AN APPROACH FOR SIMULATING AGRICULTURAL WATER MANAGEMENT IN THE SAN JOAQUIN VALLEY, CALIFORNIA

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Abstract The Central Valley Project (CVP) annually delivers about 7 million acre-feet of water for agricultural, urban and wildlife uses including supplies for approximately 3 million acres of irrigated agricultural lands, 1 million urban households and 19 wildlife refuges. Starting in February, Reclamation issues a series of potential water supply announcements indicating to its contractors what percentage of their maximum contracted water supplies may be available for delivery during the remainder of the water year. These water supply announcements are based on a combination of measured snow pack, current reservoir storages and 90 and 50 percentile exceedance estimates of additional reservoir inflows. The Central Valley Operations Office uses these estimated supplies as inputs to a Demand Model. The computed demand estimates are subsequently used as inputs to an Operations Model which computes various important metrics of system performance. If the performance metrics are unacceptable, the preliminary announcement is adjusted and the process is repeated until acceptable results are obtained. These potential water supplies can be adjusted either up or down as the fall-spring precipitation season evolves. However, agricultural water users must make decisions about the types and acreages of crops they will plant in the late winter or early spring when the uncertainty in the final water supply is still significant. Consequently, methods that reduce uncertainty in either supply or demand earlier in the year would have significant benefits to water users.

To reduce demand uncertainty, our focus has been on improving estimates of agricultural water requirements in the San Joaquin Valley by forecasting potential evapotranspiration (PET) out to 90 days in the future (Yates and Tansey, 2010) and using these PET forecasts in a physically based simulation model designed for the management of large-scale multi-organizational water supply systems. This model (Land, Atmosphere, Water Simulator, LAWS) simulates daily, field-scale land, crop, and water management practices and allows for the consideration of alternative methods for managing soil moisture on a daily basis during the irrigation season based on soil properties, crop type and vegetative growth stage using the FAO 56 dual crop coefficient method. Using water supply estimates generated by the Operations Forecast Model, a LAWS simulation is run to compute a current estimate of future water demands and to determine whether there will be an imbalance between forecasted supplies and demands. In the event of shortages, the LAWS model is used to develop alternative management strategies (such as increased groundwater pumping, recycling, water purchases, changes in crops types, acreages irrigation methods, deficit irrigation, land fallowing among others) to achieve a balance between supply and demand. These updated demand estimates are input into the Operations Forecast Model which would be re-run to determine whether the CVP system metrics are still acceptable. If unacceptable, the process can be repeated until an acceptable operation is achieved. In this way, the LAWS model is used to provide a physically based estimate of irrigation requirements and to include in the process an accounting of the various management practices that can be used in times of water scarcity.
INTRODUCTION

The Central Valley Project (CVP), operated by the U.S. Bureau of Reclamation (herein Reclamation), is one of the world’s largest water storage and conveyance systems. It is comprised of 20 dams and reservoirs (with a combined storage of 11 million acre-feet) and 500 miles of major canals, tunnels, and related facilities (Figure 1). Annually, the CVP supplies approximately 7 million acre-feet of water to agriculture, cities, and wildlife refuges throughout California’s Central Valley.

Each year, beginning in February, the CVP evaluates its water supply outlook for the year and estimates how much water is available for delivery. Through this process, CVP contractors are informed of how much water they should expect to receive, so that they may plan their operations accordingly. This process is finalized once Reclamation is secure in its assessment of the water supply forecast, typically in May.

A key factor in the water supply management process is the estimation of water exports from the Sacramento-San Joaquin Delta and the supply available from water stored in San Luis reservoir, the pumped storage facility that the CVP shares with the State Water Project (SWP). These estimates form the basis of agricultural operations in the region south of the Delta, which accounts for nearly two-thirds of total CVP deliveries.

Figure 1 - Major CVP and SWP Facilities (Courtesy of Reclamation)
The objective of this work is to develop a procedure for forecasting agricultural demands that enhances Reclamation’s ability to meet South of Delta deliveries without violating operational constraints on San Luis reservoir. Other important factors such a permitted Delta exports must be addressed separately from this procedure.

**CVP WATER MANAGEMENT**

The Central Valley Operations Office (CVOO) is responsible for managing water within the CVP, one of the most complex water delivery systems in the world. To assist in this process, CVOO has developed a spreadsheet-based simulation tool, known as the operations forecast model (Peterson and Fujitani, 2006). This tool is central in planning for annual water deliveries to contractors.

The CVOO operations forecast model is a monthly application that is used regularly throughout the winter and early spring to assess water supply conditions and to evaluate the potential for water delivery through the coming irrigation season. Forecasts are first made in mid to late February as an initial estimate of water supply availability to assist irrigators in making important decisions for the upcoming growing season. This initial forecast tends to be a conservative outlook, because there is still considerable uncertainty in precipitation and snowmelt projections. The water supply forecast is, thus, revisited as the confidence in these forecasts improves – typically until May.

The tool requires regular updating of key system inputs: inflows, river and Delta flow surrogates, and water demands. System inflows are estimated using ninetieth and fiftieth percentile inflow forecasts, which are developed based on current snow pack data and an historical projection of precipitation. River and Delta flow surrogates are estimated based on Delta hydraulic and water quality modeling. Water demand patterns are estimated based on historical water use trends and delivery request schedules provided by CVP contractors.

The tool uses an iterative process intended to match water deliveries to projected demand patterns. Upon issuing a supply forecast and setting an associated delivery schedule, the tool is used to assess whether key system metrics are met. These metrics include reservoir level needs, in-stream (between reservoir and Delta) flow requirements, and Delta requirements. If these metrics are violated, then the supply and demand forecast need to be updated and the tool rerun. This iterative process is outlined in Figure 2.
This process allows CVOO to refine supply forecasts using near real time data inputs. It is limited, however, in that it relies on historical data (i.e. precipitation and deliveries) for water demands. These data are not always accurate predictors of near-term water use patterns, because they blur climatic trends (by using historical averages) and do not account for possible short-term demand adjustments due to water transfers. This paper explores ways to enhance this methodology by using an alternative demand forecasting routine that aims to reduce PET based agricultural demand uncertainty and to explicitly represent the potential for CVP contractors to use multiple sources of supply.

LAND ATMOSPHERE WATER SIMULATOR (LAWS)

The Land Atmosphere Water Simulator (LAWS) is an integrated, flexible, and scalable tool for efficiently developing and comparing alternative water management strategies with either historical or forecasted water supply and demands conditions. LAWS provide users with the capability to evaluate alternative water management strategies based on multiple factors including: reservoir and conveyance infrastructure; irrigation system characteristics; crop types; soil moisture management practices; and groundwater and drain water re-cycling.

LAWS is designed for the management of large-scale multi-organizational water supply systems. In LAWS, the water supply system is conceptualized as a series of nested spatial units that range in size from multi-regional watersheds to individual land units as small as fields. The largest scale land area is associated with a System Manager, which may operate multiple reservoirs located in different river systems within a regional watershed. At the next smaller spatial scale, Area Managers are responsible for managing water accounts within a particular region of the water system. Within these regions, there are one or more Delivery Managers, which serve as the intermediary between irrigators and the water supply system. At the smallest scale, a Land Manager functions to apply water to an individual land unit. Within this analytical framework,
the geospatial locations of major reservoirs, rivers, canals, and drains are explicitly located through GIS. The LAWS spatial organization is shown in Figure 3.

LAWS simulates daily, field-scale land, crop, and water management practices. Daily agricultural water demands are calculated by LAWS based on the acreages and types of crops growing within a water management area. These water demands are computed using the well established crop coefficient method (Allen et al, 1998) and either historic, current or forecasted potential evapotranspiration (PET) data.

Using standard irrigation scheduling techniques (Goldhammer and Snyder, 1989), LAWS can be used to simulate the amounts and timing of agricultural demands for irrigation water from multiple water management areas. An urban water demand simulation capability also exists. In LAWS, these demands can be associated with one or more sources of supplies including reservoirs, groundwater, and/or reused drain water. Reservoir operations and water accounting features are an integral part of a LAWS simulation. A network model of the water delivery system simulates the timing of the movement of reservoir releases in rivers and main canals.

LAWS also allows for the consideration of alternative methods for managing soil moisture on a daily basis during the irrigation season based on soil properties, crop type and growth stage. LAWS computes evapotranspiration, soil water content, surface water ponding, runoff, canal and drain losses, return flows to rivers, and deep percolation to groundwater at level of spatial and
temporal resolution not present in existing planning and operations models. Although LAWS performs these calculations at the field scale, LAWS also provides users with ability to aggregate these results within larger user definable areas so that water budgets can be readily computed for arbitrary organizational regions.

APPLICATION OF LAWS TO SOUTH OF THE DELTA WATER MANAGEMENT

A LAWS application is currently being developed for this study to simulate demands and water management in the CVP service area South of the Delta (SOD). The intent of this modeling was to improve demand forecasts and to include source shifting strategies in the CVP SOD water management process. Improvements in demand forecasts were achieved by focusing on the physical processes affecting agricultural water use, including the time of planting and total acreage of various crops, physical properties of soils, irrigation technology, and meteorological forecasts. LAWS also considers source shifting strategies by allowing the user to easily update important factors that affect water deliveries, such as water transfers and groundwater pumping.

The water management process was modified to include LAWS simulations that evaluated the impact of crop planting decisions and source shifting strategies on overall SOD demand for CVP water. In addition to enhancing demand forecasts, the LAWS software was used to evaluate the San Luis ‘low point’ criteria, which aims to keep total San Luis storage above 300 thousand acre-feet at its lowest point, typically near the end of the August, in order to maintain water quality standards. This modified forecasting process is presented in Figure 4.

The LAWS application developed for this study focuses on the region of the CVP service area south of the Delta. The key features of this region are presented in Figure 5. This includes the west side of both the San Joaquin Valley and the Tulare Lake Basin. CVP deliveries to the west side of the San Joaquin Valley are made primarily from the Delta-Mendota Canal, which pumps
water from the Delta at the Jones (formerly Tracy) Pumping Plant and carries water to the Mendota Pool on the San Joaquin River. The Delta-Mendota Canal is also used in the fall and winter (September to March) to transfer water into San Luis Reservoir. The bulk of CVP deliveries from San Luis Reservoir are sent through the San Luis Canal to CVP contractors on the west side of the Tulare Lake Basin. The CVP also sends water directly from San Luis reservoir to its San Felipe Division, which includes various water users in the Santa Clara Valley. As previously mentioned, CVP shares storage in San Luis reservoir with the State Water Project (SWP). The SWP pumps water from the Delta to San Luis Reservoir through the California Aqueduct. The SWP then releases its San Luis storage back into the California Aqueduct to deliver water to its contractors in southern California. These SWP operations were considered within the LAWS model, because they influence the San Luis low point criteria.

The water supply system described above contains key infrastructural features of the two main water projects in California, the CVP and the SWP. These two projects are represented in LAWS as System Managers. The key characteristic of these two System Managers is their independent accounting of Delta exports, deliveries, and storage in San Luis reservoir.

The geographic extent of the LAWS application covers only one region of the CVP. As such, all of the contractors within this region were included within a single CVP Area Manager. Similarly, all SWP demands were included in a single SWP Area Manager. The CVP and SWP Area Managers were responsible for tracking their associated storage accounts in San Luis reservoir.

Within LAWS, the CVP and SWP Area Managers monitored San Luis storage and processed requests from several Delivery Managers. There were a total of 18 Delivery Managers associated with the CVP. Most of these represent agricultural demands associated with the major irrigation and water districts on the west side of the San Joaquin Valley and Tulare Lake.
Basin and relied on Land Managers to estimate irrigation requirements. The San Felipe Unit, which lies outside of the Central Valley, however, is a mixture of agricultural and urban water use. For this reason, we used the urban demand feature within LAWS to estimate their demands. There were only two Delivery Managers associated with the SWP, which represent the major SWP transfers to the South Bay Aqueduct and to the California Aqueduct south of Dos Amigos. Both of these used the urban demand feature in LAWS to estimate their water demands.

Irrigation requirements within all but one (San Felipe Unit) of the CVP Delivery Managers was estimated by evaluating the crop water requirements for a range of crop types. Within these Delivery Managers, we used Land Managers to estimate irrigation requirements for a range of crop types. Reported cropped acreage (2001-2007) within each CVP district that receives Delta export water were obtained from Reclamation’s South-Central California Area Office. Total cropped acreage within this region ranged from 4.216 million acres in 2001 to 5.136 million acres in 2007. While it is possible within LAWS to represent field-level operations, this approach was deemed infeasible due to the magnitude of the area considered in this study. As an alternative, we opted to aggregate single crops within a district into individual computational units within LAWS. Thus, the Land Managers represented a conglomeration of lands within a district that were growing a common crop, rather than individual fields. In this way, we were able to quickly update cropping patterns from year-to-year.

For each Land Manager, crop type and total acreage were assigned along with several physical and management factors that affect the timing and magnitude of water demands. These factors include crop water use traits (planting dates, vegetative growth stages, crop coefficients), the physical characteristics of soils (sand-silt-clay content, hydraulic conductivity), irrigation system type (furrow, flood, sprinkler, or drip), and depth of irrigation application. LAWS uses this information along with meteorological inputs to estimate actual evapotranspiration for each Land Manager (i.e. crop type). A Land Manager then makes a request for water deliveries when the consumptive use reduces soil water content below defined management thresholds.

**Demand Forecasting**

A key difference between LAWS and the CVOO demand model is that LAWS uses meteorological forecasts to estimate demand projections. In the calibration and validation of the South of Delta LAWS application we used temperature and precipitation data obtained from the California Irrigation Management Information System (CIMIS), an extensive network of agricultural weather stations. In the application of this tool within the context of refining the CVP water management process, we will rely on short-term (14-day) and medium-term (90-day) meteorological forecasts to project demands. This forecasting methodology is described in an accompanying paper by Yates and Tansey (2010).

**CONCLUSIONS**

An application of the LAWS tool is being developed for the region of the CVP that relies on water exports from the Sacramento-San Joaquin Delta. The tool is intended to enhance demand forecasts for this region and to assess the impact of various source shifting strategies on overall
water supply availability. The potential for using the approach described in this paper will be explored as additional work is completed in the future.

REFERENCES


