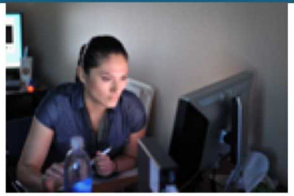
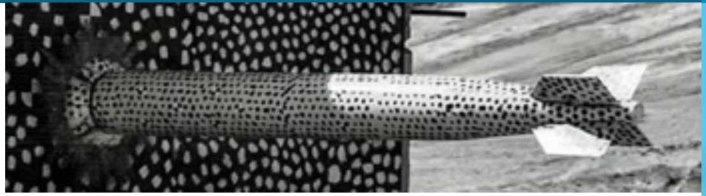
SAND2019-3850PE

Marine Renewables and Hydrokinetic Research at Sandia National Laboratories





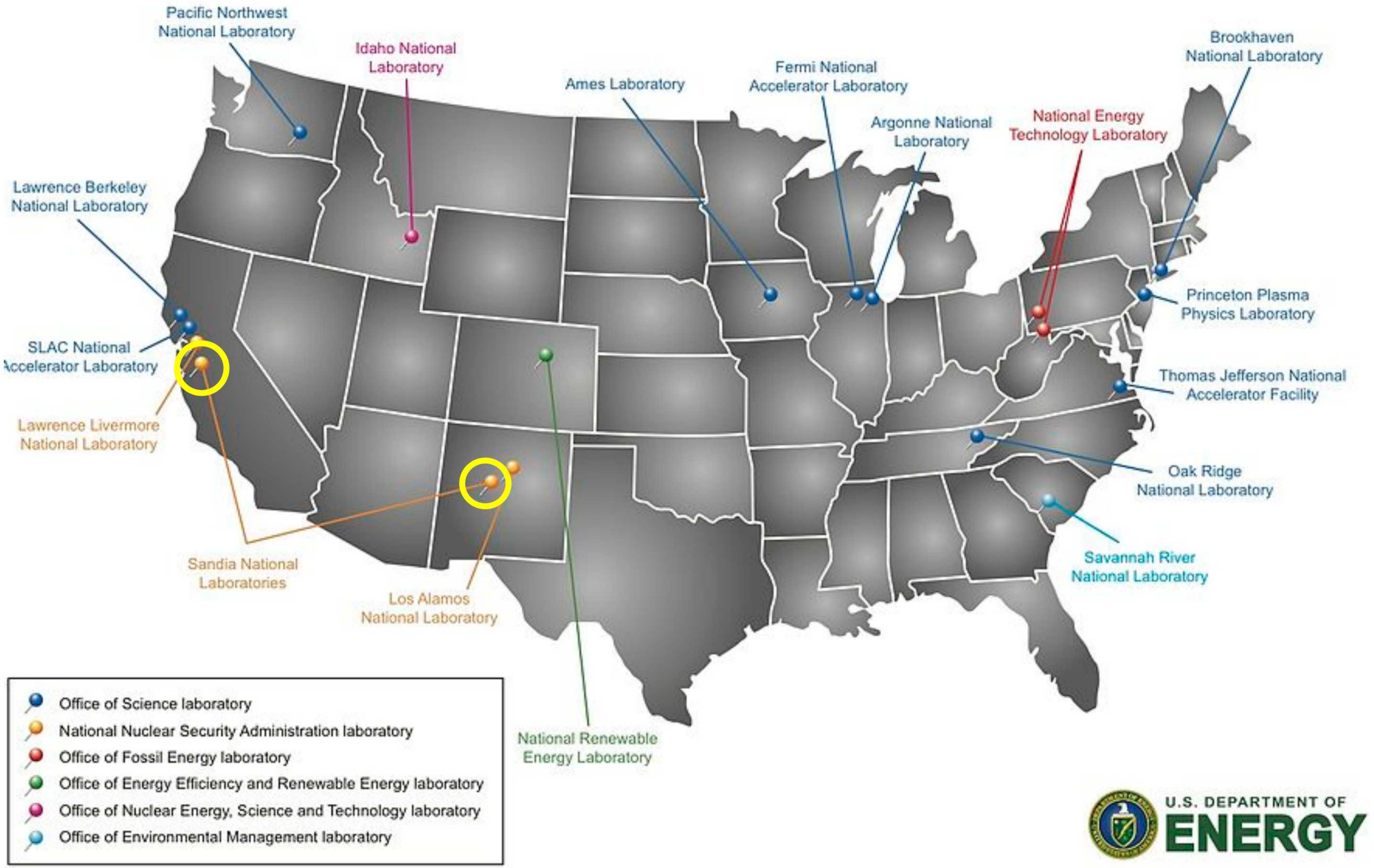
University of Edinburgh,
April 12, 2019, Edinburgh, UK

PRESENTED BY

Budi Gunawan & Sandia Water Power Team

bgunawa@sandia.gov

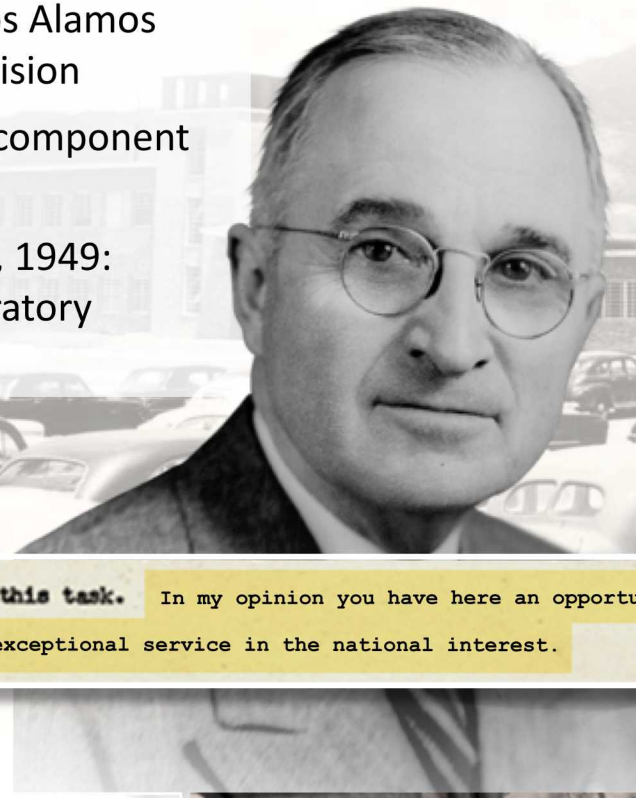
Department of Energy National Laboratories

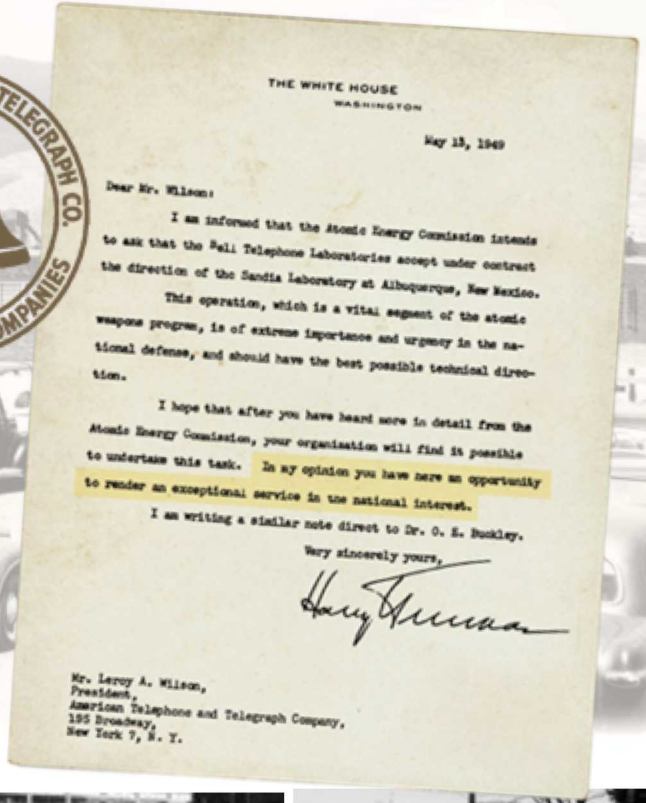


Sandia National Labs History

Exceptional service in the national interest

- July 1945: Los Alamos creates Z Division
- Nonnuclear component engineering
- November 1, 1949: Sandia Laboratory established





THE WHITE HOUSE
WASHINGTON

May 13, 1949

Dear Mr. Wilson:

I am informed that the Atomic Energy Commission intends to ask that the Bell Telephone Laboratories accept under contract the direction of the Sandia Laboratory at Albuquerque, New Mexico.

This operation, which is a vital segment of the atomic weapons program, is of extreme importance and urgency in the national defense, and should have the best possible technical direction.

I hope that after you have heard more in detail from the Atomic Energy Commission, your organization will find it possible to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

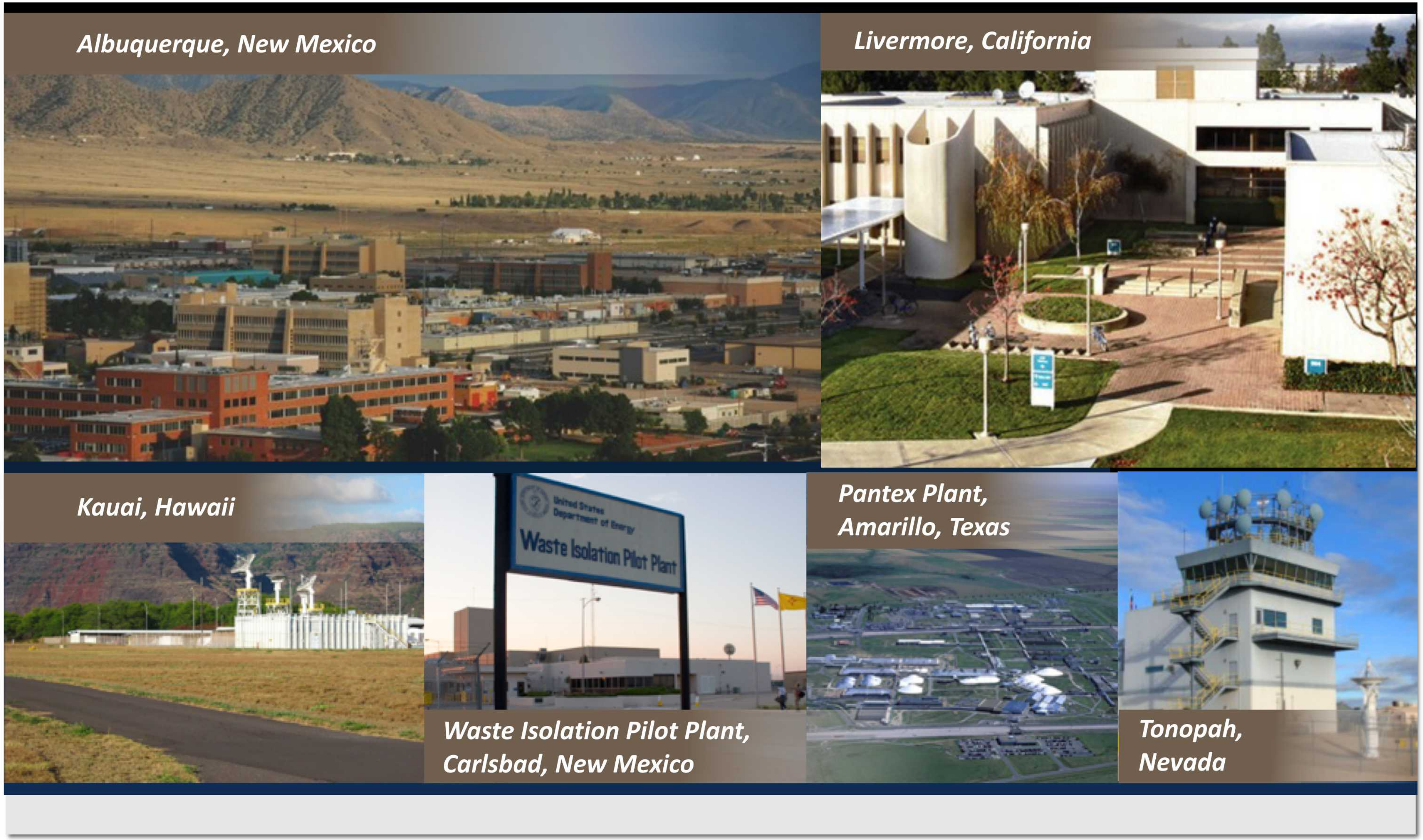
I am writing a similar note direct to Dr. O. E. Buckley.

Very sincerely yours,

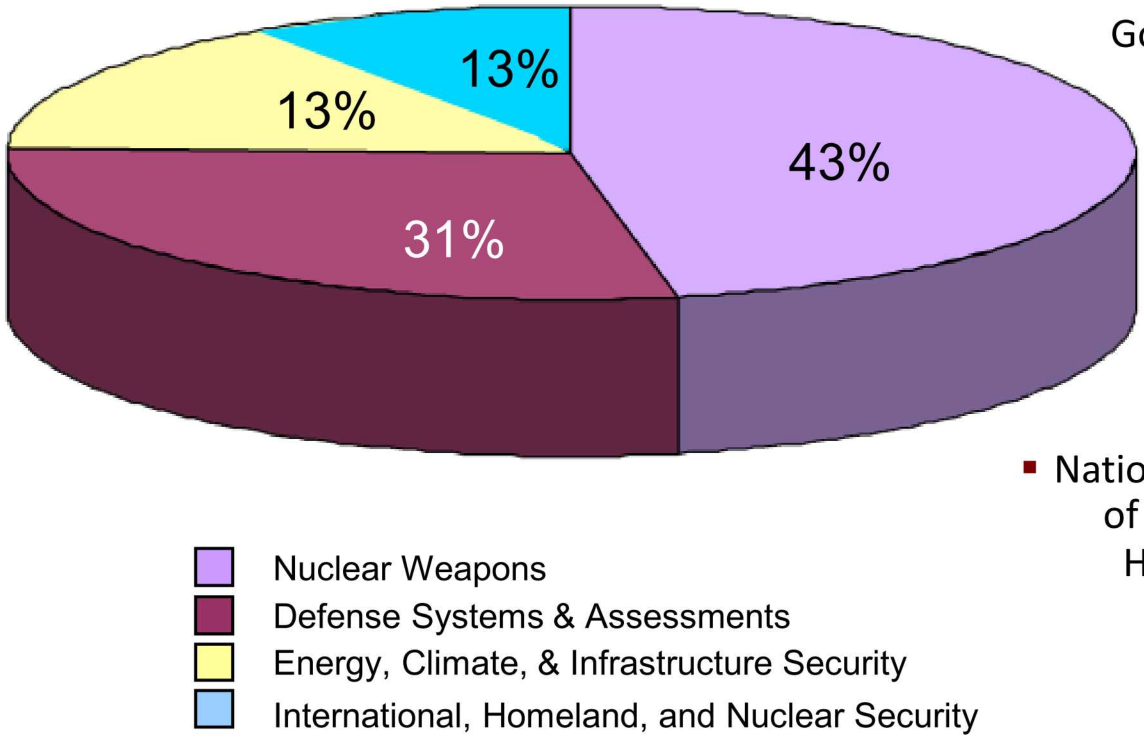
Mr. Leroy A. Wilson,
President,
American Telephone and Telegraph Company,
195 Broadway,
New York 7, N. Y.

to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

Locations


Albuquerque, New Mexico
Livermore, California
Kauai, Hawaii
Waste Isolation Pilot Plant
Waste Isolation Pilot Plant, Carlsbad, New Mexico
Pantex Plant, Amarillo, Texas
Tonopah, Nevada

Workforce & Budget



Government owned, contractor operated

Sandia Corporation

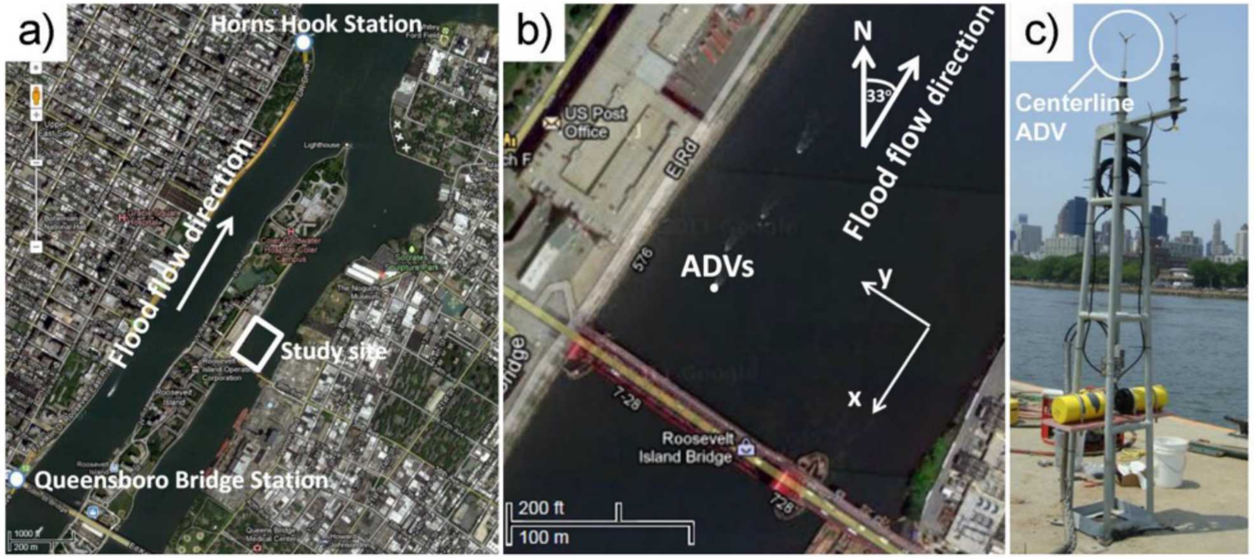
- AT&T: 1949–1993
- Martin Marietta: 1993–1995
- Lockheed Martin: 1995–2017
- National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc.: 2017-present

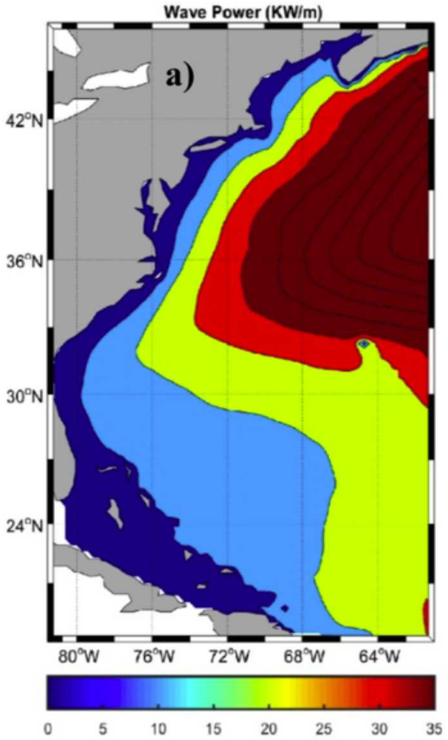
- Federally funded research and development center
- On-site workforce: 12,001 (10,715 NM, 1,286 CA)
- FY16 Budget: $3 Billion
- Renewable Energy Programs: Solar, Wind, Water, Geothermal, Biomass

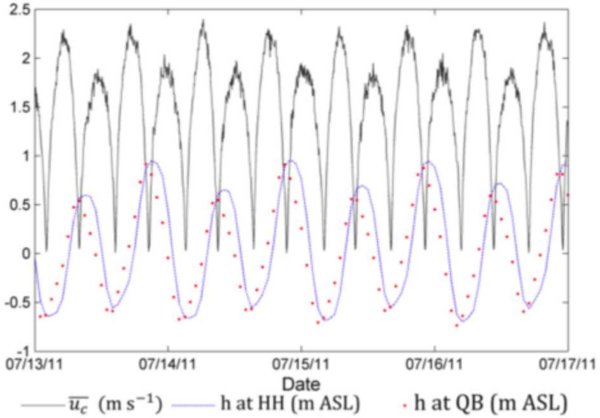
Sandia Water Power Program

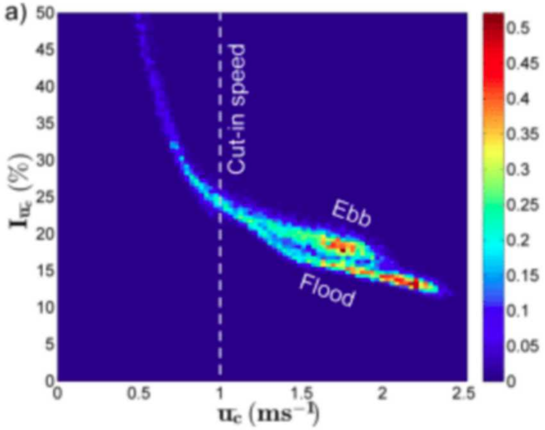
Site and Resource Assessment & Characterization

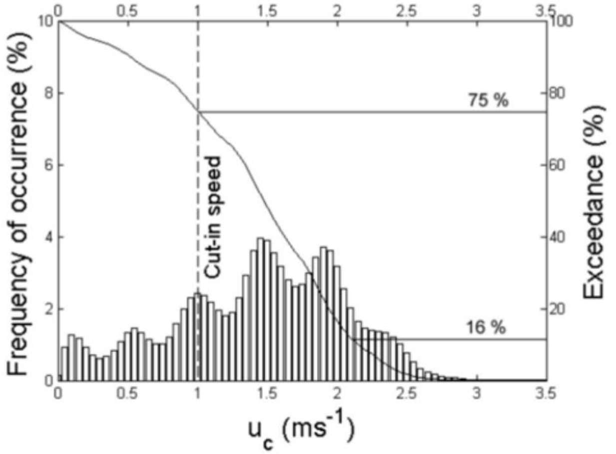
- Long term measurements of velocity (ADCP, ADV)
- Wave Modelling





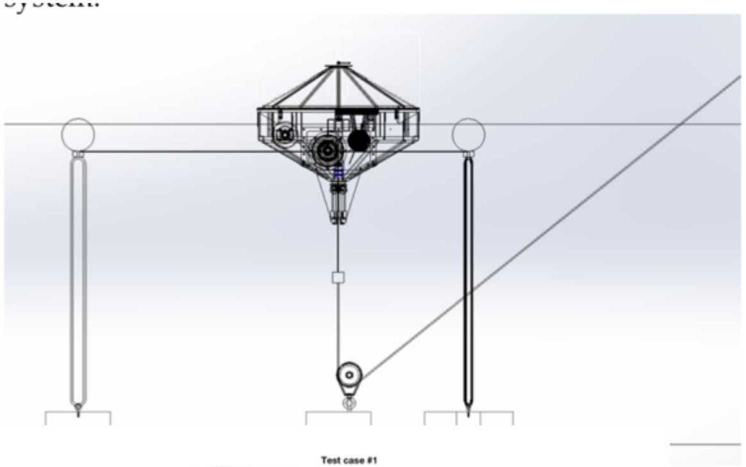


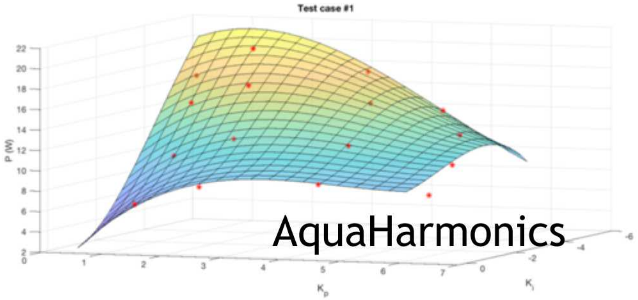




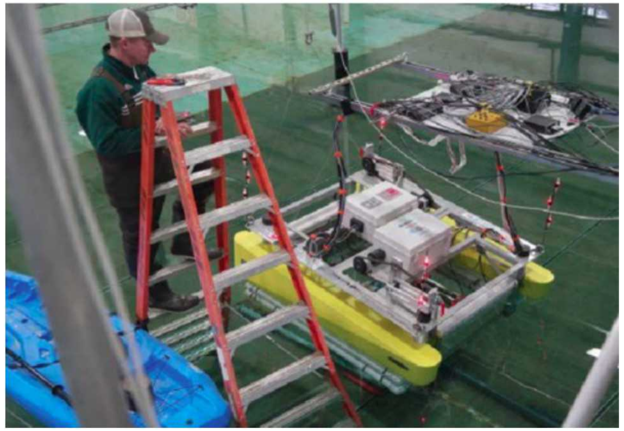
Gunawan, B., Neary, V.S. and Colby, J. (2014) Tidal energy site resource assessment in the East River Tidal Strait, near Roosevelt Island, New York, New York. Renewable Energy

Testing – Wave Energy Converters

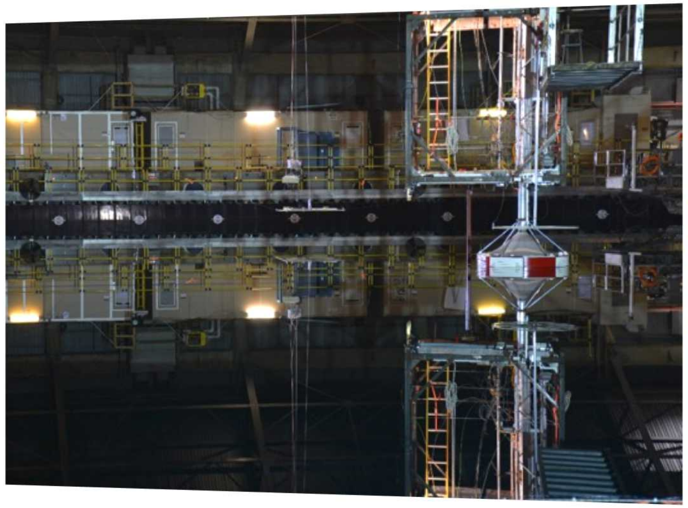


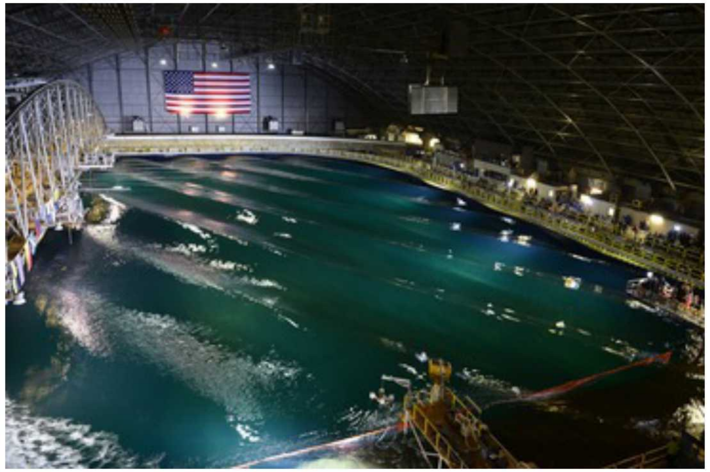


AquaHarmonics

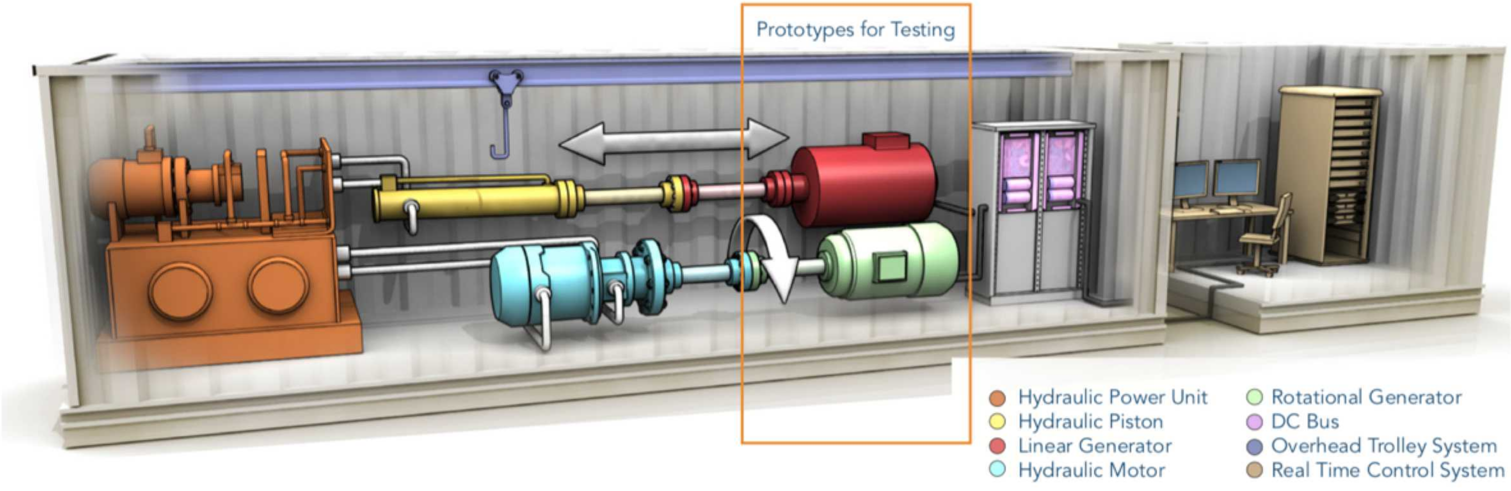


WECSim -FOSWEC





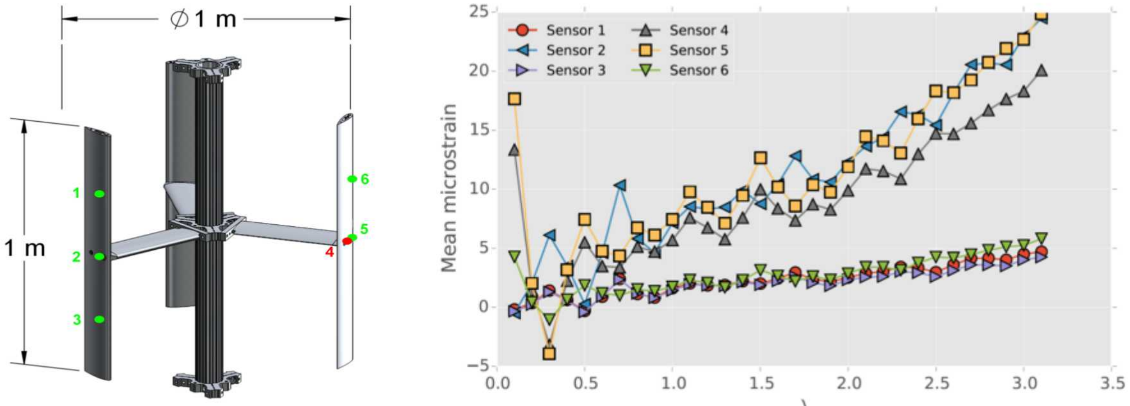
Sandia’s Wavebot testing at Navy’s maneuvering and seakeeping basin, MD



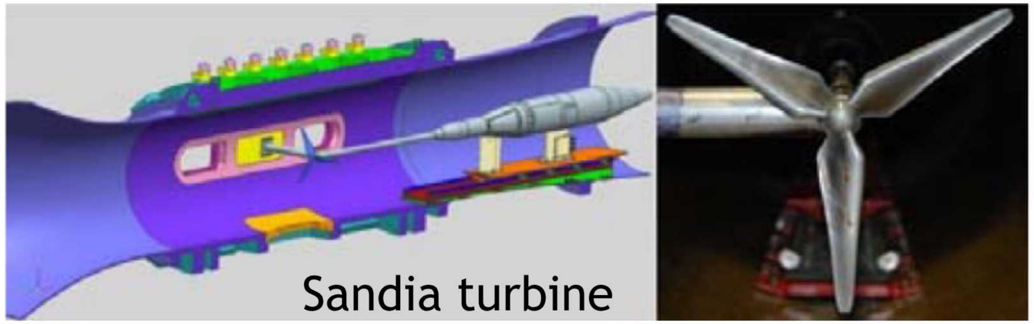
Sandia Wave Energy Power Take-off Lab (SWEPT)

•Test stand will simulate dynamics (inertia, damping, stiffness, multi- body links) of full scale WECs, as well as input from waves and wave- body interactions

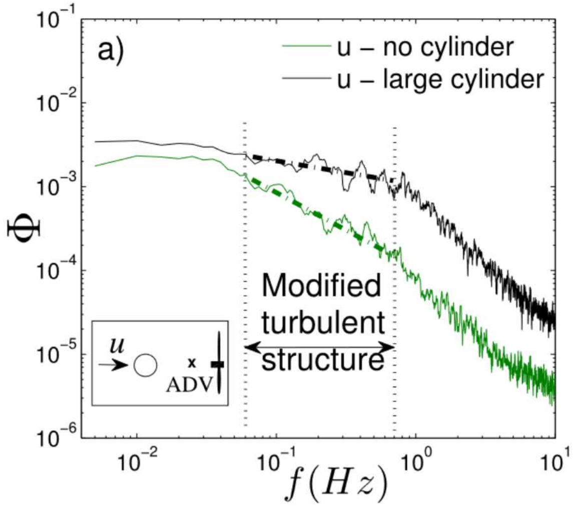
Testing - Current Energy Converters



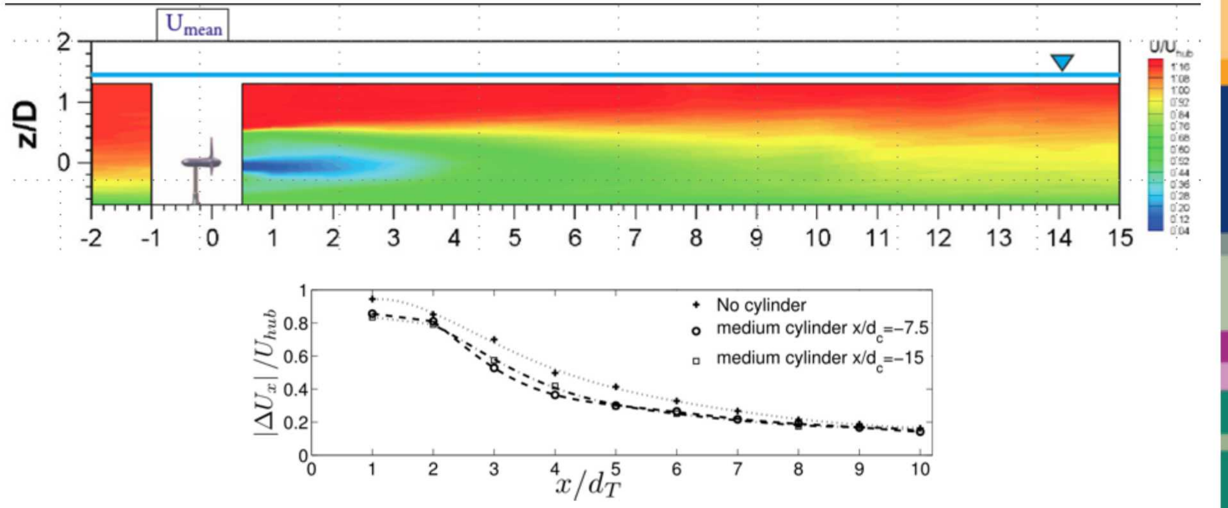
Fiber optic strain sensor testing



Sandia turbine



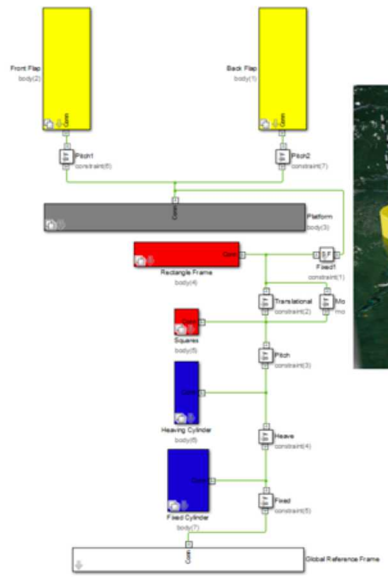
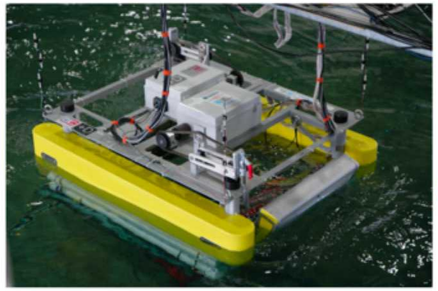
Effects of turbulence on power



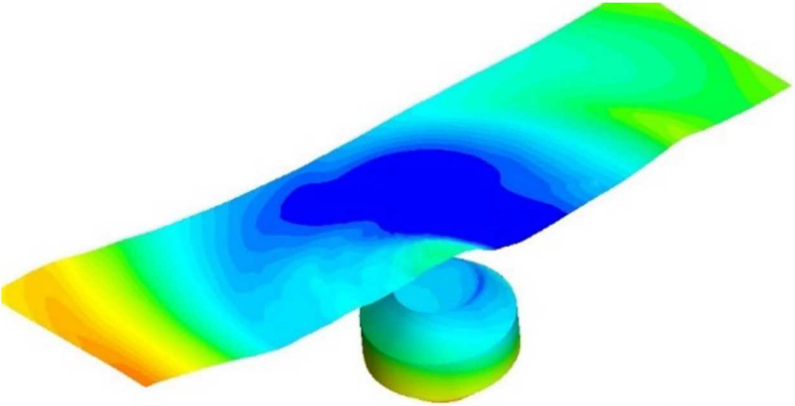
Wake flow recovery

Chamorro, L.P., Hill, C., Neary, V.S., Gunawan, B., Arndt, R.E.A. and Sotiropoulos, F. (2015) Effects of energetic coherent motions on the power and wake of an axial-flow turbine. Physics of Fluids.

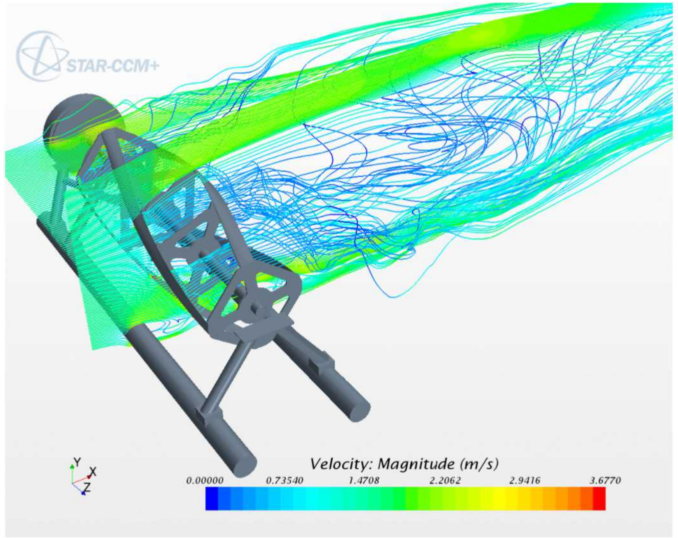
Device Modeling

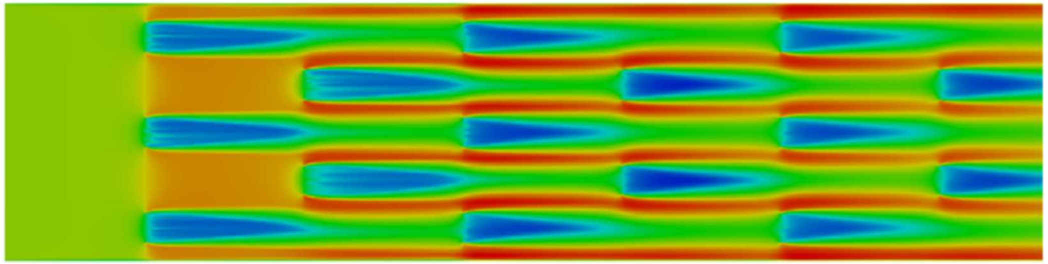
WECSim



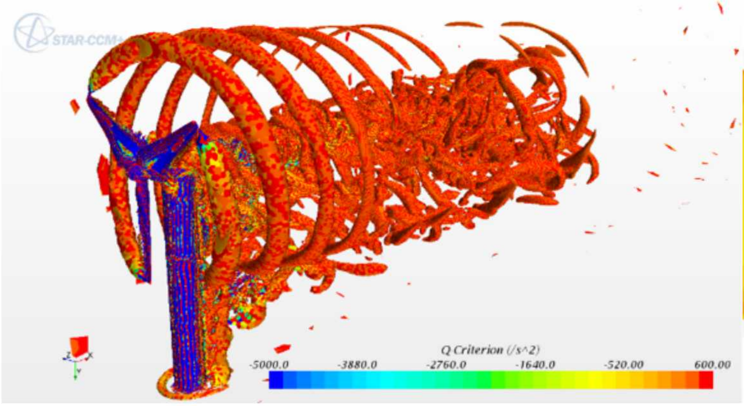
PTO model development in StarCCM+, with Calwave*

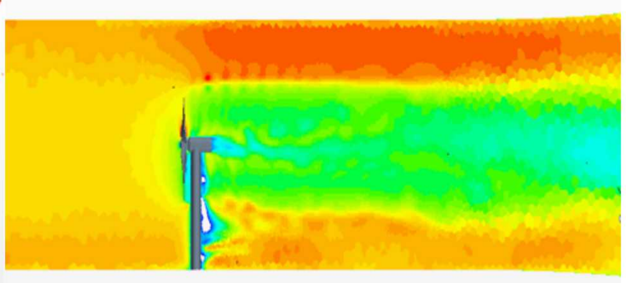


Ocean Renewable Power Company



SNL-Delft3D





Sandia turbine

*TRAN *ET AL.*: PREDICTING THE DYNAMIC CHARACTERISTICS OF A FULLY SUBMERGED WAVE ENERGY CONVERTER SUBJECTED TO A POWER TAKE-OFF FAILURE USING A HIGH-FIDELITY COMPUTATIONAL FLUID DYNAMICS MODEL (SUBMITTED TO EWTEC 2019)

Materials Research

The Challenge: Proper structural/component materials and coatings are critical to reducing engineering barriers, COE, and commercialization time

- **Structure Design & Component:** **(LOADS! uncertainty in composite/design)**
- **Environmental Exposure Issues**
- **Cost (Manufacture, O&M, Reliability)**
- **Safety & Certification**

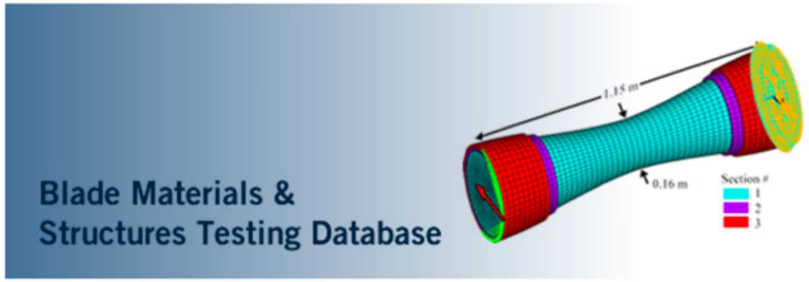
Objective: Helping MHK industry reduce uncertainty in using composites in their designs

Sea Water Effects on Composite Performance

Biofouling & Environmental Effects on Composites

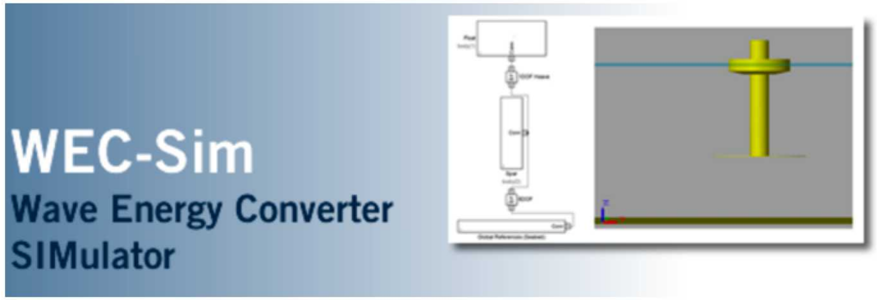
Corrosion of Metal – Carbon Fiber Composite

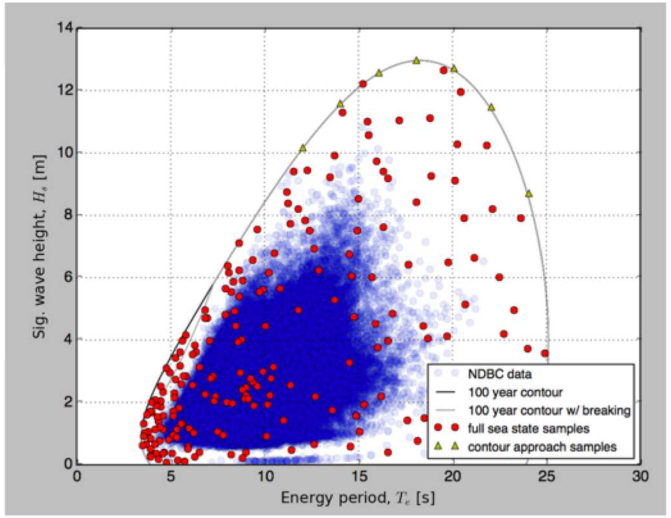
Composite joint testing



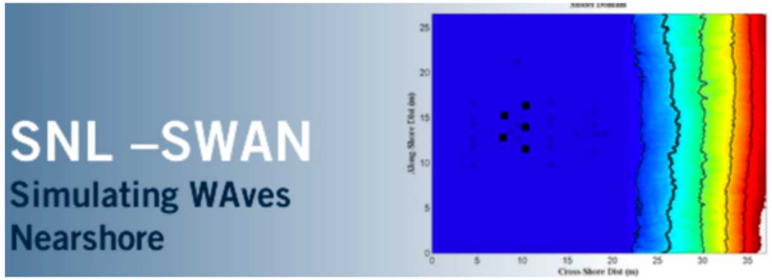
https://energy.sandia.gov/energy/renewable-energy/water-power/technology-development/advanced-materials/mhk-materials-database/

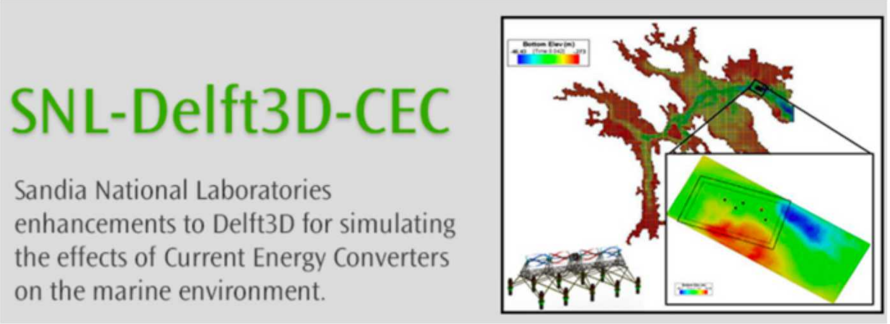
Tools Development

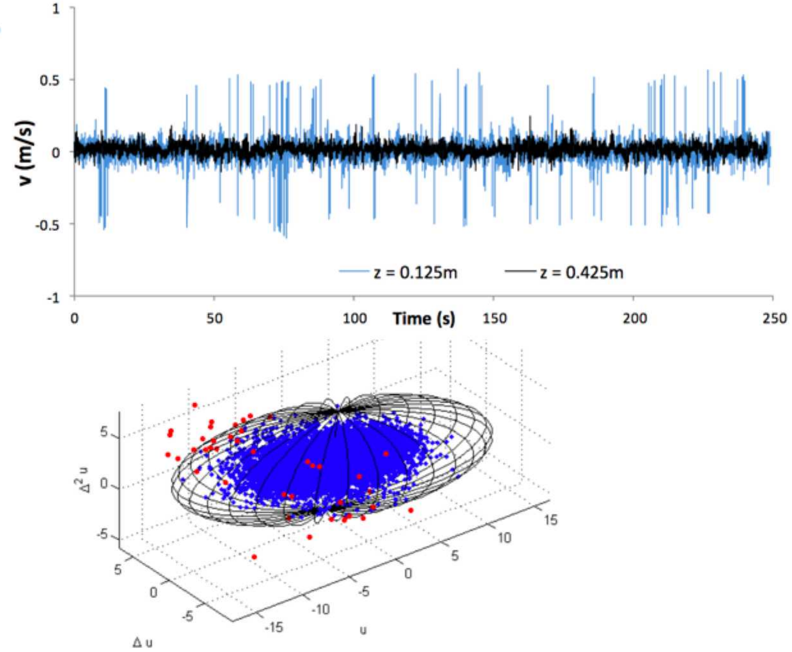




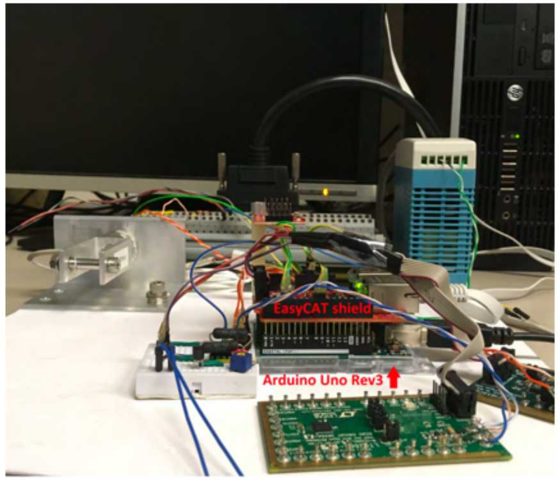
WEC Design Response Toolbox (WDRT)



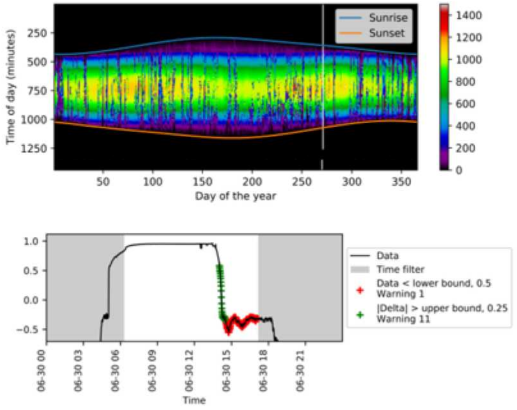




ADV and ADCP post-processing for MHK



Mini DAQ development



	System 1	System 2	System 3	System 4
Location 1	DA 1.00 QCI 1.00 EPI 0.99	DA 0.13 QCI 0.78 EPI nan	DA 1.00 QCI 1.00 EPI 0.98	DA 1.00 QCI 1.00 EPI 0.98
Location 2	DA 0.43 QCI 1.00 EPI 0.88	DA 1.00 QCI 0.93 EPI 0.01	DA 0.86 QCI 0.76 EPI 0.88	DA 1.00 QCI 0.93 EPI 0.98
Location 3	DA 1.00 QCI 0.93 EPI 0.98	DA 0.10 QCI 0.51 EPI nan	DA 0.57 QCI 0.84 EPI 0.63	DA 1.00 QCI 0.93 EPI 0.50

DA = Data availability
QCI = Quality control index
EPI = Energy performance index

Open source data QA/QC software

In collaboration with NREL and Oregon State University

Water Power Staff

Peter H. Kobos, Ph.D. – Department Manager

Giorgio Bacelli, Ph.D.—Dynamics & Control Engineer

- Systems dynamics, control and estimation
- Modeling & system identification
- Instrumentation & data acquisition

Chris Chartrand, M.S.—Numerical Analyst & Developer

- Computational fluid dynamics
- Numerical methods
- Software development

Ryan Coe, Ph.D. — Wave Energy & Fluid Dynamics Specialist

- Computational fluid dynamics
- Reduced-order modeling
- Wave tank testing

Budi Gunawan, Ph.D.— Hydrodynamic Engineer

- Experimental and computational hydrodynamics
- Device performance testing
- Sensor instrumentation

Bernadette A. Hernandez-Sanchez, Ph.D.—Chemist, MHK Advanced Materials & Coatings

- Protective coatings
- Composite materials
- Materials reliability

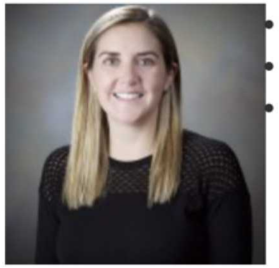
Vincent Neary, Ph.D.— Marine Hydrokinetic Technology Lead

- Hydrokinetic energy resource assessment
- Turbulent inflow characterization
- Experimental testing & numerical modeling

Jesse Roberts, MSME, MSEnvE—Environmental Analysis Lead

- Physical environmental effects of marine renewable energy
- Hydrodynamics & sediment dynamics
- Project management

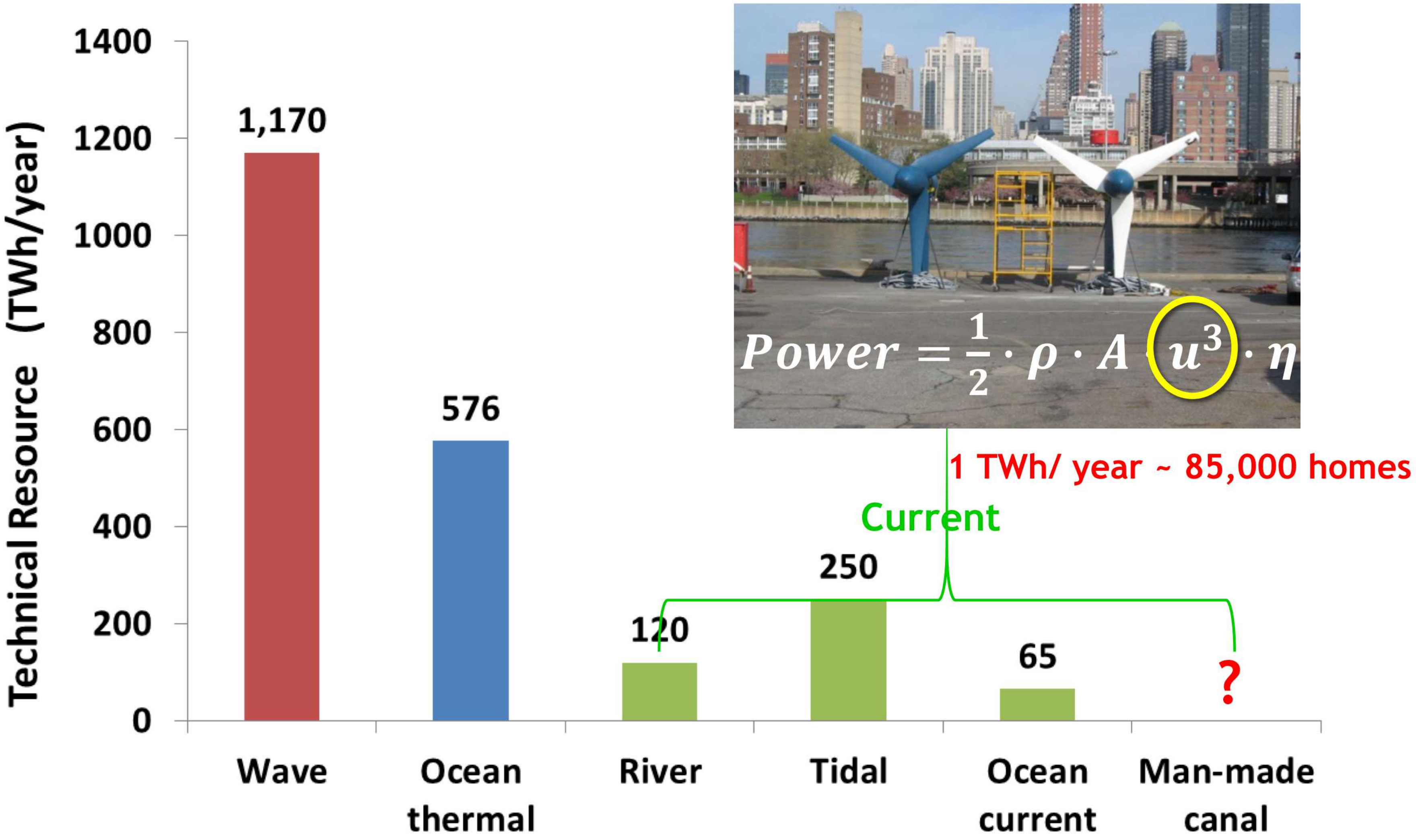
Kelley Ruehl M.S.—Wave Energy & Hydrodynamics Specialist



- Open source code development
- Hydrodynamic modeling
- Wave tank testing

Hydrokinetic Testing in an Irrigation Canal

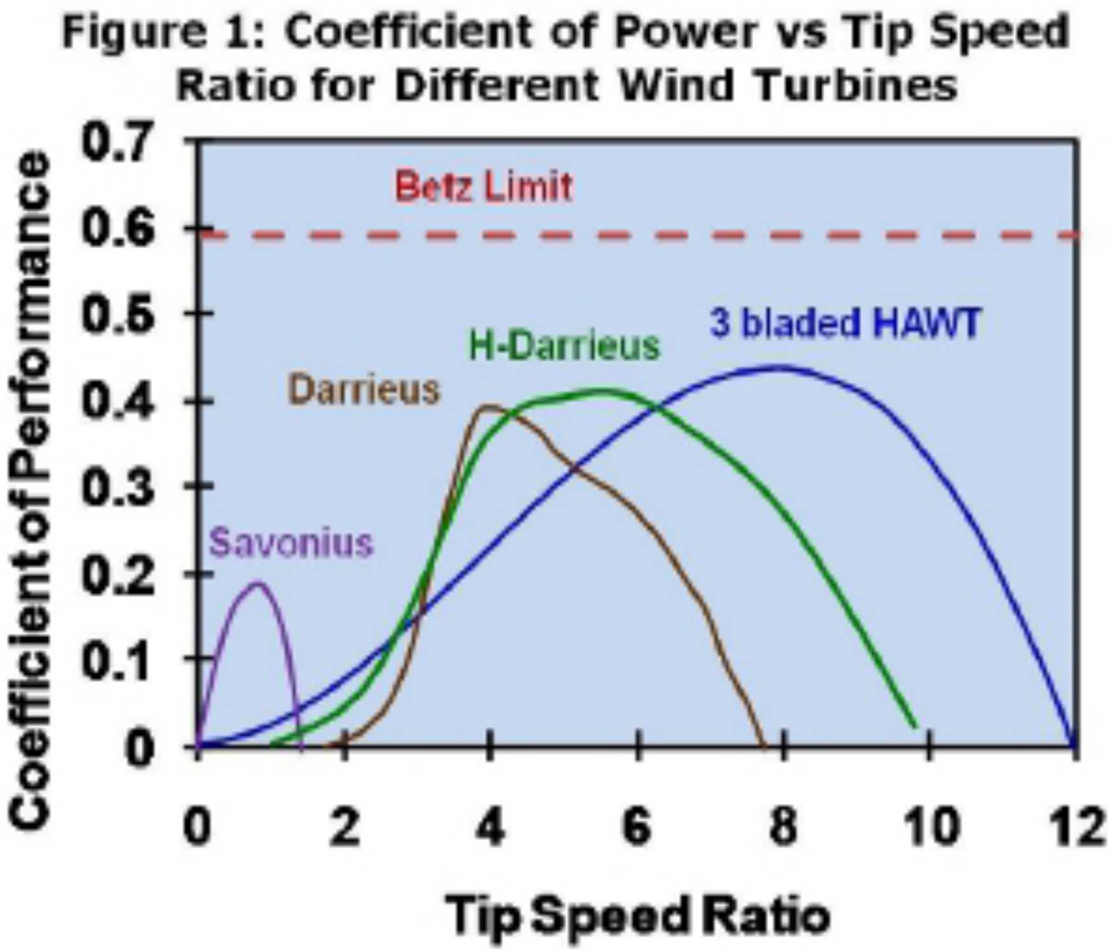
Hydrokinetic (HK) Intro: Resource



Electricity use in the US = 4,000 TWh/year

HK Intro: Measurement Examples

- Turbine performance and thrust curves
  - Hub-height velocity, power, drag/thrust



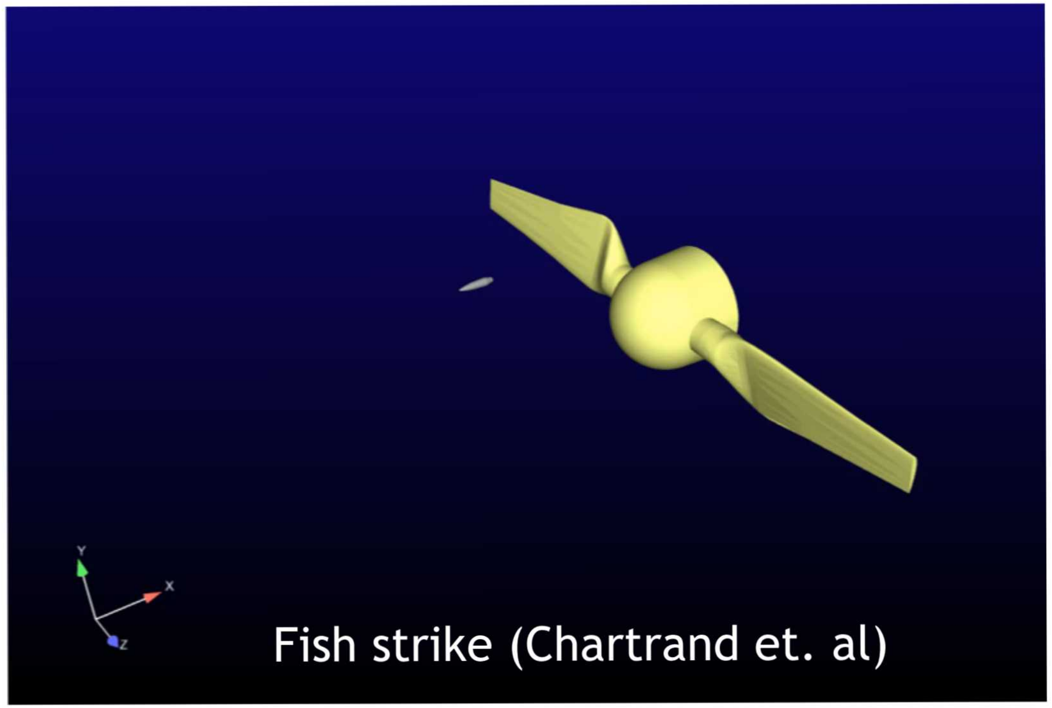
$$TSR = \frac{Tip - speed}{u}$$

$$C_p = \frac{Power}{\frac{1}{2}\rho A u^3}$$

Case Study: Instream hydrokinetic (HK) turbine at Roza Canal, Yakima, WA

Potential Effects of HK Deployment

- Flooding?
- Nearby hydroelectric power productions?
- Pumping cost?
- Aquatic organisms?



Project Objectives

Use USBR's Roza Main Canal as an "outdoor laboratory" for HK testing:

- Determine hydrodynamic effects of HK operation – field measurements (water level, velocity, energy grade line)
- Collect field data for numerical model testing/validation (hydrodynamic effects, turbine performance, array optimization)

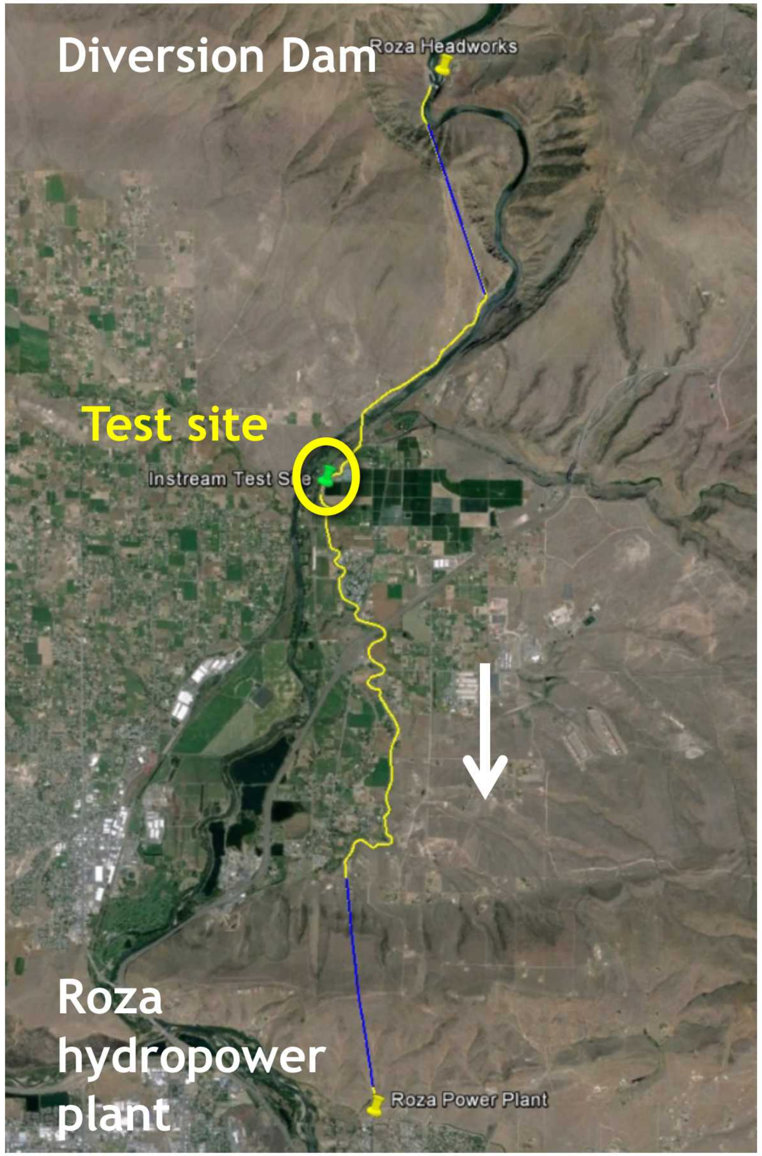
Team

Instream Energy Systems, Corp. (Shane Grovue): turbine performance characterization and demonstration testing

Reclamation (Josh Mortensen, Bryan Heiner): hydraulic impacts to canal system and HEC-RAS numerical modeling

Sandia National Laboratories (Budi Gunawan, Jesse Roberts, Vincent Neary): near field hydrodynamics, Delft3D numerical modeling, turbine performance characterization

Site



Diversion Dam
Roza Headworks
Test site
Roza hydropower plant
Roza Power Plant

Site

4.2 m

- Fr = 0.37

Early Days…

Sensors and Equipment

Hobo logger (Water level)

ADCP (Velocity & flow discharge)

ADV (Turbulence)

Remote control boat with RTK GPS

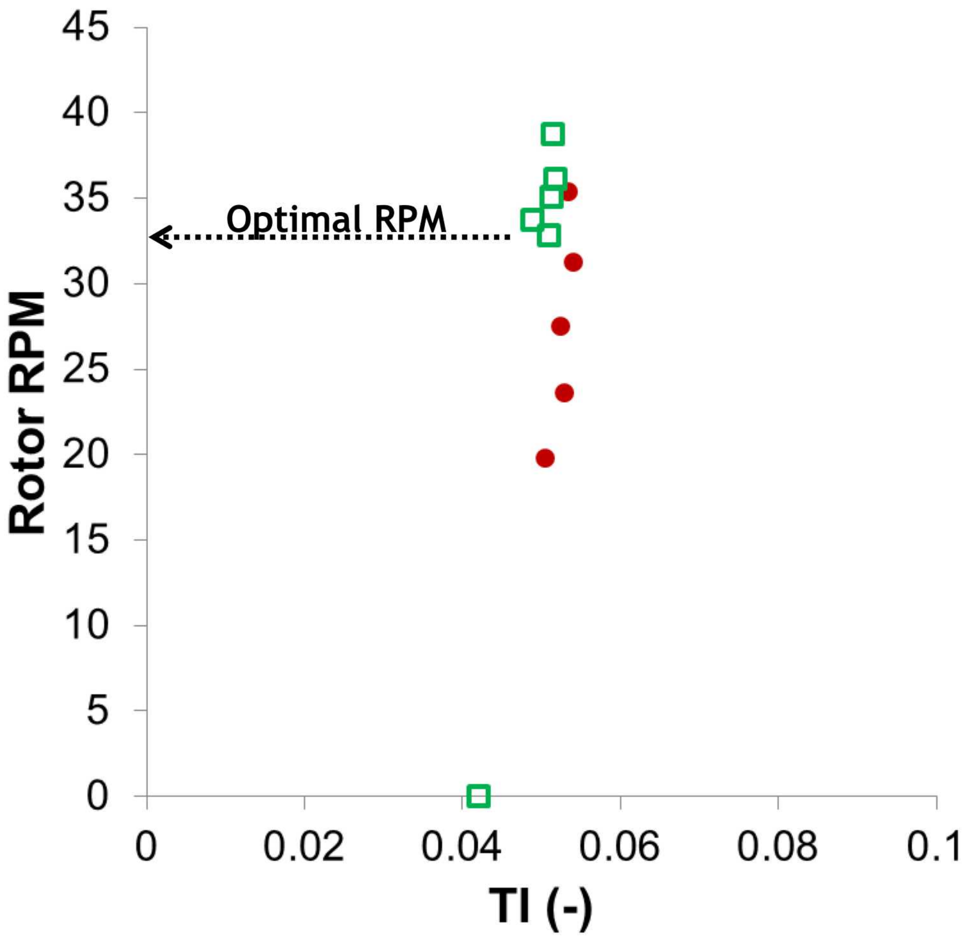
Tethered ADCP boat

Disclaimer:
The use of trade, product, or firm names in this paper is for descriptive purposes only and does not imply endorsement by the U.S. Government

Turbulence

Turbulence

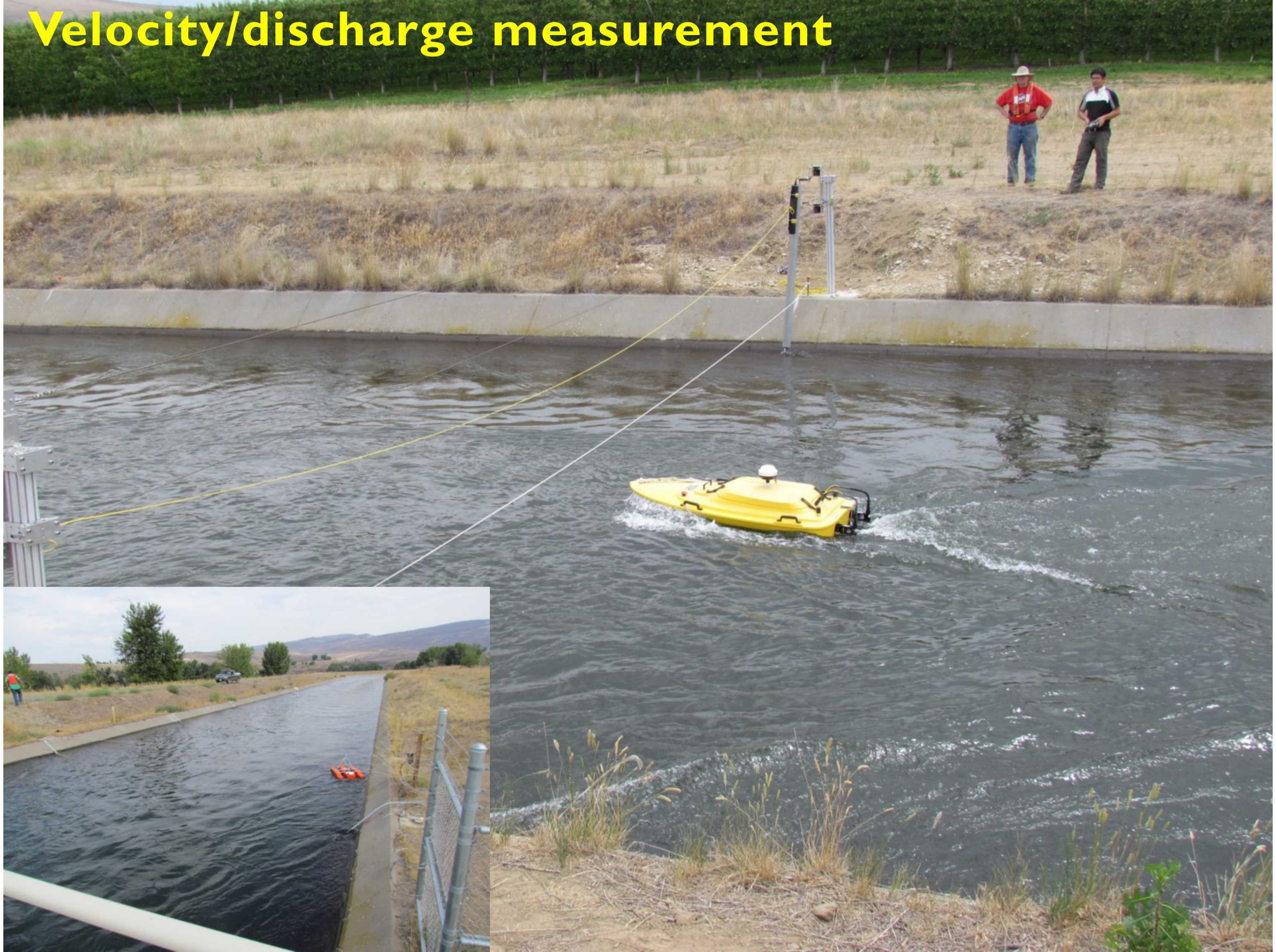
Turbulence Vs. Rotor RPM



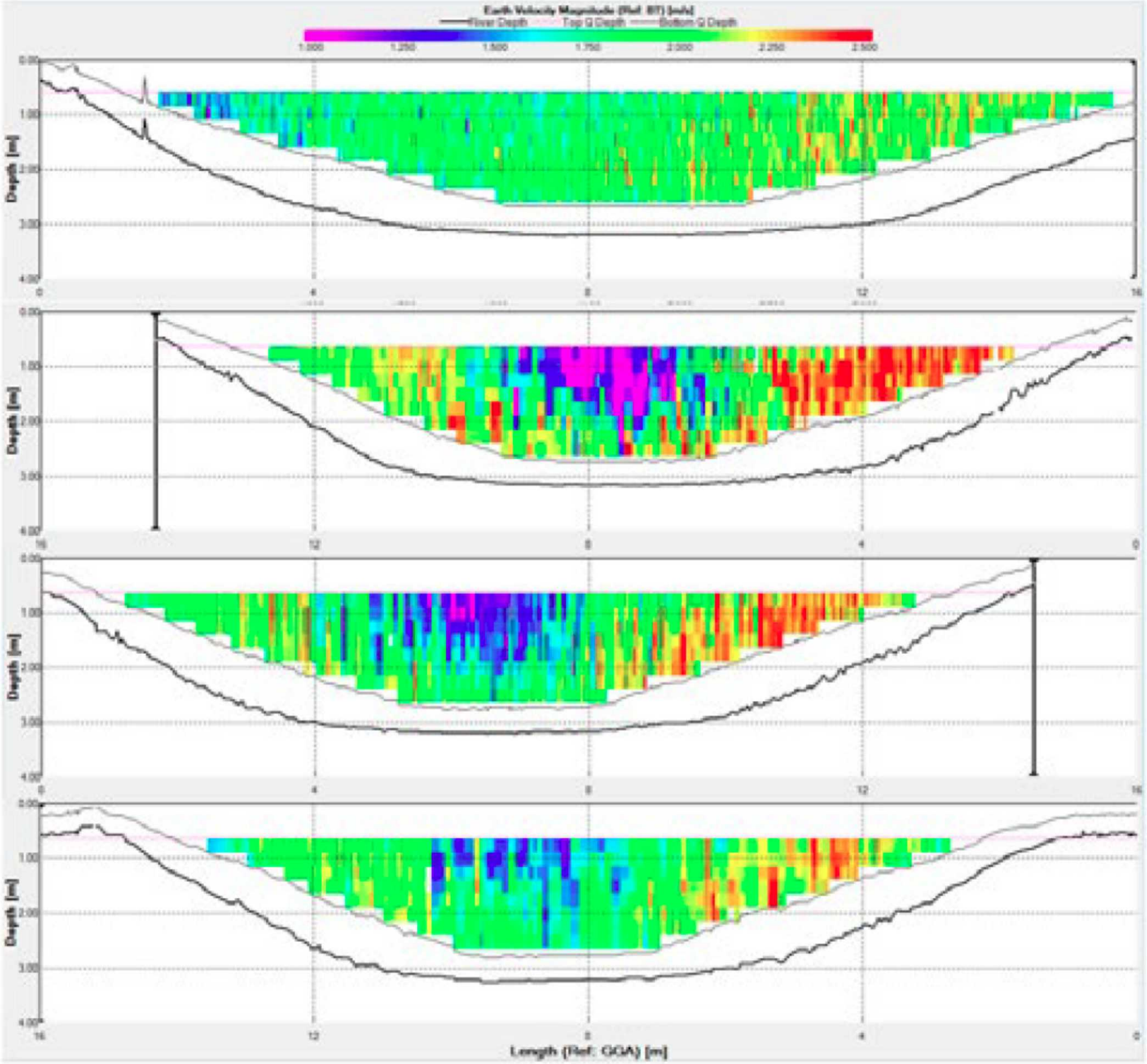
Inflow turbulence ~ 5% (rotor mid height)

Z-Boat

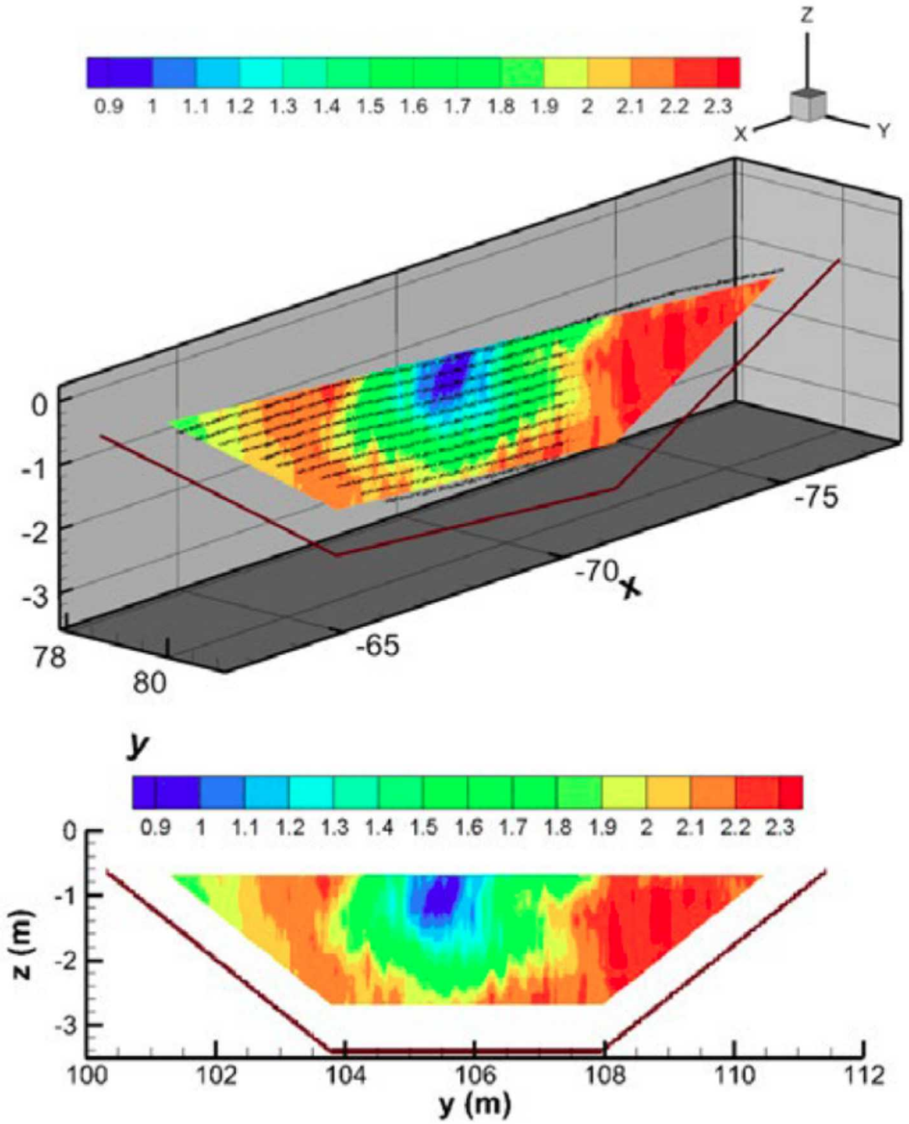
Velocity/discharge measurement




stream
Energy Systems

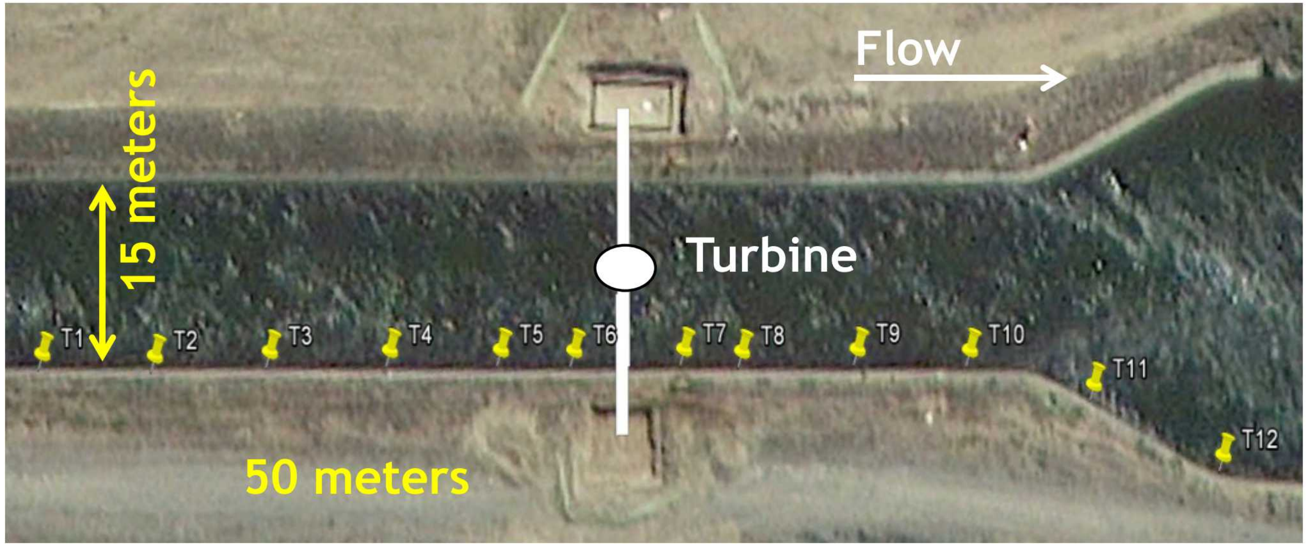


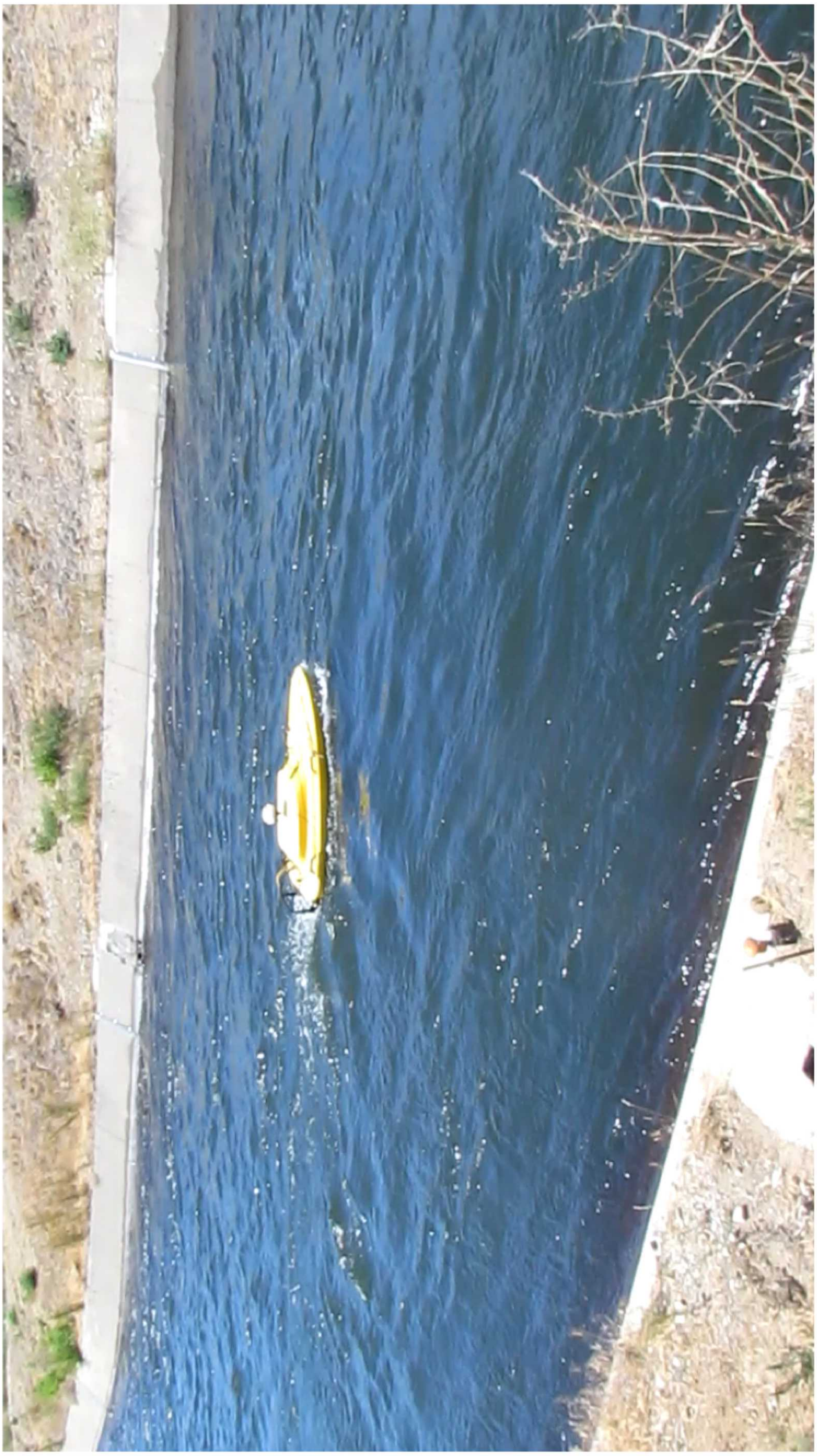
Earth Velocity Magnitude (Ref: BT) [m/s]
River Depth
Top Q Depth
Bottom Q Depth
1.000
1.250
1.500
1.750
2.000
2.250
2.500
Depth [m]
Length (Ref: GGA) [m]

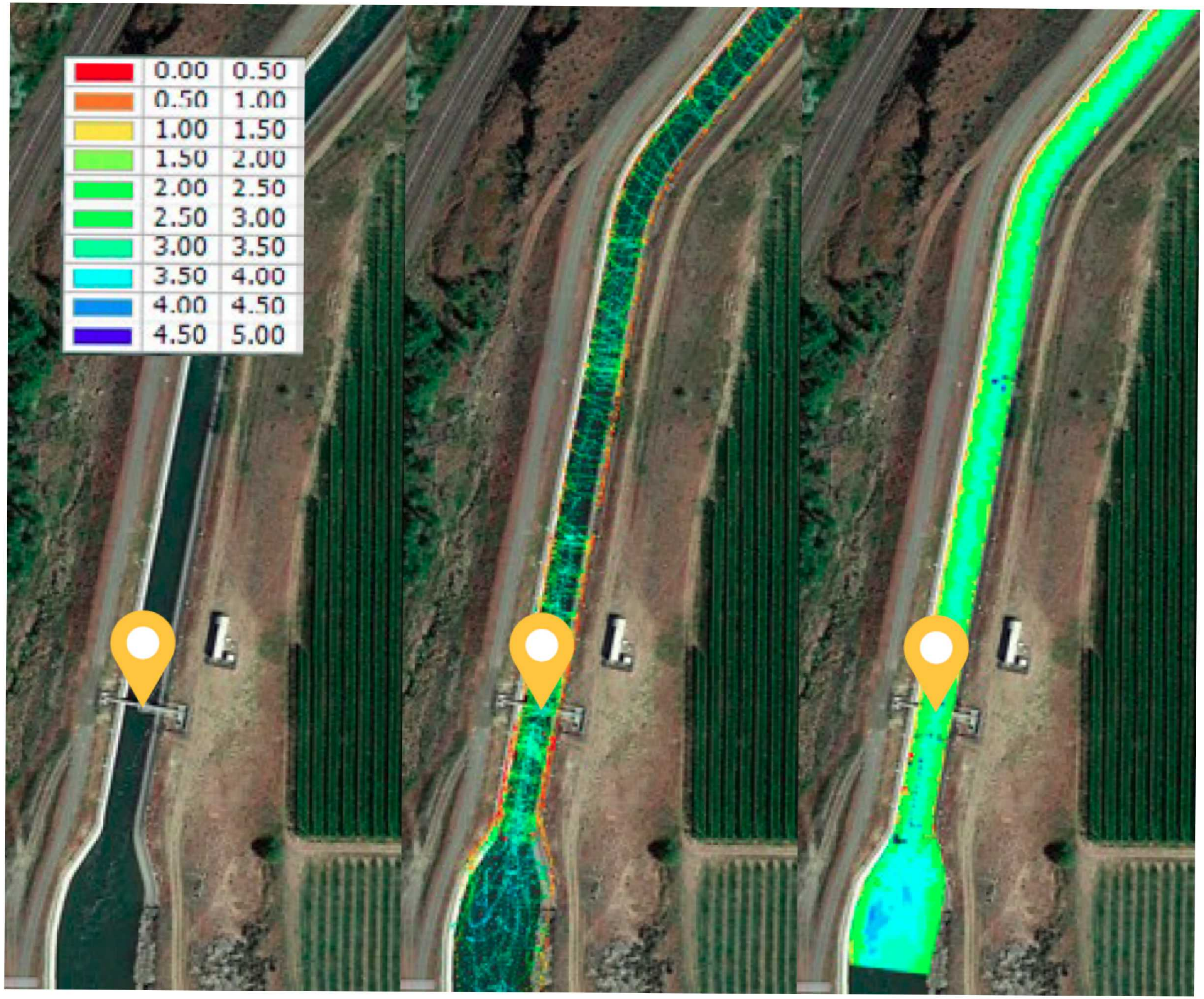

0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2 2.1 2.2 2.3
Z
X
Y
0
-1
-2
-3
78
80
-65
-70
X
-75
y
0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2 2.1 2.2 2.3
z (m)
0
-1
-2
-3
100
102
104
106
108
110
112
y (m)

Transect	Med RPM Q-BT (m3/s)	Delta	Med RPM Q-GGA (m3/s)	Delta	High RPM Q-GGA (m3/s)	Delta
T8	58.278	0.03	56.174	-0.01	59.016	0.10
T8	56.373	0.00	57.838	0.02	49.062	-0.09
T8	54.671	-0.03	56.368	-0.01	60.011	0.12
T8	57.092	0.01	57.154	0.00	47.11	-0.12
	56.603		**56.883**		**53.8**	

Transect	Med RPM Q-BT (m3/s)	Delta	Med RPM Q-GGA (m3/s)	Delta	High RPM Q-GGA (m3/s)	Delta
T9	58.151	0.07	58.329	0.04	53.09	0.03
T9	51.681	-0.05	53.291	-0.05	49.008	-0.04
T9	53.597	-0.02	57.123	0.02	51.948	0.01
T9	54.598	0.00	55.58	-0.01	51.191	0.00
	54.507		**56.08**		**51.309**	






0.00 0.50
0.50 1.00
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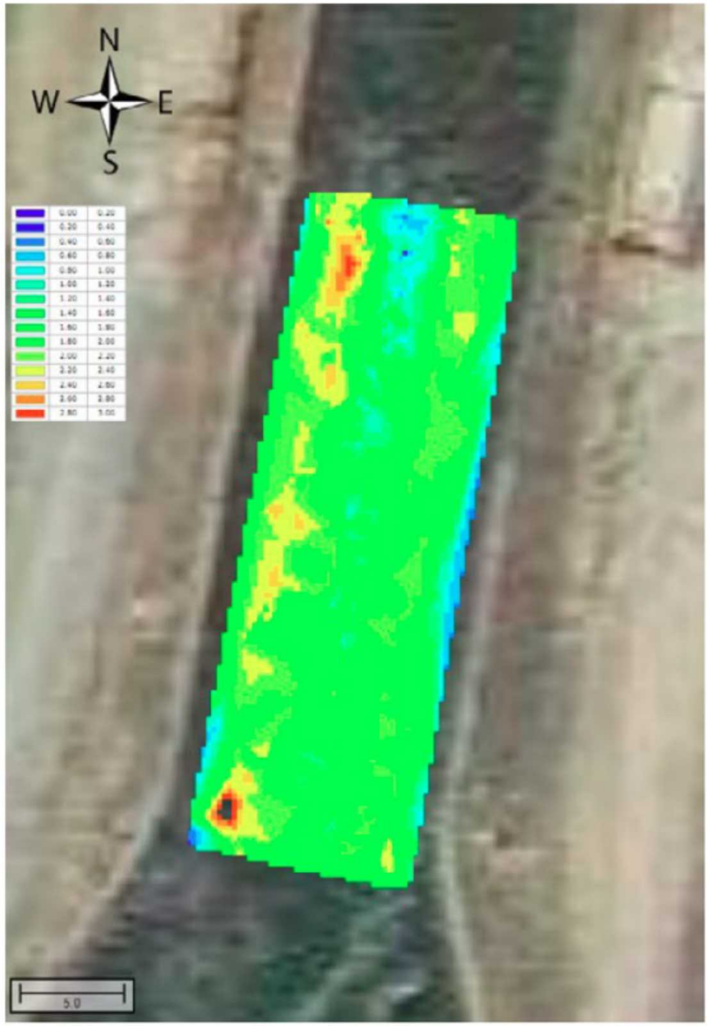
4.00 4.50
4.50 5.00


N
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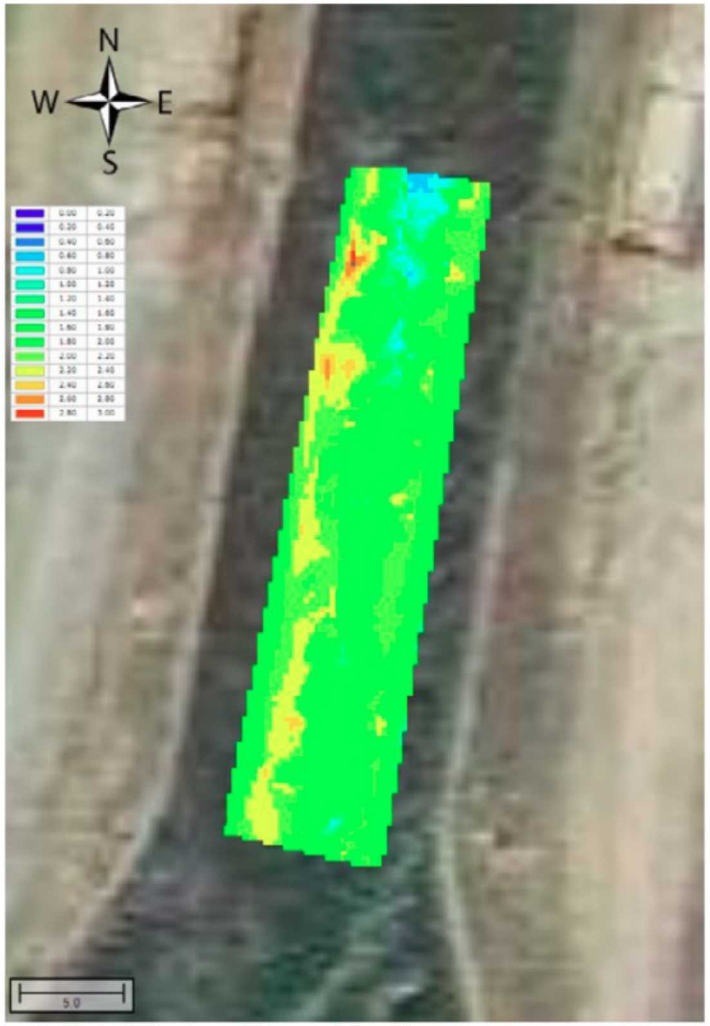
N
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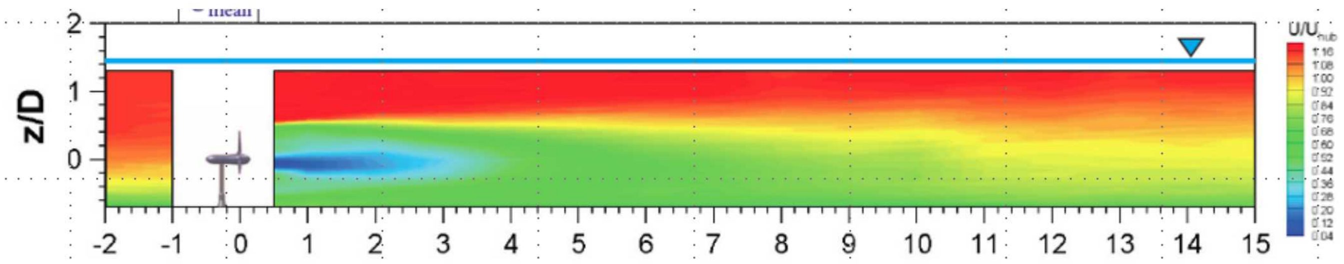
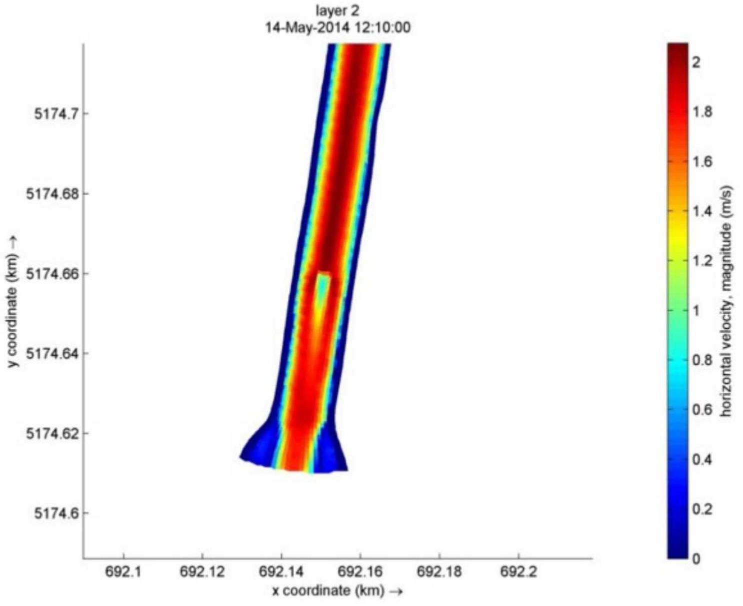
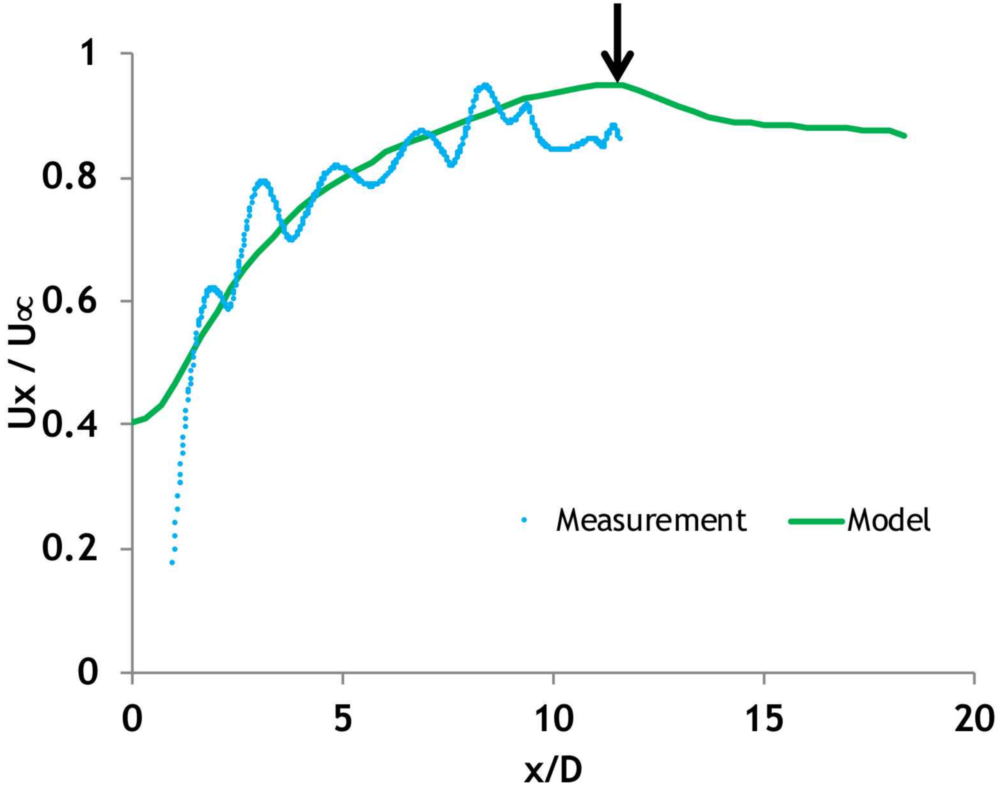

z/D
U/U_{hub}
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Single turbine simulation

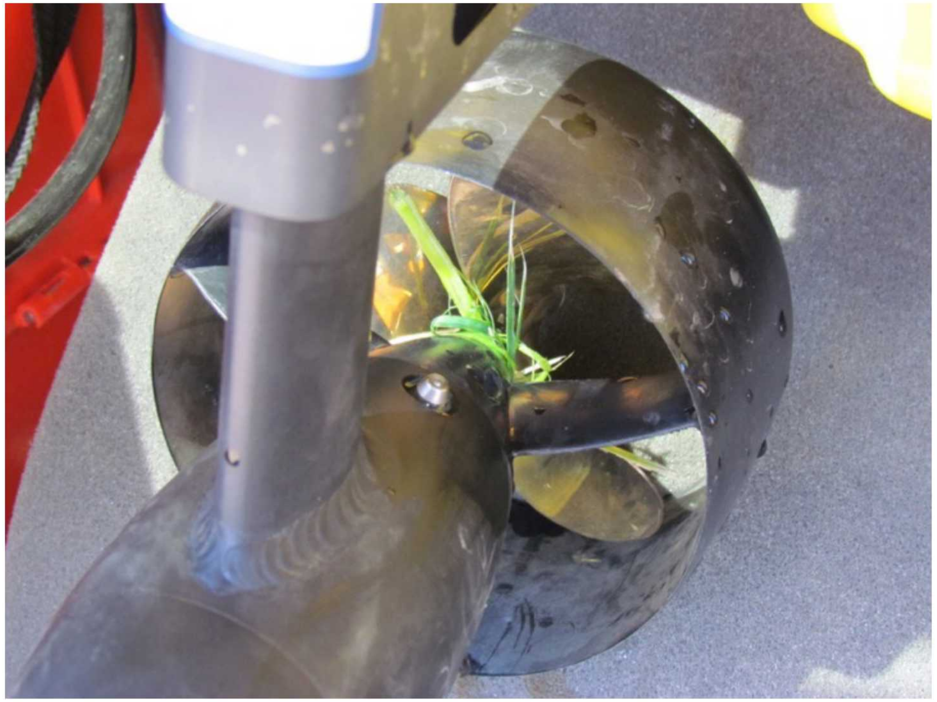
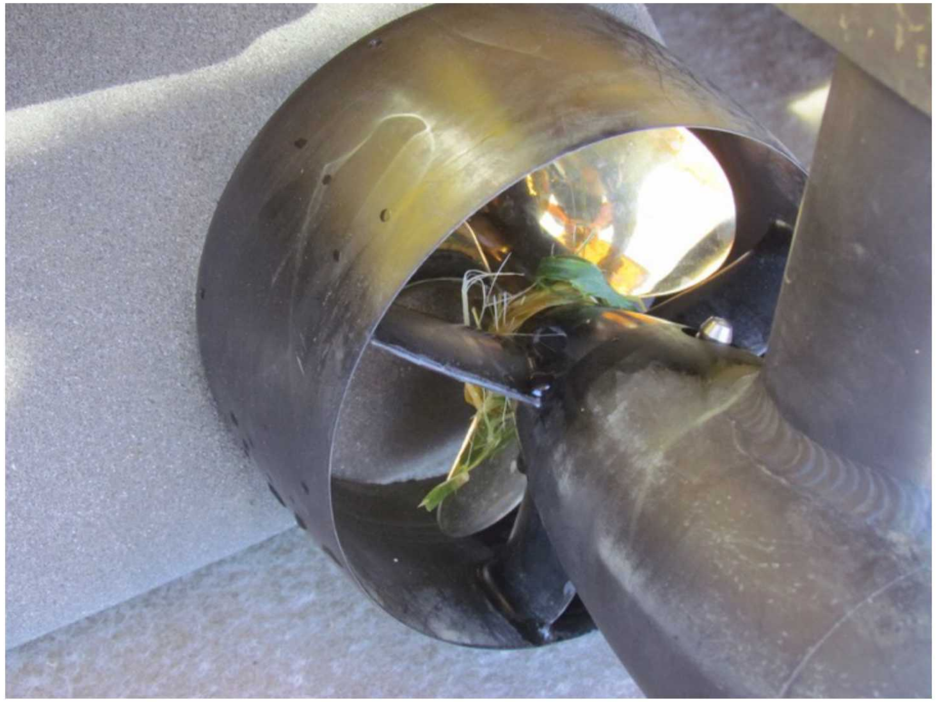
Delft3D model



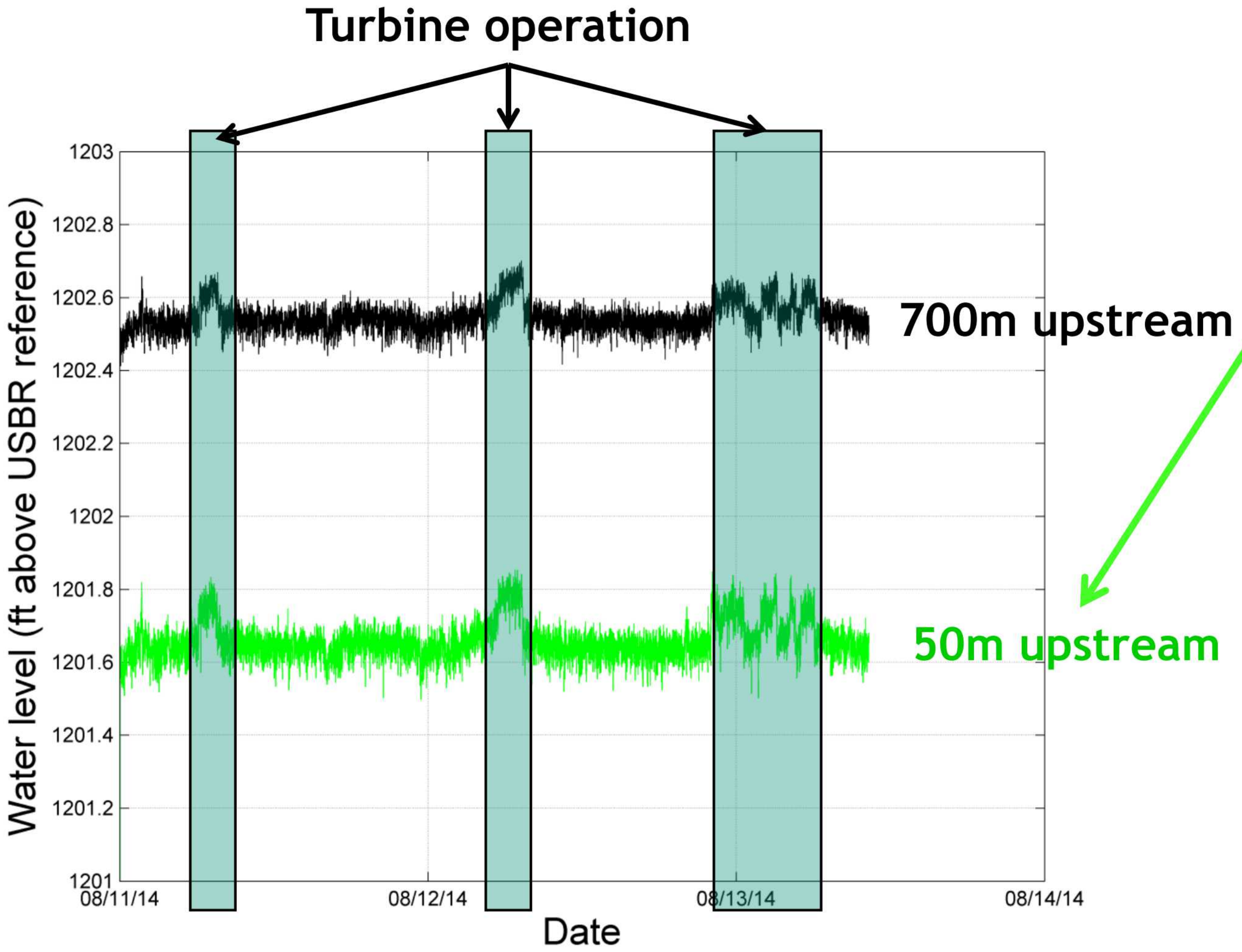
Channel enlargement



Good agreement between measurement and model

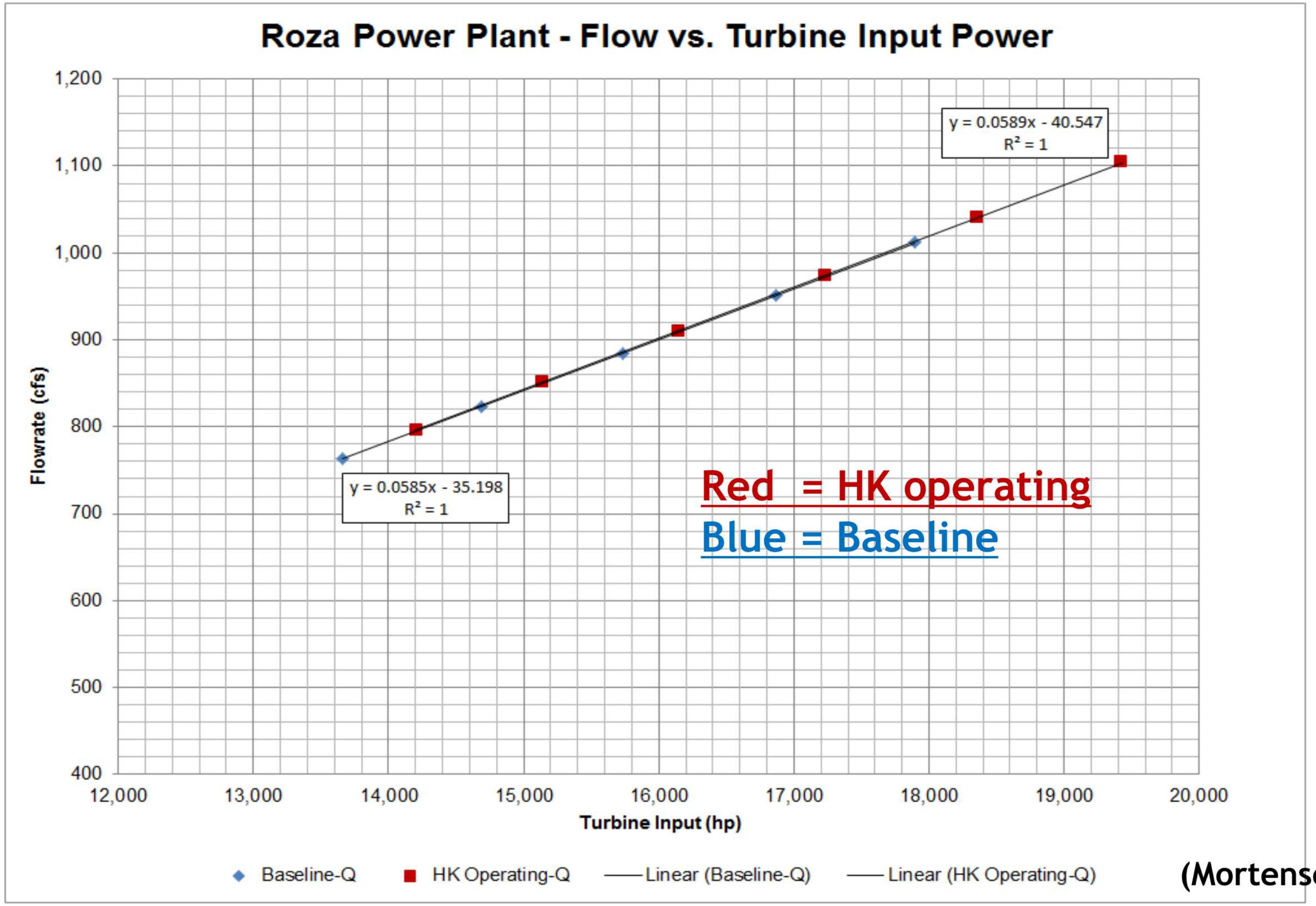



Water level - upstream



Small water level increase upstream of the turbine

Roza plant power generation



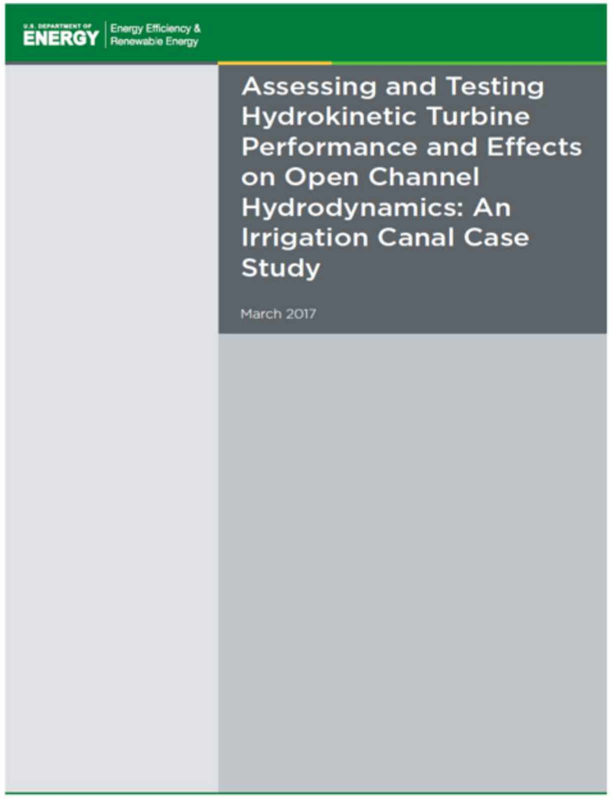
(Mortensen 2014)

No impact on Roza Power Plant power generation

Lesson Learned & Wish List

Roza Canal Project
- Minimum increase of water level
- Roza Power Plant: No impact on power production

Z-boat measurements
- Fast data collection
- Wake measurement looks promising
- Higher turbine RPM – Lower Q measurement quality in near wake
- Pay attention to vegetation, other obstacles



www.osti.gov

Wish list
- Cost-benefit analysis, trade-off between river size and boat types
- Add advance control to Z boat, for fixed vessel measurement
- Add recovery/safety mode when boat flipped

Questions ?

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More ADCPs

Table 1 Recommended measurements for the assessment of potential impacts from open-channel HK operations

No	Measurement Parameters	Locations	Main Purpose	Instrument Example
1	Bathymetry (or geometry for lined channels)	Along the channel, within 20 - 30 diameter from the turbine, and far upstream of the turbine, at the same locations with far upstream water level measurements	Determine channel bed elevations, or verify the existing bathymetry data (as-built geometry data can suffice for lined channels if verified by a field survey)	echo sounder and remotely-controlled survey boat
2	Water level	Cross sections immediately upstream and downstream of the turbine, e.g. every diameter within 5 diameters from the turbine, and every 3-5 diameters between 5 to 20 diameters from the turbine.	Determine impact on water level at locations adjacent to the turbine, where significant difference from baseline (without HK) is often expected	water level logger

~90 % recovery at 8-12 turbine diameter downstream

More ADCPs

No	Measurement Parameters	Locations	Main Purpose	Instrument Example
3	Water level	Cross sections far upstream of the turbine, e.g. at -100, -200 and -300 x/D	Determine impact on water level at far upstream of the turbine. Impact at far upstream is typically expected for open channels with subcritical flow.	water level logger
4	Downstream local velocity measurement over entire cross-section	Cross sections every 1 or 2 diameters up to 5 diameters downstream; every 2 to 5 diameters between 5 and 20 diameters downstream	Determine local velocity variations downstream of the turbine, where high velocity gradients are expected. This information is useful for turbine array design and erosion/ deposition/scouring/ silting analysis.	ADCP
5	Upstream local velocity measurement over entire cross-section	Cross sections at 5 and 10 diameters upstream	Determine inflow velocity for establishing turbine performance curves, as well as velocity gradients.	ADCP
6	Upstream and downstream velocity and turbulence, at a high sampling resolution	Ideally at the same cross sections as the upstream and downstream ADCP measurements, at turbine centerline. A minimum of 3 locations downstream and one location upstream (between 5 to 10 diameter upstream) is required for numerical model input.	Determine turbulence level and unsteady coherent structures on the flow. This information is useful for identifying and quantifying cyclical load on the turbine, and is a critical numerical model input for accurately predicting wake profiles.	ADV

~90 % recovery at 8-12 turbine diameter downstream

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