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Optimizing the dammed: Water supply losses and fish habitat gains from dam removal in California

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ABSTRACT

Dams provide water supply, flood protection, and hydropower generation benefits, but also harm native species by altering the natural flow regime and degrading aquatic and riparian habitat. Restoring some rivers reaches to free-flowing conditions may restore substantial environmental benefits, but at some economic cost. This study uses a systems analysis approach to preliminarily evaluate removing rim dams in California's Central Valley to highlight promising habitat and unpromising economic use tradeoffs for water supply and hydropower. CALVIN, an economic-engineering optimization model, is used to evaluate water storage and scarcity from removing dams. A warm and dry climate model for a 30-year period centered at 2085, and a population growth scenario for year 2050 water demands represent future conditions. Tradeoffs between hydropower generation and water scarcity to urban, agricultural, and instream flow requirements were compared with additional river kilometers of habitat accessible to anadromous fish species following dam removal. Results show that existing infrastructure is most beneficial if operated as a system (ignoring many current institutional constraints). Removing all rim dams is not beneficial for California, but a subset of existing dams are potentially promising candidates for removal from an optimized water supply and free-flowing river perspective. Removing individual dams decreases statewide delivered water by 0–2282 million cubic meters and provides access to 0 to 3200 km of salmonid habitat upstream of dams. The method described here can help prioritize dam removal, although more detailed, project-specific studies also are needed. Similarly, improving environmental protection can come at substantially lower economic cost, when evaluated and operated as a system.

1. Introduction and rationale

A dam-building era occurred in the American West from the 1930s through the 1970s (Graf, 1999). This heightened economic development by providing reliable irrigation and municipal water supplies, hydropower generation, flood protection, and recreation opportunities (Reisner, 1993). Traditional cost-benefit analyses for dam construction generally did not consider ecosystem degradation, although fish hatcheries for commercially valuable species, such as salmon and trout, were sometimes constructed as a substitute for lost upstream habitat (Waples, 1999).

During the American Environmental Movement of the 1960s and 1970s, laws such as the Endangered Species Act and Clean Water Act were passed to maintain healthy rivers and preserve native species and habitats. By that time, most large rivers were dammed in the American West, requiring water managers to simultaneously regulate water while attempting to maintain healthy, functioning ecosystems. It became apparent that fish hatcheries were imperfect substitutes for wild runs of anadromous fishes and in fact, had introduced a host of problems, including altered run timing, susceptibility to disease, and lowered fitness (Williams et al., 1991). Dams and water development also had fundamentally altered natural flow and sediment regimes, degraded aquatic ecosystems, and harmed native species (Nilsson et al., 2005; Poff et al., 1997; Power et al., 1996). Anadromous fish species, such as Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), and others, faired particularly poorly, with population declines that coincided with dam-building (Moyle and Randall, 1998).

Our understanding of aquatic and riparian ecosystem processes is improving, as is our ability and desire to manage water resources for both people and ecosystems. However, when we repeatedly fail

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to stem or reverse environmental problems, environmental regulation can come to drive water management. This has occurred in California's Bay Delta, where endangered species, altered habitat, and water supply have been on a crash course for decades (Hanemann and Dyckman, 2009; Null et al., 2012; Hanak et al., 2011). Weakening environmental laws is a poor solution if we value aquatic species, ecosystems, and the services they provide, whereas addressing environmental problems directly would allow human objectives to play a larger role in decision-making. Preserving rivers to protect species and habitats is costly (in terms of both money and species) when considered as an afterthought rather than as an explicit objective of water projects. Bernhardt and Palmer (2005) estimate $1 billion US dollars per year are spent on river restoration in the US and restoration costs in California are nearly $6 million/1000 km (km) of streams and rivers. Similarly, the global value of ecosystem services provided by rivers and lakes is estimated to be $1,700,000,000 per year (Costanza et al., 1997).

Given current knowledge of natural ecosystems and the value they provide, water projects would undoubtedly be built differently if they were designed today. It is likely that some existing dams would not be built because biophysical, socio-economic, or geopolitical costs exceed benefits (Pejchar and Warner, 2001; Brown et al., 2009). Also many large dams were built subsequently to smaller dams, creating redundancy and more storage space than water in some watersheds (Fig. 1). For these reasons, removing dams is sometimes attractive for river restoration (Pohl, 2002; Bednarek, 2001; Poff and Hart, 2002). More than 1000 dams have been removed in the U.S. for a variety of reasons, including obsolescence, safety, to avoid costly upgrades for maintenance, hydropower relicensing, to improve water quality and flow for species and habitats, to improve fish passage, and dam failure (Pohl, 2002). In large part, this indicates that dams are subject to changing societal values (Johnson and Graber, 2002) as recent removals on Washington State's Elwha River demonstrate (Gowan et al., 2006; Winter and Crain, 2008). However, prioritizing which dams to remove and the ecological effects of removing them are still emerging fields.

Nearly all dam removal studies assess effects of removing individual dams (some examples include Roberts et al., 2007; Gillenwater et al., 2006; Tomsic et al., 2007; Null and Lund, 2006). While these studies help evaluate the costs and benefits of removing a single structure, more research and better methods are needed to prioritize dams that could be removed within systems and highlight how the remaining system could be re-operated to minimize water scarcity, maintain hydropower generation, maintain flood protection, or improve environmental performance (Kareiva, 2012; Kemp and O'Hanley, 2010). Only a few have put dam removal into a larger decision-making space by representing large

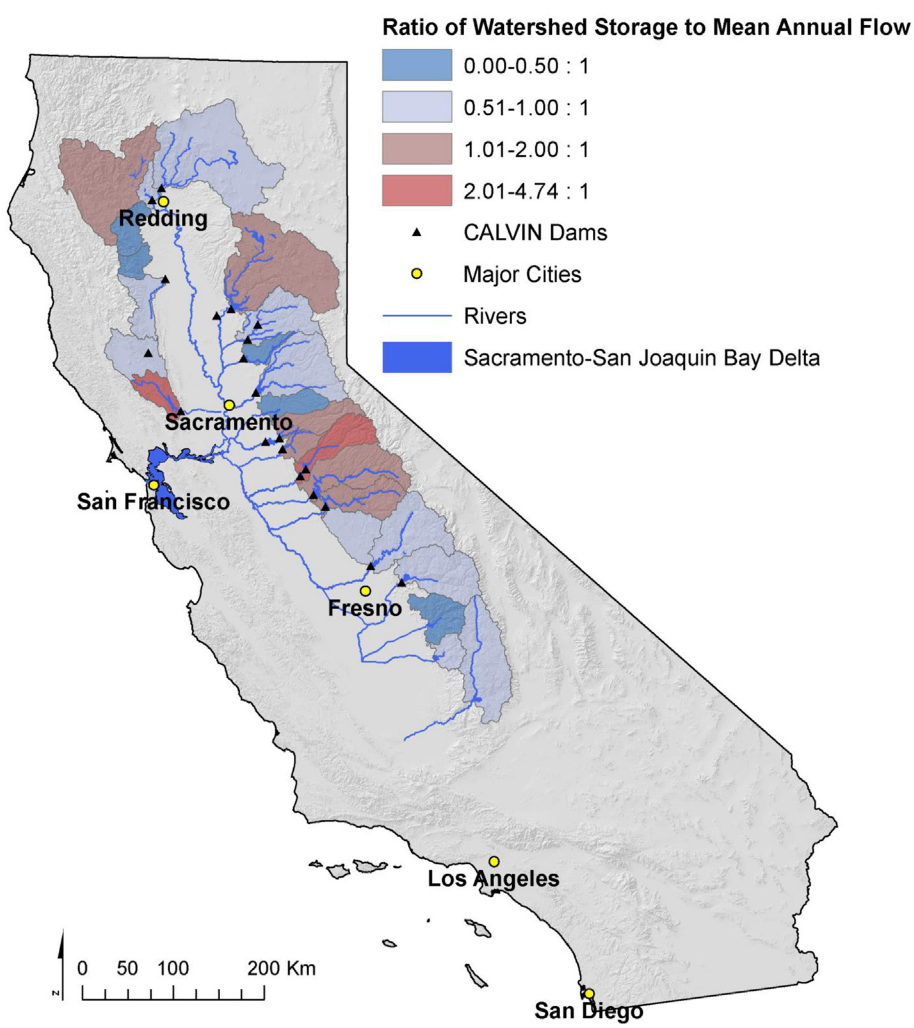

Fig. 1. Ratio of surface water storage capacity to mean annual flow by watershed. Red hues indicate watersheds with more surface storage than mean annual streamflow and blue hues indicate watersheds with less surface water storage than mean annual streamflow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)