Hydropower Licensing in the Face of Environmental Uncertainty

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FLOW 2018

April 24, 2018

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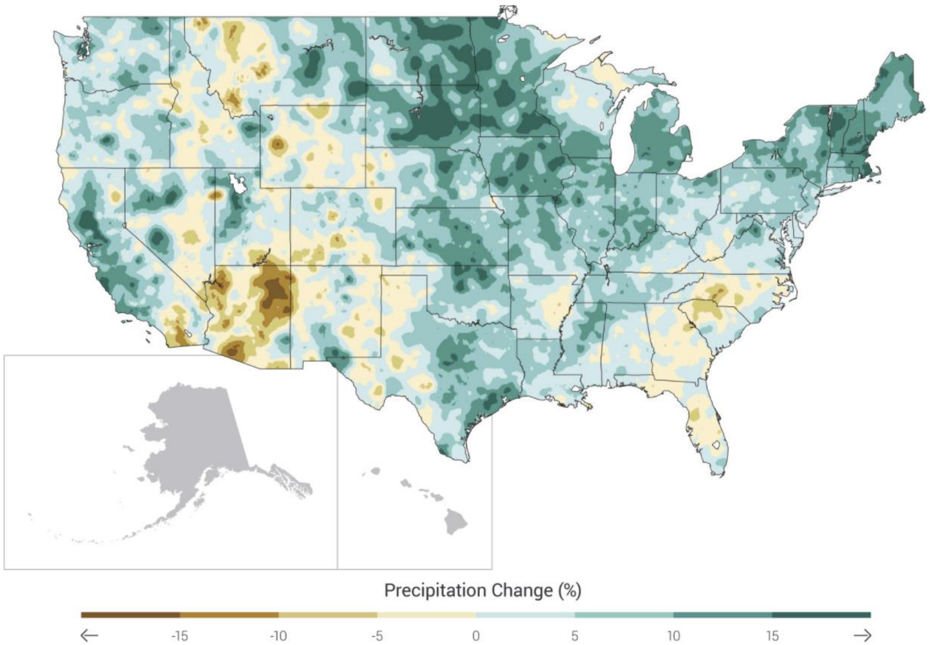
Oak Ridge National Laboratory

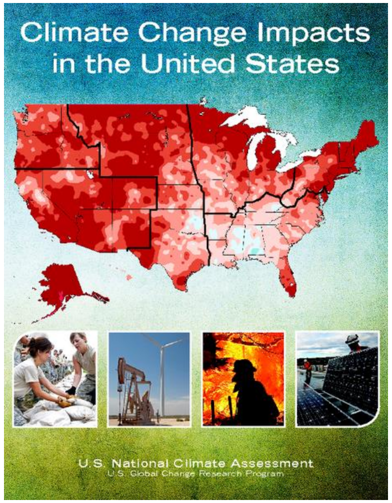
Precipitation Changes within the past two decades

- Precipitation changes 1991-2012 compared to 1901-1960 average



Peterson et al. 2013

National Climate Assessment



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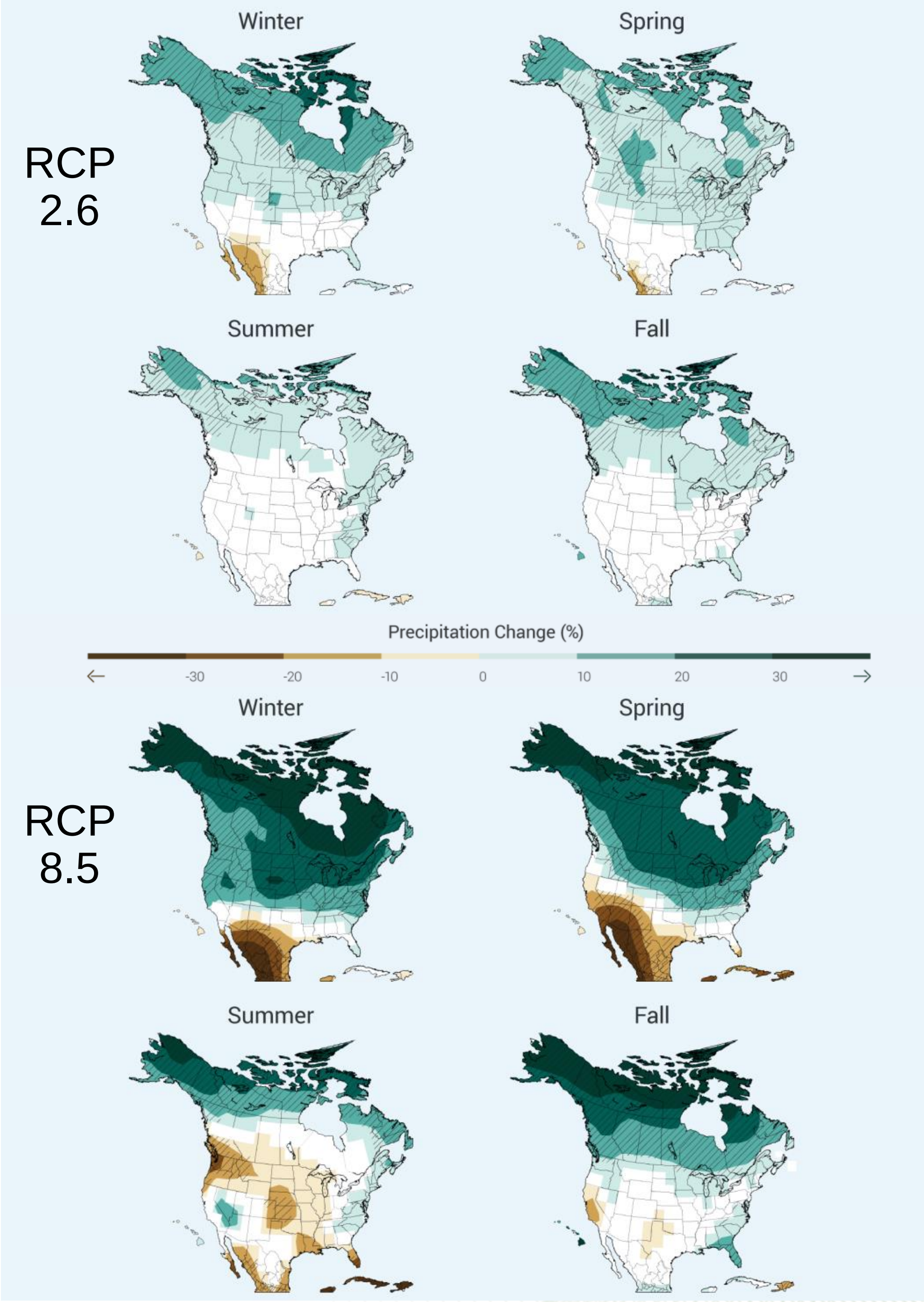
Projected Precipitation Changes

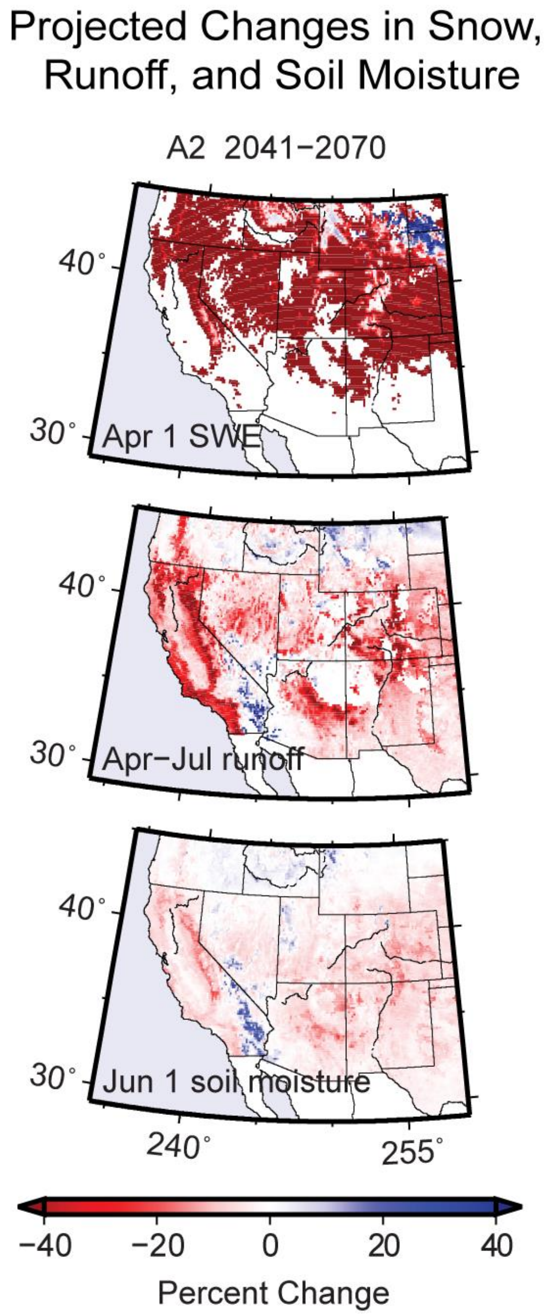
- 2070-2099 compared to 1971-2000
- Under dramatic reductions in emissions, precipitation will increase in winter and spring over most of US; however, SW still experience declines
- Under continued emission increases, the winter and spring patterns become more exaggerated. Additionally declines in summer and fall precipitation will occur over large regions of the US



Sources: NOAA NCDC / CICS-NC

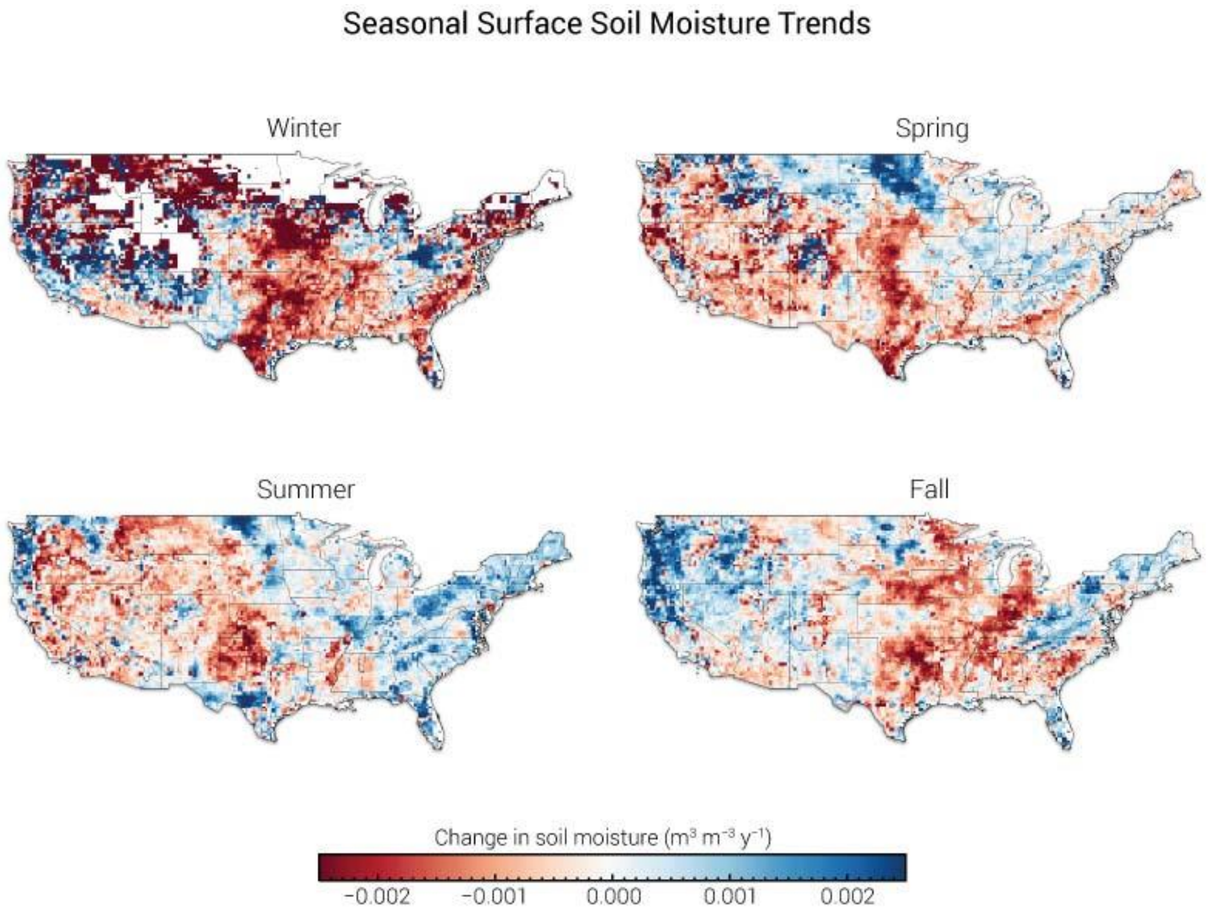
Projected Precipitation Changes

- 2041-2070 compared to 1971-2000
- A2 scenario
- Major losses in snowpack
- Significant reductions in runoff in CA
- Reductions in soil moisture



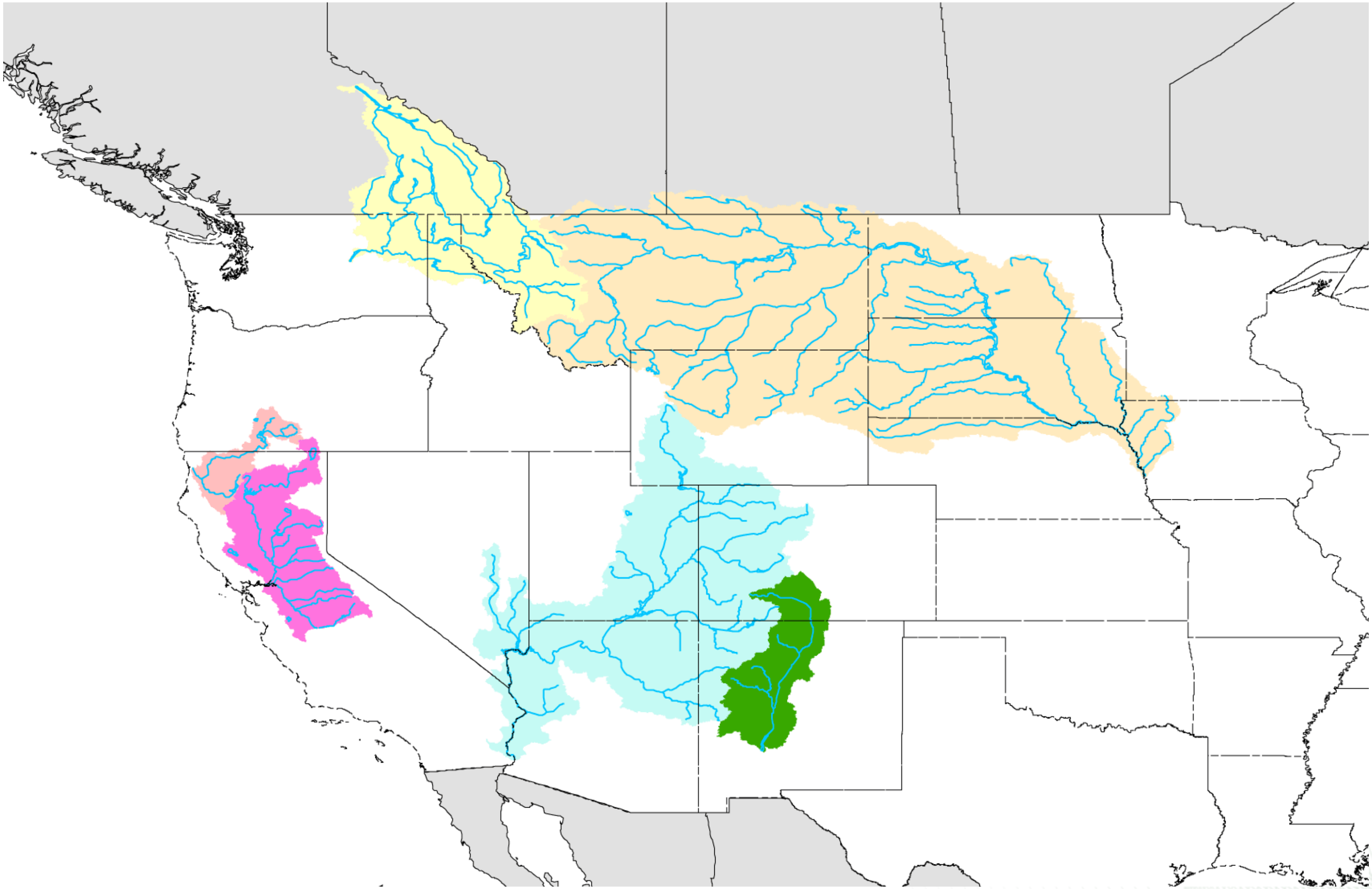
Cayan et al. 2013

Current Declines in Soil Moisture



Changes in seasonal surface soil moisture per year from 1988 to 2010 (W. Dorigo.)

Projected Changes in Runoff



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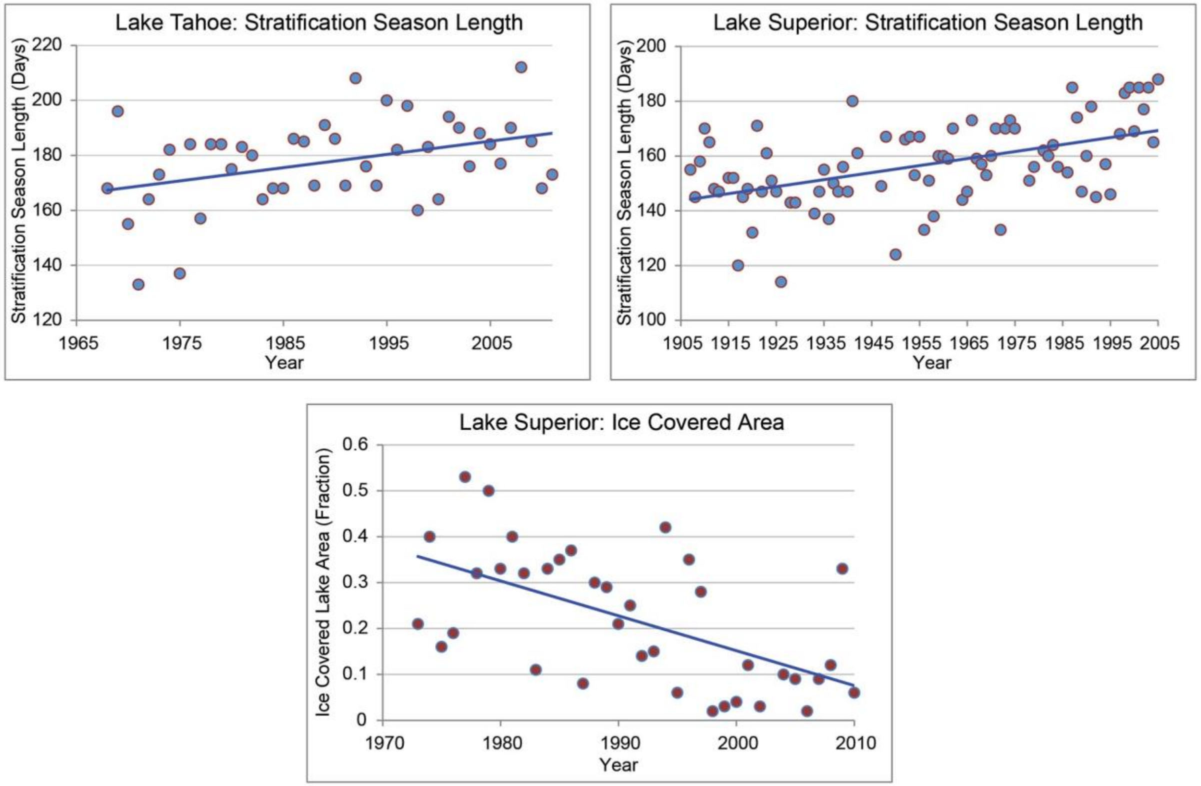
Changes in Lake Stratification and Temperature

- In response to increase air and surface water temperatures, length of the season in which differences in lake temperatures with depth cause stratification is increasing in many lakes.
- In Lake Tahoe, long water-residence times, warming air and water temperatures have caused declines in near-surface density, leading to longer stratification seasons, decreasing deep lake mixing, reducing oxygen levels, and causing impacts to many species and numerous aspects of aquatic ecosytems.
- In Lake Superior, stratification season is lengthening and annual ice-covered area is declining

Observed Changes in Lake Stratification Season and Ice Covered Area



1.UC Davis Tahoe Environmental Research Center, 2012: Tahoe: State of the Lake Report. 78 pp.

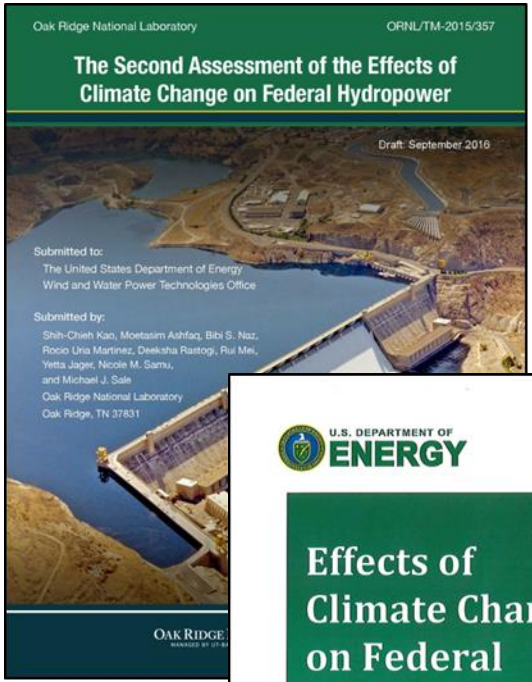
2. Wang, J., X. Bai, H. Hu, A. Clites, M. Colton, and B. Lofgren, 2012: Temporal and spatial variability of Great Lakes ice cover, 1973-2010. *Journal of Climate*, **25**, 1318-1329,

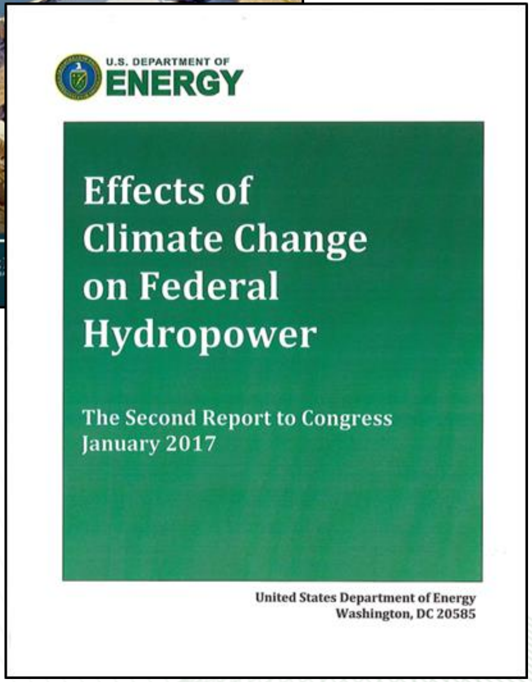
Summary of Projected Changes

- Changes in runoff vary across the US, vary by season
- Generally, with warmer temperatures, the amount of runoff generated by a given amount of precipitation will decline
- Shifts in snowmelt and precipitation types
- Droughts intensity
  - Runoff and streamflow decline in SW and SE
  - Summer drought duration and magnitude are expected to increase in most of US
- Flood frequency and magnitude increases
  - Heavy rainfall will increase and coincide with increasing impervious surfaces
- Elevated water temperatures and lower DO levels in summer

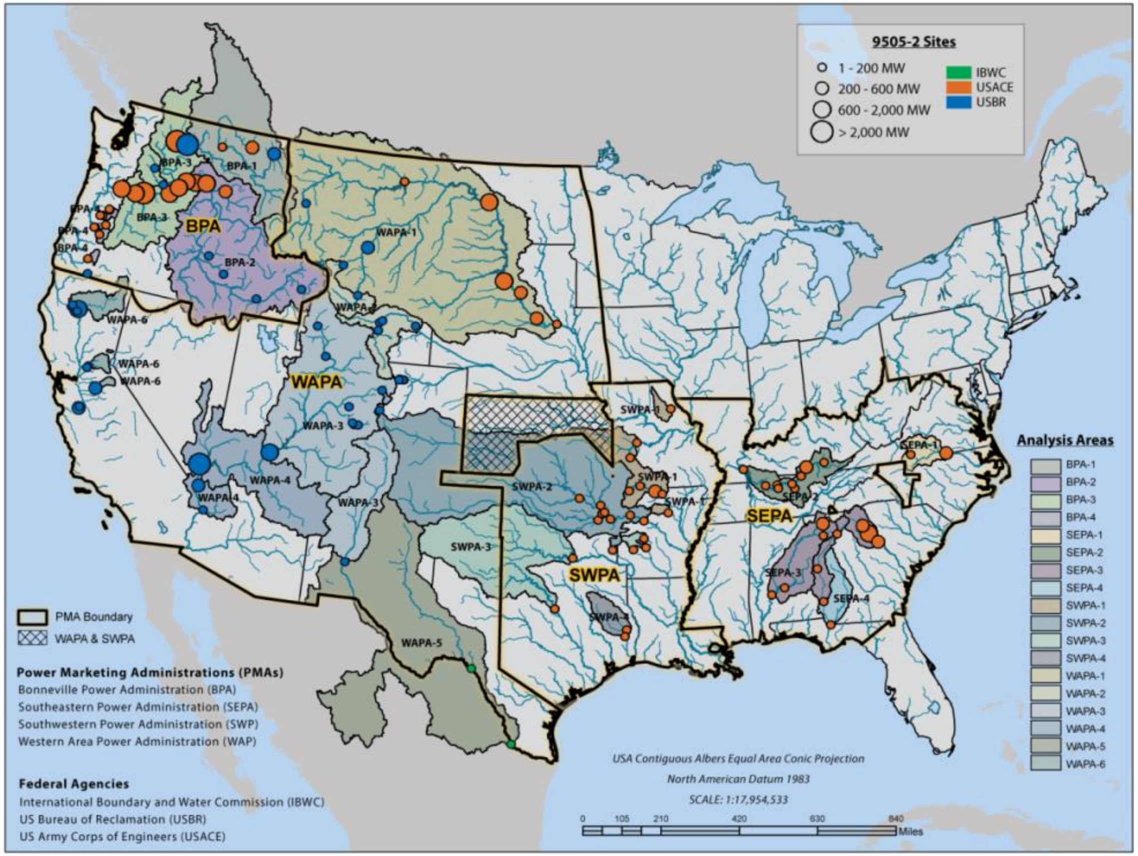
SECURE Water Act Section 9505 Assessment
Effects of Climate Change on Federal Hydropower

- Shih-Chieh Kao (PI, ORNL)
- kaos@ornl.gov
- Effects and risk of global climate change to water supplies used for hydropower generation





132 Power Plants in 18 Study Areas



Region	Hydropower plants	Installed capacity (GW)	Number of wholesale customers	Average Annual Generation (billion kWh)	Percent of electricity sales	Average Annual Revenue (million)
Bonneville	31	20.5	276	77.3	35	$2,306
Western	55	10.2	682	29.7	4	$973
Southwestern	24	2.2	102	5.8	1.4	$164
Southeastern	22	4.1	489	7.8	1.0	$242
TOTAL	**132**	**37.0**	**1,549**	**120.6**	**n/a**	**$3,685**

18 study areas defined by watershed boundary and power system.

Assessment Framework

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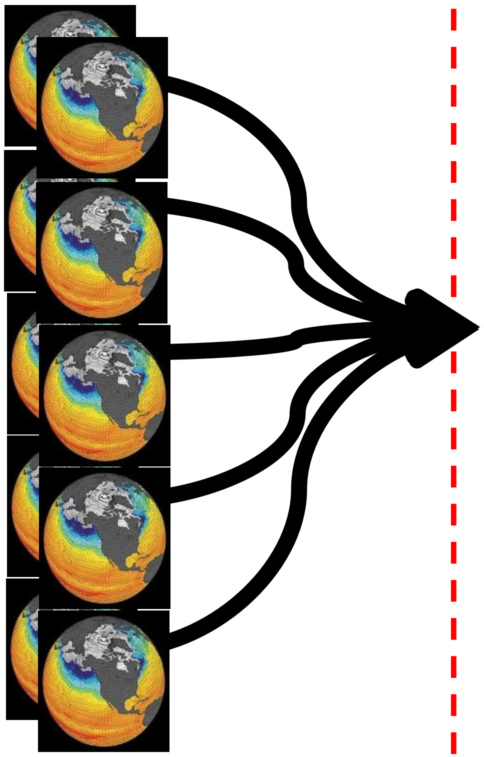
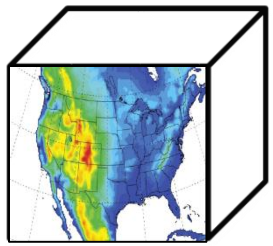
CMIP5 GCM Projections



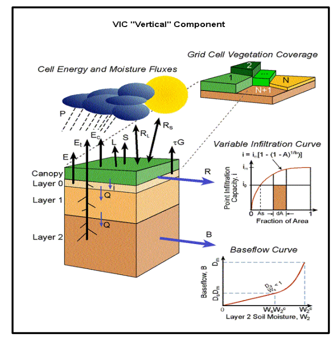
~150 km grid resolution



Regional Dynamical Downscaling (RegCM4)

~18 km grid resolution

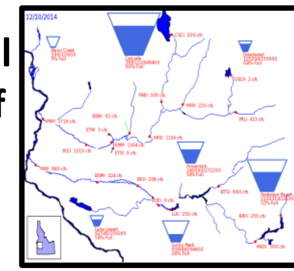
Hydrological Simulation and Calibration (VIC)



~4 km grid resolution

Watershed Runoff-Energy Storage (WRES) model

Natural Runoff Q_{in}



Regulated Runoff Q_{out}

Future Hydropower Projection

Assessment at each hydropower study area

10 sets of CMIP5/RegCM4/VIC hydro-climate projections were used in this study.

ORNL High-resolution CMIP5 Ensemble Projections

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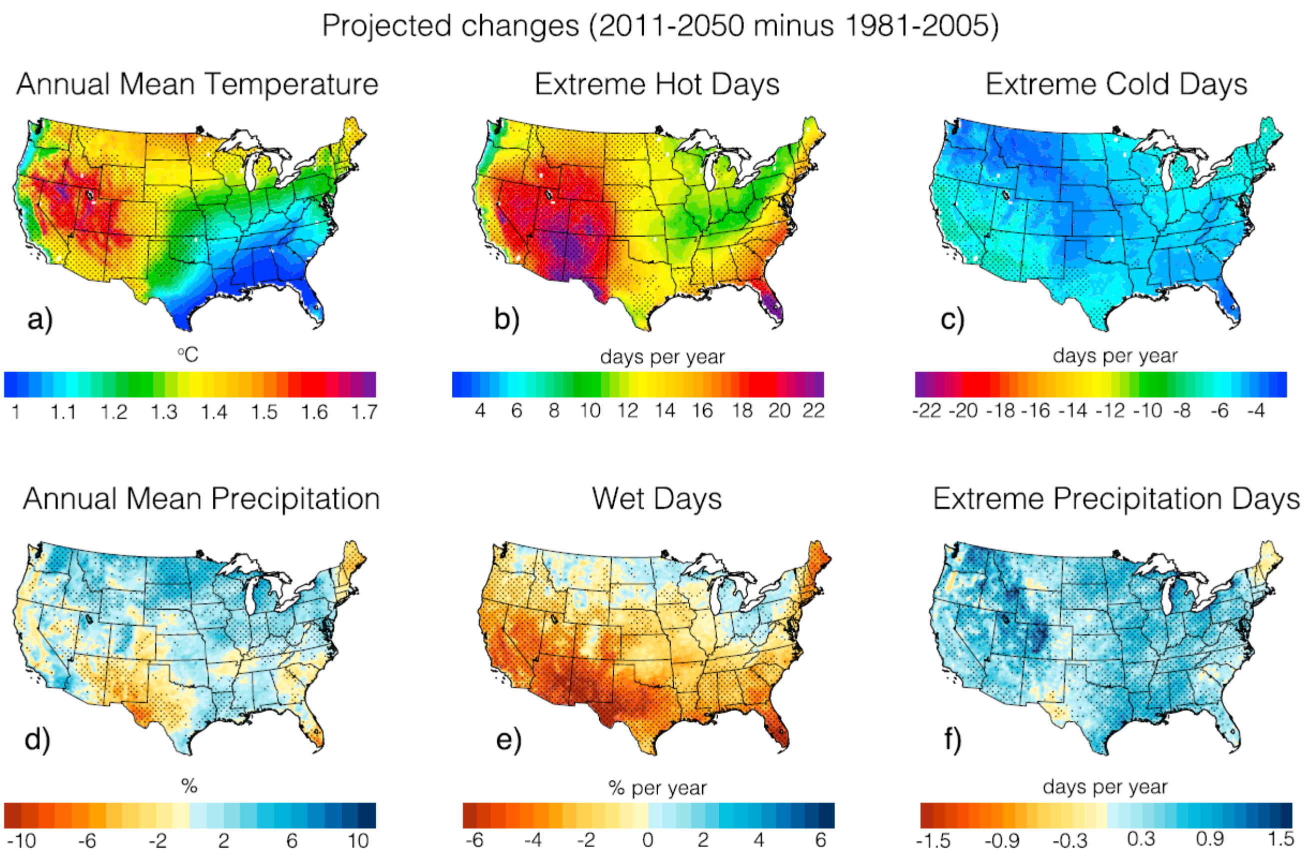

- 11 CMIP5 GCMs
- Baseline period
  - 1966–2005
- Future (RCP8.5)
  - 2011–2050
- Dynamically downscaled by RegCM4 to 18km
- Statistical correction (quantile mapping) to 4km
- ~15 Million computation hours, 200 Terabytes storage

Ashfaq, M., D. Rastogi, R. Mei, S.-C. Kao, S. Gangrade, B. S. Naz, and D. Touma (2016), High-resolution Ensemble Projections of Near-term Regional Climate over the Continental United States, *J. Geophys. Res.-Atmos.*, 121, 9943-9963, doi:10.1002/2016JD025285.

Projected Change by 10 ORNL simulations

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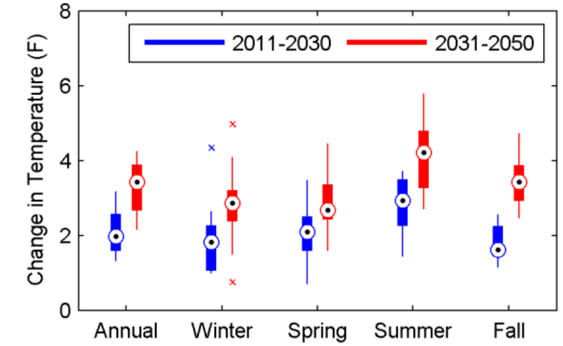
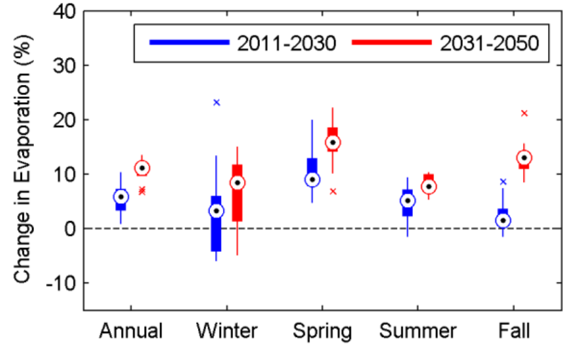
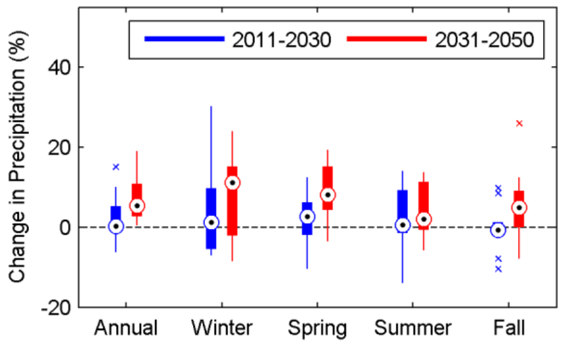
Temperature



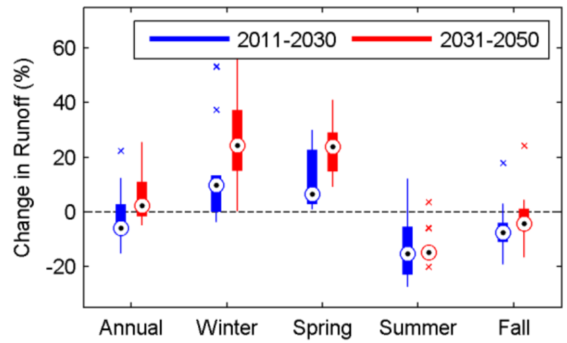
Evapotranspiration



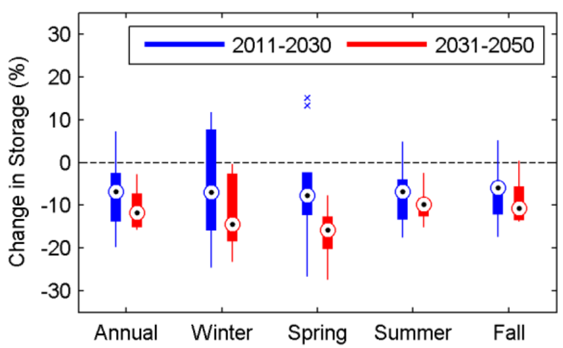
Precipitation



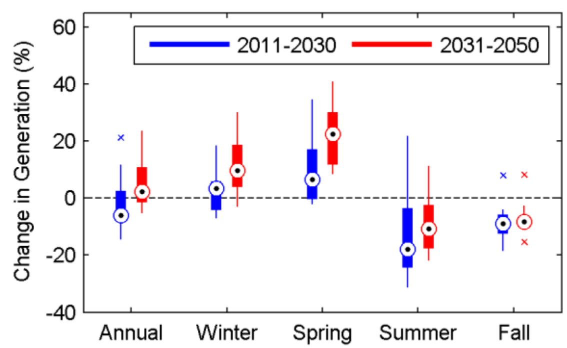
Runoff



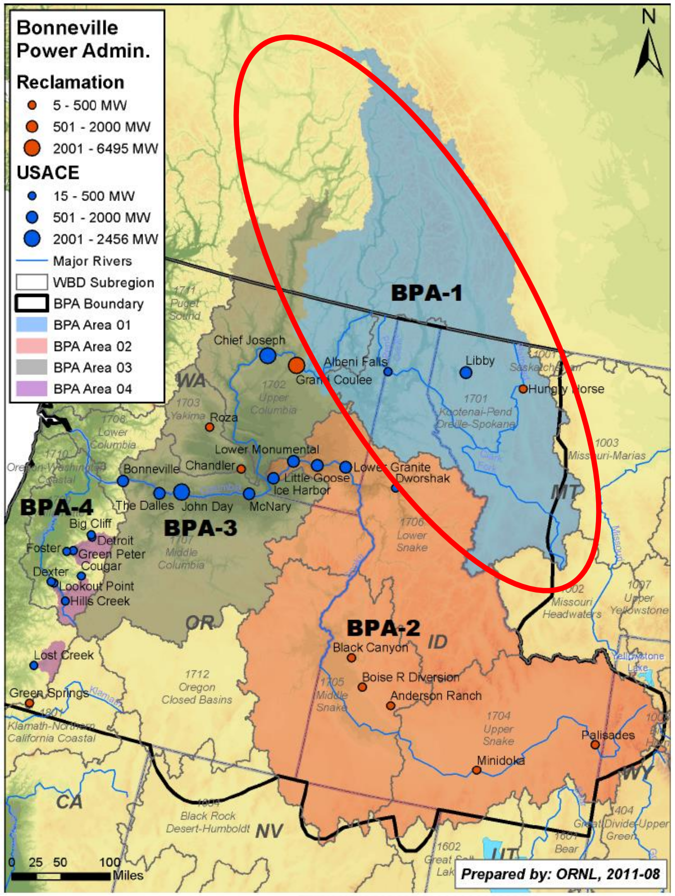
Storage



Generation



Bonneville – Area 1



Kao et al. 2016.
ORNL/SR-2015/357

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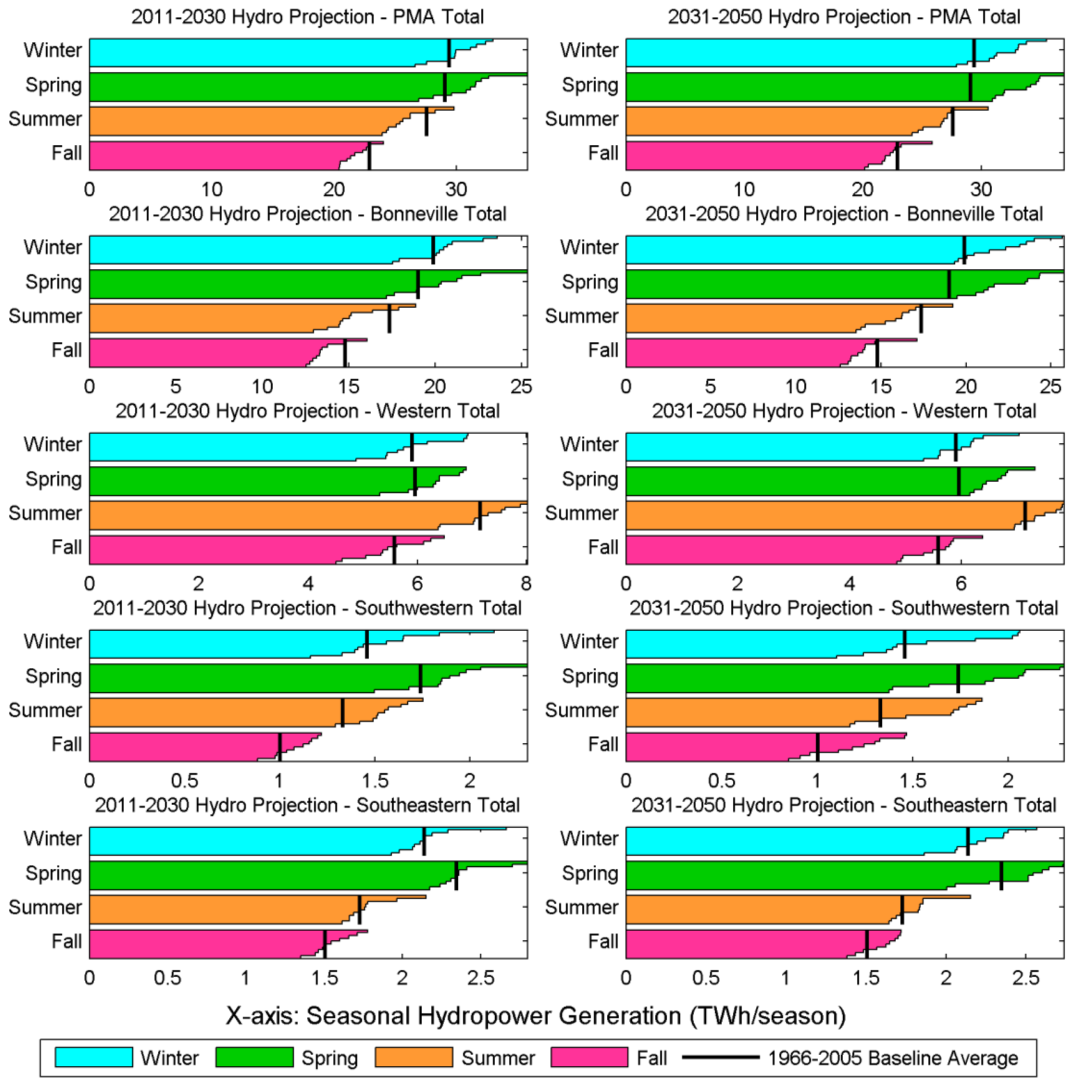
Impacts on Seasonal Hydropower Generation



- In general, more hydropower generation during winter and spring while less during summer and fall.
- Earlier snowmelt and change of runoff seasonality are the main factors affecting future hydropower generation.
- The relatively larger reservoir storage of federal hydropower fleet may help buffer the increasing future runoff variability.
- The site-specific challenges are to be better understood in the future assessment.

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Kao et al. 2016.
ORNL/SR-2015/357