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Climate Change Impacts on Hydropower in the Colorado River Basin

KEY MESSAGE: Hydropower dams along the Colorado River and its tributaries are a significant source of electricity in the southwestern U.S. and Mexico, producing enough energy to power over 780,000 households per year. Climate change is predicted to decrease streamflows and reservoir storage along the Colorado, dramatically decreasing hydropower capacity at a time when electricity demand is increasing due to regional population growth. To address this growing energy deficit, policymakers must adopt regulations and incentives that restore hydropower capacity, promote sustainable energy alternatives, and reduce energy demand throughout the region.

The Colorado River is a vital freshwater resource for the inhabitants of the southwestern U.S. and Mexico. Approximately 30 million people rely at least partially on the river and its tributaries for fresh water (USBR 2012). The Colorado flows approximately 1,450 mi (2,330 km) from the Rocky Mountains to the Gulf of California, gathering water from a 243,100 mi^2 (629,600 km^2) drainage basin. Nearly 90 percent of the river's flow is snowmelt from headwaters in Colorado, Utah, Wyoming, and New Mexico. From there, the river travels through Arizona, Nevada, and California before flowing between the Mexican states of Baja California and Sonora into the Gulf of California.

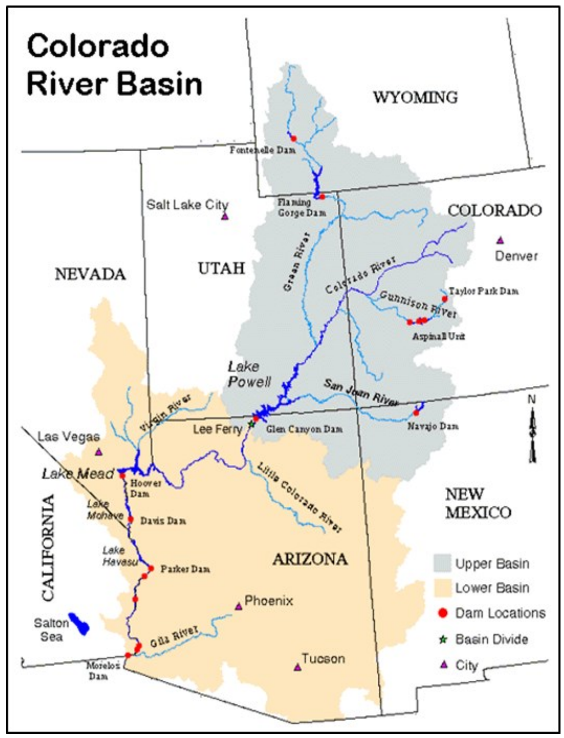

Figure 1. Major dam locations within the Colorado River Basin. Source: CRCN 2007.

Hydropower in the Colorado River Basin

The Colorado River Basin has an immense capacity to generate hydropower. Hundreds of hydroelectric dams along the river's main stem and tributaries (Figure 1) have a combined generating capacity of approximately 4,178 megawatts (MW) (Tweed 2013). In the period from 1950-1999, these dams produced an annual average of 8,478 gigawatt hours (GWh) of electricity, enough to support approximately 782,000 U.S. households (Christensen & Lettenmaier 2007, USEIA 2014).

Over 81 percent of the river's hydropower capacity comes from the Hoover and Glen Canyon Dams (Tweed 2013). Constructed between 1931 and 1935, the Hoover Dam spans the Colorado River between Arizona and Nevada, approximately 30 miles southeast of Las Vegas (Figure 2). Lake Mead, the 248 mi^2 (642km^2) reservoir created by the Hoover Dam, has a storage capacity of approximately 28.9 million acre-feet (35.6 km^3), the rough equivalent of two years of Colorado River streamflow (USBR 2012a). This reservoir drives the Hoover Dam's power plant, which is comprised of 17 main turbines, nine on the Arizona side and eight on the Nevada side, and has a maximum generation capacity of approximately 2,080 MW (USBR 2009). In an average year, Hoover Dam generates about 4,000 GWh of electricity for customers in Nevada, Arizona, and California (USBR 2009). The largest portion of this electricity goes to the Metropolitan Water District of Southern California (28.5 percent), with Nevada (23.4 percent), Arizona (19.0 percent), and Los Angeles (15.4 percent) being the next largest consumers (USBR 2009).

The Glen Canyon Dam, located roughly 350 mi (560 km) northeast of the Hoover Dam in Arizona, is the largest hydropower dam in the Colorado River Storage Project, a series of reservoirs that provides hydroelectric power, flood control, and water storage in the upper Colorado River Basin. The dam's reservoir, Lake Powell, covers 252 mi^2 (653 km^2) and has a storage capacity of approximately 27 million acre-feet (33 km^3). These waters drive the Glen Canyon Dam's power plant, which contains eight turbines and has an installed capacity of 1,320 MW. For the period 1965-2010, the Glen Canyon Dam generated an average of 4,610 GWh per year (USBR 2011). The Western Area Power Administration sells this electricity to municipalities, rural electric cooperatives, Native American tribes, and government agencies in Wyoming, Utah, Colorado, New

Mexico, Arizona, Nevada, and Nebraska (USBR 2008).

Hydropower generation in the Colorado River Basin is largely dependent on reservoir storage and streamflow. Hydropower generation is a function of hydraulic head (the falling height of water) and discharge (volume of water per unit time) passing through a turbine (Christensen & Lettenmaier 2007). While discharge can be controlled at the intake gates on the inside of the dam, hydraulic head is determined by the height of water in the reservoir above the natural height of flowing water in the river, which, in turn, is determined by the volume of water stored in the reservoir (Khemnani 2013). The Colorado River Basin has approximately 60 million acre-feet (74 km^3) of reservoir capacity on its main stem, and nearly 92 percent of this resides in Lakes Mead and Powell, making hydropower generation very sensitive to the storage volumes of these two reservoirs (Christensen & Lettenmaier 2007).

Figure 2. The Hoover Dam. Source: USBR 2013..

Impacts of Climate Change on Hydropower

Electricity generation at the Hoover and Glen Canyon Dams is already being affected by higher temperatures and reduced streamflow resulting from climate change. In 2014, water levels in Lake Mead are expected to decrease by nearly 8 feet (2.4 meters) due to a 10 percent reduction in upstream releases from Lake Powell, which has seen more than a decade of reduced inflow from major tributaries (Tweed 2013). In August 2013, Lake Mead water levels were 70 feet (21 meters) below their historical average of 1,175 feet, resulting in more than a 16 percent decrease in generation capacity (Tweed 2013). Lower reservoir levels are also expected to reduce Glen Canyon generation capacity by 8 percent in 2014, relative to the previous year (Tweed 2013). Should Lake Powell water levels fall beneath 3,487 feet (1,063 meters), just 98 feet (30 meters) below their August 2013 level, the threat of vortex action from excessive air intake could damage turbines and halt power generation at Glen Canyon Dam altogether (Tweed 2013).

While the current drought cycle is one of the worst on record, it may be indicative of future trends. Climate studies using an array of general circulation models (GCMs) and future atmospheric carbon dioxide scenarios estimate that by 2075 basin-wide average temperatures will increase 4.9 to 7.9° F (2.7-4.4° C) relative to recent historical averages (Christensen & Lettenmeier 2007). This may accompany modest increases in winter precipitation and decreases in summer precipitation, along with a reduction in average annual snowpack of up to 38 percent (Christensen & Lettenmeier 2007, USBR 2012b).

Higher temperatures and altered precipitation patterns are expected to decrease average runoff by 8-10 percent in the basin by 2075, which could lead to streamflow reductions of 8-11 percent (Christensen & Lettenmeier 2007). These factors, combined with increased summer evaporation rates, could reduce reservoir storage by as much 10-13 percent, and ultimately reduce electricity generation by 16-19 percent in the Colorado River Basin (Christensen & Lettenmeier 2007, Figure 3).

Such reductions in hydroelectricity production may have fiscal and ecological impacts. Utilities will have to buy power from other utilities or build new power plants to meet their delivery obligations – both of which are far more expensive than continued use of hydroelectricity. In 2014, the Western Area Power Administration may have to spend up to $10 million in electricity purchases to meet its delivery commitments due to decreased generation at the Glen Canyon Dam (Tweed 2013). Furthermore, the electricity generated to compensate for the hydropower energy deficit will likely come from fossil fuels, leading to an increase in greenhouse gas emissions. This increase will play into a positive feedback loop in which the effects of climate change are intensified, hydroelectric power capacity is further reduced, and more fossil fuel-based energy sources are needed.

Current Policy Situation

The over-allocation of the Colorado River's waters will likely act in conjunction with climate change to further reduce hydropower capacity in the basin. Hydropower consumes minimal water, yet hydropower capacity relies on consistent streamflows and reservoir storage, both of which are threatened by a disparity between supply and demand enshrined in current basin water policy. Allocation of the Colorado River is governed by a series of 12 major and a series of minor federal and state laws, treaties, court decisions, and compacts collectively known as the Law of the River. The Colorado Compact of 1922, the cornerstone of the Law of the River, split the basin's water between the Upper Basin states (Wyoming, Utah, Colorado, and New Mexico) and Lower Basin states (Arizona, Nevada, California), apportioning 7.5 million acre-feet (9.3 km^3) of water per year to each. The subsequent adoption of the U.S.-Mexico Treaty of 1944 allocated another 1.5 million acre-feet (1.9 km^3) of water per year to Mexico, bringing total Colorado River allocations to 16.5 million acre-feet (20.4 km^3) per year (USBR 2012b). These treaties were created in an especially wet period, so short-term stream flow data overestimated how much water would be available in the future (Christensen & Lettenmaier 2007). The Colorado River's current historical annual stream flow average (1906-2011) is approximately 16.4 million acre-feet (20.2 km^3), with current averages being even lower (USBR 2012b). In effect, the Colorado River is over-allocated. The Law of the River has functioned in recent years only because the Upper Basin states have not fully developed their portion of the Colorado (USBR 2012b), yet as existing policy allows water demand to exceed supply, the resulting reduction in streamflow and reservoir storage will adversely affect hydropower generation.

Figure 3. Lake Powell water line. The white "bathtub ring" lining the canyon wall shows the former high water mark of the reservoir. Source: NPR 2005.

Ways Forward

To maintain hydroelectric capacity in the Colorado River Basin, policymakers must support regulations and programs that protect streamflow and restore reservoir storage to historical averages. Efficiency and conservation efforts aimed at agricultural and municipal water use will be important tools in achieving these goals. Agriculture, which account for roughly 57 percent of water demand in the basin, holds the greatest potential for water savings (USBR 2012b). Programs that promote efficient irrigation technology, deficit irrigation, and water-efficient crops are just some of the ways in which policymakers can help farmers decrease their water use. In addition, water-sharing programs, in which farmers lease or sell water rights to municipalities, would provide a means to decrease irrigated acreage in the most arid regions of the basin, where evaporative losses are excessive and crop production is water inefficient. Municipalities throughout the basin have already been active in reducing per capita water use through various conservation and efficiency programs over the past several decades, yet explosive population growth has counteracted this decrease, resulting in an overall increase in water deliveries (Cohen 2011). More aggressive conservation and efficiency efforts will be necessary to reverse this trend.

Policymakers can also address threats to hydropower capacity by funding adaptive upgrades to power plants. The Hoover Dam, for example, is having five new wide-head turbines installed to allow hydropower to be generated under low water levels in Lake Mead (Tweed 2013). Such investments expand the lifespan of existing major infrastructure investments under increasingly water-scarce conditions.

Given the predicted trajectory of climate change in the Colorado River Basin, sustaining hydropower at its current level may prove untenable. Policymakers must prepare for this possibility and address the resulting energy deficit responsibly. One option is to promote the development of renewable energy sources throughout the basin. Subsidies and incentives for wind, solar, and thermal energy projects would increase the likelihood of their adoption over fossil fuel power plants, preventing further contributions to climate change. Another option is to reduce demand by promoting energy efficiency and conservation programs. If energy demands are reduced, especially in water transportation networks and urban centers, the basin's power grid may be able to absorb the loss of hydropower without having to turn to additional fossil fuel-based generation.

Overall, hydropower in the Colorado River Basin faces an uncertain future due to climate change, and dealing with that uncertainty will be a major challenge for policymakers in the coming decades. While this is a daunting task, there are many options available to maintain hydropower generation in the basin or compensate for its decrease with sustainable energy alternatives. The one certainty is that business as usual will no longer meet the needs of the basin's inhabitants, requiring decisive action from its managers and leaders.

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