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Influence of De-Regulated Electricity Markets on Hydropower Generation and Downstream Flow Regime

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The beauty of conventional hydropower is its large-scale energy storage capability and (after construction) low cost, emission-free energy production with minimal ramp-up time. Even in areas where it comprises a relatively small fraction of total generation, hydropower has long been vital in utilities' efforts to meet rapid changes in supply and demand. Nonetheless, conventional hydroelectric dams can cause significant environmental impacts, including the disruption of downstream flow patterns. Although investigations of these impacts abound in the scientific literature, most pre-date a potentially important change in how dams are operated.

Prior to the late 1990s, most electric utilities in the United States were "regulated," operating as separate non-competitive zones in which the price of electricity was fixed. Ascribing to a strategy of cost minimization, traditional hydropower generation scheduling created a periodicity in downstream flows corresponding to "peak" daily and seasonal demands. However, more recently, the advent of "de-regulated" competitive electricity markets in the U.S. has introduced additional influences that have the potential to further impact river flows below hydroelectric dams. In such markets, the price of energy ($/MWh) and grid reliability services (e.g. frequency regulation) fluctuate hourly due to variations in supply and demand. As a result, hydropower utilities have substantial financial incentives to alter their day-ahead generation schedules (set 24 hours in advance) on a real-time (hourly and sub-hourly) basis, as hydropower is well suited to take advantage of sudden, and less predictable, changes in market prices.

This study explores the potential for de-regulated market dynamics to impact flows downstream from hydroelectric dams, as well as the financial cost and efficacy of efforts to mitigate the environmental effects of altered flow regimes. Three dam sites in the PJM Interconnection electricity market are simulated with stochastic hydrologic and market inputs under three different operational scenarios: run-of-river (outflows approximate inflows), day-ahead market only and full-market participation (including real-time and regulation markets). Collectively, these scenarios span a broad range of possible operations, from a strategy that attempts to more closely mimic natural flows (run-of-river) to one in which a utility takes full advantage of its revenue generating potential using probabilistic decision analysis (full market participation). These three scenarios are compared against an unregulated scenario (no dams in place) using indicators of hydrologic alteration (IHAs) that reflect five ecologically critical components of downstream river flow (magnitude, timing, frequency, rate-of-change and duration).

Preliminary results suggest that, compared to a day-ahead only scenario, the scale of any differences in flow regime resulting from full-market participation is somewhat smaller than the additional revenue generating potential of such a strategy. However, this is based on a limited number of indicators (not all of which capture the sub-daily changes in river flow inherent to full-market participation). Implementing a run-of-river policy frequently yields "more natural[U+201F] flow regimes than the day-ahead only scenario; however, these improvements appear modest in most cases and come at a substantial cost in terms of foregone hydropower revenue. This study highlights a need for additional research on the potential ecological impacts of extremely short term (hourly and sub-hourly) fluctuations in river flows, as well as further investigation of how hydropower assets will be used in the future, e.g. within generation portfolios that are incorporating increasing amounts of renewable energy from intermittent sources.