GEOHYDROLOGIC EFFECTS ON DRAINWATER QUALITY

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ABSTRACT: This study was conducted on the water-district scale and provides insight into the effects of percolating irrigation water, local ground water, and regional ground water on the quantity and quality of drainwater from on-farm drains in the western San Joaquin Valley, Calif. Ground-water flow is downward in the upslope areas of the water district, but is upward from depths greater than 25 m below land surface in some downslope areas. Transitional areas exist where ground water flows laterally for distances as great as 3.6 km prior to interception by the on-farm drainage systems. Model results indicate that about 89% of the annual drainflow during 1987–91 originated as recharge directly above the drainage systems, and 11% of the annual drainflow was lateral- and upward-moving ground water that originated as recharge in areas upslope of the drainage systems. There is general correlation between drainage systems that discharge high concentrations of selenium and areas that intercept upward-moving ground water.

INTRODUCTION

Serious interest in the quality of agricultural drainwater discharged to the San Joaquin River, Calif. (Fig. 1), resulted from the discovery of high selenium concentrations in the drainwater and its associated detrimental effects on waterfowl (Deverel et al. 1984; Presser and Barnes 1984). Because the drainwater has been used to supplement irrigation water when supplies were temporarily limited by competing urban and environmental uses, drainwater reuse may provide a means for reducing future discharge of drainwater to the San Joaquin River. However, the total concentration of salts, trace elements, and toxic constituents in the drainwater are important criteria for determining the potential reuse of drainwater for irrigation (Tanji 1997).

Ground-water flow paths and the geochemical evolution of ground water intercepted by on-farm drainage systems affect the concentration of salts and selenium in drainwater in the western San Joaquin Valley (Fio and Deverel 1991). This paper describes a study of ground-water flow paths in drained and undrained areas of the Panoche Water District located in the western San Joaquin Valley, Calif. (Fig. 2). Simulated ground-water flow paths and chemical data from well-water samples are used to assess the distribution of selenium in ground water beneath the water district. Results from a ground-water flow model provide insight into the interaction between the ground-water system and on-farm drainage systems, and its effect on the spatial and temporal variability of drainwater quality. Other papers in this issue describe the influence of drain lateral spacing and depth on the quantity and quality of on-farm drainflow (Ayars et al. 1997; Guitjens et al. 1997). An understanding of the interaction between the ground-water system and on-farm irrigation and drainage practices is necessary for successful monitoring and evaluation of the impacts of drainwater reuse in the San Joaquin Valley.

GROUND-WATER FLOW MODEL

A three-dimensional, steady-state, finite-difference modeling approach was used to simulate average hydraulic heads, volumetric ground-water fluxes, and ground-water flow paths within the Panoche Water District (Fio 1994). The model was developed using the computer code MODFLOW (McDonald and Harbaugh 1988), and uses geohydrologic data collected during the period 1987–91. The model was calibrated against measured hydraulic heads, estimated ground-water discharge from bare-soil evaporation, and reported drainflow. The shape and direction of simulated ground-water flow paths and estimates of advective travel times were calculated from the model results using the postprocessor MODPATH (Pollock 1989). A general description of the model is provided in the following section, and readers interested in additional details on model construction, calibration, and assessment are referred to Fio (1994).

The ground-water flow model consists of eight parallel layers representing the upper 25 m of unconsolidated sediment that forms the semiconfined aquifer in this part of the western San Joaquin Valley (Belitz and Heimes 1990). The upper surface of the model corresponds to the water table, and water-table recharge is calculated from water delivery, precipitation, and consumptive-use data. The distribution of water-table recharge is specified in the model. Bare-soil evaporation is simulated in areas where the water table is less than 2.1 m below land surface. Simulated bare-soil evaporation is 0.3 m/yr where the water table is within 1.2 m of land surface, and decreases linearly to 0 m/yr at an extinction depth of 2.1 m below land surface (Belitz et al. 1992). The maximum altitude of the water table is controlled in areas having drainage sys-

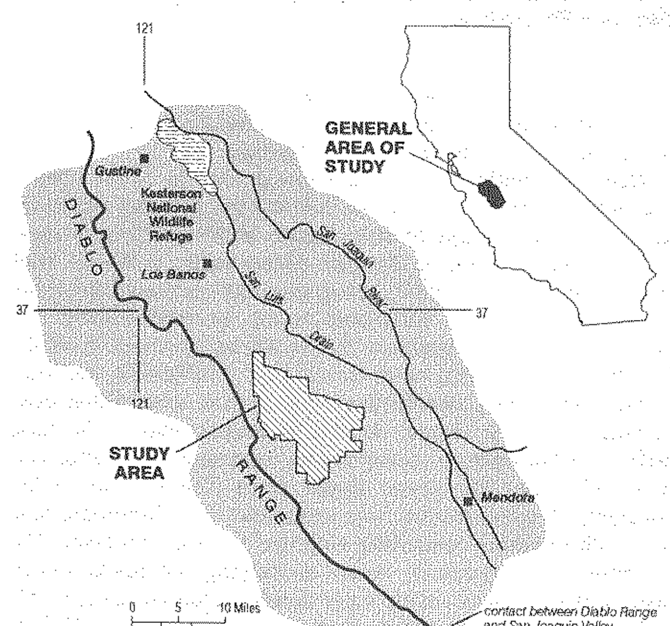

FIG. 1. Part of Western San Joaquin Valley and General Area of Study

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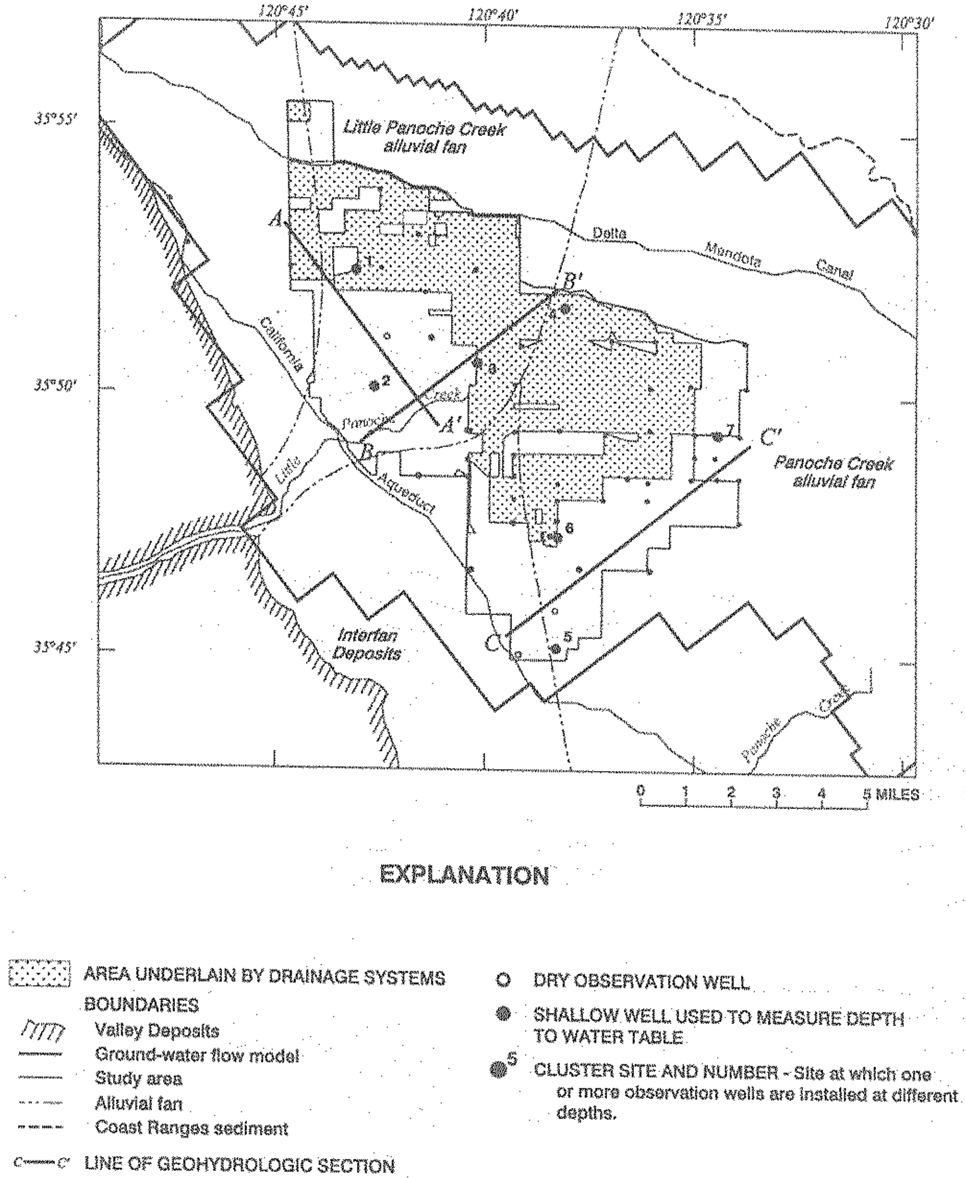


FIG. 2. Boundaries of Study Area, Areal Distribution of Observation Wells and Well Cluster Sites, and Location of Geohydrologic Sections Shown in Fig. 3.

tems. Simulated drainflow in these areas is proportional to the hydraulic head gradient between the simulated water table and the effective altitude of the drain laterals.

Deep percolation of ground water across the lower layer of the model (greater than 25 m below land surface) represents ground-water recharge to deeper parts of the aquifer; the upper semiconfined aquifer in this part of the valley is 60–90 thick (Belitz and Heimes 1990). Deep percolation across the lower model boundary is simulated using head-dependent flux boundaries. Head-dependent fluxes are represented in MODFLOW using general-head boundaries (McDonald and Harbaugh 1988). The general-head boundaries assume that deep percolation to the deeper aquifer is proportional to the head difference between the lower model layer and the aquifer system underlying the lower model layer. The proportionality constant, or conductance, was estimated from lithologic data for depth intervals coinciding with the lower model layer. The distribution of hydraulic heads underlying the lower model layer was calculated using water levels measured in relatively deep wells (average depth of the well screens was 28.2 m below land surface). Because production wells in the model area yield ground water from depths greater than 28.2 m below land surface, the prescribed head distribution includes the net effect of recharge to areas upslope of the model area and ground-water pumping from wells screened beneath the lower model boundary.

Horizontal and vertical hydraulic conductivities used in the flow model were calculated using the approach previously developed for a regional model of the western San Joaquin Valley (Phillips and Belitz 1991). Horizontal hydraulic conductivity was calculated as a weighted arithmetic average of the hydraulic conductivity of coarse- and fine-grained lithologic end members, and the vertical hydraulic conductivity was calculated as a weighted geometric average of the hydraulic conductivity of coarse- and fine-grained lithologic end members (Fio 1994). The fraction of coarse-grained sediment in each model cell was determined using information from well-driller logs, and used as input to the respective weighting functions. On average, the resulting distribution of calculated hydraulic conductivity in the model has an anisotropy of 1:125 between the vertical and horizontal flow directions.

GEOHYDROLOGY AND GROUND-WATER CHEMISTRY

Data from boreholes and observation wells and the results from the ground-water flow model were used to assess the distribution of coarse- and fine-grained sediment, altitude of the water table, ground-water flow paths, and selenium concentrations at well locations projected along geohydrologic sections A-A′, B-B′, and C-C′ (Fig. 3). The upper 12 m of sediment generally are fine grained and overlay about 9 m of coarse-grained sand and gravel. The coarse-grained sediment is underlain by about 9 m of fine-grained sediment. In the low-lying areas underlain by greater proportions of fine-grained sediment, the water table is within 3 m of the land surface and generally parallels the slope of the land surface. At higher land surface elevations, the water table tends to diverge from the land surface resulting in depths to water substantially greater than 3 m below land surface.

Ground-water flow paths at the higher land surface elevations (near sites 2 and 5), and at the fan margins (near sites 1, 6, and 7) are downward. In contrast, flow in some downslope areas (site 4) is upward; transitional areas exist between downward and upward flow (site 3). The upward flow originates from upslope recharge, and ground water can move laterally for substantial distances in the transitional areas prior to interception by downslope drainage systems. Model results indicate that movement along lateral flow paths ranges from 0.3 to 3.6 km and requires 10–90 years to reach the discharge locations. Although most of the drainflow originates as irrigation water applied above the drainage systems (89%) lateral- and upward-moving ground water contributes about 11% of the total annual volume of drainflow (Fio 1994).

Selenium concentrations in the well-water samples was variable between sites, and indicate that ground-water quality is affected in part by geologic source materials. For example,

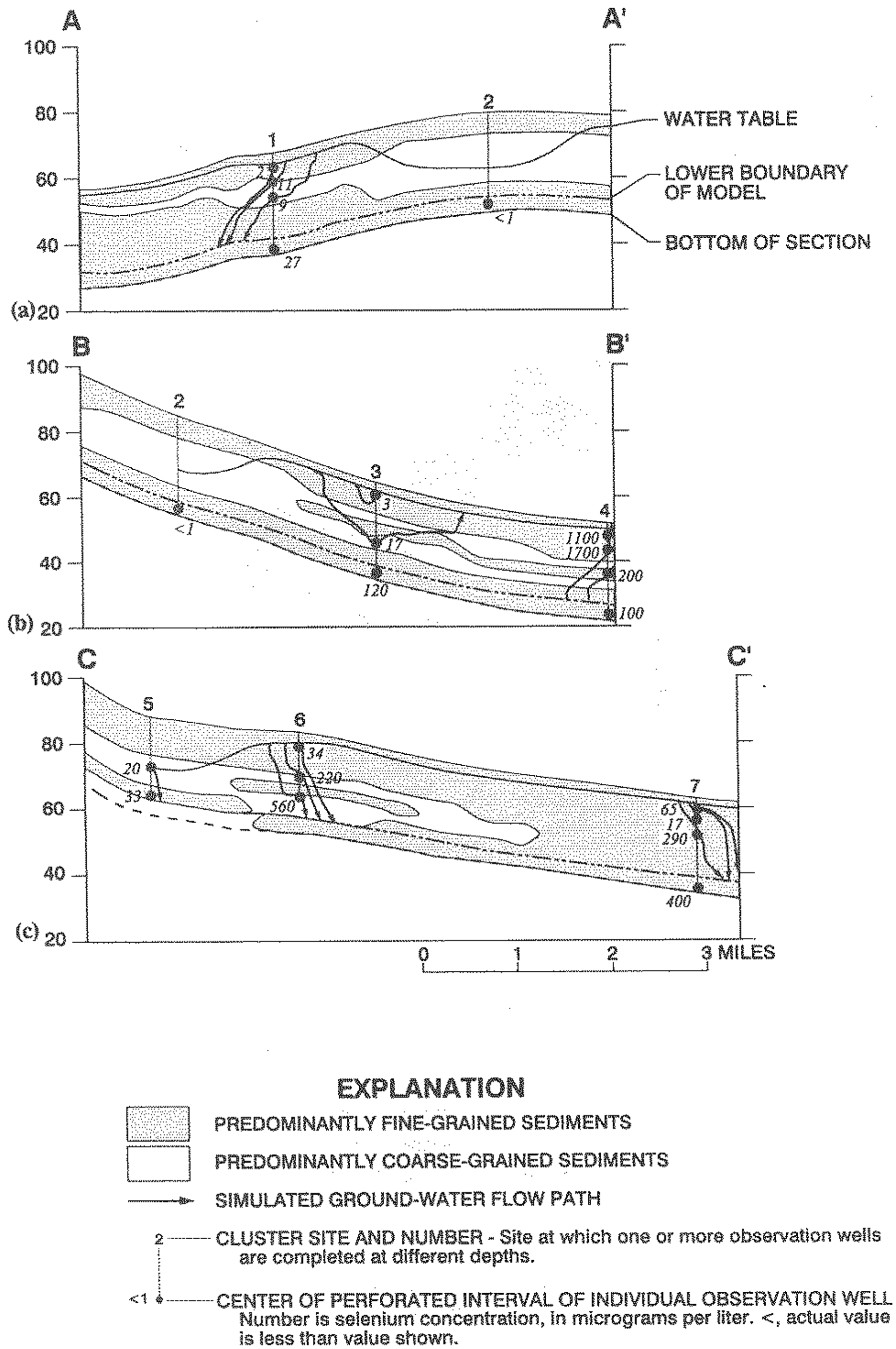


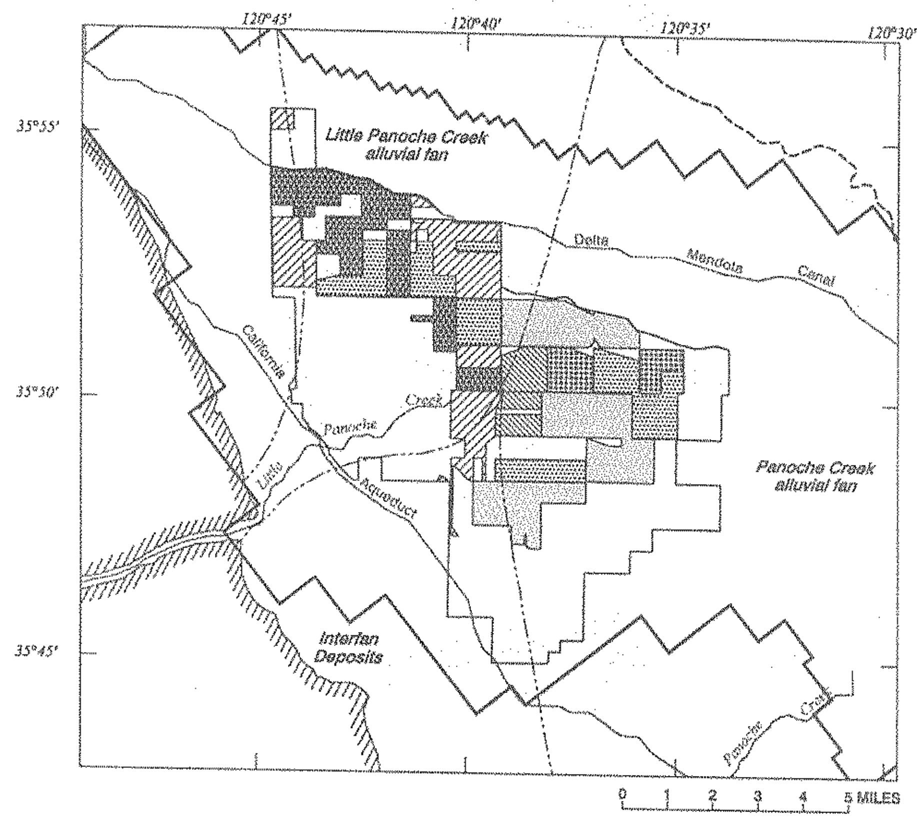
FIG. 3. Sediment Texture, Altitude of Water Table, Simulated Ground-Water Flow Paths, and Selenium Concentrations in Ground-Water Samples Projected onto Three Geohydrologic Sections

rock formations within the Panoche Creek drainage basin are considered significant sources of selenium in soil and ground water in the San Joaquin Valley (Presser et al. 1990); the ground-water samples from wells located on the Panoche Creek alluvial fan have the greatest concentrations of selenium (20–1,700 μg/L). In contrast, most ground-water samples collected from wells located on the adjacent Little Panoche Creek alluvial fan (sites 1, 2, and 3) have relatively low concentrations of selenium (<1–27 μg/L).

Selenium concentrations in ground water are also affected by ground-water flow paths and irrigation and drainage history. Selenium concentrations generally increase with depth where ground-water flow paths are downward, and generally decrease with depth at sites where flow paths are upwards. The vertical distribution of selenium concentrations in ground water is a result of the disposition of water that has undergone partial evaporation from a shallow water table. Several water samples (site 3, 27.8 m below land surface; site 4, 4.0 and 8.3 m below land surface; site 6, 13.0 and 19.4 m below land surface; and site 7, 11.4 m below land surface) are characterized as having relatively large total ionic content (not shown in Fig. 3), and selenium concentrations that range from 120 to 1,700 μg/L. Deuterium and oxygen-18 composition of samples from the fourth group of water samples deviate from meteoric and local ground-water lines (not shown in Fig. 3), indicating enrichment by partial evaporation from a shallow water table (Fio and Leighton 1994). This ground water probably was near land surface in the past, and partial evaporation from the shallow water table resulted in enrichment of stable isotopes and increased concentrations of salts and selenium (Deverel and Fujii 1988). The combination of upward ground-water flow, irrigation, and drainage has resulted in a distinct depth distribution of ground-water quality.

SPATIAL VARIABILITY IN DRAINWATER QUALITY

The spatial distribution of selenium concentrations in drainwater is similar to that found in the ground-water samples. There is general correlation between drainflows having the highest concentrations of selenium and areas that intercept upward-moving ground water. Median selenium concentrations calculated from reported concentrations in drainwater samples generally are higher from fields on the Panoche Creek alluvial fan than from fields on the Little Panoche Creek alluvial fan



EXPLANATION

SELENIUM CONCENTRATIONS, IN MILLIGRAMS PER LITER

No Data
Less than 20
Greater than or equal to 20 and less than 100
Greater than or equal to 100 and less than 500
Greater than or equal to 500 and less than 1000
Greater than or equal to 1000

BOUNDARIES
Valley Deposits
Ground-water flow model
Study area
Alluvial fan
Coast Ranges sediment

FIG. 4. Areal Distribution of Selenium Concentrations in Drainwater

(Fig. 4). The highest selenium concentrations are measured in drainwater from drainage systems in areas of upward ground-water flow. The downward displacement of ground water in these areas, enriched in salts and selenium by partial evaporation, has probably been impeded by the upward hydraulic-head gradients. In contrast, salts and selenium concentrations are displaced downward by percolating irrigation recharge in areas where vertical ground-water flow is downward.

TEMPORAL VARIABILITY IN DRAINWATER QUALITY

The temporal variability of selenium concentrations in drainwater is affected by the sources of water contributing to the drainflow. Drainflow during nonirrigated periods is mostly ground water adjacent to and beneath the drain laterals (Fio and Deverel 1991); drainflow during irrigated periods is a combination of percolating irrigation recharge and ground water. The concentrations of salts and selenium in the deeper ground water is typically greater than found in the relatively shallow ground water and percolating irrigation recharge. The concentration of selenium in drainwater can therefore show temporal variability owing to irrigation practices and the depth distribution of selenium concentrations in the ground-water profile.

Seasonal variability in drainwater quality owing to the annual irrigation cycle was assessed using reported dissolved-solids concentrations in monthly drainwater samples; ground-water salinity explains most of the variance in measured selenium concentrations in shallow ground water in this area (Deverel and Fujii 1988). The coefficient of variation was calculated for dissolved-solids concentrations; the coefficient of variation was calculated as the standard deviation divided by the yearly average, expressed as a percent. A value greater than or equal to 10% was assumed to indicate significant seasonal variability in drainwater salinity; a value lower than 10% was assumed to indicate that drainwater salinity is essentially constant during the year. The coefficient of variation was greater than 10% for drainflows from fields in the most northeastern parts of the water district, and for most of the drainage systems on the Panoche Creek Alluvial Fan (Fig. 5). These areas coincide with areas of historical ground-water discharge and high soil salinity (Deverel and Gallanthine 1989). Hence, there is a general correlation between the drainage systems

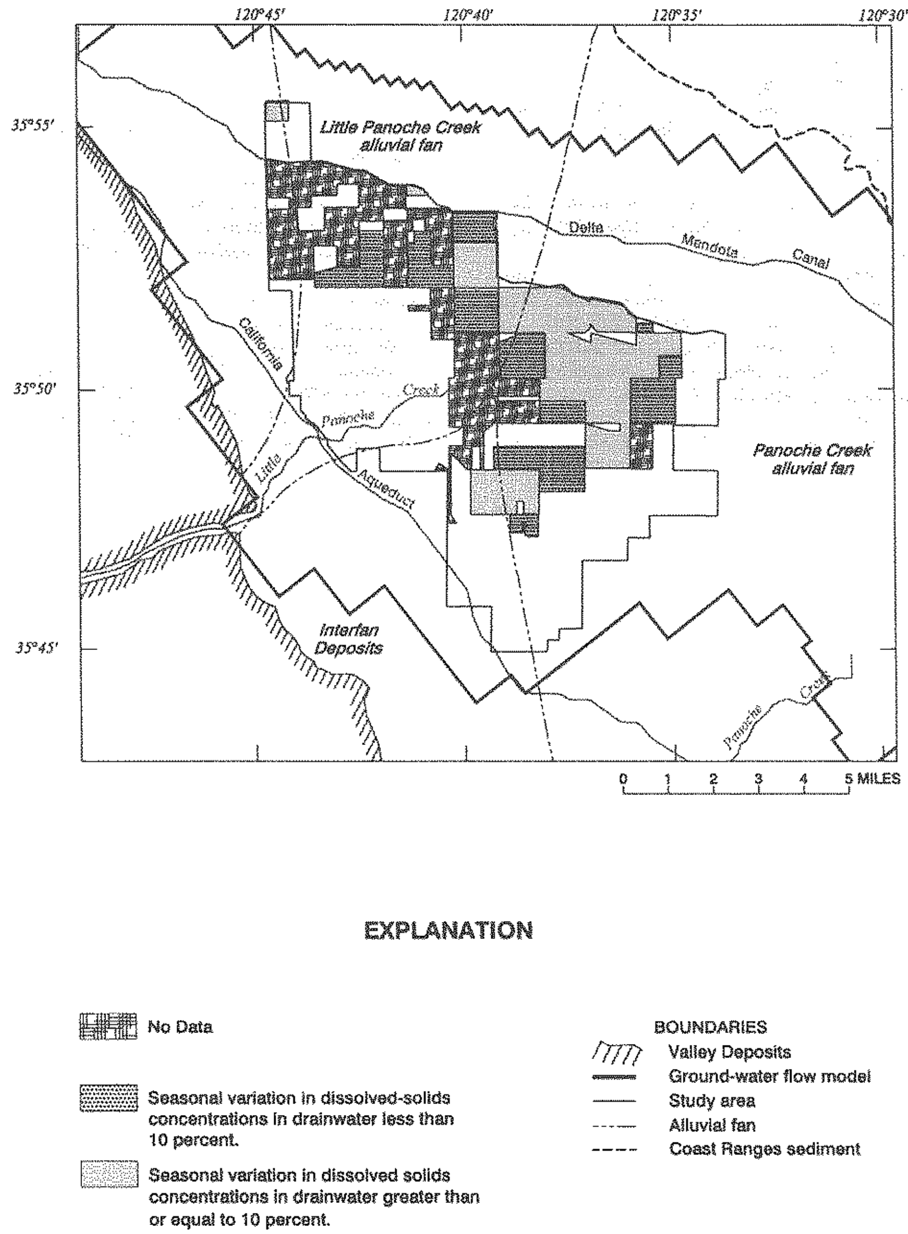


FIG. 5. Areal Distribution of Seasonal Variation in Dissolved Solid Concentrations in Drainwater in Part of Western San Joaquin Valley (Blank Areas in Water District are Undrained; Drained Areas Outside Water District Boundaries Are not Shown)

exhibiting seasonal variability in drainwater quality and drainage systems that intercept upward-moving ground water.

CONCLUSIONS

Selenium concentrations in drainwater from a water district in the western San Joaquin Valley are influenced by groundwater flow paths and the associated geochemical evolution of ground water intercepted by on-farm drainage systems. Drainflow in the water district comprises recharge that originated within the drained areas (89%) and lateral- and upward-moving ground water that originated in areas upslope of the drainage systems (11%). The highest concentrations of selenium in drainwater are measured in areas of upward-moving ground water. Shallow ground water in these areas has been enriched in stable isotopes and selenium concentrations by partial evaporation from the shallow water table. In turn, the downward displacement of shallow ground-water, enriched in selenium concentrations, has been impeded by upward hydraulic-head gradients.

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