Appendix A

Water Balance

Eastside System Model

The Eastside system was modeled and calibrated first. To simplify the analysis the upper boundary of the system was defined as being just above the soil or water surface and not including plants. This allowed all plant consumptive use to be accounted as water leaving the system. The bottom boundary was defined as the Corcoran Clay. This allowed calculation of a groundwater movement upward through the clay based upon an assumption that water confined under the clay was subjected to the same pressure as upper groundwater levels prior to pumping. See the explanation of vertical groundwater movement below for more detail. The sides bounding system were defined as vertical planes extending from the top boundary to the bottom boundary. The vertical boundary was adjusted in the plan view to encompass the approximate area of the Eastside Water District. However, the boundary was shaped to a curve in the plan view that maintained the groundwater gradient roughly perpendicular to the slope of the existing groundwater gradient during the period 1986 to 1991. This was done to allow calibrating the model by adjusting the K value for groundwater movement. After construction of the model, K was adjusted to make the model reflect the groundwater depletion that was exhibited from the period 1986 to 1991. This period was the most recent period of groundwater elevation data and cropping data. This period was selected so crop consumptive use would provide the most accurate reflection of the demands within this system. Thus the model could be calibrated to correlate with observed conditions.

The following enumeration describes the line items used in the water balance.

1. Precipitation: This is the acreage within the system times the annual average rainfall in feet.
2. Run on from precipitation: This is the tributary area that drains into the system times the average annual rainfall in feet times the runoff coefficient for the slope and ground cover conditions.
3. Imported water: This is also counted as run on. This is water actually delivered within the system from Turlock Irrigation District. This does not include water wheeled through the system via Turlock I.D. canals. For simplification, surface water flowing through the system is not included in the analysis.
4. Percolation from Significant Creeks and Canals: This is the percolation entering the system from each of the identified creeks or canals that flow through the system

and do not end within the system. The percolation was estimated based on the wetted area in acres and a percolation rate in feet per year. Where the creek or canal is not flowing year around the value was adjusted for the portion of the year it contained water. Actual flow in creeks or canals that flow in and out of the system was not accounted since the percolation from these is the only change to the system from these.

5. Horizontal GW Movement In: This is the formula K x i x A. A is the area, in acres, of the vertical boundaries below the groundwater surface, i is the slope of the groundwater surface where it crosses the boundary sloping into the system. K, hydraulic conductivity in feet per year, is determined to make the overall water balance agree with the conditions observed by the change in groundwater levels.
6. Vertical GW Movement In: This is the formula K x i x A. However, K here is the published value for the Corcoran Clay and i is assumed to be the difference in GW levels from pre-pumping levels to current levels divided by the thickness of the Corcoran Clay, assumed to be 300 feet. This total number was expected to be small enough to be negligible. However, as groundwater levels decline from overdraft the value of i will increase and upwelling of water from the confined aquifer will increase.
7. Evaporation from barren land: This is the evaporation of moisture from land that is not vegetated. It is base upon acreage times an annual evaporation value in feet.
8. Evaporation from surface impoundments: This is the annual evaporation rate in feet times the surface area in acres (average for the year) of any bodies of water that exist year around. Evaporation from bodies that exist a fraction of the year are either neglected or calculated based on the portion of the year they exist.
9. Evaporation from creeks and canals: This is calculated like surface waters that exist only a fraction of the year. This is only applied to creeks and canals that end within the system. Creeks and canals passing through the system are assumed to make no change to the system except for percolation and water diverted and remaining within the system.
10. Evaporation from irrigation water: This is the quantity of crop consumptive use minus effective precipitation multiplied by the sum of 1 minus the irrigation efficiency for the typical irrigation type used for that crop within the system. This number represents the water that evaporates during the irrigation process.
11. Runoff: This is the Precipitation times the runoff coefficient for the slope and ground cover conditions for the area of the system that drains out of the system
12. Runoff from run on: This is the quantity of run on that enters the system minus any water staying in the system from percolation.
13. Runoff from drainages originating within the system: This is the estimated runoff from drainages within the system that are fed by groundwater. These are

drainages that continue to flow after runoff generated from precipitation has ceased. This is not considered a large amount for the EWD system and is estimated based upon field observations.

14. Exported surface water: This is water that is conveyed out of the system.
15. Horizontal groundwater movement out: This is the same as horizontal groundwater movement above. However, it is applied to the area of vertical boundary beneath the groundwater surface where the groundwater surface slopes out of the system. K is the same value as used above.
16. Vertical groundwater movement out: This is the same as vertical groundwater movement above accept applied where the gradient is out of the system. This is assumed to not occur within the systems defined.
17. Consumptive Use: This is the plant consumptive use times the acreage of that crop or native vegetation. This is not adjusted for effective precipitation. This represents all water leaving the system via plant consumptive use regardless of its path within the system. Note that effective precipitation was not neglected when evaporation from irrigation water was calculated.
18. Municipal and Industrial use: This represents water that is withdrawn from the system and consumed. This does not include water used within the system or withdrawn from, then returned to, this system. Households operating septic systems would not be included in this accounting. Municipal systems that drain to sewers and are discharged within the system are also not included in this accounting. Municipal systems that drain to sewers that discharge outside the system are included in the accounting.

The Eastside system water balance is shown in Table 3.1.

Turlock System

The Turlock system was modeled after the Eastside system using the calibration information from the Eastside system. The Turlock system boundaries were defined as follows: The upper boundary of the system was defined as being just above the soil or water surface and <u>not</u> including plants. The bottom boundary was defined as the Corcoran Clay. The sides bounding system were defined as vertical planes extending from the top boundary to the bottom boundary. The vertical boundary in the plan view was defined as the centerline of the Tuolumne, Merced and San Joaquin Rivers, and the 500 foot contour running between the Tuolumne and Merced Rivers.

The same types of line items were used as in the Eastside system. However, differing conditions in the Turlock system required more rigorous review and analysis of conditions at boundaries and surface waters. These considerations are described below.

1. Precipitation: Area is the only change.
2. Run on from precipitation: This is the tributary area that drains into the system times the average annual rainfall in feet times the runoff coefficient for the slope and ground cover conditions. This did not include surface water that flowed through the system such as the rivers.
3. Imported water: This is also counted as run on. This is water actually delivered within the system from Turlock Irrigation District and Merced Irrigation District. This does not include water wheeled through the system.
4. Percolation from Significant Creeks and Canals: This definition remained the same. Note, the boundary rivers were considered to be outside of the system and therefore did not contribute a percolation amount. Instead the rivers were considered the source that supplied water to horizontal groundwater movement. Also, the gradient of the groundwater adjacent to the river was analyzed to determine if the river was recharging or draining the system.
5. Horizontal GW Movement In: This used the same formula as before with the K value set at the K determined for the Eastside system. At the boundaries of the system the slope was determined and then the groundwater movement was calculated. This analysis assumes the water was moving to or from the adjacent aquifer or river either one. For simplification the possible double counting by considering percolation from boundary rivers and groundwater movement was not reconciled.
6. Vertical GW Movement In: This was applied as before. However, the thickness of the Corcoran clay was adjusted to be representative of the Turlock system.
7. Evaporation from barren land: This is unchanged.
8. Evaporation from surface impoundments: This is unchanged.
9. Evaporation from creeks and canals: This is unchanged.
10. Evaporation from irrigation water: This is the quantity of crop consumptive use minus effective precipitation multiplied by the sum of 1 minus the irrigation efficiency for the typical irrigation type used for that crop within the system. This number represents the water that evaporates during the irrigation process.
11. Runoff: This is unchanged.
12. Runoff from drainages originating within the system: This is unchanged.
13. Exported surface water: This is water that is conveyed out of the system. In the Turlock system this includes groundwater that is pumped out to control groundwater levels in the lowest parts of the basin. This groundwater is discharged to surface waters that leave the system. Hence they are accounted here.

14. Horizontal groundwater movement out: This was analyzed as before with adjustment previously described in horizontal groundwater movement in above.
15. Vertical groundwater movement out: This is the same as vertical groundwater movement above accept applied where the gradient is out of the system. This is assumed to occur only where groundwater levels are being controlled by pumping and groundwater is high due to applied irrigation water. This is the lowest portions of the system near the San Joaquin River.
16. Consumptive Use: This is the plant consumptive use multiplied by the acreage of that crop or native vegetation. This is not adjusted for effective precipitation. This represents all water leaving the system via plant consumptive use regardless of its path within the system. Note that effective precipitation was not neglected when evaporation from irrigation water was calculated.
17. Municipal and Industrial use: This represents water that is withdrawn from the system and consumed. This does not include water used within the system or withdrawn from, then returned to, this system. Households operating septic systems would not be included in this accounting. Municipal systems that drain to sewers and are discharged within the system are also not included in this accounting. Municipal systems that drain to sewers that discharge outside the system are included in the accounting.

The Turlock system water balance is shown in Table 3.2.

Analysis of Safe Yield

The safe yield for this analysis is determined by the following equation:

Safe Yield = Groundwater Extraction – Change in Groundwater Storage. In this equation a reduction in the groundwater storage is a positive number and an increase in the groundwater storage is a negative number.

EASTSIDE SYSTEM CALCULATION OF SAFE YIELD

The safe yield was calculated for the Eastside system by using the water balance to determine the quantity of groundwater pumped and by using the change in the quantity of groundwater in storage based upon the groundwater contours and their change over a year. A five year interval was analyzed. The change in groundwater storage was then assumed to be equally spread over five years.
To calculate the change in groundwater storage the average change in groundwater elevation was multiplied by the porosity

and the area the change in elevation represented. The value used for the porosity of the aquifer materials was 0.15.

The quantity of groundwater extracted minus the change in the groundwater in storage produced the estimated safe yield.

In the EWD system the most recent interval from 1996 to 2000 had a rate of depletion of about 32,000 AFY. Subtracting the change in groundwater storage, 32,000 AFY from the groundwater usage, 157,000 AFY for the EWD system indicates a safe yield of 125,000 AFA.

TURLOCK SYSTEM CALCULATION OF SAFE YIELD USING THE WATER BALANCE

The safe yield for the Turlock system was estimated using the water balance by subtracting the change groundwater storage from the total of groundwater withdrawals.

The groundwater withdrawals are estimated by subtracting the surface water use from the crop water requirement and then adding estimated quantities of pumped municipal and private water that is used and not returned to the groundwater system.

Based upon the water balance the Turlock system has a loss in groundwater storage for the period of 1996 to 2000 of 65,000 AFY. The safe yield was determined by subtracting the current overdraft of 65,000 AFY from the current groundwater usage of 316,000 AFY, indicating a safe yield of 251,000 AFY

Model Construction

Calibration of the model

After the value of overdraft was determined for the EWD system, the value of k used to calculate the horizontal groundwater movement and was adjusted to make the values of overdraft in the water balance agree with the overdraft determined from analyzing the groundwater contours. This values was then used for all the horizontal groundwater calculations in both water balance systems.

Precipitation

Precipitation varies widely from year to year, and the majority of this precipitation falls during the winter. The reported annual average precipitation based on a forty-year average for the Basin is 11.08 inches (EWD, 1997). The Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo published evapotranspiration and precipitation results for a dry year with a precipitation of 11.5 inches. For the water balance a value of 11 inches was used.

Evapotranspiration by crop

The crop evapotranspiration (ETc) values were obtained from the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo and by using the California Department of Water Resources Evapotranspiration Zone Map.

The California Department of Water Resources Evapotranspiration Zone Map separates California into 18 zones. For this project only zone 12 was used in determining ETc, which includes the majority of EWD irrigated lands.

The resulting values for crop evapotranspiration were used as values for crop consumptive use in the water balances.

Irrigation Efficiencies

Irrigation efficiency is defined as the ratio of water beneficially used by irrigated crops, ETc, to the water applied to the crop.

The following equation can be used to calculate irrigation efficiency:

$$\text{Irrigation Efficiency} = \frac{ETc}{Applied Water}$$

The portion of applied water that is not consumed by the crop either percolates back into groundwater or evaporates. In preparing the water balance it has been assumed that fifty percent of irrigation inefficiency was attributable to evaporation.

With this assumption, and the irrigation efficiencies published below, the additional demand for water that left the water balance system was estimated by dividing the crop consumptive demand by the irrigation efficiency and dividing by two. This value was then multiplied by the crop acreage to determine the portion of water that left the system through evaporation from irrigation.

The EWD Irrigation Water Master Plan published by Boyle Engineering in 1990 evaluated irrigation efficiencies of each crop based on site visits, published data, and surveys.

Table A.1 EWD Irrigation Efficiencies

Crop	Estimated Average Irrigation Efficinecy
Alfalfa	70
Almond	75
Apricot	70
Corn	70
Dry Bean	65
Grain	70
Pasture	60
Peach/Nectarine	70
Vineyard	75
Walnut	70

Vertical Groundwater Movement

Vertical groundwater movement was calculated using the formula K x i x A. Where A was the horizontal area of potential flow. K is the published value for the Corcoran clay of 10^{-8} ft. per second converted to units of feet per year. The slope was calculated using 300 feet to approximate the thickness of the Corcoran clay and represent the horizontal value in calculating the slope. The change in elevation, 90 feet, was determined to be the difference between the existing groundwater surface elevation and its historic elevation prior to groundwater pumping. These values were used to calculate the difference in pressure and the distance over which the pressure difference occurs. This value then representing a slope for the calculation of flow of water up through the Corcoran clay.