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Subsurface Flows Water Balance Components for Irrigation Districts in the San Joaquin Valley

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Cal Poly ITRC has conducted several water balances for regions or districts within the San Joaquin Valley. In each case, the greatest unknown component for the water balance is subsurface flows (ITRC, 1994).

Water balance calculations can be confusing, especially in districts where there is groundwater pumping. Some of the common problems of creating correct water balances include:

1) Not defining the boundary of evaluation
2) Double counting water
3) Counting all pumped water as a water supply
4) Mixing of field-level and project-level values
5) Not counting some of the water balance components

This paper will discuss ITRC efforts to determine both lateral and vertical components of subsurface flow, the accuracy of the estimates, and the impact upon the accuracy of the final estimates of irrigation district or regional irrigation efficiencies.

Boundaries

The first step to create a water balance is to define the boundaries. The boundaries of the irrigation district service area need to be defined both horizontally and vertically for the water balance evaluation. This requires an accounting of all of the water that enters and leaves a 3-dimensional space.

For an irrigation district with groundwater pumping, the boundary is described as follows. The upper boundary would be the crop canopy. The horizontal boundaries would be simply the district boundaries. The lower boundary would be the bottom of the aquifer. For districts without groundwater pumping, the lower boundary would be the bottom of the root zone.

For most districts on the eastside of the San Joaquin Valley, the lower boundary is represented by the physical limit of the pumping depths. However, on the westside of the San Joaquin Valley, the usable groundwater for a district is the unconfined aquifer above the Corcoran Clay. This paper will discuss the condition on the westside where it is common to have an influence by the Corcoran Clay layer.

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Water Balance Components

The following is an example of the simple partitioning of the water balance. All of the components that enter and leave the 3-dimensional boundaries are included in the water balance. Any water that is recycled within the boundaries of the evaluation might be considered interesting but are not used for the water balance. Figure 1 shows the components for a typical water balance.

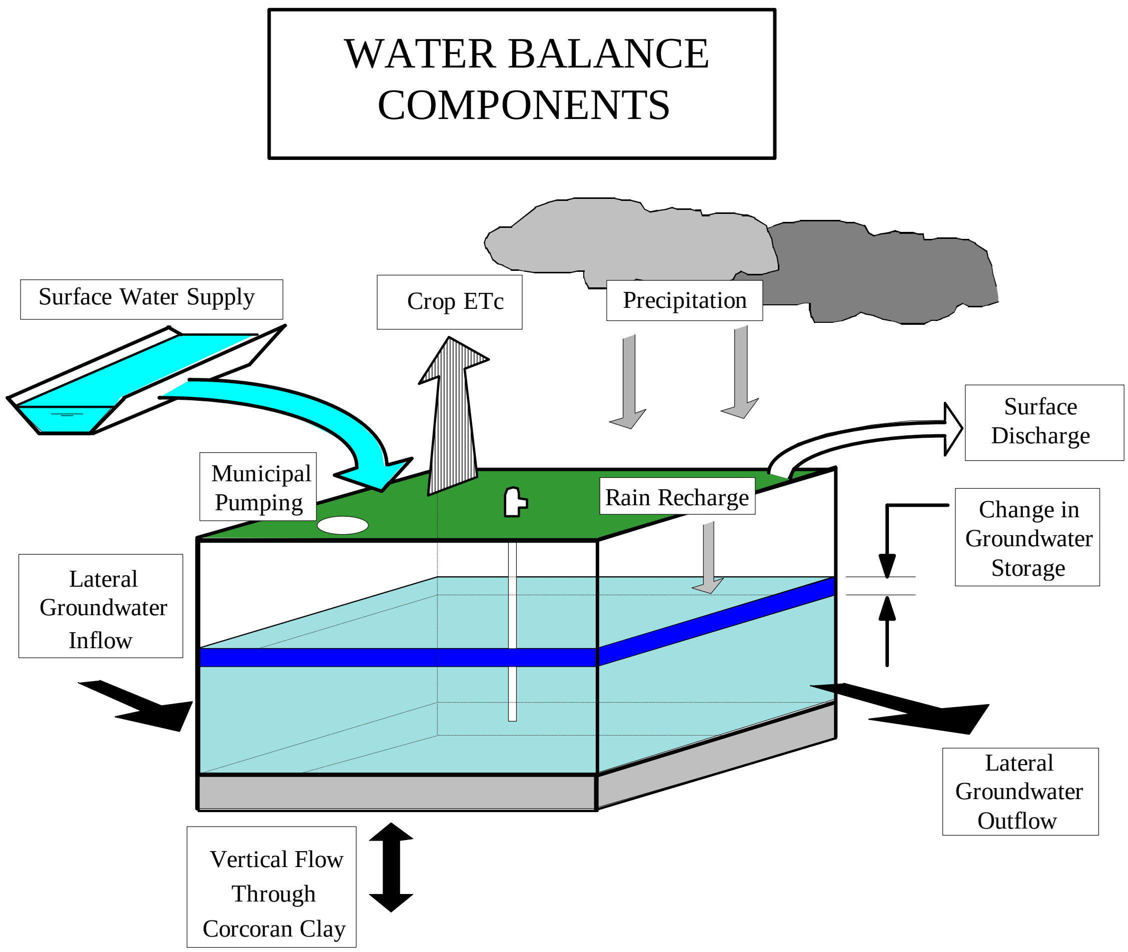

Figure 1. Water Balance Components

Groundwater

The groundwater system in the southern San Joaquin Valley provides a supply of irrigation water when surface deliveries to the area are reduced in water short years. The groundwater system in the service area is divided into two aquifer systems divided by the Corcoran Clay layer. The components which influence the groundwater supply are shown graphically in Figure 2.

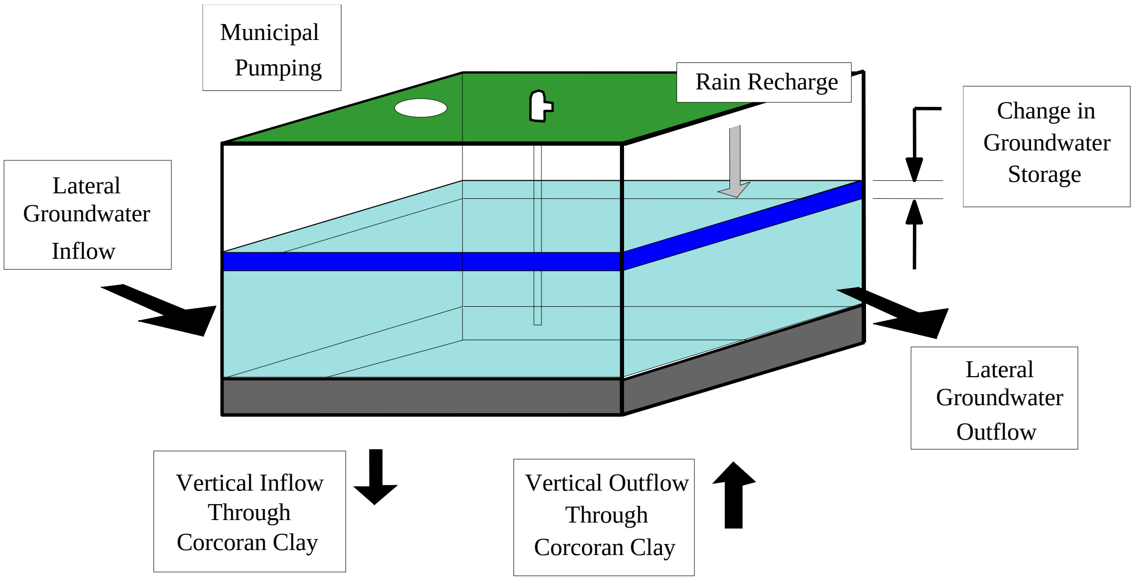

Figure 2. Groundwater Components

Subsurface Inflow/Outflow

Subsurface lateral water is typically ignored or grossly misinterpreted in the interpretation of a water balance. It is common to evaluate the groundwater gradients in the upper aquifer region above the Corcoran Clay and find that water moved from upslope water districts into the district area evaluated. Similarly, water will exit the boundary of the district area and travel to the next downstream district. This section is a summary of the evaluation procedure used to evaluate both the subsurface lateral inflow and the subsurface lateral outflow.

Groundwater flow was estimated using Darcy's Law: Q = Kia.

Where, K = the permeability of the soil
i = groundwater gradient
a = cross-sectional area perpendicular to direction of flow

The **area (a)** for this calculation is the width along a boundary where water enters the district boundary multiplied by the depth of the aquifer where flow is occurring. This typically needs to be broken into several subsections due to irregular district boundaries. The **width** of the sections needs to be estimated for both the inflow boundaries and the outflow boundaries. The **depth** of flow can be slightly more difficult to determine. The depth is typically estimated from several sources. The elevation of the Corcoran Clay can be determined from contour maps showing the elevation of the base of Corcoran Clay and the thickness (Hotchkiss, 1972). By adding the thickness of the layer at a specific point to the elevation of the layer at the same point, it is possible to calculate the elevation of the top of the Corcoran Clay.

Water elevations of the unconfined aquifer can be obtained from maps for unconfined groundwater levels (DWR, 1993) and used to determine water elevations along both the inflow and outflow border of each subsection. Figure 3 shows the width and depth used for the calculation of lateral flows.

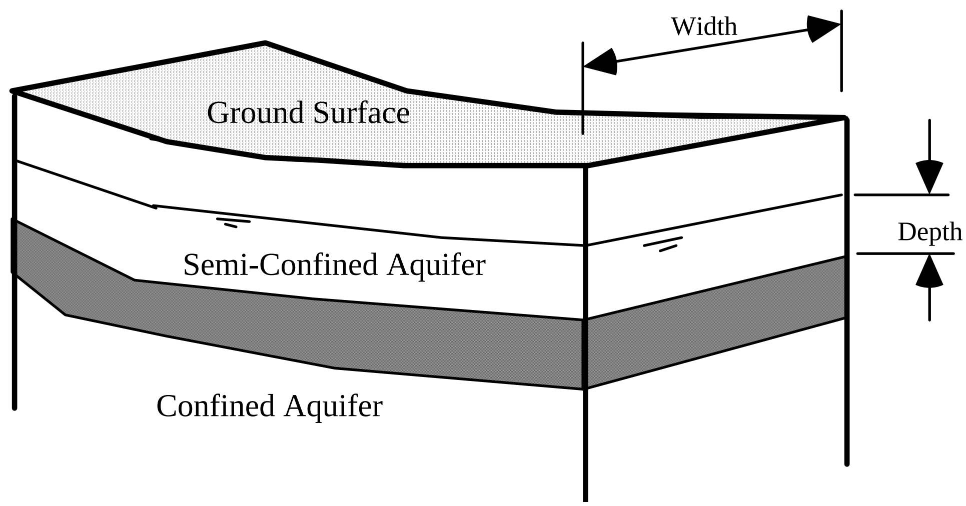

Figure 3. Cross-Section Showing Area Calculation

The following is a simple procedure to determine the **hydraulic gradient (i)**. Groundwater elevation contour maps can be used to calculate the groundwater gradient (DWR, 1993). This gradient indicates potential for and direction of groundwater movement. Taking the elevation of groundwater on each side of the subsection boundary and subtracting the one from the other yields the change in elevation. The change in elevation is then divided by horizontal distance between the points to calculate the gradient. Figure 4 shows the generalized groundwater elevation contours for Spring, 1993.

The **hydraulic conductivity (K)** the upper aquifer can be estimated from USGS reports (USGS, 1991). The $K_{unconfined}$ has been estimated at **3.5×10^{-4} feet per second** for portions of the westside of the San Joaquin Valley. This value could range significantly throughout the region depending on soil type. Other $K_{unconfined}$ values in the laboratory on soils in this region (sand, silty sand, and sandy silt) ranged from mean values of 1.4×10^{-4} to 1.0×10^{-6} feet per second.

Subsurface Lateral Flow Calculations

The following calculation is the estimate of subsurface lateral flow for a sample region shown on Figure 4. For this calculation, the width of the boundary where water is entering the district is 20,000 ft. The depth of the aquifer along this boundary is 300 feet. The hydraulic gradient is about 0.0025 ft/ft.

LATERAL seepage <u>into</u> the area of study.

Q = Kia

Q = 0.00035 ft/s x .0025 ft/ft x 20,000 ft x 300 ft

= 5.25 CFS

The following calculation assumes that this condition occurs for 365 days of the year.

Volume = QT

= 5.25 CFS x 1.9835 AF/cfs in 1 day x 365 days

= 3,801 AF

LATERAL seepage <u>from</u> the area of study.

Q = Kia

Q = 0.00035 ft/s x 0.001 ft/ft x 20,000 ft x 200 ft

= 1.40 CFS

The following calculation assumes that this condition occurs for 365 days of the year.

Volume = QT

= 1.40 CFS x 1.9835 AF/cfs in 1 day x 365 days

= 1,014 AF

Net LATERAL seepage <u>to</u> the area of study.

3,801 AF - 1,014 AF = **2,787 AF (+/- 30%)**

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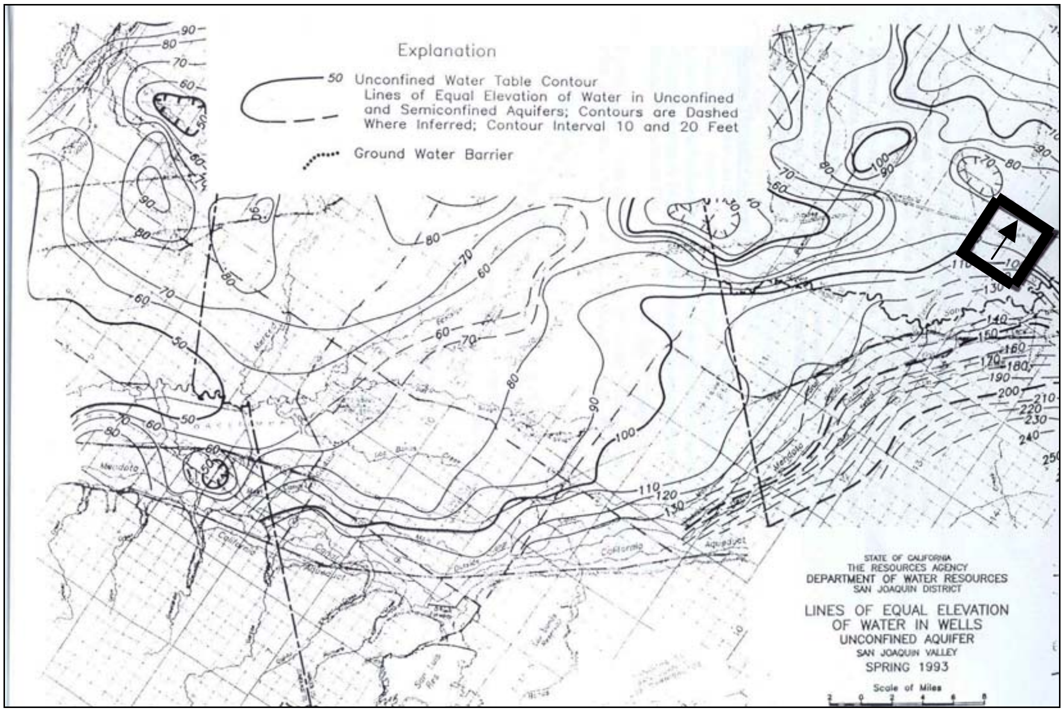
Figure 4
Lines of Equal Elevation of Water in Wells, Unconfined Aquifer - Spring, 1993



As part of the water balance calculations, it is important to assign a level of confidence to the reporting of the subsurface lateral flow value. Typically, the interval may be as high as +/-30-50% due to the potential variability of the soils on the westside of the San Joaquin Valley. However, the relative value compared to the other water balance components is typically very low so there is little impact to the overall accuracy of the water balance calculations. For example, the irrigation water applied may be as much as 10 times greater than the subsurface lateral inflow and may have an interval of less than +/- 5% due to accurate flow measurement devices.

Seepage Through Corcoran Clay

Subsurface water can also exit the boundaries of an irrigation district through the Corcoran Clay. Water can exit the lower limit of the boundary from upper aquifer (unconfined) to the lower aquifer (confined) through the Corcoran Clay. This section is a summary of the evaluation procedures used to estimate seepage through the Corcoran Clay.

Figure 5 shows generalized flow from the upper aquifer to the lower aquifer. Flow through the Corcoran Clay was estimated using Darcy's Law for flow.

Darcy's law: $Q = Kia$

Q = flow rate
K = hydraulic conductivity (ft/s)
i = hydraulic gradient (change in head with distance, feet)
a = cross sectional area of flow (square feet)

The equation is the same for the subsurface lateral flow calculation and the subsurface vertical flow calculations. However, the variables are determined differently. The **area (a)** is just the surface area of the district. For this example, it is 10,000 acres. The entire 10,000 acres are used to estimate of the water moving through the Corcoran Clay.

Hydraulic Gradient

The determination of the **hydraulic gradient (i)** is difficult due to constraints on available data. A study completed by Mendenhall (1916) showed that the portions of the westside of the San Joaquin Valley had regions of artesian wells. This indicated the water was probably migrating from the deeper aquifer to the upper aquifer. Available information suggested this has not occurred in this area after 1950.

The development of agricultural pumping in the region caused a lowering of the piezometric water surface elevations in the lower confined aquifer. Water surfaces in the upper aquifer are now higher that the water surfaces in the lower aquifer. The head difference indicates a vertical hydraulic gradient that causes water to seep through the Corcoran Clay.

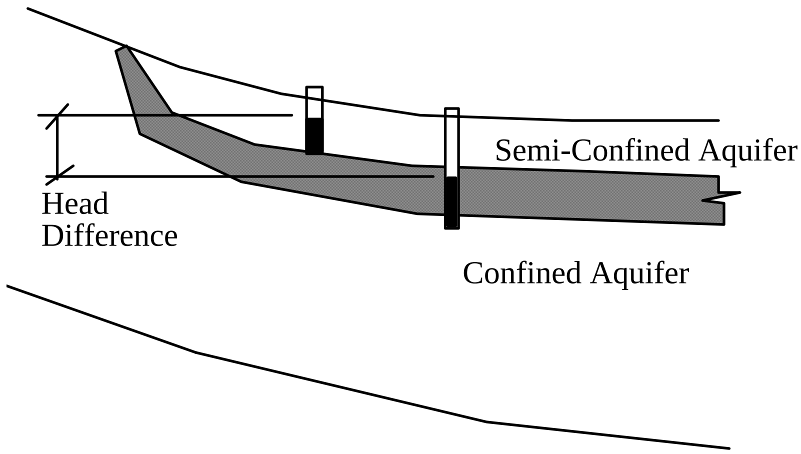


Figure 5. Head Difference Between Upper Aquifer and Lower Aquifer

The "head difference" between the upper aquifer and the lower aquifer can be estimated using data from DWR and USGS reports. For this paper, an estimate of **50 feet** was used for the "Head Difference" between the piezometric water levels between the semi-confined and the confined zones just above and below the Corcoran Clay zones. The thickness of the Corcoran Clay in is estimated to be 83 feet. The vertical gradient of the flow through the Corcoran Clay is estimated for this example at 60 feet/100 feet.

In the following paragraphs the hydraulic conductivity of the Corcoran Clay will be abbreviated as $K_{corcoran}$. Reported below are some of the estimates and the justification for the $K_{corcoran}$ estimate used.

Phillips and Belitz (1991) developed a groundwater model for the area bounded by the Coast Ranges to the west and the valley trough on the east, which is delineated by the San Joaquin River and the Fresno Slough. The northern boundary was about 10 miles south of Mendota and the southern boundary was about 10 miles north of Five Points. The results of this study estimated the $K_{corcoran}$ value may range from 0.8×10^{-8} to 1.2×10^{-8} ft/s.

Subsurface Lateral Flow Calculations

The following calculation is the estimate of seepage from the semi-confined zone to the confined zone through the Corcoran Clay.

Q = Kia = 0.00000008 ft/s x 60 ft/100ft x 10,000 ac x 43,560 sqft/ac

= 2.09 CFS

The following calculation assumes that this condition occurs for 365 days of the year.

V = QT = 2.09 CFS x 1.9835 AF/cfs in 1 day x 365 days

=1,513 AF (+/- 50%)

Conclusions

This paper presents a simple method to determine the subsurface lateral inflows and outflows for the determination of a district water balance. The procedure outlined is a simple application of Darcy's Law to determine the flow into and out of 3-dimensional boundaries of a district.

For a 10,000 acre hypothetical district on the westside of the San Joaquin Valley the following results were calculated:

Subsurface Lateral Inflow = 3,801 AF
Subsurface Lateral Outflow = 1,014 AF

Subsurface Vertical Outflow = 1,513 AF

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