Economics-Driven Simulation of the Friant Division of the Central Valley Project, California

BY

MARK RANDALL LEU
B.S. (Colorado School of Mines) 1993

THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in

CIVIL ENGINEERING

in the

OFFICE OF GRADUATE STUDIES

of the

UNIVERSITY OF CALIFORNIA

DAVIS

Approved:

Committee in Charge

2001

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

First, I thank Professor Jay R. Lund, my advisor and head of my thesis committee. He provided invaluable guidance and generously shared his knowledge in water resources engineering and systems modeling throughout the project. I would also like to thank committee members Professor Emeritus Gerald T. Orlob and Professor Miguel A. Mariño for reviewing my thesis drafts and providing useful comments.

I would like to thank Lenore Thomas and Nancy Parker of the Bureau of Reclamation for their initiation and support of this Friant modeling project. Numerous people at the Bureau of Reclamation Mid-Pacific Region office in Sacramento and the field office in Fresno provided operational information and data required for model development and I thank them as well. I would like to thank Marc Baldo at Colorado State University for providing technical support on the MODSIM model and writing the code required for model customization. I also thank Professor Lund's CALVIN modeling team for providing direction on the model approach, hydrologic data, and economic model results.

On a personal note, I want to thank my Davis friends who always provided good times and much needed stress relief throughout graduate school. I want to especially thank Joanna Fellos for her support and understanding. Lastly, this thesis would not have been possible without the guidance and support of my family.

ABSTRACT

An economics-driven simulation model of the Friant Division of the Central Valley Project in California has been developed for the U.S. Bureau of Reclamation, named FREDSIM (FRiant Economics-Driven SIMulation model). Ultimately, FREDSIM will provide a water management tool to simulate the water operations of irrigation districts within the Friant Division according to economic drivers, policy changes, facility changes, and varying hydrologic conditions. Water demands in this primarily agricultural project are met by several water sources, each with a different local availability, quantity, reliability, and cost. Agricultural economic value functions define the benefit of irrigating crops per unit of applied water. Changes investigated by FREDSIM could include increased water prices, tiered water pricing, changes in San Joaquin environmental flows, changes in upstream reservoir operations, changes in State Water Project water availability, and changes to reservoir operating rules. The preliminary model presented here produced interesting results despite its limitations and needs for refinement. FREDSIM demonstrates the concept of using economics to drive simulated water management decisions in the Friant Division on the irrigation district level. Additional model development and calibration are needed before FREDSIM is available for answering real policy and operations planning questions.

I. INTRODUCTION

The Friant Division, while mostly isolated from the rest of the Central Valley Project (CVP), is central to the functioning of California's water system, and thus has a prominent role in California water policy and management. By supplying San Joaquin River water to the Tulare Lake Basin, the Friant Division moved water south from historical riparian agricultural users on the San Joaquin River. These riparian users are, in turn, supplied with Sacramento-San Joaquin Delta (Delta) water via the Delta-Mendota Canal (DWR 1998). This trading of water provides for continued historical water economies and improved water quantity and quality for the almost hydrologically closed Tulare Lake Basin. The centrality of this San Joaquin River water and the continued thirst of Tulare Lake Basin agriculture make the Friant Division one of the most important features of California's water supply system.

The Central Valley Project Improvement Act of 1992 (CVPIA), contract negotiations with the U.S. Bureau of Reclamation (Reclamation), San Joaquin River restoration activities, Delta environmental issues, and growing urban populations statewide have led to significant changes and many proposed changes to water operations and policy within the Friant Division. These actual and proposed changes to the system have led to issues of water supply reliability, increased water costs, and groundwater overdraft.

The Friant Division is composed of Friant Dam and Millerton Lake on the San Joaquin River, the Friant-Kern Canal, and the Madera Canal serving the agricultural water needs of one million acres of the Tulare Lake and San Joaquin River Basins. On average, 1.4

million acre-feet per year are allocated to 28 long-term Friant contractors and seven Cross Valley Canal exchange contractors. While all Friant facilities are owned by Reclamation, the Friant-Kern and Madera Canals are operated by the Friant Water Users Authority (FWUA), a consortium of Friant contractors. Farmers within most contracting districts also use groundwater or other surface water supplies in some or all years to supply their irrigation demands. The Friant Division is the only CVP division developed for the conjunctive use of groundwater and surface water supplies. The emphasis on conjunctive use is reflected in the Friant pricing structure that encourages banking excess water in wet years in the ground for future withdrawal.

The importance of groundwater within the Friant Division led to several computer modeling efforts. The California Department of Water Resources (DWR) created the Hydrologic-Economic Model (HEM) in response to groundwater overdraft conditions within the San Joaquin Valley. The model simulated groundwater level fluctuation under various water management scenarios including surface water allocation and optimal agricultural production (DWR 1982). The Water Agencies of Kern County (1983) developed a model that focussed on Kern County groundwater to investigate water banking projects that could benefit water users in the southern portion of the Friant Division. Also in Kern County, DWR (1989; Andrews 1989) developed the Kern Conveyance Operations Model (KCOM) to plan the Kern Water Bank. A current modeling effort integrates surface and groundwater resources within the Tule River Basin (Ruud, et al. 1999). This GIS-based groundwater and land use model could evaluate proposed conjunctive use projects in the region, but does not include economic factors.

Recent economic studies have quantified the effects of surface water reductions within the San Joaquin Valley and the Friant Division. The economic impacts from land fallowing, reduced yields, as well as third-party impacts to the agricultural community were studied by the San Joaquin Valley Agriculture Industry after the last extended California drought peaking in 1992 (NEA 1993). The impacts of water reallocation to the eastern San Joaquin Valley due to the CVPIA were modeled by Brown, et al. (1996). This study applied the Central Valley Production Model (CVPM) to the Friant Division concluding that as surface water allocations decrease, groundwater use increases. Also, the eastern-most of the Friant water users will be affected first as local groundwater aquifers are shallow and unreliable, while all Friant users will become increasingly dependant on groundwater. The model also predicted that rising pumping costs associated with depleting groundwater storage would induce a shift to high value crops and some land fallowing (Brown, et al. 1996). This study was reviewed, modified and extended for the Friant Water Users Authority. The conclusions were similar, recognizing increased groundwater pumping as only a temporary solution to surface water reductions. The study emphasized that the economic effects of land fallowing may be small in comparison to the entire California economy, but the local economic consequences and third-party implications on local economies are substantial, especially for small communities (NEA 1997).

Friant farmers manage a multitude of crop types and several water sources for profitable farming operations. Given the multiple sources of water and the flexibility of operations, Reclamation has hypothesized that water operations within the Friant Division are based on economics, with farmers striving to maximize farm profits, yet many previous modeling efforts have neglected this objective of agricultural water operations. Due to the system's complexity, a computer model is required to simulate this behavior and quantify the water management and economic consequences of actual and potential Friant Division changes. FREDSIM, the FRiant Economics-Driven SIMulation model, has been developed to model contractor decisions according to the costs of Friant water, groundwater, and other surface water supplies and the economic losses of not meeting agricultural water demands. Ultimately, after further refinement, testing, and calibration, FREDSIM will be available to analyze the effect of changes in water policy or operations within the San Joaquin Basin or the Friant Division service area. This work demonstrates an economic-based network flow model for the Friant Division and specifies the need for model refinement.

This report is organized as follows. Friant Division background information is presented in Chapter 2, including development, infrastructure, operations, and influential water issues. Chapter 3 outlines the model objectives and the approach to meeting those objectives. All components of model development are provided in Chapter 4. Results of preliminary model runs are presented along with sample graphic output data in Chapter 5. The model's requirements for refinement are described in Chapter 6 with the conclusion. Appendices include acronyms, method details, and technical model information.

II. FRIANT DIVISION BACKGROUND

Historical Background of Irrigation in the Friant Service Area

Agricultural development in California's Central Valley began in the 1850's, with virtually no irrigation until 1870 (USACE 1933). Organized irrigation on the Eastside of the Tulare Lake and the San Joaquin Basins began in 1871 with the incorporation of the Kings River Canal and Irrigation Company. The U.S. Army Corps of Engineers (Corps of Engineers) investigated the prospects for expanded agricultural development in the Central Valley in 1873. Their investigation proposed a canal stretching from Summit Lake, west of Visalia, to the Lower San Joaquin River with inflows from the Kings, Kaweah, Tule, and Kern Rivers (USACE 1990).

By the 1920's groundwater pumping had increased greatly and overdraft conditions were reported in aquifers throughout the Tulare Lake Basin (CDEI 1922, 1927a). This initiated formal proposals for a canal running the length of the eastside of the basin from both the State of California and the Corps of Engineers (CDEI 1923; USACE 1933). A reservoir on the San Joaquin River near the town of Friant and a canal stretching to the town of Earlimart was proposed in California's Comprehensive Plan of 1927 (CDEI 1927b). The Corps of Engineers estimated the cost at $50 million (USACE 1933).

Development of the Central Valley Project's Friant Division

In 1936 the CVP was authorized by the Federal government and field surveys began on the Friant dam site. The U.S. Bureau of Reclamation settled water rights disputes downstream of the proposed Friant dam that year as well, paving the way for project construction. Friant Dam was constructed from 1939 to 1942 and first stored water in 1944. The Friant-Kern Canal and the Madera Canal were completed in 1949 and 1945, respectively. However, full operation of the Friant facilities could not occur until the completion of the Delta-Mendota Canal (DMC) in 1951, which allows for a necessary exchange of Sacramento-San Joaquin Delta water for the diverted San Joaquin water historically diverted by downstream users. The cost for building the Friant Division facilities and CVP facilities to meet exchange commitments totaled $146 million (USBR 1994).

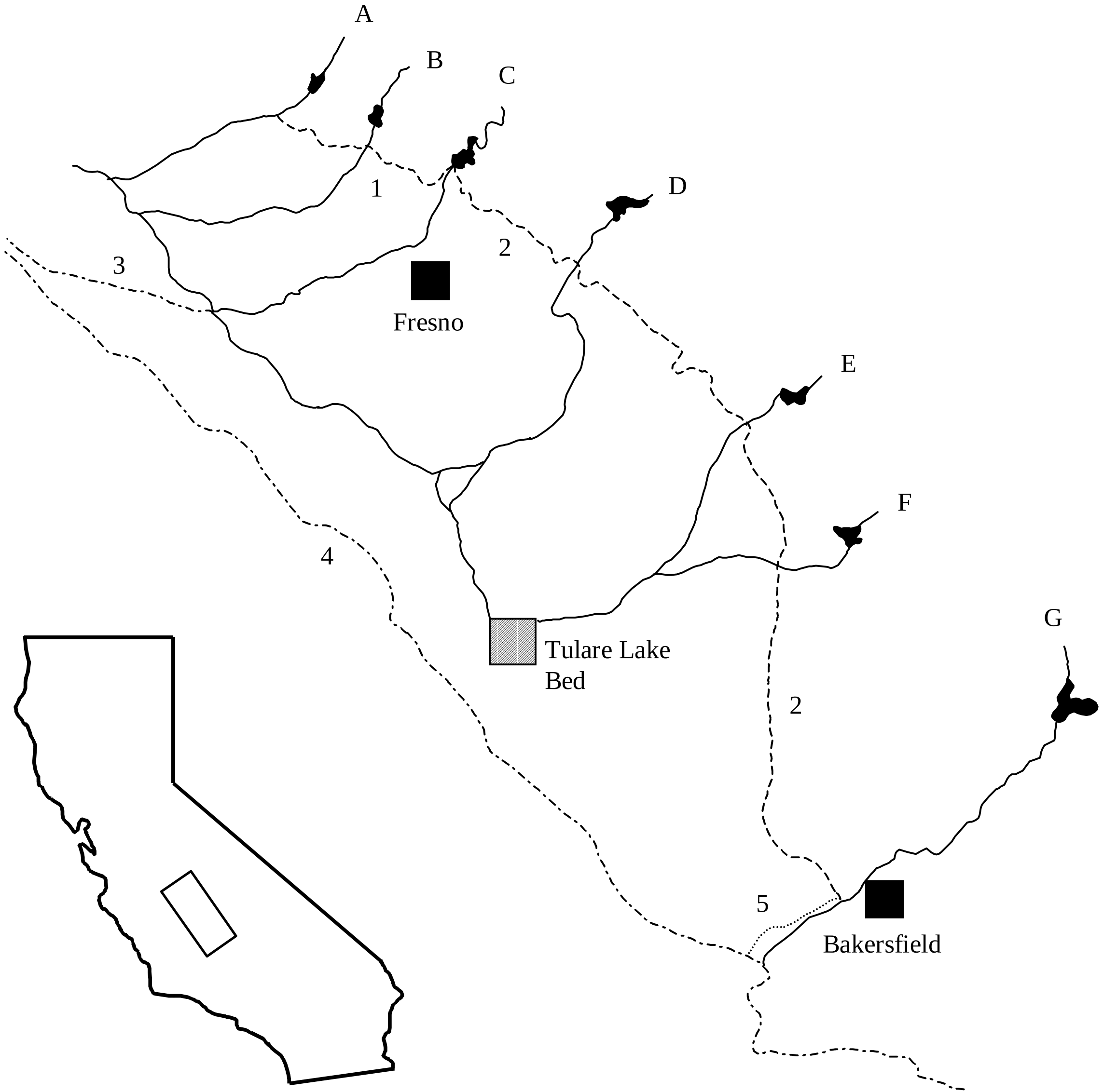
Friant Division Infrastructure

The major infrastructure of the Friant Division includes Friant Dam, which impounds the San Joaquin River just northeast of Fresno, California. The 319-foot dam forms Millerton Lake with a maximum capacity of 520,500 acre-feet. Millerton Lake is a multi-purpose facility with water conservation, flood control, and recreation as original authorized project uses. Maintaining environmental flows below Friant Dam was not an original objective of the Friant Division; however, implementing the CVPIA of 1992 may change this (USBR 1994).

The flood control requirements for Millerton Lake are to prevent flows from exceeding 8,000 cubic feet per second (cfs) below the dam or at Gravelly Ford and greatly reduce the allowable conservation storage in the reservoir. The Corps of Engineers developed a flood control diagram as authorized by Section 7 of the Flood Control Act of 1944 (USACE 1980). The diagram dictates the maximum conservation storage and flood control space allowed throughout the year. The top 170,000 acre-feet of Millerton Lake storage is reserved for fall and winter rain floods, while up to 390,000 acre-feet is reserved for spring snowmelt runoff. This conditional spring snowmelt space is a function of forecasted inflows to Millerton Lake, upstream storage space, and forecasted irrigation demand (USACE 1980). Millerton Lake is drawn down every fall to accommodate flood space requirements, thus providing very little opportunity to carry water over to the next water year (FWUA 1999).

Other than water released for flood control and riparian users, the entire flow of the upper San Joaquin River is diverted into the Madera Canal running to the north and the Friant-Kern Canal to the south. The 36-mile long Madera Canal has an initial capacity of 1,250 cfs and decreases to 625 cfs at its terminus at the Chowchilla River (USBR 1994). The Friant-Kern Canal, which runs along the eastside of the Tulare Lake Basin for 153 miles, has an initial capacity of 5,250 cfs at Friant Dam decreasing to 2,200 cfs when it discharges at the Kern River (USBR 1994; FWUA 1999). In wet winter months, the Friant-Kern Canal may be used for flood control purposes. Peak flows on the San Joaquin River or any other major river in the Friant service area can be diverted into the canal and released in another river with less flooding. These flood control operations occur only under extreme conditions to prevent flood damage on the San Joaquin River or in the historic Tulare Lake bed (Anderson 2000). In addition to the Reclamation facilities, there are numerous canal turnouts, countless miles of local conveyance facilities, and groundwater pumping and recharge facilities developed by the contracting irrigation districts. Figure 2.1 shows the Friant infrastructure with respect to the rest of California.

Figure 2.1: Vicinity Map: California and the Friant Division



Major Hydrologic and Conveyance Features	
A	Chowchilla River and Eastman Lake
B	Fresno River and Hensley Lake
C	San Joaquin River and Millerton Lake
D	Kings River and Pine Flat Lake
E	Kaweah River and Lake Kaweah
F	Tule River and Success Lake
G	Kern River and Isabella Lake
1	Madera Canal
2	Friant-Kern Canal
3	Delta-Mendota Canal
4	California Aqueduct
5	Cross Valley Canal

San Joaquin Basin and Friant Division Agriculture Background

The San Joaquin River watershed above Friant Dam drains 1,638 square miles of the Sierra-Nevada Mountains' west slope (USACE 1980). The San Joaquin River unimpaired runoff at Friant Dam is 1.7 million acre-feet on the average with 1.4 million acre-feet delivered to contractors on the Madera and Friant-Kern Canals (USBR 1991).

The one million acres within the Friant service area on the eastside of the Tulare and San Joaquin valleys have fertile soils, but are characterized by hot, dry summers. Annual precipitation in the Friant service area ranges from 6 to 11 inches with the majority of that in the form of winter rains (DWR 1998). The high Sierra-Nevada Mountains to the east average up to 60 inches of precipitation, much of which is stored as winter snow pack with runoff occurring in the spring (USACE 1980).

The Friant Division delivers water to over one million acres for agriculture from Chowchilla in the north to the Tehachapi Mountains in the south. Within the Friant service area are the nation's three top agricultural producing counties – Fresno, Tulare, and Kern. Madera County ranks number seven (USDA 2000). Friant contractors grow over 90 varieties of crops with the leading crops ranked by acreage in Table 2.1.

Table 2.1: Top Ten Friant Crops in 1996 by Acreage with Total Value

Crop Group	1996 Acres[a]	1996 Value[b]
Vineyard (table grapes and other grapes)	209,866	$750,684,000
Subtropical Orchard (grapefruit, lemons, limes, olives, oranges, tangerines, peaches, plums)	115,806	$511,832,000
Cotton	99,323	$100,470,000
Almonds	83,183	$230,140,000
Alfalfa	78,983	$69,673,000
Corn (field)	69,517	$36,098,000
Wheat	47,439	$20,077,000
Deciduous Orchard (apples, apricots, walnuts, pecans)	36,397	$131,745,000
Misc. Truck Crops (medium) (sweet corn, onion, beans, carrots, etc)	17,765	$42,446,000
Pasture	17,280	$175,000
Total for Top Ten	775,559	$1,893,340,000
Other Crops	35,437	$60,310,000
Total for all Crops	810,996	$1,953,650,000

a) Source: 1996 USBR Friant Crop Data.

b) Source: 1996 California County Agricultural Commissioners' Report Data. Note: The Friant crop value was calculated by averaging the value/acre for counties within or partly within the Friant service area (including non-Friant irrigation districts) and multiplying by the total Friant-only acreage.

Of the total Friant CVP contracts, 67,000 acre-feet are contracted to urban users (three percent of the total). There are 23 agricultural and five urban long-term Friant contractors (USBR 1991). In addition, eight entities (including one urban user) have exchange contracts for Friant water by delivering water to the Arvin-Edison Water Storage District via the Cross Valley Canal as described in a later section (FWUA 1999).

Friant Division Pricing Structure and Conjunctive Use

Like much of California and the arid West, San Joaquin River runoff at Friant varies widely between dry years and wet years ranging from 360,000 acre-feet in 1977 to 4,640,000 acre-feet in 1982 with an annual average of 1,730,000 acre-feet (FWUA 1999). In addition, Millerton Lake provides very little opportunity for carryover storage from year to year due to flood space requirements (USACE 1980). Therefore, the need for conjunctive use of surface water and groundwater within the Friant service area has been emphasized since the project’s conception in the 1930’s (CDEI 1927b; USACE 1933) and is reflected in the unique Friant pricing structure.

The CVP contracts of the Friant Division are divided into two classes. Class 1 water is the first 800,000 acre-feet available at Millerton Lake, which is considered the firm yield of the Friant project. The next 1,400,000 acre-feet is Class 2 water and only declared when inflow forecasts indicate that all Class 1 demands can be met. If the allocation for Class 1 or Class 2 is less than the full amount, each contractor’s allocation is reduced proportionally from their full entitlement. Forecasts of annual runoff are made beginning on March 1, which marks the beginning of the Friant Division water year. The forecast and allocation is updated monthly throughout the entire Friant water year, although it rarely changes after the snowmelt runoff in June or July. There is no obligation for contractors to take Friant water after it has been allocated. Contractor accounts are generally zeroed at the beginning of every water year in March, but there is a limited opportunity for carrying over water to the following water year. (Buelna 1999)

In wet years, runoff may exceed 2,200,000 acre-feet, the full allotment of Class 1 and Class 2. This excess water, or flood water, is classified as Section 215 water as named from Section 215 of the Reclamation Reform Act. Section 215 water is non-storable in Millerton Lake due to flood space requirements and can be used by non-Friant contractors. Section 215 water is usually declared as it flows into Millerton Lake during winter rain floods or spring snowmelt floods and is often declared in years with less than full Class 1 and Class 2 allocation in order to quickly evacuate water stored in the flood control storage pool. (Anderson 2000)

Historically, this two-class system with Section 215 water has allowed for managed conjunctive use and a successful, flexible project. Class 1 water is the most expensive water and is considered firm yield, although less than 800,000 acre-feet has been declared ten times since 1957 (USBR operations data 2000). Generally, Friant contractors with limited or no groundwater pumping facilities own Class 1 units giving them a reliable source of high quality water. Friant contractors with groundwater pumping and recharge facilities have a mix of Class 1 and Class 2 contracts. Since a full allocation of Class 2 water is not usually available, these contractors rely on groundwater pumping to meet their irrigation demands in many or most years. In average to wet years, excess Class 2 water is used to irrigate and to recharge the local groundwater aquifer. Essentially no local surface water storage facilities exist within individual Friant irrigation districts, but water is stored underground in wet years and withdrawn in future dry years or dry months in the current year. This stored water also can be transferred to Friant irrigation districts without groundwater facilities or those with dry local conditions. Years with abundant runoff result in a full declaration of Class 1 and Class 2 water and also Section 215 water. Historically, Section 215 water was nearly free and generally used for early season irrigation or groundwater recharge. This pricing system is unique to the CVP and has successfully facilitated the conjunctive use of surface water and groundwater resources (Vaux 1986).

A major concern of Friant contractors are escalating water prices and the threat of eliminating the two-class pricing scheme. As recent as 1989, Reclamation charged $3.50 and $1.50 per acre-foot for Class 1 and Class 2 water, respectively. Legislation in 1986 led to new operation and maintenance costs assessed to irrigators causing a fourfold increase in prices in 1989 (Moss 1998). However, the greatest impact on Friant water costs has been the passing of the CVPIA in 1992. The CVPIA mandated a Friant Surcharge and a Restoration Fund Charge added to regular water assessments resulting in a $14 increase per acre-foot delivered for Class 1, Class 2, and Section 215 water. Section 215 flood water prices are currently on the order of Class 2 prices, although Section 215 water used to be nearly free. This is gradually deteriorating conjunctive use operations within the Friant Division (Moss 1998). When the cost of recharging the groundwater aquifer for future extraction becomes greater than groundwater pumping alone, continued artificial recharge will be reduced or cease. Also, when Friant water is more expensive than groundwater pumping costs, a greater reliance on groundwater as the primary source of water will be created, thus accelerating groundwater overdraft problems in many parts of the Tulare and San Joaquin basins.

Reclamation and the Friant contractors are currently negotiating new 25-year contracts. Being considered is a proposal for tiered water pricing for the entire Central Valley Project as required by the CVPIA. Tiered pricing would eliminate the two-class system, but give each contractor a contract amount with two tiers. The first 80 percent of the contract quantity would be at one price, with the remaining 20 percent at a higher price

(CVPIA 1992). Tiered pricing is intended to promote water conservation; however, Friant Division contractors with access to groundwater and other surface water sources may see quite different results from such a pricing structure. Excess Class 2 or Section 215 water is currently less expensive than the firm Class 1 water. This less expensive water can be put into the ground (banked) for future use, but as Class 2 or Section 215 water becomes more expensive, banking excess water becomes less economical and will decrease. Water users will not pay high rates to bank water, thus relying on natural replenishment of the aquifer. As long as pumping costs are less than the combined cost of water purchase or artificial recharge and later withdrawal, there will be no artificial recharge increasing the rate of groundwater overdraft.

Friant Division Operations

All Friant operations, namely, the nearly full diversion of the San Joaquin River are made possible by an exchange of 840,000 acre-feet of Sacramento-San Joaquin Delta water for the water historically used by riparian users downstream on the San Joaquin River (FWUA 1999). The Delta-Mendota Canal (DMC) is the federal facility that conveys water from the Delta for this exchange to “Exchange Contractors”. Delta water diverted by the DMC originates as releases from the CVP’s Shasta Dam into the Sacramento River and is discharged to the San Joaquin River at the Mendota Pool. Over 20 agricultural water agencies divert water from Mendota Pool to meet their irrigation needs (DWR 1998). Releases are made from Friant Dam to meet the riparian agricultural demands between Friant Dam and Mendota Pool; however, no releases are made for instream environmental purposes (USBR 1994).

In addition to the unique conjunctive use operations of the Friant Division, Reclamation allows a transfer program within the Friant service area to further the flexibility of the system. Water transfers allow for water management that can “even out” local wet or dry conditions within the service area. Water banked in the ground in wet years can be transferred to districts without groundwater supplies. Historically, temporary transfers between Friant contractors have been unregulated. In January 2000, Reclamation announced a blanket approval for transfers within the Friant Division up to 150,000 acre-feet, recognizing the resulting system flexibility. The draft approval was outlined in an Environmental Assessment, Finding of No Significant Impact. The transfers must occur between Friant contractors or Friant contractors and the federal government to meet water deficiencies during a single irrigation season without the construction of new facilities for transferred water conveyance (USBR 2000a).

Historical alliances and other temporary agreements between contractors facilitate the transfer of water; however, documentation of water ownership versus delivery has been difficult and limited. Temporary transfers are for the most part unpredictable and triggered by local water availability and need. Some irritation districts with excess Friant water tend to always sell a portion each irrigation season. Generally, neighboring districts cooperate, thus recharging the local aquifer and benefiting both the buying and selling party (Anderson 2000).

Upper San Joaquin Reservoir Operations

In the Upper San Joaquin River above Friant Dam Southern California Edison and Pacific Gas and Electric (PG&E) have developed an extensive system of hydroelectric power plants and storage reservoirs totaling about 600,000 acre-feet. These reservoirs can significantly influence the routing of both rain and snowmelt floods (USACE 1980). Upstream reservoir operations are currently being investigated in a separate simulation model developed for Reclamation (Madeheim 2000). Table 2.2 lists basic reservoir information and capacities.

Table 2.2: Upper San Joaquin River Major Storage Facilities

Reservoir[a]	**Capacity (acre-feet)**	**Owner**	**Use**
Lake Thomas A. Edison	125,000	So. Cal. Edison	Hydropower
Florence Lake	64,400	So. Cal. Edison	Hydropower
Mammoth Pool	122,000	So. Cal. Edison	Hydropower[b]
Huntington Lake	89,000	So. Cal. Edison	Hydropower
Shaver Lake	135,300	So. Cal. Edison	Hydropower
Redinger Lake	26,100	So. Cal. Edison	Hydropower
Bass Lake	45,400	PG&E	Hydropower
Kerckhoff Lake	4,200	PG&E	Hydropower
Total	**611,400**		

a) Source: FWUA Waterline August 2000.
b) Note: Available storage in Mammoth Pool reduces the flood control storage requirements of Millerton Lake (USACE 1980).

Non-Friant Surface Water Sources

Eleven Friant contractors use Friant water as their sole source. Most contractors use groundwater and non-Friant surface water for irrigation as well. All sources of water used by Friant contractors have varied reliability, quantity and cost requiring careful consideration for every acre-foot applied to crops. Table 2.3 shows major storage facilities within the Tulare Lake and the San Joaquin River basins serving Friant contractors.

Table 2.3: Major Storage Facilities in the Friant Service Area

Reservoir	River	Owner	Avg. Annual Inflow[a] (acre-feet)	Capacity[b] (acre-feet)
Millerton Lake	San Joaquin	USBR	1,728,400	520,500
Eastman Lake	Chowchilla	USACE	74,300	150,000
Hensley Lake	Fresno	USACE	78,800	90,000
Pine Flat Lake	Kings	USACE	1,688,200	1,000,000
Kaweah Lake	Kaweah	USACE	385,400	150,000
Success Lake	Tule	USACE	144,100	82,000
Isabella Lake	Kern	USACE	705,800	570,000

a) Source: USBR 1991 Water Supply Report (1992).
b) Source: FWUA Informational Report (1999).

Cross Valley Canal Exchange

Since 1975 the locally financed Cross Valley Canal (CVC) has brought up to 128,300 acre-feet annually to the Friant service area from the California Aqueduct. An exchange agreement between the Arvin-Edison Water Storage District (AEWD) and eight water users allow for delivery of water diverted from the Delta via the California State Water Project (California Aqueduct) to AEWD via the CVC. The CVC exchangers may then divert similar amounts from the Friant-Kern Canal (FWUA 1999). The CVC exchange contractors are within the Friant service area, but were developed after all Friant water was contracted. Typical CVC exchangers have little or no access to other water supplies, yet they have permanent, high value crops. Recent reductions in Sacramento-San Joaquin Delta exports have reduced supply reliability to CVC exchangers (Moss 1998). In the wet 1999 water year, CVC exchangers were only able to take delivery of 30 percent of their allocated supplies due to federal action in the Delta (FWUA 2000a).

Friant Contractor Summary

Table 2.4 summarizes information on Friant long-term contractors and the Cross Valley Canal exchange contractors.

Table 2.4: Friant Contractors and Cross Valley Canal Exchangers

Contractor	**Model Name**	**Irrig. Acres[a]**	**Class 1 units**	**Class 2 units**	**Qmax (af/mo)[b]**	**Friant Facility[c]**	**Non-Friant Source**	**GW Facility[d]**
Arvin-Edison WSD	AEWD	129,340	40,000	311,675	46,792	FKC	Kern R.	P,R
Chowchilla WD	CHWD	63,637	55,000	160,000	39,007	MC	Chowchilla R	P,R
Delano-Earlimart ID	DEID	50,971	108,800	74,500	30,454	FKC	none	P,R
Exeter ID	EXID	12,670	11,500	19,000	11,857	FKC	none	P
Fresno Co. #18	FC18	0	150	0	40	SJ	none	--
Fresno County	FRCO	0	3,000	0	91	CVC	none	--
Fresno ID	FRID	160,097	3,000	75,000	53,611	FKC	Kings R	P,R
Fresno, City of	FRCY	0	60,000	0	40,197	SJ	none	P,R
Garfield WD	GAWD	1,375	3,500	0	755	FKC	none	--
Gravelly Ford WD	GFWD	8,498	0	14,000	3,678	SJ	Cottonwood	P,R
Hills Valley ID	HVID	3,353	2,146	0	3,825	CVC	none	P
International ID	INWD	627	1,200	0	503	FKC	none	--
Ivanhoe ID	IVID	10,514	7,700	7,900	2,983	FKC	Wutchumna	P
Kern-Tulare WD	KTWD	13,700	40,000	0	6,358	CVC	Kern R	P
Lewis Creek WD	LCWD	954	1,450	0	568	FKC	none	--
Lindmore ID	LIID	24,167	33,000	22,000	10,008	FKC	none	P,R
Lindsay, City of	LWSA	0	2,500	0	286	FKC	none	--
Lindsay-Strathmore ID	LSID	12,700	27,500	0	8,861	FKC	none	P
Lower Tule River ID	LTID	110,875	61,200	238,000	65,059	FKC	Tule R	P,R
Lower Tule River ID[e]	LTID	110,875	31,102	0	65,059	CVC	Tule R	P,R
Madera County	MACO	0	200	0	148	SJ	none	--
Madera ID	MAID	107,658	85,000	186,000	47,138	MC	Fresno R	P,R
Orange Cove ID	OCID	28,000	39,200	0	7,651	FKC	none	P
Orange Cove, City of	OCCY	0	1,400	0	6,494	FKC	none	--
Pixley ID	PXID	67,419	31,102	0	20,959	CVC	Tule R	P,R
Porterville ID	POID	13,250	16,000	30,000	3,979	FKC	Tule R	P,R
Rag Gulch WD	RGWD	5,171	13,300	0	7,442	CVC	none	P
Saucelito ID	SAID	17,702	21,200	32,800	9,877	FKC	none	P,R
Shafter-Wasco ID	SWID	32,504	50,000	39,600	18,894	FKC	none	P
So. San Joaquin MUD	SSMD	49,045	97,000	50,000	25,832	FKC	none	P,R
Stone Corral ID	SCID	5,163	10,000	0	2,072	FKC	none	P
Tea Pot Dome WD	TPWD	3,128	7,500	0	1,704	FKC	none	--
Terra Bella ID	TBID	10,068	29,000	0	4,739	FKC	none	P
Tri-Valley WD	TVWD	1,804	982	0	717	CVC	none	--
Tulare County	TUCO	10,431	3,000	0	500	CVC	none	--
Tulare ID	TUID	75,582	30,000	141,000	45,231	FKC	Kaweah R	P,R

a) 1996 irrigated acreage from the USBR Water Needs Assessment (2000b).
b) Maximum monthly capacity based on historical maximum delivery.
c) Facility abbreviations: MC = Madera Canal; FKC = Friant-Kern Canal; SJ = San Joaquin River; CVC = Cross Valley Canal by exchange.
d) Groundwater abbreviations: P = pumping; R = artificial recharge.
e) Lower Tule River Irrigation District is both a long-term Friant contractor and a CVC exchanger.

Friant Division Water Issues

Since full development of the Friant Division's irrigated acreage, project operations remained fairly constant for over 25 years. However, recent national and state water issues have affected the Friant Division's water operation and management decisions. Most of the issues are due to increased public environmental awareness and resulting laws, over-reliance on groundwater, and growing urban areas. All water issues facing the Friant Division potentially result in new policies, contracts, operations, or other changes that could alter the delivery of reliable irrigation water. These changes have economic consequences that should be considered prior to implementation.

Central Valley Project Improvement Act

One of the most influential events affecting the Friant Division was the passing of the Central Valley Project Improvement Act (CVPIA) in 1992. The CVPIA intended to elevate environmental issues to the same level as other project purposes such as irrigation, drinking water, and hydropower (FWUA Waterline April 2000). The CVPIA amended previous authorizations of the Central Valley Project to include fish and wildlife protections, restoration, and mitigation. Specific provisions of the CVPIA affecting the Friant Division are tiered water pricing, renewal of long-term contracts, and the development of a comprehensive plan for San Joaquin River restoration (CVPIA 1992). The passing of the Act required a programmatic environmental impact statement (PEIS) that was published in October of 1999 (CVPIA-PEIS 1999).

Water pricing reform is a major aspect of the CVPIA, requiring a tiered system that differs greatly from the Friant Division's established two-class system of pricing. The inverted block rate structure has a first tier, the first 80 percent of the contract total, at the applicable contract price. The next 10 percent is priced at a rate between contract rate and the full cost rate. The remaining 10 percent is priced at the full cost rate (CVPIA 1992). This tiered pricing is essentially opposite of the Friant pricing structure in which the price decreases with greater water availability and thus, encouraged groundwater banking in wet years. An increasing rate tiered system may be too costly for groundwater banking and conjunctive use operations (FWUA 2000a).

The CVPIA also mandates that all long-term contracts with Reclamation will be for 25-year terms, rather than the original 40-year terms (CVPIA 1999). Contractors have voiced concerns that the new provisions do not guarantee successive 25-year term contracts in the future (FWUA 1998). Uncertainty for future contracts has caused some alarm among agricultural lenders and appraisers (FWUA 2000a). Friant contractors and Reclamation are currently negotiating long term contracts to replace their expired original 40-year contracts. A series of interim contracts were required until Reclamation released the CVPIA's Final PEIS in December, 1999, thus initiating long-term contract negotiations (FWUA 2000a).

The CVPIA also established an Environmental Restoration Fund for habitat restoration, improvement, and acquisitions. All CVP agricultural users must pay $7 per acre-foot in addition to regular water assessments. The fund intends to ensure that by the year 2002, natural production of anadromous fish in Central Valley rivers and streams will be sustainable (CVPIA 1992).

Furthermore, the CVPIA requires establishing a comprehensive plan to address fish, wildlife, and habitat concerns specifically on the San Joaquin River from Friant Dam to the confluence with the Sacramento-San Joaquin Delta. Implementation of the plan will require another Act of Congress and no releases made from Friant Dam for river restoration will be required until authorization is made. To finance the San Joaquin River restoration plans, the CVPIA adds a $7 per acre-foot surcharge to Friant contractors establishing the Friant Restoration Fund. This is in addition to the Environmental Restoration Fund surcharge for all CVP users (CVPIA 1992). Since 1992, Friant contractors have paid $800,000 to $1.5 million per year to the Environmental Restoration Fund and the Friant Restoration Fund. Increasing Friant water costs are said to lead to a greater reliance on groundwater pumping despite the already declining levels (FWUA Waterline January 1998).

San Joaquin River Restoration

Maintaining instream flows for environmental purposes was not authorized originally as part of the Friant Division resulting in a damaged riparian habitat. In 1988 the Natural Resources Defense Council (NRDC) filed suit in U.S. District Court seeking an injunction to prevent the USBR from renewing long-term contracts for the Friant Division. The suit claimed that releases had to be made from Friant Dam for instream uses based on California's Fish and Game Code and the public trust doctrine. The court ruled that the Reclamation had indeed violated Section 7 of the Endangered Species Act when it renewed 14 Friant contracts without consulting the U.S. Fish and Wildlife Service and declared the contracts void. In 1998 the litigation settlement negotiations resulted in a cooperative agreement between the FWUA, NRDC, and the Pacific Coast Federation of Fisherman's Associations to pursue mutually acceptable restoration activities on the San Joaquin River. (DWR 1998)

The current San Joaquin River restoration study proposes to enhance riparian habitat without adversely affecting Friant water users' water reliability and cost. The focus of the study will be to establish a healthy and sustainable riverine ecosystem between Friant Dan and the confluence with the Merced River and also develop water supply alternatives to provide instream flows. (FWUA Waterline April 2000)

The cooperative effort has resulted in pilot projects to provide environmental flows below Friant Dam in the dry months of July through September in 1999 and 2000. These projects utilized flows banked from the previous winter. The 1999 project was the first time in project history that river releases were made for a purpose other than flood control or irrigation. Both pilot projects resulted in riparian vegetation seed spreading and biological and hydrologic data collection. (FWUA Waterline July 2000)

Groundwater Overdraft

The eastside of the Tulare Lake Basin and the San Joaquin Basin have experienced groundwater depletion exceeding replenishment since widespread pumping began for irrigation. The problem was initially documented in 1922 in a California Division of Engineering and Irrigation report (CDEI 1922). This condition was caused in part by California's lack of groundwater pumping regulation, which continues today throughout most of the state.

Despite the success of the Friant Division as a conjunctive use project, groundwater overdraft continues to exist throughout much of the service area. DWR forecasts groundwater overdraft in the Tulare Lake Basin to be 820,000 acre-feet in an average water year under 1995 development levels (DWR 1998). Artificial recharge projects and natural replenishment have been insufficient to maintain groundwater levels. The condition may worsen as the cost of Friant water increases and farmers can pump groundwater at a cost less than their federal contracted supplies. Increased pumping is only a temporary solution since levels will continue to drop without artificial recharge or a reduction in pumping.

Sacramento-San Joaquin Delta and CALFED

CALFED is a state-federal program initiated in 1994 to plan and implement solutions to the Sacramento-San Joaquin Delta's water quality, water supply, infrastructure, and environmental problems. CALFED released a broad seven-year program in June 2000 that lists a number of projects and programs (CALFED 2000).

Among the proposed solutions was developing surface water storage to capture peak flows during times of excess for water supply, water quality, operational flexibility, and to enhance environmental flows for fish restoration. The CALFED plan proposes to initiate a detailed feasibility study beginning in the year 2001 on the enlargement of Friant Dam (CALFED 2000). Reclamation has proposed to CALFED to raise Friant Dam 144 feet to increase capacity from 520,500 acre-feet to 1.2 million acre-feet. There have been many proposals to enlarge Millerton Lake since it was operational in 1940, yet no detailed feasibility studies have been completed to date (FWUA Waterline May 2000). The plan also seeks to expand conjunctive use projects in the San Joaquin Valley totaling up to one million acre-feet over the next seven years (CALFED 2000).

Transfers Out of the Friant Service Area

Transferring water from the agricultural sector to growing cities of California is often proposed to meet urban water demands. Federal and irrigation district regulations prevent direct transfer of Friant water out of the Friant service area. However, some recent proposals and agreements have involved the transfer of water banked in the ground in wet years within the Friant service area to urban areas.

One proposal is a groundwater banking project on the Madera Ranch southwest of the town of Madera. The project was investigated by Reclamation as a means to supply water for Delta diversions or possible environmental uses (FWUA Waterline April 1999). Reclamation has ended its pursuit of the project, but a private water company continues to pursue project development. A recent proposal calls for pumping excess water in winter months from the San Joaquin River to recharge basins on the ranch site. The banked water could be withdrawn and sold to farmers and water districts. (FWUA Waterline February 2000)

Another transfer agreement is in place between the Arvin Edison Water Storage District (AEWD) and the Metropolitan Water District of Southern California (MWD). This agreement involves the transfer of water stored underground by AEWD and delivered to MWD through a newly constructed pipeline connecting to the California Aqueduct. The agreement allows for the transfer of up to 150,000 acre-feet of San Joaquin River flood water stored in the ground to MWD in a 25-year period. (FWUA Waterline January 1998)

III. MODEL OBJECTIVES AND APPROACH

The water issues facing the Friant Division will be addressed with a combination of new contracts, operational policies, water supply projects, and conjunctive use projects. Such proposals need analytical tools to more rapidly and reliably eliminate poor alternatives, predict the reaction of water users to changing conditions, develop or negotiate promising alternatives, and quantify economic consequences.

FREDSIM is the FRiant Economics-Driven SIMulation model developed for the Bureau of Reclamation. The model is in preliminary form, but demonstrates the concept of simulating Friant Division water management operations according to economic drivers. Economic drivers are the costs of Friant water, groundwater, and other surface water supplies in addition to the agricultural economic values for water that quantify the benefits of making irrigation deliveries.

Steps of Developing the FREDSIM Model

The FREDSIM model was developed to meet the following objectives:

1. Develop an accurate schematic of the Friant Division’s physical system and contractors.
2. Organize and collect hydrologic and capacity data required for the model.
3. Develop economic benefit functions for agricultural water demands at the water district level.
4. Set up a running simulation model with a monthly time-step.
5. Demonstrate the concept of simulating Friant water operations with economic drivers.
6. Recommend model refinements.

Significant model refinements will be needed before FREDSIM is ready for operational planning and policy evaluation purposes.

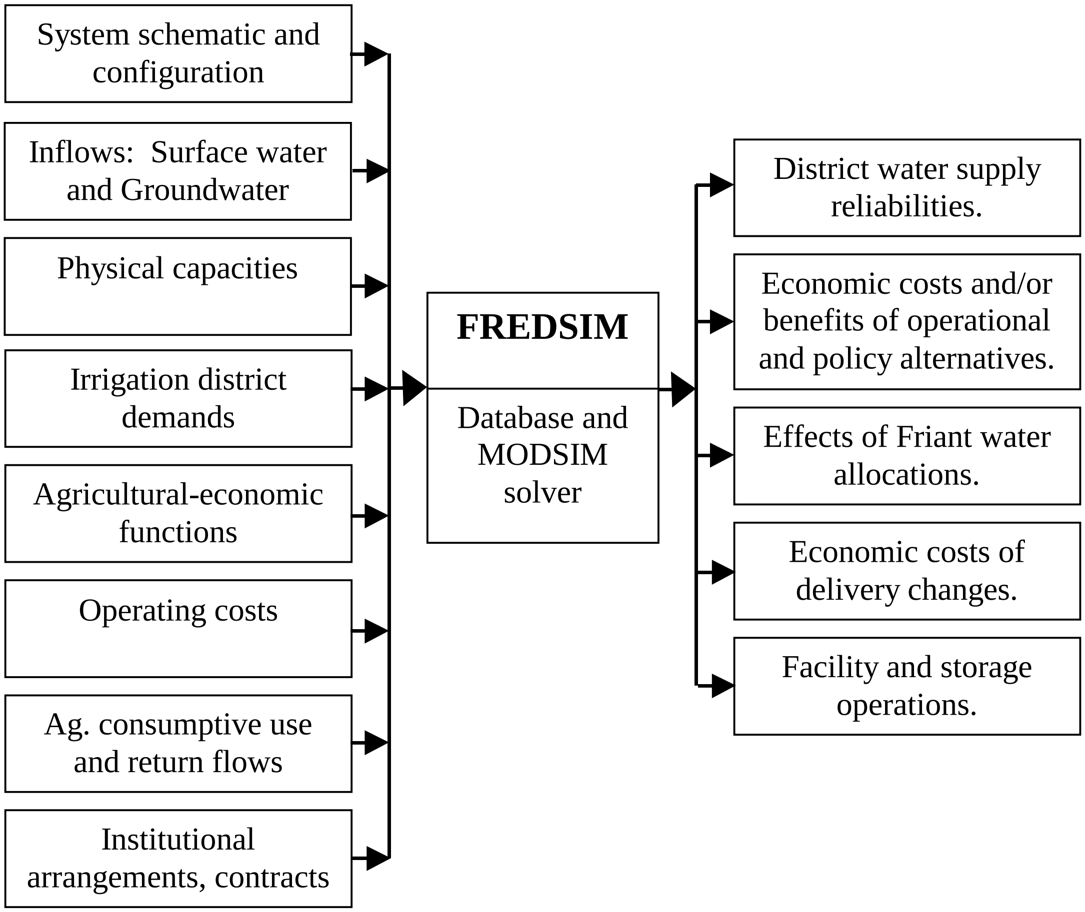
Model Approach

FREDSIM is a capacitated network flow model with an economic objective function that seeks to minimize the total economic cost of delivering water and meeting water demands at each time-step. Generally, the network consists of storage nodes representing surface water and groundwater reservoirs; non-storage nodes representing junctions, demand locations, points of diversion or inflow; and links representing water conveyance paths to connect all the nodes. Unit costs (or benefits) are placed on the links along with upper and lower bounds. Links also may represent non-physical water conveyance to simulate contractual accounting or agricultural economic benefit functions. Mass balance is achieved at every node for every time-step.

Input to the model begins with a representation of the physical system, including surface and groundwater storage reservoirs, canals, pipelines, groundwater pumps, and turnouts with their capacities. Hydrologic inputs include reservoir inflows and average evaporation rates on a monthly time-step. Average monthly demands were established for every contractor along with irrigation return flows. Another critical input to the simulation model are surface water reservoir storage goals or targets. Often these targets drive system operations and are commonly used in simulation models for system calibration. The model may also have targets that vary according to hydrologic conditions. Lastly, the intricacies of the Friant contracts are represented. The inputs are organized in a database and documented with sources, contacts, and data reliability.

Outputs of FREDSIM will ultimately quantify the agricultural economic consequences to changes affecting the Friant Division such as operational and policy alternatives, Friant water allocations, and any changes to the delivery of irrigation water. FREDSIM will also calculate irrigation district water supply reliabilities under varied hydrologic conditions. Initially, output of FREDSIM will point out the need for additional data and better understanding of many critical operational aspects of the Friant Division. The entire FREDSIM approach is outlined in Figure 3.1.

Figure 3.1: Model Approach Flowchart



FREDSIM Solver

The solver for FREDSIM is MODSIM, a generic water resources simulation package that operates on a personal computer within a Windows environment. MODSIM was developed by Colorado State University and has been applied to water resources systems in many parts of the world and several other Reclamation projects (Labadie 1994). Reclamation chose to utilize MODSIM to model the Friant Division for its flexibility, functionality, and prior success in modeling complex river basins.

MODSIM Overview

MODSIM is a network flow simulation model that employs optimization techniques to represent water management decisions at each sequential time-step in an efficient manner (Fredricks, et al. 1998). Typically, MODSIM minimizes the sum of penalties which represent water operation and allocation priorities. For FREDSIM, the quasi-optimization model will minimize the actual total economic cost while maintaining mass balance and adhering to user-specified reservoir targets and physical constraints. The model uses integer-based Lagrangian Relaxation Theory to perform iterations and converge on the optimal solution faster than real number calculations and matrix-based operations (Labadie 1994).

Technically, MODSIM is an optimization model for each individual time-step, however, it does not optimize across time-steps except perhaps in relation to penalty functions (or targets) for storage, and thus behaves without any foresight as would a simulation model. The model assumes that the decision makers have perfect information on flows and demands at each location at each time. For a monthly planning-level model, this assumption is not unreasonable.

The model has a graphical user interface with pull-down menus, toolbars, and detailed spreadsheets for inputting and editing parameters for demands, links, and reservoirs. A drawing space allows for the creation of the water system network that can also be geo-referenced. The interface also allows for user-defined output graph generation (Baldo 1995, Labadie 1997).

MODSIM Applications

Reclamation successfully used MODSIM to model complex river and reservoir operations on the Boise River and the Upper Snake River in Idaho. The models simulate complex, priority-based networks with river accretions and depletions while managing reservoir accounts (Baca 1999; Frevert, et al. 1994). In another application, the City of Fort Collins, Colorado used MODSIM as a decision support tool to maximize annual water supply yield from existing and proposed river diversions and storage rights within a basin with an appropriative water law framework (Labadie, et al. 1986). MODSIM was linked to MODFLOW, the U.S. Geological Survey’s three-dimensional finite-difference groundwater model, to model stream-aquifer interactions and conjunctive use operations within a priority-based basin (Fredricks, et al. 1998).

Economics-Driven Water Management Simulation

The FREDSIM application of MODSIM takes a different approach in simulating water supply allocation. FREDSIM uses agricultural economic benefit functions rather than single costs that reflect the strict priorities of a system. In a true priority system, the full demand of senior water users is met before the demand of junior water users. FREDSIM uses economic functions that relate applied water to actual average agricultural economic benefit on a monthly basis. In water-short years, water supply will be allocated to meet demands of high value crops before low value crops.

The economic value functions also imply crop types within an irrigation district. In water-short years, crop type decisions are implicitly deduced from water delivered at less than full demand. (I.e., irrigation districts will not irrigate low value crops such as pasture or alfalfa and will meet the demands of higher value crops such as orchards). This economic means of allocating water is appropriate in the Friant Division which has both a long history of unregulated temporary transfers within the service area and conjunctive use operations to meet shortages and use water that has been banked underground in prior wet years.

In addition to the benefits of applied agricultural water, the model considers the cost of all sources of water. Each class of Friant water has a different cost (Class 1, Class 2 and Section 215 water). Groundwater pumping costs are considered as well as the cost of non-Friant surface water. The network is solved by MODSIM so all costs plus losses of agricultural production are minimized as water delivery and supply decisions are made. As cost and/or quantity of water supplies change or crop type and acreage change, so do the water supply decisions of the Friant contractors.

Economics-driven water supply modeling was applied to the vast inter-tied water supply system of California (Howitt, et al. 1999). The recently developed optimization model, CALVIN (California Value Integrated Network), allocates water to maximize statewide economic performance while ignoring specific operating rules and water contracts. The model uses operating costs and economic value functions for both urban and agricultural water deliveries (Howitt, et al. 1999). FREDSIM similarly uses economic drivers, but has a detailed water contract representation and only optimizes per time-step. CALVIN is an optimization model, currently with perfect foresight, that finds the optimal solution for the model’s entire time horizon.

IV. MODEL DEVELOPMENT

The FREDSIM development process involved collecting historic data, operations data, physical system data, contractual data, and results from independent groundwater and agricultural-economic models. Data was organized and input in MODSIM. Customization of MODSIM using compatible programming code was developed to represent details of Friant contracts and agricultural economic value functions. The result is a preliminary form of FREDSIM that is available to demonstrate the concept of economics-driven water supply simulation of the Friant Division.

Development of FREDSIM began with an understanding of the physical system layout and connectivity. For the most part, the model schematic represents real storage nodes, junction nodes, and conveyance facilities. Simplifications were made, modeling demands at the district level, rather than individual farms. All canal turnouts, groundwater pumps, and recharge facilities were aggregated into one per contractor. Collection of readily available hydrologic data and reservoir physical data, mostly from recent modeling efforts (CALVIN, Howitt, et al. 1999) was the next step. Another critical aspect of model development was understanding the operation of Friant facilities. Meetings with Reclamation personnel involved with operations or contracts was part of the information gathering process (Buelna 1999, Anderson 2000). Model development also incorporated information from the Water Needs Assessment, prepared by Reclamation as the part of the contract renewal process. The assessment outlined typical agricultural demands for current irrigated acreage and the typical mix of water supplies for most Friant contractors (USBR 2000b).

As described in Chapter 2, the Friant Division is in a period of change. FREDSIM as presented utilized the best data and information available according to current operations. This chapter summarizes the development of all FREDSIM components.

Friant Division Physical System and Schematic

The physical system layout was determined by using the FWUA Informational Report (1999), FWUA Structures List Report (1998), regional GIS maps with irrigation districts boundaries and surface water features provided by Reclamation. The daily operations schedule from the Fresno field office listed mile markers for all the turnouts on the Friant-Kern Canal. Capacities of Reclamation canals were determined from operational data (e.g. maximum recorded flows in conveyance reaches).

The Friant schematic is a graphical representation of the physical system. The schematic is not drawn to scale, but represents the geographical layout of canals, reservoir and irrigation districts, and urban areas. The schematic has been reviewed by USBR personnel and has had limited review by the FWUA. The schematic represents to the best of current information the actual Friant system. The most notable simplification is the aggregation of surface water turnouts and groundwater pumps into single water withdrawal points for each modeled demand. The system represents seven surface water reservoirs, seven representative groundwater reservoirs, 35 demands, seven river sinks (demands), one San Joaquin River minimum flow demand, and fourteen water inflow locations. The schematic in Figure 4.1a and 4.1b shows the physical system network and roughly follows the geographical layout of project features. For simplicity, links and nodes required to model irrigation return flows, Friant accounting, and agricultural value functions are not shown on this schematic. Refer to the detailed demand schematic, Figure 4.4, for all components of a single agricultural demand.

Figure 4.1a: Friant Division System Schematic

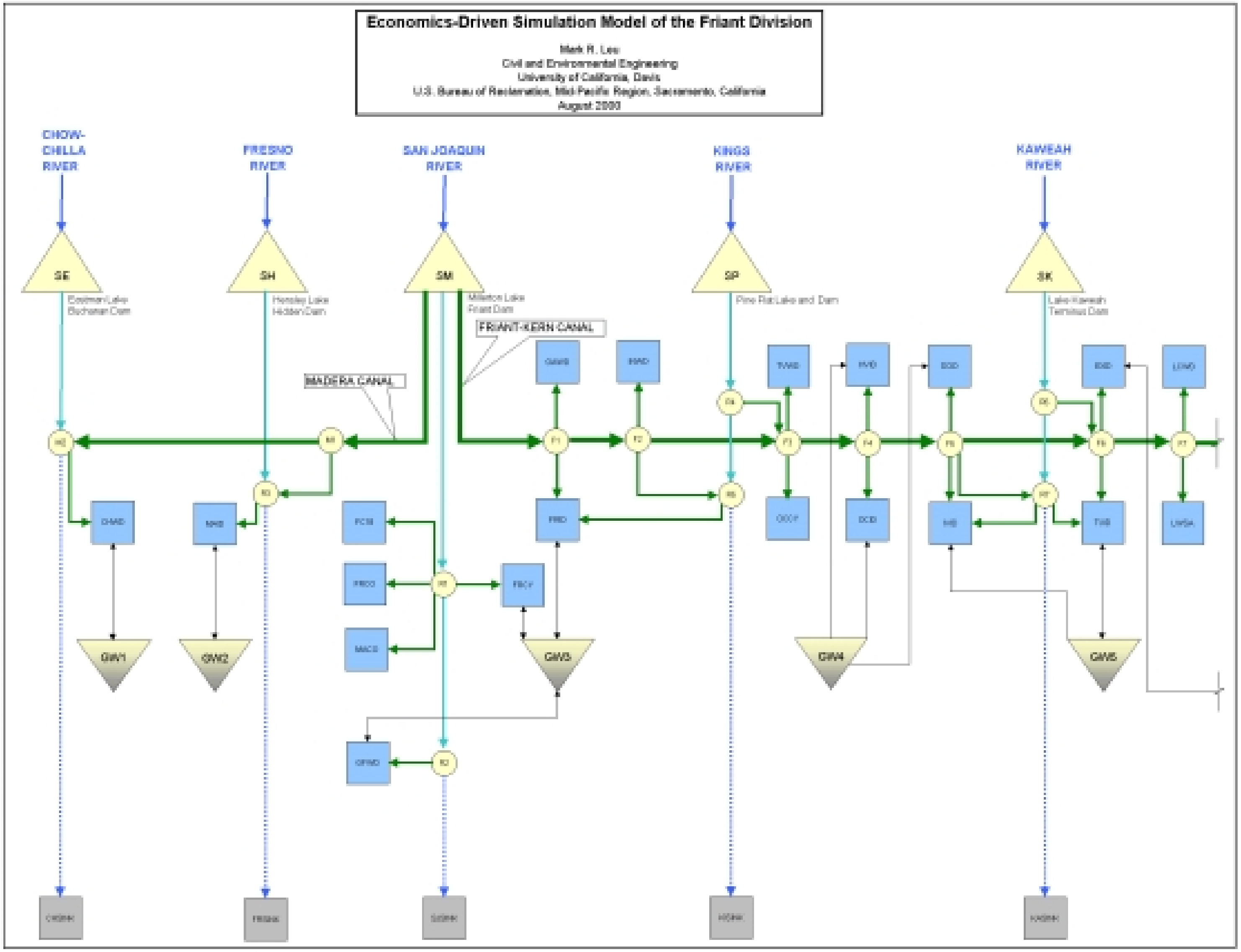
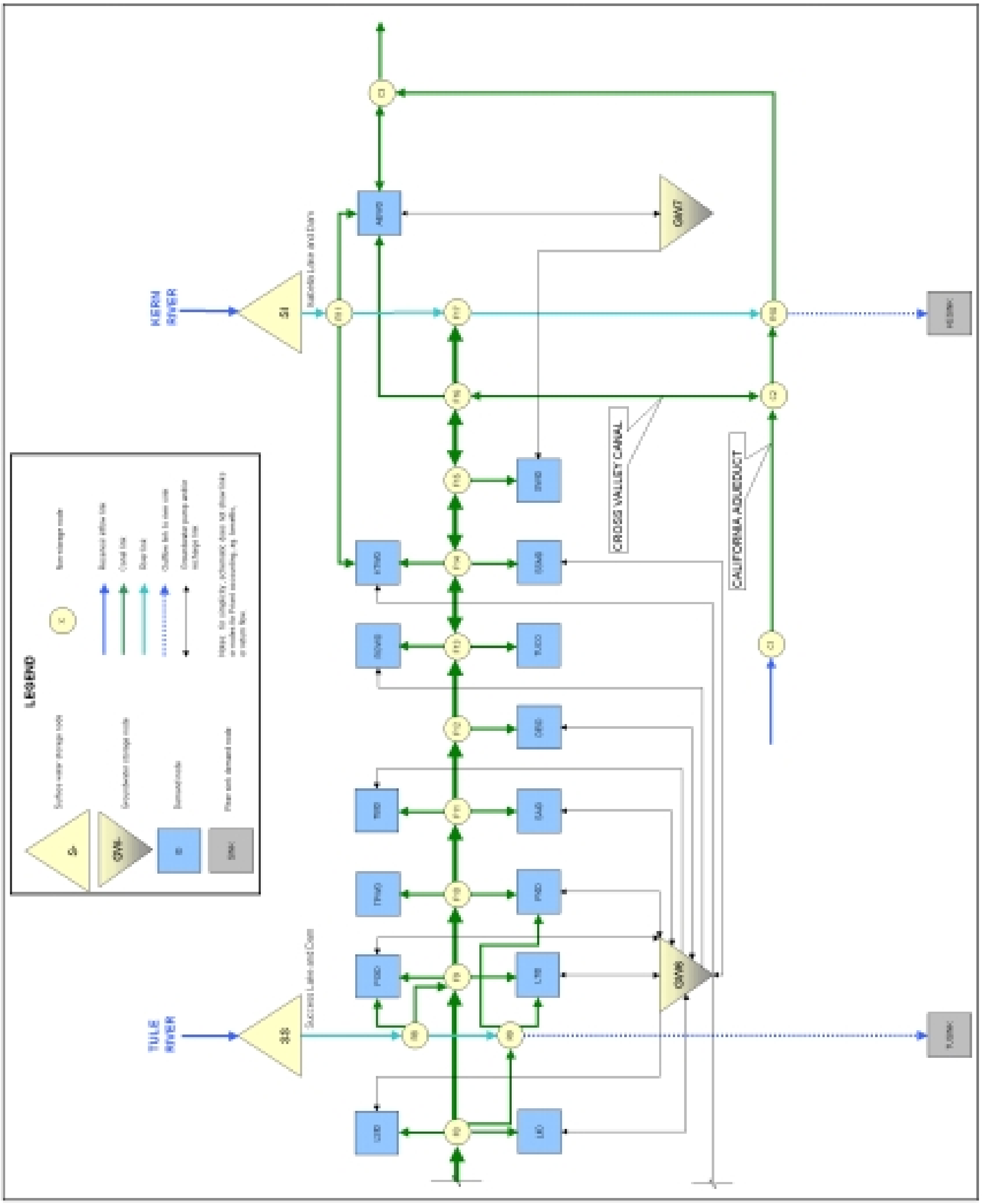


Figure 4.1b: Friant Division System Schematic (continued)

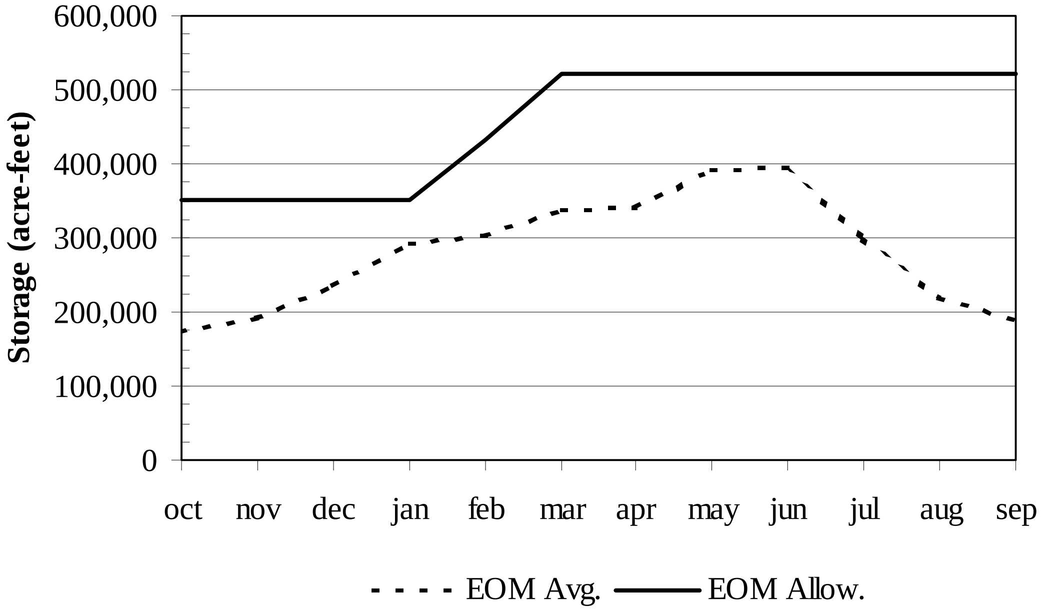


Reservoir Data and Operations

Basic surface water reservoir data was obtained from Reclamation operational data and the USACE reservoir regulation manuals. Average monthly reservoir evaporation, and reservoir elevation-capacity-surface area data was organized from a previous modeling project, CALVIN (Howitt, et al. 1999) for use in FREDSIM. Flood control requirements for all reservoirs were obtained from USACE reservoir regulation manuals. Monthly reservoir targets are based on maximum allowable storage according to physical reservoir constraints and flood control requirements. Carryover storage in Millerton Lake is not modeled in this version of FREDSIM. The rules are complex and the potential is quite limited due to flood storage space requirements. Currently, FREDSIM zeroes all contractor water accounts at the beginning of every water year.

The flood control diagram as prescribed by the Corps of Engineers requires 170,000 acre-feet of space for fall and winter floods. In addition, the diagram has provisions for conditional space during the spring snowmelt of up to 390,000 acre-feet (USACE 1980). Reclamation operational data suggest that Millerton is operated to go into the irrigation season with a full reservoir. When the water is available, every effort is made to fill Millerton at the end of May, June, and July (Buelna 1999). This version of FREDSIM will ignore the conditional snowmelt flood space requirement. Figure 4.2 shows average end-of-month (EOM) reservoir operations and the allowable storage not considering conditional space (USACE 1980).

Figure 4.2: Millerton Lake Storage 1986-1997



Hydrologic Data

FREDSIM makes use of hydrologic data from other modeling efforts such as California Department of Resources' DWRSIM and the Central Valley Groundwater and Surface Water Model (CVGSM) developed for the CVPIA-PEIS. These data were organized by another recent model, CALVIN (Howitt, et al. 1999). Table 4.1 summarizes inflow data sources.

Table 4.1: Inflows and Data Sources

Inflow	Data 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
GW1[b]	CVGSM region 13
GW2	CVGSM region 13
GW3	CVGSM region 16
GW4	CVGSM region 17
GW5	CVGSM region 18
GW6	CVGSM region 18 & 20
GW7	CVGSM region 20 & 21

a) See Howitt, et al, Appendix I (1999) for detailed surface water hydrology used in CALVIN.

b) The groundwater inflow data is derived from CVPIA-PEIS, No Action Alternative model run (USDOI 1997). FREDSIM groundwater inflows are CVGSM regional inflows factored according to approximated areas.

Groundwater

The groundwater resources of the Friant service area are modeled, though somewhat crudely, in the current version of FREDSIM. The components modeled are groundwater storage, natural inflows, pumping, irrigation return flows, and artificial recharge.

FREDSIM uses CVGSM regional irrigation efficiencies with all return flows to the groundwater aquifers. Regional inflows were adjusted for FREDSIM’s aquifer representation, with aquifers roughly corresponding to surface water basins within the Friant service area. All groundwater depletions, return flows, and recharge occur without lag. There is no representation of groundwater-streamflow interaction in FREDSIM.

The FREDSIM aquifers are modeled as simple surface water reservoirs, except with an enormous capacity and no evaporation or flood control space requirements. This approach omits interflows between groundwater basins. The capacity of groundwater reservoirs is arbitrarily set at nine million acre-feet with an initial storage of seven million acre-feet. These capacities were chosen to prevent emptying or filling for the model's time horizon.

Groundwater pumps are generally owned and operated by individual farmers in the Friant Division without regulation or data collection. The aggregated annual pumping capacity was taken from the estimates in the Water Needs Assessment (USBR 2000b) for a typical year and divided by four. This reasonable approach to approximating monthly capacity considers that pumping the annual total in a month is unrealistic, but perhaps the annual total could be pumped over the summer months. Pumping cost derivation is described below in the Water Pricing section.

Artificial (or intentional) recharge is allowed only in winter months for this preliminary model as the capacity of the recharge link is zero from April through November. Capacity of recharge facilities is based on annual typical operations provided in the Water Needs Assessment (USBR 2000b) divided by four (assuming four months of full-capacity recharge utilization per year). Artificial recharge nodes are the same as water demand nodes, but with 100 percent return flow to the groundwater reservoir. A contractor's recharge water comes from the same possible sources as irrigation water, thus incorporating the same conveyance capacities, contractual limits, and water prices.

A benefit is placed on the recharge link (see demand diagram Figure 4.4) to encourage groundwater recharge when it is available and inexpensive. The fictitious benefit of recharging must be less than the cost of groundwater pumping to avoid having FREDSIM pump for the sake of recharging. FREDSIM places a value on intentional, artificial recharge (winter ditch filling, recharge ponds), but not on regular irrigation return flows and incidental recharge (conveyance losses). FREDSIM only considers intentional recharge operations of contractors exceeding 20,000 acre-feet in a typical year.

Dynamic groundwater table levels, which could be derived from a physically-based groundwater model, are not modeled in FREDSIM. Therefore, pumping costs which are a function of pumping head do not change over time with FREDSIM. The pumping cost could change annually if a correlation between groundwater storage and pumping cost could be made in future model refinement.

Irrigation District Information

The contractor information organized and used for the development of FREDSIM originated from numerous sources. Reclamation provided contract information, GIS maps of irrigation districts and water districts, historical use data, and infrastructure information. The USBR Water Supply Report of 1991, the most recently published, provided historical annual summary data for all contractor water use. A useful information source for Friant contractor water supplies was the USBR Water Needs Assessment (2000). The assessment included “typical year” (1996) irrigated acreage and corresponding crop water demand adjusted for precipitation. The assessment included the contractors' annual local and Friant sources of water and estimates of groundwater pumping and artificial recharge. Discussions with Reclamation personnel in the Fresno field office also provided general information on irrigation district operations.

The Friant Water Users Authority provided the Informational Report and the Friant-Kern Canal Structures List to assist with understanding the system. *Waterline*, the monthly FWUA newsletter, was also used for general contractor information.

Agricultural Economics and Agricultural Water Demands

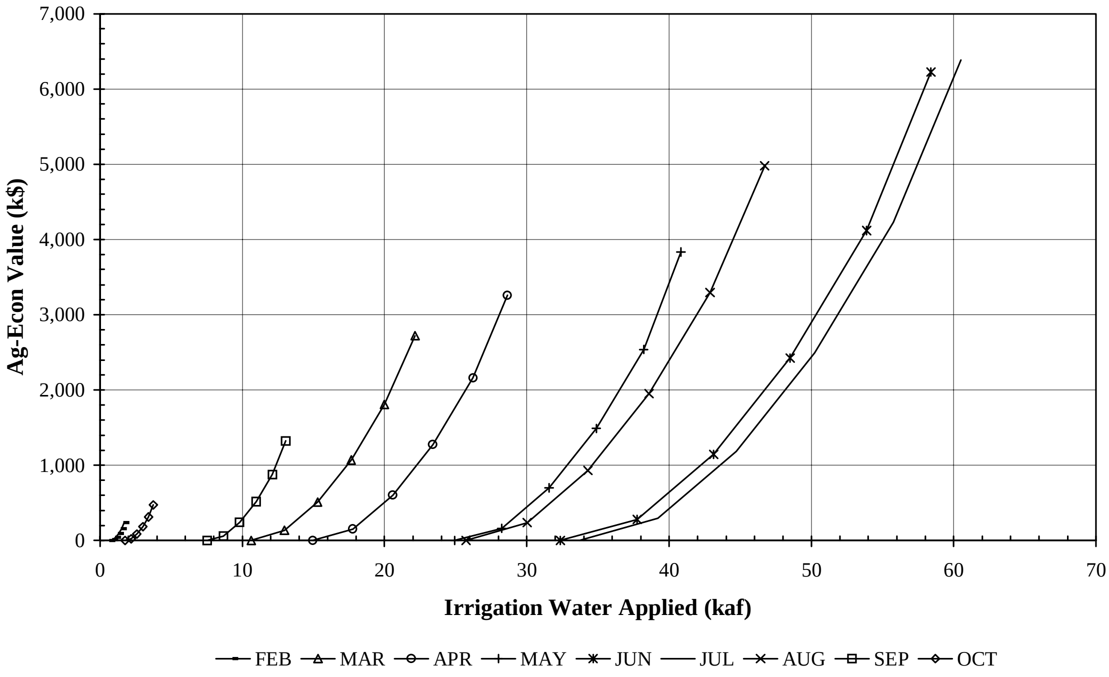
Determining the agricultural economic consequences of changes to the Friant Division requires a realistic approach of defining the economic benefit of applying water to crops. The preliminary form of FREDSIM relies on a previous modeling effort, SWAP (see Howitt, et al 1999, Appendix A), that defines monthly agricultural value functions for Central Valley Production Model (CVPM) regions. SWAP is an extension of the CVPM model developed for the CVPIA Programmatic Environmental Impact Statement (PEIS). SWAP is an optimization model that maximizes the total agricultural economic benefit according to water availability, crop prices, and land constraints.

FREDSIM takes regional SWAP results and scales them down to the individual irrigation district level. A simple scaling factor of current (1996) Friant irrigated acreage to regional irrigated acreage was used. This approach assumes the crop mix of the CVPM regions is identical to the crop mix of individual irrigation districts within those regions. SWAP assumes 2020 levels of irrigated acreage and crop types, but the results are scaled down according to 1996 irrigated acreage in the Friant Division. The agricultural demand for each contractor is determined by locating the point at which additional water will produce zero economic benefits. This approach is the best available to produce preliminary results. Ultimately, a detailed agricultural-economic study will produce more accurate agricultural values functions at the irrigation district level.

Friant demands are not adjusted for precipitation for this preliminary version of FREDSIM. Average demands are used for every year in the model runs presented in Chapter 5. Also, the demands are not reduced to represent water re-use within an irrigation district. Both of these components are not negligible, but considering the accuracy of the agricultural water demand representation, they have not warranted inclusion to the Friant demand concept. Every contractor demand was examined and compared to historic use, typical year demands according to the Water Needs Assessment, and the demands in the FWUA Informational Report. About one-third of the contractors required some total demand adjustment, but scaled SWAP results generally produced believable results with respect to water quantity.

FREDSIM agricultural economics take the form of monthly value functions based on SWAP results for each individual contractor. The value functions are transformed by piece-wise linearization into upper bounds and costs on five links connecting to the demand node. See Appendix B for additional details on the value function development. An example of monthly agricultural value functions is shown for Tulare Irrigation District (TUID) in Figure 4.3.

Figure 4.3: Agricultural Value Functions for an Irrigation District



Urban Demands

Urban demands represent three percent of the total Friant contracted water. The focus of FREDSIM is on agricultural use, but urban water demands are included, though simplified greatly. A high benefit for urban water deliveries ($700/acre-foot) is placed on a single value link rather than a multi-link, ensuring that full delivery is made if water is available. The last ten years of monthly delivery data was used to determine one standard monthly distribution of water for all urban demands. The annual demand of urban users is equal to their total Friant contract amount. FREDSIM recognizes Friant water as the sole source for urban demands. This is a fairly good assumption for smaller urban contractors, but certainly not for the City of Fresno which has an extensive history of groundwater pumping and recharge (Fresno 2000).

River Sink Demands

A river sink is a place to deliver excess water for every hydrologic basin downstream of Friant Division operations. Sinks are MODSIM demands with a very large monthly demand, but with a low benefit, and the lowest priority of the system. The network flow algorithm will always seek to meet all demands with defined economic benefits and meet reservoir storage targets before putting water down the river. The sink is also used to simplify river operations downstream of Friant contractor facilities. The river operations are not modeled beyond what is required to supply Friant contractors. Using a river sink recognizes that operations downstream exist, but the details are ignored.

Non-Friant Surface Water Sources

The diversion or storage priorities of non-Friant surface water sources within a river basin or reservoir storage is not well understood at the present time. FREDSIM assumes a water price which is the least expensive water available in the system.

All information on non-Friant sources is based on the most recent Water Supply Report published by Reclamation in 1991 and the 2000 Water Needs Assessment analysis prepared by Reclamation. The capacity of non-Friant diversion facilities was estimated by investigating annual typical diversions described in the Water Needs Assessment (USBR 2000b) and dividing by six to determine the monthly maximum delivery. Spreading annual diversion totals over six months is a reasonable approach that could be easily refined with new information. In the case of Chowchilla Water District and

Madera Irrigation District, monthly capacities were checked against maximum dam releases in mid-summer at Eastman Lake and Hensley Lake. Fresno Irrigation District, a major diverter of the Kings River, did not provide any information for the Water Needs Assessment. Their annual average totals are based on the 1991 Water Supply Report.

Model details on the rivers below Friant contractors is minimal, thus resulting inaccurate use of other sources of water. Water rights, storage rights, and priority schemes on the Kings, Kaweah, Tule, and Kern Rivers are not incorporated into the model at this time. Since all demands have equal legal priority according to FREDSIM and all users pay the same price for non-Friant sources, water allocation from non-Friant sources is based entirely on agricultural economics. FREDSIM will seek to minimize total economic penalty in the system (or maximize the benefit). FREDSIM will deliver the non-Friant sources to the agricultural demands with the highest valued crops as long as there is access to the source.

Water Prices

Water prices are essential to the economics-driven network flow simulation. The optimization routines within MODSIM will always seek to minimize all costs by drawing on the least expensive water available each time-step. Also, if the unit cost of water exceeds the unit agricultural economic benefit, the crops will not be irrigated, thus simulating water management decisions.

Friant water prices are comprised of many components which are different for each class and for each contractor (Anderson 2000). The common elements of each Friant class of water are the environmental surcharges. The Environmental Restoration Fund surcharge and the Friant Restoration Fund surcharge as described in Chapter 2 total $14/acre-foot of water delivered regardless of class or contractor. All classes of water also have an operations and maintenance (O&M) component and a capital repayment component that is identical for every contractor totaling about $10/acre-foot. Each contractor has an outstanding debt repayment component added to the price that varies depending on local projects financed by Reclamation, but is on the order of $10/acre-foot. Class 1 water, the most reliable and most expensive, has an additional storage component of $10/acre-foot. (Anderson 2000)

Non-Friant surface water supplies are assumed to be the least expensive water available in the Friant service area. There may be a storage component to non-Friant sources, but it is ignored.

Groundwater pumping costs vary greatly from district to district and within districts. FREDSIM uses one pumping cost for each entire district based on an average depth to groundwater and applies the CVPIA-PEIS approach by using a variable cost of $11/acre-foot for capital recovery plus $.20 per foot of lift for groundwater pumping (USDOI 1999). The latest depth to groundwater data available is from Reclamation’s 1991 Water Supply Report. All Friant contractor groundwater pumping costs are in Table B.5 in Appendix B. While FREDSIM recognizes the wide range of pumping costs throughout the Friant Division, it does not change the cost as groundwater levels fluctuate. All water prices in FREDSIM are the same for every year in the model run and are summarized in Table 4.2.

Table 4.2: Water Prices Used by FREDSIM

Water Supply	Price ($/af)
Class 1	$44
Class 2	$34
Section 215[a]	$26
Groundwater pumping[b]	$17 to $80
Non-Friant surface water	$10

a) Section 215 water price can decrease to encourage the evacuation of flood water from Millerton Lake (Buelna 1999). The range is $19 to $34/acre-foot. FREDSIM uses an average of $26/acre-foot.

b) Pumping cost varies within the Friant Division. See Appendix B.

Institutional Arrangements and Contracts

All Friant contracts are modeled explicitly in FREDSIM. Contract quantities and class-type were obtained from Reclamation's Mid-Pacific office. CVC contracts are also represented in FREDSIM. MODSIM allows for detailed representation of the unique Friant Division contracts with a computer scripting code that runs in parallel with a model run. See Appendix C for details on the FREDSIM script. One limitation of the current Friant ownership representation is not allowing water transfers within the service area, another critical aspect of Friant water management. This limitation is described further in Chapter 6.

As described in Chapter 2, a contract between Reclamation and water users downstream of the Mendota Pool allows for nearly full diversion of the San Joaquin River so historical agricultural economies in the San Joaquin Valley could continue after the Friant Division was operational. However, riparian users between Friant Dam and Mendota

Pool can not get delivery of DMC water and thus require year-round releases from Friant Dam to meet a minimum flow at Gravelly Ford. This contractual requirement for San Joaquin riparian water is represented with a minimum flow demand on the river.

Currently, there is limited information regarding contracts or priorities for non-Friant surface water supplies input into FREDSIM. Typical diversions from non-Friant sources are based on the Water Needs Assessment, but water rights are not modeled. This is another layer of water management complexity that is discussed in Chapter 6 and could be incorporated into future versions of FREDSIM. For model simplicity all management of non-Friant surface water is driven solely by agricultural economics.

Cross Valley Canal Exchange

The CVC exchange as described in Chapter 2 has become less reliable in recent years. Reclamation personnel indicate that a great portion of the original exchange has deteriorated. Recently, only about a third to a half of the original 128,000 acre-feet have been delivered and exchanged with AEWD (Anderson 2000).

FREDSIM takes a simplified approach to model the CVC exchange. The SWP operations can not be modeled with current information. The approach is to model the California Aqueduct with an artificial reservoir just upstream of the CVC headworks. Annual inflow at the beginning of every water year will be about a third of the original exchange quantity, 40,000 acre-feet (due to a recently uncertain supply and also simplifying the model representation). The reservoir will have a storage target of zero to essentially drain annual CVC supply in the reservoir at the end of each water year. FREDSIM assumes the exchange with AEWD is an even exchange with equal quantities exchanged every water year. CVC water delivered to AEWD and Friant water delivered to CVC exchangers is assumed to be equal to the Class 1 water.

The CVC exchangers are given ownership of Friant Class 1 water in the same manner as Friant long-term contractors. AEWD can draw on the simplified CVC when it is economically attractive. This is a greatly simplified way to model SWP operations and integration with the Friant Division, but does represent essential supplies to CVC exchangers.

Gravelly Ford Requirement

The Friant Division is responsible for maintaining a flow of 5 cfs for riparian water users at the Gravelly Ford gage on the San Joaquin River below Friant Dam and above Mendota Pool. Due to losses on the San Joaquin River, the dam release must exceed 5 cfs. In the winter the minimum release is about 50 cfs and in the summer months is about 200 cfs (Buelna 1999). A high benefit is placed on the link delivering water to the artificial demand to ensure that the demand is always met. This demand at Gravelly Ford is a flow-through demand with 100 percent of delivered water returning to the San Joaquin River. The model uses the following release schedule, Table 4.3, based on actual Reclamation operations to meet minimum flow requirements at Gravelly Ford. These total minimum releases for downstream users total 92,000 acre-feet/year.

Table 4.3: Friant Dam Minimum Release for Gravelly Ford Requirement

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
150	100	50	50	50	75	100	150	200	200	200	200

Note: releases in cubic feet per second (cfs).

Forecast Data

The MODSIM network includes a forecast demand node. This node is not an actual demand node, but rather a placeholder within the model to store a time-series of forecast runoff data for the Friant system. The Friant forecast is equal to the annual Friant Class 1 and Class 2 declaration. For simplicity, the model assumes the last forecast is equal to the forecast every month early in the water year (March through June). In actuality, the forecast changes every month until usually July when the runoff has peaked and the total seasonal runoff is more certain. Due to lack of historical Friant forecast data, only the final forecast is used for every month of that water year. Perhaps a detailed forecast could be made based on historical snowpack, and San Joaquin base flow in a future version of FREDSIM. If the time horizon of FREDSIM model runs extends to pre-project years, some correlation between runoff and the Friant annual allocation will be required to model the system. The forecast is critical to the model as it is used to establish initial contractor water ownership on a monthly basis.

Table 4.4 lists the Friant allocations used for the preliminary model runs (presented in Chapter 5). This data is a good indicator of water year types as well which could be helpful in examining model results.

Table 4.4: Friant Allocations 1985 - 1994

Year	Class 1 (af)	Class 2 (af)	Total Allocation (af)	San Joaquin Inflow to Millerton (af)
1985	800,000	196,000	996,000	1,215,500
1986	800,000	1,400,000	2,200,000	2,922,400
1987	728,000	0	728,000	1,000,200
1988	624,000	0	624,000	852,500
1989	784,000	0	784,000	927,100
1990	544,000	0	544,000	766,500
1991	800,000	0	800,000	925,200
1992	664,000	0	664,000	449,000
1993	800,000	1,260,000	2,060,000	2,456,500
1994	640,000	0	640,000	1,020,700

Source: USBR operations data
Note: Section 215 water declaration and delivery data not available.

Friant Demand Model Representation

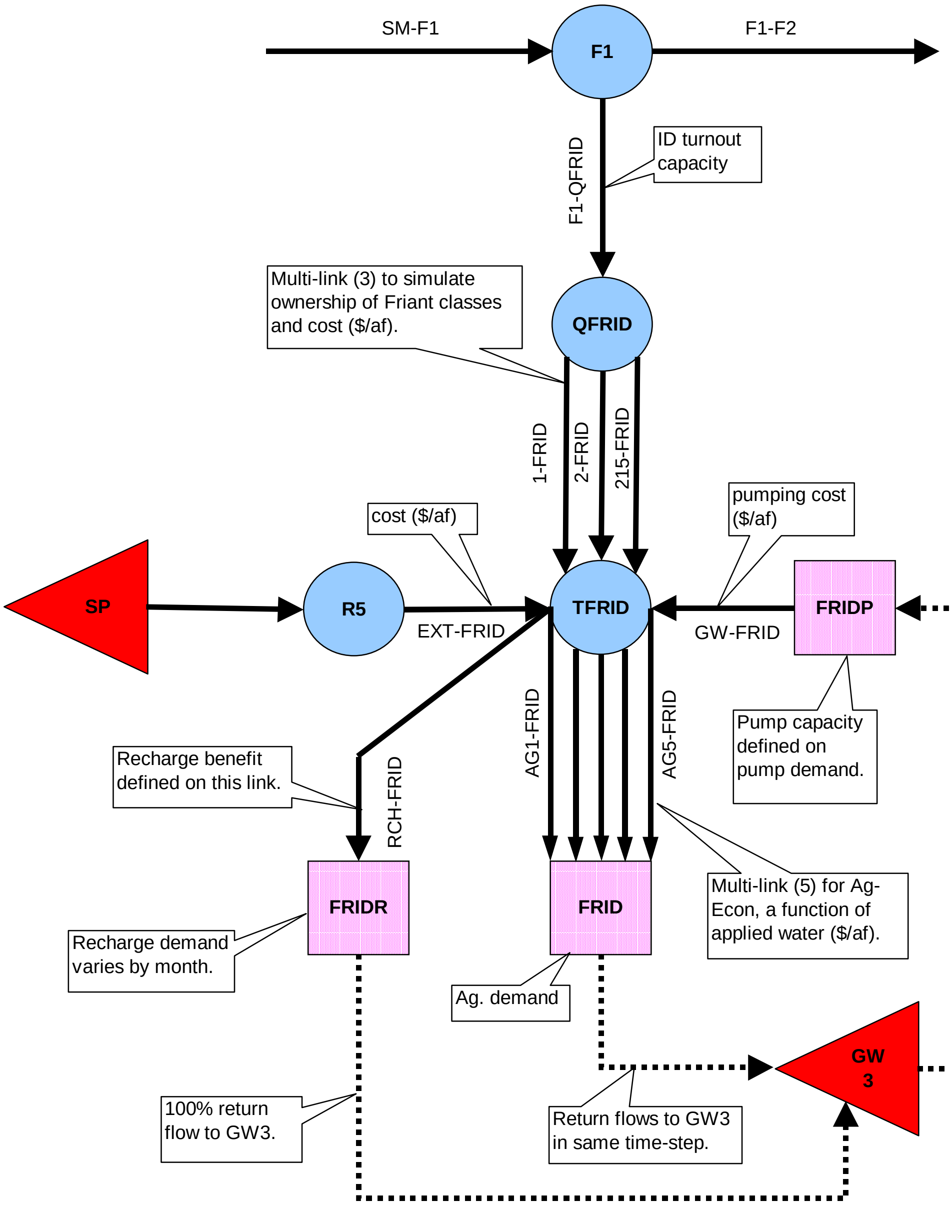
The components of every Friant demand is represented by a series of links and nodes in MODSIM, each with a consistent naming convention. This example is for Fresno Irrigation District (FRID) which has access to all possible sources of water. Friant water flow is limited by a physical capacity and an accounting capacity. The physical link with an actual capacity flows to the flow node, QFRID. From there the Friant water must go through the accounting links. The multi-link labeled 1-FRID, 2-FRID, 215-FRID are accounting links, each with a different price and a capacity that decreases as its balance of Friant water decreases.

All sources of water feed the total node, TFRID, by means of links that represent physical conveyance facilities from the FKC, Kings River, and the local groundwater basin, GW3. All groundwater pumps and canal turnouts are aggregated into one link for each. The groundwater pump is a separate demand flowing to TFRID with a cost on link GW-

FRID. Groundwater is only pumped when it is the least expensive water available. Depletions due to pumping are achieved by an artificial link connecting to GW3. Non-Friant sources or external sources feed the TFRID with a cost on link EXT-FRID.

From the TFRID node, water can be delivered to the demand through a multi-link (AG1-FRID, AG2-FRID, AG3-FRID, AG4-FRID, and AG5-FRID) that represents the agricultural value function which changes monthly. Water can also be routed to the recharge demand if economically beneficial in winter months. The recharge link, RCH-FRID, has an economic benefit that encourages recharge in the winter. The capacity of the recharge link is zero the rest of the year. Recharge is achieved by defining return flows equal to 100 percent and returning to GW3. Agricultural return flows are defined according to irrigation efficiency and occur without lag to GW3. All components of the approach to modeling a modeled agricultural demand is shown in Figure 4.4.

Figure 4.4: Sample Schematic for an Agricultural Demand in FREDSIM

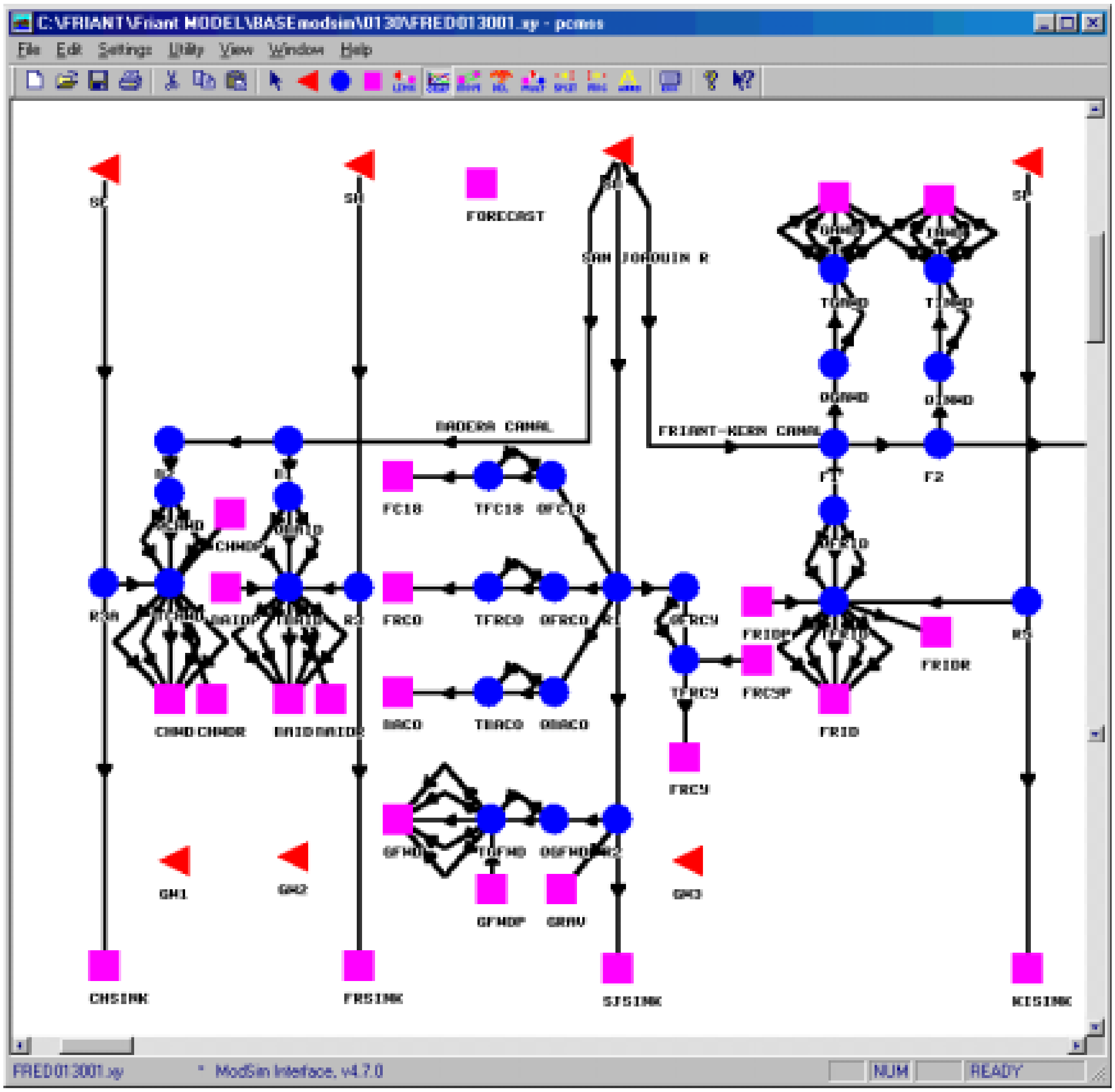


MODSIM Notes

The MODSIM graphical user interface is used to establish the model schematic and enter simple data. The MODSIM interface is shown in Figure 4.5 along with a portion of the Friant schematic. The physical configuration of the Friant system can be changed and added to within the interface. All system data can be entered with the interface by means of data input worksheets that are linked to all objects. Large amounts of data such as a hydrologic inflows, reservoir targets and evaporation rates, and demands can be input in the form of text files or directories of text files rather than spreadsheet-style data entry.

Some details modeled with FREDSIM required the customization of MODSIM using a self-compiling computer scripting code to manage some links while the model is running. The script manages the annual allocation of Friant water and contractor water accounts, defines the price of Friant water for all Class 1 and Class 2 links, defines the capacity and cost of groundwater pumping links (GW-links) and non-Friant links (EXT-links), and changes the monthly agricultural values functions for each contractor. See Appendix C for additional MODSIM details including full description of the script functionality and the entire FREDSIM schematic as constructed with the MODSIM interface.

Figure 4.5: MODSIM Interface with Partial FREDSIM Network



MODSIM Priorities

In addition to water prices and economic value functions to drive water allocation decisions, MODSIM requires that priorities must be established between reservoir storage targets and demands. The priority scheme of FREDSIM equalizes all demand priorities (except river sinks) with reservoir target priority. Due to the economic benefits derived from delivering water, all the demands will be met before water is retained in Millerton Lake to meet targets. The priority of river sink demands is the lowest of the system to ensure that water is delivered to sinks only when flood releases or spills are required. Water will not be delivered to river sinks if reservoir storage targets are achieved.

V. MODEL RUNS AND PRELIMINARY RESULTS

Preliminary Model Runs

The current preliminary version of FREDSIM is not calibrated and is thus unsuitable for real water management decision making. However, some simple and realistic scenarios were developed to demonstrate FREDSIM's ability to model the Friant Division according to economic drivers. These model runs show how the tool could be used to evaluate operational or policy proposals. These preliminary results also establish a starting point for calibration while confirming the need for more data and better information on some aspects of Friant operations.

The model runs represent realistic scenarios that could face the Friant Division in the future as system changes are implemented. It is important to consider that the model run scenarios presented are not based on actual proposals, but represent the type of changes that could be modeled with FREDSIM as part of an evaluation process. Also, the preliminary runs span ten years, from 1985-1994. While this time window does cover the extended California drought of 1987-1992 and the wet years of 1986 and 1993, an extended time window would cover a greater range of hydrologic conditions. Inflow data dating back to 1922 is available and being used in other California models (Howitt, et al. 1999). Calibration of FREDSIM will utilize the extended hydrologic data set. For all model runs, no Section 215 water was allocated due to lack of historic data. The model run scenarios are presented in Table 5.1.

Table 5.1: Model Run Scenarios

Model Run	Description
Base Case	Current representation of the Friant Division with available information.
SJ48	Base Case, but reduce Friant allocation by 48 kaf for San Joaquin River instream environmental flows. 6 kaf each month, June-September (200 cfs constant additional dam release or various pulse flow combinations).
SJ120	Base Case, but reduce Friant allocation by 120 kaf for San Joaquin River instream environmental flows. 24 kaf each month, June-September (500 cfs constant additional dam release or various pulse flow combinations).
M100	Base Case, but increase Millerton Lake storage by 100 kaf to increase operational flexibility and possibly yield.
P1	Base Case, except increase price of all Friant water such that Class 2 price exceeds the averaged cost of groundwater pumping throughout the system ($38/af). Friant prices are increased $10/af to $54/af for Class 1 and $44/af for Class 2.

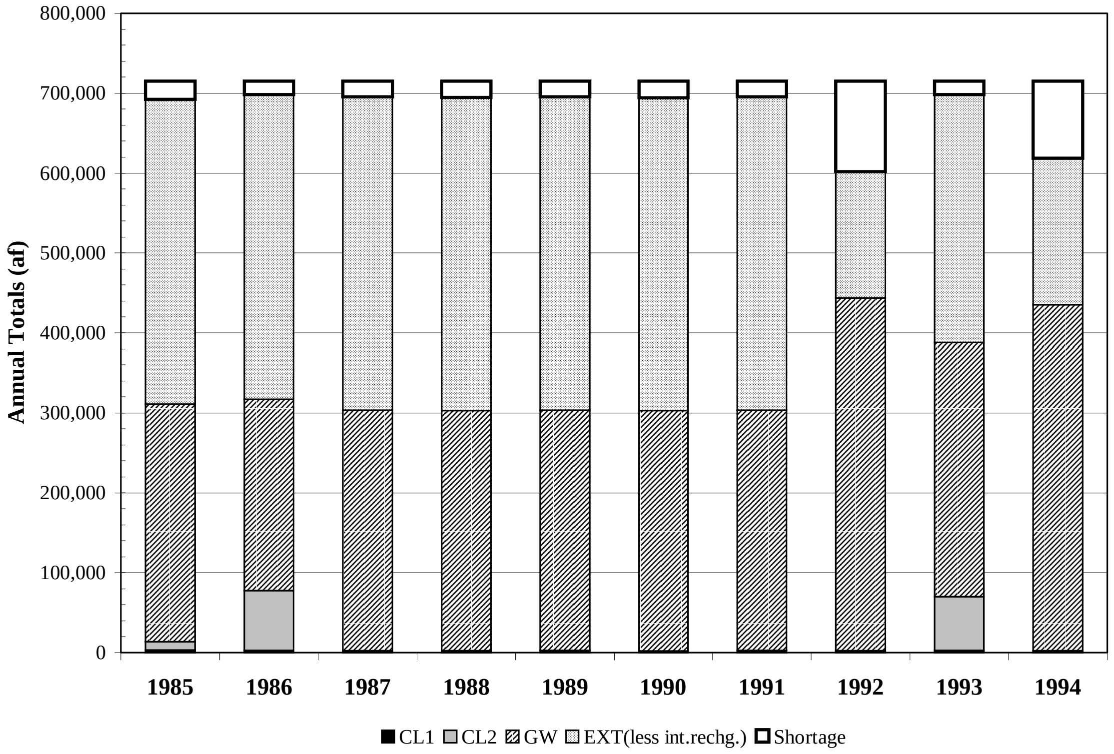
Individual Contractor Results

During a FREDSIM model run, iterations are performed to minimize the cost to the entire Friant Division at each time-step, but examination of results begins with those of individual contractors. Most Friant contractors have a mix of water supplies. Simulating the water management decisions for a single contractor demonstrates how water year types (and Friant allocations) effect the quantities of each type of water. Analyzing the effect of various water policies at the district level also can be achieved with FREDSIM in terms of water deliveries and shortages. “Shortage” in this analysis is the difference between full demand and total delivery. “Full demand” is the amount of water an irrigation district would use if it were free and unlimited in availability. Under the FREDSIM modeling approach, shortage could indicate lack of water available for economically beneficial use and thus, a decision not to irrigate the crops within a district, starting with the lowest valued crops. Presently, the model does not process economic effects of water shortages.

For demonstration purposes, the Base Case results for three Friant contractors are presented. The results are annual totals and show water management decisions based strictly on economics within a contract system on the irrigation district level. This level of examination will be critical for the calibration process and should be presented to actual water managers for refinement. Refer to Table 2.4 for a summary of all contractor information including irrigated acres, Friant contract amounts, and other sources of water.

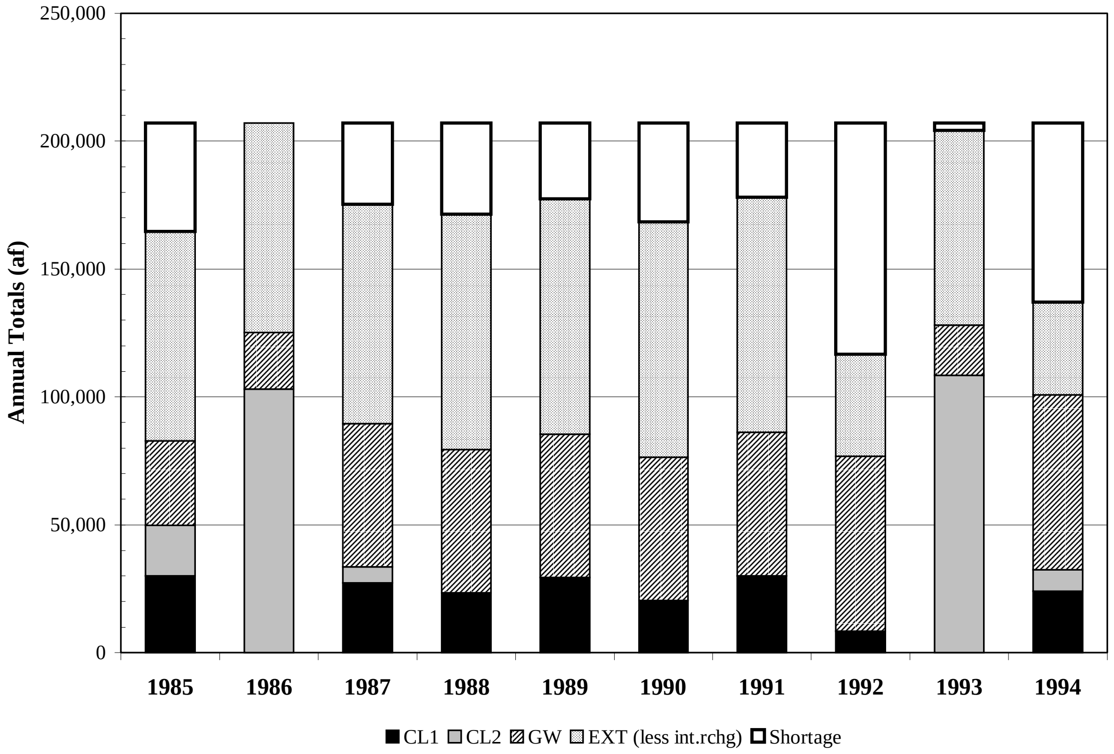
Fresno Irrigation District (FRID) is the largest of the Friant contractors in terms of irrigated acres with water supplies from the Kings River, groundwater, and Friant Class 1 and Class 2 water. Their Friant supplies are a supplemental source to their well-established water rights from the Kings River and Pine Flat Lake. FRID also has an active conjunctive use operation to withdraw groundwater and minimize overdraft in the local aquifer. Figure 5.1 shows the difference in supplies utilized by FRID to meet their annual demand of 715,000 acre-feet for every year in the model run. Clearly, FRID relies heavily on the Kings River diverting about 400,000 acre-feet annually with groundwater pumping making up the balance. Due to lack of information on Kings River operations, the FRID diversions were limited by link capacity rather than simulated water rights. The Friant water, though relatively small in comparison to other sources, is used when allocated.

Figure 5.1: Fresno Irrigation District Base Case Results



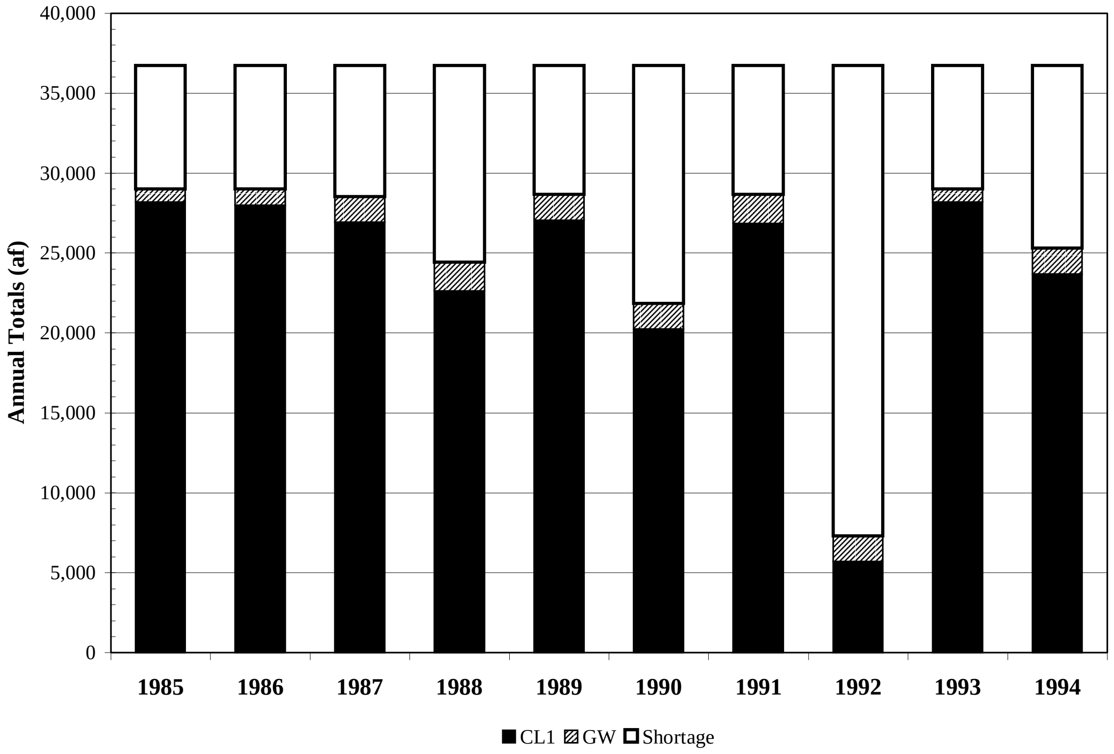
Tulare Irrigation District (TUID) is another large contractor, but has more diverse mix of potential supplies with less reliance on groundwater than FRID. Figure 5.2 shows that in wet years (1986 and 1993), groundwater pumping is reduced significantly by the use of Class 2 water. Using surface water rather than groundwater in wet years is considered “in-lieu” recharge allowing for some natural recovery of ground water levels. The full TUID demand, 207,000 acre-feet, is met only in the wet years, while a large deficit occurs in 1992, the peak of California’s last extended drought. The wet year results illustrate how Friant Class 1 water is not used by a contractor with less expensive options available.

Figure 5.2: Tulare Irrigation District Base Case Results



Terra Bella Irrigation District (TBID) is an example of a smaller contractor with heavy reliance on the firm Friant water, Class 1, to meet their annual demand of 37,000 acre-feet. Figure 5.3 is an example of results that could be used the calibration process. TBID is always short of full demand by at least 15 percent. The initial analysis could be that the modeled agricultural demand exceeds the actual TBID demand. Another possible reason for the shortages is that TBID may take advantage of short-term water transfers within the Friant Division as allowed by Reclamation. Under FREDSIM's current level of contract representation, the ownership of Friant water is not flexible. Currently, FREDSIM can not simulate irrigation districts with excess water selling to water-short districts.

Figure 5.3: Terra Bella Irrigation District Base Case Results



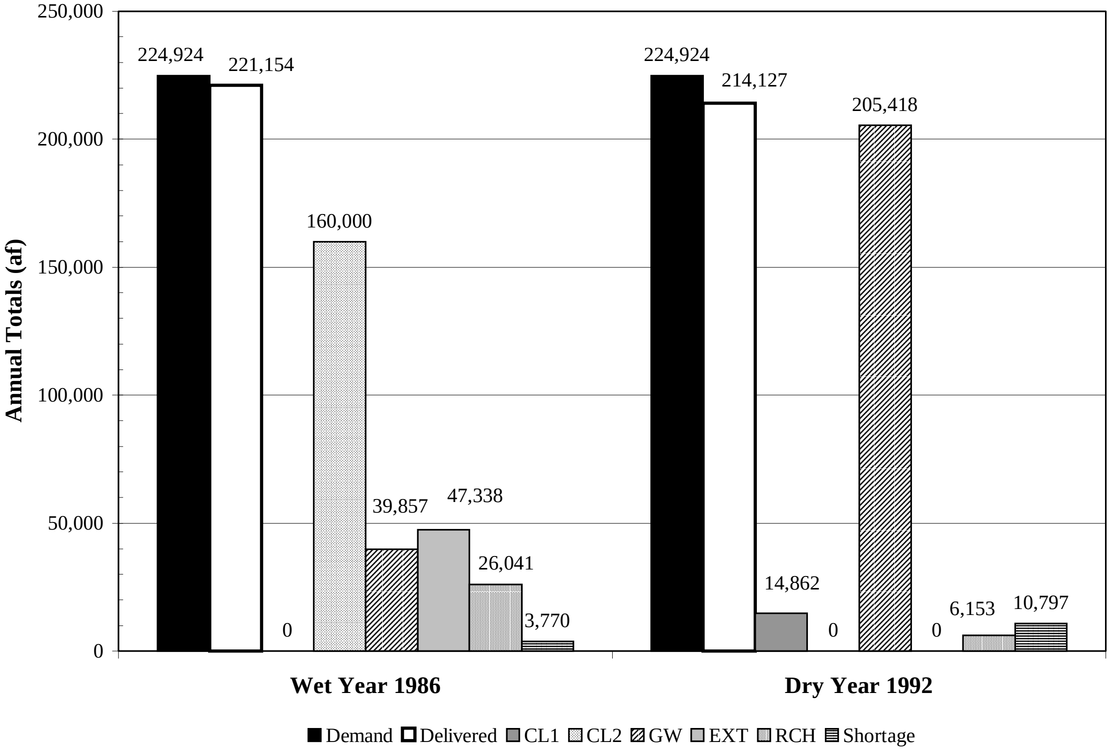
Water Year Comparison

California water management involves wide ranges of hydrologic variability along with water policy variability. Potential changes to the system must be analyzed at both the district level and the system level considering wet years and dry years. 1992 was classified as a critically dry year and 1986 as a wet year for the entire San Joaquin River Basin (DWR 2000).

The effect on the water management decisions is quite dramatic in the Figures 5.4 for Chowchilla Water District (CHWD) and in Figure 5.5 for the Friant system as a whole. Most notable is the increased use of groundwater in 1992. Despite extremely dry conditions on the Chowchilla River, CHWD maintains a high reliability for water supply.

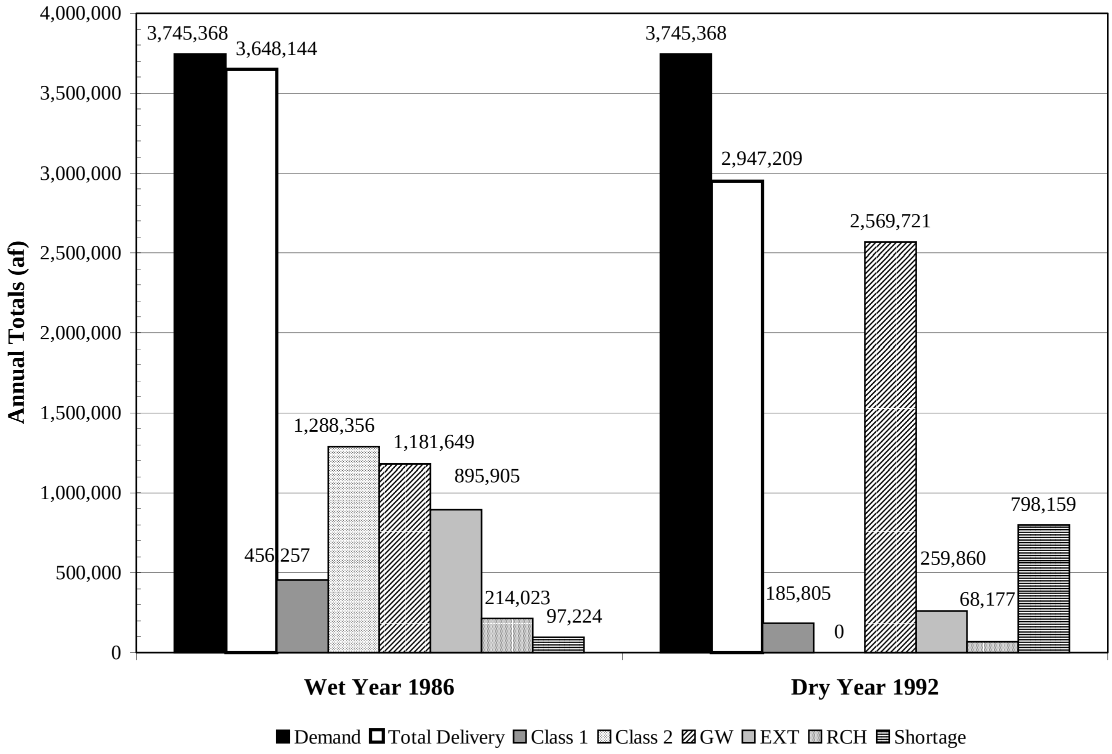
CHWD has an intentional groundwater recharge program that should help offset increased pumping in dry years. Also, CHWD makes full use of Class 2 water when it is allocated in the wet years. The mix of supplies available to CHWD allows them to nearly meet demand even in the driest of years.

Figure 5.4: Chowchilla Water District Water Year Comparison for Base Case



The system-wide effects on water supply sources to the Friant Division is evident in Figure 5.5. The distinct trend is that when surface water is not available, the deficit is replaced by groundwater. Another issue for water managers is that in the dry years, a significant shortage is projected even with increased groundwater pumping. Under these conditions permanent, high-valued crops such as vineyards and orchards will be irrigated while land fallowing increases.

Figure 5.5: Friant Division Water Year Comparison for Base Case

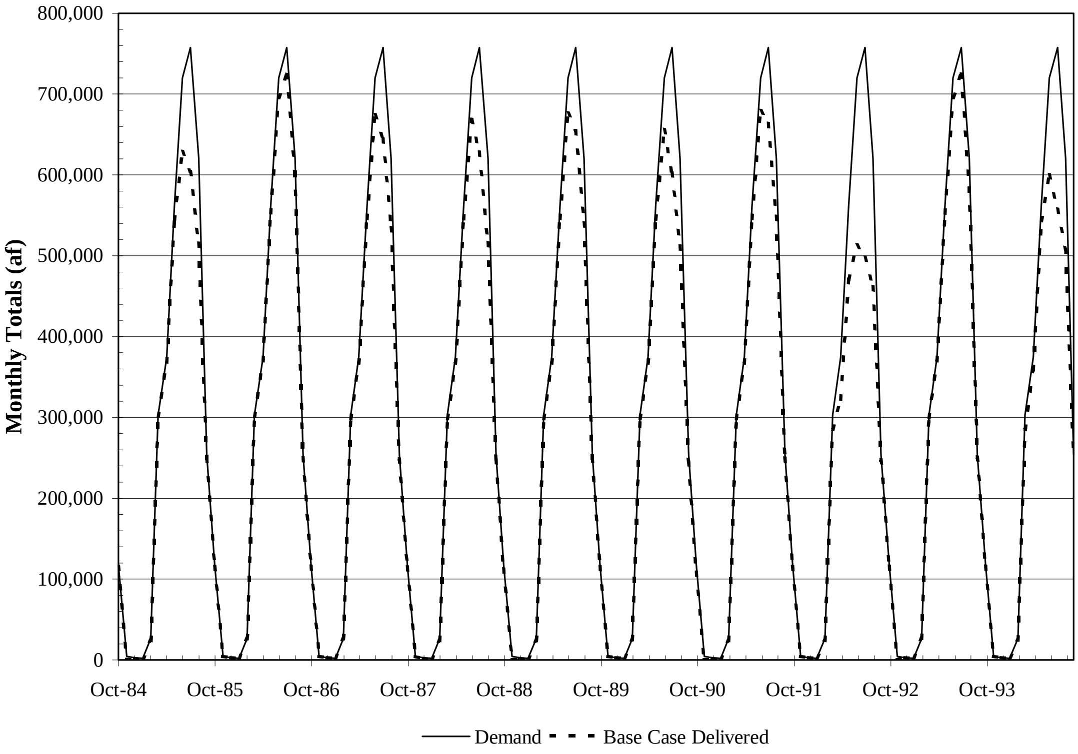


Though FREDSIM is not calibrated, Base Case model run results were checked to ensure that the model was producing reasonable results. Simulated quantities such as annual groundwater pumping, recharge, overdraft trends, and non-Friant surface water use were compared to annual water balances by FWUA (1999), the Water Needs Assessments (USBR 2000), and general trends and projections published in the DWR Bulletin 160-98 (1998). In many cases the capacity of GW-links or EXT-links (for groundwater or non-Friant surface water) were adjusted to reduce annual flow in those links. In addition, the water accounting for Friant allocation and contracts was checked for accuracy.

Friant Division Demand Results

Results examination for the Friant Division as a whole is critical to calibrate FREDSIM and ultimately, analyzing water policies or operational changes that could effect the system. The Friant Division has an annual agricultural value of about $2 billion (see Table 2.1), not including the multiplier effect of moving crops to the market place. The Friant Water Users Authority estimates this to be three to four times the gross agricultural value (FWUA 1999). A reduction in water supplies or increase in water costs will have economic implications. Any water shortage represents an economic loss. Actual economic loss is not calculated within the model at this stage of development, but shortages represent this loss. Figure 5.6 show the Base Case monthly demand results for the Friant Division for water years 1985 through 1995. The system demand is for both agricultural and urban users, including CVC exchangers.

Figure 5.6: System Demand Results for Base Case



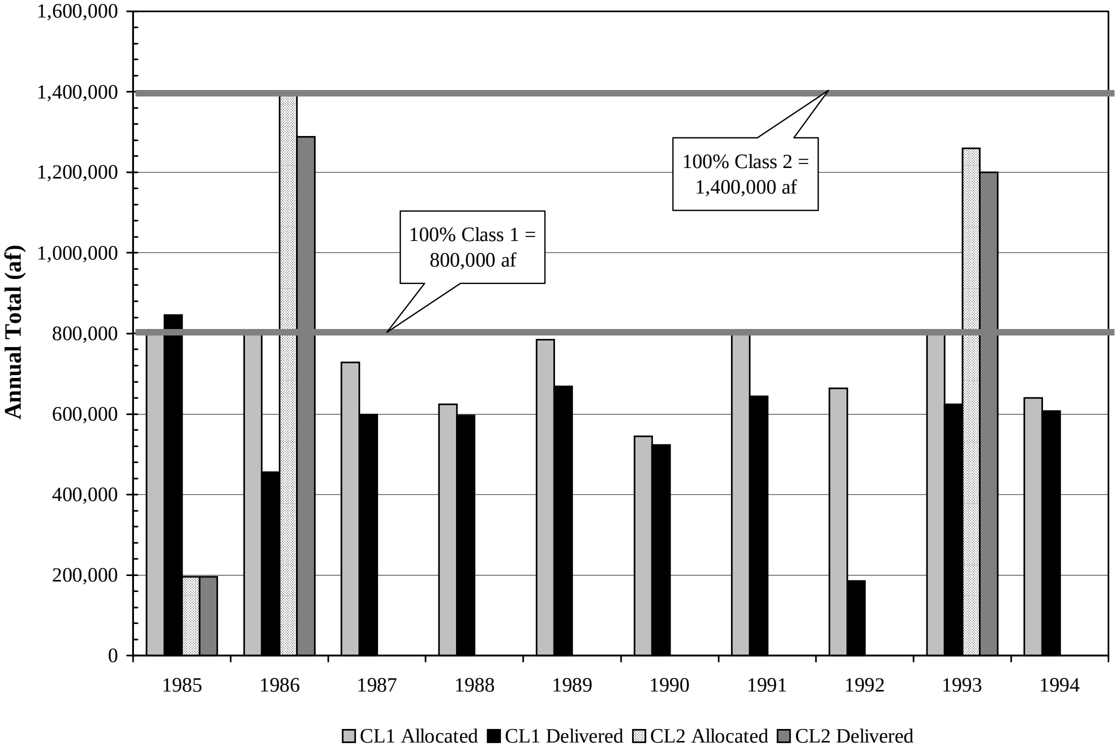
The Friant Division, with an annual demand of 3.7 million acre-feet, shows shortages in all years of the Base Case model run, but water years 1987-1992 were all classified as critically dry (DWR 2000). Again, shortages are equally an indicator of cropping decisions and water availability. The most notable shortage is in 1992, which could imply widespread land fallowing. In water-short years, the first crops not irrigated are those that produce the least value according to the agricultural value functions. Since there was virtually no shortage in the wet years of 1986 and 1993, the simulated system demand may indeed reflect the real system demand. Certainly, the agricultural water demands will be considered in the calibration process. Detailed irrigation district level agricultural economic value functions could possibly provide more accurate results than the scaled-down regional results used in this version of FREDSIM. The demand and delivery graphs for the other model scenarios look nearly identical to the Base Case and therefore, were not plotted for comparison. Reducing Friant water availability in SJ48 and SJ120 did not effect shortages as the Friant water was replaced by groundwater. Changes to Millerton Lake by increasing storage capacity (M100) or raising the price of Friant water (P1) had very little effect on the system deliveries indicating that the current price of Friant water is governing the decision on whether or not it should be used. Raising the price had virtually no effect.

Figure 5.7 shows an annual comparison of Friant water allocated versus delivered. The use of Reclamation water versus local supplies and groundwater is key to the analysis of any water policy. FREDSIM will ultimately show how water pricing changes could effect whether or not Friant farmers decide to use Friant water. The price and availability of Friant water must allow for a net economic benefit to the contractors for using it. Simulated trends that show reduced Friant deliveries are an indicator of increased groundwater use. For the Base Case, which represents the present conditions, Class 1 deliveries are less than the allocation particularly in the wet years and the very dry year. In wet years, there are less expensive supply alternatives, including Class 2 water. When Class 2 is allocated, it is generally used to near full potential.

The underused Class 1 water may be another indication that allowing transfers of Friant water may improve a FREDSIM simulation. A large district with excess Class 1 water could sell to a district with limited supplies allowing for a more flexible and possibly more reliable system.

There are two notable irregularities in the results presented in Figure 5.7. In 1985, more Class 1 water was delivered than was allocated due to the definition of the Friant water year. The data presented throughout this chapter is based on the water year October through September, but the Friant water year runs March through February. In water year 1985, there were Friant water deliveries from October to March that were part of the 1984 allocation. In 1992, the expected result would be full delivery of the allocated Class 1 water due to the extremely dry runoff conditions. FREDSIM uses historical allocation data and in 1992, the forecast used to establish allocation was significantly underestimated. The allocation was 664,000 acre-feet, but the total inflow to Millerton Lake was 449,000 acre-feet.

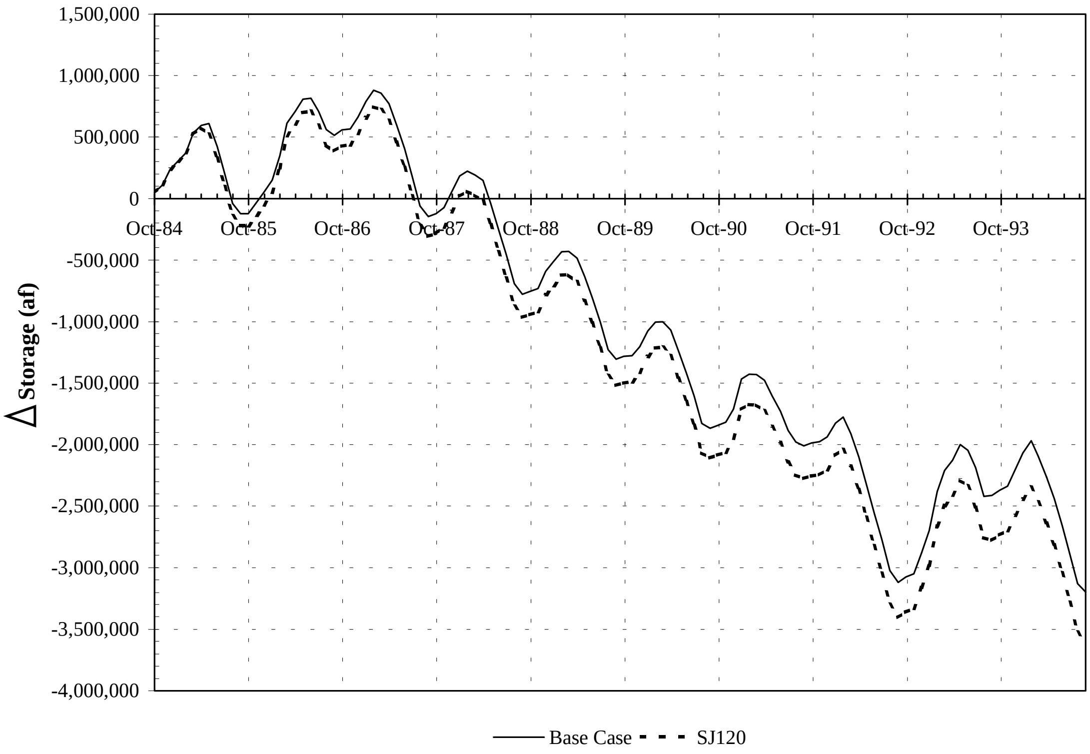
Figure 5.7: Friant Allocation and Delivery for Base Case



Groundwater Results

The analysis of the effects on groundwater will be critical to the evaluation of any water policy facing the Friant Division. Groundwater results presented here should be interpreted as showing trends only. Actual groundwater levels or storage levels are not modeled by FREDSIM as the groundwater reservoirs are highly simplified and hydraulically isolated from one another. However, the downward trend in groundwater storage resulting from pumping quantities exceeding all groundwater inflows (natural recharge, artificial recharge, irrigation return flows), is shown in all modeled scenarios. The SJ120 model run resulted in the greatest decline of groundwater storage. It is also critical to point out that as reliance on groundwater increase, pumping heads and therefore, costs increase. FREDSIM in its current state does not allow for a pumping cost as a function of groundwater reservoir storage levels. Increased pumping could in reality only be a temporary solution as pumping costs approach the cost of Class 1 water. Figure 5.8 is a graphic comparison of cumulative groundwater storage change for the Base Case model run with the SJ120 model run, which had the greatest effect on groundwater storage. The storage graph is a sum of all the modeled groundwater reservoirs of FREDSIM, clearly showing the declining groundwater resources and the effect that wet years and dry years have on storage changes.

Figure 5.8: Groundwater Aquifer Cumulative Storage Change for 1985-1994



The effect of various water policy alternatives can have significant effects on the currently declining groundwater resources within the Friant Division. Table 5.2 is a sample comparison of the annual average groundwater pumping and intentional recharge totals, and the 10-year total groundwater overdraft for all five modeled scenarios.

Table 5.2: Groundwater Results Comparison

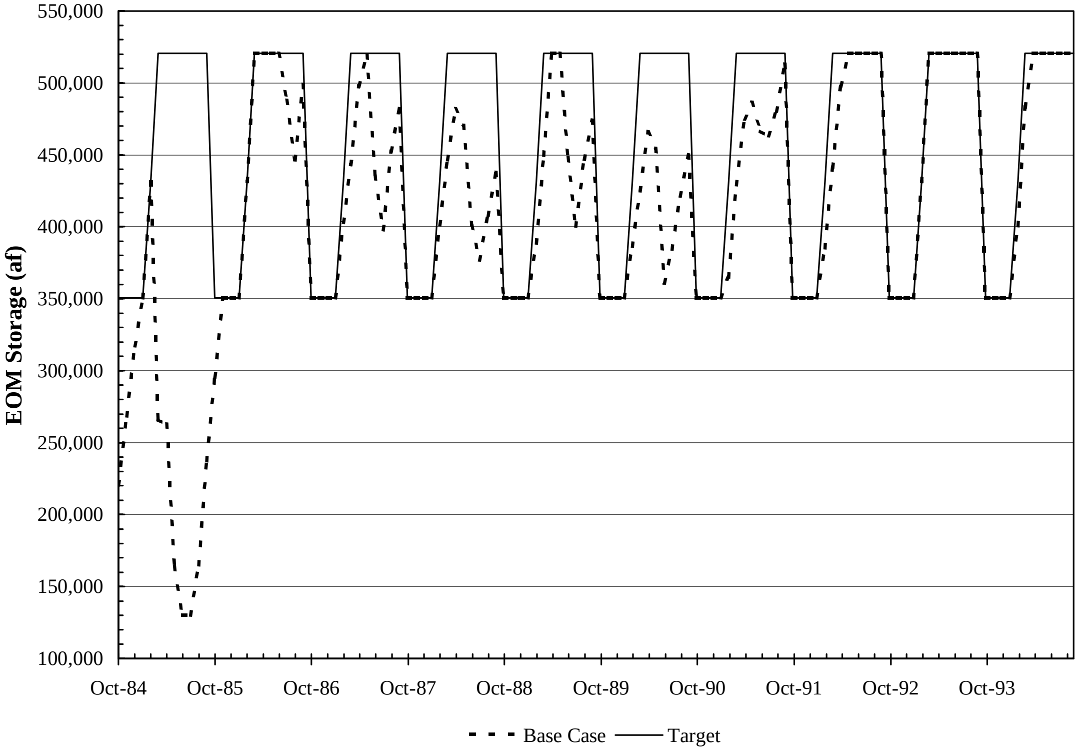
	Model Run				
	Base Case	**SJ48**	**SJ120**	**M100**	**P1**
10-year Avg. Pumping (af/yr)	2,001,000	2,013,000	2,029,000	2,001,000	2,019,000
10-year Avg. Int. Recharge (af/yr)	166,000	166,000	164,000	165,000	165,000
10-year Total Overdraft (af)	3,246,000	3,414,000	3,673,000	3,252,000	3,407,000

These sample results show that pumping increased the most for the SJ120 run, which represents establishing environmental flows on the San Joaquin River and a reduction of Friant allocation. SJ120 also showed overdraft in the Friant service area increasing 427,000 acre-feet in comparison to the Base Case over the 10-year simulation. None of the model scenarios had a significant effect on winter-time intentional recharge due to typical hydrologic conditions prior to the irrigation season. The M100 model run requires further attention since results show a reduction in intentional recharge and an increase in overdraft when Millerton Lake is enlarged.

Millerton Lake Results

The monthly time series of storage results for Millerton Lake are shown in Figure 5.9 for the Base Case along with the target storage, which is the maximum allowable storage. Millerton operations for this preliminary model run shows a reluctance for reservoir draw-down other than what is required for flood control purposes. Since meeting the reservoir target is no more a priority for the model than meeting demands, the explanation for the lack of Millerton full utilization is the current cost of Friant water. The price of Friant water is higher than most pumping costs and certainly higher the non-Friant sources of water. Additional work is need on quantifying the cost of pumping groundwater as there is the possibility that it is currently too low.

Figure 5.9: Millerton Lake Base Case Results



The M100 model run, which was an expansion of Millerton Lake capacity, showed virtually no change in results in terms of reservoir operations or Friant deliveries. The storage plot was nearly identical, but shifted by 100,000 acre-feet. This is an indicator that price drives the decision of taking Friant water rather than greater operational flexibility (more available storage). The M100 simulation may indeed be more useful when combined with simulation of carrying water over to the next water year in Millerton Lake.

FREDSIM Results

Model refinement is necessary, but even in its preliminary form, FREDSIM simulated some reasonable trends. As surface water availability is reduced due to hydrologic conditions or environmental flows on the San Joaquin River, groundwater pumping increases. This generality is intuitive, but the model can quantify the actual change in groundwater pumping, which is necessary for water supply planning. The groundwater results also show that an important model refinement should be inclusion of dynamic pumping costs due to fluctuating groundwater levels. For a ten-year model run, this may not make a significant difference, but over a longer period the effects of declining groundwater levels should make pumping groundwater economically unattractive for the users. Replacing surface water with groundwater is only a short-term solution as pumping costs increase.

Another interesting result is the lack of draw-down of Millerton Lake storage, a possible indication that the current price of Friant Class 1 water makes it unattractive to most contractors. Another possibility is that the pumping costs defined in FREDSIM are too low. As long as there is a less expensive alternative to Friant Class 1 water, the contractors will not take use it.

The FREDSIM results presented for realistic water policy scenarios should be considered a starting point for model calibration at the irrigation district level and the Friant system level. Though not calibrated, FREDSIM is a running model with preliminary results demonstrating potential as an analytical tool for real water policy evaluation.

VI. FUTURE MODEL REFINEMENTS AND CONCLUSIONS

Model Limitations and Refinements

Presently, data limitations and lack of understanding of some components of the Friant Division prevent proper model calibration. FREDSIM is a running model which demonstrates the concept and approach of economics-driven water supply simulation, proper mass balance, and network flow connectivity, but should not be considered a working model with believable results. The current model is not calibrated and should not be used for water management decision making. Additional work is required. Several recommendations are presented to enhance the validity and utility of FREDSIM.

1. Groundwater model integration. The Friant Division relies heavily on adequate groundwater as primary and supplemental water supplies. FREDSIM uses a very rough representation of groundwater for demonstration purposes only. Certainly, a physically-based groundwater model that works in conjunction with the economics-driven management model will greatly enhance the accuracy and utility of the model. Of course, calibrating groundwater inflows, outflows and levels is a complex task that has yet to be understood throughout much of the Friant service area. The location, lag time, and quantity of irrigation return flows and natural replenishment of the aquifers remain at least somewhat uncertain. Presently, FREDSIM makes no attempt to resolve these issues and the stream-aquifer interaction that greatly influences water resources within the Friant Division. A groundwater model would also define pumping costs as a function of aquifer storage levels, which would significantly influence simulated water supply decisions.

2. Agricultural economic function refinement on the irrigation district level. The current agricultural economic values for water deliveries were derived from results of the Statewide Water and Agricultural Production Model (SWAP) (Howitt, et al. 1999). FREDSIM uses the economic results for large regions within the Central Valley by distributing them into monthly economic value functions and disaggregating them proportionally by irrigated acreage. By dividing regional analysis into the irrigation district level, the model inaccurately applies the same crop type distribution to every district within a SWAP region. A detailed analysis to develop benefit functions for each agricultural contractor will improve the accuracy in determining water demands and the economic consequences of not meeting them.

3. Cross Valley Canal exchange operations improvement. Operation of the Cross Valley Canal depends on the operations of the Delta, which are undergoing considerable change. The State Water Project and Delta operations are quite complex and are not modeled in this version of FREDSIM. However, some generalities could be derived from recent operations and integrated into FREDSIM.

4. Non-Friant surface water supplies improvement. The current understanding of non-Friant surface water supplies is based on Reclamation’s Water Needs Assessment of 2000, required for the contract renewal process. Typical and average annual non-Friant supplies are known, but the monthly distribution and costs are estimated for this version of FREDSIM. Input from water managers would improve this aspect of FREDSIM.

5. Temporary water transfer simulation. FREDSIM currently does not allow use of Friant water without contractual ownership or use exceeding contract amounts. Transfers within the Friant Division are a critical aspect of water management practices of the system. Proper understanding of Friant water distribution must include a representation of these transfers. Long-term agreements and strategic alliances among Friant contractors that facilitate temporary transfers are not well documented. An approach worth investigating would be to model the Friant Division as a free internal water market. Under this scenario all water supply decisions would be based on achieving maximum economic benefit to Friant Division users without consideration of contract quantities.

6. Groundwater recharge representation. The conjunctive use of surface water and groundwater is simplified in the preliminary model. An algorithm in the MODSIM customization script could simulate intentional recharge operations during times of excess surface water supplies. Because MODSIM optimizes on a per time-step basis, it sees no value in recharging the groundwater especially in anticipation of drought or declining groundwater levels. The economic value of recharge water would have to be calibrated to encourage intentional recharge properly with consideration of pumping costs that change with groundwater levels.

7. Reservoir target calibration. Because MODSIM optimizes on a per time-step basis, it relies on reservoir storage targets to determine how far to drain or fill the reservoirs. Currently, FREDSIM uses targets based on maximum allowable storage according to the flood control requirements. This forces the model to always keep Millerton storage as high as possible after demands are met which may not accurately simulate reservoir operations. Options within MODSIM allow varying the reservoir targets according to hydrologic conditions. The monthly target can also be represented with a series of targets, each with a different penalty for not meeting it. An approach is to have the penalty increase as storage decreases in irrigation months or as storage encroaches on flood space requirements in the flood season. A careful calibration would be required to properly simulate varying reservoir operations.

8. Section 215 water ownership improvement. Section 215 flood water is currently ignored in FREDSIM due to lack of historical data. As it becomes available, allocations could be based on typical operations in recent history (last 10 years). Section 215 water is made available to anyone within the Tulare or San Joaquin basins after Friant contractors and CVC exchangers have placed orders for it. A wide range of historical operations exist with respect to flood water making simple simulation difficult.

9. USAN integration. Another Reclamation simulation model, USAN, simulates the operations of the Upper San Joaquin River above Millerton Lake. Output from USAN could easily be input as Millerton Lake inflows to understand the effects of hydropower operations above Friant Dam and the effect on the quantity and timing of irrigation deliveries. USAN is currently being calibrated by others for Reclamation.

10. Friant contractor data. In general, increased data and input from the Friant water users would have the most significant impact on the continued model development. Simulating water management decisions could be accurately calibrated and verified with more input and involvement with the actual water managers. Current negotiations between the Friant contractors and Reclamation has created a tense atmosphere. This will likely be temporary as contracts are signed and water users can feel comfortable for at least the next 25 years. While contracts may ensure some reliability of water supplies, the current era of environmental restoration will not likely fade any time soon. The economics driven model that has been developed could be a valuable tool for water users in evaluating future environmental proposals and the economic effects. Future work on FREDSIM includes demonstrating the running model for the users, soliciting their input, and addressing their concerns.

Conclusions

A running model, FREDSIM, has been developed to simulate the water supply operations of the Friant Division of the Central Valley Project according to economic drivers. This water management model is required for planning and policy analysis of the Friant Division with its unique pricing structure, conjunctive use operations, and its host of water management issues. Reclamation’s hypothesis that water management decisions are made from an economic standpoint has been represented by FREDSIM. This preliminary model demonstrates how economic drivers indeed fairly simulate the water management decisions within the Friant Division.

FREDSIM model runs for the water years 1985-1994 demonstrate how water supply decisions are made according to economics within the Friant Division. Certainly, the preliminary model run also demonstrates the need for more information. Due to recognized deficiencies in some simulated Friant operations and contractor data, a detailed calibration of the model could not be performed. However, these preliminary model runs produced some interesting results and trends while establishing a starting point for calibration. Most importantly, the preliminary model demonstrated a concept that can be refined into a useful water management tool for Reclamation’s planning or operations division, Friant water users, environmental groups, and related water policy interests to analyze future water supply policies and scenarios for the Friant Division.

REFERENCES

Anderson, Jon (2000). U.S. Bureau of Reclamation, Mid-Pacific Region. personal communication. September.

Andrews, Elizabeth S. (1989). *Simulation of Kern County, California's Conveyance System, Including Groundwater Recharge*. Master's Thesis. University of California, Davis.

Baca, R.B. (1999). *Boise MODSIM Model: A Verification, Analysis, and Calibration*. Master's Thesis. Colorado State University.

Baldo, Marc (1995). *MODSIM Water Rights Planning Model*. Department of Civil Engineering, Colorado State University. http://129.82.224.229.

Brown, C., Goldman, G., Howitt, R., Siebert, J., and Sullins, J. (1996*). Impacts of Water Reallocations on the Eastern San Joaquin Valley*. University of California.

Buelna, Antonio (1999). U.S. Bureau of Reclamation, Mid-Pacific Region. personal communication. December.

CALFED (2000). *California's Water Future: A Framework for Action*. June.

California Department of Water Resources (1982). *Bulletin 214: The Hydrologic-Economic Model of the San Joaquin Valley, Appendix C*. December.

California Department of Water Resources (1989). *Kern Conveyance Operation Model*. Division of Planning. August.

California Department of Water Resources (1993). *California Water Plan Update, Bulletin 160-93*.

California Department of Water Resources (1998). *California Water Plan Update, Bulletin 160-98*.

California Department of Water Resources (2000). *Chronological Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices.* http://cdec.water.ca.gov/cgi-progs/iodir/wsihist.

California Division of Engineering and Irrigation (1922). *Bulletin No. 3, Water Resources of Tulare County and Their Utilization*.

California Division of Engineering and Irrigation (1923). *Bulletin No. 4, Water Resources of California*.

California Divisions of Engineering and Irrigation and of Water Rights (1927a). *Bulletin No. 11, Ground Water Resources of the Southern San Joaquin Valley*.

California Divisions of Engineering and Irrigation and of Water Rights (1927b). *Bulletin No. 12, Summary Report on the Water Resources of California and a Coordinated Plan for Their Development*.

Central Valley Project Improvement Act (1992). Public Law 102-575, Title XXXIV.

Fredericks, Jeffrey W., Labadie, John W., Altenhofen, Jon M. (1998). "Decision Support System for Conjunctive Stream-Aquifer Management," *Journal of Water Resources Planning and Management*. Vol. 124, No. 2. March/April.

Fresno Department of Public Utilities (1999). *The Water Report*. Winter 1999-2000.

Frevert, Donald K., Labadie, John W., Larson, Roger K., Parker, Nancy L. (1994). "Integration of Water Rights and Network Flow Modeling in the Upper Snake River Basin," *Proceedings, 21st Annual Conference*, Water Resources Planning and Management Division, D.G. Fontane and H.N. Tuvel, eds. ASCE, Denver, Colorado.

Friant Water Users Authority (1997-2000). *Waterline: The Journal of the Friant Water Users Authority*. several monthly issues.

Friant Water Users Authority (1998). *Friant-Kern Canal Structures List*.

Friant Water Users Authority (1999). *Informational Report for the Friant-Kern Canal and Supporting Facilities*.

Friant Water Users Authority (2000a). Central Valley Project Contract Renewals: Informational Handout for the January 26 Friant Division Negotiations.

Grossi, Mark (1999). *Rescuing the San Joaquin, A Special Report*. The Fresno Bee. California. http://fresnobee.com/man/projects/savesjr/mainbar.html.

Howitt, Richard, and Lund, Jay R. (1999). *Integrated Economic-Engineering Analysis of California's Future Water Supply*. Civil and Environmental Engineering, University of California, Davis. http://cee.engr.ucdavis.edu/faculty/lund/CALVIN.

Hundley, N.J. (1992), *The Great Thirst: Californians and Water, 1770's-1990's,* The University of California Press, Berkeley, CA.

Labadie, John W. (1994). *MODSIM: Interactive River Basin Network Flow Model*. Department of Civil Engineering, Colorado State University. http://129.82.224.229/concepts/moddoc.html.

Labadie, John W. (1997). “Reservoir System Optimization Models,” *Water Resources Update*. No. 108, Summer, pages 83-110.

Labadie, John W., Bode, Dennis A., Pineda, Andrew M. (1986). “Network Model for Decision-Support in Municipal Raw Water Supply,” *Water Resources Bulletin*. Vol. 22, No. 6, December.

Littleworth, A.L. and Garner, E.L. (1995). *California Water*. Solano Press Books. Point Arena, California.

Madeheim, Huxley T. (2000). *Evaluation of Potential Increases in Millerton Lake Water Supply Resulting From Changes in Upper San Joaquin River Basin Project Operation*. Report for the U.S. Bureau of Reclamation, Mid-Pacific Region Sacramento, California.

Moss, R.M. (1998). *Written Testimony to the U.S. House of Representatives, Committee on Resources, Subcommittee on Water and Power by the General Manager of the Friant Water Users Authority*. Fresno, California. April.

Northwest Economic Associates (1993). *Economic Impacts of the 1992 California Drought and Regulatory Reductions on the San Joaquin Valley Agriculture Industry*. Report for the San Joaquin Valley Agricultural Water Committee. December.

Northwest Economic Associates (1997). *Analysis of the Impacts of Surface Water Reductions on the Eastern San Joaquin Valley of California*. Report for the Friant Water Users Authority. August.

Parker, Nancy (2000). *Draft User Manual for MODSIM*. Report for the U.S. Bureau of Reclamation. December.

Ruud, N.C., A.W. Naugle, T. Harter (1999). “A GIS-Linked Conjunctive Use Groundwater-Surface Water Flow Model for the Tule River Basin, Southeastern San Joaquin Valley, California.” *Proceedings, International Conference on Calibration and Reliability in Groundwater Modeling*. Zurich, Switzerland. September. http://www.uckac.edu/groundwater/UCCEgw-203.htm.

U.S. Army Corps of Engineers (1933). *Sacramento, San Joaquin, and Kern Rivers, California: Letter from the Secretary of War*. 73d Congress, House Document No. 191.

U.S. Army Corps of Engineers (1980). *Report on Reservoir Regulation for Flood Control: Friant Dam and Millerton Lake, San Joaquin River, California*. Sacramento District.

U.S. Army Corps of Engineers (1990). *Engineers and Irrigation: Report of the Board of Commissioners on the Irrigation of the San Joaquin, Tulare, and Sacramento Valleys of the State of California, 1873.*

U.S. Army Corps of Engineers (1999). *Draft Reservoir System Analysis for Phase I of the Sacramento and San Joaquin River Basins Comprehensive Study*. Hydrologic Engineering Center. Davis, California.

U.S. Bureau of Reclamation (1994). *Bureau of Reclamation History Program: The Friant Division*. Denver, Colorado. http://dataweb.rsgis.do.usbr.gov/html/frianth.htm.

U.S. Bureau of Reclamation, Mid-Pacific Region (1975). *Final Environmental Statement: Use of Central Valley Project Water Through Enlarged Cross Valley Canal*. Sacramento, California.

U.S. Bureau of Reclamation, Mid-Pacific Region (1992). *Forty First Annual Water Supply Report, 1991*. Fresno Office of the Central Valley Project, California.

U.S. Bureau of Reclamation, Mid-Pacific Region (2000a). *Draft Environmental Assessment: Blanket Approval of Temporary Transfers and Exchanges of Project Water Between Friant Water Service Contractors*. Sacramento, California.

U.S. Bureau of Reclamation, Mid-Pacific Region (2000b). *Friant Contractor Water Needs Assessment*. Sacramento, California.

U.S. Department of Agriculture and California Department of Food and Agriculture (2000). *California Agricultural Statistics Service: Fact Finders for California Agriculture*. http:/nass.usda.gov/ca.

U.S. Department of the Interior, Bureau of Reclamation, and Fish and Wildlife Service (1999). *Central Valley Project Improvement Act Final Programmatic Environmental Impact Statement, Executive Summary*. Sacramento, California.

Vaux, H.J. (1986). “Water Scarcity and Gains From Trade in Kern County, California,” *Scarce Water and Institutional Change*, K. Frederick, editor. Resources for the Future, Washington, D.C.

Water Agencies of Kern County (1983). *Report on Investigation of Optimization and Enhancement of the Water Supplies of Kern County*. Bakersfield, California.

APPENDIX A: ACRONYMS

af	acre-foot or acre-feet
CALFED	California and Federal partnership established for solving the water supply and environmental problems of the Sacramento-San Joaquin Delta.
CALVIN	California Value Integrated Network Model
CDEI	California Department of Engineering and Irrigation
cfs	cubic feet per second
CVC	Cross Valley Canal
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
DMC	Delta-Mendota Canal
DWR	California Department of Water Resources
FKC	Friant-Kern Canal
FREDSIM	FRiant Economics-Driven SIMulation Model
FWUA	Friant Water Users Authority
kaf	thousand acre-feet
maf	million acre-feet
SWAP	Statewide Water and Agricultural Production Model
SWP	California State Water Project
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
MC	Madera Canal
MWD	Metropolitan Water District of Southern California

Contractor Abbreviations

AEWD	Arvin-Edison Water Storage District
CHWD	Chowchilla Water District
DEID	Delano-Earlimart Irrigation District
EXID	Exeter Irrigation District
FC18	Fresno County #18
FRCO	Fresno County
FRCY	Fresno, City of
FRID	Fresno Irrigation District
GAWD	Garfield Water District
GFWD	Gravelly Ford Water District
HVID	Hills Valley Irrigation District
INWD	International Irrigation District
IVID	Ivanhoe Irrigation District
KTWD	Kern-Tulare Water District
LCWD	Lewis Creek Water District
LIID	Lindmore Irrigation District
LSID	Lindsay-Strathmore Irrigation District
LTID	Lower Tule River Irrigation District

LWSA	Lindsay, City of
MACO	Madera County
MAID	Madera Irrigation District
OCID	Orange Cove Irrigation District
OCCY	Orange Cove, City of
PXID	Pixley Irrigation District
POID	Porterville Irrigation District
RGWD	Rag Gulch Water District
SAID	Saucelito Irrigation District
SWID	Shafter-Wasco Irrigation District
SSMD	Southern San Joaquin Municipal Utility District
SCID	Stone Corral Irrigation District
TPWD	Tea Pot Dome Water District
TBID	Terra Bella Irrigation District
TVWD	Tri-Valley Water District
TUCO	Tulare County
TUID	Tulare Irrigation District

APPENDIX B: METHODS AND DETAILS

Agricultural-Economics

As stated in Chapter 4, FREDSIM utilizes scaled SWAP results to quantify the agricultural economic value of irrigating crops. The SWAP model results are step functions that relate the marginal value of agricultural production to the monthly quantity of applied irrigation water within each SWAP region (the same as CVPM regions). MODSIM, the FREDSIM solver, is a linear model, thus requiring linear functions. SWAP value functions are integrated and converted to piece-wise linear value functions that relate total value of agricultural production to applied irrigation water. There are nine monthly functions for every CVPM region representing a nine-month irrigation season. There are no irrigation demands in November through January. The preliminary agricultural economic functions for FREDSIM are regional SWAP results that are scaled down to represent individual Friant contractors. The steps to make SWAP results usable in FREDSIM are applied to the Tulare Irrigation District (TUID) value function for the month of July as an example.

1. *Obtain SWAP results for the CVPM region in which each contractor is located, using CVPIA-PEIS descriptions and maps.*

SWAP results are in the form of a penalty function. TUID is in Region 18. The loss of agricultural production (penalty) for delivering 264.1 kaf to CVPM Region 18 is $50,000,730, but there is no penalty for delivering the full demand, 474.0 kaf. Full demand is the point where the marginal value of water equals zero.

Table B.1: CVPM Region 18 SWAP Results for July

Applied Irrig. Water (kaf)	Total Ag. Penalty (k$)
264.1	50,007.73
307.2	33,138.39
350.4	19,539.04
393.5	9,272.62
436.7	2,295.81
474.0	0

2. *Scale the CVPM regional SWAP results according to irrigated acreage (1996 data or best available) for each agricultural contractor.*

TUID of CVPM Region 18 has 75,582 irrigated acres. Region 18 has 592,000 irrigated acres resulting in a scale factor of 0.1277. The point of zero penalty occurs when full demand is met (60,517 acre-feet).

Table B.2: CVPM Region 18 SWAP Results Scaled for TUID

Applied Irrig. Water (kaf)	Total Ag. Penalty (k$)
33.718	6,384.60
39.221	4,230.85
44.736	2,494.59
50.239	1,183.85
55.754	293.11
60.517	0

3. *Represent in MODSIM the five-piece-wise linear and scaled SWAP results with five links (see Figure 4.4), each with an upper bound and a cost.*

All data is rounded to integers and converted to acre-feet and dollars. Continuation of the TUID example is shown in Tables B.3 and B.4.

Table B.3: Slopes Calculated for TUID Agricultural Economic Function

Applied Water (af)	Ag. Penalty ($/af)
39,221	-391
44,736	-315
50,239	-238
55,754	-162
60,517	-62

Table B.4: Upper Bounds and Costs for TUID Agricultural Economic Links

FREDSIM Link Name	Upper Bound	Cost
	Applied Water (Δaf)	Ag. Penalty ($/af)
AG1-TUID	39,221	-391
AG2-TUID	5,515	-315
AG3-TUID	5,503	-238
AG4-TUID	5,515	-162
AG5-TUID	4,763	-62

TUID’s total July agricultural demand for applied irrigation water is 60,517 acre-feet, the sum of the five upper bounds or “Δaf’s”. There is no economic benefit to delivering more than this quantity to TUID. The names for the five links representing Tulare Irrigation District in the FREDSIM model and required by the Perl script (see script description in Appendix C) are AG1-TUID, AG2-TUID, AG3-TUID, AG4-TUID, and AG5-TUID. This naming convention is consistent for all Friant contractors using their four-letter abbreviated name. See Appendix A for these abbreviations. The steepest portion of the function is represented with the AG1-TUID link at -$391/acre-foot. The negative sign converts the penalty into a benefit of $391 for every acre-foot of water delivered in July up to 39,221 acre-feet. The benefits decrease after the initial 39,221 acre-feet are delivered.

This process was completed for all 29 agricultural contractors for every month and written into a data file readable by the FREDSIM Perl script (see Appendix C). MODSIM, which optimizes to minimize the system-wide cost every time-step, requires this conversion of agricultural economic benefits to upper bounds and negative costs on links. The first upper bound corresponds to the "endpoint" of the first line representing the first portion of the function. The next upper bound is the next increment of applied water. The slopes of the lines are calculated and the first one is projected to the y-axis. The costs are the negative slopes from endpoint to endpoint. When MODSIM runs, it "fills" the agricultural benefit links with the highest value (i.e. AG1-TUID) first as it draws from the least expensive water sources to the most expensive. As the benefits decrease, water will only be delivered if the unit benefit is greater than the unit water cost. Also, in water-short years, deliveries of local supplies (non-Friant) will be made to the contractors with higher-valued crops before lower-valued crops.

For further information on the SWAP model and SWAP results refer to the CALVIN report (Howitt, et al 1999), Chapter 6 and Appendix A.

Groundwater Pumping Costs

As described in Chapter 4, groundwater pumping costs in FREDSIM do not change as groundwater levels change, but the difference in cost between contractors is represented based on pumping head differences. It is important to note that groundwater levels change from year to year as withdrawals are made and aquifers are replenished by natural inflow, irrigation return flows, and artificial recharge. Also, groundwater depths may vary greatly within larger irrigation districts, which is not considered. For reference, the pumping costs used in this version of FREDSIM are listed in the Table B.5 along with the 1992 depth to groundwater data and the CVPM region. The equation for pumping cost from the CVPIA-PEIS is $11/acre-feet + $0.20 per foot of lift (USDOI 1999).

Table B.5: Groundwater Pumping Costs in FREDSIM

Contractor	1992 Depth to GW (ft)	Pumping Cost ($/af)	Notes	CVPM Region
AEWD	345	80		21
CHWD	126	36		13
DEID	147	40		18
EXID	61	23		18
FC18	0	0	no GW pumping.	16
FRCO	0	0		16
FRID	62	23		16
FRCY	0	0	GW pumping not modeled.	16
GAWD	110	33		16
GFWD	100	31	no data, use MAID depth.	13
HVID	40	19	no data, use OCID depth.	17
INWD	41	19		16
IVID	72	25		18
KTWD	168	45	no data, use SSMD depth.	20
LCWD	46	20		18
LIID	56	22		18
LWSA	0	0	no GW pumping.	18
LSID	59	23		18
LTID	105	32		18
MACO	0	0	no GW pumping.	13
MAID	100	31		13
OCID	40	19		17
OCCY	0	0	no GW pumping.	17
PXID	126	36	no data, use avg. LTID & DEID	18
POID	47	20		18
RGWD	158	43	no data, use avg. KTWD & DEID	18
SAID	147	40		18
SWID	263	64		20
SSMD	168	45		20
SCID	29	17		18
TPWD	139	39		18
TBID	161	43		18
TVWD	0	0	no GW pumping.	17
TUCO	0	0	no GW pumping.	18
TUID	104	32		18

APPENDIX C: MODSIM TECHNICAL INFORMATION

MODSIM Notes

Details of historical and technical information on MODSIM can be found in Fredericks (1990) and Labadie (1986, 1994). MODSIM uses the Lagrangian Relaxation Algorithm optimization routine to find optimal solutions for each time-step as discussed by Baca (1999). Details of constructing a model with MODSIM and use of the graphical user interface is found in Fredericks (1990), Baldo (1995) and Labadie (1994, 1998). The most updated and comprehensive user manual is currently being developed at the Bureau of Reclamation by Parker (2000).

MODSIM Customization

A powerful tool in conjunction with MODSIM is the use of Perl scripts. Perl is a self-compiling language common in internet files and operations. Details of a water system can be modeled without hardwiring the functionality in MODSIM. The Perl script runs within the MODSIM model run and can access MODSIM model variables during the iteration process (Parker 2000). It manages designated links by changing the upper bound and cost for variables that change monthly or annually.

Annual Functions of Perl Script

1. Sets the price of Class 1, Class 2, and Section 215 water (the cost on 1-links, 2-links, and 215-links). These water prices remain constant for the model run. This prevents the tedious entry of cost data in the interface for 35 contractors when changing Friant water prices. FREDSIM assumes that the price for each class of water is the same for all contractors, which is not necessarily true (see Chapter 2, Pricing and Conjunctive Use), but a reasonable modeling simplification.

2. Resets all Friant accounts to zero just before March 1, the beginning of the Friant water year. This version of FREDSIM does not allow contractors to carry-over their Friant water from the previous water year to the current year.

Monthly Functions of Perl Script

1. Establishes the total amount of Class 1, Class 2, and 215 water allocated for the water year. This can change monthly if the Friant forecast changes.

2. Sets the initial contractor account balances (changes upper bound on 1-links, 2-links, and 215-links) according to the Friant allocation and each contractor's ownership of Friant water.

3. Maintains a running balance for contractors' Friant water based on the previous month's delivery and account balance.

4. Applies agricultural economic value functions to the AG1-links through AG5-links (upper bounds and costs). These values change every month and repeat every year.

5. Sets the upper bound and cost for groundwater pumping (GW-links).

6. Sets the upper bound and cost for Non-Friant surface water supplies (EXT-links).

The current version of FREDSIM has disabled the original script functionality that defines the unit cost on the external sources (EXT-links) and groundwater pumping (GW-links) each month. These water prices as modeled do not change monthly and were defined in the interface rather than by the Perl script. Monthly varying groundwater pumping cost could be valuable for future FREDSIM refinement. A function could define a dynamic pumping cost (changing pumping head) to simulate changes in groundwater levels.

A data file, separate from the MODSIM input file, is required to be read by the Perl script. This file, which is mostly irrigation district parameters, is named “IRRPARAM”. Urban contractors are also in the IRRPARAM file, but only have a single economic link, AG1-link, with a steep cost ensuring that water will be delivered when available. The order of each contractor in the file is not critical. When the script reads a data point in IRRPARAM it will look for the associated link in the model to populate with upper bound and cost data. It is critical that any link listed in the IRRPARAM data file is located in the MODSIM input file, “*.xy”.

FREDSIM Schematic in MODSIM

The complete MODSIM schematic as represented in the MODSIM interface is presented in Figures C.1a and C.1b.

Figure C.1a: FREDSIM Schematic in the MODSIM Interface

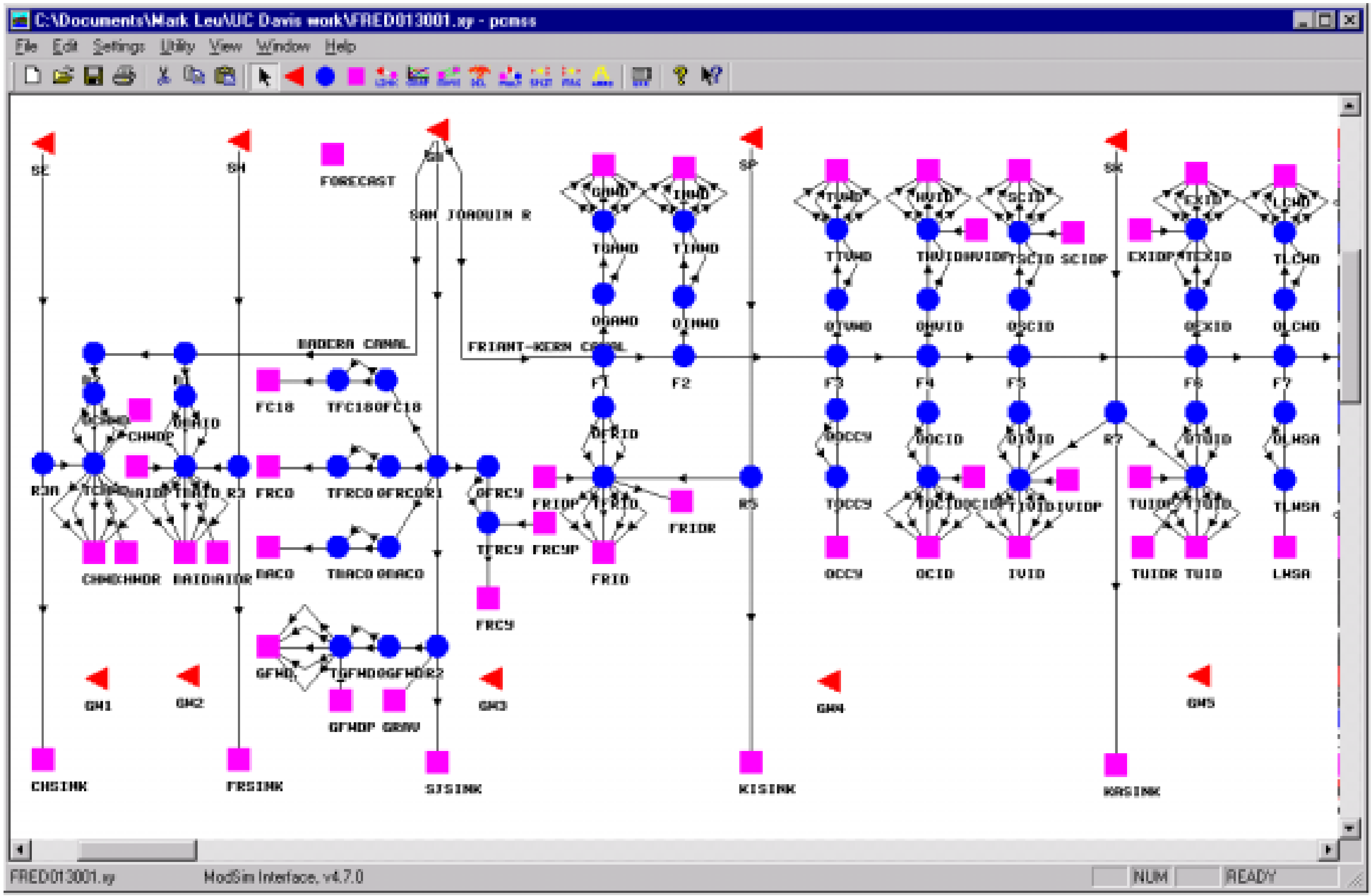
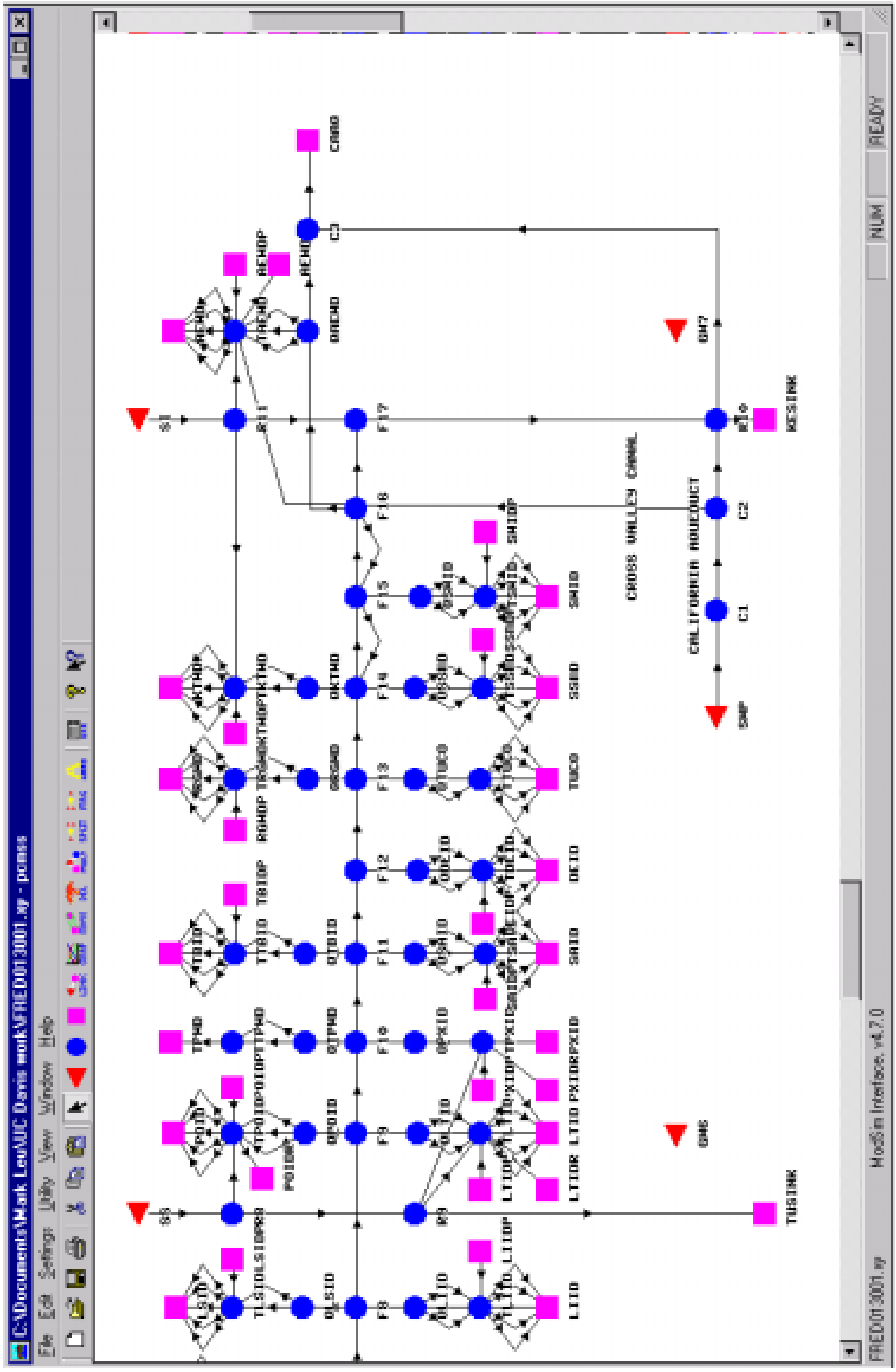


Figure C.1b: FREDSIM Schematic in the MODSIM Interface (continued)



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 FRED010101

The model will quit running if an error (missing data or missing link) occurs in reading IRRPARAM, the data file read by the Perl script. A typical model run requires about a half minute for a 10-year run on a 350 MHz Pentium PC with 96 MB of RAM. For more details on running MODSIM, refer to Parker, 2000.

Model Output

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 in Table C.1.

Table C.1: 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.