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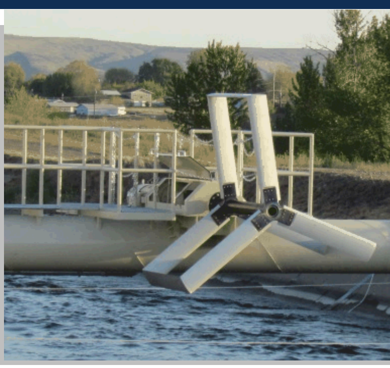
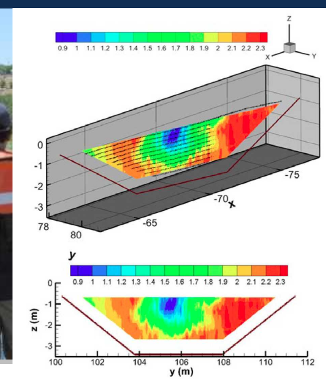
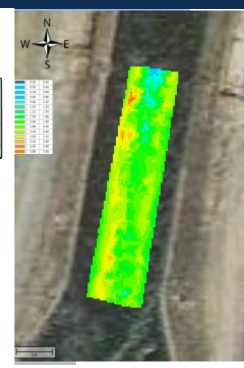
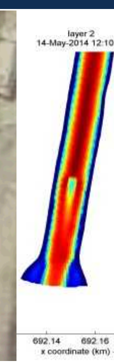
     

Characterization of Hydrokinetic Turbine Inflow and Wake Flow Using ADCPs

Budi Gunawan, Ph.D.

Teledyne Marine Technology Workshop

San Diego, CA, October 15-18, 2017

U.S. DEPARTMENT OF ENERGY

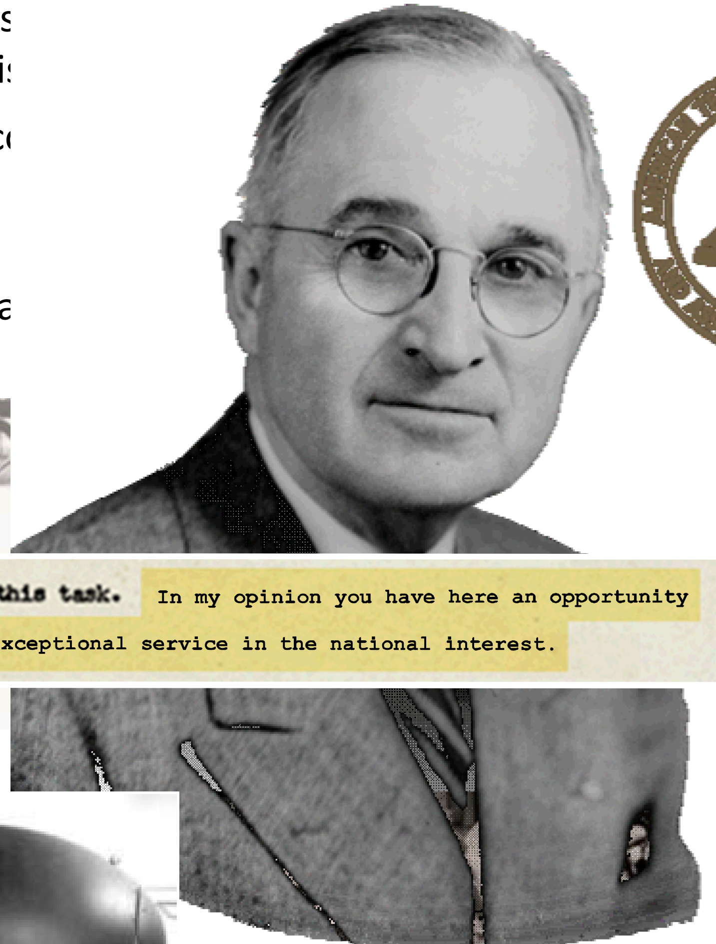
NNSA National Nuclear Security Administration

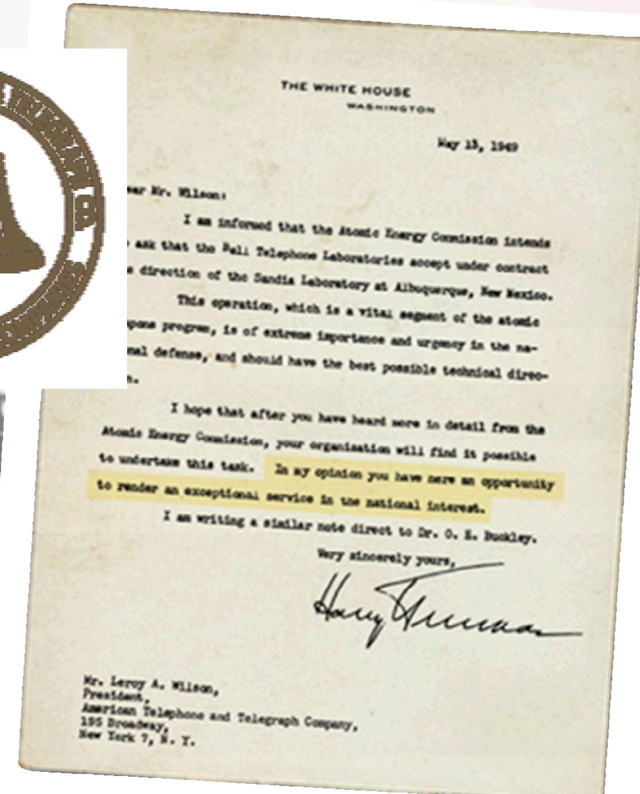
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia’s Intro: History

Exceptional service in the national interest

- July 1945: Los
  creates Z Divi
- Nonnuclear c
  engineering
- November 1,
  Sandia Labora
  established





THE WHITE HOUSE
WASHINGTON

May 13, 1949

ear Mr. Wilson:

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

This operation, which is a vital segment of the atomic
pons program, is of extreme importance and urgency in the na-
nal defense, and should have the best possible technical direc-
n.

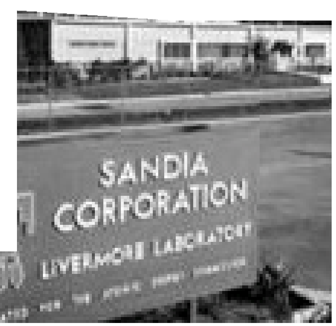
I hope that after you have heard more in detail from the
Atomic Energy Commission, your organization will find it possible
to undertake this task. In my opinion you have here an opportunity
to render an exceptional service in the national interest.

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

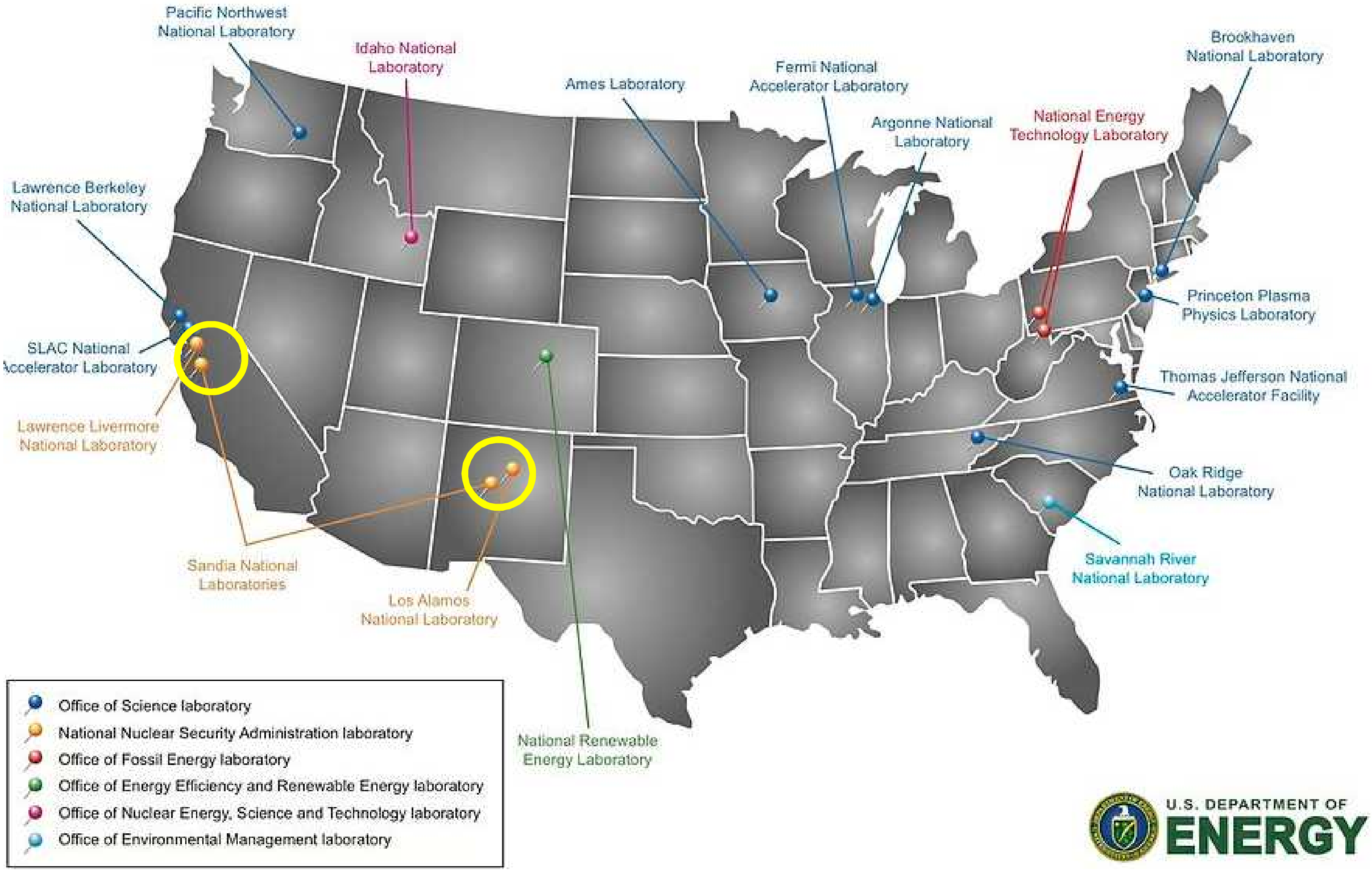
Very sincerely yours,

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.



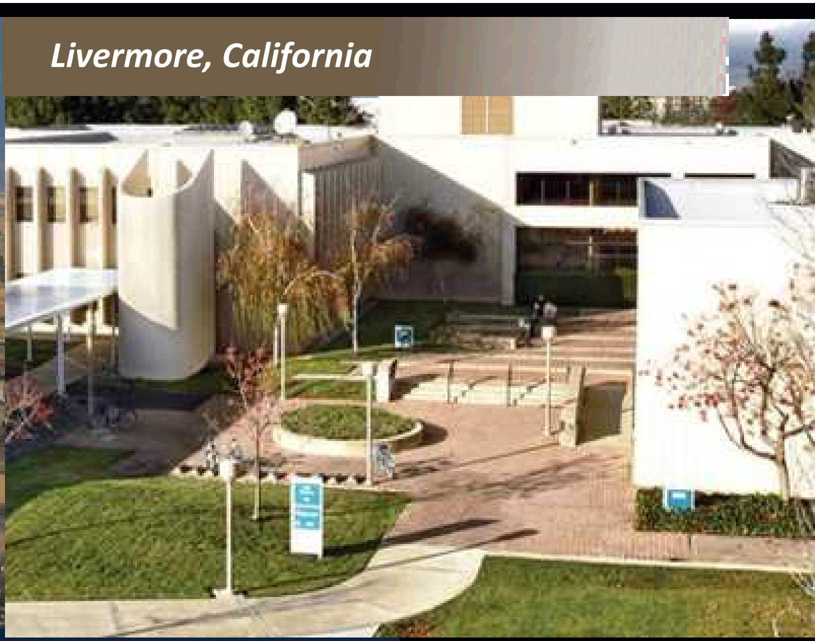
Sandia's Intro: Locations



Sandia's Intro: Sites

Albuquerque, New Mexico

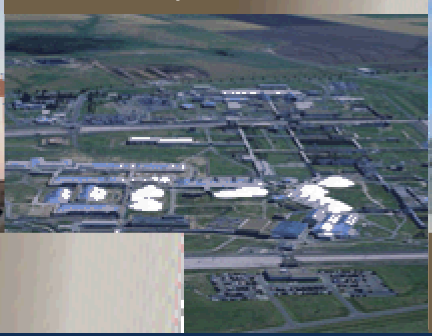
Livermore, California

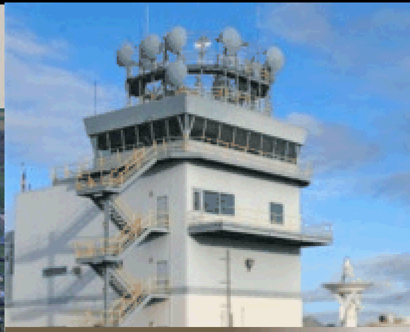


Kauai, Hawaii

Waste Isolation Pilot Plant, Carlsbad, New Mexico

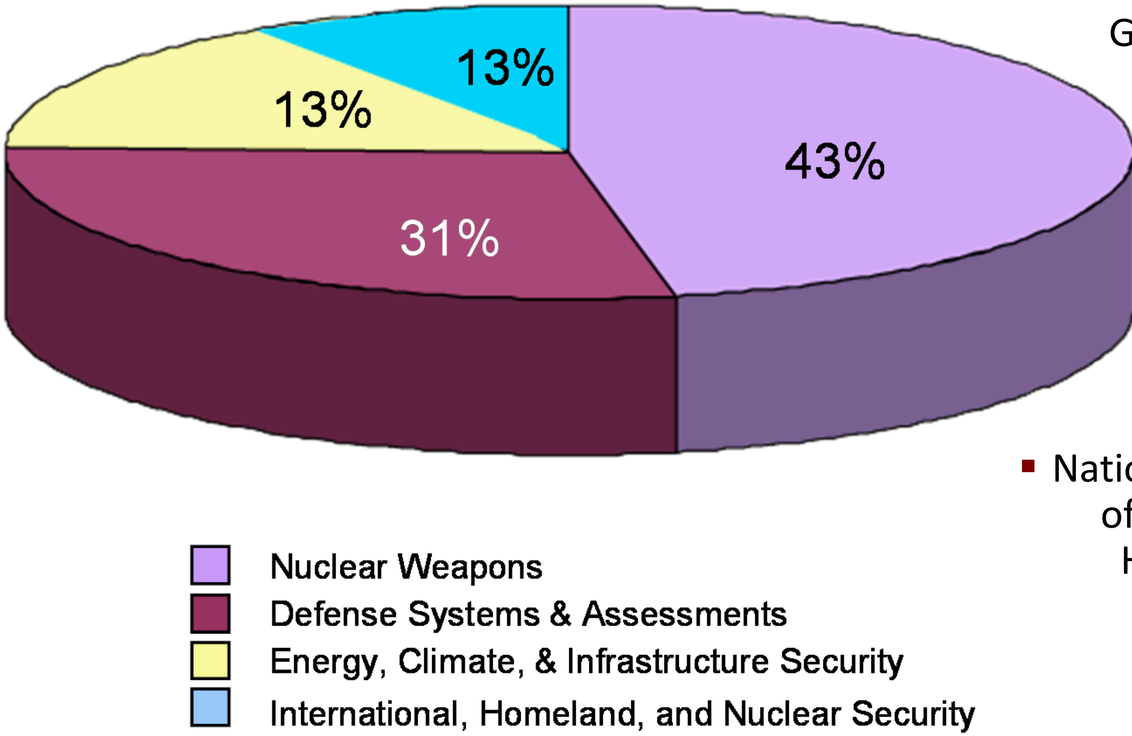
Pantex Plant, Amarillo, Texas





Tonopah, Nevada

Sandia's Intro: Workforce & Budget



Government owned, contractor operated

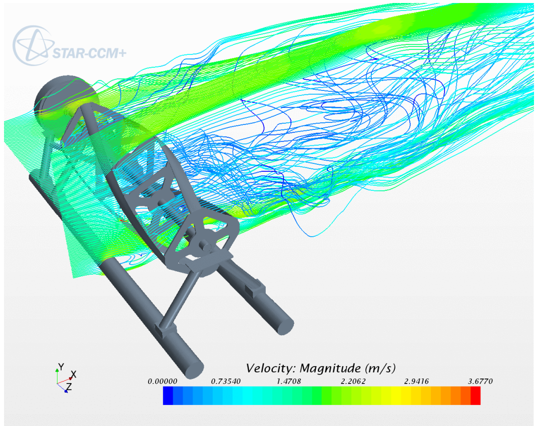
Sandia Corporation

- 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

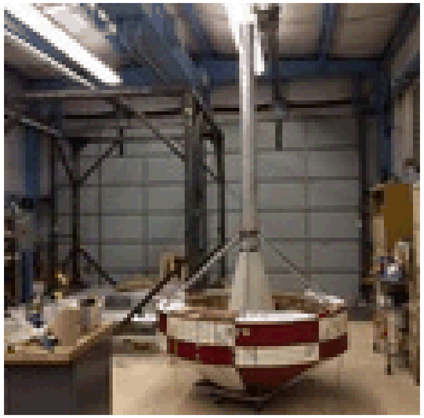
- Federally funded research and development center
- On-site workforce: 12,001 (10,715 NM, 1,286 CA)
- FY16 Budget: $3 Billion
- Renewable Energy Programs: Solar, Wind, Water, Geothermal, Biomass

Sandia's Intro: Water Power Program

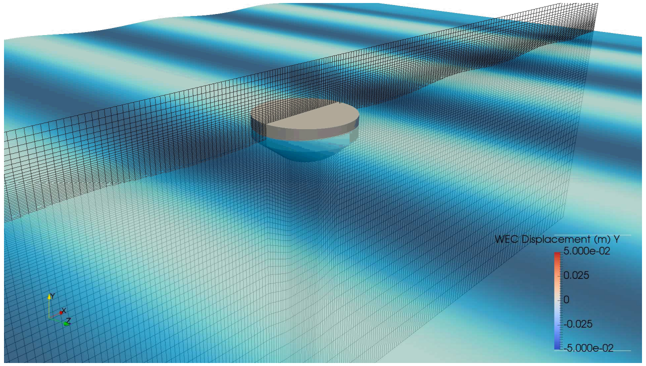
DOE Reference Models



Ocean Renewable Power Company

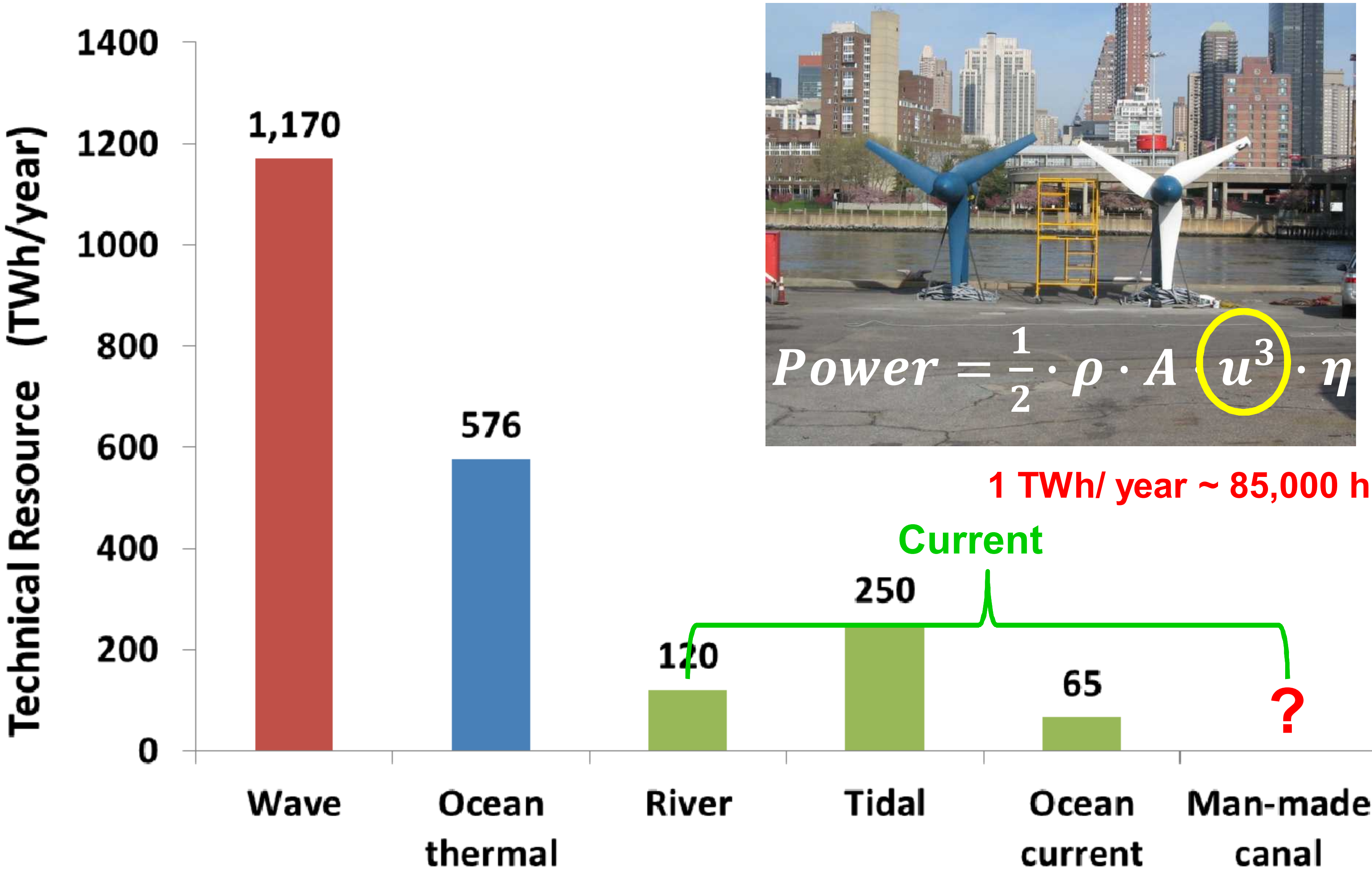


Navy's maneuvering and seakeeping basin, MD



Sandia's point absorber

Hydrokinetic (HK) Intro: Resource

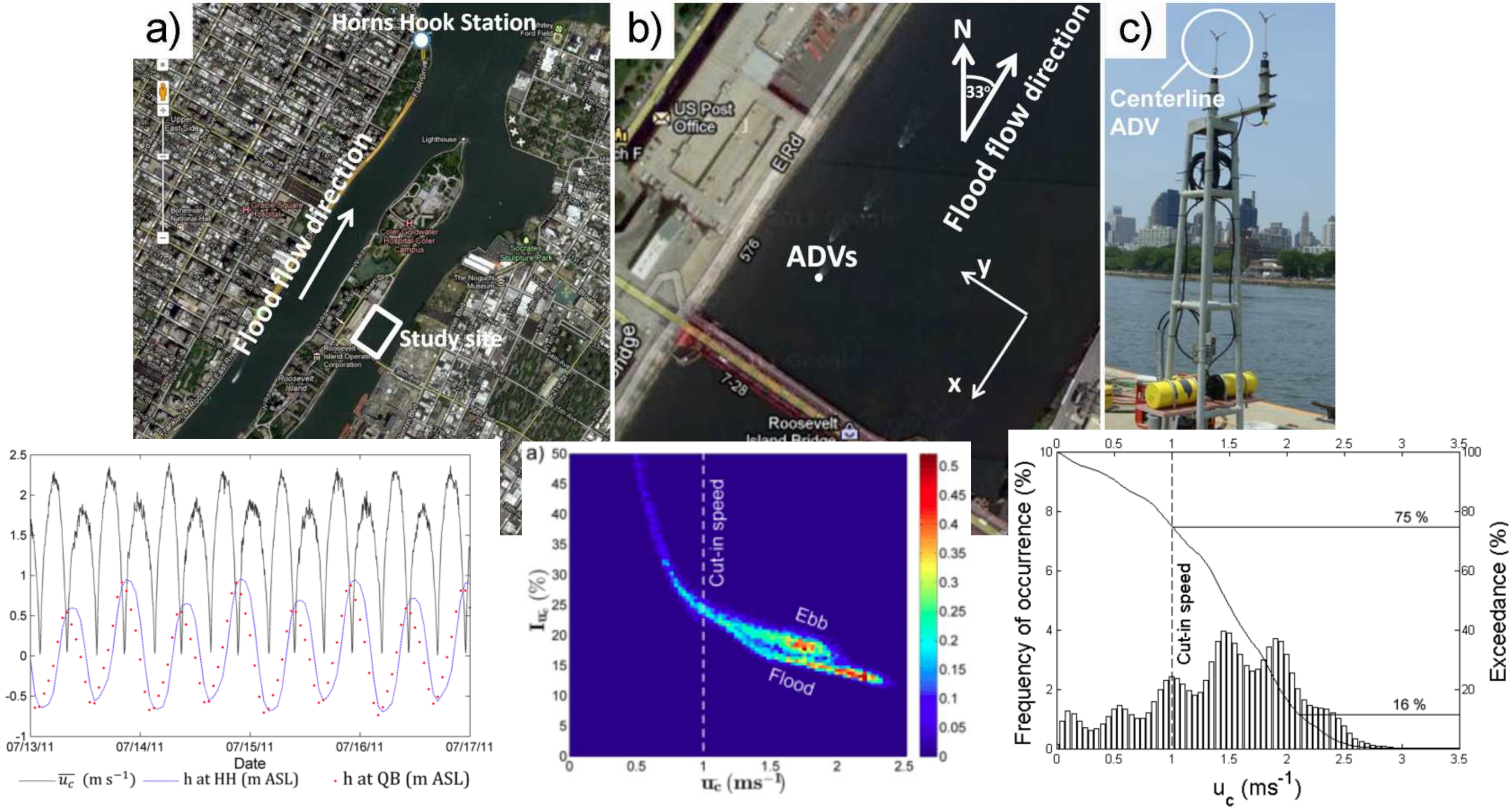


1 TWh/ year ~ 85,000 homes

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

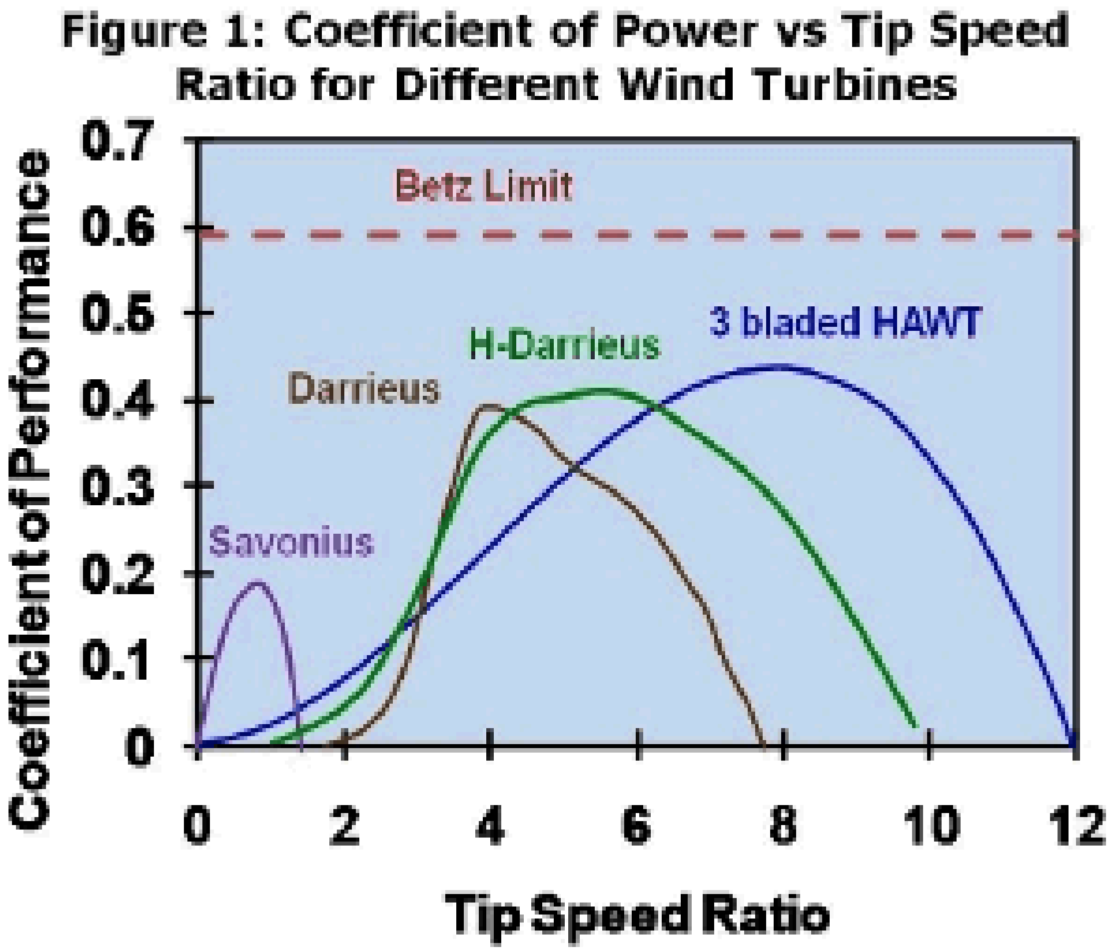
HK Intro: Measurement Examples

- Site resource assessment
  - Long term measurements of velocity (ADCP, ADV)



HK Intro: Measurement Examples

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

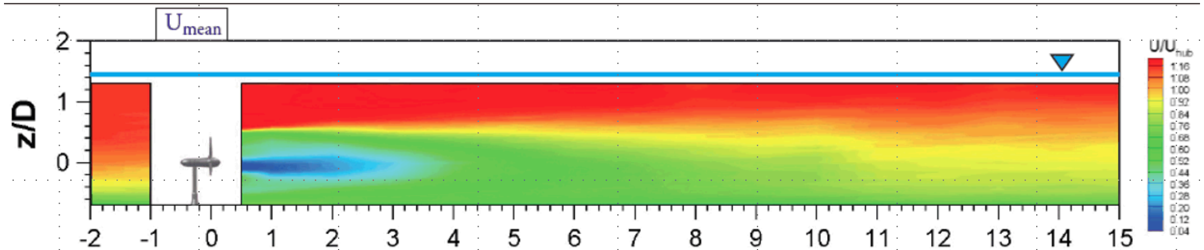


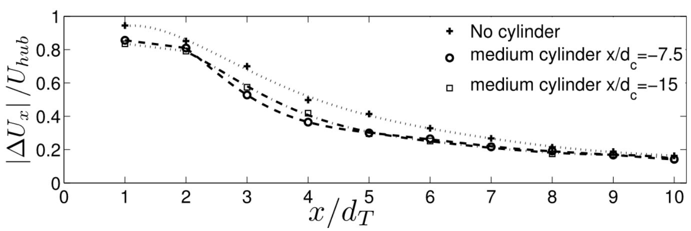
$$TSR = \frac{Tip - speed}{u}$$

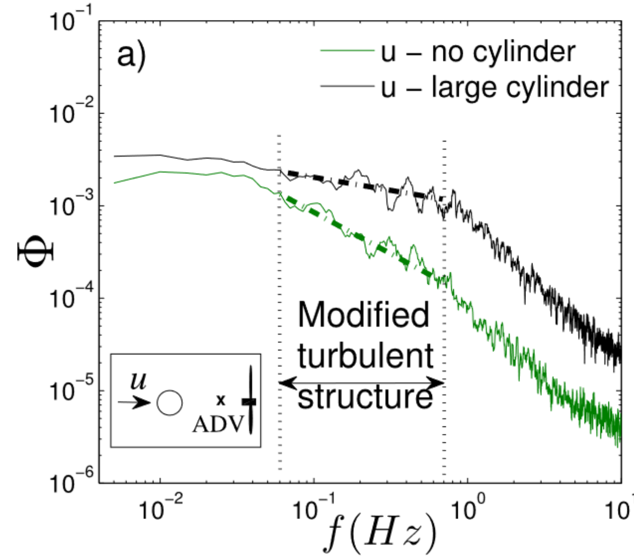
$$C_p = \frac{Power}{\frac{1}{2}\rho A u^3}$$

HK Intro: Measurement Examples

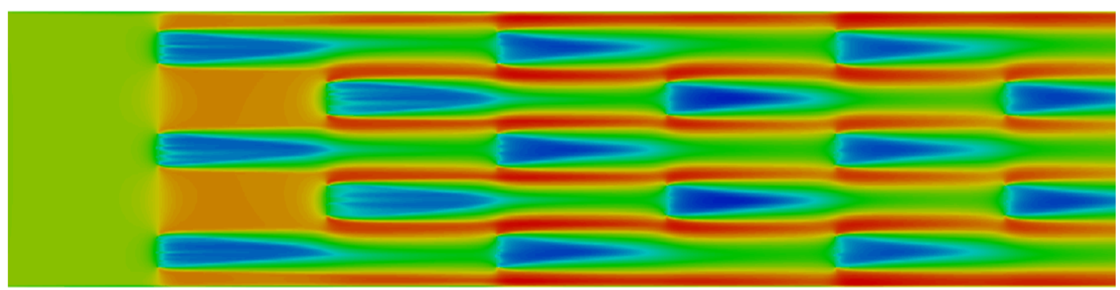
- Model development & validation
  - Bathymetry
  - Discharge – velocity contour
  - Wake flow recovery







Flow



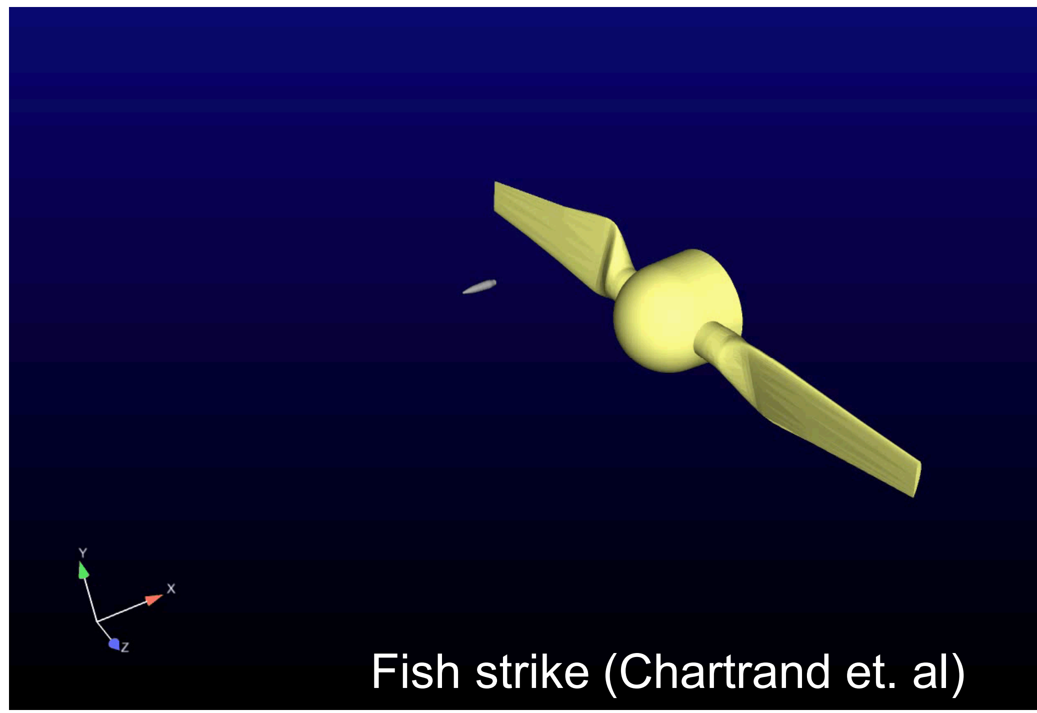
Chamorro, L.P., Hill, C., Neary, V.S., Gunawan, B., Arndt, R.E.A. and Sotiropoulos, F. (2015) Effects of energetic coherent motions on the power and wake of an axial-flow turbine. Physics of Fluids.

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?


Increasing water level



Fish strike (Chartrand et. al)

Project Objectives

Sandia National Laboratories

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)

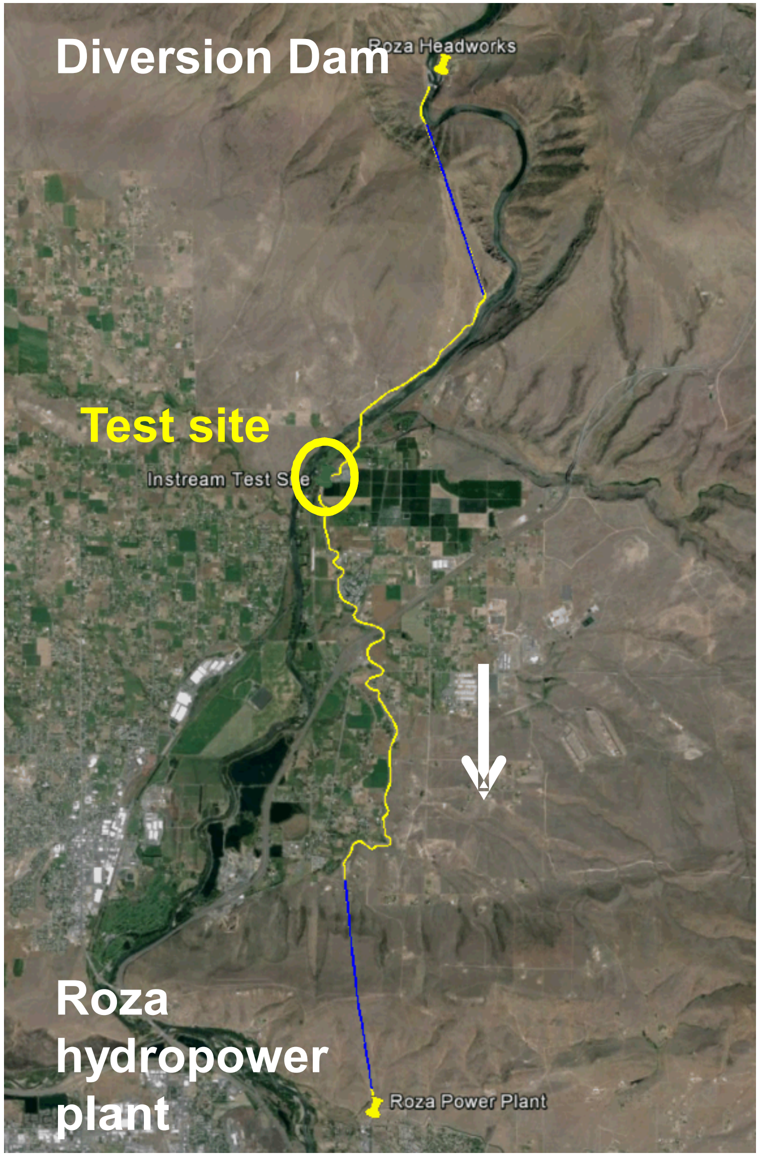
Team

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

Early Days…

Sensors and Equipment

Hobo logger (Water level)

ADCP (Velocity & flow discharge)

ADV (Turbulence)

Remote control boat with RTK GPS

Tethered ADCP boat

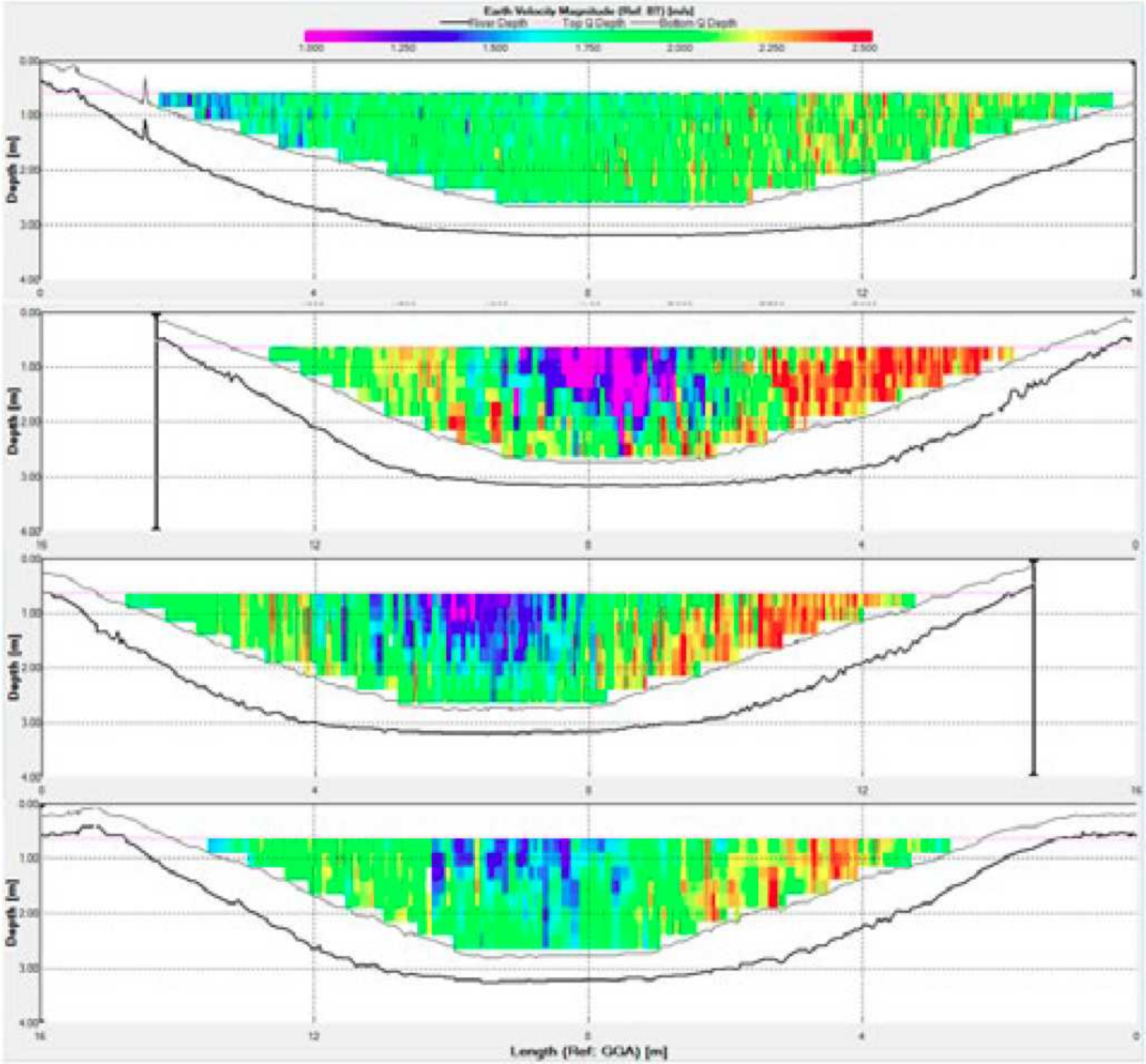
Disclaimer:
The use of trade, product, or firm names in this paper is for descriptive purposes only and does not imply endorsement by the U.S. Government

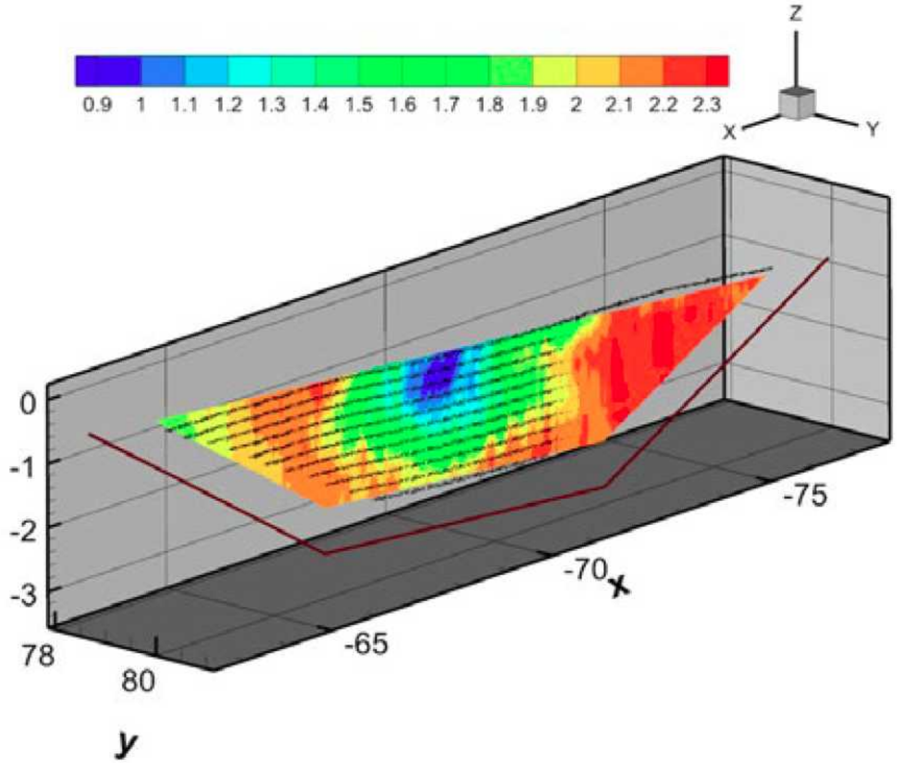
Z-Boat

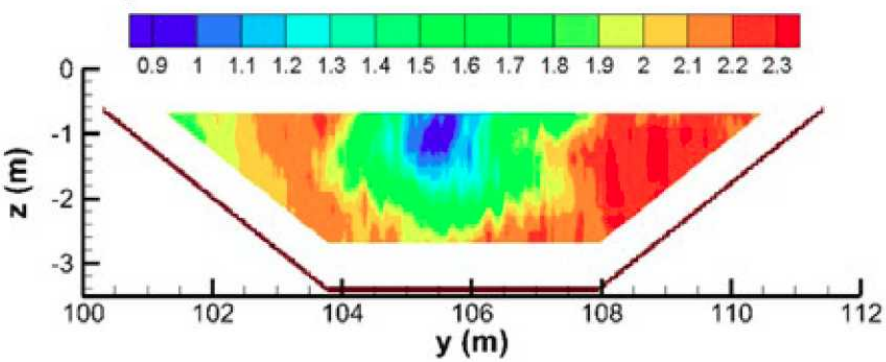
Velocity/discharge measurement

Sandia National Laboratories

Sandia National Laboratories

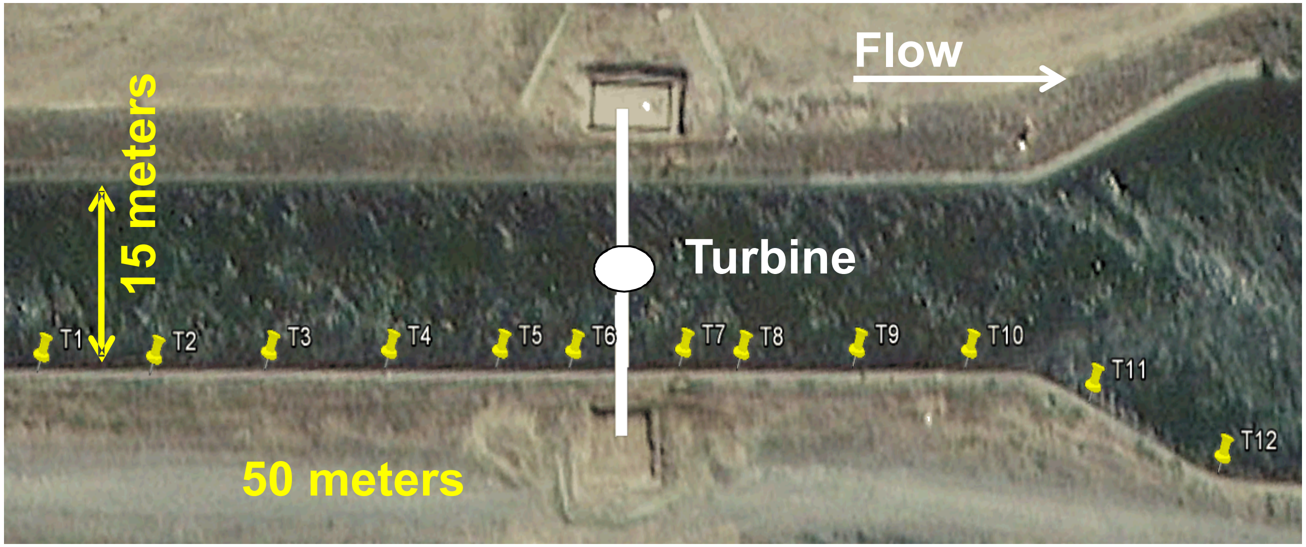


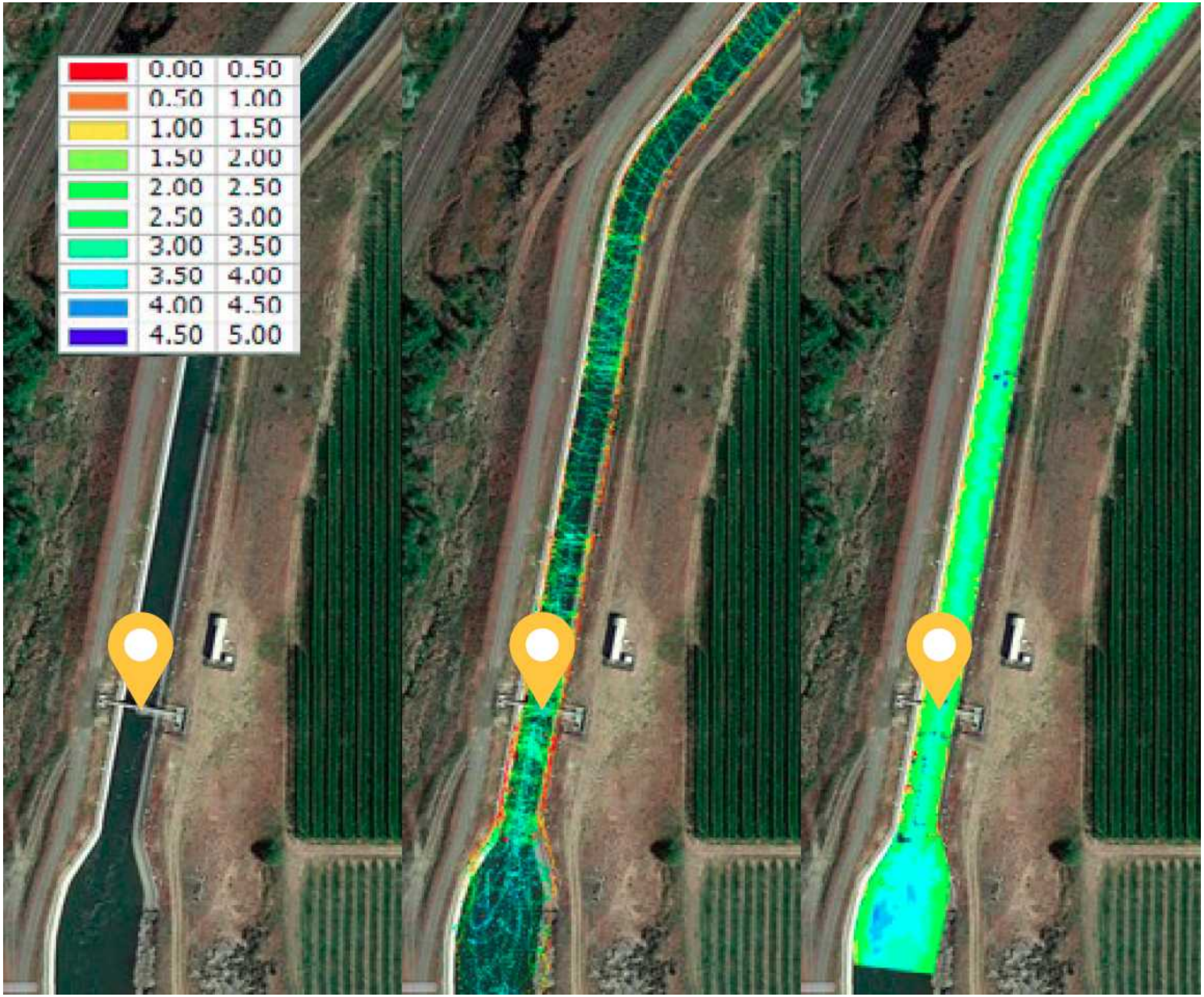

0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2 2.1 2.2 2.3
Z
X
Y
0
-1
-2
-3
78
80
-65
-70
x
-75
y


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
0
-1
-2
-3
z (m)
100
102
104
106
108
110
112
y (m)

	Med RPM				High RPM	
Transect	Q-BT (m3/s)	Delta	Q-GGA (m3/s)	Delta	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**	

	Med RPM				High RPM	
Transect	Q-BT (m3/s)	Delta	Q-GGA (m3/s)	Delta	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
1.00 1.50
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2.50 3.00
3.00 3.50
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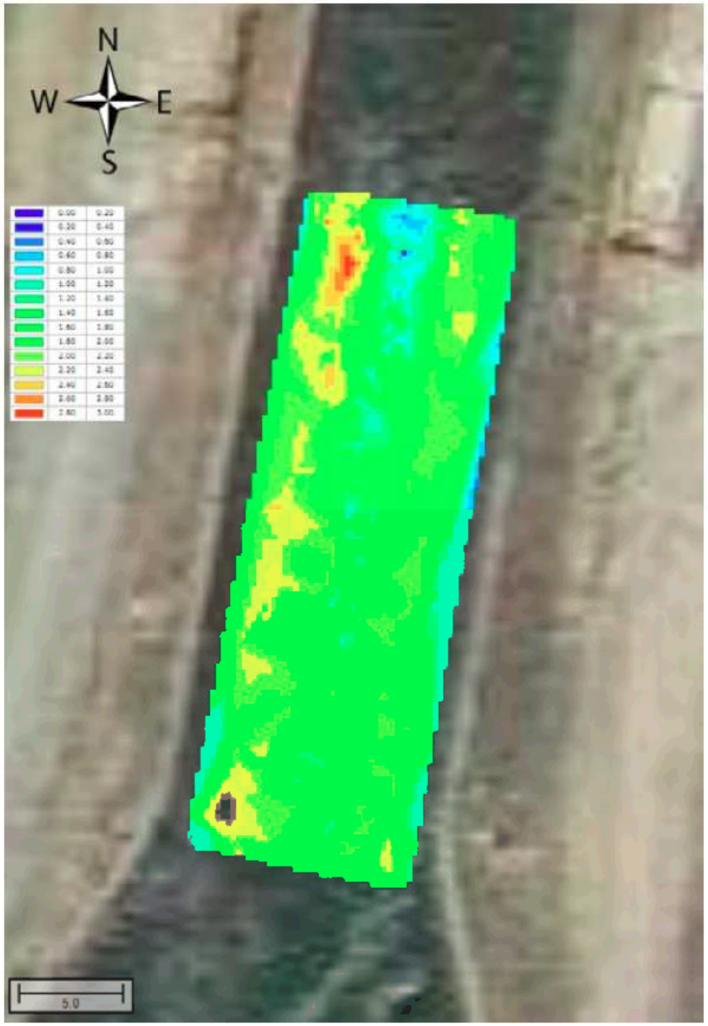
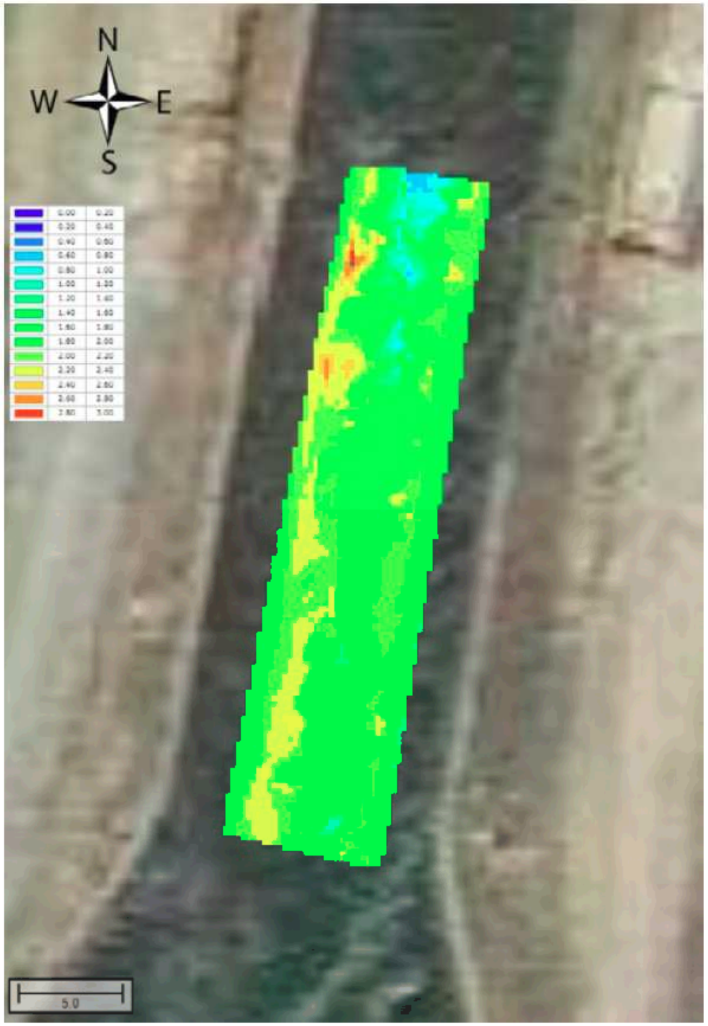
4.00 4.50
4.50 5.00


N
W
E
S
5.0


N
W
E
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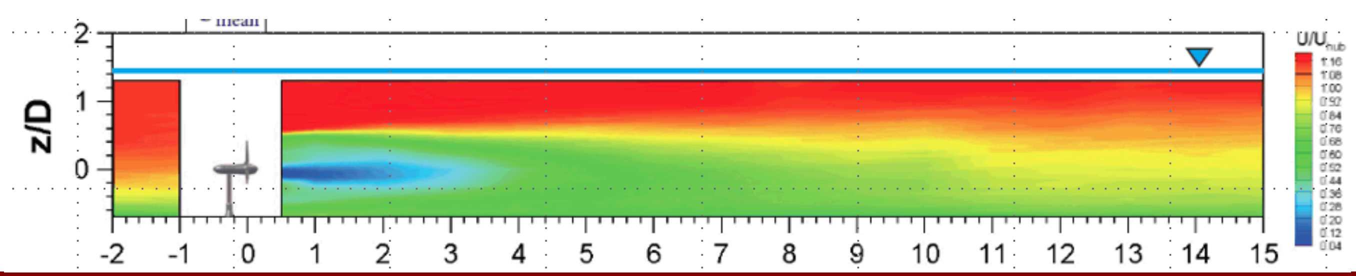
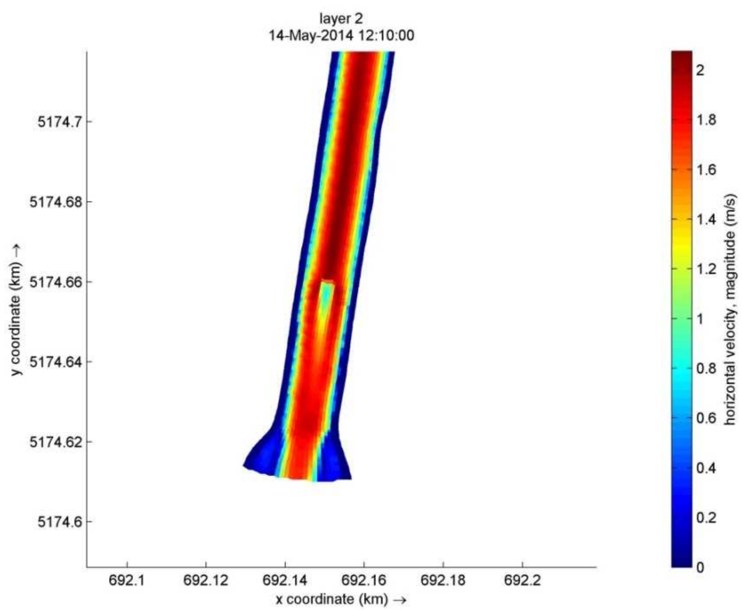
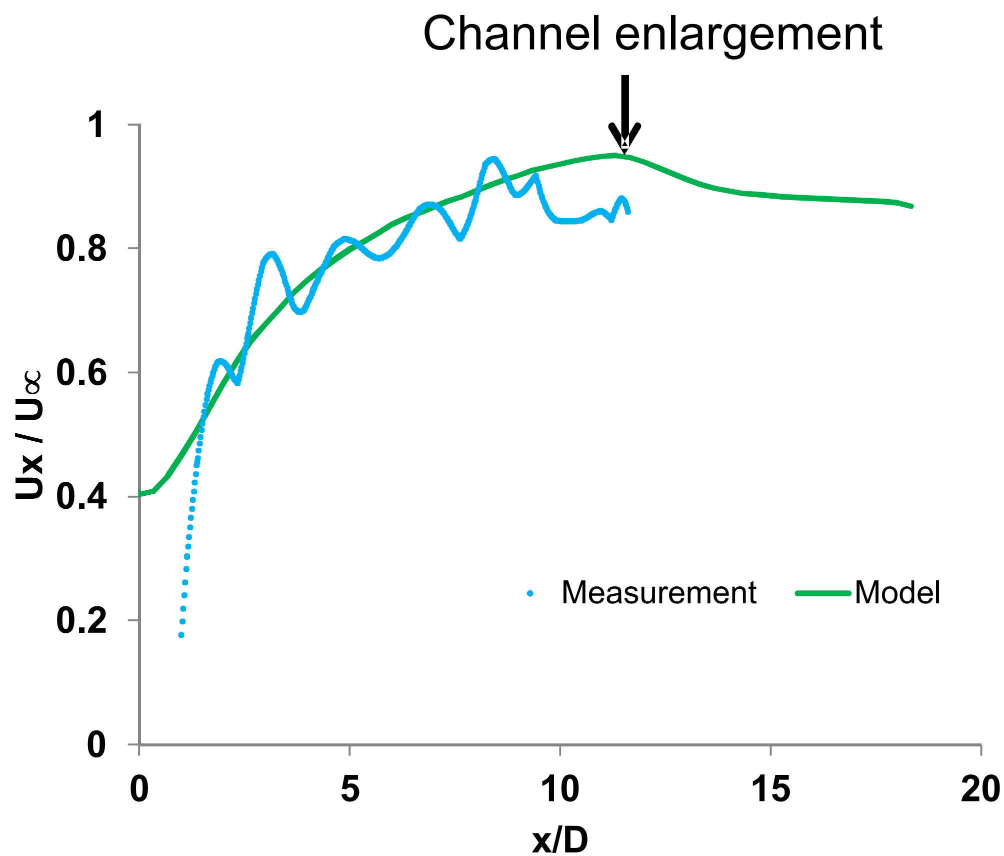

mean
z/D
2
1
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
U/U_hub
1.16
1.08
1.00
0.92
0.84
0.76
0.68
0.60
0.52
0.44
0.36
0.28
0.20
0.12
0.04

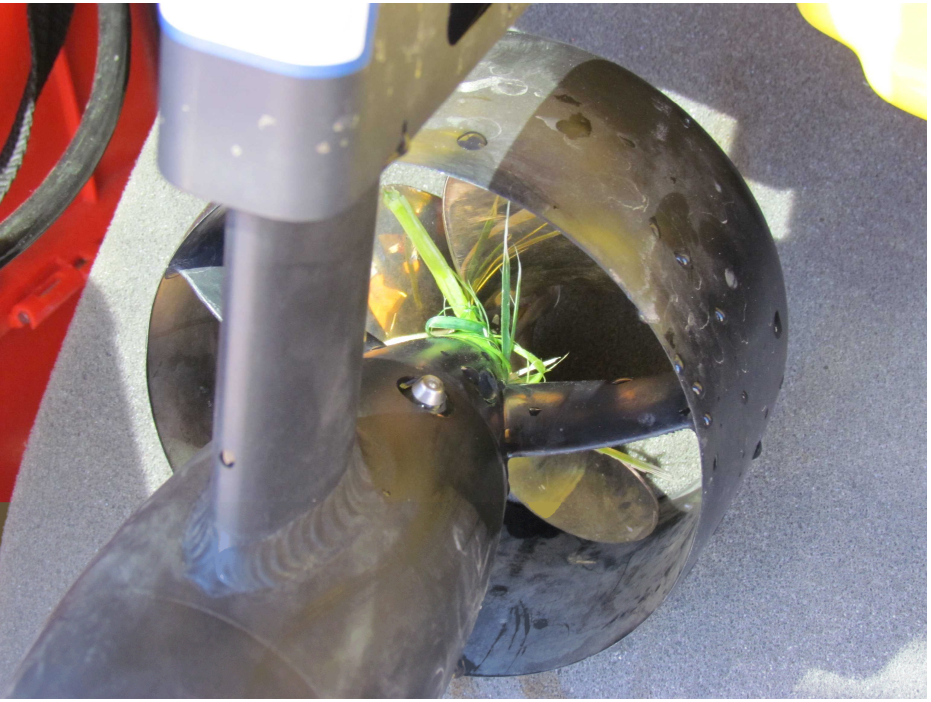
Single turbine simulation

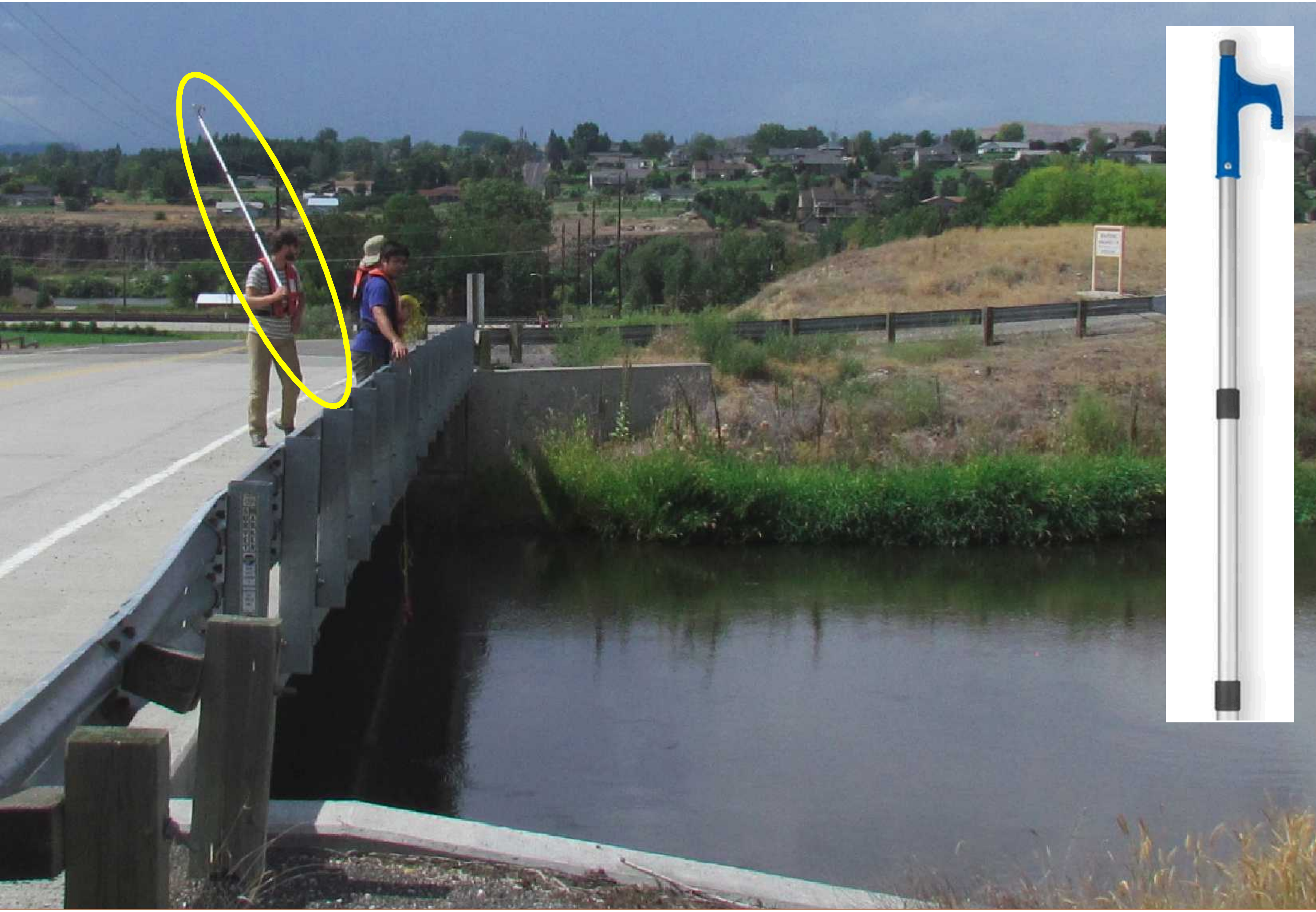
Delft3D model





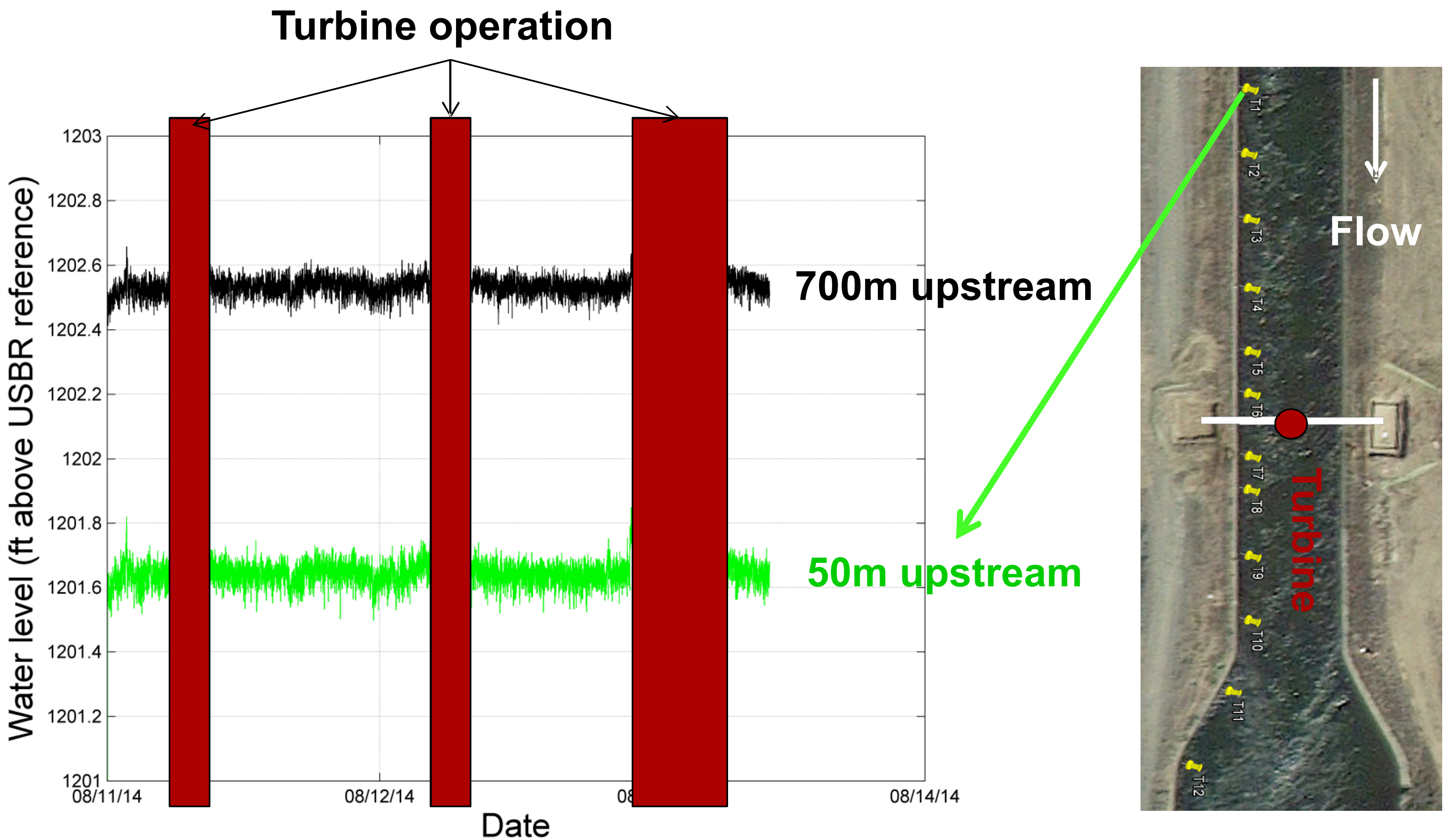
<u>Good agreement between measurement and model</u>





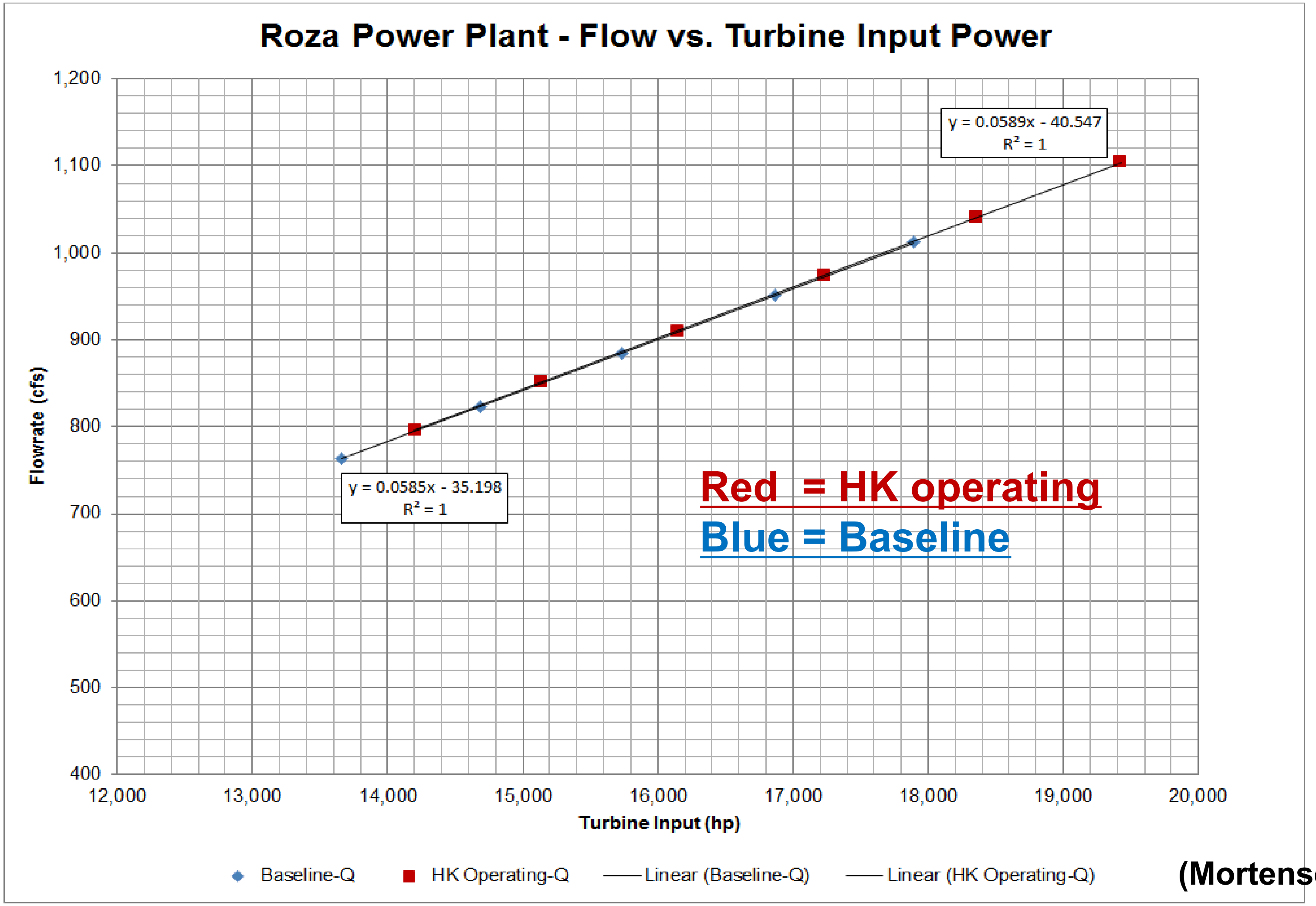

VectorStock®
VectorStock.com/1791918

Water level - upstream



<u>**Small water level increase upstream of the turbine**</u>

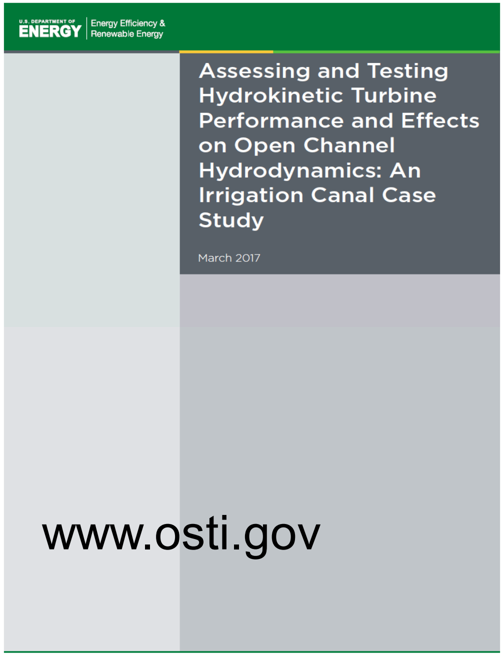
Roza plant power generation



(Mortensen 2014)

No impact on Roza Power Plant power generation

Lesson Learned & Wish List


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

Assessing and Testing Hydrokinetic Turbine Performance and Effects on Open Channel Hydrodynamics: An Irrigation Canal Case Study

March 2017

www.osti.gov

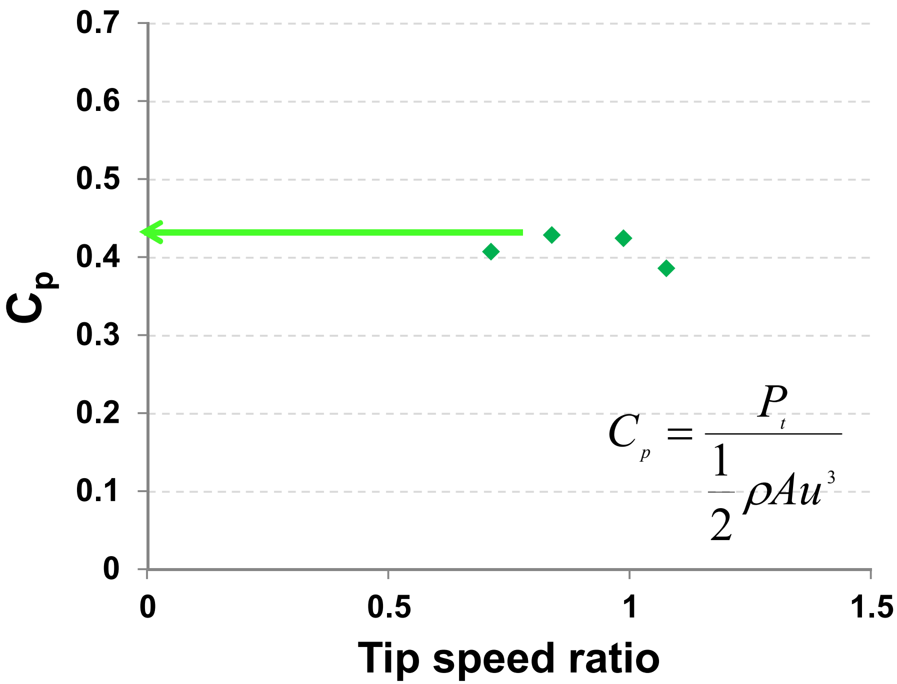
Roza Canal Project
- Minimum increase of water level
- Roza Power Plant: No impact on power production

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

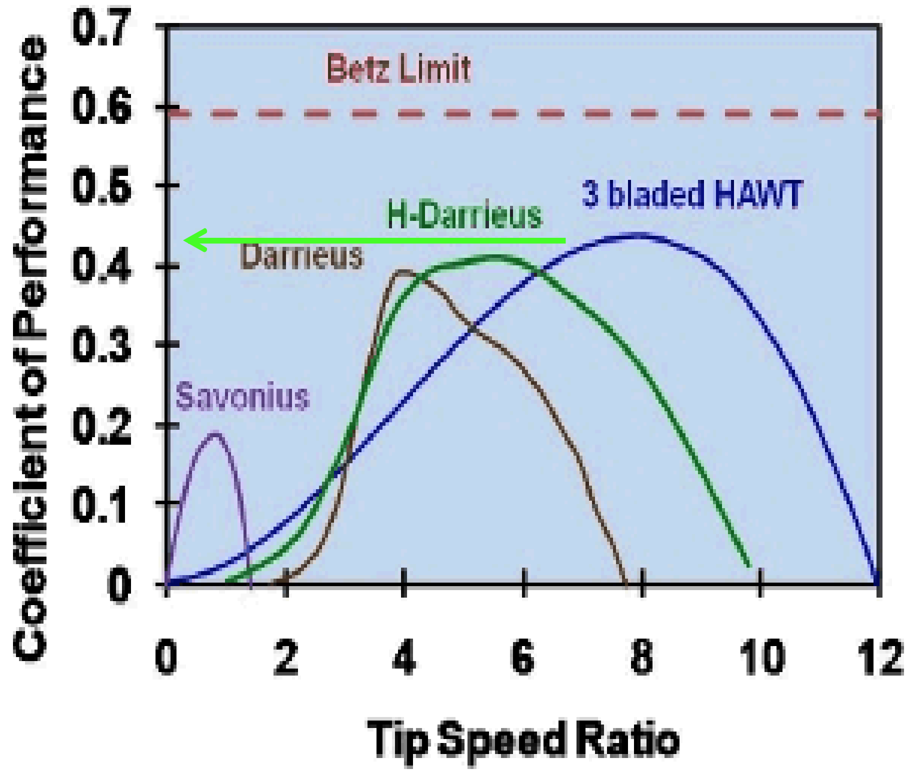
Wish list
- Cost-benefit analysis, trade-off between river size and boat types
- Add advance control to Z boat, for fixed vessel measurement
- Add recovery/safety mode when boat flipped

Power coefficient

Instream turbine



Wind turbines

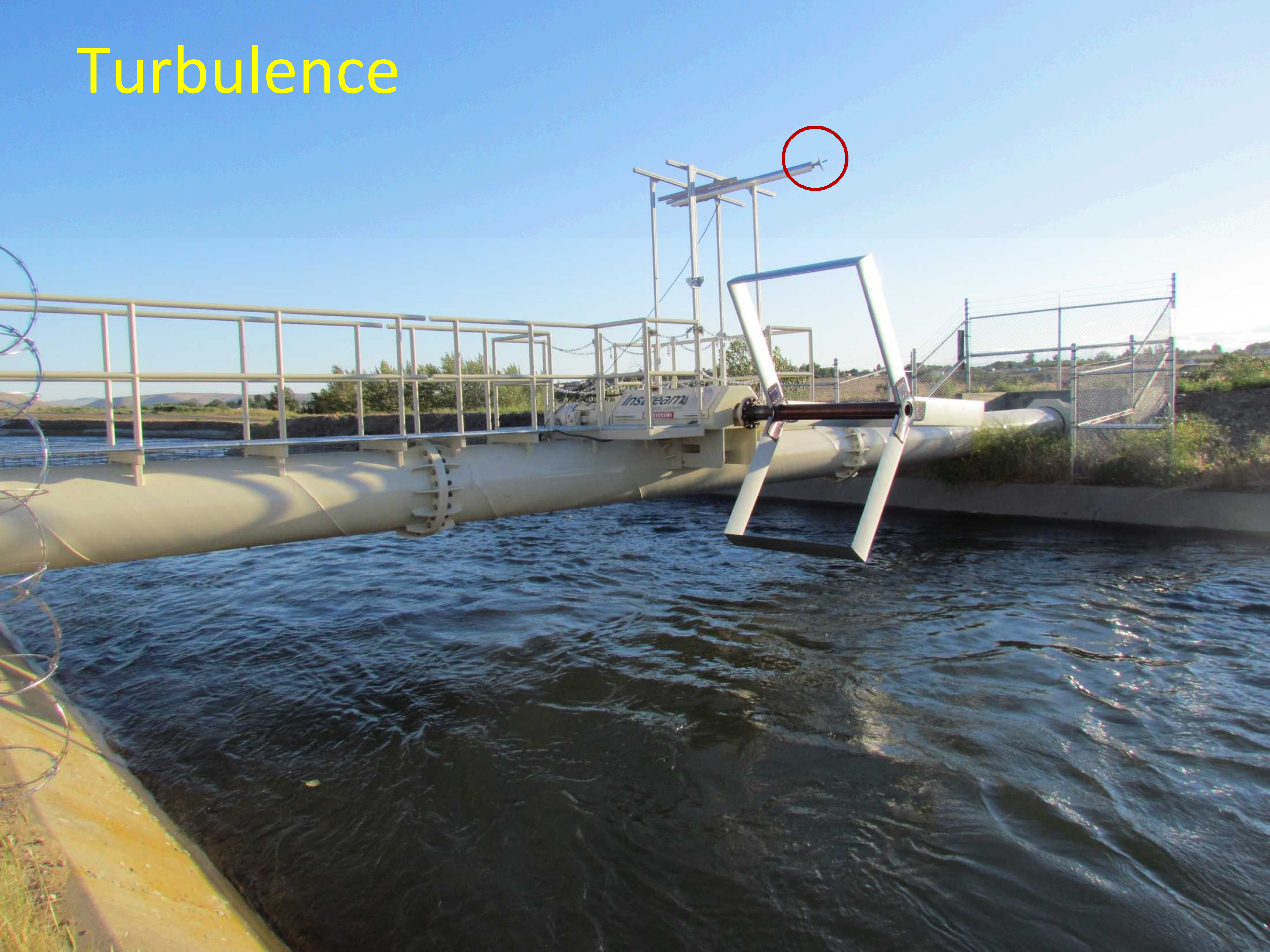


Boston University's data

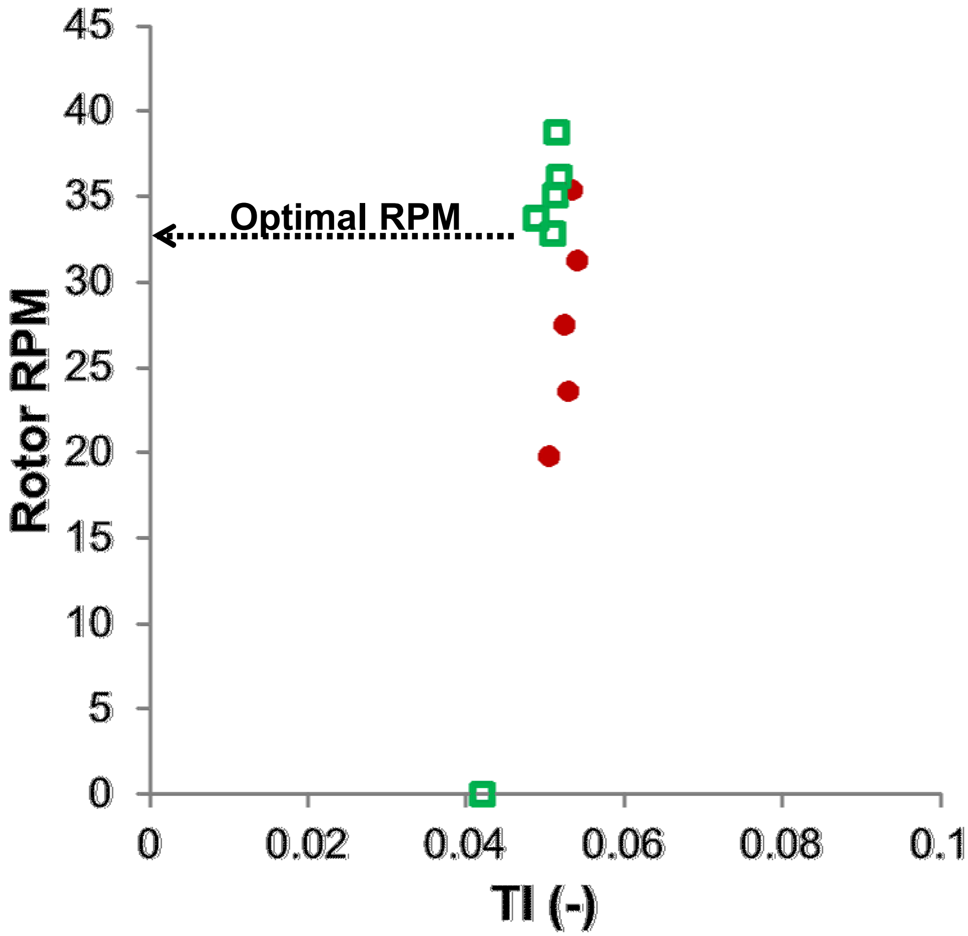
High turbine efficiency, comparable to wind turbines

Turbulence

Turbulence



Turbulence Vs. Rotor RPM



Inflow turbulence ~ 5% (rotor mid height)

Acknowledgements

This research was made possible by support from the U.S. Department of Energy's (DOE) Energy Efficiency and Renewable Energy (EERE) Office's Wind and Water Power Technologies Office. Sandia is a multi-program laboratory managed and operated by Sandia Corporation, a Lockheed Martin Company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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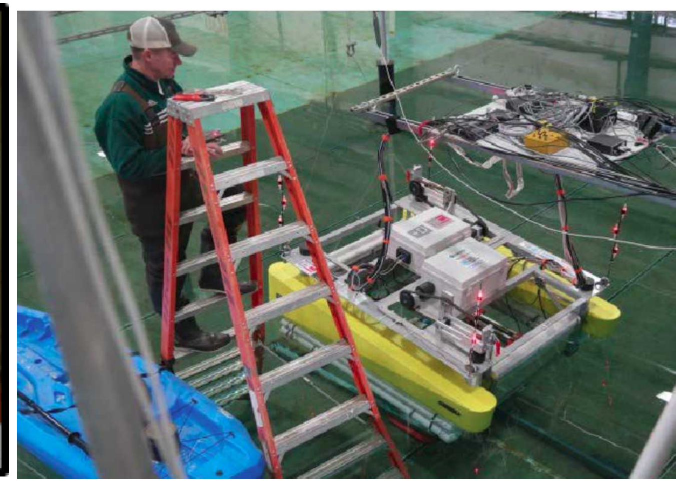
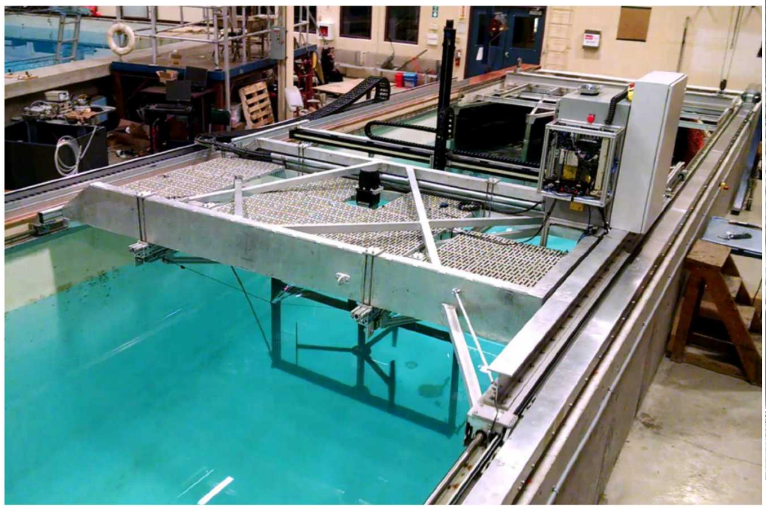
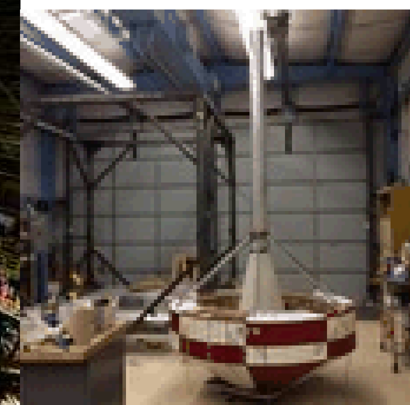
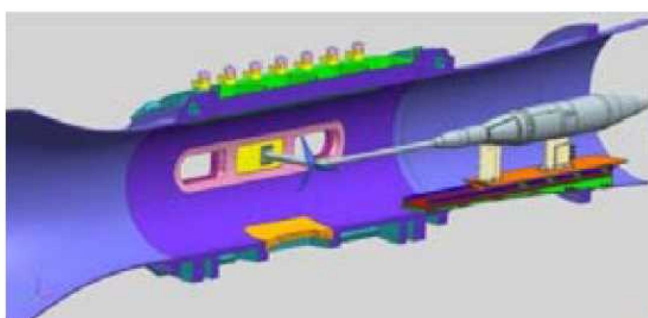
RM1: Tidal turbine
RM2: River turbine









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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