Evaluating the Feasibility for Forecast Informed Reservoir Operations (FIRO) Improvements at Reclamation Facilities

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Abstract

Reclamation water management is increasingly restricted by greater human usage, larger environmental compliance demands, and accelerating climate change. These factors interact to intensify the requirements on water resources infrastructure and the scrutiny regarding how those resources are managed. Forecast Informed Reservoir Operations (FIRO) are an approach through which Reclamation can adapt to these factors. FIRO pilot studies have demonstrated the feasibility of utilizing improved meteorological/hydrological forecasts combined with better management techniques to simultaneously improve dam safety and water availability. This work summarizes the current status of FIRO pilot studies at two Reclamation facilities -- Folsom Dam and Link River Dam (Upper Klamath Lake) -- what, if any, water management alternatives are available to increase water availability, improve environmental compliance, and adapt to a changing climate

Folsom Dam is of interest to Reclamation due to its buffering role in managing the Central Valley Project (CVP) and its significant environmental demands, an aspect not present in previous FIRO projects. With a nominal storage of a million acre-feet and generation of slightly less than 200 MW, Folsom is often utilized to balance operations across the CVP due to its short travel time to the Delta. The basin comprises 1900 square miles with hydrology typically dominated by snowmelt that is re-released by upstream storage facilities. The basin is shifting from snowmelt driven inflows toward more rainfall under climate change which may increase pressure on its limited storage. The recent installation of an axillary spillway shifted space from the flood to the conservation pools. Under consultation with the USACE, a revision to the rule curve was created which allows for limited incorporation of forecast information. The plan to raise the facility to provide additional storage gives an opportunity to revisit operations and determine if additional operations improvements can be obtained through forecasting.

Water availability issues are also prevalent in the Upper Klamath Lake basin where water supply cannot be carried over year-to-year due to limited water storage capacity. High flows occurring from November through May must sustain the Klamath Project's 230,000 acres of farmland from April through September; therefore, improving operational releases during high flows is vital to maintaining adequate water supply for irrigation. Recent extreme drought conditions have made the need for innovative solutions more urgent than ever. Currently, the flood season guide curve is determined based on long-term forecasted inflow. Absent short-term decision guidance, operators make qualitative release decisions, which may not be sufficient during extreme conditions with limited margin for error. A FIRO model for the reservoir can optimize flood releases to provide additional supply while managing flood risk by utilizing meteorological/hydrological forecasts and optimized operations decision-making.

Introduction

FIRO is a set of principles and practices that improve water management by incorporating forecast information into the water operations decision process. (Scripps Institution of Oceanography, 2021) The tighter integration of forecast information with water management can extend decision windows, quantify uncertainty, and highlight alternative operation scenarios. These benefits allow water operators to anticipate future conditions and adapt their current management decisions with high confidence. Therefore, FIRO methods can maximize the utility of existing infrastructure by altering the management practices and avoiding the need to modify the physical infrastructure. By integrating forecast and climate data into the water management practices, FIRO approaches will help Reclamation to better respond to novel and uncertain scenarios that will arise from climate change. Additionally, FIRO can improve operators' ability to balance competing use cases and make the most of limited water resources. The benefits potentially available through FIRO have led to significant interest in exploring its application at Reclamation facilities.

Implementation of FIRO generally requires three integrated components within a unified framework: meteorological forecasts, hydrologic/hydraulic modeling, and quantitative management objectives. These three components iteratively work together to translate forecast information into an operations plan.

Meteorological forecasts are the primary component of FIRO. The forecast skill over the lead time into the future dictates the extent of the benefits available from FIRO. Forecast skill generally decreases with lead time to a point where the forecast is no better than climatology; however, even with long lead times, a forecast may be beneficial if it is skillful at wet/dry determinations. Additionally, ensemble forecast products can quantify the likelihood of events to provide a basis for uncertainty estimation. An initial step in FIRO is therefore to understand the available forecast skill. While numerous ensemble forecast products exist, Reclamation has worked closely with NOAA on the Global Ensemble Forecast System (GEFS) (National Oceanic and Atmospheric Administration, 2021). Together with its 20-year historic reanalysis dataset, the GEFS provides an initial dataset to evaluate forecast skill that can be used operationally with up to a 16 day forecast lead time.

Hydrologic modeling is used to translate the meteorological forecasts to anticipated magnitudes and timings for stream flows. Hydraulic modeling may be utilized in addition if quantities such as temperature or other water quality variables are of interest in the management process. Although any model can be utilized which demonstrates skill at representing a basin, use of physics-based models is recommended with FIRO to maintain model skill when presented with new conditions. A hydrologic/hydraulic model will include management scenarios as one of the inputs and provide the impact of scenario on the system as an output. The hydrologic/hydraulic models may therefore need to be ran hundreds or thousands of times within an optimization framework to determine the best management scenario against the management objectives.

Optimization techniques are mathematical approaches that determine the best alternative from a set of possible alternatives given a constrained system or a system that is trading off competing objectives. Optimization methods supplement the decision-making process by evaluating system performance to provide specific and repeatable decision recommendations. These methods can also be useful when making decisions under uncertainty as the uncertainty can be incorporated within the optimization to produce the recommendation. The basic components of an optimization are a model for the system (the hydrologic/hydraulic model); an understanding for how constraints are imposed on the system; and a solver capable of iteratively evaluating the model against those constraints to maximize the quantitative management objectives.

The final FIRO component is the quantitative set of management objectives. These are the desired aspects of the reservoir operation for which operators actively manage: maximizing pool storage, limiting flood risk, or controlling downstream water quality. Taken together with system constraint information that gives the mandatory performance of the system, the optimization engine can use the hydrologic/hydraulic models to determine an optimal operations plan. In resource constrained cases, the optimizer can trade off management objectives based on priority. This requires that management objectives be gathered and cast as quantitative criteria that the optimizer can evaluate. Operators may additionally choose to perform a sensitivity analysis on the optimal plan by changing the priority of the management objectives.

Results

The presented work will summarize ongoing Reclamation FIRO investigations at Folsom Dam and Upper Klamath Lake. The effort will focus on precipitation forecast skill using the GEFS as the data source for the forecast and hindcast meteorological forecast ensembles. The skill of the GEFS will be evaluated as a function of forecast lead time for both event magnitudes as well as wet/dry conditions using both probabilistic and contingent metrics to understand error as a function of forecast magnitudes. This effort will result in the forecast lead time over which the GEFS performs better than climatology. The analysis will provide benchmarks to evaluate future forecast improvements as well as the lead time for which FIRO will have skill at each facility. These skill values will be used in detail when formulating the risk-based management alternative and as limiting values for hydrologic skill evaluation.

References

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