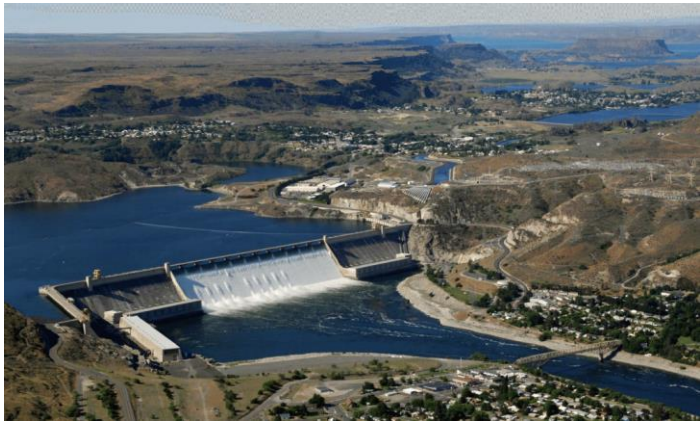

CERC-WET Topic 3 Improving Sustainable Hydropower Design and Operations

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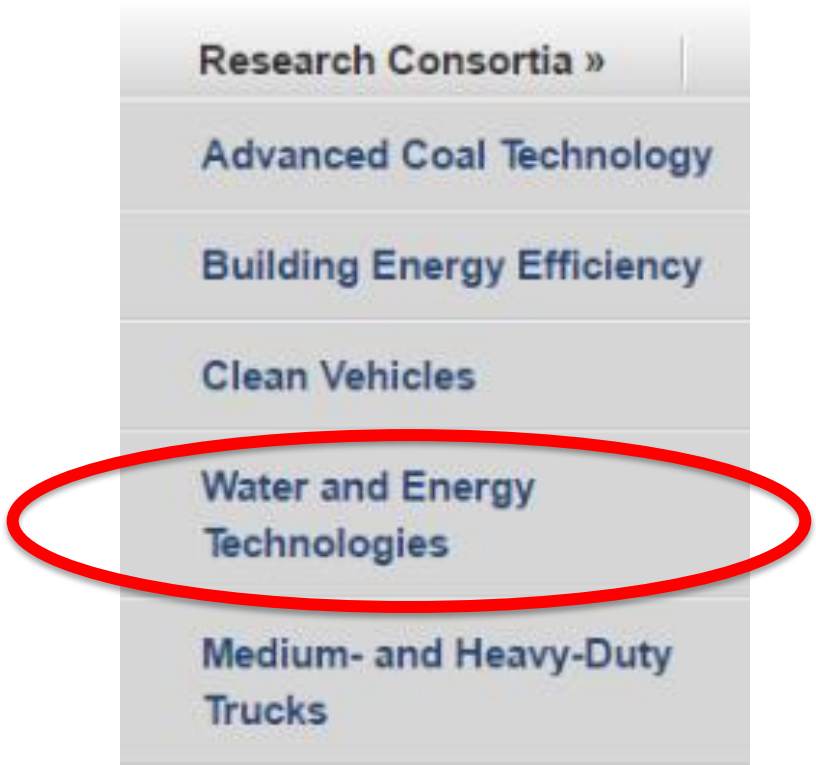
Clean Energy Research Center (CERC)

The United States and China are the world's largest energy producers, energy consumers and greenhouse gas emitters. The clean energy sectors in both countries are growing rapidly. The priorities of the ***U.S.-China Clean Energy Research Center*** reflect important areas of opportunity for both countries.

U.S. President Obama and China President Xi Jinping make Joint Announcement on the Extension and Expansion of CERC

President Xi Jinping and President Barack Obama endorse continued U.S.-China cooperation on clean energy innovation



CERC-WET Topic Area overview

- **Topic Area 1: Water Use Reduction at Thermo-electric Plants**
  U.S. Lead: Per Peterson, (UC Berkeley) / China Lead: GUO Hua (CGDG Guodian)

- **Topic Area 2: Treatment & Management of Non-Traditional Waters**
  U.S. Lead: David Sedlak, (UC Berkeley) / China Lead: HE Liu (RIPED)

- **Topic Area 3: Improving Sustainable Hydropower Design & Operation**
  U.S. Lead: Soroosh Sorooshian, (UC Irvine) Co-lead: Jay Lund (UC Davis) / China Lead: WANG Dongsheng (China Institute of Water Resources and Hydropower Research [IWHR])

- **Topic Area 4: Climate Impact Modeling, Methods, Science for E-W Systems**
  U.S. Lead: Alan DiVittorio, (LBNL) Co-lead: Soroosh Sorooshian (UC Irvine) / China Lead: XIAO Chan (NMC)

- **Topic Area5: Data/Analysis to Inform Planning, Policy, and Other Decisions**
  U.S. Lead: Nan Zhou, (LBNL) / China Lead: WANG Jianhua (IWHR)

Project Overview

Project Title: CERC-WET Topic Area 3: Improving Sustainable Hydropower Design and Operations

The Challenge:

- Large number of hydropower dams has been built globally
- Non-stationary hydroclimates are altering fundamental engineering design and operation
- A deeper understanding is required of how changing climate and varying weather condition impact on

(1) water-energy supplies, (2) electric grid reliability, (3) greenhouse gas implications, and (4) ecosystem and social economic functioning.

Partners:

Deltares Enabling Delta Life | GE | DUKE ENERGY | UNIVERSITY of CALIFORNIA OFFICE OF THE PRESIDENT | SoCalGas | SOUTHERN CALIFORNIA EDISON | ENERGY FOUNDATION building a new energy future | Walt Disney Imagineering | GLACIER TECHNOLOGIES A WHOLLY OWNED SUBSIDIARY OF BBNC

Next Generation Hydropower (HydroNEXT)

Optimization

- **Optimize technical, environmental, and water-use efficiency of existing fleet**
- Collect and disseminate data on new and existing assets
- Facilitate interagency collaboration to increase regulatory process efficiency
- Identify revenue streams for ancillary services

Growth

- Lower costs of hydropower components and civil works
- Increase power train efficiency for low-head, variable flow applications
- Facilitate mechanisms for testing and advancing new hydropower systems and components
- Reduce costs and deployment timelines of new PSH plants
- Prepare the incoming hydropower workforce

Sustainability

- Design new hydropower systems that minimize or avoid environmental impacts
- Support development of new fish passage technologies and approaches
- Develop technologies, tools, and strategies to evaluate and address environmental impacts
- **Increase resilience to climate change**

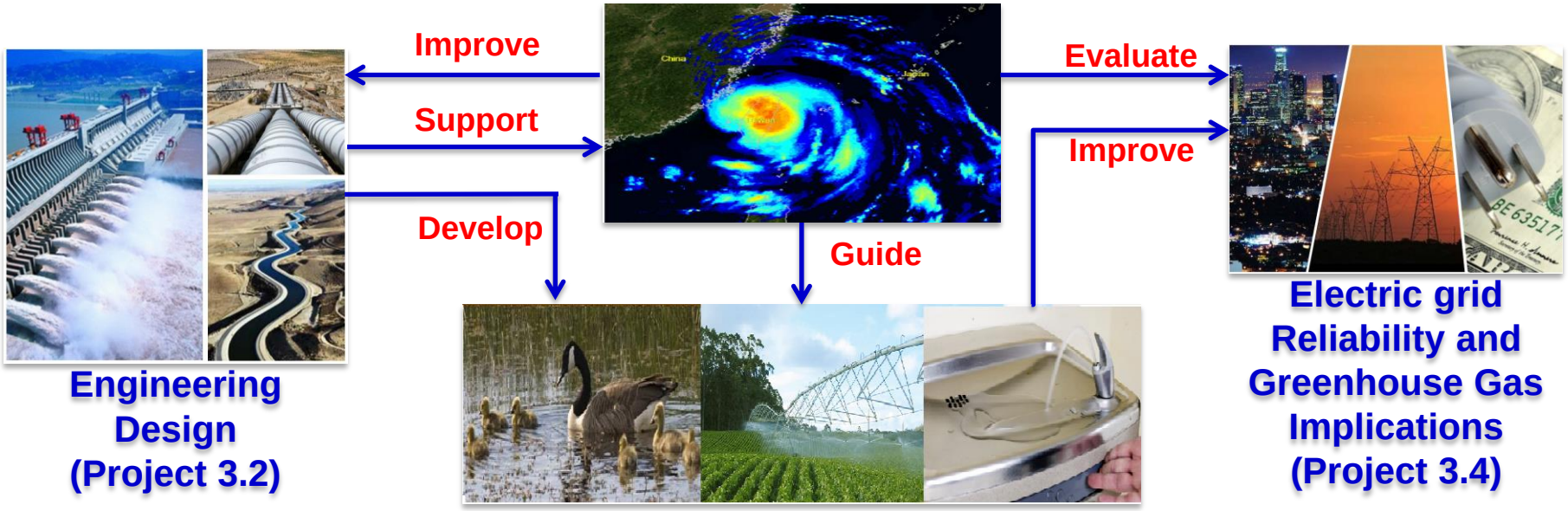
Projects Overview

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

Overall Objective: to improve sustainable hydropower *design* and *operation, and to evaluate* system reliability under non-stationary hydroclimates.

- ***Project 3.1 (Viers, UCM & Lund, UCD)*** **:** *provide the hydropower facilities short-term optimal operation strategies.*
- ***Project 3.2 (Sorooshian, Gao, UCI & Lund, UCD):*** *improve hydropower facilities life-time design and operations under non-stationary hydroclimates.*
- ***Project 3.3 (Sorooshian, Hsu, Gao, Aghakouchak, UCI):*** *develop remote-sensing precipitation monitoring and forecasts platform to support short-term hydropower scheduling and examine system resilience under extreme events.*
- ***Project 3.4 (Samuelsen, UCI):*** assess hydropower dispatch on electric grids and social impacts.

Hydrometeorology and Climate Forecasts (Project 3.3)



Linkage to Other CERC-WET Projects

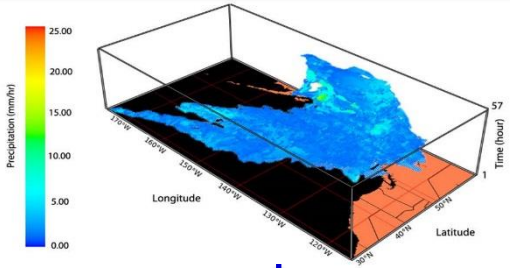
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Events-Based Precip. (Storm) Database (Project 4.3)

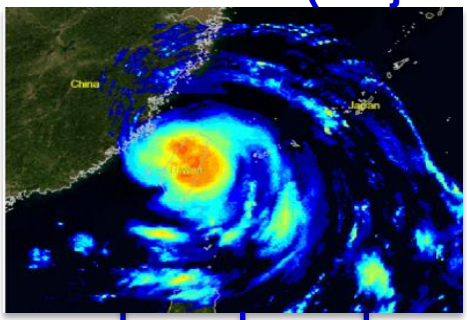
Support

Support

Historical Climate Extremes Analysis (Project 4.4)



Hydrometeorology and Climate Forecasts (Project 3.3)



Evaluate

Guide

Predict

Improve

Examine

Optimal Operation (Project 3.1)

Electric grid and Greenhouse Gas Implication (Project 3.4)

Engineering Design (Project 3.2)

Water impact of long-term energy development (Project 5.2)

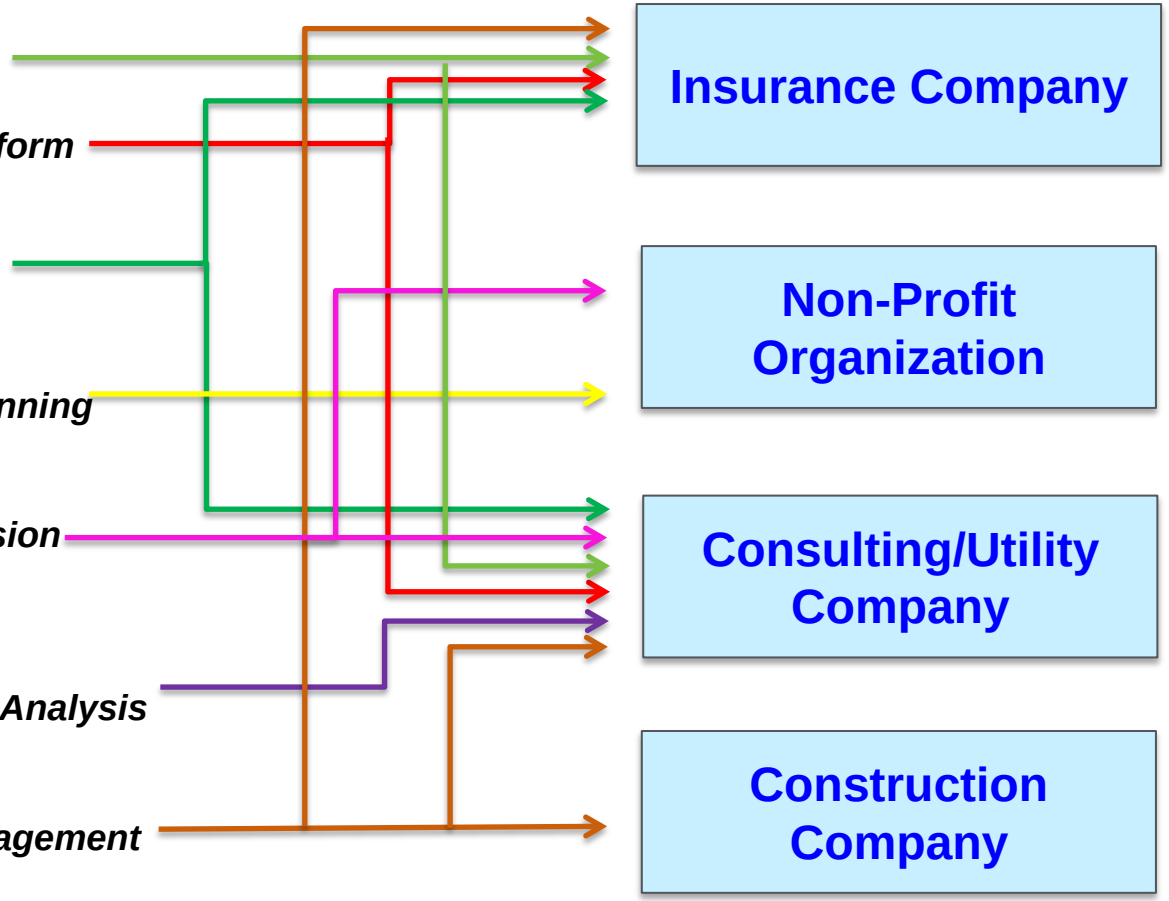
Modeling complex water-energy systems (Project 5.3)

Technology Transfer and Uses

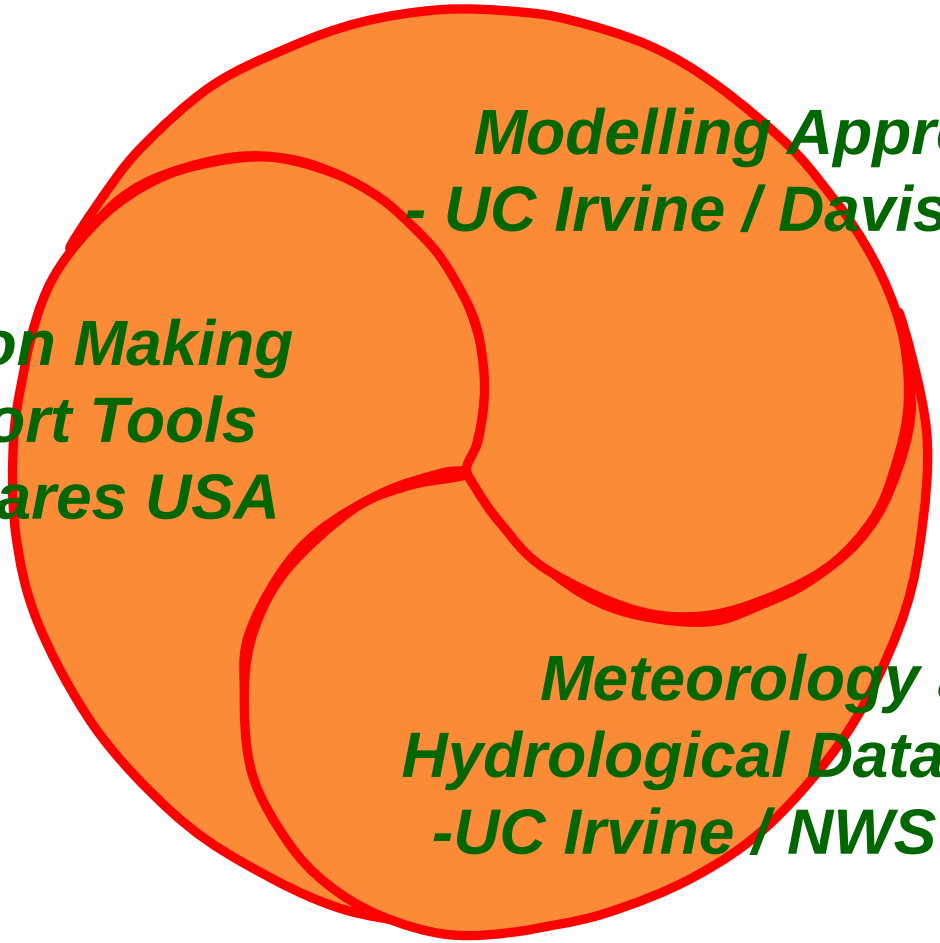
Project Outputs:

- ***Optimization Software*** (Project 3.1 and 3.2)
- ***Weather Forecasts Platform*** (Project 3.3)
- ***Global Storm Database*** (Project 3.3)
- ***Optimal Ecosystem Planning*** (Project 3.1)
- ***Reservoir System Decision Making Support*** (Project 3.2 and 3.3)
- ***Electric Grid Reliability Analysis*** (Project 3.4)
- ***Hydro facility Risk Management*** (Project 3.2)

Industry Partner:



Approach: Support Additional Hydropower System Operational Optimization from Three Elements

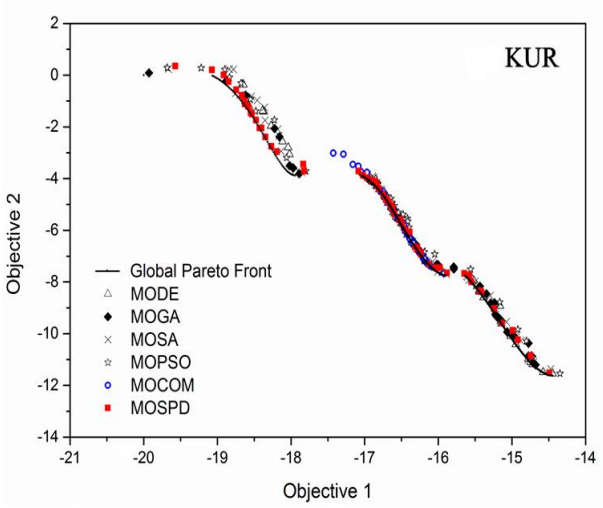


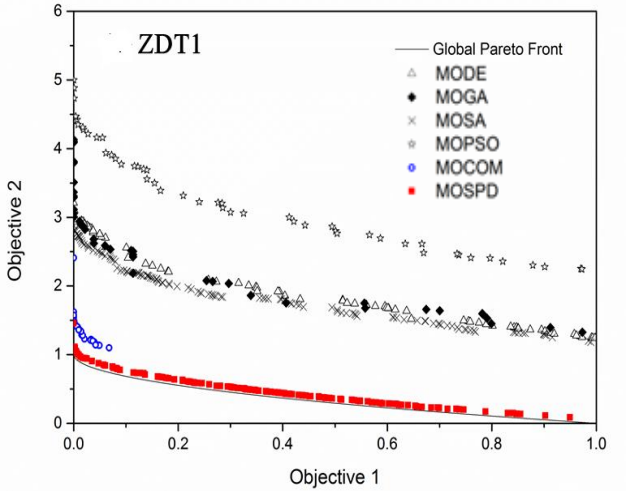
Technical Approach

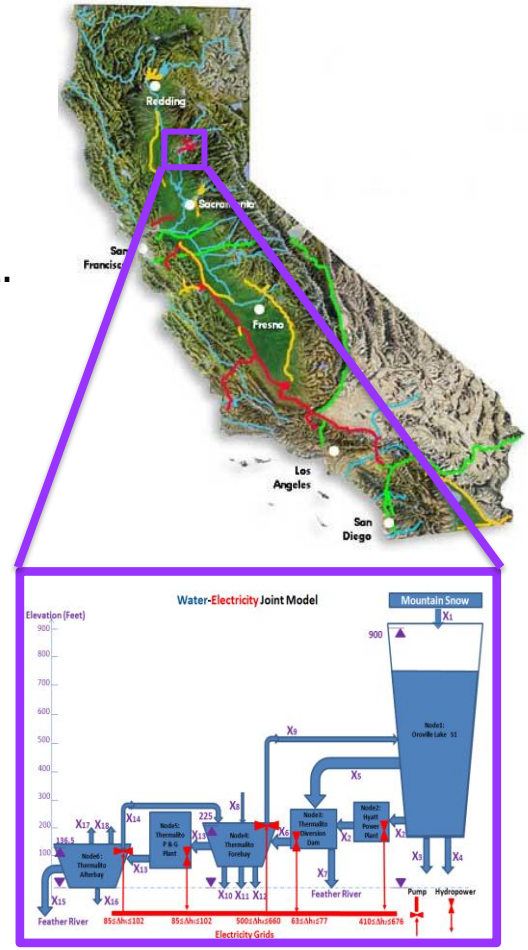
Example: Global Multi-objective Optimization Algorithms

Significance: Hydropower production is a decision making process that involves many trade-offs, such as water vs. energy, ecosystem vs. temperature increases, spills vs. turbine flows, economic benefit vs. other benefit.

Uniqueness: Advanced global evolutionary-based search algorithm to identify optimal solutions in a multi-objective context.







Source: Yang et al 2015. Environmental Modelling and Software

Progress in 2015-2016:

Many research papers have been published and a number of manuscripts are submitted for review:

Published:

- Yang, T., Gao, X., Sellars, S.L. and Sorooshian, S. (2015) **Improving the multi-objective evolutionary optimization algorithm for hydropower reservoir operations in the California Oroville–Thermalito complex**. Environmental Modelling & Software 69, 262-279.
- Yang, T., Gao, X., Sorooshian, S. and Li, X. (2015) **Simulating California Reservoir Operation Using the Classification and Regression-Tree Algorithm Combined with a Shuffled Cross-Validation Scheme.** Water Resources Research, 52, 1626–1651, doi:10.1002/ 2015WR017394.
- Miao, C., Ashouri, H., Hsu, K.-L., Sorooshian, S. and Duan, Q. (2015) **Evaluation of the PERSIANN-CDR daily rainfall estimates in capturing the behavior of extreme precipitation events over China.** Journal of Hydrometeorology (2015).
- Tarroja, B., AghaKouchak, A., Samuelsen, S., **Quantifying the Implications of Climate-Change Impacted Hydropower on Electric Grid Greenhouse Gas Emissions and Operation**, Energy, 2016. 111: 295-305.
- Liu, X., Y. Luo, T. Yang, K. Liang, M. Zhang, and C. Liu (2015), **Investigation of the probability of concurrent drought events between the water source and destination regions of China's water diversion project**, *Geophysical Research Letters*, *42*(20), 8424-8431.
- many more as listed in review report…

In review:

- Yang et al. **An Enhanced Artificial Neural Network with A Shuffled Complex Evolutionary Global Optimization with Principal Component Analysis** *Information Sciences*
- Yang et al. **Developing Reservoir Monthly Inflow Forecasts Using Artificial Intelligence and Climate Phenomenon Information** Water Resources Research
- Liu et al. **Evaluating the streamflow simulation capability of PERSIANN-CDR daily rainfall products in two river basins on the Tibetan Plateau** Hydrological and Earth System and Science

Project Budget

Topic Area 3 Budget:

FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
0	0	$290.18k	$803.869k	$290.957k	$820.518k

- Project awarded in mid-2015 but received by University of California in mid-2016
- Year 1 expenses have been reported
- Year 2 allocation have landed in all participating campuses of Topic 3
- Deltares USA Inc. provides in-kind supports for a number of projects.

Overall CERC-WET Budget:

FY2016-2020		
DOE	Cost-share	California CEC
$12,500k	$12,500k+	$ 2,500k

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators: We will continue to work with the industry partners within the CERC-WET consortium from both the United States and China, as well as any potential partners from academia, government agencies, and industry.

Communications and Technology Transfer:

- Annual CERC-WET meeting, CERC-WET stakeholder meeting, CERC-WET steering committee meeting
- American Geophysical Union Annual Meeting
- American Meteorological Society Annual Meeting
- Quarterly teleconference with DOE experts

Next Steps and Future Research

FY17/Current research: In FY17, many case studies will be jointly carried out with the China team as the following hydropower intensive areas have been identified by both U.S. and China teams:

- ***U.S.:*** *Columbia River Basin, Tennessee Valley Area, Colorado River Basin, and Northern California*
- ***China:*** *Ya-long River Basin, Jin-Sha River Basin, and Yangtze River Basin*

Proposed future research:

- Investigate the application of hydro-meteorological forecasts in support of short-term hydropower scheduling
- Enhance the optimization algorithms and decision making support tools that are currently being used by both operating agencies and industry.