CALSIM APPLICATIONS IN THE KLAMATH RIVER BASIN

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Abstract: The U.S. Bureau of Reclamation has developed an application of the CALSIM model for Klamath Project planning and operations to address evolving analysis needs in the Klamath River Basin, which has seen high-profile struggles to manage limited water supplies over several recent drought years. A spreadsheet model, KPSIM, was developed in the mid 1990's to address decision-making needs of the regulatory environment for the Project in place at the time. This regulatory environment has been shaped since 2001 by court decisions, biological assessments and opinions, and annual operating plans developed in concert with other agencies. These changes, coupled with new decision processes for upper basin water and land settlement, FERC hydropower re-licensing, and evaluation of flow requirements highlighted the need for a more flexible, expandable modeling tool.

CALSIM is a general-purpose river system modeling framework developed by the California Department of Water Resources for application to the combined Central Valley Project / State Water Project (CVP/SWP) of California. A river system is portrayed as a schematic network of nodes and links that represent storage and flow, physical and operational constraints are specified with a simple scripting language, and a linear programming / mixed integer linear programming solver is used to define the optimal distribution of water. This paper will present the replication of the spreadsheet model with CALSIM, enhanced flexibility in depicting operational complexity offered by the CALSIM model framework, and extension of the original Klamath Project planning model to represent water rights in the upper basin, hydropower generation operations below the project, and possibly water distribution within the project itself.

INTRODUCTION

Reclamation's Klamath Project, shown in **Figure 1**, straddles the Oregon-California border east of the Cascade Range, irrigating up to 240,000 acres of cropland. The project controls releases from the upper basin to the lower basin and has been a focal point in processes and decisions involving threatened and endangered species, tribal trust obligations, water rights, and water quality issues.

Upper Klamath Lake (UKL) is the project's principal storage facility with an active storage capacity of 523 taf. Net annual inflow averages 1200 taf with an approximate range of 600-2400 taf. Releases from UKL serve deliveries to irrigated lands and the Lower Klamath Lake National Wildlife Refuge and also satisfy minimum flow requirements at Iron Gate Dam below the project. In the period 1961-2004, annual Klamath River diversions averaged 405 taf, and annual total flow volume at Iron Gate averaged 1505 taf. The adjacent Lost River Basin is a closed basin whose early season high flows are diverted to the Klamath River to control water levels in Tule Lake Sump and Tule Lake National Wildlife Refuge. A key challenge to operations of the Klamath Project is the lack of carryover storage capacity – UKL almost always fills, and the full range of its conservation pool is typically exercised each year. The storable water must be managed carefully to satisfy minimum lake levels, flow requirements, and diversion demands.

THE KLAMATH PROJECT SIMULATION MODEL

KPSIM is an Excel Spreadsheet application developed in the mid 1990's to assist Reclamation with Klamath Project planning studies. The principal input criteria correspond to the four main project responsibilities described above – UKL minimum water surface elevation, Iron Gate (IG) minimum flow, and diversion requirements for irrigation and refuge deliveries. These are defined as step functions of UKL inflow or precipitation. A variable time step – full months in August-February and half months in March-July for a total of 17 time steps in a year – addresses the need to meet mid-month lake elevation targets. The model calculates release, delivery, and storage operations based on the input requirements, water supply, and the following priorities:

- First, meet the UKL minimum water surface elevation.
- Second, meet the IG minimum flow.
- Third, meet the agricultural diversion requirement.
- Fourth, meet the refuge diversion requirement.

- Fifth, store excess water in UKL.
- Finally, if storage will exceed flood control limits, spill water to the Link River.

KPSIM assesses water availability on both a time step basis and on a seasonal basis to smooth operations in anticipation of month-to-month inflow variability. This approach was appropriate at the time the model was developed. A 1992 Biological Opinion on critical habitat for endangered Lost River and shortnose sucker fish defined minimum UKL water surface elevations, minimum FERC hydropower generation set the requirements for flows below the project, and historical operations provided expected ranges of agricultural and refuge demand for a given water supply condition. A 1995 Department of the Interior (DOI) Solicitor's opinion specified the order of water supply allocation priorities as UKL storage, satisfaction of tribal trust obligations, FERC flows, agricultural deliveries, and refuge delivery. Tribal trust obligations were not quantified.

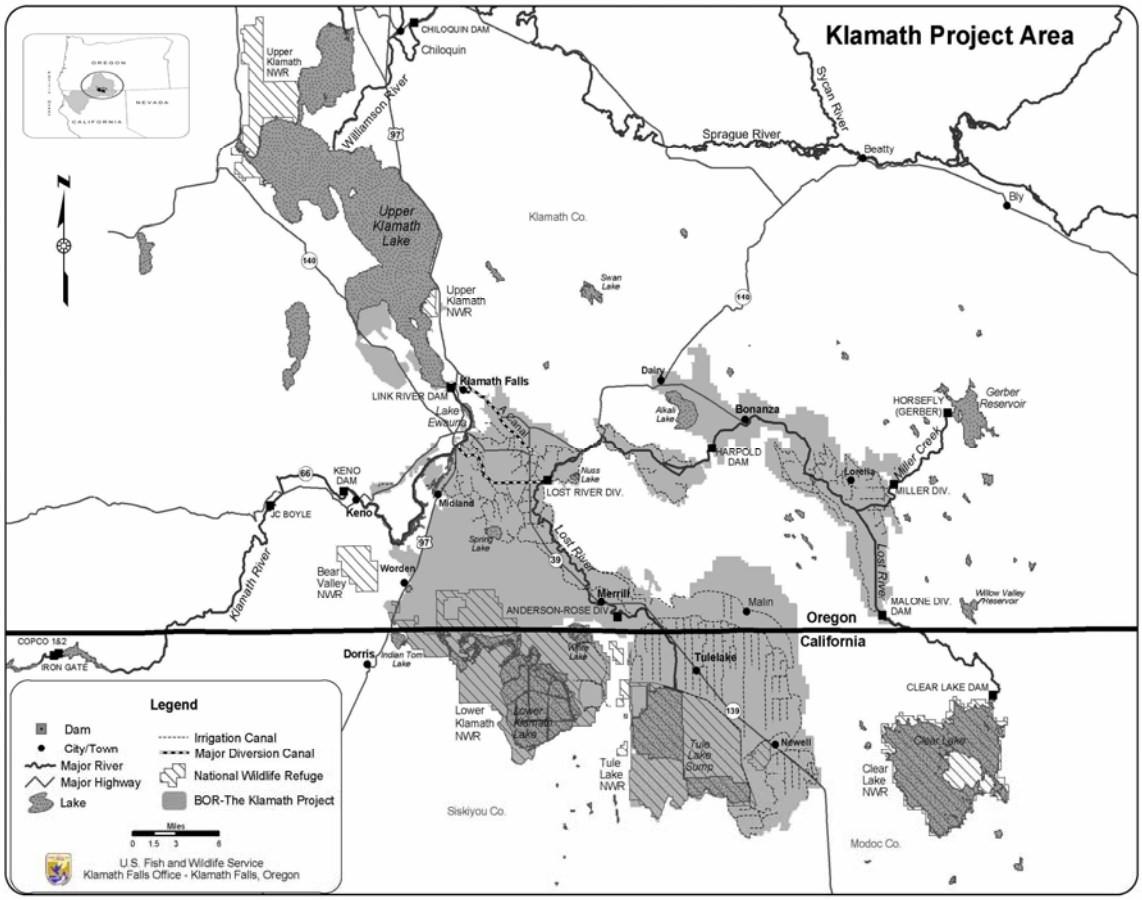

Figure 1 – Klamath Project Location and Orientation

NEEDS FOR FLEXIBILITY

By the late 1990's, proposals had been made to meet tribal trust obligations with higher lake levels and higher flows at Iron Gate, and concern for threatened coho salmon in the lower Klamath River had led to other new river flow recommendations. More recently, the National Marine Fisheries Service and U.S. Fish and Wildlife Service have tailored requirements for Iron Gate flows and UKL levels to forecasted seasonal water supplies. Reclamation's consultations with the Services on annual operating plans have led to the creation of a water bank and use of secondary storage capabilities to reduce impact to irrigation. These discussions have also stimulated ideas for resolving conflicts between competing demands for water. As the regulatory environment has changed, so have the needs for analysis to support the decision making process.

The format used by KPSIM to define lake water level, minimum flow, and delivery requirements makes it possible to enter sets of operating criteria that pose a hydrologic challenge to the river system. Furthermore, the only mechanism in the model for achieving flows at Iron Gate above the input minimum is through uncontrolled local accretions or UKL spill. These and other limitations create opportunities for conflict between competing criteria and cause difficulties in effective scenario development, which is often reduced to trial-and-error entry of criteria until desired results are seen. Although modifications have been made to add flexibility in the form of permissible relaxation of certain demands and to allow "sharing" of limited water supplies, the foundation of the model remains one where water supply responds to demands. It became clear that analysis was also needed for scenarios where demands respond to water supply.

CALSIM

CALSIM is unique among data-driven general-purpose models in that it is not bound to pre-defined object types or operations. The user defines the mass balance relationships among system nodes and links, and describes specific constraints and targets for storage and flow using the water resources simulation language (WRESL). Each storage and flow element that is assigned a relative priority, or weight, becomes part of the objective function. For each time step in the simulation period, the LP/MIP solver maximizes the objective function to determine a solution that delivers or stores water as guided by the specified priorities, constraints, and target operations.

The difference between the CALSIM framework's approach and that of a procedural model is often described as specifying "what" instead of "how". Where a procedural model follows a flow chart of steps – a process – to calculate an operation, CALSIM requires the user to state simply what the decision space of the operation is and to assign it a priority. The solver does the work of finding an optimal solution for the set of decision variables. It is the user's responsibility to both specify a problem that has a solution and adequately constrain the solution to achieve an appropriate result.

In 2002, CALSIM reached a software development threshold at the same time that the Klamath Project analysis needs began to exceed KPSIM capabilities. The initial application of CALSIM to the Klamath Project was supported by Reclamation's Science and Technology Program. Its goal was largely to demonstrate the general-purpose nature of the software, which until then had only been applied to the CVP/SWP system. The test addressed the Klamath model requirement for a custom time step and developed example logic for distributing water supply. Subsequent refinement of the application was supported by Reclamation's Klamath Area Office and Department of the Interior. Particular effort was focused on facilitating capabilities not available in KPSIM – addressing the limitations of the step functions for specifying operating criteria, adding and/or changing system facilities, and representing alternative river system management strategies.

Scenario development in KPSIM was often made difficult by the lack of ability to fine-tune operations requirements. The step functions of criteria for UKL water surface elevations and Iron Gate flows have 4 and 5 levels respectively, each of which are in place for a broad range of inflow conditions. Expanding the layers of criteria tables in the spreadsheet is a time-consuming task, requiring new table sizes and editing each associated lookup function. The structure of relational data used by CALSIM, in independently sized tables with lookups by maximum, minimum, or linear interpolation, leaves this functionality to the mechanics of data retrieval and relieves the user from the task of making structural changes for every scenario.

A key feature of general-purpose models is the ability to adjust the river system definition itself. Adding new storage facilities or changing the properties of existing ones can be time consuming in a procedural model, and evaporation functionality for multiple reservoirs taxes the need for iterations in an Excel environment. Similarly, adding or changing demands and other operational targets or limitations is both easier and more transparent in a model like CALSIM. Examples of needs for these types of changes in Klamath Project modeling have included analysis of such off-stream storage facilities as Agency Lake Ranch, Swan Lake, Lower Klamath Lake, and Long Lake, an Upper Klamath Lake storage capacity increase, and revised scenarios for irrigated acreage.

Finally, representation of alternative river system management strategies is facilitated with a flexible modeling framework. CALSIM does not prescribe any particular approach to the definition of demands and operating criteria or their implementation. The environment thus allows substantial leeway to develop allocation scenarios and to

distinguish minimum, desired, and excess levels of criteria satisfaction. The left side of **Figure 2** shows the schematic diagram of the Klamath River portion of the KPSIM network, where each delivery arc and channel arc have a single element. The right side of the figure shows a generalized network example where priorities for satisfying different levels of demand can be interleaved or specific flows tied to water supply. This is the type of network that will ultimately be more useful for future Klamath Project model scenarios.

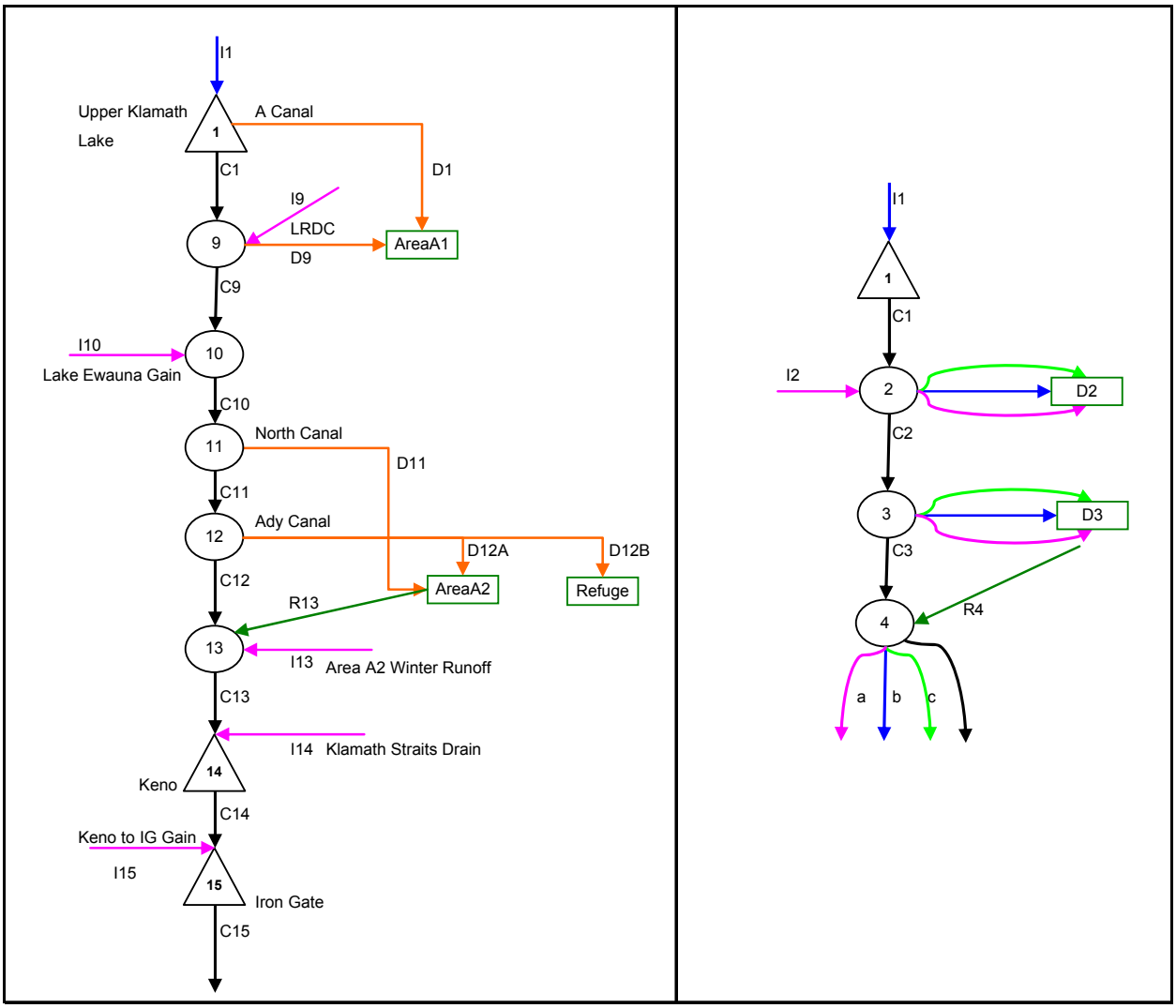

Figure 2 – Schematic Diagrams of Klamath CALSIM Application and Multi-Link Example

REPLICATION OF KPSIM WITH CALSIM

One application of CALSIM has been developed to precisely replicate the logic of the KPSIM spreadsheet model. Principally undertaken to anticipate and address calibration and validation questions, the exercise was also prepared to serve as a learning tool for those who will make the transition from KPSIM to CALSIM. The schematic network **(Figure 2, left side)** was developed to represent KPSIM connectivity, and input data from an established KPSIM scenario was used for UKL water surface elevations, IG flows, and diversion demands. The application explicitly reproduces existing KPSIM logic for computing time step and seasonal views of water supply, delivering water, and defining UKL spill.

A comparison of KPSIM and CALSIM results for Klamath River operations – lake levels, flows, and diversions – show few differences, all explained by very slight differences in lookup function results. When mapping UKL water surface elevation targets to storage targets, the respective lookup functionality of CALSIM and KPSIM result in slightly different values. These differences affect the perceived need to spill water, which in turn creates a difference in flow at Iron Gate Dam. Lower spills in one time step are typically balanced by equally higher spills in the next time step. Similarly, lookup function issues cause slight differences in deliveries. These differences amount to no more than 1.6 taf per year, less than 0.5% of the annual demand. Plots of the delivery, flow, and lake elevation differences are shown in **Figure 3**.

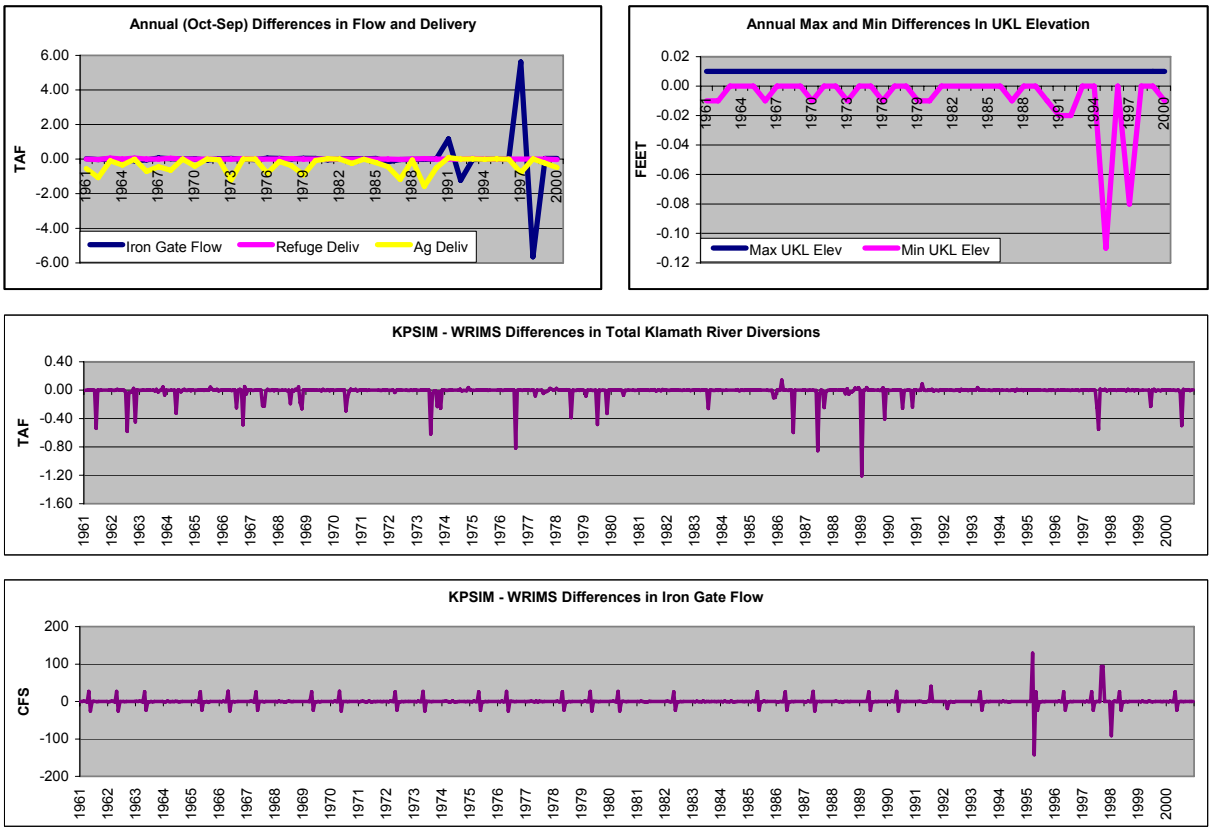

Figure 3 – Comparison of KPSIM and CALSIM Results

STAKEHOLDER CONCERNS

Many Klamath Basin stakeholders have become familiar with KPSIM, and the transparency of the spreadsheet environment has fostered trust in its use. Excel is a well-known software program, the model does not use complex formulas, a user's manual is available, and numerous training seminars gave people who wanted to understand the model the opportunity to do so. However, frustration with KPSIM limitations has been felt in the Klamath Basin community in recent years as management questions arise that go beyond what the model can address. There is a willingness among stakeholders and their technical advisors to apply new tools.

Reclamation has taken steps to address these issues and prepare the stakeholder community for migration to the CALSIM model. Consultants who already know CALSIM through work on the CVP/SWP have been given the replication model and briefed on its development history. A meeting in December 2004 reviewed the history of model use in the basin, introduced the CALSIM software and its application, detailed the differences between it and KPSIM, and presented results of the replication run. Reclamation anticipates the dedication of substantial effort, through reports, workshops, and documentation, to achieving the same level of confidence in the CALSIM application that KPSIM has enjoyed.

CALSIM APPLICATIONS IN THE EXTENDED KLAMATH RIVER BASIN

Upper Basin Water Rights Model Development: The Sprague, Williamson, Sycan, and Wood River watersheds that flow into Upper Klamath Lake provide a water supply to a network of water users distinctly separate from the Klamath Project. The Department of the Interior is engaged in water and land settlement negotiations with the Klamath Tribes and other stakeholders in the basin to work on long-term solutions to a broad range of water, land and wildlife. Discussions have included possible return of public lands that were formerly within the Klamath Tribes' reservation, restoration activities in the upper basin watershed, and describing water rights for instream flows in tributaries to Upper Klamath Lake. The State of Oregon Water Resources Department used MODSIM in 2000 to build a water rights model of the upper basin in the course of analysis for their water rights adjudication process. The decision was made by DOI to port this model to the CALSIM environment, anticipating future needs to link with the existing Klamath Project model which begins at UKL.

The CALSIM framework easily accommodates the need to represent water rights with weights on diversions and instream flows. This model is under construction and may be completed in 2006. The stand-alone version will provide information on impacts to water supply from proposed settlement flow standards, and linking the model to the existing Klamath Project application will permit analysis of whole-system scenarios.

Middle Basin Model for FERC Relicencing: Six hydroelectric power generation facilities on the Klamath River between Upper Klamath Lake and Iron Gate Dam are operated by Pacificorp. An interagency analysis team charged with studying several decommissioning scenarios in support of a settlement negotiation with PacifiCorp and other stakeholders has opted to use the CALSIM framework for a monthly model of simulated project operations. As with the upper basin model, anticipation of future capabilities to link with the Klamath Project model steered the selection of CALSIM over a stand-alone application.

Klamath Basin Hydrologic Economics Model: An analysis package originally developed in 1999 to link water supply and economic conditions with Klamath Project cropping decisions, irrigation methods, and yield targets is slated for migration to the CALSIM environment. Historically used as a post-processing utility, this tool would be more helpful if integrated into the dynamic operations of the Project model, and be able to respond to or contribute to water supply decisions as part of future Project management scenarios.

SUMMARY

Anticipated challenges in managing water supply in the Klamath Basin call for analysis tools that help clarify tradeoffs and management options. The data-driven and flexible CALSIM environment gives Reclamation and other basin stakeholders a platform that can respond to new questions efficiently and effectively.

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