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EVALUATION OF RESERVOIR MODEL INTEGRATION WITH DETERMINISTIC AND PROBABILISTIC STREAMFLOW FORECASTS

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Due to the increase in water demand and hydropower energy, it is getting more important to operate hydraulic structures in an efficient manner while sustaining multiple demands. Especially, companies, governmental agencies, consultant offices require effective, practical integrated tools and decision support frameworks to operate reservoirs, cascades of run-of-river plants and related elements such as canals by merging hydrological and reservoir simulation/optimization models with various numerical weather predictions, radar and satellite data. The model performance is highly related with the streamflow forecast, related uncertainty and its consideration in the decision making. While deterministic weather predictions and its corresponding streamflow forecasts directly restrict the manager to single deterministic trajectories, probabilistic forecasts can be a key solution by including uncertainty in flow forecast scenarios for dam operation. The objective of this study is to compare deterministic and probabilistic streamflow forecasts on an earlier developed basin/reservoir model for short term reservoir management. The study is applied to the Yuvacık Reservoir and its upstream basin which is the main water supply of Kocaeli City located in the northwestern part of Turkey. The reservoir represents a typical example by its limited capacity, downstream channel restrictions and high snowmelt potential. Mesoscale Model 5 (PSU/NCAR) and Ensemble Prediction System (ECMWF) data are used as a main input and the flow forecasts are done for 2012 year using HEC-HMS. Hydrometeorological rule-based reservoir simulation model is accomplished with HEC-ResSim and integrated with forecasts. Since EPS based hydrological model produce a large number of equally probable scenarios, it will indicate how uncertainty spreads in the future. This will provide risk ranges in terms of spillway discharges and reservoir level for operator when it is compared with deterministic approach. The framework is fully data driven, applicable, useful to the profession and the knowledge can be transferred to other similar reservoir systems.

INTRODUCTION

The increase of the world population especially in urban areas and changing climate conditions based on global warming directly pose a problem on the management of the storage reservoirs. On the other hand, energy dependence is increasing day by day and companies, governmental agencies, consultant offices need dynamic, integrated and easy tools for effective operation of the system as a whole. Management of these systems from planning to operation is very challenging since the problem deals with many complicated variables, and uncertainties such as, inflows, return flows, storages, diversions, inter/intra-basin water transfers, irrigation, and industrial and/or municipal water supply demands [1]. Thus, there is no direct solution or method for this problem and very different programming methods have been applied to improve the efficiency of the dam operation. Some of these techniques are: linear, nonlinear, dynamic, stochastic methods and heuristic approaches (Genetic algorithms, Shuffled Complex Evolution, Complex Logic and Artificial Neural Networks) [2].

On the other hand, reservoir modeling cannot be distinguished from basin and hydrological modeling during real-time operation. The hydro-meteorological basin conditions, streamflow forecasts, current reservoir levels and water usage are important as well as release decision strategies and downstream rules. One challenging and most uncertain part that effects the decisions are streamflow forecasts. For several decades, Ensemble Prediction System (EPS) data that provide 50 perturbed and one control outputs of weather prediction are developed, tested and applied for several catchments as well as deterministic counterparts. These items can be merged under communication and information technologies. In this study, a decision support system that is developed by integration of a hydrological modeling and daily hydro-meteorological rule based reservoir simulation model (HRM) is carried out with both using Mesoscale Model 5 (MM5) deterministic data and EPS data for a test basin. The main motivation is that; EPS based hydrological model produce a large number of equally probable scenarios thus; it will indicate how uncertainty spreads in the future. This will provide risk ranges in terms of spillway discharges and reservoir level for operator when it is compared with deterministic approach.

STUDY AREA

Yuvacık Dam Reservoir (Figure 1) is the main source of water supply for Kocaeli Great Municipality (KGM) and surrounding areas, providing water for a population of some 1.5 million in addition to the rapidly expanding industrial base of the region. Multi-objective operation structure of Yuvacık Dam Reservoir necessitates flood protection besides water supply, concerning the downstream channel capacity. These two functions are in conflict, since each requires reservoir storage volume but uses it in the opposite way. Serving both of these functions requires a tradeoff between them that is defined by the target storage level of the reservoir (the guide curve). Effective reservoir capacity of 51.2 hm^3 is relatively limited for the reservoir concerning the average annual inflow potential of 180 hm^3 and demand of 142 hm^3. Due to this situation, the excess water must be stored above flood control levels and operational decisions play an important role on flood and shortage risk from the operational point of view. On the other hand, the maximum amount of water to be released during daily operation is set as 100 m^3/s by the regional water authority taking the drainage discharge conditions of the downstream canal into consideration, while the spillway capacity is 1560 m^3/s. Thus, operational decisions are important whilst spillway gates are operated.

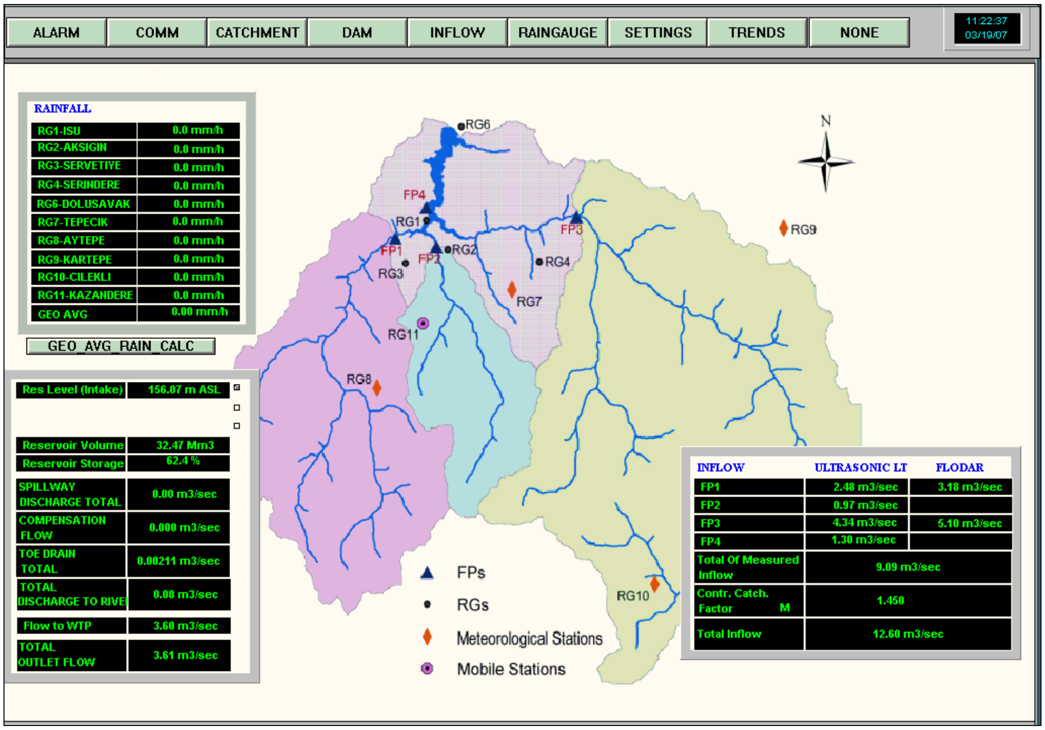

Figure 1. Yuvacık Basin and SCADA based Dam Management System

DECISION SUPPORT FRAMEWORK

The daily decisions are affected by seasonal variables and the main aim during the operation period is to achieve maximum reservoir level (nearly 98~99 % filled) when the inflow is in the recession period. Hereby, the flood pool is eventually operated as empty as possible to decrease flood risk during March – May period using Integrated Decision Support System (IDSS). This system involves online readings from site (Figure 1), observation of weather predictions, modeling streamflows using both observation and prediction data and modeling the reservoir with HRM developed by the authors. At this point, HEC-HMS [3] and HEC-ResSim [4] models are being used successively for operational purposes (Figure 2). Operational decisions and hydro-meteorological conditions during 2007-2011 water years were analyzed and simulation rule sets are developed with if-then-else statements of ResSim model. The pre-developed HRM is sensitive to snow cover, precipitation rate, inflow changes, reservoir current level and season. Also, it provides an appropriate reservoir level under given condition of the basin. Thus, it is worth merging these systems with different NWP data.

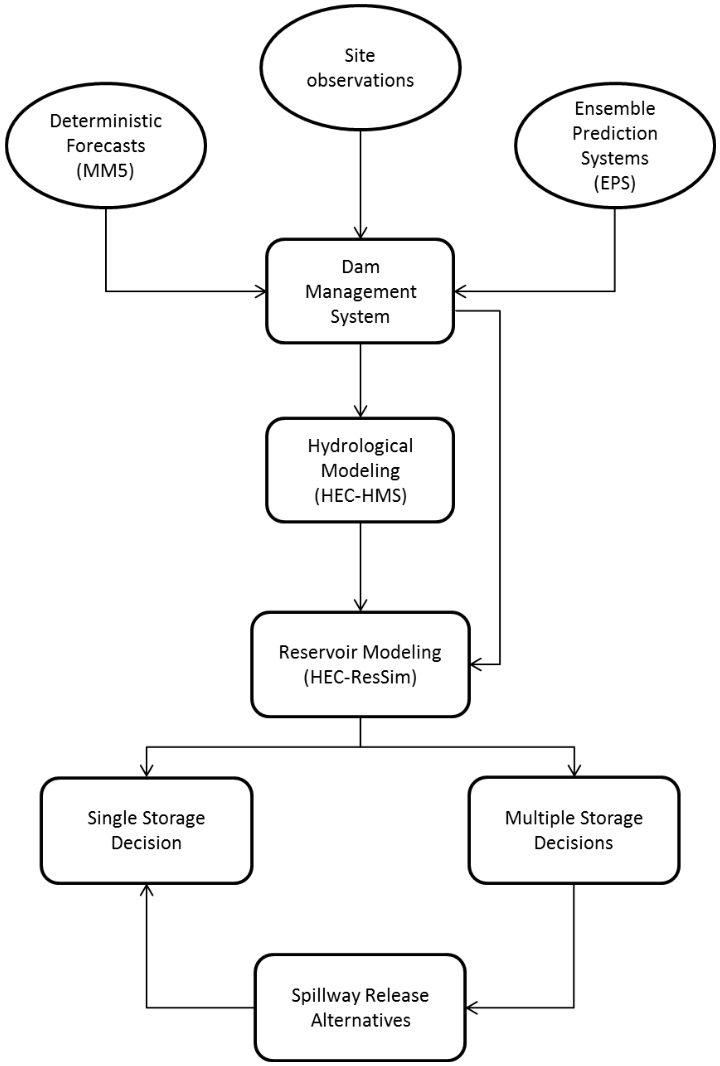

Figure 2. Integrated Decision Support System (IDSS) for multiple decisions

WEATHER PREDICTION DATA

Forecasting the current status of the weather a few days ahead with the help of mathematical models of the atmosphere is called Numerical Weather Prediction (NWP). NWP models can provide input to hydrological models with short term weather forecasts. For the probabilistic and deterministic forecast data, the increasing practice of EPS in the recent years and MM5 model results are utilized respectively.

MM5 modeling system developed by Pennsylvania State University/ National Center for Atmospheric Research to generate finer resolution forecast products both temporally and spatially to the end users. MM5 daily average air temperature and daily total precipitation (convective and non-convective) data having 4.5 km spatial resolution are provided with 24 hrs and 48 hrs ahead forecasts for this study.

Ensemble forecast techniques have comprehensive solutions, which include uncertainty, instead of a single solution. In this study, ensemble forecasts issued by the EPS of the European

Centre for Medium-Range Weather Forecasts (ECMWF) have been used. These ensembles consist of one control forecast and 50 additional perturbed forecasts starting from slightly different initial conditions which are designed to represent uncertainties in the operational analysis. The spread of the control and 50 forecasts give an estimate of the uncertainty of the predictions on that particular day. On some days, the spread might be small implying that the atmosphere is very predictable and forecasters can trust that the reality will fall somewhere in the narrow range of forecasts. On other days, the spread of the ensembles might be larger and correspond to atmospheric situations which are less predictable. As a result, the EPS spread gives very useful information about uncertainty to forecaster. In this study, EPS Surface Air Temperature and Total Precipitation forecasts produced by ECMWF up to a lead time of 9 days are used.

RESULTS

Real time operation of a reservoir necessitates the assessment of all the data and conditions in a limited time period. These are; current hydro-meteorological data (inflow into reservoir by mass-balance equations, average precipitation by rain gauges, current storage by reservoir level readings, snow potential by snow depth observation stations etc.), climate reports, radar and numerical weather predictions, forecasted streamflows and scenarios. A decision support tool is developed in this study integrating these kinds of data and conditions with a hydrological and a reservoir model for the operation of Yuvacık Dam Reservoir.

This paper presents a case study for the operation of reservoir with preset and tested user defined rules for 03-12 April 2012 rainfall/snowmelt event. First, NWP data is analyzed and simple bias correction is applied for temperature data to make it more consistent with the observed data. Then, reservoir inflows are forecasted with the aid of HEC-HMS model parameters of which have been calibrated for a number of storm and snowmelt events. The observed runoffs and hydrological model results of runoff forecasts are presented in Figure 3 as plots of ensemble of trajectories. The hydrological model is run for the time period 03-12 April 2002 with 9 days forecast data of EPS without a lead time performance analysis.

Reservoir levels and actual hydrological conditions are provided in Figure 4 together with spilled discharges. In the figure, both observed actual conditions and reservoir simulations are given and a forecast window is defined for the period through which runoff forecasts are done by the hydrological model integrated with NWP data. This rainfall/snowmelt event is selected since there is an increase is expected for the reservoir level. Short term reservoir operation strategy is applied together with runoff forecasts concerning a day lead time for deterministic NWP, MM5 data and up to 9 days lead time for probabilistic NWP, EPS data. The model results are presented both in terms of reservoir levels and amount of spilled water through the spillway. Instead of EPS spread data for 50 members, quartiles are presented to show the probabilistic reservoir operation strategies in comparison to deterministic results (Figure 5-6).

MM5 data is used in a day time-step, spillway releases are done one day ahead and consequent day's reservoir level is obtained by providing actual inflow into reservoir. On the other hand, EPS is provided by 9 days lead time, and no updating is applied. Therefore, the lead time performance of two data types cannot be evaluated in a comparative manner. Updating EPS and reservoir inflow forecasts might result in an agreement in between spilled amount of water in the second half of the event.

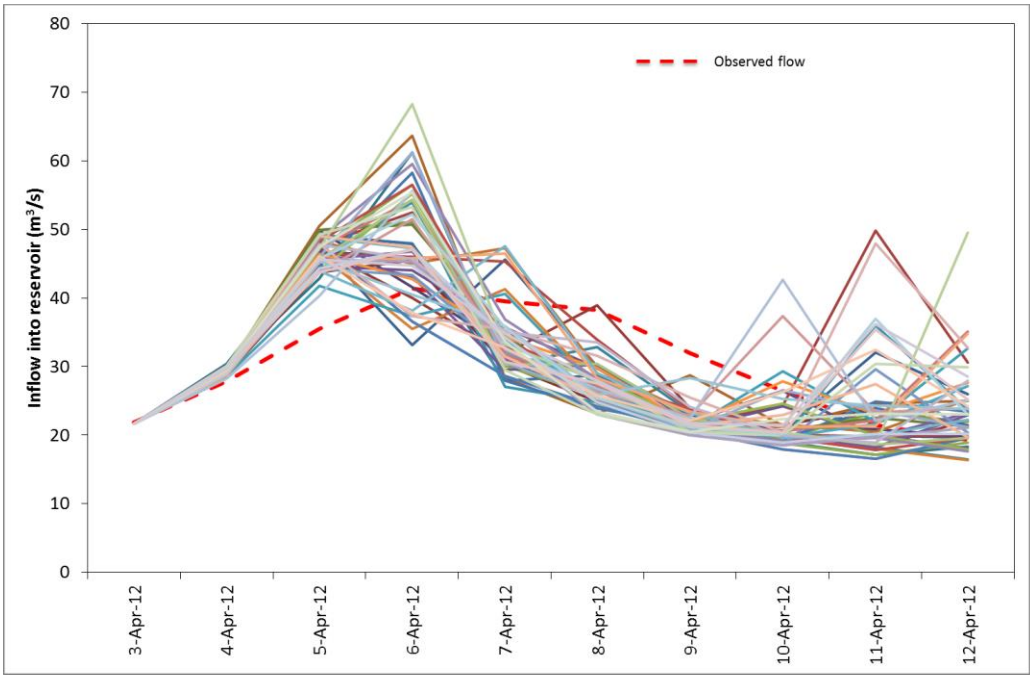

Figure 3. 51 EPS flow results for “forecast window” (03-12 April 2012)

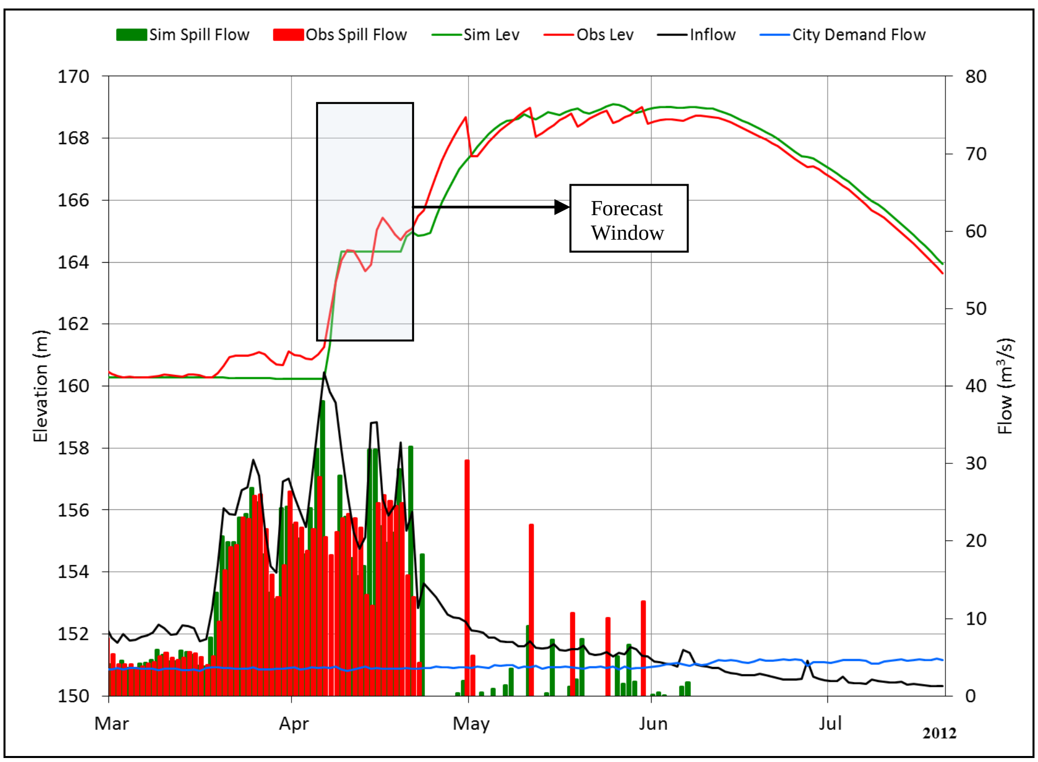

Figure 4. Daily HRM simulation results using actual data (simulated) vs. operation by company (observed) (2012 March – July)

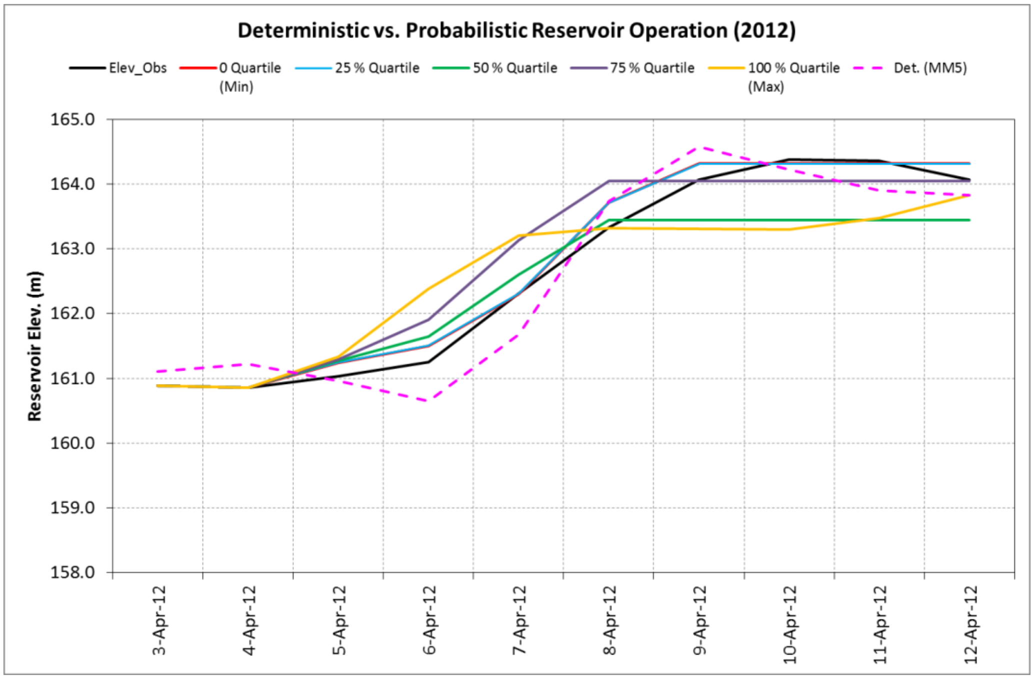

Figure 5. Deterministic vs. probabilistic reservoir operation for defined forecats window (reservoir levels)

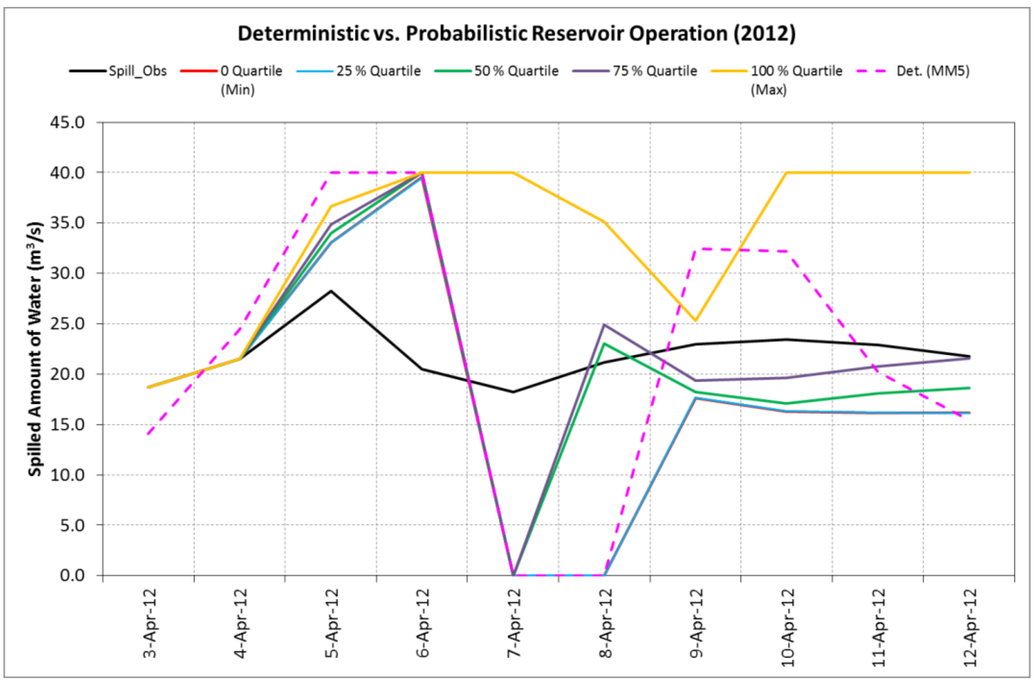

Figure 6. Deterministic vs. probabilistic reservoir operation for defined forecats window (spillway discharges)

CONCLUSIONS

The article presents a case study using NWP data and integrated reservoir management approach on the small-scale reservoir catchment located in the north-western Turkey. In this study, deterministic numerical weather prediction and ensemble prediction data based streamflow forecasts are used in reservoir model alternatively, and a comparison is carried out to show advantages of each other. Since EPS based hydrological model produce a large number of equally probable scenarios, it indicates how uncertainty spreads in the future. This will provide risk ranges in terms of spillway discharges and reservoir level for operator when it is compared with deterministic approach. The main advantage of using EPS is that operators can predict minima and maxima of the reservoir levels and risk boundaries, so that they can proceed with preoperational strategy. In the future study, the lead time performance of reservoir simulation should be potentially improved for EPS data which will hold great benefit for reservoir management during critical season for flood warnings and precautions. Reservoir water release can be potentially improved by having a reliable early forecast of precipitation. This study take into account different reservoir operation rules and assess the benefit of using EPS and can be applied for similar other areas.

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