FINAL

GRASSLAND BYPASS PROJECT

ENVIRONMENTAL IMPACT STATEMENT AND ENVIRONMENTAL IMPACT REPORT

VOLUME II – APPENDICES B – H

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and
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APPENDIX D

GROUNDWATER AND SOILS TECHNICAL REPORT

APPENDIX D
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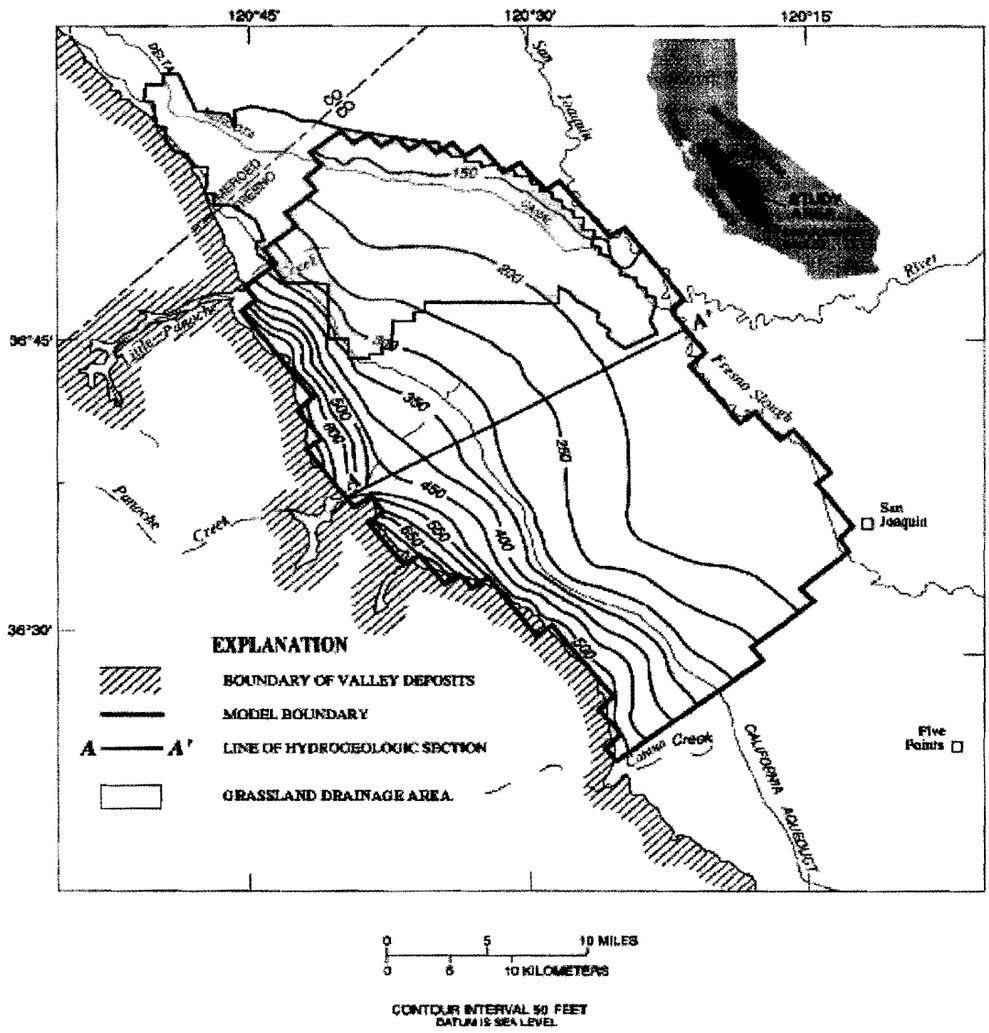
D.1 GROUNDWATER AND SOIL RESOURCES

The Grassland Drainage Area includes 97,400 acres of farmland approximately located between the California Aqueduct on the west and San Joaquin River on the east (Figure D-1). About 40-percent (37,950 acres) of the area is underlain by tile-drainage systems, which currently discharge drainwater to the Grassland Bypass. The tile-drainage systems manage the shallow water table, which otherwise cause water logging and salt accumulation in the root zone. This report describes estimated impacts to Grassland Drainage Area groundwater and soil resources under project and the No Action alternatives, including the 1,100-acre potential addition to the GDA.



Note: The Grassland boundaries are approximate. See Chapter 2 for specific boundary location.

Figure D-1. Western San Joaquin Valley and boundaries of groundwater-flow model (modified after Belitz and others, 1993).

D.2 AFFECTED ENVIRONMENT

D.2.1 Groundwater Resources

In the western San Joaquin Valley, sediments eroded from the Coast Ranges form gently sloping alluvial fans. The alluvium is more than 800 feet thick along the Coast Ranges and thins to 0 feet near the valley axis (Miller and others, 1971). The alluvium is a mixture of gravel, sand, silt and clay.

The groundwater system is divided into a lower confined zone and upper semiconfined zone, separated by the Corcoran Clay (Figure D-2). In the upper fan areas, the water table is typically located several hundred feet below land surface. In contrast, most downslope areas are underlain by a shallow water table within 7 feet of land surface (Belitz and Heimes, 1990). The shallow water table is located within the semiconfined zone, and tile-drainage systems are employed to manage water table depth. Our objective is to assess relative impacts of continued and discontinued drainage-water exports, which affect basin water and salt budgets.

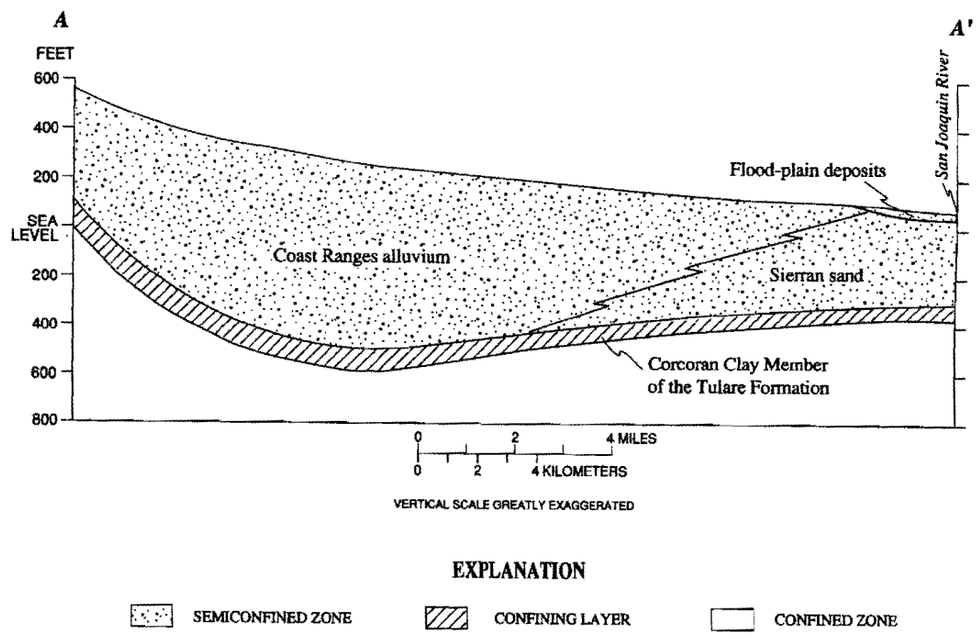


Figure D-2. Geohydrologic section of the western San Joaquin Valley (modified after Belitz and others, 1993).

Prior to agricultural development, groundwater recharge occurred primarily by infiltration of runoff in Coast Range streams. Under natural conditions, rainfall was an insignificant recharge source (Davis and Poland, 1957). Rantz (1969) reported that average annual precipitation is only 6.5 to 8 inches per year on the valley floor, but annual precipitation can vary considerably from the long-term average. For example, since 1950 reported annual rainfall in Panoche Water District has ranged from 3 to almost 16 inches per year.

During the past 40 years, recharge has increased dramatically as a result of imported irrigation water. In 1999, almost 230,000 acre-feet of surface water were applied to 97,400 acres in the Grassland Drainage Area (a mean application rate of 2.4 feet per year). Irrigation recharge increases the volume of water beneath the land surface and causes the water table to rise.

Under natural conditions, the shallow water table existed in eastern portions of the Grassland Drainage Area and in areas along the valley floor and adjacent to the San Joaquin River (Beltiz and Heimes, 1990). Groundwater discharge was primarily by evapotranspiration and water table seepage to the San Joaquin River. Presently, groundwater discharge is predominantly by tile-drainage systems and water table evaporation; groundwater pumpage as a supplemental irrigation water supply is reportedly small in the Grassland Drainage Area.

D.2.2 Drainage System Hydrology

Tile drainage systems affect groundwater-flow in upper parts of the semiconfined aquifer. Seasonal changes in groundwater levels and drainflow indicate field conditions are affected by upslope irrigation activities. Furthermore, observation well data show that groundwater movement is upward towards the drainage systems from depths as great as 50 feet below land surface (Deverel and Fio, 1991; Fio, 1994). Therefore, drainflow estimates require geohydrologic information for areas considerably larger than single fields and depth intervals substantially deeper than the water table. In particular, estimates of irrigation recharge for drained and (or) undrained areas upslope of the field, and delineation of regional groundwater flow paths intercepted by the drainage systems, are necessary to describe drainflow.

D.2.3 Soil Resources

Soil salinity is an important consideration for irrigated agriculture and drainwater management. Irrigation dissolves soil salts and leaches them to the water table. Salts present in the irrigation water further increase salt loading to soil and groundwater. For example in 1999, the dissolved solids concentration in delivered irrigation water averaged 244 mg/L. This translates into more than 76,000 tons of imported salt applied in the Grassland Drainage Area.

Most of the Grassland Drainage Area soils are derived from marine sediments in the Coast Range, and contain salts and trace elements such as boron, molybdenum, and selenium. Under natural conditions, stormwater runoff from precipitation in the Coast Range infiltrated to the groundwater system. Harradine (1950) mapped the lowest soil salinities in the upper fan areas where they were partially leached by infiltration (Gilliom and others, 1987). In the downslope areas, precipitation was an insignificant recharge mechanism. Harradine (1950) mapped the

highest soil-salinities in the downslope areas where recharge and subsequent leaching rates were low.

The presence of solid phase minerals like gypsum and calcite influence changes in soil and groundwater salinity. Based on soil samples from 17 sites in Panoche Drainage District, Tanji and others (1977) reported for the upper 6 feet of soil, 1 to 9 tons of native gypsum per acre-foot of soil. Soil saturation extracts and geochemical modeling results indicate soils are saturated with calcite and gypsum (Deverel and Fujii, 1988), and we have visibly identified salts in unsaturated and saturated-zone core samples.

An exact correlation between soil and groundwater high in salts and selenium is not observed (Gilliom and others, 1987). The highest concentrations occur in places where hydrologic processes, such as evaporative concentration, contribute to the accumulation of soluble salts and selenium in water and soil. To evaluate salt and selenium distributions in groundwater and soil it is necessary to understand the natural distribution of constituents and their redistribution by irrigated agriculture.

D.3 ENVIRONMENTAL CONSEQUENCES

D.3.1 Key Impact and Evaluation Criteria

The water table rise is the primary impact to soil and groundwater. The rising water table produces several soil and groundwater related effects. We considered the following effects to assess the potential water table impact:

- Drainwater production. Drainflow is proportional to water table depth, and flow increases as the water table rises. Potential drainflow impacts are associated with its volume and quality. We considered a 10 percent increase in annual drainflow volume and salinity as a potentially significant adverse impact.

- Bare soil evaporation. As the water table rises, the area underlain by the shallow water table increases and water table evaporation increases. In the Grassland Drainage Area, evaporation from the shallow water table caused significant salinity increases in groundwater and soil (Deverel and Fujii, 1988). Belitz and others (1993) utilized a large amount of soil moisture, soil tension, and hydraulic conductivity data for Panoche clay loam and concluded that bare-soil evaporation is significant when the water table is within 7 feet of land surface.

  Our estimated water table depth is most reliable at the water district scale. We therefore considered a 20 square mile or greater increase in area underlain by a shallow water table (within 7 feet of land surface) as a significant adverse impact; area changes less than several square miles were considered no impact. Our estimated evaporation rate is most reliable in the range between 0.0 to 0.4 feet/year, which corresponds to water table depths from 7 to 4 feet below land surface. When the water table rises above the 4 feet depth, the evaporation rate increases rapidly above 0.4 feet/year. The high evaporation rates maximize salinity increases in soil and groundwater. We therefore considered evaporation rates greater than

0.4 feet/year as a significant adverse impact, and evaporation rates less than about 0.05 feet/year as no impact.

- Uncontrolled seepage and subsurface discharge. Seepage and subsurface discharge is proportional to water table depth, and increase as the water table rises. The impacts are associated with the volume and quality. We considered a 10 percent increase in the volume and quality of annual seepage or subsurface discharge as potentially significant adverse impacts. Our analysis does not include other waters and drainwater that cannot be recycled that enters drainage canals. Uncontrolled seepage is therefore a minimum estimate of uncontrolled discharge.

- Soil salinity. Increased soil salinity decreases crop yields, and the threshold salinity level is crop specific. For example, melon and tomato yields decline when soil salinity increases above 2.5 deci-Siemen/meter (dS/m); whereas, wheat, sugar beets, and cotton yields decline when soil salinity increases above 6.0, 7.0 and 7.7 dS/m, respectively (Tanji, 1990). Our analyses assumed initial soil salinity was 4.4 dS/m, and we considered mean soil salinity increases above 10 percent as a potentially significant adverse impact.

- Groundwater salinity. Groundwater salinity changes affect drainwater and seepage quality, which in turn affect constituent loads potentially discharged to the Grassland Bypass and adjacent wetlands. We considered groundwater salinity increases greater than 10 percent as a potentially significant adverse impact.

D.3.2 Methods Used to Evaluate Impacts

Our analysis focuses on changes in groundwater-levels, soil salinity and groundwater salinity. Existing groundwater-flow and geochemical models estimated these changes for the No Action and Alternative scenarios.

D.3.2.1 Groundwater-Flow Model

We utilized a numerical groundwater-flow model to project changes in mean depth to the water table. The U.S. Geological Survey developed the model for the San Joaquin Valley Drainage Program (Belitz and others, 1993). It is a transient, three-dimensional, finite-difference model and utilizes mean recharge and pumpage data to project long-term changes in water table depth and drainflow.

The U.S. Geological Survey model represents groundwater conditions within 88,000 acres of the Grassland Drainage Area, which is 91-percent of the total area (see Figure D-1 for a comparison between model boundaries and approximate Grassland Drainage Area boundaries). Model subareas represent single water districts (Panoche and Broadview), and all or parts of Mercy Springs, Eagle Field, Oro Loma, Widren, Camp-13, and Firebaugh water and drainage districts. The model does not include Pacheco Water District and Charleston Drainage District. For our analysis, we assumed area-averaged model results are representative of mean conditions in Pacheco and Charleston.

The U.S. Geological Survey calibrated the model to reproduce 1972-88 hydrologic conditons. HydroFocus, Inc. recently evaluated model-projected groundwater levels and drainflow during the period 1989-97 (HydroFocus, Inc., 1998). They updated boundary conditions, recharge, and pumpage data and concluded updated model results are acceptable to evaluate long-term changes in water-table depth.

D.3.2.1.1 Recharge

Water table recharge is computed as applied water less consumptive use by plants. We calculated 1999 water table recharge with the following unsaturated zone water budget:

$$ID + Pe + Dr - ET = R, \text{ where} \qquad (1)$$

ID is delivered irrigation water, in feet/year;
Pe is effective precipitation, in feet/year;
Dr is recycled drainwater, in feet/year;
ET is consumptive use by plants, in feet/year; and,
R is water table recharge, in feet/year.

The reported Grassland Drainage Area water budget components are summarized in Table D-1, and indicate 1999 recharge was 0.80 feet/year. Estimated 1999 recharge was identical to average annual recharge specified in the U.S. Geological Survey model (0.80 feet/year). We utilized 1999 recharge to represent average Grassland Drainage Area conditions for our impact analysis.

Table D-1. Reported 1999 Water Budget Components for Grassland Drainage Area subareas of the groundwater-flow model.

Model Subarea	Model Area (acres)	Irrigation Delivery (feet)	Effective Precipitation (feet)	Recycled Drainwater (feet)	Consumptive Use (feet)	Water Table Recharge (feet)
Firebaugh	46,720	2.68	0.21	0.09	2.00	0.98
Panoche	30,720	2.17	0.21	0.04	1.86	0.56
Broadview	10,240	1.96	0.21	0.31	1.79	0.69
Sum/Average	87,680	2.42	0.21	0.10	1.93	0.80

D.3.2.1.2 Drainflow

Tile drainage systems consist of a parallel network of perforated drain laterals buried at variable depths and spacings. The drain laterals are typically installed at depths ranging from 6 to 9 feet below land surface, and spaced horizontally from 100 to 600 feet apart. Drainwater production is proportional to the hydraulic gradient between the water table and the drain laterals; drainflow increases as the water table rises, decreases as the water table declines, and is zero when the water table is below the drain laterals. The proportionality constant, or drain conductance,

incorporates head-loss effects due to groundwater flow through the aquifer and into the drain laterals.

We utilized the groundwater-flow model and a district drainage model to calculate drainwater production during the period 1999 through 2009. The two models are indirectly linked by annual mean water table depth. The groundwater-flow model is a regional model, and provides annual water levels and drainflows resulting from regional hydraulic stresses. In contrast, the district drainflow model correlated monthly district drainwater production to monthly water table depth. Additional information on drainage system representation in the groundwater model is provided below, and details on the district drainage model are provided later in this report.

The U.S. Geological Survey model simulates drainflow from 67 square miles of tile drainage systems, and represents 48,250 acres (about 89-percent) of the tile-drained land in the Grassland Drainage Area. The model specified a representative drain lateral depth of 7.3 feet below land surface, and representative drain conductance of 0.52 square-feet/second (Belitz and others, 1993). The conductance term represents the tile-drainage systems. However, unlined canals and ditches can intersect the water table and collect seepage that is transported with drainwater to the Bypass. We accounted for this seepage by increasing the drain conductance to 0.54 square-feet/second. We calculated the conductance increase by assuming an effective drain/aquifer system conductivity of 115 feet/day and 130 miles of unlined ditches within the Grassland Drainage Area. The adjusted conductance indicated that about 4-percent of annual drainflow is attributed to ditch seepage.

D.3.2.2 District Drainflow Model

We estimated monthly drainwater production with a district drainflow model. The model assumes monthly drainflow is proportional to the difference between water table and drain lateral depths. The proportionality constant, which represents a district-wide drain conductance, incorporates variable sediment permeability, variable numbers of drainage systems, and variable drain lateral spacing. Monthly water table depths were calculated from annual depths and seasonal changes in measured water levels. The groundwater-flow model determined the annual water table depth, which was adjusted to monthly values by month-specific factors.

Figure D-3 shows that drainflow is proportional to water table depth. The plotted water levels represent mean monthly values computed from 950 bi-weekly measurements collected in Panoche Water District. Monthly drainflows are the reported 1991 district discharge from Panoche Drainage District. Minimum water table depth and maximum drainflow occurred during March (pre-irrigation) and July (the peak of the irrigation season). Maximum water table depth and minimum drainflow occurred during October and November, after the harvest and before the winter rains. The regression equation indicates drainflow ceases when the water table falls to a depth of about 9 feet below land surface. This agrees with reported maximum drain lateral depths in Panoche Water District, and probably represents the deeper collector lines and unlined ditches in the district.

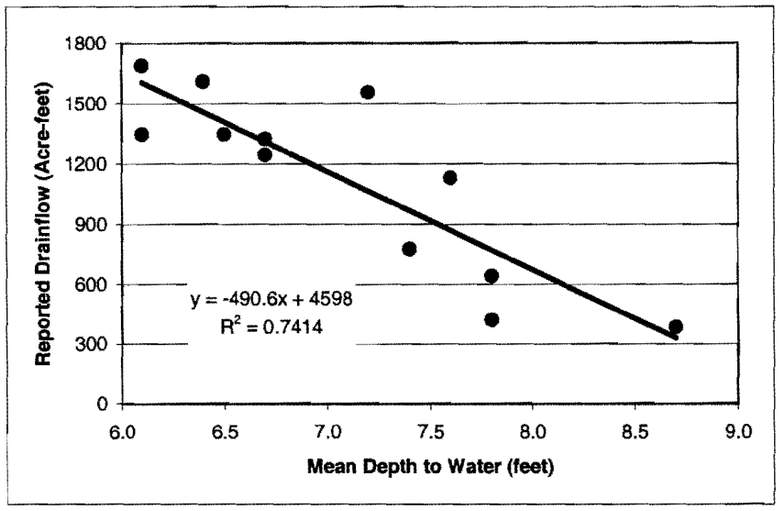


Figure D-3. Relationships between mean monthly water table depth and district discharge from Panoche Water District, 1991.

The drainflow model was calibrated by adjusting representative drain lateral depth, district drain conductance, and monthly water level factors. Calibrated drain lateral depths and monthly water level factors are representative of the entire Grassland Drainage Area; whereas, drain conductance was individually estimated for each district. During the calibration process, parameter adjustments were constrained by reported drain lateral depths, measured water levels, and normalized conductance values reported by previous studies (Belitz and others, 1993; Fio, 1994).

Results from the calibrated model are plotted in Figure D-4 and show excellent agreement between reported and simulated 1999 drainflow. The model used a representative drain lateral depth of 7.5 feet; adjusted monthly water level factors similar to measured values; and, conductance values that range from 0.065 to 0.172 per month. Because model parameters were calibrated, their reliability must be assessed.

Calibrated drain lateral depth (7.5 feet) agrees with typical design depths in the Grassland Drainage Area (6 to 9 feet). The value is close to 7.3 feet, but is slightly deeper owing to temporal and spatial differences in the models. For example, all districts reported drainflow throughout the year, and mean water table depth cannot decline below the drain laterals. In contrast, mean annual water table depth simulated by the groundwater-flow model is consistently above 7.3 feet. In regards to spatial variability, the drainflow model includes Pacheco Water District and Charleston Drainage District, which are not represented in the groundwater-flow model. Drainage systems in these areas may be slightly different relative to the mean system design represented in the groundwater-flow model.

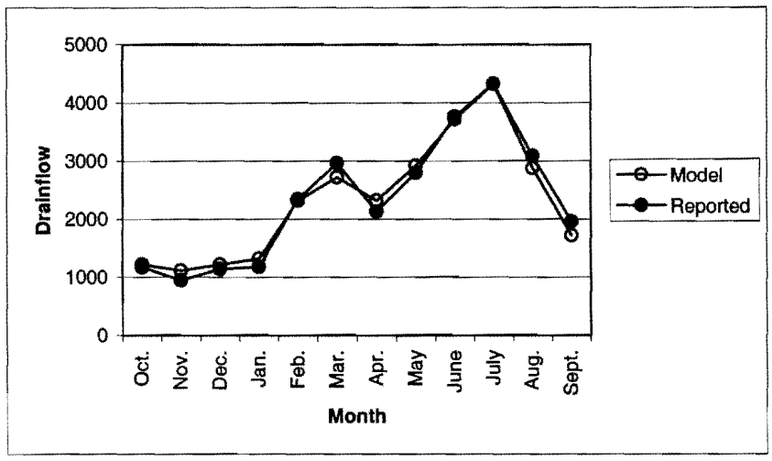


Figure D-4. Monthly estimated and reported drainwater production in the Grassland Drainage Area, 1999.

The magnitude of monthly drainflow is most sensitive to district drain conductance. Calibrated conductance values range from 0.065 to 0.172 per month, which are similar to values reported by previous studies (0.050 to 0.125 per month). We did adjust the monthly water level factors to improve the match between simulated and reported monthly drainflow (Figure D-5). We felt some adjustment was reasonable because the estimated water-level factors were determined from 1991 data, and may not be entirely representative of 1999 conditions. Furthermore, the data was collected from wells located in Panoche Water District, and they are not necessarily representative of mean water level changes throughout the entire Grassland Drainage Area.

D.3.2.3 Soil Salinity Model

We calculated the unsaturated zone salt balance for Project and No Action Alternatives. For each month, the salt mass in the soil water is:

$$SM_t = SM_{iw} + SM_p + SM_{t-1} - SM_r \pm Ss, \text{ where} \qquad (2)^1$$

SM_t is the soil water salt mass in the current month t;
SM_{iw} is the salt mass in applied irrigation water (canal and recycled drainwater);
SM_p is the salt mass in precipitation;
SM_{t-1} is the soil water salt mass from the previous month;
SM_r is the salt mass in water table recharge; and,
Ss is the soil salt mass dissolved or precipitated in the unsaturated zone.

[1] Equation (2) implicitly includes recycled drainwater in the term SM_{iw} (salt mass in applied irrigation water). As used in Equation (2), applied irrigation water includes both delivered canal water and recycled drainwater. In contrast, Equation (1) on page D-6 disaggregates applied irrigation water into delivered irrigation water (ID) and recycled drainwater (Dr).

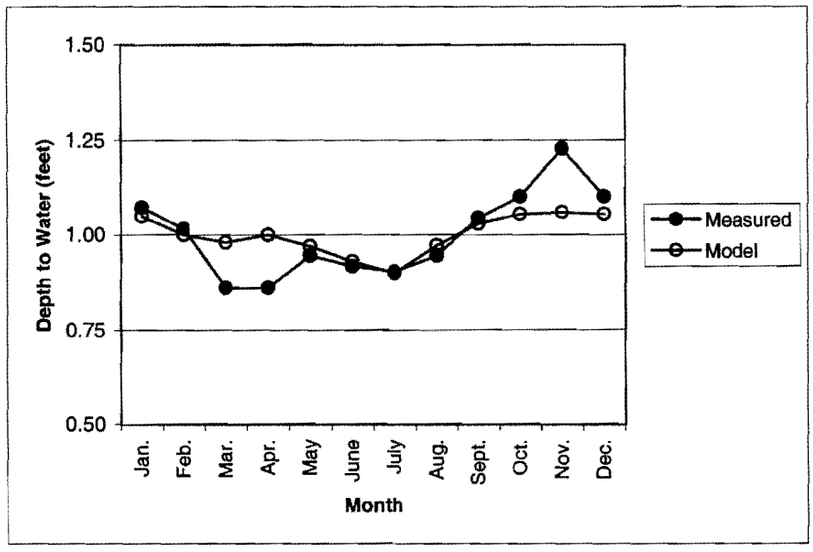


Figure D-5. Measured and calibrated monthly water level multipliers.

The concentration of soil salts was estimated as the mass of salts divided by the final soil moisture. We used the electrical conductivity of the soil saturation extract (EC_e) to represent soil water salinity. The soil moisture content above the water table was estimated as follows:

$$SM_t = SM_{t-1} + ID + Pe + Dr + ETgw - ET - R, \text{ where} \qquad (3)$$

SM_t is soil moisture in the current month t;
SM_{t-1} is soil moisture from previous month;
ETgw is the contribution of shallow groundwater to plant consumption, in feet/year; and,
ID, Pe, Dr, ET, and R were defined previously for Equation (1).

We estimated water table recharge as the water quantity above field capacity, which we assumed was 20 percent of the soil volume.

In the western San Joaquin Valley, soil salinity exhibits a high degree of spatial variability (Deverel and Gallanthine, 1989; Fujii and others, 1989; Corwin and others, 1996, 1999), which limits our ability to establish historical and present-day soil salinity values. For example, 1991 soil core data collected at 315 locations in Broadview Water District indicated the coefficient of variation for soil EC is about 55 percent (Corwin and others, 1999). Similarly, 1987 soil core data reported for 66 Broadview samples indicated the coefficient of variation is 48 percent (Wichelns, 1989). The large coefficients of variation indicate a substantial number of samples are necessary to reliably estimate mean soil salinity; mean soil salinity estimated by the previous studies was 4.4 and 3.9 (dS/m).

With the exception of Broadview, the available soil salinity data was insufficient to estimate mean soil salinity, and we considered Broadview as a surrogate for the Grassland Drainage Area.

Broadview probably represents a worse case scenario because drain water recycling was historically more intense than in other districts. Our initial estimate for average Broadview soil salinity (4.4 dS/m) is based on 1991 data collected by Corwin and others (1999).

A comparison of data collected in the same Broadview field, first by Wichelns (1989) and then by Ayars and others (1996), indicated soil salinity increased from 1987 to 1995. The field is located in the southeastern portion of the district (Township 13S and Range 13E). Wichelns (1989) reported an average soil salinity of 2.0 dS/m (sample values range from 2 to 8 dS/m), and Ayars and others (1996) reported an average soil salinity of 4.9 dS/m (sample values range from 2 to 28 dS/m). These data suggest that soil salinity may be increasing in Broadview under current drainwater recycling conditions.

Fujii and others (1989) and Deverel and Fujii (1988) indicated calcite and gypsum are the primary minerals affecting soil and groundwater salinity in the Grassland Drainage Area. Our soil salinity assessment required soil chemical composition, irrigation water composition, and rainfall composition to estimate mineral dissolution and precipitation. We estimated the initial soil water chemical composition from shallow groundwater chemistry data reported by Deverel and Fujii (1988). We based our canal water composition on information from Sposito and others (1987), and adjusted the individual constituent concentrations to match reported monthly canal water EC.

The applied irrigation water in Broadview Water District is a mixture of canal water and recycled drainwater. We assumed a chemically non-reactive, volume-weighted average of canal water and recycled drainwater to estimate irrigation water chemistry. We based the recycled drainwater composition on data reported by Deverel and others (1984), and adjusted the individual constituent concentrations to match Broadview's reported drainwater EC. The chemical composition of rainfall was based on information for Menlo Park, California reported by Hem (1985). We assumed that the chemical composition of water table recharge was equal to the soil water composition computed for the previous month.

We performed two parallel calculations to estimate monthly changes in soil salinity. One path used a spreadsheet model to estimate salt mass changes and the other path utilized the chemical thermodynamic equilibrium program PHREEQE (Parkhurst and others, 1980). We employed PHREEQE to simulate calcite and gypsum dissolution due to changes in soil water chemical composition, and utilized the results to develop a linear equation for mineral precipitation and soil water EC. We incorporated the linear function into the spreadsheet model and computed monthly changes in soil EC. Based on the soil EC results, monthly soil selenium and boron concentrations were estimated using relationships reported by Fujii and Deverel (1989) and Wichelns (1989).

D.3.2.4 Groundwater Quality Model

We used a mass balance approach to estimate changes in groundwater quality over time. The annual mass balance of salts in the upper 50 feet of groundwater was represented as:

$$GM_t = GM_r - GM_d - GW_{Dp} + GM_{t-1} \pm Sg, \text{ where} \quad (4)$$

GM_t is the salt mass in groundwater in the current month t;
GM_r is the salt mass in water table recharge;
GM_d is the salt mass in drainage;
GW_{Dp} is the salt mass in deep percolation past the 50 feet depth;
GM_{t-1} is the salt mass in groundwater from the previous month; and,
Sg is the salt mass dissolved or precipitated in groundwater.

We assumed no net change in salt mass from laterally flowing groundwater, and calculated the Equation (4) components utilizing an effective groundwater depth. The different components were estimated as follows:

- An effective groundwater depth was estimated from groundwater-flow paths and specific yield estimates. Deverel and Fio (1991) and Fio and Deverel (1991) reported that Broadview Water District drainage systems collect groundwater primarily from within 50 feet of land surface. Belitz and others (1993) estimated a specific yield of 0.3 for the shallow aquifer. The effective groundwater depth was therefore estimated as 15 feet.

- An evapoconcentration factor accounted for shallow groundwater use by plants. The evapoconcentration factor was calculated as the product of shallow groundwater use by plants and water table evaporation divided by the effective groundwater depth.

- The initial groundwater EC was represented by the arithmetic average of drainwater and groundwater analyses (5.9 dS/m) reported by Deverel and others (1984), Schmidt (1989), and Broadview water district. The constituent composition represented by the EC value was estimated from groundwater analyses reported by Deverel and others (1984).

Deverel and Fujii (1988) determined that gypsum and calcite influence groundwater chemical composition in the Grassland Drainage Area. We used PHREEQE to simulate mineral dissolution and precipitation reactions and estimate annual groundwater chemistry. We used a spreadsheet model and PHREEQE simulation results similar to our approach to the soil salinity calculations described above. A linear expression was developed and incorporated into the spreadsheet model to relate groundwater EC changes due to mineral dissolution or precipitation.

The soil salinity model and groundwater-flow model results provided salt loads to the saturated zone. We calculated annual groundwater salinity changes in recharge from the flow-weighted average of months in which recharge occurred (January, February, March, May, June and July). The salt mass removed by drainage was calculated as the product of groundwater salinity and simulated drainflow.

Selenium and boron concentrations in western San Joaquin Valley groundwater samples are significantly correlated with salinity (Deverel and Millard, 1988). We utilized Deverel and Millard's (1988) published regression equations to estimate selenium and boron concentration changes due to simulated groundwater salinity changes. The equations describe the relationship

between EC, selenium, and boron concentrations in western San Joaquin Valley alluvial-fan groundwater.

D.4 ENVIRONMENTAL IMPACTS AND MITIGATION

D.4.1 No Use Agreement (No Action)

The No Action Alternative represents probable environmental conditions without the Grassland Bypass Agreement. Without a use agreement, the collection of drainwater into a single outlet for discharge ceases. Tile drainage systems probably continue to operate, but the drainwater presumably remains within the Grassland Drainage Area. Some subsurface water will continue to seep into unlined drainage ditches and could migrate uncontrolled into downslope wetlands.

We employed constant 1999 water supply and consumptive use data to estimate groundwater and soil conditions under the No Action Alternative. The analysis begins in 2001, when the current use agreement expires, and ceases in 2009 when the proposed Project is set to end. We presumed the drainwater is recycled in a way that displaces an equal volume of canal water. Hence, the water application rate remains the same but the irrigation water salinity increases. The increase in irrigation water salinity is proportional to the fractional contribution of the canal and drainage water. Broadview's monthly canal water deliveries, recycled drainwater volumes, water table recharge, soil moisture changes, and canal and drainwater chemical composition were provided by URS (URS Greiner Woodward Clyde, written communication, December 1 and 4, 2000).

D.4.1.1 Groundwater Effects

Under the No Action Alternative, the groundwater flow model projects no net change in mean water table depth beneath the drained areas. Our simulated water table conditions have the following potential groundwater effects.

- In the drained areas, no net change in water table depth corresponds to no net drainflow increase. Projected drainflow in 2009 is about 27, 835 acre-feet. We considered this as no impact to the Grassland Drainage Area.

- Model results indicated a three square mile net increase in area affected by a water table within 7 feet of land surface (increase from 124 to 127 square miles). The rising water table increased the evaporation rate from 0.19 to 0.20 feet/year. We considered the minimal increase in area and evaporation rate a less than significant impact to the Grassland Drainage Area.

- Uncontrolled discharge includes seepage into unlined drainage ditches and other water that cannot be recycled that enters drainage ditches. Flow model results indicate no net increase in seepage. This does not include the other uncontrollable discharges, which in 1999 amounted to 13,000 acre-feet. Unlike current conditions, the seepage and other discharges

will not be collected and controlled. We considered this a potentially significant adverse impact to adjacent areas.

Groundwater beneath the Grassland Drainage Area naturally moves to the northeast towards the wetlands and San Joaquin River. The subsurface flow either discharges uncontrolled to the adjacent wetlands or the San Joaquin River, or moves downward and recharges the deeper aquifer system. Model results indicate there is no significant change in subsurface flow or deep aquifer recharge leaving the Grassland Drainage Area and therefore no significant impact to adjacent areas.

D.4.1.2 Salinity Effects

Under the No Action Alternative, soil and groundwater salinity increases as a result of increased drainwater recycling.

- Annual soil salinity increases from 6.0 to 7.9 dS/m (soil selenium increases from 66 to 87 micrograms per liter, and boron increases from 3.1 to 4.0 milligrams per liter). We considered the 32-percent mean soil salinity increase a significant adverse impact.

- Groundwater salinity increases from 5.9 dS/m to 7.3 dS/m, which we considered a significant adverse impact. Selenium concentrations in groundwater increase from 46 to 72 micrograms per liter, and boron concentration increases from 6.0 to 8.0 milligrams per liter.

D.4.2 Grassland Bypass Project

The Grassland Bypass Project is the proposed project, and is a continuation of the existing Bypass Use Agreement. The Grassland Area Farmers will continue to collect drainwater for discharge into the San Luis Drain. Some project aspects will be modified to meet increased regulatory requirements attached to the waste discharge permit.

One project modification is an In-Valley Treatment element to meet substantial load reductions due to revised water quality objectives that begin October 1, 2005. The Project proposes to increase drainage reuse and develop up to 6,200-acres for a drainwater treatment facility to help meet the new objectives (URS Greiner Woodward Clyde, 1999). The project plans to grow salt tolerant crops on dedicated lands irrigated with drainwater. The treatment element is designed to reduce drainwater volume, remove salt, selenium, and boron from concentrated drainwater, and utilize in-valley salt disposal to prevent discharge to the San Joaquin River.

We employed constant 1999 hydrologic conditions to identify potentially significant impacts due to the Grassland Bypass Project. The analysis period is 2001-09. For the purposes of our groundwater analysis, we assumed annual water application rates are constant. Two scenarios are considered to assess irrigation water quality effects. The first scenario assumes applied water quality is equal to current conditions, which include a mixture of canal water and recycled drainwater. The second scenario considers potential impacts from the In-Valley Treatment element, and applied water quality is equal to drainwater quality. Drainwater will be applied

directly to at most 6,200 acres, which represents 6-percent of the Grassland Drainage Area. The two scenarios are compared to the No Action Alternative.

D.4.2.1 Groundwater Effects

The groundwater-flow model projects no net change in mean water table depth during the project period (Figure D-6). The mean depth to water beneath drained areas remains at 6.7 feet below land surface. Our simulated water table conditions have the following potential groundwater effects:

- No net change in water table depth corresponds to no net drainflow increase. In 2009, projected drainflow is about 27,835 acre-feet and the same as estimated for the No Action Alternative. The Grassland Bypass Project is therefore considered neutral because drainwater production is the same as the No Action Alternative.

- In 2009, model results indicate that about 127 square miles will be affected by a water table within 7 feet of land surface, which is the same as the No Action Alternative. Similarly, the net bare-soil evaporation increase was the same for the Project and No Action alternatives (0.01 feet/year). The Project is therefore considered neutral relative to the No Action Alternative.

- Uncontrolled discharge includes seepage into unlined drainage ditches. Flow model results indicate no net increase in seepage under Project conditions. Unlike the No Action Alternative, seepage and other waters that cannot be recycled that enter the drainage ditches will be collected and discharged to the Grassland Bypass. The Grassland Bypass Project is therefore considered to have a significant beneficial impact relative to the No Action Alternative by controlling these discharges.

D.4.2.2 Salinity Effects

In the western San Joaquin Valley, minerals are present in the unsaturated zone. As the crop uses water, and soluble salts are evapoconcentrated, gypsum and calcite minerals are precipitated. This precipitation, salt dilution by applied water, and salt removal by drainage systems offset the salinity increases due to evapoconcentration. Soil salinity will therefore approach a constant value, and the final salinity represents a new chemical equilibrium under simulated steady-state soil moisture conditions.

For the nine-year project period (2001-2009), our analysis indicates that soil and groundwater salinity will increase as a result of current drainwater recycling. This conclusion is supported by data for Broadview Water District. Wichelns (1989) reported an average soil salinity of 2.0 dS/m for a field located in the southeastern part of the district. Ayers and others (1996) reported an average soil salinity of 4.9 dS/m for the same field. These data suggest that Broadview Water District soil salinity may already be increasing under current drainwater recycling conditions. Broadview Water District probably represents a worse case scenario because drainwater recycling was historically more intense than in other districts.

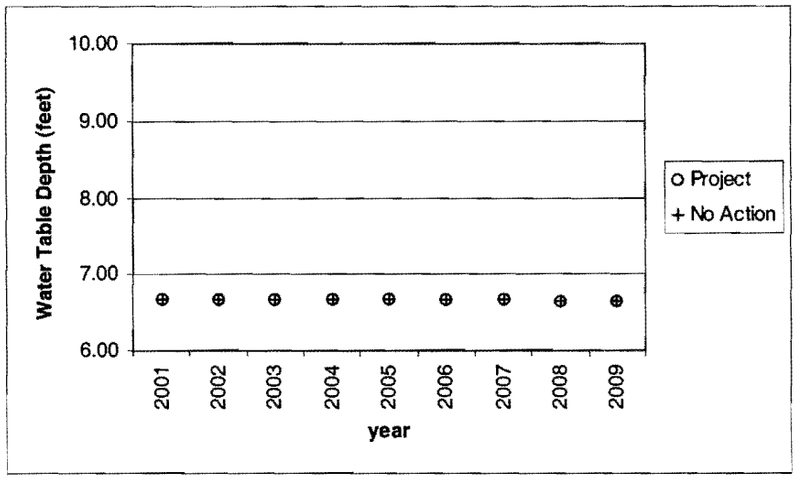


Figure D-6. Simulated mean water table depth for Project and No Action Alternatives, 2001-2009.

For the Grassland Bypass Project, our salinity modeling identified the following potential impacts to soil and groundwater:

- Simulated unsaturated-zone soil salinity increases from 6.0 dS/m to 6.8 dS/m in 2009, but is substantially less than estimated for the No Action Alternative (Figure D-7). In Broadview Water District, the coefficient of variation approaches 50 percent for soil salinity data (Wichelns, 1989; Corwin and others, 1999). This means that the soil salinity increases we simulated will not be observable over a short time period (ten years) without extensive sampling.

  Soil selenium increases from 66 to 75 micrograms per liter and boron increases from 3.1 to 3.5 milligrams per liter. The selenium and boron concentration increases are also less than the No Action Alternative. The Grassland Bypass Project is therefore considered to have a beneficial impact on soil salinity relative to the No Action Alternative.

  Simulated groundwater salinity increases from 5.9 dS/m to 6.6 dS/m in 2009 (Figure D-8). The coefficient of variation for groundwater salinity data from the Grassland Drainage Area is more than 40 percent. This means a large number of samples would be needed to detect the salinity increase. Drainwater data is limited for representing groundwater quality because salt transport, mixing along groundwater-flow paths, and irrigation management practices can conceal the short term salinity increases.

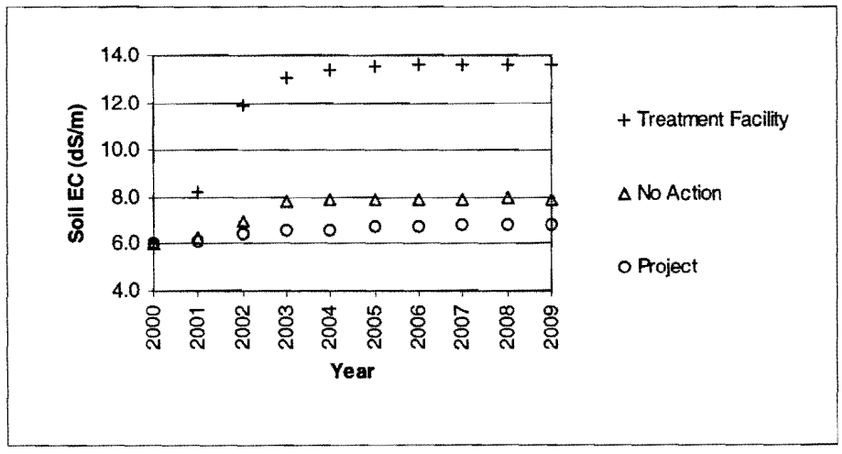


Figure D-7. Simulated annual soil salinity changes for Project and No Action Alternatives, 2001-2009.

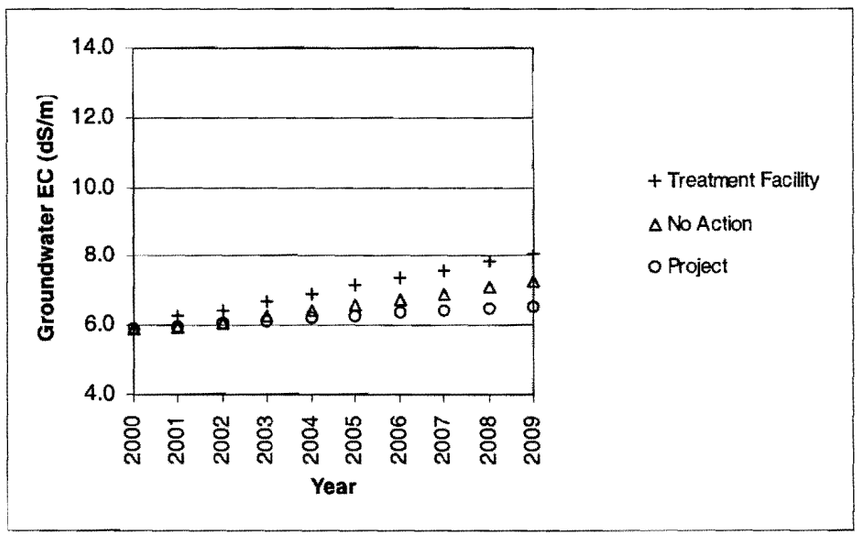


Figure D-8. Simulated annual groundwater salinity changes for Project and No Action Alternatives, 2001-2009.

Simulated groundwater selenium concentration increase from 46 to 58 micrograms per liter and boron concentrations increase from 6.0 to 6.9 milligrams per liter. Under this alternative, the Grassland Bypass Project is considered to have a potentially beneficial impact on groundwater salinity relative to the No Action Alternative.

- Soil and groundwater salinity will increase more dramatically if drainwater is applied undiluted directly to fields. The In-Valley Treatment element represents the worse case scenario where undiluted drainwater is applied directly to fields. Under these conditions, the

unsaturated-zone soil salinity is projected to increase from 6.0 to 13.6 dS/m. Similarly, groundwater salinity is projected to increase from 5.9 dS/m to 8.1 dS/m. Although these salinity increases represent significant adverse impacts, they are limited to at most 6,200 acres (6-percent of the Grassland Drainage Area), and are not irreversible. Impacted soils could be reclaimed and saline shallow groundwater removed if an alternative means of salt disposal becomes available.

The In-Valley Treatment element's objective is not agricultural production but water consumption. Treatment facility fields would be planted with salt tolerant crops and managed to limit soil salinity impacts. We therefore considered the area-limited application of undiluted drainwater as a less than significant impact to the Grassland Drainage Area. Soil and groundwater monitoring could track salinity changes at treatment facility boundaries.

D.4.3 Mud Slough Bypass Alternative

The Mud Slough Bypass Alternative constructs a new channel through the wetlands with discharge into the San Joaquin River. The proposed discharge outlet is downstream from the confluence with the Merced River. Drainwater would continue to be collected and discharged from the Grassland Drainage Area. The project includes the In-Valley Treatment element. Accordingly, estimated groundwater and soil impacts within the Grassland Drainage Area are identical to the Grassland Bypass Project.

D.4.3.1 Groundwater Effects

The groundwater-flow model projects no net change in mean water table depth during the Project period. Our simulated water table conditions have the following potential groundwater effects:

- No net change in water table depth corresponds to no net drainflow increase. Hence, projected drainflow in 2009 is about 27,835 acre-feet. The Mud Slough Bypass Alternative is therefore considered to have no impact on drainwater production relative to the No Action Alternative.

- In 2009, model results indicate that about 127 square miles will be affected by a water table within 7 feet of land surface, which is the same as the No Action Alternative. Similarly, the net bare-soil evaporation rate increase is the same for the Project and No Action alternatives (0.01 feet/year). The Project is therefore considered to have no impact on the area and rate of bare soil evaporation relative to the No Action Alternative.

- Uncontrolled discharge includes seepage into unlined drainage ditches. Flow model results indicate no net increase in seepage under Mud Slough Alternative conditions. Unlike the No Action Alternative, the seepage will be collected and discharged to the Mud Slough Bypass. The Mud Slough Bypass Project is therefore considered to have a significant beneficial impact by controlling seepage and other discharges relative to the No Action Alternative.

D.4.3.2 Salinity Effects

For the nine-year project period (2001-2009), our analysis indicates that soil and groundwater salinity will increase as a result of drainwater recycling. The salinity modeling identified the following potential impacts to soil and groundwater:

- Simulated unsaturated-zone soil salinity increases from 6.0 dS/m 6.8 dS/m in 2009. Soil selenium increases from 66 to 75 micrograms per liter and boron increases from 3.1 to 3.5 milligrams per liter. The Mud Slough Bypass Alternative is considered to have a beneficial impact on soil salinity relative to the No Action Alternative.

- Simulated groundwater salinity increases from 5.9 dS/m to 6.6 dS/m in 2009. Simulated groundwater selenium concentration increases from 46 to 58 micrograms per liter and boron concentrations increase from 6.0 to 6.9 milligrams per liter. The Mud Slough Bypass Alternative is considered to have a potentially beneficial impact on groundwater salinity relative to the No Action Alternative.

- Soil and groundwater salinity will increase more dramatically if undiluted drainwater is applied directly to fields because the applied water salinity increases. For example, the In-Valley Treatment element will apply undiluted drainwater directly to fields. The soil salinity is projected to increase from 6.0 to 13.6 dS/m. Similarly, groundwater salinity is projected to increase from 5.9 dS/m to 8.1 dS/m. We considered these salinity increases as significant adverse impacts. However, the impacts will be limited to at most 6,200 acres (6-percent of the Grassland Drainage Area) and are not irreversible. Impacted soils could be reclaimed and saline shallow groundwater removed if an alternative means for salt disposal becomes available.

  The In-Valley Treatment element's objective is not agricultural production but water consumption. Treatment facility fields would be planted with salt tolerant crops and managed to limit soil salinity impacts. We therefore considered the area-limited application of undiluted drainwater as a less than significant impact to the Grassland Drainage Area. Soil and groundwater monitoring could identify impacts and potential salinity changes at treatment facility boundaries.

D.5 CUMULATIVE EFFECTS

Cumulative effects are impacts that are insignificant on their own but when combined with other incremental effects can become significant. Although the Grassland Bypass Project and Mud Slough Bypass Alternative are projected to have less than significant water table, soil and groundwater impacts, Grassland Drainage Area irrigation recharge contributes to on-going regional increases in water table elevation, soil salinity, and groundwater salinity (Belitz and others, 1993). Conversely, irrigation recharge in adjacent and upslope areas contribute to water table elevation, soil salinity, and groundwater salinity increases in the Grassland Drainage Area.

In the Grasslands and Westlands Sub-Basins, California Department of Water Resources reported the area underlain by a water table within 10 feet of land surface has on the average increased about 20,000 acres per year during the period 1991-97 (Department of Water Resources, 2000). The San Joaquin Valley Drainage Implementation Program (1998) reported that in 1990 alone, almost 1.5 million tons of salt were imported and deposited into western San Joaquin Valley soils and water. The water table rise and salinization of soil and groundwater is a significant regional problem.

D.6 IMPACT MITIGATION SUMMARY

The following summarizes groundwater and soil impacts. The impacts are evaluated relative to the No Action Alternative and existing conditions.

Anticipated Environmental Effect	**No Action** *Compared to Existing Condition*	**Grassland Bypass** *Compared to No Action*	**Grassland Bypass** *Compared to Existing Condition*	**Mud Slough Bypass** *Compared to No Action*	**Mud Slough Bypass** *Compared to Existing Condition*
• Drainwater production	No Impact	Neutral	No Impact	Neutral	No Impact
• Area affected by shallow water	Less Than Significant Adverse Impact	Neutral	No Impact	Neutral	No Impact
• Bare-soil evaporation rate	Less Than Significant Adverse Impact	Neutral	No Impact	Neutral	No Impact
• Uncontrolled seepage and other discharges	Significant Adverse Impact	Significant Positive	No Impact	Significant Positive	No Impact
• Uncontrolled groundwater discharge	No Impact	Neutral	No Impact	Neutral	No Impact
• Soil salinity*	Significant Adverse Impact/ Not a Component of No Action	Significant Positive/ Less Than Significant Negative	No Impact/Less Than Significant Adverse Impact	Significant Positive/Less Than Significant Negative	No Impact/Less Than Significant Adverse Impact
• Groundwater salinity*	Significant Adverse Impact/ Not a Component of No Action	Potentially Positive/ Less Than Significant Negative	No Impact/Less Than Significant Adverse Impact	Potentially Postive/Less Than Significant Negative	No Impact/Less Than Significant Adverse Impact

* Drainwater recycling/ Treatment Facility.

In the Grassland Drainage Area, the spatial variability of constituents in soil and groundwater is high. This spatial variability must be considered when designing plans to monitor groundwater and soil salinity. For example in Broadview Water District, the coefficient of variation approaches 50 percent for soil salinity data (Wichelns, 1989; Corwin and others, 1999). Similarly, the coefficient of variation for groundwater salinity data is more than 40 percent. This means that the soil- and groundwater salinity increases we simulated will not be observable over a short time period (ten years) without extensive sampling. For example, our analyses estimated annual groundwater salinity could increase from about 20 to about 50 percent. Unless a large number of samples are collected, the simulated salinity increase will probably go undetected because groundwater salinity varies spatially by more than 40 percent.

A summary of our impact analysis is provided below.

D.6.1 No Action Alternative

The No Action Alternative represents probable environmental conditions without the Grassland Bypass Agreement. Tile drainage systems probably continue to operate, but the drainwater produced presumably remains within the Grassland Drainage Area.

- No net change in water table depth and projected drainflow indicates no impact to the Grassland Drainage Area.
- Minimal projected net increases in both the area affected by a shallow water table (3 square miles) and simulated bare-soil evaporation rate (0.01 feet/year) indicate a less than significant adverse impact to the Grassland Drainage Area.
- Our analysis indicated no change in seepage and subsurface flow leaving the Grassland Drainage Area. Unlike current conditions, uncontrollable flows will not be collected and therefore represent significant new adverse impacts to adjacent areas.
- The 32-percent increase in soil salinity represents a significant adverse impact.
- The 24-percent increase in groundwater salinity represents a significant adverse impact.

D.6.2 Grassland Bypass Project

The Grassland Bypass Project is the Proposed Project, and is a continuation of the existing Bypass Use Agreement. The Grassland Area Farmers will continue to collect drainwater for discharge into the San Luis Drain. An In-Valley Treatment element will also be included. Our analysis indicated the following effects:

- No net change in water table depth and projected drainflow indicates the Project is neutral relative to the No Action Alternative. The Project is a continuation of existing conditions, and therefore has no impact. No mitigation is required.

- Minimal projected net increases in both the area affected by a shallow water table (3 square miles) and simulated bare-soil evaporation rate (0.01 feet/year) are the same as the No Action Alternative. The Project is therefore considered neutral relative to the No Action Alternative. The Project is a continuation of existing conditions, so there is no impact and no mitigation is required.

- Our analysis indicated no change in seepage and subsurface flow leaving the Grassland Drainage Area. Unlike the No Action Alternative, seepage and other waters that enter the drainage ditches will be collected and discharged to the Grassland Bypass. The Grassland Bypass Project is therefore considered to have a significant positive effect relative to the No Action Alternative by controlling these discharges. The Project is a continuation of existing conditions, and there is no impact. No mitigation is required

- Simulated unsaturated-zone soil salinity increases are substantially less than the No Action Alternative. The Grassland Bypass Project is therefore considered to have a significant positive effect on soil salinity relative to the No Action Alternative. The Project is a continuation of existing conditions (no impact). Therefore, no mitigation is required.

- Simulated groundwater salinity increases are less than the No Action Alternative. The Grassland Bypass Project is therefore considered to have a potentially positive effect on groundwater salinity relative to the No Action Alternative. The Project is a continuation of existing conditions (no impact). Therefore, no mitigation is required.

- Soil and groundwater salinity will increase more dramatically if drainwater is applied directly to fields. The In-Valley Treatment element would apply undiluted drainwater directly to fields, and soil and groundwater salinity are projected to increase substantially relative to the No Action Alternative and existing conditions. We considered the salinity increases as significant adverse impacts, but the impacts would be limited to at most 6,200 acres (6-percent of the Grassland Drainage Area). The treatment facility will be managed to optimize consumptive use of water, and impacted soils could be reclaimed and saline shallow groundwater removed if an alternative means for salt disposal becomes available. We therefore concluded that direct application of drainwater results in a less than significant adverse impact. Soil and groundwater monitoring of the In-Valley Treatment Element is recommended to identify impacts and potential salinity changes at facility boundaries, if any.

D.6.3 Mud Slough Bypass Alternative

The Mud Slough Bypass Alternative constructs a new channel and/or pipeline through the wetlands with discharge into the San Joaquin River. The proposed discharge outlet is downstream from the confluence with the Merced River. Drainwater would continue to be collected and discharged from the Grassland Drainage Area. The In-Valley Treatment element will be also included. The estimated groundwater and soil impacts are therefore identical to the Grassland Bypass Project.

- No net change in water table depth and projected drainflow indicates the Project is neutral relative to the No Action Alternative. The estimated impacts are identical to the Grassland Bypass Project, and there is no impact relative to existing conditions. Therefore, no mitigation is required.

- Minimal projected net increases in the area affected by a shallow water table (3 square miles) and simulated bare-soil evaporation rate (0.01 feet/year) are the same as the No Action Alternative. The project is therefore considered neutral relative to the No Action Alternative. The estimated impacts are identical to the Grassland Bypass Project, and there is no impact relative to existing conditions. No mitigation is required.

- Our analysis indicated no change in seepage and subsurface flow leaving the Grassland Drainage Area. Unlike the No Action Alternative, seepage and other waters that enter the drainage ditches will be collected and discharged to the Grassland Bypass. The Grassland Bypass Project is therefore considered to have a significant positive effect relative to the No Action Alternative by controlling these discharges. The estimated impacts are identical to the Grassland Bypass Project, and there is no impact relative to existing conditions. Therefore, no mitigation is required.

- Simulated unsaturated-zone soil salinity increases are substantially less than the No Action Alternative. The Mud Slough Bypass Alternative is therefore considered to have a significant positive effect on soil salinity relative to the No Action Alternative. The estimated impacts are identical to the Grassland Bypass Project, and there is no impact relative to existing conditions. Therefore, no mitigation is required.

- Simulated groundwater salinity increases are less than the No Action Alternative. The Mud Slough Bypass Alternative is therefore considered to have a potentially positive effect on groundwater salinity relative to the No Action Alternative. The estimated impacts are identical to the Grassland Bypass Project, and there is no impact relative to existing conditions. Therefore, no mitigation is required.

- Soil and groundwater salinity will increase more dramatically if drainwater is applied directly to fields. The In-Valley Treatment element would apply undiluted drainwater directly to fields and soil and groundwater salinity are projected to increase substantially relative to the No Action Alternative and existing conditions. We considered the salinity increases as significant adverse impacts, but the impacts will be limited to at most 6,200 acres (6-percent of the Grassland Drainage Area). The treatment facility will be managed to optimize consumptive use of water, and impacted soils could be reclaimed and saline shallow groundwater removed if an alternative means for salt disposal becomes available. We therefore concluded that direct application of drainwater results in a less than significant adverse impact. Soil and groundwater monitoring of the In-Valley Treatment Element is recommended to identify impacts and potential salinity changes at facility boundaries, if any.

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