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Debris risks and mitigation strategies for hydrokinetic turbines

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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 caught in New Energy CEC in 2016

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

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

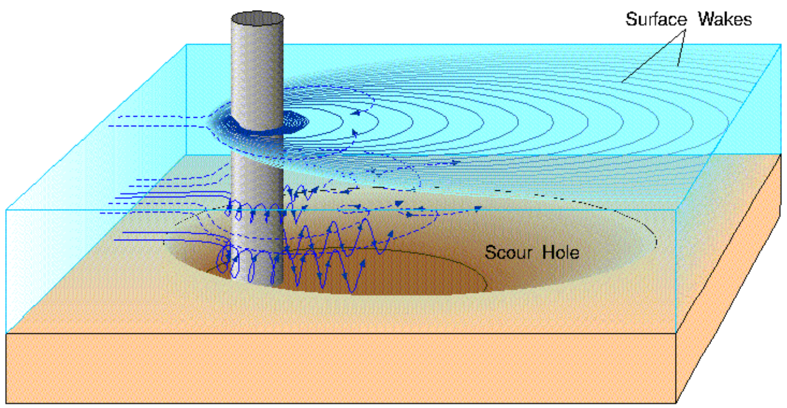
[1] R. Tyler (2011) River Debris: Causes, Impacts, and Mitigation Techniques. Report prepared for Ocean Renewable Power Company. Alaska Center for Energy and Power.
[2] J.L. Kasper, J.B. Johnson, P.X. Duvoy, N.Konefal, J. Schmid (2015) A review of debris detection methods. Northwest National Marine Renewable 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

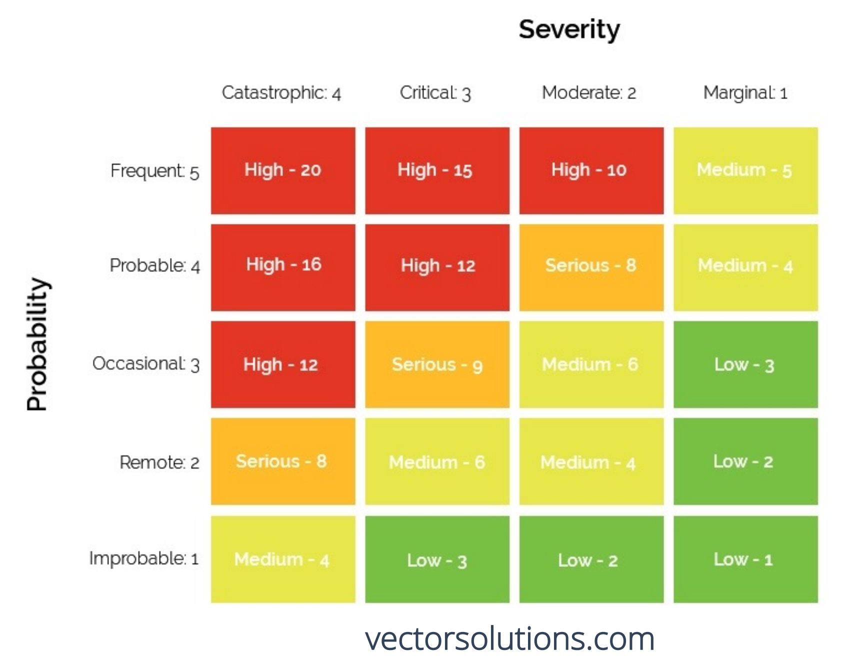


Neopane, et. Al. (2011) Sediment Erosion in Hydraulic Turbines. Global Journal of researches in engineering Mechanical and mechanics engineering
Wikipedia

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

Probability	Catastrophic: 4	Critical: 3	Moderate: 2	Marginal: 1
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

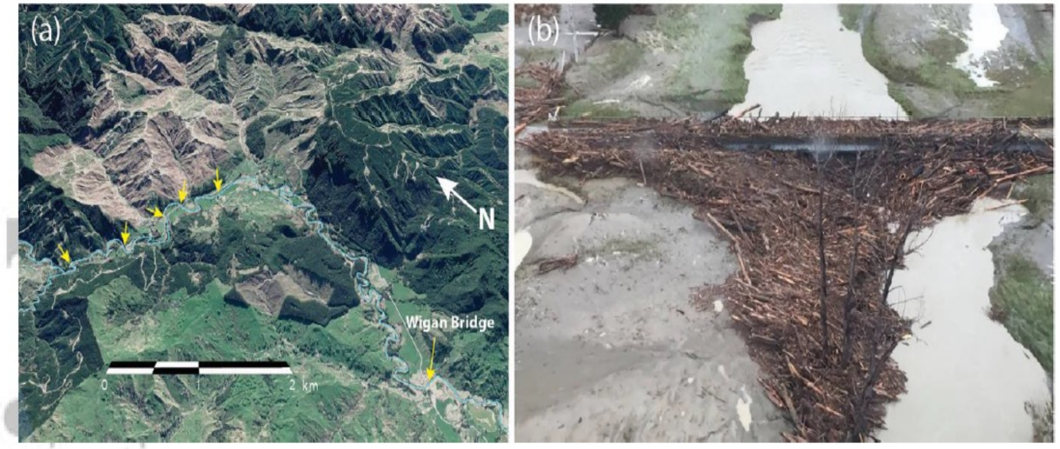
Mitigation action Vs. Cost

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]



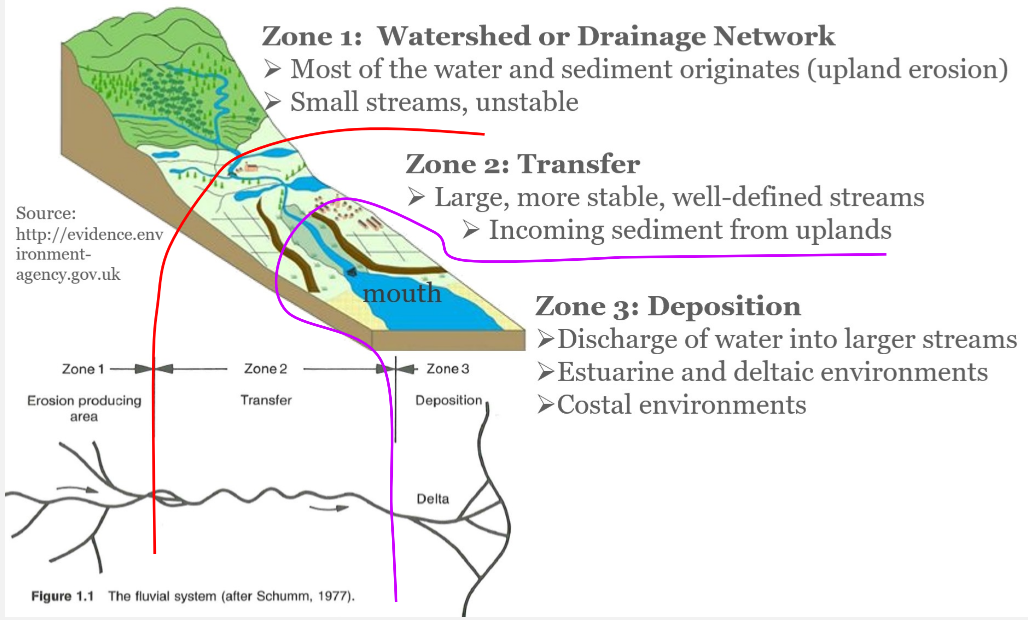

www.army.mil/


The Tijuana River

https://marinedebris.noaa.gov

[4] W.B. Dade (2012) Transport-limitations on fluvial sediment supply to the sea. Water Resources Research.

Riverine drainage zones



Zone 1: Watershed or Drainage Network

- ➢ Most of the water and sediment originates (upland erosion)
- ➢ Small streams, unstable

Zone 2: Transfer

- ➢ Large, more stable, well-defined streams
  - ➢ Incoming sediment from uplands

Zone 3: Deposition

- ➢Discharge of water into larger streams
- ➢Estuarine and deltaic environments
- ➢Costal environments

Source: http://evidence.environment-agency.gov.uk

Figure 1.1 The fluvial system (after Schumm, 1977).

Drainage Zones

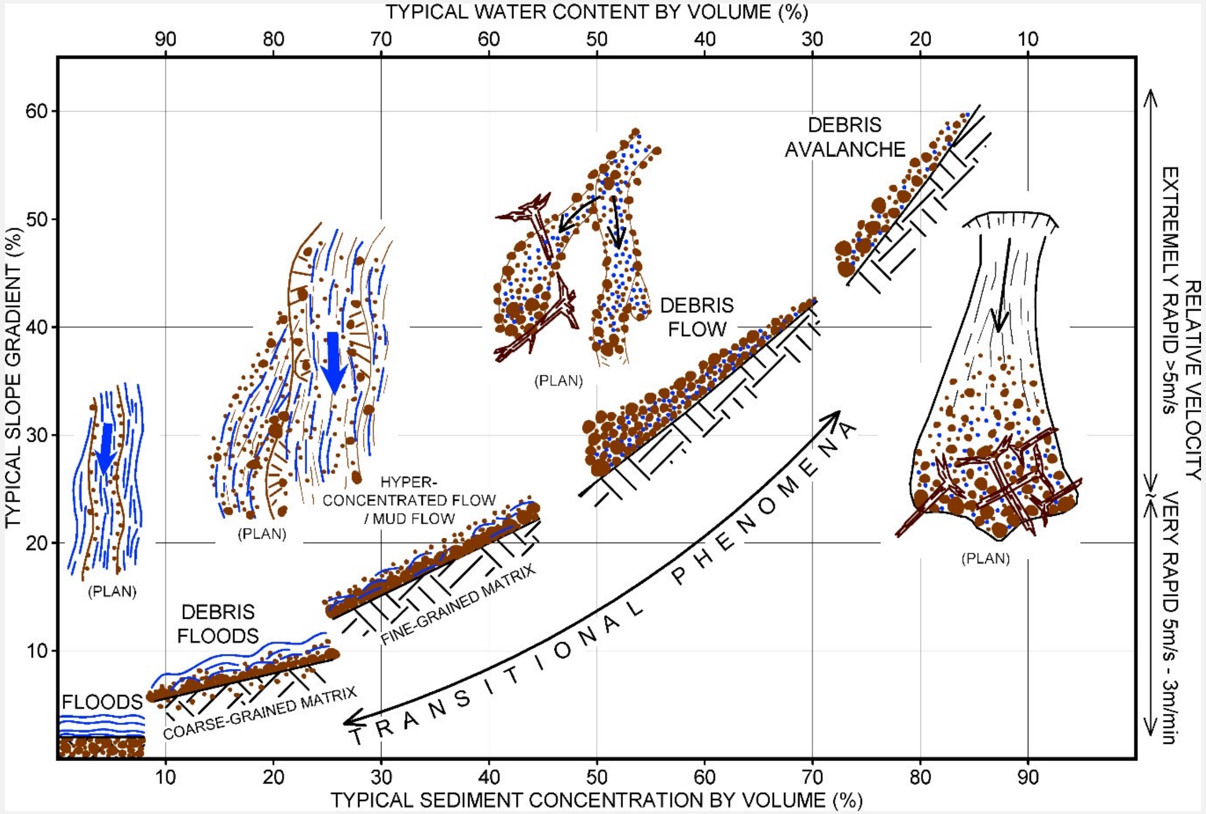
after Papanicolaou personal notes

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

Debris mobilization

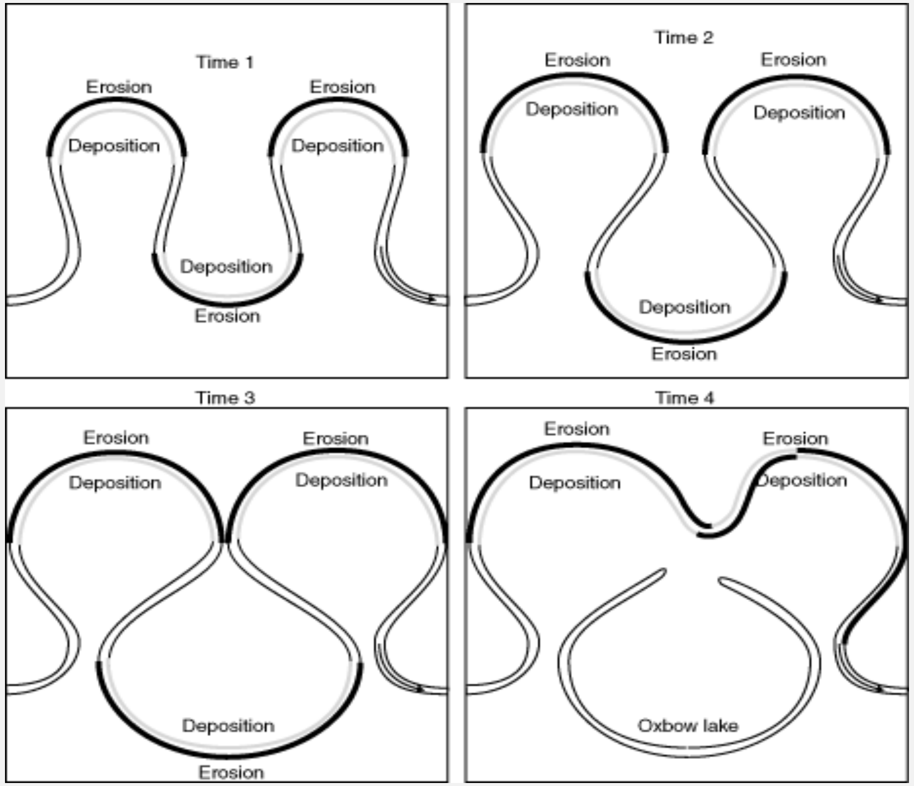
- ***Debris flow***: very rapid to extremely rapid flow of saturated non-plastic debris in a steep channel. Debris flows typically require a channel steeper than about 30% for transport over long distances and have volumetric sediment concentrations typically in excess of 50-60 %.
- ***Debris flood***: 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.



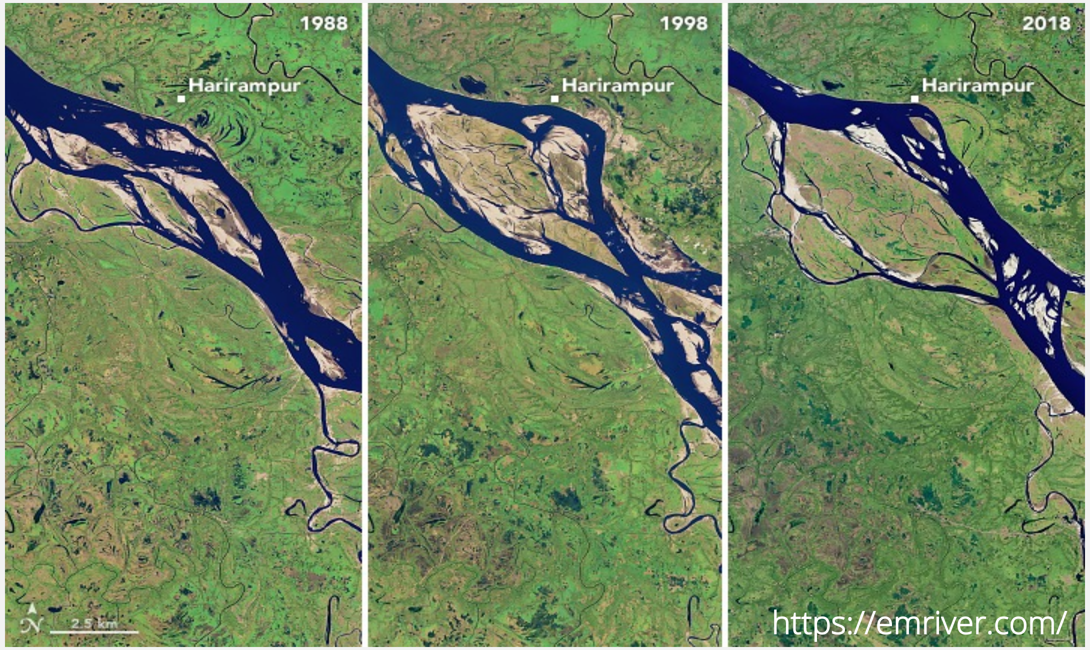
River morphodynamics

“MEANDERING RIVERS MAKE POOR POLITICAL BOUNDARIES”

https://sammanthey.wordpress.com

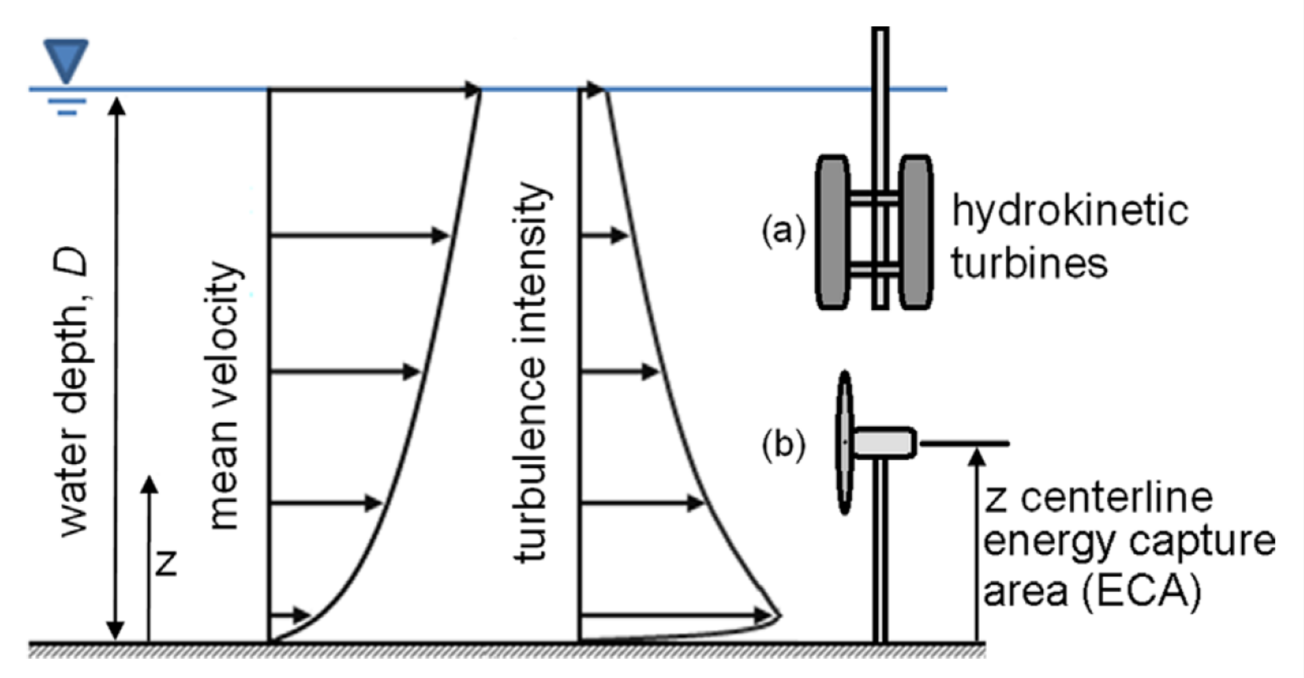


https://www.geol.umd.edu



https://emriver.com/

Location within the water column



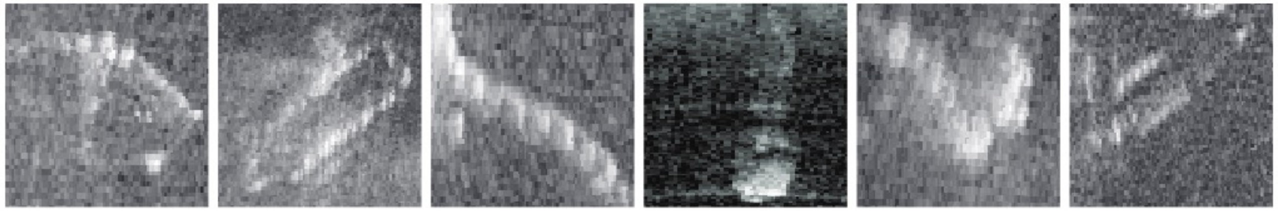
Higher water speed & more large debris exposure (wood logs, etc.)

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

Neary, V.S., Gunawan, B. and Sale, D. (2013) Turbulent inflow characteristics for hydrokinetic energy conversion in rivers. Renewable and Sustainable Energy Reviews.

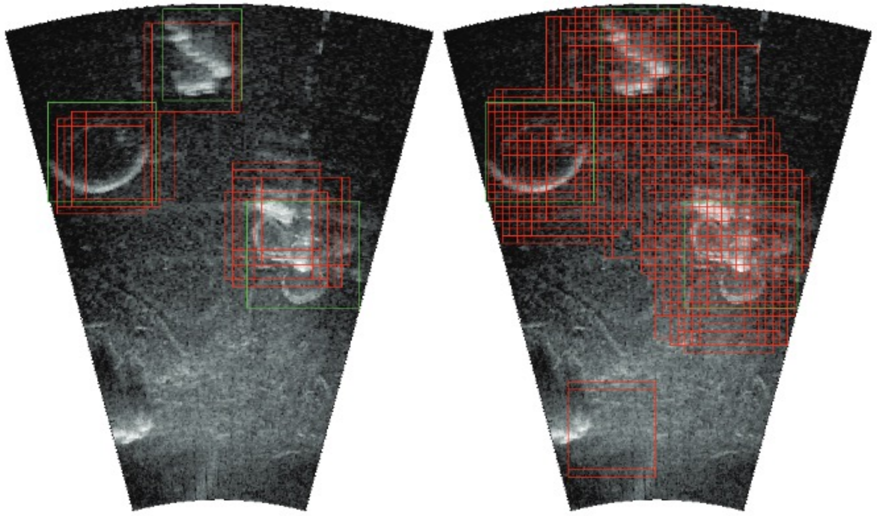
Debris detection & mitigation

Surveillance: Sonar & cameras



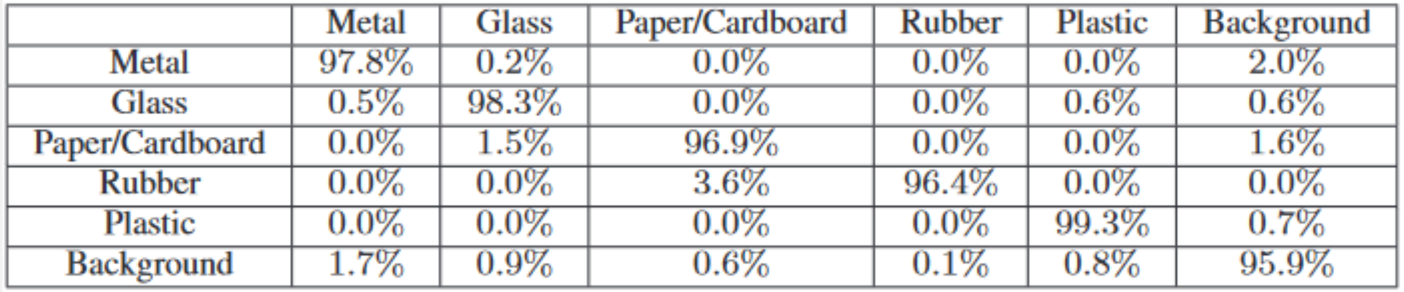
(a) Can (b) Plastic Bottle (c) Chain (d) Drink Carton (e) Hook (f) Glass Bottle

(g) Propeller (h) Tire (i) Valve



(a) Binary Detector (b) Multiclass Detector

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

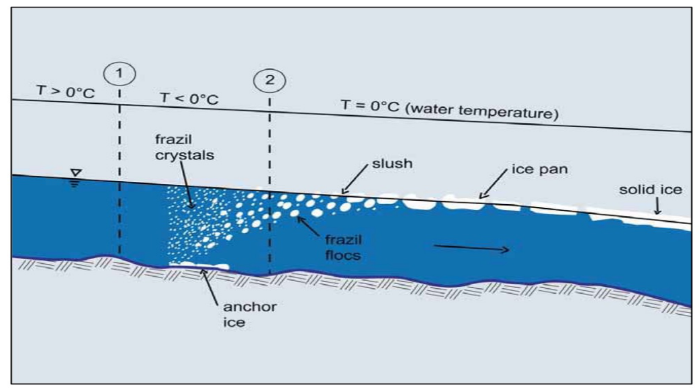


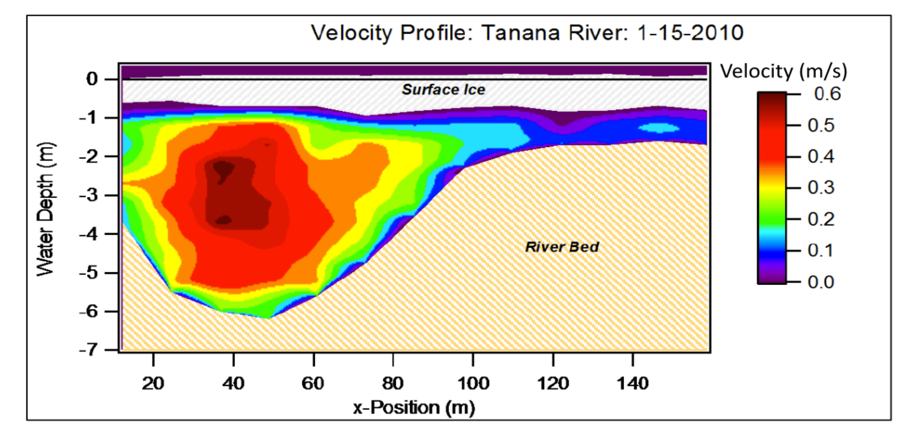
	Metal	Glass	Paper/Cardboard	Rubber	Plastic	Background
Metal	97.8%	0.2%	0.0%	0.0%	0.0%	2.0%
Glass	0.5%	98.3%	0.0%	0.0%	0.6%	0.6%
Paper/Cardboard	0.0%	1.5%	96.9%	0.0%	0.0%	1.6%
Rubber	0.0%	0.0%	3.6%	96.4%	0.0%	0.0%
Plastic	0.0%	0.0%	0.0%	0.0%	99.3%	0.7%
Background	1.7%	0.9%	0.6%	0.1%	0.8%	95.9%

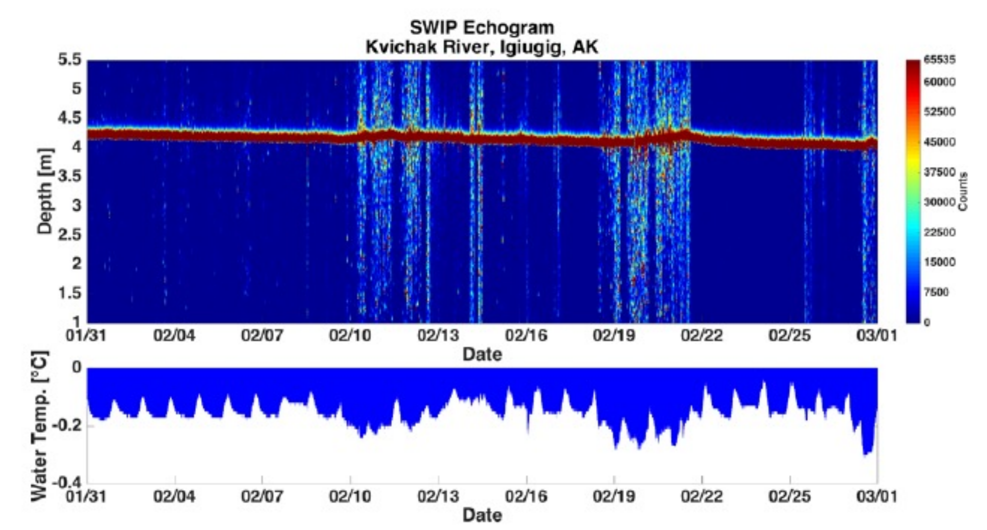
Toro (2016) Submerged Marine Debris Detection with Autonomous Underwater Vehicle

Shallow water ice and current profilers

- Shallow Water Ice Profiler (SWIP)
- ADCP



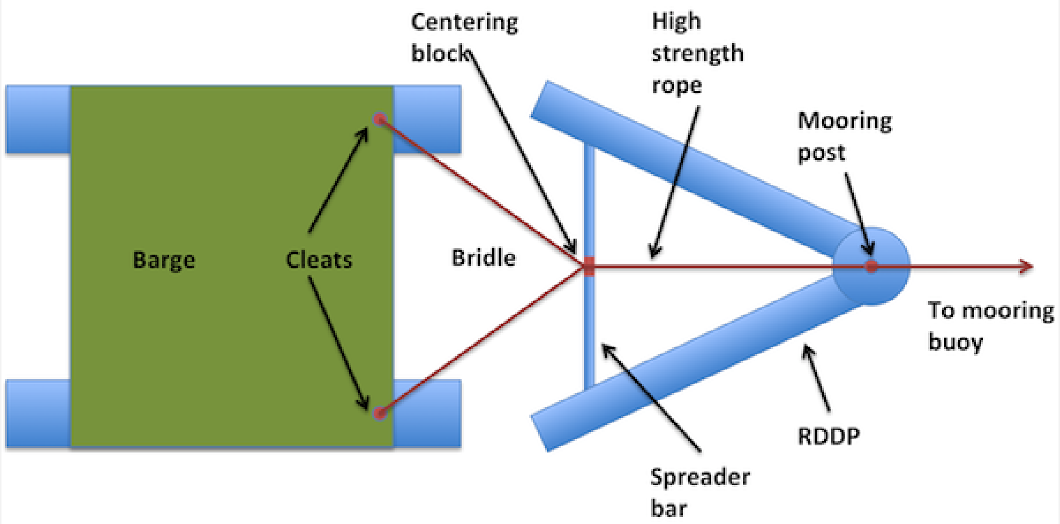




P. J. Kasper, P. Duvoy, and N. Konefal, "Kvichak River Frazil Ice Study Final Report," no. September, 2017.

Debris diversion system

Encurrent debris boom



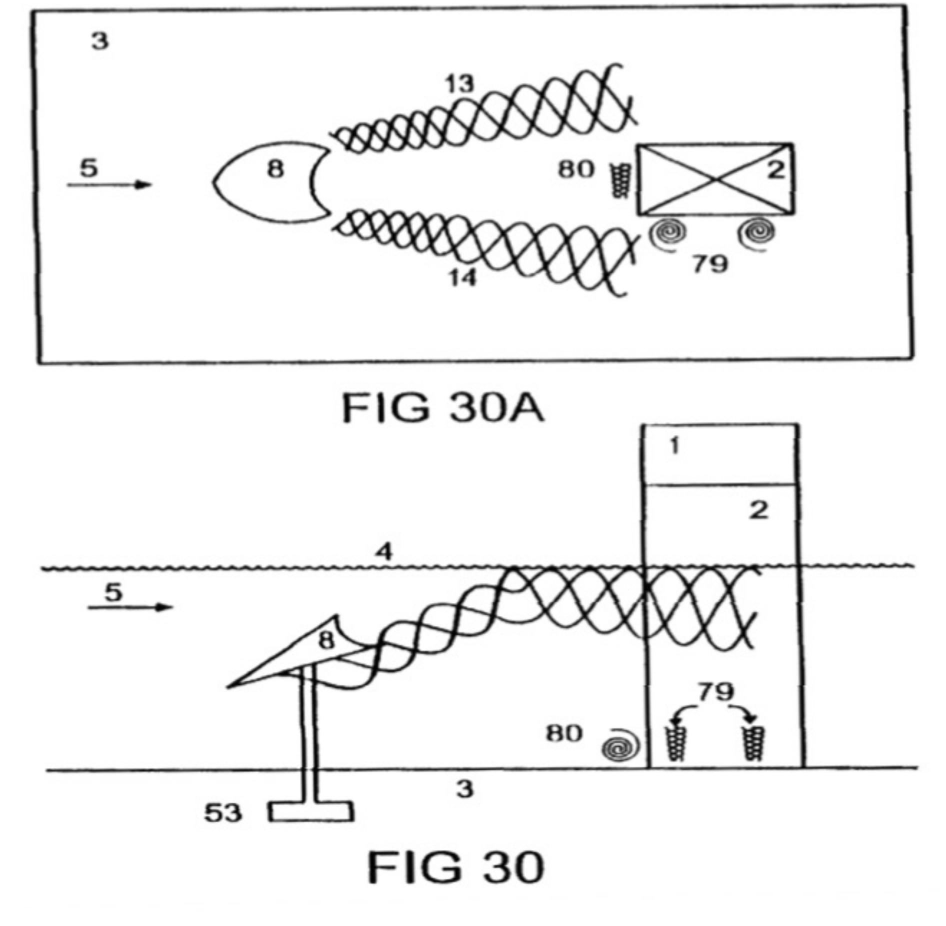


FIG 30A

FIG 30

Oppenheimer & Saunders patent, 1995

[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.

Mesh & collection systems

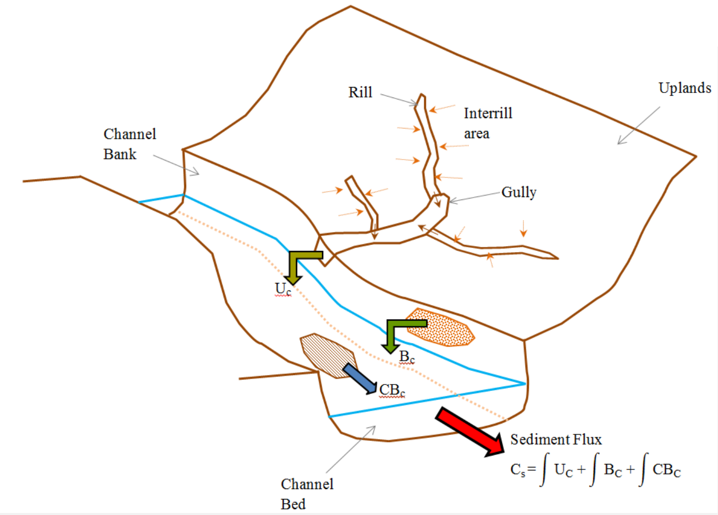
waterpowermagazine.com

https://www.smart-hydro.de/

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

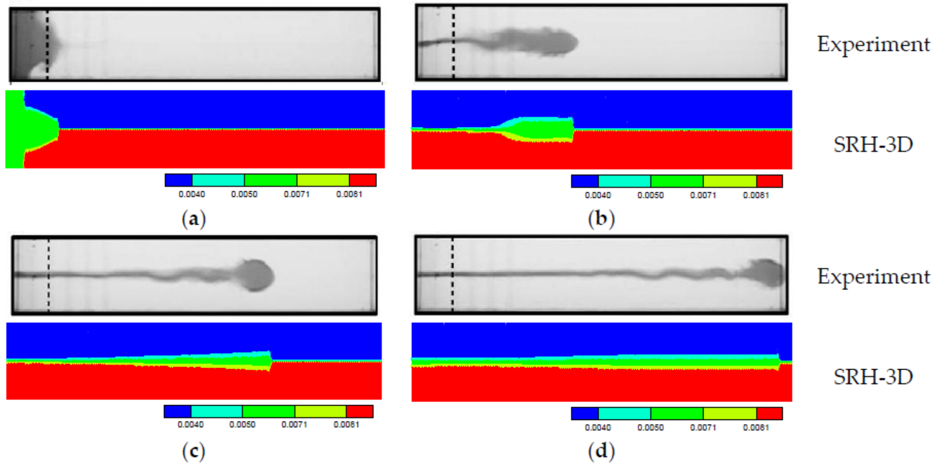
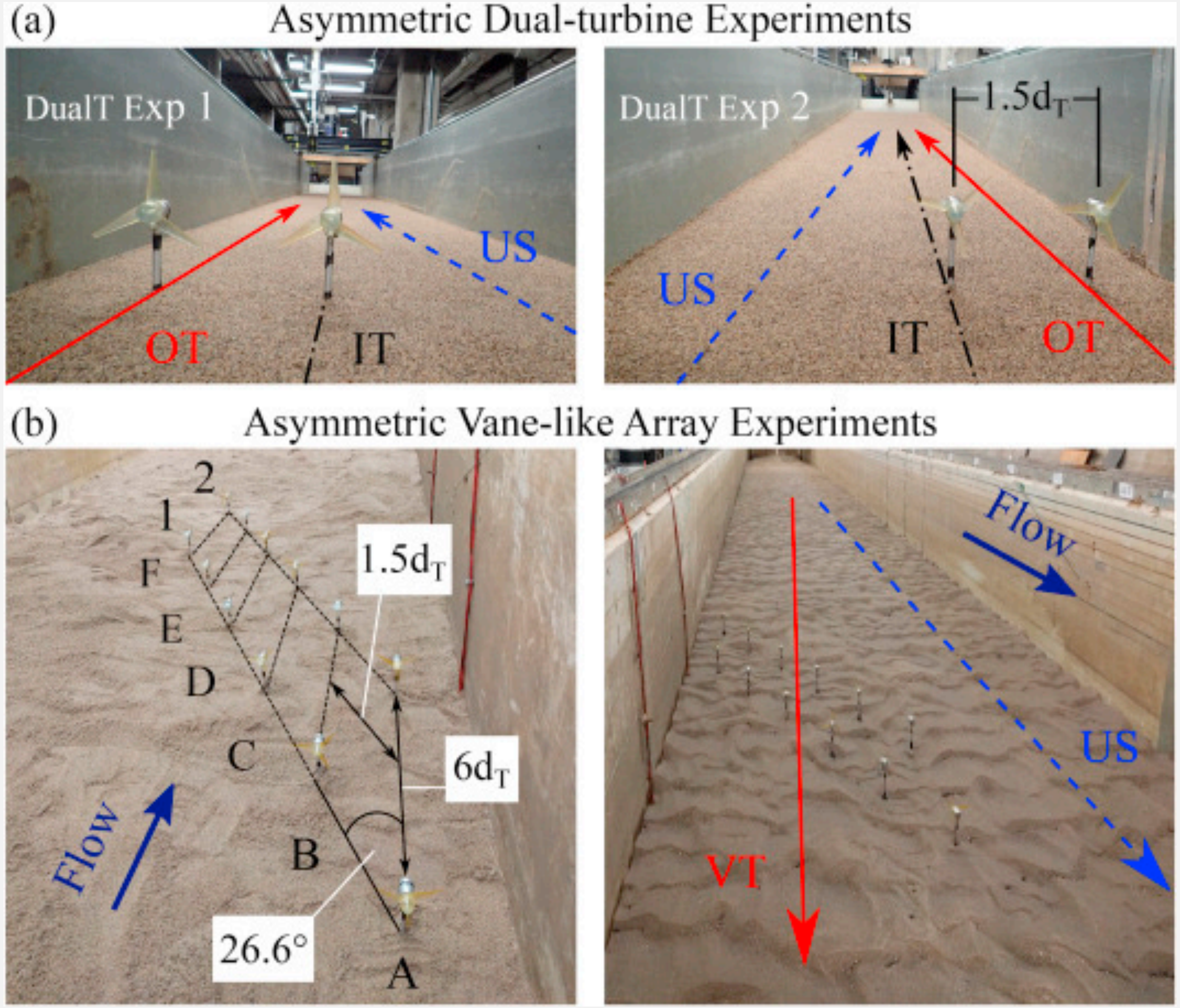


Figure 11. Temporal evolution of the SFTC intrusive gravity current—sediment concentration contours. Experiment is from [52] and visualized by adding dye. (**a**) Time = 2 s; (**b**) Time = 14 s; (**c**) Time = 26 s; (**d**) Time = 38 s.

Lai & Wu (2019) A Three-Dimensional Flow and Sediment Transport Model for Free-Surface Open Channel Flows on Unstructured Flexible Meshes. MDPI Fluids.

Physical modeling: sediment transport



Craig Hill, et al (2016) Interaction between instream axial flow hydrokinetic turbines and uni-directional flow bedforms. Renewable Energy.
MirkoMusa, et al (2019) Interaction between hydrokinetic turbine wakes and sediment dynamics: array performance and geomorphic effects under different siting strategies and sediment transport conditions. Renewable Energy.

Physical modeling: mitigation system

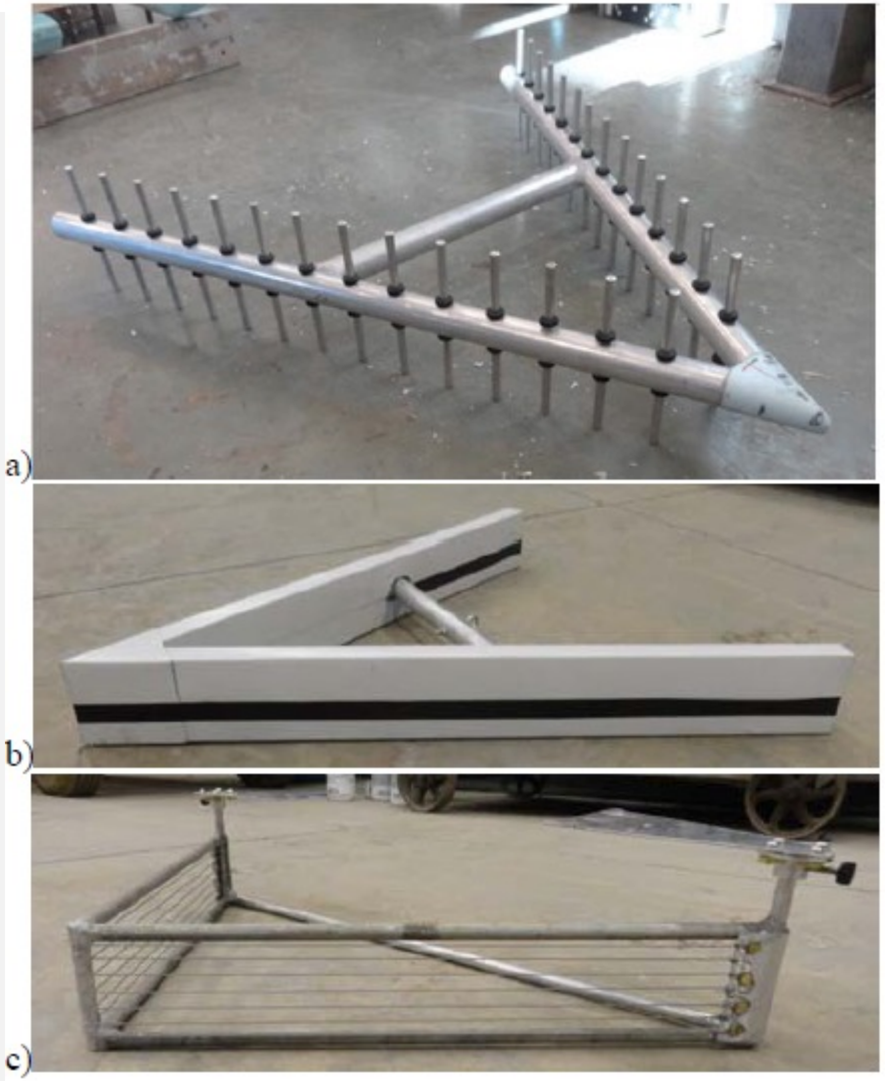
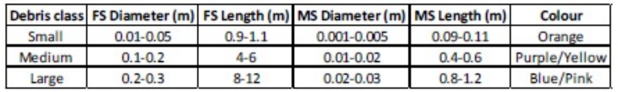


Table 1: Summary of model debris properties



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

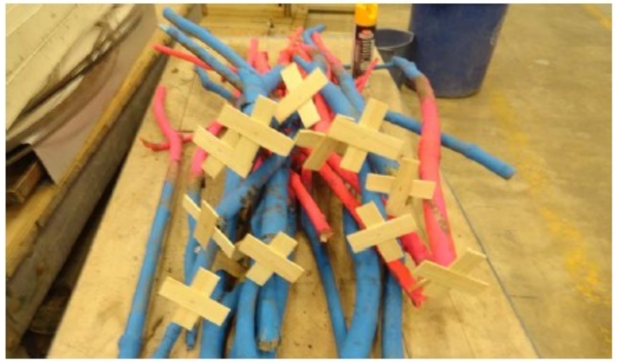


Figure 4 : Roughly half of the larger debris pieces were fitted with artificial root wads.

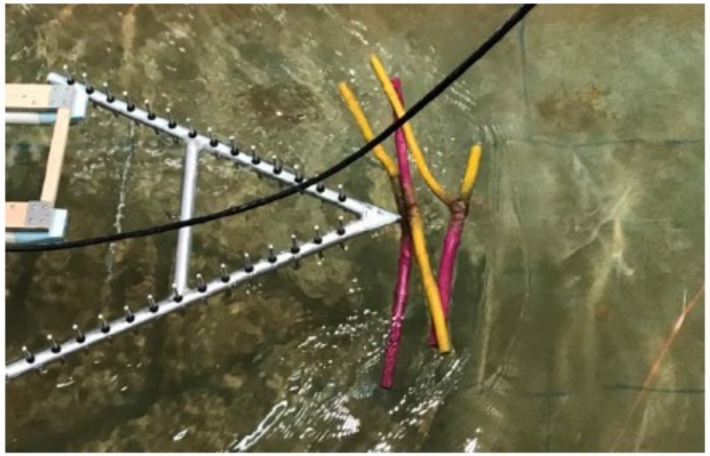


Figure 7 : Raft of medium debris pinned at the nose of Barrier 1A

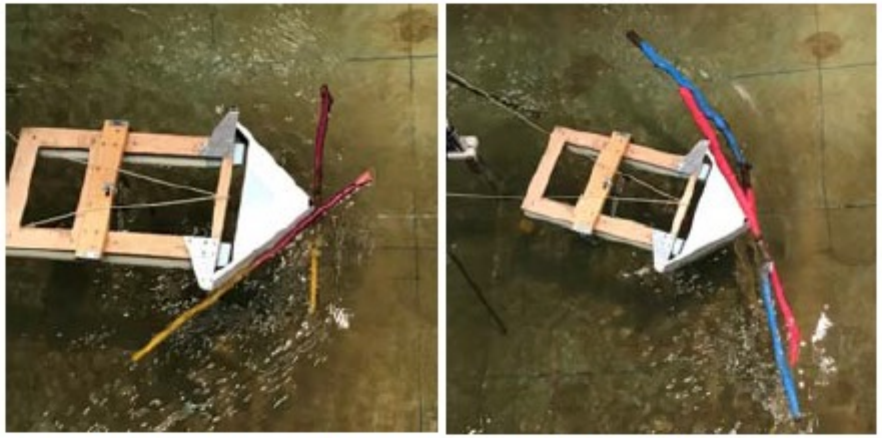


Figure 10 : Medium and large debris pinned against barrier 3B.

Andrew Cornett*, Mitchel Provan*, Michael Bear (2018) Assessment of Debris Mitigation Systems for Tidal and River Turbines. ICOE 2018.

Recommendations

Risk management framework

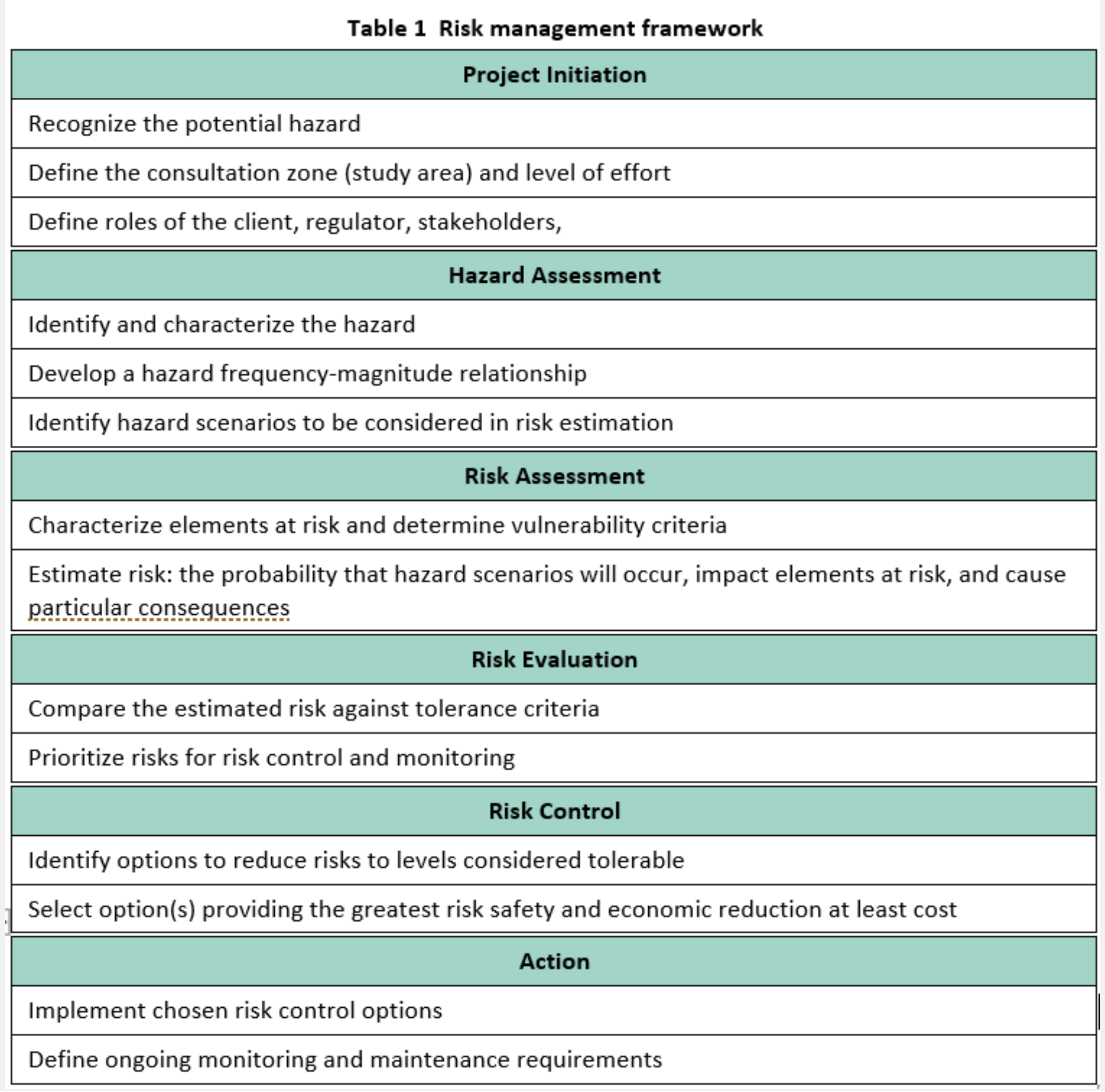


Table 1 Risk management framework

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?

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