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Computer-Based Decision Support Tools for Evaluation of Actions Affecting Flow and Water Quality in the San Joaquin Basin

N.W.T. Quinn

January 1993

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1. NEEDS AND OBJECTIVES

The objective of this report is to draw together a system of computer-based planning models that can be used to simulate the major hydrological and water quality characteristics of the San Joaquin Basin. These models range in detail and in scope from those that simulate infiltration and drainage quality at the field level to those which simulate groundwater and surface water flow at the scale of a river basin.

Current interest and ongoing investments in real time monitoring of flow and water quality at various control points along the San Joaquin River pre-supposes that this information can be manipulated to improve management of flow and water quality within the San Joaquin River. Flow and water quality data by themselves will not be of great assistance in improving conditions within the San Joaquin River since at the time the data is received, the opportunity to have taken actions will have passed. Furthermore the impacts of these actions on the river basin hydrology and environmental quality need to be understood in advance to avoid conflict between the various parties directly or indirectly affected by the action. Analyses of these impacts is especially important as a result of the recent publication of D-1630 in draft form by the State Water Resources Control Board (SWRCB) and the recent passage of Public Law 102-575, Title 34, the Central Valley Project Improvement Act. These documents create new problems for water resources engineers and planners to solve and, at the same time, create new opportunities for resolving old conflicts with creative solutions.

The contaminants carried by the San Joaquin River into the Delta will continue to limit potential use of Sacramento River Water for export as well as cause seasonal hardship to farmers in the South Delta, especially during the early spring months. Prior warning of pulse flows or, at other times, reduced flows (typically associated with high contaminant concentrations in the river) could assist Delta growers in timing their irrigation operations to coincide with periods of superior San Joaquin River water quality. Prior warning of these events could be provided with the establishment of a system of stations providing real time flow and water quality data. Real-time management of the flow and quality of subsurface drainage return flows to the San Joaquin River also may be made easier through the establishment of a network of real-time flow and water quality monitoring stations in drainage conveyance channels serving agricultural water districts as well as in the San Joaquin River. Use of this data is predicated on an ability to make forecasts and predict impacts in advance of prescribed actions must be developed. These analyses and projections require the development of accurate water flow and water quality simulation models.

In the past decade simulation models of various components of San Joaquin Valley hydrology and water quality have been developed. The objective in constructing these models was typically very specific, such as the estimation of minimum leaching and drainage requirements to sustain plant growth on an individual field or the impact of barriers on a Delta channel on salinity intrusion during times of high Delta export. Few of these models have been linked or have been considered within a hierarchical framework that follow salt from its dissolution at the farm level to its capture in drains, transport to the San Joaquin River and the Sacramento-San Joaquin Delta and its possible return via the Delta Mendota Canal or California Aqueduct to its point of origin. The challenge made in considering real time operation of water quality and flow in the San Joaquin Basin is two-fold. First to develop an understanding of the working of the

system as a whole and second to use this knowledge to project future system behavior sufficiently to enable real time management.

The goals of this preliminary effort are therefore :

(a) To catalog the existing models that have potential for incorporation into a hierarchical system model of the San Joaquin Basin hydrology and water quality.

(b) To ascertain the capability and utility of each of these models in relation to other similar models.

(c) To show how these models might be linked and used within a hierarchical modeling system to predict and project flow and water quality.

The author does not have working expertise in the hydrodynamic flow models of the San Francisco Bay Estuary and the Sacramento - San Joaquin Delta - hence a decision was made to limit this review to models of the San Joaquin Basin which the author has been directly involved in developing or reviewing. A separate report will be prepared by Reclamation staff comparing the various hydrodynamic flow models. Because references are made, within this document, to these models hence summary tables of the characteristics of these models has been included (Table 1 and Table 2).

This review concentrates on models used in planning studies rather than for project operation. Planning studies typically compare and contrast the results of model runs and are not as concerned with absolute values of water levels or temporal and spatial salinity concentrations as is true of studies of facility operations. Since it is envisioned that these models will become part of a toolbox of models used singly or in a linked manner to help solve water supply and water quality problems in the San Joaquin Valley, several criteria were paramount in model selection and in the manner in which this review was carried out. These criteria were :

(a) Model reliability and its ability to make accurate simulations of the system. Physics - based models are given preference over empirical models.

(b) The ease of use of the model and the time it would take for a novice user to become proficient in making simulations with the model. User interfaces and the inclusion of data pre-processors and output post-processors can have a great influence on making models more understandable and in accelerating the novice user along the learning curve typically associated with data-intensive simulation models.

(c) The relative expense of using and maintaining a model considers both the execution time of a simulation run and the difficulty of updating the model to reflect current conditions or to create a planning scenario that hitherto has not been developed for the model.

(d) The architecture of the model and the input and output formats that affect the ease of linking one model with another. This can be affected by model time step (hourly, daily, monthly, seasonally or annual) and by the ease with which output data files can be manipulated.

This report includes a section on the utility of the various models reviewed for planning studies contemplated during the next 5 years within Reclamation. The manner in which these models could be used for these studies is described as well as the effort that would need to be expended to link the models to make a more comprehensive analysis.

Table 1. Overview of the features of the selected models

	MODEL NAME AND ACRONYM	Model type	Model Status	Computer software / minimum computer hardware requirements (micro/mini/mainframe)	User interface	Speed of execution per year simulated (workstation)	Model ownership / public access
					o - no attempt * - primitive ** - advanced	* < 5 mins ** 5 - 30 mins *** > 30 mins	
	HYDRO-DYNAMIC SALINITY MODELS						
1	Fischer - Delta Model (FDM)	Hydro-dynamic stage and water quality	Complete / in use	Fortran / workstation or main - frame	o	**	H.B. Fischer / proprietary
2	Wong and Chen Model	Hydro-dynamic stage and water quality	Under development	Fortran / workstation or main frame	o	**	Wong / USBR public domain
3	RMA Link-Node Model	Hydro-dynamic stage and water quality	Complete / in use	Fortran / microcomputer or workstation	o	**	RMA public domain
4	DWR Delta Simulation Model (DWR-DSM)	Hydro-dynamic stage and water quality	Complete / in use / ongoing development	Fortran / SUN workstation	**	**	DWR proprietary
	REGIONAL BASIN MODELS						
5	San Joaquin Area Simulation Model (SANJASM)	Monthly surface flow balance	Complete / in use	Fortran / IBM compatible 386	o	*	USBR public domain
6	San Joaquin - Tulare Conjunctive Use Model (SANTUCM)	Monthly surface and groundwater flow	Needs more work incomplete salt model	Fortran / IBM compatible 386	o	*	USBR public domain
7	Westside Agricultural Drainage Economics Model (WADE)	Seasonal groundwater flow and salinity mass balance ; optimization	Complete	GAMS - MINOS Unix workstations	*	*	USBR public domain
8	South Delta Salinity Model (SDSM)	Monthly salinity balance and user interface for RMA link-node model	Complete / in use	C / Macintosh II or IBM compatible 386	**	*	UCD unknown
9	Central Valley Groundwater and Surface Water Mode (CVGSM)	Monthly groundwater flow	Complete / in use	Fortran / IBM 386	*	*	USBR public domain
	SUB-REGIONAL MODELS						
10	Grasslands Water Quality Simulation Model (GWSDN)	Monthly flow and selenium balance	Complete	Fortran / IBM compatible 386	*	*	USBR public domain
	GWSDN - STELLA	Monthly flow and selenium balance	Under development	STELLA / MacIntosh	**	*	LBL / USBR
	Natural Resources Workstation (NRWS)	Hydrodynamic flow and water quality	Under development	SUN / AVION workstation	**	*	CSU / USBR
11	Irrigation and Drainage Operations Model (IRDROP)	Monthly groundwater and salinity ; optimization	Complete / ongoing development	GAMS-MINOS / IBM 386 / Unix workstation	*	*	USBR public domain
12	San Joaquin Input-Output Model (SJRIO2)	Monthly surface flow and water quality	Complete / in use ongoing development	Fortran / VAX workstation	*	*	SWRCB / UCD public domain
13	San Joaquin River Model (SJRMOD)	Monthly surface flow and water quality	ongoing development	Visual basic IBM compatible	*	*	UCD public domain
	FIELD SCALE MODELS						
14	Conceptual Hydrosalinity Model (HYSAM)	Hydrosalinity mass balance	Complete / in use ongoing development	Fortran / MacIntosh / IBM compatible	*	*	UCD public domain
15	Drainage Simulation Model (TOUGH2-DSM)	Groundwater flow and solute transport	Under development	Fortran / CRAY supercomputer / SUN / AVION workstation	o	***	LBL/USBR public domain

Table 2. Utility of the selected models for Reclamation studies

	MODEL NAME AND ACRONYM	Actions to meet water quality objectives for SE, B and EC	Salt balance in the San Joaquin Valley	Drainage reduction policies and planning	Surface and groundwater conjunctive use	Structural options to control stage and water quality	Bay - Delta water quality issues
			KEY	o - should not be used * - can be used indirectly or with other linked models ** - can be used directly			
	HYDRO-DYNAMIC SALINITY MODELS						
1	Fischer - Delta Model (FDM)	*	*	*	o	**	**
2	Wong and Chen Model	*	*	*	o	**	**
3	RMA Link-Node Model	*	*	*	o	**	**
4	DWR Delta Simulation Model (DWR-DSM)	*	*	*	o	**	**
	REGIONAL BASIN MODELS						
5	San Joaquin Area Simulation Model (SANJASM)	**	*	*	**	o	*
6	San Joaquin - Tulare Conjunctive Use Model (SANTUCM)	**	**	*	**	o	*
7	Westside Agricultural Drainage Economics Model (WADE)	**	**	**	**	o	*
8	South Delta Salinity Model (SDSM)	*	**	*	*	**	**
9	Central Valley Groundwater and Surface Water Model (CVGSM)	*	*	*	**	o	*
	SUB-REGIONAL MODELS						
10	Grasslands Water Quality Simulation Model (GWSDN)	*	*	*	o	o	*
	GWSDN - STELLA	*	*	*	o	o	*
	Natural Resources Workstation (NRWS)	*	*	*	*	o	*
11	Irrigation and Drainage Operations Model (IRDROP)	**	**	**	**	o	*
12	San Joaquin Input-Output Model (SJRIO2)	**	**	**	*	*	*
13	San Joaquin River Model (SJRMOD)	**	**	**	*	*	*
	FIELD SCALE MODELS						
14	Conceptual Hydrosalinity Model (HYSAM)	*	**	*	*	o	o
15	Drainage Simulation Model (TOUGH2-DSM)	*	*	*	o	o	o

2. REGIONAL BASIN MODELS

2.1 SANJASM (San Joaquin Area Simulation Model)

2.1.1 General description and purpose of model

The San Joaquin Area Simulation Model (SANJASM) simulates surface water operations within the San Joaquin Basin between Millerton Lake and the Delta. The model considers salinity only to the extent that New Melones is operated in such a manner to meet objectives for total dissolved solids set at the monitoring station at Vernalis.

2.1.1.1 Geographic extent of the model

The SANJASM area is shown in Figure 1 and covers the upper two-thirds of the San Joaquin Valley from the San Joaquin River at Mendota Pool northward to the Sacramento - San Joaquin River Delta. The model considers the San Joaquin River and its tributaries including the Cosumnes, Mokelumne, Calaveras, Stanislaus, Tuolomne, Merced, Chowchilla and Fresno Rivers.

2.1.1.2 Features of model

The SANJASM was designed as a planning tool to help evaluate the impacts of alternative instream flow criteria, possible changes in operations, increased conjunctive use of groundwater resources, power generation and new physical facilities. The model performs mass balances of flow along each stream reach subject to operating rules for upstream reservoirs and irrigation demands at known diversion points. Operating rules include criteria such as Corps of Engineers flood control storage limits, downstream fishery flows (where applicable), minimum storage levels, releases for downstream senior water rights holders, lake evaporation and power releases.

The SANJASM calculates groundwater pumping as a residual when irrigation water demands are not satisfied by surface water diversions and project deliveries. A minimum and maximum amount of pumping are assumed for each area associated with a river node in the model. A shortage is indicated when water demands for these areas can be met neither by surface water supplies or groundwater pumping. The model does not calculate stream - aquifer interactions but rather reads stream accretions or depletions from a file which provides a time series of these fluxes which vary according to water year type.

2.1.1.3 Capability of the model : flow / flow and water quality

The model deals primarily with flow and servicing of legal contracts for water supply. The model does not explicitly consider water quality. A regression relationship has been developed between flow and TDS at the Vernalis compliance point on the San Joaquin River. The SANJASM uses this relationship to estimate TDS

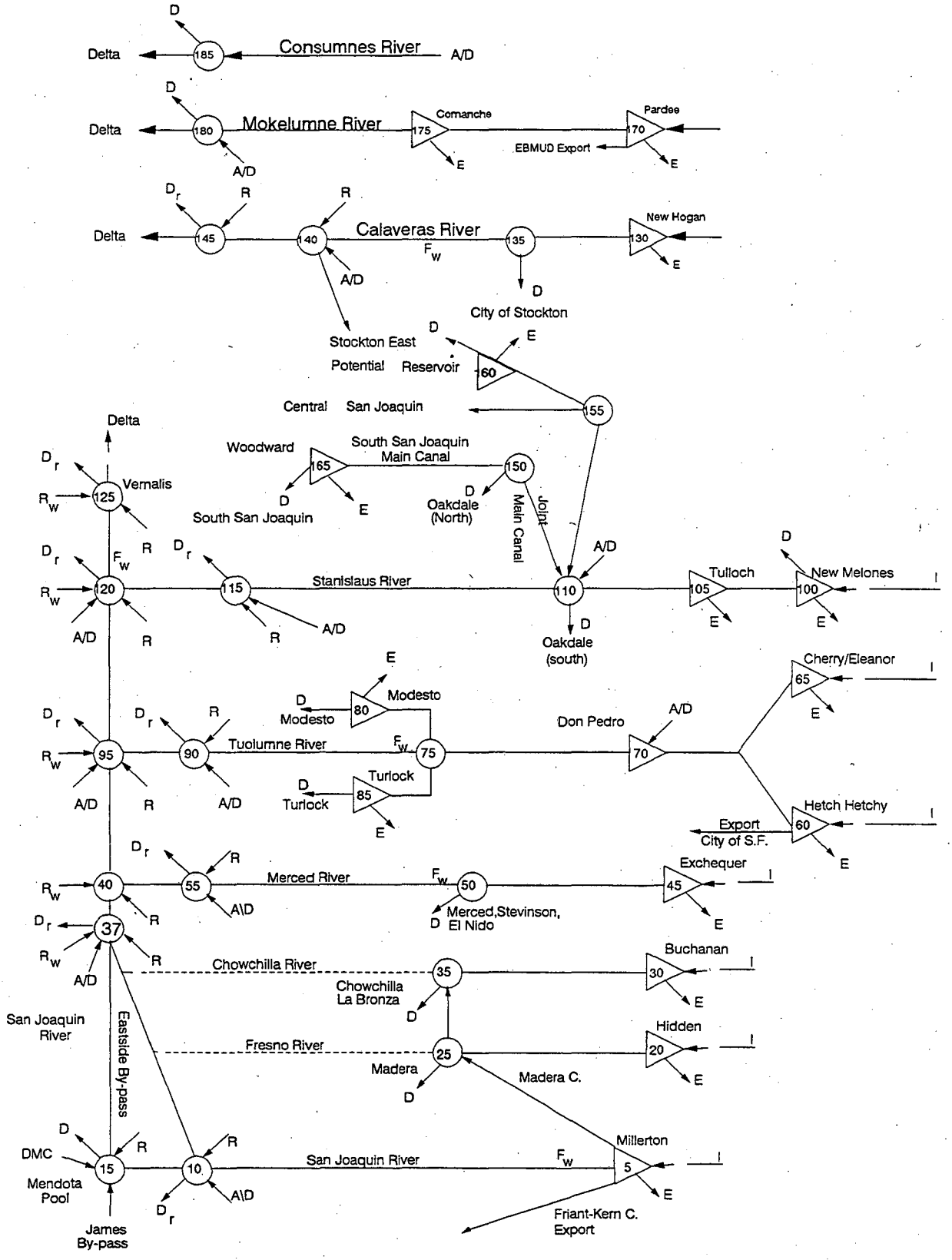

Figure 1. Nodal network and major features of the San Joaquin Area Simulation Model (SANJASM).
(Source : U.S. Bureau of Reclamation)

and hence calculate the volume of monthly release from New Melones reservoir on the Stanislaus River to meet the 500 ppm water quality criterion at Vernalis. Maintenance of the 500 ppm TDS criterion is required under Reclamation's water right permit for New Melones Reservoir to provide suitable flushing flows for agricultural operations in the South Delta.

2.1.1.4 Simulation time step

The SANJASM utilizes a monthly time step and summarizes results by water year. The model does not route flow along the river network. Use of a smaller time step for the mass balance calculations would involve considerable expansion of the already - large database required to run the model because many of the reservoir operating rules and flow constraints are data-driven. Accounting errors in the flow mass balance would be more likely at timesteps of a week or less because of the time of travel between the reservoirs and the gauging stations on the San Joaquin River, upstream of the Delta. The travel time between the east-side reservoirs and the Vernalis gauging station typically varies between 3 and 10 days depending on the tributary under consideration and the river stage.

2.1.1.5 Computer requirements and portability

The SANJASM was designed to run on an IBM compatible AT computer. The model was originally compiled using MICROSOFT Fortran and has been modified to allow it to run under LAHEY Fortran. The LAHEY compiler utilizes extended memory and provides some advantages in speed of model execution. The model runs in less than 2 minutes on an IBM compatible 486 - 33 MHz machine for a simulation period of 70 years.

2.1.2. Model development

2.1.2.1 Reasons for development of the model

Water resource management in the San Joaquin Basin is complex. Operating rules for the numerous reservoirs within the San Joaquin Basin are variable and have been modified over time in response to modifications in physical structures and in water allocation policy. Water allocation planning studies typically use modified (projected) historic reservoir inflow data together with demands for water supply at either present level or a projected level. With increased demand for water and continued interest in obtaining multiple benefits from reservoir releases, a surface water simulation model was needed to improve estimation of long term reservoir storage and the effects of various water allocation and water contracting policies.

2.1.2.2 History of development and use of the model

Reclamation retained Boyle Engineering Corporation in July 1988 to commence development of the model. Public workshops on the design, calibration and use of the model were conducted during March, 1991 to promote awareness of the model. The SANJASM has been used for water allocation studies by Reclamation

since 1990 and has most recently been used by the SWRCB for estimating tributary inflows and providing input to the SJRIO-2 model.

2.1.2.3 Further development of the model and intended future use

At the time of writing the SANJASM database includes water years from 1922 to 1980. Reclamation has made a commitment to extend the database to the year 1990 and update agricultural demand estimates to a 1990 level of development. During 1992, modifications were made to the code to improve model performance and accuracy. Significant changes include: updated regression equations to use forecasted inflow which better describe flood control operations at Millerton Reservoir and addition of a node upstream of the confluence of the Merced River which aids representation of combined irrigation surface and subsurface return flows from Mud and Salt Sloughs. The sloughs contribute between 50% and 70% of the total salt load conveyed by the San Joaquin River. The additional model node will assist in calibration of the SANJASM and in the evaluation of potential changes to current reservoir operating rules as a means of improving flow conditions and water quality in the lower San Joaquin River and in the South Delta. The SANJASM is being used to compare alternative water allocations for the Friant Division Environmental Impact Statement.

2.1.3 Evaluation of the model

2.1.3.1 Predictive capability and model reliability

The SANJASM is a monthly model which attempts to simulate major water flow between a number of control points along the San Joaquin River and within the various east - side tributaries to the San Joaquin River. Groundwater accretions or depletions to and from the San Joaquin River between these control points are assumed constant with water year type (wet, normal, dry and critically dry) and also do not vary with temporal changes in regional groundwater levels in the vicinity of the river. These accretions and depletions can constitute a significant proportion of stream flow along certain stream reaches and are critical to the accuracy of flow estimation.

The model uses a simple algorithm to determine regional groundwater pumping. The total annual amount of groundwater pumping is estimated based on year type - monthly distribution fractions are applied to this annual amount to determine monthly pumping volumes. Minimum and maximum monthly pumping volumes are established for each model node. The minimum amount of groundwater pumping is used, initially, to meet the demand(s) at each model node; next project and non-project surface water supplies are used; and if demands remain unsatisfied, groundwater pumping is applied to the maximum monthly level.

Further deliveries to meet demands at a node would be made from allocated reservoir storage. The assumption of static maximum monthly pumping amounts may be unrealistic over the long term because aquifer safe yields may have declined over time owing to over-pumping in the past and consequent subsidence due to aquifer compaction. These estimates do not consider the installed capacity for pumping groundwater in

each area nor do they consider the high cost of pumping this water. Reclamation has contracted with James Montgomery Engineers to improve upon and update aquifer safe yield data which should help to refine the existing pumping data.

2.1.3.2 Data requirements

The primary data requirements for the SANJASM are inflows, irrigation efficiencies, evaporation rates, project and non-project water demands, reservoir storage limits, reservoir rule curves and hydropower parameters. Measured flows at gauging stations along the main stem of the San Joaquin River and its tributaries and measured EC at Vernalis are used to calibrate the model.

2.1.3.3 Model outputs

Model outputs include flows in the San Joaquin River and its major tributaries, water deliveries at various demand points, return flows, reservoir releases, reservoir storage levels and groundwater pumping amounts. The monthly mean salinity at Vernalis compliance point is also determined.

2.1.3.4 Ease of calibration and performing model runs

The model can be calibrated against historic stream flows. Changes in reservoir development over the past 30 years and the inadequacy of river gauging sites and flow data make model calibration difficult. In calibration reservoir release patterns, stream accretions and depletions and streambed leakage are the primary factors that are adjusted to match the historic stream flow time series. Performing model runs is relatively easy, however simulating the effects of structural changes or policy actions may involve considerable time expenditure in manipulating the data files. Calibration of the model cannot be performed for studies which use current or future projected levels of development and for which measured flow data are not available.

2.1.3.5 Relative expense of using and maintaining model

The model is inexpensive to use, since it runs reasonably quickly (short execution time) on a microcomputer. Maintaining the model is also relatively inexpensive - however any updating of the model to a future year hydrology can take a large amount of time and requires a clear understanding of the assumptions made by the model. Reclamation is working on making the model more usable by simplifying the model logic and providing more complete comments within the code. Data sets are being restructured for easier manipulation and modules to create graphic output are being added.

2.1.3.6 Ease of linking with other models

The model can be linked with other monthly models. The model was linked with a finite element groundwater model, the IGSM to create the SANTUCM. The SANTUCM is described in Section 2.2 of this report. The model has also been used to provide boundary flows to the SWRCB SJRIO-2 model (discussed later) without

utilizing a formal linkage. The SANJASM provided monthly flows along the major east-side tributaries to the SJRIO-2 model, constituent concentrations of these flows (selenium, boron, molybdenum and TDS) can be assigned to these flows in a separate datafile. These concentrations might be developed from historical records (the SWRCB has developed a database of flow and concentration data for the period 1975-1990) ; prior year concentrations could be assigned based on similar water years.

An graphics - based, user interface is currently being developed for Reclamation's PROSIM (Project Simulation Model) by CADS-WEST for application on the Aviion workstation. The same technology could be applied to the SANJASM which would make the model both easier to comprehend and use. Should this be undertaken, it would assist in the eventual linkage of the SANJASM to a Geographic Information System (GIS) such as ARC-INFO. A GIS would be useful for display and analysis of spatial data such as cropping patterns and water requirements that are important for calculating water demands in the model.

2.1.3.7 Previous peer review

The model has been described and demonstrated to the public in two workshops, held prior to completion of the model. Informal review of the model has been performed by the SWRCB and at the DWR. Continuing review and development of the model is being conducted by the Water and Power Resources Branch, Division of Planning and Technical Services (MP-710), within Reclamation.

2.1.3.8 Model deficiencies and how these are being addressed

The severity of certain model deficiencies depend on the studies to be conducted with the model. For many simulation studies, use of historical stream gains/losses can be problematic, especially in studies where aquifer pumping may be large and varies significantly within the year and between different years. Aquifer safe yield is assumed to be static over the period of simulation, an inaccurate assumption, given the large amount of subsidence recorded in the western San Joaquin Valley, in particular in the vicinity of the city of Mendota.

Current work being conducted for Reclamation by James Montgomery Engineers (JMM) in improving the Central Valley Groundwater and Surface Water Simulation Model (CVGSM) model and in developing the Friant Surface Groundwater and Surface Water Simulation Model will help address these deficiencies. Reclamation proposes to use the FRIGSM and the CVGSM to set monthly stream-aquifer flow amounts without formally linking the models. Iterations of the surface water model and groundwater models will need to be performed to avoid mass conservation errors in the water balance.

2.1.4. Utility of the model for Reclamation planning studies

2.1.4.1 Actions to meet water quality objectives in the San Joaquin River

The model simulates water quality at Vernalis, using a simple regression algorithm. This regression provides only approximate values of monthly mean TDS. Except for studies which are concerned only with the

maintenance of water quality at Vernalis the model is of limited utility for studies of the other three trace elements of concern to the SWRCB, namely selenium, boron and molybdenum. However if the SANJASM were linked with the SJRIO-2 model (discussed later), the model then would become a useful tool for evaluating the effects of changes in reservoir operations on the east side of the San Joaquin Valley and on in-stream water quality. The SJRIO-2 model utilizes more stream nodes and therefore does a better accounting of salt and trace element load accretions or depletions. This is especially important in the case of selenium which is not conservative and can be metabolized by algae and certain aquatic plants.

2.1.4.2 Salt balance in the San Joaquin Basin

The SANJASM performs monthly flow balances along the San Joaquin River but cannot be used to perform salt balances. When linked to a model such as SJRIO or SJRIO-2 (described later) the SANJASM can be used to provide monthly tributary flows at the boundaries of the more detailed water quality model. The SWRCB has used the SANJASM in this manner to estimate the probability of exceedence of SWRCB objectives for the San Joaquin River under a variety of hydrologic conditions.

2.1.4.3 Drainage reduction policies and planning

The SANJASM treats surface and subsurface return flows as a combined surface inflow to the San Joaquin River and its tributaries. The major impact of drainage reduction policies will be on the load of contaminants transported to the San Joaquin River and on the resulting in-stream water quality. Drainage reduction policies will also reduce the volume of these flows that discharge to the San Joaquin River. Because drainage reduction policies most always result in reduced groundwater recharge, these policies will also reduce stream gains through groundwater accretions. However, without a linked groundwater model it is not possible to estimate the magnitude of this reduction. As previously discussed, the SANJASM does not perform salinity balances, hence the impact of these policies on water quality cannot be determined.

2.1.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

Projected level stream gains or losses can be read into the model as a time series or may be calculated based on a regression which includes two terms that describe groundwater pumping. The model is of limited value for assessing stream-aquifer interactions or the effect of groundwater pumping on stream flows owing to the mediocre performance of these regression relationships. Groundwater pumping amounts are estimated for each model node by the SANJASM, using logic described earlier - the effect of substituting groundwater for surface water supplies can be evaluated in terms of reservoir storage and contracted water supply. Conjunctive use of groundwater resources within the San Joaquin basin also may be used to replace or supplement water supply for fish and wildlife, for in-stream flows during critical periods, or for refuge water supply.

2.1.4.5 Structural options to control stage and water quality in the South - Delta

The downstream boundary node of the SANJASM is the control point at Vernalis. Hence, structural options for controlling water stage or salinity intrusion in the South Delta cannot be evaluated with the SANJASM. If linked with a Delta hydrodynamic flow model the SANJASM could be used to evaluate the effect of alternative reservoir release policies on flow to the Delta. However, the SANJASM could not be used to evaluate the impacts of these policies on Delta water quality, with any degree of confidence. The SANJASM is not a water quality model and the relationship between flow and salinity at Vernalis is not reliable under operating policies that might differ from historic operating policies.

2.1.5 Overall assessment and recommendations

The SANJASM is a unique model for evaluating the effect of alternative reservoir operation and instream flow criteria on contractual water supply in the San Joaquin Basin. The model contains detailed descriptions of the operating policies and in-stream flow requirements for the major tributaries of the San Joaquin River and hence may be useful if linked with models such as the SJRIO-2 model to simulate monthly water quality in the San Joaquin River and with any of the Delta hydrodynamic flow models to simulate mean San Joaquin monthly inflows into the Sacramento - San Joaquin Delta. The model cannot be used for conjunctive use planning since there is no way of assessing the effect of groundwater pumping strategies on aquifer water levels or stream aquifer accretions or depletions.

2.1.6 References

Boyle Engineering Corp. 1991. San Joaquin Area Simulation Model (SANJASM). Project Report to the US Bureau of Reclamation, Mid Pacific Region. March, 1991.

Quinn N.W.T. 1991. The San Joaquin - Tulare Conjunctive Use Model. Detailed Model Description. LBL Report 32063. March, 1992.

Shen H.W. and G.Q. Tabios, 1991. A Summary of USBR Models for Surface and Groundwater Flows in the Central Valley, California. Project report. September, 1991.

2.2. SANTUCM (San Joaquin-Tulare Conjunctive Use Model)

2.2.1. General description and purpose of model

The SANTUCM comprises three separate models : a surface water model , a groundwater model, and a salinity model. The SANTUCM was developed to simulate both surface water operations and the interaction between surface water flow and regional groundwater within the San Joaquin and Tulare Basins. A salinity model was developed to perform simple mass balances of salt load along the major tributaries and along the main stem of the San Joaquin River. The coding for the salinity model has been completed but the associated database of salt concentrations for each stream or aquifer accretion has not been developed nor has the salinity model been calibrated or verified by the model developer. The current model is therefore limited to analysis of conjunctive use strategies that entail some tradeoff between groundwater pumping and surface water deliveries and that have potential for affecting stream gains or losses and to the same studies that can be performed with the SANJASM.

2.2.1.1 Geographic extent of the model

The SANTUCM simulates surface water operations and groundwater flow within the San Joaquin Basin between Millerton Lake and the Delta including the Calaveras, Stanislaus, Tuolomne, Merced, Chowchilla and Fresno Rivers (Figures 2 and 3). In addition the model considers historic operations of reservoirs and canals and groundwater flow within the Tulare Basin. The Tulare Basin covers the southern end of the San Joaquin Valley and extends from south of Mendota to Bakersfield. The major project features modeled in the Tulare basin are the Friant Kern Canal, King's River, Tule River, Kaweah River, Kern River and the Cross Valley Canal.

2.2.1.2 Features of model

The model is designed as a planning tool to help evaluate the impacts of alternative instream flow criteria, changes in operations, increased conjunctive use of groundwater resources, power generation and new physical facilities within the San Joaquin Basin. The current SANTUCM surface water model is an older version of the SANJASM, with the addition of the Friant-Kern Canal and the project facilities described above. Substitution of the most recent version of the SANJASM could be made without difficulty. Although the model attempts to simulate project operation in both the San Joaquin and Tulare Basins, only the reservoir operations in the San Joaquin Basin are time independent and described by program logic. Within the Tulare Basin the model developer found it more difficult to describe operations by logical expressions and hence used the historic time series to simulate stream releases and diversions. This limits the utility of the SANTUCM for certain planning studies in the Tulare Basin.

The surface water model performs mass balances of flow along each stream reach, subject to operating rules for upstream reservoirs and irrigation demands at known diversion points. Operating rules include criteria

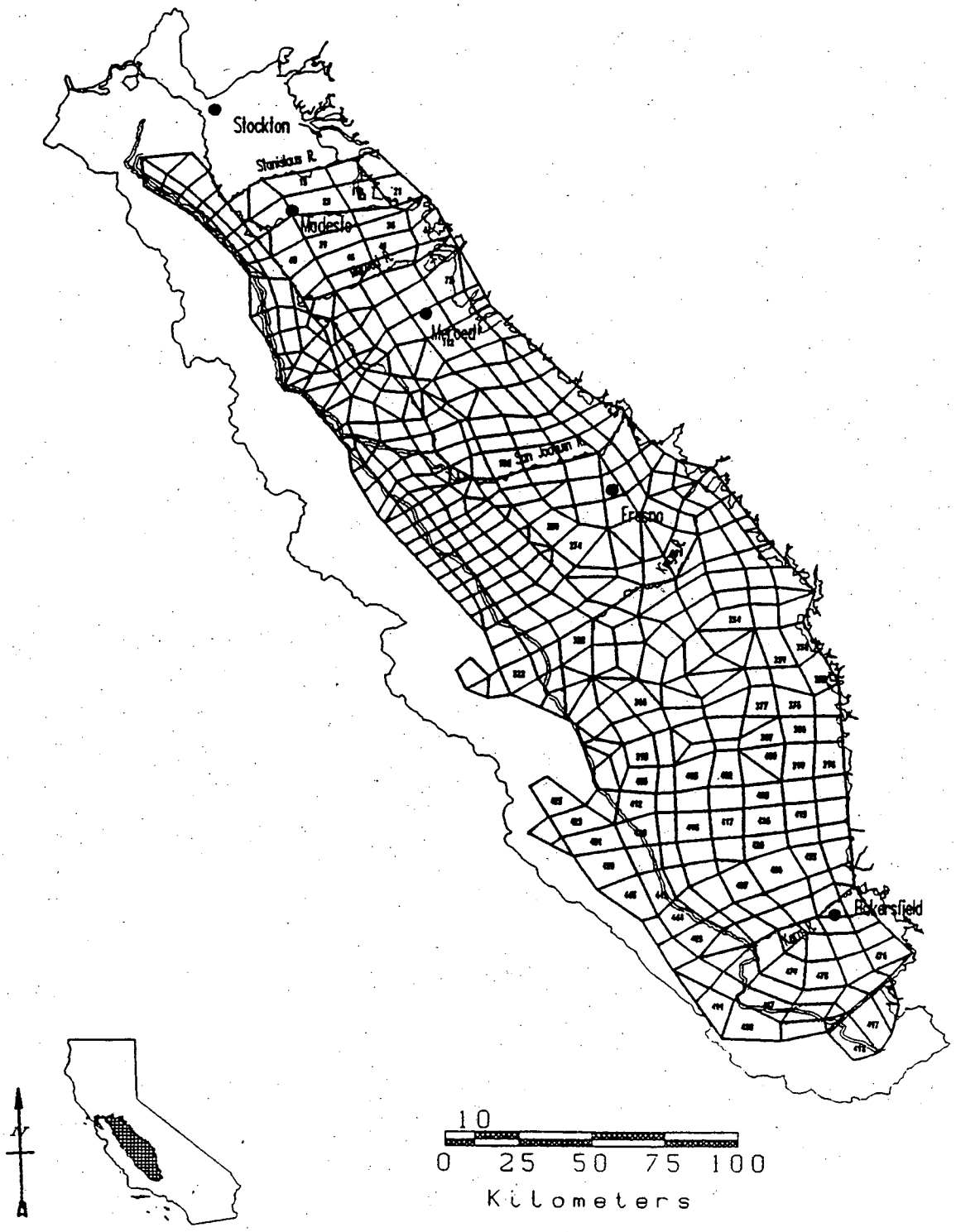

Figure 2. **Finite element network for the San Joaquin - Tulare Conjunctive Use Model (SANTUCM).**
(Source : Boyle Engineering Corp.)

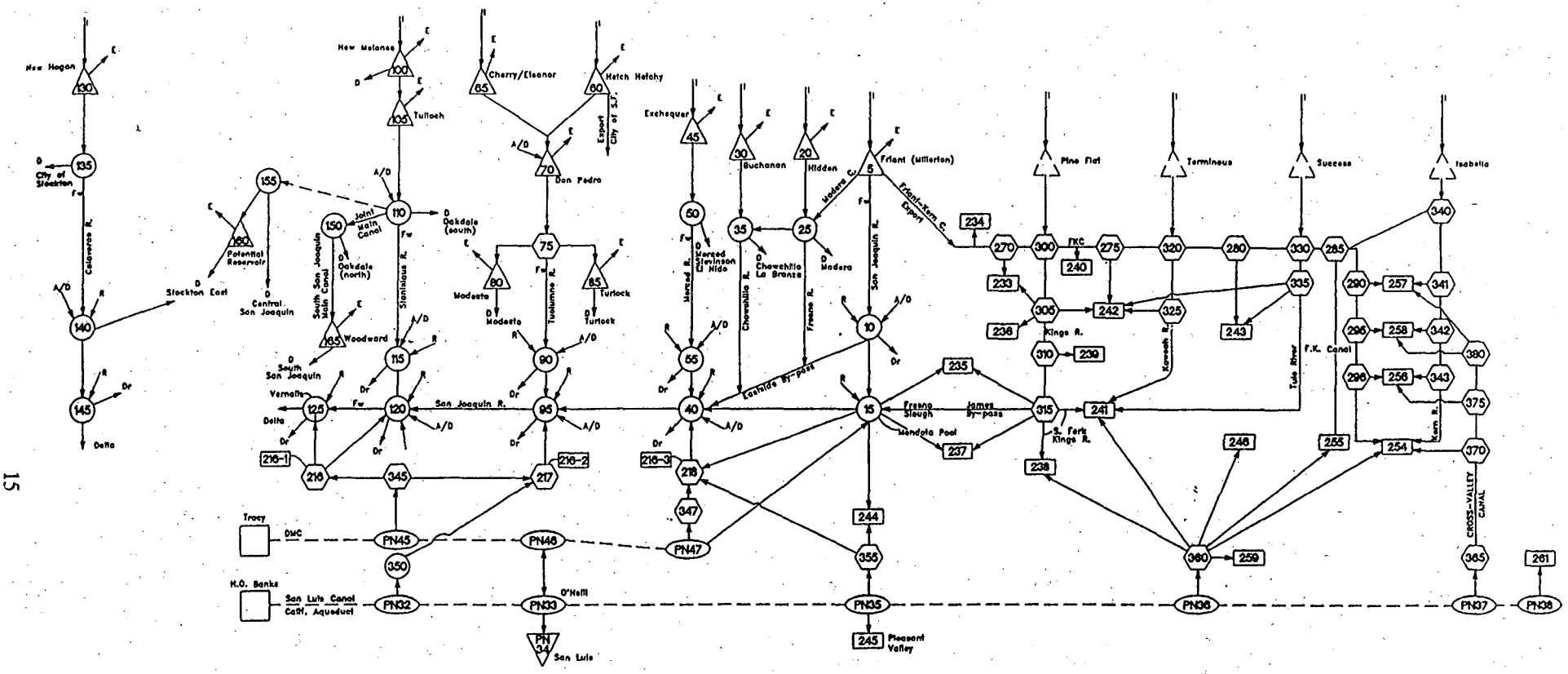

Figure 3. **Surface water network for the San Joaquin - Tulare Conjunctive Use Model (SANTUCM).**
(Source : Boyle Engineering Corp.)

such as the Corps of Engineers flood control storage limits, downstream fishery flows (where applicable), minimum storage levels, releases for downstream senior water rights holders, lake evaporation and power releases. The groundwater model uses finite element analysis to calculate water levels as affected by irrigation recharge, groundwater pumping, crop evapotranspiration, changes in aquifer storage and the interaction between surface water and groundwater. A linkage subroutine performs two or more iterations of the surface and groundwater models with the underlying assumption that estimates of stream gains and losses made by the surface water and groundwater models converge sufficiently by the second iteration to be inconsequential. Review of the SANTUCM, conducted by LBL and UC Berkeley (Tabios, Quinn and Shen; 1991) showed that this assumption was generally true only for a losing stream. The salinity model, which at the time of writing has not been completed or calibrated assigns salt concentrations to each of the nodal inflows or outflows and computes a salinity balance along the main stem of the San Joaquin River.

2.2.1.3 Capability of the model : flow / flow and water quality

The SANTUCM provides additional capability, not offered by the SANJASM, in being able to calculate river gains and losses and (if completed) to calculate salinity mass balances along the main stem of the San Joaquin River. As previously discussed in Section 2.1, time series estimates of gains and losses to the river used by the SANJASM can cause problems when used for model runs for future projected conditions, since there is no guarantee that future interactions between stream and aquifer will emulate those of the past, even for similar hydrologic years. A common deficiency of both the SANTUCM and the SANJASM is that the small number of nodal points along the main stem of the San Joaquin River, used to report river gains and losses makes the model difficult to calibrate or verify. This deficiency is particularly acute for the salt model which (even after calibration) is particularly sensitive to loading from two point sources, Mud and Salt Sloughs. As with the SANJASM, the model should be used only as a planning tool for comparative analysis. The SJRIO-2 model could be substituted for the SANTUCM salinity model to obtain more accurate estimates of in stream water quality along the main stem of the San Joaquin River.

2.2.1.4 Simulation time step

The model performs monthly water and salt balances and calculates annual summaries of total flow and salt load for each model node. More frequent accounting of flow and salt load would involve considerable expansion of the large database required to run the model, since many of the reservoir operating rules and flow constraints are data-driven. The lag between releases from reservoirs simulated in the model and eventual transport to the TDS compliance point at Vernalis can range from 3 - 8 days depending on the tributary under consideration and the monthly flow volume between model nodes. The surface water subroutines of the SANTUCM, like those in the SANJASM, do not route flow along the channel network - hence accounting errors in the flow balance would increase as the reporting interval approaches the travel time between model nodes. No real advantage

would be gained from accounting periods of less than one month in the groundwater model, since most of the input hydrologic data is derived from average annual estimates.

2.2.1.5 Computer requirements and portability

The SANTUCM requires an IBM compatible 386 or 486 machine capable of utilizing extended memory. The Lahey™ Fortran compiler was used together with the SPINDRIFT™ utility MAXFILES to improve program execution time and allow more than 20 input data files to be opened at the same time. The model runs in less than 20 minutes on an IBM compatible 486 - 25 MHz machine for a simulation period of 17 years.

2.2.2. Model development

2.2.2.1 Reasons for development of the model

The SANTUCM was intended to allow more accurate prediction of stream-aquifer interactions , especially for conjunctive use studies, where groundwater pumping might be expected to have an effect on stream accretions or depletions. Another intended purpose of the model was to consider salinity balance in the San Joaquin Basin and to permit the impact of conjunctive use policies on water quality to be evaluated. The developer of the model failed to fully test and develop a database for the salinity model - hence it can only be used for the former purpose in its current state of completion.

2.2.2.2 History of development and use of the model

The San Joaquin Valley Drainage Program retained Boyle Engineering Corporation in July 1989 to extend the development work on the SANJASM by including the major project facilities in the Tulare Basin and to link the combined model to a regional groundwater model of the San Joaquin Valley. Public workshops on the design, calibration and use of the model were conducted during March, 1991 to promote awareness of the model. The SANTUCM has been used to evaluate the impact of components of the San Joaquin Valley Drainage Program Final Plan on water tables in the study area and on water quality at Vernalis in the San Joaquin River.

2.2.2.3 Further development of the model and intended future use

The SANTUCM was evaluated by LBL between August and December, 1991. The linkage between surface and groundwater models was shown to be handicapped by certain conceptual problems, convergence was not obtained between surface water estimates of stream gains or losses at several of the surface water nodes (Tabios, Quinn and Shen; 1991). This problem resulted in poor prediction of stream - aquifer flow interactions at these nodes. Needed enhancements to the existing model are an increase in the number of nodes between Mendota Pool and the Merced River and the development of a drainage algorithm or subroutine for the groundwater model to allow the independent estimation of subsurface drainage flows from agricultural land. Subsurface drainage flows are mixed with surface irrigation return flows and conveyed to the San Joaquin River. Incorporation of water quality

in the groundwater model would improve estimation of the quality of these subsurface drainage flows as well as the mass of salt gained or lost from the San Joaquin River due to stream gains or losses.

The SANTUCM is not being currently being used by Reclamation , largely because of a low level of confidence in the current surface water - groundwater linkage. The model could be of some assistance in the evaluation of alternative actions for the current Friant EIS study. Alternatively, iterating the SANJASM and the CVGSM would accomplish the same goal, albeit less efficiently and with a much larger expenditure of staff time.

2.2.3. Evaluation of the model

2.2.3.1 Predictive capability and model reliability

The SANTUCM was developed as a regional planning tool and was not intended to be used for making predictions of surface and groundwater flow or for making system operations decisions. The model is sufficiently detailed to allow general hydrological differences between alternative scenarios to be determined; the level of confidence associated with these comparisons depend on the nature of the scenarios. Iterating the surface water and groundwater models occasionally leads to numerical oscillation of predicted stream gains or losses. Stream gains or losses are calculated independently by the surface and groundwater models, hence numerical convergence of these values would increase the level of confidence in the model. A numerical scheme to force this convergence was recommended in the LBL - UC Berkeley report (Tabios, Quinn and Shen; 1991). The salinity model has not been calibrated or verified and therefore cannot be evaluated at this time.

2.2.3.2 Data requirements

The primary data requirements for the surface water model of the SANTUCM are inflows, irrigation efficiencies, evaporation rates, project and non-project water demands, reservoir storage limits, reservoir rule curves and minimum flow requirements. The groundwater model requires aquifer parameter data for each polygon in the finite element mesh as well as regionally averaged rainfall, pumping, irrigation recharge, rainfall, evapotranspiration and initial water table and pieziometric heads. Boundary conditions must also be established for the groundwater model. Groundwater levels at individual observation wells and stream gauging data are used in model calibration and verification.

2.2.3.3 Model outputs

The primary outputs from the SANTUCM are flows in the San Joaquin River and its major tributaries, water deliveries at various demand points, return flows, reservoir releases and storage levels. Groundwater pumping activity levels can either be specified or calculated within the surface water model. Output from the groundwater model includes final water table elevations, groundwater flow and aquifer gains and losses at each river node.

2.2.3.4 Ease of calibration and performing model runs

The model was calibrated against historic stream flows. Stream accretions and depletions are the primary factors that are adjusted to match these stream flow levels. Performing model runs is relatively easy, however simulating the effects of structural changes or policy actions may involve considerable time expenditure in manipulating the data files. The groundwater model was verified by matching measured water levels to predicted water levels for a time period independent of the period used for model calibration. This is a time consuming activity and is complicated by the fact that land use, irrigation and drainage data is more readily available in some areas than in others. Many of the alternatives analysed with the SANTUCM required modifications to both groundwater and surface water models. The salinity model has not yet been completed by Boyle Engineering Corp., nor has it been calibrated for the 17 year period hydrologic time series 1960 - 1977, used for the model simulations.

2.2.3.5 Relative expense of using and maintaining model

The model is inexpensive to use, since it runs relatively quickly on a microcomputer, although execution times are considerably longer than the SANJASM if the model is run with the option to include the groundwater model. The salinity model does not add significantly to the speed of execution. Maintaining the model is also relatively inexpensive - however any updating of the model to present year hydrology can take a large amount of time and requires a clear understanding of the assumptions made by the model.

2.2.3.6 Ease of linking with other models

The model can be linked with to other monthly models in similar fashion to the SANJASM. To create the SANTUCM, the surface water subroutines within the SANJASM were coupled with a finite element groundwater model, the IGSM. The SANTUCM linkage also allows these models to be run independently. The IGSM was a precursor to the CVGSM, described in Section 4.3. The model could be linked with the SWRCB SJRIO-2 model without much additional computer coding. The SANTUCM could provide monthly flows to the SJRIO-2 model; constituent concentrations of these flows (selenium, boron, molybdenum and TDS) would need to be assigned to these flows in a separate datafile. These concentrations might be developed from historical records (the SWRCB has developed a database of flow and concentration data for the period 1975-1990); prior years could be assigned based on similar hydrologies using a methodology similar to that use by Swain (1991). The SANTUCM also estimates stream gains or losses for each river reach attributed to a groundwater node in the groundwater model and then summarizes and transfers these estimates, after a user-specified number of iterations of the two models, to the nodes of the surface water model. The SJRIO-2 model makes estimates of groundwater accretions every mile along the San Joaquin River. The SJRIO-2 model nodes would need to be mapped to the SANTUCM groundwater nodes to create the linkage between the two models.

Although linking the SANTUCM and the SJRIO-2 model may not be difficult in theory, the simple stream - aquifer routines that estimate groundwater interaction in the SJRIO-2 model may be sufficiently accurate for

most planning studies. In the western San Joaquin Valley lateral flow is relatively minor compared with the volume of irrigation recharge into the semi-confined aquifer - hence the need for the fully fledged groundwater model contained in the SANTUCM may not be warranted. Prediction of stream - aquifer interactions along each of the major tributaries to the San Joaquin River is simplified by the fact that most tributaries are losing streams in their upper reaches. The additional capability of being able to estimate these upper tributary stream losses may also not warrant the adoption of the complete groundwater model. Linking the SANJASM (which contains most of the surface water subroutines within the SANTUCM and uses steady-state estimates of monthly losses along each tributary) with SJRIO-2 may be a more efficient linkage, especially since the SANJASM is being maintained and updated by Reclamation.

The graphics - based, user interface on the Aviion workstation, currently being developed for the PROSIM, could be applicable to both the SANJASM and the SANTUCM and assist in comprehension of the modls and in their use. Should this be undertaken, it would simplify eventual linkage of the SANTUCM to a Geographic Information System (GIS) such as ARC-INFO. A GIS would be especially useful in the case of the SANTUCM for display and analysis of spatial data such as cropping patterns and water requirements, important for calculating water demands in the model and in analyzing changes in water levels and groundwater pumping, important for assessing conjunctive use strategies.

2.2.3.7 Previous peer review

The model has been demonstrated to the public in two workshops, held prior to completion of the model. Formal review of the model has been performed by Lawrence Berkeley Laboratory (LBL, 1992) and informal review of the model has been performed by the SWRCB and at the DWR. The model is not currently supported by Reclamation.

2.2.3.8 Model deficiencies and how these are being addressed

The importance of the identified model deficiencies depend on the nature of the studies to be conducted with the model. There is occasionally poor agreement between surface water model - derived and groundwater model - derived estimates of stream gains or losses at several nodal points along the main stem of the San Joaquin River. This is partly a result of combining two models which were constructed for different purposes, do not share a common spatial database and which make calculations of efficiency and return flows using different assumptions. The spatial database refers to the association between a node and the surrounding area it is assumed to represent.

The SANTUCM cannot estimate subsurface drainage and therefore cannot distinguish between surface and subsurface return flows to the river - hence it is difficult to obtain a good estimate of the water quality of the stream gains or losses. Assigning a mean salt or trace element concentration value to these accretions or depletions may not be justified, especially if the model is used to make projections of certain effects such as salt

loading to the river. The groundwater model should be improved to include simple advective solute transport and a subroutine to estimate subsurface drainage.

2.2.4 Utility of the model for Reclamation planning studies

2.2.4.1 Actions to meet water quality objectives in the San Joaquin River

With the addition of a calibrated salinity model, the SANTUCM can be used to evaluate drainage reduction, drainage timing and reservoir re-operation actions designed to meet SWRCB water quality objectives. However, as previously suggested, linking the SJRIO-2 model with the SANJASM may be a better option, since both models are being supported by their respective agencies and the groundwater model utilized by the SJRIO-2 model may be adequate for most planning studies.

2.2.4.2 Salt balance in the San Joaquin Basin

The SANTUCM will be able to perform rudimentary monthly salt balances along the San Joaquin River when the salinity model has been completed. To perform salinity balances in the San Joaquin Basin the groundwater model would need to be enhanced to consider solute transport and be calibrated with initial values of aquifer salinity. This would be a very large undertaking.

2.2.4.3 Drainage reduction policies and planning

The SANTUCM treats surface and subsurface return flows as a combined inflow to the San Joaquin River. The major impact of drainage reduction policies will be on the drainage flow and contaminant load transported to the San Joaquin River and on the resulting in-stream water quality. Drainage reduction policies will also reduce the volume of these flows that discharge to the San Joaquin River. Because drainage reduction policies most always result in reduced groundwater recharge, these policies could also reduce stream gains through accretions or, in the case of a losing stream, increase losses through depletions. With the coupled groundwater model the SANTUCM could indirectly estimate the magnitude of these effects.

2.2.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

The SANTUCM was originally constructed to perform conjunctive use planning analysis in the San Joaquin Basin. Conjunctive use of groundwater resources in some parts of the San Joaquin basin may be used to offset increased water supply to fish and wildlife resources, greater in-stream flows during critical periods, or additional refuge water supply. The San Joaquin Valley Drainage Program recommended a plan for long term management of drainage and drainage related problems in the western San Joaquin Valley which included surface and groundwater conjunctive use. Some of the hydrologic implications of this plan have been determined using the SANTUCM (Quinn, 1992).

2.2.4.5 Structural options to control stage and water quality in the South - Delta

The downstream boundary node of the SANTUCM is the control point at Vernalis. Hence, structural options for controlling water stage or salinity intrusion in the South Delta cannot be evaluated with the SANTUCM. If linked with a Delta hydrodynamic flow model, the SANTUCM could be used to evaluate the effect of alternative reservoir release policies on flows into the Delta. The SANTUCM, however, is a monthly model and is capable of estimating mean monthly flow and TDS at five stations along the main stem of the San Joaquin River. However, because the salinity model in the SANTUCM has not been calibrated or verified, greater confidence would be obtained by linking the SANJASM, the SJRIO-2 model and one of the Delta hydrodynamic flow and salinity models.

2.2.5 Overall assessment and recommendations

The SANTUCM is an extension of an older version of the SANJASM for evaluating conjunctive use opportunities within the San Joaquin Basin as well as the effect of alternative reservoir operation and instream flow criteria on contractual water supply in the San Joaquin Basin. The model contains detailed descriptions of the operating policies and in-stream flow requirements for the major tributaries of the San Joaquin River and could be usefully linked with models such as the SJRIO-2 model to simulate monthly water quality in the San Joaquin River and certain Delta hydrodynamic flow models to simulate San Joaquin monthly inflow into the Sacramento - San Joaquin Delta. For most studies that require prediction of flow along the San Joaquin River, the groundwater model is unlikely to provide substantially improved estimates of groundwater accretions or depletions than the simple groundwater model contained within the SJRIO-2 model.

2.2.6. References

Boyle Engineering Corp. 1991. San Joaquin - Tulare Conjunctive Use Model (SANTUCM). Project Report to the US Bureau of Reclamation, Mid Pacific Region. March, 1991.

Quinn N.W.T. 1991. The San Joaquin - Tulare Conjunctive Use Model. Detailed Model Description. LBL Report 32063. March, 1992.

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Swain D.G. , 1991 Surface Water Analyses Appendix for the San Luis Drainage Program. CH2M-Hill, Sacramento, CA.

Tabios G.Q, N.W.T. Quinn and H.W. Shen , 1991. Evaluation and Suggestions for Further Development of the San Joaquin - Tulare Conjunctive Use Model (SANTUCM). Draft report. October, 1991.

2.3 WADE (Westside Agricultural Drainage Economics Model)

2.3.1 General description and purpose of model

The WADE model was developed by the San Joaquin Valley Drainage Program to estimate future activity levels of agricultural production, water supply and drainage return flow quantity and quality, in response to different economic and regulatory drainage management strategies. These projections were necessary for the development of a long term plan to manage drainage and drainage-related water quality problems on the west side of the San Joaquin Valley. The WADE model comprises three submodels which simulate the economics of agricultural production, groundwater flow and hydrosalinity. The model is formulated as three separate optimization problems, solved twice annually for summer and winter seasons, each of which require simultaneous solution of sets of linear and non-linear algebraic equations, subject to resource and feasibility constraints.

2.3.1.1 Geographic extent of the model

The model was originally formulated to consider the entire west side of the San Joaquin Valley from Tracy to Bakersfield (Figure 4). This area included the areas between the San Joaquin River and the Coast Range in the Northern and Grasslands sub-basin, Westlands Water District (DWR-DAU 244) and most of the Tulare and Kern sub-basins. The area was divided into more than 180 polygons according to soil type and drainage characteristics. These polygons ranged in area from 4000 - 40,000 acres. For computational reasons, the study area was divided into 5 main study areas according to hydrologic and institutional factors. These study areas include the Northern area, the Grasslands, Westlands, Tulare and Kern. The model has been calibrated only for the Grasslands and Westlands subareas. Hence the data and the results of projection runs made with the model for the Northern, Tulare and Kern subareas should not be relied upon.

2.3.1.2 Features of model

The WADE model combines agricultural production optimization and hydrosalinity models, written using the Generalized Algebraic Modeling System (GAMS) software. The agricultural production model is formulated with a linear objective function and non-linear constraints to estimate activity levels of land use, irrigation water supply, crop production and groundwater pumping. The model also estimates annual investments in water conserving irrigation technologies to reduce irrigation applied water and in on-farm tile drainage systems to control salinization of the crop rooting zone. Groundwater flow, irrigation recharge and drainage flow are determined by mass balance calculations in the linked hydrology model (Figure 5). The hydrology model uses current values for the key independent variables obtained after each successful iteration of the agricultural production model. The salinity model, in turn, uses the flow between the root zone and the shallow aquifer, the flow between other layers in each polygon and to drains, and the flow between adjacent polygons, obtained from the hydrology model, to estimate salt transport during each model time step.

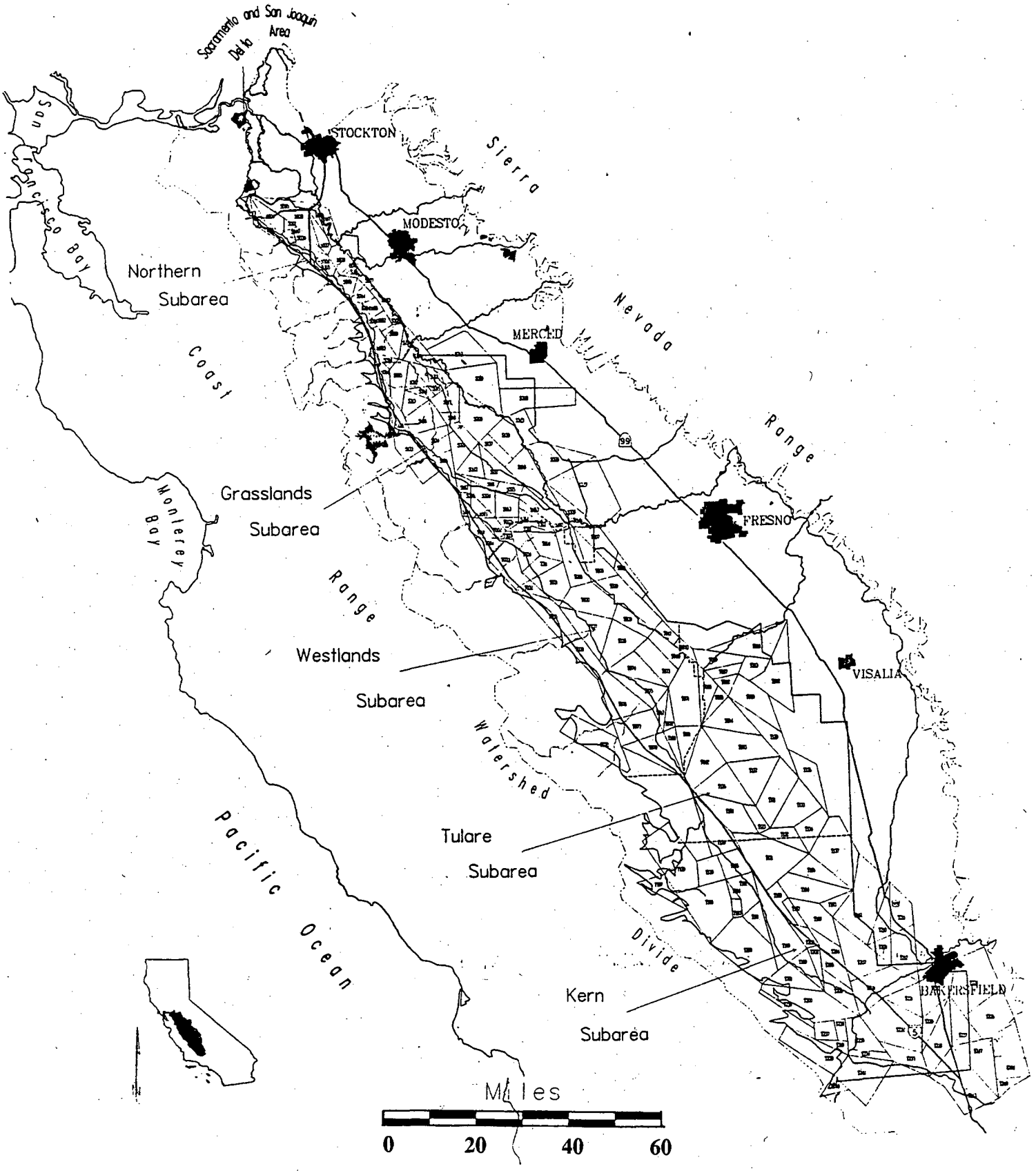

Figure 4. **Polygon cell discretization for the Westside Agricultural Drainage Economics Model (WADE).**
(Source : San Joaquin Valley Drainage Program)

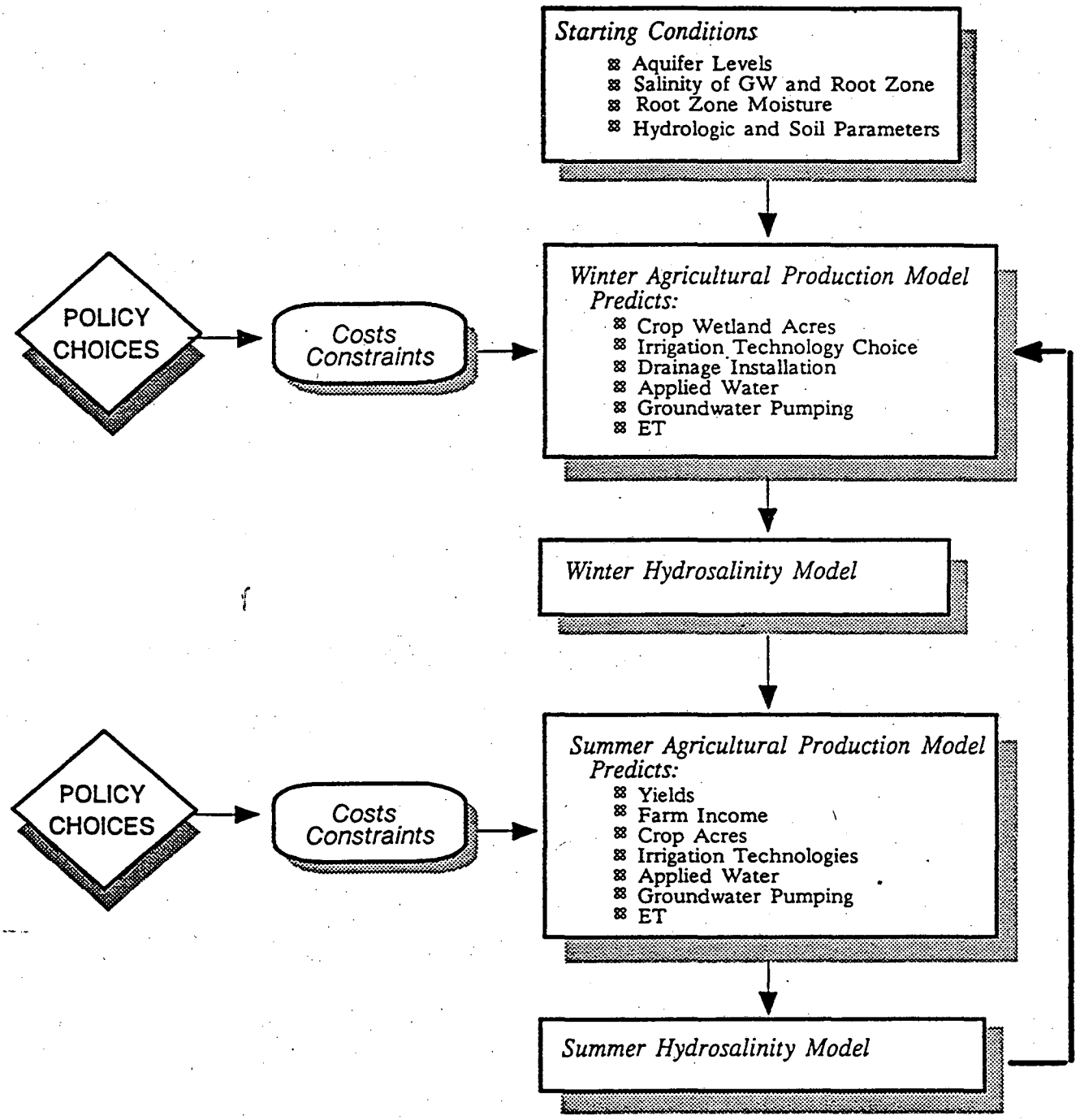

Figure 5. **Sequence of operations in the Westside Agricultural Drainage Economics Model (WADE). Drainage policy choices can be formulated as either cost constraints or limits on drainage flow or constituent load.**
(Source : Quinn et al., 1989)

2.3.1.3 Capability of the model : flow / flow and water quality

The WADE model is primarily an econometric model which attempts to represent crop production, irrigation and drainage activities over large area within the western San Joaquin Valley. The hydrology and salinity models are driven by the consequences of decisions made by the agricultural production model, in particular by irrigation recharge, water table elevation and soil salinity. These factors in turn affect the decisions made by the agricultural production model in the following year. The model polygons can be in excess of 40,000 acres and are typically assigned hydrologic parameters and salinity values based on a small number of data points. The WADE model should therefore not be expected to make accurate predictions of drainage flow and quality but rather it serves as a tool for comparing the hydrologic and agronomic consequences of various policies and for analyzing the long term consequences of some of these actions. The model is unique in combining agricultural production economics and irrigation and drainage hydrology within a single decision support system.

2.3.1.4 Simulation time step

The WADE model uses a seasonal time step and solves the three linked models (agricultural production, hydrology and salinity models) twice for each year simulated (Figure 6). The year is divided into a winter season, during which pre-season irrigation applications are made, and a summer season, during which regular season irrigation applications are made. Usable rainfall falls primarily in the winter season; groundwater pumping occurs primarily in the summer season. Output parameters are typically summarized as annual values.

2.3.1.5 Computer requirements and portability

The WADE model will run on any machine that supports the General Algebraic Modeling System (GAMS) package. This includes IBM compatible 386 and 486 machines, and Apollo, Sun and Data General workstations under the UNIX operating system. The processing speed of the computer can have a significant effect on the speed of execution of the model. The computer requirements also depend on the size and dimensionality of the model. Increasing the number of model cells, irrigation technology choices, agricultural crop selection and deficit irrigation levels can have a significant impact on model execution time.

2.3.2. Model development

2.3.2.1 Reasons for development of the model

The San Joaquin Valley Drainage Program was charged with the task of developing a comprehensive long term management plan for contaminated drainage and contaminated drainage related problems on the west side of the San Joaquin Valley. The WADE model was developed to assist in the comparison of alternative drainage management policies and to help formulate a plan which assumed no co-ordinated action to solve the drainage problem by State and Federal agencies. In developing the WADE model it was assumed that land use and

WADE HYDROLOGY MODEL

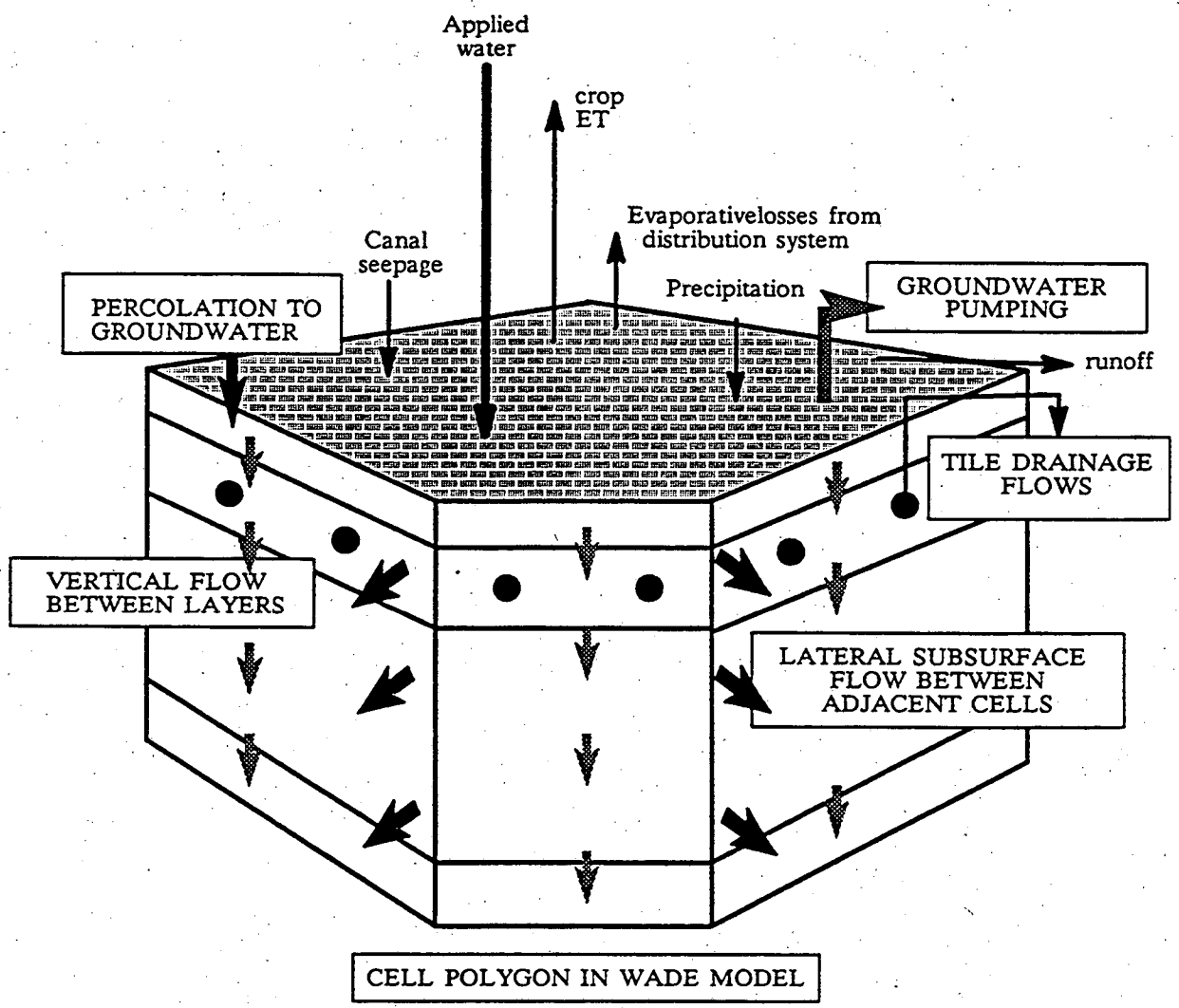

Figure 6. **Hydrologic mass balance performed by the WADE hydrology model for each polygon. The agricultural production model affects applied surface, water, tile drainage and groundwater pumping. The net seasonal deep percolation calculated by the model affects salt balance in the root zone which in turn affects crop yields and the decisions made by the agricultural production model in the following season.**
(Source : Quinn et al. ,.1989)

irrigation practices were the most important factors affecting the occurence of seasonally high, saline water tables and the requirement for discharge of subsurface drainage, high in TDS and in trace elements such as selenium, boron and molybdenum.

2.3.2.2 History of development and use of the model

The WADE model was used by the San Joaquin Valley Drainage Program in the formulation and evaluation of alternatives for the Grasslands and Westlands subareas. The model was not used for the Tulare, Kern or Northern areas, primarily because the associated WADE model database for these areas was not completely developed at the time plan formulation activities were taking place. However, even in the Grasslands and Westlands subareas, it proved difficult to incorporate the policy specific results of WADE model runs into the more generalized planning methodology adopted by the SJVDP. In the end, the WADE model served more as an educational tool, helping Program staff make sensible projections of future trends, than as a tool for plan formulation.

The San Luis Drainage Program (SLUDP) continued the work of the San Joaquin Drainage Program when the SJVDP was disbanded in 1990. The SLUDP was charged with developing comprehensive drainage plans for the San Luis Unit of the CVP and specifically for Westlands Water District to meet the legal requirements of the Barcellos judgement. The WADE model was more extensively used in the SLUDP to project future conditions in the absence of planned actions by Reclamation and to compare and evaluate four separate alternative actions formulated by Reclamation.

2.3.2.3 Further development of the model and intended future use

The model is unique in its ability to assess how future agricultural production and resource use will respond to changes in hydrologic, groundwater quality and economic conditions. Although the model could be useful if linked to models such as the CVGSM (Section 2.5), the IRDROP model (Section 3.2) and SJRIO-2 model (Section 3.3) for making drainage flow and drainage water quality projections, there are no immediate plans for its continued use or further development.

2.3.3 Evaluation of the model

2.3.3.1 Predictive capability and model reliability

The WADE model is a regional model and hence generalizes soil and groundwater conditions over a large area. The model is not a predictive tool but rather should be used for comparative analysis. The model is typically used to project future trends as a result of State or Federal agricultural or water policies and hence cannot readily be tested for accuracy and reliability. The agricultural production model is an optimization routine which assumes that farmers act largely to maximize their profits and assumes that on-farm investment decisions, in

either improved irrigation technologies or drainage systems, are made on the basis of net returns to these investments. This is undoubtedly a gross simplification of the factors influencing grower behavior.

Future commodity prices and land rents are assumed constant in the current model, since these are difficult to predict or extrapolate into the future. Initial conditions within the hydrology and salinity submodels are regionally averaged estimates of current water levels, pieziometric heads and groundwater salinity and do not reveal the wide range of conditions that can exist within any one model polygon.

2.3.3.2 Data requirements

The WADE model requires initial data on such factors as land use, crop practices, groundwater levels, groundwater pumping, tile drainage installed, irrigation technologies, commodity prices and the cost of production. The depth distribution within each polygon of water quality and aquifer hydraulic properties must also be estimated and included. A single value of each of these factors must be chosen for each polygon considered by the model. Where detailed information is available on land use and groundwater conditions the model polygons can be subdivided and the model can be re-calibrated to the more detailed mesh. In this sense the model is extremely flexible, the number of polygons included in any model run can be changed with only minor alterations to the input data, including the establishment of boundary flows into or out of the polygons along the perimeter of the study area.

2.3.3.3 Model outputs

The primary outputs of the model are land use, farm income, depth to water table, drained area, drainage flow and quality, groundwater pumping and root zone salinity. The model runs sequentially through winter and summer seasons for each year simulated - the output values at the end of one season become the initial conditions for the next season. Model outputs are produced in tabular form by GAMS and can be increased or decreased simply by listing or removing variable names from the routines responsible for formatting the output.

2.3.3.4 Ease of calibration and performing model runs

Model calibration of the agricultural production model was performed to simulate changes in land use over time. The agricultural production model is calibrated by constraining cropping activity levels to observed values, then using the dual values of the objective function to calculate the linear marginal cost function values for each crop (Howitt and Mean, 1985). These linear marginal cost functions are introduced into the agricultural production model objective function and act to dampen the sudden shifts in cropping decisions typical of a pure profit maximization objective function and which do not represent typical grower behavior. This calibration function was applied only to cropping decisions but could equally be applied to decisions related to irrigation technology selection and investments in drainage technologies, once sufficient time series data has been collected to develop reliable marginal cost functions.

Calibration was also performed of the hydrology and salinity models to improve predictions of water table depths, drainage flow and drainage water quality relative to historical field data. Calibration of the hydrology and salinity models is more of a trial and error procedure, using parameters such as Corcoran Clay leakage, boundary inflows and outflows and seasonal irrigation application efficiencies to match observed drainage flow and quality and water table elevations. Re-calibration of the hydrology and salinity models can be a laborious procedure, given the slow execution time of the model.

2.3.3.5 Relative expense of using and maintaining model

The WADE model requires two software packages to be resident on the computer before it can be run. The Generalized Algebraic Modeling System (GAMS) software is a pre-processor and post-processor, which sets up the model objective function and constraints for interpretation by the MINOS optimization package. GAMS allows data to be input to the model in tabular format and output from the model in the same general format. The input data can be readily changed in the WADE model simply by substituting new values for existing values in the data files. Program changes require some experience of GAMS syntax and some knowledge of the theory of operations research and optimization to become functional.

The data requirements of the WADE model are extensive except for model calibration and verification there is no need for additional data. This is because the model is used to make projections rather than utilize historical time series data. The WADE model uses between 15 and 50 minutes per year of CPU time on an Apollo DN3500 workstation. A 20 year simulation could take between 5 and 17 hours depending on the size of the problem. There are six calls to the matrix solver MINOS, which performs the optimization, as the model moves through the production, hydrology and salinity submodels of the winter and summer seasons.

The GAMS-MINOS program package is expensive and is required software for any computer that it used to run the model. This is in contrast to Fortran - based models such as the CVGSM, the SANJASM, the SANTUCM, the SJRIO-2 model and the TPDSM which can be transferred to the end-user as an executable program.

2.3.3.6 Ease of linking with other models

The WADE model has been used to provide time variant irrigation recharge and groundwater pumping to other models such as the USGS regional aquifer simulation model (Belitz, 1992). Projected annual groundwater pumping, crop ET, drainage installation and land retired over a 17 year simulation period by the WADE model for each polygon were transformed using an GIS area weighting algorithm to the one mile square grid, used by the USGS model. The USGS model provides a more rigorous simulation of aquifer hydrology and was used to evaluate the effects of managed groundwater pumping and land retirement on depth to water table and drainage flows over an area defined by the limits of the Panoche Creek and Little Panoche Creek alluvial fans.

The WADE model could similarly be used to provide input to the CVGSM, the SANJASM, the SANTUCM and the SJRIO-2 model. In the case of the SANJASM and the SANTUCM, the WADE model

would provide projections of land use, irrigation technology adoption and crop selection, all of which combine to allow deep percolation to the simulated in these models.

2.3.3.7 Previous peer review

The WADE model documentation (Quinn et al, 1990) was sent out for external peer review in October of 1989 and was reviewed by six individuals who provided detailed comments. None of the reviewers actually ran the model. Lack of model verification was seen as the major weakness of the documentation by the reviewers.

2.3.3.8 Model deficiencies and how these are being addressed

As previously stated, the WADE model is a regional level planning tool, best used for comparative rather than predictive purposes. In areas where a large amount of data is available, smaller polygon sizes may be used to capture some of the unique characteristics of these areas. The western San Joaquin Valley was divided into five main study areas and the WADE model was run separately for each of the five areas. The San Luis Service area is represented by the Grasslands and Westlands subareas. Lateral flow between these subareas across the boundary polygons is assumed to remain steady over the duration of the simulations. The alternative would be to combine these models - however, the execution time on an IBM compatible 486 or Apollo workstation could be in excess of 1.5 hours per year simulated. The WADE model is somewhat unweildy in its current form and should be reduced in size and customized for specific applications.

The costs to production associated with the salinity of pumped water is not currently considered in the model objective function nor are the benefits associated with reducing groundwater tables. To include these non-linear terms could make the model unstable and increase the model execution time. The model currently determines groundwater pumping activity levels purely on the basis of the economics of agricultural production. The relationship between groundwater pumpage and water table response is complex and in many instances cannot be simulated realistically with a groundwater model as simple as the one utilized by the WADE model.

Other deficiencies of the WADE model are : (1) the decision algorithms used to make irrigation technology choices and investments in drainage systems use concepts of profit maximization. Hence the model cannot capture the important non-economic factors that influence the decisions of farmers in technology transfer decisions; (2) the algorithm used to calculate drainage salinity is empirical and based on data from drainage experiments conducted by the USGS, where the proportional contribution from surface, near surface groundwater and deep groundwater sources of drainage salinity was estimated. In the absence of data for each polygon, the same distribution was used for all polygons; (3) the seasonal time step used in the model does not allow the dynamic nature of water table movement to be simulated and the cyclical processes of salt evapoconcentration in the rootzone followed by salt leaching during irrigation events.

2.3.4 Utility of the model for Reclamation planning studies

2.3.4.1 Actions to meet water quality objectives in the San Joaquin River

Drainage discharges, estimated by the WADE agricultural production model can be constrained to meet certain contaminant load objectives such as might be established in the San Joaquin River. The agricultural production model would attempt to meet this waste load allocation through such actions as increasing irrigation recycling, improving irrigation technologies and practices, crop substitution and land (idling) retirement. The relationship between drainage flows and contaminant loads, produced by the WADE model, and the concentration of these contaminants at the compliance point in the San Joaquin River, has yet to be established. During the spring months duck clubs and refuges discharge ponded water, which contains a significant salt load. This makes it difficult to develop a relationship between seasonal drainage production and salt concentrations in the San Joaquin River. The IRDROP model, described in Section 3.2, utilizes a monthly version of the WADE hydrology and salinity models, and would be a more suitable model for making this analysis.

2.3.4.2 Salt balance in the San Joaquin Basin

The WADE model has been used to develop salinity budgets for the SJVDP study areas. The model accounts for salt within four aquifer layers and estimates movement of salt between these layers. These layers include the crop root zone; the bottom of the root zone to 20 ft (shallow groundwater); 20 ft to the top of the Corcoran Clay (deep groundwater); and the sub-Corcoran Clay (confined) aquifer. Polygons in the WADE model are divided into drained and undrained areas. The combined drainage flow and salt load from polygons containing drained land in the Grassland subarea is assumed to be collected in surface drains and routed to the San Joaquin River along Mud and Salt Sloughs. The seasonal drainage flows and salt loads predicted by the WADE model were calibrated against the measured flow volumes and salt loads from Mud and Salt Sloughs.

2.3.4.3 Drainage reduction policies and planning

The WADE model is flexible in that the polygon mesh can be expanded or reduced to suit various levels of analysis. However, the gross assumptions used in estimation of lateral flow across polygon boundaries and determination of lateral flow at polygon boundaries become less defensible as the scale of analysis is reduced to the field level. The WADE model should be limited to analyses at the water district or larger scale.

The various drainage reduction policies that have been analysed with the WADE model include (a) drainage fees based on volume of discharge, (b) drainage fees based on salt (or boron, selenium) loads; (c) tiered water pricing; (d) drainage load allocations for water districts (represented by several polygons in the model); (e) regional groundwater pumping; and (e) land retirement and idling of selected lands.

2.3.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

The WADE model does not recognize the streams and tributaries to the San Joaquin River. Neither does the model recognize stream - aquifer interactions. The San Joaquin River is represented as a boundary nodes on the east side of the model. The analysis of actions involving conjunctive use of surface water and groundwater can be analysed by the WADE model as a trade - off between surface water supply and groundwater supply at the regional level. Tradeoffs between surface deliveries and groundwater pumping can be analyzed on the basis of cost. Further development of the WADE model is needed to allow the model to consider both the salinity of the pumped groundwater and the benefits of water table lowering in making groundwater pumping decisions. The present model only considers these factors during the next irrigation season.

2.3.4.5 Structural options to control stage and water quality in the South - Delta

The model cannot be used directly for this type of analysis. If linked to one of the Delta hydrodynamic flow and salinity models and the SJRIO-2 model, the WADE model could be used to predict a future time series of drainage flows and salt loads, which could then be routed down the San Joaquin River into the Delta. Much of the salt load carried into the Delta originates from agricultural operations on the west side. Water policy decisions to change the pricing structure of water supplies or restrict water deliveries to farmers can be evaluated directly with the WADE model. Consequences of such actions can be evaluated in terms of farm income, land use and drainage flow and load.

2.3.5 Overall assessment and recommendations

The WADE model was developed as a tool for drainage planning and for evaluating various policy decisions. The model is unique in this capability. The model simulates those aspects of aquifer hydrology and salt transport that have direct bearing on the economics of agricultural production. The current WADE model operates on a seasonal time step, which creates some problems when linking it to a monthly mass balance model such as SJRIO-2. In the past, a monthly distribution has been applied to the annual drainage flow data to produce monthly flows. A linear relationship between drainage load and flow was assumed to obtain drainage loads. The WADE model should be retained within Reclamation to assist in making future projections of land use, water demands and drainage discharge - these are factors that are typically static in other models or extrapolated based on recent trends.

2.3.6 References

Quinn, N.W.T. et al. 1989. Overview of the Use of the Westside Agricultural Drainage Economics Model (WADE) for Plan Evaluation by the San Joaquin Valley Drainage Program. San Joaquin Valley Drainage Program Technical Information Record.

Hatchett, S.A., N.W.T. Quinn, G.L. Horner and R.A. Howitt, 1989. A drainage economics model to evaluate policy options for management of selenium contaminated drainage. Toxic Substances in Agricultural Water Supply and Drainage. Proceedings of the Second Pan American Regional Conference on Irrigation and Drainage, Ottawa, Ontario. June 8-9, 1989.

Howitt R.E. and P. Mean. 1985. Positive quadratic programming model. Occasional Paper. Department of Agricultural Economics, U.C. Davis, CA.

3.4. South Delta Computer Aided Support System (SDCASS)

3.4.1 General description and purpose of the system

The South Delta Computer Aided Support System is not a model, rather it is a sophisticated graphics and analysis package for interpreting the results of model simulation runs performed using the RMA Link-Node model. The SDCASS is included in this overview of models of San Joaquin Basin hydrology because of the importance of the Delta as the point of origin of CVP project deliveries to the San Joaquin Valley and because water quality concerns in the South Delta are driving current efforts to better manage west-side agricultural drainage. The SDCASS described in this section is the first version of the system, developed for the MacIntosh computer by Mr John DeGeorge at U.C. Davis. A more powerful, IBM-compatible version of the same SDCASS, developed in the Microsoft Windows environment, is currently in the final stages of development.

Although the SDCASS has been developed to read output files directly from the RMA Link-Node model there is no reason why the system should not be applied to other Delta hydrodynamic and salinity models such as the Fischer Delta Model, the Wong Delta Hydrodynamic Model or the DWR Delta Simulation Model. The above-mentioned Delta hydrodynamic models are not included in this review document and will be the subject of a separate document to be prepared by MP-780 within Reclamation. The RMA Link-Node model was originally applied to the San Franscisco Bay-Delta to simulate estuary hydrodynamics and allow the estimation of water quality and spatially distributed ecological processes. The model is the most widely applied of all the Delta hydrodynamic models and variations of the original RMA model are currently used by both the Division of Planning and the Environmental Services Office within the DWR, as by several engineering consulting firms and private water agencies.

3.4.1.1 Geographic extent of the system

The major tributaries to the San Joaquin River within the San Joaquin Basin is illustrated in Figure 7. The Sacramento - San Joaquin River Delta lies north of Vernalis, a salinity compliance site, located in the lower right of the diagram in Figure 7. A map of the Delta is given in Figure 8 as represented in the RMA Link-node hydrodynamic flow and water quality model - the South Delta is generally considered to be the area to the south of the Contra Costa Canal. The geographic extent of the South Delta, defined by the SDCASS, is shown in Figure 9. The RMA Link-Node model provides the CASS with stage at each of the model nodes and flow and salinity levels along each of the model links.

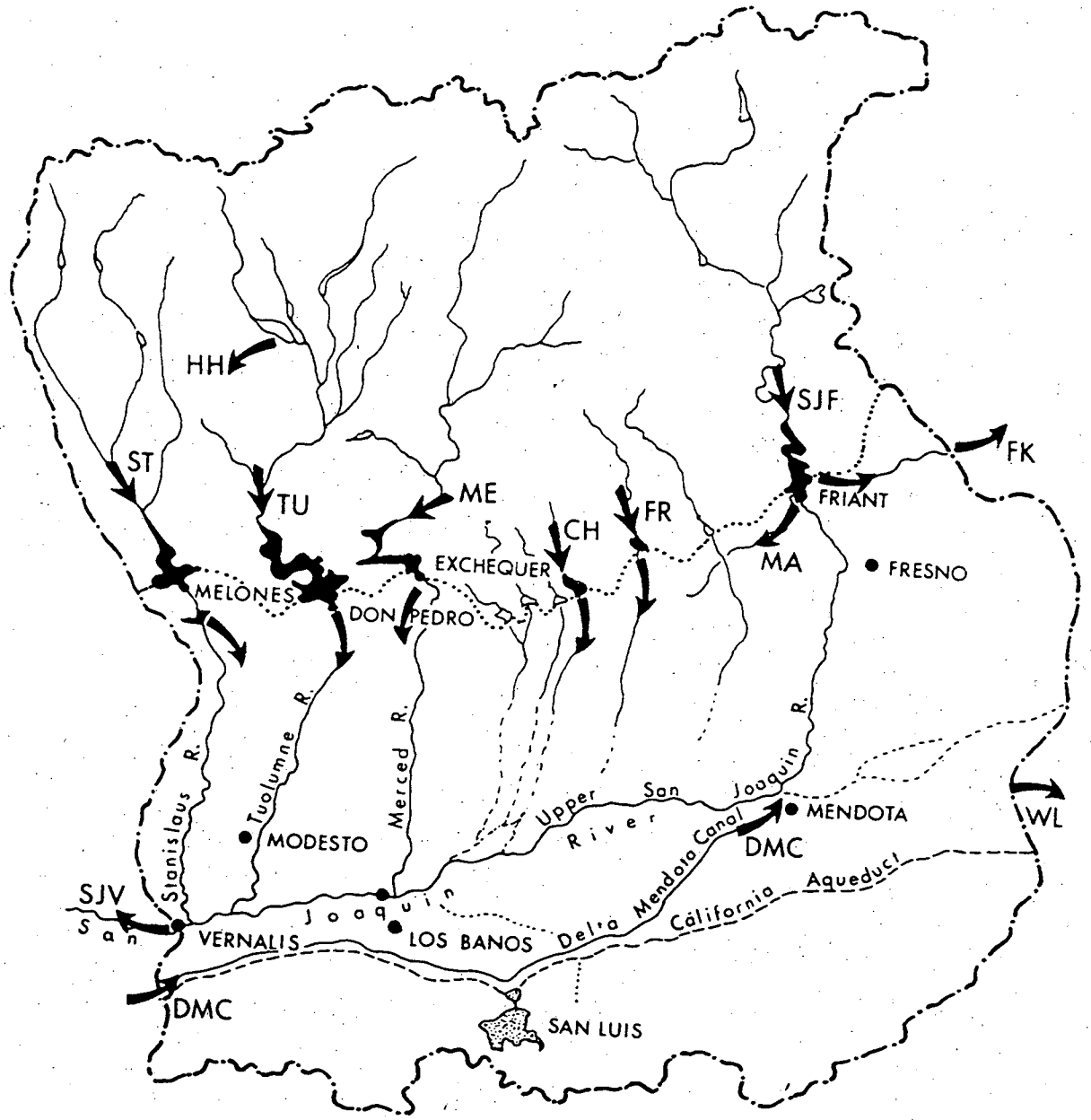

Figure 7. **Major tributaries to the San Joaquin River upstream of the Sacramento - San Joaquin Delta. The Vernalis compliance point is an upstream boundary node in the South Delta Computer Aided Support System (SDCASS).** (Source : Orlob, 1991)

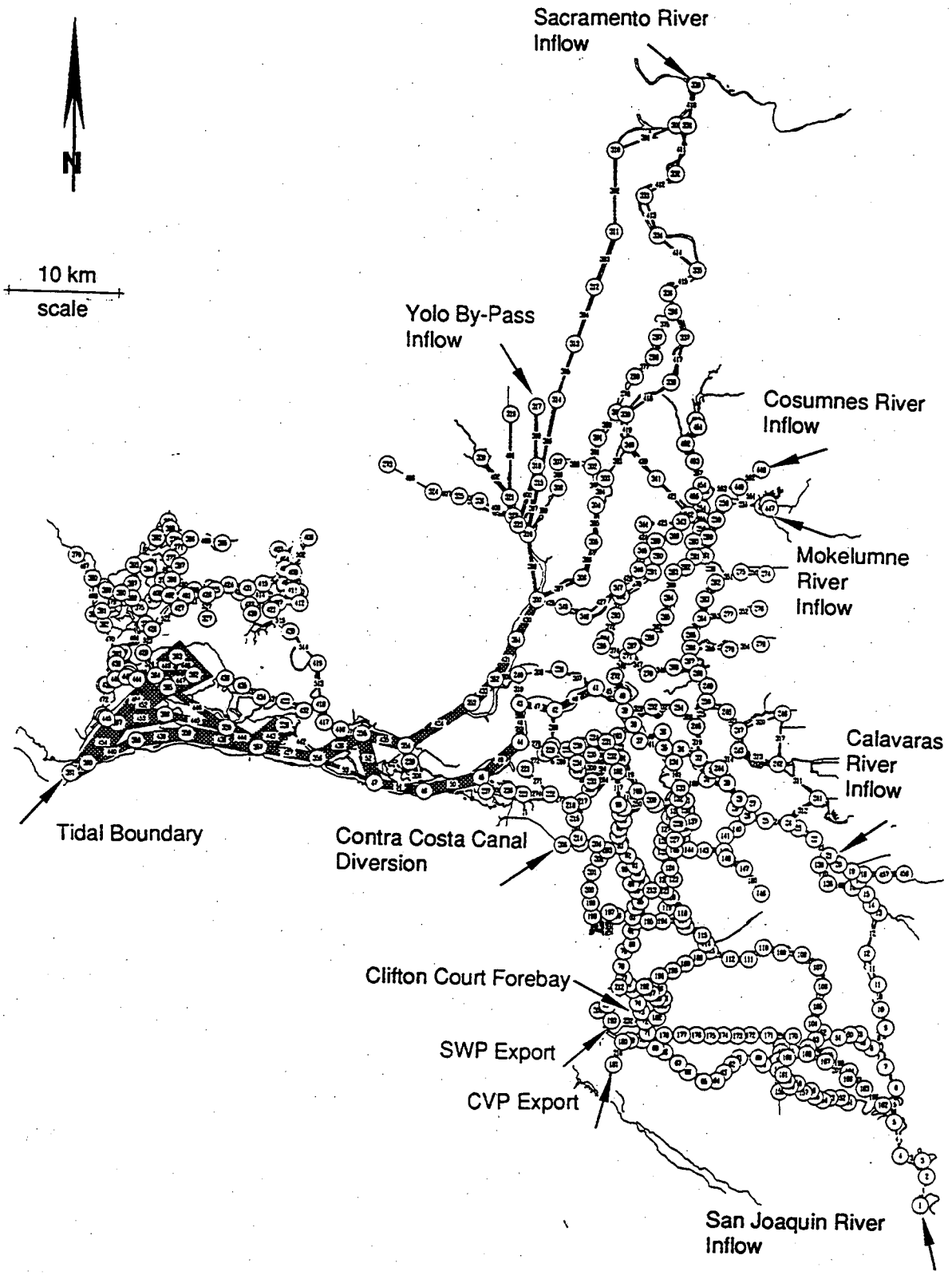

Figure 8. **RMA Link - Node model configuration for the Sacramento - San Joaquin Delta. This model supplies boundary flow and water stage information for the SDCASS.**

(Source : DeGeorge, 1992)

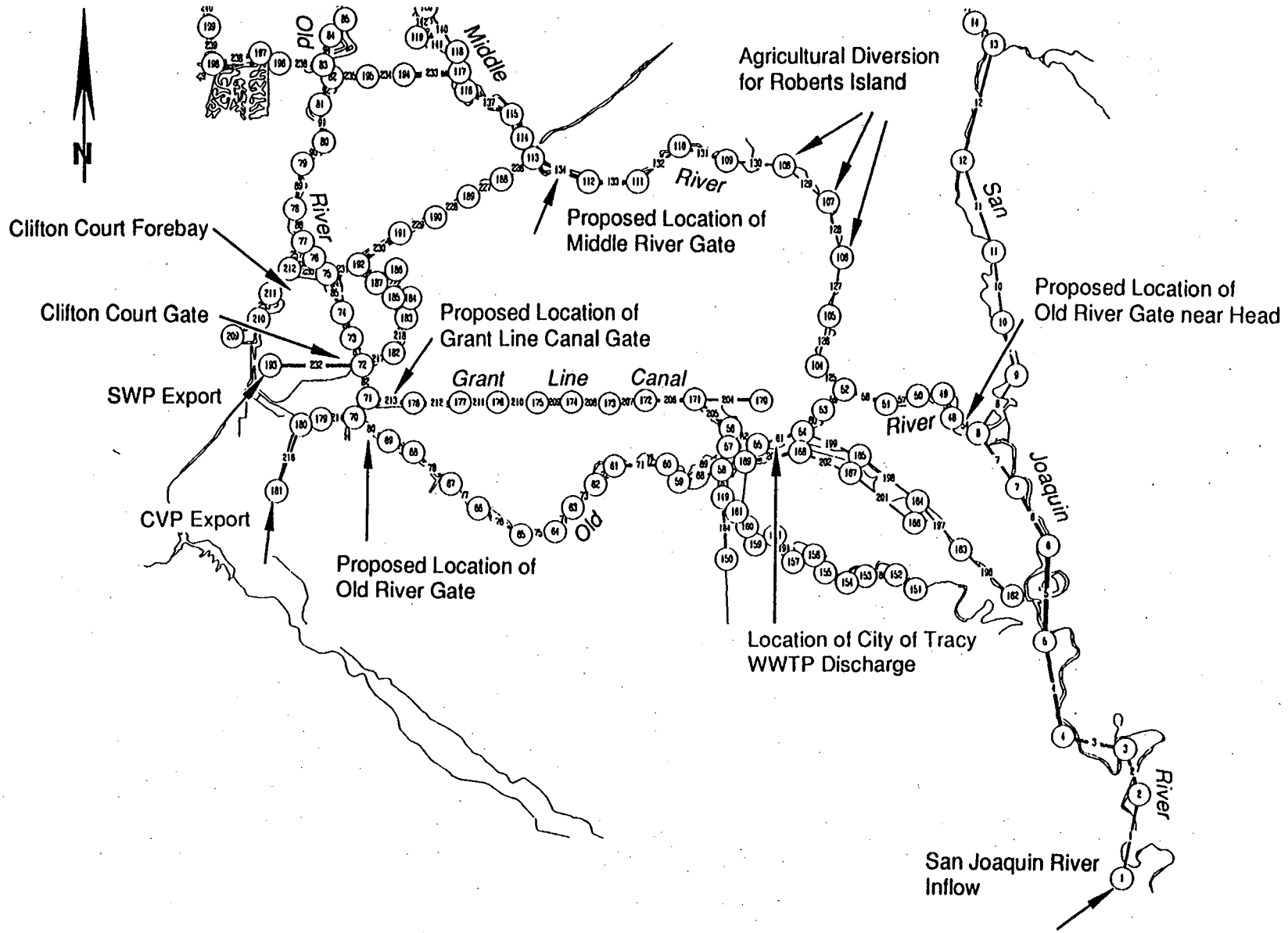

Figure 9. **Link - Node model configuration for the South Delta. These are the nodal points represented in the SDCASS.**
(Source : DeGeorge, 1992)

3.4.1.2 Features of the system

The SDCASS was originally developed for the Apple Macintosh using the Hypercard environment and has been rewritten to run under MS- windows on IBM compatible computers. The SDCASS uses a primitive geographic information system (GIS) to illustrate the geometry of the Delta channels and also those links of the RMA link-node model that occur within the South Delta. The GIS has a feature that allows the user to create a new network geometry, to control the placement of nodes and to connect channels on the screen interactively. The GIS also has the capability of displaying geo-referenced background maps on the screen, including vector maps, raster maps and site maps (DeGeorge, 1991). The IBM compatible version of the SDCASS runs within the MS Windows environment and utilizes the public domain GRASS GIS package. This MS-DOS based version contains many features not found in the Macintosh version of the SDCASS.

The RMA Link Node model is run in steady-state mode with tidally averaged inflows. The model assumes that diffusion is proportional to mean flow, which eliminates the need to solve the complete advective - dispersive equation for salt transport and helps to decrease model run time. The SDCASS reads the stage and flow data directly from the formatted output files of the hydrodynamic model.

3.4.1.3 Capability of the system : flow / flow and water quality

The RMA Link-Node model is typically run in steady-state mode using monthly average water surface elevations, flows and salinity for a series of different hydrologies given an average daily tidal cycle. The SDCASS displays water surface profiles and mean daily flow volumes (in cfs) along any of the links specified in the interactive user interface (Figures 10 and 11). Figures 12 and 13 demonstrate the help screens available in the Macintosh Hypercard SDCASS and typical tables of mean daily flow that can be written to the screen. Figures 14 and 15 compare mean water surface elevations and daily mean flow volumes (in cfs) for months January, July and October for the year 1988.

3.4.1.4 Simulation time step

The RMA Link-Node model is typically run as a tidally averaged model using the monthly averaged flow in the lower San Joaquin River as a boundary condition. The SDCASS reads the link node model output files and displays the results by year and for any or by month as specified using the system user interface. The SDCASS can also be used to animate stage during the daily tidal cycle, if produced by the RMA Link-Node model when run in dynamic mode.

3.4.1.5 Computer requirements and portability

The RMA Link-Node model takes approximately 14 hours for the flow computation and 1 hour for the water quality computation for a 25 year simulation on an IBM compatible 386 machine. The results of each simulation are typically saved as an ASCII file and, after file transfer to the MacIntosh using either diskette or modem, the SDCASS can display or animate the simulation model output. The SDCASS runs relatively

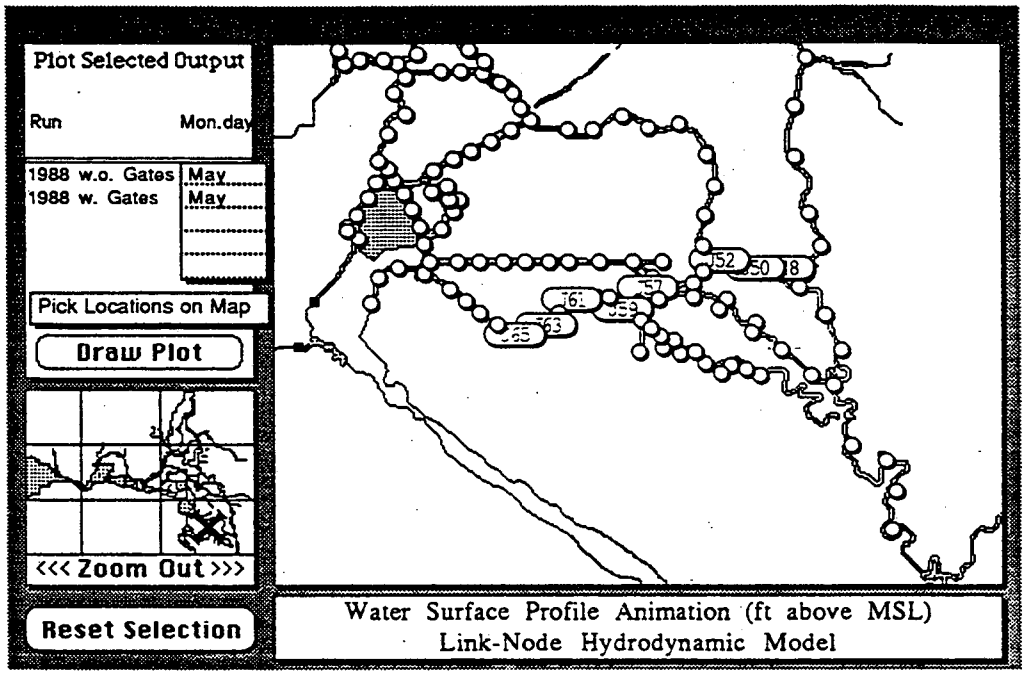

Figure 10. **Locations along Old River at which animations of water surface elevation are performed by the MacIntosh Hypercard SDCASS.** (Source : DeGeorge, 1992)

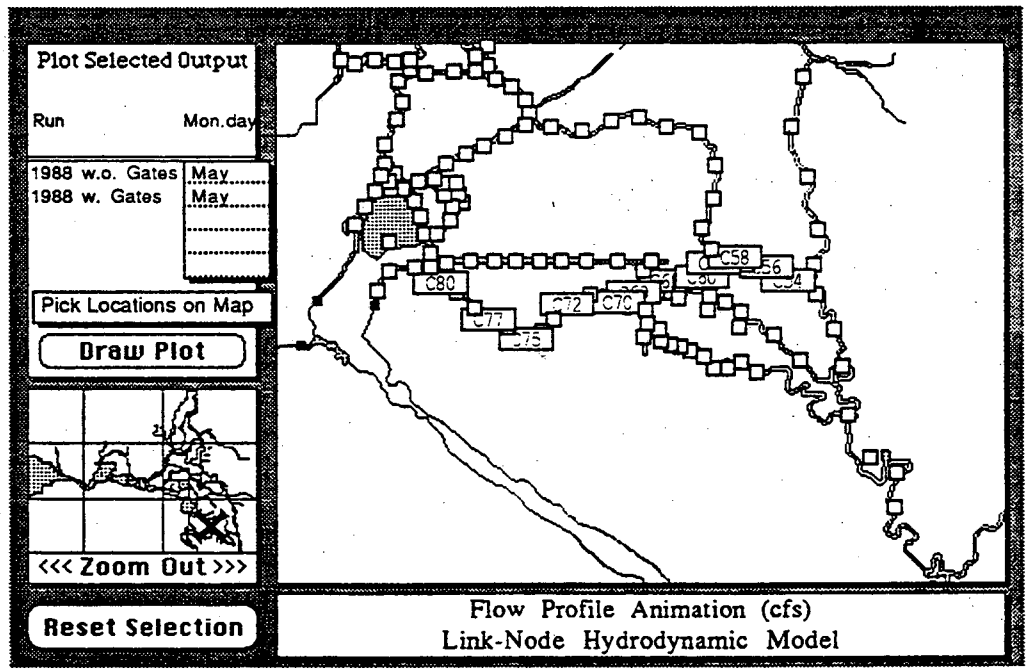

Figure 11. **Locations along Old River at which animations of the flow profile are performed by the MacIntosh Hypercard SDCASS.** (Source : DeGeorge, 1992)

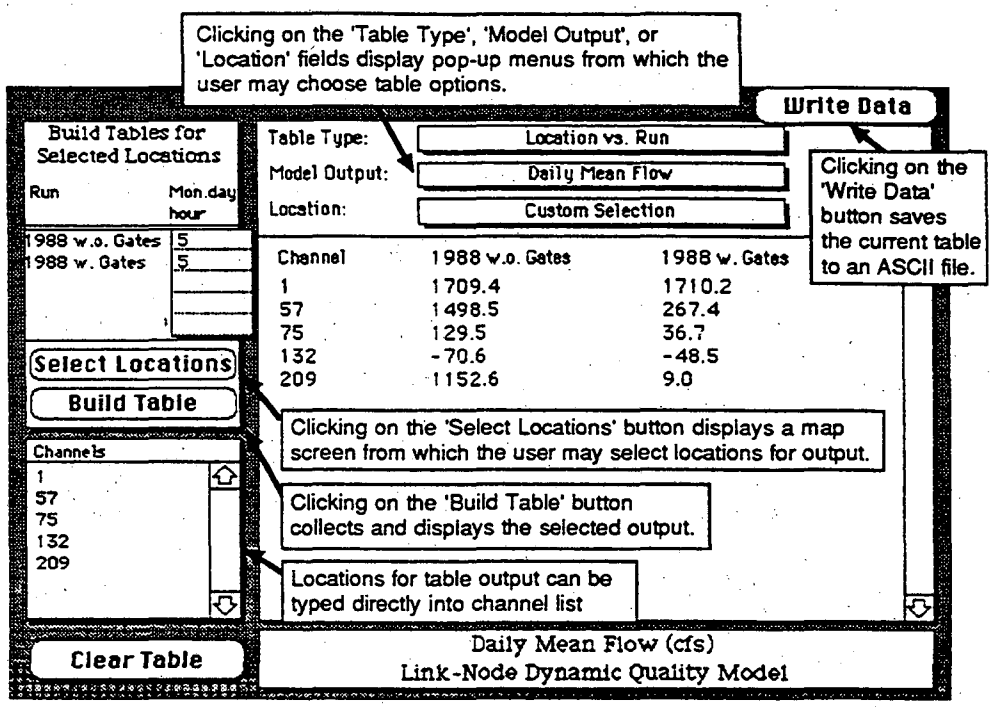

Figure 12. **User interface for the MacIntosh - based SDCASS. The user selects the nodes for which daily mean flow or stage is to be output.**
(Source : DeGeorge, 1992)

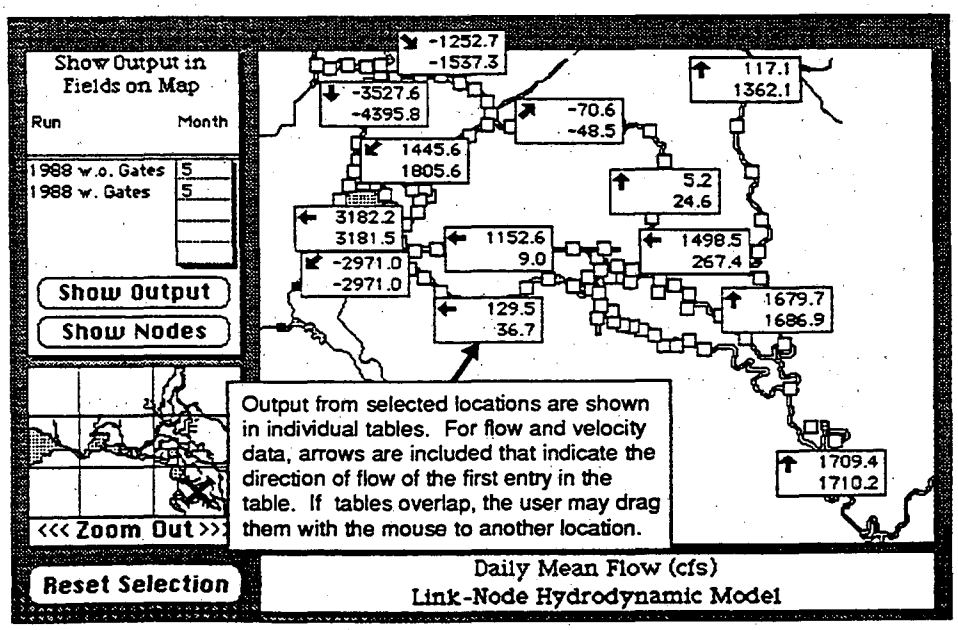

Figure 13. **Output from a simulation using the RMA link - node hydrodynamic model. The SDCASS imports only the link-node model output for the South Delta and allows the user to select nodes for display from the imported nodal data**
(Source : DeGeorge, 1992)

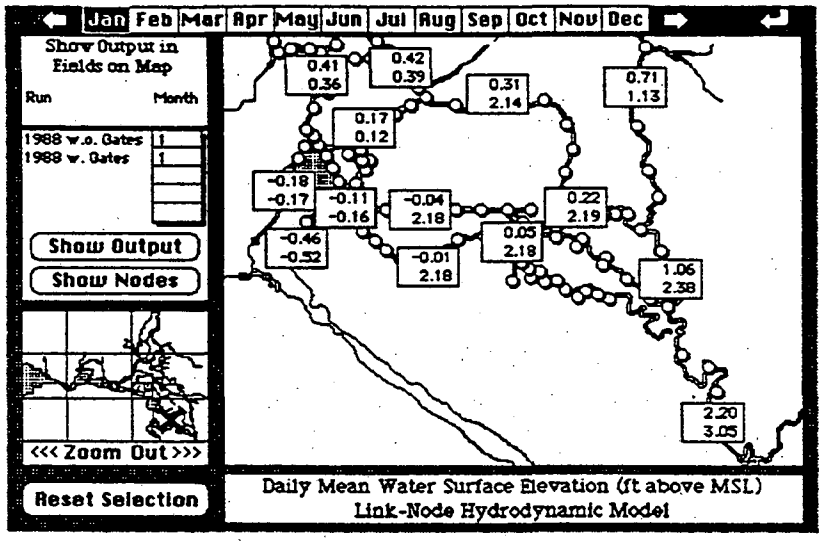

Figure 14. **Daily mean water surface elevations provided by the link-node hydrodynamic model and displayed in the SDCASS for the month of January 1986.**
(Source : DeGeorge, 1992)

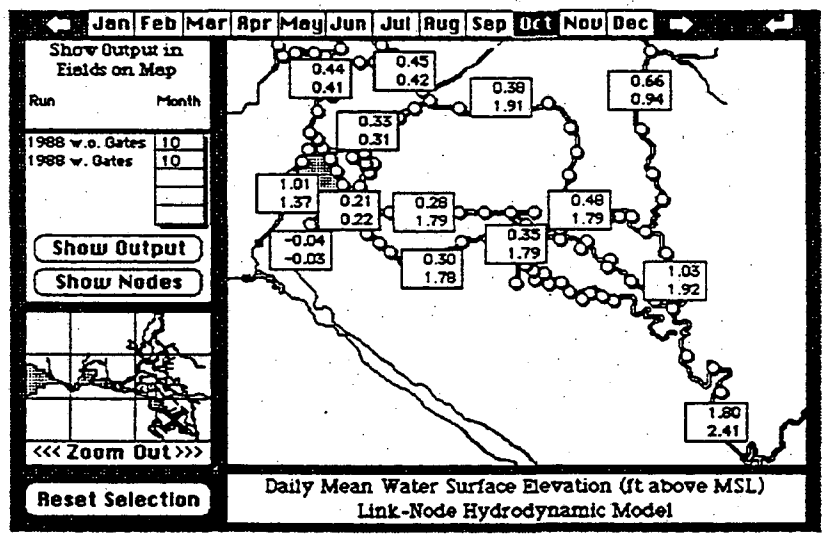

Figure 15. **Daily mean water surface elevations provided by the link-node hydrodynamic model and displayed in the SDCASS for the month of October 1986.**
(Source : DeGeorge, 1992)

slowly under Hypercard on a MacII with 4 MBytes of RAM. One of the reasons for moving to the Windows environment on an IBM compatible computer was to significantly increase the speed of execution of the SDCASS. Another is that it increases the likelihood for widespread use of the software.

3.4.2. System development

3.4.2.1 Reasons for development of the system

The South Delta CASS was developed to help the South Delta Water Agency explore actions to improve the quantity and quality of its water supply. With the co-operation of the Department of Water Resources and the US Bureau of Reclamation several structures have been constructed to help maintain water levels in the South Delta and to promote adequate movement of water through these South Delta channels (Orlob, 1992). The RMA Link Node model and the SDCASS, in combination, allow the consequences of operation of these structural facilities to be simulated under a range of hydrological conditions. The RMA link-node model and SDCASS have also been used to examine the effect of proposed tidal barriers in the South Delta on (a) water surface elevation and flow in the southern Delta channels; (b) water quality in the South Delta; and (c) Delta exports (DeGeorge, 1991). After appropriate reformatting of the output datafiles the SDCASS could also be used to examine the output from other Delta hydrodynamic models, once simulation runs have been performed for these or other scenarios which relate to South Delta channel flow and water quality.

3.4.2.2 History of development and use of the system

The South Delta CASS has been used, in conjunction with the RMA Link-Node model, to (a) examine the effect of the proposed tidal barriers on South Delta flow, water surface stage and water quality; (b) provide testimony in the SWRCB Bay-Delta hearings on an investigation of alternative water supply strategies to remedy channel depletions and high TDS concentrations within Old River, Middle River and Grant Line Canal, in the South Delta.

3.4.2.3 Further development of the system and intended future use

The IBM-compatible version of the SDCASS is still under development by Mr John DeGeorge at U.C. Davis.

3.4.3. Evaluation of the system

3.4.3.1 Predictive capability and model reliability

The SDCASS is a model post-processor and therefore cannot be evaluated in terms of predictive ability or reliability. However the SDCASS can be of great utility in the interpretation and comparison of model results from different models. Should a comparative study be made of the various Delta hydrodynamic models, described earlier, this system would be invaluable and a tremendous time saver for the required analysis.

3.4.3.2 Data requirements

Data requirements for the SDCASS are the same for all hydrodynamic flow and water quality models that include the South Delta (Table 3). The hydrodynamic flow and water quality models calculate velocities and water surface elevations at locations throughout the South Delta and require data on channel length, roughness, bathymetry, agricultural pumping return flows and diversions. The models also require information on tidal variations and salinity of the water along each element of the model network, as well as the average salinity of return flows. The SDCASS reads time, stage, flow and EC data directly from the formattted output files. Model boundary conditions are specified as monthly flows into the Delta from the San Joaquin River, which are typically obtained indirectly from river basin flow models such as the SANJASM or the SANTUCM or directly from water quality models such as the SJRIO model.

3.4.3.3 Systen outputs

The SDCASS was designed to produce animations and tabular output from the model in a manner that aids user comprehension. The SDCASS can be queried to display water elevation output at any of the model nodes and mean daily flow output for any of the model links selected using the cursor and the model network. Output can include EC concentrations at the intakes to the State and Federal pumping plants; flow and salinity of water at SWRCB monitoring sites within the Delta and flow and water quality at the points of diversion for the South Delta Water Agency.

3.4.3.4 Ease of calibration and performing system runs

Calibration and verification of the various Delta hydrodynamic models is a difficult task and there is lingering controversy regarding the reported success with which this has been accomplished. The existing database of historic Delta diversions and return flows appears inadequate to perform a reliable calibration of salt transport in the South Delta. The SDCASS can be of great assistance in both the calibration and model verification process.

3.4.3.5 Relative expense of using and maintaining system

The SDCASS currently runs under Hypercard on the Macintosh but will soon be superceded by the IBM compatible version of the CASS. Once the output data has been reformatted into a standard format that can be recognized by the SDCASS the production of graphics and animations of tidally variant flow and EC is very straighforward, aided by well composed pull-down menus. The SDCASS has the potential for saving considerable time and human resources.

Table 3. **Input data required for the RMA link-node hydrodynamic model. The SDCASS reads ASCII output files from the link-node model and represents these results graphically on a map of the South Delta.** (Source : DeGeorge, 1992)

Initial Conditions:	concentration of all constituents at all nodes
Quality at Tidal Boundary:	node corresponding to tidal boundary concentration of all constituents
Quality at Boundary Flows:	concentration of all constituents for all inflows
Coefficients:	depth of 1% light penetration benthic nitrogen source rate benthic phosphorous source rate benthic oxygen sink rate maximum reaeration rate minimum reaeration rate oxygen source rate by forced aeration
Climatological Conditions:	cloud cover dry bulb temperature dew point wind speed atmospheric pressure date
Model Options:	Julian day of start of simulation number of hydrodynamic boundary conditions number of sets of quality boundary conditions length of water quality time step number of time steps per day hour of hydrodynamic output at start of quality run number of days of simulation for each quality BC number of tidal days for each hydrodynamic BC quality BC data to be read for each BC set

2.4.3.6 Ease of linking with other models

The SDCASS is a postprocessor specific to the RMA Link-Node model which may be adapted to work with other Delta hydrodynamic models. Use with other models will require writing custom computer code to write the model results into a format that the SDCASS can understand.

2.4.3.7 Previous peer review

The MacIntosh SDCASS has been described in Mr John DeGeorge's MS thesis submitted to the Department of Civil Engineering at U.C. Davis (DeGeorge, 1991). The Microsoft Windows version of the SDCASS has not been completed at the time of writing this report, although it is probably more than 75% complete (DeGeorge, 1992, personal communication).

2.4.3.8 System deficiencies and how these are being addressed

The SDCASS is one of three graphics-based, post-processors known to the author for analysis of output from the Delta hydrodynamic and water quality models. It is the only post-processor that is specific to the South Delta. The greatest deficiency in the MacIntosh-based version of the SDCASS has been the speed of execution which is due to the use of the Hypercard software to store graphic images. Use of a MacIntosh SDCASS also might require that output be transmitted from the computer used to make the model simulation run to the MacIntosh (running the RMA Link-Node model on a MacIntosh would require a IIci or Quadra as a minimum). The IBM compatible version of the SPCASS utilizes the Microsoft Windows graphics programming libraries which has resolved many of the speed and image manipulation problems associated with the MacIntosh SDCASS.

2.4.4. Utility of the system for Reclamation planning studies

2.4.4.1 Actions to meet water quality objectives in the San Joaquin River

The SDCASS produces graphic output only for the South Delta, although the hydrodynamic models used to produce the results typically consider the entire Delta. The SDCASS could be used to evaluate the impact of these actions on flow and water quality in the South Delta if model used for making water quality projections in the San Joaquin River were linked with the RMA Link-Node model or similar hydrodynamic and water quality model (Figure 16).

2.4.4.2 Salt balance in the San Joaquin Basin

The SDCASS is useful only in the South Delta when used in conjunction with the Delta hydrodynamic and water quality models. It is therefore of limited use for this type of study

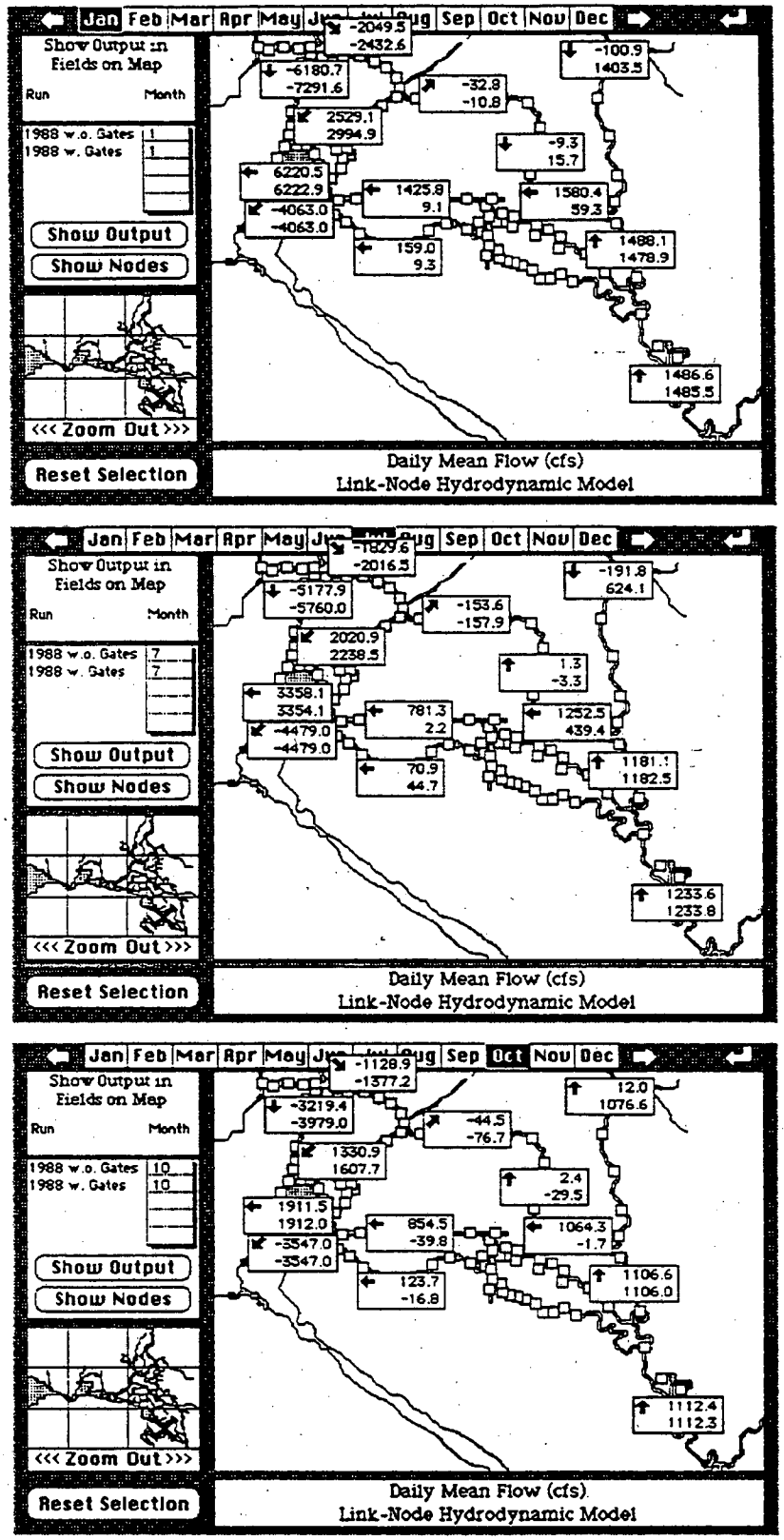

Figure 16. **Mean flow simulation results provided by the link-node hydrodynamic model and displayed in the SDCASS for the months of January, July and October 1986.** (Source : DeGeorge, 1992)

2.4.4.3 Drainage reduction policies and planning

Drainage reduction policies primarily concern return flows to the San Joaquin River from west-side agricultural water districts and wetlands in high water table areas. Estimates of drainage flow and quality from Westside agriculture made using a model such as the WADE model would need to be linked to a water quality model of the San Joaquin River such as SJRIO and a hydrodynamic model of the South Delta such as the RMA Link-Node model in order for the SDCASS to have any utility for this study.

2.4.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

Groundwater conjunctive use practices can affect the quantity and timing of salt loads, primarily along the San Joaquin River and into the Delta. The RMA Link - Node Model can be used to demonstrate the effect of these actions on salinity at the export pumps, the intake to Contra Costa Water District and the South Delta Water District. The model would need to be linked to models such as the SANJASM or the SANTUCM to explore the effect of certain changes in reservoir operations, enabled through the adoption of conjunctive use policies. The SDCASS would have only indirect use in such a study.

2.4.4.5 Structural options to control flow and water quality in the South - Delta

The various Delta hydrodynamic and water quality models have been used to test a number of structural options for salinity reduction and for maintaining adequate water elevations in the South Delta. These options are designed to prevent San Joaquin River flow from flowing directly into channels serving the South Delta, during certain critical times of the year. These models have also been used to evaluate certain non-structural options such as changing the release pattern of flows down the Merced, Stanislaus and Tuolomne Rivers. The SDCASS can be used directly to graphically represent and animate the results of these simulation runs.

2.4.5 Overall assessment and recommendations

The SDCASS has some unique features that warrant its consideration by Reclamation. Although the current MacIntosh version of the system is somewhat limited - ongoing development of the system on IBM compatible computers under the windows environment will yield an extremely useful product.

The SDCASS has the potential to significantly improve interpretation and reporting of results from Delta hydrodynamic and salinity models. The DWR-DSM model also utilizes a custom designed CASS (the Delta Graphical User Interface - DGUI). However, the DGUI runs on a SUN workstation and would require investment in the windowing software as well as significant effort to make the system compatible with Reclamation's DataGeneral AViiON workstations. Recent experience with porting graphics software from SUN workstations by the ADSS group at Colorado State University has revealed significant compatibility problems.

2.4.6 References

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2.5 CVGSM (Central Valley Groundwater Surface Water Model)

2.5.1 General description and purpose of model

The Central Valley Groundwater Surface Water Model (CVGSM) was developed in 1990 by James M. Montgomery Engineers Inc. (JMM) for a consortium of agencies comprised of the Bureau of Reclamation, the Department of Water Resources, the State Water Resources Control Board and the Contra Costa Water District. The purpose of the model was to predict water budgets for subareas of the Central Valley of california, given variations in water supplies and groundwater demands. The CVGSM is a specific application of the Integrated Groundwater Simulation Model (IGSM), a finite element model which simulates the flow of water both above and below the ground surface as well as the interaction between surface and subsurface through rivers, canals and the soil matrix.

2.5.1.1 Geographic extent of the model

The Central Valley of California covers approximately 20,000 square miles and is divided into two general watersheds which are named for the major rivers that drain them, the Sacramento Valley to the north of the Delta and the San Joaquin Valley to the south of the Delta (Figure 17). The entire model area has been divided into 1392 finite elements with an average size of 14 square miles (9000 acres). The stream node network in the San Joaquin Valley is shown in Figure 18. The network accounts for the major tributaries to the San Joaquin River and includes the Kings River and Kern River in the Tulare Basin.

2.5.1.2 Features of model

The model was designed as a planning tool for the comparison and analysis of strategies involving the conjunctive use of surface water and groundwater in the Central Valley. The model contains estimated hydrologic budgets for water use, streamflow, soil moisture and groundwater. Groundwater pumping, irrigation diversions and streamflow were estimated for the period of record, 1922 - 1980. The model can be used to make estimates of aquifer response using projections of future groundwater pumping, river flow, irrigation diversions and rainfall runoff. The time series of rainfall runoff may be estimated stochastically or estimated sequentially assuming that the future time series of rainfall will be identical to a past sequence. The soil moisture accounting portion of the model employs mass balance calculations. Groundwater flow is described by the continuity equation with source and sink terms and a vertical leakage term. These equations are solved using the finite element method.

The CVGSM divides the aquifer into three major units in both the Sacramento Valley and the San Joaquin Valley, based on 18 geological cross-sections of the Central Valley and extensive analysis of available well logs. The elements have been aligned to recognize major geologic features and the major drainage service area (DSA) boundaries used by the DWR to divide the Sacramento and San Joaquin Valleys into hydrologic

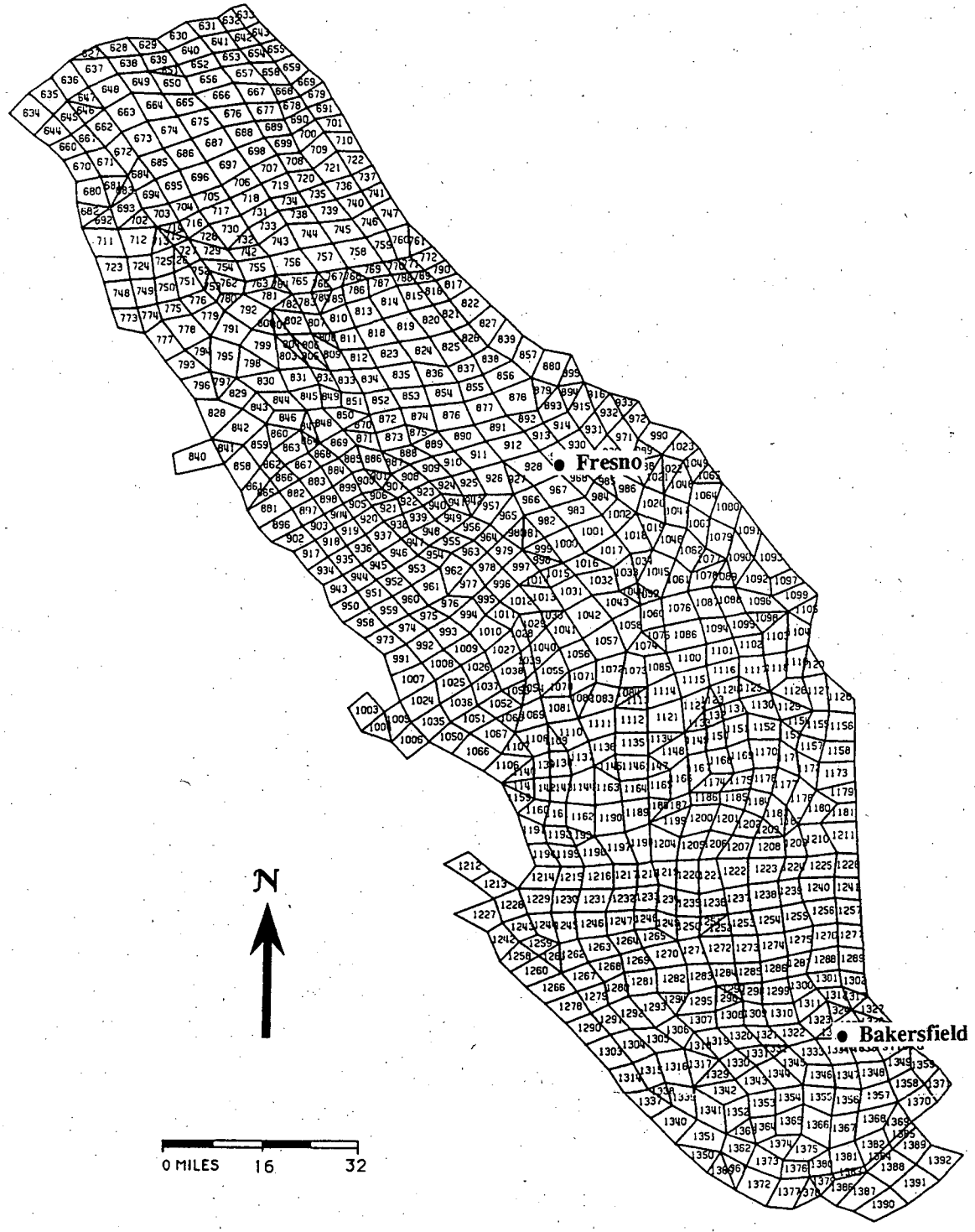

Figure 17. San Joaquin Valley portion of the CVGSM finite element network showing element numbers.
(Source : James M. Montgomery Inc., 1990)

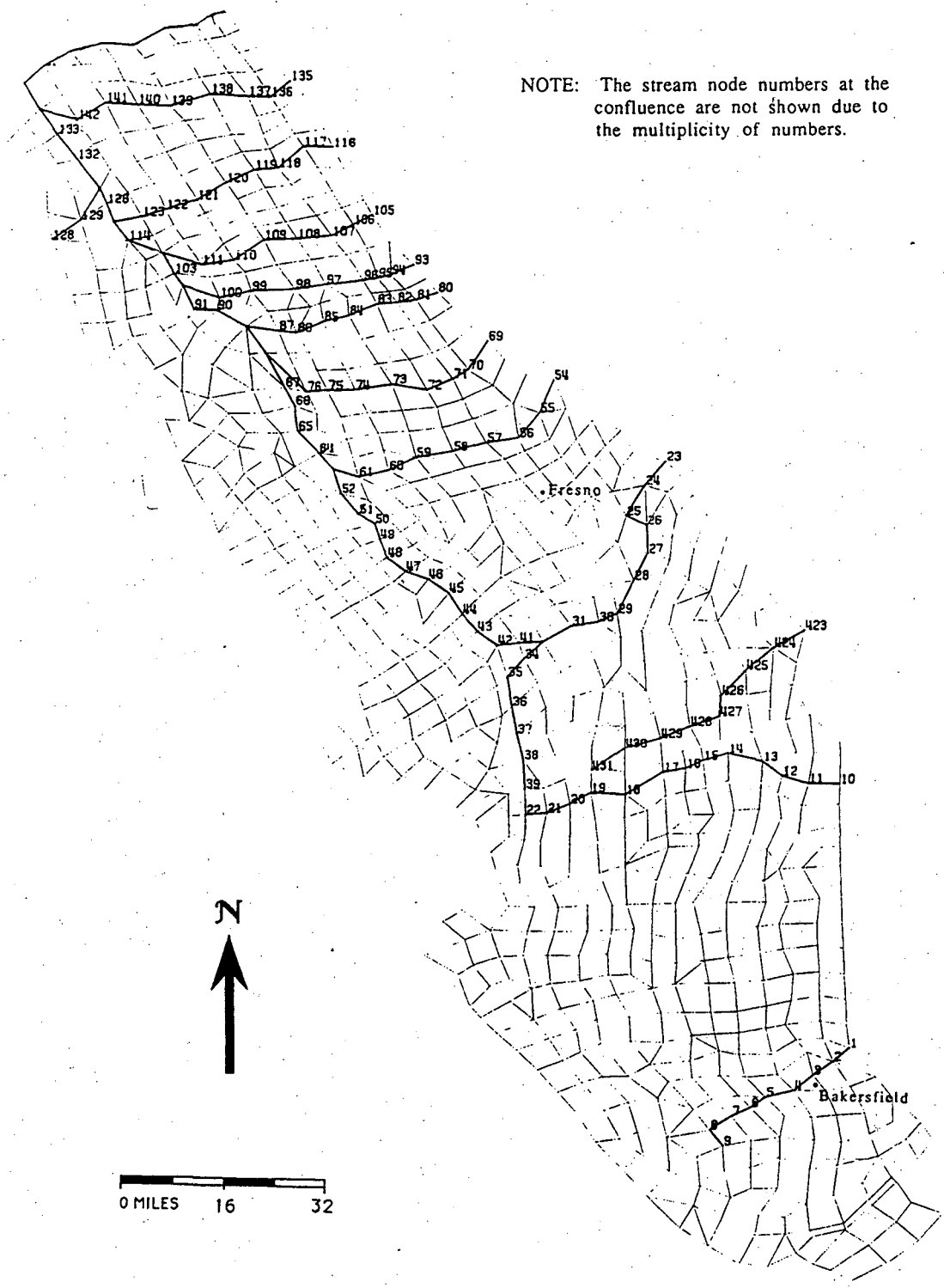

Figure 18. Stream node network and node numbers of the CVGSM. Stream - aquifer flow interaction is determined at every stream node.
(Source : James M. Montgomery Inc., 1990)

units. Surface drainage and stream cross-sections were obtained from USGS topographic maps and USGS reports.

2.5.1.3 Capability of the model : flow / flow and water quality

The CVGSM calculates river gains and losses along the main stem of the San Joaquin River, along the main stem of the Sacramento River and along the major tributaries to both rivers. The model also estimates groundwater flows and the interaction between groundwater and surface water at each stream node. Groundwater pumping affects water tables, which in turn affects the volume of groundwater flow either in to or out of the river. The model has been calibrated to simulate regional water tables and average monthly streamflows. The CVGSM does not consider water quality, either in the groundwater or in the streams and tributaries in the Sacramento and San Joaquin Valleys.

2.5.1.4 Simulation time step

The model operates on a monthly time step for 59 years (1922 - 1980). Use of a smaller time step would involve considerable expansion of the large database required to run the model and be of limited utility in a regional groundwater such as the CVGSM because of the lags associated with water infiltration and the large fluctuations in water table and irrigation return flows during the irrigation season.

2.5.1.5 Computer requirements and portability

The CVGSM requires an IBM or compatible 386 or 486 machine capable of utilizing extended memory. Lahey™ Fortran was used to compile the model owing to its superior speed. The model runs in less than 30 minutes on an IBM compatible 486 - 33 MHz machine for a simulation period of 57 years.

2.5.2 Model development

2.5.2.1 Reasons for development of the model

The development of the CVGSM was a multi-agency endeavor to standardize the analysis of groundwater conjunctive use in the Central Valley as well as update the model with more recent information. Although this objective has been realized and the model has been used by analysts within the offices of the model sponsor's, there remains some controversy and/or confusion over the hydrologic budgets developed to obtain irrigation efficiency and aquifer recharge. This has stymied more widespread adoption of the model.

2.5.2.2 History of development and use of the model

The CVGSM relies heavily on previous studies conducted by the USGS (Williamson, Prudic and Swain, 1975) and by Boyle Engineering (Boyle, 1987) for the Central Valley. The USGS RASA model is a three layer finite difference groundwater model of the Central Valley, constructed using the public domain software code

MODFLOW. Many of the interpreted aquifer characteristics and the estimates of groundwater pumping from the USGS model were used, first in the Boyle Central Valley study and then in the CVGSM. The model is still undergoing testing within the Department of Water Resources. An improved version of IGSM is currently being used for the Friant EIS study, currently being conducted by Reclamation, with assistance from James M. Montgomery Inc. In the Friant EIS study, the CVGSM was used as a first basis for setting boundary conditions for the more detailed model.

2.5.2.3 Further development of the model and intended future use

The CVGSM is still under review by the Model Support Branch within the Department of Water Resources. As previously stated, a more detailed model, the FRIGSM, has been created of the Friant-Kern Service Area using an improved IGSM code. Improvements to the original code include the capability of simulating runoff from small watersheds which drain into the Central Valley. The FRIGSM is being used to determine groundwater pumping safe yields in this study area as part of the Environmental Impact Statement being prepared to justify renewal of water service contracts. It is anticipated that these improvements will be applied to the CVGSM.

The CVGSM database has been updated by Boyle Engineering Inc. to a year 1990 level of project development. Water budgets being developed for the Friant-Kern Serice area will help to improve the accuracy of the water budgets within the CVGSM, as will more detailed information on cropping patterns, water deliveries and surface return flows. It has been suggested that the CVGSM be linked with the SANJASM to replace the SANTUCM, a linked surface water - groundwater model, which uses the older version of the IGSM. This may help to standardize analysis of potential groundwater extraction for the purpose of water contracting. Linking the CVGSM and a surface water model such as the SANJASM is a complicated and time intensive procedure owing to the different spatial aggregation in the groundwater and surface water models.

2.5.3 Evaluation of the model

2.5.3.1 Predictive capability and model reliability

The CVGSM is a monthly model which attempts to simulate major water flow between a number of control points along the Sacramento and San Joaquin Rivers and along the various east - side tributaries to both rivers. The model was formulated as a regional planning tool and because of its coarse grid and uncertain input data should be used with caution for predictive purposes. The groundwater model was calibrated by comparing predicted water levels to measurements at selected wells in the Sacramento and San Joaquin Valleys (Figure 19) for the period 1970 - 1980. Streamflow data for the entire hydrologic period were also used for calibration of stream - aquifer interactions by the model. The calibration experiments performed by JMM and reported in JMM (1991) show that the model simulates water levels and streamflows reasonably well and probably sufficiently well for most regional planning studies (Figures 20 - 23).

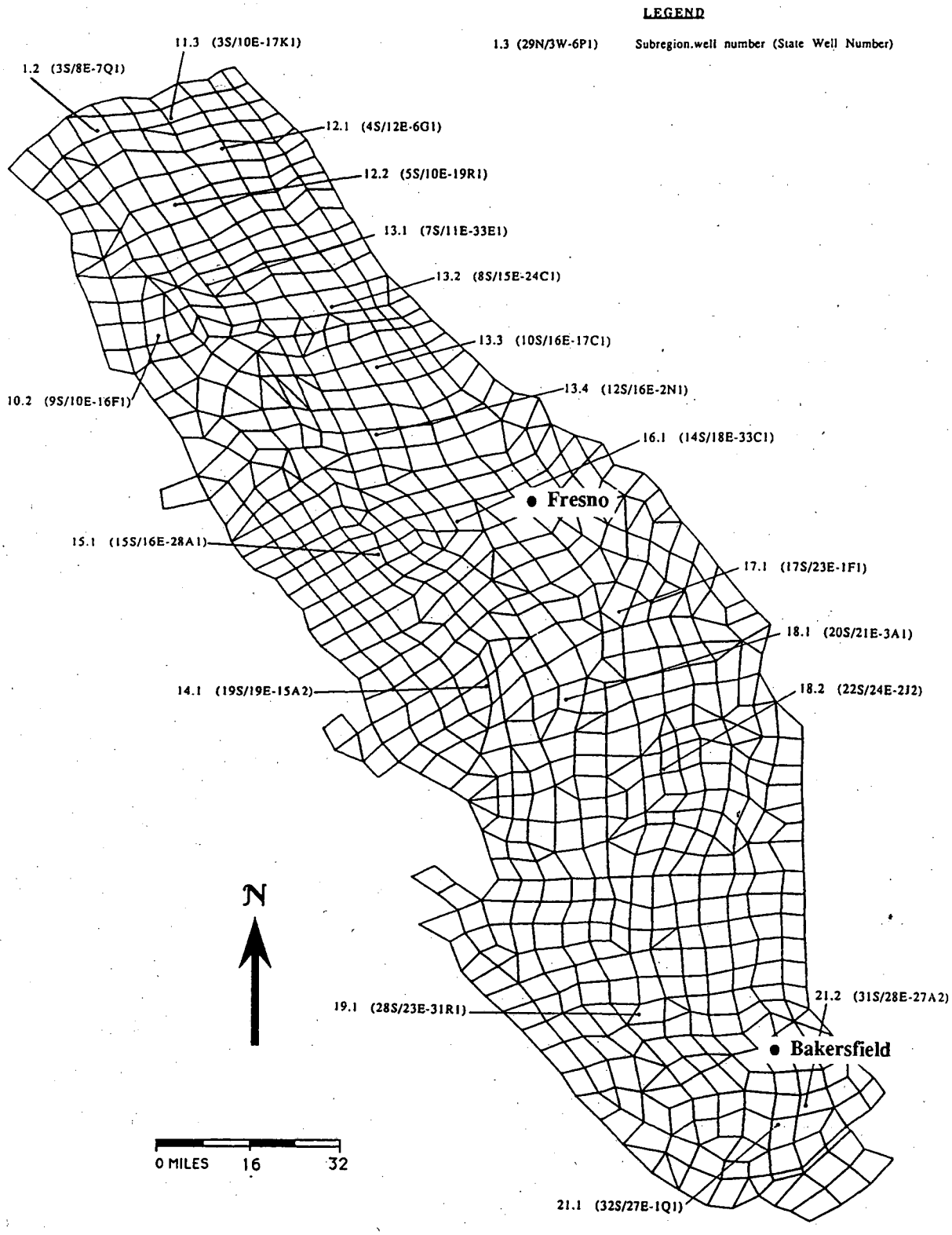

Figure 19. CVGSM calibration well locations in the San Joaquin Valley.
(Source : James M. Montgomery Inc., 1990)

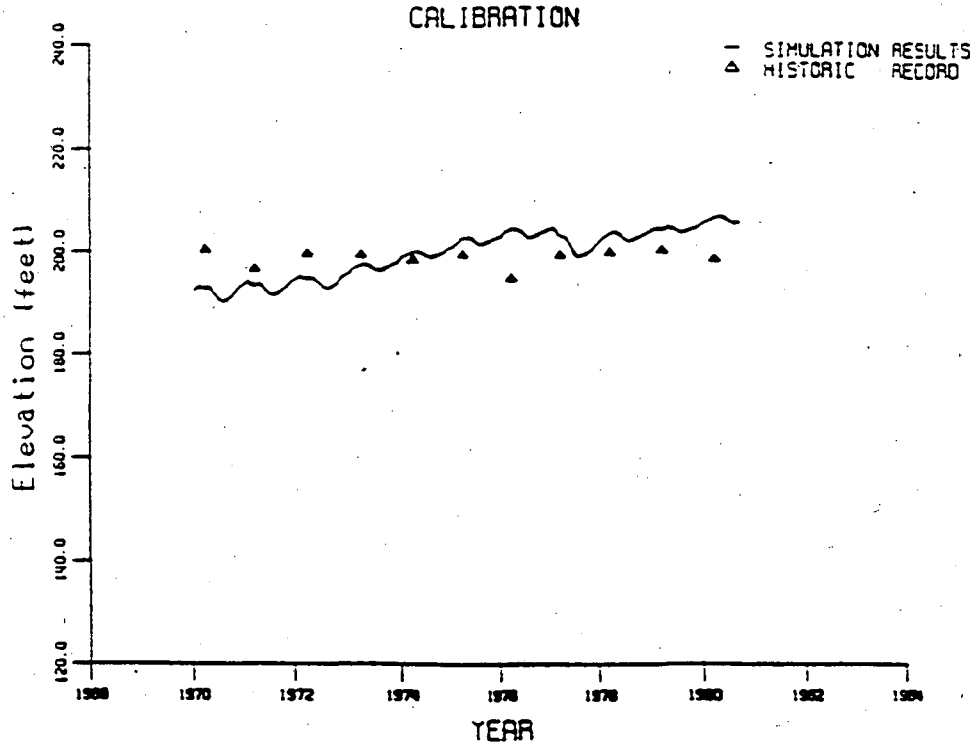

Figure 20. CVGSM calibration hydrograph for well 14.1
(Source : James M. Montgomery Inc., 1990)

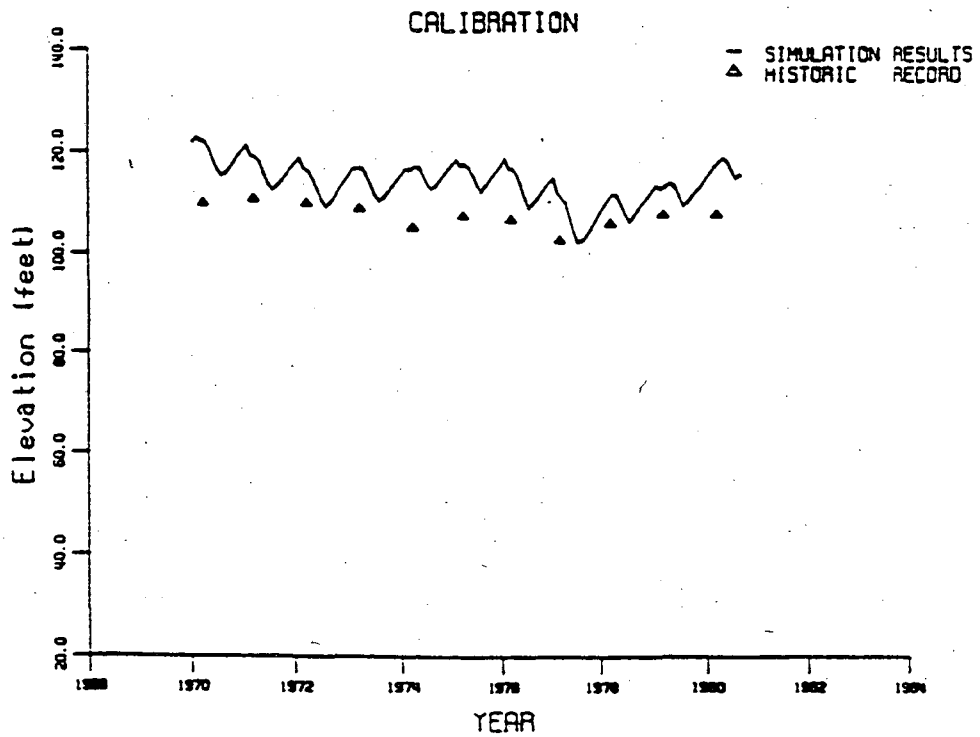

Figure 21. CVGSM calibration hydrograph for well 15.1
(Source : James M. Montgomery Inc., 1990)

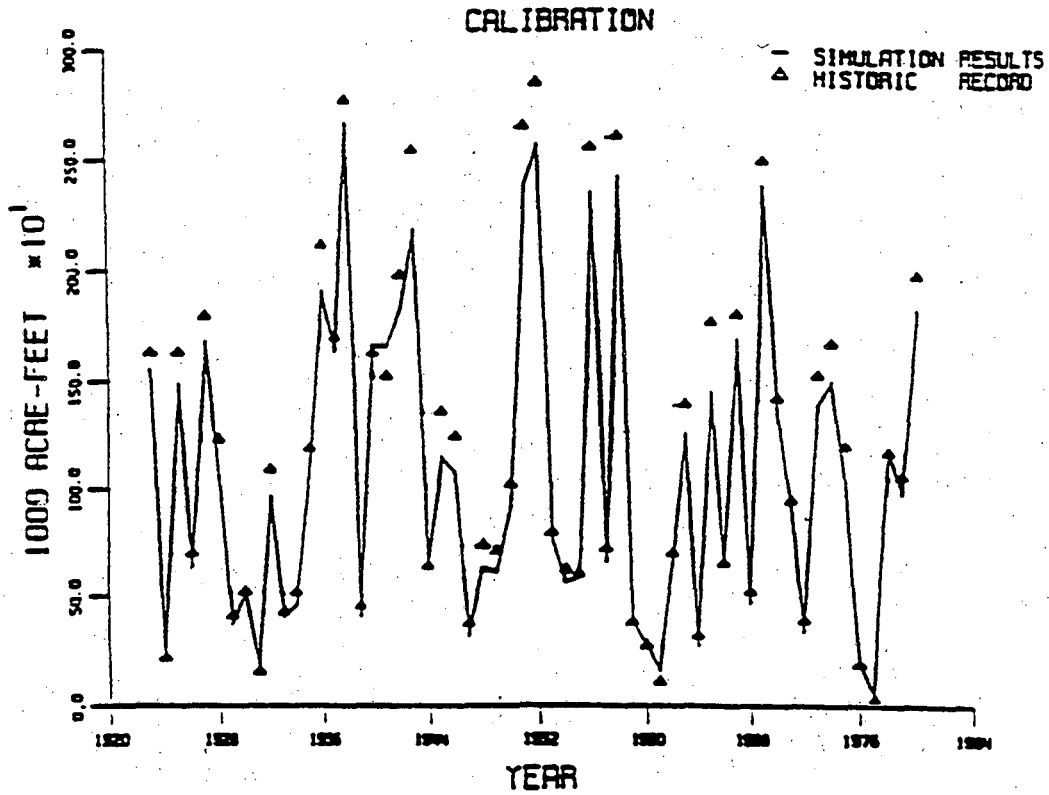

Figure 22. CVGSM flow hydrograph for DSA 59
(Source : James M. Montgomery Inc., 1990)

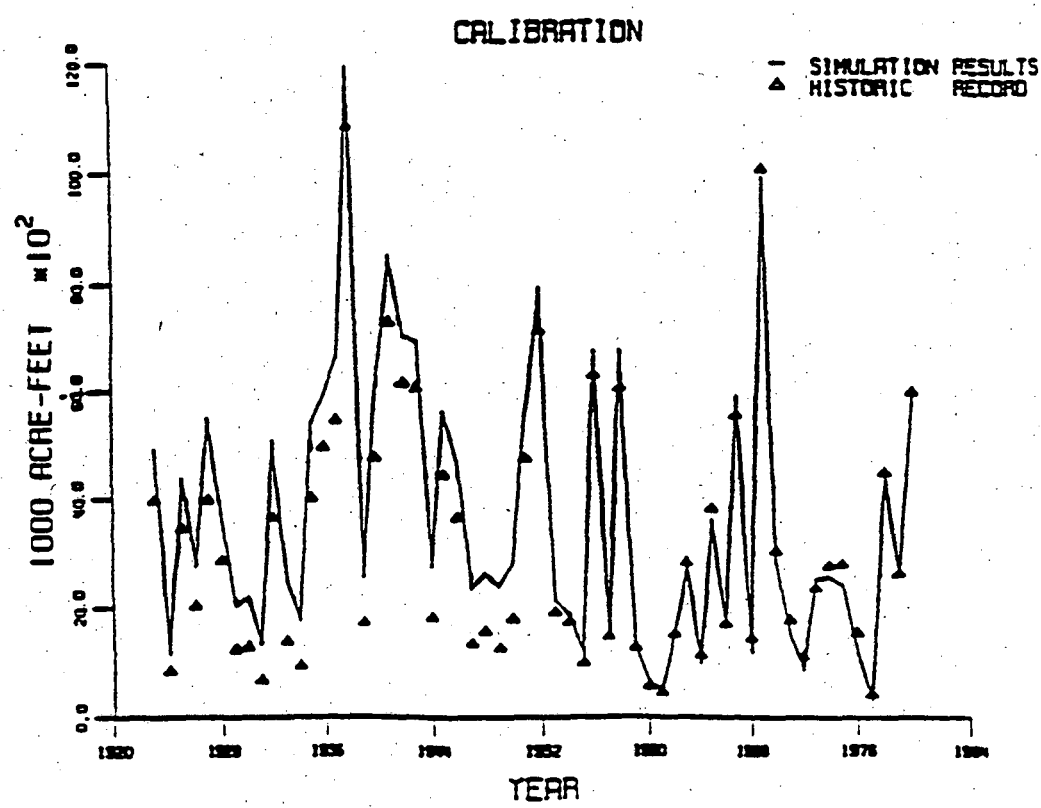

Figure 23. CVGSM flow hydrograph for DSA 49A
(Source : James M. Montgomery Inc., 1990)

A summary of the distribution of error (measured groundwater head - simulated groundwater head) is given in Figure 24 and shows that more than 75% of the predicted elevations are within 10 feet of the measured values. However, these calibration results are presented on an annual basis - calibration results presented on a monthly basis are less encouraging and in some cases the hydrographs appear out of phase with the rise and fall of the watertable. A possible contributing cause for some of the discrepancies can be ascribed to the general assignment of aquifer parameters to clusters of cells in DSA's and other geohydrologic units rather than to individual elements, where detailed information of these parameters may have been available. Calibration of a large regional groundwater model to a small number of local monitoring wells is a difficult task.

2.5.3.2 Data requirements

The primary data requirements for the surface water model of the CVGSM are the stream network and the groundwater finite element mesh. The surface water model requires data on stream inflows, irrigation efficiencies, evaporation rates, project and non-project water demands. The groundwater model requires aquifer parameter data for each polygon in the finite element mesh as well as regional rainfall, pumping, irrigation recharge, rainfall, evapotranspiration and initial water table and pieziometric heads. Boundary conditions must also be established for the groundwater model.

2.5.3.3 Model outputs

The primary outputs from the CVGSM are flows in the Sacramento and San Joaquin Rivers and their major tributaries, water table elevations and aquifer gains and losses at each river node. The model produces mass balance calculations and budgets for water use, streamflow, soil moisture and groundwater. A graphics package has been developed to assist with analysis of water table and streamflow hydrographs and to plot water table contours.

2.5.3.4 Ease of calibration and performing model runs

The model results are calibrated against historic stream flows. Stream accretions and depletions are the primary factors that are adjusted to match these stream flow levels. Performing model runs is relatively easy, however simulating the effects of structural changes or policy actions may involve considerable time expenditure in manipulating the data files. The groundwater model was verified by matching measured water levels to predicted water levels for a time period independent of the period used for model calibration. This is a time consuming activity and is complicated by the fact that land use, irrigation and drainage data is more readily available in some areas than in others.

2.5.3.5 Relative expense of using and maintaining model

The CVGSM runs quickly relative to other groundwater flow codes, such as MODFLOW; the code achieves further efficiencies in performing the transformation of land use, cropping and rainfall data into aquifer recharge

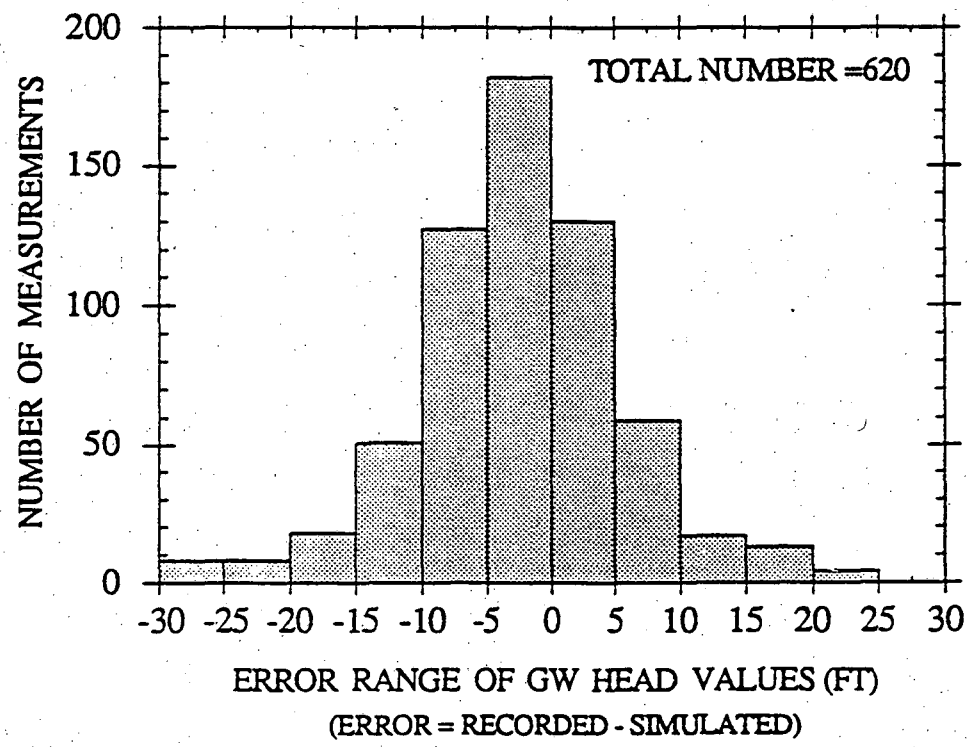

Figure 24. Summary of CVGSM groundwater calibration results. More than 60% of groundwater heads are within 10 feet of the measured values.
(Source : James M. Montgomery Inc., 1990)

within the model. This is typically performed by pre-processing programs in other models such as MODFLOW and the version of the IGSM, used by the SANTUCM. A 59 year simulation takes approximately 30 minutes on a IBM compatible 486 computer. Maintaining the model can be expensive - updating the model to present year hydrology can take a large amount of time and requires a clear understanding of the assumptions made by the model. Although the model runs quickly, it requires more disk storage than it would if it only represented the San Joaquin Basin, the study region of interest. To reduce the area of coverage would require considerable editing of data files and the establishment of new boundary conditions in the vicinity of the Sacramento - San Joaquin Delta.

2.5.3.6 Ease of linking with other models

The model can be linked with other monthly models; an earlier version of the CVGSM for the San Joaquin Valley was linked with the San Joaquin Area Simulation Model (SANJASM) to create the SANTUCM. The CVGSM could also be linked with the SWRCB SJRIO-2 model to calculate stream gains or losses for each reach attributed to each groundwater node in the San Joaquin Basin. The SJRIO-2 model currently makes estimates of groundwater accretions every mile along the San Joaquin River - the number of river nodes are more numerous in the SJRIO-2 model than in the CVGSM. The SJRIO-2 model has only been calibrated for the period 1975 - 1990, compared to the 57 years of record simulated by the CVGSM. The SJRIO-2 nodes would need to be mapped to the CVGSM groundwater nodes to create a linkage between the two models. Linkage of these two models may not provide any advantage for studies of the San Joaquin River.

For studies of the entire basin, the SJRIO-2 model considers each tributary as a San Joaquin River inflow whereas the CVGSM attempts to model flow along each tributary. Since the CVGSM is not a water quality model, linkage to the delta hydrodynamic and water quality models would only be useful in planning studies that are interested in evaluating the effect of river basin groundwater pumping and management policies on flow into the Sacramento - San Joaquin Delta.

2.5.3.7 Previous peer review

The model has been demonstrated to the public in a number of workshops. Formal review of the model has been performed by the USBR, SWRCB and the DWR.

2.5.3.8 Model deficiencies and how these are being addressed

The importance of some of the deficiencies of the current CVGSM depend on the nature of the planning studies to be conducted. Like other regional models such as the WADE model and the SANTUCM, the CVGSM uses a coarse grid to represent the hydrology of the Central Valley. At this scale the model simulates aquifer hydrology rather crudely. The model utilizes a finite element mesh which is not aligned with the mesh used in any of the existing Central Valley models which makes it difficult to compare the predictive capability of the CVGSM against other verified and more generally accepted groundwater models. The groundwater simulation

model of the Panoche Fan, developed by the USGS (Belitz and Phillips, 1992), and which uses a 1 mile square mesh and 6 aquifer layers, would be a good model to use for the purpose of verifying the CVGSM. The USGS model was able to match water levels to an error tolerance of +/- 2 feet. The groundwater budgets used to provide monthly recharge estimates to the model have been criticized by analysts with the DWR and by several members of the Bay-Delta Subcommittee on Water Use.

The model has other conceptual deficiencies :

(a) Although the coding exists to consider subsurface drainage the CVGSM does not take advantage of this code in calculating irrigation return flows. This omission is of greatest significance in areas on the west side of the San Joaquin Valley where subsurface drainage flows have been as high as 25% of surface applied water. Subsurface drainage volumes can change substantially with the rise and fall of water tables and can lead to fairly large discepancies in monthly hydrologic mass balance. Drainage volumes are known to vary from year to year and cannot be estimated reliably as a percentage of surface water deliveries.

(b) Excess rainfall and infiltration are modeled using the SCS method. This method is more typically applied to non - agricultural soils in humid zones, where there may be a large antecedent moisture content in the soil, and is more typically used in models which run on a daily time-step. Use of the SCS method with a monthly timestep may be difficult to justify on theoretical grounds.

(c) Reservoirs are not modeled explicitly but rather as point sources with inputs. This problem could be overcome through linking the model with water budgeting models such as the SANJASM for the San Joaquin River Basin or the PROSIM for the Sacramento River Basin.

(d) The model database does not recognize local subregional differences in aquifer pumping and in aquifer recharge. Pumping estimates and irrigation efficiency numbers were developed for large regional areas and assumed to apply to all elements within these areas. This severely limits the predictive power of the model. On the west side of the San Joaquin Valley a number of subregional studies have been conducted by the USGS and other private consultants which could improve the quality of the aquifer and hydrologic data used in the model to simulate the groundwater hydrology of these areas.

2.5.4 Utility of the model for Reclamation planning studies

2.5.4.1 Actions to meet water quality objectives in the San Joaquin River

The CVGSM can be used to evaluate the effect of groundwater pumping, land retirement or idling and source control on groundwater accretions to the river. However, because the model assumes that return flows are a fixed proportion of irrigation applied water it cannot predict the volume of subsurface returns explicitly, nor can it account for the effect of drainage recycling and certain other irrigation and drainage management techniques. The model does not transport solute in its present implementation and therefore cannot be used directly to assess compliance with water quality objectives. Even though the CVGSM can be coupled with other models such as SJRIO-2, little would be gained by creating this linkage.

2.5.4.2 Salt balance in the San Joaquin Basin

The CVGSM cannot be used to estimate salt balance in the San Joaquin Basin. A crude salt balance can be constructed by assigning salinity levels to the various component inflows and outflows to and from the groundwater aquifer. This, in essence, would create a model similar to the San Joaquin River Basin Salinity Model used by Professor Gerald Orlob to construct flow and salinity balances for the main stem of the San Joaquin River and its tributaries.

2.5.4.3 Drainage reduction policies and planning

The CVGSM, like the SANTUCM, treats surface and subsurface return flows as a combined inflow to the San Joaquin River. The major impact of drainage reduction policies will be on the load of contaminants transported to the San Joaquin River and on resulting in-stream water quality. Drainage reduction policies can often be simulated by a reduction in groundwater recharge, in which case the CVGSM can make reasonable estimates of drainage return flows to the river. These policies can also reduce stream gains through accretions from the regional aquifer, or in the case of a losing stream, increase losses through depletions. In the western San Joaquin Valley drainage reduction may also be achieved through drainage recycling and water table management, which cannot be simulated at this time by the CVGSM.

2.5.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

The CVGSM was originally constructed to perform conjunctive use planning analysis in the Central Valley. Conjunctive use of groundwater resources in some parts of the San Joaquin basin may be used to offset increased water supply to fish and wildlife resources, greater in-stream flows during critical periods, or additional refuge water supply. The San Joaquin Valley Drainage Program recommended a plan for long term management of drainage and drainage related problems in the western San Joaquin Valley which included surface and groundwater conjunctive use. The hydrologic implications of this plan could be analyzed with a model such as the CVGSM.

2.5.4.5 Structural options to control stage and water quality in the South - Delta

The CVGSM does not extend into the South Delta and therefore cannot be used directly for this analysis. The current version of the CVGSM does not simulate solute transport and therefore the model has limited potential for linkage to Delta hydrodynamic, water quality models to analyze solutions to South Delta water quality problems, without making simplifying assumptions about the relationship between flow and in-stream TDS. If linked with a Delta hydrodynamic model for the purposes of analyzing flows, the CVGSM could be used to evaluate the effect of certain conjunctive use policies on flows into the Delta.

2.5.5 Overall assessment and recommendations

The CVGSM is a comprehensive model of groundwater and surface water hydrology in the Central Valley of California. However approximately half of the model is applicable to the present study area. Although the model mesh does not differ significantly from that used by the SANTUCM groundwater model, the CVGSM has been independently calibrated and therefore yields different results when presented with the same conjunctive use scenarios. The CVGSM has not been linked with a surface water allocation model, as is the case of the SANTUCM, and therefore has limited ability to consider hydrologies other than those in the 1922 - 1990 time series. This time series is considerably longer than that created for the SANTUCM - and, since the data has been updated to consider a 1990 level of development, this may more than make up for the lack of reservoir operating rules and constraints for the analysis of certain scenarios. A major advantage of the CVGSM is its general support in a number of public agencies, although the model results and calibration are not universally accepted. This makes the model a more suitable candidate for linkage with other models. A report by U. C Berkeley (Tabios and Shen, 1991) recommended that a linkage be developed between the CVGSM and the SANJASM to replace the existing SANTUCM. Such a model would have increased utility for San Joaquin Basin studies if the algorithms for estimating sub-surface drainage were implemented and the model recalibrated to reproduce historic drainage return flows.

2.5.6 References

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James M. Montgomery Inc. 1990. Central Valley Ground-Surface Water Model. Central Valley, California. August, 1990.

Shen H.W. and G.Q. Tabios, 1991. A Summary of USBR Models for Surface and Groundwater Flows in the Central Valley, California. Project Report. September, 1991.

3. SUB-REGIONAL MODELS

3.0. NRWS (Natural Resources Workstation)

3.1.0 General description and purpose of model

The Natural Resources Workstation (NRWS) is an advanced graphics-based decision support system for the analysis of wetland land use and hydrology being built under contract with the Integrated Decision Support Group (IDSG) at Colorado State University. The NRWS combines a public domain geographic information system (GRASS), a consumptive use model for estimating water demands and a hydrodynamic water quality model (HEC-5Q). Implementation of the HEC-5Q model is ongoing at the present time.

The NRWS builds upon a previous model, the Grasslands Water Supply and Drainage Network Model (GWSDN), which simulates monthly surface water operations and wetland drainage releases within the Grasslands subarea of the western San Joaquin Valley. The GWSDN model was originally conceived as a means of linking the WADE and SJRIO models to allow certain scenarios, simulated by the WADE model, to be compared in their effect on water quality in the San Joaquin River. A simplified version of the original model is under development (GWSDN-STELLA) to study selenium losses within the Grassland channels. This model will simulate the impact of diverting agricultural drainage water into the San Luis Drain on effluent selenium concentrations.

This model review is concerned primarily with the NRWS which is currently under development The major features of the GWSDN and GWSDN-STELLA models are reviewed only in subsection 3.1.1.2. - the reader should refer to the references for more information of the GWSDN model.

3.1.1.1 Geographic extent of the models

The NRWS currently includes the areas which were recently purchased by Reclamation within the San Joaquin Basin for the development of new habitats for waterfowl and other migratory bird populations (Figures 25 and 26). These lands lie mostly to the north of the model area considered in the GWSDN and GWSDN-STELLA models. The model area considered in the original GWSDN model is shown in Figure 27 and includes the Grassland Resource Management District; the Los Banos, and Volta Refuges operated by the State of California Department of Fish and Game; and the Kesterson and San Luis National Wildlife Refuges, operated by the Federal Fish and Wildlife Department. The GWSDN-STELLA model considers the same general area using a simplified network and considers only the major conveyances of agricultural drainage water.

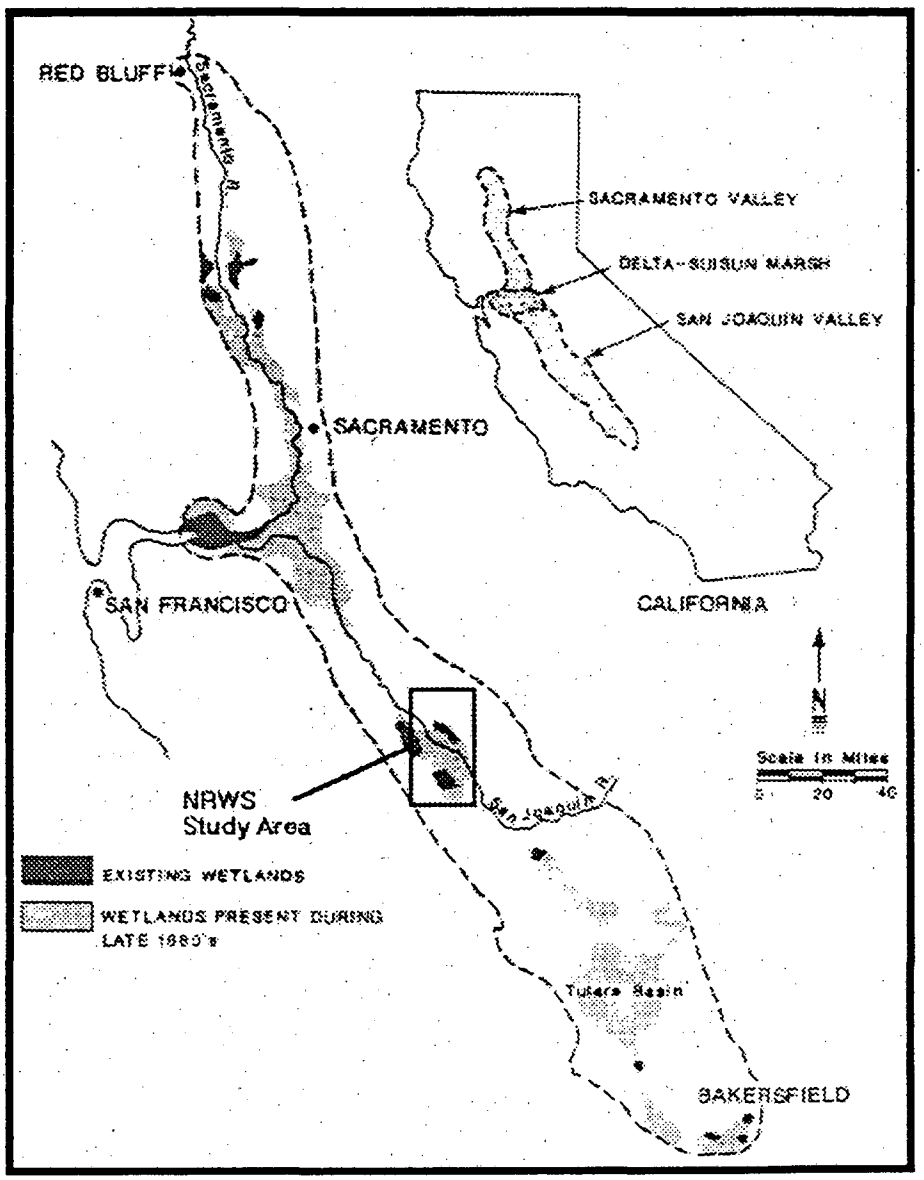


Figure 25. **Location of wetland development in the San Joaquin Valley where the Natural Resources Workstation is being applied.** (Source : Garcia, 1992)

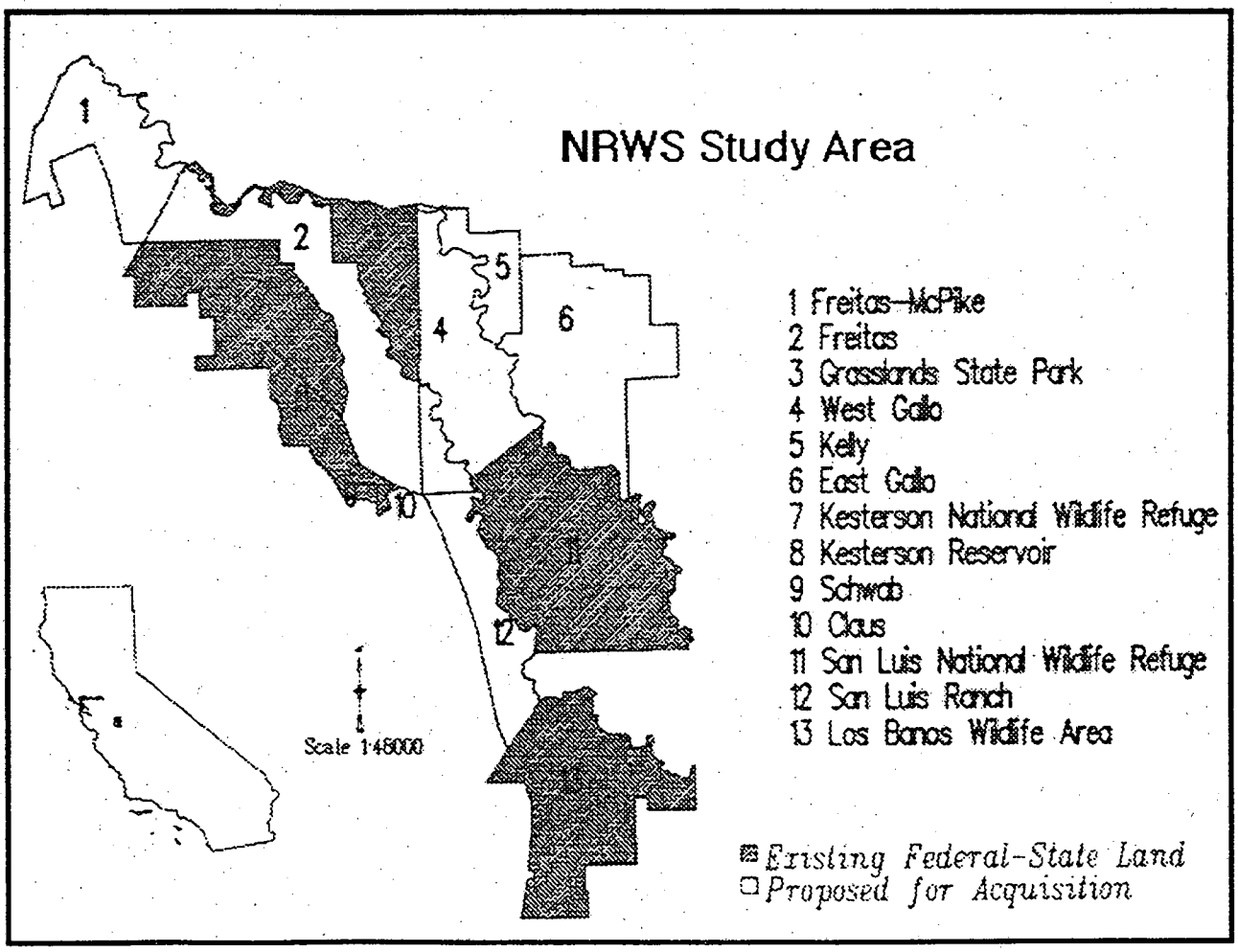


Figure 26. **Areas of wetland development in the San Joaquin Valley where the Natural Resources Workstation is being applied.** (Source : Garcia, 1992)

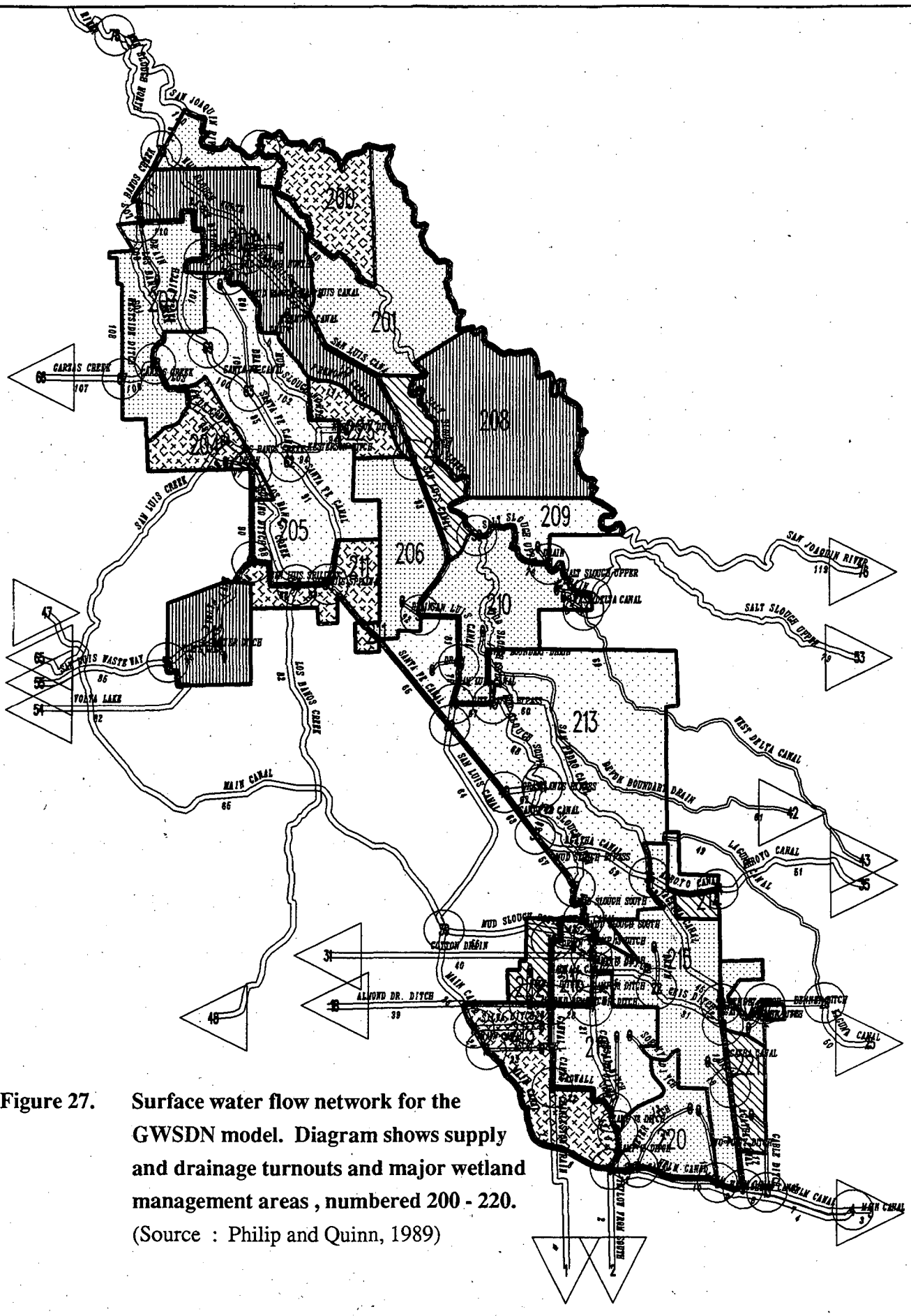


Figure 27. **Surface water flow network for the GWSDN model. Diagram shows supply and drainage turnouts and major wetland management areas , numbered 200 - 220.** (Source : Philip and Quinn, 1989)

3.1.1.2 Features of the various models

The Natural Resources Workstation (NRWS) is currently under development by Dr Luis Garcia, Director of the Integrated Decision Support Group at Colorado State University. The model uses the Army Corps of Engineers reservoir system and water quality software HEC-5Q for simulating flow and contaminant concentrations within the distribution system. A network generating and editing module has been added for making changes to the network of fresh water and drainage conveyances within the project area (Figure 28). A routine for estimating water requirements from a GIS land use database has already been implemented within the NRWS, similar to the routine employed in the GWSDN model. It is anticipated that the NRWS will be extended south into the area currently simulated by the GWSDN model and will replace the GWSDN model. The AViiON workstation has become the platform of choice for software applications within Reclamation.

The GWSDN model was constructed using computer code from the DWR COMP model. The COMP model is a database manipulation program, set up as a series of matrices that can be addressed by user defined commands in the same manner as a spreadsheet. Each channel within the network of channels, illustrated in Figure 27, is represented by a single matrix. User defined commands can add, subtract, multiply and divide flow, contaminant load or contaminant concentration data contained in each matrix. Each channel in the network is either assigned a monthly flow and a monthly mean concentration or has these parameters determined by mass balance calculations. The model contains a sub-program WETDEM to determine the demand for water by seasonal and permanent wetlands and agricultural areas within the Grassland area. These demands are serviced by deliveries from Mendota Pool and the Delta Mendota Canal, which are routed along the CCID Main Canal, the San Luis Canal and a network of smaller canals and ditches. Drainage releases are also simulated. These are specified discharges along certain channels of the grid network during the spring months. The monthly contaminant concentration of these discharges is also assigned. The GWSDN was calibrated using one year (1985) of flow and selenium concentration data.

The GWSDN-STELLA model is a simplified version of GWSDN, constructed using the Macintosh software package STELLA. This model considers only the major drainage conveyances in the Grassland area as well as the San Luis Drain (Figure 29). Flow and water quality data are defined separately for each channel of the network using a methodolgy similar to that used in the GWSDN model. The model has yet to be calibrated.

3.1.1.3 Capability of the model : flow / flow and water quality

The NRWS water quality simulation model (HEC-5Q) is a physics based, hydrodynamic model which will report stage, flow and concentrations of conservative constituents within the channel network at user-specified time intervals. In contrast the GWSDN and GWSDN-STELLA models are primarily data driven and utilize a monthly timestep, assuming steady-state conditions during each month of the year. The HEC-5Q model has the capability of simulating both conservative and non-conservative constituents - however, for the NRWS only conservative trace elements and TDS will be considered. Accurate simulation of flow and water quality within the channel network will require calibration of the HEC-5Q model, a task which will demand more

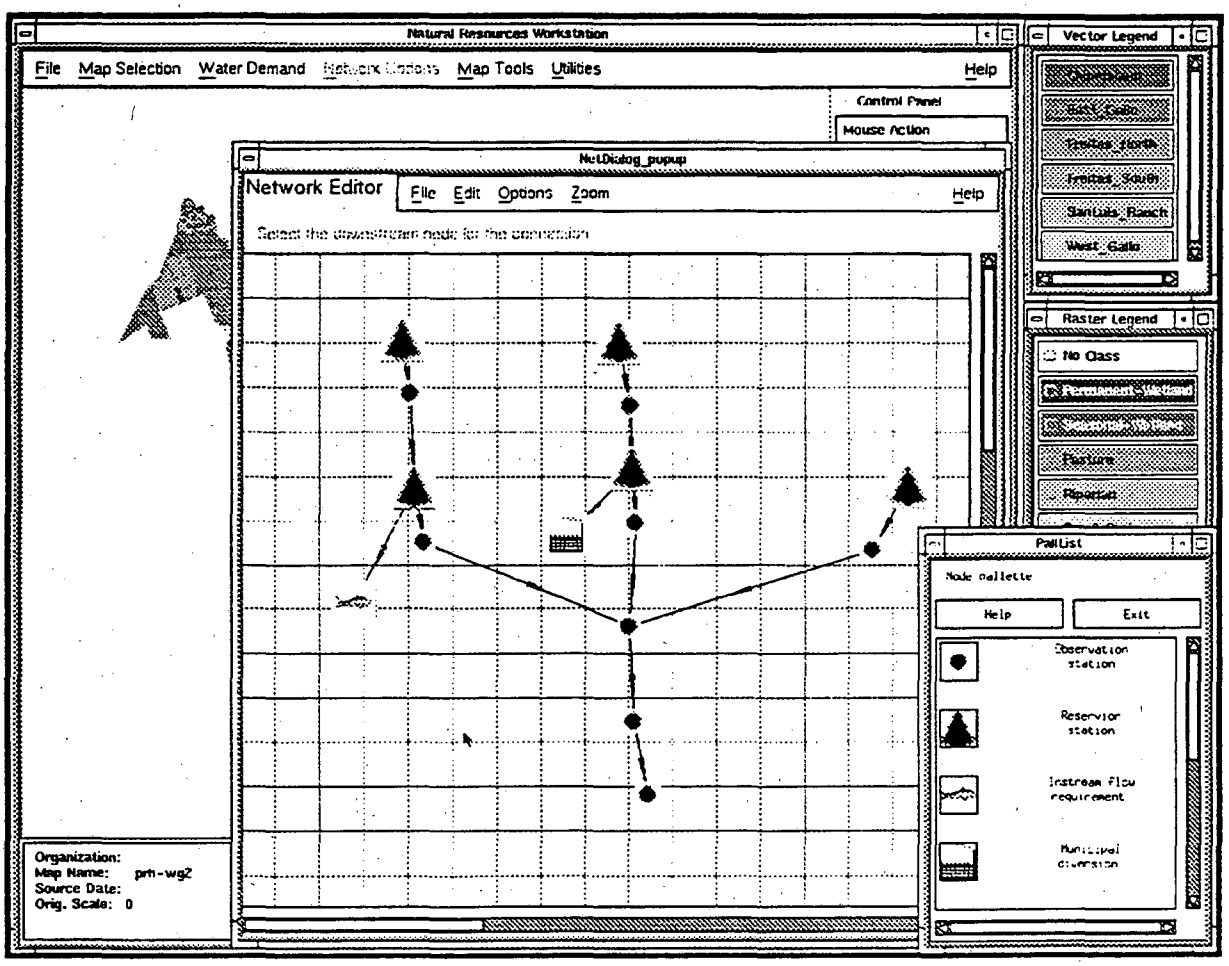


Figure 28. **Network editor used within the NRWS to construct channel network. Objects selectable in the network editor appear in the node pallette window.** (Source : Garcia, 1992)

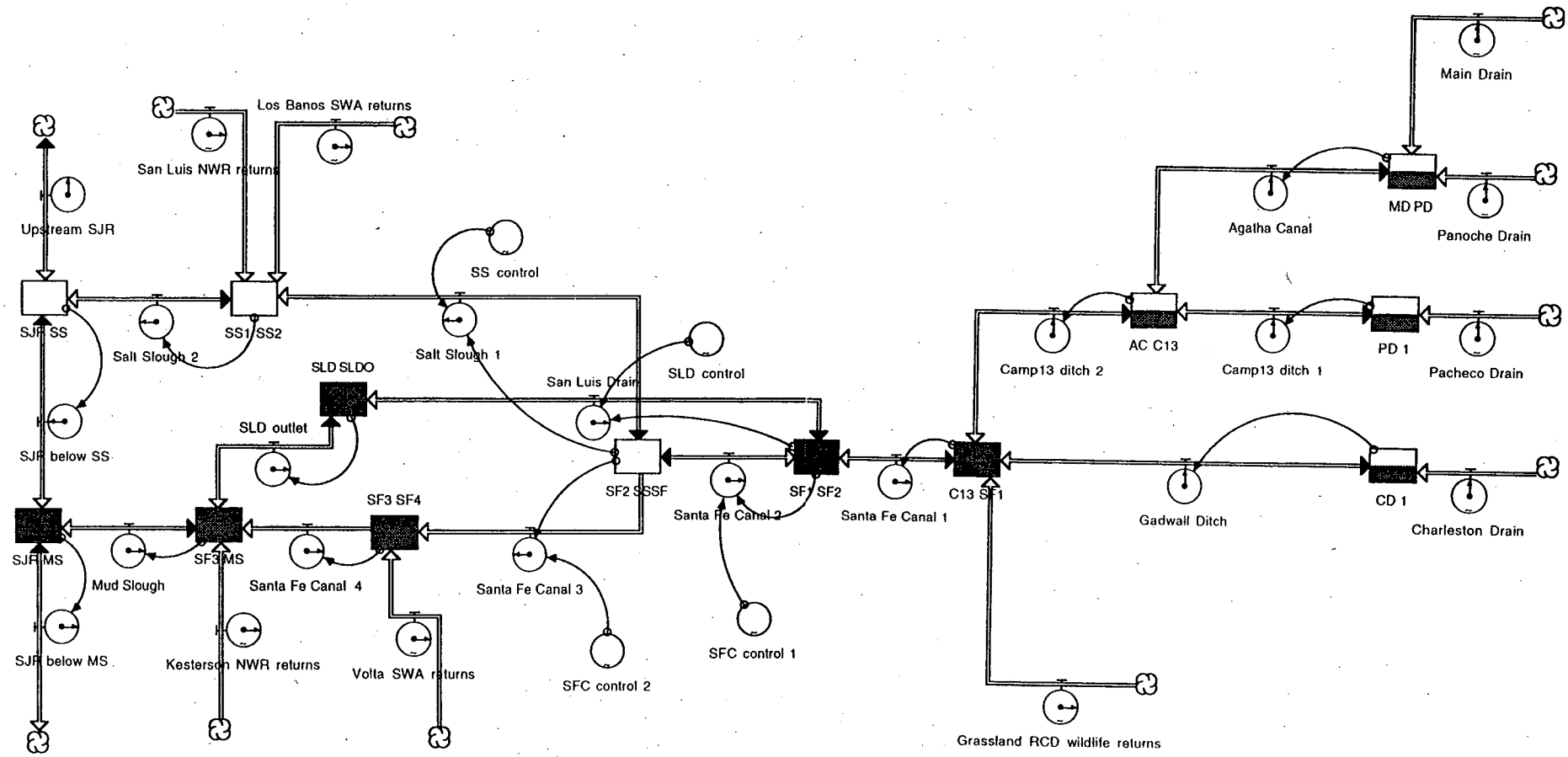


Figure 29. Channel network used by the GWSDN-STELLA model. Flow in the diagram is from right to left. Rectangular objects represent stocks of drainage or mass of selenium, circular objects with arrows control the rate of flow between stocks. Open circular objects represent kinetic expressions that further define the rate of flow between stocks.

comprehensive and more frequently sampled data than is currently collcted as part of existing monitoring programs. Real time monitoring of flow and TDS in the channels that will potentially supply water to these wetlands will be needed in order to use the NRWS for making water management decisions.

3.1.1.4 Simulation time step

The NRWS is capable of simulating the hydrodynamics of flow through the project area, given adequate data for model calibration. The model will likely require a timestep in the order of minutes or hours to solve the momentum and continuity equations in the HEC-5Q, water quality model.

3.1.1.5 Computer requirements and portability

The NRWS model of Grasslands was first implemented on a SUN workstation (UNIX operating system). The NRWS is currently being ported to run on the Data General AViiON workstation. The Data General AViiON workstation is the platform of choice within the USGS and the US Bureau of Reclamation. The capability to perform GIS manipulations, and the application of a hydrodynamic model to simulate flow in the channel network, require the use of a powerful computer such as the Aviion workstation. The graphic interface to the model was created using the proprietary software TELEUSE, copies of which can be run on most Unix-based workstations.

3.1.2 Model development

3.1.2.1 Reasons for development of the models

The NRWS was preceded by the GWSDN model. The GWSDN model was originally developed to provide a link between the San Joaquin Valley Drainage Program's WADE model and the SJRIO model, developed by the SWRCB. Limitations of the GRASDN model include the problem of accounting for wetland water storage during the period these wetlands are flooded and the model's inability to estimate the concentration of surface drainage from these wetlands during spring releases. The NRWS is being developed to assist in determining water deliveries and planning water delivery schedules to lands proposed for acquisition as refuges for waterfowl and use by other migratory birds. The NRWS will be extended to simulate both water deliveries and surface drainage return flows from managed wetlands and refuges within the Grasslands Basin.

3.1.2.2 History of development and use of the model

The NRWS is still under development and has not enjoyed any widespread use to date.

3.1.2.3 Further development of the model and intended future use

The NRWS is slated for completion by the end of 1992. The NRWS will be used to assist in allocation of water supplies among State and federal wildlife refuges and within the Grasslands Water District and to simulate the effect of operations changes on the quality of surface discharges to the San Joaquin River.

3.1.3 Evaluation of the model

3.1.3.1 Predictive capability and model reliability

The NRWS will be provided with a surface water routing model, HEC-5Q, that can run in either dynamic or steady-state mode. In steady-state mode the model can be provided with mean monthly inflows and constituent concentrations. In dynamic mode the HEC-5Q model within the NRWS can perform hydrodynamic and water quality calculations from user-defined initial and boundary conditions such as water stage and initial water supply concentrations. Real-time monitoring stations are being installed in Mud and Salt Sloughs and in the San Luis Drain and will be able to supply continuous flow and EC data, once in place. Analysis of monitoring data for certain Grasslands channels demonstrates that concentrations and flows can change dramatically from day to day, especially during the irrigation season. Likewise, wetland releases of short duration during the spring months can increase the salt load transported by the sloughs in transit to the San Joaquin River.

The complexity of the water delivery system and the dearth of continuous flow and EC records within the system will limit the accuracy of the NRWS flow model as a predictive tool. However, the model has significant value as a planning tool when used to calculate mean monthly flow and water quality and also as a repository of information on the hydrology of the Grasslands Basin.

3.1.3.2 Data requirements

Data requirements for the NRWS flow model includes stage, inflow, channel hydraulic radius, channel roughness and water quality at a sampling frequency consistent with the type of analysis to be performed with the model. The geometry of the model network should also be specified, in particular, channel length and channel branches. Other components of a water delivery system such as small ponds and diversion points can also be specified within the NRWS. Information on soil type, land use and vegetation cover type are used within the NRWS to estimate evapotranspiration losses and predict water requirements. The NRWS flow model is used to formulate operational scanarios designed to satisfy these water requirements.

3.1.3.3 Model outputs

The NRWS also calculates the monthly water demand for each of the different vegetation types within an area. Outputs from the NRWS flow model will include monthly canal discharges to each of the new wetland areas. The quantity and quality of the water resources needed to meet demands, based on various wetland development scenarios, and the quantity and quality of return flows will also be estimated with the NRWS flow model. The

NRWS can access GIS digitized aerial photographs of the study area and overlay these coverages with a number of land use types to facilitate

3.1.3.4 Ease of calibration and performing model runs

The NRWS flow model will utilize HEC-5Q for simulating the conveyance of wetland and refuge water supply within the Grasslands Basin. There are insufficient flow gauging stations and water quality monitoring sites within the Grasslands Basin to allow proper calibration of the NRWS flow model. However the model should be adequate for initial planning studies related to development planning of new wetlands. Diversions and water delivery operations within the Grasslands area occur on a schedule that is difficult to develop rules for - hence it may be unrealistic to run the model dynamically, except when the model might be used to estimate channel residence time or timelag in water deliveries. The NRWS flow model is complex and requires considerable data inputs much of which must be obtained from the literature. The ease of making model runs will be evaluated when the user interface has been completed for the NRWS flow model.

3.1.3.5 Relative expense of using and maintaining model

The NRWS will run only on Unix workstations. This model will likely be the most expensive to maintain. Model bugs will likely require the involvement of the developer. Because of the graphic nature of the interface, the increased complexity of the model may be in part offset by visual appeal and intuitive feel of the user interface.

3.1.3.6 Ease of linking with other models

The NRWS has been linked with a public domain geographical information system GRASS and employs seperate subroutines, linked to the GIS, to calculate water requirements according to land use and seepage losses from both seasonal and permanent wetlands. The NRWS also has the capability of viewing digitized aerial photographs of the study area and superimposing channels and other features over these images (Figure 30).

The NRWS could be linked to SJRIO-2, to supply the San Joaquin River model with both drainage flow and contaminant loads from Mud and Salt Slough and with the flow and contaminant loads to the river produced by spring releases of wetland water.

3.1.3.7 Previous peer review

A preliminary version of the NRWS has been demonstrated to Reclamation personnel as well as to refuge managers and representatives of the State and Federal fish and wildlife agencies.

3.1.3.8 Model deficiencies and how these are being addressed

The HEC-5Q model, when fully functional within the NRWS, will be capable of considering carry -over storage as well as other hydrologic variables such as evaporation that are currently user specified in the GWSDN

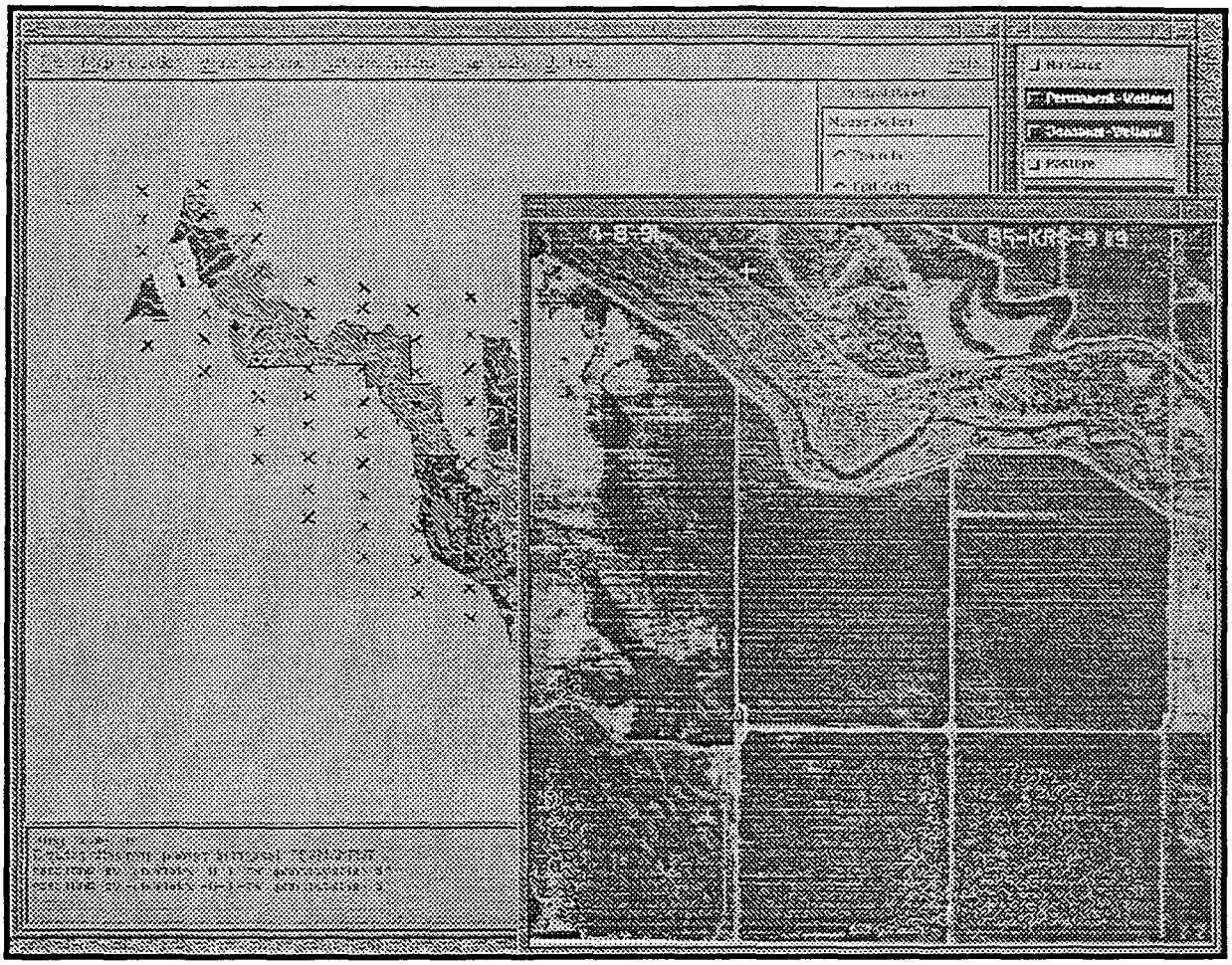


Figure 30. **Digitized aerial photographs associated with the study area can be viewed in the NRWS. Nadir points, superimposed on the map in the background, are used to select individual aerial photographs.** (Source : Garcia, 1992)

and in the GWSDN-STELLA versions of this model. However, until this development has been completed it will be difficult to ascertain model deficiencies. The HEC-5Q model was originally designed as a reservoir operations and flow routing model and is both complex and data intensive. Creating a user-friendly interface for the model will be a challenging task.

3.1.4 Utility of the model for Reclamation planning studies

3.1.4.1 Actions to meet water quality objectives in the San Joaquin River

Although the NRWS was specifically designed to explore options for water deliveries to newly created wetlands and refuges the model might also be used to link the IRDROP (or WADE) and the SJRIO models. Drainage flows containing high contaminant concentrations that are predicted by the WADE model can be routed using the NRWS to the San Joaquin River via Mud and Salt Sloughs (or the San Luis Drain, if the current proposed project to use the drain wins final approval). When completed, the model should allow a more accurate prediction of wetland water quality than is now possible and hence allow better estimates of salt and boron loading to the San Joaquin River. This would prove useful, not only for helping to manage drainage releases to meet SWRCB objectives for selenium and boron at Newman, but also to help manage salt loads in the river that currently concern the South Delta Water Agency.

3.1.4.2 Salt balance in the San Joaquin Basin

The NRWS may be capable of simulating water deliveries to newly created wetlands and refuges as well as the transport of contaminants through the Grasslands Water District once completed. Although, in theory, the model could be extended to take account of contaminant transport in the San Joaquin River it would be more sensible and cost effective to use the model to provide inputs to the SJRIO model at Mud Slough, Salt Slough and the San Joaquin River.

3.1.4.3 Drainage reduction policies and planning

Drainage reduction policies have been shown to reduce the mass loading of salts and trace elements in agricultural subsurface return flows. The extent to which these reductions in mass loading help to meet SWRCB objectives may be influenced by in-transit losses, in the case of selenium or accretions to mass loading in the case of spring wetland releases. The NRWS may have some utility in estimating the impact of these policies on water quality in the San Joaquin River if linked with the WASE or IRDROP models.

3.1.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

The NRWS does not simulate groundwater levels or solute transport in the groundwater explicitly nor does it simulate the effect of groundwater pumping on aquifer storage or stream-aquifer interactions. The NRWS is therefore not appropriate for this purpose.

3.1.4.5 Structural options to control stage and water quality in the South - Delta

The NRWS may have some utility in allowing better prediction of potential salt loading from spring wetland releases prior to their occurrence. The model will be capable of simulating evaporation and salinity build up in ponded areas and hence allow estimation of the total flow and mass loading of salts. Operation of barriers and other control structures in the South Delta to limit salinity intrusion into the South Delta might be assisted with information provided by this model. Also, under D-1630 the NRWS might be used to independently determine optimal schedules for wetland releases if linked to the SJRIO-2 model, and assist in planning studies to ensure compliance with SWRCB objectives.

3.1.5 Overall assessment and recommendations

The NRWS may prove useful for the following purposes; (a) as a simulation tool for comparing different operational strategies for delivering water to newly created wetlands and wildlife refuges; (b) as a linkage between regional drainage models such as WADE or IRDROP and water quality models of the San Joaquin River, such as SJRIO-2; and (c) as a means of simulating changes in contaminant loading when agricultural return flows are routed through Grasslands channels. The NRWS Grasslands model can be used to estimate the volume discharge and mass loading of contaminants and can help in planning release schedules to minimize downstream impacts.

3.1.6 References

Garcia L. 1992. Natural Resource Workstation. Report of accomplishments to the U.S. Bureau of Reclamation.

Philip A. and N.W.T. Quinn. 1989. Grasslands fresh water supply and drainage model. Preliminary draft report. San Joaquin Valley Drainage Program, Sacramento, CA.

3.2 IRDROP (Irrigation and Drainage Operations Model)

3.2.1 General description and purpose of model

The IRDROP model simulates water district level decisions regarding drainage recycling, groundwater pumping, short term storage, direct discharge and dilution to optimize use of San Joaquin River assimilative capacity without exceeding State Water Resources Control Board water quality objectives for selenium or boron. The model is an adaptation of the hydrosalinity routines within the WADE model, previously described in this report, to assess the feasibility and effects of drainage re-use and recycling practices proposed as part of a long term management plan for agricultural water districts in the Grasslands Basin. Recoding of the WADE hydrosalinity model was performed by CH2M-Hill, the developers of the model, because the seasonal time step employed within the WADE model was too coarse to simulate drainage management decisions and timed drainage releases to the San Joaquin River to coincide with periods of assimilative capacity. The model simulates interactions between agricultural decisions such as cropping patterns and irrigation practices and hydrologic parameters such as crop ET, drainwater volume and quality and soil salinity. The model is capable of running a 30 year simulation, given a time series of assimilative capacity estimates for the San Joaquin River for the time period 1960 - 1990.

3.2.1.1 Geographic extent of the model

The model performs subregional mass balances on the water district scale (Figure 31). Within each water district the model recognizes three land categories based on drainage conditions: (a) land with existing tile drains; (b) land without tile drains and (c) undrained land with water table depths less than 10 feet (CH2M-Hill, 1991). The geographical location of these land categories within each water district is not specified by the model. Most water districts in the Grasslands basin are assumed to have central collection facilities for temporary storage of drainage water prior to discharge to the San Joaquin River. These storage facilities could also be used for blending fresh water supply with recycled tailwater and/or subsurface drainage within the district (Figure 32). The model deals with the management of this stored or redistributed water.

3.2.1.2 Features of model

The IRDROP model calculates monthly agricultural drainage volume and quality and compares the mass loading of selenium and boron contained in the drainage water to established water quality objectives for these constituents in the San Joaquin River (Figure 33). The model then determines optimal combinations of actions such as direct discharge, drainage recycling or temporary storage to manage these drainage flows in the most efficient and cost effective manner.

The irrigation routines within the IRDROP model operate on a monthly time step and simulate irrigation operations based on root zone mass balance calculations. The model applies water to meet the monthly

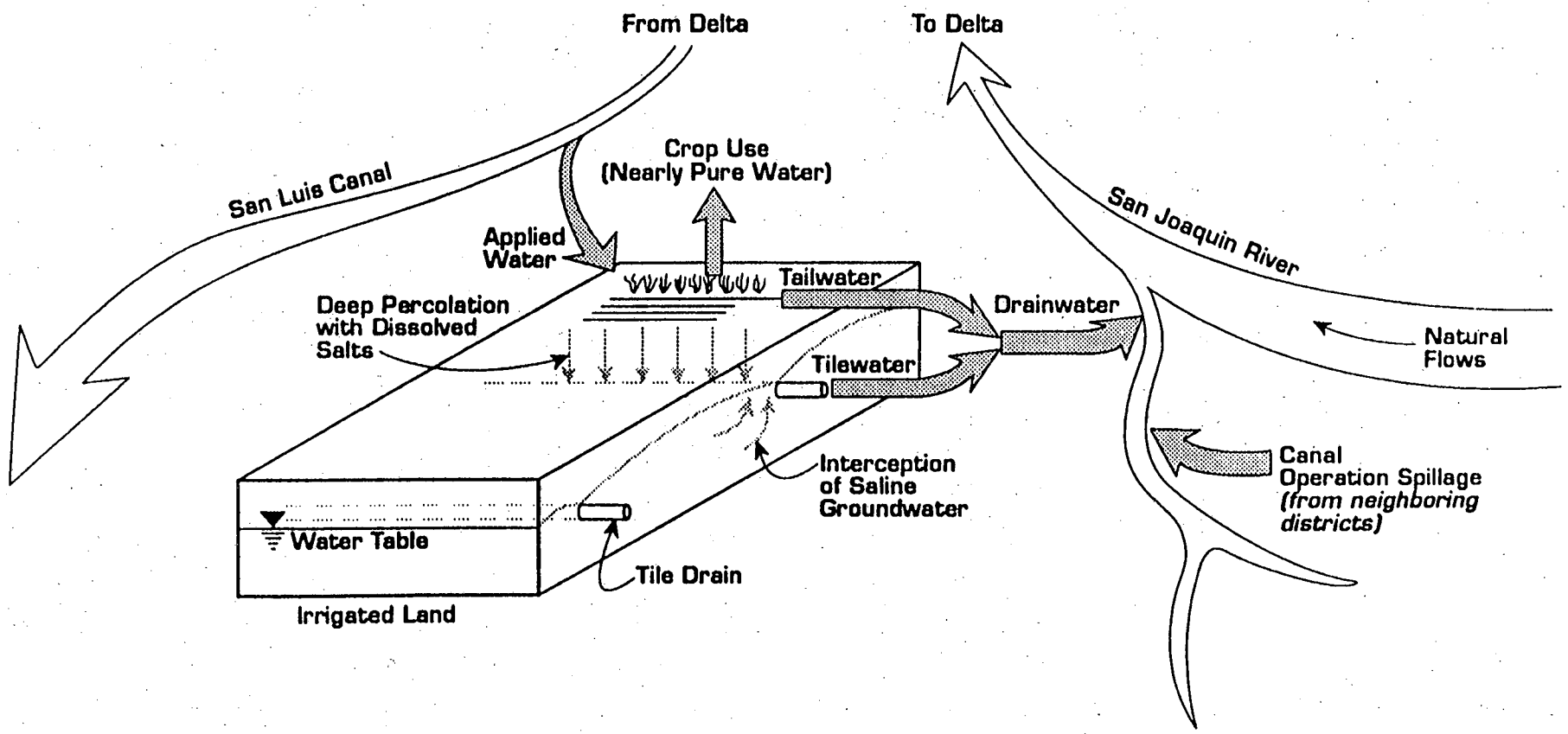


Figure 31. **Components of the hydrologic budget for the Grasslands area simulated in the IRDROP model. Separate mass balances are performed for water and salt in the model.**
(Source : CH2M-Hill, 1991)

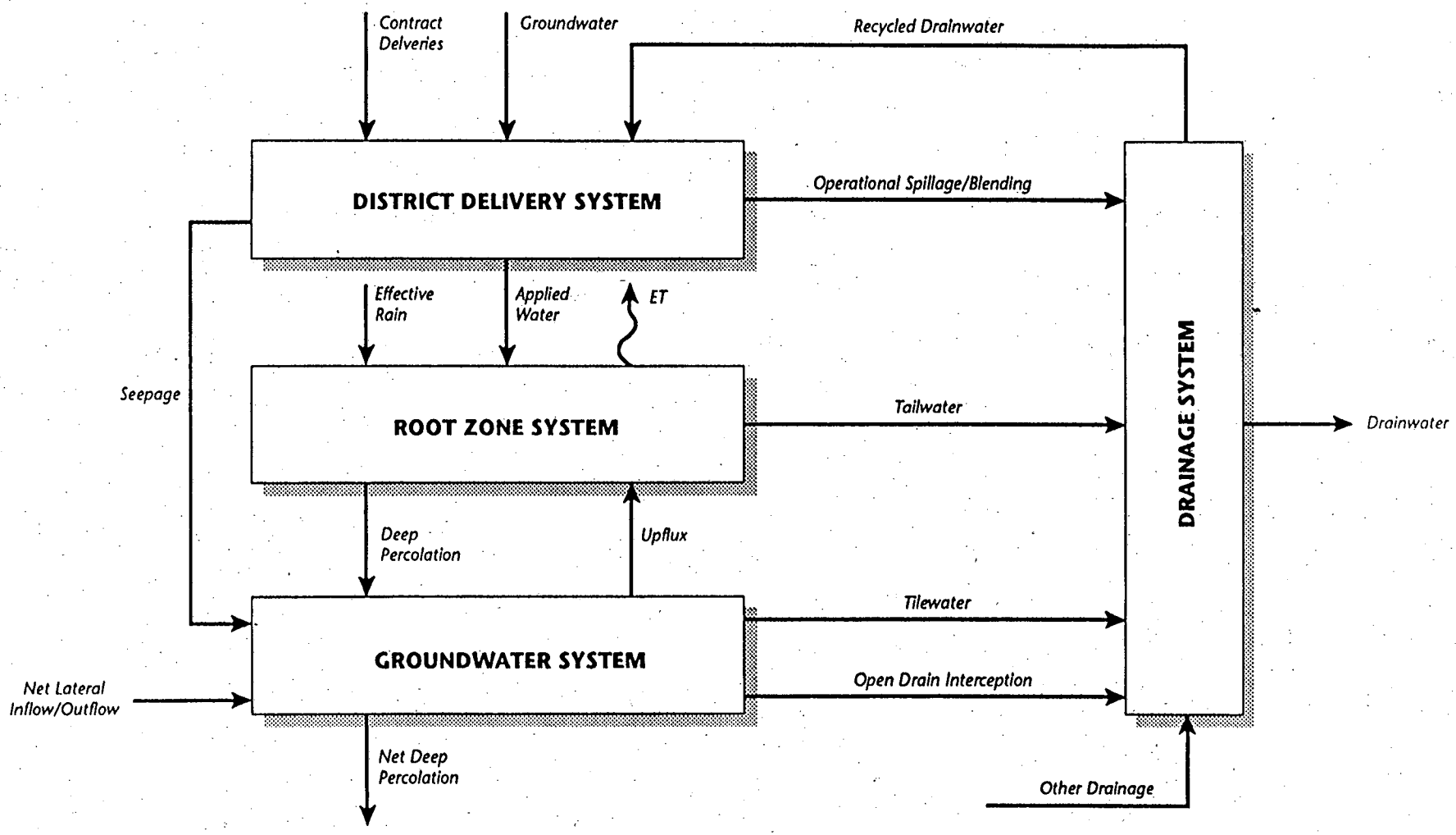


Figure 32. **Conceptual hydrologic budget for each of the water districts simulated by the IRDROP model. A set of algebraic equations is developed for each hydrologic component. These algebraic equations are written in the GAMS language and solved using the matrix solver MINOS.** (Source : CH2M-Hill, 1991)

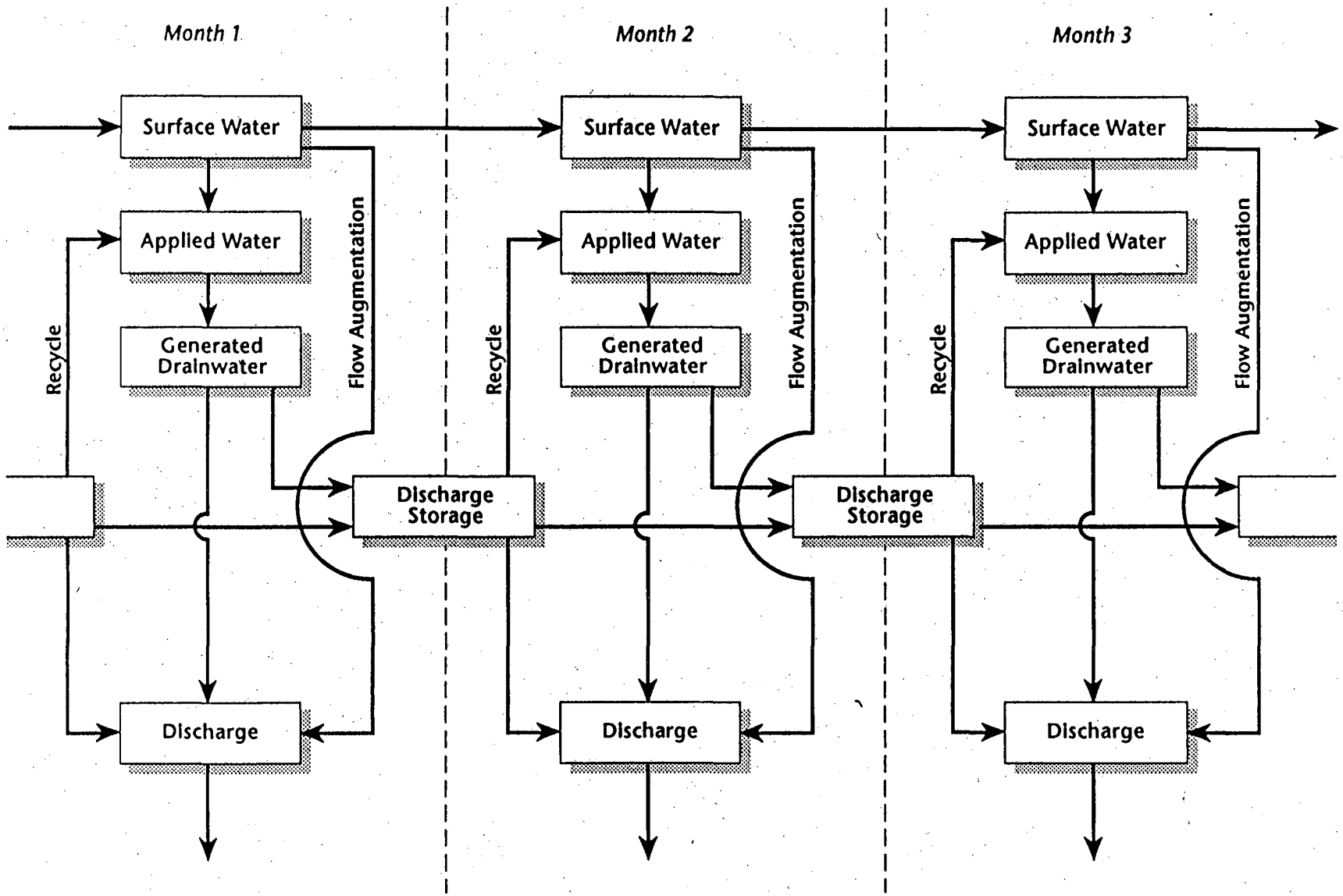


Figure 33. **Conceptual sequence of monthly operations performed by the IRDROP model for each water district within Grasslands. Surface water can be used either for irrigation or for flow augmentation to meet San Joaquin River water quality objectives. Drainage can be discharged during each month or stored in holding ponds.** (Source : CH2M-Hill, 1991)

management allowed depletion which is the percentage of the available water holding capacity of a soil that is available for crop use. When this depletion is exceeded it is an indicator that water should be re-applied. These calculations are made uniquely for each combination of agricultural crop, drainage condition and pre-irrigation regime. Water stored in the root zone and that is available to crops comes from three sources; applied surface water, effective rainfall and crop use of shallow groundwater tables. The model uses the depth to shallow groundwater to calculate potential crop use and combines this with estimates of effective precipitation to determine monthly water requirements. The algorithm used in the model assumes an extinction depth of 8.5 feet for shallow groundwater contribution to evapotranspiration and assumes a linear increase in this contribution to a maximum of 50% of potential evapotranspiration. This algorithm is the same as that used to calculate groundwater upflux in the WADE model. Drainage calculations are made in a similar manner to those in the WADE model. The average water table elevation and the effectiveness of the tile drainage system are used to estimate drainage flow and mass loading.

The IRDROP model attempts to discharge as much water as possible directly to the San Joaquin River subject to compliance with SWRCB water quality objectives. Boron and selenium loads are determined from regression relationships between salt (as TDS) and the boron and selenium concentrations. Water that cannot be discharged directly is either recycled or stored. Costs associated with surface storage and with salinity build up due to drainage recycling are factored into the decision to store water or recycle drainage water. Augmentation water is used by the model to increase allowable discharge and offset storage requirements during those months when supplemental water supplies are available.

3.2.1.3 Capability of the model : flow / flow and water quality

Drainage flow is estimated by the model as a function of water table elevation, which in turn is a function of irrigation applied water, evapotranspiration, drainage recycling and irrigation system losses (previously illustrated in Figure 31). A mass balance is performed for salts in the root zone to calculate the concentration of TDS in deep percolation. Drainage water quality is determined by assuming a fixed ratio blend of deep percolation, shallow groundwater (water table less than 20 ft below the surface) and deep groundwater (water table greater than 20ft below the ground surface). Salinity levels assigned to each component are blended at the drain according to the ratio 35% deep percolation, 40% shallow groundwater and 25% deep groundwater. Selenium and boron concentrations are determined by regression from TDS data. Improved regression coefficients were obtained when the annual data was split into three seasons and independent regression equations determined for TDS and trace element concentrations for each season.

3.2.1.4 Simulation time step

The IRDROP model currently uses a monthly time step although there is no conceptual impediment why the model should not run at a smaller time step. The only limitation to using a smaller time step is the availability

of data for model calibration. Real time monitoring stations are being placed in the main stem of the San Joaquin River and will also be placed at Mud and Salt Sloughs, which are tributary to the San Joaquin River. The data from these stations might allow the IRDROP model to be calibrated for a smaller time step and allow the model to be more effectively used in drainage operations planning and management.

3.2.1.5 Computer requirements and portability

IRDROP will run on any machine that successfully runs the General Algebraic Modeling System package. This includes IBM 386 and 486 machines, Apollo, Sun and Data General workstations running UNIX.

3.2.2 Model development

3.2.2.1 Reasons for development of the model

The IRDROP model was developed to assist in the comparison of alternative drainage management policies for the Grasslands Basin within the San Luis Unit of the Central Valley Project. The Grasslands Basin can be distinguished from the Westlands and Tulare areas to the south in that it possesses a drainage outlet. A long term plan for drainage management in the agricultural areas of Grasslands Basin, formulated by the San Luis Drainage Program, called for the construction of temporary holding ponds for agricultural drainage. These ponds would be filled during those months when the assimilative capacity of the San Joaquin River is not sufficient to accommodate the total volume and contaminant load of the drainage produced. The IRDROP model was used to minimize the total storage volume while maintaining compliance with SWRCB river criteria and other environmental requirements.

3.2.2.2 History of development and use of the model

The San Luis Drainage Program (SLDP) was formed after the San Joaquin Drainage Program disbanded in 1990. The SLDP was charged with developing a long-term solution to the drainage problem in the San Luis Unit of the CVP and compliance with the Barcellos Judgment, a lawsuit filed by Westlands, mandating the preparation of a drainage plan for drainage problem areas within Westlands. The IRDROP model was used in the San Luis Drainage Program in the Grasslands Basin to help understand the monthly patterns of water use and drainage flow and to predict the effect of various policy changes on district operations (CH2M-Hill, 1991).

3.2.2.3 Further development of the model and intended future use

The IRDROP model is not being used for planning studies at this time. The model has been placed on the Drainage Workstation and, in the next several months, will be linked with the interactive data query and analysis system currently under development within MP-405. Once this linkage is developed, the model could be useful in demonstrating the potential for timing subsurface drainage releases to match San Joaquin River assimilative capacity and also to coincide with any future scheduled pulse flows from the tributaries to the main stem of the

San Joaquin River. Decision 1630, released for review by the SWRCB, suggests the use of pulse flows during critical periods to aid fish migration. The model's utility will be enhanced as the San Joaquin River Management Program makes progress in the installation and creation of a real time monitoring network along the main stem of the San Joaquin River and once the institutional issues surrounding use of the San Luis Drain for conveyance of subsurface drainage within the Grasslands Basin are resolved.

3.2.3 Evaluation of the model

3.2.3.1 Predictive capability and model reliability

The IRDROP model is regional in its coverage and treats each water district as the unit of analysis. Although each water district has been divided into three land categories according to drainage conditions these areas are considered lumped parameters in the model and are not associated with specific tracts. Hence the model's predictive capability does not really extend beyond the water district scale. The IRDROP model has been calibrated against five years of measured water district surface water deliveries and drainage flows. Figures 34 - 37 show the results of these calibration experiments. The major calibration variables used in developing water district water balances were irrigation efficiency, vertical groundwater flux and drainage conductance. The IRDROP model was also calibrated for salinity against average monthly TDS readings at four monitoring stations, located at the major drainage outfalls for San Luis, Broadview, Panoche and Pacheco Water Districts. The simplicity of the hydrology and salinity mass balances made by the IRDROP model allow the model to perform reasonably good estimation of monthly drainage flow and salinity load at the water district level. Where large discrepancies occur these are likely the result of flows not accounted for in the water and salt mass balances, such as intercepted drainage from adjacent water districts or from adjacent unincorporated areas. The utility of the current model as a planning tool depends on the accuracy with which river assimilative capacity can be measured for each month and the validity of the regression relationships derived between concentrations of dissolved salts and the concentrations of both selenium and boron.

3.2.3.2 Data requirements

The parameters used in the IRDROP model are similar to those for the WADE hydrology and salinity models, however the monthly time step utilized by the IRDROP model greatly increases the data requirements. Individual water districts were consulted for historical records of water deliveries, cropping patterns, evapotranspiration, groundwater use, drainage flow and drainage water quality. Mass balances for water and salt imported and exported from each water district were constructed using this data. Intercepted flows were set equal to residuals, not accounted for in the mass balance computations.

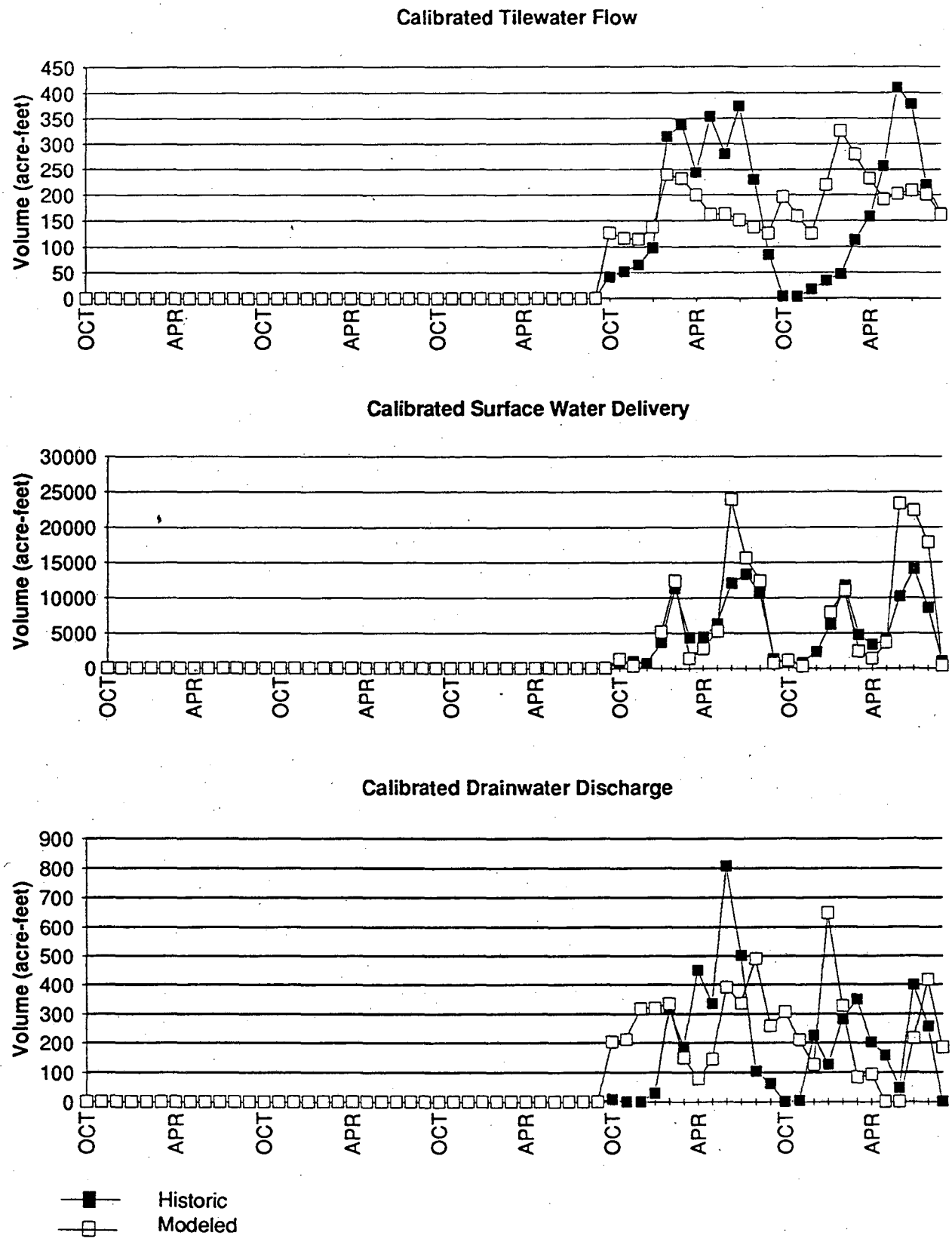


Figure 34. **Flow hydrographs for the San Luis Water District comparing calibrated and historic flows.** (Source : CH2M-Hill, 1991)

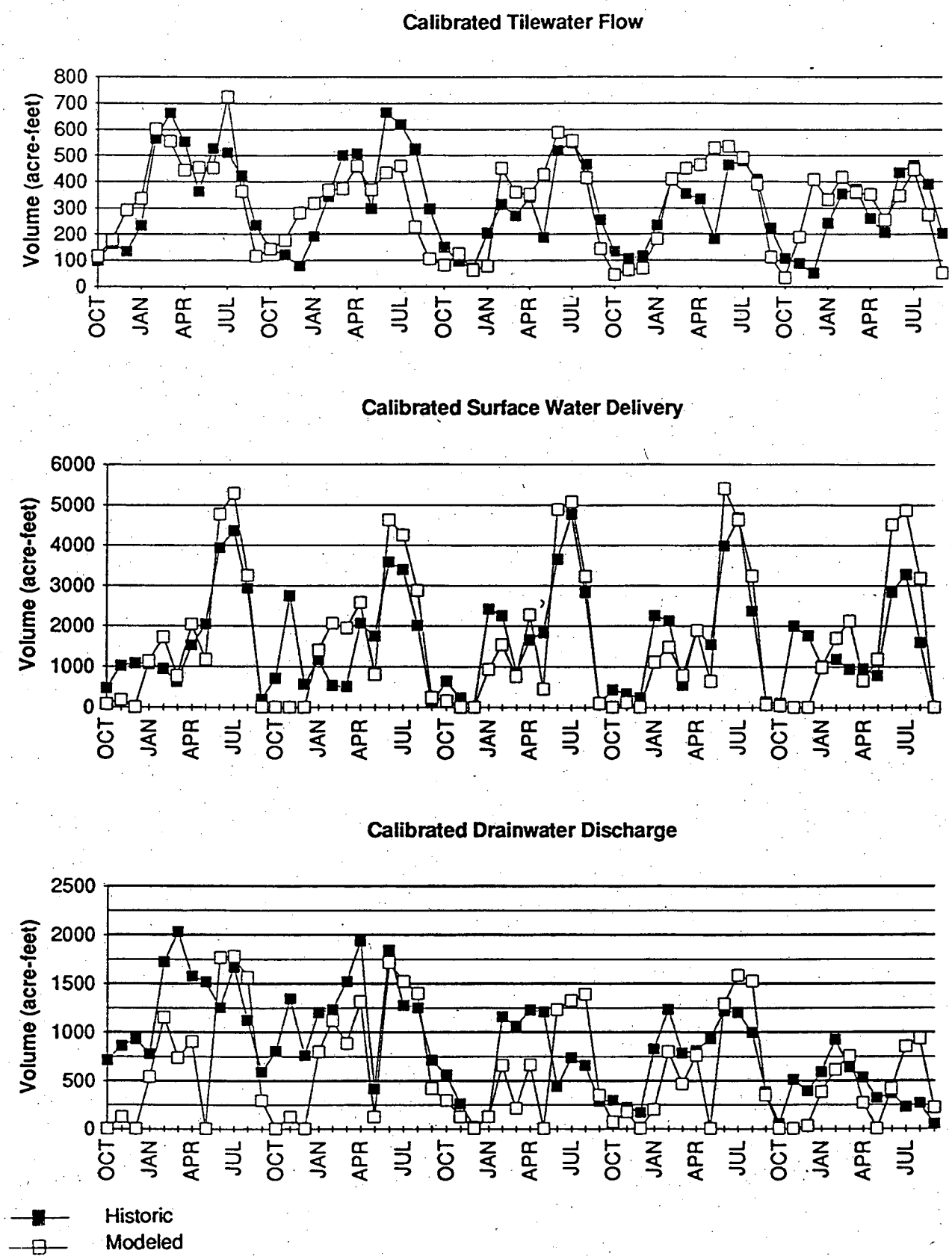


Figure 35. Flow hydrographs for the Broadview Water District comparing calibrated and historic flows. (Source : CH2M-Hill, 1991)

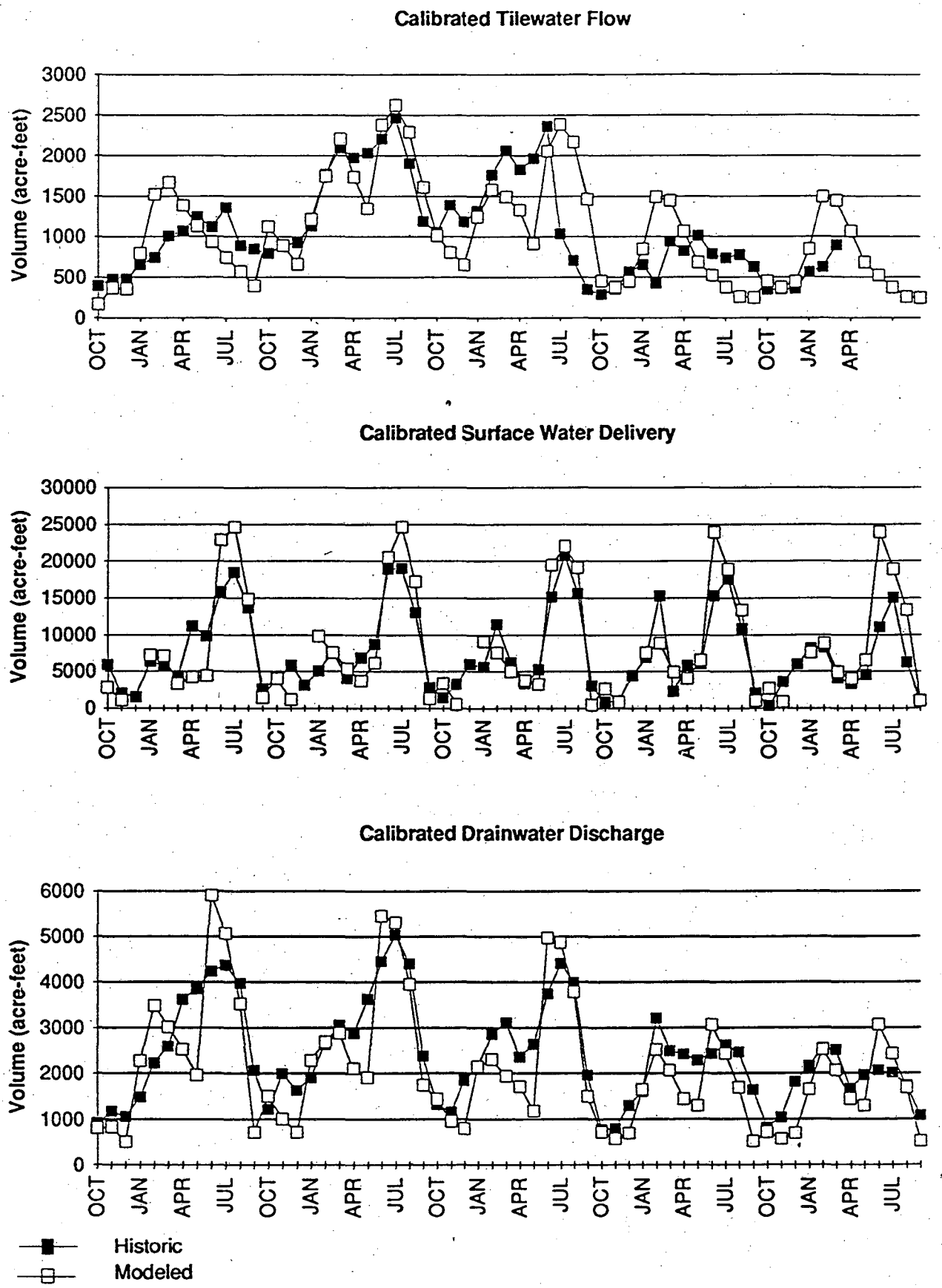


Figure 36. Flow hydrographs for the Panoche Water District comparing calibrated and historic flows. (Source : CH2M-Hill, 1991)

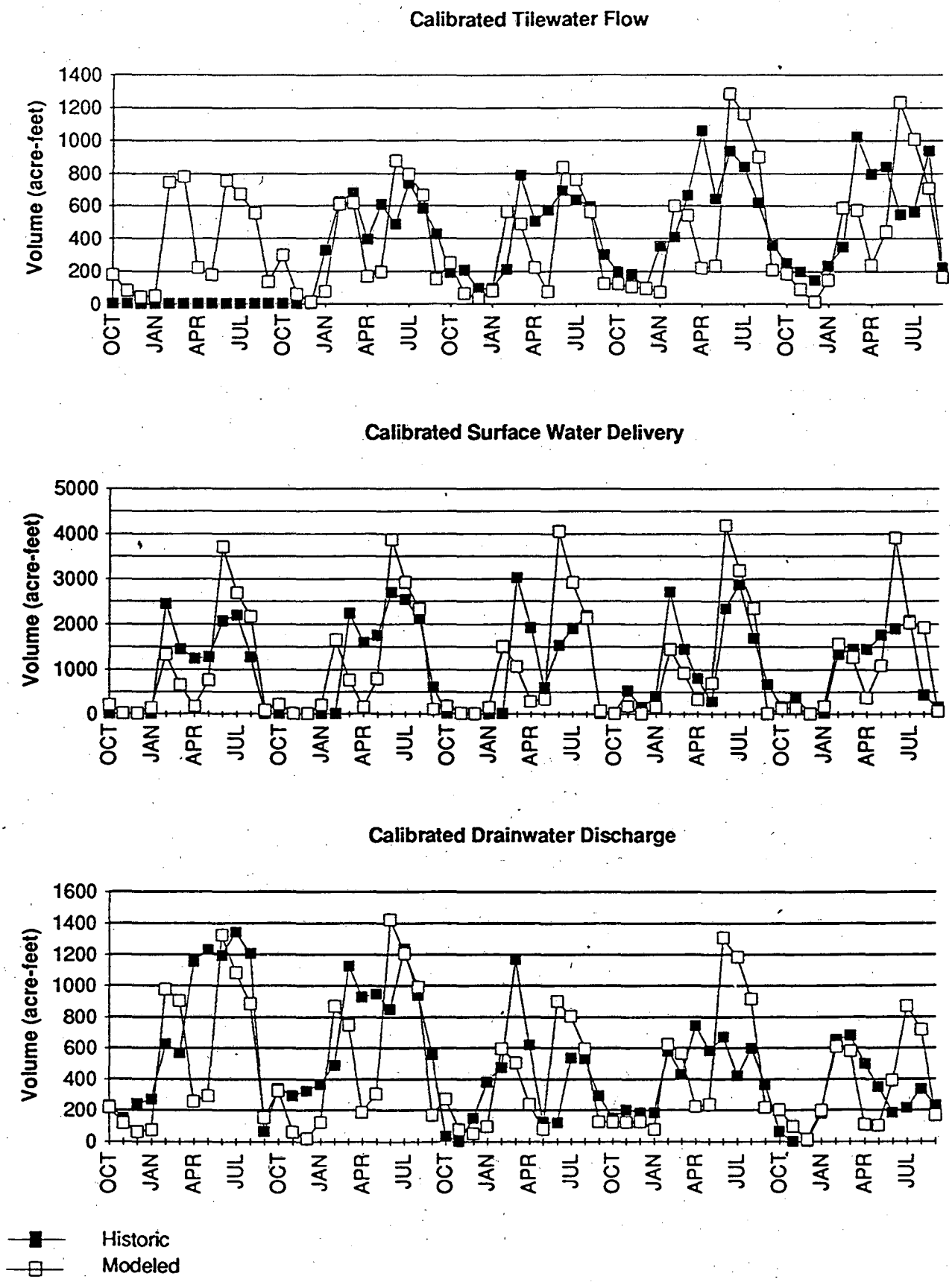


Figure 37. Flow hydrographs for the Pacheco Water District comparing calibrated and historic flows. (Source : CH2M-Hill, 1991)

3.2.3.3 Model outputs

The intermediate outputs of the IRDROP model are calibrated monthly flow volumes and salinity concentrations from San Luis, Broadview, Panoche and Pacheco water districts that constitute the northern division of the San Luis Unit. The final outputs of the model are monthly targets for drainage flow, temporary on-farm storage and drainage recycling for each water district that maximize assimilative capacity opportunities within the San Joaquin River and still meet San Joaquin River objectives for boron and selenium.

3.2.3.4 Ease of calibration and performing model runs

Calibration of the IRDROP model was performed first at the water district level and then against combined water district discharges into the San Joaquin River (previously shown in figures 34 - 37). Model calibration required the exercise of considerable judgment owing to a dearth of data on intercepted surface flows, groundwater pumping and seepage losses in the surface water distribution system. Although the IRDROP model was quite successful at matching flow hydrographs from most of the water districts the model was less successful at matching salt loads exported by each water district. Hence the estimates of selenium and boron loading from each water district were also subject to error. Improved calibration of the model will be easier if greater numbers of sumps are monitored for flow and contaminant concentrations in future district monitoring programs and if these is a more concerted effort within each water district to monitor soil and shallow groundwater concentrations of salts and important trace elements.

It is relatively easy to make IRDROP model once the data has been entered - the GAMS input format is intuitive and easy to understand. Although a knowledge of GAMS is important for making changes to the model it is not necessary for the user to make model runs.

3.2.3.5 Relative expense of using and maintaining model

The IRDROP model requires two software packages to be resident on the computer before it can be run. The Generalized Algebraic Modeling System (GAMS) software is a pre-processor and post-processor, which sets up the model objective function and constraints for interpretation by the MINOS optimization package. GAMS allows data to be input to the model in tabular format and output from the model in the same general format. All model programming is written in the GAMS language. The GAMS-MINOS program package is expensive and is required software for any computer that it used to run the model. This is in contrast to Fortran - based models such as the CVGSM, the SANJASM, the SANTUCM, the SJRIO-2 model and the TPDSM which can be transferred to the end-user as an executable program. The input data can be readily changed in the IRDROP model simply by substituting new values for existing values in the data files. Program changes, however, require some experience of the GAMS syntax.

The model execution time is considerably faster than the WADE model. A complete 30 year run using input values of San Joaquin River assimilative capacity for selenium and boron at Newman (measured at Crows Landing) takes less than 30 minutes on an IBM compatible computer. A separate analysis must be made using

a customized spreadsheet model or the SJRIO-2 model to make projections of assimilative capacity in the San Joaquin River at the compliance site.

3.2.3.6 Ease of linking with other models

The IRDROP model requires information on river assimilative capacity for selenium and boron prior to making monthly allocation decisions between direct discharge, temporary surface storage and drainage recycling. The SJRIO-2 model could be modified with little effort to provide these estimates for future projections of reservoir releases and other tributary and groundwater inflows into the San Joaquin River. The SJRIO-2 model could also be used to predict the impact of the monthly target drainage flows on concentrations of selenium, boron and TDS at Vernalis and other sites downstream of the compliance site at Newman.

Other more detailed hydrologic models could be used to refine the drainage flow and quality calculations made by the IRDROP model, in instances where more detailed hydrology and water quality data is available. The HYSAM, discussed later in this report, would be one such model. The HYSAM could also be used to predict the long term impact of drainage recycling at the levels suggested by the IRDROP model.

The WADE model could also be linked to the IRDROP model to supply seasonal projections of water deliveries and cropping patterns, subject to various economic incentives or penalties. These cropping patterns and seasonal deliveries could taken as input to the IRDROP model.

3.2.3.7 Previous peer review

The IRDROP model has not been formally reviewed. Informal review of the IRDROP model occurred within the San Luis Drainage Program by Reclamation personnel in Denver.

3.2.3.8 Model deficiencies and how these are being addressed

The IRDROP model is mostly data driven - hence the best way to improve the predictive capability of the model is to improve the database upon which the model depends. Certain assumptions such as the percentage contribution to drainage from deep percolation and the shallow and deep semi-confined aquifer need to be field tested - at present these percentages are extrapolations from published USGS drainage studies in the Panoche Water District. Errors in estimates of seepage from canals and ditches and intercepted flows from other districts can cause substantial errors in mass balance computations for each district and should be corrected through improved design of the existing monitoring system. Initial conditions for groundwater salinity can have a large effect on the prediction of drainage loads for each water district - more extensive monitoring of groundwater levels and groundwater quality in these districts will help improve these estimates.

3.2.4 Utility of the model for Reclamation planning studies

3.2.4.1 Actions to meet water quality objectives in the San Joaquin River

The IRDROP model is provided with estimates of San Joaquin River assimilative capacity for selenium and boron to determine an optimal management strategy that combines direct discharge, temporary storage and drainage recycling. These estimates of assimilative capacity are based on the SWRCB water quality objectives for selenium and boron at Newman. The model currently operates on a monthly time step but could be adapted to consider a shorter interval. Considerable effort would be required to re-design the model to work with daily data, in particular that transit times within the drainage conveyance system would need to be considered. However, the general attributes of the model are a good basis for the eventual design of a tool to work with real-time data.

3.2.4.2 Salt balance in the San Joaquin Basin

The IRDROP model performs salt budgets for each of the four water districts that comprise the San Luis Unit. The combined flow and salt load from the four water districts provide an estimate of salt export from the northern section of the San Luis Unit of the CVP.

3.2.4.3 Drainage reduction policies and planning

The model was designed to recommend district drainage operations involving direct discharge, temporary storage in holding ponds and drainage recycling after making estimates of flow and salt loading from each of the four water districts that make up the northern section of the San Luis Unit. Certain drainage reduction policies, notably those that limit total flow or salt load can be readily analyzed within the IRDROP model. Policies that affect the economics of drainage are better analyzed within the WADE model and the results of these model runs used to constrain the monthly drainage flow and load in the IRDROP model. This could be performed using percentage reductions in flow or salt load relative to the values of these factors obtained using the base condition. Alternatively annual total drainage flow and salt load obtained from the WADE model could be distributed by month using a typical flow volume distribution curve.

The various drainage reduction policies that have been analyzed with the WADE model and that could be include (a) drainage fees based on volume of discharge, (b) drainage fees based on salt (or boron, selenium) loads; (c) tiered water pricing; (d) drainage load allocations for water districts (represented by several polygons in the model); (e) regional groundwater pumping; and (e) land retirement and idling of selected lands.

3.2.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

The IRDROP model does not recognize the streams and tributaries to the San Joaquin River. Neither does the model recognize stream - aquifer interactions. Conjunctive use actions can be analysed by the IRDROP model as a trade - off between surface water supply and groundwater supply at the regional level. The major impact

that pumping would have on model results is in the TDS of surface applied water and the effect this would have on rootzone salinity. The IRDROP model is a limped parameter model and does not consider the effect of groundwater pumping on water table levels.

3.2.4.5 Structural options to control stage and water quality in the South - Delta

The IRDROP model can be used to make projections of drainage loads and flows from the west side of the San Joaquin Valley, which directly affects water quality in the San Francisco Bay-Delta. Much of the salt load carried into the Delta and Bay Estuary derives from agricultural operations on the west side. The model would need to run in conjunction with one of the Delta hydrodynamic and salinity models to be useful in this type of analysis. If linked to one of the Delta hydrodynamic models and the SJRIO-2 model, the IRDROP model could be used to predict a future time series of drainage flows and salt loads, which could then be routed down the San Joaquin River into the Delta.

3.2.5 Overall assessment and recommendations

The IRDROP model was developed as a tool for making decisions about drainage operations to maximize export of salts and drain water high in trace element concentrations without violating SWRCB objectives for the San Joaquin River. The model is unique in this capability. The current IRDROP model operates on a monthly time step, which makes it easy model to link to the SJRIO-2 model. The IRDROP model should be actively retained within Reclamation since, with further development, it could provide a basis for making real time decisions on the management of drainage into the San Joaquin River. Current investments in flow and water quality telemetry stations along the San Joaquin River and within its major tributaries including Mud and Salt Slough will help to provide the data to make this feasible.

3.2.6 References

CH2M-Hill, 1991. Draft Alternative Plans Report. San Luis Unit Drainage Program, U.S. Bureau of Reclamation.

3.3 San Joaquin River Input-Output Model (SJRIO-2)

3.3.1 General description and purpose of model

This model has evolved from the San Joaquin River Input Output model (SJRIO), developed in 1986 for the State Water Resources Control Board to study the effects of agricultural drainage on water quality in the San Joaquin River between Lander Avenue and the Vernalis monitoring station (Pickett et al., 1987). The original SJRIO model was used to estimate monthly flows and concentrations of TDS, boron and selenium at approximately 180 locations along the 60 mile reach of the San Joaquin River. SJRIO-2 is a more physics-based version of SJRIO that calculates the groundwater contribution to flow within the model and includes a stochastic streamflow simulator to allow a larger range of monthly streamflow conditions to be analyzed. Future enhancements of the SJRIO-2 model will allow the model to route streamflow down the San Joaquin River by considering the flow hydrodynamics. This will allow the model to consider the time of travel between monitoring stations along the river, a feature not available in the present model or the original SJRIO model. Agricultural drainage reduction scenarios can also be analyzed with Monte Carlo simulations to assess the effect of load reductions on concentrations of TDS, boron and selenium in the San Joaquin River.

3.3.1.1 Geographic extent of the model

The SJRIO-2 model simulates the same 60 mile reach of the San Joaquin River as SJRIO (Figure 38) extending from Lander Avenue to Vernalis and including major west side contaminant load contributions at Mud and Salt Sloughs and major east-side flow contributions from the Merced, Tuolumne and Stanislaus Rivers. Groundwater contributions to the river and groundwater losses from the river are calculated every mile along the 60 mile reach (Figures 39 and 40).

3.3.1.2 Features of model

SJRIO-2 is a deterministic mass balance water quality simulation model. The model can be run with historical data, stochastic data or a combination of both (Grober and Kratzer, 1989). The model can be used to perform a multivariate time series analysis of the data describing inflow to the San Joaquin River inflow and can generate a stochastic time series from these data. Monthly diversion data were assembled from DWR reports for water years 1976 through 1990, based on agricultural crop water use and cropping patterns (Figures 40 - 42). Agricultural surface and subsurface return flows were estimated as a percentage of the supplied irrigation water in most instances where return flows have not been measured. An assumption of constant monthly water quality was made of these return flows. Grab sample water quality data was used, where available, to establish these return flow concentrations. Groundwater accretions or depletions to the river were calculated assuming Darcy flow and hydraulic gradients determined between the unconfined water table level and the river stage for each month. The model can be run in deterministic fashion for a 14 year period or stochastically for 250 years of generated data.

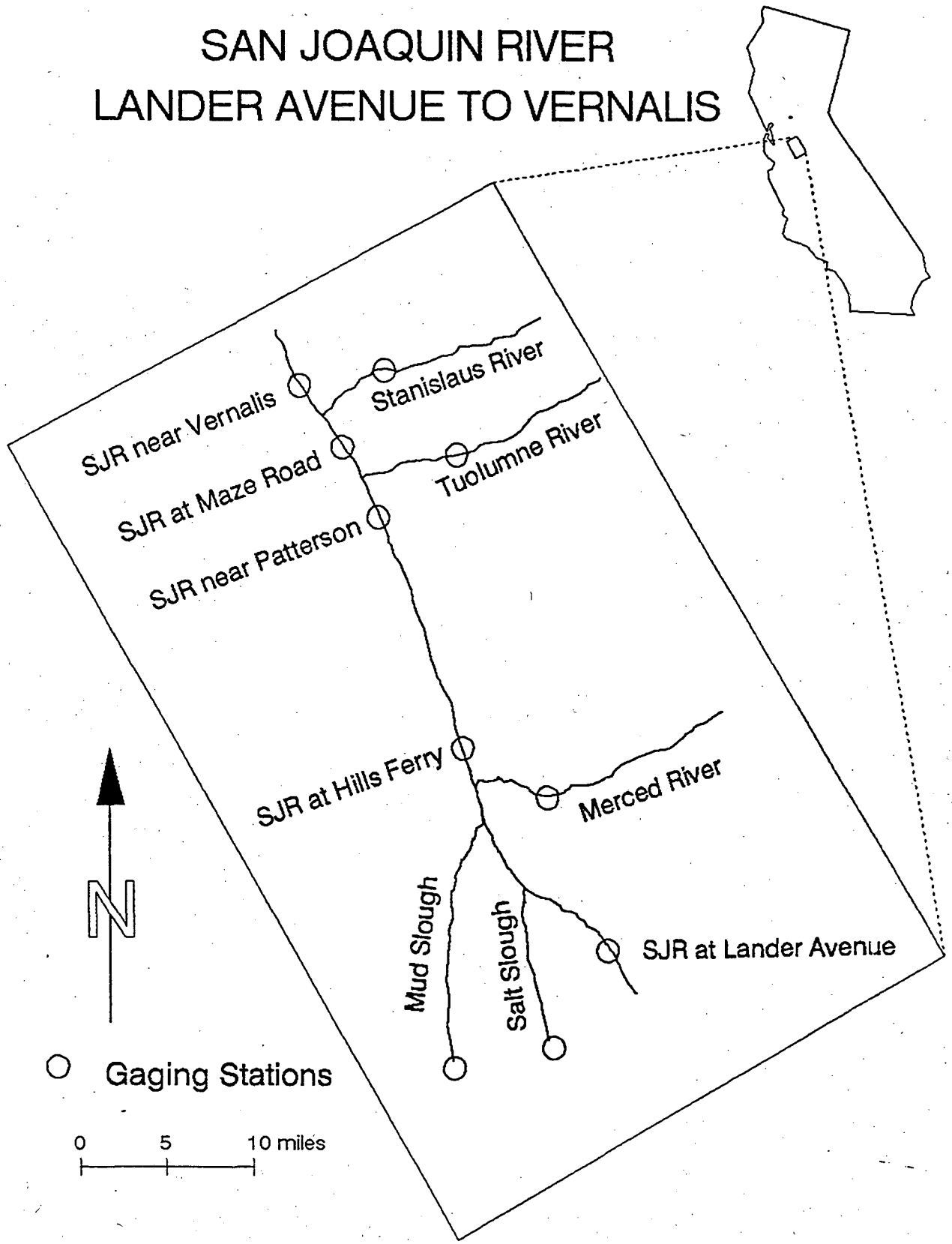


Figure 38. **SJRIO-2 model study area from the Lander Ave monitoring station to the Vernalis compliance point on the San Joaquin River.**
(Source : Grober et al. 1992)

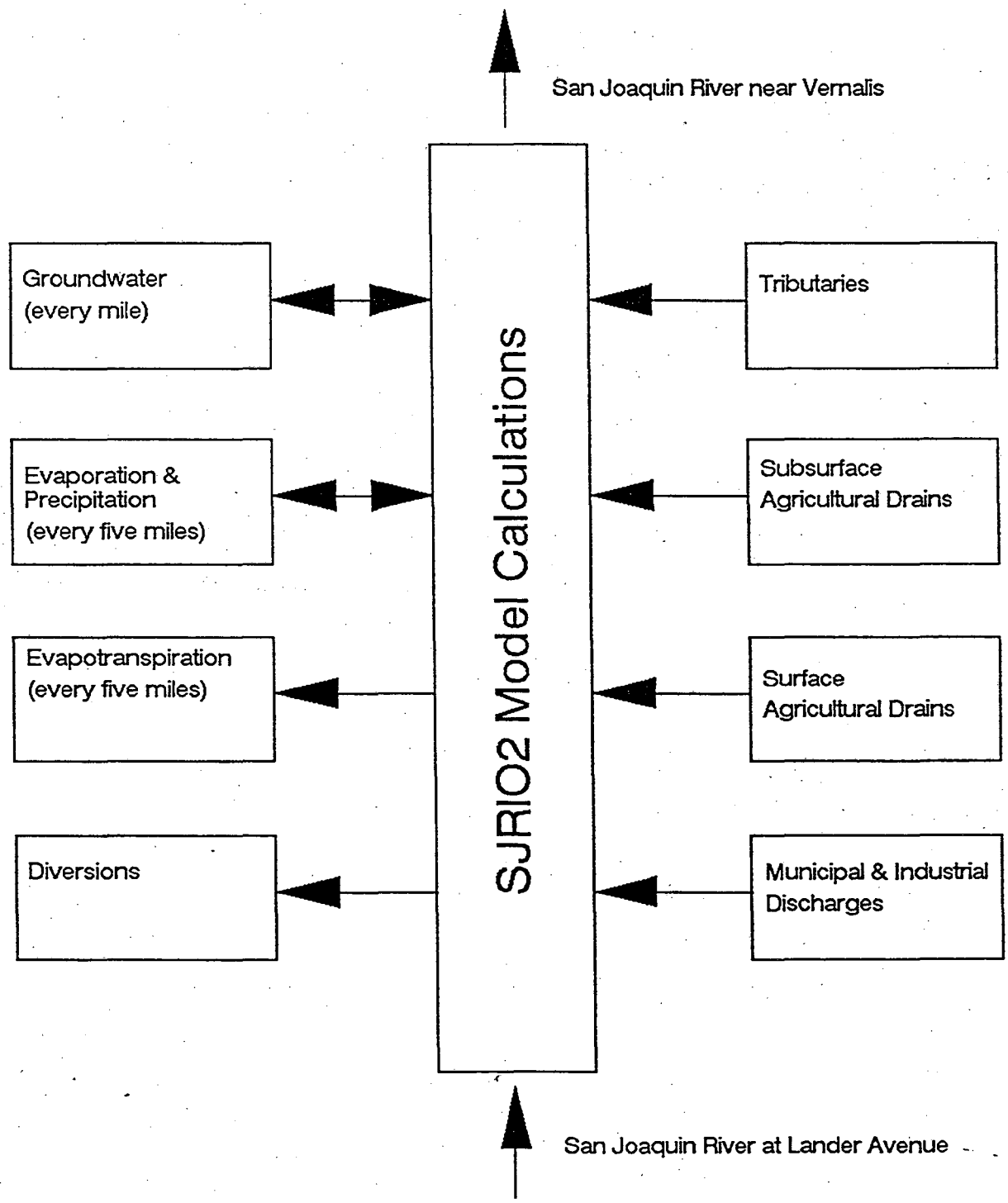


Figure 39. Hydrologic components of the SJRIO-2 model. Groundwater accretions are simulated every one half mile, evaporation, precipitation and evapotranspiration every five miles. Other gains and losses along the main stem of the San Joaquin River occur at discrete locations .
(Source : Grober et al. 1992)

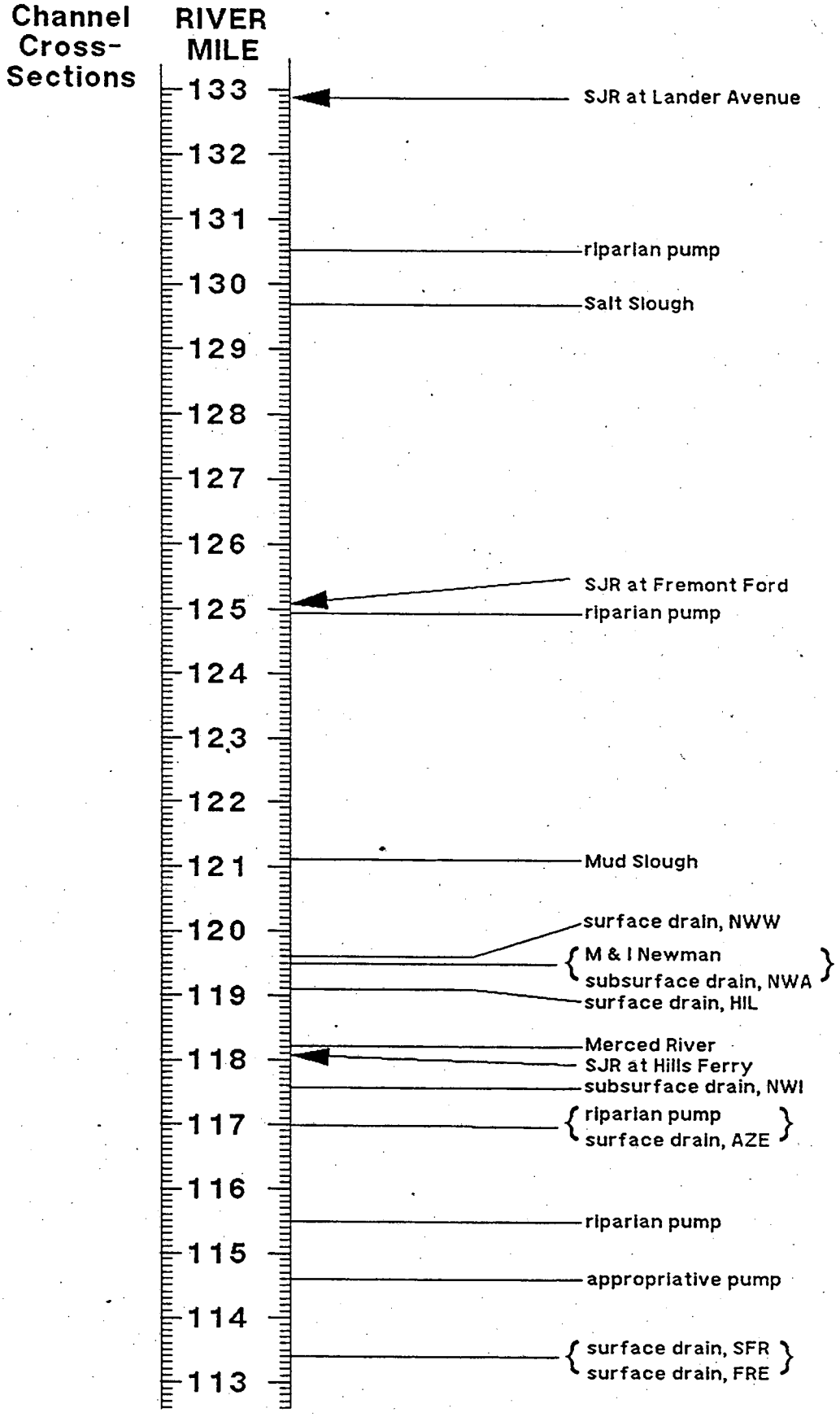


Figure 40. **Gains and losses to the San Joaquin River from Lander Avenue to Mile 112 simulated by SJRIO-2.** (Source : Grober et al., 1992)

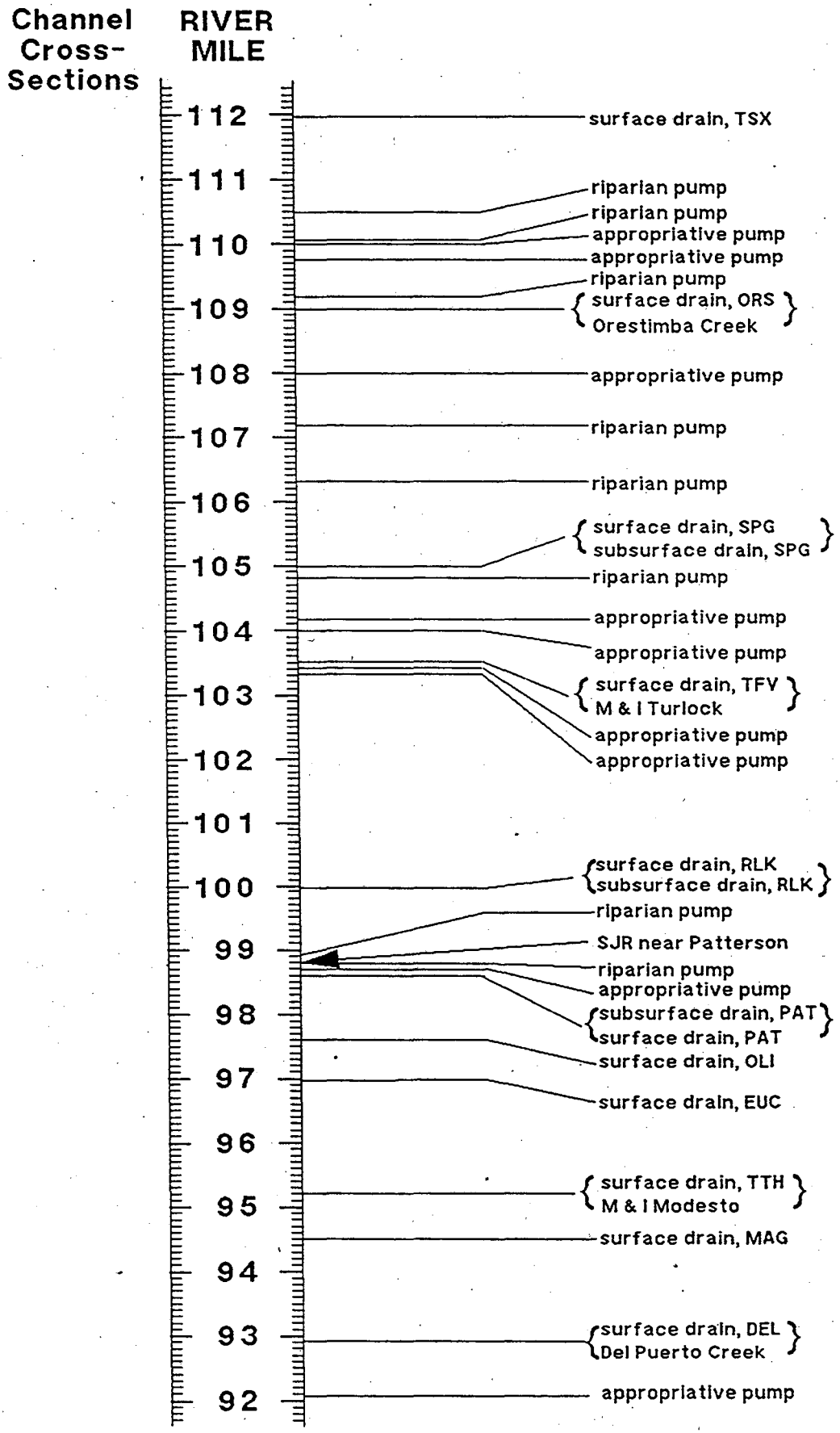


Figure 41. **Gains and losses to the San Joaquin River from Mile 112 to Del Puerto Creek simulated by SJRIO-2.** (Source : Grober et al., 1992)

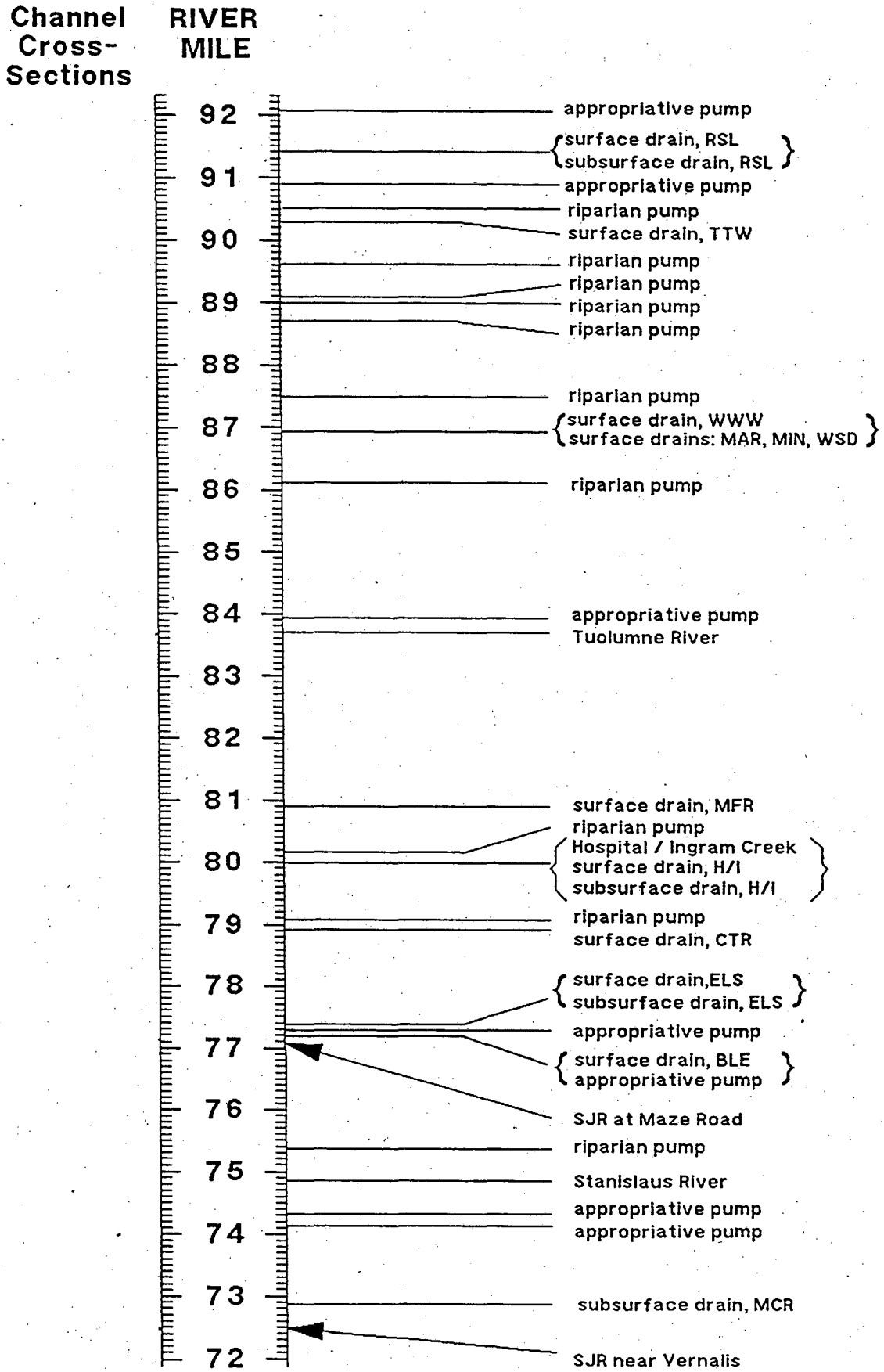


Figure 42. **Gains and losses to the San Joaquin River from Del Puerto Creek to Vernalis simulated by SJRIO-2.** (Source : Grober et al., 1992)

3.3.1.3 Capability of the model : flow / flow and water quality

The model simulates both flow and water quality on a monthly time step. Water quality values for the tributaries were calculated using a simple least squares linear regression of flow versus constituent concentration (U.C. Davis, 1992). This approach appears to be defensible owing to the small contribution of the east-side streams to the salt load in the San Joaquin River.

3.3.1.4 Simulation time step

The model operates on a monthly time step and summarizes results by water year. Using a monthly time step, the model assumes that both flow and water quality remain reasonably constant over the time step - hence the hydrodynamics of flow and water quality are assumed not to be important. At lesser, the hydrodynamics of flow becomes more important since water can take upwards of one week to pass from Lander Avenue to the gauging station at Vernalis. Groundwater flow, on the other hand, owing to the assumptions made in its prediction, is independent of the time step chosen.

3.3.1.5 Computer requirements and portability

SJRIO-2 currently runs on the SWRCB MicroVax II. The model cannot be run on other workstations or MS-DOS based machines without changes to the dimensioning of the arrays used in the model. The SWRCB intends to make these code modifications so that the model will run on these machines (Grober, 1992; personal communication). The SJRIO model took less than 1 minute to simulate flow and water quality on an Apollo workstation for each of 12 months when a study was made of model sensitivity to Mud Slough drainage loads. Owing to the increase in the model computation required SJRIO-2 would likely take 5 to 10 times longer to run than the original model. When used with stochastic input data the model execution time will increase proportionately according to the number of realizations of the independent variables used in the analysis.

3.3.2 Model development

3.3.2.1 Reasons for development of the model

The model was developed to study the effects of agricultural drainage on water quality in the San Joaquin River and assist in the formulation and evaluation of water quality objectives for selenium and boron at Newman and within Mud and Salt Sloughs.

3.3.2.2 History of development and use of the model

The SWRCB has used the original SJRIO model in planning studies related to the development of water quality objectives for the San Joaquin River and for major contaminant load-bearing return flows at Mud and Salt Sloughs. The model was subsequently used by the San Joaquin Valley Drainage Program for evaluation of the impacts of various drainage reduction strategies and in the development of a management plan for control of

selenium and boron loading on the San Joaquin River. A graphics-based version of the current SJRIO-2 model will be developed for the Data General AViiON workstation during the next 6 months.

3.3.2.3 Further development of the model and intended future use

The SJRIO-2 model is currently being considered by the EPA and the EDF as a means of allocating contaminant waste loads from agricultural water districts, given the assimilative capacity of the San Joaquin River. The model is the best available database of discharges to and diversions from the San Joaquin River and, if further enhanced to allow it to utilize real time data, the model could be used to calculate daily assimilative capacity for the San Joaquin River and in the setting of daily drainage release targets. To make these calculations SJRIO-2 would need to be run as a hydrodynamic flow and water quality model.

3.3.3 Evaluation of the model

3.3.3.1 Predictive capability and model reliability

SJRIO-2 is a data driven mass balance model which attempts to simulate mean monthly flows and contaminant loads along the San Joaquin River. Although SJRIO-2 is more physically based than the original SJRIO model, assumptions of the relationship between flow and contaminant load for the various tributaries and drainage channels, which transport agricultural return flows, are necessary for the mass balance computation along the San Joaquin River. The assumption that these relationships remain static over time is not justified for some areas where the raising or lowering of the regional water table can change the concentration of drainage return flows that end up in the San Joaquin River. Between 60% and 85% of the annual selenium and boron loads are transported through Mud and Salt Sloughs, which are inputs to the model. Hence the load contributions from other sources do not have a great impact on the model's ability to predict water quality along the reach of the river. Prediction of flow is less reliable because of the large volumes of water contributed by sources other than Mud and Salt Slough and the major tributaries.

3.3.3.2 Data requirements

SJRIO-2 requires flow and constituent concentration information for the contributions made by surface and subsurface return flows and the monthly volume of water diverted at each turnout or pump location along the river (Figure 39). Groundwater water tables are compared with calculated monthly average river stage elevations to calculate groundwater accretions or depletions. Calibration of the model is performed at four control points along the length of the San Joaquin River. Flow and contaminant concentrations are required at these locations.

3.3.3.3 Model outputs

The model produces outputs of flow and contaminant concentration each river mile along the length of the San Joaquin River and at the location of each major diversion or point of inflow. When the model is run with the

stochastically generated data the results can be presented as probabilities of exceedance of a particular flow or contaminant concentration. This is particularly helpful for risk assessment and is a parameter particularly useful to agencies such as the EPA for the analysis of compliance.

3.3.3.4 Ease of calibration and performing model runs

The original SJRIO model was provided with a user interface with prompts to assist the user during calibration of the model and while performing sensitivity analyses using the model. The SJRIO model is easy to calibrate and to run; these steps are performed by separate computer programs. SJRIO-2 is a more complex model and requires more data. Calibration is more difficult with SJRIO-2 because groundwater accretions or depletions are calculated within the model and are a function of the head gradient between mean aquifer water table and the river stage. Once calibration has been performed, the model can be run in either deterministic or stochastic mode. This can be accomplished relatively easily with SJRIO-2 - however, the execution time can range from minutes to hours, depending on whether the model is run using historical time series data or stochastically - generated, time - series data.

3.3.3.5 Relative expense of using and maintaining model

SJRIO-2 requires more data to perform simulation runs because the model calculates many of the variables that are read in from external datafiles in the SJRIO model. At present the SJRIO-2 model has not been successfully implemented on a computer other than the SWRCB MicroVax minicomputer - hence, it would require a computer of similar power to successfully run the model. SJRIO, on the other hand is currently available on Apollo, IBM and Macintosh computers. The speed of execution is relatively fast on the MicroVax, a run can be completed in under 5 minutes of CPU time. However, if using the Monte Carlo simulator, the model takes several hours to run a 250 year simulation. This could take considerably longer on a less powerful workstation or IBM-based machine. The model developer plans to have a working version of the model on an MS-DOS platform by early 1993.

3.3.3.6 Ease of linking with other models

The SJRIO-2 model can be linked with minimal difficulty and minor coding changes to several models. The model can be directly linked with the SANJASM and the SANTUCM for analyzing the effect of reservoir re-operation on water quality in the mainstem of the San Joaquin River. The SANJASM would be a more suitable model to link to the model than the SANTUCM since the SANTUCM contains a groundwater flow model, which is inferior to the groundwater subroutine contained in the SJRIO-2 model. Since the salinity model for the SANTUCM was not completed by the model's developer, this would be another redundant subroutine that could be eliminated by linking the SJRIO-2 model with the SANJASM.

For drainage reduction planning the IRDROP model could be used to estimate drainage production by the Grassland water districts and estimate the flow and salinity load delivered to Mud and Salt Sloughs for

conveyance to the San Joaquin River. The NRWS, when completed, should be able to estimate in-transit losses or additions to salt load. The SJRIO-2 model could also be used to provide input to the Sacramento - San Joaquin Delta hydrodynamic flow and salinity models. The boundary inflow along the San Joaquin River could be provided by the SJRIO-2 model.

3.3.3.7 Previous peer review

The model has undergone internal peer review within the SWRCB and within the Civil Engineering Department at U.C. Davis.

3.3.3.8 Model deficiencies and how these are being addressed

The model makes a number of simplifying assumptions regarding the annual variability of the water quality of agricultural and non-agricultural return flows. These same average monthly subsurface flows are used for all water years simulated by the model (Grober et al, 1992). A large proportion of the salt and trace element loading to the San Joaquin River is contributed by Mud and Salt Sloughs, which are gauged and typically sampled at least once per month - hence the error caused by this assumption is not large. However, there is evidence to show that the on-farm relationship between load and flow on the west side of the San Joaquin Valley is not consistent for all water year types. The assumption that the constituent concentrations of river accretions remain unchanged during the year needs to be verified through increased drainage flow and water quality monitoring and the completion of constituent mass balance studies on short reaches of the San Joaquin River.

West side surface return flows were estimated to be approximately 30% of supplied irrigation water. This assumption is unlikely to provide accurate estimates of monthly flow from upslope agricultural areas into the San Joaquin River, owing to the complexity of the tailwater re-use practices in the area. Improved subregional mass balance studies are required to improve prediction of these surface return flows.

Although the model can calculate changes in groundwater accretions to the river in response to changes in water table levels in the semiconfined aquifer, the salt and trace element concentrations of these accretions to the river are assumed to remain constant over time. There is insufficient available data to challenge this assumption. The volume flow rate of groundwater accretions to the river have been estimated by the USGS to be between 2-3 cubic feet per second per mile. Accretions can account for as much as 20% of the monthly flow in the San Joaquin River and up to 50% of the monthly salt load.

The model time step is sufficient for most planning studies but may not be suitable for operations studies where the SJRIO-2 model is linked with the Delta hydrodynamic flow and salinity models. There is a limit in this type of mass balance model to the degree the time step can be reduced without seriously compromising its predictive capability. At time steps of a week or less the total travel time from Lander Avenue to Vernalis is of the same order of the model time step. Hence a fully hydrodynamic model of flow in the river may needed if a smaller time step is contemplated.

3.3.4 Utility of the model for Reclamation planning studies

3.3.4.1 Actions to meet water quality objectives in the San Joaquin River

The SJRIO model has been used by the SWRCB and the SJVDP to evaluate the effect of actions such as source control and drainage management practices on compliance with monthly water quality objectives for selenium and boron in the San Joaquin River. The SJRIO-2 model can similarly be used directly to make these analyses.

3.3.4.2 Salt balance in the San Joaquin Basin

The SJRIO and SJRIO-2 models can be used to estimate salt and trace element loads leaving the San Joaquin Valley. To perform a salt balance a separate analysis must be made of salt imported into the Valley through the State Water Project and Federal CVP and flowing through the Valley from eastside tributaries to the San Joaquin River. The San Joaquin River Model (SJRMOD), included in Section 3.4 of this report, is a more conceptually simple mass balance model which incorporates some of the same features.

3.3.4.3 Drainage reduction policies and planning

The SJRIO and SJRIO-2 models both lend themselves to the analysis of drainage reduction policies when linked to drainage policy models such as the WADE and IRDROP models. The WADE and IRDROP models predict flow and salt loads from agricultural water districts to the San Joaquin River. For analysis of the effects of on-farm management policies on selenium loading to the San Joaquin River, the SJRIO and SJRIO-2 models could be linked to the NRWS, upon its completion.

3.3.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

The SJRIO and SJRIO-2 models do not explicitly consider groundwater pumping, or the effect of groundwater pumping in the vicinity of the San Joaquin River. This analysis is more appropriately performed in models such as the SANTUCM or the CVGSM. If the effects of these conjunctive use practices on water flow in the east-side tributaries or on flow and contaminant loading from Mud and Salt Sloughs can be obtained from other models, the SJRIO and SJRIO-2 models could then be used to estimate the effect of these actions on water quality at the various compliance sites along the San Joaquin River.

3.3.4.5 Structural options to control stage and water quality in the South - Delta

When linked to any of the four hydrodynamic flow and salinity models described in Tables 1 and 2, the SJRIO and SJRIO-2 models can be most useful in investigations of the effect of drainage flow and load reductions on water quality in the San Francisco Bay-Delta. These reductions can be simulated as percentage reductions in flow and contaminant load contributed at Mud and Salt Sloughs or from any of the large number of sources of flow or contaminant load along the main stem of the San Joaquin River. The SJRIO model was provided with a user interface to allow the SJVDP to make quantitative changes in the load or flow of TDS, boron or selenium,

expressed either as a percentage of the historical mass load or as a mass of contaminant contributed during any particular month. The SJRIO and SJRIO-2 models can be linked with the SANJASM and the hydrodynamic flow and salinity models to look at the effect of reservoir re-operation on flow and water quality in the Bay-estuary. The model cannot directly assist in this analysis except to provide average monthly flow and contaminant concentration levels as a San Joaquin boundary condition to the hydrodynamic flow and salinity models previously described in Section 1 (Tables 1 and 2).

3.3.5.0 Overall assessment and recommendations

The SJRIO and SJRIO-2 models are important models for the analysis of policy options and actions affecting flow and water quality in the San Joaquin River. The models constitute the best repository of flow and water quality data for the San Joaquin River. The SJRIO-2 model contains 14 years (1975 - 1990) of monthly flow and water quality data that includes TDS, boron and selenium The models can be readily linked with Delta hydrodynamic flow and salinity models to provide these models with monthly averaged flow and constituent load levels at the upstream boundary and with simulation models of irrigation and drainage practices to evaluate the effect of source control and drainage reduction actions on compliance with SWRCB water quality objectives for the San Joaquin River. A graphical user interface is currently being developed for the SJRIO-2 model to aid understanding of the model by the end-user and to aid interpretation of model results.

3.3.6 References

Grober L.F. and C.R Kratzer, 1989. Stochastic modeling of water quality in the San Joaquin River, California, using Monte Carlo Simulation. Proceedings of the Sixteenth Annual Conference of the ASCE Water Resources and Planning and Management Division. May 21-24, 1989. Sacramento, CA.

Pickett P.J. and C.R. Kratzer, 1988. An evaluation of drainage reduction as a method for meeting recommended water quality objectives for selenium, salinity and boron in the San Joaquin River. Report to the San Joaquin Valley Drainage Program.

Grober L.F., M. L. Kavvas, E.A Rashmawi and M.E. Grismer, 1992. Stochastic water quality modeling and numerical groundwater simulation for the lower San Joaquin River Basin. Report to the State Water Resources Control Board. April, 1992.

3.4 San Joaquin River Model (SJRMOD)

3.4.1 General description and purpose of model

The South Delta Water Agency sponsored the development and application of a simple salt balance computer model to be applied to the main stem of the San Joaquin River from Mendota to Vernalis. The model, identified as SJRMOD, is designed to assist in the evaluation of alternative management strategies to regulate the accretion of salts (measured as TDS) from the west side of the San Joaquin Valley. The model is also expected to have general utility in the assessment of any alternative concerned with regulation of runoff and water quality along the course of the river (Orlob, 1993 - written communication).

3.4.1.1 Geographic extent of the model

The SJRMOD accounts for flow and TDS concentrations over a 60 mile reach of the San Joaquin River from eight river reaches from Lander Avenue to Vernalis, including the major west side contaminant load contributors at Mud and Salt Sloughs and major east-side flow contributions from the Merced, Tuolumne and Stanislaus Rivers. The model does not deal with groundwater contributions to the river explicitly.

3.4.1.2 Features of model

The SJRMOD is a deterministic mass balance surface water quality simulation model and is similar in design to the original San Joaquin River Input-Output model. The model can be run with historical or synthetic data or a combination of both types of data .

3.4.1.3 Capability of the model : flow / flow and water quality

The SJRMOD simulates both flow and water quality on a monthly time step.

3.4.1.4 Simulation time step

The SJRMOD operates on a monthly time step and summarizes results by water year. Using a monthly time step, the model assumes that both flow and water quality remain reasonably constant over the time step - hence the hydrodynamics of flow and water quality are assumed not to be important.

3.4.1.5 Computer requirements and portability

The SJRMOD runs on an IBM - compatible computer under Microsoft Windows. The model executes in approximately one minute on an IBM-compatible 486 computer. When used with stochastic input data the model execution time will increase proportionately according to the number of realizations of the independent variables used in the analysis.

3.4.2 Model development

3.4.2.1 Reasons for development of the model

The SJRMOD was developed to study the effects of agricultural drainage on water quality in the San Joaquin River and to assist in the formulation of a plan for optimal management of salt in the river. The model simulates seasonal patterns of flow and water quality along the river and at specific locations between Mendota and Vernalis. and can estimate the changes in salt load and TDS concentrations resulting from alternative control options. These control options include; regulating flows below impoundments on the east side of the San Joaquin Valley; augmenting water quality control releases from reservoirs such as New Melones that have storage of water for quality control; and controlled drainage releases from tile drainage sumps on the west side of the San Joaquin Valley.

3.4.2.2 History of development and use of the model

An earlier version of the model was used by Orlob (1991) to examine the effect of various changes to current east-side reservoir operations and release schedules to flow and salt concentrations in the Old River and Middle River, that provide water supply to the South Delta. This spreadsheet version of SJRMOD provided mean monthly flow and salt concentration data to the RMA link-node model, which was used to transport salt loads from the upstream boundary nodes at Vernalis through the South Delta. The RMA link node model was linked to the SDCASS (described in section 2.4) to produce graphic displays and animations of flow and slat concentrations at selected stations within the South Delta.

3.4.2.3 Further development of the model and intended future use

The major enhancement to the SJRMOD, being undertaken at the present time, is the addition of graphics to the model code using the graphics development software toolbox Visual Basic ™. This enhancement will make the model easier to use and make the results of model runs easier to interpret. The model may be used in a linked fashion with the RMA hydrodynamic model to allow the effects of future reservoir operating rules and drainage releases from the west-side agricultural water districts on South Delta water quality and flow to be evaluated. The model could be linked with SANJASM, in the same way as has been done with SJRIO-2, for detailed studies of projected reservoir releases using existing reservoir operating rules.

3.4.3 Evaluation of the model

3.4.3.1 Predictive capability and model reliability

The SJRMOD is a data driven mass balance model which attempts to simulate mean monthly flows and salt loads along the San Joaquin River. The model is less physically based than the SJRIO-2 model since it does not explicitly simulate groundwater flow to the San Joaquin River, nor does it recognize some of the minor

triburaty flows to the river. As in the case of SJRIO-2, assumptions must be made of the relationship between flow and contaminant load for the various tributaries and drainage channels, which transport agricultural return flows, are necessary for the mass balance computation along the San Joaquin River. The assumption that these relationships remain static over time is not justified for some areas where the raising or lowering of the regional water table can change the concentration of drainage return flows that end up in the San Joaquin River.

3.4.3.2 Data requirements

The SJRMOD requires monthly flow and TDS concentration data for the contributions made by the major surface and subsurface return flows and the monthly volume of water diverted at each major turnout along the San Joaquin river, when run with historic time series data. The model can also accept synthetic tributary flow data, which must be supplied to the model, unlike SJRIO-2, which can generate flow data using Monte Carlo techniques. Subsurface drainage to the river is lumped and applied at three sites along the main stem of the San Joaquin River. Groundwater inflow is ignored.

3.4.3.3 Model outputs

The model can produce monthly output of flow and TDS concentrations at each junction node along the main stem of the San Joaquin River.

3.4.3.4 Ease of calibration and performing model runs

The SJRMOD is simple to calibrate because of the relatively small number of model inputs and the graphic interface being created for the model should make it easy to perform simulation runs. Once calibration has been performed, the model can be run using real or synthetic data. This can be accomplished relatively easily with the SJRMOD - execution time should range from seconds to minutes, depending on whether the model is run using historical time series data or with stochastically - generated, time - series data.

3.4.3.5 Relative expense of using and maintaining model

The SJRMOD requires less data to perform simulation runs than the SJRIO-2 model because of its relatively simple configuration compared to the State Water Resources Control Board SJRIO-2 model. The SJRMOD uses commonly available data for input, requiring no additional data collection activities, and hence should be inexpensive to maintain.

3.4.3.6 Ease of linking with other models

The SJRMOD could be linked with minimal difficulty and minor coding changes to several models. The model could be linked with the SANJASM and the SANTUCM for analyzing the effect of reservoir re-operation on water quality in the mainstem of the San Joaquin River. Inflows from the major tributaries would be provided by these USBR surface water contracting and accounting models. For drainage reduction planning the IRDROP

model could be used to estimate drainage production by the Grassland water districts and estimate the flow and salinity load delivered to Mud and Salt Sloughs for conveyance to the San Joaquin River. The NRWS, when completed, should be able to estimate in-transit losses or additions to salt load. Both of these models would provide inputs of flow and TDS from west-side sources to the SJRMOD. The SJRMOD can be used, in turn, to provide input to the Sacramento - San Joaquin Delta hydrodynamic flow and salinity models. The boundary inflow along the San Joaquin River are provided by the SJRMOD.

3.4.3.7 Previous peer review

An earlier spreadsheet version of the current model was informally reviewed by the San Joaquin Valley Drainage Program and the State Water Resources Control Board. The current model has not published nor has it undergone external peer review.

3.4.3.8 Model deficiencies and how these are being addressed

As with the SJRIO-2 the SJRMOD makes a number of simplifying assumptions regarding the annual variability of the water quality of agricultural and non-agricultural return flows. These same average monthly subsurface flows are used for all water years simulated by the model. A large proportion of the salt and trace element loading to the San Joaquin River is contributed by Mud and Salt Sloughs, which are gauged and typically sampled at least once per month - hence the error caused by this assumption is not large.
West side surface return flows were estimated in the SJRMOD based upon historical records. For future scenarios the historical concentration of salts in these return flows and total salt loading from west-side sources cannot be relied upon to remain constant or be well correlated with water year type owing to the dynamic nature of drainage reduction and water conservation programs within the Grasslands Basin.

Unlike the SJRIO-2 model the SJRMOD cannot calculate changes in groundwater accretions to the river in response to changes in water table levels in the semiconfined aquifer. The volume flow rate of groundwater accretions to the river have been estimated by the USGS to be between 2-3 cubic feet per second per mile. Accretions can account for as much as 20% of the monthly flow in the San Joaquin River and up to 50% of the monthly salt load.

The model time step is sufficient for most planning studies but may not be suitable for operations studies where the SJRMOD is linked with the Delta hydrodynamic flow and salinity models. There is a limit in this type of mass balance model to the degree the time step can be reduced without seriously compromising its predictive capability. At time steps of a week or less the total travel time from Lander Avenue to Vernalis is of the same order of the model time step. Hence a fully hydrodynamic model of flow in the river may needed if a smaller time step is contemplated.

3.4.4 Utility of the model for Reclamation planning studies

3.4.4.1 Actions to meet water quality objectives in the San Joaquin River

An early version of the SJRMOD has been used by Professor Gerald Orlob (Orlob, 1990), working under contract with the South Delta Water Agency, to evaluate the effect of changes to increasing releases from east-side reservoirs and amending current reservoir operating rules on flows and TDS concentrations in the South Delta. The model could be used, like SJRIO-2, to evaluate the effect of these changes on SWRCB objectives for TDS at Vernalis and to evaluate the ability to maintain required USBR water quality standards at Vernalis through releases from New Melones Reservoir. Like SJRIO-2 this model could be linked to the USBR SANJASM to simulate monthly reservoir operations in east-side reservoirs, route these releases down the San Joaquin River and provide input average monthly boundary inflows to Delta hydrodynamic and salinity models. Unlike SJRIO-2, the SJRMOD only performs salinity mass balances and does not deal with boron and selenium.

3.4.4.2 Salt balance in the San Joaquin Basin

The SJRMOD can be used to estimate salt loads entering and leaving the San Joaquin Basin. Unlike the SJRIO-2 model, the SJRMOD performs a salt balance which includes salts imported into the Valley through the State Water Project and Federal CVP as well as the salts entering Valley from eastside tributaries into the San Joaquin River.

3.4.4.3 Drainage reduction policies and planning

The SJRMOD can only be used for the analysis of drainage reduction policies when linked to drainage policy models such as the WADE or IRDROP models or other groundwater models that permit estimation of drainage return flows. The WADE and IRDROP models predict flow and salt loads from agricultural water districts to the San Joaquin River. The current SJRMOD uses estimates of mean annual drainage return flow from the historical record. Drainage policies are simulated by multiplying the flow and salinity data from each of the three drain flow sites by fixed percentages to emulate the hydrochemical effect of each policy scenario.

3.4.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

The SJRMOD does not explicitly consider groundwater pumping, or the effect of groundwater pumping in the vicinity of the San Joaquin River. This analysis is more appropriately performed in models such as the SANTUCM or the CVGSM. However, even if groundwater accretions or depletions to the river were determined through use of another model, the SJRMOD treats groundwater as a lumped parameter input to the river and therefore cannot be used for detailed analysis of the effect of groundwater conjunctive use on flow or salinity at compliance sites along the San Joaquin River.

3.4.4.5 Structural options to control stage and water quality in the South - Delta

When linked to any of the four hydrodynamic flow and salinity models described in Tables 1 and 2, the SJRMOD could be useful in investigations of the effect of drainage flow and load reductions on water quality in the San Francisco Bay-Delta. These reductions can be simulated as percentage reductions in flow and contaminant load contributed at Mud and Salt Sloughs or from any of the large number of sources of flow or contaminant load along the main stem of the San Joaquin River. The SJRMOD could also be linked with the SANJASM and the hydrodynamic flow and salinity models to simulate the effect of reservoir re-operation on flow and water quality in the Sacramento - San Joaquin Delta. The model cannot directly assist in this analysis except to provide average monthly flow and contaminant concentration levels as a San Joaquin boundary condition to the hydrodynamic flow and salinity models previously described in Section 1 (Tables 1 and 2).

3.4.5.0 Overall assessment and recommendations

The SJRMOD is an important model for the evaluation of possible actions that affect flow and water quality in the San Joaquin River. The model can be readily linked with reservoir operation simulation models , such as SANJASM, and Delta hydrodynamic flow and salinity models such as the RMA link-node model, to simulate flow and the transport and mixing of salts from the water storage facilities in the mountains, into and along the San Joaquin River and through the Sactamento - San Joaquin Delta. Simulation models of irrigation and drainage practices could be linked to this model to evaluate the effect of drainage reduction actions on compliance with Vernalis (a) SWRCB water quality objectives and (b) USBR salinity standards and of these actions on flow and water quality in the South Delta. As with SJRIO-2, a graphical user interface is being constructed for the model to improve understanding of the model and to improve communication of model results.

The model is not as detailed as the SJRIO-2 model and should defer to this model where the study calls for the analysis of actions that could alter irrigation diversions, draigae and groundwater return flows to the San Joaquin River.

3.4.6 References

Orlob, G.T., 1991. San Joaquin Salt Balance : Future Prospects and Possible Solutions. In : A. Dinar and D. Zilberman, 1991. The Economics and Management of Water and Drainage in Agriculture, Kluwer Academic Publishers, NY.

4. FIELD-SCALE MODELS

4.1 HYSAM (Hydrosalinity model)

4.1.1 General description and purpose of model

This model is an extension of a hydrosalinity model, previously developed by Professor Ken Tanjii and co-workers at U.C. Davis for analysis of subsurface return flows from irrigation projects in the Glenn-Colusa and Panoche irrigation districts in California. The most recent version of the steady-state model (Karajeh, 1991) was modified by CH2M-Hill to simulate annual transients in root zone and shallow aquifer salinity (Dickey, personal communication, 1992). Both anions and cations are accounted for in the HYSAM and drainage constituent concentrations are estimated from the initial composition and fluxes of these constituents during the irrigation season.

4.1.1.1 Geographic extent of the model

The geographic extent of the model is defined by the user and may vary from field to water district scale, depending on the data availability. The hydrologic unit of analysis should be chosen at a scale that allows estimation of all major hydrologic variables including recharge, lateral inflow/outflow, deep percolation, evaporation and evapotranspiration.

4.1.1.2 Features of model

HYSAM is a mass balance, deterministic simulation model which has been modified to perform annual salinity budgets over a 50 year planning horizon as a result of cropping practices, irrigation recharge, drainage and drainage recycling practices. The original model is time independent hence it can be adapted to analyze root zone salt fluxes for any time step selected by the user, provided data are available to make these analyses. Of particular importance is the model's ability to estimate gypsum equilibrium chemistry within the crop root zone. Gypsum is present in high concentrations in much of the western San Joaquin Valley and can add significantly to the total dissolved solids in subsurface drainage water. The model can be used in planning studies to investigate the sensitivity of root zone salinity to various source control options including irrigation recycling, water conservation, improved cropping practices and controlled tile drainage.

4.1.1.3 Capability of the model : flow / flow and water quality

HYSAM is a water quality model and is provided with all hydrologic inputs and the time duration during which these hydrologic inputs occurred. Table 4 lists the various flow and water quality inputs to the model.

4.1.1.4 Simulation time step

As previously stated the HYSAM can be used to simulate salt fluxes at any time step. Most applications of the model have utilized an annual time step. The San Luis Drainage Program utilized the model to investigate the potential harmful effects of the long term application of drainage reduction practices such as drainage recycling on root zone salinity. The assumption made to convert the steady-state model to a transient model was that the final root zone salt concentration at the end of one irrigation season is the initial root zone salinity at the beginning of the next season.

4.1.1.5 Computer requirements and portability

The original version of the HYSAM was written for the Macintosh computer in BASIC. The model has been modified to run on IBM compatible computers and translated to the FORTRAN language. The computer code is completely portable.

4.1.2 Model development

4.1.2.1 Reasons for development of the model

Recent modifications to the HYSAM were made to provide an independent means of estimating the transients in root zone salinity predicted by the WADE model. The WADE model was used by Reclamation to evaluate the impacts of various drainage control and reduction policies on agricultural production and drainage flow and quality. Re-running the WADE Model using the output from the IRDROP Model would have required setting constraints on many of the parameters normally chosen by the WADE Model and would have been a time consuming activity. The comparative simplicity of the HYSAM Model, its fast execution time and its capability to account for gypsum concentrations made it a good choice of model for the purpose.

4.1.2.2 History of development and use of the model

The original steady-state model (HYSAM) was developed by Tanjii and Aragues (Aragues et al., 1990) to perform hydrologic and salinity mass balances of the Violada Irrigation District in Spain. The model was later modified by Quilez to improve the salinity balance algorithms of the model (Quilez, written communication, 1988). CH2M-Hill modified the model for use in evaluating drainage reduction and management plans for the San Luis Unit, in the San Joaquin Valley. The model has also been used to evaluate irrigation practices at agroforestry sites and to determine the required annual leaching requirement to prevent salt accumulation in the root zone of eucalyptus trees.

Table 4. **Input data values for the HYSAM model. When HYSAM is linked with the WADE model, the land area and the drainage water volume are fixed by the WADE model simulation. The HYSAM model calculates equilibrium salt concentration in the root zone.** (Source : Dickey, 1991)

Variable	Meaning	Units	Value Used to Model Drainwater and Salt Flows
AA	Surface Area	ha	Total fixed by Wade model simulation. For each year, divided among 4 ECe levels.
c	Eff. Prec. Coef.	ha-m/ha-m	0.5, an approximate weighted average for Westlands.
Cdiw	TDS of Diverted Irr. Wat.	mg/l	250.
Clat	Concentration of Lateral Flow	mg/l	0.
Cp	TDS of Precipitation	mg/l	10.
Cptw	Salt Pickup by Tailwater	mg/l	1.
Crim	TDS of Rim Inf./Outfl.	mg/l	0.
Csppr	Salt Pickup of Prec. Runoff	mg/l	1.
Db	Soil Bulk Density	g/cm3	1.4
Dr	Ave. Rooting Depth	m	6 feet, an approximate weighted average for Westlands.
Dwhc	Unit Water Hold. Cap.	m/m	Total porosity, assumed to be 0.47.
ECe	EC of Soil Sat. Paste Extract	dS/m	Modeled from an initial value.
ECgw	ECw of Shallow Groundwater	dS/m	Modeled from an initial value.
f	Deep Percolation Coef.	ha-m/ha-m	The amount of water percolating past the drains. This was assumed 0.1 acre-foot/acre, and f=0.1/(0.1+fm*drain flow).
fm	Rootzone Portion of Drainflow	ha-m/ha-m	Assumed to be 0.8, or 20% of drain flow contributed by existing shallow groundwater.
Gypsum	Gypsum in Rootzone	MT/ha	Modeled from an initial value.
Initec	Initial Salinity	dS/m	See Table 2.
Initgw	Initial Shallow GW ECw	dS/m	See Table 2.
Initgypp	Initial Rootzone Gypsum	MT/ha	See Table 2.
Qdiw	Diverted Irr. Wat.	ha-m	Qet - e*Qp + (fm*FLOW+0.03048)*AA, to force drainflow to equal FLOW plus contribution from shallow groundwater. Assumes 0.1 a-f/a percolates past drains.
Qet	Evapotranspiration	ha-m	2.31 acre-feet/acre, an approximate weighted average for Westlands.
Qfsw	Final Stored Soil Water	ha-m	0.25 inch per inch.
Qisw	Init. Stored Soil Water	ha-m	0.25 inch per inch.
Qlat	Lateral Influx of Water	ha-m	0.
Qp	Precipitation	ha-m	AA*(annual precipitation of 0.6 ac-ft/ac).
Qpet	Pot. Evapotranspiration	ha-m	Assumed 5.51 acre-feet/acre.
Qrim	Rim Inflow/Outflow	ha-m	0.
Qsdw	Drainage Water Volume	ac-ft/ac	Fixed by Wade model simulation.
Sp	Saturation Percentage	g water/g soil	0.8
year	Year Modeled	na	Year number.

4.1.2.3 Further development of the model and intended future use

The HYSAM has been used for a number of conceptual studies by Ken Tanjii and his graduate students in the Land, Air and Water Resources Department at U.C. Davis. Plans for future development of the model are unknown at this time.

4.1.3. Evaluation of the model

4.1.3.1 Predictive capability and model reliability

The model employs a simple mass balance algorithm for determining salt balance within the root zone and hence is as reliable as the data used to calibrate the model. The comparative simplicity of the model makes it easy to follow the computational logic and eliminate data entry errors.

4.1.3.2 Data requirements

The model requires data on all sources of water to the crop root zone and all sinks that extract water from the crop root zone. Major water sources include precipitation, applied irrigation water, groundwater, flow into the system, recycled drainage and water in storage. Major water sinks include evaporation, transpiration, deep percolation and subsurface drainage. Lateral groundwater flow can be either a source or a sink. Each of the sources and sinks is assigned a salt concentration.

4.1.3.3 Model outputs

The primary output variable is the salinity of the crop root zone.

4.1.3.4 Ease of calibration and performing model runs

HYSAM can be run interactively or can read from a data input file. CH2M-Hill calibrated the HYSAM with predicted drainage flows obtained from the WADE model. The volume of diverted irrigation water was calculated within the model such that the WADE model drainage prediction was matched for each major subarea. The irrigation efficiency and the leaching fraction were the calibration variables used.

4.1.3.5 Relative expense of using and maintaining model

A 50 year simulation on an IBM - 486 33 Mhz computer takes less than one minute to run .

4.1.3.6 Ease of linking with other models

The model is relatively simple and it would not be difficult to link it to another hydrologic model. For example, the model could be used with the SANTUCM (assuming the salinity module is completed by the model's original developer) or with the SJRIO-2 model to develop salt budgets within the semiconfined aquifer and to determine long - term salinity levels of accretions to the San Joaquin River. The HYSAM may also be

used with the NRWS Grasslands Model to help develop salinity budgets for managed wetlands and agricultural lands within the Grasslands area.

4.1.3.7 Previous peer review

The HYSAM has been published and peer reviewed in journal articles (Aragues et al, 1990).

4.1.3.8 Model deficiencies and how these are being addressed

The model is conceptually simple and has no obvious deficiencies. The model serves the purpose for which it was developed.

4.1.4 Utility of the model for Reclamation planning studies

4.1.4.1 Actions to meet water quality objectives in the San Joaquin River

The model cannot be used by itself to make this type of study. However the HYSAM can be used in combination with models such as the WADE model or the IRDROP model to improve the accounting of salts within each of the agronomic and hydrological areas defined by the models. The HYSAM could also be used in combination with the SJRIO-2 model to simulate potential changes in the chemistry of the shallow groundwater aquifer and hence the quality of groundwater accretions to the San Joaquin River.

4.1.4.2 Salt balance in the San Joaquin Basin

Because the HYSAM is a simple mass balance model it can used for either field scale or regional scale analysis of salt fluxes. The model was successfully calibrated with hydrologic and salinity data from the Panoche Water District (Tanjii et al., 1977). The model was modified by CH2M-Hill to run sequentially and hence simulate long term average drainage flow and quality from an area of irrigated, artificially drained land over a 50 year period.

4.1.4.3 Drainage reduction policies and planning

The model was used by CH2M-Hill in their examination of drainage management options for Westlands Water District and the agricultural water district that comprise the remainder of the San Luis Unit. The IRDROP and WADE model outputs for drainage flow and salinity were compared to results obtained from the HYSAM for the purpose of verifying the trend of the results produced by the two less-detailed mass balance models.

4.1.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

The model does not predict groundwater flow or the effect of groundwater pumping and treats them both as inputs. The model could be linked to other models such as the CVGSM or the SANTUCM, neither of which are currently capable of performing salinity mass balances, as long as there exists sufficient information on the

depth distribution of water quality in both the shallow and deep groundwater aquifers. Information on the deep aquifer is of importance if the quality of groundwater pumpage is an important component of the overall salinity mass balance.

4.1.4.5 Structural options to control stage and water quality in the South - Delta

Although the model is not directly relevant to this analysis it may have value if it can be used to improve predictions made by models such as the IRDROP and the SJRIO-2 models. These models help in prediction of the monthly salt load reaching Vernalis prior to reaching the South Delta.

4.1.5 Overall assessment and recommendations

The HYSAM is a conceptually simple, easy to use model of salt fluxes in the crop rooting zone and the shallow groundwater aquifer. The model has been used in place of the WADE salinity model to evaluate the long-term potential for drainage reduction scenarios, such as the combination of water table management, drainage recycling, temporary storage and discharge to the San Joaquin River, as suggested by the San Luis Drainage Program. The model has also been used to evaluate leaching requirements for eucalyptus plantations in the San Joaquin Valley with applied water of various salt concentrations. The model has been implemented on Macintosh and IBM - compatible personal computers and on an Apollo workstation. The execution time of the model is fast and the model interface allows the user to conduct sensitivity analysis studies quickly and inexpensively.

4.1.6 References

Aragues, R., K.K. Tanjii D. Quilez and J.Faci, 1990. Conceptual irrigation return flow hydrosalinity model. In : Agricultural Salinity Assessment and Management. ASCE, New York.

Dickey, J. 1991. Technical memorandum. Draft Report, San Luis Drainage Program. U.S. Bureau of Reclamation, Sacramento, CA.

U.S. Bureau of Reclamation, 1991. Alternative Plans Report. San Luis Drainage Program. U.S. Bureau of Reclamation, Sacramento, CA.

4.2. TOUGH2-DSM (Drainage simulation model)

4.2.1 General description and purpose of model

The TOUGH2-DSM (Transport of Unsaturated Groundwater and Heat- Drainage Simulation Model) is a case specific application of the numerical simulation code TOUGH2, which was developed at Lawrence Berkeley Laboratory to simulate the coupled transport of groundwater, air and heat in porous and fractured media (Pruess, 1987;1991). Fluid flow in the generic TOUGH2 code is based on a multiphase form of Darcy's law with relative permeability and capilliary pressure of the porous medium, given as functions of phase saturation. Although the TOUGH2 code was designed for geothermal and reservoir engineering applications, and is generally considered a tool for scientific rather than engineering investigations, the generality, versatility and acceptance of the code make it useful as a standard against which to compare other simulation models.

The TOUGH2-DSM application is to assist in the conceptual design of new drainage systems and in the retrofit design of existing drainage systems to control the flow of salts and certain trace elements into the tile drains. Controlled drainage can be achieved by a number of methods. Two of the most effective of these methods are (a) the installation of tile drains at shallower depths and closer drain spacings and (b) the installation of in-line weirs or other flow control devices (Figure 43). The model is being used to investigate and contrast the effect of each of these methods on flow and annual contaminant loads from the tile drains.

4.2.1.1 Geographic extent of the model

The TOUGH2-DSM considers a two-dimensional cross section of the unconfined or semiconfined aquifer between subsurface drains. The TOUGH2-DSM considers a single tile drain, located on the right boundary of the model grid, and a left boundary located a distance equivalent to half the typical drain spacing from the right hand boundary (Figure 44). Streamlines into the tile drain are assumed to be symmetrical on either side of the tile drain - hence actual drain flow from each drainage lateral is twice the simulated value. The model simulates an aquifer cross section (Y and Z directions) and assumes a model thickness of 1 meter in the X direction.

4.2.1.2 Features of model

The TOUGH2 model, used to construct the TOUGH2-DSM, is a two phase, multicomponent heat and mass transport code that has recently been augmented with brine and dispersion modules capable of modeling the migration of dissolved salts to tile drains (Oldenberg and Pruess, 1993). The TOUGH2 model is very versatile and can be used to study a wide variety of multiphase (unsaturated) hydrogeological and reservoir engineering problems. However, this generality also places more demands on the model user to make correct choices of model boundary conditions and functional relationships between liquid saturation and parameters such as relative permeability and capillary pressure.

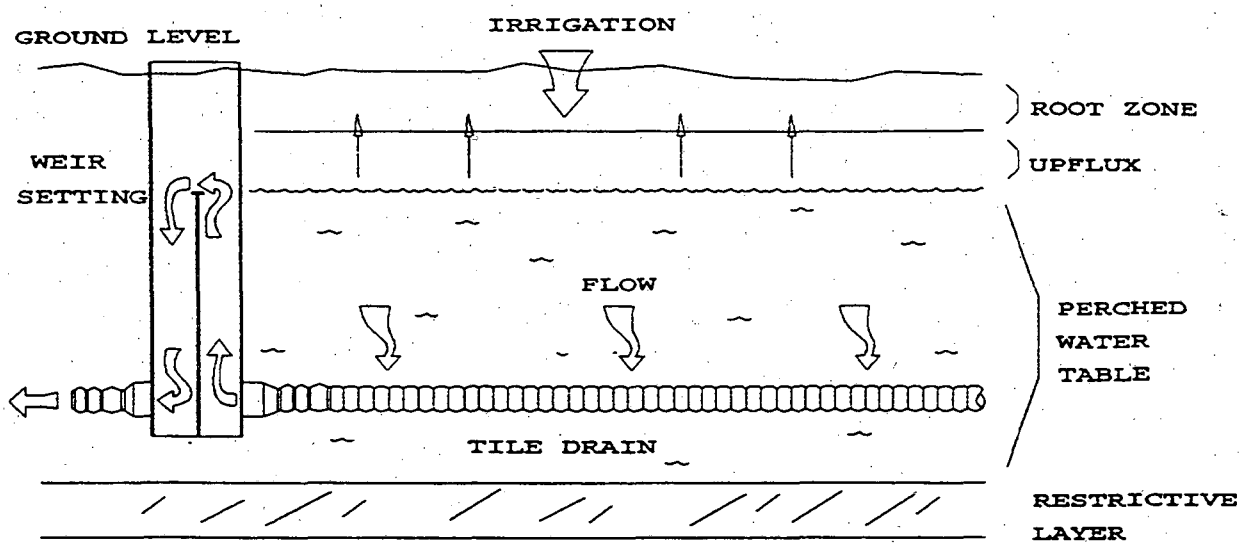


Figure 43. **Cross sectional diagram of water table management using a DOS-IR valve with an adjustable weir. Raising the weir setting reduces tile drainage flow and keeps water table close to the soil surface for a longer period of time. This permits greater upward capilliary flow and allows the crop to take advantage of this moisture. Careful management of salts in the rooting zone is important if crop yields are to be sustained.**

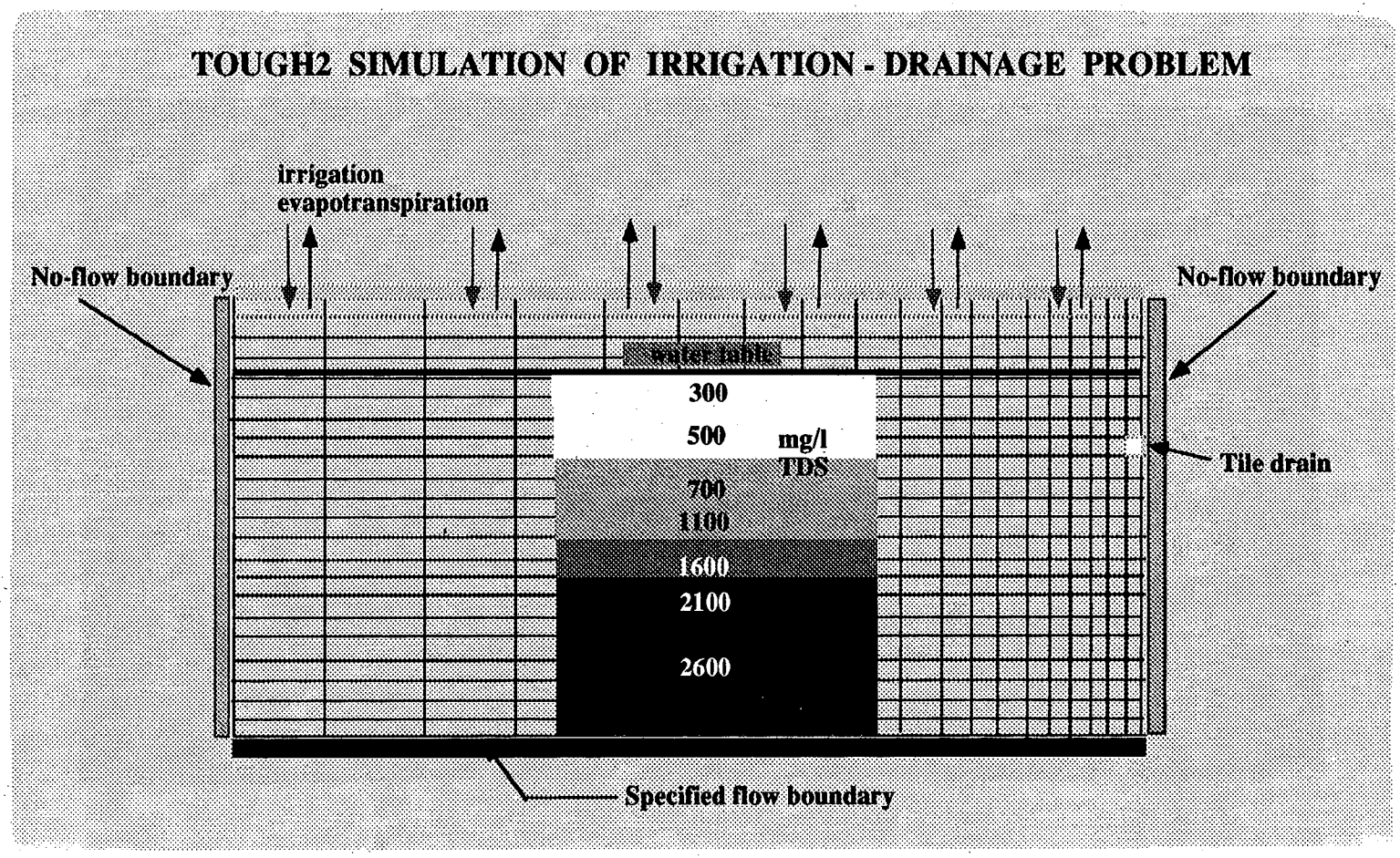


Figure 44. Cross - sectional diagram of the DSM using the LBL TOUGH2 model. The top grid layer of the DSM is an air reservoir. Irrigation recharge and evapotranspiration occur in the second grid layer; the tile drain is located 2 meters below the ground surface in the ninth vertical grid block on the right side model boundary. The shallow aquifer is assumed to be stratified with respect to salts as shown in the diagram.

The TOUGH2-DSM utilizes a two-dimensional flow field in the Y and Z directions, the specification of zero flow at the right and left hand boundaries, a seepage face for a portion of the right hand boundary, and a specified flow condition at the top boundary corresponding to irrigation or evaporation and a no-flow condition at the bottom boundary (Figure 44). Initial salt concentrations within the aquifer in the TOUGH2-DSM are assigned fractional values with respect to a reference salt concentration of 20,000 ppm TDS, which has a value of 1.00 in TOUGH2-DSM.

4.2.1.3 Capability of the model : flow / flow and water quality

The TOUGH2-DSM is a two dimensional solute transport model and considers flow of dissolved salts through the regional aquifer into a tile drain. Transport is by hydrodynamic dispersion and advection including the effects of the dissolved salts on liquid phase density.

4.2.1.4 Simulation time step

The time step size is automatically determined such that it is the maximum possible size that permits solution within a pre-specified number of iterations and error tolerance. The user can specify the frequency with which output is produced by the simulation model. This is typically done by providing the elapsed time after which each output is produced.

4.2.1.5 Computer requirements and portability

The TOUGH2-DSM simulates flow which includes dispersion, fluid density and fluid viscosity effects within a porous media and is very demanding of computer time. The current TOUGH2-DSM model should be limited to mainframe computers, RISC-based computers or supercomputers. The TOUGH2-DSM currently takes approximately 1 hour of CPU time on a CRAY YMP to run a 1 year irrigation and drainage simulation.

4.2.2 Model development

4.2.2.1 Reasons for development of the model

The TOUGH2-DSM was developed to allow the extrapolation of results from a drainage experiment, originally conducted in the Fallon Irrigation District in Nevada, to sites in the western San Joaquin Valley experiencing drainage problems. The experiments at the Fallon Irrigation District were initiated to test the short-term effect on water quality of reducing the depth of agricultural tile drains. Hence the model will help to determine the aquifer conditions under which an investment in water table control technologies might result in a marked improvement in drainage water quality. The model may also help in devising operating strategies for the use of these technologies to minimize the load of salts and trace elements in drainage return flows.

4.2.2.2 History of development and use of the model

The TOUGH2-DSM is still under development. When completed it will be the first application of the the TOUGH-2 code to an agricultural drainage problem.

4.2.2.3 Further development of the model and intended future use

The TOUGH2-DSM may be of most future utility in verifying other more conceptually simple and faster - running solute transport codes. The TOUGH2-DSM model is too cumbersome and its computer requirements are too great for it to be useful as a design tool. A solute transport model has been developed at Colorado State University which considers flow in the unsaturated zone in one dimension and flow in the saturated zone (below the water table) in two dimensions. This model may have great potential as a substitute for the TOUGH2-DSM since the Colorado State University model should run 10 to 20 times faster. Computation of flow and solute transport in the unsaturated zone is more time intensive than when performed for the saturated zone. This model will be built with a graphic user interface on the Data General AViiON workstation and may be available for evaluation in the Fall of 1993.

4.2.3.0 Evaluation of the model

4.2.3.1 Predictive capability and model reliability

This has yet to be evaluated.

4.2.3.2 Data requirements

The TOUGH2-DSM requires information on the quantity and timing of surface applications of irrigation water and detailed data on aquifer geohydrological properties to a depth of 20 meters below the ground surface. Cropping data and average daily evapotranspiration data are also required, in addition to water table data, to determine hydrologic balances of the shallow semiconfined aquifer. The depth distribution of salt or any other trace element of study must also be provided.

4.2.3.3 Model outputs

The model predicts water table elevations and the flow and TDS concentration of tile drainage water at a reporting interval chosen by the analyst. Primary variables pressure, gas saturation and mass fractionalong with secondary variables (e.g. density, capilliary pressure) are also output at each nodal point in the model domain.

4.2.3.4 Ease of calibration and performing model runs

The current TOUGH2-DSM is handicapped by the time it takes to make runs. The modular structure of TOUGH2 and the data structures that has been created for model input facilitate understanding and make it

relatively easy to make changes to the data and set up model runs. Model calibration has not yet been completed for the Fallon site.

4.2.3.5 Relative expense of using and maintaining model

The model is very expensive to use in its present form owing to the time it takes to run. The TOUGH2-DSM currently takes more than 1 hour of CPU time on a Cray YMP to perform an annual simulation using the Fallon data. Simplification of the current model by reducing the number of phases to one and neglecting hydrodynamic dispersion would reduce model execution time considerably.

4.2.3.6 Ease of linking with other models

Linkage with other models may be unrealistic owing to the slow execution speed of TOUGH-DSM. However, the model could potentially be used to calibrate the drainage equations in the WADE and IRDROP models for a number of specific aquifer conditions. These conditions might include different salinity profiles in the semi-confined aquifer; a number of different tile depth and tile spacing designs; and a range of semiconfined aquifer heterogeneities.

4.2.3.7 Previous peer review

The TOUGH2-DSM has not been peer reviewed. However, the TOUGH and TOUGH2 codes have been extensively verified and validated (Moridis and Pruess, 1992; Pruess, 1987).

4.2.3.8 Model deficiencies and how these are being addressed

The major deficiency of the current model is its slow execution time. Simplifications of the model will help to address this problem and conjugate gradient iterative solvers are aslo to being implemented to speeed solution of the dispersion equations at the present time. Adoption of the Colorado State University solute transport model is an alternative to the continued use of the TOUGH2-DSM - this alternative model will be evaluated when made available in the Fall of 1993.

4.2.4 Utility of the model for Reclamation planning studies

4.2.4.1 Actions to meet water quality objectives in the San Joaquin River

The model cannot be used directly for this analysis. However, the model can be used to improve prediction of drainage flow and salinity in the WADE and IRDROP models, previously described.

4.2.4.2 Salt balance in the San Joaquin Basin

The model can be used indirectly, as described above, to improve regional estimates of salt export from the drainage basin.

4.2.4.3 Drainage reduction policies and planning

The TOUGH2-DSM model can be used directly to evaluate the potential for improvement of drainage water quality through installation of shallow drainage systems or through in-line weirs and other water table control technologies. The model can also be used, as stated above, to improve the predictive capability of WADE and IRDROP models.

4.2.4.4 Surface and ground water conjunctive use planning in the San Joaquin Basin

The model is not relevant to this study,

4.2.4.5 Structural options to control stage and water quality in the South - Delta

The model is not directly relevant to this study, although it can be used indirectly to improve drainage predictions in the IRDROP model, which, in turn, can be linked to Delta hydrodynamic flow and salinity models to make this type of analysis.

4.2.5 Overall assessment and recommendations

The TOUGH2-DSM can be used to calibrate the drainage and hydrosalinity equations within the WADE and IRDROP models. The model may also be useful in calibration of more simple models that simulate unsaturated - saturated zone interactions and the transport of salts to subsurface tile drains. Linkage of this model with other hydrosalinity models is not appropriate at the present time because of the large amount of time it takes to make model runs. Simplifying the model by assuming strictly advective flow without dispersion would not seroiusly affect its utility for the analysis of contaminant flow into tile drains and would significantly increase the speed of execution. The model will continue to be developed unless it is determined that the Colorado State University solute transport model is superior, after it has been evaluated.

4.2.6 References

Oldenburg C.M. and K. Pruess. 1992. A Two-Dimensional Dispersion Module for the TOUGH2 Simulator. Lawrence Berkeley Laboratory Report, LBL-32505.

Moridis G.J. and K. Pruess 1992. TOUGH Simulations of Updegraff's Set of Fluid and Heat Flow problems. Lawrence Berkeley Laboratory Report, LBL-32611.

Pruess K. 1991. TOUGH2. A General Purpose Numerical Simulator for Multiphase Fluid and Heat Flow. Lawrence Berkeley Laboratory Report, LBL-29400.

Pruess K. 1987. TOUGH Users Guide. Lawrence Berkeley Laboratory Report, LBL-20700.

5. DEVELOPMENT OF DECISION SUPPORT SYSTEMS

5.1 Introduction

This section discusses the importance of user interfaces in creating decision support systems from models, such as those described in this review. Decision support systems can be developed by linking existing databases and simulation models, by making databases more accessible and models easier to understand, and by enhancing the capability of these existing models to explore more creative solutions to problems. Linkage of relevant models and the creation of graphical user interfaces to these models can lead to a more comprehensive analysis of a particular issue and can increase the efficiency with which the analysis is performed. A good user interface limits dialog with the analyst to modify those factors or model parameters that are most important in making decisions or which have the greatest impact on model results. A necessary capability of a good user interface is graphic display of output in a form that provides an appropriate level of information for making decisions without overwhelming the analyst with unnecessary detail.

5.2 Graphic User Interfaces

Of the models selected in this review only four have graphic user interfaces. With the exception of the SDCASS user interface, developed by John DeGeorge at U.C. Davis for post-processing of results from the RMA link-node model, and the CVGSM post-processing software, all of these systems are still under development. The user interfaces under development are being constructed on different platforms: the NRWS, which currently runs on the SUN workstation, is being ported to the DataGeneral AViiON; the GWSDN-STELLA model (described briefly in Section 3.1) is implemented using the high end language STELLA, which is currently available on the Macintosh only; the SDCASS, currently available on the MacIntosh will soon be available on IBM compatible computers. The CVGSM postprocessing software on the IBM-PC allows flow and water table hydrographs to be plotted directly from output data files and supports contouring of water level data. This post-processing software is not transportable to other computer systems. The marriage of user interfaces to particular computer system causes difficulties in making linkages between some of the models summarized in this review. Graphics development software packages have yet to be developed that allow graphics based user interfaces to work on more than one system.

There is a current initiative within Reclamation to move existing models from mainframe and IBM compatible computers to Unix- based workstations. The DataGeneral AViiON workstation offers advantages of superior speed and built-in graphics libraries that aid the development of user interfaces for models. Co-processor cards and software emulators are being perfected which will allow those simulation models, that currently run only on MS-DOS or Macintosh -, based systems, to be run within a window on the AViiON workstation. This will eliminate the need for software conversion between systems, which is a costly procedure and which invariably results in competitive versions of the same decision support system.

Factors that should be considered in future development of decision support systems and graphical user interfaces on the DataGeneral AViiON workstations and other platforms within Reclamation are :

- o Standardization of graphic input and output formats for all models
- o Modular design of interfaces that allow its application to more than one model. For example menus developed for the CVGSM could also be used by the groundwater submodel of the SANTUCM. Elements of the Delta Graphical User Interface (DGUI), currently under development for the DWR-Delta Simulation Model could also be applied to the Natural Resource Workstation (NRWS).
- o Selection of alternative input and output formats that allow linkage to geographic information systems such as GRASS or ARC-INFO that allow seamless linkage to other models. This has been addressed in the NRWS modeling effort being conducted for the USBR by Colorado State University.
- o Selection of optimization modules for use with river basin models such as the SANJASM, the SANTUCM and the CVGSM that allow projections to be made of parameters such as reservoir releases or groundwater pumping based on economic or policy considerations. Tabios and Shen (1993 - in review) have recently completed a dynamic optimization module for the USBR PROSIM model, a water allocation model for the Sacramento Valley, similar in concept to the SANJASM. This module allows the evaluation of current rules that decide operations of Shasta, Clair Engle and Fulsom reservoirs by comparing the performance of current rules with the optimal strategy, given perfect foresight of future reservoir inflows. This module also permits optimal operating rules to be evaluated where the relative weightings of power revenues, penalties for allocation shortfall to water contractors and fish release constraints are adjusted.

  Optimization methods have also been developed for error minimization purposes to assist in model calibration. These could be used with those models where sufficient historic data is available for calibration purposes.
- o Modules containing stochastic data generators using techniques such as the Monte Carlo method to increase the variety of conditions simulated by the model. A module has been constructed for the SANJASM to provide the SJRIO-2 model with a 250 year time series of tributary inflow data and to the allow the construction of probability of exceedance statistics for water quality at the Vernalis gauging station.

5.3. Linkage of existing models

A conceptual organization of decision support models into a number of "workstations is presented in Figure 45. Each of the four workstations shown contain models and decision support systems relevant to the themes of (a) drainage and salinity; (b) surface water and groundwater flow; (c) surface and groundwater data management and access; and (d) geographic information display and analysis. These workstations have been named, in order: the Drainage Workstation (a), the Planning Workstation (b), the Groundwater Workstation (c) and the GIS Workstation (d). The GIS Workstation is shown in the centre of the other three workstations (Figure 45) because of its role in facilitating information exchange between the various models residing on the other workstations. Linkage of model databases is the primary first step in being able to perform integrated analyses of planning decisions, proposed changes to existing structures, newly

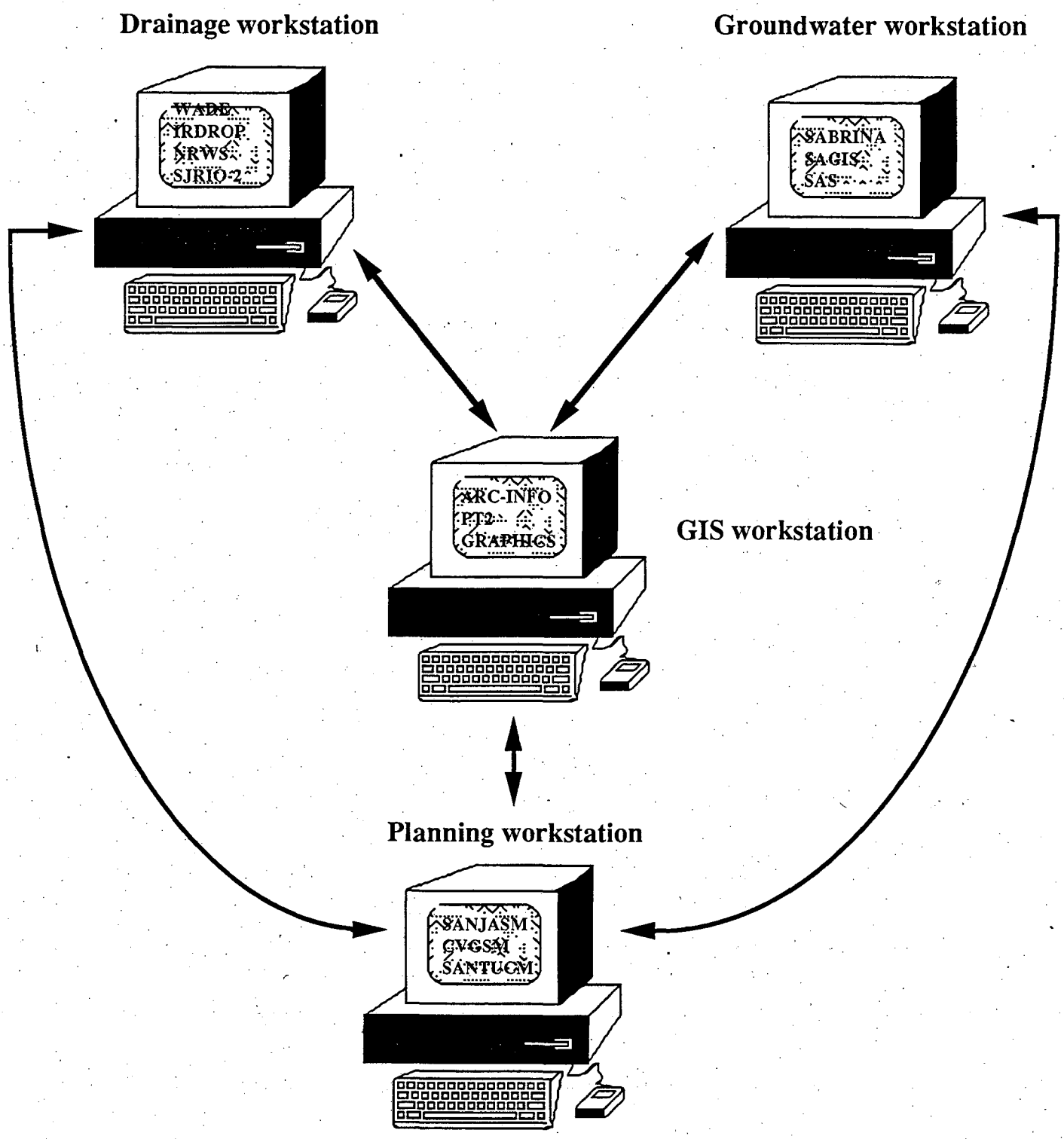


Figure 45. Conceptual organization of decision support system tools within Reclamation into a number of networked workstations. Each workstation can access any of the models, data and applications on the other workstations. The GIS workstation is central to each of surrounding workstations, providing a repository of all geographic data and providing data processing capability.

promulgated water quality objectives or criteria and other actions that might perturb the existing hydrological and geochemical environment in the San Joaquin Valley. The second step is linkage of the various computer-based simulation models and decision support systems residing on each of the Workstations. This will be more challenging since, in most cases, each model or decision support system was developed for a different purpose. Existing models may need to be broken down into modules or, at a later stage recreated as "objects". (Computer languages and database management systems have been created that treat data, equations and heuristics as objects - this promises to revolutionize the way computer modeling is performed in the future and will have a profound effect on model integration). Analysis of a particular problem or event may be performed by linking these self contained modules (or assembling these "objects" on a computer screen) and then creating a linkage with a database to provide initial conditions and parameter values for each model.

The first step of this model integration and linkage process has been started with the development of GIS-based database and trend analysis software. Two products, SAGIS and SABRINA, are being developed for the Groundwater Workstation, described below, which will allow display and analysis of surface water and groundwater data for both the San Joaquin and Sacramento Valleys. On the Drainage Workstation a GIS-based database and trend analysis package, PT2, has been implemented with data and coverages for the Grasslands drainage basin on the west side of the San Joaquin Valley. The GIS is a useful tool for model linkage where (a) the data associated with the model can be associated with geographic areas and (b) in instances where the data values remain relatively constant over time periods of a week or more. Examples of data which lend themselves to representation in a GIS are land use, water table elevations, groundwater salinity or groundwater trace element concentrations. Other data, not as readily displayed as maps or GIS coverages, may be associated with these features as linked attributes. These attributes may also be shared by different models and across workstations.

The following sections describe the models currently in place on the Drainage, Planning and Groundwater Workstations. The GIS Workstation is the repository of all the generalized coverages and INFO databases that contain information on such themes as the land use, geology, hydrology and geochemistry of the San Joaquin and Sacramento Valleys. The ARC-INFO software package is used to make all GIS data manipulations and to perform GIS modelling on the GIS Workstation. The list of dedicated workstations may expand to include a Fisheries Workstation and an Economics Workstation in the near future.

5.3.1 The Drainage Workstation

The Drainage Workstation contains a series of models , specifically chosen for the analysis of issues and actions that affect the hydrology and water quality of subsurface drainage within the San Joaquin Valley. Figure 46 illustrates the important models and decision support systems that currently reside on the Drainage Workstation and examples of typical data transfer between these models. External communication with the Planning Workstation occurs for access to the SANJASM and the CVGSM, where these models reside.

Linkage of models within the Drainage Workstation is best described using an example. A sequence of steps designed to improve timing of subsurface discharges to the San Joaquin River is illustrated in Figure 47. This sequence

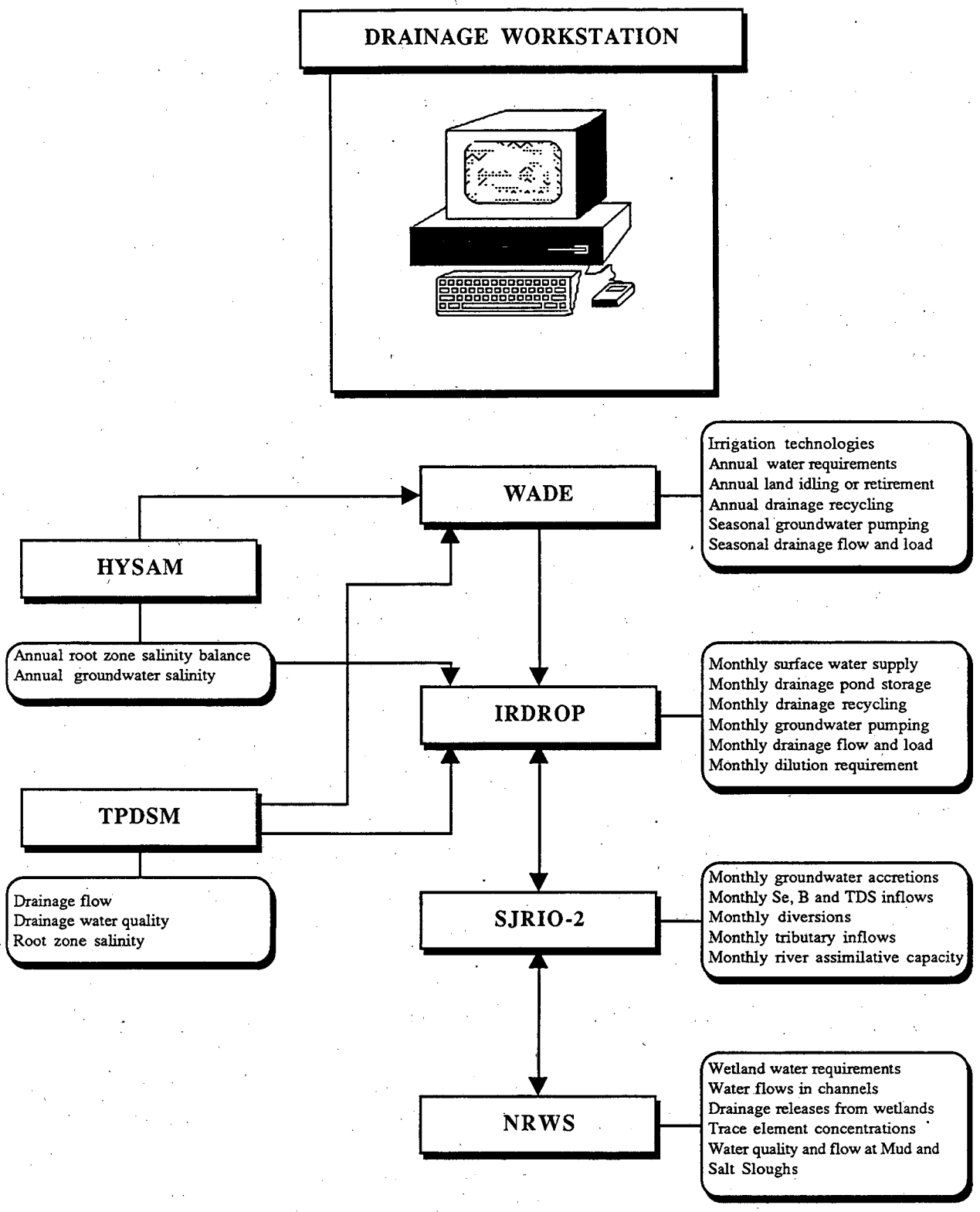
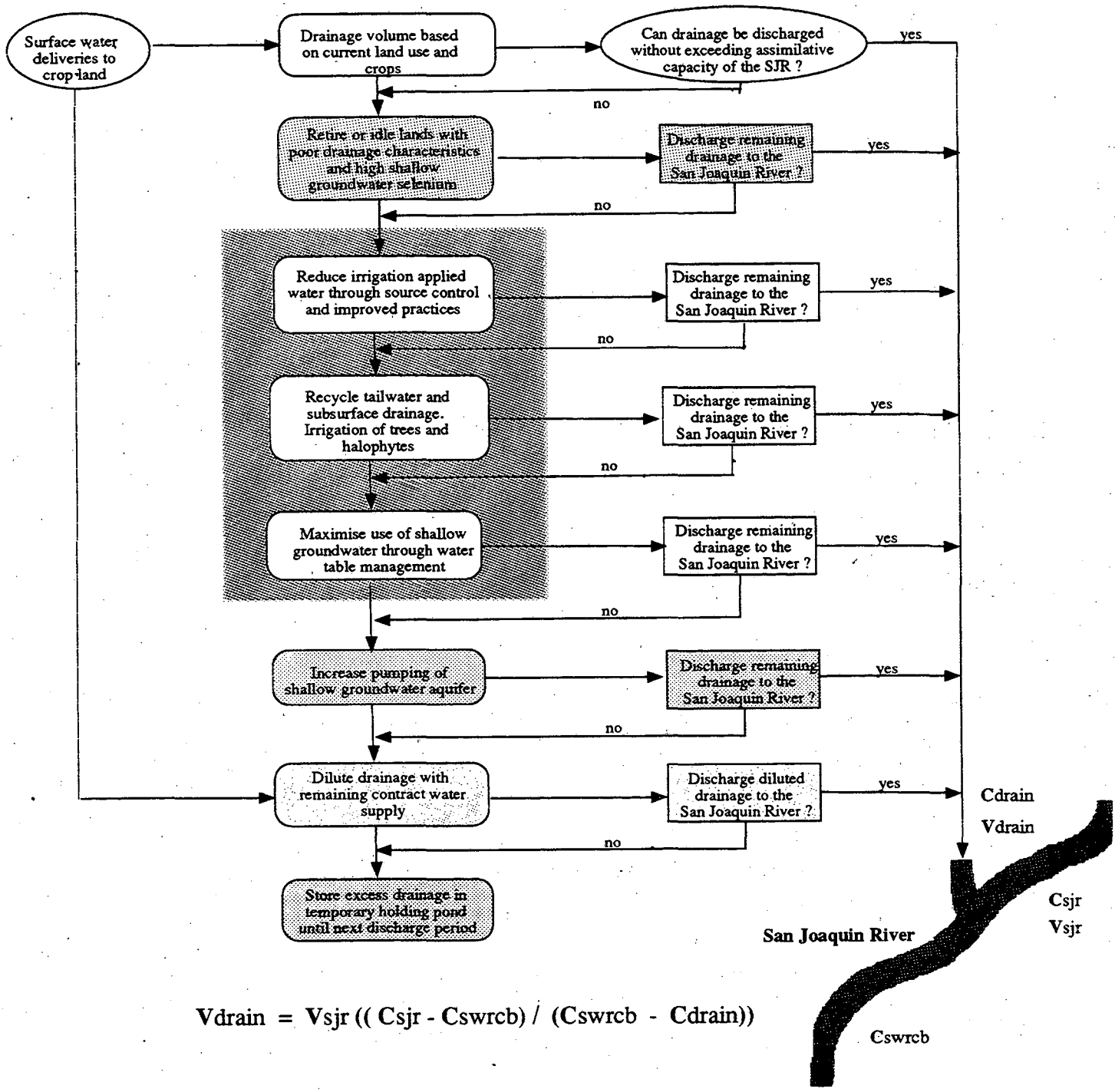


Figure 46. **The important computer-based simulation models and decision support systems available on the Drainage Workstation. Linkages between these models and these decision support systems are shown.**



$$Vdrain = Vsjr\,((Csjr - Cswrcb) / (Cswrcb - Cdrain))$$

Figure 47. **The sequence of operations and decisions that need to be made in managing drainage discharges to the San Joaquin River, ensuring compliance with SWRCB water quality objectives and optimizing opportunities for salt export from agricultural water districts in the Grasslands Basin. This sequence is based on the plan formulation methodology adopted by the San Joaquin Valley Drainage Program.**

is based on the planning methodology adopted by the San Joaquin Valley Drainage Program during the development of a long term management plan for the Grasslands Basin. Projections of drainage volume and constituent load based on the costs of agricultural production can be made with the WADE model. The WADE model can provide generalized projections of levels of land idling and retirement, groundwater pumping, irrigation and drainage technology investment and drainage recycling based on constraints placed on allowable drainage production from each water district (roughly matched with model polygons) or from multiple water districts that discharge drainage through the Grasslands Basin to the San Joaquin River. Refinement of each of these components on a monthly basis can be made with the IRDROP Model, once the amount of retired land, available water for dilution purposes and irrigation water requirements have been set by the WADE model. Thus, linkage between the two models would provide a more comprehensive decision tool by combining the forecasting capability of the WADE model with the operations planning capability of the IRDROP model.

Routing of surface water and drainage flows through the Grasslands area will be permitted once the Natural Resources Workstation (NRWS) has been successfully implemented on the Drainage Workstation. Estimated monthly selenium removal in transit through the network of Grassland channels and ditches may be determined using either the NRWS or the GWSDN-STELLA model (described briefly in Section 3.1. Interative solution of the IRDROP model and the NRWS will help to further refine the estimates of selenium losses and correct target drainage flow loading to meet monthly mean assimilative capacity in the San Joaquin River. Monthly projections of San Joaquin River assimilative capacity might be derived from past records of San Joaquin River flows during different classifications of the water year. Water year type typically ranges from wet to critically dry.

At present the IRDROP model runs on a monthly timestep - hence the model cannot be used to develop daily or weekly targets for drainage loading to the San Joaquin River. The model will need further development to run with shorter timesteps if it is to be useful to water districts for making daily or weekly operations decisions to take advantage of real-time gaged and forecasted river flows. Data processing software for converting the information from telemetered water quality sites on the San Joaquin River to estimates of daily assimilative capacity also needs to be developed. The hydrodynamic version of the current SJRIO-2 model, currently being developed by Leslie Grober at U.C. Davis, could be adapted to estimate these daily assimilative capacities for selenium, boron and TDS. Iterations of the IRDROP and hydrodynamic SJRIO-2 model might be required, depending on the short-term options chosen for drainage load management, to ensure compliance with water quality objectivesin the San Joaquin River.

A schematic of how this system might be constructed is shown in Figure 48. The models shown in the box on the right of the diagram in Figure 48 perform various functions including data reduction, analysis and process simulation which terminate in a set of recommended actions. These steps are performed sequentially, as follows:

(a) pre-process real time data from telemetry stations;

(b) perform the time series analysis of flow and electrical conductivity;

(c) perform seasonally-based multiple regression analysis to calculate boron and selenium concentrations;

(d) determine in stream assimilative capacity for the limiting constituent;

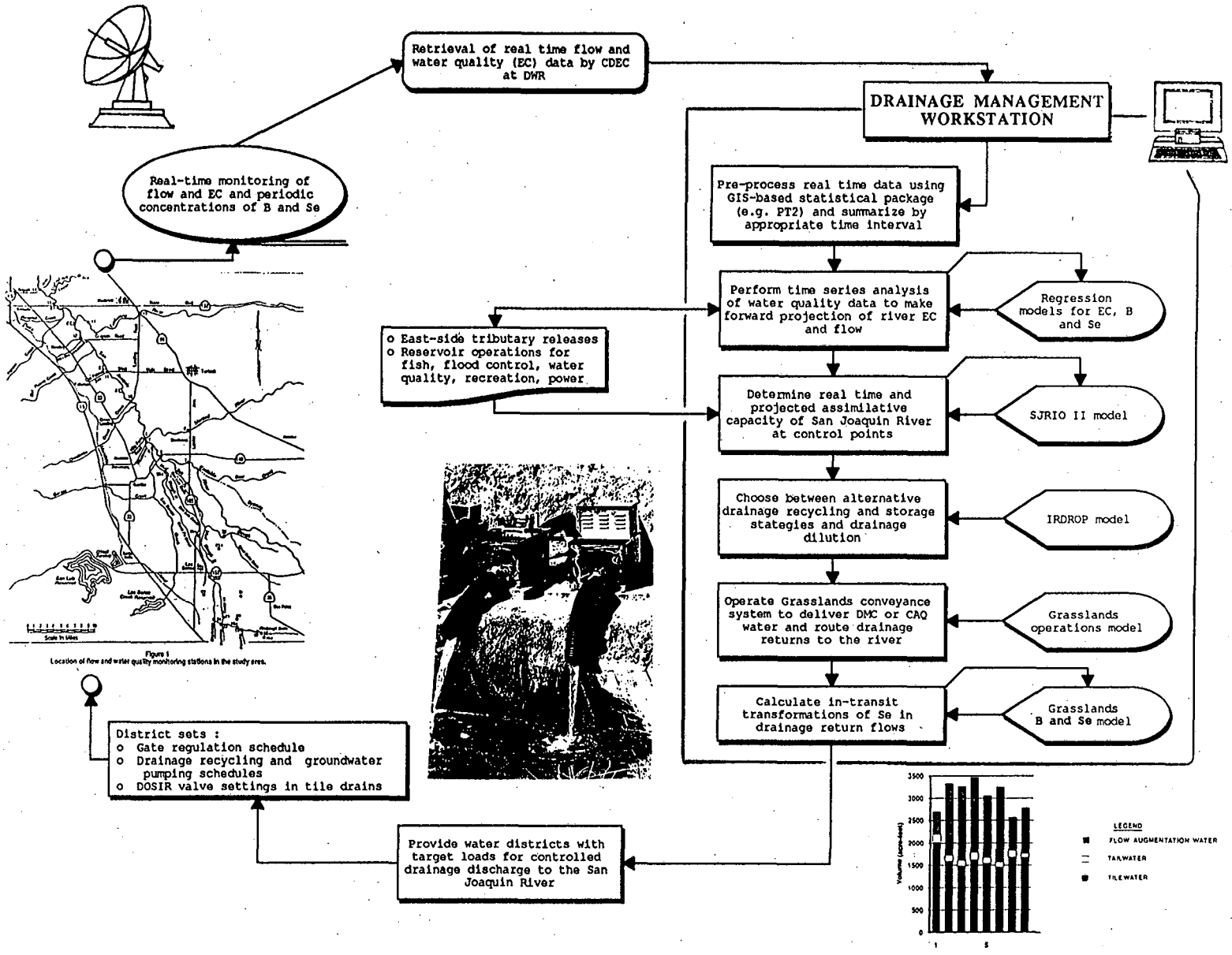


Figure 48. Schematic of information flow through a conceptual system for managing drainage discharges to the San Joaquin River, ensuring compliance with SWRCB water quality objectives and optimizing opportunities for salt export from agricultural water districts in the Grasslands Basin.

(e) choose between different management strategies that either hold or release drainage flows to the limit of river assimilative capacity;

(f) calculate the in-transit selenium loss within the system at the planned discharge rate and recalculate flow if selenium is the constituent limiting the assimilative capacity of the San Joaquin River;

(g) determine periodic (daily, weekly, monthly) targets for drainage discharges based on forecasted drainage flow and river assimilative capacity.

Telemetry data will be provided by stations in Mud and Salt Sloughs; at upstream and downstream sites on the San Joaquin River from these tributary inflows; and at sites at the outlet from each water district and, in some cases from locations within local water districts. At the present time only the site at Salt Slough is telemetered for flow, EC and temperature. Panoche Water District intends to add telemetry capability to the existing monitoring site at PE14, at the northern boundary of the Panoche Drainage District. The site will monitor continuous flow, EC and temperature data.

Implementation and linkage of the various models on the Drainage Workstation will be an ongoing activity during 1993 and 1994.

5.3.2 The Planning Workstation

The Planning Workstation will be operated by MP-710 within Reclamation to address water allocation isssues in the Federal Service Areas in the San Joaquin Valley. The models with application to the San Joaquin Basin are SANJASM, SANTUCM, CVGSM and the Delta hydrodynamic models, notably the Fischer Delta Model and the Wong Model. Figure 49 shows an internal linkage between these models on the Planning Workstation for water allocation studies and their impacts in the San Joaquin Valley. The FRIGSM is the most recent model to be added to the Planning Workstation and can be used to generate scenarios that might impact flows from Millerton Reservoir down the San Joaquin River. This analysis might be of utility in forecasting monthly assimilative capacity in the San Joaquin River. The major purpose of the FRIGSM is the estimation of safe yield in the Friant-Kern Service Area for the purposes of examining future water contracts.

5.3.3 The Groundwater Workstation

The Groundwater Workstation currently includes the GIS-based data storage, retrieval and analysis programs, SAGIS and SABRINA. SAGIS provides the GIS and graphics component of the Groundwater Workstation. SAGIS uses ARC-INFO and also uses a small database management system (using the database program ORACLE) to store the results of analysis and to communicate with SABRINA. SABRINA is the database component of the Groundwater Workstation and is composed using ORACLE. SABRINA is owned by the Santa Ana Watershed Authority and used for basic data storage, data manipulation, data analysis and presentation (David Moore, MP710 - written communication). The combination of SAGIS - SABRINA accomodates any number of water quantity and water quality parameters and a variety of monitoring station types, including stream gages, groundwater wells and weather stations.

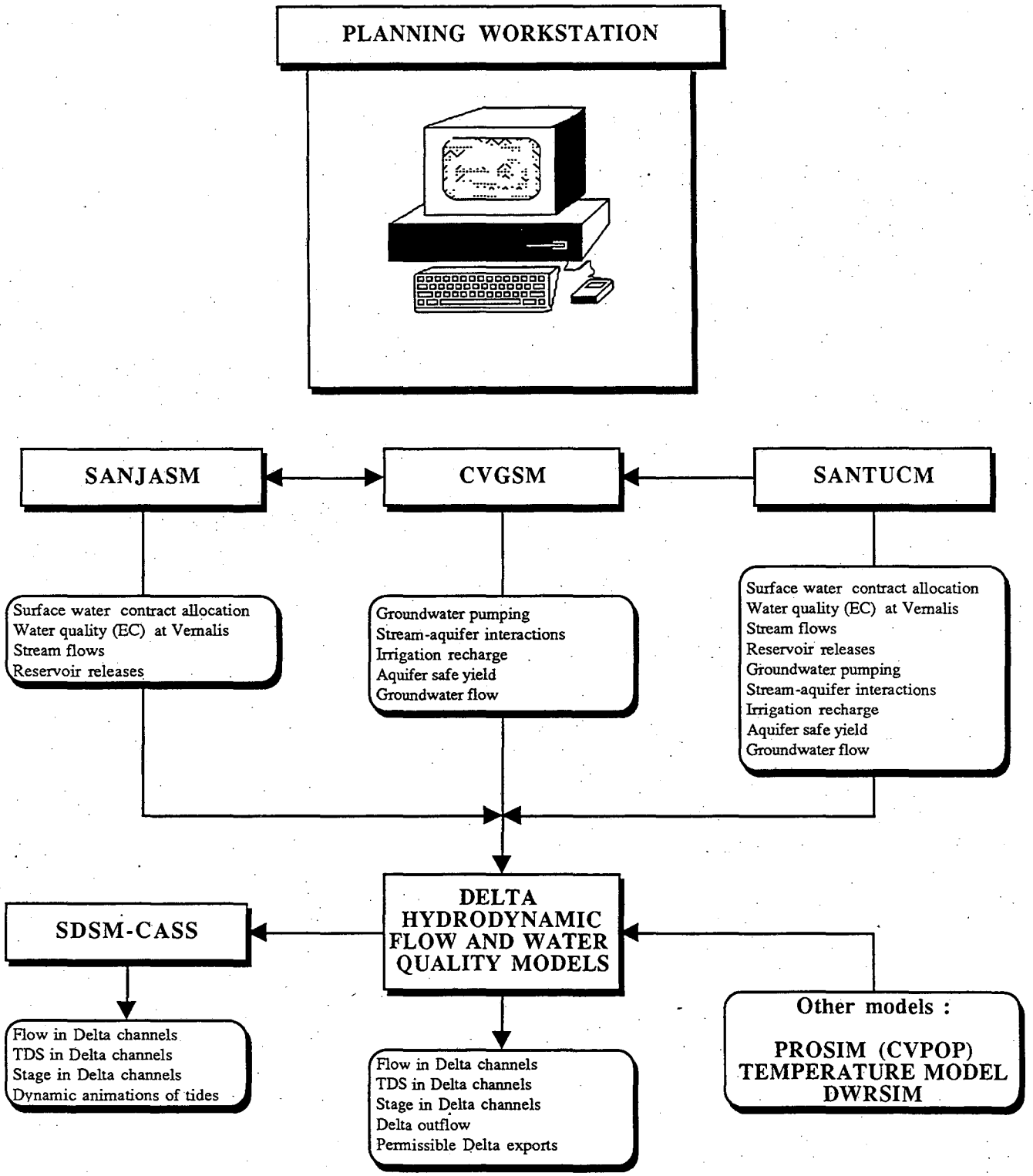


Figure 49. **The important computer-based simulation models and decision support systems available on the Planning Workstation. Linkages between these models and between these decision support systems are shown.**

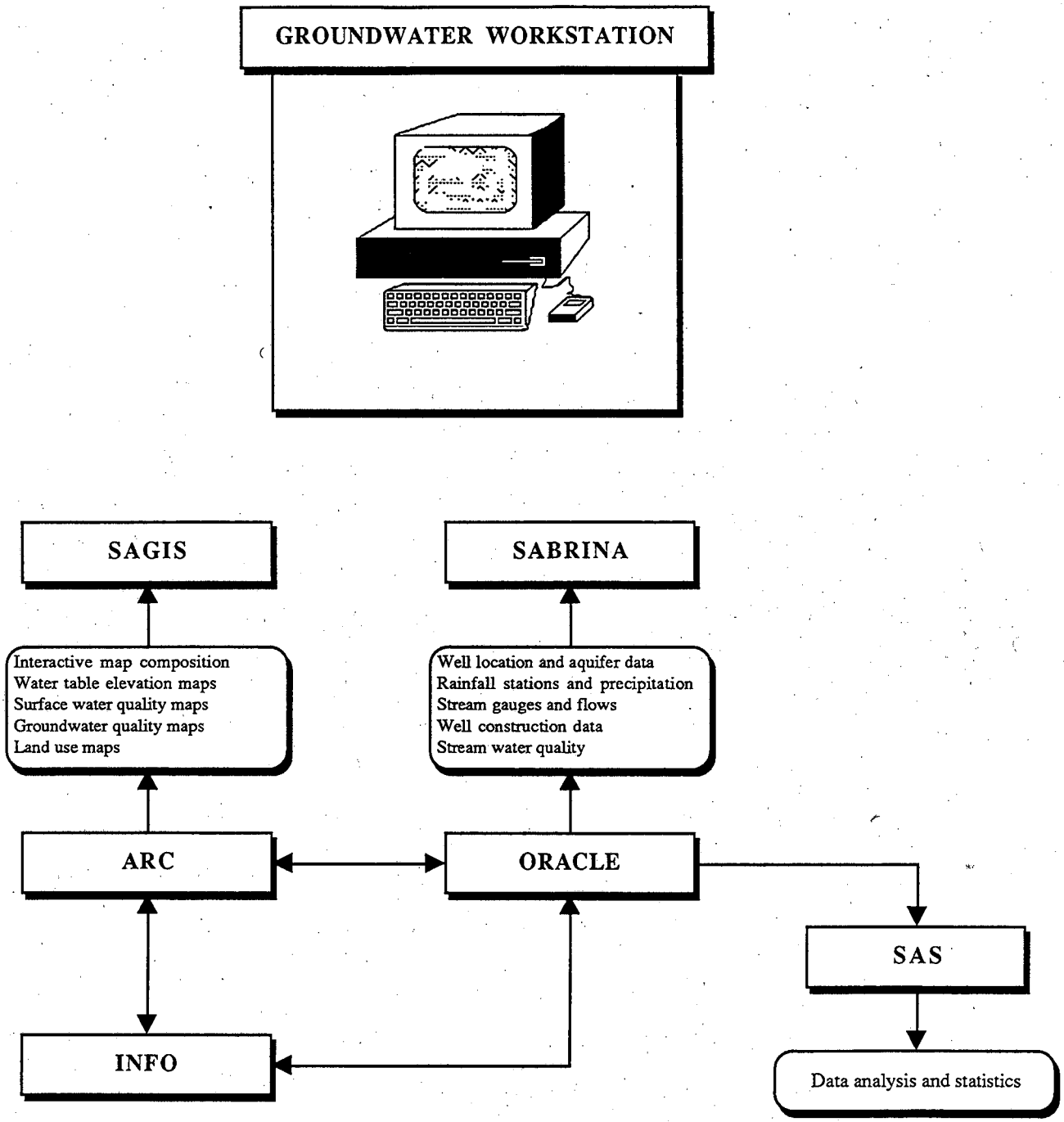


Figure 50. **The important computer-based simulation models and decision support systems available on the Groundwater Workstation.**

Also mounted on the Groundwater Workstation is the SAS statistical analysis package. This is a powerful analytical tool for performing a variety of statistical analyses and creating sophisticated graphics. Output from SAGIS or SABRINA can be exported directly into SAS. Figure 50 shows linkage between these software tools on the Groundwater Workstation.

5.3.4 The GIS workstation

The GIS Workstation is the central repository of all the base maps and combined feature coverages, developed since 1987 by Reclamation and the San Joaquin Valley Drainage Program. Other coverages and maps have been incorporated into the database from other agencies and private concerns in addition to those digitized by Reclamation. The GIS Workstation is networked to other GIS workstations within California including those owned by the Department of Water Resources and the US Geological Survey. The PT2 package, which is GIS based, resides on the GIS workstation and can be networked to access the relevant models on the Drainage Workstation. In a similar way, models that reside on the Drainage Workstation can seek out files on the GIS workstation for data input and can be networked to direct output to the INFO database on the GIS Workstation. Figure 51 illustrates how this flow of information might occur.

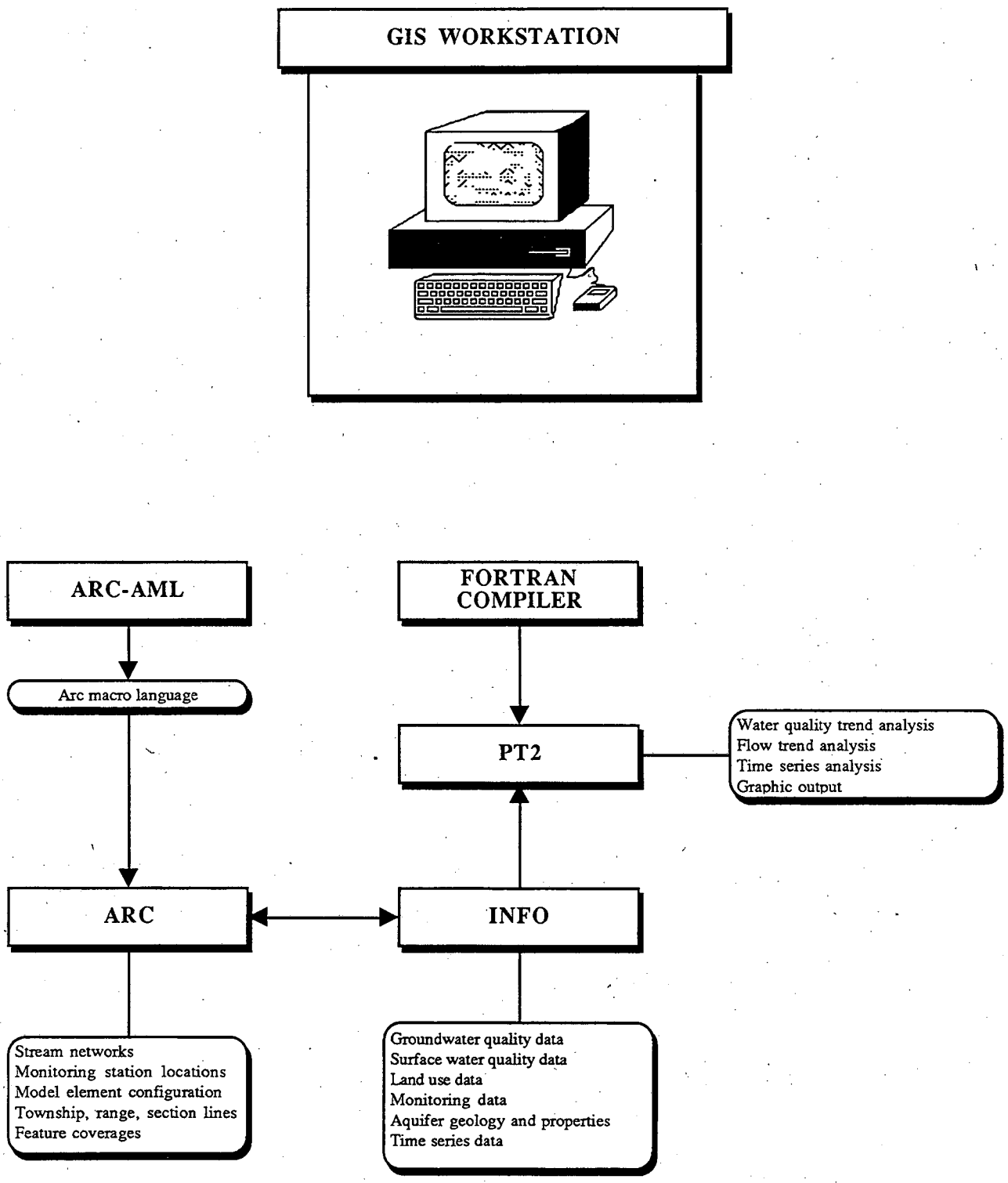


Figure 51. The important graphics - based software and GIS software available on the GIS Workstation.

6. SUMMARY

This document is a prelimary effort to draw together some of the important simulation models that are available to Reclamation or that have been developed by Reclamation since 1987. This document has also attempted to lay out a framework by which these models might be used both for the purposes for which they were originally intended and to support the analysis of other issues that relate to the hydrology and to salt and water quality management within the San Joaquin Valley. To be successful as components of a larger Decision Support System the models should to be linked together using custom designed interfaces that permit data sharing between models and that are easy to use.

Several initiatives are currently underway within Reclamation to develop GIS - based and graphics - based decision support systems to improve the general level of understanding of the models currently in use, to standardize the methodology used in making planning and operations studies and to permit improved data analysis, interpretation and display. The decision support systems should allow greater participation in the planning process, allow the analysis of innovative actions that are currently difficult to study with present models and should lead to better integrated and more comprehensive plans and policy decisions in future years.

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