A Review of Debris Detection Methods

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Abstract

Debris in rivers and along coastlines occurs frequently. However very little quantitative information is available on the size, location, dynamics and most importantly the risk debris poses to river and marine energy converters. This report reviews techniques and instruments for quantifying debris, its potential for damaging marine hydrokinetic infrastructure and technologies that may be suitable for quantifying debris at prospective hydrokinetic energy sites. The different detection options discussed include mechanical, video and sonar technologies.

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1. Introduction

Following the premature termination of two pilot river hydrokinetic energy projects in Alaska in 2010 due to riverine debris (see Figure 1), the Alaska Hydrokinetic Energy Research Center (AHERC) began an intensive effort to understand and mitigate the impact of surface debris on hydrokinetic infrastructure. These two pilot projects demonstrated that river energy converters (RECs) operating on large, uncontrolled rivers are subject to impacts from woody debris that can result in damage and potentially unsustainable operation and maintenance costs in addition to creating safety hazards (Johnson et al. 2013; Tyler, 2011). As a result of these early industry problems AHERC published multiple reports describing the issue and strategies for mitigating the effects of surface debris (Tyler 2011; Bradley and Seitz, 2012; Schmid 2012; Johnson et al 2013, 2014, 2015). The culmination of this work was the development the “research debris diversion platform” (RDDP) for protecting in-stream hydrokinetic infrastructure from the effects of surface debris (Johnson et al. 2014). The RDDP was developed to reduce the risk of debris impacts on RECs deployed from surface platforms (e.g. barges). The effectiveness of the RDDP has been demonstrated through multiple years of testing at AHERC’s Tanana River Test Site in Nenana, Alaska (Johnson et al. 2013).

Figure 1. Debris accumulation on the bow of the 5 kW New Energy EnCurrent^{TM} turbine barge on the Yukon River at Ruby, Alaska (from Pelunis-Messier 2010)

The RDDP is a “V” with its apex facing upstream (Figure 2). A freely rotating cylinder approximately 1m in diameter covered in low-friction plastic is mounted forward of the apex (called the debris sweep). Debris that impacts the sweep are typically deflected and then slide downstream, along the pontoon surface. In this manner, debris is diverted from the region behind the RDDP. Numerous direct impact tests of debris on the RDDP during extended deployments have demonstrated the effectiveness of the RDDP in deflecting debris from the region immediately downstream (Johnson et al. 2013).

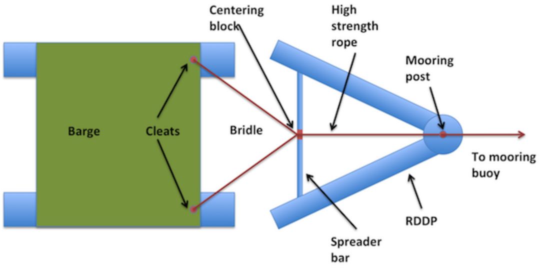

Figure 2. Mooring configuration of the test barge and RDDP**.**

Maximum protection from debris is achieved by tethering a floating REC platform (a barge) via a bridle to a spreader bar on the rear of the RDDP. This arrangement prevents massive debris from rotating the RDDP+barge system about its forward mooring point; the barge and RDDP move as a unit with the combined mass of the barge/RDDP system reduces rotation.

The impact of the RDDP on device power output and its effectiveness at diverting debris are well documented (Johnson et al 2015a,b); While the RDDP effectively protects floating river energy converter platforms from surface woody debris, turbulence generated by flow deflection around the RDDP resulted in an 8% decrease in power output of one REC deployed 14.5 m downstream of the RDDP (Johnson et al. 2015a). This same REC's power output was not affected by RDDP generated turbulence 50 m downstream of the RDDP since RDDP generated turbulence dissipated rapidly with increasing distance from the debris diverter (Johnson et al 2015a).

It should be noted that the RDDP only deflects surface debris. The quantity and characteristics of subsurface debris are the subject of ongoing research. Note that a permanent, fixed subsurface debris diverters analogous to the RDDP would likely be very costly to construct, difficult to anchor as well as likely to result in unacceptably large losses in power output.

The documented decrease in power output of a REC moored behind the RDDP and additional costs associated with installing debris diversion systems suggests that alternative methods for dealing with debris should be sought. These may include designing debris tolerant hydrokinetic energy converters and/or passive mitigation strategies such as debris avoidance. In the case of subsurface debris, alternatives to fixed debris diverters should be given strong consideration. Alternatives to fixed subsurface diverters may include active systems which are engaged through remotely generated information on approaching debris but this approach is fraught with potential problems, engineering challenges and would likely be costly to implement. Also, existing debris mitigation methods such as the RDDP are for uni-directional flow and thus would likely require significant changes for use in protecting tidal or wave energy converters. Whichever strategy is implemented, knowledge of the debris likely to be encountered at prospective hydrokinetic energy sites should be acquired beforehand (1) in order to determine if debris is an issue and (2) for design and engineering and/or mitigation purposes. Information collected should include at the least, estimates of the likelihood of impacts and expected loads so a thorough cost-benefit analysis can be carried out prior to the start of a project. Note while the focus of this report thus far is on debris in rivers, the same concerns apply to coastal locations as well, especially sites in proximity to rivers (e.g. Figure 3).

Figure 3. Woody debris littering a coastal beach near Yakutat, AK. Photo Courtesy of W. Lucey, City and Borough of Yakutat.

Debris occurs at all depths in Alaskan rivers due to trees, branches and twigs with varying amounts of absorbed water (Johnson, 2010) with debris varying in size from small mulch-like material to intact trees. In order to quantify the range of debris encountered, Bradley (2012) developed a size classification scheme. Small debris comprises any debris that can be removed from the river by hand and lifted above one's head. Medium-sized debris is anything too large to lift over one's head, but too small to have sufficient buoyancy to carry the weight of a person downriver. Large debris is anything that is large enough to have sufficient buoyancy to support a person (Bradley 2012). Large debris generally enters the river via outside bank erosion (Bradley 2012, Figure 4).

Figure 4. Large debris entering a river via bank erosion (photo courtesy of Jack Schmid, Alaska Center for Energy and Power, 2010).

In rivers, debris volume generally increases as river discharge increases (Johnson et al. 2013) since rising water levels entrain debris stranded on the banks and also increases bank erosion. Similar processes likely operate along coastlines as well; large storms with significant rainfall have the potential to increase debris loads in nearby coastal rivers as well move debris and other material along the coast via storm surges and increased wave action. In some rivers when the water level is rising, debris tends to follow the thalweg, or main channel, of the river while when water levels drop debris is more prevalent along riverbanks (Cheng & Shen 1979). When the water level is steady debris generally follows the thalweg (Lagasse et al. 2010). No such similar characterizations of debris paths are currently available for the coastal zone. While such conditions obviously make for challenging deployments, simple, effective and inexpensive avoidance strategies can be developed simply by observing the path of debris e.g. a river turbine placed slightly outside of the thalweg stands may be out of the path of debris entirely. For example at AHERC's Tanana River Test Site, the Anchor point and test barge is located in the main channel, but just to the right of the primary path of debris flow. This occurs because the RDDP and test barge are down stream from a river bend and slightly upstream of the crossover point of the thalweg from the left bank to the right bank at the downstream river bend. Most debris floating around the upstream river bend emerges from the bend near the left bank of the river as a result of river current and debris inertia. Debris then remains in the thalweg slightly to the left of our anchor site (Figure 6) passing behind the test barge as it float across the river to the right bank.

While a simple debris avoidance strategy may not obvious a-priori, in developing a basic understanding of prospective hydrokinetic energy sites, such simple solutions may present themselves. In the absence of an adequate site characterization however, no such solution would be apparent.

2. Overview of Methods and Technologies for Debris Quantification

In order to collect enough information on debris at potential hydrokinetic energy sites, a combination of different techniques and/or methodologies will likely be necessary. Here we briefly describe visual, mechanical, video and sonar techniques for quantifying the prevalence, size and impact forces of debris on infrastructure in marine and riverine environments. While much of what we report is based on AHERC's experience at the Tanana River Test Site, sonar techniques in particular have been more broadly applied. Techniques and technologies for observing debris range from simple and inexpensive to much more complicated and potentially more costly methods.

One effective and easily implementable approach to characterizing debris is regular, visual observations of debris. Bradley (2012) and Bradley and Seitz (2012) observed debris on the Tanana River hourly for several months and developed the Parker size classification scale described elsewhere in this document. While several months worth of debris observations may seem excessive and costly, Bradley's measurements were made in conjunction with mandatory baseline fisheries observations that required personnel to be on site. As part of their regular baseline fisheries studies, Bradley and Seitz. also gathered extensive samples of the different types of debris as well (the figure on the report cover is of a large tree that damaged one of the fisheries sampling platforms employed by Bradley and Seitz).

Schmid (2012) describes a mechanical means for detecting debris deployed as part of a Denali Commission funded project to examine subsurface debris in the Tanana River (the Mechanical Debris Detection Device or MDDD, Figure 5). The MDDD consisted of a set of "self clearing" tines equipped with strain gauges along the length of the tines to measure tine deformation in the event of debris impacts. After significant delays in acquiring components, the MDDD was only briefly deployed with mixed results; parts for the MDDD were specified just prior to the Fukushima-Daichi nuclear disaster which impacted the ability of the Japan based strain gauge manufacturer to supply parts for the project which then delayed construction and deployment of the MDDD. After substantial delays, the MDDD was briefly deployed from near the bank of the Tanana River. AHERC is currently developing other methods of measuring the frequency and forces of subsurface debris impacts that are suitable for more energetic environments than the MDDD's anchor structure proved capable of handling. Despite the mediocre performance of the MDDD, mechanical means of quantifying debris are likely more cost effective and more readily implementable than many other means of debris detection. Furthermore, of the methods considered here, mechanical detection (e.g. using load cells) provides the only direct measure of impact forces imparted on infrastructure by debris, an important piece of information when designing debris tolerant energy converters.

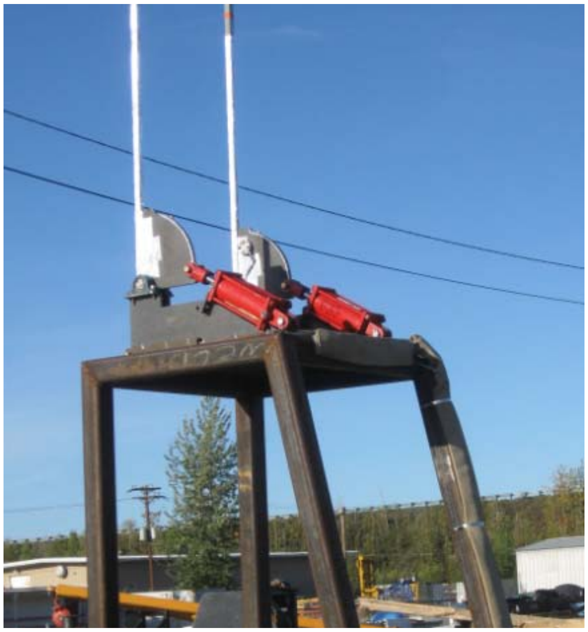

Figure 5. The mechanical debris detection device or MDDD. From Schmid 2012

While the MDDD proved difficult to implement, the use of other mechanical sensors such as load cells mounted on the RDDP platform regularly provides AHERC important information about the forces debris exert on hydrokinetic infrastructure. Johnson et al. (2014, 2015) describe impacts on the RDDP that regularly approach 6000 N up to a maximum of 29,000 N (Johnson et al. 2015). Load cells are typically mounted between a fairlead at the apex of the RDDP and a Samson post aft of the RDDP apex, that the mooring line is connected to on the RDDP (Figure 2). While load cells potentially represent an inexpensive and easily implementable means of characterizing the frequency and impact forces of debris, they require a platform such as the RDDP to be in place. Note to eliminate uncertainty about the cause, interpretation of such high loading events is best done using information from multiple sensors including load cells as well as video or sonar as described below to corroborate each sequence of events. As the reported loads demonstrate, any mounting platform needs to be robust enough to withstand significant impacts and thus the mounting platform may represent a significant expense.

Beyond physically sampling debris, recent progress has been made in developing remote sensing techniques including video based observations for debris quantification. Johnson et al. (2015b) describe the successful implementation of the video debris observation system or VDOS. The VDOS consists of an automated power supply, two 1 frame per second cameras and a server for archiving images of the Tanana River Test Site (Figure 6). While the software tools for automating the analysis of the VDOS imagery are still in development, simple quantitative descriptions based on subsampled VDOS data are easily analyzed manually in order to quantify debris by size, location and frequency (e.g. Johnson et al. 2015b). Overall, the VDOS is suitable for deployment in remote locations for site assessments where debris is of concern and represents a step forward from past attempts to utilize photography to analyze debris (c.f. Johnson et al. 2014).

Figure 6. Test barge with an Oceana Energy, Inc. turbine on deck behind the instrument tent, tethered behind the RDDP at the Tanana River Test Site, Alaska. A large debris object floats downstream nearby. (Photo taken by the Video Debris Observation System)

In addition to visual, mechanical and video based methods of debris characterization sonar methods hold promise for subsurface debris characterization and may be the only means of remotely sensing debris in environments where visibility is limited. While sonar is expensive, as with other methodologies it is likely possible to achieve multiple goals while limiting the total number of deployments and thus mitigate the overall costs. For example, bathymetric surveys are a basic component of International Electrotechnical Commission certified resource assessments including the IEC 62600-101 (Wave Resource Assessment) and -201 (Tidal Resource Assessment) Technical Specifications (TS) and will likely be required for the -301 (River Resource Assessment) TS as well. In addition to acquiring bathymetric information, most modern multibeam sonar systems, standard equipment for accurate bathymetric surveys, acquire acoustic backscatter data or “snippets” data. Snippets data is analogous to the information collected by side scan sonar. Side scan sonar is widely used for marine hazard surveys including identifying debris. For example, side scan sonar was used to detect deadhead logs from historic lumbering on the banks of the Chickasawhatchee and Ichawaynockaway Creeks in Georgia (Kaeser 2008). The Georgia study used a 455 kHz Humminbird 981c SI system with a range of 20-24m (Kaeser 2008). This study found the sonar equipment was able to identify two-thirds of the known deadhead caches (Kaeser 2008). An image of a log produced by the side scan sonar is shown in **Figure 7**.

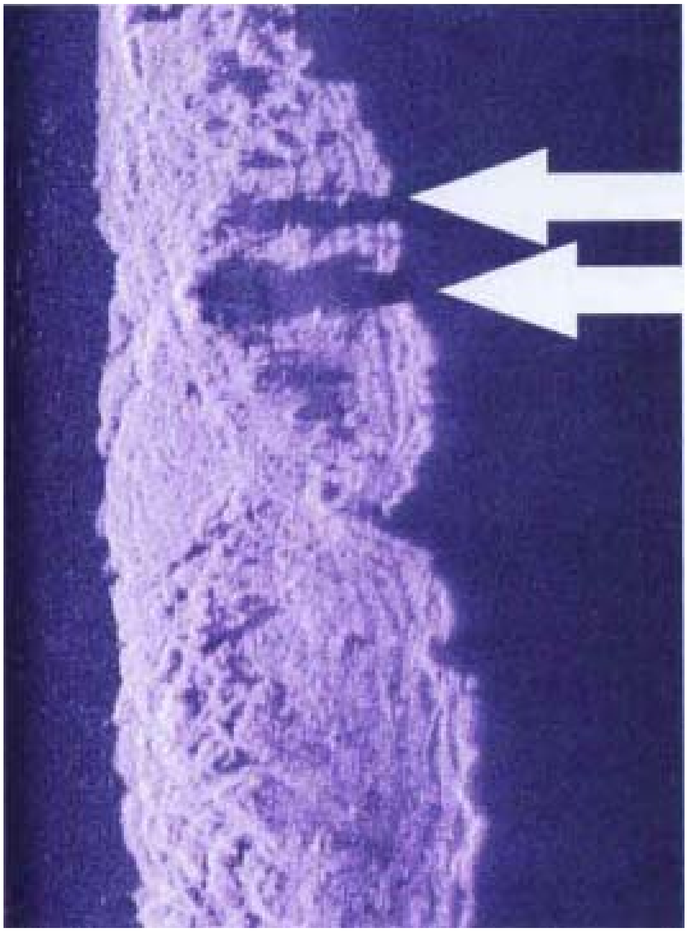

Figure 7: Image produced by sonar equipment of two cypress trees (white arrows, from Kaeser 2008).

Technologies suitable for fisheries observations, which are typically required for permitting prospective hydrokinetic energy sites may also be suitable for debris quantification. For example, the Alaska Department of Fish and Game regularly uses multibeam imaging sonars such as a DIDSON “sonar camera” (1.8 and 1.1 MHz) as well as splitbeam sonars (such as a Biosonics 200 kHz split beam, e.g. Maxwell 2004) for fisheries research in turbid Alaska rivers. Maxwell (2004) found that in side-by-side tests, the DIDSON was able to identify a tungsten calibration sphere at a range of 16m while the Biosonics splitbeam could identify the test sphere at a range of 21m without bottom interference and 30m with bottom interference (Maxwell, 2004). A review of debris by Tyler (2011) found that DIDSON technology could be used to identify debris in the water column of rivers. Split beam sonars are also standard fisheries oceanography tools as well (e.g. Medwin and Clay, 1998). An image of subsurface debris identified by DIDSON equipment is shown in Figure 8. AHERC is in the process of evaluating the use of dual sonar systems including split beam and multibeam, imaging sonars for combined fisheries and debris quantifications in turbid conditions.

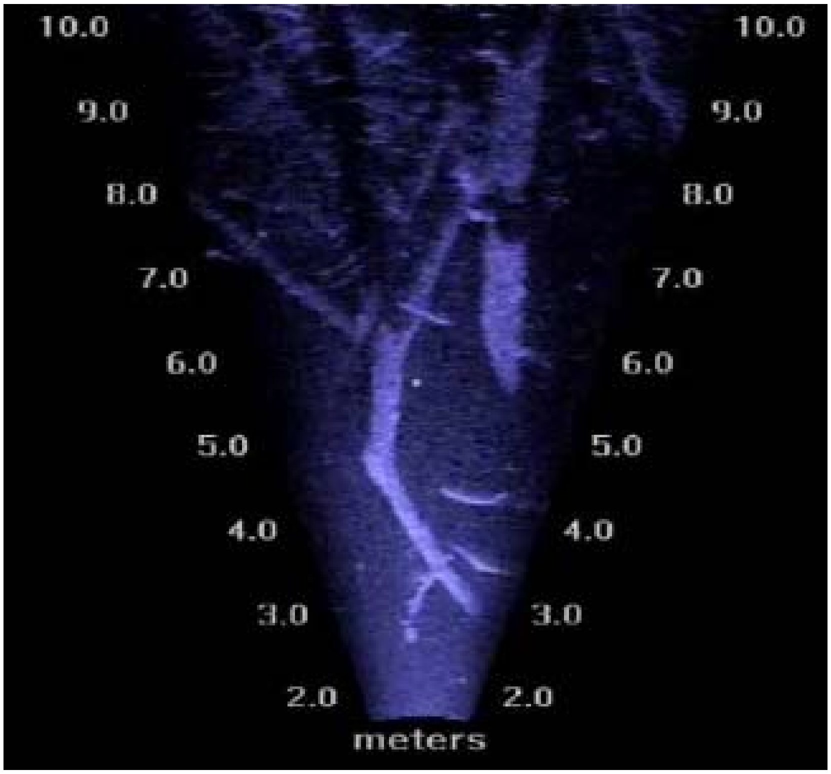

Figure 8: Submerged debris in the Red River, Manitoba Canada, seen from a DIDSON camera. From Tyler 2011.

As Maxwell (2004) and others have found, lower frequency sonars appear to be optimal as they have longer ranges and can see through silty water better than higher frequencies units. For example the range of a UAF owned 2250 kHz Blueview imaging sonar is limited to <15 m in the silt laden Tanana River while a 900 kHz transducer for the same system is capable of imaging targets at distances up to 30 m in the same conditions. Splitbeam sonars are typically even lower frequency (UAF owns a 120 kHz Simrad EK60 split beam sonar) and thus have greater range than most imaging sonars.

Despite their promise, both split beam and imaging sonars require significant time spent post-processing data unless a means of near-real time processing can be developed (e.g. the Pacific Northwest National Laboratory led Nekton Interaction Monitoring System project and other similar tools may prove suitable for analyzing debris as well as fisheries interactions with turbines). Furthermore, licenses for post-processing software are often prohibitively expensive; a license for an industry standard post-processing toolbox, Echoview is approximately $40,000 and the cost increases with increasing numbers of processing modules.

Note given typical river velocities on the order of 2 m/s, in order to engage an active debris mitigation system a sonar with a range of 12 m would only allow for 6 seconds between identification and full engagement of an active debris mitigation scheme while a sonar with a range of 30 m would allow for a 15 s window between identification to activate debris mitigation. Considering the known power reduction by mitigation systems such as the RDDP, before any mitigation measure was engaged, there would need to be a high degree of confidence that the debris was a credible threat otherwise the system might falsely engage the mitigation system too frequently with the result that power output was significantly reduced i.e. when no threat was truly imminent. Building such an accurate system would require significant software and hardware development and would likely be prohibitively expensive, perhaps even requiring an array of expensive sonars to accurately track debris and engage defenses in a timely manner. Thus while the idea of an active system is attractive, there are significant basic hurdles that would need to be overcome before such a system could become a reality.

3. Conclusions and Recommendations

Characterizing debris at prospective hydrokinetic energy sites before project implementation is a simple way to reduce overall project risk. While many technologies to detect and characterize debris are in development, by combining easily implementable debris monitoring strategies (e.g. visual observations, automated video observations, load cell measurements or other mechanical detection) with mandatory baseline studies that will likely include some form of fisheries monitoring as well as acoustic bathymetric and hazard surveys, baseline site assessments should be able to incorporate a minimum level of debris characterization by leveraging data gathered as part of these other data collection efforts and thus reduce overall project risk. Such basic knowledge of debris should be viewed as mandatory for developers since it will inform overall project risk assessments, inform operation and maintenance cost projections as well as being useful in the design stage. Furthermore, while the research debris diversion platform is a proven, effective solution to surface debris, further knowledge of debris may present other, less burdensome and/or costly solutions to debris problems. At this time, we do not recommend pursuit of “active debris mitigation” technologies as the engineering challenges to success of this approach are significant as would be the costs of developing such a technology. Rather, cost effective means of characterizing debris will more likely involve dual purpose measurements that can be exploited to provide information on multiple environmental parameters (e.g. fisheries and debris or bathymetry and debris). Thus efforts should be focused on further developing sonar technologies and software for such systems for improved measurements of debris as well as other environmental factors relevant to prospective hydrokinetic energy sites. Overall, any effective debris measurement scheme will likely, necessarily, include a combination of physical (e.g. load cell) as well remotely sensed (video or sonar) data acquisition.

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