Can Hydroelectric Facilities Flexibly Support Wind Integration?

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How flexible are hydroelectric multi-use dams?

- **Problem**
  Supplemental energy required to correct for *errors* in the wind power forecast

- **Our study**
  Model the capacity allocation decision for a multi-use dam to provide reserve capacity to compensate for wind forecast errors

- **Result**
  - Deriving opportunity costs for a profit-maximizing hydro dam
  - Operational conflicts and drought are severe hurdles for dams when providing *flex-reserves*
Wind integration challenges

Need a mechanism that can respond to the timing and magnitude of wind forecast errors, currently does not exist. Possible options:

- Utility-scale energy storage: high costs, property right difficulties and limited plans
- Competitive prices: generators providing supplemental energy need sufficient compensation (NREL 2012)
  - We find that if prices were similar to PJM regulation prices, dams still have little incentive to divert capacity for compensating forecast errors
What are flex reserves?

- Reserve-type service used to compensate for errors in wind forecast
  - Response time longer than seconds (regulation) but shorter than hourly or half-hourly (synchronized reserves)
- Model uses PJM regulation prices ($/MWh) as a proxy for prevailing prices in this market
- Participating generators compensate during periods with ‘too little’ wind (undersupply) and ‘too much’ wind (oversupply)
  - We find that off-peak flex reserve allocations during both over and undersupply periods are larger than on-peak
  - On-peak capacity allocations, particularly during severe drought years, face largest operational conflicts
Case study: Roanoke River Basin

Pennsylvania- New Jersey-Maryland (PJM) territory, Dominion Zone
- Eleven of 13 states + DC have renewable goals
- Wind (pink) includes 40% of planned investments

Kerr Dam (star) in Hardwood Bottomland Forest, border North Carolina and Virginia

Kerr Dam provides energy, flood control, recreation, and “ecosystem services” to support the Hardwood Forest
Performance across hydro-climate gradient

- We compare simulated flex-reserve operations to historical data over 2006-2008
  - 2006: typical wet year (Palmer Drought Index, PDI 0 to > 4)
  - 2007: transition to severe drought (PDI < -3 Aug-Dec)
  - 2008: sustained drought (PDI -6 in Jan to -1 Dec)
- The drought we model would be considered a 1-in-100 year event, but increased population and pressures on water supplies make these events more likely
- Forecast data provided by PJM, aggregated hourly for a 24 hour ahead forecast from January to June 2010
Model description: Profit maximizer

**Stakeholders:** U.S. Corps of Engineers, Southeastern Power Administration, Preference Utilities, Dominion Power

- **Scheduled energy**
- **Flex reserves capacity**

**SCENARIO 1:** Business-as-usual reservoir guide curve

**SCENARIO 2:** Ecosystem services reservoir guide curve

**Dam Guide Curves:**
Guide curves at Kerr Dam

<table>
<thead>
<tr>
<th>Kerr reservoir level (ft-msl)</th>
<th>Reaches (cfs)</th>
<th>Kerr reservoir level (ft-msl)</th>
<th>Releases (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 300</td>
<td>Up to 8,000</td>
<td>Below 302</td>
<td>Up to 11,000 *</td>
</tr>
<tr>
<td>300-312</td>
<td>Up to 20,000</td>
<td>302-303</td>
<td>Up to 20,000 *</td>
</tr>
<tr>
<td>312-315</td>
<td>Up to 25,000</td>
<td>303-315</td>
<td>Up to 35,000 *</td>
</tr>
<tr>
<td>315-320</td>
<td>Up to 35,000</td>
<td>Above 315</td>
<td>BAU operations</td>
</tr>
<tr>
<td>320-321</td>
<td>85% of inflow or up to 35,000 (choose highest)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Above 321</td>
<td>Reservoir inflow</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Occurs during April 1 - June 30

** From Jan. 1 - March 31, release up to 20,000 cfs to a reservoir level of 303 feet. Above 303 feet, follow the ecosystem services release schedule, and all other times follow BAU operations.
Multi-use dams are complex

- Drought
- Operational constraints
  - Guide curve rules to meet multiple services
  - Energy declaration
- Legal limits
  - Federal protection policies
  - Local stakeholder priorities
- Providing wind integration services conflicts with current operational policies

Adjusting prices alone cannot resolve operational constraints
Ecosystem services conflict with flex reserves needed for curtailment

Curtailment requires Kerr to ‘store’ capacity equivalent to at least the capacity offered for flex reserves (oversupply)

More incentive to offer capacity during off-peak hours in a wet year

Transitioning to dry year, operational policies conflict with flex reserve requests, even with 50% price increase
Meeting 100% of the forecast error

Violation is the difference between the daily energy declaration and the combined daily magnitude of oversupply and undersupply events.

Water scarcity due to drought causes the largest violations.

Decision to provide flex reserves requires alterations to operational policies—vary in terms of magnitude and timing of releases.
How would the ecosystem services guide need to change?

Trade-off between enhancing the downstream environment and maintaining revenue-maximizing practices, requiring fundamental reform of operating policies for flex reserve provisions (drought)
How does a flex reserve policy impact multi-use dams like Kerr?

- Flex reserve revenues small, further reduced with drought
  - Represent 2% of revenue currently generated (BAU)
- Reservoir hydropower policy (energy declaration) require substantial alterations to provide flex reserves
  - In dry year would need to be nearly double that of a wet year to meet the 100% of the forecast errors
- Water scarcity would severely hinder the use of multi-use dams for wind integration services
  - Releases for flex reserves would need to exceed total volume of reservoir 20% with ecosystem provisions (infeasible)
Thank you


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Are there seasonal differences to providing flex reserves?
Wind forecast error distribution

![Wind forecast error distribution graph](image-url)
Next steps resolving wind integration challenges

- Need an understanding of what an optimal water management policy is to provide substantial flex reserves.
- Future work will implement a many agent framework to identify operational and policy conflicts for more than one decision maker under uncertainty.
- Test how regional wind integration penalties will impact generators incentives to provide flex reserves.
Outline topics

- Motivation: Large-scale renewable integration across the U.S.
- Case study: Mid-Atlantic U.S. electrical territory, Roanoke River Basin
- Model design: Managing energy services (scheduled market, flex reserves)
- Results: reservoir operational conflicts main barrier to integrating wind