



Debris risks and mitigation strategies for hydrokinetic turbines



Presented by: Budi Gunawan Ph.D.

Athanasios Papanicolaou Ph.D., Craig Hill Ph.D., Jeremy Kasper Ph.D., Emily Browning

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budi.gunawan@sandia.gov

Key contributors:

- Athanasios Papanicolaou (USDA National Laboratory for Agriculture and the Environment)
- Craig Hill (University of Minnesota Duluth)
- Jeremy Kasper (University of Alaska Fairbanks)
- Emily Browning (University of Alaska Fairbanks/[Sandia](#))



Debris interaction

Harmful interactions with debris and sediments can damage turbine structures and degrade turbine performance (impact loading, accumulation)

“Three pilot river hydrokinetic projects, including those in Yukon River, Alaska, and Mackenzie River, Northwest Territories, had to be entirely removed from the flow because of riverine debris [1 ,2] “



Debris accumulation on 25 KW New Energy turbine at Eagle AK [2]



Debris caught in New Energy CEC in 2016

“The potential for dangerous interactions with floating debris is a leading consideration when evaluating potential sites for deployment of hydrokinetic power systems” [1]

[1] R. Tyler (2011) River Debris: Causes, Impacts, and Mitigation Techniques. Report prepared for Ocean Renewable Power Company. Alaska Center for Energy and Power.

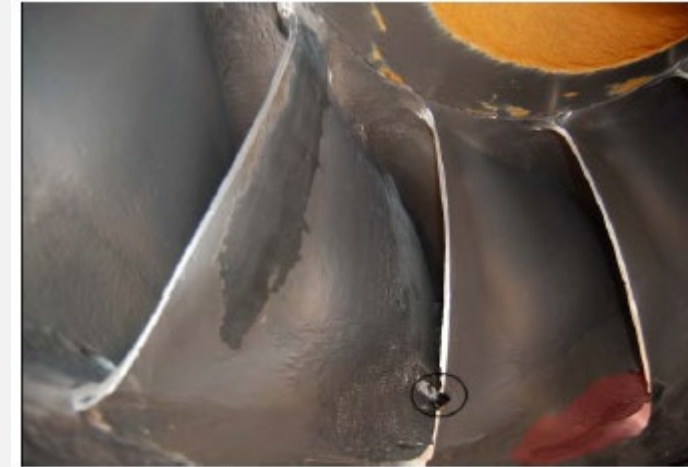
[2] J.L. Kasper, J.B. Johnson, P.X. Duvoy, N.Konefal, J. Schmid (2015) A review of debris detection methods. Northwest National Marine Renewable Energy Center.

[3] Johnson, Schmid, Kasper, Seitz, Duvoy (2014) Protection of In-River Hydrokinetic Power-Generating Devices from Surface Debris in Alaskan Rivers, Report by Alaska Center for Energy and Power.

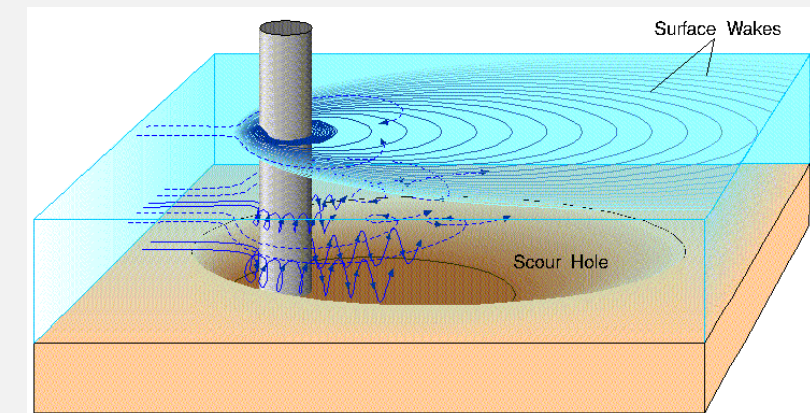
Harmful consequences

Types of problems:

- **Accumulation**
 - Sinking the device
 - Reduce power performance/halt operation
 - Requires continues cleaning (\$\$\$)
- **Impact loading**
 - Turbine & structure damage
 - Pitting, erosion, abrasion
- **Scouring & deposition**
 - Local: Affect support structure (mooring anchor, bed-mounted structure)
 - Morphodynamics



(b) Erosion at pressure side of blade



Knowledge gaps

1. Risk analysis

- A. Debris types
- B. Frequency of occurrence
- C. Location within water column
- D. Locations within the river systems
- E. Travel speed
- F. Modeling

2. What detection & mitigation options are available?

- A. Surveillance
- B. Diversion
- C. Rack and mesh

		Severity			
		Catastrophic: 4	Critical: 3	Moderate: 2	Marginal: 1
Probability	Frequent: 5	High - 20	High - 15	High - 10	Medium - 5
	Probable: 4	High - 16	High - 12	Serious - 8	Medium - 4
	Occasional: 3	High - 12	Serious - 9	Medium - 6	Low - 3
	Remote: 2	Serious - 8	Medium - 6	Medium - 4	Low - 2
	Improbable: 1	Medium - 4	Low - 3	Low - 2	Low - 1

vectorsolutions.com

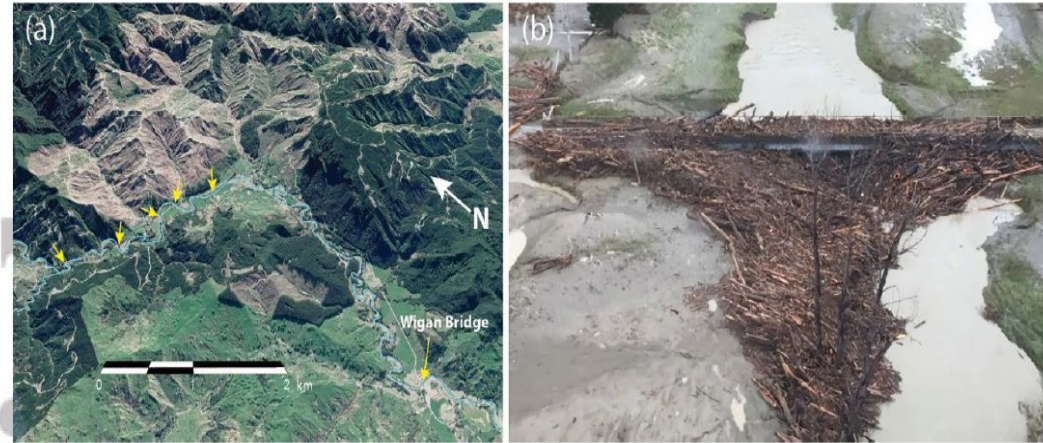
Mitigation action Vs. Cost

Riverine systems

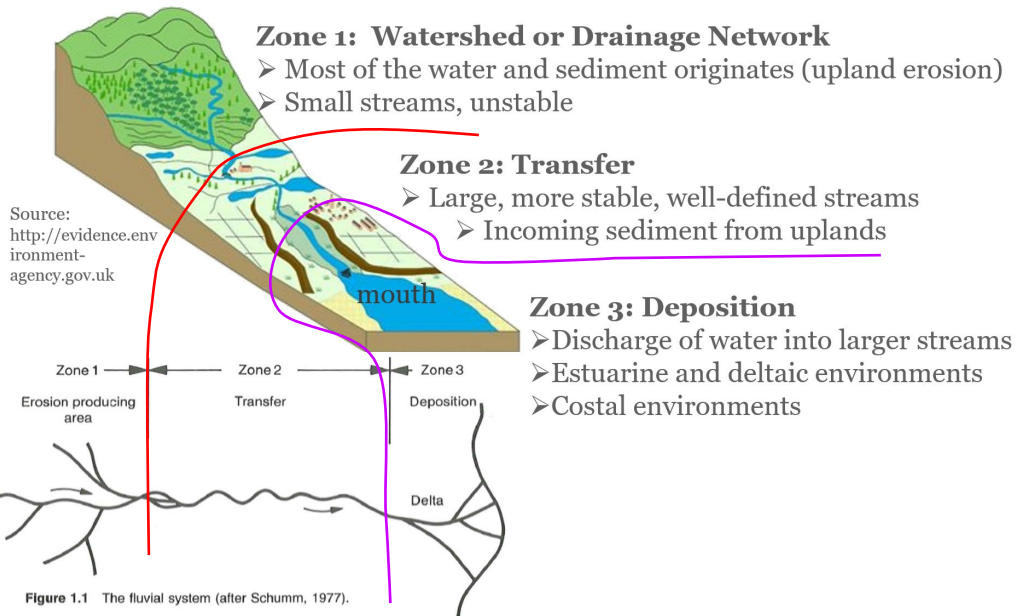
Common type of debris:

- Sediment, e.g. gravel, cobble, sand, clay
- Wood logs & tree branches
- Ice
- Trash

“20 billion tons of solid detritus and large wood debris are shed by the world’s land masses through rivers into the coastal ocean” [4]



Riverine drainage zones



Common characteristics:

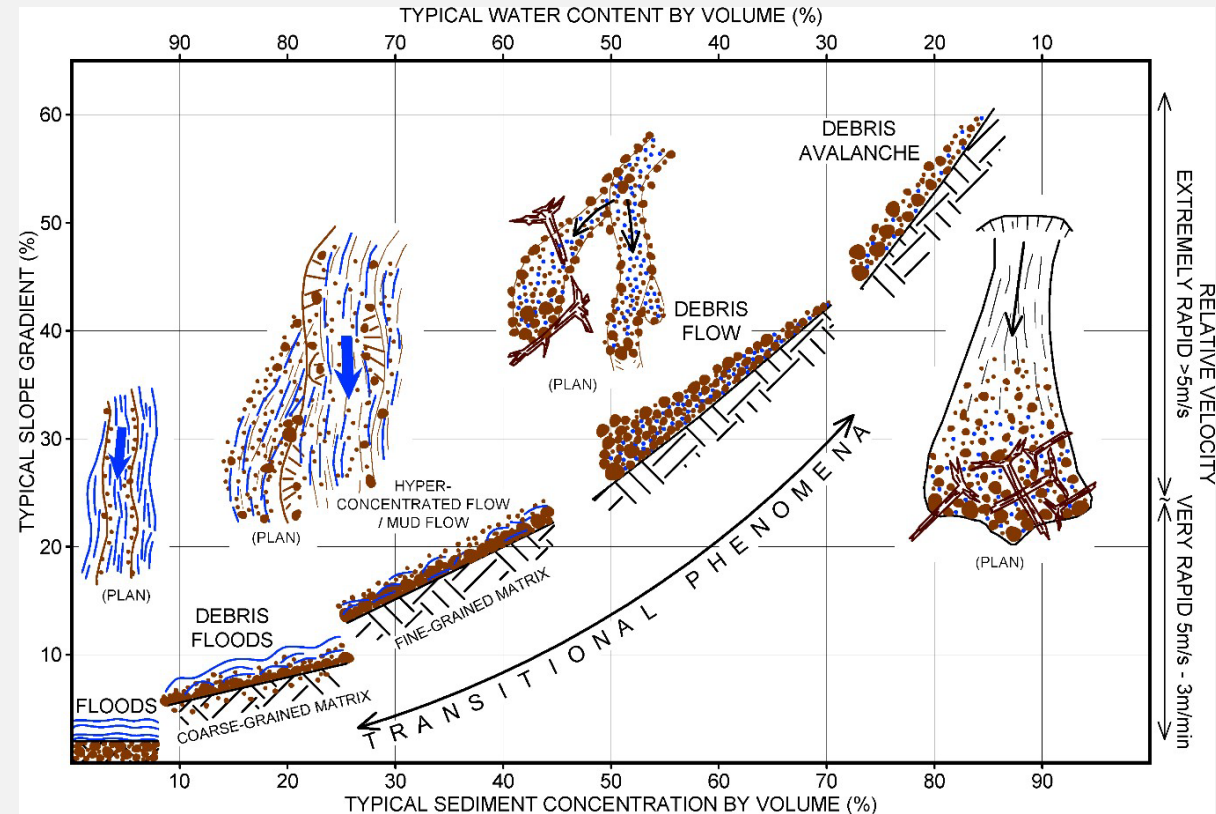
- **Zone 1:** fast moving water, small & shallow streams, unstable, less trash
- **Zone 2:** more stable, larger streams
- **Zone 3:** deposition, tidal, slower moving water



after Papanicolaou personal notes

Debris mobilization

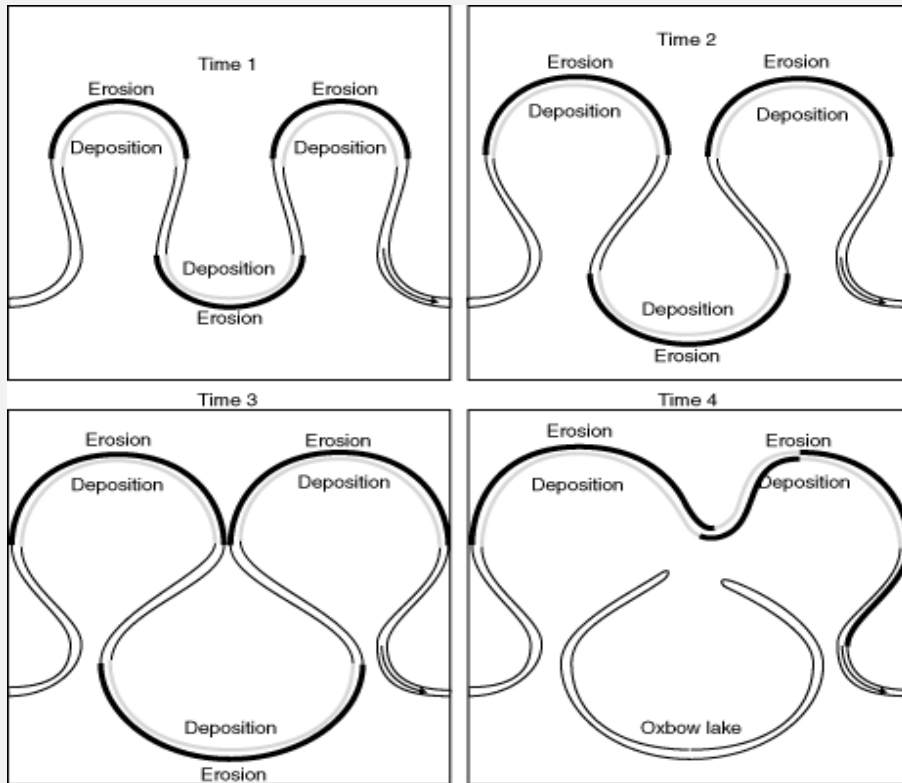
- **Debris flow**: very rapid to extremely rapid flow of saturated non-plastic debris in a steep channel. Debris flows typically require a channel steeper than about 30% for transport over long distances and have volumetric sediment concentrations typically in excess of 50-60 %.
- **Debris flood**: very rapid surging flow of water and debris in a steep channel. Debris floods typically occur on creeks with channel gradients between 3 and 30% and have a lower proportion of debris compared to debris flows.
- **Debris hazard** (geohazard): the continuum of floods, debris-floods and debris-flows (referred to as hydrogeomorphic processes) with their associated phenomena of channel bed scour, bank erosion, avulsion and debris deposition, that have the potential to cause economic damages, injury and potentially loss of life.



River morphodynamics

“MEANDERING RIVERS MAKE POOR POLITICAL BOUNDARIES”

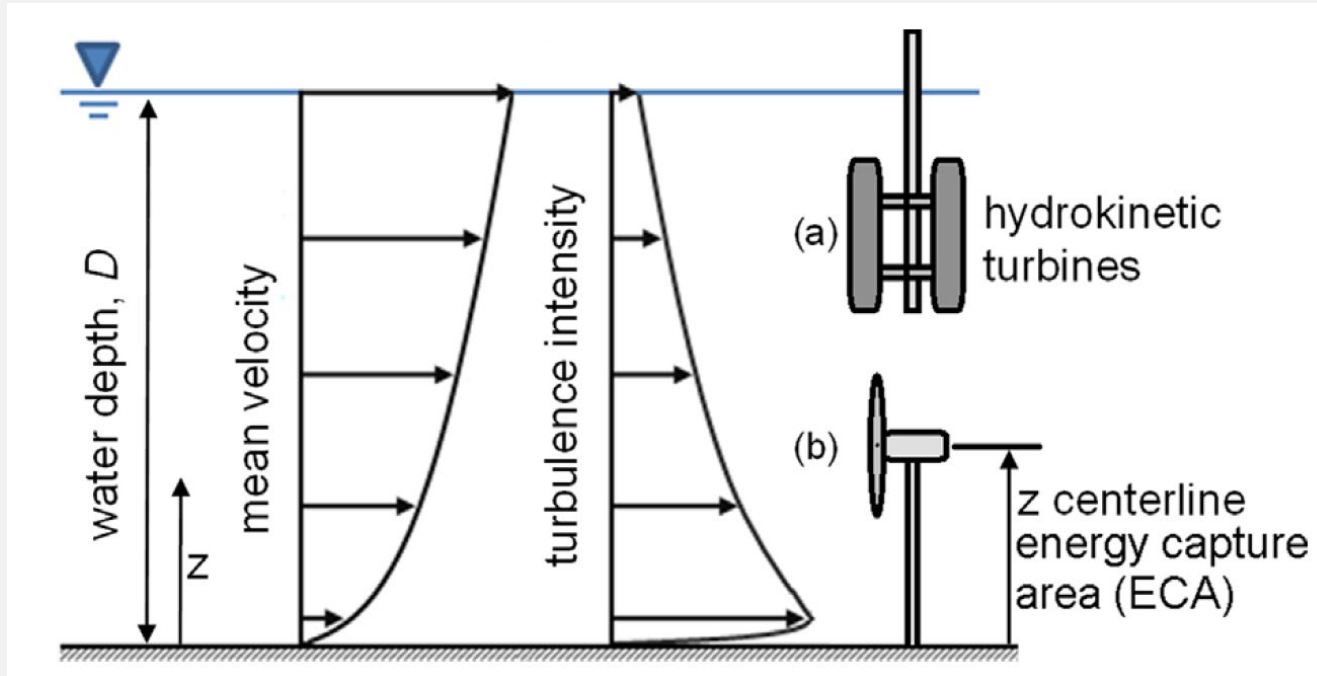
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<https://www.geol.umd.edu>



Location within the water column



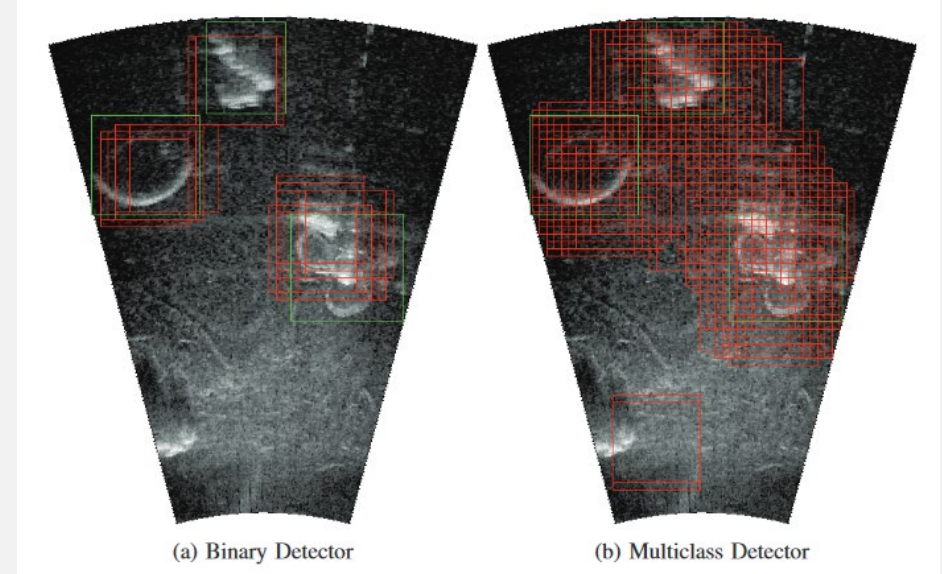
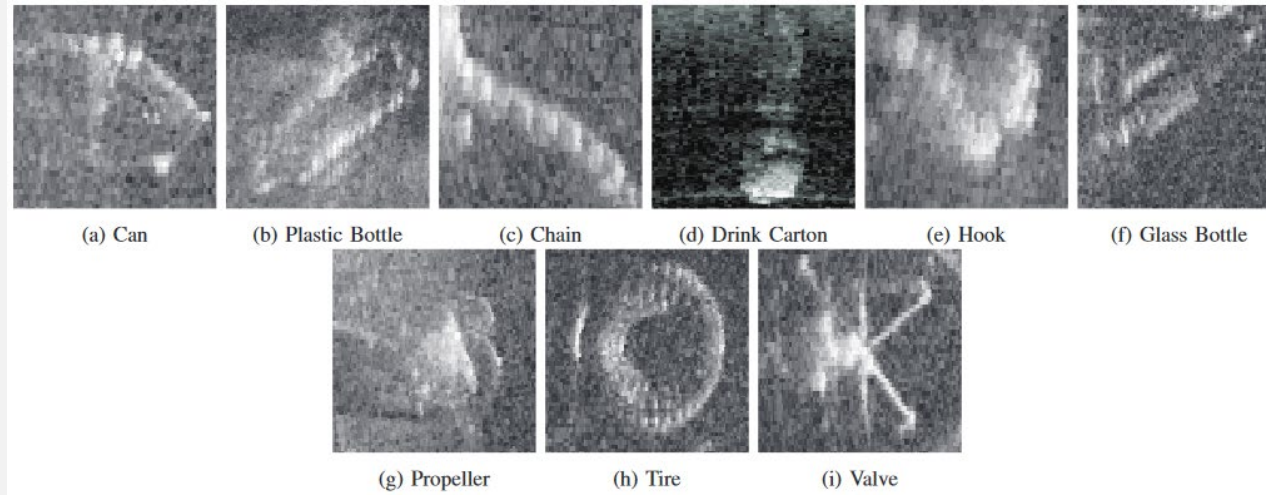
Higher water speed & more large debris exposure (wood logs, etc.)



Lower water speed & more sediment exposure (erosion, deposition)

Debris detection & mitigation

Surveillance: Sonar & cameras

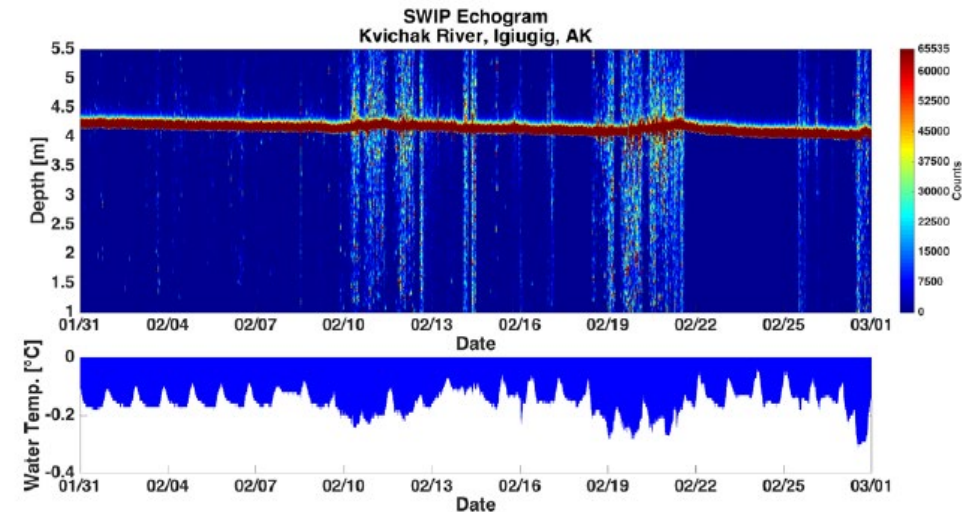
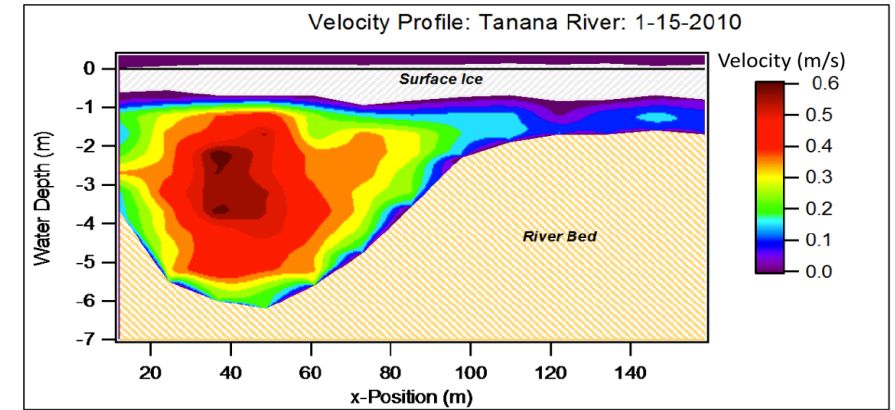
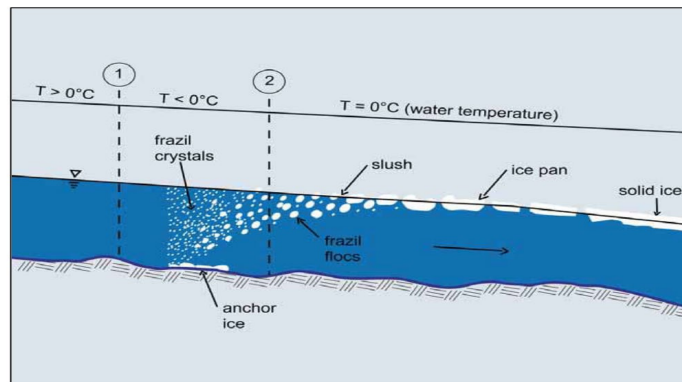


- FLS hires imagery
- Debris classifier: Convolutional Neural Networks (CNN)
- AUV
- < 10 m range
- Centi- to mili- meter resolution

	Metal	Glass	Paper/Cardboard	Rubber	Plastic	Background
Metal	97.8%	0.2%	0.0%	0.0%	0.0%	2.0%
Glass	0.5%	98.3%	0.0%	0.0%	0.6%	0.6%
Paper/Cardboard	0.0%	1.5%	96.9%	0.0%	0.0%	1.6%
Rubber	0.0%	0.0%	3.6%	96.4%	0.0%	0.0%
Plastic	0.0%	0.0%	0.0%	0.0%	99.3%	0.7%
Background	1.7%	0.9%	0.6%	0.1%	0.8%	95.9%

Shallow water ice and current profilers

- Shallow Water Ice Profiler (SWIP)
- ADCP



Debris diversion system



Encurrent debris boom

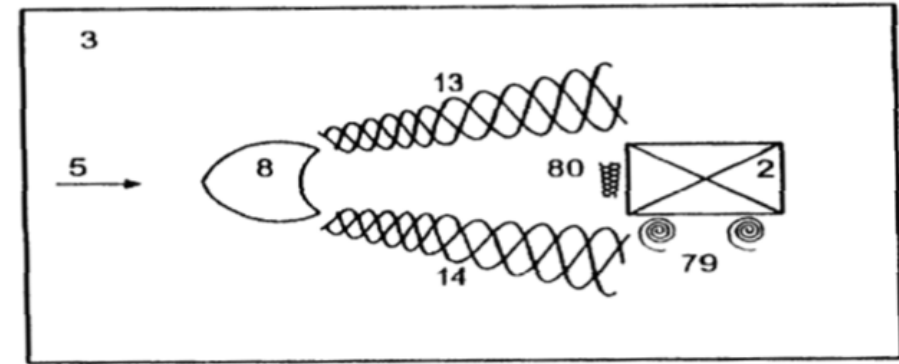
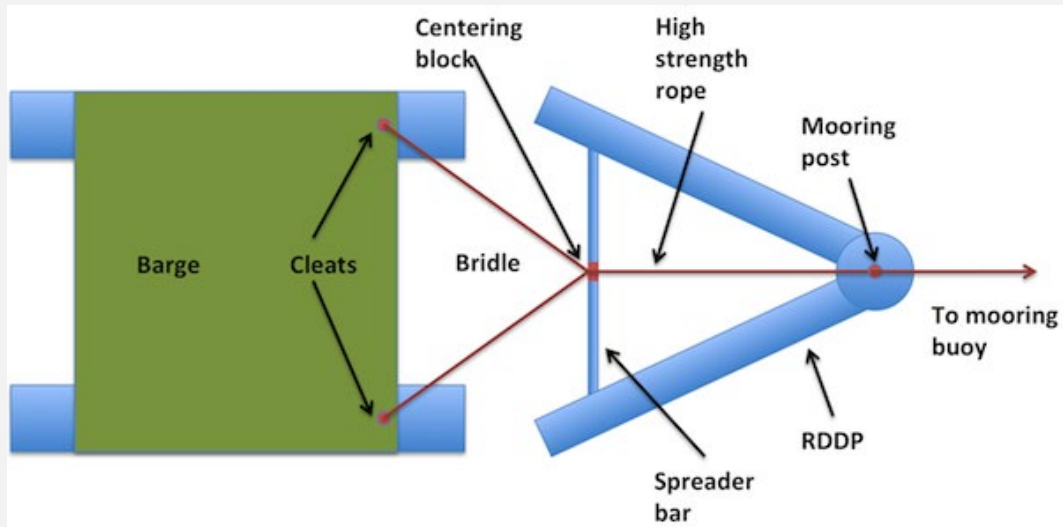


FIG 30A

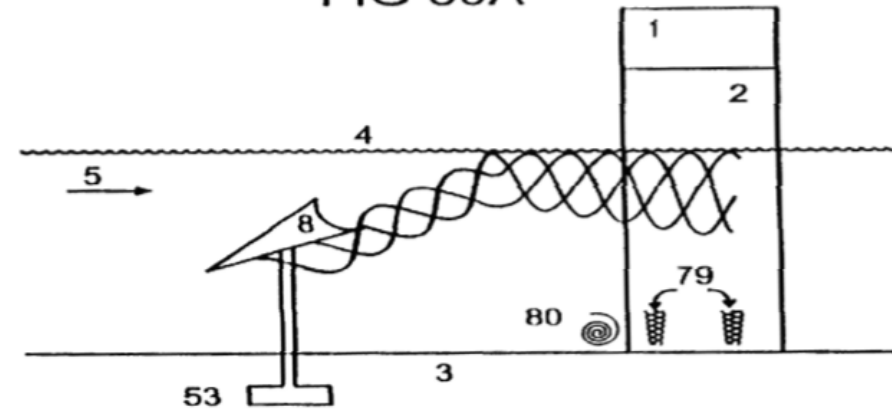


FIG 30

Oppenheimer & Saunders patent, 1995

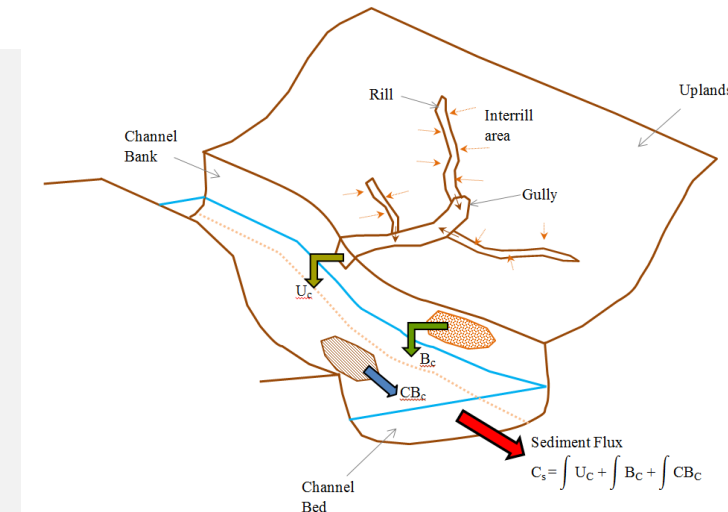
Mesh & collection systems



Modeling

Numerical modeling

- Analytical models
- Lower fidelity models: EDDA, SRH 2D (Reclamation's)
 - Limited usage in predicting debris and sediment transports around structures such as HK platforms
- Higher fidelity model: FLOW- 3D and SRH 3D
 - Relatively expensive
 - No platform for examining the tradeoffs between different components of the system from run to run.
- Debris impact modeling



Papanicolaou and Abban 2016

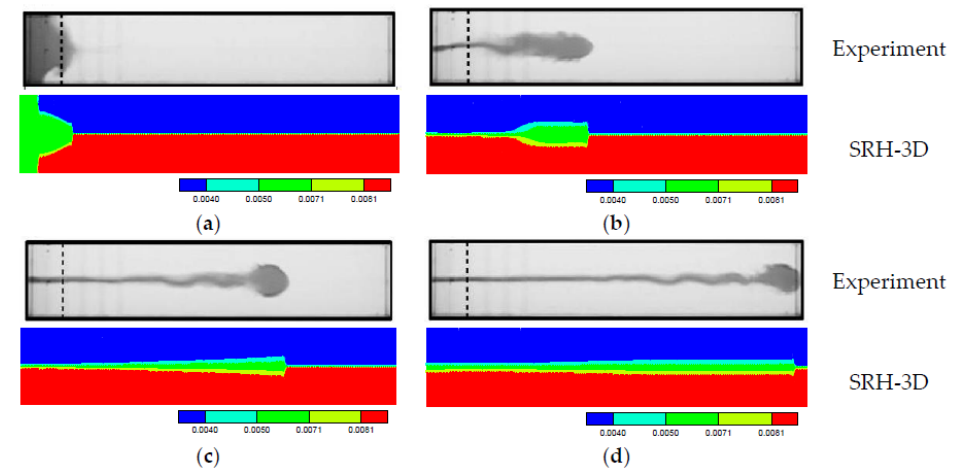
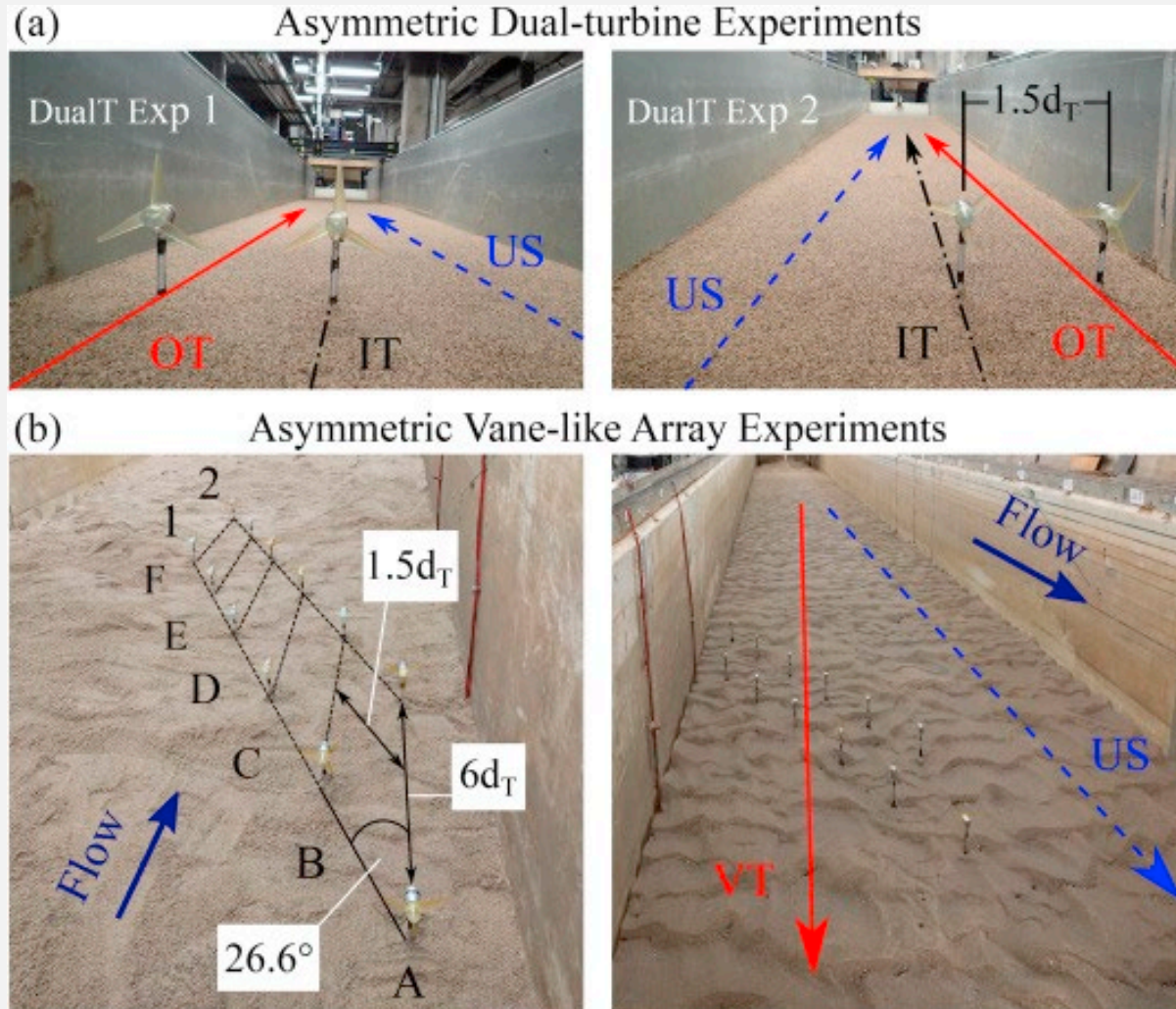


Figure 11. Temporal evolution of the SFTC intrusive gravity current—sediment concentration contours. Experiment is from [52] and visualized by adding dye. (a) Time = 2 s; (b) Time = 14 s; (c) Time = 26 s; (d) Time = 38 s.

Physical modeling: sediment transport



Physical modeling: mitigation system

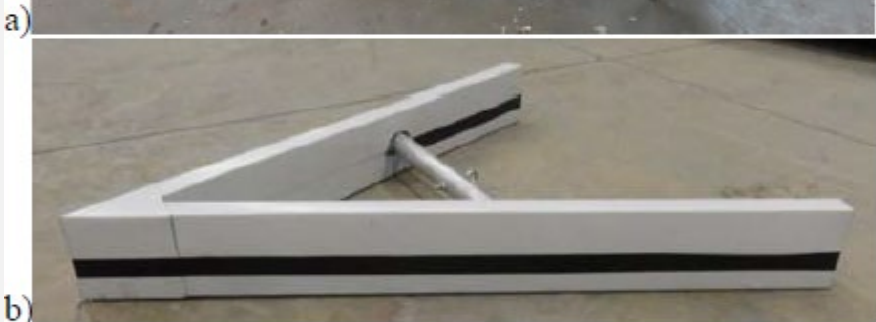


Table 1: Summary of model debris properties

Debris class	FS Diameter (m)	FS Length (m)	MS Diameter (m)	MS Length (m)	Colour
Small	0.01-0.05	0.9-1.1	0.001-0.005	0.09-0.11	Orange
Medium	0.1-0.2	4-6	0.01-0.02	0.4-0.6	Purple/Yellow
Large	0.2-0.3	8-12	0.02-0.03	0.8-1.2	Blue/Pink



Figure 4 : Roughly half of the larger debris pieces were fitted with artificial root wads.

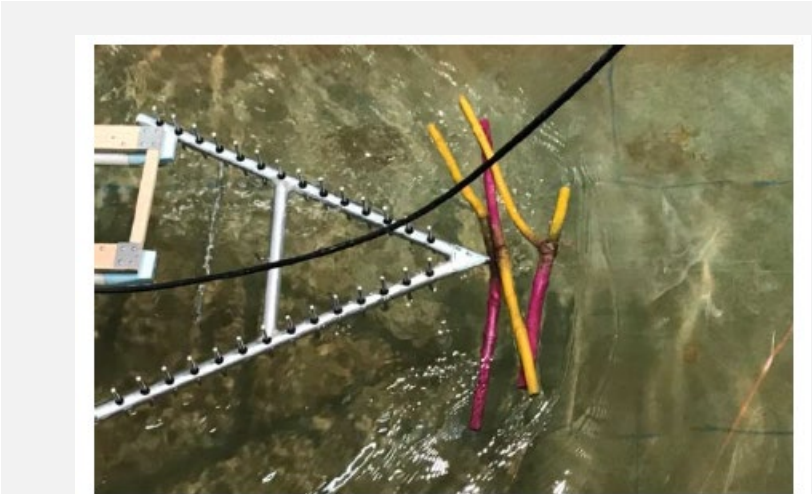


Figure 7 : Raft of medium debris pinned at the nose of Barrier 1A

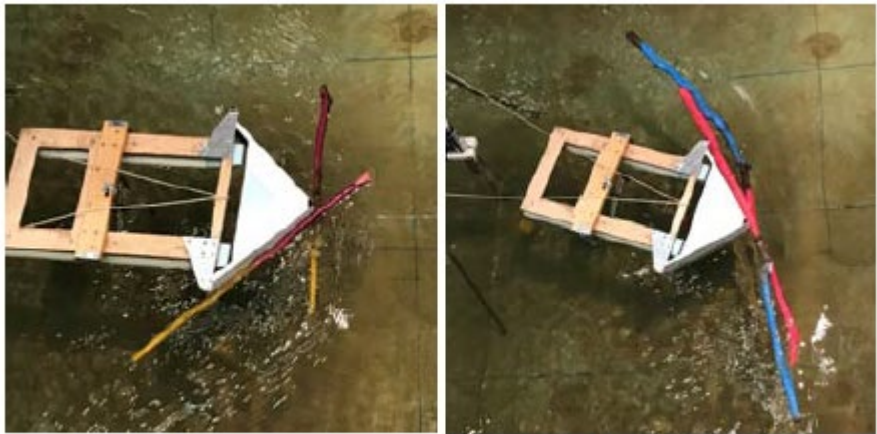


Figure 10 : Medium and large debris pinned against barrier 3B.

Recommendations

Risk management framework

Table 1 Risk management framework

Project Initiation
Recognize the potential hazard
Define the consultation zone (study area) and level of effort
Define roles of the client, regulator, stakeholders,
Hazard Assessment
Identify and characterize the hazard
Develop a hazard frequency-magnitude relationship
Identify hazard scenarios to be considered in risk estimation
Risk Assessment
Characterize elements at risk and determine vulnerability criteria
Estimate risk: the probability that hazard scenarios will occur, impact elements at risk, and cause particular consequences
Risk Evaluation
Compare the estimated risk against tolerance criteria
Prioritize risks for risk control and monitoring
Risk Control
Identify options to reduce risks to levels considered tolerable
Select option(s) providing the greatest risk safety and economic reduction at least cost
Action
Implement chosen risk control options
Define ongoing monitoring and maintenance requirements

Future research needs

1. Understand the type, location and frequency of debris at HK sites

- Improve detection methods (range, accuracy)
 - Algorithm (neural network, more training)
 - Hardware (sonar, camera, on-device load sensors)
 - Length of monitoring period
- Correlate detection with frequency of occurrence
 - Is modeling required to extend the period or record for statistical analysis?
 - Develop numerical tools to estimate frequency, debris size, e.g. expand existing CFD/sediment transport models
- High risk site avoidance
 - Utilize CFD-morphodynamics tools at early stage - predict morphology/bathymetry change over the design life and beyond
 - Ice debris interaction
- Large debris interaction modeling
 - Impact loading – estimate load response at device
 - Debris accumulation model

Future research needs

2. Debris mitigation options

- More innovations on deflection methods for surface and submerged debris
 - Evaluation of effectiveness through physical testing and numerical modeling
 - Trade off between deflection and energy loss (drag, wake)
 - Passive Vs. active Vs. cost
- Operation and maintenance
 - Automated Vs. hand cleaning
- Scouring, erosion and deposition control
 - Structure material selection
 - Protection materials, e.g. geotextile
 - Abrasion coating for rotor and turbine structure
- Explore the use of debris/trash system for other applications (marine, hydropower)



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Questions?

budi.gunawan@sandia.gov