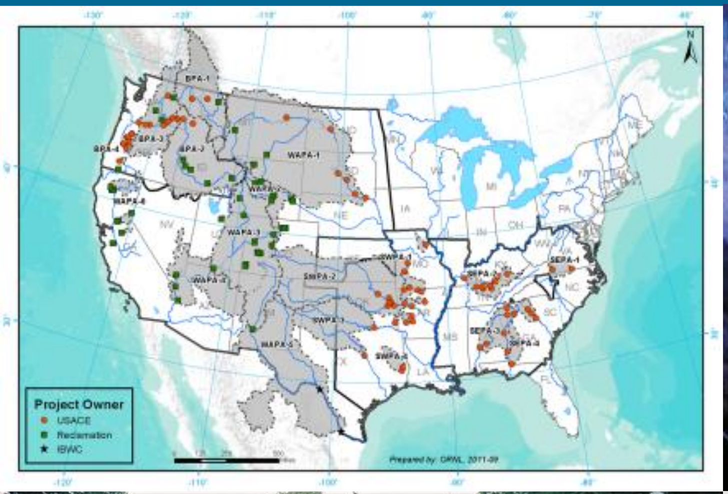
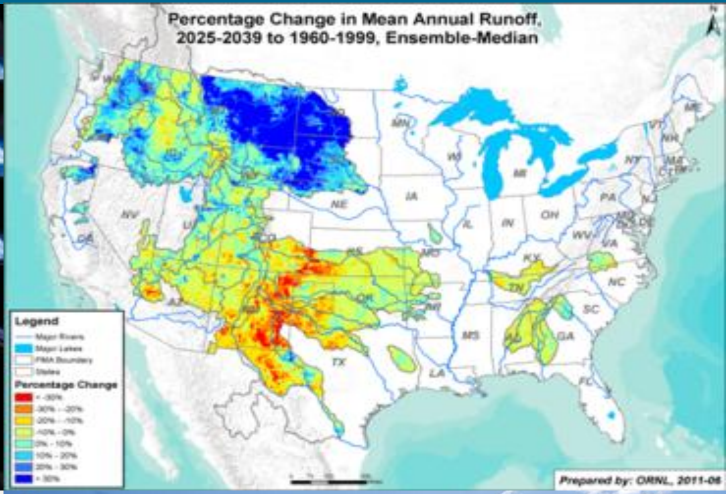
# Energy Production and Climate Resilience Strategies: Hydropower

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy




IEA Committee on Energy Research and Technology – EGRD Workshop

Utrecht, The Netherlands
November 13, 2013


**Hoyt Battey**
***Wind and Water Power Technologies Office***
**U.S. Department of Energy**

# Overview

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- Hydropower Background / Context
- Assessing Hydropower / Climate Change Interactions
  - New U.S. study of potential impacts
  - Future improvements needed
- Related Emerging Issues
  - Deforestation / land-use change impacts to precipitation and hydropower production
  - GHG emissions from reservoirs
  - Hydropower and water consumption
- Technologies / Strategies to Address Risks
- Conclusions
- Questions

# Potential Hydropower Issues



- Changes to amounts of available water
  - Decreasing precipitation / runoff leads to facility sizing imbalances
  - Additive negative effects with other water uses during times of scarcity
  - Increasing precipitation / runoff may not necessarily equate to additional generation
  - If extreme events increase, flood control will become a greater priority over energy
- Changes to timing of water and generation
  - Shifting precipitation patterns within years
  - Earlier and faster periods of snowmelt-fed runoff can pose significant challenges
- Additional water quality / critical habitat issues could also impact generation and / or ancillary services
  - General trend of increasing temperatures combined with lower summer flows
  - River sediment leads can increase if extreme high-flow events become more frequent

# Why this is Important: Hydropower's Attributes



| | |
|---|---|
| **Back-up and reserve** | **Hydropower plants** have the ability to enter load into an electrical system from a source that is not on-line. **Hydropower** can provide this service while not consuming additional fuel, thereby ensuring minimal emissions. |
| **Quick start capability** | **Hydropower's** quick-start capability is unparalleled, taking just a few minutes – compared to 30 minutes for other turbines and hours for steam generation. This entails savings in start-up and shut-down costs of thermal plant and allows for a steadier operation, saving fuel and extending plant life. |
| **Black start capability** | **Hydropower plants** have the capability to run at a zero load. When loads increase, additional power can be loaded rapidly into the system to meet demand. Systems with available **hydroelectric** generation are able to restore service more rapidly than those solely dependent on thermal generation. |
| **Regulation and frequency response** | **Hydropower** contributes to maintaining the frequency within the given margins by continuous modulation of active power and to meet moment-to-moment fluctuations in system power requirements. **Hydropower's** fast response ability makes it especially valuable in covering steep load gradients (ramp rates) through its fast load-following. |
| **Voltage support** | **Hydropower plants** have the ability to control reactive power, thereby ensuring that power will flow from generation to load. They also contribute to maintaining voltage through injecting or absorbing reactive power by means of synchronous or static compensation. |
| **Spinning reserve** | **Hydropower** supports the dynamic behavior of grid operation. **Hydropower plants** can provide spinning reserve – additional power supply that can be made available to the transmission system within a few seconds in case of unexpected load changes in the grid. **Hydropower** units have a broad band of operations and normally operate at 60-80% of maximum power. This results in spinning reserve of up to 100%. |
| **Reservoir Benefits** | Multi-purpose hydropower schemes, providing irrigation and flood/drought control as well as other non-energy benefits, can enhance regional development; hydropower development can be integrated with water supply and agriculture |

# Growth of Hydro Worldwide



- Currently, hydropower accounts for approximately 20% of total installed energy capacity (as of 2012), thanks to steady growth, as seen in the global increase from 858 GW in 2006 to 2012 levels of 1,065 GW
- Global cumulative hydropower installed capacity is expected to increase from 1,065 GW last year to 1,407 GW in 2020
- More than 60 countries use hydropower to meet more than half of their electricity needs
  - Including Austria, Brazil, Canada, New Zealand, Norway, Switzerland, and Venezuela
- Much of the significant growth in recent years, (and what is projected for the coming decade), has taken place in areas where water stressors are high or increasing
  - China, India, Pakistan, Central and Eastern Africa

***Section 9505 of the 2009 Omnibus Public Lands Act***
***HYDROELECTRIC POWER ASSESSMENT.***

(a) Duty of Secretary of Energy- The Secretary of Energy, in consultation with the Administrator of each Federal Power Marketing Administration, **shall assess each effect of, and risk resulting from, global climate change with respect to water supplies that are required for the generation of hydroelectric power at each Federal water project** that is applicable to a Federal Power Marketing Administration.

(b) Access to Appropriate Data-

(1) IN GENERAL- In carrying out each assessment under subsection (a), the Secretary of Energy shall consult with the United States Geological Survey, the National Oceanic and Atmospheric Administration, the program, and each appropriate State water resource agency, to ensure that the Secretary of Energy has access to the best available scientific information with respect to presently observed impacts and projected future impacts of global climate change on water supplies that are used to produce hydroelectric power.

(2) ACCESS TO DATA FOR CERTAIN ASSESSMENTS- In carrying out each assessment under subsection (a), with respect to the Bonneville Power Administration and the Western Area Power Administration, the Secretary of Energy shall consult with the Commissioner to access data and other information that--

(A) is collected by the Commissioner; and

(B) the Secretary of Energy determines to be necessary for the conduct of the assessment.

(c) Report- Not later than 2 years after the date of enactment of this Act, and every 5 years thereafter, the Secretary of Energy shall submit to the appropriate committees of Congress a report that describes--

(1) each effect of, and risk resulting from, global climate change with respect to--

(A) water supplies used for hydroelectric power generation; and

(B) power supplies marketed by each Federal Power Marketing Administration, pursuant to--

(i) long-term power contracts;

(ii) contingent capacity contracts; and

(iii) short-term sales; and

(2) each recommendation of the Administrator of each Federal Power Marketing Administration relating to any change in any operation or contracting practice of each Federal Power Marketing Administration to address each effect and risk described in paragraph (1), including the use of purchased power to meet long-term commitments of each Federal Power Marketing Administration.

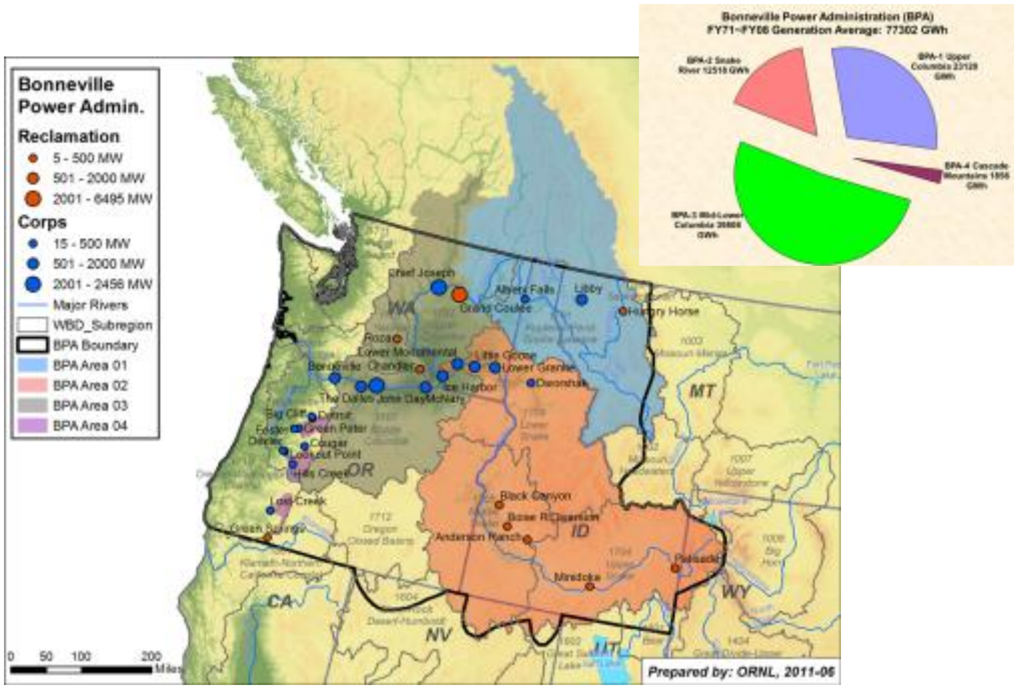
# U.S. Hydropower Installations

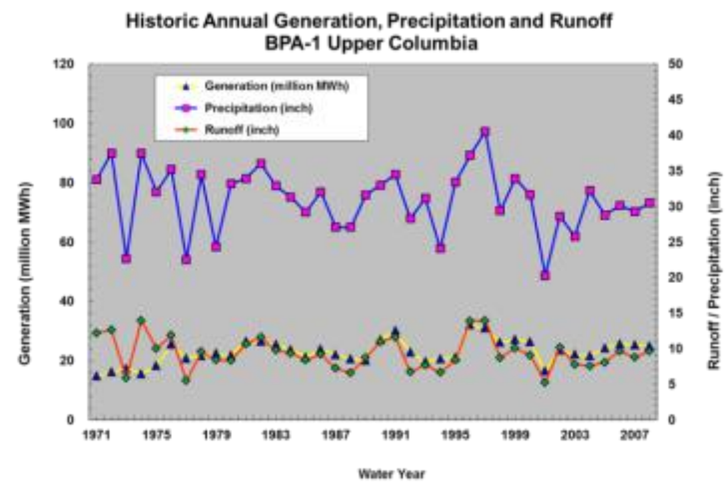

<u>With 78GW of installed capacity in the U.S.:</u>

- Hydropower provided 7.8% (or 319 TWh) of U.S. electricity generation in 2011
- Hydropower provided 62% of all U.S. renewables generation
- The U.S. Hydropower industry employs over 300k people at over 2500 US companies.

# Federal Hydropower Systems

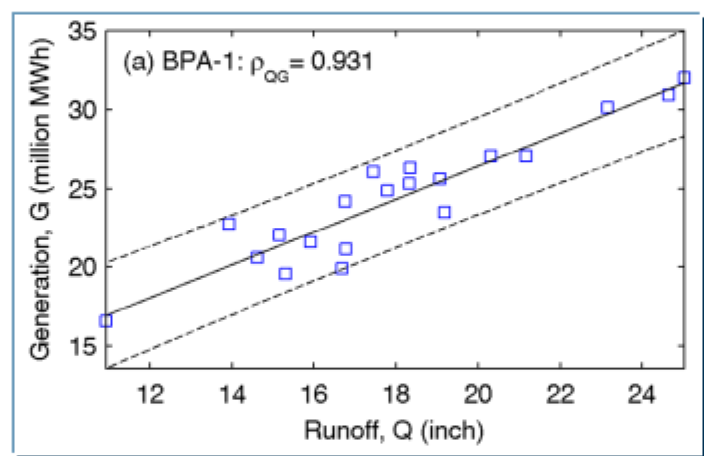
Each region was divided into four to six subareas, based on river basins and power systems. ***The relation between annual generation and runoff was a key to predicting hydropower effects.***



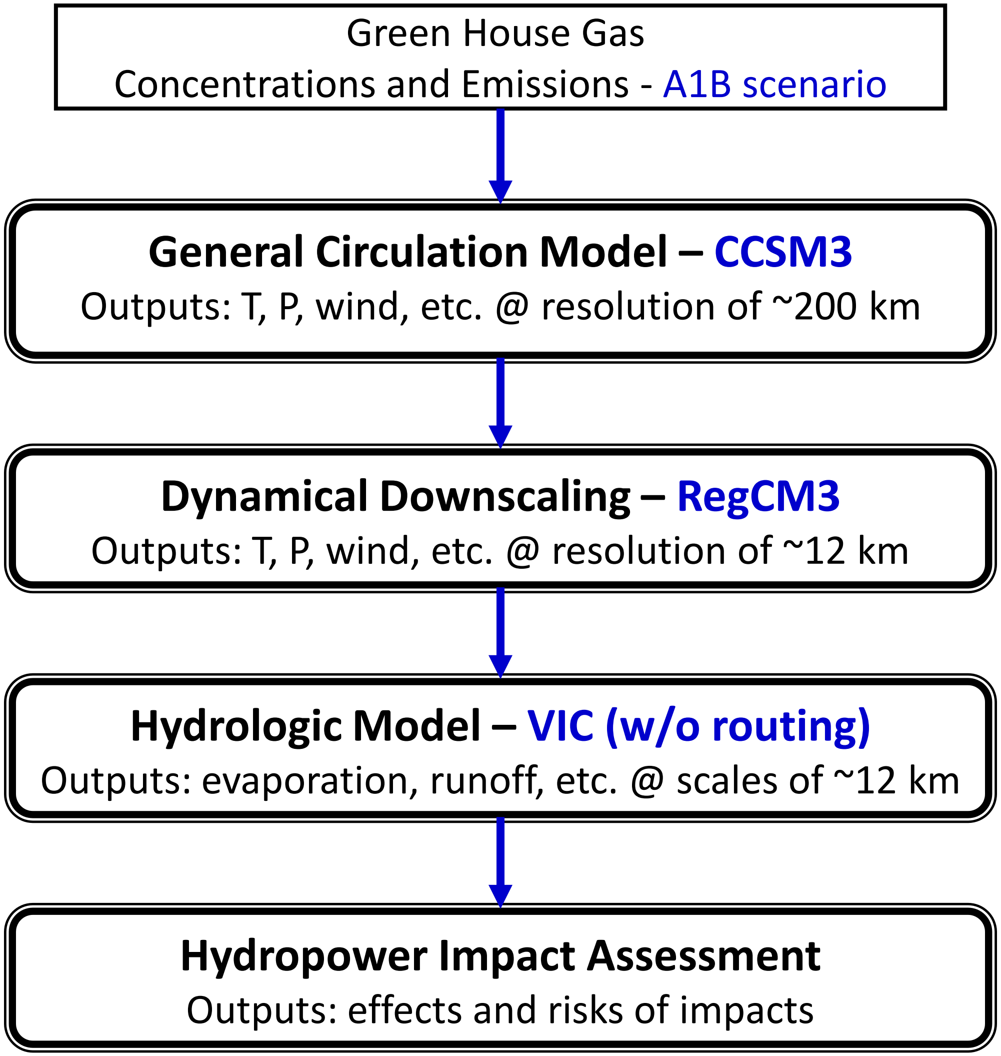

| Area No. | Major Watersheds | *Number of Plants* | | | *Total Installed Capacity[1] (MW)* |
|---|---|---|---|---|---|
| | | **Corps** | **Reclamation** | **Total** | |
| BPA-1 | Upper Columbia | 2 | 2 | 4 | 7804 |
| BPA-2 | Snake River | 5 | 5 | 10 | 3692 |
| BPA-3 | Mid-Lower Columbia | 5 | 2 | 7 | 8544 |
| BPA-4 | Cascade Mountains | 9 | 1 | 10 | 475 |
| Total | | 21 | 10 | 31 | 20515 |

[1] EIA 2008 total nameplate capacity. Include both conventional hydro and pumped-storage.



# 9505 Assessment Approach

- One consistent approach for use in all parts of U.S.
- A comprehensive database from "best available" sources:
  - observed temperature and precipitation from PRISM data from Oregon State University
  - observed runoff from US Geological Service Waterwatch data
  - hydropower systems data from Oak Ridge National Lab's WaterPower GIS
  - generation data from Energy Information Administration and Power Marketing Administrations
  - a series of simulation models to project future climate



# Emissions Scenario + Model Ensembles

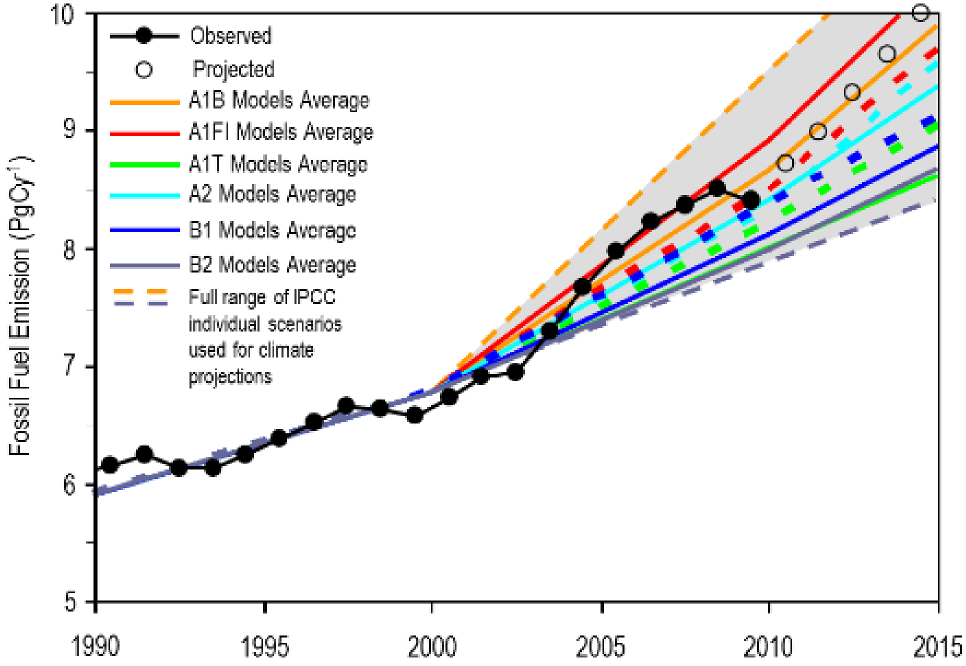



**Figure 2-3. Fossil fuel emissions: actual vs. IPCC Scenarios (Raupach et al., 2007, updated 2010; courtesy of Gregg Marland).**

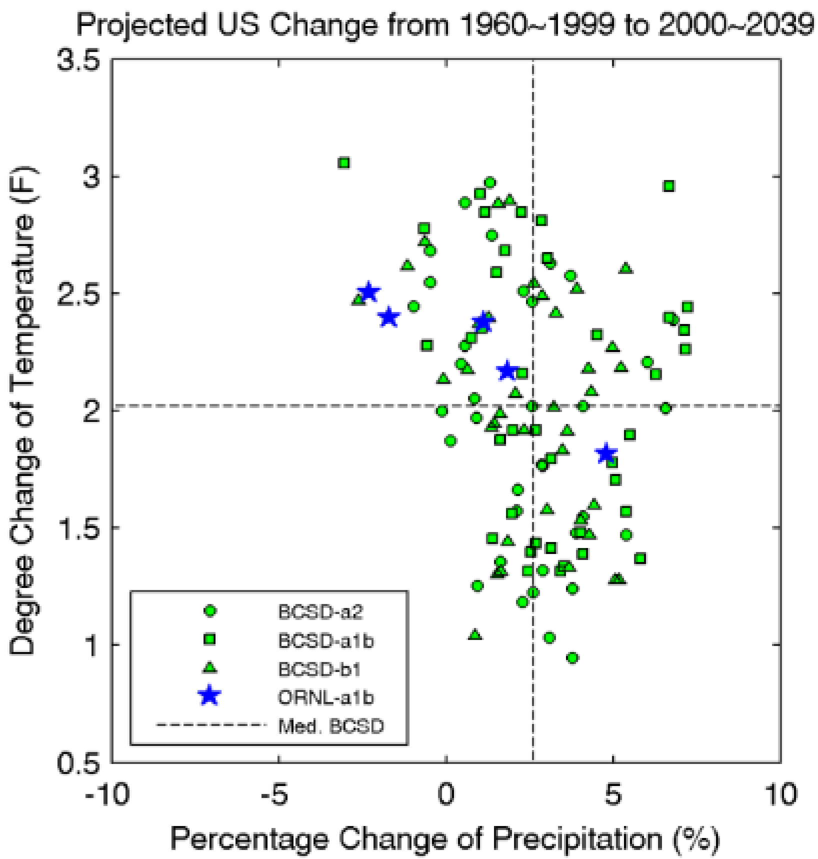
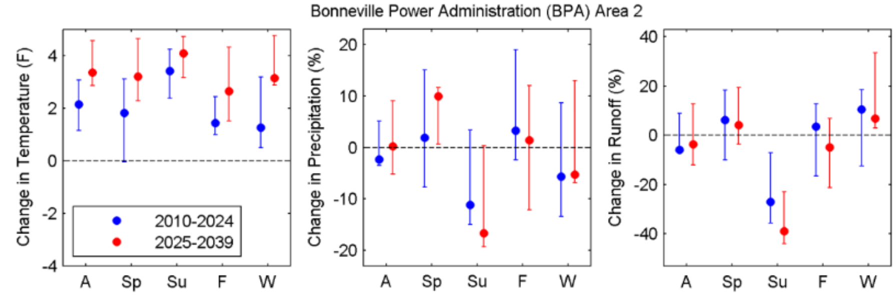


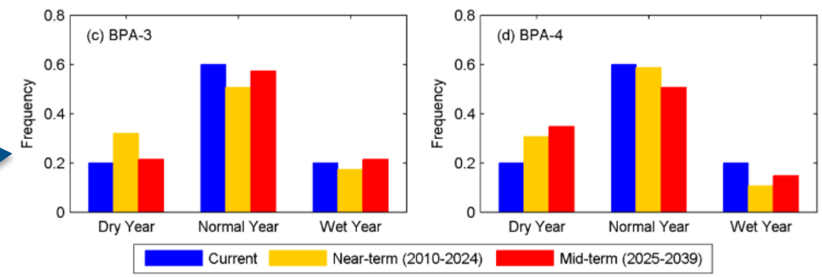

**Figure 2-7. Comparison of the 9505 ensemble data with other model outputs.**

# Multiple Assessment Endpoints

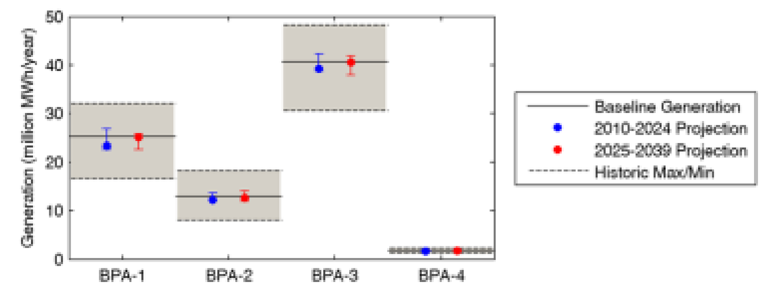
Assessment endpoints are both quantitative and qualitative:

- Projected climate change in each subregion and season:
  - Air temperature, precipitation, and runoff
  - 2010-2024 and 2025-2039
- Change in frequency of water year types
- Relative intensity of dry periods by season
- Change in annual hydropower generation, based on projected runoff
- Literature review for comparison of direct and indirect effects estimated by others

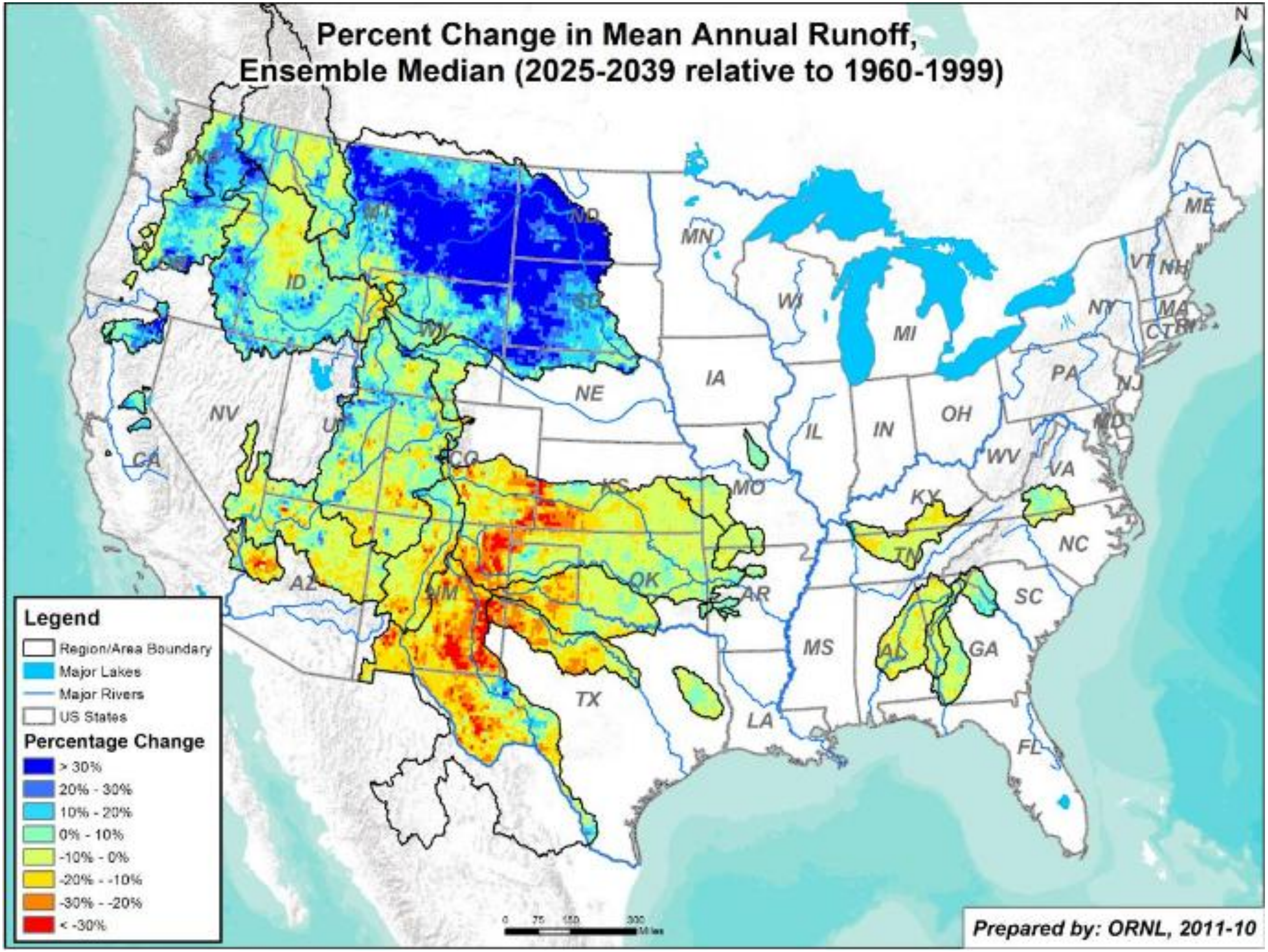



| | 10-year low runoff (inches/season), 2010-2024 future projection | | | |
|---|---|---|---|---|
| | Spring (Mar–May) | Summer (Jun–Aug) | Fall (Sep–Nov) | Winter (Dec–Feb) |
| BPA-1 | 4.05 (-20%) | 3.61 (-32%) | 1.83 (-3%) | 1.59 (2%) |
| BPA-2 | 2.01 (-13%) | 1.22 (-21%) | 0.82 (9%) | 0.80 (4%) |
| BPA-3 | 2.91 (-16%) | 2.27 (-25%) | 1.38 (7%) | 1.39 (8%) |
| BPA-4 | 5.06 (-23%) | 2.50 (-45%) | 8.67 (13%) | 10.23 (-9%) |
| | 10-year low runoff (inches/season), 2025-2039 future projection | | | |
| | Spring (Mar–May) | Summer (Jun–Aug) | Fall (Sep–Nov) | Winter (Dec–Feb) |
| BPA-1 | 4.26 (-16%) | 3.32 (-37%) | 1.78 (-6%) | 1.65 (6%) |
| BPA-2 | 2.05 (-11%) | 1.00 (-35%) | 0.71 (-6%) | 0.89 (16%) |
| BPA-3 | 2.78 (-20%) | 1.87 (-38%) | 1.31 (2%) | 1.37 (7%) |
| BPA-4 | 5.22 (-21%) | 2.43 (-47%) | 7.58 (-1%) | 10.47 (-7%) |



# Results: Climate Modeling



# Results: Climate Modeling

## Strongest climate change was in temperature, and Spring/Summer runoff.

| Area of analysis | Temperature | | | | | Precipitation | | | | | Runoff | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | Sp | Su | F | W | A | Sp | Su | F | W | A | Sp | Su | F | W |
| BPA-1 | 5+ | 5+ | 5+ | 4+ | 5+ | 0 | 1+ | 0 | 1+ | 0 | 0 | 0 | 5- | 0 | 0 |
| BPA-2 | 5+ | 5+ | 5+ | 4+ | 5+ | 0 | 0 | 1- | 0 | 0 | 0 | 1+ | 5- | 0 | 1+ |
| BPA-3 | 5+ | 5+ | 5+ | 4+ | 5+ | 0 | 0 | 1- | 1+ | 0 | 0 | 0 | 5- | 0 | 1+ |
| BPA-4 | 5+ | 5+ | 5+ | 4+ | 5+ | 1- | 1- | 0 | 1+ | 0 | 1- | 1- | 5- | 1+ | 1+ |
| WAPA-1 | 5+ | 4+ | 5+ | 4+ | 5+ | 2+ | 2+ | 0 | 2+ | 0 | 2+ | 4+ | 2+ | 2+ | 2+,1- |
| WAPA-2 | 5+ | 5+ | 5+ | 5+ | 5+ | 0 | 1+ | 2- | 0 | 1+ | 1+,1- | 3+ | 3- | 1- | 2+,2- |
| WAPA-3 | 5+ | 5+ | 5+ | 5+ | 5+ | 0 | 0 | 2- | 0 | 1+,1- | 1+,1- | 2+ | 4- | 1- | 2+ |
| WAPA-4 | 5+ | 5+ | 5+ | 5+ | 5+ | 0 | 0 | 1+,1- | 0 | 1- | 1+,1- | 1+ | 4- | 1- | 1+ |
| WAPA-5 | 5+ | 5+ | 5+ | 5+ | 5+ | 1- | 0 | 2- | 0 | 1- | 2- | 1+,1- | 2- | 1- | 2- |
| WAPA-6 | 5+ | 5+ | 5+ | 5+ | 5+ | 0 | 0 | 2- | 0 | 1- | 1- | 1- | 4- | 0 | 1+ |
| SWPA-1 | 5+ | 5+ | 5+ | 5+ | 4+ | 1- | 0 | 2- | 0 | 0 | 1- | 0 | 0 | 1- | 1- |
| SWPA-2 | 5+ | 5+ | 5+ | 5+ | 5+ | 1- | 1+ | 3- | 0 | 0 | 1- | 1+ | 1- | 1- | 0 |
| SWPA-3 | 5+ | 5+ | 5+ | 5+ | 5+ | 1- | 0 | 3- | 0 | 0 | 1- | 0 | 2- | 1- | 0 |
| SWPA-4 | 5+ | 5+ | 5+ | 5+ | 4+ | 1+ | 0 | 1- | 1+ | 0 | 1+ | 0 | 1- | 1+,1- | 0 |
| SEPA-1 | 5+ | 5+ | 5+ | 5+ | 4+ | 0 | 0 | 1+,1- | 0 | 0 | 0 | 0 | 1+,1- | 0 | 0 |
| SEPA-2 | 5+ | 5+ | 5+ | 5+ | 3+ | 1- | 0 | 2- | 0 | 0 | 1- | 0 | 0 | 1- | 1- |
| SEPA-3 | 5+ | 5+ | 5+ | 5+ | 3+ | 1- | 0 | 1+,1- | 0 | 0 | 0 | 0 | 1+,1- | 0 | 0 |
| SEPA-4 | 5+ | 5+ | 5+ | 5+ | 3+ | 0 | 0 | 1+,1- | 0 | 1- | 0 | 0 | 1+,1- | 1+ | 0 |

*Tabulated values refer to the number of ensemble members showing statistically significant change from historical to future periods.*

# Results: Hydropower Impacts

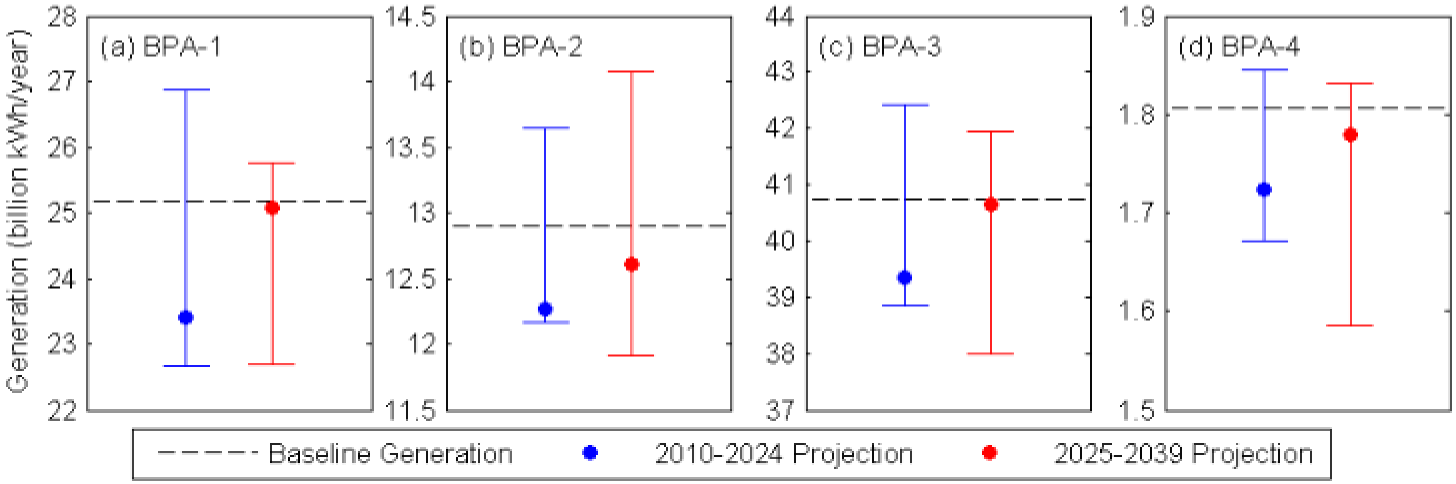



**Figure 3-6. Projected annual hydropower generation in the Bonneville region, based on observed correlations with runoff.** Dashed line for baseline reference is the mean of simulated 1960–1999 annual generation across five ensemble members; circles are the 15-year mean for the median ensemble member; and the range plotted around each circle extends from the highest to the lowest ensemble member, as a measure of model uncertainty.

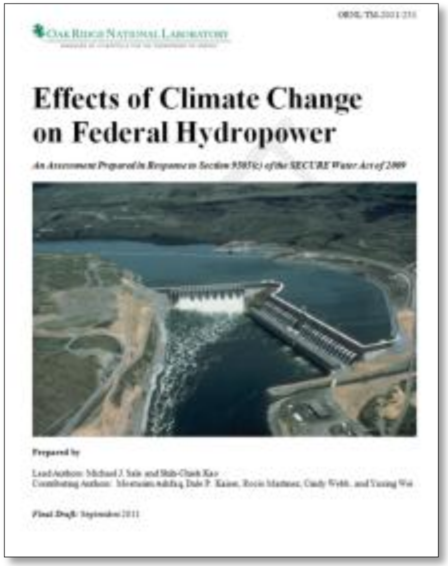
- Main points:
  - Changes to average annual generation appear modest (+/- 2% to 5%), though not high agreement between ensembles
  - Generally, increases in dry water years across regions (from an average of 2 per decade to 3), with increases in wet water years in some
  - Much more significant seasonal impacts: some dramatic decreases in summer generation (30-40%), often linked to timing of snowmelt

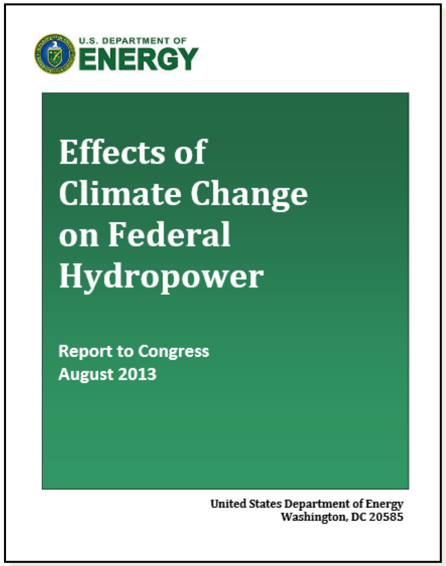
# Products

## Two main products:

- ***9505 Assessment Report***
  - Technical report with details on assessment methods and results
  - Published as an Oak Ridge National Lab report, available at: http://nhaap.ornl.gov/
  - Completed September 2012, but not widely publicized until Report to Congress was delivered

- ***9505 Report to Congress***
  - Short summary of the assessment, including recommendations from Power Marketing Administration administrators
  - Delivered to Congress August 2013
  - Available at: http://www1.eere.energy.gov/water/



# Next steps

- **Next 9505 assessment is due April 2016, and the second phase of the analysis is just getting underway**
- **Improve granularity of hydropower generation and reservoir data**
  - Monthly or daily data will allow for coupled analysis with the more granular outputs of models
- **Develop better modeling of water / power systems**
  - More complete water balances within regions/river basins to account for interactions with multiple-use water management
  - Incorporate routing of runoff with more granular dynamic downscaling (ideally less than 1km)
  - Evaluation of risks from extreme events
- **Better quantify uncertainty of results related to future emissions (more emissions scenarios)**
- **Extend analysis to nonfederal hydropower**

# Related Emerging Issues: Consumptive Water Use

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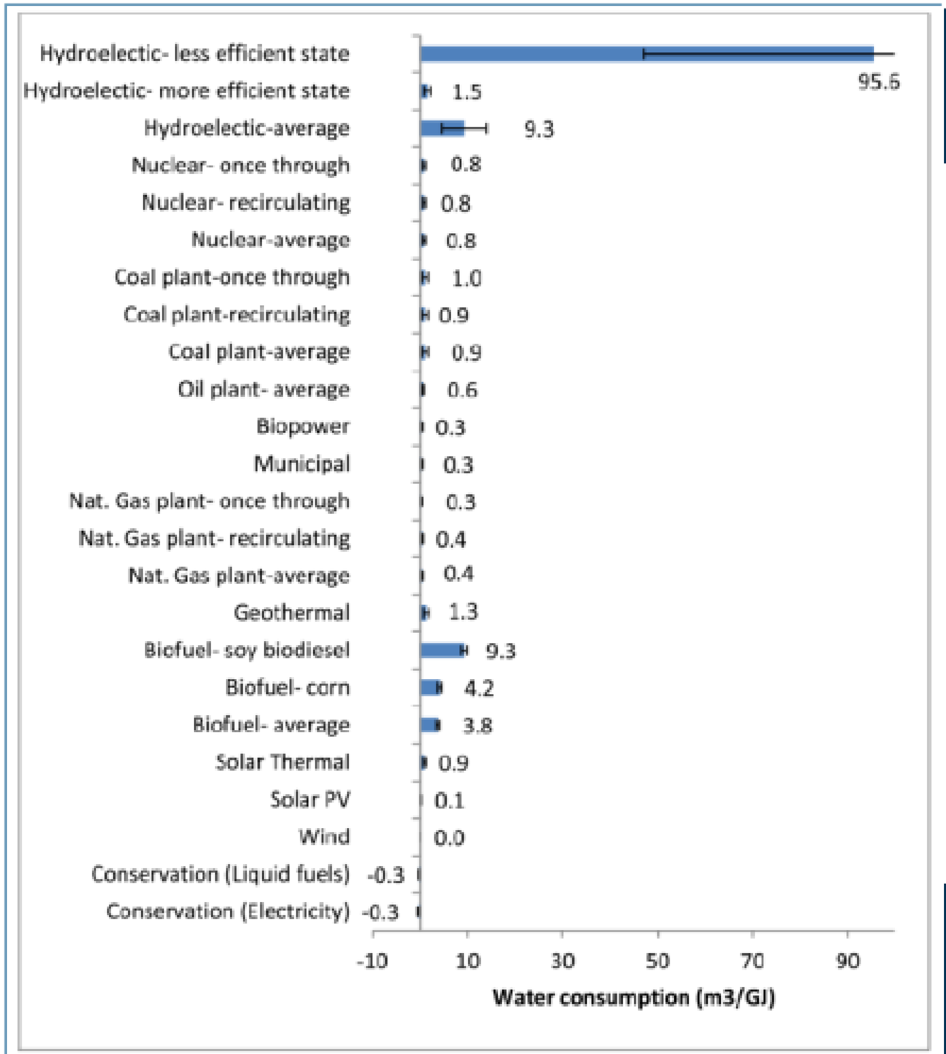
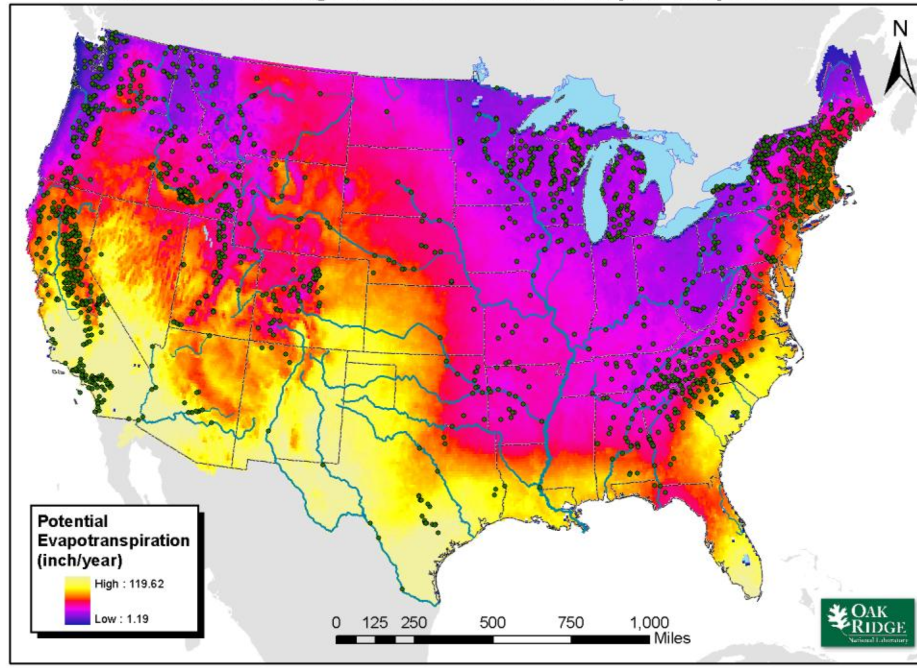



***McDonald et al. 2012: "hydropower is the most water-use intensive form of energy production"***

***New Analysis Needed:***

**1) Better site-specific data is available**

**1960-1999 Average Annual Potential Evapotranspiration**




**2) Better modeling is possible**

$$WUI = \frac{\text{Coef.} * \text{Evap.} * \text{Res. Area}}{\text{Annual generation}}$$

# Related Emerging Issues: GHG Emissions from Reservoirs

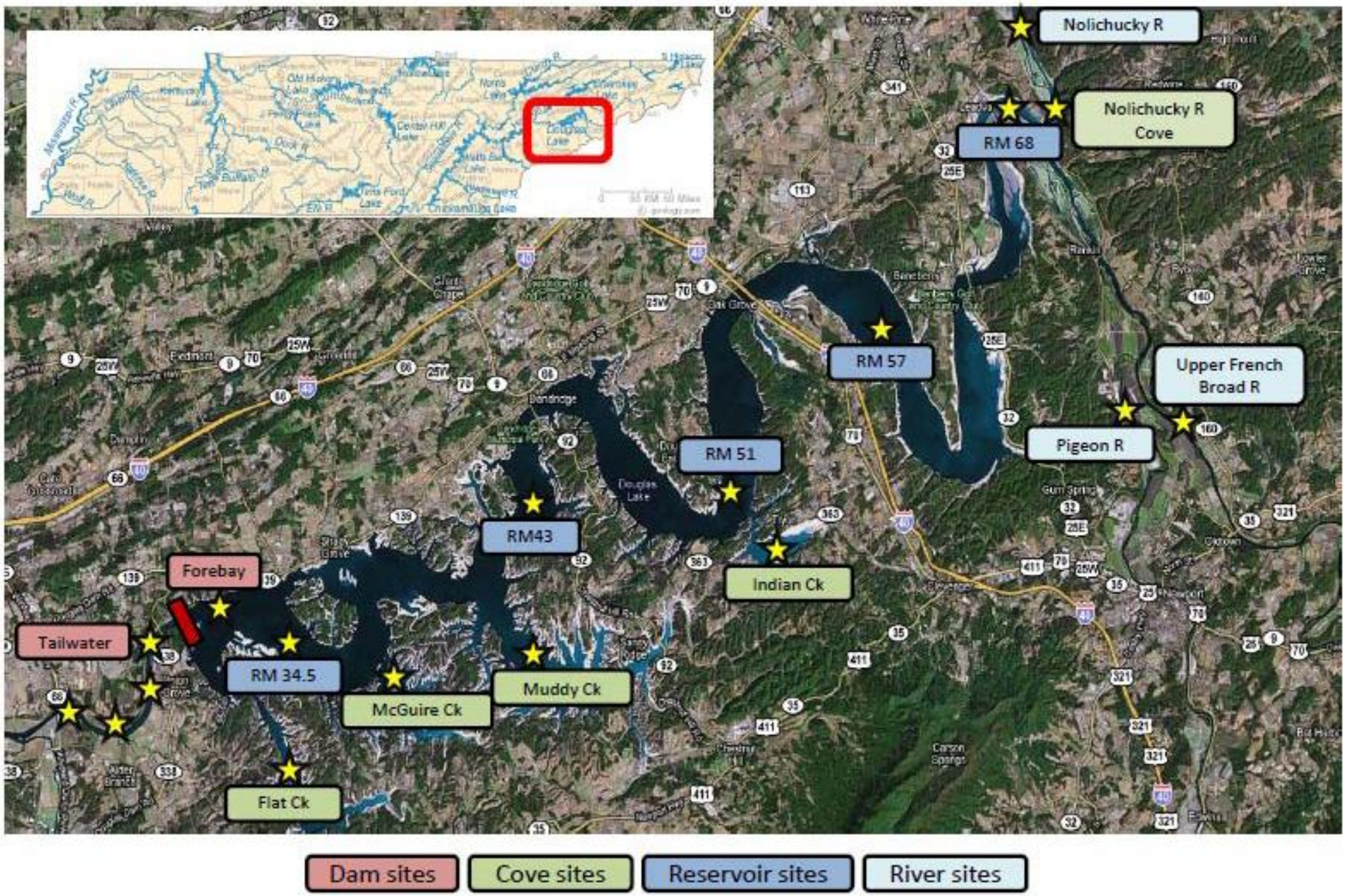


- **GHG emissions have been shown to be relatively high in some tropical reservoirs, but insufficient data to draw a conclusions on a wider scale, or in temperate reservoirs.**
- **Leads to uncertainty for hydropower as a non-carbon-emitting energy source in future regulatory and market contexts.**
- **DOE National Labs are attempting to address this uncertainty by:**

1) Developing protocols for measuring GHG emissions at hydropower reservoirs
2) Demonstrating those protocols at a range of reservoirs around the country
3) Developing predictive relationships to allow the modeling of GHG emissions
4) Understanding rates and controls of GHG emissions for use by hydropower stakeholders

# Example: Douglas Reservoir Sample Sites

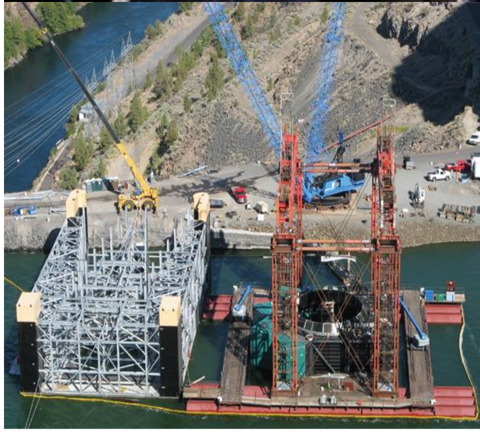
## 18 Sites Sampled in Multiple Seasons at Reservoir in Eastern Tennessee

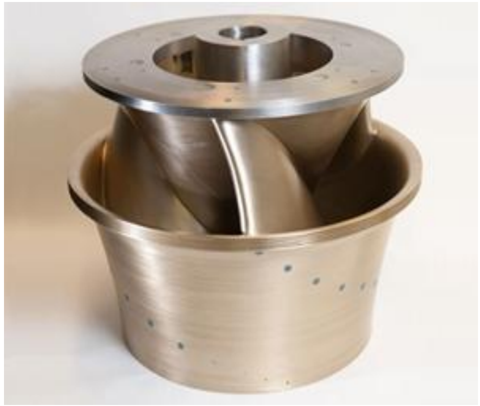


# Technologies / Strategies to Address Risk: Advanced Systems

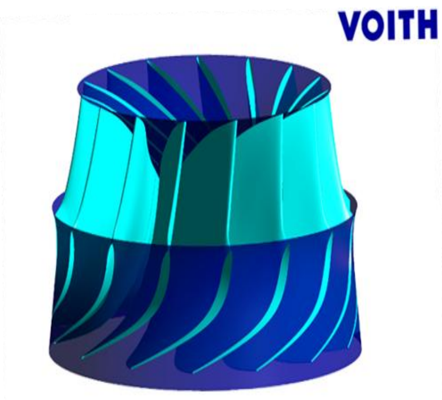


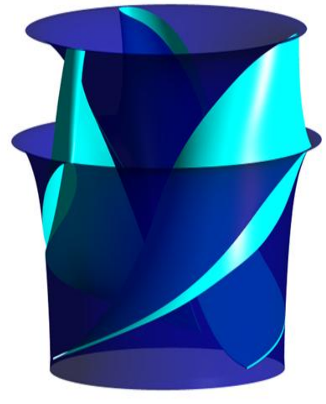
- **Aerating turbines to improve water quality (dissolved gases)**
  - Handful of units currently deployed
  - Results are not being widely disseminated
- **Selective Water-withdrawal intakes**
  - Recently deployed at U.S. hydropower project in Oregon
  - Allows for better downstream temperature control
- **Alden  Fish-Friendly Turbine**
  - A technology a decade in the making
  - 94% Efficient (comparable to similar Francis units), 94-100% aquatic species survival





**Typical Francis Runner**



**New Alden Runner**

# Technologies / Strategies to Address Risk: Improving Water Quality Modeling

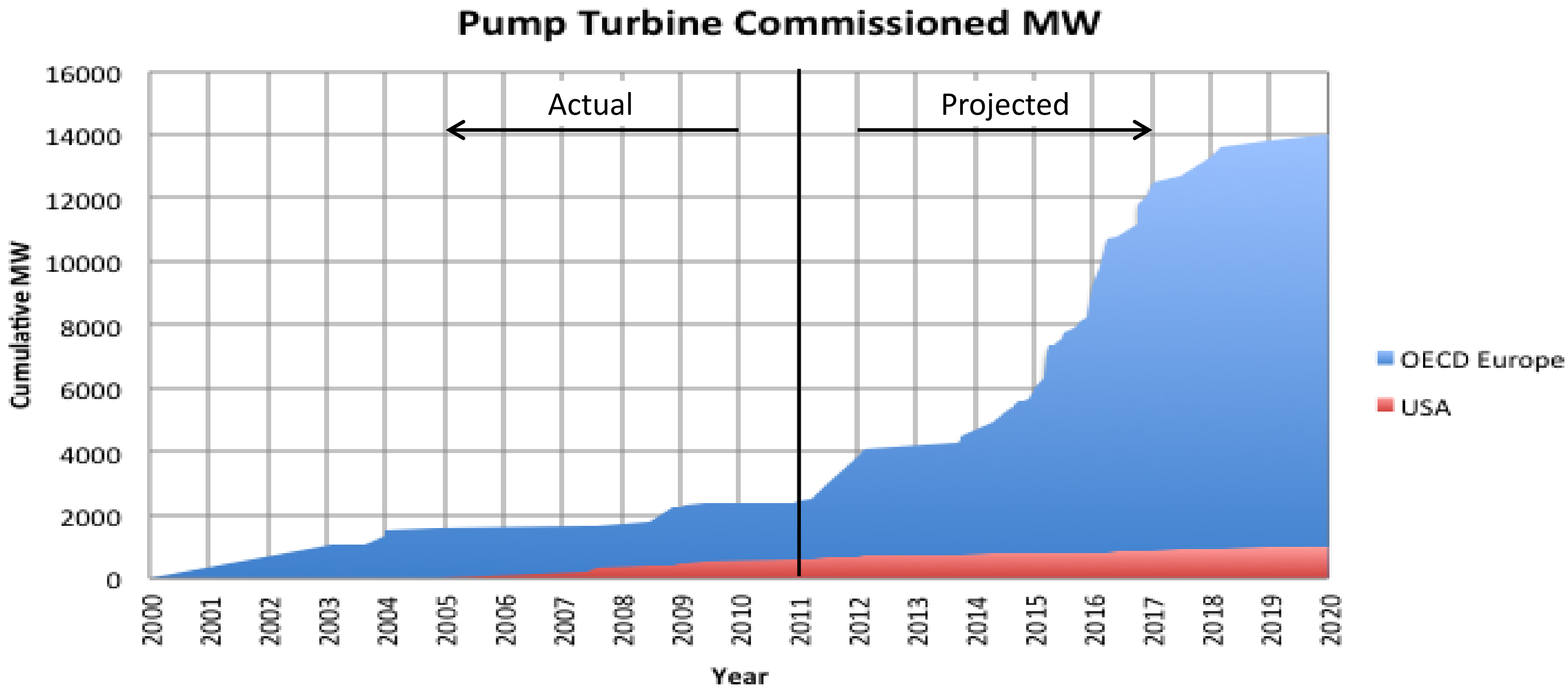


DOE has also been working with the Army Corps and Bureau of Reclamation to create improved models and operational tools to help predict both temperature and total dissolved gas concentrations above and below hydropower dams (projects currently in the Cumberland Basin in the central U.S. and the Columbia Basin in the Pacific Northwest), thus optimizing power generation while maintaining environmental compliance for water quality.

# Technologies / Strategies to Address Risk: Advanced Pumped-Storage Systems



Large amounts of advanced Pumped Storage technologies are being deployed in Europe as *a means for integrating increasing quantities of variable renewable energy and adding grid stability / resiliency*. However, barriers in the U.S. (slower growth of renewables and slow changes to market structures) have prevented this proven technology from being deployed as rapidly




*Source: Voith Hydro, March 2012*

# Flexibility = Grid Security

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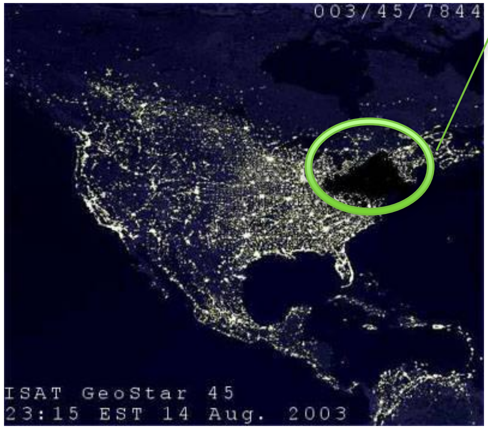
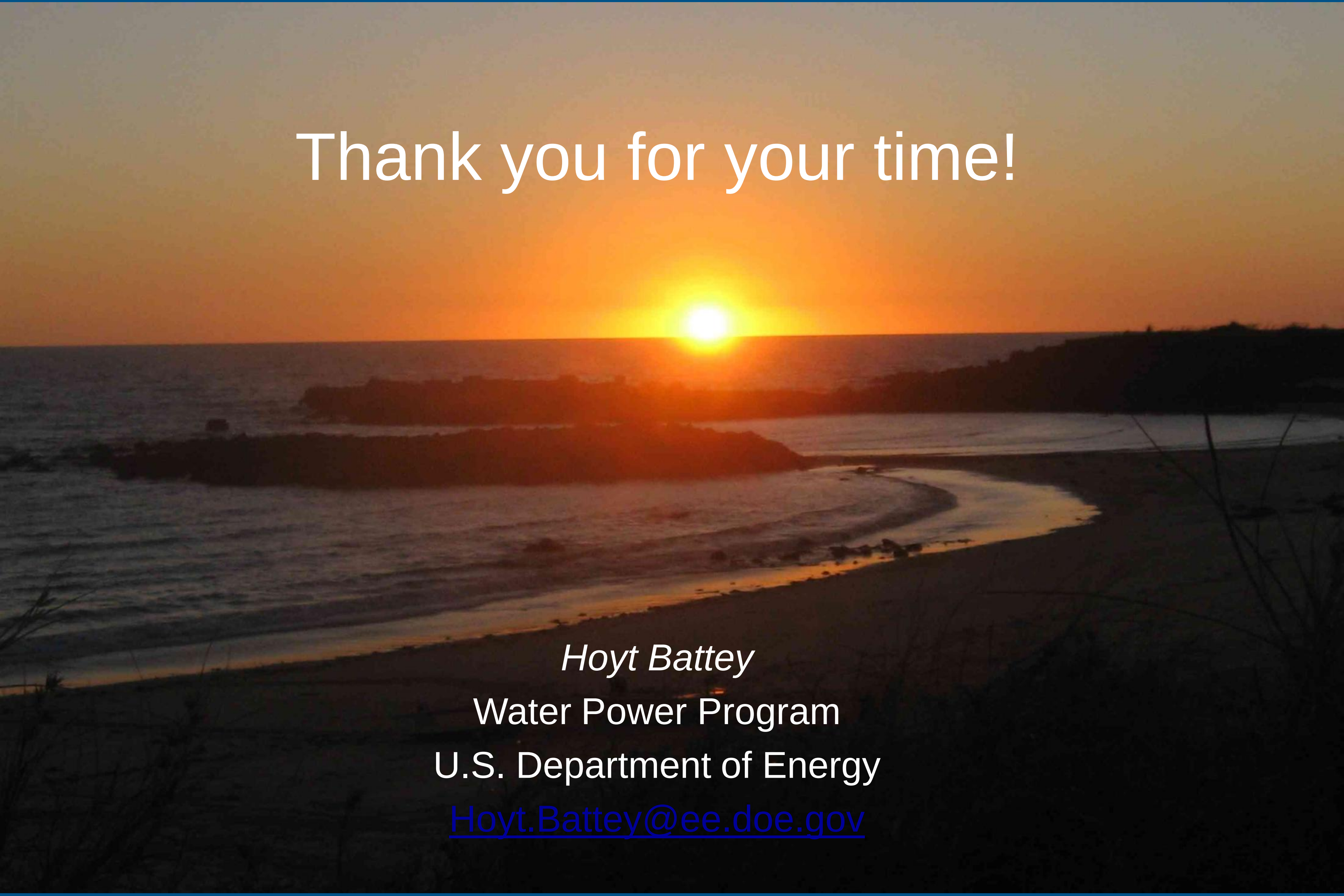
- ✓ **Fastest ramp rate of any form of generation!**
- ✓ **Capable of ramping to accommodate renewable fluctuation**


**Steve Kerns, Bonneville Power Administration**

- ✓ **Used to restore power in blackout of 2003:**

> ***"[During the blackout,] one relatively large island remained in operation serving about 5,700 MW of demand, mostly in western New York, anchored by the Niagara and St. Lawrence hydro projects. This island formed the basis for restoration in both New York and Ontario."***
>
> — US-Canada Power System Outage Task Force report, 2005





# Thank you for your time!

*Hoyt Battey*
Water Power Program
U.S. Department of Energy
Hoyt.Battey@ee.doe.gov