2014 WATER POWER PROGRAM PEER REVIEW

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

Compiled Presentations

February 25-28, 2014

Hydropower Technologies

PR-5A00-61853

Contents

Contents (continued)

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2014 Water Power Program Peer Review

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

Existing Hydropower

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February 25, 2014

Strategic Objectives of the Hydropower Program Element

- Support a resurgence in hydropower research, manufacturing and development in the U.S.
- Analyze opportunities to develop new hydropower capacity in the U.S., and facilitate the development and demonstration of environmentally-friendly technologies to harness these resources
- Improve performance / flexibility of hydropower systems and evaluate major risks to the existing hydropower fleet
- Develop tools and information that will drive the development and utilization of Pumped-Storage Hydropower (PSH) and hydropower systems to increase grid flexibility and integrate variable renewables
- Address a wide range of environmental and market barriers to facilitate significant deployment, and develop a vibrant U.S. hydropower workforce and research community

Water Power Program

Team – comp

DOE Hydropower Activities

- Existing Hydropower
- New Hydropower
- Hydropower Market Acceleration and Deployment
- Integration and Pumped Storage Hydropower

Key Counterparts and Collaborators:

Industry

- ORNL
- ANL
- PNNL
- INL
- NREL
- SNL

Water Power Program
Portfolio Priorities – Hydropower

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The 2014 Water Program Peer Review Agenda has sessions that will cover projects and activities in these priority areas.

★ Existing Hydropower: Optimize existing hydropower technology, flexibility, and/or operations	• Tuesday, 2/25
New Hydropower: Advance new hydropower systems and/or components for demonstration or deployment	• Wednesday, 2/26
Market Acceleration: Reduce deployment barriers and environmental impacts of hydropower	• Thursday, 2/27
Pumped Storage Hydro: Enable next-generation pumped storage technologies to facilitate renewable integration	• Thursday, 2/27

Why Focus on Existing Hydropower?

As the nation's dominant RE option, it benefits the Nation to maintain, improve and expand the nation's existing hydropower infrastructure

New tools are needed to measure and analyze efficiency of hydropower plants, and optimize generation and flexibility across hydro systems. Better information is also needed on the state of the hydropower fleet, and on the risks posed by changing climate and other water use pressures

Consider:

1. Opportunities exist to improve hydro fleet optimizations in key areas (see next slide)
   - Capacity weighted average age of a hydro plant in the U.S. is in the range of 35-45 years.
   - Estimates show 5-8%% generation gains can be made through optimization, but more importantly, the fleet will have tools to better adapt to changing conditions
   - Resources ($) for the federal fleet are particularly limited to make improvements

2. Competing water-use issues and climate change concerns continue to pressure the goals of increased hydropower generation:
   - Hydropower is only one of many water uses, need to better predict effects of changes to other uses on hydropower
   - Need to coordinate analyses of potential climate change impacts

3. New technologies, practices + standards can be more rapidly disseminated and adopted
   - There are some codes and standards but not adequate sharing of best practices

The Drivers for a Focus on Modernization

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Case Studies and Assessments Prove Value of Modernization Efforts:

TVA's Hydropower Modernization (HMOD) Initiative

- TVA's HMOD program began in 1992 to address the reliability issues of an aging fleet and to increase TVA's hydroelectric capacity and efficiency over the long term.
- HMOD Achievements:
  - Ensured continued reliability and performance of TVA's existing hydropower assets (totaling 5,905 MW of capacity).
  - Increased hydro capacity by 560 MW (9.48% increase) with an **average efficiency gain of 4.8%**

Corps' Hydropower Modernization Initiative (HMI)

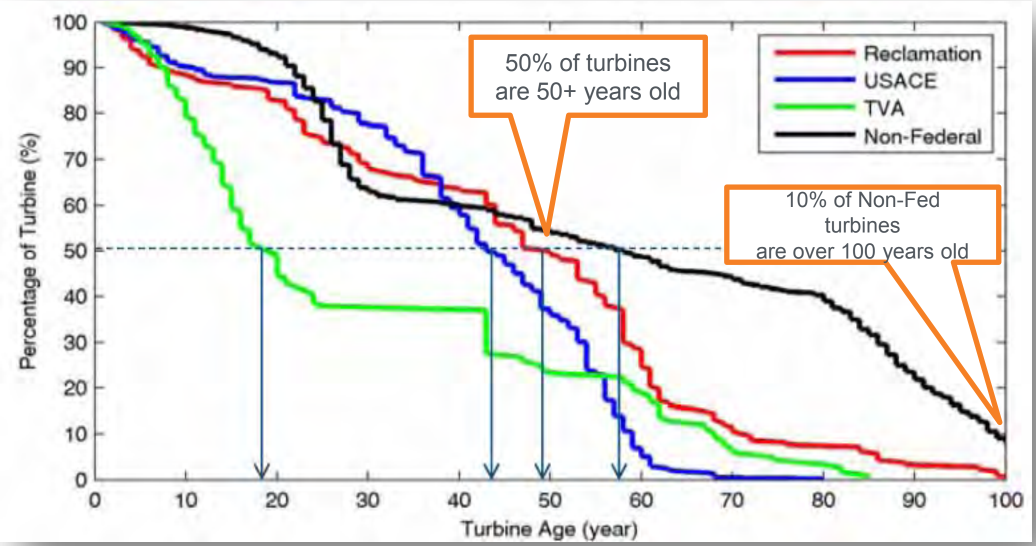
- In Phase I of this initiative, completed in 2010, the Corps concluded that modernization of six "critical needs" projects (identified as "requiring rehabilitation") could produce 341 GWH in additional electricity (**avg. 8% per plant**) @ a cost of approximately $600 million.
- Phase II looked at facilities outside the Federal Columbia River Power System (i.e., projects not eligible for funding by BPA) and concluded that if the Corps took no action to modernize the 54 units not financed by BPA, it would forego potential revenues of approximately $7 billion over a 20 year horizon. Costs for the upgrades necessary to avoid the aforementioned losses were estimated at $3.7 billion.

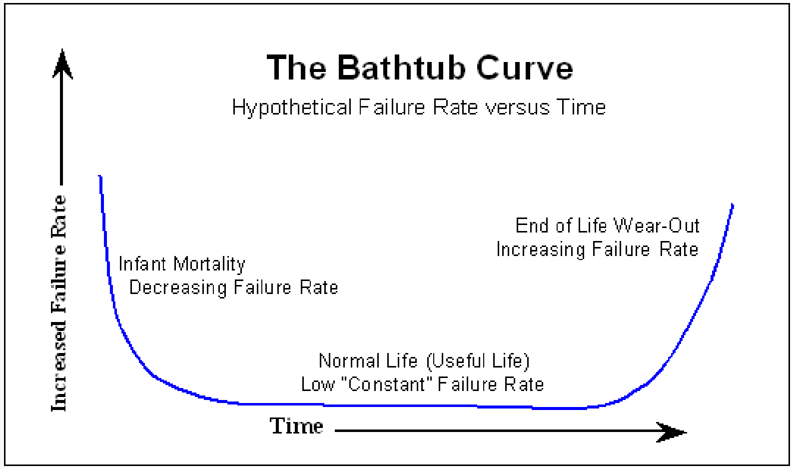
US DOE Hydropower Advancement Project (HAP)

- Initial assessments at 8 hydropower facilities show a **7.1% average increase** in generation for surveyed facilities

Critical Need: Support Modernization of the existing hydropower fleet

- Major equipment @ over ½ of US hydropower plants was designed and installed 50+ years ago.
- The efficiency and capacity of aging equipment has declined as its physical condition deteriorates over time.
- Many hydropower plants are routinely operated outside original design specs in order to meet grid demands.
- Unscheduled down time and maintenance/replacement costs are on the rise…jeopardizing the availability of these valuable assets





The Opportunity

- Increase the capacity, generation and value of hydropower at existing U.S. hydropower facilities through fleet modernization by applying the advances that have been made in materials and hydro-mechanical designs that improve efficiency and performance of turbines, generators, and other hydropower components of hydropower systems.

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Goal:

- Maximize sustainable generation and performance from existing hydropower infrastructure.

Priorities:

- Understand the challenges faced by today's industry
- Maintain/improve generation and flexibility of the existing hydropower fleet

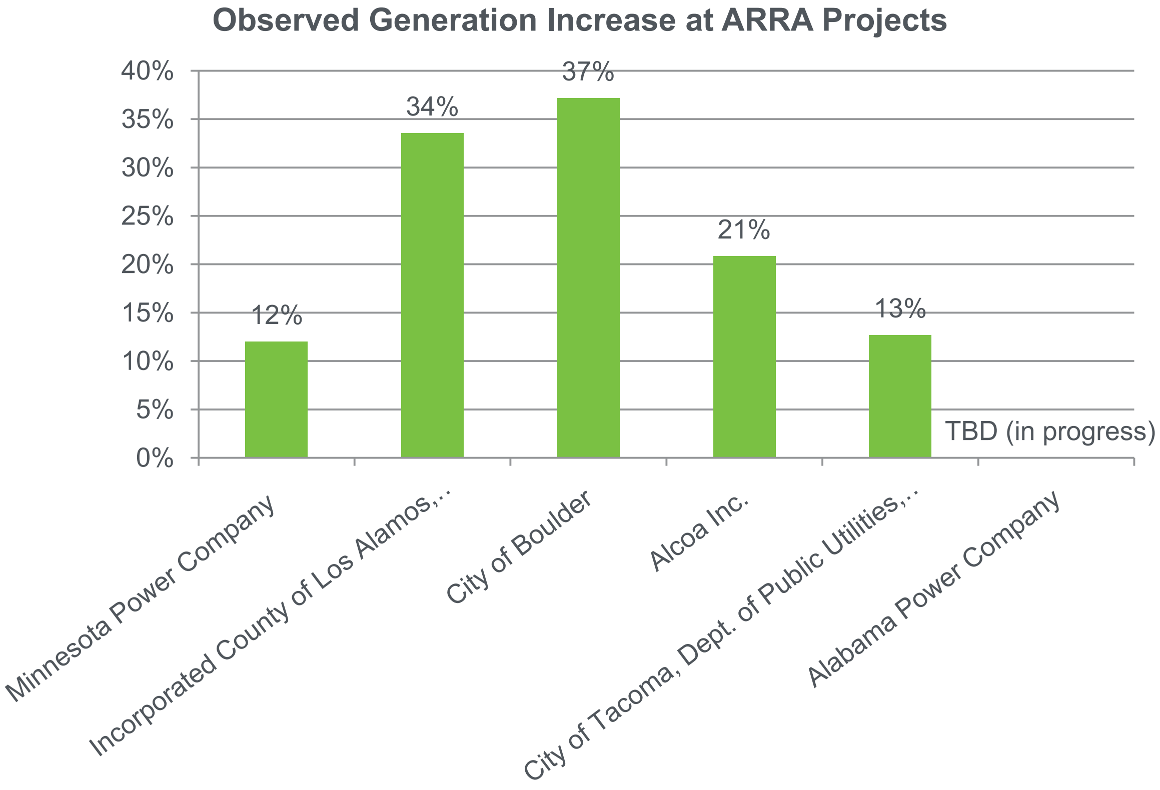
DOE Unique Role:

- Assess and report on the state of the industry and water resource issues (resource availability, climate change impacts, etc.)
- Make available critical information, and develop tools and methodologies to improve performance.

FY12 / FY 13 Project Portfolio

American Recovery and Reinvestment Act (ARRA) Hydro Modernization Program (FY10 – FY13)

7 Competitive Awards	
DOE Funding:	$29.8M
Private Funding:	$117.7M
Average Generation Increase:	23%



Installing new turbine runner at Boulder Canyon Hydroelectric Project

Hydropower Advancement Project (HAP)

Objective: to accelerate increases in U.S. hydropower asset performance and value by: (a) providing a fact-based quantitative estimate of additional energy available through improvements and expansions of all U.S. hydropower assets; (b) identify barriers to implementation of hydropower asset improvement and expansions; (c) prioritize research that would accelerated increases in hydropower asset performance and value, and (d) develop and disseminate Best Practices, Assessment, and Analysis Tools to stimulate and accelerate increases in hydropower asset performance and value

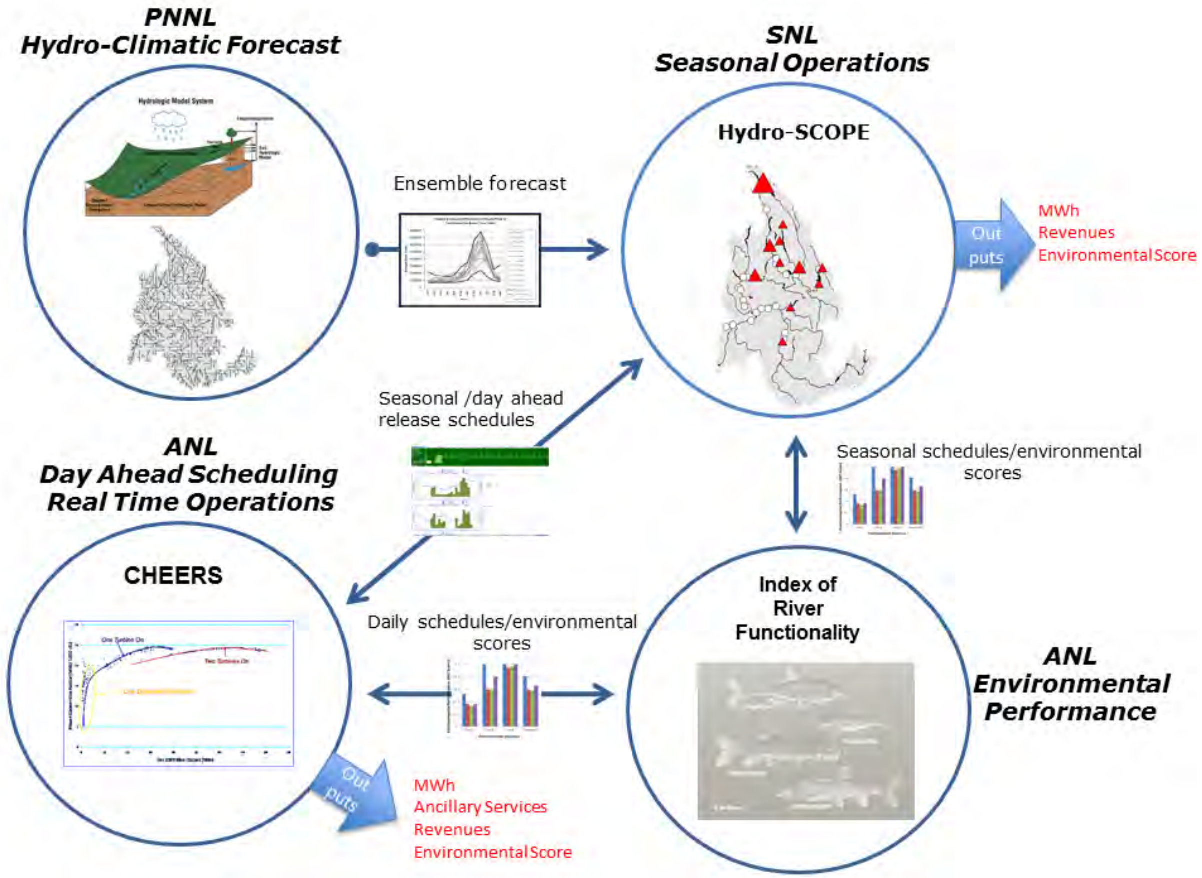
HAP Assessment Results

Plant Installed Capacity (MW)	Design Head (feet)	Turbine Type	Year of initial Commissioning / upgrade	Current Annual Average Generation (MWh)	Potential Annual Generation Increase (MWh)	Potential Generation Increase (%)	Preliminary Cost Est. for Recommended Upgrades * (10^6 $)
28.2	59	Francis	1925 / 2006	46,900	4,600	9.8%	3.6
135	160	Francis	1951 / 1990	342,900	14,400	4.2%	28.1
152	400	Francis	1964 / 2007	436,400	9,600	2.2%	1
38	53.5	Propeller/Francis	1962 /1993	77,300	8,500	11%	13
31	54	Kaplan	1919 / 1990	85,900	24,740	28.8%	20.4
57.6	216	Francis	1949 / 1997	108,100	7565	7%	18
50	273	Francis	1945 / 2005	230,000	27,603	12%	19.2
64	403	Francis	1912 / 2006	365,900	23,417	6.4%	13.8
Total				**1,693,400**	**120,425**	7.1%	

- **Advances have been made in materials and hydro-mechanical designs that improve efficiency and performance of turbines, generators, and other hydropower components of hydropower systems since these aging plants and equipment were commissioned.**
- **There is significant opportunity to increase the capacity, generation and value of hydropower at existing U.S. hydropower facilities through the fleet modernization.**

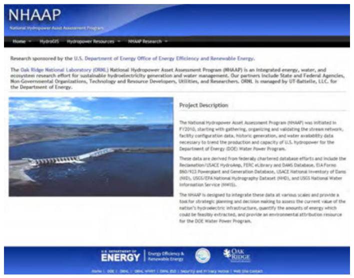
Water Use Optimization Toolset

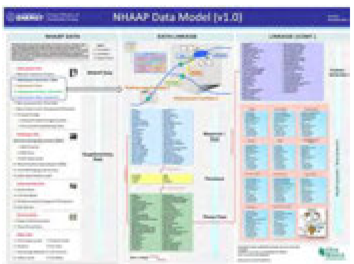
Objective: Develop and demonstrate an advanced analytical tool set that links water, power and environmental performance to facilitate optimization of hydropower planning and operations.

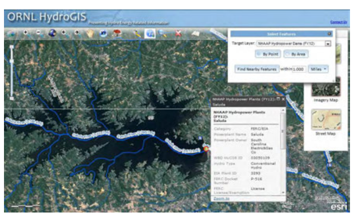


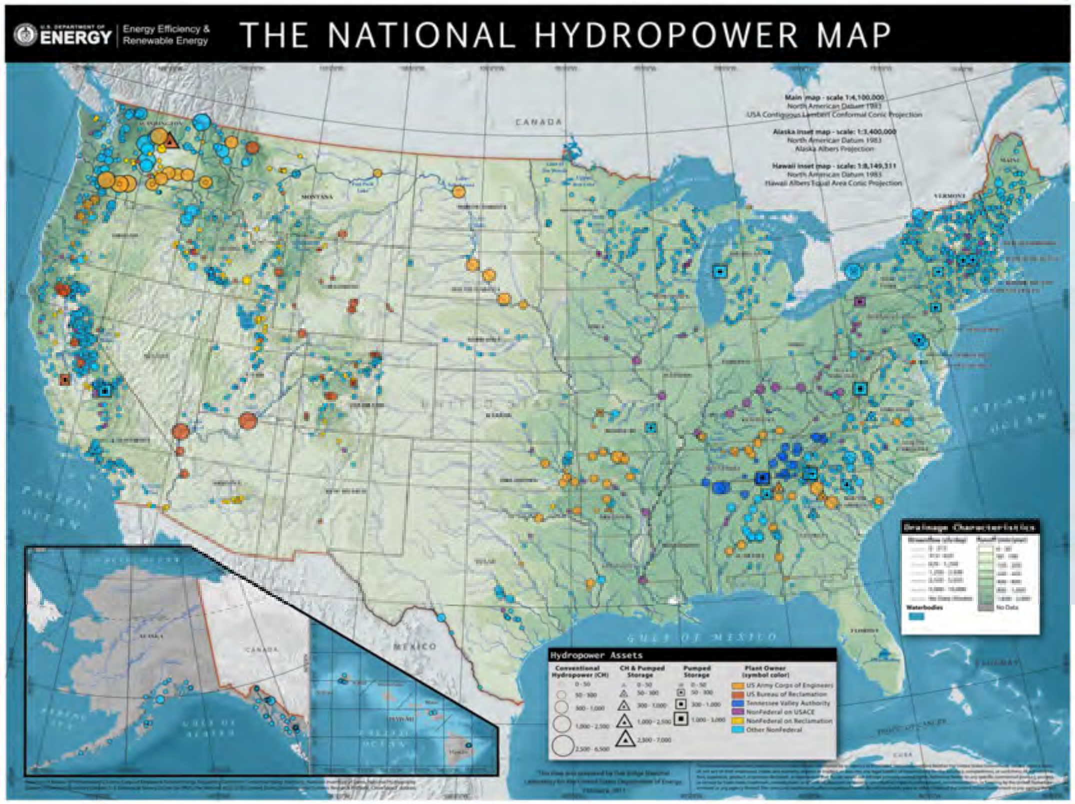
National Hydropower Asset Assessment Program

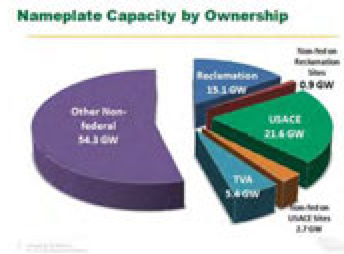
Objective: Provide tools for strategic planning and decision making to assess the current value of the nation's hydroelectric infrastructure, quantify amount of energy that can be feasibly extracted, and provide environmental attribution resource for the DOE Water Power Program

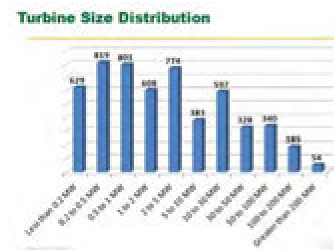


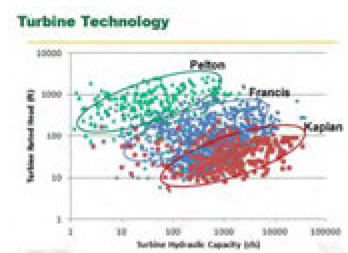












National Hydropower Asset Assessment Program (NHAAP)

– Existing Hydro Fleet Database and Analyses

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February 25th, 2014

Purpose & Objectives

Problem Statement

- A nationally comprehensive hydropower database was not available
  - scattered regulatory responsibilities and ownership among various agencies (FERC, USACE, Reclamation, and TVA)
- No standard format for hydropower-related data
  - challenge to integrate various types of existing data
- A complete and integrated US hydropower database is required to support various R&D efforts

Purpose & Objectives

The main objectives of National Hydropower Asset Assessment Program (NHAAP) are to:

- provide an up-to-date US hydropower database that includes information of existing hydropower facilities, infrastructures, future resources, hydrography, water availability, and environmental attributes
- perform update and expansion of the NHAAP data content to ensure the accuracy and timeliness of the US hydropower statistics
- provide publicly-accessible hydropower data through NHAAP Public Portal to promote the hydropower market acceleration and deployment.

Purpose & Objectives

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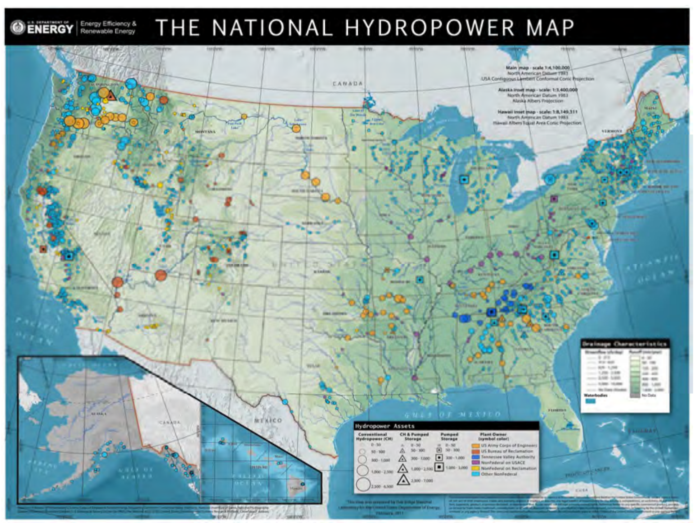
This project aligns with the following DOE Program objectives and priorities

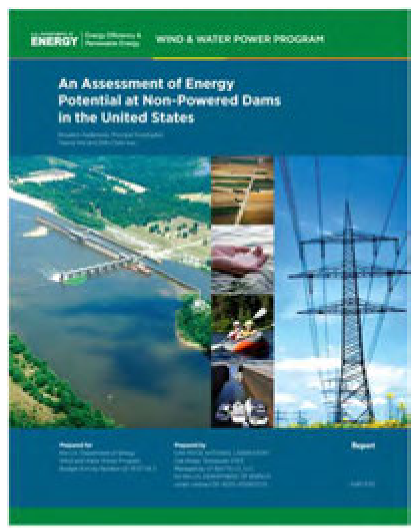
- *Advance new hydropower systems and/or components for demonstration or deployment*
  - NHAAP provides various types of hydropower data (e.g., existing fleet information and future development potential) for different research needs
  - NHAAP provides market analysis for the applicability of new technologies across the U.S. fleet.

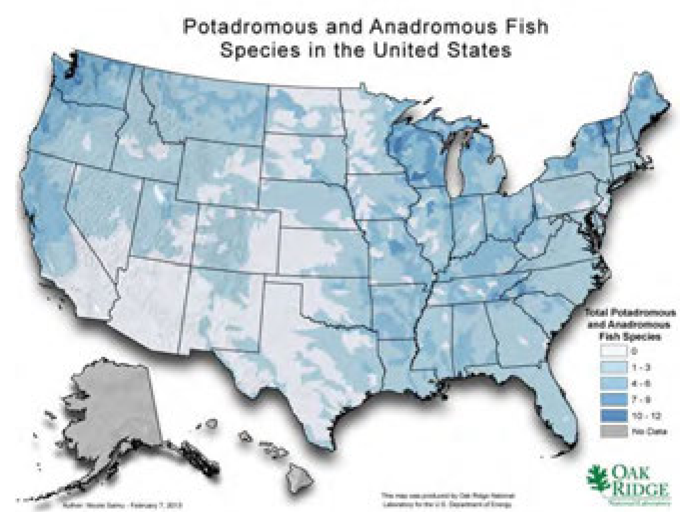
- *Reduce deployment barriers and environmental impacts of hydropower*
  - NHAAP captures both hydropower and environmental related information (e.g., endangered fish species and water usage) for joint assessment

Three main components in NHAAP

- Existing Fleet Database
- Hydropower Resource Potential
- Environmental Attributes







The **NHAAP Existing Fleet Data** integrates and constantly updates hydropower information from credible sources

Public Available Data Sets

- EIA Form 860 (1990-2011)
- EIA Form 906/920/923 (1970-2011)
- USACE National Inventory of Dams
- FERC Licenses and Exemptions
- National Hydrography Dataset Plus
- Other national geo-spatial data

Proprietary Information

- Non-public databases (e.g., FERC DAMS and BPA HydroAMP)
- Hydropower information provided by projects owners (e.g., Reclamation, TVA)
- Other data acquired through NDAs

Quarterly Data Update/Expansion

- Cross-referencing projects across various data sets
- Dynamical data update
- Quality assurance and quality control

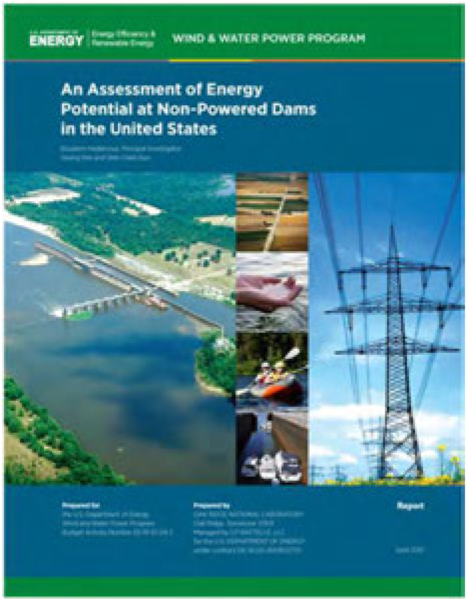
Integrated NHAAP Hydropower Information

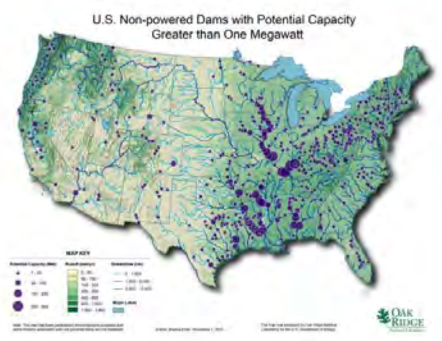
Dam / Reservoir Layer	Power Plant Layer	Generator / Turbine Layer	Historic Generation

- For each data entry, the data source and sensitivity are marked.
- Most of the information are displayed and shared through http://nhaap.ornl.gov/
- Facility and unit-level hydropower configuration/performance data treated as privileged or confidential commercial information.

DOE **Hydropower Resource Potential** findings and supporting data layers are housed within NHAAP

- FY10-11 Non-powered dam (NPD) resource assessment
- FY11 Pumped-storage assessment
- FY12-13 New stream-reach development (NSD) resource assessment
- The NHAAP team provides support and advice to the hydropower community that uses these results.





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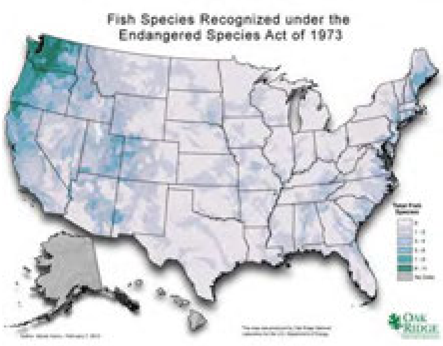
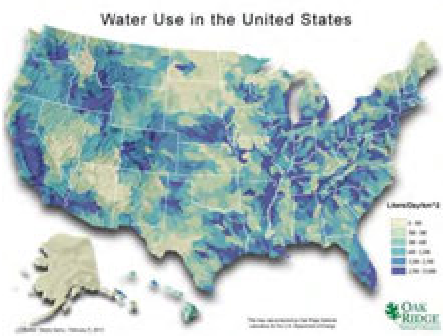
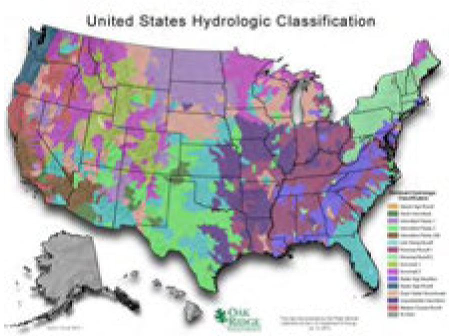
NHAAP labels **Environmental Attributes** to existing and potential sites to support analyses of potential environmental concerns

- Environmental issues are defined as any ecological, geopolitical, socio-economic, or landscape development concerns arising with regard to hydropower construction or operation.
- Geospatial environmental data layers are obtained from multiple sources. Datasets are either provided "as-is" or summarized into new derived forms to characterize potential environmental concerns.

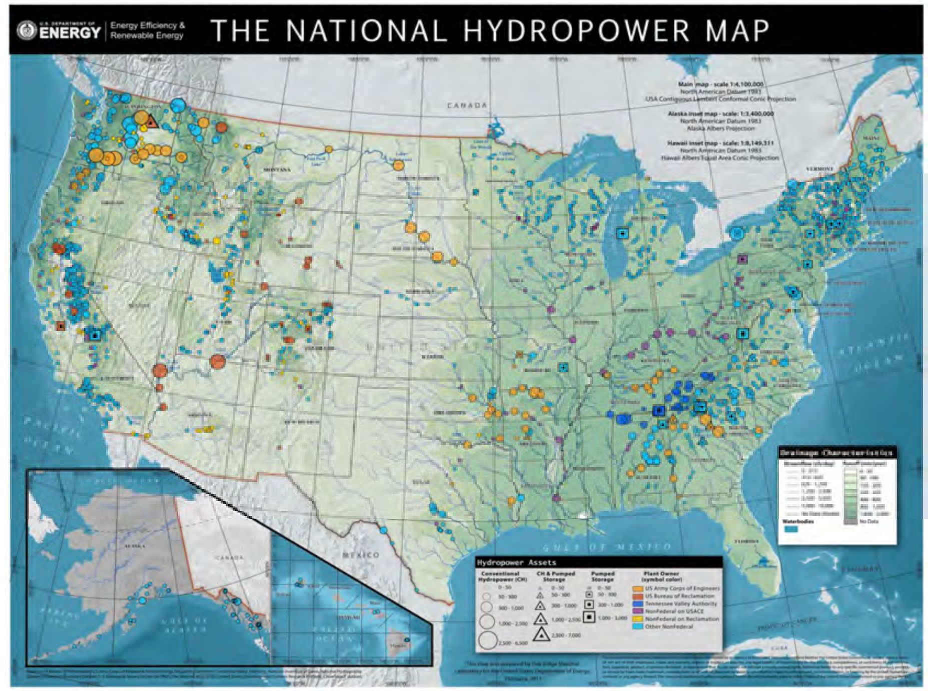


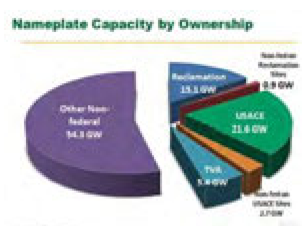


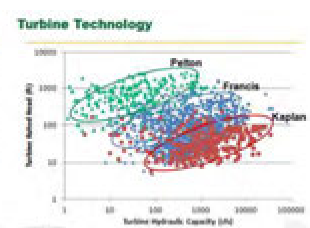


A comprehensive US hydropower database for DOE Water Power Program

- Extensive time was devoted for project-by-project data integration and quality control.
- Constantly updated with the latest hydropower developments
- Provides maps, summary tables, and visualizations to support various program activities.



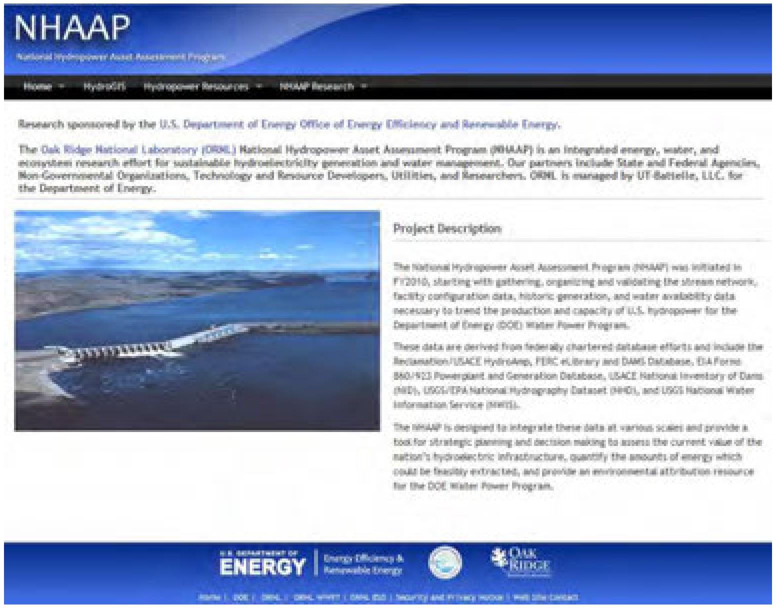


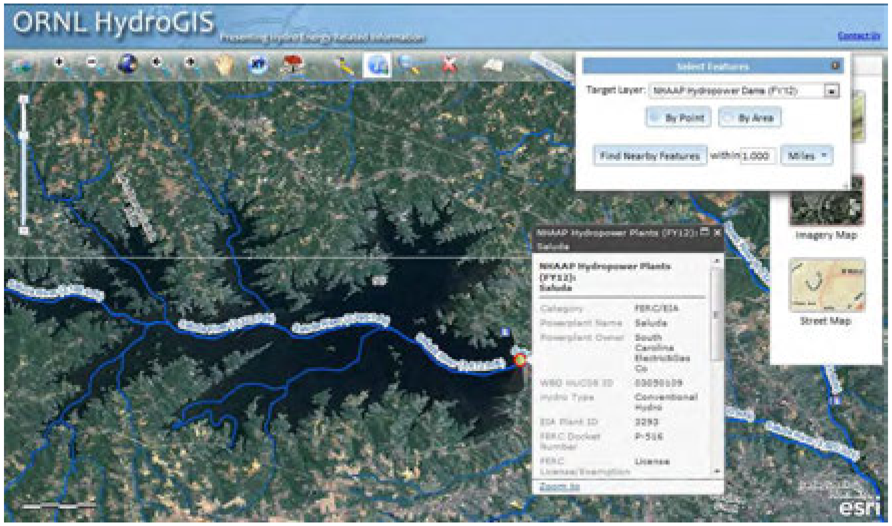


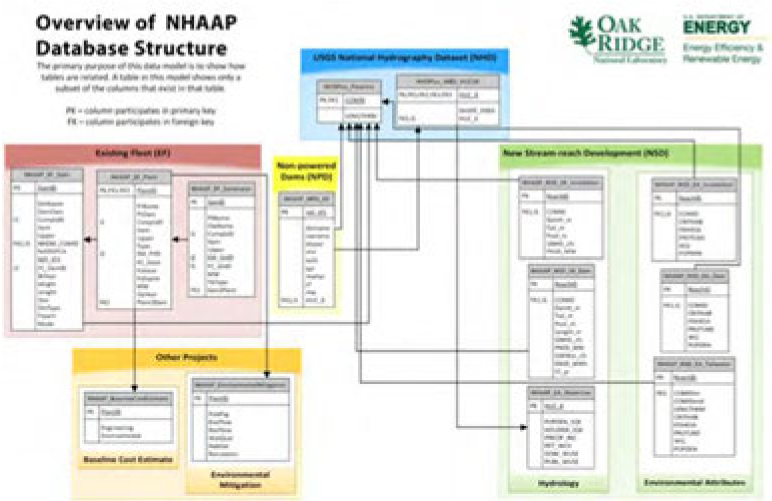
Accomplishments and Progress

All publicly accessible data are shared through NHAAP Public Portal (http://nhaap.ornl.gov/).

- NHAAP Team provides supports for further data inquires.
- Users may register for web-based HydroGIS system to view most of the geo-spatial layers.







Project Plan & Schedule

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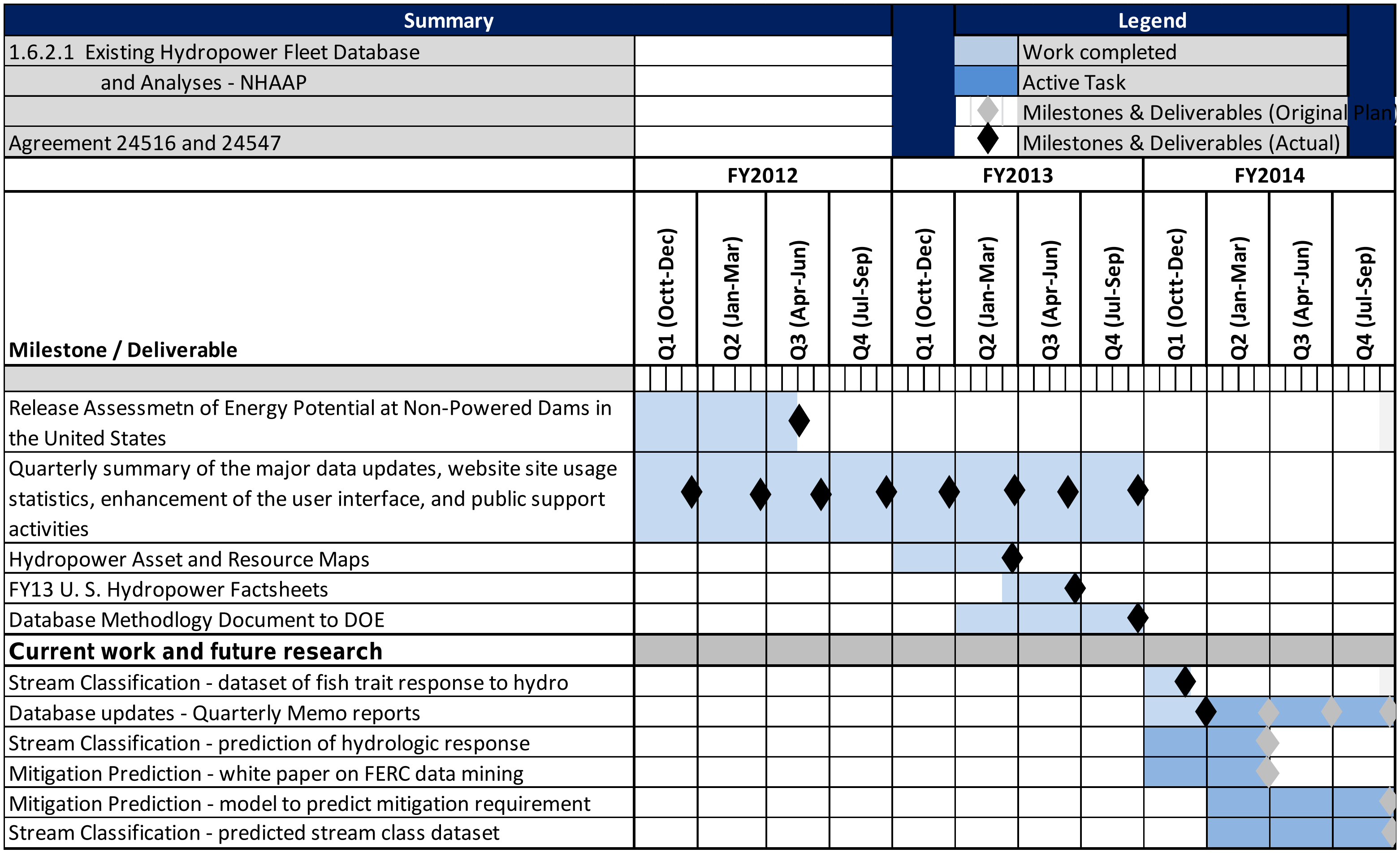

Comments

- NHAAP was initiated in FY2010.
- The baseline supporting activities were quarterly summarized and reported to HQ.
- Other specific tool development projects were tracked by separate milestones and deliverables.

Project Budget

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Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$650K	$0	$300K	$0	$600K	$0

- NHAAP activities began in FY2010.
- ~$400K per year has supported annual baseline activities including (1) coordination and outreach, (2) data updates and expansions, and (3) IT operation and maintenance.
- Specific analysis projects were initiated in FY2013 to enhance NHAAP capabilities:
  - Stream Classification Tool
  - Predictive Mitigation Model

Research Integration & Collaboration

- Collaborating agencies
  - Federal Energy Regulatory Commission (FERC)
  - US Bureau of Reclamation (Reclamation)
  - US Army Corps of Engineers (USACE)
  - Tennessee Valley Authority (TVA)
- Summary of major data support during FY12-13
  - Energy Information Administration (EIA)
    - Location of existing fleet
  - US Army Corps of Engineers (USACE)
    - Existing fleet information for Hydropower and Dams World Atlas
  - US Bureau of Reclamation (Reclamation)
    - Provide information on national non-powered dam resources
  - National Hydropower Association (NHA)
    - Provide existing fleet information for supply chain analysis
  - National Renewable Energy Laboratory (NREL)
    - Existing fleet and resource information for ReEDS parameterization

Next Steps and Future Research

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- In FY2014, the ORNL NHAAP team will focus on:
  - Data coordination and outreach activities
  - Data update and expansion activities
  - IT operation and maintenance
  - Development of stream classification tool
  - Development of predictive mitigation model
- The NHAAP data are used to support multiple on-going or completed Wind and Water Power Program research projects:
  - Wind and water power strategic planning
  - Cost Data Collection and Modeling for Hydropower
  - Annual Hydropower Market and Trends report
  - Basin Scale Opportunity Assessment
  - Hydropower Advancement Project
  - Quantification of Reliability and Cost Impacts for Hydropower Assets
  - Biological Design Criteria for New Hydropower Turbines

Summary

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- A comprehensive US hydropower database has been created for DOE Water Power Program to support various R&D efforts.
- A dynamical data integration framework has been created for constant database update and expansion.
- The NHAAP Team will continue to focus on collaboration and research integration to promote the US hydropower market acceleration and deployment.

BACKUP SLIDES

Summary of NHAAP Products

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Hydropower Resource Category/Project Name	NHAAP Data Layer	Shapefile Geometry	Geospatial Coverage
Existing Fleet (EF)	EF_Dam	Point	Existing main hydropower dams for the United States.
	EF_Plant	Point	Existing hydropower plants for the United States.
	EF_Generator	Point	Existing hydropower generators and attributes for the United States.
New Stream-reach Development (NSD)	NSD_SR_Dam	Point	Estimated potential locations for new hydropower development within stream-reaches.
	NSD_SR_Inundation	Polygon	Inundated areas where estimated potential locations for new hydropower development within stream-reaches exist.
	NSD_EA_Dam	Point	Environmental concerns summarized per NSD_SR_Dam location.
	NSD_EA_Inundation	Polygon	Environmental concerns summarized per inundated area where estimated potential for new hydropower development exists.
	NSD_EA_Tailwater	Line	Environmental concerns summarized per tailwater reach where estimated potential for new hydropower development exists.
Non-powered Dam	NPD	Point	Non-powered dams in the United States.
Pumped Storage	PS	Point	Pumped storage facilities in the United States.
Environmental Attribution(EA)	EA_FishTraits	Polygon	Fish trait distribution in the United States (by sub-basin).
	EA_ListedFishSpecies	Polygon	Federally listed fish species of concern in the United States (by sub-basin).
	EA_WaterUse	Polygon	Water use in the United States (by sub-basin).
	EA_HydrologicClass	Polygon	Hydrologic classes in the United States (by sub-basin).
	EA_ProtectedLands	Polygon	Protected areas of the United States (by sub-basin).

9505 Water Use Analysis

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February 25th, 2014

Purpose & Objectives

Problem Statement

- How may climate change affect US hydropower generation?
  - Need methods beyond statistical extrapolation.
  - Need to translate scientific understanding into engineering feasible solution.

- Section 9505 of the SECURE Water Act require DOE to report to Congress on climate change effects at federal hydropower facilities
  - Report should be submitted every 5 years until 2023.
  - The 2nd report is due March 2016.

SECURE Water Act 9505 Assessment:

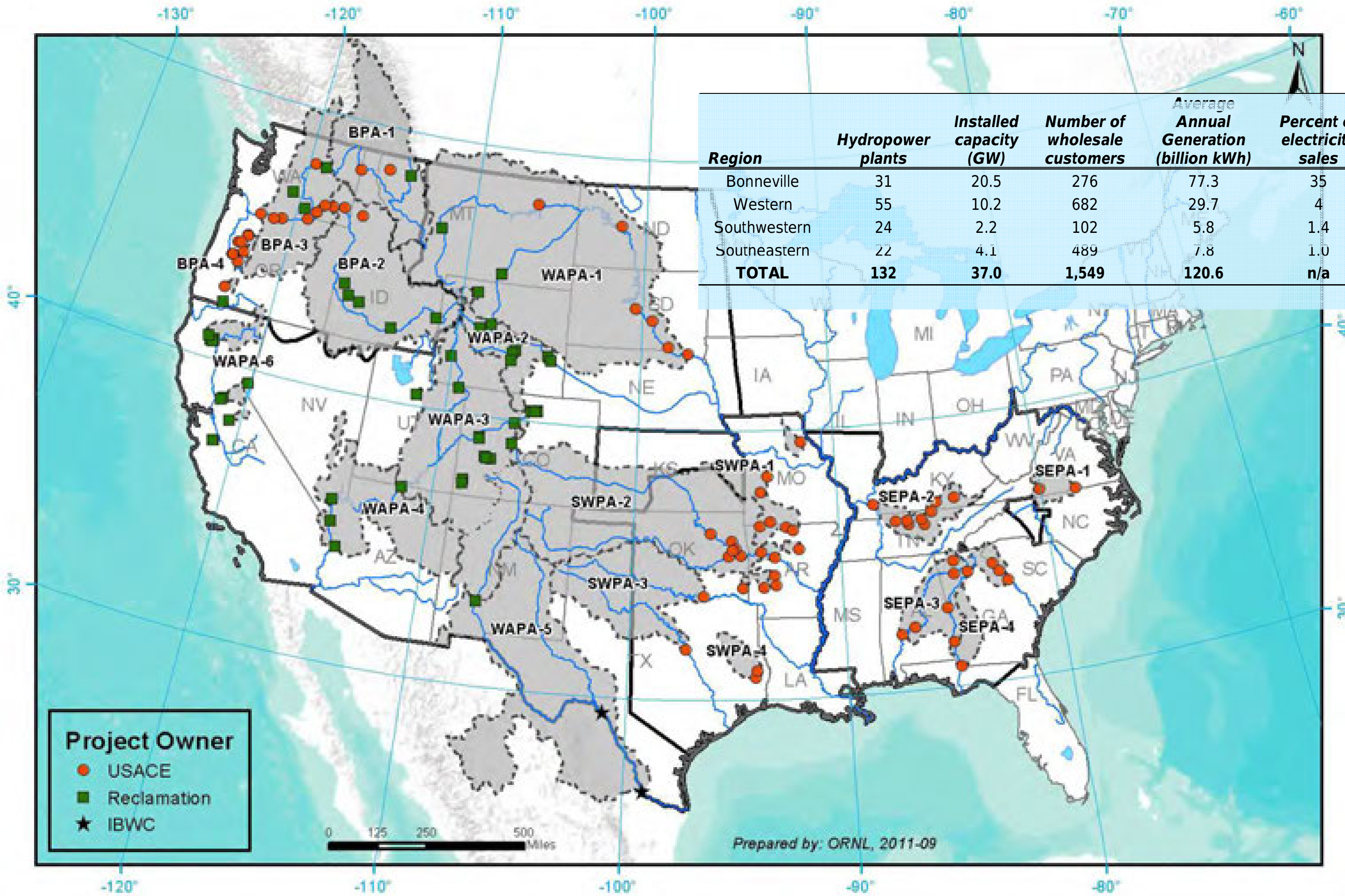
- Analyze the climate change effects on water supplies for hydropower and power sales from DOE Power Marketing Administrations (PMAs).
- DOE to lead, in consultation with PMAs, USGS, NOAA, and states, as well as USACE and Reclamation
- Include recommendations from PMA administrators
- The 9505 Assessment will enable better understanding of the future of the federal portion of the US hydropower portfolio; it will also build working relations with PMAs on hydropower issues.

Purpose & Objectives

This project aligns with the following DOE Program objectives and priorities

- *Optimize existing hydropower technology, flexibility, and/or operations*
  - The 9505 assessment analyzes water usage and operation of the US federal hydropower system (132 plants nationwide).
- *Reduce deployment barriers and environmental impacts of hydropower*
  - The 9505 assessment evaluates how climate change may affect hydropower generation.

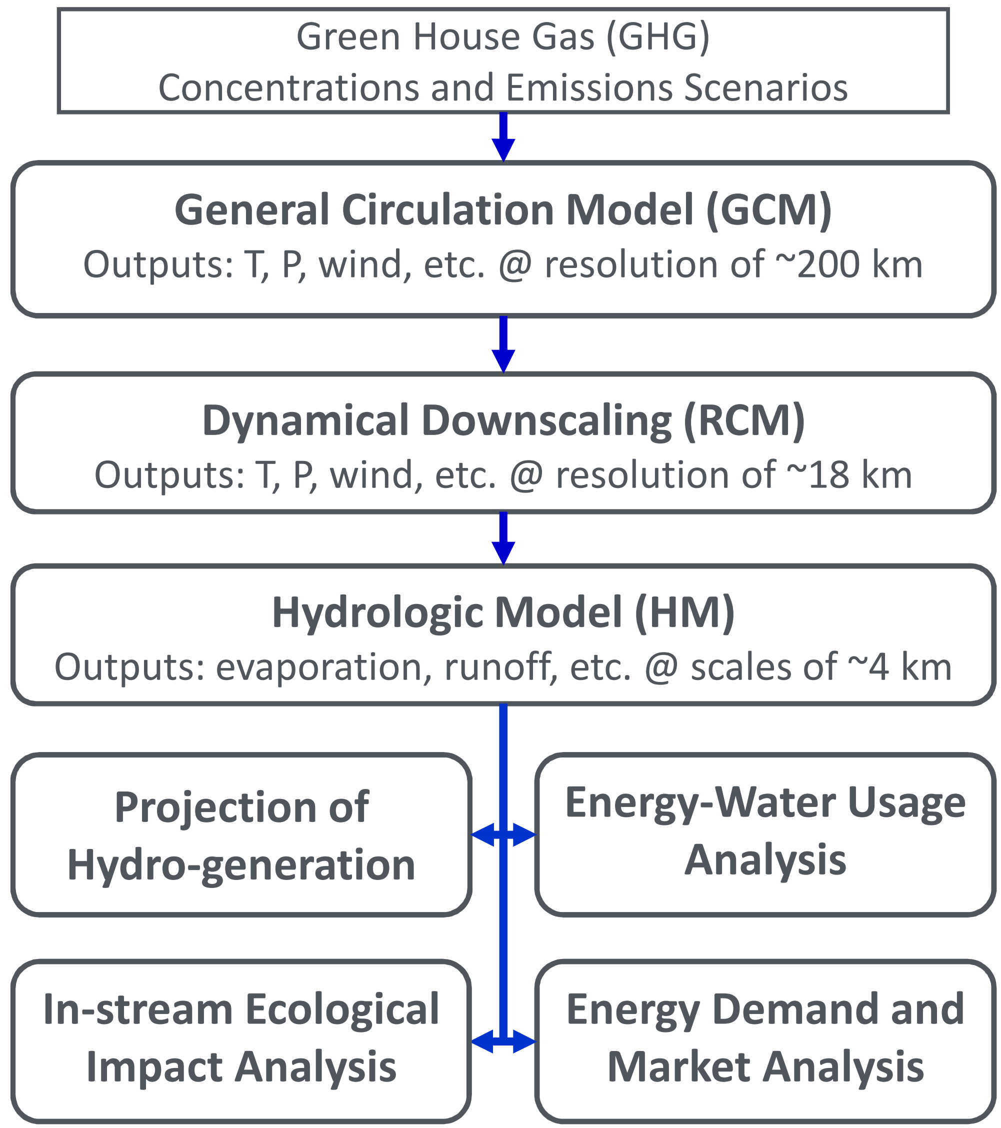
18 study areas in 4 PMA regions, defined by watershed boundary and power system



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**

Consistent approach for use in all parts of US

- Energy-water data from "best available" sources:
  - observed runoff from USGS WaterWatch Program
  - hydropower systems data from DOE/ORNL NHAAP database
  - generation data from EIA and PMAs
- A series of hydro-climate models is linked to project future hydro-meteorological conditions for:
  - projection of federal hydropower generation
  - analysis of future energy-water usage
  - in-stream ecological impact analysis
  - energy demand and market analysis



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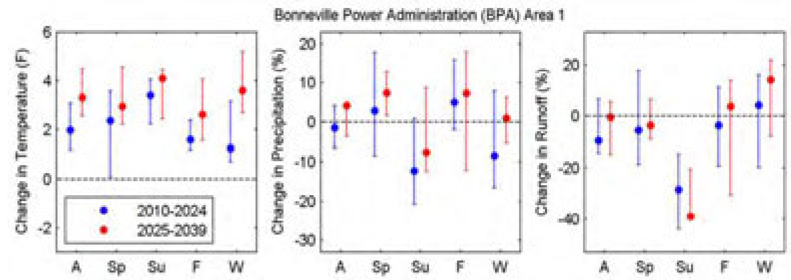
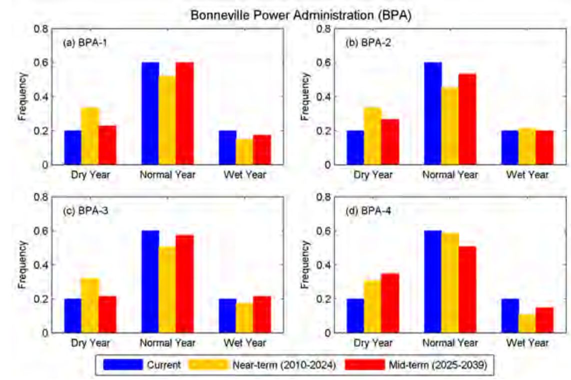
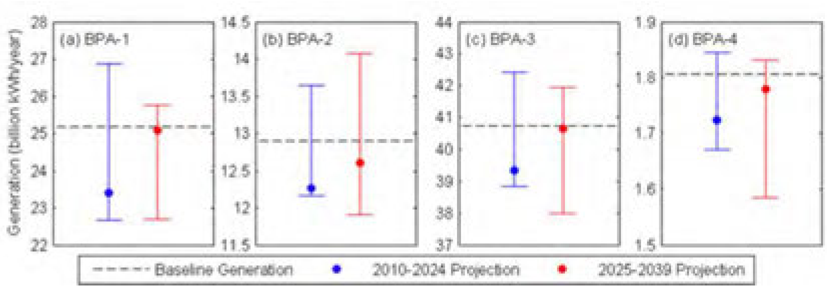
Projections of Climate and Power

- Results for near-term and mid-term periods, and for 18 areas, annual and seasonal basis
- Air temperature, precipitation, and runoff
- Frequency of water year types
- Intensity of critical low-flow periods
- Change in annual hydropower generation





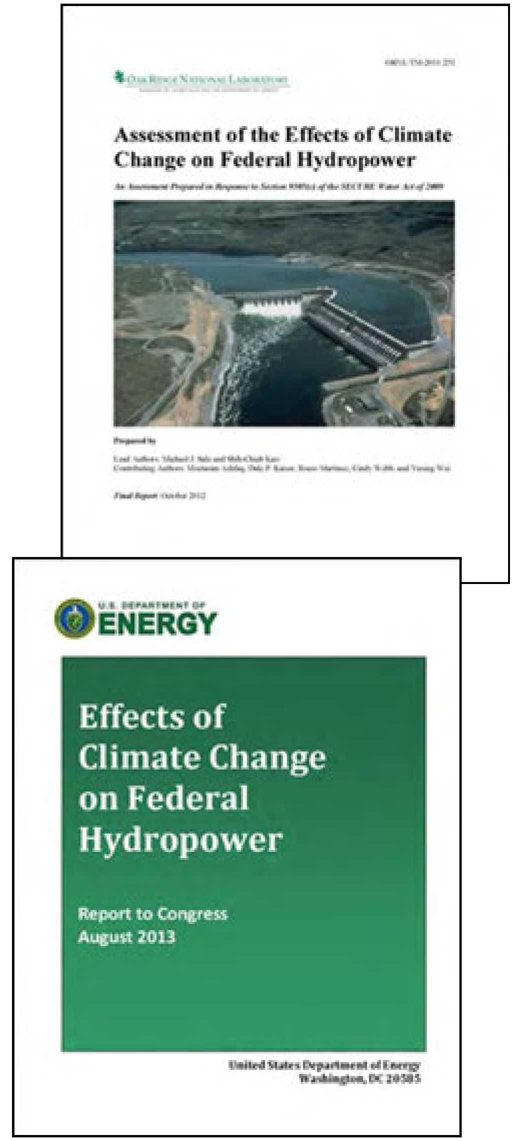


	10-year low runoff (inches/season), 1960-1999 baseline simulation			
	Spring (Mar–May)	Summer (Jun–Aug)	Fall (Sep–Nov)	Winter (Dec–Feb)
BPA-1	5.05	5.29	1.89	1.56
BPA-2	2.30	1.54	0.76	0.76
BPA-3	3.48	3.01	1.29	1.29
BPA-4	6.58	4.56	7.67	11.26
	10-year low runoff (inches/season), 2010-2024 future projection and percent change from baseline[a]			
	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 and percent change from baseline[a]			
	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%)

[a] The percentage indicates the relative change compared to baseline.

Two products for the 1st assessment

- ***9505 Assessment Report***
  - ORNL technical manual with details on assessment methods and results, publicly available at http://nhaap.ornl.gov/content/climate-change-impact-assessment
  - Peer-reviewed by a group of technical reviewers (>18), including water and power resource managers, climate scientists, academia, and federal/state water agency staffs
- ***9505 Report to Congress***
  - Short (~20 pages) summary of the assessment, including recommendations from Power Marketing Administration administrators
  - Concurrence reviewed by DOE, submitted to Congress on September 2013



Accomplishments and Progress

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Summary of major findings from the 1st assessment

- Changes can be expected in temperature (+) and water availability (+/-), especially in extreme water years and some seasons and regions
- Current PMA contracting mechanisms are sufficient to deal with expected climate variability
- Water management and investments in new equipment should focus on maintaining operational flexibility to preserve current generation
- Continued monitoring of climate data and scientific advancements is needed to determine when and if current practices need to be changed
- Policy analyses should be conducted to integrate multiple water uses with climate variability to prepare for future adaptations
- Continual learning and adaptive management should be practiced

Project Plan & Schedule

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

Summary		Legend
1.6.2.4 9505 Water Use Analysis		Work completed
		Active Task
		Milestones & Deliverables (Original Plan)
Agreement 21967 and 26523		Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Milestone / Deliverable	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Produce Regional factsheets												
Submit final 9505 assessment report to HQ												
Project Management Plan for 9505-2												
Current work and future research												
Identify Climate Model Projections to be utilized												
Develop Suitable Assessment EndPoints												
Refine Assessment Methods												
Methodology Report defining approach												

Comments

- The 1st 9505 assessment was initiated in FY2011 and completed in early FY2012.
- The 2nd 9505 assessment was initiated in late FY2013 and will be completed by early FY2016.
- The ORNL Team will work closely with HQ to ensure that the assessment can be completed on time for DOE concurrence review.

Project Budget

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Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0	$0	$1,000K	$0	$0	$0

- The second 9505 assessment budget for FY2013-2015 is estimated to be around $1,600K.
- 11% of the FY2013 funding ($1,000K) has been expended.

Research Integration & Collaboration

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- Partners and subcontractor
  - DOE Power Marketing Administrations (Bonneville Power Administration, Western Power Administration, Southwestern Power Administration, and Southeastern Power Administration)
  - Dr. Michael Sale (BCS Incorporated)
- Other collaborating agencies
  - US Bureau of Reclamation (Reclamation), US Army Corps of Engineers (USACE), US Geological Survey (USGS), National Oceanographic and Atmospheric Administration (NOAA), and Environmental Protection Administration (EPA)
- Communications and technology transfer
  - Conference presentations at HydroVision, American Geophysical Union (AGU), and American Society of Civil Engineers (ASCE) Environmental and Water Resources Institute (EWRI) meetings
  - Agency and organization briefing at Federal Energy Regulatory Commission (FERC), Climate Change Collaboration (C3) Group in the Pacific Northwest, Federal Caucus in the Pacific Northwest, National Hydropower Association (NHA), and Federal Climate Change and Water Working Group (CCAWWG)

Next Steps and Future Research

- Data collection, monitoring, data management and analysis
  - Develop new methods and data to resolve seasonal generation patterns, effects of water storage and use, etc.
  - Develop indicators of "stress events" for power marketing systems
- Better modeling of water power systems
  - Provide more complete water balances within regions/river basins to account for interactions with multiple-use water management
  - Evaluate the risks from extreme events and link to predictive climate variables
- Communication between hydropower industry and climate science communities
  - Work to ensure science products are relevant to end users
  - Participate in Federal Climate Change and Water Working Group
- Develop additional assessment end points that are relevant to PMAs, Corps, and Reclamation asset management decision-makers

Next Steps and Future Research

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

- Address indirect effects, including:
  - Water temperature and water quality
  - Evaporative losses and GHG emissions
  - Flow requirements for fish passage and habitat protection of fish and wildlife
  - Climate-induced changes in electricity demand and alternative supplies (wind)
- Consider case studies linked to on-going/previous studies – explain what improvements we can make with new analysis
  - Connection to DOE's Water use optimization research?
  - How can the second 9505 assessment add value to local (past/on-going) operational studies/planning processes?
- Develop screening criteria and ranking methods to identify areas where the next assessment will provide greatest benefits

Summary

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- An assessment framework has been established to evaluate the potential climate change impacts on US hydropower generation.
- The 1st 9505 report has been submitted to Congress on September 2013. The 2nd 9505 report is due March 2016.
- Intensive collaboration among PMAs, USACE, Reclamation, NOAA, USGS, and other agencies will be key to the 2nd 9505 assessment.

BACKUP SLIDES

SECURE Water Act of 2009
Section 9505. 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.

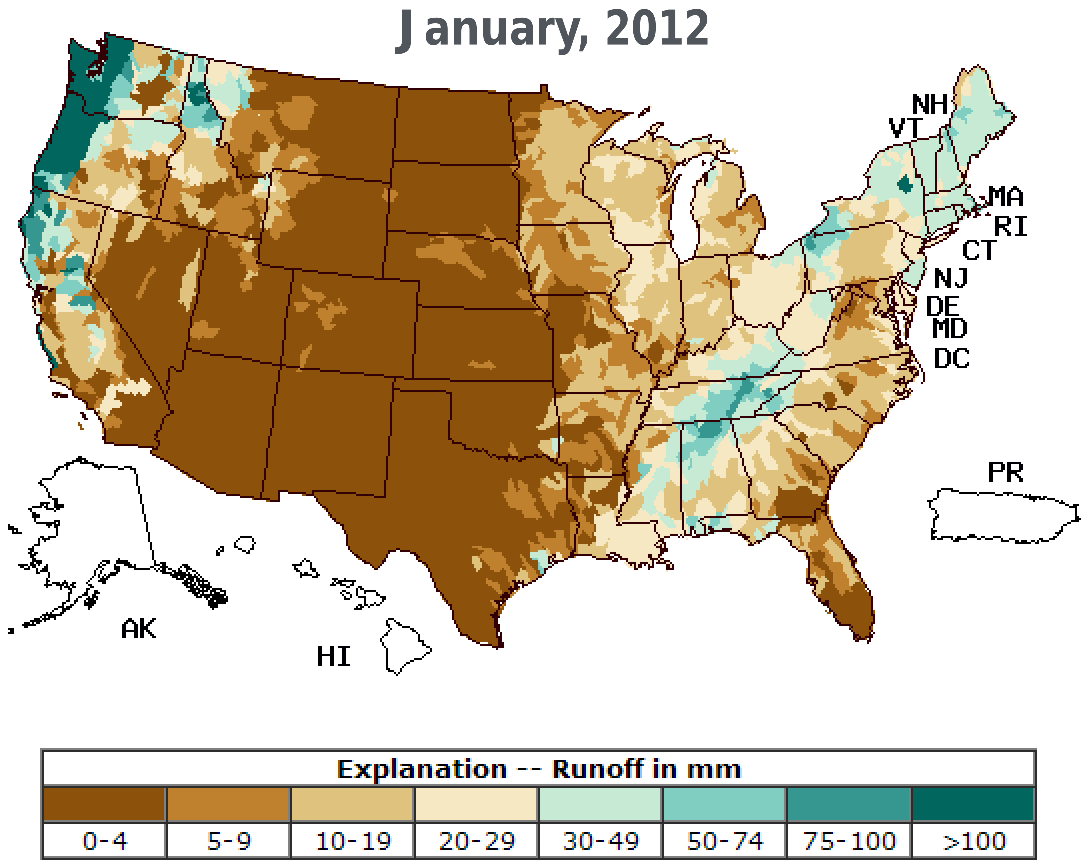
(c) Report- Not later than 2 years after the date of enactment of this Act, and every 5 years thereafter, the Secretary of Energy shall submit to the appropriate committees of Congress a report that describes--
(1) each effect of, and risk resulting from, global climate change with respect to--
(A) water 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.

A wide range of data types and sources where integrated

Subject	Data Source	Reference
Hydropower Project Characteristics	• National Hydropower Asset Assessment Project (NHAAP), ORNL • Form 860 Database, EIA • National Inventory of Dams (NID), USACE • Hydropower Asset Management Partnership (HydroAMP), Reclamation/Hydro-Québec/ USACE/Bonneville	Hadjerioua et al., 2011
Hydropower Generation	• From 906, 920, and 923 Database, EIA • Bureau of Reclamation (Reclamation) • U.S. Army Corps of Engineers (USACE) • DOE Power Marketing Administrations (PMAs)	
Observed Runoff and Streamflow	• WaterWatch Program, USGS • HYDAT Database, Environment Canada	Brakebill et al., 2011
Observed Temperature and Precipitation	• PRISM Research Group, Oregon State University • University of Delaware Air Temperature & Precipitation	Daly et al., 2002; Willmott and Matsuura, 1995
Watershed Boundary	• Watershed Boundary Dataset (WBD), NRCS • National Hydrography Dataset (NHD), USGS/EPA	USGS and USDA-NRCS (2009)
Topography	• Global 30 Arc Second Elevation Data (GTOPO30), USGS	
Land Cover	• Moderate Resolution Imaging Spectroradiometer (MODIS), NASA	
General Circulation Model (GCM)	• Community Climate System Model version 3 (CCSM3)	Collins et al., 2006
Regional Climate Model (RCM)	• Abdues Salam Institute for Theoretical Physics Regional Climate Model version 3 (RegCM3)	Pal et al., 2007
Hydrologic Model	• Variability Infiltration Capacity (VIC) model	Maurer et al., 2002
CMIP3 Projected Monthly Temperature and Precipitation (used in SWA9503)	• Bias Corrected and Spatial Downscaled (BCSD) dataset, Reclamation/Santa Clara University/LLNL, http://gdo-dcp.ucllnl.org/downscaled_cmip3_ projections/	Maurer et al, 2007

USGS WaterWatch Runoff

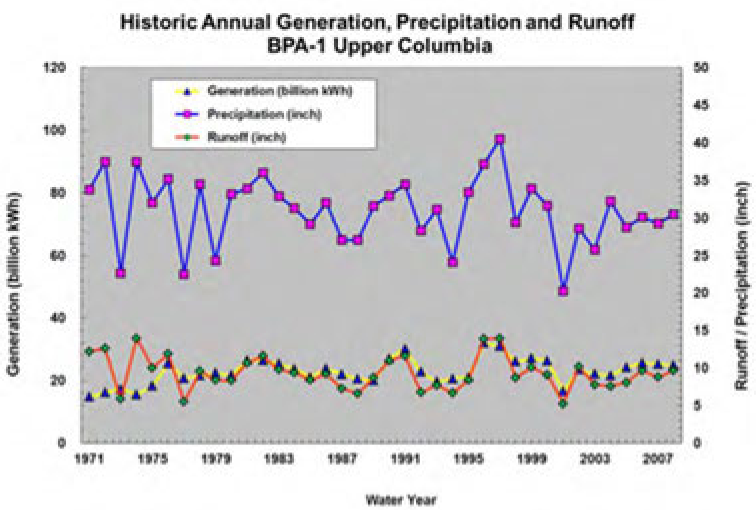
- A monthly time-series of flow per unit area, assimilated from > 6,000 USGS NWIS gauge observations.
- In the same unit with precipitation
- Available for each HUC8 subregions
- Available from 1901 till present
- A good estimate of local runoff

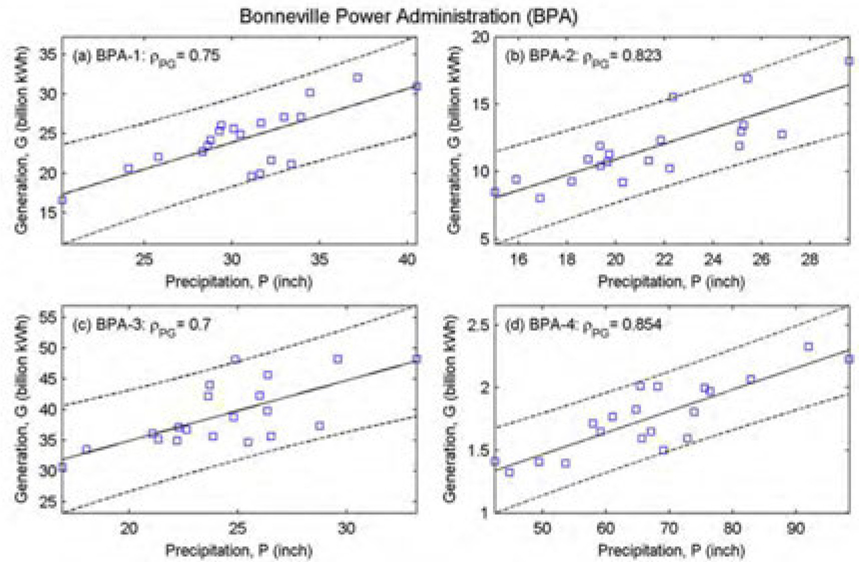


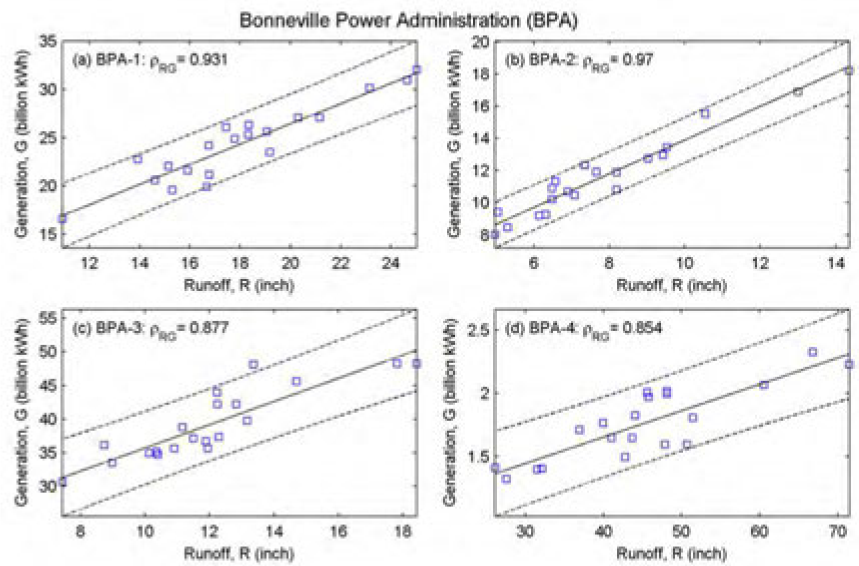
Hydrologic Sensitivity

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

- Hydropower generation is highly variable year-to-year
- Annual runoff is a good predictor of annual generation
- In some areas, multi-year runoff is a better predictor of generation
- Will be extended to monthly runoff-generation relationship in the 2nd assessment







Accomplishments of the 1st assessment

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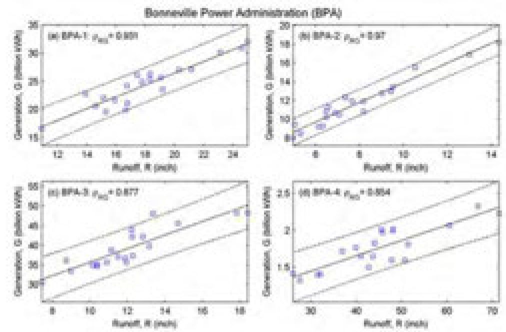
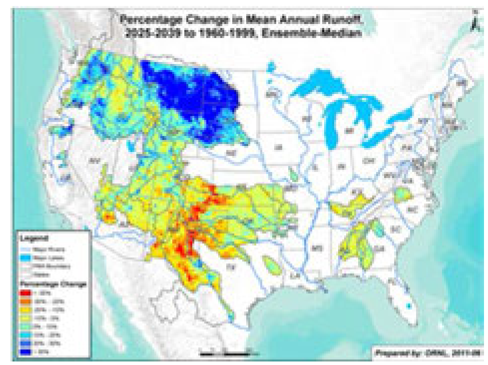
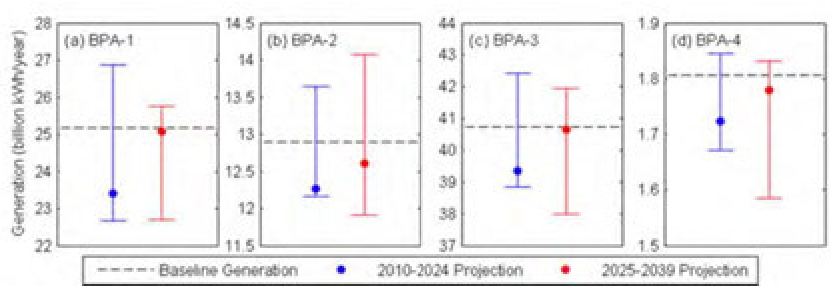
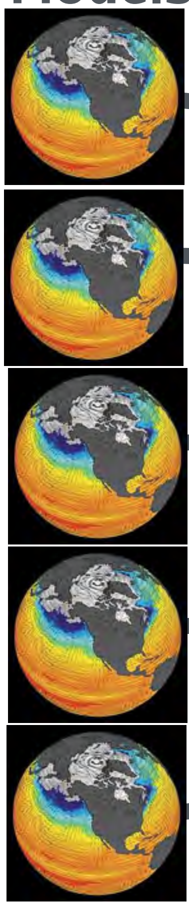
- Assembled a comprehensive database describing federal projects, power outputs, and climate variables
- Quantified for the first time the sensitivity of federal hydropower generation to water availability (runoff from upstream watersheds) on a nationwide basis
- Assembled state-of-the-art models to project hydropower-relevant climate variables into the future
- Estimated future climate change impacts to federal hydropower and completed an rigorous technical review to ensure the quality and defensibility of the assessment



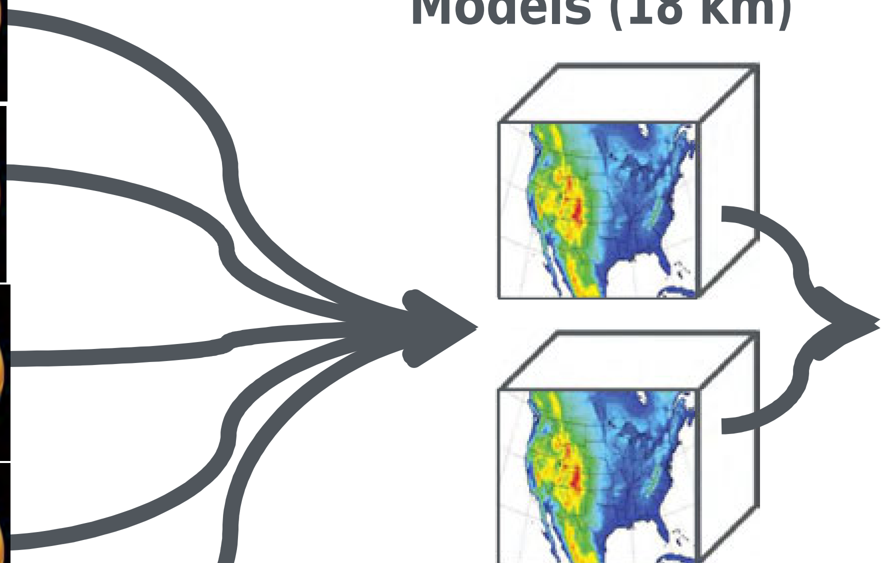




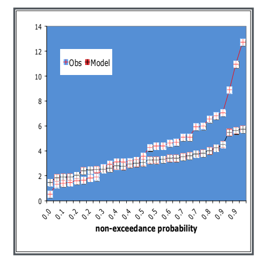
Global Climate Models



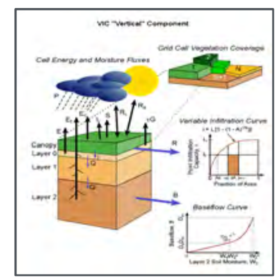
Regional Climate Models (18 km)



Statistical Correction



Hydrological Model (4 km)



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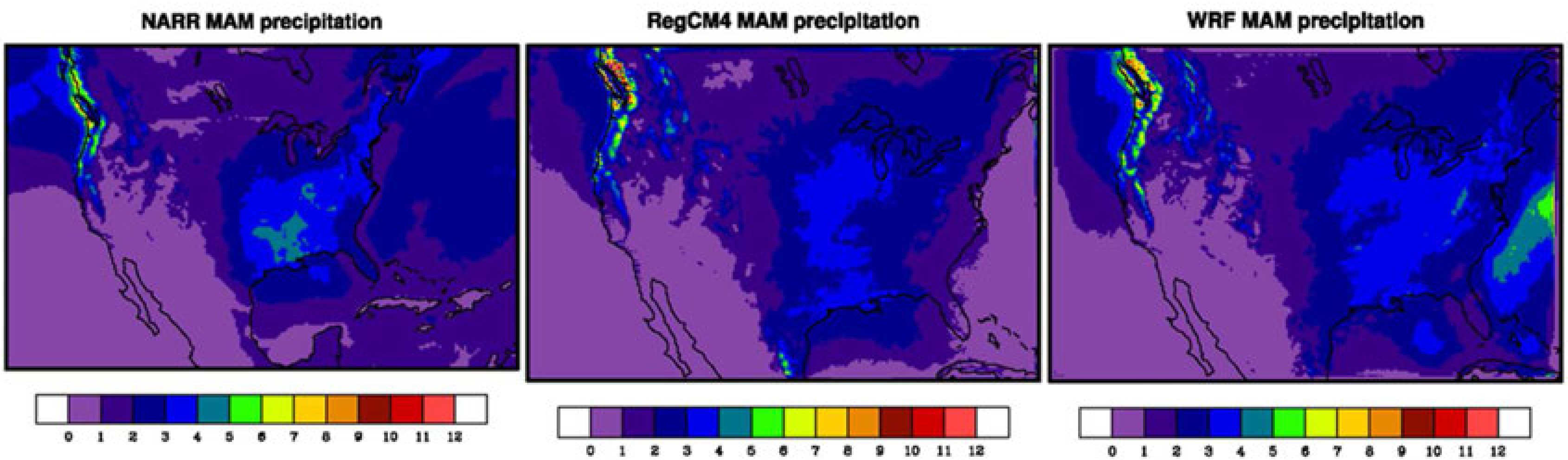
- **RegCM**
  - 7 GCMs completed: CCSM4, GFDL-ESM2M, NorESM1-M, FGOALS-g2, bcc-csm1-1, MIROC5, CanESM2
  - 6 GCMs in preparation: MPI-ESM-MR, IPSL-CM5A-LR, CMCC-CM, CSIRO-Mk3.6.0, CNRM-CM5, MRI-CGCM3
- **WRF**
  - 3 GCMs completed: GFDL-ESM2M, NorESM1-M, CCSM4
  - 3 GCMs in preparation: MPI-ESM-MR, MIROC5, CMCC-CM



Variable Infiltration Capacity (VIC) Model

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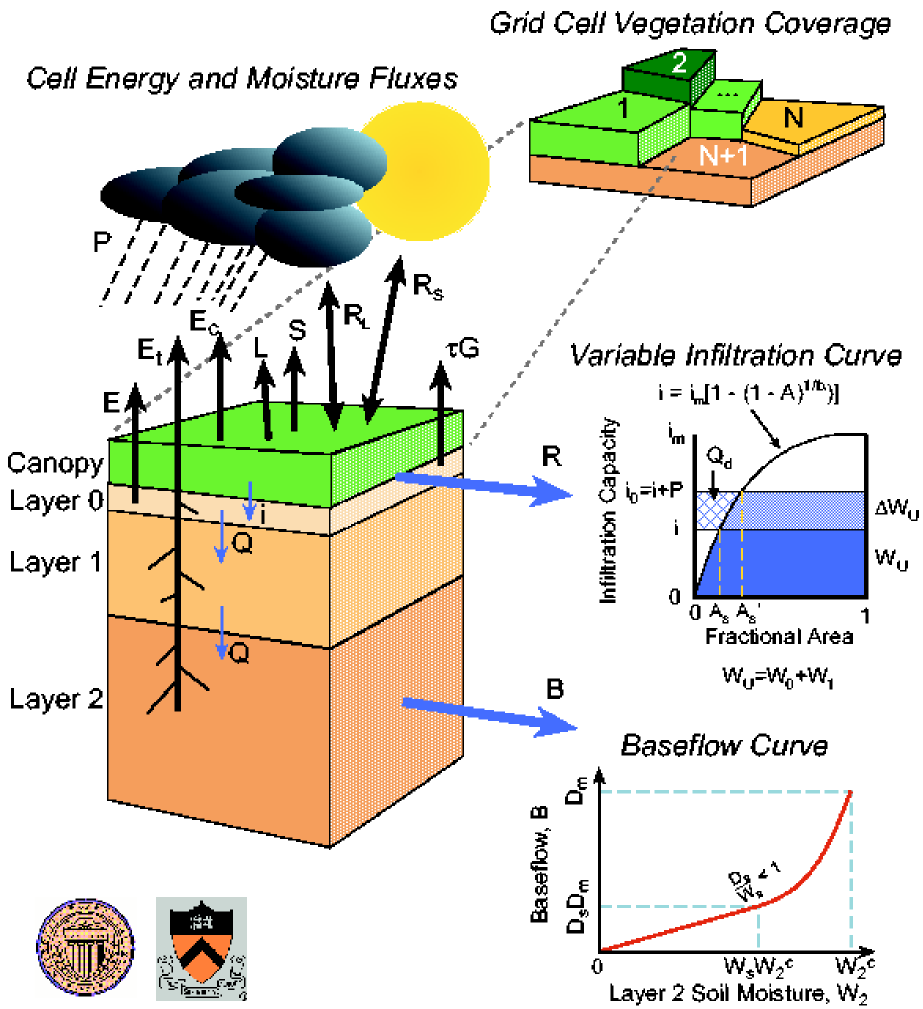
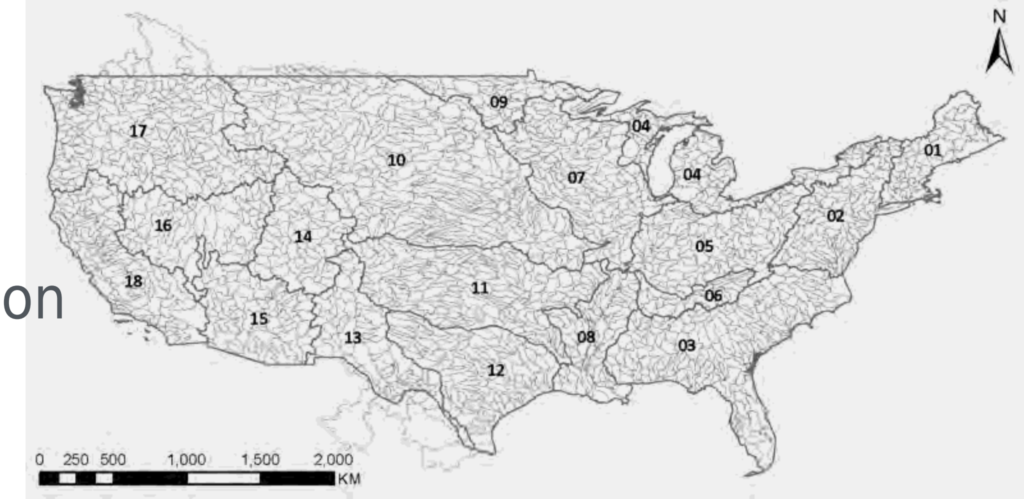


UNIVERSITY OF WASHINGTON

- Semi-distributed hydrologic model driven by a set of surface meteorological data
- Represents vegetation, has three soil layers with variable infiltration, non linear base flow
- Simulated hydrology at each grid cell for all time steps
- Widely applied in a number of large river basins over the continental US and the globe.

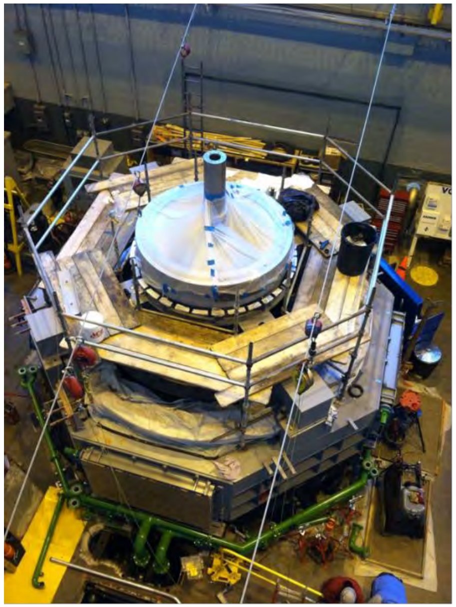
- **Organize various key hydrologic model inputs at 1/24 degree (~4 km) grid for the conterminous US**
  - Topography
  - Soil characteristics
  - Vegetation
  - Land surface classification
  - Meteorological forcing
  - Runoff observation



- **Perform model calibration using high performance computing for 2017 US HUC8 subbasins**
- **Provide an improved foundation for the 9505-2 assessment**

Oubeidillah, A. A., S.-C. Kao, M. Ashfaq, B. S. Naz, and G. Tootle (2014), A Large-Scale, High-Resolution Hydrological Model Parameter Data Set for Climate Change Impact Assessment for the Conterminous US, *Hydrology and Earth System Sciences*, *18*, 67–84, doi:10.5194/hess-18-67-2014.

Recovery Act: Hydroelectric Facility Modernization Project




Recovery Act: Hydroelectric Facility Modernization Funding Opportunity Announcement Number: DE FOA 0000120

Brian Hunter

U.S. Department of Energy, Wind and Water Power Technologies Office

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Feb. 25, 2014

Hydroelectric Facility Modernization Project

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

- The objective of the Hydroelectric Facility Modernization Funding Opportunity Announcement (FOA) was to develop, deploy, and test hydropower projects that would modernize the existing hydropower infrastructure in the U.S. and increase both the quantity and value of hydropower generation, including environmental performance.
- The program's focus was to support the deployment of turbines and control technologies to increase and maximize system generation at existing non-Federal hydroelectric facilities through cost-shared partnerships.

FOA Summary:

- FOA issued 6/30/2009 (closed 8/20/2009)
- Funding appropriated by the American Recovery and Reinvestment Act of 2009 (Pub. L. 111-5)
  - The Recovery Act's purposes were to stimulate the economy and to create and retain jobs.
- $32 million available for new awards under this announcement
- Two topic areas:
  - Deployment of Hydropower Upgrades at Projects >50 MW (up to $25M, 80% cost share required): 3 projects selected
  - Deployment of Hydropower Upgrades at Projects < 50 MW (up to $7M, 50% cost share required): 4 projects selected

FOA Recipients

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FOA Sub Topic	Project Recipient	Project Title	Recovery Act Funding	Non Federal Cost Share	Project Location
Upgrades at Large Projects (> 50MW) * 80% Non-Federal Cost Share Required	Alabama Power Company	Upgrades to Alabama Power Hydroelectric Developments	$6,000,000	$24,000,000	Alabama
	Alcoa, Inc.	Tapoco Project: Cheoah Upgrade	$12,174,956	$57,001,147	North Carolina
	City of Tacoma	North Fork Skokomish Powerhouse at Cushman No. 2 Dam	$4,671,304	$22,082,626	Washington
Upgrades at Small Projects (< 50MW) * 50% Non-Federal Cost Share Required	City of Boulder	Modernization of the Boulder Canyon Hydroelectric Project	$1,180,000	$4,682,858	Colorado
	City of North Little Rock	Replacement of Current Mechanical Seal System with Rope Packing System	$450,000	$536,245	Arkansas
	Los Alamos County	Installation of a Low-Flow Unit at the Abiquiu Hydroelectric Facility	$4,558,344	$4,675,763	New Mexico
	Minnesota Power	Fond du Lac Hydroelectric Facility Modernization	$815,995	$4,783,061	Minnesota
		Total:	**$29,850,599 (20.2%)**	**$117,761,700 (79.8%)**	

Recovery Act: Upgrades to Alabama Power Hydroelectric Developments – Alabama Power Company

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

Purpose & Objectives

- Upgrades to four units at three hydropower facilities (Lay Dam, Jordan Dam, and Bouldin Dam) located on the Coosa River System. The four-unit upgrades include the installation of high-efficiency turbines to increase the efficiency and reliability of the individual units and the Coosa River System as a whole.

Impact of the Project

- The Coosa upgrades will provide additional low-cost renewable energy generation to meet demand and are expected to increase annual generation by 7.3%.
- In addition, the new units will reduce fish injury and turbine mortality, while increasing reliability and reducing maintenance costs.

Technical Approach

- Vendor selection / Fabrication of New Turbine
- Vendor mobilization, Turbine Installation and Commissioning
- Performance Testing - verify power output, flow, and efficiency

Partners:

- Southern Company Services, Inc.
- Andritz Hydro Corporation
- Weir American Hydro Corporation

Accomplishments & Progress:

- Planned for completion in 2014, the upgrades are expected to increase annual generation by 7.3%, enough to power over 3,000 more homes.
- In addition, the modern turbine and generators will be more reliable and let fish pass with less chance for injury or damage to the turbine.
- Job creation: Estimate 156 quarterly jobs created (39 FTE)

Project Plan & Schedule:

1/1/2010 - 3/1/2014 (4.25 year Project Period)

Project Budget:

DOE Funding: $6,000,000 (20%)
Non-Federal Cost Share: $24,000,000 (80%)
Total Project Funding: $30,000,000

Location: Coosa, Chilton, and Elmore Counties in east central Alabama

Recovery Act: Tapoco Project: Cheoah Upgrade – Alcoa, Inc.

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

Purpose & Objectives

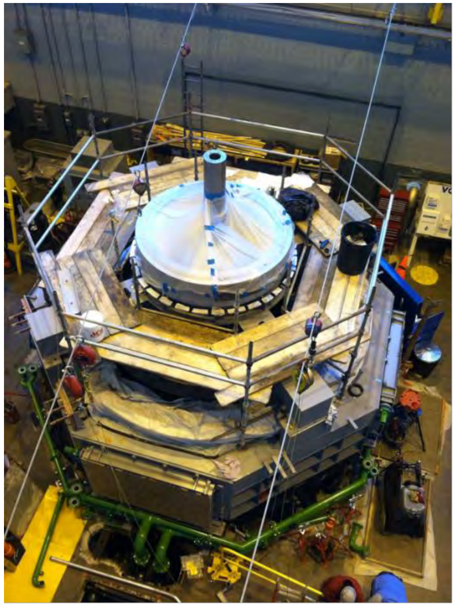
- Upgrades include installation of two new high-efficiency turbines, generators, and transformers, as well as improvements to the balance of plant equipment and preparation work for the installation of two additional units
- Replaced or rehabilitated equipment with an average age of 90 years (4-5 decades beyond typical unit life)
- The facility includes 5 Francis turbine units with a generation capacity of 110MW. Rehabilitation efforts increased plant capacity to an estimated 162 MW, a 40% increase.

Impact of the Project

- Rehabilitation of 1920's technology with new state-of-the-art stainless steel runners increased facility efficiency by 40% and extended usable life of equipment by another half century
- Increased generation capacity from 22MW to 33MW per turbine, 4 units in total.
- Four new high-efficiency turbines, generators, transformers, and balance of plant equipment will be rehabilitated

Technical Approach

- Completed detailed engineering documentation, mobilization, pre-outage construction, demolition, substation outage, turbine installation, and unit commissioning



Partners:

- Fluor Global Corp.
- Voith Hydro Inc.

Accomplishments & Progress:

- Completed installation and commissioning of 2 units under DOE period of performance
- Initial estimates predicted increased generation capacity from 22 to 27.5MW per turbine. Testing has shown actual increases to be ~33MW per turbine representing a nearly 50% increase in generating capacity per unit and 40% for the 5 unit facility.
- Job creation: 153 FTEs + 700 jobs retained by project

Project Plan & Schedule:

1/1/2010 - 12/31/2012 (3 Year Project Period)

Project Budget:

DOE Funding: $12,174,956 (17.6%)
Non-Federal Cost Share: $57,001,147 (82.4%)
Total Project Funding: $69,176,103

Location: Robbinsville, NC

Recovery Act: North Fork Skokomish Powerhouse at Cushman No. 2 Dam – City of Tacoma

Purpose & Objectives

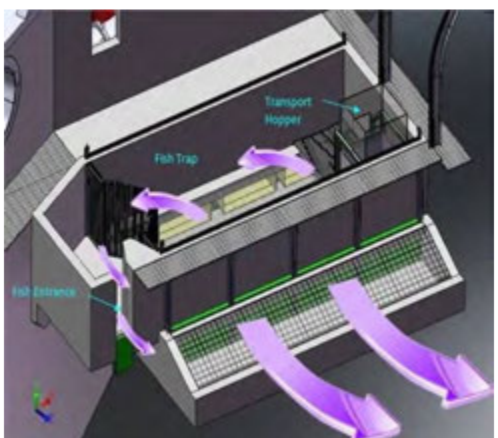
- The City of Tacoma Department of Public Utilities in Washington installed two Francis turbine/generator units adding approximately 3.6 MW of annual electrical generation, increasing annual generation by 14%. The project is located at an existing dam, Cushman No. 2, which is part of the Cushman Hydroelectric Project owned by Tacoma Power.

Impact of the Project

- The installation of the new powerhouse will generate 3.6 megawatts (MW) of additional clean, renewable energy using previously diverted/discharged, but unutilized water flow.
- Fish passage has been blocked since the construction of the two Cushman dams in the late 1920s. This project developed an innovative fish collection and passage system (fish collection structure attached to the draft tubes of the hydroelectric units) that supports the reintroduction of Washington's endangered steelhead and salmon populations upstream of the Cushman Hydroelectric Project.

Technical Approach

- Turbine/Generator Procurement and Installation
- Powerhouse General Construction Contract
- Transmission Design and Construction
- Fish Facilities Design and Construction



Partners:

- Tacoma Power, Northwest Hydraulic Consultants, Golder Associates, Skokomish Tribe

Accomplishments & Progress:

- Project completed 6/30/2013
- The new powerhouse will generate an estimated 21,950 MWh adding to the current generation of 173,000 MWh annually, a 13% increase in generation for the Cushman No. 2 Project.
- Job creation: The project produced 67 Full Time Equivalent jobs during the course of design and construction. Significant other jobs were produced when considering the manufacture of associated equipment and materials.

Project Plan & Schedule:

1/1/2010 - 6/30/2013 (3.5 year Project Period)

Project Budget:

DOE Funding: $4,671,304 (17.5%)
Non-Federal Cost Share: $22,082,626 (82.5%)
Total Project Funding: $26,753,930

Location: Tacoma, WA

Recovery Act: Modernization of the Boulder Canyon Hydroelectric Project –City of Boulder

Purpose & Objectives

- Modernization of the 100-year-old Boulder Canyon Hydroelectric Project, originally constructed in 1910
- Replace two 1920's 10MW Pelton turbines with a single state of the art 5MW Pelton turbine
    - Historic water flow has been significantly redirected to meet the city's current municipal needs and minimum instream flow negatively impacting plant performance
    - One of the units suffered catastrophic failure in 2000
    - Increase annual generation by as much as 30% over existing by installing a unit appropriately sized for the available water flow.

Impact of the Project

- Improved safety for personnel and equipment
- Improved protection of the Boulder Creek environment
- Modernization and integration of control equipment into Boulder's municipal water supply system
- Preservation of significant historical engineering information prior to modernization

Technical Approach

- Procure appropriately sized equipment
- Complete engineering design services
- Complete final permitting activities – FERC conduit exemption
- Preserve historically significant features, equipment, and information
- Project construction

Partners:

- Canyon Industries (turbine/generator manufacture), AECOM (design/engineering), Gracon Corporation (general construction contractor)

Accomplishments & Progress:

- Project completed 12/31/2012
- Turbine efficiency has increased 18 to 48% depending on flow
- Historically significant features, equipment, and engineering data have been documented, photographed, and archived
- Improved safety for personnel and equipment
- Better environmental protection: Removed 2 1940's oil cooled transformers from river bank
- Job creation: 40,000 hours billed to project (19 FTE)

Project Plan & Schedule:

1/1/2010 – 12/31/2012 (3 year Project Period)

Project Budget:

DOE Funding: $1,180,000 (20.1%)
Non-Federal Cost Share: $4,682,858 (79.9%)
Total Project Funding: $5,862,858

Location: Boulder, CO

Recovery Act: Hydroelectric Facility Improvement Project, Replacement of Current Mechanical Seal System with Rope Packing System – City of North Little Rock, AR

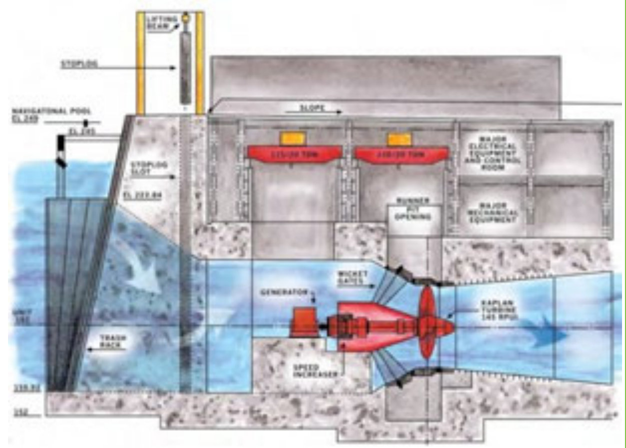
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Purpose & Objectives

- The project replaced the turbine shaft seal system to increase the production of electricity and reduce maintenance outages.
- Tub grinder purchased under this award will be used to mulch debris (tree trunks, branches, etc.) cleared from the facility intake area, which was previously burned

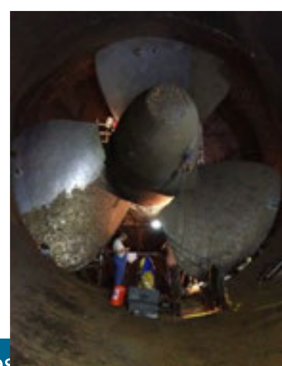
Impact of the Project

- Replacing the shaft seal system will improve the reliability and running efficiency of the turbine unit by significantly decreasing maintenance downtime over standard mechanical shaft seal systems.
- Maintenance downtime will be decreased significantly (approx. 1300 hours per year) and the City hopes to regain approximately $1.4 million in annual lost generation due to current mechanical seal maintenance downtime



Technical Approach

- Rope packing creates a seal around the rotating shaft where it exits the draft tube and enters the speed increaser and generator to prevent water from entering. Rope packing prevents water from entering the generator pit inside the plant while still allowing the propeller shaft to turn



Partners:

- Hydro Consulting & Maintenance Services, Garver Engineers and Consultants, Inc.

Accomplishments & Progress:

- Project re-scoped in 2012
- Vendor selected to engineer, fabricate, and install rope packing system – Oct 2012
- Seal conversion was completed in February 2013 with turbine generator unit back on-line
- Further testing and adjusting was done throughout the first two weeks of March 2013
- The replacement of the packing will only be necessary every 3-5 years at 24 hours of outage per replacement. (previous outage time was 7-14 days every four months).

Project Plan & Schedule:

1/1/2010 – 2/28/2013 (3 year Project Period)

Project Budget:

DOE Funding: $450,000 (45.6%)
Non-Federal Cost Share: $536,245 (54.4%)
Total Project Funding: $986,245

Location: North Little Rock, AR

Recovery Act: Installation of a Low Flow unit at the Abiquiu Hydroelectric Facility -Incorporated County of Los Alamos

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

Purpose & Objectives

- Construct a new powerhouse addition to the existing Abquiu Hydroelectric Facility to house a 3.1MW low flow turbine-generator
- Original powerhouse has 2 identical 6.9MW Francis style turbine-generators
    - New powerhouse increased capacity 22% to 16.9MW
- Increase operational flexibility
    - Provides for energy capture during periods of low flow (winter months)
    - Provides for more efficient operation equipment
    - Extends usable flow range for power production
- Capture energy from bypass flows

Impact of the Project

- Increased generation capacity
    - Uses bypass flows to produce additional energy
- Increased annual generation
    - Provides for year round generation
    - Improved flexibility and more efficient operation of facility
- Improved dissolved oxygen content
    - Bypassed flows now run through low flow unit

Technical Approach

- Design-build contract
- Procurement of long lead time equipment
- Coffer dam construction
    - Temporary and permanent coffer dam construction
- Construction of powerhouse addition
- Connection of penstock to existing stub out
- Installation of turbine-generator
- Integration with original powerhouse

Partners:

- RMCI, Andritz Hydro

Accomplishments & Progress:

- Project completed 3/31/12
- Actual capacity increased by 3.15MW
- Flow range extended from 250cfs – 1300cfs to 75cfs – 1550cfs
- Plant efficiency increased due to the flexibility to mix and match flows through any combination of the units
- Job creation: 50 FTE in the field construction jobs were created during the course of the project
- Dissolved oxygen can now be added to the river during low flow periods
- All power produced by low flow unit qualifies for RECs

Project Plan & Schedule:

11/1/2010 – 3/31/2012 (1.5 year Project Period)

Project Budget:

DOE Funding: $4,558,344 (49.4%)
Non-Federal Cost Share: $4,675,763 (50.6%)
Total Project Funding: $9,234,107

Location: Abiquiu, NM

Recovery Act: Fond Du Lac Hydroelectric Project –Minnesota Power Company

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

Purpose & Objectives

- Rehabilitate a 12MW Francis turbine at the Fond Du Lac hydroelectric project constructed in 1924.
- Performance of the 12MW turbine had degraded over time and was due for overhaul including
  - Wear item replacement including bushings, bearings, and seals
  - Repair of a crack in the head cover limiting gate opening to 78%
- ARRA funding expanded overhaul plans to include:
  - Replacement of the original cast iron runner with a state of the art stainless steel runner
  - Rewinding of the generator, both stator and rotor

Impact of the Project

- Rehabilitated equipment and extend usable life of equipment
  - Expanded overhaul could completed during planned outage
- Improved facility efficiency
  - Planned overhaul would increase annual generation by 3,000 MWh annually
  - Expanded overhaul would increase annual generation by and additional 6,000 MWh annually

Technical Approach

- Replaced cast iron runner with new stainless steel runner
- Rewound generator
- Improved turbine bearing cooling system
- Generator excitation system upgraded
- Replaced head gate
- Automated overhead crane

Partners:

- American Hydro, National Electric Coil, GE Energy

Accomplishments & Progress:

- Project completed 9/1/2013
- Project challenges include unplanned repair of penstock resulting in significant delays (inspection of unit water ways indicated the penstock was in poor condition) and 500yr flood breached the forebay at the upstream Thompson station
- Equipment returned to service June 2013
  - Pond level reduced by 5ft until repairs complete at Thompson
  - Under low flow and low pond, unit was able to achieve 12MW generating capacity
- Job Creation: Employed 32 trades people for 20,000 hours (9.6 FTE)

Project Plan & Schedule:

9/1/2010 – 9/1/2013 (3 year Project Period)

Project Budget:

DOE Funding: $815,995 (14.7%)
Non-Federal Cost Share: $4,783,061 (85.3%)
Total Project Funding: $5,559,056

Location: Duluth, MN

Project Management Accomplishments & Challenges

- Buy American Requirements
- Davis-Bacon Act requirements (prevailing wage, reporting, etc.)
- FederalReporting.gov requirements
- National Environmental Policy Act (NEPA) / Environmental Permitting
- Active Project Management:
  - One project redirected/re-scoped – City of North Little Rock
  - One project canceled - Energy Northwest
  - Alternate project selected – Minnesota Power

Accomplishments and Progress

- Projects demonstrated impressive power generation improvements from upgrading existing facilities with modern turbine technologies.
- The increased generation resulting from the Recovery Act projects is estimated to exceed 135,000 MWh annually; enough to meet the annual electric usage of more than 10,000 average U.S. homes
- Effective use of private / public partnerships to increase power generation/capacity at existing hydroelectric facilities
- Contributed to local and national economic recovery by creating skilled jobs in the manufacturing and construction industries (created over 337 FTE direct jobs)

Hydroelectric Facility Modernization Project

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

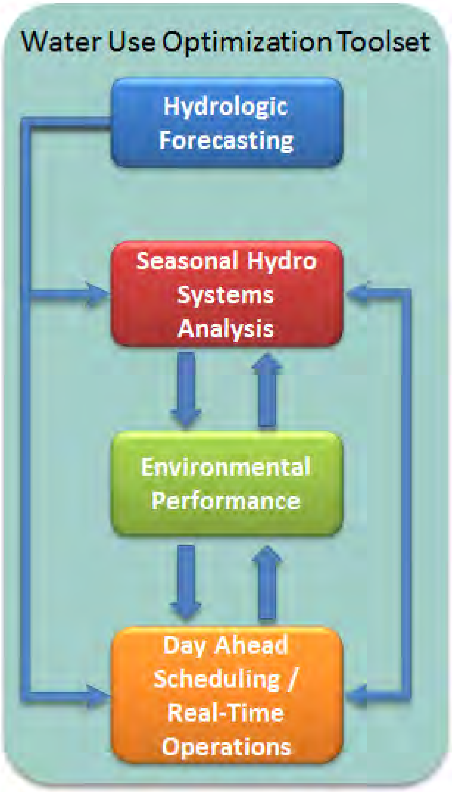
"Upgrading America's hydroelectric facilities presents one of the best opportunities to increase our supply of clean, renewable energy and provide consumers with affordable, reliable power. By partnering with local communities and utilities, we can take steady, responsible steps that protect the environment and deploy every source of American energy."

- David Danielson, Assistant Secretary for Energy Efficiency and Renewable Energy

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

Water Use Optimization Toolset

Project Overview



Project Team: Argonne National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, Oak Ridge National Laboratory

1.6.1.1 Water Use Optimization Toolset

John Gasper
Argonne National Laborator
jgasper@anl.gov, 202 488 2420
February 25, 2014

Purpose & Objectives

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

Problem Statement: An increasingly water-constrained environment is limiting hydropower planning and operational flexibility to meet water, power and environmental requirements

Project Objective: Develop, demonstrate and transfer an advanced analytical toolset that links water, power and environmental performance to facilitate optimization of hydropower planning and operations

Impact of Project:

Increased energy and grid services from available water

Enhanced environmental benefits from improved hydropower operations and planning.

This project aligns with the following DOE Program objectives and priorities

- Advance new hydropower systems and/or components for demonstration or deployment
- Optimize existing hydropower technology, flexibility, and/or operations - Primary Alignment
- Enable next generation pumped storage technologies to facilitate renewable integration
- Reduce deployment barriers and environmental impacts of hydropower

Technical Approach Overview

Phase 1. Toolset Development and Demonstration (FY 10-13)

Development: Creation of advanced, integrated software for analysis of the economic and environmental implications from hydropower dispatch scheduling and operations options.

Demonstration: Demonstration of the potential water, power, ancillary services and environmental benefits from application of WUOT in real world environments

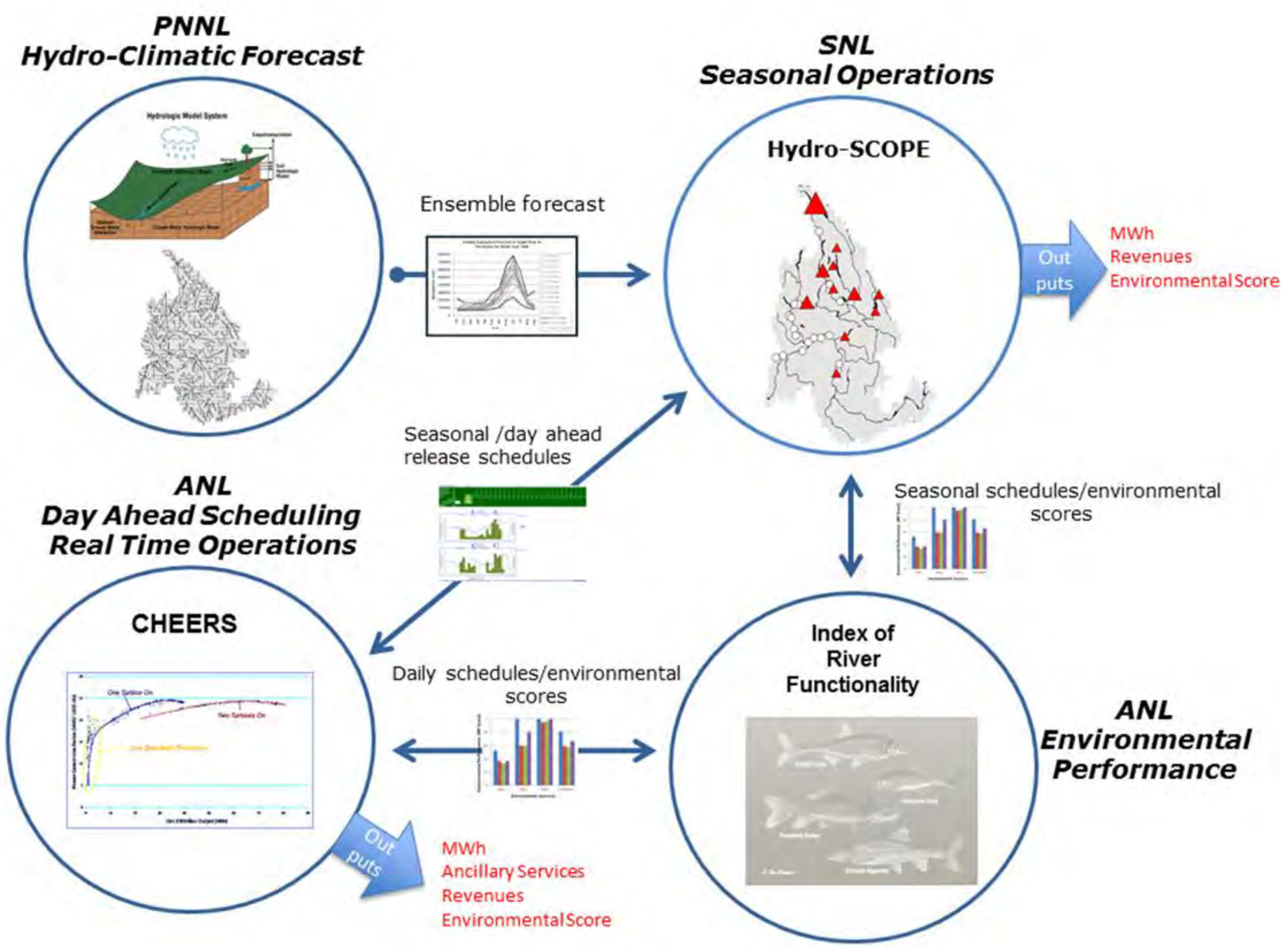
Phase 2. Toolset Refinement, Technology Transfer (FY13 +)

Refinement: Revise software based on input from tech review team, demonstration site users

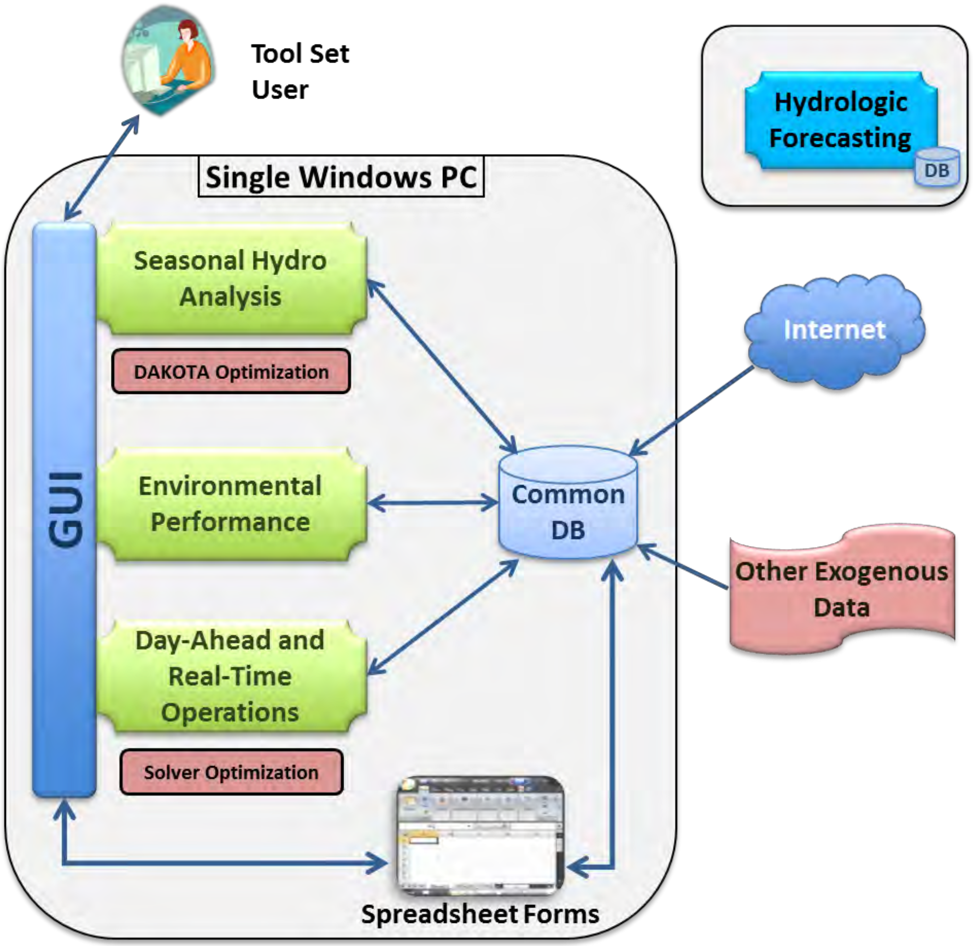
Technology Transfer: Facilitate application of the toolset by the hydropower industry (e.g., toolset demonstrations and training, stakeholder outreach, support material development, institutional and intellectual property process facilitation)

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

Water Use Optimization Toolset Conceptual Design



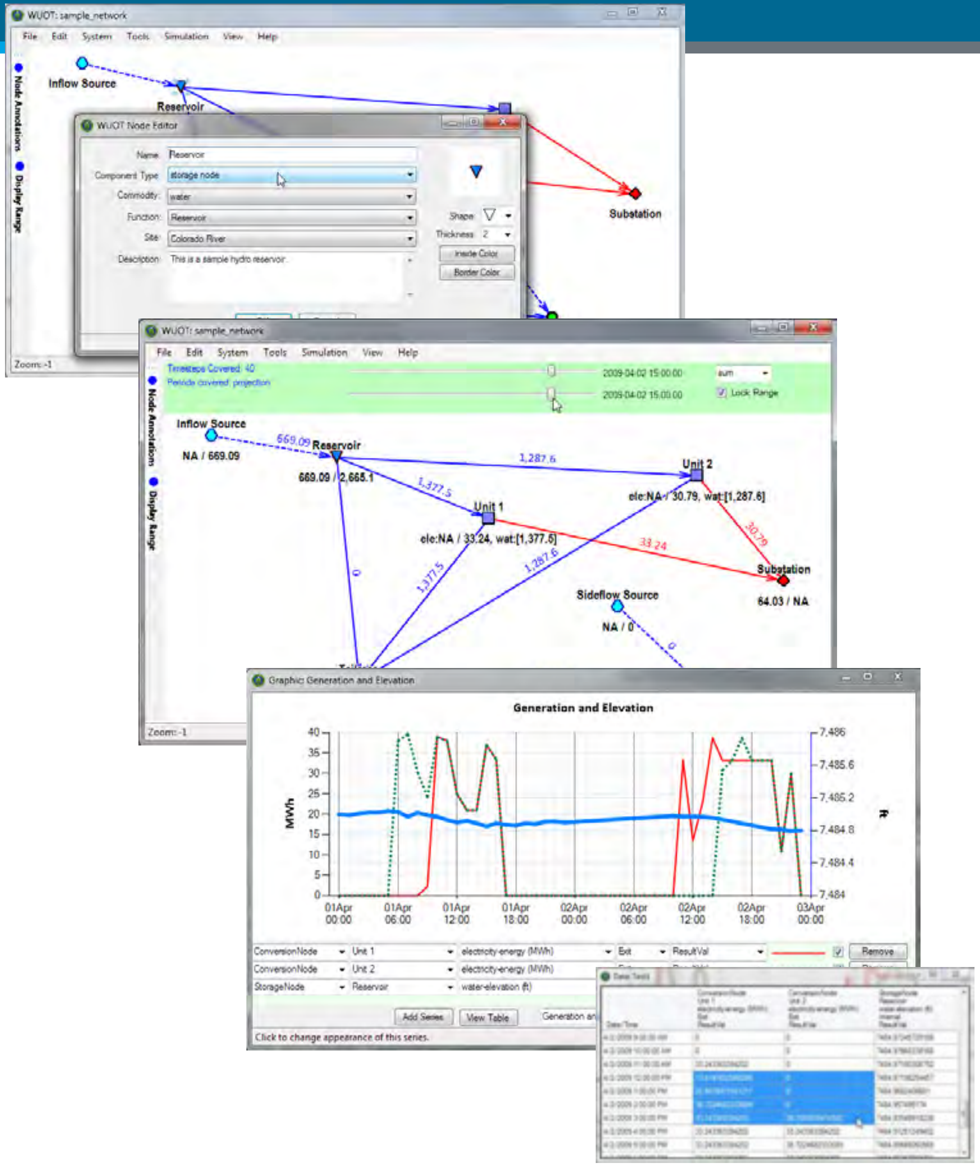
Water Use Optimization Toolset Conceptual Design (continued)



Technical Approach: Development

Toolset Nerve Center: Graphical User Interface (GUI)

- Used to describe system as a network of objects
  - Boundary nodes (Inflows)
  - Storage nodes (Reservoir)
  - Conversion nodes (Turbine/Generator)
  - Junction nodes (Confluence)
  - Links (River, Canal, Power Transport)
- Add, view, configure network components
- Execute tools
- Explore results



Technical Approach: Demonstration

Objectives:

- Demonstrate potential water, power, ancillary services and environmental benefits from application of WUOT in multiple environments
- Prove WUOT useful, useable, used

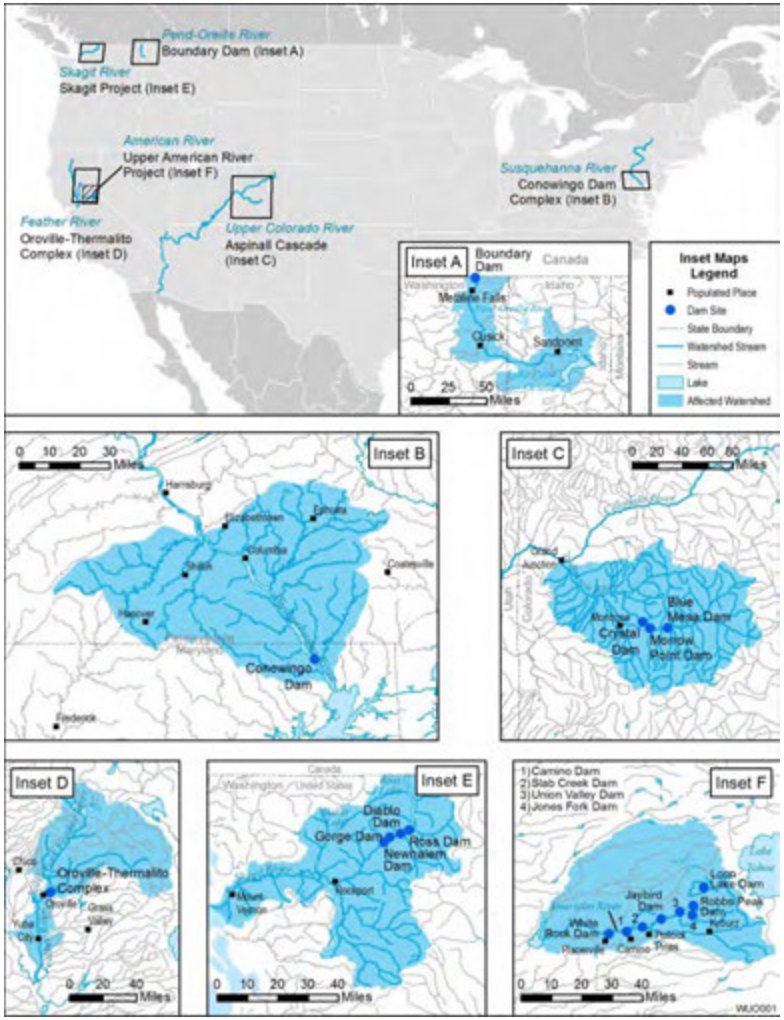
Approach:

Proof of Concept: retrospective analysis

Application: use of WUOT by site operational systems

5 Demonstrations ongoing:

- Aspinall Unit – Western Area Power, Bureau of Reclamation (FY 10)
- Oroville-Thermalito Complex – California Department of Water Resources (FY10)
- Conowingo Dam /Muddy Run PSH – Exelon (FY12)
- Skagit/ Pend-Oreille Rivers, Seattle City Light (FY 13)
- Upper American River System - Sacramento Municipal Utility District (FY13)



Technical Approach: Refinement, Technology Transfer

- **Refinement:** develop and carry out plan to enhance functionality and operational efficiency based on comments received from the technical review team and demonstration partners
  - User input/output features
  - Analytical capability
- **Technology Transfer:** develop and carry out plan to facilitate transfer and use by the hydropower community
  - Hydropower community outreach: Workshops, presentations, publications, additional demonstrations
  - Development, presentation of technology transfer materials and training
  - Assistance in institutional and intellectual property issues

Accomplishments and Progress

FY 10-13: Phase 1. Toolset Development and Demonstration

Software Development: completed Alpha, Beta versions of software

Toolset Demonstration: completed retrospective analyses at two sites, initial software application and training at two sites

FY13+: Phase 2. Toolset Refinement and Transfer

Toolset Refinement: Preparation/implementation of Toolset Refinement Plan, completed Beta 1 version of software

Toolset Transfer: Preparation/implementation of Technology Transfer Plan, initiated 3 additional demonstrations, Bureau of Reclamation PSH system analysis, 2 DOE PSH analysis, 2 unsolicited expressions of interest to use WUOT in small hydro and unpowered dam applications

Project Plan & Schedule

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

Summary		Legend
WBS Number 1.6.1.1		Work completed
Project Number 1.6.1.1		Active Task
Agreement Number 20079		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Water Use Optimization Toolset												
Q1 Milestone: Complete initial version of GUI interface												
Q3 Milestone: Initiate Aspinall Cascade demonstration anallysis.												
Q4 Milestone: draft WUOT DevelopmentTechnical Report												
Q1 Milestone: WUOT Beta version												
Q2 Milestone: Develop technolgy transfer plan												
Q3 Milestone: Develop toolset refinement plan, Beta 1 version of software												
Q 4 Milestone: Complete final development and demonstration phase report												
Current work and future research												
Q 1. Milestone: Install upgraded software at Aspinall Cascade												
Q 2 Milestone: Complete retrospective analysis of Conowingo Dam Complex												
Q 4 Milestone: Conduct Eastern Outreach Workshop												
Q 4 Milestone: Beta 2 version of software												

Comments

- Development and Demonstration: Planned: FY10-12 Actual: FY10 -13,
- Tech Transfer/Refinement FY13+
- Challenges - scope expansion, development and testing realities, Non-Disclosure Agreements, data acquisition and quality

Project Budget

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

Budget History ($)					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
ANL 1,486K	0	1,166K	0	842K	0
PNNL 638K	0	770K	0	666K	0
SNL 587K	0	724K	0	601K	0

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators:

Project Partners:
Argonne National Laboratory: John Gasper, John Hayse, Matt Mahalik, Sam Saha, Tom Veselka
Pacific Northwest National Laboratory: Andre Coleman, Kenneth Hamm, Nathalie Voisin, Mark Wigmosta
Sandia National Laboratories Asmeret Bier, Janet Barco, Tom Lowry, Marissa Reno, Dirk Vanwestrienen
Oak Ridge National Laboratory: Yetta Jager, Brennan Smith

Subcontractors: University of Washington: Dr. Dennis Lettenmaier

Technical Review Team: 25 staff representing 12 industry organizations (California Department of Water Resources, Western Area Power Administration, U.S. Bureau of Reclamation, Southern Company, Brookfield Energy, Puget Sound Energy, Alabama Power, New York City Dept of Environment, Avista Corporation, Exelon Generation, Seattle City Light, Sacramento Municipal Utility District, PJM Interconnection LLC

Demonstration Site Partners: California Department of Water Resources, Bureau of Reclamation, Western Area Power Administration, Exelon, PJM Interconnection LLC, Seattle City Light, Sacramento Municipal Utility District

Communications and Technology Transfer:

Presentations: over 30 at forums including: NHA Annual Meeting, NHA Operators Committee, NHA Research Committee, HydroVision, HydroVision International, American Geophysical Union, American Water Resources Association, World Bank, National Wildlife Service

Workshops: NHA, HydroVision

National Laboratory and Professional Journal Publications: 6

Code applications: Bureau of Reclamation, California Department of Natural Resources, Western Area Power Administration, DOE PSH R&D

Next Steps and Future Research

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

FY14/Current research: **Phase 2: Refinement and Technology Transfer**

Refinement :

Review, modification of Refinement Plan: 12/31/13,
Beta 2 version of software: 9/30/14

Technology Transfer

Review and modification of Technology Transfer Plan: 6/30/14 ,
Additional retrospective analyses: Conowingo – 3/31/12, Seattle City Light - 9/30/14, Sacramento Municipal Utility District – 12/31/13,
Additional/enhanced toolset applications – as appropriate,
Conduct of two regional workshops : 6/30/14, 9/30/14

Proposed future research: **Phase 2: Refinement and Technology Transfer**

Refinement: Continued development of WUOT capability and functionality based on user and reviewer feedback including enhanced user interface, and web-enablement,

Technology Transfer: Continued activities to facilitate toolset awareness and deployment in the hydropower community including stakeholder outreach, toolset applications (sponsored, cost shared, user-funded), and training

Water Use Optimization Toolset

Hydrologic Forecasting

Mark Wigmosta, Andre Coleman, Nathalie Voisin, Cindy Rakowski,
Richard Skaggs,
PNNL

Dennis Lettenmaier and Bart Nijssen
University of Washington

1.6.1.1 Water Use Optimization Toolset

Presenter: Mark Wigmosta

Organization: PNNL

Contact Info: mark.wigmosta@pnl.gov

Date: 2/25/2014

Purpose & Objectives

Problem Statement: Lack of reliable inflow forecasts to the nation's reservoir system may result in overly conservative operational constraints to meet multiple water use objectives and mitigate the impacts of hydrologic extremes (flood, drought).

Objectives: Develop an Enhanced Hydrologic Forecast System to provide a national multi-scale ensemble streamflow forecasting system for the WUOT :

- Meteorological and streamflow forecasts at multiple user-defined locations and temporal and spatial scales
- Longer lead times with reduced forecast uncertainty
- An increased opportunity for plant to system optimization

Impact of Project: Opportunity to optimize water use efficiency for electricity generation and environmental performance while meeting operational objectives

This project aligns with the following DOE Program objectives and priorities

- Advance new hydropower systems and/or components for demonstration or deployment
- Optimize existing hydropower technology, flexibility, and/or operations - Primary Alignment
- Enable next generation pumped storage technologies to facilitate renewable integration
- Reduce deployment barriers and environmental impacts of hydropower

Technical Approach

Background

Current Forecasting Approaches/Products used in Demonstration Basins

- Persistence
- NOAA-NWS
- Commercial providers (3TIER Inc.)
- Internal – typically regression-based against snowpack or measured streamflow
- Some combination of those listed above

Project team has collaborated with multiple agencies on all the above

No single source for all end users

- “Multi-model”

Need for rapid customization to suit individual plant/system requirements

- Hydroclimatic conditions
- Spatial scale and domain
- Required forecast locations
- Required forecast temporal scale
- Required forecast lead times

Technical Approach

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

Build on Existing Capabilities: Integrate and enhance PNNL and University of Washington/Princeton University ensemble forecast systems

- Address principle components of forecast uncertainty
  - Automatically update model estimates of snow and soil water storage using real-time assimilation of remotely-sensed snow cover, observed snow water equivalent, and streamflow
  - Use an ensemble of meteorological forecasts to drive an advanced, spatially-distributed hydrologic model
- Generate an ensemble of streamflow forecasts that capture the uncertainty in weather forecasts
- Value added custom forecasts at user-specified locations

This Project Delivers to DOE and the Forecast Community:

- DOE & hydropower industry forecast requirements in the face of increased competition for water and more uncertainty in available water supply
  - Traditional objectives (power, flood control, irrigation/water supply)
  - Emerging needs for renewable integration and environmental requirements
  - Non-stationarity impacts from climate variability, land use change and increasing population
- Physics-based, distributed hydrologic model
- Consistent, national approach for multi-scale ensemble streamflow forecasting
- Automated assimilation of spatial and temporal data

Technical Approach

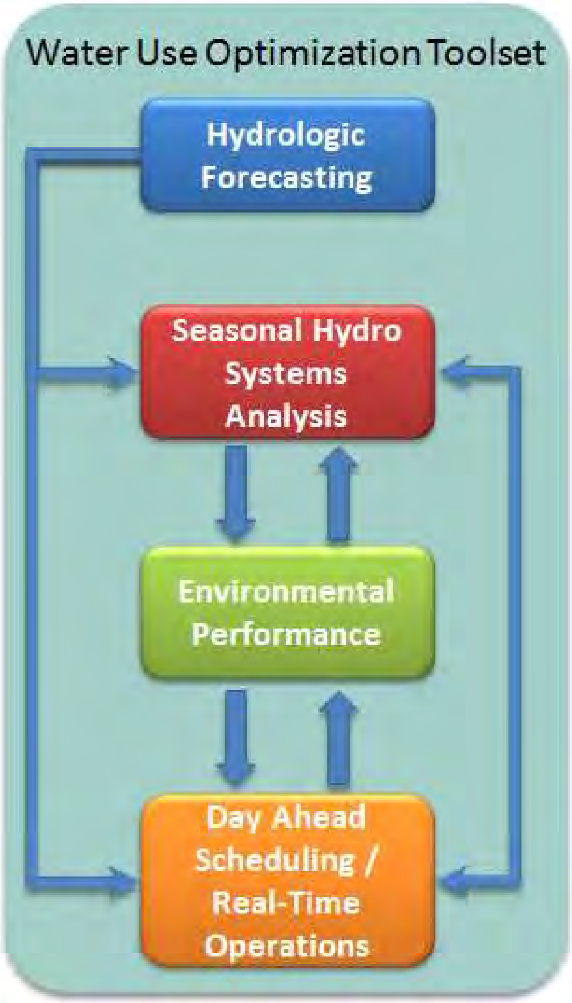
Seasonal Climate Forcing:
- 1/8th degree* gridded hourly meteorological ensemble
- 49 plausible climates (plus mean)

Seasonal Streamflow Forecast:
- Issued every 7 days
- 49 ensemble traces (plus mean)

Medium Range Meteorological Forecast:
- 1/8th degree* gridded, 13-day, 15-member, hourly meteorological ensemble

Medium Range Hydrological Forecast:
- Issued daily out to 13 days for 15 ensemble members

* moving to finer resolution of 1/16th degree



Accomplishments and Progress

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

- Completed Forecast System Design Document (FY10)
- Completed evaluation of remote sensing and alternative ensemble forecast methodology (FY10)
- Installation of UW/PU forecast system on PNNL compute cluster (FY10)
  - Ongoing modernization and optimization of core software
  - More flexible and generic approach
- Prototype Enhanced Hydrologic Forecast System (EHFS) (FY11)

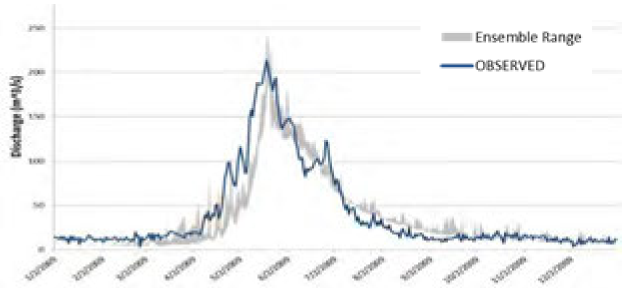
- Complete development of Enhanced Hydrologic Forecast System (EHFS) (FY12)
- Completed application in two demonstration basins (FY12-13):
  - Feather River, CA, Oroville-Thermalito Complex – California Department of Water Resources
  - Gunnison River, CO, Aspinall Unit – Western Area Power Authority, Bureau of Reclamation
    - Calibration
    - Seasonal forecasts
    - Medium-range forecasts
    - Retrospective evaluation
- Applications in three additional demonstration basins are underway (FY13-14)
  - Completed model setup and calibration for Susquehanna River – Conowingo Dam - Exelon
  - Model setup for Skagit River - Seattle City Light
  - Preliminary discussions - Sacramento Municipal Utility District
- 16 - Publications & presentations

Accomplishments and Progress

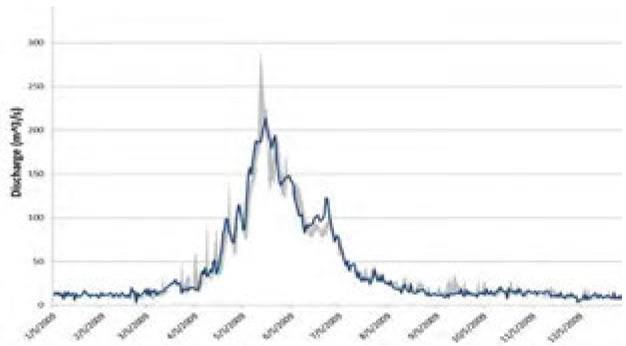
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Blue Mesa: 2009 1-Day Lead Forecast Ensemble

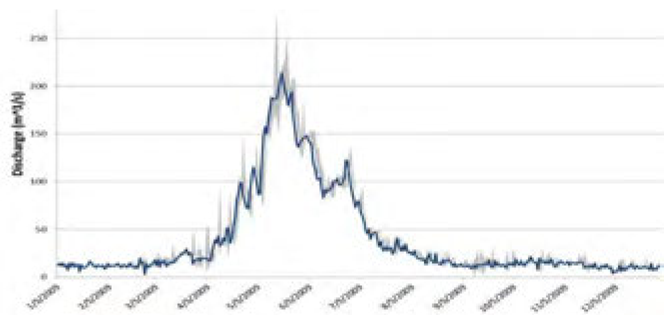
Forecast without data assimilation or post-processing



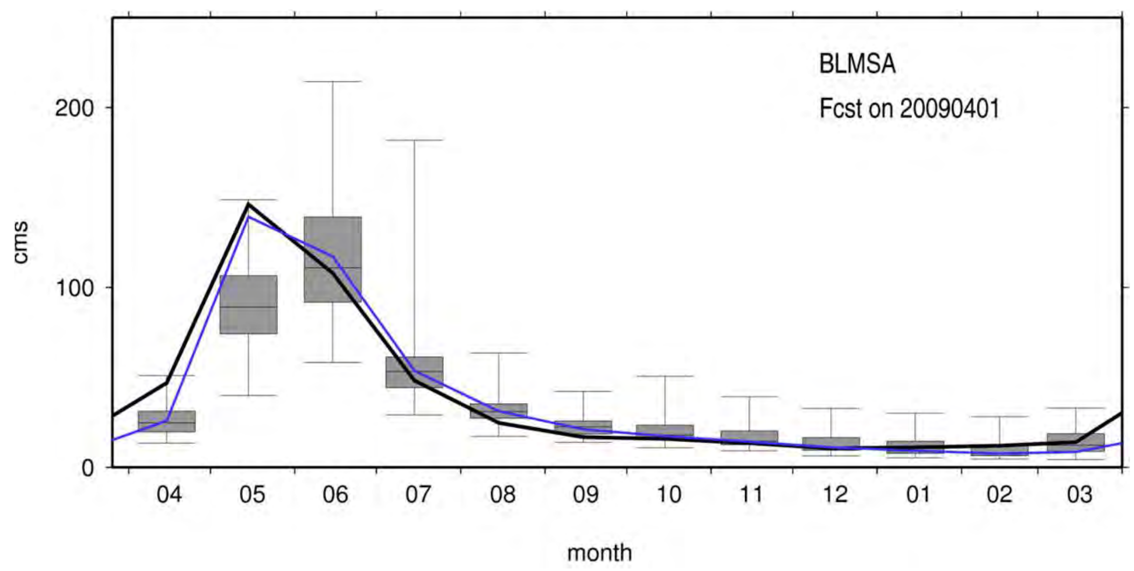
Forecast with data assimilation



Forecast with data assimilation and post-processing



Seasonal forecast issued April 1, 2009



Project Plan & Schedule

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

Summary	
WBS Number 1.6.1.1	
Project Number 1.6.1.1	
Agreement Number 20081	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Complete Enhanced Hydrologic Forecast System (EHFS)												
CRSP EHFS setup and calibration												
CRSP Retrospective Analysis												
CDWR EHFS setup and calibration												
CDWR Retrospective Analysis												
Current work and future research												
Conowingo Retrospective Analysis												
Seattle City Light Retrospective Analysis												
Additional Software Enhancements												

Comments

- Development and Demonstration: Planned: FY10-12 Actual: FY10 -13,
- Tech Transfer/Refinement FY13+
- Challenges - development and testing realities, data availability and quality

Project Budget

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

Budget History*					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$500K + $138K FY11 carryover		$580K + $190K FY12 carryover		$400K + $266K FY13 carryover	

* Total funding for 3 year project = $1,480K

Partners, Subcontractors, and Collaborators:

Project Partners:
Argonne National Laboratory: John Gasper, John Hayse, Matt Mahalik, Sam Saha, Tom Veselka
Sandia National Laboratories: Asmeret Bier, Janet Barco, Tom Lowry, Marissa Reno, Dirk Vanwestrienen
Oak Ridge National Laboratory: Yetta Jager, Brennan Smith

Subcontractors: University of Washington: Dr. Dennis Lettenmaier

Informal Collaborators: 3TIER Inc. (Renewable Energy Assessment and Forecasting Services) recently acquired by Vaisala Corporation, National Center for Atmospheric Research - Research Applications Laboratory, NOAA-NWS

Demonstration Site Partners: California Department of Water Resources, Bureau of Reclamation, Western Area Power Administration, Exelon, PJM Interconnection LLC, Seattle City Light, Sacramento Municipal Utility District

Communications and Technology Transfer:

Presentations: 14 including: NHA Annual Meeting, HydroVision, American Geophysical Union, Hydrological Ensemble Prediction EXperiment (HEPEX) monthly webinar, AGU Chapman Conference, National Weather Service - Office of Hydrologic Development seminar

Workshops: NHA, HydroVision

National Laboratory and Professional Journal Publications: 2

Next Steps and Future Research

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FY14/Current research:

- Additional retrospective analyses:
  - Exelon
  - Seattle City Light
  - Sacramento Municipal Utility District

- Two regional workshops

Proposed future research:

- Continued development of EHFS capability and functionality based on user and reviewer feedback
  - Integration of 3TIER hydrologic forecasts (Seattle City Light)
  - Integration of NWS forecasts (Seattle City Light, SMUD)
  - Particle filter data assimilation
- Continued activities to increase toolset visibility and promote technology transfer to the hydropower community including stakeholder outreach, toolset applications (sponsored, cost shared, user-funded), and training

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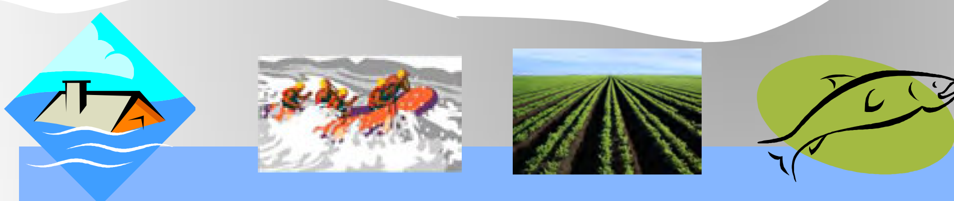
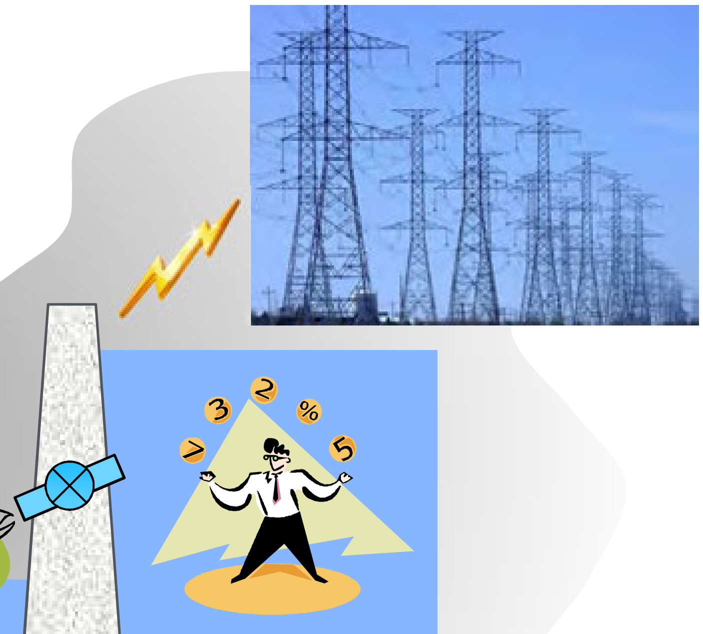
Laboratory Team:

Thomas Lowry (*Hydrological Modeling & Model Development*)
Dirk Vanwestrienen (*Integration Programming, GUI development*)
Asmeret Bier (*Optimization & Mathematics*)
Marissa Reno-Trujillo (*Model Simulation & Data Processing*)
William Peplinski (*Data Collection, Processing, & QA*)





HydroSCOPE: Hydropower Seasonal Concurrent Optimization for Power and the Environment

Seasonal Hydrosystems Analysis and Optimization

Water Use Optimization Toolset

Presenter: **Thomas S Lowry**
Sandia National Laboratories
505 284 9735, tslowry@sandia.gov
February 25, 2014

Purpose & Objectives

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Problem Statement:

There are gaps between day-ahead operations and longer-term objectives and planning that result in lost revenue, lower efficiencies, and increased environmental and operational risk by limiting the ability of hydro-power operators, managers, and planners to optimize operations across multiple scales of space and time.

This task provides operators with this ability by creating a systems-level simulation and optimization tool that integrates with an advanced hydrologic forecasting tool, an environmental performance assessment tool, and a day-ahead optimization tool to inform and guide short-term operations in the context of longer-term objectives and considerations.

Impact of Project:

In combination with the other tools being developed as part of this project, the successful completion and implementation of this work will allow operators to increase system efficiency and performance while simultaneously reducing risk from forecasting and operational uncertainty. Small gains in any of these areas can result in significant benefit to hydropower operators, downstream water users, and the environment.

This project aligns with the following DOE Program objectives and priorities

- Advance new hydropower systems and/or components for demonstration or deployment
- Optimize existing hydropower technology, flexibility, and/or operations - Primary Alignment
- Enable next generation pumped storage technologies to facilitate renewable integration
- Reduce deployment barriers and environmental impacts of hydropower

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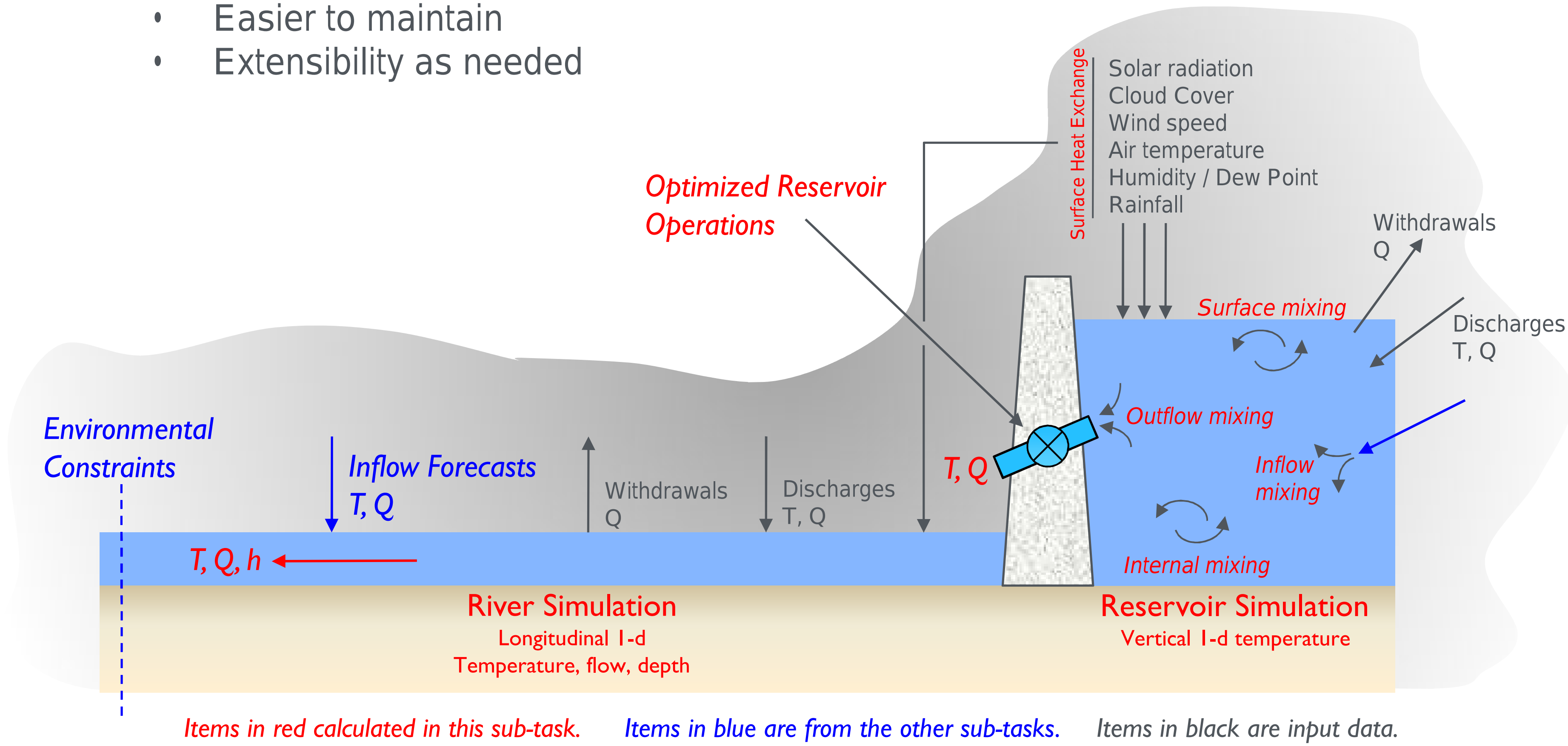
Technical Approach – System Dynamics and Optimization

- Object oriented design within a system dynamics framework (nodes and links)
  - Easier to maintain
  - Extensibility as needed



Coupled object-oriented 1-d reservoir and river routing model for flow and temperature.

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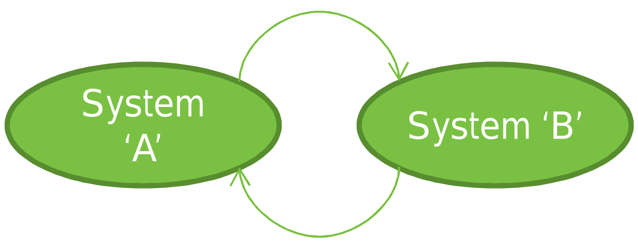
Technical Approach – System Dynamics and Optimization

- Object oriented design within a system dynamics framework (nodes and links)
  - Easier to maintain
  - Extensibility as needed
- Focus is on the ***dynamic relationships*** – i.e. 'causal relationships'
  - Lowers data requirements
  - Reduces execution time
  - Maintains accuracy where needed



Schematic of a causal loop where the state of system 'A' is dependent on the state of system 'B', which in turn is dependent on the state of system 'A'

$$\frac{\partial A}{\partial t} = f(x, y, z, t, A, B)$$

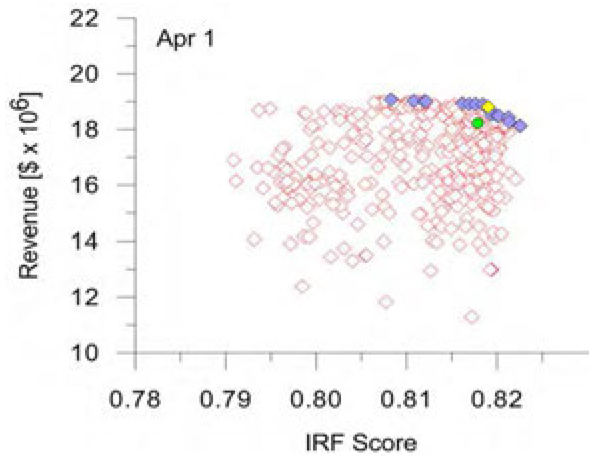
$$\frac{\partial B}{\partial t} = f(x, y, z, t, A, B)$$

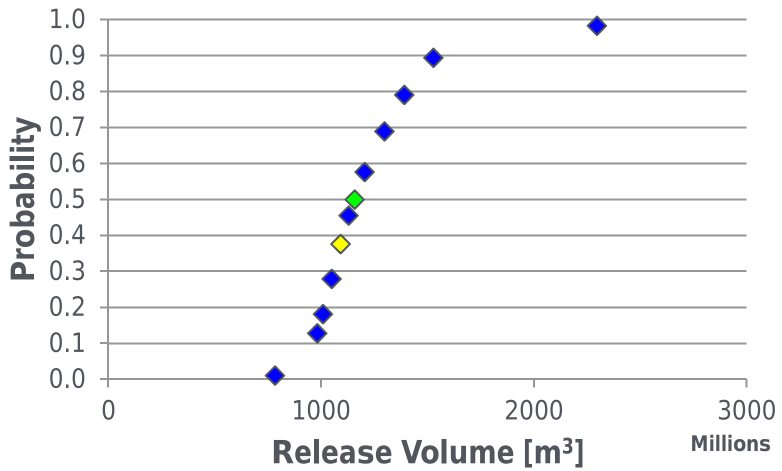
Mathematically, a set of causal loops can be represented as a system of equations simultaneously evaluated at each timestep.

The goal is to simulate the flow and temperature dynamics at key points in the system.

Technical Approach – System Dynamics and Optimization

- Object oriented design within a system dynamics framework (nodes and links)
  - Easier to maintain
  - Extensibility as needed
- Focus is on the ***dynamic relationships*** – i.e. 'causal relationships'
  - Lowers data requirements
  - Reduces execution time
  - Maintains accuracy where needed
- DAKOTA optimization software (*dakota.sandia.gov*)
  - Multi-objective genetic algorithm approach
  - Tradeoff analysis – Pareto front
  - Uncertainty analysis





DAKOTA provides a suite of tools to the user for performing optimization and dealing with uncertainty.

Key Technical Issues

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- Uncertainty, hydrological and operational

  Robust methods for addressing uncertainty can be computationally expensive and difficult to interpret.

  While these issue are not unique to this project, we have begun to explore methods of using input uncertainty to reduce operational risk and increase system resiliency. In addition, DAKOTA provides capabilities for conducting uncertainty quantification, parameter estimation (i.e., calibration), and sensitivity/variance analysis that are relatively easy to implement at the user level.

- Technology Transfer

  Creating a distributable, easy to use tool is a time-consuming, incremental process.

  Decisions have been made regarding the balance of complexity and the ease of use in the development of HydroSCOPE. This process has involved three steps in succession, 1. creating a scientifically robust and accurate tool, 2. integrating the tool within the architecture of the WUOT, and 3. making the tool easy to use.

- Computational Overhead

  Optimization is computationally expensive.

  The technical approach of this task was carefully considered to try and keep the computational requirements to a minimum, with the goal of keeping a single, six-month simulation to 30 seconds or less. In addition, we are exploring options to speed up the optimization process, including the use of surrogate-based optimization and/or linearizing the model. This will also help us better address the issues regarding uncertainty.

Uniqueness of Approach

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- HydroSCOPE
  - System dynamics approach with object oriented design
  - Fast execution (e.g., 6-mo basin simulation w/ 3 reservoirs < 30 sec.)
  - Extensible to simulate other systems (e.g., agricultural water demands, integrated thermoelectric power production, etc.)
  - Can be used as a stand alone tool to conduct strategic planning, scenario analysis, uncertainty analysis, and the like
  - Leverages the DAKOTA optimization software developed at Sandia that provides a suite of tools that allow for optimization with gradient and non-gradient methods, uncertainty quantification, parameter estimation, sensitivity/variance analysis, surrogate-based optimization, mixed integer non-linear programming, or optimization under uncertainty.
- General
  - Enables optimization across multiple scales of time and space
  - Provides a common data repository where data only need to be processed once but can be used by several of the tools

Schematic and sample output from the Aspinall Cascade, Gunnison River retrospective analysis

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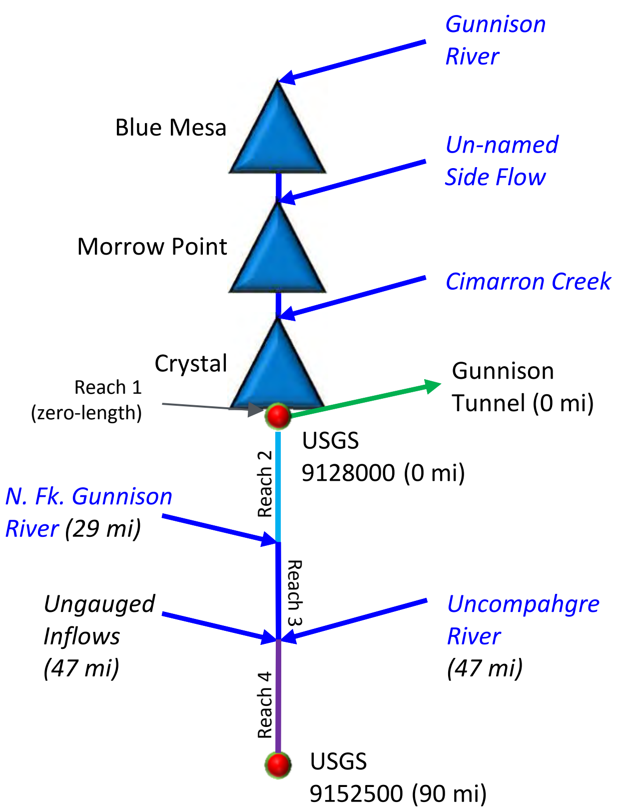
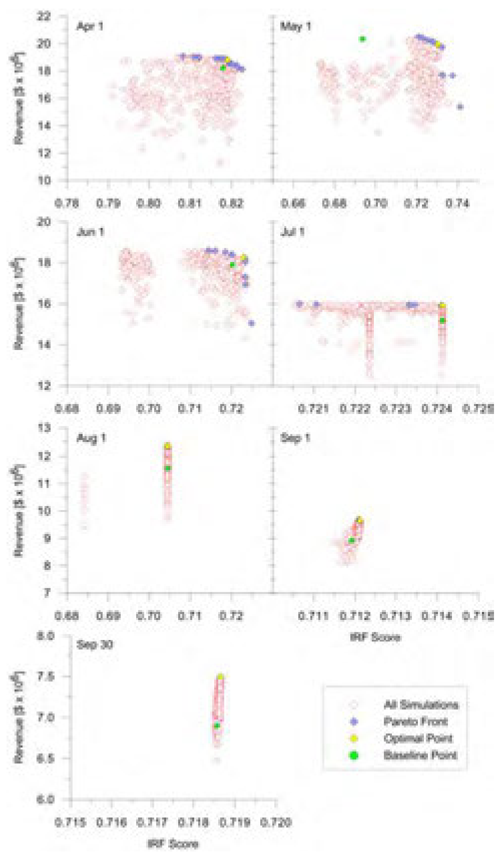
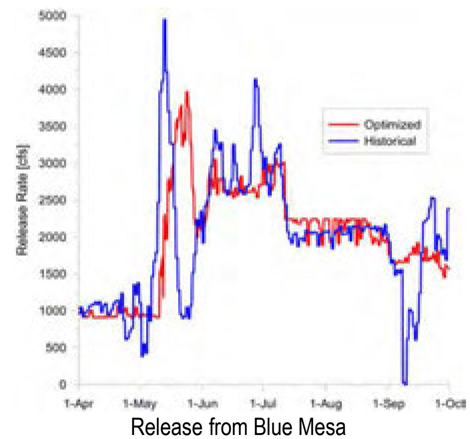
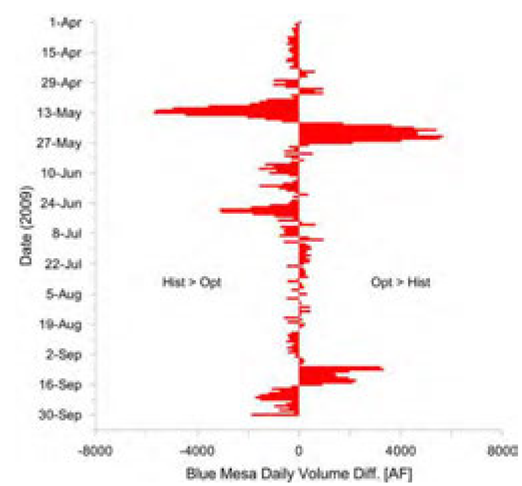
- Two retrospective analyses completed









Models are successfully producing the needed results.

- Analyses show potential improvement in environmental score and total revenue

Site Name	Environmental Score	Total Revenue
Aspinall Cascade	0.80%	3.45%
Oroville Complex	0.61%	2.95%

- Developing methods for addressing uncertainty
  - Lowry, Thomas S., Mark Wigmosta, Asmeret Bier, Nathalie Voisin, J anet Barco, Andre Coleman, and Richard Skaggs, 2012, "*An Integrated Risk Approach for Assessing the Use of Ensemble Streamflow Forecasts in Hydroelectric Reservoir Operations*", American Geophysical Union Annual Conference, Dec. 2012, San Francisco, CA
  - Lowry, Thomas S., Mark Wigmosta, Nathalie Voisin, "*Using Multi-Temporal Scale Uncertainty Information and Specific Forecast Skill to Improve Reservoir Operations*", accepted for presentation at the International Conference on HydroInformatics, Aug. 2014, New York, NY
- Simulation engine for flow and temperature calculations are "fully" debugged and completed

The retrospective analyses have provided important lessons that help strengthen code development and identified areas to expand functionality (e.g. addressing uncertainty).

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	
Project Number - 1.6.1.1	
Agreement Number - 20082	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Water Use Optimization Toolkit Seasonal Model												
Q1 Milestone: Produce working beta version of simulation engine												
Q2 Milestone: Produce summary report of testing and verification activities												
Q3 Milestone: Continue model development for second beta version												
Q4 Milestone: Produce report describing model capabilities and performance												
Q1 Milestone: Complete software development and version 1.0 of model												
Q1 Milestone: Submit a draft list of toolset refinements												
Q1 Milestone: Conduct kickoff meeting with Exelon energy												
Q2 Milestone: Revise and complete toolset refinement plan												

Comments
- Project start date: Oct, 2010
- Beta 2 version of toolset scheduled to be delivered at end of FY14
- Schedule slips can be attributed to
  - Loss of key team member at end of CY12
  - Unanticipated problems and delays with client-supplied data
  - Client schedule (for BoR workshop)

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$587k	$0	$724k	$0k	$601k	$0k

- Loss of a key project member resulted in underspending the first half of FY13 resulting in a $201k carryover to FY14. New team members have been added and work tasks have been more evenly distributed to avoid this situation in the future.
- Q1 FY14 spending was $137k, or 23% of the available budget

Project Management

- This project has successfully delivered all milestones and performed within 20% of the allocated budget with the exception of the FY13-14 carryover as indicated above

Research Integration & Collaboration

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There are no additions for this sub-task for the integration, collaboration, and technology transfer efforts over those described in the Water Use Optimization Toolset project-summary presentation.

Next Steps and Future Research

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FY14/Current research:

1. Provide options for users to turn features on or off (e.g., temperature simulation)
2. Expand user input/out features and functions
3. Enhance code to speed up database integration
4. Develop documentation materials to support technology transfer activities

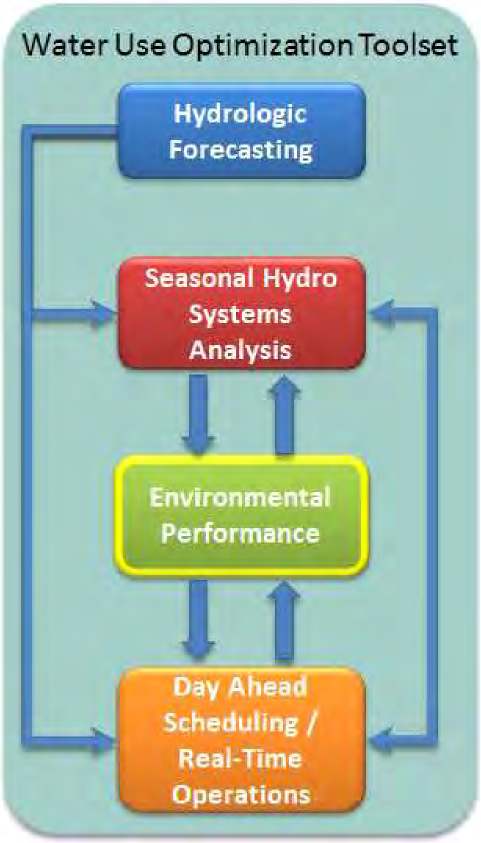
Proposed future research:

1. Create additional simulation modules for DO, sediment transport, etc.
2. Create additional system objects to simulate external water demand, CO2/GHG emissions, other economic valuations, etc.
3. Develop linearized code to speed optimization
4. Address issues concerning changes in: the energy portfolio, climate, energy & water demand, and the like

Water Use Optimization Toolset

Environmental Performance Tool

Index of River Functionality (IRF) Model



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1.6.1.1 Water Use Optimization Toolset

John W. Hayse
Argonne National Laboratory
Hayse@anl.gov, 630 252 3449
February 25th, 2014

Purpose & Objectives

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

Problem and Objective:

Address the need to improve consideration of environmental performance of hydropower operations by developing a tool for evaluating environmental performance and integrating that capability with other hydropower planning tools

Impact of Project:

- Helps regulators, schedulers and operators consider effects of alternate operational regimes on environmental performance
- Allows explicit evaluation and optimization of tradeoffs between power generation/economic value and environmental performance

Purpose & Objectives

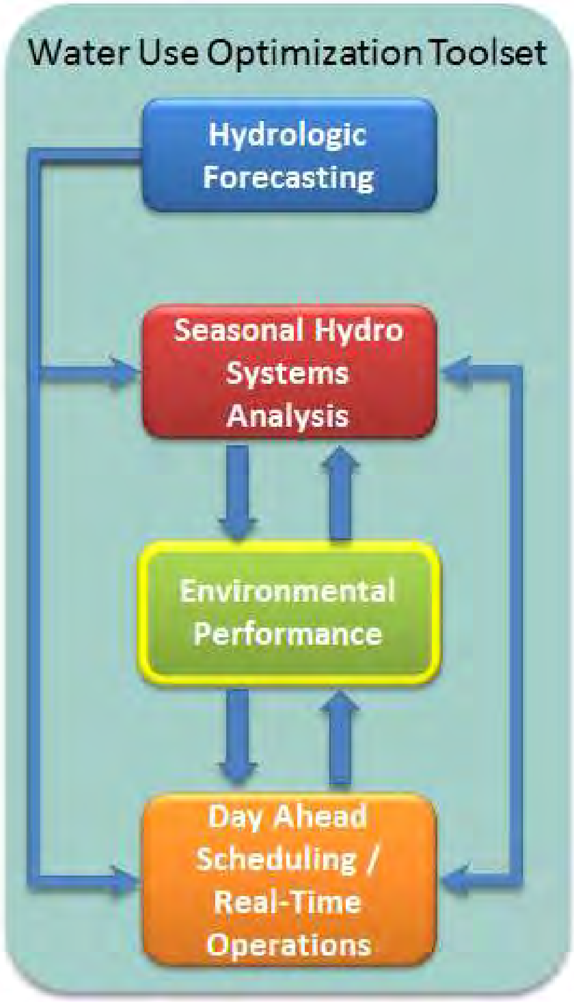
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

This project aligns with the following DOE Program objectives and priorities

- Optimize existing hydropower technology, flexibility, and/or operations - Primary Alignment
- Reduce deployment barriers and environmental impacts of hydropower
- Enable next generation pumped storage technologies to facilitate renewable integration
- Advance new hydropower systems and/or components for demonstration or deployment

IRF Tool is integrated with other WUOT components

- Interacted with Seasonal Analysis Tool to conduct optimization by providing environmental performance scores for alternate release patterns
- IRF tool provides guidance to Day Ahead Scheduling Tool regarding operational limits to protect environmental performance



IRF Tool can also be used standalone

Technical Approach

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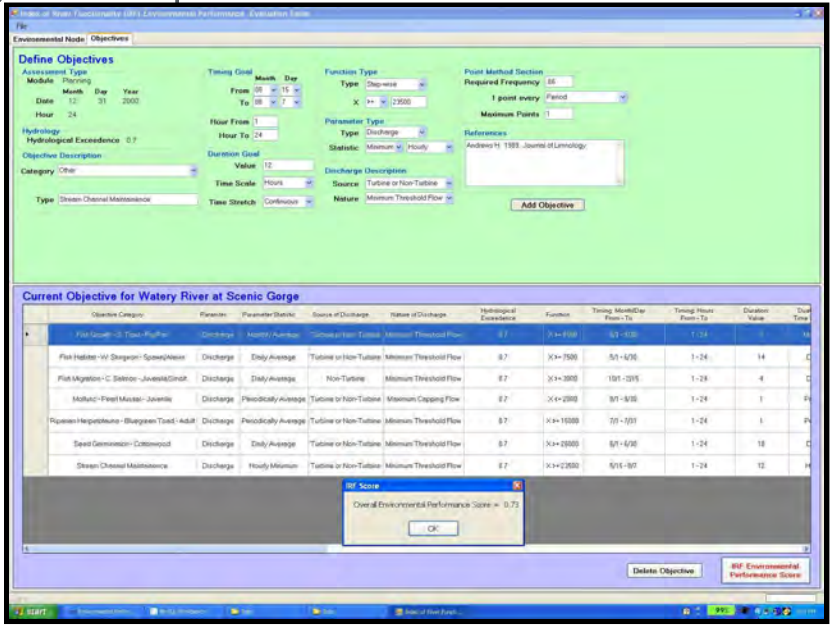
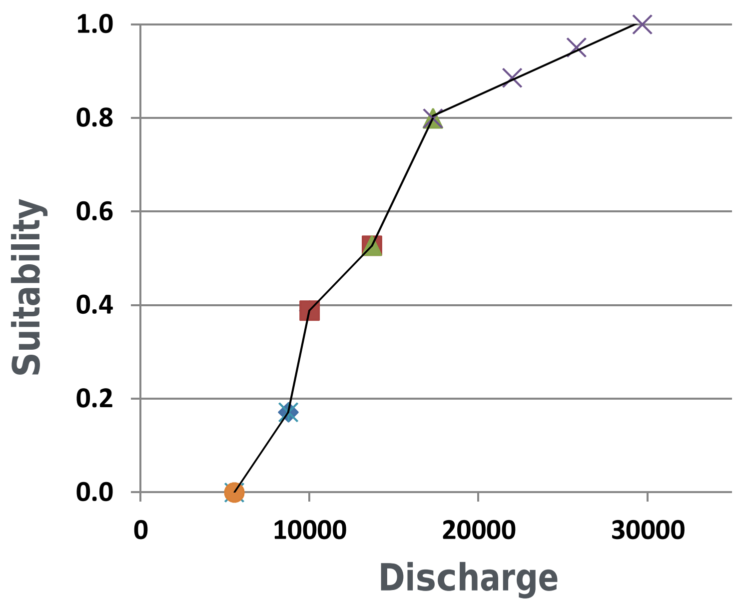
- Produces a single overall environmental performance score for the entire network being modeled
  - Based on ecosystem approach that considers various aspects of flow regime
  - Evaluates degree to which objectives are accomplished by a flow-regime
  - Multiple (and potentially conflicting) objectives can be addressed simultaneously
  - Can also evaluate reach-specific or objective-specific scores

- Site-specific environmental objectives are defined and considered
  - Water-quality objectives (e.g., water temperature, dissolved oxygen) can be considered
  - Can accommodate objectives for multiple species and life-stages



Technical Approach

- Uses relationships between downstream conditions and suitability for defined objectives to calculate environmental performance for operational regimes
  - Considers ranges of potentially suitable conditions
    - maintains flexibility and avoids imposition of preconceived operational limits
  - Allows site-specific environmental data to be considered
  - Provides opportunity for stakeholder involvement



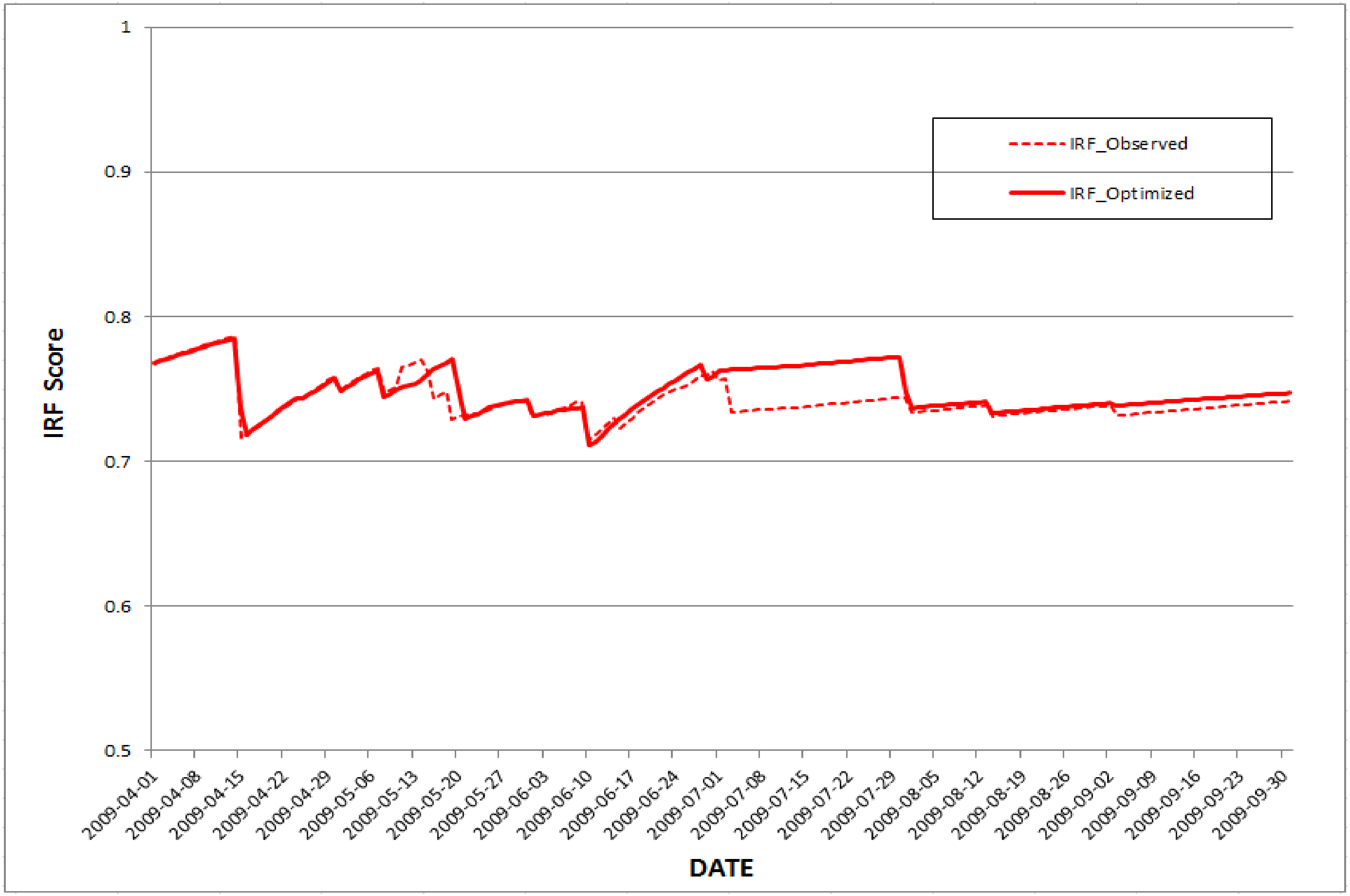
Minimum Daily Discharge at the Whitewater Gauge and Suitability for Fish Larval Entrainment into Floodplain Areas in the Lower Gunnison River

Development:

- Database and mathematical formulation have been designed and successfully implemented
- Successfully implemented a methodology for integration with Hydroscope to allow optimization between hydropower generation/value and environmental performance

Demonstration:

- Completed two retrospective analyses
  - Aspinall Unit (Gunnison River, Colorado)
  - Oroville-Thermolito Complex (Feather River, California)



Comparison of Environmental Performance for Gunnison River
(Optimized Hydroscope Output vs. Actual Operation during 2009)

Project Plan & Schedule

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Summary		Legend
WBS Number 1.6.1.1		Work completed
Project Number 1.6.1.1		Active Task
Agreement Number 20079		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Water Use Optimization Toolset												
Q1 Milestone: Identified preliminary env. perf. criteria for CRSP and Oroville Demos												
Q2 Milestone: Preliminary working version of IRF Tool completed.												
Q4 Milestone: Devleop preliminary data exchange protocol for IRF-Hydroscope												
Q2 Milestone: Develop technolgy transfer plan												
Q3 Milestone: Develop toolset refinement plan, Beta 1 version of IRF software												
Q 4 Milestone: Complete final development and demonstration phase report												
Current work and future research												
Q 2 Milestone: Complete retrospective analysis of Conowingo Dam Complex												
Q 4 Milestone: Conduct Eastern Outreach Workshop												
Q 4 Milestone: Beta 2 version of software												

Comments

- Development and Demonstration: Planned: FY10-12 Actual: FY10 -13,
- Tech Transfer/Refinement FY13+
- Challenges - scope expansion, development and testing realities, Non-Disclosure Agreements, data acquisition and quality

FY 12, 13 Project Plan & Schedule

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Phase 1: Development and Demonstration Planned: FY10-12
Actual: FY10 -13

Development : Software architecture development, coding, and testing.

Demonstration: Apply IRF Tool to demonstrate proof of concept utility.

Challenges - data availability and quality

Phase 2: Refinement and Technology Transfer

Refinement:

- Preparation/implementation of Toolset Refinement Plan – completed 6/30/13
- Development of beta+ version of software – planned and completed 9/30/13

Technology Transfer:

- Work with CDWR and BOR staff regarding application and improvement of IRF methodology
- Presentations and publications

Next Steps and Future Research

FY14/Current research

- Retrospective Analyses for Conowingo (Susquehanna River), Skagit (Skagit River), and Sacramento Municipal Utility District (Upper American River) Projects

Proposed future research

Refinement: Continued development of IRF capability and functionality based on user and reviewer feedback

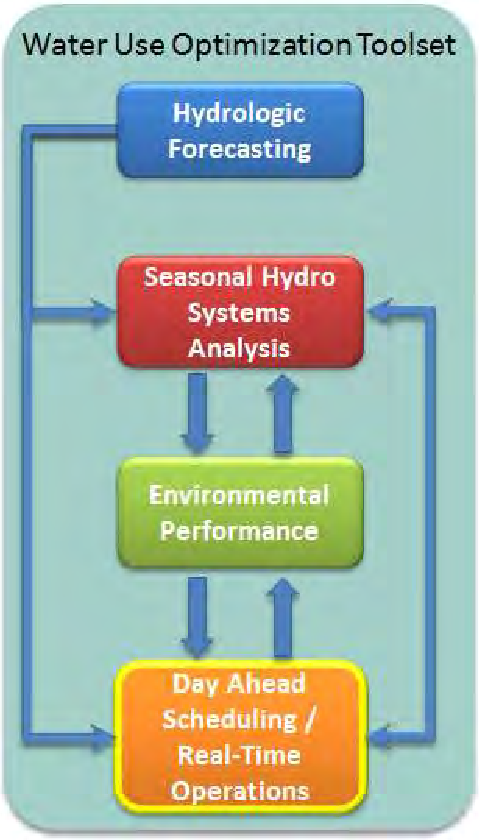
- Enhancements for data management, input specification, and user interface

Technology Transfer: Continued application of toolset (sponsored, cost shared, user-funded), training, publications and presentations

Water Use Optimization Toolset

Day-ahead Scheduling and Real-time Operations Tool

Conventional Hydroelectric and Environmental Resource Systems (CHEERS) Model



Argonne NATIONAL LABORATORY

1.6.1.1

Water Use Optimization Toolset

Thomas Veselka

Argonne National Laboratory

tdveselka@anl.gov, 630 252 3449

February 25th, 2014

Purpose & Objectives

Problem and Objective:

Address the need to improve the performance of hydroelectric and environmental resources through the development and application of an enhanced day-ahead scheduling and real-time operation tool

Impact of Project:

- Helps schedulers and operators improve hydropower efficiency, generating more power with the same amount of water while complying with environmental operating criteria
- Improves the economic value of both hydropower generation and ancillary services
- Supports power grid operations, including more efficient wind and solar integration
- Provides organizations access to a cost-free tool

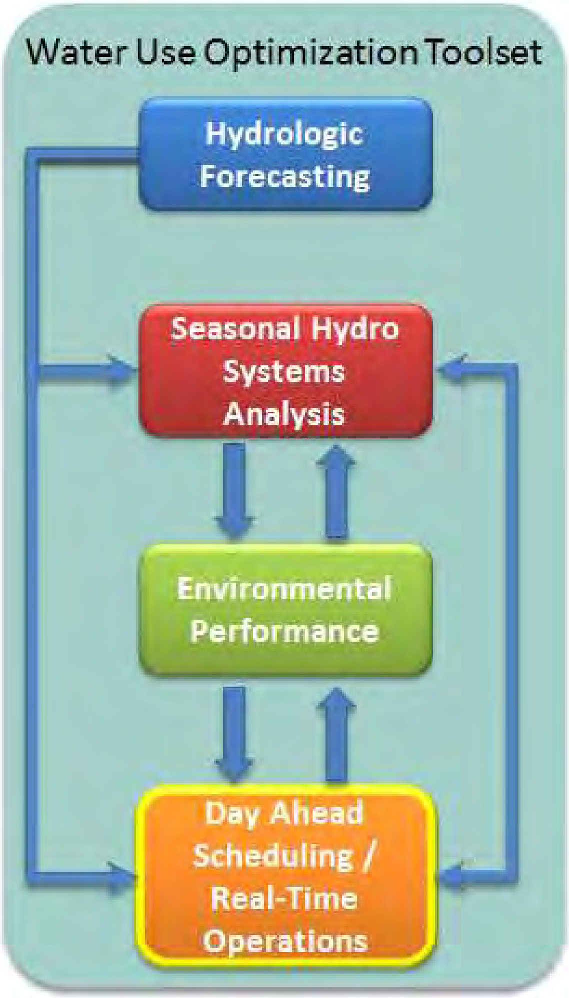
Purpose & Objectives

This project aligns with the following DOE Program objectives and priorities:

- **Optimize existing hydropower technology, flexibility, and/or operations**
- Advance new hydropower systems and/or components for demonstration or deployment
- Enable next generation pumped storage technologies to facilitate renewable integration
- Reduce deployment barriers and environmental impacts of hydropower

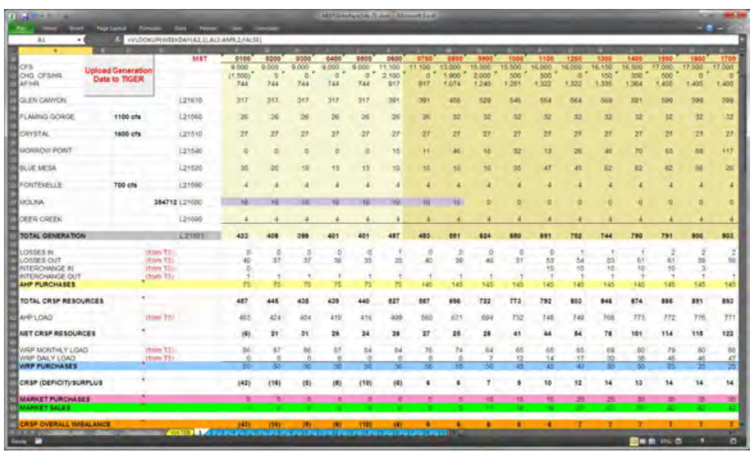
CHEERS is integrated with each of the other WUOT tools

- Forecasting tool provides system inflows and sideflows
- Seasonal tool provides reservoir conditions and temporal release volumes
- Environmental tool provides operational guidance to achieve environmental objectives



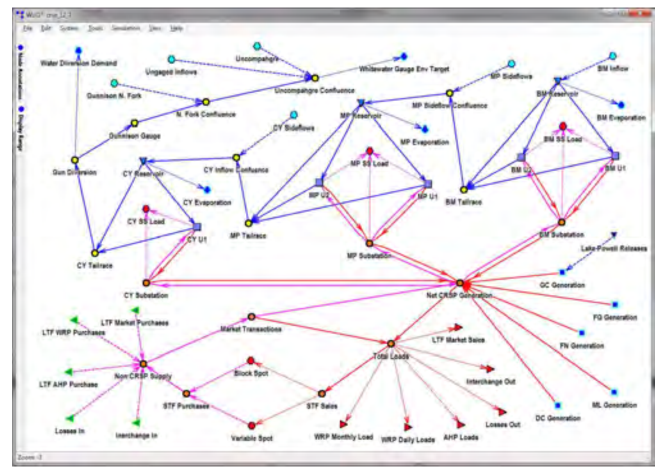
CHEERS can also be run in stand-alone mode

- CHEERS is a network-based optimization model
- Helps operators manage water and power by producing day-ahead and real-time schedules
  - Incorporates dispatcher goals and guidelines
  - Integrated into an organization's business process



Western's existing tool

automated information transfer



CHEERS network model of the Colorado River Storage Project

Technical Approach

Schedules produced by CHEERS guide when, where, and how to:

- Release water from storage
- Produce energy and ancillary services
- Serve customer loads
- Buy and/or sell energy and ancillary services on the market
- Manage other resources such as energy exchanges

Model results provide temporal values for all network components (water flow past gauges, transmission infrastructure loading, turbine head levels, etc.)

Technical Approach

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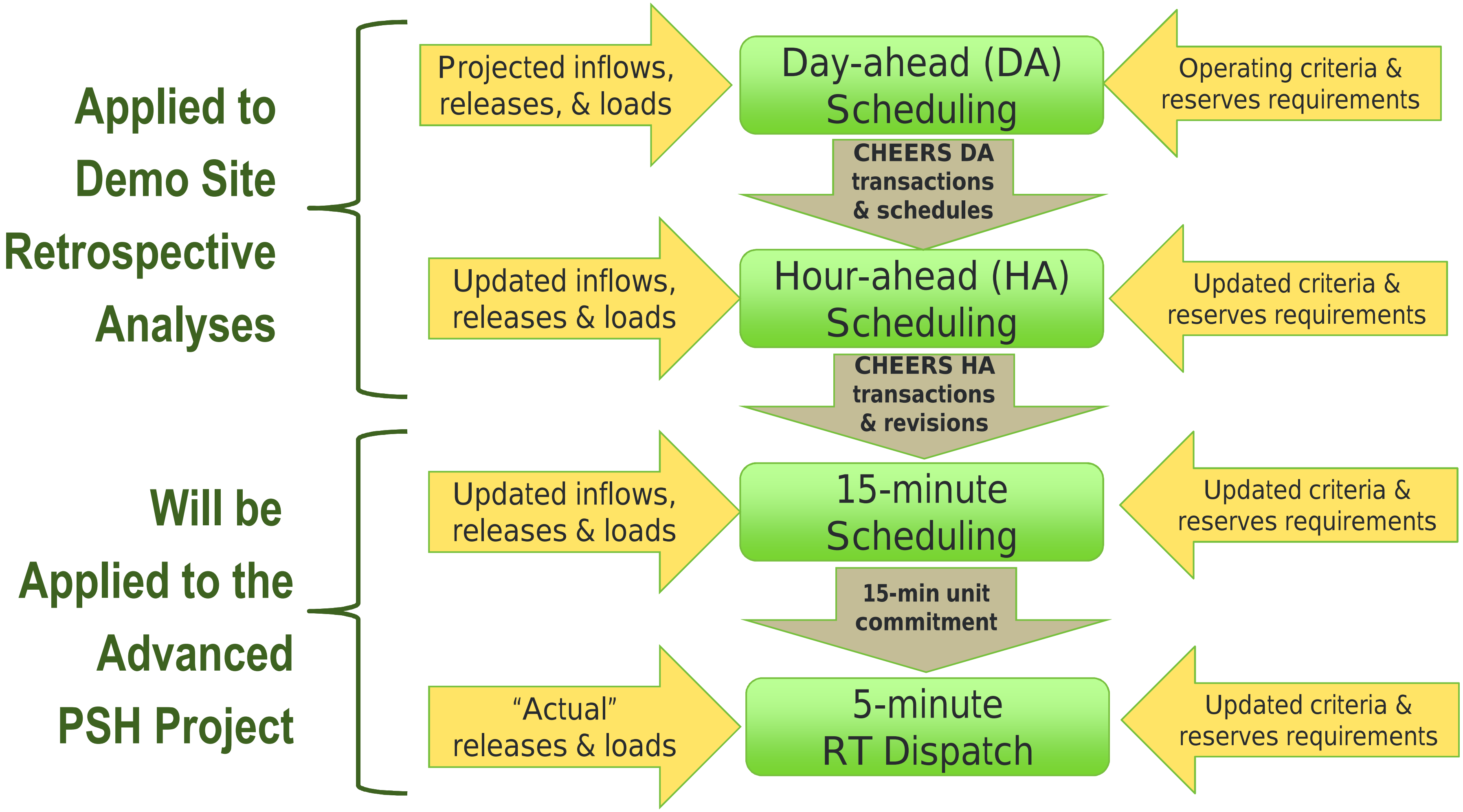
CHEERS Run Sequencing Mimics Standard Operating Procedures



CHEERS schedules include unit commitments, output levels, and ancillary service commitments

CHEERS Key and Unique Features:

- Flexible definition and use of modeled time
- Customizable model runs and iterations
- Model components are generic, not specific
- Modeled commodities (water, electricity, services, currency) and attributes are extendable
- System representation can range from simple to complex
- Operational relationships and constraints not predetermined
- Used for actual scheduling or/and for research

ADAPTABILITY

Users can model resources and situations not anticipated by the developers, without requiring source code modifications

Development:

- User interface, database, mathematical formulation, and site integration have been designed and successfully implemented

Demonstrations and Research Application:

- Completed two retrospective analyses
- Results are scheduler approved and meet rules and guidelines

	Generation Increase	Economics
CRSP:	1 - 2%	net cost reduction 19 - 25%
CDWR (same spills):	0%	revenue increase 14%
CDWR (lower spills):	14%	revenue increase 23%
CDWR (ancillary sales):	-5%	revenue increase 49%

- Used for DOE Project: Modeling and Analysis of the Value of Advanced Pumped Storage Hydropower in the U.S.

Accomplishments and Progress

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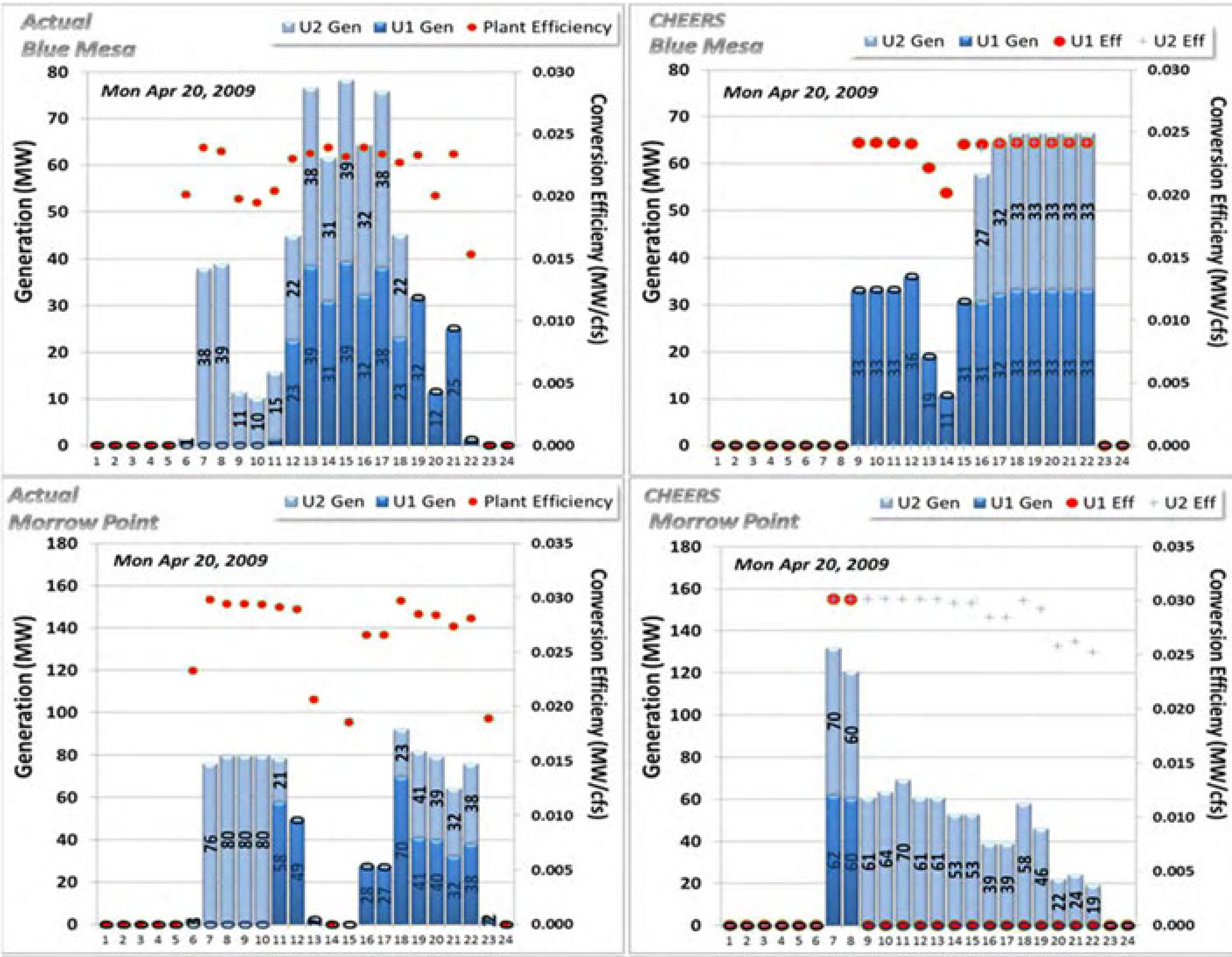
Actual Operation | **CHEERS Suggestion**

Blue Mesa Plant

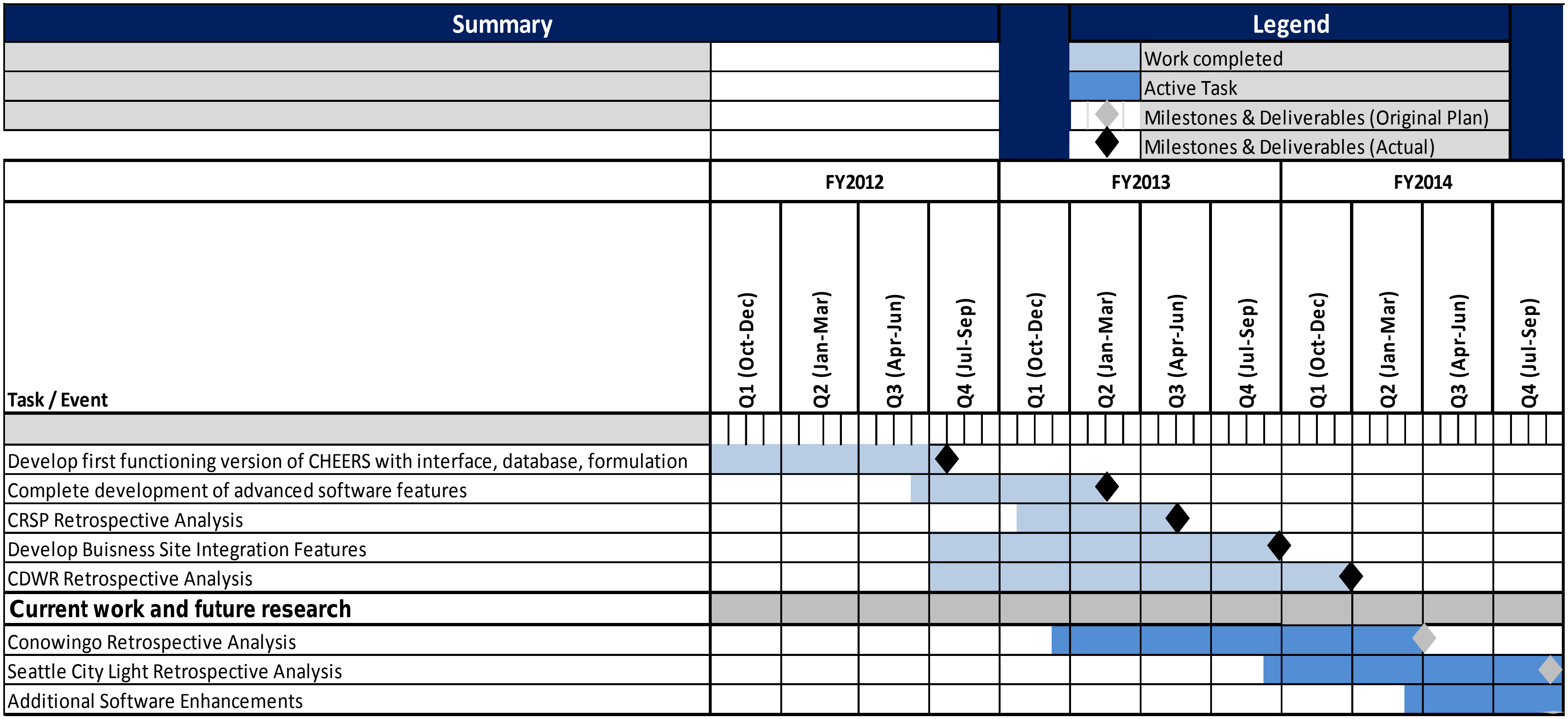
Morrow Point Plant



CHEERS Improvements

- Less ramping
- Higher efficiency
- Fewer Unit starts and stops

Project Plan & Schedule



Comments

- Development and Demonstration: Planned: FY10-12 Actual: FY10 -13,
- Tech Transfer/Refinement FY13+
- Challenges - development and testing realities, data quality, “curse of dimensionality”

FY 12, 13 Project Plan & Schedule

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

Phase 1: Development and Demonstration

Planned: FY10-12 Actual: FY10 -13

Development : Software architecture development, coding and testing

Demonstration: Apply toolset to demonstrate proof of concept and interface with site business systems

Awards:

- HydroVision – 1st place paper for Project Management and Operations, 7/12
- MORS Symposium – best in the Operational Energy Focus Session, 6/13

Phase 2: Refinement and Technology Transfer

Refinement:

- Preparation/implementation of Toolset Refinement Plan – planned and completed 6/30/13,
- Development of Beta 1 version of software – planned and completed 9/30/13

Technology Transfer:

- Software installed at CDWR and Western
- Worked on-site with CDWR and Western staff developing business model integration procedures and flexible data transfer routines

Next Steps and Future Research

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

FY14/Current research

- Retrospective Analysis for Conowingo, Skagit, and SMUD systems

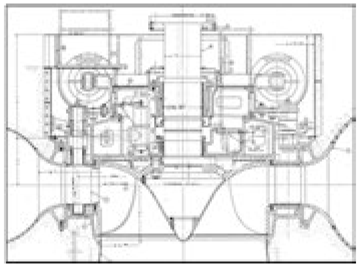
Additional CHEERS-Specific Technology Applications and Technology Transfer:

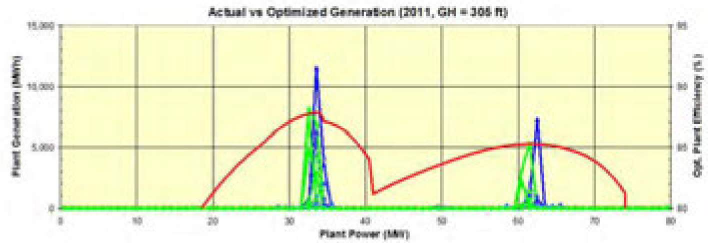
- Bureau of Reclamation (BOR) Pumped Storage Site Evaluations, FY14 & FY15
- DOE Pumped Storage Hydropower Real Time Market Analysis, FY14
- CHEERS tech transfer to BOR, FY14
- Potential application to power existing dam sites for Northern Illinois Hydropower and American Municipal Power, FY14 & FY15

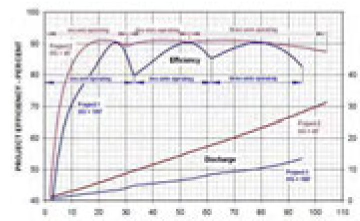
Proposed future research

Refinement: Continued development of CHEERS capability and functionality based on user and reviewer feedback

- Enhancements for data management, input specification, and user interface
- DC power flow and locational marginal price calculations
- Incorporation of stochastic market prices and real-time contingency events







Hydropower Advancement Project

Brennan T. Smith

Oak Ridge National Laboratory

smithbt@ornl.gov, (865) 241 5160

Purpose & Objectives

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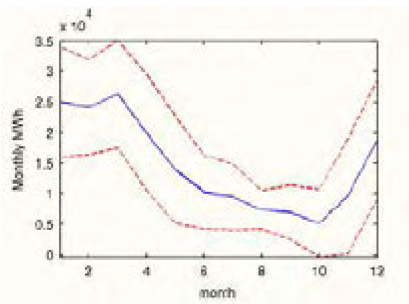
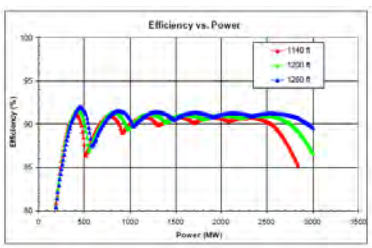




Purpose: Accelerate improvement and expansion of existing U.S. hydropower facilities to increase of annual generation and value

Objectives and Impact:

- Provide a fact-based quantitative estimate of additional energy available through improvements and expansions of U.S. hydropower assets,
- identify barriers to implementation of hydropower asset improvements and expansions,
- prioritize research that would accelerate increases in hydropower asset performance, and
- develop and disseminate Best Practices, Assessment Manual, and Analysis Tools to stimulate and accelerate increases in hydropower asset performance and value.

The HAP captures institutional and expert knowledge that is steadily disappearing from the hydropower industry.

Purpose & Objectives

Program Alignment:

The HAP scope was conceived and adjusted under an evolving set of Water Power Program objectives over the 2010-2012 life of the project. The HAP aligns with a current Program objective to:

- **Optimize existing hydropower technology, flexibility, and/or operations**

  The HAP documented and demonstrated best practices and methodologies to assess and improve the condition and performance of existing hydropower facilities.

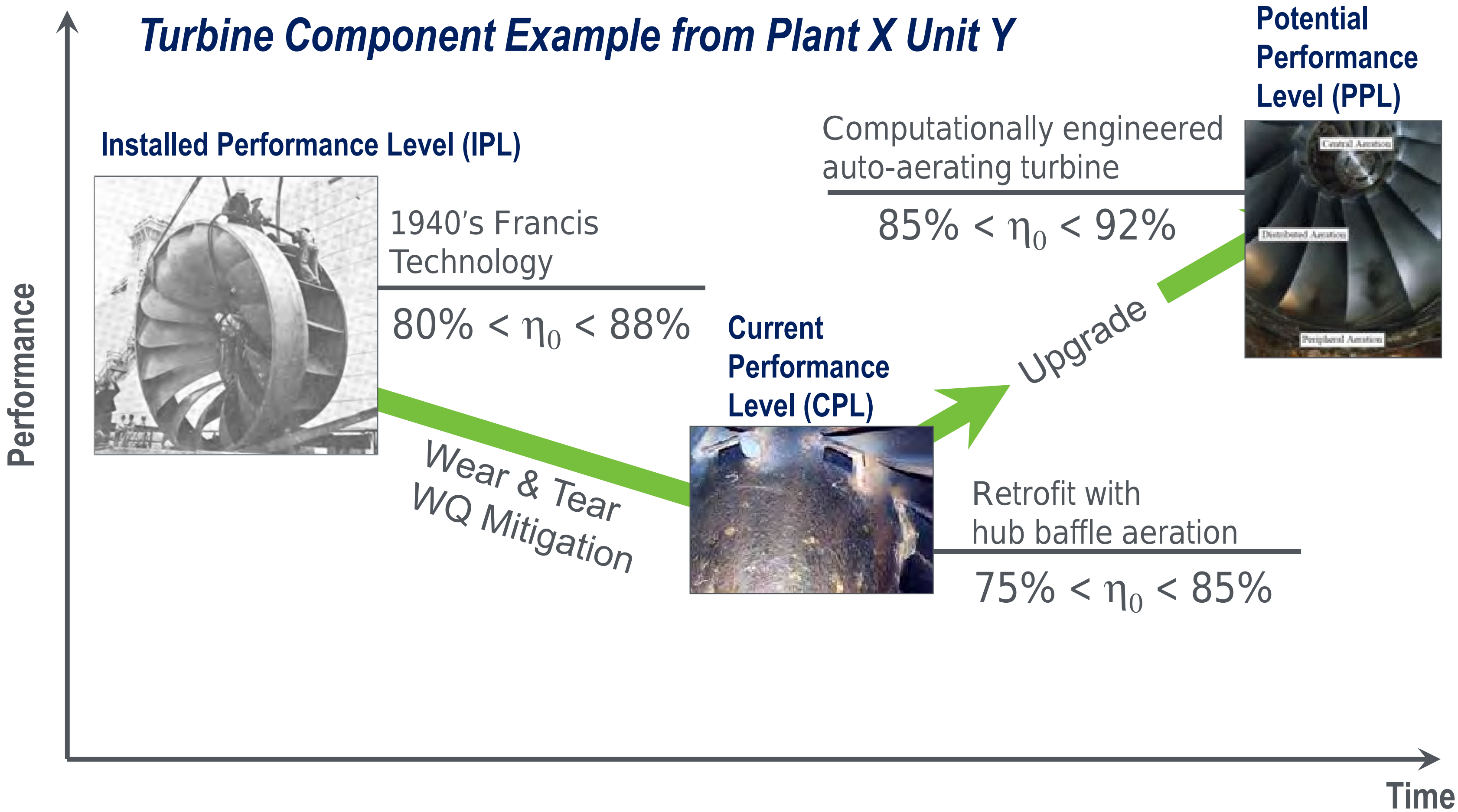
HAP Performance Levels & Assessment

Installed performance level (IPL) – achievable by the facility under design conditions and constraints that existed immediately after commissioning (installed name-plate capacity performance in most cases).

Current performance level (CPL) – usually lower than the installed performance level (IPL) due to wear and tear, or due to the operational changes in the constraints placed on a facility that prevent it from operating as originally designed.

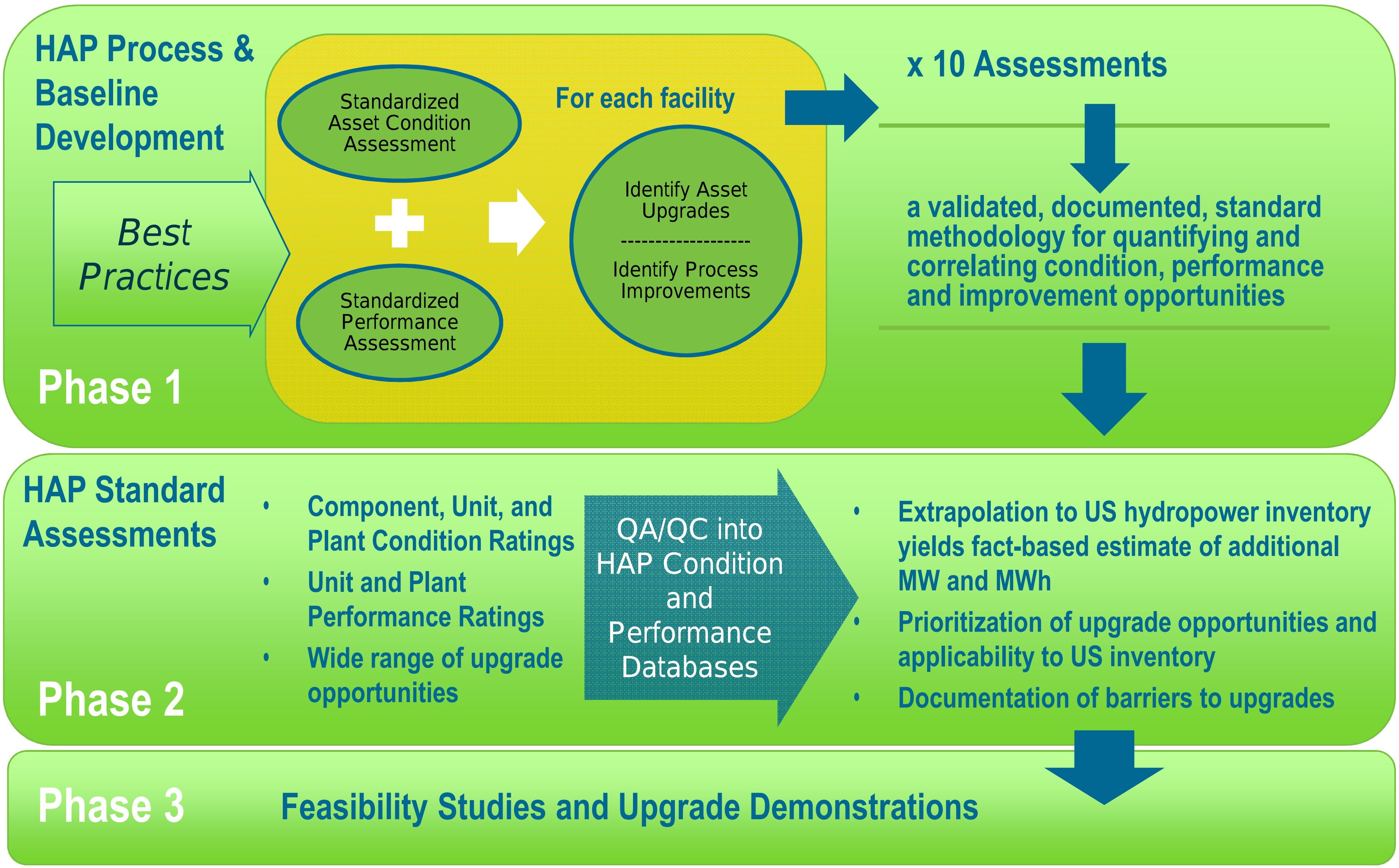
Potential performance level (PPL) – achieved under current operating constraints through upgrading or expanding to the best available technology and implementation of best practices for operations and maintenance.

HAP Performance Levels & Assessment



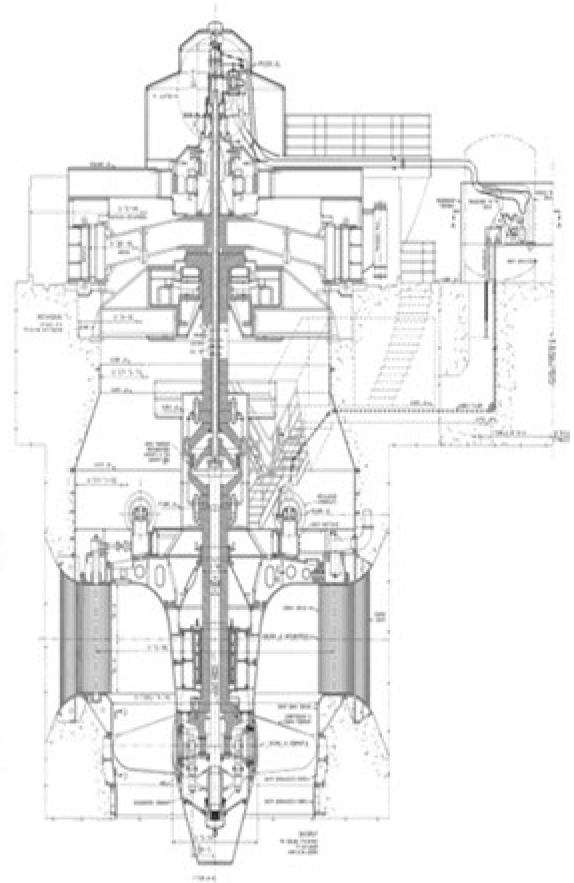
Technical Approach

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



Hydropower Technology Taxonomy

- Hydropower Facility
  - 1. Headwater/Reservoir
  - 2. Dam/Weir
  - 3. Water Conveyance
    - 3.1 Trash Racks
    - 3.2 Intakes
    - 3.3 Tunnels
    - 3.4 Penstocks
    - 3.5 Control/Shut-off Valves
    - 3.7 Flumes/Open Channels
    - 3.8 Draft Tube Gates
  - 4. Powerhouse
    - 4.1 Power Train Equipment
      - 4.1.1 Turbine
        - 4.1.1(a) Francis Turbine
        - 4.1.1(b) Propeller/Kaplan Turbine
        - 4.1.1(c) Pelton Turbine
      - 4.1.2 Governor
      - 4.1.3 Generator
        - 4.1.3.1 Stator
        - 4.1.3.2 Rotor
        - 4.1.3.3 Ventilation & Cooling System
        - 4.1.3.4 Neutral Grounding
        - 4.1.3.5 Thrust Bearing & Cooling System
        - 4.1.3.6 Guide Bearing & Cooling System
        - 4.1.3.7 Generator Shaft
      - 4.1.4 Exciter
      - 4.1.5 Transformer
      - 4.1.6 Circuit Breakers
    - 4.2 Balance of Plant/Auxiliary Components
    - 4.3 Instruments & Controls
    - 4.4 Powerhouse Structures
  - 5. Tail water
  - 6. Switch Yard
  - 7. Navigation Locks



Standardization of physical hierarchy is key to meaningful analyses and trending

- Provides physical and functional hierarchy for Best Practices, Ratings, and Component Condition Database
- Provides consistent nomenclature for facility characterization, reporting and team/assessor communication
- Enables detailed component level queries of component conditions across multiple projects
- A reference and basis for future asset management research

Technical Approach

Best Practices Catalog (BPC)

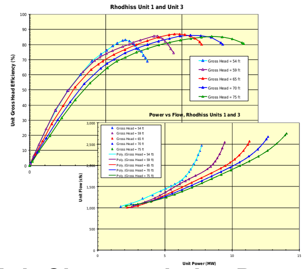
- **Concepts**
  - ➢ Functional requirements
  - ➢ Typical configurations for components
  - ➢ Efficiency role of components
  - ➢ Reliability role of components
  - ➢ Concise history of technological evolution
  - ➢ Summary of State-of-the-art technology
  - ➢ Typical O&M requirements
  - ➢ References to testing protocols
- **Components covered**
  - ➢ Turbines (Francis, Propeller, Pelton)
  - ➢ Generators
  - ➢ Water Conveyances
  - ➢ Main Transformers
  - ➢ Trash Racks & Intakes
  - ➢ Instrumentation and controls for condition monitoring
  - ➢ Instrumentation and controls for automation
- **Special topics**
  - ➢ Uncontrolled water leakage
  - ➢ Flow releases
  - ➢ Operational impacts of environmental mitigation systems

Condition Rating Workbooks

- **Excel Workbook files**
  - ➢ User (assessor) fields to enter part scoring
  - ➢ Predefined rating scales for ease of use and consistency among different assessors
  - ➢ Providing additional guidance for files and fields
- **Components covered**
  - ➢ Turbines (Francis, Propeller, Pelton)
  - ➢ Generators
  - ➢ Water Conveyances
  - ➢ Main Transformers
  - ➢ Trash Racks & Intakes
  - ➢ Instrumentation and Controls for Automation and Condition Monitoring
  - ➢ Instrumentation for Unit Performance Measurement
- **Rating structure**
  - ➢ Component specific weighting factors for parts (e.g. wicket gates, runner, shaft, …)
  - ➢ Weighted scores for Age, Physical Condition, Technology Level, Operating Impact, Maintenance Demands, and/or other specific metrics

Overview of Performance Assessment

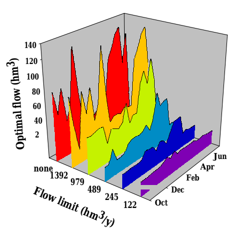
DATA



Unit Characteristics Data:
1. Installed Performance Level (IPL)
2. Current Performance Level (CPL)
3. Potential Performance Level (PPL)

Timestamp (Five minute intervals)	Station Total Output (MW)	Station Total Flow (CFS, computed)	Forebay Water Level (elev., ft)	Tailrace Water Level (elev., ft)	Unit 1 (MW)	Unit 2 (MW)	Unit 3 (MW)	Unit 1 (Gate Position)	Unit 2 (Gate Position)	Unit 3 (Gate Position)
10/1/2004 0:00	23.7	950	996.5	934	7.9	7.9	7.9	76.2	71.5	68.9
10/1/2004 0:05	24	950	996.6	934	8.1	8.1	7.8	73.4	71.4	62.7
10/1/2004 0:10	23.8	950	996.7	934	7.9	8.2	7.7	75.1	76.8	62.7
10/1/2004 0:15	23.7	950	996.6	934	7.8	8.1	7.8	79.7	77.6	68.9
10/1/2004 0:20	23.4	950	996.8	934	7.7	7.9	7.8	74.3	74.3	71.5
10/1/2004 0:25	23.3	950	996.7	934	7.8	7.8	7.7	71.8	71.8	71.4
10/1/2004 0:30	23.6	950	996.5	934	7.7	7.7	8.2	70.8	70.8	76.8
10/1/2004 0:35	24.6	950	996.6	934	8.2	8.2	8.2	72.9	68.9	77.6
10/1/2004 0:40	24.1	950	996.7	934	7.9	8.1	8.1	76.2	71.8	76.2
10/1/2004 0:45	23.6	950	996.6	934	7.8	7.9	7.9	73.4	70.8	74.9
10/1/2004 0:50	23.3	950	996.8	934	7.7	7.8	7.8	75.1	68.9	72.9
10/1/2004 0:55	23.2	950	996.7	934	7.8	7.7	7.7	79.7	71.5	72.9
10/1/2004 1:00	23.4	950	996.8	934	7.8	7.8	7.8	72.9	68.9	77.6

Facility Operational Data



Facility Hydrological Data

ANALYSIS TOOLS

Optimization Engine

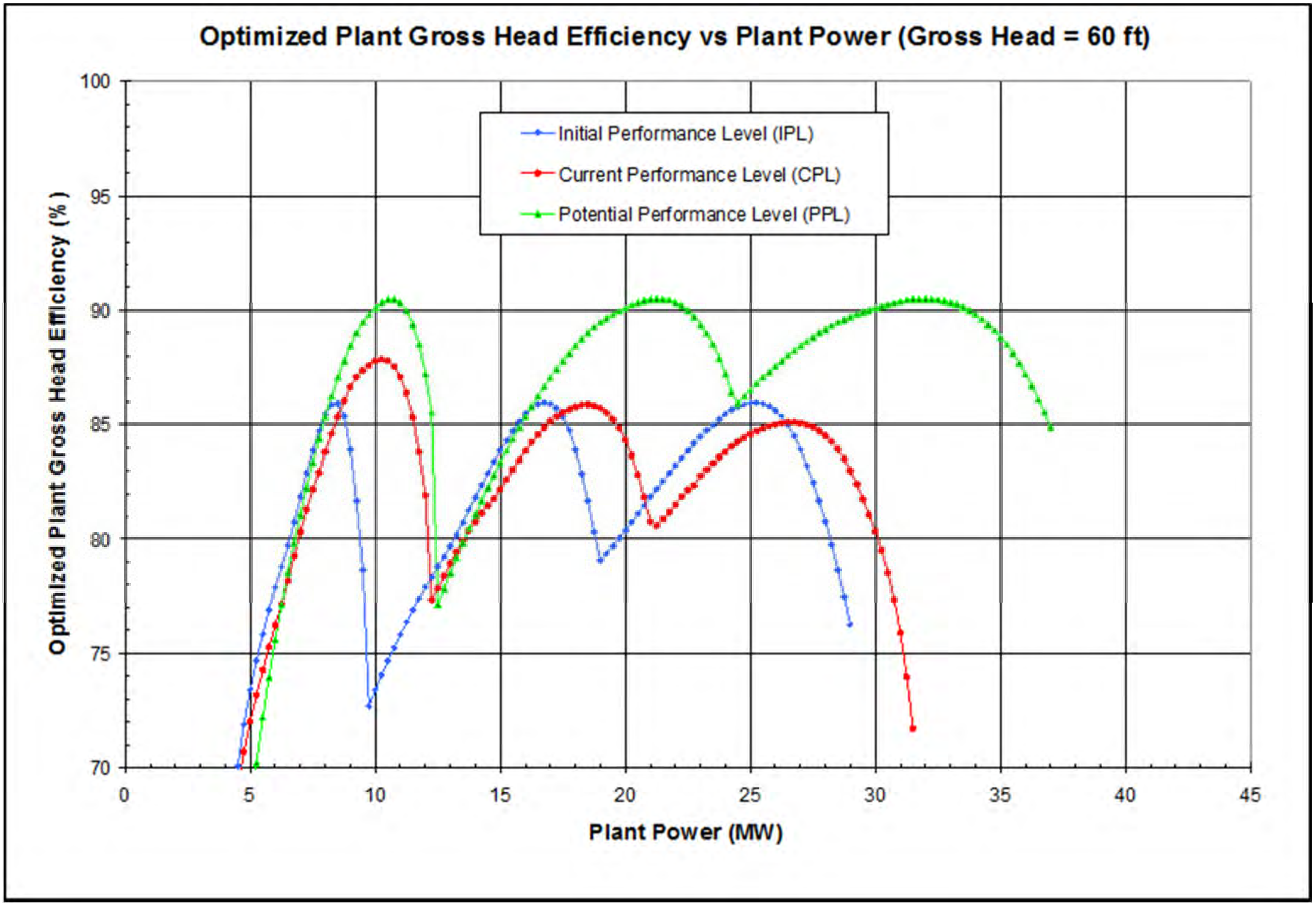
Computation Engine

PERFORMANCE ANALYSES

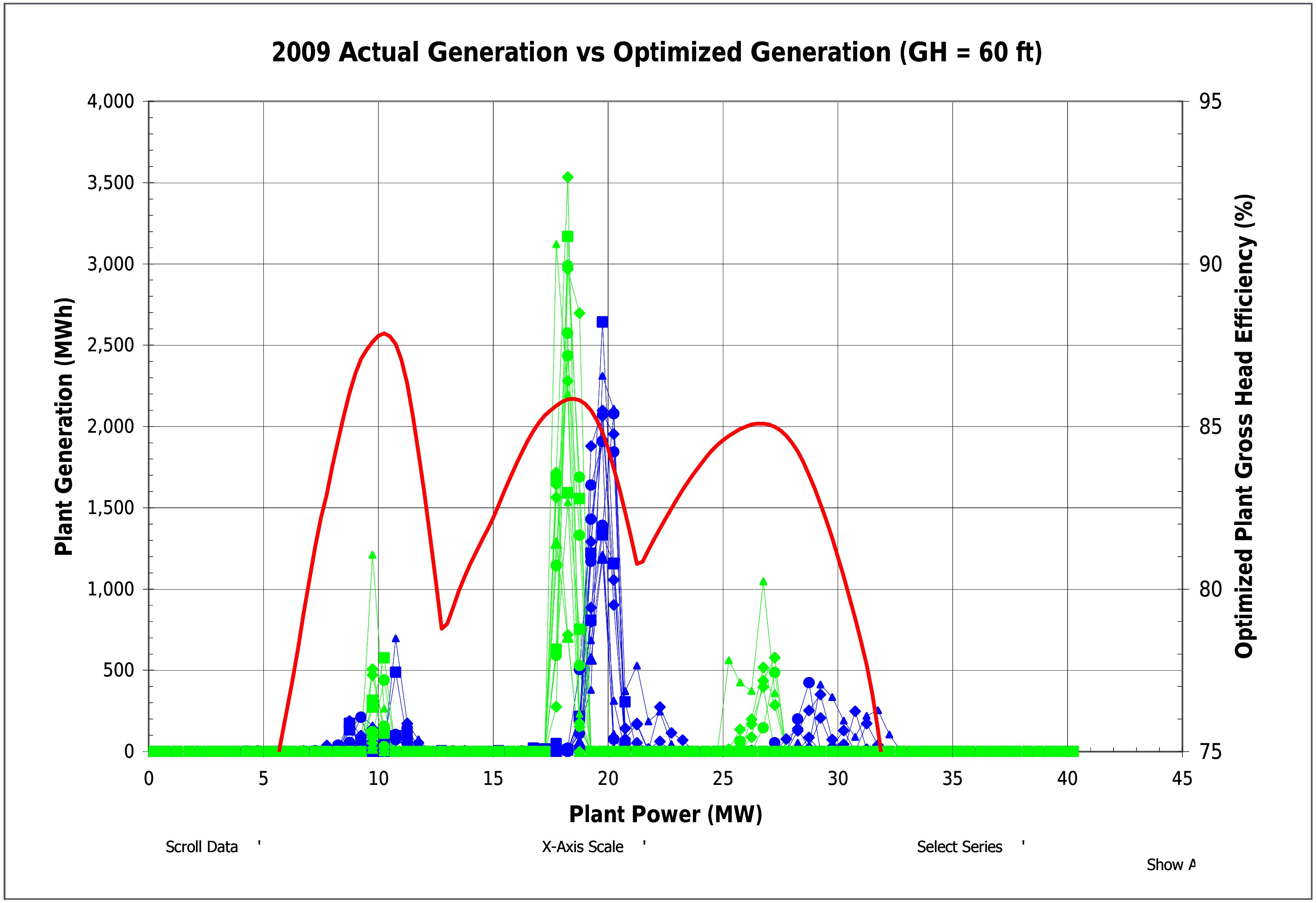
Optimization Engine →
- Operation Efficiency Analyses
- Scheduling Analyses
- Avoidable Loss Analyses
- Correlation Analyses

Computation Engine →
- Average Energy Production
- Long Term Production Potential
- Long Term Stream Power

Opt. Plant Gross Head Efficiency vs Plant Power (GH = 60 ft)



Typical Results from Scheduling Analyses (2009; GH = 60 ft)



Accomplishments and Progress

Online documentation and tools to support the assessment process:

- Hydropower Technology Taxonomy
- Best Practices Catalog

Assessment Manual

- Process Guidance
- Component Rating Workbooks
- Component Rating Checklists
- Plant Performance Calculator

Duke Energy's Rhodhiss Facility

Reports provide insight into the state of existing U.S. hydropower assets

- Non-Public Business-Sensitive Assessments
  - Protected by Non-Disclosure Agreements
  - Individual Project Performance and Condition Ratings
  - QA/QC of selected flow and generation data
- Public reports with overall findings

✓ Center Hill (USACE-Nashville)
✓ Rhodhiss (Duke Energy)
✓ Flaming Gorge (Reclamation)
✓ Watauga (TVA)
✓ Tuckertown and Falls (APGI)
✓ Nisqually (Alder/LaGrande; Tacoma)
• *Rock Creek and Caribou I (PG&E)* - suspended

Reclamation's Flaming Gorge Facility

Accomplishments and Progress

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

Significant new energy can be obtained through upgrades and improved efficiency, but there are challenges to be addressed.

Plant Installed Capacity (MW)	Design Head (feet)	Turbine Type	Year of initial Commissioning / upgrade	Current Annual Average Generation (MWh)	Potential Annual Generation Increase (MWh)	Potential Generation Increase (%)	Preliminary Cost Est. for Recommended Upgrades* (10^6 $)
28.2	59	Francis	1925 / 2006	46,900	4,600	9.8%	3.6
135	160	Francis	1951 / 1990	342,900	14,400	4.2%	28.1
152	400	Francis	1964 / 2007	436,400	9,600	2.2%	1
38	53.5	Propeller /Francis	1962 /1993	77,300	8,500	11%	13
31	54	Kaplan	1919 / 1990	85,900	24,740	28.8%	20.4
57.6	216	Francis	1949 / 1997	108,100	7565	7%	18
50	273	Francis	1945 / 2005	230,000	27,603	12%	19.2
64	403	Francis	1912 / 2006	365,900	23,417	6.4%	13.8
Total				**1,693,400**	**120,425**	**7.1%**	

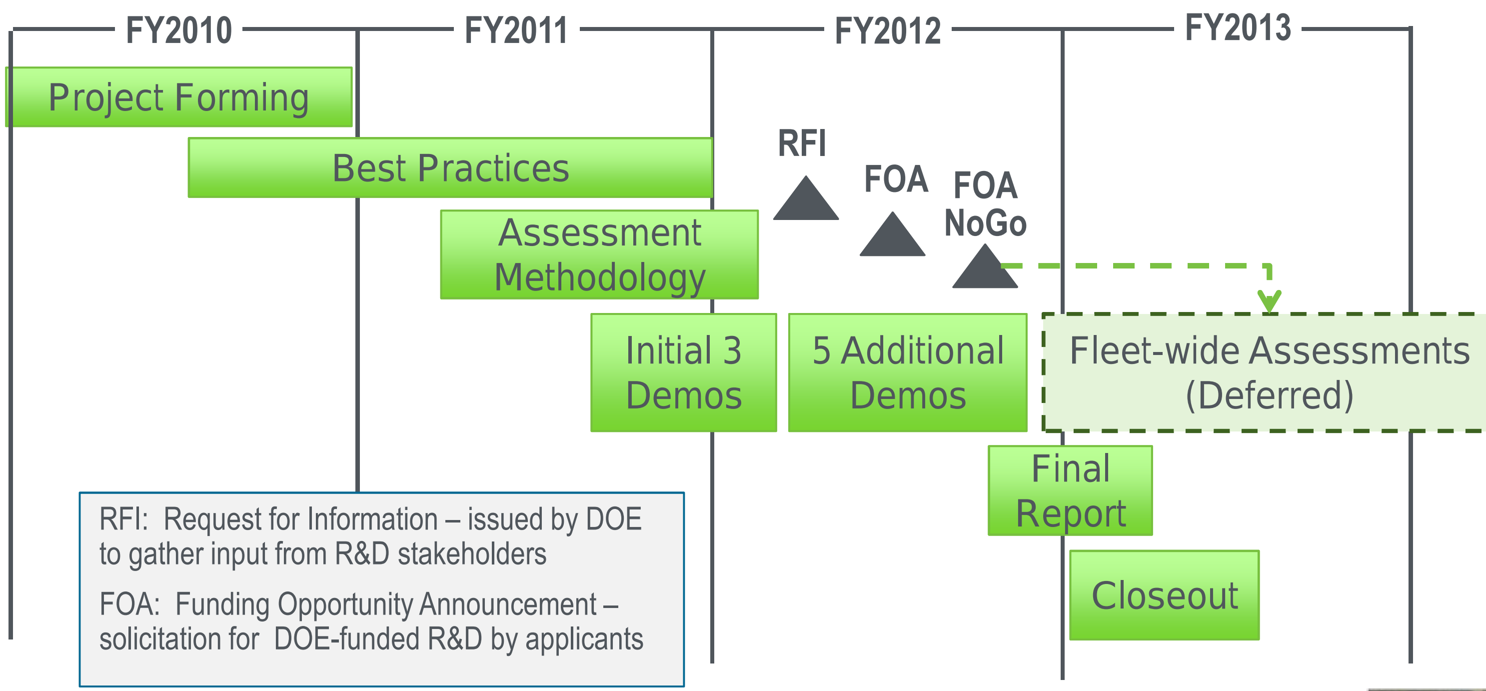
Challenges
- Licensing amendment risks
- Competing water uses
- Reliability concerns
- Increased market dynamics
- Competition for capital

7.1% average increase in generation for surveyed facilities (very site-specific)

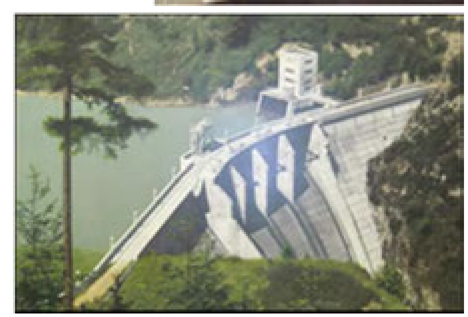
TVA's Watauga Facility

Project Plan & Schedule

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



Alcoa Falls Facility



Tacoma Power's LaGrande Dam

Basis for August 2012 FOA No-Go decision:

- FY2013 budgets did not evolve as expected
- Less than enthusiastic industry response to FOA
- Shift in programmatic focus towards new hydropower R&D

Project Budget

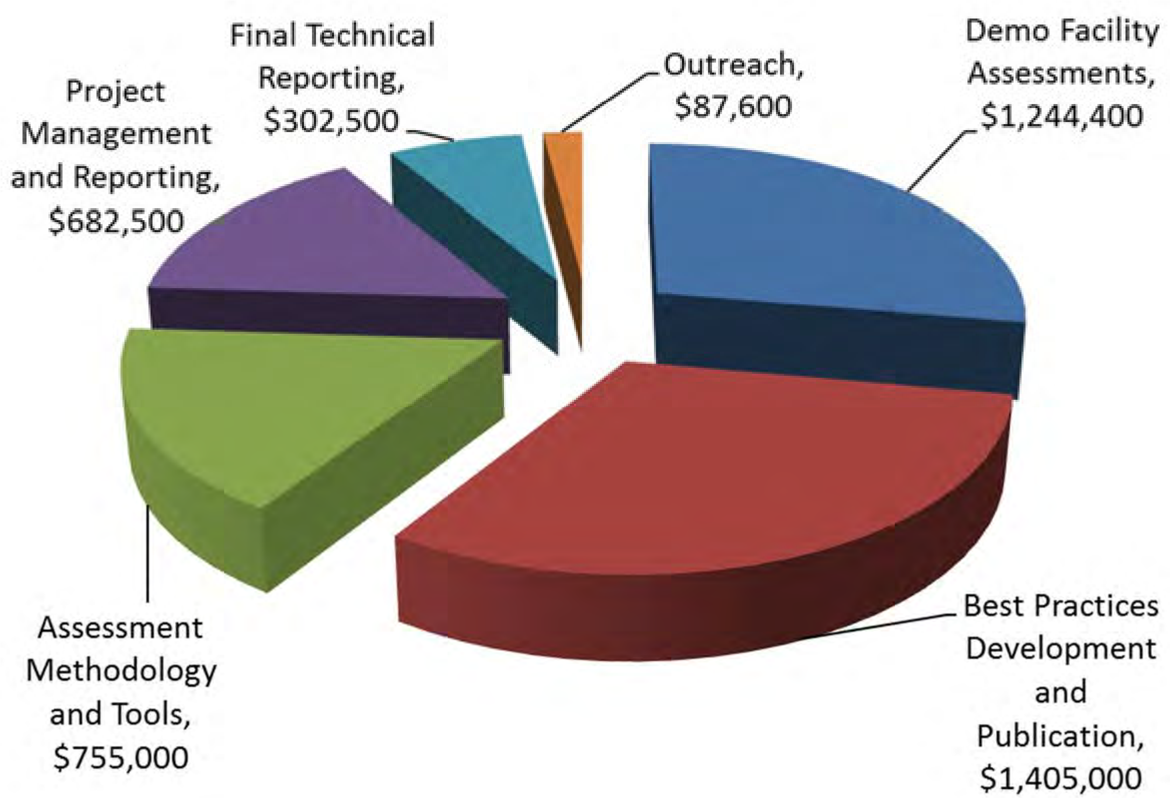
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Budget History					
FY2010-2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$4,477K	$80K*	0	0	0	0

*Expenses for hydropower facility staff participation are estimated at 8 sites, 100 hours per site, and $100 per hour labor expenses.

Total Cost of HAP

$4.477M

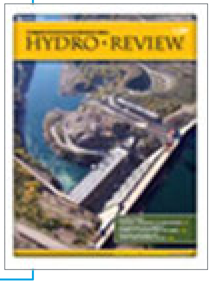


Partners, Subcontractors, and Collaborators:

- **Mesa and Associates**
  - Hydropower Design, Asset Management, and Operations Expertise
  - Equipment best practices drafting, assessment methodology, execution of condition assessments
- **Hydro Performance Processes, Inc.**
  - Optimization best practices, performance assessment methodology and execution
- **Facility Owners**
  - Corps of Engineers, Reclamation, Duke Energy, TVA, Alcoa Power Generation, Tacoma Power, PG&E

HAP Communications and Technology Transfer:

- Hydrovision 2012 pre-conference workshop on asset assessment
- Technical presentations:
  - March, P., P. Wolff, B.T. Smith, Q. Zhang, R. Dham. *Data-Based Performance Assessments for the DOE Hydropower Advancement Project*, Hydrovision 2012, Lousiville, KY.
  - Zhang, Q., B. T. Smith, M. Cones, P. March, R. Dham, M. Spray, *Methodology and Process for Condition Assessment at Existing Hydropower Plants*, Hydrovision 2012, Lousiville, KY.
  - Smith, B.T., Q. Zhang, M. Cones, P. March, R. Dham, and M. Spray. *Best Practices Implementation for Hydropower Efficiency and Utilization Improvement*, Hydrovision 2012, Lousiville, KY.
  - Smith, B.T. *Hydropower R&D at ORNL*. 3rd Annual Hydro Plant Maintenance & Reliability Workshop, November 6-7, 2013, Denver, CO.
- Journal Paper
  - Zhang, Q. and B. T. Smith. 2013. Developing a Quantitative Method for Assessing Plant Conditions. *Hydro Review*, December 2103.



Outcomes:

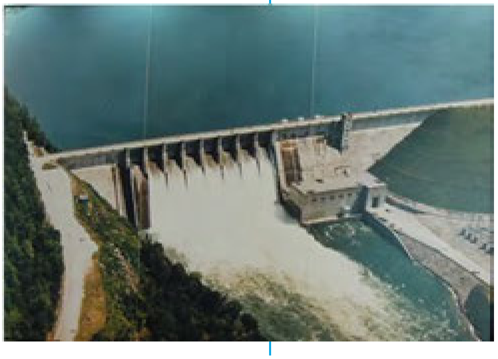
- DOE will use the results of the HAP to inform its R&D investments for existing hydropower facilities.
- The HAP captured and documented industry best practices for 20 power plant component systems. Those best practices are available to all as reference materials.
  - NHA-HPC Operational Excellence Subcommittee interested in stewardship of Best Practices documents.
  - Nomenclature and hierarchy of hydropower technology established by the HAP is being used in multiple Program efforts
  - Leveraged decades of practitioner experience into public documents that can inform next generation of hydropower engineers
- The HAP showed that there is significant potential for increases in annual generation from existing hydropower assets (7.1% average for assessed facilities).
- Lesson learned: responses to advertised HAP opportunities revealed a desire for focus on best practices for operating and improving small and mid-sized hydropower facilities more so than large facilities

Next Steps and Future Research

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

Proposed future research: The HAP is concluded, but experience and results gained provide insights into the scope, objectives, and technical approach for multiple new projects and inquiries:

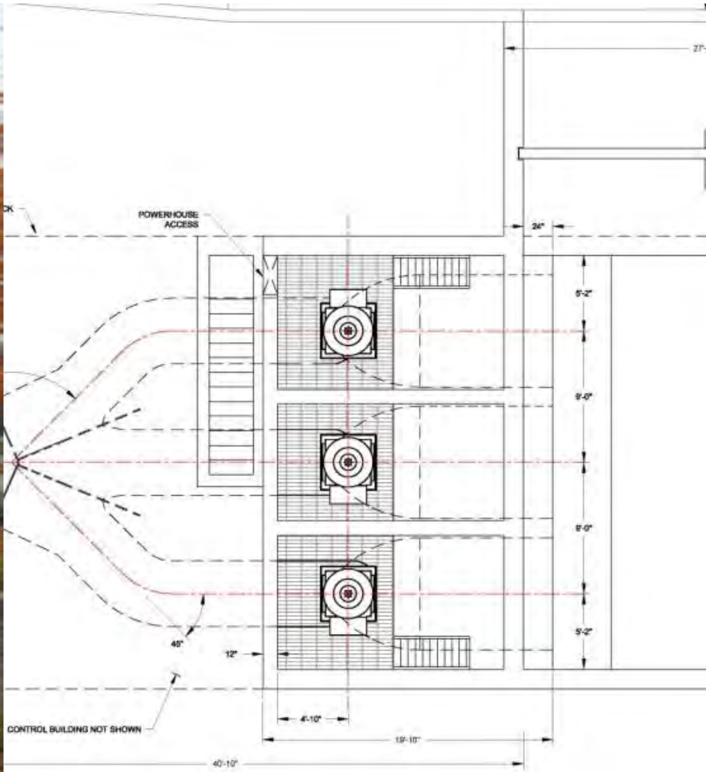
- New Projects
  - Hydropower Flow Measurement
  - Hydropower Cost Modeling
  - New Hydropower Innovation Collaborative
  - Quantification of Reliability and Cost Impacts for Hydropower Assets
- DOE/DOI/DOD Hydropower MOU items
  - Data collection and archiving best practices for hydropower systems
- Hydropower Benchmarking as a management driver for best practices and capital investments



Corps of Engineers Center Hill Facility

Water Power Peer Review

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



The 45 Mile Hydroelectric Power Project (*formerly the 51 Mile Hydroelectric Project*)

J Gordon

Earth By Design, Inc.

jgrenewables@hotmail.com, 541 385 1135

February 20, 2014

Purpose & Objectives

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

Problem Statement: Demonstrate developing low-head hydro sites utilizing innovative technologies and advanced methodologies to lower Levelized Costs of Energy (LCOE)

Impact of Project: Provide demonstrated evidence of the ability to develop low-head hydropower across the U.S. at an affordable rate, expanding the potential for more low-head hydro sites to be developed[1].

This project aligns with the following DOE Program objectives and priorities: Advance new hydropower systems and/or components for demonstration or deployment

Technical Approach

- Project Goals are achieved through:
  - Innovative solutions to construction of hydroelectric power in confined spaces, in a mature, open access, control area governed by State and Federal PURPA laws.
  - Integration of unique, innovative hydroelectric turbine technology with a lower cost providing long-term, reliable energy production.
- This project is addressing the key issues of:
  - Traditionally high costs associated with the construction of hydroelectric power and technology.
  - Streamlining the process of working with stakeholders and regulatory agencies to more rapidly construct projects.
  - Demonstrate a high-efficiency, high baseload project that provides significant power for the grid.
- Unique aspects of the project include:
  - Innovative construction and manufacturing methodologies.
  - Innovative technology with strong performance results.
  - Effective planning and management utilizing advanced expertise in the hydroelectric industry coordinated with Stakeholder support.

Accomplishments and Progress

- The most important technical accomplishments between 2012 – 2013 were the identification of an innovative technology solution, meeting regulatory deadlines and proceeding with construction.[1]
  - **Beyond the original scope of this project, multiple technologies were identified and evaluated with the ability to meet the goals of this grant (within the LCOE goals).**
  - **Additionally, a new project site was identified and secured for improving overall performance of this project.**
- This project is on target with its initial goals for identifying and testing the right technology and is well underway to putting that technology into place for demonstrated performance.
- This project has received strong support for its clean methodologies and strategies for site selection and reduced footprint by multiple stakeholders.[2]

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	
Project Number	
EE00005430	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: 45 Mile Hydroelectric Project: Developing Low Head Hydro at a reduced LCOE												
Task 1: Permitting and Interconnection Activities												
Task 2: Engineering Design Services												
Task 3: Technology Demonstration, Testing and Reporting												
Task 4: Construction												
Task 7: Plant Operations												
Task 6: Final Site Equipment Testing & Reporting												
Current work and future research												
Task 5: Equipment Testing												

Comments:

- Project planned completion date and testing period on schedule. A full, 3.0 MW hydroelectric facility will be constructed 2.5 years[1].

- Changes from site relocation, additional technology evaluation, engineering work, and working through the permitting and licensing process to better identify mitigation opportunities delayed initial milestones, setting back some of the start dates for other tasks (without affecting the availability of a demonstration & testing period).

- Key points in 2013: Completion of pre-construction activities; including interconnection and transmission, permitting and licensing, vendor services, technology evaluation and identification, and financing.

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$ 898,600	$ 649,048	$ 125,000	$ 344,790	$ 176,400	$ 4,495,649

- Budget has changed due to:
  - A change in project site location
  - Additional technology evaluation (not in original scope)
  - Minor, additional regulatory work
- 40% of the budget has been expended to date with an accelerated expenditure by EBD anticipated through construction, demonstration of technology and project completion.

Partners, Subcontractors, and Collaborators:

The primary group that EBD is working with includes:

- Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee
- DOE Golden Field Office, Colorado,
- Knight Piésold & Co. Denver, Colorado

Communications and Technology Transfer:

Two Technical Papers were presented at[1]:

- Hydrovision International Conference, July, 2012
- Hydrovision International Conference, July, 2013

Next Steps and Future Research

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

FY14/Current research: In 2014, construction that is already underway will be completed, followed by a report with findings about the performance, readiness, capability, strengths and weaknesses, limitations, and potential full-scale deployment and application in the United States.

The upcoming milestones for this project are:

- April, 2014: Installation of turbines
- September, 2014: Demonstration and evaluation of technology

Proposed future research: This project will provide readily quantifiable data for realizing the potential from low-head hydro sites nation-wide, expanding on assessments of hydropower development opportunities.

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

IEA HYDROPOWER
The International Energy Agency Implementing Agreement for Hydropower Technologies and Programmes

CEATI INTERNATIONAL
Centre for Energy Advancement through Technological Innovation

EUCG Your Energy Information Source
A global association of utility professionals and member companies which is recognized as the electric energy industry source for performance information

International Collaboration

Brennan T. Smith

Oak Ridge National Laboratory

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Purpose & Objectives

- Purposes
  - International collaboration enhances the breadth and depth of scientific and technical research for the Water Power Program
  - DOE-funded hydropower research outcomes are shared with and vetted by an international community of researchers and practitioners.
  - DOE Water Power Program participants gain access to research and practices from the international hydropower community.

- Program alignment
  - Optimize existing hydropower technology, flexibility, and/or operations
  - Reduce deployment barriers and environmental impacts of hydropower
  - Some technology and new development R&D

Technical Approach

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

International Collaboration occurs in three major forum:

- International Energy Agency, Implementing Agreement for Hydropower Technologies and Programs
  - Executive Committee
  - Annex II – Small Scale Hydropower
  - Annex IX – Hydropower Services
  - Annex XI – Hydropower Rehabilitation
  - Annex XII – Hydropower and the Environment
    - Task 1: Managing the Carbon Balance in Freshwater Reservoirs
    - Task 2: Update of Phase 1 Recommendations on Hydropower and the Environment
  - Annex XIII – Hydropower and Fish
- CEATI Interest Groups
  - Hydraulic Plant Life, Hydropower Operations, Dam Safety
- Electric Utility Cost Group, Hydroelectric Productivity Committee

Technical Approach

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

ORNL efforts in FY2014 are focused on ensuring that forum participation is highly leveraged:

- Requiring research targets for IEA Annexes and mapping to Programmatic activities:
  - Annex II Small Scale Hydro: Technology Database, Policy Analysis → DOE New Hydropower Innovation Collaborative
  - Annex XII Task 1: GHG modeling → DOE WQ Optimization, Reservoir GHG Modeling Workshop
  - Annex IX Task 2: Hydro non-energy services – DOE cost modeling and market reporting
  - Annex IX Task1 by ANL, Annex XIII by PNNL
- CEATI
  - Hydropower Flow Measurement Research with ASME PTC-18
  - Quantification of Reliability and Cost impacts for Hydropower Assets
- Electric Utility Cost Group, Hydroelectric Productivity Committee
  - Active collaboration on DOE Hydropower Cost Model, Hydropower Market Report
  - Adjustment of cost and productivity metrics for hydrologic and regional labor cost variation

Technical Approach

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

- Annex II – Small-Scale Hydro
  - Subtask A1/B2: Website and Innovative Technologies Catalog
    - http://www.small-hydro.com
  - Subtask A3: Policy and Programs – draft report with country submissions at Hydro 2014, October 2014
  - Subtask A5: Sustainable Small-Scale Hydropower in Local Community
- Annex XII Task 1 - Managing the Carbon Balance in Freshwater Reservoirs
  - ORNL/PNNL/DOE GHG measurements and analysis included in *Volume 1: Guidelines for the Quantitative Analysis of Net GHG Emissions from Reservoirs*
  - ORNL will host April 2014 workshop to prepare draft *Vol. 2, Guidelines and Best Practices for the Modeling of GHG Emissions*
    - *Cost-hosted with CEPEL/Brazil*
    - *Participation from International Hydropower Association*

Project Plan & Schedule

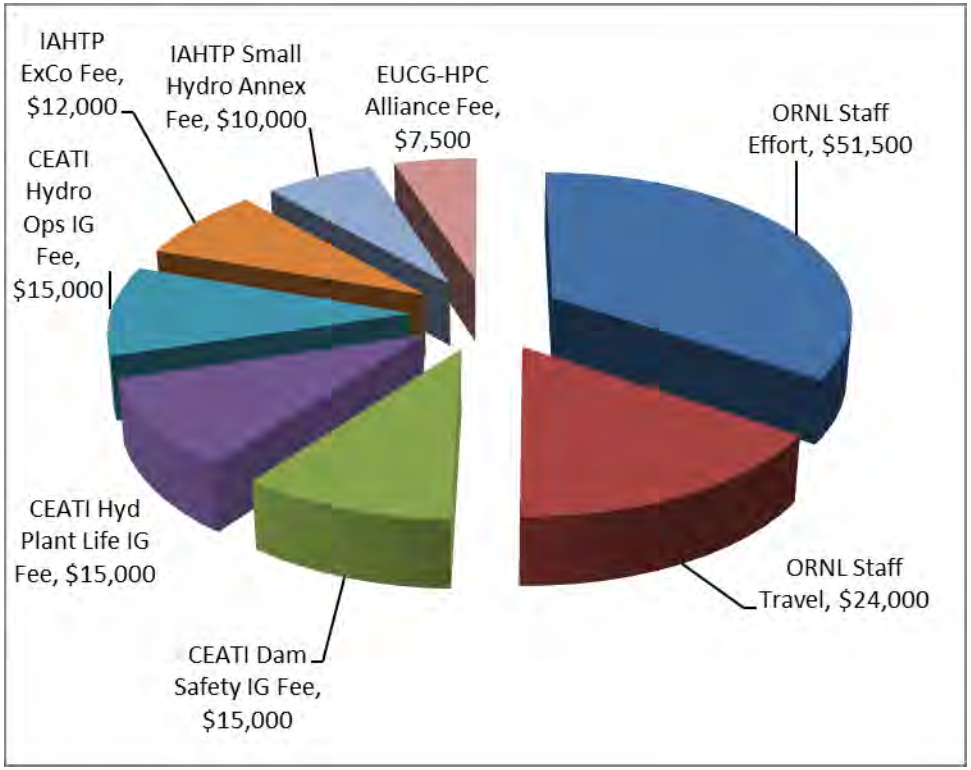
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- IEA participation:
  - USA participation in October 2013 ExCo/Annex meetings cancelled during federal shutdown
  - April 2014 Annex XII GHG modeling workshop at ORNL
  - May 2014 Annex II, Small Hydro Policy & Experience Workshop, Hydroenergia 2014, Istanbul (tentative)
  - June 2014 IEA ExCo, Rovaniemi, Finland
- CEATI Spring Workshop, March 17-21, 2014, Palm Desert, CA
  - ORNL and HQ staff to establish scope of participation
- EUCG Hydroelectric Productivity Committee
  - CRADA finalized, data sharing begins February 2014
  - Data assimilation and initial hydrologic, labor adjustments March 2014
  - Annual Report draft and Analyses Plan firmed at April 2014 meeting

Project Budget

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

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
0	0	$150K	0

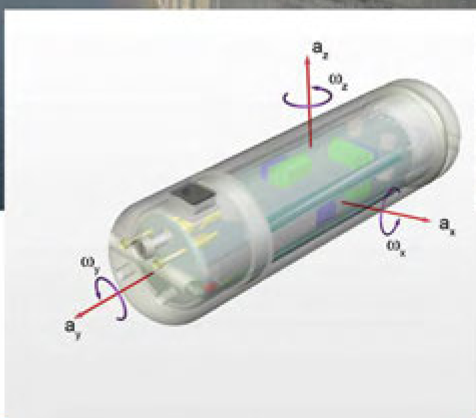


Communications and Technology Transfer

- ORNL issues quarterly activity reports to disseminate international activities to Water Power Program participants.
  - HQ and Golden Field Office staff
  - Other national laboratories
- Regular reports of IEA and CEATI engagement with ORNL and program participants are made to Program partners.
  - Hydropower MOU partners (Corps and Reclamation)
  - Federal Inland Hydropower Working Group
  - National Hydropower Association
- Specific issue-based international collaborations are included in outreach for funded program activities.
  - New Hydro Innovation Collaborative
  - Hydropower Flow Measurement
  - Quantification of Reliability and Cost Impacts
  - Hydropower Cost Modeling
  - Hydropower Market Report

Next Steps

- IEA Hydropower
  - Prepare matrix to map Program activities to IEA activities
  - Harmonize Annex II Small-Scale Hydro activities with New Hydropower Innovation Collaborative
- CEATI
  - Assimilate Interest Group priorities and activities
- EUCG-HPC
  - Finalize CRADA
  - Proceed with data assimilation and analysis
  - Year 1 CRADA review in March 2015



Hydropower International Collaboration—IAHTP Annex XIII on Fish Passage Issues

Daniel Deng, Rich Brown, Simon Geerlofs
Pacific Northwest National Laboratory
Simon.geerlofs@pnnl.gov 206 528 3055
February 25, 2014

Purpose & Objectives

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

Problem Statement: Rapid development of international hydropower resources requires state of the art science on fish passage issues; U.S hydropower growth will require advanced and proven approaches.

Impact of Project: leverage learning on fish passage issues associated with rapid international hydropower development to the U.S. context

This project aligns with the following DOE Program objectives and priorities Reduce deployment barriers and environmental impacts of hydropower

Technical Approach

- Support the WWPTO and partners through participation in the IEA Implementing Agreement on Hydropower Technology Program's (IEA-IAHTP) Annex XIII on Fish Passage.

- Attend and present at Annex XIII meetings, engage with annex partners, and contribute expertise in fish passage biological issues, instrumentation, field research, and data analysis.

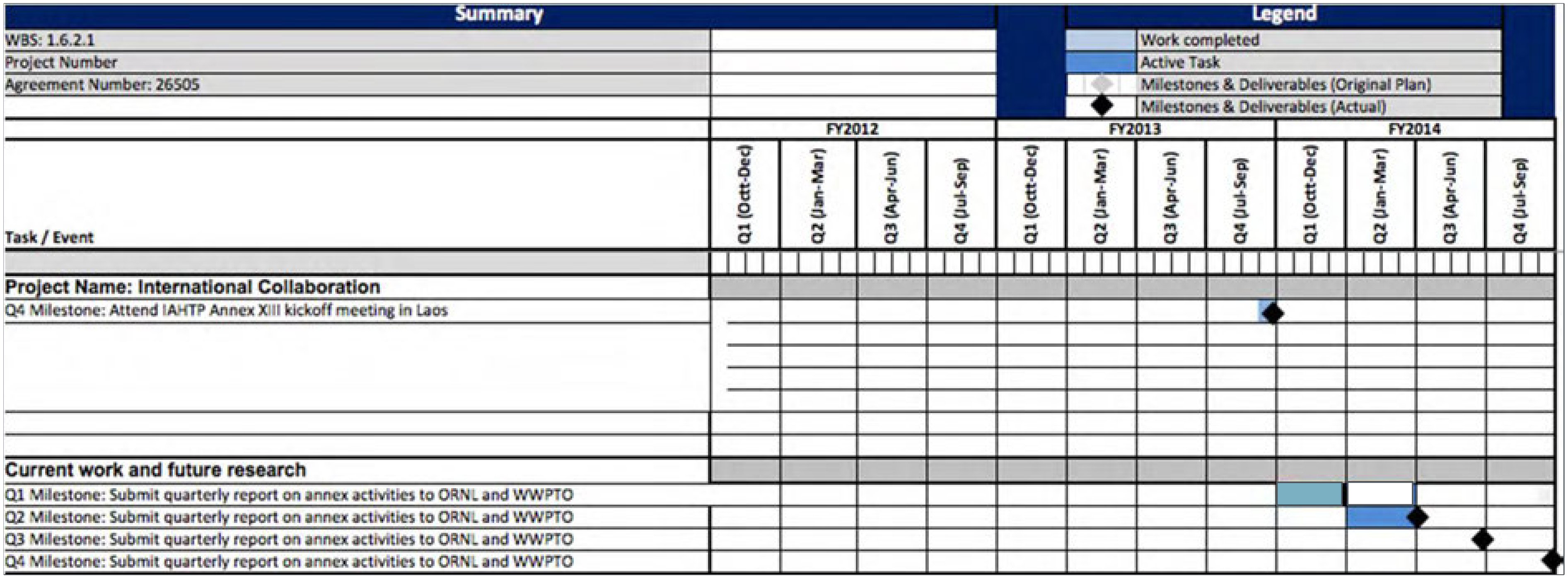
- Submit quarterly reports to ORNL and the WWPTO on annex activities in quarters where activity occurs.

Accomplishments and Progress

- DOE Funding was received in late Q4 of FY 13.
- Dr. Daniel Deng and Dr. Rich Brown attended the Annex XIII kickoff meeting in Laos in August, 2013 (before receipt of DOE funding) and delivered a presentation on
  - US experience with fish passage issues
  - Monitoring technologies related to fish and hydropower
- Annex VIII is still in formative period—Leadership is being provided by Norway.
- A second annex meeting was held in Trondheim Norway in December; PNNL was unable to attend but participated in meeting planning.
- Following the Trondheim meeting, Annex XIII lead Niels Nielsen met with PNNL in Richland, WA to discuss meeting outcomes.
- Progress report provided to ORNL and WWPTO

Project Plan & Schedule

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



Comments

- Funded in Q4, 2013. Planned completion in FY 2016
- On schedule
- Next meeting is tentatively planned to be held in Australia in May, 2014.

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
		75k	10k	74k (carryover only, no additional funding)	

- No budget variances
- Approximately 15% of funds have been expended
- Dr. Deng and Dr. Brown utilized a combination of internal DOE funds and an honorarium from the University of Laos to participation in Annex XIII initial meetings and conversations before arrival of DOE funds.

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators: Partners include ORNL, ANL, and participating Annex XIII nations.

Communications and Technology Transfer: Annex XIII activities are still in the formative phase—project results have not been communicated beyond Annex participants.

Next Steps and Future Research

FY14/Current research: In FY 14, PNNL will partner with ORNL and ANL to support the WWPTO in IAHTP activities. FY 14 work focuses on participation in Annex XIII on fish passage. PNNL will participate in Annex meetings and report back to partner labs and the WWPTO.

Proposed future research: Annex XIII work planning is still underway. Future research is unclear.

International Collaboration

IEA - *INTERNATIONAL ENERGY AGENCY*

IMPLEMENTING AGREEMENT FOR
HYDROPOWER TECHNOLOGIES AND PROGRAMMES

Norwegian Water Resources and Energy Directorate *Statkraft*	*US-Department of Energy* *Argonne National Laboratory* *Oak Ridge National Laboratory*

6.2.1 Collaboration with the International Energy Agency (IEA) on Annex IX: Hydropower Services

Vladimir Koritarov

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630 252 6711

February 24 28, 2014

Purpose & Objectives

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

Purpose: International Energy Agency's (IEA) *Implementing Agreement for Hydropower Technologies and Programmes* includes several Annexes which deal with various topics of interest to IEA member states. Annex IX focuses on Hydropower Services and includes two tasks:

Task 1 – Energy Management Services

Task 2 – Water Management Services and other Socio-Economic Contributions

Argonne has been designated by DOE to lead Task 1 activities for United States.

Main Objectives: To develop an understanding of key issues associated with the expedited large-scale provision of hydropower management services, especially those that facilitate integration of variable renewable resources, such as wind energy and solar energy.

This project aligns with the following DOE Program objectives and priorities:

- Optimize existing hydropower technology, flexibility, and/or operations
- Enable next generation pumped storage technologies to facilitate renewable integration

Annex IX - Project Impact

- Inform and enable better understanding of various services provided by hydropower and how these services are valued in different regions of the world
- Annex IX Statement of Objectives envisions for Task 1:
  - Several case studies to be conducted in different countries/regions (e.g., United States, Norway, Japan, Brazil, etc.) to investigate how the provision of ancillary services is valued and rewarded in different regions.
  - The objectives of the U.S. study include analyzing the coordination of hydropower services with wind and solar generation in U.S. regional markets, non-markets, and balancing authorities.

IEA Operating Agent for Annex IX is Ms. Karin Seelos (Norway)

Technical Approach

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

- Most of Task 1 activities in the U.S. are conducted within the framework of the study “Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the United States”
- Study is sponsored by DOE/WWPTO and carried out by a project team led by Argonne
- In addition to Argonne, the project team members include Energy Exemplar, LLC, MWH Americas, Inc., NREL, and Siemens Energy, Inc.
- Study goal is to develop detailed dynamic simulation models of PSH plants, analyze technical capabilities of PSH plants to provide various grid services, and assess the value of these services under different market structures and for different levels of RE in the system.

Technical approach has two main components:

(1) **Advanced Technology Modeling:** Develop and test vendor-neutral dynamic simulation models of advanced PSH plants, including adjustable speed and ternary technologies

(2) **Production Cost and Revenue Modeling:** Simulate Western Interconnection and different balancing authorities within the region to assess potential revenues of PSH plants and the economic value of various contributions and services that they provide to the power system.

Accomplishments and Progress (1/3)

- Developed and tested prototype vendor-neutral models of advanced PSH technologies, including adjustable speed and ternary units
- Integrated dynamic models into PSS®E software and performed testing by simulating actual utility systems within the Western Interconnection (WI)
- Published and made available vendor-neutral models (block diagrams and transfer functions) for integration into other software packages
- Improved modeling representations of advanced PSH plants in other software tools (PLEXOS, CHEERS, FESTIV)
- Developed a matrix of different services and contributions that PSH plants provide to the power system

Accomplishments and Progress (2/3)

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

- Performed production cost and revenue simulations to address a wide range of control issues and timeframes
- Studies were carried out for different geographical areas, including WI, state of California, and for the SMUD balancing authority
- Simulations were performed for different levels of penetration of RE resources:
  - Baseline (RPS-mandated) RE scenario
  - High Wind RE scenario from WWSIS-2 study
- Analyses were performed utilizing both cost-based approach to determine the economic value of PSH plants (WI and SMUD) and market-based approach to determine potential PSH revenues in competitive markets (California)

- The work on various Annexes of the IEA's Implementing Agreement is overseen and coordinated by the Executive Committee (ExCo).
- ExCo conducts regular meetings at which the progress of work on different Annexes is reviewed. Last three ExCo meetings were held in Washington DC (May 2012), Japan (Feb 2013), and Austria (Oct 2013).
- In addition to ExCo meetings, Annex IX organizes regular workshops at large international hydro conferences (HYDRO and HydroVision) to inform the public about the research and to coordinate the work on different country studies.
- Argonne/DOE representatives were actively participating in these activities.

As defined by the ExCo, the target dates for key milestone events of Annex IX are as follows:

▪ Collection of country case studies	2013/2014
▪ Synthesis Report	2014/2015
▪ Communication Material/Strategy	2015
▪ Dissemination	2015
▪ Annex IX completion	2015

Comments

- Project start date (Argonne): May 2012
- Project end date: Dec 2015

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
0K	**0K**	**0K**	**0K**	**75K**	**0K**

- Expended to date (Dec 31, 2013): $9.1K (12%)

Comments

- Project number: 6.2.1
- Agreement number: 26506

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

Argonne National Laboratory (Argonne) – Project Lead
Siemens PTI, Inc.
Energy Exemplar, LLC.
MWH Americas, Inc.
National Renewable Energy Laboratory (NREL)

In addition, collaborating with Statkraft (Norway), EdF (France), Toshiba (Japan), HM-Hydro (Japan), and other organizations involved in Annex IX activities.

Communications and Technology Transfer:

- Presented at special IEA Annex IX workshops organized in conjunction with the HydroVision and HYDRO international conferences
- Organized and conducted a panel session at IEEE 2013 PES General Meeting
- Published article about the project in Hydro Review magazine
- Presented at several DOE workshops

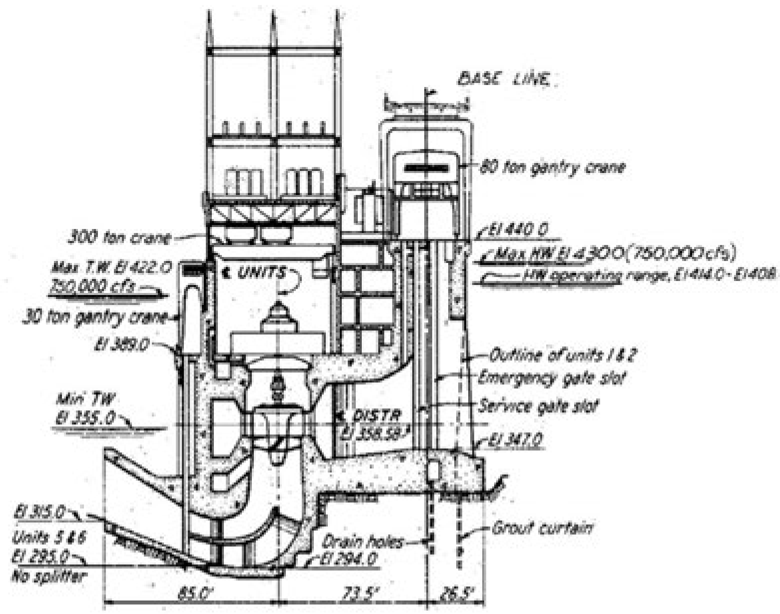
FY14/Current research:

- Complete the analysis of simulation runs performed during the project and compile key findings into the case study report for the United States
- Review case studies prepared for Annex IX by other countries and their key findings related to the valuation of grid services in other regions

Proposed future research:

- Collaborate with Norway and other Annex IX participating countries on preparing the Synthesis Report

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



Quantification of Reliability and Cost Impacts for Hydropower Assets

Brennan T. Smith
Oak Ridge National Laboratory
smithbt@ornl.gov (865) 241 5160
February 25, 2014

OAK RIDGE National Laboratory

Purpose & Objectives

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

Problem Statement: *How can current or future condition monitoring, cost tracking, and data archiving enable robust quantification of reliability and cost impacts experienced by hydropower assets?*

- The asset reliability and cost risks of transitioning hydropower assets from an energy-production role to a power system flexibility provider role are unconfirmed or undetermined.
- The asset reliability and cost impacts (+/-) of adopting new hydropower technology and new O&M practices are not well understood.
- The asset reliability and cost impacts of implementing new regulatory, environmental, and operating constraints are not well understood.

Asset Change → **Impact**

Are asset data management practices capable of detecting impacts and determining causality?

Purpose & Objectives

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

Impact of Project:

- Informed decision-making by asset managers
  - Allocation of flexible dispatch and impacts across multiple facilities and units
  - Risk-based value decisions on adoption of new technology and practices

- Right-sizing of condition and cost tracking data efforts
  - Asset managers can focus limited reporting resources on high-value data

- Informed regional and national policy-making
  - Quantification of hydropower flexibility risks and costs (not assignment)
  - Value-based decisions of hydropower technology RDD&D scale-up investments

Purpose & Objectives

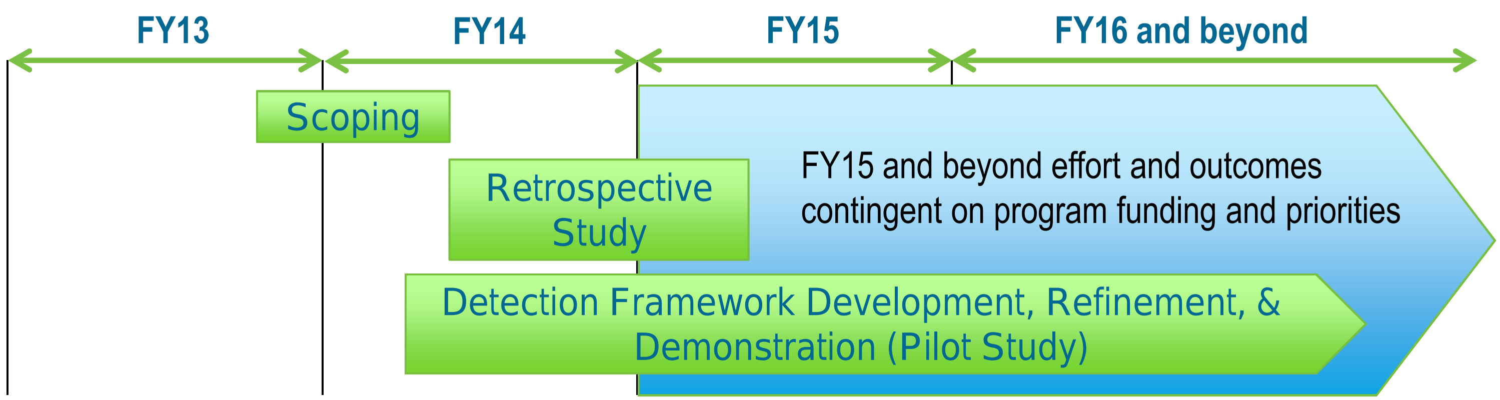
This project aligns with the following DOE Program objectives and priorities:

- Advance new hydropower systems and/or components for demonstration or deployment
  - The project will enable asset managers and DOE program planners to consider full costs and risks of new technology in prioritizing investments.
- Optimize existing hydropower technology, flexibility, and/or operations
  - Optimization and allocation of flexibility, capacity, and production requires individual unit and facility data-based cost and risk characteristics.
- Reduce deployment barriers and environmental impacts of hydropower
  - Full accounting of risks and costs addresses perceived risks and identifies externalities

Technical Approach

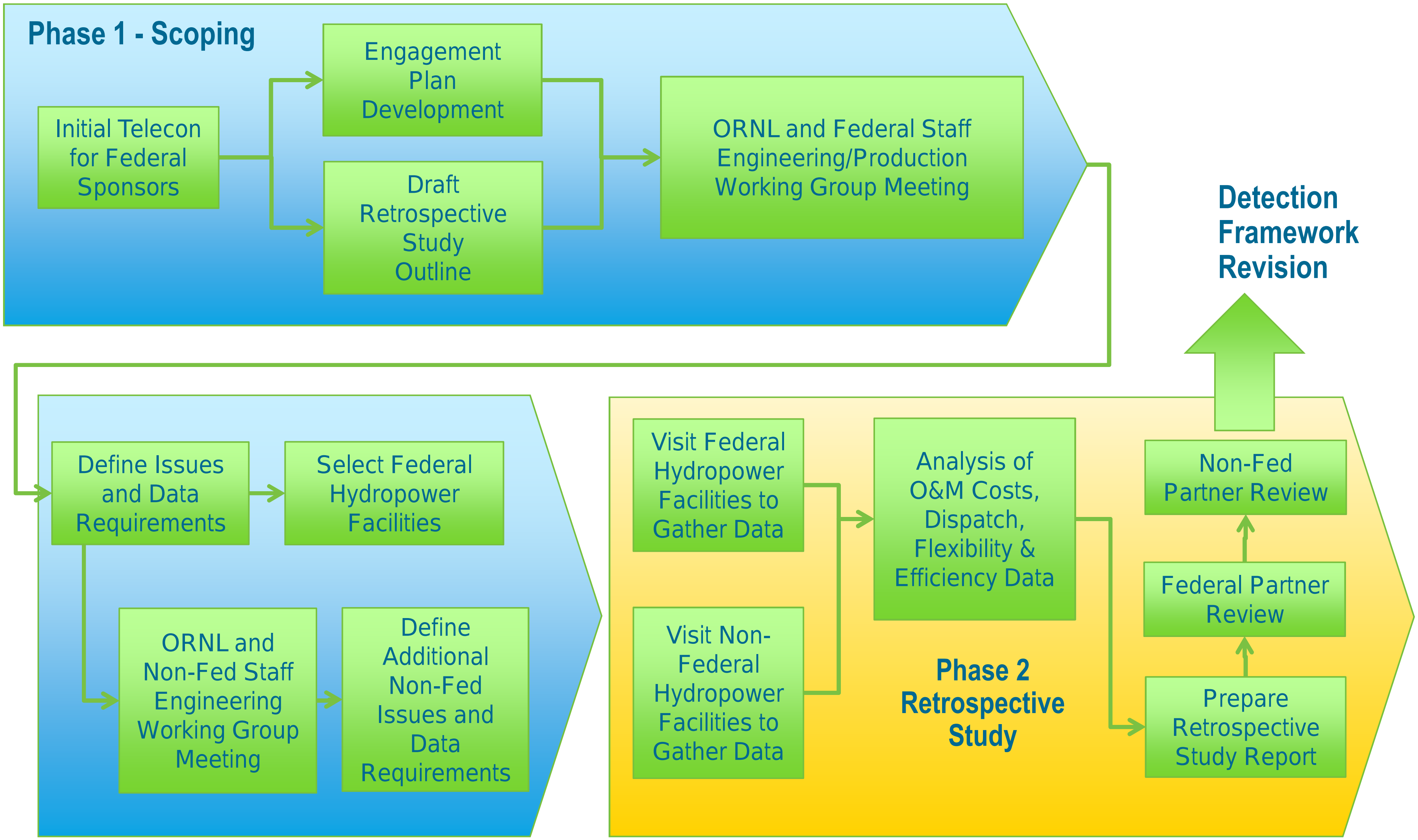
The project plan includes three major phases:

1. **Scoping process** with (a) federal and (b) non-federal fleet and facility asset managers,
2. **Retrospective study** of selected facilities based on hypothesis that existing data enterprises are sufficient to quantify change impacts, and
3. Development, refinement, and demonstration (pilot) of an **Impacts Detection Framework** to guide future data collection and decision-making investments.



Technical Approach

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



Technical Approach

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

- Impacts Detection Framework Development
  - Examples of hypothesized impact pathways
    - Generator thermal cycling
    - Rough zone cavitation
    - Reservoir drawdown/recovery effects
    - TDG exceedence
  - Dispatch metrics – can we discern using unit characteristics and [hourly/minute/change] archived data analyses?
    - Mode of operation – storage, run-of-river, or in between and to what degree?
    - Baseline efficiency optimization practices
    - Intensity of operations – starts/stops, rough zone excursions, inc/dec frequency, temperature cycling – is condition monitoring data adequate?
    - Invocation of constraints – can we determine when regulatory or environmental constraints control generation?
    - Volume of ancillary services
  - Cost data
    - Alignment with ORNL/DOE HCM and industry cost breakdown structures
    - Preventive maintenance, repairs, staffing
    - Differentiation of costs by unit or component
  - Reliability and forced outage data

Technical Approach

Key Issues Addressed:

- **Realistic consideration** of how federal and non-federal asset management decisions are made – *emphasis on up-front scoping*
- **Change metrics** – *the scoping process will define metrics for flexibility and other operating outcomes so as to quantify change.*
- **Adequacy of data** – *we will test the hypothesis that current practices are adequate to answer management and research questions*
- **Complexity of data** – *we will consider granularity of condition monitoring and cost data and the feasibility of capturing finer details*

Project Plan & Schedule

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

Summary	Legend
1.6.1.2 Flexible Operations O and M and Lifetime Impact Study	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
Agreement 26522	Milestones & Deliverables (Actual)

Milestone / Deliverable	FY2012 Q1 (Oct-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Oct-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Draft Hydropower MOU Section for Reliability-Flexibility Sub-task publication of FY2014-2016 DOE-ORNL-Industry Work Plan												
Current work and future research												
Publication of Prospectus for Hydropower Flexibility Collaborative												
Technical Scoping workshop with MOU (Corps, Reclamation) and non-federal partners												
Publication of Hydropower Flexibility-Reliability Correlation and Cost Impacts Detection Framework Report												
Publication of initial quarterly report.												

Comments

- Project was initiated in September 2013
- Release of prospectus to MOU partners delayed by two weeks – no long-term impact
- Milestones and deliverables will be modified to incorporate federal hydro management and technical input/meetings earlier in the scoping – engagement plan in Q2 FY14, draft Framework in Q3 FY14, Retrospective Study Report delivery will be shifted to FY15.

Project Budget

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$300,000	0	0	0

- No significant budget variances
- 20% of funds expended through Q1 FY2014
- There is potential for funding and in-kind contribution from industry consortia in FY2015—discussions are ongoing.

Research Integration & Collaboration

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

ORNL Execution Team

- Research Staff:
  - Energy analyst
  - Hydro-mechanical engineer
  - Sensors and controls engineer
- Signal Hydropower Consultants
  - Jim Miller, principal consultant
  - Hydropower Asset Management and Cost Benchmarking
- Hydro Performance Processes
  - Patrick March, principal consultant
  - Hydropower Dispatch Analysis
- UTK/ORNL Bredesen Center
  - Stephen Signore, Energy Science & Engineering Ph.D. student
  - Hydropower O&M impacts thesis

Federal & Industry Partners

- MOU Partners
  - Corps of Engineers
    - Hydroelectric Design Center, Portland (OR)
  - Reclamation
    - Power Resources Office
    - Research & Development Office
    - Technical Service Center Staff
  - BPA Asset Management
- Non-Federal Asset Owners
  - Preliminary discussions underway
- Industry Consortia
  - Ongoing and planned discussions with CEATI, EPRI, EUCG, and NERC about collaborative opportunities

Communications and Technology Transfer

- Initial outreach and scoping is limited to federal partners
- Non-federal partners will be identified in FY2014 through industry consortia: NHA, CEATI, EPRI, EUCG
- FY14 products are internal:
  - Federal hydropower engagement plan
  - Retrospective study outline and draft
  - Internal presentations to technical committees of CEATI, EUCG, NHA Hydraulic Power Committee
- External publications are anticipated in FY15:
  - Technical report and peer-reviewed journal pub on Retrospective Study
  - Hydro Review / HRW advocacy article for new framework implementation
  - Technical presentation at Hydrovision 2015

Next Steps and Future Research

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FY14/Current research:

- Prospectus transmitted to federal partners in January 2014, initial management meeting in February, engagement plan and engineering meeting in March.
- Select facilities for retrospective analysis in March, on-site visits and data collection in April, analysis completed in FY2014
- Develop scope of work and prospectus for FY2015 demonstration of Impacts Detection Framework (e.g. new data acquisition and cost tracking) at multiple facilities.

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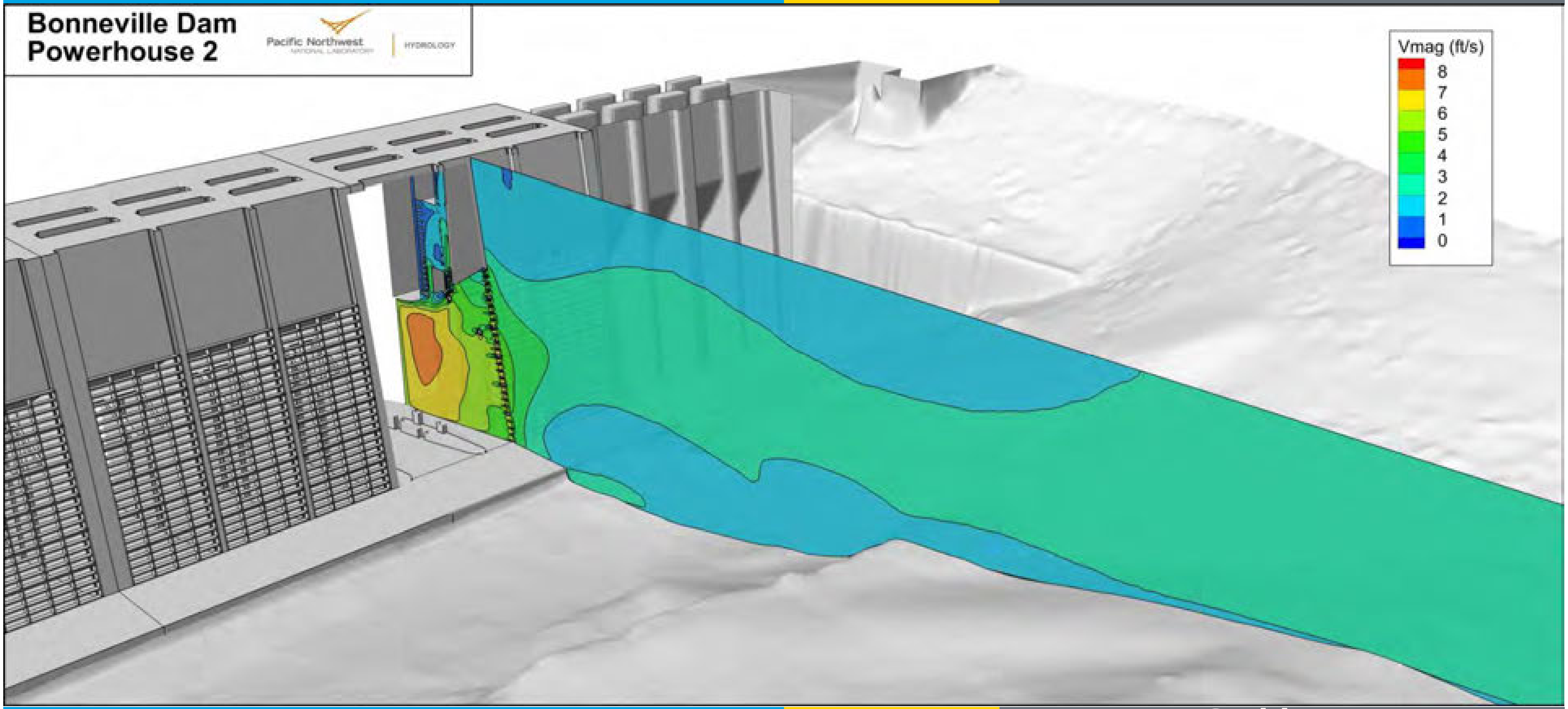

Hydropower Flow Measurement

A joint ORNL/PNNL effort supporting the DOE/DOI/DOD Hydropower MOU

February 24, 2014

Brennan Smith
Oak Ridge National Laboratory
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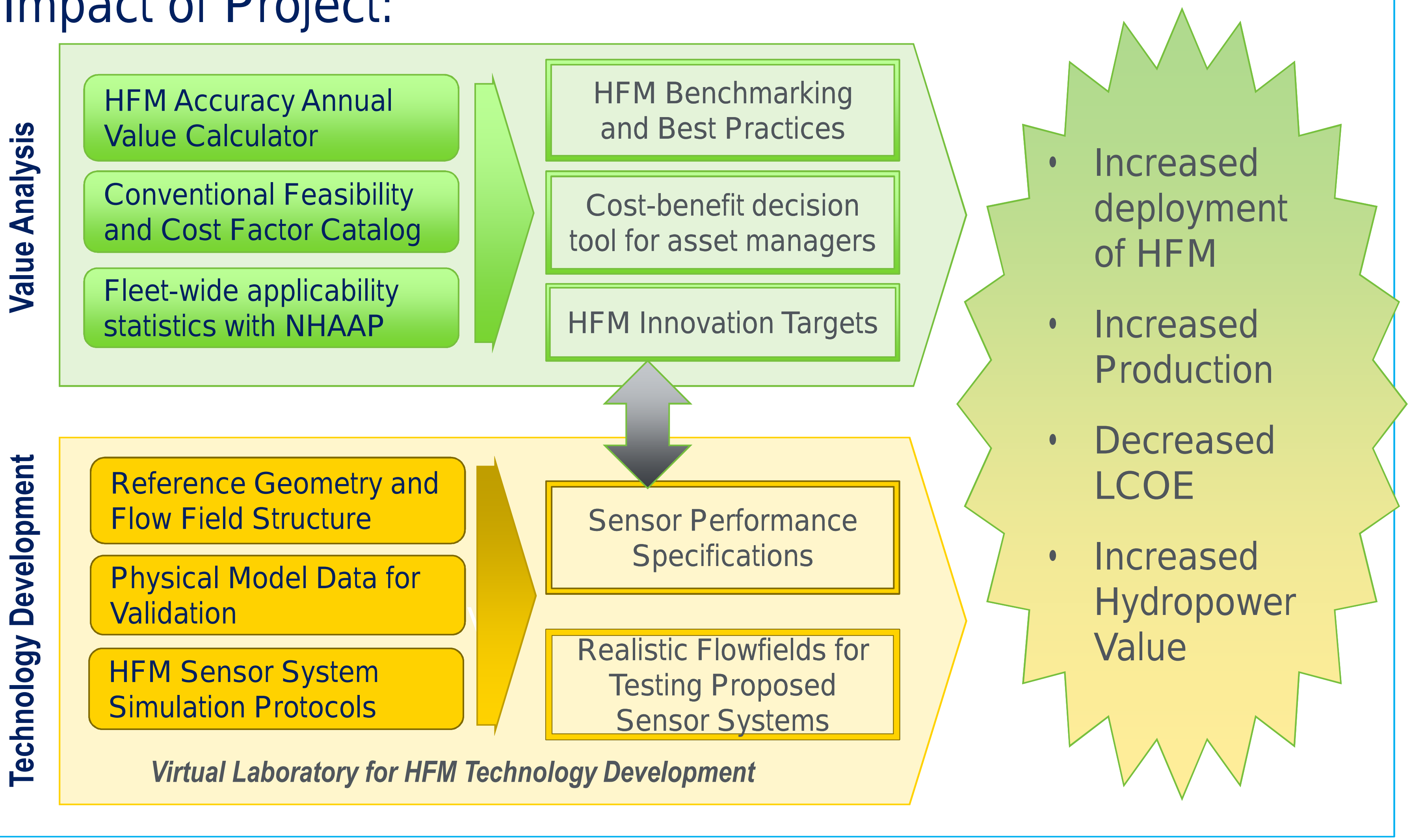
Marshall Richmond
Pacific Northwest National Laboratory
marshall.richmond@pnnl.gov

Problem Statements:

- Accurate turbine flow rate measurement underpins best practices for hydropower operations, water management, and sustainability.
- The value of turbine flow rate measurement accuracy is not well-quantified across the U.S. hydropower fleet.
- Accurate and cost-effective flow measurement in short converging turbine intakes is a long-standing technical challenge not yet overcome by industry or research communities.
- Innovations in flow sensor systems technology, simulation, and deployment will be required for short converging turbine intakes.

Impact of Project:



Purpose & Objectives

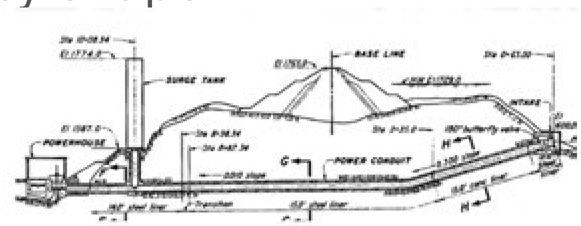
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

This project aligns with the following DOE Program objectives and priorities:

- Advance new hydropower systems and/or components for demonstration or deployment
  - Cost and accuracy targets for advanced sensor systems
  - Computational simulation of sensor system performance accelerates sensor technology development
- Optimize existing hydropower technology, flexibility, and/or operation
  - Provide asset managers with tools for estimating flow measurement upgrade return-on-investment and cost-benefit analysis
  - More accurate flow → more accurate performance → optimal dispatch → more energy from available water

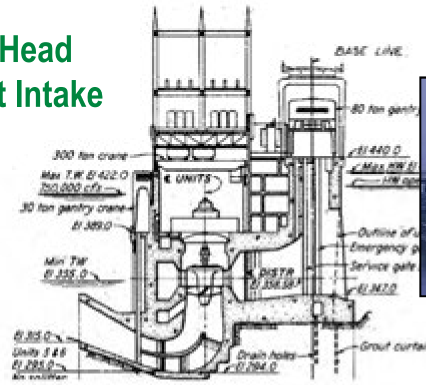
Value Analysis Depends on Intake and Turbine Designs

- Accuracy: Flow separation, turbulence, efficiency shape
- Benefit: Efficiency shape, dispatch history
- Cost: Access to flow path, installation pathway

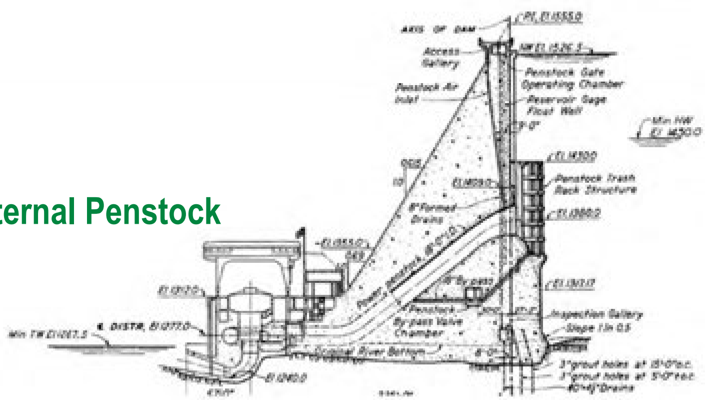


Very Long Diversion Penstock

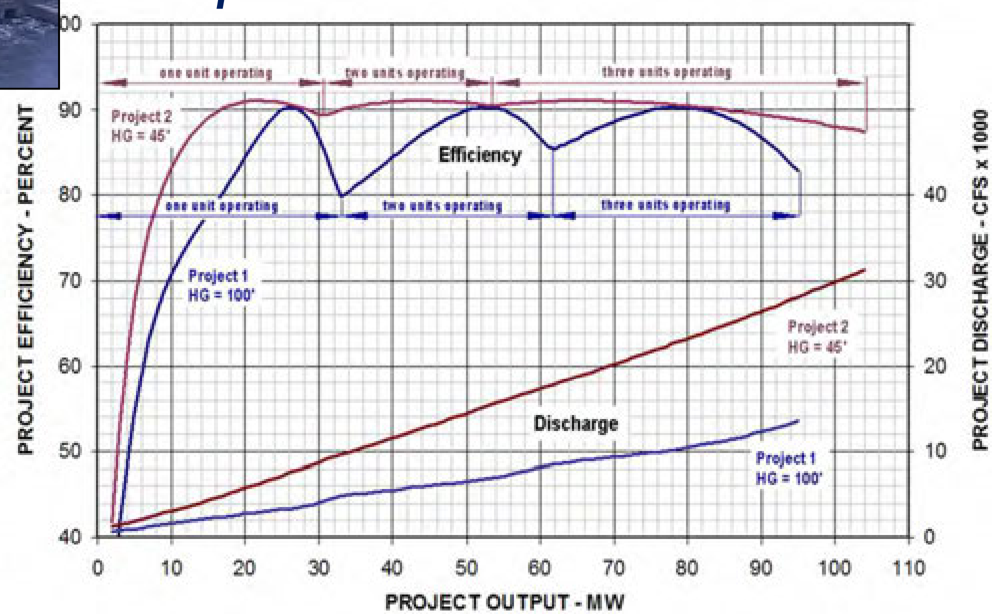
Low-Head Short Intake



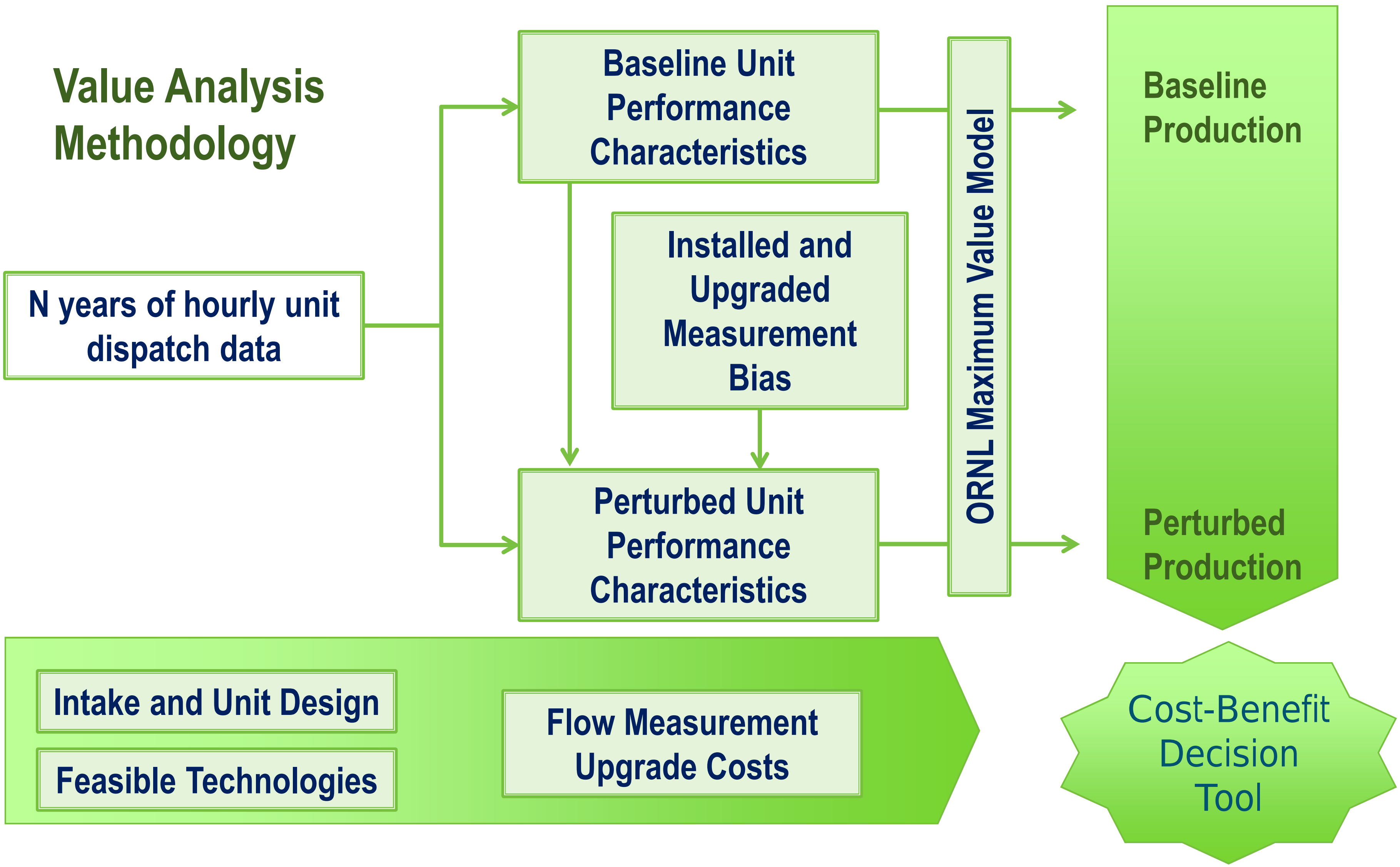
Internal Penstock



Kaplan vs. Francis Performance



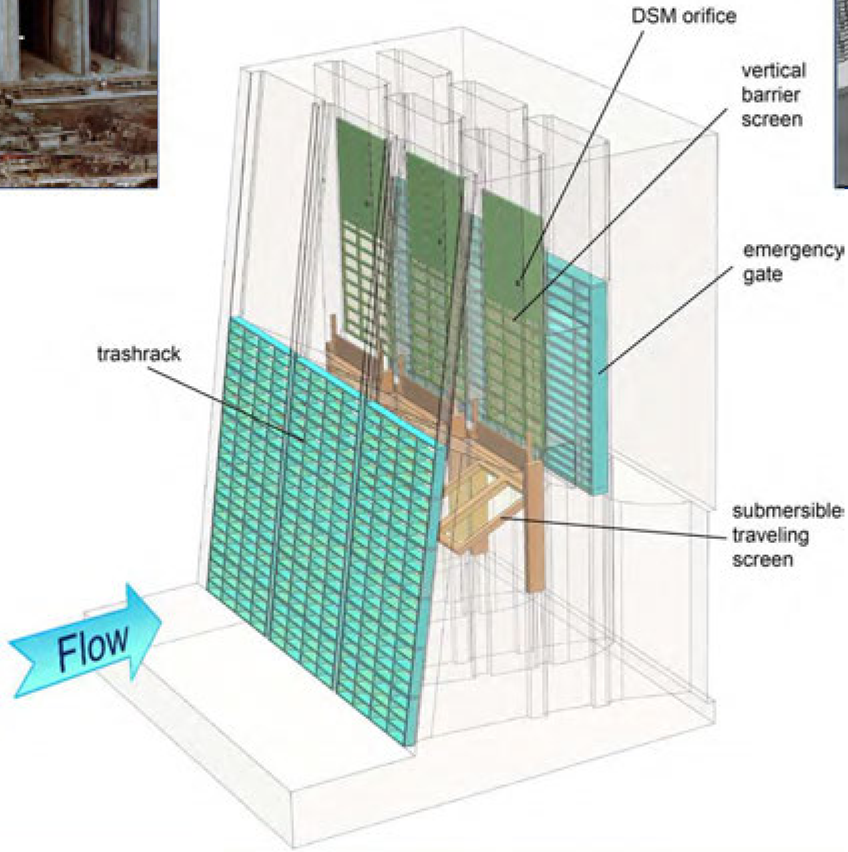
Technical Approach - ORNL

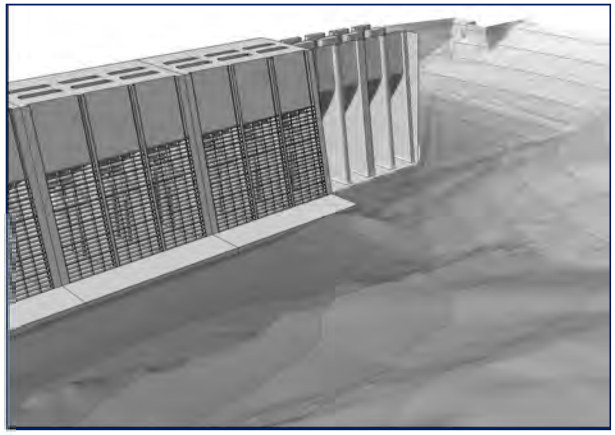


Reference Geometry and Flow Field Structure

- Develop detailed geometry model of single LHSI
  - In collaboration with Corps, Reclamation, utility partners
- Simulate flow field with 3D computational fluid dynamics (CFD) model
  - Utilize DOE high performance computing (HPC) resources
- Transient turbulent flow considerations:
  - large scale: forebay
  - small scale: within intake
- Virtual sensor simulation
  - Use realistic CFD simulated flow fields to test proposed instrumentation systems

Technical Approach - PNNL: Geometry Model





Technical Approach - PNNL: Computational Fluid Dynamics

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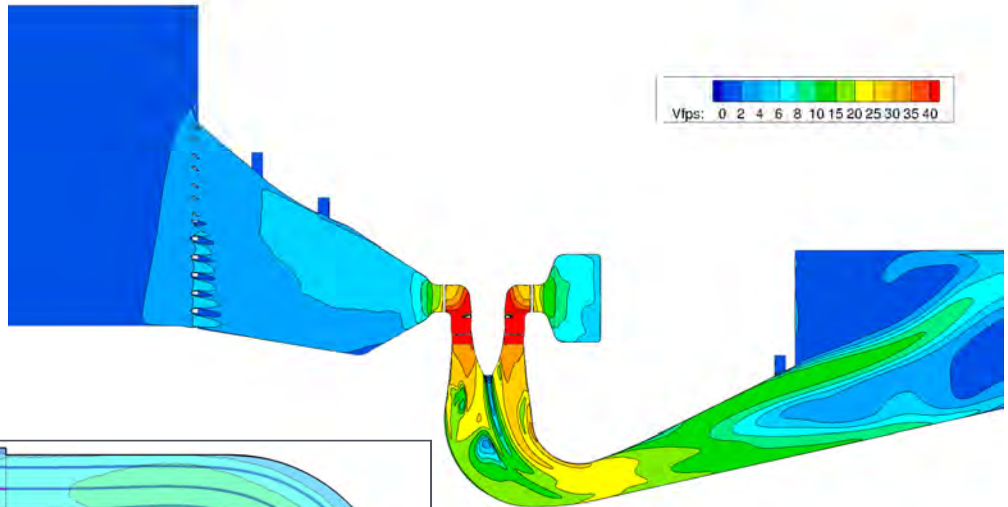

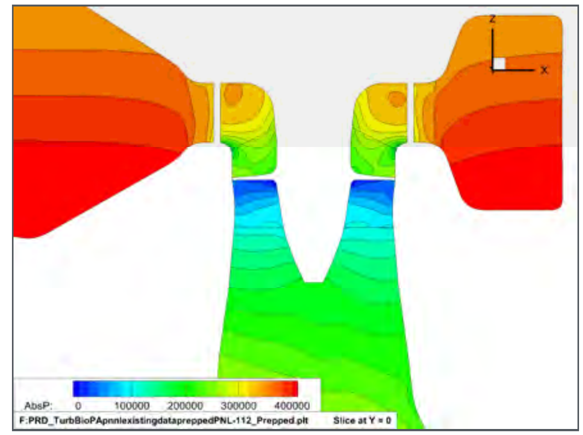

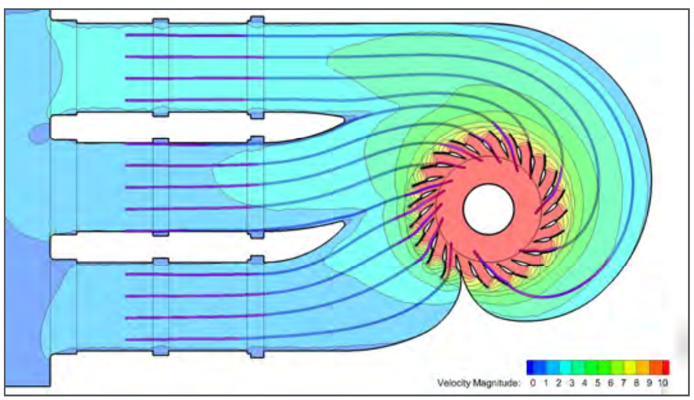

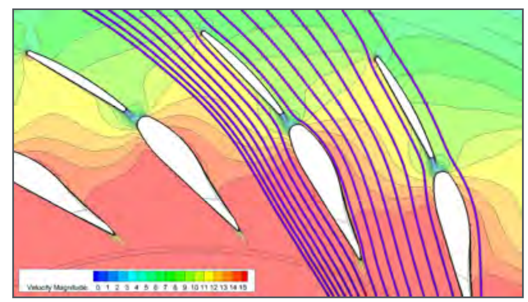

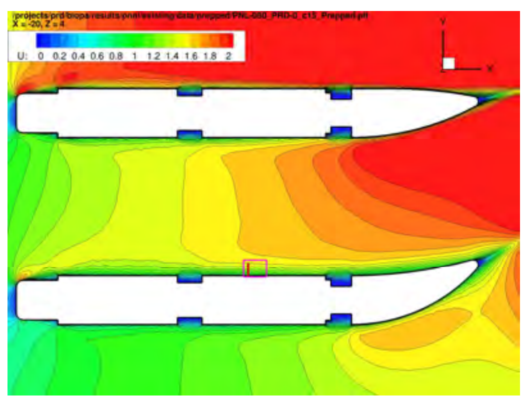

Technical Approach - PNNL: Non-uniform Approach Flow

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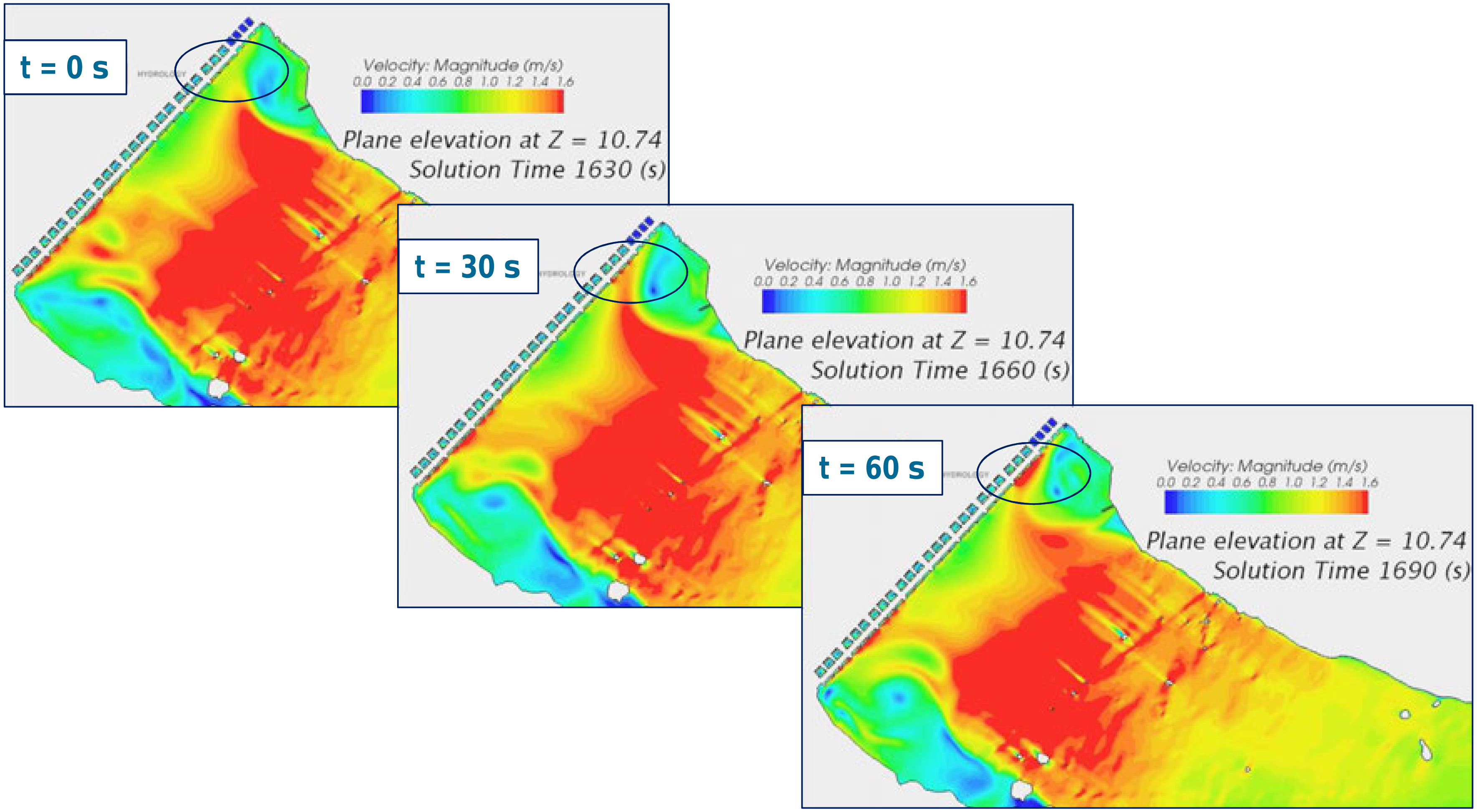
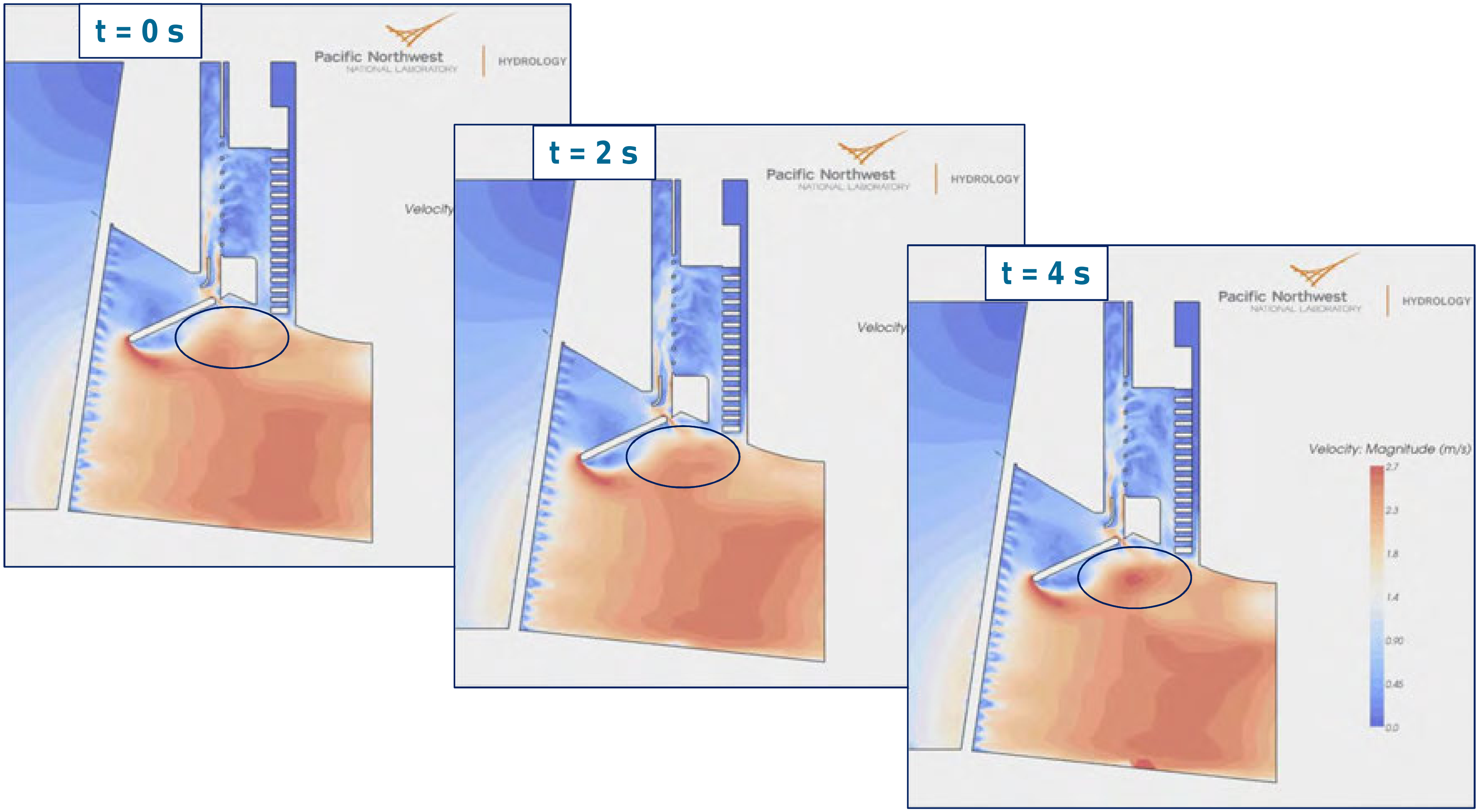
Transient-flow Considerations

Large Scale – Forebay Approach Flow



Transient-flow Considerations

Small Scale – Eddy Resolving Simulations



Project Plan & Schedule - PNNL

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Summary	Legend	
WBS Number or Agreement Number 1.6.1.2		Work completed
Project Number		Active Task
Agreement Number 26494		Milestones & Deliverables (Original Plan)
	◆	Milestones & Deliverables (Actual)

	FY2013	FY2014				FY2015
Task / Event	**Q4 (Jul - Sep)**	**Q1 (Octt-Dec)**	**Q2 (Jan-Mar)**	**Q3 (Apr-Jun)**	**Q4 (Jul-Sep)**	**Q1 (Octt-Dec)**
Project Name: Flow Measurement Tech for Converging Intake Turbines						
Q4 Milestone: Project kickoff	◆					
Q1 Milestone: Develop internal draft of HFM Master Plan document		◆				
Q2 Milestone: Conduct initial technical workshops with hydropower engineering staffs			◆			
Q3 Milestone: Conduct workshop with formal technical committees				◆		
Q4 Milestone: ORNL publishes HFM Value Analysis Tool online					◆	
Q4 Milestone: PNNL publishes Preliminary Reference Flow Field Report					◆	
Q4 Milestone: ORNL and PNNL finalize initial versions of HFM Master Plan					◆	
Q4 Milestone: PNNL finalizes initial version of Intake Reference Flow Field Research Plan					◆	

Comments

- HFM project at PNNL initiated in September 2013

Project Plan & Schedule - ORNL

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

Summary		Legend
WBS Number or Agreement Number 1.6.1.2	(light blue)	Work completed
Project Number	(blue)	Active Task
Agreement Number 26494	◇ (grey)	Milestones & Deliverables (Original Plan)
	◆	Milestones & Deliverables (Actual)

Task / Event	FY2013 Q4 (Jul - Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)	FY2015 Q1 (Octt-Dec)
Project Name: Flow Measurement Tech for Converging Intake Turbines						
Q4 Milestone: Project kickoff	◆					
Q1 Milestone: Develop internal draft of HFM Master Plan document		◆				
Q2 Milestone: Conduct initial technical workshops with hydropower engineering staffs			◆			
Q3 Milestone: Conduct workshop with formal technical committees				◆		
Q4 Milestone: ORNL publishes HFM Value Analysis Tool online					◆	
Q4 Milestone: ORNL publishes HFM Technology Deployment Status Report for US Fleet					◆	
Q4 Milestone: ORNL and PNNL finalize initial versions of HFM Master Plan					◆	

Comments

- HFM project at ORNL initiated in September 2013

Project Budget - PNNL

PNNL - Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$300K	n/a	$0K	n/a

- Initial funding received in September 2013 (end of FY13)
- Approximately 10% spent to date

Project Budget - ORNL

ORNL - Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$300K	0	0	0

- Initial funding received in September 2013 (end of FY13)
- Approximately 10% spent to date

Partners, Subcontractors, and Collaborators – HFM Team:

- Oak Ridge National Laboratory
  - Hydro Performance Processes (Max Value Model)
  - Principia Research Corp. (Chief of Test expertise)
- Pacific Northwest National Laboratory
- MOU Agency Partners
  - US Army Corps of Engineers
  - Bureau of Reclamation
- Public and Private Utilities
- Hydro Industry
  - ASME PTC-18, CEATI
  - Hydro Research Foundation Graduate Fellowship Program

Communications and Technology Transfer:

- Topical project reports will be available on contributing team members websites and selected project results will be presented at national and international conferences.
- Nonproprietary test data will made available via websites.
- Results will be submitted to peer-reviewed journals.

PNNL Next Steps in FY2014

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1. PNNL and ORNL develop annotated HFM master plan document
2. PNNL initiates discussion with partner organizations for selection of turbine(s) for intake reference flow field simulations
3. PNNL and ORNL conduct technical workshop with federal and non-federal partners to scope HFM needs
4. PNNL conducts CFD simulations for initial reference intake geometry and operating conditions
5. PNNL and ORNL conduct workshop with technical committees (ASME PTC-18; IEC TC-4)
6. PNNL delivers reference flow field and research plan reports

ORNL Next Steps in FY2014

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

1. PNNL and ORNL develop annotated HFM master plan document
2. ORNL continues cataloging of flow measurement technologies with cost and feasibility factors.
3. ORNL prepares matrix of intake designs and flow measurement technology applicability
4. PNNL and ORNL conduct technical workshop with federal and non-federal partners to scope HFM needs
5. PNNL and ORNL conduct workshop with technical committees (ASME PTC-18; IEC TC-4)
6. ORNL delivers Hydropower Flow Measurement (HFM) Technology Deployment Status Report
7. ORNL publishes online flow measurement value calculator

Next Steps and Future Research

FY2015 – FY2016: Out-year goals for this subtask include support of a major DOE Water Power HFM field demonstration activity in FY2016, and support of technology transfer activities in FY2015-16.

- **FY2015**
  - Reference Flow Field simulation and measurement
  - Technical Reports/manuscripts documenting Reference Flow Field Research
  - HFM Sensor Systems Technology Needs Report
  - Site-Specific Case Studies of HFM Upgrade Analysis

- **FY2016**
  - ORNL and PNNL technical support of HFM Field Demonstration Activity

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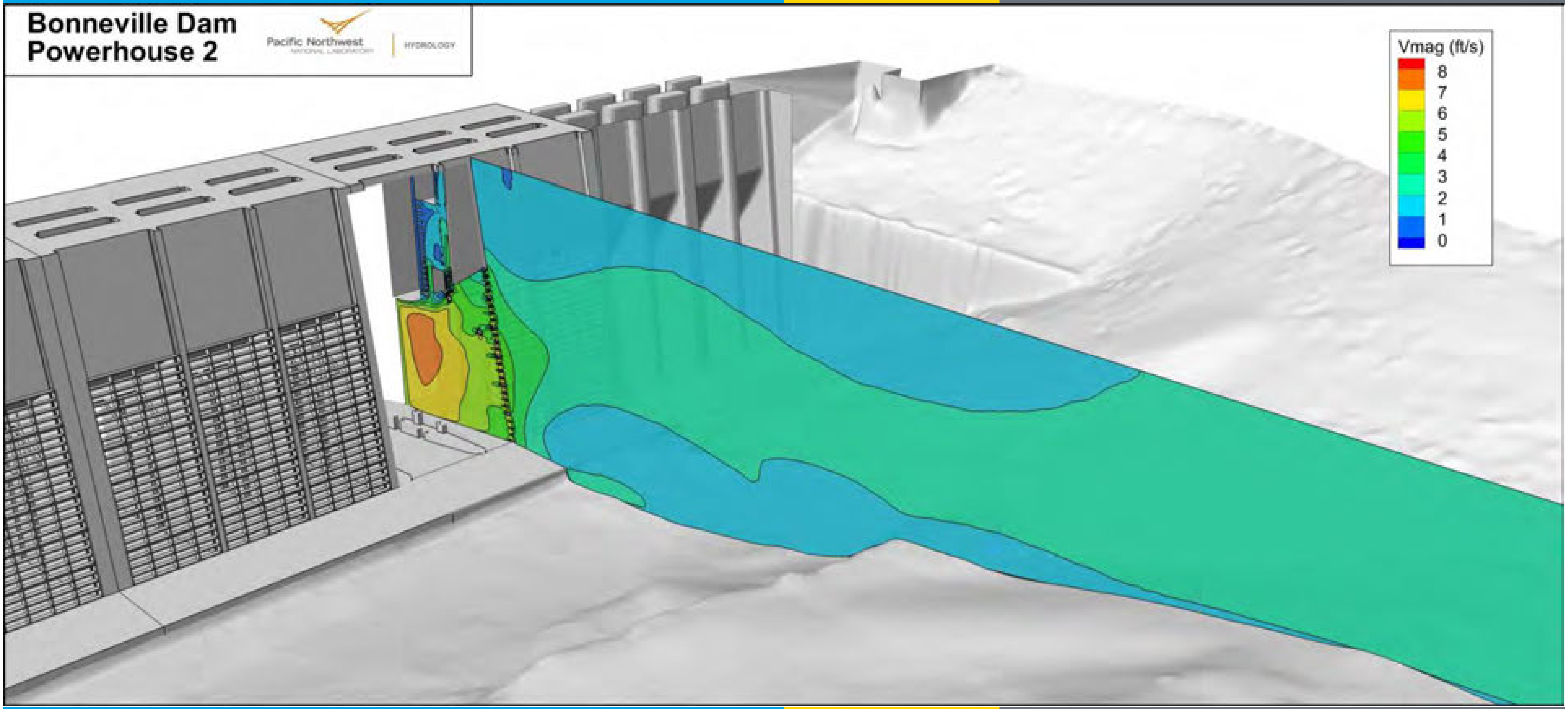


Hydropower Flow Measurement

A joint ORNL/PNNL effort supporting the DOE/DOI/DOD Hydropower MOU

February 24, 2014

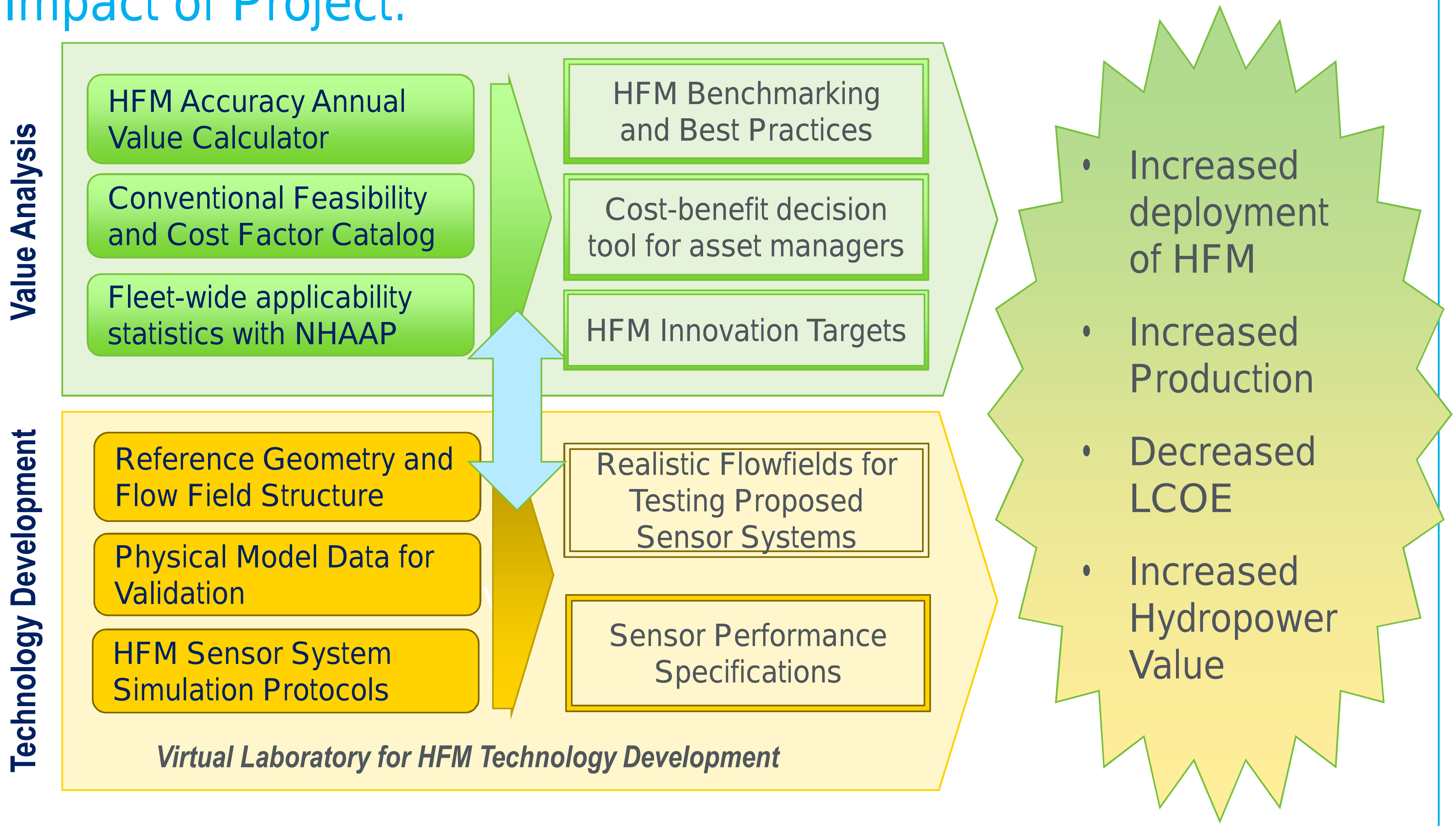
Marshall Richmond
Pacific Northwest National Laboratory
marshall.richmond@pnnl.gov

Purpose & Objectives

- Accurate turbine flow rate measurement underpins best practices for hydropower operations, water management, and sustainability.
- The value of turbine flow rate measurement accuracy is not well-quantified across the U.S. hydropower fleet.
- Accurate and cost-effective flow measurement in short converging turbine intakes is a long-standing technical challenge not yet overcome by industry or research communities.
- Innovations in flow sensor systems technology, simulation, and deployment will be required for short converging turbine intakes.

Purpose & Objectives

Impact of Project:



Purpose & Objectives

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

This project aligns with the following DOE Program objectives and priorities:

- Advance new hydropower systems and/or components for demonstration or deployment
  - New absolute flow measurement technologies
  - Advanced computational tools for engineering design
- Optimize existing hydropower technology, flexibility, and/or operation
  - Development of absolute flow measurement systems will allow for turbine unit and powerhouse optimization

Reference Geometry and Flow Field Structure

- Develop detailed geometry model of single LHSI
  - In collaboration with Corps, Reclamation, utility partners
- Simulate flow field with 3D computational fluid dynamics (CFD) model
  - Utilize DOE high performance computing (HPC) resources
- Transient turbulent flow considerations:
  - large scale: forebay
  - small scale: within intake
- Virtual sensor simulation
  - Use realistic CFD simulated flow fields to test proposed instrumentation systems
- Physical model and/or field data for model validation

Technical Approach - PNNL: Geometry Model

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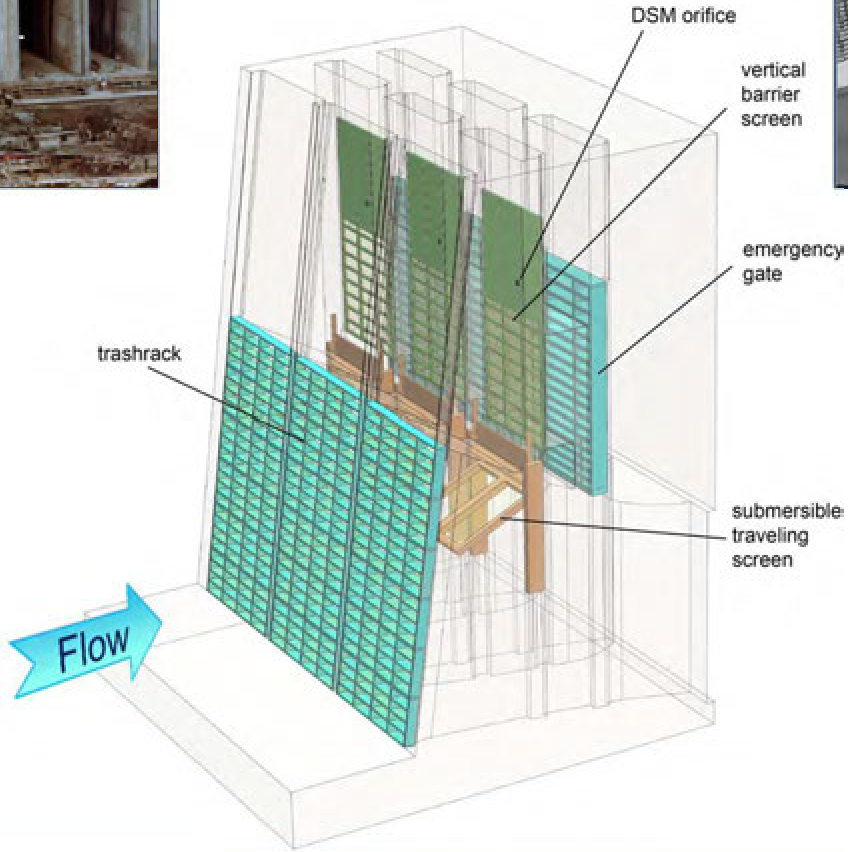

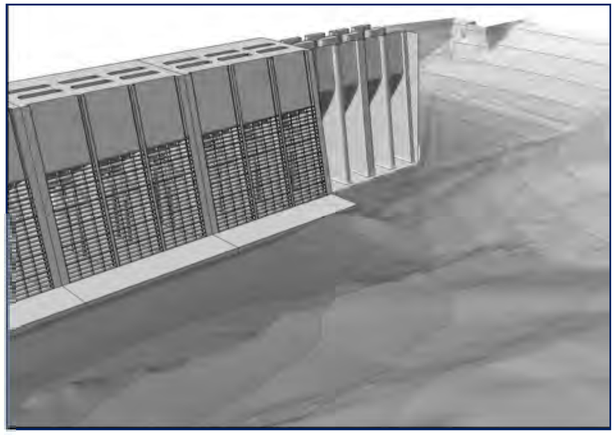

Technical Approach - PNNL: Computational Fluid Dynamics

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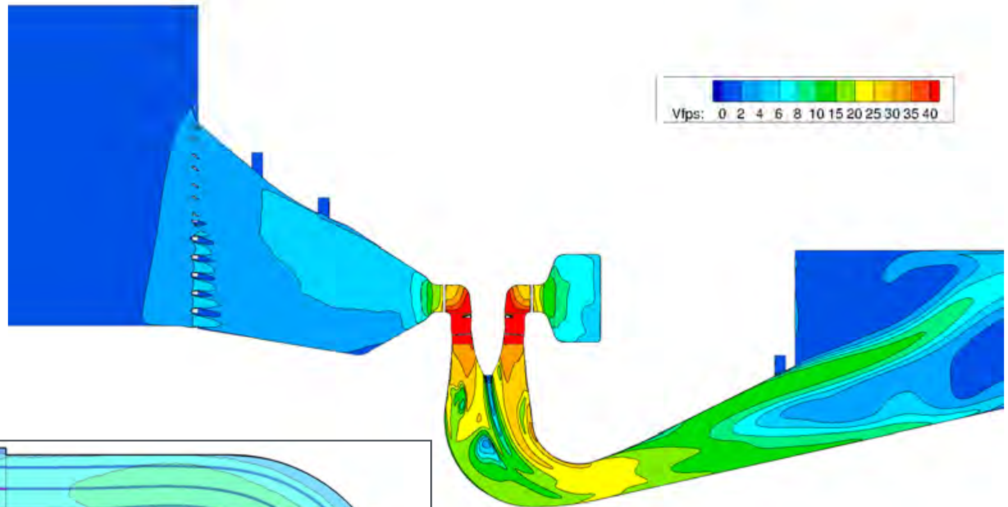
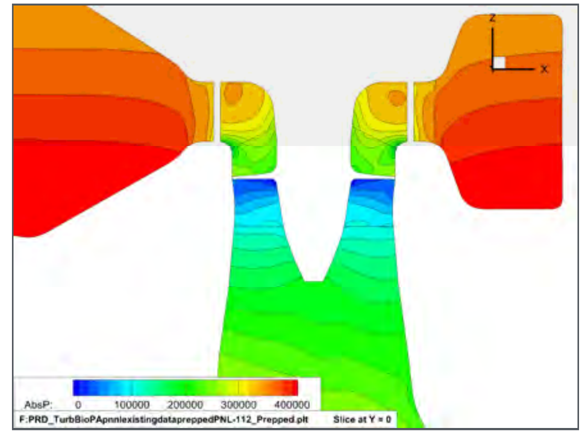
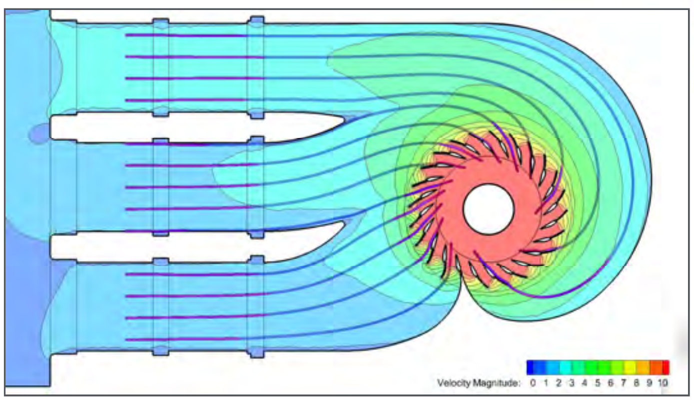
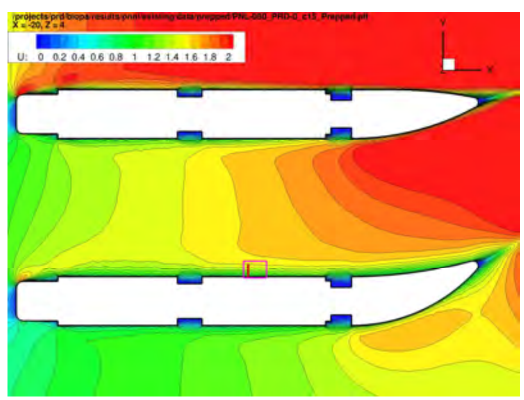
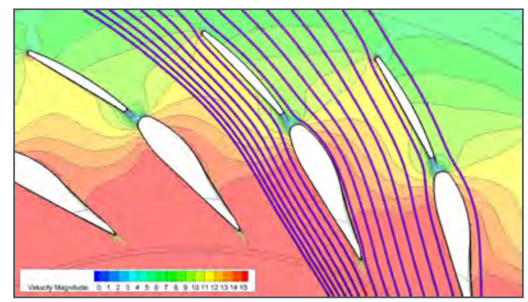




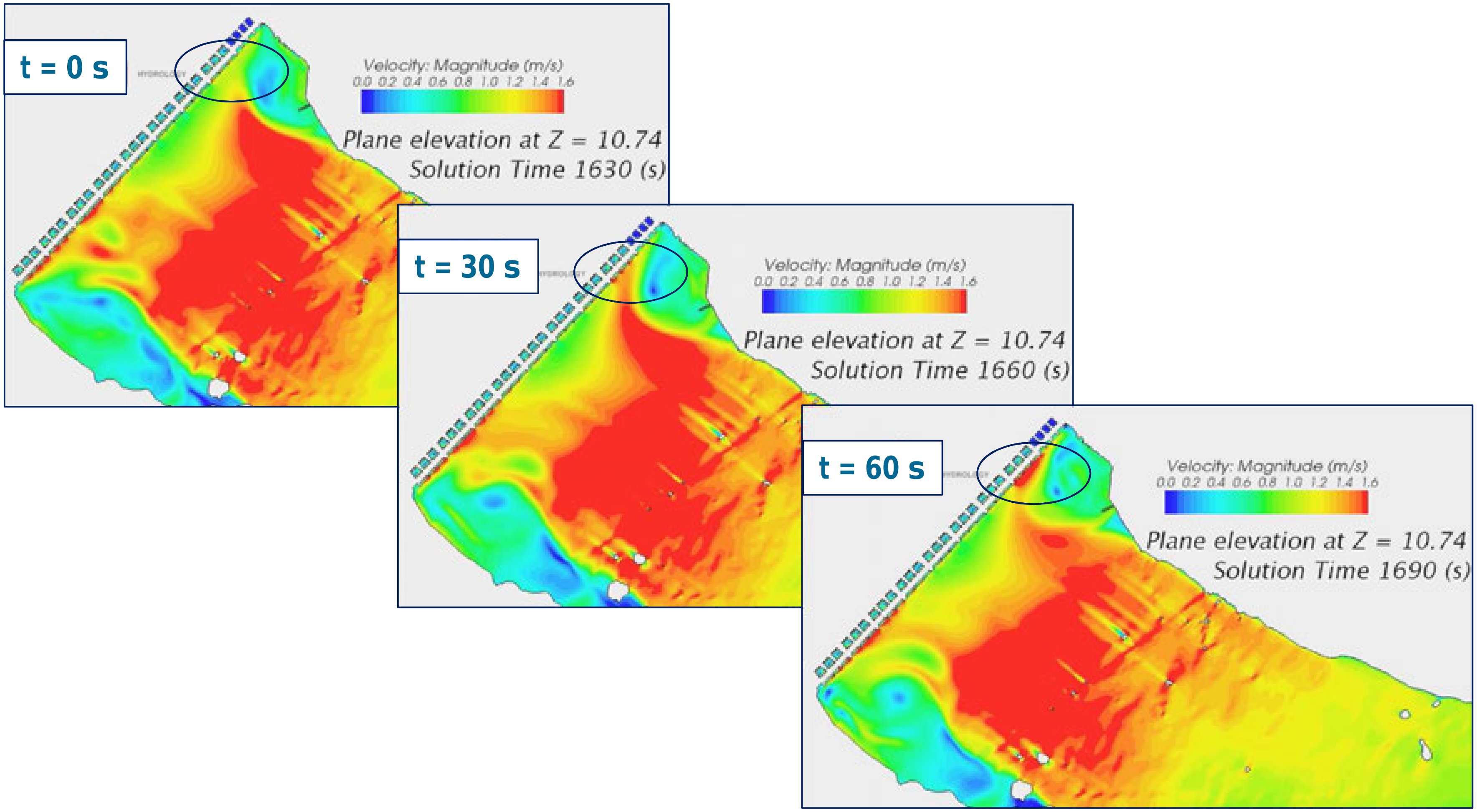






Transient-flow Considerations

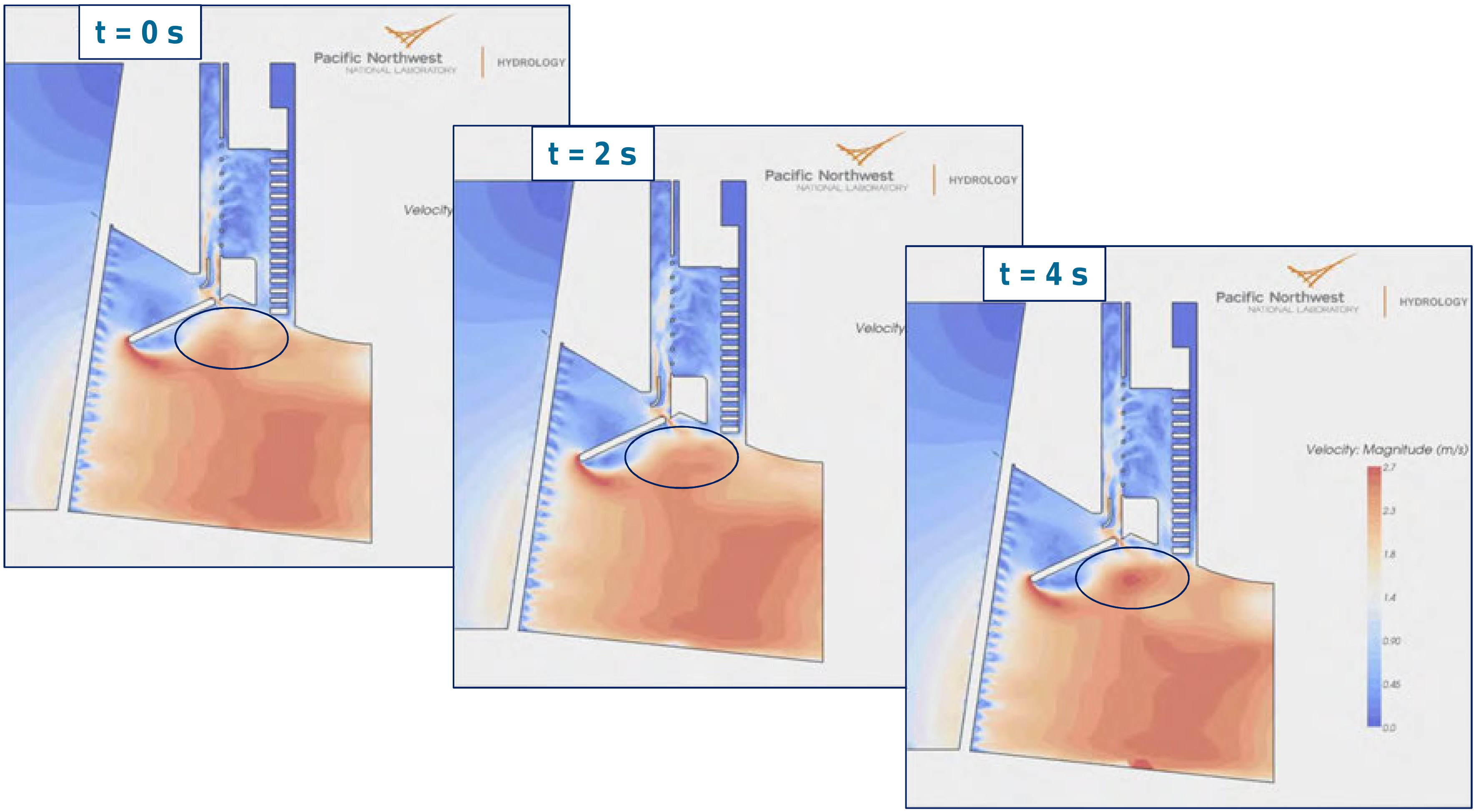
Large Scale – Forebay Approach Flow



Technical Approach - PNNL: Intake Turbulence

Transient-flow Considerations

Small Scale – Eddy Resolving Simulations



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

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

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- Pacific Northwest National Laboratory
- MOU Agency Partners
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  - Site-Specific Case Studies of HFM Upgrade Analysis
- **FY2016**
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2014 Water Power Program Peer Review

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

New Hydropower

Michael Reed
Program Manager, Water Power
Wind and Water Power Technologies Office
February 26, 2014

Strategic Objectives of the Hydropower Program Element

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- Support a resurgence in hydropower research, manufacturing and development in the U.S.
- Analyze opportunities to develop new hydropower capacity in the U.S., and facilitate the development and demonstration of environmentally-friendly technologies to harness these resources
- Improve performance / flexibility of hydropower systems and evaluate major risks to the existing hydropower fleet
- Develop tools and information that will drive the development and utilization of Pumped-Storage Hydropower (PSH) and hydropower systems to increase grid flexibility and integrate variable renewables
- Address a wide range of environmental and market barriers to facilitate significant deployment, and develop a vibrant U.S. hydropower workforce and research community

New Hydropower - Team Composition

DOE Hydropower Activities

- Existing Hydropower
- New Hydropower
- Hydropower Market Acceleration and Deployment
- Integration and Pumped Storage Hydropower

Key Counterparts and Collaborators:

Industry

ORNL	ANL	PNNL
INL	NREL	SNL

Water Power Program
Portfolio Priorities – Hydropower

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The 2014 Water Program Peer Review Agenda has sessions that will cover projects and activities in these priority areas.

<u>Existing Hydropower:</u> Optimize existing hydropower technology, flexibility, and/or operations	• Tuesday, 2/25
★ <u>New Hydropower:</u> Advance new hydropower systems and/or components for demonstration or deployment	• Wednesday, 2/26
<u>Market Acceleration:</u> Reduce deployment barriers and environmental impacts of hydropower	• Thursday, 2/27
<u>Pumped Storage Hydro:</u> Enable next-generation pumped storage technologies to facilitate renewable integration	• Thursday, 2/27

Why Focus on New Hydropower?

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New Hydropower is the single largest potential contributor to the vision to double hydropower generation in the United States.

Consider:

1. New Hydropower is deployable in the near-term at non-powered dams and long-term at new sites with substantial solvable LCOE reduction challenges.
2. Hydropower technologies and design philosophies for the types of sites still available in the U.S. can **dramatically reduce environmental impacts,** but remain expensive**. Innovation and cost-reduction is a natural role of the DOE.**
3. Industry prioritizes "Large Hydro" R&D, and is not pursuing the innovations necessary to make the sustainable development of hydropower at typical U.S. sites economical.
4. Developers need incentives to take risks and some initial technology successes in order to deploy new technologies or pursue substantial new site development.

The Program's Perspective:

Hydropower is seeing a resurgence of interest in the United States:

- March 24, 2010: DOE, DOI and the USACE sign an interagency MOU to strengthen the long-term relationship between the agencies, committing to prioritize the generation and development of sustainable hydropower at federal hydropower facilities.
- Resource assessments completed if FY2012 show that a doubling of hydropower is feasible.
  - NPDs: 12 GW
  - Canals & Conduits: 1-2 GW
  - New Hydro: 68 GW
- The "Hydropower Regulatory Efficiency Act of 2013," (aka., HR 267) modifies the Federal Power Act and the Public Utility Regulatory Policies Act to promote and facilitate the development of hydroelectric power capacity.
- The Bureau of Reclamation "Small Conduit Hydropower Development and Rural Jobs Act" (aka., HR 678) authorizes hydropower development, streamlines the regulatory process, and reduces administrative costs for small canal and pipeline hydropower development projects.
- FY 14 appropriations provides funding for incentive payments for hydropower generation (Section 242 of the Energy Policy Act of 2005).

Goal:

- Reduce costs and impacts of sustainable new hydropower development

Priorities:

- Understanding the technical, economic and environmental challenges faced by today's industry
- Developing a wide range modular systems that can take advantage of new hydro resources at
  - Non-Powered Dams (NPDs),
  - Water conveyance systems (e.g., canals and conduits)
  - New Stream-reach Development (NSD)

DOE Unique Role:

- Significant leadership required for both technology development (COE reduction) and deployment barrier reduction
  - Undertake the necessary assessments, and make information available to inform decision makers and identify priorities
  - Leverage investments in related Programs and industries to the benefit of new hydro developers

FY12 / FY 13 Project Portfolio

DOE Activities in New Hydropower (FY11-FY13)

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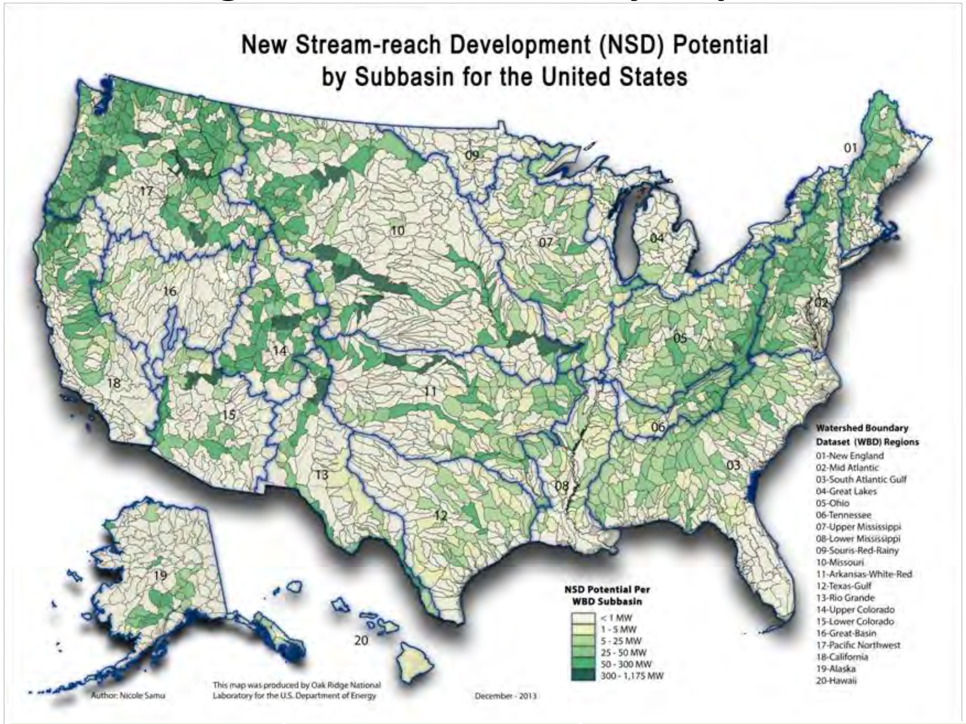
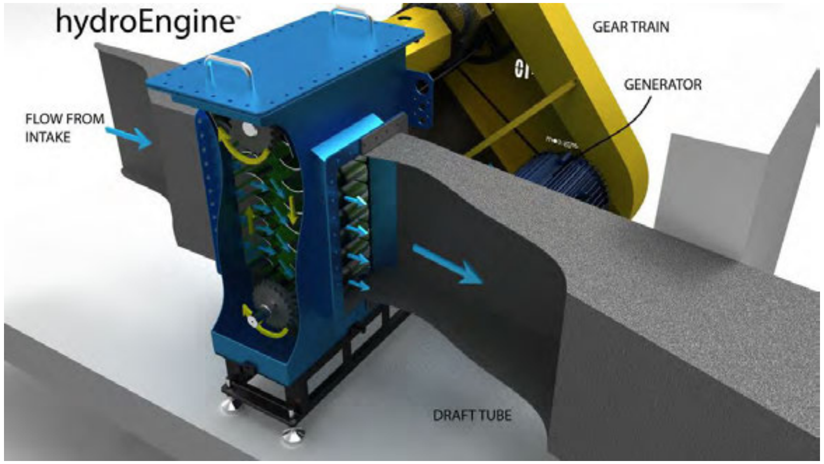
Assessing Potential of New Hydropower



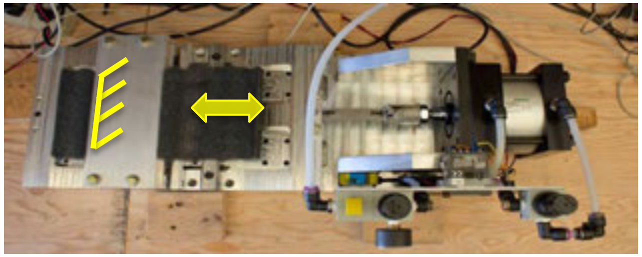
	Stream reach (>1MW)	Stream reach (<1MW)
Potential Capacity	56.3 GW	28.4 GW
Potential Energy*	302 TWh	157 TWh
Mean Capacity Factor*	67 %	63 %

Systems and Components R&D

Project Highlight: Develop & test a reliable powertrain for the SLH hydroEngine™.



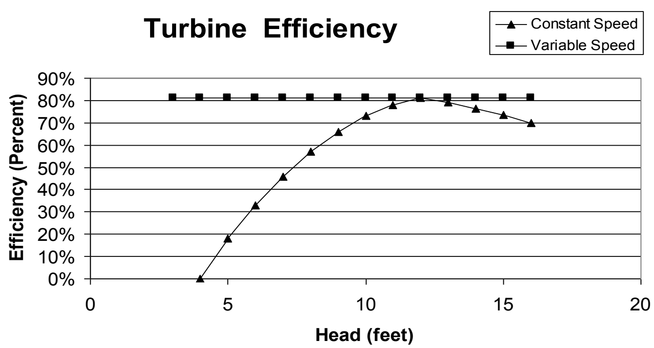
Shear fatigue test rig, 500 kW-scale belt attachment system



DOE Activities in Existing Hydropower (FY11-FY13)

Advanced Hydropower Demonstrations

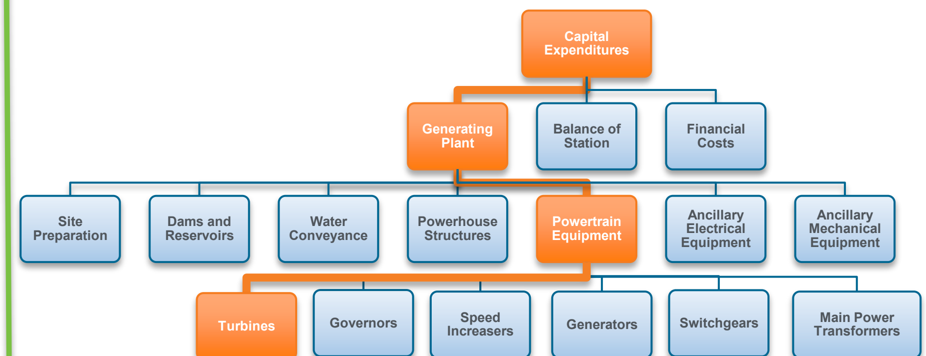
Project Highlight: Demonstration of Variable Speed Permanent Magnet Generator at Small, Low-Head Hydro Site

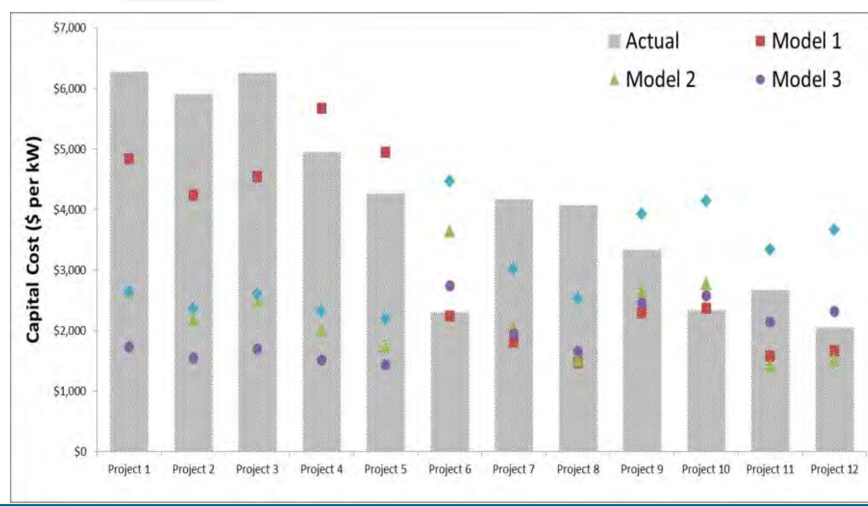


Project Highlight: Demonstration SLH, with potential to reduce the LCOE of low-head hydropower projects.

Cost Data Collection and Modeling

Objective: Identify and evaluate cost reduction opportunities for new hydropower development, and evaluate best practices of plant O&M and technology upgrades to improve efficiencies and generation





So What Happened?

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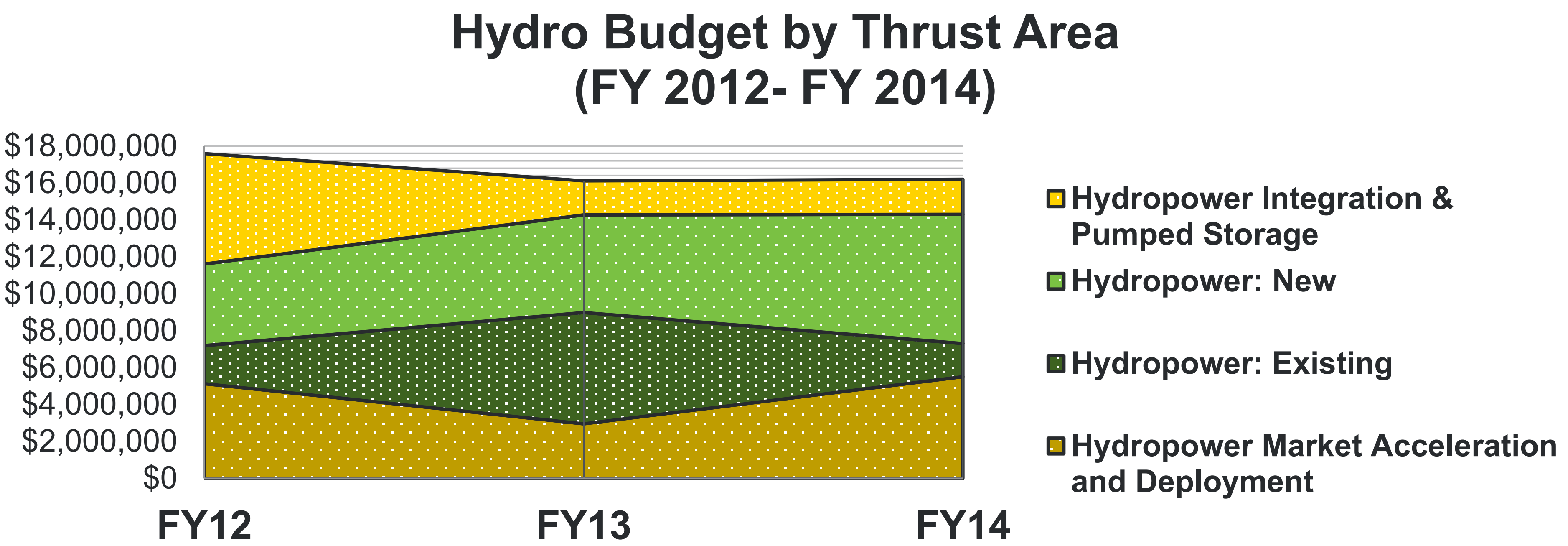
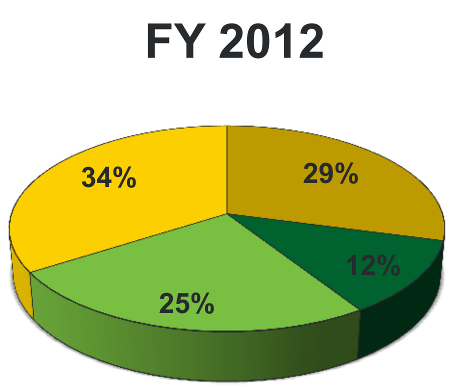
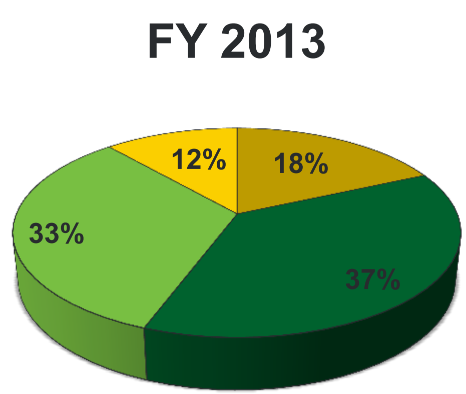
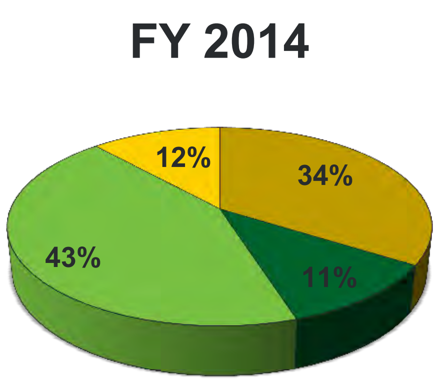
- Industry vocalizes a goal to double hydropower
- DOE undertook resource assessments to determine if the goal was credible, and if the Program could support it.
- Resource Assessments indicate that the most significant opportunity for increased hydropower generation is at new hydropower sites (NPDs, C&Cs, NSDs)
- DOE states its support for industry's goal to double hydropower.
- As funding was limited, the Program pivoted to New Hydropower Development.

Hydropower Budget (FY 2012 – FY 2014)









New Hydropower - Portfolio Adjustments (FY11 – FY14)

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Technical Area	Priorities or Changes in Portfolio (FY11 vs FY14)	Key Collaborators	Upcoming Milestones
Modeling & Analysis	• NHAAP – New Hydro Assessment • Assemble credible cost data and develop LCOE estimating tools to inform R&D priorities • NEW: Launch of New Hydropower Innovation Collaborative (NHIC), highlighting opportunities for new, low-impact development in U.S	ORNL Industry, ORNL ORNL	Baseline Cost Model and Integrated Design/Assessment Model due Q3 FY14 Draft NHIC report due 03/31/2014
Systems and Components R&D	• NEW: Launch of Incubator Program to introduce off-roadmap tech innovations • NEW: Launch CEMI to integrate advanced materials & manufacturing techniques into clean energy technologies	Industry	Under development
Demonstrations	• Hydro Projects funded in FY 2011 FOAs are now nearing construction phase – performance testing will follow to demonstrate improvements in technology	Industry, ORNL	Project Specific Performance Testing

New Hydropower Investments - FY 14

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

Technical Area	Key Projects/Activities
Modeling & Analysis	**Cost data collection and modeling:** • evaluation of contemporary hydropower cost and performance to informing Program R&D priorities **New Hydropower Innovation Collaborative :** • Highlight prevalence of opportunities for new, low-impact development in U.S.

Systems and Components R&D	• **New hydropower development (2011 FOA)**
	• **Incubator: Off-roadmap technology development**
	• **Clean Energy Manufacturing Initiative**
	• **SBIR/STTR (See Poster Presentations)**
	    • Modular, drop-in hydropower system design
	    • Nanoscale Coating System

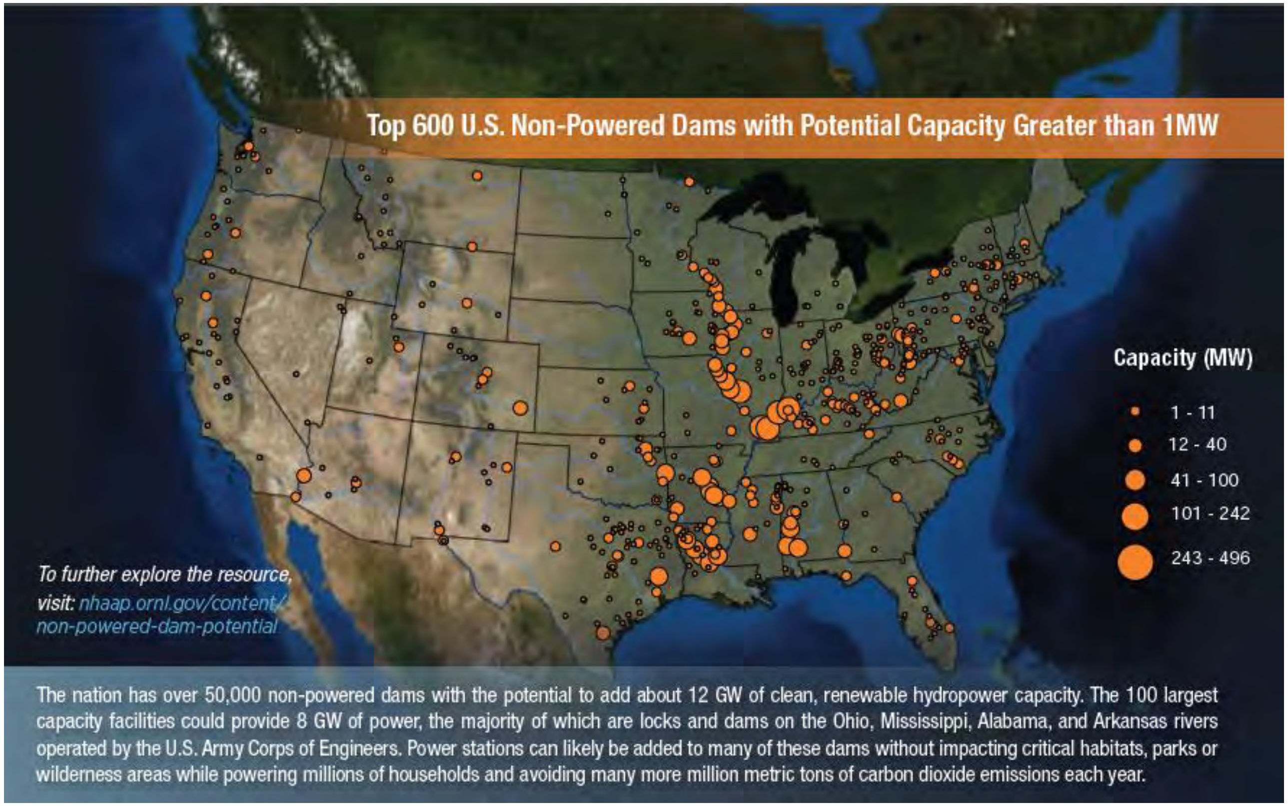
Demonstrations	**Advanced hydropower development (2011 FOA)** • TA1: Sustainable Small Hydropower • TA2: Sustainable Pumped storage Hydropower • TA3: Environmental Mitigation Technologies for Conventional Hydropower • TA4: Advanced Conventional Hydropower system Testing at a Bureau of Reclamation Facility

New Hydropower: Questions for Peer Reviewers

- From an overall investment perspective, what hydro resources should be prioritized, and why?
- What are the most pressing needs of today's industry? Do the Program's goals align with these needs?
- Are the Program's investments in line with its stated goals and priorities?
- Are there any gaps in the portfolio? In what else should the Program invest?
- What is the next big thing we should be thinking about?
- In what research areas do you believe DOE's investments can make a significant impact towards increasing hydropower generation, development and deployment?

Adding Generation at Non-Powered Dams

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



Broad support from NGO community:

"These types of projects are cheaper to build, easier to permit, and much less harmful to the environment than hydropower that involves new dam construction, so we're doing all we can to encourage developers to put their energy here"
- American Rivers

3% of Existing Dams are Powered
12.1 GW NPD potential nationwide
8.3 GW at the Top 100 NPDs

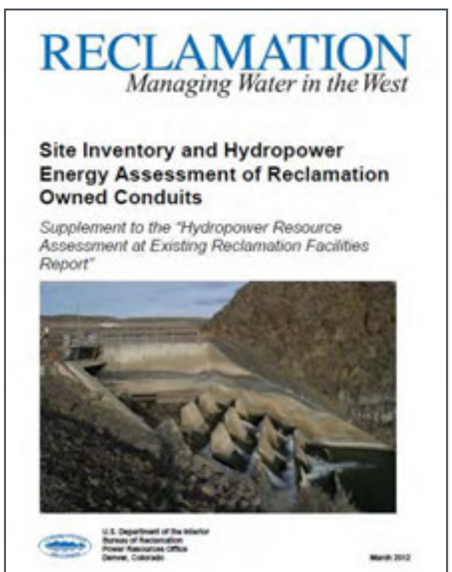
Ranking 24th in the Oak Ridge survey of potential hydropower sites is the non-powered Montgomery Locks & Dam, spanning the Ohio River near Monaca, Pennsylvania. Built in the 1930s to increase the navigational depth of a shallow part of the river, this site has the potential to generate nearly 100 MW of electricity.

Majority of environmental impact has already incurred with dam construction and operation for water control

Adding Generation at Canals and Conduits

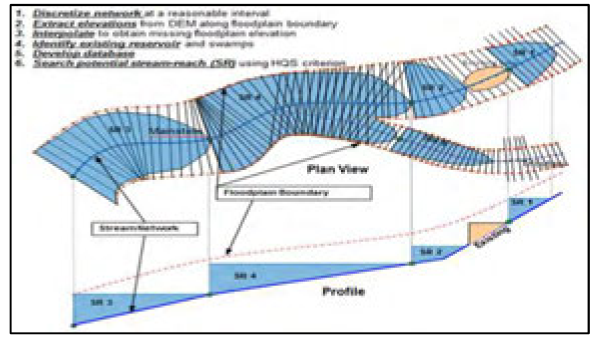
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

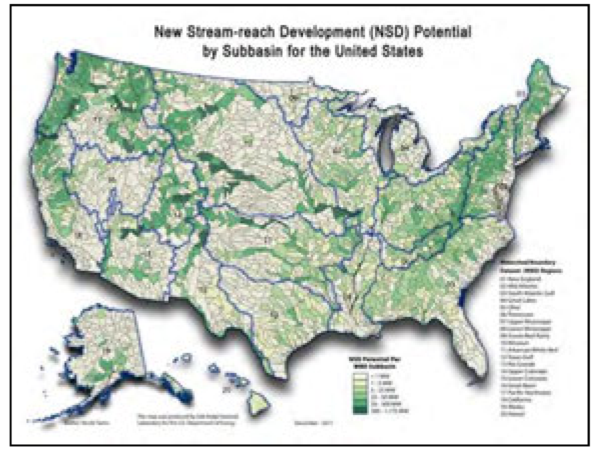
1. Canal and conduit projects are able to generate electricity from existing water flows, exploit synergies with infrastructure already in place and often requiring less of a capital investment (as the majority of civil construction costs have already been absorbed).
2. HR 678 defines the term ‘conduit’ as any tunnel, canal, pipeline, aqueduct, flume, ditch, or similar manmade water conveyance that is operated for the distribution of water for agricultural, municipal, or industrial consumption and not primarily for the generation of electricity.
3. Expedited FERC Permitting Process



Key Findings:

- ✓ **225MW of capacity and 1TWh of generation** that could practically be produced annually from Bureau of Reclamation canal infrastructure.
- ✓ This assessment noted that it could not assess all Reclamation canals (up to half may have been missed), and Reclamation canals only make up a portion of canal infrastructure in the U.S. (estimates are from 25-33% of irrigation canals).
- ✓ Likely resource base is estimated to be relatively small (possibly 1-2GW with other very small additions for municipal water systems)





National Hydropower Asset Assessment Program (NHAAP)

– New Hydro Assessment

Shih-Chieh Kao

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February 26th, 2014

Oak Ridge National Laboratory

Purpose & Objectives

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

Problem Statement

- Multiple new US data sets allow the refinement of hydropower resource estimates from undeveloped stream-reaches.

- The previous national hydropower resource assessment was not designed specifically for undeveloped stream-reaches.
  - The total resource estimates cannot be easily broken down into different resource categories (upgrade/expansion, non-powered dam, and undeveloped stream-reaches).

- New resource assessment is needed for the improvement of future hydro energy projection.

Purpose & Objectives

New Stream-reach Development (NSD) resource assessment is designed to identify new hydropower potential from ~ 3 million undeveloped US stream-reaches

- specifically for new run-of-river projects
- focus on opportunities > 1MW capacity
- estimate potential capacity (MW), monthly energy (MWh), inundated area (acre), and reservoir storage (acre-ft)
- provide comprehensive environmental attributes
- will be used to update hydropower supply curve for energy deployment projections and to support other hydropower market acceleration studies

Purpose & Objectives

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

This project aligns with the following DOE Program objectives and priorities

- *Advance new hydropower systems and/or components for demonstration or deployment*
  - NSD identifies regions with high undeveloped hydropower potential for more in-depth future deployment analysis.

- *Reduce deployment barriers and environmental impacts of hydropower*
  - All potential hydropower stream-reaches are labeled with various environmental attributes (e.g., critical habitat and endangered species) to support further deployment barrier and environmental impact analysis.

Multiple new national geospatial data sets are used in NSD

Data Type	Data Source	Note
Watershed Boundary	Watershed Boundary Dataset, NRCS	
River Geometry, Mean Annual Flow, Existing Water Bodies	National Hydrography Dataset Plus (NHDPlus), EPA/USGS	3 million flowlines (NHDPlus version 1)
Existing Dams	National Inventory of Dams (NID), USACE	84,000 dams
Existing Hydropower Plants	National Hydropower Asset Assessment Program (NHAAP), ORNL	
Topography	National Elevation Dataset (NED), USGS	10-meter resolution
Daily Flow Time Series	National Water Information System (NWIS), USGS	22,000 stations
Monthly Runoff Time Series	WaterWatch Runoff, USGS	Unit runoff for each HUC08
Flood Zone	Flood Insurance Study (FIS), FEMA	100-year flood elevation is used as the hydraulic head
Environmental Attributes	Critical Habitats, Wild and Scenic River, Conservation Lands, Water Use, Federally Listed Fish, and Fish Traits	

Technical Approach

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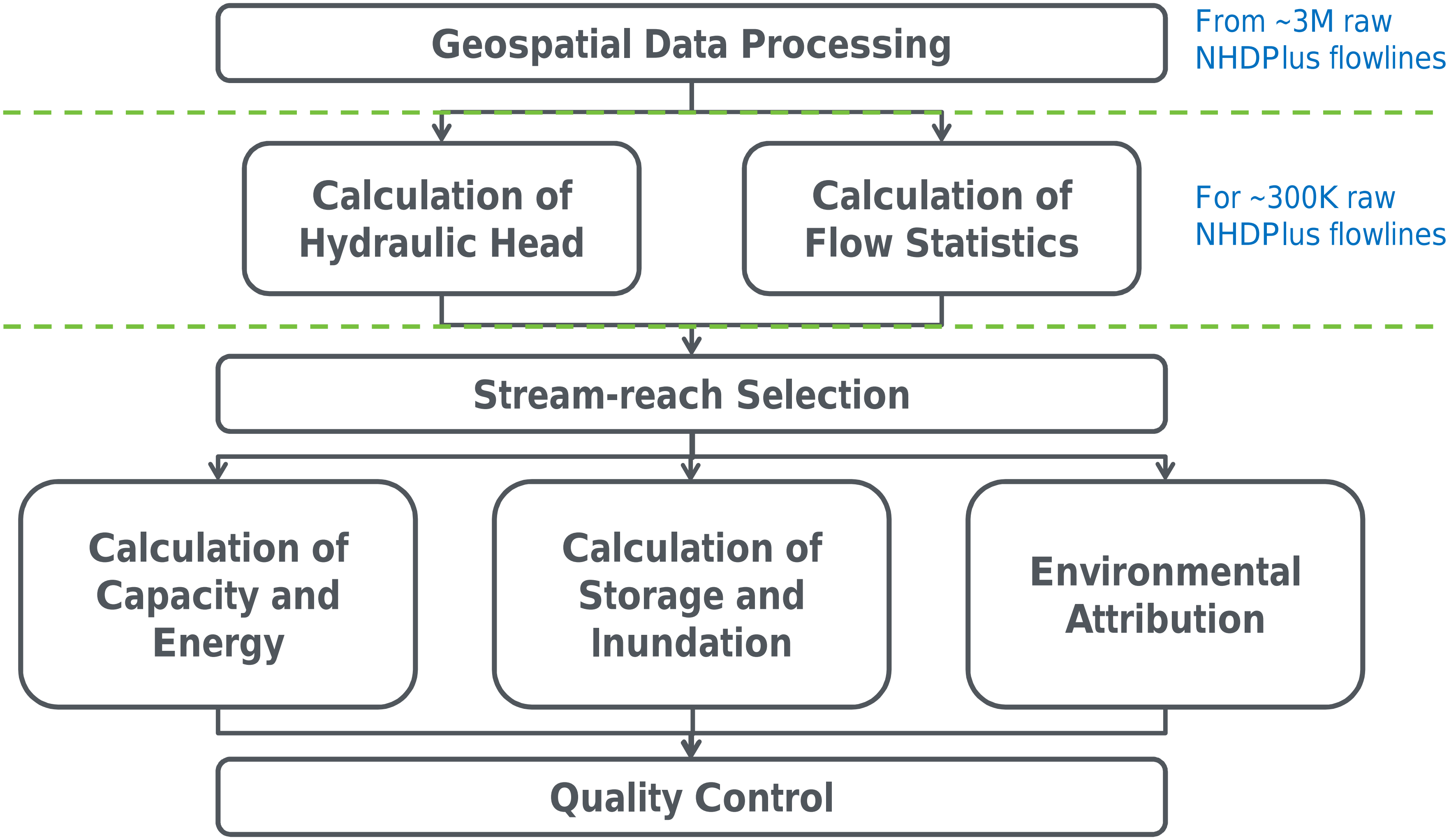
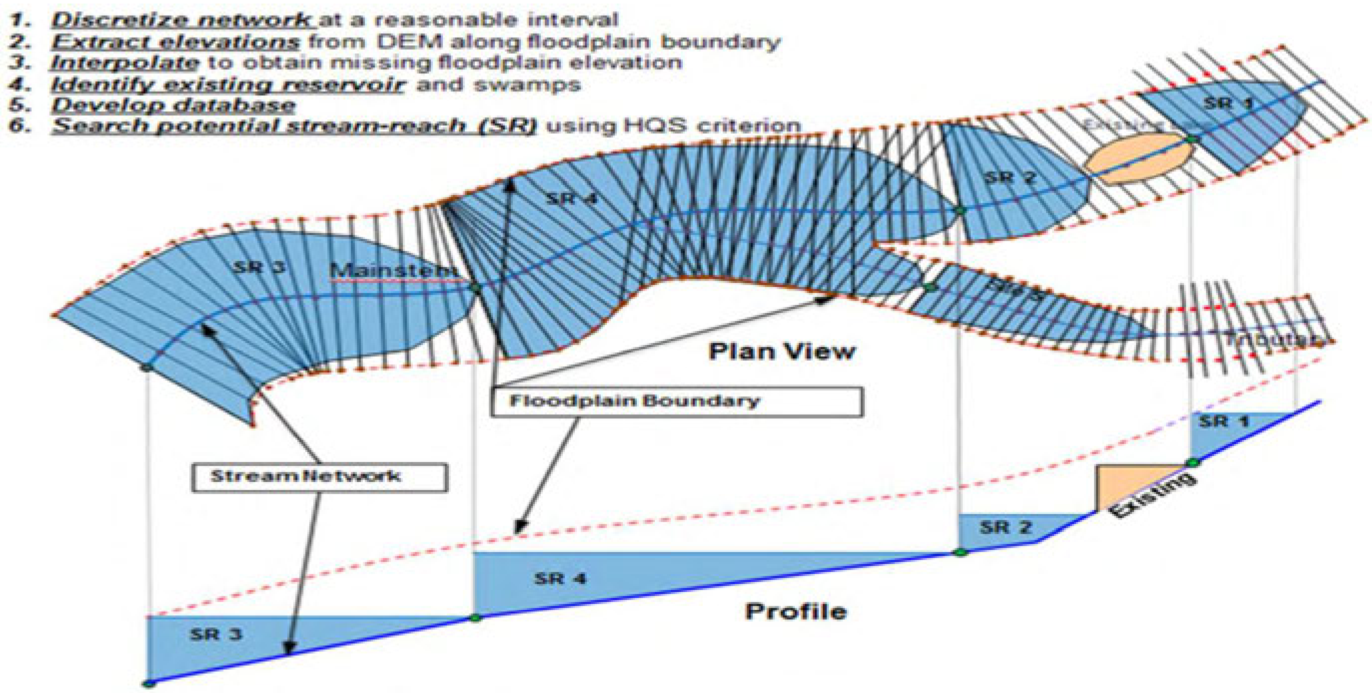


Note: Given the data limitations and different needs, AK and HI are analyzed through different approaches.

Within each US Hydrologic Subregion (HUC04), stream-reaches are selected based on head * flow * slope



Pasha, M. F. K., D. Yeasmin, S.-C. Kao, B. Hadjerioua, Y. Wei, and B. T. Smith (2014), Stream-reach Identification for New Run-of-River Hydropower Development through a Merit Matrix–Based Geospatial Algorithm, *ASCE Journal of Water Resources Planning and Management*, in press.

Accomplishments and Results

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

New hydropower stream-reaches are identified with comprehensive attributes.

Basic Attributes
Coordinates
State
County
Hydrologic unit
Site elevation (ft)
River name
Channel Slope
Head (ft)
Flow (cfs)
Capacity (MW)
Energy (MWh/year)
Reservoir storage
Inundated area
Residence time

Federally Listed Fish
Endangered
Threatened
Candidate
Species of Concern
Proposed Endangered
Proposed Threatened
Population Endangered
Population Threatened
Population Candidate
IUCN Critically Endangered
IUCN Endangered
IUCN Vulnerable
IUCN Near Threatened

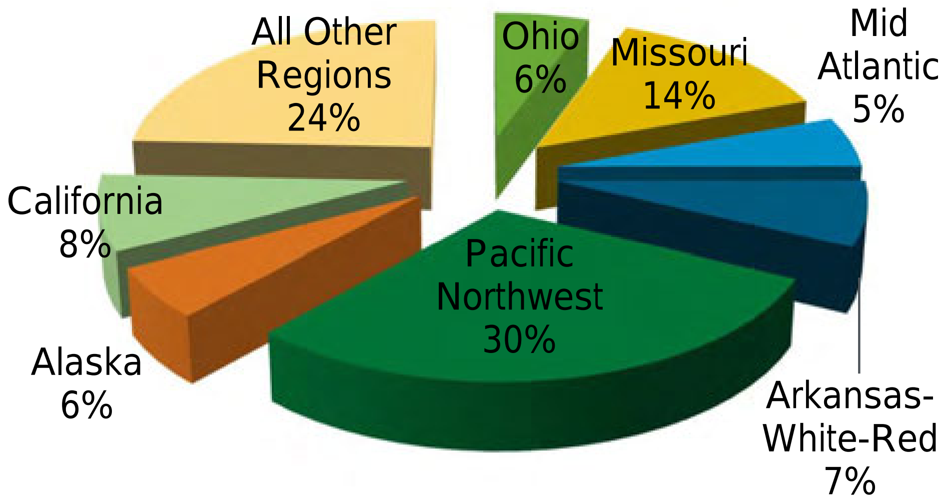
Critical Habitats
Endangered
Threatened
Species of Concern
Fish
Bird
Plant
Amphibian
Reptile
Mammal
Snail
Crustacean
Fern
Arachnid
Insect

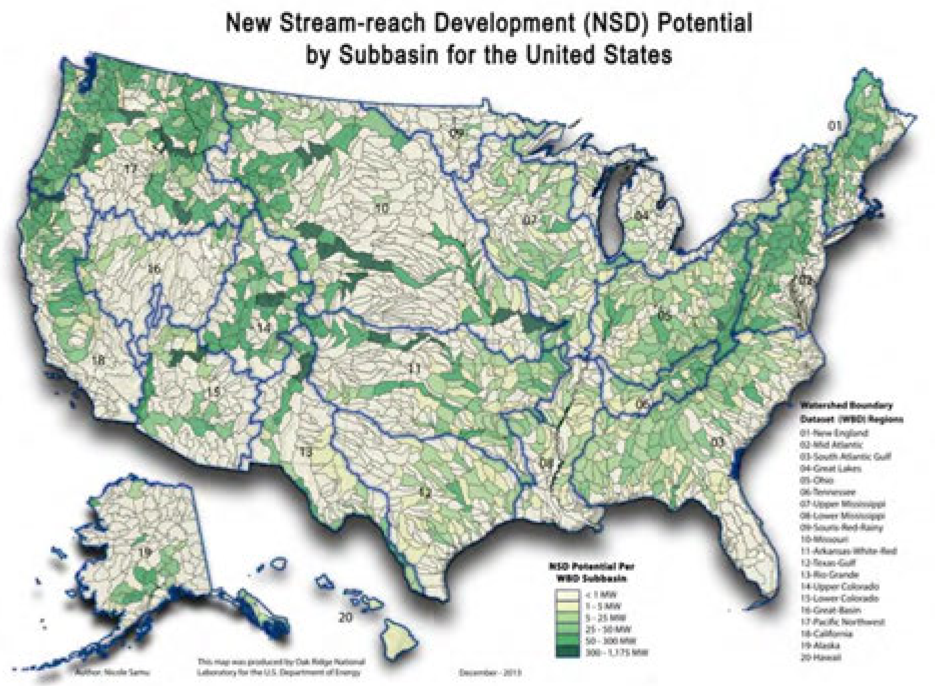
Water Use
Aquaculture
Domestic
Industrial
Irrigation
Livestock
Mining
Public Service
Thermo-Electric
Surface Water Total
Ground Water Total
Total Freshwater Use

Fish Traits
Anadromous Species Serial
Spawners Seasonally
Restricted Spawners Habitat
Specialists Lotic Specialist

GREY: Environmental attributes

Summary of national findings





	Stream-reach (>1MW)	Stream-reach (<1MW)
Potential Capacity	56.3 GW	28.4 GW
Potential Energy*	302 TWh	157 TWh
Mean Capacity Factor*	67 %	63 %

Note: Given the different approach, potential energy and mean capacity factor were not computed for AK.

Accomplishments and Results

- Two peer-review methodology workshops were organized in December 2011 for resource characterization and in June 2012 for environmental attribution.
- The national assessment was completed in 2013.
  - It found a total of 84.7 GW capacity and 460 TWh energy in the US
  - After national parks, wild/scenic rivers, and wilderness areas were excluded, the remaining capacity was reduced to 67.7 GW.
- A detailed comparison with a previous resource assessment was conducted and included in the final report.
- Two ORNL technical manuals (Hadjerioua et al. 2013, and Kao et al. 2014) and one peer-reviewed journal article (Pasha et al., 2014; *JWRPM*) have been published or are in press.
- Detailed information, reports, data, and maps were publicly disseminated through http://nhaap.ornl.gov/nsd

Project Plan & Schedule

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

Summary		Legend
1.6.2.1 New Hydropower Assessment - NHAAP		Work completed
		Active Task
		Milestones & Deliverables (Original Plan)
Agreement 24516 and 24547		Milestones & Deliverables (Actual)

Milestone / Deliverable	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Resource Class Methodoloy External Review												
Complete first six HUC regions and remainder regions												
Develop and apply DEM methdology to regions												
Environmental data attribution												
Interactive webinar with Environmental Community												
Publication of DEM methodology for New Stream Reach												
Compelte draft assessment 100 HUC04 subregions												
Complete 180 assessmetns for 180 HUC 04 subregions												
All HUC04 subregions compeleted												
Submit methodology and summary results												
Current work and future research												
Publication of New Stream Reach final report												

Comments

- The FY2012 focus was on methodology development, review, and revision.
- The FY2013 focus was on assessment across the entire US.
- The final report will be published in early 2014.

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,231K	$0	$315	$0	$0	$0

- The main assessment work was completed within the given budget.
- The remaining funding (5%) will be utilized for the follow-up report revision and outreach activities.

Research Integration & Collaboration

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- Subcontractors for geospatial data preparation and tool maintenance
  - Fayzul Pasha (CSU Fresno), Dilruba Yeasmin (Xcel Engineering)
- Collaborating agencies
  - US Army Corps of Engineers (Kyle Jones, William D. Proctor, Crane Johnson, Debbie Solis), US Bureau of Reclamation (Michael Pulskamp), US Fish and Wildlife Service (Frankie Green), US Geological Survey (Eric Evenson, Kernell Ries, Kristine Verdin), US National Park Service (Joan Harn), NOAA National Marine Fisheries Service (Timothy McCune), Alaska Energy Authority (Doug Ott, Audrey Alstrom), Bonneville Power Administration (Mark Jones), California Department of Water Resources (Mark Anderson), North Carolina Wildlife Resources Commission (Chris Goudreau), Hawaii Department of Business, Economic Development and Tourism (Andrea T. Gill)
- External reviewers and commenters
  - Norman Bishop (Knight Piesold), Linda Church-Ciocci (NHA), Dave Culligan (HDR|DTA), Don Erpenbeck (MWH), John Gasper (ANL), Ron Grady (HDR), Paul Jacobson (EPRI), Kurt Johnson (Telluride Energy), Jeff Leahey (NHA), Andrew Munro (NHA/GCPUD), Rick Miller (HDR|DTA), Jonathan Higgins (The Nature Conservancy), James Parham (Parham & Associates), Scott Robinson (Southeast Aquatic Resources Partnership), John Seeback (American Rivers), Eric Van Deuren (Mead & Hunt), Dave Youlen (ECRE)

Next Steps and Future Research

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- The NSD resource data are currently used by multiple Wind and Water Power Program research projects:
  - Wind and water power strategic planning
  - Cost Data Collection and Modeling for New Hydropower
  - Basin Scale Opportunity Assessment
- Potential future research
  - Development of an unified U.S. hydropower resource catalog that documents the hydropower potentials across NSD, non-powered dam (NPD), constructed waterways, and upgrade/expansion of existing plants.
  - Provide constant update/maintenance using the latest geospatial datasets (e.g., NID 2013 and NHDPlus version 2).
  - Further collaboration with EIA for the National Energy Modeling System (NEMS) projection.
  - Enhancement of the stream-reach selection methodology for the consideration of different development approaches (i.e., choose among dam, diversion, or in-stream MHK).

Summary

- The national new stream-reach development resource assessment is now completed.
- Using the latest geospatial data and improved methodology, a total of 84.7 GW capacity and 460 TWh energy was found in the US.
- The NSD findings will be used to update hydropower supply curve for energy deployment projections and to support other hydropower market acceleration studies.

BACKUP SLIDES

Calculation of Capacity and Energy

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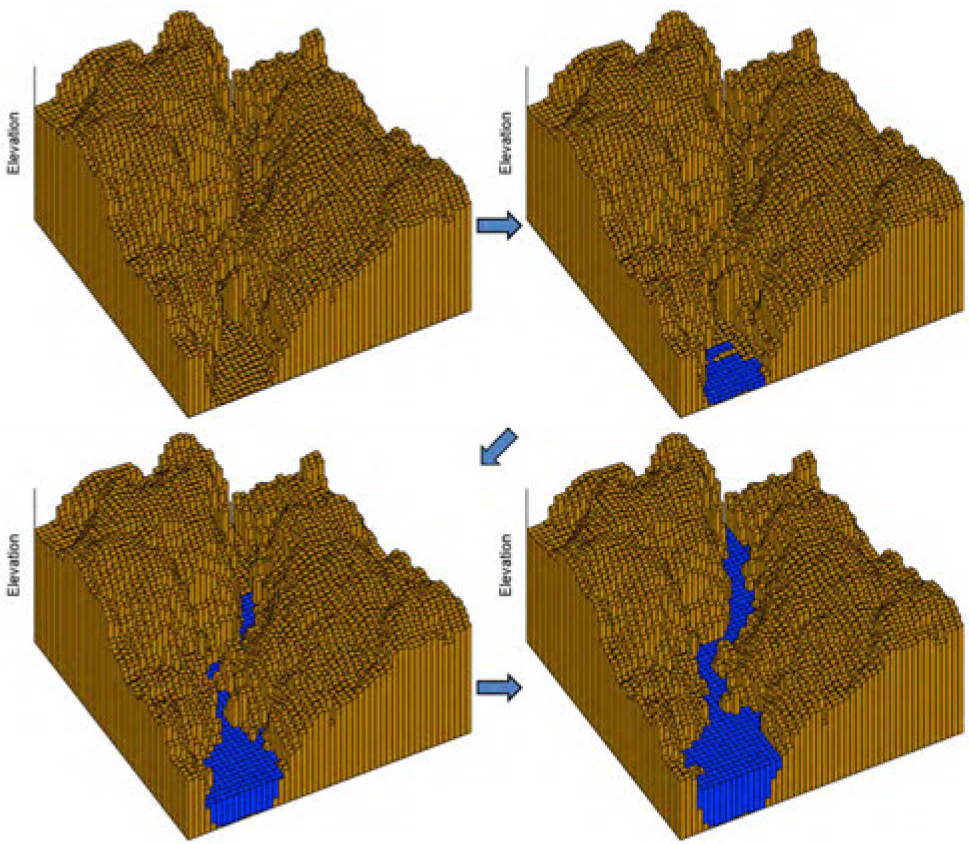
$$P = c * \gamma * \eta * H_{ref} * Q_{30}$$

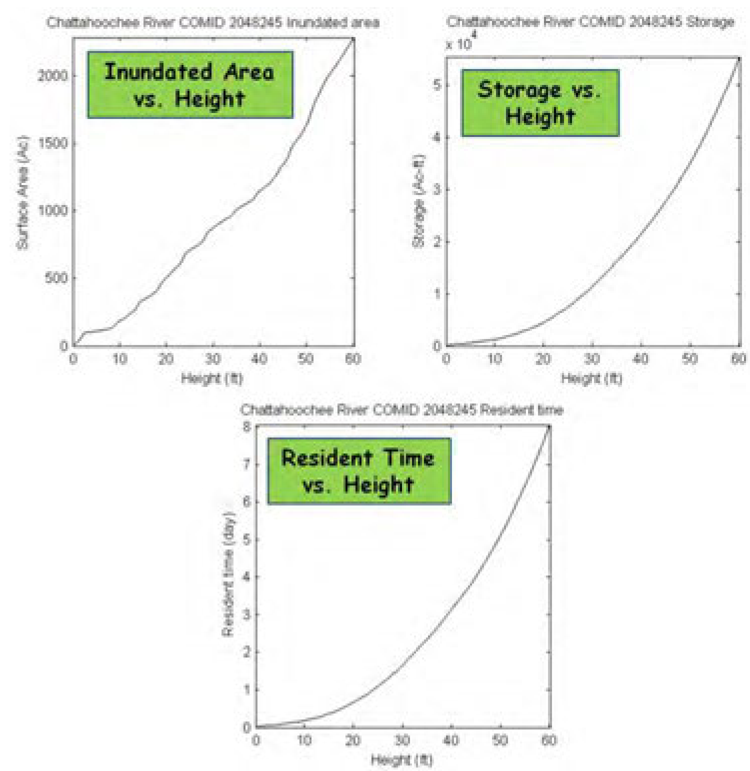
- P: capacity (W)
- η: efficiency, assumed to be 0.85
- H_{ref}: head (ft), 100-year FEMA flood elevation
- Q_{30}: flow (cfs), 30% exceedance quantile

- The assessment is designed for the dam-development model
- Diversion model equivalent is also provided:
  - The outlet of penstock placed at the location of dam
  - The penstock is placed along the river reach for the entire reservoir length.
  - Based on the assumed penstock characteristics, reduce head to account for head loss.
- Numerically integrate energy from flow-duration curve (synthesized from the USGS WaterWatch Runoff dataset).

Calculation of Storage and Inundation

- Estimate the relationships between height, storage, and inundated area
  - Automated algorithm for national-scale assessment.





Environmental Attribution
"New potential is not all bad, not all good"

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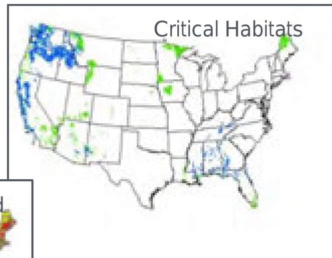
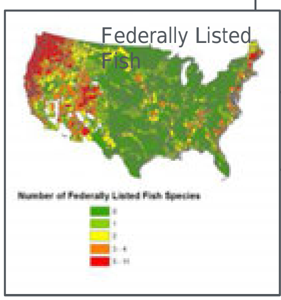
Existing and potential development locations are tagged with an ever-expanding set of ecological and socio-economic attributes that can be used to model developmental difficulty.

Issues Include:

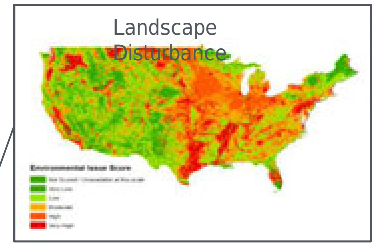
- Ecological
- Socio-Economic
- Geopolitical

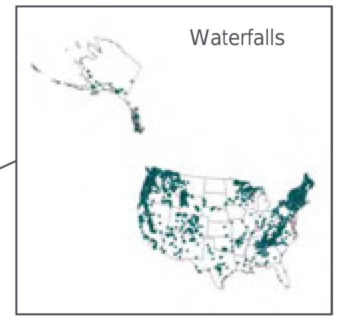


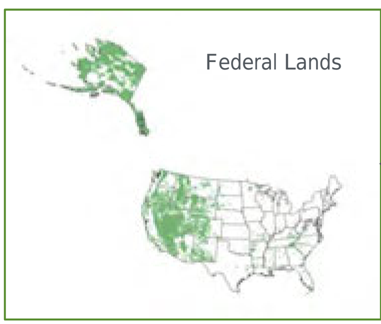


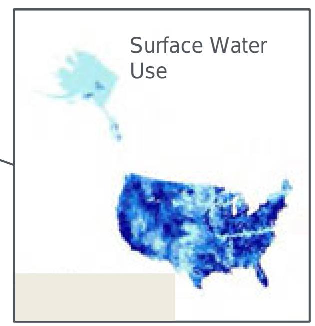
Environmental Data Layers

- **Critical Habitats**
- **Federally Listed Fish**
- **Fish Traits**
- **Landscape Disturbance**
- **Land Ownership**
- **Recreation**
- **Water Use**
- **Water Quality**









Summary of Differences between INL(2004, 2006) and ORNL(2014)

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- Hydropower Resource Class
  - INL: Total hydropower potential (NPD + new hydro + expansion)
  - ORNL: New run-of-river projects
- Treatment of Existing Hydropower Plants
  - INL: Subtracting total raw power by total existing capacity
  - ORNL: Excluding developed stream-reaches directly
- Estimation of Capacity and Energy
  - 85% efficiency, Q_{30} and spill are considered in ORNL (2014)
- Identification of Stream-reaches
  - Fixed length versus optimization
- New Geo-spatial Datasets
  - River geometry, elevation, flow, and existing facilities
- Environmental Attribution versus Exclusion

Stream-reach Selection based on Head * Flow * Slope

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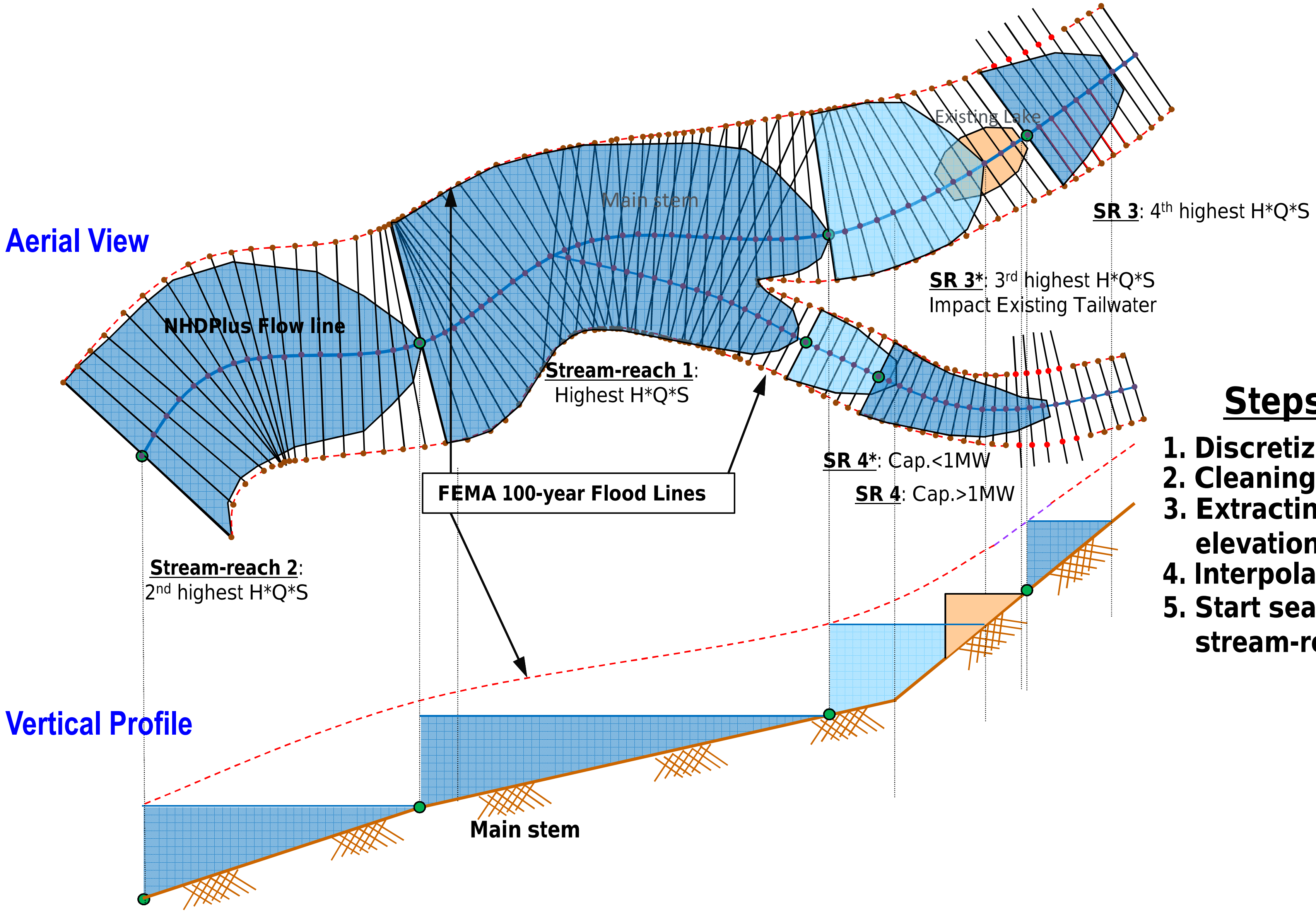

Steps

1. Discretization
2. Cleaning
3. Extracting NED elevation
4. Interpolation
5. Start searching stream-reaches

Water Power Peer Review

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Slab Creek Powerhouse Project

David Hanson

Sacramento Municipal Utility District

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February 26, 2014

Purpose & Objectives

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

Problem Statement: Incremental additions to generation at existing hydroelectric projects face challenges associated with siting difficulties and cost limitations.

Impact of Project: Demonstration of circumstances in which the addition of small hydro to existing projects, following relicensing process, adds to renewable generation.

Aligns with DOE Program objectives and priorities:

- Optimize existing hydropower technology, flexibility, and/or operations
- Reduce deployment barriers and environmental impacts of hydropower

Objectives

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- Demonstrate how power tunnels can be used in the construction of small hydro plants to take advantage of minimum flows when placing the plant at the base of the dam is not feasible or economical.

- Demonstrate the value of a 2.7 MW Francis turbine that generates an average annual 10.5 GWh of energy from highly variable minimum releases discharged from a hydroelectric dam, thereby achieving a small-hydro Levelized Cost of Energy of $0.074/kWh.

Slab Creek Dam on South Fork American River

Terms of New License for Upper American River Project (expected)

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- Minimum Flow releases from Slab Creek Dam that range from 63 to 415 cfs, depending on water year and season

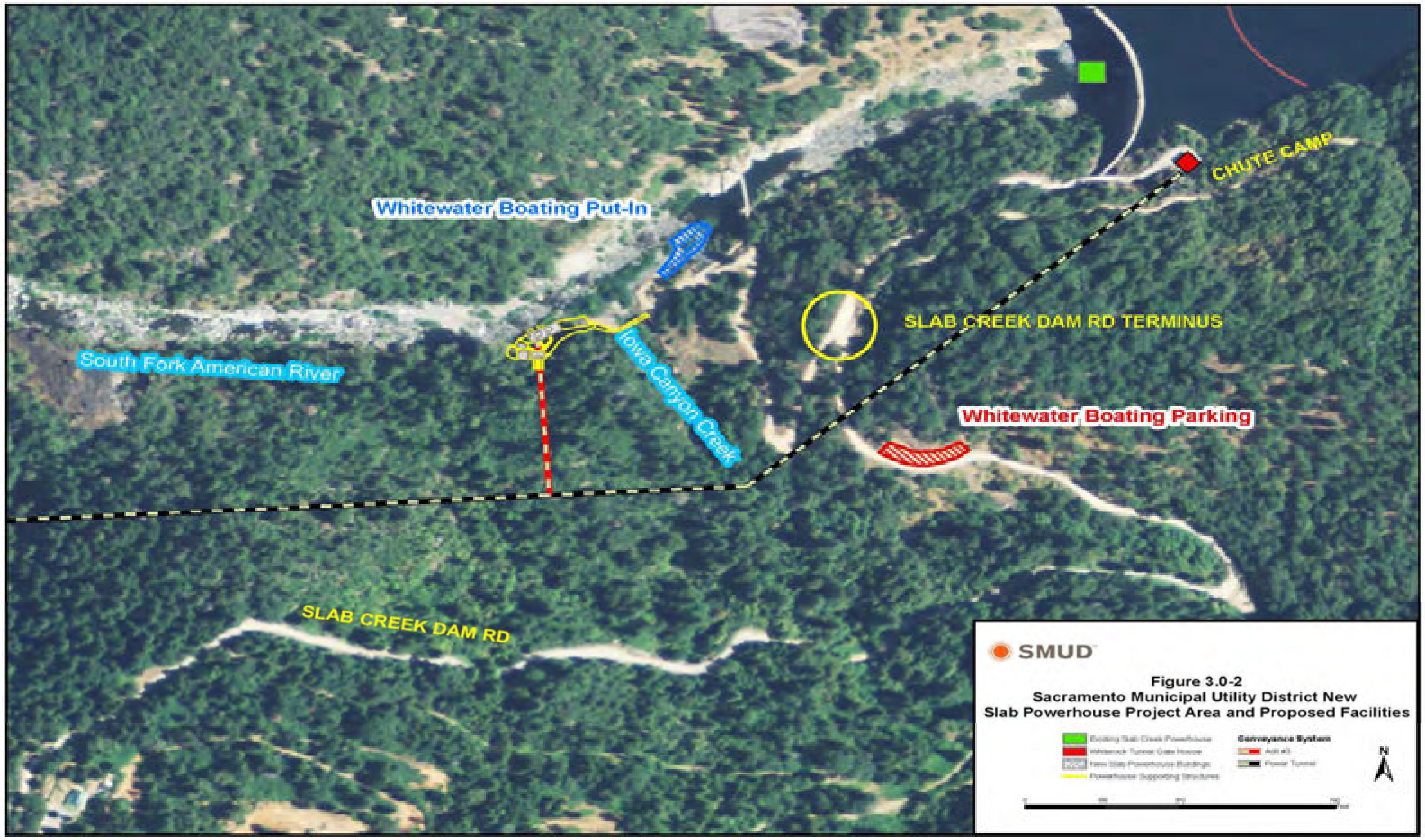
- Whitewater Boating Flow releases from Slab Creek Dam that range from 850 to 1,500 cfs, depending on whether the focus is kayaking or rafting

- Three years from date of license issuance to make facility modifications to accommodate new minimum and boating flows.

Facility Modification Challenges

- Releasing up to 415 cfs through the existing 36-inch penstock through Slab Creek Dam creates unacceptably high water velocities
- Spilling up to 1,500 cfs over the top of the dam limits operations and presents safety issues if downstream powerhouse trips off line.
- Steepness of canyon, cost of new penetration through dam, and presence of uncontrolled spills over dam limit construction of new release facilities at base of dam

Use of Existing Tunnel/Adit



Conceptual Design of new release facilities (powerhouse & boat valve)

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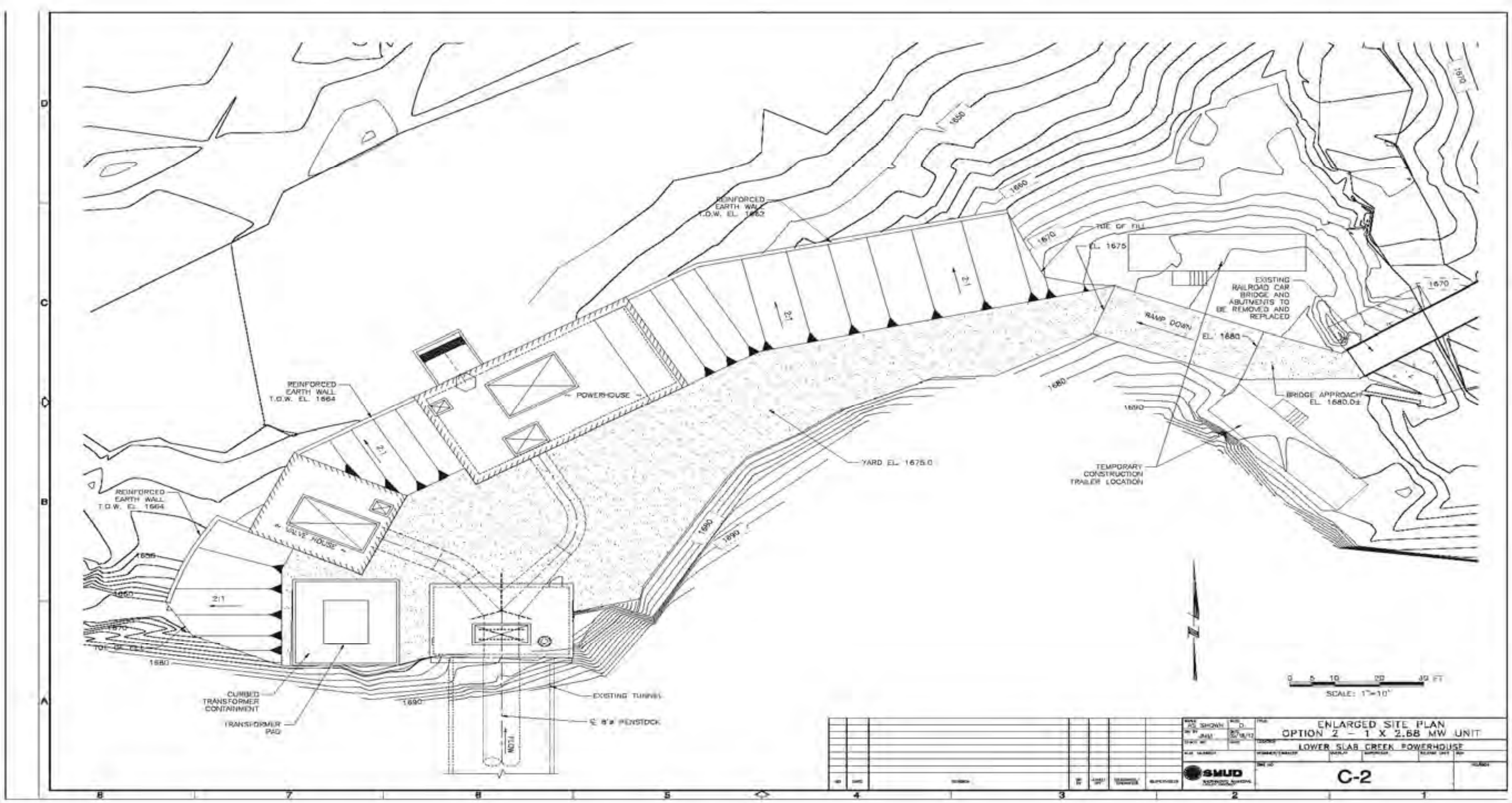

New Slab Creek Powerhouse Rendering

Overview of Delays in performing DOE Grant work

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- 2005 UARP License Application
- 2008 FERC Final EIS completed
- 2008 SMUD Final EIR completed
- 2013 Water Quality Certification completed
- 2014 Expected FERC release of New UARP license

SMUD Progress leading to performing DOE Grant work

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

- 2010 Performed baseline environmental studies and developed preliminary design concepts
- 2011 Released Initial Consultation Document / Held public meetings
- 2012 Performed additional environmental studies and reached comprehensive agreement with resources agencies regarding conceptual design and mitigation measures
- 2013 Released draft License Amendment Application for review and comment
- 2013 State Water Resources Control Board releases 401 Water Quality Certification
- 2014 Incorporated comments to generated final License Amendment Application
- Q2 FY2014 Expected release of new license for Upper American River Project

Revised Schedule

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

Task Number	Task Description	Task Completion Date
1.0	Project Administration	December 2017
2.0	FERC Licensing and Permitting	July 2015
3.1	Final Design Contractor Selection	July 2014
3.2	10% Design	October 2014
3.3	50% Design	February 2015
3.4	90% Design	May 2015
3.5	100% Design	July 2015
4.0	Construction and System Testing	December 2017

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0	$0	$0	$0	$0	$0

Partners, Subcontractors, and Collaborators:

- Contractors have not been determined at this date.

Communications and Technology Transfer:

- Industry Conferences NHA, NWHA, HydroVision

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Harnessing the Hydroelectric Potential of Engineered Drops

Sharon Atkin

Percheron Power, LLC

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February 26, 2014

Problem Statement

Significant unrealized hydroelectric potential exists in low-head engineered drops in canals and conduits across the U.S

Reliable, cost-effective hydroelectric plants to harness this potential need to be developed and successfully demonstrated

Percheron Power is developing an innovative, low-head hydroelectric plant on a large irrigation canal

- Permit/License, Design, Develop, Construct, Operate
- First Archimedes Hydrodynamic Screw Hydroelectric Plant in U.S.
- One of Largest (nameplate capacity) AHS Plants in World

Impact of Project

- Demonstrates to federal agencies, irrigation districts, and other irrigation system owners and operators that the AHS technology is simple, robust, economical, and does not negatively impact canal operations
- Supports development of new small hydropower projects by making previously marginal low-head sites viable
- Potential for broad applicability of this lower cost technology system to man-made and natural low head drops across the U.S

Archimedes Hydrodynamic Screw Turbine

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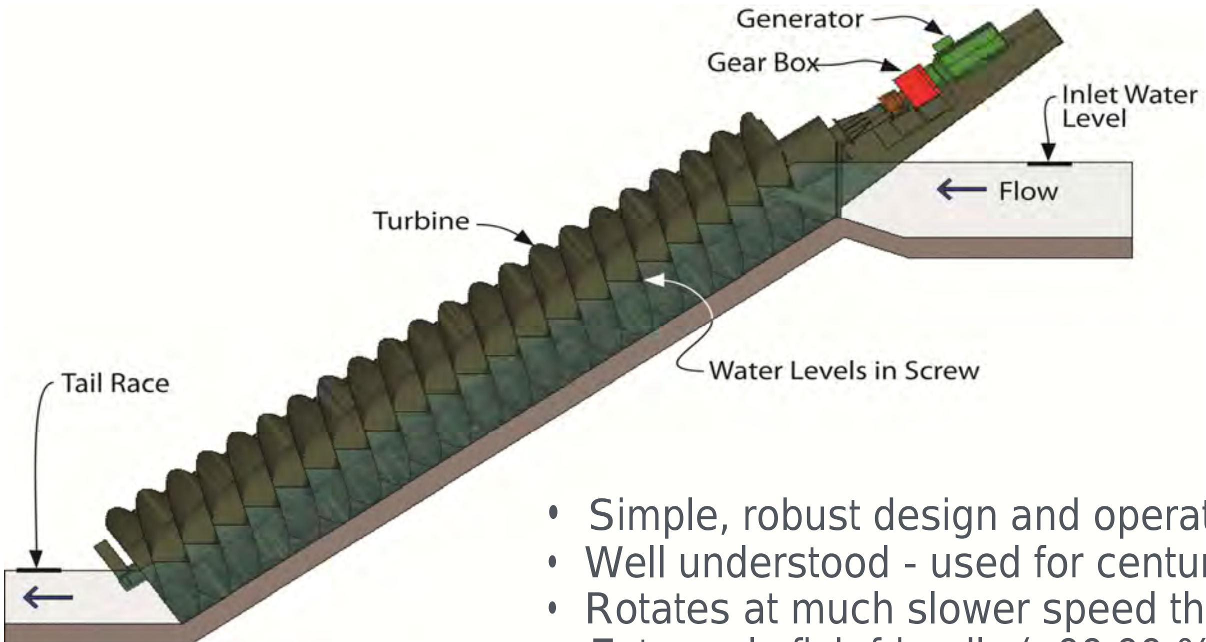
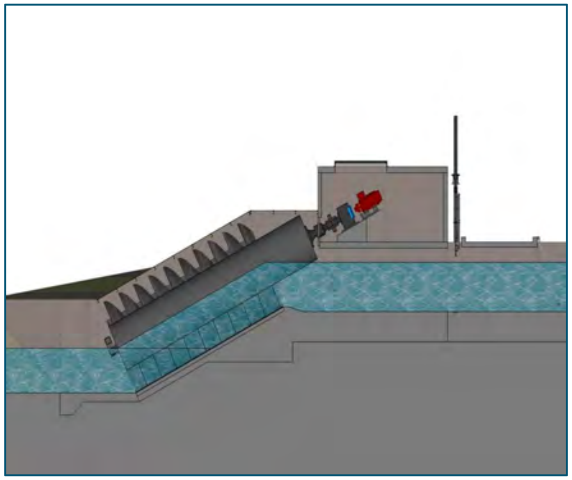




- Simple, robust design and operation
- Well understood - used for centuries to "lift" water
- Rotates at much slower speed than Kaplan turbines
- Extremely fish friendly (>99.99 % survival)
- Can tolerate large debris so less trash screening

This project aligns with the following DOE Program objectives and priorities

- **Hydropower**
- Advance new hydropower systems and/or components for demonstration or deployment
- Optimize existing hydropower technology, flexibility, and/or operations
- Reduce deployment barriers and environmental impacts of hydropower

Key Issues and Potential Barriers to Success

- Support of canal owners and operators is critical to successful deployment of technology
  - Canal owners and operators require "proof" and guarantees of no impact to irrigation operations/deliveries
  - All work impacting the canal must be performed during non-irrigation season (typ. Oct – Mar)
  - Potential revenue to them from "green" power sales is secondary to irrigation mission

South Canal Drop 2 of the Uncompahgre Valley Project selected and approved for the AHS Demonstration Plant

- 100 Year Old Canal in SE Colorado
- Utilize 15.9 feet of head and 1000 cfs design flow
- 1 MW plant will produce ~4,000 MWhrs annually
- New interconnection infrastructure in place and NEPA recently completed for adjacent plants

We involve the canal operators, Reclamation and local utility throughout the process to ensure their input, comfort level, and approval

FY 2013 Actions

- Site Survey of Canal area and Water Level Measurements Completed
- Preliminary Design and Engineering Cost Estimates Completed for 4 Design Variations
  - Reviews with Stakeholders resulted in selection of "in-canal" option with new concrete bypass
- Historical Flows Analyzed and flow duration curves Developed
- Request for Proposals for supply of Turbine System Developed and Submitted -- needed turbine(s) selected before design of plant
  - 3 Competitive Responses Received
  - Questions/Clarifications/Negotiations with Vendors Concluded
  - Vendor Selection Made
  - Contracts Prepared and Under Negotiation
- Detailed Design for Balance of Plant (civil works) now focused on one design layout using specific turbine system selected through RFP

Selected Rehart GmbH for Turbine System Manufacture

- Located in Ehingen, Germany
- 59 AHS Plants Operating with 7 Under Construction
  - 37 Germany
  - 11 United Kingdom
  - 9 Austria
  - 9 Other (Belgium, France, Luxemburg, Turkey, Bulgaria, India)
  - None yet in US
  - Recently formed Rehart USA

Rehart AHS Plant Operating in Hausen, Germany (Black Forest Region)

2 ea 250 KW/19 ft head/210 cfs/11.2 ft dia screws

Rehart Plant Operating in Hausen, Germany

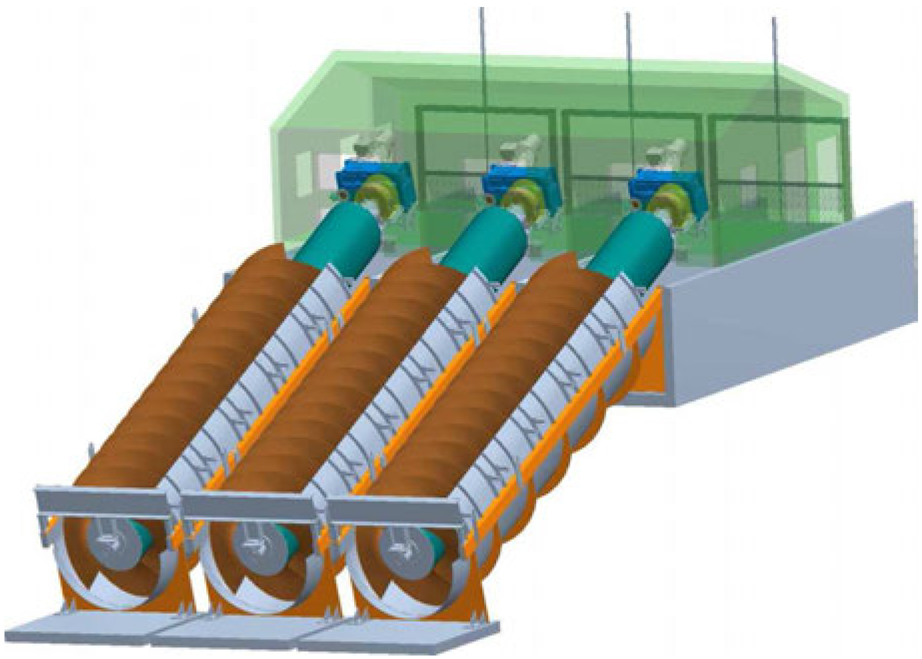
Generator End of AHS Turbine

Control Room

Turbine System Overview

Rehart to provide complete "water to wire" system

- Three Turbines in Parallel
- Three Generators/Gearboxes
- Three Sluice Gates
- Trash Rack
- Low Voltage Control System
- Emergency Brakes
- Frequency Converter

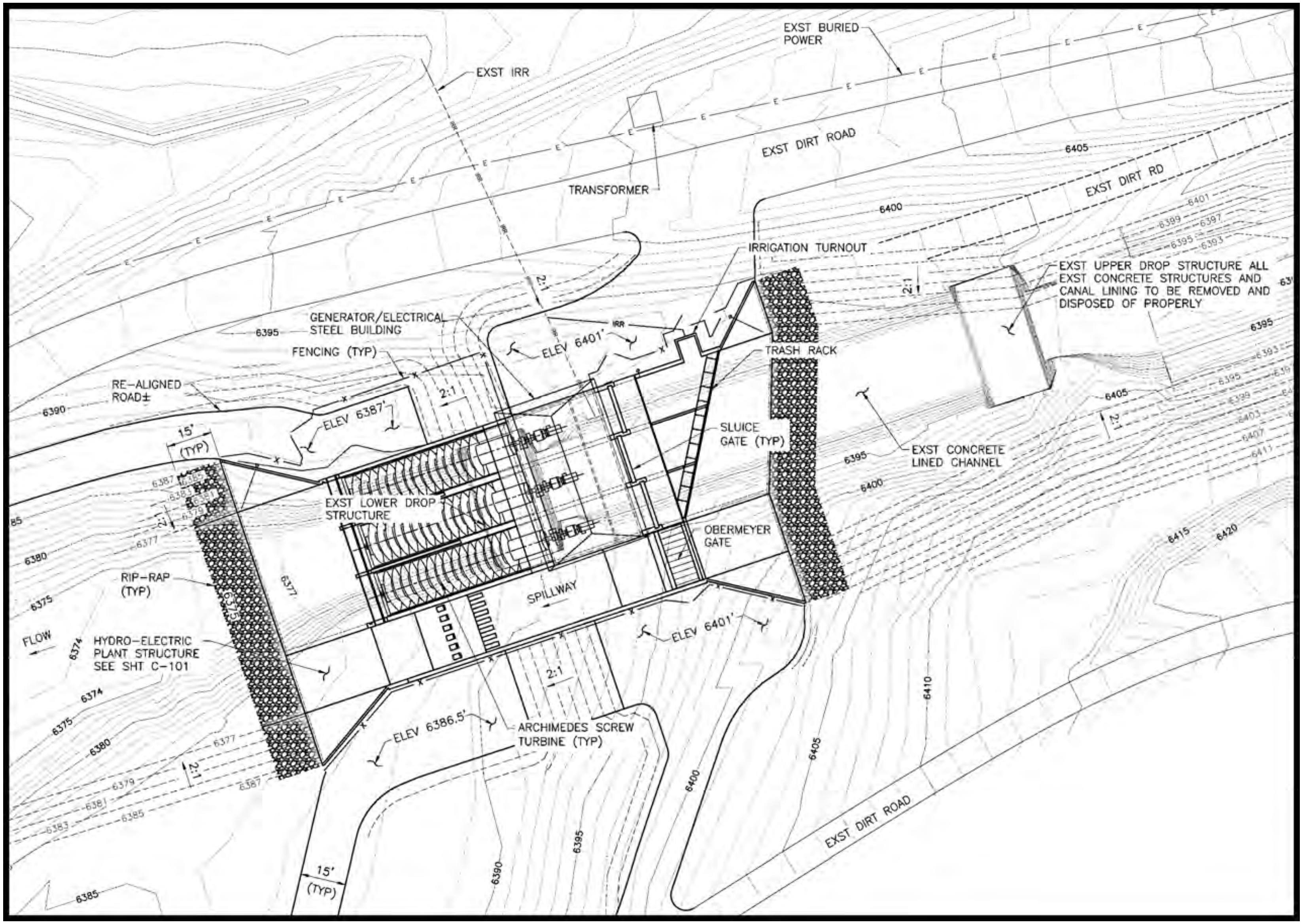


- Rehart will supervise installation and perform field testing/commissioning on site
- Performance Bond and Performance Guarantee Part of Contract
- Complete System under Warranty for Minimum of 2 Years

Plant Design Integrated with Turbine System Selection

- Balance of Plant civil design by J-U-B Engineers, Inc.
- HEC-RAS Models benchmarked against field water level data to set design elevations for turbines
- Utilized Reclamation Standards (Basin Type III Spillway)
- Ability to bypass any/all flows not going through turbines
- Selected Obermeyer Gate in Bypass for flow control
- Geotechnical Survey and Design Overview by Buckhorn Geotech
- Design Reviewed/Approved by Reclamation and Water Users in December 2013
- Detailed Structural Design Underway

Drop 2 Site Plan

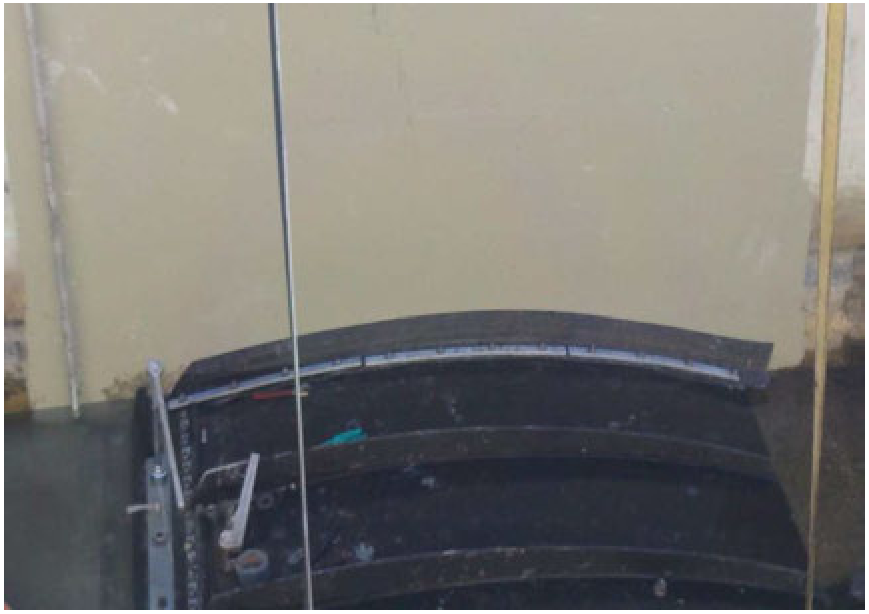


Obermeyer Gate Selection

- Over 450 gates in operation
- Made by Obermeyer Hydro Inc. in Fort Collins CO for 25 years
- Steel Gate Panel height controlled with air bladder and PLC control system
- Controls water level to within 1-2 inches, even with loss of power

Open Position in Canal

Closed/Flat Position in Canal



Project Plan & Schedule

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Summary	
WBS Number or Agreement Number	DE-EE0005428
Project Number	
Agreement Number	DE-EE0005428-3

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Harnessing the Hydroelectric Potential of Engineered Drops												
Budget Period 1												
Provide Notice of Intent for LOPP to Reclamation												
Complete Agency and Stakeholder Consultations on Conceptual Design												
Develop Information and Perform Studies Required for LOPP												
Negotiate LOPP with Reclamation												
Complete Preliminary Design for Consultations												
Select Turbine System												
Complete Detailed Design												
Receive Reclamation and other Approvals to Construct												
Go No-Go Decision to Proceed with Construction of Plant												
Current work and future research - Budget Period 2												
Provide Notice to Proceed to Turbine Manufacturer												
Execute Interconnection/Transmission/Power Off Take Agreements												
Solicit Bids for Balance of Plant												
Place Long Lead Procurements												
Complete all in Water-Work (April 2015)												
Install Turbines and Complete Powerhouse (Feb 2015)												
Commissioning and Interconnection to Grid (May 2015)												

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
0	0	403.3 K (289K actual)	403.5K (317K actual)	1,137.6K	2,302.2K

- Project budget was originally planned with the expectation of performing the onsite canal work Nov 2013 to Mar 2014
  - Grant Agreement signing and initial approvals of other work were delayed
  - Turbine selection needed to be performed before detailed plant design
  - New Reclamation Law in August 2013 allows for new LOPP process
  - Increased risk of impacting irrigation operations if canal work not started by November 2013
  - Decision of all (especially irrigation operators) was to wait until next off irrigation season to excavate canal/construct plant
  - Results in 6 month shift of startup/commissioning of Plant
- No budget 6-month extension approved by DOE in Oct 2013 to reflect this schedule

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators/ Communications and Technology Transfer

- J-U-B Engineers, Inc. for Balance of Plant Design (Kennewick, WA)
- Buckhorn Geotech for Site and Geotech Survey/Design (Montrose, CO)
- Rehart GmbH for Turbine System Design/Manufacture (Germany)
- 3Helix Power for Turbine Technology Integration (Arlington, VA)
- Dr. Dirk-Michael Nuernbergk, a Drexel University visiting scholar and current professor at Ernst Abbe University in Jena, Germany for turbine performance analysis (Germany)
- Reclamation and Water Users for design review and approvals
- DMEA for Interconnection (Montrose, CO)
- Several Water/Utility/Contracts Attorneys and Experts regarding international turbine procurement, interconnection, power purchase agreements, etc. (WA,ID, CO)
- Rehart U.S.A. for potential future manufacture of AHS turbines in U.S. (Salisbury, NC)

Next Steps and Future Research

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- FY14/Current research:
  - Complete all agreements and approvals with Reclamation for construction of plant
  - Select power purchaser for project output and execute agreement
  - Complete interconnection applications, studies, and approvals
  - Provide Notice to Proceed for Turbine Manufacture
  - Prepare and issue bid documents for Balance of Plant/Select Contractor
- FY15/Planned research to complete project:
  - All plans, approvals, contracts, and agreements are expected to be in place prior to shutdown of the irrigation canal in October 2014
  - On-site work will begin as soon as the canal is “dry” in FY2015 (Nov 2014) to ensure completion by March 2015 when irrigation season resumes
  - Testing and commissioning of the AHS Plant will occur in May 2015

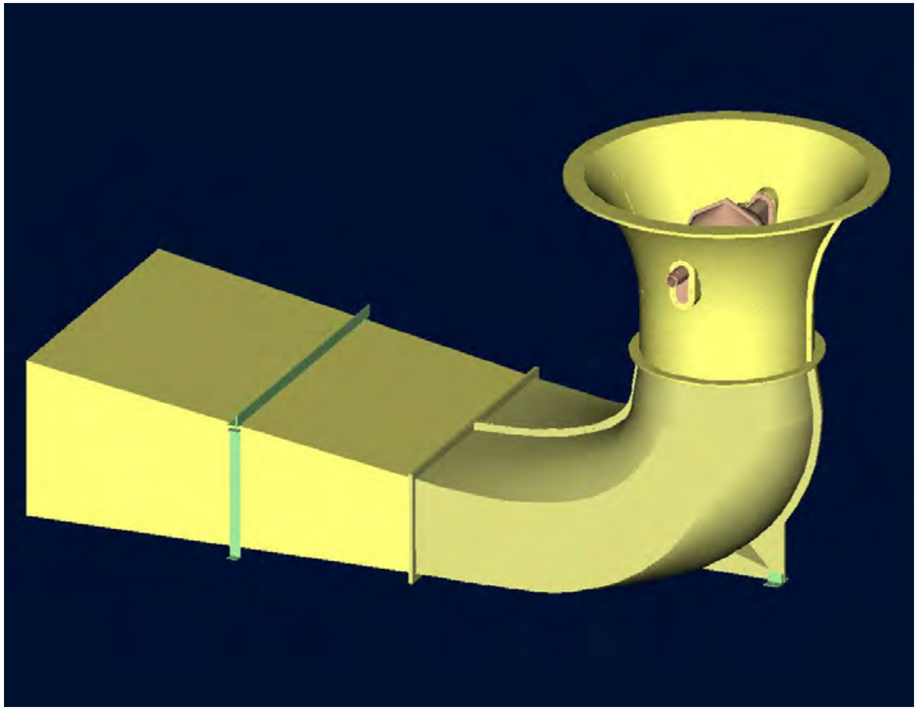
Next Steps and Future Research

- Proposed Future Research:
  - Transfer/License AHS technology of European manufacturer
  - Select and qualify U.S. manufacturer for AHS Turbines
  - Perform assessments and develop “pipeline” of follow-on low head sites for future AHS plants
  - Design prototype modular AHS turbine installations to reduce civil works cost

Elephant Butte Irrigation District Drop 8 structure

Historic low-head drop structure built in 1900's

Modular and self-supporting 10 kW harvester



Easy to fabricate, assemble and deploy

Hydropower Energy Resource (HyPER) Harvester

Nadipuram (Ram) R. Prasad
Satish J. Ranade
New Mexico State University
naprasad@nmsu.edu 575 646 3623

February 2014

Purpose & Objectives

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- Conduct CFD studies of a Venturi turbine with a submarine enclosing a generator and impeller assembly, and derive preliminary design parameters

- Design, fabricate, assemble, deploy and test two, *revolutionary* 10,000 Watt prototypes as conventional hydropower generators, at the Elephant Butte Irrigation District Drop 8 structure

Challenge and Impact of Project

Challenge: Develop a harvester with minimal impact on the historic structure and meet all NEPA environmental requirements to build a micro-hydropower plant.

Impact of Project: Demonstrate efficient hydropower generation from low-head resources and pave the way to generate sufficient power from over 100,000 low-head drop sites across the U.S. to meet DOE's Year 2030 vision.

This project aligns with the following DOE Program objectives and priorities

1. Advance new hydropower systems and/or components for demonstration or deployment

2. Reduce deployment barriers and environmental impacts of hydropower

Alignment with DOE Objective 1

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Harvester has a modular architecture comprising :

- Venturi-turbine with generator and impeller assembly module
- Discharge elbow module
- Draft tube module

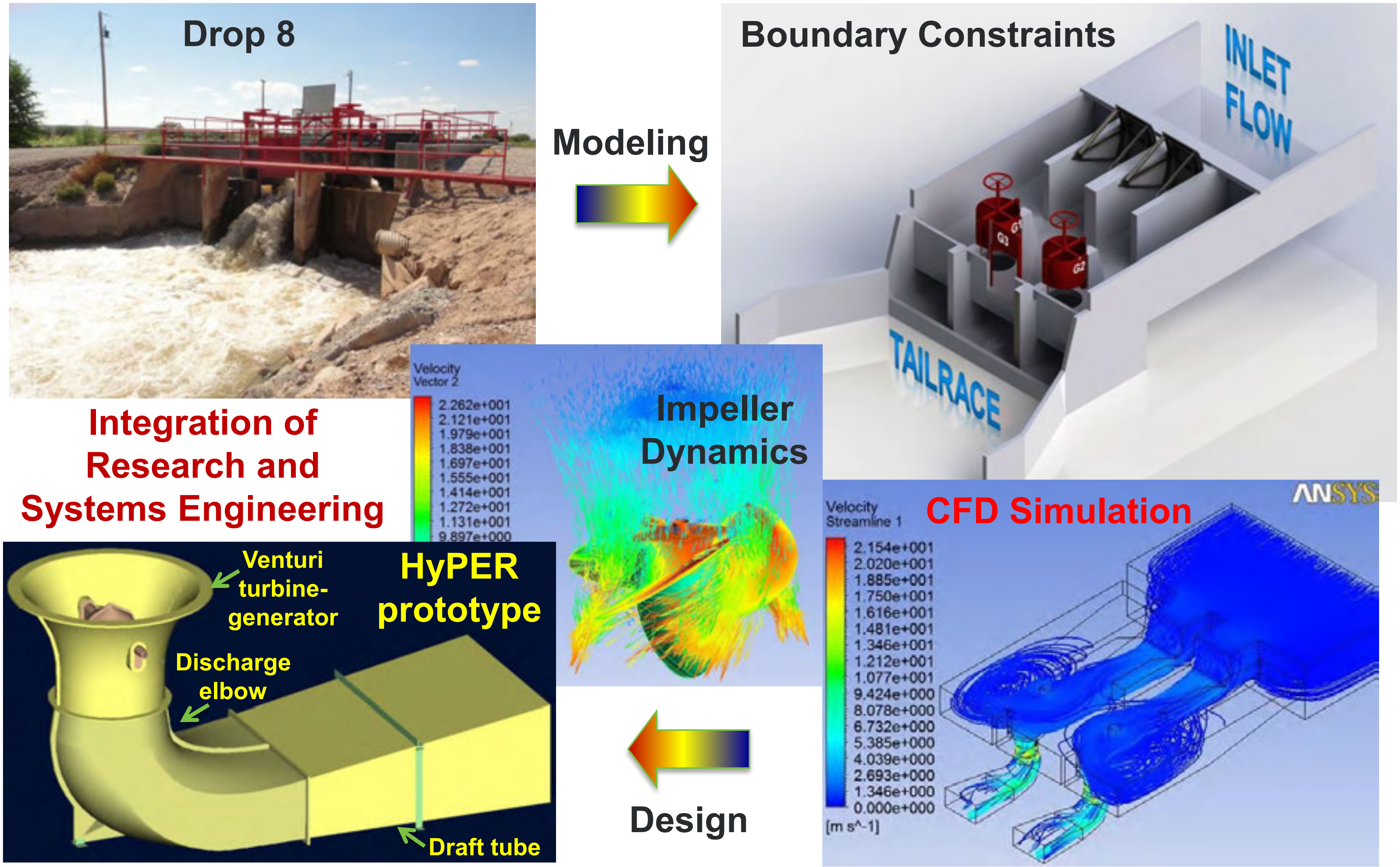
Modularity makes it easy for deployment as a plug-and-play system for hydropower generation.

Alignment with DOE Objective 2

Harvester is designed to be self-supporting with no impact on the load-bearing capacity of the drop structure.

This self-supporting feature makes the harvester less intrusive while meeting NEPA requirements for an environmentally friendly technology and reducing deployment barriers.

Technical Approach



There are three unique and significant aspects of the hydropower technology:

1) it is an easily manufactured miniaturization of the Kaplan turbine concept making it the most efficient means for power generation;
2) the plug-and-play modular architecture makes it easy to transport and deploy;
3) the self-supporting feature minimizes the load-bearing impact on existing structures.

Ideal discharge through each drop

For the pressure head *h* = *2.22 m*, the ideal velocity at the drop

$$V_{ideal} = \sqrt{2gh} = \sqrt{2 * 9.81 * 2.22} = 6.6\ m/\sec$$

The diameter of drop orifice is 1.3208m (R = 0.6604m)

$$\text{Area of c/s } A = \pi(0.6604)^2 = 1.3701\ m^2$$

Ideal discharge through each drop orifice

$$Q_{ideal} = AV_{ideal} = 1.3701 \times (6.6) = 9.042\ m^3/\sec$$

CFD simulation: G3 Open

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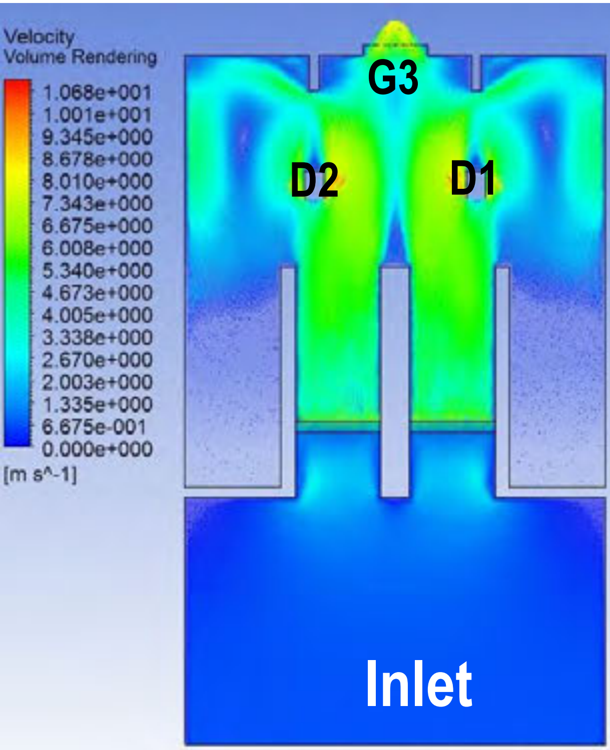
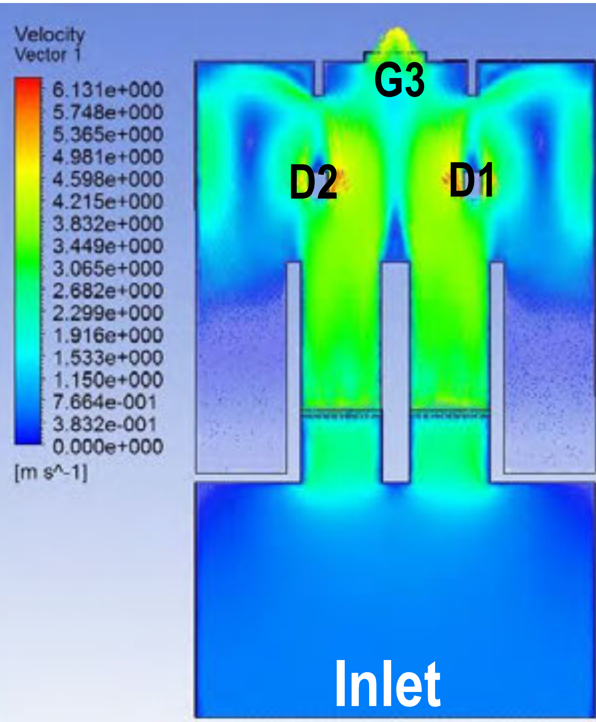
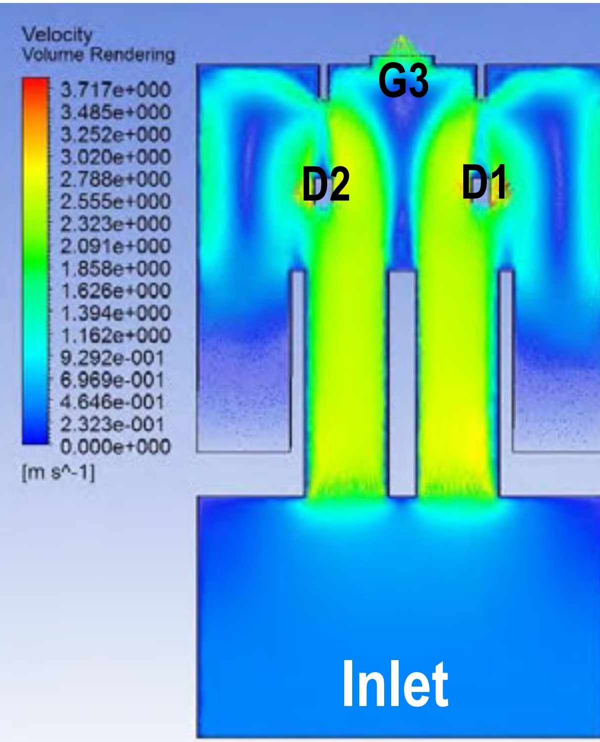
High Flow	Medium Flow	Low Flow



Discharge Q, (m^3/s)	
Inlet	14.16
Drop D1	-4.81
Drop D2	-4.81
Gate G3	-4.54



Discharge Q, (m^3/s)	
Inlet	8.48
Drop D1	-2.84
Drop D2	-2.85
Gate G3	-2.79



Discharge Q, (m^3/s)	
Inlet	3.27
Drop D1	-1.29
Drop D2	-1.23
Gate G3	-0.75

CFD simulation: G3 Closed

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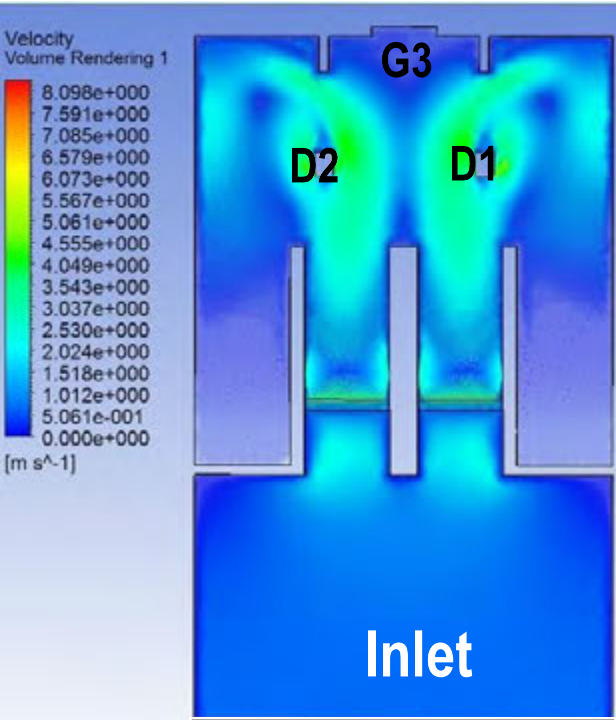
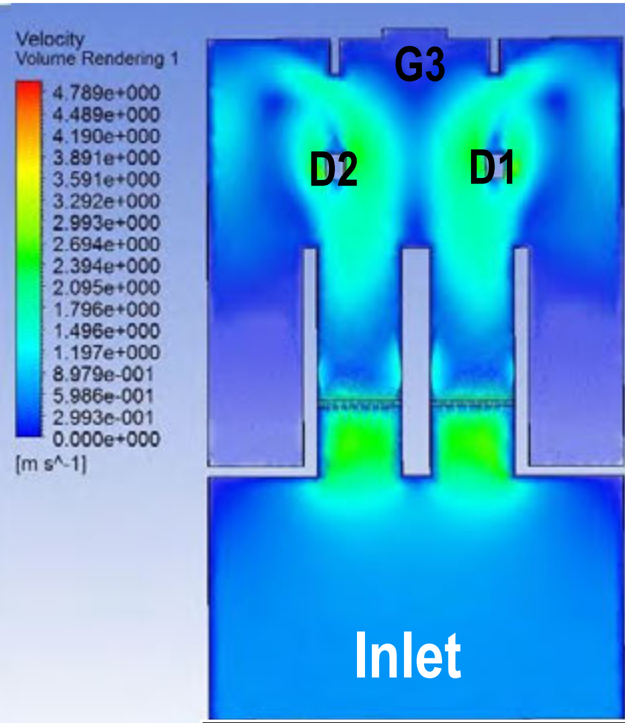
High Flow



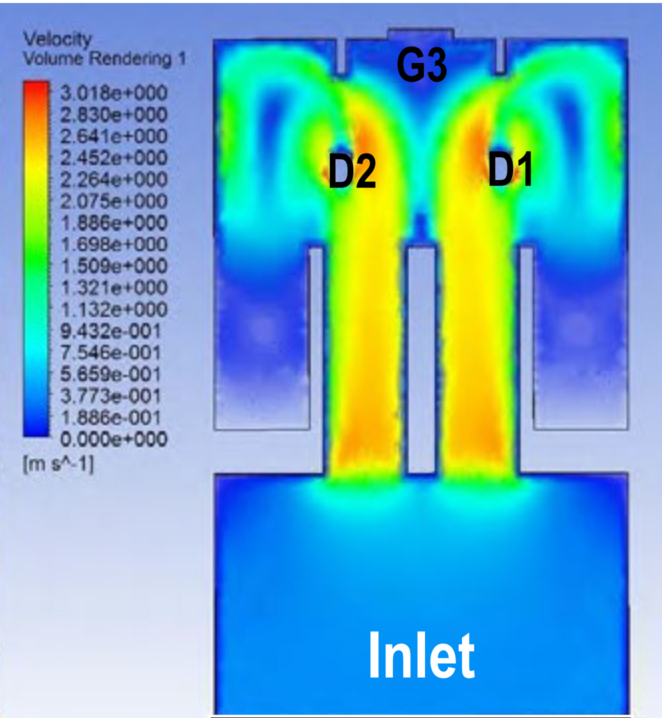
Discharge Q, (m^3/s)	
Inlet	14.16
Drop D1	-4.95
Drop D2	-4.95
Overflow	-4.26

Medium Flow



Discharge Q, (m^3/s)	
Inlet	8.68
Drop D1	-4.34
Drop D2	-4.34
Overflow	0.00

Low Flow



Discharge Q, (m^3/s)	
Inlet	3.28
Drop D1	-1.64
Drop D2	-1.64
Overflow	0.00

Maximum discharge through orifice

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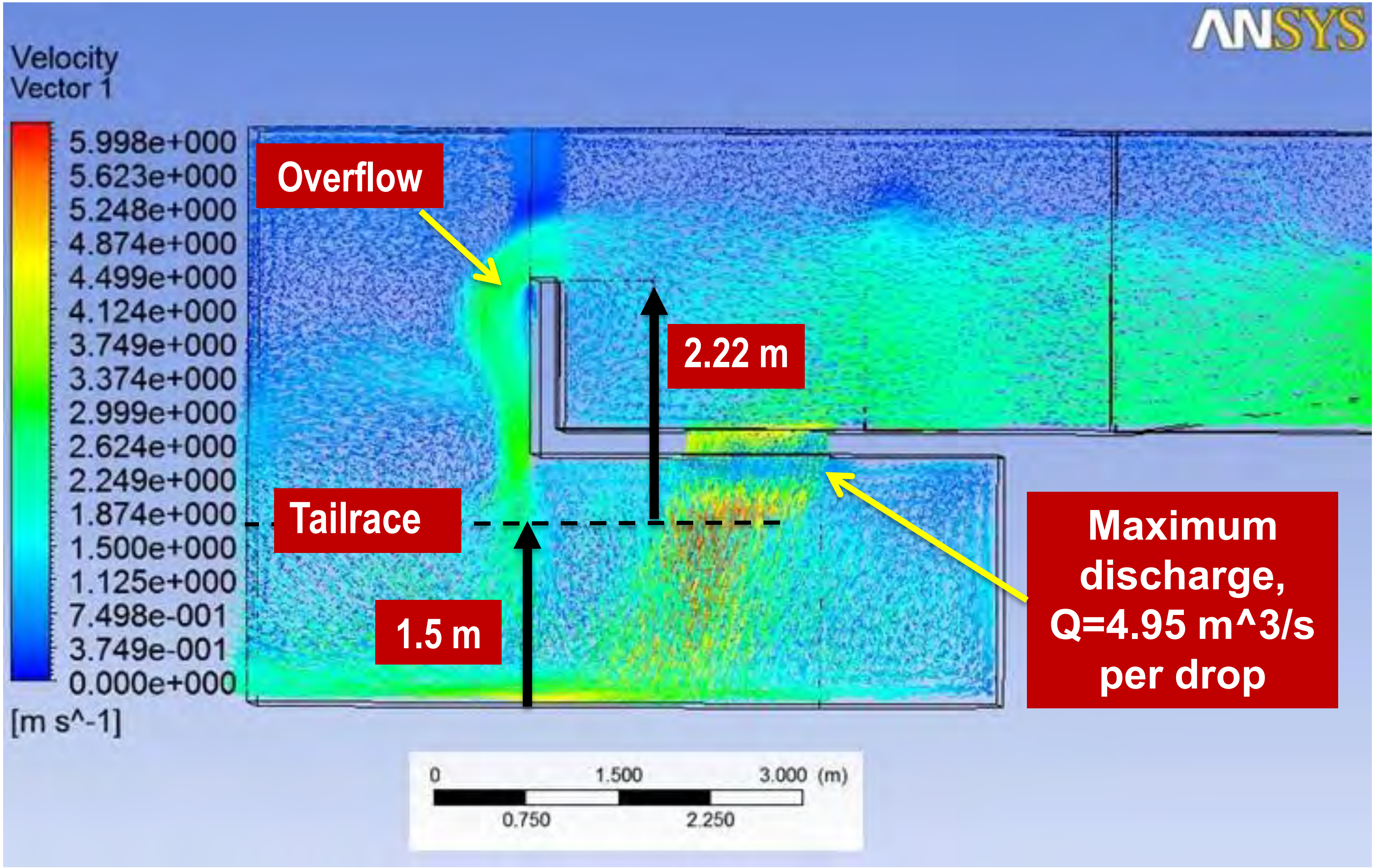


Estimate of power potential at Drop 8

Actual discharge through the orifice is less than the ideal discharge due to losses caused by friction

Coefficient of discharge $C_D = \frac{Q_{Actual}}{Q_{Ideal}} = \frac{4.95}{9.042} = 0.547$

With an effective head $h = 2.22m$ and efficiency $\eta = 0.8$ the potential power at each drop

$$P_e = \eta \, \rho \, Q \, g \, h$$

$$= 0.8 * 1000 * 4.95 * 9.81 * 2.22$$

$$= 86{,}242 \; Joules/\sec \; or \approx 86.24 \; kW$$

Estimate of hydropower from 2 drops is approx. 172.5 kW

Shaft Speed

For a pressure head of 2.22 meters, the specific speed is computed as:

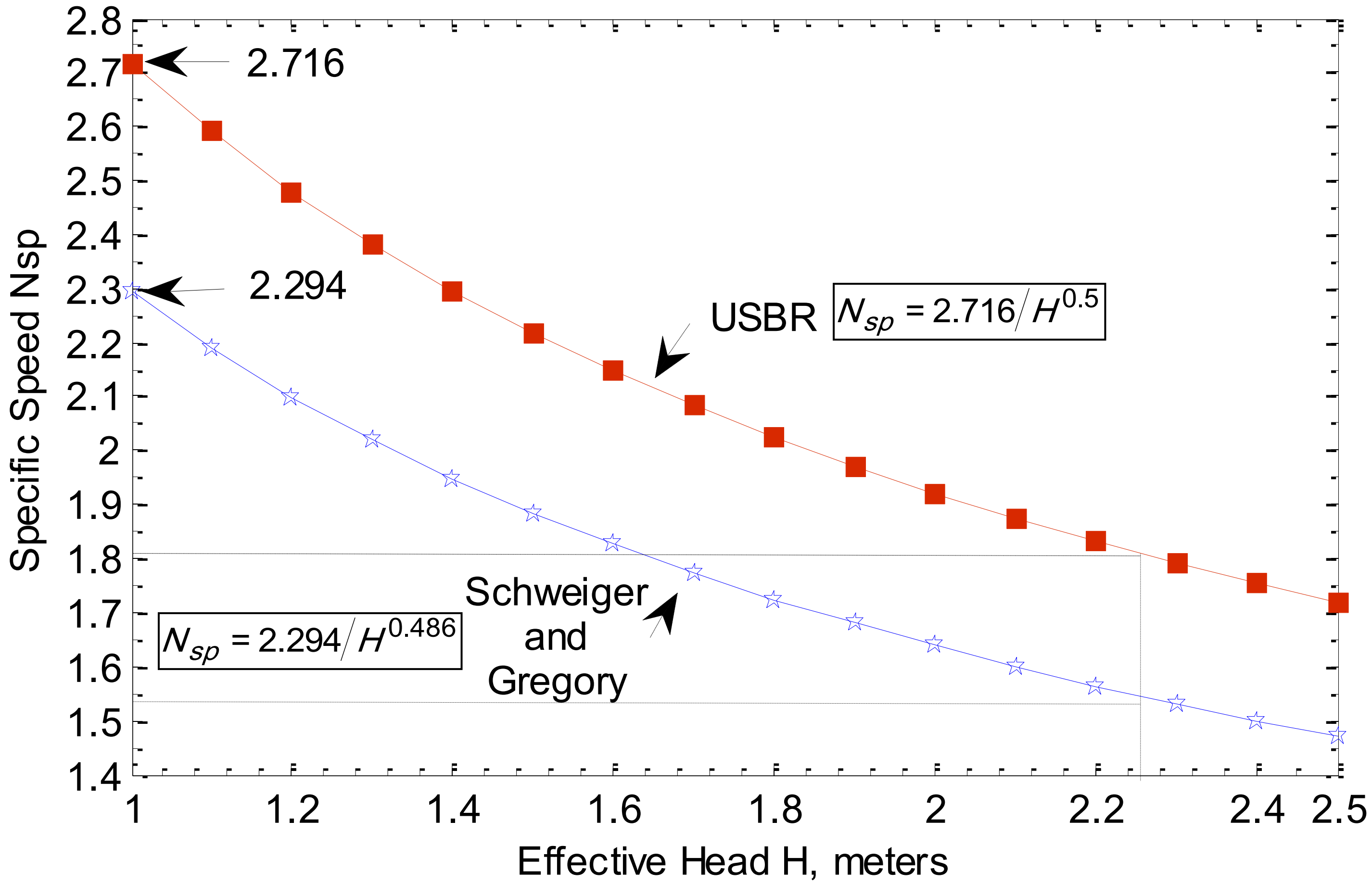
$$N_{sp} = \frac{2.294}{H^{0.486}} = \frac{2.294}{2.22^{0.486}} = 1.557 \qquad \textbf{(Schweiger \& Gregory)}$$

With 86.24 kW of available power, the shaft speed

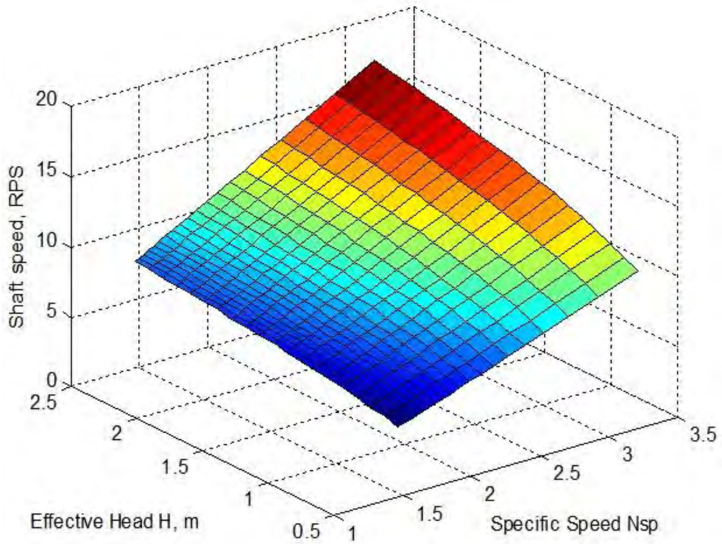
$$N = \frac{N_{sp}(gH)^{1.25}}{\sqrt{P_{avail}}} = \frac{1.557 \times (9.81 \times 2.22)^{1.25}}{\sqrt{86.24}} = 7.888\ rev/\sec$$

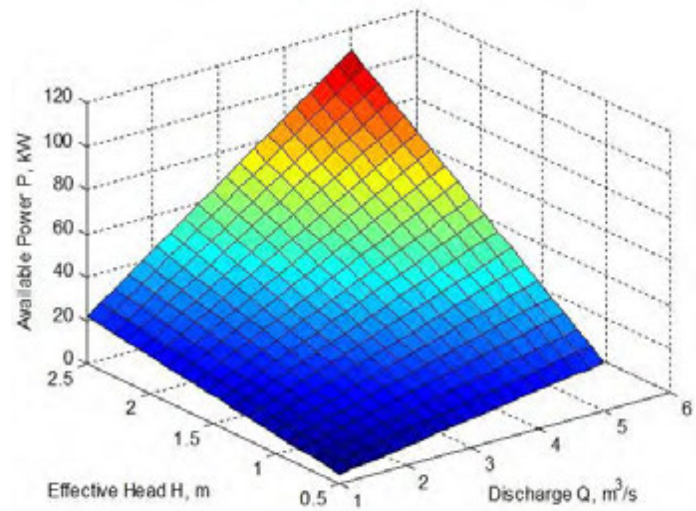
$$473.3\ RPM\ or\ 49.5611\ rads/\sec$$

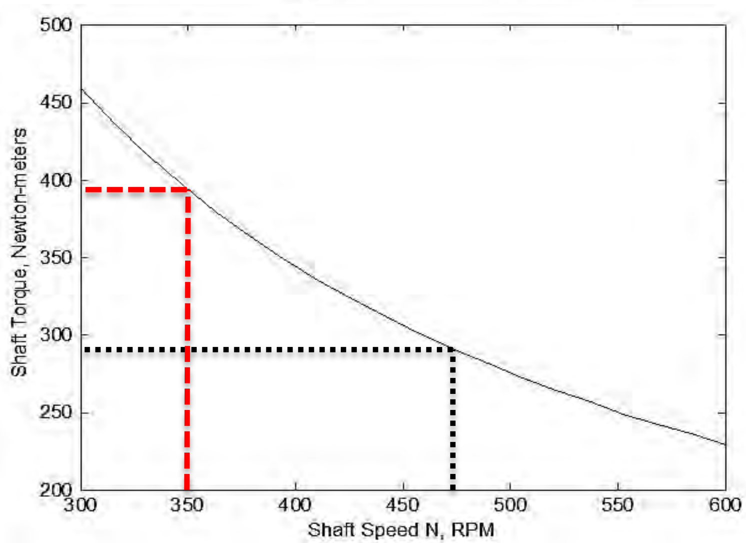
Specific speed

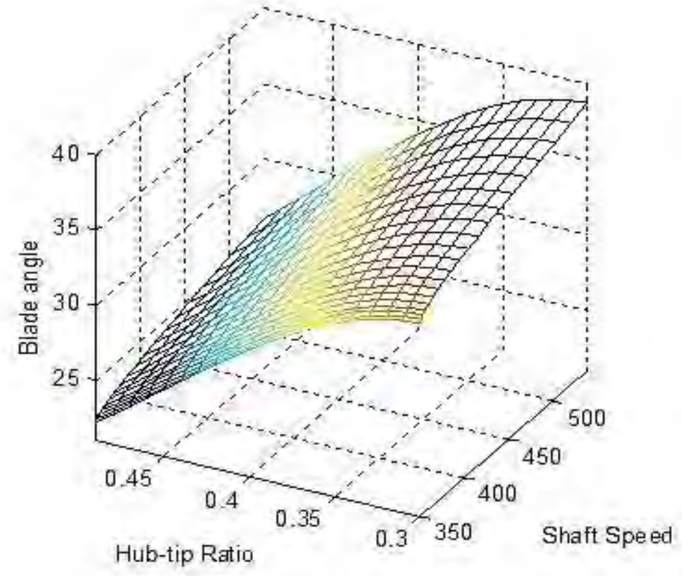


Shaft speed, Torque and Blade angle









Alternator selection

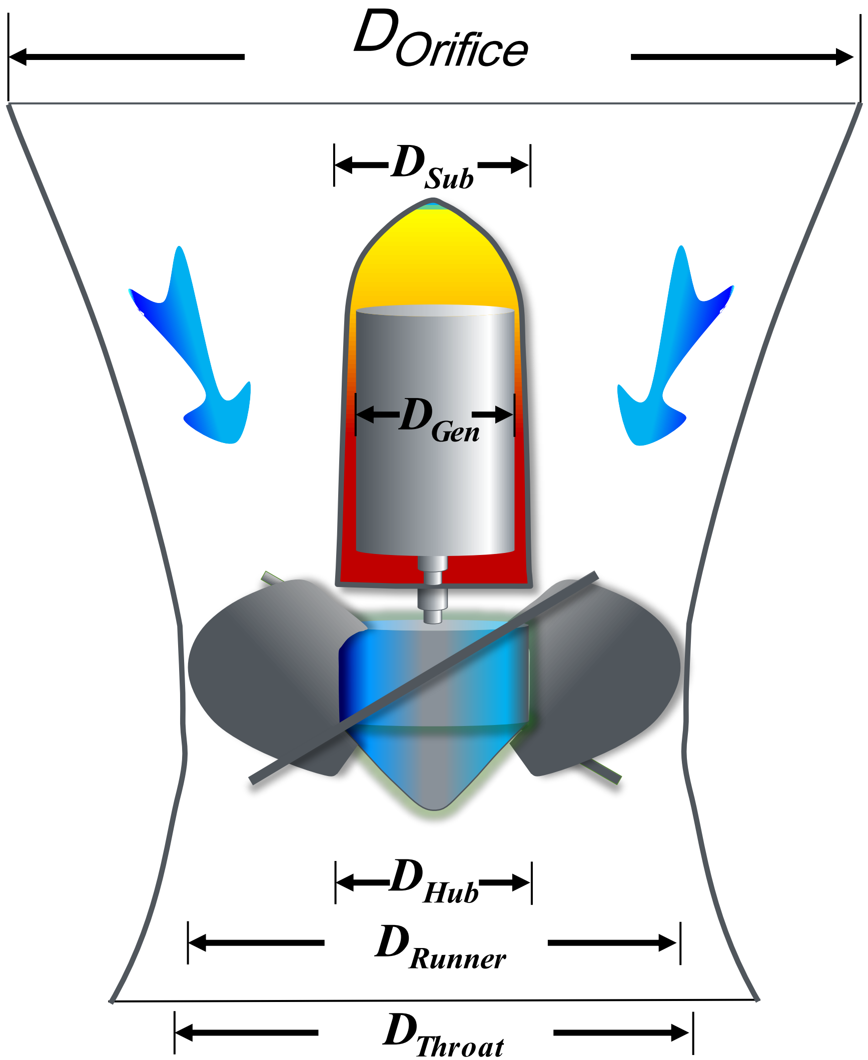
TECHNICAL CHARACTERISTICS
300 STK ALTERNATORS

See also the curves of Voltage, Torque, Efficiency vs Speed

http://www.alxion.com/

			300STK1M		300STK2M		300STK4M		300STK6M		300STK8M	
	Rated speed	Rpm	350	800	350	800	350	800	350	800	350	600
Rated Power at Rated speed	Rated power (1)(2)	W	1444	3793	3141	8270	6858	14240	9782	17399	13201	19965
	Input torque at rated speed(1)(2)	N.m	52.5	52.4	104	111	225	187	310	226	415	348
	Efficiency at rated power (1)(2)	%	75	87	82	89	84	92	87	92	87	92
	Current at rated power (1)	Amps	3.7	9.9	7.3	19.2	16.8	34.2	23.6	42.9	30.4	50
	Voltage at rated power (1)(2)(3)	V	232	230	255	258	242	251	247	247	258	240
Rated Power at Half speed	Rated Power at half speed (1)(2)	W	496	1706	1276	3665	2688	7985	4333	11700	5853	11058
	Input torque at half speed (1)(2)	N.m	40.5	52.4	99	104.5	186	225	310	309	415	414
	Efficiency at half speed (1)(2)	%	67	78	71	84	78	85	77	88	77	85
	Number of poles (number of pairs of poles)		24 (12)									
	Cogging torque	N.m	0.5		1		2		3		4	
	Phase résistance at 20°C	Ohm	8.75	1.24	2.87	0.51	0.97	0.15	0.53	0.08	0.4	0.1
	Phase inductance (5)	mH	33.4	4.8	17.3	3	8.1	1.25	5.2	0.75	4.1	1.03
	Voltage at no load (back emf) at 20°C (4)	V	329.0	284.0	335.0	316.0	323.0	289.0	311.0	277	323	277
	Rotor inertia	10^3 Kg.m2	26.4		52.7		105.5		158.2		211	
	Weight	Kg	11.5		18		31		44		57	
	Power cable square section (6)	mm^2	4x1.5		4x1.5	4x2.5	4x1.5	4x6	4x4	4x10	4x4	4x10
	Power cable diameter	mm	Ø8		Ø8	Ø9.6	Ø8	Ø13.4	Ø11.1	Ø16.7	Ø11.1	Ø16.7

Venturi-turbine parameters



For the off-the-shelf alternator selected, the Venturi parameters are based on the diameter of the alternator and the impeller hub-tip ratio.

$$D_{Sub} > D_{Gen}$$

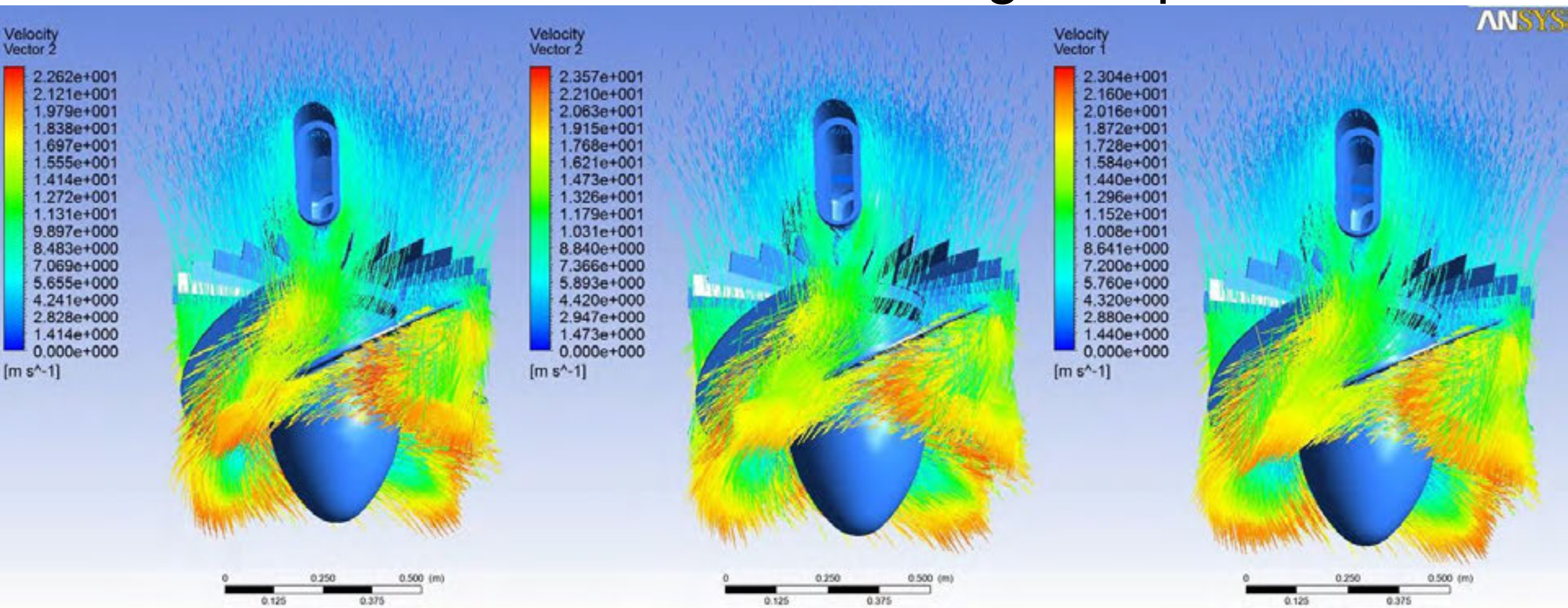
$$D_{Hub} = D_{Sub}$$

$$D_{Hub} / D_{Runner} = 0.42$$

$$D_{Throat} = D_{Runner} + \delta D$$

Gap between runner tip and turbine is less than 5mm

Comparison of flat blade 29 degree blade angle with and without 15 degree tip



Flat blade 29 degree | **15 degree tip up** | **15 degree tip down**

Low-cost impeller design

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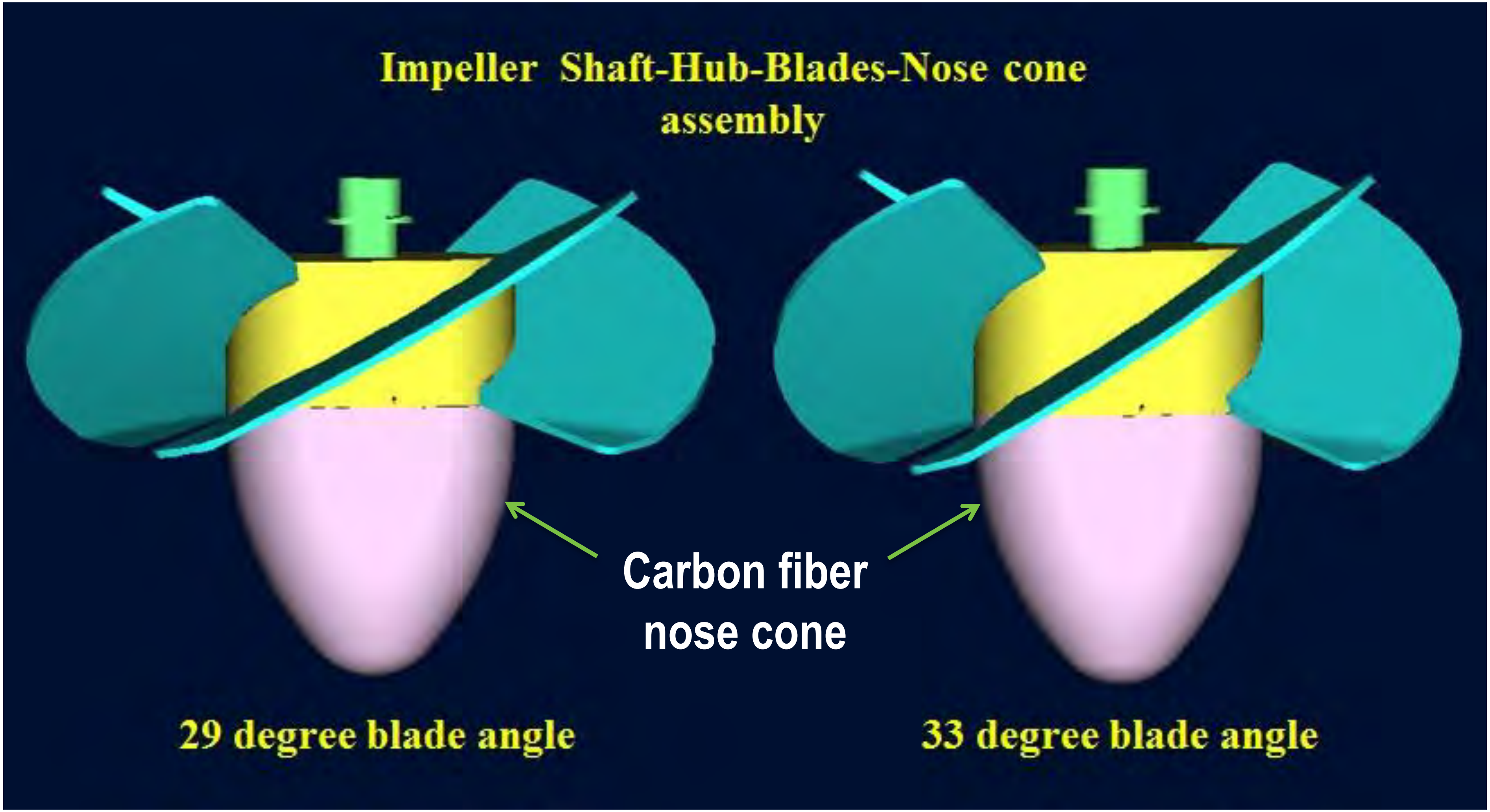
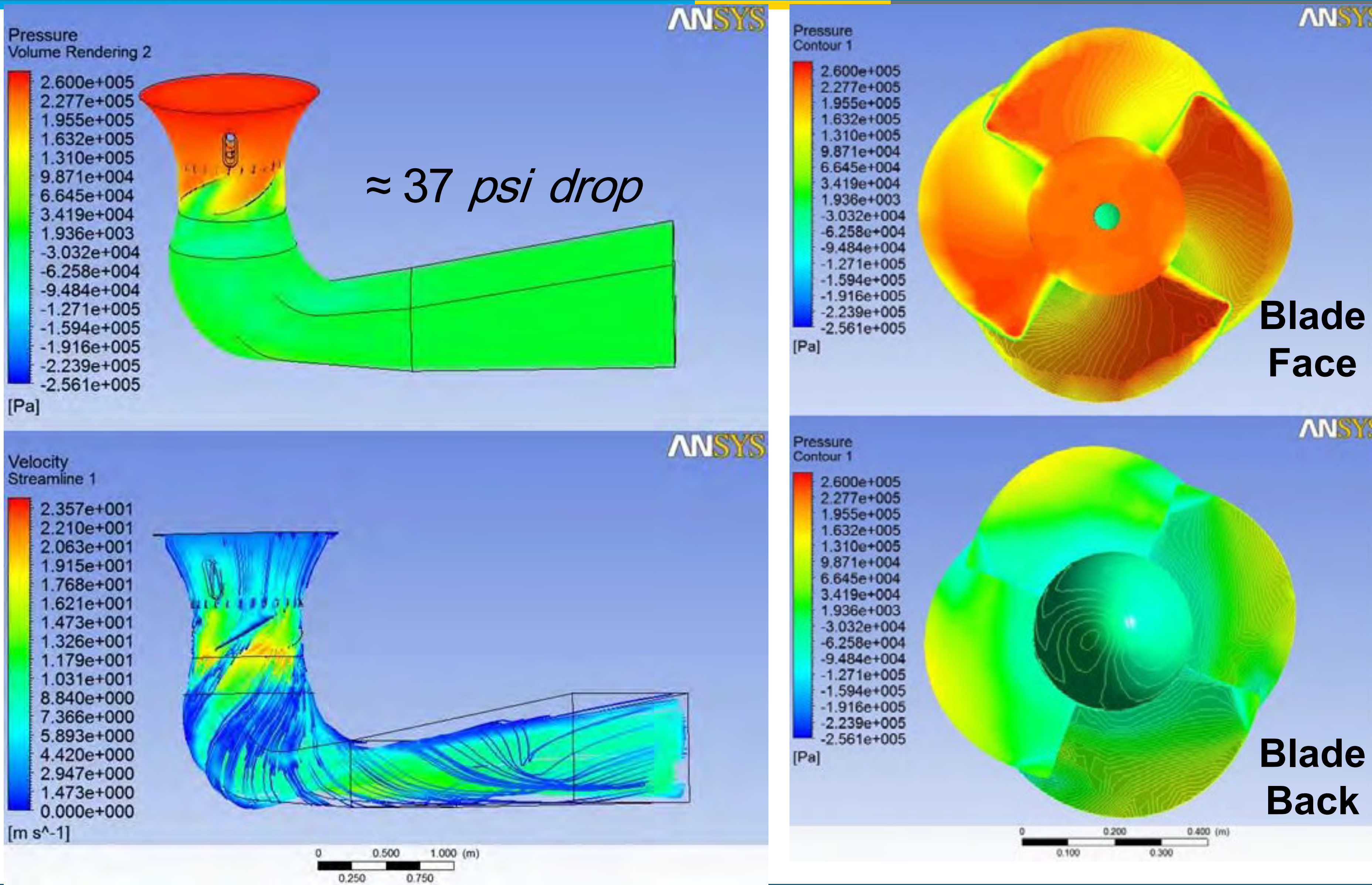
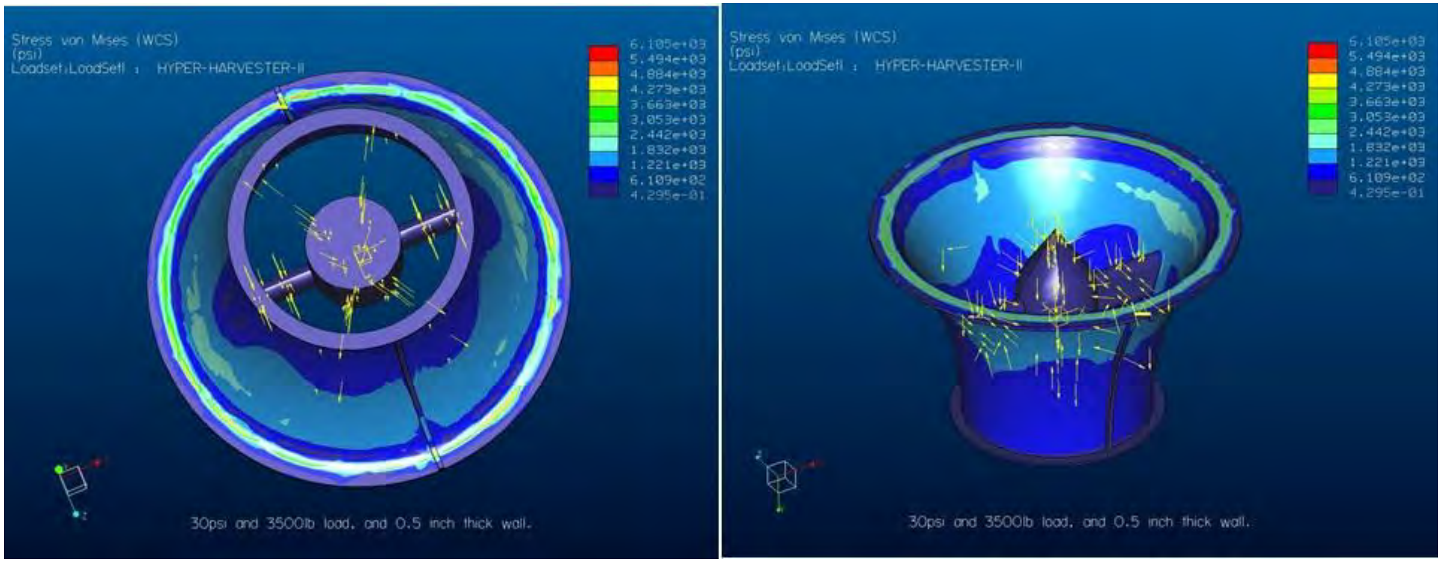


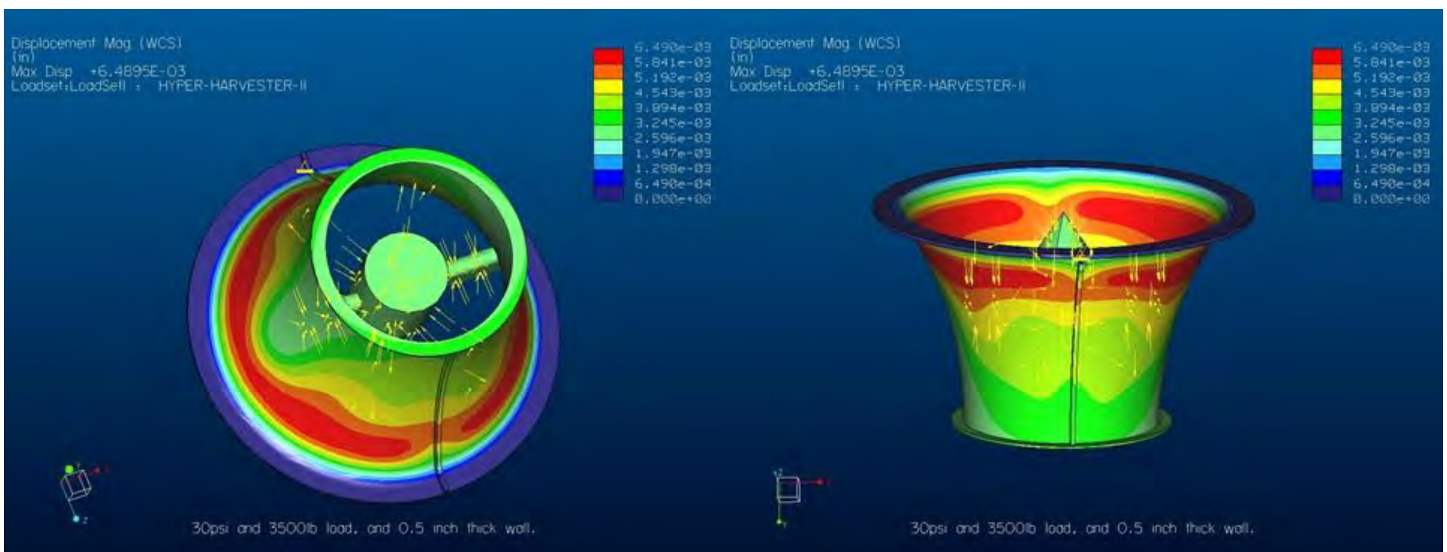
Fluid dynamics inside the harvester



Venturi turbine Stress analysis

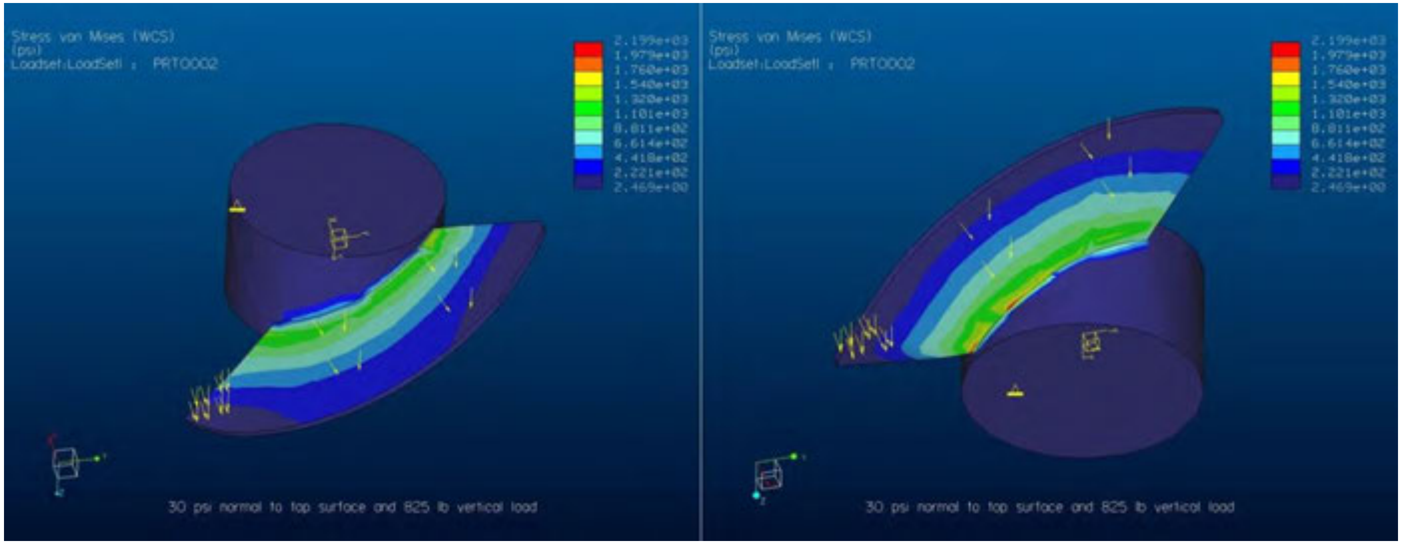


Stress



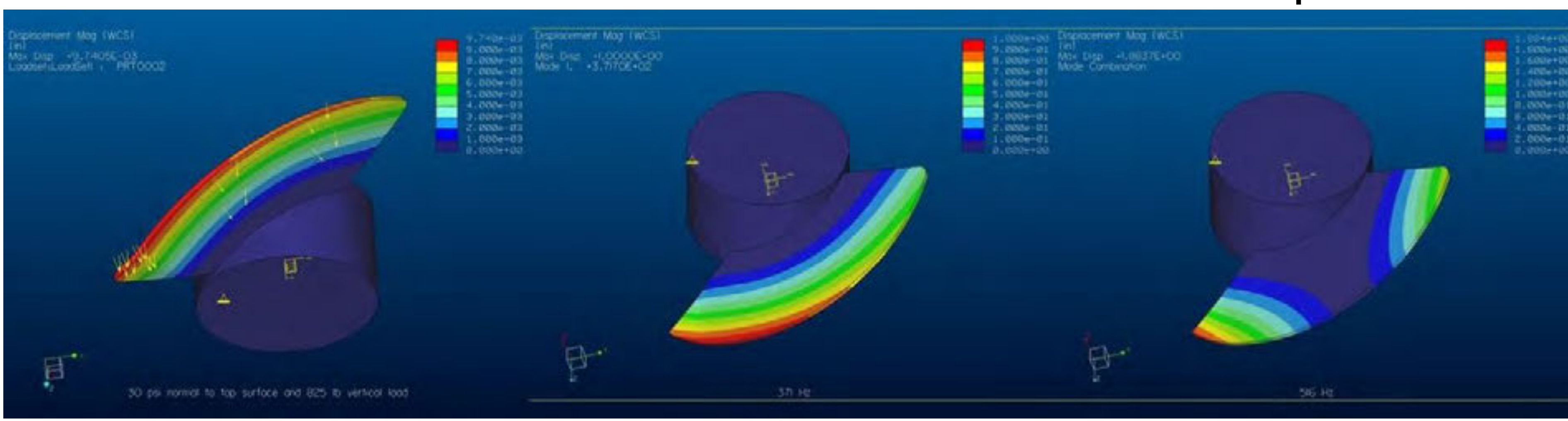
Displacement

Impeller blade stress analysis



Stress

Displacement

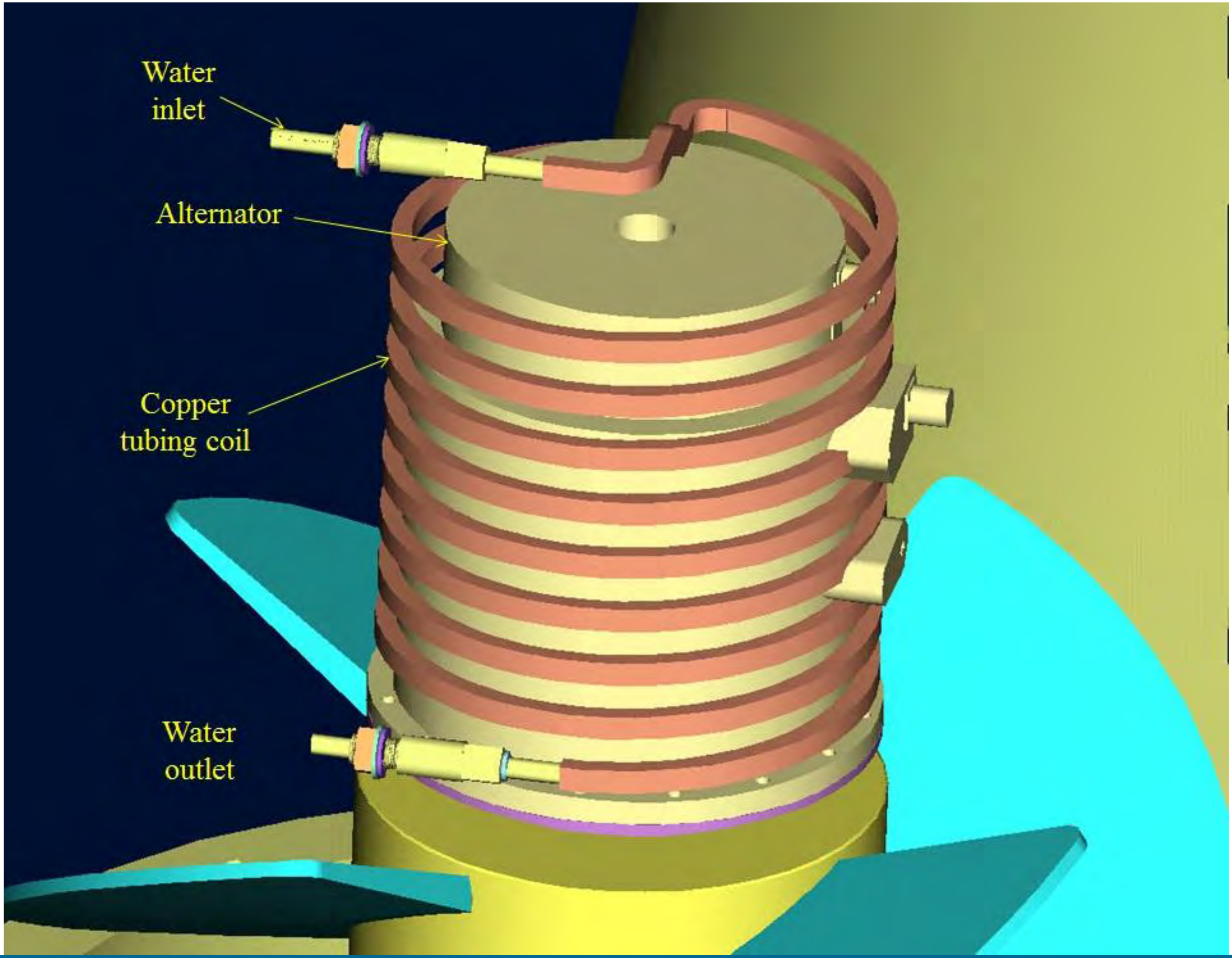


Static

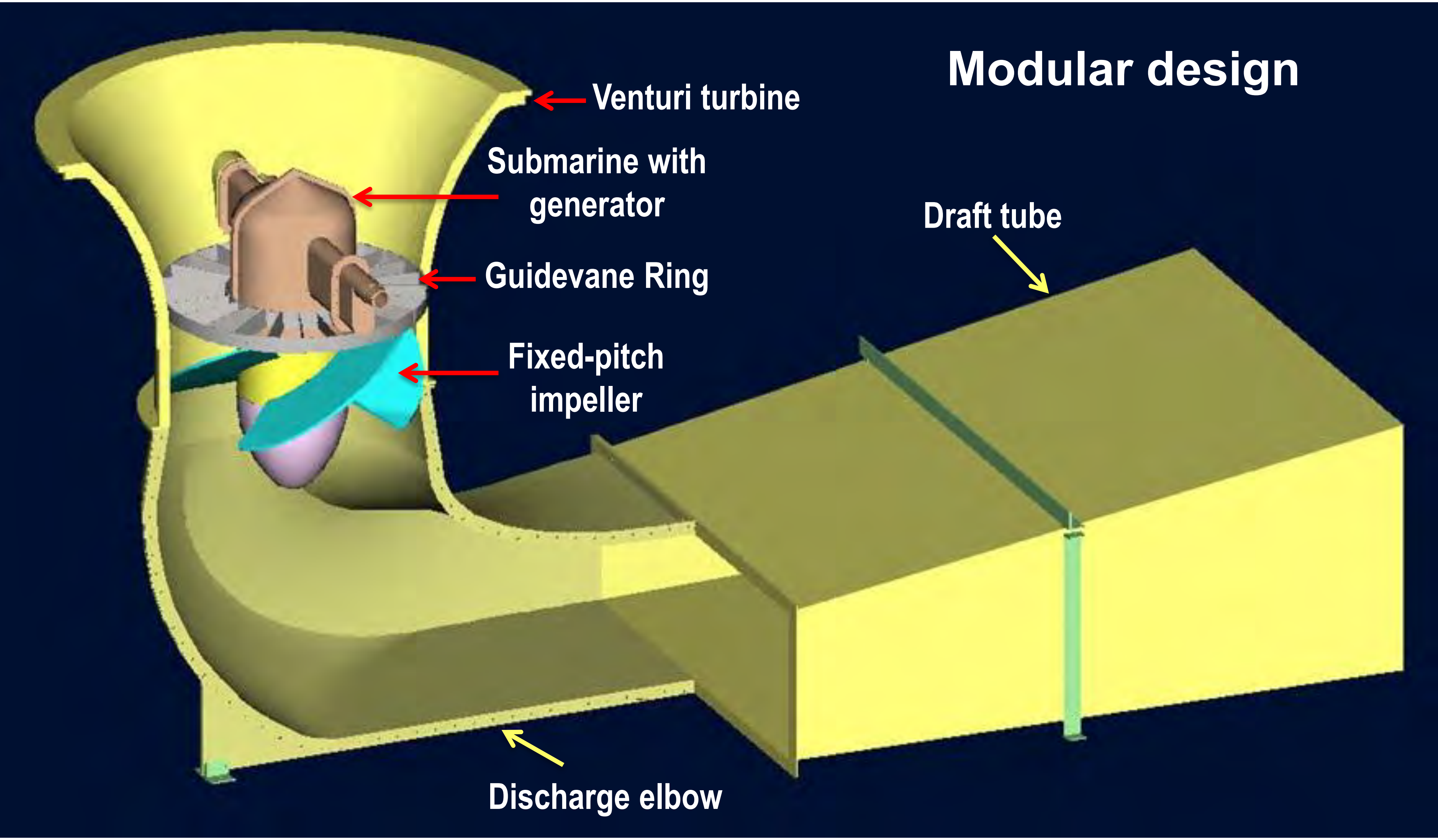
Mode-1 371 Hz

Mode-2 516 Hz

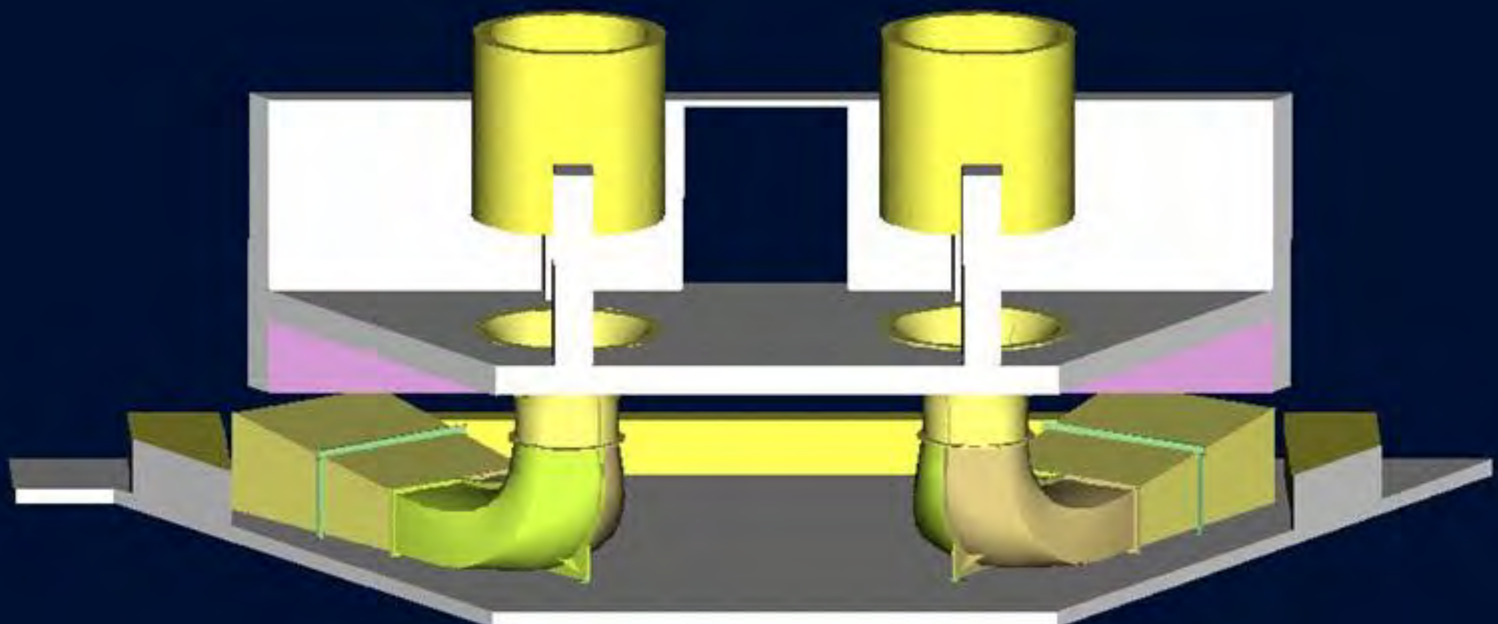
Alternator cooling system



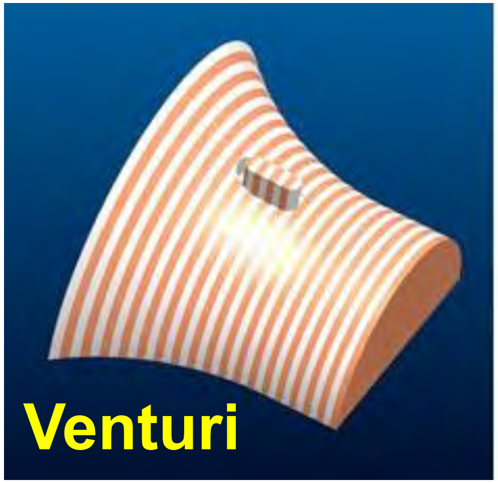
Modular harvester components



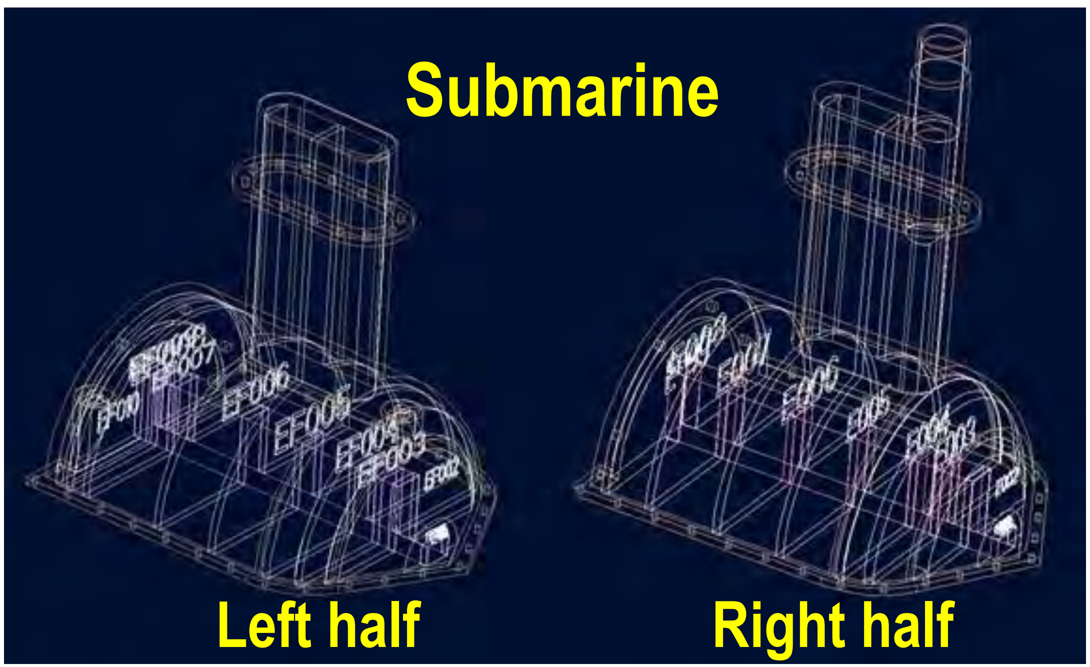
North-South view of HyPER harvester prototypes at EBID Drop 8 structure showing structural symmetry and symmetrical configuration



Carbon composite moldings



Reusable half-section molds made of Styrofoam and wood are used to fabricate Carbon composite moldings of the Venturi turbine, discharge elbow, submarine enclosure, and impeller nose cone



Cavitation

Due to irregular flows at Drop 8, it is more than likely that cavitation will occur when the effective head decreases and the impeller is not fully submerged in the tailrace.

Anodizing the impeller helps to increase corrosion resistance and lessen the wear and tear due to silt and other unavoidable debris that pass through trash guards placed at the inlet to the drop structure.

Principal design attributes

Modularity brings a plug-and-play architecture to the hydropower harvester

Light weight Carbon composite moldings minimize the tooling needs and time required to fabricate critical harvester components

Welded blades fixed-pitch impeller provides cost-benefit at low power output levels

Light weight and modularity increase portability

Shape and form offer scalability

The most important technical accomplishment is the modular design which permits a non-intrusive means for deployment at the site.

This capability enables the deployment of harvesters at other historic sites across the U.S. where NEPA rules restrict the modification of existing structures for the purpose of hydropower generation.

Accomplishments and Progress

Research and harvester design have been completed and manufacturing drawings have been produced on schedule.

Although progress was delayed by nearly 5 months due to NEPA evaluation and budget period 2 approvals, prototype manufacturing has begun and every effort is being made to keep the project on schedule.

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	
Project Number	DE-EE0005411
Agreement Number	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Apr-Jun)	Q2 (Jul-Sept)	Q3 (Oct-Dec)	Q4 (Jan-Mar)	Q5 (Apr-Jun)	Q6 (Jul-Sept)	Q7 (Oct-Dec)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Hydropower Energy Resource (HyPER) Harvester												
Q1 Milestone: CFD simulations provide estimated potential at Drop 8												
Q2 Milestone: Optimized Venturi-thurbine parameters computed												
Q3 Milestone:Three-blade and Four-blade impellers examined												
Q4 Milestone: Design Review meeting -- Detailed design report to DOE												
Q5 Milestone: Manufacturing drawings produced: Approved by DOE & NEPA												
Q6 Milestone: Fabrication started												
Current work and future research												
Complete fabrication of composite material moldings												
Complete assembly of turbine generator and integrate sensor-based instrumentation												
Deploy two, 10 kW HyPER harvesters at EBID Drop 8 structure												
Test and demonstrate harvester performance												

Project Budget

Budget History					
BP1 (June 2012- May 2013)		BP2 (June 2013- May 2014)		Total Budget	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$106,650	$26,662	$192,662	$48,166	$299,312	$74,828

- Original budget was split in two equal parts for BP1 and BP2, with BP2 subject to a go/no-go decision in June 2013
- BP1 focused on simulations and design with no expenditures for prototype building
- Funds remaining from BP1 were shifted to BP2

Partners and Collaborators:

- EBID is a cost-sharing partner and collaborator
- The vast network of canals provide a real-World laboratory for developing practical approaches to low-head energy harvesting.
- Canals with existing structures allow the development and testing of novel harvesting technologies.
- The diversity in low-head flow-rates during an irrigation season allow the design of efficient low-cost impellers.
- EBID's contributions, therefore, are significant.

Conference Papers

- *"Hydropower Energy Recovery (HyPER) from water-flow systems in Vietnam"*, 10th IPEC, HCM City, Vietnam, Dec. 12-14, 2012.

- *"Exploring Low-head Hydropower Energy Resource (HyPER) in waterways of Vietnam"*, 2013 AUN/SEED – 5th Regional Conference on Advances in Systems and Information, Thailand, July 2013.

Journal and Magazine Publications

"*Hydropower recovery from irrigation canal systems: Fluid dynamic simulations*", Final draft under preparation for submission to IEEE (Jan. '14)

"*Micro-hydropower reaction turbine design*" Final draft under preparation for submission to Electric Power Systems Research Journal (Feb. '14)

"*Micro-hydropower in the 21st century and beyond*" Draft under preparation for submission to Water Power & Dam Construction Magazine (Mar. '14)

Communications and Technology Transfer

•Poster won First Place at the 2012 Annual University Research Council Poster Competition Fair http://www.research.nmsu.edu/urc/12/.

•Poster and a 1/5th size scaled cut-out model of the *HyPER* prototype displayed at the Leyendecker Plant Science Center Centennial Field Day on Aug. 25th, 2012, Las Cruces, NM.

•Telephone interview with USDA Radio News regarding *HyPER* harvester technology on January 18, 2013.

Outreach and student engagement

Senior Capstone Team design and fabricate a Venturi turbine-generator system and successfully demonstrate a bench top prototype simulating the shaft speed characteristics expected at an irrigation site using a off-the-shelf 300 W DC generator.

Funded entirely by: Klipsch School of Electrical & Computer Engineering
New Mexico State University
Las Cruces, NM 88003

Next Steps and Future Research

FY14/Current research: Two 10 kW prototypes of the HyPER harvester are presently being manufactured. This includes the fabrication of Carbon composite moldings of the turbine and discharge tube, custom fabrication of impellers, and the assembly of all off-the-shelf electromechanical components

Proposed future research: Trash guard protection is critical to the longevity of the harvester. Silt and other fine particles will pass through the impeller. However, small rocks will have an impact on the impeller blades and settle inside the discharge tube. Methods to mitigate the debris build-up need to be investigated.

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

NATEL ENERGY

SLH100 Demonstration Project

Monroe Drop, Oregon

Abe Schneider

Natel Energy, Inc.

abe@natelenergy.com 510 342 5269 x1002

February 27, 2014

Purpose & Objectives

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

Problem Statement:

Deploy one SLH hydroEngine^{TM} in an irrigation drop to demonstrate operation and cost, addressing a primary barrier to new low-head hydropower development.

Impact of Project:

Demonstrate operation of the SLH, which has the potential to reduce the levelized cost of electricity (LCOE) of low-head hydropower projects.

This project aligns with the following DOE Program objectives and priorities:

- Advance new hydropower systems and/or components for demonstration or deployment
- Reduce deployment barriers and environmental impacts of hydropower

Technical Approach

Technical approach

1. Complete full plant design utilizing one SLH100 unit
2. Obtain necessary permits, licenses
3. Negotiate interconnection and power sales agreements
4. Construct plant and gather operational data

Key issues

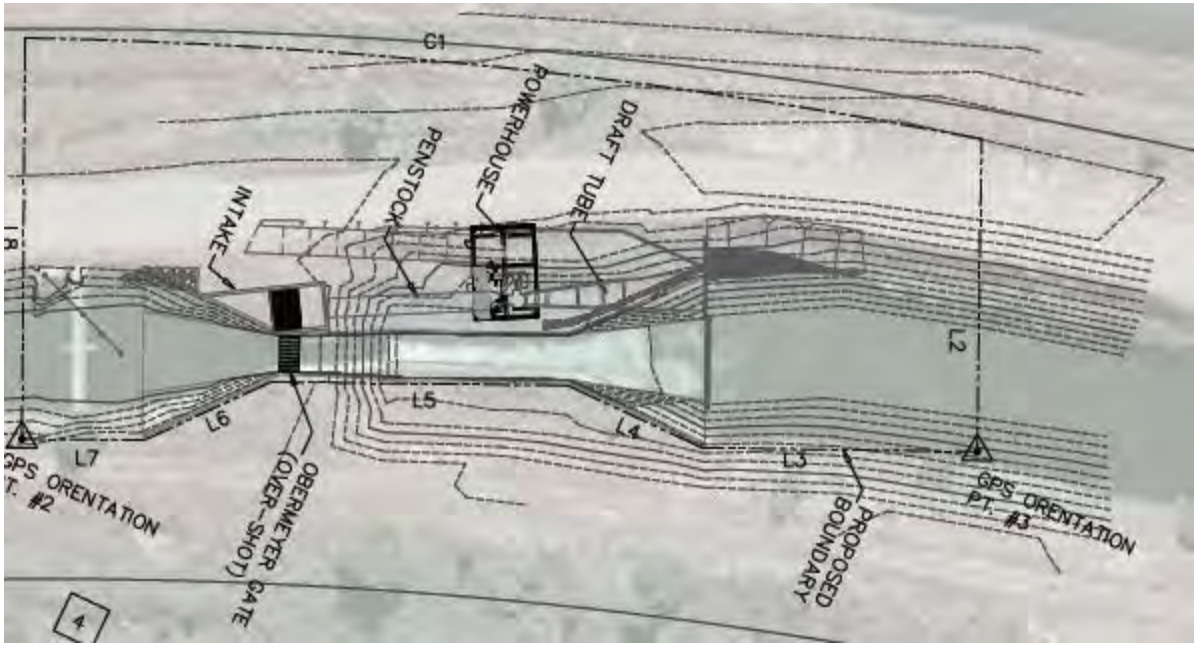
- Project design to result in an overall economic project
- Permitting was more complicated for this project due to federal lands

Unique aspects of approach

- Close partnership with the irrigation district
- Selected site that is representative of many irrigation sites from a civil works perspective

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

Final Plant Layout



Accomplishments and Progress

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

- Project Selection

    A site representative of many irrigation sites was selected and a close partnership with the irrigation district defined.

- Project Design

    Plant design is 100% complete and the design process incorporated significant feedback from a civil construction firm which identified design changes that saved over $250,000 on the civil construction.

- Permitting

    The project has worked with the USBR, USFS, Oregon agencies and FERC to obtain the necessary permits.

- Contracts

    The project has negotiated interconnection and power offtake agreements with PacifiCorp.

Project Plan & Schedule

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

Summary	
DE-EE0005420	
SLH100 Demonstration at Monroe Drop	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: SLH100 Demonstration at Monroe Drop												
Milestone: Preliminary Plant Design												
Milestone: Obtain Interconnection and Power Purchase Agreements												
Milestone: Final Plant Design												
Milestone: Obtain necessary permits												
Milestone: Install and commission SLH100												
Milestone: Operational monitoring and final report complete												
Current work and future research												
Manufacture SLH100 for installation												
Site preparation for install (civil and interconnect)												
SLH100 installation												
Plant monitoring and final report												

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$32k	$32k	$217k	$217k	$496k	$750k

- The project schedule has been extended due to delays in permitting
- The company's investors provided the cost-share funds.

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators:

JAL Construction (Civil)

TOMCO (Electrical)

Communications and Technology Transfer:

No technical presentations have made.

Next Steps and Future Research

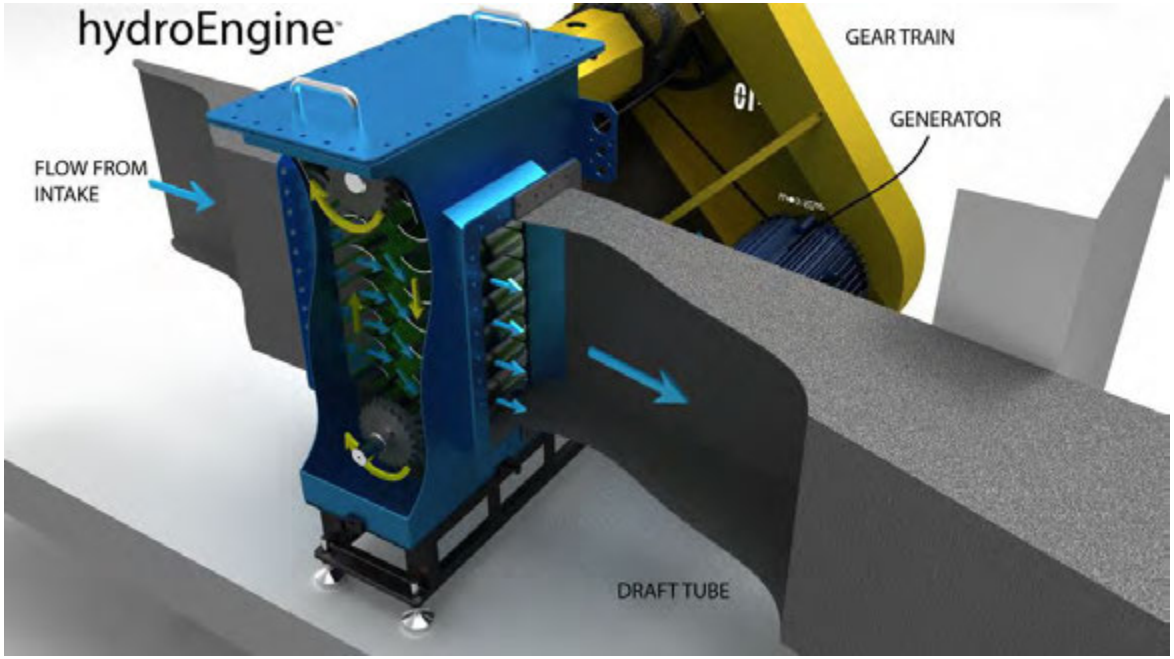
FY14/Current research:

This project is ongoing.

Proposed future research:

Plant design, with a focus on intakes, trash racks and draft tubes would yield additional cost savings.

Continued monitoring of the plant in operation will yield valuable data on reliability and ways in which ongoing maintenance costs evolve and can be reduced.



NATEL ENERGY

SLH Timing Belt Powertrain

Abe Schneider

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abe@natelenergy.com

510 342 5269 x1004

February 27, 2014

Purpose & Objectives

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

Problem Statement:

Develop & test a reliable powertrain for the SLH hydroEngine^{TM}.

Impact of Project:

Enable development of new low-head hydropower capacity by reducing capital costs, maintenance costs, and LCOE, while improving reliability.

This project aligns with the following DOE Program objectives and priorities:

Advance new hydropower systems and/or components for demonstration or deployment.

The project integrates with the recipient's other DOE-funded projects by enabling SLH scale-up to 500kW size (DE-SC0003343) and demonstration in a field setting (DE-EE0005420).

Unique problem:

Because of the unique racetrack-like path of the blades in the SLH, a flexible powertrain is required. Is it possible to engineer a powertrain that can enable low LCOE for the SLH?

Unique solution:

- Carbon-fiber reinforced drive belts
- Novel blade-to-belt attachment system
- Ultra high cycle fatigue testing

Technical approach:

1. Identify requirements: loads, DOF's, UI, life
2. Design conceptualization & down-select
3. Endurance testing
4. Design-for-manufacture
5. Determine LCOE

(Step 1) Powertrain technical requirements (spec) definition

- **Long life**

  15,000 hours between belt replacements

  load reversal (fatigue): **77 million cycles**

  3.4 years service interval at 50% capacity factor

- **Low maintenance**

  Maintenance-free attachment

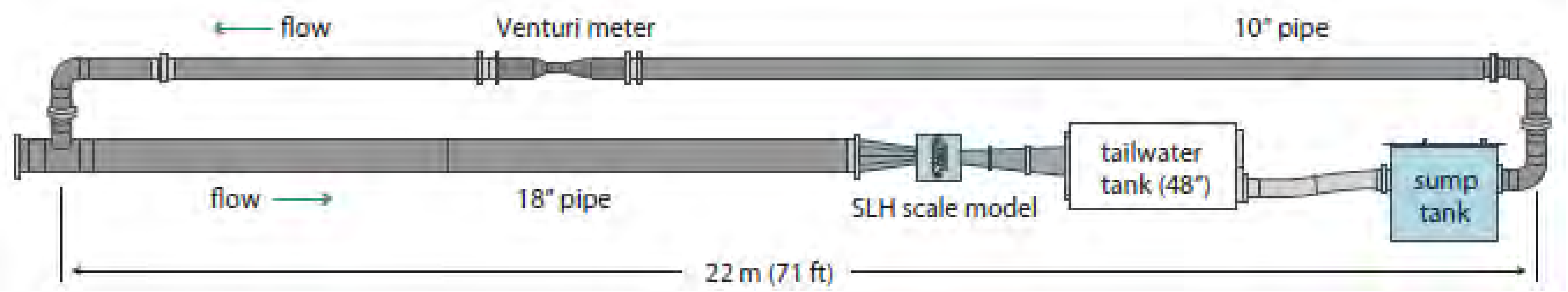
  Easy dis/assembly of individual blades from belt

- Loads (lift, drag, moment from CFD & hydraulic scale model test)

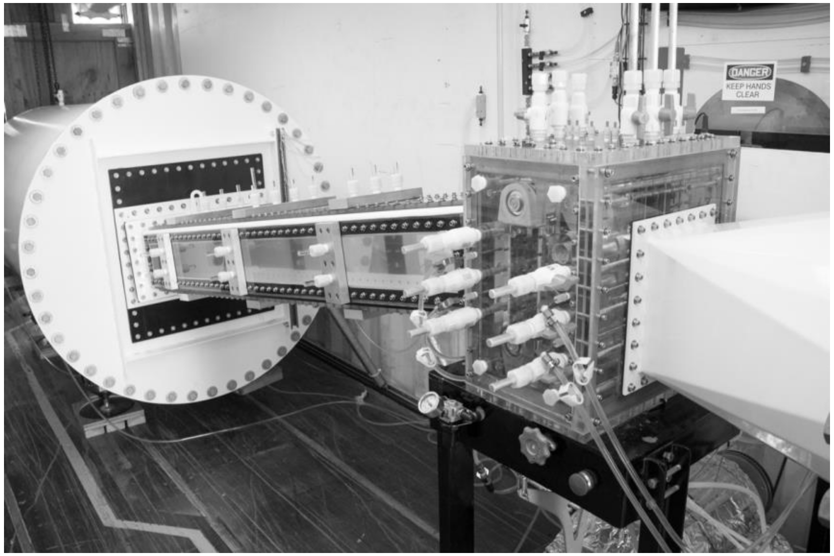
  500kW scale lift load: + 5.8/-2.5 kN (+1300/-560 lb)

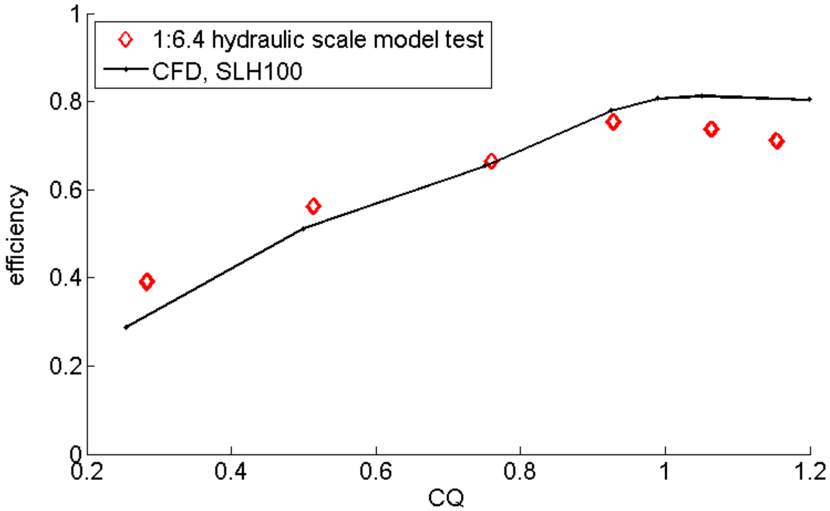
- Motions (from belt articulation & blade loading)

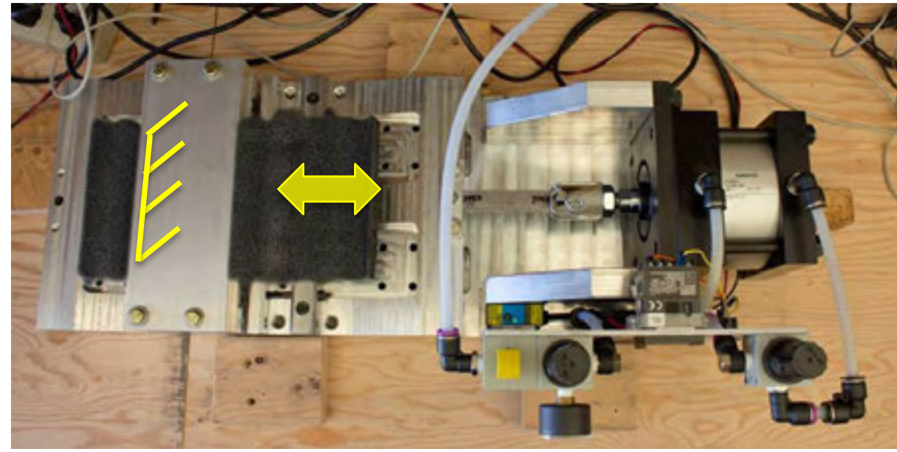
  6 DOF attachment; strains computed with FEA, loads from CFD



Following recommendations of IEC-60193, PTC 18-2002, and in consultation with Alden, Natel designed, built and commissioned an onsite 1:6.4 scale model hydraulic test facility to confirm CFD-derived loads.







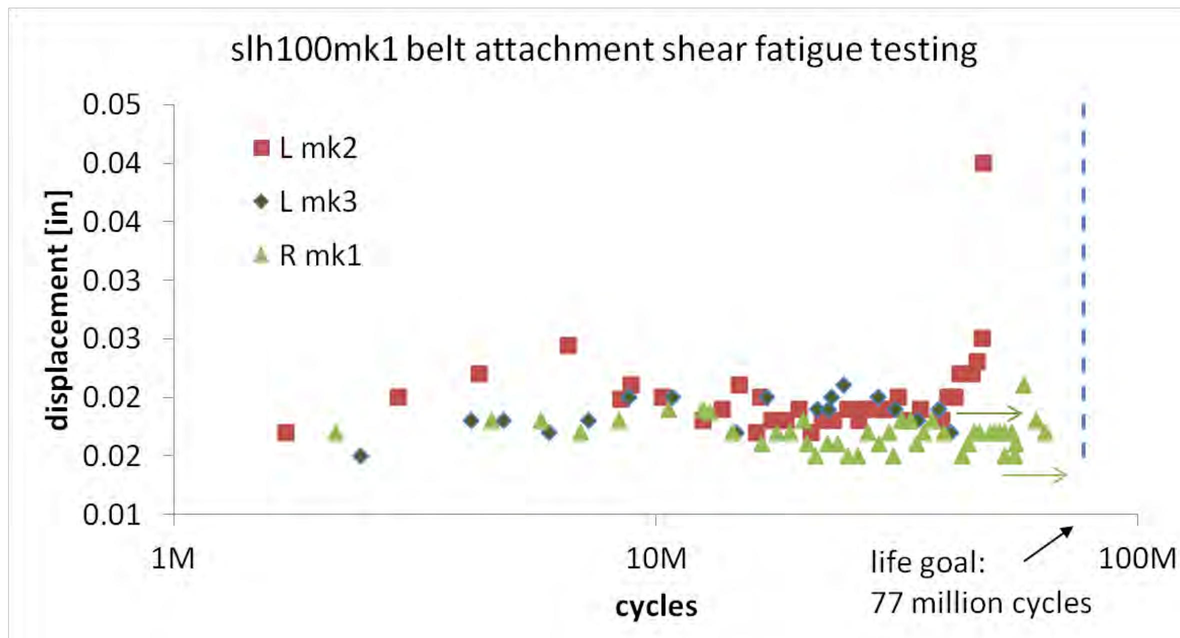
Shear fatigue test rig, 500 kW-scale belt attachment system

Runs 24/7/365

Load: +1/-0.5 ton (1.5x actual)

(same as weight of VW Bug)

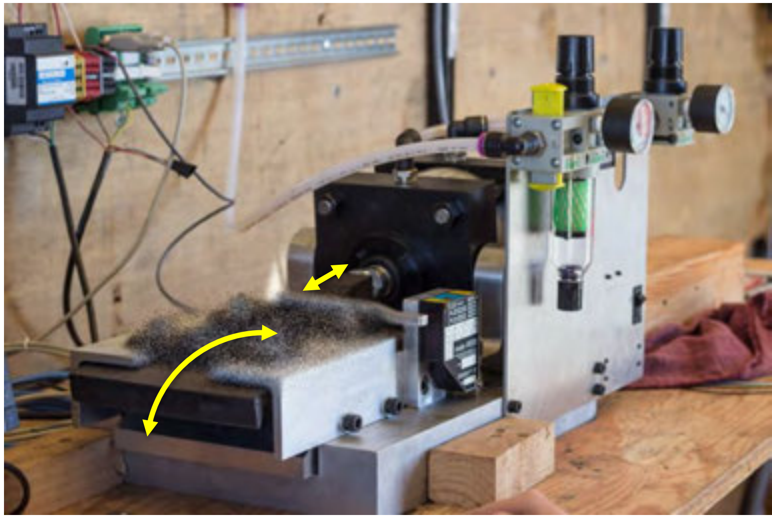
On track to meet life goal: 77 million cycles



Accomplishments & Progress

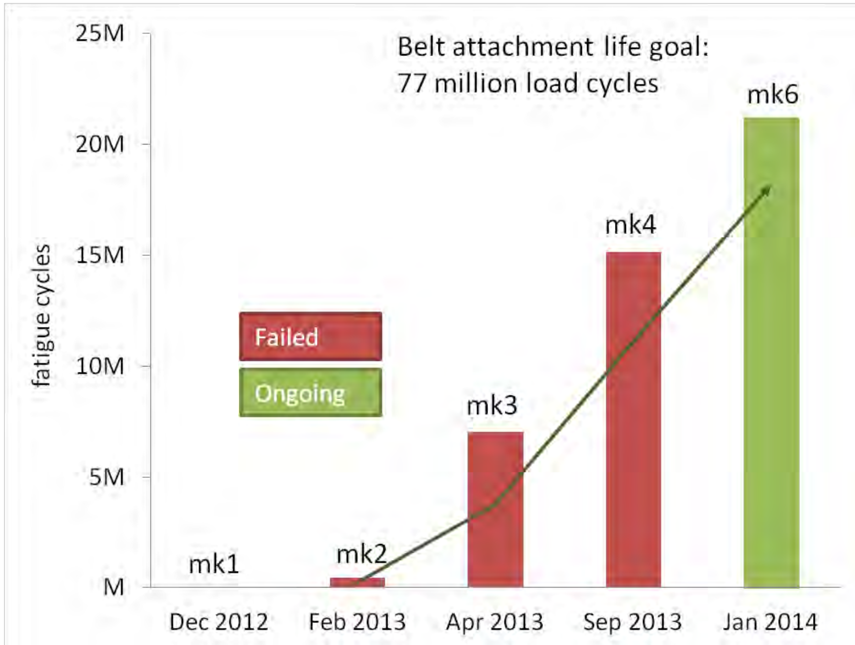
Articulation fatigue test rig, 500 kW.

Simulates actual attachment system:
- Loads: shear, moment (1.1-1.3x load factor)
- Motions: bending, articulation



Steady progress, over many design iterations, to attain life goal.

Best design:
21 million cycles, ongoing...

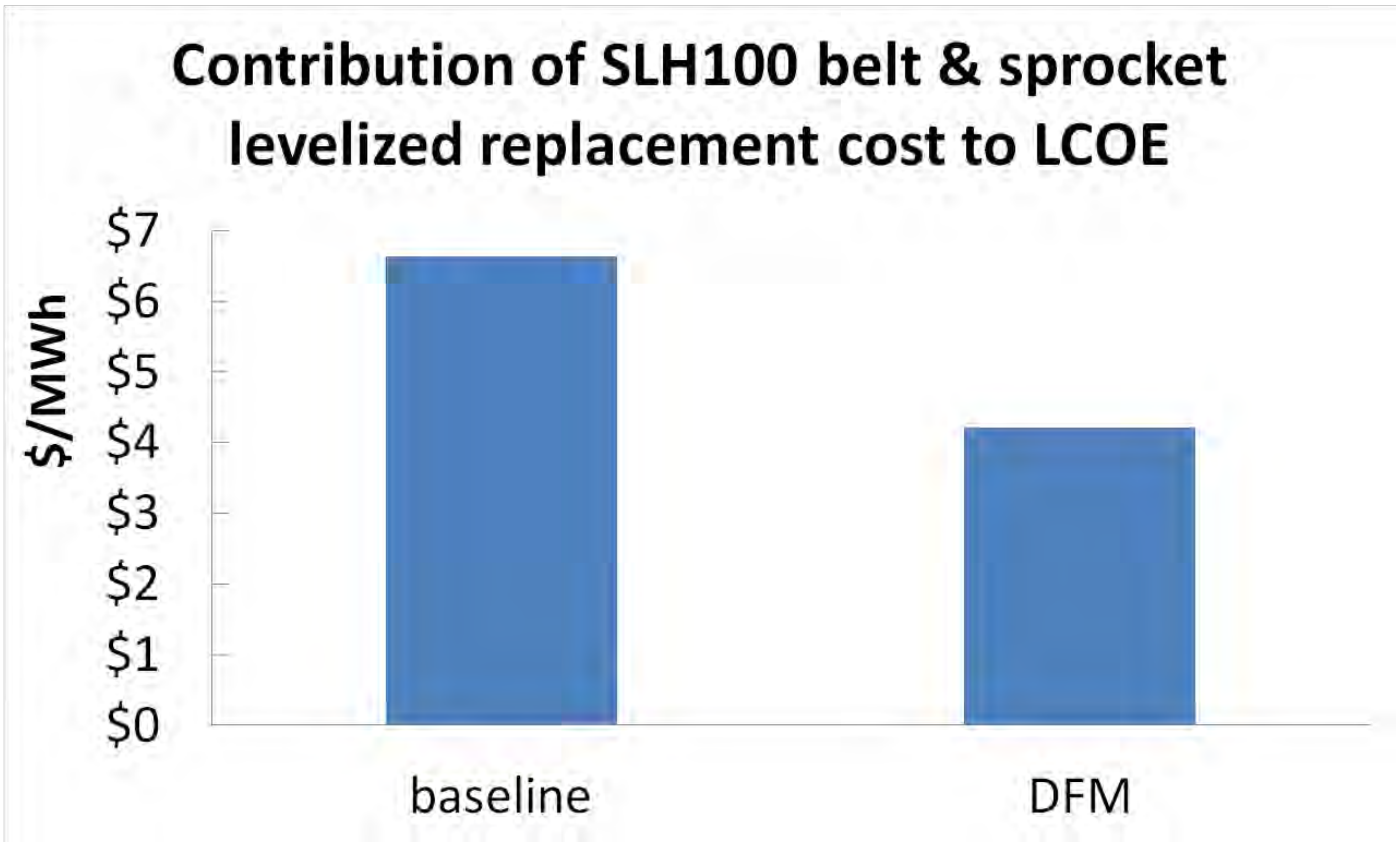


(Step 4) **Design for Manufacture**

Every component in the powertrain optimized for:

- Symmetry
  Left-hand and right-hand parts same.
- Off-the-shelf components where possible
- Multifunctional parts
  Combined function of multiple components into fewer parts.
- Multi-use design
  Powertrain system can allow SLH's of different size, as well as broader industrial use.
- Modular design
  Versatility in production, mitigation of change risk.
- Reduction of processing steps
  Stainless steel, optimization of order of heat treat, passivation, and machining.
- Near net shape
  Investment castings drive out machining cost.
- Tolerance optimization
- Development of assembly aids

(Step 5) **Optimize LCOE impact of powertrain**



* at production volumes of 100 SLH/year

CONCLUSIONS:

- **Carbon reinforced drive belts can withstand SLH loads** for power ratings at 50kW and 500kW scales.
- SLH **blades can be mounted** to these drive belts with a connection that can withstand expected operating loads.
- SLH drive **belts, with blade attachments, can live** through the required cyclic fatigue loading.
- SLH100 500kW-scale powertrain can be implemented with **LCOE impact of between $4-6/MWh**.

Project Plan & Schedule

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

Summary	
DE-EE0005412	
SLH Timing Belt Powertrain	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: SLH Timing Belt Powertrain Development												
Q1 Milestone: 50kW-scale belt attachment testing (v1, v2a, v2b)												
Q2 Milestone: Shear fatigue testing: 10 million cycles passed												
Q3 Milestone: Initiate articulation testing												
Q3 Milestone: First articulation tester passes 1M cycles												
Q1 Milestone: Scale Model Hydraulic Test Facility commissioned												
Q2 Milestone: Confirm loads with scale model tests												
Q3 Milestone: Articulation tester passes 10M cycles												
Current work and future research												
Continue fatigue testing on latest design prototypes												
DFM pass complete & release production parts for manufacture												
Technical report evaluating test results												
Submit patent applications for selected inventions												

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$87K	$30K	$213K	$162K	-	-

- Workplan was modified to substitute development of onsite hydraulic test facility instead of endurance testing of 50kW scale prototype at Alden Research Laboratory.
- More effort was expended on bench level component fatigue testing at full 500 kW scale, than initially planned.
- Project has been completed; 100% of the budget used.
- The company’s investors provided the cost-share funds.

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

Alden Research Laboratory

- Preliminary tests on 50 kW scale hydroEngine using belt powertrain.
- Consulted on design of 1:6.4 scale model hydraulic test facility.

Communications and Technology Transfer:

No public presentations have made, pending patent filing.

Disclosure of invention: DOE "S" Number 135,519

Next Steps and Future Research

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

FY14/Current research:

This project has been completed.

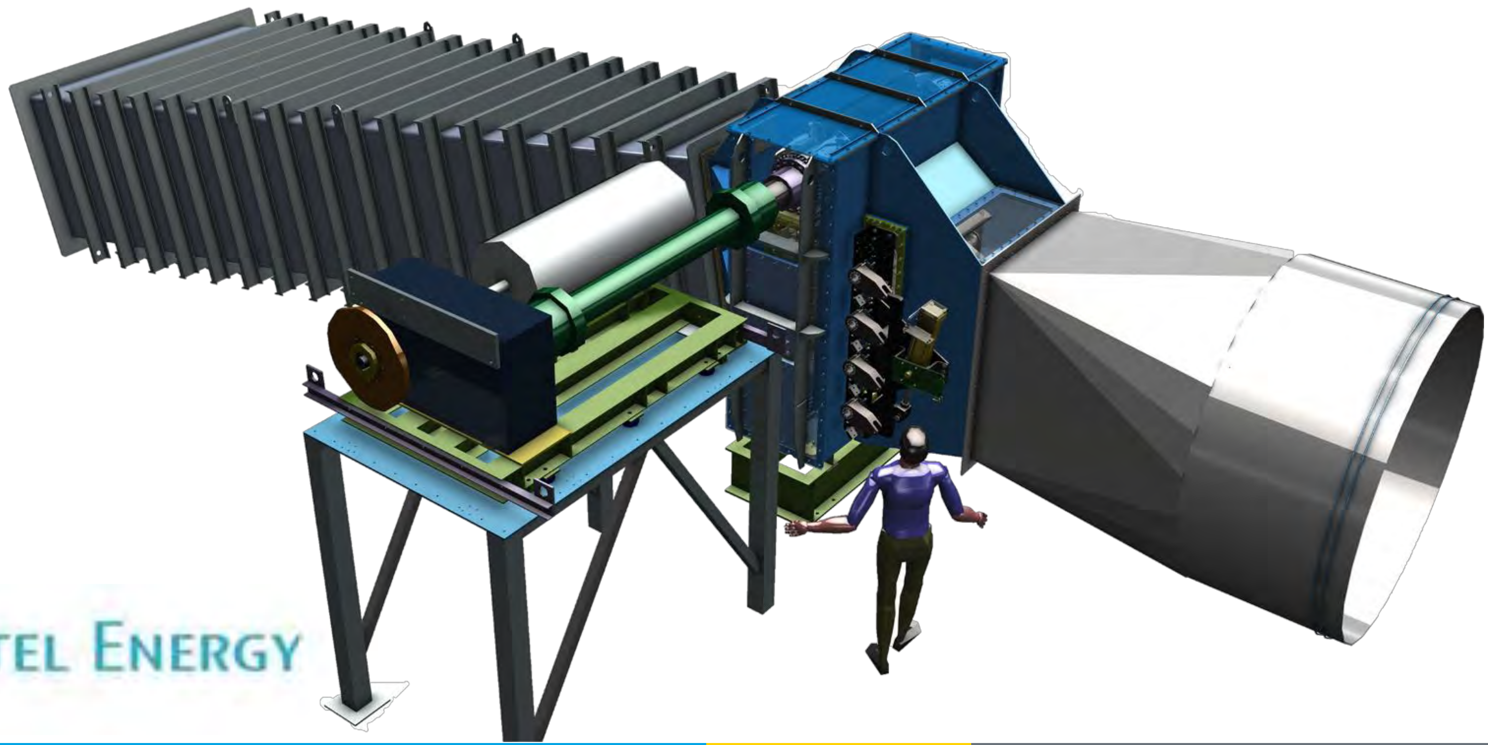
Proposed future research:

Continued fatigue testing, including:

- more statistical certainty (replicates)
- environmental conditions (corrosion fatigue, abrasive particles, temperature fluctuations, etc)
- larger system scope (belt-to-sprocket interactions, full scale system testing)
- alternate designs and materials

Scale-up to MW-class machines

- requires development of new belt carcass (no commercially available belts at larger size)



NATEL ENERGY

Scale-Up of Low-Head SLH HydroEngine™

Abe Schneider

Natel Energy, Inc.

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510 342 5269 x1004

February 27, 2014

Purpose & Objectives

Problem Statement:

Design and manufacture a ~~200~~ **500 kW** scale SLH hydroEngine^{TM}.

Impact of Project:

Scale-up of SLH technology to utility-relevant size; help reduce high capital cost and resulting high levelized cost of electricity (LCOE), which are major barriers to low-head hydropower projects.

This project aligns with the following DOE Program objectives and priorities:

Advance new hydropower systems and/or components for demonstration or deployment.

The project integrates with the recipient's other DOE-funded projects utilizing belt powertrain innovations (DE-EE0005412) and enabling demonstration in a field setting (DE-EE0005420).

Unique problem:

The hydroEngine^{TM} has been demonstrated at small scale (<50 kW).

Is it possible to scale up the SLH to a utility-relevant size?

Such a machine must be capable of withstanding large loads with very high fatigue cycles, and be cost-effective to produce.

Unique solution & innovations:

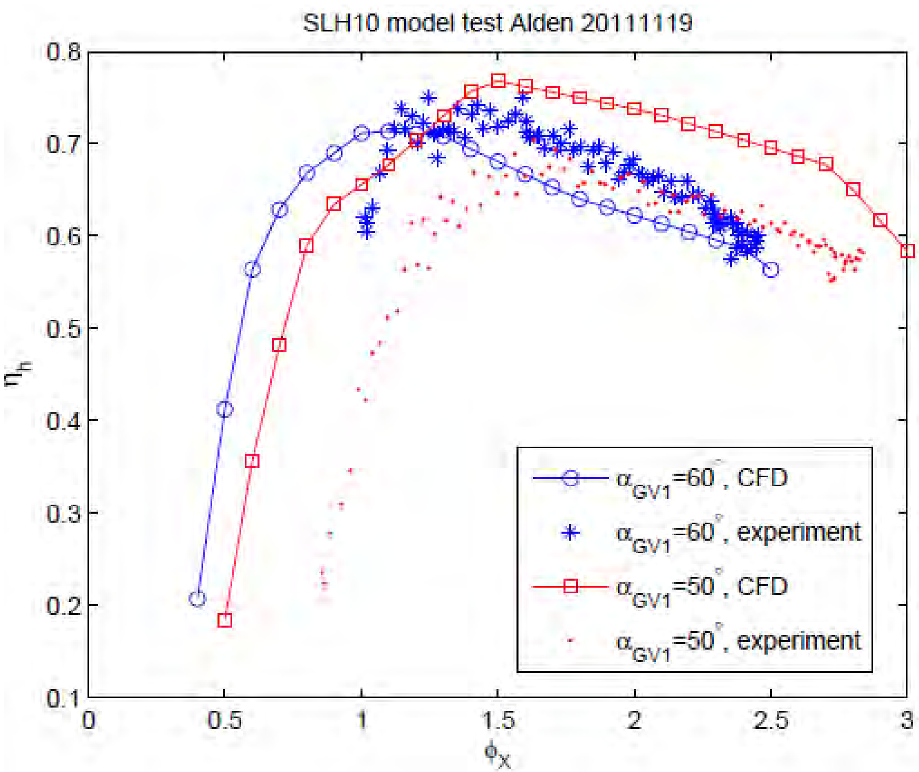
- Carbon-fiber components (blades, guidevanes, belts, axles)
- Novel blade-to-endplate attachment system, blade shape
- Ultra high cycle fatigue testing

Technical approach:

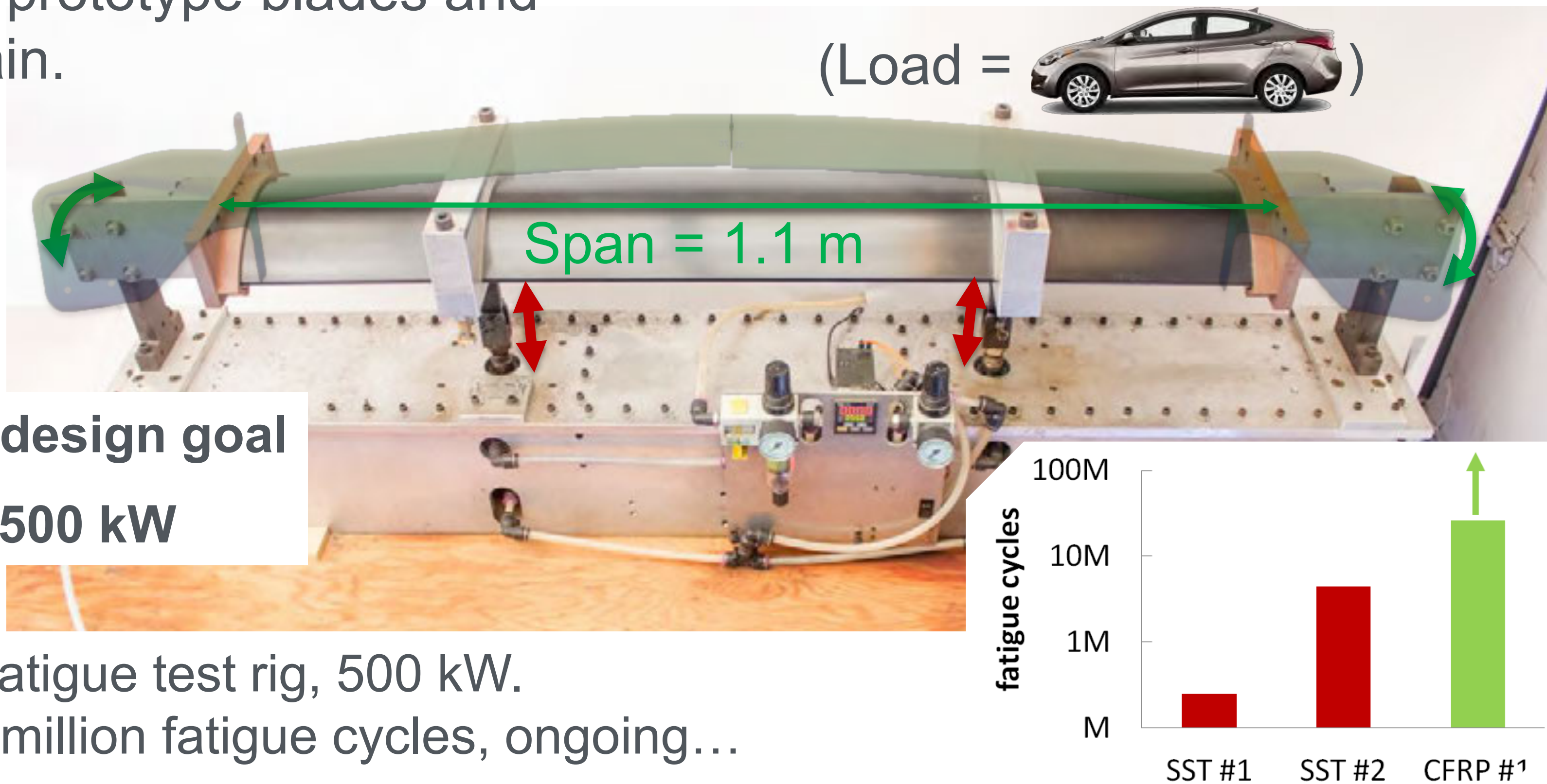
1. Scale model testing & CFD; design refinement
2. Full scale blade and powertrain design & endurance testing
3. Balance of machine design
4. Further scale-up feasibility assessment

Objective: Construct and evaluate performance of small-scale prototype machine (SLH10, 0.1m^2 intake) at Alden Research Laboratory

- Efficiency ~0.75, matching CFD predictions
- First demonstration of timing-belt powertrain
- Peak power ~30 kW



Objective: Design and construct full-scale SLH100 prototype blades and powertrain.



Increased design goal

200 kW -> 500 kW

Full blade fatigue test rig, 500 kW.
CFRP >25 million fatigue cycles, ongoing…

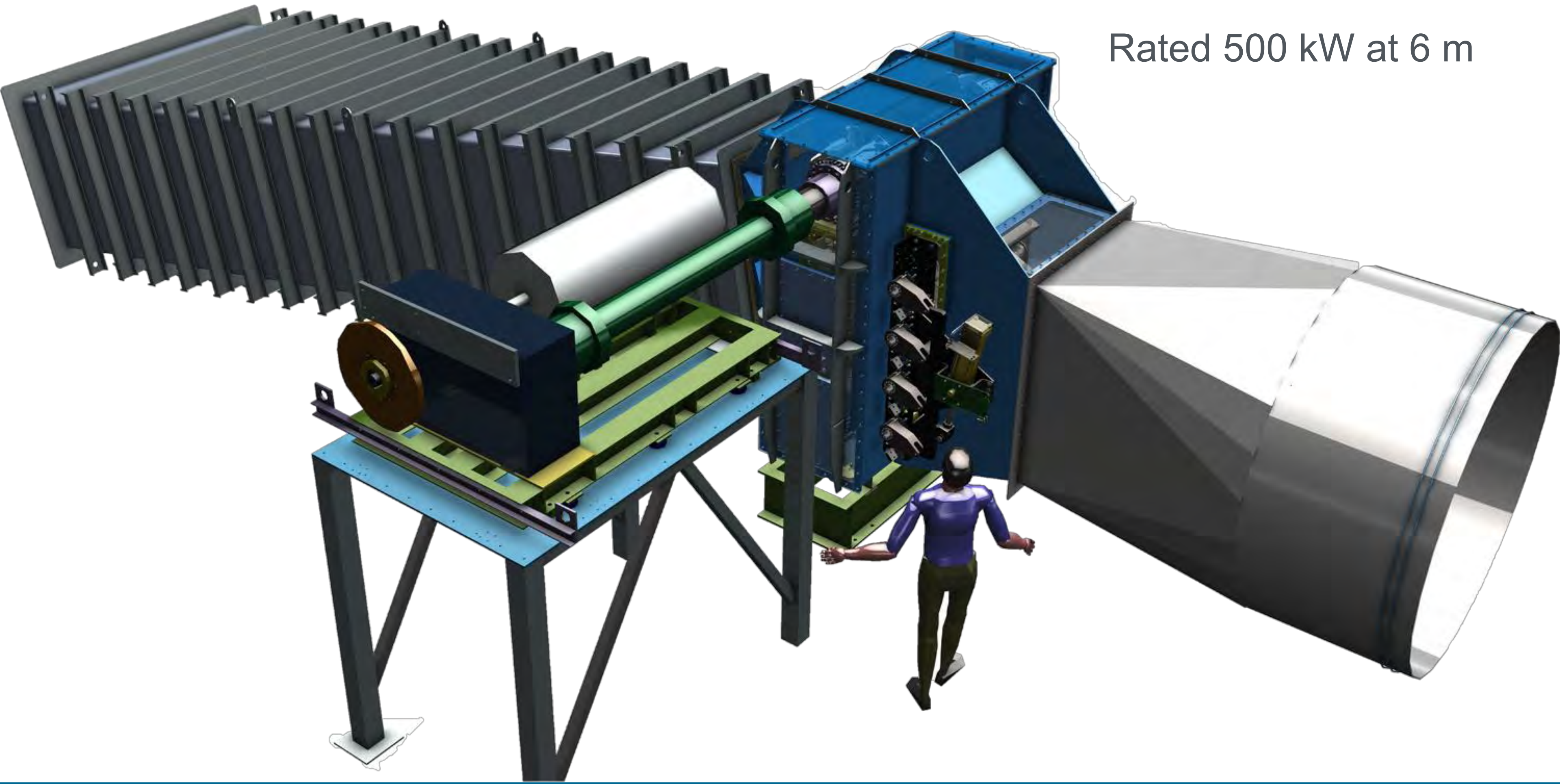
Simulates blade + endplate + clamp + belt attachment system:
- Loads: reversing force, bending moment (+1.2/-0.25 tons; 1.1x load factor)
- Motions: bending, attachment articulation

Accomplishments and Progress

Objective: Construct full-scale SLH100 prototype for commercial demonstration.

SLH100mk1:

Rated 500 kW at 6 m



Objective:

Design and feasibility assessment for 1 MW+ machine.

- 1 MW-scale SLH blades and powertrain are technically feasible
  - Design alternatives:
    - higher head (narrow body): could use same powertrain as SLH100
    - higher flow at same head (larger throat): would require new, larger belt carcass
- Further study is recommended.

Project Schedule

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

Summary	
DE-SC0003343	
Scale-Up of Low-Head SLH HydroEngine™	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2011				FY2012				FY2013			
Task / Event	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Scaleup of Low-Head SLH Hydroengine												
1: SLH10 scale model tests at Alden Laboratory												
3: a) Initial SLH-100 blade/endplate/powertrain mechanical design.												
3: b) Fatigue testing results for final SLH-100 blade candidate designs												
4a: SLH-100 200kW-scale prototype complete.												
4b: Initial specification for SLH-100 generator, controls, switchgear.												
5: Feasibility assessments for SLH-500 class unit												
Current work and future research												
Continued fatigue testing of final design components for SLH100												
Analysis of field performance data from SLH100 demonstration site												
Optimization of SLH & civil works design, performance, and cost												
Design, prototype, and test components of MW+ machines												

Extended timeframe enabled use of carbon fiber for key components to increase rated capacity and reliability of the SLH.

Project Budget

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

Budget History					
FY2011		FY2012		FY2013	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$438K	$101K	$457K	$107K	$56K	$62K

- Project has been completed; 100% of the budget used.
- Company's investors provided the cost-share funds.

Partners, Subcontractors, and Collaborators:

Alden Research Laboratory, Holden, Massachusetts

Communications and Technology Transfer:

No technical presentations have made, pending filing of selected patents.

Next Steps and Future Research

FY14/Current research:

This project has been closed.

Proposed future research:

Field testing of SLH100mk1 prototype

Continued fatigue testing, including:

- more statistical certainty (replicates)
- environmental conditions (corrosion fatigue, abrasive particles, temperature fluctuations, etc)
- larger system scope (belt-to-sprocket interactions, full scale system testing)
- alternate designs and materials

Scale-up to MW-class machines

- may require development of new belt carcass (no commercially available belts at larger size)

Optimization of civil works (cost vs function)

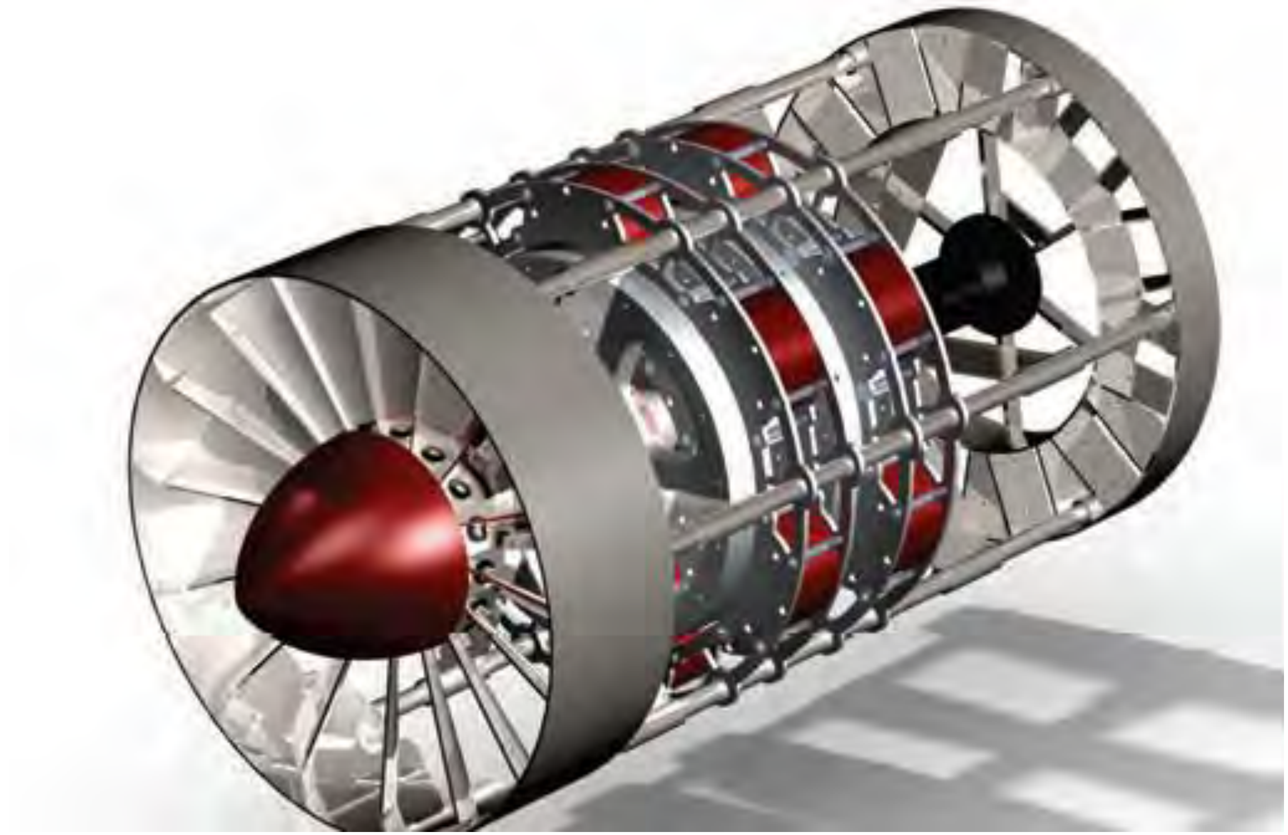
Draft tube optimization (efficiency, cost)

Low maintenance axles

- Innovative options include water-tolerant antifriction bearings, hydrostatic bearings, seals

Water Power Peer Review

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



W4e Hydropower Turbine Generator System Validation

Brian Hunter **(for Walker Wellington)**

U.S. Department of Energy, Wind and Water Power Technologies Office

brian.hunter@go.doe.gov, (720) 356 1590

Feb. 26, 2014

Purpose & Objectives

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

Problem Statement: The objective of the project was to validate the design predictions/intention for the W4e hydropower direct drive in-line turbine generator

Impact of Project: W4e is a direct drive, modular turbine / generator designed specifically for low-head conduit applications. This project characterized W4e hydro turbine generator over a range of head and flow conditions.

This project aligns with the following DOE Program objectives and priorities [select best fits & delete others]:

To be provided at a later date. Please leave this section blank until further guidance is provided

Technical Approach

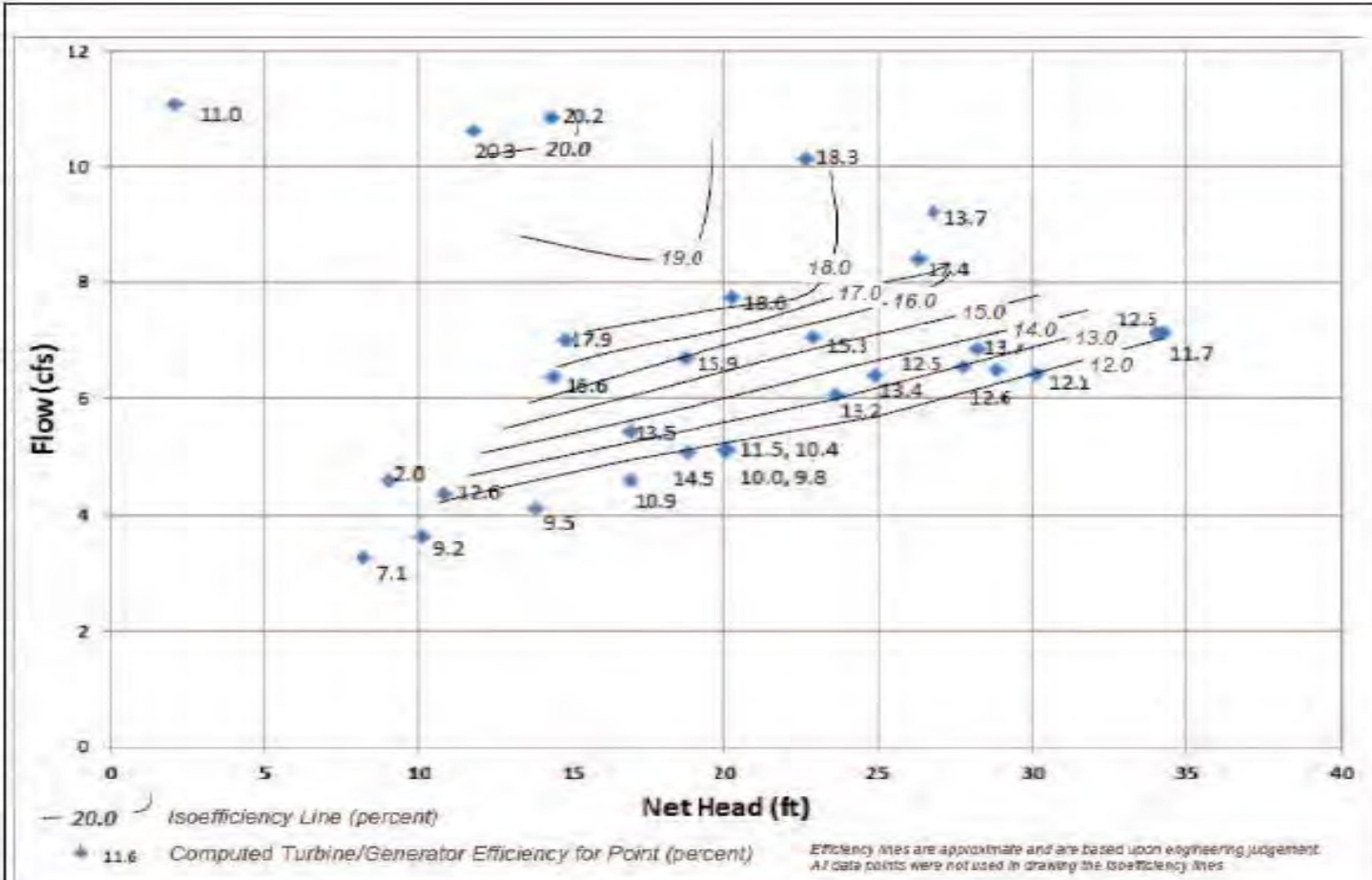
- Laboratory testing program developed for a prototype version of the turbine
- An existing W4e hydro turbine generator was modified for installation in the testing facility.
- Hydraulic performance testing was conducted, measuring power generated at flow rates from 3 to 12 cubic feet per second (cfs) with head conditions from 9 to 34 feet.
- Data generated by the testing program was collected, validated, and analyzed by an Independent Engineering firm.

Accomplishments and Progress

- Laboratory testing completed in May 2013
- Turbine testing was performed at Alden Laboratories. Thirty one successful test runs were completed during the test period.
- This testing demonstrated that the design is capable of generating electricity over a wide range of heads (9-30 ft.) and flows (3-12 cfs) which are appropriate for relatively low head/low flow conditions.
- However, the power output and the efficiencies were lower than anticipated.

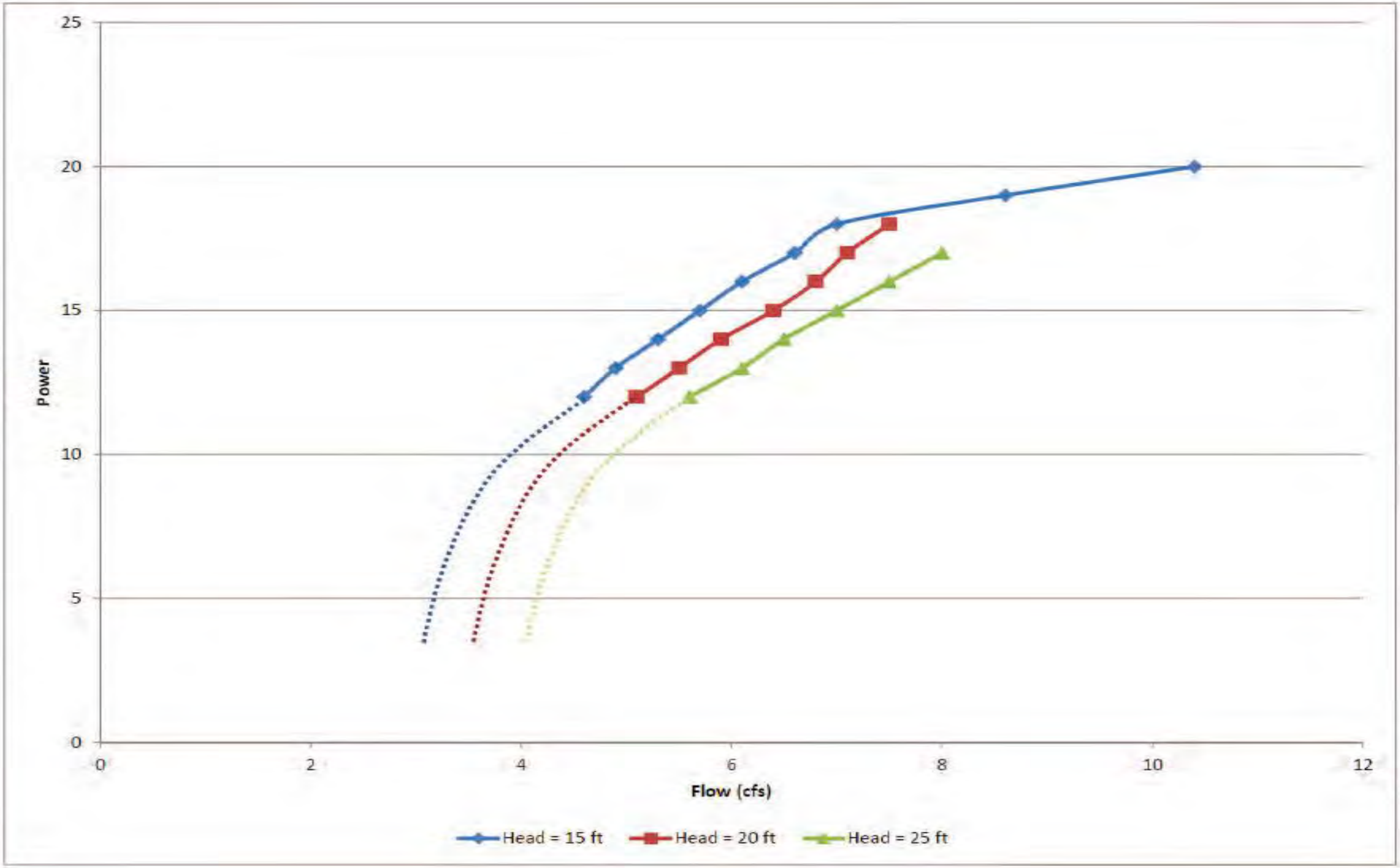
Accomplishments and Progress

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



Accomplishments and Progress

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



Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	DE-EE0005425
Project Number	20325
Agreement Number	24928

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

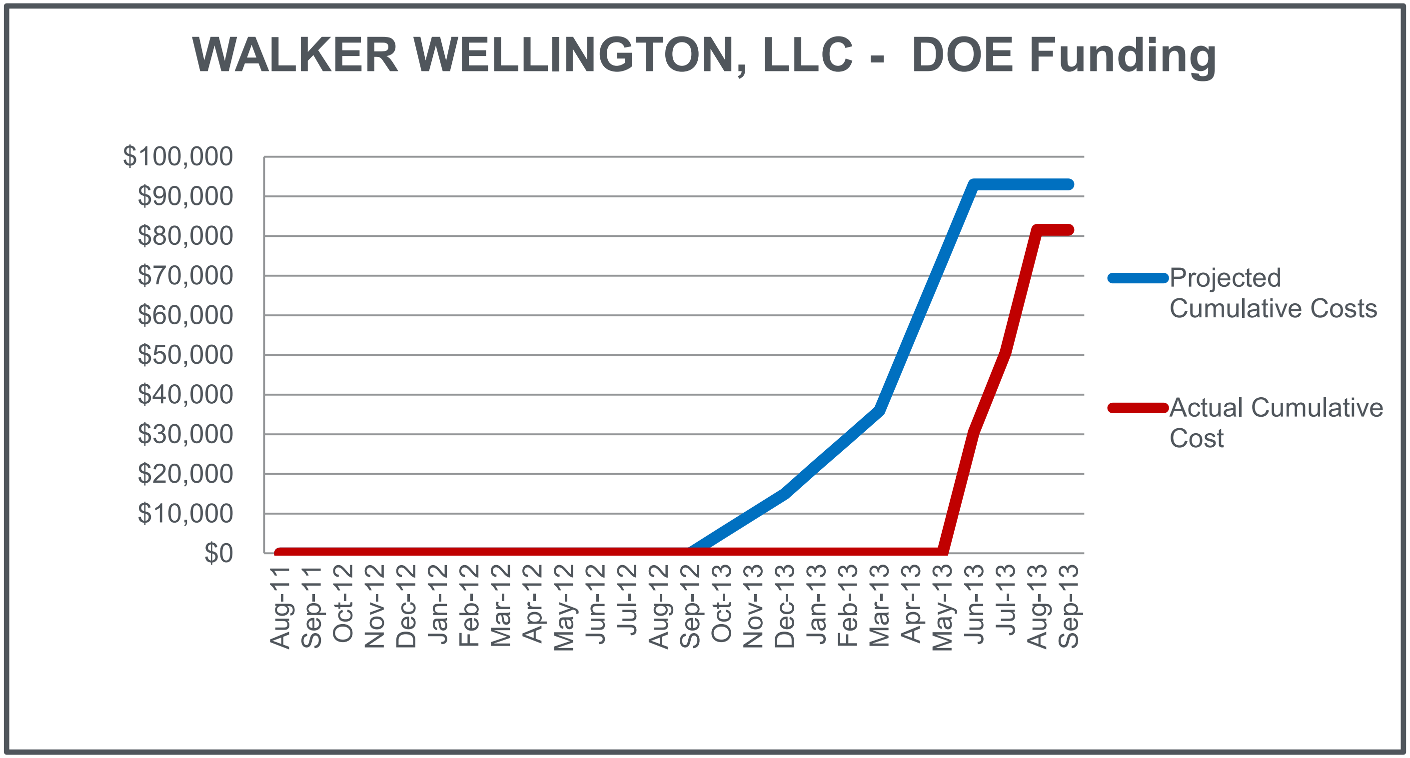
	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: W4e Hydropower Turbine Generator System Validation												
Task 1.0 Project Kickoff Meeting												
Task 2.0 W4e System Prepared for Testing												
Task 3.0 Installation of W4e Hydro Turbine Generator												
Task 3.1 W4e Hydro Turbine Generator Performance Testing												
Task 4.0 Project Completion & Reporting												

- Period of Performance: 9/30/2011 – 9/30/2013 (2 years)
- Project was delayed but was completed within the original Period of Performance and under budget.

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$ 0	$ 0	$ 89,772.15	$ 23,250.00	$ 0	$ 0



Partners, Subcontractors, and Collaborators:

Walker Wellington, LLC – Turbine Developer
Blue Water, LLC – Turbine designer and manufacturer
Alden Research Labs – Testing facility
GZA GeoEnvironmental, Inc. – Independent Engineer

Communications and Technology Transfer:

Full testing report is publically available at DOE Office of Scientific and Technical Information website (OSTI.gov) under OSTI ID 1096577

Next Steps and Future Research

FY14/Current research: Project Completed 9/30/2013.

Proposed future research: Further vetting of the equipment after additional modifications may result in the equipment performing at improved efficiencies

Small Hydropower Research and Development Technology Project

February 26, 2014

Near Space Systems, Inc.

Small Hydropower Research and Development Technology Project

Mo Blackmore

Near Space Systems,
mblackmore@globalnearspace.com
719.685.8107
February 26,2014

Purpose & Objectives

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

Problem Statement: Research and develop the next generation of small hydroturbine designs to significantly reduce costs, production time, installation time, and maintenance in order to significantly expand the use of U.S. hydropower resources

Impact of Project: Hydroturbine design that maximizes the energy transfer from flowing water to electrical power generation and is simple to produce, install and operate, with forecasted reductions in systems cost and LCOE

This Project Aligns with the Following DOE Program Objectives and Priorities:

- Advance new hydropower systems/components for demonstration and deployment
- Optimize existing hydropower technology, flexibility, and/or operations
- Enable next generation pumped storage technologies to facilitate renewable integration
- Reduce deployment barriers and environmental impacts of hydropower

Technical Approach

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

Technical Approach Employ a clean sheet approach to maximize all aspects of small hydroturbine design and performance

- Identify candidate technologies and develop requirements
  - Baseline current technologies, literature search, develop requirements
- Analyze and prioritize candidate technologies for enhanced/improved small hydroturbines
  - Develop criteria, conduct trade studies, prioritize technologies
- Investigate new small hydropower technologies for application to near-term candidate hydro sources
  - Develop list of sources, characterize sources factors, develop site plans
- Produce a prototypical design for a next generation small hydroturbine generator
  - Use integrated systems plan for prioritized technologies; validate result
  - Project computational tool provided multi-factor LCOE-based analysis of prototypical design/site installation

Accomplishments and Progress

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

Accomplishments: Project yielded a prototypical design that mitigates the shortfalls of conventional hydroturbines

- No mechanical transfer mechanisms between the turbine and the generator
- Hydroturbine operates without lubrication; long-life, maintenance-free bearings
- Designed to be environmentally inert: Does not introduce foreign chemicals / particulate matter into the hydro ecology
- Axial flux generator optimizes power production and manufacturing efficiency
- Rotor design optimizes magnetic flux into generator field coils
- Turbine blades are optimized for head and flow of particular hydro flows
- Turbine rotor design facilitates blade stability and ease of manufacture
- Modular design enables numerous production/application/installation factors
- Housing is made of lightweight, low cost, long-life materials for reliability
- Design is scalable for particular water flow and power requirements
- System requires little or no maintenance - extremely rugged, reliable design
- Project computational tool provides evaluation of hydropower installations
- Project's new fish protective device promises marked increase in fish survival
- Design forecasts decreased system costs and LCOE

Project Plan & Schedule

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

Summary		Legend	
WBS Number or Agreement Number			Work completed
Project Number DE-EE0005427/001			Active Task
Agreement Number		◇	Milestones & Deliverables (Original Plan)
		◆	Milestones & Deliverables (Actual)

Task / Event	FY2011 Q1 (Octt-Dec)	FY2011 Q2 (Jan-Mar)	FY2011 Q3 (Apr-Jun)	FY2011 Q4 (Jul-Sep)	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)
Project Name: Small Hydropower Research and Development Technology Project												
Milestone 1: Identify Candidate Technologies and Develop Requirements					◇◆							
Milestone 2: Analyze and Prioritize Candidate Technologies							◇◆					
Milestone 3: Investigate Small HydropowerTech for Source Applications									◇◆			
Milestone 4 Produce a Prototype Design for Next Gen Hydroturbine												◇◆

Comments

- Project original initiation date: Sep 30, 2011
- Project planned completion date: Sep 30, 2013
- Project completed on Sep 30, 2013
- No slipped milestones or slips in schedule
- Project current status: Project complete. In Close-out

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$51.594K	$45.557K	$248.406K	$253.365K	$0K	$0K

- Variances: Recipient contributed more than required cost share in FY2013. No modification to project plan required.
- Project is complete and in close-out. No project budget funds remaining.
- No other funding sources.

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators: Not Applicable

Communications and Technology Transfer: Not Applicable.

Next Steps and Future Research

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FY14/Current research: N/A - Project complete.

Proposed future research:

- Construct prototype next generation small hydroturbine
- Evolve prototype hydroturbine to production model
- Deploy a production-level new small hydroturbine to an actual hydro site for installation and initial commercial operation

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

Laboratory Demonstration of a New American Low-Head Hydropower Turbine

Wayne Krouse

Hydro Green Energy

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27FEB14

Purpose & Objectives

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

Problem Statement: There are currently no utility scale, low cost, American made, low head hydropower turbines in the marketplace.

Impact of Project: Demonstrate ways to lower the LCOE for the U.S. low-head hydropower resource to enable many utility scale hydropower projects to become economically viable in todays marketplace.

This project aligns with the following DOE Program objectives and priorities:

Advance new hydropower systems and/or components for demonstration or deployment

Technical Approach

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

Hydro Green Energy, LLC (HGE), in partnership with HDR Engineering, Mechanical Solutions and Alden Laboratory used two different CFD source codes to validate numerical modeling. After rotor dynamics and FEA were complete, 2D drawings were prepared and components for the subscale machine were fabricated.

Fabrication is 80% complete. Assembly and hydraulic testing of the subscale machine in a closed loop system will occur throughout the remainder of 1Q14.

This subscale model test will adhere to the PTC-18 test code for hydraulic turbines.

Accomplishments and Progress

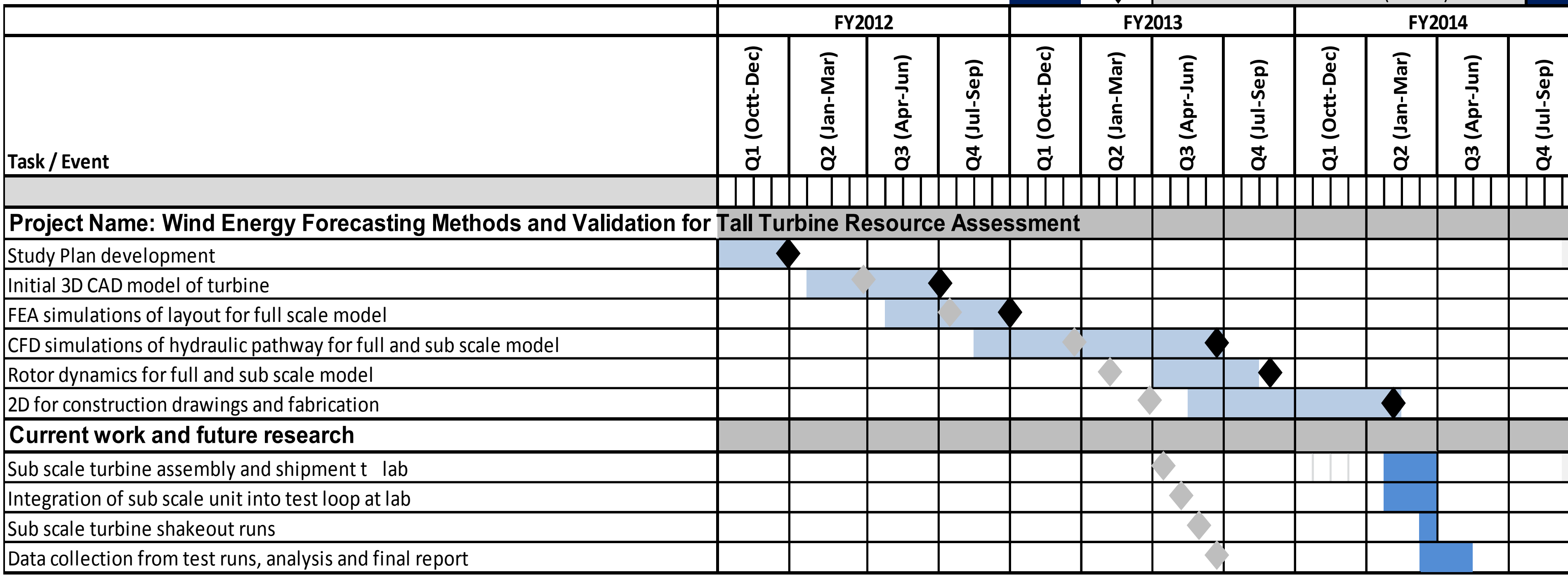
Technical accomplishments –

- Validation of power output and efficiency using 2 different CFD codes
- Completion of high level rotor dynamics and FEA for both full scale and sub scale units.
- Completion of high level rotor dynamics and FEA for the sub scale unit.
- Initiation of fabrication of sub scale unit.

Our target was met in CFD in obtaining power output of 750 kW and greater than 81.0% efficiency from 10 feet of gross head that would fit in HGE's patented modular hydropower systems constrained space.

Project Plan & Schedule

Summary		Legend
WBS Number or Agreement Number -		Work completed
Project Number -		Active Task
Award Number - DE-EE0005426		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)



Comments

- Initiation date - December 2011; Original completion date – February 2013
- Significant time was lost during equipment layout due to estimated loads; significant time was lost during
- CFD optimization to hit the performance targets for the project.
- High level FEA in 2012 and high level CFD in 2013 were go/no-go decisions

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$104,347	$24,340	$98,225	$6,326	$97,428 (projected)	$533,400+ (projected)

- The project is significantly over budget.
- Costs for engineering design for subscale fabrication are slightly higher than originally estimated. Fabrication costs are significantly higher than originally estimated.
- HGE is paying the difference in funding requirements.

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators: Mechanical Solutions, HDR Engineering and Alden Labs.

Communications and Technology Transfer: Detailed information of development program has only been presented to DOE and at DOE conferences to date.

Next Steps and Future Research

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

FY14/Current research: We expect fabrication and assembly to be completed by the end of February. Shipment will occur at the beginning of March. Integration into test stand and commencement of testing will occur in March.

Proposed future research: A full scale turbine will be fabricated and installed at our 5.25 MW project at the US Army Corps of Engineers (USACE) Braddock Locks & Dam on the Monongahela River outside of Pittsburgh, PA. We expect construction to begin in 2015 on that project pending a FERC license and USACE permit approvals.

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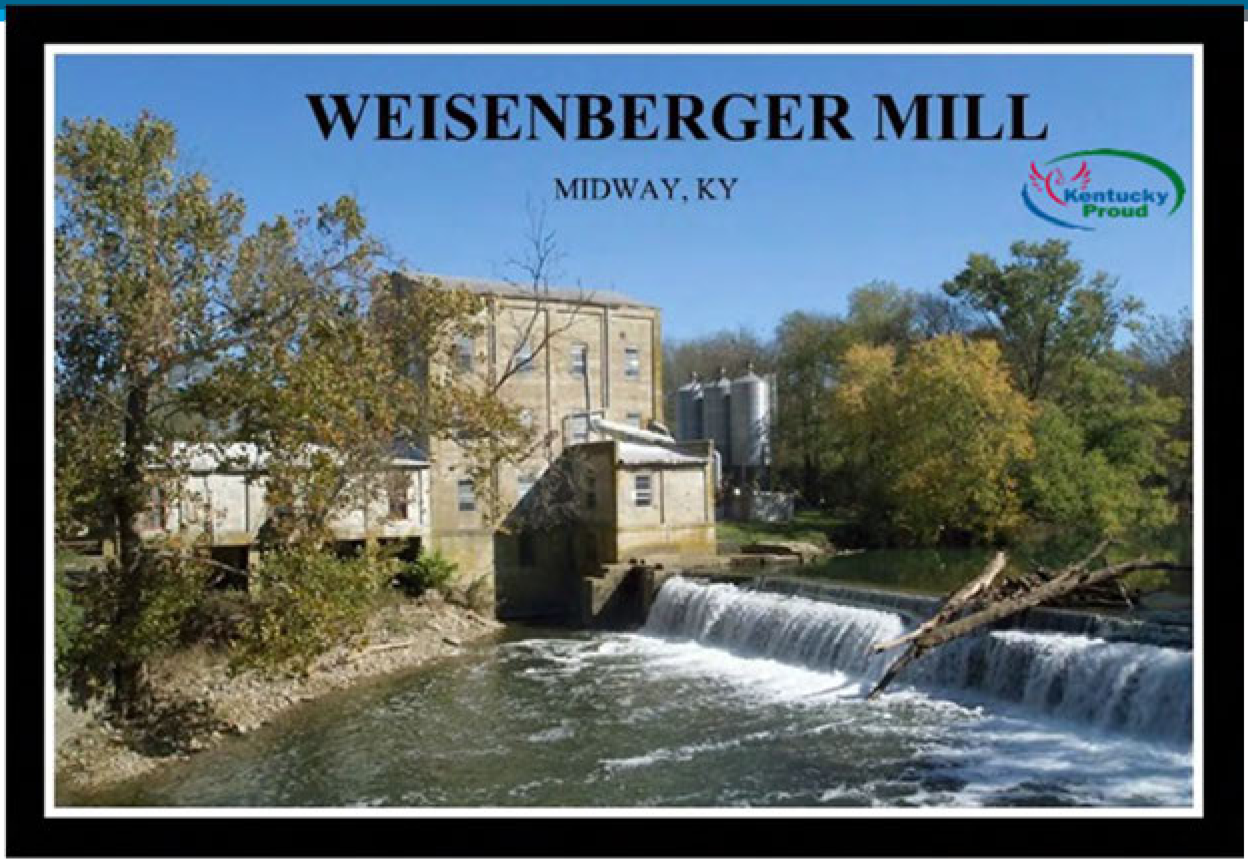

DEMONSTRATION OF VARIABLE SPEED PERMANENT MAGNET GENERATOR AT SMALL, LOW-HEAD HYDRO SITE

David Brown Kinloch
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(502) 589-0975
February 26, 2014

Purpose & Objectives

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

Problem Statement: Small Low-head hydro sites tend to have low overall efficiencies due to fixed blade turbines and fixed speed generators not being able to respond to significant head variations as the stream flow changes. Efficiencies are lower unless the flow and head are at the design point, resulting in many sites not being viable for development.

Impact of Project: Variable-speed Permanent Magnet Generators (PMG) have been suggested as a new option for small, low-head sites that would offer higher efficiencies and simpler installations. This project attempts to determine if PMG technology can meet the goals suggested by advocates, using an apples-to-apples comparison of the old and new technology. This new PMG technology could make development of thousands of small low-head site feasible.

This project aligns with the following DOE Program objectives and priorities: Advance new hydropower systems and/or components for demonstration or deployment

The Small Hydro Dilemma

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- Induction Generators
  - Simple and Lower Cost
  - Higher Speed requiring Speed Increaser
  - Lower Efficiency / Poor Power Factor

- Synchronous Generators
  - High Cost / Higher Efficiency
  - Complex and Expensive Controls / Switchgear
  - Too complicated for many small developers

- Synchronous or Induction:
  - Fixed Speed cannot match the turbine's need for varying speed to be most efficient over the entire range of net heads.

Head affects Optimal Speed

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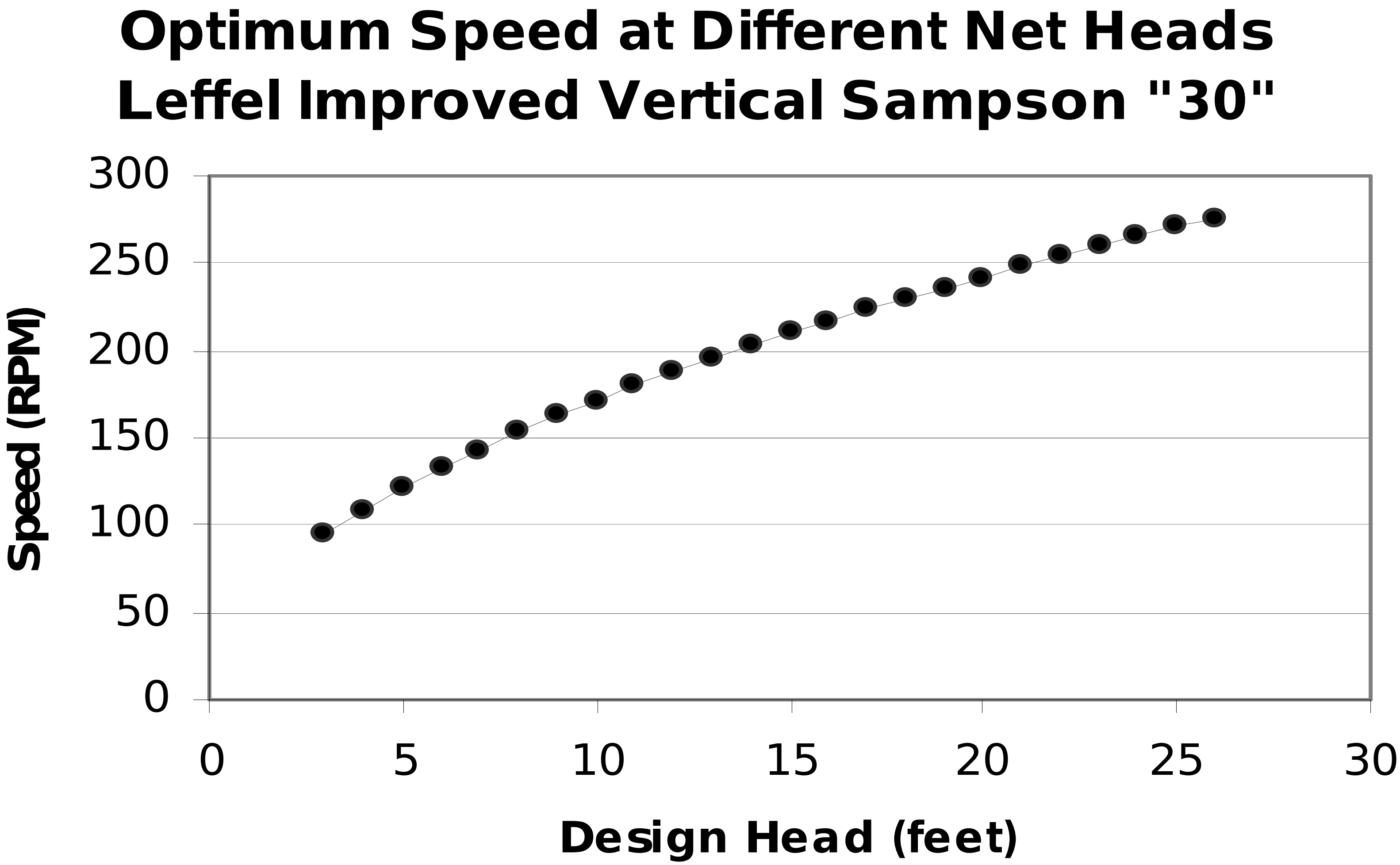

Leffel Sampson “30” Performance Curve

– Source: Leffel Bulletin 38

Fixed Blade Turbine Efficiency

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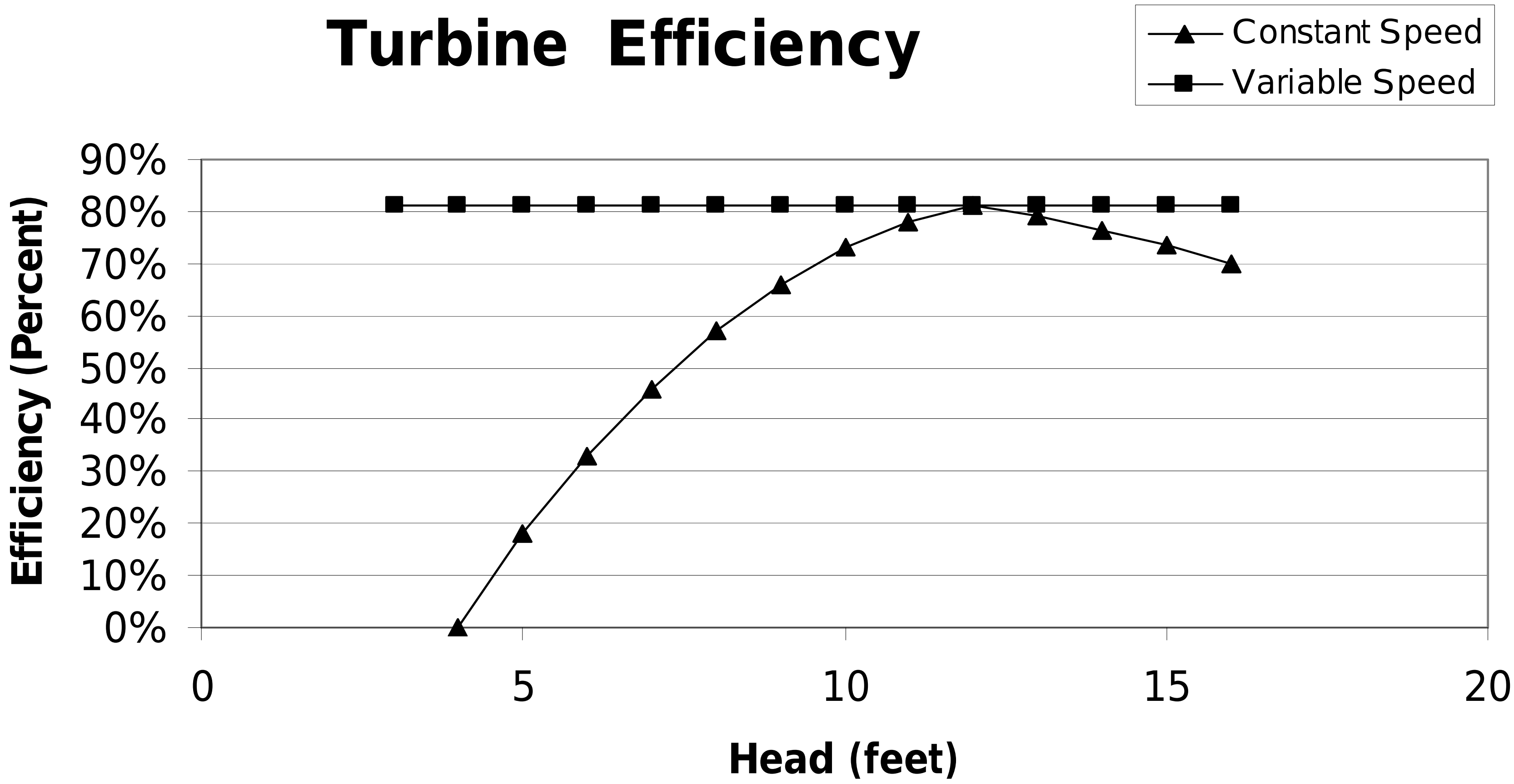

Comparison of Constant Speed and Variable Speed Turbine Efficiencies at variable heads.

Source: Leffel Bulletin 38; and Hydromechanics of Variable Speed Turbines, Cesar Farell, Javiar Arroyave, Nicholas Cruz, and John S Gulliver, St. Anthony Falls Hydraulic Laboratory, August 1983.

Technical Approach

SOLUTION:

Apply PMG technology developed for the Wind Industry

- PMG Developed and used by Wind Industry for constantly changing wind speeds
- Allows generator to run at the varying optimum turbine speeds
- Provides high efficiency over a full range of turbine speeds

DEMONSTRATION PROJECT:

- Weisenberger Mill offers an ideal demonstration site with an existing low-efficiency induction generator system. This allows for an "Apples-to-Apples" comparison by collecting performance data from the existing system, changing to a PM generator, then collecting and comparing data with the new PMG system.

Unique Approach for Hydro:

- Wind Industry controls speed with a turbine power curve programmed into inverter to adjust to rapid changes in wind speed
- Many small hydro sites use old rebuilt turbines that either don't have existing power curves or don't perform to original power curves
- Hydro net head changes very slowly, unlike wind speeds. A PLC can be programmed to test for optimum speeds at regular intervals to ensure maximum output at all times.
- A self-calibrating PMG system will allow less technically sophisticated developers to get a system operational without expensive assistance – lowering development costs

PROJECT PROGRESS (As of December 31, 2013)

- Pre-installation data collection is complete
- Existing generating system has been dismantled
- PM Generator has been built
- Testing complete on PM Generator with Inverter
- Generator mounting frame is built and partially installed
- New controls are being built and nearly complete
- All system components at job site or to be delivered soon
- Solution is being implemented for Mill floor problem

Project Delays

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- Drought delayed collection of Pre-installation data
- Inverter design – problems with inverter built for project -- eventually changed to "off the shelf" ABB variable speed motor drive for inverter
- With inverter change, controls and switchgear had to be redesigned for 480 Volt instead of 240 Volt
- Generator weight – originally planned to strengthen floor, weight concerns caused a redesign to build a generator frame supported from concrete walls
- 100 year-old Mill floor had dropped – turbine thrust bearing frame needed to be supported from above

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	DE-EE0005429
Project Number	
Agreement Number	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Demonstration of Variable Speed Permanent Magnet Generator at Small Low-Head Hydro Site												
Task 1.0: Set-up Data Collection												
Task 2.0: Order Major Components												
Task 3.0: Mounting Frame and Supports												
Task 4.0: New Control System												
Task 5.0: New Generator and Inverter												
Task 6.0: Post-Installation Data Collection												
Task 7.0: Data Analysis												
Task 8.0: Project Management & Reporting												

Comments:

- Project Delays have caused equipment installation to be moved back
- Project may go on beyond original completion date depending on time needed to collect sufficient Post-installation data

Project Budget

Budget History					
FY2012		FY2013		FY2014 (Q1FY14)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$22,029	$15,731	$14,197	$11,522	$9,030	$12,146

As of December 31, 2013 (end of Q1FY14)

- 80.8% of DOE Funding spent ($45,256 of $56,000)
- 70.3% of Cost Sharing provided ($39,399 of $56,078)
- 4 of 5 Cost Share contributors have nearly met obligation (all but $2,869 for all 4 combined)
- Center for Applied Energy Research cost share at end of project ($13,810)
- Project will go over budget – all additional costs will be borne as Cost Share – increasing Cost Share percent of project

Partners, Subcontractors, and Collaborators:

Project Team:

- Shaker Landing Hydro – 30 years in small hydro
- Weisenberger Mill – existing project site
- Potencia Industrial – leader in PMG technology
- Center for Applied Energy Research – Kentucky's energy research facility
- Kentucky Utilities Co. - local utility – independent data collection

Communications and Technology Transfer:

- Initial Paper presented at HydroVision 2012 by David Brown Kinloch
- Final Paper to be prepared by the Center for Applied Energy Research and Shaker Landing Hydro

Next Steps and Future Research

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

FY14/Current research:

- Installation of PMG system to be completed
- Post-Installation Data Collection
- Process Data and Comparison with Pre-Installation Data

Proposed future research:

- Plans to ramp up technology from 50 KW site to 2 new hydro projects that are 2.64 MW each.
- FERC licenses have been filed on these projects and are currently being processed by the FERC.
- Discussions with manufacturer of "Turbinator" turbine/generator – add variable speed PMG component

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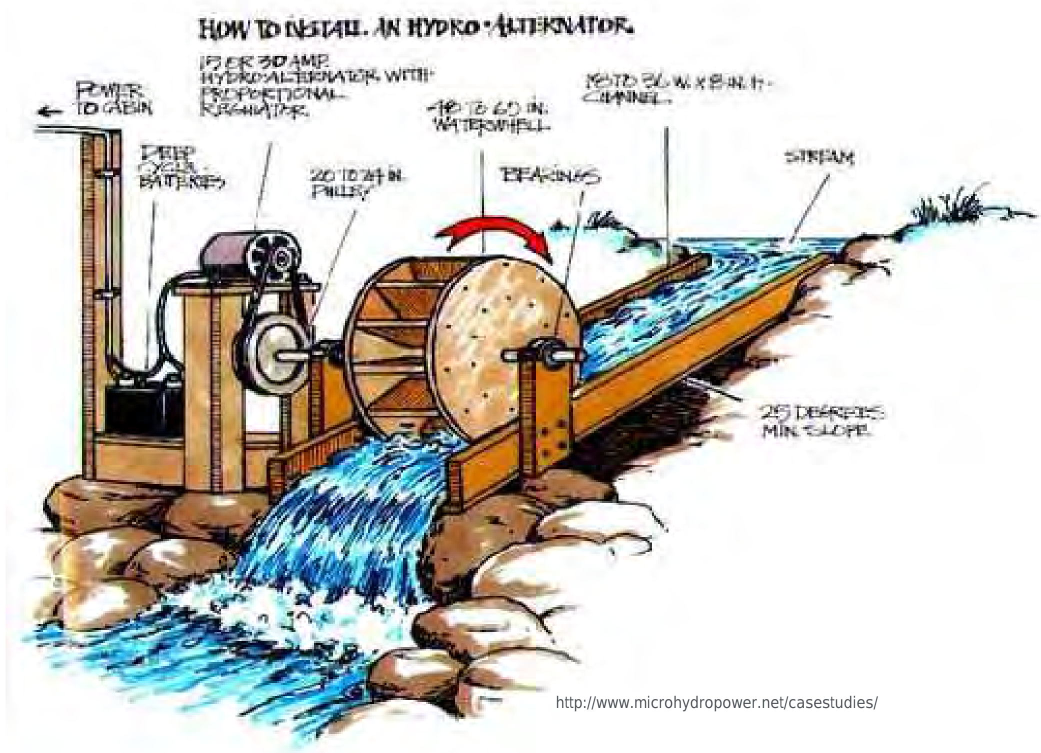


http://www.microhydropower.net/casestudies/

Cost Data Collection and Modeling for Hydropower

Qin Fen (Katherine) Zhang
Patrick O'Connor
Oak Ridge National Laboratory
Zhangq1@ornl.gov 865 675 1646
February 26, 2014

Problem Statement

- Significant effort has been spent to improve the estimation of remaining U.S. hydropower resources, but it is not yet clear how much could be developed with competitive economic returns – Cost data needed

- No recent, comprehensive, public cost model is available for reconnaissance-level evaluation of hydropower opportunities in the U.S. – Data gaps identified

- No tools exist to systematically and quantitatively evaluate cost-reduction opportunities or estimate the impacts of new technology on hydropower lifecycle costs – Modeling capability needed

Purpose & Objective

High-quality data on hydropower costs, and expanded modeling capabilities to predict and analyze those costs are essential for improved strategic planning by many stakeholder groups

DOE Water Power Program: *Validated research priorities and cost reduction and deployment targets*

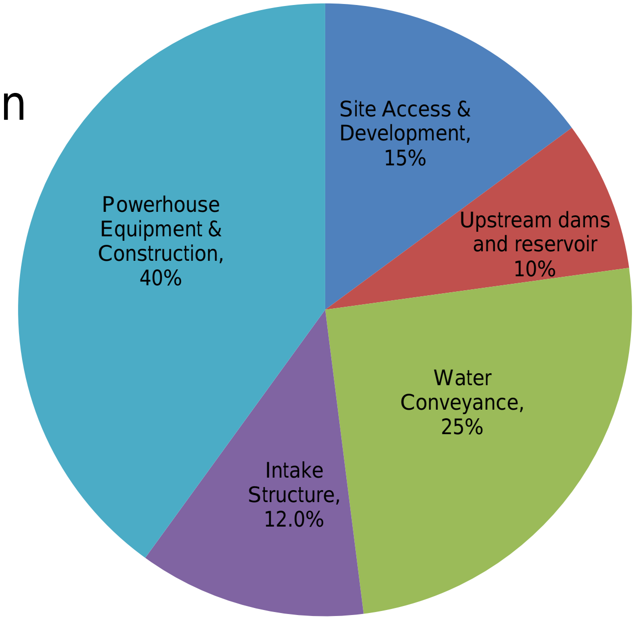
Utilities: *More accurate evaluation of hydropower options in IRPs*

Developer and Finance communities: *Confidence in initial evaluation of economic feasibility of a project*

Primary objectives

To Support DOE R&D agenda via:

1. Improved estimation of the cost of hydropower in the current U.S. regulatory environment
2. Quantification of the cost drivers and barriers to new deployment at different types of sites
3. Evaluation of the cost reduction potential from new technologies and potential R&D pathways



Robust data collection is the foundation for modeling and analyses

Alignment with DOE Program Objectives and Priorities:

- **Advance new hydropower systems and/or components for demonstration or deployment**
  Analyzing capital and lifecycle cost distributions to identify cost drivers, evaluating impacts of new technologies to inform cost reduction potentials

- **Optimize existing hydropower technology, flexibility, and/or operations**
  Evaluating effects of the best practices of plant O&M and technology upgrades to improve plant efficiencies and generations

- **Reduce deployment barriers and environmental impacts of hydropower**
  Analyzing regulatory and environmental mitigation cost trends, evaluating lifecycle impacts of new, sustainable mitigation technologies

Technical Approach Overview:

1. Data Structure and Collection

- Data sharing agreements with facility owners and industry groups
- Framework to collect, manage project costs and design parameters
- Two-pronged data collection effort

2. New Modeling Capabilities

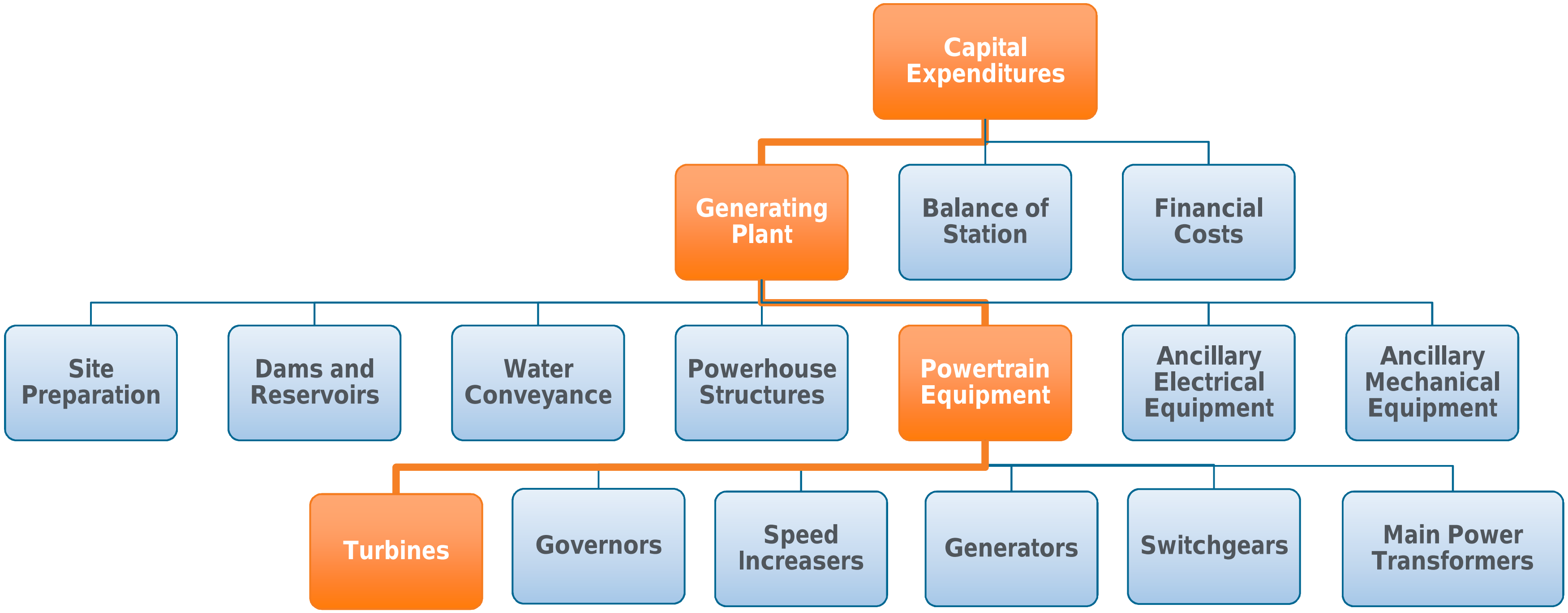
- *Baseline Cost Model*: collection of statistical tools for predicting the current costs of developing hydropower
- *Integrated Model*: characterization of new technology impacts through site-specific project design and operational simulation to account for tradeoffs in technology selection

3. Targeted Analyses

- Validate the developed models
- Extract useful insights to inform R&D decision making

Data Collection

- Formalized "Cost Breakdown Structure" (CBS) and quality controlled database to ensure completeness and consistency of collected data (v.1 complete)

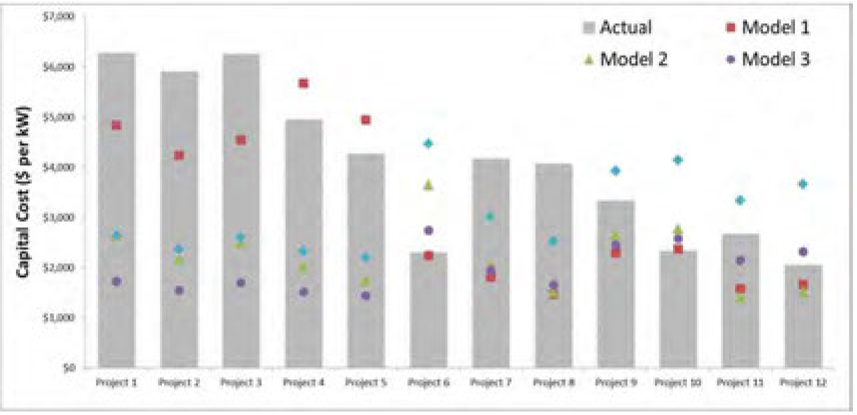


- Development of key partnerships with industry consortia, commercial data aggregators, developers, OEMs, suppliers for project total costs and high priority component costs

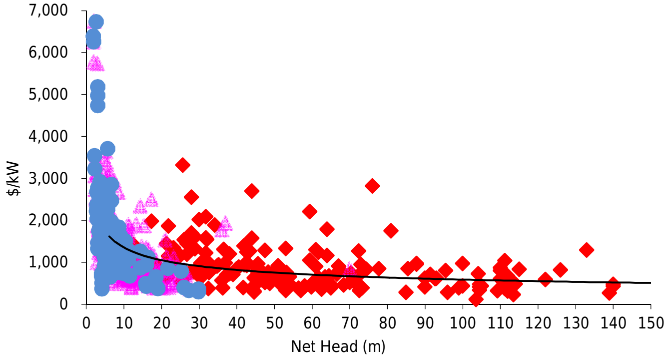
Baseline Cost Model

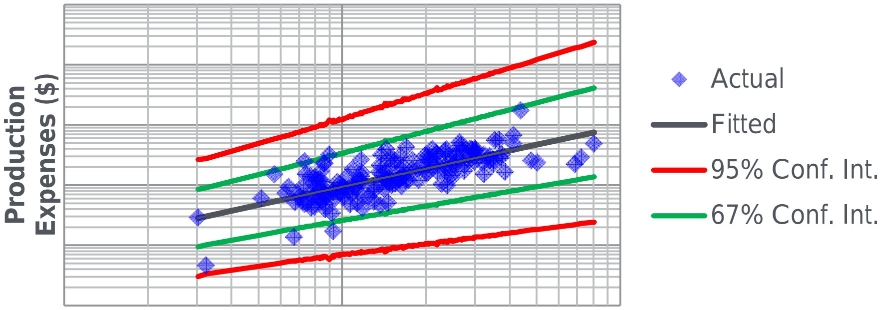
- Leverage 100 years of industry expertise and recently constructed project data to validate, update, or improve existing statistical cost models

  - Caution needed for extrapolating existing models



- Derive new models as necessary through rigorous regression analyses:

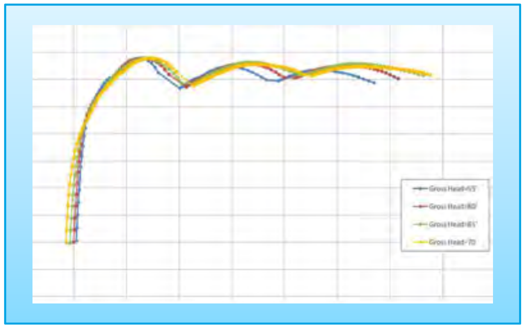




Integrated Model

- Incorporating technology choice, plant layout and design to cost-benefit analysis
- Optimizing plant operations to maximize generation under multiple technical and market constraints
- Combining statistical- and engineering- based cost estimates
- Focusing on small, low-head NPD and ROR sites initially (FY2014)
- Validating against recent project data

Source: HPPi, MESA, and ORNL, *Performance Assessment Manual*, Oak Ridge, Tennessee: Oak Ridge National Laboratory, Revision 2, June 2012



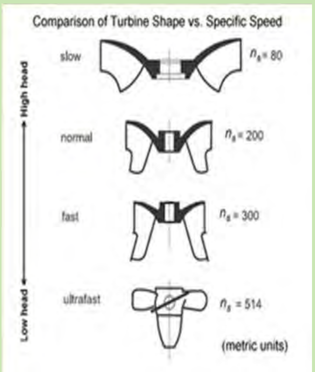
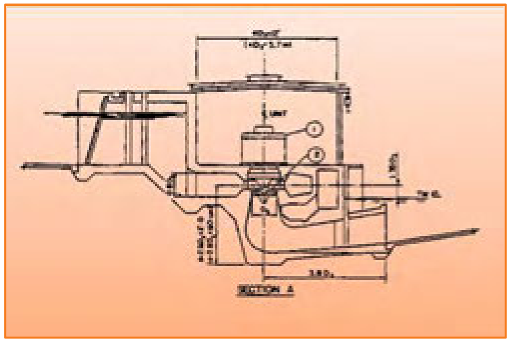


Image adapted from European Community's 'Layman's Guidebook (on how to develop a small hydro site)'



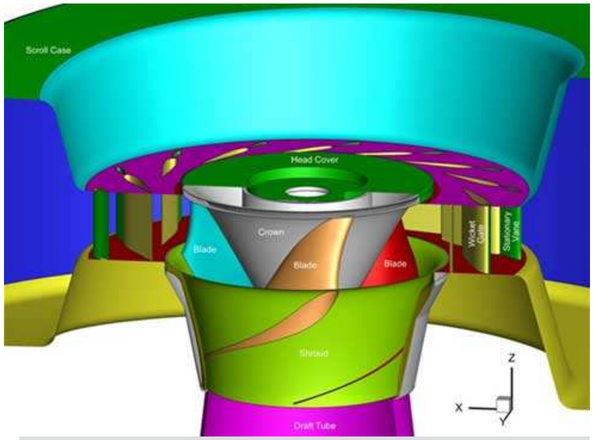
Source: USBR, *Reconnaissance Evaluation of Small Low-Head Hydraulic Installations,* Tudor Engineering Co.• July 1. 1980.

Case Study Analyses

Models will be used to evaluate complicated R&D questions, and the Alden "Fish Friendly Turbine" is a planned case study analysis

Fish Friendliness has high positive and negative cost implications…

- Improved minimum pressures at design points, reduced cavitation (higher setting, reducing excavation costs)
- Slower speed (increased generator cost)
- Increased turbine diameter (increased costs)
- Increased efficiency (increased generation)
- Fish spill unnecessary (increased generation)
- Downstream passage unnecessary (lower costs)



Cutaway View of Distributor and Runner Photo courtesy of Voith Hydro Inc.

…and requires a lifecycle analytical approach to evaluate whole-plant impacts across potential sites and markets

Project Plan & Schedule

Summary			Legend
1.7.1.1 Cost Data Collection and Modeling for Hydropower			Work completed
			Active Task
			Milestones & Deliverables (Original Plan)
Agreement 26552			Milestones & Deliverables (Actual)

Milestone / Deliverable	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Current work and future research												
1. Detailed Work Scope Plan												
2. Refined Version of Cost Breakdown Structure with Definitions and Data Quality Confidence for Major Cost Categories												
3. Prioritized List of Data Providers and Collaborators												
4. Hydropower Maximum Value Model												
5. Hydropower Baseline Cost Model and Integrated Design and Assessment Model (Initial Version)												

Comments:

- This project was initiated later September 2013.
- Maximum Value Model is a component of the Integrated Model, as well it is shared across other projects

Project Budget

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

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$1,500,000	$0	$500,000	$0

- Congressional budget negotiations delayed project funding until the end of Q4 FY 2013 — data collection, model development, and subcontracts have been initiated.

- To date (1st Quarter FY14), $200K (10%) spent on initial efforts.

Partners, Subcontractors, and Collaborators

- Hydro Power Performance Inc. (HPPi) for Maximum Value Model
- Industry Info Resources (IIR) for capital cost data
- ARRA and FOA hydropower projects funded by DOE for gathering detailed breakdown cost data
- Development of partnerships with industry consortia
- Individual utilities, developers and vendors

Communications and Technology Transfer

- Hydropower Maximum Value Model and Integrated Model will be publically available via website (FY14).
- Baseline Cost Estimating Tools will be publically available via published ORNL TM report (FY14)
- Journal papers for dissemination of major findings (FY14- FY15).
  - Baseline Cost Model components
  - Integrated Model optimization framework
  - Select advanced technology case studies

- Technical presentations in HydroVision Conference 2014 - 2015
- Review panel engaged for comment on preliminary results (late FY14)

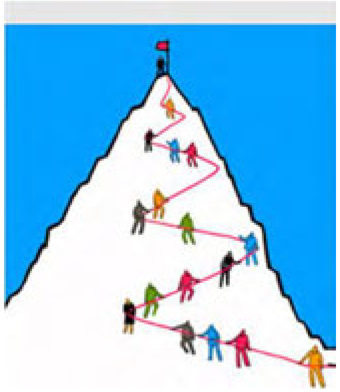
Cost data collection is an on-going, long-term effort with additional model extensions and analyses to be determined with DOE WWPTO for FY 2015

- Follow-on detailed data collection for components with strong cost reduction potential
- Update and validate cost estimating tools with new data inputs
- Refine and expand the Integrated Model to incorporate more detailed engineering process
- Journal articles to validate modeling approach

http://www.docstoc.com/docs/40431236/Hydro-power-plants

Summary

- **Current hydro cost data are fragmented and estimates from**
  - different sources
  - different project development stages
- **ORNL is engaged in collecting, interpreting and analyzing cost data to extract**
  - representative historic trends
  - insights regarding key cost drivers etc.
  - useful cost equations and economic assessment models
- **The purpose of this project is to improve the quality of cost-related information and modeling capability**
  - at the national/regional strategic planning level for policymakers and other industry stakeholders
  - at a site-specific level to evaluate new technology impacts



Backup Slides

Technical Approach – Overview

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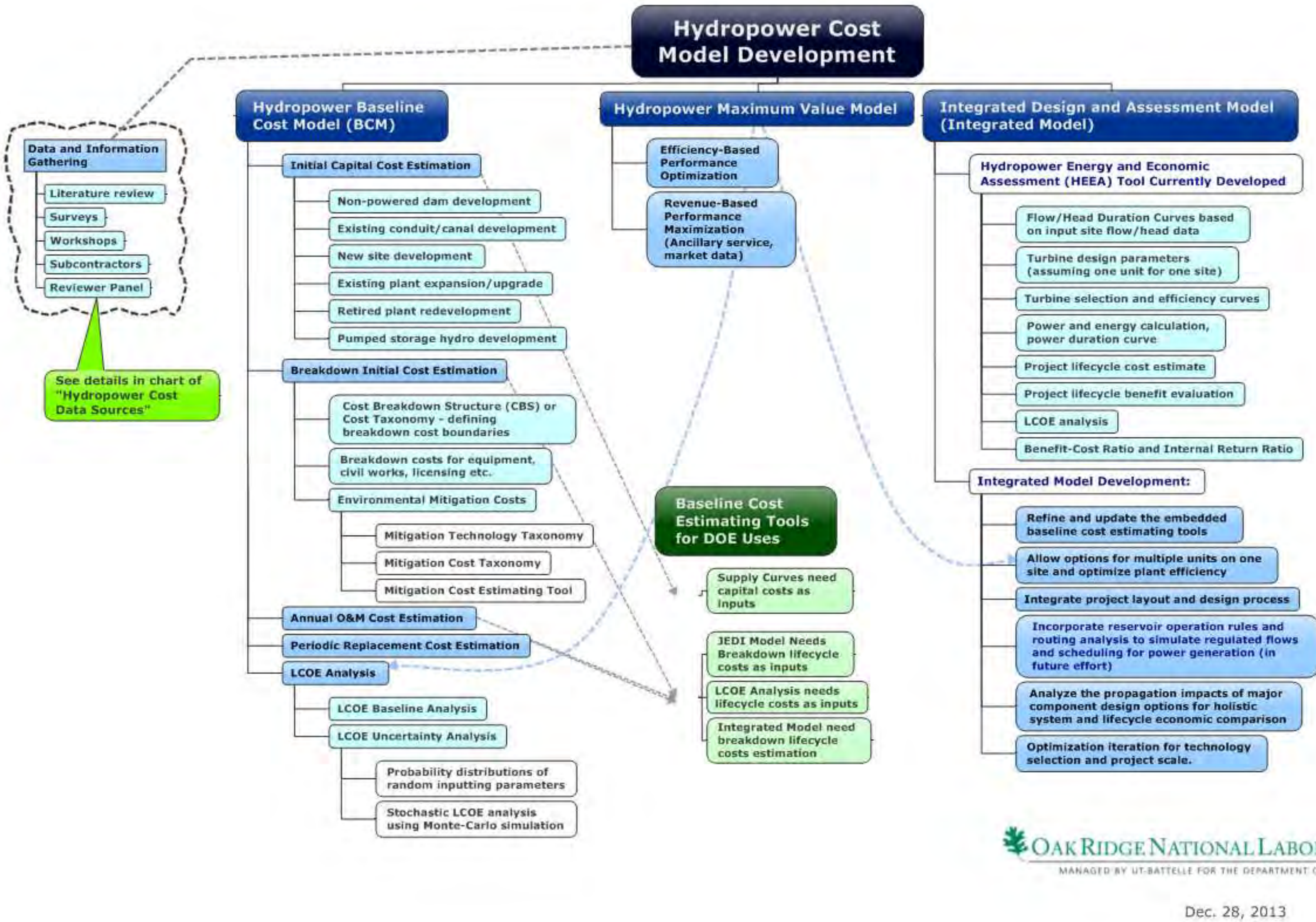

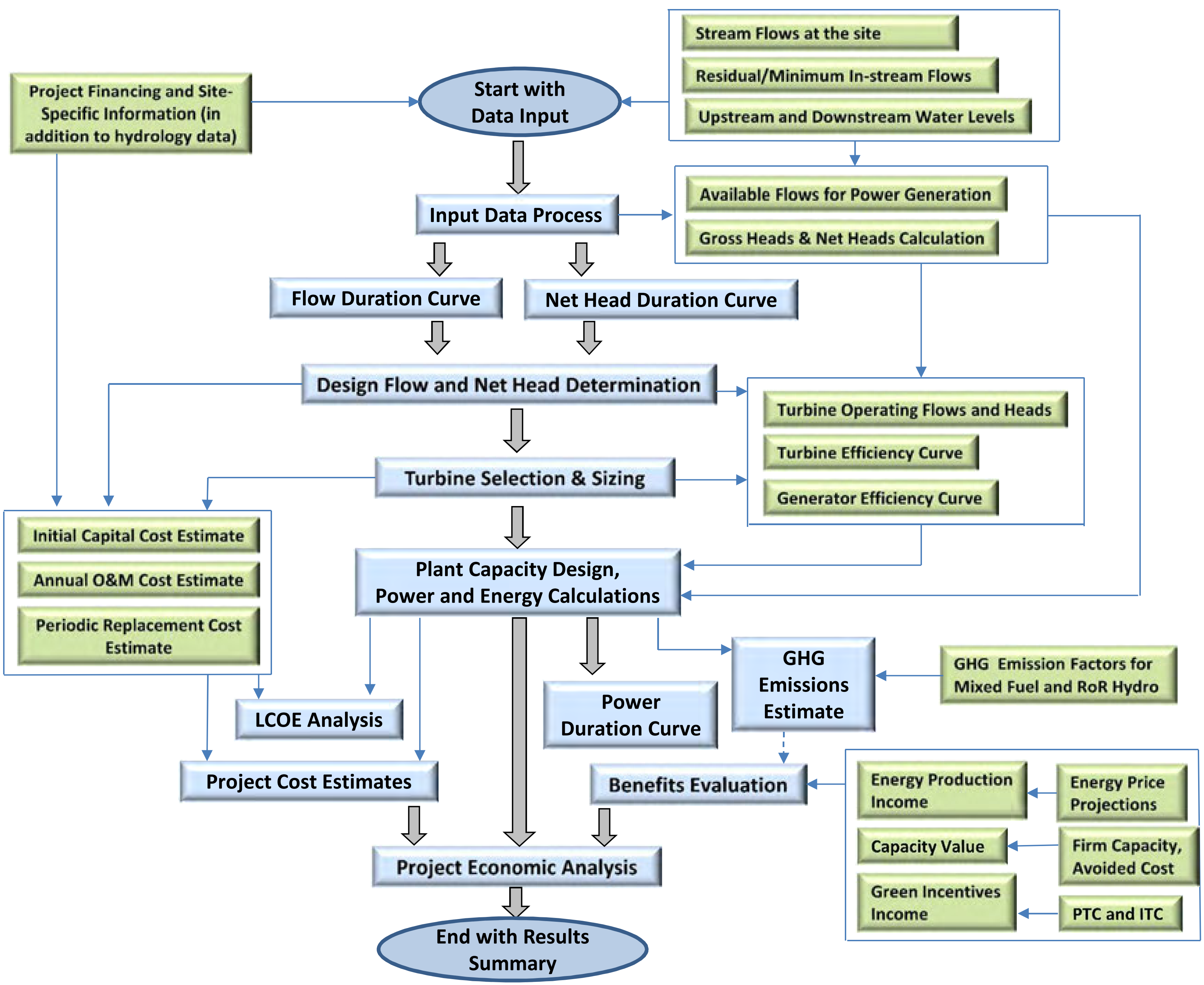
Project Financing and Site-Specific Information (in addition to hydrology data)
Start with Data Input
Stream Flows at the site
Residual/Minimum In-stream Flows
Upstream and Downstream Water Levels
Input Data Process
Available Flows for Power Generation
Gross Heads & Net Heads Calculation
Flow Duration Curve
Net Head Duration Curve
Design Flow and Net Head Determination
Turbine Operating Flows and Heads
Turbine Efficiency Curve
Generator Efficiency Curve
Turbine Selection & Sizing
Initial Capital Cost Estimate
Annual O&M Cost Estimate
Periodic Replacement Cost Estimate
Plant Capacity Design, Power and Energy Calculations
GHG Emissions Estimate
GHG Emission Factors for Mixed Fuel and RoR Hydro
LCOE Analysis
Power Duration Curve
Project Cost Estimates
Benefits Evaluation
Energy Production Income
Energy Price Projections
Capacity Value
Firm Capacity, Avoided Cost
Green Incentives Income
PTC and ITC
Project Economic Analysis
End with Results Summary

Technical Approach - Data Quality Control

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- **Identifying project development stage associated with cost data**
  - Planning? Engineering? Construction? Or Actuals?
- **Understanding cost scope and granularity of the cost**
  - Financing cost included in the total capital?
- **Data availability of design parameters?**
  - Installed capacity, hydraulic head, dam height, length of water conveyance.
- **Applying escalation factors to make cost data from different years comparable** - Is escalation enough to explain large gap in costs between past and present?
- **Checking sample sizes** – to make regression analyses statistically significant
- **Searching for outliers** - Outliers often reflect special site-specific conditions
- **Disaggregating by resource class, size and hydraulic head**

Resource class	Size	Hydraulic head
Non-Powered-Dams (NPD) Existing Conduits New Site Development (NSD) Pump-Storage Hydropower (PSH)	- Small - Medium - Large	Low-head Medium-head High-head

Technical Approach – Data Fitting & Validation

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Regression Analysis - Using the least squares method to determine parameters in the hypothesized relationship models. One example of empirical formula developed by Gordon:

Parameters to be estimated

$$ICC\ (\$ / \text{kW}) = a * S * H^{b} * P^{c}$$

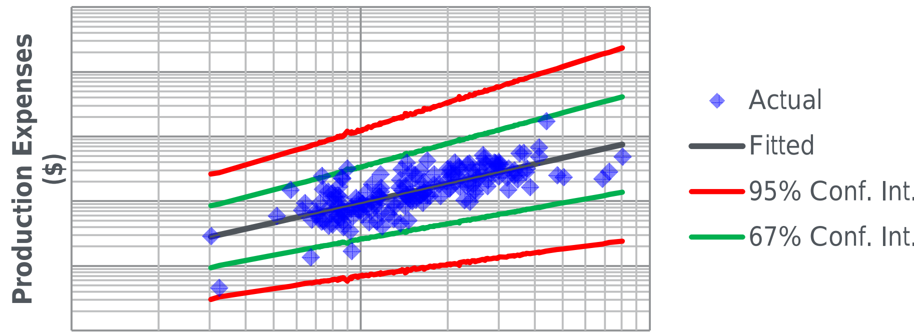
INITIAL CAPITAL COST (Dependent variables)

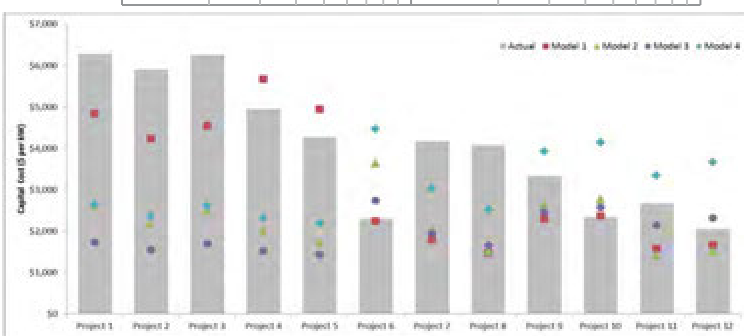
SITE FACTOR, HYDRAULIC HEAD, PLANT CAPACITY (Independent variables)

Regression Model Validation:

(1) Examining the in-sample fit of the estimate equation – providing confidence intervals, R^2 comparison etc.

(2) Out-of-sample validation - Reserving some data points for testing the equation's predictive ability





Source: CleanPower AS, Norway

New Hydropower Innovation Collaborative

Brennan T. Smith

Oak Ridge National Laboratory

smithbt@ornl.gov, (865) 241 5160

February 25, 2014

Purpose & Objectives

Problem Statements:

- Hydropower development opportunities exist, but at what size and cost?
  - DOE resource assessments indicate that new hydropower facilities will be kilowatt and megawatt scale, not gigawatt scale.
  - Traditional economies of scale favor large hydropower; traditional financing mechanisms do not.
- Innovation is more than just technology advancement
  - New hydropower must be innovated from "Concept to Commissioning and Beyond."
  - Technology innovation can and should affect policy evolution.
  - Don't forget the non-energy value streams
- Renewables must compete.
  - Innovative hydropower must be qualified hydropower
  - Clean, green energy incentives are not enough.
  - Natural gas generation parity is a moving target.
  - New hydropower will have lower LCOE and CAPEX than existing hydropower.

Purpose & Objectives

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Objectives:

- Target audience:
  - Primary: Congress, Financiers, Utilities, Developers
  - Secondary: DOE and Lab Program Planning
  - Not guidebooks—idea books!
- Distinguish <u>project innovation</u> from <u>policy innovation</u> with distinct efforts:
  - ***New Pathways to Hydropower Feasibility*** will address concept to commissioning innovative design, technology, installation, and operations.
  - ***A New Agenda for Hydropower Transformation*** will address barriers and incentives for pathways.
  - Innovate, then advocate!
- Characterize risks and rewards of innovation pathways
  - Identify phases of development and innovations in each.
  - Identify factors affecting applicability of innovation pathways.
  - Cost reductions must be qualified; might not be immediately quantified
  - Consider how government and industry can accommodate failure and learning.

Purpose & Objectives

Impacts:

- Decision-makers and energy stakeholders…..
  - believe that innovation can increase and accelerate new hydropower development.
  - move beyond the myth that hydropower development will always be damaging, difficult, and expensive.
- DOE gets a coherent, bona fide assessment of innovation potential and impact to use in program planning.
- Industry forums and participants leverage government research resources to …..
  - discuss, plan, and execute projects that are explicitly and specifically innovative
  - embrace intelligent, first-adopter risk-taking
  - disseminate lessons learned, successful innovations, and updated state-of-the-art → *Innovative Technology Catalog*

Purpose & Objectives

This project aligns with the following DOE Program objectives and priorities:

- Advance new hydropower systems and/or components for demonstration or deployment
- Reduce deployment barriers and environmental impacts of hydropower

Technical Approach

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- New Pathways to Hydropower Feasibility Report will document innovative ideas from industry thought leaders in every aspect of project development:
  - Power System Flexibility Needs, Site Hydrology and Water Management, Turbine Technology, Generator and Power Conversion Technology, Electrical Interconnection, Civil Technology, Asset Ownership and Operation, Project Development Phasing, Project Financing, Environmental Assessment and Mitigation, and Licensing and Regulation
  - Not intended to be a developer's handbook
  - Intended to provoke and focus discussion among developers, vendors, researchers, regulators, and other stakeholders about how to reduce the costs of small hydropower development and energy production.

Technical Approach

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

- An ***Agenda for Small Hydropower Transformation Report*** with targeted recommendations for specific incentive programs and policy evolution to overcome first-adopter barriers:
  - appropriate criteria to classify specific small hydropower development efforts and sites as demonstrative of transformative ideas,
  - appropriate incentives for demonstration of transformative small hydropower designs and technology
  - identification of gaps in state and federal incentive programs for small hydropower development
  - overall funding levels that would be required to incentivize significant deployment of innovative small hydropower technology
  - Not a DOE or ORNL report, published by HRF and industry collaborators.

Technical Approach

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

1. Engage hydropower development experts as New Pathways Report authors (Dec 2013)
2. Confirm structure of project development phases and New Pathways Report outline(Jan 2014), assign authors
3. Convene equipment vendor panel to advise on and initially populate technology catalog (Dec 2013)
   - Voith, Mavel, Alden, Alstom, Andritz participating
   - Other providers encouraged via email and direct contact to submit technologies specs to HRF/CSU for inclusion in database.
   - Technology catalog structure added to ORNL NHAAP data model to ensure cross-reference to existing and future hydropower development sites
4. HRF receives authored sections; editor drafts New Pathways Report.
5. ORNL reviews and publishes New Pathways Report in conjunction with HRF.
6. HRF proposes additional policy authors to participate in Agenda for Hydropower Transformation Report draft.
   - Author meeting details TBD
7. HRF makes authors assignments, edits, obtains review, and publishes Agenda for Hydropower Transformation Report.

Project Plan & Schedule

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

Summary	Legend
WBS Number or Agreement Number	Work completed
Project Number	Active Task
Agreement Number	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Wind Energy Forecasting Methods and Validation for Tall Turbine Resource Assessment								
Q1 Milestone: Subcontract to HRF								
Q2 Milestone: New pathways Report Draft to DOE								
Q3 Milestone: Agenda Report to DOE								
Q4 Milestone: Final Agenda for Hydro Transformation Report published								

- Initiated September 2013
- Completion of all products in FY2014

Project Budget

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

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$315K	0	0	0

- $295K sub-contract to the Hydro Research Foundation
  - Approximately 10% invoiced through Q1 FY2014
- $10K in ORNL expenses through Q1 FY2014
- Additional funding will be required at ORNL in Q3 FY2014 to complete publication of reports and Innovation Portal integration with NHAAP.

Partners, Subcontractors, and Collaborators:

- ORNL has sub-contracted most of the work scope to the Hydro Research Foundation
- Colorado State University engaged by HRF to support Hydro Innovation Portal and Technology Database
- Industry authors and contributing though leaders

Communications and Technology Transfer

- New Pathways to Hydropower Feasibility Report published by ORNL and HRF
- New PathwaysReport available and disseminated at 2014 NHA Annual Meeting
- Small Hydropower Innovation Portal with Technology Database, accessible via DOE Water Power, HRF, and ORNL NHAAP websites
- Agenda for Hydropower Transformation – Policy report published by HRF

Next Steps and Future Research

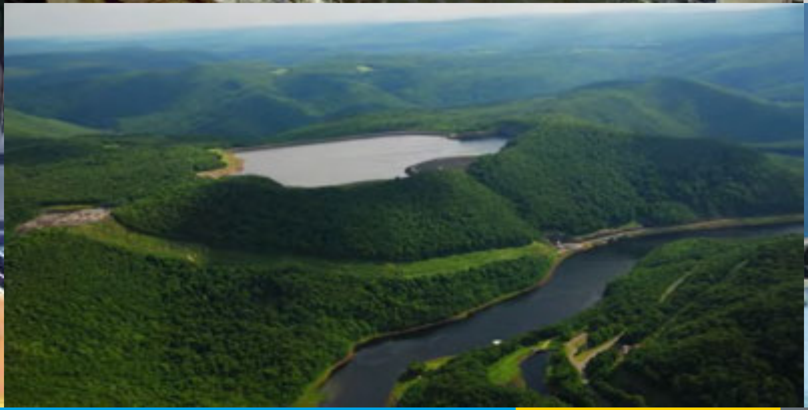
FY14/Current research:

- Author's kickoff workshop in Denver December 2013
  - Convened by HRF Exec Dir. (D. Linke) and Report editor Carl Vansant
- HRF/CSU/ORNL Technology Portal Kickoff meeting December 2013
- Technology vendor panel webinar in December 2013
- Remaining Work
  - HRF to finalize outline with ORNL, finalize author assignments
  - CSU/HRF to finalize technology database structure
  - New Pathways Report draft in March, Final in June
  - Transformation Agenda Report draft in June, final in September 2014

2014 Water Power Program Peer Review

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




Hydropower Market Acceleration and Deployment

Wind and Water Power Technologies Office
Hoyt Battey
2/27/14

Goals: Catalyze the reduction of market barriers to increase the certainty of development outcomes and spur deployment. The MA&D thrust aims to minimize key risks to deployment to reduce the cost and time associated with permitting hydropower projects. This includes undertaking research and developing tools to evaluate and mitigate environmental impacts; providing data to accelerate permitting timeframes and drive down costs; increasing opportunities for workforce development. Better understanding of barriers and effective regulatory and stakeholder engagement will help to preserve and expand the nation's hydropower resources.

Priorities:

- **Environmental Research and New Technology Validation:** new research and the development of technologies to assess and mitigate the environmental impacts of hydropower development, and performance testing of new technologies for environmental compatibility
- Address **regulatory barriers** collaboratively with other federal agencies involved in permitting and licensing of hydropower and identify new opportunities
- **Share information** about the hydropower market and help to **develop a qualified, next-generation workforce** by re-engaging U.S. universities to pursue hydropower R&D

FY 14 Budget: ≈$5 million

DOE Unique Role: As a science-based agency, DOE is uniquely situated to support novel environmental research, develop new tools, and synthesize and distribute credible, unbiased information.

Hydropower Organizational Structure: Market Acceleration and Deployment

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

Market Acceleration and Deployment

- Environmental Research and New Technology Validation
- Regulatory Initiatives
- Information Sharing and Workforce Development

Key Counterparts and Collaborators

- Pacific Northwest National Laboratory
- Oak Ridge National Laboratory

Hydropower Key Objectives

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The 2014 Water Program Peer Review Agenda has sessions that will cover projects and activities in these priority areas:	
Optimize existing hydropower technology, flexibility, and/or operations	• Tuesday, 2/25
Advance new hydropower systems and/or components for demonstration or deployment	• Wednesday, 2/26
Enable next-generation pumped storage technologies to facilitate renewable integration	• Thursday, 2/27
Reduce deployment barriers and environmental impacts of hydropower	• Thursday, 2/27

Hydropower Budget (FY 2012 – FY 2014)

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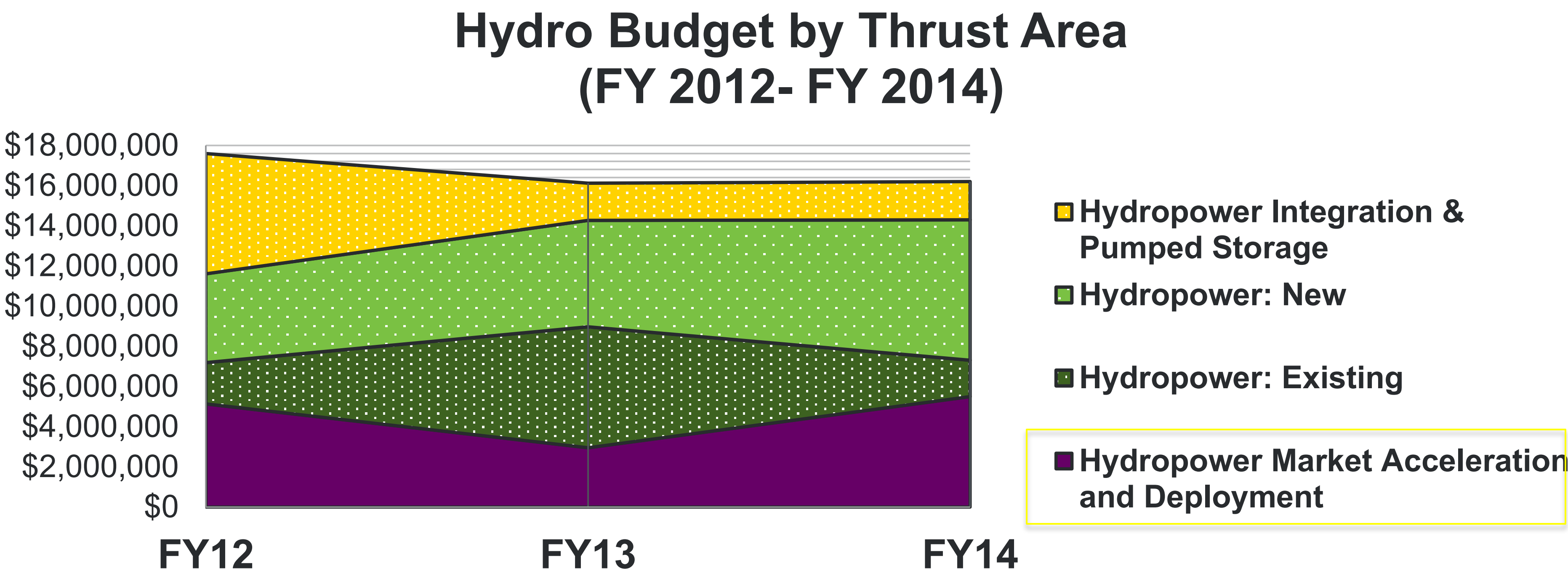

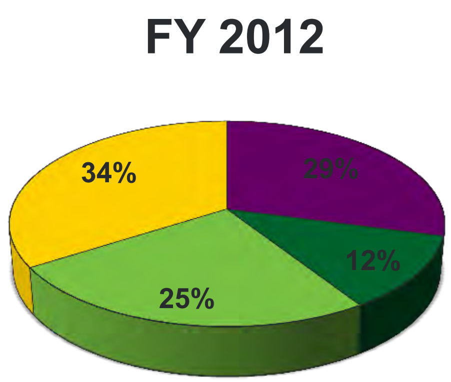

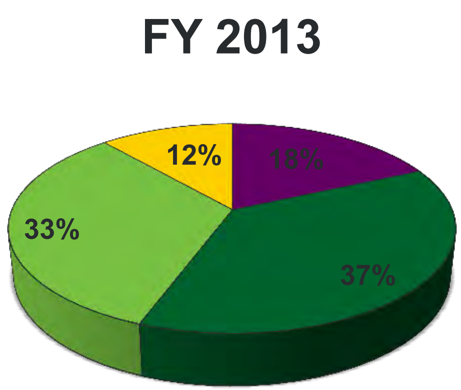

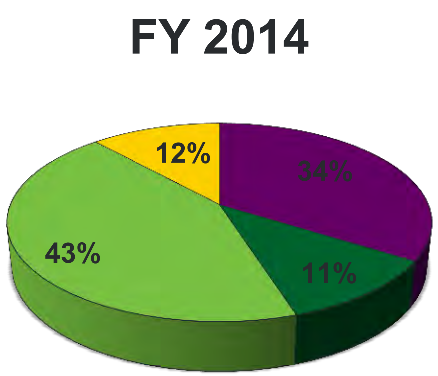

Main Elements of the MA&D Portfolio

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Technical Area	Key Projects/Activities	FY14 Funding

Environmental Research & New Technology Validation	• Water Quality Modeling Improvements
	• Biological Design Criteria for New Hydropower
	• Basin Scale Opportunity Assessment
	• Lab Call (*posters*)
	  • Traits-based criteria for Fish Passage
	  • Instream Flows
	  • GHG Emissions Monitoring
	• Sensor Fish Re-Design
		$3.8M
		($1.9M FY14 AOP funds + $1.9M in prior year carryover)

Information Sharing and Workforce Development	• University Research Awards • Workforce Development Needs Assessment • Hydropower Market Report	$1.4M *($0 FY14 AOP funds + $1.4M in prior year carryover)*

Market Acceleration and Deployment Priorities in FY12 and Beyond

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

Technical Area	Priorities or Changes in Portfolio FY11 vs FY14	Partners	Upcoming milestones
Environmental Research & New Technology Validation	The MA&D program completes lab call activities initiated in FY 2009 and shifts focus on developing advanced environmental modeling and measurement tools, such as the "sensor fish" and biological design criteria for new turbines. Targeted activities advancing water-quality modeling will enhance hydropower systems optimization and operation—increasing energy generation, system flexibility, and environmental benefits. Future work will focus on environmental evaluation of newly developed technologies	• ORNL • PNNL	• Demonstrate new Sensorfish design • Demonstrate improved water quality operational models • Publish multiple papers and peer-reviewed articles on FY10-FY13 research results
Information Sharing and Workforce Development	University Research Awards and Workforce Development Needs Analysis are fully funded in FY 2012 and FY 2013. In FY 2014, DOE will work with other federal agencies to provide input into the development and implementation of administration-wide STEM activities, which will reach more students and address national workforce needs.	• Hydro Research Foundation • Navigant Consulting • ORNL	• Make new university research awards • Complete national workforce needs assessment • Publish first-ever hydro market report

Market Acceleration and Deployment Technology Transfer

- All project leads are <u>highly</u> encouraged or required to submit papers to peer-reviewed publications and make in-person presentations at major industry meetings and conferences

- For new technologies or tools (Sensorfish, advanced water quality models, biological design criteria) industry end-users are involved throughout the development process and multiple operational demonstrations are pursued.

Questions for the Peer Review Panel

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

- Market / Environmental Barriers faced by the hydropower industry are large and, to date, our resources to address these barriers have been relatively small. Where will we get the biggest return for our investments moving forward?

- Licensing processes and regulatory uncertainties are often identified as one of the most significant barriers to the further development of hydropower in the U.S., but DOE does not have much direct influence. What is an appropriate role for DOE to play in helping to catalyze change and address these issues?

Market Acceleration and Deployment Agenda Overview

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

Subject Area	Time	Topic	Presenter
Market Acceleration: Environmental Studies and New Technology Validation	9:30 AM	Sensor Fish	Z. Daniel Deng, Pacific Northwest National Laboratory
	9:50 AM	Turbine aeration design software for mitigating adverse environmental impacts resulting from conventional hydropower turbines	Roger Arndt, Regents of the University of Minnesota
	10:15 AM	Water Quality Modeling Improvements at Columbia and Cumberland River Basins	Boualem Hadjerioua, Oak Ridge National Laboratory
	10:40 AM	BREAK	
	10:55 AM	Biological Design Criteria for New Hydropower Turbines NEW	Gary Johnson, Pacific Northwest National Laboratory
	11:05 AM		Mark Bevelhimer, Oak Ridge National Laboratory

Market Acceleration and Deployment Agenda Overview

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

Subject Area	Time	Topic	Presenter
Market Acceleration: Regulatory Initiatives	11:25 AM	Basin Scale Opportunity Assessment	Simon Geerlofs, Pacific Northwest National Laboratory (Lead)
	11:40 AM		Mark Bevelhimer, Oak Ridge National Laboratory
	12:05 PM	Lunch	
Market Acceleration: Information Sharing and Workforce Development	1:05 PM	Hydropower Fellowship Program	Deborah Linke, Hydro Research Foundation
	1:25 PM	Hydropower Workforce and Education/Training Needs Assessment NEW	Hoyt Battey, DOE
	1:45 PM	Annual Hydropower Market and Trends Report NEW	Rocío Uría-Martínez, Oak Ridge National Laboratory

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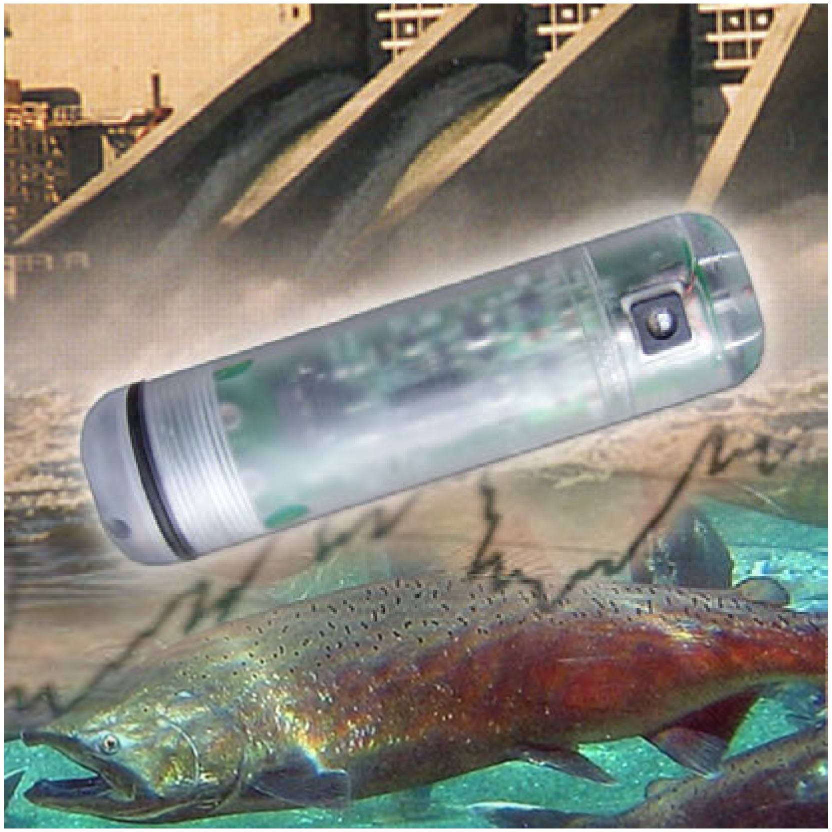

Sensor Fish

Z. Daniel Deng

PNNL

zhiqun.deng@pnnl.gov; 509 3726120

02/27/2014

Purpose & Objectives

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

Problem Statement: For both development of new hydro technologies and operation of existing assets, it is critical to understand the nature of physical conditions to which fish are exposed when they pass through hydro dams and to identify the locations and operations where conditions are severe enough to injure or kill fish.

Impact of Project: The redesigned sensor fish is a tool to accelerate conventional hydro development by shortening schedules and decreasing costs for validation of performance claims to regulators and providing feedback to design engineers.

This project aligns with the following DOE Program objectives and priorities

- Advance new hydropower systems and/or components for demonstration or deployment
- Optimize existing hydropower technology, flexibility, and/or operations
- Enable next generation pumped storage technologies to facilitate renewable integration
- Reduce deployment barriers and environmental impacts of hydropower

Technical Approach

Sensor Fish Redesign:

Identify range of planned applications [ORNL]

Derive design specifications

Review Design specifications

- This step is the feedback loop to those that contributed to application space definition and is also a “one-over” technical review of the approach and detailed specifications for the new Sensor Fish. At this step alternatives for components that are available for sensor construction are identified. The availability of specialized components typically influences final design specifications.

Construct Prototype

- A two step process of benchtop layout and assessment of circuit design, components, and housing alternatives followed by manufacture of electronic and mechanical parts and assembly into a testable prototype.

Prototype testing

- Using benchtop tools, specialized jigs and fixtures, and a water filled test tank and flume

Technical Approach (Application space by ORNL)

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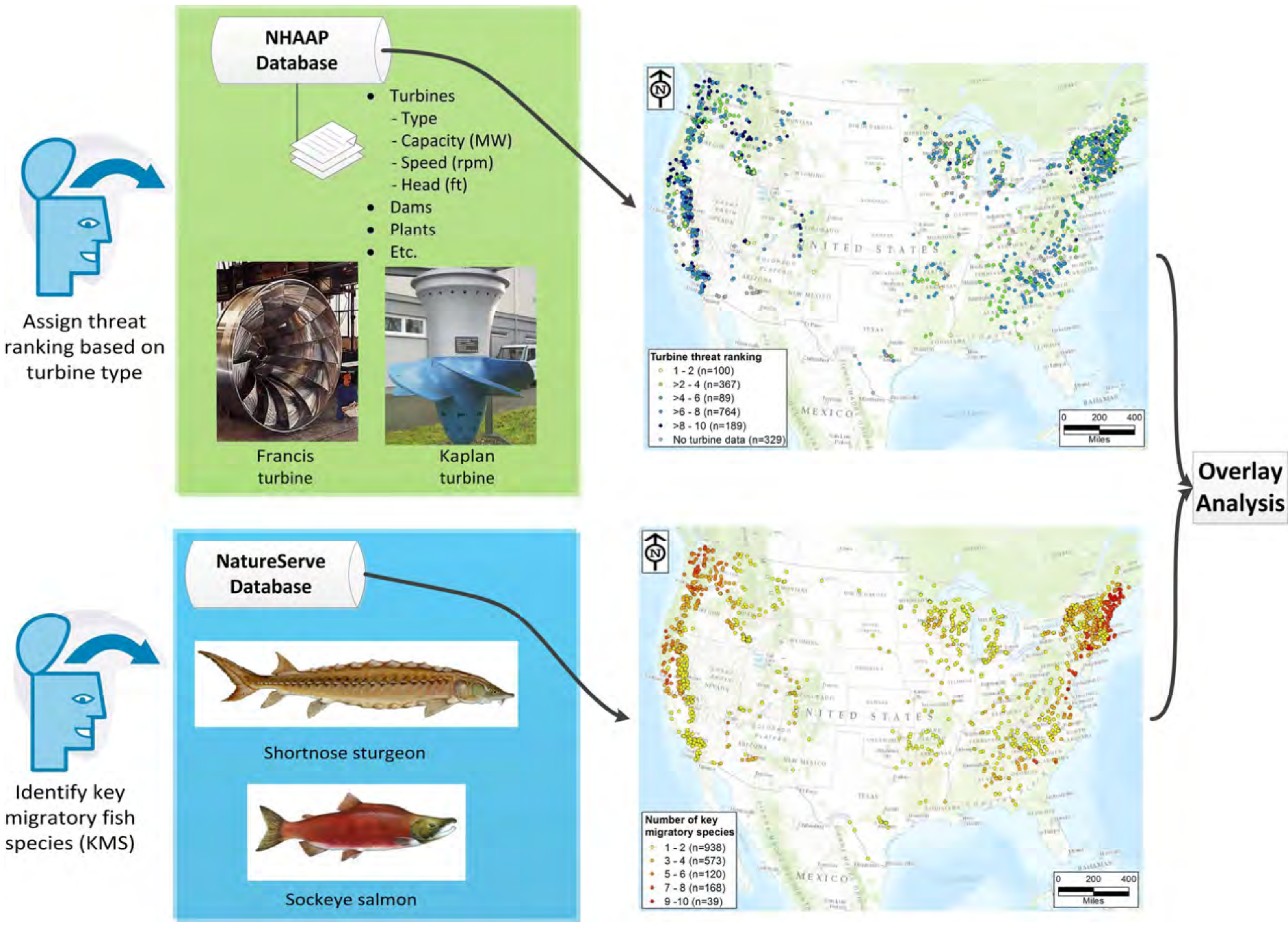
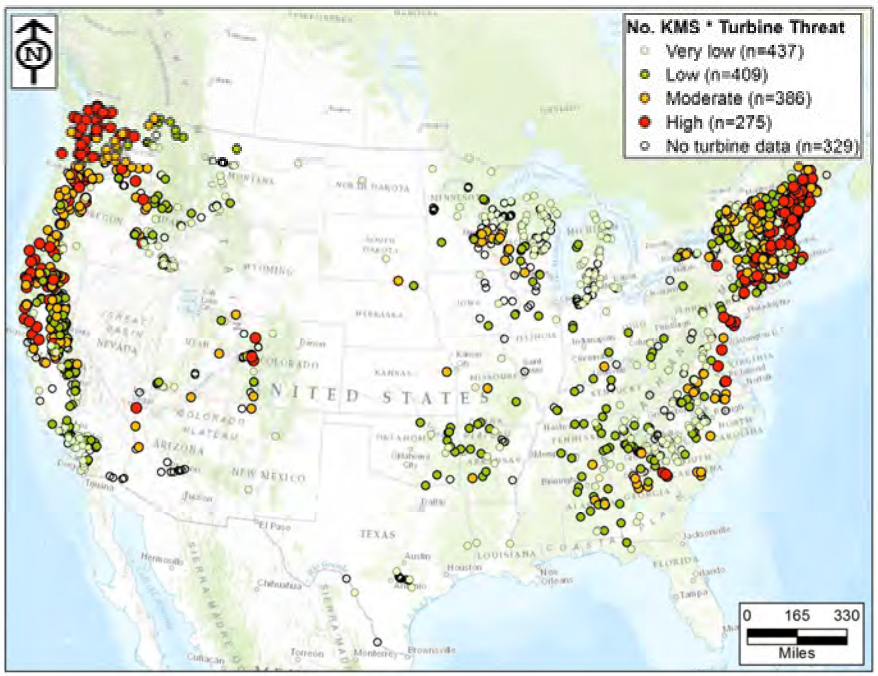


Project results summarized in white paper *Evaluation of Application Space Expansion for the Sensor Fish (ORNL, 2014)*

Key deliverables:

Overlay of geographic distribution of turbine threat and key migratory species presence



Tabular summaries of turbine threat and key migratory species per plant

Plant name	Owner name	Turbine threat (1 to 10)	Total KMS in HUC8	Nameplate capacity (MW)	Years to expiration	State	Plants in top 100 per owner
Grand Coulee	U S Bureau of Reclamation	7.0	5	6,809	ND	WA	12
Chief Joseph	USACE Northwestern Division	7.0	5	2,456	ND	WA	12
Hoover Dam	U S Bureau of Reclamation	7.3	5	2,079	ND	NV	12
Muddy Run	Exelon Power	5.5	8	1,072	1	PA	2
John Day	USACE Northwestern Division	4.0	5	2,160	ND	WA	12
Glen Canyon Dam	U S Bureau of Reclamation	7.0	4	1,312	ND	AZ	12
The Dalles	USACE Northwestern Division	4.0	5	1,820	ND	WA	12
Robert Moses Niagara	New York Power Authority	7.0	2	2,429	44	NY	3
Conowingo	Exelon Power	5.6	8	533	1	MD	2
Wanapum	PUD No 2 of Grant County	4.0	5	1,160	39	WA	2
Rocky Reach	PUD No 1 of Chelan County	3.5	5	1,300	39	WA	2

Plant name	Owner name	Scientific name	Common name
Grand Coulee	U S Bureau of Reclamation	*Acipenser transmontanus*	White Sturgeon
		Oncorhynchus kisutch	Coho Salmon
		Oncorhynchus mykiss	Steelhead
		Oncorhynchus nerka	Sockeye Salmon
		Oncorhynchus tshawytscha	Chinook Salmon
Chief Joseph	USACE Northwestern Division	*Acipenser transmontanus*	White Sturgeon
		Oncorhynchus kisutch	Coho Salmon
		Oncorhynchus mykiss	Steelhead
		Oncorhynchus nerka	Sockeye Salmon
		Oncorhynchus tshawytscha	Chinook Salmon
Hoover Dam	U S Bureau of Reclamation	*Gila cypha*	Humpback Chub
		Gila elegans	Bonytail
		Gila seminuda	Virgin River Chub
		Ptychocheilus lucius	Colorado Pikeminnow
		Xyrauchen texanus	Razorback Sucker
		Acipenser brevirostrum	Shortnose Sturgeon

Accomplishments and Progress (Design)

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Completed design, built functional prototypes, with sensing capabilities at 2 kHz sampling rate

- 3D Accelerations
- 3D Rotation velocity
- Orientation
- Temperature
- Pressure
- Recovery
- Significant cost reduction

Evaluated them in the laboratory and simulated turbine passage environment.

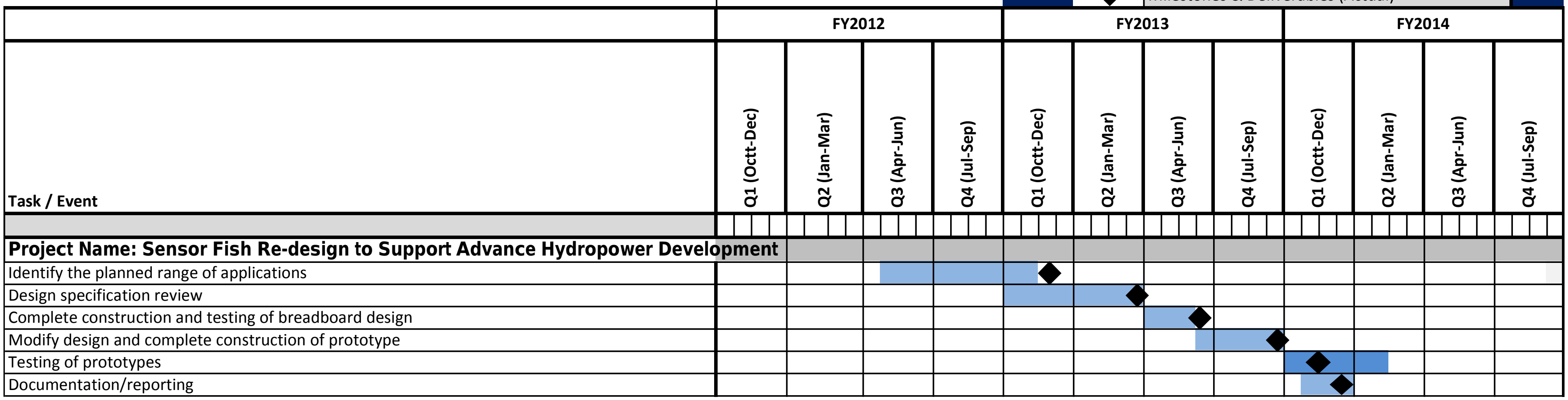
Design features met the original technical targets.

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	4.1.1.4
Project Number	20688
Agreement Number	20084

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)



Comments

- 2011 WWPTO FOA Award—Initiated in FY 12
- Project on schedule and completed—Sensor Fish undergoing testing with Corps of Engineers at Ice Harbor Dam in FY 14

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
125000	0	125000	25000	0	0

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

EPRI (Doug Dixon, Paul Jacobson)
ORNL (Mark Bevelhimer, Glenn Cada)
USACE Turbine Survival Program
Grant County PUD

Communications and Technology Transfer:

Poster/Conference paper in HydroVision 2013.
Reference Design Documentation (PNNL internal)
PNNL Invention report (in progress)
Journal article (in preparation, planned for submission in 2014)
Prepare for technology transfer to commercial vendor after first round of manufacturing.

Next Steps and Future Research

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- ❑ The new Sensor Fish is being planned for various applications
  - Kaplan turbines
  - Francis turbines
  - Spillways
  - Pumping stations
  - Small hydros
  - Gravitation water vortex turbine
  - Irrigation structures
- ❑ In different countries
  - USA
  - Brazil
  - Laos
  - Netherlands
  - Australia
  - China
  - Canada
  - Austria

Turbine aeration design software for mitigating adverse environmental impacts resulting from conventional hydropower turbines

Roger Arndt, Acting PI
arndt001@umn.edu
Fotis Sotiropoulos, co PI
fotis@umn.edu

Purpose & Objectives

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Problem Statement: Develop aeration technology for hydroturbines to minimize environmental impact due to low dissolved oxygen

Objectives:

1. Develop aerating test bed to verify computational codes – available to all
2. Develop aeration computation model to solve important aspects of bubbly flow
   – verify with test bed measurements – available to all
3. Run test bed on Alstom aerating blade design – Proprietary
4. Improve performance of Alstom aerating blade design with computational model

Impact of Project: The project will provide the necessary technology base for design of cost-effective aerating turbines. The techniques developed during this portion of the project will be directly applicable to numerous aerating turbine designs

Technical Approach

Physical Model Experiments: test bed to verify software

Wake Studies

Bubble size and distribution determined using shadow image velocimetry

Determine impact of flow field on entrainment

Mass/Oxygen Transfer

Determination of mass transfer relation by comparison of models to test bed results

Computational simulation of test bed results

Two phase LES developed and validated with proposed experiments.

Once validated for the standard NACA0015 blade geometry, the code will be implemented to guide design of advanced aerating turbine runner.

Industrial Collaboration:

Alstom Hydro Global Technology Center, Montreal, Canada

Our Team

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

- Roger Arndt, Acting PI
- John Gulliver, PI (on medical leave)
- Fotis Sotiropoulos, co PI
- Jerry Hong, ME Professor, Unpaid consultant
- Can Kang, Visiting Professor, Jiangsu University
- Chris Ellis, Senior Research Associate
- Garrett Monson, Graduate Student (Now at Houston Engineering)
- Ashish Karn (Graduate Student)

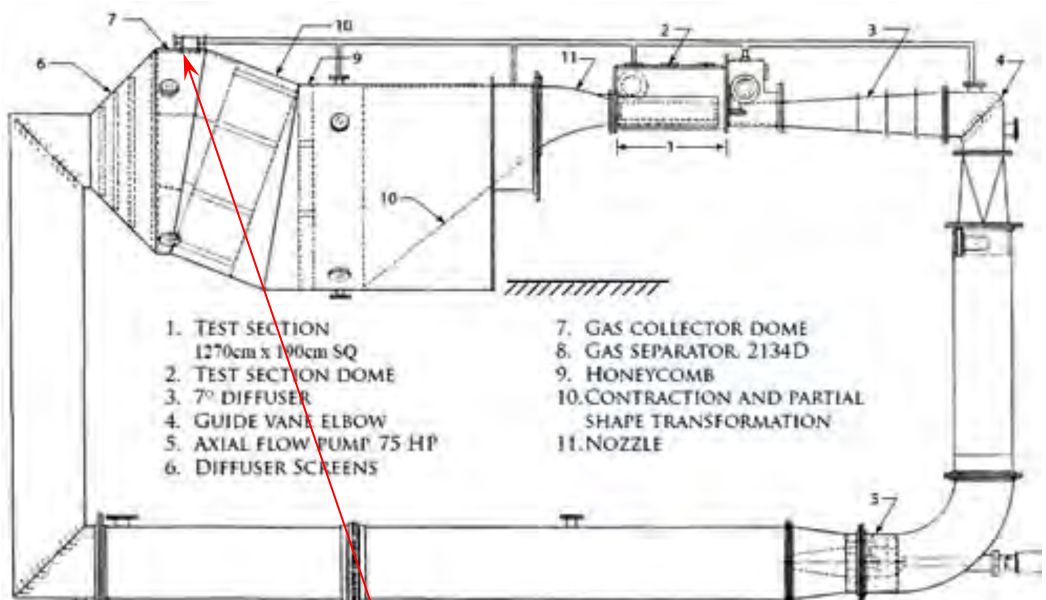
Previous Contributions From

- Seung Jae Lee (Research Associate, Now at Seoul University)
- Ellison Kawakami (Research Fellow, Now at 3M)

Objectives

- Determine quantity of air entrained
- Bubble size of entrained air at given location after entrainment
- Oxygen transfer across bubbles
  - Bubble size, turbulence, liquid film coefficient
- Development of SIV technique

SAFL High-speed Water Tunnel



Gas collector dome upstream of test section allows for extended run time with no visible effects on operating conditions

Advantages:

- Special degassing system allows for continuous operation with ventilation
- Flexibility allows for quick transition between models and experiments
- Ability to generate periodic unsteady flows to replicate sea states

Amply equipped with:

TRPIV, PIV, LDA/PDA, High-speed shadowgraph, high-speed cameras, force balance and pressure sensors, DO sensors, high-speed digital photography

Disadvantages:

- Small size introduces blockage effects

Ventilated Foil

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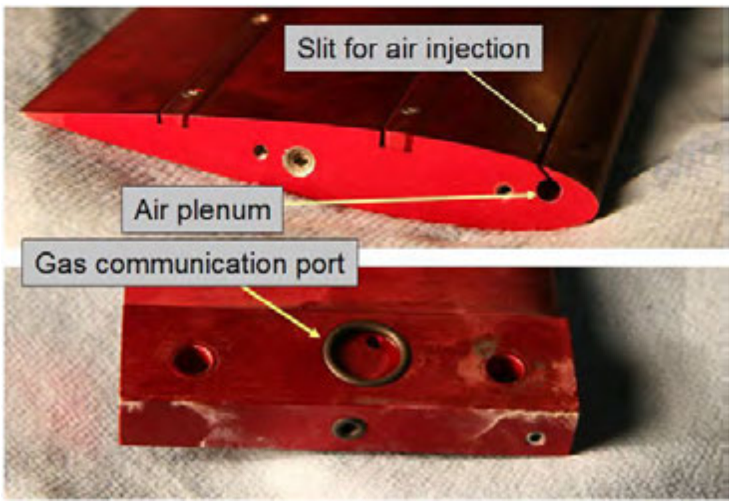
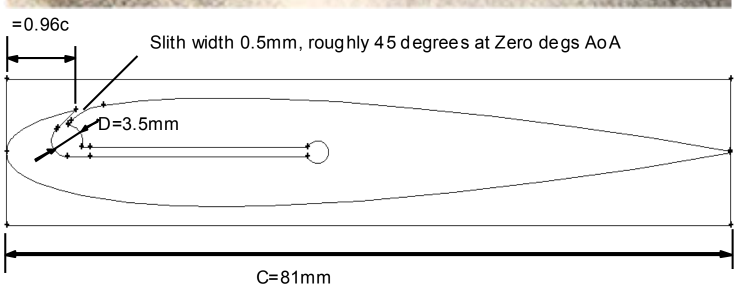
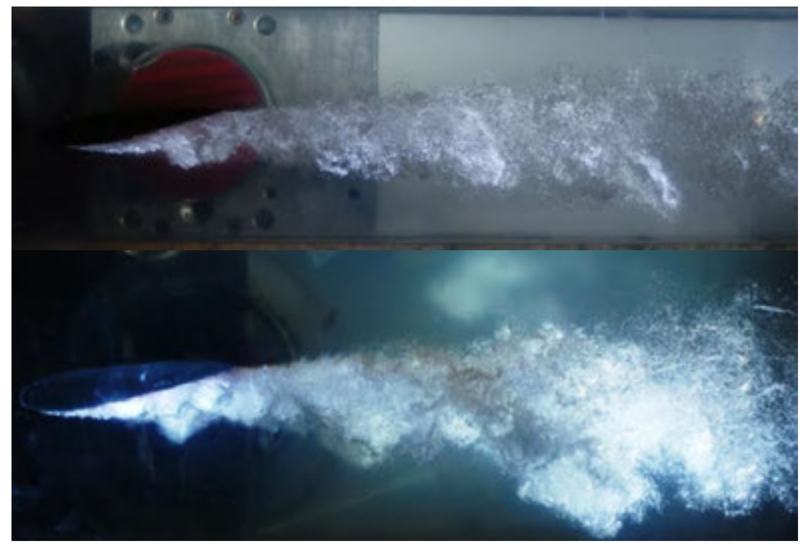
NACA 0015 Modified for air injection



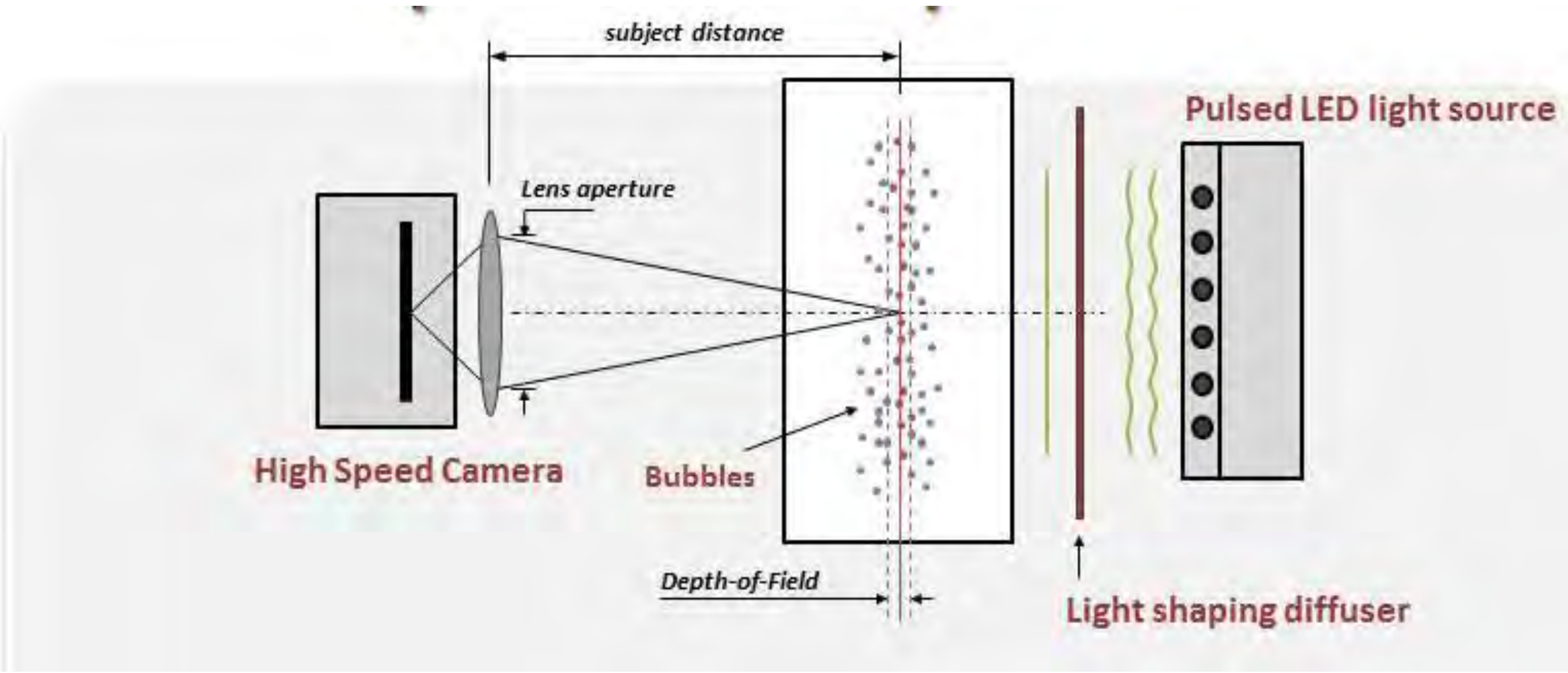


Ventilation Flow Increasing



Ref: Kjeldsen and Arndt
The 12th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery
ISROMAC12-2008-20115
Honolulu, Hawaii, February 17-22, 2008

Optical Setup for SIV



- **High Speed Camera**: Photron APX RS
- **Light Source**: Pulsed LED array *(capable of 10 kHz with a 5 microsecond pulse width)*
- **Light shaping diffuser** is placed to ensure uniform back-lighting in the images.

Recognition of individual bubbles

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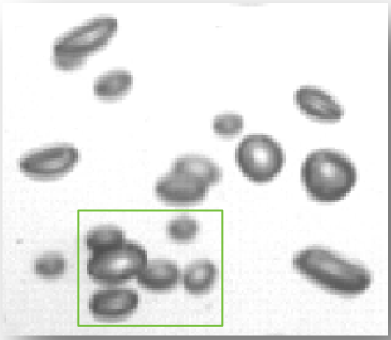
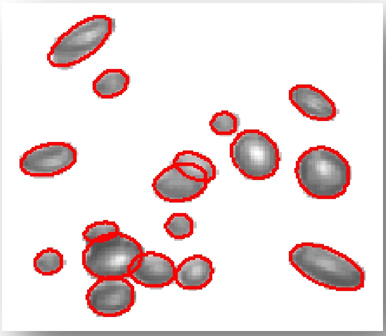
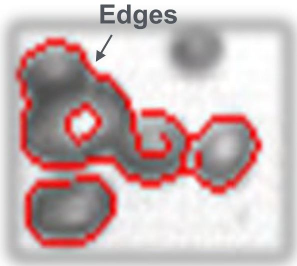


Image Source

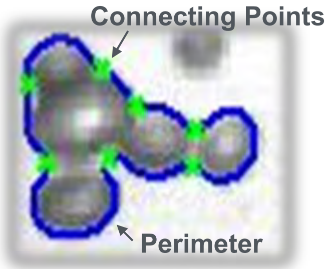


Detected Bubbles



Subtraction of reference image → **Edge Detection** *With Canny Algorithm* → **Finding Perimeter**

Reference : Canny (1986)

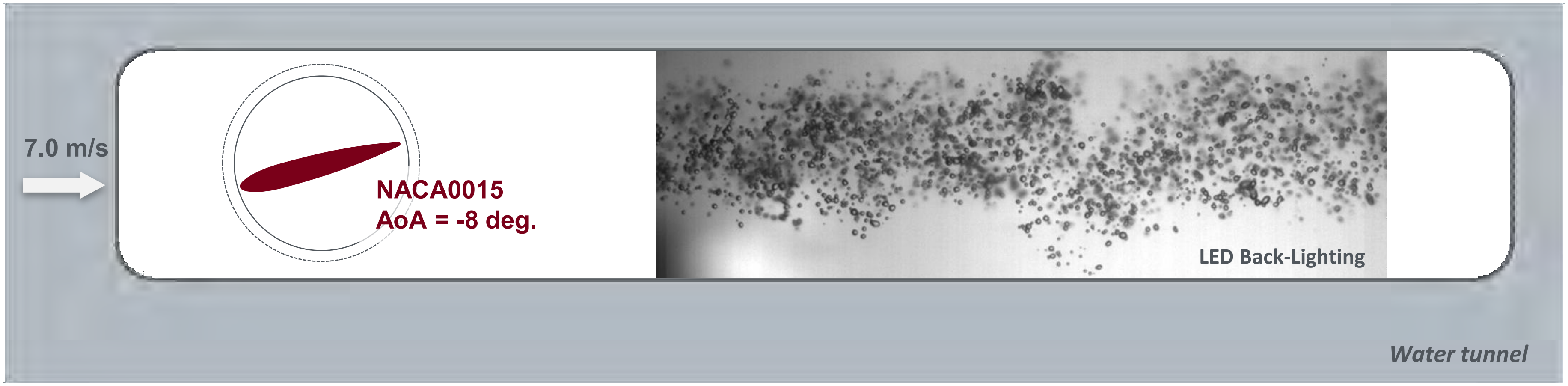


Calculation of curvature → **Curvature peaks** → **connecting points**

Reference : Pla (1996), Shen et al (2000), Berg et al (2002), Honkanen (2003, 2005)

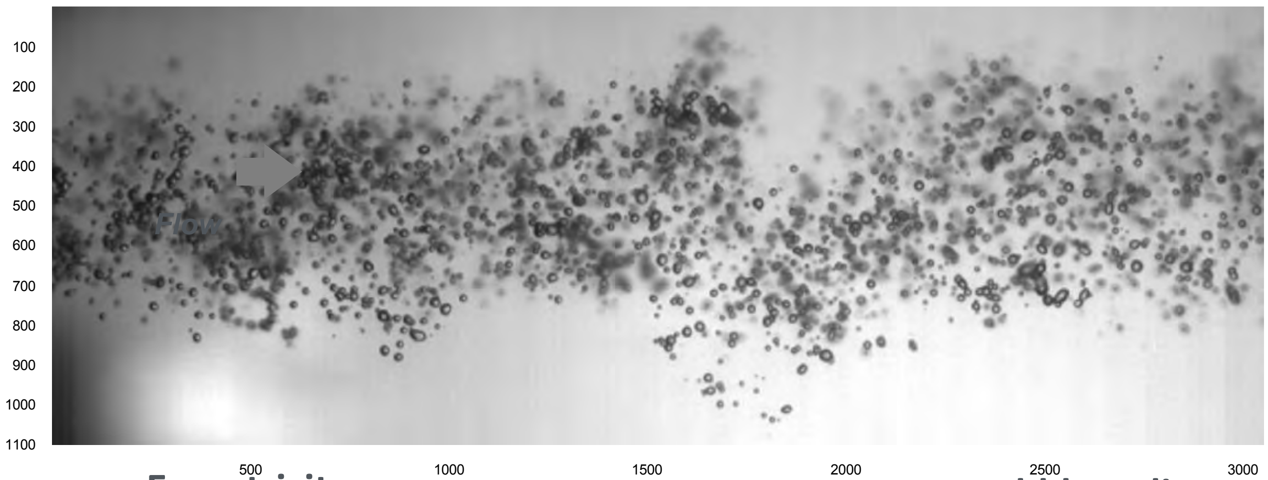
Select two points → **Fitting ellipses** → **Recognition of a bubble**

Preliminary tunnel results



- **High Speed Camera** : Photron APX RS *(capable of 3000 frames per second at full resolution)*
- **Light Source** : Pulsed LED array *(capable of 10 kHz with a 5 microsecond pulse width)*
- **Light shaping diffuser** is placed to ensure uniform back-lighting in the images.

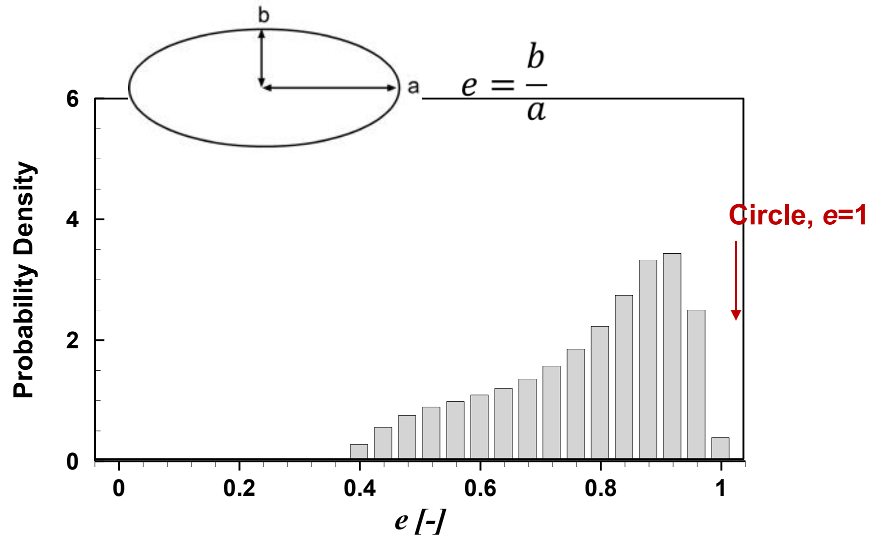
Initial Bubble Shape and Size



Bubble shadow image

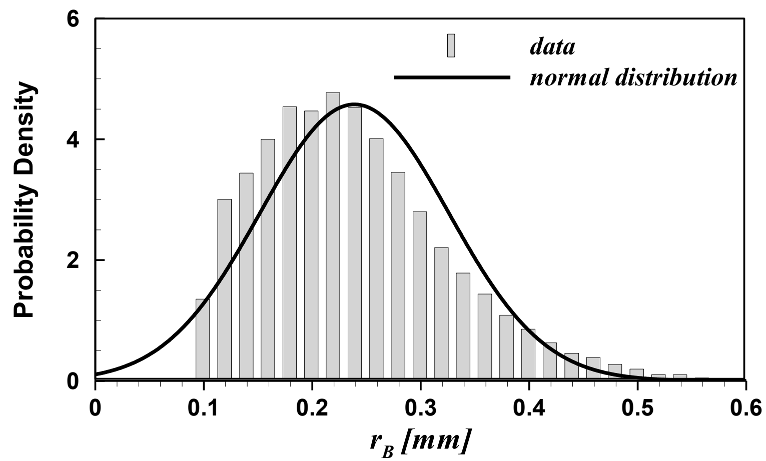
Eccentricity, e

$$e = \frac{b}{a}$$



Bubble radius, r_B

$$r_B = \sqrt{ab}$$



New Analysis

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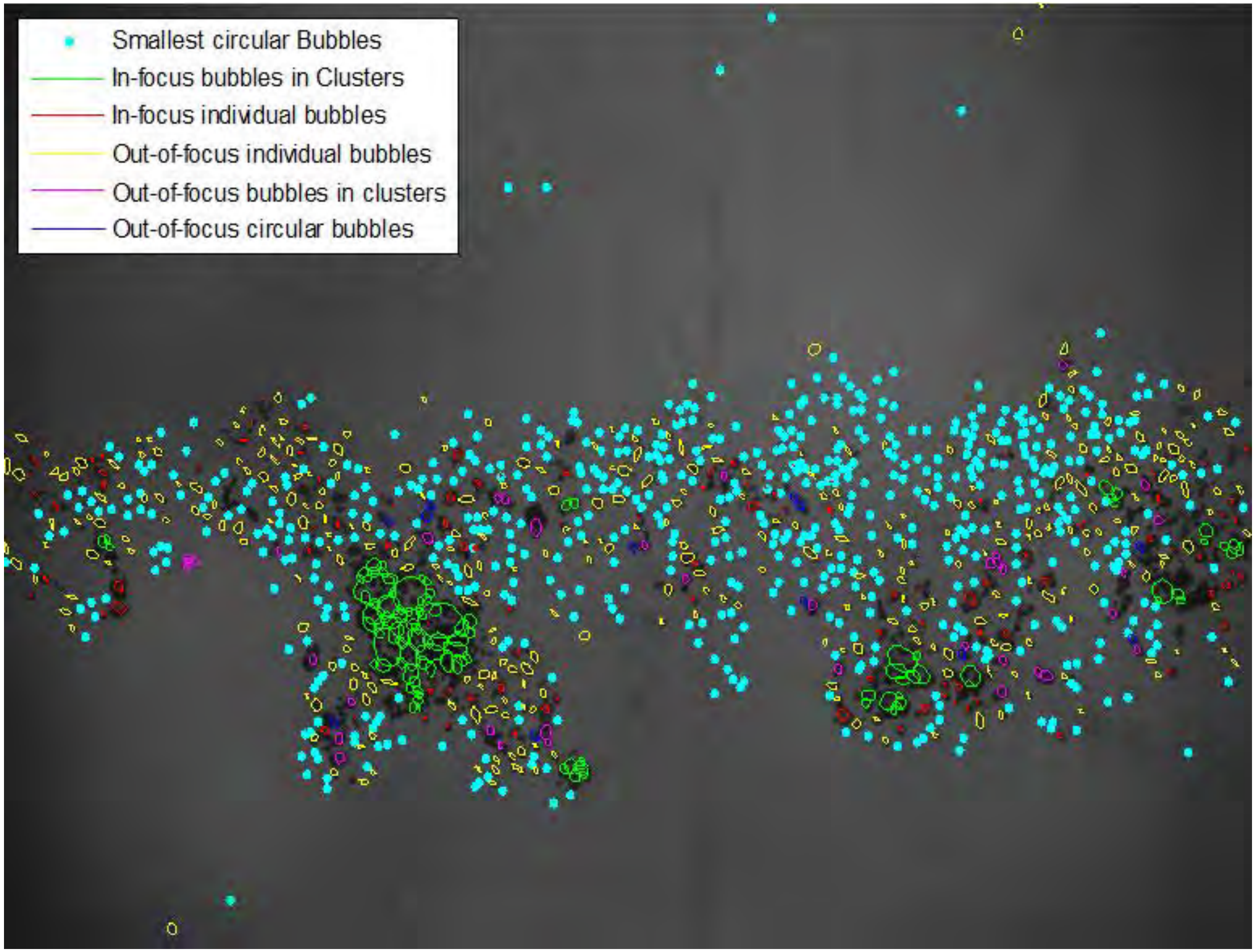
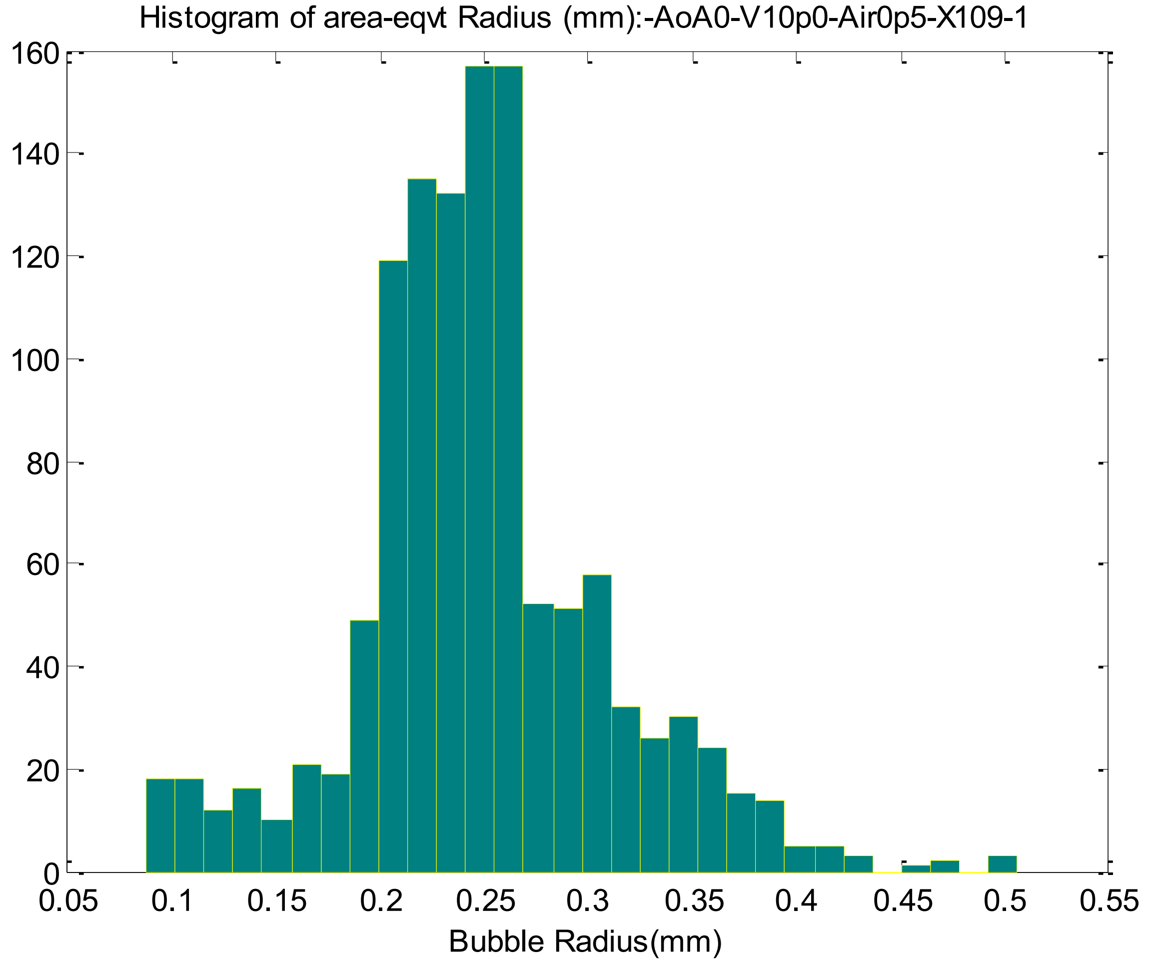
Our dramatically improved analysis allowed us to fully account for all bubbles in the wake, significantly Improving our bubble size data base



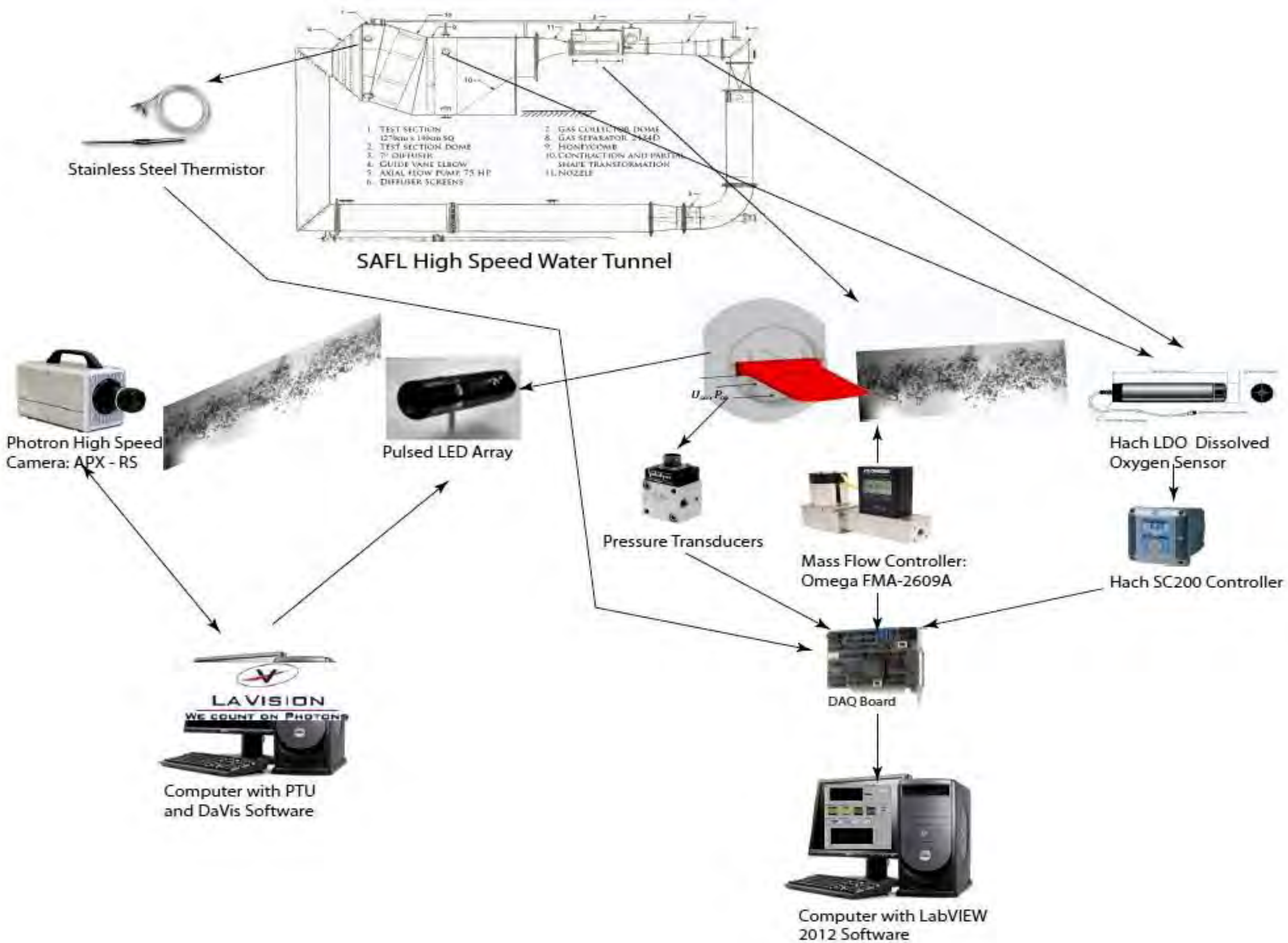
Preliminary calculations based on the current analysis gave a predicted volume flow rate of 0.47 – 0.49 LPM which compares favorably with the 0.5 LPM injected.

Bubble Size Distribution

Compares favorably with previous results



Mass Transfer: Experimental Setup



Residence Time

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WT t_r scaling

- Test section – beginning of draft tube
  - t_r ~ 0.12 s
- Diffuser, right, bottom, and left legs – draft tube
  - t_r ~ 21.07 s
- Settling Chamber – tail-water
  - t_r ~ 29.21 s
- Total t_r ~ 50.4 s

Field t_r scaling

- Typical draft tube: t_r ~ 7-9 s

  Sheppard, A. R., & Miller, D. E. (1982)
- Typical tail-water depth: 7 m, Rise velocity: 0.25 m/s
  - t_r ~ 28 s
- Total t_r ~ 40 s

Field model Scales nicely with tunnel t_r of ~50 s

Comparison with Experiments

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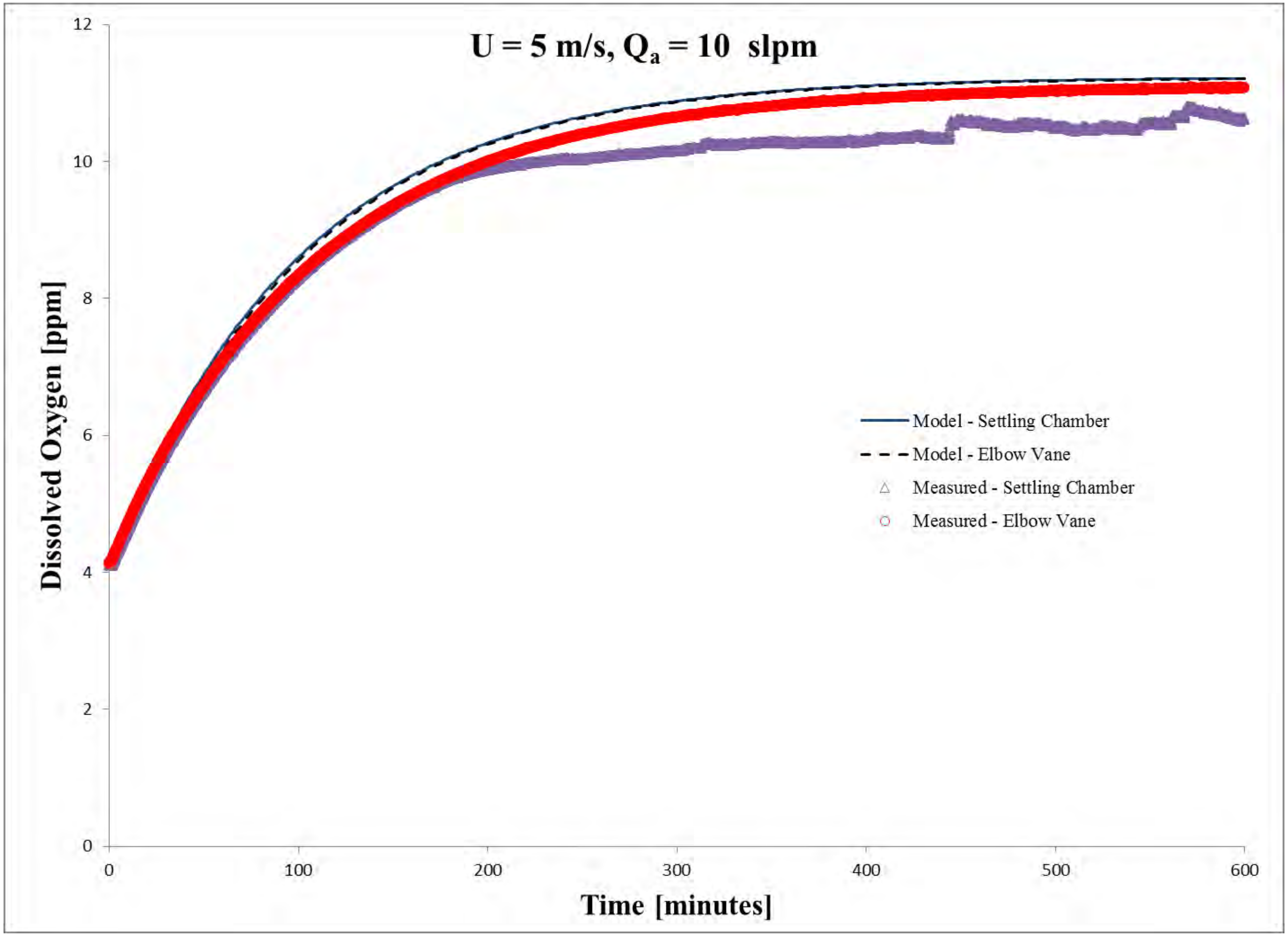
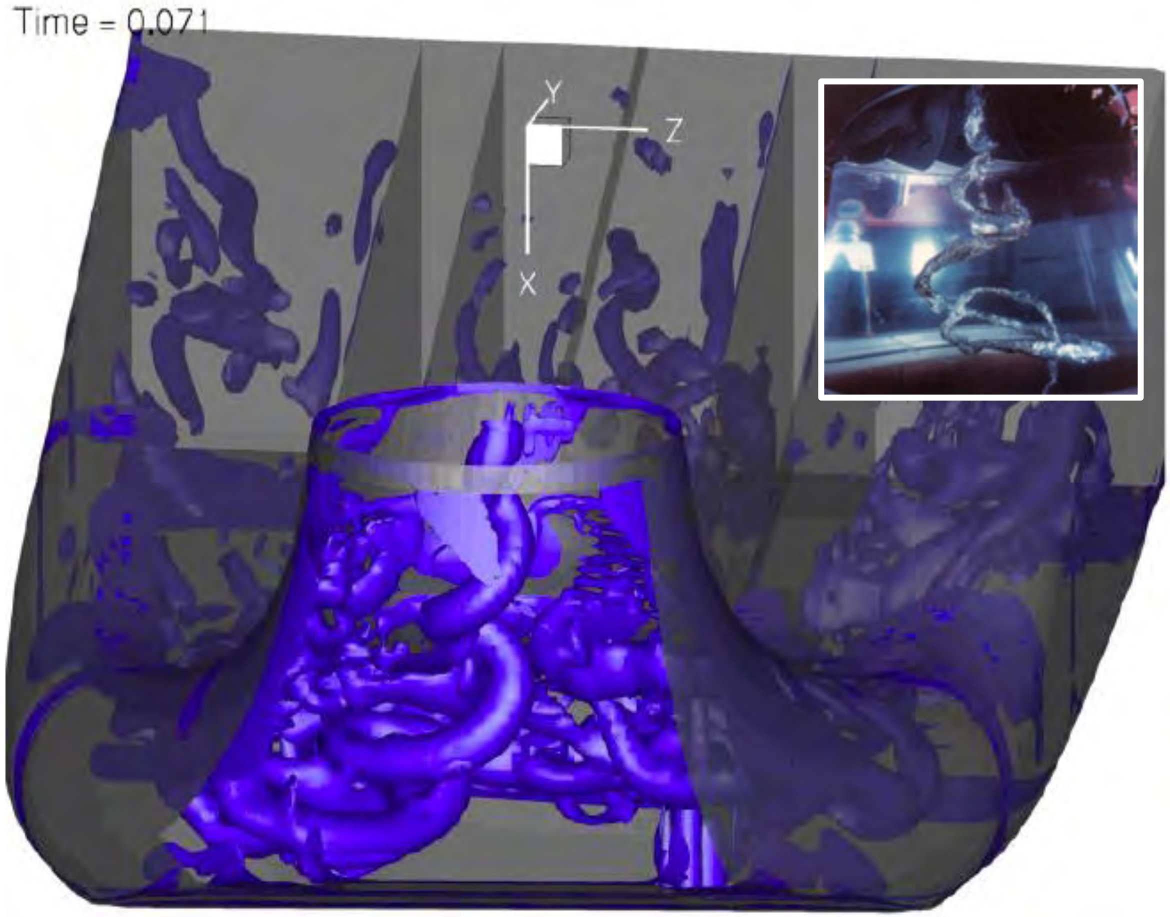
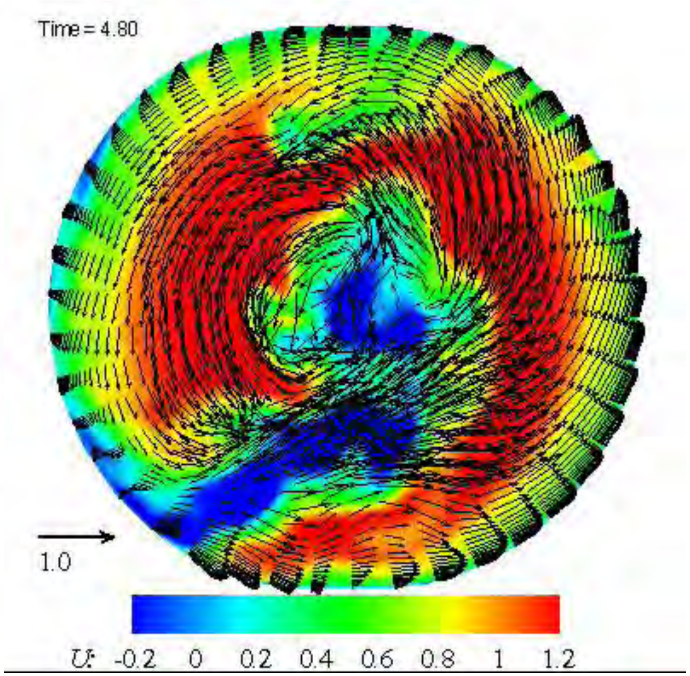


SAFL Computational Research for Environmentally Friendly Hydropower





High-fidelity unsteady modeling of turbulence in real-life draft tubes

SAFL Computational Research for Environmentally Friendly Hydropower

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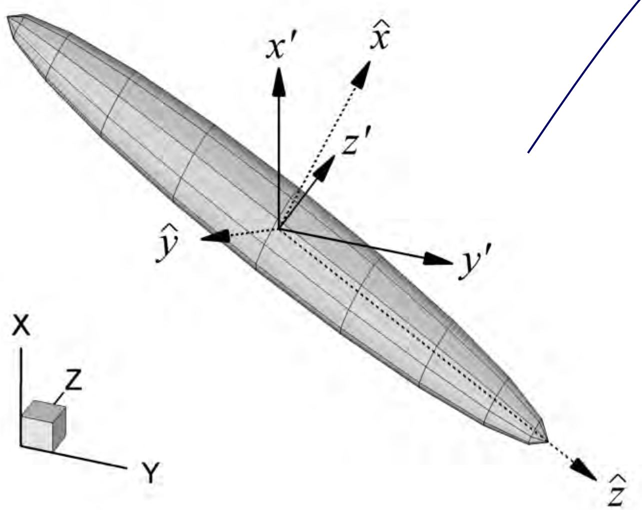
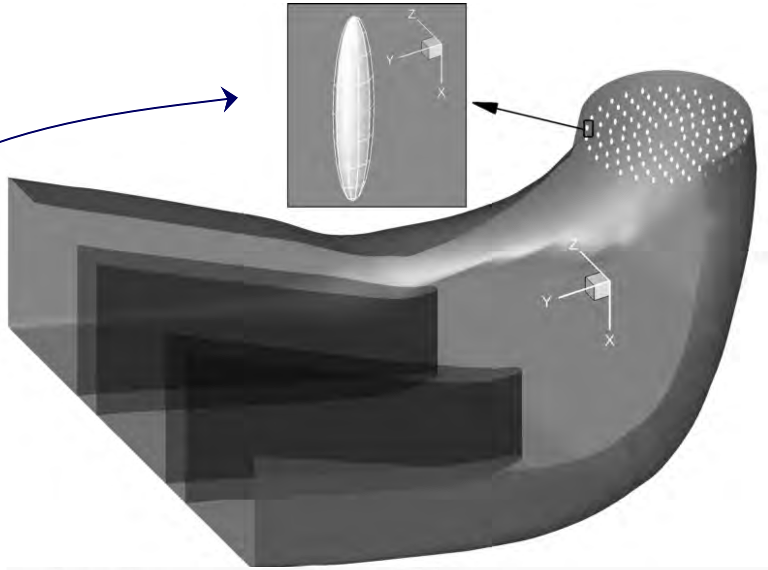
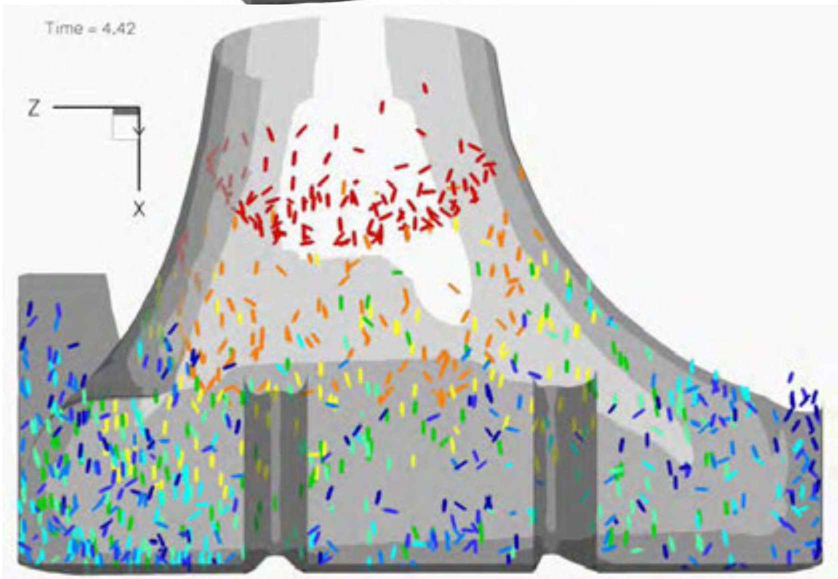
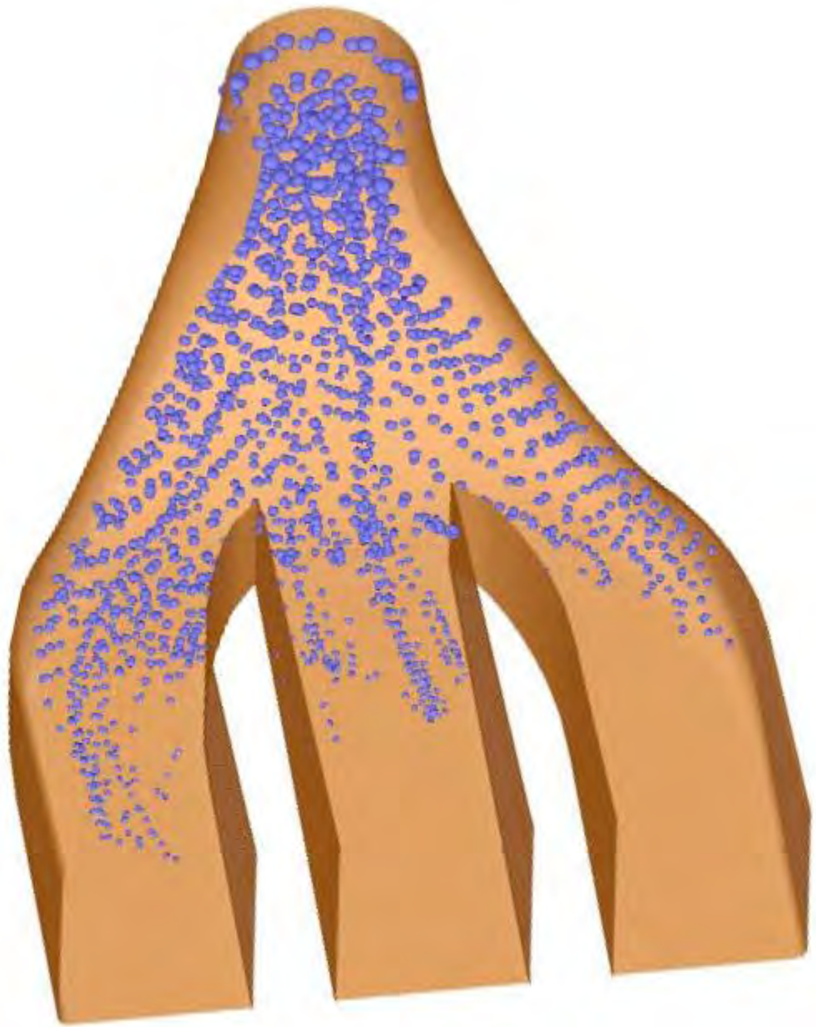






The Virtual Sensor Fish Model

6 degree of freedom tracking of 3D rigid fish-like bodies in simulated unsteady turbulent flowfields – Sotiropoulos et al (1999)



The TVA Norris draft tube
Sotiropoulos et al. (1998)

The Virtual Bubble Model for Aerating Turbines

One-way coupling Lagrangian tracking of air bubbles with mass transfer

Fully-coupled 2-phase flow large-eddy simulation model

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Governing equations

Liquid phase

$$\nabla.\tilde{u}_l = 0$$

$$\frac{\partial}{\partial t}\left(\rho_l \tilde{u}_l\right) + \nabla.(\rho_l \tilde{u}_l \tilde{u}_l) + \nabla\tilde{p} = \nabla.\tau^R - \rho_l \vec{g} - \alpha_g \rho_l \vec{g}$$

Gas phase

$$\frac{\partial}{\partial t}(\alpha_g \tilde{\rho}_g) + \nabla.(\alpha_g \tilde{\rho}_g \tilde{u}_g) = \nabla.\left(\frac{\rho_g}{\rho_l}\mu_l^{turb}\nabla\alpha_g\right)$$

$$\frac{\partial}{\partial t}\left(\alpha_g \tilde{\rho}_g \tilde{u}_g\right) + \nabla.(\alpha_g \tilde{\rho}_g \tilde{u}_g \tilde{u}_g) + \alpha_g \nabla\tilde{p} = \alpha_g \nabla.\tau + \nabla.\left(\alpha_g T_g^{\mathrm{Re}}\right) + \alpha_g \tilde{\rho}_g \vec{g} + M_k'$$

- Models for interfacial forces, including Drag, lift, virtual mass and turbulent dispersion
- Subgrid scale models for liquid/gas shear and bubble induced turbulence

Numerical implementation

Liquid equations (pressure and velocity)

- ❑ Fractional step to integrate liquid momentum and mass equations
- ❑ Liquid momentum solved by Crank-Nicolson scheme
- ❑ Advective term WENO, diffusive terms by central differencing
- ❑ Central differencing for pressure correction equation

Gas momentum equation

- ❑ Crank-Nicolson scheme
- ❑ TVD scheme (superbee flux limiter) for advective term, central differencing for diffusive term

Gas mass balance equation

- ❑ Crank-Nicolson scheme
- ❑ TVD scheme for advective term, central differencing for turbulent diffusion term

Notes

- ❑ 3D, time accurate
- ❑ All solvers are based on Krylov subspace methods (GMRES, Newton-Krylov)
- ❑ Parallel
- ❑ Works with structured curvilinear grids

Validation of the 2-phase flow LES solver

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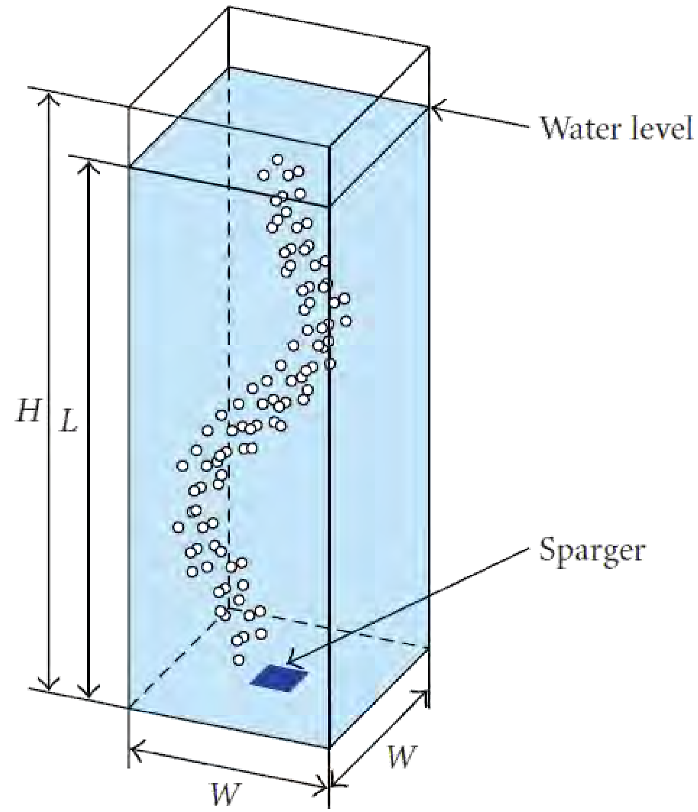
Gas-liquid flow in a bubble column*

- Column size: 15×15×100 cm^3
- Sparger plate:

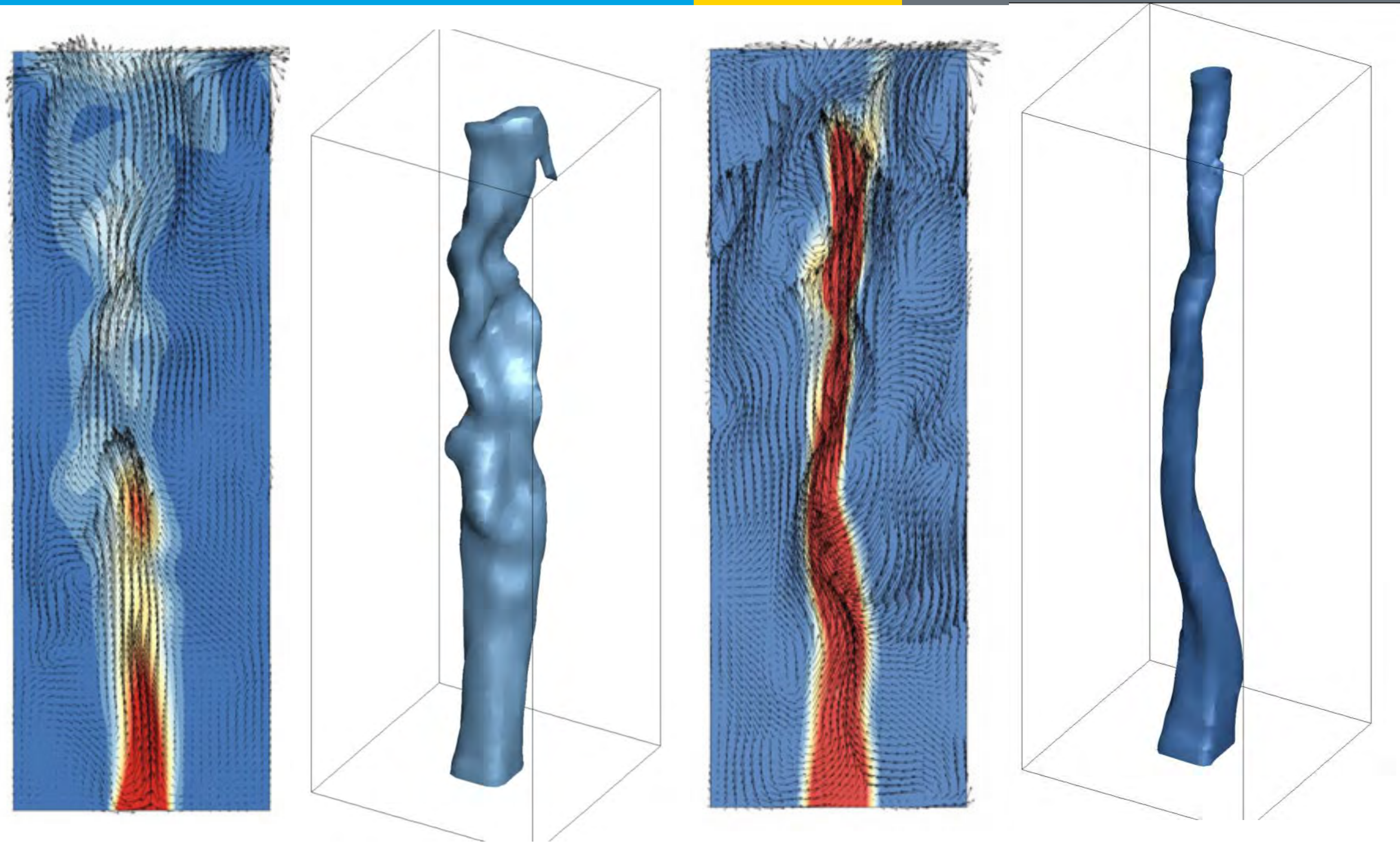
  38.5×38.5 mm^2

  49 holes of 1mm diameter
- Liquid filled up to 45 cm
- Bubble jet superficial velocity: 5 mm/s
- Bubble jet release velocity: 7.85 cm/s



**N.G. Deen, B.H. Hjertager, T. Solberg, Comparison of PIV and LDA measurement methods applied to the gas-liquid flow in a bubble column, 10th international symposium on applications of laser techniques to fluid mechanics, 2000]*

Validation of the 2-phase flow LES solver



Liquid velocity vectors (left) and iso-surface of gas volume fraction (right) at 2 instants in time

Validation of the 2-phase flow LES solver

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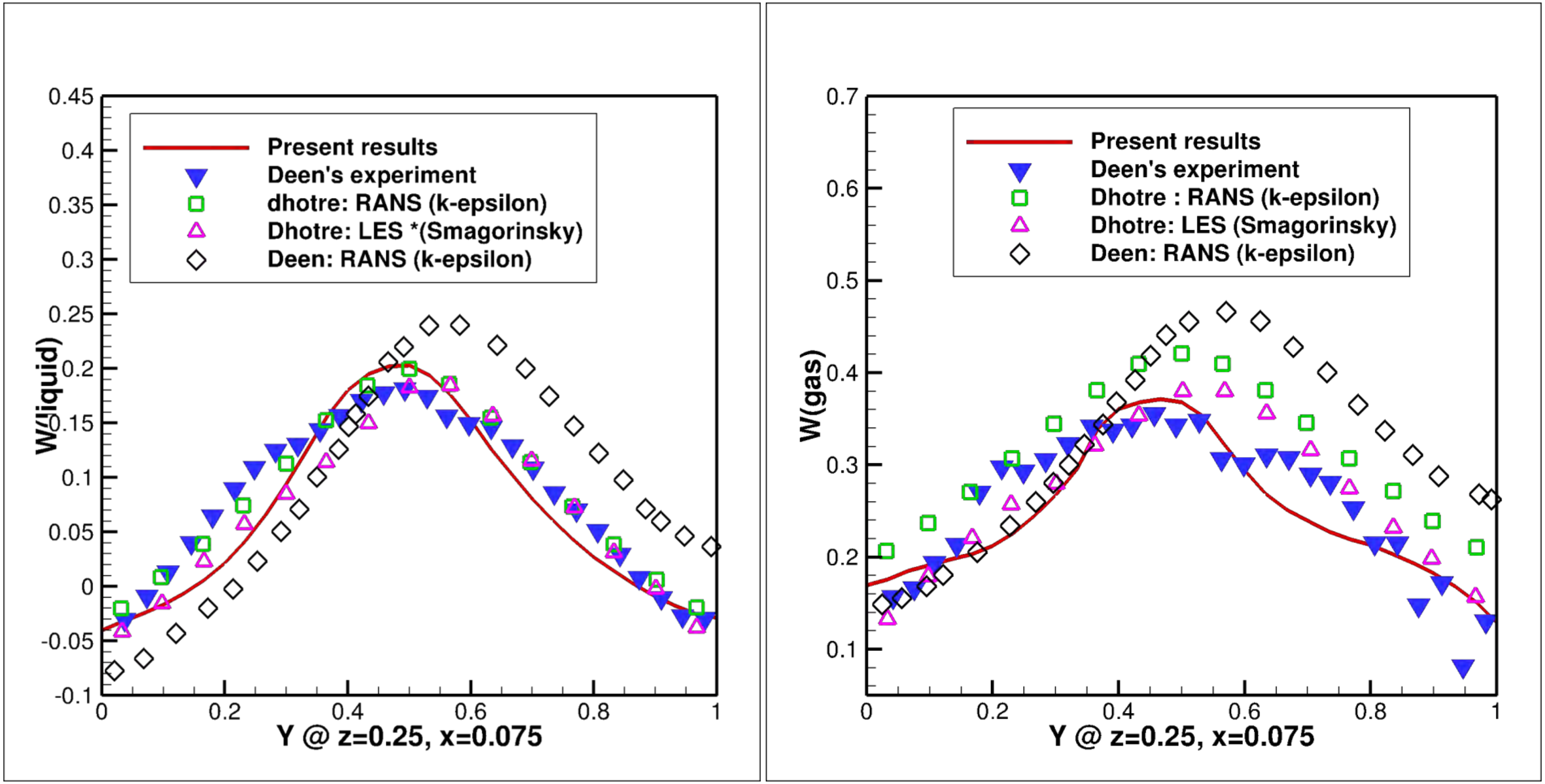
Comparison of time-averaged liquid and gas velocity profiles*



1) M.T. Dhotre, Niceno, B.L. Smith, Large eddy simulation of a bubble column using dynamic sub-grid scale model, Chem. Eng. J., 2008
2) N. G. Deen, T. Solberg, B. H. Hjertager, Large eddy simulation of the Gas–Liquid flow in a square cross-sectioned bubble column, Chem. Eng. Sci., 2001

Ongoing Work

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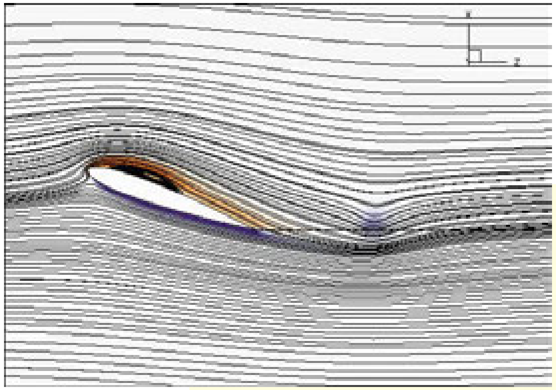
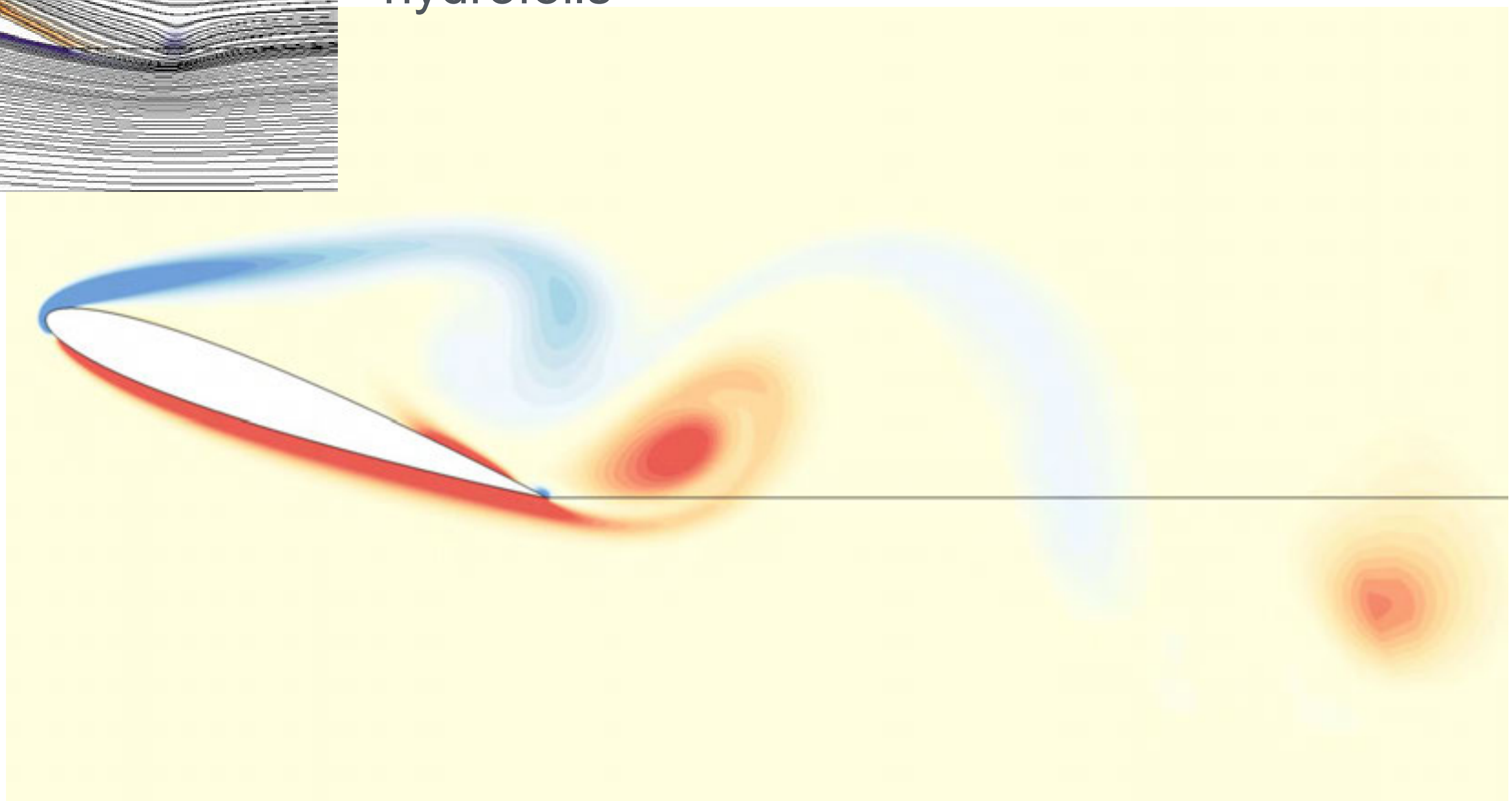


Extending the computational code to simulate flow around the NACA0015 & NACA0012 hydrofoils



Contours of vorticity at 20 degrees angle of attack

Future development of the LES code

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- ❑ Implement a bubble population balance equation to enable the calculation of bubble size distribution.
- ❑ Implement a mass transfer model to enable dissolved-oxygen simulations.

Accomplishments and Progress

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- **Our bubble measurement technique has been improved:**
  - reduced background fluctuations generated by out-of-focus bubbles
  - reduced computational time (time went from 20 minutes per image to 3-7 seconds per image, allowing a much larger data set to be collected)
  - 45,000 images have been analyzed, providing a significant bubble size data base
- **Significant progress made in developing the numerical code:**
  - Developed a new fully-coupled 2-phase flow LES model for gas/liquid flows
  - Validated the 2-phase flow model for a rising bubble plume case
  - Extended the code to simulate turbulent flow past hydrofoils

Research Integration & Collaboration

- Alstom Hydro Global Technology Center, Montreal, Canada is providing substantial cost-share (50% of the total project cost) to this work and acting as a key industrial partner. Their engineers have already visited three times for extended periods, getting ready for the research on the Alstom hydrofoil.

- Presentations and Publications:
  - ✓ Conference in Montreal to present the proposed research
  - ✓ Lee, Seung-Jae, Kawakami, E and Arndt, REA Proc.8th Int. Symposium on Cavitation August, 2012, Singapore
  - ✓ Lee, Seung-Jae, Kawakami, E and Arndt, REA Proc. ASME FEDSM 2013 July 7-11, 2013, Incline Village, Nevada, USA
  - ✓ Arndt, REA, Presentation at American Physical Society 66th Annual Meeting Division of Fluid Dynamics 24 – 26 November 2013 Pittsburgh, Pennsylvania

Project Budget

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FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
[$145K]	[$24K]	[$76K]	[$103K]	[$11K]	[$12K]

Next Steps and Future Research

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FY14/Current research:

- Investigation of Alstom design
- Further investigation of bubbly wake
  - ✓ fitting bubble size distribution to theory (Bubble breakup model)
- Computations:
  - ✓ Consider the bubble size distribution by solving the bubble population balance equation.
  - ✓ Solve for mass transfer across the phases
  - ✓ Validate the code with ventilated foil data

Questions?

Water Power Peer Review

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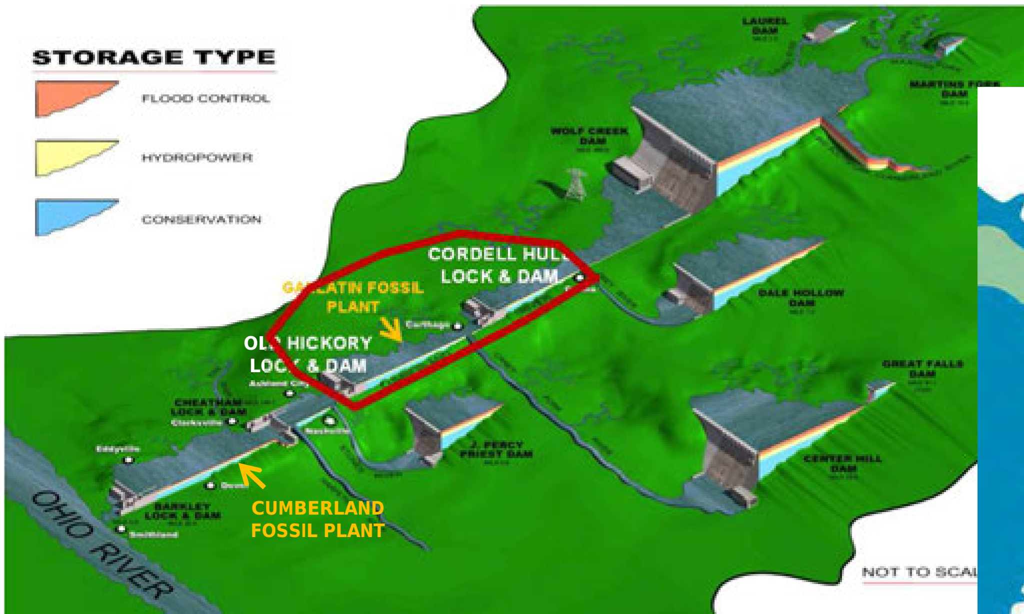
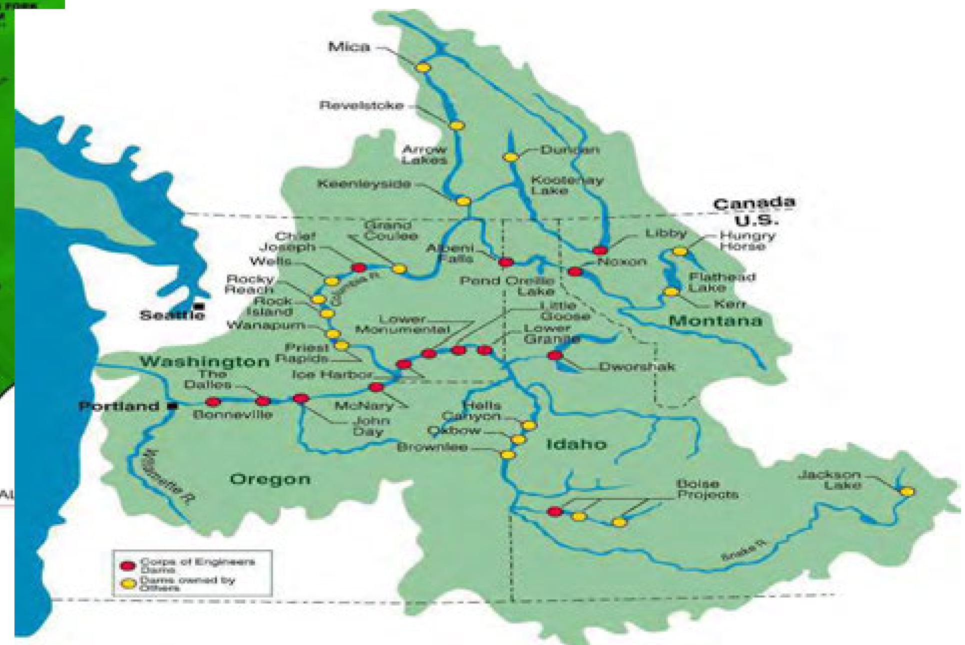
Water Quality Scheduling Research





Water Quality Modeling Improvements at Columbia and Cumberland River Basins

- **Boualem Hadjerioua**
- ORNL
- hadjeriouab@ornl.gov
- (865) 574 5191

- February 26 28, 2014

OAK RIDGE National Laboratory

Purpose & Objectives

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Problem Statement:

- The complexity of water quality dynamic cannot be currently represented in real-time hydropower dispatch systems

- Water quality scheduling research is to enable real-time hydropower operators to integrate water quality dynamics into their optimization dispatch tools.

Alignment with DOE Program Objectives:

- Optimize existing hydropower technology, flexibility, and/or standards.

Purpose & Objectives

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

- Purpose of ORNL Water Quality Modeling work is to advance **mathematical modeling science** so as to be generalizable for implementation in various Decision Support Systems (DSS)
  - Reduction in model complexity to allow use in real-time decision making
  - Development of physics-based and mass-transfer models

- **IMPACT**: Eliminate or minimize the need to "leave some on the table" as buffer when scheduling the system to meet water quality targets.

Complex Process
Hydrodynamic
Water quality
Mass transfer

↓

Reduce Complexity
Mathematical Approaches

↓

Ready for Use
Real-time Scheduling

Technical Approach

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- Collaboration with Academia and Federal Hydropower MOU partners to develop, implement, and demonstrate the use of advanced water quality models in systems optimization
  - Reclamation, the Army Corps, and TVA all manage complex, constrained multi-purpose systems with significant modeling needs
  - Partnerships with universities to generate and/or implement state-of-the-art mathematical modeling techniques

- Efforts thus far under the MOU:
  - Temperature and Dissolved Oxygen (DO) modeling (Cumberland River)
  - Total Dissolved Gas (TDG) modeling (Columbia River

Technical Approach – Methodology

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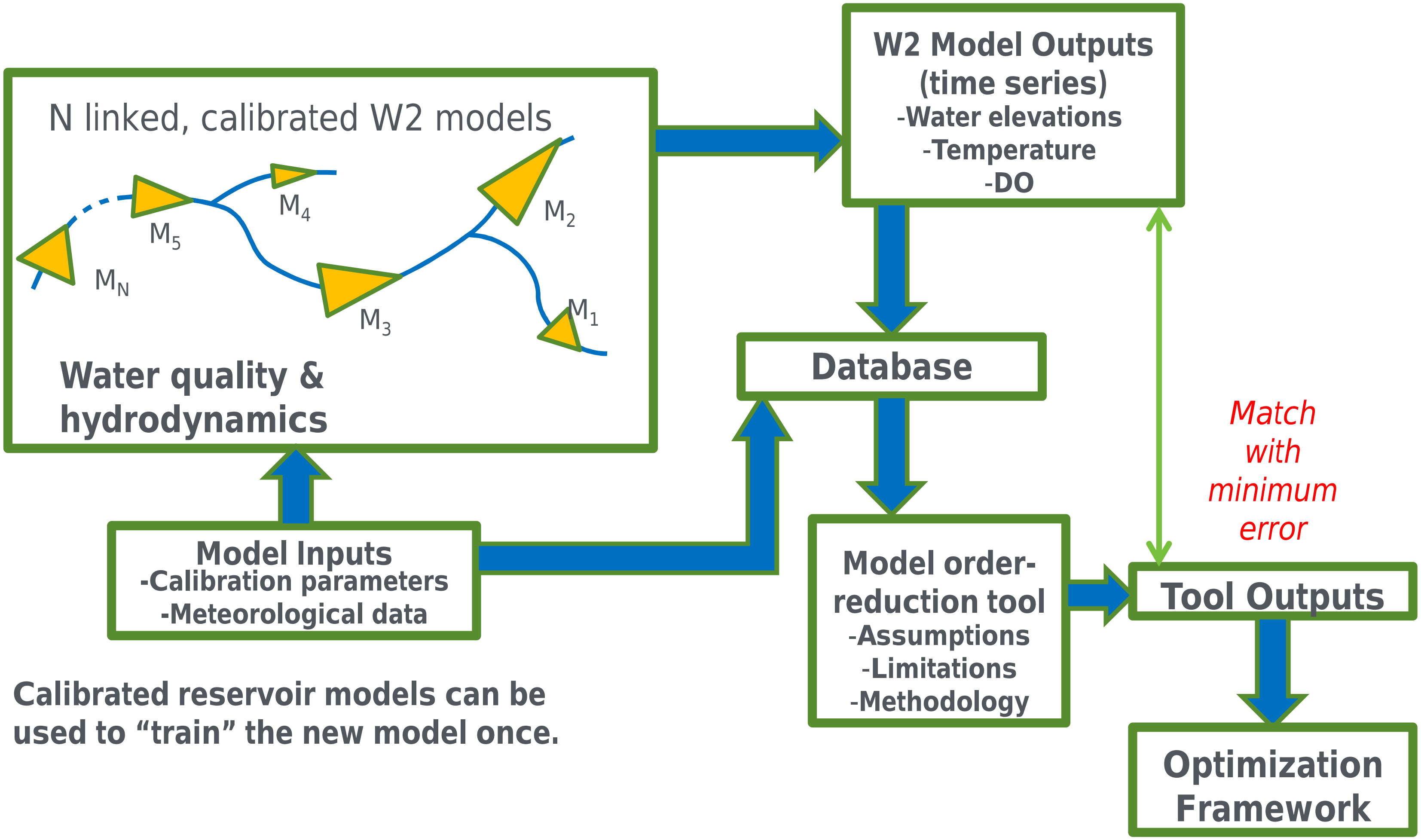

Calibrated reservoir models can be used to "train" the new model once.

Decision makers can quickly model various scenarios, obtain accurate outputs, and optimize operations.

Technical Approach-

Mathematical Formulation and Analysis

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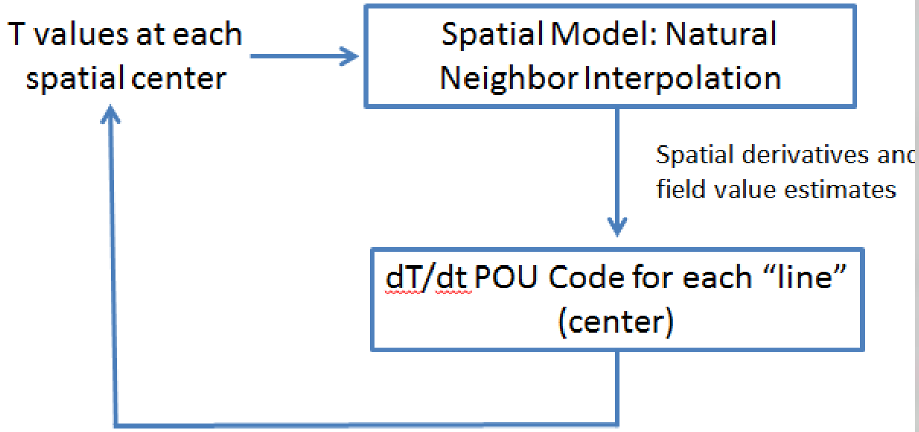
Method of Lines Model Outline



Update for next time step (Euler Method):

$$T(i+1) = T(i) + \frac{\partial T(i)}{\partial t}\Delta t$$

Where $\Delta t = \approx 1 \text{ hr}$

Model reduction methods:

Considering the system in the form *(E, A, B, C, D)*

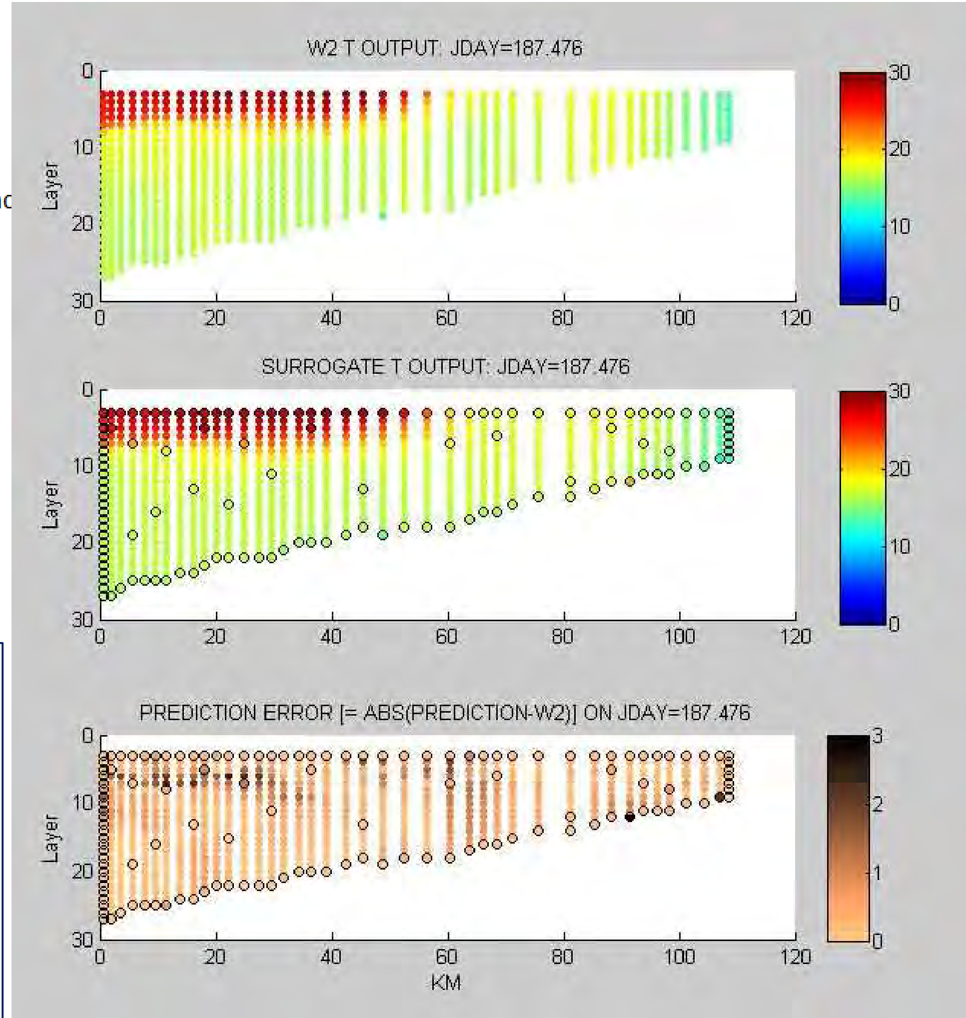
$W^T EV\, dx/dt = W^T AVz(t) + W^T Bu(t)$ $x + R^q$, $u + R^m$
$y(t) = CVz(t) + Du(t)$ $y \in R^l$

This results in the state-space system *(E^r, A^r, B^r, C^r, D), where*

$E^r = W^T EV$, $A^r = W^T AV$, $B^r = W^T B$, $C^r = CW^T V$

(r : reduced model). If the initial system was in state-space form (A,B,C,D) then E=I (n ×q identity matrix), and matrices W and V are enforced to be biorthogonal,* that is, *$W^T V = I$.

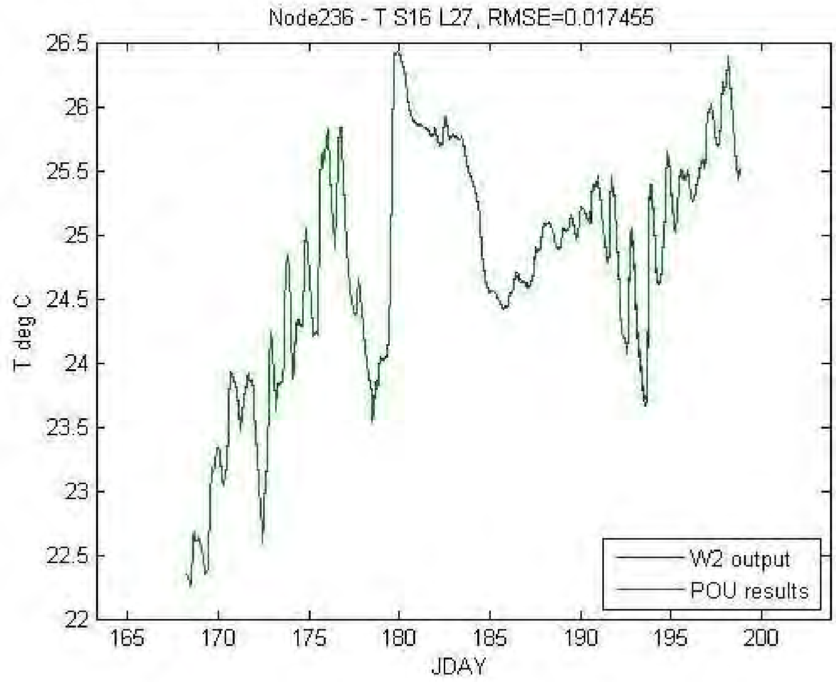
POU: Partition of Unity interpolation surrogate model



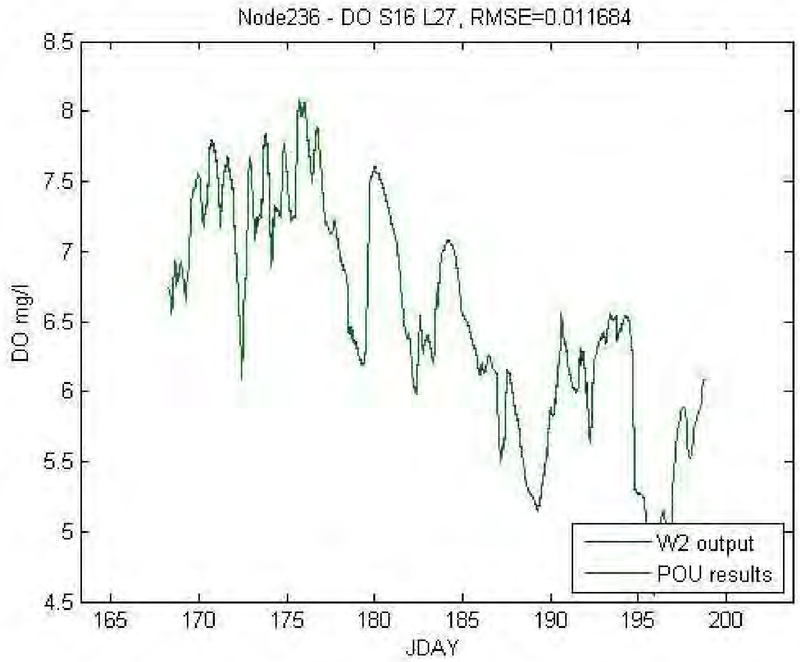
Cordell Hull Reservoir Model Reduction Snapshot

Surrogate Model Development
Old Hickory: Temperature & DO Results

Temperature at Turbine Discharge



Dissolved Oxygen at Turbine Discharge



W2: original water quality model
POU: Partition of Unity interpolation surrogate model

Uniqueness: Development of the first multiple reservoirs system high fidelity model reduction than can be used in operational scheduling, planning, and decision making by hydropower operators.

Accomplishments and Progress- Results to Date

- Delivered to USACE Updated and Calibrated CE-QUAL-W2 models for Cordell Hull and Old Hickory reservoirs.
  - Completed 1/27/12
- Developed surrogate models for 2 reservoirs
  - Cordell Hull completed 6/30/13
  - Old Hickory completed 7/15/13
- Defined optimization model constraints for 2 reservoirs in conjunction with USACE
  - Completed 12/15/13

Technical Approach-

Mathematical Formulation and Analysis

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

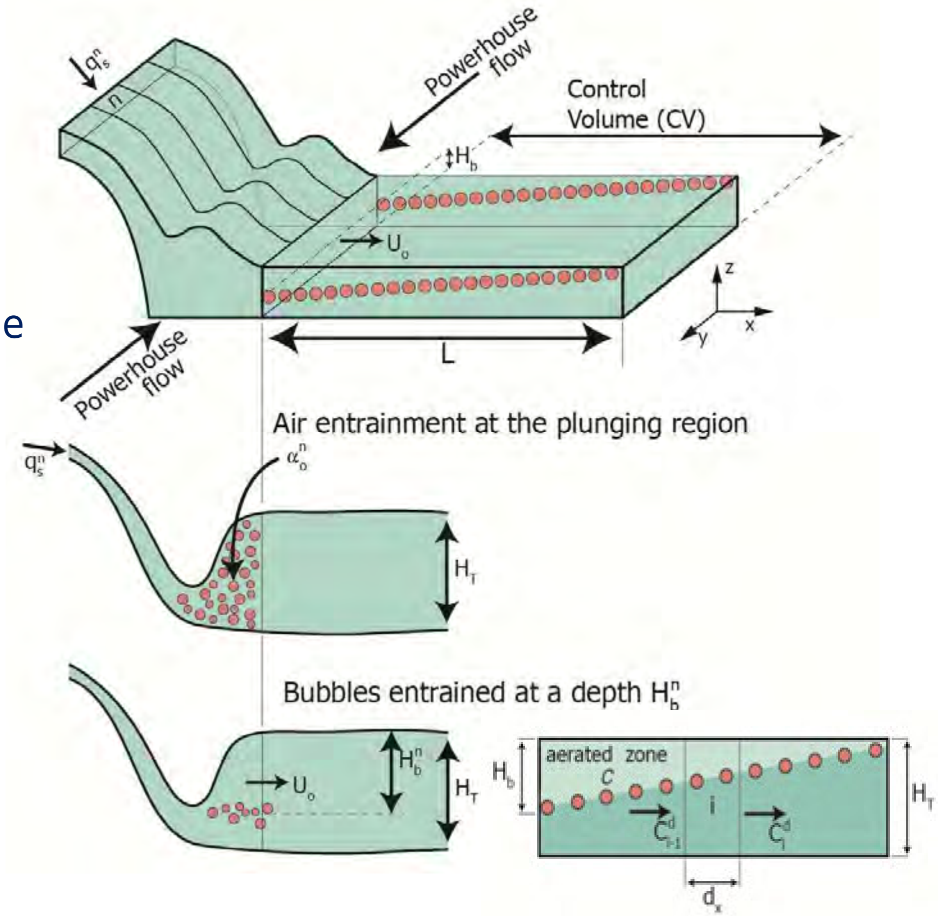
TDG Model Overview

TDG representative equations are developed based on the main physical processes in TDG production and mixing:

- Air entrainment in the spillway face and during the plunging of spill water in the tailrace
- Bubble dissolution
- Entrainment of powerhouse water into the spillway region

The independent variables

- Tailwater elevation
- Dam height
- Powerhouse flowrate
- Spillway flowrate
- Unit spill per bay
- Atmospheric pressure and temperature



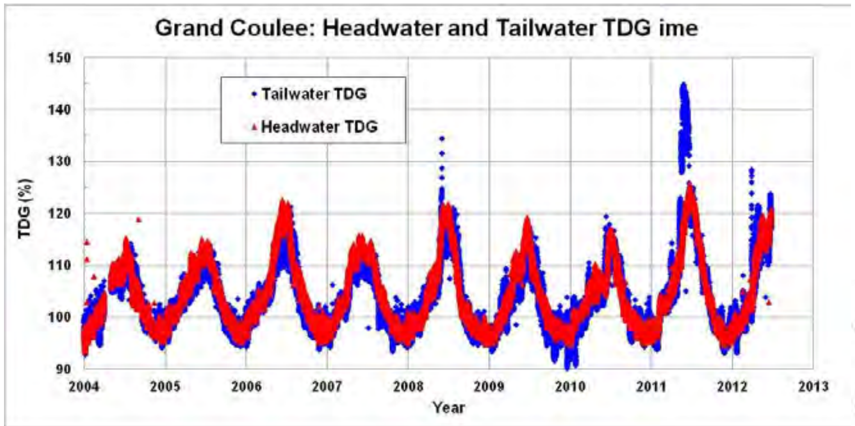
Approach Uniqueness

No known prior predictive TDG derivation methods have employed such mathematical derivation techniques to include all physical processes governing TDG production and mixing analysis to develop a fully mechanistic approach to derive predictive TDG equations.

TDG Concentration Formulation

$$C_d = \frac{(Q_s + C_{we}\,Q_p)}{(Q_s + Q_p)}\left(\frac{P_a}{He} + \frac{\rho\, g\, H_T}{2\, He}\right)X_d + \frac{(Q_p - C_{we}\,Q_p)}{(Q_s + Q_p)}C_o$$

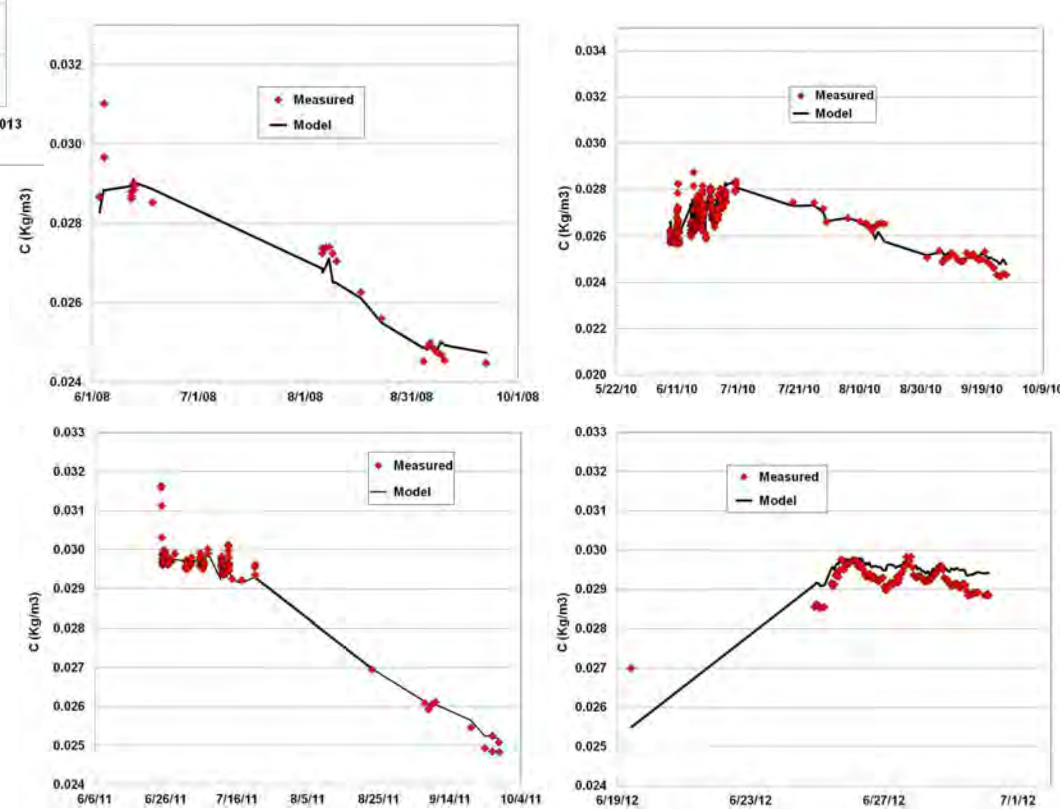
Results to Date



Hourly data for seven dam on the Mid-Columbia and Dworshak 2004-2012

Grand Coulee Dam

Derivation Results



Grand Coulee Tailwater, Measured Vs. Modeled, 2008, 2010, 2011, and 2012

Project Plan & Schedule

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

Summary		Legend
1.9.1.1 Water Quality Modeling Improvements Columbia Cumberland River Basins		Work completed
		Active Task
		Milestones & Deliverables (Original Plan)
Agreement 26881		Milestones & Deliverables (Actual)

Milestone / Deliverable	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Cumberland - model bathymetry for two reservoirs												
Cumberland - Water blance calibration CE-QUAL-W2												
Cumberland - Water quality calibration												
Cumberland - coupled ODEs for one reservoir completed												
TDG - Literature Review												
TDG - parameterization and data collection												
TDG - revised white paper with proposed methodology												
TDG-Kick off with USACE and Reclamation												
Soft and hard contstraint database development												
Summarize TDG approach, water operational model												
Document TDG module approach												
Certify Completion of differential equation												
Model order reduction of Old Hickory Lake												
Collection of input from reservoir stakeholders												
Exectuion/demonstration of Cordell Hull/Old Hickory model												
Current work and future research												
Cumberland River Cordell Hull Reservior ojective functions												
Validation of the Cordell Hull Reservoir model												
Linking cumberland Models												
Validate two linked models												

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0K	$0	$583,555K	$0	$50K	$0

FY2013 Budget supporting activities include:

- FY2013-FY2014 funding for Cumberland River Water Quality project and Columbia River TDG Project

Research Integration & Collaboration

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

Collaboration:

Cumberland River System:

1. Vanderbilt University, Nashville, TN
2. David Lipscomb University, Nashville, TN
3. USCOE Nashville District

Columbia River System:

1. University of Iowa, Iowa
2. Bureau of Reclamation, Denver, Colorado
3. USCOE, Portland, Oregon
4. CADWES, University of Colorado (In progress)

Communications and Technology Transfer:

Cumberland River System:

- Technical paper and Poster presentation, Hydro Vision Conference, 2013
- Two Journal publications (in Progress)
- Two Ph.Ds dissertations (in Progress)

Columbia River System:

- Poster presentation and Technical paper, Hydro Vision Conference, 2012 and 2013

Next Steps and Future Research

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Next Steps end of FY2014

•The results of this project will produce a linked, two-reservoir, high-fidelity optimizaeable hydropower generation simulation system for a portion of the Cumberland River.

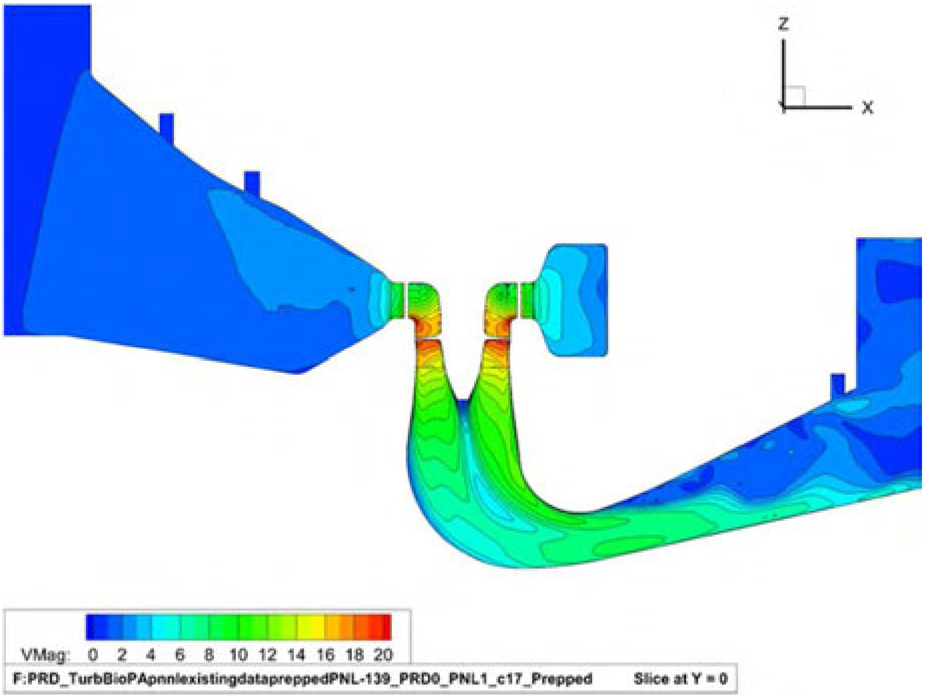
• Provide representative TDG equations to be implemented in an operational scheduling tool for the Mid-Columbia hydropower projects

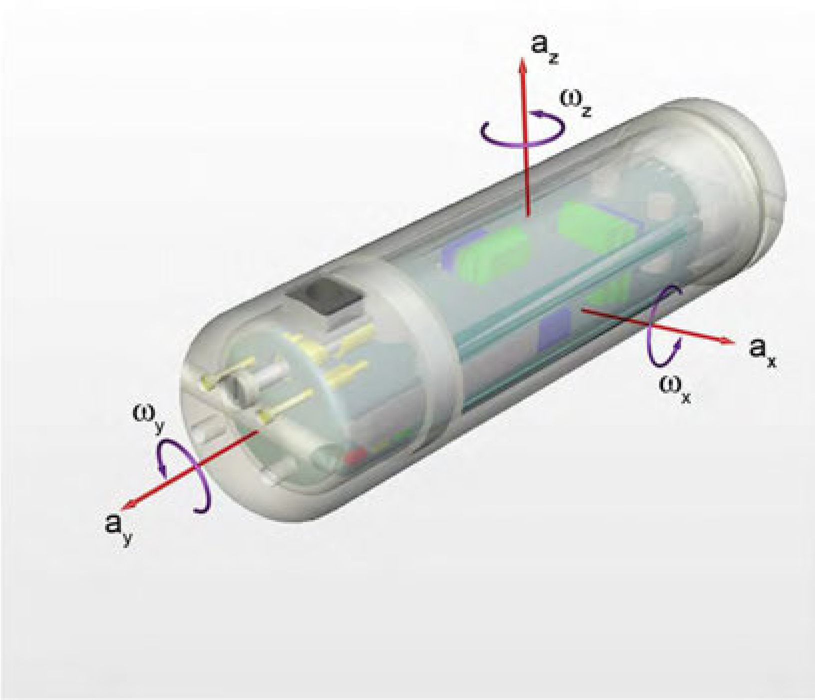
Future Proposed Research

• Fine-tuning the optimization approach to further address stakeholder needs that may be identified following initial model implementation.

• As envisioned by the U.S. Army Corps of Engineers Nashville District, extension of the two-reservoir system to an entire, Cumberland River system-wide linked model capable of local and global (system-wide) optimization, further enabling model application to additional river systems.

•Test and validate the TDG equations to other river systems.





Biological Design Criteria for New Hydropower Turbines

Gary Johnson
PNNL
gary.johnson@pnnl
February 27, 2014

Purpose

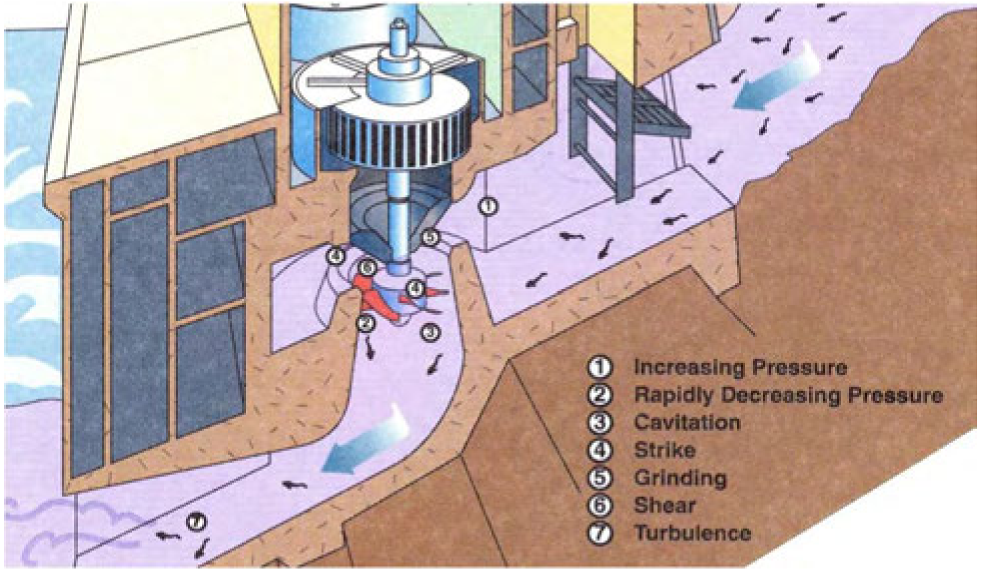
Problem Statement: Comprehensive, standardized, quantitative tools to assess potential biological impacts of new or refurbished hydro-turbines during design and evaluation phases are lacking.

Impact of Project: Incorporating biological performance based on applications of advanced technologies to establish dose/response relationships between physical conditions and fish injury will reduce design costs and accelerate permitting processes.

Alignment with DOE Program: This project aligns with the Hydropower Market Acceleration and Deployment Program goal to reduce deployment barriers and environmental impacts of hydropower.

Overall Objective

Define and predict the response of a variety of fish species to turbine passage to inform the design of new turbines to achieve improved biological performance and make the evaluation of existing turbines more efficient and less costly.

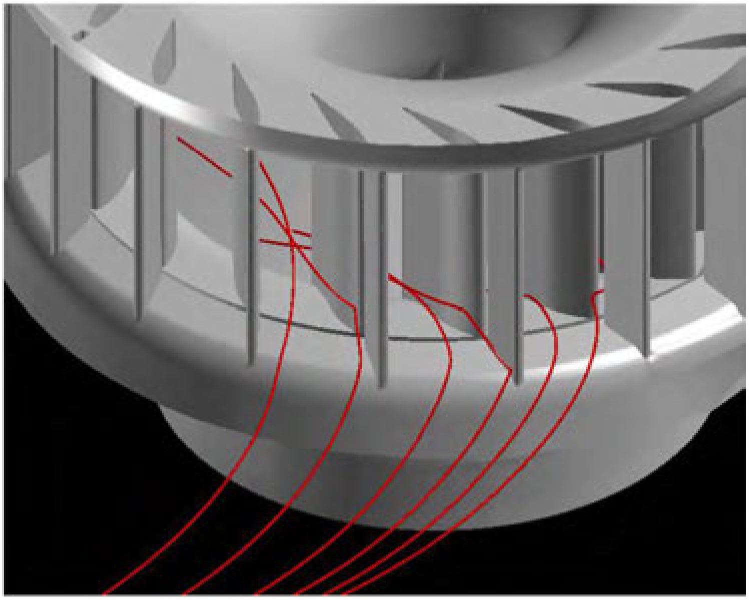


Specific Objectives

1. *Retrospection*: Using PNNL's sensor fish database, perform a retrospective analysis of biological quality of flow through hydro turbines (pressure, shear, turbulence) incorporating a traits-based approach to include non-salmon species and assess consequences to fish of exposure (collision, strike)
2. *SF Utilities*: Develop new software utilities for Gen 2 sensor fish data that map SF data to exposure events, and estimate of biological response.
3. *Biological Performance Assessment (BioPA) Tools*: Incorporate improved CFD hydraulic simulations (e.g., turbulence, shear, machine motion) and simulation of fish into BioPA tools.
4. *Small Hydro-Turbines*: Apply BioPA and SF tools to small hydro systems.
5. *Technology Transfer*: Conduct workshops with industry and regulators to gain feedback on the project and encourage broad use of the BioPA design and SF evaluation tools. Provide software for BioPA tools and SF utilities to industry. Publish articles and reports.

Background

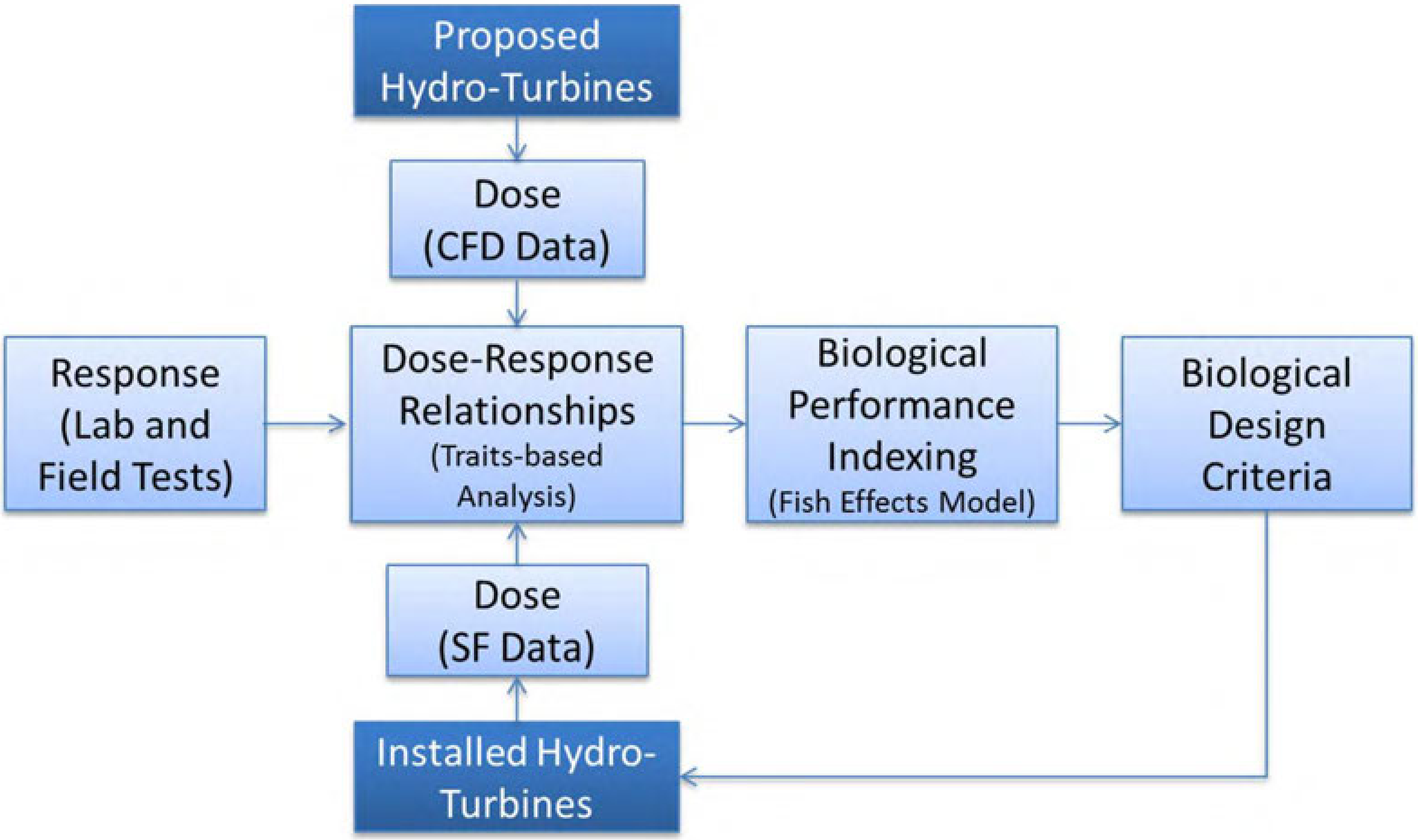
- Build on previous DOE- and USACE-funded work:
  - DOE Advanced Hydropower Turbine Systems Program (1995-2006)
  - USACE Turbine Survival Program (~1995 to present)
  - DOE FOAs (2009 and 2011)



(From 2004 AHTS annual report)

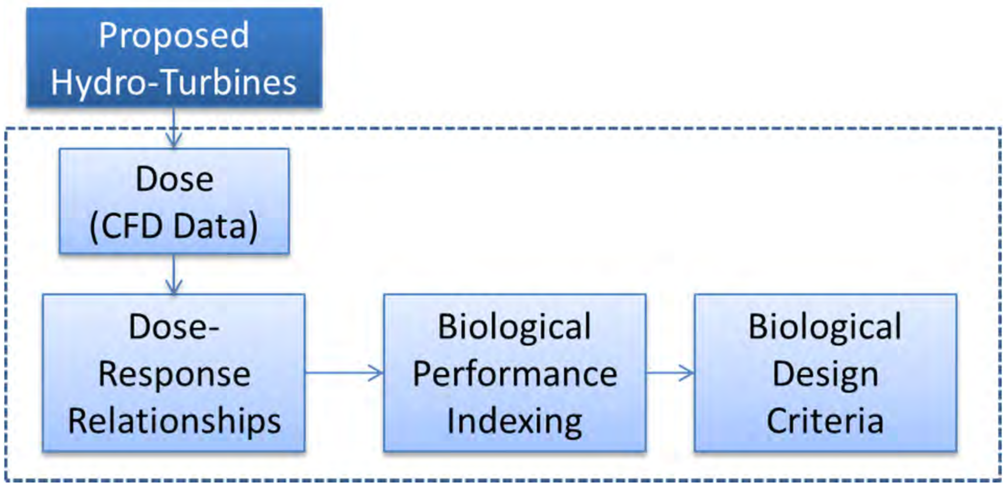
Overall Technical Approach

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

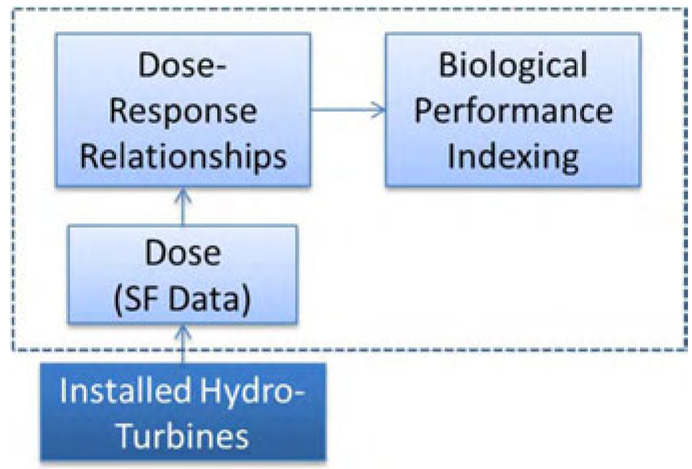


BioPA and SF Components

BioPA



SF



Technical Approach

- Key Issue:
  - Data gaps and extrapolation of data for salmonids to infer the response of other species of concern (see ORNL's traits-based approach)
- Unique aspects:
  - Advanced CFD modeling and computing capability
  - Generation 2 SF technology
  - State-of-art dose/response data

Project Plan & Schedule FY14

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Milestone/ Deliverable	Q1	Q2	Q3	Q4
BioPA application set				
BioPA species of concern				
50% draft specifications for SF utilities				
95% spec's				
Updated SF database				
Prototype SF utilities				
Retrospective analysis (updated dose/response relationships)				
Industry working group and outreach				

Note: Scoped as a 3-yr project – started Sept 2013.

Project Budget

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

FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$800K	$0K	$700K	$0K

- Budget variances: None
- Initial funding Sept 2013.
- Project budget expended to date: ~15%
- Other funding sources: None

Partners, Subcontractors, and Collaborators:

- Oak Ridge National Laboratory (Mark Bevelhimer)
- University of Washington (John Skalski)
- Corps of Engineers, Grant County OUD, and other hydro operators TBD

Communications and Technology Transfer:

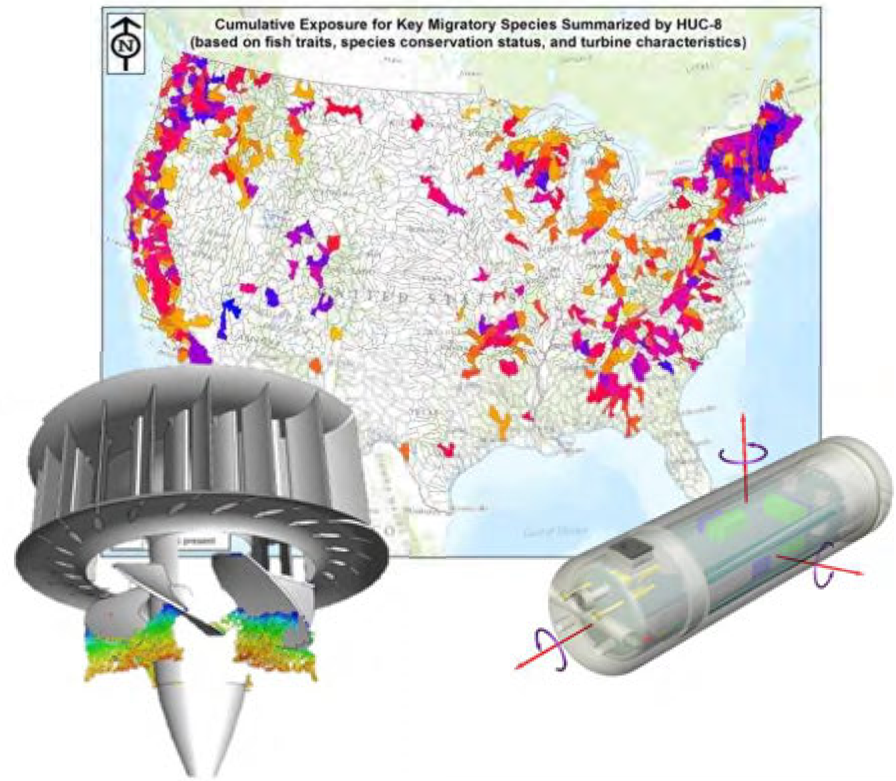
- Hydrovision and AFS conferences, special workshop(s) with industry user groups, technical reports, and journal articles.

FY14/Current research:

- Complete the retrospection and update dose/response relationships and work with ORNL to apply the traits-based approach.
- Continue development of BioPA tools and SF utilities.
- Work with ORNL to develop a fish effects model that will use time series of stressor exposure as predicted by CFD modeling and SF observations. This model will predict probability of injury and mortality for a variety of turbine conditions and designs.

Proposed future research: For the second year of the project, we will propose to further refine the BioPA tools and SF utilities based on feedback from industry. We will also work with DOE WWPTO to identify additional studies to address information deficiencies revealed in the 2014 analysis that help to better define the relationships between turbine conditions and biological response in fish.

Biological Design Criteria for New Hydropower Turbines: Biological Response Relationships



Biological Design Criteria for New Hydropower Turbines

Mark Bevelhimer
Oak Ridge National Laboratory
bevelhimerms@ornl.gov,
865-576-0266
February 2014

OAK RIDGE National Laboratory

Purpose & Objectives

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

Problem Statement: Comprehensive, standardized, quantitative tools to assess potential biological impacts of new or refurbished hydro-turbines during design and evaluation phases are lacking.

Impact of Project: Incorporating biological performance based on applications of advanced technologies to establish dose/response relationships between physical conditions and fish injury will reduce design costs and accelerate permitting processes.

Alignment with DOE Program: This project aligns with the Hydropower Market Acceleration and Deployment Program goal to reduce deployment barriers and environmental impacts of hydropower.

Purpose & Objectives

Objectives: Overall objective is to define and predict the response of a variety of fish species to turbine passage in order to make the evaluation of existing turbines more efficient and less costly and to inform the design of new turbines to achieve better fish passage. Specific objectives are to provide:

1. A national assessment of the nature of fish passage issues in the U.S. (i.e., geographic distribution and species of concern) that can be used to direct turbine research and development, and

2. An interpretation of physical characteristics of new turbines (as revealed by sensor fish data and CFD model predictions) in terms of the biological criteria for fish passage survival.

Technical Approach

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

- **Update biological design criteria** and develop methods for broader application
  - new turbines types and wider variety of species
- Employ **traits-based approach (TBA)** to expand inference space
  - Use relevant biological characteristics (e.g., size, swim bladder type, and integument type) to infer sensitivity to turbine passage stressors.
- Conduct a "spatial analysis" on the **status of fish passage issues** in the U.S.
  - FERC hydropower licensing database (data from NHAAP subtask)
  - contact with regulatory and resource agencies
- Use fish trait information to provide a **broader interpretation of biological effects** based on measured (SF) and modeled (CFD) physical conditions. (In collaboration with PNNL)
- Develop a **fish effects model** that will use time series of stressor exposure as predicted by CFD modeling and SF observations to predict probability of injury and mortality for a variety of turbine conditions and designs. (In collaboration with PNNL)

Accomplishments and Progress

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

Q1 : Updated literature review on biological performance standards for turbine design

Author	Year	Title
Keefer, M. L.;...	2013	High-Head Dams Affect Downstream Fish Passage Timing and Survival in the Middle Fork Willamette River
Pompeu, P. S....	2012	Existing and Future Challenges: The Concept of Successful Fish Passage in South America
Pflugrath, B. ...	2012	Maximum Neutral Buoyancy Depth of Juvenile Chinook Salmon: Implications for Survival during Hydroturbine Passa...
Keefer, M. L.;...	2012	Reservoir entrapment and dam passage mortality of juvenile Chinook salmon in the Middle Fork Willamette River
Deng, Z. D.; ...	2012	Development of external and neutrally buoyant acoustic transmitters for juvenile salmon turbine passage evaluation
Colotelo, A. H...	2012	The effect of rapid and sustained decompression on barotrauma in juvenile brook lamprey and Pacific lamprey: Impli...
Carlson, T. J.; ...	2012	The Influence of Tag Presence on the Mortality of Juvenile Chinook Salmon Exposed to Simulated Hydroturbine Pas...
Brown, R. S.; ...	2012	Pathways of barotrauma in juvenile salmonids exposed to simulated hydroturbine passage: Boyle's law vs. Henry's law
Brown, R. S.; ...	2012	Quantifying Mortal Injury of Juvenile Chinook Salmon Exposed to Simulated Hydro-Turbine Passage
Weiland, M. ...	2011	A Cabled Acoustic Telemetry System for Detecting and Tracking Juvenile Salmon: Part 1. Engineering Design and Ins...
Deng, Z. Q.; C...	2011	Fish Passage Assessment of an Advanced Hydropower Turbine and Conventional Turbine Using Blade-Strike Modeling
Deng, Z. D.; ...	2011	A Cabled Acoustic Telemetry System for Detecting and Tracking Juvenile Salmon: Part 2. Three-Dimensional Tracki...
Stephenson, ...	2010	Assessing barotrauma in neutrally and negatively buoyant juvenile salmonids exposed to simulated hydro-turbine pa...
Deng, Z. Q.; ...	2010	Injury and Mortality of Juvenile Salmon Entrained in a Submerged Jet Entering Still Water
Deng, Z. Q.; C...	2010	Use of an autonomous sensor to evaluate the biological performance of the advanced turbine at Wanapum Dam
Calles, O.; Ols...	2010	Size-dependent mortality of migratory silver eels at a hydropower plant, and implications for escapement to the sea
Richmond, M...	2009	Response relationships between juvenile salmon and an autonomous sensor in turbulent flow
Calles, O.; Gr...	2009	Connectivity Is a Two-Way Street-the Need for a Holistic Approach to Fish Passage Problems in Regulated Rivers
Brown, R. S.; ...	2009	Assessment of Barotrauma from Rapid Decompression of Depth-Acclimated Juvenile Chinook Salmon Bearing Radi...
Pelicice, F. M....	2008	Fish-passage facilities as ecological traps in large neotropical rivers
Ferguson, J. ...	2008	Combining turbine blade-strike and life cycle models to assess mitigation strategies for fish passing dams
Deng, Z. Q.; C...	2007	Evaluation of blade-strike models for estimating the biological performance of Kaplan turbines

List of fish/turbine traits included in vulnerability assessment

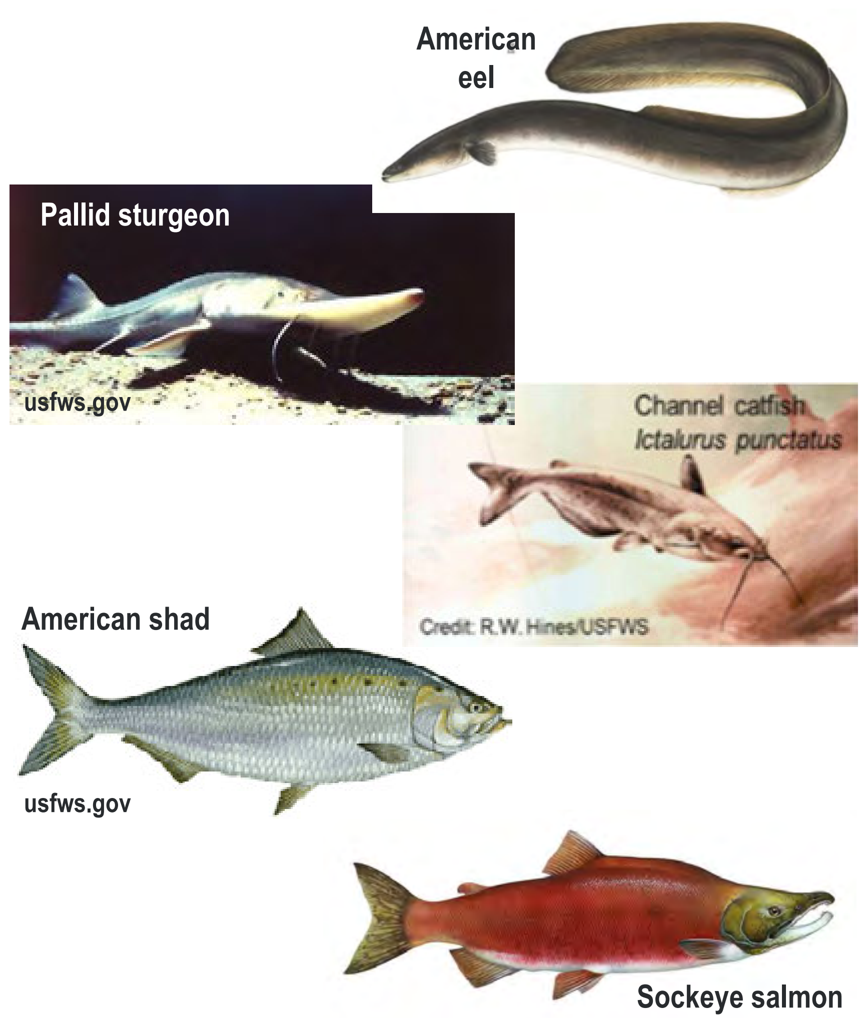
(Frimpong and Angermeier; McManamay; DeRolph)

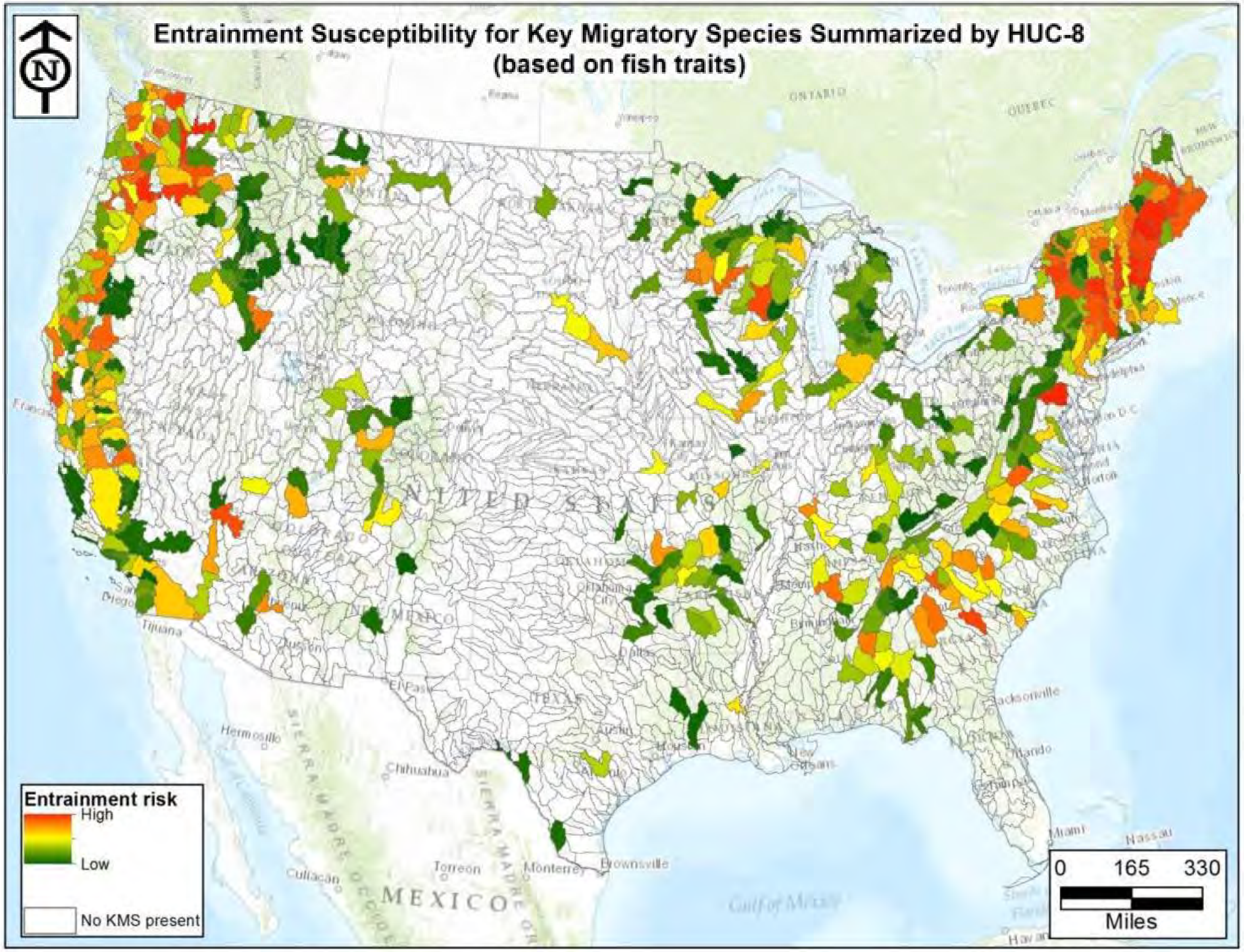
Fish Susceptibility to Entrainment
- Migratory habits
- Feeding habits
- Swim speed
- Habitat preference

Fish Sensitivity to Passage
- Swim bladder morphology (barotrauma)
- Size (strike)
- Integument (shear)

Turbine Threats to Entrained Fish
- Pressure change/Strike potential

Fish Population Sustainability
- Federal T&E Status
- NatureServe Conservation Status
- IUCN Categories
- Life history group





Entrainment Susceptibility for Key Migratory Species Summarized by HUC-8
(based on fish traits)
N
Entrainment risk
High
Low
No KMS present
0 165 330
Miles
MEXICO

Project Plan & Schedule

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

Summary	
1.9.1.2 Biological Design Criteria for	
New Hydropower Turbines	
Agreement 26883	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Milestone / Deliverable	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Current work and future research												
Update literature review and data needs analysis												
National spatial analysis of fish passage issues												
Complete model framework for fish passage												
Summarize year 1 results in technical report												

Comments

- Project original initiation date – Oct 1, 2013
- Currently funded through – Sept 30, 2015

Project Budget

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$300K	$0	$300K	$0

- Budget variances: None
- Initial funding Sept 2013.
- Project budget expended to date: ~5%
- Other funding sources: None

Partners, Subcontractors, and Collaborators:

Pacific Northwest National Laboratory (Marshall Richmond) is the lead for the project. ORNL's biological analysis is designed to complement PNNL's engineering/technology analysis of internal turbine conditions.

Communications and Technology Transfer:

- Hydrovision and AFS conferences, special workshop(s) with industry user groups, technical reports, and journal articles.

FY14/Current research:

- Continued development of **traits based analysis**.
- Continue "spatial analysis" on the **status of fish passage issues** in the U.S.
    - incorporate FERC license information from data mining task
- Work with PNNL to develop a **fish effects model** that will use time series of stressor exposure as predicted by CFD modeling and SF observations. This model will predict probability of injury and mortality for a variety of turbine conditions and designs.

Proposed future research:

For the second year of the project we will propose additional studies to address information deficiencies revealed in the 2014 analysis that help to better define the relationships between turbine conditions and biological response in fish.

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The Basin-Scale Opportunity Assessment (BSOA) Initiative

Simon Geerlofs and Gary Johnson
Pacific Northwest National Lab

February 27, 2014

Introduction

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

Problem: Hydropower and environmental protection/restoration goals are often at odds with one another—particularly at the site scale.

Impact: Identification of opportunities to increase hydropower ***and*** improve environmental conditions at the basin scale can reveal pathways for deployment of low impact or sustainable technologies.

Goal: From 2010 Sustainable Hydropower MOU: "*Identify ecosystems or river basins where hydropower generation could be increased* ***while simultaneously*** *improving biodiversity and taking into account impacts on stream flows, water quality, fish, and other aquatic resources.*"

Endpoint: Opportunity assessment approach, tools, and information that can be used to inform collaborative hydropower and environmental planning processes.

DOE Program objectives and priorities: Reduce deployment barriers and environmental impacts of hydropower.

Specifically, the project aligns with the **2010 Hydropower MOU:**

- Signed in March 2010, Sustainable Hydropower MOU highlights 7 key areas for interagency collaboration, including:
  - "Exploring opportunities for collaboration across entire river basins to increase generation *and* improve environmental conditions."

Objectives

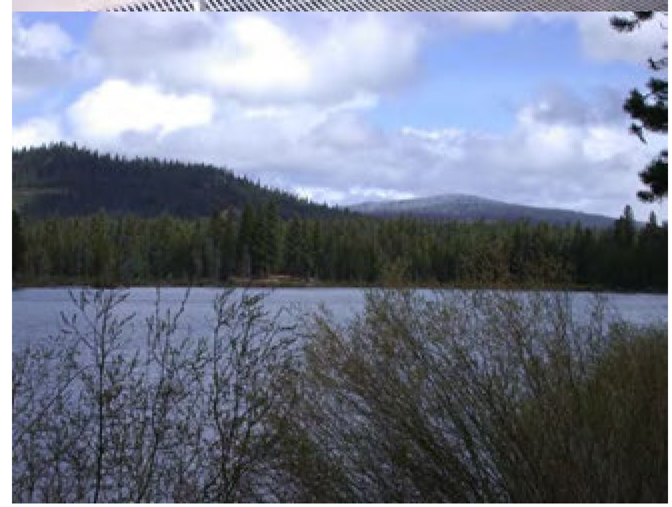
1A) Develop and export a multi-phase technical approach to basin scale hydropower assessment within the context of basin-wide environmental protection/restoration (FY11&12).

1B) Test approach through a pilot study in the Deschutes basin (FY12&13).

2A) Develop a specialized methodology for high-level Rapid Scoping Assessments (FY13).

2B) Apply Rapid Scoping Assessment methodology in the Connecticut and Roanoke basins (FY13) and the Big Horn basin (FY14).

3) Package and export methodology and approach through peer-reviewed products (FY14).



Technical Approach—Pilot Study

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ID Issues

High level scoping fed by stakeholders and literature

Opportunities

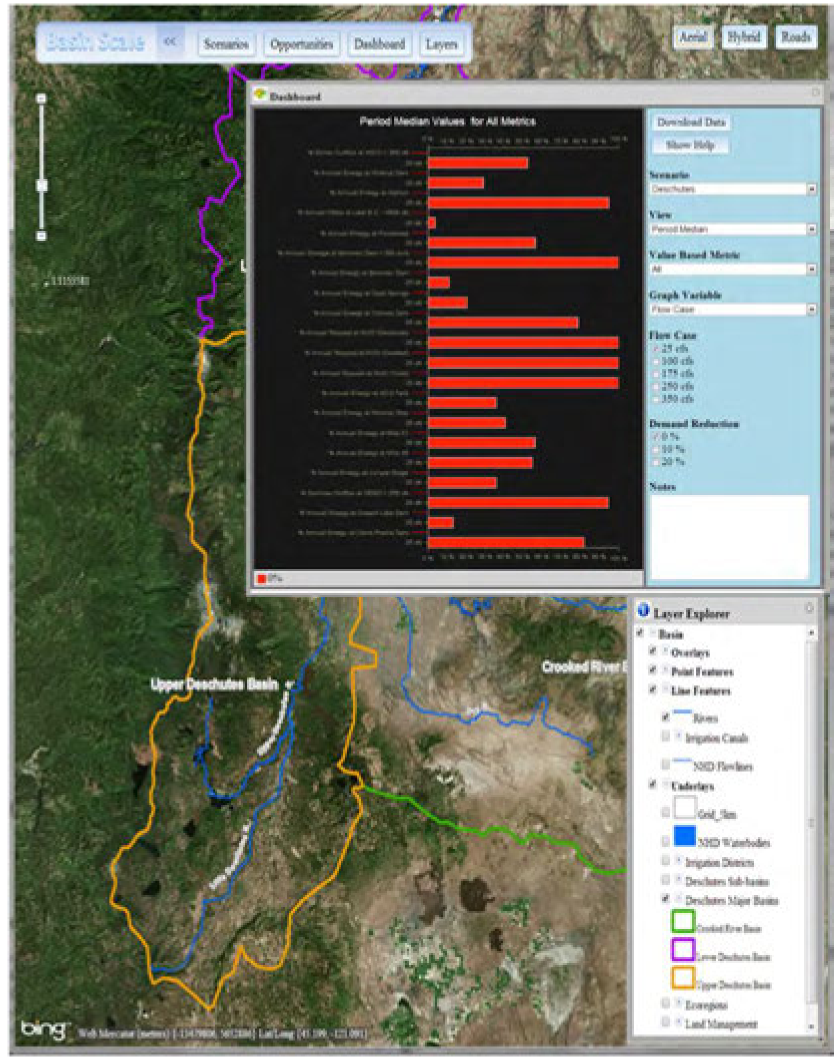
Hydro opportunities as well as opportunities to address environmental issues at site and basin scale

Scenarios

Determine common factors underlying hydro and environmental issues—define potential management scenarios to test integration of opportunities

Evaluate

Leverage existing data, develop operational models to evaluate scenarios—collaborative data visualization



Distilled Technical Approach

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- Through pilot study—ORNL and PNNL developed a three-phase technical approach for Basin Scale Opportunity Assessments.
- Each phase is intended to provide stand alone products and information useful to specific audiences.
- Each phase serves as a stage gate for subsequent steps.

Phase 1—Rapid Scoping Assessments (~120 day duration)

Phase 2—Stakeholder Engagement (3-6 months)

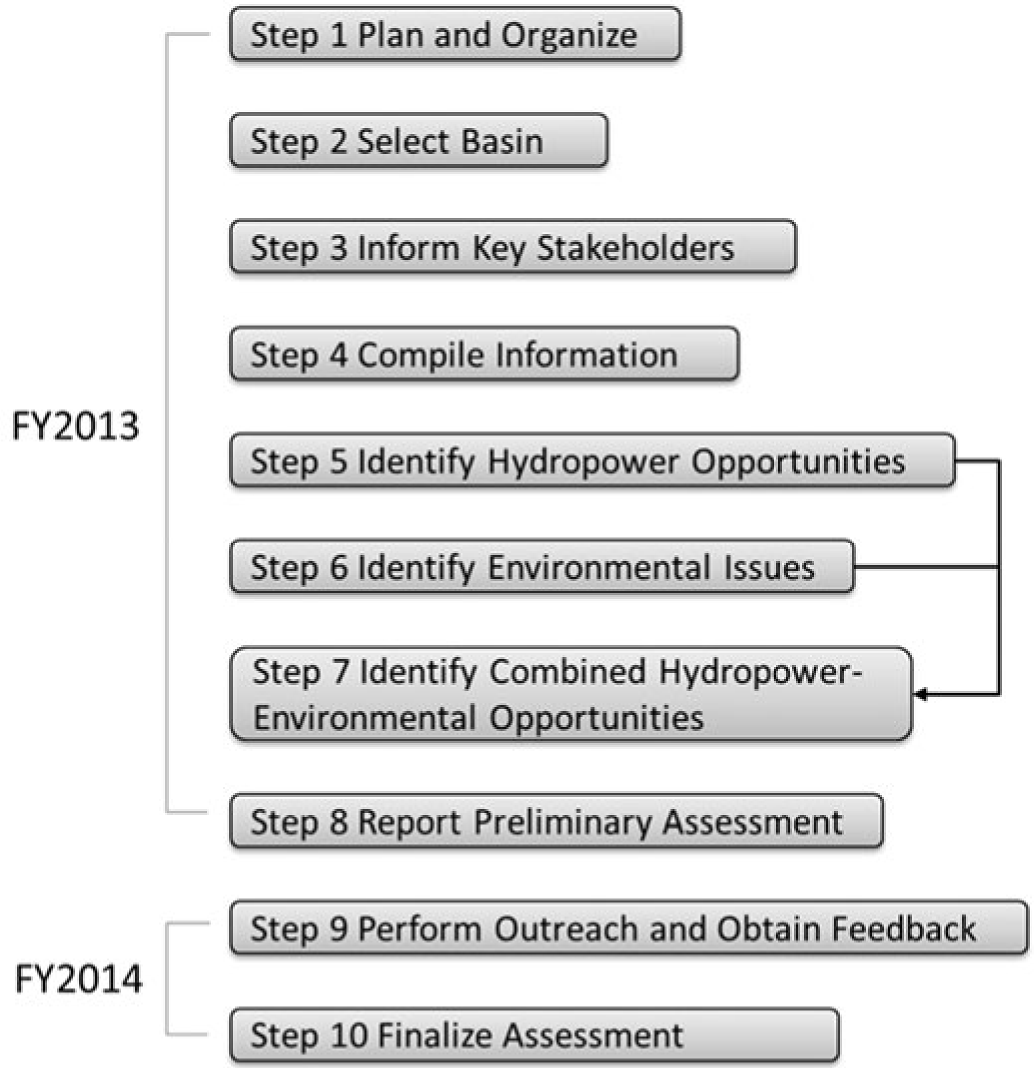
Phase 3—Full Technical Analysis (1-2 years)

Note: Much of the rest of the presentation will focus on Rapid Scoping Assessments in the Connecticut and Roanoke basins.

Technical Approach—Rapid Scoping Assessments

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

The intent of a Phase 1 Rapid Scoping Assessment for a given basin is to identify the stakeholder and hydrologic context, list and map possible hydropower opportunities and environmental issues in the basin, and perform geospatial analysis to identify potential combined hydropower-environmental opportunities.



Technical Approach: Phase 1 Combined Hydropower-Environmental Opportunities

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We developed a geospatially driven data model to examine spatially explicit interactions between hydropower opportunities and environmental issues to identify, combined hydropower-environmental opportunities.

Identify data elements

↓

Compile information

↓

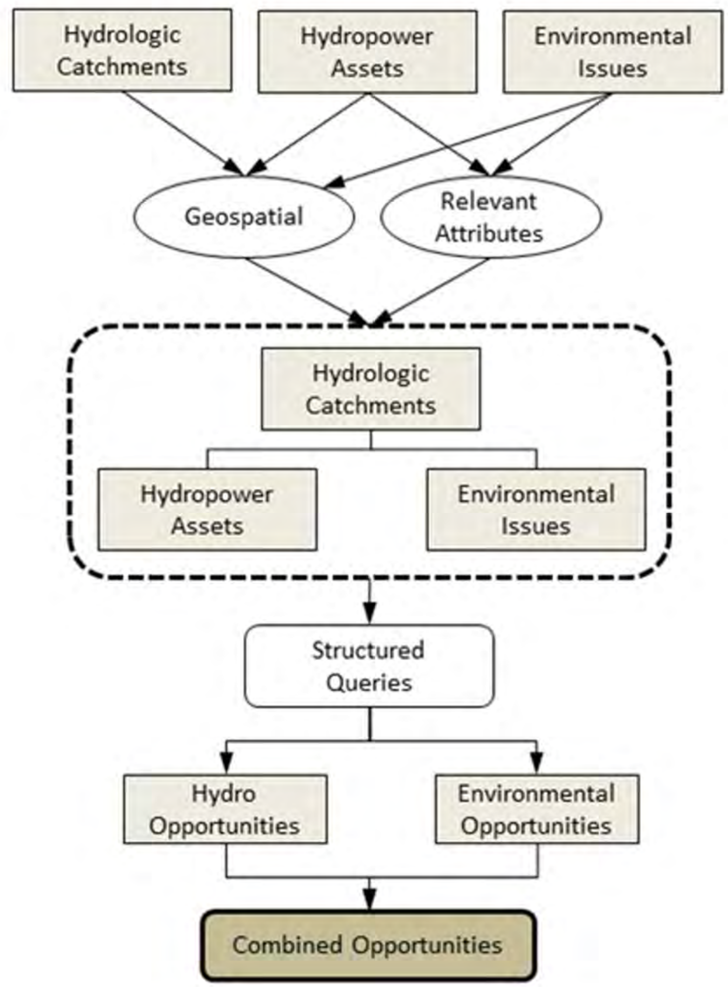
Generate relational geospatial database

↓

Define criteria for “win-win” opportunities

↓

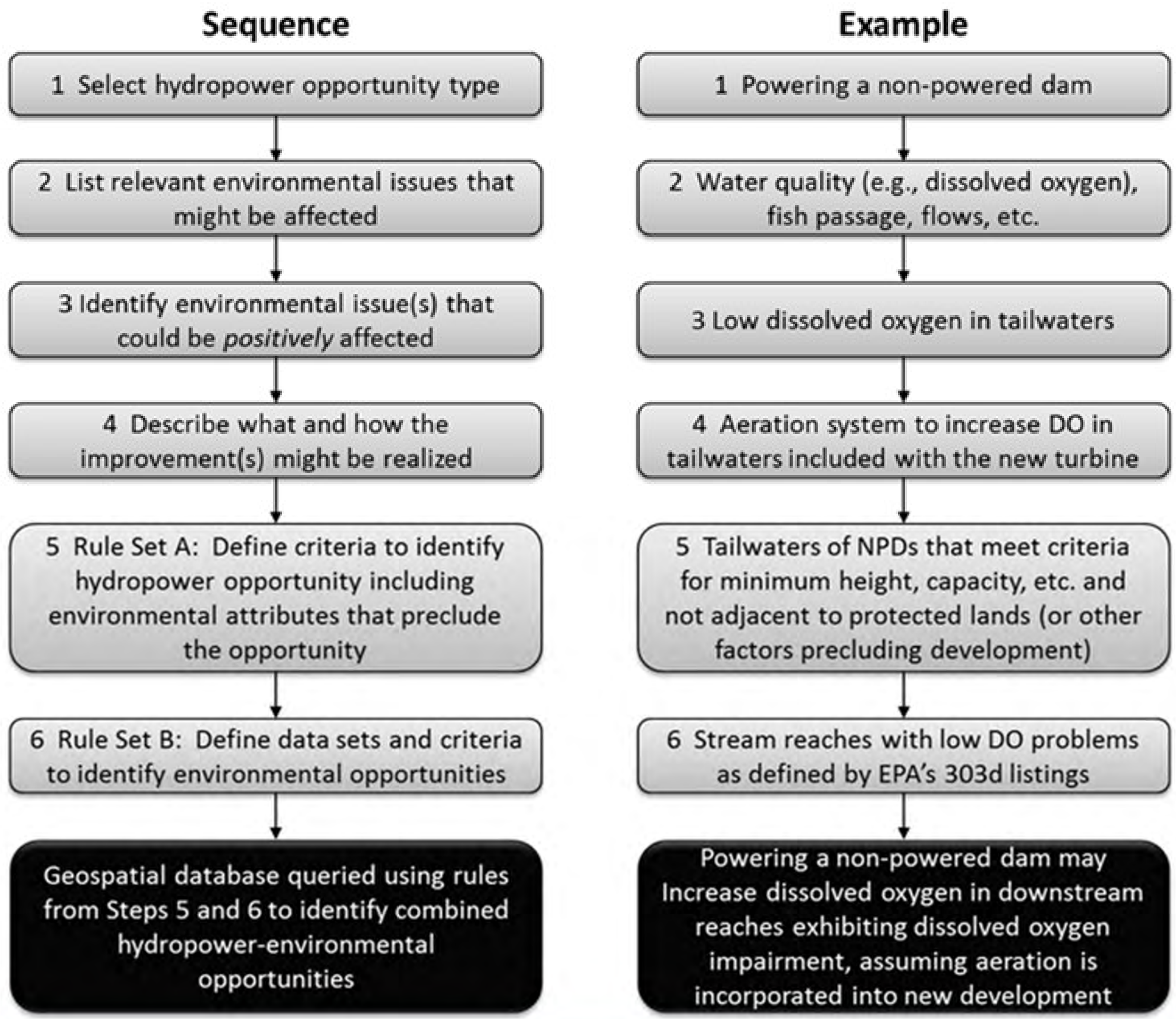
Perform structured queries



Technical Approach: Phase 1 Combined Hydropower-Environmental Opportunities

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

sequential process for identifying combined hydropower-environmental opportunities.



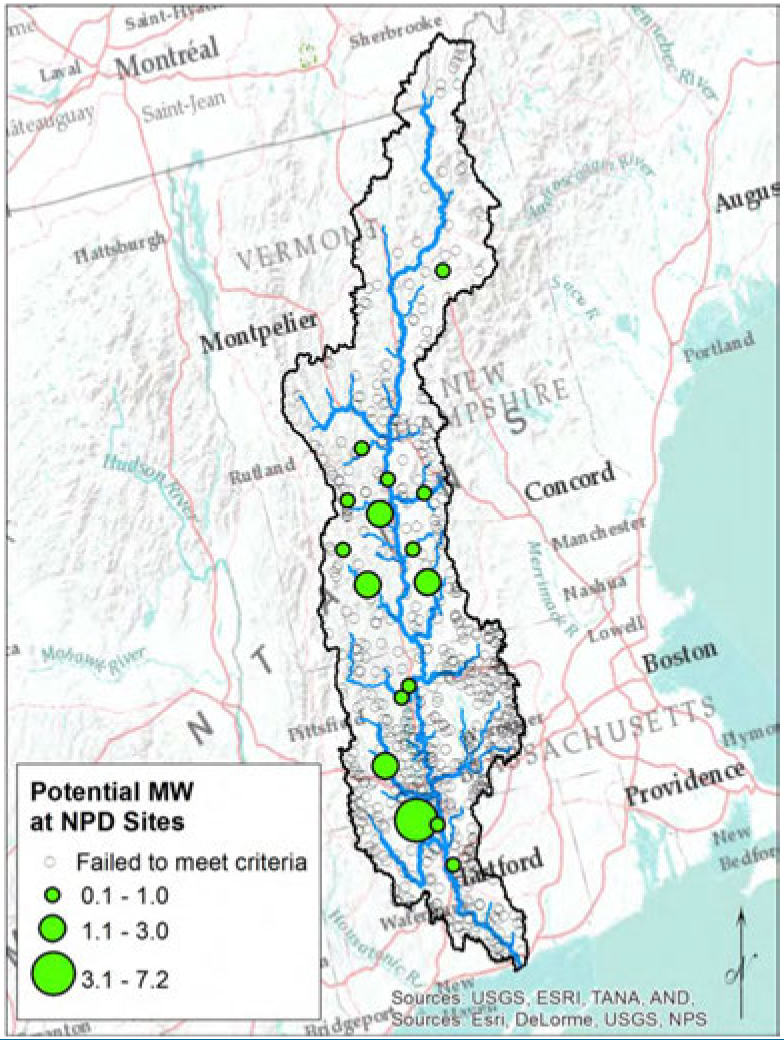
In FY12&13 for the Deschutes, the project team completed:

- a pilot assessment in Oregon’s Deschutes Basin;
- a unique and flexible geospatial data model to rapidly highlight the association between hydropower actions and environmental response;
- extensive stakeholder outreach activities to identify research needs and develop integrated scenarios for system-scale analysis;
- a daily hydrologic model that allows for exploration of hydropower development scenarios and concomitant effects on surface water flows.

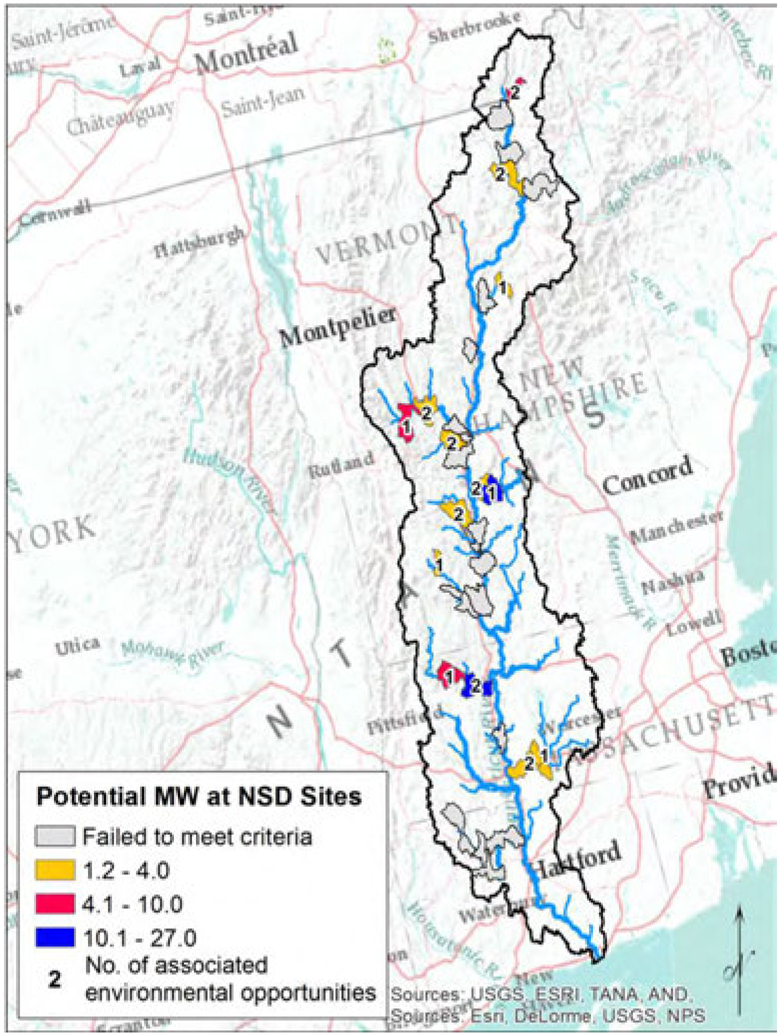
- In collaboration with ORNL, we developed a methodology for rapid scoping assessment and successfully applied it to the Connecticut (PNNL) and Roanoke (ORNL) basins.
- Connecticut results summary (ORNL to present Roanoke results):

Environmental Opportunity	Non-Powered Dams		New Site Developments	
	Number	MW	Number	MW
Total number and megawatts of sites that have at least one potential environmental opportunity**	17	20.7	20	35.2

Non-Powered Dams



New Site Developments



Project Plan & Schedule FY14

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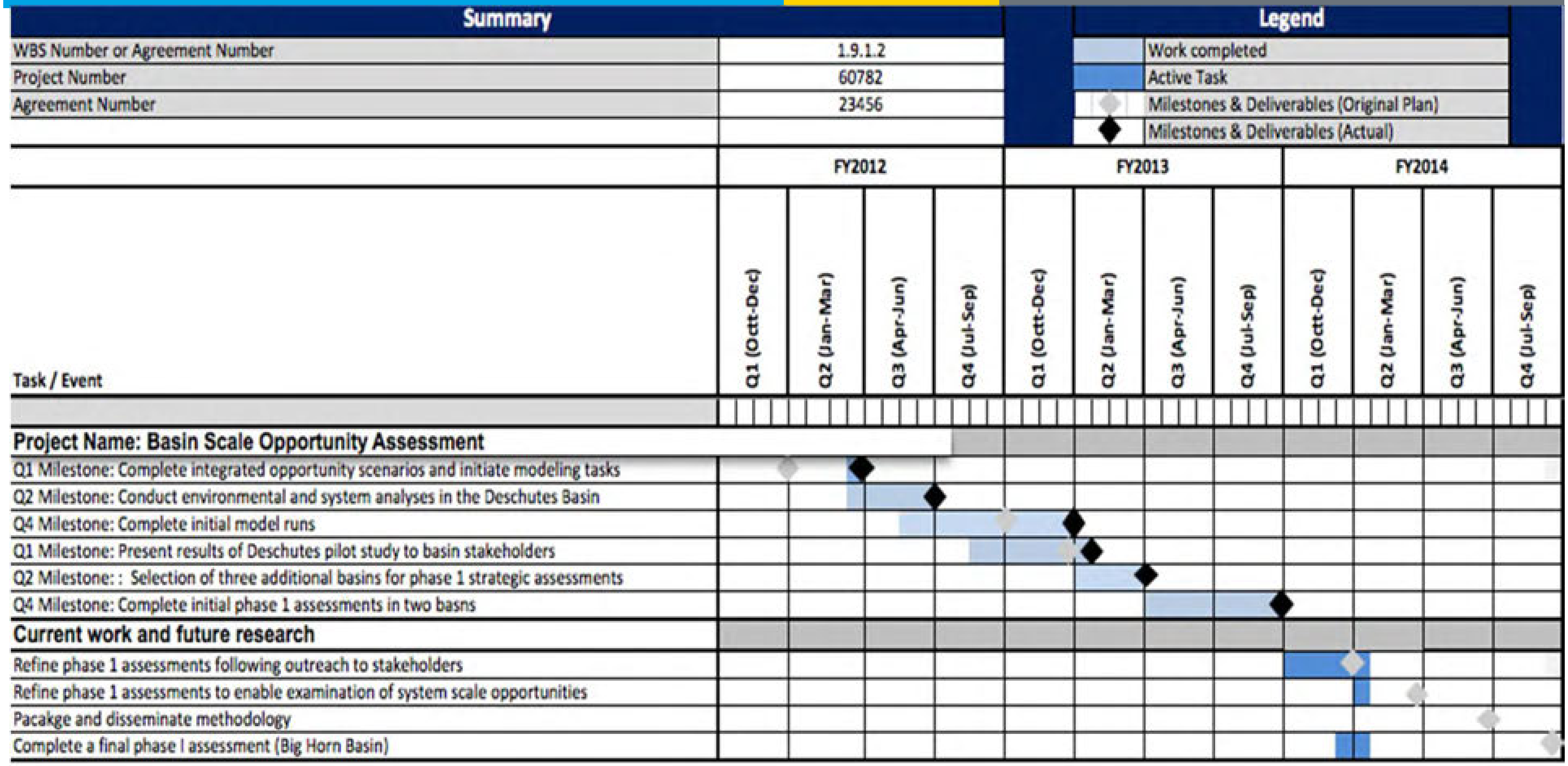

The project started in FY11 and will end in FY14.

Delays in FY 12 and into FY13 due to very late receipt of funding in FY 12 (Received in March, 2012 due to continuing resolution)

Milestone/ Deliverable	Q1	Q2	Q3	Q4
Phase 1 methodology refinements				
Outreach to CT and RO basins on preliminary FY13 Scoping Assessments				
Finalized CT and RO Scoping Assessments				
Scoping Assessment for Big Horn basin				
Packaging and dissemination				

Project Budget

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

1.9.1.2 Basin Scale Opportunity Assessment

Funding Type	FY12 Funding Level	FY13 Funding Level	FY14 Beginning Uncosted Obligations	FY14 Encumbered Balances	FY14 Funding Level	Total FY14 Funding Level	FY15 Funding Level	FY16 Funding Level
WC0100000	**$1,028,060**	**$221,940**	**$0**	**$0**	**$500,000**	**$500,000**	**$0**	**$0**
Operating	$1,028,060	$221,940	$0	$0	$500,000	$500,000	$0	$0
Project Total	**$1,028,060**	**$221,940**	**$0**	**$0**	**$500,000**	**$500,000**	**$0**	**$0**

- The project is ~80% spent to date.
- Spending has tracked budgets in all years
- There are no other funding sources.

Partners, Subcontractors, and Collaborators:

- Oak Ridge National Laboratory (Deschutes Pilot Study and Phase 1 Rapid Scoping Assessments)
  - Mark Bevelhimer, Chris Derolph, Ryan McManamay, Bo Saulsbury, Brennan Smith
- Argonne National Laboratory (Deschutes Pilot Study)
  - Tom Veselka

Communications and Technology Transfer:

- The results of the Deschutes Basin Pilot Study and the modeling tools developed for the study have been presented on multiple occasions to Deschutes basin stakeholders—RiverWare model serves as a flexible planning tool for the basin.
- Preliminary results of the rapid scoping assessment for the CT were presented in a webinar (January 2014).
- Journal articles on methods and results are being formulated.

Next Steps and Future Research

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

FY14/Current research:

- Refine Phase 1 methodology and apply to Connecticut (PNNL lead) and Roanoke (ORNL lead)
- Package and disseminate the BSOA methodology
- Complete an additional Phase 1 assessment (Big Horn basin)

Proposed future research:

- The project is scheduled to end in FY14 (September 2014).

Water Power Peer Review

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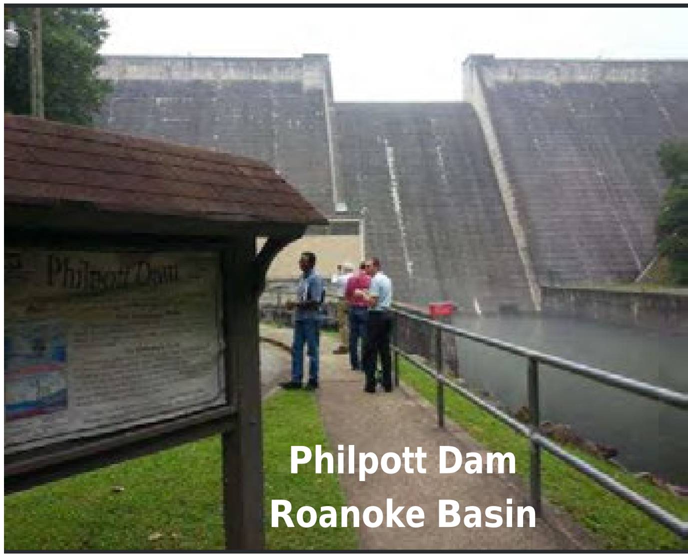


The Basin-Scale Opportunity Assessment (BSOA) Initiative

Mark Bevelhimer

Oak Ridge National Laboratory

bevelhimerms@ornl.gov, 865-576-0266

February 2014

OAK RIDGE National Laboratory

Introduction

Problem: Hydropower and environmental protection/restoration goals are often at odds with one another—particularly at the site scale.

Impact: Identification of opportunities to increase hydropower ***and*** improve environmental conditions at the basin scale can reveal pathways for deployment of low impact or sustainable technologies.

Goal: From 2010 Sustainable Hydropower MOU: "*Identify ecosystems or river basins where hydropower generation could be increased* ***while simultaneously*** *improving biodiversity and taking into account impacts on stream flows, water quality, fish, and other aquatic resources.*"

Endpoint: Opportunity assessment approach, tools, and information that can be used to inform collaborative hydropower and environmental planning processes.

Alignment

DOE Program objectives and priorities: Reduce deployment barriers and environmental impacts of hydropower.

Specifically, the project aligns with the **2010 Hydropower MOU:**

- Signed in March 2010, Sustainable Hydropower MOU highlights 7 key areas for interagency collaboration, including:
  - "Exploring opportunities for collaboration across entire river basins to increase generation *and* improve environmental conditions."

Objectives

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1A) Develop and export a multi-phase technical approach to basin scale hydropower assessment within the context of basin-wide environmental protection/restoration (FY11&12).

1B) Test approach through a pilot study in the Deschutes basin (FY12&13).

2A) Develop a specialized methodology for high-level Rapid Scoping Assessments (FY13).

2B) Apply Scoping Assessment methodology in the Connecticut and Roanoke basins (FY13) and the Big Horn basin (FY14).

3) Package and export methodology and approach through peer reviewed products (FY 14).

John Kerr dam and powerhouse on the Roanoke River

Technical Approach—Pilot Study

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ID Issues

High level scoping fed by stakeholders and literature

↓

Opportunities

Hydro opportunities as well as opportunities to address environmental issues at site and basin scale

↓

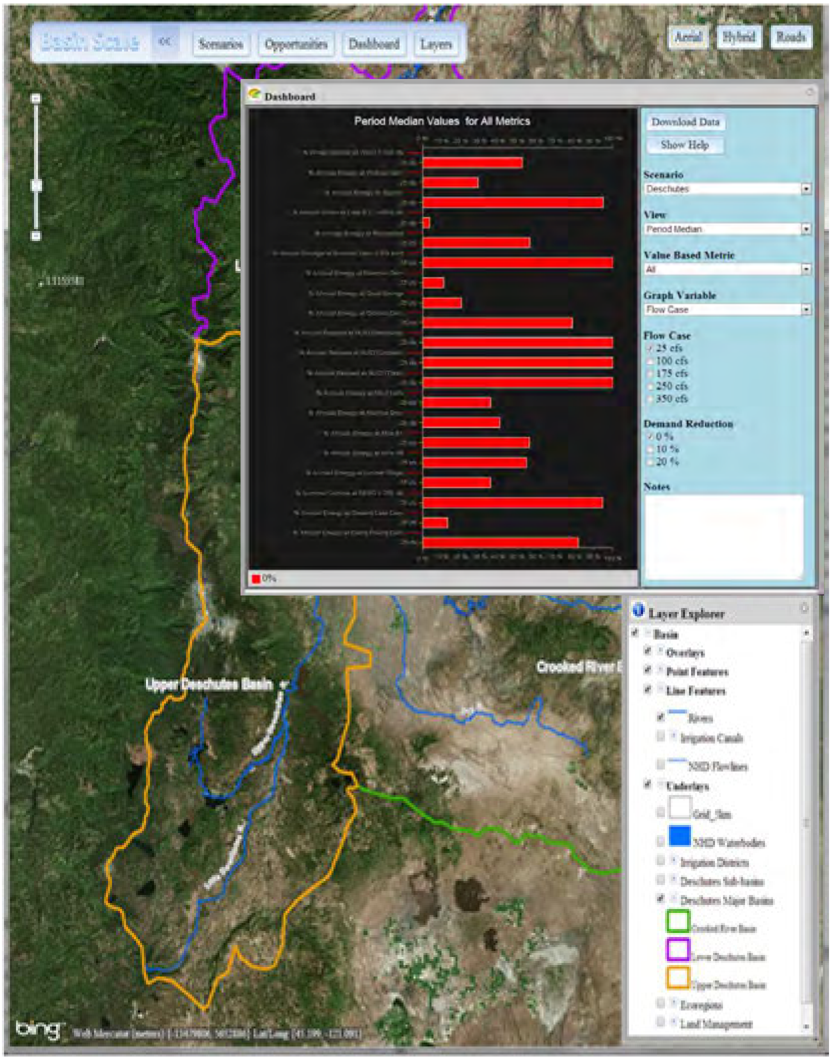
Scenarios

Determine common factors underlying hydro and environmental issues—define potential management scenarios to test integration of opportunities

↓

Evaluate

Leverage existing data, develop operational models to evaluate scenarios—collaborative data visualization



Distilled Technical Approach

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- Through pilot study—ORNL and PNNL developed a a three-phase technical approach for Basin Scale Opportunity Assessments.
- Each phase intended to provide stand alone products and information useful to specific audiences.
- Each phase serves as a stage gate for subsequent steps.

Phase 1—Rapid Scoping Assessments (~120 day duration)

Phase 2—Stakeholder engagement (3-6 months)

Phase 3—Full Technical Analysis (1-2 years)

Note: Much of the rest of the presentation will focus on Rapid Scoping Assessments in the Connecticut and Roanoke basins.

Technical Approach—Rapid Scoping Assessments

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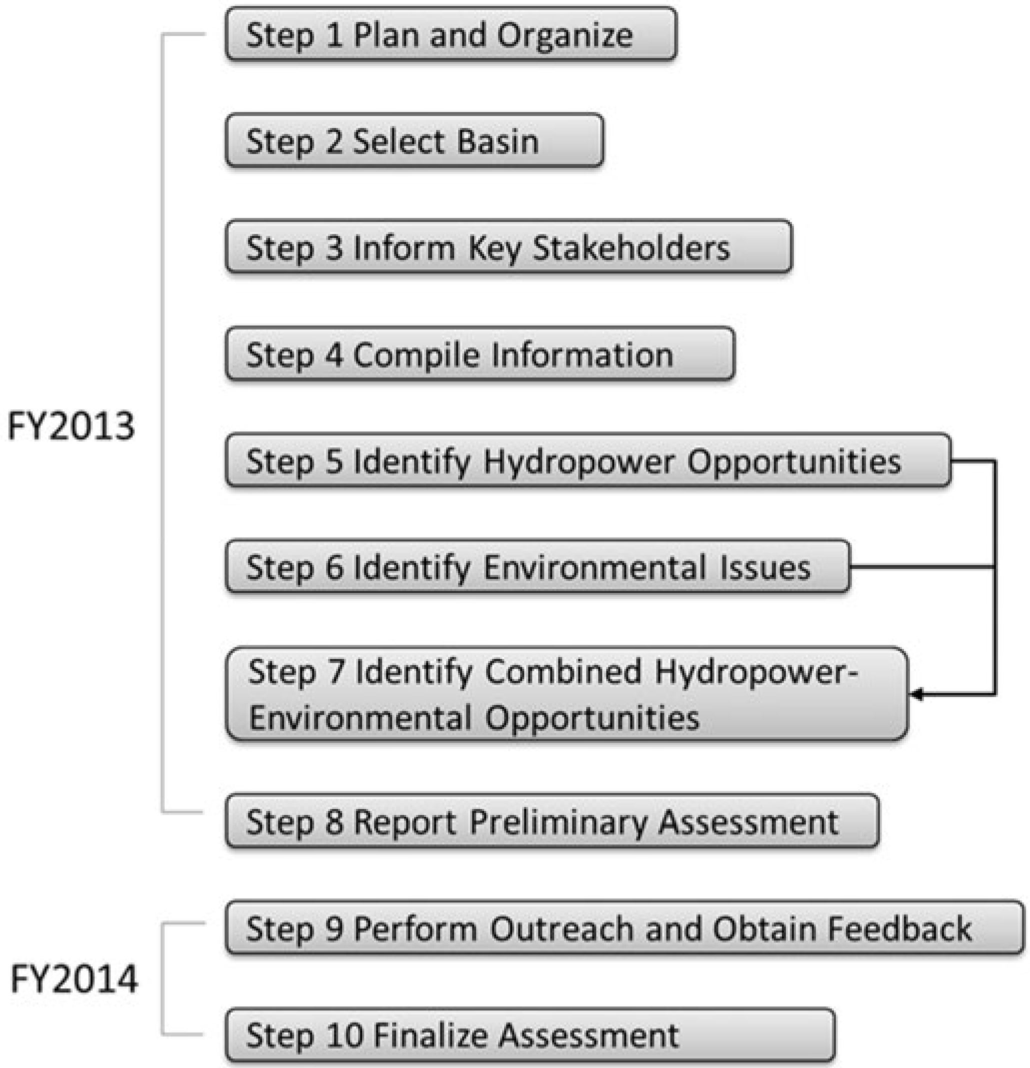
The intent of a Phase 1 Rapid Scoping Assessment for a given basin is to identify the stakeholder and hydrologic context, list and map possible hydropower opportunities and environmental issues in the basin, and perform geospatial analysis to identify potential combined hydropower-environmental opportunities.



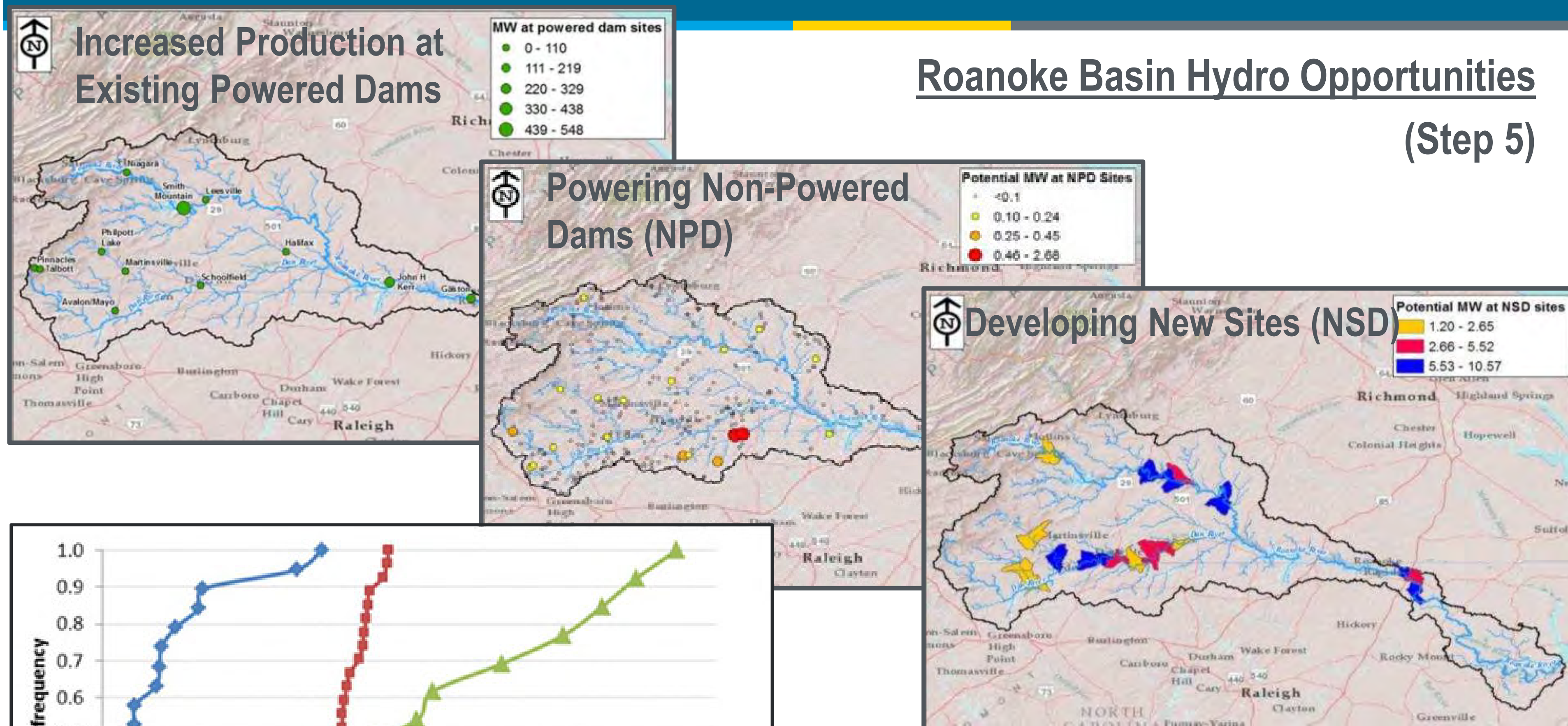
Accomplishments and Progress

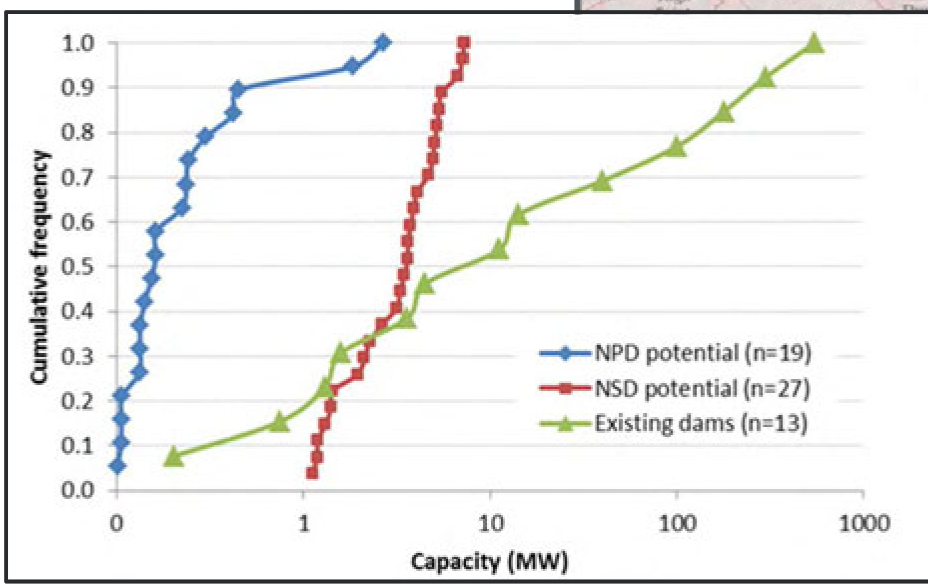
ORNL-Specific Accomplishments

- Contributed to Deschutes Basin final report
- Created tool for assessing and selecting U.S. basins as candidates for Phase 1 assessment demonstration (Step 3)
- Contacted Roanoke stakeholders and collected basin information (Steps 3 & 4)
- Compiled hydropower opportunity data from NHAAP database for Roanoke and Connecticut basins (Step 5)
- Compiled environmental opportunity data from NHAAP database for Roanoke and Connecticut basins (Step 6)
- Completed complementary hydro-enviro opportunities assessment for Roanoke basin (Step 7)
- Collaborated with PNNL to complete Phase 1 Methodology Report
- Presented preliminary results to USACOE staff during site visits to two USACOE projects in the Roanoke Basin (Sept 2013)

Roanoke Basin Hydro Opportunities

(Step 5)

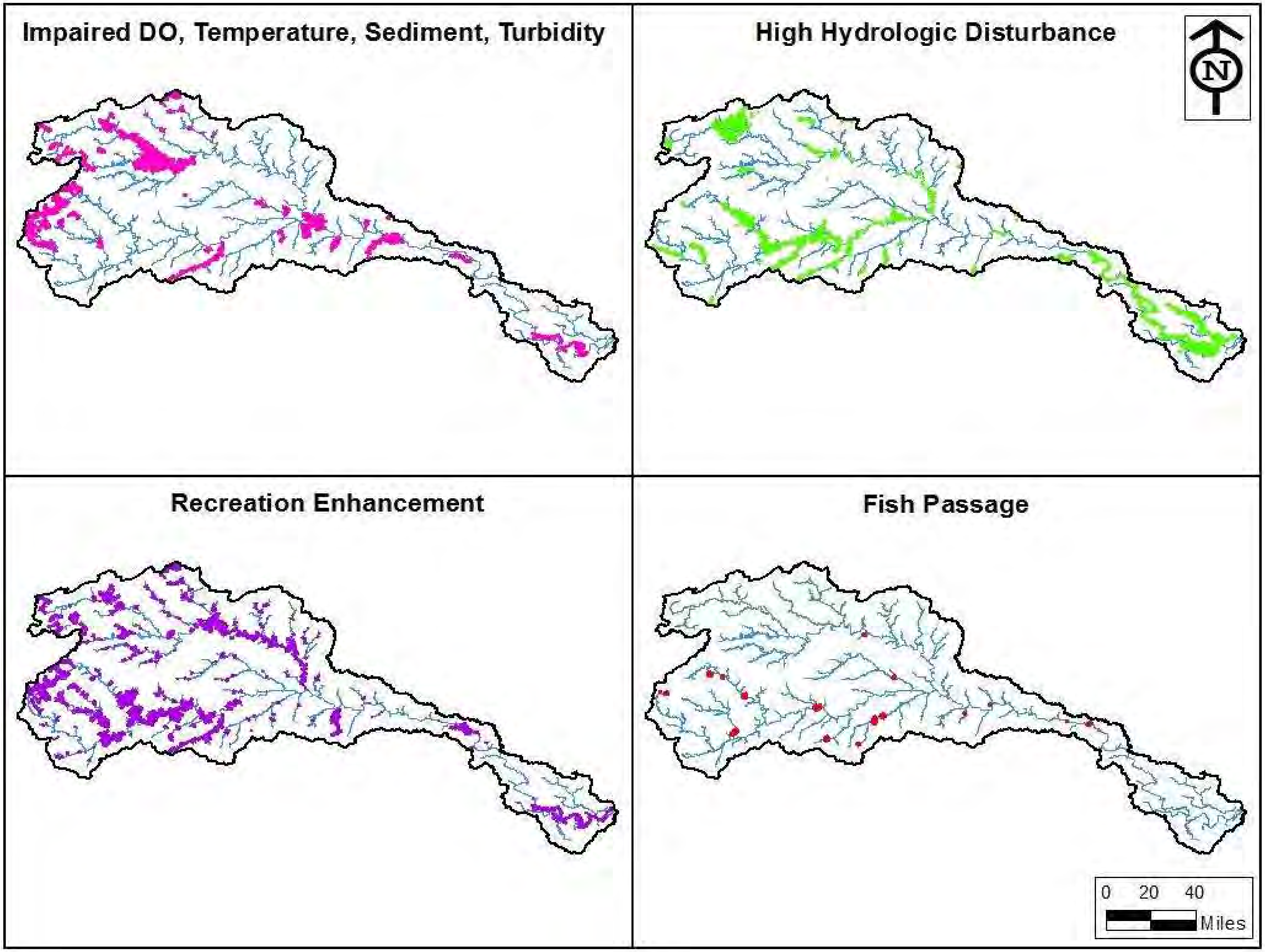




◀Generation capacity and potential

Accomplishments and Progress

Roanoke Basin Environmental Opportunities (Step 6)

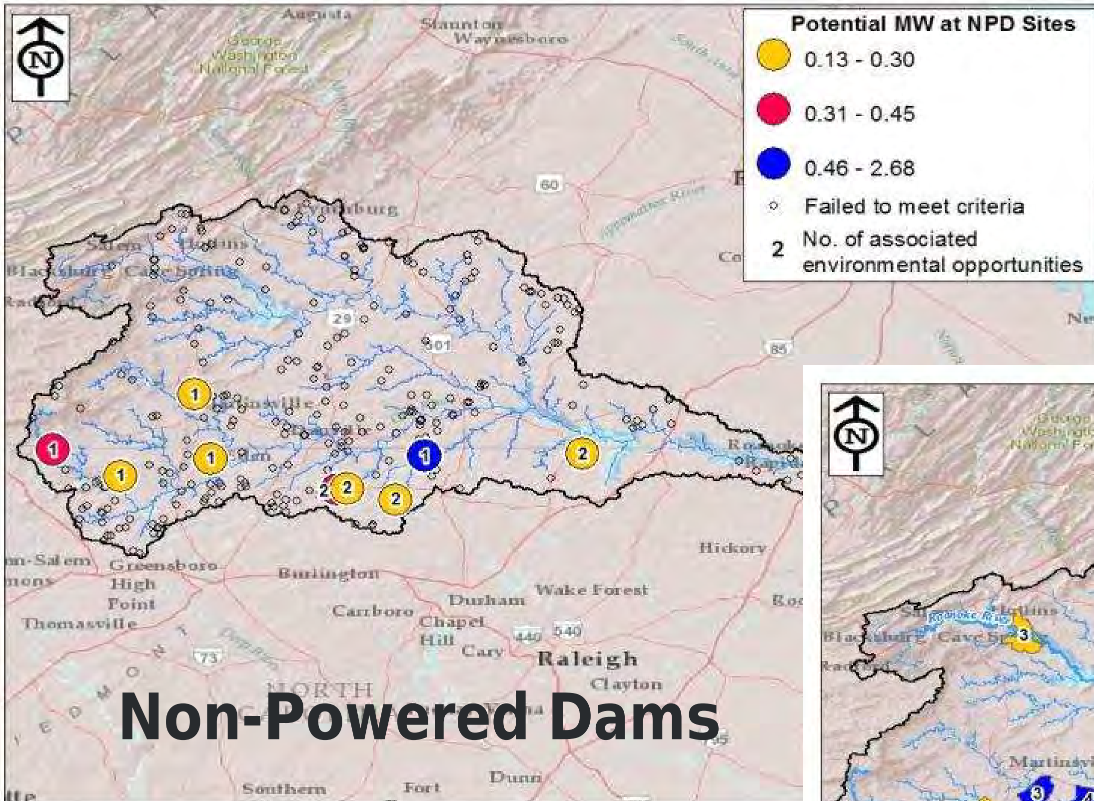


Complementary Opportunities (Step 7)

Environmental Opportunity	Non-Powered Dams (NDP)		New Site Development (NSD)	
	# Sites	MW	# Sites	MW
New development or adding a new turbine could provide better flow management in downstream reaches that have sedimentation or turbidity impairments.	3	0.85	2	2.51
New development or adding a new turbine could provide better thermal control in downstream reaches exhibiting temperature impairment.	1	0.42	0	0
New development/adding turbine could provide better flow management in downstream reaches exhibiting high hydrologic disturbance.	4	1.04	15	63.9
Adding hydropower operation could provide better flow management in existing whitewater paddling reaches below existing dams.	2	0.65	NA	NA
Assume improvements to fish passage can be made as part of project development, either through facility modification or dam removal.	2	2.98	0	0
New development/adding turbine could enhance existing trout population through stocking or habitat modifications.	2	0.69	NA	NA
New development/adding turbine could modify flows to provide new whitewater boating opportunity.	2	0.32	13	54.2
New development/adding turbine could create access to improve reservoir recreational fishing opportunity.	1	0.30	18	61.0
Total number and megawatts of sites that have at least one potential environmental opportunity	**9**	**4.8**	**27**	**97.6**

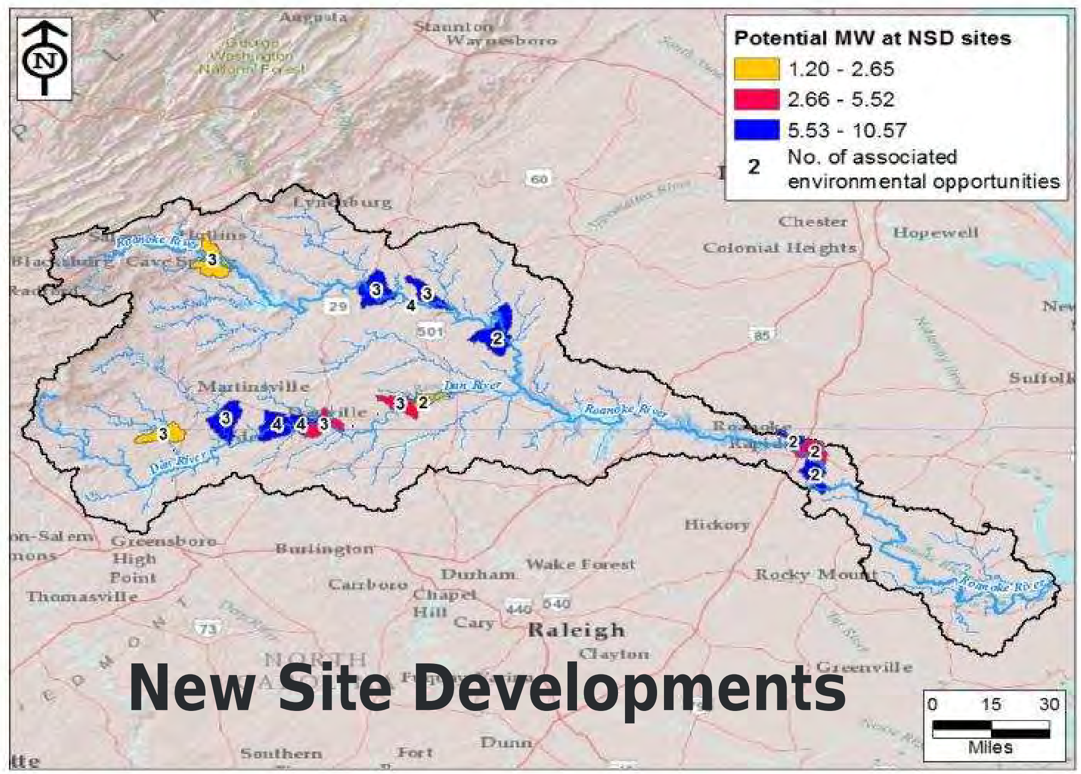
Accomplishments and Progress

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



Complementary Opportunities

9 NPD and 27 NSD opportunities identified



Project Plan & Schedule

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

Summary			Legend
1.9.1.3 Basin Scale Opportunity Assessment			Work completed
			Active Task
			Milestones & Deliverables (Original Plan)
Agreement 23466			Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Milestone / Deliverable	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Second Deschutes Basin Stakeholder Workshop												
Deschutes post-project report												
Roanoke Basin Strategic Analysis Report												
Roanoke Supplemental basin report												
Current work and future research												
Refine Phase 1 to enable rapid identification of opportunities												
Phase 1 scoping for Roanoke Basin												
Interactive panel at Hydrovision												
Report summarizing revised methodology and lessons learned												

Comments

- The project started in FY11 and will end in FY14.

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$325K		$325K		$350K	

- There have been no significant variances from the project budget
- To date 45% of the project budget has been expended.

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

- PNNL (project lead; Simon Geerlofs, Gary Johnson, Jerry Tagestad, Kyle Larson)

Communications and Technology Transfer:

- Presented preliminary results to USACOE staff during site visits to two USACOE projects in the Roanoke Basin (Sept 2013)
- Webinar for Roanoke Basin stakeholders (Jan 2014)
- Basin Scale Approach Symposium at national fisheries conference (Aug 2014)
- Planned publications on techniques and results

Next Steps and Future Research

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

FY14/Current research:

- Refine Phase 1 assessment
- Validate Phase 1 approach through stakeholder feedback
- Incorporate unaffiliated mitigation and connectivity opportunities
- Results and methods dissemination (publications and conference symposium)

Proposed future research:

- The project is scheduled to end in FY14 (September 2014).

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HYDRO RESEARCH FOUNDATION

Hydro Fellowship Program

Deborah Linke
Hydro Research Foundation
Contact Info: Deborah@hydrofoundation.org
720-722-0473
February 27, 2014

Purpose & Objectives

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

Problem Statement: Recognizing the need to stimulate new academic interest in hydropower and the large number of opportunities for employment due to aging workforce.

Impact of Project: Funding 43 researchers to conduct cutting edge research with 18 of 24 graduates entering the workforce and viable research findings for industry.

This project aligns with the following DOE Program objectives and priorities

Hydropower

- Advance new hydropower systems and/or components for demonstration or deployment
- Optimize existing hydropower technology, flexibility, and/or operations
- Enable next generation pumped storage technologies to facilitate renewable integration
- Reduce deployment barriers and environmental impacts of hydropower

Technical Approach

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

- Twelve person Steering Group from a broad array of industry and academic organizations.
- Nationwide recruitment of applicants from 1,200 contacts at 125 universities.
- On-line application process.
- Input on research topics coordinated with industry.
- Fellowship includes tuition & health insurance allowances, living stipend, advisor discretionary fund, and attendance at Fellows Roundtable & HydroVision.
- Fellows are provided a Steering Group and industry mentor relevant to research area.
- Program is widely publicized and has received support from five industry partners not envisioned in grant.

Accomplishments and Progress

- This nationwide program has funded a diverse group of 43 Fellows. In 2012-2013, 20 new Fellows joined the program. Of those, 24 have completed their work with the Foundation and their results are published online.
- Two research roundtables were held where Fellows presented findings and updates and were exposed to industry opportunities.
- Five partnerships were created with Avista Foundation, Knight Piesold, Weir American Hydro, US Army Corps of Engineers, and PennWell Corporation.
- Each Fellow has been paired with a mentor from industry ensuring a ready-made personal hydropower network.

Accomplishments and Progress

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

Year	2010	2011	2012	2013
# of applications	51	31	45	58
# of universities	34	20	19	29
# of Fellowships	9	14	10	10
# of participating universities	8	11	8	9
% Master's students	45	50	60	20
% Doctoral Students	55	50	40	80
# of graduates	5	6	5	8
# graduates working/seeking employment	4	5	4	5

Project Plan & Schedule

Comments

- Initiation date: January 1, 2010
- Milestones for 2012-2013
  - Award of third and fourth round of Fellowships-completed on time and to 20 students which doubles the original proposed reach.
  - Conduct Hydro Fellows Roundtable July or each year- Completed on time with unique learning opportunities and facility tours.
  - Publish findings to HRF Website- underway and progressing smoothly.
  - Cost/Time extension awarded to Foundation to continue work for $750,000.
- No slipped milestones or scheduling and no Go/no-go decision points for FY12 and FY13.

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,028,136	$0	$1,004,115	$31,072	$689,970	$44,336

- Addition of cost/time extension and cost-share contributions from industry partners.
- 77% of program budget has been expended to date.
- Receiving in-kind and cash contributions from five industry partners.

Partners, Subcontractors, and Collaborators:

Each Fellow has an academic advisor and university with whom they are working. The University are as follows:

- Alaska Pacific University
- Carnegie Mellon University
- Colorado School of Mines
- Colorado State University
- Cornell University
- Georgia Institute of Technology
- Lehigh University
- Montana State University
- Oregon State University
- The Pennsylvania State University
- University of California - Berkeley
- University of Colorado - Boulder
- University of Idaho
- University of Iowa
- University of Massachusetts - Amherst
- University of Minnesota
- University of New Mexico
- University of North Carolina - Chapel Hill
- University of Tennessee - Knoxville
- University of Washington
- Virginia Tech
- Washington State University
- Worcester Polytechnic University

Technical Approach cont.

The Foundation has created partnerships/mentorships with:

- Alaska Energy Authority
- Alden Laboratory
- Alstom
- US Army Corps of Engineers
- Avista Foundation
- Avista Corporation
- Bonneville Power Administration
- US Bureau of Reclamation
- Duke Energy
- Flow Science
- Golder and Associates
- Grant County PUD
- Hatch
- HDR Inc.
- Hydrologics
- Idaho Power
- Knight Piésold and Co.
- Oak Ridge National Laboratory
- PennWell Corporation
- San Francisco Water
- Sandia National Labs
- Weir American Hydro

Communications and Technology Transfer:

- Five Fellows presented at HydroVision 2012 in Louisville, KY, one presented on the highest rated panel during the event, and one received an award for his paper.
- Additionally, the program made 15 presentations during 2012.
- In 2013, seven Fellows presented at HydroVision 2013 in Denver, CO. The Program Director moderated the opening organizational update session in front of 3,000 delegates.
- The program has published all findings at www.hydrofoundation.org and received high publicity through industry publications such as *USSD Dam Safety*, *HydroReview*, and *NHA Today*.

Next Steps and Future Research

FY14/Current research: Working to finish Fellowships for 19 current Fellows in program and explore paths to continue programing through additional funding and broadening scope of educational opportunities. By December 2014, this grant will be complete and final results submitted.

Proposed future research: Work to expand programming efforts to under-graduates, continue focus on graduate level research, and continue to foster relationships within industry to keep this vibrant program growing.

Hydropower MA&D: Workforce and Education/Training Needs Assessment

Wind and Water Power Technologies Office
Hoyt Battey
2/27/14

Purpose & Objectives

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

Problem Statement:

- It is important to have a skilled and thoroughly educated workforce for the domestic hydropower industry that will support current infrastructure and potential future growth. U.S. hydropower workforce needs are varied and include positions in research, development, maintenance, education, operations, and siting.

- In recent years, there has been no comprehensive nation-wide assessment of the current workforce, the types of training, workforce development or educational opportunities available, or potential gaps that may exist given different scenarios for growth or development of the industry

Impact of Project:

- This project will help the hydropower industry to make well-informed decisions about potential strategies or investments in education, training and workforce development. U.S. universities and other federal government agencies that invest in developing STEM (Science, Technology, Engineering and Mathematics) curriculum are also particularly interested in overlap with the clean-energy sector.

This Project aligns with the following DOE Program objectives and priorities

Hydropower

- Reduce deployment barriers and environmental impacts of hydropower

Navigant Consulting

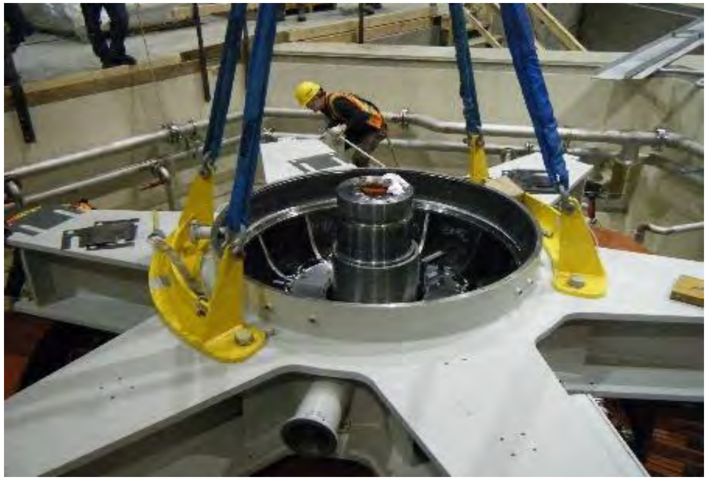
Workforce Development for Hydropower

Project Summary:

- Estimate size of current hydropower workforce
- Catalog skills, training and educational needs of hydropower workforce and how those are met
- Project potential size of hydropower workforce in 20 years (given different growth scenarios) and where skillset gaps may exist relative to today's workforce
- Determine if additional training/educational programs are needed to meet hydropower workforce needs for the next 20 years
- Ensure that the methodology of this study is well-aligned with similar projects for other U.S. clean-energy industries

DOE Funding	Cost-Share	Total Project Cost
$349,000 (+$100,000 to NREL)	$0	$449,000

Partners:
NREL



General Timeline

- Months 1-2
  - Define and assess employment at existing hydropower plants
  - Define and assess other hydropower employment
  - Catalog current skillsets and educational / training requirements
- Months 3-5
  - Survey and develop database of current training programs and education centers
  - Project potential hydropower industry growth scenarios to 2035
- Months 6-7
  - Estimate growth scenarios in workforce and changes in skills
- Months 8-10
  - Evaluate potential gaps in training / educational capacity
- Months 11-15
  - Finalize conclusions, deliver draft report, complete DOE concurrence and publish final report

Communications and Technology Transfer Plans:

- Goal of this project is to produce a joint Navigant / NREL / DOE report, with the intention of reaching more audiences
- Results will be presented at relevant industry conferences in 2015
- All projects are highly encouraged to submit research articles to peer reviewed journals for publication.

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New Project: Annual Hydropower Market and Trends Report

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02/27/2014

Oak Ridge National Laboratory

Purpose & Objectives: Problem Statement

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

Lack of an open-access, periodic report that communicates US hydropower market trends: development activity, supply chain evolution, fleet performance.

- Scattered information needs to be analyzed in broader context and processed into useful metrics

Successful market reports exist for other electric generation technologies (e.g., wind). Why not for hydropower?

- Hydropower's complexities (e.g., federal/non-federal divide in ownership, multipurpose nature of projects) complicate unified reporting
- Perception of lack of activity

Purpose & Objectives: Provide Context and Detail to Interpret Trends

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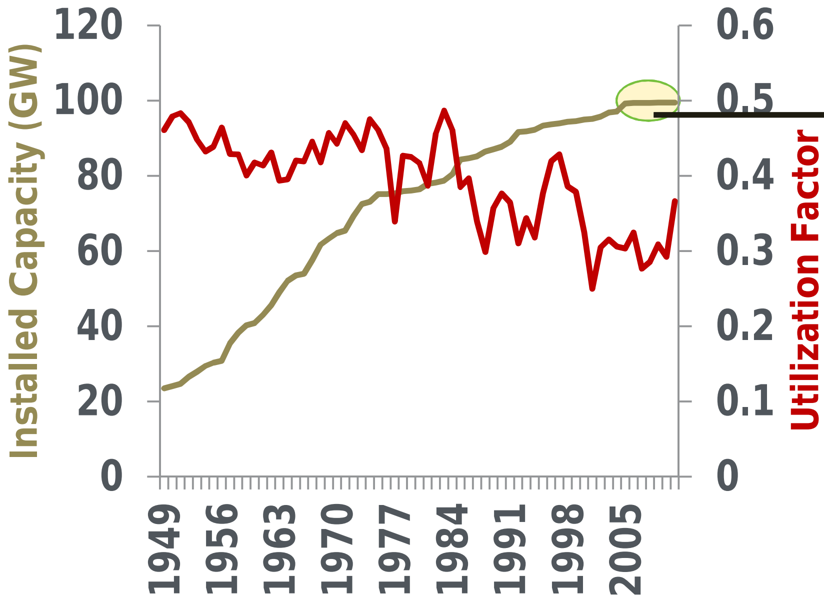
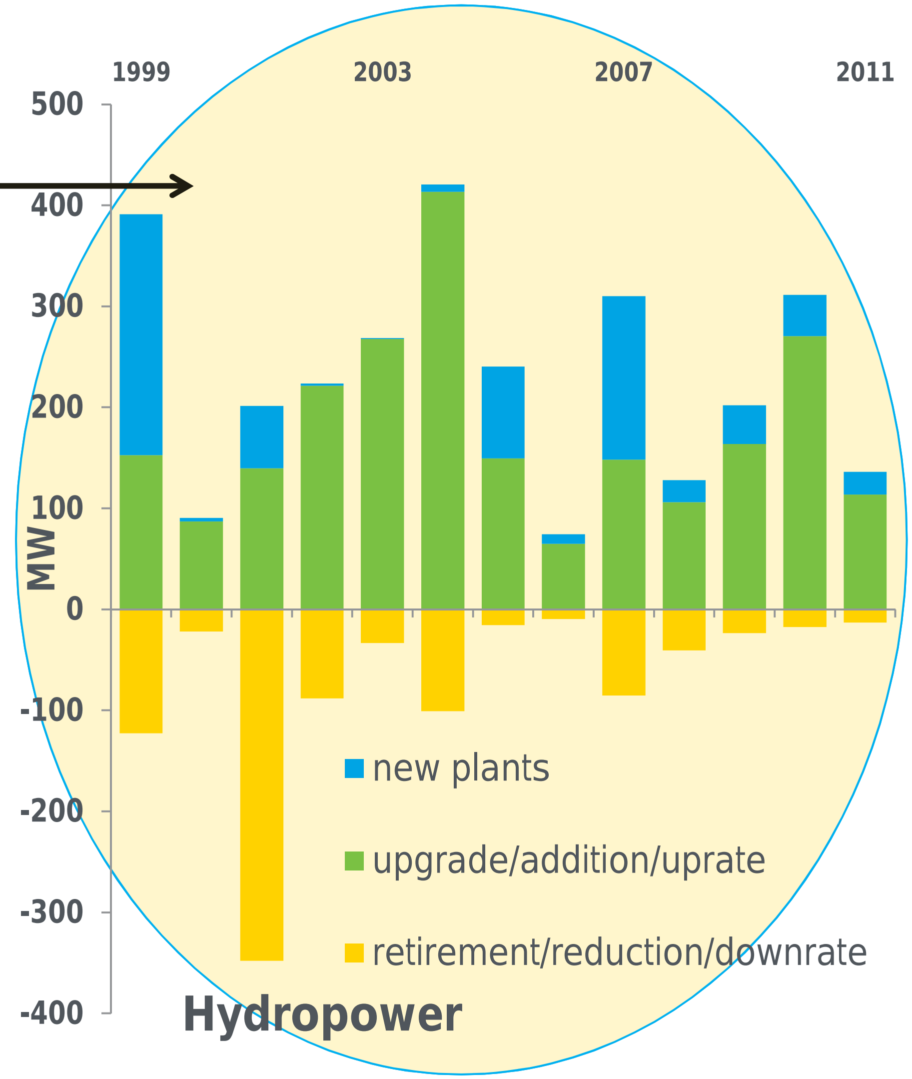
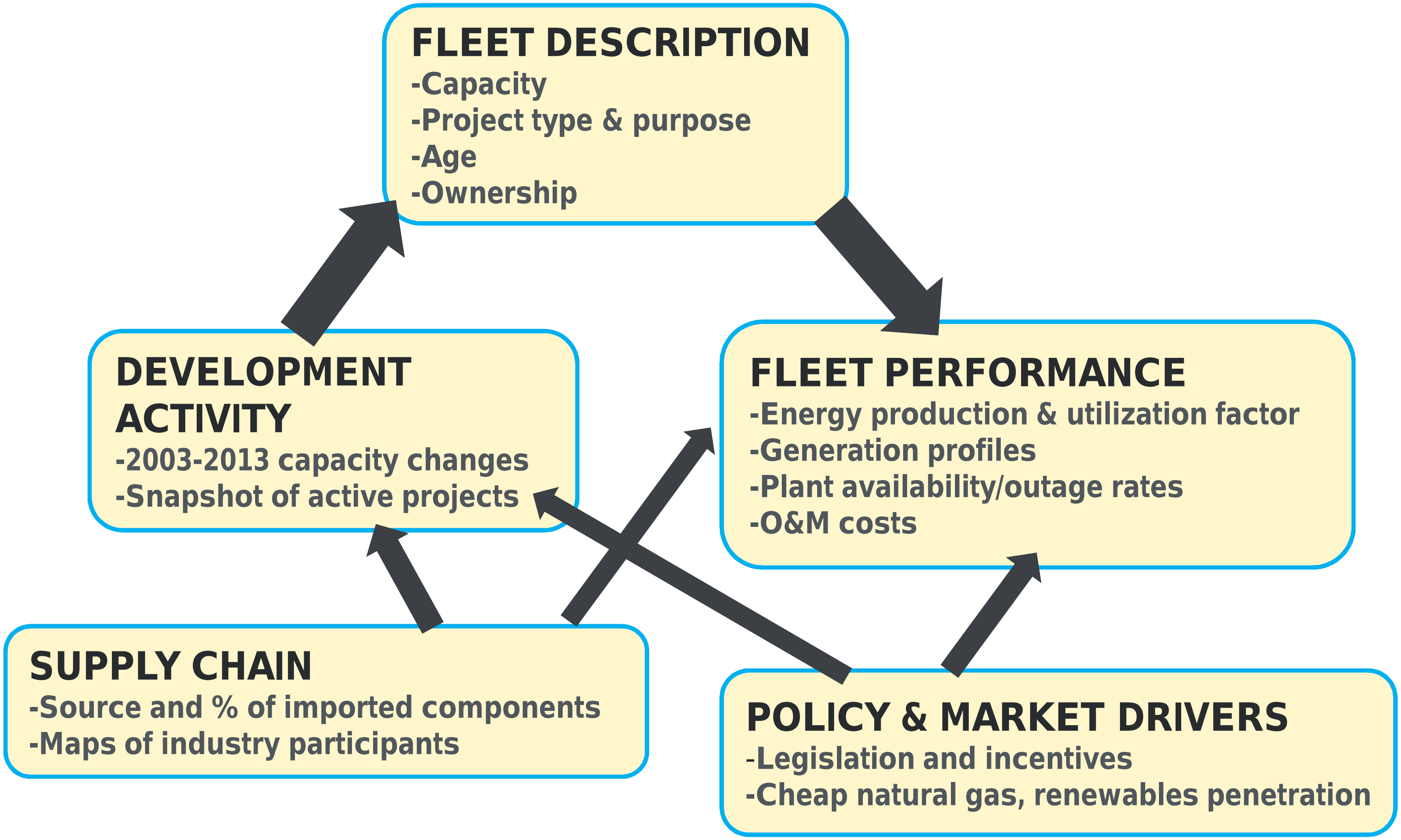




How should we interpret recent flat capacity level and overall decreasing trend in utilization factor?

Zooming in is necessary to provide useful answers but costly in terms of data gathering and analysis

Purposes & Objectives: Topics to be Covered



Purpose & Objectives: Project Impact

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1. Comprehensive updates on project portfolio and supply chain developments

   - Focus on aspects that are important for DOE's Water Power Program strategic goals

     (e.g., - technology choices in new projects
     - degree of dependence on imported components
     - attributes of successful vs. abandoned projects)

2. Metrics/indicators that reveal hydropower utilization patterns

   - Identify knowledge gaps and propose ways to address them

Medium-term objective: Becoming a reference publication for the hydropower industry

Purpose & Objectives: Alignment with DOE Program

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

This project aligns with the following DOE Program objectives and priorities

- *Optimize existing hydropower technology, **flexibility** and/or **operations***

  → By improving understanding of current hydropower utilization patterns and uncovering opportunities for improvement

- *Reduce **deployment barriers** and environmental impacts of hydropower*

  → By tracking the development pipeline and investigating and communicating the reasons why potentially sound projects drop from it

Technical Approach: Methods

- Construct robust databases that can be easily updated and facilitate analysis
  - Leverage synergies with other ORNL-Water Power Program projects (NHAAP, Cost Modeling, Strategic Planning)
- Seek consistency with other Water Power Program projects (e.g., cost breakdown structure, development categories)
- Create effective, information-dense visualizations to display metrics and trends
- Ensure replicability by providing documentation/metadata

Technical Approach: Classifications for Development Activity and Supply Chain

PROJECT STATUS

- **Pre-permit application**
- **License application**
- **Project development: PPA, financing, permits, interconnection agreements, engineering**
- **Construction/Installation**
- **Refurbishment**
- **Decommissioning/dam removal**

Which project development steps create most obstacles to new hydropower projects?

How many companies service the hydropower industry/fleet at each of these stages and where are they located?

PROJECT CATEGORIES

- **Greenfield projects**
- **Projects using pre-existing infrastructure (non-powered dams, conduits, capacity additions/upgrades on existing fleet)**

What fraction of total investment corresponds to each category?

Technical Approach: Performance Analysis

- Regression analysis of plant-level annual utilization factor (1998-2012) to identify the effect of various attributes:

  -HUC region (as a proxy for hydrology)
  -Size
  -Project type (storage vs. run of river)
  -Ownership (federal, cooperative, municipality, industrial, private utility, private non-utility)
  -Market structure (ISO vs. non-ISO)
  -Natural gas prices

- Utilization factor is an incomplete measure of hydropower's value to the electricity system
  (e.g., PSH (pumped storage hydro) often have low utilization factors but described as "jewels" in the system)

  -Hourly generation data better reveals how flexibly a plant/fleet is being operated
  -Hydropower also provides valuable ancillary services when is not generating

SCARCE AVAILABLE INFORMATION

Project Plan & Schedule

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

Summary	
1.6.2.2 Annual Hydropower Market and Trends Report	
Agreement 22647	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Milestone / Deliverable	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Current work and future research												
Summary of U.S. Hydropower Fleet												
Draft Hydropower Market and Trends Report Outline												
Draft Installation Trends Section												
Draft Industry Trends Section												
Draft Hydropower Market and Trends Report												
Metadata companion to Hydropower Market and Trends Report												

Comments

- Start date: September 1, 2013
- Planned completion date: FY15Q4 but, ideally, the Market Report will continue on subsequent years
- Draft of fleet description section delayed because detailed outline was still under discussion by the end of FY13Q4

Project Budget

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$1,091,000	$0	$0	$0

- Funding arrived late in September 2013.
- Portion of the project budget that has been expended to date: ~ 10%

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- **ORAU** (Oak Ridge Associated Universities)
  - Post-masters student to work on data collection and analysis
- **BCS, Inc.**
  - Organization of external review workshop
- **HRF** (Hydropower Research Foundation)
  - Participation in review process
- **IIR** (Industrial Info Resources)
  - Purchase of data on development activity and existing fleet outages
- **Industry Consortium**
  - Collaborative agreements to leverage O & M data

Communications and Technology Transfer:

- 1st Hydropower Market Report (December 2014)
- External review workshop (pre-publication)
- HydroVision/NHA Annual Conference (post-publication)
- Journal article on utilization factor analysis (FY15)

Next Steps and Future Research

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FY14/Current research:

- Complete the 1st Hydropower Market Report

- Incorporate feedback from workshop participants and report reviewers

- Identify questions to be addressed in subsequent report editions or through other research projects

Summary

The Hydropower Market Report aims to improve knowledge about hydropower's present to help DOE and the industry shape hydropower's future.

Outreach: Comprehensive picture of hydropower's development and performance trends put in the context of policy and market drivers and with attention also to supply chain configuration

Analysis: Understand

- driving factors of successful projects
- attributes of projects with highest utilization factors or more operational flexibility
- information gaps on hydropower utilization

Pumped Storage Hydro and Grid Integration

Wind and Water Power Technologies Office
Charlton Clark
February 27, 2014

Overview – Pumped Storage Hydro and Grid Integration

Goals – Define and demonstrate the benefits of new technologies in PSH

Priorities – Develop models of adjustable speed PSH for use by system planners, show the grid services provided by adjustable speed PSH, and provide information on the economic impact of adjustable speed PSH.

FY 14 Budget: $2M

DOE Unique Role – Provide unbiased technical information to support the deployment of PSH.

PSH/Grid Integration
Charlton Clark
Jim Reilly

Key Counterparts and Collaborators

NREL

ANL

INL

ORNL

Portfolio Priorities – Hydropower

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The 2014 Water Program Peer Review Agenda has sessions that will cover projects and activities in these priority areas.	
Advance new hydropower systems and/or components for demonstration or deployment	• Wednesday, 2/26
Optimize existing hydropower technology, flexibility, and/or operations	• Tuesday, 2/25
Enable next-generation pumped storage technologies	• Thursday, 2/27
Reduce deployment barriers and environmental impacts of hydropower	• Thursday, 2/27

Hydro Budget (FY 2012 – FY 2014)

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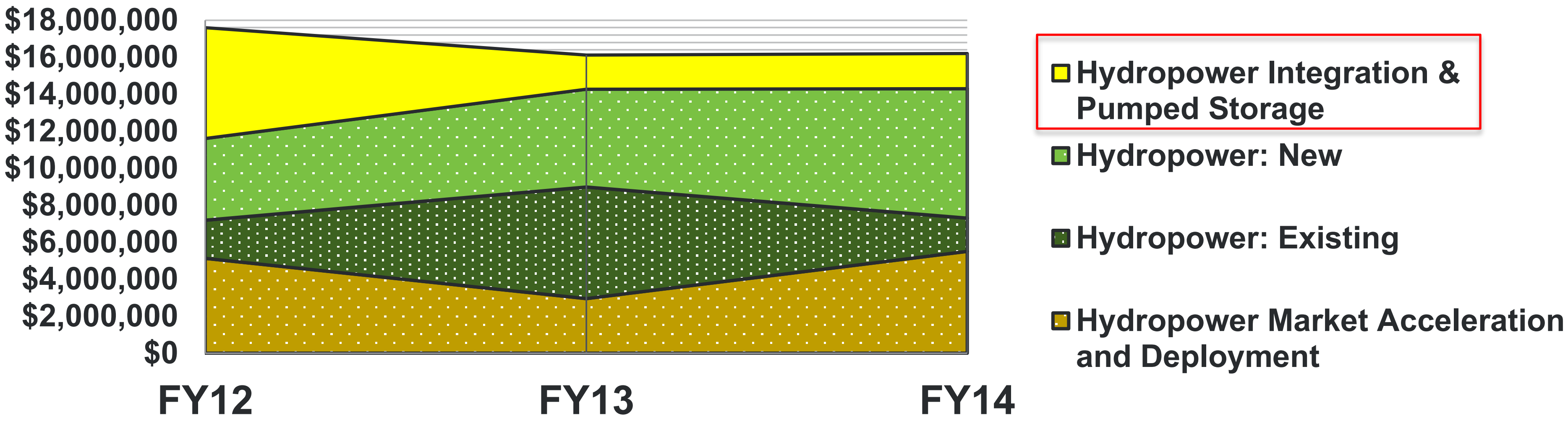
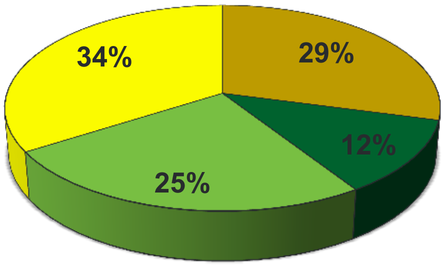
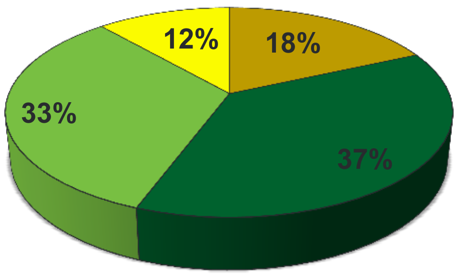
Hydro Budget by Thrust Area (FY 2012- FY 2014)



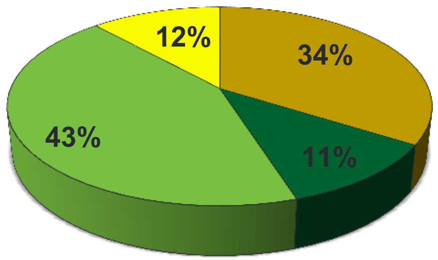
FY 2012



FY 2013



FY 2014



Main Elements of the PSH/Grid Integration Portfolio

Technical Area	Key Projects/Activities	FY14 Funding
8.1 Modeling Advanced Technologies	PSH Transient Simulation Modeling	$900k
8.2 Maximizing Existing Fleet Flexibility	N/A in FY’14	$0
8.3 Advanced Technology RD&D	Modular PSH Feasibility and Economic Analysis	$750k

Priorities in FY14 and Beyond

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Technical Area	Priorities or Changes in Portfolio FY11 vs FY14	Include key collaborators	Upcoming milestones
8.1 Modeling Advanced Technologies	New Focus Area Since FY'11	ANL, NREL, INL	Complete: Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the U.S.
8.2 Maximizing Existing Fleet Flexibility	Activities being defined for possible launch in FY'15	TBD	
8.3 Advanced Technology RD&D	New Focus Area: Exploration of the development of Modular PSH system	ORNL	Case Study on: Evaluation of feasibility and viability of MPSH

Evolution of the PSH/Grid Integration Portfolio

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The Program is working to increase the understanding of how adjustable speed PSH, MPSH, and other advanced technologies can be utilized to better ensure a reliable and economic power system:

- Technical Analysis
- Model Development
- Economic Analysis
- Information Sharing

PSH Agenda Overview

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Subject Area	Time	Topic	Presenter
Pumped Storage Hydro	2:25 PM	Modeling and Analysis of Value of Advanced PSH in the US	Vladimir Koritarov, Argonne National Laboratory (Lead)
	2:40 PM		Erik Ela, National Renewable Energy Laboratory
	2:50 PM		Question & Answer
	3:00 PM	BREAK	
	3:15 PM	Iowa Hill Pumped-Storage Project	Scott Flake, Sacramento Municipal Utility District
	3:35 PM	Real Time Market Analysis	Vladimir Koritarov, Argonne National Laboratory (Lead)
	3:50 PM		Erik Ela, National Renewable Energy Laboratory
	4:00 PM		Question & Answer

Technology Transfer

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ANL Lead Project: "**Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the U.S.**" had developed non-proprietary vendor neutral models of Adjustable Speed PSH and has installed these models in two commonly used power system software packages (PSLF, PSEE)

Questions for the Peer Review Panel

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Are these the right types of investments for DOE to be making in PSH?

What additional areas, if any, should we be working on?

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Modeling and Analysis of Value of Advanced PSH in the U.S.

Project Team: Argonne National Laboratory, Energy Exemplar, LLC, MWH Americas, Inc., National Renewable Energy Laboratory, Siemens PTI, Inc.

8.1.1 Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the U.S.

Vladimir Koritarov

Argonne National Laboratory
koritarov@anl.gov
630-252-6711
February 24-28, 2014

Purpose & Objectives

Problem Statement: Develop detailed models of advanced PSH plants to analyze their technical capabilities to provide various grid services and to assess the value of these services under different market structures.

Main Objectives:

- Improve modeling representation of advanced PSH plants in power system and electricity market simulation models
- Quantify their technical capabilities to provide various grid services
- Analyze the value of these services under different market conditions and levels of variable renewable generation (wind & solar) in the system
- Provide information on full range of benefits and value of PSH plants

This project aligns with the following DOE Program objectives and priorities:

- Optimize existing hydropower technology, flexibility, and/or operations
- Enable next generation pumped storage technologies to facilitate renewable integration

Project Impact

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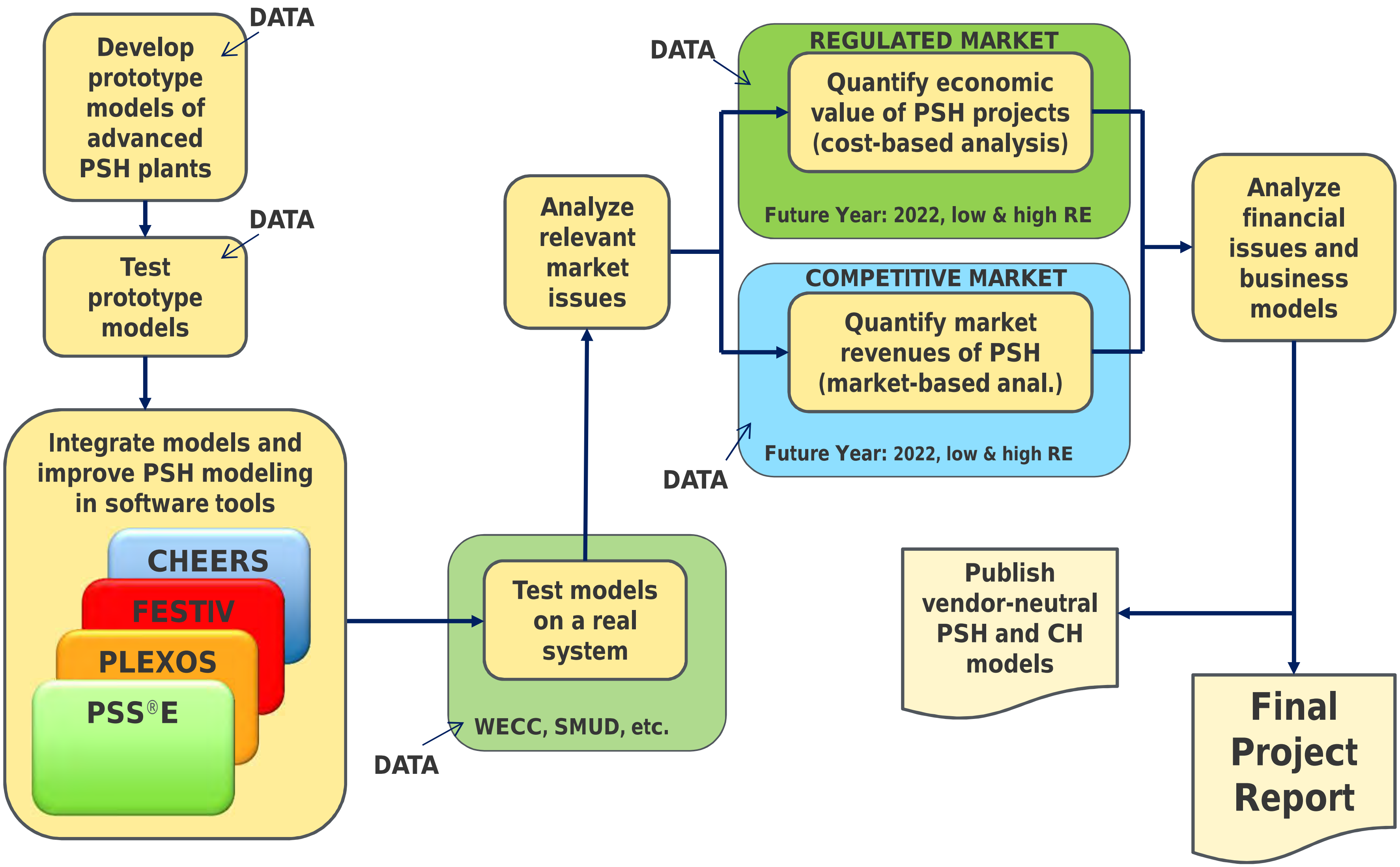
- Provided hydro industry with cost-free dynamic models of advanced PSH technologies (adjustable speed and ternary PSH units). These models were previously not available in the U.S.
- Enabled modeling of dynamic responses of advanced PSH technologies, necessary for preparation of feasibility and transmission interconnection studies of new PSH projects
- Integrated new dynamic models into the PSS®E software to be distributed as part of standard PSS®E library of models.
- Published vendor-neutral dynamic models and made them available (as block diagrams and transfer functions) for integration into other software packages.
- Improved modeling representation of PSH plants in other power system and electricity market simulation tools (PLEXOS, FESTIV, CHEERS).
- Provided information to hydro industry and other stakeholders on the full range of benefits and value of PSH plants in the system.

Technical Approach – Schematic Flowchart of Project Tasks



Organization of Project Team and Task Force Groups

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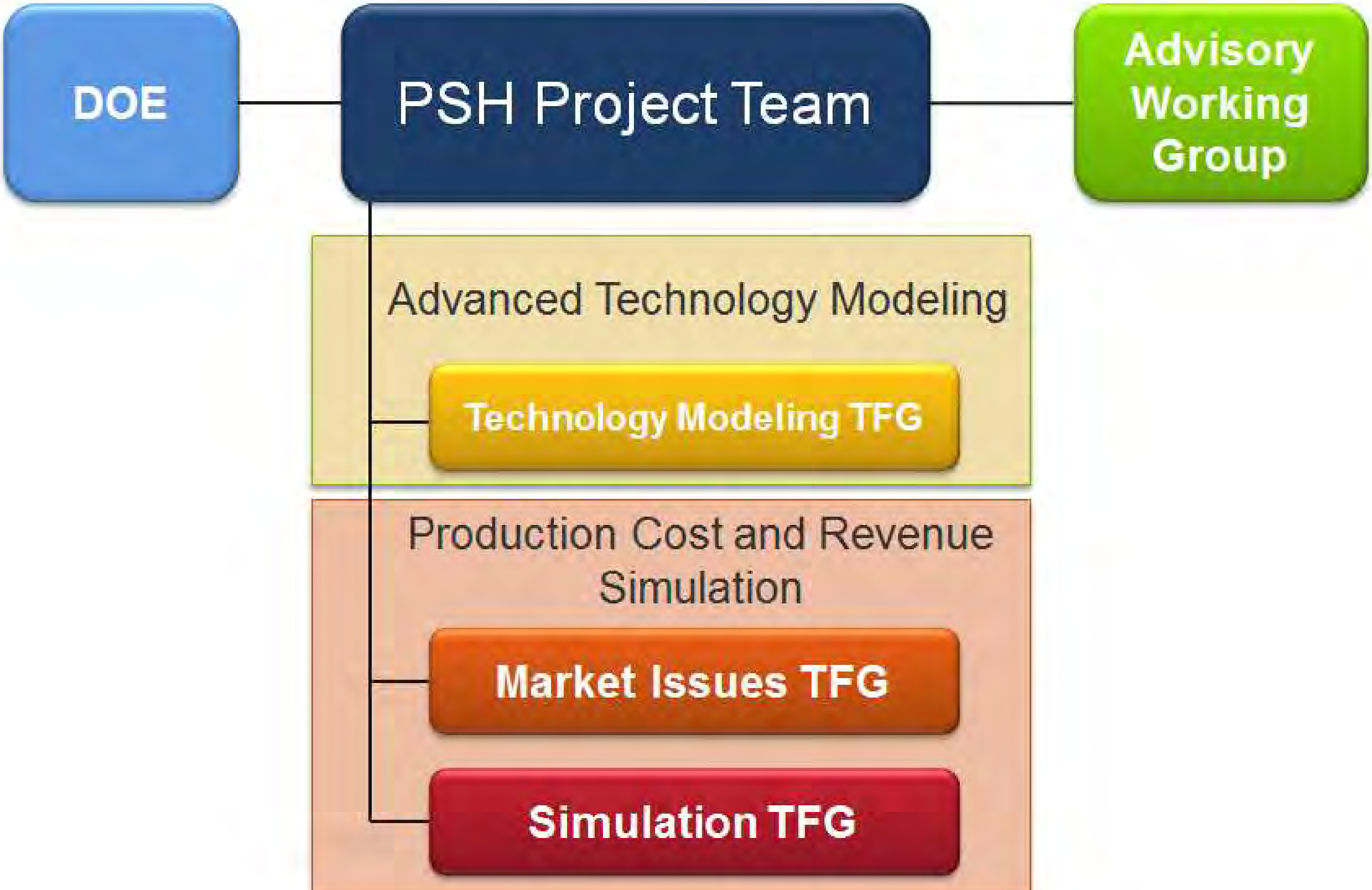

Advisory Working Group Members

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

Michael Reed, DOE/EERE	Zheng Zhou, MISO	Jiri Koutnik, Voith Hydro
Rajesh Dham, DOE/EERE	Matt Hunsaker, WECC	Rick Miller, HDR
Charlton Clark, DOE/EERE	Tuan Bui, CDWR	Rick Jones, HDR
Rob Hovsapian, DOE/EERE	David Harpman, BOR	Christophe Nicolet, PVE
Rachna Handa, DOE/OE	Kyle L. Jones, USACE	Peter McLaren, CAPS
Rahim Amerkhail, FERC	Scott Flake, SMUD	Landis Kannberg, PNNL
Michael Manwaring, NHA	Greg Brownell, SMUD	Klaus Engels, E.ON
Douglas Divine, NHA	Paul Jacobson, EPRI	Kim Johnson, Riverbank Power
Mark Jones, BPA	Alan Soneda, PG&E	Steve Aubert, ABB
Elliot Mainzer, BPA	Osamu Nagura, HM-Hydro	Le Tang, ABB
Xiaobo Wang, CAISO	Teruyuki Ishizuki, Toshiba	Ali Nourai, DNV KEMA
Debbie Mursch, Alstom		

Analysis Addressed Wide Range of Control Issues & Timeframes

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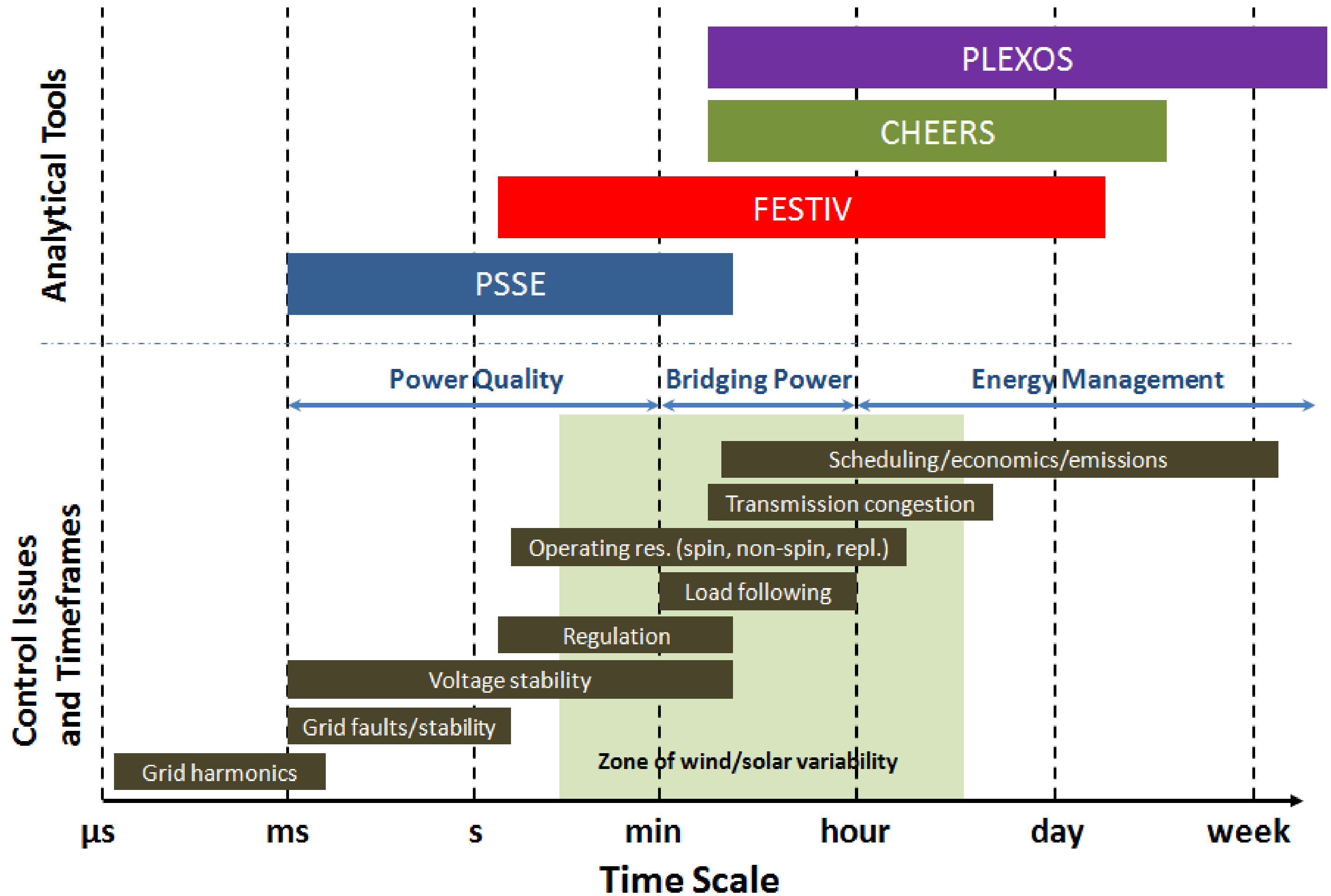
Analysis aimed to capture PSH dynamic responses and operational characteristics across different timescales, from a fraction of a second to days/weeks.



Model Development

- Technology Modeling TFG has developed vendor-neutral dynamic models for advanced PSH technologies and described them in three reports:
  - ✓ Review of existing CH and PSH models in use in the United States
  - ✓ Dynamic simulation models for adjustable speed PSH
  - ✓ Dynamic simulation models for ternary PSH units
- Draft models and reports were reviewed by the AWG members
- Reports have been cleared for unlimited distribution and are now publicly available on project website: www.dis.anl.gov/psh

Integration and Testing of Dynamic Models

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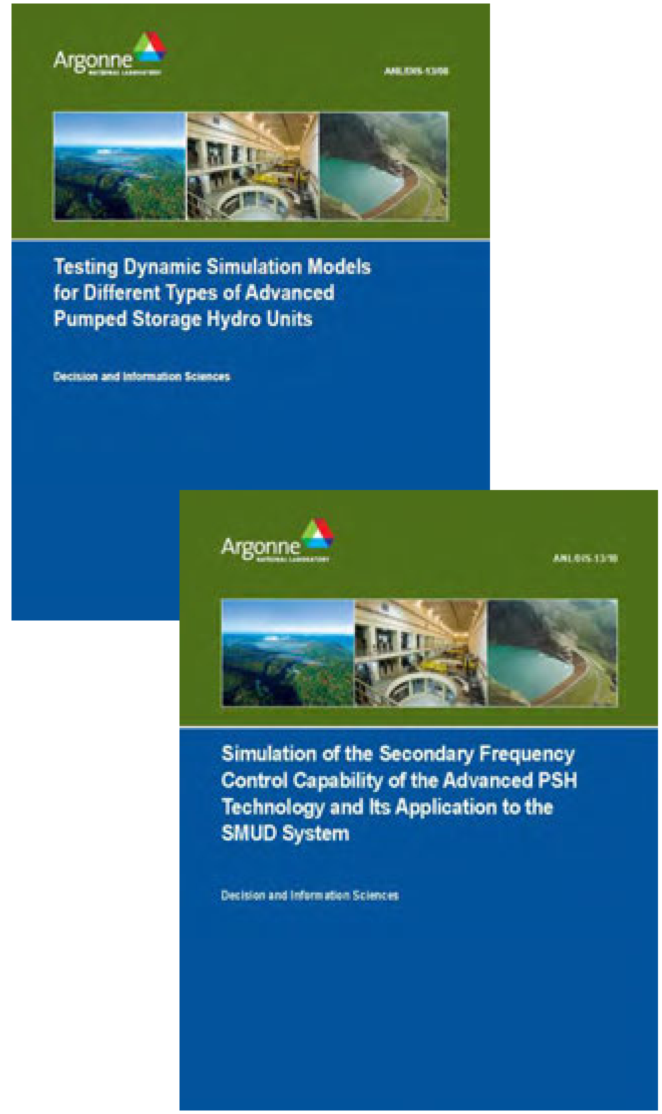
Model Integration and Testing

- Dynamic models for adjustable speed PSH and ternary units were coded and integrated into the PSS®E model
- Testing of these models for both generating and pumping mode of operation was performed using PSS®E test cases and dynamic cases for WI
- Additional AGC studies have been performed for SMUD balancing authority
- Published a report on frequency regulation capabilities of advanced PSH technologies



Production Cost and Revenue Simulations

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- Project Team first developed a matrix of various PSH contributions and services provided to the power system
- A suite of computer models (PLEXOS, FESTIV, and CHEERS) was utilized to simulate system operation and analyze various control issues occurring at different timescales
- Production cost and revenue simulations were performed to analyze the operation of PSH and the value of their services and contributions to the power system

	PSH Contribution
1	Inertial response
2	Governor response, frequency response, or primary frequency control
3	Frequency regulation, regulation reserve, or secondary frequency control
4	Flexibility reserve
5	Contingency spinning reserve
6	Contingency non-spinning reserve
7	Replacement/Supplemental reserve
8	Load following
9	Load leveling / Energy arbitrage
10	Generating capacity
11	Integration of variable energy resources (VER)
12	Portfolio effects
13	Reduced cycling of thermal units
14	Reduced transmission congestion
15	Voltage support
16	Improved dynamic stability
17	Reduced environmental emissions
18	Energy security
19	Transmission deferral
20	Black start capability

PLEXOS Modeling

- Focus on western U.S. (several levels of geographical scope, including entire WI, CAISO/California, and individual balancing authority - SMUD)

- A "future year" (FY) representation of the WI system is largely based on WECC's long-term projections for 2022

- Simulation Period:
  - DA simulations (hourly time step) for entire year to determine maintenance schedule of thermal units and annual-level PSH economics
  - DA-HA-RT sequential simulations (hourly and 5-minute time step) for typical weeks (third week in January, April, July, and October) to analyze PSH operation under conditions of variability and uncertainty of renewable resources

PLEXOS Inputs were Based on TEPPC 2022 Common Case

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- WECC's TEPPC 2022 case served as foundation for building FY cases (certain case parameters and data varied depending on scenario assumptions)
- Both cost-based and market-based approaches were used in analysis
- Two levels of variable energy resources were analyzed:
  - Base RE scenario (RPS mandate)
  - High RE scenario (High Wind from WWSIS-2)

TEPPC Load Bubbles

- 39 load regions in WI
- 8 spinning reserve sharing groups
- 20 flexibility & regulation reserve sharing groups

PLEXOS Modeling Representations of Simulated Areas

Model/System	Western Interconnection	California	SMUD
Load Regions	39	9	1
Buses	over 17,000	over 4,000	over 250
Transmission Lines	over 22,000	over 5,952	over 300
Interfaces	91	31	0
Generators	over 3,700	over 700	over 60
Existing Fixed Speed PSHs	8	4	0
New Adjustable Speed PSHs	3	2	1
Network Representation	Nodal	Nodal	Zonal
Simulation Time Step (Annual Runs)	1-hour	1-hour	1-hour
Simulation Time Step (Weekly Runs)	5-minutes	5-minutes	5-minutes
Simulation Approach	Cost-based	Bid-based	Cost-based

- Simulation cases:
  - Without PSH plants
  - With existing conventional (fixed-speed) PSH plants
  - With existing fixed-speed PSH and new adjustable speed PSH

Representation of Renewable Resources within WI

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- Wind and solar generation profiles from WWSIS-2 study

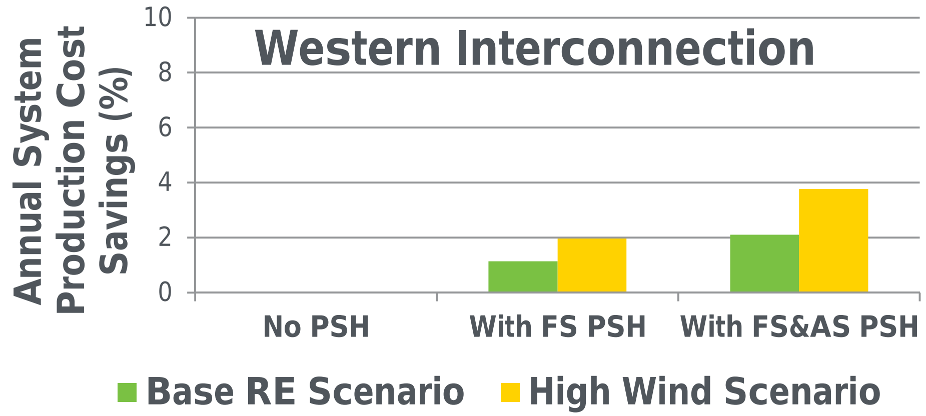
Scenario	Number of Wind Plants	Number of Solar Plants
Base	79	60
High Wind	151	405

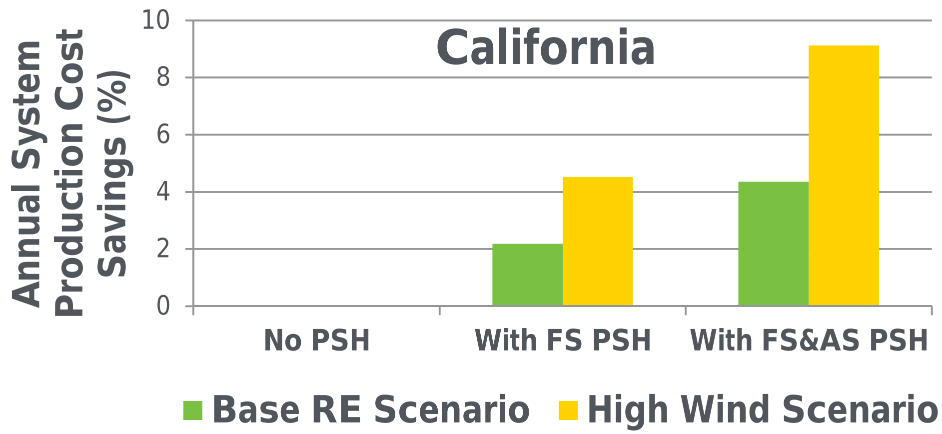
- To provide for most realistic representation of system operation, PLEXOS simulations utilized two sets of RE generation data – forecasted and actual
  - Hourly wind/solar generation forecasts for each wind or solar generator in DA and 4-HA simulations
  - 5-min "actual" wind/solar generation profiles for each wind/solar generator in real-time simulations

Sample PLEXOS Modeling Results

- Detailed PLEXOS modeling results are provided in a project report published by Energy Exemplar.
- A summary of PLEXOS modeling results is also included in the Final Project Report

Annual reduction in total system operating costs due to PSH:





FESTIV Modeling

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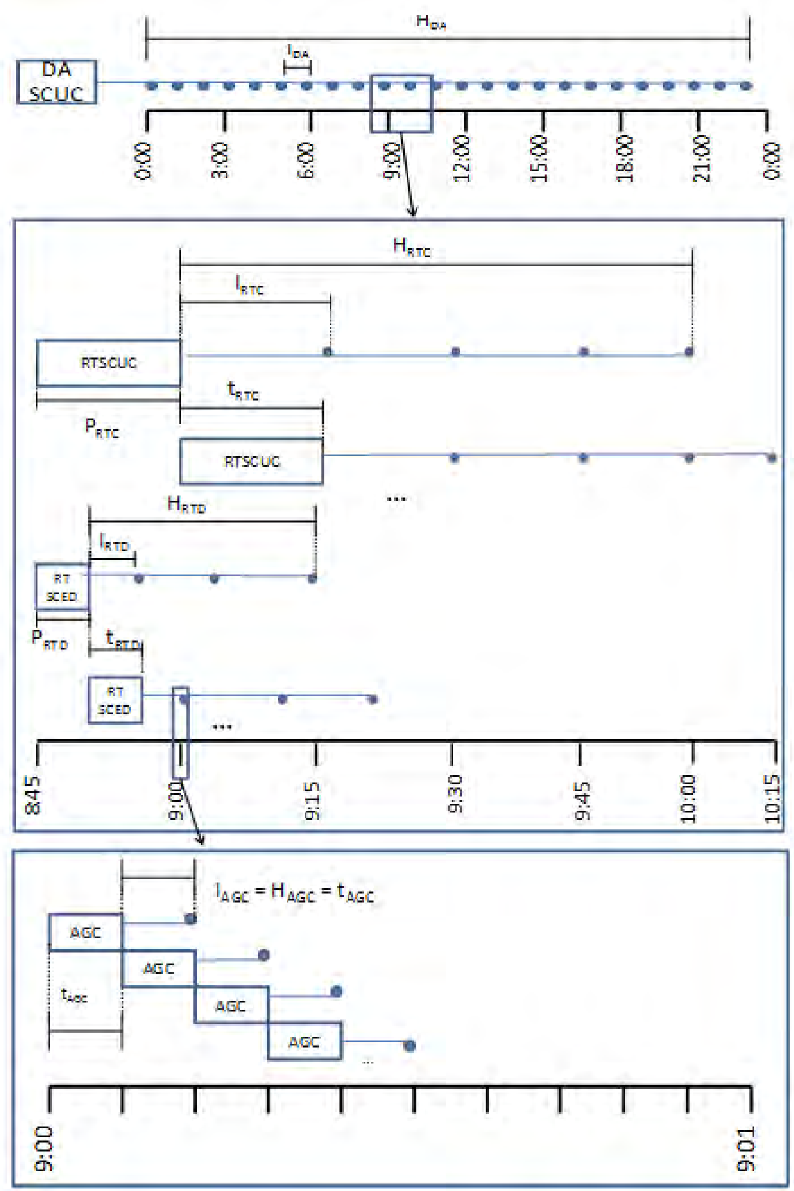
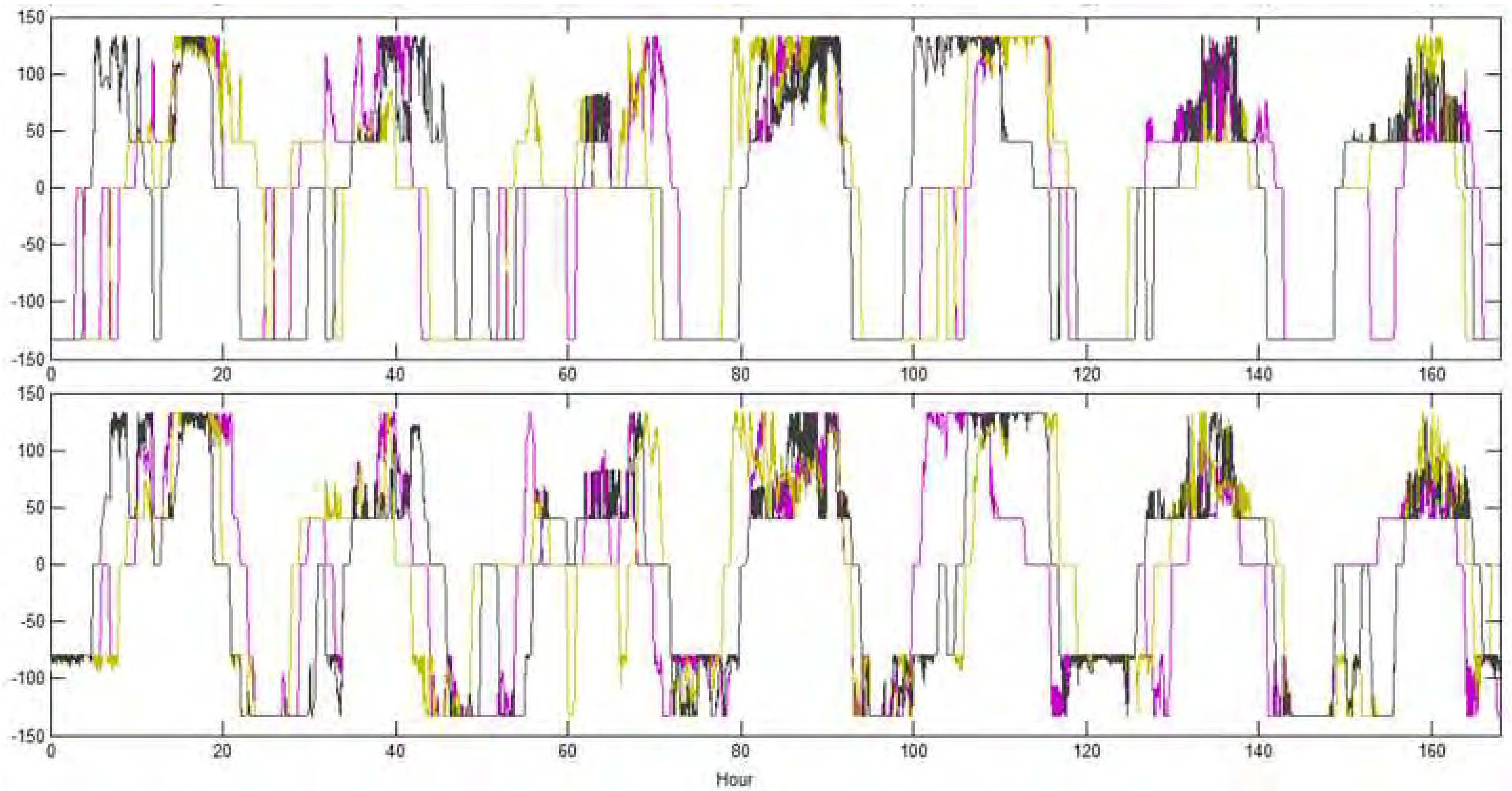
- NREL's Flexible Energy Scheduling Tool for Integration of Variable Generation (FESTIV)
- Models DASCUC, RTSCUC, RTSCED, and AGC
- All models interconnected
- Temporal Flexibility
  - Can model in 4 second intervals
- Focus on short-term reliability
- Metrics:
  - Reliability:
    - AACEE (Absolute ACE in Energy, MWh)
    - Number of CPS2 violations and CPS2 score
    - σ_{ACE} (standard deviation of ACE for the study period, MW)
  - Costs:
    - Total production costs
    - LMPs
    - Unit Utilization
    - PSH Utilization



- FESTIV simulation results for a week in July show a need for significant ACE regulation by adjustable PSH in pump mode:

Fixed-Speed PSH

Adjustable-Speed PSH

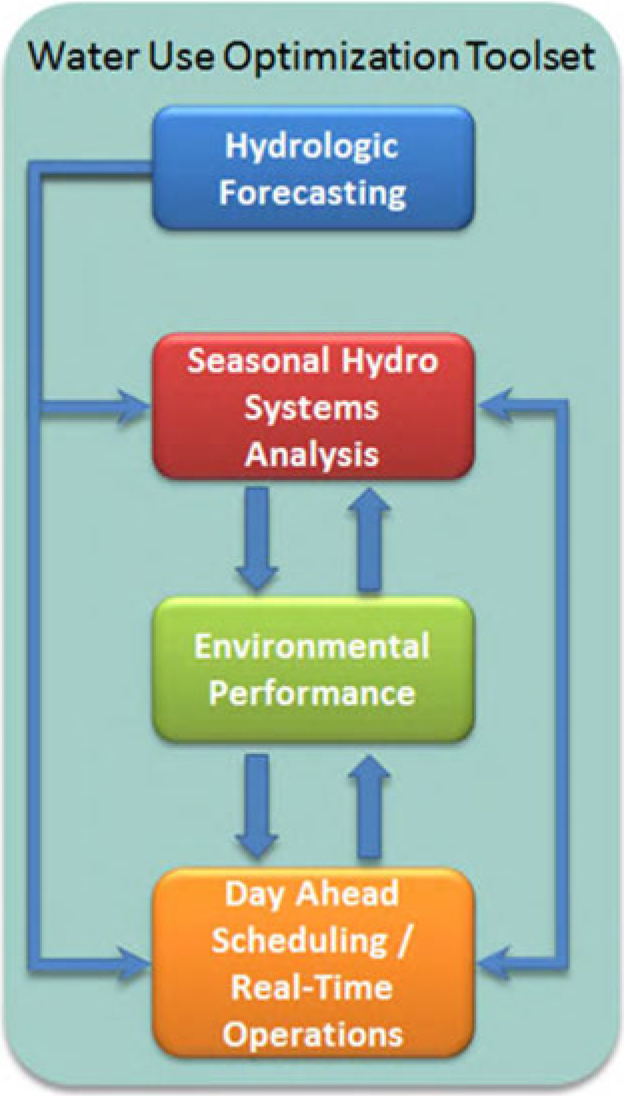


CHEERS Modeling of Fixed- and Adjustable-Speed PSH Operations

- The *Conventional Hydropower Energy and Environmental Systems* (CHEERS) tool optimizes day-ahead scheduling and real-time operations

- CHEERS is a component of the *Water Use Optimization Toolset* (WUOT) that is funded by the DOE Water Power Program

- Simultaneously optimizes power & environmental objectives
  - Maximize economic value of generation and ancillary services
  - Incorporates guidance for improving river habitat functionality



Key Project Outputs

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- Developed vendor-neutral dynamic models for advanced PSH technologies:
  - Adjustable speed PSH employing doubly-fed induction generators
  - Ternary PSH units
- Models tested and integrated into PSS®E software
- Vendor-neutral models published and made available for integration into other software packages
- Performed production cost and revenue runs to evaluate the benefits of PSH plants in cost-based and market-based environments and for different levels of variable resources in the system
- A total of 7 technical reports produced during the study (5 reports are already available on the project website: www.dis.anl.gov/psh)
- Published several journal and conference papers (IEEE, HydroVision, Hydro, NHA, etc.)
- Organized and conducted a panel session dedicated to dynamic PSH models during the 2013 IEEE PES General Meeting
- Conducted four Advisory Working Group Meetings

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number: 25055	
Project Number: 8.1.1	
Agreement Number: 25055	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Modeling and Analysis of Value of Advanced PSH in the US												
Q3 Milestone: Begin project, set up subcontracts, Advisory Working Group, etc.												
Q4 Milestone: Develop and test initial prototype dynamic PSH models												
Q1 Milestone: Integrate dynamic PSH models into PSSE software and perform testing												
Q2 Milestone: Perform preliminary production cost and revenue runs for WI												
Q3 Milestone: Analyze the economic value and market revenues of PSH plants in WI												
Q4 Milestone: Analysis of market issues and financial modeling of new PSH projects												
Q1 Milestone: Complete the analysis and compile the results into a Final Project Report												
Q2 Milestone: Review the draft Final Project Report with AWG and DOE												
Current work and future research												
Participate at the CPUC Technical Workshop on PSH												
Conduct a workshop at the NHA 2014 Annual Meeting												
Prepare and submit conference paper for HydroVision 2014 (abstract was acepted)												
Conduct analysis on optimization of PSH operation in real time markets												

Comments

- Project initiation date: March 12, 2012
- Project end date: March 31, 2014

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
1,465K	0K	0K	0K	0K	0K

- There were no budget variances
- Expended to date (Dec 31, 2013): 1,355K (92.5%)

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators:

Argonne National Laboratory (Argonne) – Project Lead
Siemens PTI, Inc.
Energy Exemplar, LLC.
MWH Americas, Inc.
National Renewable Energy Laboratory (NREL)

Communications and Technology Transfer:

- Conducted 4 Advisory Working Group meetings (one as 2-day workshop)
- Organized and conducted a panel session at IEEE 2013 PES General Meeting
- Presented at NHA 2013 Annual Conference, 2013 HydroVision, 2013 HYDRO, etc.
- Published article about the project in Hydro Review magazine
- Presented at three IEA Hydro Annex IX workshops
- Presented at several DOE workshops
- Project technical reports (7 total) publicly available at: www.dis.anl.gov/psh
- Vendor-neutral dynamic models of advanced PSH technologies published and made available for integration into other software tools

Next Steps and Future Research

FY14/Current research:

Q1: Complete the analysis of simulation runs performed during the project and compile key findings into the final project report.
Q2: Perform review of the draft report by the AWG and DOE. Incorporate comments received and submit final report to DOE.

Proposed future research: Analyze the value and economic viability of small-scale PSH plants, such as modular PSH and facilities that may utilize existing quarries or mines as lower reservoirs, etc. Investigate which PSH concepts may be potentially promising options for development in current and future electricity markets. Analyze the impacts of small and modular PSH facilities on transient stability and reliability of system operation.

Modeling and Analysis of Value of Pumped Storage Hydro in the United States

Erik Ela
NREL
erik.ela@nrel.gov (303) 384-7089
2/27/2014

Purpose & Objectives

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

Problem Statement: There is little understanding of the operational characteristics and value that conventional and advanced pumped storage hydro resources provide to the electric power system.

Impact of Project: This project will inform the utility industry about where pumped storage provides greatest value, where market design may inhibit further flexibility, and the models needed to appropriately investigate the value and power system characteristics of pumped storage hydro.

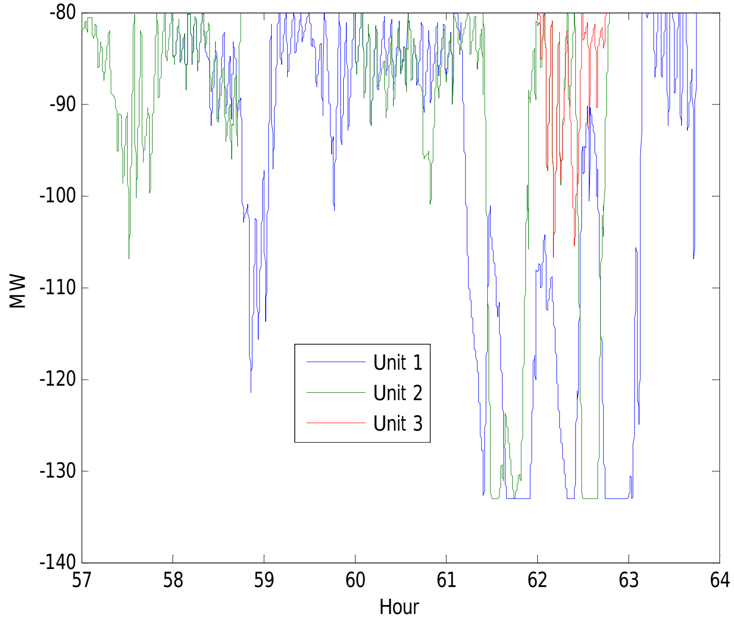
This project aligns with the following DOE Program objectives and priorities:

- *Optimize existing hydropower technology, flexibility, and/or operations*
- *Enable next-generation pumped storage technologies to facilitate renewable integration*

Technical Approach

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

1. Review of wholesale electricity market designs and relationship to PSH
   a) Survey to ISOs and other grid operators on advisory working group about PSH operation.
   b) Detailed review of market design in the United States and how it relates to PSH.
   c) Table representing 10 market design topics and suggestions that should be further explored.



Pumping output of Adjustable-speed PSH units at high time resolution

2. Utilization of the advanced FESTIV model to understand the impacts and improvements of PSH on both system reliability and system efficiency
   a) Model enhancements to incorporate PSH operations at multiple timescales (daily, hourly, five-minute, four-second operation).
   b) Multiple 1-week simulations on Sacramento Municipal Utility District system.
   c) With and without high penetration of variable renewable generation.
   d) Impact of forecast accuracy, impact of fast frequency control.

Accomplishments and Progress

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

Role of PSH in market design and system operations

- Determined list of 10 market design topics and suggestions that should be evaluated further.
- Full optimization in day-ahead and real-time markets, inter-temporal lost opportunity costs, make-whole payments for lost revenue
- Ancillary service markets that value fast response when fast response needed

Using the FESTIV tool to simulate operations of PSH

- Simulated multiple weeks with variable renewable generation, without variable renewables, with large forecast error, and with fast frequency regulation service.
- Evaluate efficiency (production costs), and reliability criteria (area control error – ACE, control performance standards – CPS2)
- Conventional PSH generally improves reliability and reduces costs.
- Adjustable-speed PSH improves reliability and reduces costs further.

Evaluate efficiency (production costs), and reliability criteria (area control error – ACE, control performance standards – CPS2)

1-week simulation of SMUD system, (1) as normal, (2) with 3 units conventional PSH, and (3) with 3 units adjustable-speed PSH

		(1) Base Case	(2) Conventional PSH	(3) Adjustable-Speed PSH
Efficiency	Total Production Cost	$5.394M	$5.101M	$5.021M
Reliability Metrics	Number of CPS2 Violations	40	16	15
	CPS2 Score	96.0%	98.4%	98.5%
	Absolute ACE in Energy [AACEE]	3201	2736	2593
	σ_{ACE} [MW]	29.3	21.3	20.2

Project Plan & Schedule

Summary

WBS Number or Agreement Number 1.8.1.2		Work completed
Project Number		Active Task
Agreement Number 26509		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

	FY2012		FY2013			
Task / Event	**Q3 (Apr-Jun 2012)**	**Q4 (Jul-Sep 2012)**	**Q1 (Oct-Dec 2012)**	**Q2 (Jan-Mar 2013)**	**Q3 (Apr-Jun 2013)**	**Q4 Jul-Sep 2013)**
Project Name: Modeling and Analysis of pumped storage hydro						
Q3 Milestone: Develop project roles and structure with project team						
Q4 Milestone: Using PSH models developed by project partners, integrate PSH representation in FESTIV						
Q1 Milestone: Validate FESTIV model using test system data - draft a report on changes						
Q2 Milestone: Complete first set of simulation runs using system data						
Q2 Milestone: Complete chapter on market design topics and role of PSH in wholesale markets						
Q3 Milestone: Complete analysis of results from FESTIV model, and a comparison of systems						
Q4 Milestone: Complete NREL inputs to final Pumped Storage Hydro Modeling and Analysis Project Report						

Comments

- 1.5-year project: April 2012 – September 2013

Project Funding History

Budget History (Funding)					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$230k	n/a	$196k	n/a	n/a	n/a

Project Spending

Budget Actuals and Future Spend Plan		
Funds spent by end of FY 2012	Funds spent by end of FY 2013	Spend Plan FY14
$34k	$192k	$0k

- Project received funding midway through FY12, spending mostly in FY13.
- Project has ended in FY13.

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators: Argonne National Laboratory (Project Lead), Siemens PTI, MWH Global, Energy Exemplar, Brendan Kirby (subcontract), industry advisory working group, SMUD project team.

Communications and Technology Transfer:

- Paper and poster presentation: HydroVision (July 2013)
- Presentation: IEEE PES General Meeting 2013 panel on pumped storage modeling (July 2013)
- Paper and presentation: IEEE PES General Meeting (forthcoming July 2014)
- Advisory Working Group Presentations (April 2013)
- Final report (2014)

Next Steps and Future Research

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FY14/Current research: Project closed out at the end of FY13. However, real-time market analysis and transient PSH modeling continue as follow-on projects inspired by this project.

Proposed future research:

- Further research on how PSH and advanced PSH can be used for integrating variable renewables.
- How PSH can provide various forms of operating reserve.
- Better optimization algorithms for ISO/RTO to utilize PSH.

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Iowa Hill Pumped-Storage Project

Scott Flake

Sacramento Municipal Utility District

scott.flake@smud.org, 916 732 6741

February 27, 2014

Purpose & Objectives

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

Problem Statement: Increasing the use of pumped-storage technology in the U.S. to better integrate variable renewable generation such as wind and solar.

Impact of Project: Aid SMUD in evaluating the need to for the Iowa Hill Pumped-storage

Aligns with DOE Program objectives and priorities:

- Enable next generation pumped storage technologies to facilitate renewable integration
- Advance new hydropower systems and/or components for demonstration or deployment

Geotechnical Investigation Objectives

- Identify Geotechnical defects in subsurface that may results in delays and costly remedial measures
- Determine depth of weathered zone, landslides, and toppled rock in project area
- Develop detailed information through the powerhouse cavern, tunnels, and shafts on geological structures, contacts and shears as well as on minimum in-situ stresses
- Evaluate the extent and impact of water bearing geologic structures

Geotechnical Investigation Technical Approach

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Four core drilling operations at Iowa Hill project site

- Two horizontal bores from lower reservoir
- Two vertical bores from on top of Iowa Hill

Horizontal test drift from lower reservoir with additional bores into powerhouse cavern area

Field and laboratory testing of core samples

Geotechnical Investigation Progress

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Geotechnical Investigation Progress

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Geotechnical Investigation Progress

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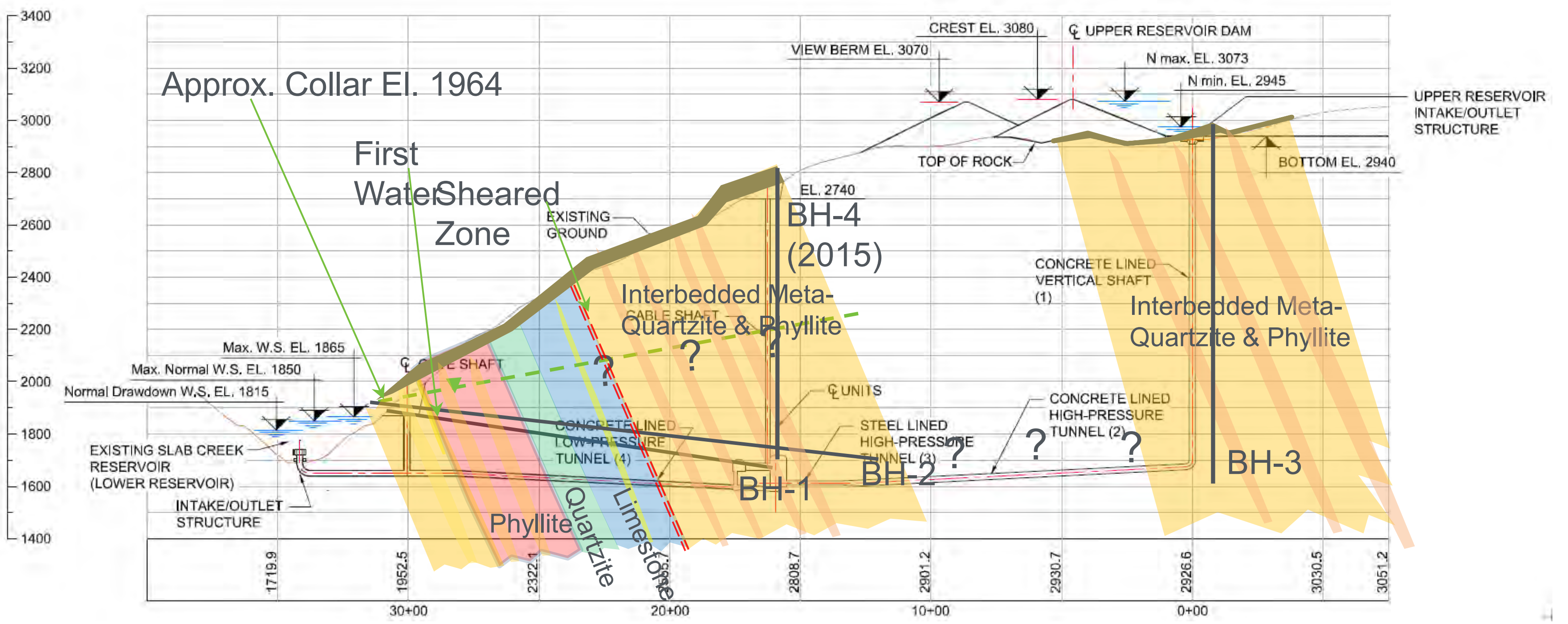
Iowa Hill PSD Hydraulic Profile



Projected Geologic Profile

(based on interpretive geology from Boreholes BH-1 and BH-3)

Value Stream Modeling Analysis Technical Approach

- Regional Study using renewable resource data from West Wind and Solar Integration Study (WWSIS 2)
- Studied Iowa Hill inside SMUD BA, along with CA & NWPP
- Simulation with and without Iowa Hill to study impact on cost and performance. Recip Engine option also simulated
- Examined study area with future RPS scenarios from base to very high penetration, including realistic modeling of solar and wind.
- Used Plexos market simulation software to forecast value of flexible resources and storage in these scenarios

Value Stream Modeling Analysis Model Scenarios

Renewable Scenario	Renewable Penetration Levels	
	SMUD BA, and CA	NW and Rest of WI
Base	Base from WWSIS 2 Study (20% for CA and WI)	
High-wind	High-wind (33% mix from WWSIS2 Study)	
CA High-wind	High-wind (33%)	Base
CA High-mix	High-wind (50%)	Base
CA High-mix, WI high wind	High-wind (50%)	High-wind (33%)
High Solar	High-mix solar portion (30 %)	High-mix solar portion (33%)

Value Stream Modeling Results Comparison IH to Recip. Engines

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	Production Cost Savings ($ Million)			Production Cost Savings ($/kw-year)		
	IH w AS trading	IH wo AS trading	Recip w AS trading	IH w AS trading	IH wo AS trading	Recip w AS trading
TEPPC-Base	12	11	3	30	28	11
CA High-Wind & WI Base	12	11	2	30	28	7
CA High-Mix & WI Base	19	18	3	48	45	8
WI High-Wind	43	47	10	108	118	36
CA High-Mix & WI High-Wind	52	53	17	130	133	48

Value Stream Modeling Results

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- Adjustable-speed turbines provide more benefits than fixed-speed turbines (65% more saving in High-Wind)
- Reduction in variable generation curtailment (valued up to $1.5M/year in SMUD BA and $35M/year in study area)
- Reduce reserve shortfall and increasing reliability
- Reduce starts and ramping of thermal units
- Improve UARP operating efficiency
- Avoidance of new generation capacity
- Significantly greater operational savings in dry water years

Iowa Hill Pumped-storage Project Overall Schedule

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Summary												
Iowa Hill Pumped-Storage Project DE-EE0005414												

Legend: Work Completed; Active Task; ◊ Milestone

	FY 2012				FY2013				FY2014			
	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Iowa Hill Pumped-Storage Project Milestones												
Q1 FY2014: Select Geotechnical Drilling Contractor									◊			
Q2 FY2014: Phase 1 Geotech: Initial 3 bore holes											◊	
Q4 FY2013: Develop Plexos Model								◊				
Q1FY2014: Value stream model runs									◊			
Q3 FY2014: Value stream modeling tech. report											◊	
Current and Future Work												
Phase 2 Geotech (Test Drift and Coring)												

Project Budget

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Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0	$0	$211,614	$352,586	$1,465,318 est.	$2,340,437 est.

- Approximately 5% of budget has been used to date
- Significant increase in budget expenditures will occur in FY2014 and FY2015, as the geotechnical investigation core drilling and tunnel takes place

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- Geotechnical Investigation Contractors
  Jacobs Associates, Crux Subsurface, Foxfire
- Value Stream Modeling Contractors
  EPRI, Energy Exemplar

Communications and Technology Transfer:

- DOE Technical Reports
- Workshops -- CPUC (January 2014)
- Industry Conferences – EUCI (January 2014), NHA, NWHA, HydroVision
- IEEE or trade journal publications

Next Steps and Future Research

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FY14/Current research:

- Completion of Value Stream Modeling Report (Q2 FY2014)
- Second Phase of Geotech Investigations (FY2015)
- Final geotechnical report (Q3 FY2015)

Proposed future research:

- Further evaluation of variable-speed turbines
- Model thermal plant retirements in 50% RPS cases
- Three-stage simulation (add HA and RT)
- Evaluate Hydro Condition (dry and/or wet year)

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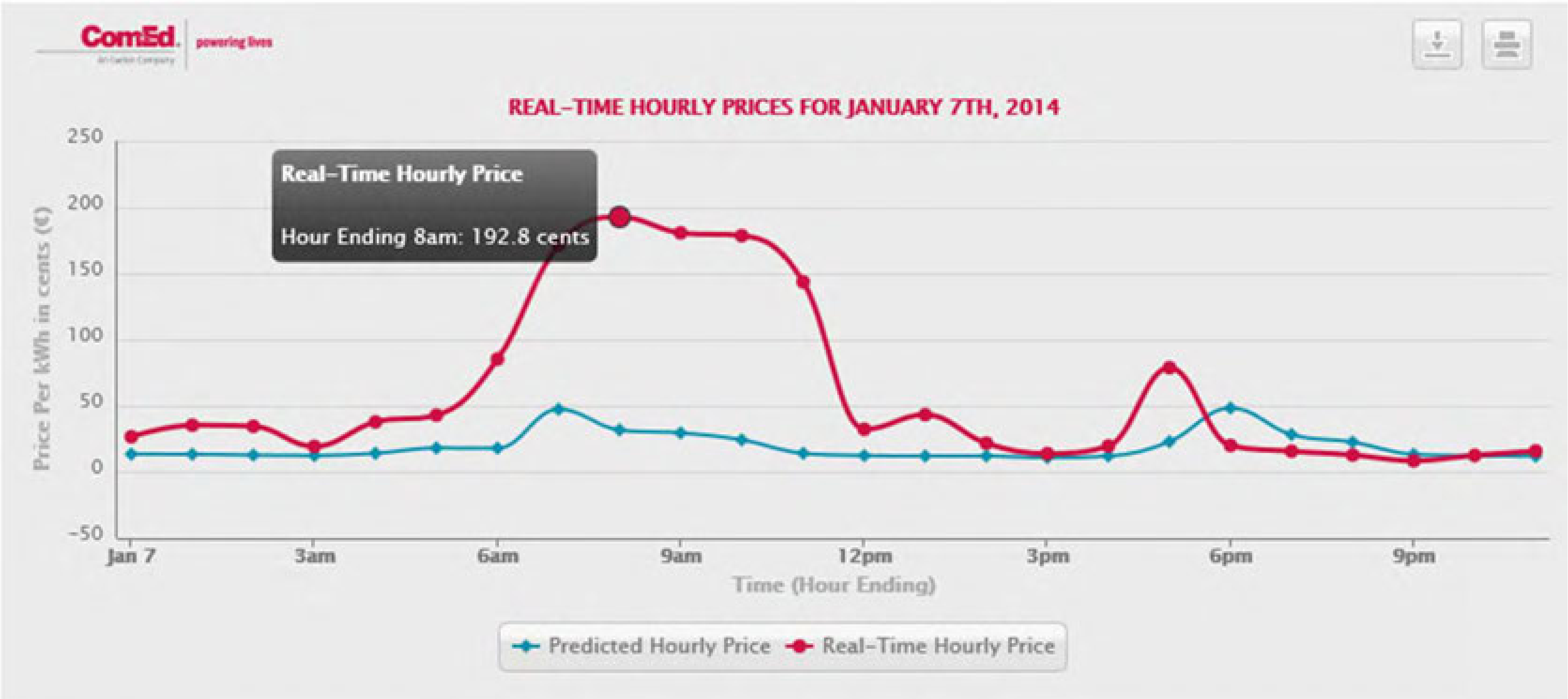
PSH Real Time Market Analysis



8.1.2 Optimization of Pumped Storage Hydro Operation in Real Time Markets

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February 27, 2014

Purpose & Objectives

Problem Statement: In most electricity markets in the U.S., the operation of PSH plants is not fully optimized and their flexible operational characteristics are not fully utilized. Utilizing the flexibility of PSH operation is especially important with larger penetration of variable RE resources.

Project Impact: Project will provide information to market operators and PSH plant owners on potential cost savings and increased efficiency that can be achieved with better optimization of PSH operations.

This project aligns with the following DOE Program objectives and priorities:

- Optimize existing hydropower technology, flexibility, and/or operations
- Enable next generation pumped storage technologies to facilitate renewable integration

PSH Provide Flexibility to Power System Operation

- PSH plants typically have a large capacity that can be dispatched on a short notice and quickly ramped up or down
- They can also quickly change their mode of operation, from generating to pumping and vice versa, practically doubling the dispatchable capacity they provide to the system.
- In most markets, PSH plants have to submit separate bids for generation and pumping, which may result in acceptance of bids in some hours and not in others.
- Also, the flexible operational characteristics of PSH plants are not fully utilized (e.g., mode changes within the hour are typically not allowed).

PSH Capabilities Are Not Fully Utilized in Current Electricity Markets

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- PSH plants typically bid their generation and pumping loads into day-ahead (DA) market.
- Bids are normally based on projections of market prices
- Except for PJM, the operation of PSH plants is typically not optimized over the 24 hour DA period
- In RT markets, electricity prices and many other variables may change from their projected DA values
- While PSH plants can make some adjustments to their schedule in RT, they are typically not allowed to change their mode of operation within the hour (e.g., from generation to pumping)

Real-Time Prices can be Very Different from Projected DA Values

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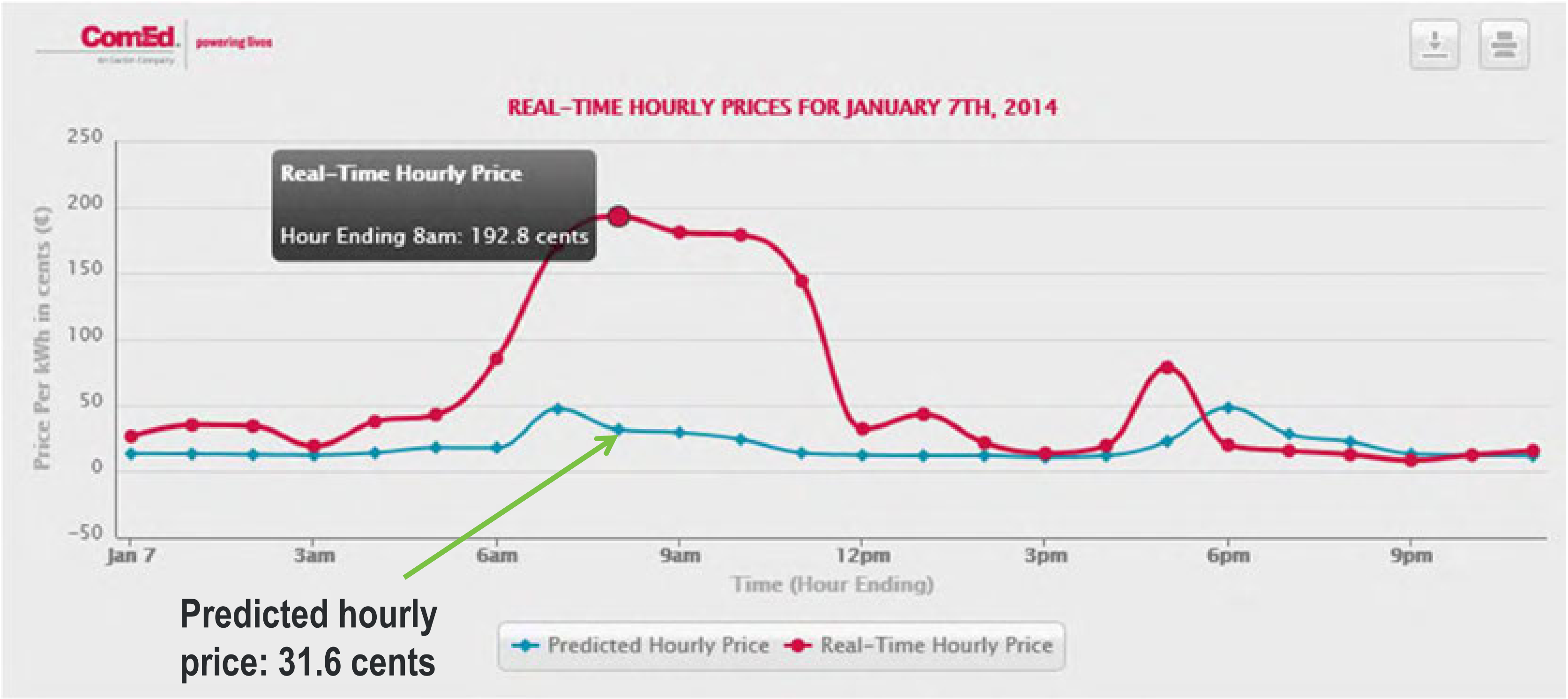

- A large-scale PSH, if available in the system, could be an excellent resource to stabilize the prices in real time

PSH Can Switch Its Mode of Operation within Minutes

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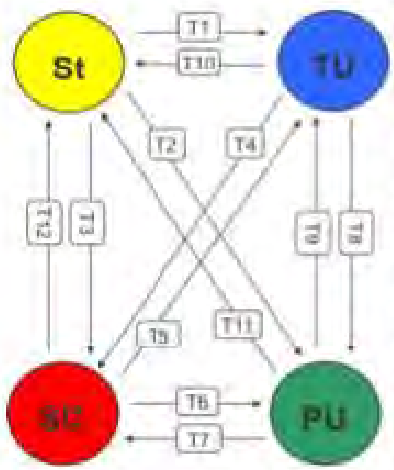
Mode change times for various PSH technologies:



T	Pump Turbine Mode change			time [seconds] A	B	C	D	E
1	Standstill	→	TU-Mode	90	75	90	90	65
2	Standstill	→	PU-Mode	340	160	230	85	80
5	SC-Mode	→	TU-Mode	70	20	60	40	20
6	SC-Mode	→	PU-Mode	70	50	70	30	25
8	TU-Mode	→	PU-Mode	420	240	470	45	25
9	PU-Mode	→	TU-Mode	190	90	280	60	25

Reversible PT
A – advanced conventional (2012)
B – extra fast response conventional
C – VarSpeed, DFIM
Ternary set
D – with hydraulic torque converter + hydr. short circuit, horiz, with Francis Turbine
E – same as E but vertical with Pelton Turbine

Modeling of PSH in Existing Electricity Markets Is Sub-Optimal

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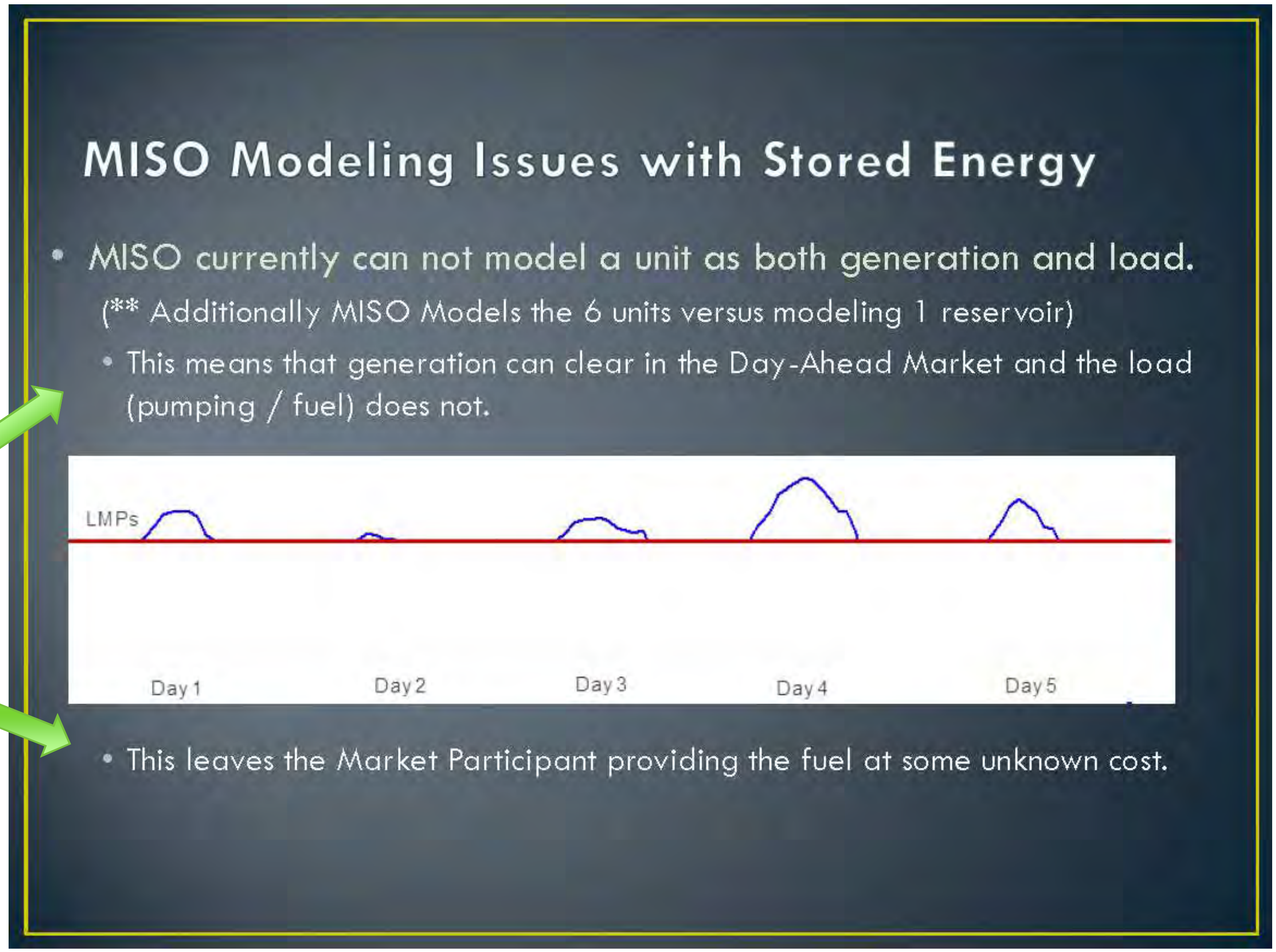
- MISO example for Ludington PSH (1,872 MW):



Disconnect between generation and pumping

Source: Darrell Newcomer (Consumers Energy), Ludington Pumped Storage Overview, presented at 2011 Energy Storage Workshop.

Technical Approach

- Compare two scenarios:
  1. Current market operation of PSH plants in DA and RT markets
  2. Optimal PSH operation in DA and RT markets
- Scenario 2 will optimize the PSH operation in DA market and then re-optimize its operation again during the RT market
- Optimizations will be performed from the system operator's point of view, to minimize total system operating costs
- Production cost model (CHEERS) with different time steps will be utilized (4-stage DA-HA-15min-RT simulation)
- Differences in overall system production cost will provide information on potential cost savings that could be achieved with the optimized operation of PSH plants

Technical Approach

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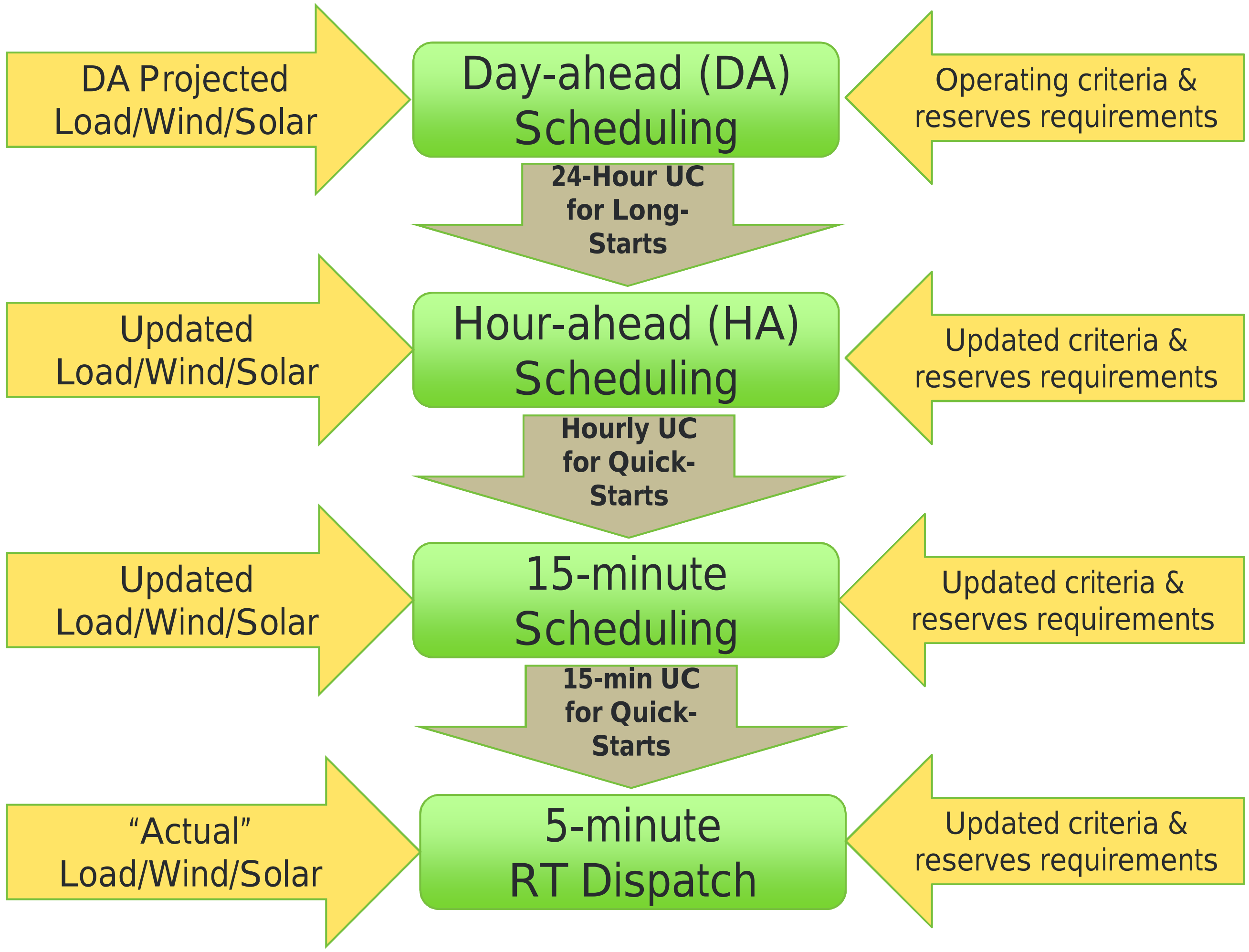
4-stage CHEERS sequential simulation approach from DA to RT



Accomplishments and Progress

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- New project: Activities started in November 2013 with a joint ANL-NREL kickoff meeting
- Argonne's modeling team reviewed potential utility systems that could be used as test bed for the analysis
- CSU (Colorado Springs Utilities) was selected as test case for CHEERS simulations
- CSU has a diverse plant mix and also plans on adding a PSH plant in the future
- Data for CSU modeling have been collected
- In process of developing a CHEERS modeling case for CSU

Project Plan & Schedule

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Summary		Legend
WBS Number or Agreement Number: 26508		Work completed
Project Number: 8.1.2		Active Task
Agreement Number: 26508		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: PSH Real Time Market Analysis												
Q1 Milestone: Decide on the test system and assemble data for analysis												
Q2 Milestone: Set up the modeling case and perform baseline simulations												
Q3 Milestone: Review baseline modeling results and perform additional cases												
Q4 Milestone: Document results and submit for publication in peer-reviewed journal												
Current work and future research												
Submit journal article for publication												
Update model with new capabilities												

Comments:

- Project start date: October 31, 2013
- Project end date: September 30, 2014

Project Budget

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Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0K	$0K	$0K	$0K	$250K	$0K

- No budget variances
- Expended up to date (Dec 31, 2013): $43.8K (18%)

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- Project partner: NREL (Erik Ela, Ibrahim Krad, etc.)
- Planned collaborators: CSU, Arizona State University, and Wichita State University

Communications and Technology Transfer:

- Dissemination of analytical results and computer models through:
  - IEEE
  - PSERC
  - NHA and other industry organizations
  - Journal articles and conference papers

FY14/Current research:

Current project activities and key milestones:

- Q2 Milestone: Set up CHEERS modeling case and perform baseline simulations (March 31, 2014)
- Q3 Milestone: Review baseline modeling results and perform additional cases (June 30, 2014)
- Q4 Milestone: Document results and submit for publication in peer-reviewed journal (September 30, 2014)

Proposed future research:

Working with market operators and PSH plant owners on implementing the PSH optimization approach developed during the study for daily PSH operations.

Water Power Peer Review

Real-Time Market Analysis

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February 27, 2014

Purpose and Objectives

Problem statement: In U.S. wholesale electricity markets, it is typically up to the Pumped Storage Hydro (PSH) operator, not the market operator, to determine the operation mode of the plant. The PSH plant owners do not have the information required to make the most efficient decisions to reduce costs and maintain reliability. For the market operator to perform the optimization, however, is a challenging modeling task.

Impact of project: By fully optimizing PSH in both day-ahead and real-time markets, we would be utilizing PSH to its full potential and creating significant reliability and efficiency benefits. The benefits would also be seen by increased revenues of the PSH plant owners.

This project aligns with the following DOE Program objectives and priorities:

•*Optimize existing hydropower technology, flexibility, and/or operations*
•*Enable next generation pumped storage technologies to facilitate renewable integration.*

Technical Approach

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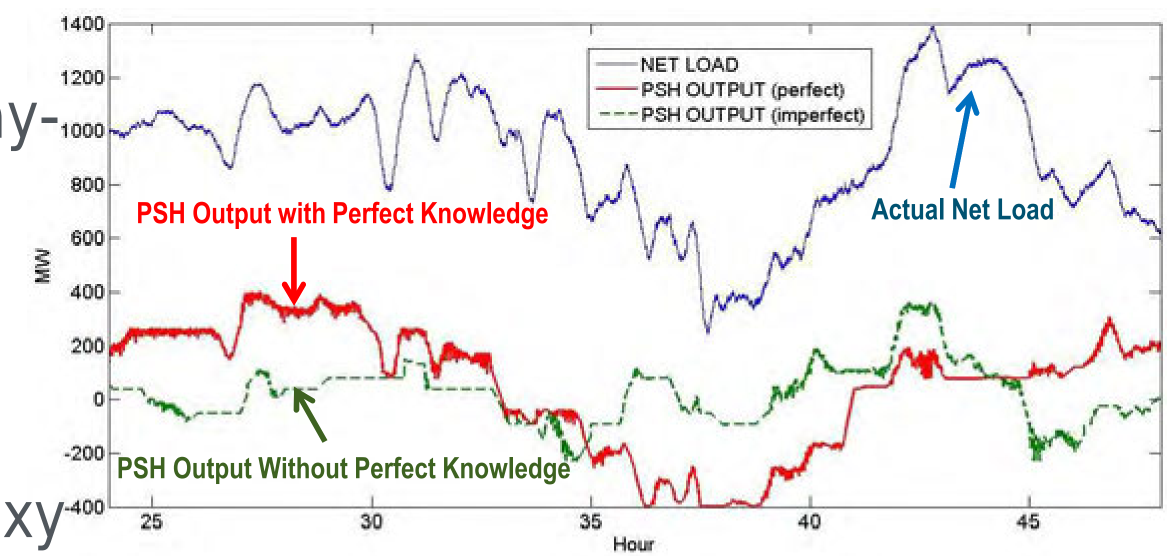
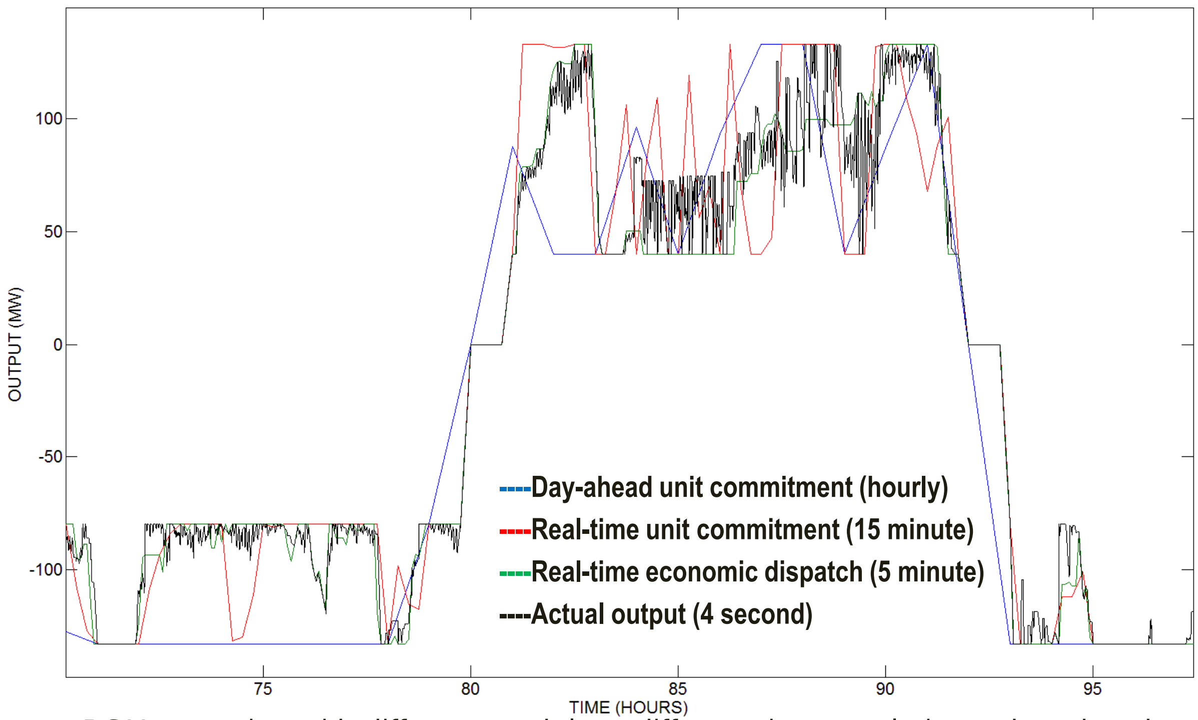
- These topics appeared as critical issues in market design topics for PSH from 2012-2013 project: (1) full optimization in day-ahead markets and (2) full optimization in real-time markets.
- Evaluate the difference over using different time horizons.
- Develop proxy algorithms in real-time markets using primal and dual values from the day-ahead market.
- Incorporate the uncertainty in load and variable generation into proxy algorithms.



PSH output compared to net load with and without perfect knowledge

Technical Approach

- Compare new proxy algorithms with base case
  - PSH based on historical PSH operation, pump at night, generate during peak
  - Real-time mode fixed from day-ahead solution regardless of changing conditions
- Objective: Improve operation of PSH with limited impact on computation time of real-time market
- Objective: Ability to fully model PSH at multiple timescales with variable and uncertain power systems.



PSH operation with different models at different time resolutions: day-ahead hourly, fifteen minute real-time, five-minute dispatch, and 4-second actual

Project Plan and Schedule

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

Summary	Legend	
WBS Number or Agreement Number		Work completed
Project Number		Active Task
Agreement Number		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

Task / Event	FY2014				FY2015			
	Q1 (Octt-Dec 2013)	Q2 (Jan-Mar 2014)	Q3 (Apr-Jun 2014)	Q4 (Jul-Sep 2014)	Q1 (Octt-Dec 2014)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Real-time Market Analysis								
Q1 Milestone: Project Team will assemble the data and develop scenarios including defining the power system to be modeled.								
Q2 Milestone: Project Team will develop necessary models and/or update the analytical tools used for real-time optimization								
Q3 Milestone: Project team will implement the modeling changes needed to the appropriate power system model and run initial results								
Q4 Milestone: Prepare a draft technical paper summarizing results of real-tiem market analysis								

Comments

- Original plan for NREL to perform modeling work. However, increased efficiency led to NREL subcontracting Power Systems Engineering Center (PSERC)
- Change to subcontract will delay project (1 quarter). Subcontract process now underway.

Project Budget

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

Project Funding History

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$150k	n/a	$150k	n/a

Project Spending

Budget Actuals and Future Spend Plan	
Funds spent by end of FY 2013	Spend Plan FY14
$0K	$115k

- $150k was received at the end of FY13; no spending until FY14
- Plan to preserve 25% carry over per DOE guidance
- FY14 project costs as of December 31st: $9k

Research Integration and Collaboration

Partners, Subcontractors, and Collaborators: NREL will work with PSERC, in particular Arizona State University and Wichita State University. NREL will leverage the PSERC Industry Advisory community which contains numerous ISO/RTO members. Collaborate closely with ANL on their work.

Communications and Technology Transfer: Continue collaboration with IEEE PES community and ISO and RTO communities. At least one journal paper planned at completion of project.