Report as of FY2007 for 2006NC65B: "Improved Water Management Strategies for the Neuse basin Utilizing Climate-Information based Probabilistic Streamflow Forecasts"

Publications

- Conference Proceedings:
  - Arumugam, S., N. Devineni, and S. Ghosh, December 11-15, 2006. Multi-model Ensembling based on Predictor State Space: Seasonal Streamflow Forecasts and Causal Relations, American Geophysical Union Conference, San Francisco.
- Other Publications:
  - Sankarasubramanian, A., N. Deveneni, and S. Ghosh, 2006, Multi-model Ensembling of Probabilistic Streamflow Forecasts: Role of Predictor State, Space in Skill Evaluation, Institute of Statistics Mimeo Series 2595,NC State University.

Report Follows

Title

Improved Water Management Strategies for the Neuse basin utilizing Climate-Information based Probabilistic Streamflow Forecasts

Project Summary

A strategy to improve water allocation in the Neuse basin is proposed by developing a seamless integration climate-information based streamflow forecasts into water systems planning (3 months to 6 months) and operation. The proposed research will develop long-lead probabilistic streamflow forecasts in the Neuse basin contingent on both local land-surface and exogenous climatic conditions. Retrospective streamflow forecasts will be combined with a reservoir management model to understand the utility of streamflow forecasts in operating the Falls Dam. With the decadal variability in the tropical Atlantic Sea Surface Temperature (above-normal conditions) resulting in more hurricanes, it is imperative to develop a prognostic approach for water management in the Neuse basin given the basin accounts for 22% of state's population. Such an approach based on climate information could help water managers to prepare well in advance to reduce the impacts resulting from hydroclimatic extremes.

Benefits/Information from this project will support other ongoing activities in the Neuse including Neuse river basin planning program (supported by DENR), National Water Quality Assessment Program (supported by USGS) and NC Drought Monitoring (supported by Division of water resources, DENR) in coordination with the state's climate office. Analyses from this research will also promote identification of alternate river basin management plans during critical drought conditions including conjunctive use, instream flow maintenance and estuaries management. Informative web portal will de developed that summarizes the hydroclimatic predictability of the Neuse basin as well as updates of streamflow potential for the seasons ahead. Potential implications and its relevance to several ongoing researches in the Neuse basin will include quantitative representation of uncertainty in streamflows to support TMDL process, development of seasonal water management plans considering conjunctive use for the coastal zone and prediction outlooks for floods and droughts. We envisage that this effort for Neuse basin will motivate other basins in NC to incorporate to follow a prognostic, climate-information driven approach towards water management.

Methodology

Probabilistic Streamflow Forecasts Development: First, an assessment of different AGCMs' ability to predict both winter (January-March) and summer (June-September) precipitation over the Neuse basin will be investigated. This will be analyzed online at IRI data library (http://iridl.ldeo.columbia.edu/). Based on that, the best AGCM will be selected for developing the streamflow forecasting model. Three different approaches can be adopted when developing climate-information based streamflow forecasts: (a) Couple AGCM outputs with a Regional Spectral Model (RSM) whose outputs are combined with a large-scale watershed model16(b) Statistically downscale AGCM precipitation to streamflow at a particular point of interest18,19 (c) Develop a low dimensional statistical model that predicts the streamflow based on dominant climate predictors that influence the streamflow/rainfall potential over the basin17. Given only one year for this study, we will pursue approaches (b) and (c) to develop climate-information based streamflow forecasts. Coupling of AGCM with RSM and a watershed model will be pursued as future research activities. To pursue approach (b), we will develop different statistical downscaling methodologies to predict streamflow based on the selected AGCM's precipitation grids18,19. To develop a low-dimensional statistical model, detailed diagnostic analyses will be first carried out to identify the dominant predictors that influence the streamflow potential of the Neuse basin. The study will exploit the NC state climatological office's database

(http://www.nc-climate.ncsu.edu/cronos/) and various other databases including climate Diagnostic Center (http://www.cdc.noaa.gov/PublicData/) to perform diagnostic analyses for predictor identification. We will employ state-of-the-art multivariate techniques including independent component analyses (ICA)20 to develop predictors that are independent to each other. Once the predictor set is developed, we will develop retrospective probabilistic streamflow forecasts for the Falls Lake using different statistical approaches including parametric and nonparametric regression techniques. Figure 6 shows an example of a probabilistic streamflow forecasts developed for a reservoir system in Ceara, North East Brazil.

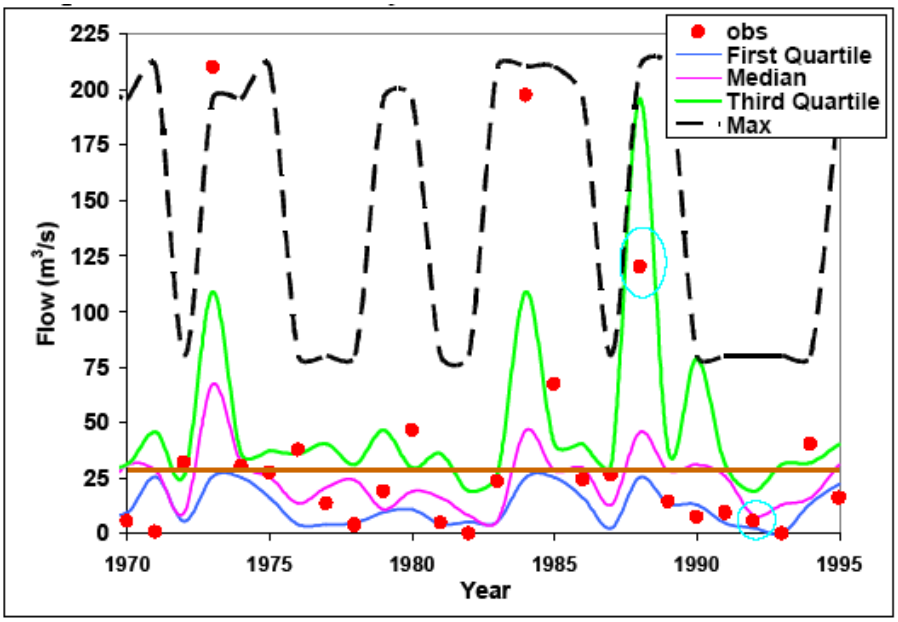

Figure 6: Retrospective, Leave one-out cross-validated 7-months ahead streamflow forecast ensembles for the Oros reservoir, Ceara, NE brazil17.The correlation between the observed streamflow and the predicted median streamflow is 0.7 over the period 1949-1996. Predictors employed for this purpose include Nino3.4 and Atlantic Dipole17. Note the ensembles shift according to the nature of flows for the two circled years in comparison to the long-term average (solid brown line). More than 60% of the mass is above the long-term average for the above normal inflow year in 1988, whereas in a below normal year in 1992, more than 80% of the mass is below the long-term average.

Reservoir Analyses: To develop a customized reservoir management model for the Falls Lake, the study will employ MORAPS, which has been tested on many basins for climate forecasts application. Figure 7 shows a snapshot of MORAPS for representing a multi-reservoir system in the Greater Horn of Africa14. MORAPS incorporates novel features with the ability to run both retrospective analyses and to perform adaptive analyses of reservoir systems for real-time decision-making. Downscaled streamflow forecasts based on AGCM precipitation can also be used as an input to the model. MORAPS also incorporates a novel contract structure11,15 with an ability to perform the analyses under both optimization and simulation modes. Using retrospective streamflow forecasts developed from the study, we will employ MORAPS to identify optimal operating policies for the Falls Dam for reducing downstream flood damages as well as meeting both water quality and water quantity targets.

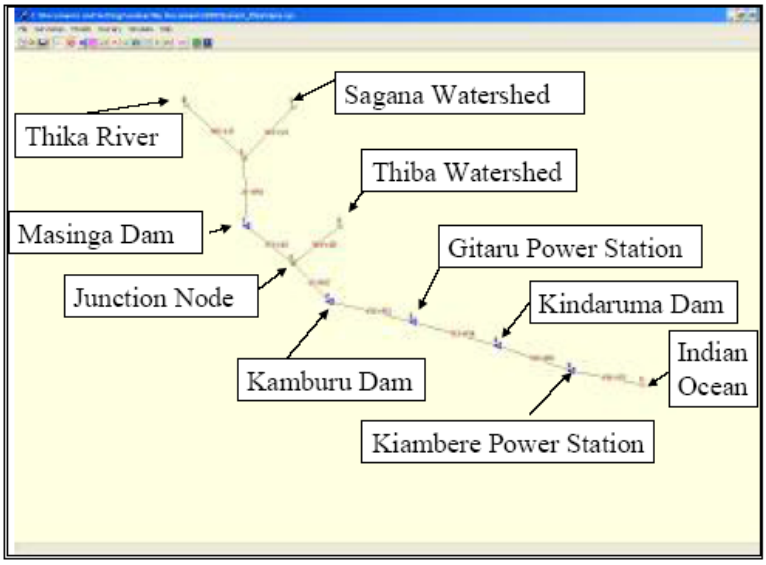

Figure 7: A snap shot of the Tana River 7-Forks Reservoir Management Model in the Greater Horn of Africa shown within MORAPS (Authors: Sankarasubramanian Arumugam, PI of this proposal and Upmanu Lall; copyrighted to IRI, Columbia University).

Dissemination: An important goal of this research is to develop a prognostic approach to improvise water management in the Neuse basin, which can help local/state water managers prepare well in advance for mitigation of the impacts resulting from hydroclimatic extremes. In this regard, we would like to invite NC DENR (Division of Water Resources), USACE (Wilmington District) and NC Drought Monitoring Council as external advisory board. In collaboration with them, we plan to perform the retrospective analyses of Falls Lake management contingent on probabilistic streamflow forecasts. A web portal will also be developed as part of the project that will update the long-lead streamflow forecasts for the Neuse basin on a monthly basis. We envisage that this effort for Neuse basin will motivate other basins in NC to incorporate to follow a prognostic, climate-information driven approach towards water management.

Relevance to Other Neuse Basin Initiative and Scope for Future Research

Given the diversity of hydrologic and geographic settings as well as water management issues related to the ongoing developments in the basin, Neuse has been a target basin towards monitoring, understanding and modeling of hydrological processes from both national and state agencies. Neuse which is located in the Albemarle-Pamlico drainage basin has been identified as one of the 20 selected basins for National Water Quality Assessment Program from the USGS33. Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI), a collection of Universities for advancing hydrologic science, has identified Neuse as a target basin for setting up hydrologic observatory34. NC state DENR has developed a detailed water management plans to protect water quality and quantity issues in the basin given 22% of state's population live in the Neuse basin35,36,37. Several non-profit organizations, NC Water Resources Research Institute and Neuse River Foundation support many basin wide initiatives38,39,40. Research findings from this proposal will support the above programs in quantifying the uncertainty related seasonal streamflow potential as well as in providing prediction outlooks on floods and droughts. Findings from this research will also support future research initiatives of the PI that includes understanding the linkages between climate variability and ground water availability,

utility of climate forecasts in reservoir/lake water quality management to guide the TMDL process and in understanding the importance of policy instruments in forecast applications in water management.

Principle Findings

Three specific objectives are encompassed in the proposed study: (a) Development of a climate-information based streamflow forecasting model (b) Perform retrospective analyses on the utility of climate forecasts in improving Falls Lake operation (c) Dissemination of results from the analyses with various state agencies that coordinate water-related activities in the Neuse basin.

Objective 1: Development of a climate-information based streamflow forecasting model

Substantial progress on streamflow forecasting model development has been made:

- Two low dimensional (one regression and another resampling) streamflow forecasting models were developed, one for January-March and another one for July-September, using sea surface temperature conditions in tropical Pacific, tropical Atlantic and NC Coast. Both models have been verified and validated.
- Based on the comments on one of the reviewer in the proposal, we developed multi-model ensembles of streamflow forecasts for predicting the summer flows, July-September and it has been found to improve single model forecasts. This work has been published as a report in the Institute of Statistics, Mimeo Series (http://www.stat.ncsu.edu/library/mimeo.html). A paper on the new methodology on multimodel forecasts is also under revision in Water Resources Research.
- The multimodel combination methodology was also extended to combine various General Circulation Models (GCMs) so that multimodel precipitation forecasts could be used for downscaling to Falls Lake. Three different GCMs, ECHAM4.5, CCmV6, and COLA, were combined for the entire US. The multimodel precipitation forecasts are much better than the single model forecasts as shown below using Rank Probability Skill Score. This is another paper in preparation for submission to the Journal of Climate.

Objective 2: Perform retrospective analyses on the utility of climate forecasts in improving Falls Lake operation

Progress on this objective is summarized as follows:

- A Falls Lake Management Model has been developed and verified in modeling releases for the period July-August-September.
- The model has been tested with multi-model forecasts developed from the earlier objective and the importance of multimodel forecasts in improving reservoir management has been analyzed.
- Performance of the model using forecasts was analyzed to support the following decision analyses: (a) Restrictions if the forecasts suggests dry year (b) Having additional storage beyond 251.5 msl during wet summer years (c) Probability of meeting the target storage at 251.5 msl by the end of summer.

Objective 3: Dissemination of results from the analyses to various state agencies that coordinate water-related activities in the Neuse basin.

- Reasonable progress has been made and a project website has been developed with a content management system http://www.ce.ncsu.edu/research/hydroclimatology/.

- We issued a forecast for the summer of 2006 and it was reasonably on target (observed streamflow – 331 cfs and predicted streamflow – 346 cfs).
- We are currently trying to schedule a meeting with NCDENR to share the findings from this study.

Significance

Benefits/Information from this project will support other ongoing activities in the Neuse including Neuse river basin planning program (supported by DENR), National Water Quality Assessment Program (supported by USGS) and NC Drought Monitoring (supported by Division of water resources, DENR) in coordination with the state's climate office. Analyses from this research will also promote identification of alternate river basin management plans during critical drought conditions including conjunctive use, instream flow maintenance and estuaries management. Informative web portal will de developed that summarizes the hydroclimatic predictability of the Neuse basin as well as updates of streamflow potential for the seasons ahead. Potential implications and its relevance to several ongoing researches in the Neuse basin will include quantitative representation of uncertainty in streamflows to support TMDL process, development of seasonal water management plans considering conjunctive use for the coastal zone and prediction outlooks for floods and droughts. We envisage that this effort for Neuse basin will motivate other basins in NC to incorporate to follow a prognostic, climate-information driven approach towards water management.

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