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Case Study

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A STOCHASTIC MODELING APPROACH FOR RISK MANAGEMENT OF WATER RESOURCES SYSTEMS

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Abstract: This study presents a stochastic modeling approach for quantifying and analyzing various uncertainties associated with water resources systems. Based on probabilistic chaos expansion (PCE) and multivariate analysis, a probabilistic simulation method is developed to construct a surrogate for complex hydrological models and to support efficient stochastic simulations. Stepwise cluster analysis (SCA) is used to establish complex nonlinear relationships among various system components. PCEs are established based on the probabilistic collocation method to generate probabilistic runoff time series. The proposed approach is demonstrated using the climatic and hydrological data from two watersheds, i.e., the Grand River Watershed in Canada and the Xiangxi River Watershed in China. Results show that the proposed approach is effective in tackling the complexities in water resources systems, particularly with respect to the inherent uncertainties involved in hydrological modeling. This work can provide robust decision support for risk management of water resources systems, such as hydraulic infrastructure design, reservoir operation, and floodplain planning. The developed modeling framework will help decision makers not only to improve their effectiveness in managing water risks, but also to enhance their preparedness for and response to water related hazards.

Keywords: Stochastic simulation; multivariate analysis; uncertainty quantification; hydrological modeling; risk management; water resources systems

1 Background

Water resources are crucial to the sustainable development of our societies. Recently, water related hazards have imposed significant pressure on our infrastructure, jeopardizing public safety and hampering economic growth (Mann and Wolfe, 2016; Li et al, 2016). The catastrophic floods in Alberta in 2013 forced the evacuation of over 100,000 people, and caused a total damage that exceeded CAD $6 billion. California has been facing severe drought since 2012, and, in 2015, it incurred an economic impact of USD $2.7 billion and 21,000 job losses. The modeling and analysis of water related hazards are crucial to the effective risk management of water infrastructure systems (DiFrancesco and Tullos, 2014). However, the prediction and management of water related hazards are facing various challenges arising from numerous sources of uncertainties and interconnected complexities, such as random precipitation events, stochastic flow processes, imprecise estimates of system parameters, and fuzzy information in decision making processes (Mockler et al, 2016; Li et al, 2015). Water resources systems feature nonlinear, dynamic, and uncertain characteristics. Such complexities and their interactions can lead to difficulties in clarifying the related vulnerabilities and risks (Polasky et al., 2011).

In this study, stepwise cluster analysis (SCA) and probabilistic chaos expansion (PCE) are used to quantify various uncertainties and complexities in hydrological systems, and thus to provide robust decision support for the risk management of water resources systems.

2 Methods

SCA is a multivariate analysis tool that can capture complex and nonlinear relationships among multiple variables (Li et al, 2016). The essence of SCA is to classify the multivariate relationships in the sense of probability using a cluster tree. PCE is an uncertainty quantification method that has gained much attention recently due to its computational efficiency in stochastic simulation (Rui et al, 2013). In this study, PCEs are established based on the probabilistic collocation method to generate probabilistic runoff time series. SCA is used to imitate rainfall-runoff relationships, as well as the discrete relationships between hydrological model inputs and PCE coefficients.

3 Results

The proposed approach was applied to the Grand River Watershed in Canada and the Xiangxi River Watershed in China, to tackle the uncertainties in model parameters and complexities of nonlinear relationships. Results show that the proposed approach is effective in tackling the complexities in water resources systems, particularly with respect to the inherent uncertainties involved in hydrological modeling. SCA shows a superior efficiency in tackling discrete nonlinear relationships compared to traditional regression methods. It also has an advantage in automatic predictor discrimination. The performance of PCE is compare to the traditional numerical Monte Carlo simulation. The PCE established is demonstrated to be an efficient tool for stochastic hydrological simulation. The results also show that the incorporation of SCA into the PCE framework can facilitate probabilistic hydrological forecasting.

4 Conclusions

In this study, SCA and PCE were used to quantify and analyze various uncertainties associated with hydrological systems. The proposed approach was demonstrated through two applications, i.e., the Grand River Watershed in Canada and the Xiangxi River Watershed in China. The results provided robust decision support for the risk management of water resources systems. Applications of the proposed approach can be extended to many other complicated modeling systems to support the associated uncertainty quantification and risk analysis.

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