Low-Head, Short-Intake Flow Measurement Research

WBS 1.1.1.601

Hydropower Program

October 10, 2019

Dr. Marshall Richmond

Dr. Samuel Harding

Pacific Northwest National Laboratory

Project Overview

Project Summary

- Accurate and cost-effective flow measurement (FM) in short converging turbine intakes is a long-standing technical challenge.
- This project addresses these challenges through innovations in:
  - ✓ Advanced computational tools for engineering design
  - ✓ Analysis and implementation of absolute flow measurement technologies (hardware and software)
  - ✓ Validation data sets from field tests and CFD.

Project Objective & Impact

- Advanced FM in short converging intakes using absolute flow measurement techniques, impacting:
  - ✓ Active monitoring and control for optimized power generation
  - ✓ Long-term water-use efficiency
  - ✓ Sustainable water management objectives
  - ✓ Confirmation of performance obligations
- Kaplan units account for 54% of the turbines installed at new plants during 2007-2017 (Hydropower Market Report, 2018).

Project Information

Project Principal Investigator(s)

Marshall Richmond

Samuel Harding

WPTO Lead

Mark Christian

Project Partners/Subs

USACE Seattle – Chief Joseph Dam

USACE Hydroelectric Design Center (HDC)

Project Duration

- Start: October 1, 2013
- End: September 30, 2019

Alignment with the Program

Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

Technology R&D for Low-Impact Hydropower Growth

R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet

Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

Alignment with the Hydro Program

Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

- Understand the needs of the rapidly evolving grid and how they create opportunities for hydropower and PSH.
- Investigate the full range of hydropower's capabilities to provide grid services, as well as the machine, hydrologic, and institutional constraints to fully utilizing those capabilities.
- Optimize hydropower operations and planning—alongside other resources—to best utilize hydropower's capabilities to provide grid services.
- Invest in innovative technologies that improve hydropower capabilities to provide grid services

The project aligns with the WPTO goal of improving optimization of hydropower plants at both the powerhouse and individual unit scales.

Improved flow measurement for plants with short converging intakes empowers a better understanding of unit/plant efficiency. Accurate efficiency measurements enables a broad portfolio of benefits including:

a) Increased generation from existing water
b) Improved understanding of system health
c) Enhanced assessment of performance obligations

Development of flow measurement systems was achieved through:

a) Computational tools
b) Laboratory experiments
c) Field validation studies

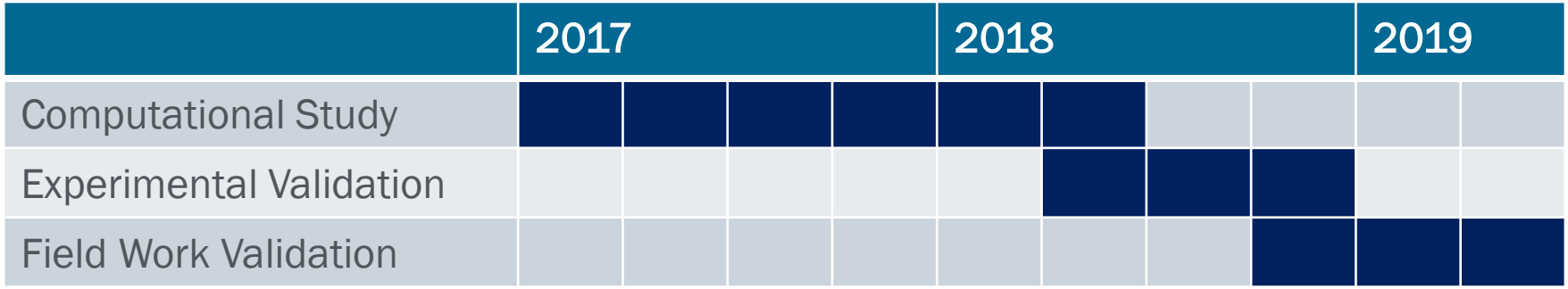
Project Budget

FY17	FY18	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019)	
Costed	Costed	Costed	Total Costed	Total Authorized
[$193.3K]	[$108.7K]	[$109.7K]	[$411.7K]	[$523.7K]

Management and Technical Approach

Management Approach:

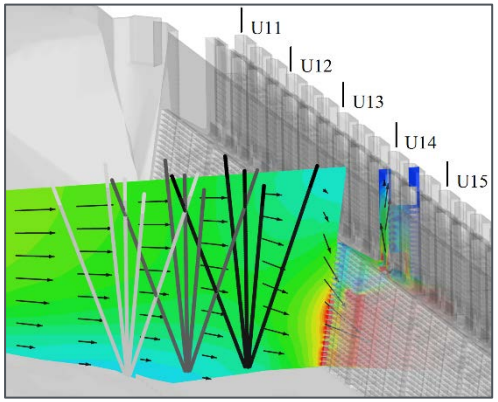
- The PNNL project team is led by nationally and internationally recognized researchers for each major technical area involved in this project.
- The project team communicates regularly with WPTO
- The project has seen success in the computational, laboratory and field study milestones over the FY17-FY19 period, including:
  - ✓ A refined numerical test bed simulation for an intake reference flow and virtual sensor measurements and compare to refined laboratory test data,
  - ✓ Representative testing of instrumentation in the laboratory, and
  - ✓ Successful field validation experiments at Chief Joseph Dam, WA.

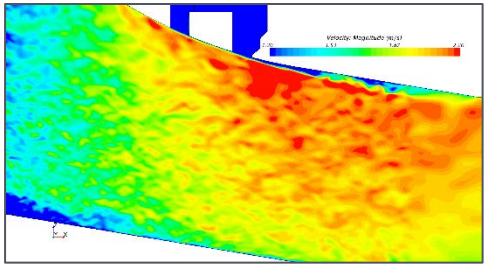


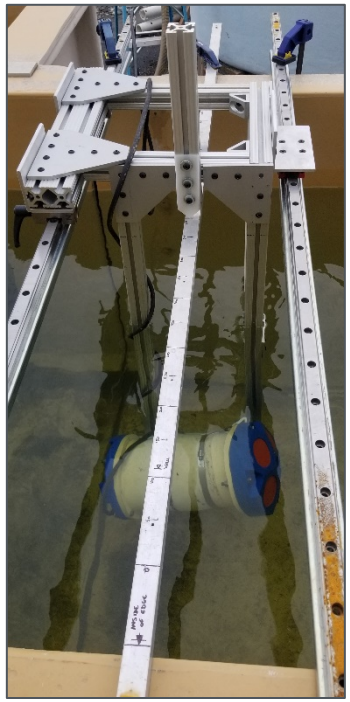
Management and Technical Approach

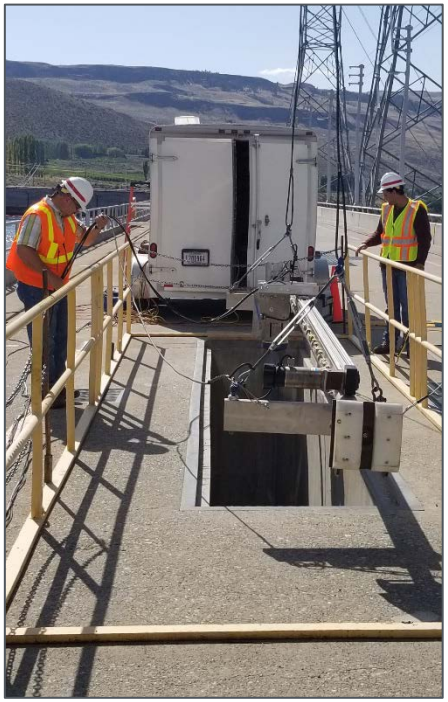
Technical Approach:

Computational Analyses → Laboratory Experiments → Field Validation





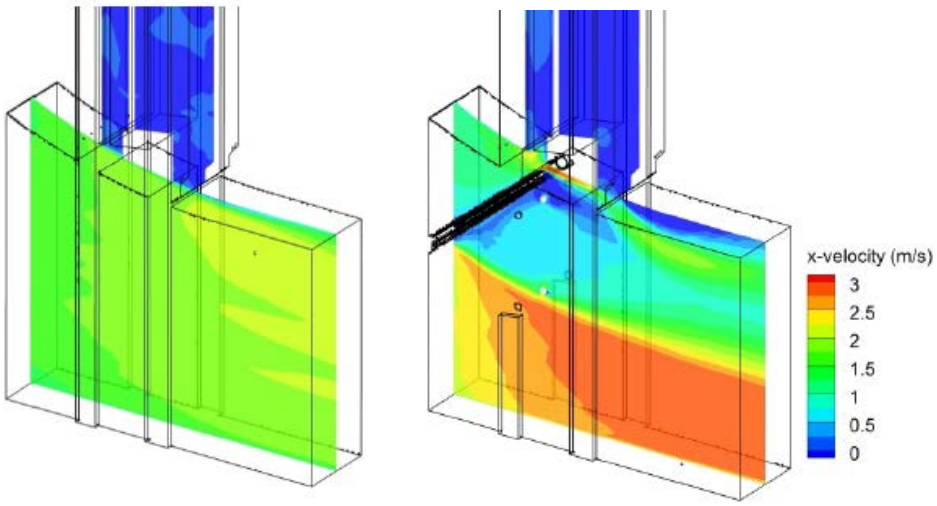




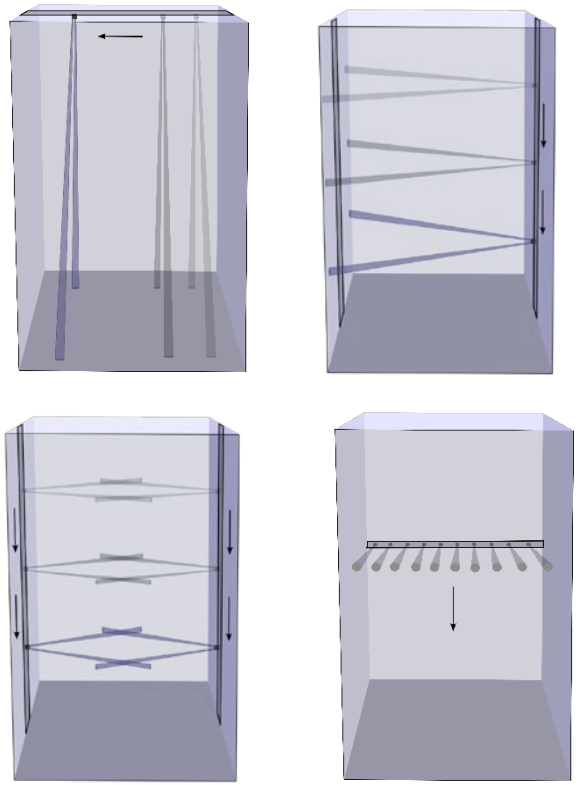
Management and Technical Approach

Technical Approach:

Computational Analyses → Laboratory Experiments → Field Validation



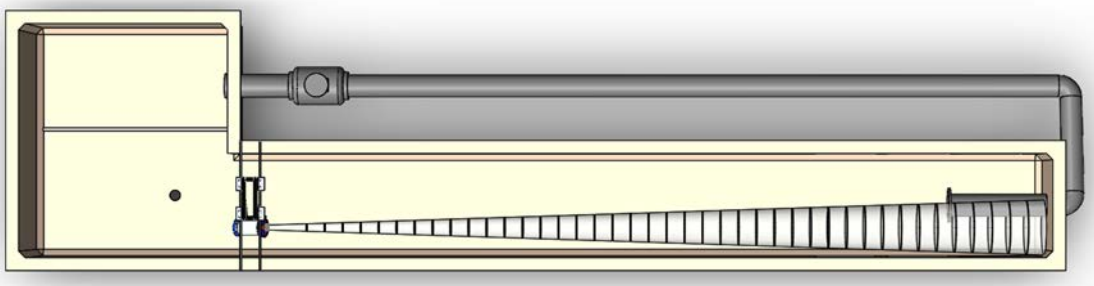
+

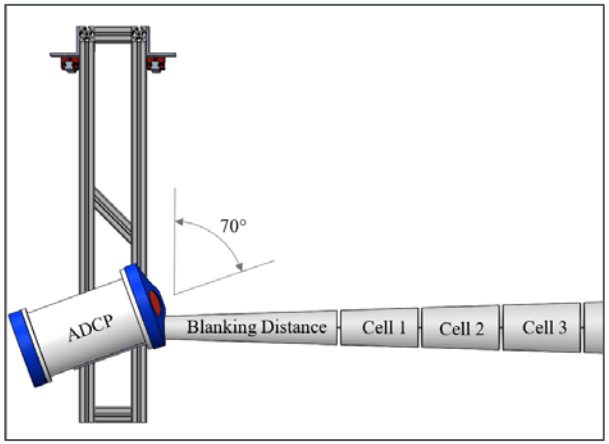


Management and Technical Approach

Technical Approach:

Computational Analyses → Laboratory Experiments → Field Validation





Management and Technical Approach

Technical Approach:

Computational Analyses → Laboratory Experiments → Field Validation

Chief Joseph Dam, Columbia River, WA


Ultrasonic Flow Meter

VS.


Scanning ADCP at Gate Slot

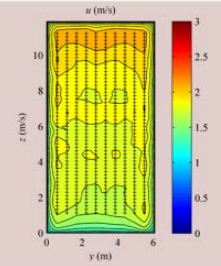
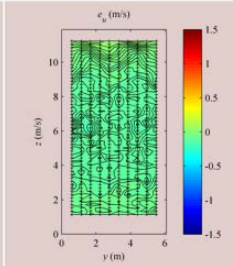
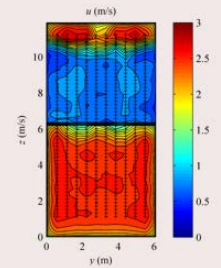
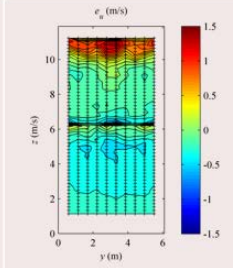
End-User Engagement and Dissemination Strategy

- The project received valuable feedback from the hydropower community during one-on-one meetings, webinars, conferences, and workshops.
  - Collaborative field study partners (Chief Joseph Dam, USACE Seattle) resulted from presenting the concept to members of the USACE Hydroelectic Design Center (HDC).
  - Communication of these results with USACE has been ongoing.
- Results of this study will be communicated to the hydropower community through peer reviewed publications and technical reportsof the technology demonstration.

Technical Accomplishments

Computational Analyses → Laboratory Experiments → Field Validation

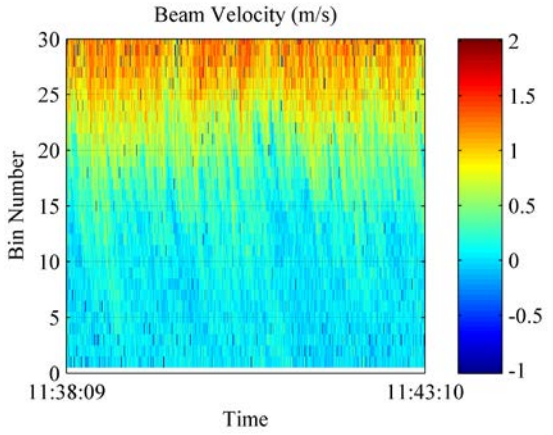
- Completed "Virtual Instrument" study of flow measurement in short converging intakes.
- Journal articles published since last WPTO Peer Review:
  - ✓ Romero Gomez, P.D.J., S. Harding, M Richmond. 2017. The Effects of Sampling Location and Turbulence on Discharge Estimates in Short Converging Turbine Intakes, *Engineering Applications of Computational Fluid Dynamics*, 11(1), 513-525.
  - ✓ Romero-Gomez, P., and M.C. Richmond. 2017. Movement and collision of Lagrangian particles in hydro-turbine intakes: a case study, *Journal of Hydraulic Research*, 55, 706-720.
- CFD techniques proven in preliminary studies applied to field validation intake (Chief Joseph Dam, USACE, WA)

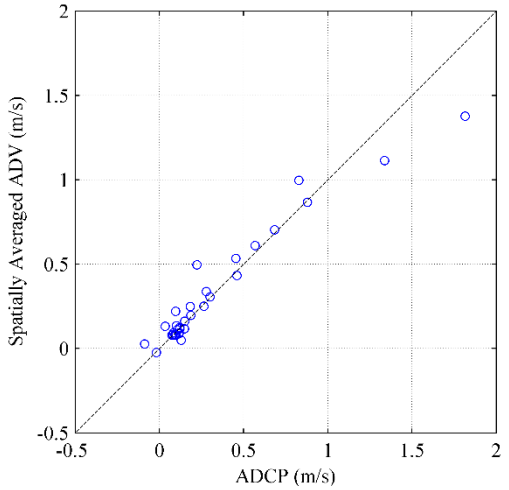
	VI Velocity contour (with wall interpolation)	Velocity error: u_{CFD} - u_{VI}
Single Down-looking Scanning ADCP Undisturbed flow		
Single Down-looking Scanning ADCP Disturbed flow		

Technical Accomplishments (Cont.)

Computational Analyses → Laboratory Experiments → Field Validation

- The performance of the ADCP near solid boundaries has been investigated using a series of validation experiments in the laboratory at PNNL.
- These tests explored the accuracy of the ADCP measurement in close proximity to side-walls through validation with high resolution acoustic Doppler velocimeter (ADV) point measurements in non-homogeneous jet flow within a large recirculating water flume.
- These results are being prepared for publication in a technical report.

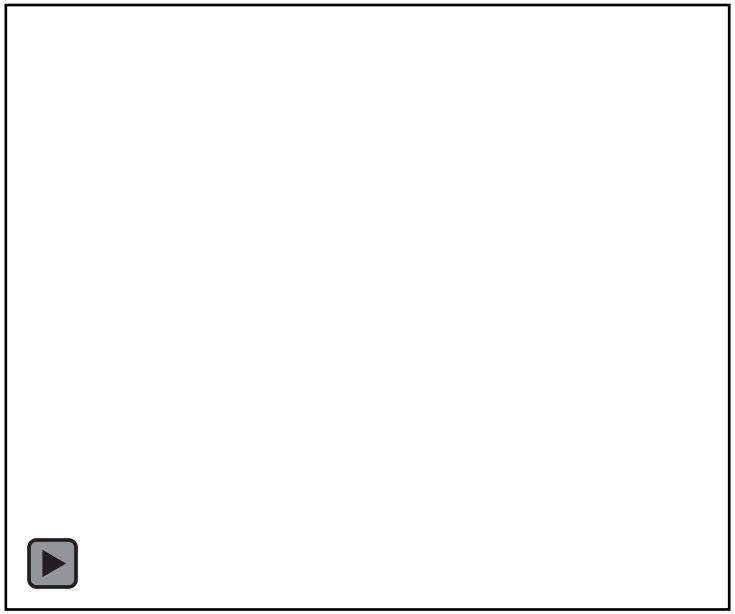




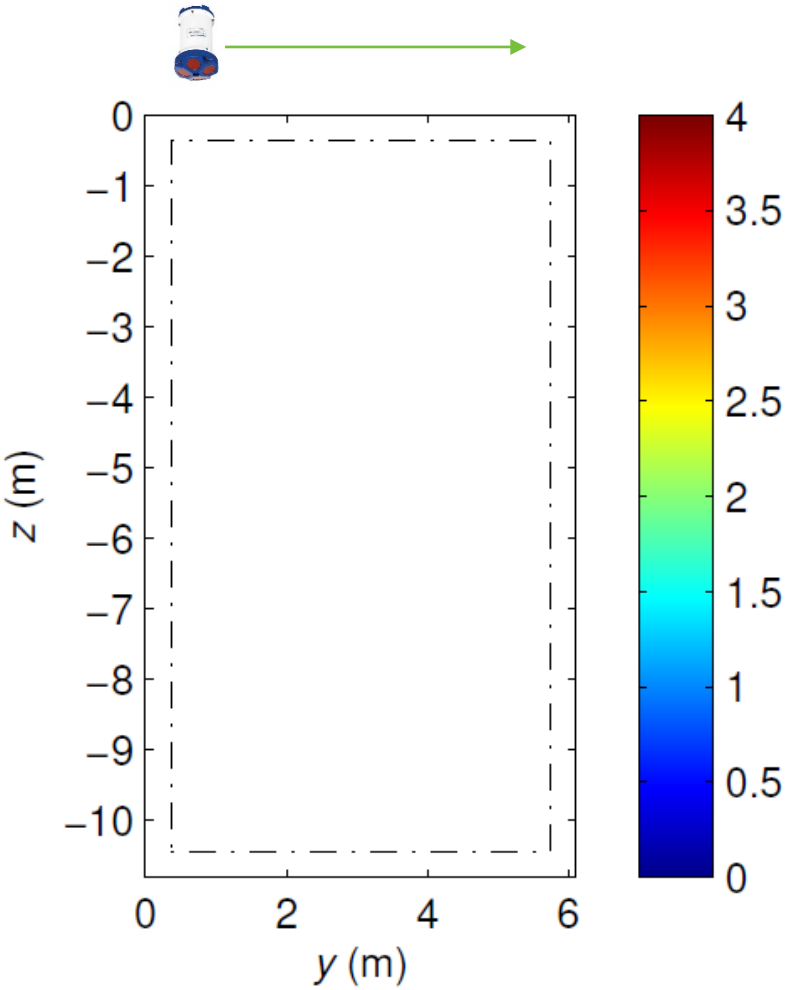
Technical Accomplishments (Cont.)

Computational Analyses → Laboratory Experiments → Field Validation

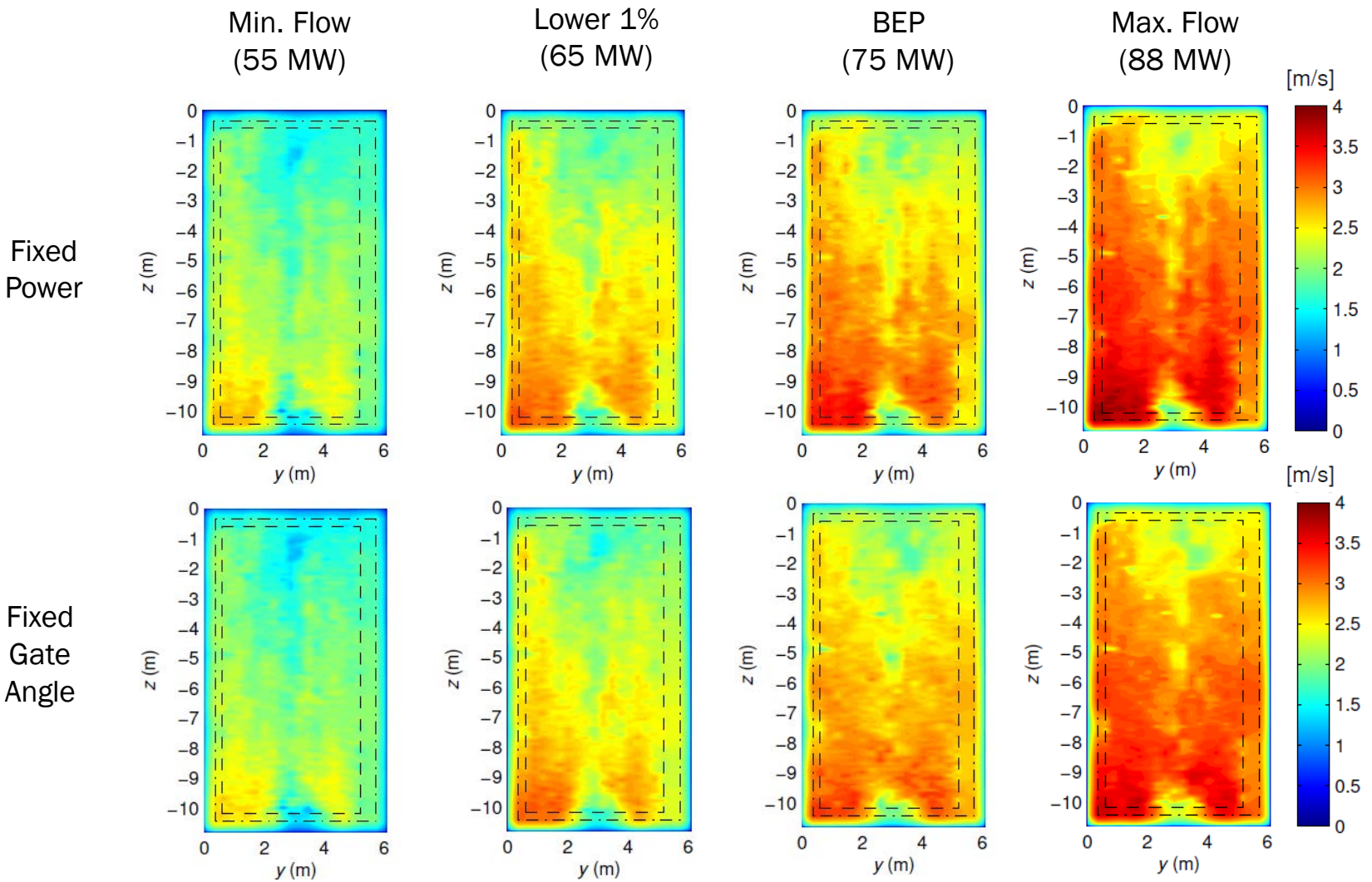
- Field validation of the selected discharge measurement system was performed at Chief Joseph Dam, WA.
- Software was developed to control the linear actuator (right), and calculate a discharge from the measured velocity data.
- Discharges were validated against existing ultrasonic flow measurement results available on the selected intake, showing agreement to <3% for full operational range of the unit.
- These results are being prepared for publication in a technical report.



Progress Since Project Summary Submittal

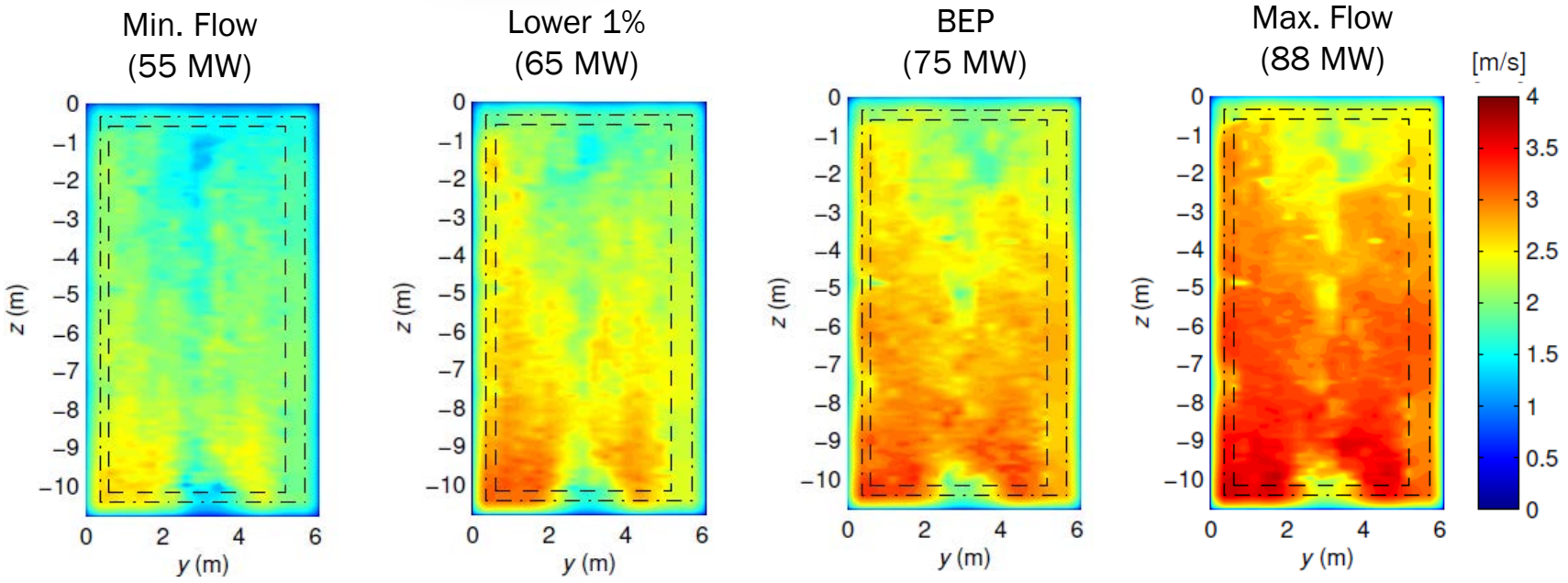


Progress Since Project Summary Submittal



Progress Since Project Summary Submittal

vs



Q_{error} : -2.6% -2.1% -0.6% -1.2%

Progress Since Project Summary Submittal

vs

	$Q_{error}(\%) = \frac{Q - Q_{ref}}{Q_{ref}}$			
	Min Flow (55 MW)	Lower 1% (65 MW)	BEP (75 MW)	Max. Flow (88 MW)
Constant Power	2.6 %	2.6 %	2.6 %	1.6 %
Constant Gate Angle	2.6 %	2.1 %	0.6 %	1.2 %

Questions?

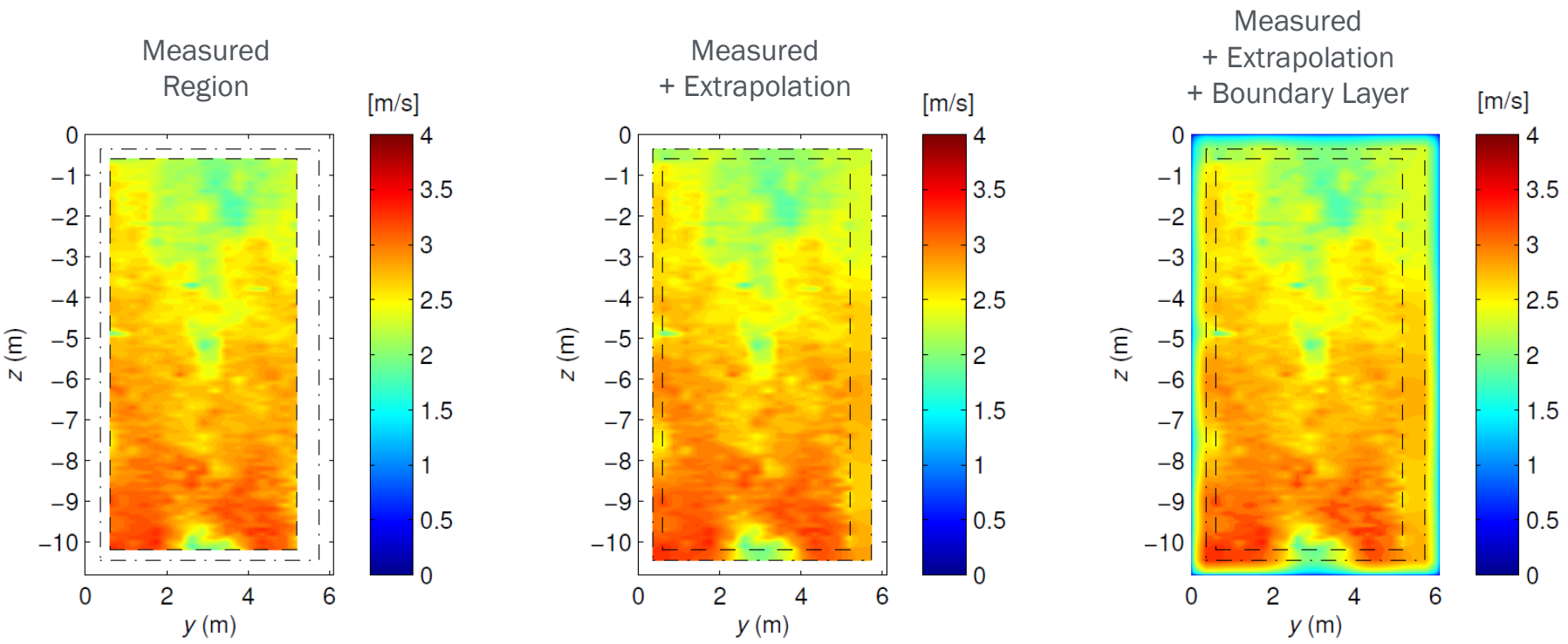
samuel.harding@pnnl.gov

Acknowledgements:

Chief Joseph Dam

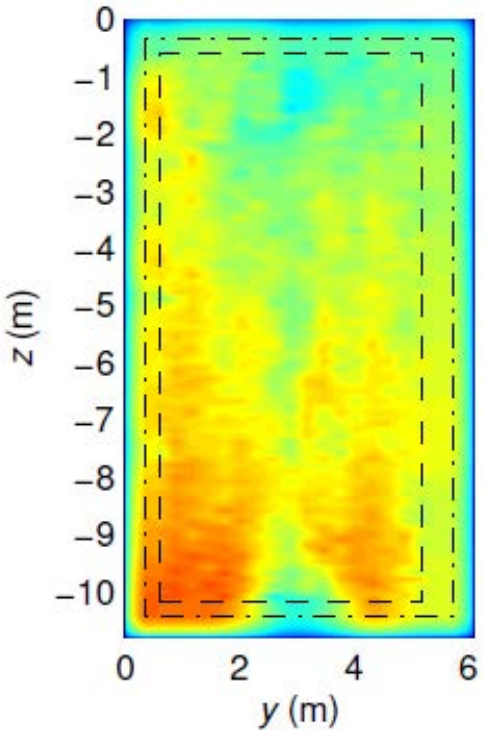
Hydroelectric Design Center

Treatment of Unmeasured Regions



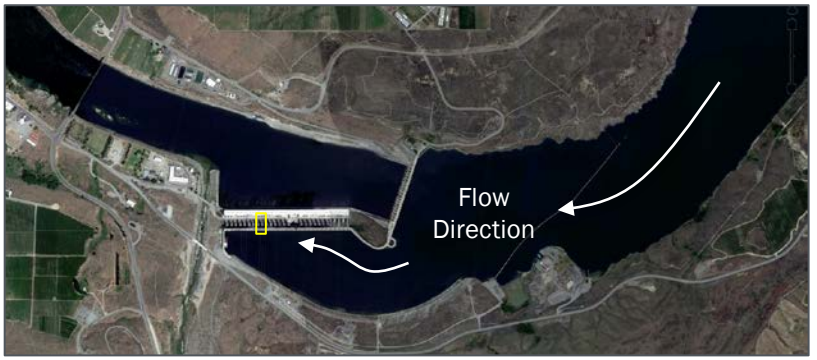
Non-homogeneous Flow

Lower 1%
(65 MW)



Q_{error} = 2.6%

Flow Asymmetry:



Flow Disturbance: