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Collaborative modelling and integrated decision support system analysis of a developed terminal lake basin

Richard G. Niswonger [a,*], Kip K. Allander [a], Anne E. Jeton [b]

[a] U.S. Geological Survey, 2730 Deer Run Road, Carson City, Nevada 89701, United States
[b] 1682 Sunshine Road, Minden, Nevada 89423, United States

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SUMMARY

A terminal lake basin in west-central Nevada, Walker Lake, has undergone drastic change over the past 90 yrs due to upstream water use for agriculture. Decreased inflows to the lake have resulted in 100 km^2 decrease in lake surface area and a total loss of fisheries due to salinization. The ecologic health of Walker Lake is of great concern as the lake is a stopover point on the Pacific route for migratory birds from within and outside the United States. Stakeholders, water institutions, and scientists have engaged in collaborative modeling and the development of a decision support system that is being used to develop and analyze management change options to restore the lake. Here we use an integrated management and hydrologic model that relies on state-of-the-art simulation capabilities to evaluate the benefits of using integrated hydrologic models as components of a decision support system. Nonlinear feedbacks among climate, surface-water and groundwater exchanges, and water use present challenges for simulating realistic outcomes associated with management change. Integrated management and hydrologic modeling provides a means of simulating benefits associated with management change in the Walker River basin where drastic changes in the hydrologic landscape have taken place over the last century. Through the collaborative modeling process, stakeholder support is increasing and possibly leading to management change options that result in reductions in Walker Lake salt concentrations, as simulated by the decision support system.

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1. Introduction

Developed terminal-lake basins pose unique challenges for water resource managers. Terminal lakes are especially sensitive to changes in water availability and distribution because they rely on the residual of upstream water use, and are often given low priority. Decision support systems (DSSs) used in the context of collaborative modeling among resource stakeholders, managers, and scientists offers a pathway toward restoring complex systems like terminal-lake basins. A DSS provides a platform for establishing reference points among stakeholders, such as the current state of the system, and the response of the system to projected management change scenarios. Ultimately, stakeholders must have confidence in the DSS in order to establish mutual understanding and consensus on implementing changes for restoring the system. In this present work, we rely on state-of-the-art integrated management and hydrologic models as components of a DSS to improve the collaborative modeling process that is being used to restore the Walker Lake basin in west-central Nevada.

In the context of this work, the phrase collaborative modeling is used to describe collaboration between resource stakeholders, managers, and scientists to design and evaluate management change options through the use of a DSS for improving water resources (Langsdale et al., 2013). Central to the collaborative modeling process presented herein is the design and development of a DSS that can simulate the complex interactions between climate, hydrology, and water management. As the system being studied herein has changed drastically over the last century due to development, the DSS considers broad changes in the hydrologic landscape and the feedbacks associated with climate, hydrologic processes affecting water availability, and water management. Central to the DSS design are interactions between resource stakeholders, water managers, and scientist before, during, and after DSS development and application.

By their nature, terminal lakes persist due to long-term balances between inflow and outflow. Thus, if lake inflow is reduced by drought and/or by diversions from tributary streams, desiccation can occur (Cooper and Koch, 1984). Surface

* Corresponding author. Tel.: +1 775 887 7727.
E-mail addresses: rniswon@usgs.gov (R.G. Niswonger), kalland@usgs.gov (K.K. Allander), aejeton@aol.com (A.E. Jeton).

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evaporation typically is the largest outflow from a terminal lake. Lake surface evaporation in amounts greater than lake inflow will result in evapo-concentration of salts and high total dissolved solid (TDS) concentrations, even for lakes that receive dilute inflow (Beutel et al., 2001). Among other issues, managing terminal lakes often requires maintenance of lake storage and TDS concentrations in order to avoid critical thresholds in lake water quality that can include degradation of drinking water supplies, reduction in recreational value, and deterioration of valuable fisheries and other ecological components (Galat et al., 1981). Adding to the difficulty of managing water resources, terminal lakes accumulate changes in flows throughout tributary basins, which may include thousands of square kilometers and diverse hydrogeologic settings. Also, storage in large lakes reflects climatic conditions over multiple years (Hunt et al., 2008; Virdi et al., 2012). Large regional-scale influences that occur over long time periods make managing water resources in terminal-lake basins very challenging.

Advancements in DSS design has focused on stakeholder interactions, system usability and interfacing, and to a lesser degree on rigorous coupling of policy, management, and hydrologic processes (Jamieson and Fedra, 1996b; Yates et al., 2005; Letcher et al., 2007; Koch and Grünewald, 2009; Langsdale et al., 2013). Meanwhile, research has been on-going to couple climate, terrestrial, hydrologic, and management processes (VanderKwaak and Loague, 2001; Maxwell and Miller, 2005; Therrien et al., 2006; Panday and Huyakorn, 2004; Markstrom et al., 2008; Kim et al., 2008; Paniconi and Wood, 1993; Hanson et al., 2010; Condon and Maxwell, 2013). Given these somewhat disparate lines of research, the use of integrated hydrologic models as components of a DSS is a logical next step for water resources management (Sophocleous et al., 1999; Rosegrant et al., 2000; Xu et al., 2001; Liu et al., 2008; Valerio et al., 2010). Here we stress the importance of coupling management and hydrologic processes to realistically represent feedbacks among water management operations and hydrologic processes, such as those associated with climate variability, conjunctive use of surface water and groundwater, and changes in land use and the hydrologic landscape. Previous works using DSSs typically have not focused on feedbacks among hydrologic components due to their simplistic representation of hydrologic processes or non-iterative coupling of system components (e.g., Arnold et al., 1998). Systems dynamics models have been used as DSSs for improving management of water resources (Langsdale et al., 2007; Letcher and Jakeman, 2003). Systems dynamics modeling has been a popular approach due to the general nature of the modeling platform that can be used to represent many different processes. However, this approach does not rely on physically-based governing equations, which limits its applicability to water resources problems, most notably the simulation of surface water and groundwater interactions and other diffusive processes related to aquifer flow and storage.

Integrated models have not previously been used in the context of a DSS for collaborative modeling. Feedbacks between water use and hydrologic processes have been simulated using integrated models (i.e., Hanson et al., 2010; Rassam, 2011; Condon and Maxwell, 2013). However, these studies did not include the stakeholder component in the design and implementation of water management change within the DSS and were thus more hypothetical in nature. In the present work, collaborative modeling was used to design management change options; simulation capabilities needed to evaluate the management change were used to design the DSS, and DSS results were reviewed by stakeholders to further develop management change scenarios and for moving toward management change implementation. Stakeholders collectively referred to as the Walker Water Group include representatives from the Walker Federal Water Master, the Walker River Irrigation District, the Walker River Paiute Tribe, the Walker Lake Working Group, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, the Nevada Department of Wildlife, the Mason/Smith Valley Conservation District, and Nevada State Engineer's Office. The Walker Water Group met 9 times since January, 2010 to collaborate on development, application, and evaluation of the DSS.

Integrated models provide a means of simulating all of the important hydrologic processes within regional systems within a single, coupled processes framework. Thus, unlike DSSs used previously that require separate modeling components for different parts of the hydrologic system and data conversion and transfer, the approach described herein represents all climatic, hydrologic, and management components internally and avoids the need to develop application-specific data compatibility and transfer. Benefits to this approach include a DSS that is applicable over a greater range of system behavior, including extreme climate conditions, and feedbacks between water supply and demand. For example, during water scarcity, there are feedbacks between water management and water availability that are very difficult to simulate using a conventional, uncoupled DSS design. For the integrated approach, constraints on water allocation caused by water scarcity are simulated implicitly. Thus, a more realistic and seamless representation of coupled components of the DSS adds greater flexibility to the collaborative modeling process and therefore results in a more usable DSS. There is some increase in computational time associated with using integrated models as components of a DSS. However, due to the design of the integrated model presented herein, additional computation time is insignificant relative to other aspects of collaborative modeling process (i.e., information transfer, analysis of results, and consensus building with stakeholders) and the time savings associated with added richness of information provided by an integrated model. Furthermore, external linkages must be developed and modified when using a conventional DSS to consider management change, whereas this is not necessary for a DSS consisting of integrated modeling components.

Humans alter nearly all components of the hydrologic landscape, and these alterations cascade through tributary basins, and have a cumulative impact on terminal lakes. Humans control flow and storage in reservoirs, streams, and wetlands, and release contaminants and nutrients into these systems. Similarly, water availability, and indirectly, climatic conditions affect how water is managed. For example, during periods of water scarcity, water may not be delivered to low priority users, and thus, the location and rate of diversions or reservoir releases depend on flow and storage in the system. Feedbacks between water availability and water management are complicated when a diversion or release is dependent on water availability at a distant, downstream location in the system due to the established delivery rules or water rights priority. Similarly, reservoir releases are dependent on complex feedbacks between water supply and demand. Management and hydrologic models must be properly coupled to simulate these complicated interactions, which are apparent in developed terminal lake basins (Brooks et al., 2012). Properly simulating the effects of drought or population growth during periods of water scarcity requires simulating nonlinear feedbacks between supply and demand.

DSSs used for water management include representation of key system components, typically categorized into climatic, hydrologic, ecologic, management, institutional, and socio-economic components (Jamieson and Fedra, 1996a). The climatic and hydrologic component of a DSS considers relations among climate, surface water, and groundwater. Ecologic components represent wildlife habitat and water quality, natural vegetation, and associated linkages to water resources, such as stream and groundwater dependent ecosystems. Management components represent human controls on the hydrologic system, typically including reservoir storage and release, diversions from streams, and