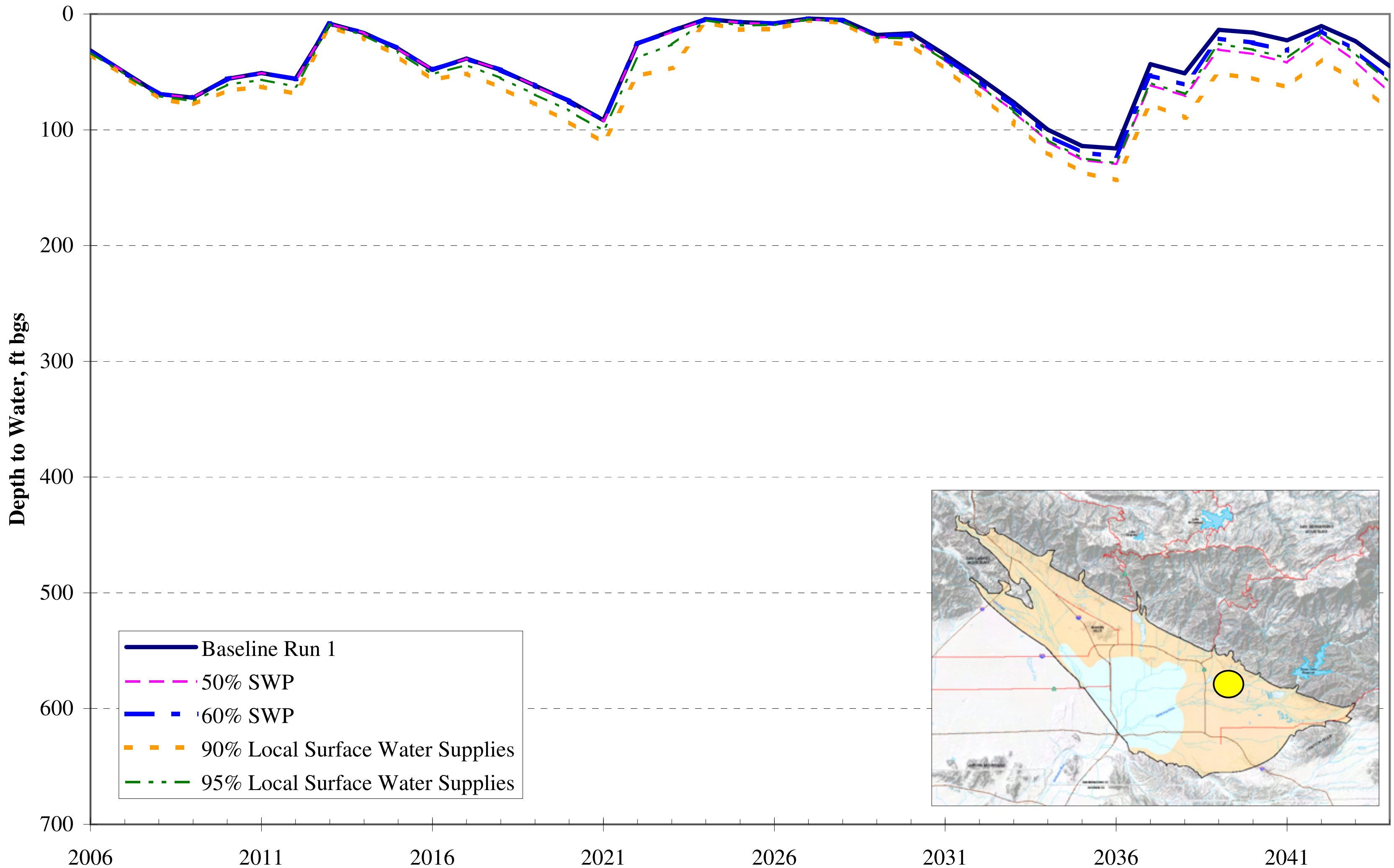
Appendix C

Depth to Water for East Valley Water District Well 120
Sensitivity Analysis Model Runs 2006-2044

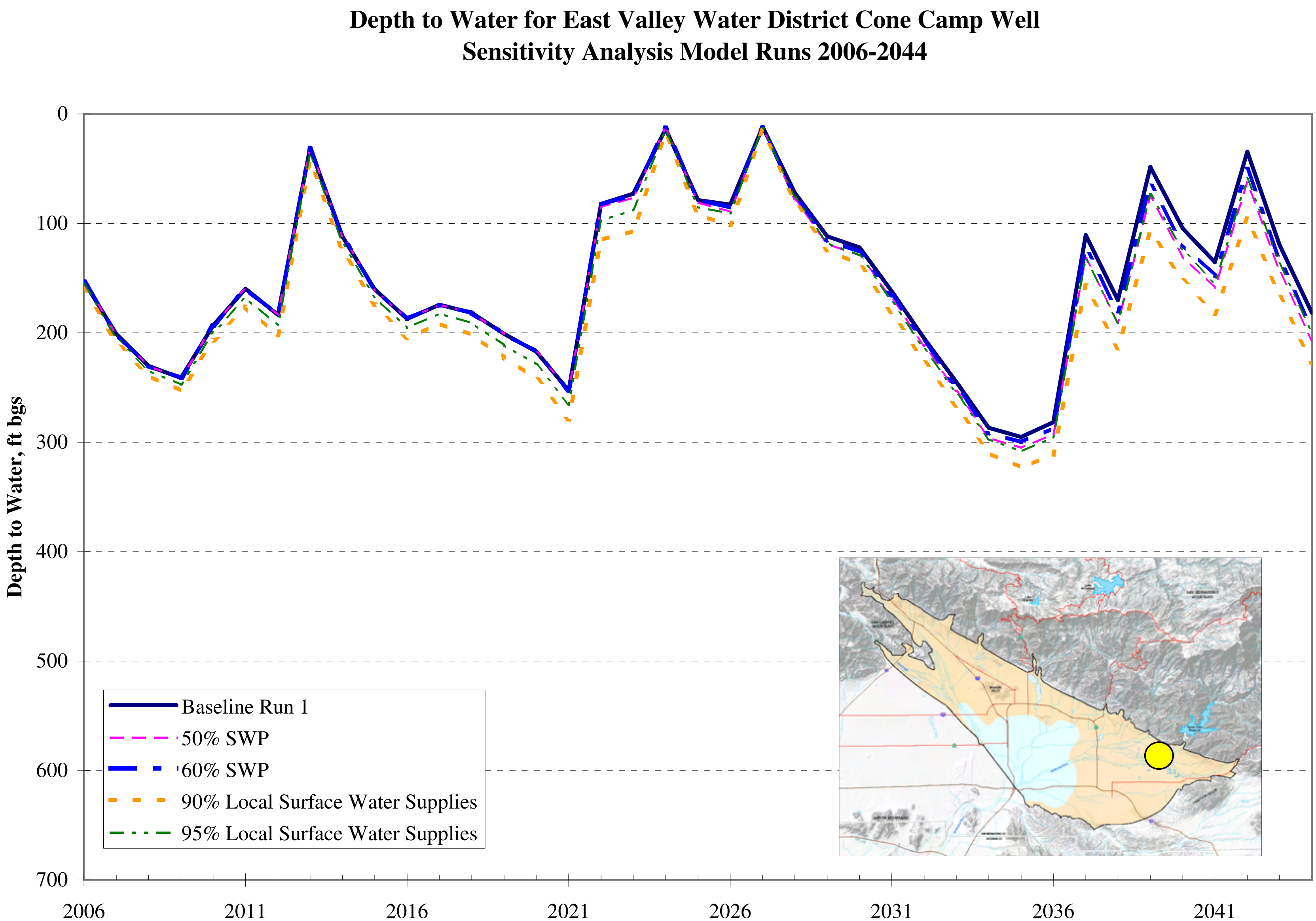


Appendix C

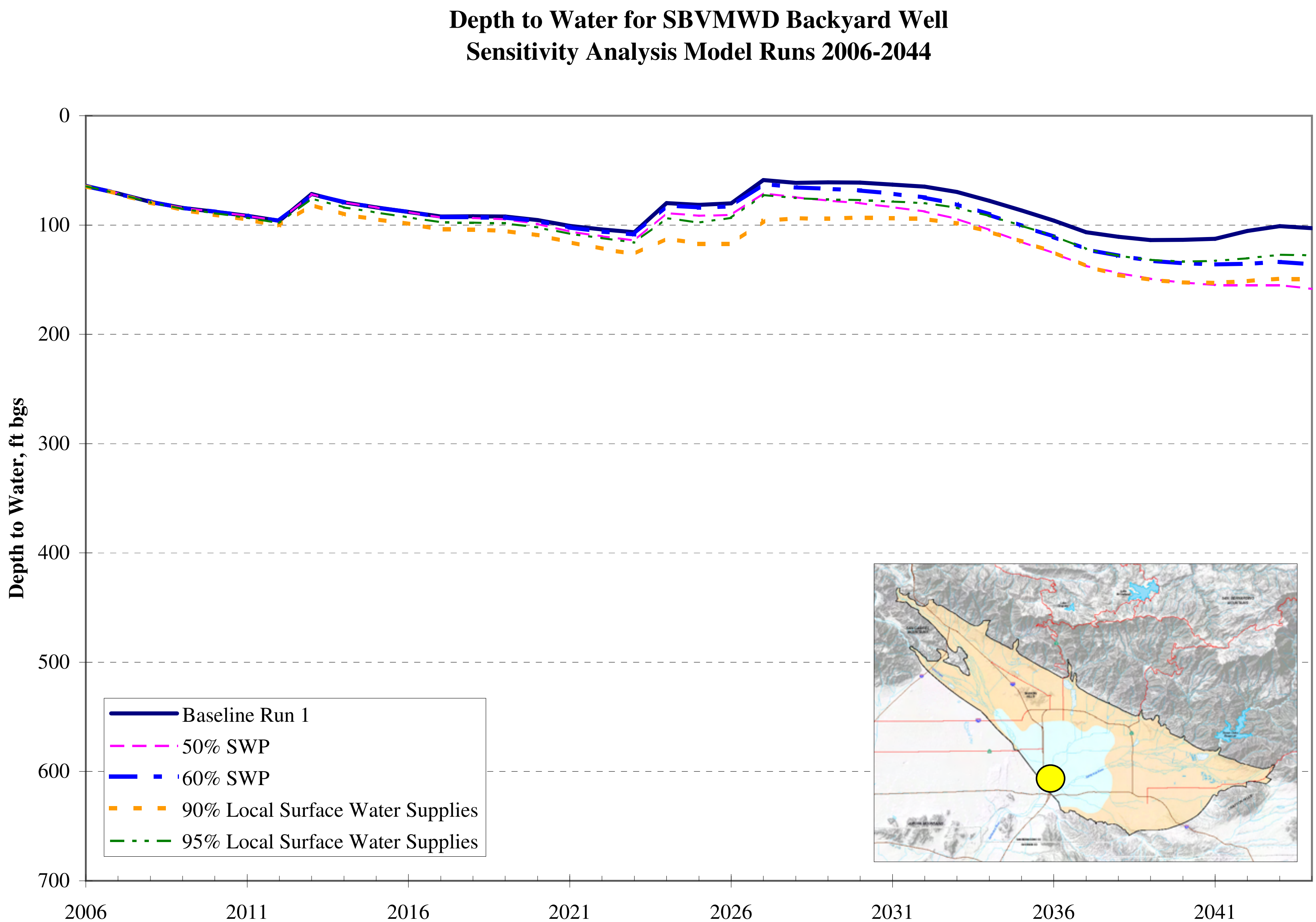
Depth to Water for East Valley Water District Well 146 A
Sensitivity Analysis Model Runs 2006-2044



Appendix C


Depth to Water for East Valley Water District Cone Camp Well
Sensitivity Analysis Model Runs 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
50% SWP
60% SWP
90% Local Surface Water Supplies
95% Local Surface Water Supplies

Appendix C


Depth to Water for SBVMWD Backyard Well
Sensitivity Analysis Model Runs 2006-2044
Depth to Water, ft bgs
0
100
200
300
400
500
600
700
2006
2011
2016
2021
2026
2031
2036
2041
Baseline Run 1
50% SWP
60% SWP
90% Local Surface Water Supplies
95% Local Surface Water Supplies

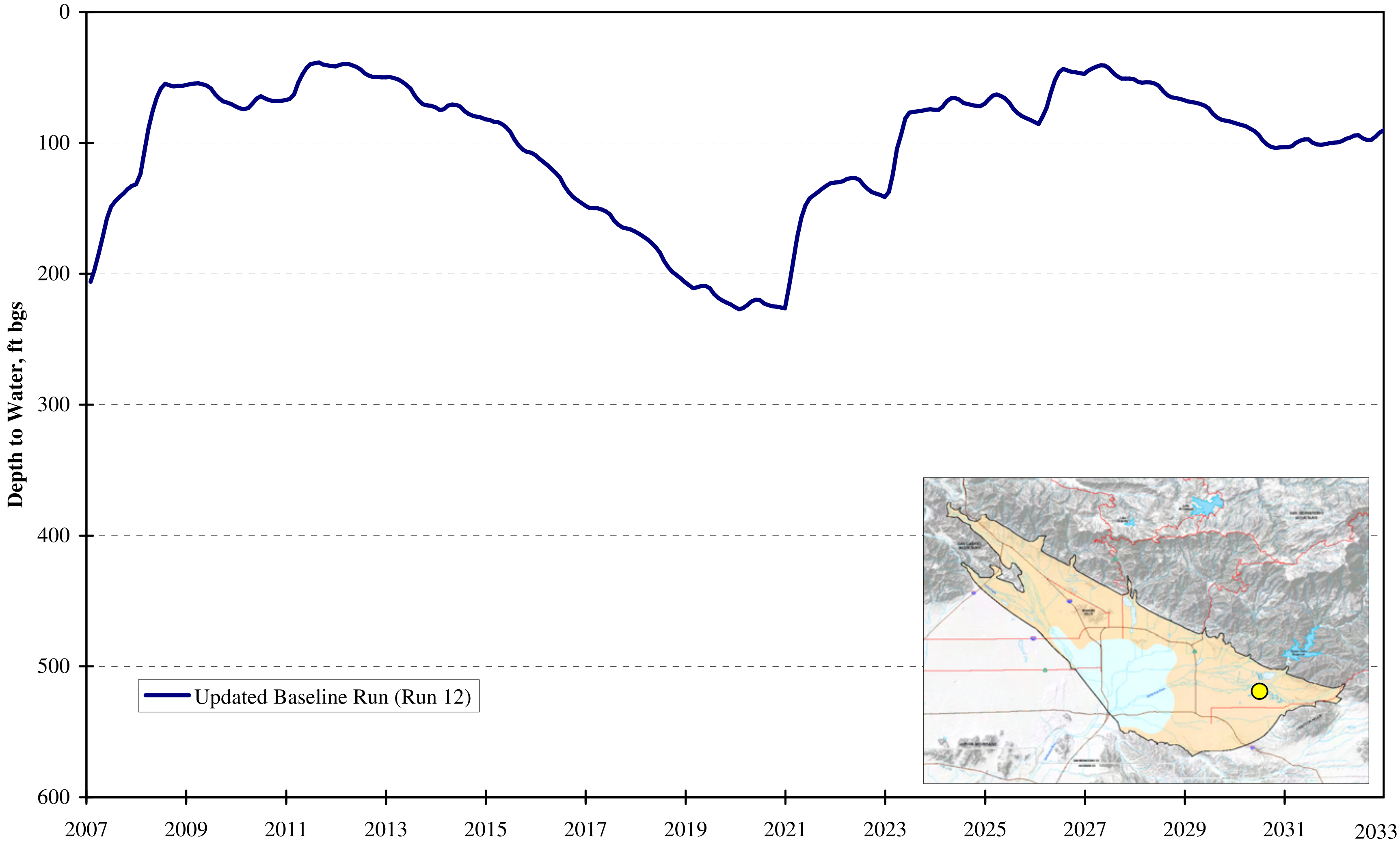
Appendix C

APPENDIX D

Selected Hydrographs of Updated Baseline Run (Run 12)

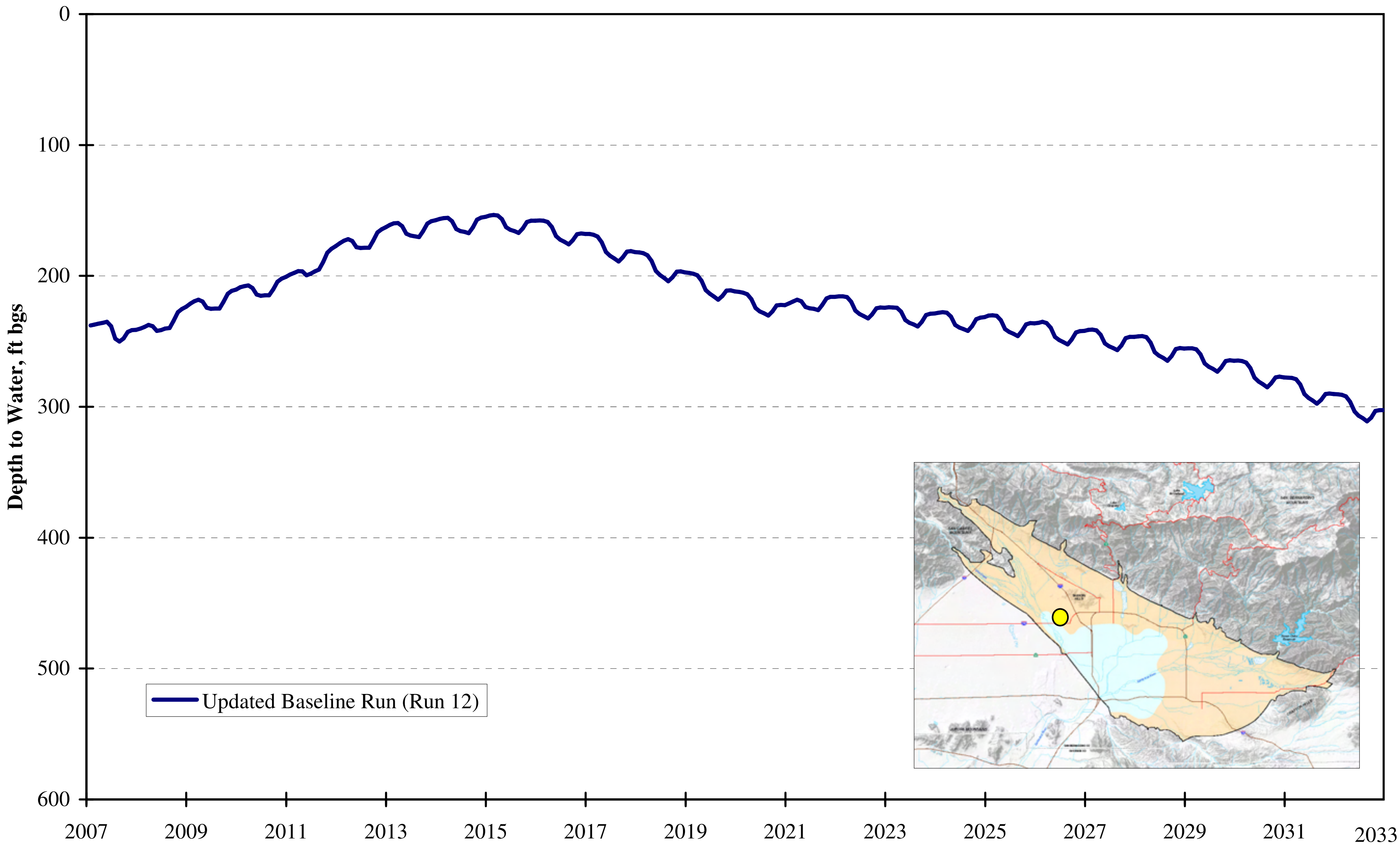
GEOSCIENCE Support Services, Inc.

Depth to Water for SBVMWD San Bernardino Ave. Well
Updated Baseline Run (Run 12) 2007-2032



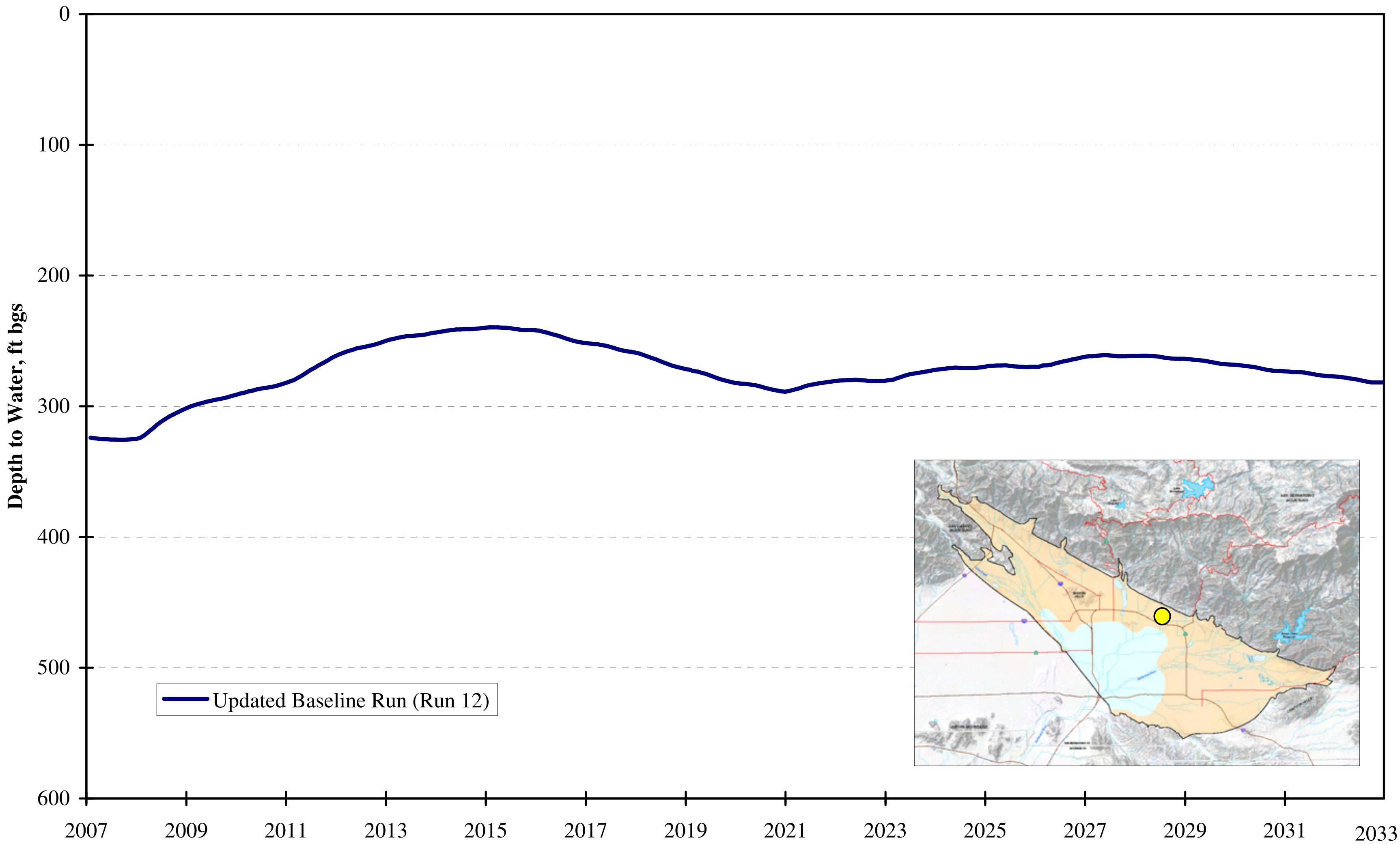
Appendix D

Depth to Water for City of San Bernardino Mt. Vernon Well
Updated Baseline Run (Run 12) 2007-2032



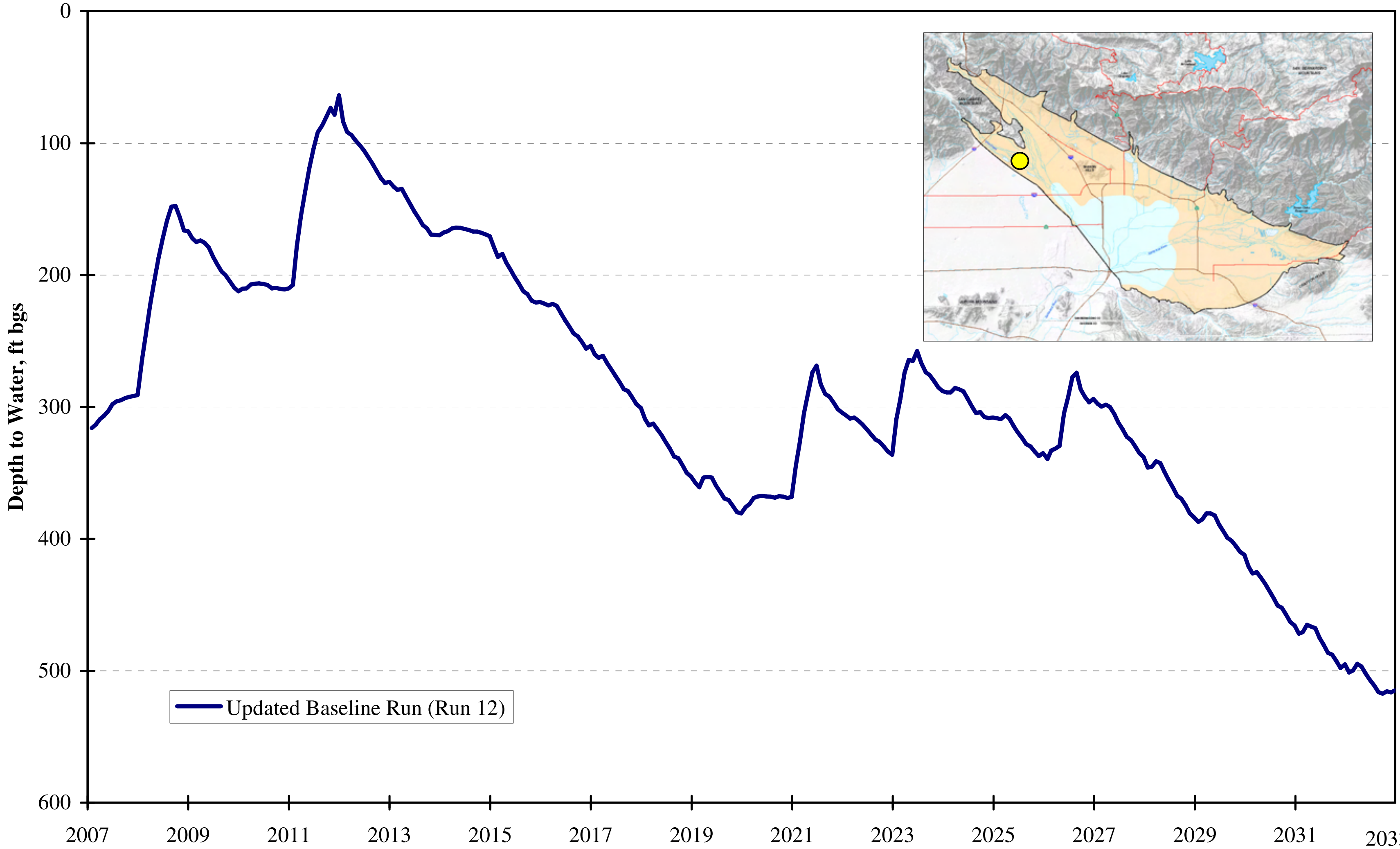
Appendix D

Depth to Water for East Valley Water District Well 62
Updated Baseline Run (Run 12) 2007-2032

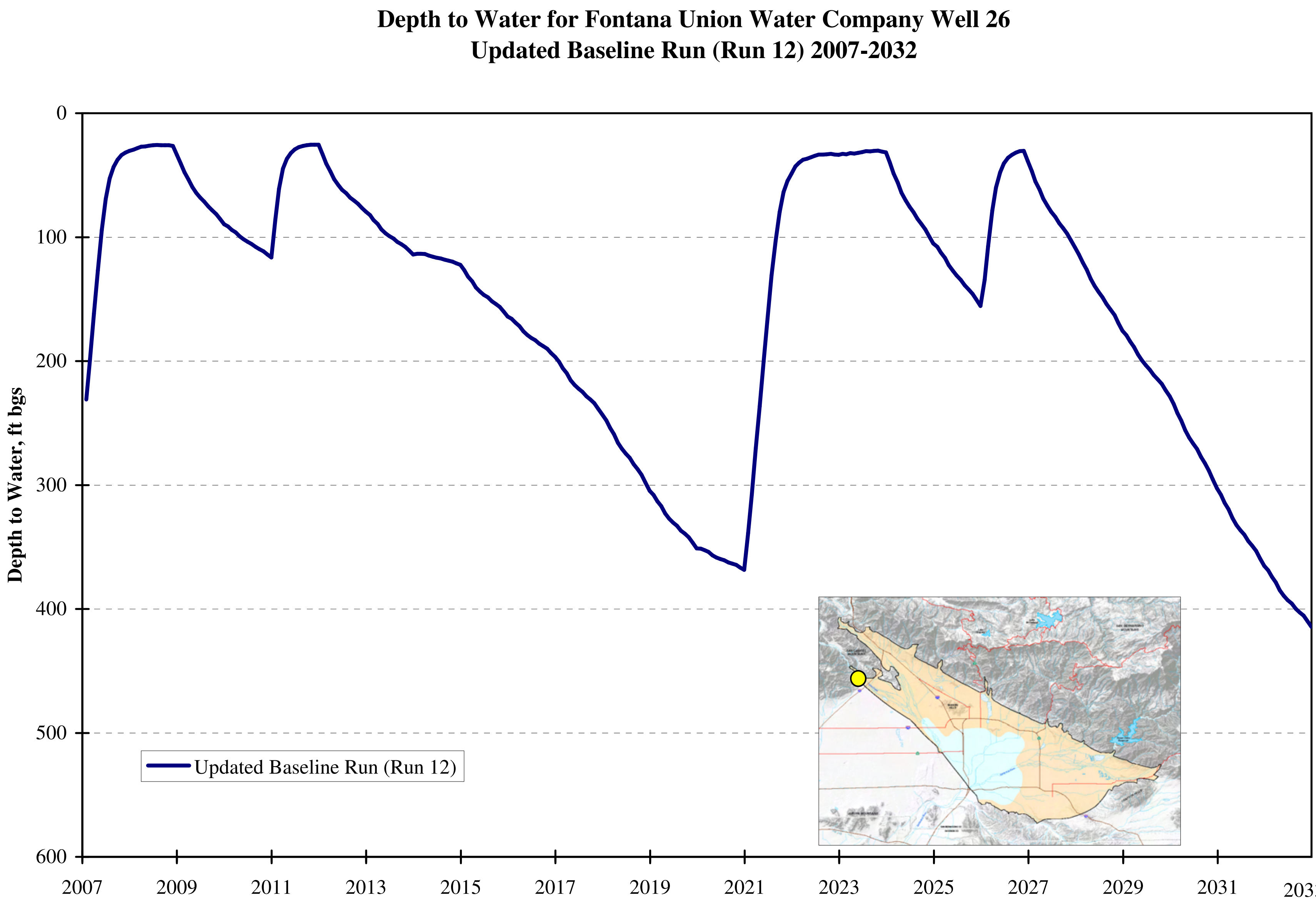


Appendix D

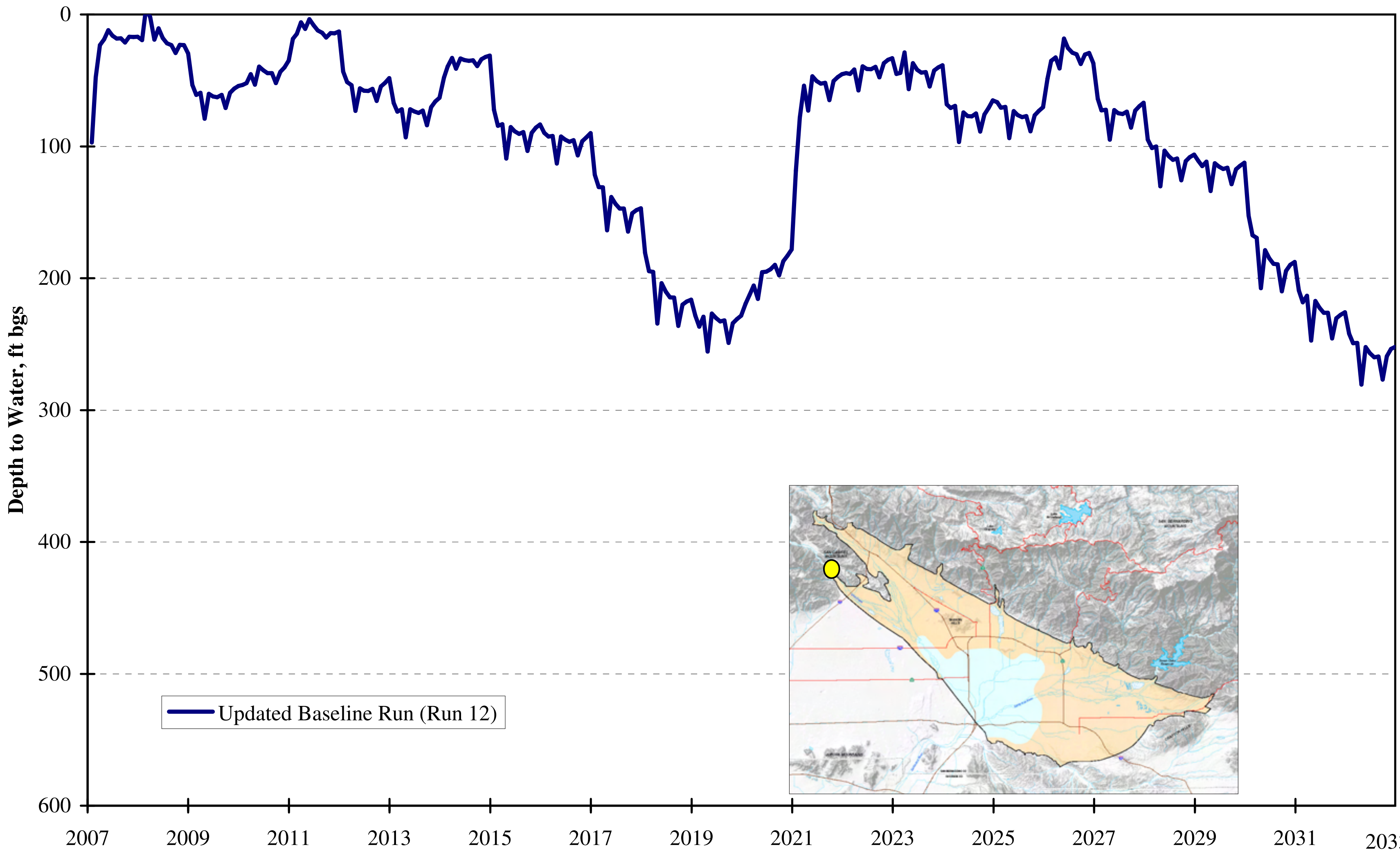
Depth to Water for Fontana Union Water Company Well 13
Updated Baseline Run (Run 12) 2007-2032



Appendix D

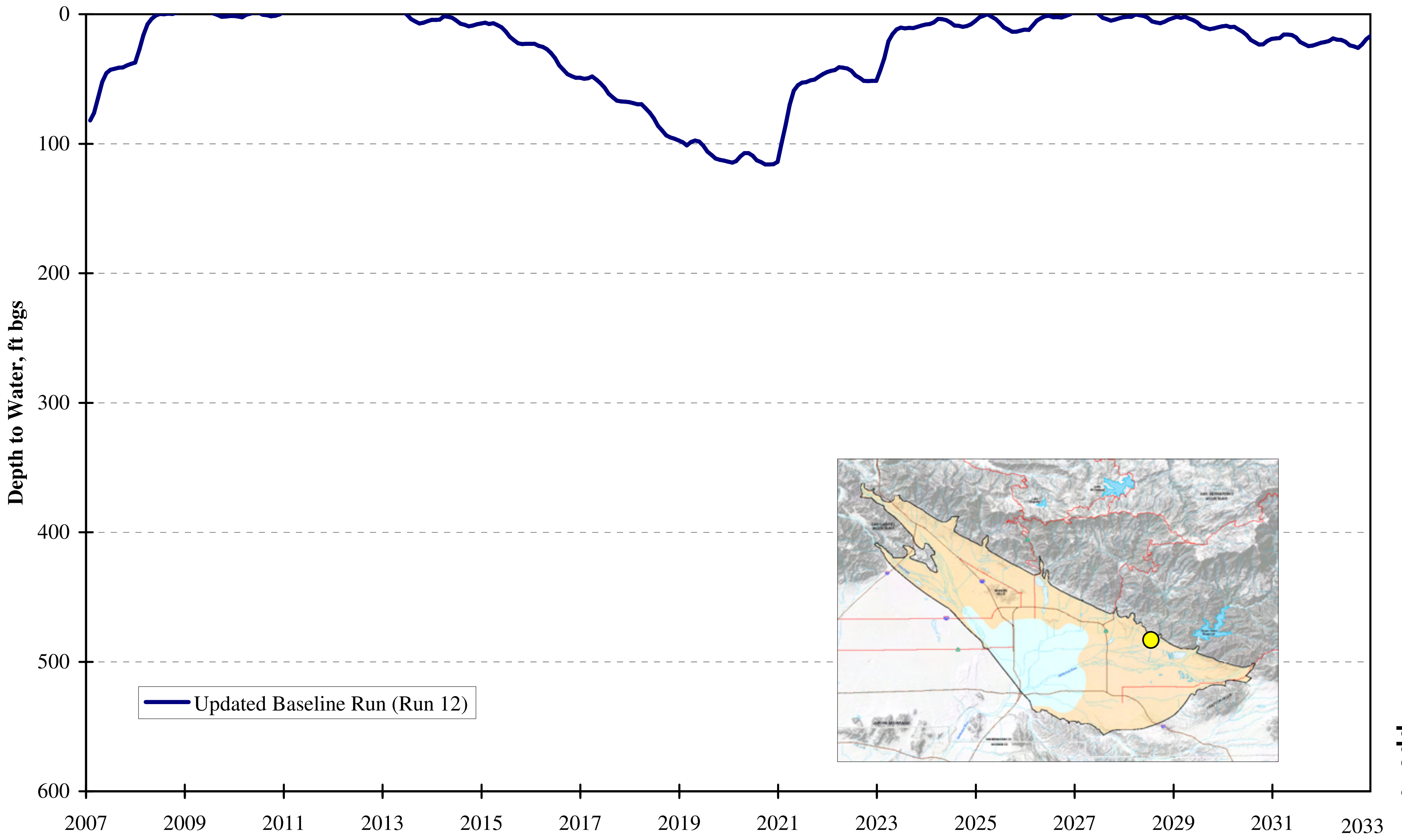

Depth to Water for Fontana Union Water Company Well 26
Updated Baseline Run (Run 12) 2007-2032
Depth to Water, ft bgs
0
100
200
300
400
500
600
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
Updated Baseline Run (Run 12)

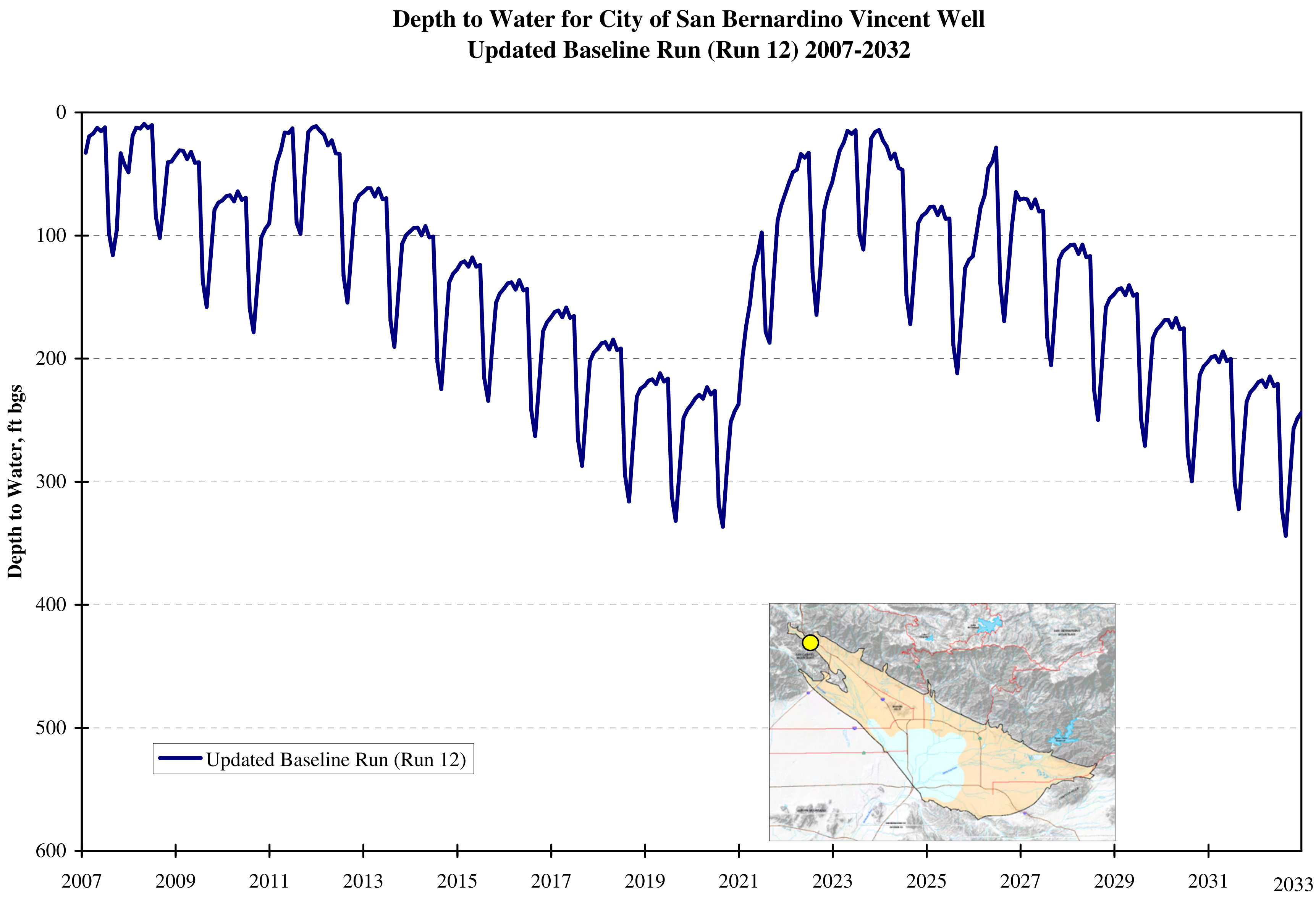
Depth to Water for Fontana Union Water Company Well 27
Updated Baseline Run (Run 12) 2007-2032



Appendix D

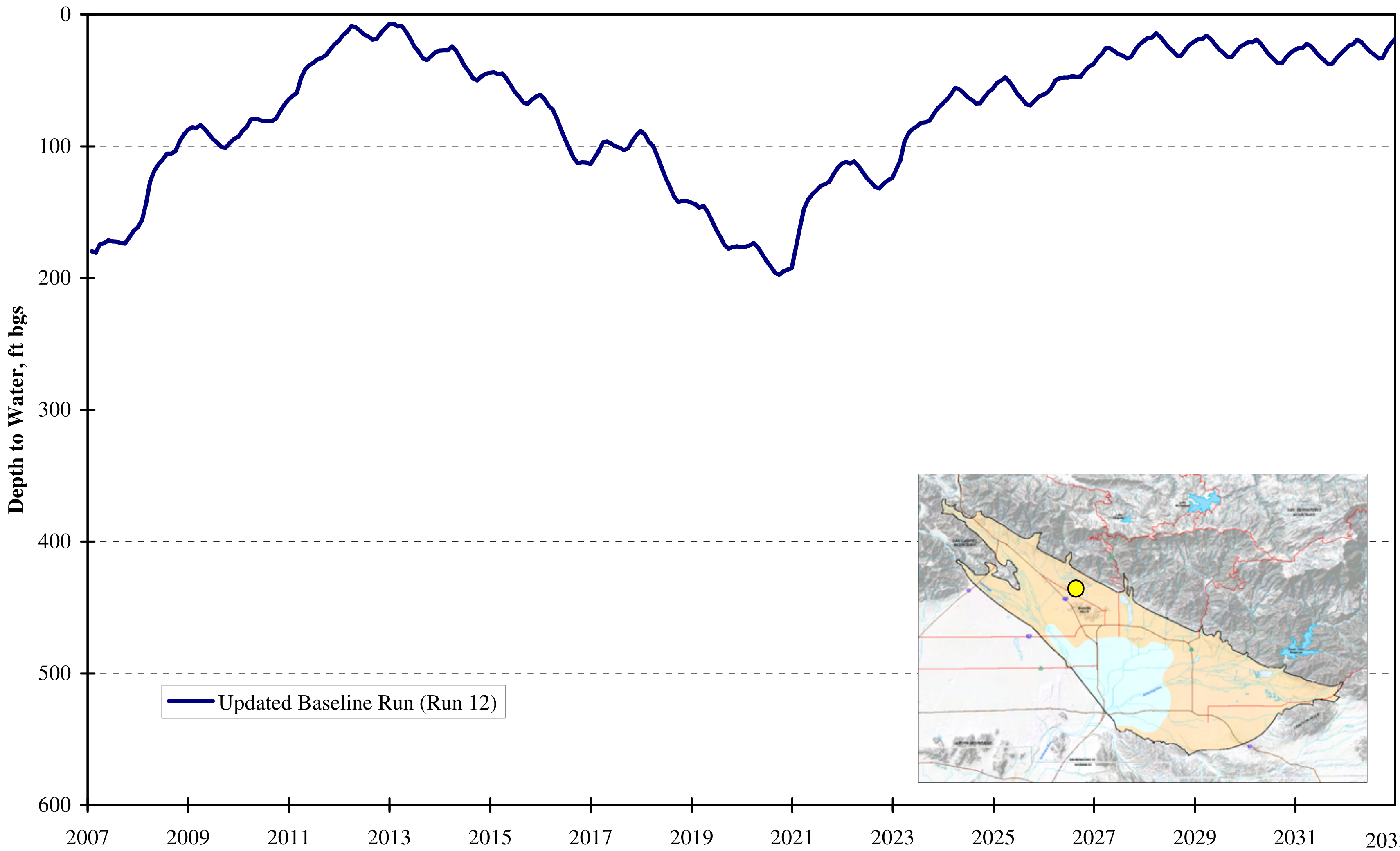
Depth to Water for East Valley Water District Well 120
Updated Baseline Run (Run 12) 2007-2032




Depth to Water for City of San Bernardino Vincent Well
Updated Baseline Run (Run 12) 2007-2032
Depth to Water, ft bgs
0
100
200
300
400
500
600
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
Updated Baseline Run (Run 12)

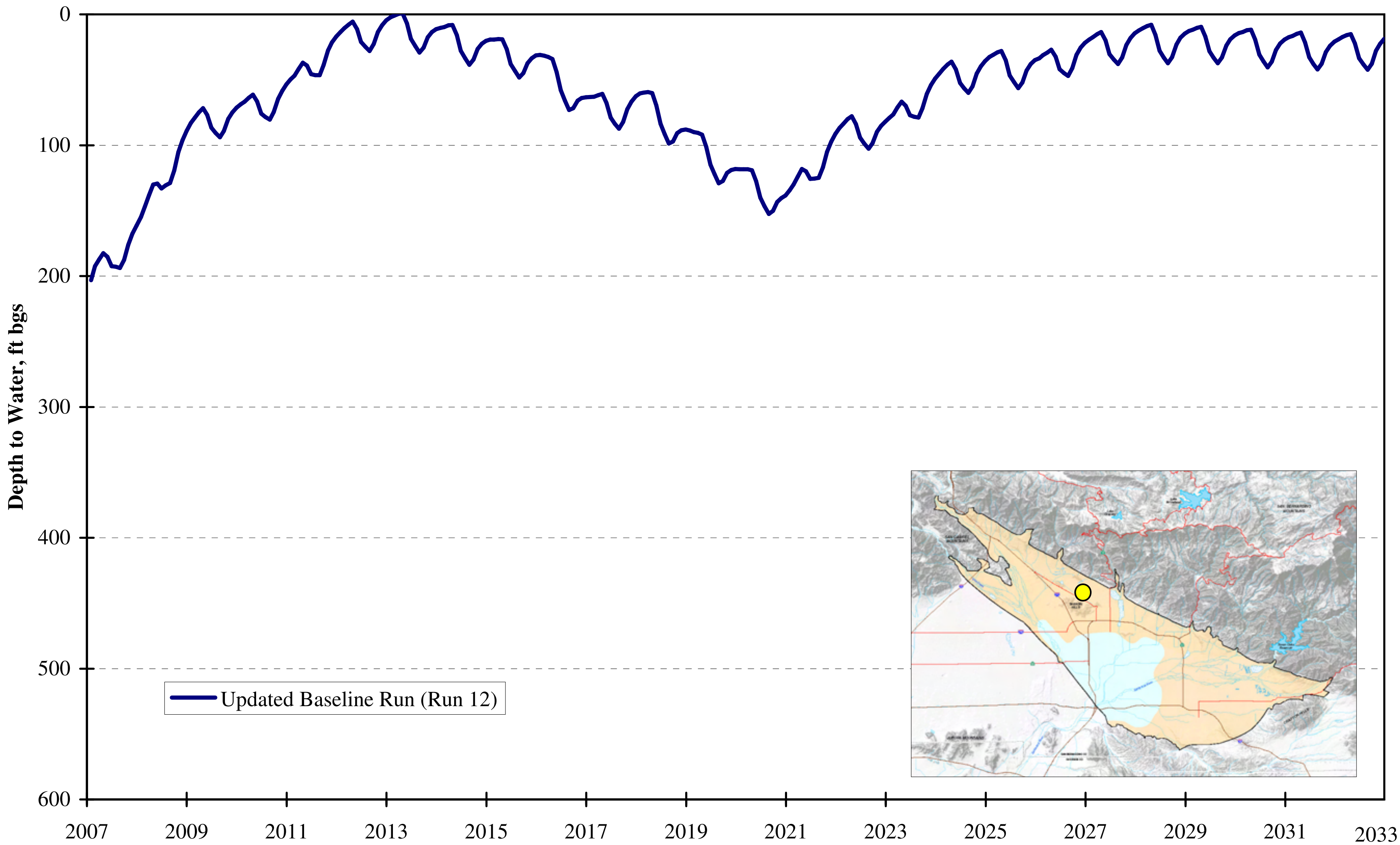
Appendix D

Depth to Water for City of San Bernardino Devil Canyon Well No. 1
Updated Baseline Run (Run 12) 2007-2032



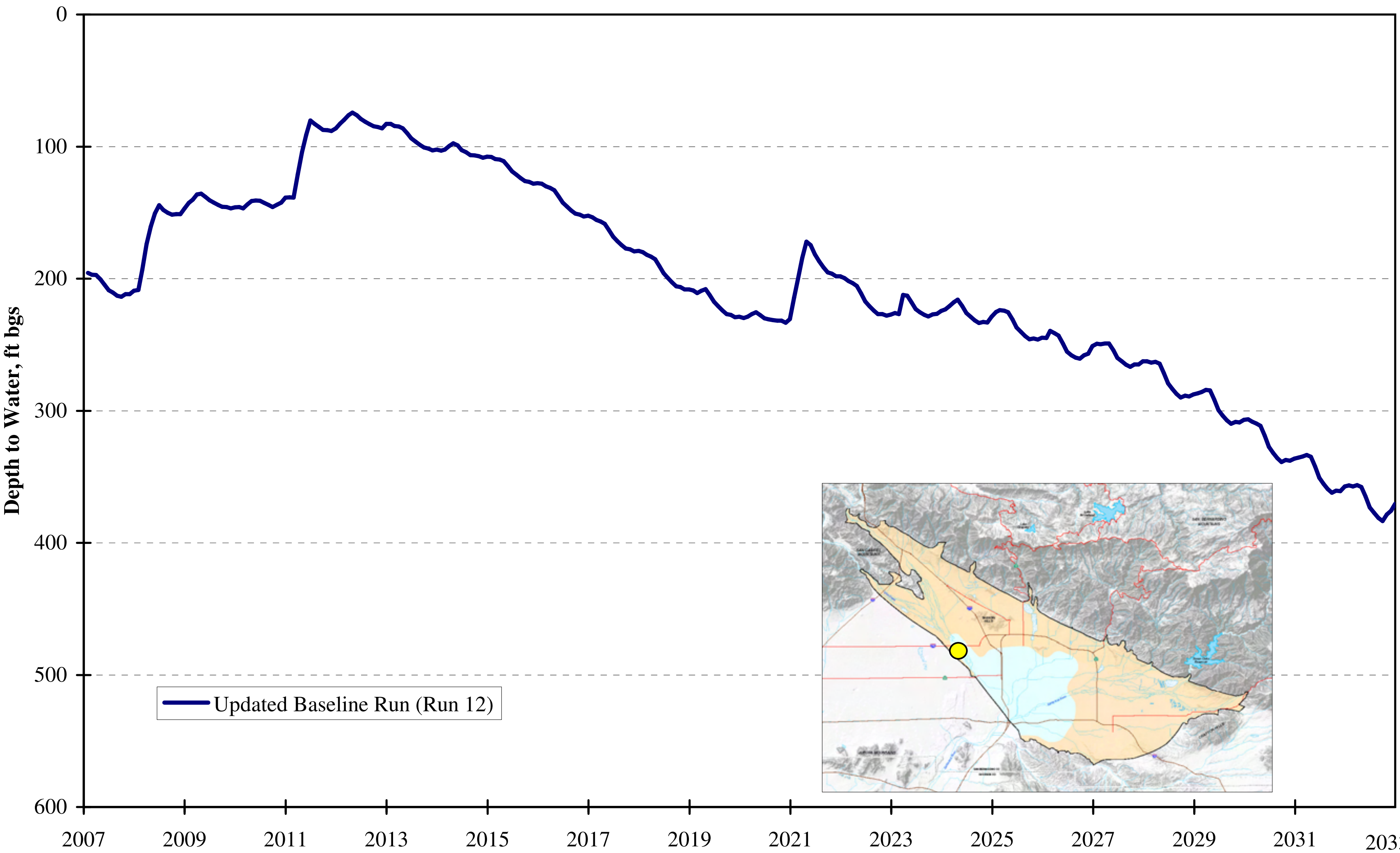
Appendix D

Depth to Water for City of San Bernardino Newmark 3 Well
Updated Baseline Run (Run 12) 2007-2032



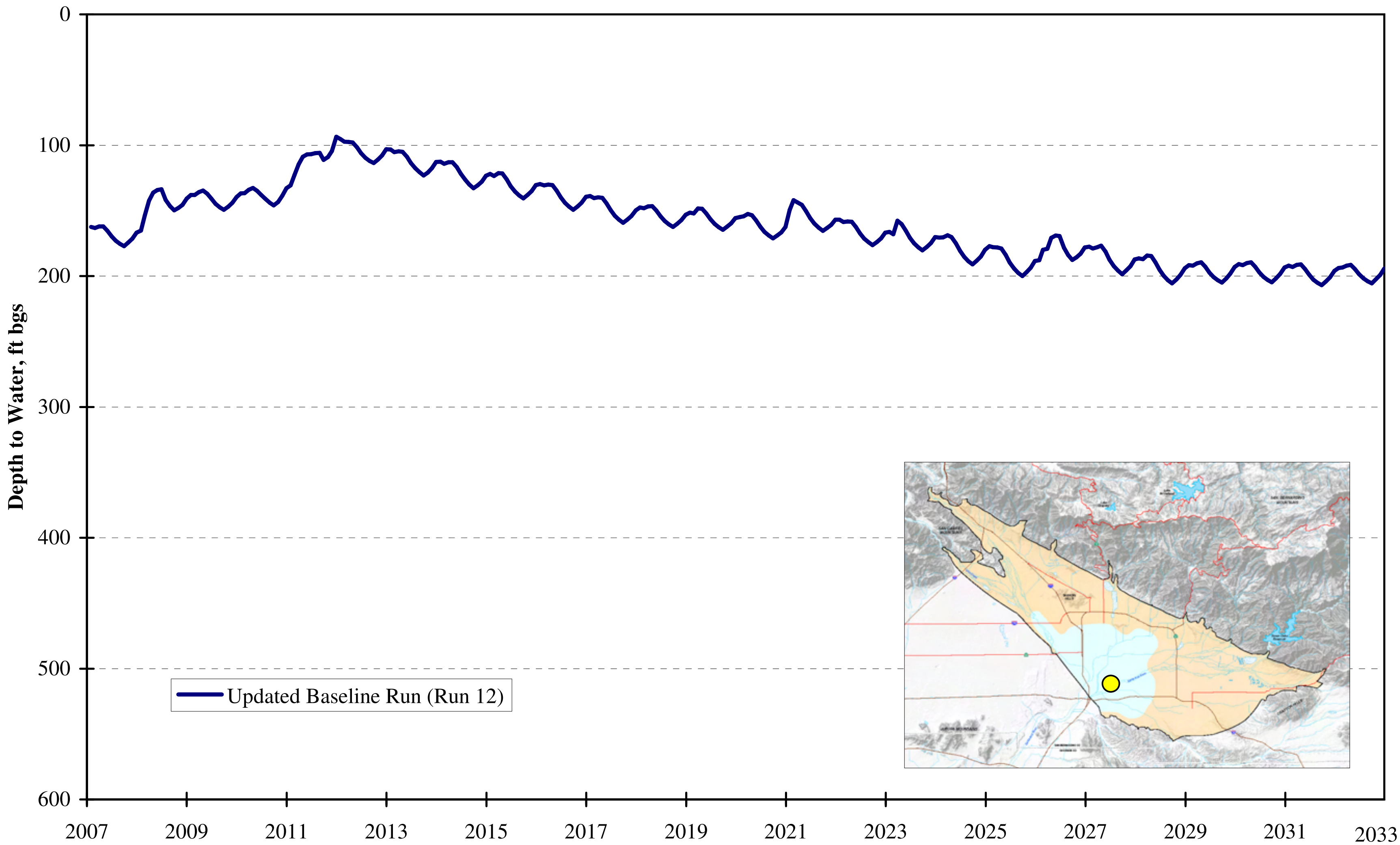
Appendix D

Depth to Water for West Valley Water District Lord 7 Well
Updated Baseline Run (Run 12) 2007-2032



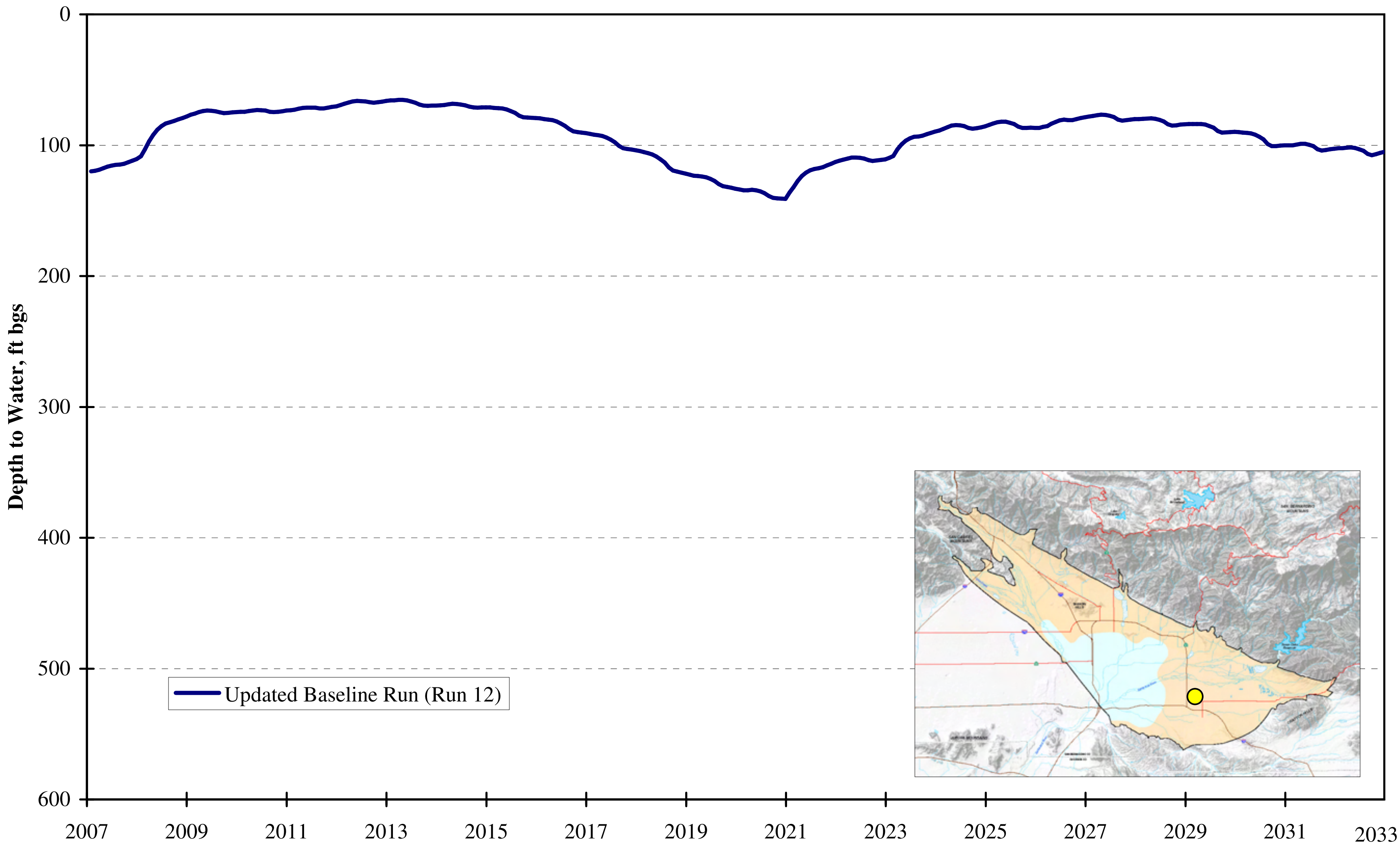
Appendix D

Depth to Water for City of Riverside Raub 1 Well
Updated Baseline Run (Run 12) 2007-2032



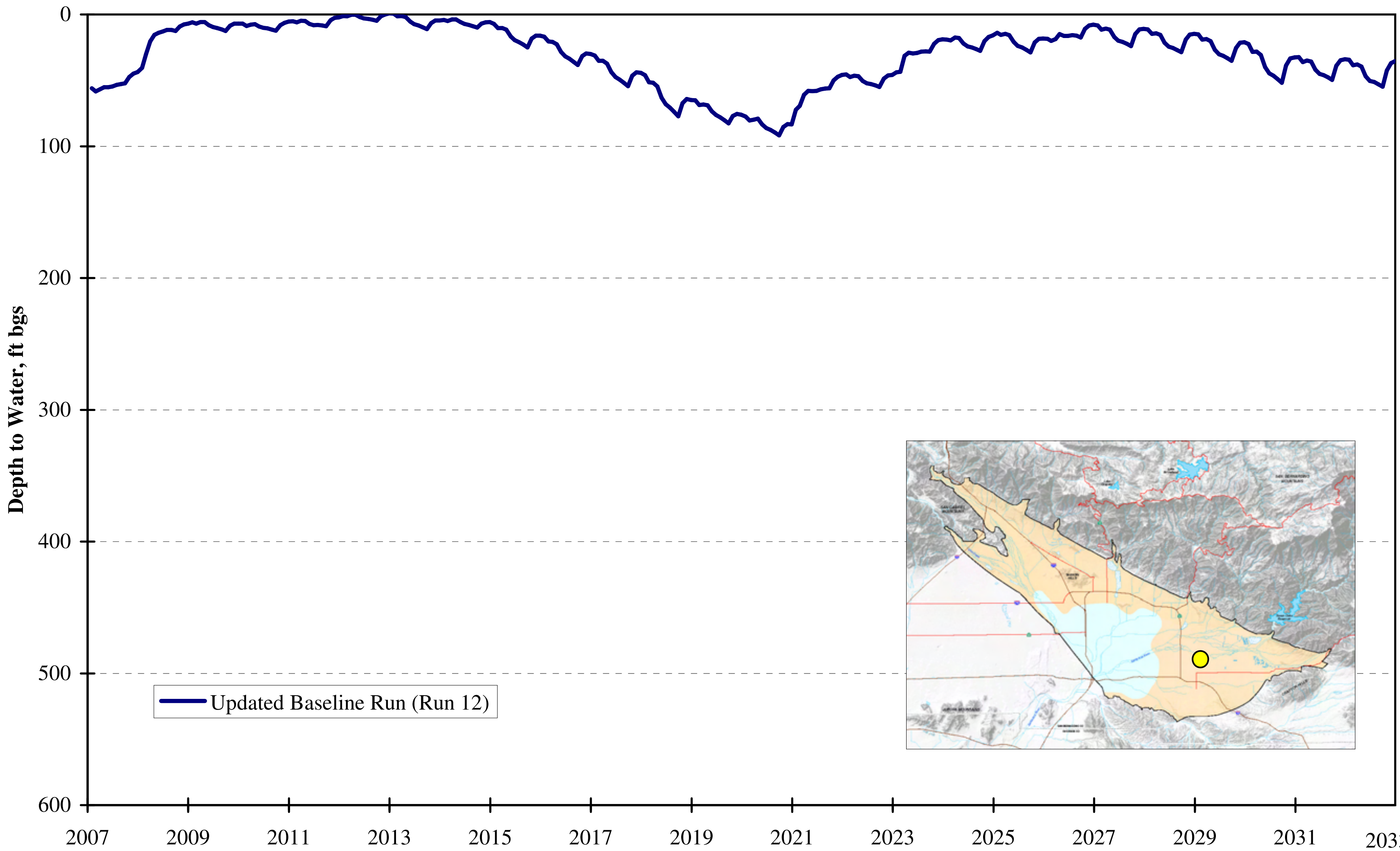
Appendix D

Depth to Water for City of Redlands Well 32
Updated Baseline Run (Run 12) 2007-2032



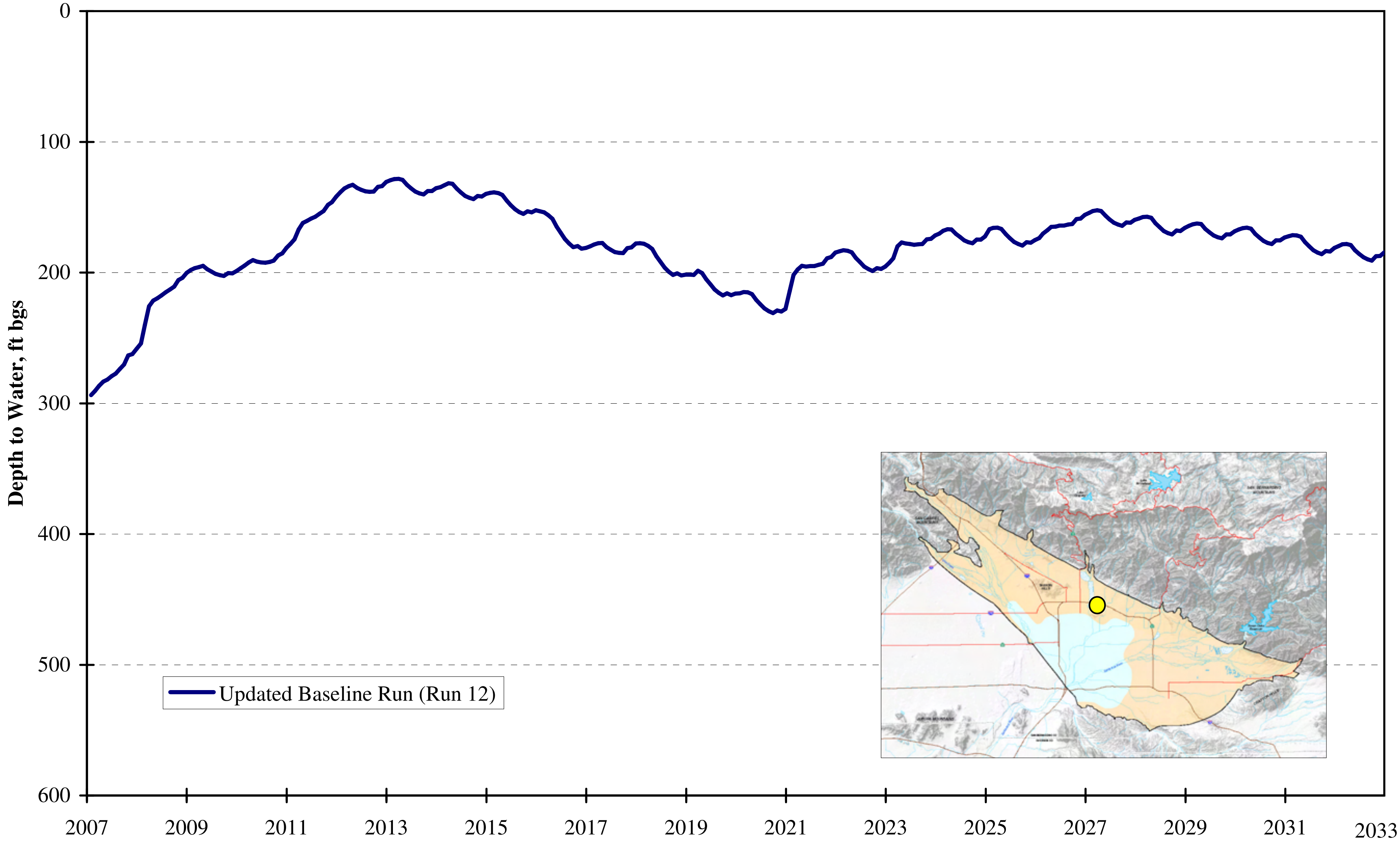
Appendix D

Depth to Water for City of Redlands Orange Street Well
Updated Baseline Run (Run 12) 2007-2032

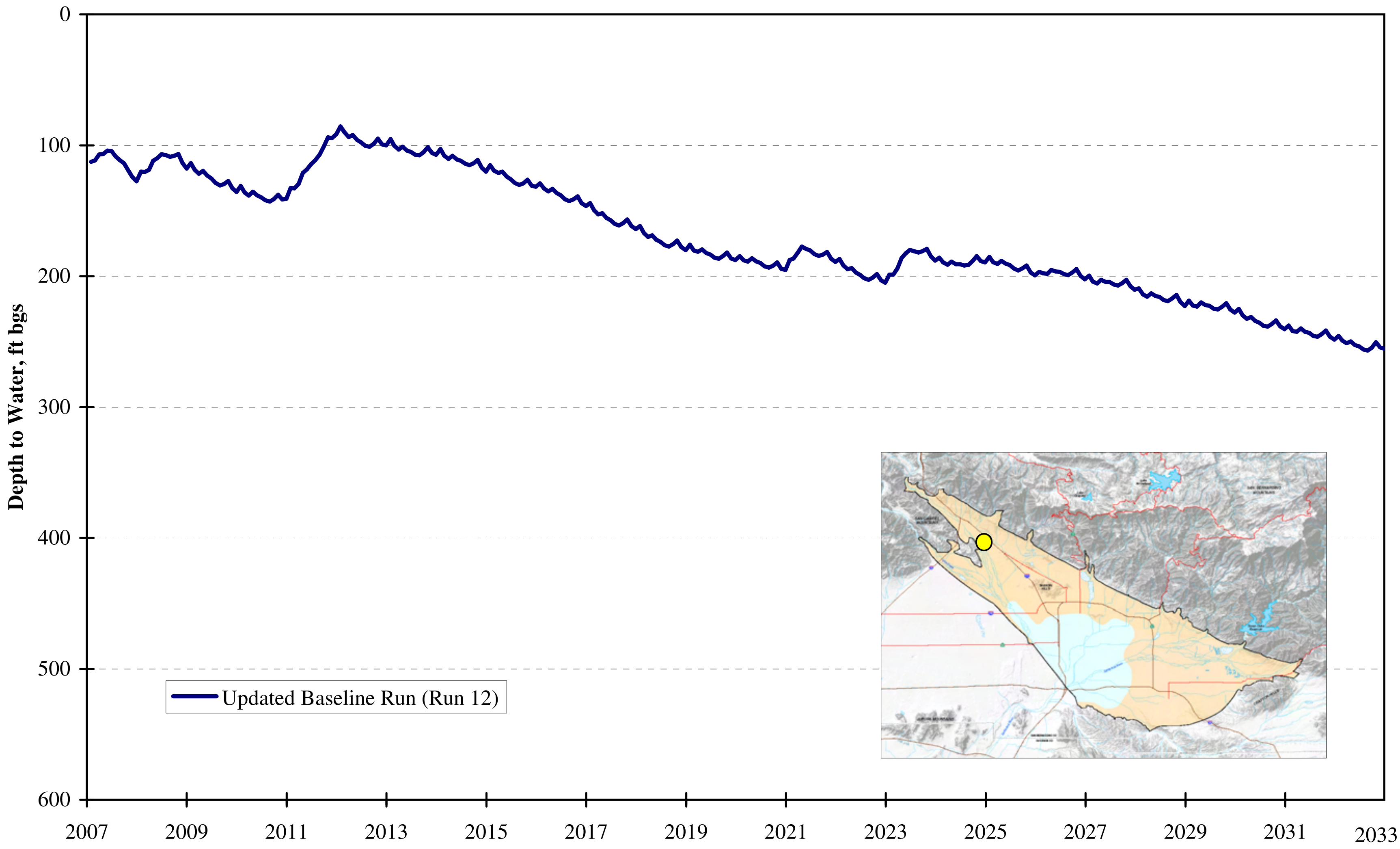


Appendix D

Depth to Water for East Valley Water District Well 24A
Updated Baseline Run (Run 12) 2007-2032

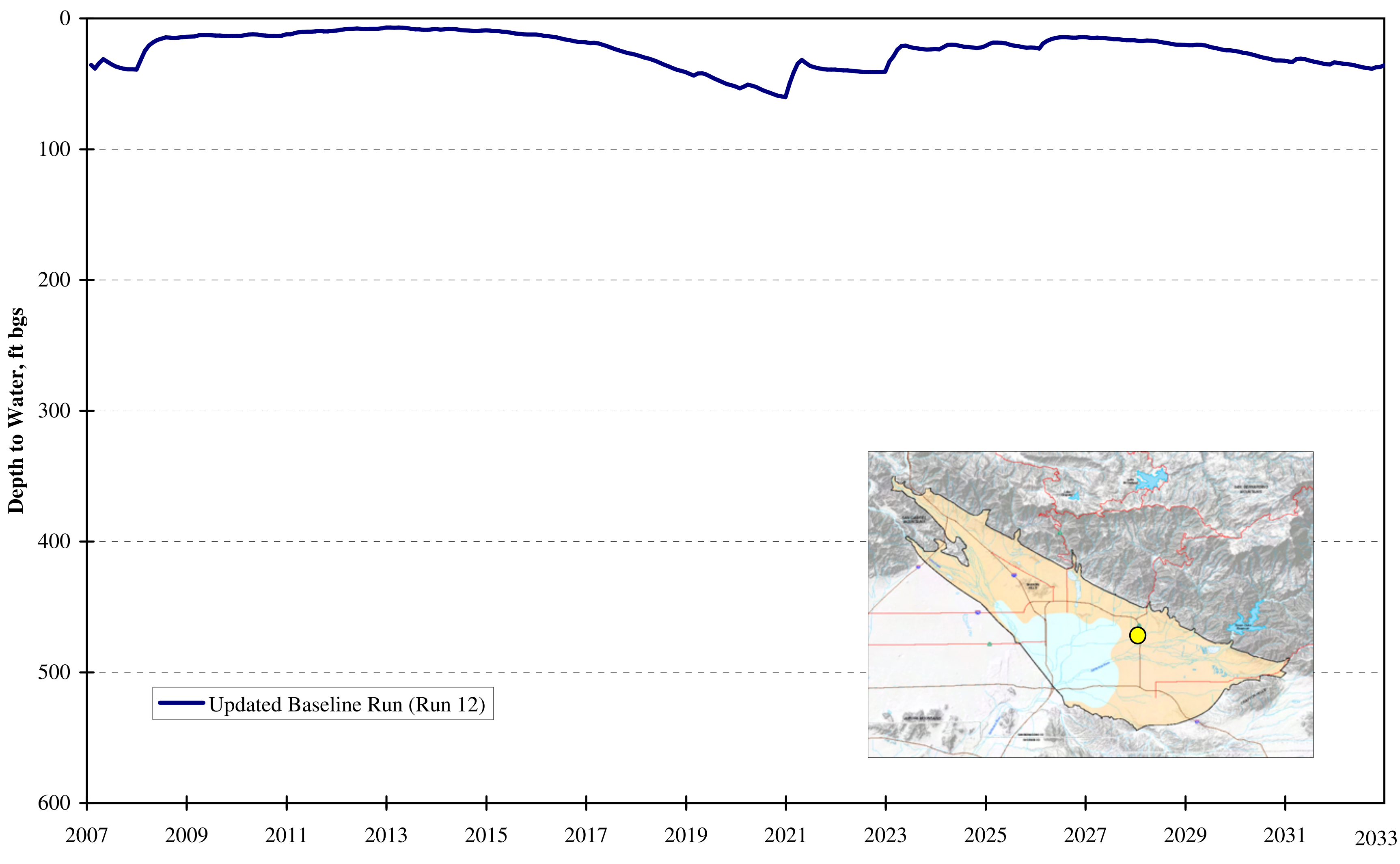


Depth to Water for City of San Bernardino Cajon Well No. 1
Updated Baseline Run (Run 12) 2007-2032



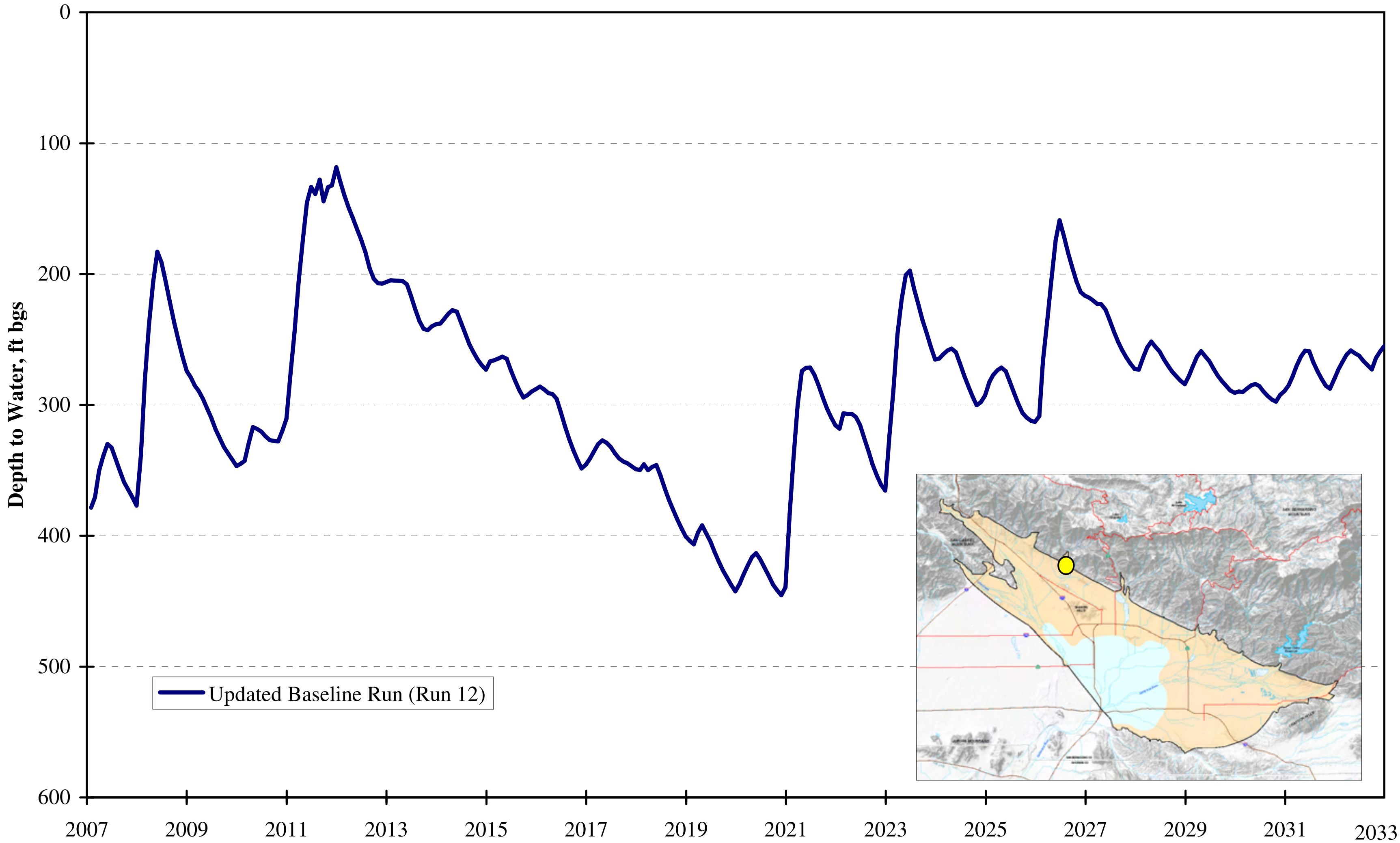
Appendix D

Depth to Water for East Valley Water District Well 40
Updated Baseline Run (Run 12) 2007-2032



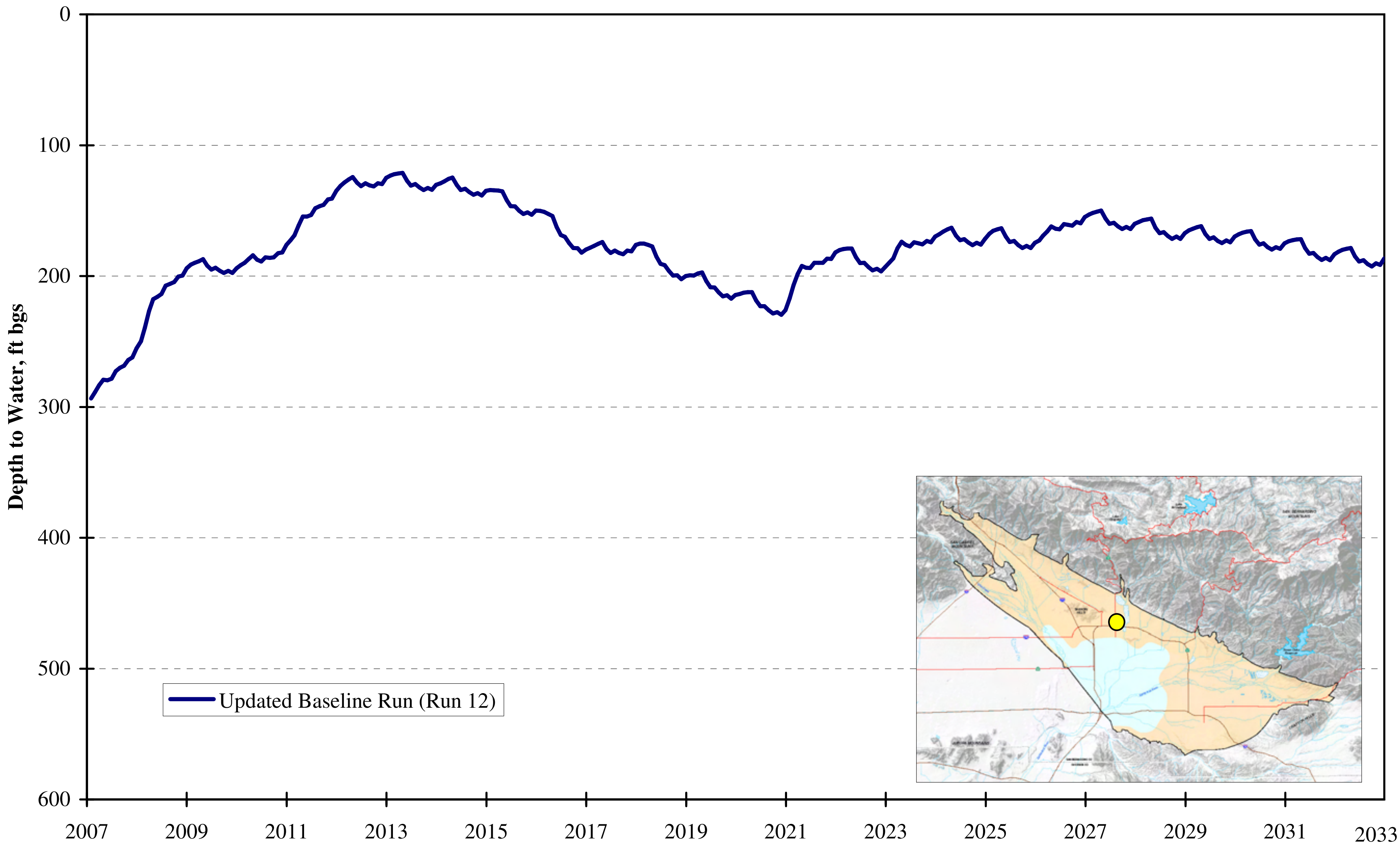
Appendix D

Depth to Water for City of San Bernardino Devil Canyon Well No. 3
Updated Baseline Run (Run 12) 2007-2032



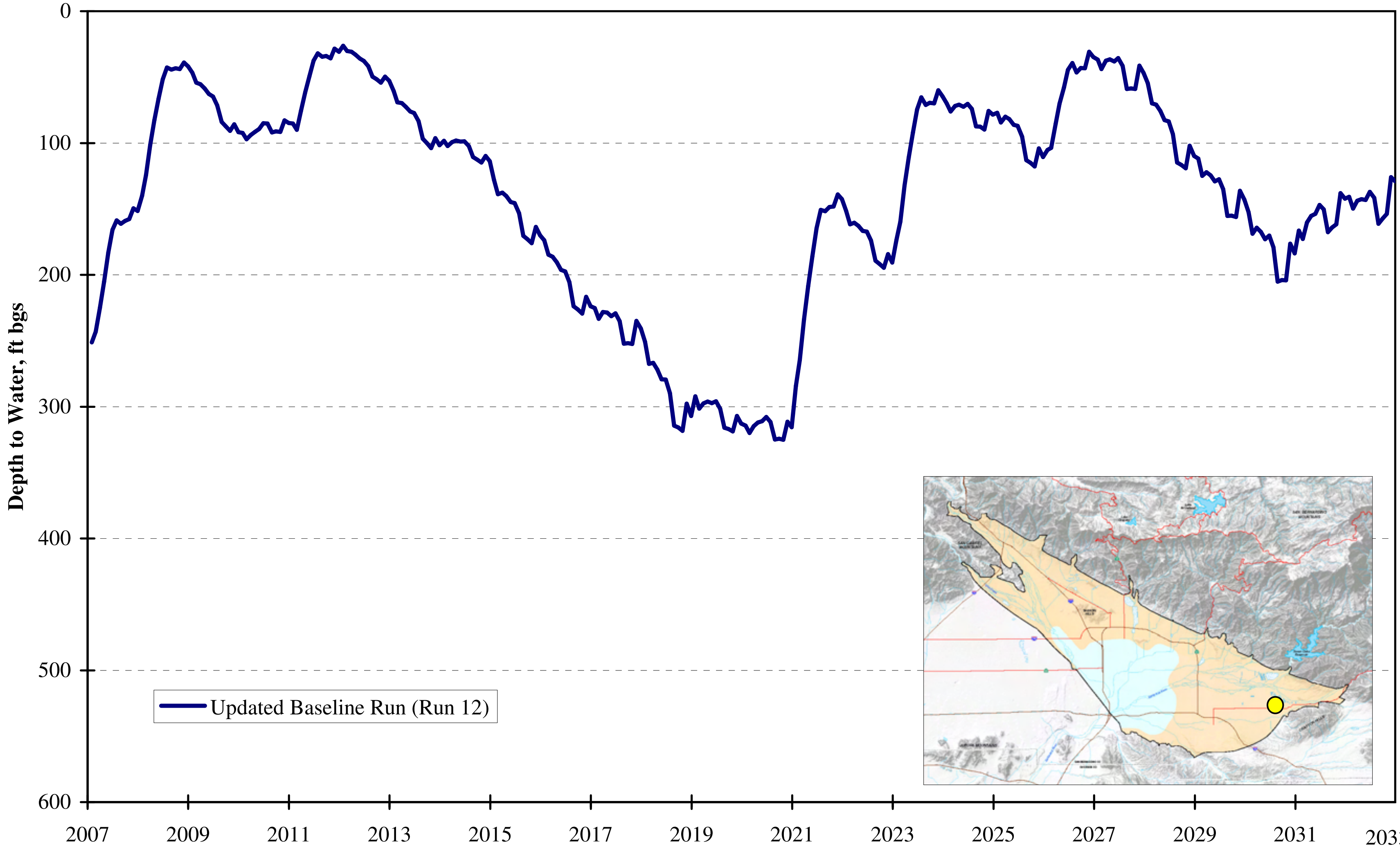
Appendix D

Depth to Water for City of San Bernardino Leroy Street Well
Updated Baseline Run (Run 12) 2007-2032

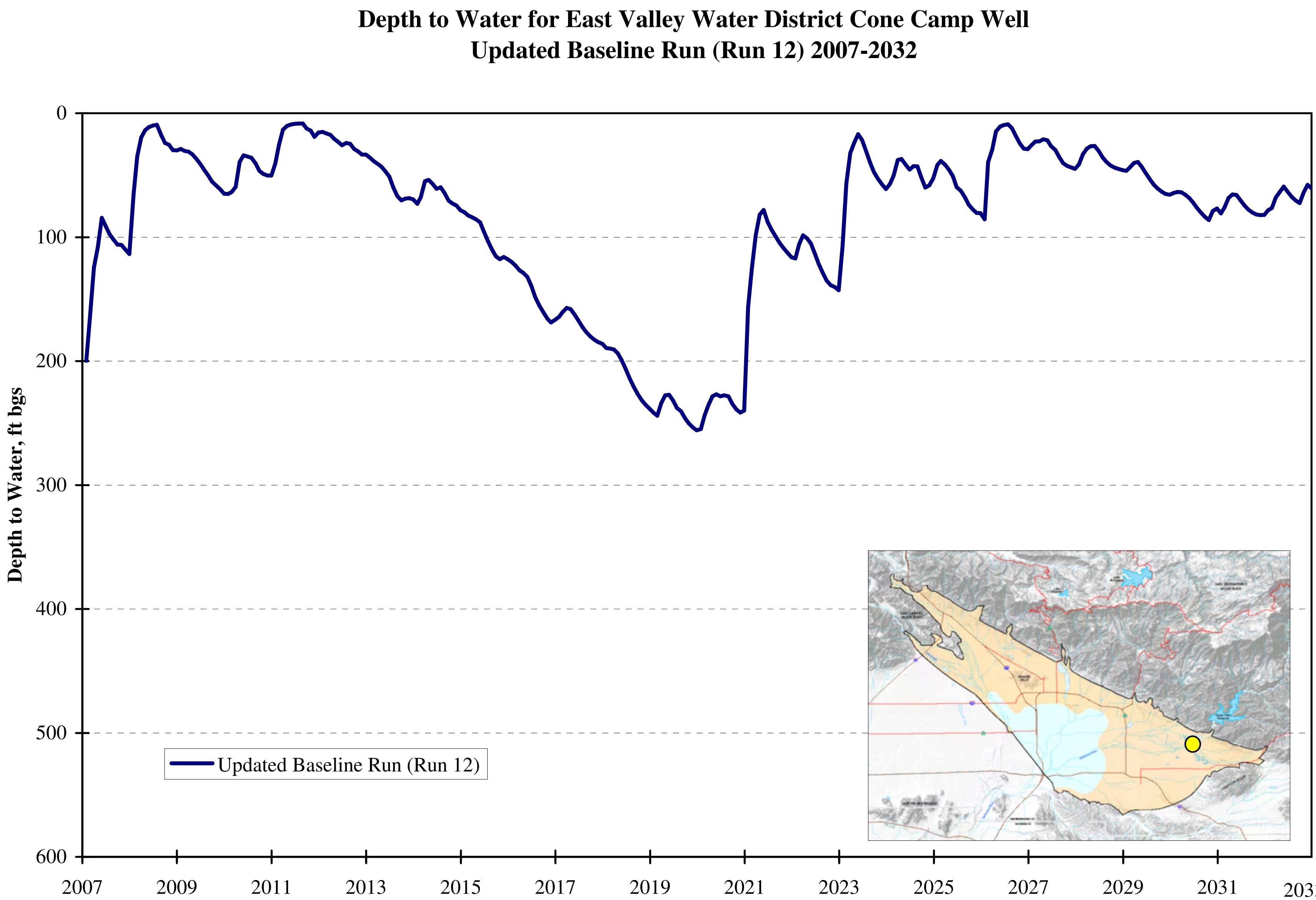


Appendix D

Depth to Water for City of Redlands Agate 2 Well
Updated Baseline Run (Run 12) 2007-2032

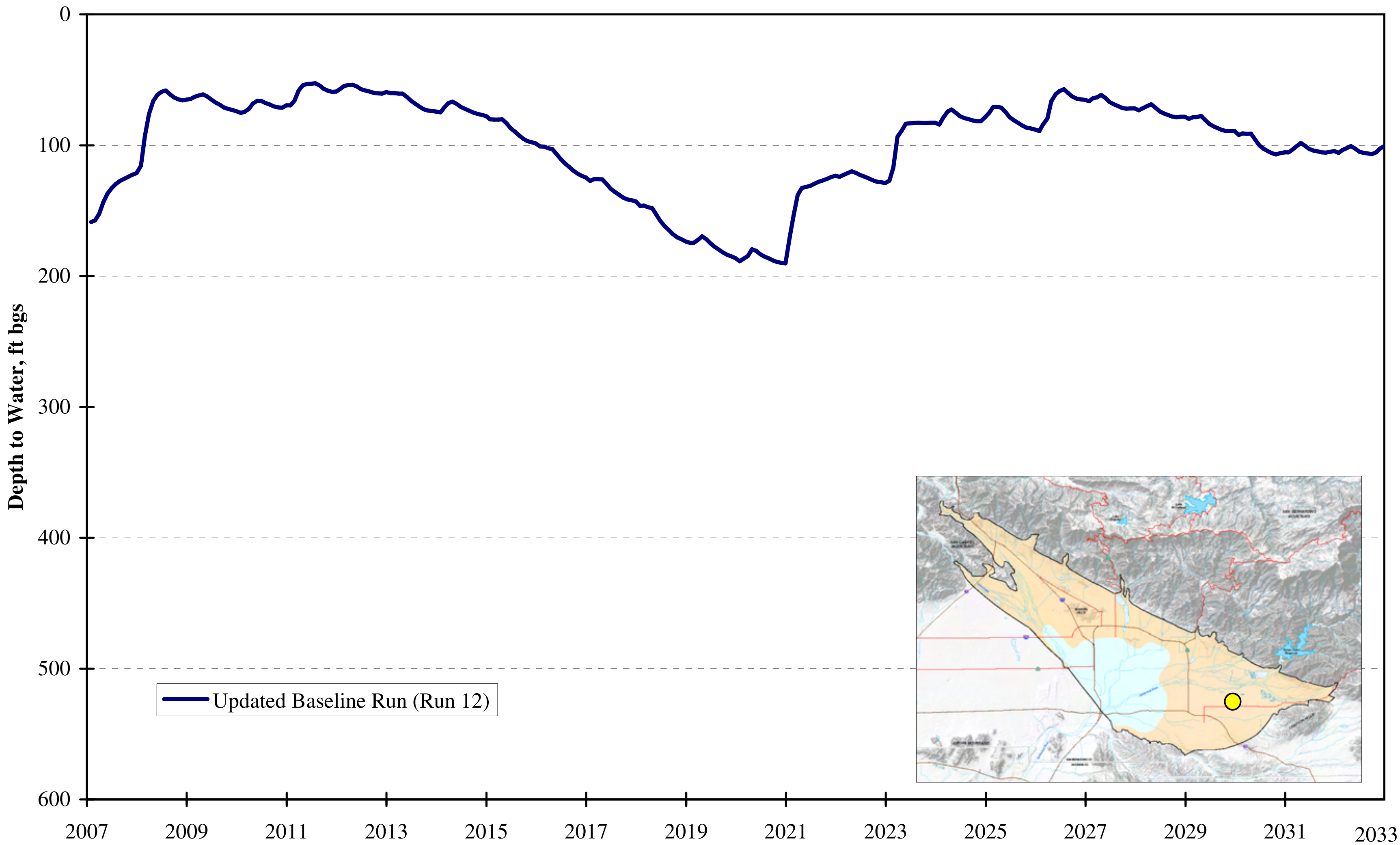


Appendix D


Depth to Water for East Valley Water District Cone Camp Well
Updated Baseline Run (Run 12) 2007-2032
Depth to Water, ft bgs
0
100
200
300
400
500
600
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
Updated Baseline Run (Run 12)

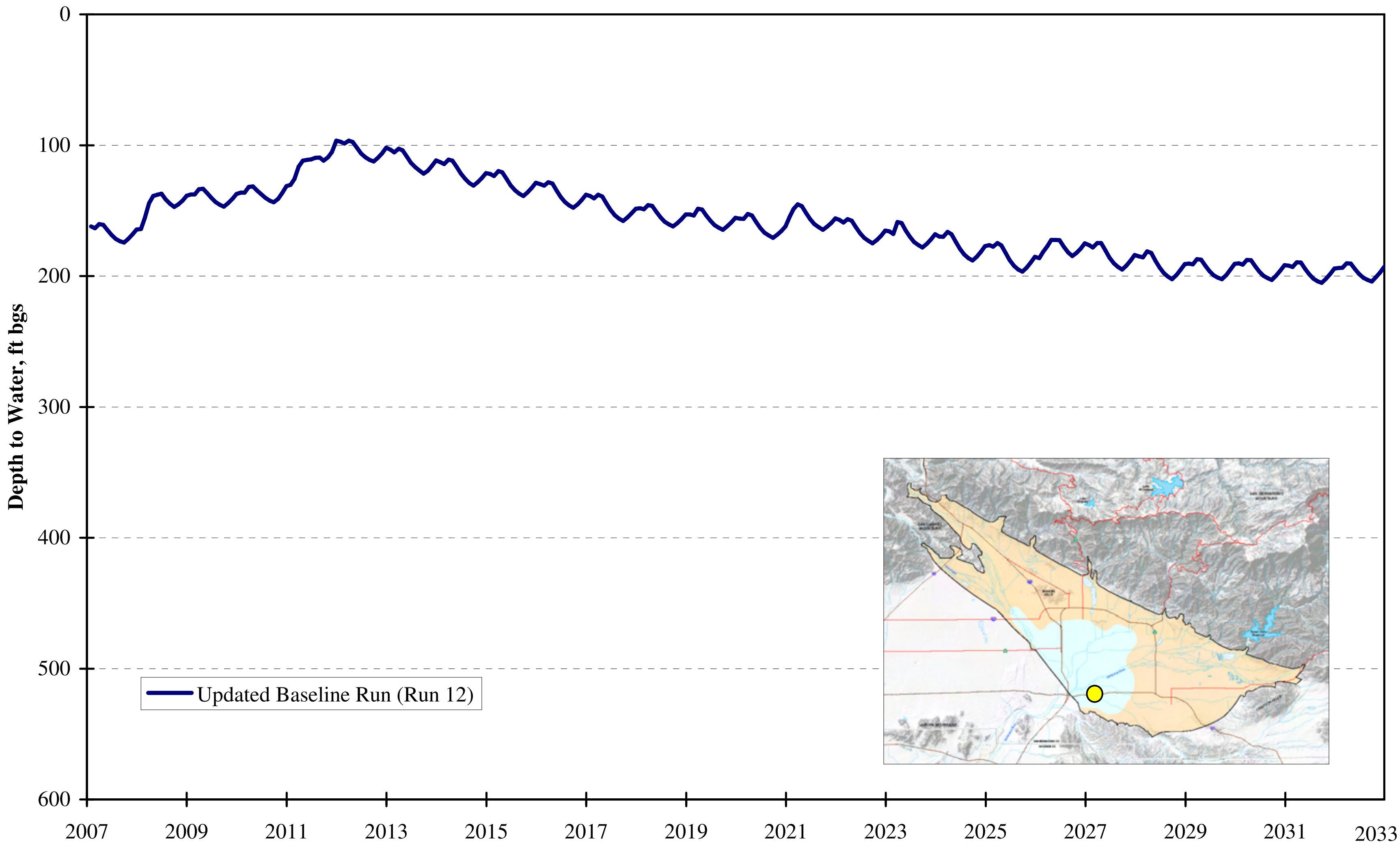
Appendix D

Depth to Water for Bear Valley Mutual Water Company Nelson Street Well
Updated Baseline Run (Run 12) 2007-2032



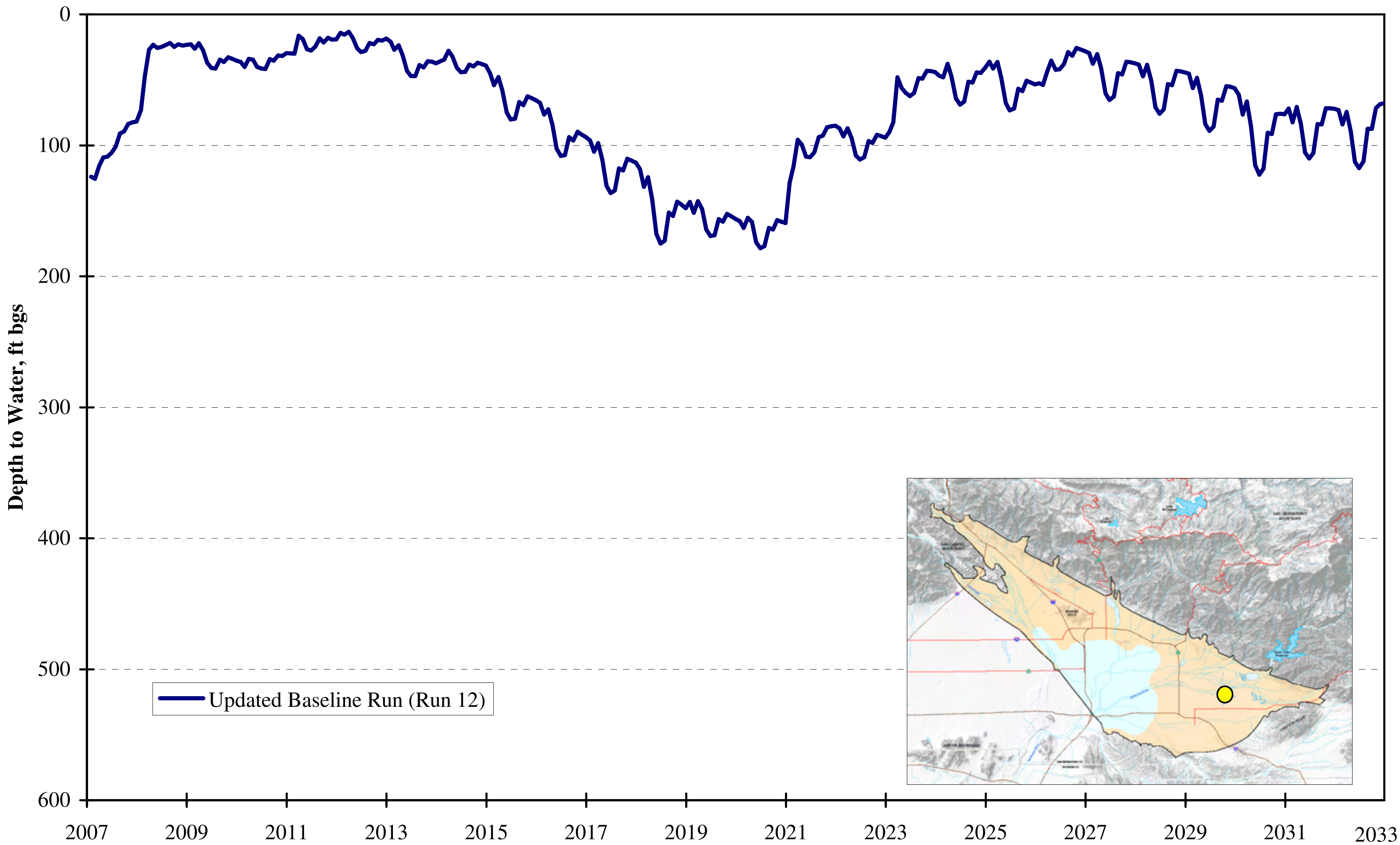
Appendix D

Depth to Water for Gage Canal Company Lower Kelly Well
Updated Baseline Run (Run 12) 2007-2032



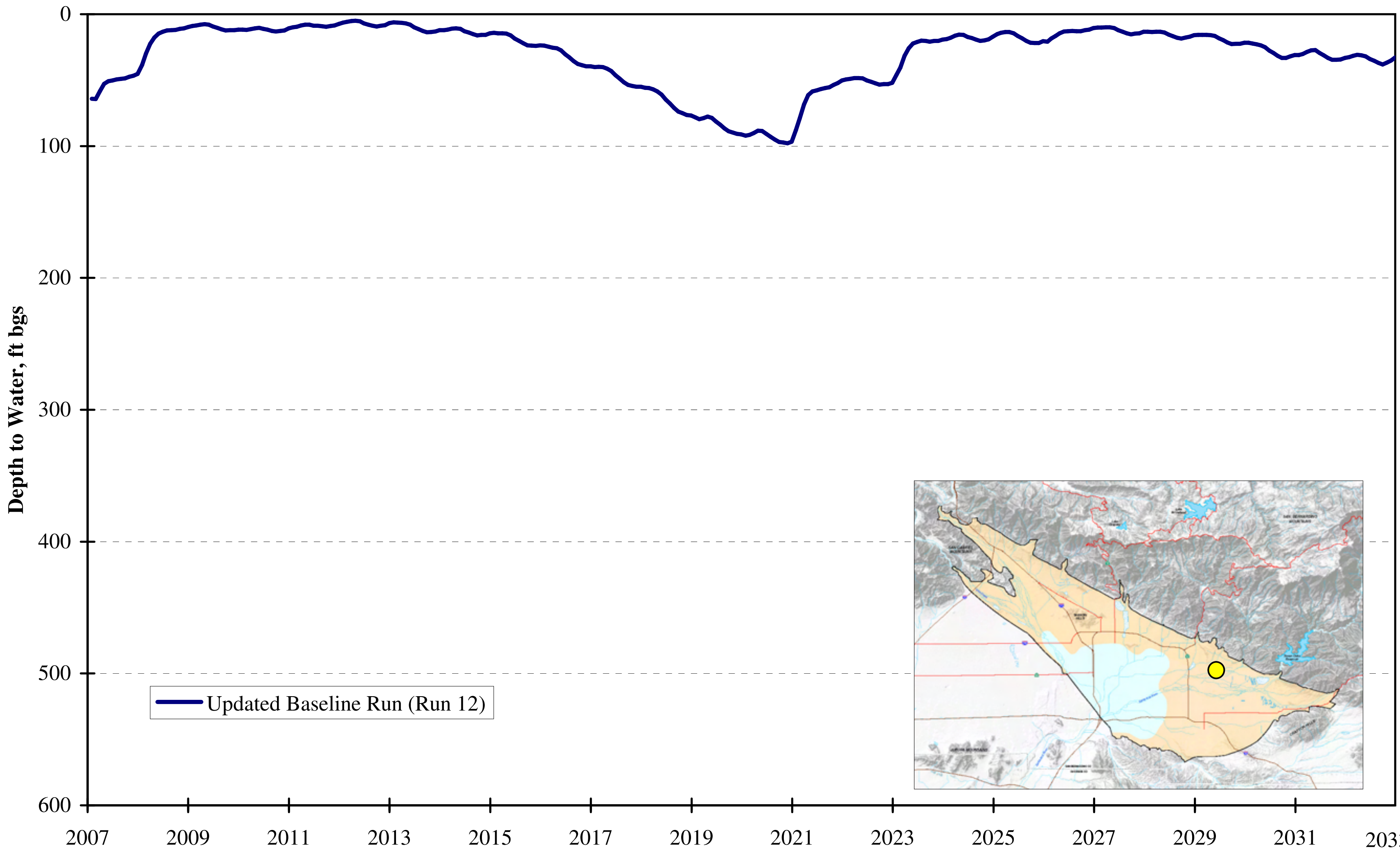
Appendix D

Depth to Water for City of Redlands Airport Well No. 2
Updated Baseline Run (Run 12) 2007-2032

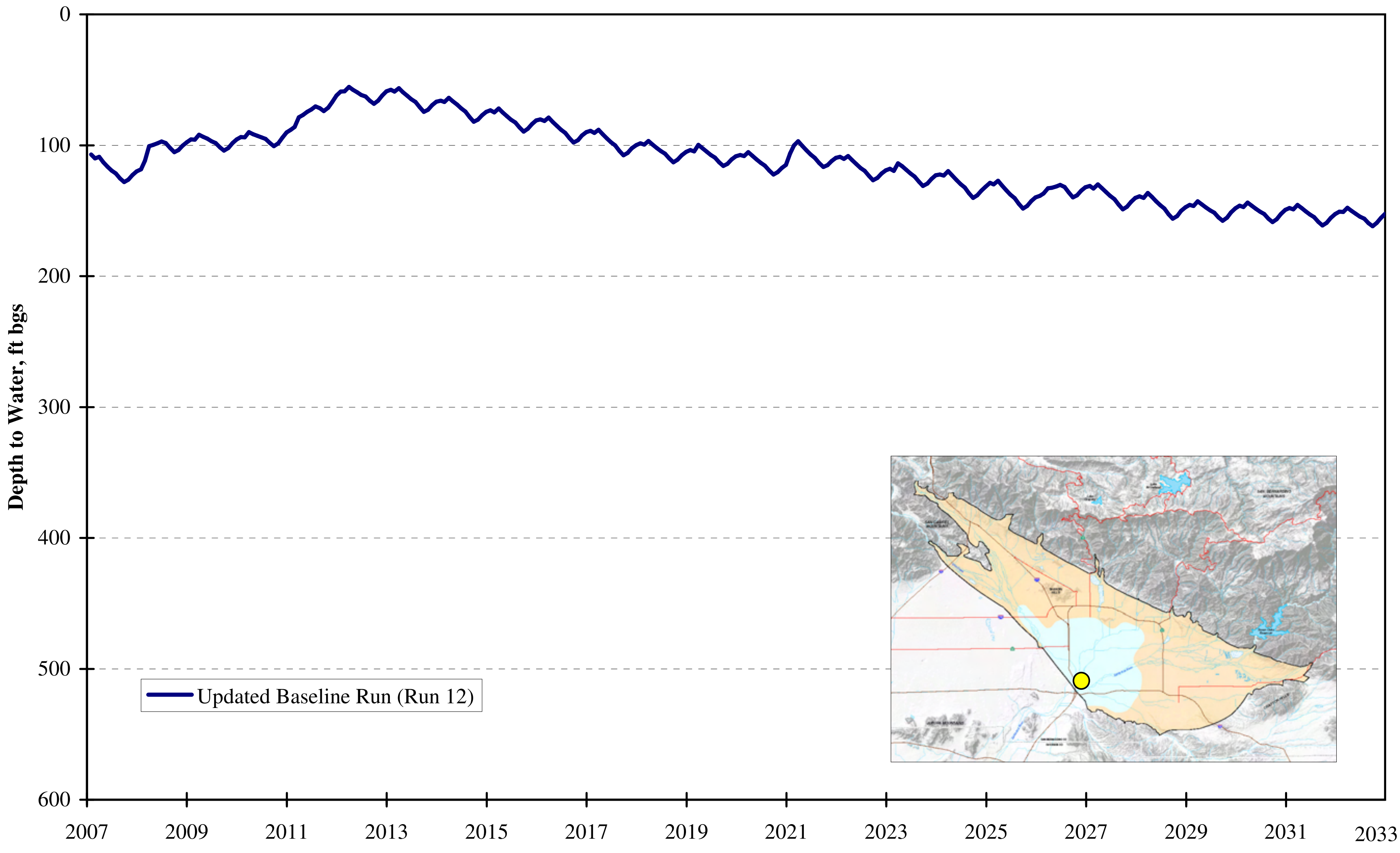


Appendix D

Depth to Water for East Valley Water District Well 146A
Updated Baseline Run (Run 12) 2007-2032



Depth to Water for SBVMWD Backyard Well
Updated Baseline Run (Run 12) 2007-2032



Appendix D