APPRAISAL LEVEL STUDY OF A BRACKISH WATER TREATMENT PLANT

CITY OF GOODYEAR ARIZONA

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1.0 INTRODUCTION

As Arizona's water resources become fully utilized, water providers will begin to look at sources of water that were previously considered unusable to meet future demands. These sources are brackish water for potable uses and effluent for non-potable uses.

Brackish water is defined as having a total dissolved solids (TDS) content of 1,000 milligrams per liter (mg/L) to about 25,000 mg/L. Although there is no drinking water standard for TDS, a drinking water secondary maximum contaminant level (SMCL) of 500 mg/L exists for water. Water in the southwest Salt River Valley (SRV) has historically seen TDS levels ranging from 800 to 2,500 mg/L due to many factors including the natural drainage pattern of the SRV, long-term agricultural irrigation, and effluent discharge into the river. In addition to high TDS, this area often experiences high levels of nitrate, fluoride, and arsenic and will require advanced treatment to achieve potable standards.

A portion of the southwest SRV is also classified as "water logged" by the Arizona Department of Water Resources (ADWR). Water levels in this area are often as high 10 feet below land surface (bls) and would reach the surface if it were not for drainage wells in the area. Farmers may use this water for agricultural irrigation and are exempt from the groundwater rules imposed by the 1980 Arizona Groundwater Code.

The purpose of this study is to quantify the physical availability of brackish water for potable use after desalination in the southwest SRV and whether this supply can be used long-term. This study was conducted by Brown and Caldwell on behalf of WESTCAPS. In cooperation with the Central Arizona Salinity Study (CASS) this study also incorporated information on similar desalination projects throughout the southwest, legal issues facing the use of brackish water.

2.0 WATER SUPPLY, ADEQUACY, RELIABILITY AND QUALITY

Brown and Caldwell (BC) has been tasked with conducting predictive simulations using the ADWR 2002 SRV model to estimate the quantity of groundwater that may be available for extraction from the water logged area present in the southwest corner of the West Salt River Valley (WSRV) groundwater basin. More specifically, this area is located north to south between the Buckeye Irrigation District Canal and the Buckeye Hills, and east to west from approximately the 91st Avenue Wastewater Treatment Plant (WWTP) to Gillespie Dam. Difficulties in completing this task were encountered due to the applicability of the SRV model for the increased spatial level of scrutiny required for this work and uncertainties regarding long-term estimates needed for WSRV recharge and pumping. This letter report presents a summary of our findings.

2.1 PHASE 1 - BACKGROUND

Concerns over the applicability of the SRV model for developing long-term estimates of available water from the water logged zone were raised by the BC modeling staff initially based on the close proximity of the water logged area to the southwestern boundaries of the model. This was a concern because the ADWR 2002 SRV and WESTCAPS models had simulated the interface between the WSRV basin and the southeastern portion of the Lower Hassayampa basin as a constant hydraulic head or water level. What this would result in is a constant source of subflow into the SRV model with the volumetric flux depending on the magnitude of groundwater levels within the southwestern corner of the SRV model. Another way of stating this is that the more drawdown that occurs in the water logged area, the greater the flux of groundwater from the Lower Hassayampa basin into the southwestern corner of the SRV model. Because the true long-term groundwater elevation conditions along the boundary between the WSRV and the Lower Hassayampa basins are unknown but are expected to decline, utilization of the SRV model boundary conditions could potentially result in an unrealistically optimistic estimate of the available groundwater in the area. ADWR's assumptions and boundary condition were suitable for their needs because the focus of their interest was not the water logged zone and they were willing to sacrifice some accuracy in that portion of the model to assist the remainder of the model domain to the east. The U.S. Bureau of Reclamation (BOR) elected not to modify this model boundary when conducting the WESTCAPS modeling.

A second concern was driven by ADWR's recognition that the region of the SRV model from approximately Gillespie Dam east to approximately the western boundary of the Town of Goodyear water service area is an "Area of Insufficient Data & Low Model Confidence" (Figure 18, ADWR Modeling Report No. 8).

BC addressed the problem of the inappropriate boundary condition through the reassigning of the model cells along the boundary as specified flux. This approach would hold steady the influx of water into the WSRV basin from the Lower Hassayampa basin regardless what occurred with water levels within the WSRV. If extensive water level declines occur in the Lower Hassayampa basin, which is expected to occur, then this boundary condition will still over-assign the flux of water into the WSRV. A more accurate representation of this boundary condition for long-term simulations either requires some consensus on what to assume will happen in the future within the Lower Hassayampa Basin or the combing of the WSRV model with the model of the Hassayampa Basin currently under development by Brown and Caldwell. Based on discussions with ADWR modeling personnel, this latter option is being pursued by ADWR but will likely not be completed until the 2007 or later time frame.

2.2 BASECASE MODEL

To evaluate the impacts that different proposed groundwater extraction scenarios may have on water levels within the water logged area, a baseline groundwater elevation condition needed to be established. This basecase condition is defined as the groundwater elevation that would be expected into the future using accurate estimates of aquifer stresses. These stresses include:

- Groundwater pumping,
- Recharge (stream channel, agricultural, canal leakage, and managed recharge projects), and
- Subflow in from and out to adjacent groundwater basins

Because the possible volume of groundwater available for extraction was to be looked at as far into the future as the year 2110, estimates of the above-listed aquifer stresses is also needed out to the year 2110 to accurately predict the basecase groundwater conditions. Although not rigorously evaluated as part of this work, the assumptions made by ADWR in their Current Trends Analysis (CTA) model simulations run out to 2025 are known to be different than those made by the BOR with the WESTCAPS model. Because the WESTCAPS model was completed after the CTA model it is assumed that it included more updated estimates of population growth, the rate and location of urbanization, and the estimated recharge from managed facilities. Based on this, the previously completed WESTCAPS model was viewed as the "best" basecase model. However, to facilitate the possible review of this work by the ADWR, the 2002 Updated SRV model was selected to be used. It should be noted that both models simulated continued shallow groundwater conditions within the water logged area out to 2025. The WESTCAPS basecase model also simulated continued shallow groundwater levels out to 2100.

2.2.1 Basecase Model Assumptions

In the absence of working with the various governmental entities in developing estimates of updated groundwater pumping and recharge into the future, an approach that used a representative or reasonable set of estimates was developed. Based on a review of the annual groundwater pumping as used in the SRV model for the WSRV portion of the model from 1982 through 2002 (Figure 1) and the total pumpage as used in the SRV model for just an Area of Interest (AOI) (Figure 2), described by a rectangular area that includes the water logged area but also the Roosevelt Irrigation District (RID) north of the water logged area and the Goodyear service area, the 1996 pumping volumes were determined to represent a reasonable long-term average value. This analysis, based on these two areas, was felt to adequately represent historic groundwater pumping trends in the portion of the SRV model (southwestern corner) of primary interest for this work.

Although a similar approach was initially completed for recharge, the 2002 recharge estimate developed by ADWR for the SRV model was selected. The primary reason for its use was that although it represented the lowest total recharge over the 1983 to 2002 period (Figure 3), the trend over that period was strongly decreasing and the use of anything other than the 2002 estimate could not be defended.

Using these assumptions, the following set of conditions was used to conduct the basecase model simulation:

- 1983 – 2002: Exact same values as used in the 2002 ADWR Update Model
- 2002 – 2004: 2002 SRV model values were held constant over this time period
- 2005 – 2110: ADWR SRV model pumping file for 1996 and recharge file for 2002

2.2.2 Basecase Model Results

Groundwater elevation contour maps for the year 2004, 2025, and 2110 are presented on Figures 4 through 6, respectively.

A review of the contours for 2004 reveal that groundwater flow lines along the Gila River generally continue to flow into the water logged area. However, as indicated by the groundwater flow direction arrows, a groundwater divide exists in the northern portion of the City of Goodyear service area. This groundwater divide is the result of groundwater being drawn north towards the cone of depression associated with the Luke Sink. Although 2004 field water level measurements are not available to compare the contours with, overall, the water levels presented are felt to reasonably simulate what has occurred in the WSRV.

A review of the contours for 2025 reveals an approximately 25-foot decline in water levels within the water logged zone along with a westerly migration of the groundwater divide. Based on the groundwater elevation contours all of the groundwater entering from the Gila River Indian Community (GRIC) and which is recharging from the 91st Avenue WWTP flows towards the Luke Sink.

A review of the contours for 2110 reveals an additional 125 feet of groundwater decline and the movement of most of the groundwater underlying the former water logged area, including much of the subflow entering from the Lower Hassayampa Basin, towards the large groundwater declines in the central portion of the WSRV. Although previous simulations completed by WESTCAPS also show large declines in portions of the WSRV due to continued pumping, they do not show the extreme and spatially extensive effect indicated by the BC basecase model.

The significant difference between the BC basecase model and the WESTCAPS model is exemplified by looking at a series of water level hydrographs from the WESTCAPS basecase simulation and presented here as Figure 7. As can be seen on Figure 7, large drawdowns were observed in the north and central portions of the WSRV in the WESTCAPS basecase simulation but virtually no drawdown was observed in the water logged zone. This discrepancy precluded the developing of simulations to determine how much water may be available within the water logged zone.

2.3 DETERMINATION OF CAUSES OF MODEL DIFFERENCES

A number of issues were investigated in an effort to explain why the BC Basecase model simulated such large drawdowns in the water logged area. It was finally determined that the discrepancy had to be related to differences in the future assumptions regarding recharge and groundwater pumping between the two models. A review of the WESTCAPS report identified that a number of managed recharge projects were assumed in the WESTCAPS basecase simulation that were not present in the ADWR SRV model for 2002. To evaluate this as the possible cause, the BC Basecase model was then re-run with 107,500 acre-feet per year of recharge being added to the WSRV groundwater basin. Although the actual name and justification for each of the recharge projects was not clear in the WESTCAPS report, the major projects that were identified included 11,500 acre-feet per year from the CAP Agua Fria Recharge Project, 10,000 acre-feet per year near Avondale, and 13,000 acre-feet per year near the Beardsley Canal. An additional 60,000 acre-feet per year was included along the Agua Fria River to simulate the Agua Fria Linear Recharge Project. Although this recharge lessened the magnitude of water level drawdown within the water logged area it still did not recreate the absence of drawdown observed in the WESTCAPS Basecase simulation.

A recommendation was then made by the committee to also reduce groundwater pumping within the area encompassing the Buckeye Irrigation District (BIC) and RID for the future portion of the simulations. BC then developed a new series of MODFLOW simulations that included the 107,500 acre-feet of additional recharge and reduced the pumping by the BIC and the RID within the AOI (defined previously) by one-half starting in the year 2010. This one-half reduction was based on the 2002 pumping rates and resulted in 43,000 acre-feet per year less pumping.

The results of these simulations are presented on Figures 8 for the year 2025 and on Figure 9 for the year 2110. A series of hydrographs comparing water level drawdowns at specific locations within the water logged area for the BC Basecase simulation versus the revised simulation with increased recharge and decreased pumping are presented as Figures 10 through 22. An analysis of Figures 8 through 22 indicate that although much higher water levels are sustained within the water logged area through the combination of increased recharge in the central portion of the WSRV and decreased pumping by the BIC and RID, relatively significant groundwater declines are still observed. This is most easily observed with the hydrographs (Figures 10 through 22). These figures also indicate that even prior to 2002, when the model inputs are solely those used by the ADWR model, water level drawdowns that exceed what is observed in the field.

Further research obtained electronic copies of the WESTCAPS MODFLOW recharge and pumping well files from the BOR. These were then evaluated graphically and in tabular format. This format provided the ability to better compare the two models. At the scale of the WSRV a more quantitative view of the difference between the BC Basecase simulation compared to the WESTCAPS basecase simulation are presented in Figures 23 through 26. These figures reveal that differences exist in the total amount of recharge and pumping applied to the predictive simulations and to the timing when which the changes are applied. The differences are even more graphic when looking at just the AOI (Figures 27 through 30).

2.4 PHASE 1 RECOMMENDATIONS

The poor match to field conditions, even prior to 2002 by the ADWR model is believed to be due to a combination of the area being an area of insufficient data and low model confidence, as previously cited by ADWR, and the coarse scale at which this portion of the WSRV is modeled. The dynamic nature of the surface water/groundwater interaction in the water logged area requires this area to be modeled at a finer level of spatial discretization than the one-square mile cells used by the ADWR. A recommended model cell size is approximately 1,000 feet on a side, which is similar to the width of the river channel.

Until a more accurate and defensible simulation tool is developed, estimating the true volume of brackish water that may be available can only be done in a crude manner using some simple water budget approaches. However, the large volume of surface flows that exit at Gillespie Dam, as recorded by USGS gage data, combined with the limited subflow entering the area from the Hassayampa Basin clearly identify that a significant volume of water (groundwater or surface water) does leave the WSRV basin and should be available for capture within the water-logged area. This is graphically shown on Figures 31 and 32. The large volume of surface flow leaving the basin generally ranges between 20,000 to approximately 120,000 acre-feet per year with numerous years greatly exceeding these numbers due to flood flows. Accurately capturing these flows both spatially and throughout time is key to accurately estimating the long-term water available in the water logged area.

2.5 PHASE 2 – WATER BALANCE STUDY

As a follow-up to the numerical modeling analysis completed in Phase 1, and in response to the recommendations described in Section 2.4, BC conducted a focused water balance study on the water logged area using the SRV model and available raw data. It was expected that the detailed water budget analysis would provide fundamental information for guiding the possible development of a refined numerical model in the water logged area as that is the only appropriate tool for evaluating long-term water availability. The study area is identified in Figure 33.

In this study, a detailed water budget has been prepared for current conditions of a revised AOI (relative to that used in Phase 1) encompassing the water logged area using the best available data. The revised AOI is identical to the Phase 1 AOI (Figure 1) in the north-south direction but now extends east to west from the Buckeye Heading to the Gillespie Dam.

Additionally, an accounting of the Gila Rive flow in the Water logged area is conducted and this flow is compared with that measured at the Gillespie Dam.

2.5.1 Approach

Publicly available data from state agencies and previous studies were collected and analyzed to provide background information for this study. Groundwater inflow and outflow components in the AOI were then identified. The groundwater budget in the AOI was developed in two approaches. In Approach 1, the groundwater budget in the AOI was estimated through simulations of the SRV model by conducting a zonal water budget analysis for the specific study area, and the budget was designated as SRV model simulated budget. In Approach 2, the flow components were either derived directly with raw data if they were available, or estimated by the SRV model when direct estimation of them became difficult (i.e., groundwater underflow). The groundwater budget developed in Approach 2 is denoted as BC estimated water budget. Finally, these two water budgets were compared and the differences between them were identified and explained.

2.6 GROUNDWATER INFLOW COMPONENTS

Groundwater inflow components primarily consist of groundwater underflow and agriculture related recharge including agricultural irrigation return flow, and canal seepage. The BIC canal was simulated as a stream in the SRV model and the BIC canal seepage was presented by stream recharge accordingly.

2.6.1 Groundwater Underflow

Groundwater underflow changes with groundwater flow field conditions, but it can be estimated through flow-net analysis and groundwater flow model simulations. Since groundwater flow models are often calibrated with field data, the groundwater underflow estimates derived from model simulations are deemed to be more representative of underflow conditions and contain less uncertainty. The groundwater underflow component in the AOI for both approaches was estimated using the SRV model.

Groundwater underflow enters the AOI from two major directions: the east boundary of the AOI, and the northwest corner of the AOI where groundwater enters the study area from the Hassayampa groundwater basin. Using the SRV model, groundwater underflow estimated from the east direction gradually decreased from over 22,000 acre-feet per year (AFY) in 1980s to about 12,000 AFY in 2002. This groundwater underflow component declined about 10,000 AFY during the 20-year (1983-2002) model simulation period.

Unlike the groundwater underflow component from the east, groundwater underflow from the Hassayampa basin remained more or less steady, and it was estimated by the SRV model to slightly fluctuate around the rate of 12,000 AFY during the 20-year model simulation period.

The SRV model also simulated a small groundwater underflow component coming across the north boundary since 2000. This component increased from 13 acre-feet (AF) in 2000 to 138 AF 2002. This component is not included in the BC water budget.

2.6.2 Agriculture Related Recharge

The AOI is dominated by agricultural activities, and three irrigation districts including BIC, RID, and Arlington Canal Company (ACC) exist in the study area. Consequently, agricultural irrigation return flow and canal seepage are significant flow components and they have the greatest influence on the water budget when compared to other inflow components.

2.6.2.1 SRV Model

Due to the absence of active artificial recharge project in the AOI, the recharge component simulated in the SRV model is interpreted as agriculture irrigation return flow. In the SRV model this recharge component was simulated to show a declining trend from 117, 000 AF in 1983 to 58,000 AF in 2002.

2.6.2.2 BC Estimation

Agricultural recharge represents water returned to the aquifer as percolation from agricultural irrigation return flows. Empirically, excess applied irrigation is estimated as the product of the total amount of water applied to the agricultural land minus that lost to evaporation and transpiration by the plant. This is approximated as the irrigation inefficiency. The irrigation inefficiencies vary with different irrigation districts. For instance, the BIC has an irrigation inefficiency of 29 percent, while the RID has an irrigation inefficiency of 41 percent (Corkhill, et al., 1993).

The primary sources of water used for irrigation in the study area include groundwater and diverted Gila River water of which the treated effluent released from 91st Avenue WWTP is the primary source.

In general, depths to water between the BIC canal and south of the Gila River in the AOI are very shallow, therefore, the agricultural recharge is considered to reach the aquifer rapidly and no recharge lag time is considered.

Buckeye Irrigation District

The BIC uses both pumped groundwater and diverted surface water for irrigation. The BIC pumpage since 1984 were retrieved from ADWR 55 database (ADWR, 2004). To alleviate the water logging condition, BIC began to pump selected wells for drainage in 1984. The drainage pumpage is excluded from the calculation of total amount of water applied for irrigation.

The sources of diverted surface water include river water diverted at the Buckeye Heading which primarily consists of effluent released from the 91st Avenue WWTP and water discharged to the Gila River channel through the Salt River Project (SRP) feeder Canal and diverted at the Buckeye Heading. According to previous studies (Montgomery and Associates, 1988), records of the Gila River water diversion are currently only available prior to 1989, and the five year (1984-1988) average diverted volume of 143,229 AFY is assumed for that diverted during the period of 1989 to 2003. Similarly, records of the diverted water which is furnished by SRP are available until 1986, and the 12-year average (1975 to 1986) annual diverted volume of 21,688 AF was assumed for the period from 1987 to 2003. For both diverted surface water sources, the annual volume since late 1980s were approximated using average values and were therefore associated with a certain degree of uncertainty.

The summation of groundwater and diverted surface water results in the total amount of water potentially available for irrigation. Since BIC main and south extension canals are unlined canals, significant amount of water can be lost through canal seepage during the water conveyance to the field.

A seepage study was conducted in 1987 (Desert Agricultural and Technology Systems) to estimate the seepage losses from Arlington Canal Company (ACC) main canal, BIC main canal and south extension canal. This study estimated that the total seepage loss from the BIC main canal and south extension canal was about 32,530 AFY.

The total amount of water used for irrigation for each year during the period of 1984 to 2003 was then calculated by adding the total BIC pumpage and the total diverted surface water, and deducting the BIC drainage pumpage and the BIC canal seepage. Multiplying this total amount of water applied for irrigation with the ADWR estimated irrigation inefficiency of 29 percent results in the estimated amount of potential agricultural irrigation return flow. This return flow recharge component was estimated to vary within a narrow range around 50,000 AFY. Combing the return flow recharge with the canal seepage, the total BIC agricultural recharge fluctuates around 80,000 AFY and is presented on Table 1.

Roosevelt Irrigation District

Pumped groundwater is the sole source of water used for irrigation in RID. RID currently operates 102 wells. Forty-eight (48) wells are located on RID lands within the AOI (west of the Agua Fria River) and designated as the "District wells". The remaining wells are located on SRP lands lying east of the Agua Fria River and designated as "Tolleson" wells.

Because these RID-Tolleson wells are outside of the AOI domain, and pumpage from these wells were excluded from the calculation of total groundwater withdrawn within the AOI. However, a an important component of the AOI water balance is that water withdrawn from these Tolleson wells is imported into the study area for irrigation uses on the RID properties. Therefore, the Tolleson pumpage was accounted for in the calculation of the RID irrigation return flow.

Unlike the BIC canals, the RID canals became lined in 1986, and the estimate of potential canal seepage reduced significantly from 37,000 AFY when unlined to only 2,500 AFY after lined (Corkhill, et al., 1993).

The total amount of water used for irrigation for each year during the period of 1984 to 2003 in RID was calculated by adding the total RID Tolleson well pumpage and RID district well pumpage and deducting the RID canal seepage. Multiplying this total amount of water applied for irrigation with the ADWR estimated irrigation inefficiency of 41 percent results in the estimated amount of potential agricultural irrigation return flow. Table 2 presents the estimated agricultural related recharge for the RID. As exhibited on Table 2, the RID total agricultural related recharge is estimated to range from 38,000 AFY to 76,000 AFY.

Arlington Canal Company

Approximately 40 percent of ACC properties are within the southwestern portion of the AOI. Based on this, the agricultural recharge inside the study area is prorated at 40 percent of the total ACC agricultural recharge. Most of the ACC irrigation water supply is presently obtained from surface water diversions from the Gila River. At this point in the Gila River this water is a combination of groundwater being forced toward the land surface, treated effluent released from the 91st Avenue WWTP, drainage and tail water from BIC (Montgomery and Associates, 1988).

Though the ACC irrigation water use is not directly available, review of ADWR files provides the historical ACC irrigation acres. The total volume of water that ACC applied for each year is then approximated using the ACC irrigation acres and an estimated water consumption rate of 4.76 acre-feet/acre. The ACC irrigation inefficiency is estimated to be 29 percent. The total ACC irrigation return flow within the AOI was estimated to decrease slightly from 7,300 AF in 1984 to 5,400 AF in 2003.

The ACC canals are not lined, and the ACC canal seepage was estimated to be about 12,000 AFY (DATS, 1987). Detailed estimation of the ACC agricultural recharge is presented on Table 3.

2.6.3 Stream Recharge

In the ADWR SRV model, the BIC canal as well as the Gila River was simulated as a stream. Therefore, the stream recharge estimated by the SRV model showed a combination of recharge from both if the Gila River recharges groundwater, and the contribution from the BIC canal was not separated from the potential Gila River recharge if there was any.

Due to the shallow depths to water observed in the study area, the stream recharge contributed from Gila River is considered minimal by BC. As a result, BC interprets that the SRV simulated stream recharge is chiefly contributed from the BIC canal. This SRV model simulated stream recharge was added to the SRV model simulated return flow to represent the SRV model simulated total agricultural recharge when compared to the agricultural recharge estimated by BC.

2.7 GROUNDWATER OUTFLOW COMPONENTS

Groundwater outflow components consist of groundwater underflow, groundwater pumpage, groundwater discharged to Gila River, and evapotranspiration.

2.7.1 Groundwater underflow

Groundwater underflow leaves the AOI mainly in two areas. Specifically, groundwater underflow exits the study area through the northeast boundary toward the Luke Sink cone of depression, and through the southwest along the Gila River near Arlington. The SRV model simulated groundwater underflow near Arlington fluctuated within a narrow range around 9,000 AFY, while the groundwater underflow leaving for the Luke cone of depression exhibited a large range from 18,887 AFY in 1984 to 4,607 AFY in 2002. The SRV model also simulated a groundwater underflow component leaving the study area through the south boundary. This component is very small and stays below 100 AFY through the entire model simulation period. This underflow component was not considered in the BC water budget

2.7.2 Groundwater Pumpage

For the BC water budget, groundwater pumpage in the study area was retrieved from ADWR 55 well database which include all the pumpage reported through the Registry of Groundwater Rights (ROGR). The Tolleson pumpage, though was imported into the study domain, was excluded from the pumpage total as it was withdrawn from the area outside of the AOI. All the BIC pumpage are within the study area, and only partial pumpage of the RID and ACC are within the study area. Figure 34 displays the historical groundwater pumpage by different parties.

For the SRV model simulated water budget, the pumpage was obtained through the model output in the well package.

2.7.3 Groundwater Discharged to Gila River

Groundwater discharged to Gila River was estimated by the SRV model and it ranged from over 4,000 AFY to over 13,000 AFY during 1984 to 2002.

2.7.4 Evapotranspiration

Evapotranspiration represents the estimated amount of groundwater lost through transpiration from plants that utilize groundwater. Saltcedar is one of the common phreatophytes in the study area. In areas where 100 percent volume density growth occurs, the saltcedar may consume as much as 7.2 acre-feet per acre of groundwater per year (Montgomery and Associates, 1988). Due to the presence of the Gila River and the shallow depths to groundwater observed in the water logged area, the evapotranspiration is considered a significant outflow component.

However, this component can not be easily estimated without field investigations on the types of phreatophytes present, the water consumption rate, spreading, and growth density of each phreatophyte. This component is currently estimated through the SRV model simulation. This component was estimated to decrease over time with an nearly 6,000 AFY in early 1980s to slightly over 1,500 AFY in 2000s.

2.8 SRV MODEL SIMULATED BUDGET VERSUS. BC WATER BUDGET

A groundwater budget contains groundwater inflow components, groundwater outflow components, and the groundwater change-in-storage which is the balance of the two components. The accumulated change-in-storage over time is frequently reflected on groundwater hydrographs. Therefore, the accumulated groundwater change-in storage over time is expected to show a similar trend of that of groundwater hydrographs.

2.8.1 SRV Model Simulated Water Budget

Table 4 demonstrates the water budget with all the flow components being estimated from the SRV model simulations. As shown in this table, groundwater change-in-storage is negative which is indicative of groundwater being released from aquifer storage for most of the years except for 1986, 1987, 1992, 1993, and 1998. 1992, 1993, and 1998 are wet years. The accumulated change-in-storage over time is presented on Figure 34 and it displays a general declining trend.

2.8.2 BC Estimated Water Budget

Some of the flow components such as groundwater underflow and stream discharge which can not be easily estimated were inherited from the SRV model simulation and directly used in the BC budget. BC's effort was primarily spent on the estimation of agricultural related recharge. Table 5 summarizes the BC estimated water budget. Compared to the SRV model simulated water budget, the BC water budget shows a completely different trend. The annual change-in-storage is positive which is indicative of water stored in the aquifer storage for most of the years except for 1988, 2002, and 2003. The accumulated change-in-storage over time is illustrated on Figure 35, on which the accumulated change-in-storage over time shows a general increasing trend.

2.8.3 Differences between the Two Water Budgets

The differences between the SRV model simulated budget and the BC estimated stem from two aspects: the different number of flow components, and variations in estimates for the same flow component. Table 6 summarizes the differences between the two water budgets. As to the flow components, the BC budget contains all the components that the SRV budget has except for the underflow exiting the model domain through the south boundary of the study domain and the underflow entering the study area from the north boundary since 2000. BC budget excludes these components as no data is available to support the recognition of these components. On the other hand, these two components were simulated to be very small (ranging from 13 AFY to 138 AFY) by the SRV model. Therefore, this difference is considered to be minor.

The significant difference between the SRV budget and the BC budget relies on the estimated agricultural recharge. During the water budget analysis period (1984-2002), the SRV model simulated a much smaller agricultural related recharge than the BC estimation, and the maximum annual recharge difference could be as high as 55, 822 AFY. When the water budget balance is accumulated, these differences were multiplied through the budget period and resulted in a significant difference on the water budget trend over a long term.

Another noticeable difference between the two water budgets is observed to be on the groundwater pumpage. This discrepancy was resulted from the difference on the size of study areas covered by each budget analysis. A small portion of the west BC water budget area was simulated as inactive cells in the SRV model, and the pumpage in this area was not simulated by the well package of the SRV model.

2.9 EXPLANATION OF PHASE 2 RESULTS

As discussed earlier, when groundwater inflow is less than groundwater outflow, water is released from aquifer storage and water levels decline accordingly. On the contrary, when groundwater inflow is greater than groundwater outflow, water is taken into aquifer storage and water levels increase. As a result, the accumulated change-in-storage over time is expected to follow the same trend of groundwater level change over time.

To investigate which water budget is more representative of aquifer conditions in the water logged area, historical groundwater level measurements in the study area are retrieved from the ADWR GWSI databases (2004). Figures 36 and 37 are groundwater contour maps for the study area in 1991 and 2002, respectively. The selection of 1991 and 2002 is because more water level measurements were taken in these two years, and the period is long enough to show a general trend. Figure 38 presents water level changes over the 10-year period. As seen on Figure 38, water level rise has been observed in most of the study area. This observed water level increasing trend is similar to that exhibited by the BC water budget. The SRV model simulated budget, however, shows a general declining trend suggesting that water levels would decline in the waterlogged area.

It should be recognized that it is the difference in the estimated agricultural recharge that distinguishes the BC water budget from the SRV budget. Since the BC estimated agricultural recharge represents the potential maximum agricultural recharge, and some of the inputs inevitably involve certain degree of uncertainties, the estimated recharge is associated with some level of uncertainties as well. But the water budget trend is deemed to be more representative than the SRV model simulated budget when compared to water level trend in this area.

2.10 ESTIMATED AND OBSERVED SURFACE FLOW AT THE GILLESPIE DAM.

An accounting of the Gila River flow in the waterlogged area was conducted by adding the treated effluent released from the 91st Avenue WWTP, BIC drainage pumpage and groundwater discharged to Gila River to the natural Gila River flow component, and deducting the BIC diversion at the Buckeye Heading. Due to the lack of gage data, the natural Gila River flow component in the water logged area is difficult to estimate. Therefore, the balance of Gila River is only estimated with the available components. Figure 39 presents each of the estimated surface flow components.

The Gila River flow is measured at the Gillespie Dam, the measured flow at this gage and the estimated Gila River flow in the water logged area are compared on Figures 40 and 41 at different scales for better demonstration. Due to the absence of the natural flow component, especially in wet years, the two curves did not compare well, the peak flow observed in the Gillespie Dam in 1993 was missing in the estimated Gila River flow.

2.11 PHASE 2 SUMMARY AND CONCLUSIONS

Publicly available data from state agencies and previous studies were collected and analyzed to provide background information for this water budget study for a period from 1984 to 2002. Groundwater inflow components are identified to be primarily composed of groundwater underflow and agricultural recharge. Groundwater underflow enters the study area from the east boundary and from the Hassayampa groundwater basin. Agricultural recharge includes irrigation return flow and canal seepage which are resulted from the long-term agricultural activities of the BIC, RID and ACC.

Groundwater outflow mainly consists of groundwater underflow, groundwater pumpage, groundwater discharged to Gila River, and evapotranspiration. Groundwater underflow leaves the study area primarily through the northeast boundary to the Luke cone of depression and in the southwest part of the study area near Arlington.

Upon the identification of flow components, the water budget in this area is derived using two approaches. In Approach 1, the SRV model is simulated first and all the flow components within the study area are derived through a zonal water budget analysis using model outputs.

In Approach 2, some of the flow components which can not be easily estimated (i.e., underflow and stream discharge) were inherited from those simulated by the SRV model. The groundwater pumpage were retrieved from ADWR 55-well database. Primary effort was spent on estimating the agricultural recharge including irrigation return flow and canal seepage for each irrigation district.

The irrigation return flow was estimated as a product of the total amount of water applied for irrigation for each irrigation district and the ADWR estimated irrigation inefficiency. ADWR files and previous studies were reviewed carefully to identify the water sources utilized by BIC, RID, and ACC, and the amount of each water source applied. In the absence of water use records (i.e. ACC), total water use for irrigation was approximated using irrigation acres and an estimated water consumption rate. For the BIC, when the surface water diversion records for the period beginning 1990s were not available, they were estimated using the 5-year or 10-year average values.

The SRV water budget estimated negative annual change-in-storage which is indicative of water level declining for most of the years except for wet years, and the accumulated change-in-storage over time showed a general declining trend suggesting that water levels in the study area generally declines with time except for wet years.

The BC estimated water budget demonstrated positive annual change-in-storage for most of the years, and the accumulated change-in-storage over time exhibited a general increasing trend with time. This trend shows a similar pattern as that revealed on the groundwater level changes. Consequently, the BC estimated water budget is considered to be more representative of the groundwater conditions in the water logged area.

The significant difference between the SRV model simulated budget and the BC budget is variations on the estimate of the agricultural recharge. The SRV model simulated agricultural recharge is smaller than that estimated by BC, and the maximum difference could be as high as over 55,000 AFY.

Additionally, an accounting of the Gila River flow was conducted in the water logged area by adding the treated effluent released from the 91st Avenue WWTP, the BIC drainage pumpage and groundwater discharged to Gila River to the its natural flow component and deducting the BIC diversion at the Buckeye Heading. Since the natural Gila River component is not currently available, the surface flow in the water logged area was estimated using the available flow components. This estimated surface flow in the water logged area was then compared to the surface flow measured at the Gillespie Dam. These two curves did not match well due to the missing Gila River natural component, and the discrepancy was significant during wet years.

2.12 PHASE 2 RECOMMENDATIONS

The development of an accurate accounting of potential excess water within the water-logged area requires the development of an accurate groundwater-surface water numerical model. Work completed as part of this study has identified that the existing ADWR SRV model does not adequately represent this portion of the SRV basin. Further work evaluating the components of the water budget for the southwestern portion of the WSRV using both the ADWR model and available data suggests that the difficulties in accurately representing the groundwater system in the area caused are caused by, at a minimum the following:

1. Inappropriate mathematical representation of the groundwater-surface water system by using a saturated flow numerical model developed with relatively coarse discretization, both spatially and vertically.

2. More accurate information on the actual volume of water (both surface and groundwater) used by the irrigation districts, in particular the BIC and the percent of this volume returned to the groundwater/surface water system.

3. Inadequate data regarding Gila River flows, primarily from the Buckeye Header to Gillespie Dam.

The first two issues can be resolved, or at least their inherent uncertainty semi-quantified, with the development of a more finely discretized (both laterally and vertically) flow model and the use of automated parameter estimation tools. Recommended model discretization includes 1/4 to 1/2-mile lateral grid spacing and the refinement of the existing model layer 1 to an estimated 3 layers. The third issue can be evaluated using a more finely discretized flow model but will require either better field measurements or much better accounting on all of the hydrologic components that can affect Gila River flows.

Even with these issues resolved, the development of long-term estimates of the water resources in the water-logged area will be affected by hydrologic stresses upstream (east, north and northwest) of the water-logged area throughout the entire WSRV, and how those stresses, in particular pumping and artificial recharge, will change over time. Because these stresses will never be known with certainty, any analysis of long-term (e.g., greater than 5 to 10 years) brackish water availability will require to use of model automated parameter estimation techniques and appropriate uncertainty analysis. These tools exist presently but would require the refining of the model grid as described above.

3.0 BENCHMARKING OF DESALINATION PROJECTS

Desalination is used in many regions of the United States as a way to access additional water resources. There are currently two primary methods of desalination used in the United States: Reverse Osmosis (RO) and Electrodialysis Reversal (EDR). Both of these methods utilize thin semi-permeable membranes to separate product water (permeate) from brine (concentrate). RO is the most commonly used membrane treatment in the US, composing 74 percent of municipal plants in the US (Mickley, 2001). The primary advantage of RO over ED/EDR is the capability of removing organics, microorganisms, and taste and odor compounds. Additionally, EDR power consumption increases with as TDS increases, making RO preferable for treating highly saline waters.

CASS reviewed over 30 reports on brackish water treatment facilities to determine what issues would arise in desalination of brackish water in the southwest SRV. Of the 30 facilities, five are highlighted in Table 7 and include both RO and EDR projects. Three of the projects are located in Central Arizona and have water quality information specific to the region. Additional projects are located in California and utilize brackish water with similar TDS levels.

TABLE 7 - SUMMARY OF PERTINENT DESALTING PROJECTS IN THE SOUTHWEST

PROJECT	**CENTERRA WELL FACILITY,** GOODYEAR, AZ	**GILA BEND FACILITY,** GILA BEND, AZ	**LEWIS PRISON FACILITY,** BUCKEYE, AZ	**CHINO I DESALTER,** CHINO, CA	**GOLDSWORTHY DESALTER,** TORRANCE, CA
Source Water TDS, mg/L	>1,900	1,000-2,000	2,000-2,500	871	~3,800
Treatment Method	RO	RO	EDR	RO	RO
Capacity	2.5 mgd	1.0 mgd	1.35 mgd	8.0 mgd	2.5 mgd
System Recovery	79%	Unknown	Unknown	90%	81.3%
Year Online	2002	2002	1988	2000	2001
Capital Cost	$1.98M	Unknown	$1.1M	$25M	$6.5M
Operating Cost	$0.93/kgal	Unknown	Unknown	$525/AF	Unknown
Concentrate Disposal	Sanitary Sewer	Evaporation Ponds	Evaporation Ponds	Ocean Outfall	Sanitary Sewer
Notable Items	Source water has high in nitrates.	Source water high in chlorides.		Source water high nitrates. Also treated by Ion Exchange and for VOC.	

3.1 CENTERRA WELL REVERSE OSMOSIS FACILITY, GOODYEAR, ARIZONA

The City of Goodyear, Arizona (COG) has recently begun processing brackish groundwater from the City's existing Centerra Well. Brackish water is pumped from the well through approximately 2 miles of raw water transmission pipeline to a new 2.5 million gallon per day (mgd) RO Water Treatment Facility located at an existing COG potable water booster pump station and 2 million gallon storage reservoir site.

The Centerra Well was drilled in 1949 to supply irrigation water to local farmers. Its total depth is 1,000 feet, with a 20-inch diameter outer well casing extending the entire depth. In 2004, the well was rehabilitated with a 16-inch diameter inner well casing extending to 500 feet. The well has been filled in below a depth of 502 feet, and a concrete plug installed between 490 feet and 502 feet. The inner casing is perforated between 234 and 490 feet. The Centerra Well has historically been utilized as an irrigation well, but was converted to a municipal well as part of this project. Water quality at the Centerra Well is summarized below.

TABLE 8 – CENTERRA WELL RAW WATER QUALITY

Parameter and Value	Calcium, mg/L	Magnesium, mg/L	Sodium, mg/L	Sulfate, mg/L	Barium, mg/L	Nitrate (N), mg/L	SDI, units
	163	69	414	505	0.04	17.9	1.2 – 5.6
Parameter and Value	Fluoride, mg/L	Temperature, °F	TDS, mg/L	Total Alkalinity (CaCO3), mg/L		pH, units	Arsenic, mg/L
	0.7	51.8	1,940	193		7.4	0.003

As shown in Table 8, the Centerra Well contains significant amounts of TDS in excess of 1,900 mg/L, and elevated levels of nitrates. The treatment goal is to produce a finished water product with a TDS content of 500 mg/L or less and a nitrate concentration (as N) of 10 mg/L or less.

The RO system includes four individual RO trains that will be operated at a minimum recovery of 75 percent. To meet the treatment goals, a water blending scenario is used. Overall, the Centerra Well will provide 3.2 mgd raw water of which 0.5 mgd will be used for blending, with an estimated concentrate flow of 0.7 mgd. Blended product is anticipated to have a TDS concentration of 479 mg/L and nitrate concentration is projected to be 5.29 mg/L. The 0.7 mgd concentrate TDS is projected to be 7,447 mg/L.

A threshold inhibitor compound is added to the RO feedwater to prevent the precipitation of sparingly soluble salts in the concentrate stream. In addition, a sodium hypochlorite system is used for disinfection of finished water prior to discharging into the storage reservoir. Concentrate is disposed of in the sanitary sewer.

3.2 GILA BEND REVERSE OSMOSIS FACILITY, GILA BEND, ARIZONA

In 2002, the Town of Gila Bend completed the construction of a 1-mgd groundwater RO facility. The facility includes three independent treatment trains. Groundwater for the facility is supplied from a series of wells 5 miles south of the town. The feed water TDS averages between 1,000 to 2,000 mg/L. Pre-treatment and post-treatment requirements are unknown. However, concentrate from the RO system is disposed of in evaporation ponds located at the RO site.

In recent years, the Town has experienced problems with the system. The RO system has been producing about 300 gpm for 16 to 17 hours per day using two treatment trains. This is significantly less than the designed 1 mgd. The problems have been contributed to inadequate pretreatment and the membrane housings due to high chlorides in the feed water. The Town recently began replacing the existing stainless steel housings with fiberglass housings. The first skid with replaced housings has been operating for six months and it appears this will fix most of the problems with the system.

3.3 LEWIS PRISON ELECTRODIALYSIS REVERSAL FACILITY, BUCKEYE, ARIZONA

The Lewis Prison EDR facility is fed by two groundwater water wells with a TDS concentration of 2,000 mg/L. The capacity of the facility is 1.35 mgd treated with three EDR units. The facility is expandable up to 1.8 mgd with 4 trains. Pretreatment includes acid addition and cartridge filtration. The EDR permeate is post-treated with caustic to provide pH adjustment and chlorination for disinfection. The concentrate is disposed of in onsite evaporation ponds.

3.4 CHINO I DESALTER, CHINO, CALIFORNIA

The Chino I Desalter was commissioned in 2000 and was built to treat high TDS groundwater with high nitrates. The facility was constructed by the Santa Ana Water Production Authority (SAWPA) and was then transferred to the Chino Basin Desalter Authority (CDA). The plant is currently being expanded to 13 mgd by adding Ion Exchange and volatile organic compound (VOC) removal towers to the facility. The expansion is to be commissioned in early 2005.

The treatment plant was designed to produce potable water with TDS of less than 350 mg/L and less than 25 mg/L of Nitrates. The source water TDS is 871 mg/L. Pretreatment methods include Acid, Threshold Inhibitor, and Cartridge Filtration. The treatment process includes Reverse Osmosis, Ion Exchange of the bypass stream, and VOC of second bypass stream. The RO permeate is decarbonated and blended with the two bypass streams and then Sodium Hydroxide is added. The design capacities for the main treatment include 6 mgd RO, 3 mgd VOC bypass, and 4 mgd Ion Exchange bypass. Eighty percent of the RO stream is recovered. Concentrate from the RO system is sent to Ocean Outfall through the Santa Ana Regional Interceptor (SARI).

3.5 GOLDSWORTHY DESALTER, TORRANCE, CALIFORNIA

The objective of the Goldsworthy Desalter is to provide a new local potable supply utilizing a localized high salinity groundwater source. The owner of the facility is the Water Replenishment District of Southern California. The average TDS is approximately 3,800 mg/L. Pretreatment technologies include cartridge filtration, sulfuric acid addition, and threshold inhibitor injection. Reverse Osmosis is used as the primary treatment method. The RO permeate is further processed by decarbonation and sodium hydroxide addition prior to blending. Blend goals include using as much bypass volume as possible to optimize production up to a 500 mg/L TDS limit. The RO treatment capacity is 2.5 mgd with the option to expand to 5 mgd. Overall the recovery rate of the system is 81.3 percent. Concentrate from the RO system is discharged to the sewer.

4.0 CONCENTRATE DISPOSAL

As the need for additional water resources results in advanced treatment of saline waters, large volumes of concentrate will be produced and will have to be addressed as part of the treatment process. Managing concentrate streams is typically the most difficult and costly portion of desalination. There are several broad ranges of concentrate management alternatives available including: Evaporation Options, Land Application Options, Transportation Options, Well - Injection Disposal Options, Zero Discharge Options, and Proprietary Volume Reducing Options.

Research on these alternatives indicates that finding the concentrate management solution is a very site specific process requiring consideration of several factors including: concentrate flow rate; environmental regulations governing water quality' geophysical features of a given area, cost requirements for implementation and need of desalination treatments. Currently, there is no single solution that can address all of Arizona's concentrate management needs and further research is required.

4.1 EVAPORATION

Evaporation is the process where water changes from liquid to a gas or vapor. Heat breaks the bonds that hold water molecules together allowing water molecules to become a vapor. Evaporation stops working when humidity in the air reaches 100 percent. Evaporation is an effective concentrate volume reduction option in hot, sunny, dry climates. Evaporation technologies include: evaporation ponds; enhanced evaporation ponds (using Wind-Aided Intensified eVaporation (WAIV) or Turbo Misters); Solar Ponds; and DewVaporation.

Evaporation ponds for concentrate management require building an evaporation pond of a depth and surface area large enough to accommodate maximum volume of brine, plus capacity for storm water and capacity for precipitated salts. Ponds may require impervious liners of clay and/or membranes to prevent saline water from filtering into the groundwater. They are extremely land intensive. This technology is used being used in Arizona.

WAIV is a relatively new technology that is used in conjunction with evaporation ponds to reduce the surface area of the ponds and uses wind to promote evaporation that is being developed and tested in Israel. The WAIV unit is a vertical support structure that suspends a series of cloth sheets. Water is pumped from a pond to the top of the WAIV unit where the water trickles down the cloth sheets. As air passes over the cloth surfaces, evaporation occurs and salts are deposited on the sheets. Excess liquid is drained back to the pond, while the salts deposited in a trough below the fabric for disposal in a landfill.

The Turbo Misting technology works by spraying concentrate into the air to increase the water surface area, which accelerates the evaporation rate. This technology allows water droplets to be dispersed throughout a wind stream, to be exposed to air to allow time for evaporation. The salts, sediment, and water remaining will drop into a lined catch pond. This technology has been tested by the US Bureau of Reclamation at the Salton Sea, California.

Solar ponds work like evaporation ponds, but use the salinity gradient ponds for integrated concentrate disposal and energy generation. The Salt Gradient ponds attempt to recover heat from ponds to generate electricity or as a pre-heat to a boiler or temperature raising process. However, solar ponds by themselves are not a method of concentrate disposal. This technology was tested in El Paso, Texas.

DewVaporation™ (DewVap) is based on a combination of evaporation and dew formation and is composed of a series of towers that use air and heat to further concentrate the concentrate. DewVap is in the research stage in Arizona.

4.2 LAND APPLICATION

Land application involves using concentrate from desalination treatment for irrigation of salt tolerant vegetation. It is anticipated that plants will uptake the water they require and the remaining portion of the water will percolate into the groundwater system. Contamination of the aquifer may then become an issue if liners are not used. Typically land application is possible only with low salinity concentrate or diluted concentrate.

4.3 TRANSPORTATION

Transportation options involve removing concentrate from the source via pipelines to the ocean outfalls or discharge to other surface waters or sewer.

4.3.1 Surface Water Discharge

Surface water discharge is the most commonly used municipal concentrate disposal method in the US. Disposal can occur in the ocean, estuaries, rivers, or lakes. The cost for surface water disposal is very site specific. Costs are dependent on the length of pipeline to the disposal site, the diameter of pipeline required, dissipation structure requirements, and physiography of the disposal site. The Bureau of Reclamation conducted the done on such a pipeline to the ocean, called the Central Arizona Salinity Interceptor (CASI). Because of cost of the pipeline (related to Arizona's distance from the ocean) and the loss of water resource from the state, water resources professionals have postponed further work on this alternative indefinitely.

4.3.2 Sewer Disposal

Sewer disposal of concentrate is the second most common concentrate management technology in the US, after surface water discharge. This option works by simply allowing dischargers to put concentrate into the sanitary sewer system. It is important to note that high volume of concentrate can impact the WWTP capacity issues and upgrades may be required to accommodate additional flow. Sewer disposal may not be feasible if TDS levels inhibit the wastewater treatment process. Data presented at the 2003 Salinity Summit in Las Vegas, Nevada identified that WWTP process inhibition occurs when TDS reaches ~3,000 mg/L. Disposal of concentrate in sewage may also be an issue if TDS levels exceed federal discharge standards (i.e. National Pollutant Disposal Elimination System). For those areas that use effluent as source water for non-potable uses, sewer disposal has the potential to degrade the value of effluent for reuse due to higher TDS. This option is currently being used in Arizona.

4.4 INJECTION

Inland injection options involve putting concentrate into an underground aquifer that is structurally isolated from potable groundwater sources.

4.4.1 Deep Well Injection

Deep well injection has been used for disposal of industrial and hazardous wastes since the 1950s. This method of concentrate disposal is most commonly used in Florida and Texas, but has not proven feasible in Arizona. Concentrate disposal wells fall under the jurisdiction of Class I wells which require that the well must be sited in an aquifer formation having at least 10,000 mg/L TDS and must be separated from overlying potable aquifers by hydrologically impermeable formation that prevents upward migration of the injected concentrate. The geology required for deep well injection must be porous (such as sandstone or limestone), deep and isolated. Geology consisting of shale or clay is not typically suitable for deep well injection because it is impermeable. Deep well injection works by pumping concentrate under pressure into the ground. The depth of the well is very site specific, but typically injection wells range from 2,500 to 15,000 feet below land surface. Concentrate is highly corrosive, therefore operational materials require careful evaluation to avoid reduced equipment life cycle. Fouling and scaling of injection well can be a problem that may require the concentrate to be pretreated for pH to prevent plugging of the receiving formation.

4.4.2 Recharge into Poor Quality Aquifers

Recharge into poor quality aquifers may be accomplished by the use of spreading basins, vadose zone injection wells, or injection wells discharging directly into an aquifer. Recharge into poor quality aquifers is not feasible in Arizona because environmental regulations do not allow the further degradation of aquifers.

4.5 ZERO LIQUID DISCHARGE

Zero liquid discharge works by reducing the volume of water to nothing leaving salt in concentrate in crystallized form. Several alternatives exist including brine concentrators and crystallizers. New technologies are continually developing.

4.5.1 Brine Concentrators

Brine concentrators use evaporation to recover water from concentrate. A brine concentrator works by compressing the vapor released from boiling solution, which raises the pressure and saturation temperature of the vapor so that it may be returned to the evaporator body as heating steam. The latent heat of the vapor is used to evaporate more water instead of being rejected to cooling water. Scaling of the heat transfer tubes may be prevented by the seeded slurry process. Calcium sulfate and silica precipitates build up on calcium sulfate seed crystals in the recirculation brine instead of scaling on the heat transfer surfaces. Brine reject from the concentrator ranges between 2 to 10 percent of the feed water with TDS concentrations as high as 250,000 mg/L. Brine concentrators are large towers and require high quality construction materials because of brine's corrosive effects. Brine concentrators are not dependent on weather or geographical conditions and approximately 150 brine concentrators are currently operating in the US, many at power plants. Brine concentrators are reliable but they are exceedingly expensive to operate. The limiting factor for this process is the cost of power to operate them and not the capacity. Electrical costs can range from 60 to 100 kW*HR/ 1000 gal of feed water. Brine concentrators are used on power plants cooling towers throughout Arizona, but are currently cost prohibitive for large concentrate flows.

4.5.2 Crystallizers

Crystallizers have been used successfully for many years for industrial, single-component applications, where only one compound is isolated as a solid from a concentrated brine liquid stream. Capacity for crystallizers ranges from 2 to 50 gpm. Crystallizers are typically used in conjunction with other volume reducing technologies, such as brine concentrators. This application has not been used on large concentrate flows and is expensive to operate.

4.6 PROPRIETARY VOLUME REDUCING TECHNOLOGIES

New concentrate management alternatives are developing on a continual basis. Many of these alternatives reduce the volume of concentrate by precipitating solids from the concentrate and recovering fresh water. These developing technologies are patented and will require that users pay license fees as part of the capital expenditures. Most of these technologies are in the developmental stages and have not been used on a large scale concentrate flow in the United States. Additional research on these technologies is required before they can be implemented as a concentrate management solution.

4.6.1 High Efficiency Reverse Osmosis

HERO (High Efficiency Reverse Osmosis) is a proprietary process system developed by Aqua-Tech to increase water recovery from industrial processes by overcoming two significant impediments to high-recovery RO, hardness (calcium and magnesium), and silica. This system is comprised of a collection of well-defined treatment processes; lime softening, filtration, weak acid cation (WAC) exchange and reverse osmosis. Therefore, reliability should be high if designed with an adequate understanding of the feed water to be treated. The process begins with lime softening of the concentrate to remove the majority of hardness typically found in challenged waters. The product is then filtered through a sand filter to remove particulate matter, and treated by WAC exchange to remove residual hardness not removed by conventional lime softening. Unlike conventional softening, which replaces hardness with sodium, WAC exchange sites are regenerated with hydrogen ions. The product maintains the high pH produced during the lime softening process, which prevents silica precipitation during subsequent RO treatment of the concentrate. A key process to consider is filtration, since particulate matter can foul both the WAC and RO systems. System wide, corrosivity must be accounted for. This technology will however require higher than average operation and maintenance skills, but is within the ability of the industry to acquire and develop. HERO is a developing technology that has only been used for small-scale flows in industry throughout the US. Further research is required.

4.6.2 Sal-Proc

Sal-Proc (SP) is a unique and proprietary treatment option that extracts dissolved elements from concentrate and produces valuable chemical products that are used in other industries. This technology is owned by Geo-Processors and has been successfully piloted, demonstrated and operated commercially in Australia. Pilot plants have been done for small scale operations (57 to 350 gallons per minute). SP works by using common chemistry practices to selectively remove the salts in concentrate. Saline waters vary in their chemical composition and would, therefore, produce different product streams in the SP process. Some of these salt products include gypsum, magnesium hydroxide, precipitated calcium carbonate, sodium chloride, and sodium and potassium sulfate in crystalline, slurry, and liquid forms. These compounds are useable or saleable products and may be used to offset or even eliminate treatment costs, which sets the Geo-Processors technologies apart. The process equipment for typical operations can be found in the chemical process industry and water/wastewater treatment plants. Reliability of such equipment would be the same as that found in existing municipal water and wastewater treatment facilities. Operating staff may require some specialization. This process could be sized, designed and operated in timely manner after thorough evaluation of water quality and flow quantities. Sal-Proc is a unique design with respect to cost-benefit analysis because the capital costs and operating costs can potentially be recovered (or substantially off-set) by the sale of the marketable by-products produced by the treatment process. Potential revenue obtained from this process differentiates this technology from other technologies from a cost comparison standpoint. The costs for this technology vary depending on the desired objectives. These objectives may include sustainable management of saline impaired waters, operational improvement, reduction of the footprint of an operation, recovery of products or a combination thereof. There are many different process routes that may be used depending on the water quality of the source water and the desired products to be recovered, and/or objectives to be achieved. Further research is required

5.0 LEGAL ISSUES

Currently, there are no direct regulations regarding desalination or concentrate management. Desalination is regulated by way of the need to achieve potable drinking water standards. The Safe Water Drinking Act, enforced by the USEPA and established in 1974, is the main federal law that regulates drinking water in the United States.

A Maximum Contaminant Limit (MCL) is established as the maximum permissible level of a contaminant in water which is delivered to any user of a public water system. These levels are determined by the USEPA based on scientific research to protect against health risks and do take into consideration technology and costs of treatment. The National Secondary Drinking Water Regulations are non-enforceable water quality guidelines. Secondary MCLs are established for contaminants that may have cosmetic or aesthetic effects, but are not considered to present a risk to human health. TDS has a secondary MCL of 500 mg/L. TDS over this level may impair the taste of water, scale water-dependent appliances and prohibit the growth of plants.

Groundwater quantity in Central Arizona is regulated by the Arizona Department of Water Resources. ADWR regulates the volume of groundwater pumped through the Groundwater Management Code of 1980 (Code). The Code was established to eliminate groundwater overdraft in areas where groundwater pumping has led to severe declines in water levels and to provide means for allocating groundwater resources for Arizona's water demand needs. The Code established "Active Management Areas (AMA) within the state where groundwater level decline was most severe and most of the regulatory power of the Code in located in the AMAs. These AMAs are: Phoenix, Tucson, Prescott, Pinal, and Santa Cruz.

The Code also created a system of groundwater rights that limits groundwater withdrawals, prohibit development of new irrigated farmland, require new developments to prove a long-term water supply is available and dependable, and require the measuring and reporting of groundwater uses for these rights. Management goals were developed for each AMA and these goals were to be met with the implementation of a series of five management plans, each one more stringent than the prior. The management plans consist of conservation requirements for industrial, municipal, and agricultural groundwater users. Currently the Code is operating in its Third Management Plan (TMP), which expires on December 31, 2009.

Brackish groundwater is subject to the Code's regulation. Therefore, pumping and desalination of this water would require that brackish groundwater be counted against groundwater allotments and would also require the groundwater pumper to pay fees for utilizing this water.

An area located in the southwest Phoenix AMA is exempt from the conservation requirements because of its designation as a "waterlogged area" under Arizona Revised Statute (A.R.S.) § 45-411.01. Water levels in this area of the Phoenix AMA are as high as 10 feet bls and without drainage; water would rise to the surface. In addition to being water logged, water in this area is also brackish. The waterlogged area is designated as the being within service areas of the Buckeye, Arlington, and St. John Irrigation Districts. These irrigation districts and Irrigation

Grandfathered Right holders near these districts are allowed to pump as much water as they require and are exempt from conservation requirements and withdrawal fees until the end of the Fourth Management Plan Period (December 31, 2019). A hydrologic review of this area and this statute must be done before December 15, 2015 by ADWR, to extend this exemption.

Under Assured Water Supply (AWS) Rules (A.A.C. R12-15-705 (T)), holders of an AWS certificate or designation water providers within the designated waterlogged area are allowed to exclude the uses of the following types of groundwater:

- Surface water
- Contaminated Groundwater
  - Groundwater Pumping for Remedial Action (under approval of ADEQ)
  - Groundwater is treated, blended or exchanged to achieve water quality standards
  - Groundwater would have otherwise not been pumped
  - Groundwater is withdrawn before 2025
- Water excluded from conservation requirements under Title 45. This exemption is to be reviewed on a periodic basis, not to exceed 15 years.

Currently, no water provider has utilized the AWS exemption for pumping in the waterlogged area.

6.0 CONCLUSIONS

Desalination of brackish water is already occurring in the southwest SRV, because there is need for additional water resources. It is anticipated that this need will grow in the future. Conclusions to be drawn from this study are:

Insufficient/Inadequate Information Exists to Reliably Estimate Long-term Availability of Brackish Groundwater.

An inadequate understanding of the basin-wide water budget, in particular in the area around the Water-logged Area, results in an inability to produce reliable estimates of brackish water available for long-term (> 5 years out) use. Estimates of the current water budget are hindered by poor information on groundwater-surface water interactions in the water-logged area. Long-term estimates of available brackish water are hindered by the same problem and inadequate information regarding future changes in pumping, the retirement of agricultural lands, and the location and magnitude of recharge projects.

Importance of Identifying Site Specific Water Quality

The three projects located in Central Arizona are relatively close in proximity (>100 mile radius) and have a similar range of TDS concentrations, but water quality varies for other constituents. Because variation in water quality can affect pre-treatment and post-treatment requirements, it is important that water quality information be site specific before desalination is implemented.

Further Research is required to Increase Recovery Rates in Desalination Technologies

Current desalination recovery rates range from 75 to 85 percent. Low recovery rates increase the cost of desalination projects because it increases the amount of concentrate that has to be managed. Increasing the desalination recovery rate is also important to preserving water resources and meeting regulatory requirements of the Groundwater Code.

There is No Single Solution for Concentrate Management
Disposal using evaporation ponds is feasible in the arid southwest climate, but is extremely land intensive. Disposal in the sewer is easily implemented, but may have significant issues with regards wastewater treatment plant processes and capacity.

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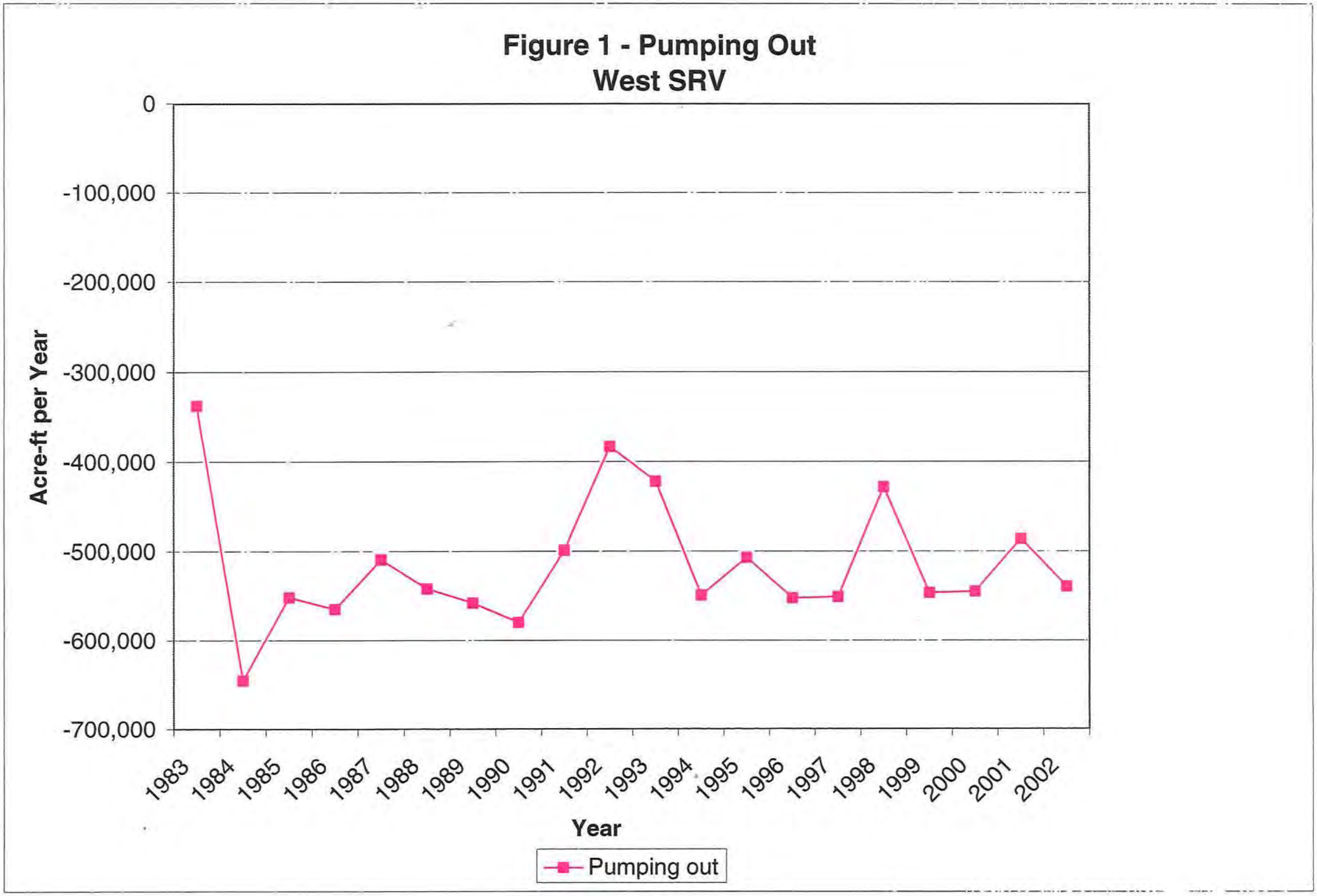


Figure 1 - Pumping Out
West SRV
0
-100,000
-200,000
-300,000
-400,000
-500,000
-600,000
-700,000
Acre-ft per Year
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Year
Pumping out

Figure 2 - Total Pumpage for the Area of Interest

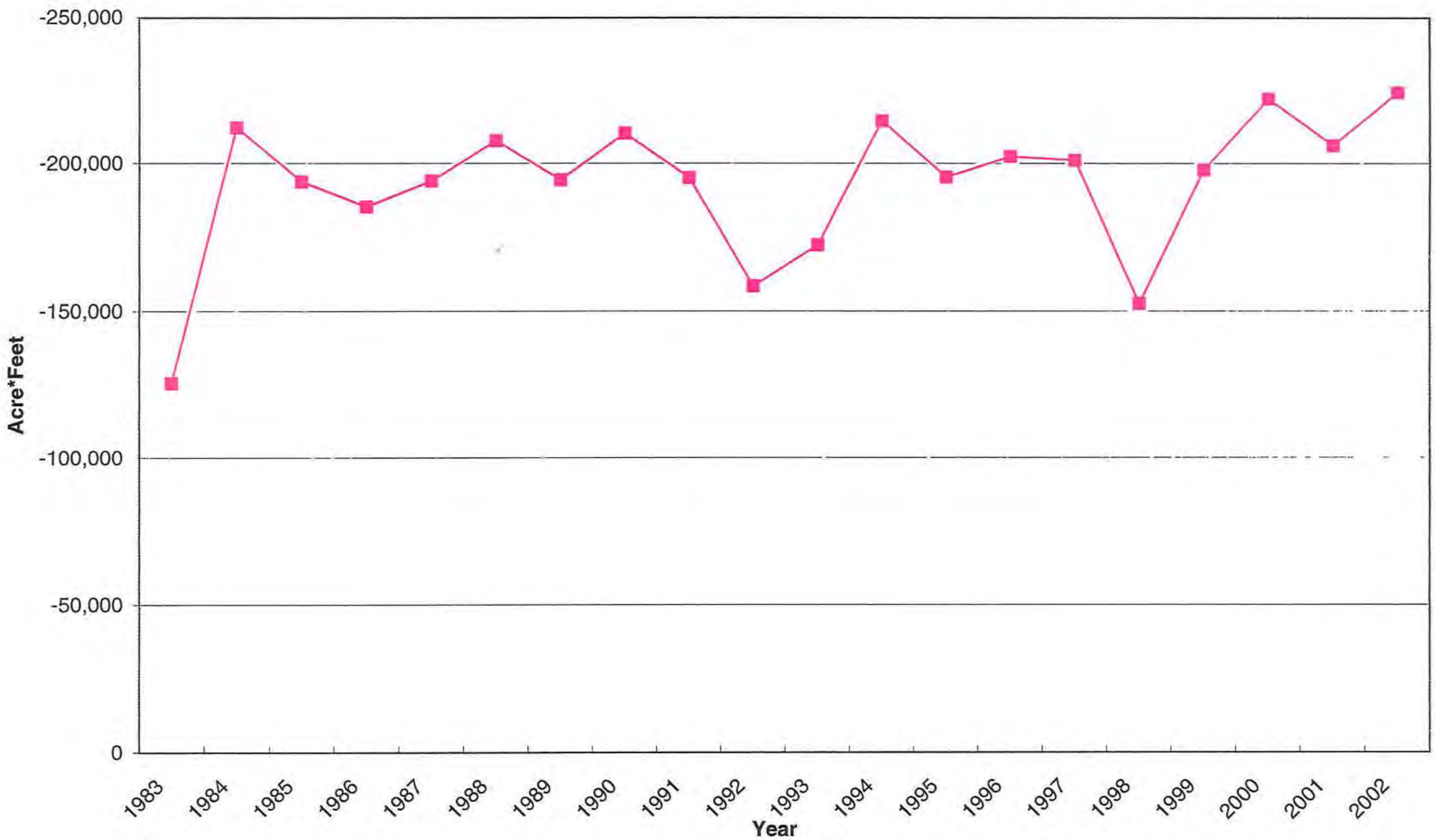


Figure 3. Total Recharge for Area of Interest

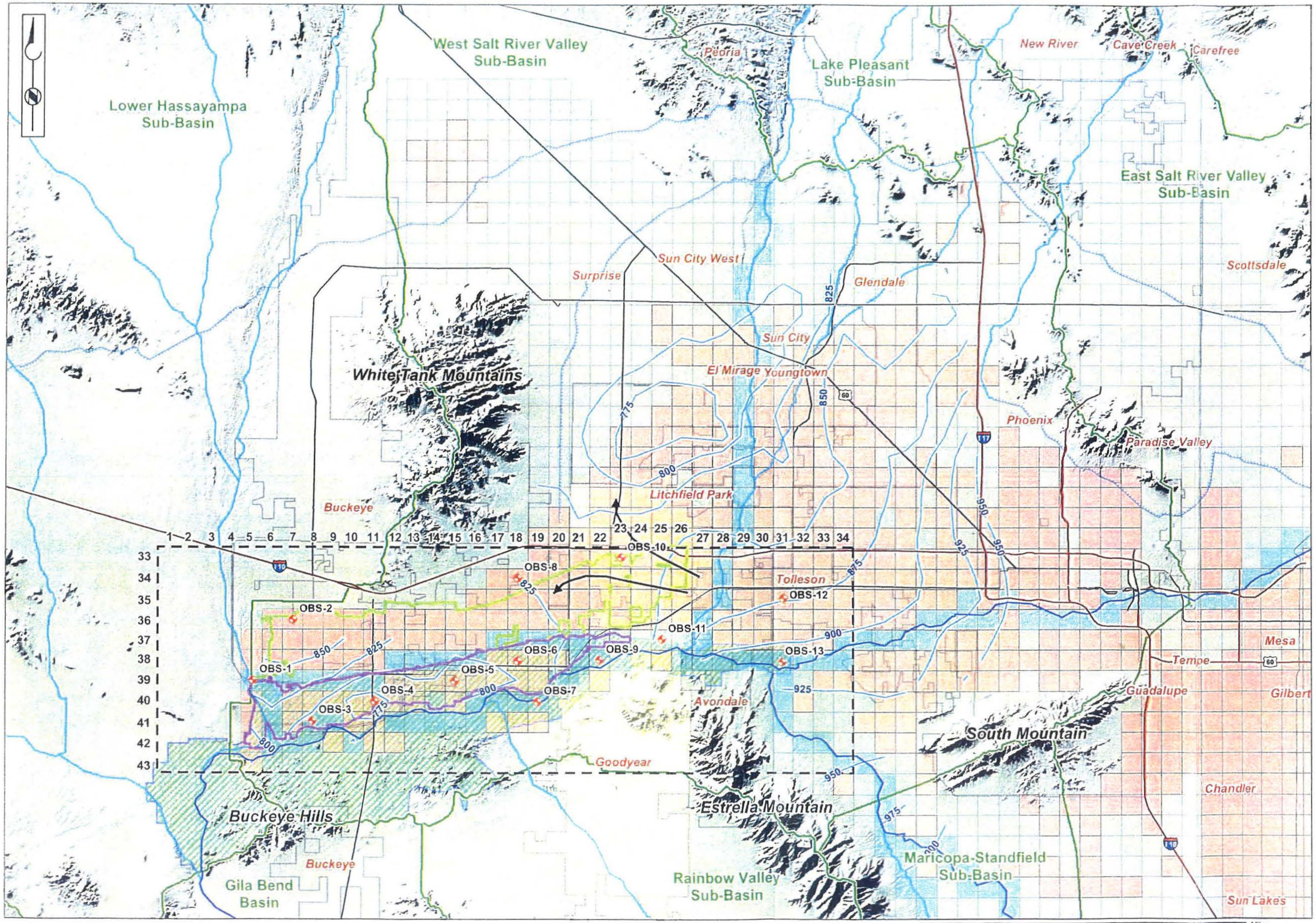


FIGURE 4
LAYER 2
2004 SIMULATED
GROUNDWATER ELEVATION
CONTOURS

BRACKISH WATER STUDY
GOODYEAR, ARIZONA

BROWN AND CALDWELL

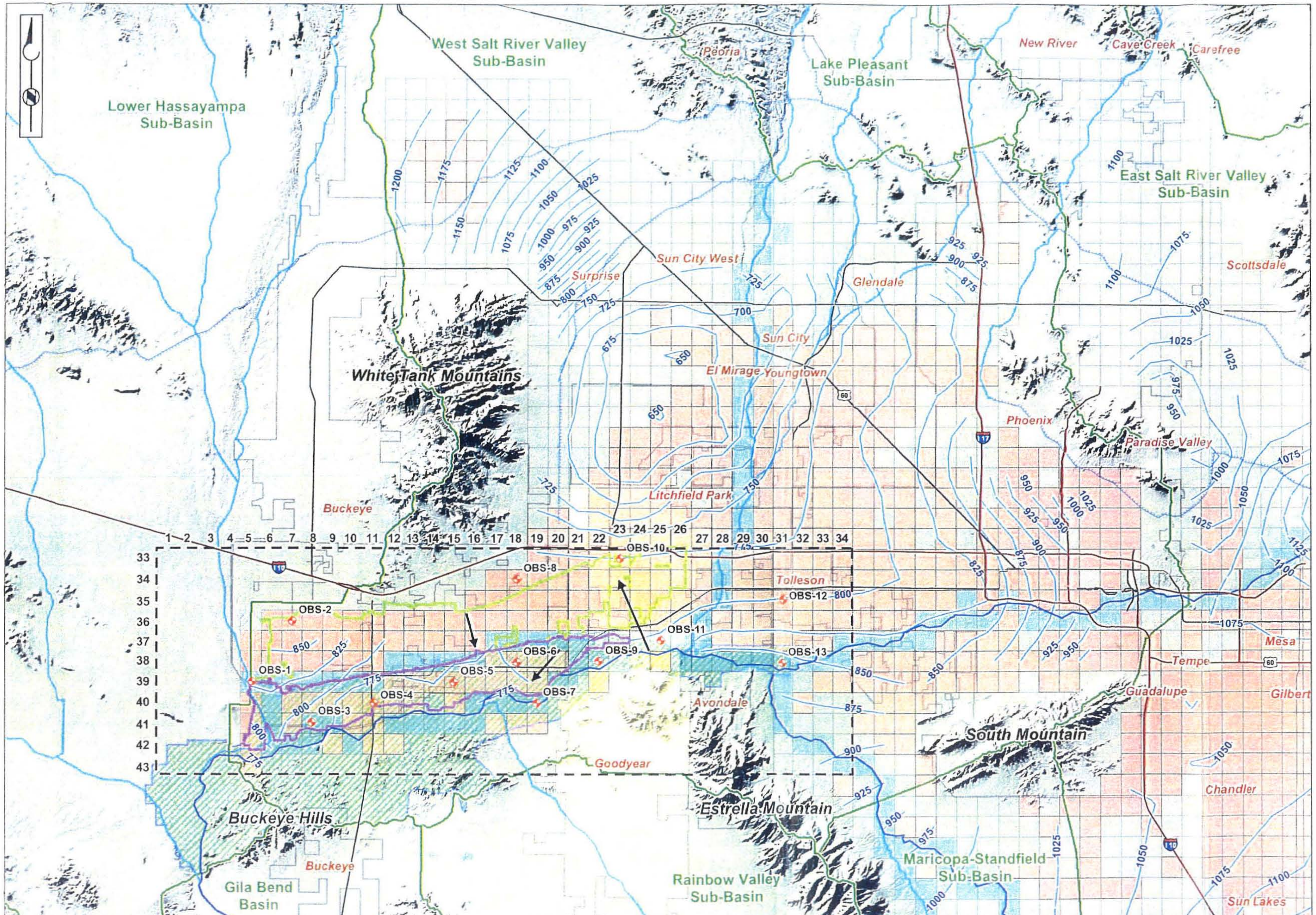


FIGURE 5
LAYER 2
2025 SIMULATED
GROUNDWATER ELEVATION
CONTOURS
BRACKISH WATER STUDY
GOODYEAR, ARIZONA

BROWN AND CALDWELL

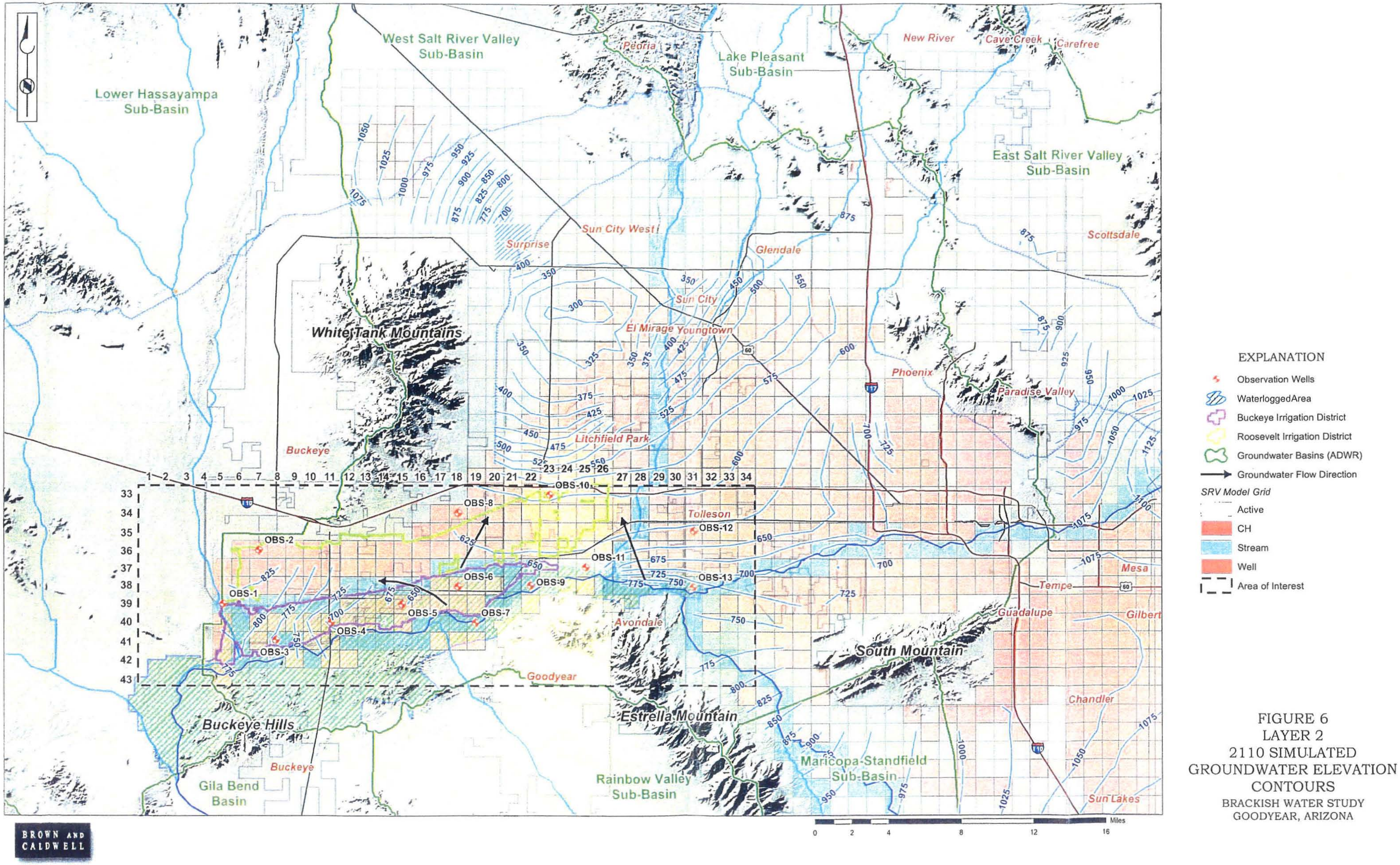
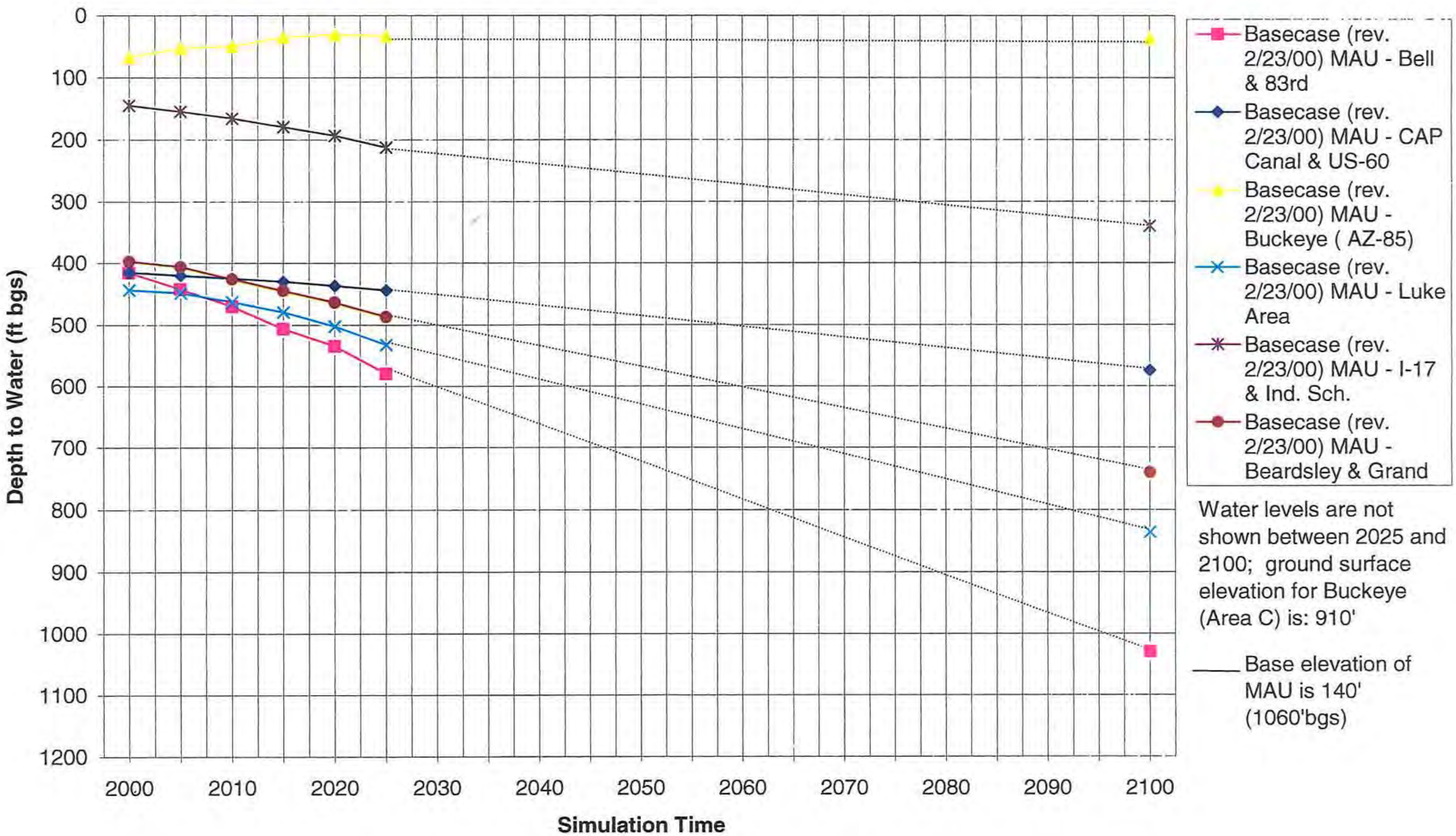


FIGURE 6
LAYER 2
2110 SIMULATED
GROUNDWATER ELEVATION
CONTOURS
BRACKISH WATER STUDY
GOODYEAR, ARIZONA

Figure 7 - WESTCAPS Basecase (rev. 2/23/00) - Comparison of Hydrographs Middle Alluvial Unit - Simulated Depths to Water



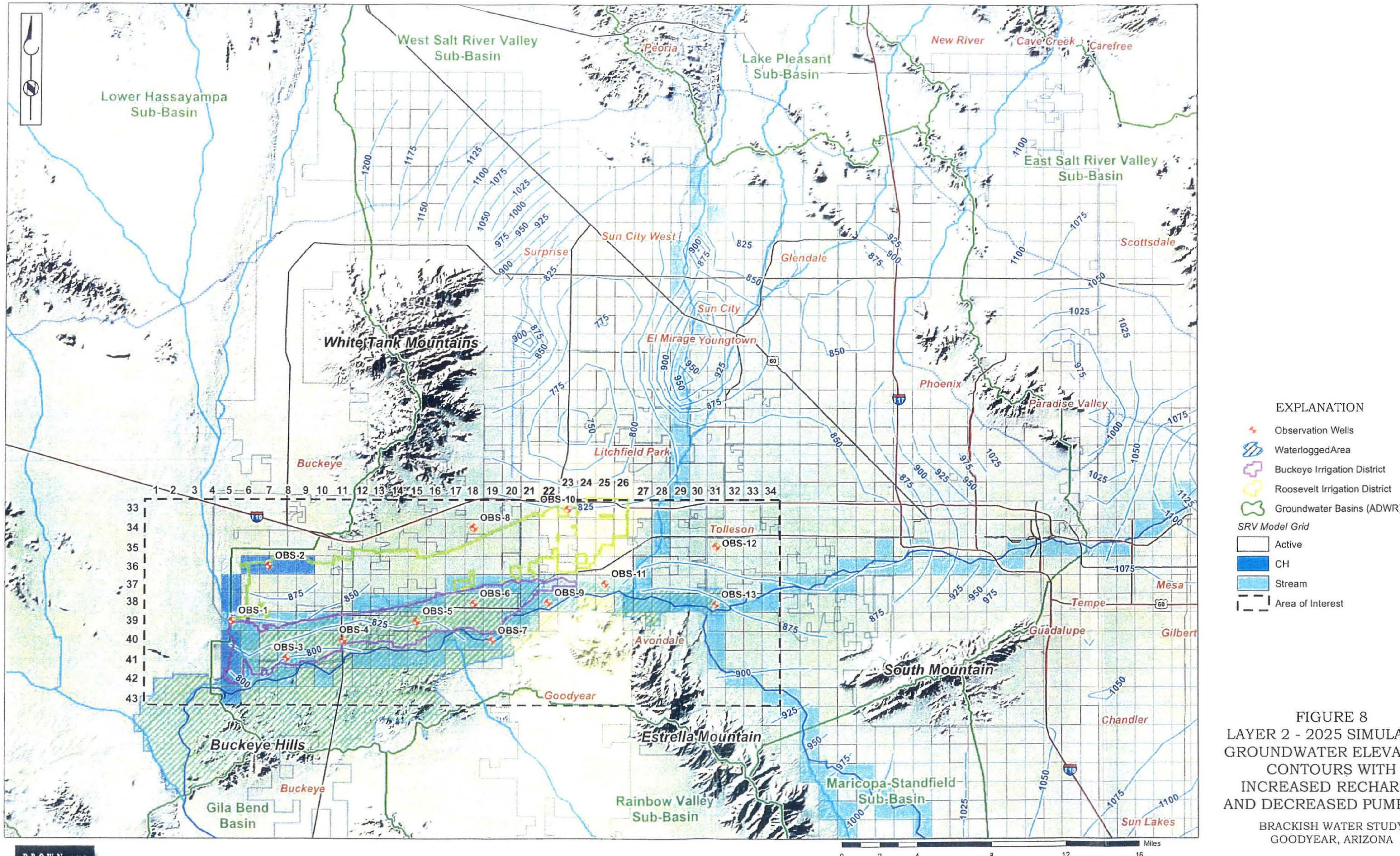
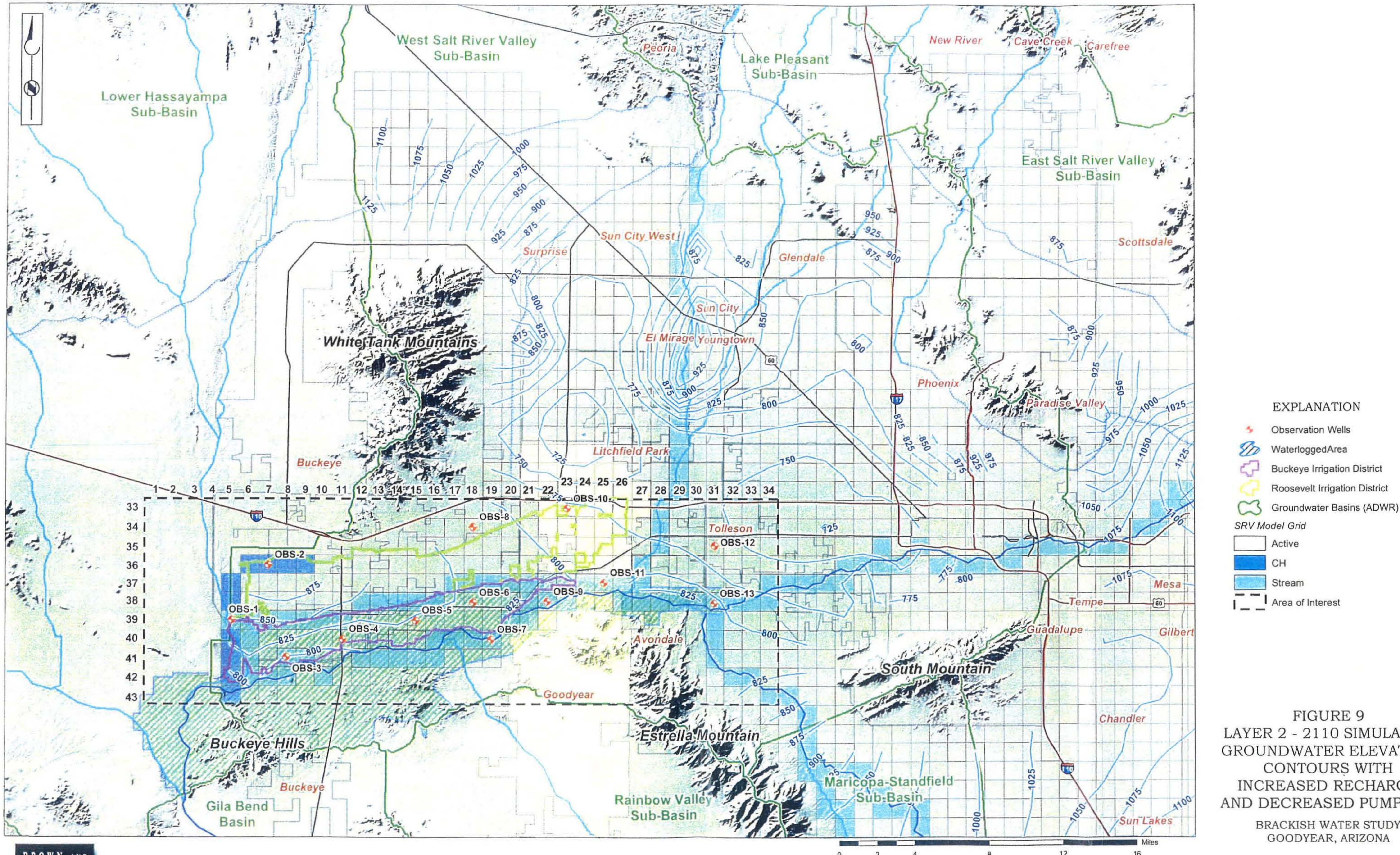


FIGURE 8
LAYER 2 - 2025 SIMULATED GROUNDWATER ELEVATION CONTOURS WITH INCREASED RECHARGE AND DECREASED PUMPING*

BRACKISH WATER STUDY
GOODYEAR, ARIZONA

BROWN AND CALDWELL

*Model for 2002 through 2110 uses 1996 pumping rates and 2002 recharge rates with the following two changes
1 107 5K added in recharge project from 2011 through 2110s. Aqua Fria 60K (10K in each cell 22,30 23,30. 24,30. 25,29. 26,29. and 27,29).
Litchfield Park 20K acre FT/year (5K in each cell 30,30; 30,31; 31,30: 31,31) and 3K near Phx-Litchfield II (cell 34 24)· 5,750 to 18.18 and 19,18 11 5K total. and 13K to 24, 13
2 Reduced pumping by half (~43K) in the general RID-BIC area from 2011 through 2110



BROWN AND CALDWELL

FIGURE 9
LAYER 2 - 2110 SIMULATED GROUNDWATER ELEVATION CONTOURS WITH INCREASED RECHARGE AND DECREASED PUMPING*

BRACKISH WATER STUDY
GOODYEAR, ARIZONA

*Model for 2002 through 2110 uses 1996 pumping rates and 2002 recharge rates with the following two changes
1. 107.5K added in recharge project from 2011 through 2110s. Aqua Fria 60K (10K in each cell 22,30, 23,30: 24,30 25,29, 26,29, and 27,29).
Litchfield Park 20K acre FT/year (5K in each cell 30,30; 30,31; 31,30, 31,31) and 3K near Phx-Litchfield II (cell 34, 24), 5,750 to 18,18 and 19,18 11 5K total; and 13K to 24, 13
2 Reduced pumping by half (~43K) in the general RID-BIC area from 2011 through 2110.

Figure 10. Obs-1

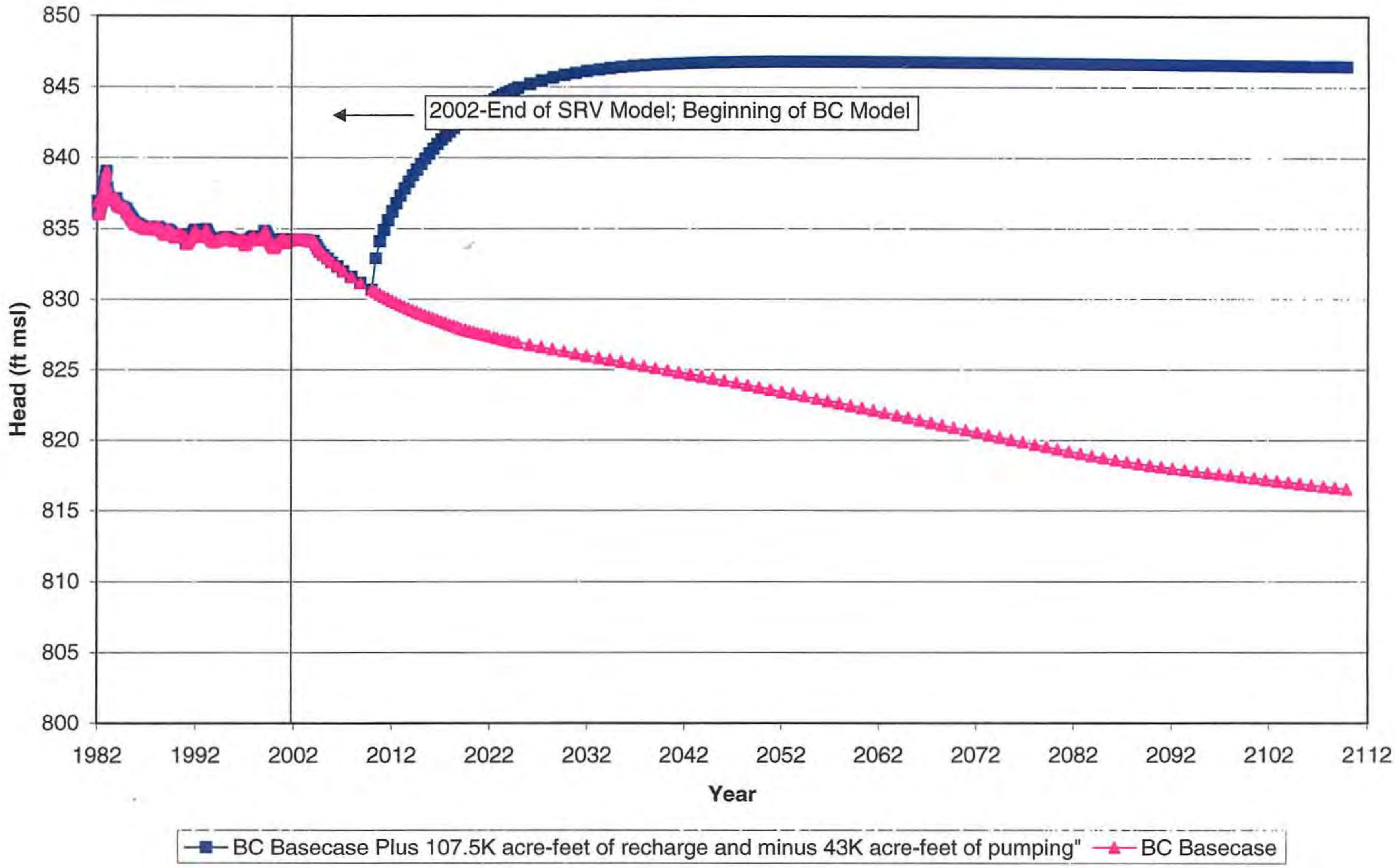


Figure 11. Obs-2

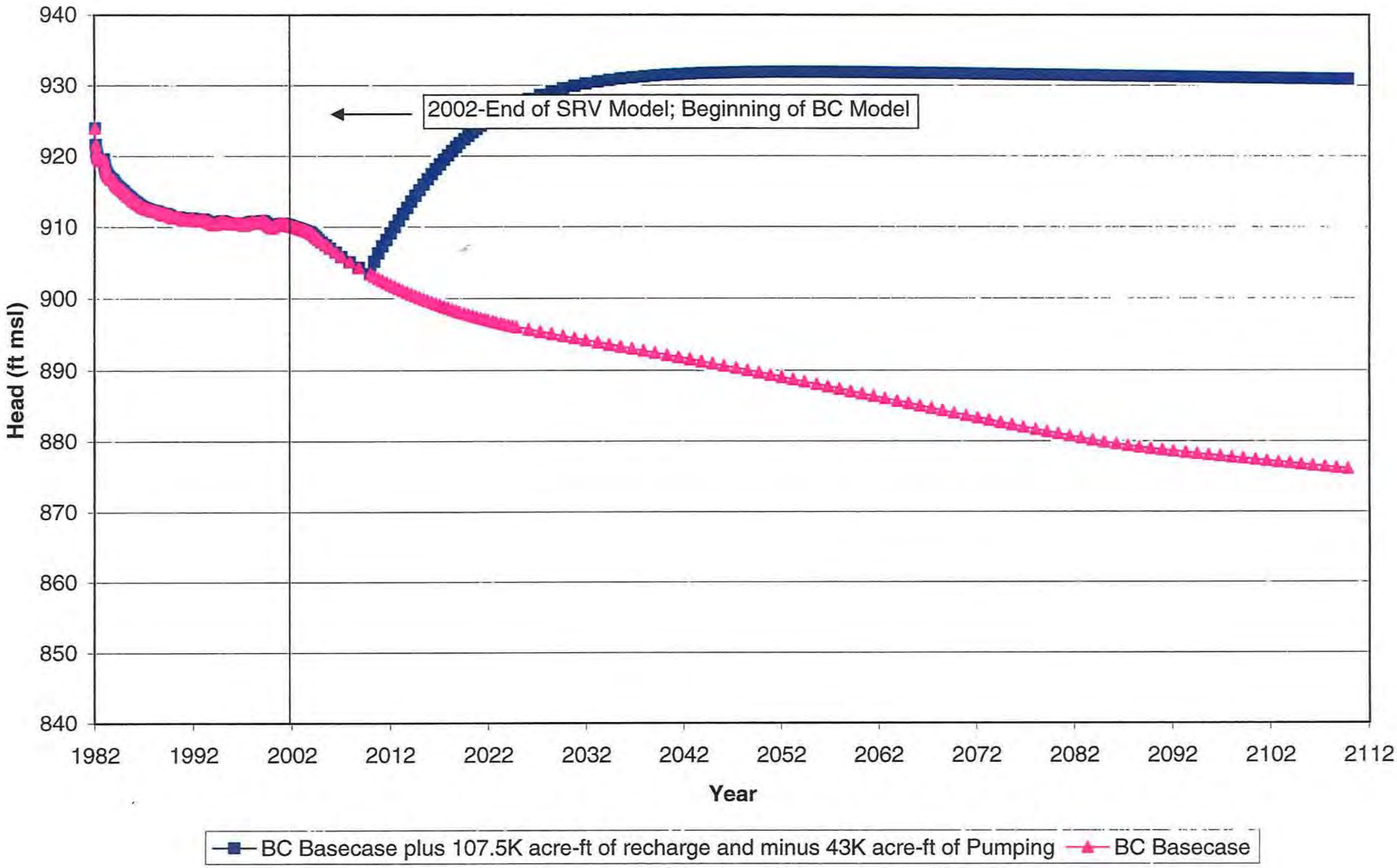


Figure 11. Obs-2

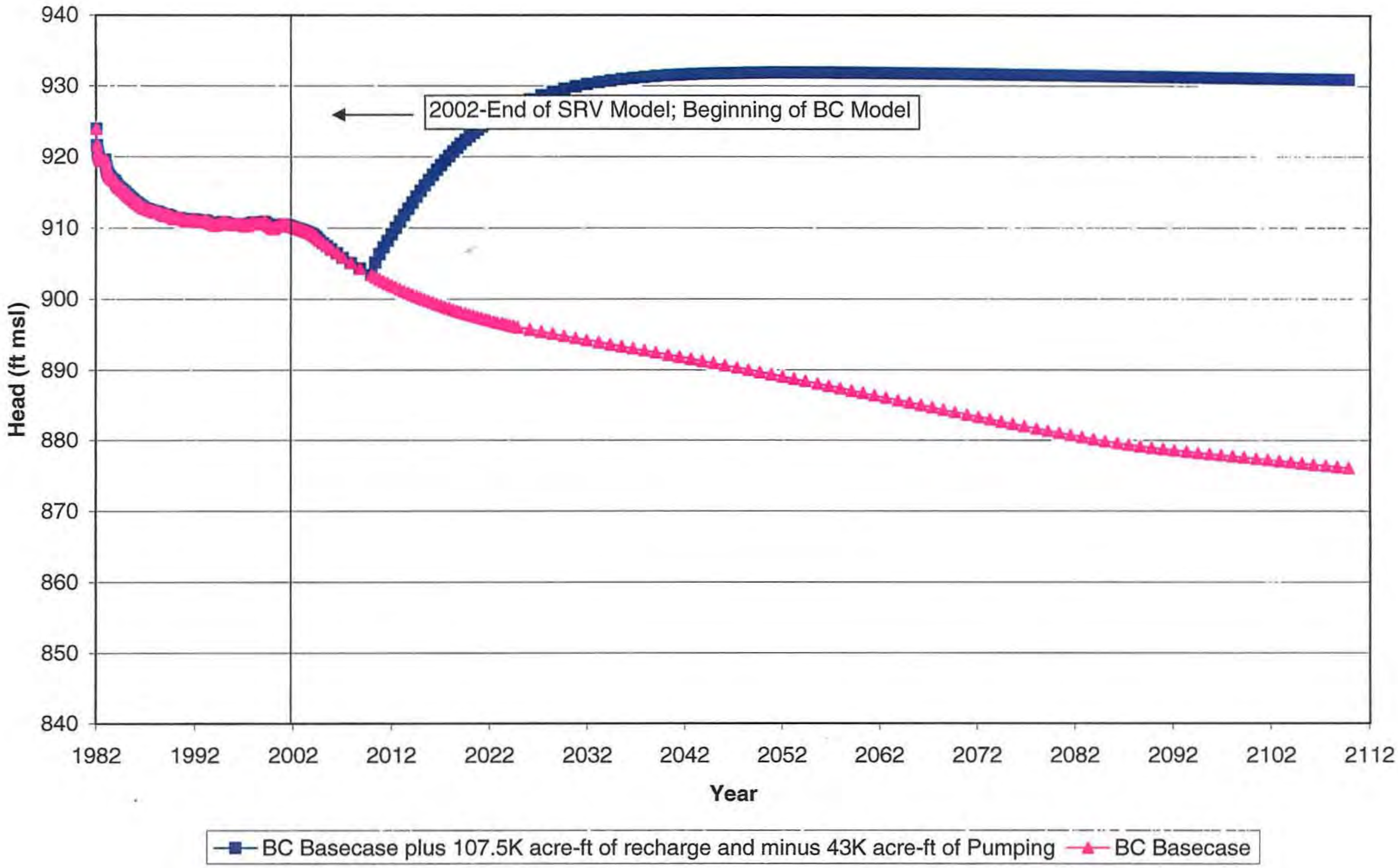


Figure 12. Obs-3

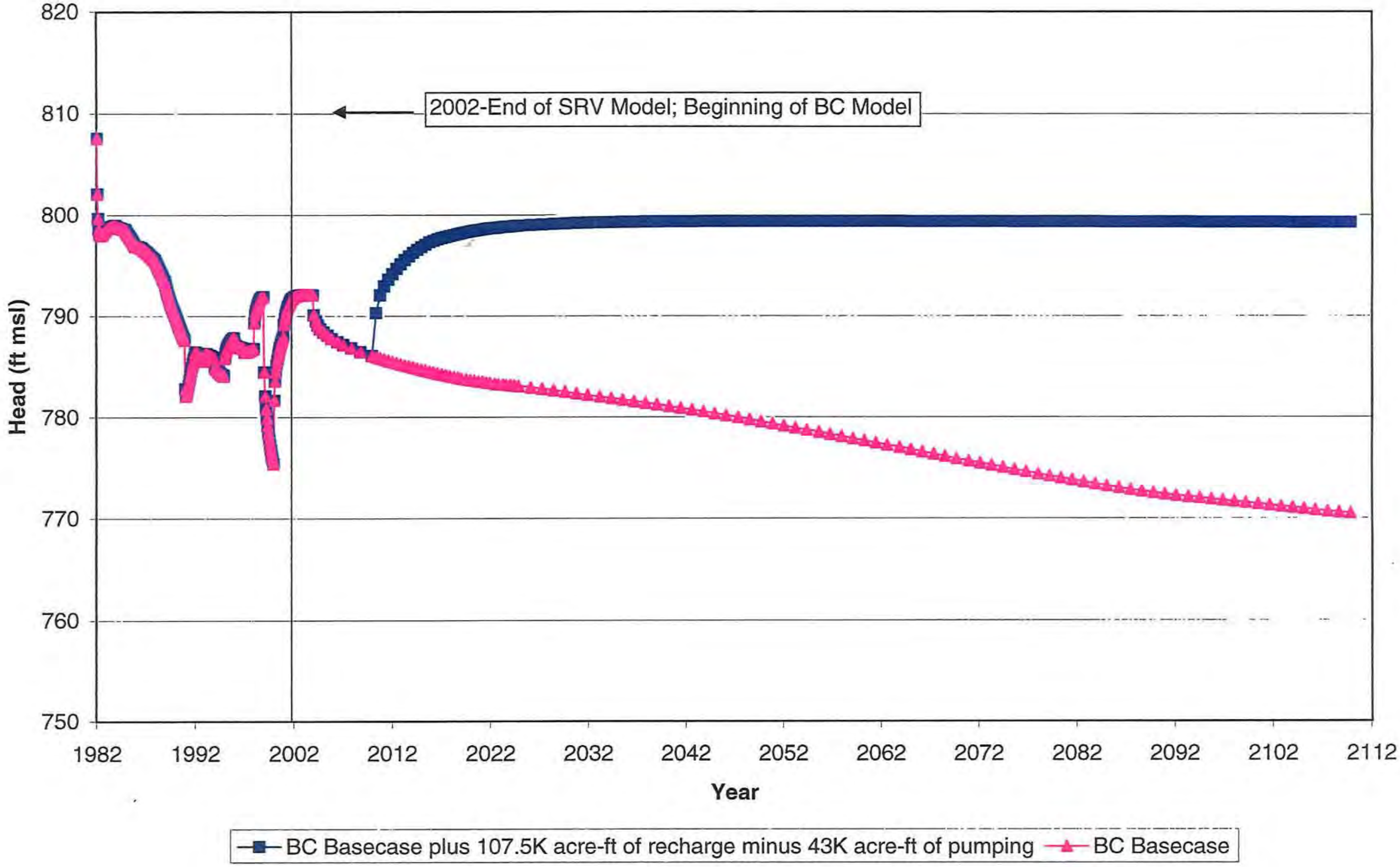


Figure 13. Obs-4

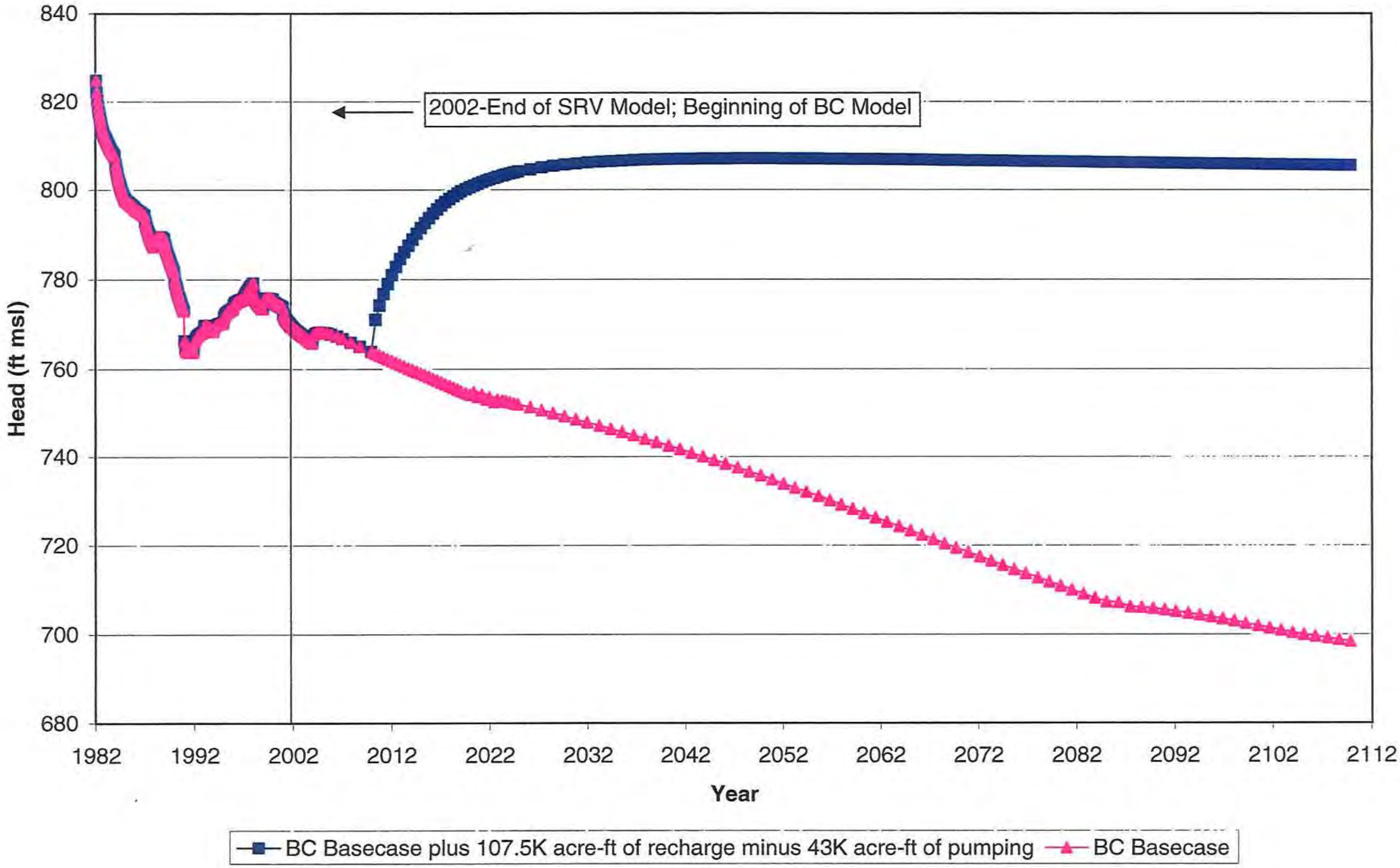


Figure 14. Obs-5

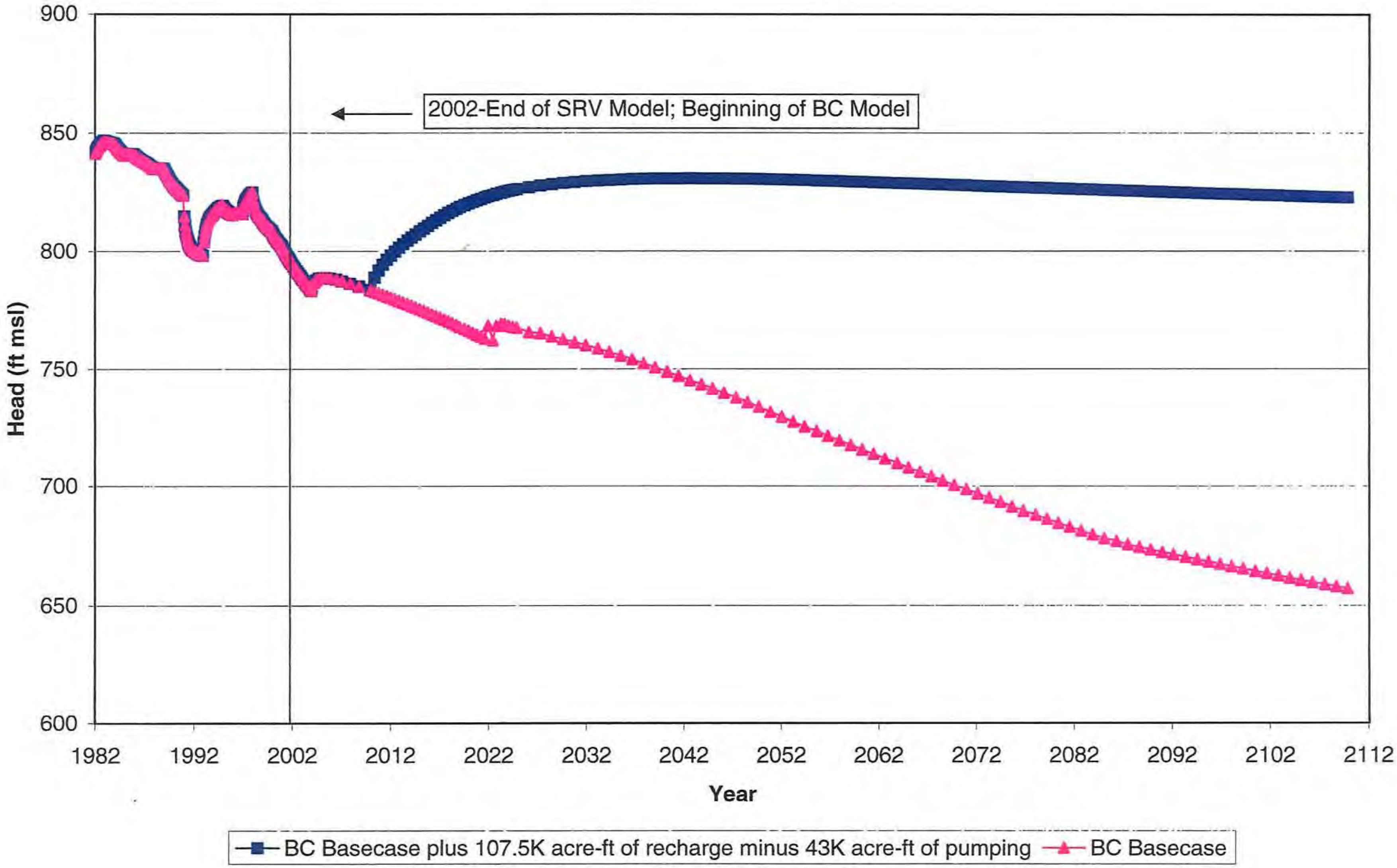


Figure 15. Obs-6

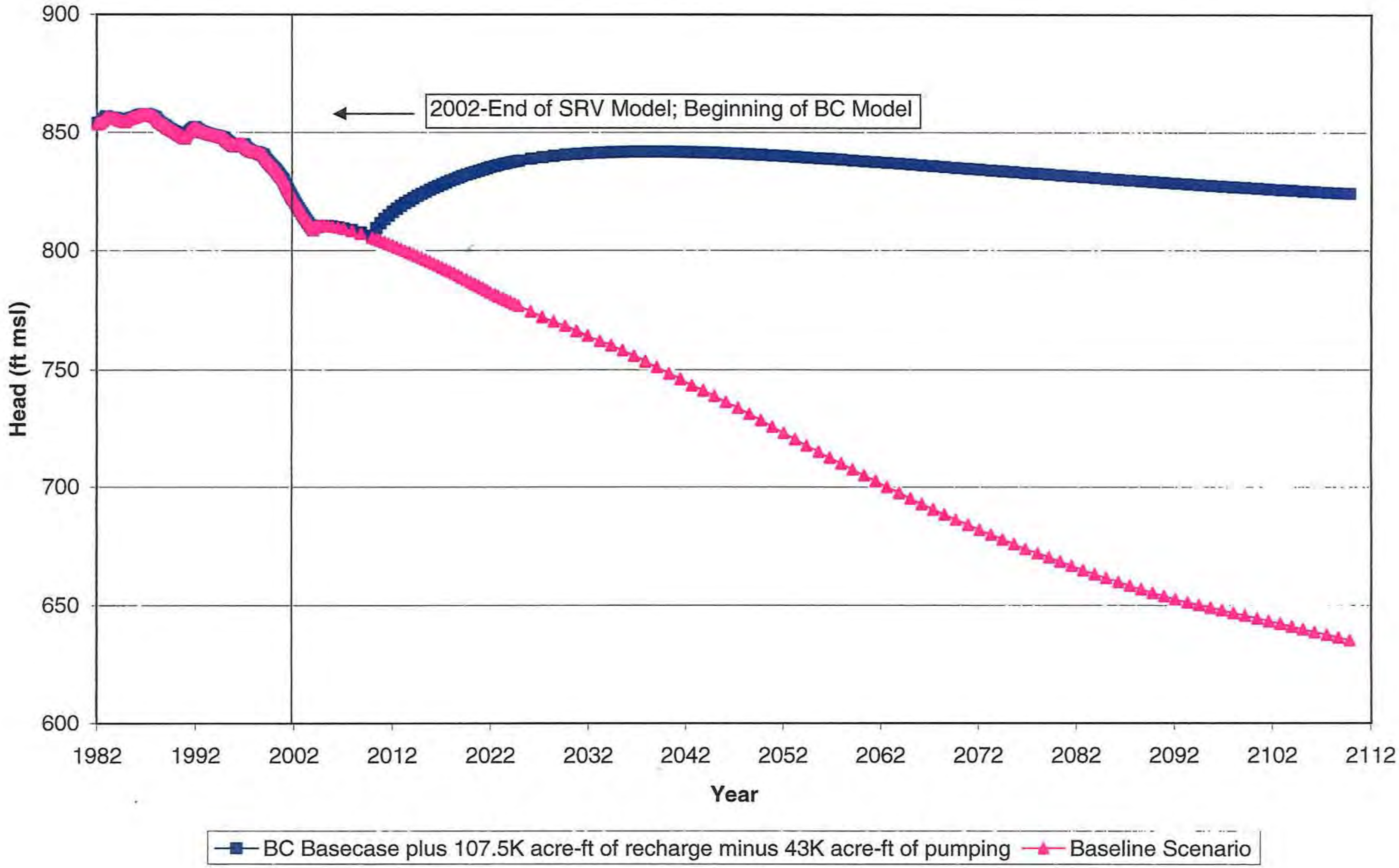


Figure 16. Obs-7

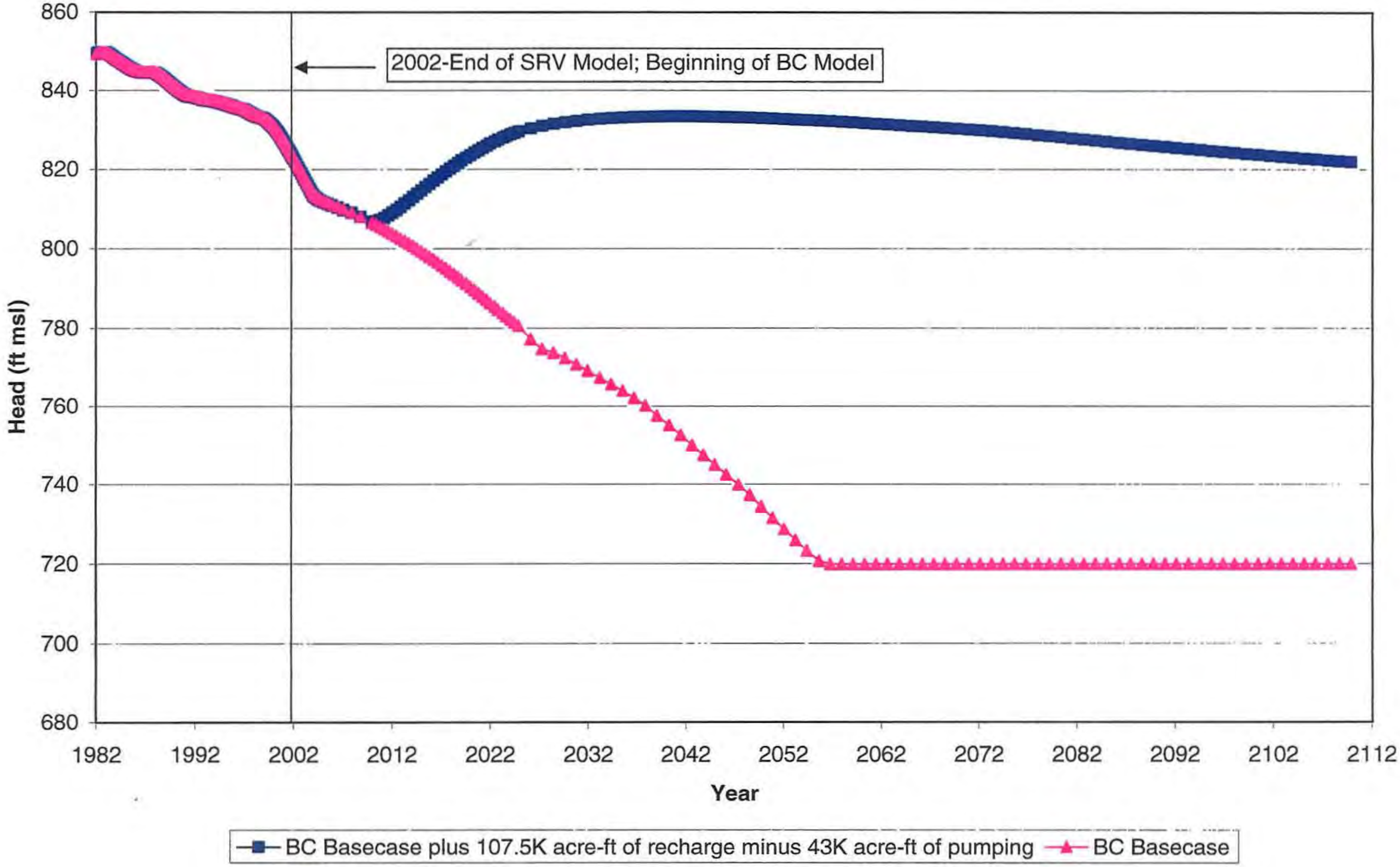


Figure 17. Obs-8

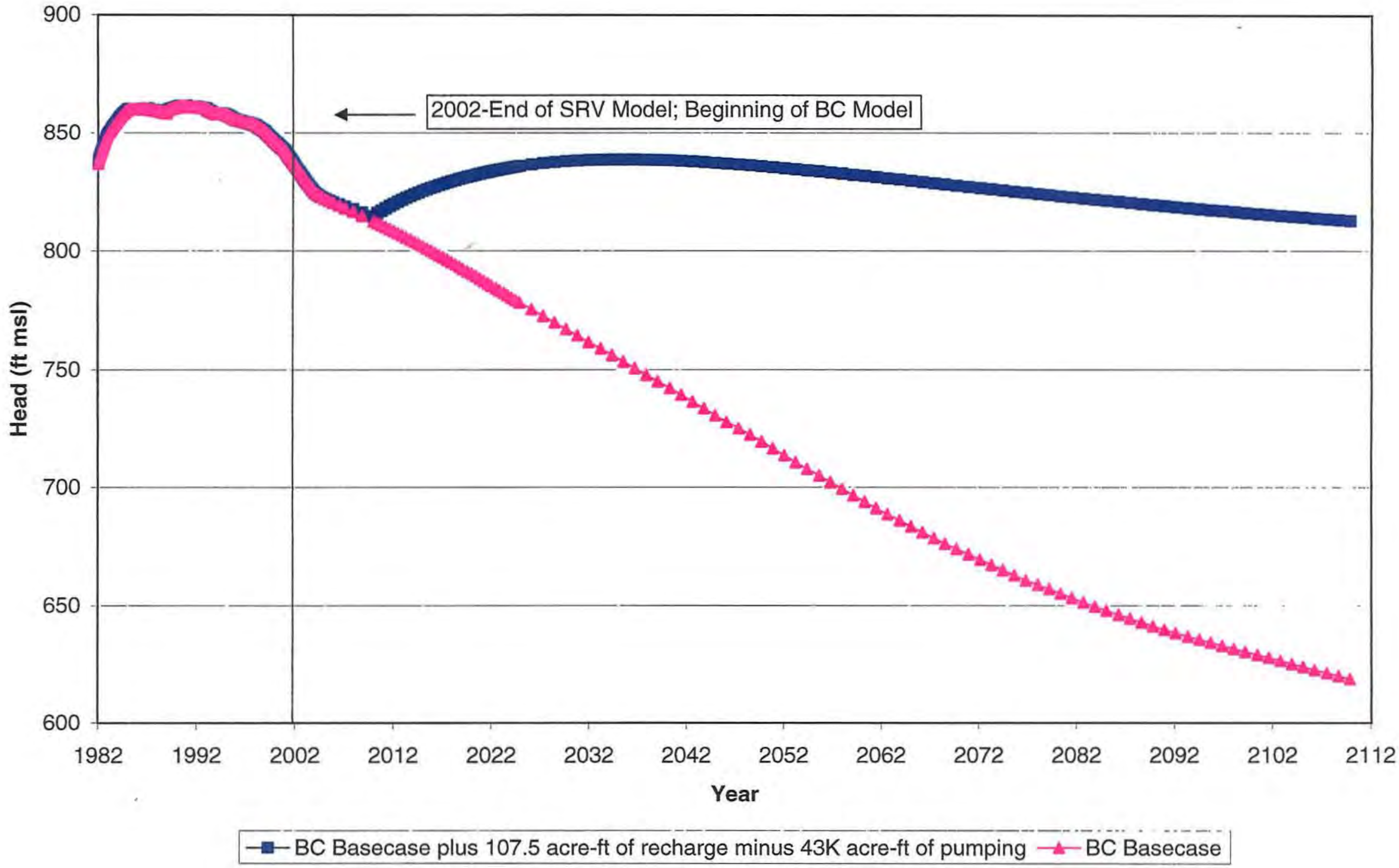


Figure 18. Obs-9

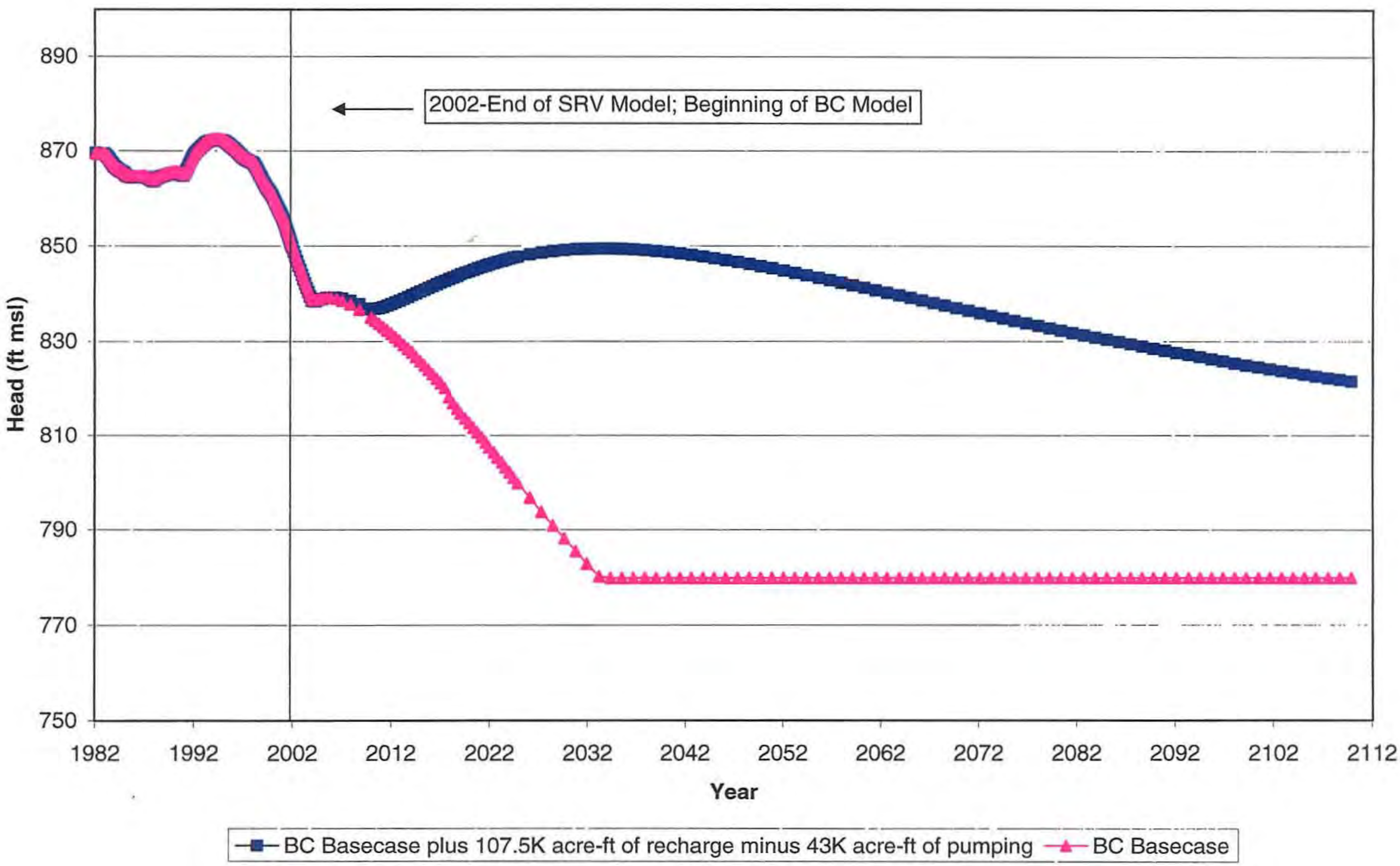


Figure 19. Obs-10

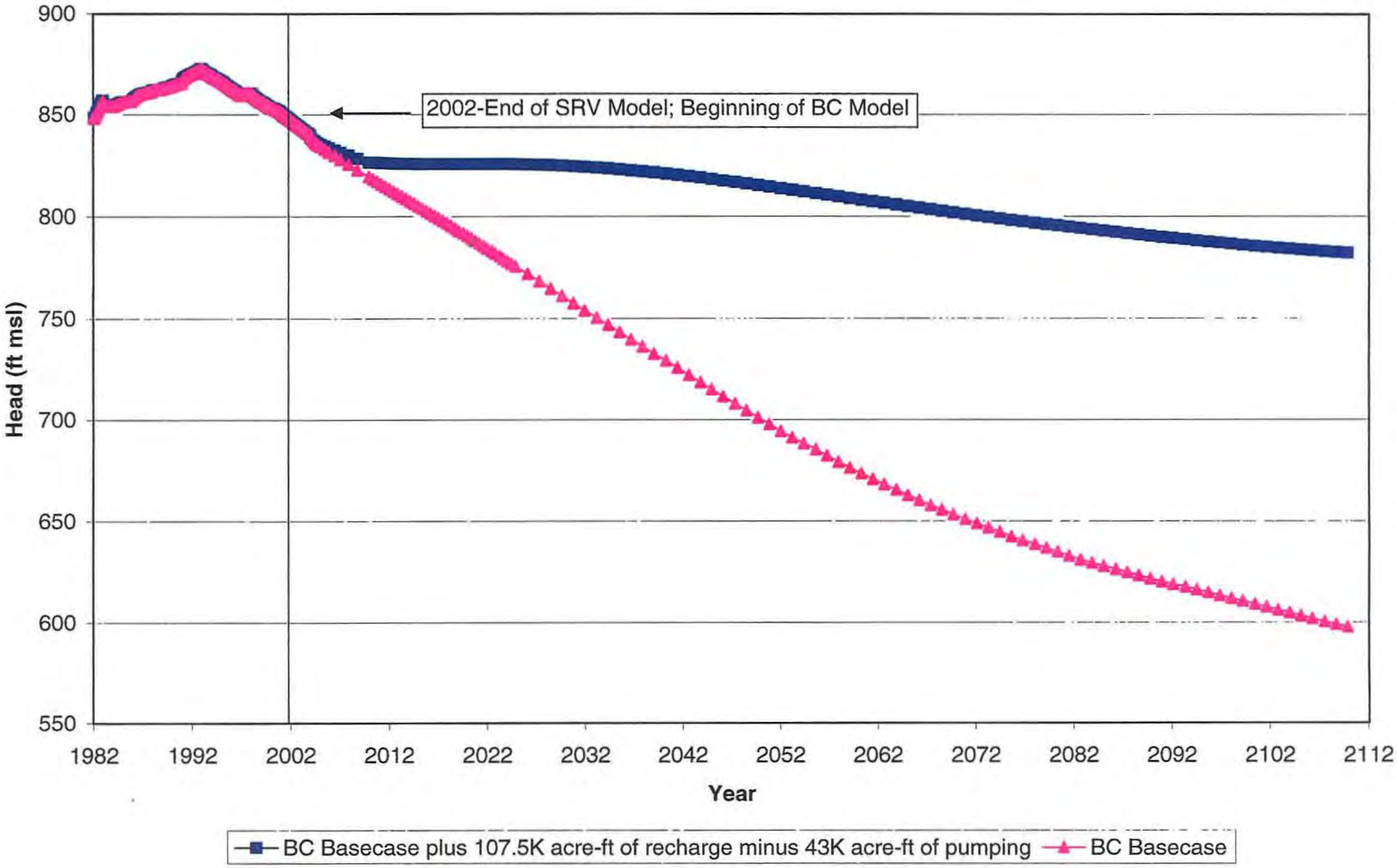


Figure 20. Obs-11

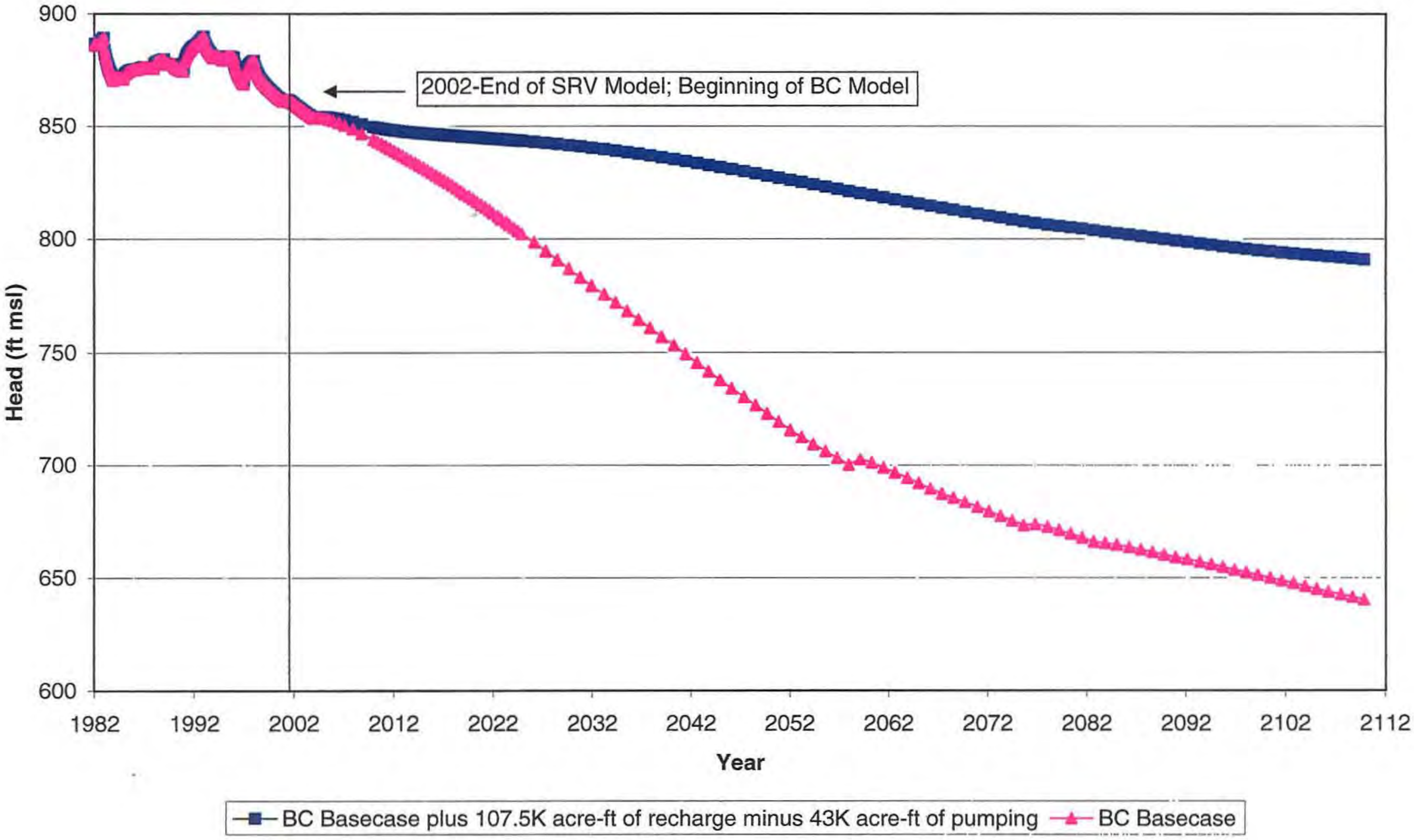


Figure 21. Obs-12

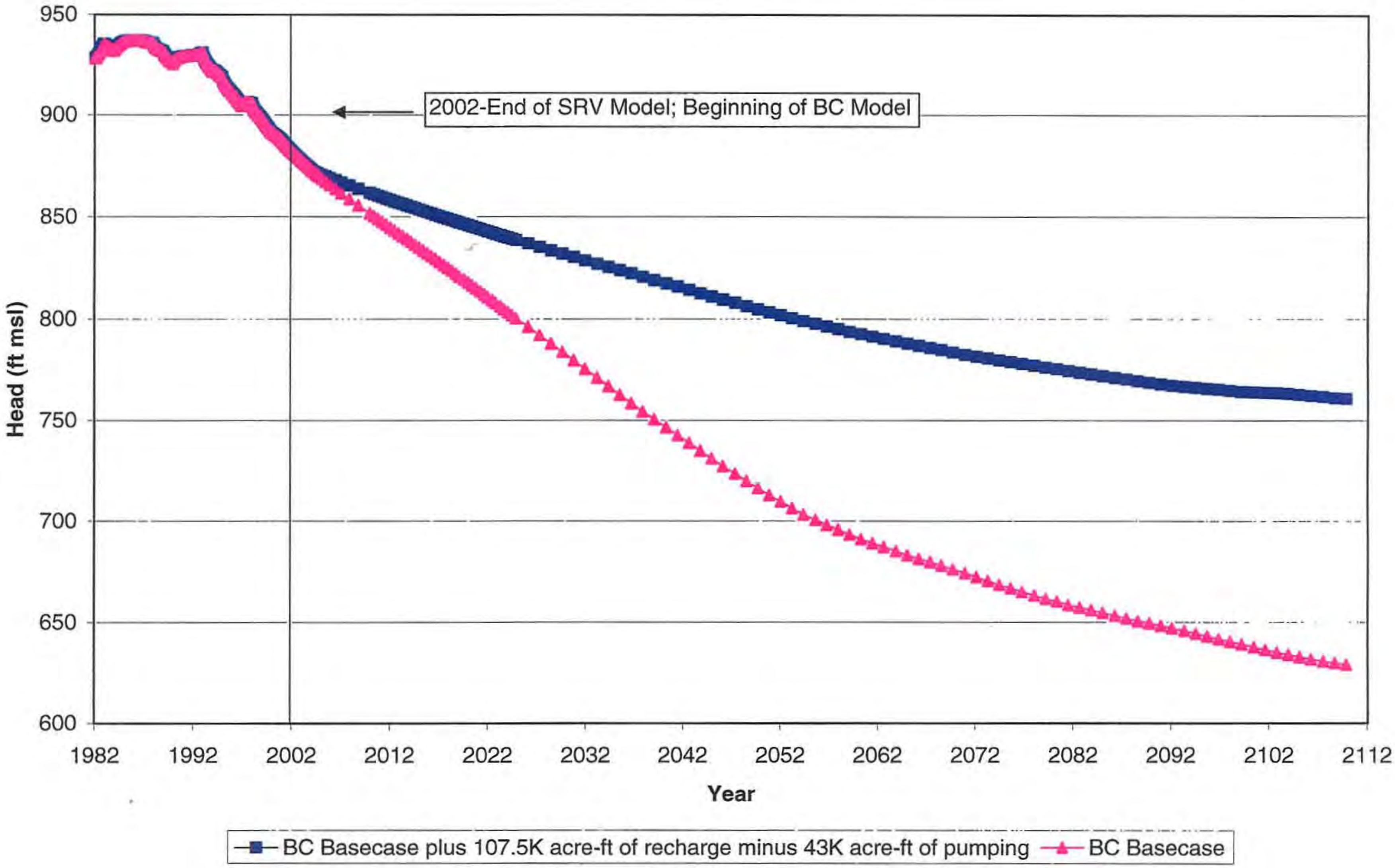
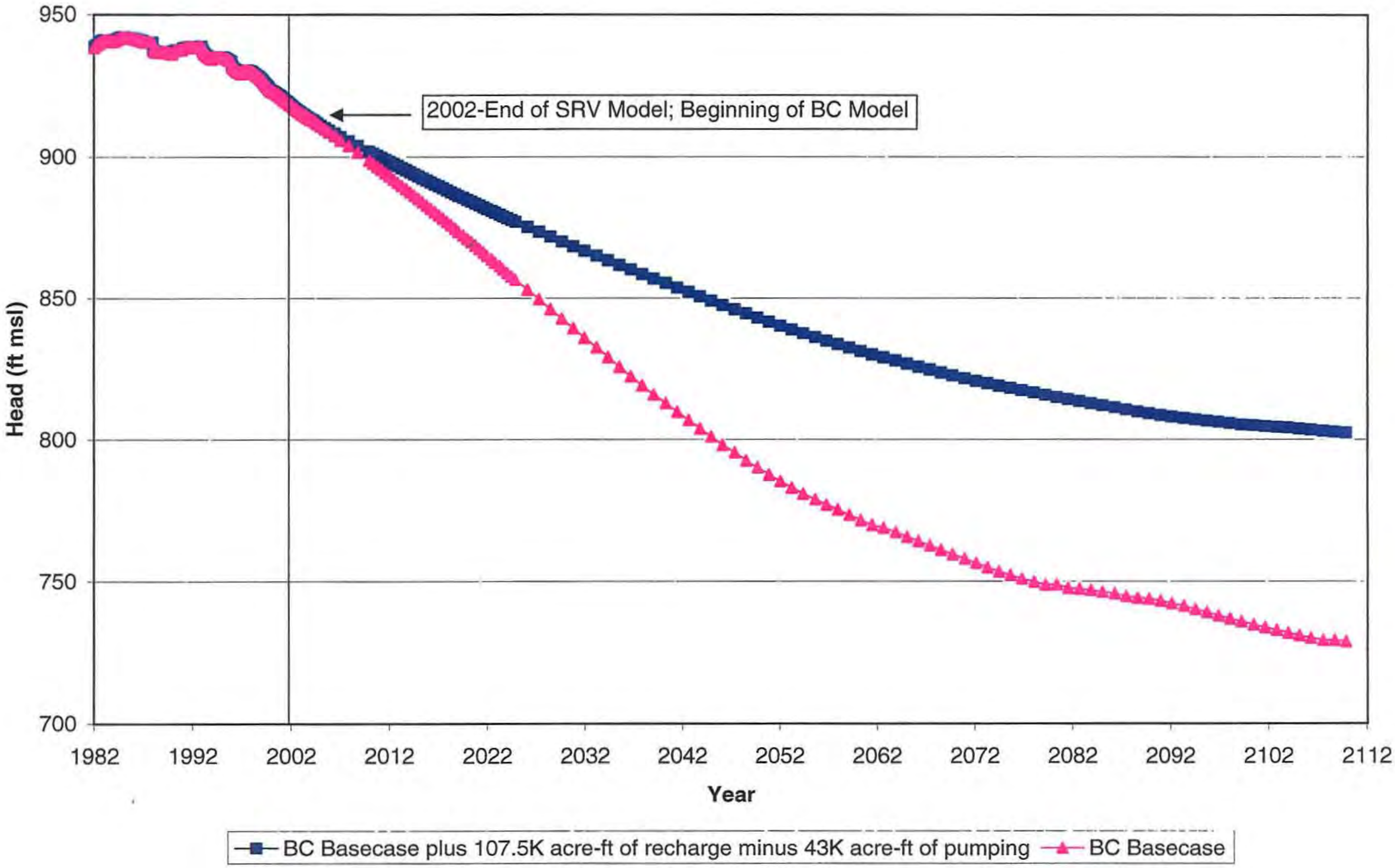


Figure 22. Obs-13



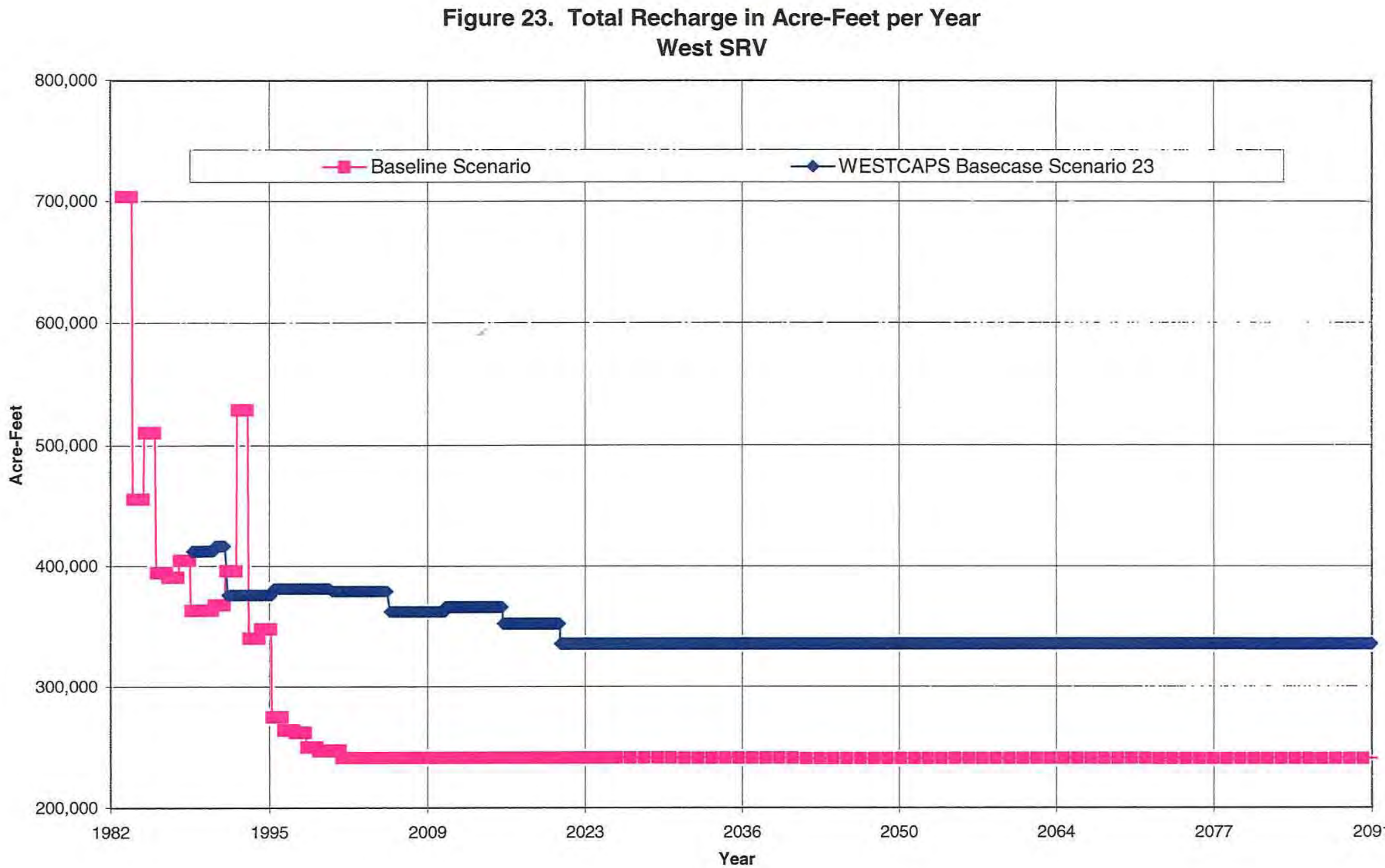


Figure 23. Total Recharge in Acre-Feet per Year
West SRV
Baseline Scenario
WESTCAPS Basecase Scenario 23
800,000
700,000
600,000
500,000
400,000
300,000
200,000
Acre-Feet
1982
1995
2009
2023
2036
2050
2064
2077
2091
Year

Figure 24. Total Cumulative Recharge in Acre-Feet
West SRV

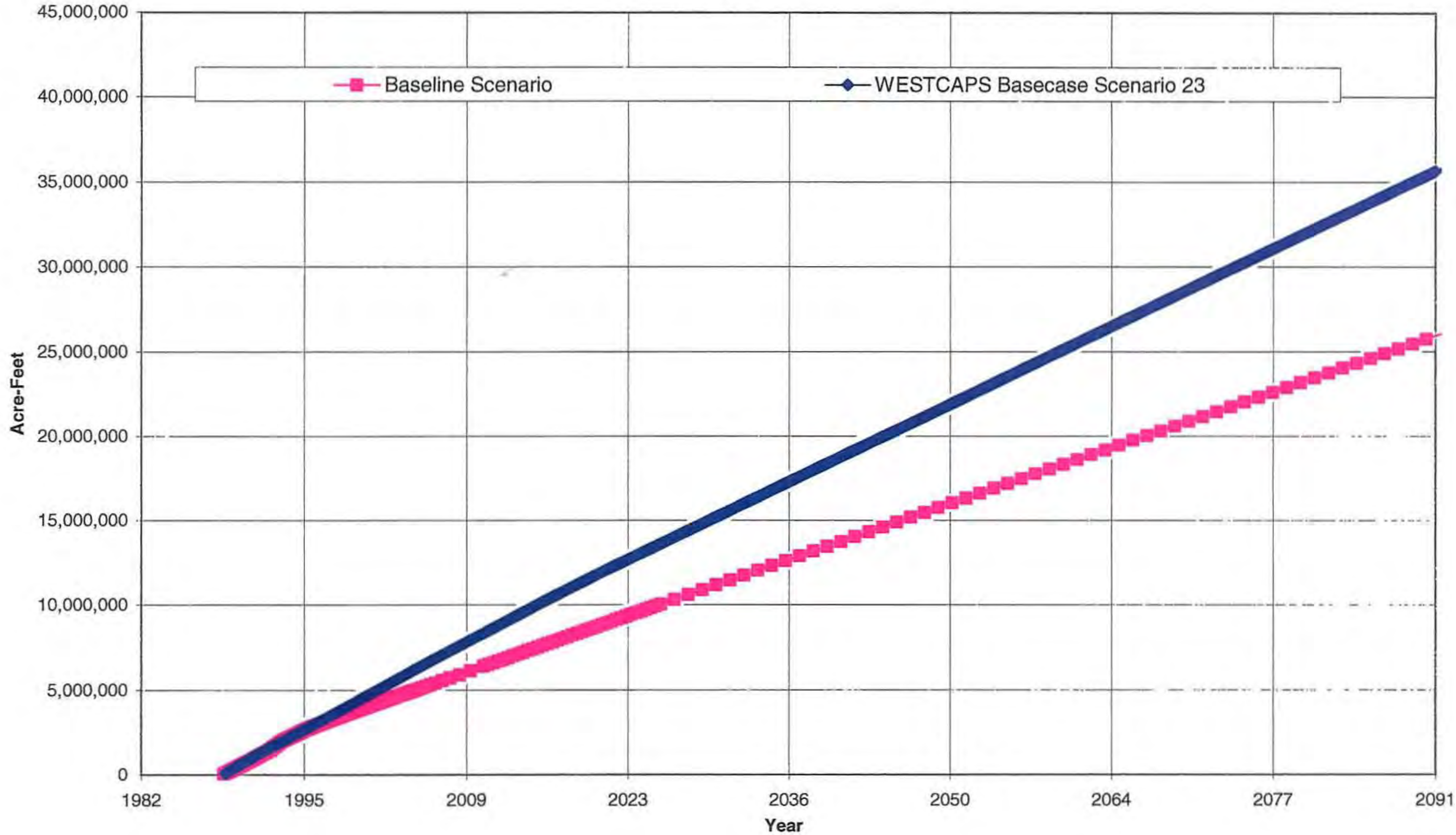


Figure 25. Total Pumpage in Acre-Feet per Year
West SRV

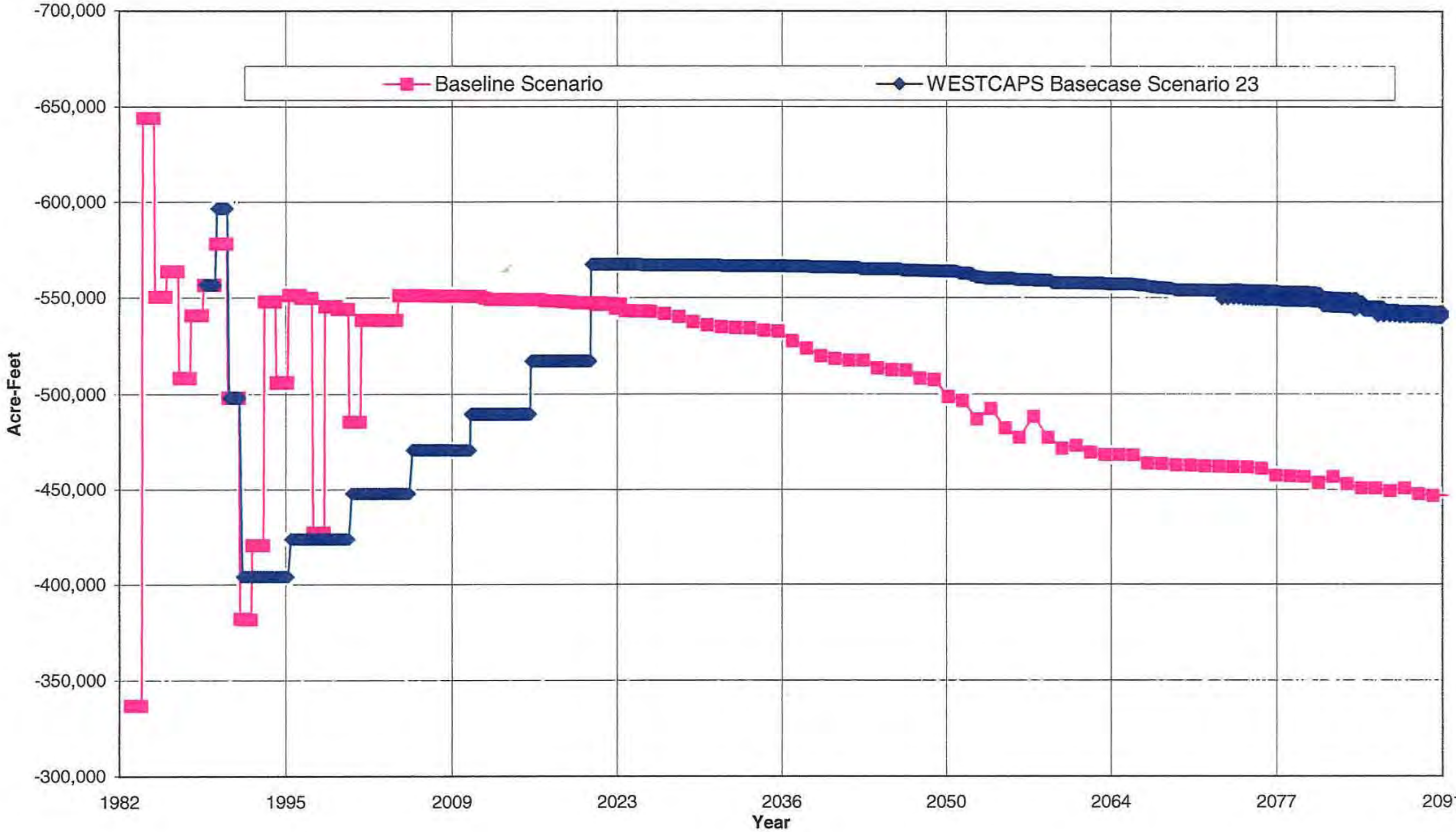


**Figure 26. Total Cumulative Pumping in Acre-Feet
West SRV**

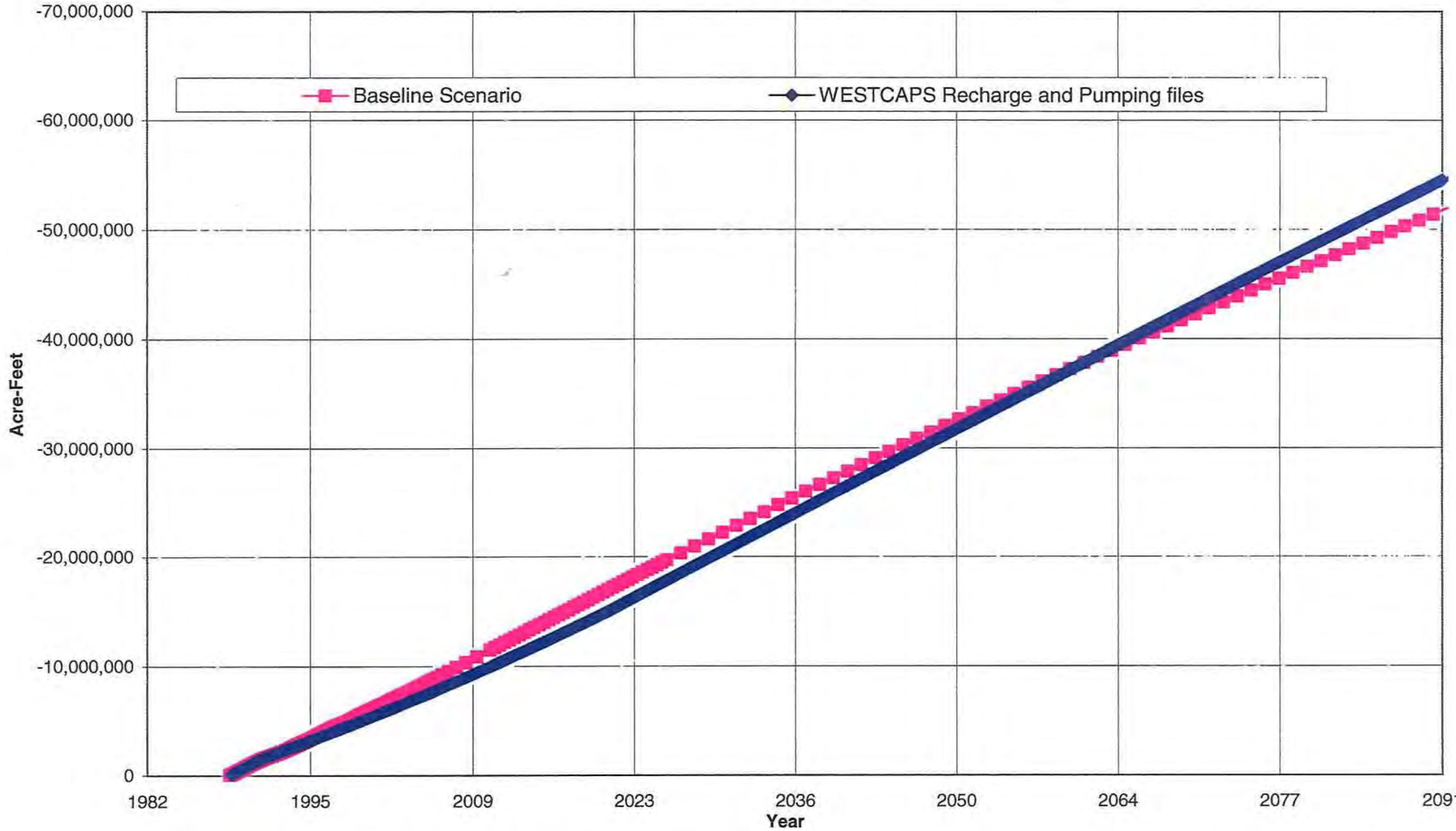


Figure 27. Total Recharge in Acre-Feet per Year
Area of Interest

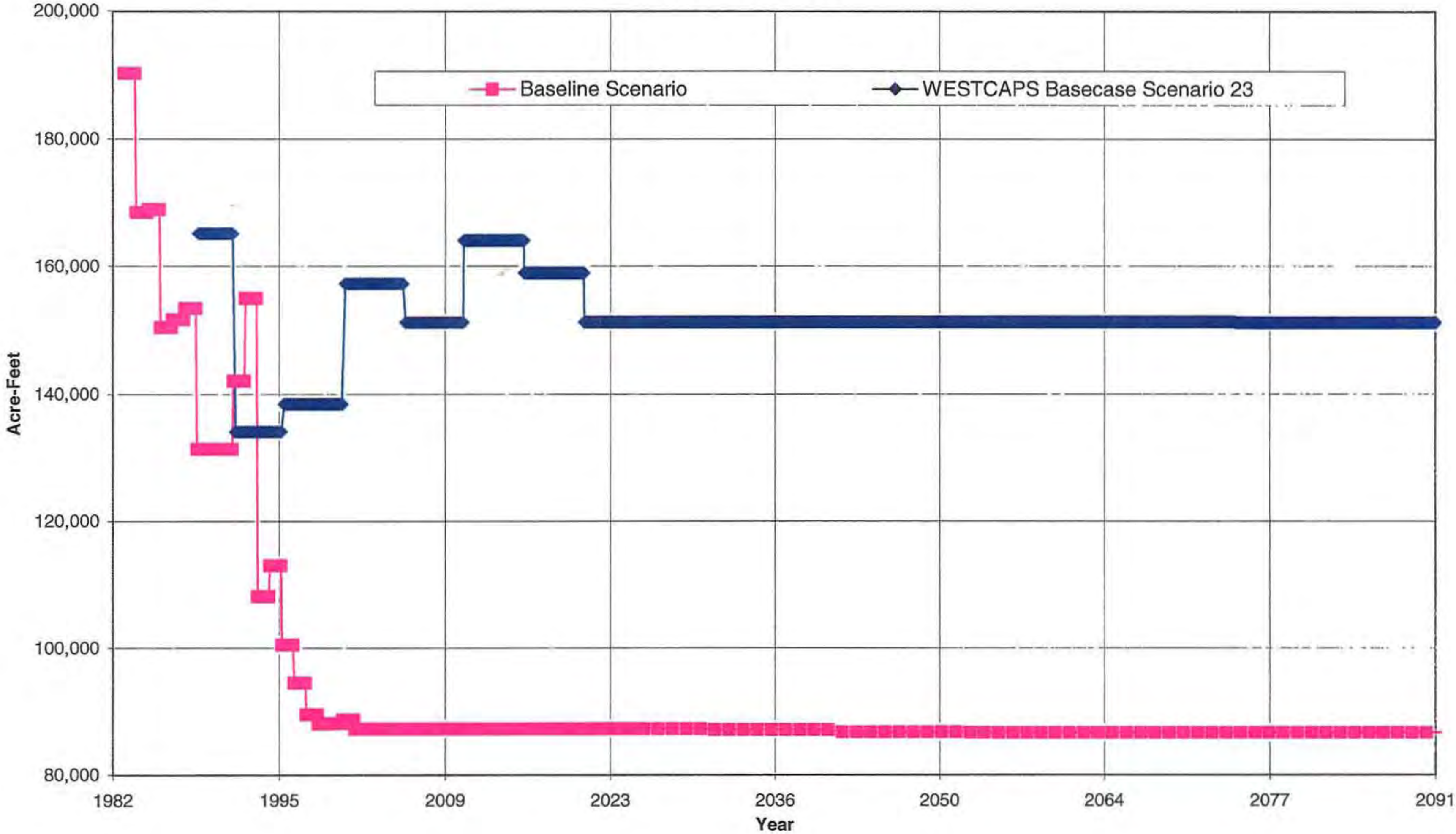
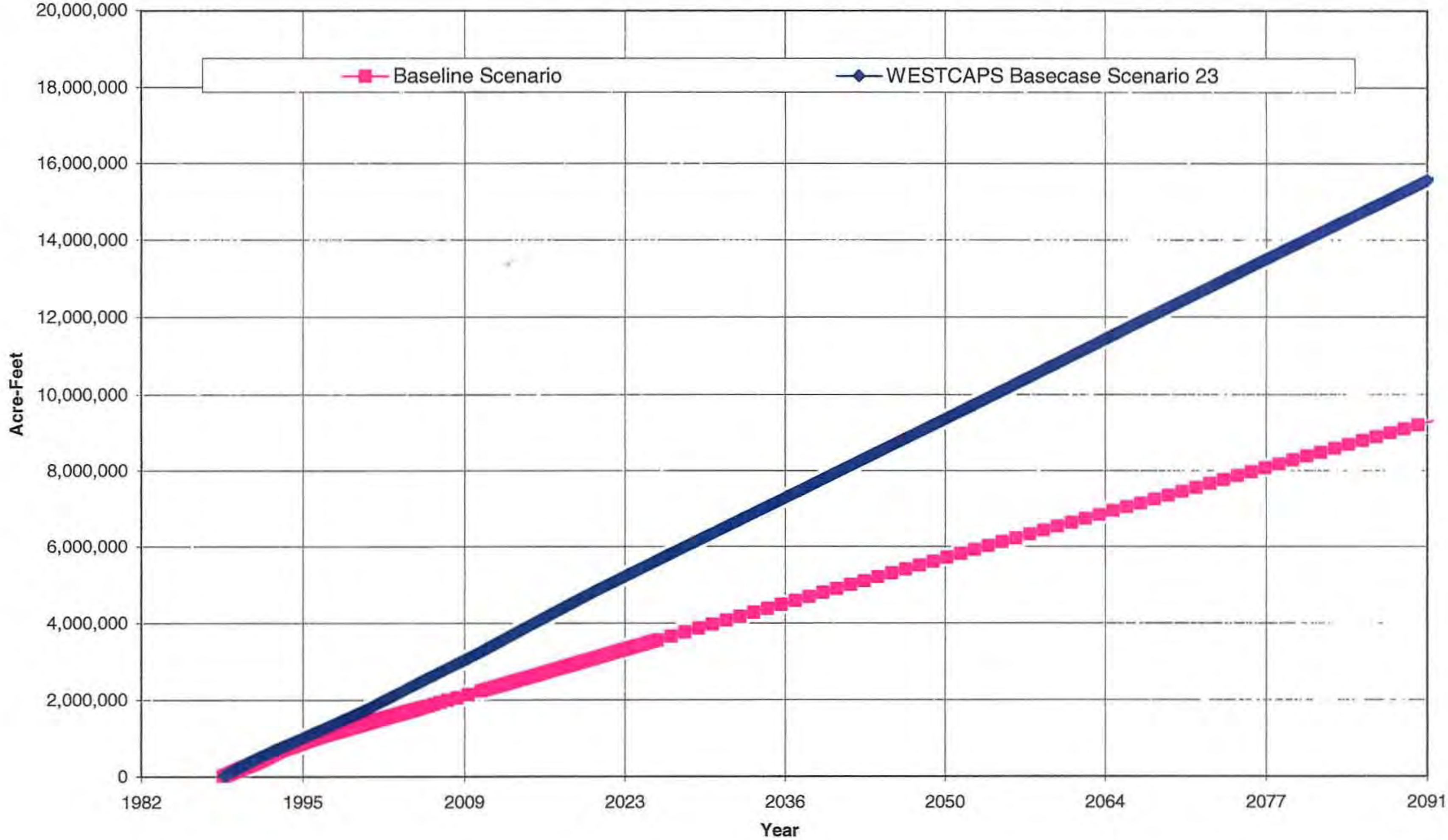


**Figure 28. Total Cumulative Recharge in Acre-Feet
Area of Interest**



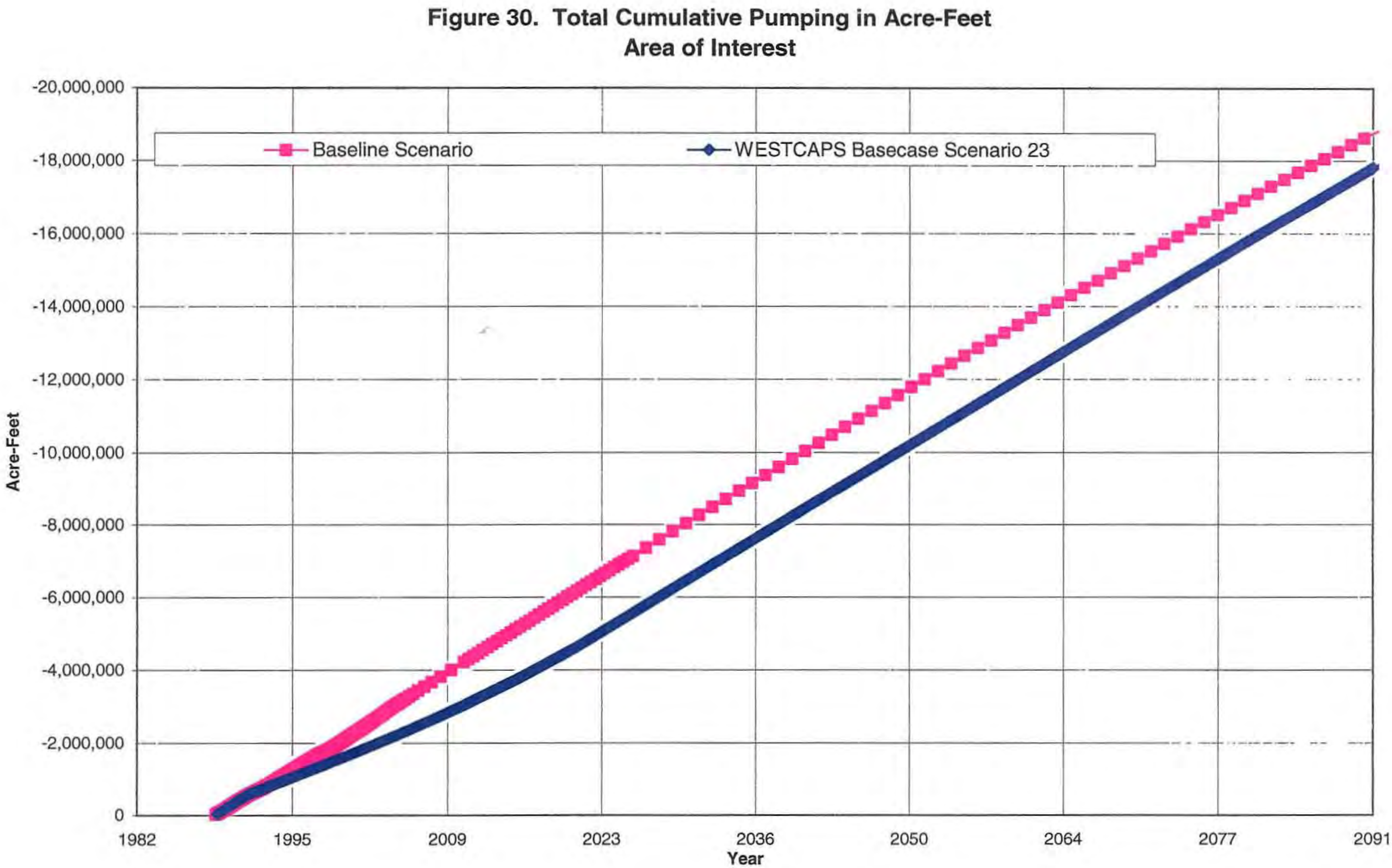


Figure 30. Total Cumulative Pumping in Acre-Feet
Area of Interest
Baseline Scenario
WESTCAPS Basecase Scenario 23
-20,000,000
-18,000,000
-16,000,000
-14,000,000
-12,000,000
-10,000,000
-8,000,000
-6,000,000
-4,000,000
-2,000,000
0
Acre-Feet
1982
1995
2009
2023
2036
2050
2064
2077
2091
Year

Figure 31. Total Annual Streamflow

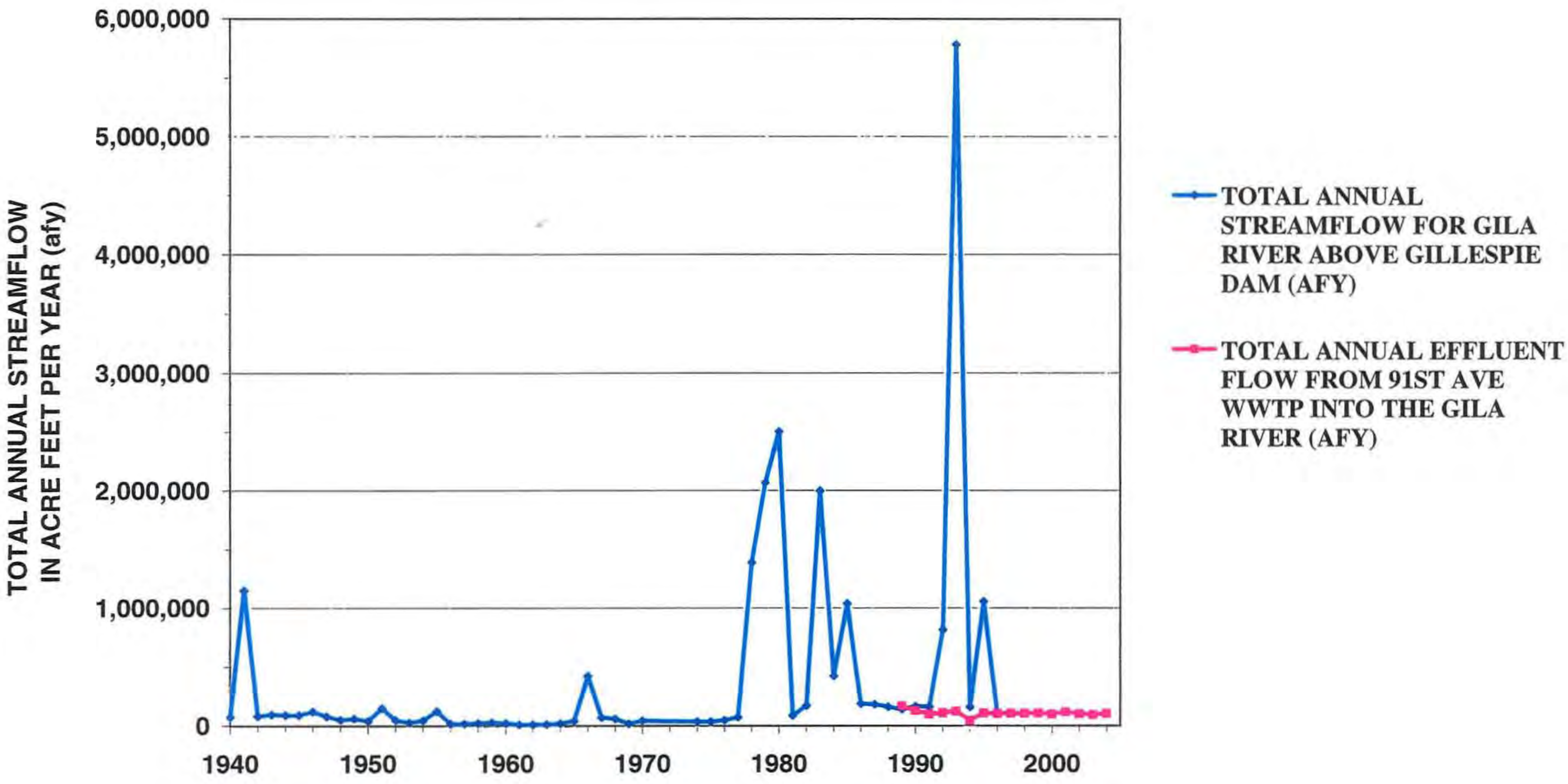
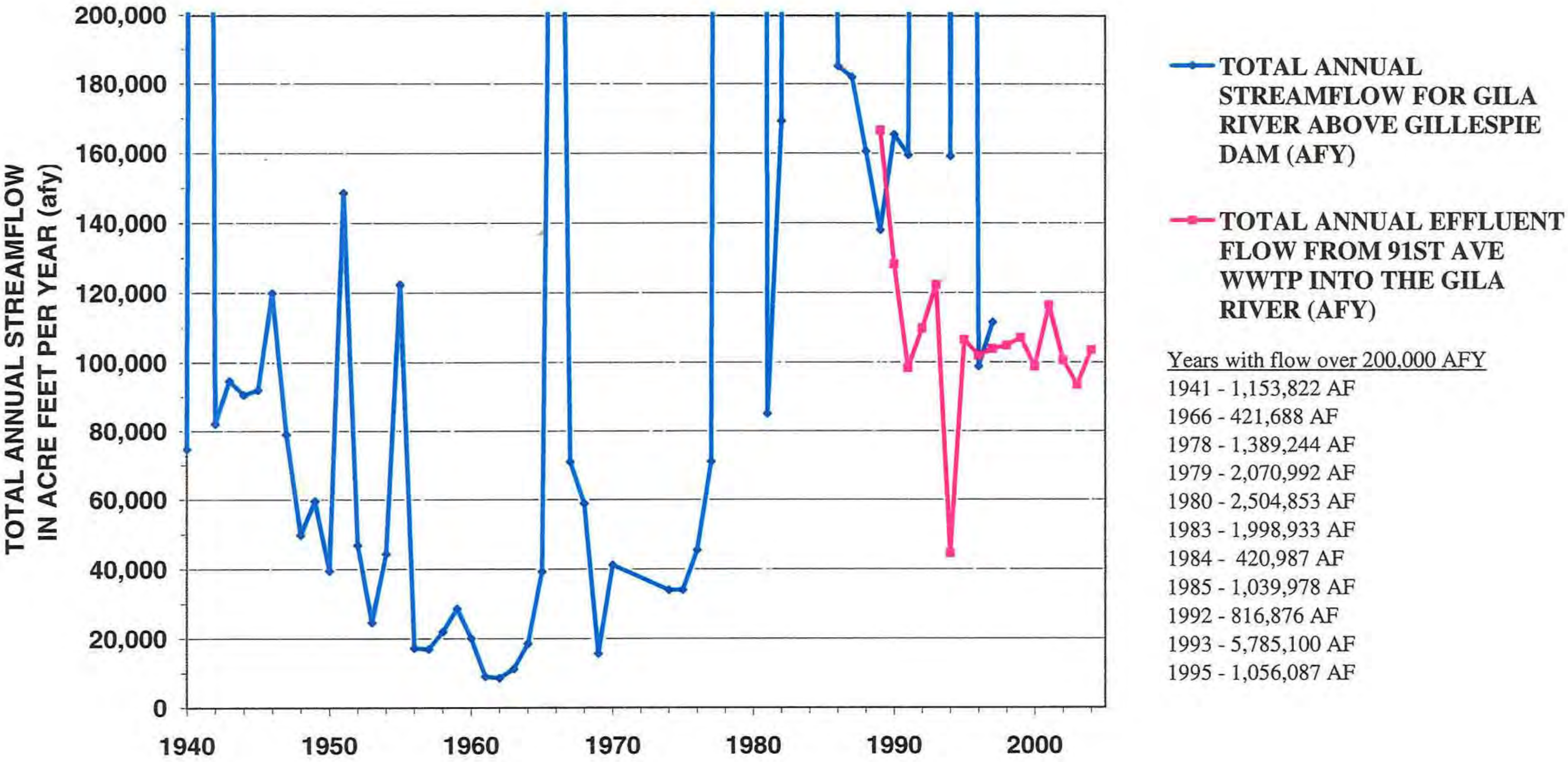
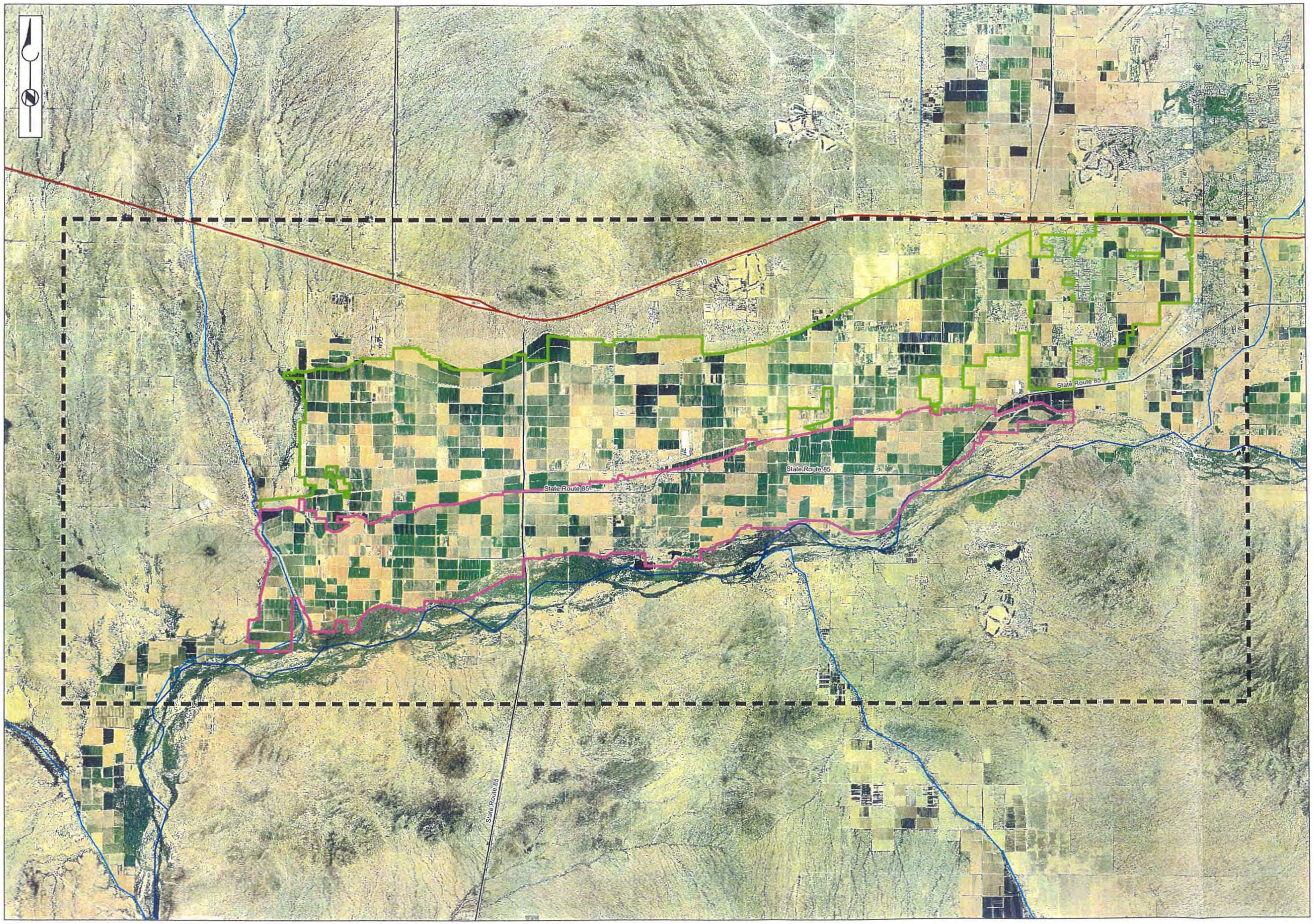


Figure 32. Total Annual Streamflow



Years with flow over 200,000 AFY
1941 - 1,153,822 AF
1966 - 421,688 AF
1978 - 1,389,244 AF
1979 - 2,070,992 AF
1980 - 2,504,853 AF
1983 - 1,998,933 AF
1984 - 420,987 AF
1985 - 1,039,978 AF
1992 - 816,876 AF
1993 - 5,785,100 AF
1995 - 1,056,087 AF



EXPLANATION

Buckeye Irrigation District

Roosevelt Irrigation District

Area of Interest

0 0.5 1 2 3 4 Miles

FIGURE 33
LOCATION OF THE
AREA OF INTEREST (AOI)

BRACKISH WATER STUDY
GOODYEAR, ARIZONA

BROWN AND CALDWELL

BCTUC01| T:\BC_PHX\Goodyear_City_of\26555_Brackish_Water_Study\GIS\ARCMAPS\WORKING\POSTER_33.mxd

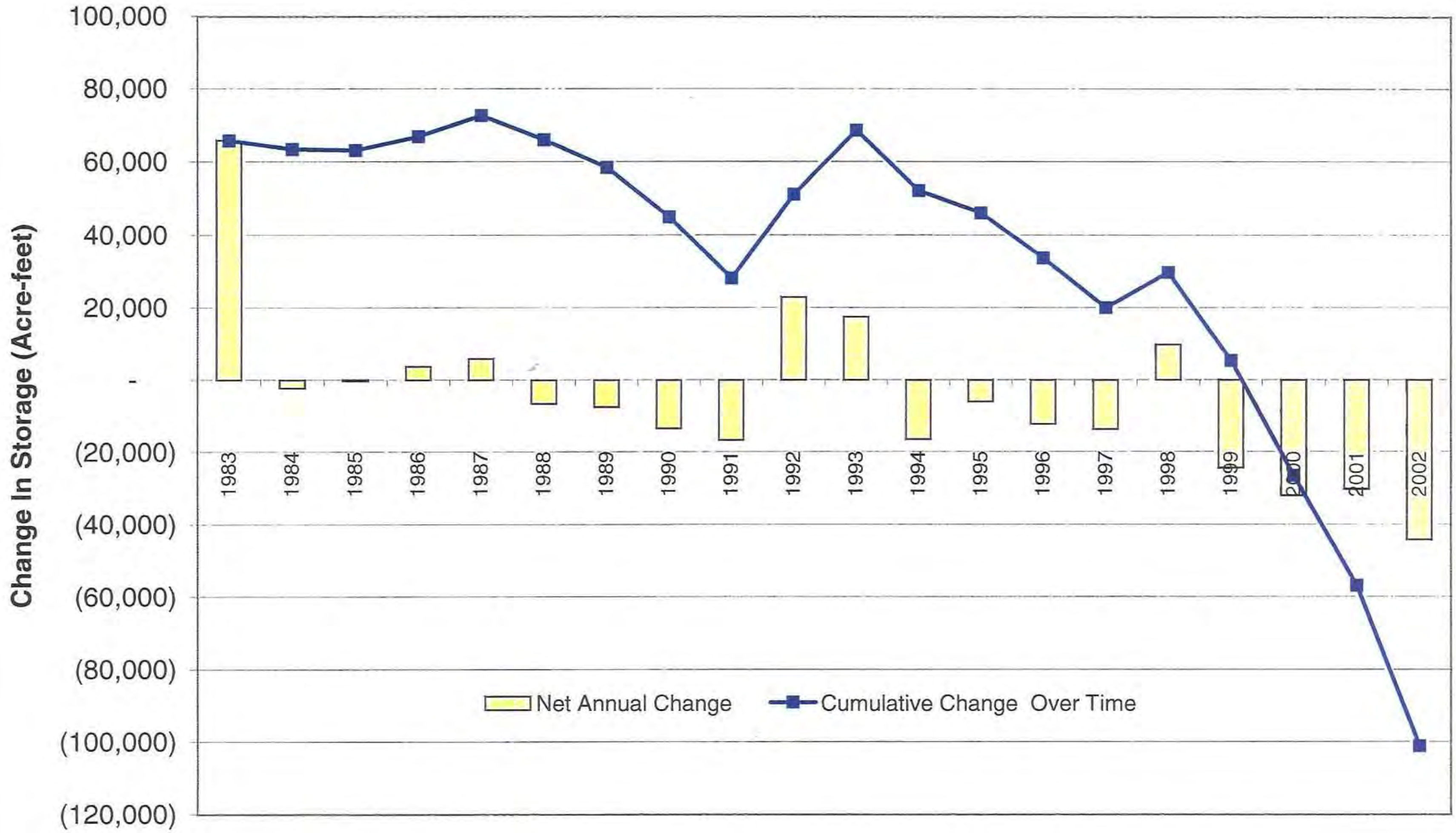


FIGURE 35
SRV Model Simulated Water Budget
Brackish Water Study
City of Goodyear, Arizona

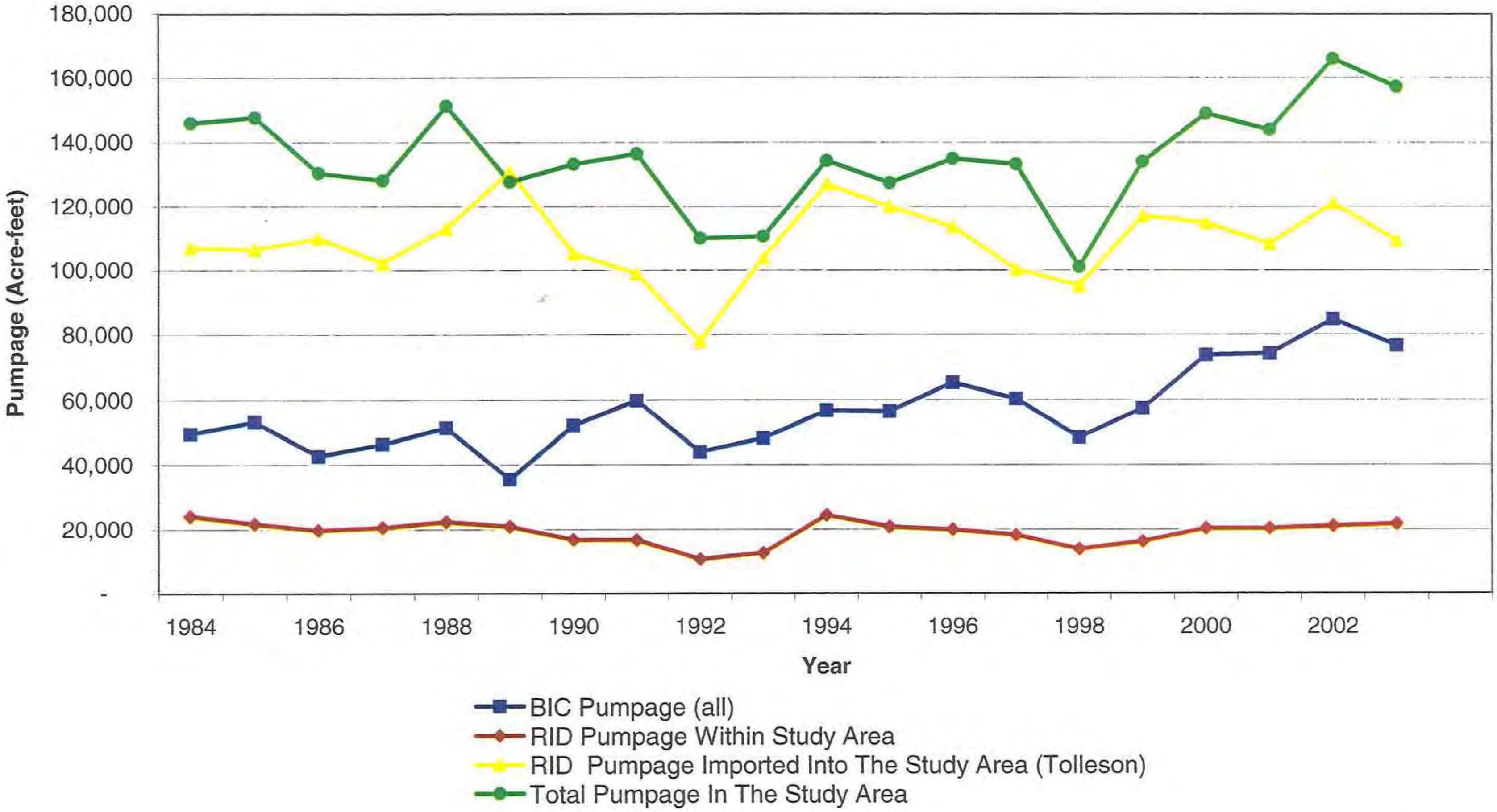


FIGURE 34
Pumpage By Different Parties
Brackish Water Study
City of Goodyear, Arizona

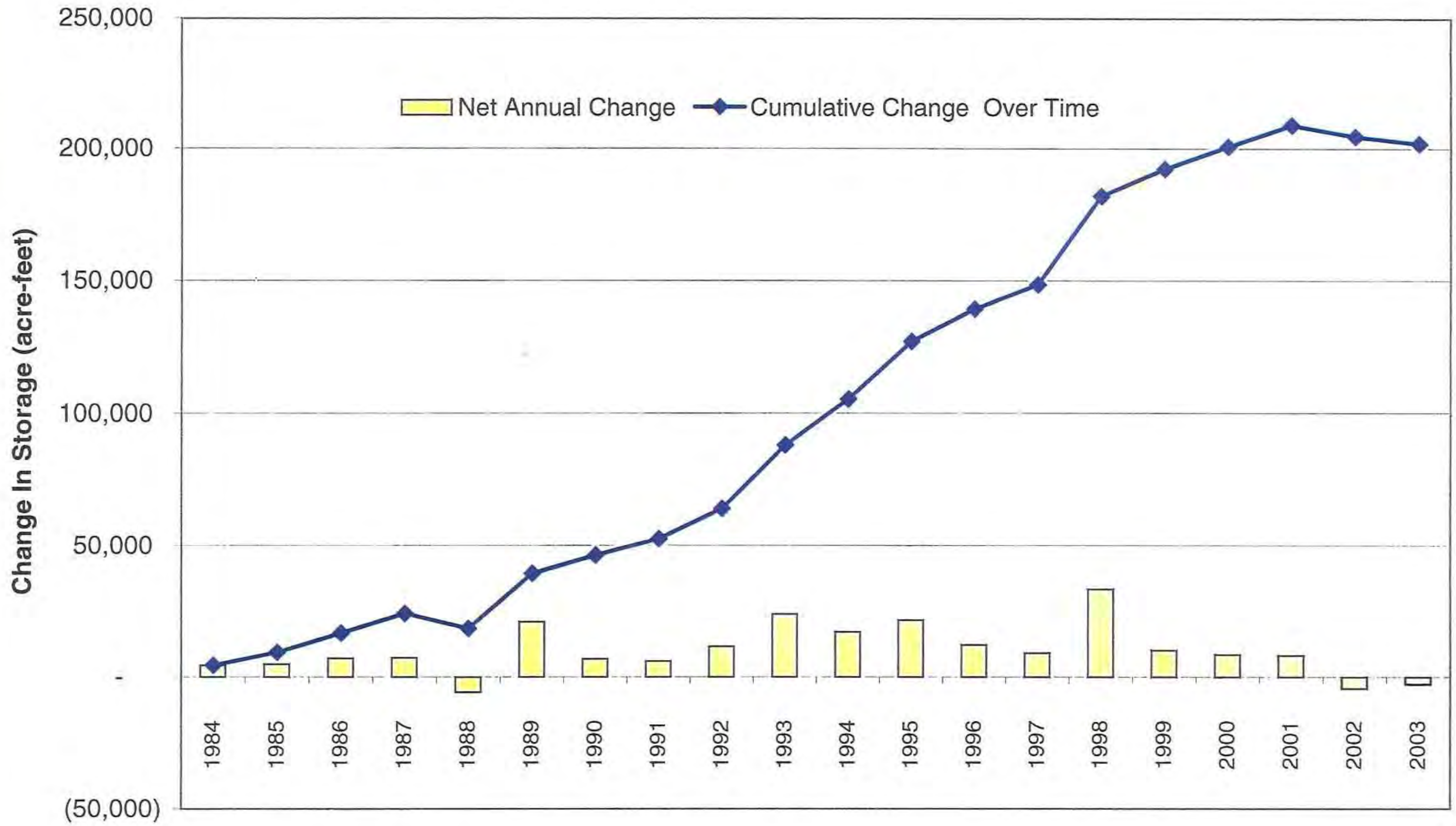
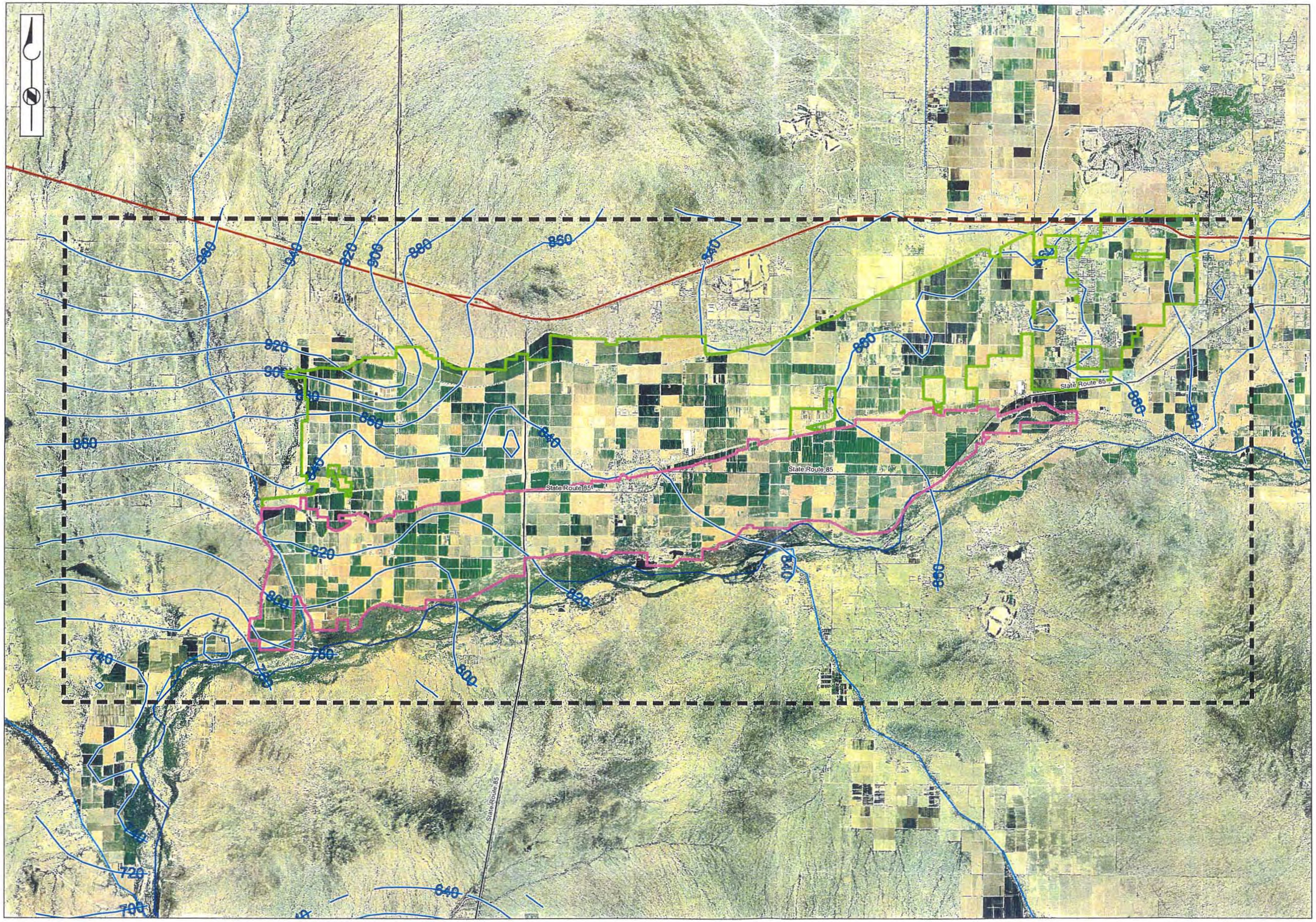


FIGURE 36
BC Estimated Water Budget
Brackish Water Study
City of Goodyear, Arizona



EXPLANATION

Buckeye Irrigation District

Roosevelt Irrigation District

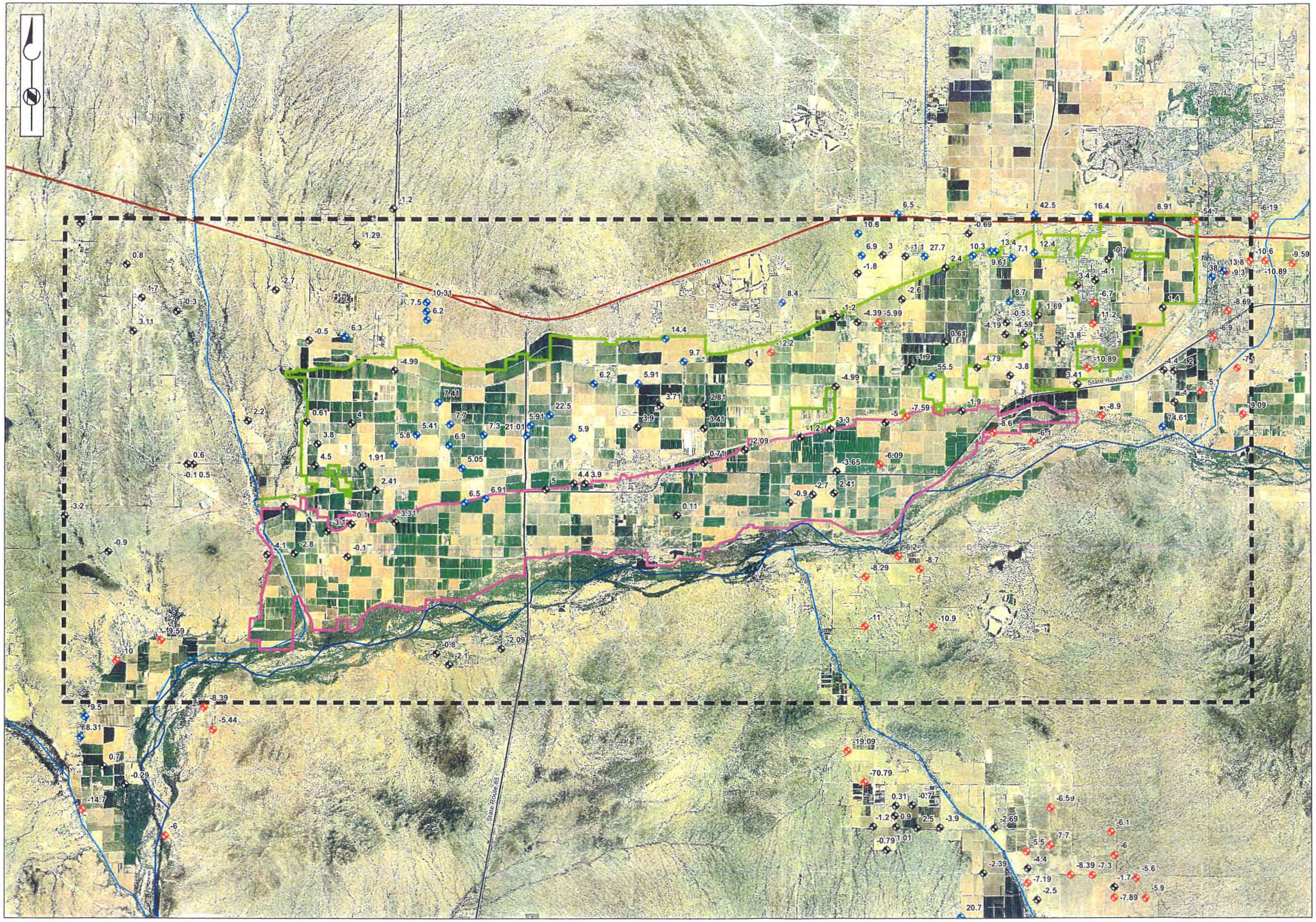
Miles 0 0.5 1 2 3 4

FIGURE 37
1991
WATER LEVEL
ELEVATIONS

BRACKISH WATER STUDY
GOODYEAR, ARIZONA

BROWN AND CALDWELL

\\SCTUC01\TABC_FHX\Goodyear_City_of\29553_Brackish_Water_Study\GIS\ARCMAPS\WORKING\POSTER_WLs_1991-2002.mxd



EXPLANATION

Buckeye Irrigation District

Roosevelt Irrigation District

Water Level Elevations

Negative

5 to -5

Positive

FIGURE 39
1991 TO 2002
WATER LEVEL
ELEVATION CHANGE

BRACKISH WATER STUDY
GOODYEAR, ARIZONA

Miles
0 0.5 1 2 3 4

BROWN AND CALDWELL

[BC (UC01] T:\BC_PHX\Goodyear_City_of\25555_Brackish_Water_Study\GIS\ARCMAPS\WORKING\POSTER_WLs_1991-2002.mxd

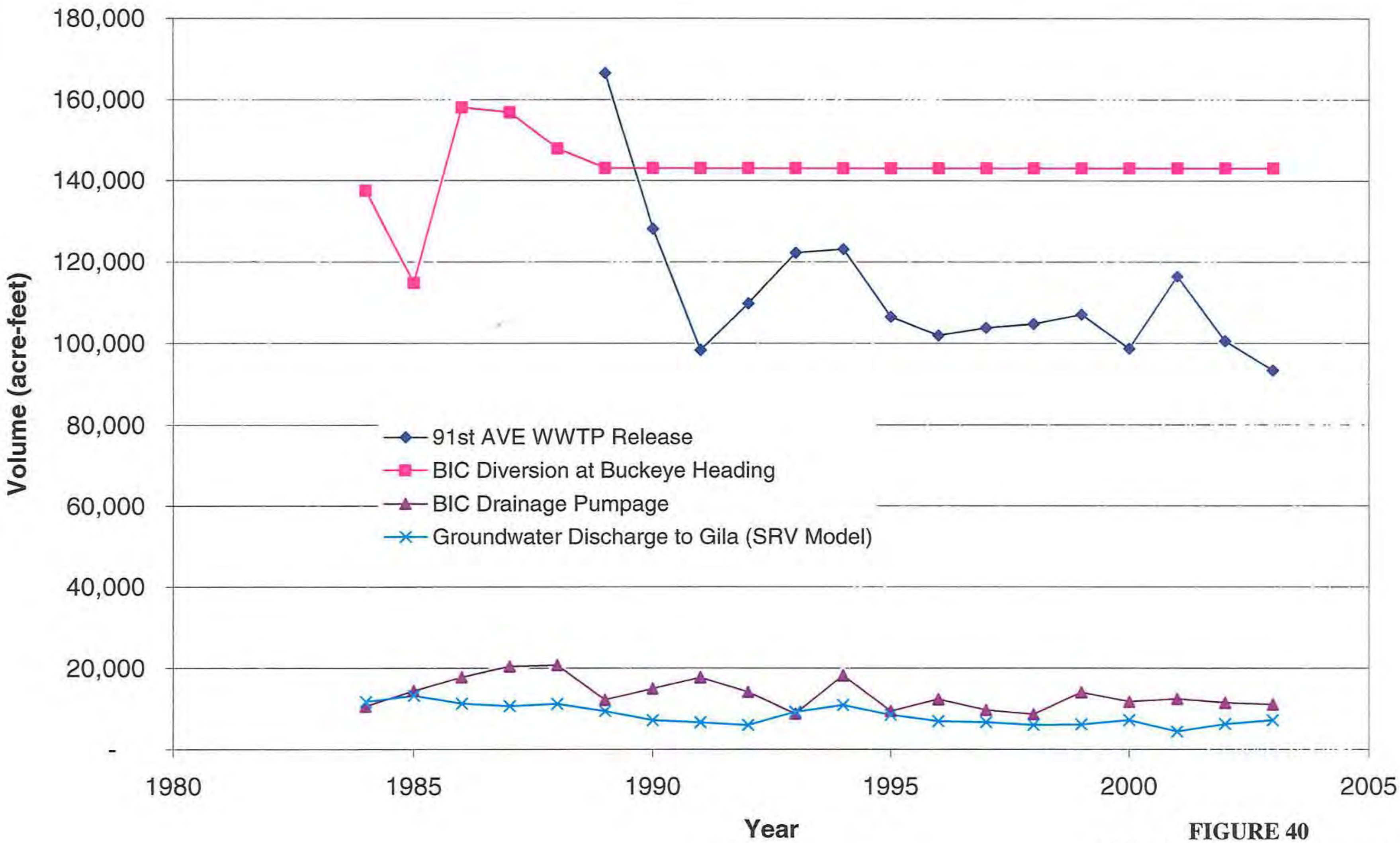


FIGURE 40
Gila River Flow Components
Brackish Water Study
City of Goodyear, Arizona

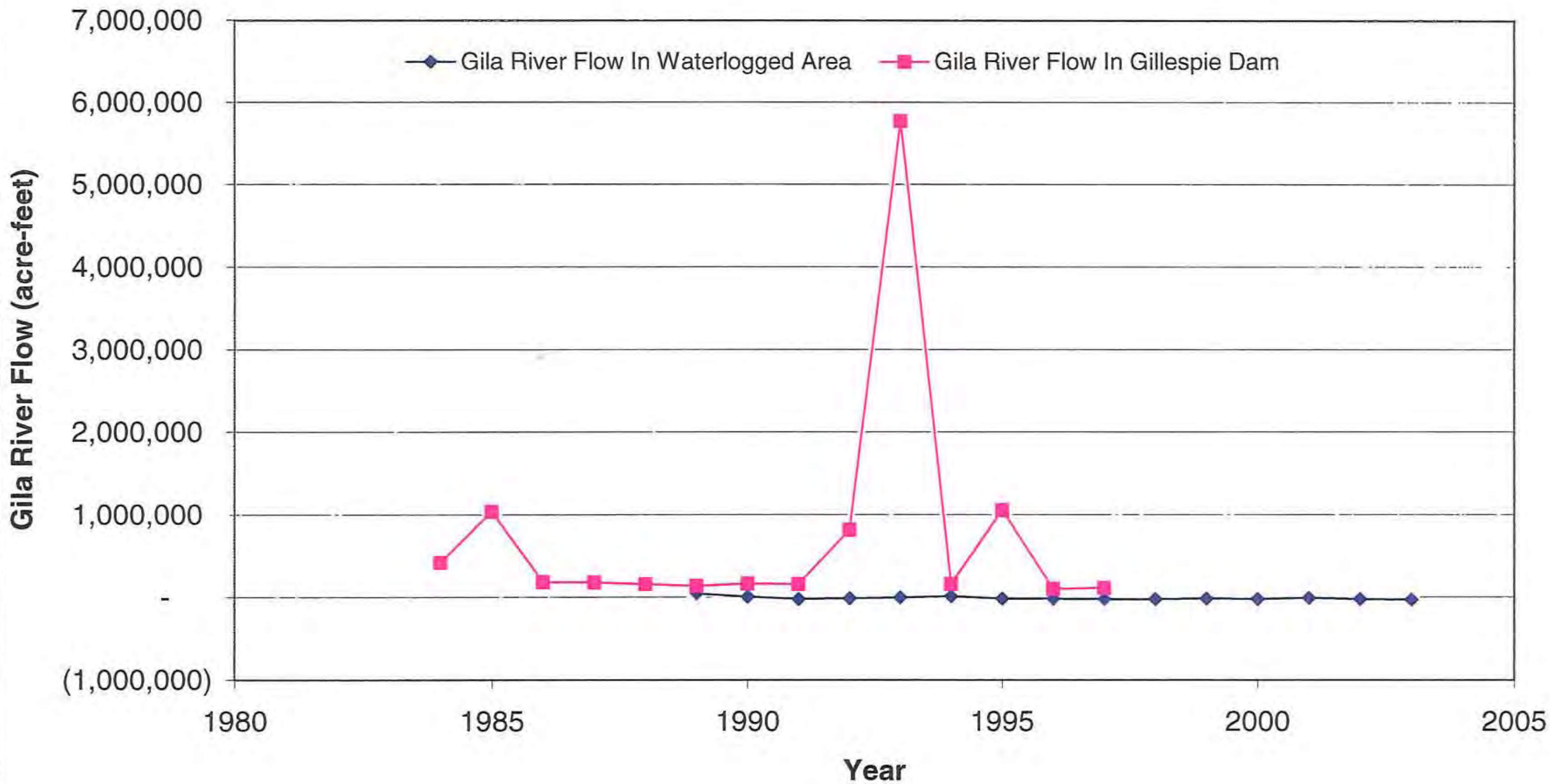


FIGURE 41
Comparison of Gila River Flow in Waterlogged Area vs. Gila River Flow at Gillespie Dam
Brackish Water Study
City of Goodyear, Arizona

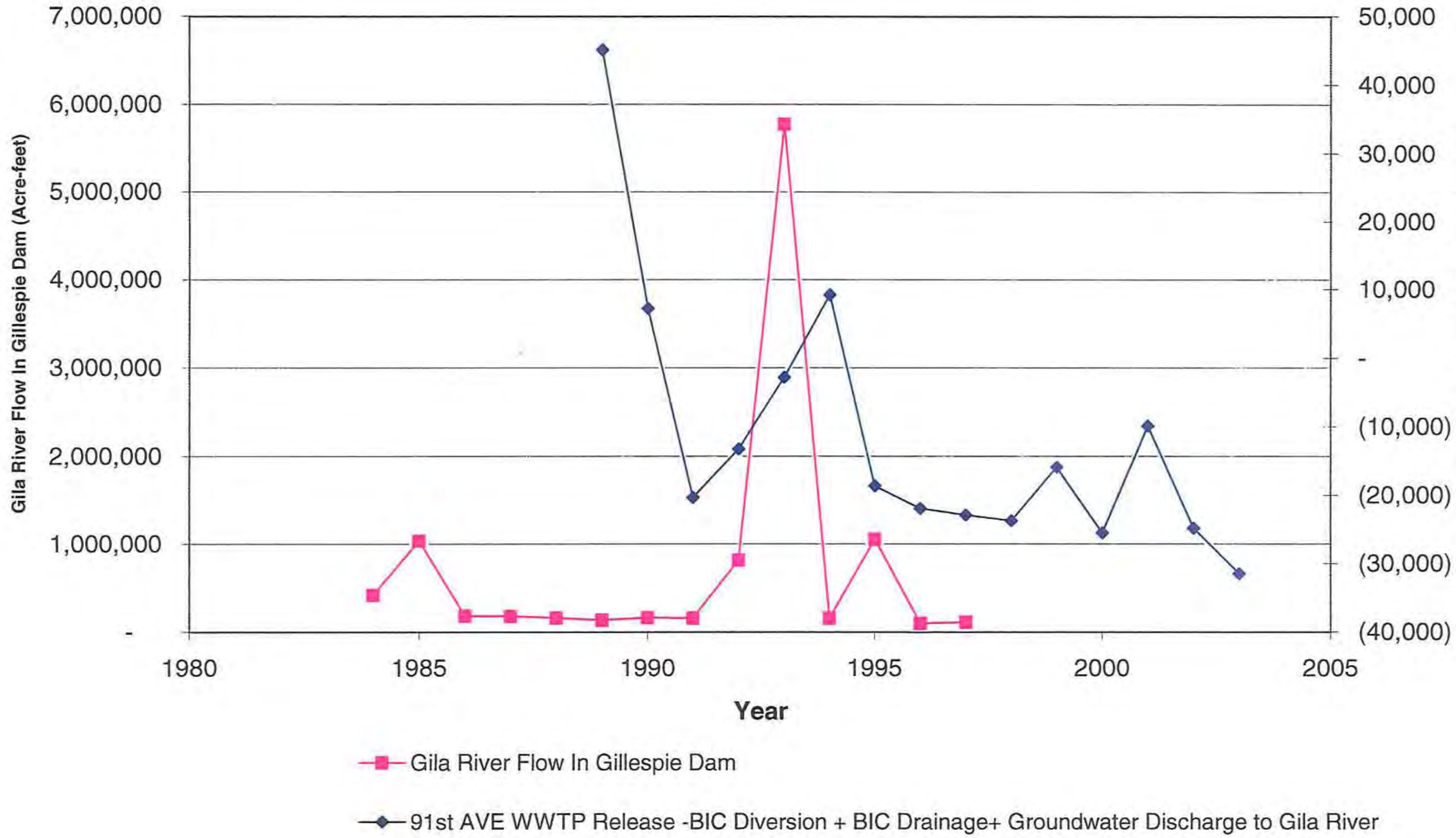


FIGURE 42
Comparison of Gila River Flow in Waterlogged Area
vs. Gila River Flow at Gillespie Dam
Brackish Water Study
City of Goodyear, Arizona

Table 1. Estimated Agricultural Recharge for BIC

Year	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
BIC Total Pumpage (including drainage pumping)	49,706	53,364	42,758	46,527	51,557	35,534	52,227	59,910	44,097	48,360	56,746	56,476	65,389	60,338	48,570	57,378	73,747	74,186	84,914	76,581
BIC-Drainage Pumpage	10,655	14,452	17,862	20,490	20,805	12,279	15,018	17,835	14,204	8,811	18,302	9,558	12,413	9,788	8,685	14,093	11,803	12,506	11,515	11,071
BIC Pumpage for Irrigation	**39,050**	**38,912**	**24,896**	**26,036**	**30,752**	**23,255**	**37,209**	**42,075**	**29,894**	**39,549**	**38,444**	**46,918**	**52,976**	**50,550**	**39,885**	**43,285**	**61,944**	**61,680**	**73,399**	**65,510**
River Water Diversions, Buckey Heading	137,664	114,944	158,294	157,133	[illegible]	143,229	143,229	143,229	143,229	143,229	143,229	143,229	143,229	143,229	143,229	143,229	143,229	143,229	143,229	143,229
SRP Surface Water Buckeye	18,321	31,206	22,595	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668	21,668
Total Surface Water Diversion, Buckeye	**155,985**	**146,150**	**180,889**	**178,801**	**169,799**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**	**164,897**
Total Water Delivered for Irrigation	**195,035**	**185,062**	**205,785**	**204,837**	**200,551**	**188,152**	**202,106**	**206,972**	**194,791**	**204,446**	**203,341**	**211,815**	**217,873**	**215,447**	**204,782**	**208,182**	**226,841**	**226,577**	**238,296**	**230,407**
Water Loss Through Canal (only consider canal seepage)	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**	**32,530**
Total Water Supplied for Irrigation	**162,505**	**152,532**	**173,255**	**172,307**	**168,021**	**155,622**	**169,576**	**174,442**	**162,261**	**171,916**	**170,811**	**179,285**	**185,343**	**182,917**	**172,252**	**175,652**	**194,311**	**194,047**	**205,766**	**197,877**
Irrigation Return Flow (29% ineffiicency from ADWR)	47,127	44,234	50,244	49,969	48,726	45,130	49,177	50,588	47,056	49,856	49,535	51,993	53,749	53,046	49,953	50,939	56,350	56,274	59,672	57,384
BIC Canal Seepage (DATS,1987)	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530
BIC Agricultural Recharge Total	**79,657**	**76,764**	**82,774**	**82,499**	**81,256**	**77,660**	**81,707**	**83,118**	**79,586**	**82,386**	**82,065**	**84,523**	**86,279**	**85,576**	**82,483**	**83,469**	**88,880**	**88,804**	**92,202**	**89,914**

Table 5. BC Estimated Water Budget in the Waterlogged Area

Year	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Inflow Components																				
Groundwater Underflow from Hassayampa Basin (SRV model)	12,012	11,780	11,541	11,865	11,835	12,130	12,481	12,504	12,262	12,139	13,378	12,732	12,546	12,178	11,130	11,172	12,383	11,683	12,160	12,160
Groundwater Underflow from ESRV (SRV model)	22,287	24,333	23,460	22,463	22,776	21,808	19,041	20,658	18,834	19,794	16,109	16,553	14,585	14,844	14,410	14,470	14,389	13,143	12,596	12,596
Total Underflow	*34,299*	*36,113*	*35,001*	*34,328*	*34,611*	*33,938*	*31,522*	*33,162*	*31,096*	*31,933*	*29,487*	*29,285*	*27,131*	*27,022*	*25,540*	*25,642*	*26,772*	*24,826*	*24,756*	*24,756*
BIC Irrigation Return Flow	47,127	44,234	50,244	49,969	48,726	45,130	49,177	50,588	47,056	49,856	49,535	51,993	53,749	53,046	49,953	50,939	56,350	56,274	59,672	57,384
BIC Canal Seepage	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530	32,530
BIC Total Recharge	*79,657*	*76,764*	*82,774*	*82,499*	*81,256*	*77,660*	*81,707*	*83,118*	*79,586*	*82,386*	*82,065*	*84,523*	*86,279*	*85,576*	*82,483*	*83,469*	*88,880*	*88,804*	*92,202*	*89,914*
RID Irrigation Return Flow	*39,320*	*38,142*	*52,968*	*50,192*	*55,288*	*62,345*	*50,488*	*47,260*	*35,826*	*47,300*	*62,023*	*57,599*	*54,615*	*48,327*	*44,126*	*54,379*	*55,233*	*52,396*	*58,101*	*53,641*
RID Canal Seepage	37,000	37,000	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
RID Total Recharge	*76,320*	*75,142*	*55,468*	*52,692*	*57,788*	*64,845*	*52,988*	*49,760*	*38,326*	*49,800*	*64,523*	*60,099*	*57,115*	*50,827*	*46,626*	*56,879*	*57,733*	*54,896*	*60,601*	*56,141*
ACC Irrigation Return Flow	*7,371*	*7,232*	*7,232*	*7,093*	*7,093*	*6,954*	*6,954*	*6,954*	*6,954*	*6,954*	*6,815*	*6,815*	*6,815*	*6,815*	*6,815*	*6,815*	*6,701*	*6,701*	*6,259*	*5,424*
ACC Canal Seepage	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
ACC Total Recharge	**19,371**	**19,232**	**19,232**	**19,093**	**19,093**	**18,954**	**18,954**	**18,954**	**18,954**	**18,954**	**18,815**	**18,815**	**18,815**	**18,815**	**18,815**	**18,815**	**18,701**	**18,701**	**18,259**	**17,424**
ACC Recharge Within Study Area (40% of Total)	**7,749**	**7,693**	**7,693**	**7,637**	**7,637**	**7,582**	**7,582**	**7,582**	**7,582**	**7,582**	**7,526**	**7,526**	**7,526**	**7,526**	**7,526**	**7,526**	**7,480**	**7,480**	**7,304**	**6,970**
Total Agriculture Related Recharge	***163,726***	***159,600***	***145,935***	***142,828***	***146,682***	***150,087***	***142,277***	***140,460***	***125,493***	***139,767***	***154,114***	***152,148***	***150,920***	***143,929***	***136,635***	***147,874***	***154,093***	***151,180***	***160,107***	***153,025***
Total Inflow	**198,024**	**195,713**	**180,936**	**177,156**	**181,293**	**184,025**	**173,799**	**173,622**	**156,589**	**171,700**	**183,601**	**181,433**	**178,051**	**170,951**	**162,175**	**173,516**	**180,865**	**176,006**	**184,863**	**177,781**
Outflow Components																				
Total Pumpage (BIC+RID+ACC+others)	146,140	147,916	130,588	128,276	151,393	127,805	133,418	136,576	110,144	110,786	134,487	127,509	135,150	133,385	101,090	134,190	149,147	144,112	166,112	157,360
Groundwater Underflow Near Arlington (SRV model)	9,216	9,645	9,901	9,736	9,651	9,311	9,114	9,115	10,006	9,947	8,606	9,405	8,929	9,068	9,551	9,737	8,761	9,142	9,608	9,608
Groundwater Underflow to the Luke Cone of Depression (SRV model)	18,887	16,036	17,193	15,184	12,226	14,754	14,500	13,571	13,268	13,048	11,756	12,552	11,999	10,755	9,495	9,930	8,199	6,595	4,607	4,607
ET Loss (SRV model))	5,897	5,783	5,270	5,283	4,314	3,927	3,012	2,198	2,213	2,999	3,017	3,377	2,914	2,511	2,468	2,236	1,775	1,630	1,704	1,704
Groundwater Discharge to Gila River (SRV model))	13,304	11,349	10,749	11,257	9,494	7,192	6,727	6,020	9,279	10,993	8,498	6,942	6,729	6,013	6,144	7,189	4,396	6,268	7,232	7,232
Total Outflow	**193,444**	**190,729**	**173,701**	**169,736**	**187,078**	**162,989**	**166,771**	**167,480**	**144,910**	**147,773**	**166,364**	**159,785**	**165,721**	**161,732**	**128,748**	**163,282**	**172,278**	**167,747**	**189,263**	**180,511**
Change In_Storage	**4,580**	**4,983**	**7,235**	**7,421**	**(5,785)**	**21,036**	**7,028**	**6,142**	**11,679**	**23,927**	**17,237**	**21,648**	**12,330**	**9,220**	**33,427**	**10,235**	**8,587**	**8,258**	**(4,400)**	**(2,730)**
Cumulated Change_In_Storage With Time	4,580	9,564	16,799	24,220	18,434	39,471	46,498	52,641	64,320	88,247	105,484	127,132	139,463	148,682	182,109	192,344	200,931	209,190	204,790	202,059

Table 4. SRV Model Simulated Water Budget in the Waterlogged Area

ear	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
nflow Components																				
nderflow from the East	22,179	22,287	24,333	23,460	22,463	22,776	21,808	19,041	20,658	18,834	19,794	16,109	16,553	14,585	14,844	14,410	14,470	14,389	13,143	12,596
nderflow from the North	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	38	139
onstant Head Inflow (Hassayampa Basin)	12,125	12,012	11,780	11,541	11,865	11,835	12,130	12,481	12,504	12,262	12,139	13,378	12,732	12,546	12,178	11,130	11,172	12,383	11,683	12,160
tream Recharge (Including BIC Canal)	52,867	46,608	48,030	46,614	46,437	46,036	46,594	47,212	46,797	45,140	52,695	47,178	46,825	45,541	45,358	44,288	44,911	46,197	46,399	46,127
echarge (Irrigation Return Flow)	111,714	104,427	104,427	89,495	89,495	89,495	69,219	69,219	69,219	86,551	76,237	68,879	68,744	69,323	66,691	61,687	60,492	59,866	59,141	58,158
Total Inflow	**198,885**	**185,334**	**188,570**	**171,110**	**170,260**	**170,142**	**149,751**	**147,953**	**149,178**	**162,787**	**160,865**	**145,544**	**144,854**	**141,995**	**139,071**	**131,515**	**131,045**	**132,848**	**130,404**	**129,180**
utflow Components																				
nderflow to the North (Luke Cone of Depression)	23,936	18,887	16,036	17,193	15,184	12,226	14,754	14,500	13,571	13,268	13,048	11,756	12,552	11,999	10,755	9,495	9,930	8,199	6,595	4,607
nderflow to the South	71	72	77	86	83	72	77	82	83	100	78	53	54	74	92	94	96	92	87	81
onstant Head Outflow (Arlington Area)	7,763	9,216	9,645	9,901	9,736	9,651	9,311	9,114	9,115	10,006	9,947	8,606	9,405	8,929	9,068	9,551	9,737	8,761	9,142	9,608
tream Outflow (Groundwater Discharge to the Gila iver)	11,817	13,304	11,349	10,749	11,257	9,494	7,192	6,727	6,020	9,279	10,993	8,498	6,942	6,729	6,013	6,144	7,189	4,396	6,268	7,232
echarge	-	-	-	-	-	-	1,696	1,696	1,696	-	-	-	-	-	-	-	-	-	-	-
/ells Outflow	84,729	140,328	145,932	124,194	122,898	141,058	120,381	126,347	133,264	104,969	106,305	130,143	118,587	123,711	124,382	94,039	126,296	141,618	136,926	150,192
T Outflow	4,594	5,897	5,783	5,270	5,283	4,314	3,927	3,012	2,198	2,213	2,999	3,017	3,377	2,914	2,511	2,468	2,236	1,775	1,630	1,704
Total Outflow	**132,910**	**187,704**	**188,822**	**167,393**	**164,441**	**176,815**	**157,338**	**161,478**	**165,947**	**139,835**	**143,370**	**162,073**	**150,917**	**154,356**	**152,821**	**121,791**	**155,484**	**164,841**	**160,648**	**173,424**
hange_in_Storage	**65,975**	**(2,370)**	**(252)**	**3,717**	**5,819**	**(6,673)**	**(7,587)**	**(13,525)**	**(16,769)**	**22,952**	**17,495**	**(16,529)**	**(6,063)**	**(12,361)**	**(13,750)**	**9,724**	**(24,439)**	**(31,993)**	**(30,244)**	**(44,244)**
umulative Change_in_Storage	65,975	63,605	63,353	67,070	72,889	66,216	58,629	45,104	28,335	51,287	68,782	52,253	46,190	33,829	20,079	29,803	5,364	(26,629)	(56,873)	(101,117)

Table 6. Differences Between the SRV Model Simulated and BC Estimated Water Budget

…ear	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Inflow																			
…otal Underflow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	38	139
…otal Agricultural Related Recharge	(12,691)	(7,143)	(9,826)	(6,896)	(11,151)	(34,274)	(25,846)	(24,444)	6,198	(10,835)	(38,057)	(36,579)	(36,056)	(31,880)	(30,660)	(42,471)	(48,030)	(45,640)	(55,822)
…otal Inflow	(12,691)	(7,143)	(9,826)	(6,896)	(11,151)	(34,274)	(25,846)	(24,444)	6,198	(10,835)	(38,057)	(36,579)	(36,056)	(31,880)	(30,660)	(42,471)	(48,017)	(45,602)	(55,683)
Outflow																			
…otal Pumpage (BIC+RID+ACC+others)	(5,812)	(1,984)	(6,394)	(5,378)	(10,335)	(7,424)	(7,071)	(3,312)	(5,175)	(4,481)	(4,344)	(8,922)	(11,439)	(9,003)	(7,051)	(7,894)	(7,529)	(7,186)	(15,920)
…roundwater Underflow Near Arlington (SRV model)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
…roundwater Underflow to the Luke Cone of Depression …RV model)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
…T Loss (SRV model))	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
…W Discharge to Gila River (SRV model))	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
…nderflow to the South	72	77	86	83	72	77	82	83	100	78	53	54	74	92	94	96	92	87	81
…otal Outflow	**(5,740)**	**(1,907)**	**(6,308)**	**(5,295)**	**(10,263)**	**(7,347)**	**(6,989)**	**(3,229)**	**(5,075)**	**(4,403)**	**(4,291)**	**(8,868)**	**(11,365)**	**(8,911)**	**(6,957)**	**(7,798)**	**(7,437)**	**(7,099)**	**(15,839)**
Change_in_Storage	(6,951)	(5,236)	(3,519)	(1,601)	(888)	(26,927)	(18,857)	(21,215)	11,273	(6,432)	(33,766)	(27,711)	(24,691)	(22,970)	(23,703)	(34,674)	(40,580)	(38,502)	(39,844)