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ABSTRACT

The San Joaquin - Tulare Conjunctive Use Model (SANTUCM) was developed to evaluate possible long-term scenarios for long term management of drainage and drainage related problems in the western San Joaquin Valley of California. The unique aspect of the conjunctive use model is its coupling of a surface water delivery operations model with a regional groundwater model. A salinity model has been added to utilize surface water model output and allow assessment of compliance with State Water Resources Control Board water quality objectives for the San Joaquin River. The results of scenario runs, performed to date,using the SANTUCM model show that water table lowering and consequent drainage reduction can be achieved through a combination of source control, land retirement and regional groundwater pumping. The model also shows that water transfers within the existing distribution system are technically feasible and might allow additional releases to be made from Friant Dam for water quality maintenance in the San Joaquin River. However, upstream of Mendota Pool, considerable stream losses to the aquifer are anticipated, amounting to as much as 76% of in-stream flow.

INTRODUCTION

The continued irrigation of agricultural land in the western San Joaquin Valley of California could eventually lead to drainage problems on 800,000 acres by the year 2040 (SJVDP, 1990). A number of actions have been proposed to address this problem and related problems of soil salinization and high selenium concentrations in drainage return flows. The majority of these actions have focused on the control of drainage problems at their source in order to reduce groundwater recharge and hence reduce the need for drainage. Other actions include (a) regional pumping of groundwater to lower high saline water tables; (b) selected land retirement to control regional water tables and reduce the capture of high salinity and high selenium groundwater by tile drains; (c) re-operation of reservoirs such as Millerton Lake to allow greater drainage loading in the San Joaquin River during certain critical times of the year; and (d) replacement of existing tile drainage systems in selenium source areas with more closely spaced, shallow tile drains.

THE DRAINAGE PROBLEM

The San Joaquin River serves only the northern half of the San Joaquin Valley, the San Joaquin Basin. The southern half of the San Joaquin Valley, the Tulare Basin, drains to the south and does not have a drainage outlet. Evaporation ponds currently provide drainage disposal to approximately 15,000 acres of the Tulare basin. However, the costs of compliance with recently promulgated evaporation pond regulations for construction and operation of these facilities make it unlikely that many more will be built.

On-farm source-control solutions by themselves will not solve the problem. Soil heterogeneity and inherent difficulties in the ability of irrigation technologies to apply water uniformly limit the potential improvement in irrigation efficiency possible, through the use of improved technologies. In fact, overstatement of the potential for source control can lead to the oversight of other measures that become evident with a more macrospective or regional view of the overall water delivery and groundwater system and their interactions.

The Delta Mendota Canal (DMC) and California Aqueduct (CAQ), originate in the San Francisco Bay Delta and provide much of the irrigation water used on the west side of the San Joaquin Valley and in the Tulare Basin. The Friant-Kern Canal (FKC) delivers water from Millerton Lake to users along the foothills of the eastern slope of the Sierra. The Cross Valley Canal (CVC) is the other major surface water conveyance structure in the San Joaquin Valley which transports water from the Aqueduct to users along the eastern slope of the Sierra Nevada mountain range. Water flows into the Tulare Basin originate from seven primary sources: King's, Kaweah, Tule, and Kern rivers and the DMC, CAQ and FKC. Those spills from the King's River that can be accomodated along the James By-Pass, flow north into the San Joaquin River and into the Delta.

PLANNING STUDIES FOR FUTURE MANAGEMENT OF THE SAN JOAQUIN BASIN

A central assumption to most planning studies (SJVDP, 1990), that have been conducted to address drainage and drainage related problems in the western San Joaquin Valley, is that the San Joaquin River continues to be used as a means of drainage disposal to the limit of the river's assimilative capacity. The monthly assimilative capacity of the river has been defined in terms of compliance with the State Water Resources Control Board objectives for TDS, selenium and boron. Most future scenarios developed in these planning studies (SJVDP,1990) led to an ultimate reduction in future agricultural irrigation demands for water supply. Opportunities exist for creative use of this potentially available water supply to restore, mitigate and in some instances enhance environmental resources within the basin. The effect of drainage management plan on the future operations of the San Joaquin River basin and the effect this plan might have when combined with other management opportunities for enhancement of water quality, fisheries, wildlife habitat and recreation.

MODELING OF SURFACE AND GROUNDWATER RESOURCES

A series of simulation and optimization models were constructed in the 1970's and early 1980's to study alternative operating policies for the Central Valley Project and to allow closer co-ordination between the Federal and State water projects. Planning studies conducted using these models were primarily concerned with water quantity issues - the servicing of legal contracts for agricultural and municipal water supply and power contractural obligations. The issues of environmental protection in these models were largely limited to the maintenance of fish and wildlife habitat in the major tributaries to the san Joaquin River and the San Francisco Bay Delta.

Water quality issues have become of greater significance in the past 5 years. Computer-based, simulation models can aid in comprehension of these interactions where sufficient data has been gathered to permit model calibration and validation. In cases where these relationships cannot be formulated mathematically, sets of rules can be developed setting bounds or constraints on such factors as minimal monthly flows in a river to allow fish migration during critical times of the year; maximum permissible daily water temperatures to protect fish habitat or fish populations, or releases of water of adequate quality to refuges to sustain wildfowl populations. These rules can be incorporated into decision support systems to assist in the development and evaluation of alternative solutions to contamination problems, and to present these solutions in a manner that allows consensus building among potentially responsible or affected groups. Planners also need to comprehend the models they use and to be able to explain the assumptions made by these models to others.

SAN JOAQUIN-TULARE CONJUNCTIVE USE MODEL

The San Joaquin-Tulare Conjunctive Use Model (SANTUCM) was developed by Boyle Engineering Corporation and Water Resources Managment Inc. under the direction of the SJVDP. The model was designed to allow the inclusion of water quality considerations in long term water contracting studies and allow prediction of long term water supply and water quality trends and environmental effects. SANTUCM simulates the surface water operations and groundwater flow within the San Joaquin-Tulare Basin on monthly time interval. In the surface water portion of the model, the river system is represented as a network of links and nodes as shown in Figure 1. In the groundwater portion of the model, the groundwater aquifer system is represented by a two-layered, two-dimensional finite element network. The solution of the surface water model is achieved by mass balance calculations whereas the groundwater flow model is solved numerically using the finite element method. The model can be run in three different ways: (1) surface water model only; (2) groundwater model only and (3) linked surface water and groundwater models. SANTUCM contains a salinity model which tracks the salt (TDS) balance at each surface water node and its interaction with corresponding groundwater finite elements.at surface water nodes along each of the tributaries and along the San Joaquin River.

The groundwater model study area was divided into quadrilateral and triangular areas or elements, chosen to recognize, to the extent possible, water district boundaries, rivers, major tributaries and flow restricting groundwater features. In the groundwater model, the flow calculations and flow interactions between stream and aquifer are performed at the same nodes. In the surface water and salinity models stream reaches are defined that comprise of a number of groundwater nodes. These nodes were located at the confluences of rivers and larger tributaries, at major points of diversion along canals and aqueducts and at reservoirs or locations at which large quantities of surface water can be stored.

The surface water components considered in the model are reservoirs (storage nodes); canal and river systems (arcs or links); hydropower plants; natural flow and water import points (inflow nodes); municipal, industrial, agricultural demand points (demand nodes); fish and wildlife flow requirements (flow-through-demand links). The hydrologic processes modeled include evapotranspiration; direct runoff; infiltration; stream and groundwater aquifer interaction.

In the surface water model, the major inputs include streamflows; irrigation efficiences; evaporation rates; project and non-project water demands; reservoir storage limits; reservoir rule (flood control) curves; hydropower parameters. In the groundwater model, the major inputs include the groundwater grid system; groundwater levels and flow data; groundwater pumping data. Other inputs are soil type and land use data; various initial and boundary conditions for both surface water and groundwater flow components.

The major model outputs include flow values in streams and canals; stream gains and losses; water deliveries at various demand points; return flow rates; reservoir releases and storage levels; hydropower generation; pumping rates; groundwater levels; recharge factors.

The reservoir operating criterion is based on demands. A demand is met by first pumping a certain (minimum) amount of groundwater and then delivering surface water to meet the remaining demand. If this is not satisfied, the model assumes that additional groundwater is pumped up to a certain maximum. The model recognizes three types of demands: nonproject demand, such as senior water rights; project demands, such as irrigation and municipal demands; demands to serve fish and wildlife resources and navigation. Surface water available for nonproject demands is based mainly on available natural inflows for a given time period. Surface water available for project demands as well as fish and wildlife is based on available natural inflows and water that may be drafted from reservoirs.

Reservoir releases are based on allowable storages, target storages, flood control rules and release gate capacities. It is assumed that the reservoir operating rules (including storage criteria) have been formulated based on some specific objectives and constraints. Between competing reservoirs, the priority of which reservoir to draw first is based on the so-called "space" rule. In the space rule, the ratio between available (free) storage for a given time period and annual storable inflow (long term annual difference of reservoir inflows and demands) is computed for each reservoir. The reservoir with a lowest ratio would have the highest priority among the reservoirs from which water can be drawn.

In SANTUCM, the surface water-groundwater linkage computation process is contained in a "do-loop" by computing first the volume of water in the streams (in the surface water model portion of SANTUCM) followed by calculation of the amount of stream gains or losses (in the groundwater model portion) represent estimates of recharge or discharge, respectively in the groundwater. Then the groundwater model is executed and new estimates of stream gains or losses are computed. These new estimates of stream gains or losses are applied to the streams in a second iteration of the mass balance routines in the surface water model. Mass balances are performed of TDS into and out of each stream node once the surface water hydrology has been resolved.

PLANNING STUDIES CONDUCTED USING THE SANTUCM MODEL

The results of scenario runs, performed to date, using the SANTUCM model show that water table lowering and consequent drainage reduction can be achieved through a combination of source control, land retirement and regional groundwater pumping. These scenario runs assumed a 1990 level of development for land use, storage and conveyance facilities and hydrology data for the period 1960 - 1977. A base run was made to provide a datum to compare the results of the four scenario runs shown in Figure 4. The model was operated to meet the SWRCB target of 500 ppm TDS at the Vernalis monitoring site shown in Figures 2 and 3. The four scenarios were formulated as combinations of the following actions:

(a) Regionally controlled groundwater pumping combined with source control of irrigation applications. Additional groundwater pumping of 0.4 acre-ft/acre was assumed in candidate regions with an aquifer depth of more than 200 feet of useable groundwater (less than 1250 ppm TDS) and aquifer recharge from irrigation was reduced by 0.35 acre-ft/acre in the same areas (Figure 2). This action resulted in an available water supply of 130,000 acre-ft/year.

(b) The 130,000 acre-ft of water supply that would normally be delivered to these areas through the DMC and CAQ will instead be delivered via the CVC to the Friant Kern Service area. This area is currently served by Friant Dam and the FKC. If the CVC exchange capacity is exceeded during any month, this water is released from Mendota Pool into the San Joaquin River to enhance river flows to aid fish migration.

(c) The 130,000 acre-ft are made available on the same monthly distribution pattern as (b) but at Mendota Pool via Salt and/or Mud Sloughs. The dual objective of this action is to enhance fish flows and dilute contaminated drainage water return flows to the San Joaquin River that occur above the confluence with the Merced.

(d) Retire or idle Class 4 (USBR classification) agricultural land in areas identified with high saline water tables (depth to groundwater less than 10 ft) and with high selenium concentrations in the shallow groundwater of greater than 50 ppb. A total of 75,000 acres are targeted resulting in an available water supply of 198,000 acre-ft/year.

(d) Utilize the 198,000 acre-ft by off-setting monthly Friant-Kern deliveries to the monthly capacity constraints of the CVC (as in (b)). Similarly, the excess water supply would be delivered via the DMC to Mendota Pool.

Scenario 1	(a)	+	(b)		
Scenario 2	(a)	+	(c)		
Scenario 3	(d)	+	(b)		
Scenario 4	(a)	+	(d)	+	(b)

RESULTS AND CONCLUSIONS

The scenarios analyzed with the SANTUCM model illustrate the utility of coupling a surface water delivery operations model with a regional groundwater model. The SANTUCM model shows that water table lowering and consequent drainage reduction can be achieved through a combination of source control, land retirement and regional groundwater pumping. The model also shows that water transfers within the existing distribution system are technically feasible and might allow additional releases to be made from Friant Dam for water quality maintenance in the San Joaquin River.

In Scenario 1 an average of 113,000 acre-ft/year were released from Friant Dam in excess of the base run. Spills during some years reduced the release below planned release of 130,000 acre-ft. Of the 113,000 acre-ft released only 27,000 acre-ft reached Vernalis in any one year, a 76% loss (Figure

4). Most of the stream-aquifer losses occurred in the San Joaquin River in the reach immediately upstream of Mendota Pool. Pumping at 2040 levels over the projected 1990 - 2007 period results in more than 5ft of drawdown over the entire pumped area and up to a 1 ft rise along the San Joaquin River above Mendota Pool.

In Scenario 2 releases made directly from Mendota Pool on a irrigation demand pattern (similar to the drainage discharge pattern) increases the monthly flow in the San Joaquin River. Annual flows reaching Vernalis amount to 127,000 acre-ft/yr (Figure 4). Groundwater effects are similar to those in Scenario 1.

Of the 198,000 acre-ft/yr of water supply made available in Scenario 3, 68,000 acre-ft/yr could not be accomodated by the CVC and was released directly to the San Joaquin River at Mendota Pool. An average increased flow of 100,000 acre-ft/yr reached Vernalis (Figure 4). Groundwater levels were reduced by between 5 ft and 10 ft over the areas retired from irrigated agriculture.

A combined total of 328,600 acre-ft/yr was reallocated in Scenario 4. A total of 98,600 acre-ft was directly delivered to Mendota Pool and the remainder released from Friant Dam. Losses along the upper reaches of the river resulted in rising water tables in the groundwater aquifer along the river and at the confluence of the San Joaquin River and the Stanislaus River. The model shows that the mean additional flow reaching Vernalis would be about 220,000 acre-ft/yr (Figure 4).

The large losses of surface water supply experienced along the upper reaches of the San Joaquin River and at the confluence with the Stanislaus River in all scenarios analyzed with the SANTUCM model suggests that the resource cost of restoring the fishery in the upper San Joaquin River may be high. Water quality is enhanced most cost effectively by directly diverting water to Mendota Pool. It is anticipated that the SANTUCM model will enjoy considerable use in the current efforts by State and federal Agencies to develop a water quality action plan for the San Joaquin River Basin.

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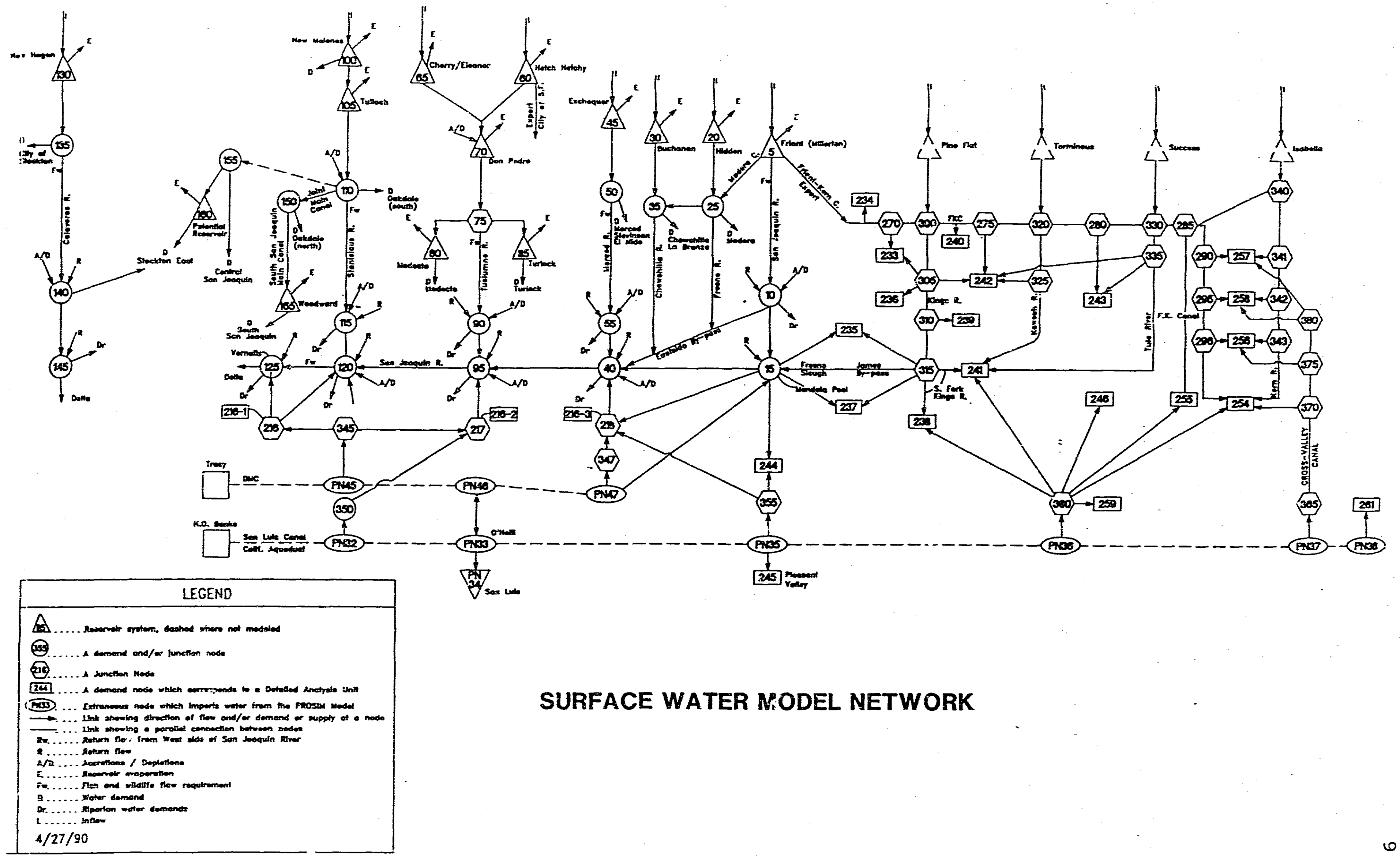
Figure 1.

SAN JOAQUIN - TULARE CONJUNCTIVE USE MODEL



SURFACE WATER MODEL NETWORK

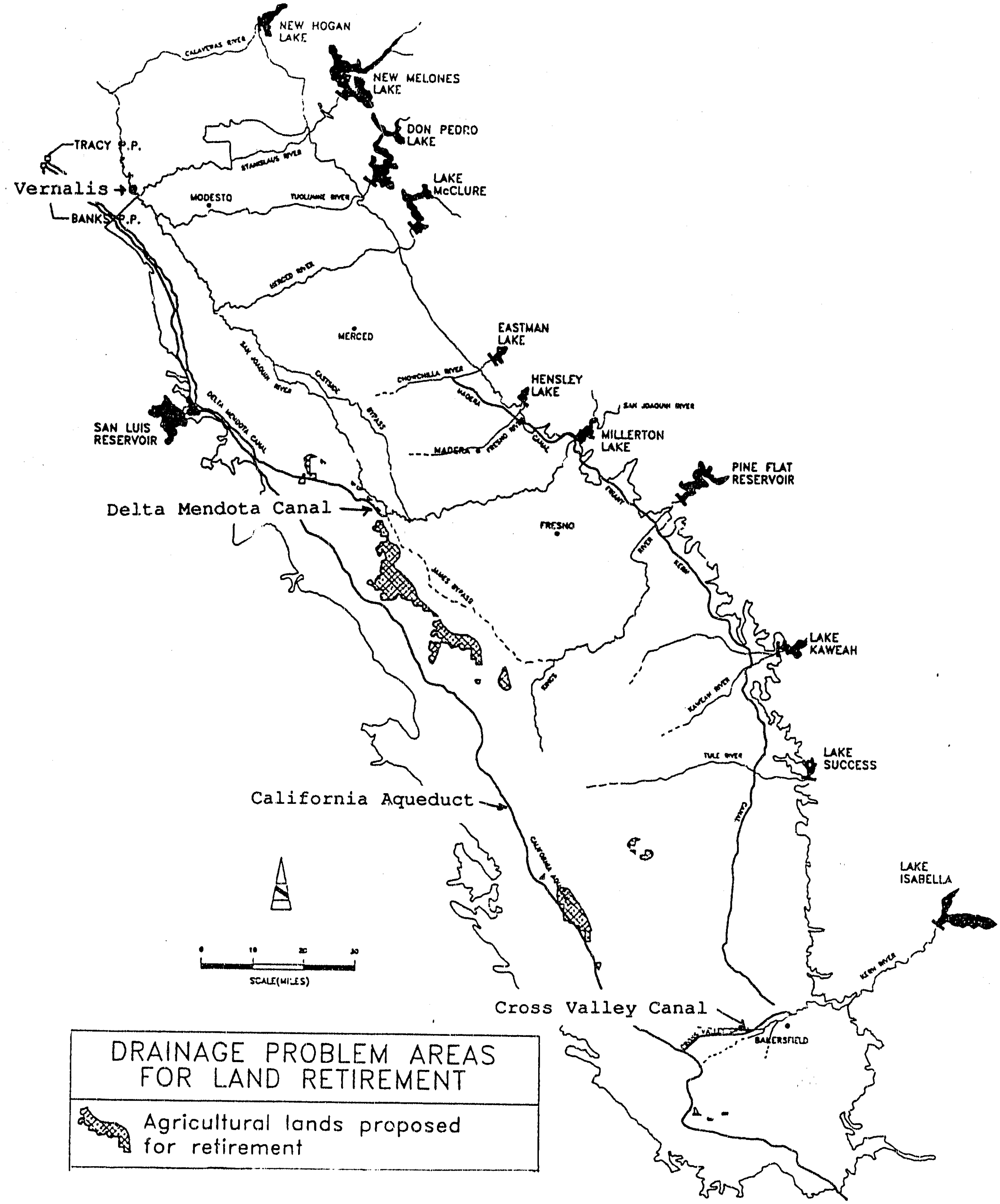


Figure 2. Groundwater pumping and source control in drainage problem areas

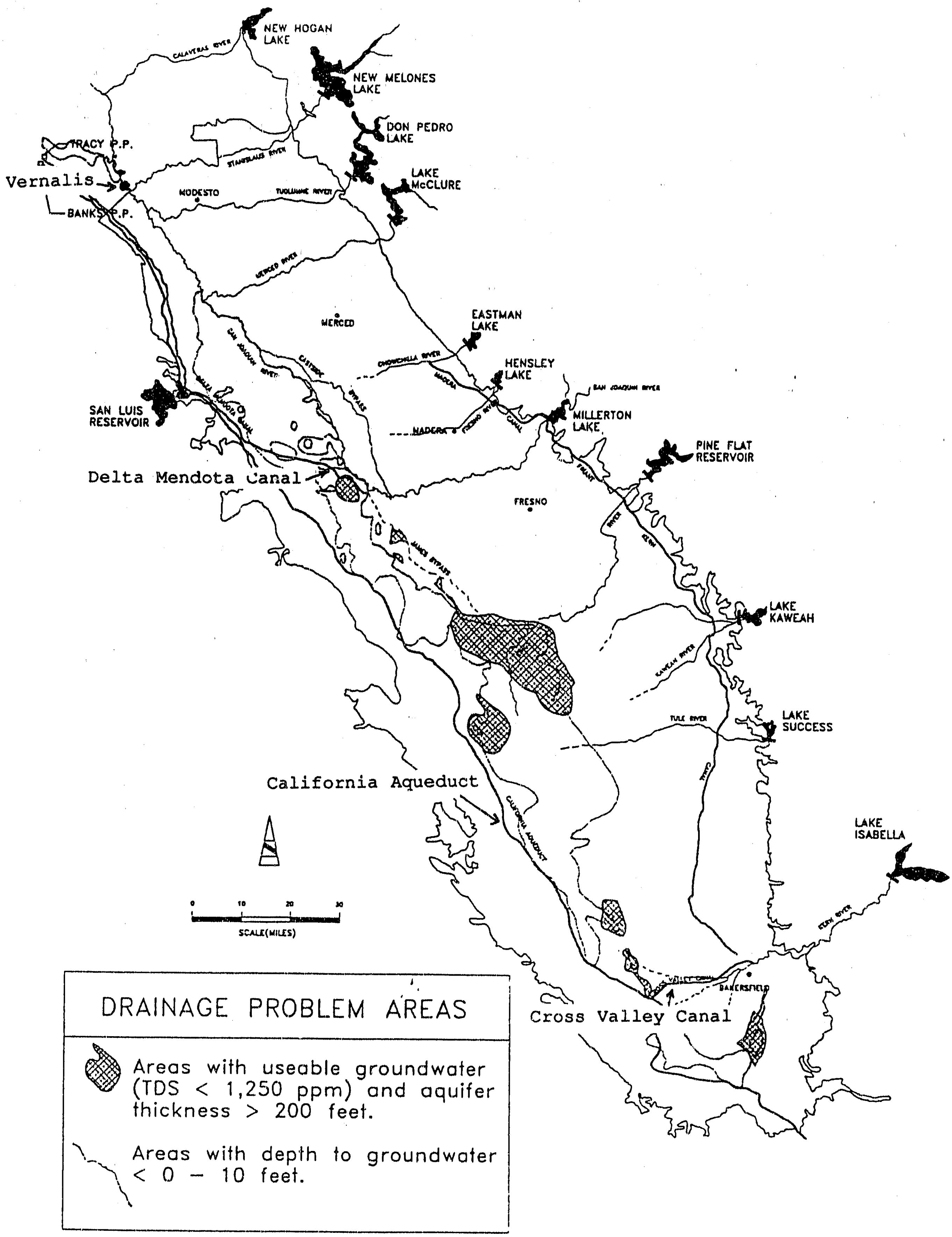
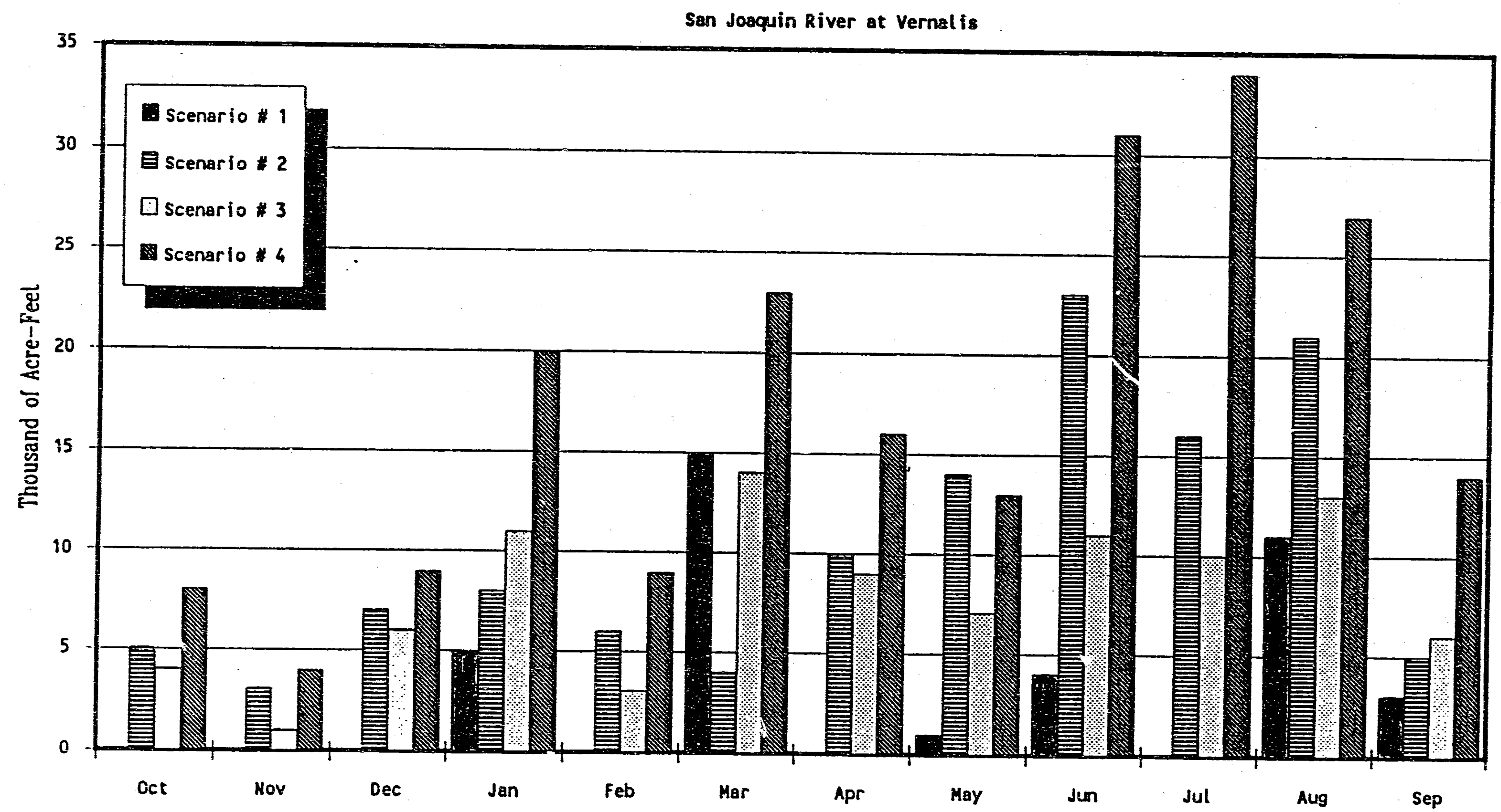


Figure 3. Land retirement in drainage problem areas

Figure 4. Average monthly differences between scenario and base runs



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