MODELING OF FRIANT WATER MANAGEMENT AND GROUNDWATER

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ABSTRACT

Improvements to FREDSIM model are presented here and include variable groundwater pumping costs calculation, development of economic performance functions at the irrigation district level and improvement in the physical and operational representation of groundwater for conjunctive use modeling. FREDSIM is a network-flow simulation model driven by irrigation district economic. Groundwater is represented by a system of individual zones with subsurface flow modeled by Darcy law and conductance data used to represent response to hydraulic gradients. The simulation model updates the groundwater heads at each time step and recalculates the pumping cost based on energy requirements. Preliminary results indicate consistent behavior of the approach with adjustments necessary in the lag representation of groundwater flows. Results show that users change supply sources and quantities, and transfer water reacting to variations in water price, economic value and water availability. For higher changes in surface and groundwater prices, significant operations change may compromise current conjunctive use operations. The historical overdraft pattern is still occurring despite the increase in groundwater prices. Reduction of this overdraft requires reduction of groundwater pumping. In terms of surface water this is equivalent to 33% of contract surface supplies that would be required as non-local transfers. Without additional surface supplies, a 49% reduction in overdraft (9.8 maf) would cost an additional $5 million/yr average in scarcity costs, a 26% increase.

INTRODUCTION

Model Development

This report presents new developments made in the FREDSIM model (FRiant Economics-Driven SIMulation model). Initial FREDSIM development is found in Leu (2001). Major new developments include updating economic functions with new functions developed at the irrigation district level, development of a scheme for variable heads and groundwater pumping costs, improving the representation of groundwater operations by including spatial and temporal pumping pattern data, updated pumping capacities based on groundwater model results and spatial information on conveyance losses and irrigation inefficiency deep percolation. The run period was extended from the initial 10 years to 73 years with preliminary data on Friant deliveries based on correlation with Millerton Lake historic inflows.

Project Area Description

The Friant Division project area includes agricultural regions supplied by the Friant Kern canal south of San Joaquin River and the Madera canal at north of San Joaquin. Approximately 1,000,000 acres of land are supplied, ranging from the community of Chowchilla to the Tehachapi Mountains in Kern County to the south. Both Friant and Madera canals are supplied with water from Millerton Lake (Friant Dam) located in the San Joaquin River, and operated by the Friant Water Users Association (FWUA) (Leu, 2001). FWUA is a group of users with water supply contracts with the United States Bureau of Reclamation (USBR). Friant Dam is operated by USBR.

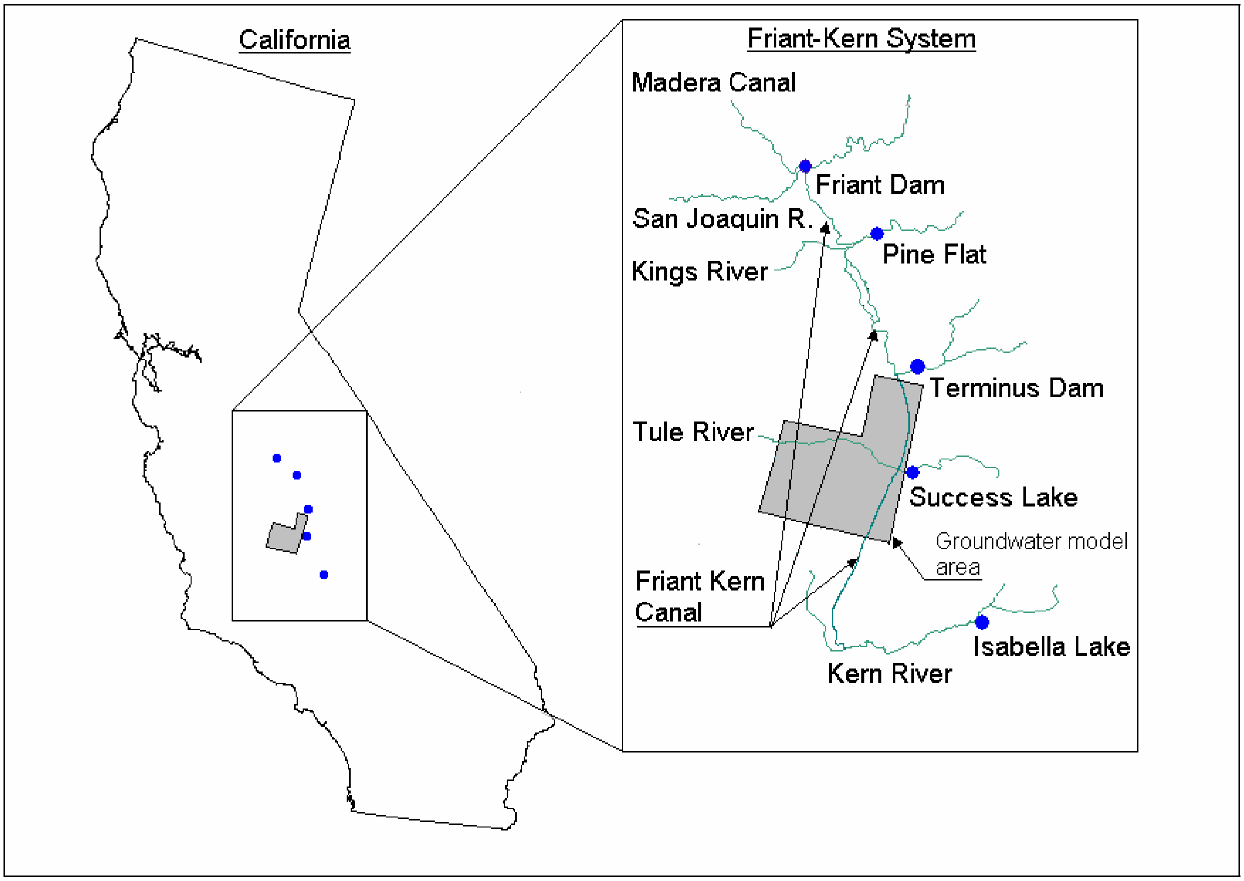

Figure 1 – Project area

METHOD

Introduction

This section presents the approach used in the development of FREDSIM (FRiant Economics-Driven SIMulation model). FREDSIM model is developed from the irrigation district level of detail using the decision support system MODSIM. Components modeled include irrigation districts, cities (as demand nodes), surface and groundwater reservoirs, the Friant and Madera canals, the Cross Valley canal, and some diversion structures connecting Friant and Madera canals to the irrigation districts and demands. The system's network is built in MODSIM with data on canal and reservoir capacities, reservoir historic inflows, seepage losses and water costs. The groundwater representation tracks head fluctuation in different portions of the aquifer and their respective pumping costs.

MODSIM Program

MODSIM is a computer based decision support system that uses a capacitated network flow approach for simulation and optimization of water resources systems. The MODSIM solver uses an out-of-kilter algorithm and has been applied with success in the simulation of diverse river basin systems (Dai and Labadie. 2001; Fredericks and Labadie, 1998). Components of a water system are represented by nodes and links. The types of nodes available are *storage nodes* (representing surface reservoirs and groundwater basins), *non-storage demand nodes* (representing demand locations such as irrigation districts and cities) and *non- storage nodes* (representing river confluences and diversion points). Nodes are connected by links representing either the physical system, i.e. rivers, artificial canals and pipelines; or the institutional/contractual elements such as water rights and delivery contracts. Nodes and links also store information on flows and storage upper and lower bounds, costs and hydrologic losses.

MODSIM finds the least cost network flows iteratively for each time step and the results are used as initial conditions for the following time step. Although it can be defined as an optimization model, MODSIM's sequential operation by optimizing individual time steps allows it to be used as an efficient simulation tool (Labadie, 1995). The linear optimization problem solved each time step is (Labadie, 1995):

$$\text{Min } Z = \sum_{l \in A} c_l q_l \qquad (1)$$

Such that

$$\sum_{j \in O_i} q_i - \sum_{k \in I_i} q_k = 0; \forall i \in N \qquad (2)$$

$$l_l \le q_l \le u_l; \forall l \in A \qquad (3)$$

Where A is the set of network links, c_l is the cost per unit of flow rate on link *l*, q_l is the integer value flow rate in link *l*; O_i is the set of links starting at node *i*, I_i is the set of links ending at node *i*, N is the set of all nodes, l_l is the lower bound for flow on link *l* and u_l is the upper bound for flow in link l.

Mass balance is maintained in all nodes through equation (2) and upper and lower bound constraints are represented in constraint (3). Hydrologic losses along links are incorporated by an iterative algorithm.

<u>FREDSIM concept</u>

FREDSIM simulates water operations in the Friant Division as a system driven by economic performance at the irrigation district level. Estimates regarding the water economic value in the system are placed as costs in links and the MODSIM solver optimizes (equation 1) to find the least cost flow path to supply the system's demands.

Costs representing water economic value are built from water's *marginal economic value*, or, how much the water user would be willing to pay to have one additional unit of water. At full supply the marginal value of water is zero; as water gets scarcer users place a higher value on it. In the model, economic demand functions are expressed as economic losses relative to full supply deliveries.

The economic functions are generated by the SWAP (Statewide Agricultural Production) model as piece-wise linear functions. SWAP is a farm optimization model that maximizes economic benefit within land, water and capital constraints, based on data on crop prices, yields and elasticities. Detail on SWAP model appears in Howitt et al (1999).

The marginal value for each demand level in the function is represented in MODSIM as a benefit (negative cost) attached to an *economic link* delivering water to a given demand. The corner points in the function are entered as upper bounds on each link. The economic functions are fixed by year and vary by month. A set of 12 functions is developed for each irrigation district or water district. Each function has five segments.

As the optimization process takes place, the solver will face five pathways to deliver water to each demand. Once it is trying to minimize the total cost, the water will be delivered preferably through the link with the lower cost, in this case the one with the higher negative value. This link represents the first segment in the demand function where a higher value is placed in the first amounts of water available. As more water is available the first high value link may reach its upper bound and the next unit of water available has now a smaller marginal value. At this point the additional water will flow through the link with the second lower penalty slope. The process continues as the links reach their upper bounds and additional water available is moved to lower cost links, representing the latter segments of the demand function where the marginal value for water is lower. This configuration drives the allocation of water among the demands and defines allocation priorities and supply preferences. If different demands have access to diverse supply sources with different costs, the next unit of water will be drawn from a source which cost is not higher than the marginal value of the water at the present level of supply. If the marginal value of water is very low (close to full supply), and no supply sources with lower cost are available, no more water is supplied to the demand. This is a case where some level of water scarcity is considered optimal. Another important aspect is that economic functions reflect the crop values of a given demand, ensuring that scarce water is always delivered first to higher value crops. The model schematic appears in Figure 2.

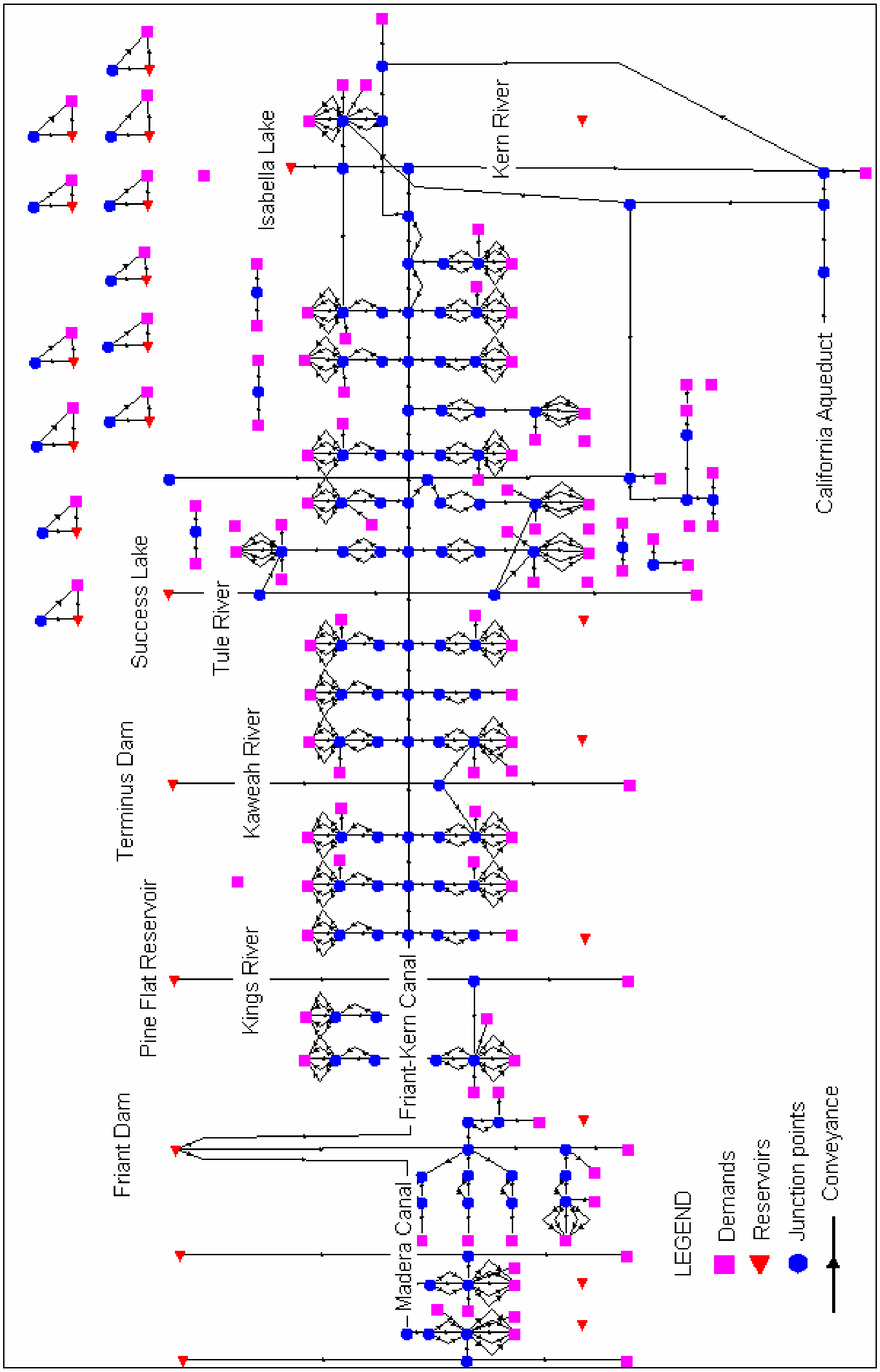

Figure 2 – FREDSIM schematic

Groundwater Operations in FREDSIM

Groundwater is an important water supply source in the Friant Division. While groundwater supply provides flexibility, intensive exploitation when surface water is unavailable or more expensive, reflects on groundwater's cost as water levels in the aquifer are lowered and more energy is required to pump it over higher heads. This dynamic affects groundwater use when one's objective is to maximize the economic value of water allocation in the system. Heavy reliance on groundwater may not be an option in the long run.

Preliminary results found in Leu (2001) in the initial development of the FREDSIM model show a constant, declining trend in groundwater storage when groundwater pumping cost is fixed. Where pumping cost is more attractive than the cost of other sources, groundwater will be continuously exploited with no awareness of further impacts. As noted by Leu (2001), over a longer period the effects of the declining groundwater levels may increase pumping cost reducing the groundwater's appeal as a lower cost supply.

The approach presented here takes a further step in modeling groundwater in the Friant system by representing variable heads as function of storage in the groundwater aquifers. Additionally, subsurface flows are estimated as responses to spatial variation in pumping and/or recharge. Additional information to model the groundwater behavior is provided by Ruud et al (2002). In Ruud et al (2002), part of the project region is modeled with MODFLOW in order to simulate subsurface flows as response to external stresses of pumping and deep percolation.

Groundwater zones concept

The primary objective of the groundwater representation in FREDSIM at this point is to track and update pumping heads with temporal and spatial variation, so that pumping costs can also be estimated. The aquifers are subject to external spatially variable stresses that add or subtract stored water. Some irrigation districts pump more water or have higher deep percolation losses. The aquifer geologic characteristics also vary spatially, meaning that the same stress may cause different responses in different places.

In an unconfined porous media, one way to link the water table to storage is through the s*pecific yield* or drainage porosity. Specific yield is the ratio of the volume of water that is drained by gravity forces over the bulk media volume Charbeneau (2000). This means that by lowering the water table by an amount Δh over an area A, the volume of water drained from an unconfined porous media is given by:

$$V_{drained} = Sy * A * \Delta h \qquad (4)$$

Equation (4) allows estimation of a variation in head when water is removed or added to an unconfined aquifer, provided that the section considered is small enough so that the specific yield can be assumed as homogeneous. Specific yield information is available for part of the project area based on GIS maps developed in Ruud et al (2002).

Another important aspect is the presence of subsurface fluxes that occur as heads variy spatially and hydraulic gradients are established. Darcy law is applied to establish a linear relationship between flux and the hydraulic gradient defined by the difference in head between two adjacent cells. This relationship is presented in equation (5).

$$Q_{ij} = C_{ij}^{eff} * \Delta h_{ij} \qquad (5)$$

Where Q_{ij} is the flux between sections j and j, Δh_{ij} is the difference in head and C_{ij}^{eff} is the *effective conductance* between cells i and j. Areas with homogeneous specific yield define the boundaries of the sections and the conductance parameter can be estimated running the modeled area in MODFLOW and observing the paired data Q_{ij} vs. Δh_{ij} (further detail in Ruud et al, 2002). Homogeneous specific yield values are obtained by averaging the specific yield data for a given cell. By fitting the paired data with a linear regression curve we can estimate the slope, which is the conductance parameter searched. The goodness of fit will depend ultimately on how the cell boundaries and specific yield values were devised and if those boundaries and values can capture the aquifer's behavior acceptably. If the cells are too large, the cell average specific yield value may become a meaningless representation of the aquifer's characteristics or, if it is too small, a given cell may suffer significative influence of other non-adjacent cells and the linear relationship among two adjacent cells described in equation (5) may not hold. Both situations result in poor fit. A few attempts were made with different sizes, boundaries, and specific yield values for the cells until acceptable fits for equation (5) were obtained. The cells are also referred to as groundwater *zones* and are treated as individual, interconnected, groundwater reservoirs. The final configuration of the groundwater zones appears in Figure 3

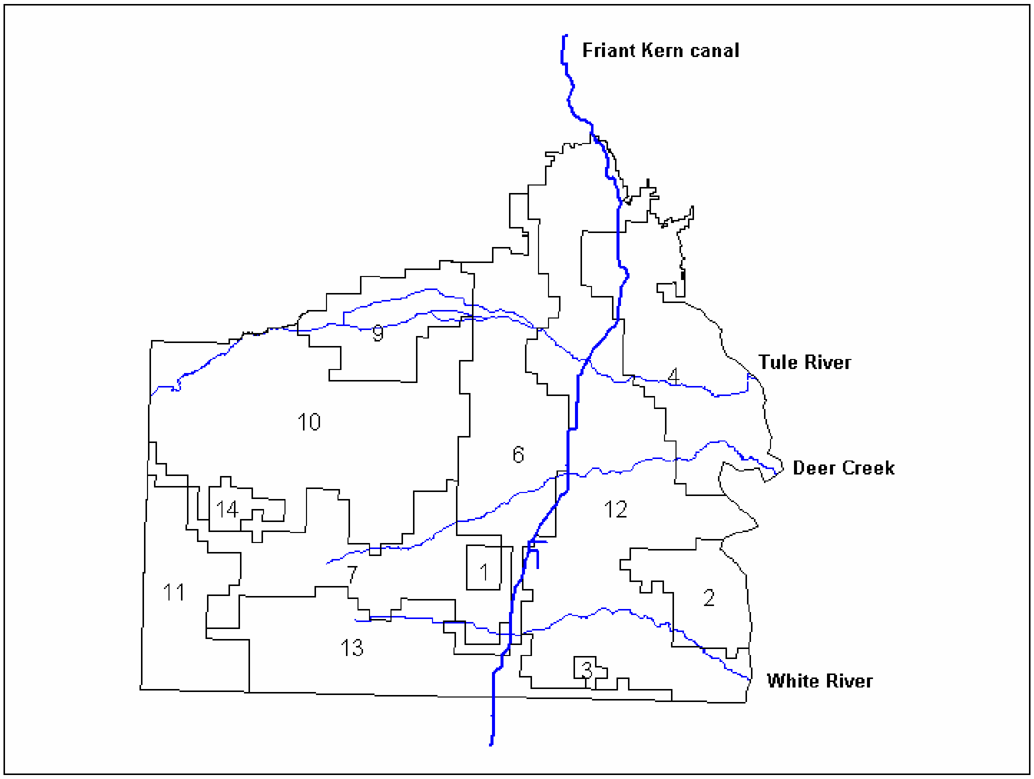

Figure 3 - Groundwater zone definitions

There are 12 groundwater zones[*] identified by the numbers in Figure 3. Their areas and specific yield values are presented in Table 1, and the conductance values and correlation coefficient R^2 of the linear fit appear in Table 2.

Table 1 - Groundwater zones definition

GW zone	Specific Yield	Area (acres)
1	0.1200	2,986.5
2	0.0630	19,554.3
3	0.0630	1,493.3
4	0.0630	54,288.9
6	0.0970	59,059.8
7	0.1030	52,026.2
9	0.1365	26,619.0
10	0.1200	104,023.3
11	0.0785	33,095.4
12	0.0760	130,030.1
13	0.0880	52,962.7
14	0.1340	5,226.3

After testing different configurations, some zones still did not present a satisfactory correlation with adjacent zones and in this case no linear correlation and flux estimation can be drawn. Some zones presented a high degree of correlation, with R^2 values as high as 0.94 indicating that boundaries defined and specific yield values are suitable to describe a linear relationship between hydraulic gradient and flux.

[*] Identification numbers range from 1 to 14. Groundwater zones #5 and #8 were merged with other zones at the end and are not present. The original numbers were maintained.

Table 2 - Effective conductance values

GW zone "i"	GW zone adjacent "j"	R^2 coefficient	Conductance (acres-foot/month)
1	7	0.55	8.19
2	12	0.96	13.60
3	12	0.91	6.41
4	12	0.44	55.14
6	7	0.48	6.84
	9	0.81	7.56
	10	-	
	12	0.81	36.16
	13	0.49	4.09
7	11	-	-
	13	0.51	26.73
	1	0.71	8.82
	10	0.85	126.92
	14	-	
	6	0.48	6.84
9	10	0.49	45.18
	6	0.81	7.56
10	6	-	
	9	0.49	45.18
	7	0.85	126.92
	14	0.86	6.19
11	7	-	-
	13	-	
12	2	0.96	13.60
	3	0.91	6.41
	4	0.44	55.14
	6	0.81	36.16
	13	-	
13	6	0.49	4.09
	7	0.51	26.73
	11	-	
	12	-	

The Irrigation districts that overlap the groundwater modeled area are presented in Figure 4. The list of districts appears in Table 3.

Table 3 - Demands with variable pumping cost

Irrigation District/Demand	MODSIM name
Delano-Earlimart ID	DEID
Kern-Tulare WD	KTWD
Lindmore ID	LIID
Lindsay-Strathmore ID	LSID
Lower Tule River ID	LTID
Pixley ID	PXID
Porterville ID	POID
Rag Gulch WD	RGWD
Saucelito ID	SAID
Tea Pot Dome WD	TPWD
Terra Bella ID	TBID

Groundwater supply for those districts is modeled with variable head/cost. A district will have access to the groundwater in the zones it overlays and the amount pumped from each zone is defined according to pump pattern data, processed from GIS maps developed in (Ruud et al, 2002). The pump pattern provides the percentage of total groundwater use that a district extracts from each of the groundwater zones it has access to. See appendix Table 17 for details. The pumping pattern varies by month and by year type[*]. The other two stresses affecting the groundwater zones are deep percolation from conveyance seepage losses and irrigation inefficiency. The amount of water that deep percolates from a given district due to irrigation inefficiency is distributed among the groundwater zones underneath it according to the area occupied by each one. Conveyance losses are distributed among groundwater zones according to the percentage of the main delivery structure length that overlays each groundwater zone.

[*] Year types considered are based on a dry year (1977), a wet year (1983) and a normal year (1982)

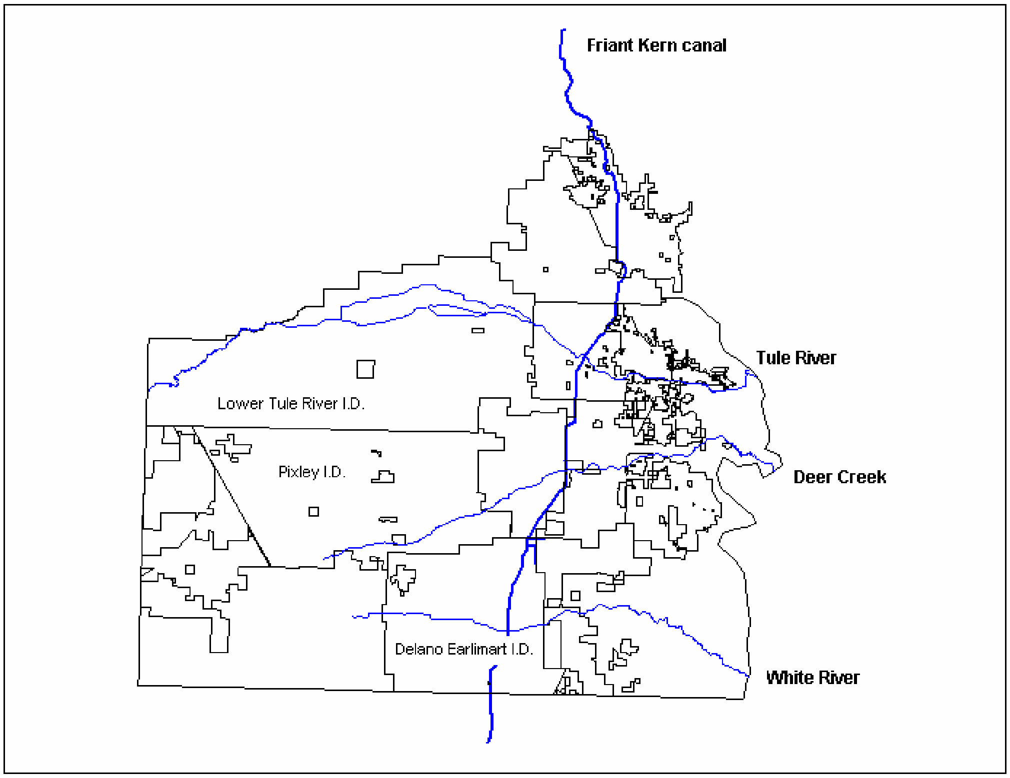

Figure 4 - Irrigation districts on modeled area

Regional water table level (head) calculation

Water table level for each groundwater zone is updated every time step based on storage variations of each zone. The groundwater zones are set in MODSIM's network as storage nodes. Storage will change as water is pumped, deep percolates, or flows from/to adjacent zones. Head calculations are made in a *Perl script* subroutine that runs parallel to the MODSIM run. At each time step, heads are re-calculated and their value used to calculate the new pumping cost, which is used by MODSIM to solve flows the current period. The Perl script subroutine accesses the necessary variables from MODSIM after each time step, performing the required calculations and sending the updated values (pumping costs) back. Variations in storage due to pumping and deep percolation are managed directly by MODSIM with the pump pattern percentages and deep percolation distribution set in the model's interface. Subsurface Darcy fluxes are calculated separately in the Perl subroutine using equation (5), the conductance parameters and the difference in head between the zones. The operation is repeated for all adjacent zones and the fluxes are accumulated to obtain the final net volume that a given groundwater zone will exchange with the adjacent zones in the present time step. The net volumes are added to the groundwater zones node through a set of artificial inflow and demand nodes.

After MODSIM solver converges to the optimal solution, the heads are updated in the perl subroutine based on the difference between the optimal storage and the previous storage (equation 6)

$$h_i^{t+1} = h_i^t + \frac{\Delta S_i}{Sy_i * A_i} \qquad (6)$$

Where h_i^{t+1} is the updated head at groundwater zone i, h_i^t is the initial head, ΔS_i is the storage change, Sy_i and A_i are respectively the specific yield and area of groundwater zone i.

Pumping cost calculation

Pumping cost is calculated based on the energy required to pump water over the total head, considering head losses due to well and pump inefficiencies. The term "total head" includes the regional water table level *h*, plus the local drawdown *s* generated during pumping. Calculation of drawdown is based on aquifer transmissivity and storage coefficient data and can be made using the *Thiem* equation, for confined aquifers, or *Theis* equation, for unconfined aquifers. Thiem equation (7) estimates steady-state drawdown for confined and semi-confined aquifers and is used here as an initial approach. Necessary assumption to use this equation is small drawdown relative to the aquifer saturated thickness.

$$s = \frac{Q_{well}}{2\pi T} \ln \frac{r_{eff}}{r_{well}} \qquad (7)$$

Q_{well} is the well pumping rate, based on typical well flow capacity T is the aquifer transmissivity, defined as the integral of the hydraulic conductivity over the aquifer saturated thickness, r_{eff} is the effective radius, and defines the distance from the well bore at which there is no drawdown effect, and r_{well} is the well bore radius.

The *input power* IP_j [kw] required to pump water over the total head ($s + h$) [ft] in a given groundwater site and at a given pumping rate Q_{well} [gpm] can be calculated through the expression (8) (Harter, 2001).

$$IP_j = \frac{Q_{well} * (2 * s + h_{reg\ j}^{\ t}) * 0.735}{3{,}960 * e_o} \text{ [kw]} \qquad (8)$$

A 50% efficiency for both well and pump is assumed. The *energy consumed* E_{well} [kw-hr] by a well operating at these conditions during a period of time t_p [hr] is then (9):

$$E_{well\ j} = IP_j * t_p \text{ [kw-hr]} \qquad (9)$$

The volume of water V_{well} [gal] extracted after time t_p is given by (10)

$$V_{well} = Q_{well} * t_p * 60 \text{ [gal]} \qquad (10)$$

The energy required to pump a unit volume of water E_o [kw-hr/gal] is:

$$E_{o\ j} = \frac{E_{well\ j}}{V_{well}} = \text{ [kw-hr/gal]} \qquad (11)$$

As seen, the energy required does not depend on the pumping time, nor on the well pumping rate Q_{well}. Now, defining the energy cost as *c* [$/kw-hr], one can finally obtain the unit pumping cost per volume PC_j [$/af] as:

$$PC_j = \frac{E_{o\,j} * c}{n} = \frac{(2 * s + h_{reg\,j}^{\;t}) * 0.735 * c}{3{,}960 * e_o * n} \quad [\$/af] \qquad (12)$$

Where *n* (3.069E-06) converts US gallons to acre-feet.

Although some variations on the pumping cost may occur within a time step, they are assumed to be negligible and the pumping cost is only re-calculated at the beginning of a given time step, using the end-of-period head from the previous time step. This assumption seems reasonable since groundwater flow is rather slow and the impact of pumping on water depth may take some time to develop.

<u>Economic Functions</u>

New sets of economic functions were developed at the irrigation district level. Functions were developed based on the Statewide Agricultural Production Model (SWAP). The SWAP model maximizes economic returns subject to resource, production and policy constraint, and calculates the monthly *shadow value* per unit of water for each level of water supply. Based on detailed information about crop acreages for each irrigation district, demand functions were developed at the irrigation district level.

Based on the economic functions and current water supply levels, water *scarcity* and *scarcity costs* are evaluated. Scarcity is defined here as the difference between a water supply level were the marginal value for additional water is zero (full supply) and the current supply level. This represents a case where water may be available for supply, but it is not economically worthwhile to use it. The *area* below the economic function between these two points in defined as the *scarcity cost* (Figure 5), and represents the loss of economic value from deliveries being less than full supply.

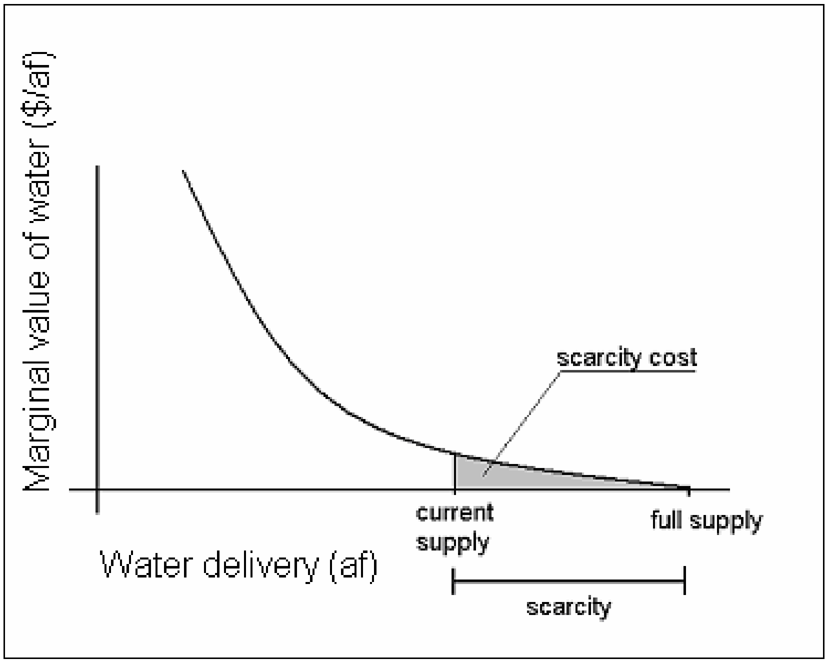

Figure 5 - Economic (demand) function and water scarcity

<u>Surface Water Distribution Support Model</u>

To generate water demand functions, the SWAP model requires input on applied water and evapotranspiration of applied water for all irrigation districts. The LAIUZ (Land-Atmosphere Interface and Unsaturated Zone) model, developed to compute water budget over the land surface and unsaturated zone, was used to provide applied water demand over each land unit of the project area. Land units are defined by their respective landuse type and were later aggregated into irrigation districts. Mass balance is performed in LAIUZ based on precipitation, irrigation applications, water demand, consumptive use, percolation, recharge, excess irrigation and groundwater pumping (Naugle, 2001).

Evapotranspiration of applied water (ETAW) refers to the portion of ET supplied by irrigation, i.e. excluding water already present in the soil (soil moisture) and precipitation water. LAIUZ is originally configured to output demand for applied water based on ET. Thus some adjustments were introduced in the model to separate the required ETAW.

On the adjustments, the effective precipitation Peff is initially calculated as

$$Peff = \begin{cases} (ETa + fc - \phi), & Pe > (ETa + fc - \phi) \\ Pe, & Pe \le (ETa + fc - \phi) \end{cases} \qquad (13)$$

Where ETa is the evapotranspiration in a given month, Pe is the precipitation; fc is the field capacity and ϕ is soil moisture content. Equation (13) sets the amount of space available in the soil to store water as the summation of evapotranspiration plus the field capacity, minus water already present (ϕ). If precipitation in a given month exceeds this amount, then the effective precipitation is (ETa + fc - ϕ), otherwise the effective precipitation Peff equals the precipitation. Effective precipitation may increase the amount of water stored in the soil and this effect is carried to the next month with an accounting storage variable Speff0. The evapotranspiration of applied water ETAW is then calculated as (14)

$$ETAW = \begin{cases} 0, & ETA < (Speff\,0 + Peff) \\ (ETa - Speff\,0 - Peff), & ETA > (Speff\,0 + Peff) \end{cases} \qquad (14)$$

Equation 14 adds soil water content from the previous month (Speff0) to the effective precipitation on the present month and compares the total with the evapotranspiration ETa in the present month. If ETa is smaller, all water used by crops is being provided by effective precipitation and soil moisture and in this case ETAW is zero. If ETa exceeds (Speff0 + Peff) then a portion of the ETa will be provided by irrigation applied water. This portion is the ETAW and it is calculated in equation (14) as (ETa – Speff – Peff). Whenever ETAW is zero, the amount of water over ETa is carried to the next month in the variable Speff0.

One important aspect that limits this approach is the temporal distribution of ETa and precipitation. The calculations are performed monthly and all ETa is lumped at the end of the month. In a more detailed temporal scale, precipitation and evapotranspiration can vary and the actual amount of water stored in the soil as effective precipitation will not be same as the monthly total calculated in (13). Sequences of days with low evapotranspiration, paired with a higher precipitation, may result in monthly totals of effective precipitation considerably lower than the lumped monthly sum of equation (13), for the same monthly totals of precipitation and evapotranspiration. Overestimated effective precipitation will result in underestimates for ETAW. This limitation may be one reason why ETAW estimates from LAIUZ are consistently lower than ETAW present in other data sources (Table 5). A more detailed model is required at this point to account for proper temporal variations in evapotranspiration and precipitation.

Crop categories

Land use categories from the LAIUZ database originally included 61 types. The land use categories related to agricultural use present in the project area were grouped into the SWAP crop categories (Table 4). Land acreages are based on DWR land survey, year of 1985 (Zhang, 1993)

Table 4 - Crop categories

LAIUZ crop group	SWAP crop	SWAP crop abbreviation
orange	citrus	CITR
olive(avg)	olives	OLVS
peaches(avg)	peaches	PEAC
prunes(avg)	prunes	PRUN
almonds(avg)	almonds	ALMD
walnuts(avg)	walnuts	WALN
cotton	cotton	COTT
corn	corn	CORN
misc. field crops(avg)	miscelaneous	MISC
grain and hay crops	wheat, miscelaneous grains, miscelaneous hay	WHET, MGRN, MHAY
alfafa &alfafa mixtures	alfafa	ALFH
tomatoes	miscelaneous vegetables	MVEG
vineyard	grapes	GRPE
mixed pasture	pasture	PAST

ETAW data

ETAW data output from LAIUZ is presented by crop type and by month. For comparison, annual totals of ETAW for each crop type are compared to other sources of data and the percent variation is calculated (Table 5).

Table 5 - ETAW comparison table

LAIUZ crop	LAIUZ ETAW (ft/yr)	**Bulletin 160-93 Tulare** (ft/yr)	% LAIUZ difference	**CU model cvpm 18** (ft/yr)	% LAIUZ difference	**cvpm model cvpm 18** (ft/yr)	% LAIUZ difference	**Bulletin 160-98 cvpm 18** (ft/yr)	% LAIUZ difference
Alfalfa &alfalfa mixt.	2.79	3.00	-7.0%	3.12	-10.6%	3.14	-11.1%	3.10	-10.0%
Almonds (avg)	2.37	-	-	2.34	1.3%	-	-	2.30	3.0%
Orange	1.88	1.90	-1.1%	1.90	-1.1%	1.92	-2.1%	1.90	-1.1%
Corn	1.98	2.00	-1.0%	1.71	15.8%	2.02	-2.0%	2.00	-1.0%
Cotton	2.27	2.50	-9.2%	2.34	-3.0%	2.53	-10.3%	2.50	-9.2%
Vineyard	1.84	2.10	-12.4%	2.00	-8.0%	2.13	-13.6%	2.10	-12.4%
misc. field crops(avg)	1.98	2.00	-1.0%	1.71	15.8%	2.02	-2.0%	1.97	0.5%
Tomatoes	1.97	2.30	-14.3%	2.01	-2.0%	2.23	-11.7%	2.00	-1.5%
Olive(avg)	2.2	2.60	-15.4%	1.90	15.8%	1.92	14.6%	1.90	15.8%
Mixed pasture	2.47	3.20	-22.8%	3.36	-26.5%	3.34	-26.0%	3.30	-25.2%
Peaches(avg)	2.3	2.50	-8.0%	2.34	-1.7%	2.74	-16.1%	2.69	-14.5%
Prunes (avg)	2.3	2.50	-8.0%	2.34	-1.7%	2.74	-16.1%	2.69	-14.5%
Walnuts(avg)	2.66	2.50	6.4%	2.34	13.7%	2.74	-2.9%	2.69	-1.1%
Grain and hay crops	0.45	1.00	-55.0%	0.38	18.4%	0.91	-50.5%	0.90	-50.0%

Differences are around 15% with some cases over 20% or as low as 1%. Comparing to bulletins 160-93, 160-98 and CVPM model, the LAIUIZ ETAW values are consistently lower, while comparison with CU model ETAW presents more balanced differences. Consistently lower ETAW values are a concern since they will result in lower demand for water from the SWAP model and may cause FREDSIM to underestimate potential water scarcities which drive the model.

MODEL RUNS

Three runs were made with the economic functions generated by SWAP for each irrigation district. All runs include the subsurface flows based on estimated conductance values. The first run, FPlow (fixed original lower groundwater pumping cost), maintains the original groundwater pumping costs based on Leu (2001) (table 3.1, second column) regardless of variations on water table level. Some of the original groundwater pumping costs were adjusted so the model prioritizes the use of contract water over groundwater when enough surface water is available for supply. During dry periods, the scarce surface supply is complemented with groundwater. These operations are verified in URS (2002).

The second run, FPhigh (fixed updated, higher groundwater pumping cost), updates the groundwater pumping cost based on detailed water table data and equation (12). The pumping cost is calculated based on the initial head and maintained through the 73 years run period.

The third run, VP (variable groundwater pumping cost) updates the pumping cost every month based on water table fluctuation. Since the groundwater model does not cover the entire project area, only the irrigation districts included in the groundwater model (Table 3) have variable pumping costs. The remaining districts (representing 73 % of total water demand) are modeled with the original FREDSIM pumping cost (Table 6, first column).
The run period was extended from the original 10 years to 73 years based on historical inflow data to the surface reservoirs. The forecast for class 1 and class 2 deliveries to Friant was correlated with annual inflows at Millerton and the correlation function was used to extend the class 1 and class 2 forecasts for the entire historical inflow record. Although the correlation coefficient was acceptable, the ten years of class 1 and class 2 deliveries used in the correlation are a short period of time for this sort of statistical analysis; a longer record of class 1 and class 2 deliveries should be used in future model improvements.

The purpose of the runs comparison is to evaluate possible changes in operations driven by the region’s economics as the groundwater cost varies.

Table 6 - Groundwater pumping costs

Irrigation District	Original pumping Cost[1,2] ($/af)	Adjusted pumping cost FPlow run[2] ($/af)	Updated pumping cost FPhigh run[2,3] ($/af)	Variable pumping cost VP run average[4] ($/af)	Variable pumping cost VP run minimum[4] ($/af)	Variable pumping cost VP run maximum[4] ($/af)
AEWD	80	80	80	-	-	-
CHWD	36	45	45	-	-	-
DEID	40	45	59*	75	58	97
EXID	23	45	45	-	-	-
FC18	0	0	0	-	-	-
FRCO	0	0	0	-	-	-
FRID	23	45	45	-	-	-
FRCY	0	0	0	-	-	-
GAWD	33	45	45	-	-	-
GFWD	31	45	45	-	-	-
HVID	19	45	45	-	-	-
INWD	19	45	45	-	-	-
IVID	25	45	45	-	-	-
KTWD	45	45	96*	96	60	119

LCWD	20	45	45	-	-	-
LIID	22	45	122*	128	113	142
LWSA	0	0	0	-	-	-
LSID	23	45	132*	133	125	147
LTID	32	45	73*	87	52	120
MACO	0	0	0	-	-	-
MAID	31	45	45	-	-	-
OCID	19	45	45	-	-	-
OCCY	0	0	0	-	-	-
PXID	36	45	45*	81	45	112
POID	20	45	114*	127	113	139
RGWD	43	45	61*	91	60	136
SAID	40	45	78*	110	78	130
SWID	64	64	64	-	-	-
SSMD	45	45	45	-	-	-
SCID	17	45	45	-	-	-
TPWD	39	45	117*	130	117	143
TBID	43	45	117*	130	117	142
TVWD	0	0	0	-	-	-
TUCO	0	0	0	-	-	-
TUID	32	45	45	-	-	-

[1] Source: Leu, 2001
[2] Zero costs indicate no GW use in that irrigation district
[3] Only costs marked (*) were updated due to data availability
[4] average, max and min values for 73 years run period

<u>Demands for Irrigation Water</u>

Maximum annual demands based on the new economic functions appear in Table 7. Original economic functions were based on scaled down values from CVPM regions calculated by SWAP model (Leu, 2001). The new functions are based on irrigation district data run on SWAP model. Where additional data sources were available, values were checked for consistency. For example, Arwin Edison's 2000 water year summary report (ARVIN-EDISON, 2000) reports 262,634 af of deliveries including Cross Valley Canal exchanges, Friant water, Kern river supply and groundwater pumping.

Table 7 - Economic Demands

Irrigation District abreviation	Irrigation District name	Maximum Economic Demand – Original Economic Functions(af/yr)	Maximum Economic Demand – New Economic Functions(af/yr)	Estimated crop Consumptive use based on FWUA / MWDSC (2001)(af/yr)
AEWD	Arvin-Edison Water Storage District	408,389	269,809	303,857
CHWD	Chowchilla Water District	224,915	208,100	150,357
DEID	Delano-Earlimart Irrigation District	174,992	145,328	115,110
EXID	Exeter Irrigation District	46,221	34,600	31,140
FC18	Fresno County #18	138	150	n/a
FRCO	Fresno County	2,989	3,001	n/a
FRCY	Fresno, City of	59,989	60,001	n/a
FRID	Fresno Irrigation District	714,862	566,934	438,187
GAWD	Garfield Water District	3,492	4,330	n/a

GFWD	Gravelly Ford Water District	30,027	23,709	n/a
HVID	Hills Valley Irrigation District	10,757	6,310	8,086
INWD	International Irrigation District	1,293	1,301	n/a
IVID	Ivanhoe Irrigation District	38,353	34,400	26,600
KTWD	Kern-Tulare Water District	45,650	10,839	28,363
LCWD	Lewis Creek Water District	1,442	1,451	n/a
LIID	Lindmore Irrigation District	76,990	61,124	158,551
LSID	Lindsay-Strathmore Irrigation District	29,991	34,899	77,004
LTID	Lower Tule River Irrigation District	404,555	302,365	310,029
LWSA	Lindsay, City of	2,487	2,499	n/a
MACO	Madera County	187	199	n/a
MAID	Madera Irrigation District	380,510	309,578	238,838
OCCY	Orange Cove City	1,386	1,398	n/a
OCID	Orange Cove Irrigation District	89,886	79,300	68,352
POID	Porterville Irrigation District	48,337	38,917	33,131
PXID	Pixley Irrigation District	245,990	114,191	204,609
RGWD	Rag Gulch Water District	18,858	6,626	10,376
SAID	Saucelito Irrigation District	55,993	45,207	44,681
SCID	Stone Corral Irrigation District	18,829	17,534	13,057
SSMD	So. San Joaquin Municipal Utility District	184,992	164,070	365,936
SWID	Shafter-Wasco Irrigation District	126,992	108,600	n/a
TBID	Terra Bella Irrigation District	36,728	24,853	62,206
TPWD	Tea Pot Dome Water District	7,993	9,366	7,844
TUCO	Tulare County	38,052	38,061	n/a
TUID	Tulare Irrigation District	206,990	248,800	175,721
TVWD	Tri-Valley Water District	5,783	5,792	n/a

RESULTS

Fixed Groundwater Pumping Costs vs. Variable Groundwater Pumping Cost – Overall results

The results analysis compares the FPlow run (original groundwater pumping costs) to FPhigh (updated groundwater pumping costs based on new head data and equation 12, and then FPhigh to VP (variable groundwater pumping cost). A significant difference in pumping cost is found by comparing FPlow to FPhigh (Table 8) and the results analysis look at the impact of this difference in water supply operations. The second comparison looks at the results differences between maintaining the updated pumping cost fixed through the whole run time (FPhigh) and letting it vary according to fluctuations in head (VP)

Supply mix comparison between both runs appear in Tables 8 and 9. Supply sources available include contract water (Friant Kern canal deliveries class 1 and class 2) groundwater and other surface supplies (EXT). EXT is used for supply or groundwater recharge in wet periods. Values are in acre-feet/year, 73 year average.

Table 8 - Supply mix: Original pumping cost (FPLOW) vs. updated pumping cost (FPHIGH)

	FPLOW				FPHIGH			
	Class 1 (af/yr avg.)	Class 2 (af/yr avg.)	EXT (af/yr avg.)	GW (af/yr avg.)	Class 1 (af/yr avg.)	Class 2 (af/yr avg.)	EXT (af/yr avg.)	GW (af/yr avg.)
AEWD	0	98,467	39,461	139,725	0	98,467	39,461	139,725
CHWD	7,936	56,321	36,828	107,016	7,854	56,196	36,828	107,190
DEID	62,822	26,118	0	55,507	93,056	26,118	0	19,880
EXID	4,147	6,869	0	23,581	3,962	6,869	0	23,766
FC18	144	0	0	0	144	0	0	0
FRCO	925	0	0	0	925	0	0	0
FRCY	57,499	0	0	0	57,499	0	0	0
FRID	1,144	27,045	345,738	204,700	452	27,045	345,738	204,700
GAWD	3,357	0	0	0	3,357	0	0	0
GFWD	0	4,484	0	13,511	0	4,484	0	13,511
HVID	0	0	0	6,310	3	0	0	6,307
INWD	1,151	0	0	0	1,151	0	0	0
IVID	0	2,858	4,800	26,742	19	2,858	4,800	26,723
KTWD	0	0	9,509	0	0	0	9,509	0
LCWD	1,386	0	0	0	1,386	0	0	0
LIID	6,563	7,960	0	46,601	31,624	7,960	0	20,252
LSID	26,366	0	0	3,096	26,371	0	0	1,245
LTID	23,225	80,502	65,579	144,208	54,659	80,502	67,721	97,434
LWSA	2,351	0	0	0	2,351	0	0	0
MACO	199	0	0	0	199	0	0	0
MAID	4,077	67,073	45,686	200,420	3,526	67,073	45,686	200,971
OCCY	1,340	0	0	0	1,340	0	0	0
OCID	4,000	0	0	75,300	4,049	0	0	75,251
POID	1,091	7,052	18,957	14,639	7,952	7,052	21,162	6,478
PXID	0	0	17,267	101,400	3	0	12,857	103,801
RGWD	3,472	0	0	3,084	4,091	0	0	1,542
SAID	2,707	11,843	0	30,656	19,014	11,843	0	13,396
SCID	2,900	0	0	14,634	2,907	0	0	14,627
SSMD	46,009	18,088	0	99,896	46,061	18,088	0	99,844
SWID	47,916	14,313	0	38,107	47,916	14,313	0	38,217
TBID	8,368	0	0	16,480	24,312	0	0	454
TPWD	3,664	0	0	5,696	7,192	0	0	1,998
TUCO	933	0	0	0	933	0	0	0
TUID	24,266	50,845	109,333	39,709	24,266	50,845	109,333	39,709
TVWD	304	0	0	0	304	0	0	0
Total	**350,262**	**479,838**	**693,158**	**1,411,018**	**478,878**	**479,713**	**693,095**	**1,257,021**

The increase in groundwater cost from FPlow to FPhigh reduces the groundwater supply as seen in Table 4.1 (irrigation districts in red are the ones modeled with updated groundwater cost from FPlow to FPhigh). All modeled districts reduce groundwater pumping over 50% (with the exception of LTID, 32%). Terra Bella irrigation district (TBID) presents a reduction of 97% in groundwater pumping as the cost is updated from $45/af in FPlow to $117/af in FPhigh. This operation is followed by an increase in Class 1 TBID water supply from 8.4 kaf/yr to 24.3 kaf/yr, on average, to make up for the difference.

The effects of groundwater cost changes ripple over other surface operations. The next least expensive supply source is other surface, non-contract water (EXT). Irrigation districts with higher crop values will switch to other surface supplies reducing their availability to other districts. For example, Porterville Irrigation District (POID) and Lower Tule River Irrigation District (LTID) reduce groundwater pumping by 56% and 32% respectively and increase Class 1 and other surface supplies (in this case, from Tule River) to compensate. This increase in withdrawals from Tule River affects Pixley Irrigation District (PXID), which has its supply from Tule River reduced from 17.3 kaf/yr to 12.8 kaf/yr, average.

Table 9 - Supply mix: updated pumping cost (FPhigh) vs. variable pumping cost (VP)

	FPhigh				**VP**			
	Class 1 (af/yr avg.)	**Class 2** (af/yr avg.)	**EXT** (af/yr avg.)	**GW** (af/yr avg.)	**Class 1** (af/yr avg.)	**Class 2** (af/yr avg.)	**EXT** (af/yr avg.)	**GW** (af/yr avg.)
AEWD	0	98,467	39,461	139,725	0	98,467	39,461	139,725
CHWD	7,854	56,196	36,828	107,190	7,670	56,131	36,828	107,343
DEID	93,056	26,118	0	19,880	93,262	26,118	0	19,673
EXID	3,962	6,869	0	23,766	3,939	6,869	0	23,773
FC18	144	0	0	0	144	0	0	0
FRCO	925	0	0	0	925	0	0	0
FRCY	57,499	0	0	0	57,499	0	0	0
FRID	452	27,045	345,738	204,700	452	27,045	345,738	204,700
GAWD	3,357	0	0	0	3,357	0	0	0
GFWD	0	4,484	0	13,511	0	4,484	0	13,511
HVID	3	0	0	6,307	3	0	0	6,307
INWD	1,151	0	0	0	1,151	0	0	0
IVID	19	2,858	4,800	26,723	10	2,858	4,800	26,732
KTWD	0	0	9,509	0	0	0	9,509	0
LCWD	1,386	0	0	0	1,385	0	0	0
LIID	31,624	7,960	0	20,252	31,624	7,960	0	20,252
LSID	26,371	0	0	1,245	26,371	0	0	1,245
LTID	54,659	80,502	67,721	97,434	53,926	80,504	64,260	99,657
LWSA	2,351	0	0	0	2,351	0	0	0
MACO	199	0	0	0	199	0	0	0
MAID	3,526	67,073	45,686	200,971	3,529	67,073	45,686	200,934
OCCY	1,340	0	0	0	1,340	0	0	0
OCID	4,049	0	0	75,251	4,020	0	0	75,251
POID	7,952	7,052	21,162	6,478	7,965	7,050	21,699	6,707
PXID	3	0	12,857	103,801	9,102	0	15,883	92,334
RGWD	4,091	0	0	1,542	4,091	0	0	1,542
SAID	19,014	11,843	0	13,396	19,014	11,843	0	13,396
SCID	2,907	0	0	14,627	2,884	0	0	14,627
SSMD	46,061	18,088	0	99,844	45,940	18,088	0	99,844
SWID	47,916	14,313	0	38,217	47,916	14,313	0	38,217
TBID	24,312	0	0	454	24,312	0	0	454
TPWD	7,192	0	0	1,998	7,192	0	0	1,998
TUCO	933	0	0	0	933	0	0	0
TUID	24,266	50,845	109,333	39,709	24,240	50,845	109,333	39,734
TVWD	304	0	0	0	304	0	0	0
Total	**478,878**	**479,713**	**693,095**	**1,257,021**	**487,050**	**479,648**	**693,197**	**1,247,956**

Some small changes are verified by comparing run FPhigh to variable pumping cost VP (Table 9), mostly on irrigation districts with intense groundwater use (e.g. PXID). Groundwater pumping cost for Pixley increases from $45/af in the first month to $111/af in the last month of the 73 years run, resulting in reduction of amount pumped of approximately 11%. Class 1 and other surface supplies are increased to substitute the groundwater.

As groundwater costs increase, irrigation districts switch to other cheaper supply sources to maximize revenue and avoid scarcity. When groundwater costs start at a higher value than other surface supply sources, further increase will have little effect on pumping until the pumping cost exceeds that the district's willingness to pay for additional water. Since class 1 and class 2 water are limited by contract amounts (i.e. the districts can not trade water among themselves) the system's flexibility to cope with increase in groundwater costs by switching to other surface water supplies is also limited. Tables 10 and 11 present overall results for the whole project area and for the districts subject to variable groundwater pumping cost respectively. The results compared are from the FPlow run (original groundwater pumping costs) and VP (variable pumping costs). Numbers presented are 73-year averages.

Table 10 - Overall average results – all FRIANT contractors

	Variable pmp cost **FPlow run**		Fixed pmp cost **VP run**	
Totals (taf/yr avg)		% Total		% Total
Demand	2,984	100.0%	2,984	100.0%
Total Supply	2,891	96.9%	2,865	96.0%
Scarcity	93	3.1%	119	4.0%
Total Supply	2,891	100.0%	2,865	100.0%
Surface contract supply	867	30.0%	1,004	35.0%
Surface other supply[1]	613	21.2%	613	21.4%
GW supply	1,411	48.8%	1,248	43.6%

[1]Excluding artificial recharge

Effects of increased groundwater pumping costs include substitution of groundwater for contract water and increase in scarcity in VP run. Of the 163 taf/yr average reduction in groundwater supply, 137 taf is replaced by contract water (Table 10), the remaining 26 taf accounting for increase in scarcity. This reflects the region's capability in accommodating for some changes in operating policy. Economic penalties associated with the supply change are investigated in the scarcity costs section. Advantages of the groundwater/surface water operating policy in run VP includes less aquifer overdraft and related problems. Groundwater storage is analyzed is further detail in the next section.

Table 11 - Overall results – GW modeled FRIANT contractors[1]

	Fixed pmp cost **FPlow run**		Variable pmp cost **VP run**	
Totals (taf/yr avg)		% Total		% Total
Demand	794	100.0%	794	100.0%
Total Supply	786	99.0%	760	95.7%
Scarcity	9	1.1%	34	4.3%
Total Supply (taf/yr avg)	786	100.0%	760	100.0%
Surface contract supply	272	34.6%	410	53.9%
Surface other supply[2]	93	11.8%	93	12.2%
GW supply	421	53.6%	257	33.8%

[1]See table 2.3
[2]Excluding artificial recharge

Groundwater operations

Most irrigation districts face increasing groundwater pumping costs, once groundwater is a significant portion of the supply and intensive groundwater pumping is present during the 73 years run period.

Differences in groundwater pumping from FPlow run (fixed original groundwater pumping costs) to FPhigh (fixed updated groundwater pumping costs) are significant due to the difference in cost but as we move from FPhigh to the variable pumping cost run VP differences in pumping are limited to irrigation districts highly dependent on groundwater supply (Pixley ID). Time series of annual average pumping appear in Figure 6. In very dry years the differences among the three runs are smaller as surface supply is limited and the irrigation districts turn to groundwater to avoid scarcity costs. In wet years the higher price of groundwater in runs FPHIGH and VP results in districts switching supply to less expensive surface water available.

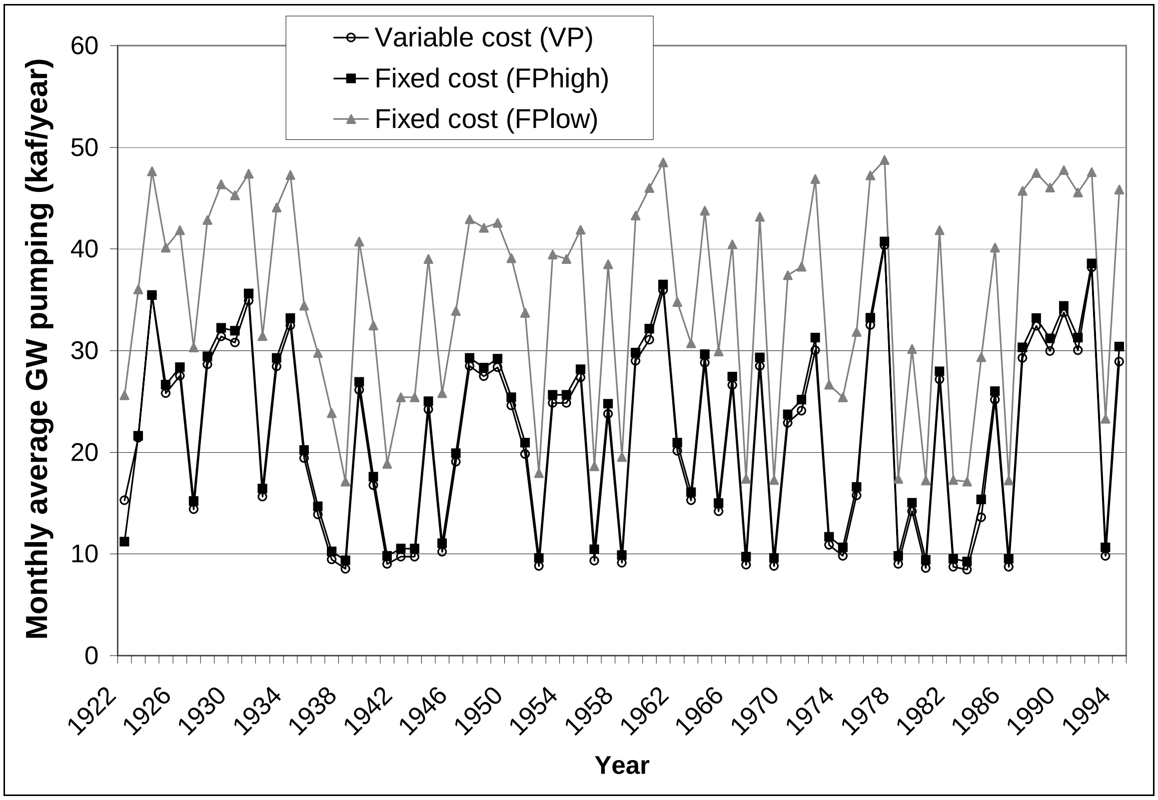

Figure 6 - Monthly average GW pumping total for modeled districts[1]

In the variable pumping cost run (VP) the gradual increase in pumping costs produces further reductions in pumping, but Pixley ID is basically the only irrigation district affected. Overall, short period, seasonal, variations in pumping cost do not affect pumping.

Groundwater pumping in Pixley is reduced in the months of March and April and replaced by class 1 water. As the months get drier (i.e., May, June, July) class 1 water availability is reduced and Pixley resorts to groundwater pumping to match demand. With fixed pumping cost, variations in groundwater pumping are driven by surface water availability. With pumping cost varying, a second factor is introduced and some change is perceived in the pumping pattern (Figure 7). Faster increases in cost during dry years reduces pumping in VP, as opposed to a more variable pumping pattern in the fixed pumping cost run FPhigh.

Since Pixley is willing to pay $125/af of water for the last portion of supply, according to its economic function, and pumping costs increase up to $109/af there is no cutback in GW pumping due to scarcity in VP run compared to FPhigh run. Although the irrigation district faces decreases in net revenue as the water cost increases, it is still economically attractive to use groundwater supply at the margin. This explains partially the relative unresponsive pattern of groundwater pumping to fluctuations in pumping cost. The other factor leading to the lack of response to pumping costs is surface water operations. The limited availability of surface water (at a lower cost than groundwater) and the non-representation of inter-district transfers limits districts to resort to groundwater pumping when surface water (contract water plus local sources) is not enough, while in practice surface water could be purchased from other districts.

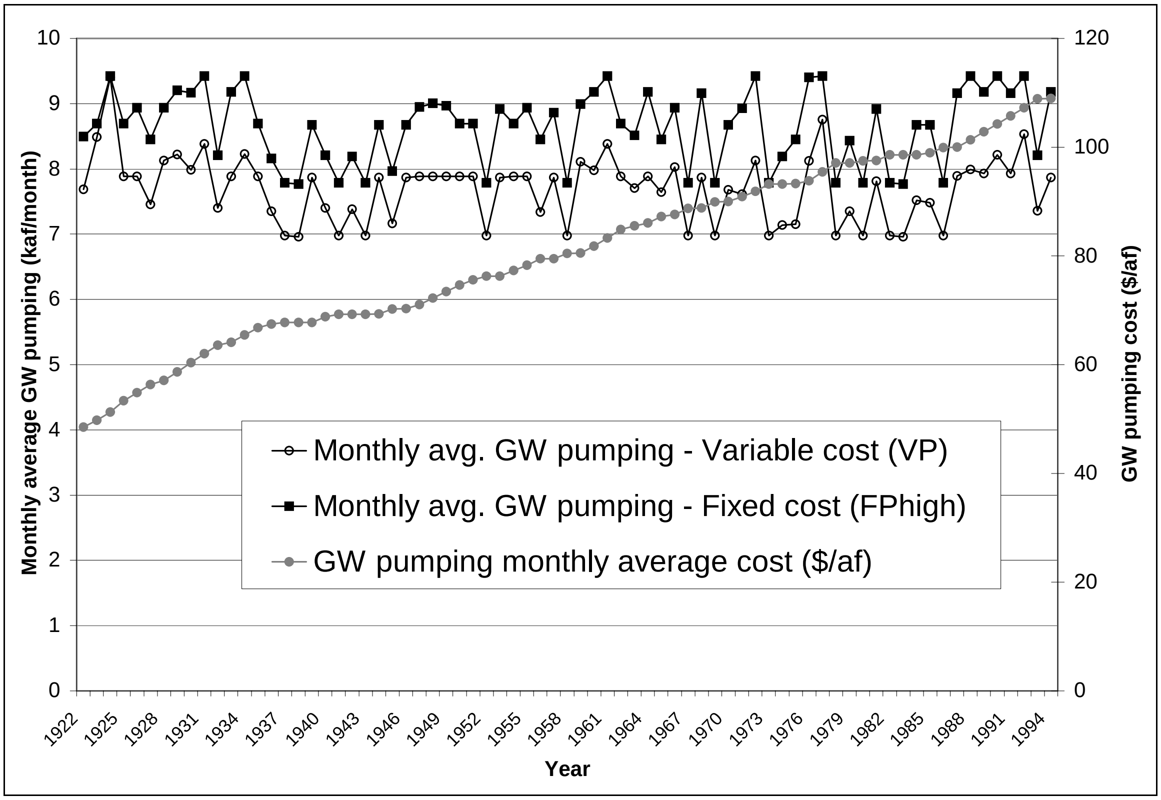

Figure 7 - Groundwater pumping in Pixley (PXID) irrigation district

Groundwater heads and pumping cost

In the first 20 years of simulation groundwater heads are mostly dominated by subsurface flows moving towards equilibrium from the initial heads. This is a limitation of the present approach where there is no detailed representation of lags in the system. Subsurface flows are lagged by one month. The consequence is the steeper initial portion of the pumping cost curves. Irrigation districts depending most on groundwater basins with lower initial water tables (e.g., LTID) face an initial period of declining costs as water table in their main groundwater supply basins rise to equilibrium with neighbor groundwater basins.

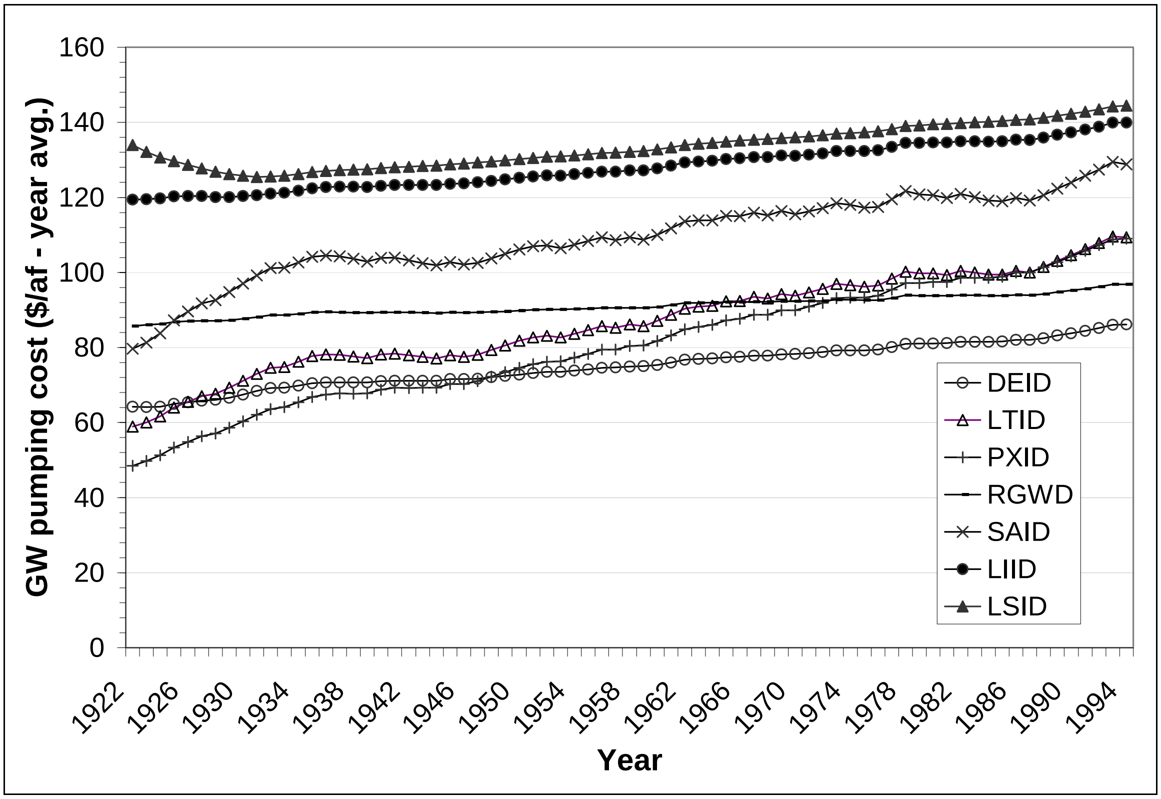

Figure 8 - Year average groundwater pumping costs

After the initial 20 years of simulation heads are mostly driven by groundwater pumping. The steep section during the drought years from 1987 to 1992 in Figure 8 for Pixley ID is paired with a sequence of years of continuous high volume pumping, driving the groundwater pumping costs up.

Irrigation districts share groundwater supply and are affected by neighbor districts operations. This is particularly true for POID where groundwater pumping accounts for a small part of the total withdrawal on its main groundwater supply, site GW12. Other irrigation districts withdrawing groundwater from GW12 are Lower Tule River ID (LTID), Lindmore ID (LIID), Lindsay Strathmore ID (LSID), Delano Earlimart ID (DEID), Kern Tulare Water District (KTWD) and Ragh Gulch Water District (RGWD). Figure 9 presents the time series of pumping heads[1] and respective pumping costs for groundwater site GW12 including the droughts of 1976-1977 and 1987-1992. The intensive pumping during 1976-1977 drives the heads from around 528 ft to 536 ft. After that, the sequence of wet years until 1988 results in a stable/slight increase in pumping heads and cost until just before 1987, where a long dry period starts. The stepwise pattern of head increase reflects the monthly pumping pattern, with the flat section from September to May, and the “jump” carrying the effect of the concentrated pumping from July through August (Figure 9).

[1] The term pumping *head* refers to the distance between the water table and the ground level, i.e., the higher the head, the higher the pumping cost.

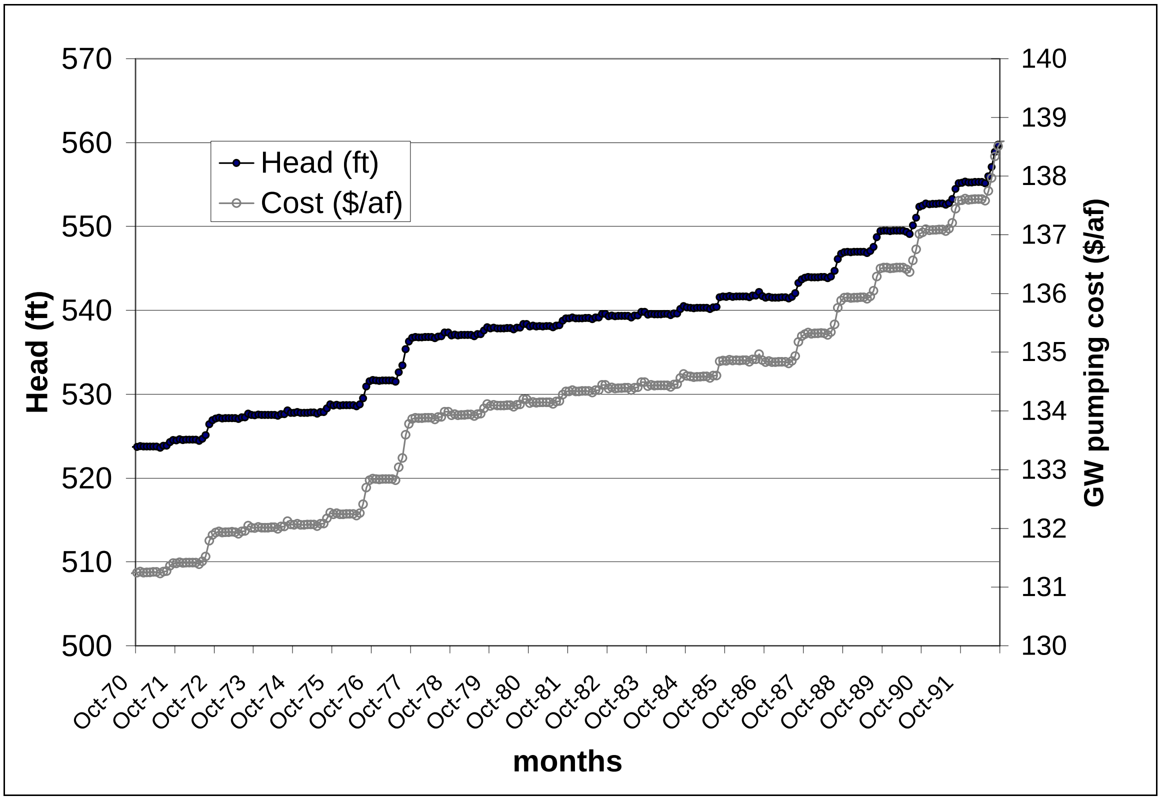

Figure 9 - Groundwater site GW12 heads and pumping costs for 1970-1991

Groundwater pumping infrastructure capacity is based on historic pumping in dry periods (1976-1977 drought). Although the escalating groundwater operating costs in the VP run reduce the pressure on the infrastructure, the upper bounds on pumping capacity are still being reached in some irrigation districts indicating there is a positive marginal value in expanding it. Irrigation districts with binding groundwater pumping capacity include Saucelito ID (SAID), Lindsay Strathmore ID (LSID), Rag Gulch WD (RGWD), Delano Earlimart ID (DEID), Lindsay ID (LIID), Terra Bela ID (TBID), Tea Pot Dome WD (TPWD) and Lower Tule River ID (LTID).

Groundwater Storage

Reduced groundwater pumping results in an end-of-period (EOP) storage increase of about 34% from FPlow to FPhigh run, and of 1.6% from FPhigh to the variable pumping VP run, over the 73-year simulation period (Figure 10). The small difference in storages between FPhigh run and VP run reflect the lack of response in groundwater pumping to variations in pumping cost, given economic conditions and the relative prices of groundwater compared to surface water.

The cost of this reduction in aquifer overdraft is an increase in the average annual scarcity from 8 taf to 34 taf for the eleven irrigation districts modeled with variable pumping cost (Table 3). Relative to the target demands (full supply), this represents an increase in scarcity from 1% to 4%.

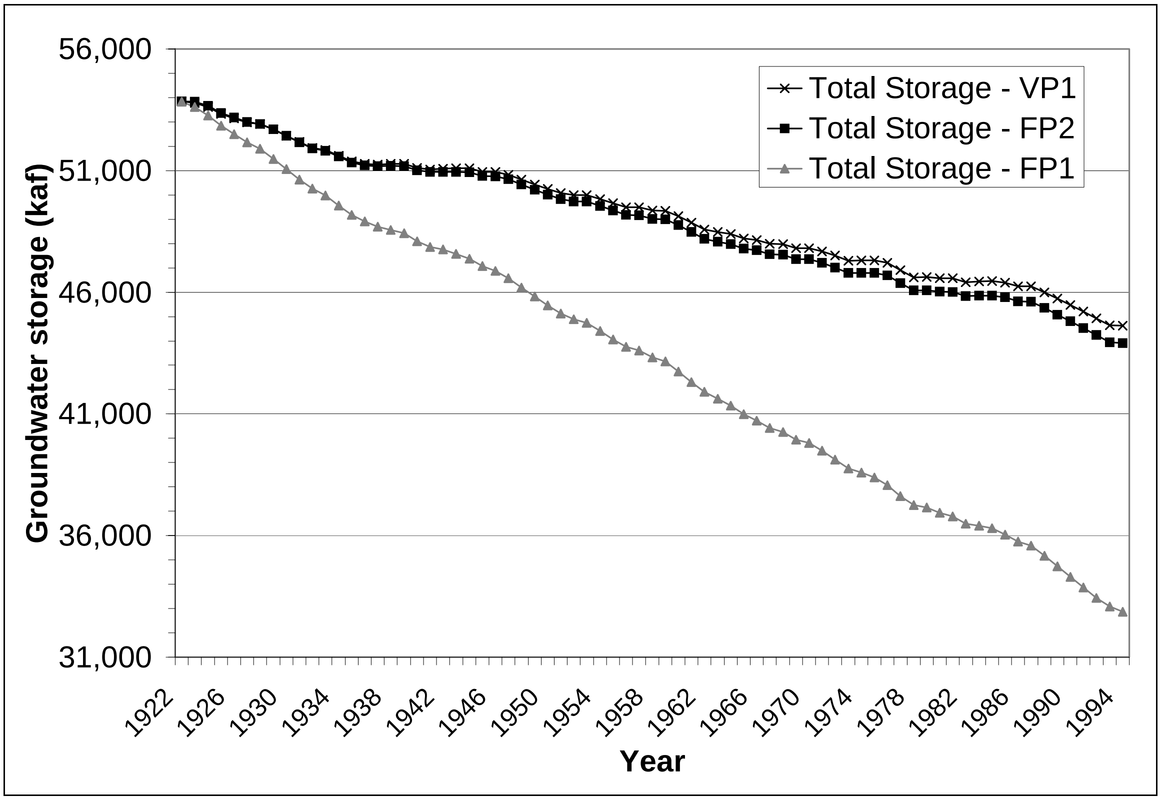

Figure 10 - Groundwater storage

Additional benefits from total operating costs also must be considered. As pumping costs increase and groundwater use is reduced the total groundwater operating cost decreases, and scarcity cost increases. When properly calibrated, model will allow examination of trade-offs in overdraft against increases in scarcity and evaluate potential for improvement in regional water management operations and policies. Groundwater and surface water operations can be changed by varying surface contract water price, or subsidizing energy costs to change groundwater pumping cost. The model will help to evaluate the costs and benefits of such changes.

Surface Water Operations

When groundwater pumping costs increase irrigation districts may look at alternative supplies to reduce operating and scarcity costs. Changes in external surface supply (EXT) are verified and water is reallocated based on its economic value. For example, Porterville ID (POID), Lower Tule River ID (LTID) and Pixley ID (PXID) share surface supply from the Tule River, with VP run results appearing in Figure 11 for the 1987-1992 drought. Water has the highest marginal value for Porterville ID. Whenever surface supply is available from Tule River, POID will take priority unless its target demand has already been met, or the delivery infrastructure reaches its capacity (4.6 taf/month). Due to the high pumping cost, groundwater is used only during the dry months, when there is not enough surface supply. The upper bound for Tule River delivery infrastructure is often reached for Porterville and Pixley irrigation districts, indicating potential benefits for expanding its capacity.

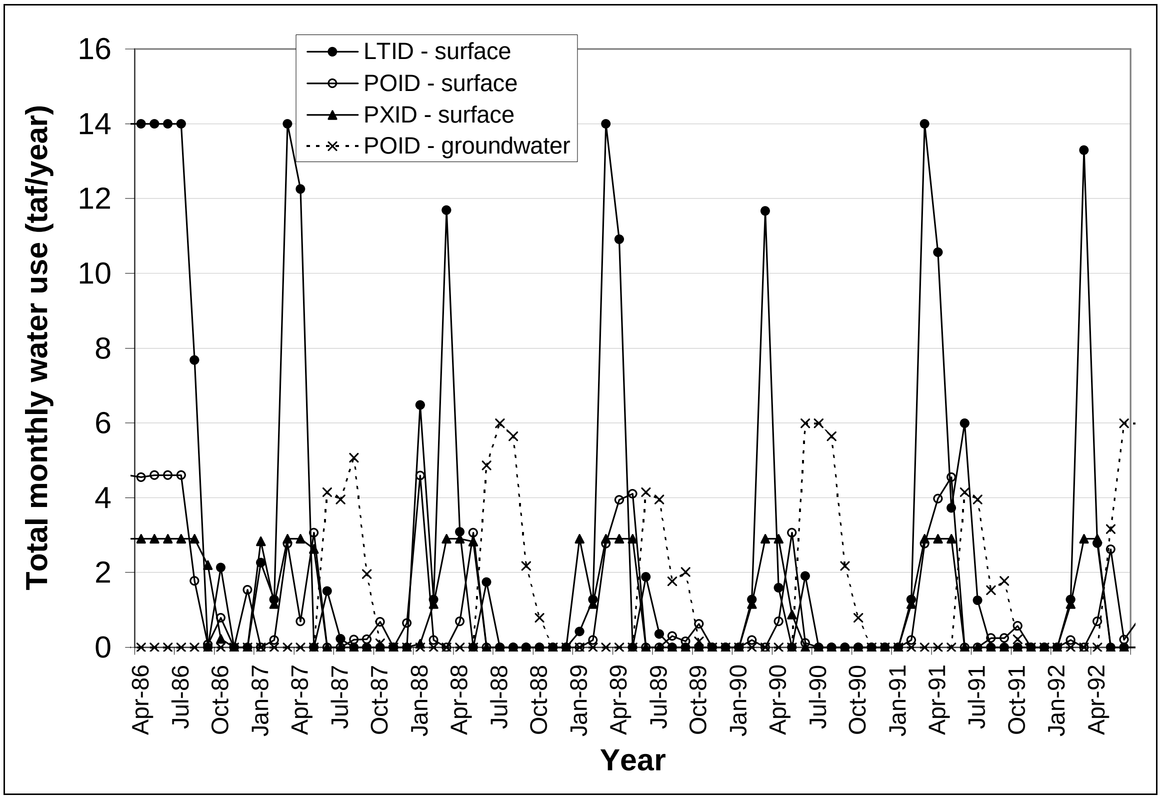

Figure 11 - Tule River supply for 1987-1992 drought – VP run

Scarcity Costs

Irrigation districts face scarcity as water costs increase beyond their willingness to pay. The economic loss associated with these scarcities is based on foregone benefits from supply cutbacks. Since willingness to pay for additional water is higher with lower supply levels, the total economic loss, or penalty, depends not only on the cutback itself, but also on the level of supply being applied.

Total annual scarcities are plotted in Figure 12 for 73-year period. During dry years the difference between FPlow and VP runs is higher, reflecting the economic impact of high pumping costs when surface water is limited. Differences from FPhigh and VP run are virtually inexistent.

The lower groundwater pumping cost run (FPlow) results in 21 maf of total overdraft over 73 years and a $19 million/yr average penalty in scarcity costs. Avoiding this overdraft would require reducing groundwater pumping by either cutting back in production or acquiring supplemental non-local surface supplies averaging 288 kaf/yr. The groundwater pumping curtailment seen in VP run could reduce the overdraft to 9.2 maf at a cost of $24 million/yr in scarcity costs, if no supplemental surface supply is available. To eliminate the 9.2 maf overdraft 126 kaf/yr average of supplemental surface supplies would be needed.

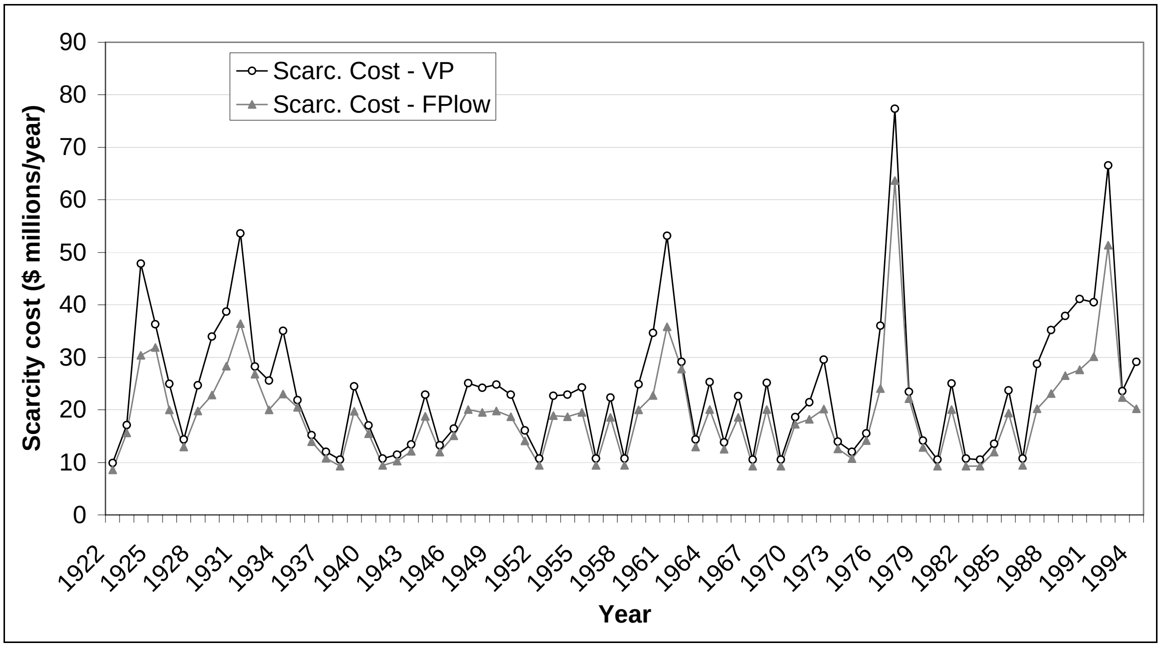

Figure 12 - Annual scarcity costs

Policy study

Friant users adopt conjunctive use operations extensively to increase water availability and flexibility in its use. These operations include artificial recharge through infiltration ponds and natural streams, and groundwater pumping (Naugle, 2001; ARVIN EDISON, 2000a, 2000b). Although not all of those operations are modeled in detail in the present study, some reactions of the system to possible management policies can be evaluated using the simulation model presented. Policies such as energy price changes and surface water price chances can affect conjunctive use operations by altering the balance between surface water and groundwater use. The policies analyzed here include variation of surface water prices and variation of energy cost. The model version used is the variable groundwater pumping cost and for easier understanding of the impacts, only the Friant contractors modeled with variable groundwater cost are included in the analysis.

Surface water price change

Class 1 and Class 2 water are the most important components of surface water supply to contractors and changes in their price are expected to affect the relative value of groundwater, change pumping patterns, operating costs and end-of-period groundwater storage. Contract water prices have been increased in the past due to increasing operation and maintenance costs (LEU, 2000); and notably after CVPIA act in 1992, for environmental regulation. To simulate the effects of surface water price changes in the Friant system, a few runs were made with prices listed in Table 12.

Table 12 - Changes in contract water price

Run	Class 1 price ($/af)	Class 2 price ($/af)
P1	24	14
P	44	34
P2	54	44
P3	64	54
P4	84	74
P5	104	94
P6	124	114
P7	144	134
P8	174	164
P9	204	194

Increase in surface water prices results in users switching to groundwater use and intensifying aquifer overdraft. This effect accumulates and is felt in later years where the volumes pumped actually drop when groundwater becomes too expensive. Higher surface water prices cause higher groundwater pumping in the first years. At the highest surface water prices the aquifer is so intensely exploited in the first years that groundwater pumping declines after 1961 and is pumped in much less quantity during the 1976-1977 drought compared to scenarios with lower surface water price (Figure 13). At this high surface water price there is a large economic impact and drought conjunctive use operations are compromised.

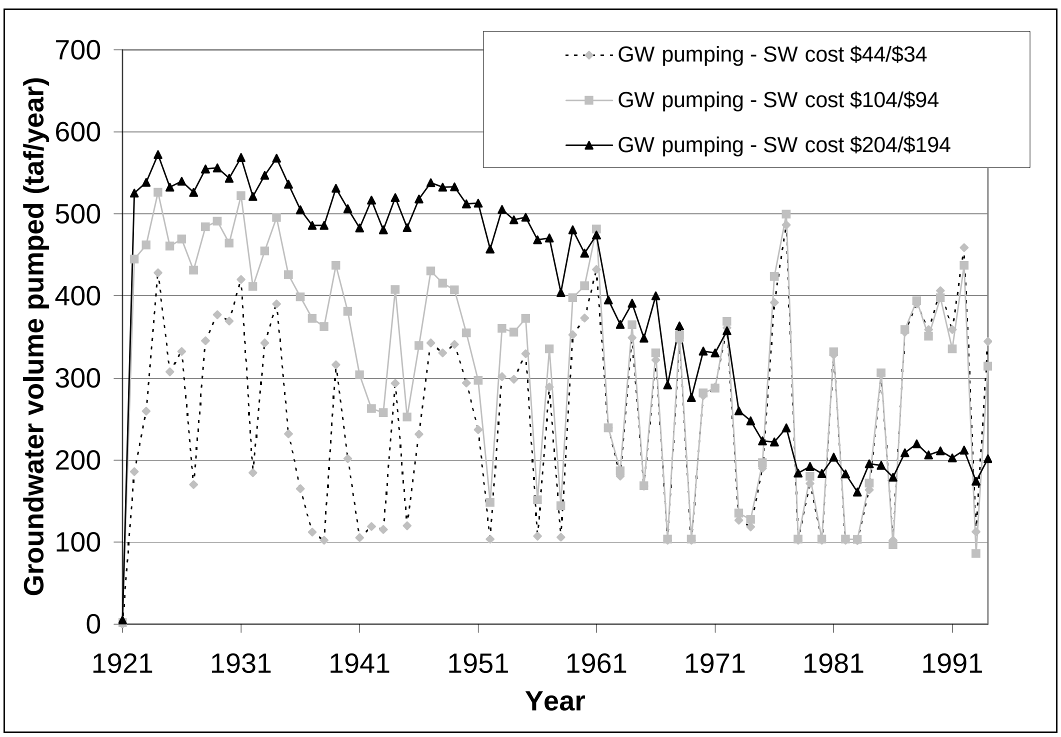

Figure 13- Groundwater pumping under different scenarios of surface water pricing

Economic impact appears in Figure 14 (scarcity costs related to surface water prices and End-of-Period overdraft). Reduction of supply options caused by significant increase in surface water prices leads to penalties over $35 million/year with severe overdraft conditions in parts of the system.

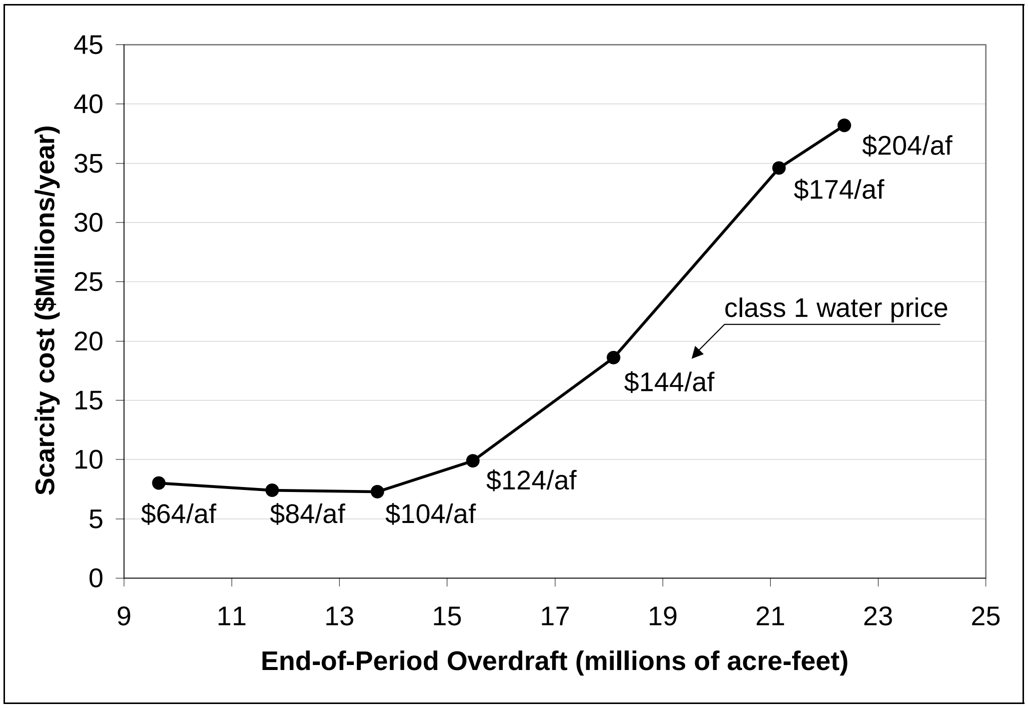

Figure 14 - End-of-Period overdraft and scarcity costs

Figures 15 and 16 present end-of-period (EOP) groundwater storage for the variable head modeled groundwater reservoirs and different contract Friant water. EOP starts being strongly affected when surface water costs surpasses the groundwater pumping cost and groundwater pumping starts replacing surface water. Groundwater basins exploited by irrigation districts with higher value crops and high demand are susceptible to higher overdraft impact. The largest groundwater reservoir considered, GW10, has its withdrawn water split between the Lower Tule River (LTID) and Pixley (PXID). Lower Tule has the highest groundwater demand, while Pixley has the highest percentage of total supply as groundwater. The result is the noticeable reduction in EOP storage in GW10 as soon as surface water price for Class 1 goes over $64/af.

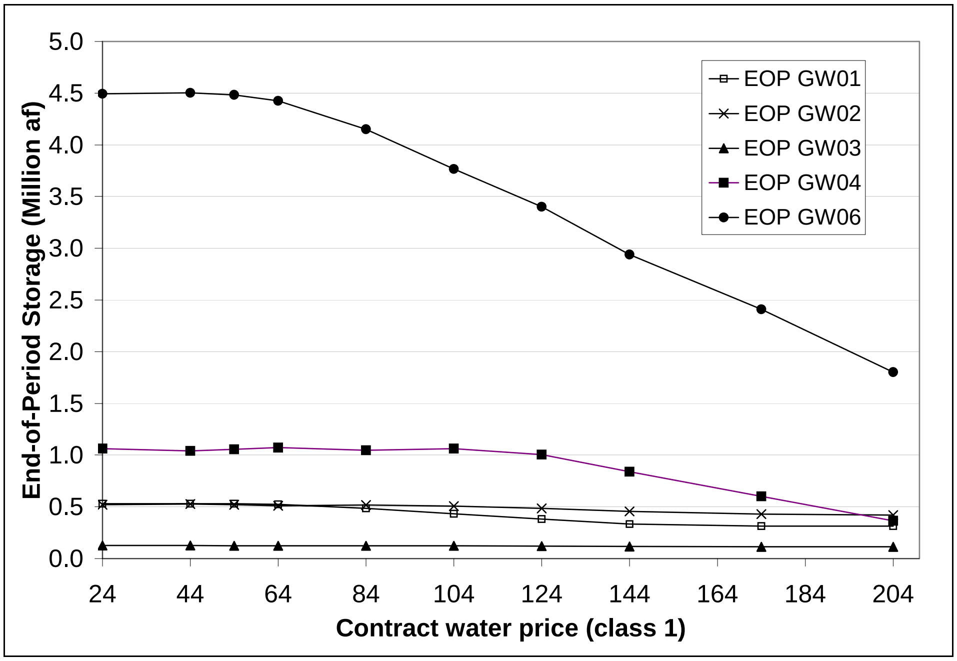

Figure 15 - EOP groundwater storage for varying surface water price

GW06 is shared by most districts and suffers a high overdraft impact as surface water price increases, with EOP storage dropping to half in the last run. GW04 suffers about the same reduction but it is not until the surface water price surpasses $124/af that a noticeable reduction in the EOP groundwater storage occurs. Most of the water in GW04 is used by Lindsay Strathmore (LSID) and Lindmore (LIID) irrigation districts with high value crops.

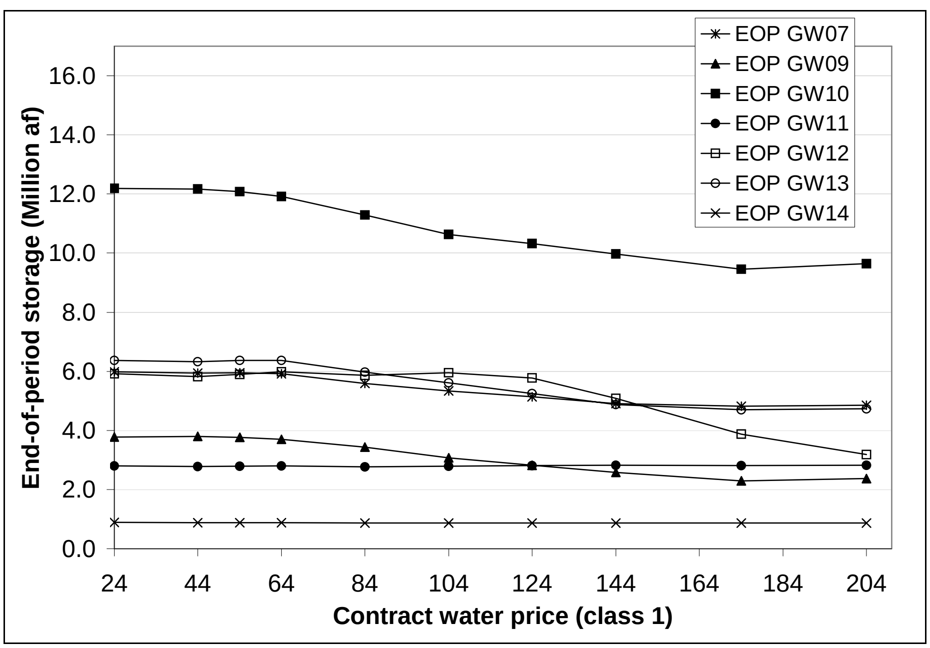

Figure 16 - EOP groundwater storage for varying surface water price

The impact of increases in surface water costs is high in scarcity and scarcity costs, but some distortions on the model behavior are also apparent. For increases in contract water up to $109/af class 1 and $94/af class 2 the scarcities actually are reduced for some districts (Tables 13 and 14). In a lower contract water price scenario, it will be prioritized over groundwater (if it costs less) and used whenever there is demand. During the drier, high demand months, the district will not have enough contract water available and resorts to groundwater, sometimes reaching the pumping capacity and facing scarcity. As the contract water price increases, groundwater will be prioritized (if it costs less) replacing contract water in early months (March-April). This contract water "saved" will be available during the dry months, when the pumping capacity is reached. the result is a lower scarcity.

Table 13 - Scarcity levels

		Scarcity level (taf/year)									
Friant contractor	C2/C1 Price ($/af)	14/ 24	34/ 44	44/ 54	54/ 64	74/ 84	94/ 104	114/ 124	134/ 144	164/ 174	194/ 204
Delano-Earlimart	DEID	5.7	6.3	6.3	5.2	3.8	2.1	13.9	35.6	47.0	47.7
Kern-Tulare WD	KTWD	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Lindmore	LIID	1.2	1.3	1.3	1.3	1.3	1.3	0.9	1.5	12.3	14.3
Lindsay-Strathmore	LSID	7.3	7.3	7.3	7.3	7.3	7.3	7.2	6.6	5.8	10.0
Lower Tule River	LTID	14.8	14.9	13.4	12.0	9.9	9.3	14.2	46.4	106.9	112.5
Pixley	PXID	0.0	0.0	0.0	0.0	0.0	1.4	6.5	11.8	15.5	15.9
Porterville	POID	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.7	5.9	7.0
Rag Gulch	RGWD	1.0	1.0	0.9	0.9	0.9	0.9	0.5	0.2	0.1	0.1
Saucelito	SAID	0.9	1.0	1.0	1.0	0.9	1.3	2.7	5.3	14.1	20.6
Tea Pot Dome	TPWD	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.0	0.0	0.0
Terra Bella	TBID	0.1	0.1	0.1	0.1	0.1	0.1	0.1	2.6	6.6	6.6
Total (taf/yr)		**32.7**	**33.6**	**31.9**	**29.4**	**25.8**	**25.2**	**47.7**	**112.2**	**215.4**	**236.0**
Total all contractors (tafyr)		**142**	**119**	**97**	**105**	**152**	**192**	**254**	**340**	**454**	**476**

MODSIM is run as a simulation tool and does not optimize water use across time (i.e., the model has zero foresight even within an irrigation season). Farmer's actual decisions are based in some foresight, given forecasts and knowledge of water availability for coming months. Factors like groundwater pumping capacity and surface water availability are coordinated across months, so lower scarcity at the higher contract water price scenarios is highly improbable. Thus, increases in contract water price are expected to increase scarcity and scarcity costs, contrary to what the model presents for cost increases up to $94/$104.

For further increase in contract water prices, the model's behavior is coherent and scarcity and scarcity costs go up in total values. However, irrigation districts with high groundwater pumping costs and very high crop value continue to present distorted behavior for almost all scenarios, e.g., TPWD, LIID, LSID.

A possible improvement to correct this issue is to develop value functions for contract water use to capture the benefit of seasonal use, so the model can evaluate the trade-offs between paying more per af to start using groundwater earlier (if it is more expensive than surface water) and having more contract water available during high demand, very dry months.

Table 14 - Scarcity costs – year average

		Scarcity cost ($1,000/year)									
Friant contractor	C1/C2 Price Scenarios ($/af)	14/ 24	34/ 44	44/ 54	54/ 64	74/ 84	94/ 104	114/ 124	134/ 144	164/ 174	194/ 204
Delano-Earlimart	DEID	928	1062	1062	870	626	342	1782	4826	6880	7010
Kern-Tulare WD	KTWD	669	669	669	669	669	669	669	669	669	669
Lindmore	LIID	204	215	215	215	215	215	152	255	2082	2469
Lindsay-Strathmore	LSID	3747	3750	3750	3750	3750	3750	3696	3411	2022	2372
Lower Tule River	LTID	2044	2060	1846	1664	1369	1278	1958	6429	16375	17368
Pixley	PXID	0	0	0	0	0	179	877	1606	2141	2197
Porterville	POID	37	44	34	31	31	24	21	111	951	1153
Rag Gulch	RGWD	557	569	541	523	523	520	304	97	45	41
Saucelito	SAID	136	144	144	144	134	202	406	820	2333	3819
Tea Pot Dome	TPWD	70	71	71	71	71	71	46	15	6	2
Terra Bella	TBID	17	18	18	18	18	18	18	401	1108	1134
Total ($million/yr)		**8.4**	**8.6**	**8.4**	**8.0**	**7.4**	**7.3**	**9.9**	**18.6**	**34.6**	**38.2**
Total all contractors ($million/yr)		**26.2**	**24.0**	**21.8**	**22.1**	**25.6**	**29.4**	**36.7**	**48.2**	**65.7**	**69.6**

Energy prices change

Given the high groundwater use in the system, a significant part of supply operating costs depends on energy consumption and is susceptible to changes in energy prices. Energy prices have increased from around $0.06/kwh in the early eighties to about $0.1/kwh at the present (AECA, 2002). In the other hand, some irrigation districts can implement programs to stabilize power costs like development of power plants, long-term power contracts, and shifting irrigation schedules to off-peak hours (FWUA /MWDSC,2001).
This section investigates some potential impacts in the Friant division from increase and reduction in energy costs. The impact is evaluated in terms of groundwater operating costs. Three energy cost scenarios are evaluated, 0.08$/kwh, 0.1$/kwh and 0.12$/kwh. The 0.1$/kwh is the cost used in all previous runs and model analysis so far. The model is presently capable of running with energy cost varying per Friant contractor and per month, if data is available to do so.

A reduction of 20% in energy cost, from $0.1/kwh to $0.08/kwh has a relatively small effect on pumping amounts, about 2% increase overall with Delano Earlimart (DEID) and Rag Gulch (RGWD) presenting the highest increases (approximately 4% and 6% respectively) (Table 15). The impact on operating costs is noticeably higher as expected, 17% overall reduction. The increase in the amount pumped is expected to lower the heads and as more energy is required to extract the same amount of water, part of the gains of pumping with cheaper energy are reduced.

Table 15 - Groundwater pumping and operating cost for energy cost scenarios

	Avg. GW pumping (taf/yr)			Avg, GW operating cost (k$/yr)		
Energy cost scenario	0.08$/kwh	0.1$/kwh	0.12$/kwh	0.08$/kwh	0.1$/kwh	0.12$/kwh
Contractor						
DEID	20,491	19,673	19,607	1,294	1,529	1,818
KTWD	0	0	0	0	0	0
LIID	20,252	20,252	19,829	2,051	2,552	2,979
LSID	1,245	1,245	1,245	133	166	198
LTID	103,937	99,657	98,926	7,015	8,261	9,806
POID	6,401	6,707	5,065	654	851	761
PXID	93,458	92,334	91,479	6,255	7,527	8,894
RGWD	1,641	1,542	1,542	145	174	208
SAID	13,396	13,396	12,994	1,191	1,468	1,693
TBID	454	454	357	48	60	56
TPWD	1,998	1,998	1,998	209	261	312
Totals	**263,273**	**257,258**	**253,042**	**18,996**	**22,849**	**26,726**

An increase of 20% in energy costs causes a similar effect in the opposite direction. The reduction in the amount pumped and the lower heads alleviate part of the impact on the operating costs.

Further effects on scarcity costs are presented in Table 16. Reducing energy cost from $0.1/kwh to $0.08/kwh does not result in significant changes but an increase to $0.12/kwh heavily affects irrigation districts where the demand is smaller and groundwater is a significant portion of the total district water supply. like Pixley (PXID) and Porterville (POID). Other districts with higher value crops such as Lindsay (LIID) and Lindsay Strathmore (LSID) face smaller or zero impacts.

Table 16 - Scarcity costs for energy cost scenarios

	Avg. Scarcity cost (k$/year)		
Energy cost scenario / Contractor	0.08$/kwh	0.1$/kwh	0.12$/kwh
DEID	1050.7	1062.2	1062.2
KTWD	669.2	669.2	669.2
LIID	215.0	215.0	283.8
LSID	3749.9	3749.9	3749.9
LTID	1792.1	2059.9	2173.6
PXID	0	0	65.3
POID	34.2	44.3	184.9
RGWD	533.9	568.9	568.9
SAID	143.6	143.6	203.5
TPWD	70.5	70.5	70.5
TBID	17.7	17.7	33.8
Total ($Millions/year)	**8.3**	**8.6**	**9.1**

LIMITATIONS

Model limitations are presented here. These limitations provide orientation for results interpretation and future model improvement.

Artificial Recharge

Artificial recharge is conducted in the region but information regarding infrastructure and operations is still lacking. According to Naugle (2001), significant amounts of water are recharged through diversion ditches and natural streams, whenever irrigation districts have access to surplus water.

Applied Water Demands and Evapotranspiration of Applied Water (ETAW)

ETAW and applied water (AW) are required input in SWAP model. The AW/ETAW ratio is used to determine the optimal investment in irrigation technology and the demand functions are based on AW data. ETAW data provided by LAIUZ is based on monthly calculations where shorter time intervals mismatches between evapotranspiration, precipitation and soil moisture content may result in discrepancies in effective precipitation calculations and underestimates of ETAW. A model with higher detail in the temporal discretization is required to improve this calculation. Presently, the California Department of Water Resources (DWR) is developing a model to simulate weather variables including ETo, ETc, effective precipitation and ETAW in a daily basis (SIMETAW model) that could be used to improve the economic functions of FREDSIM.

Model Hydrology

The simulation was extended to a 73 years period. The Friant deliveries class 1 and class 2 were correlated to inflows at Millerton Lake during the same period (1985-1994) and extended to the rest of Millerton inflow time series. A longer times series of Friant deliveries is necessary for a sound statistical correlation.

Limited area modeled with groundwater model

The response factors (conductance) used to estimate subsurface flows require a detailed groundwater model to be estimated. So far only a small portion of the project area, including 11 irrigation districts, is included in this detailed study. Remaining irrigation district operations affect the groundwater supplies and these impacts are not yet fully represented.

Lack of model foresight and risk aversion

As currently set, the model optimizes water allocation in a monthly time step where no value is put on future water demands. Farmers do make decisions considering seasonal variability in both demand and supplies, as well as infrastructure capacity and risk aversion. To overcome this limitation, value functions that incorporate potential future use benefits of inputs should be added to the model on groundwater and surface water storage. These functions will enable it to evaluate trade-offs between supply sources with different prices and different seasonal availabilities, and trade-offs of some beneficial uses, like artificial recharge.

CONCLUSIONS

A scheme of variable groundwater heads and pumping costs was implemented at this stage of FREDSIM development, along with new developed economic functions at the irrigation district level. The groundwater system behaves coherently with heads and costs responding to increases in pumping and reduction in storage. The initial portion of the simulation is dominated by subsurface flows indicating that additional adjustments are necessary in the lag representation and initial conditions. The new calculated pumping costs are considerably higher that the original costs used but overdraft conditions still seem to be present in most of the modeled area, although at much lower rates with the new costs. With more detailed representation of artificial recharge a better insight could be drawn from on overdraft, and management options such as surface water price change could be evaluated in addressing overdraft problems.

Results show that users change supply sources and quantities, and transfer water reacting to variations in water price, economic value and water availability. Changes in surface and groundwater prices affected operations produced small variations in overall pumping and groundwater storage, except for contractors relying on groundwater for most of their supply.

Reduction of historical overdraft requires reduction of groundwater pumping. In terms of surface water this is equivalent to 33% of contract surface supplies. Without additional surface supplies, a 49% reduction in overdraft (9.8 maf) would cost an additional $5 million/yr average in scarcity costs, a 26% increase.

The direct effect of surface water availability and prices on supply balance between surface and groundwater has consequences for management programs including conjunctive use operations. Intensive groundwater pumping under high surface water prices resulted in aggravated overdraft conditions limiting considerably groundwater supply in dry seasons and dry years. With high surface water prices, the efficacy of conjunctive use programs relying on alternation between recharge in wet periods and pumping on dry periods is reduced.

ETAW values used in the development of the economic functions are systematically smaller than results from other models indicating that the economic demands used may be underestimated. A more detailed model to simulate ETAW for different weather conditions is required for further improvement.

High spatial and temporal variability in groundwater pumping was found by processing data from the groundwater model for use in FREDSIM. This variability is included as a constraint in the simulation model to enable a better characterization of present conditions when the model optimizes the water allocation for a given time step.

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APPENDICES

Appendix A1 – Groundwater Pumping Pattern

Groundwater supply scheme for irrigation districts with variable head and pumping cost calculation is presented in Table 17. Values represent percentages of total groundwater supply that a given irrigation district withdraw from each groundwater site it has access to. In some examples, such as LTID, significant variations are present along the year, supply from GW09 goes from 13% in October to 30% in march. Inclusion of this data is important to constrain the solver to a supply mix pattern that is consequence of other factors, like present location of pumping infrastructure. Since the pumping cost is attached to the GW sites, the solver would tend to withdraw water from the cheapest source only if left unconstrained.

Table 17 - Percentages of supply withdrawn from groundwater sites

ID/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
DEID												
GW01	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.05	0.06	0.05	0.05
GW06	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.13	0.11	0.11	0.12	0.12
GW07	0.21	0.25	0.21	0.21	0.32	0.25	0.28	0.25	0.23	0.29	0.27	0.28
GW12	0.00	0.00	0.00	0.00	0.15	0.18	0.20	0.13	0.14	0.10	0.10	0.08
GW13	0.79	0.75	0.79	0.79	0.53	0.57	0.34	0.45	0.47	0.45	0.46	0.48
KTWD												
GW03	0.00	0.00	0.00	0.00	0.62	0.62	0.27	0.22	0.15	0.17	0.19	0.26
GW12	0.64	0.00	0.00	0.00	0.00	0.00	0.67	0.62	0.68	0.64	0.62	0.54
GW13	0.36	1.00	1.00	1.00	0.38	0.38	0.06	0.17	0.18	0.19	0.19	0.21
LTID												
GW06	0.35	0.12	0.37	0.37	0.14	0.14	0.15	0.28	0.21	0.19	0.21	0.22
GW09	0.13	0.24	0.14	0.14	0.28	0.30	0.25	0.25	0.26	0.24	0.24	0.23
GW10	0.31	0.62	0.27	0.27	0.58	0.55	0.59	0.45	0.52	0.56	0.54	0.54
GW12	0.21	0.02	0.22	0.22	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
PXID												
GW01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GW06	0.00	0.07	0.00	0.00	0.09	0.10	0.09	0.13	0.14	0.11	0.10	0.10
GW07	0.03	0.37	0.00	0.00	0.36	0.33	0.31	0.31	0.26	0.24	0.26	0.27
GW10	0.97	0.54	1.00	1.00	0.53	0.52	0.54	0.53	0.57	0.63	0.62	0.62
GW14	0.00	0.02	0.00	0.00	0.02	0.05	0.06	0.03	0.03	0.02	0.02	0.01
LIID												
GW04	0.11	0.11	0.11	0.11	0.14	0.19	0.33	0.29	0.23	0.20	0.22	0.25
GW06	0.00	0.00	0.00	0.00	0.00	0.25	0.15	0.17	0.25	0.32	0.27	0.24
GW12	0.89	0.89	0.89	0.89	0.86	0.57	0.53	0.53	0.52	0.48	0.51	0.51
LSID												
GW04	0.35	0.36	0.33	0.33	0.57	0.63	0.43	0.42	0.38	0.40	0.41	0.44
GW12	0.65	0.64	0.67	0.67	0.43	0.37	0.57	0.58	0.62	0.60	0.59	0.56
POID												
GW06	0.05	0.03	0.05	0.05	0.04	0.05	0.07	0.11	0.10	0.12	0.11	0.11
GW12	0.95	0.97	0.95	0.95	0.96	0.95	0.93	0.90	0.90	0.88	0.89	0.89
RGWD												
GW03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.03	0.08	0.14	0.19
GW12	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.83	0.85	0.81	0.72	0.56
GW13	1.00	1.00	1.00	1.00	1.00	1.00	0.04	0.07	0.12	0.11	0.14	0.25
SAID												

GW06	0.00	1.00	0.00	0.00	1.00	1.00	0.91	0.94	0.95	0.97	0.96	0.96
GW12	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.07	0.05	0.03	0.04	0.04
TPWD												
GW04	0.00	0.00	0.00	0.00	0.00	0.13	0.28	0.32	0.15	0.18	0.18	0.19
GW12	1.00	1.00	1.00	1.00	1.00	0.87	0.72	0.68	0.85	0.82	0.82	0.81
TBID												
GW02	0.00	0.00	0.00	0.00	0.14	0.09	0.09	0.05	0.03	0.04	0.04	0.04
GW04	0.00	0.00	0.00	0.00	0.00	0.31	0.13	0.14	0.13	0.14	0.15	0.19
GW12	1.00	1.00	1.00	1.00	0.86	0.60	0.78	0.81	0.84	0.82	0.81	0.77

Appendix A2 – Model Metadata

Metadata 1 - Seepage Data

Location folder	Data files
Friant project\Other data\Surface\Seepage_analysis	seepage split.xls other files in the location folder

Notes:

For seepage consideration it will be used the % diversion channel loss
from Naugle (2001) table 4.4.

This table lists percentage of water lost through seepage when water is conveyed through the diversion channel en route to each district. Information on the diversion channels that supply each district is in Naugle (2001) Table 4.5

In MODSIM, this loss is applied to each link connecting the district's total node to its supplies). The Return node the channel loss is applied to a "seepage node". Once the objective is to distribute the seepage through the GW sites under the channel network, and the link does not allow for multiple return nodes a intermediate seepage node is created. From the seepage node the water is split to the GW sites according to information available on location of the diversion network relative to the GW sites. This is described in more detail in the following:

LTID - Lower tule river
Main network delivering water to LTID icludes Poplar ditch, Woods-central ditch and Tule river. In the lack of more detailed information, It will be obtained the percentage of total length of all canals that is located over a given GW site as way to split the seepage.

APID - Alpaugh
Alpaugh receives water from FKC (CVC exchange) through Deer creek. It is accounted the Lower Deer Creek plus a extention to the district. The extention runs over GW site 7

ATID - Atwell Island
Same as Alpaugh

DEID - Delano Earlimart
Delano Earlimart receives FKC water through white River but it is ignored in alec model. Since only FKC turnouts are considered and no other information about the channel network is available, the seepage will be split to the GW sites based on area percentage that they have on DEID

PXID - Pixley
According to Naugle (2001), the certain diversion to Pixley is Deer Creek. Split of seepage is made based on percentage lengths of lower Deer creek over the GW sites

POID - Porterville
Since most of Porteville is over GW zone 12, 90% of all diversion seepage loss will be sent to GW12 and 10% to GW6.

Metadata 2 – Infiltration return from Irrigation districts

Location folder	Data files
Friant project\Other data\Economic Functions	Crop_acreage_per_ID.xls
Friant project\Other data\Groundwater	areas_district_vs_edit5.xls

Notes:

Irrigation efficiency data from Naugle (2001). Values were processed by taking average weighted by crop area

Metadata 3 – Time series of groundwater demand

Location folder	Data files
Friant project\Other data\Groundwater	pump_pattern.xls
Friant project\Other data\Nels_received\received_04_19_pump_pattern1977_corrected\gui-data	Grid-Pumpage-1977.DBF* Grid-Pumpage-1977.SHP* Grid-Pumpage-1977.SHX*
Friant project\Other data\Nels_received\Received_04_10_pump_pttn_cropac\gui-data	Grid-Pumpage-1980.DBF* Grid-Pumpage-1980.SHP* Grid-Pumpage-1980.SHX* Grid-Pumpage-1983.DBF* Grid-Pumpage-1983.SHP* Grid-Pumpage-1983.SHX*

* Files sent by Nels Ruud

Metadata 4 - Initial groundwater storages

Location folder	Data files
Friant project\Other data\Nels_received\Received_05_09_Initial_Storages\storage	Initial Storage F1985.DBF* Initial Storage F1985.SHP* Initial Storage F1985.SHX*

* Files sent by Nels Ruud

Metadata 5 – Hydraulic conductance values

Location folder	Data files
Friant project\Other data\Nels_received\updated_cond_12_16	districts.dbf* districts.shp* districts.shx* flux-del-districts.xls* flux-del-edit5.xls*
Friant project\Other data\Groundwater\conductance	flux-del_edit5_upd_04.xls

* Files sent by Nels Ruud

Metadata 6 – Economic functions

Location folder	Data files
Friant project\Other data\Hatchett_received	WATERDMDaw.txt*
Friant project\Model runs\VP\Data files	WATERDMDaw4_bcvp043.xls

* Files sent by Steve Hatchett

Metadata 7 – Inflows to surface reservoirs

Reservoir	Source
San Joaquin R at Millerton[a]	DWRSIM (IN18)
Chowchilla R at Eastman	DWRSIM (IN53)
Fresno R at Hensley	DWRSIM (IN52)
Kings R at Pine Flat	USACE
Kaweah R at Kaweah	USACE
Tule R at Success	USACE
Kern R at Isabella	USACE

Metadata 8 – Surface reservoir targets

Location folder	Data files
Friant project\Other data\Surface Reservoirs	res targets.xls*

*file developed by Marc Leu

Metadata 9 – Friant Kern Canal Capacities

Location folder	Data files (paper document)
-	Friant Water Users Authority (1998) *Friant Kern Canal Structures List.*

Appendix A3 – Reference Manual

The model reference manual uses the same basic instructions presented in Leu (2001) for preparation and running the model, since no structural modification was introduced. One program to convert the .txt MODSIM output into HEC DSS format was developed and it is presented here, along with three post-processing EXCEL spreadsheets where DSS data can loaded for faster results interpretation.

Preparation for a FREDSIM Model Run

1. Input inflow data into the model using the interface and ADA directory. Data files in the ADA directory do not need to be in the same directory as model files.

2. Check that reservoir targets and evaporation, and water demand time-series data correspond with hydrologic time-series data. Make adjustments.

3. In the MODSIM interface change the Time Scale to monthly and set the number of years in the model run plus one.

4. Name the FREDSIM file (*.xy) the same root name as the Perl script (*.pl). Naming model runs is critical because MODSIM will overwrite any output data files with the same name.

5. Place MODSIM and Perl software files into the same directory as the *.xy, *.pl, and the IRRPARAM data file.

Steps for Running FREDSIM

1. Open a DOS window and change the directory on the command line to the current model's directory. The executable MODSIM file is MODCMD.exe.

2. The command for running is MODCMD followed by the file name without file extensions. For example: C:\MODCMD bcvp043

Output files are placed in the same directory as the software and input files and have the same root name as the model input files. All model output must be post-processed in a spreadsheet for high quality plots and other data analysis. The MODSIM interface can be opened after the model run and used for simple plots of model run results. The output files along with a brief description are listed below.

MODSIM Output Files

File Ext.	Output Data	Notes
*.acc	Link output	Flow data in links.
*.flo	Link output	Flow data in links with notation of constrained flow.
*.dem	Demand results	Demands, supplies, and shortage data.
*.res	Reservoir operation results	Water balance data for storage nodes.
*.gw	Groundwater results	FREDSIM does not use the groundwater capabilities of MODSIM, thus the *.gw file is not used. Groundwater reservoir results are output to the *.res file.
test2.txt	groundwater pumping cost, per groundwater zone, per irrigation district, per month	
test3.txt	groundwater carryover storage, per groundwater zone, per month	

All the output files (except of test2.txt and test3.txt) can be converted to HEC DSS format running the program MODSS_v04. Once converted to DSS, the data can be loaded into EXCEL spreadsheets for easier processing. Three processing templates were developed:

Template processing file	Description
Charts_template_v4.xls	This file reads data of head, storage and pumping cost from test2.txt. and test3.txt output files and create two charts for each GW zone: a Head &. Cost vs. time and a Head & Storage vs. time
Scost_template.xls	This file reads economic data from IRRPARAM file and water supply data from DSS output and calculates scarcity values and scarcity costs
Scarcity&Supply.xls	Sorts DSS output data loaded for each irrigation district.