FORECAST-COORDINATED OPERATIONS FOR THE YUBA-FEATHER RIVER RESERVOIR SYSTEM: INTERAGENCY COOPERATION

Author(s): **Rob Hartman, Hydrologist-in-Charge, California Nevada River Forecast Center, National Weather Service, Sacramento, CA, Robert.Hartman@noaa.gov; David Ford, President, David Ford Consulting Engineers, Sacramento, CA, ford@ford-consulting.com; Art Hinojosa, Chief of Hydrology Branch, Division of Flood Management, California Department of Water Resources, Sacramento, CA, hinojosa@water.ca.gov;, Curt Aikens, General Manager, Yuba County Water Agency, Marysville, CA, caikens@ycwa.com, Stu Townsley, Chief, Water Management Section, US Army Corps of Engineers, Sacramento, CA, Edwin.S.Townsley@usace.army.mil**

Abstract: Oroville Reservoir on the Feather River and New Bullards Bar Reservoir on the Yuba River in northern California are operated, in part, to reduce flood damage and risk to life at points downstream. Each reservoir operates independently for locations immediately downstream, and the reservoirs are operated jointly for common downstream points. Recent studies demonstrate that joint operation of the Yuba-Feather system is best accomplished when weather, water, and management information are shared and when operational decisions are coordinated amongst the agencies involved. These agencies include the California Department of Water Resources (DWR), the Yuba County Water Agency, the US Army Corps of Engineers, and the National Weather Service (NWS).

To facilitate effective information sharing, a decision support system (DSS) has been planned, with funding from the State of California and with input from and cooperation of all involved agencies. When created and implemented, this DSS will allow reservoir operators to make better-informed decisions about releases, and it will allow forecasters to make better-informed forecasts that incorporate accurate, timely information about selected releases.

The DSS will be deployed in a distributed manner, with hardware and software at the joint state and federal operations center, at the California State Resources Building, and at the Sacramento office of the Corps of Engineers.

In this paper, we describe in more detail our vision of the system when deployed, and we report on the current work status. Finally, we describe the interagency cooperation that is key to the success of this project and offer some observations about how such cooperation can be fostered elsewhere.

SITUATION: OPPORTUNITY FOR IMPROVED OPERATING AND FORECASTING

Study area

The Yuba-Feather River system includes the basins generally upstream of the confluence of the Feather River and the Bear River in northern California, as shown in Figure 1. Major reservoirs in the system are New Bullards Bar Reservoir and Oroville Reservoir, which are operated for multiple purposes. Here, we consider operation for flood damage reduction downstream. As the reservoirs store water, they can reduce excessive flows in the Yuba or Feather Rivers at Marysville and neighboring Yuba City. The reservoirs can also store water to reduce flows downstream along the Sacramento River.

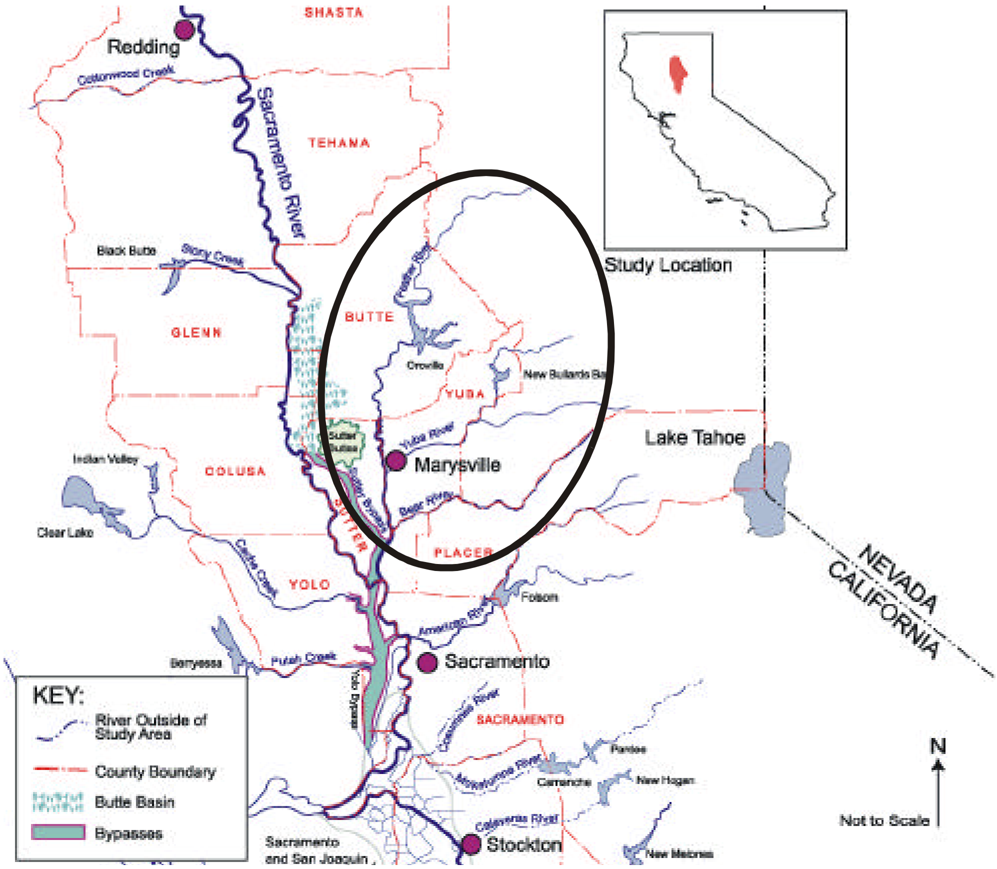

Figure 1. Yuba-Feather system study area (adapted from USACE, 2002b)

Yuba-Feather system operation

Decisions about system operation are made by state and local agencies, with input and guidance from federal agencies.

Water managers at the Yuba County Water Agency (YCWA) and the California Department of Water Resources' (DWR) Operations Control Office (OCO) make decisions about operation of New Bullards Bar and Oroville, respectively. Managers of both agencies get forecasts of inflows and downstream flows from the California-Nevada River Forecast Center (CNRFC) of the National Weather Service (NWS) and the DWR Division of Flood Management (DFM).

The Sacramento District of the US Army Corps of Engineers also plays a role in the management of excess water in the system. Construction of the reservoirs used federal funds, so in accordance with, Section 7 of the Flood Control Act of 1944, the Corps prescribes regulations for use of storage allocated for flood control, and ensures that the operation follows regulations.

During flood periods, operational decisions for the reservoirs are made as follows (more or less):

1. Weather and water states are measured throughout the basins. Observations are both automatic and manual and are reported by radio, telephone, Internet, microwave, and satellite. These data are collected in the California Data Exchange Center (CDEC) and stored in the CDEC database.
2. The CNRFC and DWR DFM staff retrieves the data from the CDEC database, and forecast reservoir inflow and local flow (uncontrolled flow downstream of the reservoirs) throughout

the basin and future water levels in the basin's channels. The runoff forecasts are made with the CNRFC's NWSRFS model. This simulates behavior of the watersheds using the Sacramento Soil Moisture Accounting model and behavior of the channels using lumped routing models and rating functions. The inflow and local flow forecast is provided to system reservoir operators through a combination of e-mails and ftp.

3. Reservoir operators use the inflow, local flow, and water level forecasts to make decisions about releases. The decisions made include current operation—how much to release now—and future operations—how much to release in the future if the forecasts are correct. When making release decisions, the operators consider their mission and authorities, the needs of their customers, the authorized operation purposes, approved operation rules, and the current state of their reservoirs.

4. Operators provide release schedules to NWS and DWR forecasters; these are releases that the operators intend to make in the near future. This step is necessary because these releases—which NWS cannot reasonably forecast with NWSRFS—have a significant impact on downstream flows. For example, the stage at Marysville is a consequence both of the release from New Bullards Bar and of the uncontrolled runoff from the watershed between the reservoir and the city.

   The release information arrives at the State-Federal Joint Operation Center (JOC) in a variety of formats, through various formal and informal routes. This information is stored in the CDEC database and relayed to the CNRFC operations floor.

5. NWS and DWR forecasters use the release schedules to complete the system-wide forecast, routing the releases and combining those with forecasted runoff from the uncontrolled subwatersheds downstream of the reservoirs.

In some sense, this operational scenario is a chicken-and-egg situation. The NWS must forecast inflows so operators can make release decisions. But the operators must be able to determine the downstream impacts of the releases, including the combined effects of releases at and below the Yuba-Feather confluence. And NWS must know the release schedule to forecast stages downstream. In short, the release decisions require the forecasts, and the forecasts require release decisions. Effective interaction and information exchange are critical for both.

Opportunity for improvements

Our intuition tells us, our experience demonstrates, and a recent DWR study (DWR, 2005) confirms that Yuba-Feather system reservoirs best manage excess water with careful coordination between Oroville and New Bullards Bar operators. This includes information sharing regarding anticipated future releases.

In March 2000, California voters approved the 2000 Water Bond, which authorized general obligation bonds to support safe drinking, water quality, flood protection, and water reliability projects throughout the state. With funding from this, YCWA investigated opportunities for improved flood management. As a component of that investigation, YCWA developed the concept of forecast-coordinated operations (F-CO). This called for sharing data, hydrologic forecasts, and operation information amongst the involved agencies.

More or less simultaneously, DWR's DFM recommended development of a decision support system (DSS) that would enhance data and information sharing, with common models and databases.

Eventually, these similar-objective proposals were coordinated and integrated, with significant input from DWR OCO, DWR DFM, NWS, and the Corps. A subsequent proposal by YCWA for development and deployment of an F-CO DSS with funding from water bond monies was prepared, submitted, and accepted.

TASK: DEVELOP A FORECAST-COORDINATED OPERATION SYSTEM

The task, then, was to design, develop, and deploy a forecast-coordinated operations system for the Yuba-Feather river reservoir system. This was to be a system used by the operators, accepted by the regulators, enlightening to the forecasters, and most importantly, beneficial to the citizens of California. In our vision, the heart of the system is a DSS: an automated information technology system that provides for convenient, quick sharing of information. But equally important, we saw that participation and acceptance by all involved agencies of the DSS design and plans for how it is used were critical to successful satisfaction of the goal of coordinated operations.

Goals and guidelines

The overall goal of the DSS is to improve the flow of information, thus allowing operators to make better-informed release decisions and to allow forecasters to make forecasts that include accurate, timely information about those releases. More specifically, we agreed that the DSS should:

- Be an improvement over current information sharing. Scheduled releases are shared amongst operators and forecasters now. The DSS must improve the flow of information and simplify data handling.
- Be linked to a powerful reservoir system and river routing simulation software program, so that both operators and forecasters can have access to the analytical processing tool for studying what-if scenarios as they make release decisions.
- Be sufficiently flexible to accommodate changes to system operation and system features, as these changes are sure to happen over the next few years.
- Be simple enough to be readily usable by system operators, yet complex enough to provide them with answers to questions that they are likely to ask when making operation decisions.
- Be scalable. The ultimate goal is to develop a DSS that can be used for other reservoir systems throughout California.

Constraints on development

F-CO provides an opportunity for improved operation of the reservoirs in the system and an opportunity for improved forecasting of downstream flows and stages. But to achieve this improved operation and forecasting, the mechanism by which F-CO is implemented must satisfy constraints on both operators and forecasters. Agency staff and consultants met throughout 2004 and identified constraints that must be met by the DSS. These include requirements that the DSS:

- Fit within context of the existing CNRFC/DWR forecast-modeling system.
- Fit the context of the existing CDEC data system.
- Limit disclosure of sensitive information, including hydropower releases planned by utilities.
- Be developed and deployed quickly.
- Fit within the existing institutional arrangements.
- Be a system-wide solution, implemented across the agency boundaries.

- Have implementation, operation, and maintenance costs that are acceptable within the current budgetary requirements of the agencies involved.
- Use available information technology (IT) human resources for development and for support.
- Use available IT hardware for implementation.
- Be uninterruptible.
- Be secure.

ACTIONS: WHAT WE ARE DOING TO ACHIEVE FORECAST-COORDINATED OPERATIONS

Overall strategy

The strategy for designing, developing, and deploying the F-CO DSS was to "lash everyone into the same lifeboat." The YCWA project manager structured a project management team that included senior decision makers from all agencies, plus their consultants. This management team meets at least monthly to review progress, address policy and administrative issues, and provide direction to staff. Project delivery teams work on specific tasks to realize project goals, including, but not limited to development of the DSS. These delivery teams report to and seek direction from the management team.

DSS design

The F-CO team collectively agreed to a DSS that works in a client-server configuration, with user access via a Web-enabled interface. This design has the following advantages:

- It consolidates the IT management, removing that chore from the reservoir operators at YCWA and DWR OCO.
- It allows the agencies involved to rely on centrally-located databases that will support the sharing of models and modeling results, rather than requiring each agency to maintain their own databases. However, it allows each agency to maintain a copy of the critical DSS software components to ensure uninterruptible operation.
- It provides for convenient remote access, both under normal operations and during flood emergencies, when staff may be displaced or facilities inaccessible.

The overall structure of this client-server configuration and the flow of data and information amongst the components are shown in Figure 2.

Operational decision support starts with inflow and local flow forecasts provided by the CNRFC, using NWSRFS (item 1 in the figure). The forecast relies on data retrieved from the CDEC database (item 2). The forecast is stored in the CDEC database (item 2), thus permitting efficient, rapid exchange with all agencies involved. Procedures are currently in place for these actions.

The initial inflow and local flow forecast is retrieved from the CDEC database, and the HEC-ResSim reservoir system simulation program (item 3) is executed to find an initial release forecast. That release forecast blindly follows default operation rules. The release forecast is posted to the CDEC database, secure from public access.

HEC-ResSim is executed on a server at the JOC; this server is managed by DWR CDEC staff. The HEC-ResSim model uses a configuration database (item 4) stored at CDEC. [A redundant installation of HEC-ResSim will be housed at the State of California Resources Building. This redundant configuration will be synchronized with the version at the JOC and will be configured to operate in a fail-over mode. This is not illustrated in the figure.]

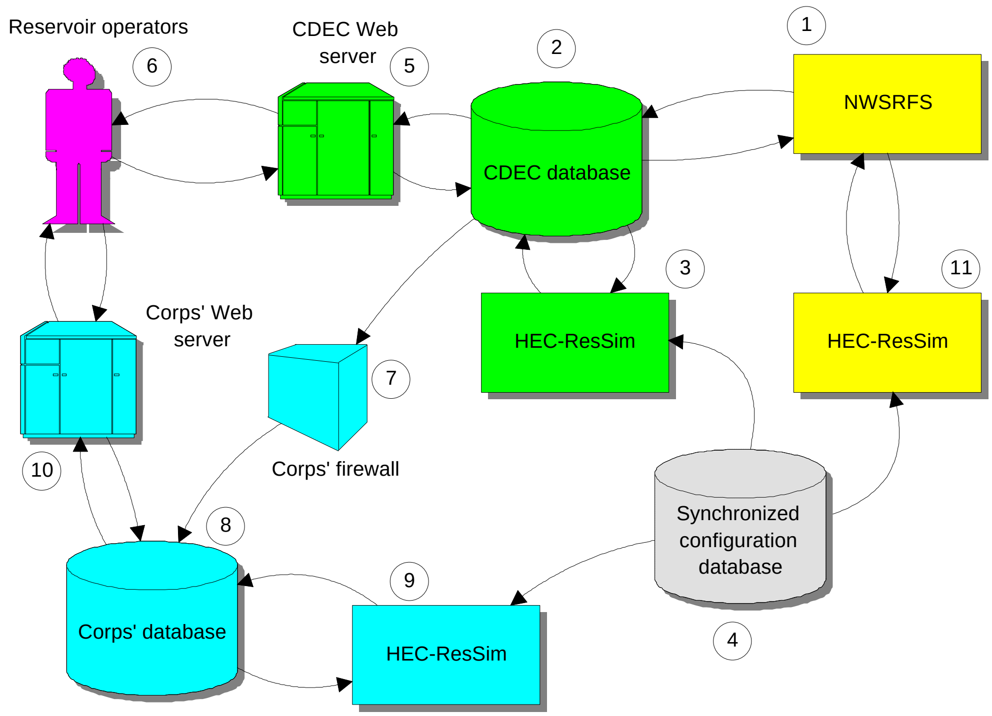

Figure 2. Generalized configuration of F-CO DSS deployment

The NWSRFS inflow and local flow forecast and the initial release forecast from HEC-ResSim are made available through the CDEC Web server (item 5) to the Oroville and New Bullards Bar operators (item 6) through a Web interface.

Through the Web interface, the operators view the forecasts and the initial release forecast proposed by HEC-ResSim. And with the Web interface, the operators can override and alter the release forecast. If they alter the release forecast, the new values are transmitted by the Web server back to the CDEC database, where these are stored temporarily in a secure area. Then the modified release forecast is retrieved and analyzed automatically with HEC-ResSim, thus providing to the operators a system-wide assessment of the impacts of changes that they propose. These results are provided to the operators through the CDEC Web server and the Web interface.

Once operators are satisfied that they have selected the best releases, they are saved and relayed to NWSRFS. With the release schedule, routings are completed and the final system-wide forecast is completed by the NWS and DFM forecasters. This system-wide forecast is posted again to the CDEC database, where it is available for public access.

To ensure continuity of operations by the NWS, the CNRFC also maintains within the NWSRFS suite a version of the HEC-ResSim program (item 11). Thus, in the event of a failure of communications with the operators or some delay in transmitting release schedules, NWS staff can simulate operation following the basic operating rules, forecasting both a release schedule and resulting system-wide flows and water levels. The NWS version of HEC-ResSim uses a HEC-ResSim configuration database (item 4) that is identical to that used by DWR and by the Corps. Procedures are established amongst the agencies to ensure that the HEC-ResSim configuration databases are fully synchronized.

On a parallel path, the Sacramento District of the Corps maintains and operates a system that includes an identical version of the HEC-ResSim program (item 9) and the HEC-ResSim configuration database (item 4), running on a server in the District office. The configuration database is synchronized with that used by DWR and the NWS. For execution at the Corps office, HEC-ResSim retrieves inflow and local flow forecasts from the Corps database server (item 8), which, in turn retrieves those forecasts from the CDEC database. A firewall (item 7) ensures security of the communications between the state and federal computer systems. The Corps system includes also a Web server (item 10). This provides a redundant path over which the inflow and local flow forecasts are available to reservoir operators and through which operators can evaluate release forecasts if the state system is not available. In that case, the operators would evaluate alternative release schedules by running the HEC-ResSim model on the Corps' server, posting their final release schedules to the Corps database until the CDEC database again is available.

CURRENT STATUS

As of October 2005, development of the F-CO DSS has progressed as follows:

- The design described above has been accepted by all agencies.
- DWR CDEC staff made changes to the database, as required.
- DWR CDEC staff and YCWA consultants prepared and presented a working prototype of the DSS, including the Web interface.
- CNRFC staff expanded application of NWSRFS to the Yuba-Feather system to ensure that the flows forecasted are at locations consistent with the HEC-ResSim model.
- DWR staff and consultants developed an initial representation of the reservoir system with the HEC-ResSim program.
- The Corps' Hydrologic Engineering Center is engaged in enhancing the HEC-ResSim program to meet F-CO needs. CNRFC is overseeing this work, and YCWA is administering the contract, with DWR funding.
- The management team continues to meet regularly, as originally planned.
- Other non-DSS activities are progressing on schedule. These include adding rain and snow sensors and updating emergency protocols.

LESSONS: WHAT WE LEARNED THAT MAY HELP YOU

Most of us have been involved in projects that have not fully realized their potential. This particular effort appears to be unusually successful. It is important, therefore, to examine this effort and identify the attributes that have lead toward success. This is done in the spirit of helping other worthwhile projects garner the energy and support needed to succeed.

Lesson 1. *Address a high impact issue that everyone can identify with and benefit from.* While it may seem simple and obvious, coordinated reservoir operation is the exception rather than the rule. As structural flood mitigation becomes more difficult and expensive, it is increasingly important to fully exercise non-structural measures. F-CO has benefits for operating agencies, oversight agencies, forecasting agencies, and downstream communities. The operating agencies have had the desire to coordinate their actions, but the basis, mechanics, and informational support are traditionally lacking. Oversight agencies want to help the operating agencies manage their flood control space and need tools and information on both ends to be effective. Forecasting agencies need anticipated release information to support downstream forecasts and warnings.

And finally, downstream residents want the reservoirs to perform in a fashion that limits their exposure to damage while maintaining other water management benefits. F-CO provides benefits to everyone.

Lesson 2. *Cast a vision and support it.* While the benefits of F-CO seem obvious, they were not taken for granted. Project promoters cast a vision of future operations where the combined system would be capable of handling floods larger than could be “controlled” independently. Early on, a prototype of the system was developed to demonstrate the “proof of concept.” Project participants also made an intentional effort to get the word out. Support and momentum were maintained and clarity was gained by presenting the project concept and plans at professional meetings and workshops.

Lesson 3. *Maintain momentum.* Large and long project often suffer from fatigue. In this case, momentum has been maintained through two practices. First, the project has clearly defined phases. A phased implementation allows for preliminary results that keep the champions, participants, and beneficiaries motivated. Second, the project has a management team that meets regularly and has a high level of accountability, both to their own agencies and to the project team.

Lesson 4. *Initial and on-going funding and support are essential.* Garnering resources in today’s climate can be difficult, but a clear winner with multi-sector support has a greater likelihood of success. It is also very important that the operating agencies commit to the on-going operation and maintenance of all projects enhancements including instrumentation and IT. In this case, YCWA and the State Water Project eagerly agreed to support all new gaging needed to improve the quality of forecasts issued in support of the F-CO.

Lesson 5. *Teamwork works*. And finally, it’s entirely possible that this project has been successful because it is a balanced partnership. Put differently, “nine 100 pound gorillas are better than one 900 pound gorilla.” YCWA, DWR, USACE, and the NWS come to the table and work on components that are individually mission-critical. At the same time, they are critical to the success of this project. No one is capable of steering the project in the wrong direction or preventing it from moving forward. The effort is also supported by respected and well-qualified engineering consultants who perform analyses and work that exceeds the capacity of the cooperating agencies. This important contribution allows the project to move forward smoothly and more quickly than otherwise possible.

REFERENCES

California Department of Water Resources (2004). *Enhanced reservoir data sharing for forecast-coordinated operation of Yuba-Feather River reservoirs*. Prepared by David Ford Consulting Engineers, Inc. under contract number 4600001508, task order no. 16. Sacramento, CA

California Department of Water Resources (2005). *Oroville and New Bullards Bar Reservoirs flood operation assessment*. Prepared by David Ford Consulting Engineers, Inc. under contract number 4600001508, task order no. 17. Sacramento, CA

US Army Corps of Engineers (2003). *HEC-ResSim reservoir system simulation, version 2. CPD-82*. Institute for Water Resources, HEC, Davis, CA.

USACE (2002b). *Sacramento and San Joaquin River basins comprehensive study, Interim report.* Sacramento District, Sacramento, CA.