Nonstationary Statistical Approaches for Hydrologic Planning

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It is no longer possible to consider streamflow and other hydrologic processes as a stationary process. Nearly all of the methods developed for the planning, management and operation of water resource systems assume stationarity of hydrologic processes. Nonstationarity can result from a myriad of human influences ranging from agricultural and urban land use modifications, to climate change and water infrastructure. Most previous work in trend detection associated with extreme events has focused on the influence of climate change, alone. This study takes a different approach by developing statistical models for hydrologic planning in watersheds which are subject to a very broad range of anthropogenic influences. A nonstationary flood frequency model is introduced as well as a nonstationary monthly stochastic streamflow model for use in water resource planning applications.

**Nonstationary Flood Frequency Analysis:** A simple statistical model is developed which can both mimic observed flood trends as well as the frequency of floods in a nonstationary world. This model is used to explore a range of flood planning issues in a nonstationary world. A decadal flood magnification factor is defined as the ratio of the T-year flood in a decade to the T-year flood today. Using historical flood data across the entire U.S. we obtain typical flood magnification factors in excess of 2-5 for many regions of the U.S. particularly those regions with higher population densities. Importantly, nonstationarity in flood flows is shown to result from a variety of anthropogenic processes including changes in land use, climate and water use, with likely interactions among those processes making it very difficult to attribute trends to a particular cause. Multivariate regression models are shown to provide a useful tool for developing the type of conditional forecasts of the moments of extreme events necessary for planning in a nonstationary world.

**Nonstationary Stochastic Streamflow Models:** A nonstationary monthly stochastic streamflow model is developed for an urbanizing watershed. The model relates current monthly streamflow to the previous months streamflow, the same months streamflow in the previous year, as well as rainfall, land use and water use. Again, interactions among land use, water use, and climate are shown to be extremely
important factors in explaining the anthropogenic induced changes in streamflow. Such a stochastic streamflow model may be useful for water supply and other watershed planning and management problems.

Planning in a nonstationary and uncertain world is not a new challenge for engineers, because the classic ‘capacity expansion problem’ and other planning problems have always involved both nonstationarity and uncertainty. What is new are the increased variety of sources of uncertainty and nonstationarity which are now inherent in nearly all water resource planning problems making it essential to incorporate nonstationary planning models of the type discussed here.