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] “

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

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

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

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- **Mitigation action Vs. Cost**
- vectorsolutions.com
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

Drainage Zones

- **Zone I**: Source of supply
- **Zone II**: depocenter
- **Zone III**: tidal environment source and depocenter

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”
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)
Debris detection & mitigation
Surveillance: Sonar & cameras

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

Shallow water ice and current profilers

- Shallow Water Ice Profiler (SWIP)
- ADCP
Debris diversion system

Encurrent debris boom

Oppenheimer & Saunders patent, 1995

Mesh & collection systems

[Images of mesh and 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
Physical modeling: sediment transport

1. How can we quantify debris risk?

A. Types


Physical modeling: mitigation system

1. How can we quantify debris risk?

Table 1: Summary of model debris properties

<table>
<thead>
<tr>
<th>Debris class</th>
<th>FS Diameter [cm]</th>
<th>FS Length [cm]</th>
<th>MS Diameter [cm]</th>
<th>MS Length [cm]</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>0.15 - 0.35</td>
<td>0.0 - 0.1</td>
<td>0.03 - 0.06</td>
<td>0.02 - 0.31</td>
<td>Orange</td>
</tr>
<tr>
<td>Medium</td>
<td>0.5 - 0.6</td>
<td>8.0</td>
<td>0.12</td>
<td>0.06 - 0.3</td>
<td>Yellow/Black</td>
</tr>
<tr>
<td>Large</td>
<td>0.2 - 0.3</td>
<td>8.12</td>
<td>0.02 - 0.05</td>
<td>0.12</td>
<td>Blue/Pink</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Table 1 Risk management framework</th>
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</thead>
<tbody>
<tr>
<td><strong>Project Initiation</strong></td>
</tr>
<tr>
<td>Recognize the potential hazard</td>
</tr>
<tr>
<td>Define the consultation zone (study area) and level of effort</td>
</tr>
<tr>
<td>Define roles of the client, regulator, stakeholders,</td>
</tr>
<tr>
<td><strong>Hazard Assessment</strong></td>
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<tr>
<td>Identify and characterize the hazard</td>
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<tr>
<td>Develop a hazard frequency-magnitude relationship</td>
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<tr>
<td>Identify hazard scenarios to be considered in risk estimation</td>
</tr>
<tr>
<td><strong>Risk Assessment</strong></td>
</tr>
<tr>
<td>Characterize elements at risk and determine vulnerability criteria</td>
</tr>
<tr>
<td>Estimate risk: the probability that hazard scenarios will occur, impact elements at risk, and cause particular consequences</td>
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<tr>
<td><strong>Risk Evaluation</strong></td>
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<tr>
<td>Compare the estimated risk against tolerance criteria</td>
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<tr>
<td>Prioritize risks for risk control and monitoring</td>
</tr>
<tr>
<td><strong>Risk Control</strong></td>
</tr>
<tr>
<td>Identify options to reduce risks to levels considered tolerable</td>
</tr>
<tr>
<td>Select option(s) providing the greatest risk safety and economic reduction at least cost</td>
</tr>
<tr>
<td><strong>Action</strong></td>
</tr>
<tr>
<td>Implement chosen risk control options</td>
</tr>
<tr>
<td>Define ongoing monitoring and maintenance requirements</td>
</tr>
</tbody>
</table>
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)
Questions?

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