Adaptive hydrologic modeling approaches for optimizing water infrastructure design and management under nonstationarity

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Introduction

Traditional hydrologic design, which assumes static climate conditions, fails to consider the fluctuating nature of weather patterns and the need for multiple-objective consideration, like flood control, recreation, and energy production. Hunu et al. (2024) proposed an adaptive management framework that provides a practical approach for accounting for a changing climate and multiple objectives. The proposed adaptive management framework consists of: (1) a hydrologic modeling approach that accounts for climate nonstationarity and multiple objectives, and (2) a strategy to handle uncertainties, such as climate predictions, urbanization effects, and evolving basin objectives. It suggests biennial updates for baseline conditions to maintain both adaptability and practicality.

This paper describes the adaptive hydrologic modeling approach. A case study of the Buckhorn Creek Basin in North Carolina illustrates the application and outcomes. This basin serves various purposes including recreation, energy production, and water supply. The study demonstrates the necessity for innovative hydrologic modeling approaches in water infrastructure design and management due to climate change and varied stakeholder goals

Material and methods

The method for developing the modeling approach involved three main stages:

1. Collection of data including terrain data, land cover data, soils data, historical rainfall data, hydrologic and hydraulic infrastructure data, and observed data such as peak flow rates and water surface elevations for model calibration and verification.
2. Future rainfall data development from projections from General Circulation Models (GCMs)
3. Model development using the public domain United States Army Corps of Engineers (USACE) HEC-RAS model (USACE, 2022). HEC-RAS was chosen because it is both a hydrologic and hydraulic analysis, has considerably faster runtimes compared to the other available options, and has desirable features such as two dimensional (2D) flexible meshing ability, rain-on-grid modeling ability, ability to model hydraulic structures in 2D, ability to model infiltration and flow extractions such as pumping, and the ability to directly create and export results as GIS files.

Due to the nonstationarity of climate, future precipitation projections are needed for designing water infrastructure as climate conditions may be different at the end of the design life of the infrastructure than they are at present. Precipitation projections are usually derived from GCMs. There are multiple GCMs available, most of which provide projections that may be biased and, therefore, need to be downscaled to provide more accurate estimates. For this project, the Bias Corrected Constructed Analogs (BCCA) V2 Daily Climate Projections (Bracken, 2016) was used. The GCM projections were downscaled to improve their accuracy.

The process used for developing the hydrologic model involved delineation of the contributing drainage area for the basin, building of the 2D computational mesh, application of inflow and outflow boundary conditions, and validation of the model. The computational mesh was configured to model all the key features within the Buckhorn Creek basin including the Shearon Harris Lake, Sharon Harris Dam, Buckhorn Dam, and the impoundment behind Buckhorn Dam. The validated model was used to simulate several scenarios developed based on the traditional approach and the adaptive management framework and the results compared to ascertain the advantages of the new adaptive management framework. The scenarios represent expected changes in climate and basin stakeholder priorities.

Results and concluding remarks

The results in Table 1 demonstrate how the adaptive hydrologic modeling approach can be applied in water infrastructure design within multi-use basins to account for a changing climate and stakeholder priorities. It also shows the need for the application of the new adaptive approach in our changing environment.

The traditional approach fails to account for all basin needs for most of the scenarios because of predicted changes in basin needs, which the traditional approach is inadequate to handle. However, using the new approach makes it possible to meet the basin requirements even under uncertain and nonstationary conditions such as changing climate, basin uses, and land use.

The combination of the hydrologic modeling method and the adaptive management framework results in more accurate data for decision making since the climate projections being used for the design and management of the water infrastructure are reviewed and updated bi-annually. It also provides an opportunity to tailor the design and management of water infrastructure to changes to basin use requirements, and land uses.

Table 1. Comparison of results from the hydrologic model for traditional and new approach

Basin Use	**Wet / Dry Conditions**	**Traditional Approach**		**New Approach**	
		Scenario 1 (Year 2020)	**Scenario 2 (Year 2022)**	**Scenario 1 (Year 2020)**	**Scenario 2 (Year 2022)**
Water Supply	Wet Conditions	Pass	Fail	Pass	Pass
	Dry Conditions	Pass	Fail	Pass	Pass
Power Generation	Wet Conditions	Pass	Pass	Pass	Pass
	Dry Conditions	Pass	Fail	Pass	Pass
Recreation	Wet Conditions	Fail	Fail	Pass	Pass
	Dry Conditions	Fail	Fail	Pass	Pass
Environmental Flows	Wet Conditions	Pass	Pass	Pass	Pass
	Dry Conditions	Pass	Fail	Pass	Pass

References

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