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Environmentally Sound Irrigated Agriculture in the Arid West: New Challenges for Water Resources Planners and Environmental Scientists

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New Challenges for Water Resources Planners and Environmental Scientists**

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INTRODUCTION

The last decade has witnessed an escalation in the frequency of conflict between the agricultural users of water and the environmental community in the State of California. Increasing pressures of urbanization and agricultural expansion have been blamed for a significant loss of wetlands and wintering habitat for wildfowl. Likewise, operation of the system of reservoirs and canals by the Federal, State and private utility companies, to provide hydropower, irrigation water supply and water for municipal and industrial uses, has threatened the fisheries within many of California's major streams and rivers.

However, it wasn't until the selenium contamination problem at Kesterson Reservoir in the western San Joaquin Valley and the demonstrated toxic effects of selenium and several other trace elements such as arsenic and uranium on populations of fish, wildfowl and small mammals, that the debate has become heated. Such has been the public response to the events at Kesterson Reservoir, that the Federal and State agencies responsible for water resources planning have come to view the selenium issue as the herald of a long term transformation in the way competing uses of the water and land resources of the State are resolved. Selenium may eventually be viewed as the "tip of the iceberg" as science improves in its ability to detect causality between activities such as irrigated agriculture and ecosystem damages to mammals, fish and wildfowl, exposed to contaminants.

The issue of irrigation-induced contamination problems has increased the complexity of the task of planning future water resources operations and allocation within the State. This complexity is appreciated today as the Federal Government conducts environmental impact studies, prior to signing long-term contracts with Central Valley Project water districts for water supplies. Even this action is not without controversy. The quantity of water available for diversion and delivery to Federal contractors is dependent on the water rights permits granted by the State Water Resources Control Board. In California, the State has primacy over water allocation but the Federal Government has the right, under Federal Reclamation Law, to renew water service contracts at current levels, provided beneficial use of water supplies is not diminished. Demonstrating beneficial use of surface water deliveries and the absence of negative environmental impacts is becoming increasingly difficult. Hence the challenge for water resource planners and environmental scientists within the Federal Government. This new challenge is one of determining new strategies for managing the limited water resources of the State, preserving to the extent possible, contractual water supplies and the income stream

that this generates without compromising environmental quality. Equally challenging is the task of developing water policy and incentive programs, that will be politically and institutionally acceptable, and which will catalyse the adoption of these new strategies by the agricultural, municipal and industrial users of water in the State of California.

IRRIGATION RELATED PROBLEMS IN THE WESTERN SAN JOAQUIN VALLEY

The western San Joaquin Valley is arid, receiving too little rainfall to make commercial agriculture viable without supplemental irrigation. Alluvial deposits, from which much of the Valley soils are derived, are marine in origin and are mostly high in native salts. These salts are readily solubilized by infiltrating water. The transport of salts from the near surface soils to the groundwater was initiated by infiltrating rainfall and greatly accelerated by the onset of irrigation. Of the estimated seven million tons of salt that are added annually to soils in the San Joaquin Valley, about half of this salt load is thought to derive from water imported through the Federal (CVP) and State Water Projects (SWP).

Authorization of the San Luis Unit of the CVP required the construction of drainage facilities to collect drainage water from the service area. Drainage relief for 300,000 acres of farmland was initially envisaged. The US Bureau of Reclamation (USBR) began construction of the San Luis Drain, initially with the support of the State, until work was suspended in 1975 due to budget constraints and the increasing concern over the potential effect of discharge of agricultural return flows into the Delta. At the terminus of the San Luis Drain Kesterson Reservoir was built as a regulating reservoir. In 1970, Kesterson Reservoir became part of a new national wildlife refuge operated by the USBR and the Fish and Wildlife Service. Kesterson received drainage discharge from approximately 5000 acres of Westlands Water District, between the years of 1980 and 1985. In theory, conjunctive use of this facility was an example of efficient management of water resources, providing benefits to both agriculture and the environment. However, in 1983, selenium was implicated as the major cause of embryo mortality and severe deformities in wildfowl which prompted the closure of Kesterson and the plugging of drainage laterals to the collector drains, that discharged into the San Luis Drain. Drainage problems similar to those at Kesterson have been manifested in evaporation ponds in the southern San Joaquin Valley.

SALINITY AND SUSTAINABLE AGRICULTURE

Without adequate drainage, water tables in irrigated areas tend to rise. As water tables rise the influence of capillarity becomes greater, leading to waterlogging and the evapoconcentration of salts and trace elements including boron and selenium within the crop root zone. If water tables continue to rise a situation arises whereby the rate at which salts build up in the soils exceeds the effect of flushing flows, made to leach salts out of the root zone. When this occurs, crop yields of salt sensitive crops decline, eventually leading to a situation where the cost of production exceeds the income derived from sale of the crops, resulting in the eventual

abandonment of the land for irrigated agriculture.

Even with adequate drainage, the problem of disposal of drainage contaminated with selenium and other trace elements has to be dealt with. In those areas which are underlain by shallow, saline water tables, where the upper aquifer contains very high concentrations of boron, selenium and other salts and where evapoconcentration of salts in the near surface soils can occur, drainage flows are typically high in these constituents. The higher the concentration of these contaminants, the greater the volume of dilution water required to ensure that combined drainage flows meet stringent State Water Quality Control Board criteria for TDS, boron and selenium, set at various river and tributary control points along the San Joaquin River system. These criteria were set to protect sensitive fish and wildfowl habitat in the Bay-Delta estuary and to protect the quality of water pumped from the Delta for municipal and industrial uses in Southern California.

SOLUTIONS TO AGRICULTURAL DRAINAGE PROBLEMS

Examination of various options have shown that the most promising solutions to the drainage problems of the San Joaquin Valley require a reduction of the volume of drainage volume at its source. This can be achieved through such measures performed either singly or in combination such as irrigation scheduling, tailwater and drainage recycling, adoption of improved irrigation technologies and irrigation management practices and changes in crop selection to deeper rooted, more salt tolerant crops. Other techniques such as controlled pumping of the groundwater aquifer and drainage reuse on tree crops such as atriplex or eucalyptus are short to medium term measures, which help to reduce the volume of drainage discharge requiring disposal. However, the continued irrigation of agricultural land will eventually lead to a projected 800,000 acres requiring drainage by the year 2040 (SJVDP, 1990). The San Joaquin river serves only the northern half of the San Joaquin Valley, the San Joaquin Basin. The southern half of the San Joaquin Valley, the Tulare Basin, drains to the south and does not have a drainage outlet. Evaporation ponds currently provide drainage disposal to approximately 15,000 acres of the Tulare basin. However, the costs of compliance with recently promulgated evaporation pond regulations for construction and operation make it unlikely that many more will be built..

On-farm solutions by themselves will not solve the problem. Soil heterogeneity and inherent difficulties in the ability of irrigation technologies to apply water uniformly limit the potential improvement in irrigation efficiency possible, through the use of improved technologies. In fact, overstatement of the potential for source control can lead to the oversight of other measures that become evident with a more macroscopic or regional view of the overall system. These measures include (a) regional pumping of groundwater to lower high saline water tables; (b) selected land retirement to control regional water tables and reduce the capture of high salinity and high selenium groundwater by tile drains; (c) re-operation of reservoirs such as Millerton Lake to allow greater drainage loading in the San Joaquin River during certain critical times of the year; (d) blending of agricultural and municipal waste

streams to reduce treatment costs and (e) replacement of existing tile drainage systems in selenium source areas with closer spaced, shallow systems.

IMPLICATIONS FOR WATER RESOURCES PLANNING

In the 1970's and early 1980's, prior to the Kesterson issue, the USBR initiated a series of model development projects. These projects utilized expertise within the agency and enlisted the services of consultants within the academic community (Coleman, 1979). A series of simulation and optimization models resulted from this association which were primarily designed to allow more efficient operation of the central Valley Project operations and allow closer coordination between the Federal and State water projects, the CVP and the SWP. Planning studies conducted using these models were primarily concerned with water quantity issues - the servicing of legal contracts for agricultural and municipal water supply and power contractual obligations to the Pacific Gas and Electric Company. The issue of environmental protection, accounted for in these models, were largely limited to the maintenance of fish and wildlife habitat in the myriad channels that make up the Sacramento - San Joaquin Delta.

Since Kesterson water quality issues have become of greater significance. As knowledge of ecotoxicology has improved, so the need to understand the complex dynamics of sensitive ecosystems within the areas served by these water projects and also those subject to return flows from these areas has become more acute. Computer-based, simulation models can aid in comprehension of these interactions where sufficient data has been gathered to permit model calibration and verification. In cases where these relationships cannot be formulated mathematically, sets of rules can be developed setting bounds or constraints on such factors as minimal monthly flows in a river to allow fish migration during critical times of the year; maximum permissible daily water temperatures to protect fish habitat or fish populations, or releases of water of adequate quality to refuges to sustain wildfowl populations. These rules can be incorporated into decision support systems to assist in the development and evaluation of alternative solutions to contamination problems where they occur, and to present these solutions in a manner that allows consensus building among potentially responsible or affected groups.

Water quality concerns are magnified in the current period of water shortage as California faces a fourth year of drought. In the current highly charged atmosphere water resource supply disputes between competing users becomes beholden to the legal and the political process. Legal and political judgements are inherently inefficient at making decisions on water resource allocation. A new approach to surface and groundwater resource modelling is required in these times to facilitate, not only technology transfer between the water resource planner and the practitioner, but also the involvement of the representatives of the different political players in the water resources decision making process. To serve as planning tools, these decision support systems should attempt to capture only the most important elements of these complex systems. These elements cannot ignore political trends and realities, such as

increased environmental awareness, trends towards more stringent environmental regulation, increasing urbanization and greater responsibility by the State, local governments and the private sector for natural resources management. Planners also need to be able to comprehend the models they use and be able to explain the assumptions made by these models to others.

HIERARCHICAL SYSTEMS APPROACH

Two types of models are described in this paper. The first mentioned are models created as decision support systems for use in water operations planning and water contracting studies for agricultural users of water in the Central Valley. The second set of models are those which have been developed to help in the formulation of long term strategies for management of drainage and drainage-related contamination problems, specifically on the west side of the San Joaquin Valley. The current initiative to link these types of models will allow the inclusion of water quality considerations in long term water contracting studies and help to create a more realistic simulation of long term trends and environmental effects. The adoption of a hierarchical approach in creating this linkage will eventually allow the use of an entire system of models, many of which have been developed at different spatial scales to supplement and support current analysis. For example, detailed, data intensive studies conducted at the field or farm level can be designed in such a manner to provide input to larger scale sub-regional and regional models. Larger areas can then be classified according to the range of conditions recognized in these smaller scale studies. The benefit of having field level studies to support some of the simplifying assumptions, made in the more general regional models, also helps to enhance agency credibility in public meetings with water district personnel and Valley growers.

Central to the development of a hierarchical system of models for water resources planning in the 1990's is the simultaneous use of geographic information systems for data management and retrieval. The use of common databases amongst water resources planning models not only greatly enhances the productivity of the analyst and the ability to evaluate the consistency of data used in different studies but it also creates new opportunities for the involvement of other parties at an early stage of project planning. The use of geographic information systems for data input to models and display of models output has become feasible with recent technological advances in GIS software. This capability will be within the grasp of analysts within the USBR within a few years.

OPERATIONS PLANNING MODELS

The USBR has supported the development of two such decision support systems to replace the existing surface water operations models under this new initiative. These decision support systems are respectively the Project Simulation Model (PROSIM) and the San Joaquin - Tulare Conjunctive Use Model (SANTUCM). These models are described as decision support systems because of the manner in which they have been constructed. Emphasis was placed on speed of operation and ease of use. The models were written to allow easy comprehension of

the model assumptions and the rapid performance and analysis of "what-if" games related to different operating policies. Such models have been used with remarkable success in regions such as the Potomac River basin for developing consensus among various factions who might otherwise have found it difficult to consider the consequences of alternative policies.

An earlier version of the PROSIM model was used to resolve a conflict between the California Department of Fish and Game and the Fish and Wildlife service on one side and the Oakdale and South San Joaquin Irrigation Districts on the other, over fish flow requirements in the Stanislaus River below New Melones Reservoir. The conflict was resolved when the model users were able to show that the existing pattern of releases gave sufficient protection to the salmon fishery and in fact gave better protection during dry years than a release policy that provided releases equal to the fish flow entitlement (Randall et al., 1988)

COUPLED SURFACE AND GROUNDWATER MODELS

PROSIM (Project Simulation Model) is a monthly model of water and power operations of the Sacramento basin portions of the Central Valley Project (CVP) and State Water Project (SWP), including the San Luis Reservoir, the California Aqueduct and the Delta Mendota Canal. The model considers three types of demands which include; non-project demands, such as senior water rights; project demands such as agricultural irrigation demands and municipal demands; and demands for instream flows for fisheries and navigation or wildlife refuges. Groundwater pumping is calculated in the model as a residual to meet any remaining deficiency at a demand node in the model network after accounting for a certain minimum level of pumping and surface water allocations. SANJASM (San Joaquin Simulation Model) is a monthly model of water and power operations in the San Joaquin basin of the San Joaquin Valley.

The rules for groundwater pumping in PROSIM and SANJASM are static and assume that groundwater can be pumped to satisfy residual demand at each node in the network. The models do not keep track of groundwater storage and do not take into account the quality of groundwater pumpage. To more closely account for groundwater storage and to estimate groundwater contributions to stream and river flows in the basins a comprehensive groundwater model was constructed. CVGSM is a multilayered, two dimensional finite element model which simulates groundwater recharge and aquifer response on a monthly basis. Soil moisture accounting models and unsaturated flow equations are used to compute runoff and deep percolation losses to the groundwater respectively. Surface water flow between nodes located along major streams is modelled using regression and mass balance techniques, allowing stream-aquifer interactions to be calculated along the reach of each river segment.

Both PROSIM and SANJASM will be linked to CVGSM under the current model development initiative. The first attempt at making this linkage has been the SANTUCM (San Joaquin-Tulare Conjunctive Use Model). The model builds upon SANJASM and adds a hydrosalinity and a groundwater model, to estimate stream-aquifer interactions and allow the

long term effect of groundwater pumping to be evaluated. The sequential coupling of the surface water and groundwater models permits salinity to be considered through the use of a mass balance analysis of each node of the stream aquifer network.

AGRICULTURAL PRODUCTION AND DRAINAGE MODELS

The overarching premise of this system of models is that future irrigation demands will be related to historical demands or can be predicted by a stochastic model of projected demands, based on the historical record. The historical record may be of utility in developing a trace of rainfall-runoff relations for future years but tend to ignores the political and economic realities of agriculture in areas such as the western San Joaquin Valley and the salt and selenium problems associated with tile drainage. Solutions to this problem will likely have an effect on future irrigated and irrigable areas within the San Joaquin Valley, future crop selection, the adoption of water conserving irrigation technologies and the annual volume of groundwater pumped. All these factors in turn affect the demand for surface supplies and will have a long term impact on future allocations to agricultural water users. Market forces also influence cropping decisions, which in turn have significant impacts on agricultural water requirements. A means of accounting for these factors is important in planning studies using the PROSIM, SANJASM and SANTUCM models.

REGIONAL DRAINAGE AND WATER QUALITY

A regional model , specifically constructed to account for the effects of likely solutions to westside drainage problems is the Westside Agricultural Drainage Economics (WADE) model. This is a policy model comprised of three interacting sub-models (a) an agricultural production sub-model which simulates cropping decisions, farm revenue, irrigation and drainage technology selection and activity levels of drainage recycling, groundwater pumping and irrigation recharge; (b) a hydrology and (c) a salinity sub-model which estimates the effect of these management decisions on regional water tables, root zone and aquifer salinization, and drainage volume and quality. The sub-models solve sequentially for a winter pre-irrigation period and a summer irrigation period for each year simulated.

The agricultural production sub-model is formulated as a linear optimization model - hence the sub-model attempts to prescribe what actions the growers should perform to maximize net returns to investments in land and labor in response to a variety of Federal, State or Water District policy options or incentive programs or in the absence of any Federal or State interventions. The model can be constrained to adhere to certain environmentally based restrictions. Water quality criteria for the San Joaquin River are set in terms of allowable loadings of TDS, selenium and boron during any particular month. Hence, policy variables such as water pricing, drainage charges and drainage discharge limits can be adjusted until these river water quality criteria are satisfied.

In order to more closely represent physiographic, geochemical and institutional differences that affect irrigation and drainage management across subareas within the western San Joaquin

Valley the study area was subdivided into 180 cells based on soil characteristics, drainage conditions and institutional arrangements for irrigation supply and drainage disposal. Area specific solutions to local drainage problems could then be prescribed more realistically by the WADE model. For instance, in areas with good quality groundwater, the higher cost of groundwater pumping can be offset by lowered water tables and reduced tile drainage flows. This is especially true if drainage charges are levied based on the volume of discharge. Conversely, where the salinity of groundwater pumpage is high, the effect of these salts on root zone salinity may restrict pumping activity, even if the cost of surface water exceeds that of pumped groundwater.

MODEL HIERARCHY

A hierarchy of more site-specific simulation models have been developed to improve the predictive capability of the WADE model. Results from these models are being generalized into systems of rules for inclusion in the SANTUCM model. Two examples of these simulation models, that function at the field or farm scale, are described below.

DRAINAGE WATER QUALITY

The quality of tile drainage is not constant but rather changes over time as flowlines into the tile drain intercept zones within the semiconfined aquifer which contain high concentrations of native salts and trace elements such as Se and B. Tile drainage contains a higher proportion of groundwater from shallow depths in the aquifer immediately after irrigation applications than during the non-irrigation season. A steady-state, two-dimensional model of solute flow to two drainage laterals, calibrated with field data, has been used to develop rules for the contributions of various aquifer layers to flow and constituent load in tile drains for the WADE model. A transient model is currently under development to allow estimates to be made of drainage water quality over time. The model will also be used to assist in the re-design of tile drainage systems using shallow, closely spaced drains to minimize the capture of deeper groundwater that contains higher selenium and boron concentrations.

QUALITY OF GROUNDWATER PUMPAGE

The semiconfined aquifer in much of the western San Joaquin Valley is stratified both with respect to texture and to water quality. High salinity groundwater occurs in a zone ranging between 30 ft and 150 ft below the ground surface. Groundwater pumping in the semiconfined aquifer will cause drawdown of the zone of high salinity towards the well. Depending on the rate of pumping, the depth of the well screen, the aquifer characteristics and the depth distribution of TDS within the aquifer, the average TDS of the pumped water will increase to a level that it is no longer suitable for irrigation application to crops. A two dimensional finite element model of flow into a pumped well, located in an anisotropic and chemically stratified aquifer, has been used to estimate the usable life of these wells and to

develop conservative pumping strategies to prolong the usable life of the aquifer. This model will be used to provide groundwater pumping rules for SANJASM and SANTUCM models with additional data on the depth distribution of contaminants in the aquifer.

SUMMARY

This is an exciting time for water resources planners and environmental scientists in the State and Federal Agencies in California. The growing environmental awareness of the public has raised their interest in the manner by which water is managed and allocated. Current and future impending water shortages are challenging engineers and planners to make sound policy and system operations decisions to maximize the utility of scarce water resources while ensuring that the environment within which we live is adequately protected to the satisfaction of an informed public. New and innovative decision support systems are needed to meet these challenges that are flexible, comprehensible and accurate and which allow the public a more visible role in the planning process. These changes may help to bring the agricultural and environmental communities closer together in finding solutions to water resources problems and wrest policy making for water resources management out of the hands of lawyers and the courts and restore it to those whose livelihoods are affected by the intentions of these policies.

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