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# HYDROPOWER RELICENSING AND CLIMATE CHANGE[1]

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ABSTRACT: Hydropower represents approximately 20% of the world's energy supply, is viewed as both vulnerable to global climate warming and an asset to reduce climate-altering emissions, and is increasingly the target of improved regulation to meet multiple ecosystem service benefits. It is within this context that the recent decision by the United States Federal Energy Regulatory Commission to reject studies of climate change in its consideration of reoperation of the Yuba-Bear Drum-Spaulding hydroelectric facilities in northern California is shown to be poorly reasoned and risky. Given the rapidity of climate warming, and its anticipated impacts to natural and human communities, future long-term fixed licenses of hydropower operation will be ill prepared to adapt if science-based approaches to incorporating reasonable and foreseeable hydrologic changes into study plans are not included. The licensing of hydroelectricity generation can no longer be issued in isolation due to downstream contingencies such as domestic water use, irrigated agricultural production, ecosystem maintenance, and general socioeconomic well-being. At minimum, if the Federal Energy Regulatory Commission is to establish conditions of operation for 30-50 years, licensees should be required to anticipate changing climatic and hydrologic conditions for a similar period of time.

(KEY TERMS: climate change; environmental regulations; hydropower; relicensing; water law; water policy.)

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## INTRODUCTION

Hydropower represents approximately 20% of the world's energy supply (Sommers, 2004), is viewed as both vulnerable to global climate warming (Lehner *et al.*, 2005; Minville *et al.*, 2009) and an asset to reduce climate-altering emissions (Kosnik, 2008; Resch *et al.*, 2008), and is increasingly the target of improved regulation to meet multiple ecosystem service benefits (Renöfält *et al.*, 2009). It is within this context that the recent decision by the United States (U.S.) Federal Energy Regulatory Commission (FERC) to reject studies of climate change in its consideration of reoperation of the Yuba-Bear Drum-Spaulding (YBDS) hydroelectric facilities in northern California will be shown in this article to be poorly reasoned and risky.

Through the Federal Power Act (FPA), the U.S. FERC is the sole issuer of licenses for nonfederal hydroelectric operations. Since 2005, licenses often undergo an Integrated Licensing Process (ILP; *Energy Policy Act §241*), which provides opportunity for affected parties to recommend issues for consultative investigation and possible mitigation, such as impacts to downstream fisheries. In light of global

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warming (IPCC, 2007) and an overwhelming body of scientific evidence for changes to the hydrologic regime (Dettinger *et al.*, 2004; Hayhoe *et al.*, 2004; Stewart *et al.*, 2004, 2005; Maurer *et al.*, 2007), a coalition of stakeholders recently requested that climate change and its potential impact to YBDS hydropower operations be included as one of several studies undertaken in the ILP. FERC denied this study request on the grounds that

> Although there is consensus that climate change is occurring, we are not aware of any climate change models that are known to have the accuracy that would be needed to predict the degree of specific resource impacts and serve as the basis for informing license conditions. (FERC, 2009)

The YBDS hydroelectric generation and water conveyance facilities are a complex mix of infrastructure, operations and jurisdictions between a private utility (Pacific Gas and Electric) and public utility (Nevada Irrigation District). Because of the complexity of operations and geographic proximity, these utilities have filed joint applications to FERC to renew existing hydropower generation licenses, which if approved will ensure a series of operating rules for the life of the license, typically 30-50 years in length.

The potential energy used in hydropower operations is a common pool resource with public discretion as to its end use. Hydropower provides a quick source of reliable energy due to its ability to transform potential energy from stored water into kinetic energy, and ultimately electricity, on very short notice, often within seconds, and thus adds significant flexibility to an energy supply portfolio. Hydropower is also a renewable source of energy that does not emit greenhouse gases through generation, and presently contributes 15%–24% of California's total power system supply (CEC, 2005, 2008). Recent shifts in policy (e.g., California Assembly Bill 32 (Franco *et al.*, 2008)) have placed an emphasis on developing and maintaining hydropower as part of its efforts to curb greenhouse gas emissions, and sustain developed energy sources. As such, the public has an inherent interest in the continued maintenance and production of energy from its rivers.

However, hydroelectricity is produced with detrimental environmental consequences. Hydropower systems adversely impact riverine ecosystems in numerous ways (Ligon *et al.*, 1995; Poff and Hart, 2002; Poff *et al.*, 2007), including the disruption of fish migratory routes; alteration to the flow regime, which can disrupt reproduction of aquatic and riparian organisms alike; alteration of geomorphic processes that can either deprive sediment from downstream ecosystems or create conditions of scour and incision; and alter the quality of downstream waters, most typically temperature. The environmental impacts of hydropower vary across time, including hourly peaking operations that rapidly change downstream flow conditions and long-term impoundments in large reservoirs that alter the downstream hydrologic regime on inter- and intra-annual bases.

The impacts of global climate warming to the hydrological regime include changes in the spatial and temporal distribution of precipitation patterns, and its intensity and extremes; widespread melting of snow and ice; increased rates of evaporation and transpiration; and changes to soil moisture and runoff fluxes (IPCC, 2008). Similar observations have been made in the regional context of western North America, most notably a shift in the seasonality of snowmelt runoff (Stewart *et al.*, 2005; Maurer *et al.*, 2007), as well as long-term trends to California's larger rivers (Dettinger *et al.*, 2004; Vicuna *et al.*, 2007; Anderson *et al.*, 2008). California's climate is expected to warm by 2-6°C over the next 50-100 years (Hayhoe *et al.*, 2004), with reduction in snowpack, earlier runoff, and reduced spring and summer flows (see Hidalgo *et al.*, 2009). Despite the lack of consensus in overall precipitation changes in California (Dettinger, 2004; Vicuna *et al.*, 2007), the Mediterranean seasonal precipitation regime of wet winters and dry summers is not projected to change (Cayan *et al.*, 2008).

Recent studies of Sierra Nevada water resources under climate warming suggest that these general climatic and hydrologic changes will result in substantial changes in the timing, magnitude, duration, and frequency of flows (Vicuna and Dracup, 2007; Young *et al.*, 2009), posing significant challenges to hydropower generation under a *status quo* approach to operations. For example, Mehta *et al.* (2011) used a rainfall-runoff model (WEAP21) and coupled water demand prioritization module for the area in question to simulate hydroclimatic response to uniform increases of 2, 4, and 6°C to observed air temperatures and historical precipitation for the period 1981-2000 in weekly time steps. The period of simulation included an extended drought (1987-1992), the wettest year on record (1983), and the flood year of record (1997), which represent extremes in the historical discharge record. This study shows that without changes to water management operations (i.e., reservoir storage and release schedules) shifts toward earlier timing of hydropower generation and reduction in total annual generation result, with a 5-20% reduction in hydropower generation overall with 2-6°C warming, respectively, largely from a reduction in seasonal snowpack and annual streamflow. Summer seasonal hydropower reductions range from 25 to 35% with 2°C warming, which is the anticipated warming for early to mid-21st Century and more in the scope of FERC licenses now under consideration. These results are not isolated. Vicuna *et al.* (2010), for example, used multiple global climate models (GCMs) to derive rainfall-runoff responses for the nearby Merced River, where averaged results indicated progressively decreasing streamflow releases through turbines and corresponding increases in uncontrolled spills over the current century. The implication of this projected system behavior is that to maintain hydropower generation and revenue near historical levels, changes in operations will be made to compensate for seasonal shifts and overall declines in water supply.

There are currently 54 such hydropower projects licensed by FERC located in the western Sierra Nevada with 7.1 GW of potential generation capacity annually (see Supporting Information). These projects license 47% of the large dams in the western Sierra Nevada ($n = 291$) and include 110 powerhouses and 826 km of water conveyances (i.e., ditches, canals, penstocks, and tunnels). Notably, there are 1,858 km of rivers downstream from FERC projects, representing 53% of all regulated rivers in the western Sierra Nevada. Not only does this hydropower infrastructure represent a vast economic investment but also clearly places FERC projects and their regulation at the center of any adaptive solution to reconciling water and ecosystem management, hydropower generation, and climate warming.

## POOR REASONING

The stated reasons by FERC for not explicitly including climate change in the YBDS relicensing ILP is two-fold: inaccuracy in climate change models, and the lack of a clear nexus between changing hydroclimatic conditions and project operations. The latter point refers to regulatory language that specifies commissioned ILP studies must be able to show how licensed operations will impact a specific resource and how the issue will inform the development of license requirements. The reasoning used to determine model inaccuracy, however, is less clear.

As Girvetz *et al.* (2009) point out, most GCMs are often too coarse for many scientific and planning questions, but that is not to say that they are inaccurate. In fact, hindcasted hydrology from multiple GCMs has been resolved over decadal time periods to be used in extensive detection and attribution studies (Hidalgo *et al.*, 2009). However, questions remain regarding which of the GCMs should be used for regional applications, the method of downscaling, and the distribution and any consensus among model results (see Pierce *et al.*, 2009). Recent improvements in downscaled regionally adjusted climate ensembles, when coupled with hydrological models, have reproduced observed flows at relatively fine scales ($\sim$150 km$^2$) (Vicuna *et al.*, 2007), and are now being used in relative risk assessments to water supply (Vicuna *et al.*, 2010). These models are highly accurate, in that they reliably reproduce observed conditions over large areas and long time frames using physical principles, and thus one can conclude that other factors, such as uncertainty or imprecision, are behind FERC's reasoning.

Although downscaled global climate and hydrological models both have uncertainty in their respective outcomes (IPCC, 2008), uncertainty by itself is insufficient to discount model findings as inaccurate. Temperature-driven impacts to the hydrological system can be anticipated with higher certainty than precipitation, as GCMs tend to agree on the direction of temperature change if not the magnitude (IPCC, 2007), but the source of uncertainty is complex. Uncertainty in climate change models can be partitioned into internal variability, model uncertainty, and scenario (i.e., emissions) uncertainty (Hawkins and Sutton 2009). Internal variability refers in part to the natural fluctuations of a given climate, which in the case of California is highly variable on seasonal and annual bases. This source of uncertainty is already integrated into hydropower operations modeling, presumably. Model uncertainty refers to the different responses climate models have to atmospheric forcing and forecasts are often averaged into ensembles to reduce such uncertainty. Uncertainty in emissions scenarios, the third source, is the largest component of overall uncertainty over longer time estimates (Hawkins and Sutton 2009) and is compounded by the underlying socioeconomics of human behavior. For planning purposes, however, Hawkins and Sutton (2009) found that overall uncertainty in climate change models is minimized and model signal-to-noise ratio is maximized at the 40- to 50-year time horizon, which is concordant with the issuance of a FERC license.

Regardless of inherent uncertainty in climate change modeling and data coarseness, hydrological models themselves are generally accepted within the FERC relicensing process, and well used by most if not all water utilities for planning purposes. In fact, rainfall-runoff simulation modeling is sufficient for state and federal governments to anticipate changes in operations and delivery in the coming decade (Christensen *et al.*, 2004; Anderson *et al.*, 2008). Thus, it is not the uncertainty or inaccuracy in climate-driven hydrological models that concerns licensees. Rather it is the imprecision of these models, and their inability to specify a quantitative condition in the future, that runs counter to FERC's charge under the FPA, which is to provide surety to licensees.

Thus, in its rejection of incorporating climate change into future hydropower operations licensing, FERC is conceding to the licensee's lack of operational specificity under such conditions.

A critical interpretation of the FPA and FERC's ability to regulate is the project nexus. As described by FERC (2005), they will consider studies in the ILP that meet all of several criteria. Most notably, the nexus between project operations and the resource to be studied must be identified, in addition to how study results would inform the development of license requirements. The clearest connection between climate warming, hydrology, and subsequent alterations to operations, and thus potential license conditions, is the direct effect of extreme climatic events, such as drought, on downstream receiving waters. In the case of YBDS, 463 million cubic meters is expropriated per water year on average, which if fully exercised in times of prolonged drought, could leave many rivers and streams barren. Knowing the likelihood and frequency of violating minimum instream flow conditions – or water delivery contracts – given future climate conditions would appear to be important and have a clear nexus to operations. Indirect effects will also impinge on downstream ecosystems. With increasing atmospheric temperatures, stream and reservoir inflow temperatures will also increase toward equilibrium. Managing cold water releases will become more difficult, especially for smaller volume reservoirs with limited cold water pools, or in reservoirs that increasingly fail to stratify in warmer months due to reduced storage. While exceedance studies for such conditions, and for potential retrofits to outlet works to improve likelihood of meeting water quality objectives, are not current standard ILP practice, they do meet the many criteria imposed by FERC for consideration. Furthermore, when the biological response to an exceeded temperature threshold is mortality, it appears misleading to suggest that a re-examination of the license condition is a sufficient remedy.

## RISKY DECISIONS

The ILP focuses in part on the impact of hydropower operations on downstream aquatic ecosystems and recent relicensing efforts have resulted in operational rules intended to minimize longer-term ecosystem impacts, such as incorporation of environmental flows intended to maintain ecosystem condition (King *et al.*, 2003; Arthington *et al.*, 2006). While the focus on environmental flows in relicensing is worthwhile, flow prescriptions are completely within the operational framework of licensees (i.e., flow releases are dependent upon upstream reservoir storage, or in the case of the Sierra Nevada, snowpack) and wholly with the underlying assumption of hydrological stationarity. In other words, observed variability in hydrological records, however limited, is assumed to be sufficiently robust to be used as boundary conditions for operations modeling into the future, and thus in the determination of downstream environmental flows and release schedules. It is an unfortunate assumption, and an inherently risky one, given that we now know that the future is not likely to look like the recent past (Milly *et al.*, 2008).

In order to adapt to a climate warming altered hydrology, an overall modification of the statewide water distribution system is anticipated to maintain deliveries (Tanaka *et al.*, 2006). Further, Sierra Nevada hydropower systems are likely to alter the timing of releases to maintain revenues (Madani and Lund, 2007). However, it is not well known how specific hydropower projects will need to adapt to changing resource conditions (Madani and Lund, 2010). Therefore, it is risky to not explore the full potential dimensions of future climate warming and hydrologic response. For example, a central component of ILP relicensing efforts is an analysis of water year types to define different operational rules for wet and dry years – in California there are very few "normal" years – based on the cumulative seasonal flow for a given river basin, and often indexed against a regional composite such as the forecasted Sacramento River Index (DWR, 2010). Dry year operating rules tend to favor human uses (e.g., hydropower, withdrawals for domestic and agricultural consumption), whereas wet years allow for more environmental flows. Aside from the assumption of stationarity in the hydrological record, it is conceivable that without any investigation into climate change impacts on hydrological response operational rules would be set forth for the next 30-50 years based on a wet year-dry year dichotomy that will inevitably trend toward dry, due in part to increased surface runoff during periods of saturation in snow dominated systems (Barnett *et al.* 2005) limiting infiltration and subsequent subsurface runoff.

## POTENTIAL REMEDIES

Poor reasoning and risky decisions aside, FERC is probably challenged to meet its regulatory mandate while balancing many political and economic interests. The scientific parsing of one given hydropower project is insufficient to alter an established process, such as the ILP; however, there are a few potential remedies that could improve decision making and its outcomes. At minimum, FERC should mandate that all hydropower licensing efforts include climate change studies as a standard part of their review, and in fact the State of California requires such reviews by all natural resource regulatory agencies (Schwarzenegger, 2008). The failure to comply with California Environmental Quality Act mandates for addressing future environmental conditions is now the basis for *Plumas County and Plumas County Flood Control and Water Conservation District* vs. *California Department of Water Resources* (Superior Court of California 2008), which points to the "failure to address what is known today and exploration of reasonable climate change-related impacts." Similarly, the preparation of National Environmental Protection Act (NEPA) scoping documents, which are intended to represent a *reasonably foreseeable* range of alternatives for future operations, should include a climate-impacted alternative. Perhaps in anticipation of future consideration, the Department of Interior has recently released Order 3289, which states "the Department must consider and analyze potential climate change impacts when undertaking long-range planning exercises … and making major decisions regarding potential use of resources under the Department's purview" (Salazar, 2009). The fact that it is not considered presently in NEPA preparation will probably provide fertile ground for litigation in any relicensing effort going forward (Smith, 2008).

More importantly, however, changes to the FPA are needed to allow greater frequency in the review of license terms, to increase the aggregation of licenses, and to embrace regionalization of water operations. Through the implementation of ILP, we know that there will be negotiated changes to future operations of YBDS and other such facilities. These changes will be intended to mitigate the adverse ecological effects of river regulation with a move toward natural flow regimes (Poff *et al.*, 1997; Richter *et al.*, 2003), and intended to ensure the public trust in sustaining natural resources. We also anticipate that there will be climate warming induced hydrological change. Therefore, it is reasonable to assert that fixed long-term licenses are not in the public's best interest and a more frequent review of license conditions is warranted. This point is further reinforced by several considerations reviewed by FERC (2001), including provisions that allow licensees to utilize *status quo* operations during periods of dispute that can be perpetuated to delay enactment of or reform to license conditions. Further, we can anticipate that the net benefits of reoperation will necessarily be localized unless policies can be adapted to encourage a broader geographic assessment of impacts and greater coordination of hydropower operations within basins. This aggregation of licenses would not only help minimize cumulative downstream effects of serial flow manipulation but also minimize direct liability by any one licensee to protect and enhance downstream resources.

Lastly, changes in FPA should be made to allow licensees and stakeholders to engage in regionalization, in which specific projects and water resources are assessed for their marginal benefit to the public trust. For example, nearly all of California's natural runs of anadromous salmonids are on the brink of extinction (Moyle *et al.*, 2008), due in large part to dams blocking migratory accesses to spawning grounds (NMFS, 2009). Regional assessments of climate warming impacts on hydrological response may reveal that some basins are better suited for hydropower delivery, while others at sustaining salmon populations. Given the recent Biological Opinion by the National Marine Fisheries Service (NMFS, 2009), it is highly likely that FPA Section 18 prescriptions for fish passage will affect most if not all Sierra Nevada projects impairing reaches of historical salmon habitat. Individual licensees will not probably want to solely bear the burden of fish passage and habitat maintenance when such impairments are cumulative (Bezerra and West, 2005); thus, regional or watershed approaches could help licensees proportionally share responsibilities.

It is clear that FPA licensing is one of many concerns to hydropower operators, as regulators are beginning to more rigorously enforce the federal Clean Water Act §401(c) (see Pollak, 2007) and will continue to engage in the application of the federal Endangered Species Act §7 (see Wood, 2004). The current comingling of regulatory authorities, coupled with decentralized decision making on a project-by-project *ad hoc* basis, makes regionalization difficult, but all the more important. The current situation suggests that an independent body – such as California's Independent System Operator for the energy grid or the Bonneville Power Authority for Columbia River operations – may be needed to provide operational and regulatory coherence and reliability to a system of utmost socioeconomic importance. Further, future hydrologic and hydropower operations research needs to focus on optimizing operations for multiple downstream demands and flow requirements within a nonstationary hydroclimatic framework.

## CONCLUSION

Given the rapidity of climate warming, and its anticipated impacts to natural and human communities, it is reasonable to assert that long-term fixed licenses of hydropower operation that do not explicitly incorporate a mechanism for adaptation are not in the interest of the public or the environment. Further, it is reasonable to presume that some adaptation will be necessary given the magnitude of anticipated change. The current approach by FERC, however, is likely to result in *reactive* adaptation with near-term, single actor solutions held in the private domain. The public trust would be better served by *anticipatory* adaptation with mid- to long-term, multiple actor solutions held in the public domain. The reason for this is that the licensing of hydroelectricity generation cannot be issued in isolation due to downstream contingencies such as domestic water use, irrigated agricultural production, ecosystem maintenance, and general socioeconomic well-being. The stated policy of FERC is to issue licenses for the full 50-year term "absent compelling reasons to do otherwise" (FERC, 2001, p. 99). In practice, FERC establishes conditions of operation for <50 years for a variety of reasons (typically 30-40 years), and there are now compelling reasons to consider changing climatic and hydrologic conditions for a similar period of time.

## SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

**Table S1.** Listing of FERC Licenses Issued for the Western Sierra Nevada, California.

Please note: Neither AWRA nor Wiley-Blackwell is responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

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