Biologically-Based Design and Evaluation of Hydro-Turbines (BioDE)

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Project Overview

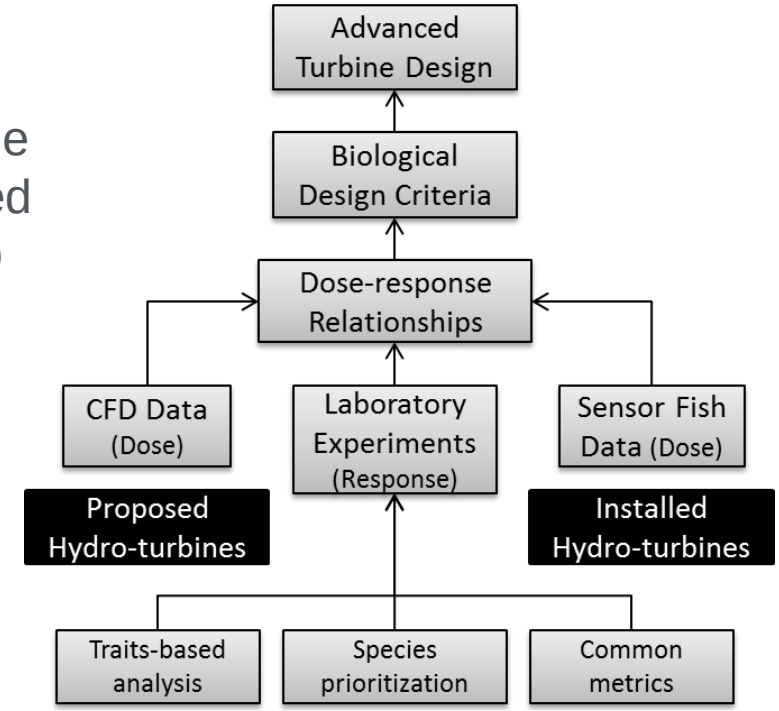
Challenge: "***One of the greatest challenges for hydro remains the understanding and mitigation of impacts to fish***" (2014 DOE Hydropower Program Peer Review).

Overall Goal: Influence advanced, fish-friendly turbine designs based on biological design criteria derived from scientific, validated predictions of impacts to fish from turbine passage

Who Benefits: Hydropower owners and operators, turbine manufacturers, regulatory and resource agencies, and the fish

Main Objectives:

1) Design Tools – Develop, deploy, and support computational fluid dynamics (CFD) modelling and analysis software (Biological Performance Assessment, BioPA)
2) Evaluation Tools – Deliver and apply Sensor Fish and other devices to obtain direct measurements of water and fish (Hydropower Biological Evaluation Tools)
3) Dose-Response – Derive dose-response relationships using laboratory experiments that relate mortality of fish to in-turbine stressors (strike, rapid decompression, shear).



Next Generation Hydropower (HydroNEXT)

Optimization

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

Growth

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

Sustainability

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

Program Strategic Priorities: Impacts

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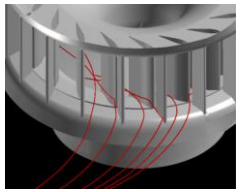
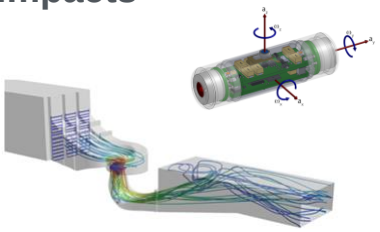
Sustainability

Design new hydropower systems that minimize or avoid environmental impacts



Develop technologies, tools, and strategies to evaluate and address environmental impacts



BioPA and Hydropower Biological Evaluation Toolsets

Impacts

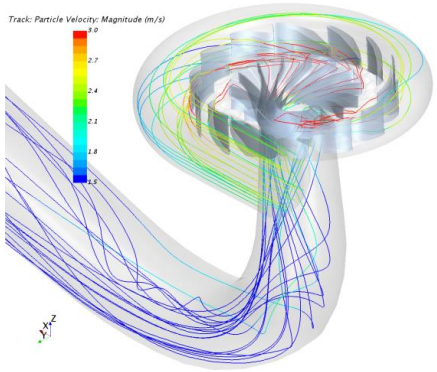
- Higher survival and reduced injury to fish
- Expanded inference space to many species through Traits-Based Analysis (TBA)
- Reduced design and regulatory review time
- Increased sustainable hydropower development
- Endpoint: Routine application of BioDE design and evaluation tools, including state-of-the-art biological design criteria, to advance sustainable hydropower

- Transfer of technology
- Improved designs for proposed turbines
- Field evaluations of new hydro-turbines
- Final Products: Biological Performance Assessment (BioPA) and Hydropower Biological Evaluation toolsets (HBET)

Technical Approach

Design Tools

Advanced CFD models to characterize the environment of proposed turbines, i.e., pressure, shear, and probability of blade strike and collision.



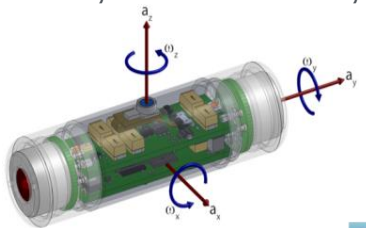
CFD model output of streamlines through a Francis turbine

Analysis software (BioPA) integrates CFD results (dose) with lab experiment results (response) to provide a *relative* index of biological performance for different turbine designs.

Validation of BioPA's predictions of biological performance (impacts) is an ongoing high priority.

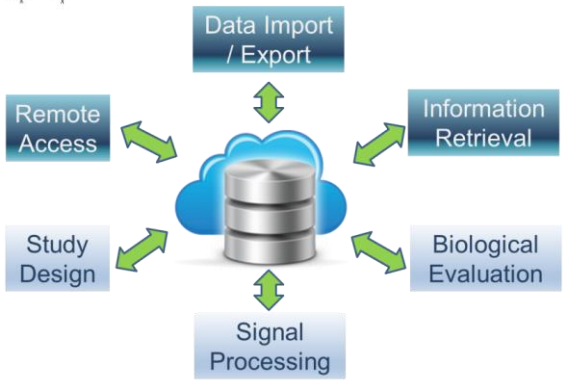
Evaluation Tools

Advanced sensor technology to characterize the environment of installed turbines, i.e., pressure, acceleration, rotational velocity.



Schematic of sensor fish device showing 3-D measurement frame

Computerized Evaluation Toolset



Sensor fish data are also used to validate the CFD model output for the Design Tools.

The Sensor Fish and associated applications tools are termed the Hydropower Biological Evaluation toolset.

Technical Approach

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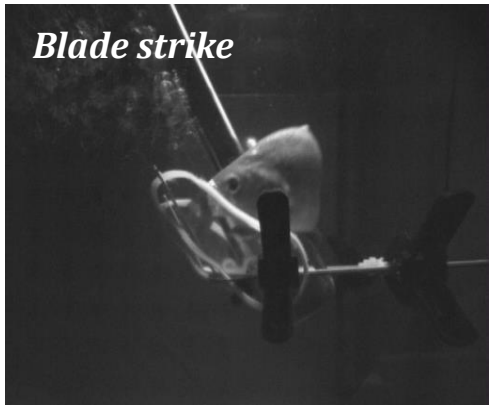
Dose-response Laboratory Experiments – Fish mortality and injury rates are assessed following exposure to simulated turbine stressors of varying magnitude and duration. Results are paired with dose measurements from turbine characterizations in BioPA and HBET toolsets.

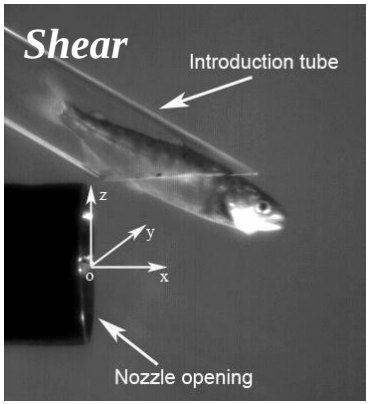
Simulated rapid decompression stressor to assess effects of:

- Rate of pressure change
- Pressure nadir
- Species/life stage
- Total dissolved gas levels



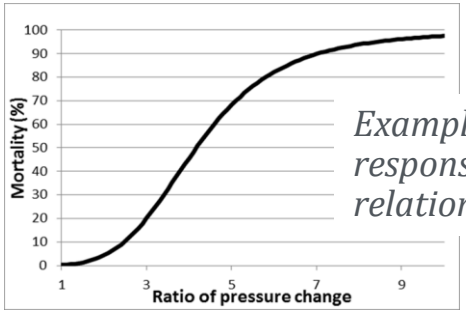
Simulated blade strike stressor to assess effects of:

- Blade velocity
- Blade width
- Fish size
- Body location & angle of strike
- Species/life stage



Simulated shear stressor to assess effects of:

- Water velocity
- Strain rate
- Species/life stage



Example dose-response relationship

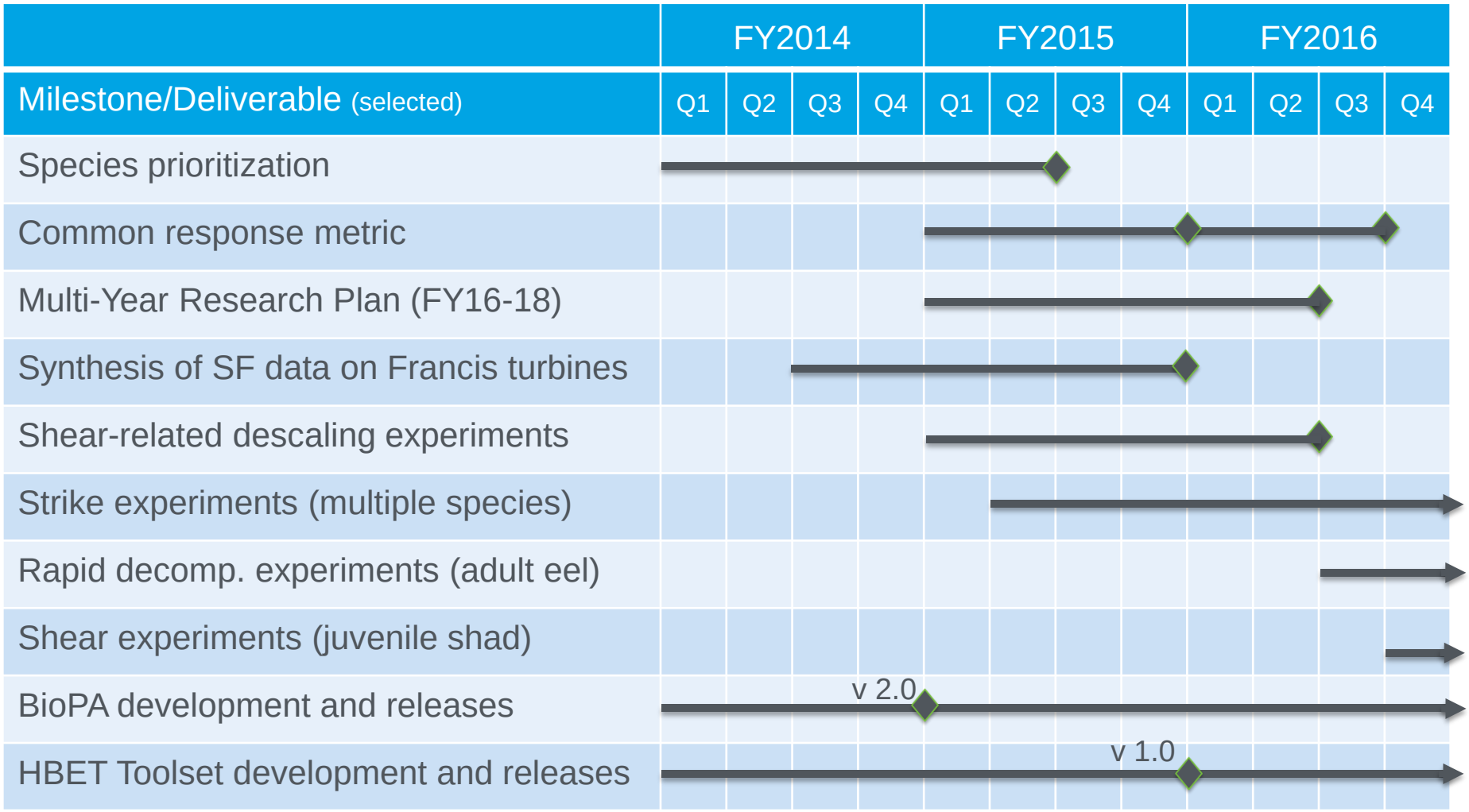
Supporting Tasks

- Species prioritization
- Common response metrics
- Traits-based inference space
- Population-level interpretation
- Field studies with Sensor Fish

Accomplishments and Progress (FY14–16)

Accomplishment	Significance
****Release of BioPA version 2.0**	**State-of-the-art design tools for the hydropower community**
Synthesis of Sensor Fish data on Francis turbines (Fu et al. 2016)	Up-to-date understanding of hydraulic conditions in the Francis turbine environment
****Release of the Hydropower Evaluation Toolset version 1.0**	**Standard, easy-to-use tools for Sensor Fish study design, signal processing, and biological evaluation**
Collection of Sensor Fish field measurements for the Natal Turbine	Characterization of hydraulic conditions for this new, innovative, small hydropower turbine
Prioritization of fish species (Pracheil et al. In Press)	Analytical process based on regulatory needs to prioritize fish species for dose-response experiments
Determination of a common response metric (mortal injury) for laboratory experiments (Colotelo et al. 2016)	Comparability and integration across various stressor/species experimental results
Determination of the relationship between fish scale type and susceptibility to descaling	Refinement and expansion of the Traits Based inference space
****Completion of dose-response experiments for strike on multiple species, shear on juvenile American shad, and rapid decompression on adult American eel**	**Expansion of dose-response relationships to cover new species and enhancements for existing species**
Completion of a Multi-Year Research Plan (FY16-18) (PNNL/ORNL 2016a)	A strategic and tactical framework for implementation of the BioDE
****Convening of two Industry Involvement Group meetings, two AFS sessions, and three one-on-one webinars (PNNL/ORNL 2016b)**	**Feedback and lessons learned from the hydropower community**
Formation of a BioDE Scientific Peer Review Group (Cada, Carlson, Kirejczyk)	Independent, scientific review and input on BioDE research priorities, objectives, and methods

Project Plan & Schedule



Project Budget and Partners

Budget History

FY2014				FY2015				FY2016		
PNNL	ORNL	Total		PNNL	ORNL	Total		PNNL	ORNL	Total
$700K	$300K	$1,000K		$750K	$400K	$1,150K		$1,000K	$400K	$1,400K

- Approximately 90% of the three-year project budget has been expended to date.
- This project does not have cost share.

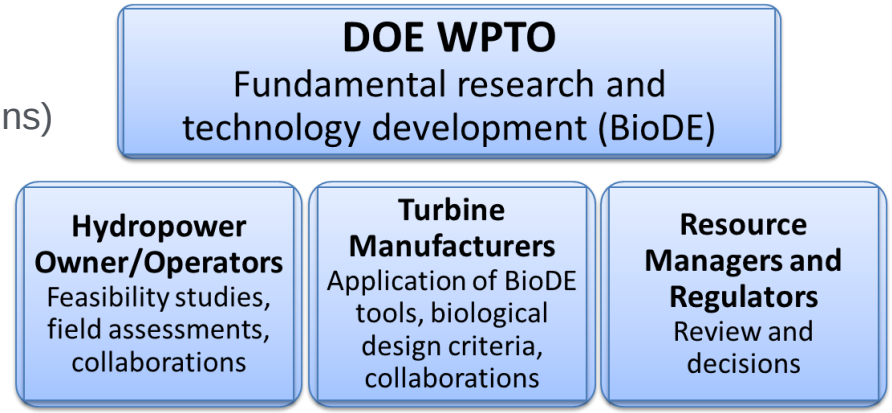
Partners, Subcontractors, and Collaborators:

- PNNL/ORNL collaboration
- Industry (e.g., Bonneville Power Administration, U.S. Army Corps of Engineers, Grant Public Utilities District (PUD), Alstom, Andritz, Voith)
- Resource and regulatory agencies (e.g., Federal Energy Regulatory Commission, National Marine Fisheries Service, U.S. Fish and Wildlife Service)

Research Integration & Collaboration

Communications and Technology Transfer:

- Industry Involvement Group (HydroVision) (two sessions)
- Special sessions and symposia (two sessions)
- “One-on-one” webinars (three webinars)
- Talks and posters at conferences (various)
- Technical reports (three reports)
- Website (under development)



Journal Articles (recent):

- Colotelo et al. 2016. A comparison of metrics to evaluate the effects of hydro-facility passage stressors on fish. *Environmental Reviews*. Published online: doi/abs/10.1139/er-2016-0006#.V-p-8fkrIQg.
- Deng et al. 2016. Evaluation of Boundary Dam Spillway Using an Autonomous Sensor Fish Device, Journal of Hydro-environment Research doi:dx.doi.org/10.1016/j.jher.2016.10.004
- Deng et al. 2016. "Sensor Fish: an autonomous sensor package for characterizing complex flow fields and fish passage." EWRI Currents 18(3):11.
- Fu et al. 2016. Assessing hydraulic conditions through Francis turbines using an autonomous sensor device. *Renewable Energy* 99:1244-1252.
- Pracheil et al. 2016. A fish-eye view of riverine hydropower systems: understanding the biological response to turbine passage. *Reviews in Fish Biology and Fisheries* 26: 153–167.
- Romero-Gomez and Richmond. 2016. Numerical simulation of circular cylinders in free-fall. *Journal of Fluids and Structures* 61:154-167.
- Pracheil et al. (In Press). Traits-based approach for prioritizing species for monitoring and surrogacy selection. *Endangered Species Research*.
- Richmond and Romero-Gomez. (In Press). Fish passage though hydropower turbines: simulating blade strike using the discrete element method. IOP Journal.

Next Steps and Future Research

FY17/Current research includes advancing the BioPA toolset with cutting edge CFD technology and new dose-response relationships; performing experiments for rapid decompression (prioritized: adult eel) and (prioritized: shear/juvenile striped bass); validating the BioPA toolset with field data; characterizing hydraulic conditions at hydropower facilities; and continuing outreach and technology transfer activities

Proposed future research 1) expand biological design criteria to relate results to additional priority species through additional dose-response experiments, 2) refine and validate the design tools for accurate predictions, 3) develop modeling tool for rapid assessment of population-level implications, and 4) advance and apply the turbine evaluation technologies

Plans and priorities will be integrated into the BioDE Multi-Year Research Plan for FY18–FY21 with input and review from the BioDE Scientific Peer-Review Group and project partners.

Acknowledgments include DOE WPTO, the Corps, Grant County PUD, Electric Power Research Institute, Bureau of Reclamation, and turbine manufacturers.