Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Quantification of Interdependencies and Vulnerabilities between Water and Energy in the Western Interconnection

N Voisin, M. Kintner-Meyer, R. Skaggs, J. Dirks, T. Nguyen, D. Wu, Y. Xie, M. Hejazi

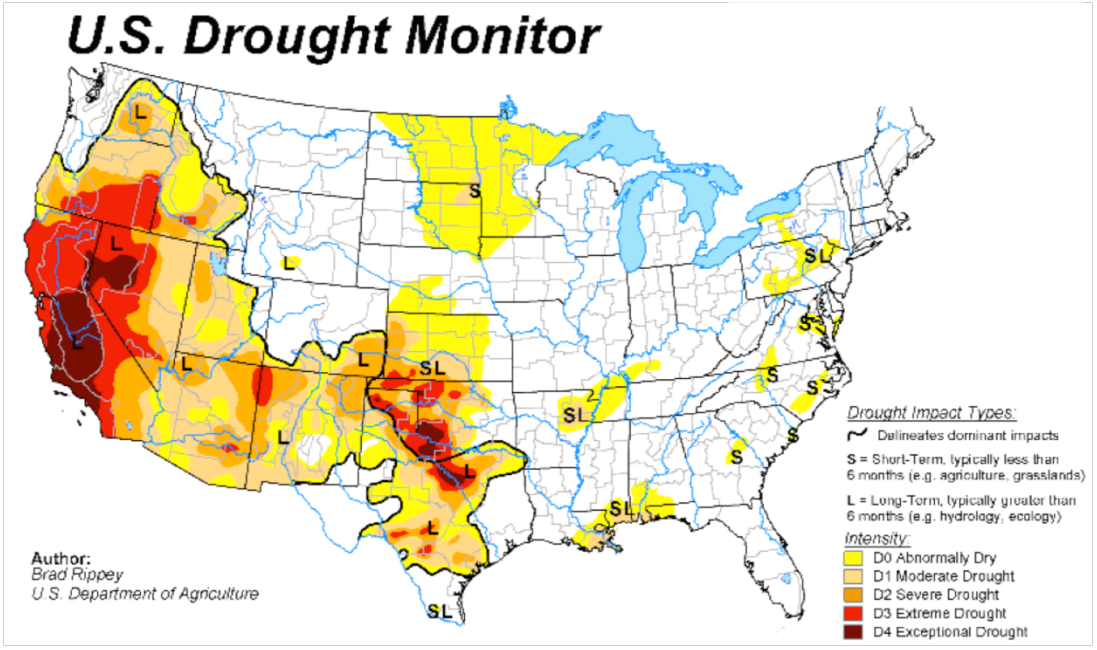
JGCRI 2015 Integrated Assessment Workshop and GCAM Community Modeling Meeting
Dec 1st, 2015

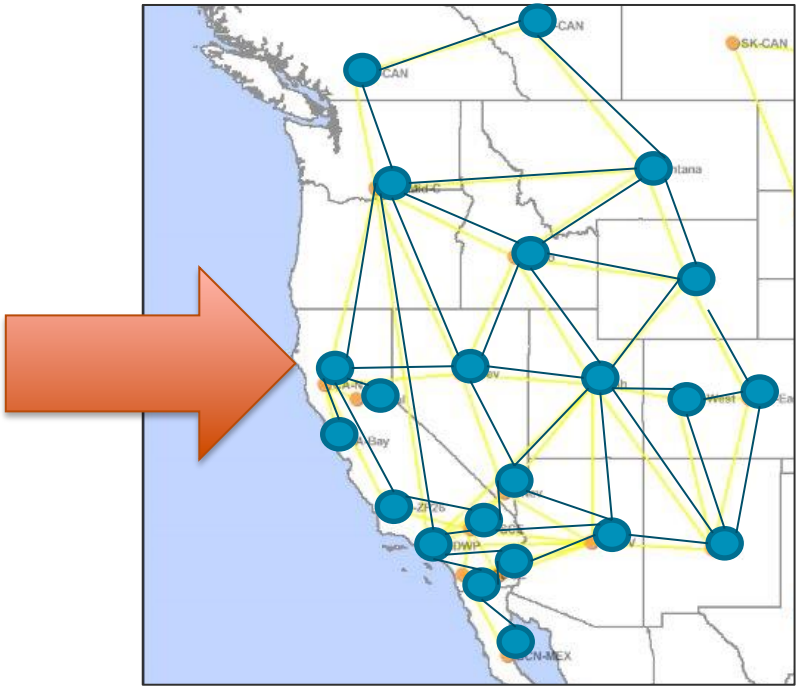
Scope: Quantification of Interdependencies between Water and Energy in the Western Interconnection

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Objectives:

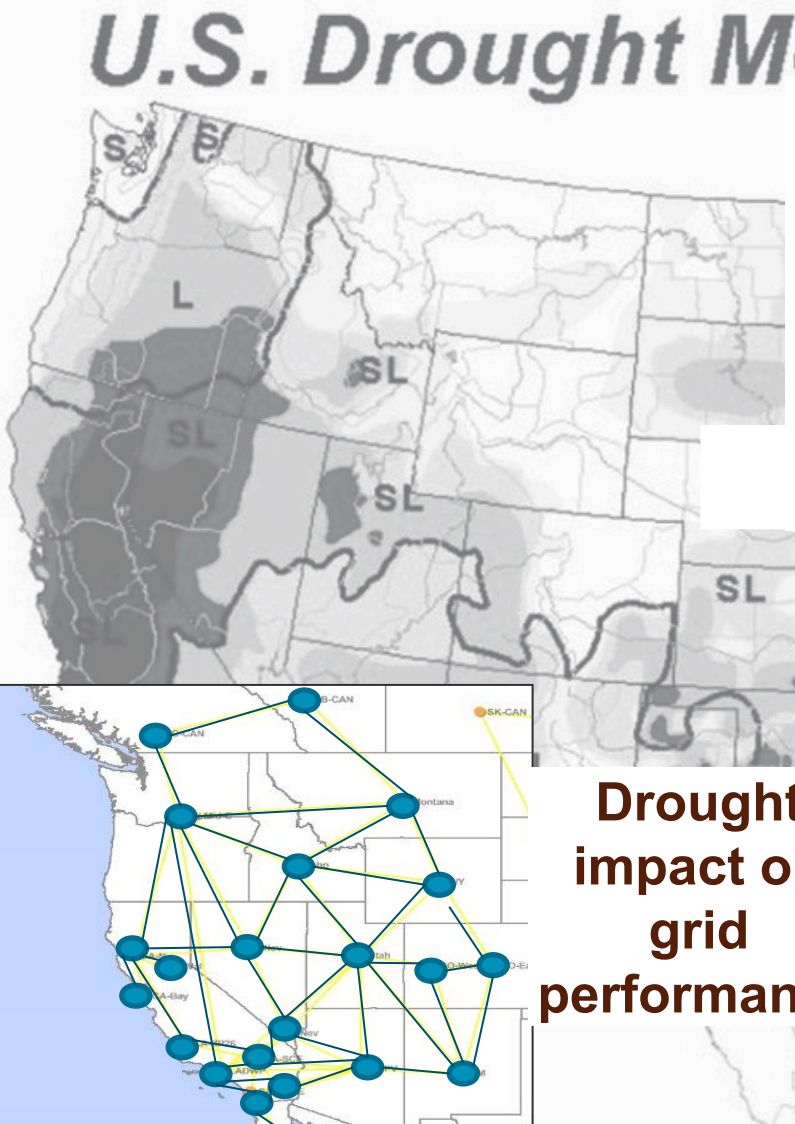
  Assess impact of drought on the reliability of the grid and energy production costs

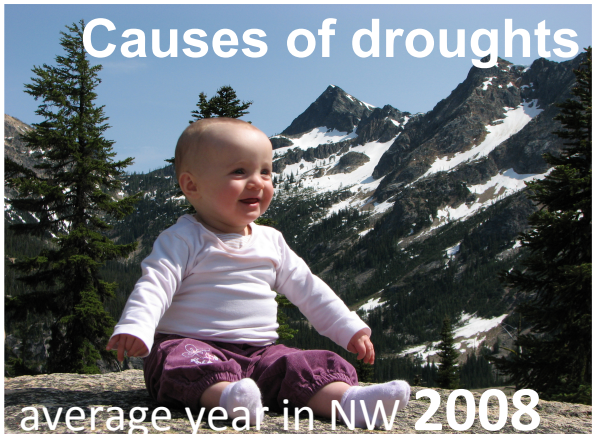




Scope: Integrate operational grid performance into drought impact assessment

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965





Drought impact on grid performance

Background

69% of Installed Generation Capacity Relies on Fresh Surface Water Over the Western Interconnection

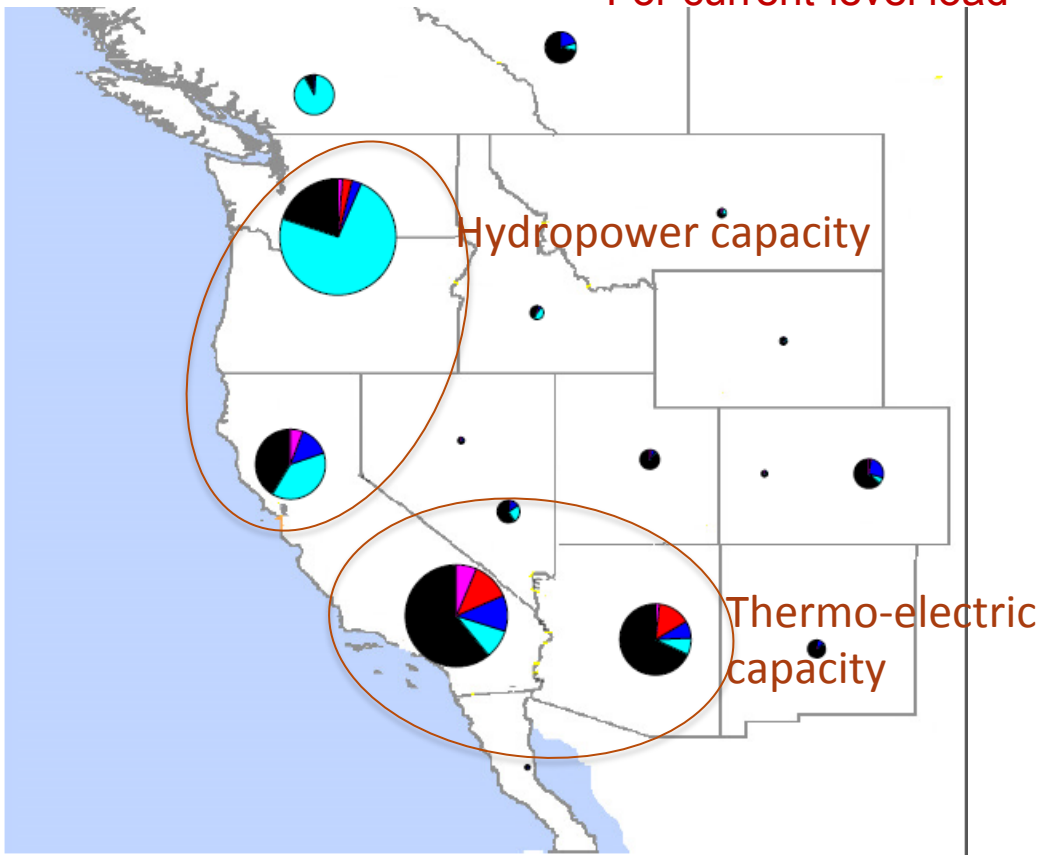
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Baseline

Installed Capacity: 257,000 MW		
Hydro:	25%	**23%**
Steam: (Thermal)	45%	**39%**
Nuclear:	4%	**4%**
Turbine (CT):	10%	**-**
Other:	16%	**3%**

Capacity dependent on fresh surface water dependent (no ocean, no groundwater)

Generation capacity For current-level load



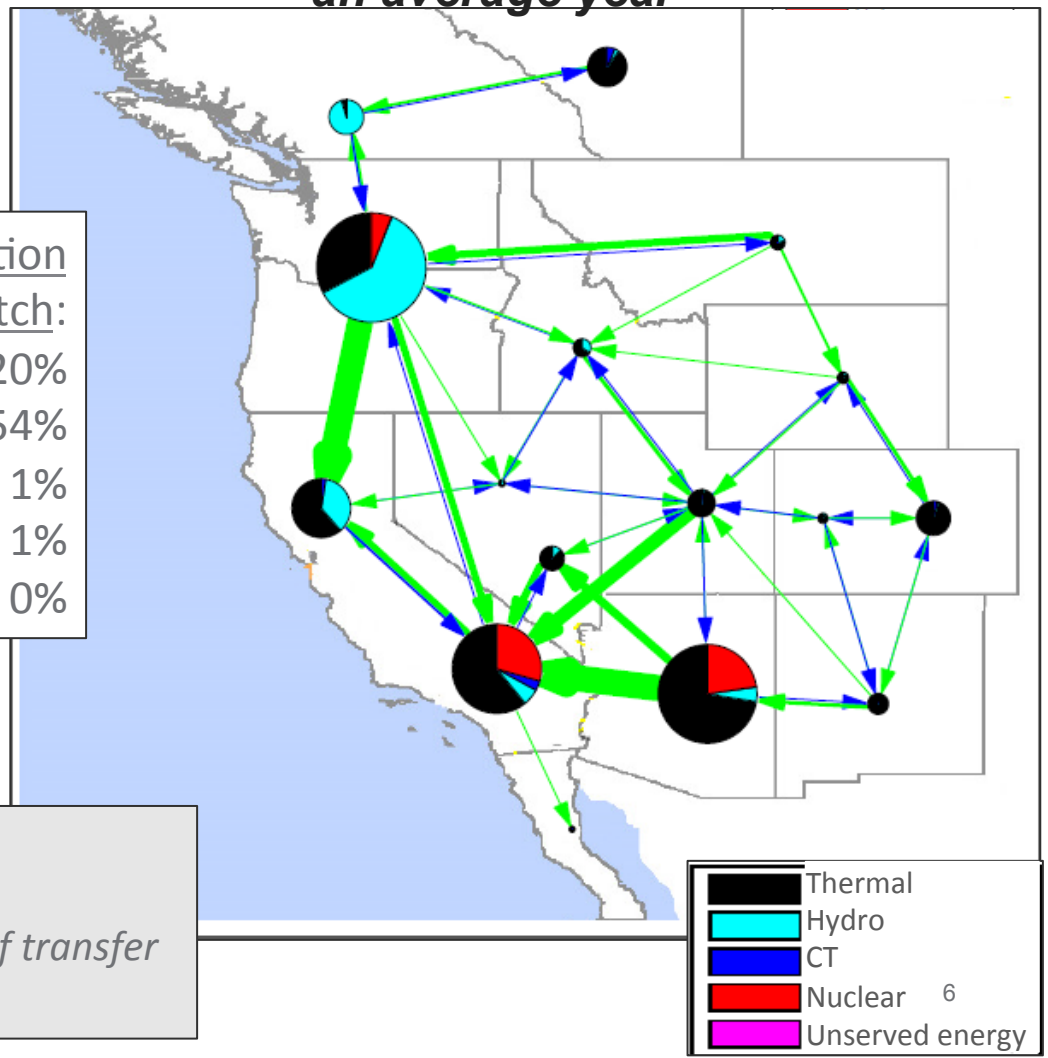
Size of pies indicates overall capacity
Pie slices indicate the sources of energy

In Operations: Droughts Affect the Generation Capacity, Which Affects the Generation Dispatch …

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

August transmission and generation mix for an average year

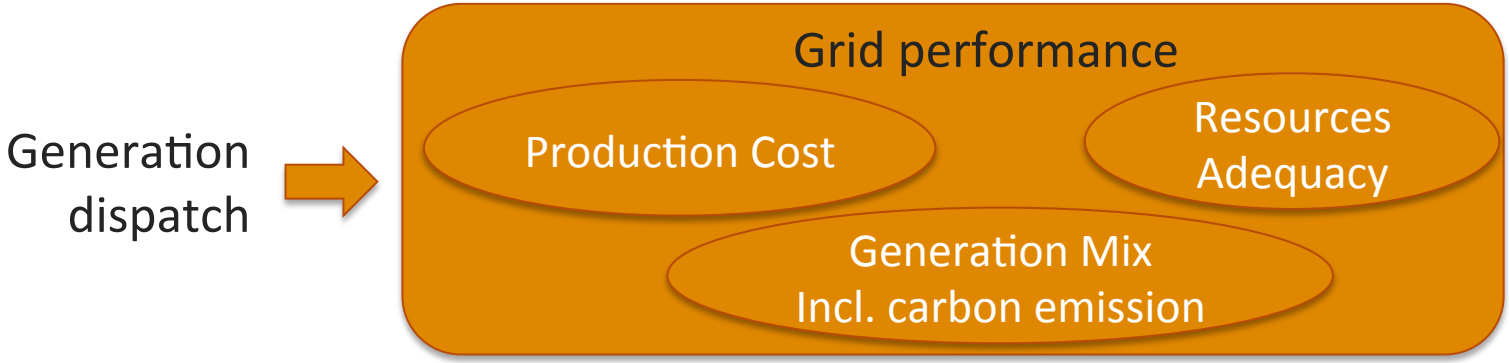
Installed Capacity: 257,000 MW			Baseline generation dispatch:	
Hydro:	25%	**23%**	Hydro:	20%
Steam:	45%	**39%**	Steam:	54%
Nuclear:	4%	**4%**	Nuclear:	1%
Turbine:	10%	**-**	Turbine:	1%
Other:	16%	**3%**	Unserved:	0%



Size of pies indicates overall generation
Pie slices indicate the sources of energy
Green arrows indicate direction and magnitude of transfer
Blue arrows are off-peak transfers

Variations in generation dispatch will result in a change in performance. However this is a non linear relationship.

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965



Scientific questions

1. What is the performance of the current Western electric grid under different droughts?

2. How do inter-annual variability and region interdependencies affect the reliability?

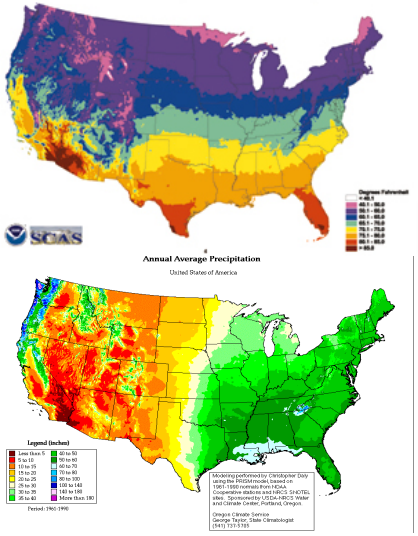
3. What is the performance of the current Western electric grid under *future* droughts? What is the uncertainty with respect to emission scenarios?

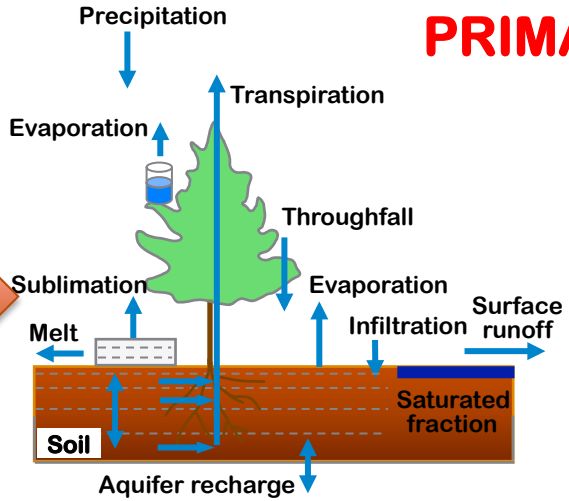
Technical approach

Link between water availability and operational grid performance: integrated modeling approach

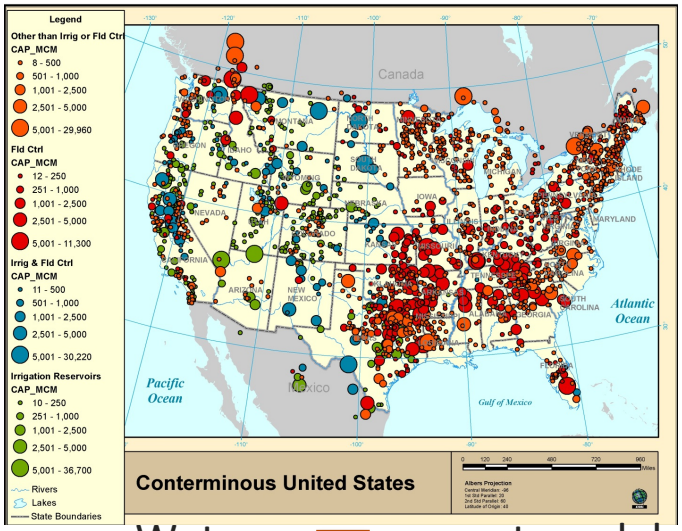
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Climate





PRIMA Water availability



Water management model

GCAM Water Demand

Energy Demand

(historical default for this analysis)

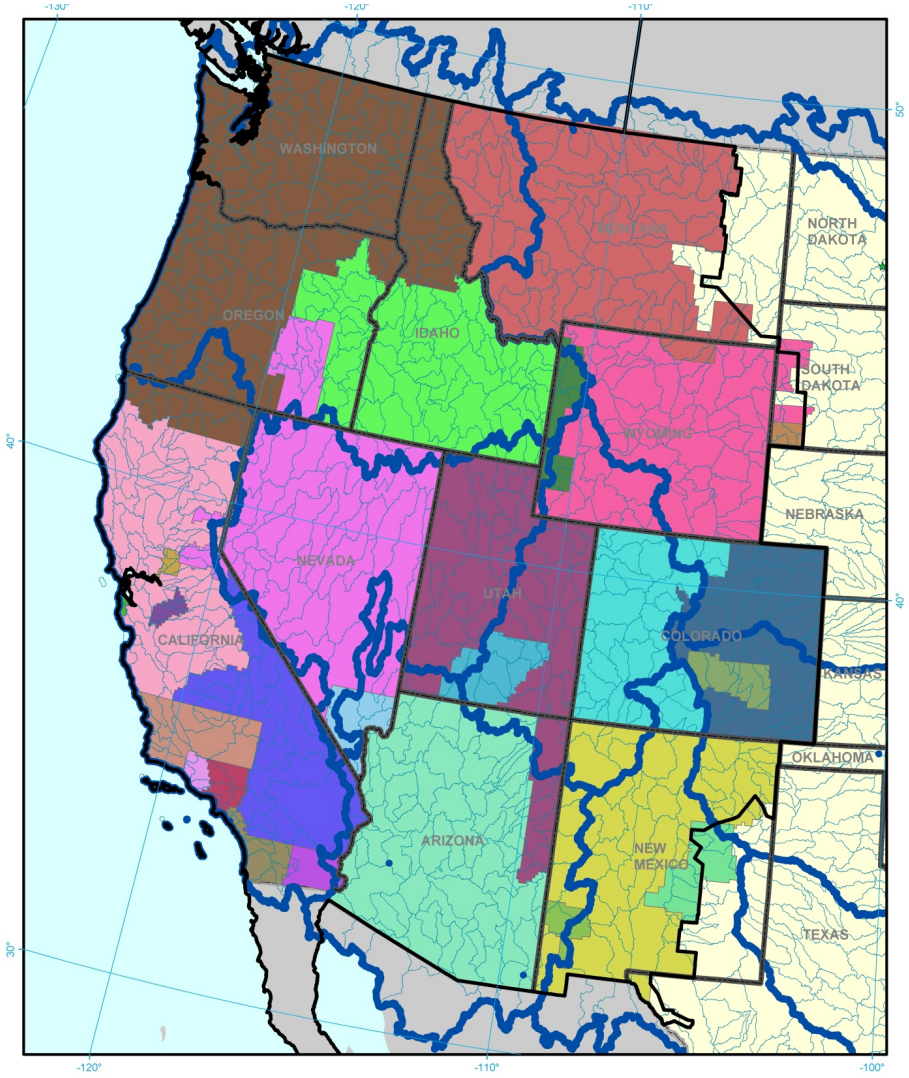
Energy generation and transmission

(NOT expansion model)

Jurisdictions of decision making affecting joint water-grid management

- Droughts affects hydrologic regions
- Generation dispatch performed at the balancing authority scale

The production cost modeling helps with the mapping of the drought severity to the electricity management scale



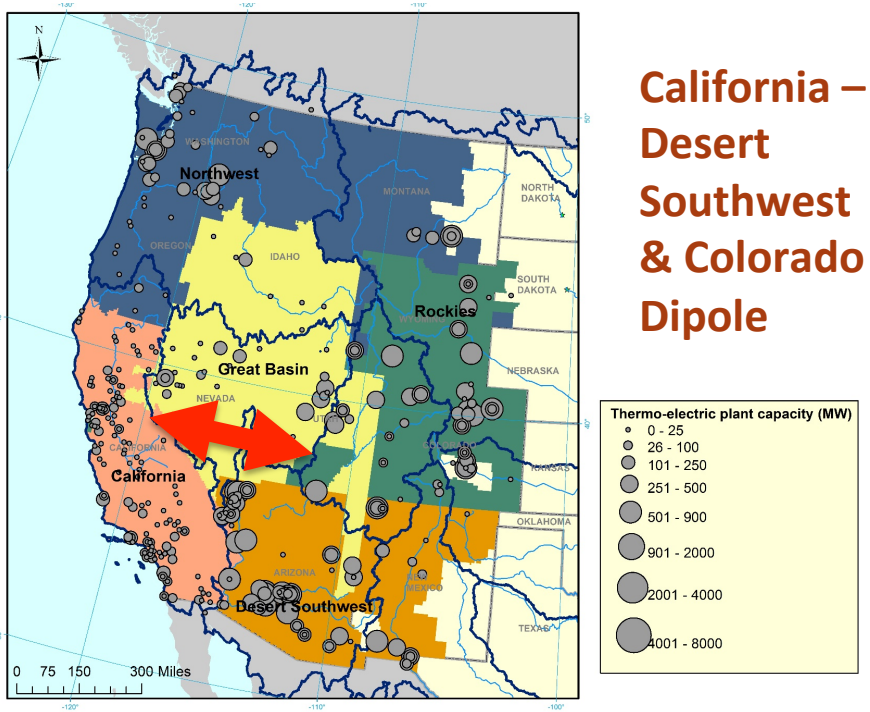
[Production cost model optimizes hourly generation dispatch across utilities within the BA with respect to production cost and generation portfolio (integration of renewables) then optimizes transmission.]

Generation dispatch and regional variability: combined effect of hydropower & thermo-electricity

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

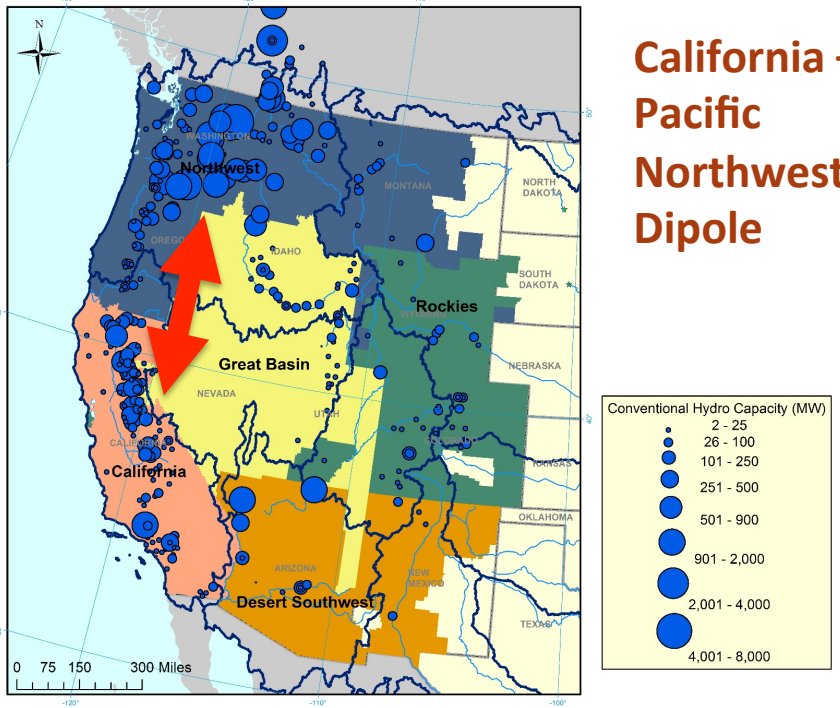
Regional dipoles within water-dependent technologies and across technologies.

Water-dependent thermo-electricity within hydrologic and electricity regions



California – Desert Southwest & Colorado Dipole

Hydropower within hydrologic and electricity regions

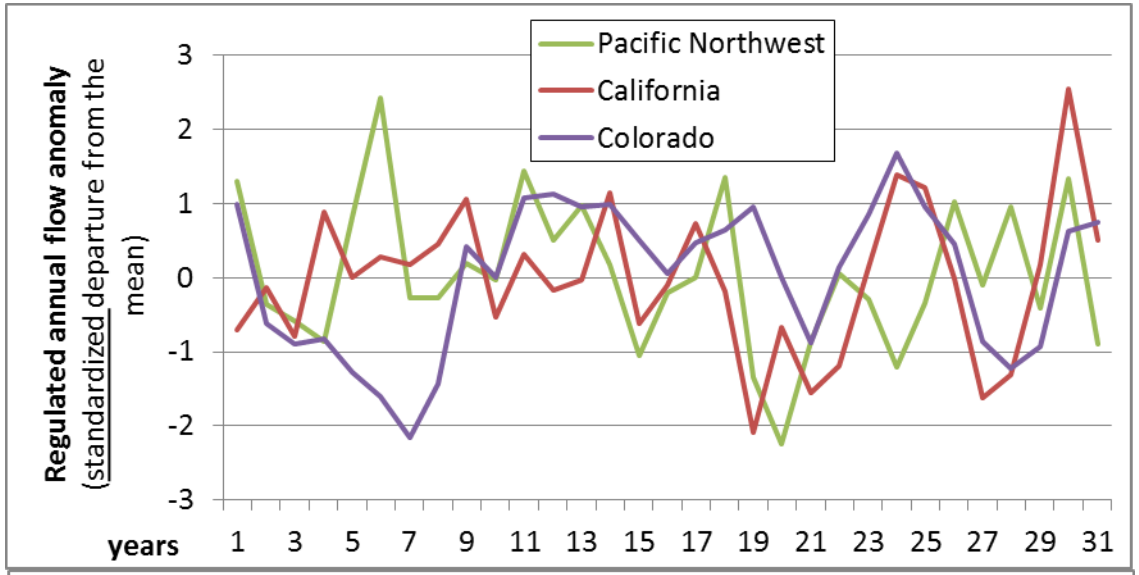


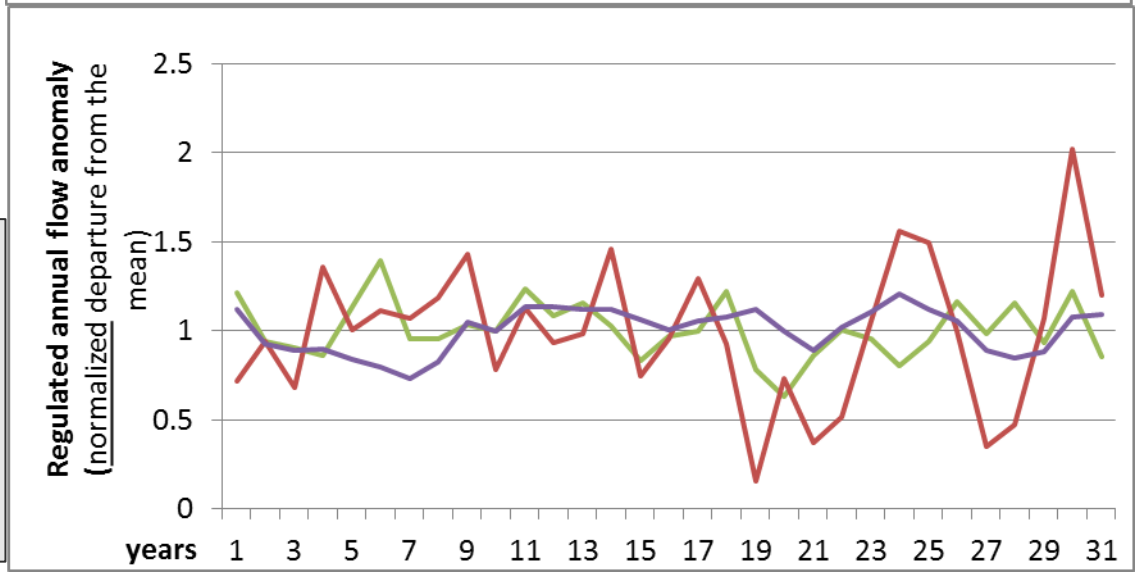
California – Pacific Northwest Dipole

PRIMA provides the inter-annual water availability. There is no average water year!

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Vulnerability assessments should cover a portfolio of regional variability





Upper panels emphasizes how the Hydropower and thermo-electric dipole regions are in and out of phase under historical climate

Upper panel highlights the range of inter-annual variability in each region

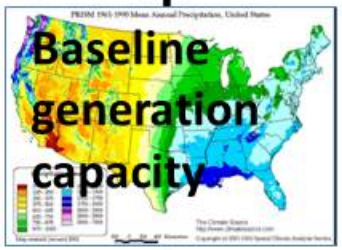
Experimental Approach and Technical Challenge

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Baseline

Temperature

Precipitation

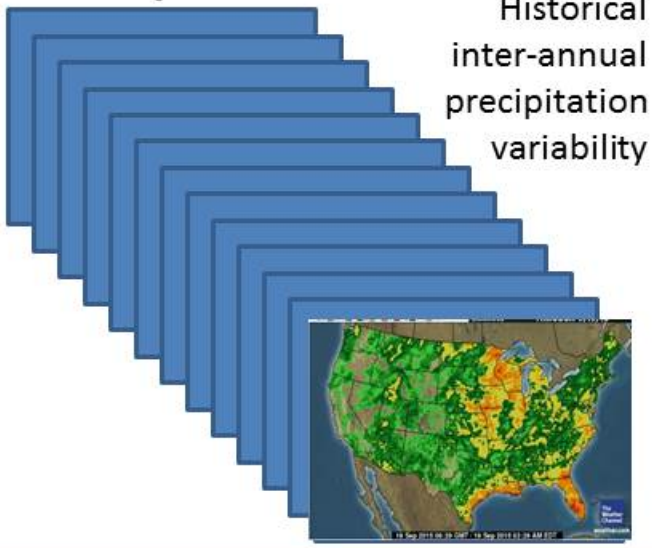


Production Cost Model

Estimate of resources adequacy, production cost, reliability of grid

Developed modeling framework to assess full risk distribution

Historical inter-annual precipitation variability



Production Cost Model

Range of estimates for resources adequacy & production cost; risk distribution of grid performance

Technical challenge:
translate inter-annual precipitation variability

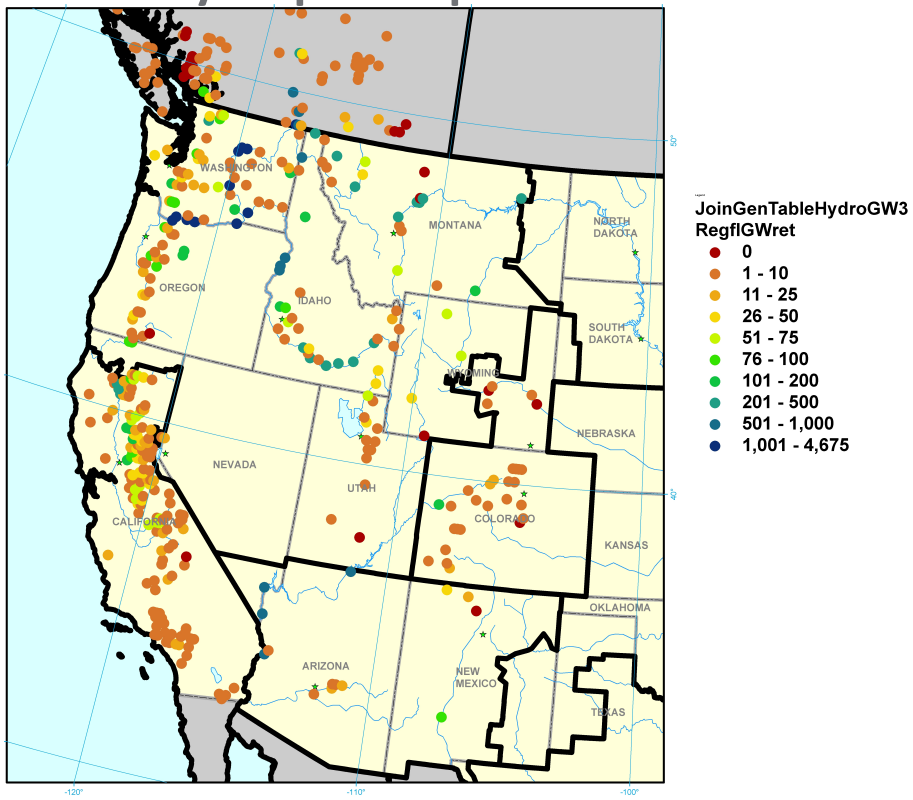
water availability in rivers, i.e. regulated and impounded flow with consumptive uses (PRIMA)

Impact on production cost model input, i.e. :
(1) variable potential hydropower generation &
(2) thermo-electric capacity relying on fresh surface water cooling

Derating of water-dependent energy generation and capacity

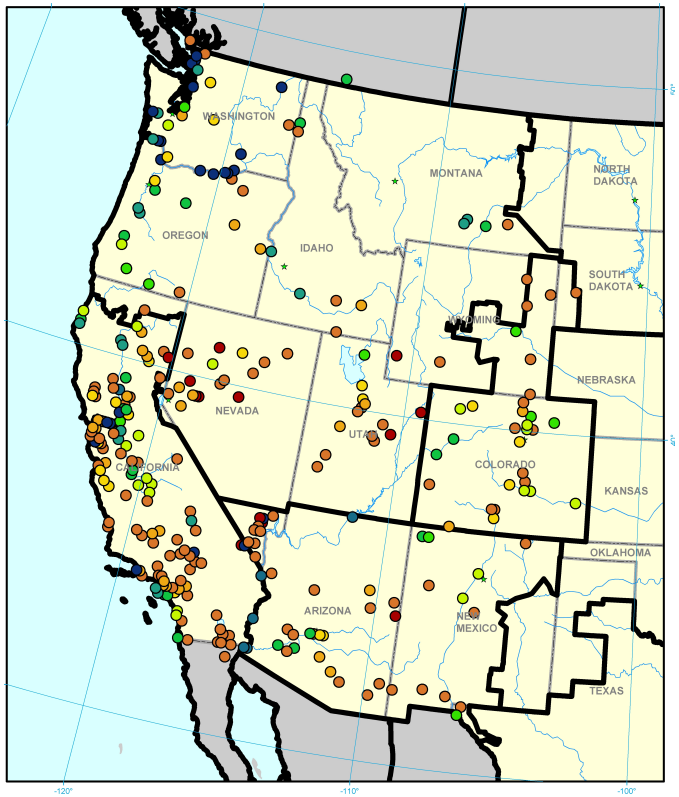
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Hydropower plants



Vulnerable thermo-electric plants

- cooling technology -> once-through, recirculating or cooling pond
- source of cooling -> freshwater, (NO groundwater, waste water , ocean)



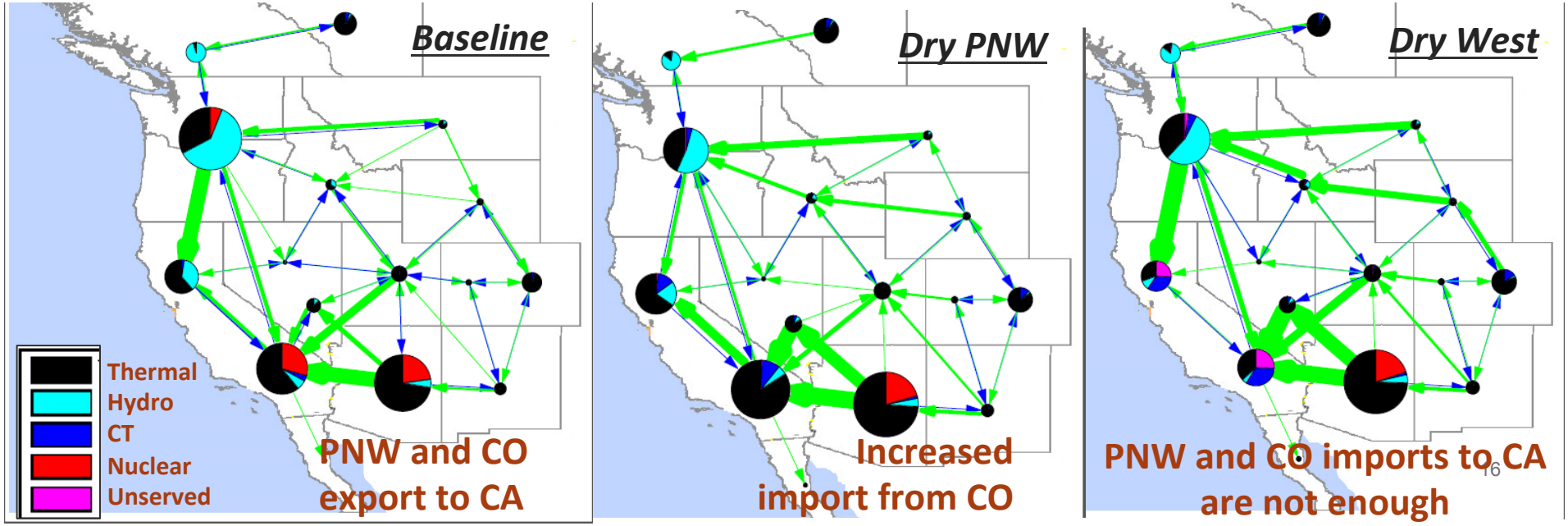
Derating based *on ratio of drought regulated flow over long term 1986-2015* ***regulated flow***

Results

Different droughts affect generation dispatch differently

- Effect of inter-annual variability in cross-regional water availability on reliability of the balancing authorities

August transmission and generation mix



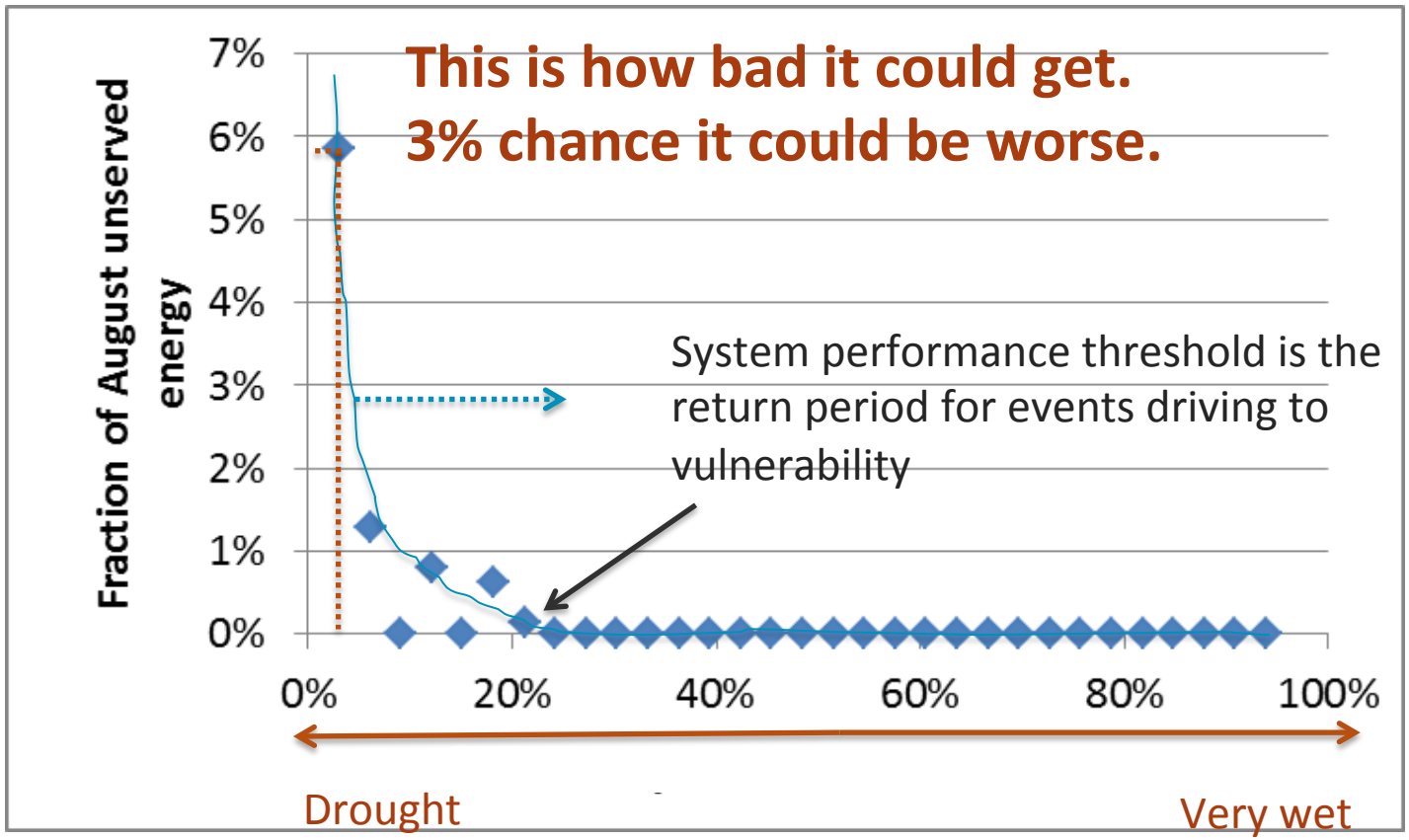
100% August demand met

100% August demand met

6% August demand NOT met

Risk Distribution for Grid Performance - Effect of Inter-Annual Variability in Regional Water Availability on Reliability of the Grid

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965



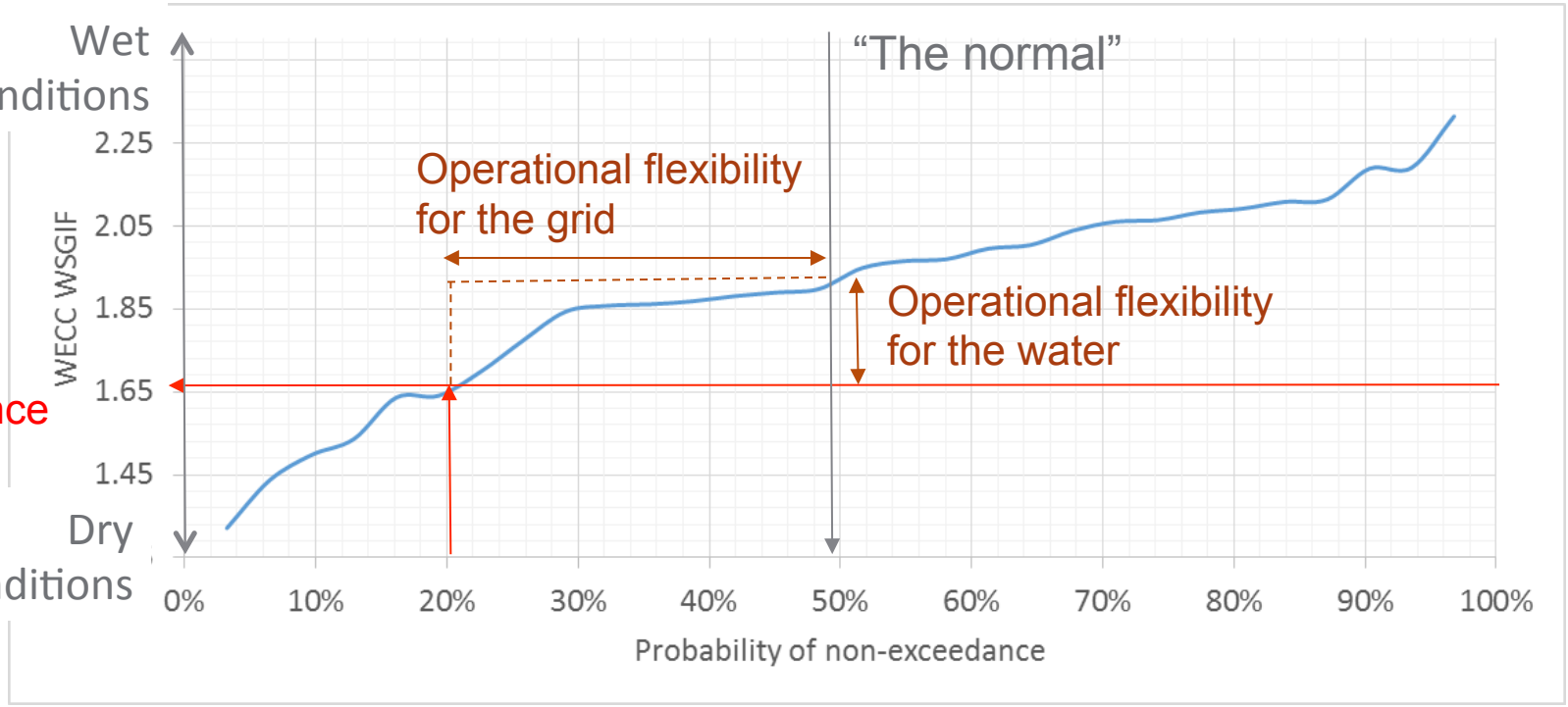
We developed an index linking water availability and impact on capacity, associated with a probability of occurrence.

Established risk distribution and system performance threshold can be used for designing contingency plans.

Predictive model based on water availability

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

WSGIF = Water Scarcity Grid Impact Factor (= Drought severity metric)
= Impact of water availability on potential generation

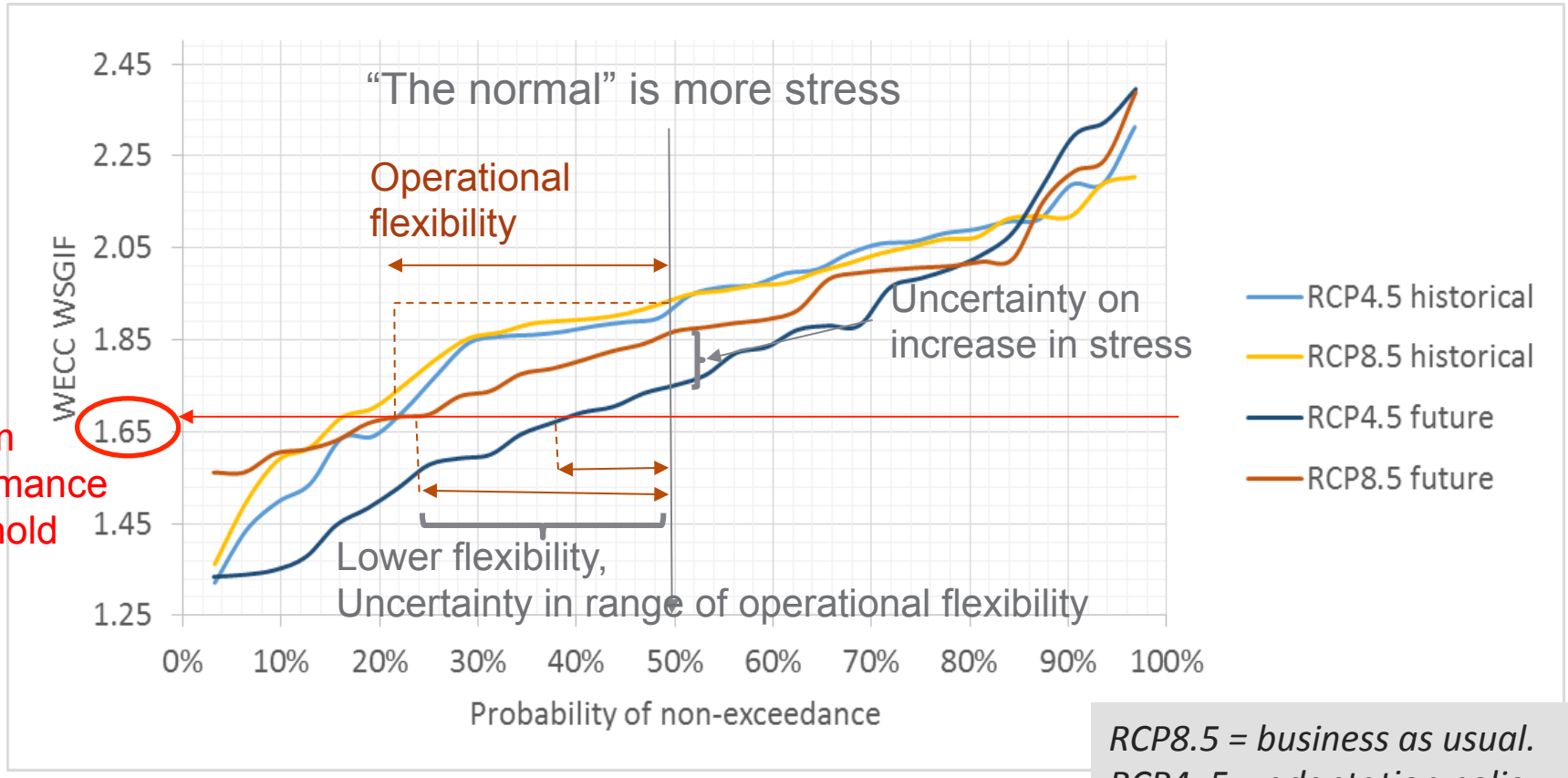


System Performance Threshold

New normal is increased stress and lower operational flexibility for the grid

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- The projected new normal is higher stress on the grid generation potential.
- Significant uncertainty to how much but agreement on trend
- Uncertainty in extremes as it might depend on sequencing of events



RCP8.5 = business as usual.
RCP4. 5 = adaptation policy

Conclusions and Path Forward:

1. **Risk distribution established for grid performance as a function of inter-annual water availability**
2. **Identified drought patterns driving to higher vulnerability**

Path forward:

- Integrate GCAM inter-annual water and electricity demands
- Improve the derating of (fresh surface water dependent) power plants
- Represent changes in reservoir operations due to changes in:
  - runoff seasonality
  - environmental constraints
  - load seasonality
  - water demand
    -> with feedbacks into GCAM

Acknowledgements

- Funding from:
  - PNNL FY15 Energy and Environment Directorate Laboratory Directed Research Development
  - PNNL Regional Integrated Assessment Modeling framework (RIAM)
  - grant to PNNL by Office of Electricity State Assistance Program

Grid management planning based on independent hydrologic regions or balancing authorities increases grid vulnerability

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

> Fazio said managers plan for hydropower generation based on the lowest water year on record. And this year doesn't look like it will be nearly that bad.
>
> OPB, May 2015 John Fazio, Senior Power Systems Analyst, Northwest Power Council

-> up to 19% unserved energy in August

-> lower operational flexibility

Specific regional patterns drive to vulnerability