TECHNICAL MEMORANDUM

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Groundwater Substitution Transfer Impact Analysis, Sacramento Valley

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This technical memorandum presents results of preliminary model simulations performed to estimate the effects of groundwater pumping associated with a hypothetical groundwater substitution water transfer program on groundwater levels and stream flow. The model simulations were performed using the SACFEM groundwater model, developed by CH2M HILL. SACFEM is a three-dimensional, finite-element, numerical groundwater flow model of the Sacramento Valley. It has been calibrated to observed transient groundwater elevations using a monthly time step for the period from water years 1970 through 2003. The model’s development and calibration are documented in a memorandum entitled “Documentation of the SACFEM Groundwater Flow Model,” produced by CH2M HILL and dated July 2, 2009.

The primary objective of this effort focused on simulating the hypothetical pumping program, and evaluating the results to determine whether improvements to the model are necessary to better match conditions observed in the field. It should be noted that site-specific information regarding well construction and aquifer properties was not available for many of the projects evaluated herein. Aquifer testing and additional site-specific data would be required to obtain more accurate estimates of stream flow and groundwater level effects that result from groundwater pumping at these locations. Lessons learned from these model simulations should lead to recommendations that could improve the analytical capabilities of SACFEM.

Additionally, the simulations were performed to provide preliminary estimates of the extent to which groundwater substitution water transfers effectively increase water supply. These transfers make surface water available for transfer by pumping groundwater to replace surface water that would have otherwise been diverted from streams. The effect of these transfer operations on stream flow has two components. First, stream flow is assumed to increase by the amount of groundwater that is pumped to replace the surface water that would have been diverted. Second, stream flow is depleted because of the interaction of the groundwater pumping with surface water. The groundwater model simulations provide estimates of the amount, and timing of stream flow depletion that results from pumping groundwater during transfer operations.

Groundwater Substitution Transfer Pumping

The distribution of groundwater pumping used in this simulation was provided by the California Department of Water Resources (Department) and roughly reflects the characteristics of projects associated with the 2009 Drought Water Bank Program. The Department provided geographic coordinates, production well construction details, and pumping schedules for a group of wells similar to those in the program. This included 266 wells distributed among 15 proposed projects. The locations of these wells are shown on Figure 1 (figures are presented at the end of this technical memorandum). The modeled vertical distribution of groundwater substitution transfer pumping was determined from the well construction details provided by the Department. To assign the pumping stresses in the model, CH2M developed a pre-processing utility that compared the well screen intervals with the model layer interface elevations at each well location. The pumping stress at each well was distributed through the model layers according to the length of well screen within each layer and the aquifer transmissivity within each layer. The resulting distribution of pumping by layer, by month, for all of the wells pumping in the modeled groundwater substitution transfer operation is summarized on Figure 2.

Model Simulations

The groundwater model simulations were performed using the entire 34-year period of record used to calibrate the SACFEM model (water years 1970 through 2003). Four model simulations were performed, in accordance with direction from the Department. These simulations are described below:

- **Baseline –** This is a 34-year simulation with baseline groundwater conditions and no groundwater substitution transfer pumping. The approach that was taken for this baseline simulation was to develop initial conditions that approximated groundwater conditions at the beginning of water year 2009, and assume that future hydrology will mimic the 1970 though 2003 historical climatological period. The initial condition was defined as the simulated heads computed by the model for the last month of water year 1988 (September). These conditions were selected because they were the conditions most similar to those at the end of water year 2008 within the available 1970 through 2003 calibration period. Water years 1988 and the 2008 were both classified as critical years, and the river runoff volumes for these years were reported to be 9.23 million acre-feet and 10.21 million acre-feet, respectively. The Sacramento Index for 1988 was 4.65, while the Sacramento Index for 2008 was 5.15. This suggests that groundwater conditions simulated by the calibrated model for September 1988 are similar to those that existed in September 2008. Therefore, these conditions were used as initial conditions for the groundwater substitution transfer simulations over a 34-year period starting with water year 2009, and future climatic conditions were assumed to reflect those that existed during the 1970 through 2003 period.
- **Scenario 1 –** In this simulation, 82,000 acre-feet of groundwater substitution transfer pumping occurs in 1976 only. Water year 1976 was a critical year followed by a critical year (1977) and subsequent above-normal and below-normal years.

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- **Scenario 2 –** In this simulation, 82,000 acre-feet of groundwater substitution transfer pumping occurs in 1987 only. Water year 1987 was a dry year followed by a critical year (1988) and subsequent dry and critical years.
- **Scenario 3 –** In this simulation, 82,000 acre-feet of groundwater substitution transfer pumping occurs in 1994 only. Water year 1994 was a critical year followed by a wet year (1995) and subsequent wet years.

These three scenarios were selected to investigate a range of hydrologic conditions during and following the operation of a hypothetical groundwater substitution transfer program. The intent was to better understand the implications of having a relatively wet weather pattern follow a year with program operation, as opposed to having a sequence of dry years follow a year with program operation.

Simulation Results

The results of the model simulations were used to evaluate the effects of groundwater substitution transfer operations on both stream flows and groundwater elevations. The effects on stream flow are discussed first, followed by effects on groundwater levels.

Effects on Stream Flows

The effects on stream flows were computed by first running a model simulation assuming no groundwater substitution transfer pumping, to define the baseline conditions, and then running a model simulation assuming that groundwater substitution transfer pumping operated in one of the years discussed above (1976, 1987, or 1994). The difference in surface water/groundwater interaction between the simulation containing the transfer pumping and the baseline simulation was assumed to be due to operation of the groundwater substitution transfer program. This surface water/groundwater interaction represents a combination of both groundwater discharge to streams and direct leakage of surface water from streams into the underlying aquifer system. This methodology factors out the variability in agricultural pumping, deep percolation of applied water and precipitation, and other climate-driven processes because they are represented identically in both the baseline and the groundwater substitution transfer simulations. The result is that the only source of water available to replenish the groundwater removed from storage by transfer pumping is that provided by head-dependent boundary conditions, or in this case, surface streams. These assumptions are discussed in more detail below.

The Role of Delta Conditions in Interpreting Effects on Stream Flow

One objective of conducting this model simulation was to estimate the extent to which groundwater substitution transfer operations increase stream flow downstream of the simulated projects, thereby making additional water available for transfer from the Sacramento-San Joaquin River Delta (Delta). The model simulations were used to estimate the total effect of transfer pumping on stream flow, as discussed above. When estimating how much water the transfer operations might make available in the Delta for transfer, however, some stream flow impacts can be disregarded. The impacts to stream flow during "excess Delta conditions," in general, do not affect the volume of water made available for transfer. The groundwater pumping impacts to stream flow that reduce the amount of water made available for transfer occur during "balanced Delta conditions."

Two types of estimates of transfer pumping effects on stream flow are discussed below: effects during both excess and balanced Delta conditions, and effects during only balanced Delta conditions. To arrive at the estimate of stream flow losses during balanced Delta conditions, estimates of stream flow losses occurring during excess Delta conditions, as defined by monthly records of Delta conditions over the period from 1970 to 2003 (see Figure 3), were ignored. In this technical memorandum, estimates of stream flow losses occurring only during balanced conditions are referred to as "filtered for Delta conditions." The unadjusted simulation results showing the total effect of transfer pumping on stream flow, including impacts during both excess and balanced Delta conditions, are referred to as "unfiltered for Delta conditions."

The effects of transfer pumping on surface stream flow were evaluated by constructing four different graphical representations of the simulation output for each scenario:

- A time series of simulated stream flow depletion due to groundwater substitution transfer pumping, unfiltered for Delta conditions
- A time series of simulated stream flow depletion due to groundwater substitution transfer pumping, filtered for Delta conditions
- A time series of simulated stream flow depletion due to groundwater substitution transfer pumping as a percent of the total amount of groundwater pumped for transfer, filtered for Delta conditions
- A cumulative time series of simulated stream flow depletion due to groundwater substitution transfer pumping as a percent of the total amount of groundwater pumped for transfer, filtered for Delta conditions

Simulated Effects on Stream Flow of 1976 Transfer Operations

The effects of the simulated groundwater substitution transfer pumping in 1976 (Scenario 1) on stream flow are summarized on Figures 4a through 4d. The distribution of the monthly reduction in stream flow resulting from groundwater substitution transfer pumping, unfiltered for Delta conditions, is shown on Figure 4a. The figure indicates that the maximum stream depletion occurs shortly after the pumping starts in June 1976 and the rate of depletion declines over time. The peak monthly stream depletion, about 2,100 acre-feet, occurs during the last month of transfer pumping. The results also show that the influence of the 1976 transfer pumping affects stream flow for an extended period of time following the operation of the program. Even if the small-magnitude effects predicted later in the simulation (less than ~100 acre-feet per month) are considered to be numerical artifacts, the results still predict a significant effect. This is due to the assumption that all of the water available to replenish groundwater substitution transfer pumping originates from streams, and the response of the head-dependent boundaries results in an asymptotic reduction in stream effects.

Figure 4b presents results of the 1976 groundwater substitution transfer simulation, filtered for Delta conditions. The result of ignoring stream flow losses in months with excess Delta conditions is that some months with losses shown on Figure 4a show no losses on Figure 4b. The stream flow losses that affect the amount of water available for transfer, although still significant in this analysis, are less than if the losses during excess Delta conditions are considered.

The values of monthly reduction in stream flow shown on Figure 4b were divided by the total volume of groundwater pumped during transfer operations (about 82,000 acre-feet) to arrive at losses as a percent of the transfer pumping, which are shown on Figure 4c. The percentage values were then summed up on a monthly basis to create Figure 4d.

In terms of the amount of water that transfer operations are attempting to make available, the 1976 transfer simulation results predict a significant effect, shown on Figure 4d. Over a five-year period following the start of groundwater pumping for transfers in June 1976, modeled stream flow losses resulting from that pumping, when filtered for Delta conditions, are 39 percent of the volume pumped over the four-month transfer period.

Simulated Effects on Stream Flow of 1987 Transfer Operations

The results of the simulations conducted to evaluate the effects of a groundwater substitution transfer program operated in 1987 (Scenario 2) on stream flow are summarized on Figures 5a through 5d. The distribution of the monthly reduction in stream flow, unfiltered for Delta conditions, is shown on Figure 5a. Similar to the results of the 1976 transfer simulation, the results of the 1987 simulation show that the maximum stream depletion occurs shortly after the pumping starts in June 1987, and the rate of depletion declines over time. Also similar to the 1976 evaluation, the peak monthly stream depletion is just over 2,100 acre-feet.

Similar to the results of the 1976 transfer simulation, Figure 5b presents results of the 1987 transfer simulation, filtered for Delta conditions. Certain months on Figure 5b show no transfer pumping impacts to stream flow. As noted above, these are months with excess Delta conditions. The differing sequences of hydrologic conditions following the 1976 versus 1987 transfer operation simulations are apparent by comparing Figures 4b and 5b. The 1976 transfer pumping period was followed by a critical year, followed by an above-normal year and a below-normal year. This is reflected on Figure 4b in the gaps in impacts, reflecting excess Delta conditions, during the winters of 1978, 1979, and 1980. The 1987 transfer pumping was followed by a critical year, followed by subsequent dry and critical years. This hydrologic pattern is indicated on Figure 5b by the continued impacts predicted throughout 1988, 1989, and 1990.

The values of monthly reduction in stream flow shown on Figure 5b were divided by the total volume of groundwater pumped during transfer operations (about 82,000 acre-feet) to arrive at losses as a percent of the transfer pumping, which are shown on Figure 5c. The percentage values were then summed up on a monthly basis to create Figure 5d.

In terms of the amount of water that transfer operations are attempting to make available, this simulation also predicts a significant effect. Over a five-year period following the start of the simulation in June 1987, modeled stream flow losses resulting from the transfer pumping, when filtered for Delta conditions, are 44 percent of the volume pumped over the four-month transfer period. This is an increase of 5 percent compared to the stream flow losses in the five years following the simulated 1976 transfer operations. The 1987 scenario resulted in more significant stream flow losses than the 1976 scenario because there were fewer months in the five-year period following 1987 with excess Delta conditions than in the five-year period following 1976.

Simulated Effects on Stream Flow of 1994 Transfer Operations

The effects of simulated groundwater substitution transfer pumping in 1994 (Scenario 3) on stream flow are summarized on Figures 6a through 6d. The distribution of the monthly reduction in stream flow, unfiltered for Delta conditions, is shown on Figure 6a. Similar to the results of the previous two simulations, the results of the 1994 simulation show that the maximum stream depletion occurs shortly after the pumping starts in June 1994, and the rate of depletion declines over time.

Figure 6b presents results of the 1994 transfer simulation, filtered for Delta conditions. As noted above, months with excess Delta conditions show no transfer pumping impacts to stream flow. The differing sequences of hydrologic conditions following the 1987 and 1994 transfer simulations are apparent by comparing Figures 5b and 6b. The 1987 transfer pumping period was followed by a critical year, followed by subsequent dry and critical years. This is seen on Figure 5b by the consistent series of impacts predicted throughout 1988, 1989, and 1990. The 1994 transfer period was followed by a wet year, followed by additional wet years. This hydrologic pattern results in additional months with excess Delta conditions, expressed on Figure 6b by the many months from 1995 to 1999 where no impact to stream flow is shown.

The values of monthly reduction in stream flow shown on Figure 6b were divided by the total volume of groundwater pumped during transfer operations (about 82,000 acre-feet) to arrive at losses as a percent of the transfer pumping, which are shown on Figure 4c.

The cumulative distribution of stream flow depletion, similar to those shown for the 1976 and 1987 scenarios, is shown on Figure 6d for the 1994 scenario. When filtered for Delta conditions, total stream flow losses resulting from the 1994 transfer pumping over the five-year period after transfer pumping started in June 1994 amount only to about 19 percent of the volume pumped over the four-month transfer period. Compare this to the five-year period with relatively dry conditions following the 1987 transfer pumping, which resulted in stream flow losses of about 44 percent. Much of the difference in the stream flow depletion following the 1987 and 1994 simulations is due to the effect of considering excess Delta conditions in the analysis.

Effects on Groundwater Levels

The effects of groundwater substitution transfer pumping on surrounding groundwater levels were evaluated by constructing both plan view contour maps of drawdown at various time intervals following pumping, and charts that show the magnitude of groundwater elevation change over time at a particular location. Drawdown contours were developed from groundwater elevation data for model layer 2. Layer 2 was selected because it is the layer with the greatest volume of groundwater substitution transfer pumping (see Figure 2). The drawdown contour maps were constructed for the following time periods: the final month of pumping (September) and 3 months, 7 months, 12 months, 2 years, and 5 years following the cessation of pumping. Based on the drawdown distributions portrayed in the drawdown contour maps, eight impact zones were identified. Charts showing groundwater elevation change over time were then constructed for the location of maximum drawdown within each impact zone for each of the transfer pumping periods simulated. The locations of maximum drawdowns within the eight impact zones are shown on Figure 1.

Groundwater Elevation Effects – Drawdown Maps

The simulated distribution of drawdown, assuming a 1976 groundwater substitution transfer program for model layer 2, is shown on Figures 7a through 7f. As expected, the maximum magnitude of drawdown occurs at the end of the pumping period, in September 1976 (Figure 7a). The maximum drawdown in September is about 15 feet in the Yuba Basin and generally less than 15 feet in the remaining portions of the valley. These maximum drawdown values occur very close to the production wells, and drawdown diminishes rapidly with distance from the production wells. The magnitude of drawdown also diminishes rapidly with time. Figure 7b shows the residual drawdown forecast by the model three months following the cessation of pumping. By April 1977 and prior to the start of the next production season (Figure 7c), the predicted residual drawdown is less than 2 feet over the entire valley, except for within the Yuba Basin. Groundwater drawdown persists for a longer time in the Yuba area because of both lower aquifer transmissivity in the Yuba Basin and the proximity of the project pumping to the eastern boundary of the groundwater basin. Because the aquifer pinches out to bedrock to the east, very little recharge replenishes the aquifer system from this area, and drawdown persists for longer than in other areas of the valley. Figure 7d shows that, even after 12 months following the transfer pumping, there appears to be some residual drawdown. Figures 7e and 7f show the predicted drawdown distribution two and five years following the transfer pumping. The results show that, after two years (Figure 7e), almost no appreciable drawdown remains, except for an area with several feet of residual drawdown limited to the Yuba Basin. Based on the present analysis, and from a practical standpoint, it appears that the impact of transfer pumping should be considered only for up to two years following the pumping. As evidenced on Figure 7f, after five years, the groundwater system appears to have reached complete equilibrium. This same set of drawdown maps was constructed for the 1987 and 1994 (Scenarios 2 and 3) groundwater substitution transfer programs. Inspection of these figures indicated that the drawdown distribution following both of these simulated programs was identical to that computed for the 1976 pumping program. So, in the interest of brevity, these figures are not reproduced here. In essence, the drawdown distributions shown on Figures 7a through 7f also accurately depict the simulated extent of drawdown for the five years following the 1987 and 1994 transfer operations, as well as 1976 transfer operations.

Groundwater Elevation Effects – Groundwater Elevation Change Charts

Charts showing groundwater elevation change over time were also developed to investigate the effects of groundwater substitution transfer pumping on surrounding groundwater levels. These charts plot the difference between groundwater elevation time series from simulations with transfer pumping and time series from baseline simulations. These charts are analogous to monthly drawdown estimates for the locations of maximum drawdown in the eight impact zones identified and discussed previously. Similar to the other charts, all of the groundwater data shown in these analyses are from model layer 2, where the maximum quantity of groundwater substitution transfer pumping was assigned.

The groundwater elevation change charts for the 1976 transfer pumping simulation are shown on Figures 8a through 8h for Impact Zones 1 through 8, respectively. Similar to the groundwater drawdown contour maps, these results suggest that Impact Zones 1, 3, and 6 experience the greatest overall magnitude of drawdown at their maximum locations, while Impact Zones 2, 5 and 8 experience the least drawdown at their maximum drawdown locations. Similar results were obtained for the 1987 groundwater elevation change charts (Figures 9a through 9h) and the 1994 groundwater elevation change charts (Figures 10a through 10h).

Conclusions

The SACFEM model simulations appear to provide a reasonable depiction of the response of the groundwater and surface water system in the valley. The main conclusions from these model simulations are as follows:

- The magnitude of drawdown in the groundwater aquifers in the valley that is due to the hypothetical transfer pumping is relatively small. At the locations of maximum drawdown near each simulated project location, peak drawdown magnitudes are less than 20 feet and rapidly diminish with time. By the subsequent spring following a transfer pumping year, residual drawdown at these maximum locations recover to several feet or less. At further distances from the pumping zones, water levels recover to within a foot or two of pre-pumping levels. The results also show that after two years following the pumping, almost no appreciable drawdown remains. Based on the present analysis, and from a practical standpoint, it appears that the impact of transfer pumping should be considered for only up to two years following the pumping.
- The effect of groundwater substitution transfer pumping on stream flow, when considered as a percent of the groundwater pumped for the program, is significant. The impacts were shown to vary as the hydrology of the periods following the transfer program varied. The three scenarios presented here estimated effects of transfer pumping on stream flow when dry, normal, and wet conditions followed transfer pumping. Estimated stream flow losses in the five-year period following each scenario were 44, 39, and 19 percent of the amount of groundwater pumped during the four-month transfer period.
- When consideration of Delta conditions following the operation of a groundwater substitution transfer program are incorporated into the analysis, the influence of wet years versus dry years following pumping are very significant. The reduction in impacts following the pumping in 1994, which is followed by several wet years, is clearly evident in comparison to the simulated impacts following the 1976 and 1987 pumping.

Model Limitations

The current configuration of the SACFEM model includes a comprehensive transient surface water budget and agricultural pumping demand schedule; however, because of resource limitations during model development, several simplifying assumptions were made. The first regards the stage of the surface streams across the valley. Because of the lack of readily available data, the stream stages were assumed to be at average levels, with no increase in stage during winter higher-flow conditions. An analysis was performed to determine when specific unregulated streams would likely go dry in particular year types, and these estimates were included in the model simulations, but no attempt was made to quantify the transient rise and fall in river stage that would occur over the winter and spring months.

The second simplifying assumption that was made was that the quantity of deep percolation that reaches the groundwater table is not influenced by a change in groundwater elevations due to groundwater substitution transfer pumping. In most areas of the valley, this assumption is likely valid. In areas where the groundwater table lies beneath the root zone, changes in groundwater levels would have no effect on the amount of deep percolation that reaches the water table. However, in some limited areas where the water table is very shallow or at the ground surface, recharge that is currently rejected because of locally saturated conditions could begin to percolate once the groundwater levels drop. Areas where this may occur are groundwater discharge areas or areas of intensive irrigation, such as rice production areas.

The primary result of these simplifications on model predictions is most likely the extended duration of the predicted impacts of groundwater substitution transfer pumping on stream flow. As documented in this technical memorandum, the current configuration of the model predicts that a fairly modest-scale groundwater substitution transfer pumping program of approximately 82,000 acre-feet results in ongoing impacts to streams that persist for a decade or more. While the magnitudes of these effects are predicted to decline significantly over time, the overall duration of the impacts still appears long. This may be due to the fact that the only head-dependent boundary conditions in the model are streams and, therefore, all of the water needed to replenish the reduction in groundwater storage due to groundwater substitution transfer pumping must come from streams. This results in an asymptotic recovery curve where the rate of change of aquifer recovery decreases over time as groundwater levels rise and, consequently, a very long recovery period. If the effects of transient stream stages are incorporated into the model, during the winter months there will be a larger hydraulic gradient between the streams and the underlying groundwater in a groundwater substitution transfer pumping scenario than in a baseline conditions scenario. While this relationship also exists in the current static stream stage configuration, the gradient changes would be greater under a transient stream simulation. Whether this change is significant enough to shorten the duration of predicted stream impacts considerably is unknown.

If a defensible methodology can be developed to estimate the magnitude of any increase in deep percolation volume due to the depressed groundwater levels that result from groundwater substitution transfer pumping, this additional deep percolation could be imposed on the model as an additional specified recharge flux. This approach would shorten the duration of predicted stream flow impacts, but the magnitude of the effect would depend on the magnitude of the imposed increase in deep percolation volume.

It should also be considered that the actual duration of stream impacts due to groundwater pumping is relatively unknown. Stream gage data are almost always of insufficient accuracy to directly measure the change in stream flow due to groundwater discharge or stream leakage. Therefore, it is also possible that the long-duration effects predicted by the model are a good representation of the actual response of the hydrologic system to groundwater pumping. The recommended studies described briefly below may provide additional insight about the accuracy of the SACFEM model in predicting the magnitude and timing of stream flow impacts due to groundwater pumping.

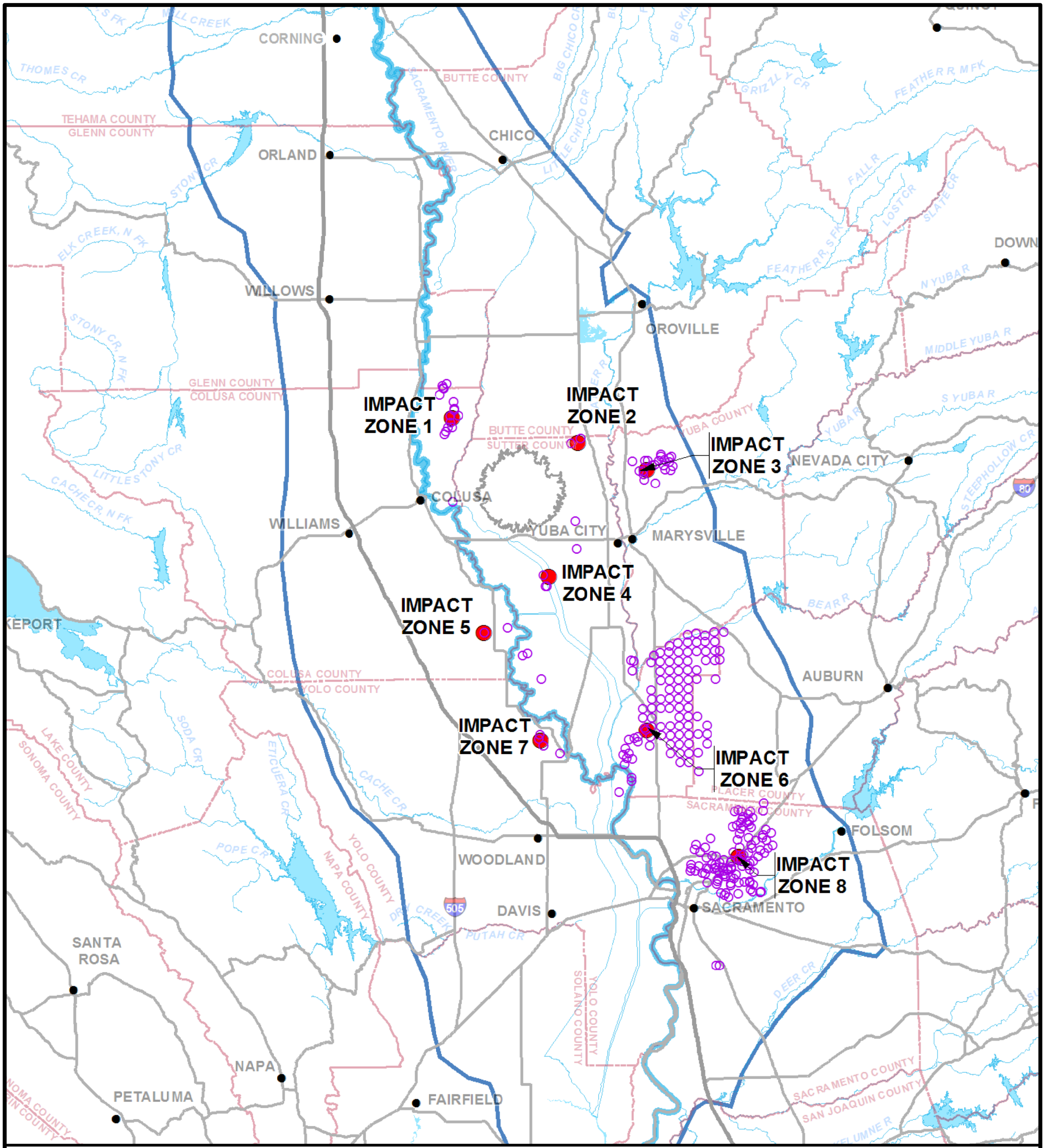
Recommendations

To better evaluate the implications of the model simplifications discussed above on SACFEM model predictions, the following studies are recommended:

- Gather available stream stage data for the primary streams within the model domain. To the extent possible, develop a methodology to assign transient stream stages on a monthly basis to the streams that are active in SACFEM. This will require transient stage data for each stream in the model and for all of the different reaches along a particular stream.
- Further investigate the relationship between groundwater levels and the magnitude of deep percolation that recharges that aquifer system. One potential approach is to analyze groundwater elevation data sets from past groundwater substitution transfer pumping projects that have been adequately monitored to provide estimates of the spatial distribution and timing of groundwater level recovery following pumping. These data can be compared to simulations of the pumping projects to identify where deviations occur between simulated and observed groundwater levels. The results of analyses of this type may provide direction as to where the discrepancies between model-simulated and actual deep percolation distributions originate.

AQUA-Exhibit 64

Figures



LEGEND

○ SIMULATED GROUNDWATER SUBSTITUTION TRANSFER WELL LOCATION

N

0 15 30 Miles

FIGURE 1
LOCATION OF MAXIMUM GROUNDWATER ELEVATION CHANGE IN EACH IMPACT ZONE

GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

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AQUA-Exhibit 64

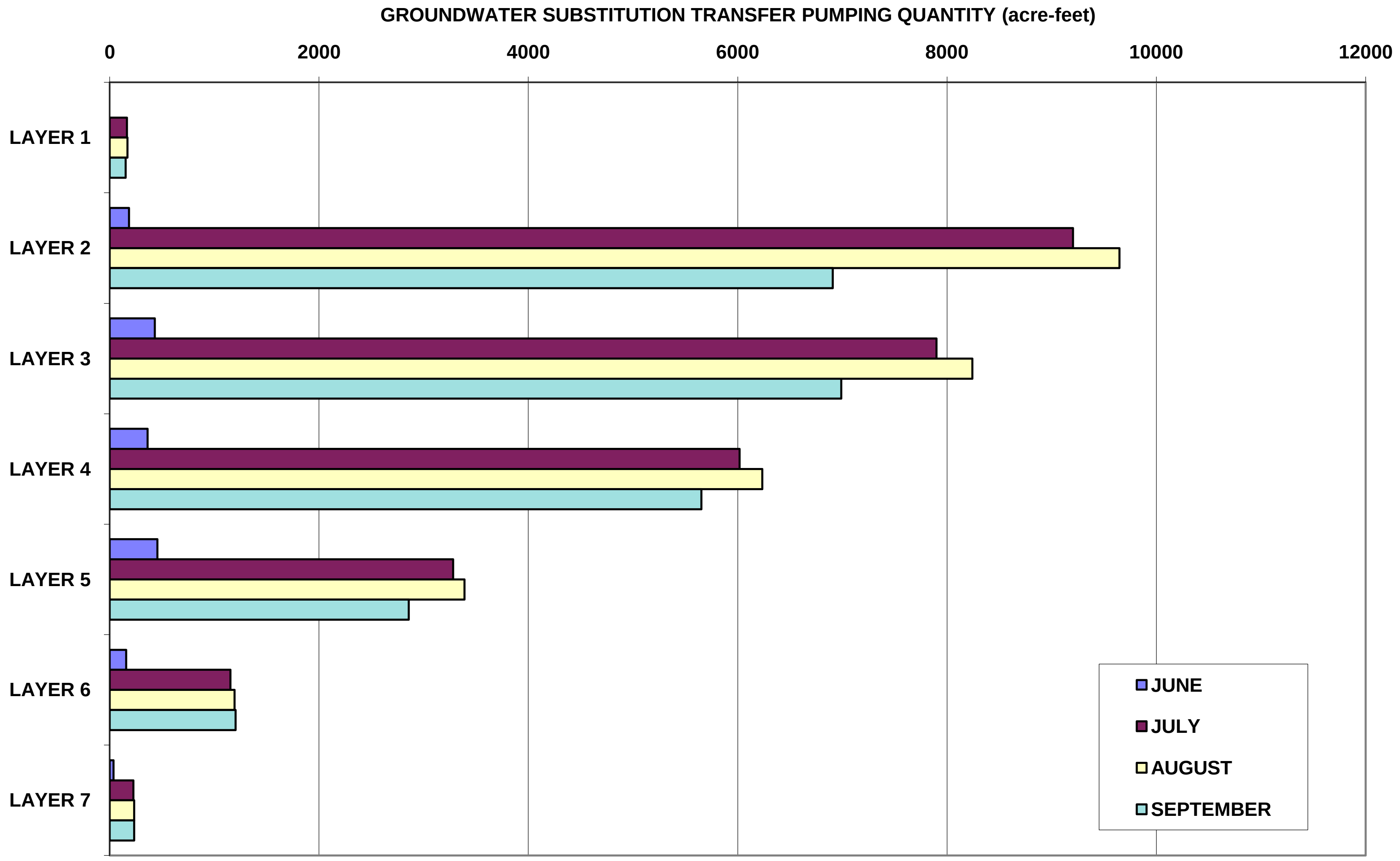

FIGURE 2
SIMULATED PUMPING VOLUME BY LAYER

GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

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AQUA-Exhibit 64

Water Year	October	November	December	January	February	March	April	May	June	July	August	September
1970	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Surplus	Surplus	Balanced	Balanced	Balanced
1971	Balanced	Surplus	Surplus	Surplus	Balanced	Surplus	Balanced	Surplus	Balanced	Balanced	Balanced	Surplus
1972	Balanced	Balanced	Surplus	Surplus	Balanced	Surplus	Balanced	Surplus	Surplus	Balanced	Balanced	Balanced
1973	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Balanced	Balanced
1974	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Surplus
1975	Surplus	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Surplus
1976	Surplus	Surplus	Surplus	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced
1977	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced
1978	Balanced	Balanced	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Balanced
1979	Balanced	Balanced	Balanced	Surplus	Surplus	Surplus	Balanced	Surplus	Balanced	Balanced	Balanced	Balanced
1980	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Balanced
1981	Balanced	Balanced	Balanced	Surplus	Balanced	Surplus	Surplus	Surplus	Balanced	Balanced	Balanced	Balanced
1982	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Surplus
1983	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus
1984	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Surplus	Surplus	Balanced	Balanced	Balanced
1985	Balanced	Surplus	Surplus	Surplus	Balanced	Balanced	Surplus	Surplus	Balanced	Balanced	Balanced	Balanced
1986	Balanced	Balanced	Surplus	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Surplus
1987	Balanced	Balanced	Balanced	Surplus	Surplus	Surplus	Balanced	Surplus	Balanced	Balanced	Balanced	Balanced
1988	Balanced	Balanced	Surplus	Surplus	Balanced	Balanced	Surplus	Balanced	Balanced	Balanced	Balanced	Balanced
1989	Balanced	Balanced	Balanced	Balanced	Balanced	Surplus	Surplus	Balanced	Balanced	Balanced	Balanced	Balanced
1990	Balanced	Balanced	Balanced	Surplus	Balanced	Balanced	Balanced	Surplus	Balanced	Balanced	Balanced	Balanced
1991	Balanced	Balanced	Balanced	Balanced	Balanced	Surplus	Balanced	Surplus	Balanced	Balanced	Balanced	Balanced
1992	Balanced	Balanced	Balanced	Balanced	Surplus	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced
1993	Balanced	Balanced	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Surplus
1994	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Surplus	Surplus	Balanced	Balanced	Balanced	Balanced
1995	Balanced	Balanced	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus
1996	Surplus	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Balanced	Surplus
1997	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Balanced
1998	Balanced	Balanced	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus
1999	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Surplus	Balanced	Balanced	Surplus
2000	Balanced	Balanced	Balanced	Surplus	Surplus	Surplus	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced
2001	Balanced	Balanced	Balanced	Surplus	Surplus	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced	Balanced
2002	Balanced	Balanced	Surplus	Surplus	Balanced	Balanced	Surplus	Surplus	Balanced	Balanced	Balanced	Balanced
2003	Balanced	Surplus	Surplus	Surplus	Balanced	Balanced	Surplus	Surplus	Balanced	Balanced	Balanced	Surplus

🟩 Surplus = Surplus

🟦 Balanced = Balanced

FIGURE 3
MONTHLY DELTA CONDITIONS FOR WATER YEARS 1970 THROUGH 2003

GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

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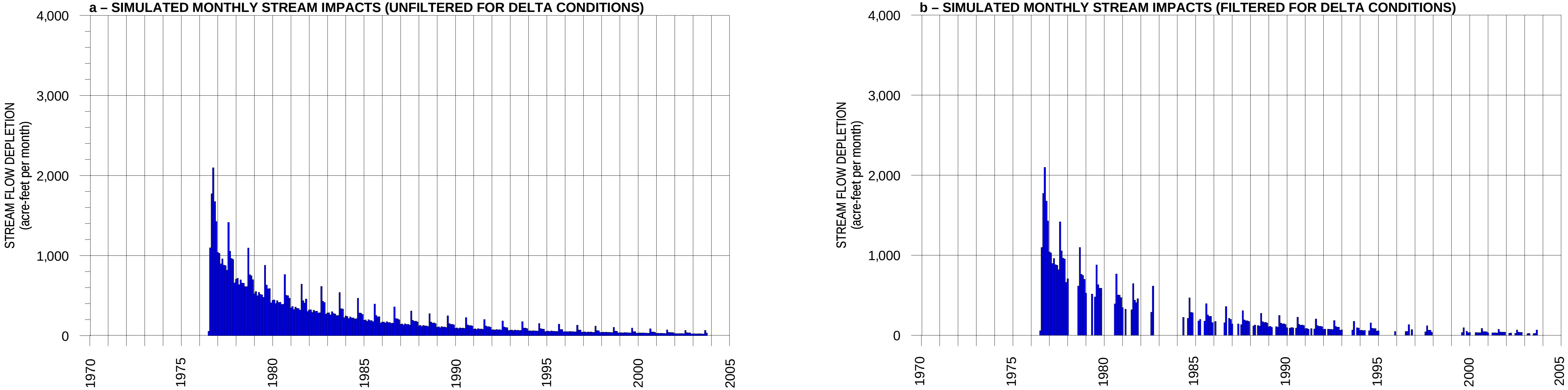
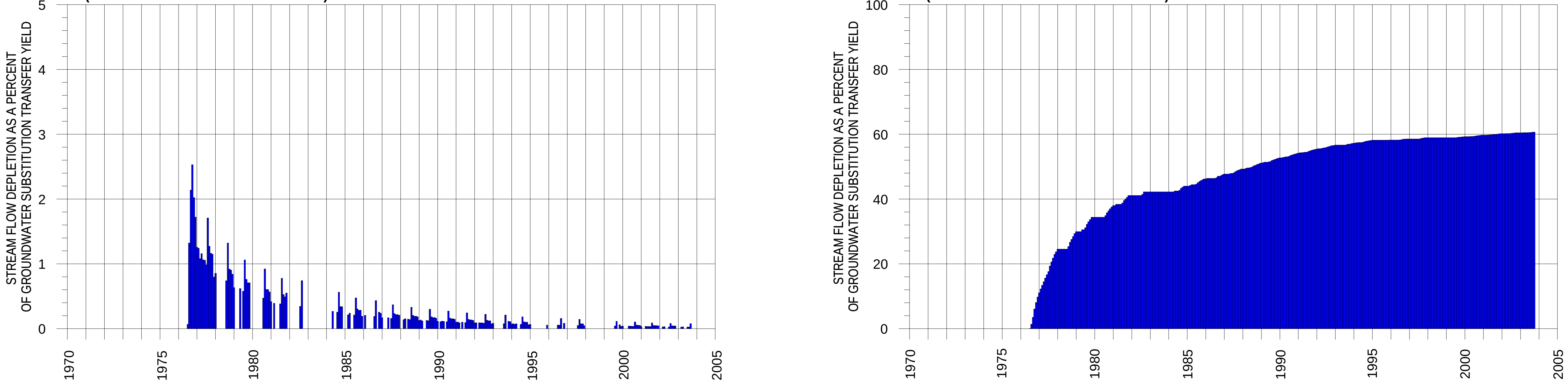
AQUA-Exhibit 64


a – SIMULATED MONTHLY STREAM IMPACTS (UNFILTERED FOR DELTA CONDITIONS)

b – SIMULATED MONTHLY STREAM IMPACTS (FILTERED FOR DELTA CONDITIONS)


c – SIMULATED MONTHLY STREAM IMPACTS AS A PERCENT OF TOTAL VOLUME
OF GROUNDWATER PUMPED DURING TRANSFER OPERATIONS
(FILTERED FOR DELTA CONDITIONS)

d – CUMULATIVE MONTHLY STREAM IMPACTS AS A PERCENT OF TOTAL VOLUME
OF GROUNDWATER PUMPED DURING TRANSFER OPERATIONS
(FILTERED FOR DELTA CONDITIONS)

FIGURE 4
STREAM IMPACTS FROM
1976 GROUNDWATER SUBSTITUTION
TRANSFER PUMPING
GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

FIG04.grf

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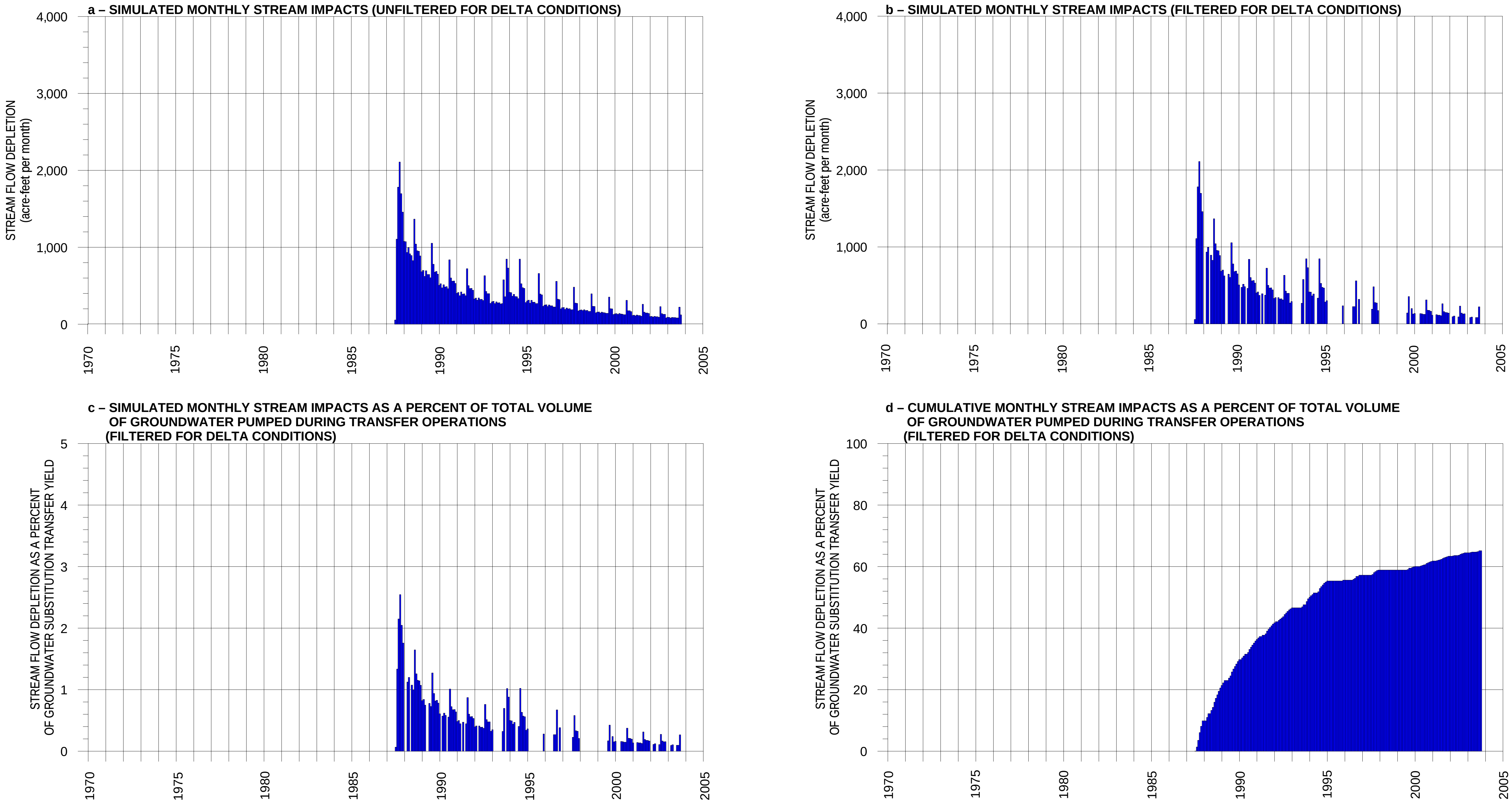
AQUA-Exhibit 64


a – SIMULATED MONTHLY STREAM IMPACTS (UNFILTERED FOR DELTA CONDITIONS)

b – SIMULATED MONTHLY STREAM IMPACTS (FILTERED FOR DELTA CONDITIONS)

c – SIMULATED MONTHLY STREAM IMPACTS AS A PERCENT OF TOTAL VOLUME OF GROUNDWATER PUMPED DURING TRANSFER OPERATIONS (FILTERED FOR DELTA CONDITIONS)

d – CUMULATIVE MONTHLY STREAM IMPACTS AS A PERCENT OF TOTAL VOLUME OF GROUNDWATER PUMPED DURING TRANSFER OPERATIONS (FILTERED FOR DELTA CONDITIONS)

FIG05.grf

FIGURE 5
STREAM IMPACTS FROM 1987 GROUNDWATER SUBSTITUTION TRANSFER PUMPING

GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

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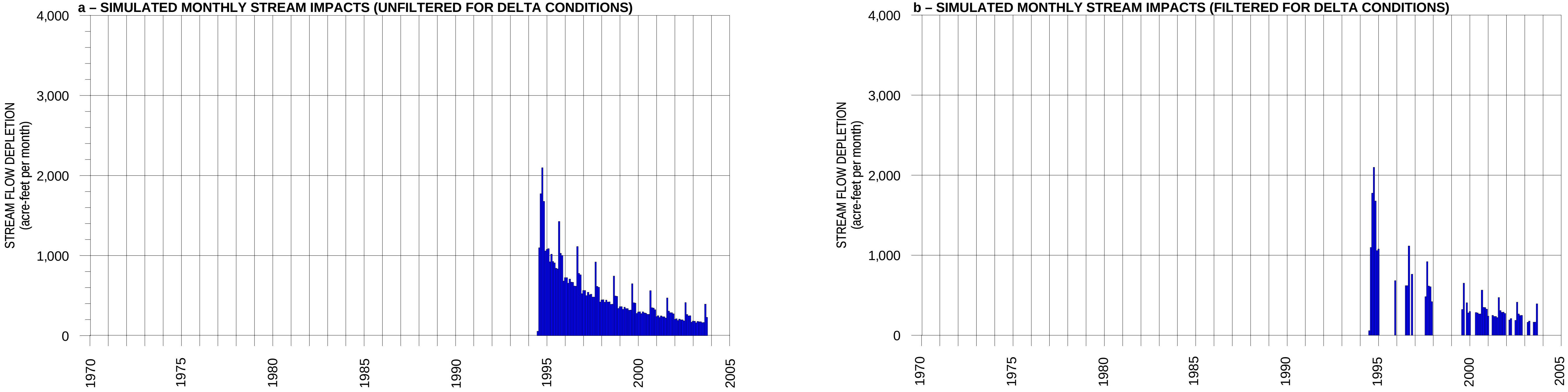
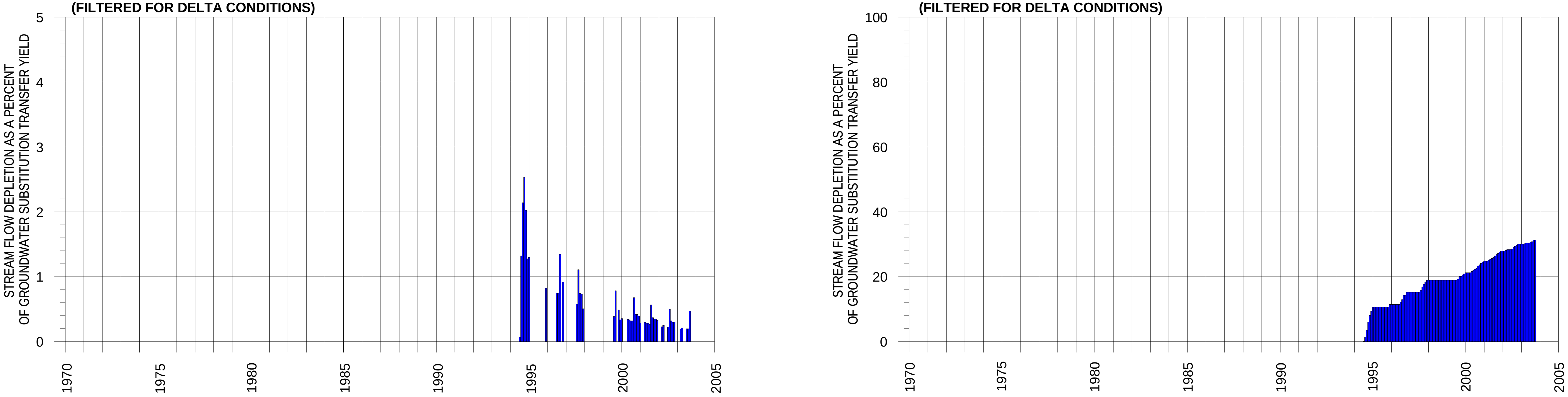

a – SIMULATED MONTHLY STREAM IMPACTS (UNFILTERED FOR DELTA CONDITIONS)

b – SIMULATED MONTHLY STREAM IMPACTS (FILTERED FOR DELTA CONDITIONS)

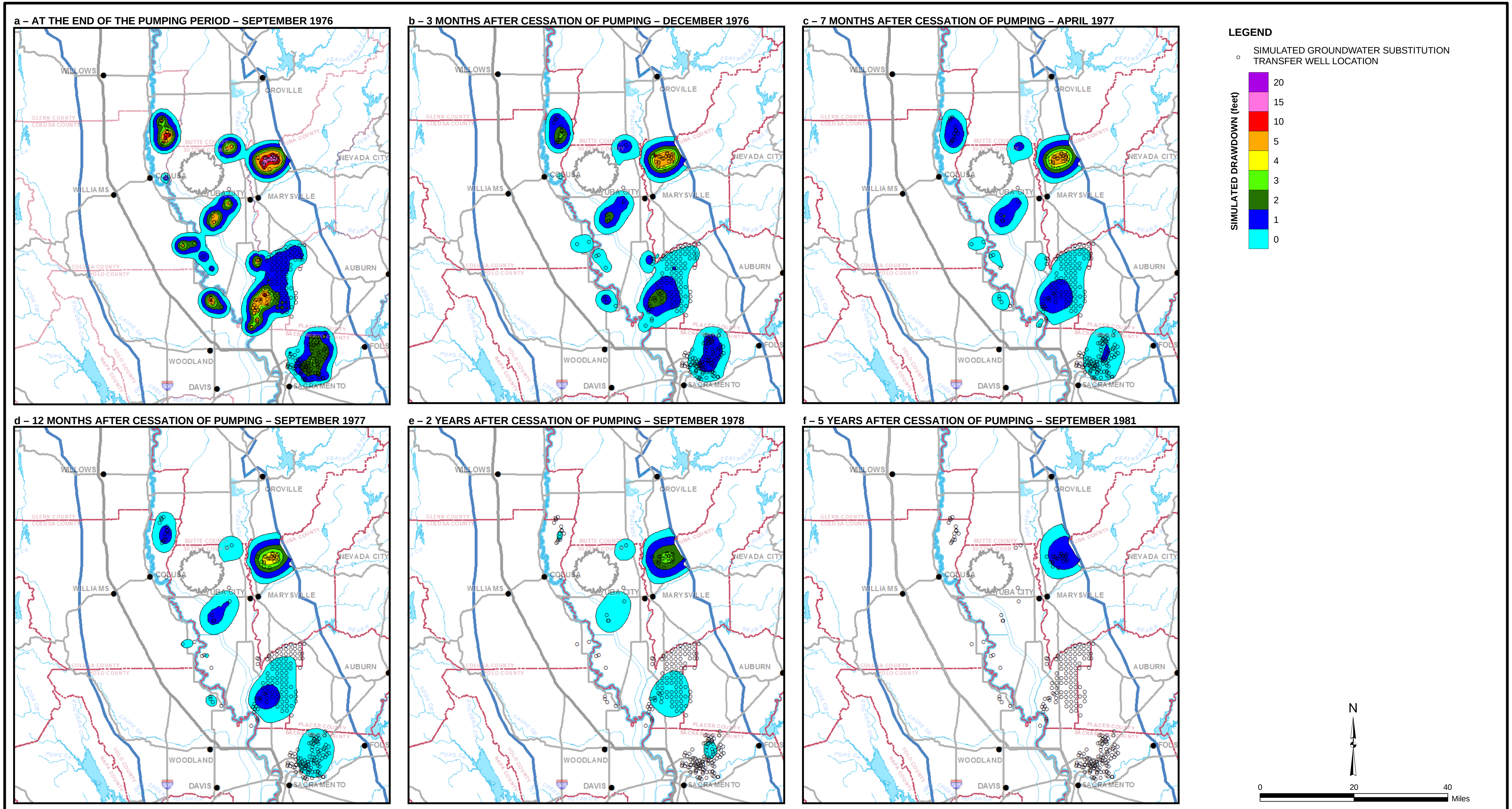

c – SIMULATED MONTHLY STREAM IMPACTS AS A PERCENT OF TOTAL VOLUME OF GROUNDWATER PUMPED DURING TRANSFER OPERATIONS (FILTERED FOR DELTA CONDITIONS)

d – CUMULATIVE MONTHLY STREAM IMPACTS AS A PERCENT OF TOTAL VOLUME OF GROUNDWATER PUMPED DURING TRANSFER OPERATIONS (FILTERED FOR DELTA CONDITIONS)

FIG06.grf

FIGURE 6
STREAM IMPACTS FROM
1994 GROUNDWATER SUBSTITUTION
TRANSFER PUMPING
GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

AQUA-Exhibit 64


a – AT THE END OF THE PUMPING PERIOD – SEPTEMBER 1976

b – 3 MONTHS AFTER CESSATION OF PUMPING – DECEMBER 1976

c – 7 MONTHS AFTER CESSATION OF PUMPING – APRIL 1977

d – 12 MONTHS AFTER CESSATION OF PUMPING – SEPTEMBER 1977

e – 2 YEARS AFTER CESSATION OF PUMPING – SEPTEMBER 1978

f – 5 YEARS AFTER CESSATION OF PUMPING – SEPTEMBER 1981

FIGURE 7
LAYER 2 SIMULATED GROUNDWATER DRAWDOWN FROM 1976 GROUNDWATER SUBSTITUTION TRANSFER PUMPING

GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

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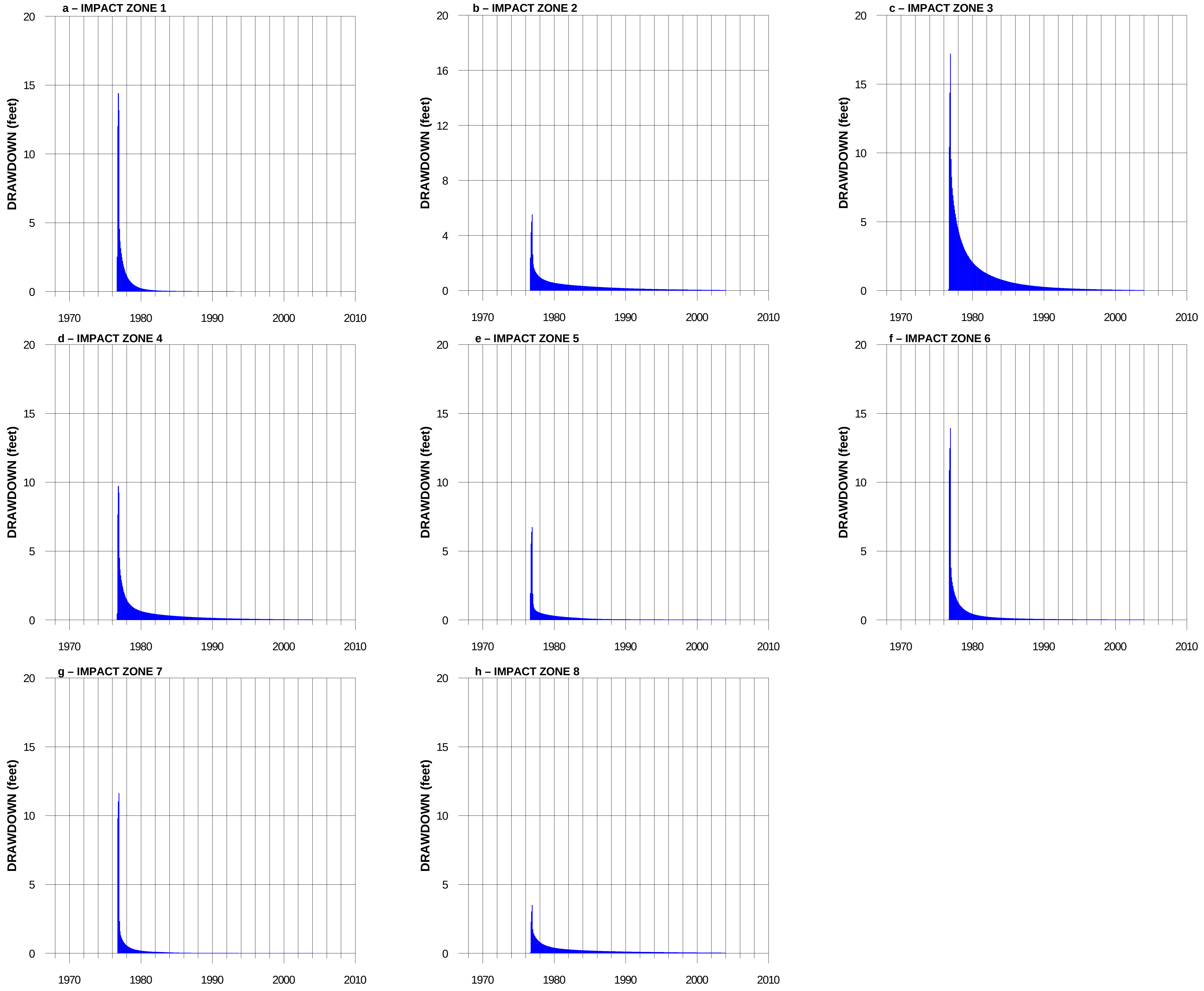

FIG8.grf

FIGURE 8
GROUNDWATER ELEVATION CHANGE – SCENARIO MINUS BASELINE HEADS UNDER 1976 GROUNDWATER SUBSTITUTION TRANSFER SIMULATED PUMPING
GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

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AQUA-Exhibit 64

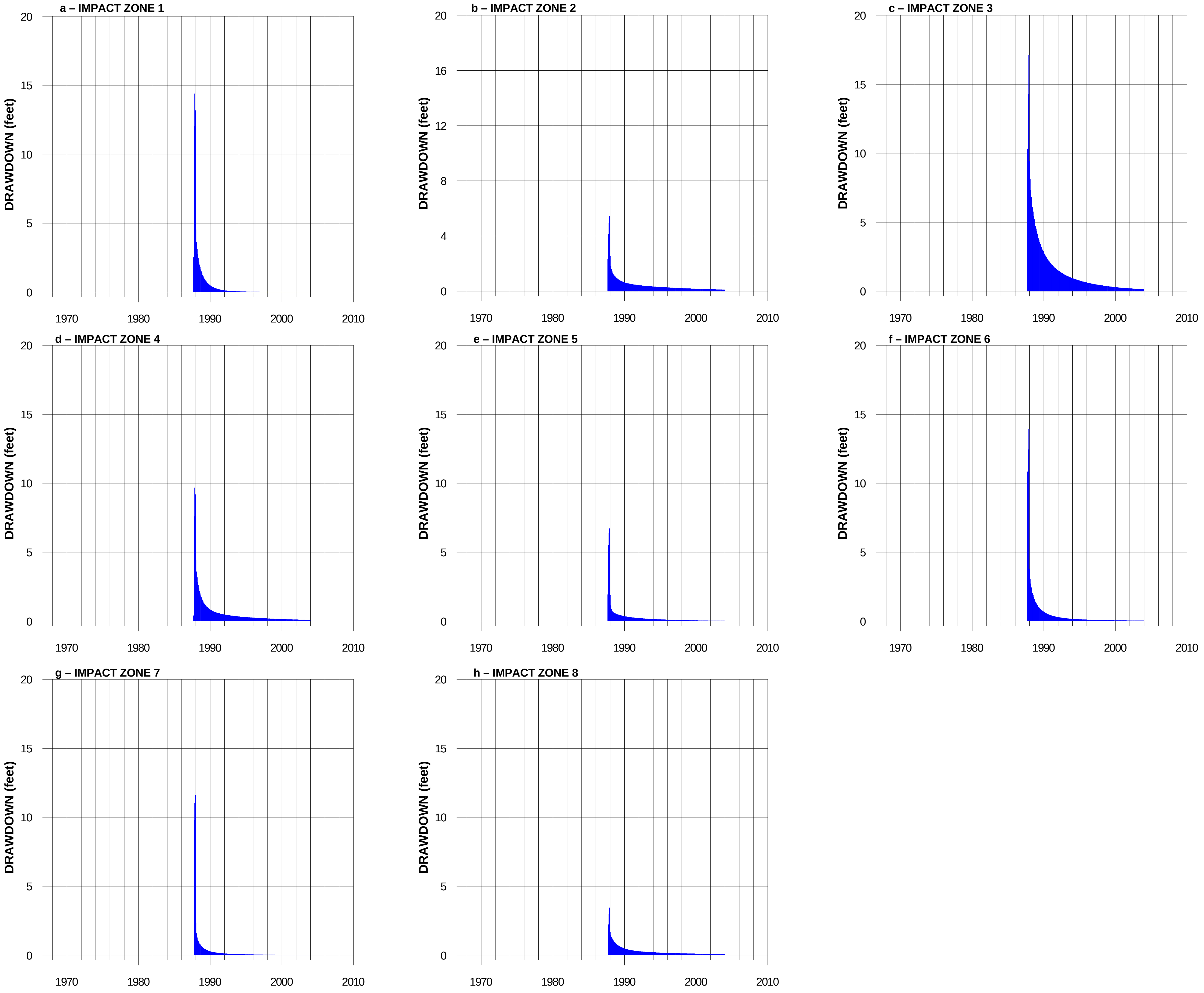

FIGURE 9
GROUNDWATER ELEVATION CHANGE – SCENARIO MINUS BASELINE HEADS UNDER 1987 GROUNDWATER SUBSTITUTION TRANSFER SIMULATED PUMPING
GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

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FIG9.grf

AQUA-Exhibit 64

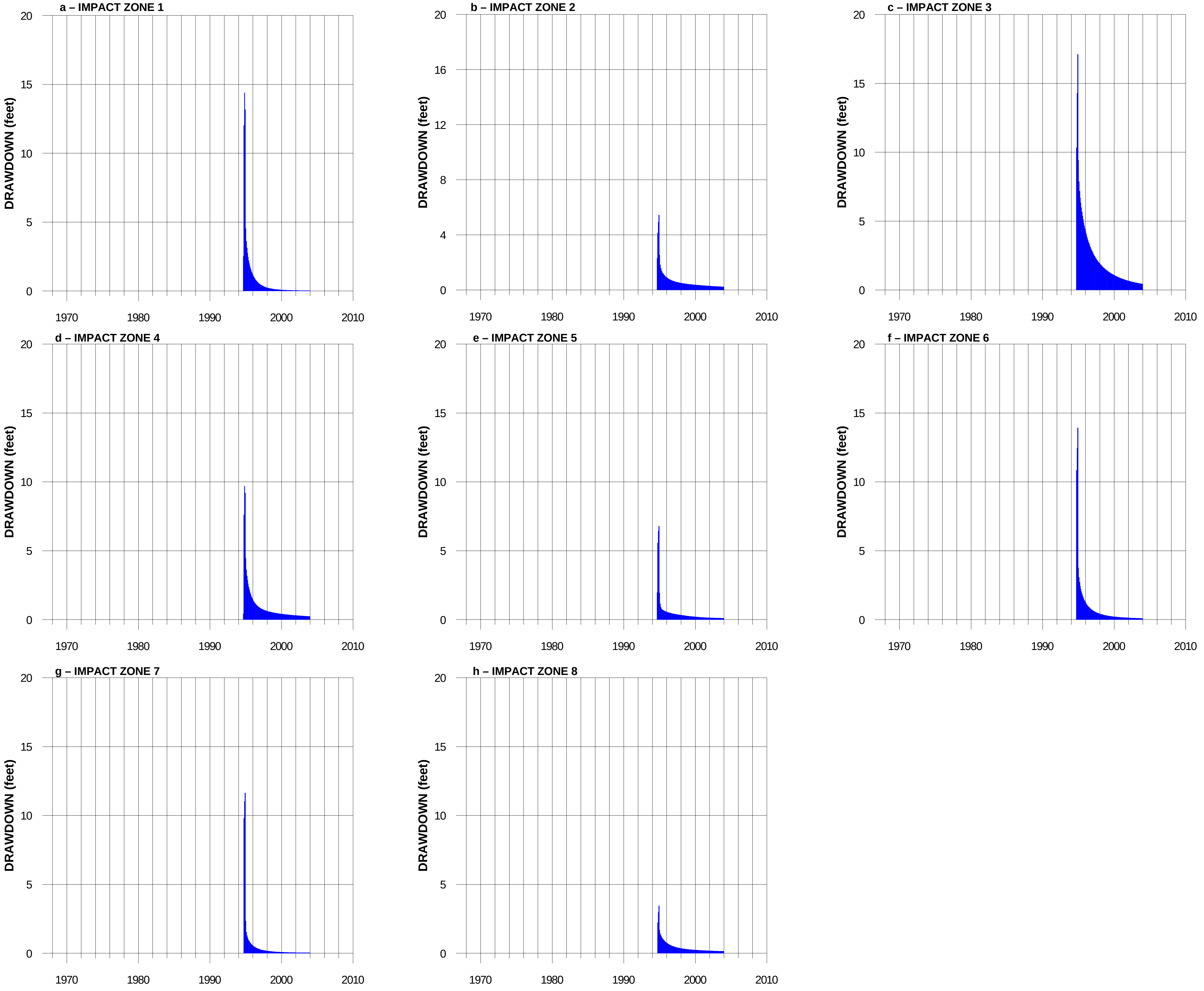

FIGURE 10
GROUNDWATER ELEVATION CHANGE – SCENARIO MINUS BASELINE HEADS UNDER 1994 GROUNDWATER SUBSTITUTION TRANSFER SIMULATED PUMPING

GROUNDWATER SUBSTITUTION TRANSFER IMPACT ANALYSIS
SACRAMENTO VALLEY

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FIG10.grf