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Coupling desalination to reservoir operation to reduce dependence on streamflow forecasts

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Introduction

Surface water flows are changing due to human interferences and recent and expected future climatic changes. Thus, the conventional approach to managing reservoirs that are based on passive operating policies is becoming no longer effective as they rely on streamflows conforming to historical patterns. This makes it increasingly necessary to adopt a forward-looking adaptive approach to reservoir operations. Such an approach entails short- and long-term streamflow forecasts. However, the value of a forecast depends on its form. Ensemble forecasts are of greater value than deterministic forecasts (Fan et al. 2014). The lead time of a forecast is another important factor (Zhao et al. 2012).

To generate ensemble forecasts of adequate lead time and accuracy is not a straightforward process that can only increase in difficulty with time. Climate change is altering precipitation and temperature patterns, causing streamflows to deviate from their historical norms. In other words, streamflows are becoming more and more non-stationary and therefore, harder and harder to predict from past records. While recent efforts (Kalra et al. 2013) have advanced our forecasting ability, streamflow forecasting remains a problematic task due to inherent natural variabilities. Moreover, the level of expertise and quantity of data required to use these improved methods are not always available to local water agencies (Pagano 2014).

In light of these concerns, we examine the potential of coupling of reservoir, seawater desalination and wastewater recycling operations, depending on available budget, to reduce the dependence on high-quality streamflow forecasts. Desalinated seawater and recycled wastewater effluent are unaffected by climate fluctuations, and hence, their potential to somewhat compensate for the lack of certainty in reservoir flows. However, they are relatively expensive. The coupling of the three sources is in line with the growing emphasis on integrated water resources management, which advocates the planning and management of different water sources and facilities in a coordinated manner.

Methods

We consider a semi-hypothetical case comprising a single 3000 million m^3 reservoir, a 2 million m^3/day seawater desalination plant and a 2 million m^3/day wastewater recycling facility. Weekly inflows to the reservoir are artificial values simulated from real climate data for a location in India using a simple hydrologic model. Water demands are based on actual demands for the region. Figures representing the transportation cost of reservoir water and operating costs of seawater desalination and wastewater recycling are taken as the averages of literature values. We develop a linear program to minimize the weighted sum of cumulative water shortage and excess spill from the reservoir. The model is forward looking, and solves to yield the optimal weekly reservoir releases and production rates of desalinated seawater and recycled wastewater over the next 10 weeks given an ensemble of forecast tracks of inflows for that period. Appropriate constraints are included to limit total operating cost to be within budget. The linear program is solved repeatedly on a rolling basis. With each new iteration, the forecast of inflows and optimal decisions for the current time period are updated.

Results and Discussion

Refer to Figure 1 for results for three levels of forecast quality, viz. perfect, average and poor. The results are generated assuming a ten-year operating horizon, and a rolling operating budget that is 2%

greater than the base budget. (The base budget is defined here as the amount of funds required to supply all demands from the reservoir alone assuming inflows are sufficient.) Figure 1 gives the maximum values of a water shortage index and an excess spill index, computed on a weekly basis from the outputs of the linear program. Results are presented for a single-reservoir system and compared to results for the joint system. From the results, it can be seen that there is no shortage nor excess spill when forecasts are perfect. Further, as expected, as forecast inaccuracy increases, so does shortage, as well as excess spill. However, with seawater desalination and wastewater recycling, the increase in shortage is mitigated, even with an operating budget that is just 2% more than the base budget. Incorporating seawater desalination and wastewater recycling, however, has little effect on excess spill from the reservoir.

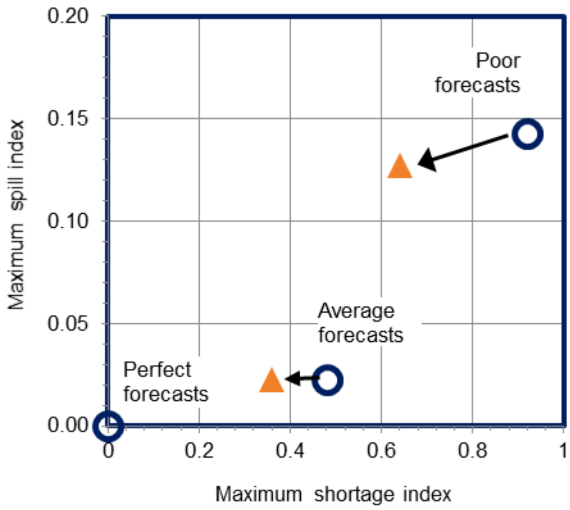

Figure 1 Maximums of a water shortage index and an excess spill index for three levels of forecast quality for a single-reservoir system (circles) and the joint reservoir-seawater desalination-wastewater recycling system (triangles).

Summary

Accurate streamflow forecasting is critical for reservoir operation for water supply and flood control purposes. However, it may not be possible to obtain accurate forecasts due to short- and long-term weather fluctuations. We propose coupling stable supply alternatives like seawater desalination and wastewater recycling with reservoir operation to mitigate the negative effects of inflow forecast uncertainty. Results show such a joint system to have the potential to reduce water shortage (though not excess spill), especially when inflow forecasts are highly inaccurate, without requiring a significant increase in operating budget.

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