IGIUGIG HYDROKINETIC PROJECT

APPENDIX A: PROJECT PLANS

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511-002

November 15, 2018

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613-4008
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

Appendix A: Project Plans includes the following documents:

- Inspection and Maintenance Plan
- Project Safeguard Plans
    - Project and Public Safety Plan
    - Project Removal and Site Restoration Plan
    - Navigation Safety Plan
    - Emergency Shutdown Plan
- Adaptive Management Plan
- Fish Monitoring Plan

ORPC

INSPECTION AND MAINTENANCE PLAN

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT No. 13511-002

November 15, 2018

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613-4008
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

TABLE OF CONTENTS

1.0 INTRODUCTION

The Project's inspection and maintenance plan has three main parts: 1) system health monitoring, 2) regular maintenance, and 3) major maintenance.

1.1 System Health Monitoring

System health monitoring will be performed remotely throughout operations. Data collected from the system sensors will be collected by the supervisory control and data acquisition (SCADA) system located in the shore station. The data will be automatically reviewed by the SCADA system to detect if parameters are within acceptable limits for the system. Data from the SCADA system will be stored locally and will be backed up on a regular basis to systems outside Igiugig. Communications from Igiugig to outside computers will be by internet. The system health monitoring system will not be responsible for actions related to collecting, storing, processing, assessing or transmitting data associated with fish monitoring. Those actions are covered under the Fish Monitoring Plan.

The SCADA system will monitor multiple sensor streams as described in the Supporting Design Report. Data will be aggregated into averages, with averaging periods from one minute to one day, depending on the given data stream. Preset limits will be set for critical data streams. If a parameter exceeds allowable preset limits a code will be generated. The code will activate an indicator on the remote application viewer. If the predefined critical limits are reached the system will automatically shut down. Notification will be made through an indicator on the remote application viewer.

The data from system operations will be collected, processed, and presented for viewing on remote commuter systems in Maine and Alaska. The data will be viewable through a dedicated internal computer system. System operational parameters may be modified from the remote application.

1.2 Regular Maintenance

The RivGen® device will be retrieved at a time of the operators choosing and will depend on issues of staff availability, availability of village backup power, weather conditions, and other operational considerations. It is expected that the system will be retrieved yearly for the first several years of the project, but this inspection interval maybe extended if an assessment is made that the System Health Monitoring system is showing that all critical systems are in acceptable health. It is anticipated that initial regular maintenance may require up to 20 days.

Regular maintenance will be performed while the system is floating on the surface of the river. Access to the system will be made by a small vessel. Visual inspection of the entire RivGen® device(s) will be conducted. Maintenance of the Project site including the shore station and markings will be performed as required and inspected on an annual basis at a minimum. Power system components to be reviewed during regular maintenance include:

1.2.1 Mooring System

The connections of mooring lines to the pontoons will be inspected and documented.

1.2.2 RivGen® Device

A visual review of the device will be conducted to ensure that all major components are present and in acceptable conditions. In the event that oils and lubricants are required to be replaced, then these will be replaced at this time. Minor adjustments to the system may be required and will take place at this time.

1.2.3 Cables

Power and data cables connected to the RivGen® device will be visible when the device is on the surface. The cable connections to the RivGen® device will be visually inspected and documented at this time. Visual inspection of the cable junction box will be conducted to monitor cable stability.

1.2.4 Shore Station

A visual inspection of the shore station will be conducted. Any maintenance related to weathering of the shore station will take place on an as-needed basis.

1.2.4 Project Signage

A visual inspection of project signage will be conducted. Any maintenance related to weathering or displacement of the signs will take place on an as-needed basis.

1.3 Major Maintenance

Major maintenance to the RivGen® device(s) and other equipment is anticipated at five-year intervals. If system health monitoring or regular maintenance inspections determine it is necessary prior to a five-year interval, then a major maintenance event will be scheduled. The device will be raised to the surface, disconnected from the mooring system, and brought to shore at the Village of Igiugig. Depending on the nature of the work required the work may be conducted on the water, near shore, on land, or in a dedicated facility either in Igiugig, or elsewhere.

The following section provides additional details on the nature of major maintenance.

1.3.1 RivGen® Device

The RivGen® device has the following components which are subject to inspection and maintenance:

Turbines

Turbines are not expected to require major maintenance during the project life.

Bearings

Major maintenance inspections will be performed to measure and check that bearings are properly aligned and in good operating condition. Disassembly of the driveline may be required to confirm that the driveline bearings are acceptable.

Generator

Generator seals will be inspected and if required, replaced.

The generator internal kingpin bearing seal will be inspected and if required, replaced.

The generator internal kingpin bearing will be inspected and if required, replaced.

The generator internal kingpin bearing grease will be replaced with new grease.

The generator internal oil will be replaced with new oil.

Touch up painting of the generator may be performed.

Replacement of anodes on the generator may be performed.

Removal of any growth interfering with generator heat transfer will be performed.

Handling of oil and grease will be performed in accordance with regulatory requirements.

Chassis, fairing system, and pontoon support structure

Touch up painting of the structural steel will be performed.

Replacement of sacrificial anodes may be performed.

Electronics case

Touch up painting of the structural steel will be performed.

Replacement of sacrificial anodes may be performed.

Removal of any growth interfering with generator heat transfer will be performed.

Mechanical brake

Brake seals will be inspected and if required, replaced.

The brake internal oil will be replaced with new oil.

Touch up painting of the brake may be performed.

Replacement of sacrificial anodes on the brake may be performed.

Removal of any growth interfering with brake heat transfer will be performed.

Handling of oil and grease will be performed in accordance with regulatory requirements.

Ballast System Components

Replacement of ballast system components will be conducted as required.

Cleaning of ballast system components will be performed as required.

SCADA Instrumentation

Removal of any growth interfering with operation will be performed.

Environmental monitoring equipment

Removal of any growth interfering with operation will be performed.

1.3.2 Mooring System

The anchors will not be inspected as they are designed to remain in place for the duration of the project.

The anchor chain will be inspected at the connection of the chain to the mooring line. Measurements of chain link diameter will be made and documented to track corrosion of the chain. The anchor chain may be turned "end over end" and reused if the corrosion amounts are less than the allowance, and if fatigue calculations indicate that this is acceptable. If corrosion levels are not acceptable, the anchor chain may be replaced with a new chain.

The chaffing on the synthetic mooring line will be visually inspected and documented. If abrasion is significant the chaffing may be replaced or reinforced.

The mooring line jewelry will be visually inspected and documented. If corrosion exceeds acceptable levels these items may be replaced.

2.0 DOCUMENTATION AND REPORTS ON INSPECTIONS AND MAINTENANCE

Inspection and maintenance documentation will be integral to the first years of the Project as standard maintenance intervals are developed for the RivGen® Power System. All inspections and maintenance will be documented prior to and following the maintenance event. Documentation will record the date of the inspection, the individuals present at inspection, the weather and other conditions surrounding the inspection. Documentation will outline and elaborate on observations and noticeable changes. All inspection and maintenance documentation will have a designated signoff chain and will be stored for future reference.

SAFEGUARD PLANS

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511-002

November 15, 2018

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613-4008
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 PROJECT AND PUBLIC SAFETY PLAN

1.1 Purpose

The purpose of the Public Safety Plan for the Igiugig Hydrokinetic Project (Project) by the Igiugig Village Council (IVC) is to describe: (1) safety devices and measures to ensure the safety of the public near the Project components; (2) ways in which the Project will be monitored to determine if there is an emergency; (3) procedures taken during an emergency; (4) procedures for reporting the emergency to local, state, and federal agencies; (5) contingency measures to modify operations or to implement the Project removal plan; (6) procedures for the annual testing of emergency equipment; and (7) procedures for annually coordinating with response agencies.

Safety Devices and Procedures

Safety devices and measures include educating and informing the public about the Project, instituting visual warnings of hazards, and installing signs that restrict access to Project components.

Educating and Informing the Public

Since 2008, IVC has actively discussed the Project through public information sessions and numerous meetings with village residents and regional tribes and groups, such as the Alaska Rural Energy Conference. IVC has utilized the village website (www.igiugig.com), library and town office to announce the information sessions and provide information about the Project. In addition, Project partners, such Ocean Renewable Power Company, Inc (ORPC), have provided educational information about the RivGen® Power System and its demonstration project to community members at Igiugig, on their website (www.orpc.co), and at professional conferences.

IVC will also work to ensure public safety in the vicinity of the Project. Consistent with the pre-commercial demonstration testing activities on the Kvichak River in 2014 and 2015, IVC will continue to collaborate with USCG to provide safety marine information broadcasts and Local Notices to Mariners, relaying Project coordinates as necessary to prevent the anchoring or deployment of fishing gear, dredging equipment, or any other submarine or surface equipment that risks entanglement with and/or damage from the devices. Thus far, consultations have raised no navigational safety concerns. IVC will continue to keep agencies and all interested parties informed for the duration of the Project to ensure that any future safety concerns are promptly addressed.

Visual Warnings

IVC will provide signs and markers at the shore station and on the river bank to ensure public safety while the device(s) are operating and while cables are installed. Warning signs stating "Caution: High Voltage" will be displayed on sides of the shore station while cables are installed. Signs will be posted on the river bank indicating the shore-side exit of the power transmission cable from the water and the presence of hydrokinetic turbines in the water as shown on Figure 1.

Figure 1. Warning sign for RivGen® Power System at Igiugig, 2014

Inspection and Maintenance

The shore station will be inspected and maintained at regular maintenance intervals as described in the Inspection and Maintenance Plan. There will be a single cable running from each RivGen® device to shore. Each cable will be steel-armored and will carry: a three-phase AC power cable, a two-phase AC control power and data cable, and a fiber optic data cable. The two cables will run along the river bottom from each RivGen® device to a junction box on the unnamed island to the east of the deployment site. Near shore, the cables will be installed within articulated ductile iron pipe or similar to protect the cables from ice and debris.

The cables are rated for 1 kV. The cables will be buried at a depth of at least two ft at all feasible locations along the terrestrial cable route to prevent accidental contact with the cables from occurring. The cable will be inspected and maintained during regular project maintenance intervals, as described in the Inspection and Maintenance Plan. ORPC will work with IVC to develop Lock Out Tag Out (LOTO) procedures to insure components are de-energized during inspections and maintenance and all inspections and maintenance will be conducted by trained personnel.

1.2 Operations Monitoring

Over the course of the Project, IVC will monitor the operation of the RivGen® Power System in several ways. On the turbine generator units (TGUs), sensors will monitor water speed and direction, and turbine rotational speed. They will also detect leaks in sealed components including the generator, electronic cases, mechanical brake, and pontoon permanent buoyancy chambers. Inside the generator and electronics case, sensors will monitor power generation, current, rotational speed, temperature, relative humidity, and oil pressure. Data collected from these various sensors will be coordinated in the supervisory control and data acquisition (SCADA) system located in the shore station.

The shore station is located in a relatively accessible area near the village, and as such, will not be monitored on a 24-hour, continuous basis. Access to the shore station will be restricted via a lockable door to qualified personnel trained in safe use of the facility. The shore station will primarily serve as an interface between engineering and environmental monitoring equipment and will house a set of servers that collect and store data from Project operations monitoring. All of the Project data will be available and viewable across ORPC's company intranet and on a limited-access internet website. Control of the RivGen® Power System will be implementable locally at the shore station and remotely over the limited-access intranet. Fault conditions will generate alerts that will be logged on the data servers and displayed on the local and remote viewing consoles. Certain alerts will trigger automatic shutdown of the system. These shutdowns will be logged, and designated personnel will receive notifications by electronic mail or instant messaging. IVC designated personnel will be able to check the status and respond to the alerts via intranet or locally at the shore station.

1.3 Procedures Taken during an Emergency

When a shutdown notification is generated from a fault condition, personnel IVC designates to receive the alert will investigate the operation parameters of the RivGen® Power System through the intranet, through the limited access internet website, or at the shore station.

IVC designated personnel will assess the shutdown to determine if a safety issue has occurred. If so, the appropriate emergency response agencies will be contacted and IVC's safety officer will be informed. A list of emergency response agencies is included in Table 1. If necessary, the operation of the RivGen® Power System can be suspended remotely or from the shore station as described in the Emergency Shutdown Plan.

Once the operation of the RivGen® Power System has been stopped, the issue will be evaluated, and the appropriate action will be taken to mitigate the cause of the incident, including the possible decommissioning of the RivGen® Power System if there is a continued safety risk. If it is determined that further action is needed in addition to the shutdown of the RivGen® Power System, IVC will notify the appropriate response agencies. If it is determined that the RivGen® device and/or underwater cables need to be removed, IVC will follow the protocol outlined in the Project Removal and Site Restoration Plan.

Inspection and retrieval of deployed components of the RivGen® Power System will be coordinated by IVC.

Table 1. *Local and regional emergency response agencies.*

Agency	Contact Information
Igiugig Volunteer Fire Department	907-533-3211
Igiugig Public Safety Officer, State Trooper (King Salmon)	907-533-3211
Igiugig Village Council	907-533-3211
Igiugig Village Health Clinic	907-533-3207
Igiugig Electric Company	907-533-3211
Alaska Office of Environmental Policy and Compliance Anchorage Region	907-271-5011
Igiugig Village Response Team	907 533-3207
US Coast Guard, Sector Anchorage	907 428-4200

1.4 Reporting

Within one week of any incident that has caused a safety hazard, damage, or non-fatal injury to the public or their property, IVC will notify the Federal Energy Regulatory Commission (FERC), the Department of Energy, and other agencies and organizations as listed in Table 1. Within one month of any such incident, a written report will be issued detailing the incident including the sequence of events, the measures that have been taken to neutralize the cause of the incident, and a plan to prevent its future recurrence.

1.5 Contingency Measures

In accordance with FERC pilot project license requirements, the RivGen® Power System can be modified, shut down, or removed if it presents a hazard to public safety. The Project Removal and Site Restoration Plan describes the removal of the RivGen® Power System and subsequent restoration of the site.

1.6 Annual Testing of Emergency Equipment

Emergency procedures and equipment will be tested and documented annually. These include the fault condition notification procedure, and RivGen® Power System emergency shutdown procedures and equipment. IVC will coordinate testing with local public safety officials as listed in Table 1.

1.7 Annual Coordination with Response Agencies

IVC or its designee will inform emergency response agencies, as listed in Table 1, of the results of the annual safety protocol test, including any relevant changes or modifications to established emergency procedures.

In the event that a safety issue arises during the course of the Project, IVC will hold a workshop with local health and safety officials to discuss the issue and help prevent its recurrence. Whenever major changes to the Project and Public Safety Plan are implemented, IVC will meet with local health and safety officials to discuss the changes and their effect on public safety.

2.0 PROJECT REMOVAL AND SITE RESTORATION PLAN

2.1 Introduction

The purpose of the Project Removal and Site Restoration Plan is to describe: (1) procedures for removal of land-based Project facilities, including restoration measures for the disturbed land areas; (2) procedures for removal of underwater facilities; (3) provisions for monitoring the effects of the removal activities; (4) an implementation schedule that provides for all removal and restoration activities to be completed by no later than the expiration date of the license; and (5) a financial assurance plan.

2.2 Project Removal

Conditions requiring relocation or removal of Project components include an emergency, a FERC order, or the expiration of the pilot project license without the issuance of a standard license.

2.3 Removal of Land-Based Facilities

Shore Station

An 8 ft x 20 ft modular building will serve as the shore station for the Project. The shore station is located at the public fishing access area in Igiugig. It houses the power electronics and the SCADA system. The shore station is accessed via an existing road. The shore station is located approximately 30 m (100 ft) from riverbank and 213 m (700 ft) from the bank of the main channel of the Kvichak River. The location of the shore station is shown in Exhibit G. Plan and elevation views of the shore station are provided in Exhibit F.

The modular building and all project equipment will be removed from the site at the conclusion of the Project.

Cables

For each RivGen® device there will be a single cable running from each device to shore. Each cable will be steel armored and will a carry: a three-phase AC power cable, a two-phase AC control power and data cable, and a fiber optic data cable. The two cables will run along the river bottom from each RivGen® device to a junction box on the unnamed island to the east of the deployment site. Near shore, the cables will be installed within articulated ductile iron pipe or similar to protect the cables from ice and debris. The submerged cables will be deployed at approximately the same time as the RivGen® device.

From the junction box to the shore station there will be three separated cables for each TGU for a total of six cables. For each RivGen® device these are one three-phase export power cable, one stainless steel braid armored two-phase control and data cable, and one stainless steel braid armored fiber optic cable. Together these cables will comprise a bundle of six cables. The cable bundle will be buried from the junction box, across the island and backwater area, and up a trail to the shore station prior to the installation of the first RivGen® device.

The cables will be removed at the conclusion of the Project. The terrestrial portion of the cable corridor will be excavated, and the cables will be removed. The corridor will be back-filled with the excavated materials. The area will be returned to existing grade. The cables will be disposed of in an appropriate manner, including recycling if possible. The land where the cables were located is expected to revegetate naturally.

The underwater portions of the cable will be removed with terrestrial and marine equipment as needed to free the cables from the sediment and remove from the river. Terrestrial equipment will be located on the island or mainland to pull the cable free of the river, or as needed onboard the local barge if necessary. The cables will be disposed of in an appropriate manner, including recycling if possible. Some parts of the cables may be removed in sections and properly disposed of (including recycling if possible).

2.4 Removal of Underwater Facilities

The underwater portion of the RivGen® Power System includes a pontoon support structure which supports the TGU, electrical cabling, monitoring equipment, and mooring system consisting of a single anchor connected by chain and soft line for each RivGen® device.

One of the unique features of the RivGen® Power System is that the RivGen® device is essentially self-deploying and self-retrieving, using ballasting operated from a nearby vessel to submerge and retrieve it. Retrieval is done by filling the chambers with air and reversing the installation sequence. IVC expects to employ work boats and support vessels as needed for retrieval. The RivGen® device(s) will be removed in this manner.

The RivGen® mooring system will be removed following the removal of the RivGen® device(s). This will be conducted using marine equipment to pull the mooring system out of the water and deliver it shore.

2.5 Environmental Considerations

At the time of Project removal, IVC or its designee will consult with the appropriate regulatory agencies to obtain recent information on federally listed threatened and endangered species.

2.6 Implementation Schedule

IVC anticipates that it will take approximately 12 days to decommission and remove the Project. Seasonal conditions may prohibit removal until weather and safety allow proper removal. Crews will be able to work simultaneously to remove terrestrial and marine components of the Project. It is anticipated that it will take 5 days for removal of the shore station and terrestrial portion of the cables and will take 2 days to return the cable corridor to existing grade. Table 2 outlines the timeframe for the removal of each subsea Project component.

Table 2. *Timeframe for removal of components.*

Component	Time to Remove (days)
Underwater cables	2
RivGen® device (2)	5
Shore station and project equipment	5
Total	**12**

2.7 Financial Assurance Plan

Should it be necessary to relocate or remove the RivGen® Power System completely, IVC will commit to the financial and operational responsibility for full site restoration. IVC assures that, at least 90 days before commencing construction and installation of the Project, it will file proof of the purchase of a surety bond, or equivalent financial assurance instrument, to cover the pro rata portion of the costs of removing Project facilities and restoring the Project area in accordance with the Project Removal and Site Restoration Plan required by this pilot license and included in the final pilot project license application. During the term of the pilot project license, IVC will maintain the bond, or equivalent financial assurance for the removal of installed Project facilities and restoration of the site. By January 1 of each license year, or as otherwise directed by FERC or its authorized representative, IVC will file proof of the maintenance of the bond or equivalent financial assurance.

3.0 NAVIGATION SAFETY PLAN

3.1 Purpose

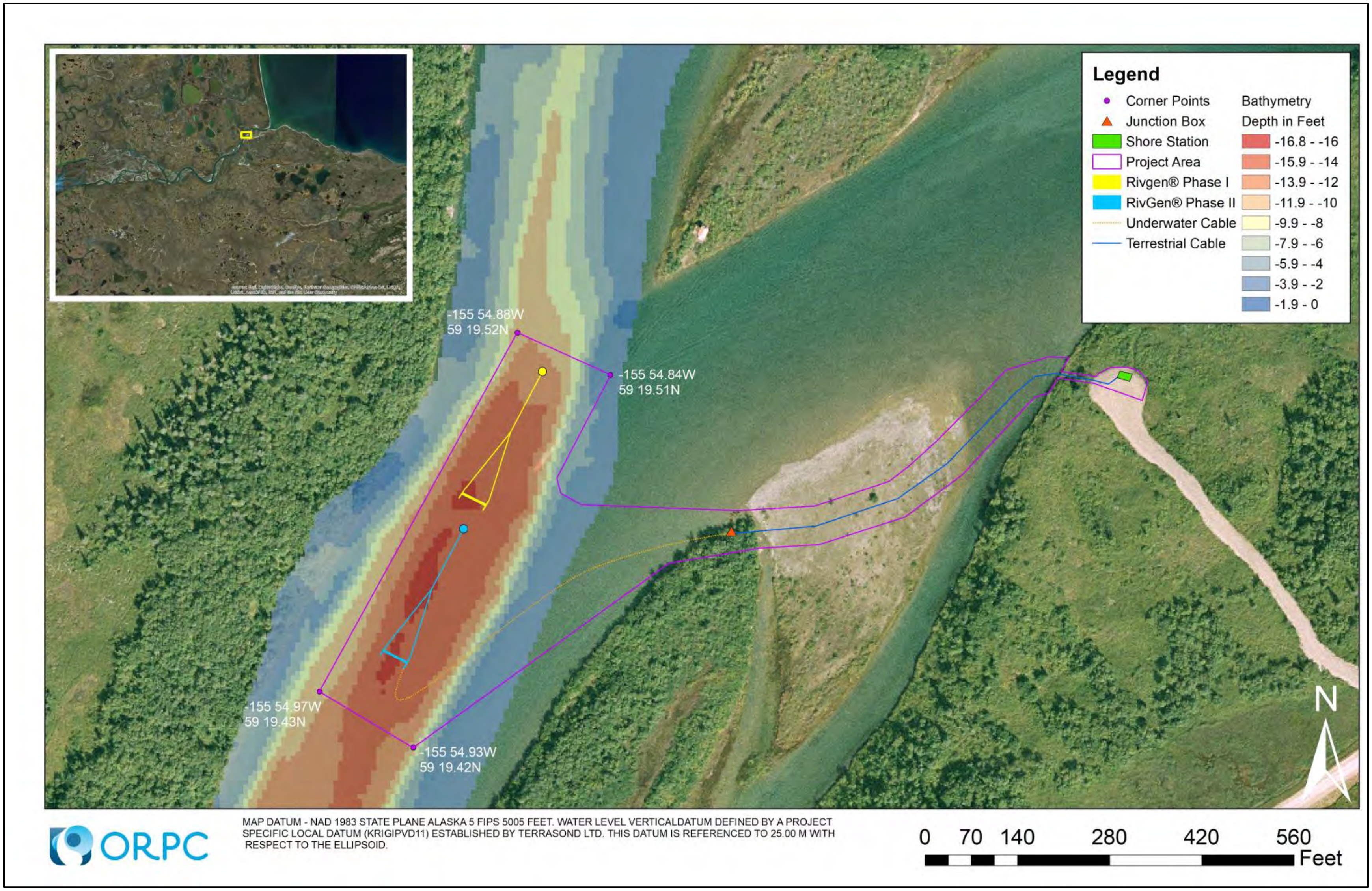
The Igiugig Village Council developed a Navigation Safety Plan for the purpose of protecting the public and the Igiugig Hydrokinetic Project facilities from events such as collisions between commercial and recreational vessels and in-water Project facilities; entanglement of fishing gear, anchors, or other underwater devices that may damage or become entangled with Project transmission, anchoring, and mooring lines; and electrocution.

A Navigation Safety Plan was previously prepared for the Anchorage Waterways Division of the United States Coast Guard (USCG) for 2014 and 2015 RivGen® Power System testing in Igiugig.

3.2 Proposed Project Area

The Kvichak River is a fast flowing and suitably deep river that is the primary outflow of Lake Iliamna, Alaska’s largest lake. Unlike most Alaskan rivers, the water in the Kvichak River is clear, allowing for visible inspection of the turbine during deployment and operations. Figure 2 shows the proposed Project infrastructure and river depth. Figures 3 shows the deployment of a RivGen® device in 2014.

Because there will be no Project equipment or appendages above the water surface, impact to the natural viewshed or hindrance to marine traffic is not anticipated, other than possible surface marker buoys. The area’s current marine traffic use consists primarily of recreational and subsistence fishing. Published cruising guides discourage recreational boaters from the area because of the river current velocity. Due to the remote river location and the extremely shallow braided portion of the Kvichak River downstream of Igiugig vessels in the area of the Project typically have a draft of 1 m (3 ft) or less.



MAP DATUM - NAD 1983 STATE PLANE ALASKA 5 FIPS 5005 FEET. WATER LEVEL VERTICALDATUM DEFINED BY A PROJECT SPECIFIC LOCAL DATUM (KRIGIPVD11) ESTABLISHED BY TERRASOND LTD. THIS DATUM IS REFERENCED TO 25.00 M WITH RESPECT TO THE ELLIPSOID.

Figure 2. Project location at Igiugig, Alaska. Source: ORPC

Figure 3: Deployment of the RivGen® 1.0 device on the Kvichak River in 2014

3.3 Proposed Technology

The ORPC RivGen® device (Figure 4) measures approximately 15.9 m long (52.2 ft) x 3.5 m high (11.5 ft) x 14.54 m wide (47.2 ft). The device is completely submersible and anchored to the riverbed at a prescribed depth below the water surface to avoid possible conflicts with surface navigation. For the installation in the Kvichak River, ORPC will deploy the RivGen® Power System on a relatively deep region of riverbed with depths ranging from 4.7 m and 5.8 m (15.4 ft to 19 ft). As proposed, the clearance of the top of the device will be at a depth of approximately 1-1.5 m (3-5 ft) or more feet below the river surface, which is a depth acceptable to local waterway users.

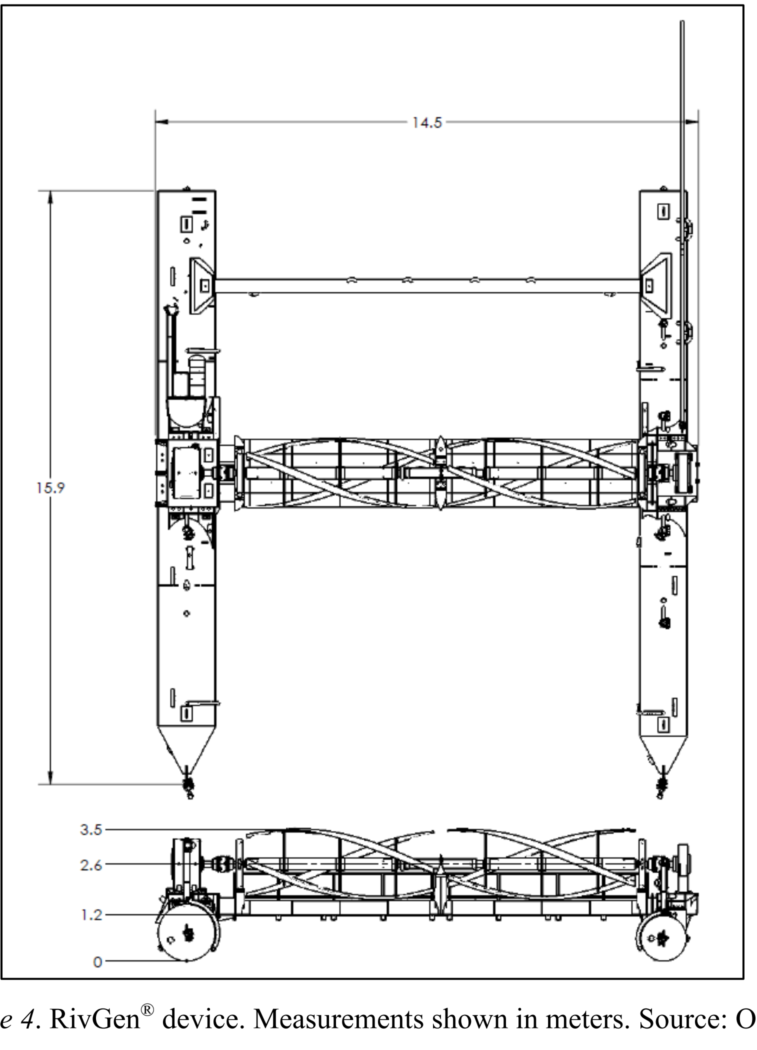


Figure 4. RivGen® device. Measurements shown in meters. Source: ORPC

3.4 Navigation Safety

Surface Buoys

The site, selected partially on recommendations from local officials and fishing interests, will be marked by three surface buoys at each RivGen® device when site conditions allow to notify mariners of it presence and gain public familiarity. The buoys will be removed prior to winter to avoid interactions with surface ice. ORPC proposes to use low drag or CC Polyform Buoys or similar due to the high river velocity and visibility.

On-shore Signage

The underwater power and data cable is unlikely to cause damage to or entanglement with vessels or equipment for several reasons. The cables will be armored, and terrestrial portion buried, and nearshore sections of the underwater cables may be placed in a heavy ductile iron conduit. Visible signs will be posted on shore indicating the shore-side exit of the cable from the water (Figure 1).

3.5 Reporting

Within 7 days of obtaining knowledge of any incident that has caused a hazard to navigation, IVC staff will notify the organizations and agencies listed in Table 3. Within one month of any such incident a written report will be issued detailing the incident, the measures that have been taken to neutralize its cause, and a plan to prevent its recurrence. The contact list will be reviewed and updated on a yearly basis by IVC.

Table 3. *Organizations and agencies receiving reports of navigation hazards.*

ORGANIZATION	CONTACT
Village of Igiugig	AlexAnna Salmon
United States Army Corps of Engineers	Jennifer Martin
United States Coast Guard, Sector Alaska	BMC James Doxtater

3.6 Consultations

IVC has been actively engaged in public outreach regarding the Project. Prior to the installation of the Project, IVC will hold a public meeting in Igiugig to describe the Project in detail including location, depth and associated navigational hazards. Additionally, at the start of the commercial fishing season, a navigation hazard message will be issued on marine radio.

4.0 EMERGENCY SHUTDOWN PLAN

4.1 Purpose

The purpose of the Emergency Shutdown Plan is to describe the methods and procedures required to cease Project operation in the event that doing so becomes necessary for the protection of the environment or the public. In the event of an emergency, rotation of the turbines will stop and the RivGen® Power System will no longer generate power.

4.2 Procedures Taken during an Emergency

When an alert is generated from a shutdown condition, personnel designated to receive the alert will investigate the operation parameters of the RivGen® Power System through the intranet, through the limited access internet website, or at the shore station. IVC personnel will assess the parameters to determine if a safety issue has occurred. If so, the appropriate emergency response agencies will be contacted. A list of emergency response agencies is included in Table 1. The Igiugig Electric Company will also be notified of any safety issue. If necessary, the operation of the RivGen® Power System can be suspended remotely or directly from the shore station.

4.3 Shutdown of the RivGen® Power System

IVC designated personnel will be able to shut down the RivGen® Power System by multiple means - through the intranet, through the limited access internet website, or at the shore station. If the SCADA system, which collects data on the operating conditions of the RivGen® Power System becomes non-functional an automatic shutdown will commence. In addition, manual shutdown can be implemented from the on-shore station by activating the emergency shutdown control signal to each of the TGUs. This can also occur by switching off the control power sent from the shore station to the central processing unit located in the electrical case below the permanent magnet generator of each TGU. In addition, if certain hardware failures occur, such as the severance of the underwater cable, the RivGen® Power System will automatically shut down due to the loss of control power.

Once the operation of the RivGen® Power System has been stopped, the issue will be evaluated, and the appropriate action will be taken to mitigate the cause of the issue, including the possible removal of the RivGen® Power System if it is deemed to pose a risk to public safety. If it is determined that further action is needed in addition to the shutdown of the RivGen® Power System, IVC or its designee will notify the appropriate response agencies as listed in Table 3. If it is determined that the RivGen® device and/or underwater cables need to be removed, IVC will follow the protocol outlined in the Project Removal and Site Restoration Plan.

Inspection and retrieval of deployed components of the RivGen® Power System will be coordinated by IVC's qualified personnel.

4.4 Reporting

IVC or its designee will report any Project-related conditions causing or that may cause injury or mortality to any federally listed threatened or endangered species under the Endangered Species Act (ESA) or marine mammal afforded protection under the Marine Mammal Protection Act (MMPA), and any other safety incidents affecting the environment or the public as soon as possible, but no longer than seven days after becoming aware of the threat or incident. IVC will report by telephone to FERC's Office of Energy Projects director and to the agencies listed in Table 4. The contact list will be reviewed and updated on a yearly basis.

Table 4. *Organizations receiving emergency reports.*

Organization	Contact
FERC	Dianne Rodman
Alaska Department of Natural Resources	Nikita Robinson
	Clifford Larson
Alaska Department of Fish & Game	Kate Harper
	Kevin Keith
National Oceanic and Atmospheric Association (NOAA)	Sue Walker
United States Fish and Wildlife Service	Kimberly Klein
United States Coast Guard	Casey Loken
United States Army Corps of Engineers	Jennifer Martin
Igiugig Native Corporation	Christina Salmon
Bristol Bay Native Corporation	Jason Metrokin
Bristol Bay Native Association	Ralph Andersen

Upon initial notification, IVC will consult with the office director and notified entities on the immediate course of action to take to prevent injury or minimize or eliminate the threat to the extent possible. IVC will propose to the office director immediate measures, based on consultation with the agencies and tribe(s), and implement such immediate measures as the office director so directs, which may include immediate shutdown of all Project operations.

No later than thirty days after becoming aware of any such threat or incident, or on any alternative schedule specified by the office director, IVC or its designee will file with FERC and submit to the aforementioned agencies and tribe(s) a written report on the condition affecting the ESA-listed or MMPA-protected species, other environmental resources, the public, or property. The written report, in addition to any information required by the office director at the time of initial contact, will include the following: (a) the location, date, time, and causes of the condition to the extent known; (b) a description of any unusual occurrences or operating conditions preceding the condition; (c) an account of any measure(s) taken to immediately alleviate the condition; (d) a description of any injuries or mortalities of the ESA-listed or MMPA-protected species, or any adverse effects on other environmental resources, the public, or property as applicable; (e) a description of the measures recommend by the agencies and tribe(s); and (f) a description of the measures or actions that would be taken to prevent further such occurrences.

ADAPTIVE MANAGEMENT PLAN

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511-002

November 15, 2018

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613-4008
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PART 1. INTRODUCTION TO ADAPTIVE MANAGEMENT

A. Purpose

This Adaptive Management Plan (AMP) was developed for the Federal Energy Regulatory Commission's (FERC's) pilot project license application (P-13511) for Igiugig Village Council's (IVC's) Igiugig Hydrokinetic Project (Project). The AMP is an essential part of IVC's implementation of the Project and provides a strategy for achieving the Project's objectives. The AMP reflects the implementation of a similar AMP for Ocean Renewable Power Company's (ORPC's) Cobscook Bay Tidal Energy Project (P-12711), which has been upheld as an industry model and incorporates a collaborative approach that has been integral to the project since its beginning (ORPC Maine, 2012).

The collaborative approach that was adopted for this AMP was first discussed during a regulatory stakeholder meeting held on January 23, 2013 as part of Alaska Energy Authority's River In-Stream Energy Conversion (RISEC) project. The RISEC project culminated with the testing of ORPC's RivGen® Power System at the Project site in 2014.

The AMP recognizes that many scientific uncertainties exist and that environmental conditions constantly change. It, therefore, is designed to be modified within the Project time line and acknowledges that elements such as key environmental uncertainties, applied studies, and institutional structure may evolve over time.

Part 1 of the AMP gives the rationale for utilizing adaptive management for the Project. Part 2 describes the Fish Monitoring Plan, which has a data collection approach based on monitoring, applied scientific studies, and management targets that will provide data for management response. Part 3 describes the proposed organizational structure and protocols by which Project managers, regulatory agencies, scientists, and stakeholders will work together for effective adaptive management decision-making. The comprehensiveness of this approach will provide direction for the Project based on the best current information. Part 4 includes references that were consulted in preparing the AMP.

B. Project Background

IVC is applying to FERC for a hydrokinetic pilot project license for the Igiugig Hydrokinetic Project. The Project is located in the Kvichak River at Igiugig, Alaska (Figure 1). The Project will be carried out in two separate phases over an expected ten-year pilot project license term. In Phase I, IVC will install and monitor a single-device (figure 2) ORPC RivGen® Power System for an initial period of up to 12 months. In Phase II, after operating and monitoring this initial power system, IVC will decide whether to install the second RivGen® device to create a two-device RivGen® Power System. Electricity generated by the Project will be delivered by an underwater cable to a shore station in Igiugig, Alaska, where it will be power-conditioned and connected to the power grid operated by the Igiugig Electric Company.

The Project will deploy the ORPC RivGen® Power System, a proprietary power system designed to generate electricity at river sites with water depths of up to 10 m (32.8 ft) and to connect directly into an existing diesel-powered microgrid. The RivGen® Power System will be powered by the turbine generator unit (TGU). The TGU will rest on a buoyant pontoon support structure, allowing the RivGen® device to be floated to the project site. At the Project site, the RivGen® device will be connected to a mooring system and ballasted so that it submerges and settles on the river bottom. Retrieval of the device will be accomplished by deballasting the pontoons with an external supply of compressed air. The RivGen® device is essentially self-deploying, and installation will only require commonly available vessels and minimal construction equipment. Components of the RivGen® Power System are compactly sized to travel to remote sites where they can easily be assembled on shore near the Project site.

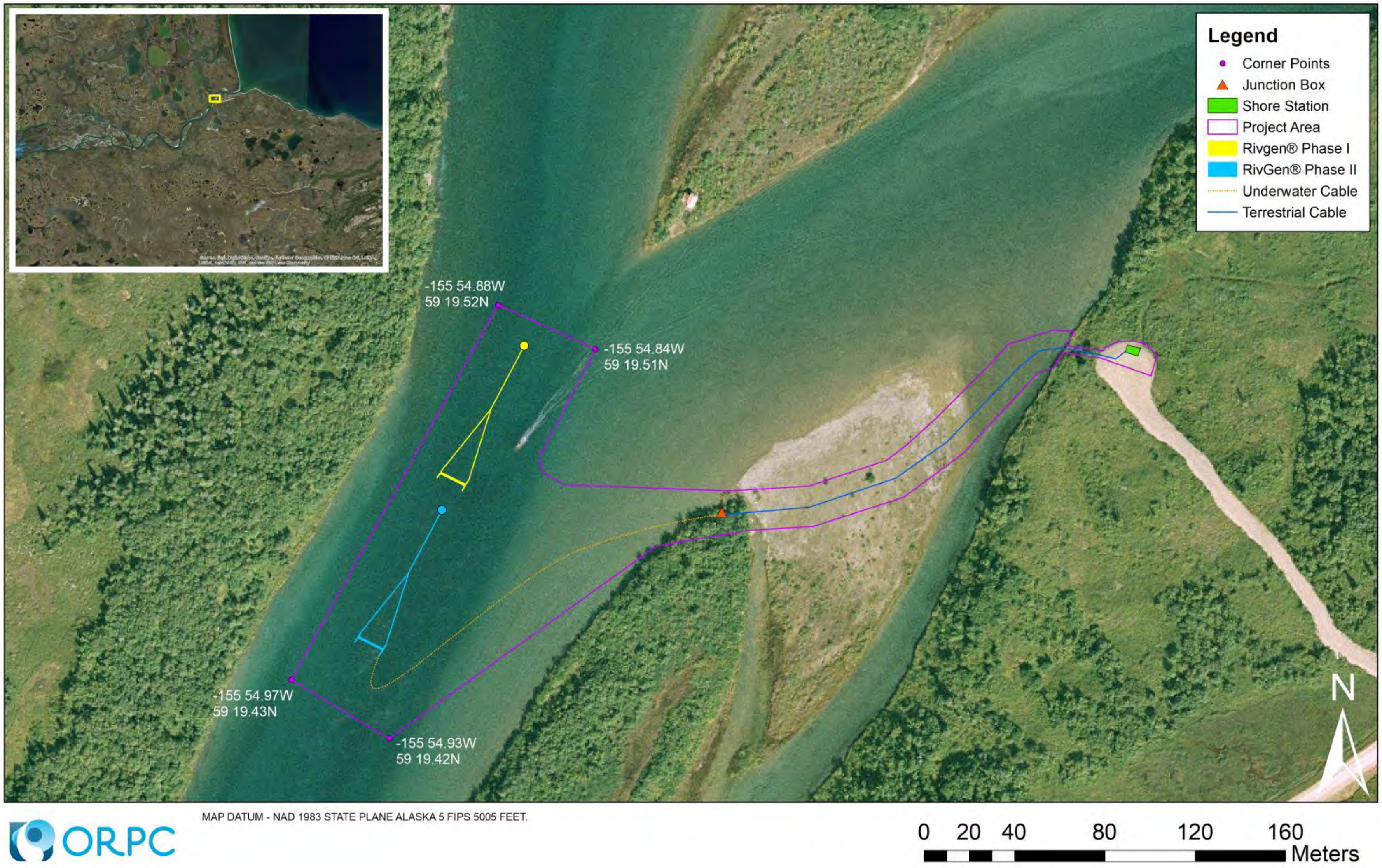


Figure 1. Project layout showing the location of the RivGen® Power System (Phase I) and addition of a second RivGen® device (Phase II).

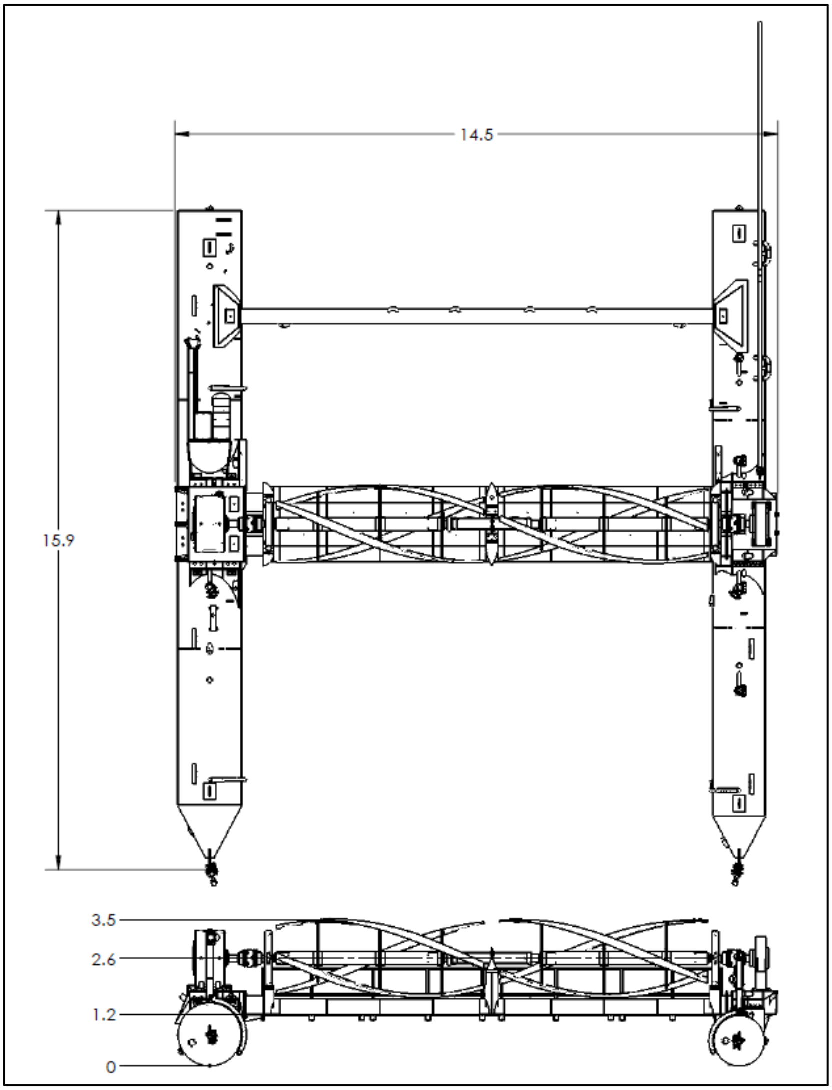


Figure 2. RivGen® 2.0 device. Measurements shown in meters. Source: ORPC

FERC Final Pilot License Application

IVC consulted with federal and state resource agencies and stakeholders to develop comprehensive environmental study plans to monitor the RivGen® Power System and surrounding environment at the Project site in 2014 and again in 2015. ORPC, on behalf of IVC and in collaboration with technical experts, drafted environmental monitoring plans, held workshops and conference calls with resource agencies and stakeholders to discuss and resolve comments on the plans. The Fish Monitoring Plan for this FERC Final Pilot License Application incorporates lessons learned from 2015 monitoring of the deployed RivGen® Power System in Igiugig, subsequent data analysis and development of automation techniques by the Pacific Northwest National Laboratory (PNNL), and continued analysis of effects from ORPC's TidGen® Power System previously deployed in Cobscook Bay, Maine. IVC and ORPC are committed to present the data and reports to federal and state resource agencies with recommendations on modifications of the methods to improve the scientific knowledge on all impacts of the Project during Phase I of deployment.

Consultation has occurred with the following federal and state agencies regarding RivGen® Power System testing and installation on the Kvichak River:

- Federal Energy Regulatory Commission
- U.S. Army Corps of Engineers
- NOAA National Marine Fisheries Service
- U.S Fish & Wildlife Service
- U.S. Coast Guard
- Alaska Department of Fish and Game (ADF&G)
- Alaska Department of Natural Resources

C. Adaptive Management Defined

Given the collaborative approach that has evolved over several years in developing IVC's Igiugig Hydrokinetic Project, as well as ORPC's experience related to the Cobscook Bay Tidal Energy Project, adaptive management is defined here as *a collaborative, consultative process among Project owners and management, state and federal agencies, and stakeholders that monitors and reviews the results of policies, Project actions and environmental data, and integrates this new learning into policy and management actions, adapting as necessary*. In this approach, policy and management actions are viewed as scientific experiments that are conducted among scientists, managers, and other stakeholders on key policy decisions. This concept is important because the environmental outcomes of management policies are often uncertain. To be effective, decision-making processes are flexible and are designed to be adjusted in the face of uncertainties as outcomes from management actions and other events are better understood.

D. Adaptive Management Plan Objectives

The Project's AMP is structured in a manner that is consistent with the processes and relationships that IVC and its representatives have developed with regulatory agencies and project stakeholders throughout permitting efforts.

The objectives of the Project's Adaptive Management Plan include the following:

- Generate science-based information for managers, agencies, and stakeholders

- Establish a mechanism to assess the effectiveness of environmental studies and monitoring plans included in the FERC pilot project license
- Provide guidance on changes to monitoring requirements, including scope, frequency, and targets
- Communicate effectively IVC and agency recommendations for changes to the FERC pilot project license
- Convert information into effective management decisions
- Involve the public to help provide management direction
- Store and organize information for use by management and the public
- Include the results of environmental studies associated with hydrokinetic projects from around the world

PART 2. PLANNING PHASE: MONITORING

IVC and its representatives have worked with federal and state agencies, scientists, and local stakeholders to lay the groundwork for adaptive management during the Project's implementation and operation. Environmental studies and monitoring plans were subsequently prepared based on these consultations and included data collection approaches, monitoring, and applied studies from the scientific community. The development of these plans laid the foundation for an adaptive management approach to hydrokinetic monitoring. The monitoring plans' objectives are repeated here:

Fish Monitoring Plan

The Project will install a RivGen® Power System in phases at the same site on the Kvichak River where RivGen® Power Systems were installed in 2014 and 2015. Installation entails deploying the device(s) on the river bed, where water current will rotate a pair of turbines to generate hydroelectric power. This is a relatively new technology that is still in the demonstration phase with few comparable attempts in Alaska. LGL reported results of the fish and wildlife monitoring conducted during the 2014 demonstration season and 2015 operations (Nemeth, Priest, & Patterson, 2014). The Pacific Northwest National Laboratory also conducted data analysis on the video collected in 2015 and developed automation techniques that have been incorporated into the Fish Monitoring Plan.

The overall goal of the Fish Monitoring Plan is to monitor the RivGen® device for potential fish interactions to inform the regulatory process and provide the basis for future modifications based on observed effects. The specific objectives are as follows:

1. Document the presence and timing of fish at the RivGen® device by species and life stage

2. Characterize fish movements past the RivGen® device during the sockeye salmon smolt out migration
3. Describe the behavioral response of sockeye salmon smolt that comes into the vicinity of the RivGen® device
4. Describe any observable acute effects from contact with the RivGen® device, including disorientation, injury, or mortality during the sockeye salmon smolt out migration

2015 Monitoring

In 2015, fish and wildlife monitoring was performed by LGL, in accordance with the 2015 Monitoring Plan and ADF&G Fish Habitat Permit FH 15-II-0038. The RivGen® was deployed from approximately July 10, 2015 through September 15, 2015, which overlapped with part of the migration of adult salmon and rainbow trout, among other species. This time period did not overlap with the main migration timing of juvenile sockeye salmon, which migrate annually downstream from approximately May 21 through June 10.

Fish movements at the RivGen® device were described using video footage collected from five underwater cameras mounted to the power system pontoons. Video footage was collected 24 hours/day July 19-25, 2015, and again August 19-27, 2015; review was done by watching the first ten minutes of a selected hour from each of the four primary cameras (the fifth camera was a backup). Spatially, the camera field of view captured the port side of the RivGen® device, including upstream and downstream views of the port side turbine (only, due to reduced visibility from variable river turbidity of the starboard side turbine). In accordance with the 2015 Monitoring Plan, footage was reviewed to achieve partial temporal coverage during different categories of turbine operating status and daytime/nighttime conditions. At night, two underwater lights lit the viewing area. In addition, bird and marine mammal surveys were conducted for 15 minutes each morning of monitoring. Methods and the overall approach were similar to those described for the demonstration study conducted at the same site in 2014.

Blocks of video footage from portions of 238 different hours were reviewed in season in 2015. There were 359 events with fish, composed of approximately 1,202 individual fish from at least six species. Most fish observations were of solitary fish; the largest school was approximately 100 fish. Species composition varied from July to August and from day to night. Salmon smolt were almost exclusively seen at night and were more prevalent in July than August. Several instances of fish moving through the RivGen® turbine were noted and reported in season as part of the Project's adaptive management process. LGL did not detect any obvious physical injuries to fish and saw no altered behavior by wildlife near the

RivGen® device. Cameras, lights, and power system components all operated reliably. All video footage was archived.

PNNL Monitoring Analysis

Video data collected as part of the 2015 RivGen® Power System monitoring provided a valuable opportunity for further analysis to better quantify interactions between fish and the turbine. As a result, DOE commissioned PNNL to conduct data analysis and to develop potential automation techniques for future monitoring. The goal of PNNL's analysis of video data collected around ORPC's RivGen® device deployed in the Kvichak River during July and August 2015 was to gain an understanding of the implications of using underwater video cameras as a fish monitoring technique. The data were analyzed manually and used to develop automated algorithms for detecting fish in the video frames and describing their interaction behavior relative to the device. In addition, PNNL researchers developed a web application, EyeSea, to combine manual and automated processing, so that ultimately the automated algorithms could be used to identify where human analysis was needed (i.e., when fish are present in video frames).

The manual analysis began to look at all data from the start of deployment of the RivGen® device, primarily using video from Camera 2 that looked directly at the upstream side of the turbine, so any interaction could be identified; this was to ensure rare events were seen, and initially focused on nighttime data when more fish were present. This process highlighted the amount of time it takes to identify fish, and ultimately only 42.33 hours of video were reviewed because of the time-consuming analysis. The data were classified as "Fish" when the reviewer was confident it was a fish, and "Maybe" is defined by an object that during manual analysis is deemed to possibly be a fish, but not a definite identification. The two classes were distinguished based on the movement, shape, and color characteristics. Fish events were further classified by "adult", "juvenile", or "unidentifiable" age. Behavioral attributes were noted and were broadly divided into Passive and Avoidance activities. In over 42 hours of the data reviewed, there were 20 potential contact interactions, of which three were "Maybe" classifications, 12 were juveniles, and 5 were adults. While only 11.5 percent of the video data were analyzed from Camera 2, these results are from the time when most fish were present over the turbine deployment period (ADF&G data) and provide preliminary evidence that fish strike or collision of fish in the Kvichak River with an instream turbine is rare.

PART 3. PROPOSED ORGANIZATIONAL STRUCTURE AND PROTOCOLS

A. FERC License Articles

This Adaptive Management Plan has been prepared in anticipation of a FERC pilot project license article, which specifically requires an AMP Plan. As an example, ORPC's Cobscook Bay Tidal Energy Project FERC license article required the following:

> *The plan shall include: 1) protocols for consultation with federal and state agencies on preliminary results of monitoring studies and any necessary modifications, with documentation of consultation and any recommended or proposed modification included in each environmental monitoring plan report filed with the Commission; 2) the allowance for minor modifications (i.e. location, frequency) to the monitoring plans without prior Commission approval in cases where all consulted entities are in agreement, with modifications and the record of consultation included in the required reports of the affected monitoring plans; 3) the allowance for major modifications (i.e. termination of monitoring, change in reporting schedule) to the monitoring plans upon Commission approval; and 4) a provision for consultation and Commission approval on the effectiveness of the monitoring and the operation of the project in Phase 1 prior to commencing with Phase 2 deployment.*

B. Organization

An Adaptive Management Team is proposed to implement the AMP. The Adaptive Management Team for the Project is identified in Table 1.

Agencies

The Adaptive Management Team will have representatives from federal and state agencies and may include the following:

- U.S. Fish and Wildlife Service
- National Marine Fisheries Service
- U.S. Coast Guard
- U.S. Army Corps of Engineers
- Alaska Department of Fish and Game
- Alaska Department of Natural Resources
- Alaska Department of Environmental Conservation

Project Owner

The Adaptive Management Team will also include representatives from the Igiugig Village Council or their designee.

Project Stakeholders

The Adaptive Management Team will identify key project stakeholders who may include representatives from the following:

- Native tribes
- Commercial or recreational fishing associations
- Local resource agencies
- Borough officials

The Adaptive Management Team will have the ability to add or remove members as it sees appropriate.

Table 1. *Adaptive Management Team*

ORGANIZATION	ROLE	RESPONSIBILITY
IVC or designee	Project Owner	Communication
U.S. Fish & Wildlife Service	Federal Regulator	Compliance with established regulations
National Marine Fisheries Service	Federal Regulator	Compliance with established regulations
U.S. Coast Guard	Federal Regulator	Compliance with established regulations
U.S. Army Corps of Engineers	Federal Regulator	Compliance with established regulations
Alaska Department of Fish and Game	State Regulator	Compliance with established regulations
Alaska Department of Natural Resources	State Regulator	Compliance with established regulations
Alaska Department of Environmental Conservation	State Regulator	Compliance with established regulations
ORPC	Project Developer	Advisory
University of Alaska Fairbanks	Technical Advisor	Advisory

C. Communications

IVC or its designee is responsible for disseminating information to the Adaptive Management Team, agencies, stakeholders, and the public at large via appropriate delivery systems (at the Adaptive Management Team direction).

D. Consultation Protocols

Protocols will be established for consultation with federal and state agencies on preliminary results of monitoring studies and any necessary modifications, with documentation of consultation and any recommended or proposed modification included in each environmental monitoring plan report filed with the Commission.

Project protocols for consultation will include the following:

- The Adaptive Management Team, whose membership is described above, will meet annually at a minimum for the first several years of the Project. Additional details of meeting content and frequency will be determined by the Adaptive Management Team.
- The purpose of Adaptive Management Team meetings is to consult on the results of the environmental monitoring plans, and scientifically based recommendations from IVC, advisors, and agencies.
- The Adaptive Management Team will support the common goal of delivering a sound and effective environmental monitoring assessment of the Project.
- The Adaptive Management Team will be copied on all relevant communication regarding the monitoring outputs and program results.
- IVC, in collaboration with its technical advisors, will make recommendations on necessary modifications to the environmental monitoring plans to the Adaptive Management Team for concurrence or comment based on scientist input and consultation with the jurisdictional regulator. The modification process shall be utilized by IVC in response to unforeseen or unanticipated actions or results during the operation of the Pilot Project.
- IVC or its designee will document the consultations and modifications and disseminate among the Team.
- IVC or its designee will file the Adaptive Management Team consultations and modifications with FERC following each annual meeting and disseminate to stakeholders.
- The Adaptive Management Team will contribute to the FERC annual report that summarizes data and recommended or approved changes and will distribute the annual report to the public.
- The annual report will include inputs from the local community as well as other stakeholders.
- Additional membership to the Adaptive Management Team will be the decision of all members of the Adaptive Management Team before permission is granted.

E. Minor Modification Allowances

Article 404 of ORPC's FERC pilot project license (P-12711.005) allowed minor modifications of the AMP:

> *The allowance for minor modifications (i.e., location, frequency) to the monitoring plans without prior Commission approval in cases where all consulted entities are in agreement, with modifications and the record of consultation included in the required reports of the affected monitoring plans*

Following this precedent, IVC will utilize the following protocols to make minor modifications to monitoring plan methods, schedules, and parameters without prior Commission approval based on the following:

- Adaptive Management Team members agree (documented) by consensus.
- Description of modifications and the record of consultation are documented in the required reports of the affected monitoring plans.
- Communication of intent and scope will be made with FERC's Compliance Division as the situation develops that may require a minor license modification.

F. Major Modification Allowances

Major modifications (i.e., termination of monitoring and change in reporting schedule) to the monitoring plans are allowed upon FERC approval under the hydrokinetic pilot license. Because there is a potential for public review and comments, major modifications will require the following prior to seeking Commission approval:

- Consulting agencies must review and comment. Then the Adaptive Management Team will submit the proposed changes to FERC so that the 30-day comment period can be published, and comments can be considered prior to the Major modification.
- Scientifically based tools to substantiate the changes
- Data based
- Scientifically proven acceptance

G. Consultation and Commission Approval

Provisions for consultation and Commission approval on the effectiveness of the monitoring and the operation of the project in Phase I will be provided prior to commencing with Phase II deployment.

Since the inception of the Project, IVC has worked collaboratively and in consultation with state and federal regulatory agencies, scientists and stakeholders. IVC has confidence in this group to provide sound and effective environmental monitoring assessments and will apply this same structure for consultation on the effectiveness of the Project's Phase I monitoring and operation when seeking Commission approval to proceed to Phase II.

The process for determining a decision to commence Phase II will include the following:

- The Adaptive Management Team will first make the recommendation to proceed/not proceed to Phase II.
- Agencies with standing membership on the Adaptive Management Team will have a vote.
- Other agencies will provide input.
- The Adaptive Management Team will submit a notice to FERC with their recommendation.
- The Adaptive Management Team notice will reflect the need for adaptability to the Project's next phase of operation.

H. Dispute Resolution

The Adaptive Management Team will decide at its first meeting how it will seek dispute resolution. The working relationships IVC and ORPC have developed to date through the 2014 and 2015 deployments at the Project site has been very effective. IVC, therefore, expects agencies with jurisdiction pertaining to specific environmental aspects of the project will continue to have final approval of any modifications to the monitoring programs.

PART 4. REFERENCES

ORPC Maine. (2012). Cobscook Bay Tidal Energy Project (P-12711), *Adaptive Management Plan*, May 21, 2012.

Nemeth, M.J., Priest, J.T. & Patterson, H.M. (2014). Assessment of fish and wildlife presence near two river instream energy conversion devices in the Kvichak River, Alaska in 2014. Final report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, for Gray Stassel Engineering, Anchorage, AK.

ORPC
OCEAN RENEWABLE
POWER COMPANY

FISH MONITORING PLAN

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511-002

November 15, 2018

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613-4008
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 GENERAL DESCRIPTION OF THE IGIUGIG HYDROKINETIC PROJECT

Igiugig Village Council (IVC) is applying to the Federal Energy Regulatory Commission (FERC) for an original hydrokinetic pilot project license for the Igiugig Hydrokinetic Project (Project), P-13511-001. The Project is located in the Kvichak River at Igiugig, Alaska (Figure 1). The Project will be carried out in two separate phases over an expected ten-year pilot project license term. In Phase I, IVC will install and monitor a single-device Ocean Renewable Power Company, Inc. (ORPC) RivGen® Power System for an initial period of 12 months (Figure 2). In Phase II, after operating and monitoring this initial power system for one year, IVC will decide whether to install the second RivGen® device to create a two-device RivGen® Power System. Electricity generated by the Project will be delivered by an underwater power cable to a shore station in Igiugig, Alaska, where it will be power-conditioned and connected to the power plant owned by the Igiugig Electric Company.

The Project will deploy the ORPC RivGen® Power System, the proprietary energy power system designed to generate electricity at river sites with water depths of 5 m (16.4 ft) or more and to connect directly into an existing diesel-powered micro-grid (Figure 2 and Figure 3). The RivGen® Power System is powered by the turbine generator unit (TGU).

Figure 1. The Project layout showing the location of the RivGen® Power System (Phase I) and the addition of the second RivGen® device (Phase II).

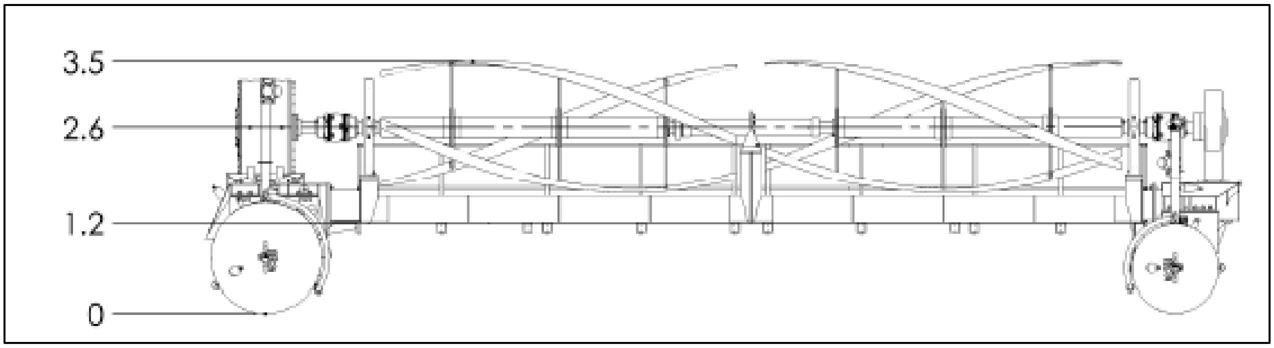


Figure 2: RivGen® device (profile view). Dimensions in meters. Source: ORPC

ORPC designed the RivGen® Power System to generate electricity at river sites with water depths of 5 m (16.4 ft) or more and connect directly into an existing diesel-powered microgrid. The RivGen® Power System is powered by the TGU. The TGU rests on a buoyant pontoon support structure frame, allowing the RivGen® Power System to be floated to the project site. Once anchored at the Project site, the RivGen® device is ballasted so that it submerges and settles on the river bottom. As a result, the RivGen® Power System is essentially self-deploying, and installation requires only commonly available vessels and minimal construction equipment. All components of the RivGen® Power System are compactly sized to travel to remote sites where they can easily be assembled on shore near the Project site.

ORPC power systems are designed around the proprietary turbine generator unit, or TGU. The TGU is made up of ORPC's proprietary advanced design cross-flow (ADCF) turbines, with slowly rotating foils that extract energy from moving water to power a central underwater permanent magnet generator. The ADCF turbines are fabricated to resist corrosion. The TGU includes a fairing system to increase the overall capture area of the RivGen® turbines and accelerate the flow entering the power generating portion of a foil's rotation.

The TGU has a rated capacity of 35 kW at 2.25 meters per second (m/s). ORPC has used empirical data and existing literature data of the annual flows in the Kvichak River to estimate the Project's annual electrical generation. The methods used for estimating annual generation are described in Section A.1.5. Exhibit F drawings (F-1 through F-6) show the placement of the TGU on the pontoon support structure, the dimensions of the TGU, and the height of the TGU above the riverbed. In addition, Exhibit F includes construction drawings, which include existing Project structures, including the shore station, buried transmission cable between the shore station and diesel microgrid, and the associated step-up transformer.

The RivGen® device measures approximately 15.8 m (51.8 ft) long x 3.5 m (11.5 ft) high x 14.4 m (47 ft) wide. The chassis sits on the pontoon structure of the TGU which is 1.2 m (4 ft) off the river bottom. The total weight of the TGU is approximately 26,000 kg (57,320 lbs).

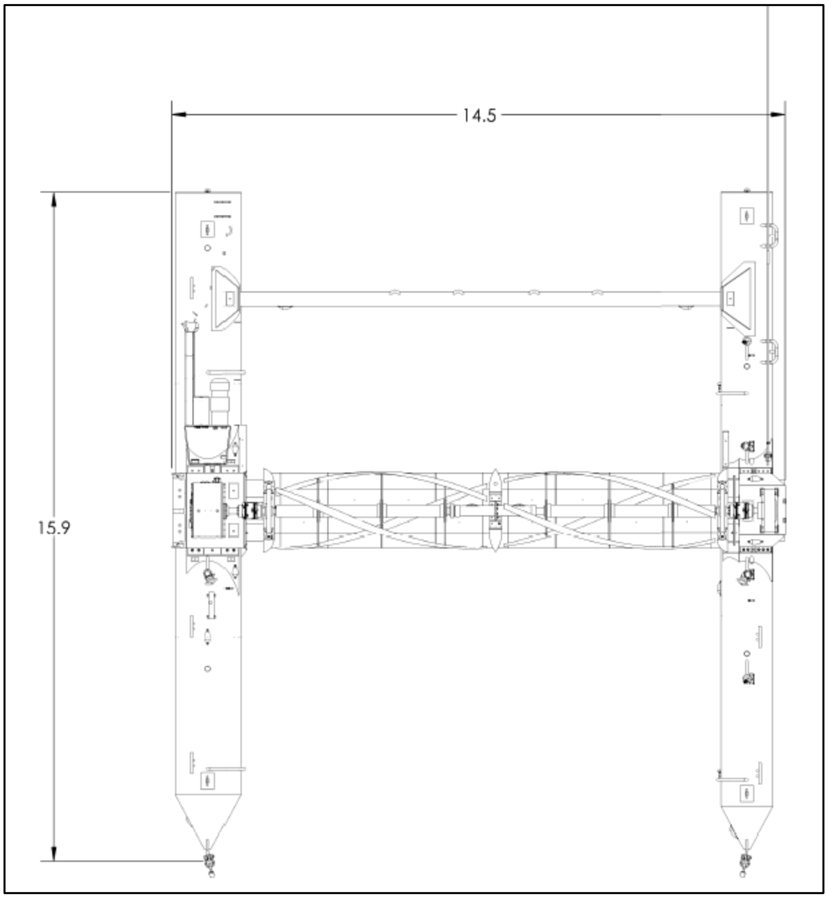


Figure 3. RivGen® device (top view). Dimensions in meters. Source: ORPC

1.2 PILOT LICENSING PROCESS

The purpose of the Project is to study the installation of ORPC's RivGen® Power System and its effect on the Kvichak River environment. FERC's pilot licensing program has been designed to support the advancement and orderly development of innovative hydrokinetic technologies for projects that are small, short-term, removable and carefully monitored. The purposes of FERC's pilot license program are to test new hydrokinetic technologies, determine the appropriate sites for hydrokinetic projects, and collect information on the environmental and other effects of these new generating devices.

The concept of adaptive management is foundational to ORPC's study plan development. As stated by FERC (2006), "adjustments to measures required during the license term will be based on information gleaned from ongoing monitoring or other post-license studies." ORPC believes that given the uncertainty associated with the relatively new pilot project process, the ability to adjust monitoring studies through adaptive management, based on experienced gained through the Project, allows for more effective studies. ORPC is proposing the adaptive management approach as the most responsible path forward for this Project, considering the available ecological and environmental data. This approach is also more appropriate to the pilot project license program's goals and objectives than attempting to finalize each study plan prior to deploying the Project's first phase. A Project Adaptive Management Plan is included in Appendix A of the final pilot license application (FPLA).

For the purposes of monitoring fish interactions with the RivGen® Power System, the proposed video monitoring system was developed under guidance from researchers at the Pacific Northwest National Laboratory (PNNL), University of Alaska Fairbanks (UAF), and University of Washington (UW). It was informed by previous monitoring work performed by LGL Alaska Research Associates, Inc. (LGL). Fish presence, behavior, and potential effects from the devices will be evaluated. Monitoring will be implemented with consideration of the anticipated fish species, specifically, sockeye salmon smolt, and the unique physical characteristics of the device to ensure adequate monitoring.

2.0 GOALS AND OBJECTIVES

The Project will install a two-device RivGen® Power System in phases at the same site on the Kvichak River where RivGen® Power Systems were installed in 2014 and 2015. Installation entails deploying the device(s) on the river bed, where water current will rotate a pair of turbines to generate hydroelectric power. This is a relatively new technology that is still in the demonstration phase, with few comparable attempts in Alaska. LGL reported results of the fish and wildlife monitoring conducted during the 2014 demonstration season and 2015 operations (Attachment 1). The Pacific Northwest National Laboratory also conducted data analysis on the video collected in 2015 (Attachment 2).

The overall goal of this Plan is to monitor the RivGen® device for potential fish interactions for one year to inform the regulatory process and provide the basis for future modifications based on observed effects. After collecting monitoring data for a year, IVC will convene a meeting with the Adaptive Management Team (outlined in the Adaptive Management Plan) to collectively evaluate fish monitoring data and adjust future monitoring efforts based on known effects. The specific objectives are as follows:

1. Document the presence and timing of fishes at the RivGen® device by species and life stage
2. Characterize salmon movements past the RivGen® device during migration periods
3. Describe the behavioral response of salmon that come into the vicinity of the RivGen® device
4. Describe any observable acute effects from contact with the RivGen® device, including disorientation, injury, or mortality during salmon migrations

3.0 STUDY AREA

The RivGen® Power System will be deployed on the Kvichak River near the village of Igiugig, Alaska. Igiugig is at the outlet of Lake Iliamna, approximately 60 river miles upstream from where the Kvichak River empties into Bristol Bay. The RivGen® Power System will operate at the site of previous deployments, with coordinates of -155.9150 and 59.3247. At this site, water depth is approximately 5 m, the river width is approximately 128 m, substrate is scoured cobbles and gravel, and the maximum current velocity in the center of the channel is approximately 2.5 m/s (Thomson, Kilcher, & Polagye, 2014). The site is just downstream from Fly Island and about 100 ft from the right bank (facing downstream) in a part of the river that is deep and has high water velocity. The selected site is near Site 10 as described by TerraSond in 2011, whose surveys included measurements of hydrology characteristics, including bathymetry and current velocities throughout the immediate area (Figure 1).

4.0 BACKGROUND AND RELEVENT INFORMATION

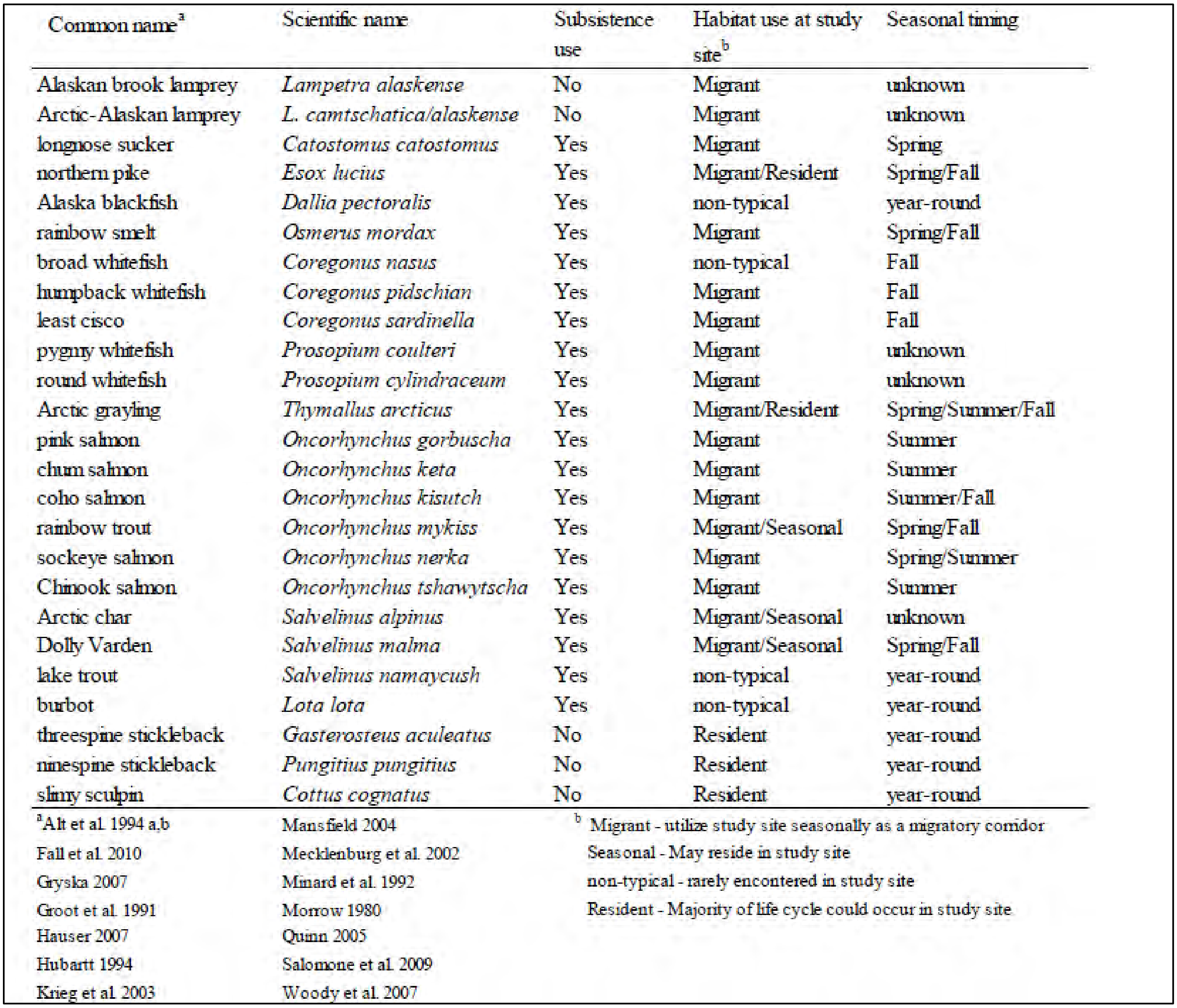
4.1 RESOURCE DISCUSSION

Fish Species Composition

Approximately 25 species of fish are known to inhabit the Kvichak River, including all five species of Pacific salmon (*Oncorhynchus* spp.) found in Alaska (Table 1). Most, though likely not all, are present near Igiugig at some point during the year, either as year-round resident species or as migratory species that pass through seasonally en route to spawning or feeding locations. Many species are harvested in two Igiugig fisheries (subsistence and recreational); salmon may also be harvested in a third fishery (commercial) downstream in Bristol Bay. The Alaska Department of Fish and Game (ADF&G) manages all fish species taken in each of these three fisheries.

Fish species in the Kvichak River that have the potential to be observed near Igiugig are presented in Table 1. Each species has its own unique aspects of timing and behavior that influence the likelihood for encountering or being affected by the RivGen® device(s). Table 2 shows anticipated seasonal presence of selected fish species near Igiugig. In general, fishes that are found in the study area use this stretch of river as a corridor for migration among over-wintering, feeding and spawning grounds. Fishes locate themselves in the river according to preferred habitat characteristics such as water flow and food availability. Adult and juvenile fishes tend to be located in environments where they have relatively low energy expenditure and high food intake. Therefore, typical preference in a river for holding or migrating is near the bottom, along the shores, and behind relatively large structures such as boulders. In this regard, adult fishes are expected to avoid the higher energy portion of the river. Juvenile salmon migrating downstream to the ocean, conversely, often choose the high energy environments (surface, thalweg, and no structure) where they can swim with the water flow and conserve internal energy. Therefore, the location of the RivGen® device(s) in the thalweg of the river makes it more likely to encounter downstream-migrating fish (such as juvenile sockeye salmon) than upstream-migrating fish (such as adult salmon). Further details are provided in subsequent parts of this section for high priority species.

Table 1. *List of Fish Species in the Kvichak River*



Common name[a]	Scientific name	Subsistence use	Habitat use at study site[b]	Seasonal timing
Alaskan brook lamprey	*Lampetra alaskense*	No	Migrant	unknown
Arctic-Alaskan lamprey	*L. camtschatica/alaskense*	No	Migrant	unknown
longnose sucker	*Catostomus catostomus*	Yes	Migrant	Spring
northern pike	*Esox lucius*	Yes	Migrant/Resident	Spring/Fall
Alaska blackfish	*Dallia pectoralis*	Yes	non-typical	year-round
rainbow smelt	*Osmerus mordax*	Yes	Migrant	Spring/Fall
broad whitefish	*Coregonus nasus*	Yes	non-typical	Fall
humpback whitefish	*Coregonus pidschian*	Yes	Migrant	Fall
least cisco	*Coregonus sardinella*	Yes	Migrant	Fall
pygmy whitefish	*Prosopium coulteri*	Yes	Migrant	unknown
round whitefish	*Prosopium cylindraceum*	Yes	Migrant	unknown
Arctic grayling	*Thymallus arcticus*	Yes	Migrant/Resident	Spring/Summer/Fall
pink salmon	*Oncorhynchus gorbuscha*	Yes	Migrant	Summer
chum salmon	*Oncorhynchus keta*	Yes	Migrant	Summer
coho salmon	*Oncorhynchus kisutch*	Yes	Migrant	Summer/Fall
rainbow trout	*Oncorhynchus mykiss*	Yes	Migrant/Seasonal	Spring/Fall
sockeye salmon	*Oncorhynchus nerka*	Yes	Migrant	Spring/Summer
Chinook salmon	*Oncorhynchus tshawytscha*	Yes	Migrant	Summer
Arctic char	*Salvelinus alpinus*	Yes	Migrant/Seasonal	unknown
Dolly Varden	*Salvelinus malma*	Yes	Migrant/Seasonal	Spring/Fall
lake trout	*Salvelinus namaycush*	Yes	non-typical	year-round
burbot	*Lota lota*	Yes	non-typical	year-round
threespine stickleback	*Gasterosteus aculeatus*	No	Resident	year-round
ninespine stickleback	*Pungitius pungitius*	No	Resident	year-round
slimy sculpin	*Cottus cognatus*	No	Resident	year-round

[a] Alt et al. 1994 a,b
Fall et al. 2010
Gryska 2007
Groot et al. 1991
Hauser 2007
Hubartt 1994
Krieg et al. 2003
Mansfield 2004
Mecklenburg et al. 2002
Minard et al. 1992
Morrow 1980
Quinn 2005
Salomone et al. 2009
Woody et al. 2007

[b] Migrant - utilize study site seasonally as a migratory corridor
Seasonal - May reside in study site
non-typical - rarely encontered in study site
Resident - Majority of life cycle could occur in study site

Table 2. Anticipated seasonal presence of selected fish species near Igiugig. Light gray – run duration, gray – run peak (Source: LGL)

Species	**Jan-Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov-Dec**
Sockeye salmon (smolt)			░▓	▓░					
Sockeye salmon (adult)				░	▓░	░			
Chinook salmon				░	░	░			
Pink salmon					░	░▓░	░		
Chum salmon					░	░▓░	░		
Coho salmon					░	░▓	▓		
Rainbow trout		░	▓	▓░			░▓	▓░	░

Subsistence Fish Harvest

For the communities within the Kvichak River watershed, the subsistence way of life is a fundamental part of their cultural and physical wellbeing. Each year residents harvest, distribute, and consume many fish species found in the river. Historically, salmon have been the mainstay for subsistence, but a considerable portion of the subsistence take is also comprised of non-salmon species that can be harvested year-round. Recent studies estimate that greater than 18,000 lbs of non-salmon fish are harvested regionally on an annual basis (Krieg et al., 2005). Several different harvest techniques, including angling and nets, are employed as the fish move seasonally from their over-wintering grounds to summer spawning and feeding habitats (Fall, Holen, Davis, Krieg, & Koster, 2006).

Of the 16 different non-salmon fish used by the people of Igiugig, seven are estimated to be harvested by greater than 25 percent of the households in the village (Kreig et al., 2003). Rainbow trout, Dolly Varden, and northern pike comprise the species of greatest subsistence harvest (besides salmon), in descending order (Kreig et al., 2005). A summary of these seven species is provided as well as descriptions of how they use the habitat near the outlet of Lake Iliamna downstream to Kaskanak Creek.

Rainbow trout (*Oncorhynchus mykiss*) are the freshwater resident form of this species found in the Kvichak River watershed. The anadromous form (steelhead) has not been documented in the Bristol Bay region. During the spring, rainbow trout will congregate between the outlet of Lake Iliamna and

Kaskanak Flat; these fish will include both spawners and nonspawners. ADF&G conducted abundance studies from 1986 through 1991 near Igiugig (Minard et al., 1992). Much of the sampling for these studies was conducted immediately below Igiugig, in the braided portions of the river where the fish gathered in shallow, low velocity areas. The authors noted that rainbow trout gathered in large numbers at these sites during April and May. By mid-June, they disperse into Lake Iliamna to spend the summer months before migrating to tributaries of the lake and to the Kvichak River in the fall. Abundance estimates in 1988, 1989, and 1990 were 2,038 (SE=1,252), 2,912 (775), and 4,460 (1,441), respectively. Annual survival ranged from 28 percent to 30 percent, and average age was six years (Krieg et al., 2003, Mecklenburg et al., 2002, Minard et al., 1992, and Morrow, 1980).

Rainbow trout support a substantial sport fishing industry that is managed by ADF&G. In addition to being economically valuable to the residents of Igiugig, rainbow trout are also a highly regarded subsistence resource. Krieg et al. (2003) reported that 100 percent of the households in Igiugig will include rainbow trout in their annual subsistence harvest. Local fishing guides indicate that rainbow trout can be located anywhere in the river, but that fishermen tend to drift “lines” down the channel that are most productive (Brian Kraft, personal communication, Alaska Sportsman’s Lodge). These lines are defined by bathymetry, water flows, and food characteristics that are the most energetically beneficial to the rainbow trout. Observations during 2014 and 2015 showed that the lines drifted by sport fisherman were inshore of the device towards the eastern bank of the river and that there was no observed interference between trout sport fishing practices and the RivGen device whether it was deployed on the river bed or on the surface during maintenance events. It is possible that the RivGen® Power System structure may provide some preferred habitat (e.g., shelter or cover) for rainbow trout. This condition may encourage them to come in close proximity with the device even though the high-power density region of the channel is not usually preferred. Overall, it is anticipated that adult rainbow trout may encounter the device(s) and any in-water mooring or electrical cables running to shore.

Arctic grayling (*Thymallus arcticus*) are found throughout the Kvichak drainage. During the winter months, Arctic grayling will be found in lakes or larger rivers that provide sufficient habitat while frozen. During the spring, they will migrate up streams to their spawning and feeding grounds, so the Kvichak River at Igiugig is likely used only as a migration corridor rather than an area of residence. Arctic grayling will spawn in low energy portions of the streams; this is also where the fry will rear before heading to the overwintering grounds. Arctic grayling have been caught in the Kvichak at Igiugig, but the majority of this species is harvested further downstream near the outlet of Pecks, Ole and Kaskanak Creeks (Gryska, 2007, Krieg et al., 2003, and Morrow, 1980). No information on population abundance or cross-channel distribution at Igiugig is available but based on their preferred habitat it is not anticipated that adult or juvenile grayling will encounter the RivGen® device(s). However, they will likely encounter moorings and electrical cables running to shore.

Northern pike (*Esox lucius*) are found in the lakes and rivers throughout southwest Alaska, including the Kvichak River. These fish will overwinter in the slower water of large rivers and deeper lakes, and then migrate to their summer spawning and feeding grounds in slow moving streams, sloughs, and along the lake shore. The Kvichak River at Igiugig is likely used only as a migration corridor rather than an area of residence because of predominant high-water velocity. Igiugig residents harvest pike during the spring and fall in the Kvichak River (Alt, 1994a, Krieg et al., 2003, and Mecklenburg et al., 2002), Kvichak tributaries of Ole and Pecks Creeks, and Lake Iliamna tributaries of Upper and Lower Talarik Creeks (Ida Nelson, personal communication, Igiugig resident). No information on population abundance or cross-channel distribution at Igiugig is available but based on their preferred habitat it is not anticpated that adult or juvenile pike will encounter the hydrokinetic device. However, they will likely encounter any in-water mooring and electrical cables running to shore.

Humpback whitefish (*Coregonus pidschian*) can take advantage of many different freshwater and marine habitats and are found in freshwater residential and anadromous forms. These fish are found throughout the Kvichak River watershed and make up a large component of the subsistence fishery. Despite the relative importance of this fish, little is known of its life history or population size. A recent study by Woody and Young (2007) examined strontium concentrations in humpback whitefish taken from Lake Clark and found no definitive evidence that those fish migrated to and from saltwater. It is known that spawning occurs during the fall and takes place in the upper reaches of streams, or the littoral zones of lakes. Based on harvest records for Igiugig residents, humpback whitefish are caught near the village as they migrate to or from their spawning grounds located in the tributaries of the Kvichak River (Alt, 1994b, Fall et al., 2010, Woody and Young, 2007, and Krieg et al., 2003). Residents fish for humpback whitefish in October and November (Ida Nelson, personal communication, Igiugig resident). At Igiugig, the Kvichak River is likely used only as a migration corridor rather than an area of residence by the humpback whitefish. No information on population abundance or cross-channel distribution at Igiugig is available but based on their preferred habitat it is not anticipated that adult or juvenile humpback whitefish will encounter the RivGen® device(s). However, they will likely encounter any in-water mooring and electrical cables running to shore.

Dolly Varden (*Salvelinus malma*) in the Kvichak River watershed exist in anadromous and freshwater resident forms. Generally, the freshwater residents will be in the upper reaches of the streams that drain into Lake Iliamna, and the anadromous form is found in the mainstem and larger tributaries of the Kvichak River. Resident Dolly Varden will rear in slow moving water on the stream bottoms and then move to stream pools or eddies once they are large enough. Anadromous forms will spawn in the summer and fall and may remain in the streams up to 20 months before migrating back to sea. The juvenile anadromous form will remain in the freshwater 2 to 4 years using the stream bottom for cover and feeding. Once large enough, they make the transformation into smolts and migrate to sea around May and June (Hubartt, 1994, Kreig et al., 2003, Mecklenburg et al., 2002, and Morrow, 1980). The anadromous form of this species is harvested January through April in the Kvichak (Kreig et al., 2005) via ice fishing. Local fishing guides indicate that Dolly Varden are caught incidentally when targeting rainbows, but are uncommon (Brian Kraft, personal communication, Alaska Sportsman's Lodge). Overall, it is anticipated that adult Dolly Varden may encounter the RivGen® device(s) and moorings or electrical cables running to shore, but it would be a rare occurrence due to their low abundance in the Project area.

Longnose suckers (*Catostomus catostomus*) are harvested by Igiugig residents during the spring, usually in late May and early June. These fish reside in lakes or stream pools and will migrate to gravel sections of streams in the spring for spawning. Based on the harvest records, Igiugig residents harvest these fish in the feeder streams of the upper Kvichak River, namely Pecks and Ole Creeks, in addition to the Kaskanak Flats area (Krieg et al., 2003, Mansfield, 2004, Mecklenburg et al., 2002, and Morrow, 1980). No information on population abundance or cross-channel distribution at Igiugig is available but based on their preferred habitat it is not anticipated that adult or juvenile longnose suckers will encounter the RivGen® device(s). However, they will likely encounter in-water moorings and electrical cables running to shore.

Rainbow smelt (*Osmerus mordax*) are anadromous fish that migrate up the Kvichak River each spring from the ocean and are thought to spawn in the tributaries of Lake Iliamna. Little is known about their life history or population size. However, based on traditional ecological knowledge, the rainbow smelt are only present from spring to early fall (Gotthardt & McClory, 2006, Mecklenburg et al., 2002, and Kreig et al., 2003). The Kvichak River at Igiugig is likely used only as a migration corridor rather than an area of residence. No information on population abundance or cross-channel distribution at Igiugig is available, but based on their preferred habitat, it is anticipated that out-migrating adult or juvenile rainbow smelt will encounter the RivGen® device(s) and in-water mooring or electrical cables running to shore.

Adult Sockeye Salmon

Socioeconomic Importance

Bristol Bay, Alaska, produces the greatest number of sockeye salmon (*Oncorhynchus nerka*) in the world. During 1991-2010, the region produced an average annual sockeye salmon run of 38 million (SD 12 million); the Kvichak stock represented 21 percent of this average. Bristol Bay sockeye have been intensively harvested since the early 1900s, mostly in commercial fisheries located in marine waters near river confluences (Clark et al., 2006). Commercial harvest from 1991 to 2010 averaged 26 million for Bristol Bay as a whole, and 4 million for the Kvichak River.

Subsistence fishing for sockeye salmon in Bristol Bay has occurred since inhabitance and continues to be an important source of protein for local residents (Morstad, Jones, Sands, Salomone, Buck, & West, 2010). In 2009, the subsistence harvest of sockeye for the Kvichak River/Iliamna Lake sub-district totaled 46,772 from 187 permits, and in the Igiugig region totaled 1,071 from 5 permits (Salomone, Morstad, Sands, Jones, Baker, Buck, West, & Kreig, 2011). In addition to the subsistence fishery, sockeye salmon have been an essential segment of the sport fishing industry for that region. From 1997 through 2008 the annual sport fish harvest of sockeye salmon in the Kvichak River averaged 1,860 fish (Dye& Schwanke, 2009).

Management

To manage and sustain the fisheries, federal and state agencies have collected detailed records of catch, spawning escapement, and age composition for the nine major Bristol Bay sockeye salmon stocks (including the Kvichak River) since 1952. The Bristol Bay region remains relatively pristine, biodiversity of salmon remains high (Hilborn et al., 2003), and salmon populations have not been influenced by hatcheries. Therefore, Bristol Bay provides a unique long-term history of wild salmon population dynamics, largely unaffected by alterations to habitat or genetics.

ADF&G’s salmon management objectives include managing for sustained yield (largely accomplished by adhering to escapement goals), maintaining genetic diversity and overall health of the escapement (the number of fish that spawn each year), providing for an orderly fishery, helping to ensure high quality fishery products, and harvesting fish consistent with regulatory management plans. The Commissioner delegates management authority to Area Management Biologists, who regulate time and area openings for otherwise closed fisheries.

ADF&G's fishery biologists develop escapement goals for salmon based on the sustained yield principle, in accordance with the Policy for the Management of Sustainable Salmon Fisheries (5 AAC 39.222) and the Policy for Statewide Salmon Escapement Goals (5 AAC 39.223). Typically, the relationship between escapement levels and subsequent adult salmon returns is an important part of escapement goal development.

Timing

Average run timing (2000-2010) shows that 25 percent of Kvichak River spawners return by June 30, 50 percent by July 5, and 75 percent by July 10 (Figure 4). During this period, run timing ranged plus or minus three days, with the earliest having 50 percent return by July 2 and the latest by about July 8 (based on combined catch and escapement). Sockeye salmon usually take two to four days to travel from the fishing district upstream to the counting tower at Igiugig (T. Baker, personal communication, research biologist, ADF&G).

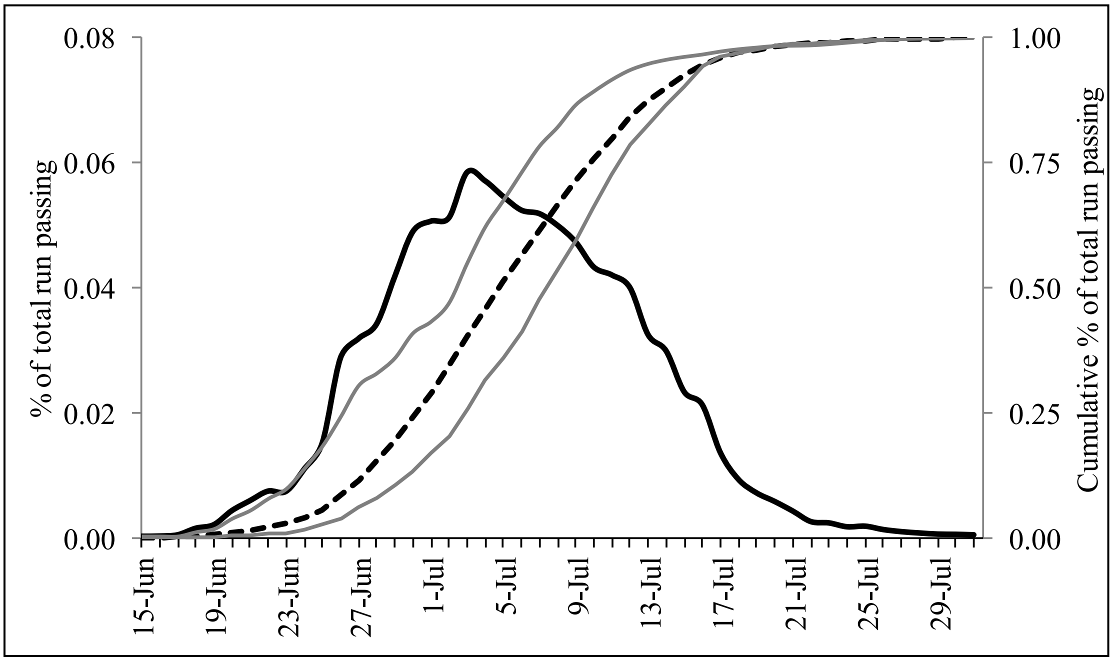


Figure 4. Run timing curves for Kvichak River sockeye salmon. The average run timing from 2000 to 2010 are indicated by thick black lines (daily=solid line and cumulative=dashed line). The earliest and latest cumulative curves during this time period are indicated by gray lines. Source: LGL

Distribution

When current velocities in the thalweg are high, sockeye salmon are extremely bank-oriented while migrating upriver due to the energetic gain in swimming against slower waters near the bank (Woody, 2007, and Anderson, 2000). Taking advantage of this life history trait, W. F. Thompson (1962) developed the tower counting system for Bristol Bay in 1953. When tower counts were compared to weir counts (assumed to be a complete census) on the Egegik River, relative error was -7.4 percent (Rietze, 1957; Spangler & Rietze, 1958). Therefore, we can assume that most sockeye were visible from the counting towers and not swimming in the thalweg; otherwise, the observed relative error would have been much greater. At Igiugig, Anderson (2000) found nearly all sockeye passed 3.0 - 9.1 m from the left bank (facing upstream) and 3.7 - 9.1 m from the right bank. Igiugig was chosen for the enumeration project because current velocities in the thalweg likely preclude adult salmon swimming across or through the middle of the river in this area. It is anticipated that adult sockeye salmon encounters with the RivGen® device(s) will be minimized by device placement in the river thalweg. Adult salmon are expected to encounter moorings and electrical cables running to shore.

Abundance

Total abundance of adult sockeye salmon returning to individual Bristol Bay rivers is calculated from catch and escapement estimates. Escapement of sockeye salmon to the Kvichak River is estimated with a counting tower operated by ADF&G near Igiugig. Commercial catch of Kvichak River sockeye salmon happens downstream, in Bristol Bay saltwater; catch of fish bound for the Kvichak River is estimated based on age-specific stock composition methods. From 2006 through 2010, the estimated Kvichak River sockeye salmon run averaged 6.1 million total fish, with a range of 4.2 to 9.2 million fish (Table 3). Kvichak River sockeye salmon vary among four main age classes: 1.2, 1.3, 1.4, and 2.3 (European notation—1st number=freshwater age, 2nd=ocean age, Table 4). On average, 60 percent return 5 years after the year in which they were spawned, as Age-2.2s or Age-1.3s (return time is calculated by adding the freshwater and ocean ages plus one year for overwinter incubation of the eggs). Age-2 fish are usually the most abundant and exert strong influence on total run size.

Table 3. *Historical catch and escapement of Kvichak River sockeye salmon.*

Year	Catch	Escapement	Total
1956	4,168,343	9,443,318	13,611,661
1957	3,540,189	2,842,810	6,382,999
1958	549,396	534,785	1,084,181
1959	281,930	673,811	955,741
1960	7,976,500	14,602,360	22,578,860
1961	6,863,814	-	6,863,814
1962	1,833,401	2,580,884	4,414,285
1963	223,459	338,760	562,219
1964	763,486	957,120	1,720,606
1965	17,785,664	24,325,926	42,111,590
1966	4,168,575	3,755,185	7,923,760
1967	1,800,652	3,216,208	5,016,860
1968	387,565	2,557,440	2,945,005
1969	3,760,565	8,394,204	12,154,769
1970	16,581,224	13,935,306	30,516,530
1971	3,764,861	2,387,392	6,152,253
1972	342,150	1,009,962	1,352,112
1973	21,791	226,554	248,345
1974	148,595	4,433,844	4,582,439
1975	1,605,407	13,140,450	14,745,857
1976	1,458,180	1,965,282	3,423,462
1977	739,464	1,341,144	2,080,608
1978	3,815,636	4,149,288	7,964,924
1979	13,418,829	11,218,434	24,637,263
1980	12,743,074	22,505,268	35,248,342
1981	5,234,733	1,754,358	6,989,091
1982	1,858,475	1,134,840	2,993,315
1983	16,534,901	3,569,982	20,104,883
1984	12,523,803	10,490,670	23,014,473
1985	6,183,103	7,211,046	13,394,149
1986	787,303	1,179,322	1,966,625
1987	3,526,824	6,065,880	9,592,704
1988	2,654,364	4,065,216	6,719,580
1989	11,456,509	8,317,500	19,774,009
1990	10,551,217	6,970,020	17,521,237
1991	3,808,873	4,222,788	8,031,661
1992	5,718,947	4,725,864	10,444,811
1993	5,287,523	4,025,166	9,312,689
1994	13,893,613	8,355,936	22,249,549
1995	17,391,906	10,038,720	27,430,626
1996	1,983,269	1,450,578	3,433,847
1997	179,480	1,503,732	1,683,212
1998	1,072,760	2,296,074	3,368,834
1999	6,663,209	6,196,914	12,860,123
2000	1,033,814	1,827,780	2,861,594
2001	330,538	1,095,348	1,425,886
2002	-	703,884	703,884
2003	34,244	1,686,804	1,721,048
2004	2,163,318	5,500,134	7,663,452
2005	532,450	2,320,332	2,852,782
2006	2,687,895	3,068,226	5,756,121
2007	1,420,384	2,810,208	4,230,592
2008	2,873,889	2,757,912	5,631,801
2009	3,297,344	2,266,140	5,563,484
2010	5,018,048	4,207,410	9,225,458
10 yr avg.	3,967,974	3,552,998	7,322,573

Table 4. *Age composition of Kvichak River sockeye salmon, in percentages*

Year	Age 1.2	Age 1.3	Age 2.2	Age 2.3	2-ocean	3-ocean	Total run (millions)
1990	4	7	75	14	79	21	18
1991	51	13	17	19	68	32	8
1992	23	23	41	12	65	35	11
1993	22	25	45	7	67	33	10
1994	7	7	83	2	90	10	23
1995	9	4	75	12	84	16	28
1996	12	35	20	33	32	68	4
1997	47	12	31	9	78	22	2
1998	51	26	18	4	69	31	4
1999	58	9	28	4	87	13	13
2000	12	60	20	8	32	68	3
2001	9	84	1	5	10	90	1
2002	45	15	37	2	83	17	1
2003	64	17	15	4	79	21	2
2004	23	3	73	1	96	4	8
2005	18	41	32	9	50	50	3
2006	45	31	17	7	62	38	6
2007	63	18	3	16	66	34	4
2008	73	25	1	0	74	26	6
2009	18	40	40	2	57	43	6

Sockeye salmon abundance in Bristol Bay has fluctuated significantly during the past century (Figure 5). Two notable aspects of the Kvichak River sockeye salmon are a historic 5-year cyclic pattern in abundance, and an overall decline in abundance beginning in the mid-1990s. Reasons for the cycle are unclear and the subject of much discussion. Some data indicate an interaction of marine and freshwater processes, reinforced by historical fishing patterns and escapement goal policy. Ruggerone and Link (2006) provided evidence that the cyclic abundance of Kvichak sockeye salmon was maintained by dispensatory fishing mortality, density-dependent interactions between brood lines, low productivity of the Kvichak River watershed, and the relatively stable 5-year life cycle of Kvichak River salmon rather than natural dispensatory mortality caused by predators or marine derived nutrients. Whatever the cause, the cycle began to change during the mid-1990s and the Kvichak River stock has failed to dominate the Bristol Bay run since. Speculation about factors causing the Kvichak River stock collapse grew as the series of low runs continued from 1996 through 2005.

The history and accuracy of tower counting systems in Bristol Bay is described by Woody (2007), while methods for efficiently estimating sampling error (precision) can be found in Reynolds et al. (2007).

Towers are constructed on clear streams such as the Kvichak River at sites amenable to sampling, which is circumscribed by a set of guidelines (Woody, 2007). As previously mentioned, tower counts were very close to weir counts on the Egegik River (relative error was -7.4 percent), (Rietze, 1957; Spangler & Rietze, 1958). The sources of error counting include observer variability, aspects of migration, weather conditions, and sampling error due to subsampling (Woody, 2007).

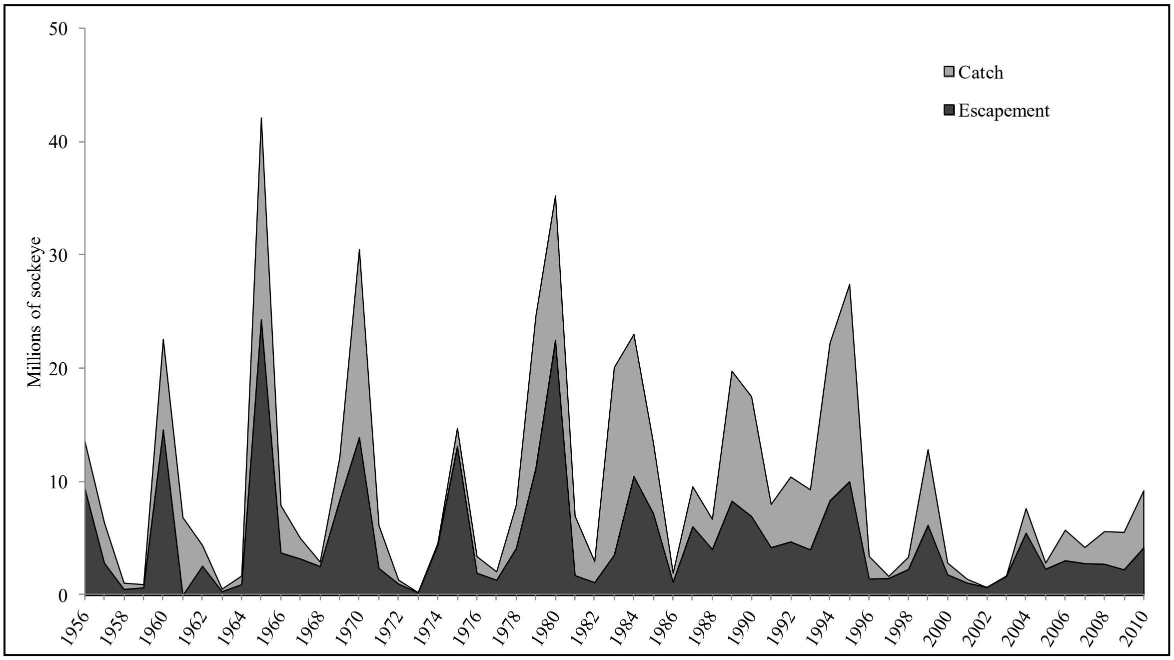


Figure 5. Catch and escapement trends for Kvichak River sockeye salmon. Source: LGL

Juvenile Sockeye Salmon

As Pacific salmon complete the fresh water stage of their life cycle, they undergo physiological changes to make the transition to salt water. This parr-smolt transformation includes changes in morphology and behavior that favors increased survival at sea (Groot and Margolis, 1991). In the early 1950s, fisheries scientists from the University of Washington and U.S. Fish and Wildlife Service started collecting biological data from the out-migrating sockeye salmon smolts in the Bristol Bay region (LGL, unpublished data). Smolts were first monitored from the Kvichak River near the village of Igiugig in 1957. ADF&G became the lead organization in 1961 and has collected smolt data annually since then (e.g., Crawford, 2001).

Biological data collected from the Kvichak River smolt studies usually include age, length, and weight, along with some information on smolt run timing and relative abundance. Fyke nets were used from 1956 through 1970 to capture smolts, so relative abundance estimates were based on catch per unit effort. In 1971, hydroacoustics were first tested on the Kvichak River to determine if total smolt abundance could be estimated. The results were rigorous enough that this method was used by ADF&G through 2000 (Crawford & West, 2001). Due to problems with aging sonar equipment and budget cuts, ADF&G sonar portion of smolt monitoring on the Kvichak River was discontinued in 2001; biological data continued to be gathered annually (Crawford and Fair, 2003). In 2007, the Bristol Bay Science and Research Institute (BBSRI) designed and built a new sonar system to estimate smolt outmigration in the rivers of Bristol Bay. This was first tested on the Kvichak River in 2008 and has operated annually since then, concurrent with ongoing biological data collected by ADF&G (Wade, Degan, Link, & Nemeth, 2013.).

Sockeye salmon smolt behavior on the Kvichak River has been characterized over the years using fyke net catches and sonar data. Across years, smolts tend to follow the same general behavior patterns in regard to run timing and distribution in the water column (Wade et al., 2013). These behaviors are thought to be driven in part driven by the evolutionary pressure for survival (Groot & Margolis, 1991).

Timing

Interactions between growth rate, body size, and environmental conditions are the primary factors that trigger the parr-smolt transformation. Photoperiod appears to drive this transformation, but water temperature also influences the timing of the annual outmigration (Groot & Margolis, 1991; Quinn, 2005). On the Kvichak River, outmigration generally coincides with the melting of ice on Lake Iliamna (mid-May) and is the timing for smolt sampling projects (Crawford, 2001). The length of the outmigration for sockeye salmon is somewhat compressed relative to other species of Pacific salmon

(Quinn, 2005). On the Kvichak River, the entire duration of the run is 2 to 3 weeks long, with the majority of fish out-migrating in the last week of May. From 2008 through 2012, greater than 85 percent of total smolts were detected in a period of 9 days, with 4-day peaks during this time accounting for > 50 percent (Wade, Degan, Link, & Raborn, 2010a, Wade, 2010b, Wade, 2011, Wade, 2012; and Wade et al., 2013), (Figure 6 and Figure 7).

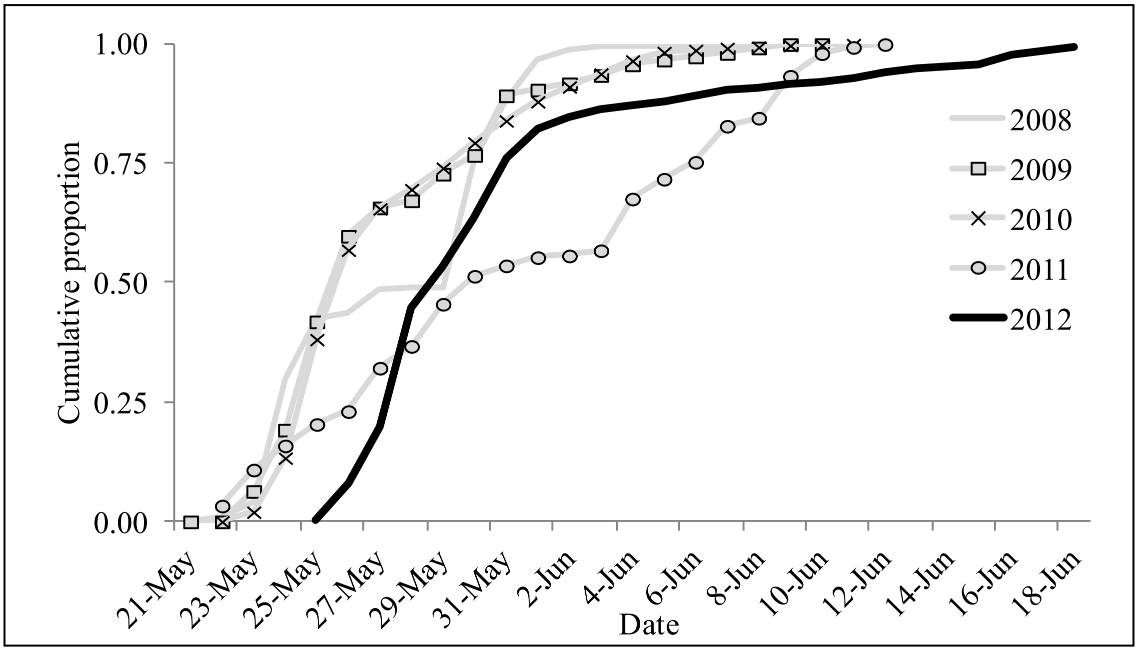


Figure 6. Run timing of sockeye salmon smolt out-migration, Kvichak River, 2008-12. Source: LGL

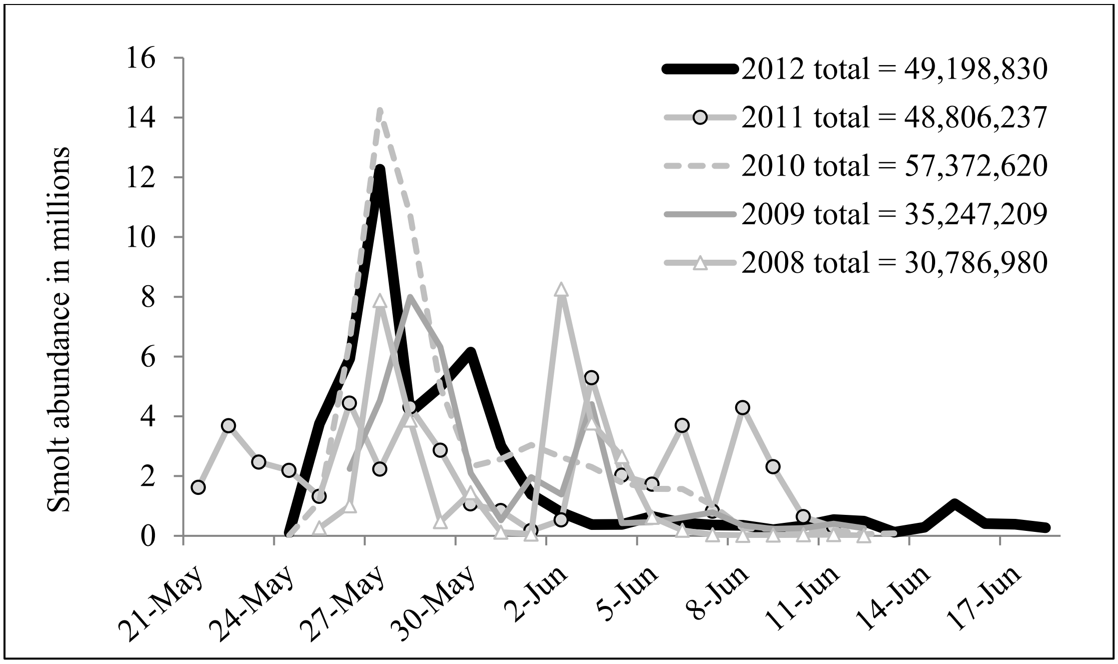


Figure 7. Estimated daily sockeye salmon smolt abundance, Kvichak River, 2008 – 2012. Source: LGL

Distribution

Past studies of sockeye salmon smolt behavior on the Kvichak River have indicated the majority of out-migrating smolts will migrate in the upper portion of the water column. Using video (from 2000) and acoustic data (2000 and 2001), Maxwell, Mueller, Degan, Crawford, McKinley and Hughes (2009) found that all smolts traveled in the top 1.0 m of water, and the majority of smolts were in the top 0.3 m. The Bristol Bay Science and Research Institute (BBSRI) study (2008-2012) characterized vertical distribution down to 2.5 m in depth, and then divided these data into two categories (dark, daylight) to check for diel differences in distribution. On the Kvichak River, the smolt vertical distribution was consistent across years for both periods of daylight and darkness (Figure 8). During the periods of darkness > 90 percent of smolts were detected in the upper 1.0 m and on average > 80 percent were found in the upper 0.5 m. Daylight distribution tended to be a little deeper, but in all cases > 81 percent were found in the 0.0 to 1.5 m strata. By utilizing the upper portion of the water column, smolts travel in the higher velocity water and therefore reduce the amount of energy expended to reach the sea.

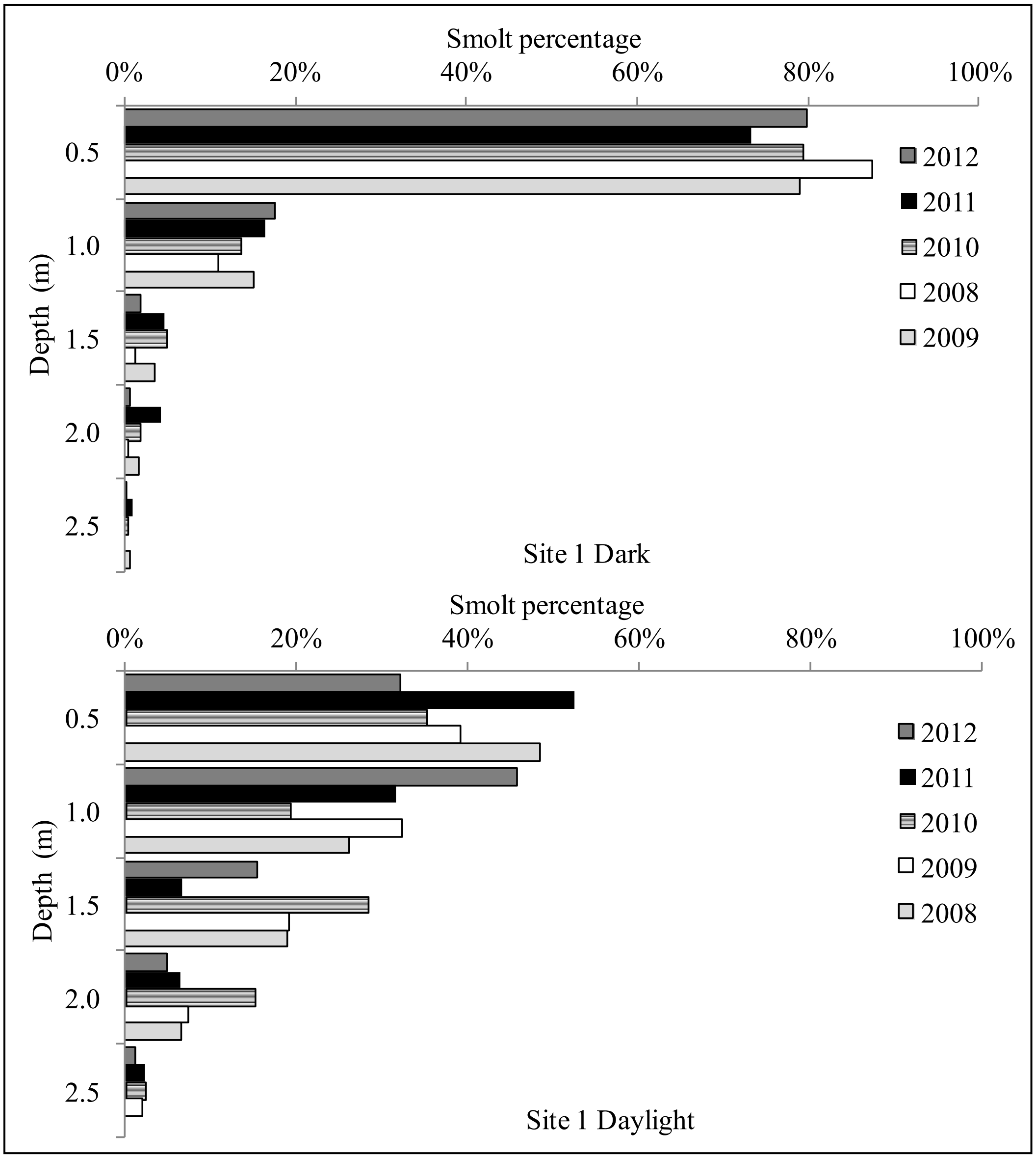


Figure 8. Vertical distribution of out-migrating sockeye salmon smolts, Kvichak River, 2008 – 2012.

Source: LGL

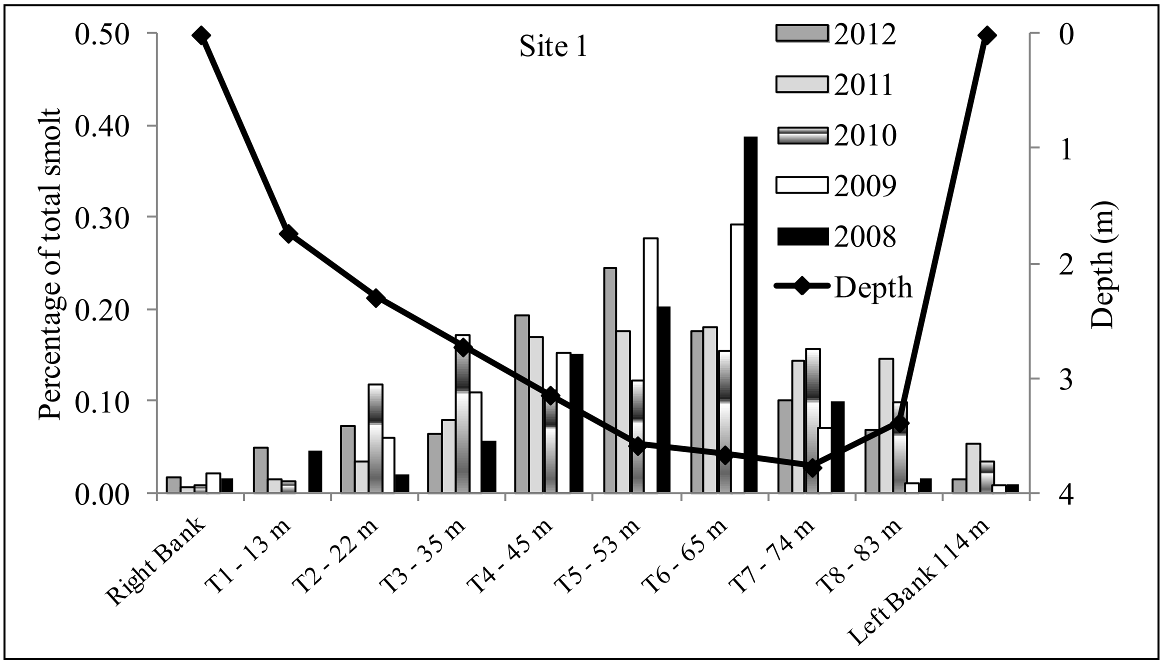


Figure 9. Cross-river distribution of sockeye salmon smolt, Kvichak River, 2008 – 2012. Source: LGL

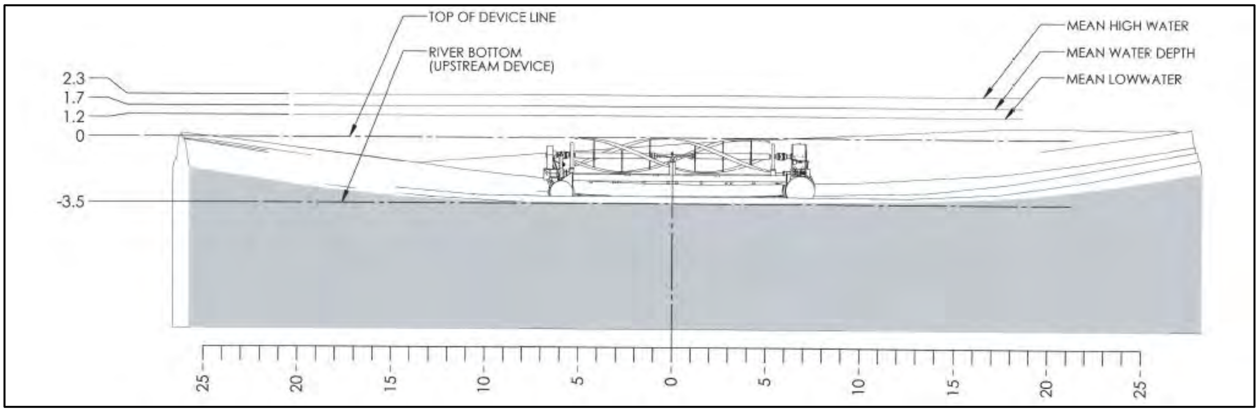


Figure 10. Cross section of RivGen® device from downstream, looking upstream. Generic river bed profile using 1:200 scale.

Abundance

Sockeye salmon smolt abundance on the Kvichak River was estimated annually from 1957 to 2001 by ADF&G, then annually since 2008 by BBSRI (Wade et al., 2013). Methods to estimate smolt abundance have gone through three fundamentally different changes since inception (LGL, unpublished data), so comparison of absolute numbers across eras is not valid. It is believed that estimates from hydroacoustics more accurately reflect the actual number of fish. During the period of time when the ADF&G sonar was thought to be operating correctly (1972-1992), annual estimates varied from 15 to 342 million smolts. The BBSRI estimates for Site 1 on the Kvichak River have ranged from 30-57 million smolts. Given the short duration of the smolt outmigration, it is possible that more than 20 million smolts move down the river in a 24-hour period.

Other Salmon

The Kvichak River is home to all five species of Pacific salmon in Alaska (sockeye, Chinook, coho, chum, and pink salmon), all of which are fished commercially and for subsistence (Table 5). There are also in-river sport fisheries for Chinook, coho, and sockeye salmon. Pacific salmon are anadromous and share similar life histories with respect to spawning migration. In general, pink and chum spawn in the lower reaches of rivers while sockeye, Chinook, and coho salmon will travel further up the basin to preferred spawning and rearing habitat. Juvenile pink and chum salmon typically migrate downstream immediately after hatching (Groot & Margolis, 1991).

Table 5. *Historical salmon harvest in the Kvichak River region.*

Naknek/Kvichak Harvest - 20 Year Average[a]	Sockeye	Chinook	Coho	Chum	Pink
Commercial (1990 - 2010)[b]	8,238,895	2,816	4,436	255,487	73,661
Subsistence (1989 - 2009)	77,653	1,323	1,218	844	957

[a] Morstad et al. 2010, Salomone et al. 2011

[b] Commercial fishing is limited to Kvichak Bay (i.e., no commercial fishing occurs in the Kvichak River).

Although extensive research has been conducted on sockeye salmon in the Kvichak River, little effort has been dedicated to the study of the other four species of salmon near the Project. ADF&G conducts annual spawning ground surveys in the Naknek/Kvichak drainage, but the majority of the effort is in the Naknek River and its tributaries (Salomone, et al. 2009), which are downstream of Igiugig and the Project. According to the ADF&G Anadromous Waters Catalog, several streams above the Village of Igiugig support spawning populations of sockeye, Chinook, and coho salmon, whereas pink and chum salmon are rarely found (Table 6).

Table 6. *Distribution of salmon in tributaries of the Kvichak River by life stage.*

	Species/Lifestage[a]				
Location	Sockeye	Chinook	Coho	Pink	Chum
Kaskanak Creek	p	s	s	s	s
Ole Creek	s	p	p		p
Pecks Creek	s	p	p		s
Belinda Creek	s	s			
Dennis Creek	s				
Gibraltar Creek	s				s
Kakhonak River	s				
Copper River	s	s			
Tommy Creek	s				
Iliamna River	s	p	p	p	p
Pile River	s				
Knutson Creek	s				
Canyon Creek	s				
Chekok Creek	s		p		
Chekok Bay Creek	s		p		
Stonehouse Creek	s				
Eagle Bay Creek East	s				
Eagle Bay Creek West	s				
Roadhouse Creek	s		s		
Newhalen River	s	s	p		
Pete Andrews Creek	s				
Upper Talarik Creek	s, r	s	s, r	p	s
Lower Talarik Creek	s	p	s		
324-10-10150-2155	s		p		

[a] p - present, m - migration, r - rearing, s - spawning. Alaska Department of Fish and Game (2011). Anadromous Waters Catalog Overview.

Aside from sockeye salmon, little is known about the age and run timing of juvenile salmon upstream of Igiugig (ADF&G, 2011). ADF&G records incidental non-sockeye salmon catch that occurs during the sockeye salmon smolt project on the Kvichak River, but abundance and run timing are not estimated using these data (Crawford, 2001). Regardless, the out-migrating smolts from these other species could encounter the RivGen® device(s) (Quinn, 2005; Groot & Margolis, 1991). The age at which Chinook and coho will smolt varies from system to system but ranges from 0 to 2 years for Chinook and 0 to 4 years for coho (Morrow, 1980; Quinn, 2005; Groot & Margolis, 1991). Age-1 and older Chinook and coho smolts are larger than the respective aged sockeye smolts, so they may be better able to avoid the RivGen® device(s).

Chum and pink salmon usually out-migrate immediately after emergence from the gravel (Groot & Margolis, 1991); therefore, juvenile chum and pink salmon originating upstream of Igiugig would likely have already migrated past the Project site by the time of redeployment in late June.

4.2 RESULTS OF PREVIOUS MONITORING

4.2.1 2015 MONITORING

Fish and wildlife monitoring was performed by LGL in 2015, in accordance with the 2015 Monitoring Plan and ADF&G Fish Habitat Permit FH 15-II-0038. Data was collected around the RivGen® 1.F Power System deployed in the Kvichak River in July and August 2015. The RivGen® was deployed from approximately July 10 through September 15 in 2015, which overlapped with part of the migration of adult salmon and rainbow trout, among other species (Table 2). This time period did not overlap with the main migration timing of juvenile sockeye salmon, which migrate downstream from approximately May 21 through June 10 (Figure 6).

Fish movements at the RivGen® device were described using video footage collected from five underwater cameras mounted to the pontoons of the power system. Video footage was collected 24 hours/day July 19–25 and again August 19–27, 2015; review was done by watching the first 10 minutes of a selected hour from each of the four primary cameras (the fifth camera was a backup). Spatially, the camera field of view captured the port side of the RivGen® device, including upstream and downstream views of the port side turbine (only, due to reduced visibility from variable river turbidity of the starboard side turbine). In accordance with the 2015 Monitoring Plan, footage was reviewed to achieve partial temporal coverage during different categories of turbine operating status and daytime/nighttime conditions. At night, two underwater lights lit the viewing area. In addition, bird and marine mammal surveys were conducted for 15 minutes each morning of monitoring. Methods and the overall approach were similar to those described for the demonstration study conducted at the same site in 2014.

Blocks of video footage from portions of 238 different hours were reviewed in season in 2015. There were 359 events with fish, composed of approximately 1,202 individual fish from at least six species. The majority of fish observations were of solitary fish; the largest school was approximately 100 fish. Species composition varied from July to August and also from day to night. In particular, salmon smolt were almost exclusively seen at night, and were more prevalent in July than August. Several instances of fish moving through the RivGen® turbine were noted and reported in season as part of the Project's adaptive management process. LGL did not detect any obvious physical injuries to fish and saw no altered behavior by wildlife near the RivGen® device. Cameras, lights, and power system components all operated reliably. All video footage was archived. The LGL monitoring report in included as Attachment 1 to this Plan. (LGL 2015)

4.2.2 PNNL DATA ANALYSIS

Video data collected as part of the 2015 RivGen® Power System monitoring provided a valuable opportunity for further analysis to better quantify interactions between fish and the turbine. As a result, the U.S. Department of Energy commissioned PNNL to conduct data analysis and to develop potential automation techniques for future monitoring. The goal of PNNL's analysis of video data collected around ORPC's RivGen® device deployed in the Kvichak River during July and August 2015 was to gain an understanding of the implications of using underwater video cameras as a fish monitoring technique. The data were analyzed manually and used to develop automated algorithms for detecting fish in the video frames and describing their interaction behavior relative to the device. In addition, PNNL researchers developed a web application, EyeSea, to combine manual and automated processing, so that ultimately the automated algorithms could be used to identify where human analysis was needed (i.e., when fish are present in video frames). The EyeSea software is discussed further in Section 6.3.1 of this Plan.

The manual analysis began to look at all data from the start of deployment of the RivGen® device, primarily using video from Camera 2 that looked directly at the upstream side of the turbine, so any interaction could be identified; this was to ensure rare events were seen, and initially focused on nighttime data when more fish were present. This process highlighted the amount of time it takes to identify fish, and ultimately only 42.33 hours of video were reviewed because of the time-consuming analysis. The data were classified as "Fish" when the reviewer was confident it was a fish, and "Maybe" is defined by an object that during manual analysis is deemed to possibly be a fish, but not a definite identification. The two classes were distinguished based on the movement, shape, and color characteristics. Fish Events were further classified by "adult", "juvenile", or "unidentifiable" age. Behavioral attributes were noted and were broadly divided into Passive and Avoidance activities. In over 42 hours of the data reviewed, there were 20 potential contact interactions, of which 3 were "Maybe" classifications, 12 were juveniles, and 5 were adults. While only 11.5% of the video data were analyzed from Camera 2, these results are from the time when most fish were present over the turbine deployment period (ADF&G data) and provide preliminary evidence that fish strike or collision of fish in the Kvichak River with an instream turbine is rare.

On only one occasion was an actual contact confirmed, and this was an adult fish that contacted the camera, not the turbine itself. This experience highlights the difficulties associated with confirming a strike or collision event as either having occurred or having been a near-miss. More interactions were detected at night; this was probably biased by nighttime use of artificial light, which may have attracted fish, but also could have increased detection probability because light is reflected from the fish itself.

The full PNNL report (Matzner, et al. 2017) is included as Attachment 2.

4.3 BEST AVAILABLE SCIENCE

As an emerging industry, development of marine and hydrokinetic projects has been hampered by a lack of best available science that demonstrates environmental interactions with power systems. However, results of LGL fish and wildlife monitoring in 2014 and 2015 as well as analysis completed by PNNL in 2015 were consistent with a growing global knowledge base of recently published data that indicates negligible environmental effects from hydrokinetic turbines. Many of the global studies associated with marine energy project are accessible on the Tethys website managed by PNNL: https://tethys.pnnl.gov/

Detailed environmental studies have been conducted around ORPC power systems in both tidal and river environments. ORPC's TidGen® Power System was used for the Cobscook Bay Tidal Energy Project in Maine. The TidGen® device is comprised of the same core technology as the RivGen® device but on a larger scale. In Cobscook Bay, researchers have an understanding of changes in fish density over time. Monitoring recorded little interactions between fish and turbine foils and revealed that small fish move through the turbines. Side-looking sonar revealed some deflections or avoidance behavior occurring in the range of seven to fifteen meters from the turbine. Mobile transects indicated fish responded further away from the device, in the range of 10 to 140 meters from the device. The behavioral effect footprint around device may be within ten to one hundred and forty meters, and it has been observed that once fish move past the device, direction of movement was with the water current as shown in Figure 11. It should be noted that the TidGen® device is over twice the size of the RivGen® device.

Additional resources for best available science are included in Section 11, References of this Plan.

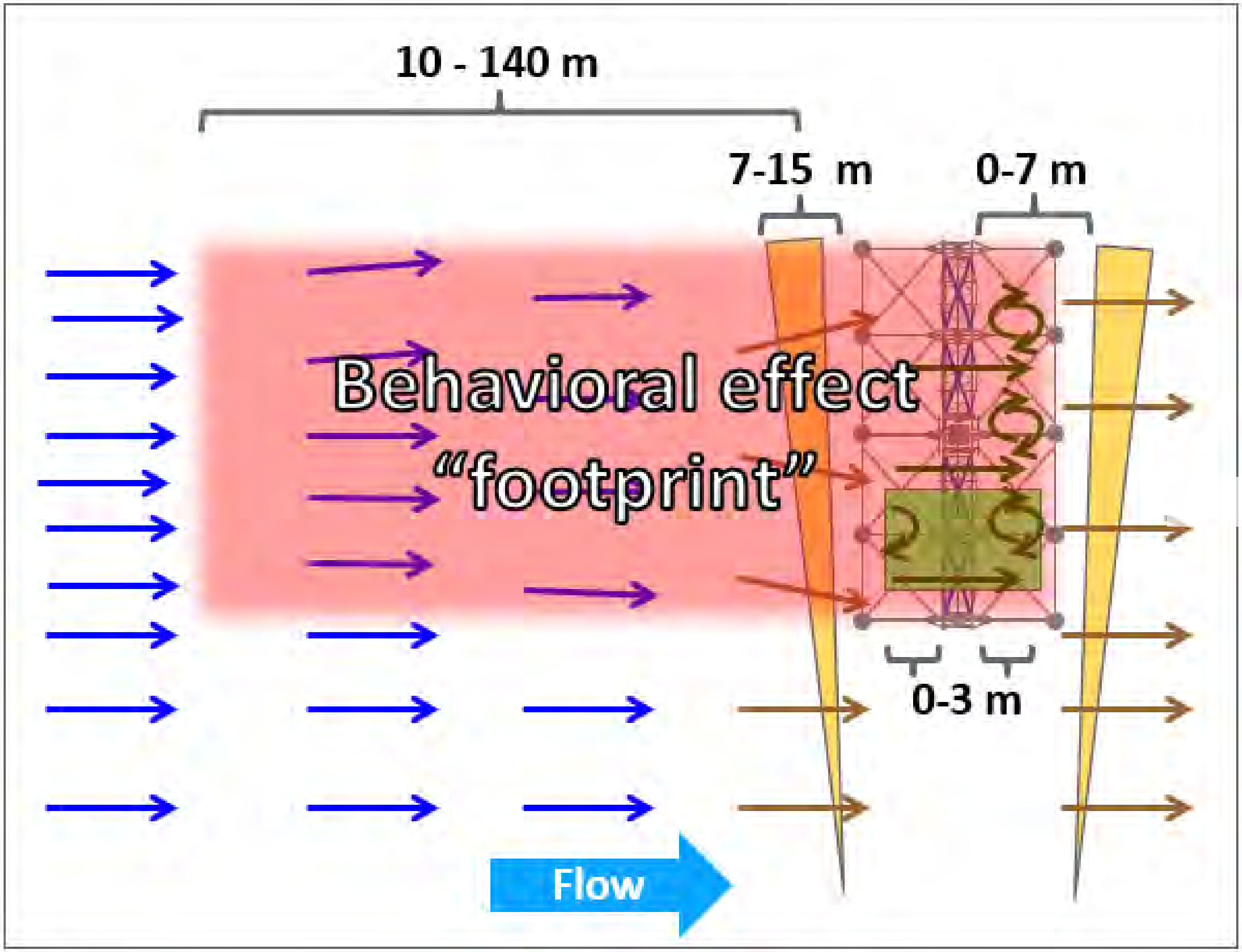


Figure 11.Synthesis of fish studies for ORPC's Cobscook Bay Tidal Energy Project (Source: University of Maine)

5.0 PROJECT NEXUS

The Fish Monitoring Plan prepared by ORPC and UAF describes a rationale for preparing the monitoring plan, objectives, and how the objectives will be achieved. The issues, observations, and data required for this process are based on content as per FERC regulations §5.6(d)(3)(i), §5.6(d)(3)(iv), §5.11, §5.18(b)(5)(ii)(B), and §5.18(b)(5)(ii)(C). In addition, the information needs of ADF&G to prepare a Fish Habitat Permit (FHP, Title 16 Permit) are considered as based on Durst (2011). The primary objective of the monitoring program is to document how migrating fish interact with and pass the RivGen® device(s).

6.0 METHODOLOGY

The Fish Monitoring Plan has been developed to incorporate lessons learned from 2014 and 2015 testing of the RivGen® Power System at the Project location in the Kvichak River at Igiugig and an adaptive management process. Faculty and staff of UAF College of Fisheries and Ocean Sciences and Alaska Hydrokinetic Energy Research Center (AHERC) will work with the Project lead, IVC, and Project partner, ORPC, to monitor interactions between fishes and a hydrokinetic turbine in the Kvichak River, near Igiugig, Alaska.

6.1 OVERVIEW

The Fish Monitoring Plan has been prepared by ORPC and UAF with input from Project partners at UW and PNNL. The issues, observations, and data required for the Fish Monitoring Plan are based on content required by FERC regulations §5.6(d)(3)(i), §5.6(d)(3)(iv), §5.11, §5.18(b)(5)(ii)(B), and §5.18(b)(5)(ii)(C). In addition, the information needs of ADF&G to prepare a Fish Habitat Permit (FHP, Title 16 Permit) were considered as based on Durst (2011).

Monitoring results and lessons learned from the 2014 and 2015 RivGen® Power System testing at the Project location has informed the Fish Monitoring Plan. This Plan will include monitoring equipment, operation schedule, and revised monitoring costs.

6.2 EQUIPMENT

It is recommended that two pairs of underwater stereo cameras (two cameras per stereo pair for a total of four cameras) will be mounted on the port pontoon of the pontoon support structure to record fish behavior. Forward camera(s) will be placed so that the field of view (FOV) includes both the upstream end and the side of the devices. Aft camera(s) will be placed so that the FOV include the downstream end and the side of the devices. Cameras will be mounted in a way that most effectively captures the intended FOVs (Figures 12 and 13).

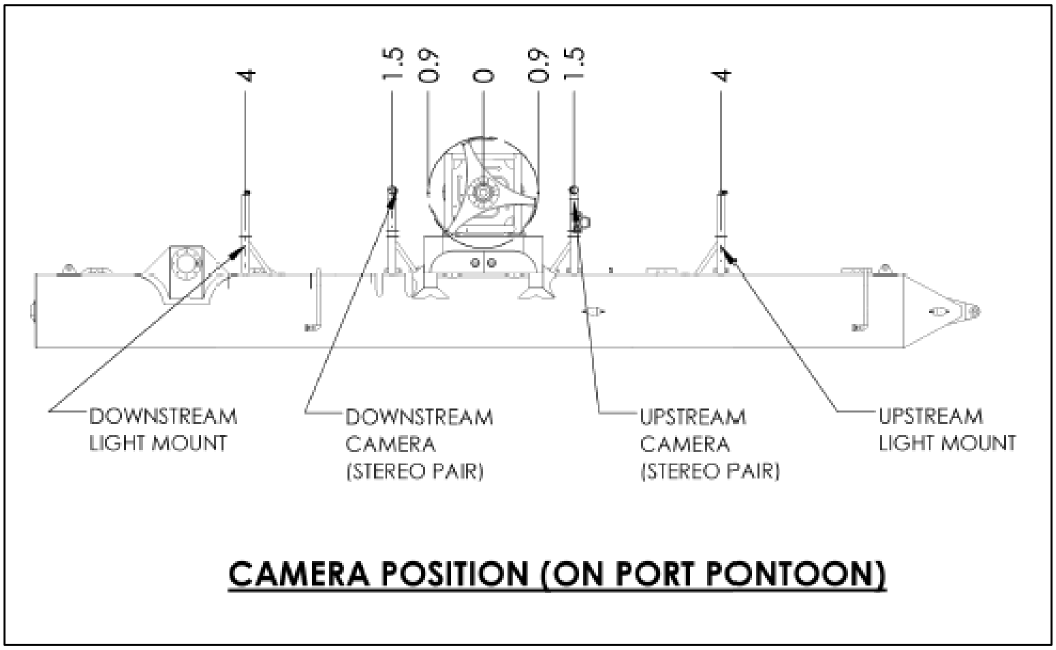


Figure 12. Cross-section view of RivGen® device environmental monitoring system. River flow from right to left. Dimensions in meters. (Source: ORPC)

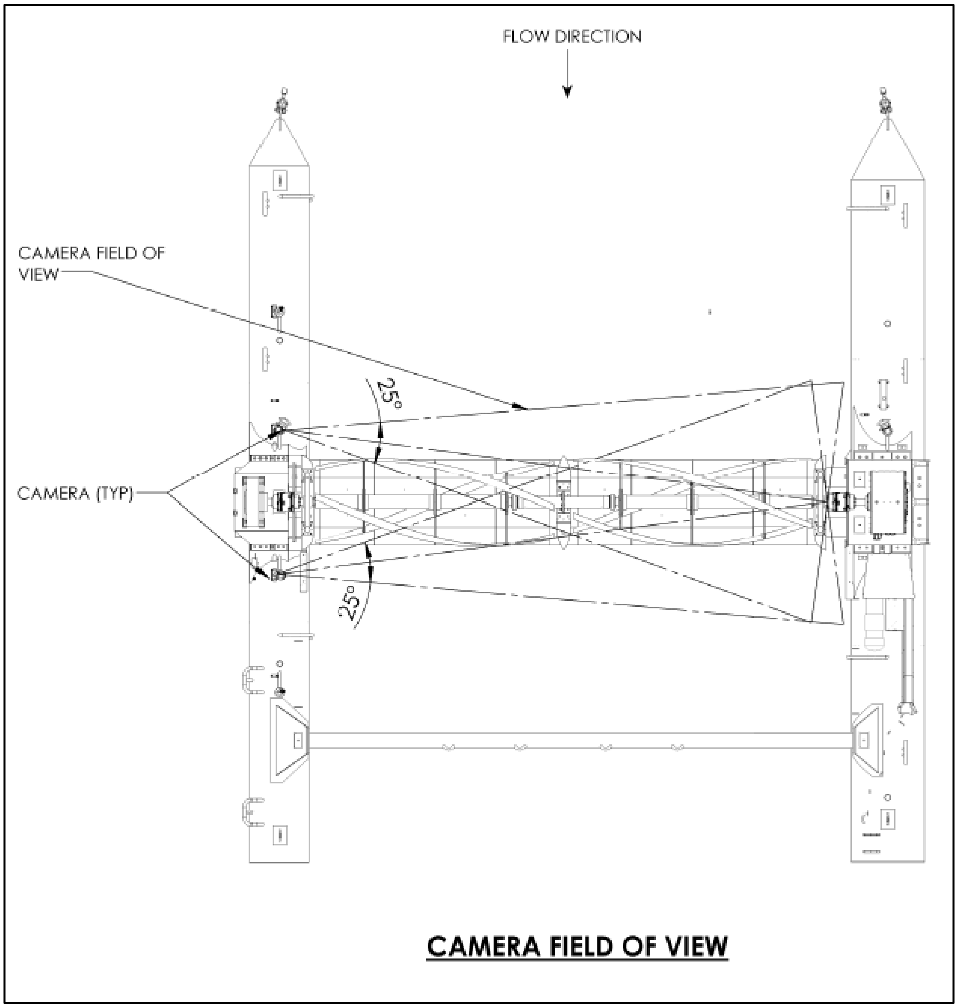


Figure 13. Plan view of RivGen® device environmental monitoring system showing camera beam angles. River flow from top to bottom.

6.2.1 CAMERAS

Cameras will be high resolution (600 TV Line) monochrome cameras capable of operating in low light conditions (0.01 lux). Cameras will have a wide-angle lens with a 25° FOV and an operating distance of 18 m (Table 7). Upstream and downstream cameras will be set in a stereo-optic configuration within a marine science grade acrylic enclosure with clear wide-angle dome ports and wet-mateable connectors. A polyurethane-jacketed data/power cable will run from each camera to the environmental monitoring module located on the device. Specifications for the camera and associated accessories are included in Attachment 3.

Table 7. *Environmental Monitoring Cameras. Source: ORPC*

Lens focal length	Minimum Camera Resolution	Estimated total pixels on target at Minimum resolution	Uncompressed data rate (MB per frame)
16 mm	800x600	25	0.96

6.2.2 LIGHTS

The environmental monitoring system will include lights to provide better illumination of the video field of view during night time monitoring. Because a sonar camera (e.g., DIDSON or ARIS) will not be included in the environmental monitoring system, it will not be possible to assess the effects of the lights on fish behavior, specifically whether the lights are an attractant or repellent to fishes. Generally, it is thought that lights are an attractant, so behavioral analyses conducted while the lights are on 10 minutes of each hour will be considered to represent the upper bound in number of fish/turbine interactions. During time periods when fish behavior will not be observed (50 minutes of each hour), lights will be turned off. Light specifications are included in Table 8 and Attachment 3.

Table 8. *Environmental Monitoring Lights. Source: ORPC*

Typical Lumen Output (Flood)	Efficacy	Color	Beam Angle
0-10,000 dimmable	94 lm/w[1]	Daylight White (5,000 k ~ 6,000 k)	Spot: 35 degrees

6.3 DATA ANALYSIS

During initial deployment of the Phase I RivGen® device (Summer 2019), UAF personnel will be present onsite in Igiugig for deployment of cameras and initial video collection. While onsite, UAF personnel will evaluate video to ensure that the collected footage is appropriate for monitoring interactions between fishes and the turbine. Additionally, UAF personnel will work with PNNL personnel and project partners to design the most feasible method for delivering recorded video footage to the UAF campus for subsequent analyses of potential fish/turbine interactions. Once the Project lead and partners are comfortable with the camera set up and method of video footage delivery, UAF personnel will conduct video analyses, in consultation with PNNL, at the UAF campus (approximately July 2019-May 2020). Video captured by cameras deployed at the base of the turbine will be analyzed to identify interactions between fishes and the turbine, including strikes, avoidance behavior, and lack of reaction utilizing the EyeSea software developed by PNNL. For each interaction between fishes and the turbine, species will be identified, and size will be estimated.

Should the turbine be deployed in late Spring 2020 it will likely be before or during the peak of the sockeye salmon smolt outmigration. Sockeye salmon smolt typically emigrate from Lake Iliamna to the Bering Sea, via the Kvichak River in a large pulse lasting <4 weeks (last two weeks of May and first two weeks of June) and consisting of 10s of millions of individuals (Nemeth et al. 2014). Because of the socioeconomic importance of sockeye salmon coupled with the short, intense emigration through the Kvichak River, this has been identified as ADF&G's priority monitoring period due to the elevated potential for fish/turbine interactions. As a result, UAF personnel will be on-site at all times while the turbine is deployed during the sockeye smolt outmigration from May 21 through June 10, 2020 and will conduct video analyses, as requested by ADFG. The adult sockeye salmon migration (25 June to 15 July) has also been identified as a priority time period. During priority time periods, 10 minutes of every hour around the clock will be recorded. The video collected will be run through supervised analysis each afternoon by EyeSea software, in which the software will identify fish interaction events and UAF fish biologists will classify the events after identification. After daily video review, daily summaries of fish/turbine interactions will be provided to IVC, ORPC, ADFG and interested parties as part of the adaptive management plan. Additionally, once every three days, validation of EyeSea software will be accomplished by comparing results of identification of fish interactions by EyeSea software and UAF fish biologists. During this validation, one total hour of randomly chosen 10-minute video segments (6 total segments x 10 minutes each segment = 1 total hour) will be reviewed by both EyeSea software and visually by UAF fish biologists, and the number of fish interactions will be compared. As the rigor the EyeSea software in reliably detecting fish events is validated intervals between groundtruthing events will be extended based on input from the AMT. Finally, during non-priority time periods, video recording duration will be reduced as part of the AMP. For example, during winter, video of 10 minutes of every 3 hours will be recorded and run through supervised analysis.

6.3.1 EYESEA SOFTWARE

In parallel to PNNL's analysis of the 2015 video data collected around the RivGen® device, EyeSea was developed to convert the video data to a usable form and to enable manual and automated analysis of the data that would have a standardized output. The project goal was to develop software algorithms that could identify video frames with fish present to inform and accelerate manual analysis. To achieve this, independent manual analysis was completed for specific video clips (i.e., visual analysis and annotation by a human observer was the standard for assessing the algorithms). The analysis process indicated that some confounding aspects of the algorithm development could potentially be solved with recommended improvements in the initial camera data collection methods.

For the algorithm development, background subtraction, optical flow, and Deep Learning techniques were considered. The Deep Learning approach was determined to need too much training data for this application, so its use was not continued. The optical flow analysis was considered promising, but did not give immediate results, so it needs further investigation. Therefore, background subtraction was the primary focus in algorithm development. Three methods of background subtraction were tried: Robust Principal Components Analysis (RPCA), Gaussian Mixture Model (GMM), and Video Background Extraction (ViBE). A classification technique was then applied to the foreground images to determine fish presence. Using this combination, fish could be accurately identified when occupying a higher number of pixels (>200 pixels, 98.2 percent correct; 100–200 pixels, 99.6 percent correct; 5–100 pixels, 85.4 percent correct; 2–5 pixels, 66.3 percent correct).

ORPC and UAF are collaborating with PNNL to use the EyeSea software as a tool for analyzing data collected as part of this Project. As part of this collaboration, video collected during the Project will be used to further refine the software for the future. Additionally, it is anticipated that PNNL will continue to make improvements to the software prior to implementation in 2019. The full PNNL report (Matzner, et al. 2017), including both data analysis and algorithm development, is included as Attachment 2.

6.3.2 DATA STORAGE

Data Storage will include mention of the following:

- Data will be stored on two separate Tb-sized Raid Hardrives or similar.
- Data will be accessed daily when UAF personnel are in field and a minimum of bi weekly when UAF personnel are reviewing data remotely.

6.3.3 SAMPLE RATE

Due to data volume and hard drive storage constraints, ten minutes of each hour throughout a 24 hour period will be recorded by video cameras regardless of whether the turbine is spinning or not, during priority periods. For this study, priority periods are defined as the sockeye smolt outmigration (May 21-June 10) and the adult sockeye salmon migration (25 June to 15 July). These video recordings will be stored on hard drives. Each afternoon, video footage will be run through supervised analysis by UAF personnel. In this supervised analysis, EyeSea software will identify fish interactions and these will subsequently be classified by UAF fish biologists. During expected migratory periods of smolts and adults, we will start by running four hours of video per day through supervised analysis and interaction classification. After a week of daily summaries are produced and sent to ADFG, IVC will consult with ADF&G to confirm the sampling rate is adequate to assess fish interactions and if necessary make adjustments through the adaptive management process. For example, if fish interactions are relatively common and/or fish interactions are difficult to visually classify, the amount of recorded video could be increased (for example, to 15 min of each hour). In contrast, if fish interactions are extremely rare and there are no documented turbine-fish collisions, the amount of recorded video could be decreased, with the concurrence of ADF&G and the Adaptive Management Team, to wisely use staff and equipment resources. During non-priority time periods, such as winter, video of 10 minutes of every 3 hours will be recorded and run through supervised analysis. Reporting to ADF&G during these non-priority time periods will initially occur on a bimonthly basis but may be reduced to monthly summary reports if fish interactions are extremely rare and non-consequential. During shoulder seasons between priority and non-priority time periods, video sampling rate will be gradually scaled back at a rate with which IVC, ORPC, UAF and ADFG are comfortable.

6.4 FIELD VERIFICATION

UAF personnel will be onsite during initial deployment in 2019 and any operations that overlap with the main migration timing of juvenile sockeye, which migrate downstream from approximately May 21 through June 10 annually (Figure 6). UAF personnel will adjust camera settings and operational modes, and review data acquired through different settings to optimize data acquisition during these sensitive periods. Furthermore, they will process and review data on a daily basis, perform manual groundtruthing checks to ensure EyeSea software is adequately identifying fish events within a reasonable margin of error, and report any fish events that reveal likely impacts to ADF&G. Manual groundtruthing will initially occur once every three days during priority periods. To accomplish this validation of EyeSea software, one total hour of randomly chosen 10 minute video segments (6 total segments x 10 minutes each segment = 1 total hour) will be reviewed by both EyeSea software and visually by UAF fish biologists, and the number of fish interactions will be compared. As the rigor the EyeSea software in reliably detecting fish events is validated intervals between groundtruthing events will be extended based on input from the AMT.

6.5 ADAPTIVE MANAGEMENT

The project team will implement an adaptive management approach that has proven valuable in previous projects implemented by ORPC. ORPC has demonstrated that through an engaging and open adaptive management process, project license conditions can be modified to keep levels of monitoring proportional to measured environmental risk. Adaptive management is a structured, iterative process of scientific decision making in the face of uncertainty with an aim to reducing uncertainty over time via system monitoring.

ORPC developed an Adaptive Management Plan as a condition of its FERC pilot project license for the Cobscook Bay Tidal Energy Project in Maine. The plan and the project's adaptive management team have been touted in the industry as a model based on its transparency and demonstrated actions. Key elements of the Plan's success include the following:

- Strong relationships built on integrity and trust
- Science-based data collection by respected technical advisors
- Initiating adaptive approach in the pre-consent phase and continuing through project operation
- Building an environmental interaction knowledge base of ORPC power systems deployed at other sites and pertinent global industry information

ORPC has developed monitoring plans for the Igiugig Hydrokinetic Project that will advance the Project in an environmentally responsible manner and build on lessons learned from past renewable energy projects and data gathered around its power systems, including 2014 and 2015 testing of the RivGen® Power System at the Project location. An Adaptive Management Plan is included in Appendix A of the FPLA.

7.0 REPORTING

IVC will file full summary reports with the regulatory agencies annually. These reports, authored by UAF fisheries personnel, will describe analyses conducted on video footage collected by cameras deployed on the turbine. The results of these analyses will directly address the four study objectives:

1. Document the presence and timing of fish at the RivGen® device by species and life stage
2. Characterize fish movements past the RivGen® device during the sockeye salmon smolt out migration
3. Describe the behavioral response of sockeye salmon smolt that comes into contact with the RivGen® device
4. Describe any observable acute effects from contact with the RivGen® device, including disorientation, injury, or mortality during the sockeye salmon smolt out migration

Should altered fish activity be noted at any time during the observations, the appropriate federal and state resource agencies will be notified for consultation. This is particularly important during the sockeye salmon smolt outmigration, when analyses will be conducted daily.

8.0 SCHEDULE

Pending receipt of the FERC pilot license, monitoring will be performed around the single-device RivGen® Power System beginning in 2019. UAF will review and certify all data collected, and IVC will issue reports on monitoring progress to the appropriate regulatory agencies for technical review biannually. Monitoring methods and frequency will be reviewed by IVC and its partners with appropriate regulatory agencies and modifications made as appropriate through an adaptive management process. This process will inform continued monitoring for Phase I as well as be used to determine appropriate levels of monitoring for Phase II prior to the installation of the second RivGen® device. All data collected in this monitoring effort will be in the public domain, in accordance with the public nature of the FERC pilot license process.

9.0 BUDGET

IVC is targeting an average annual environmental monitoring cost of approximately $30,000 over the course of the ten-year pilot license. It is anticipated that levels of annual monitoring, and associated costs, costs will be higher during the first several years of the Project when initial monitoring efforts will cost approximately $175,000 and be reduced in accordance with protocols established in the Project Adaptive Management Plan.

10.0 DISCUSSION OF ALTERNATIVE APPROACHES

IVC believes the Project has little potential to affect fish and wildlife. ORPC has been testing hydrokinetic power devices in field environments since 2007, and during this time, has not observed any negative environmental effects of these devices. In addition, the Project is small relative to the available habitat in the Kvichak River and will be monitored for direct interaction with aquatic life. IVC believes that the Fish Monitoring Plan, in conjunction with the Adaptive Management Plan, is sufficient to inform licensing decisions, that it is appropriate to the size and scope of the Project, and that the approaches proposed in the study are in general accordance with those recommended by the resource agencies.

11.0 REFERENCES

Bevelhimer, M., Scherelis, C., Colby, J., Tomichek, C., and Adonizio, M.A. 2015. Fish behavioral response during hydrokinetic turbine encounters based on multi-beam hydroacoustics results. In Proceedings of the 3rd Marine Energy Technology Symposium (METS), April 27–29, 2015, Washington, D.C.

Broadhurst, Melanie, Sue Barr, and C. David L. Orme. 2014. “In-Situ Ecological Interactions with a Deployed Tidal Energy Device; an Observational Pilot Study.” Ocean & Coastal Management, vol. 99, 31-38. doi:10.1016/j.ocecoaman.2014.06.008

Durst, J. (2011). Fish population concerns related to hydrokinetic development and permit requirements in state waters. ADF&G. Presented at the Alaska Hydrokinetics Technical Conference, Dena’ina Center, Anchorage, AK.

Hammar, Linus, Sandra Andersson, and Linda Eggertsen. 2013. "Hydrokinetic Turbine Effects on Fish Swimming Behaviour." PLoS ONE, vol. 8(12), 1- 12. http://dx.doi.org/10.1371/journal.pone.0084141

LGL (2015). LGL Alaska Research Associates, Inc. Fish and Wildlife Monitoring Plans and Reporting for RivGen® Power System testing, Igiugig, Alaska, 2014 and 2015.

LGL Alaska Research Associates, Inc. (unpublished data). An historical review of the Bristol Bay smolt monitoring program and recommendations for future smolt sampling. Unpublished report prepared by the Bristol Bay Science and Research Institute, Dillingham, AK.

Matzner, S.; Trostle, C.; Staines, G.; Hull, R.; Avila, A.; Harker-Klimes, G. (2017). Triton: Igiugig Fish Video Analysis. Report by Pacific Northwest National Laboratory (PNNL). pp 60.

Nemeth, M. J., Priest, J.T. and Patterson, H.M., 2014. Assessment of fish and wildlife presence near two river instream energy conversion devices in the Kvichak River, Alaska in 2014. Final report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, for Gray Stassel Engineering, Anchorage, AK. 28 pp. + appendices.

Nemeth, M. J., G. D. Wade, D. J. Degan, and M. R. Link. 2014. Sockeye salmon smolt abundance and inriver distribution in Bristol Bay, Alaska: results from the Kvichak, Ugashik, and Egegik rivers in 2013. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK, 55 pp. + appendices.

Shen, H., Zydlewski, G.B., Viehman, H.A., Staines, G. 2016. Estimating the probability of fish encountering a marine hydrokinetic device. Renewable Energy 97: 746-756.

TerraSond (2011). Kvichak River RISEC Project. Resource reconnaissance and physical characterization. Final Report. Prepared by TerraSond Ltd., Palmer, AK for Dept. of Community and Economic Development, AIDEA/AEA, Rural Energy Group, Anchorage, AK

Thomson, J., Kilcher, L. and Polagye, B. (2014). Flow measurements during RivGen® deployment Igiugig, AK. 2014. U.S. Department of Energy, DE-EE0006397.

Viehman, H. 2012. Fish in a tidally dynamic region in Maine: Hydroacoustic assessments in relation to tidal power development. Master's thesis. University of Maine, Orono, Maine, USA.

Viehman, H., Zydlewski, G.B., McCleave, J., and Staines, G .2014. Using acoustics to understand fish presence and vertical distribution in a tidally dynamic region targeted for energy extraction. Estuaries and Coasts. Doi:10.1007/s12237-014-9776-

Viehman, H., and Zydlewski, G.B .2014. Fish interaction with a commercial-scale tidal energy device in a field setting. Estuaries and Coasts. doi:10.1007/s12237-014-9767-8

Viehman, H., Zydlewski, G.B., McCleave, J., Staines, G. 2015. Using acoustics to understand fish presence and vertical distribution in a tidally dynamic region targeted for energy extraction. Estuaries and Coasts. 38(S1): 215-226.

Viehman, H., Zydlewski, G.B. 2015. Fish interaction with a commercial-scale tidal energy device in a field setting. Estuaries and Coasts. 38(S1): 241-252.

Viehman, H. 2016. Hydroacoustic analysis of the effects of a tidal power turbine on fishes. PhD Dissertation. University of Maine, Orono, Maine, USA.

Viehman H, Zydlewski GB. 2017. Multi-scale temporal patterns in fish passage in a high-velocity tidal channel. PLoS ONE.12(5), e0176405.

Attachment 1

Data Analysis for Monitoring of the RivGen® in the Kvichak River, 2015
LGL Alaska Research Associates, Inc., November 11, 2015

Alaska Research Associates, Inc.

LGL Alaska Research Associates, Inc.
2000 W International Airport Road Suite C1
Anchorage, Alaska 99502 USA
Tel: (907) 562-3339 Fax: (907) 562-7223

To: Nate Johnson and Monty Worthington, Ocean Renewable Power Company
From: Justin Priest and Matt Nemeth, LGL Alaska Research Associates, Inc.

Re: Data Analysis for Monitoring of the RivGen® in the Kvichak River, 2015

Date: November 11, 2015

This memo summarizes the preliminary data analyses from fish and wildlife monitoring at the RivGen® Power System, a submerged hydrokinetic device operated by the Ocean Renewable Power Company (ORPC) in the Kvichak River in July and August 2015. Monitoring was performed by LGL Alaska Research Associates, Inc., in accordance with the 2015 Monitoring Plan developed in March 2015 and Alaska Department of Fish and Game (ADF&G) Fish Habitat Permit FH 15-II-0038. Data presented here are preliminary and may change after final QA/QC. Interim results and figures were also presented in monthly progress reports at the end of July and August.

Fish movements at the RivGen® device were described using video footage collected from five underwater cameras mounted to the pontoons of the power system. Video footage was collected 24 hours/day July 19–25 and again August 19–27, 2015; review was done by watching the first 10 minutes of a selected hour from each of the four primary cameras (the fifth camera was a backup). Spatially, the camera field of view captured the port side of the RivGen® device, including upstream and downstream views of the port side turbine (only). In accordance with the Monitoring Plan, footage was reviewed to achieve partial temporal coverage during different categories of turbine operating status and daytime/nighttime conditions (Figure 1). At night, two underwater lights lit the viewing area. In addition, bird and marine mammal surveys were conducted for 15 minutes each morning of monitoring. Methods and the overall approach were similar to those described for the demonstration study conducted at the same site in 2014.

Blocks of video footage from portions of 238 different hours were reviewed inseason in 2015. There were 359 events with fish, composed of approximately 1,202 individual fish from at least six species. The majority of fish observations were of solitary fish; the largest school was approximately 100 fish. Species composition varied from July to August and also from day to night. In particular, salmon smolt were almost exclusively seen at night, and were more prevalent in July than August. Several instances of fish moving through the RivGen® turbine were noted and reported inseason as part of the Adaptive Management Plan. We did not detect any obvious physical injuries to fish, and saw no altered behavior by wildlife near the RivGen® device. Cameras, lights, and power system components all operated reliably. All video footage has been archived.

Preliminary results are presented in more detail below, organized by each Objective from the 2015 Monitoring Plan. Where appropriate, data are also presented in Tables and Figures below.

Data analyses listed by 2015 monitoring objective:

1) Summary of monitoring effort.
   a) Video review effort, by RivGen® device status and time group.
      (1) Table 1. Review effort by RivGen® device status and month.
      (2) Figure 1. Daily schedule of RivGen® device operations and data review effort.

2) Presence and timing of fish and wildlife at the RivGen® device (Objective 1 from Monitoring Plan).
   a) Fish monitoring observations.
      (1) Table 2. Number of fish observation events and number of fish, by month, day/night status, and RivGen® device operating status.
      (2) Table 3. Species and number of fish observed, by month and day/night status.
      (3) Table 4. Fish per reviewed hour block, by species, month, and day/night status.
      (4) Figure 2. Hourly summary of review effort, raw observations, and observations standardized by review effort for fish.
   b) Wildlife monitoring observations.
      (1) Table 5. Bird and wildlife observations by species group.

3) Characterize fish movements past the RivGen® device (Objective 2).
   a) Basic movement type.
      (1) Table 6. Movement classification/direction by species, day/night, and RivGen® status.
   b) Movements in relation to the RivGen® device.
      (1) Table A (to be determined): Movement of fish under, over, or through the turbine area.
      (2) Evidence of passage delay: We saw no obvious evidence of passage delay. Adult salmon were clearly able to move around the device, both going upstream (mostly in the daytime), or downstream (mostly at night). Adult salmon also showed general milling behavior that did not appear to be repeated attempts to move past the device. Finally, juvenile salmon were seen transiting past the device, usually travelling downstream. Juvenile salmon sometimes held downstream of the turbine briefly.

4) Describe the behavioral response of fish or wildlife contacting the RivGen® device (Objective 3).
   a) Table B (to be determined): Number of fish showing obvious attraction to, avoidance of, or sheltering at the RivGen® device in 2015, by species and day/night status.

b) Evidence of avoidance or attraction by fish: We saw no obvious evidence of attraction to the RivGen® device. Any such attraction would likely have only been detected as fish markedly altering course to move directly towards the RivGen® device; we saw no instances of this. We did see instances of avoidance by fish moving downstream, which sometimes altered course to move either over or under the turbine. Avoidance by upstream-moving fish (i.e., fish that avoided the RivGen® device altogether by moving away from it before coming into camera view) would not be easily detectable because the fish would have already altered their course before being able to be observed.

c) Evidence of avoidance or attraction by wildlife: There was no evidence of attraction or avoidance by wildlife during the study; all animals observed showed no behavioral changes near the RivGen® device. No marine mammals were observed in 2015.

5) Describe any acute effects from contact with the RivGen® device (Objective 4).

a) Evidence of disorientation, injury, or mortality: Acute effects of fish moving through the RivGen® device, including any potential adverse effects were documented and reported in four Adaptive Management Reports delivered within 48 hours of the incident. We saw no obvious indication of moribund or inert behavior that might indicate injury or mortality. We did see some potential disorientation by juvenile salmon moving downstream. In these events, schools of fish dispersed as they approached the RivGen® device from upstream; afterwards, downstream of the RivGen® device, these fish milled or moved around abruptly in the eddy behind the turbines, before resuming downstream movement.

Table 1. Summary of the review effort during all RivGen® device operational statuses, 2015. "Partial" hours were when turbines only operated during part of an hour block. "Spinning Whole Hour (Stbd turbine only)" hours were operations when only the starboard turbine was operational.

	July		August		Total	
Device Status	Not Reviewed	Reviewed	Not Reviewed	Reviewed	Not Reviewed	Reviewed
Day						
Not Spinning	26	39	25	11	51	50
Partial	1	16		4	1	20
Spinning Whole Hour		44		69	0	113
Spinning Whole Hour (Stbd turbine only)				17	0	17
Day Subtotal	*27*	*99*	*25*	*101*	*52*	*200*
Night						
Not Spinning	32	6	24	3	56	9
Partial		3			0	3
Spinning Whole Hour		1	20	18	20	19
Spinning Whole Hour (Stbd turbine only)			2	7	2	7
Night Subtotal	*32*	*10*	*46*	*28*	*78*	*38*
Total	59	109	71	129	130	238

Table 2. Summary of the total number of fish events and individuals during all device statuses, 2015. A "Fish Event" is defined as an observation of at least one fish during subsampling review. "Spinning Whole Hour (Stbd turbine only)" was when only the starboard turbine was operational.

	July			August			Total	
Device Status	# Fish Events	Total Fish Seen		# Fish Events	Total Fish Seen		# Fish Events	Total Fish Seen
Day								
Not Spinning	17	26		2	3		19	29
Partial	16	39		1	1		17	40
Spinning Whole Hour	57	196		19	19		76	215
Spinning Whole Hour (Stbd turbine only)				10	10		10	10
Day Subtotal	*90*	*261*		*32*	*33*		*122*	*294*
Night								
Not Spinning	150	736		5	5		155	741
Partial	16	75					16	75
Spinning Whole Hour	4	15		49	64		53	79
Spinning Whole Hour (Stbd turbine only)				13	13		13	13
Night Subtotal	*170*	*826*		*67*	*82*		*237*	*908*
Total	260	1,087	0	99	115	0	359	1,202

Table 3. Total number of fish by species during day/night and month, 2015.

	July		August			
Species	Day	Night	Day	Night	Total	Total %
Chum salmon (adult)			14	12	26	2.2%
Coho salmon (adult)			5	2	7	0.6%
Pink salmon (adult)				2	2	0.2%
Sockeye salmon (adult)	259	51	1	1	312	26.0%
Unidentified adult salmon			9	8	17	1.4%
Unidentified juvenile salmonid		773	1	52	826	68.7%
Rainbow trout			1		1	0.1%
Lamprey spp.	1		1	1	3	0.2%
Unknown species	1	2	1	4	8	0.7%
Total	261	826	33	82	1,202	100.0%

Table 4. Number of fish detected per reviewed hour block by species, 2015. Data are standardized to 10-minute review blocks.

	July		August		
Species	Day	Night	Day	Night	Total
Chum salmon (adult)	-	-	0.1	0.4	0.1
Coho salmon (adult)	-	-	0.0	0.1	0.0
Pink salmon (adult)	-	-	0.0	0.1	0.0
Sockeye salmon (adult)	2.6	5.1	0.0	0.0	1.3
Unidentified adult salmon	-	-	0.1	0.3	0.1
Unidentified juvenile salmon	0.0	77.3	0.0	1.9	3.5
Rainbow trout	-	-	0.0	0.0	0.0
Lamprey spp.	0.0	0.0	0.0	0.0	0.0
Unidentified species	0.0	0.2	0.0	0.1	0.0
Total	2.6	82.6	0.3	2.9	5.1

Table 5. Summary of bird and wildlife observations near the RivGen® device, 2015. Data are standardized to the 15-minute sampling periods.

Taxonomic Group	Sightings	Number of individuals sighted	Number of individuals within 15 m of device	Number of individuals per sample period
Passerines	34	41	4	2.7
Bald Eagles	6	7	0	0.5
Other Raptors	1	1	0	0.1
Waterfowl and Loons	8	11	0	0.7
Gulls, Jaegers, and Terns	53	133	0	8.9
Corvids	3	3	0	0.2
Shorebirds	10	12	0	0.8
Terrestrial mammals	0	0	0	0
Marine mammals	0	0	0	0

Table 6. The number of fish events classified by movement type for each species, 2015. Proportions are per subtotaled day and night.

Movement Type	Chum salmon (adult)	Coho salmon (adult)	Pink salmon (adult)	Sockeye salmon (adult)	Unidentified adult salmon	Unidentified juvenile salmon	Rainbow trout	Lamprey spp.	Unidentified species	Total	Subtotal %
Day											
Milling	5	3		33	5				1	47	38.5%
Travel down	4			8	4	1		2	1	20	16.4%
Travel up	2	1		33			1			37	30.3%
Travel, other	2	1		12						15	12.3%
Undetermined				3						3	2.5%
Day Subtotal	*13*	*5*	*0*	*89*	*9*	*1*	*1*	*2*	*2*	*122*	*100.0%*
Night											
Milling	2	1	2	6	2	20			1	34	14.3%
Travel down	9	1		30	6	142		1	4	193	81.4%
Travel up				3		2				5	2.1%
Travel, other						1				1	0.4%
Undetermined				2		2				4	1.7%
Night Subtotal	*11*	*2*	*2*	*41*	*8*	*167*	*0*	*1*	*5*	*237*	*100.0%*
Total	24	7	2	130	17	168	1	3	7	359	100.0%

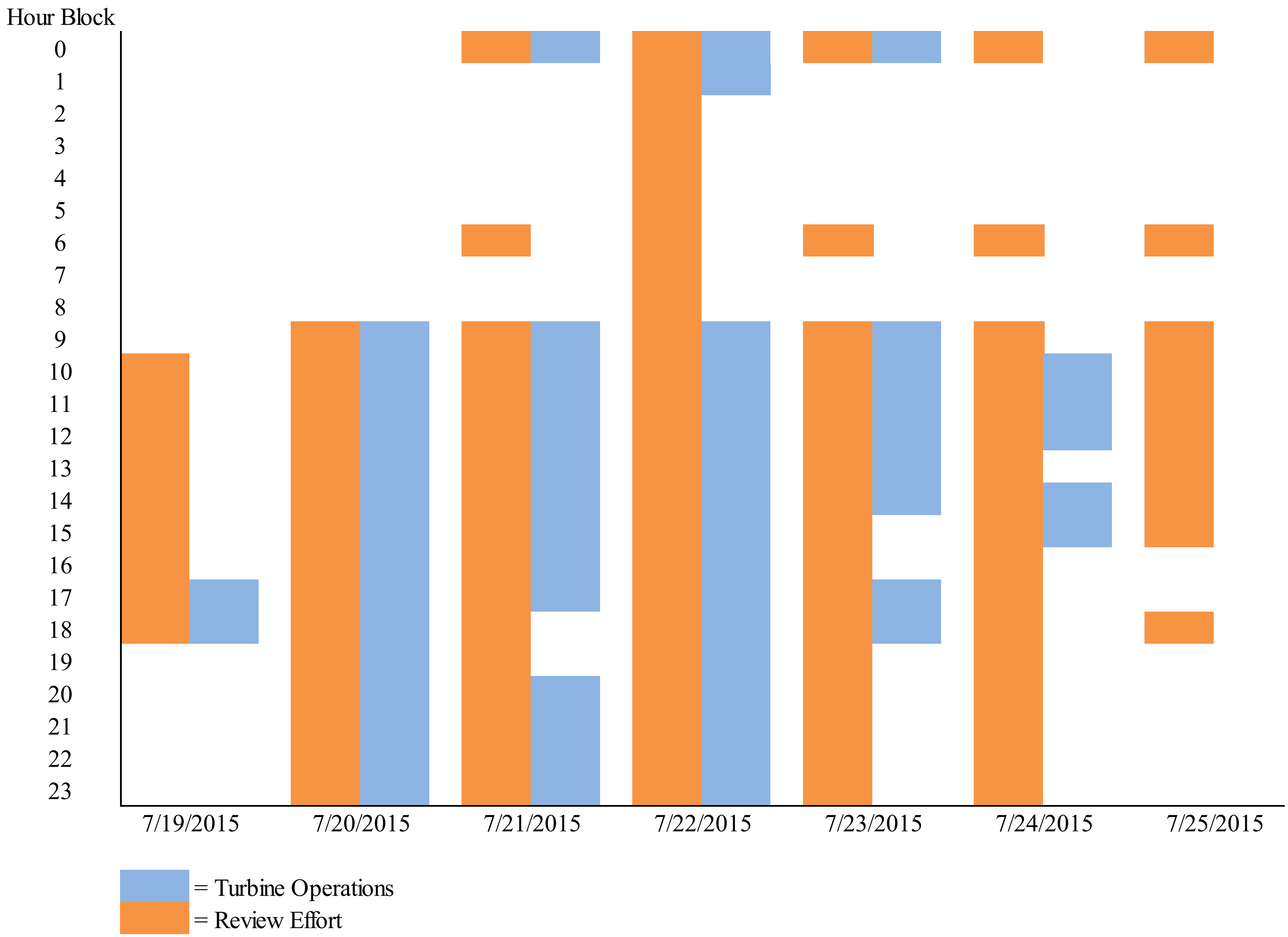


Figure 1A. Summary of turbine operations and review effort of the video system, July 2015. "Half" hours were operations when only one of the two turbine sides was operational.

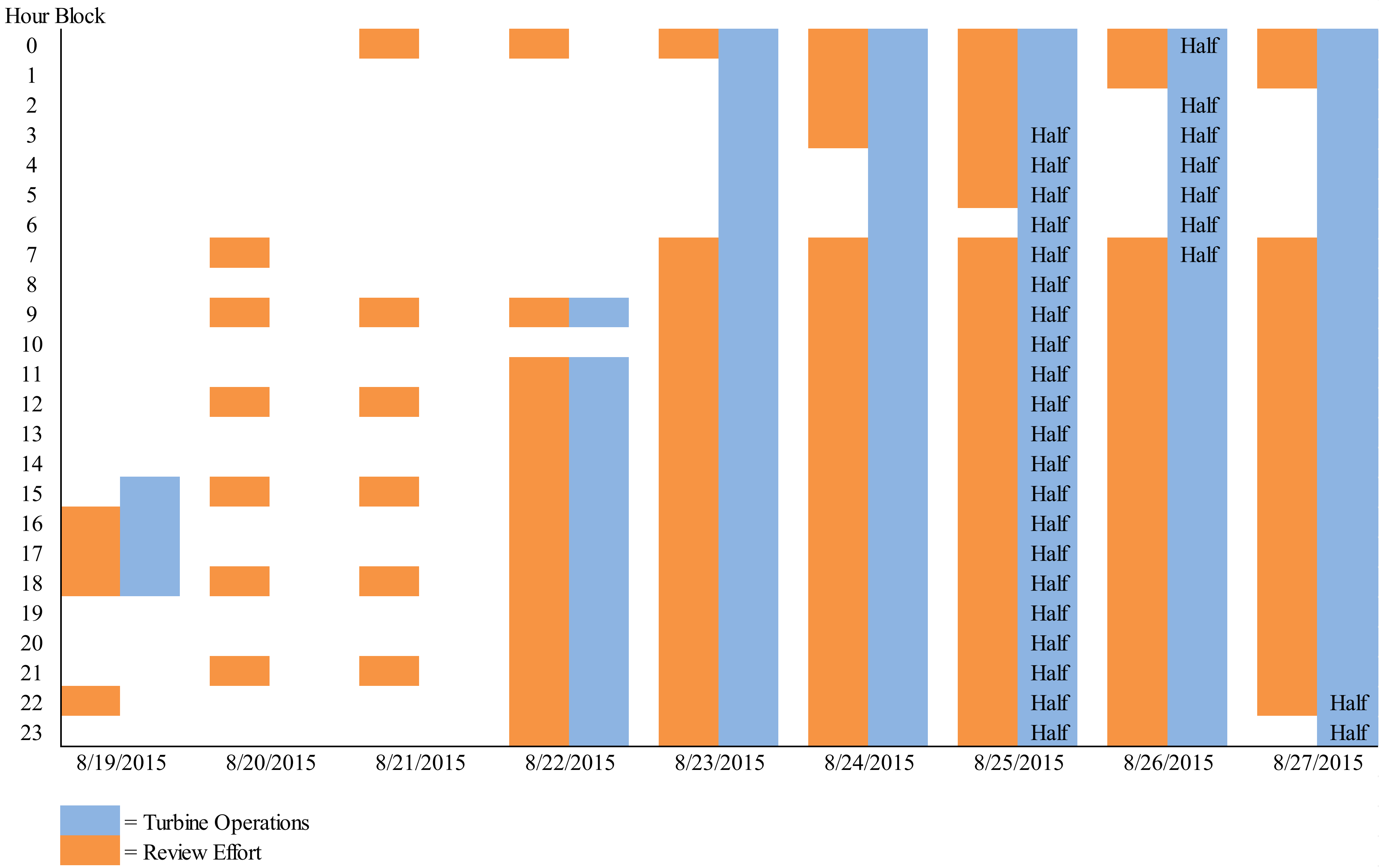


Figure 1B. Summary of turbine operations and review effort of the video system, August 2015. "Half" hours were operations when only the starboard turbine was operational.

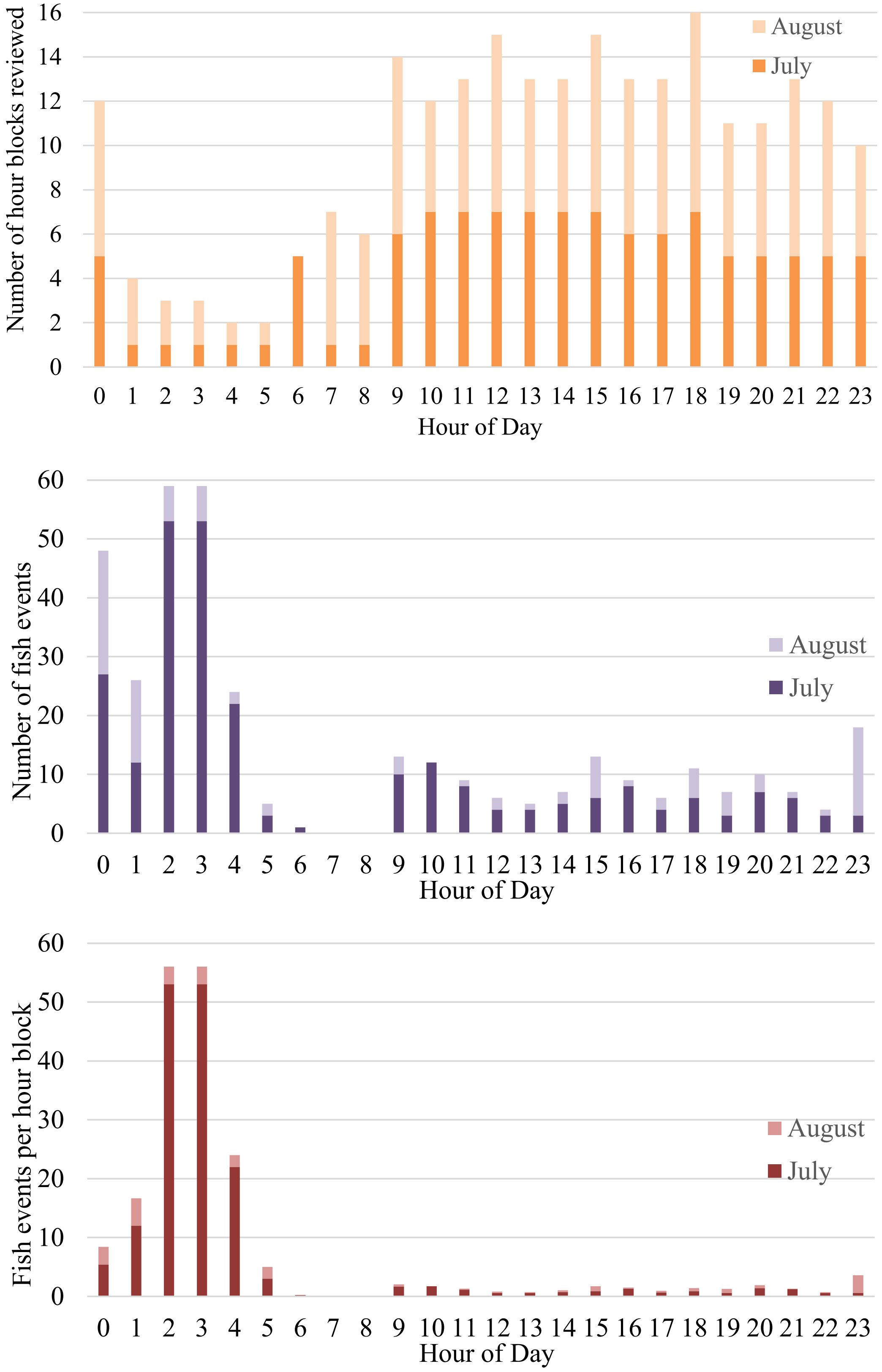


Figure 2A, 2B, 2C. Review effort by hour of day, number of fish events by hour of day, and fish events per hour, by hour of day.

Attachment 2

Triton: Igiugig Fish Video Analysis
PNNL, August 2017

PNNL-26576

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

Triton: Igiugig Fish Video Analysis

Project Report

August 2017

S Matzner
C Trostle
G Staines
R Hull
A Avila
GEL Harker-Klimeš

TRITON

U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

This document was printed on recycled paper.
(8/2010)

Triton: Igiugig Fish Video Analysis

Project Report

August 2017

S Matzner
C Trostle
G Staines
R Hull
A Avila
GEL Harker-Klimeš

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Tidal and instream turbine technologies are currently being investigated for power generation in a variety of locations in the US. An environmental permitting and consenting requirement parallels this exploration generating the need to ensure little or no harm, in the form of strike or collision, befalls marine animals from device deployments. Monitoring methods (e.g., underwater cameras, active acoustics, passive acoustics) around turbine deployments provide empirical data allowing regulators and other stakeholders to assess risk. At present, there is a high level of concern and limited data precluding robust conclusions, which creates a challenge to regulators who must make decisions based on perceived risk versus actual risk. However, the data that are currently available to the scientific community for analysis indicate the issue to be of low risk to date, and strike or collision to be rare events. One such dataset that provides insight to the rarity of strike and collision risk to fish came from an instream turbine deployment in Alaska that used underwater video as the monitoring method.

This document describes the analysis of video data collected around the Ocean Renewable Power Company's RivGen® device deployed in the Kvichak River during July and August 2015 to gain an understanding of the implications of using underwater video cameras as a fish monitoring technique. The data were analyzed manually and used to develop automated algorithms for detecting fish in the video frames and describing their interaction behavior relative to the device. In addition, Pacific Northwest National Laboratory (PNNL) researchers developed a web application, EyeSea, to combine manual and automated processing, so that ultimately the automated algorithms could be used to identify where human analysis was needed (i.e., when fish are present in video frames).

The goal of the project was to develop software algorithms that could identify video frames with fish present to inform and accelerate manual analysis. To achieve this, independent manual analysis was completed for specific video clips (i.e., visual analysis and annotation by a human observer was the standard for assessing the algorithms). The analysis process indicated that some confounding aspects of the algorithm development could potentially be solved with recommended improvements in the initial camera data collection methods.

The manual analysis began to look at all data from the start of deployment of the RivGen® device, primarily using video from Camera 2 that looked directly at the upstream side of the turbine so any interaction could be identified; this was to ensure rare events were seen, and initially focused on Nighttime Data when more fish were present. This process highlighted the amount of time it takes to identify fish, and ultimately only 42.33 hours of video were reviewed because of the time-consuming analysis. The data were classified as "Fish" when the reviewer was confident it was a fish, and "Maybe" fish when it was difficult to distinguish. The two classes were distinguished based on the movement, shape, and color characteristics. Fish Events were further classified by "adult", "juvenile", or "unidentifiable" age. Behavioral attributes were noted and were broadly divided into Passive and Avoidance activities. In over 42 hours of the data reviewed, there were only 20 potential contact interactions, of which 3 were Maybe classifications, 12 were juveniles, and 5 were adults. While only 11.5% of the video data were analyzed from Camera 2, these results are from the time when most fish were present over the turbine deployment period (from Alaska Department of Fish and Game data) and provide preliminary evidence that fish strike or collision of fish in the Kvichak River with an instream turbine is rare.

On only one occasion was an actual contact confirmed, and this was an adult fish that contacted the camera, not the turbine itself. This experience highlights the difficulties associated with confirming a strike or collision event as either having occurred or having been a near-miss. More interactions were

detected at night; this was probably biased by nighttime use of artificial light, which may have attracted fish, but also could have increased detection probability because the light is reflected from the fish itself.

For the algorithm development, background subtraction, optical flow, and Deep Learning techniques were considered. The Deep Learning approach was determined to need too much training data for this application, so its use was not continued. The optical flow analysis was considered promising, but did not give immediate results, so it needs further investigation. Therefore, background subtraction was the main focus in algorithm development. Three methods of background subtraction were tried: Robust Principal Components Analysis (RPCA), Gaussian Mixture Model (GMM), and Video Background Extraction (ViBE). A classification technique was then applied to the foreground images to determine fish presence. Using this combination, fish could be accurately identified when occupying a higher number of pixels (>200 pixels, 98.2% correct; 100–200 pixels, 99.6% correct; 5–100 pixels, 85.4% correct; 2–5 pixels, 66.3% correct).

In parallel, EyeSea was developed to convert the video data to a usable form and to enable manual and automated analysis of the data that would have a standardized output.

Recommendations for further research, and optimizing methods for enhancing data collection and analysis include the following:

- Research
  - Conduct more studies of the effect of lights on fish behavior.
  - Investigate the use of low light video applications as an alternative to using lights.
  - Further investigate optical flow techniques and their applicability for automated analysis.
  - Further refine the parameters for background subtraction in automated analysis.
- Standardized techniques
  - Include markings on the turbines to determine relative range and size of fish within the field of view.
  - Use a standardized (non-proprietary) video format that has a consistent frame rate of at least 25 frames per second.
  - Use a scientific camera designed for underwater measurement in low light environments that has a field of view appropriate for the observations and a pixel resolution high enough to determine fish within the given range.
  - Carefully consider the use of lights and how they illuminate the areas of interest.
  - Standardized and detailed record keeping and metadata collection
  - Use other monitoring technologies (e.g., strain sensors on turbine blades) to determine actual collision or strike events.

Acknowledgments

The authors thank the invaluable contribution of the Advisory Committee members who steered how the data were analyzed, and provided input for solutions: Nathan Johnson (Ocean Renewable Power Company), Steve Brunton (University of Washington), Gayle Zydlewski (University of Maine) and Andrea Copping (Pacific Northwest National Laboratory). PNNL also thanks the Ocean Renewable Power Company team in Alaska who provided information about the deployment, and Justin Priest and the team from LGL Alaska who provided information about the initial processing techniques.

PNNL also thanks the U.S. Department of Energy for funding this project and providing ongoing advice.

Acronyms and Abbreviations

DOE	U.S. Department of Energy
FY	fiscal year
GMM	Gaussian Mixture Model
MPC-HC	Media Player Classic-Home Cinema
MHK	marine and hydrokinetic
LGL	LGL Alaska
ORPC	Ocean Renewable Power Company
PNNL	Pacific Northwest National Laboratory
RPCA	Robust Principal Components Analysis
TRL	Technology Readiness Level
ViBE	Video Background Extraction

Glossary

Term	Definition
asynchronous architecture	A system that does not depend on strict arrival times of signals for operation.
avoidance	Used in all instances to encompass behaviors that showed some form of active change; no attempt was made to distinguish between avoidance and evasion.
background subtraction	A computer vision technique used to separate an image (or video frame) into background and foreground, where foreground means objects or regions of interest and is application-dependent.
bilateral filter	A non-linear, edge-preserving, and noise-reducing smoothing filter for images.
“blobs”	Groups of connected pixels of similar intensity.
canonical analysis	A method of regression analysis to determine relationships between a predictor variable and a criterion variable.
collision	When a fish swims into a static object.
compare/ comparison	Qualitative, nonstatistical assessment of the project video data.
contrast stretch	An image enhancement technique that improves the contrast in an image by increasing the range of intensity values.
Deep Learning	Application of learning tasks to artificial neural networks.
directed motion	Motion that demonstrated intended movement; used in this report to describe fish-like movement
EyeSea	A database-driven website for accessing video data files and analysis data.
Event	A place in time during manual video processing marked by a reviewer as having a fish-like object or fish in two or more frames
false positive	Detection of a fish by the algorithm when there was not a fish
Fish	An object that is deemed to be a fish during a manual analysis event
Fish Event	An event deemed to contain a fish during manual analysis
forward-stepping linear discriminant analysis	A method for finding a combination of features that characterizes two or more classes of objects.
histogram equalization	A technique for adjusting image intensities to enhance contrast.
July 22 Data	The full 24-hour manual analysis data of July 22, 2015.
Maybe	An object that during manual analysis is deemed to possibly be a fish, but not a definite identification.
Maybe Event	An event that during manual analysis is deemed to contain an object that could possibly be a fish
MySQL	An open-source relational database management system.
near-field	Relative term referring to an object or fish being relatively close the turbine within the video camera field of view.

neural network	A computer system based on how networks within biological brains work, which “learns”, i.e., improves its performance, by considering examples that have been labeled with key parameters.
Nighttime Data	Data from hours 00:00 – 06:00 and 23:00 – 00:00 from July 19, 23:00 to July 23, 03:00
OpenCV	Open Source Computer Vision Library
optical flow	An image processing technique used to compute motion of an object based on changes in the individual pixels in an image.
Rayleigh distribution	A continuous probability distribution characterized by a shape parameter used to model the magnitude of a multi-component vector.
strike	When a fish is hit by a moving part of the turbine
true negative	An object classified as non-fish by automated analysis that was deemed to be a non-fish by a human reviewer, or a frame classified by automated analysis as containing no fish that was not included in the frames containing fish noted by human analysts.

Contents

Figures

Tables

1.0 Introduction

The Triton initiative is a U.S. Department of Energy (DOE)-funded capability at the Pacific Northwest National Laboratory's (PNNL's) Marine Sciences Laboratory in Sequim, Washington. It aims to support DOE-funded projects that are developing technologies for measuring and monitoring the environment around marine energy devices through the mid- to high-level Technology Readiness Levels (TRLs). Ultimately, the initiative is intended to facilitate the permitting process and reduce the overall cost of marine renewable energy.

As part of the initiative, the Igiugig Fish Video Analysis project described herein used video data collected by LGL Alaska around an Ocean Renewable Power Company (ORPC) RivGen® device deployed in Alaska. The data on fish interactions around the operating device were made available to PNNL for further manual/human processing and use in developing automated processing software.

This final report summarizing the project tasks and results follows two previous reports: a data quality report (Trostle 2016) and a project progress report (Avila et al. 2016). The ensuing sections of this report briefly describe the project, the manual analysis of the video data, development of an automated algorithm for detecting fish presence in video frames, development of the software to enable data processing, and finally present conclusions and recommendations for future projects. Appendices A and B, respectively, contain manual annotations and the video data set used to develop the algorithm.

2.0 Description of Project

The ORPC RivGen® device (Figure 2.1) was deployed in the Kvichak River (Figure 2.2) from 19 to 25 July and 19 to 28 August in 2015. The device's two-turbine turbine generator unit (TGU) is supported by a chassis incorporating a pontoon support structure. The structure acts as a foundation when the device is deployed on the riverbed and gives it self-deployment and retrieval capabilities. The system is designed to generate reliable, renewable electricity in rivers near remote communities that have no access to large, centralized power grids.

Figure 2.1. Photograph of the ORPC RivGen® device.

Figure 2.2. Location of the RivGen® device near Igiugig, Alaska.

Five video cameras were attached to the ORPC RivGen® device to monitor fish upstream and downstream of the turbine foils. While the system was deployed, LGL Alaska (LGL) monitored the video for fish-turbine interactions, subsampling 10 minutes per hour (at the top of the hour) (LGL 2015). After the deployment was completed, the raw data, metadata, and a spreadsheet with processed events were released to PNNL for further analysis. Specifically, this was to develop automated algorithms that detected fish within the frames so that manual analysis could focus only on times when fish were present. To do this, manual analysis was required to annotate the video so that it could inform the algorithm development.

3.0 Manual Analysis

3.1 Methods

The development of tidal current and in-stream river current turbines as an industry is relatively new. It is in the early research and development stages that require testing to determine ideal technology and resource choices. The required technologies for monitoring fish interactions around turbine installations have the same early research stage limitations. This project used an underwater optical camera data set that captured numerous instances of fish and a turbine in the same field of view. Cameras and lights were manufactured by IAS systems. Cameras were customized SeeMate™ color to monochrome units with a F2.9 angle lens. Lights were SeeBrite™ omnidirectional model 24L-SS-LED-350. Power came from shore

and data were stored on digital video recorders. Manual processing of the data provided a baseline for software algorithm development as well as qualitative comparisons of fish behavior near the device.

3.1.1 Data Set

The data set comprised underwater video data from five cameras aligned on one side of the RivGen® device (Figure 3.1)—two upstream of the rotor and three downstream—recording 24 hours per day from 19–26 July and 19–28 August. Illumination from two artificial light sources was used between approximately 2300 and 0600 each night. PNNL received the raw video data (6,418 files; 368 hours), along with supplemental reports from LGL in December 2015. LGL had previously processed the first 10 minutes of certain hour blocks of the data, typically coincident with the turbine spinning; observed events were recorded in a spreadsheet that was provided to PNNL with the data set.

For PNNL, the first step was to determine whether the data quality was good enough for the proposed analysis. The research team needed to be able to visually observe fish presence, behavior, species, and any adverse impacts. In February 2016, the data quality was deemed satisfactory, but not suitable for species determination/identification. For additional information regarding the usability and overall quality of the video, see the Quality Check Summary Report (Trostle 2016).

During an Advisory Committee meeting (including participants from ORPC, PNNL, the University of Washington, and the University of Maine) held in March 2016, it was decided that the data set should be manually processed giving priority to nighttime segments (00:00 – 06:00 and 23:00 – 00:00) from July, for which previously subsampled data from LGL showed the highest frequency of fish interactions with the turbine. Additionally, camera 2 (Figure 3.1) was given priority because it showed the upstream view of the rotor. This meant that it:

In this study, "collision" refers to when a fish swims into a static object, and "strike" refers to a moving part hitting a fish.

- could show potential fish collision or strike interactions with the turbine,
- could show near-field avoidance behavior,
- had a sufficient light source, and
- could be used to coarsely estimate the size and distance of fish relative to the turbine and supporting structures.

As data processing progressed, team members realized that full manual analysis of both July and August nighttime video data would be excessively time-consuming. For every 1 hour of raw video data, it took reviewers approximately 13 to 15 hours to manually review and annotate the video. Due to the amount of time it took for manual review, only part of the July Nighttime Data (July 19, 20, 21, and some of July 23), all of the July 22 Data, none of the August data, and the data required for the test bed development were reviewed (see Section 4.1). Of 18 days of video data recorded by LGL, PNNL was able to review 1 full day, 3 nighttime segments, 4 half-hour blocks on July 23, and 16 five-minute sections for the test bed—a total of 42.33 hours. The PNNL team decided to concentrate on particular subsets of data that would allow for meaningful comparisons. Statistical analysis was not performed on any of the manual review data because of the relatively short period analyzed. Therefore, all uses of the term compare/comparison regarding manual processing for this report refer to qualitative, non-statistical assessment of the data. These comparisons have been grouped into four categories:

- July 22 Data: A full day, July 22 (hereafter referred to as July 22 Data), was analyzed because it was important to include a full day inclusive of daytime data for preliminary comparisons of the first 10 minutes of each hour to the full 60 minutes of each hour. This also allowed for diel differences to be qualitatively compared.

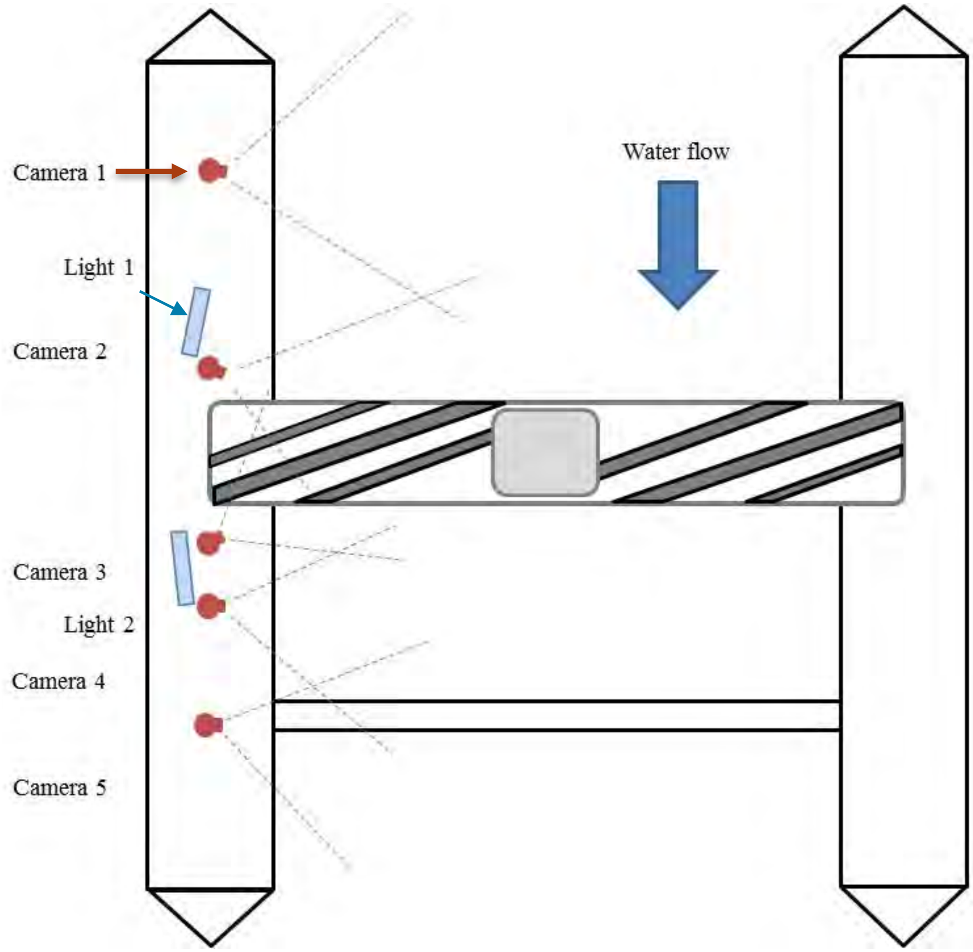


Figure 3.1. Schematic showing approximate locations and views of cameras by number on the RivGen® device.

Lights are represented by blue rectangles. (Not to scale. The pontoon structure is 19.8 m long, 11.5 m wide and 1.7 m high. The turbine [TGU] is 10.4 m long, 1.5 m wide, and 1.5 m high.) (Figure courtesy of LGL and ORPC.)

- Nighttime Data: Nighttime only (00:00 – 06:00 and 23:00 – 00:00) data from July 19, 23:00 to July 23, 03:00 (hereafter referred to as Nighttime Data) were processed as mentioned in the bulleted paragraph. The data from July 23 Nighttime Data consist of only the first half-hour of each hour block (e.g., 01:00 to 01:30). These data represent the majority of the processing effort for this study. The first night (July 19) of data collection had technical issues with the lighting system and data were collected without a light source.
- Light Effects Data: The hour block from 23:00 – 00:00 for July 19–22 were processed with varying artificial light operations to gain a preliminary understanding of any effect lights may have on fish detection probability and fish behavior.
- Collision/Strike Data: Events with fish interactions where possible collision or strike occurred were separated into a small subset and further analyzed. Reviewers observed a total of 20 events that had possible collision or strike interactions. These events were separated for further comparisons.

3.1.2 Manual Processing

The data were provided in a proprietary format that was difficult to manipulate for the proposed processing and analysis procedures. Data files were changed to .mp4 format for ease of use with minimal

change in data quality. Two reviewers worked together to establish processing protocols and definitions for parameters annotated for each event. A subsample of data was processed by each reviewer and compared for similarity to ensure data processing would be consistent and accurate throughout the analysis.

The reviewers visually processed the data in half-hour blocks using Media Player Classic-Home Cinema (MPC-HC). Reviewer 1 processed the first half-hour and Reviewer 2 the second half-hour. Whenever a reviewer visually assessed a fish or an object that had characteristics different from the surrounding water column debris (i.e., shiny and/or non-passive movement) that was present in the field of view for more than one frame, it was deemed an event. For each event, the numerical annotation method explained in the *Igiugig Video Analysis – FY16 Progress Report* (Avila et al. 2016) was used to describe the event characterizations. Parameters for these characterizations are described in Appendix A. Manual review did not distinguish between the terms "avoid" and "evade" throughout this report. Because the reviewers were unaware of the exact distance of the objects from the turbine, and because they did not use the behavioral responses of the objects and fish to decide between the two terms, "avoid" was used in all instances to describe behaviors that showed some form of active change assumed to be related to the turbine. Important classification annotations referenced throughout this report are whether or not an event was a Fish Event or a Maybe Event. A Fish Event meant that the reviewer was positive the object was a fish, whereas a Maybe Event meant the reviewer was not sure (hereafter referred to as Fish or Maybe Events, respectively). The designations between these two annotation descriptions are important for comparison and analysis purposes, as well as for informing the algorithm development.

Objects that were not definitively defined as fish were still deemed events and recorded as Maybe Events. It was important to include these for two reasons. First, video quality could possibly affect the reviewer's determination of whether or not an event contained a fish, and erring on the side of capturing all events with some false positives was preferable to missing some Fish Events. Second, software and automated algorithm development was a major objective of this research. Objects often had characteristics similar to fish and could be identified as events by the automated algorithms. This again allows more confidence in capturing all Fish Events at the cost of some additional false positives.

To keep the reviewers calibrated during review, both started with a training period to go over the parameters and define characterizations. They separately reviewed the same video and compared results for 2–3 weeks, addressing any discrepancies in annotations. As the reviewers began processing the data individually, they kept in regular contact, went over interesting or questionable interactions, reviewed each other's annotations, and discussed methods to ensure calibration at bi-weekly meetings.

Even with these checks, during analysis, an inconsistency was discovered between reviewers. While both reviewers saw a similar number of events, meaning they were stopping for the same objects, the distinction between calling an object a Fish Event or Maybe Event did not always correspond. This meant that some of the objects one reviewer deemed as a Fish, the other reviewer deemed as a Maybe fish.

Comparisons were made using the July 22 Data to show any similarities that exist in event occurrence and fish count estimates between processing of the first 10 minutes per hour, and processing of the full hour. Additionally, figures for visualization were also made to display

- differences between definite Fish Events and objects with non-passive behavior,
- fish count differences between day and night, and
- fish count differences between when the device was spinning and static.

For the Nighttime Data, the behavior types that are associated with different categories of events were compared. This categorization of events was based on the Appendix A annotation, "Fish?". This annotation was simply a question to the reviewer about whether the object observed during a designated event was definitely a Fish or a Maybe. Initially, All Events that included Fish and Maybe Events were considered. Categories separated All Events into Fish and Maybe Events. Fish Events were further

categorized by annotations from Appendix A designating the fish as juvenile (likely a salmon smolt), adult (likely a salmon), or unidentifiable as determined by the reviewer. The category separation flow chart is shown in Figure 3.2. After behavior types were attributed to the categories of events by percentage (Figures 3.4–3.10), behavior types were coarsely grouped. Each of the behavior types the reviewers used for the annotation description was designated as either Avoidance, Passive, or Other (Table 2).

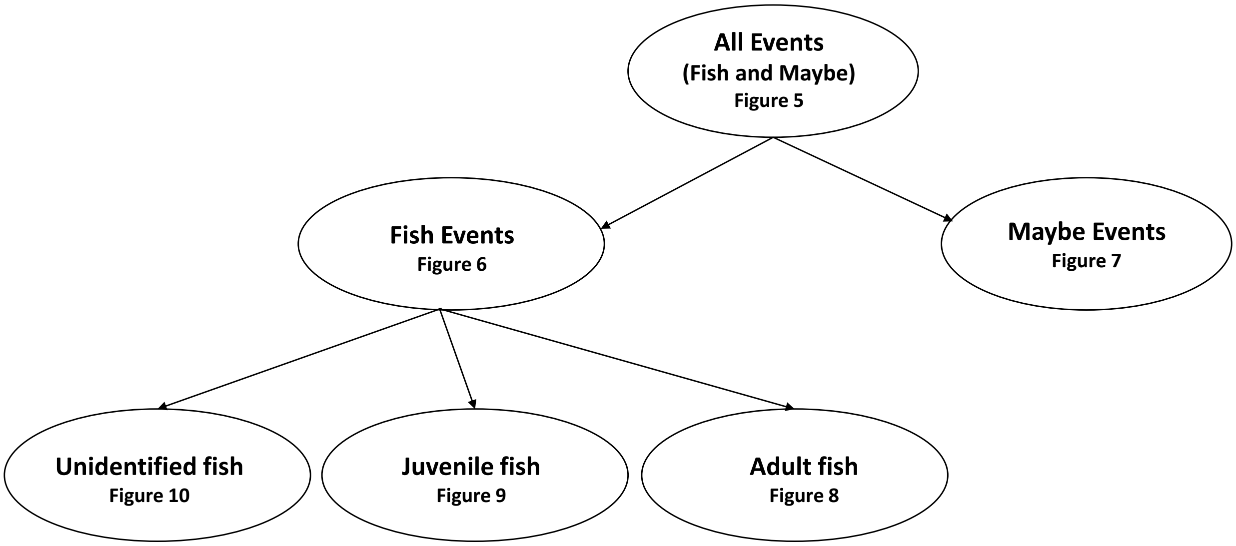


Figure 3.2. Flow chart showing the different categories of events used to visualize behavior types (Figures 3.4–3.9) attributed by data processing reviewers. All events that had potential fish collision or strike were placed in a separate subset (3.10).

Table 3.1. Grouping of annotated behavior types into Avoidance, Passive, and Other.

Avoidance	Passive	Other
Milling	Straight across (above or below)	Unable to tell
Pause	Through turbine	Other
Against current	Toward static parts	
Avoid reverse	Face first	
Avoid below		
Avoid above		
Avoid around		

A simple comparison of the Lights Effects Data was to determine whether more events were observed when the lights were on or off during varied light operations from July 19–22. This was possible because on July 19 the lights were off due to technical difficulties. The lights were turned on the next day and they were used for the remainder of Nighttime Data collection.

The last subset of data comparisons were the events when fish collision or strike may have occurred in the Nighttime Data. This data set includes only events that were positively determined by both data reviewers to be Fish and excludes the Maybe Events; hence, there is no disparity between reviewer determinations.

3.2 Results

Currently, no established video data analysis techniques exist for assessing fish interactions. Using the above methods, qualitative comparisons were made with the data set to highlight differences in 1) subsampling of the first 10 minutes of each hour and the entire hour; 2) nighttime behavior types; 3) possible collision and strike events; and 4) the effects of nighttime illumination. The data were further summarized between whether an object was a Fish or Maybe Event, and the categorical groupings associated with the observed behaviors.

3.2.1 Fish Presence/Behavior

3.2.1.1 July 22 Data Subsampling Comparisons

For the July 22 subset of data there were 2,538 events: 260 were Fish Events, 2,256 were Maybe Events, and 22 Events were a combination of Fish and Maybe occurrences. The majority (81%) of events occurred during nighttime hours. Only one Fish Event occurred during daytime—in hour 19 in the processed data. Fish abundance or frequency of events does not appear to be related to whether the turbine was spinning (hours 1–2) or static (hours 3–6), but does seem to coincide with low light levels (hours 1–6 and hour 24). To compare the 10-minute sampling regime with full analysis, the 10-minute counts were multiplied by six to produce an hour estimate. This assumes that the first 10 minutes is representative of the subsequent five 10-minute blocks. The comparison between these processing methods shows that when the first 10 minutes is subsampled and multiplied by 6 to approximate an hourly estimate the numbers are inflated for hours 3–6. Hour 1 is underestimated, for hour 2 the estimates are similar, and hours 3–6 are over-estimated for both the number of Fish and number of events (Figure 3.3).

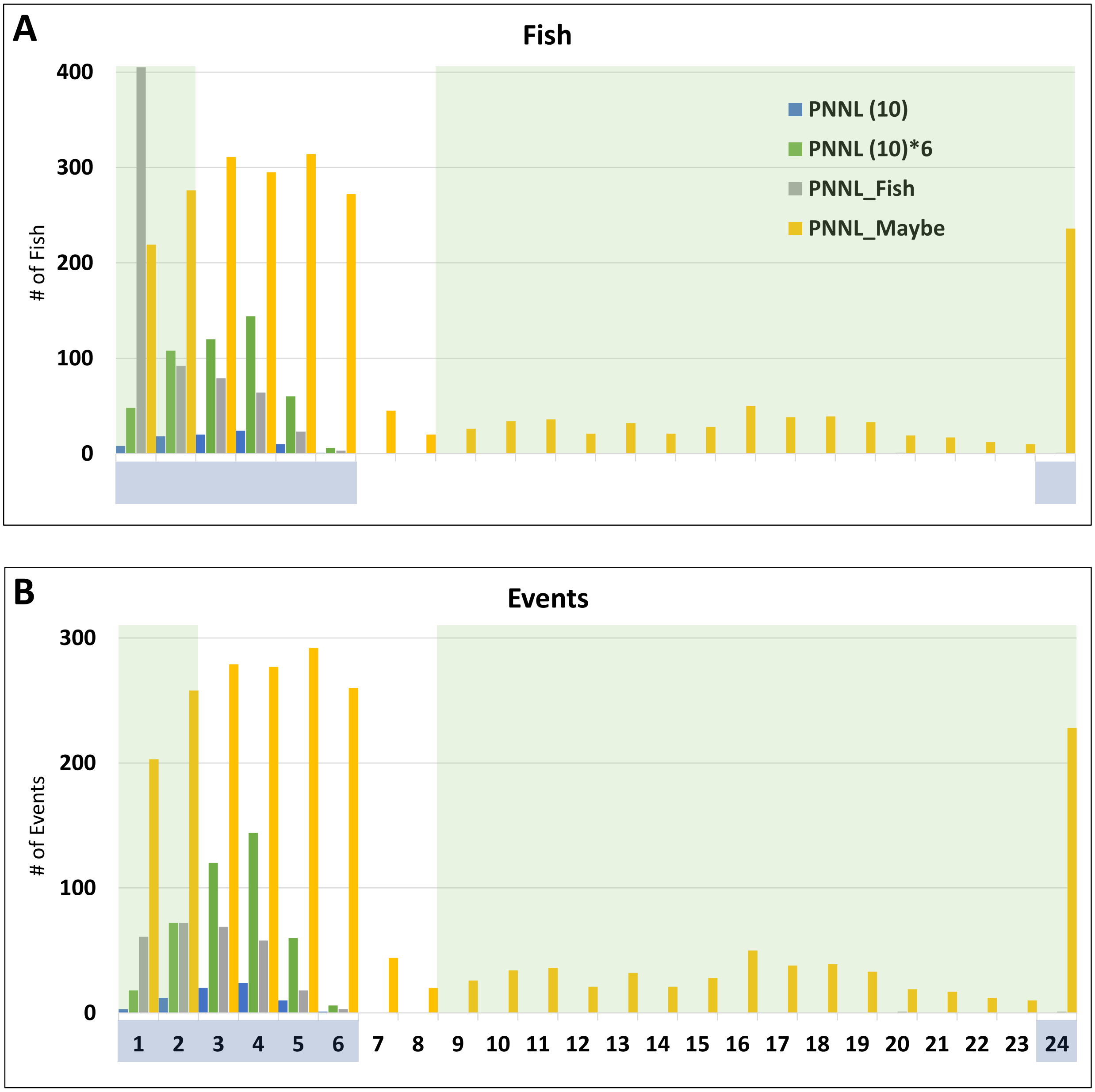


Figure 3.3. Bar graphs showing processed data for July 22, 2015.

*The horizontal axis represents each hour block for both graphs and the dark shaded numbers represent hour blocks that are after sunset and before sunrise (Nighttime Data). The green shaded background of the plot areas show when the RivGen® was spinning. Graph A displays Fish and Maybe counts as observed during manual processing by hour blocks. Graph B displays the number of events. The blue bar, "PNNL (10)", represents the estimates from PNNL's processing of the first 10 minutes of each hour. The orange bar, "PNNL (10)*6", represents PNNL's estimate multiplied by 6 to be an approximation for the full hour. The gray bar, "PNNL_Fish", represents PNNL's count of "Fish" for Graph A or "events" for Graph B for the full hour. The yellow bar, "PNNL_Maybe", represents the count of objects (Graph A) or events (Graph B) with non-passive behavior but not determined to be fish.*

3.2.1.2 Nighttime Data Behavior Types

Other than processing the July 22 Data, PNNL only processed Nighttime Data. For the category that includes both Fish and Maybe Events, there were 629 Fish Events, 4,149 Maybe Events, and 51

combination events that included both Fish and Maybe occurrences. Each event was broken down into the described behavior specific to the annotation list found in Appendix A. Grouping all of these described behaviors by annotation behavior type (e.g., avoid around, avoid above—see Appendix A) provides some evidence of what the dominant behaviors are within the camera field of view in front of the RivGen® during nighttime hours. The dominant behavior for Fish and Maybe Events was "through turbine", followed by "straight across", followed by "toward static parts" (Figure 3.4). Note that this comparison is not separated by Fish or Maybe Events or any other qualifier, and the Passive behavior group dominates with 80% of the behavior, compared to ~19% for the Avoidance group.

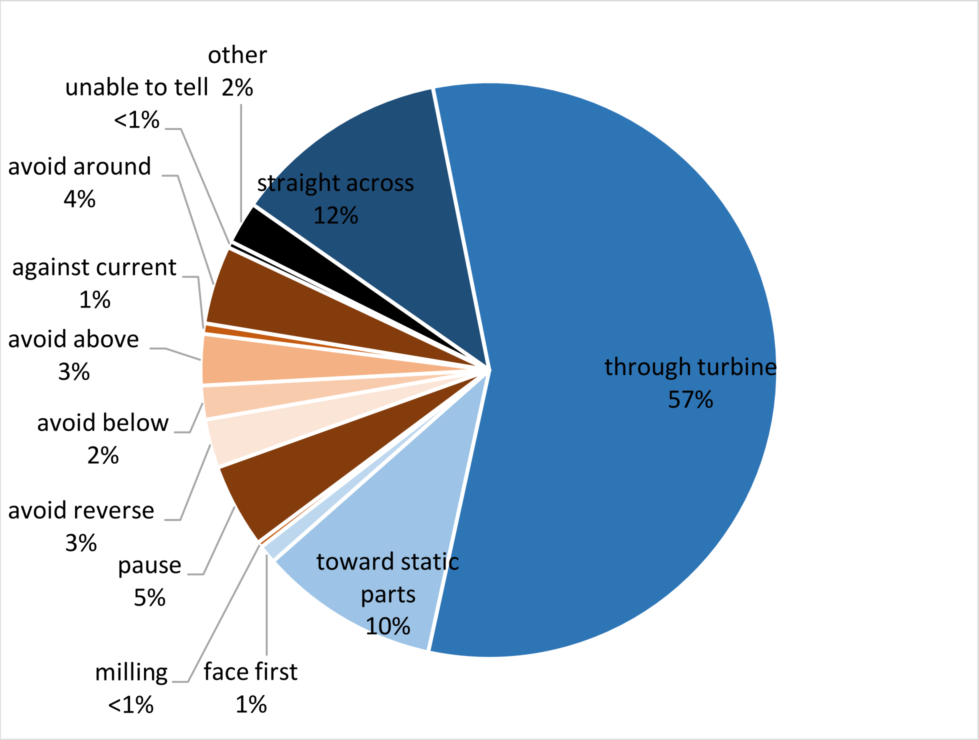


Figure 3.4. Behavior types recorded by reviewers for Nighttime Data. Data included are both Fish and Maybe Events for all sizes; n = 4,829.

The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

The Nighttime Data were separated into Fish and Maybe Events to visualize how reviewer-described behaviors may be different for each. Combination events (n = 51) that had both Fish and Maybe Events were removed because it was impossible to separate behavior annotations associated with a Fish object or a Maybe object during the event. For Fish Events the top three dominant behaviors were "through turbine", "avoid around", and "pause" (Figure 3.5), and for Maybe Events the top three behaviors were "through turbine", "straight across", and "into static parts" (Figure 3.6). There is a distinct qualitative difference in behavior types (Avoidance vs. Passive) between the Fish Events and Maybe Events. Figure 3.5 shows Fish Events dominated by the Avoidance group of behaviors (62%) and Figure 3.6 shows Maybe Events dominated by the Passive group of behaviors (80%). This abundance of passive behaviors is expected, because one of the qualifiers when distinguishing between Fish and Maybe Events was how the objects moved. It is important to note that there was some disparity between what the two reviewers designated as a Fish or Maybe Event as described in "Manual Processing."

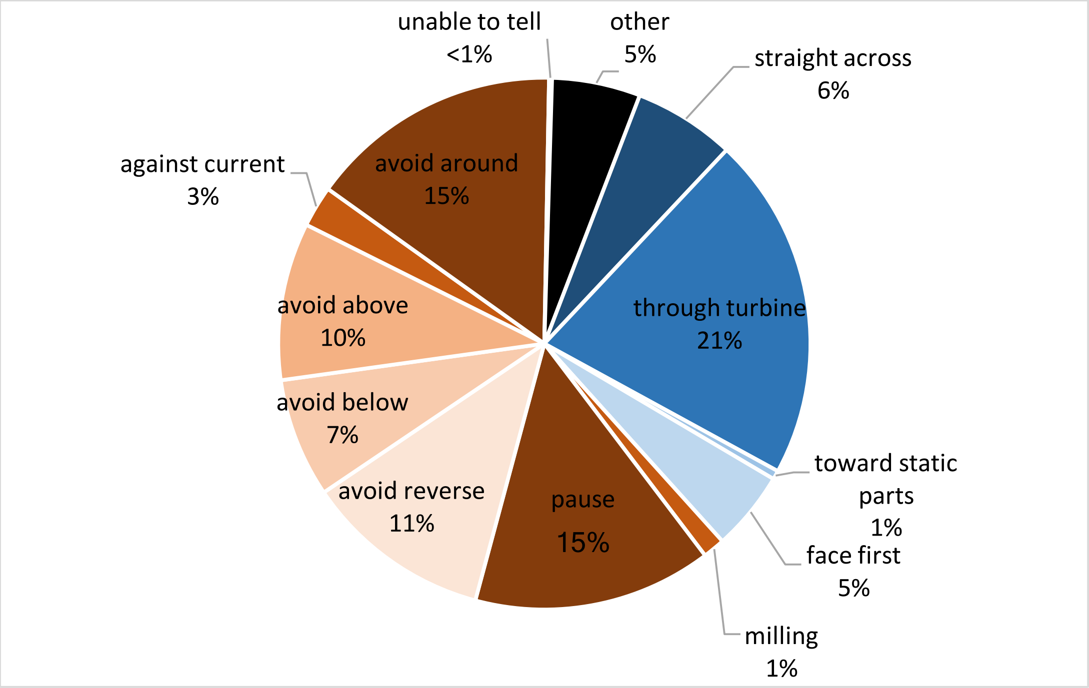


Figure 3.5. Behavior types recorded by reviewers for Fish Events in Nighttime Data for all sizes (n = 618).

Maybe and Combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

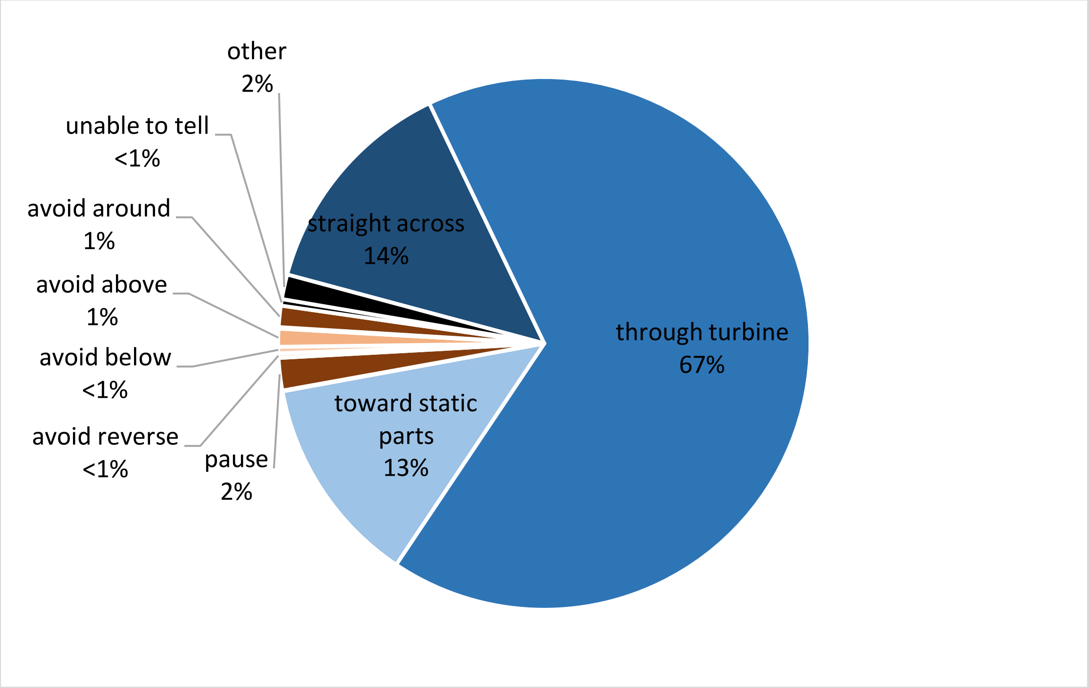


Figure 3.6. Behavior types recorded by reviewers for Maybe Events in Nighttime Data for all sizes (n = 4,149).

Fish and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

Within the Fish Events category, a separation was made to categorize juvenile, adult, and unidentifiable fish. Eleven Fish Events had a combination of adult, juvenile, or unidentifiable Fish Events that were removed from these comparisons. There were 174 adult Fish Events for which the dominant behaviors were "pause", "avoid around", and "avoid reverse" (Figure 3.7). There were 259 juvenile Fish Events, for which the dominant behaviors were "through turbine", "avoid around", and "pause" (Figure 3.8). Determining whether it was an adult or juvenile was sometimes impossible. This created the category of an unidentified Fish Event of which there were 185. The dominant behavior was "through turbine", "avoid around", and "pause" (Figure 3.9). Adult fish displayed Avoidance behavior 82% of the time compared to only 14% passive behavior. The behavior groups for juveniles were split, showing 50% Avoidance behaviors and 44% Passive behaviors. And the fish that were unidentifiable demonstrated dominant Avoidance behavior 57% of the time and Passive behavior 36% of the time.

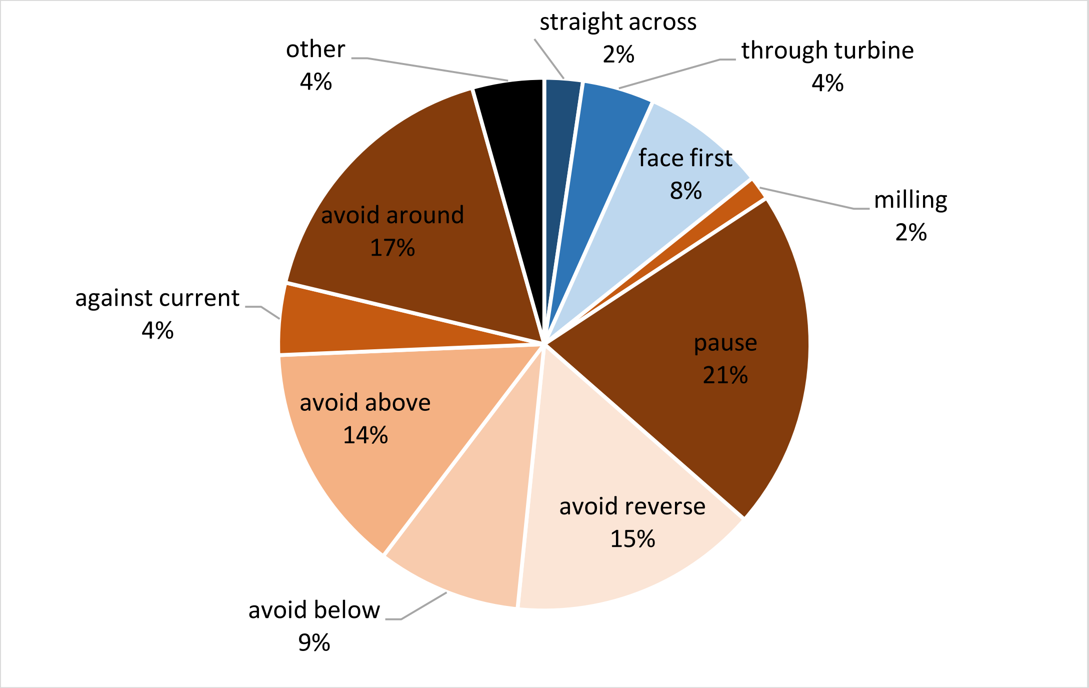


Figure 3.7. Behavior types recorded by reviewers for adult Fish Events in Nighttime Data (n = 174). *Juvenile and unidentified Fish Events, Maybe Events, and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.*

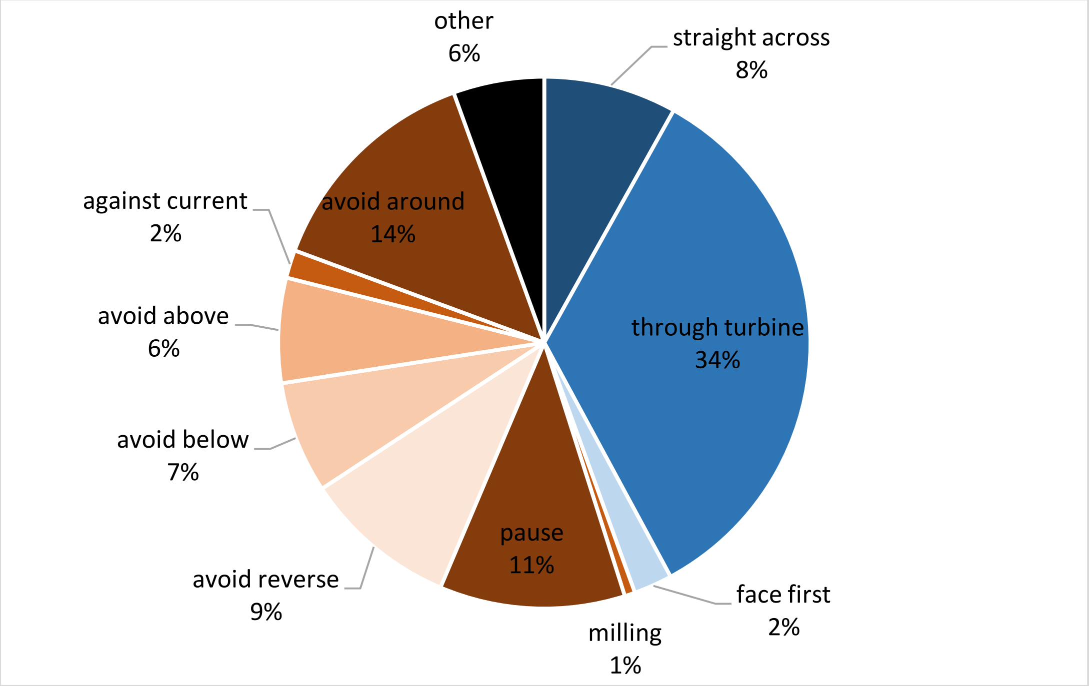


Figure 3.8. Behavior types recorded by reviewers for juvenile Fish Events in Nighttime Data. (n = 259).

Adult and unidentified Fish Events, Maybe Events, and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

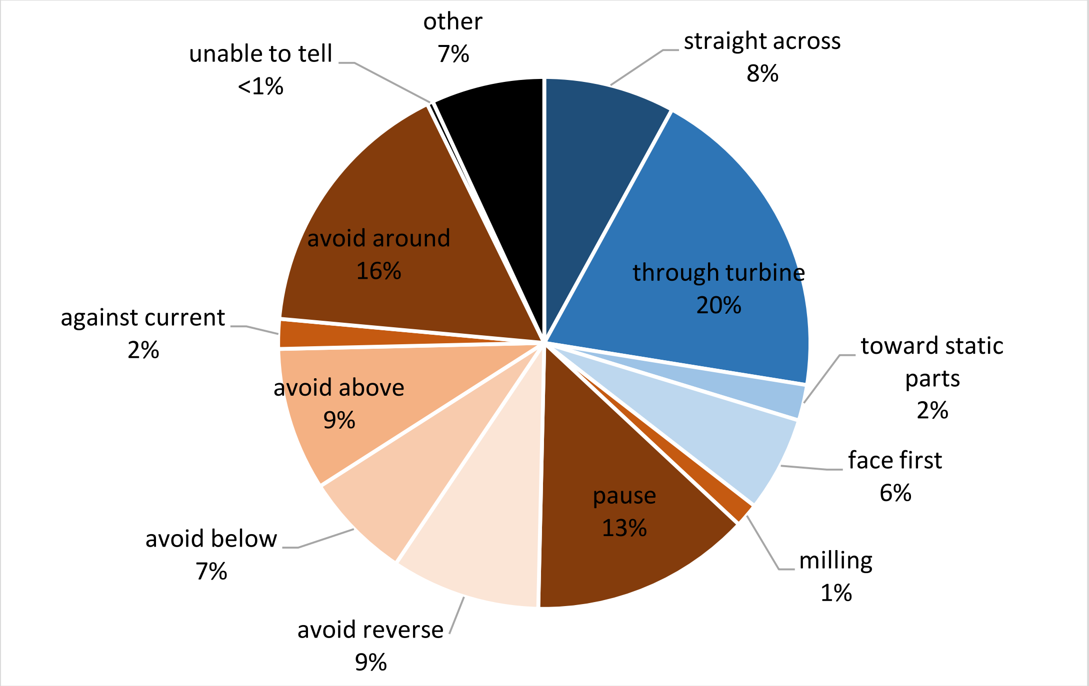


Figure 3.9. Behavior types recorded by reviewers for unidentified Fish Events in Nighttime Data (n = 185).

3.2.1.3 Fish Collision and Strike

Reviewers found a total of 20 events involving possible collision or strike (12 strike and 8 collision). All strike events in this data set refer to moving parts of the turbine hitting an object or fish, while collision refers to an object or fish coming into contact with a static part of the device (this could include the blade when it is not turning). Of these 20 potential events, 17 were Fish Events and 3 were Maybe Events. Of the 17 Fish Events, juveniles made up 12 of the events and adults made up 5 events. All but one of the juvenile Fish Events had multiple fish in the field of view, up to ~50. All of the adult events were single fish. All juvenile Fish Events occurred between 00:00 and 01:00, except two which occurred at 01:03 and 03:02. The turbine was spinning for all but one of the juvenile Fish Events and none of the adult Fish Events. Juveniles made up 11 of the strike events, while the remaining strike occurrence was a Maybe Event. No adults were involved in any of the strike events. Of the 8 collision events, adults made up 5, a single juvenile made up 1, and the rest were Maybe Events. The one juvenile collision and 4 of the 5 adult collision events occurred with a static blade. The last adult collision occurred with the camera and was the only confirmed collision. Behavior for these events was dominated by Avoidance group behaviors “through turbine”, “avoid around”, and “pause” (Figure 3.10).

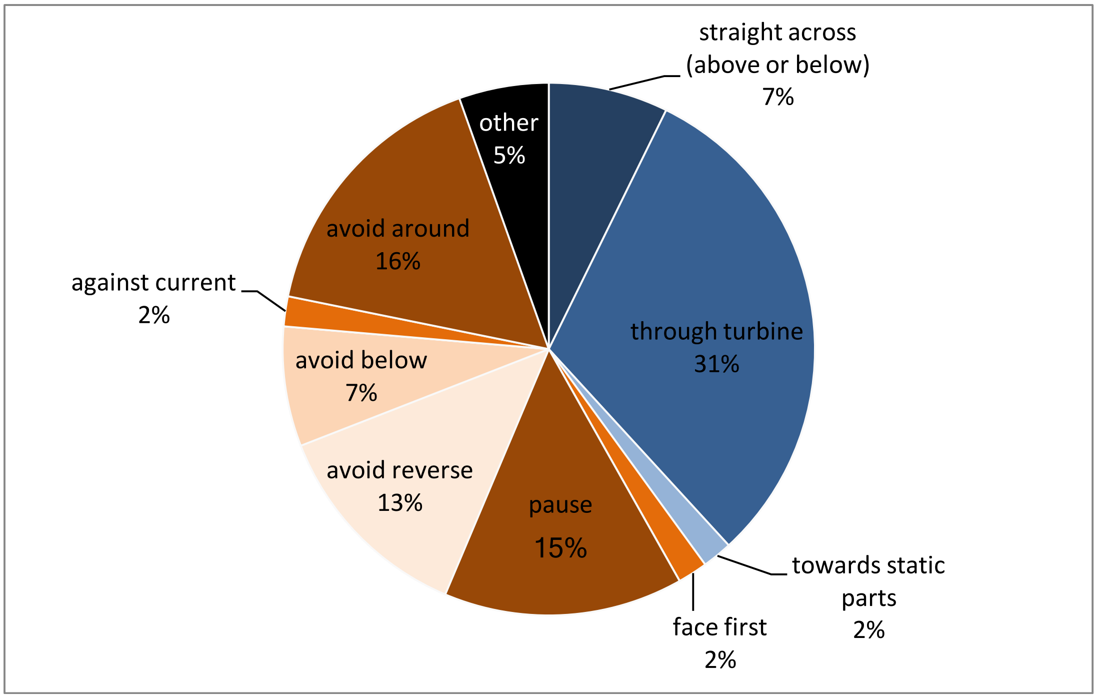


Figure 3.10. Behavior types recorded by reviewers for potential collision or strike Fish Events in Nighttime Data (n = 17).

The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

3.2.1.4 Light Effects

On July 19, the lights remained off through the night, while on every other night the lights turned on as it became dark. A light operations record was not kept during deployment, so manual reviewers at PNNL watched the video and estimated the operational status of the lights (Figure 3.11). Events observed over four nights during hour block 23 (23:00–00:00) when light operations varied were compared to show fish presence while the lights were on and off (Table 3.2). Over the four-night comparison of hour block 23 (a total of 4 hours), the lights were off 45% and on 55% of the total time.

Only 5 events were recorded by the reviewers on July 19 when the lights remained off the entire hour. All 5 events on July 19 occurred in the first 9 minutes of the hour block, and they were all Maybe Events. On July 20, 1 Maybe Event occurred while the lights were off during the first 34 minutes of hour block 23, and 144 events (1 Fish Event, 143 Maybe Events) occurred while the lights were on in the last 26 minutes of hour block 23. On July 21, 2 Maybe Events occurred while the lights were off during the first 14 minutes of hour block 23, and 65 events (2 Fish Events, 63 Maybe Events) occurred while the lights were on during the last 46 minutes of hour block 23. On July 22, 135 Maybe Events were recorded by reviewers when the lights remained on during hour block 23. Over the four-night comparison, approximately 2% of the total events occurred while the lights were off, and 98% occurred while the lights were on.

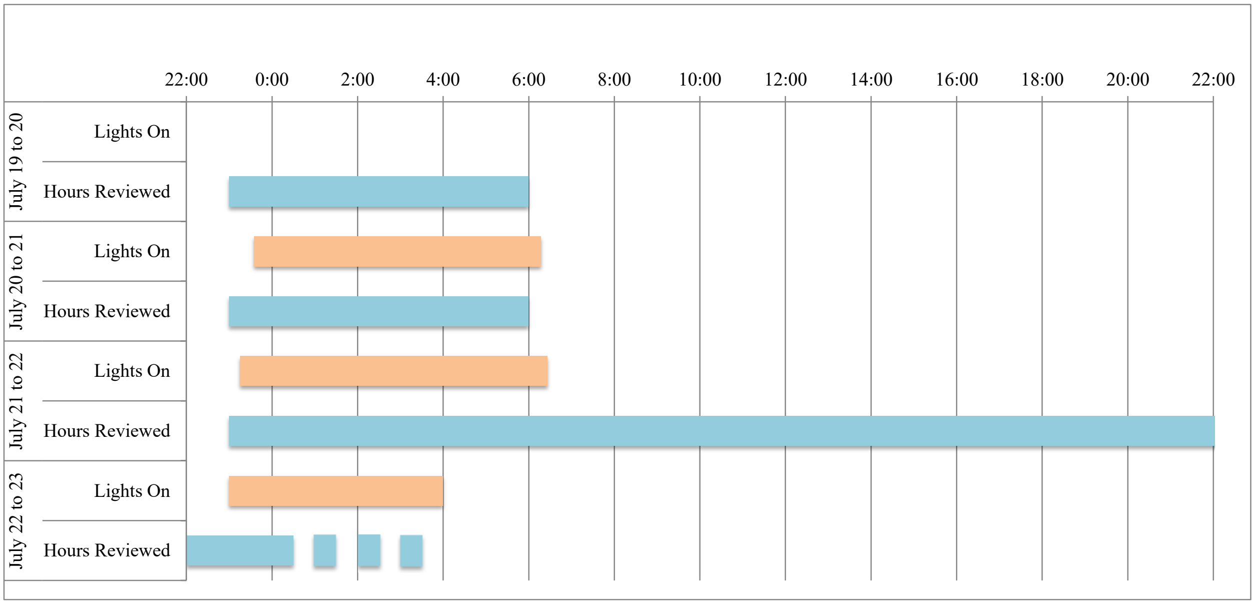


Figure 3.11. Visual approximation of light operations determined by watching the video data and noting when the turbine and objects began to look brighter (lights on), or when the turbine and objects began to look darker (lights off).

Although a light operations record was not kept, PNNL staff watched the video data to estimate when the lights came on and turned off. The orange bars represent the duration of time the lights were estimated to be on, while the blue bars represent the duration of time manually reviewed by the two reviewers. The x-axis on Figure 3.11 shows a total range of 24 hours, from hour 22:00 on one day and up to hour 22:00 of the next day. This was done to show the light operations and review effort in a more continuous manner. The major y-axis labels list the dates reviewed with minor label divisions of when the lights were on and the hours reviewed on those dates. From the night of July 19 to the morning of July 20, the lights remained off, and the reviewers manually processed video data from 23:00–06:00, although only part of hour blocks 23 and 5 were visible. From the night of July 20 to the morning of July 21, the lights were estimated to be on from 23:35–06:17 and the reviewers manually processed video data from 23:00–06:00. From the night of July 21 to the morning of July 22, the lights were estimated to be on from 23:15–06:26 and the reviewers manually processed video data from 23:00–22:00. From the night of July 22 to the morning of July 23, the reviewers manually processed video data from 23:00–00:30, 01:00–01:30, 02:00–02:30, and 03:00–03:30. The lights were estimated to turn on at 23:00 and remained on during all of the manual review effort on July 23, but an estimation of when the lights turned off that day was not done.

Table 3.2. Comparison of the number of events recorded by reviewers during hour block 23 (23:00–00:00) over four nights when the lights were on and off, including the duration of light operation status and totals.

Hour Block 23	Lights Off		Lights On		Total
Date	Duration	Number of Events	Duration	Number of Events	Number of Events
7/19/2015	60 minutes	5	0 minutes	No data	5
7/20/2015	34 minutes	1	26 minutes	144	145
7/21/2015	14 minutes	2	46 minutes	65	67
7/22/2015	0 minutes	No data	60 minutes	135	135
Total	108 minutes	8	132 minutes	344	352

3.3 Discussion

Perceived risk and shortage of empirical data about fish interactions with tidal and in-stream turbines like ORPC's RivGen® means that monitoring is required during turbine deployment. For near-field interactions, optical cameras are the ideal choice because acoustic devices are limited at such close ranges because of transmitted sound scattering from the turbine blades. For this research, the use of cameras provided a useful data set that allowed the capture of hundreds of fish interactions with an operational commercial-scale device. These interactions included 17 possible collisions with static components and possible strike with dynamic components of the device. These 17 events accounted for 2.75% of all Nighttime Fish Events and 0.07 % of total hours processed. Only through intense manual processing effort was it possible to find the extremely rare events of collisions and possible strikes that were observed. These processed data also allowed comparison of a complete manually processed data set to the same subsampled processed data set. Of the 17 possible collision or strike events, only 1 was in the first 10 minutes of the hour. This means that 16 of the events would have been missed, pointing to the importance of full data set processing to ensure these rare events are observed. While strike and collision are of major concern, the behaviors used by fish as they approach these devices are important for continued research and to determine the need for monitoring around turbines. The types of behavior provide input parameters to models as well as identifying differences that may exist between different species or age classes of fish.

The previous analysis by LGL primarily processed data to coincide with times that the RivGen® device was spinning, which was typically during daylight hours. The PNNL research team concentrated on nighttime because 66% of all fish observed by LGL were observed during nighttime even though this time composed less than 10% of their total processed data.

3.3.1.1 July 22 Data Subsampling Comparisons

PNNL processed the first 10 minutes of each hour, illustrating the difference between subsampling and full analysis. Processing sub sets of data is common for researchers faced with the daunting task of large data sets, and it is considered a valid way to process large amounts of data. In this instance, when subsampled data [(10)*6] were compared to the fully processed (all 60 minutes of each hour) 24 hours of data on July 22, the number of Fish Events per hour was the same for hour 2, less for hour 1, and more for hours 3, 4, 5, and 6 (Figure 3.3B). While there was some discrepancy between the two, a larger sample size for comparison would be required for validation. The number of fish (counts) had similar results with the (10)*6 estimates being larger than the actual 60-minute counts for hours 2–6 (Figure 3.3A). Counts be skewed if large schools of fish are present. The first hour block in the July 22 fish count data (Figure 3.3A) is a good example of this; the full hour count data are more than four times the (10)*6 estimate. This was simply a case of several schooling Fish Event occurrences that were made up of tens of juvenile fish observed from minute 10 to 60. Subsampling may provide a valid estimate of Fish Events but fish counts may be biased low if events with large schools of fish are missed.

Having the entirety of the July 22 video processed provided evidence that the majority of Fish Events occur during nighttime. For this single day, it also indicated that the number of Fish Events did not dramatically increase or decrease based on whether the turbine was static or spinning. For the total data manually reviewed by PNNL, the turbine was spinning for 44% of the time, and not spinning for 56% of the time. After the RivGen® spinning ceased (typically around 01:00), the number of Fish Events decreased from then until 06:00. The occurrence of Fish Events is more likely to be related to light levels because Fish Events decrease temporally as sunrise approaches. If the driver for frequency of Fish Events is light levels, then use of artificial lighting to increase detection probability at night introduces a possible complication.

3.3.1.2 Nighttime Data Behavior Types

Describing the behavior of Fish and Maybe Events captured from a single camera is subjective for most of the descriptions (see Appendix A). While an observed movement upstream or downstream is definitive in nature, movement toward or away from the camera or attempting to use depth of field to describe an event is difficult and accuracy is impossible. Nevertheless, behavior was described for all Fish and Maybe Events during PNNL processing of the data. An extensive list of behavior types that described in detail the majority of observed fish behavior was used. Additionally, specific behaviors were qualified as being Avoidance or Passive behaviors (Table 3.1). For the manually processed data set, the extent to which behavior is addressed for each processed event is important to understand fish behavior in general as well as differences between behaviors of fish based on their size or age class.

The binary grouping of all specific behaviors into Avoidance and Passive behavior groups provided evidence of two important findings:

- First, the amounts of Avoidance and Passive behavior differ between Maybe and Fish Events. During the PNNL processing, both reviewers agreed that movement or behavior of the object during an event had a strong bearing on whether or not it was deemed to be a Maybe or Fish Event. More movement, especially those representing non-passive examples, typically led to classification as a Fish Event. The Avoidance group of behaviors is therefore important for separating Fish Events from Maybe Events. However, not all fish entering the field of view will necessarily change their behavior before exiting. Fish already in line to avoid the turbine may not change their trajectory and thus fall under one of the Passive group's behaviors.
- Second, the amount of Avoidance/Passive behavior differs between adult and juvenile Fish Events. Fish Events that consisted of adult fish had only 17% Passive behavior and of this amount only 4% were specifically "through turbine" (Figure 3.7). In contrast, juvenile Fish Events had a 50/50 split between Avoidance and Passive behavior and 34% of the Passive behavior was "through turbine". This comparison shows evidence that adult fish are better at avoiding the turbine than juvenile fish. Although juvenile fish behavior may consist of Avoidance behaviors, the juveniles tended to be less successful in actually avoiding the device and often went "through the turbine" even after attempting an Avoidance behavior.

Behavior types or groups may play an important role in algorithm development in the future. A variety of qualifiers are used in algorithm development, and behavior or movement is an important one for animal detection algorithms used with remote sensing devices and specifically optical cameras. Often, threshold metrics are used for initial investigations into automating an animal being in a frame. However, if this is successful and a variety of animal types have potential for being detected, then the next step is grouping them by some qualifying characteristic. Often size is the first characteristic for grouping followed by movement or behavior. Knowing the movements and behavior associated with the fish detected in these data has the potential to further general knowledge or inputs for modeling. Improved automated analysis to decrease the effort required to process and analyze these types of data and ultimately create cost-

effective methods. Use of these methods by developers and researchers can provide meaningful data accepted by regulatory bodies that require monitoring.

3.3.1.3 Fish Collision and Strike

As fish collision, strike, and near-miss events are generally accepted to be rare at marine and hydrokinetic (MHK) installations, it is important to process most, if not all, of the data collected to ensure these events are not missed. If an entire data set is not to be processed, then large-scale time blocks likely to coincide with the highest probability event occurrences, decided upon with expert opinion or existing empirical data and statistical analysis, should be processed. The sequence of the processing steps used for camera data set described herein is a good example of efficient gathering of useful information. The initial subset processing performed by LGL for the first 10 minutes of certain hour blocks made it clear that most Fish Events occurred during nighttime. This is a highly productive first step for a large data set for which no established processing methods exist, except for manually reviewing the data. As a logical first step, it saved time and provided the foundation for taking the next step to gather meaningful results. PNNL followed up and concentrated processing effort on nighttime hour blocks based on the LGL information that indicated more events occurred at night. This concentration on the Nighttime Data provided more meaningful comparisons of a variety of fish behaviors showing differences in adult and juvenile behaviors. The processed data also captured 17 events, out of a total of 618 Fish Events, with possible collision and strike between fish and a commercial-scale device, indicating how rare these events are and the difficulty associated with observing them. Even with capturing the events with possible collision or strike, actual contact is difficult to verify because uncertainty remains based mostly on the data quality specific to camera selection, lighting, placement, and field of view. Collision was only confirmed in one instance when an adult fish collided with the camera. Additionally, it is important to note that the outcome of a collision, strike, or near-miss event was not possible to determine because of data quality and the short duration that a fish was in the actual field of view.

Camera selection for underwater fish observations is not a trivial matter. The field of view, resolution, low light capacity, and frame rate are just a few of the parameters that are crucial to gathering high-quality, meaningful data. After data have been collected, the file type becomes important for effective processing that leads to useful analysis. The cameras used to collect the data presented in this report were customized SeeMate ™ color to monochrome units with a F2.9 wide angle lens, manufactured by IAS systems (North Vancouver, British Columbia). The images had a resolution of 352 × 240 pixels. Each camera had a variable frame rate (less than 10 per second), and a field of view of "approximately one-third of the area between the pontoons and the left (portside) one-third of the TGU"[1] (LGL 2015). Pixel resolution, field of view, and light capturing ability created limitations in the data set, and complications continued because the output files were of a proprietary format. Significant amounts of unplanned time and resources were required for file conversion to a non-proprietary format, followed by testing several video-file viewers to determine the one best suited for this analysis, which included requirements like moving forward and backward through each frame capture without skipping or freezing up. Based on this work, literature review, and discussions with other researchers, a brief set of guidelines for camera selection for future applications is given in the Recommendations section.

3.3.1.4 Light Effects

On every night except July 19 the lights turned on as natural light levels decreased to illuminate continued monitoring fish presence and interaction. A comparison was done to better understand the potential impact of artificial lights during this environmental monitoring effort during hour block 23 from July 19

---

[1] LGL Alaska Research Associates, Inc., 2015 *Fish and Wildlife Monitoring Plan for RivGen® Testing on the Kvichak River, Alaska in 2015*

to 22. As it became dark on July 19, the field of view began to fade into a grainy, grayscale image with portions of it becoming black over time. If fish were present during the last 15 minutes of hour 23:00 on July 19, it would have been very difficult for the reviewer to see or document their presence. When comparing the first half of hour 23:00 on July 19 to the same hour on July 20, the images of both nights seem similar, but when the lights appear to turn on at approximately 23:35 on July 20, the turbine is illuminated, potentially creating an opportunity for light to reflect off fish and be visible to the camera, as well as make the image sharper and clearer. In contrast, on July 19 the image degrades over time. Nighttime illumination probably affects the detection probability of fish by the reviewers, and may alter an avoidance/attraction response by the fish.

The number of events that occurred when the lights were on was considerably higher than when the lights were off (344 compared to 8, respectively), and with a similar operation duration (55% compared to 45%, respectively). The number of events when comparing lights on and off differs considerably, yet the reason for this in this application is not well understood. Artificial lights may have attracted fish, thereby causing more events, or more fish may have been present during the last half of hour 23 when the lights were generally on every night except July 19; the data from July 22 when the lights were on for the full hour show more fish during the second half hours (135 vs 94), but this does not account for the extreme difference observed overall. Alternatively, fish presence may be similar on all nights, but the artificial light provides the source needed to make them visible to the optical cameras and in turn, reviewers. Additionally, on July 22 when all 24 hours were reviewed, Nighttime events (when the lights were on from 00:00–06:26, and 23:00–00:00) made up 99.9% of the total events for that day, with only 1 daytime Fish Event overall (although 436 Maybe Events during the daytime). Due to this clear difference and the lack of baseline understanding of fish attraction or deterrence related to this variable, the role of artificial lights during environmental monitoring needs to be further investigated.

4.0 Automated Analysis

Automated analysis was investigated to develop algorithms for detecting fish presence in the video, so that an entire video data set could feasibly be analyzed automatically without the need for manual sampling. Reducing the volume of data to just those video segments during which fish were present would optimize human labor time, and the reduced-volume approach could also be used to perform a quick preliminary analysis of the data. Ultimately, the system could be fully automated, and the software optimized to run in real time as part of an underwater observation system for long-term monitoring of the effects of MHK devices on animal populations.

The vision for an automated video processing system consists of three main components: preprocessing, detection, and classification (Figure 4.1). The preprocessing component filters the raw video frame to improve its quality in terms of contrast, color balance, and smoothness. The detection component identifies objects that might be fish, and the classification component classifies the detections to filter out false positives such as kelp, shadows, or other objects that are not of interest. These three components interact, and each requires many design decisions in order to realize an effective system. Under this project, candidate algorithms were investigated for each of the components, and an infrastructure was developed to tie the components together into a web-based application developed by PNNL called EyeSea.

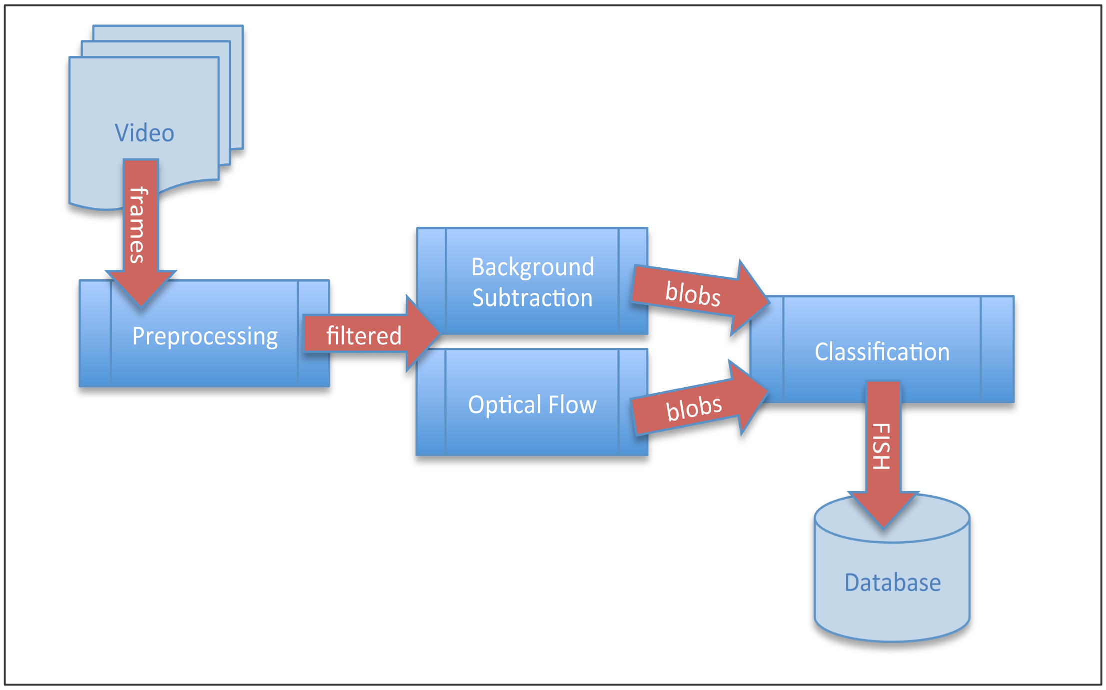


Figure 4.1. The automated processing chain.

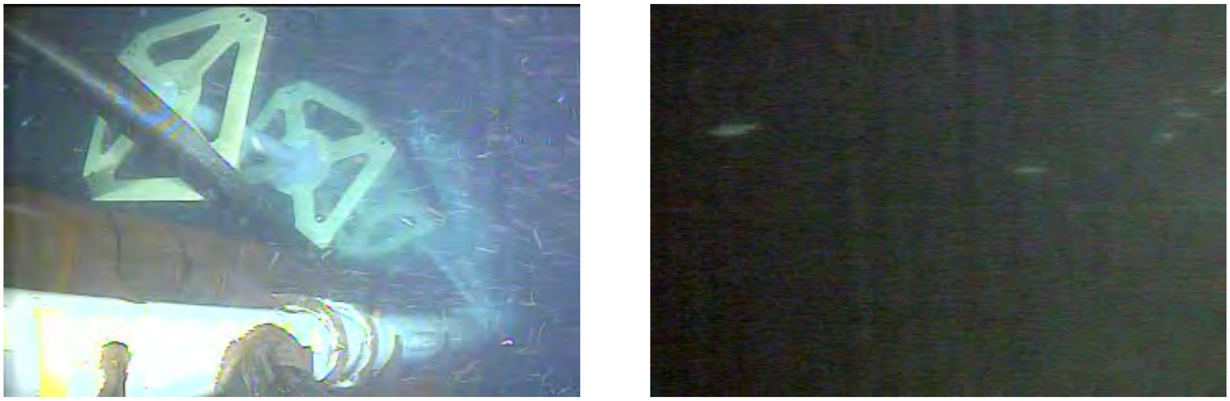
4.1 Methods

A testbed was developed to evaluate the performance of different algorithms; it consisted of a development data set and a processing pipeline. This meant that algorithms could be evaluated in a consistent, reproducible manner. A development data set was assembled from a subset of the full Igiugig data set consisting of 16 five-minute video segments containing Fish Events (Appendix B). The video segments were selected to represent different lighting conditions, different camera views and different sizes of fish, individuals and schools (Figure 4.2). Each video consisted of a total of 7500 frames, and even though the segments were chosen to include fish, only 6% of the total frames did in fact contain fish (the presence of fish is not a common event). The data were annotated as described in the Manual Analysis section. The processing pipeline was adapted from the Fish4Knowledge (Boom et al. 2014) code[2] for fish detection with custom code. The pipeline was used to batch process all the development videos using a particular detection algorithm, and to calculate the resulting detection rate and false positive rate by comparing the detections to the manual analysis annotations (Figure 4.3).

---

[2] http://groups.inf.ed.ac.uk/f4k/

a) Camera 1, daylight b) Camera 1, night



c) Camera 3, night illuminated d) Camera 4, night illuminated

Figure 4.2. Example images of fish in the different cameras with different illumination.

For the detection algorithms, background subtraction and optical flow were investigated. Three different background subtraction techniques were evaluated: Robust Principal Components Analysis (RPCA) (Candès et al. 2011), Gaussian Mixture Model (GMM) (Lee 2005) and Video Background Extraction (ViBE) (Barnich and Van Droogenbroeck 2009). The optical flow analysis consisted of a dense optical flow calculation using the Farnebäck algorithm (Farnebäck 2003) and a sparse feature-based flow calculation using the Lucas-Kanade method (Lucas and Kanade 1981), both as implemented in OpenCV.[3] For classification, models were developed using forward-stepping linear discriminant analysis (Lotlikar and Kothari 2000) on the detected objects to distinguish between fish and non-fish objects. The features used for classification were object size, intensity, shape, and motion.

---

[3] http://opencv.org

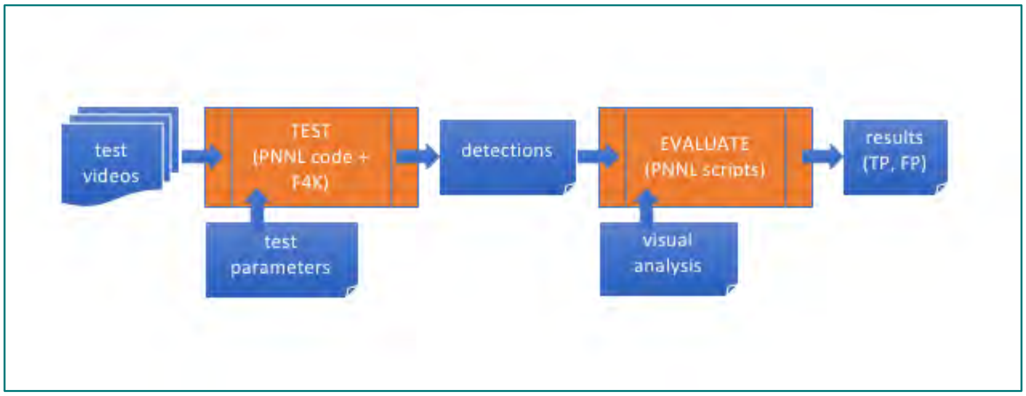


Figure 4.3. The developed testbed pipeline for evaluating different detection algorithms.

Background subtraction is a computer vision technique that is used to separate an image (or video frame) into background and foreground, where foreground means objects or regions of interest and is application-dependent. In this study, foreground is defined as fish and everything else is considered background, even other objects that might be moving such as the turbine itself and floating debris. This is a challenging data set for background subtraction because of the low quality of the video and the highly dynamic background. RPCA, GMM, and ViBE algorithms were selected based on recommendations from researchers at the University of Washington and the Fish4Knowledge project (Boom et al 2014) as being robust relative to background motion. The recommended parameter values for each algorithm were used.

The foreground images resulting from the background subtraction were further processed to group connected pixels of similar intensity into “blobs”. These objects were then classified as fish or non-fish. The blob size was highly variable ranging from 1 pixel to over 10,000 pixels, so the blobs were divided into five size groups and classification models for each group were developed separately.

The motivation for including optical flow is the hypothesis that fish motion is different than other motion in the scene, such as the motion of objects drifting with the current and the motion of the turbine foils turning. The researchers who performed the manual analysis said that one of the features they used to recognize fish was directed motion. Optical flow is the motion (spatial displacement) of light intensity from one video frame to the next. It is calculated for video by matching regions in one frame with regions in the subsequent frame, where the matching is based on edges and gradients of light intensity, and the flow is the displacement. There are several algorithms for calculating optical flow in the literature. For this application, the Farnebäck algorithm was chosen to calculate a dense optical flow over the entire image. Initial tests of both the sparse and the dense optical flow methods indicated that the sparse method was not effective when analyzing the raw video because of the lack of strong gradient features that could be tracked from one frame to the next. Dense methods are more robust relative to some changes in object intensity and shape because dense methods use more surrounding context for matching features.

In a parallel effort, a Deep Learning model was applied to the development data set. The open-source machine learning library TensorFlow was used to build a convolution neural network and train it on a portion of the data set. This type of neural network must be trained on labeled data to generate a model for classifying new data. For this video analysis, the inputs to the network were the individual video frames, labeled as “fish” or “no fish”. A subset of the labeled data (video frames) was selected at random to train the network and the resulting model was tested on the remaining data. This process was repeated over multiple iterations, where a new subset of the data was selected for training at each iteration. This iterative process is necessary to find the subset of the data that produces the best model.

4.2 Results and Discussion

One project goal was to reduce human labor time, hence the performance objectives were a 90% detection rate and a 30% false positive rate. The detection rate is the percentage of actual fish present that are detected, and the false positive rate is the percentage of reported detections that are not fish. It was important to detect most of the fish at the cost of some false positives because the false positives could be sorted out by human analysts, but too many false positives would reduce the benefit of the automation.

For an initial comparison of the background subtraction algorithms, the recommended parameter values for each algorithm were used (Table 4.1). The algorithms were evaluated for how well they correctly identified which frames contained fish. A frame was classified as "fish" if it contained one or more detections (foreground objects). The algorithms all performed similarly on the test bed data set (Table 4.2). The best detection rate was 67.51% (ViBE), which was much lower than the goal of 90%. The false positive rate was high, but the best true negative rate was better than 57%, which means that over 57% of the frames containing no fish were correctly labeled as such.

Table 4.1. Background subtraction algorithm parameters.

RPCA	ViBE	GMM
Window size = 50 Interval = 10 Threshold = 50	History = 20 Learning = 50 Radius = 20 Match criteria = 2 Update probability = 1/8	alpha = 0.02 threshold = 0.7 upper difference = 220 lower difference = 30

Table 4.2. Background subtraction frame classification results.

Algorithm	Percent of Fish Frames Correctly Detected	Percent False Positives	Percent True Negatives
RPCA	57.45	92.18	**57.60**
ViBE	**67.51**	**91.51**	54.48
GMM	63.79	92.29	52.19

The figures in bold indicate the best performance between the algorithms.

The background subtraction alone is not sufficient to meet the performance objectives, but the results offer valuable insight into the effects of night and day, the use of lights, and camera placement (see Section 7.0 for specific recommendations). The individual videos were analyzed to better characterize the algorithm performance under different conditions (Figure 4.4). All algorithms performed best on the videos from camera 1 at night, where there was no turbine in view and lights were on but angled away from the camera's field of view. All algorithms performed poorly in terms of false positives on the video from cameras 3 and 4 at night. The turbine was in view in both these cameras and the lights were aimed at the turbine. All algorithms performed worst on the video from camera 1 during the day, when most of the reported detections were false positives and most of the actual fish present were not detected. During the day, the fish were in low contrast with the background, so they were more difficult to detect. The lights at night reflected off the fish, increasing the fish's contrast with the background, so they were easier to

detect. Floating debris that was similar in size to small fish also reflected the light causing false positives (Figure 4.5).

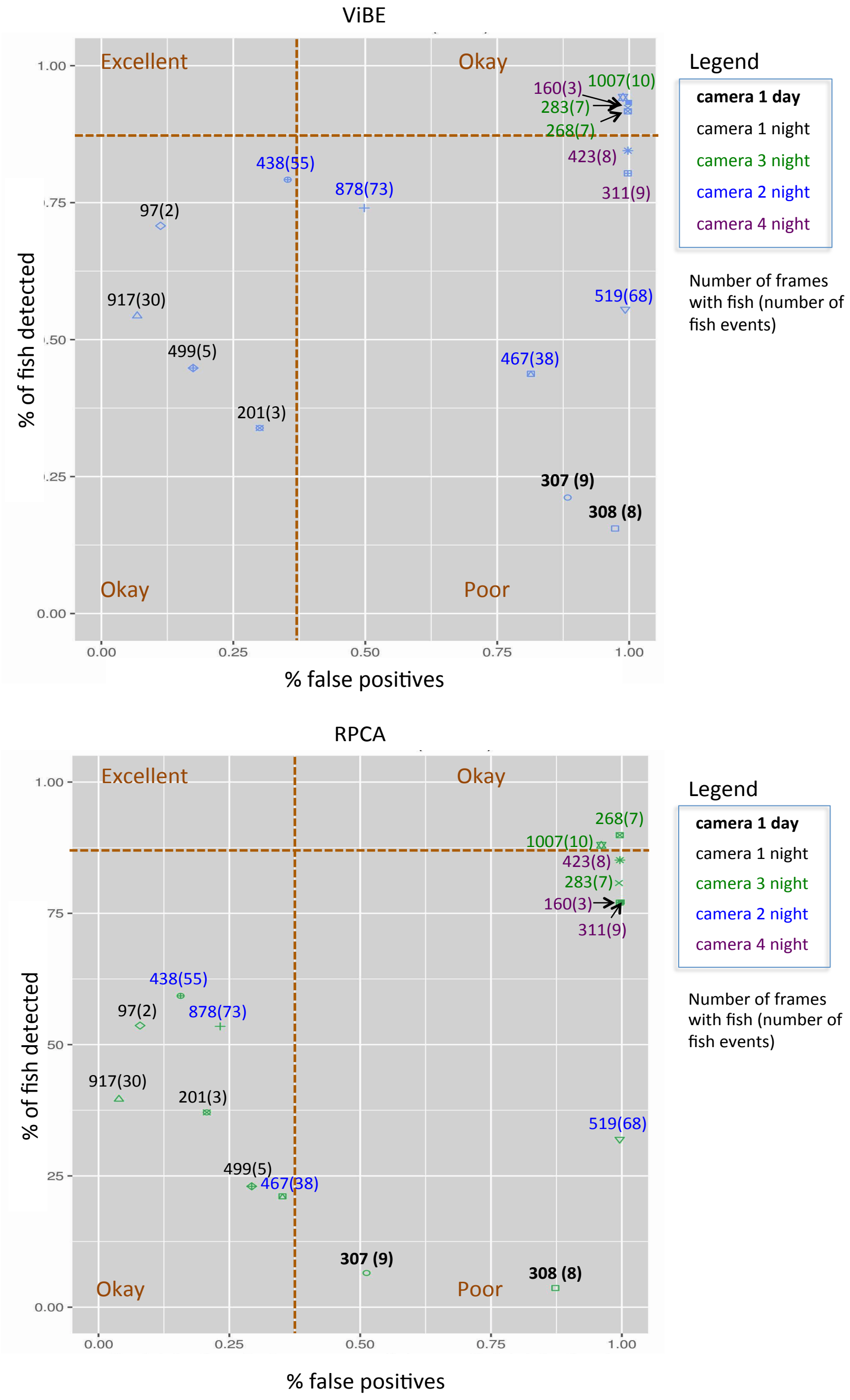


Figure 4.4. The detection rate and false positive rate by test video for RPCA (top) and ViBE (bottom). *The numbers on the scatter plots indicate the number of frames (out of 7500 per video) that contained fish and the number in parentheses is the number of Fish Events. A Fish Event is when a particular fish is in view; an event usually spans multiple consecutive frames.*

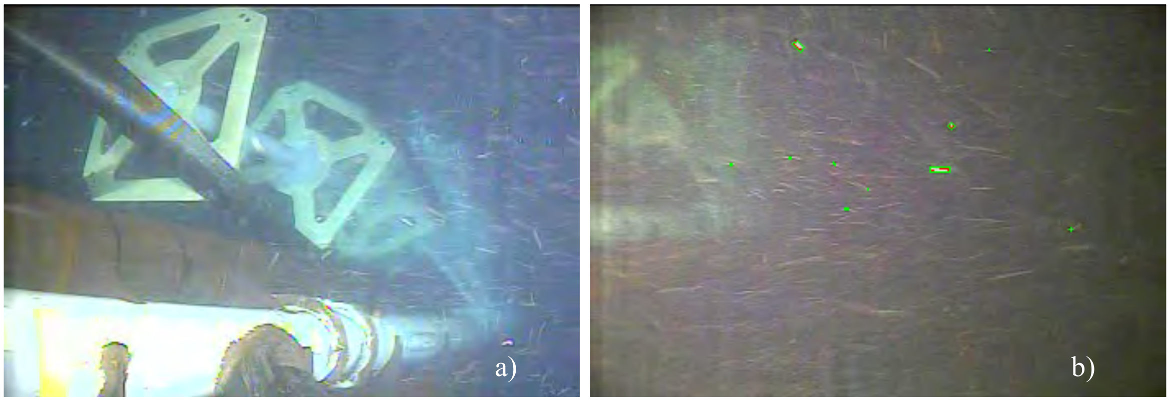


Figure 4.5. Example frame from camera 4 at night with small fish (a) and the detected objects from ViBE (b). The small fish are detected but there are also some false positives from the illuminated debris. These false positives were eliminated during post-processing.

Using the results of the initial evaluation as a baseline, preprocessing techniques were evaluated. The two techniques included with the Fish4Knowledge code were histogram equalization and contrast stretch. The preprocessing did not add significant computation time, but neither technique improved the performance and in some cases had a negative effect. A bilateral filter (Tomasi and Manduchi 1998) is often used in photographic applications, and this technique was tested on two of the videos, one from camera 3 and one from camera 4. Only two videos were processed because the computation was extremely slow on a desktop computer, but the results were promising (Figure 4.6).

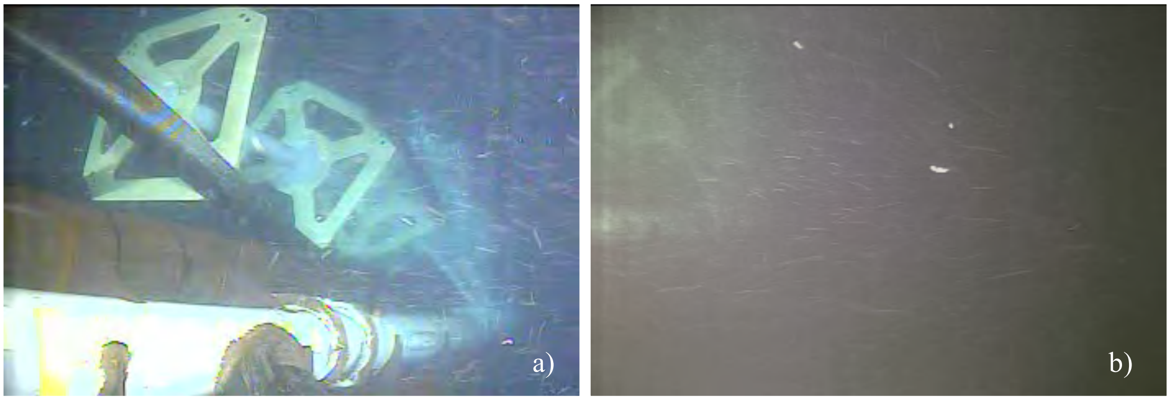


Figure 4.6. The raw frames (a) are preprocessed with a bilateral filter to reduce the clutter from debris (b).

The parameters of the best performing algorithm, ViBE, were varied to find the optimal values for the Igiugig data set. An exhaustive search for the optimal values of all five parameters was beyond the scope of this project, so two parameters with a strong influence on performance, the radius and the match criteria, were varied. The radius is the relative difference in intensity between background and foreground; a higher value will reduce the sensitivity and a lower value will reduce the precision (more false positives). Because detecting all the fish was more important than eliminating false positives, the radius was reduced and values of 20, 18, and 16 were evaluated. The match criterion is the minimum number of historical values that must fall within a current pixel's radius to consider the pixel to be background. A lower value will reduce sensitivity and a higher value will increase false positives and processing time. Values of 2 and 4 were evaluated. The best combination of values was radius = 16 and match criterion = 4 (Table 4.3).

Table 4.3. ViBE parameter tuning results.[(a)]

	Match = 2	Match = 4
Radius = 18	52% / 39%	70% / 54%
Radius = 16	55% / 42%	**74% / 59%**

(a) The first number in each cell is the true positive rate and the second number is the false positive rate. The figures in bold indicate the best combination of values.

A classification model for the detected objects significantly improved the performance by reducing the number of false positives. The detected objects were classified as "fish" or "non-fish" based on human analysis, and were divided into five size categories. A random sample of approximately 50 of each class (~100 observations) in each size category was used to develop a linear discriminant model for each category. For each size class, forward-stepping linear discriminant analysis followed by canonical analysis was used to determine the best model. Variables considered for the model included the blob size, blob solidity, blob eccentricity, and blob intensity. The models were tested on the remaining blobs that were not used for model development and the results are shown in Table 4.4. The larger blobs were classified most accurately; the accuracy decreased with decreasing blob size. The size of fish that can be accurately classified is dependent on their distance from the camera (the same size blob could be a large fish further away vs. a small fish close to the camera), and having the capacity to judge distance more effectively is discussed further in the Recommendations.

Table 4.4. Detected object classification results.

	Fish		Non-Fish		
Object Size in Pixels (number of fish objects)	True Positive	False Negative	True Negative	False Positive	Percent Correct
200+ (549)	533	16	3753	63	**98.2**
100 – 200 (320)	290	30	12,715	22	**99.6**
5 – 100 (2805)	2281	524	61,356	10,369	85.4
2 – 5 (2114)	1485	629	109,995	23,365	66.3
Total	4589	1199	187,819	33,819	84.6

The optical flow was calculated to generate a displacement in the horizontal and vertical dimensions for each pixel in the video frames, dx and dy, respectively. The displacements were then used to calculate the direction and magnitude of the motion from frame to frame. Direction was defined with 0 being toward the right and 180 toward the left. Five points in different regions of the frame were selected, and the motion was characterized at those points for one of the videos from camera 4 at night (Figure **4.7**). The direction of the motion appeared to be uniformly distributed across all directions and the magnitude appeared to follow a Weibull distribution (Figure 4.8). Due to the flow of the current from left to right in the video, the direction of motion was expected to be concentrated around 0 degrees. The uniform distribution that was observed may be due to the small, random motion of the floating debris. It may also indicate that the optical flow algorithm was not accurately matching points from one frame to points in the subsequent frame, due to the lack of distinctive features in the scene and the algorithm's bias toward small motion. The distribution of the magnitude of the motion shows that most of the calculated motions were small, with some outliers. The small motions may be due to debris and noise in the images, and the

outliers may indicate darting fish. The results are inconclusive and indicate a more in-depth investigation is needed, including testing the use of the bilateral filter for preprocessing to reduce the clutter in the scene.

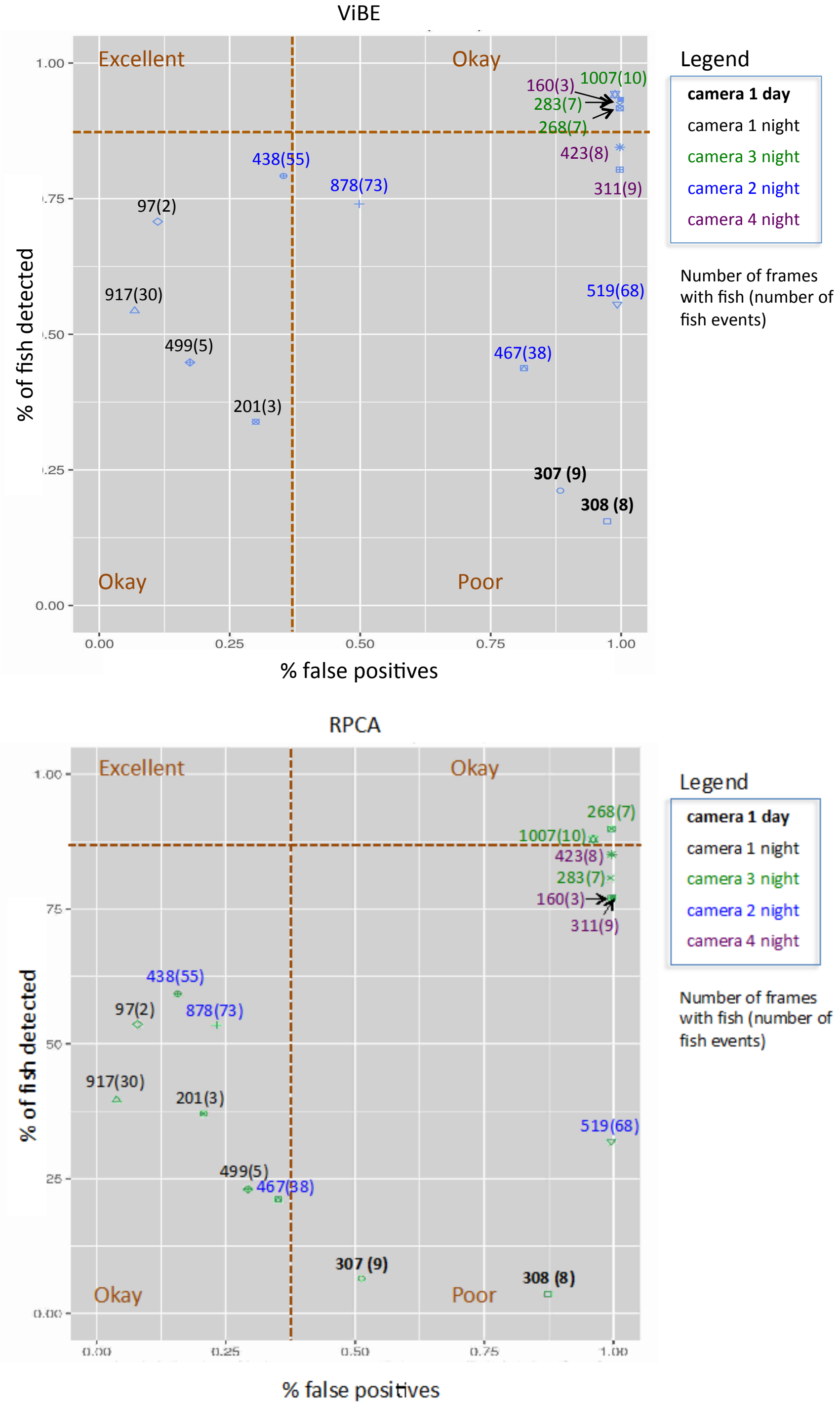
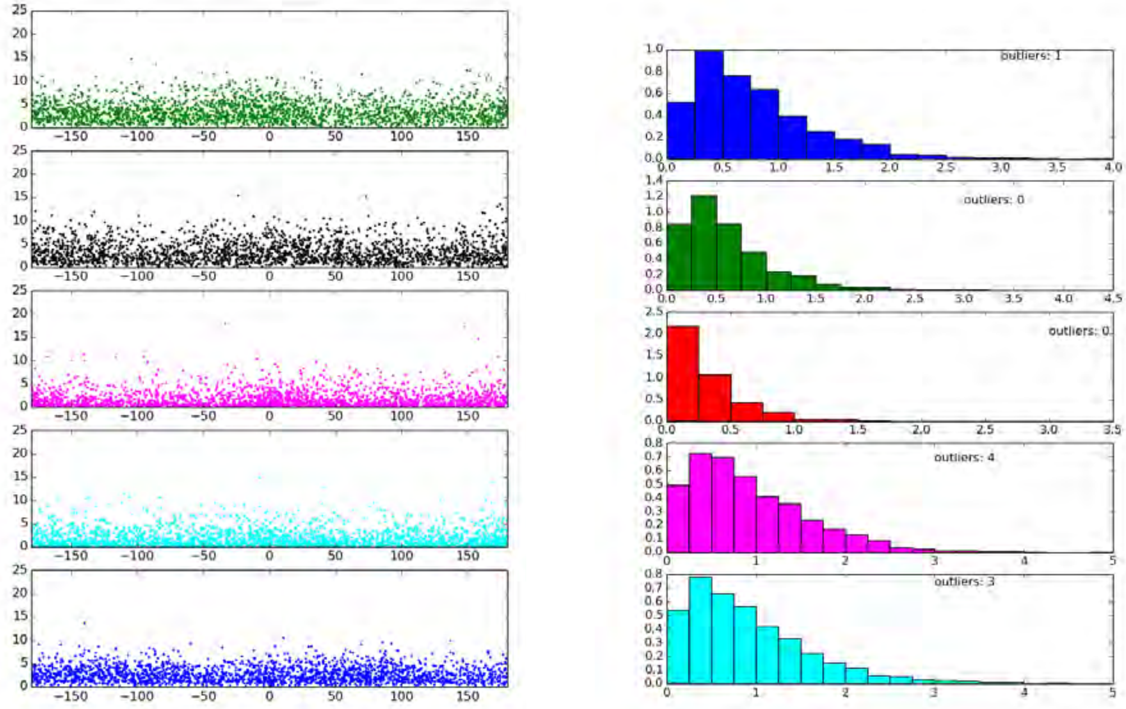


Figure 4.7. The detection rate and false positive rate by test video for RPCA (top) and ViBE (bottom). *The numbers on the scatter plots indicate the number of frames (out of 7500 per video) that contained fish and the number in parentheses is the number of Fish Events. A Fish Event is when a particular fish is in view; an event usually spans multiple consecutive frames.*



a) Magnitude vs. Direction

b) Magnitude Distribution

Figure 4.8. The magnitude and direction of motion at five points in the video were characterized using optical flow. The direction appeared to be uniformly distributed across all directions (a), and the magnitude appeared to follow a Rayleigh distribution that implies the motion in the x and y directions are independent (b).

The best Deep Learning model developed over the iterative learning process achieved 79% correct classification of both “fish” and “no fish” frames. This result is promising and on par with the background subtraction/blob classification results. This approach could be suitable for batch processing a large volume of recorded data, like the Igiugig data set, especially if the processing can be done on a high-performance computing system of parallel nodes. However, this approach would not be suitable for a real-time system because of the computational intensity, and the requirement for training data that is specific to the location being monitored.

5.0 Software

5.1 Need and Requirements

EyeSea is a web application that was developed by PNNL to meet the need for a central repository for accessing and analyzing the terabytes of video data from the Igiugig project. During the manual analysis of the video data it was found that the proprietary format of the video data required the use of the vendor’s specific software, which ultimately did not meet the requirements of the analysis team. Fortunately, an open-source video encoder (https://ffmpeg.org/) enabled the transcoding of the video data to the standard h264 format. This allowed the analysis team to use other more feature-rich software to perform the analysis of the video data. There was still the issue of how to make the h264 encoded video data available to the analysis team and also how to store results of the video analysis. To solve this issue a database-driven web site was designed, called “EyeSea”. This web-based application was developed in

parallel with the algorithm development, and was envisioned as the framework for ultimately providing a user-friendly front-end to the automated analysis, combining all the analysis tools into one comprehensive "human-in-the-loop" system for video analysis.

5.2 Functionality

The database was designed to store video metadata (e.g., date, time, location, timezone), analysis results (e.g., fish detected, species of fish, location of fish in video frame), and site-specific data (e.g., log-in information, batch processing information). Figure 5.1 shows the schema of the database that was ultimately implemented in MySQL.

Once the database had been designed the next step was to implement the web application. Bottle (https://bottlepy.org), a web framework for Python, was used to implement the web site. An asynchronous architecture was designed to allow users to query video data and later return and view the transcoded results. This was necessary to enable users to query videos encompassing large amounts of time without causing a browser timeout. Although the website was designed to play back the video inside the web browser, an option was added to allow users to download the video to their local machine for later offline playback. The website was later extended to allow for in-browser analysis of video. Figure 5.2 shows a screen capture example of the in-browser video playback.

EyeSea was also designed to facilitate batch processing and analysis of video. A set of scripts were written that could be deployed on a cluster of servers for parallel processing of multiple videos. The servers query the database for jobs to process and communicate to the database the status of the job as they are completed. The batch processing feature of EyeSea was used to extract Fish Events for later use in the analysis algorithm development testbed.

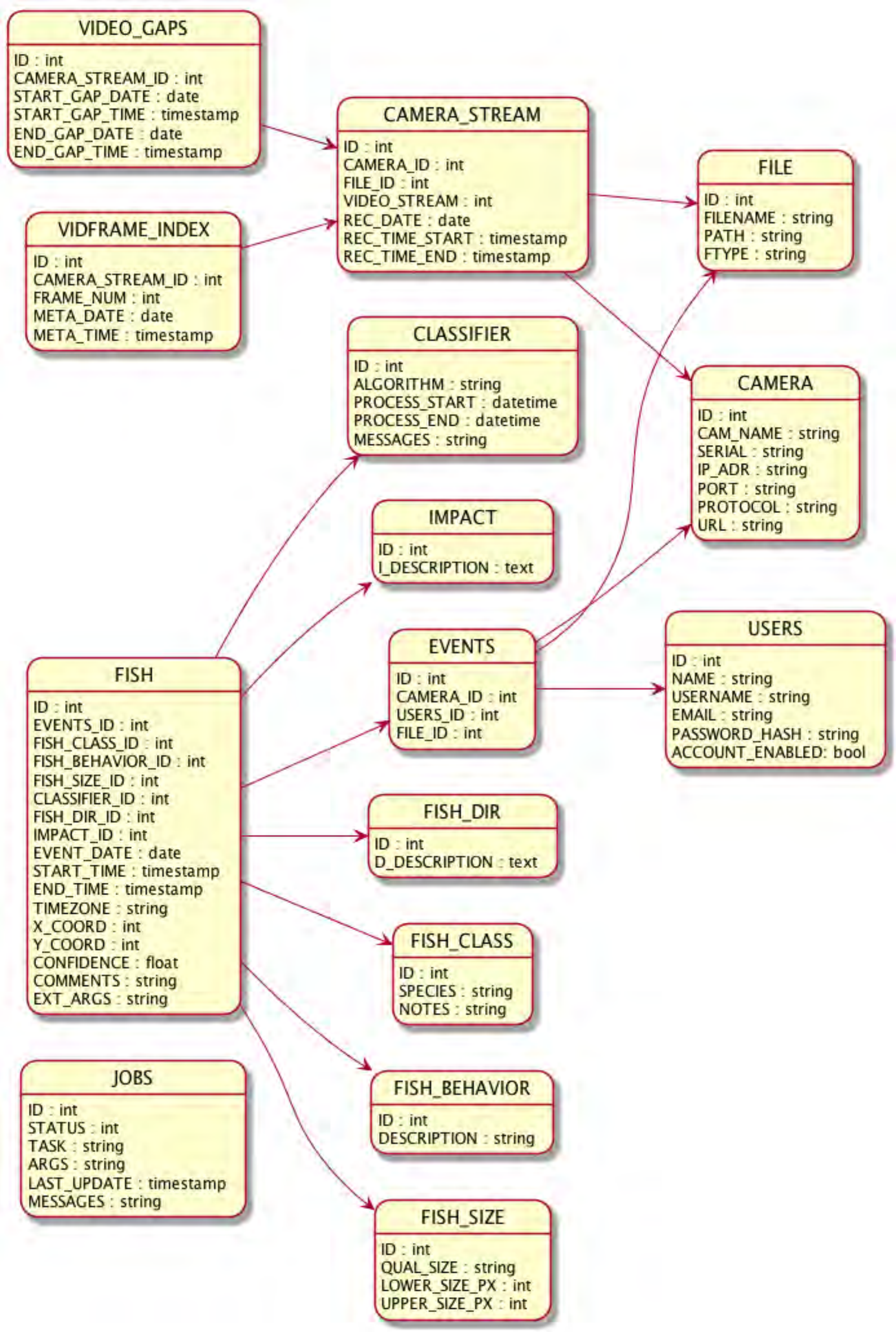


Figure 5.1. EyeSea database schema.

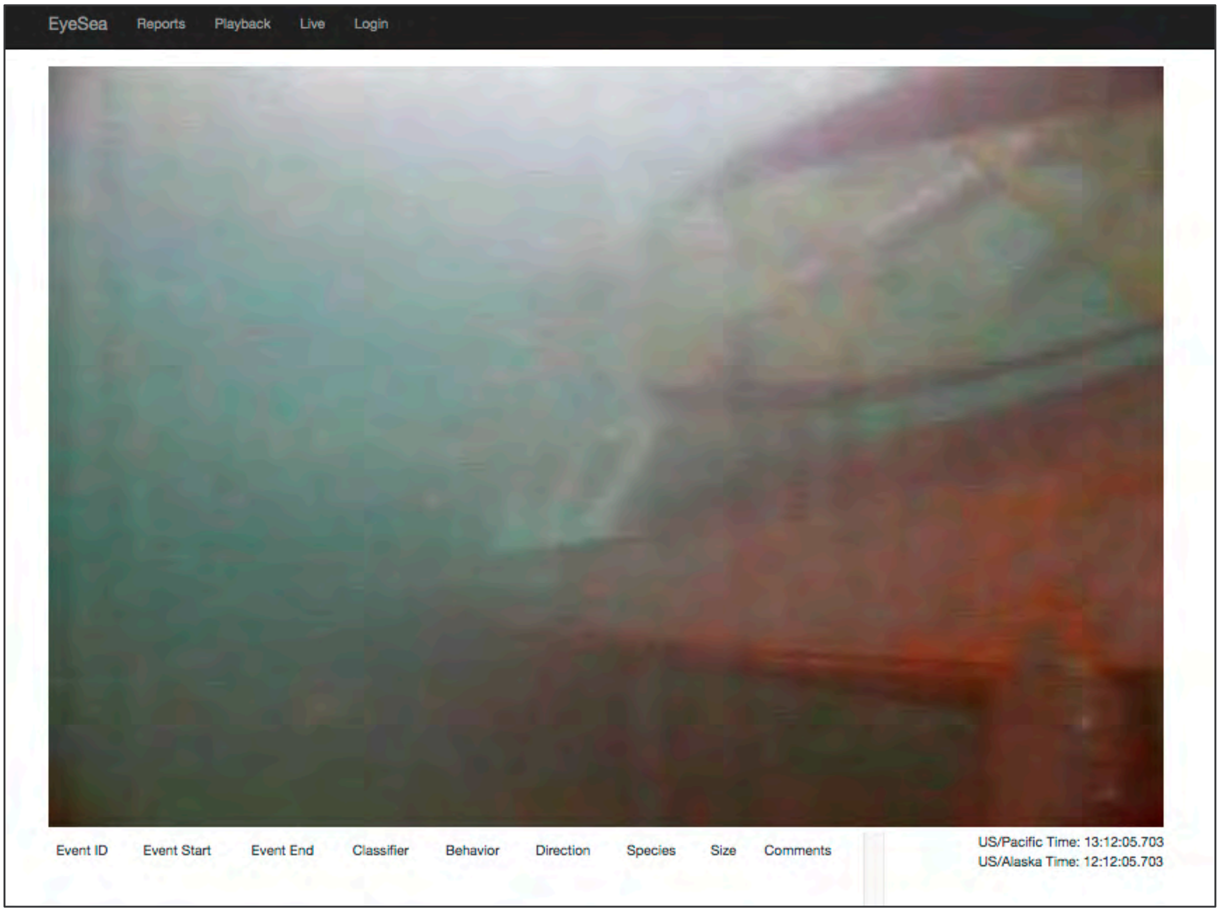


Figure 5.2. The EyeSea web application in playback mode.

6.0 Conclusions

6.1 Manual Analysis

The main points derived from the manual analysis of the data are as follows:

- Manual review of low-quality data is time-consuming. In this data set it took approximately 13–15 hours to manually review and annotate 1 hour of raw video data.
- Most interactions between the fish and the turbine occur at night.
- The frequency of fish interactions does not appear to be affected by whether the turbine is spinning or static.
- Processing subsamples (10 minutes) is likely effective for capturing unbiased event counts, but may not be effective for individual fish counts.
- Reviewer interpretation of Fish and Maybe Events in this data set is similar across two reviewers (qualitative analysis), but care is needed when assigning the designation of objects to introduced categories (quantitative analysis).
- Adult fish are qualitatively more likely to avoid collision or strike than juvenile fish.
- Adult fish are qualitatively more likely to show avoidance behavior as opposed to passive behavior relative to juveniles.

- More events occur when lights are on than when lights are off. Fish may be attracted to lights, lights may increase detection probability, or both.
- These data demonstrate the use of optical cameras for observing fish interactions with a deployed device in an underwater setting; however, improvements could be made with camera specifications and lighting parameters to increase the detection probability of fish, in both manual and automated review. Doing so may significantly decrease the manual and automated processing time.
- Observing "definite" vs. "probable" strike or collision is still extremely difficult and more research needs to be done to develop technologies or combine multiple technologies to gain confidence in determining actual contact with the device.

6.2 Automated Analysis

The main conclusions of the automated analysis effort were as follows:

- Tools available for detecting and tracking fish and other animals in underwater video are lacking. It was necessary to develop a new framework for semi-automated, human-in-the-loop analysis of underwater video. This framework can be used to test new algorithms and refine existing algorithms for automated fish detection and characterization, as well as support human expert analysis and standardized, reproducible information reporting.
- Reducing data volume is the first issue to address with automated processing. Large volumes of data are difficult to work with in terms of transferring, storing, and searching. A computationally simple background subtraction algorithm (ViBE) detected 74% of the human-identified Fish and Maybe fish, and is suitable for use in a real-time system to reduce data volume by saving only video that might contain fish.
- Reducing false positives is the second issue to address with automated processing. A statistical model can be used to classify detections as fish or not-fish, such as the one reported here that achieved a correct classification rate of 85% overall, and 92% for detections larger than 5 pixels. However, the statistical model required labeled training data that took time to assemble from the data and the model may not be transferable to other data sets. A classification model based on motion characteristics would potentially be more effective over a wider range of data.
- Underwater video recorded in energetic locations present challenges to automated processing that require algorithms specifically designed for this purpose. "Out of the box" algorithms such as those provided in the openCV library exhibited limited effectiveness, especially the optical flow techniques. Parameter tuning of the background subtraction algorithms did improve performance.

A combination of the automated detection developed under this project and human analysis could provide more accurate Fish Event information than the current practice of sampling, and with less labor time and cost than full analysis. Human analysis is currently the "gold standard" for accuracy, but it is very time-consuming so labor costs can be high and there may be long delays between collecting data and generating results. Sampling the video for analysis, e.g. analyzing 10 minutes of every hour reduces the labor time but sacrifices accuracy and increases the risk of missing rare events. The automated fish detection algorithms developed under this project can be completed quickly, but the resulting information is not as nuanced as that provided by human analysts and the detection accuracy is not yet sufficient so a "human-in-the-loop" approach is recommended. The automated detection software can be used to eliminate most of the video that does not contain fish, and the ensuing human analysis can be limited to those segments most likely to contain fish. With the developed processing system, this approach would reduce labor time by half over the full analysis, and would improve the reporting accuracy over sampling-based methods.

The performance of the automated processing can be further improved, based on the promising results demonstrated here. Future work should include incorporating computationally efficient bilateral filtering as a preprocessing stage, an intelligent scheme for parameter selection based on environmental conditions and video quality, and the integration of motion features. Further development of the EyeSea software should include a learning mode for tuning algorithm parameters using annotations provided by human experts.

7.0 Recommendations

The analysis of the Igiugig video data, both human/manual and automated, provided valuable insight into how to improve underwater video deployments in the future.

Since PNNL's review of the video data incorporated different approaches and anticipated outcomes than those of the original monitoring plan, recommendations arose regarding the monitoring process and methods for making project development and analysis more efficient in future studies. The water in the Kvichak River was described as being very clear compared to other rivers in the original monitoring report, yet the video data were described in PNNL's Quality Check Summary Report (Trostle 2016) as being "usable", in that the reviewers would be able to describe fish presence. The declaration of "usable" embodies the overall quality of the video data, including the following factors: resolution, frame rate, the placement of the cameras and light sources, the field of view, and the settings of the digital video recorder camera system. Careful consideration of the anticipated review and analysis objectives should be applied when making a camera selection. Those who will be reviewing the data should consider the questions they would like to answer and make sure that their camera selection, settings, and placement have the potential to address those questions.

To increase the quality of the video, future studies should use a low lux camera with a higher resolution and faster, even frame rate, but be aware that this will increase data accumulation because the files will be larger. Higher resolution video data would increase the likelihood that the manual reviewers could decipher between Maybe and Fish Events, identify taxonomic classification, and have more confidence regarding strike and collision. An increase in frame rate will improve the ability to detect actual strike because there would be more frames to describe the interaction around the turbine. It would also allow the reviewer, and possibly the algorithm, to use behavior as a qualifier, because sometimes the object would move significantly between frames, making behavior difficult to determine. Additionally, in some cases an object would only be in the field of view for one or two frames, making it difficult to determine if the object was a fish or not. In this study, objects that were only in one frame were not recorded as an event, because there was insufficient information to describe or categorize the object. With a more frequent frame rate and higher resolution, those objects could be included and give the study a broader picture, because the probability of missed events would be lower.

During manual video review, the reviewers realized that full manual analysis was too time-consuming. For this data set it took manual reviewers approximately 13–15 hours to process 1 hour of raw video data. A number of factors affect this approximation of time, including light operations, whether it was day or night, the number of fish, the behavior(s) of the fish, the amount of debris, the quality of the video, and whether or not the turbine was spinning. No 1-hour segment was identical to another in terms of time spent by manual reviewers due to the variability in the factors listed above, making the time spent extremely inconsistent. For this reason, future studies should be cautious when developing a timeframe estimate for manual processing, and reviewers should be wary that the anticipated estimation of time spent may change.

As described in the Quality Check Summary Report, a great deal of work and time was put into understanding the methods and settings implemented throughout the study, and converting the video from

a propriety format (.par), which was designed to be tamperproof, to a more appropriate format for the development of automated processing and analysis (.mp4). A more accessible format, such as .mp4 or .avi could be used for ease of use and to enable automated analysis before manual review.

As PNNL reviewers sifted through the video data, they noticed a variation in the light operations. In general, the lights seemed to be on at night and off during the day, with at least one exception on July 19, but a light operation record was not maintained during the study. Because there were many more Fish Events at night, it is important to get a better understanding of the effect artificial lights have on fish behavior (e.g., whether lights attract or repel fish). It is also important to quantify the difference the lights make to the physical parameters of detection (e.g., define more robust limits of detection, and define optimal placement and settings of light sources and cameras to increase manual and automated detection potential).

Recommendations for future underwater environmental monitoring are listed below:

- **General setup.** Include an indication of range within the field of view to help reviewers distinguish size and location in relation to the turbine. Also, aim the camera so the field of view is aligned with particular turbine components, possibly in combination with sensors on the turbine foils to increase the detectability potential and promote a higher level of confidence during potential strike and collision events. The aiming of each camera will likely require an iterative process of viewing early data and making adjustments to achieve ideal viewings for manual processors as well as ideal background for algorithm applications.
- **Video format**. A standard format (e.g., .avi, .mp4) should be used, rather than a proprietary format. When the video is in a standard format, researchers have a wide array of existing tools that they can use for analysis and processing. A proprietary format restricts researchers to using vendor-supplied software that often is not designed for the type of analysis required.
- **Camera type.** Choose a camera that has underwater capability with high pixel resolution in low light conditions, the capability to mount and adjust placement settings, appropriate data storage and transmission, and a suitable field of view range for the study area.
- **Camera resolution and placement.** The camera resolution will determine the size of objects in pixels at a given distance from the camera. Objects that are less than five pixels in total size are difficult to detect, both algorithmically and visually. Higher resolution will increase the volume of data, but low resolution will restrict the size of fish that can be reliably detected. The size of a fish in pixels, along the horizontal dimension, is

  length of fish in meters / meters per pixel

  The meters per pixel is

  $$\frac{2r\tan\frac{\alpha}{2}}{n}$$

  where r is the distance to the fish in meters, α is the horizontal camera field of view angle, and n is the number of pixels in the horizontal dimension. For example, a 10 cm (4 in.) fish would be 10 pixels long at 10 m from a 320 × 240 pixel camera with a 20 degree horizontal field of view. This calculation will also help determine how far from the turbine to locate the camera. Test the placement of the cameras and lights to optimize manual and automated detection probability. Note where the sun will be throughout the study and test different angles to avoid glare.

- **Frame rate.** Ideally, the frame rate should be constant, meaning that there is a fixed interval of time between frames. The Igiugig video had a variable frame rate that resulted in uneven motion of objects from frame to frame. Higher frame rates increase the volume of data, but if the frame rate is too low the number of frames in which a fish may be in the field of view is decreased, decreasing the

probability of detection. A rate of 30 frames per second is a reasonable choice to balance data volume with detection likelihood.

- **Lighting**. Fish specific to this study are typically more active at night, so some sort of illumination is needed if video is the only monitoring technique used. The light also generated more false positives from reflecting debris. An indirect light source, like the lighting viewed from camera 1 in the Igiugig video may be the best choice. If lights are to be used, the lights should be on throughout the study to maintain a more controlled environmental setup, and increase light sources with more angles of incidence to prevent fish from disappearing when they turn at an angle that does not reflect light from a single source. However, while improving the detection of fish and debris, this practice may also introduce possible bias because of the lights themselves increasing detection probability or attracting fish, both of which complicate comparisons when lights are turned off or confounded by diel differences.
- **Detailed record keeping**. The following aspects should be recorded:
  - all monitoring operations, including camera operation, light operation, power operation, turbine status, and any other introduced monitoring systems.
  - water flow, weather conditions and any significant events that occurred during the study.
  - any maintenance issues or disruptions throughout the study.
  - review efforts.
- **Other monitoring**. Consider adding other monitoring technologies to help determine whether actual collision or strike occurred and to have a backup technology for behavioral monitoring. Strain gauges or other devices physically attached to the blades of a turbine could be used to complement the video data for those times when a collision or strike is possibly seen. Having coincident data sets providing evidence of collision or strike would be better than just one. For instance, if a reviewer thinks a strike was seen on the video data, the same timestamp could be searched for blade-attached strain gauges to see if there was a spike. If there was an anomaly on the strain gauge, then that is more evidence of a strike. The absence of strain gauge data would be evidence that the interaction was more likely a near-miss.

To inform future studies, additional research into specific aspects would also be useful, in particular a study to assess the effects of lights on fish, in conjunction with an evaluation of light and camera placement and settings toward the optimization of detection probability to find an ideal experimental design for manual and automated detection. The study would record details of the placement, including heading, pitch and roll of both the lights and the cameras, light operations, intensity, wavelength, exact range in relation to the device and cameras, as well as camera operations, range, resolution, frame rate, and settings. For algorithm development, further research is recommended into different optical flow techniques, and the refinement of parameters for the background subtraction. Each of these aspects would improve the results derived from future monitoring. Each study site will have specific physical characteristics that will affect underwater video camera data collection. However, as research continues on future data sets, general application principles will arise that can be applied to most situations.

8.0 References

Avila A, Hull R, Matzner S, Staines G, Trostle C, and Harker- Klimeš G. 2016. *Igiugig Video Analysis – FY16 Progress Report* PNNL-25909 Pacific Northwest National Laboratory, Richland, WA.

Barnich O and Van Droogenbroeck M. 2009. ViBe: a powerful random technique to estimate the background in video sequences. In proceedings of *Acoustics, Speech and Signal Processing, 2009.*

ICASSP 2009. IEEE International Conference on Acoustics, Speech and Signal Processing (pp. 945–948). IEEE.

Boom BJ, He J, Palazzo S, Huang PX, Beyan C, Chou H-M, Lin F-P, Spampinato C, and Fisher RB. 2014. A research tool for long-term and continuous analysis of fish assemblage in coral-reefs using underwater camera footage. *Ecological Informatics*, 23:83–97.

Candès EJ, Li X, Ma Y, and Wright J. 2011. Robust principal component analysis? *Journal of the ACM (JACM) 58*(3), 11.

Farnebäck G. 2003. Two-frame motion estimation based on polynomial expansion. In proceedings of *Scandinavian Conference on Image Analysis* (pp. 363–370). Springer Berlin Heidelberg.

Lee DS. 2005. Effective Gaussian mixture learning for video background subtraction. *IEEE transactions on pattern analysis and machine intelligence 27*(5), 827–832.

LGL Alaska Research Associates, Inc. 2015. *Fish and Wildlife Monitoring Plan for RivGen® Testing on the Kvichak River, Alaska in 2015*.

Lotlikar R and Kothari R. 2000. Fractional-step dimensionality reduction. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 22(6): 623–627.

Lucas BD and Kanade T. 1981. An iterative image registration technique with an application to stereo vision. *International Joint Conferences on Artificial Intelligence (IJCAI)* 81: 674–679.

Tomasi C and Manduchi R. 1998. Bilateral filtering for gray and color images. In *Computer Vision, 1998. Sixth International Conference on Computer Vision* (pp. 839–846). IEEE.

Trostle C. 2016. *Igiugig Fish Video Study– Quality Check, Summary Report*. Pacific Northwest National Laboratory, Richland, WA.

Appendix A

Manual Annotation

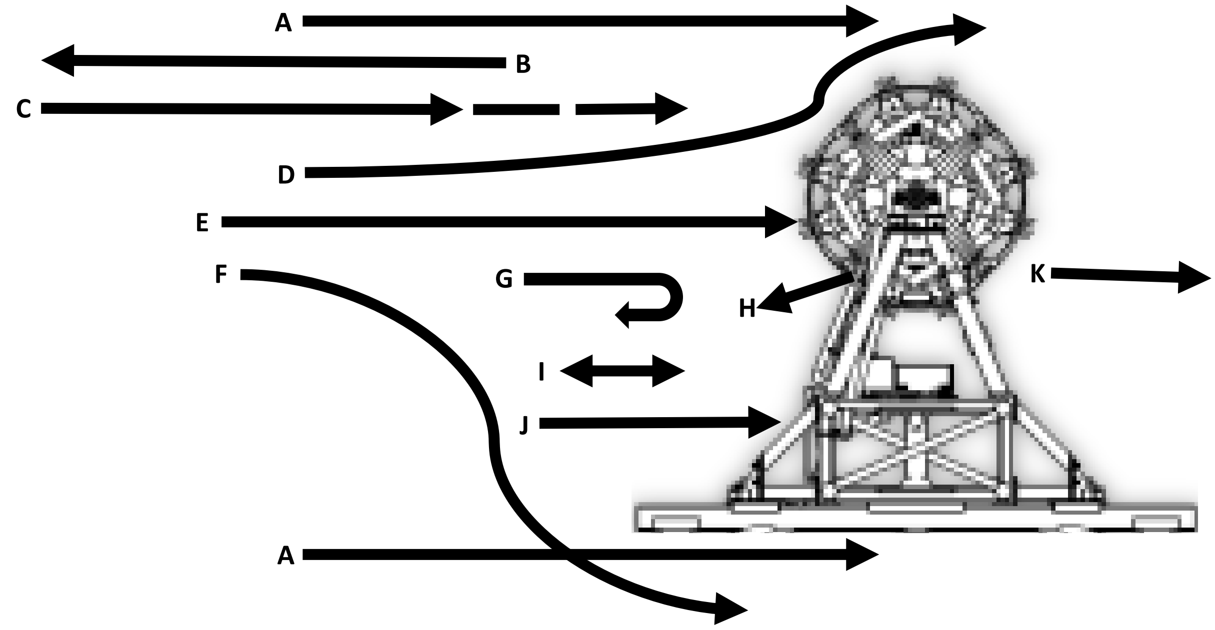
Appendix A

Manual Annotation

Annotation	Description of Annotation
Event	Reference number per event; restarting for each half-hour block of data
Date	Day video data was collected; yyyy/mm/dd
File	Filename given to each half-hour block of data; includes day and time
FileStartTime	Time that file starts on the given day it was collected
StartTime	Time that an event begins; begins 00:00:000 per half-hour block of data
EndTime	Time that an event ends; ends 29:59:999 per half-hour block of data
Lights	Either on or off; binary
Spinning	Either yes or no; binary
Camera	Designated number of camera; these data only include Camera 2
Fish?	Is the event triggering object a fish; yes, no, maybe
Number	How many objects or fish occur during an event
Size	Size of objects or fish seen during an event; measured as length on computer monitor; unidentifiable, small (<0.5 in), medium (0.5–3.0 in), large (>3.0 in.); was adjusted relative to monitor screen sizes
Species	Visually identifiable relative size designation or salmon; unidentifiable, juvenile, salmon, adult
VideoQuality	Relative anecdotal comparison of each event relative to others based on clarity of event triggering object in field of view; horrible, bad, okay, good, excellent
Notes	To clarify any previous annotation categories
Location	Where the event triggering object is in the water column; based on computer monitor divided into thirds; bottom, middle, top
Direction	All observed directions of the event triggering objects or fish; downstream, upstream, cross river toward, cross river away
Behavior	Reviewer description of all object or fish behaviors observed during an event. • straight across • against current • pause • avoid above • through turbine

- avoid below
- avoid reverse
- out of turbine
- milling
- toward static parts
- through wake
- avoid around
- unable to tell
- other

Impact	Reviewer determination if there was collision or strike during an event
Comments	To clarify any previous categories since “Notes”



A- straight across
B- against current
C- pause
D- avoid above
E- through turbine
F- avoid below
G- avoid reverse
H- out of turbine
I- milling
J- toward static parts
K- through wake
L- unable to tell (not shown)
M- other (not shown)

Appendix B

Video Data Set Used for Algorithm Development

Video Data Set Used for Algorithm Development

Video File (Date, time, camera)	Day | Appendix BLights	Turbine | Spinning | None	Fish Events	Fish Frames
20150719_175830-1.mkv	Day	None	7	308
20150720_110030-1.mkv	Day	None	9	307
20150722_030200-1.mkv	Lights	None	30	917
20150722_030200-2.mkv	Lights	Turbine	72	878
20150722_030200-3.mkv	Lights	Turbine	7	283
20150723_000330-1.mkv	Lights	None	2	97
20150723_000330-2.mkv	Lights	Spinning	68	519
20150723_000330-3.mkv	Lights	Spinning	7	268
20150723_000330-4.mkv	Lights	Spinning	8	423
20150724_000000-1.mkv	Lights	Turbine	5	499
20150724_000000-2.mkv	Lights	None	53	438
20150724_000000-3.mkv	Lights	Turbine	10	1007
20150724_000000-4.mkv	Lights	Turbine	9	311
20150825_040330-1.mkv	Lights	None	3	201
20150825_040330-2.mkv	Lights	Turbine	38	467
20150825_040330-4.mkv	Lights	Turbine	3	160
Total			**334**	**7569 (6%)**

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT OF
ENERGY

Proudly Operated by **Battelle** *Since 1965*

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

www.pnnl.gov

Attachment 3

Monitoring Equipment Specifications

FLIR BLACKFLY® S

P/N: BFS-PGE-31S4, GIGE VISION

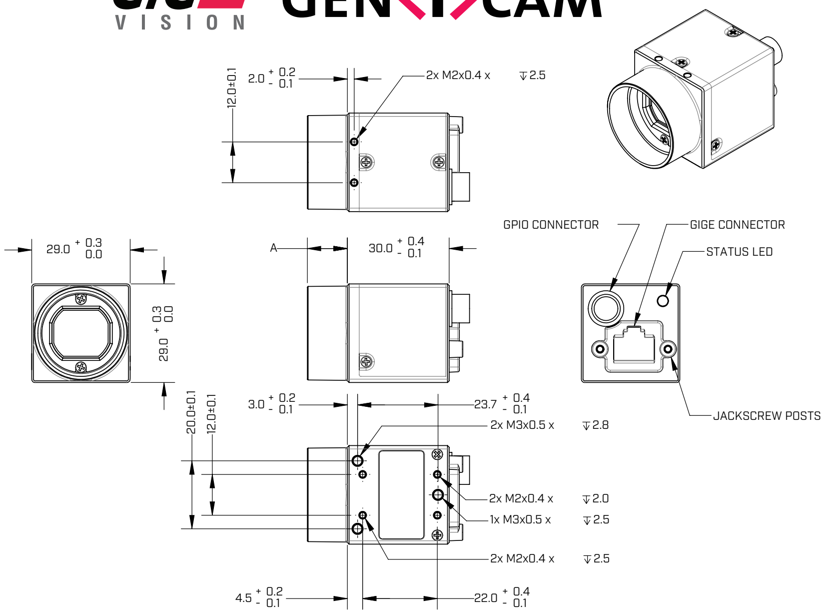
SMALL PACKAGE, POWERFUL RESULTS

The Blackfly S combines the newest CMOS image sensors with our new and intuitive Spinnaker software development kit. The many new advanced camera features are designed to meet your complex imaging needs and speed up development time.

KEY FEATURES

- Leverage the latest **CMOS sensors** and new on-camera image processing features. Harness increased **binning** flexibility, powerful **auto-exposure** controls and robust **color transformation** tools.
- Improve cycle time using advanced camera controls and programmable logic Utilize **sequencer, chunk data, event notification, counters, timers** and **logic blocks**.
- Accelerate your time to market using our **GenICam3 API, GUI API library**, detailed **API logging** and comprehensive **documentation**.
- IEEE 1588 Precision Time Protocol for **accurate clock synchronization** with no user oversight.

GiGE VISION GEN<i>CAM



www.flir.com/mv

FLIR® | The World's Sixth Sense®

Specifications

	BFS-PGE-31S4M	BFS-PGE-31S4C
Resolution	2048 x 1536	
Frame Rate*	35 FPS	
Megapixels	3.1 MP	
Chroma	Mono	Color
Sensor	Sony IMX265, CMOS, 1/1.8"	
Readout Method	Global shutter	
Pixel Size	3.45 µm	
Lens Mount	C-mount	
ADC	12-bit	
Minimum Frame Rate**	1 FPS	
Gain Range**	0 to 48 dB	
Exposure Range**	11 µs to 30 s	
Acquisition Modes	Continuous, Single Frame, Multi Frame	
Partial Image Modes	Pixel binning, decimation, ROI	
Image Processing	Gamma, lookup table, and sharpness	Color correction matrix, gamma, lookup table, hue, saturation, and sharpness
Sequencer	Up to 8 sets using 2 features, exposure and gain	
Image Buffer	240 MB	
User Sets	2 user configuration sets for custom camera settings	
Flash Memory	6 MB non-volatile memory	
Opto-isolated I/O	1 input, 1 output	
Non-isolated I/O	1 bi-directional, 1 input	
Auxiliary Output	3.3 V, 120 mA maximum	
Interface	GigE PoE	
Power Requirements	Power over Ethernet (PoE), or 12 V nominal (8 - 24 V) via GPIO	
Power Consumption	3 W maximum	
Dimensions/Mass	29 mm x 29 mm x 30 mm / 36 g	
Machine Vision Standard	Gige Vision v1.2	
Compliance	CE, FCC, KCC, RoHS, REACH. The ECCN for this product is: EAR099.	
Temperature	Operating: 0°C to 50°C Storage: -30°C to 60°C	
Humidity	Operating: 20% to 80% (no condensation) Storage: 30% to 95% (no condensation)	
Warranty	3 years	

*Frame rates are measured with Device Link Throughput Limit of 380 MBps and Acquisition Frame Rate disabled. Values are rounded down to whole numbers.

**Values are the same in binning and no binning modes.

FLIR Integrated Imaging Solutions

CANADA
12051 Riverside Way
Richmond, BC, Canada
V6W 1K7
T: +1 866.765.0827 (toll free)
T: +1 604.242.9937
F: +1 604.242.9938
E: mv-sales@flir.com
www.flir.com/mv

USA
T: +1 866.765.0827 (toll free)
E: mv-na-sales@flir.com

EUROPE
T: +49 7141 488817-0
F: +49 7141 488817-99
E: mv-eusales@flir.com

CHINA
T: +86 10 8215 9938
F: +86 10 8215 9936
E: mv-chinasales@flir.com

ASIA
E: mv-asiasales@flir.com

For a full list of international distributors and offices visit www.flir.com/contact-us

Tamron M118FM16, 16mm, 1/1.8", C mount Lens

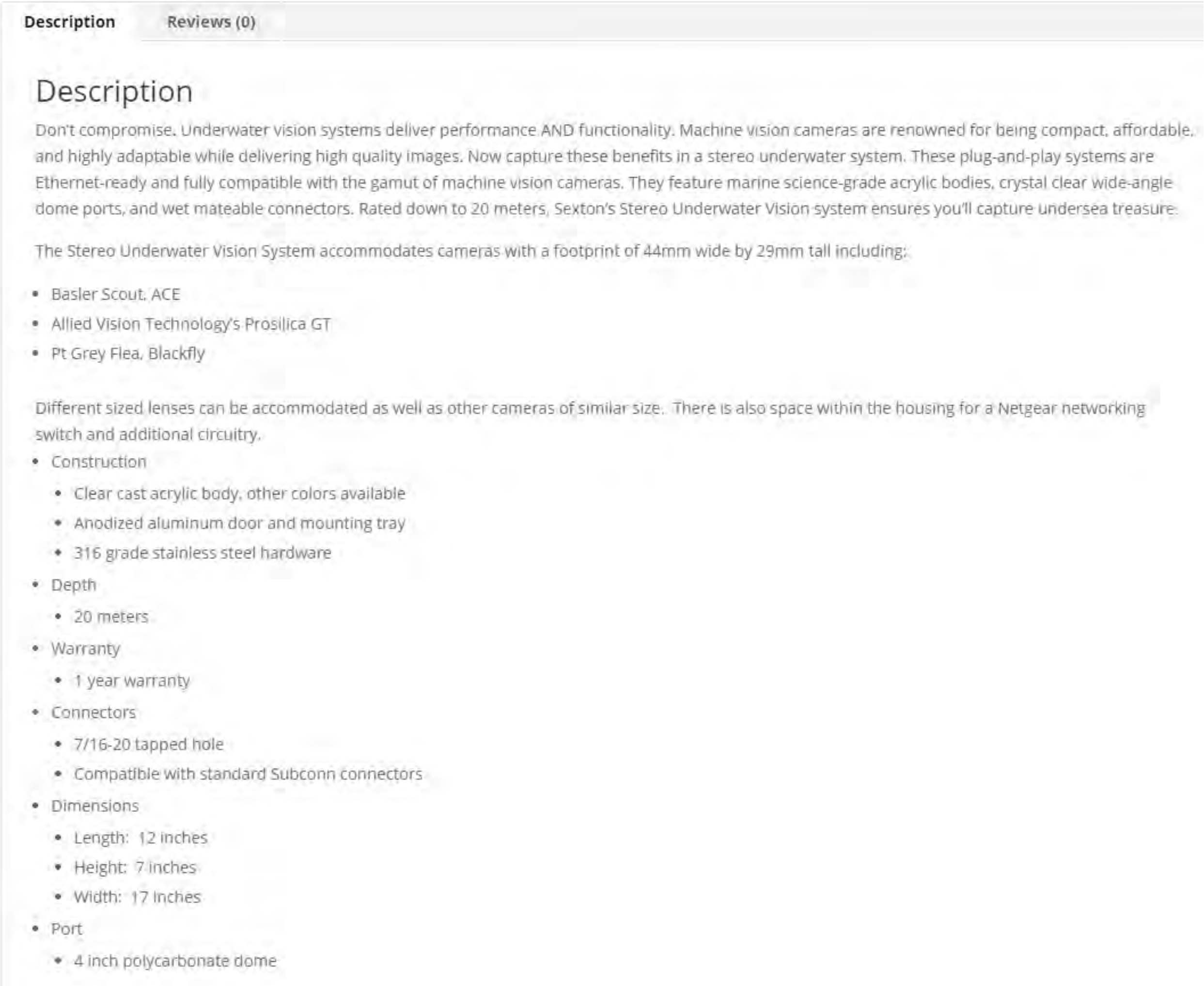
HOME / MACHINE VISION CAMERAS / ACCESSORIES / LENSES / TAMRON M118FM16, 16MM, 1/1.8", C MOUNT LENS

Specifications | Documents

Manufacturer Part Number	Tamron M118FM16;
Focal Length	16mm;
Optical Format	1/1.8";
Lens Mount	C Mount;

Stereo Underwater Vision System

Categories: Camera Enclosures, Instrument Enclosures, Networking



Description

Don't compromise. Underwater vision systems deliver performance AND functionality. Machine vision cameras are renowned for being compact, affordable, and highly adaptable while delivering high quality images. Now capture these benefits in a stereo underwater system. These plug-and-play systems are Ethernet-ready and fully compatible with the gamut of machine vision cameras. They feature marine science-grade acrylic bodies, crystal clear wide-angle dome ports, and wet mateable connectors. Rated down to 20 meters, Sexton's Stereo Underwater Vision system ensures you'll capture undersea treasure.

The Stereo Underwater Vision System accommodates cameras with a footprint of 44mm wide by 29mm tall including:

- Basler Scout, ACE
- Allied Vision Technology's Prosilica GT
- Pt Grey Flea, Blackfly

Different sized lenses can be accommodated as well as other cameras of similar size. There is also space within the housing for a Netgear networking switch and additional circuitry.

- Construction
  - Clear cast acrylic body, other colors available
  - Anodized aluminum door and mounting tray
  - 316 grade stainless steel hardware
- Depth
  - 20 meters
- Warranty
  - 1 year warranty
- Connectors
  - 7/16-20 tapped hole
  - Compatible with standard Subconn connectors
- Dimensions
  - Length: 12 inches
  - Height: 7 inches
  - Width: 17 inches
- Port
  - 4 inch polycarbonate dome

LED SeaLite®

Patents Pending

FEATURES

Wide, Flood, Spot, or Switchable Dual Beam Configurations

Up to 10,000 Lumens

4,000 m, 6,000 m, and 11,000 m Depth Rated Options

Flicker-Free Digital and Analog Dimming Interfaces

Customer Serviceable

SeaSense™ Protocol

T: 858-576-1261
F: 858-576-0219

4033 Ruffin Road
San Diego, CA
92123-1817 USA

www.deepsea.com
sales@deepsea.com

LED SeaLite®

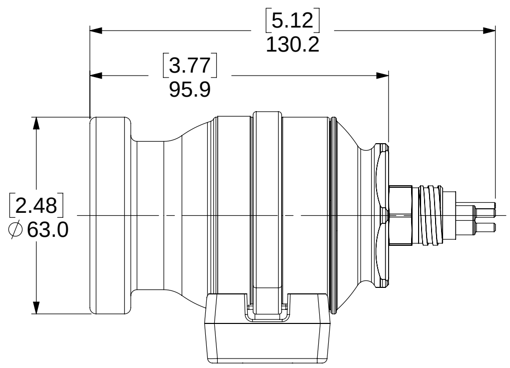
	LSL-1000	LSL-2000	LSL-2025
Optical Specifications			
Typical Lumen Output (Flood)	10,000		See www.deepsea.com/multiray for sample configuration specifications.
Efficacy	63 lm/w[1]	94 lm/w[1]	
Lux at 1 m	Wide[2]: 2,300 lx Flood: 5,600 lx Spot: 14,000 lx		
Color	Day Light White 5000 K ~ 6500 K Warm White 2600 K ~ 3700 K Contact Sales for Color Options		
CRI	Day Light White: 70 Warm White: 80		
Beam Angle (HPFW)	Wide[2]: 115° Flood: 75° Spot: 35°		Wide[2]: 115° Flood: 75° Spot: 40°
Environmental Specifications			
Depth Rating	4,000 m Acrylic Port 6,000 m or 11,000 m Sapphire Port		
Thermal Protection	Intelligent Thermal Rollback		
Operational Temperature	-10°C to 40°C [14°F to 104°F][3]		
Storage Temperature	-40°C to 100°C [-40°F to 212°F]		
Electrical Specifications			
Voltage	90~140 VAC 50/60 Hz 110~160 VDC	10~48 VDC[1]	
Power	160W @ 120 VAC 60 Hz	106W @ 24 VDC	
Dimming	RS232[4], RS485[4], Phase/Triac	RS232[4], RS485[4], 0~5V, 0~10V, 4~20mA	
Mechanical Specifications			
Housing	Hard Anodized 6013 Aluminum Titanium		
Port	Standard: Sapphire Optional: Acrylic		
Outer Diameter	63.0 mm [2.48 in]		
Overall Length (Without Connector)	Acrylic Flood/Wide: 95.9 mm [3.77 in] Sapphire Flood: 93.3 mm [3.67 in] Acrylic/Sapphire Spot: 99.6 mm [3.92 in]		
Weight in Air[5]	Sapphire Flood: 490 g Sapphire Spot: 510 g	Sapphire Flood: 450 g Sapphire Spot: 470 g	
Weight in Water[5]	Sapphire Flood: 240 g Sapphire Spot: 260 g	Sapphire Flood: 200 g Sapphire Spot: 220 g	
Connector[6]			
Default	SEACON MCBHMP SS Please contact sales for more options.		

[1] 100% output available above 20 VDC. 50% output from 10~20 VDC due to input current limits.
[2] Wide beam angle only available on Acrylic port 4,000 m depth rating.
[3] For 120 VAC versions, thermal rollback may reduce light output in water temperatures exceeding 25° C [77° F]. See Manual for additional information.
[4] For RS232 and RS485, see Manual.
[5] Nominal values are measured with MCBHMP connector and aluminum housing.
[6] Ensure that ampacity ratings for interconnect system are suitable for your operating conditions. See Manual for more information.

LED SeaLite®

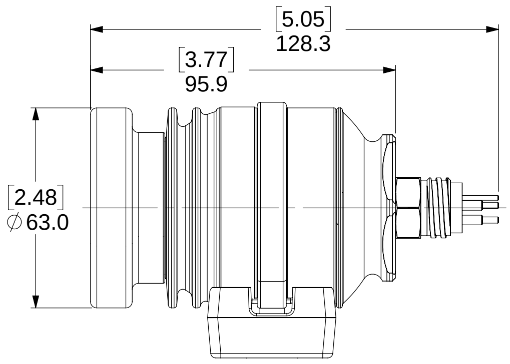
Dimensions

Flood Beam Acrylic Port



FLOOD/WIDE ACRYLIC ALUMINUM

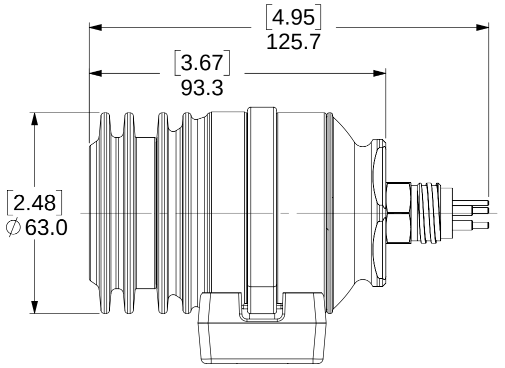
mm [inch]



FLOOD/WIDE ACRYLIC TITANIUM

mm [inch]

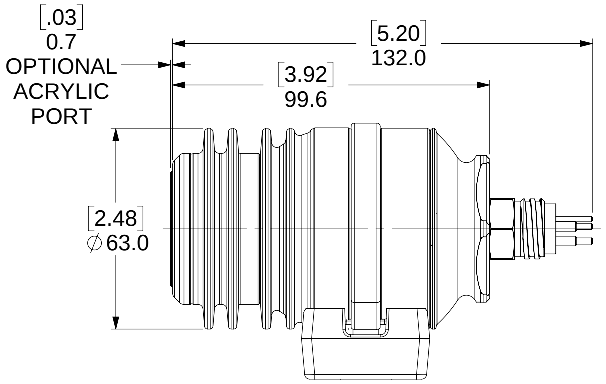
Flood Beam Sapphire Port



FLOOD SAPPHIRE

mm [inch]

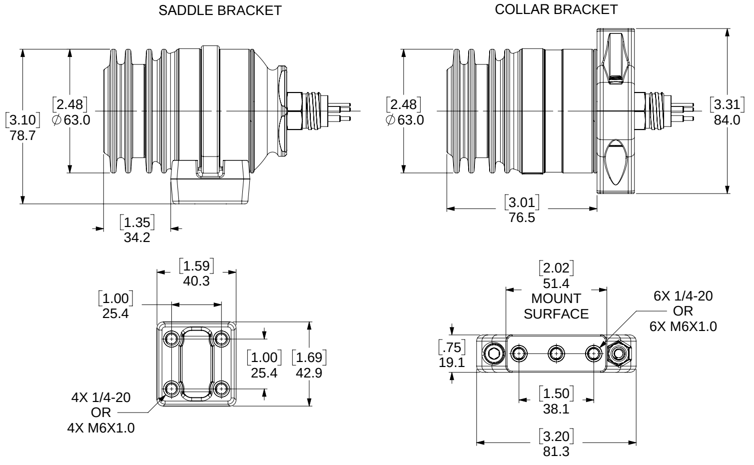
Spot Beam



SPOT ACRYLIC/SAPPHIRE

mm [inch]

Bracket



mm [inch]

**Specifications subject to change without notice.*

IGIUGIG HYDROKINETIC PROJECT

APPENDIX B: ESSENTIAL FISH HABITAT ASSESSMENT

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511-002

November 15, 2018

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613-4008
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

Appendix B: Essential Fish Habitat Assessment includes the following document:

- Essential Fish Habitat Assessment

ESSENTIAL FISH HABITAT ASSESSMENT

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511-002

November 15, 2018

NOAA National Marine Fisheries Service
PO Box 21668
709 W. 9th St., Rm 420
Juneau, Alaska 99802-1668

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 BACKGROUND AND HISTORY

The Igiugig Village Council (IVC) is applying to the Federal Energy Regulatory Commission (FERC) for a ten-year pilot project license for the Igiugig Hydrokinetic Project (Project). This Essential Fish Habitat Assessment has been prepared for this license application.

The Project will be installed as a new source of clean, locally produced, renewable electricity generated from water currents in the Kvichak River in Igiugig, Alaska, to displace high cost, polluting diesel generated power. The Project will be carried out in two separate phases over an expected ten-year pilot project license term. In Phase I, IVC will install and monitor a single-device Ocean Renewable Power Company, Inc. (ORPC) RivGen® Power System for an initial period of up to 12 months. In Phase II, after operating and monitoring this initial power system, IVC will decide whether to install the second RivGen® device to create a two-device RivGen® Power System. Electricity generated by the Project will be delivered by an underwater cable to a shore station in Igiugig, Alaska, where it will be power-conditioned and connected to the power grid operated by the Igiugig Electric Company.

1.1 2015 RivGen® Power System Monitoring Results

Fish and wildlife monitoring was performed by LGL Alaska Research Associates, Inc (LGL) in 2015, in accordance with the 2015 Monitoring Plan and the Alaska Department of Fish & Game (ADF&G) Fish Habitat Permit FH 15-II-0038. Data was collected around the RivGen® 1.F Power System deployed in the Kvichak River in July and August 2015. The RivGen® was deployed from approximately July 10 through September 15, 2015, which overlapped with part of the migration of adult salmon, rainbow trout, and other species. This time period did not overlap with the main migration timing of juvenile sockeye salmon, which migrate annually downstream from approximately May 21 through June 10.

Fish movements at the RivGen® device were described using video footage collected from five underwater cameras mounted to the pontoons of the power system. Video footage was collected 24 hours/day July 19–25 and again August 19–27, 2015; review was done by watching the first 10 minutes of a selected hour from each of the four primary cameras (the fifth camera was a backup). Spatially, the camera field of view captured the port side of the RivGen® device, including upstream and downstream views of the port side turbine only (due to reduced visibility from variable river turbidity of the starboard side turbine). In accordance with the 2015 Monitoring Plan, footage was reviewed to achieve partial temporal coverage during different categories of turbine operating status and daytime/nighttime conditions. At night, two underwater lights lit the viewing area. In addition, bird and marine mammal surveys were conducted for 15 minutes each morning of monitoring. Methods and the overall approach were similar to those described for the demonstration study conducted at the same site in 2014.

Blocks of video footage from portions of 238 different hours were reviewed in season in 2015. There were 359 events with fish, composed of approximately 1,202 individual fish from at least six species. The majority of fish observations were of solitary fish; the largest school was approximately 100 fish. Species composition varied from July to August and from day to night. Salmon smolt were almost exclusively seen at night and were more prevalent in July than August. Several instances of fish moving through the RivGen® turbine were noted and reported in season as part of the Project's adaptive management process. LGL did not detect any obvious physical injuries to fish and saw no altered behavior by wildlife near the RivGen® device. Cameras, lights, and power system components operated reliably. All video footage was archived. The LGL monitoring report is included as Attachment 1 (LGL, 2015).

1.2 2015 PNNL Data Analysis

Video data collected as part of the 2015 RivGen® Power System monitoring provided a valuable opportunity for further analysis to better quantify interactions between fish and the turbine. As a result, the U.S. Department of Energy (DOE) commissioned the Pacific Northwest National Laboratory (PNNL) to conduct data analysis and to develop potential automation techniques for future monitoring. The goal of PNNL's analysis of video data collected around ORPC's RivGen® device deployed in the Kvichak River during July and August 2015 was to gain an understanding of the implications of using underwater video cameras as a fish monitoring technique. The data were analyzed manually and used to develop automated algorithms for detecting fish in the video frames and describing their interaction behavior relative to the device. In addition, PNNL researchers developed a web application, EyeSea, to combine manual and automated processing, so that ultimately the automated algorithms could be used to identify where human analysis was needed (i.e., when fish are present in video frames).

The manual analysis began to look at all data from the start of deployment of the RivGen® device, primarily using video from Camera 2 that looked directly at the upstream side of the turbine, so any interaction could be identified; this was to ensure rare events were seen, and initially focused on nighttime data when more fish were present. This process highlighted the amount of time it takes to identify fish, and ultimately only 42.33 hours of video were reviewed because of the time-consuming analysis. The data were classified as "Fish" when the reviewer was confident it was a fish, and "Maybe" is defined by an object that during manual analysis is deemed to possibly be a fish, but not a definite identification. The two classes were distinguished based on the movement, shape, and color characteristics. Fish events were further classified by “adult”, “juvenile”, or “unidentifiable” age. Behavioral attributes were noted and were broadly divided into Passive and Avoidance activities. In over 42 hours of the data reviewed, there were 20 potential contact interactions, of which 3 were “Maybe” classifications, 12 were juveniles, and 5 were adults. While only 11.5 percent of the video data were analyzed from Camera 2, these results are from the time when most fish were present over the turbine deployment period (ADF&G data) and provide preliminary evidence that fish strike or collision of fish in the Kvichak River with an instream turbine is rare.

On only one occasion was an actual contact confirmed, and this was an adult fish that contacted the camera, not the turbine itself. This experience highlights the difficulties associated with confirming a strike or collision event as either having occurred or having been a near-miss. More interactions were detected at night; this was probably biased by nighttime use of artificial light, which may have attracted fish, but also could have increased detection probability because light is reflected from the fish itself. The full PNNL report (Matzner, et al. 2017) is included as Attachment 2.

2 DESCRIPTION OF THE PROJECT AREA AND PROJECT ACTIVITIES

Because the 2019 deployment of the RivGen® Power System has financial support from DOE, the Proposed Action is subject to the provisions of the National Environmental Policy Act (NEPA). However, the Proposed Action may qualify for a NEPA categorical exclusion under 10 CFR Part 1021, section B5.25 Small Scale Renewable Energy Research and Pilot Projects in Aquatic Environments (see Federal Register Vol. 776, No. 198 at p. 63797), provided that it will not affect ESA-listed species or their designated critical habitat.

The Project will be carried out on the Kvichak River near Igiugig, Alaska, at approximately the same location as in the 2014 and 2015 RivGen® Power System deployments. Though the work occurs in the aquatic environment, the only ESA-listed species known to occur in the area is Steller’s eider (*Polysticta stelleri*), a seabird that may only be present from late September to April. Stellar’s eider is a trust resource for U.S. Fish and Wildlife Service (USFWS). A number of non-endangered fish species are likely to be present and non-endangered marine mammals (fresh water seals and Beluga whales) may be present in the Project area.

This Essential Fish Habitat (EFH) Assessment addresses DOE's proposed Action to provide federal funding to the Project in compliance with Section 305(b)(2) of the Magnuson-Stevens Act, that requires federal action agencies to consult with NOAA's National Marine Fisheries Service (NOAA NMFS) on all actions, or proposed actions, authorized, funded, or undertaken by the agency, that may adversely affect EFH.

2.1 Project Area

The Project's location will be the Kvichak River, near the community of Iguigig, Alaska (Figure 1). This community is located at the outlet of Iliamna Lake, the largest lake in Alaska. Access is by boat or plane, only, with the nearest major settlement, Seldovia, Alaska, 100 miles to the east on the far side of Cook Inlet.

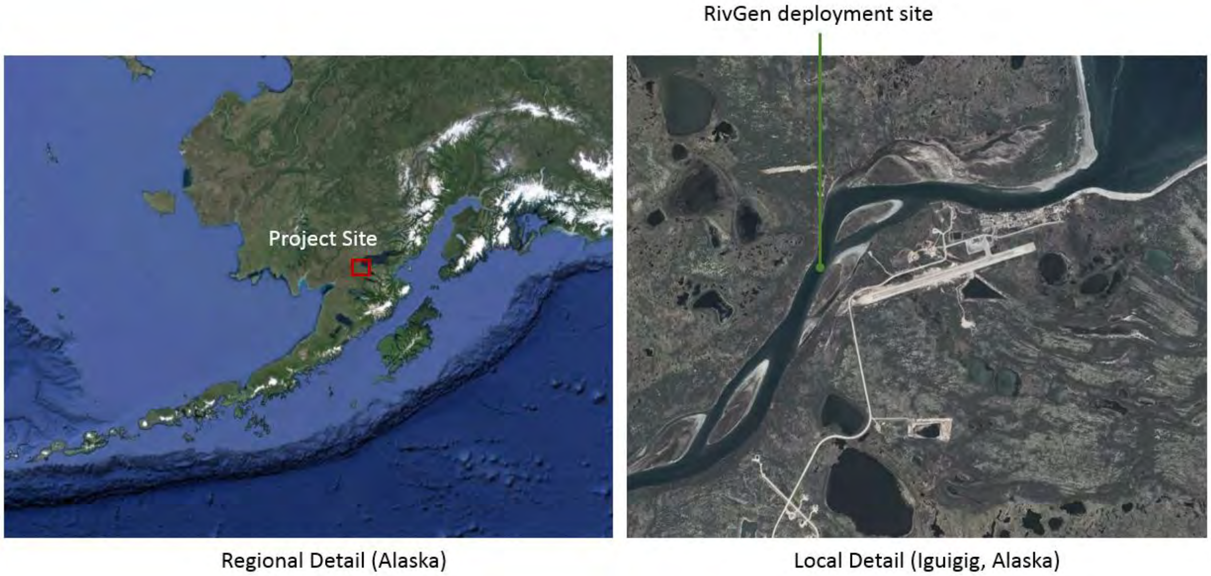


Figure 1. Project area (regional and local detail)

The RivGen® turbine will be deployed at approximately 59.3254° North Latitude and –155.9145° West Longitude. The Kvichak River has been previously characterized at this location (TerraSond, 2011). The water depth is approximately 5 m (16.4 ft), the river width is approximately 128 m (420 ft), the riverbed is composed of scoured cobbles and gravel, and the maximum current velocity in the center of the channel is approximately 2.35 m/s. (Thomson, et al, 2018).

2.2 2019 Deployment

The Igiugig Village Council will deploy the ORPC RivGen® Power System in the Kvichak River in summer 2019. The location will be approximately the same as in 2015 to maximize capture of the river velocity. Based on historical records, the timing of the deployment in early summer will occur after the salmon smolt run but during the adult sockeye run. The RivGen® device will be run under varying operating conditions until the end of 2020 at which point IVC will evaluate whether to install a second RivGen® device. This period will include the same timeframe of testing in 2014 and again in 2015 during which time biological monitoring indicated no observed adverse effects to the aquatic environment. The device will be equipped with cameras to capture images of the sockeye salmon out migration in 2020. The Fish Monitoring Plan in Appendix A of the FERC final pilot license application has additional detail of this monitoring effort. The Igiugig Village Council anticipates no adverse effects to the aquatic environment.

2.3 RivGen® Power System

The Igiugig Village Council will use the next advancement of ORPC's RivGen® Power System for the Project (Figure 2 and Figure 3). The Project will deploy the ORPC RivGen® Power System, a proprietary power system designed to generate electricity at river sites with water depths of up to 10 m (32.8 ft) and connect directly into an existing diesel-powered microgrid. The RivGen® Power System will be powered by the turbine generator unit (TGU). The TGU will rest on a variable ballast pontoon support structure, allowing the RivGen® device to be floated to the Project site. At the Project site, the RivGen® device will be connected to a mooring system and ballasted so that it submerges and settles on the river bottom. Retrieval of the device will be accomplished by deballasting the pontoons with an external supply of compressed air. The RivGen® device is essentially self-deploying, and installation will only require commonly available vessels and minimal construction equipment. Components of the RivGen® Power System are compactly sized to travel to remote sites where they can easily be assembled on shore near the Project site.

The TGU has a rated capacity of 35 kW at 2.25 m/s. ORPC has used empirical data and existing literature of the annual flows in the Kvichak River to estimate the Project's annual electrical generation. The RivGen® device (Figure 2) measures approximately 15.9 m long (52.2 ft) x 3.5 m high (11.5 ft) x 14.5 m wide (47.2 ft). On the pontoon support structure, the RivGen® TGU sits 1.2 m (4 ft) off the river bottom. The total weight of the RivGen® device is approximately 26,000 kilograms (kg) (57,320 lbs).

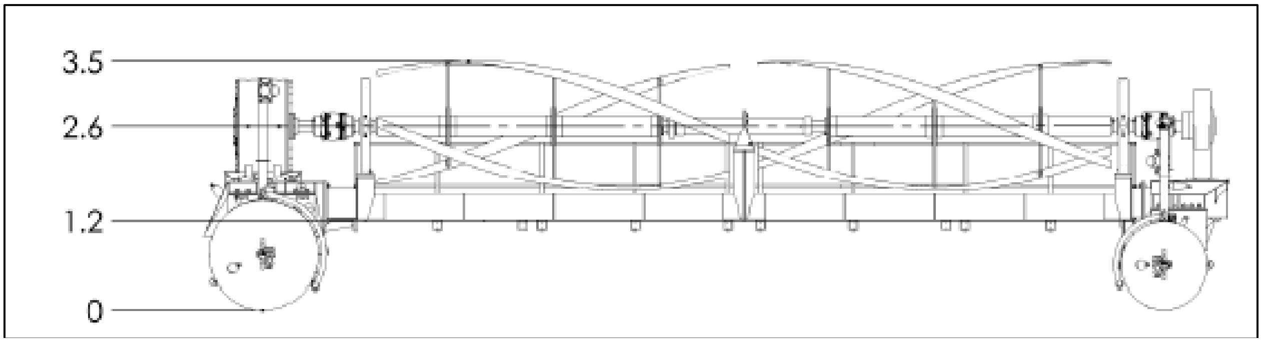


Figure 2. Schematic of the RivGen® device, showing turbine generator unit mounted across pontoon support structure. Source: ORPC

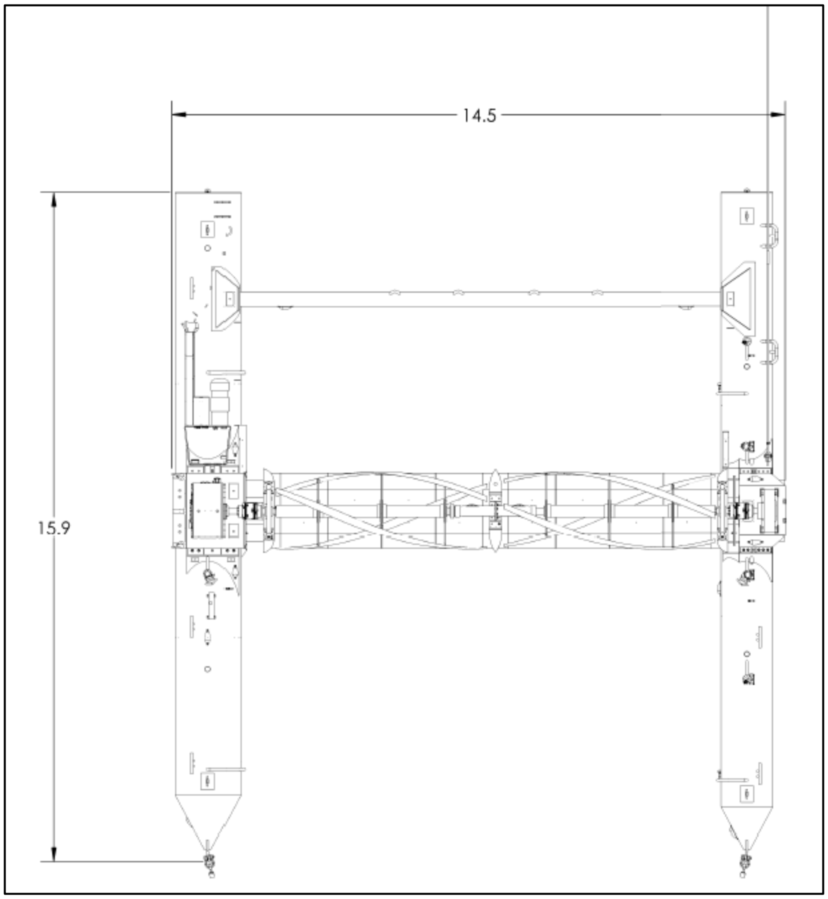


Figure 3. Top view of 2015 RivGen® device. Source: ORPC.

2.4 Prior Consultation of RivGen® Power System Testing

Prior consultation regarding RivGen® Power System testing and associated wake/inflow measurements took place with state and federal resource agencies as part of 2014 testing. Permitting for testing in 2014 was conducted by Gary Stassel Engineering on behalf of the IVC and included ORPC's RivGen® Power System as well as a device from Boschma Research, Inc. Collectively the 2014 testing is referred to as the Igiugig River In-Stream Energy Conversion (RISEC) Project. There were multiple discussions and permitting actions that facilitated 2014 and 2015 testing:

- The permitting process of the river in-stream energy conversion (RISEC) Project (funded in part by a grant to ORPC Alaska, "RivGen® Power System Commercialization Project," by Alaska Energy Authority Emerging Energy Technology Fund, no. 7310043) complied with or satisfies the NEPA requirements of 10 CFR Part 1021, Subpart D, Appendix B (effective November 11, 2011) DOE Categorical Exclusion B5.25 Small-scale renewable energy research and development and pilot projects in aquatic environments.
- ORPC executed a Memorandum of Understanding with the Igiugig Village Council on January 16, 2015 to provide permitting assistance for the 2015 RivGen® deployment.
- FERC permitted short-term testing in 2014 and 2015 under the guidelines of the Verdant Exemption (telephone record June 9, 2014 and February 24, 2015).
- Alaska Department of Fish and Game (ADF&G) Title 16 Habitat Permit for 2014 and 2015 deployments of ORPC's RivGen® Power System at the Project site. The 2015 permit, which includes a revised Fish and Wildlife Monitoring Plan, was granted by ADF&G on March 25, 2015.
- Alaska Department of Natural Resources (DNR) issued a Temporary Water Use Authorization on December 31, 2014 for the planned deployment of ORPC's RivGen® Power System in 2015. A Project Temporary Land Use Authorization was issued for 2015 testing on March 4, 2015.
- The U.S. Coast Guard approved using the same project safety protocols as those described in the 2014 Navigation Safety Plan for 2015 activities.
- Essential Fish Habitat Assessment, "Ocean Renewable Power Company RivGen® Turbine Testing and Associated Turbulence and Wake Measurements," prepared for USFWS and NOAA NMFS Section 7 consultation, was submitted by ORPC for its DOE-funded project on April 3, 2015. A determination was made that the project would not adversely affect Essential Fish Habitat during the 2015 RivGen® Power System deployment.

The Project is possibly within the range of the North American breeding Steller's eider (*Polysticta stelleri*) which was listed as threatened in 1997 (USFWS, 2002). Steller's edier is a seaduck that inhabits the near-shore marine waters of lower Cook Inlet, Kodiak Island, and the Alaska Peninsula during the winter (late September through April) and breeds in the Arctic Coastal Plan. Eiders may cross the Project area during winter and spring migrations, but limited satellite telemetry suggests that the likely migration route across the Alaska Peninsula is further south, over Lake Becharof (Rosenberg, 1995).

3 CRITICAL HABITAT AND SPECIES IN THE PROJECT AREA

3.1 Affected Environment

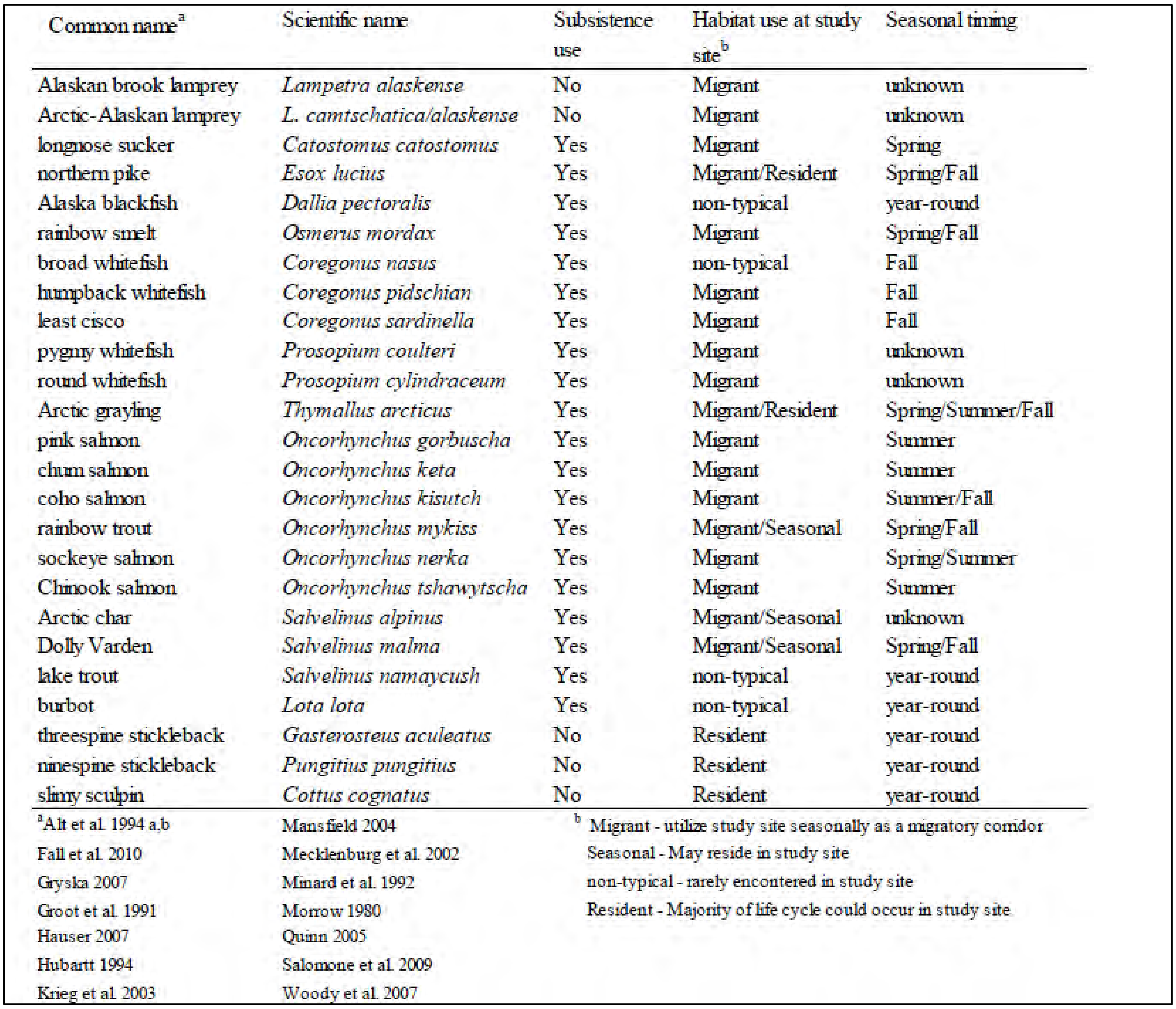
The Kvichak River has been specified as being important for the spawning, rearing, or migration of anadromous fishes pursuant to AS 16.05.871(a). The Kvichak River is known to support Arctic char, Dolly Varden, whitefish, and Chinook, coho, sockeye, chum, and pink salmon. Due to the significant anadromous fish in the river, there is substantial historical data on fish species and presence.

This Fisheries and Marine Mammal Resources section is based on Fish and Wildlife Monitoring Plans and Reporting by LGL and subsequent analysis by the PNNL for RivGen® Power System testing at the Project location in 2014 and 2015. The University of Alaska Fairbanks (UAF) has provided an updated Fish and Wildlife Monitoring Plan for this RivGen® deployment to incorporate the work done by LGL, PNNL, and continuing fish monitoring activities to satisfy the ADF&G Fish Habitat Permit (FHP, Title 16 Permit).

3.2 Fish Species Composition

Approximately 25 species of fish are known to inhabit the Kvichak River, including all five species of Pacific salmon (Oncorhynchus spp.) found in Alaska (Table 1). Each species has its own unique aspects of timing and behavior that influence the likelihood for encountering or being affected by the RivGen® device. In general, fishes that are found in the study area use this stretch of river as a corridor for migration among over-wintering, feeding and spawning grounds. Fishes locate themselves in the river according to preferred habitat characteristics such as water flow and food availability. Adult and juvenile fishes tend to be located in environments where they have relatively low energy expenditure and high food intake. Therefore, typical preference in a river for holding or migrating is near the bottom, along the shores, and behind relatively large structures such as boulders. In this regard, adult fishes are expected to avoid the higher energy portion of the river. Juvenile salmon migrating downstream to the ocean, conversely, often choose the high energy environments (surface, thalweg, and no structure) where they can swim with the water flow and conserve internal energy. Therefore, the location of the RivGen® device(s) in the thalweg of the river makes it more likely to encounter downstream-migrating fish (such as juvenile sockeye salmon) than upstream-migrating fish (such as adult salmon). Further details are provided in subsequent parts of this section for high priority species.

Table 1. *List of fish species in the Kvichak River.*



Common name[a]	Scientific name	Subsistence use	Habitat use at study site[b]	Seasonal timing
Alaskan brook lamprey	*Lampetra alaskense*	No	Migrant	unknown
Arctic-Alaskan lamprey	*L. camtschatica/alaskense*	No	Migrant	unknown
longnose sucker	*Catostomus catostomus*	Yes	Migrant	Spring
northern pike	*Esox lucius*	Yes	Migrant/Resident	Spring/Fall
Alaska blackfish	*Dallia pectoralis*	Yes	non-typical	year-round
rainbow smelt	*Osmerus mordax*	Yes	Migrant	Spring/Fall
broad whitefish	*Coregonus nasus*	Yes	non-typical	Fall
humpback whitefish	*Coregonus pidschian*	Yes	Migrant	Fall
least cisco	*Coregonus sardinella*	Yes	Migrant	Fall
pygmy whitefish	*Prosopium coulteri*	Yes	Migrant	unknown
round whitefish	*Prosopium cylindraceum*	Yes	Migrant	unknown
Arctic grayling	*Thymallus arcticus*	Yes	Migrant/Resident	Spring/Summer/Fall
pink salmon	*Oncorhynchus gorbuscha*	Yes	Migrant	Summer
chum salmon	*Oncorhynchus keta*	Yes	Migrant	Summer
coho salmon	*Oncorhynchus kisutch*	Yes	Migrant	Summer/Fall
rainbow trout	*Oncorhynchus mykiss*	Yes	Migrant/Seasonal	Spring/Fall
sockeye salmon	*Oncorhynchus nerka*	Yes	Migrant	Spring/Summer
Chinook salmon	*Oncorhynchus tshawytscha*	Yes	Migrant	Summer
Arctic char	*Salvelinus alpinus*	Yes	Migrant/Seasonal	unknown
Dolly Varden	*Salvelinus malma*	Yes	Migrant/Seasonal	Spring/Fall
lake trout	*Salvelinus namaycush*	Yes	non-typical	year-round
burbot	*Lota lota*	Yes	non-typical	year-round
threespine stickleback	*Gasterosteus aculeatus*	No	Resident	year-round
ninespine stickleback	*Pungitius pungitius*	No	Resident	year-round
slimy sculpin	*Cottus cognatus*	No	Resident	year-round

[a] Alt et al. 1994 a,b
Fall et al. 2010
Gryska 2007
Groot et al. 1991
Hauser 2007
Hubartt 1994
Krieg et al 2003
Mansfield 2004
Mecklenburg et al. 2002
Minard et al. 1992
Morrow 1980
Quinn 2005
Salomone et al. 2009
Woody et al. 2007

[b] Migrant - utilize study site seasonally as a migratory corridor
Seasonal - May reside in study site
non-typical - rarely encontered in study site
Resident - Majority of life cycle could occur in study site

3.2.1 Subsistence Fish Harvest

For the communities within the Kvichak River watershed, the subsistence way of life is a fundamental part of their cultural and physical wellbeing. Each year residents harvest, distribute, and consume many fish species found in the river. Historically, salmon have been the mainstay for subsistence, but a considerable portion of the subsistence take is also comprised of non-salmon species that can be harvested year-round. Recent studies estimate that greater than 18,000 lbs of non-salmon fish are harvested regionally on an annual basis (Krieg et al., 2005). Several different harvest techniques, including angling and nets, are employed as the fish move seasonally from their over-wintering grounds to summer spawning and feeding habitats (Fall, Holen, Davis, Krieg, & Koster, 2006).

Of the 16 different non-salmon fish used by the people of Igiugig, seven are estimated to be harvested by greater than 25 percent of the households in the village (Kreig et al., 2003). Rainbow trout, Dolly Varden, and northern pike comprise the species of greatest subsistence harvest (besides salmon), in descending order (Kreig et al., 2005). A summary of these seven species is provided as well as descriptions of how they use the habitat near the outlet of Lake Iliamna downstream to Kaskanak Creek.

3.2.2 Non-salmon Fish

Rainbow trout (*Oncorhynchus mykiss*) are the freshwater resident form of this species found in the Kvichak River watershed. The anadromous form (steelhead) has not been documented in the Bristol Bay region. During the spring, rainbow trout will congregate between the outlet of Lake Iliamna and Kaskanak Flat; these fish will include both spawners and nonspawners. ADF&G conducted abundance studies from 1986 through 1991 near Igiugig (Minard et al., 1992). Much of the sampling for these studies was conducted immediately below Igiugig, in the braided portions of the river where the fish gathered in shallow, low velocity areas. The authors noted that rainbow trout gathered in large numbers at these sites during April and May. By mid-June, they disperse into Lake Iliamna to spend the summer months before migrating to tributaries of the lake and to the Kvichak River in the fall. Abundance estimates in 1988, 1989, and 1990 were 2,038 (SE=1,252), 2,912 (775), and 4,460 (1,441), respectively. Annual survival ranged from 28 percent to 30 percent, and average age was six years (Krieg et al., 2003; Mecklenburg et al.; 2002, Minard et al., 1992; and Morrow, 1980).

Rainbow trout support a substantial sport fishing industry that is managed by ADF&G. In addition to being economically valuable to the residents of Igiugig, rainbow trout are also a highly regarded subsistence resource. Krieg et al. (2003) reported that 100 percent of the households in Igiugig will include rainbow trout in their annual subsistence harvest. Local fishing guides indicate that rainbow trout can be located anywhere in the river, but that fishermen tend to run “lines” down the channel that are most productive (Brian Kraft, personal communication, Alaska Sportsman’s Lodge). These lines are defined by bathymetry, water flows, and food characteristics that are the most energetically beneficial to the rainbow trout. Observations during 2014 and 2015 showed that the lines drifted by sport fisherman were inshore of the device towards the eastern bank of the river and that there was no observed interference between trout sport fishing practices and the RivGen device whether it was deployed on the river bed or on the surface during maintenance events. It is possible that the RivGen® Power System structure may provide some preferred habitat (e.g., shelter or cover) for rainbow trout. This condition may encourage them to come in close proximity with the device even though the high-power density region of the channel is not usually preferred. Overall, it is anticipated that adult rainbow trout may encounter the device(s) and any in-water mooring or electrical cables running to shore.

Arctic grayling (*Thymallus arcticus*) are found throughout the Kvichak drainage. During the winter months, Arctic grayling will be found in lakes or larger rivers that provide sufficient habitat while frozen. During the spring, they will migrate up streams to their spawning and feeding grounds, so the Kvichak River at Igiugig is likely used only as a migration corridor rather than an area of residence. Arctic grayling will spawn in low energy portions of the streams; this is also where the fry will rear before heading to the overwintering grounds. Arctic grayling have been caught in the Kvichak at Igiugig, but the majority of this species are harvested further downstream near the outlet of Pecks, Ole and Kaskanak Creeks (Gryska, 2007, Krieg et al., 2003, and Morrow, 1980). No information on population abundance or cross-channel distribution at Igiugig is available, but based on their preferred habitat it is not anticipated that adult or juvenile grayling will encounter the RivGen® device. However, they will likely encounter moorings and electrical cables running to shore.

Northern pike (*Esox lucius*) are found in the lakes and rivers throughout southwest Alaska, including the Kvichak River. These fish will overwinter in the slower water of large rivers and deeper lakes, and then migrate to their summer spawning and feeding grounds in slow moving streams, sloughs, and along the lake shore. The Kvichak River at Igiugig is likely used only as a migration corridor rather than an area of residence because of predominant high water velocity. Igiugig residents harvest pike during the spring and fall in the Kvichak River (Alt, 1994a, Krieg et al., 2003, and Mecklenburg et al., 2002), Kvichak tributaries of Ole and Pecks Creeks, and Lake Iliamna tributaries of Upper and Lower Talarik Creeks (Ida Nelson, personal communication, Igiugig resident). No information on population abundance or cross-channel distribution at Igiugig is available but based on their preferred habitat it is not anticipated that adult or juvenile pike will encounter the hydrokinetic device. However, they will likely encounter any in-water mooring and electrical cables running to shore.

Humpback whitefish (*Coregonus pidschian*) can take advantage of many different freshwater and marine habitats and are found in freshwater residential and anadromous forms. These fish are found throughout the Kvichak River watershed and make up a large component of the subsistence fishery. Despite the relative importance of this fish, little is known of its life history or population size. A recent study by Woody and Young (2007) examined strontium concentrations in humpback whitefish taken from Lake Clark and found no definitive evidence that those fish migrated to and from saltwater. It is known that spawning occurs during the fall and takes place in the upper reaches of streams, or the littoral zones of lakes. Based on harvest records for Igiugig residents, humpback whitefish are caught near the village as they migrate to or from their spawning grounds located in the tributaries of the Kvichak River (Alt, 1994b; Fall et al., 2010; Woody & Young, 2007; and Krieg et al., 2003). Residents fish for humpback whitefish in October and November (Ida Nelson, personal communication, Igiugig resident). At Igiugig, the Kvichak River is likely used only as a migration corridor rather than an area of residence by the humpback whitefish. No information on population abundance or cross-channel distribution at Igiugig is available, but based on their preferred habitat it is not anticipated that adult or juvenile humpback whitefish will encounter the RivGen® device. However, they will likely encounter any in-water mooring and electrical cables running to shore.

Dolly Varden (*Salvelinus malma*) in the Kvichak River watershed exist in anadromous or freshwater resident forms. Generally, the freshwater residents are in the upper reaches of the streams that drain into Lake Iliamna, and the anadromous form is found in the mainstem and larger tributaries of the Kvichak River. Resident Dolly Varden will rear in slow moving water on the stream bottoms and then move to stream pools or eddies once they are large enough. Anadromous forms will spawn in the summer and fall and may remain in the streams up to 20 months before migrating back to sea. The juvenile anadromous form will remain in the freshwater 2 to 4 years using the stream bottom for cover and a feeding. Once large enough, they make the transformation into smolts and migrate to sea around May and June (Hubartt, 1994; Kreig et al., 2003; Mecklenburg et al., 2002; and Morrow, 1980). The anadromous form is harvested January through April in the Kvichak (Kreig et al., 2005) via ice fishing. Local fishing guides indicate that Dolly Varden are caught incidentally when targeting rainbows, but this is uncommon (Brian Kraft, personal communication, Alaska Sportsman's Lodge). Overall, it is anticipated that adult Dolly Varden may encounter the RivGen® device and moorings or electrical cables running to shore, but it would be a rare occurrence due to their low abundance in the Project area of the Kvichak River.

Longnose suckers (*Catostomus catostomus*) are harvested by Igiugig residents during the spring, usually in late May and early June. These fish reside in lakes or stream pools and will migrate to gravel sections of streams in the spring for spawning. Based on the harvest records, Igiugig residents harvest these fish in the feeder streams of the upper Kvichak River, namely Pecks and Ole Creeks, in addition to the Kaskanak Flats area (Krieg et al., 2003; Mansfield, 2004; Mecklenburg et al., 2002; and Morrow, 1980). Information on population abundance or cross-channel distribution at Igiugig is not available but based on their preferred habitat it is not anticipated that adult or juvenile longnose suckers will encounter the device. However, they will likely encounter in-water moorings and electrical cables running to shore.

Rainbow smelt (*Osmerus mordax*) are anadromous fish that migrate up the Kvichak River each spring from the ocean and are thought to spawn in the tributaries of Lake Iliamna. Little is known about their life history or population size. However, based on traditional ecological knowledge, the rainbow smelt are only present from spring to early fall (Gotthardt & McClory, 2006; Mecklenburg et al., 2002; and Kreig et al., 2003). The Kvichak River at Igiugig is likely used only as a migration corridor rather than an area of residence. No information on population abundance or cross-channel distribution at Igiugig is available, but based on their preferred habitat, it is anticipated that out-migrating adult or juvenile rainbow smelt will encounter the device and in-water mooring or electrical cables running to shore.

3.2.3 Adult Sockeye Salmon

Socioeconomic Importance

Bristol Bay, Alaska, produces the greatest number of sockeye salmon (*Oncorhynchus nerka*) in the world. During 1991-2010, the region produced an average annual sockeye salmon run of 38 million (SD 12 million); the Kvichak stock represented 21 percent of this average. Bristol Bay sockeye have been intensively harvested since the early 1900s, mostly in commercial fisheries located in marine waters near river confluences (Clark et al., 2006). Commercial harvest from 1991 to 2010 averaged 26 million for Bristol Bay as a whole, and 4 million for the Kvichak River.

Subsistence fishing for sockeye salmon in Bristol Bay has occurred since inhabitance and continues to be an important source of protein for local residents (Morstad, Jones, Sands, Salomone, Buck, and West, 2010). In 2009, the subsistence harvest of sockeye for the Kvichak River/Iliamna Lake sub-district totaled 46,772 from 187 permits, and in the Igiugig region totaled 1,071 from 5 permits (Salomone, Morstad, Sands, Jones, Baker, Buck, West, and Kreig, 2011). In addition to the subsistence fishery, sockeye salmon have been an essential segment of the sport fishing industry for that region. From 1997 through 2008 the annual sport fish harvest of sockeye salmon in the Kvichak River averaged 1,860 fish (Dye and Schwanke, 2009).

Management

To manage and sustain the fisheries, federal and state agencies have collected detailed records of catch, spawning escapement, and age composition for the nine major Bristol Bay sockeye salmon stocks (including the Kvichak River) since 1952. The Bristol Bay region remains relatively pristine, biodiversity of salmon remains high (Hilborn et al., 2003), and salmon populations have not been influenced by hatcheries. Therefore, Bristol Bay provides a unique long-term history of wild salmon population dynamics, largely unaffected by alterations to habitat or genetics.

ADF&G’s salmon management objectives include managing for sustained yield (largely accomplished by adhering to escapement goals), maintaining genetic diversity and overall health of the escapement (the number of fish that spawn each year), providing for an orderly fishery, helping to ensure high quality fishery products, and harvesting fish consistent with regulatory management plans. The Commissioner delegates management authority to Area Management Biologists, who regulate time and area openings for otherwise closed fisheries.

ADF&G’s fishery biologists develop escapement goals for salmon based on the sustained yield principle, in accordance with the Policy for the Management of Sustainable Salmon Fisheries (5 AAC 39.222) and the Policy for Statewide Salmon Escapement Goals (5 AAC 39.223). Typically, the relationship between escapement levels and subsequent adult salmon returns is an important part of escapement goal development.

Timing

Average run timing (2000-2010) shows that 25 percent of Kvichak River spawners return annually by June 30, 50 percent by July 5, and 75 percent by July 10 (Figure 4). During this period, run timing ranged plus or minus three days, with the earliest having 50 percent return by July 2 and the latest by about July 8 (based on combined catch and escapement). Sockeye salmon usually take two to four days to travel from the fishing district upstream to the counting tower at Igiugig (T. Baker, personal communication, research biologist, ADF&G).

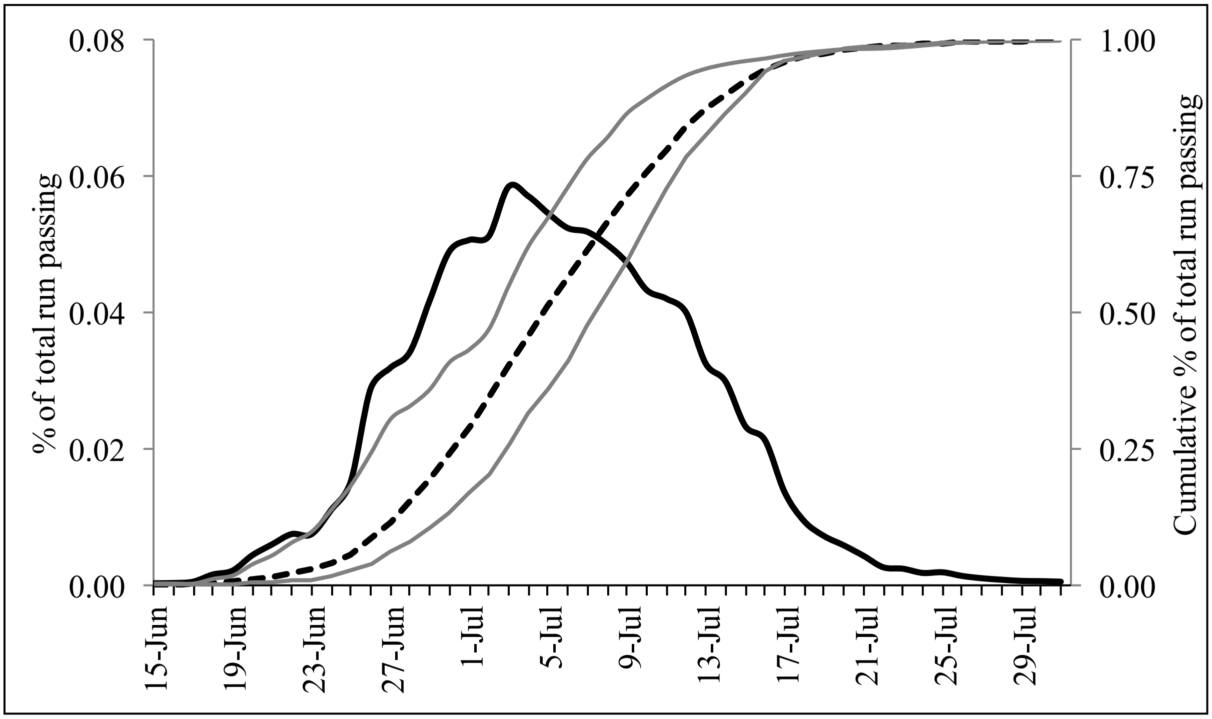


Figure 4. Run timing curves for Kvichak River sockeye salmon. The average run timing from 2000 to 2010 are indicated by thick black lines (daily=solid line and cumulative=dashed line). The earliest and latest cumulative curves during this time period are indicated by gray lines. Source: LGL

Distribution

When current velocities in the thalweg are high, sockeye salmon are extremely bank-oriented while migrating upriver due to the energetic gain in swimming against slower waters near the bank (Woody, 2007; and Anderson, 2000). Taking advantage of this life history trait, W. F. Thompson (1962) developed the tower counting system for Bristol Bay in 1953. When tower counts were compared to weir counts (assumed to be a complete census) on the Egegik River, relative error was -7.4 percent (Rietze, 1957; Spangler, and Rietze, 1958). Therefore, we can assume that most sockeye were visible from the counting towers and not swimming in the thalweg; otherwise, the observed relative error would have been much greater. At Igiugig, Anderson (2000) found nearly all sockeye passed 3.0 - 9.1 m from the left bank (facing upstream) and 3.7 - 9.1 m from the right bank. Igiugig was chosen for the enumeration project because current velocities in the thalweg likely preclude adult salmon swimming across or through the middle of the river in this area. It is anticipated that adult sockeye salmon encounters with the RivGen® device will be minimized by device placement in the river thalweg. Adult salmon are expected to encounter moorings and electrical cables running to shore.

Abundance

Total abundance of adult sockeye salmon returning to individual Bristol Bay rivers is calculated from catch and escapement estimates. Escapement of sockeye salmon to the Kvichak River is estimated with a counting tower operated by ADF&G near Igiugig. Commercial catch of Kvichak River sockeye salmon happens downstream, in Bristol Bay saltwater; catch of fish bound for the Kvichak River is estimated based on age-specific stock composition methods. From 2006 through 2010, the estimated Kvichak River sockeye salmon run averaged 6.1 million total fish, with a range of 4.2 to 9.2 million fish (Table 2). Kvichak River sockeye salmon vary among four main age classes: 1.2, 1.3, 1.4, and 2.3 (European notation—1st number=freshwater age, 2nd=ocean age, Table 3). On average, 60 percent return 5 years after the year in which they were spawned, as Age-2.2s or Age-1.3s (return time is calculated by adding the freshwater and ocean ages plus one year for overwinter incubation of the eggs). Age-2 fish are usually the most abundant, and exert strong influence on total run size.

Table 2. *Historical catch and escapement of Kvichak River sockeye salmon.*

Year	Catch	Escapement	Total
1956	4,168,343	9,443,318	13,611,661
1957	3,540,189	2,842,810	6,382,999
1958	549,396	534,785	1,084,181
1959	281,930	673,811	955,741
1960	7,976,500	14,602,360	22,578,860
1961	6,863,814	-	6,863,814
1962	1,833,401	2,580,884	4,414,285
1963	223,459	338,760	562,219
1964	763,486	957,120	1,720,606
1965	17,785,664	24,325,926	42,111,590
1966	4,168,575	3,755,185	7,923,760
1967	1,800,652	3,216,208	5,016,860
1968	387,565	2,557,440	2,945,005
1969	3,760,565	8,394,204	12,154,769
1970	16,581,224	13,935,306	30,516,530
1971	3,764,861	2,387,392	6,152,253
1972	342,150	1,009,962	1,352,112
1973	21,791	226,554	248,345
1974	148,595	4,433,844	4,582,439
1975	1,605,407	13,140,450	14,745,857
1976	1,458,180	1,965,282	3,423,462
1977	739,464	1,341,144	2,080,608
1978	3,815,636	4,149,288	7,964,924
1979	13,418,829	11,218,434	24,637,263
1980	12,743,074	22,505,268	35,248,342
1981	5,234,733	1,754,358	6,989,091
1982	1,858,475	1,134,840	2,993,315
1983	16,534,901	3,569,982	20,104,883
1984	12,523,803	10,490,670	23,014,473
1985	6,183,103	7,211,046	13,394,149
1986	787,303	1,179,322	1,966,625
1987	3,526,824	6,065,880	9,592,704
1988	2,654,364	4,065,216	6,719,580
1989	11,456,509	8,317,500	19,774,009
1990	10,551,217	6,970,020	17,521,237
1991	3,808,873	4,222,788	8,031,661
1992	5,718,947	4,725,864	10,444,811
1993	5,287,523	4,025,166	9,312,689
1994	13,893,613	8,355,936	22,249,549
1995	17,391,906	10,038,720	27,430,626
1996	1,983,269	1,450,578	3,433,847
1997	179,480	1,503,732	1,683,212
1998	1,072,760	2,296,074	3,368,834
1999	6,663,209	6,196,914	12,860,123
2000	1,033,814	1,827,780	2,861,594
2001	330,538	1,095,348	1,425,886
2002	-	703,884	703,884
2003	34,244	1,686,804	1,721,048
2004	2,163,318	5,500,134	7,663,452
2005	532,450	2,320,332	2,852,782
2006	2,687,895	3,068,226	5,756,121
2007	1,420,384	2,810,208	4,230,592
2008	2,873,889	2,757,912	5,631,801
2009	3,297,344	2,266,140	5,563,484
2010	5,018,048	4,207,410	9,225,458
10 yr avg.	3,967,974	3,552,998	7,322,573

Table 3. *Age composition of Kvichak River sockeye salmon, in percentages.*

Year	Age 1.2	Age 1.3	Age 2.2	Age 2.3	2-ocean	3-ocean	Total run (millions)
1990	4	7	75	14	79	21	18
1991	51	13	17	19	68	32	8
1992	23	23	41	12	65	35	11
1993	22	25	45	7	67	33	10
1994	7	7	83	2	90	10	23
1995	9	4	75	12	84	16	28
1996	12	35	20	33	32	68	4
1997	47	12	31	9	78	22	2
1998	51	26	18	4	69	31	4
1999	58	9	28	4	87	13	13
2000	12	60	20	8	32	68	3
2001	9	84	1	5	10	90	1
2002	45	15	37	2	83	17	1
2003	64	17	15	4	79	21	2
2004	23	3	73	1	96	4	8
2005	18	41	32	9	50	50	3
2006	45	31	17	7	62	38	6
2007	63	18	3	16	66	34	4
2008	73	25	1	0	74	26	6
2009	18	40	40	2	57	43	6

Sockeye salmon abundance in Bristol Bay has fluctuated significantly during the past century (Figure 5). Two notable aspects of the Kvichak River sockeye salmon are a historic 5-year cyclic pattern in abundance, and an overall decline in abundance beginning in the mid 1990s. Reasons for the cycle are unclear and the subject of much discussion. Some data indicate an interaction of marine and freshwater processes, reinforced by historical fishing patterns and escapement goal policy. Ruggerone and Link (2006) provided evidence that the cyclic abundance of Kvichak sockeye salmon was maintained by dispensatory fishing mortality, density-dependent interactions between brood lines, low productivity of the Kvichak River watershed, and the relatively stable 5-year life cycle of Kvichak River salmon rather than natural dispensatory mortality caused by predators or marine derived nutrients. Whatever the cause, the cycle began to change during the mid-1990s and the Kvichak River stock has failed to dominate the Bristol Bay run since. Speculation about factors causing the Kvichak River stock collapse grew as the series of low runs continued from 1996 through 2005.

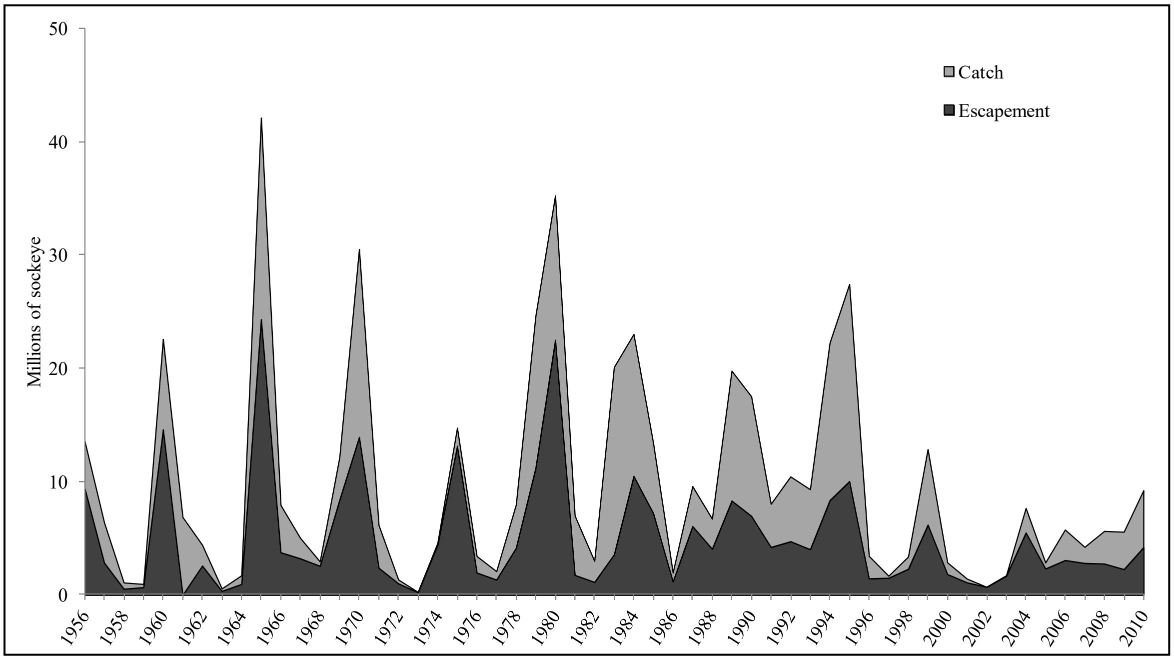


Figure 5. Catch and escapement trends for Kvichak River sockeye salmon. Source: LGL

The history and accuracy of tower counting systems in Bristol Bay is described by Woody (2007), while methods for efficiently estimating sampling error (precision) can be found in Reynolds et al. (2007). Towers are constructed on clear streams such as the Kvichak River at sites amenable to sampling, which is circumscribed by a set of guidelines (Woody, 2007). As previously mentioned, tower counts were very close to weir counts on the Egegik River (relative error was -7.4 percent), (Rietze, 1957, Spangler and Rietze, 1958). The sources of error counting include observer variability, aspects of migration, weather conditions, and sampling error due to subsampling (Woody, 2007).

3.2.4 Juvenile Sockeye Salmon

As Pacific salmon complete the fresh water stage of their life cycle, they undergo physiological changes to make the transition to salt water. This parr-smolt transformation includes changes in morphology and behavior that favors increased survival at sea (Groot & Margolis, 1991). In the early 1950s, fisheries scientists from the University of Washington and U.S. Fish and Wildlife Service started collecting biological data from the outmigrating sockeye salmon smolts in the Bristol Bay region (LGL, unpublished data). Smolts were first monitored from the Kvichak River near the village of Igiugig in 1957. ADF&G became the lead organization in 1961, and has collected smolt data annually since then (e.g. Crawford, 2001).

Biological data collected from the Kvichak River smolt studies usually include age, length, and weight, along with some information on smolt run timing and relative abundance. Fyke nets were used from 1956 through 1970 to capture smolts, so relative abundance estimates was based on catch per unit effort. In 1971, hydroacoustics were first tested on the Kvichak River to determine if total smolt abundance could be estimated. The results were rigorous enough that this method was used by ADF&G through 2000 (Crawford & West, 2001). Due to problems with aging sonar equipment and budget cuts, ADF&G sonar portion of smolt monitoring on the Kvichak River was discontinued in 2001; biological data continued to be gathered annually (Crawford & Fair, 2003). In 2007, the Bristol Bay Science and Research Institute (BBSRI) designed and built a new sonar system to estimate smolt outmigration in the rivers of Bristol Bay. This was first tested on the Kvichak River in 2008 and has operated annually since then, concurrent with ongoing biological data collected by ADF&G (Wade, Degan, Link, & Nemeth, 2013.).

Sockeye salmon smolt behavior on the Kvichak River has been characterized over the years using fyke net catches and sonar data. Across years, smolts tend to follow the same general behavior patterns in regards to run timing and distribution in the water column (Wade et al., 2013). These behaviors are thought to be driven in part driven by the evolutionary pressure for survival (Groot & Margolis, 1991).

Timing

Environmental conditions are the primary factors that trigger the parr-smolt transformation. Photoperiod appears to drive this transformation, but water temperature also influences the timing of the annual outmigration (Groot & Margolis, 1991, Quinn, 2005). On the Kvichak River, outmigration generally coincides with the melting of ice on Lake Iliamna (mid-May) and is the timing for smolt sampling projects (Crawford, 2001). The length of the outmigration for sockeye salmon is somewhat compressed relative to other species of Pacific salmon (Quinn, 2005). On the Kvichak River, the entire duration of the run is 2 to 3 weeks long, with the majority of fish out-migrating in the last week of May. From 2008 through 2012, greater than 85 percent of total smolts were detected in a period of 9 days, with 4-day peaks during this time accounting for > 50 percent (Wade, Degan, Link, and Raborn, 2010a; Wade, 2010b; Wade, 2011; Wade, 2012; and Wade et al., 2013; Figure 6 and Figure 7).

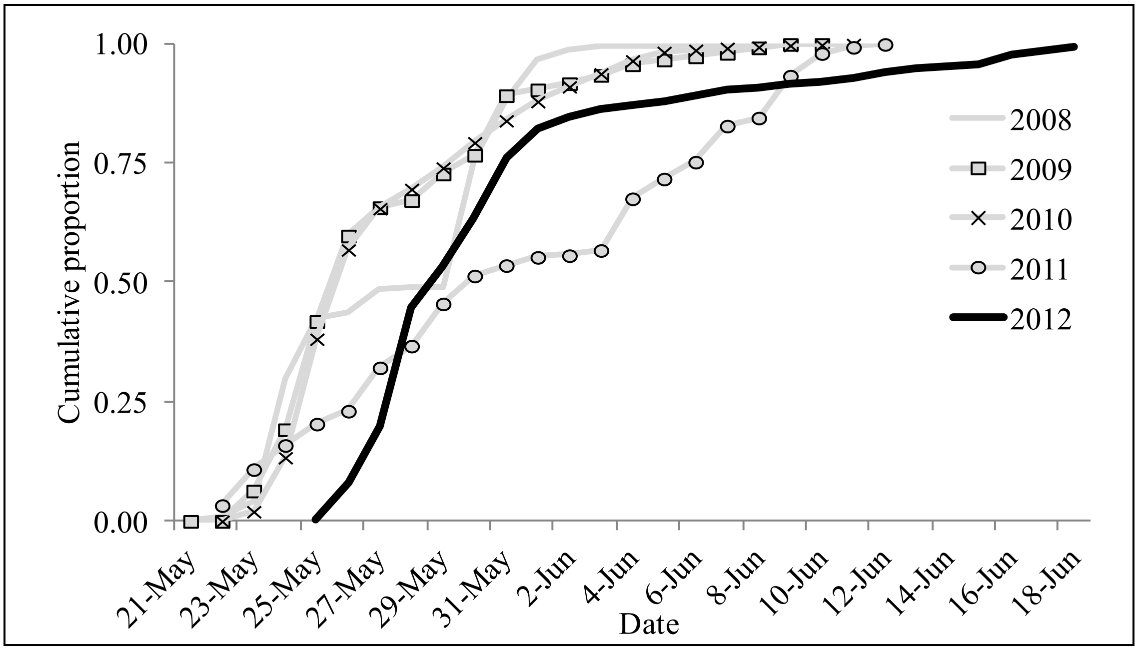


Figure 6. Run timing of sockeye salmon smolt outmigration, Kvichak River, 2008-12. Source: LGL

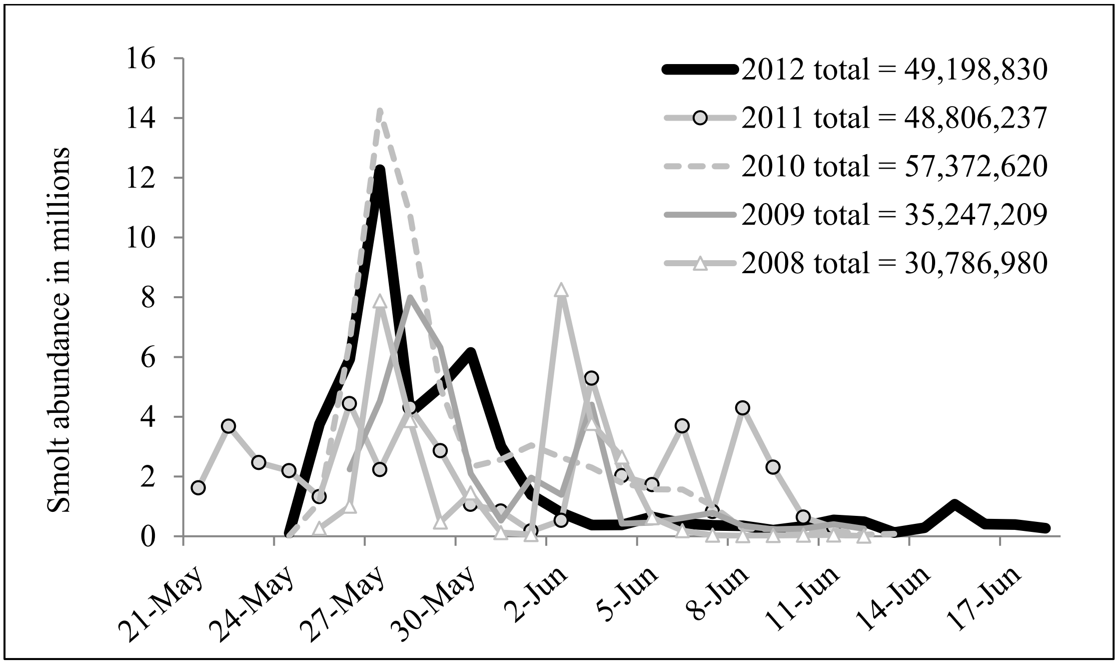


Figure 7. Estimated daily sockeye salmon smolt abundance, Kvichak River, 2008 – 2012. Source: LGL

Distribution

Past studies of sockeye salmon smolt behavior on the Kvichak River have indicated the majority of out-migrating smolts will migrate in the upper portion of the water column. Using video (from 2000) and acoustic data (2000 and 2001), Maxwell, Mueller, Degan, Crawford, McKinley and Hughes (2009) found that all smolts traveled in the top 1.0 m of water, and the majority of smolts were in the top 0.3 m. The BBSRI study (2008 – 2012) characterized vertical distribution down to 2.5 m in depth, and then divided these data into two categories (dark, daylight) to check for diel differences in distribution. On the Kvichak River, the smolt vertical distribution was consistent across years for both periods of daylight and darkness (Figure 8). During the periods of darkness > 90 percent of smolts were detected in the upper 1.0 m and on average > 80 percent were found in the upper 0.5 m. Daylight distribution tended to be a little deeper, but in all cases > 81 percent were found in the 0.0 to 1.5 m strata. By utilizing the upper portion of the water column, smolts travel in the higher velocity water and therefore reduce the amount of energy expended to reach the sea.

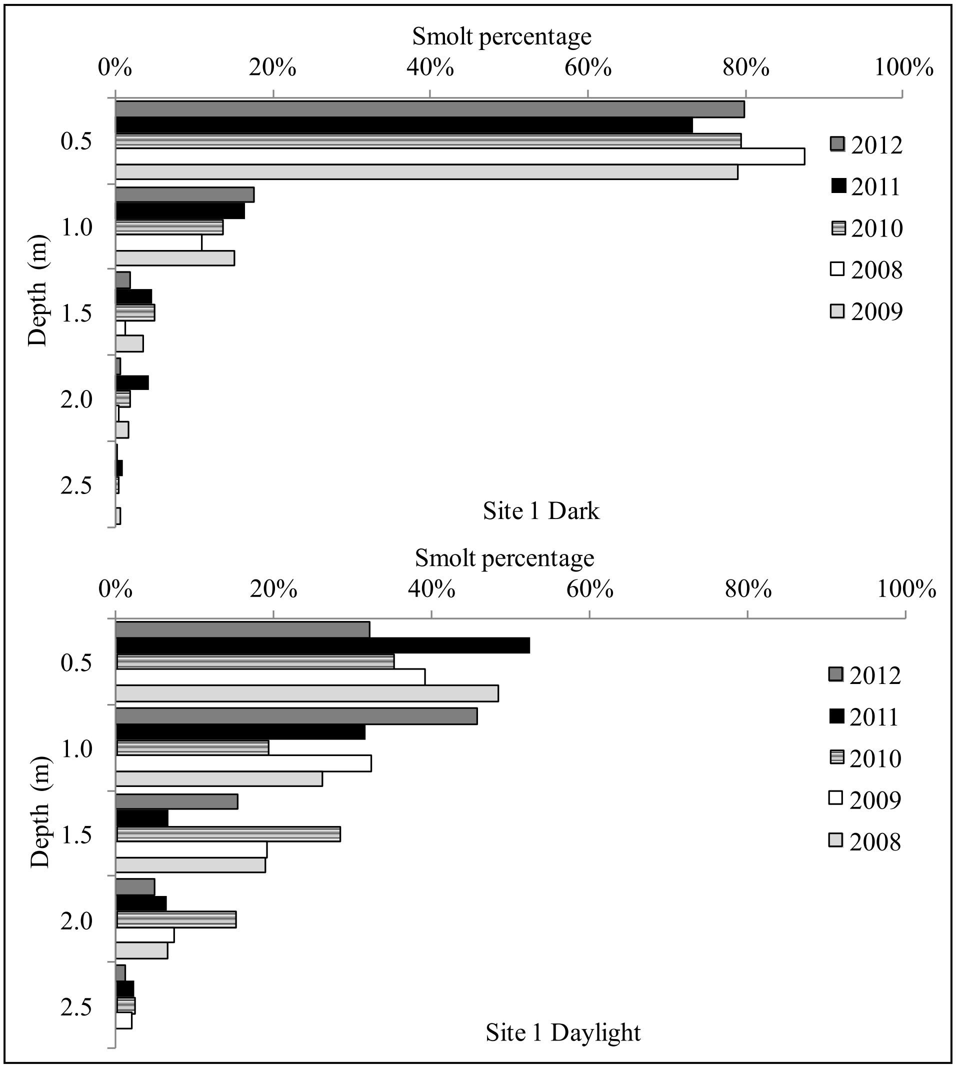


Figure 8. Vertical distribution of out-migrating sockeye salmon smolts, Kvichak River, 2008 – 2012.

Source: LGL

Smolt cross-river distribution follows consistent general patterns across years. In areas where there is a more pronounced thalweg, the majority of the smolts travel in higher velocity areas. Sonar Site 1 on the Kvichak River (Wade et al., 2013) is a good example of this distribution; the majority of the smolts were detected in the faster water which coincides with the center of the river channel (Figure 9). It is unlikely that juvenile sockeye would encounter the RivGen® device(s) due to the device submergence approximately 3-5 ft below the river surface. In addition, it is possible the devices will not be present during the sockeye smolt run due to the annual inspection and maintenance period that will coincide with Lake Iliamna ice out.

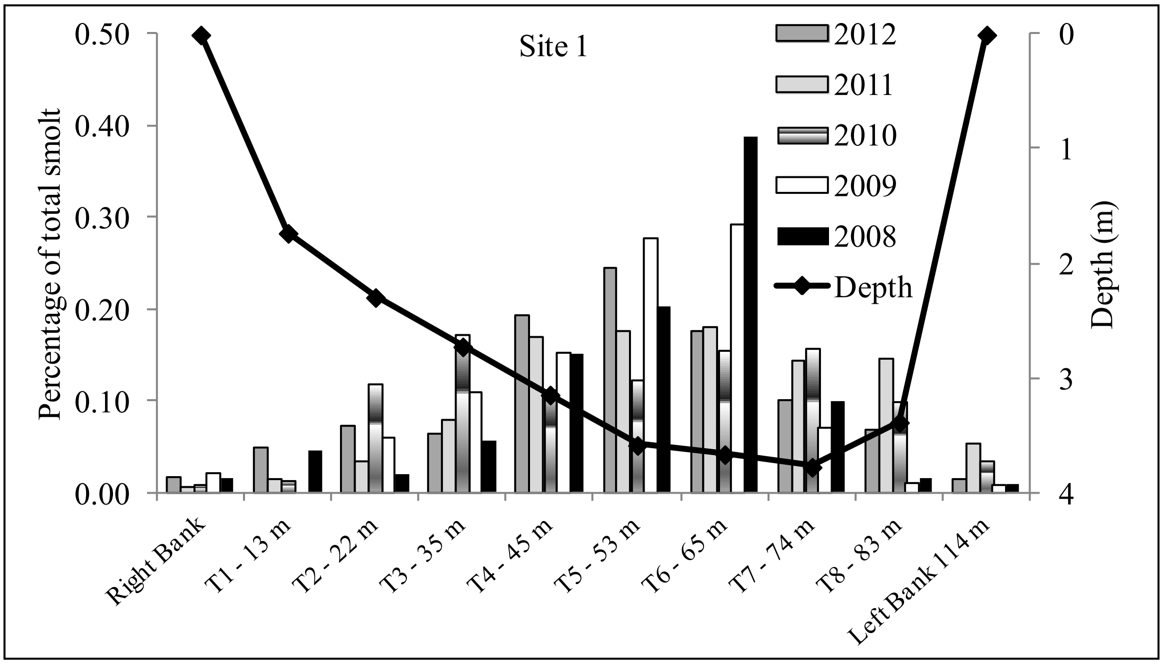


Figure 9. Cross-river distribution of sockeye salmon smolt, Kvichak River, 2008 – 2012. Source: LGL

Abundance

Sockeye salmon smolt abundance on the Kvichak River was estimated annually from 1957 to 2001 by ADF&G, then annually since 2008 by BBSRI (Wade et al., 2013). Methods to estimate smolt abundance have gone through three fundamentally different changes since inception (LGL, unpublished data), so comparison of absolute numbers across eras is not valid. It is believed that estimates from hydroacoustics more accurately reflect the actual number of fish. During the period of time when the ADF&G sonar was thought to be operating correctly (1972-1992), annual estimates varied from 15 to 342 million smolts. The BBSRI estimates for Site 1 on the Kvichak River have ranged from 30 – 57 million smolts. Given the short duration of the smolt outmigration, it is possible that more than 20 million smolts to move down the river in a 24-hour period.

3.2.5 Other Salmon

The Kvichak River is home to all five species of Pacific salmon in Alaska (sockeye, Chinook, coho, chum, and pink salmon), all of which are fished commercially and for subsistence (Table 4). There are also in-river sport fisheries for Chinook, coho, and sockeye salmon. Pacific salmon are anadromous and share similar life histories with respect to spawning migration. In general, pink and chum spawn in the lower reaches of rivers while sockeye, whereas Chinook, and coho salmon will travel further up the basin to preferred spawning and rearing habitat. Juvenile pink and chum salmon typically migrate downstream immediately after hatching (Groot & Margolis, 1991).

Table 4. *Historical salmon harvest in the Kvichak River region.*

Naknek/Kvichak Harvest - 20 Year Average[a]	Sockeye	Chinook	Coho	Chum	Pink
Commercial (1990 - 2010)[b]	8,238,895	2,816	4,436	255,487	73,661
Subsistence (1989 - 2009)	77,653	1,323	1,218	844	957

[a] Morstad et al. 2010, Salomone et al. 2011

[b] Commercial fishing is limited to Kvichak Bay (i.e., no commercial fishing occurs in the Kvichak River).

Although extensive research has been conducted on sockeye salmon in the Kvichak River, little effort has been dedicated to the study of the other four species of salmon near the Project. ADF&G conducts annual spawning ground surveys in the Naknek/Kvichak drainage, but the majority of the effort is in the Naknek River and its tributaries (Salomone et al., 2009), which are downstream of Igiugig and the hydrokinetic project. According to the ADF&G Anadromous Waters Catalog, several streams above the village of Igiugig support spawning populations of sockeye, Chinook, and coho salmon, whereas pink and chum salmon are rarely found (Table 5).

Aside from sockeye salmon, little is known about the age and run timing of juvenile salmon upstream of Igiugig (ADF&G, 2011). ADF&G records incidental non-sockeye salmon catch that occurs during the sockeye salmon smolt project on the Kvichak River, but abundance and run timing are not estimated using these data (Crawford, 2001). Regardless, the outmigrating smolts from these other species could encounter the RivGen® device if their behavior during active outmigration is similar to sockeye salmon smolts (Quinn, 2005; Groot & Margolis, 1991). The age at which Chinook and coho will smolt varies from system to system, but ranges from 0 to 2 years for Chinook and 0 to 4 years for coho (Morrow, 1980; Quinn, 2005; Groot & Margolis, 1991). Age-1 and older Chinook and coho smolts are larger than the respective aged sockeye smolts, so they may be better able to avoid the RivGen® device(s).

Chum and pink salmon usually outmigrate immediately after emergence from the gravel (Groot & Margolis, 1991); therefore, juvenile chum and pink salmon originating upstream of Igiugig would likely have already migrated past the Project site by the time of redeployment in late June.

Table 5. *Distribution of salmon in tributaries of the Kvichak River, by life stage.*

	Species/Lifestage[a]				
Location	Sockeye	Chinook	Coho	Pink	Chum
Kaskanak Creek	p	s	s	s	s
Ole Creek	s	p	p		p
Pecks Creek	s	p	p		s
Belinda Creek	s	s			
Dennis Creek	s				
Gibraltar Creek	s				s
Kakhonak River	s				
Copper River	s	s			
Tommy Creek	s				
Iliamna River	s	p	p	p	p
Pile River	s				
Knutson Creek	s				
Canyon Creek	s				
Chekok Creek	s		p		
Chekok Bay Creek	s		p		
Stonehouse Creek	s				
Eagle Bay Creek East	s				
Eagle Bay Creek West	s				
Roadhouse Creek	s		s		
Newhalen River	s	s	p		
Pete Andrews Creek	s				
Upper Talarik Creek	s, r	s	s, r	p	s
Lower Talarik Creek	s	p	s		
324-10-10150-2155	s		p		

[a] p - present, m - migration, r - rearing, s - spawning. Alaska Department of Fish and Game (2011). Anadromous Waters Catalog Overview.

3.3 Marine Mammals

3.3.1 Harbor Seals

Lake Iliamna is home to one of the two known harbor seal (*Phoca vitulina*) populations that reside in freshwater lakes year-round (Hauser, Allen, Rich, & Quinn, 2008). Since 1991 there have been a number of aerial surveys to estimate the population of these seals; the estimates range from 105 in 2005 (National Marine Mammal Laboratory, unpublished) to 321 in 1998 (Small, Pendleton, & Wynne, 2001). Distribution is concentrated near the islands located in the northeastern portion of the lake (Withrow & Yano, 2009). Although there are no barriers to prevent the seals from leaving the lake, there has been no indication that seals move up or down the river (Mathisen & Kline, 1992). According to Hauser the seals feed predominately on spawning sockeye salmon during the summer and smaller resident fishes during the remainder of the year.

Although the chances of interactions between harbor seals and the device are thought to be rare, a set protocol to notify appropriate regulatory agencies will be followed in the event a negative interaction does occur. Harassment will be expressly prohibited.

3.3.2 Beluga Whales

Beluga whales (*Delphinapterus leucas*) are an important subsistence resource in the Bristol Bay region, where the population has been estimated to be approximately 2000 animals (Frost & Lowry, 2002). Due to the decline in sockeye returning to the Kvichak River in the late 1990s and early 2000s, state and federal agencies have increased beluga whale research in that region of Bristol Bay. Belugas whales in both Kvichak Bay and Kvichak River are known to prey on the outmigrating sockeye smolts during the spring outmigration and the returning adults in the summer (Quakenbush, 2002; Markowitz & Link, 2006). In 2002 and 2003 a cooperative study was conducted by ADF&G to determine the potential impact these whales may have on the salmon population (Quakenbush, 2003). By tagging and tracking whales and collecting stomach contents the researchers hoped to gain a better understanding of how much time the whales spend in the Kvichak River and how many smolts and adults they would consume during this period. In addition to this study aerial surveys were flown to estimate in-river abundance.

Of the estimated 300 – 400 beluga whales in the Kvichak River system, 5 were tagged with satellite transmitters to track their distribution. Tagging occurred in early May and the whales were tracked through August (Quakenbush, 2003). Whales that stayed in the Kvichak River would only travel as far up as Levelock and one was detected just inside of the Alagnak River. Notably, tags in 2002 were equipped with a stand-by mode that activated when the tags come out of saltwater (these tags are used on seals and sea lions to save battery life when they haulout). Therefore, the tags may not have transmitted in the fresh water further up the Kvichak River. The author of the report stated that she did not know of any documented instances of whales traveling above Kaskanak Flats (Lori Quakenbush, personal communication, 2011). There is an anecdotal report of a beluga whale siting near Igiugig in 2011 (AlexAnna Salmon, IVC President, personal communication).

Although the chances of interactions between beluga whales and the device are thought to be low, a set protocol to notify appropriate regulatory agencies will be followed in the event a negative interaction does occur. Harassment will be expressly prohibited.

4 EFFECTS OF THE ACTION

4.1 RivGen® Power System Deployment

The introduction of the Project's underwater infrastructure will change habitat in the immediate project area by placement of Project components, the presence of which will represent "new" habitat features (hard structure on the riverbed and in the water column). The Project components may have additional effects on riverine life during operations, including aggregations near the Project, avoidance of the Project, and possible turbine foil strike and collision with the Project components. Areas of shelter, structure, or cover are typically sought by fish for protection from predators (Johnson & Stickney, 1989).

The Project consists of structures that will occupy the water column (TGU and pontoon support structure) and sit on the riverbed (pontoon support structure, anchors, and cables). Fish and other may be attracted to the structure provided by Project components or to potential flow refugia provided by the structures.

ORPC expects that the spatial siting of the RivGen® Power System will minimize interactions of fish with the device. In particular, device locations in the middle of the river channel (thalweg) reduce risk associated with migrating fish species that tend to occupy shallow bank areas. In addition, the top of the device will be located 1-1.5 m (3-5 ft) below the river surface which is intended to minimize interactions with sockeye salmon smolt if it were present during the run (2019 deployment will occur after the outmigration). Figure 10 shows the relative cross-sectional position of the RivGen® device in relation to the riverbed, banks and migration corridors.

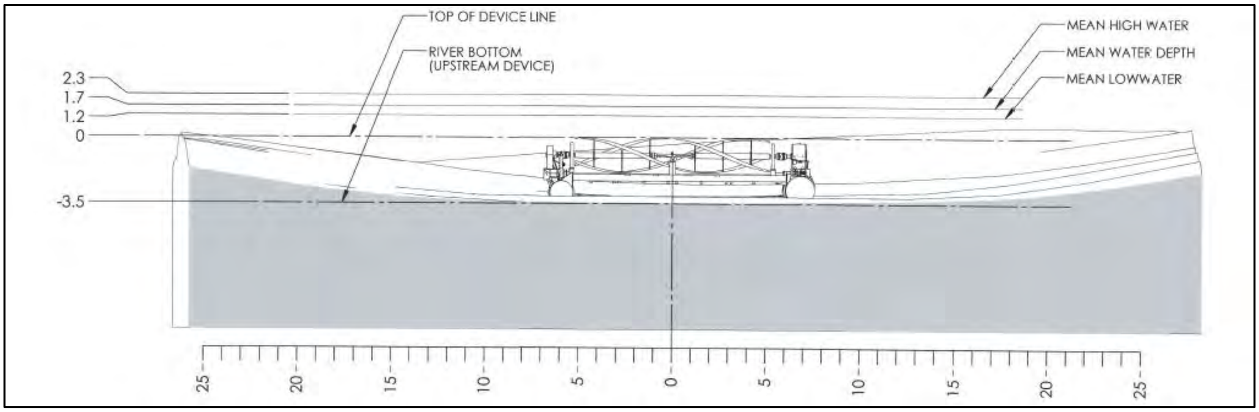


Figure 10. Cross section view of RivGen® device from downstream, looking upstream. Generic river bed profile using 1:200 scale and measurements in meters.

Another potential concern is that the presence and operation of the Project may deter species from using parts of the Kvichak River. While ORPC anticipates that fish (and marine mammals in the rare instance that they are present) will be able to detect and avoid the turbines, ORPC does not expect the Project will deter species from otherwise using the habitat in an area where aquatic species are already exposed to a variety of anthropogenic uses.

4.2 Fish Monitoring

The Fish Monitoring Plan has been prepared by ORPC and UAF with input from project partners at the UW and PNNL. The issues, observations, and data required for the Fish Monitoring Plans are based on content required by FERC regulations §5.6(d)(3)(i), §5.6(d)(3)(iv), §5.11, §5.18(b)(5)(ii)(B), and §5.18(b)(5)(ii)(C). In addition, the information needs of ADF&G to prepare a Fish Habitat Permit (FHP, Title 16 Permit) were considered as based on Durst (2011).

The 2019 Fish Monitoring Plan, included as Attachment 3 to this EFH assessment, is the basis for future monitoring for the Project. Monitoring results and lessons learned from the 2014 and 2015 RivGen® Power System testing at the Project location has informed the Fish Monitoring. This plan includes monitoring equipment, operation schedule and revised monitoring costs.

The 2019 Fish Monitoring Plan recommends that two pairs of underwater stereo cameras (two cameras per stereo pair for a total of four cameras) will be mounted on the port pontoon of the pontoon support structure to record fish behavior. Forward camera(s) will be placed so that the field of view (FOV) includes both the upstream end and the side of the devices. Aft camera(s) will be placed so that the FOV include the downstream end and the side of the devices. Cameras will be mounted in a way that most effectively captures the intended FOVs (Figures 11 and 12).

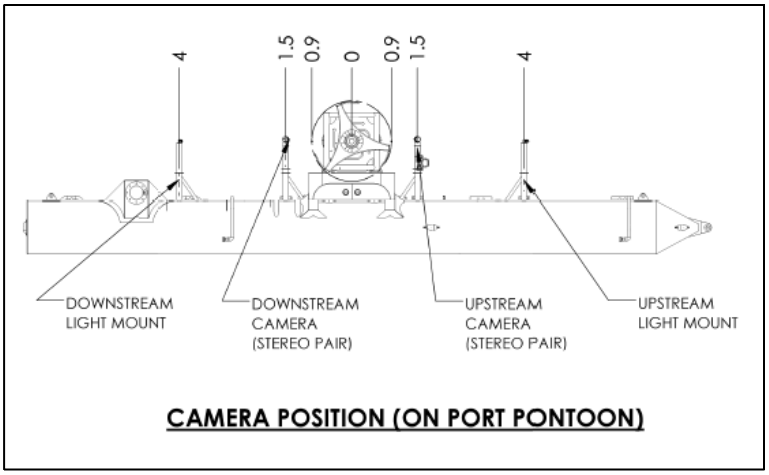


Figure 11. Cross-Section view of RivGen® device environmental monitoring system. River flow from right to left. Measurement in meters.

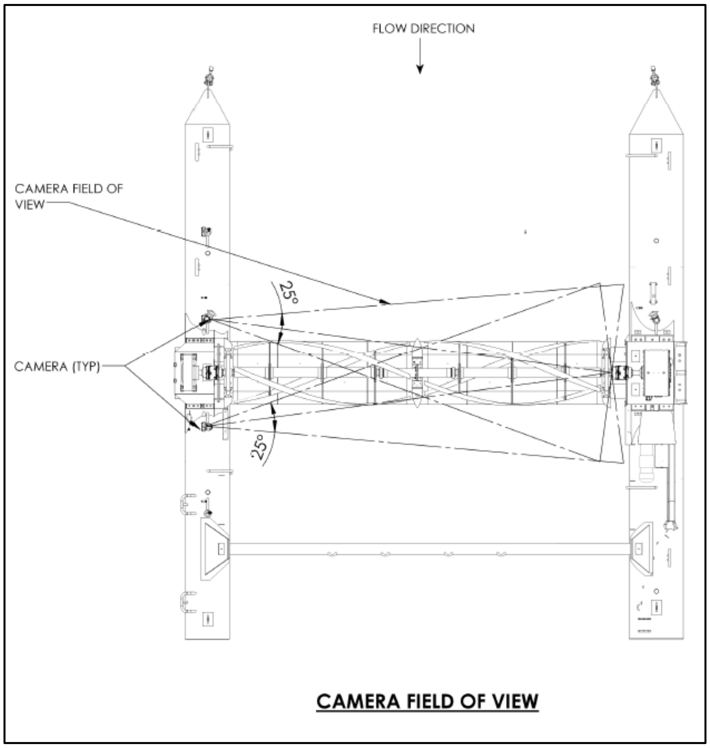


Figure 12. Plan view of RivGen® device environmental monitoring system showing camera beam angles. River flow from top to bottom.

Cameras will be high resolution (600 TV Line) monochrome cameras capable of operating in low light conditions (0.01 lux). Cameras will have a wide-angle lens with a 25° FOV and an operating distance of 18 m (Table 6). Upstream and downstream cameras will be set in a stereo-optic configuration within a marine science grade acrylic enclosure with clear wide-angle dome ports and wet mate connectors. A polyurethane-jacketed data/power cable will run from each camera to the environmental monitoring module located on the device.

Table 6. *Environmental Monitoring Cameras. Source: ORPC*

Lens focal length	Minimum Camera Resolution	Estimated total pixels on target at Minimum resolution	Uncompressed data rate (MB per frame)
16 mm	800x600	25	0.96

The environmental monitoring system will include lights to provide better illumination of the video field of view during night time monitoring. Because a sonar camera (e.g., DIDSON or ARIS) will not be included in the environmental monitoring system, it will not be possible to assess the effects of the lights on fish behavior, specifically whether the lights are an attractant or repellent to fishes. Generally, it is thought that lights are an attractant, so behavioral analyses conducted while the lights are on 10 minutes of each hour will be considered to represent the upper bound in number of fish/turbine interactions. During time periods when fish behavior will not be observed (50 minutes of each hour), lights will be turned off. Light specifications are included in Table 7.

Table 7. *Environmental Monitoring Lights. Source: ORPC*

Typical Lumen Output (Flood)	Efficacy	Color	Beam Angle
0-10,000 dimmable	94 lm/w[1]	Daylight White (5,000 k ~ 6,000 k)	Spot: 35 degrees

During initial deployment of the Phase I RivGen® device (Summer 2019), UAF personnel will be present onsite in Igiugig for deployment of cameras and initial video collection. While onsite, UAF personnel will evaluate video to ensure that the collected footage is appropriate for monitoring interactions between fishes and the turbine. Additionally, UAF personnel will work with PNNL personnel and project partners to design the most feasible method for delivering recorded video footage to the UAF campus for subsequent analyses of potential fish/turbine interactions. Once the Project lead and partners are comfortable with the camera set up and method of video footage delivery, UAF personnel will conduct video analyses, in consultation with PNNL, at the UAF campus (approximately July 2019-May 2020). Video captured by cameras deployed at the base of the turbine will be analyzed to identify interactions between fishes and the turbine, including strikes, avoidance behavior, and lack of reaction utilizing the EyeSea software developed by PNNL. For each interaction between fishes and the turbine, species will be identified, and size will be estimated.

Should the turbine be deployed in late Spring 2020 it will likely be before or during the peak of the sockeye salmon smolt outmigration. Sockeye salmon smolt typically emigrate from Lake Iliamna to the Bering Sea, via the Kvichak River in a large pulse lasting <4 weeks (last two weeks of May and first two weeks of June) and consisting of 10s of millions of individuals (Nemeth et al. 2014). Because of the socioeconomic importance of sockeye salmon coupled with the short, intense emigration through the Kvichak River, this has been identified as ADF&G's priority monitoring period due to the elevated potential for fish/turbine interactions. As a result, UAF personnel will be on-site at all times while the turbine is deployed during the sockeye smolt outmigration from May 21 through June 10, 2020 and will conduct video analyses, as requested by ADFG. The adult sockeye salmon migration (25 June to 15 July) has also been identified as a priority time period. During priority time periods, 10 minutes of every hour around the clock will be recorded. The video collected will be run through supervised analysis each afternoon by EyeSea software, in which the software will identify fish interaction events and UAF fish biologists will classify the events after identification. After daily video review, daily summaries of fish/turbine interactions will be provided to IVC, ORPC, ADFG and interested parties as part of the adaptive management plan. Additionally, once every three days, validation of EyeSea software will be accomplished by comparing results of identification of fish interactions by EyeSea software and UAF fish biologists. During this validation, one total hour of randomly chosen 10-minute video segments (6 total segments x 10 minutes each segment = 1 total hour) will be reviewed by both EyeSea software and visually by UAF fish biologists, and the number of fish interactions will be compared. As the rigor the EyeSea software in reliably detecting fish events is validated intervals between groundtruthing events will be extended based on input from the AMT. Finally, during non-priority time periods, video recording duration will be reduced as part of the AMP. For example, during winter, video of 10 minutes of every 3 hours will be recorded and run through supervised analysis.

4.3 Collision Risk

The blunt-shaped RivGen® foils have a relatively slow normal operating rotational speed of 60 RPMs, depending on the river velocity, with a normal operating tip speed of 0 to 12 m/s (0 to 39 ft/s). When the turbines are in operation, the rotating foils are expected to produce a pressure wave, which is expected to deter marine mammals from passing through the turbine.

ORPC performed a detailed assessment of foil strike on fish in the Biological Assessment for the FERC-licensed Cobscook Bay Tidal Energy Project which utilized similar turbine technology (ORPC, 2012). Although the document focused on Atlantic salmon and Atlantic sturgeon, it is also applicable to other marine fish, as well as marine mammals that may encounter the TidGen® or RivGen® Power System. Existing information reveals that there is extremely low risk of effects from hydrokinetic turbine foil strikes on fish (ORPC 2012; Normandeau, 2009, Hydro Green Energy, 2010; Verdant Power, 2010; EPRI, 2010; Amaral et al., 2008 and 2010b; Scottish Executive, 2007; Wilson et al., 2007; AECOM, 2009; and Nemeth 2014). In developing a model to predict the foil strike mortality for fish entrained in hydrokinetic turbines, Amaral et al. (2010c) have concluded that no mortality should occur for any fish at any size when foils move at speeds less than 4.5 m/s (15 ft/s). This could be inferred to marine mammals as well. The maximum normal operating foil tip speed of the TGUs is 6 m/s (19 ft/s); however, these speeds will rarely be reached: flow speeds at this project site rarely exceed 2.35 m/s and are generally less.

Detailed environmental studies have been conducted around ORPC power systems in both tidal and river environments. ORPC's TidGen® Power System was used for the Cobscook Bay Tidal Energy Project in Maine. The TidGen® device is comprised of the same core technology as the RivGen® device but on a larger scale. In Cobscook Bay, researchers have an understanding of changes in fish density over time. Monitoring recorded little interactions between fish and turbine foils and revealed that small fish move through the turbines. Side-looking sonar revealed some deflections or avoidance behavior occurring in the range of seven to fifteen meters from the turbine. Mobile transects indicated fish responded further away from the device, in the range of ten to one hundred and forty meters from the device. The behavioral effect footprint around device may be within 10 to 140 meters, and it has been observed that once fish move past the device, direction of movement was with the water current as shown in Figure 13. It should be noted that the TidGen® device is over twice the size of the RivGen® device.

Additional resources for best available science are included in Section 7, References of this Plan.

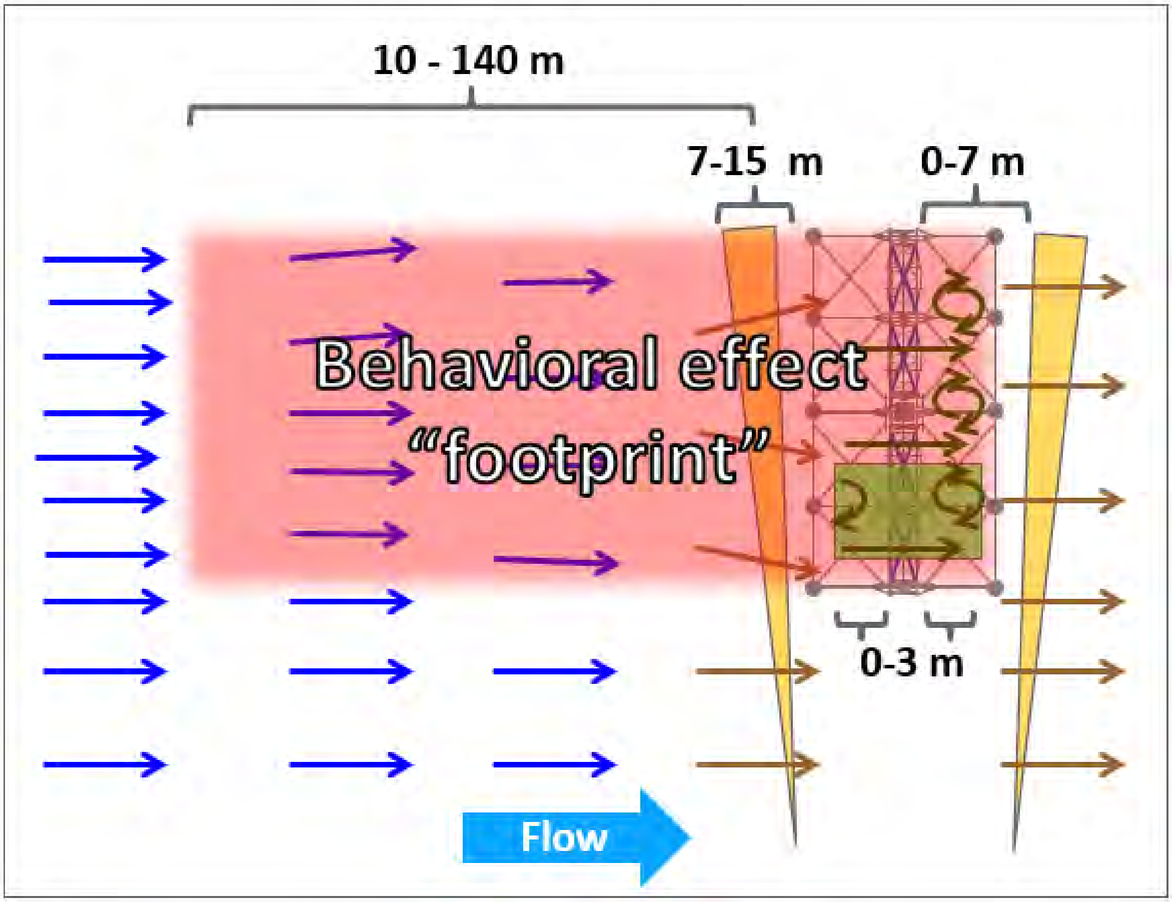


Figure 13. Synthesis of fish studies for ORPC's Cobscook Bay Tidal Energy Project. Source: University of Maine

Based on assessments conducted around operating ORPC power systems in Cobscook Bay, Maine, and in the Kvichak River, as well as the above discussion IVC believes the potential for fish or marine mammals to experience turbine foil strike is minimal. Through the continued use of video monitoring technology mounted on the RivGen® pontoon support structure, near field fish behaviors and effects will be assessed as described in the Fish Monitoring Plan (Attachment 3). If adverse effects (e.g., foil strike) are observed, the mitigation measures could be implemented.

Marine mammals are uncommon in the Project area. Lake Iliamna harbor seals and Beluga whales have been discussed previously. ORPC has designed an open pontoon support structure, and mooring lines are expected to be taught during operations, which will minimize the likelihood of marine mammals becoming entangled.

The small percentage of channel width occupied by the RivGen® Power System and the demonstrated ability of these species to sense and avoid structures in the water should minimize potential collision risk. However, ORPC acknowledges that there is some uncertainty regarding how marine mammals and fish will interact with the TGU. Therefore, ORPC continues to collect pre-deployment surveys for fish and marine mammals and proposes to conduct post-deployment monitoring to evaluate fish and wildlife response and interaction with the RivGen® device.

5 PROPOSED MITIGATION

The Alaska Department of Fish and Game issued a Title 16 Habitat Permit for 2015 testing of ORPC's RivGen® Power System at the Project site. The 2015 permit, which included a revised Fish and Wildlife Monitoring Plan, was granted by ADF&G on March 25, 2015. Based on the results of monitoring during the 2015 deployment, as well as further data analysis and development of automation techniques by PNNL, ORPC and UAF drafted a revived Fish Monitoring Plan for the RivGen® Power System to be installed beginning in 2019. The Fish Monitoring Plan is included in Attachment 3.

6 CONCLUSIONS

In conclusion, we have determined that DOE's proposed Action to fund the Project will not adversely affect Essential Fish Habitat occurring within the Project as a result of the RivGen® Power System Deployment.

7 REFERENCES

ADF&G (2002). Alaska Department of Fish & Game. Alaska Aquatic Nuisance Species Management Plan. 2002. Retrieved from: http://www.adfg.alaska.gov/FedAidPDFs/RIR.5J.2002.10.pdf

ADF&G (2011). Anadromous Waters Catalog Overview. Available: http://www.adfg.alaska.gov/sf/SARR/AWC (November 2011).

ADF&G, Recreational Angler Access Project (2015). Alaska Department of Fish and Game. Retrieved from: http://www.adfg.alaska.gov/index.cfm?adfg=fishingsportangleraccesssouthcentral.kvichakriver

ADF&G, Alaska Sport Fishing Survey (2015). Retrieved from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/index.cfm?ADFG=area.results

AEA (2012). Alaska Energy Authority. *Statistical Report of the Power Cost Equalization Program* (Fiscal Year 2011). 2012. Retrieved from http://www.akenergyauthority.org/programspce.html

AEA (2013). Statistical Report of the Power Cost Equalization Program. Retrieved from http://www.akenergyauthority.org/programspce.html

AEA (2015). Renewable Energy Policies. 2015. Retrieved from : http://alaskarenewableenergy.org/why-renewable-energy-is-important/renewable-energy-policies/

Alaska Rural Energy (2010). Igiugig, Alaska. Retrieved from: http://www.akruralenergy.org/2010/2010REC_Chicken-and-Greenhouse-Development-Iguigig_Alvarez.pdf

Alaska State Geo-spatial Data Clearinghouse (2015). Retrieved from: (http://www.asgdc.state.ak.us/)

Alt, K. (1994a). Whitefish. Alaska Department of Fish and Game, Wildlife Notebook Series (Revised), Juneau.

Alt, K. (1994b). Northern Pike. Alaska Department of Fish and Game, Wildlife Notebook Series (Revised), Juneau.

A. N. Popper and R. R. Fay, "Rethinking sound detection by fishes," Hearing Research, vol. 273, pp. 25-36, 2009.

Anchorage Consumer Price Index (2010). Alaska Department of Labor, Retrieved from: http://labor.alaska.gov.research/cpi/inflacioncalc.htm.

Anderson, C.J. (2000). Counting tower projects in the Bristol Bay area, 1955–1999. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A00-08, Anchorage, AK

Bevelhimer, M., Scherelis, C., Colby, J., Tomichek, C., and Adonizio, M.A. 2015. Fish behavioral response during hydrokinetic turbine encounters based on multi-beam hydroacoustics results. In Proceedings of the 3rd Marine Energy Technology Symposium (METS), April 27–29, 2015, Washington, D.C.

Broadhurst, Melanie, Sue Barr, and C. David L. Orme. 2014. "In-Situ Ecological Interactions with a Deployed Tidal Energy Device; an Observational Pilot Study." Ocean & Coastal Management, vol. 99, 31-38. doi:10.1016/j.ocecoaman.2014.06.008

Brna, P.J. & Verbrugge, L.A., Eds. (2013). Wildlife resources of the Nushagak and Kvichak River watersheds, Alaska. Final Report. Anchorage Fish and Wildlife Field Office, U.S. Fish and Wildlife Service, Anchorage Alaska.

Clark, J.H., MacGregor, A., Mecum, R.D., Krasnowski, P. & Carroll, A.M. (2006). The commercial salmon fishery in Alaska. Alaska Fishery Research Bulletin. 12:1-146.

Crawford, D.L. 2001. Bristol Bay salmon smolt studies using upward-looking sonar, 2001. Alaska Department of Fish and Game, Commercial Fisheries Division. Regional Information Report No. 2A03-27, Anchorage, AK

Crawford, D.L., & West, F.W. (2001). Bristol Bay sockeye salmon smolt studies for 2000. Alaska Department of Fish and Game, Regional Information Report 2A01-12, Anchorage, AK

Crawford, D.L., & Fair, L.F. (2003). Bristol Bay salmon smolt studies using upward-looking sonar, 2002. Alaska Department of Fish and Game, Commercial Fisheries Division. Regional Information Report No. 2A03-17, Anchorage, AK

Detterman, R.L. & Reed, B.L. (1973). Surficial Deposits of the Iliamna Quadrangle, Alaska: Geology of the Iliamna Quadrangle, Alaska. Geological Survey Bulletin, 1368-A

DNR (2013). Alaska Department of Natural Resources. Region 10: Western Iliamna Lake, Kvichak River. http://dnr.alaska.gov/mlw/planning/areaplans/bristol/2013/pdf/bbap_amend2013_ch3_reg10.pdf

Dunaway, D.O. & Flesichman, S.J. (1996). Surveys of the sockeye salmon sport fishery in the upper Kvichak River, Alaska, 1995. Alaska Dept. of Fish and Game, Division of Sport Fish, Research and Technical Services, Anchorage, AK.

Dunn, J.L. & Alderfer, J. (2006). *National Geographic Field Guide to the Birds of North America*, fifth edition. National Geographic Society, Washington, D.C.

Durst, J. (2011). Fish population concerns related to hydrokinetic development and permit requirements in state waters. ADF&G. Presented at the Alaska Hydrokinetics Technical Conference, Dena'ina Center, Anchorage, AK.

Dye, J.E. & Schwanke, C.J. (2009). Report to the Alaska Board of Fisheries for the recreational fisheries of Bristol Bay, 2002, 2008, and 2009. Alaska Department of Fish and Game, Special Publication No. 09-14, Anchorage, AK

EPA (2014). U.S. Environmental Agency. Calculation from http://www.epa.gov/cleanenergy/energy-resources/calculator.html last viewed February 25, 2014.

Fall, J.A., Holen, D.L., Davis, B., Krieg, T. & Koster, D. (2006). Subsistence harvests and uses of wild resources in Iliamna, Newhalen, Nondalton, Pedro Bay, and Port Alsworth, Alaska, 2004. Alaska Department of Fish and Game, Division of Subsistence Technical Paper No. 302, Juneau, AK

Frost, K.J. & Lowry, L.F. (2002). Alaska Beluga Whale Committee surveys of beluga whales in Bristol Bay, Alaska, 1999-2000. Alaska Beluga Whale Committee Draft Report 02-1.

Gotthard, T.A. & McClory, J.G. (2006). Alaska Natural Heritage Program, Environment and Natural Resources Institute, University of Alaska Anchorage, Anchorage, AK.

Groot, C. & Margolis, L., eds. (1991). Pacific Salmon Life Histories. University of British Columbia Press, Vancouver, BC

Gryska, A. (2007). Arctic Grayling. Alaska Department of Fish and Game, Wildlife Notebook Series (Revised), Juneau, AK

Hastings, M.C. and Popper, A.N. 2005. Effects of sound on fish. Prepared for Jones & Stokes under California Department of Transportation Contract No. 43A0139, Task Order 1. Sacramento, California. January 28, 2005.

Hammar, Linus, Sandra Andersson, and Linda Eggertsen. 2013. "Hydrokinetic Turbine Effects on Fish Swimming Behaviour." PLoS ONE, vol. 8(12), 1- 12. http://dx.doi.org/10.1371/journal.pone.0084141

Hauser, D.D., Allen, C.S., Rich, H.B. & Quinn, T.P. (2008). Resident Harbor Seals (*Phoca vitulina*) in Iliamna Lake, Alaska: Summer Diet and Partial Consumption of Adult Sockeye Salmon (*Oncorhynchus nerka*). University of Washington, Seattle, WA.

Hilborn, R., Quinn, T.P., Schindler D.E. & Rogers, D.E. (2003). Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences 100:6564-6568.

Homer, C.C., Huang, L., Yang B., Wylie, B., & Coan, M. (2004). Development of a 2001 National Land Cover Database for the United States. Photogrammetric Engineering and Remote Sensing 70:829-840.

Hubartt, D. (1994). Dolly Varden. Alaska Department of Fish and Game, Wildlife Notebook Series, Juneau, AK

Igiugig (2010). Igiugig Village Corporation. Igiugig Village Community Comprehensive Strategic Plan. Submitted to Alaska Department of Community and Economic Development. Retrieved from: http://www.commerce.state.ak.us/dca/plans/Igiugig-SAP-2001.pdf

Igiugig (2012). Lake and Peninsula Borough Comprehensive Plan, Igiugig: Community Action Plan. 2012. Retrieved from: http://www.lakeandpen.com/vertical/sites/%7B0B64B15E-4D75-4DD6-ACBB-14563D943AB9%7D/uploads/Igiugig_CommunityPlan_9-17-12.pdf

Igiugig (2015). Annual Report. Igiugig Village Council. Annual Presidential Report, January 13, 2015. Earth Justice 2014. Earth Justice, Renewable Village (video). Retrieved from: http://earthjustice.org/video/renewable-village

Igiugig (2015). Village of Igiugig. Subsistence Living. Retrieved from: http://www.igiugig.com/village-life/about-igiugig/subsistance-living

Jacobson, P., Ravens, T., Cunningham K., & Scott, G. (2012). Assessment and Mapping of the Riverine Hydrokinetic Resource of the Continental United States. EPRI Technical Report. Retrieved from http://www1.eere.energy.gov/water/pdfs/riverine_hydrokinetic_resource_assessment_and_mapping.pdf

Karlstrom, T.N.V. (1960). The Cook Inlet, Alaska, glacial record and quaternary classification. Geological Survey Research 1960. US Geol Survey Prof Paper 400-B, p B330-B332

Karlstrom, T.N.V. (1964). Quaternary geology of the Kenai Lowland and glacial history of the Cook Inlet region, Alaska. US Geol Survey Prof Paper 443

Krieg, T., Chythlook, M., Coiley-Kenner, P., Holen, D., Kamletz, K. & Nicholson, H. (2003). Subsistence Fisheries Assessment: Kvichak River Watershed Resident Species. Federal Subsistence Fishery Monitoring Program, Final Project Report No. FIS 02-034. U. S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program, Fishery Information Service, Anchorage, AK.

Krieg, T., Chythlook, M., Coiley-Kenner, P., Holen, D., Kamletz, K. & Nicholson, H. (2005). Freshwater fish harvest and use in communities of the Kvichak watershed, 2003. Federal Subsistence Fishery Monitoring Program, Final Project Report No. FIS 02-034. U. S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program, Fishery Information Service, Anchorage, AK.

LGL (2015). LGL Alaska Research Associates, Inc. Fish and Wildlife Monitoring Plans and Reporting for RivGen® Power System testing, Igiugig, Alaska, 2014 and 2015.

LGL Ecological Research Associates and JASCO Research (2005)

LGL Alaska Research Associates, Inc. (unpublished data). An historical review of the Bristol Bay smolt monitoring program and recommendations for future smolt sampling. Unpublished report prepared by the Bristol Bay Science and Research Institute, Dillingham, AK.

Markowitz, T.M. & Link, M.R. (2006). Estimating the effects of smolt predation by beluga whales on Kvichak River sockeye salmon. Unpublished report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, for the North Pacific Research Board, Anchorage, Alaska, and the Bristol Bay Science and Research Associates, Dillingham, AK

Mathisen, O.A. & Kline, T.C. (1992). Harbor seals in Iliamna Lake, Bristol Bay, Alaska. Final report on Aerial Census in 1991, Juneau Center for Fisheries and Ocean Services, University of Alaska Fairbanks (JCDOS 9203)

Matzner, S.; Trostle, C.; Staines, G.; Hull, R.; Avila, A.; Harker-Klimes, G. (2017). Triton: Igiugig Fish Video Analysis. Report by Pacific Northwest National Laboratory (PNNL). pp 60.

Maxwell, S., Mueller, A., Degan, D. Crawford, D., McKinley, L. & Hughes, N. (2009). An evaluation of the Bendix smolt counter used to estimate outmigrating sockeye salmon smolt in the Kvichak River, Alaska, and the development of a replacement sonar, 2000-2001. Alaska Department of Fish and Game, Fishery Manuscript No. 09-02, Anchorage, AK

Mecklenburg, C.W., Mecklenburg, T.A. & Thorsteinson, L.K. (2002). Fishes of Alaska. American Fisheries Society, Bethesda MD

Minard, R.E., Alexandersdottir, M. & Sonnichsen, S. (1992). Estimation of abundance, seasonal distribution, and size and age composition of rainbow trout in the Kvichak River, Alaska, 1986-1991. Fisheries Data Series No. 92-51. ADF&G.

Morrow, J.E. (1980). The freshwater fishes of Alaska. Alaska Northwest Publishing Company, Anchorage, AK.

Morstad, S., Jones, M., Sands, T., Salomone, P., Buck, G. & West, F. (2010). 2009 Bristol Bay area annual management report. Alaska Department of Fish and Game, Fishery Management Report No. 10-25, Anchorage, AK

Muller, E.H. (1953). Northern Alaska Peninsula and eastern Kilbuck Mountains, Alaska, Péwé, T L, and others, Multiple glaciations in Alaska, a progress report U S Geol Survey Circ 289.

Murphy, Paul G. (2015). Estimation of Acoustic Particle Motion and Source Bearing Using a Drifting Hydrophone Array Near a River Current Turbine to Assess Disturbances to Fish, University of Washington

Nemeth, M. J., Priest, J.T. and Patterson, H.M., 2014. Assessment of fish and wildlife presence near two river instream energy conversion devices in the Kvichak River, Alaska in 2014. Final report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, for Gray Stassel Engineering, Anchorage, AK. 28 pp. + appendices.

Nemeth, M. J., G. D. Wade, D. J. Degan, and M. R. Link. 2014. Sockeye salmon smolt abundance and inriver distribution in Bristol Bay, Alaska: results from the Kvichak, Ugashik, and Egegik rivers in 2013. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK, 55 pp. + appendices.

NOAA (2011). National Oceanic and Atmospheric Administration, Alaska Fisheries Science Center, Community Profiles for North Pacific Fisheries – Alaska: Igiugig, 2011. Retrieved from: http://www.afsc.noaa.gov/REFM/Socioeconomics/Projects/CPU.php

Normandeau Associates, Inc. (2009). An estimation of survival and injury of fish passed through the HydroGreen energy hydrokinetic system, and a characterization of fish entrainment potential at the Mississippi lock and dam No. 2 hydroelectric project. Westmoreland, NH.

NPS, Katmai (2015). National Park Service. Katmai National Park and Preserve. 2015. Retrieved from: http://www.nps.gov/katm/planyourvisit/basicinfo.htm

NPS, Lake Clark (2012). National Park Service. Lake Clark National Park and Preserve. Superintendent's Annual Report, 2012. Retrieved from: http://www.nps.gov/lacl/learn/management/upload/2012-Supt-Rpt_FINAL-resized.pdf

NPS, Lake Clark (2015). National Park Service. Lake Clark National Park and Preserve. Retrieved from: http://www.nps.gov/lacl/index.htm

NPS, Stats, Katmai (2014). National Park Service. Katmai National Park and Preserve. Annual Park Recreational Visitation. https://irma.nps.gov/Stats/SSRSReports/Park%20Specific%20Reports/Annual%20Park%20Recreation%20Visitation%20(1904%20-%20Last%20Calendar%20Year)?Park=KATM

NPS, Stats, Lake Clark (2015). National Park Service. Lake Clark National Park and Preserve. Annual Park Recreation Visitation. https://irma.nps.gov/Stats/SSRSReports/Park%20Specific%20Reports/Annual%20Park%20Recreation%20Visitation%20(1904%20-%20Last%20Calendar%20Year)?Park=LACL

ORPC (2011). ORPC Alaska, Nenana, Alaska Hydrokinetic RivGen® Power System, Grant: UAF 11-0017

ORPC (2012). Ocean Renewable Power Company, Cobscook Bay Tidal Energy Project, FERC pilot project license application. P-12711-005.

ORPC (2014). Ocean Renewable Power Company, Advanced Energy Harvesting Control Schemes for Marine Renewable Energy Devices, grant funded by U.S. Department of Energy, 2014-2015, DE-EE0006397

Quakenbush, L. (2003). Summer movements of Beluga whales captured in the Kvichak River, in May 2002 – 2003. Alaska Beluga Whale Committee, Report 03-3, Alaska Department of Fish and Game, Fairbanks, AK.

Quakenbush, L. (2002). Summer movements of Beluga whales captured in the Kvichak River, in May 2002. Alaska Beluga Whale Committee, Report 02-3, Alaska Department of Fish and Game, Fairbanks, AK.

Quinn, T.P. (2005). The behavior and ecology of Pacific Salmon and Trout. University of Washington Press, Seattle, WA, 2005

Reed, B.L. & Lanphere, M .A. (1969). Age and chemistry of Mesozoic and Tertiary plutonic rocks in south-central Alaska. Geologic Society of America Bulletin, v. 80, p 23-44

Reynolds, J.H., Woody, C.A., Gove, N.E. & Fair, L.F. (2007). Efficiently estimating salmon escapement uncertainty using systematically sampled data. Pages 121-129 in C.A. Woody (editor). Evolution, ecology and management of sockeye salmon. American Fisheries Society Symposium No. 54. Bethesda, MD.

Rietze, H.L. (1957). Western Alaska salmon investigations; field report on the evaluation of towers for counting migrating red salmon in Bristol Bay, 1956. Mimeo report to the U.S. Department of the Interior, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Juneau, AK.

Ruggerone, G.T. & Link, M.R. (2006). Collapse of Kvichak sockeye salmon production brood years 1991-1999: Population characteristics, possible factors, and management implications. Unpublished report prepared by Natural Resources Consultants, Inc. and LGL Alaska Research Associates, Inc. for the North Pacific Research Board, Anchorage, AK, 2006

Salomone, P., Morstad, S., Sands, T., Jones, M., Baker, T. Buck, G., West, F. & Kreig, T. (2011). 2010 Bristol Bay area annual management report. Alaska Department of Fish and Game, Fishery Management Report No. 11-23, Anchorage, AK

Salomone, P., Morstad, S., Sands, T. & Jones, M. (2009). Salmon spawning ground surveys in the Bristol Bay Area, Alaska, 2008. Alaska Department of Fish and Game, Fishery Management Report No. 09-42, Anchorage, AK

Sandia National Laboratories, FY13Q3 Water Power Report, MHK Array Placement Analysis: SNL: SNL-EFDC Model Application to Cobscook Bay, ME, June 30, 2013

Schroeder, R.F., Andersen, D.B., Bosworth, R., Morris, J.M. & Wright, J.M. (1987). Subsistence in Alaska: Arctic, Interior, Southcentral, Southwest, and Western Regional Summaries. Alaska Department of Fish and Game, Division of Subsistence Technical Paper No. 150, Juneau, AK

SCORP (2009). Alaska Statewide Comprehensive Outdoor Recreation Plan, 2009-2014, Alaska Department of Natural Resources.

Scottish Executive. 2007. Scottish Marine Strategic Environmental Assessment. March 2007.

Selkowitz, D.J., & Stehman, S.V. (2011). Thematic accuracy of the National Land Cover Database (NLCD) 2001 land cover for Alaska. Remote Sensing of Environment 115:1401-1407.

Shen, H., Zydlewski, G.B., Viehman, H.A., Staines, G. 2016. Estimating the probability of fish encountering a marine hydrokinetic device. Renewable Energy 97: 746-756.

Small, R.J., Pendleton, G.W. & Wynne, K.M. (2001). Aerial survey of harbor seals in Southern Bristol Bay, Alaska, 1998 – 1999. Pages 71 – 83 in: Harbor Seal Investigations in Alaska. Annual Report for NOAA Award NA87FX0300. Alaska Department of Fish and Game, Division of Wildlife Conservation, Anchorage, AK

Southwest Alaska Municipal Conference (2011). Igiugig Village Council. “Igiugig’s Local Food Production: A Communal Effort with Commercial Potential. Strong Communities, Vibrant Economies, February 11, 2011.

Spangler, P.J. & Rietze, H.L. (1958). Field report on the evaluation of towers for counting migrating red salmon in Bristol Bay, 1957. Mimeo Report to the U.S. Department of the Interior, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Juneau, AK.

Sustainable Kodiak (2011). Village chickens and community gardens thriving in Igiugig. Sustainable Kodiak. September 27, 2011.

Talbot, S. (2010). Vegetation Mapping in Boreal Alaska. Proceedings of the Fifth International Workshop: Conservation of Arctic Flora and Fauna (CAFF) Flora Group., in: S. Talbot, et al. (Eds.), Circumboreal Vegetation Mapping (CBVM) Workshop, Helsinki, Finland, November 3-6th, 2008, CAFF International Secretariat, CAFF Flora Expert Group (CFG).

TerraSond (2011). Kvichak River RISEC Project. Resource reconnaissance and physical characterization. Final Report. Prepared by TerraSond Ltd., Palmer, AK for Dept. of Community and Economic Development, AIDEA/AEA, Rural Energy Group, Anchorage, AK

Thompson, W.F. (1962). The research program of the Fisheries Research Institute in Bristol Bay, 1945–1958. In T. S. Y. Koo, editor. Studies of Alaskan red salmon. University of Washington Press, Seattle. WA

Thomson, J., Kilcher, L. & Polagye, B. (2014). Flow measurements during RivGen® deployment Igiugig, AK. 2014. U.S. Department of Energy, DE-EE0006397.

U.S. Census (2010). American Fact Finder. Retrieved from: http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml

United States Army Corps of Engineers (USACE). 2008. Environmental Assessment and Finding of No Significant Impact: Anchorage.

USFWS. 2007. United States Fish and Wildlife Service. National Bald Eagle Management Guidelines. Retrieved on 12 February 2012 from the United States Fish and Wildlife webpage: http://www.fws.gov/pacific/eagle/NationalBaldEagleManagementGuidelines.pdf

VanStone, J.W. (1984). Handbook of North American Indians: Mainland Southwest Alaskan Eskimo, Washington, D.C., Smithsonian, 1984, 224-225.

Viehman, H. 2012. Fish in a tidally dynamic region in Maine: Hydroacoustic assessments in relation to tidal power development. Master's thesis. University of Maine, Orono, Maine, USA.

Viehman, H., Zydlewski, G.B., McCleave, J., and Staines, G .2014. Using acoustics to understand fish presence and vertical distribution in a tidally dynamic region targeted for energy extraction. Estuaries and Coasts. Doi:10.1007/s12237-014-9776-

Viehman, H., and Zydlewski, G.B .2014. Fish interaction with a commercial-scale tidal energy device in a field setting. Estuaries and Coasts. doi:10.1007/s12237-014-9767-8

Viehman, H., Zydlewski, G.B., McCleave, J., Staines, G. 2015. Using acoustics to understand fish presence and vertical distribution in a tidally dynamic region targeted for energy extraction. Estuaries and Coasts. 38(S1): 215-226.

Viehman, H., Zydlewski, G.B. 2015. Fish interaction with a commercial-scale tidal energy device in a field setting. Estuaries and Coasts. 38(S1): 241-252.

Viehman, H. 2016. Hydroacoustic analysis of the effects of a tidal power turbine on fishes. PhD Dissertation. University of Maine, Orono, Maine, USA.

Viehman H, Zydlewski GB. 2017. Multi-scale temporal patterns in fish passage in a high-velocity tidal channel. PLoS ONE.12(5), e0176405.

Village of Igiugig (2015). Retrieved from website: http://www.igiugig.com/village-life/about-igiugig/history-culture

Visit Bristol Bay (2015). Retrieved from: http://www.visitbristolbay.com/visitor-guide/wildlife.html

Wade, G.D., Degan, D.J., Link, M.R. & Raborn, S.W. (2010a). Evaluation of an up-looking sonar system designed to enumerate sockeye salmon smolts on the Kvichak River, 2008. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK

Wade, G.D., Degan, D.J., Link, M.R. & Raborn, S.W. (2010b). Estimates of hourly, daily, and seasonal sockeye salmon smolt abundance on the Kvichak River in 2009. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK, 44 p + Appendix.

Wade, G.D., Degan, D.J., Link, M.R. & Raborn, S.W. (2011). Estimates of hourly, daily, and seasonal sockeye salmon smolt abundance on the Kvichak and Ugashik Rivers in 2010. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK.

Wade, G.D., Degan, D.J., Link, M.R. & Raborn, S.W. (2012). Monitoring of sockeye salmon smolt abundance and inriver distribution using sonar on the Kvichak, Egegik, and Ugashik rivers in 2011. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK

Wade, G. D., Degan, D. J., Link, M. R. & Nemeth, M. J. (2013). Monitoring sockeye salmon smolt abundance and inriver distribution using sonar on the Kvichak and Ugashik rivers in 2012. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK

Weilgart, L.S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology 85, 1091-1116.

Wilson, B., Batty, R., Daunt, F., and Carter, C. 2007. Collision risks between marine renewable energy devices and mammals, fish and diving birds. Report to the Scottish Executive. Scottish Association for Marine Science, Oban, Scotland, PA37 1QA, 110 p.

Withrow, D.E. & Yano, K.M. (2009). Recent counts of freshwater seals in Alaska's Lake Iliamna. MMML, Alaska Fisheries Science Center, NMFS, NOAA, Seattle, WA.

Woody, C.A. (2007). Counting towers as an abundance estimation tool for salmon. Pages 363-384. In Johnson, D.H., B.M. Shrier, J.S. O'Neal, J.A. Knutzen, X. Augerot, T.A. O'Neil, T.N. Pearsons, editors. Salmonid Field Protocol Handbook. American Fisheries Society, Symposium No. 57. Bethesda, MD.

Woody, C.A. & Young, D. (2007). Life history and essential habitats of humpback whitefish in Lake Clark National Park, Kvichak River watershed, Alaska. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program, Annual Report (Study No. 05-403). U.S. Geological Survey, Alaska Science Center, Anchorage, AK.

Wright, J., J.M. Morris, and R. Schroeder. (1985). Bristol Bay Regional Subsistence Profile. Alaska Department of Fish and Game, Division of Subsistence Technical Paper No. 114, Juneau, AK

Attachment 1

Data Analysis for Monitoring of the RivGen® in the Kvichak River, 2015
LGL Alaska Research Associates, Inc., November 11, 2015

Alaska Research Associates, Inc.

LGL Alaska Research Associates, Inc.
2000 W International Airport Road Suite C1
Anchorage, Alaska 99502 USA
Tel: (907) 562-3339 Fax: (907) 562-7223

To: Nate Johnson and Monty Worthington, Ocean Renewable Power Company
From: Justin Priest and Matt Nemeth, LGL Alaska Research Associates, Inc.

Re: Data Analysis for Monitoring of the RivGen® in the Kvichak River, 2015

Date: November 11, 2015

This memo summarizes the preliminary data analyses from fish and wildlife monitoring at the RivGen® Power System, a submerged hydrokinetic device operated by the Ocean Renewable Power Company (ORPC) in the Kvichak River in July and August 2015. Monitoring was performed by LGL Alaska Research Associates, Inc., in accordance with the 2015 Monitoring Plan developed in March 2015 and Alaska Department of Fish and Game (ADF&G) Fish Habitat Permit FH 15-II-0038. Data presented here are preliminary and may change after final QA/QC. Interim results and figures were also presented in monthly progress reports at the end of July and August.

Fish movements at the RivGen® device were described using video footage collected from five underwater cameras mounted to the pontoons of the power system. Video footage was collected 24 hours/day July 19–25 and again August 19–27, 2015; review was done by watching the first 10 minutes of a selected hour from each of the four primary cameras (the fifth camera was a backup). Spatially, the camera field of view captured the port side of the RivGen® device, including upstream and downstream views of the port side turbine (only). In accordance with the Monitoring Plan, footage was reviewed to achieve partial temporal coverage during different categories of turbine operating status and daytime/nighttime conditions (Figure 1). At night, two underwater lights lit the viewing area. In addition, bird and marine mammal surveys were conducted for 15 minutes each morning of monitoring. Methods and the overall approach were similar to those described for the demonstration study conducted at the same site in 2014.

Blocks of video footage from portions of 238 different hours were reviewed inseason in 2015. There were 359 events with fish, composed of approximately 1,202 individual fish from at least six species. The majority of fish observations were of solitary fish; the largest school was approximately 100 fish. Species composition varied from July to August and also from day to night. In particular, salmon smolt were almost exclusively seen at night, and were more prevalent in July than August. Several instances of fish moving through the RivGen® turbine were noted and reported inseason as part of the Adaptive Management Plan. We did not detect any obvious physical injuries to fish, and saw no altered behavior by wildlife near the RivGen® device. Cameras, lights, and power system components all operated reliably. All video footage has been archived.

Preliminary results are presented in more detail below, organized by each Objective from the 2015 Monitoring Plan. Where appropriate, data are also presented in Tables and Figures below.

Data analyses listed by 2015 monitoring objective:

1) Summary of monitoring effort.
   a) Video review effort, by RivGen® device status and time group.
      (1) Table 1. Review effort by RivGen® device status and month.
      (2) Figure 1. Daily schedule of RivGen® device operations and data review effort.

2) Presence and timing of fish and wildlife at the RivGen® device (Objective 1 from Monitoring Plan).
   a) Fish monitoring observations.
      (1) Table 2. Number of fish observation events and number of fish, by month, day/night status, and RivGen® device operating status.
      (2) Table 3. Species and number of fish observed, by month and day/night status.
      (3) Table 4. Fish per reviewed hour block, by species, month, and day/night status.
      (4) Figure 2. Hourly summary of review effort, raw observations, and observations standardized by review effort for fish.
   b) Wildlife monitoring observations.
      (1) Table 5. Bird and wildlife observations by species group.

3) Characterize fish movements past the RivGen® device (Objective 2).
   a) Basic movement type.
      (1) Table 6. Movement classification/direction by species, day/night, and RivGen® status.
   b) Movements in relation to the RivGen® device.
      (1) Table A (to be determined): Movement of fish under, over, or through the turbine area.
      (2) Evidence of passage delay: We saw no obvious evidence of passage delay. Adult salmon were clearly able to move around the device, both going upstream (mostly in the daytime), or downstream (mostly at night). Adult salmon also showed general milling behavior that did not appear to be repeated attempts to move past the device. Finally, juvenile salmon were seen transiting past the device, usually travelling downstream. Juvenile salmon sometimes held downstream of the turbine briefly.

4) Describe the behavioral response of fish or wildlife contacting the RivGen® device (Objective 3).
   a) Table B (to be determined): Number of fish showing obvious attraction to, avoidance of, or sheltering at the RivGen® device in 2015, by species and day/night status.

b) Evidence of avoidance or attraction by fish: We saw no obvious evidence of attraction to the RivGen® device. Any such attraction would likely have only been detected as fish markedly altering course to move directly towards the RivGen® device; we saw no instances of this. We did see instances of avoidance by fish moving downstream, which sometimes altered course to move either over or under the turbine. Avoidance by upstream-moving fish (i.e., fish that avoided the RivGen® device altogether by moving away from it before coming into camera view) would not be easily detectable because the fish would have already altered their course before being able to be observed.

c) Evidence of avoidance or attraction by wildlife: There was no evidence of attraction or avoidance by wildlife during the study; all animals observed showed no behavioral changes near the RivGen® device. No marine mammals were observed in 2015.

5) Describe any acute effects from contact with the RivGen® device (Objective 4).

a) Evidence of disorientation, injury, or mortality: Acute effects of fish moving through the RivGen® device, including any potential adverse effects were documented and reported in four Adaptive Management Reports delivered within 48 hours of the incident. We saw no obvious indication of moribund or inert behavior that might indicate injury or mortality. We did see some potential disorientation by juvenile salmon moving downstream. In these events, schools of fish dispersed as they approached the RivGen® device from upstream; afterwards, downstream of the RivGen® device, these fish milled or moved around abruptly in the eddy behind the turbines, before resuming downstream movement.

Table 1. Summary of the review effort during all RivGen® device operational statuses, 2015. “Partial” hours were when turbines only operated during part of an hour block. “Spinning Whole Hour (Stbd turbine only)” hours were operations when only the starboard turbine was operational.

	July		August		Total	
Device Status	Not Reviewed	Reviewed	Not Reviewed	Reviewed	Not Reviewed	Reviewed
Day						
Not Spinning	26	39	25	11	51	50
Partial	1	16		4	1	20
Spinning Whole Hour		44		69	0	113
Spinning Whole Hour (Stbd turbine only)				17	0	17
Day Subtotal	*27*	*99*	*25*	*101*	*52*	*200*
Night						
Not Spinning	32	6	24	3	56	9
Partial		3			0	3
Spinning Whole Hour		1	20	18	20	19
Spinning Whole Hour (Stbd turbine only)			2	7	2	7
Night Subtotal	*32*	*10*	*46*	*28*	*78*	*38*
Total	59	109	71	129	130	238

Table 2. Summary of the total number of fish events and individuals during all device statuses, 2015. A “Fish Event” is defined as an observation of at least one fish during subsampling review. “Spinning Whole Hour (Stbd turbine only)” was when only the starboard turbine was operational.

	July			August			Total	
Device Status	# Fish Events	Total Fish Seen		# Fish Events	Total Fish Seen		# Fish Events	Total Fish Seen
Day								
Not Spinning	17	26		2	3		19	29
Partial	16	39		1	1		17	40
Spinning Whole Hour	57	196		19	19		76	215
Spinning Whole Hour (Stbd turbine only)				10	10		10	10
Day Subtotal	*90*	*261*		*32*	*33*		*122*	*294*
Night								
Not Spinning	150	736		5	5		155	741
Partial	16	75					16	75
Spinning Whole Hour	4	15		49	64		53	79
Spinning Whole Hour (Stbd turbine only)				13	13		13	13
Night Subtotal	*170*	*826*		*67*	*82*		*237*	*908*
Total	260	1,087	0	99	115	0	359	1,202

Table 3. Total number of fish by species during day/night and month, 2015.

	July		August			
Species	Day	Night	Day	Night	Total	Total %
Chum salmon (adult)			14	12	26	2.2%
Coho salmon (adult)			5	2	7	0.6%
Pink salmon (adult)				2	2	0.2%
Sockeye salmon (adult)	259	51	1	1	312	26.0%
Unidentified adult salmon			9	8	17	1.4%
Unidentified juvenile salmonid		773	1	52	826	68.7%
Rainbow trout			1		1	0.1%
Lamprey spp.	1		1	1	3	0.2%
Unknown species	1	2	1	4	8	0.7%
Total	261	826	33	82	1,202	100.0%

Table 4. Number of fish detected per reviewed hour block by species, 2015. Data are standardized to 10-minute review blocks.

	July		August		
Species	Day	Night	Day	Night	Total
Chum salmon (adult)	-	-	0.1	0.4	0.1
Coho salmon (adult)	-	-	0.0	0.1	0.0
Pink salmon (adult)	-	-	0.0	0.1	0.0
Sockeye salmon (adult)	2.6	5.1	0.0	0.0	1.3
Unidentified adult salmon	-	-	0.1	0.3	0.1
Unidentified juvenile salmon	0.0	77.3	0.0	1.9	3.5
Rainbow trout	-	-	0.0	0.0	0.0
Lamprey spp.	0.0	0.0	0.0	0.0	0.0
Unidentified species	0.0	0.2	0.0	0.1	0.0
Total	2.6	82.6	0.3	2.9	5.1

Table 5. Summary of bird and wildlife observations near the RivGen® device, 2015. Data are standardized to the 15-minute sampling periods.

Taxonomic Group	Sightings	Number of individuals sighted	Number of individuals within 15 m of device	Number of individuals per sample period
Passerines	34	41	4	2.7
Bald Eagles	6	7	0	0.5
Other Raptors	1	1	0	0.1
Waterfowl and Loons	8	11	0	0.7
Gulls, Jaegers, and Terns	53	133	0	8.9
Corvids	3	3	0	0.2
Shorebirds	10	12	0	0.8
Terrestrial mammals	0	0	0	0
Marine mammals	0	0	0	0

Table 6. The number of fish events classified by movement type for each species, 2015. Proportions are per subtotaled day and night.

Movement Type	Chum salmon (adult)	Coho salmon (adult)	Pink salmon (adult)	Sockeye salmon (adult)	Unidentified adult salmon	Unidentified juvenile salmon	Rainbow trout	Lamprey spp.	Unidentified species	Total	Subtotal %
Day											
Milling	5	3		33	5				1	47	38.5%
Travel down	4			8	4	1		2	1	20	16.4%
Travel up	2	1		33			1			37	30.3%
Travel, other	2	1		12						15	12.3%
Undetermined				3						3	2.5%
Day Subtotal	*13*	*5*	*0*	*89*	*9*	*1*	*1*	*2*	*2*	*122*	*100.0%*
Night											
Milling	2	1	2	6	2	20			1	34	14.3%
Travel down	9	1		30	6	142		1	4	193	81.4%
Travel up				3		2				5	2.1%
Travel, other						1				1	0.4%
Undetermined				2		2				4	1.7%
Night Subtotal	*11*	*2*	*2*	*41*	*8*	*167*	*0*	*1*	*5*	*237*	*100.0%*
Total	24	7	2	130	17	168	1	3	7	359	100.0%

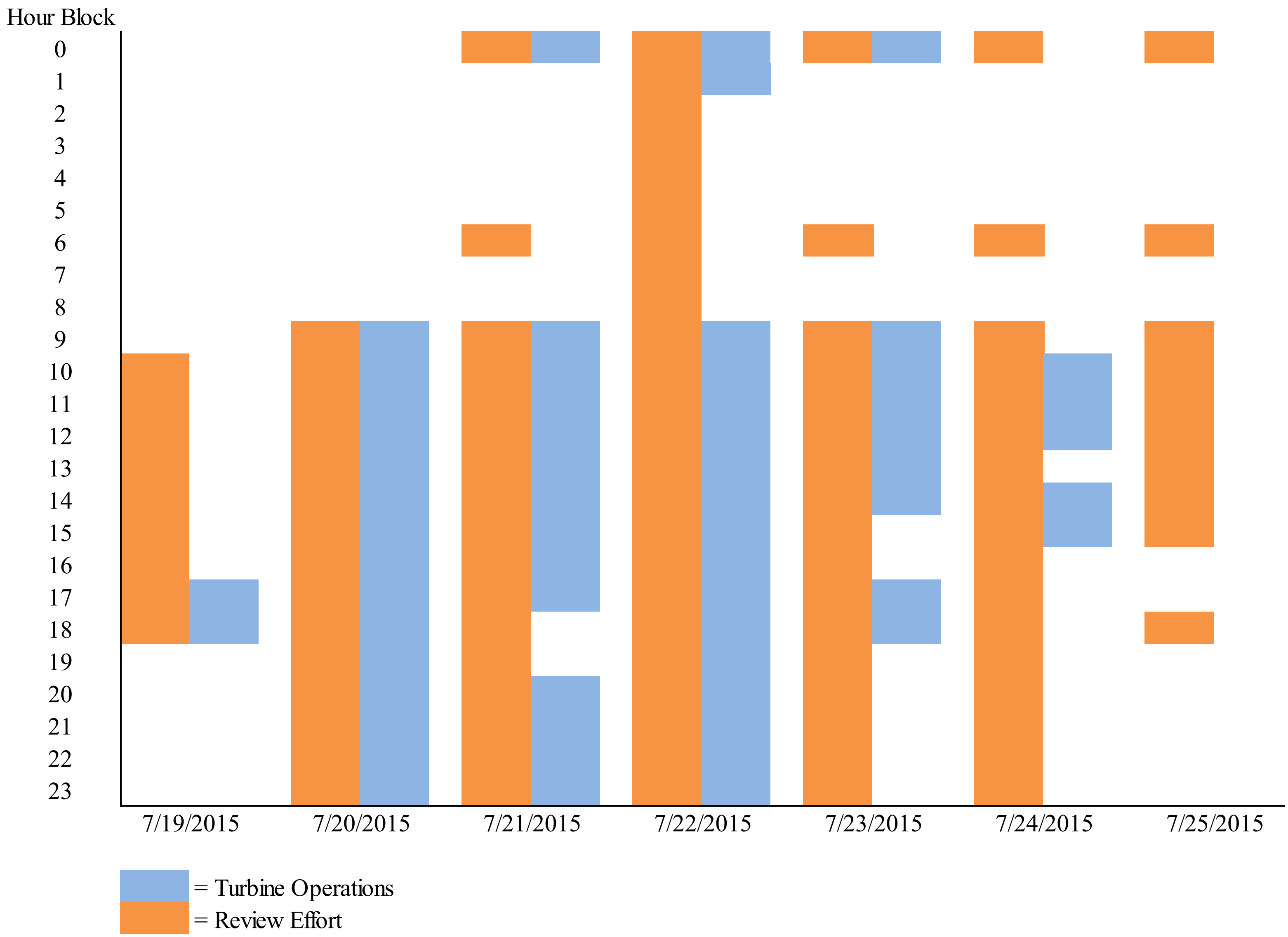


Figure 1A. Summary of turbine operations and review effort of the video system, July 2015. "Half" hours were operations when only one of the two turbine sides was operational.

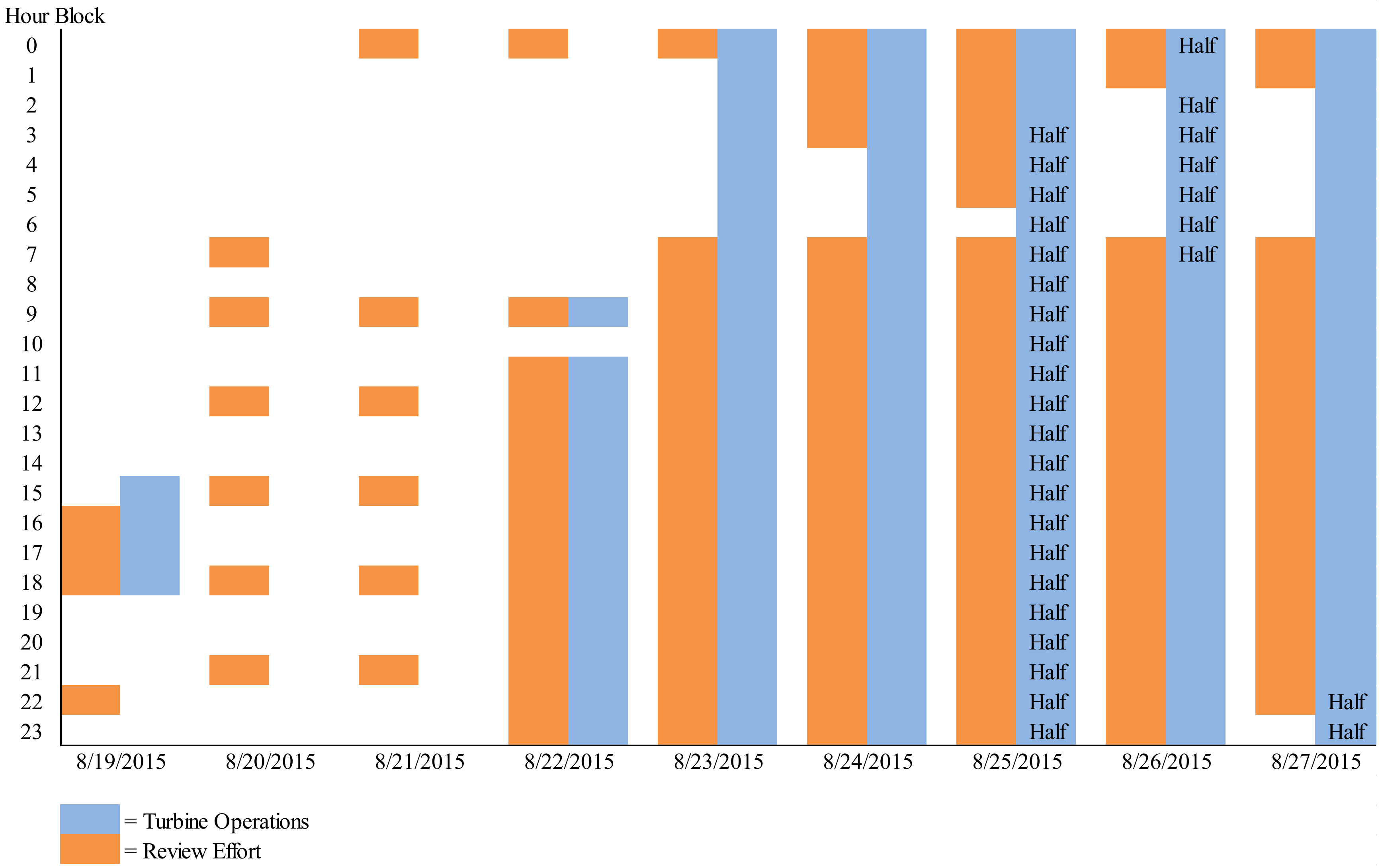


Figure 1B. Summary of turbine operations and review effort of the video system, August 2015. "Half" hours were operations when only the starboard turbine was operational.

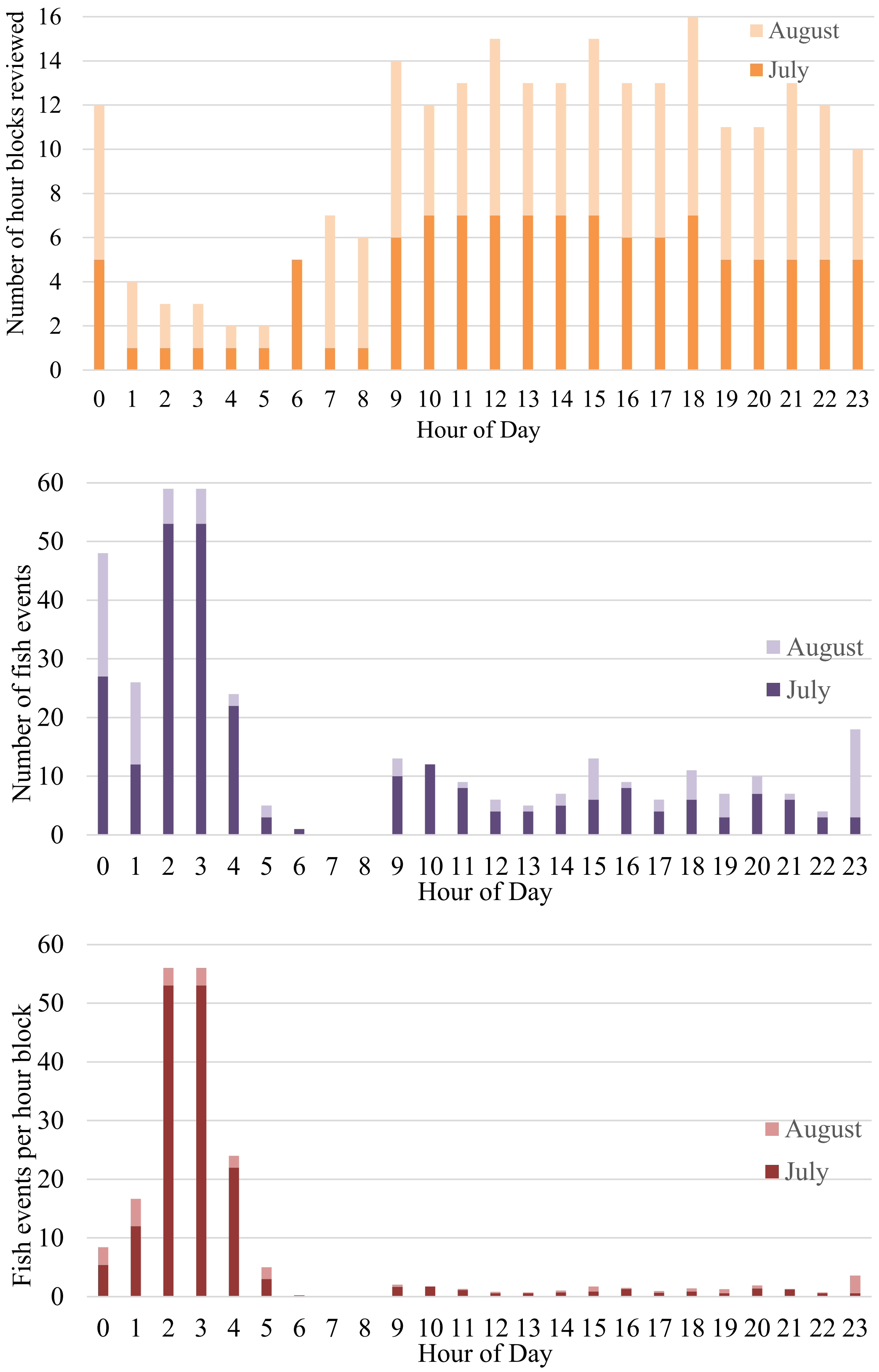


Figure 2A, 2B, 2C. Review effort by hour of day, number of fish events by hour of day, and fish events per hour, by hour of day.

Attachment 2

Triton: Igiugig Fish Video Analysis
PNNL, August 2017

PNNL-26576

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

Triton: Igiugig Fish Video Analysis

Project Report

August 2017

S Matzner
C Trostle
G Staines
R Hull
A Avila
GEL Harker-Klimeš

U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

TRITON

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

Triton: Igiugig Fish Video Analysis

Project Report

August 2017

S Matzner
C Trostle
G Staines
R Hull
A Avila
GEL Harker-Klimeš

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Tidal and instream turbine technologies are currently being investigated for power generation in a variety of locations in the US. An environmental permitting and consenting requirement parallels this exploration generating the need to ensure little or no harm, in the form of strike or collision, befalls marine animals from device deployments. Monitoring methods (e.g., underwater cameras, active acoustics, passive acoustics) around turbine deployments provide empirical data allowing regulators and other stakeholders to assess risk. At present, there is a high level of concern and limited data precluding robust conclusions, which creates a challenge to regulators who must make decisions based on perceived risk versus actual risk. However, the data that are currently available to the scientific community for analysis indicate the issue to be of low risk to date, and strike or collision to be rare events. One such dataset that provides insight to the rarity of strike and collision risk to fish came from an instream turbine deployment in Alaska that used underwater video as the monitoring method.

This document describes the analysis of video data collected around the Ocean Renewable Power Company's RivGen® device deployed in the Kvichak River during July and August 2015 to gain an understanding of the implications of using underwater video cameras as a fish monitoring technique. The data were analyzed manually and used to develop automated algorithms for detecting fish in the video frames and describing their interaction behavior relative to the device. In addition, Pacific Northwest National Laboratory (PNNL) researchers developed a web application, EyeSea, to combine manual and automated processing, so that ultimately the automated algorithms could be used to identify where human analysis was needed (i.e., when fish are present in video frames).

The goal of the project was to develop software algorithms that could identify video frames with fish present to inform and accelerate manual analysis. To achieve this, independent manual analysis was completed for specific video clips (i.e., visual analysis and annotation by a human observer was the standard for assessing the algorithms). The analysis process indicated that some confounding aspects of the algorithm development could potentially be solved with recommended improvements in the initial camera data collection methods.

The manual analysis began to look at all data from the start of deployment of the RivGen® device, primarily using video from Camera 2 that looked directly at the upstream side of the turbine so any interaction could be identified; this was to ensure rare events were seen, and initially focused on Nighttime Data when more fish were present. This process highlighted the amount of time it takes to identify fish, and ultimately only 42.33 hours of video were reviewed because of the time-consuming analysis. The data were classified as "Fish" when the reviewer was confident it was a fish, and "Maybe" fish when it was difficult to distinguish. The two classes were distinguished based on the movement, shape, and color characteristics. Fish Events were further classified by "adult", "juvenile", or "unidentifiable" age. Behavioral attributes were noted and were broadly divided into Passive and Avoidance activities. In over 42 hours of the data reviewed, there were only 20 potential contact interactions, of which 3 were Maybe classifications, 12 were juveniles, and 5 were adults. While only 11.5% of the video data were analyzed from Camera 2, these results are from the time when most fish were present over the turbine deployment period (from Alaska Department of Fish and Game data) and provide preliminary evidence that fish strike or collision of fish in the Kvichak River with an instream turbine is rare.

On only one occasion was an actual contact confirmed, and this was an adult fish that contacted the camera, not the turbine itself. This experience highlights the difficulties associated with confirming a strike or collision event as either having occurred or having been a near-miss. More interactions were

detected at night; this was probably biased by nighttime use of artificial light, which may have attracted fish, but also could have increased detection probability because the light is reflected from the fish itself.

For the algorithm development, background subtraction, optical flow, and Deep Learning techniques were considered. The Deep Learning approach was determined to need too much training data for this application, so its use was not continued. The optical flow analysis was considered promising, but did not give immediate results, so it needs further investigation. Therefore, background subtraction was the main focus in algorithm development. Three methods of background subtraction were tried: Robust Principal Components Analysis (RPCA), Gaussian Mixture Model (GMM), and Video Background Extraction (ViBE). A classification technique was then applied to the foreground images to determine fish presence. Using this combination, fish could be accurately identified when occupying a higher number of pixels (>200 pixels, 98.2% correct; 100–200 pixels, 99.6% correct; 5–100 pixels, 85.4% correct; 2–5 pixels, 66.3% correct).

In parallel, EyeSea was developed to convert the video data to a usable form and to enable manual and automated analysis of the data that would have a standardized output.

Recommendations for further research, and optimizing methods for enhancing data collection and analysis include the following:

- Research
  - Conduct more studies of the effect of lights on fish behavior.
  - Investigate the use of low light video applications as an alternative to using lights.
  - Further investigate optical flow techniques and their applicability for automated analysis.
  - Further refine the parameters for background subtraction in automated analysis.
- Standardized techniques
  - Include markings on the turbines to determine relative range and size of fish within the field of view.
  - Use a standardized (non-proprietary) video format that has a consistent frame rate of at least 25 frames per second.
  - Use a scientific camera designed for underwater measurement in low light environments that has a field of view appropriate for the observations and a pixel resolution high enough to determine fish within the given range.
  - Carefully consider the use of lights and how they illuminate the areas of interest.
  - Standardized and detailed record keeping and metadata collection
  - Use other monitoring technologies (e.g., strain sensors on turbine blades) to determine actual collision or strike events.

Acknowledgments

The authors thank the invaluable contribution of the Advisory Committee members who steered how the data were analyzed, and provided input for solutions: Nathan Johnson (Ocean Renewable Power Company), Steve Brunton (University of Washington), Gayle Zydlewski (University of Maine) and Andrea Copping (Pacific Northwest National Laboratory). PNNL also thanks the Ocean Renewable Power Company team in Alaska who provided information about the deployment, and Justin Priest and the team from LGL Alaska who provided information about the initial processing techniques.

PNNL also thanks the U.S. Department of Energy for funding this project and providing ongoing advice.

Acronyms and Abbreviations

DOE	U.S. Department of Energy
FY	fiscal year
GMM	Gaussian Mixture Model
MPC-HC	Media Player Classic-Home Cinema
MHK	marine and hydrokinetic
LGL	LGL Alaska
ORPC	Ocean Renewable Power Company
PNNL	Pacific Northwest National Laboratory
RPCA	Robust Principal Components Analysis
TRL	Technology Readiness Level
ViBE	Video Background Extraction

Glossary

Term	Definition
asynchronous architecture	A system that does not depend on strict arrival times of signals for operation.
avoidance	Used in all instances to encompass behaviors that showed some form of active change; no attempt was made to distinguish between avoidance and evasion.
background subtraction	A computer vision technique used to separate an image (or video frame) into background and foreground, where foreground means objects or regions of interest and is application-dependent.
bilateral filter	A non-linear, edge-preserving, and noise-reducing smoothing filter for images.
“blobs”	Groups of connected pixels of similar intensity.
canonical analysis	A method of regression analysis to determine relationships between a predictor variable and a criterion variable.
collision	When a fish swims into a static object.
compare/ comparison	Qualitative, nonstatistical assessment of the project video data.
contrast stretch	An image enhancement technique that improves the contrast in an image by increasing the range of intensity values.
Deep Learning	Application of learning tasks to artificial neural networks.
directed motion	Motion that demonstrated intended movement; used in this report to describe fish-like movement
EyeSea	A database-driven website for accessing video data files and analysis data.
Event	A place in time during manual video processing marked by a reviewer as having a fish-like object or fish in two or more frames
false positive	Detection of a fish by the algorithm when there was not a fish
Fish	An object that is deemed to be a fish during a manual analysis event
Fish Event	An event deemed to contain a fish during manual analysis
forward-stepping linear discriminant analysis	A method for finding a combination of features that characterizes two or more classes of objects.
histogram equalization	A technique for adjusting image intensities to enhance contrast.
July 22 Data	The full 24-hour manual analysis data of July 22, 2015.
Maybe	An object that during manual analysis is deemed to possibly be a fish, but not a definite identification.
Maybe Event	An event that during manual analysis is deemed to contain an object that could possibly be a fish
MySQL	An open-source relational database management system.
near-field	Relative term referring to an object or fish being relatively close the turbine within the video camera field of view.

neural network	A computer system based on how networks within biological brains work, which “learns”, i.e., improves its performance, by considering examples that have been labeled with key parameters.
Nighttime Data	Data from hours 00:00 – 06:00 and 23:00 – 00:00 from July 19, 23:00 to July 23, 03:00
OpenCV	Open Source Computer Vision Library
optical flow	An image processing technique used to compute motion of an object based on changes in the individual pixels in an image.
Rayleigh distribution	A continuous probability distribution characterized by a shape parameter used to model the magnitude of a multi-component vector.
strike	When a fish is hit by a moving part of the turbine
true negative	An object classified as non-fish by automated analysis that was deemed to be a non-fish by a human reviewer, or a frame classified by automated analysis as containing no fish that was not included in the frames containing fish noted by human analysts.

Contents

Figures

Tables

1.0 Introduction

The Triton initiative is a U.S. Department of Energy (DOE)-funded capability at the Pacific Northwest National Laboratory's (PNNL's) Marine Sciences Laboratory in Sequim, Washington. It aims to support DOE-funded projects that are developing technologies for measuring and monitoring the environment around marine energy devices through the mid- to high-level Technology Readiness Levels (TRLs). Ultimately, the initiative is intended to facilitate the permitting process and reduce the overall cost of marine renewable energy.

As part of the initiative, the Igiugig Fish Video Analysis project described herein used video data collected by LGL Alaska around an Ocean Renewable Power Company (ORPC) RivGen® device deployed in Alaska. The data on fish interactions around the operating device were made available to PNNL for further manual/human processing and use in developing automated processing software.

This final report summarizing the project tasks and results follows two previous reports: a data quality report (Trostle 2016) and a project progress report (Avila et al. 2016). The ensuing sections of this report briefly describe the project, the manual analysis of the video data, development of an automated algorithm for detecting fish presence in video frames, development of the software to enable data processing, and finally present conclusions and recommendations for future projects. Appendices A and B, respectively, contain manual annotations and the video data set used to develop the algorithm.

2.0 Description of Project

The ORPC RivGen® device (Figure 2.1) was deployed in the Kvichak River (Figure 2.2) from 19 to 25 July and 19 to 28 August in 2015. The device's two-turbine turbine generator unit (TGU) is supported by a chassis incorporating a pontoon support structure. The structure acts as a foundation when the device is deployed on the riverbed and gives it self-deployment and retrieval capabilities. The system is designed to generate reliable, renewable electricity in rivers near remote communities that have no access to large, centralized power grids.

Figure 2.1. Photograph of the ORPC RivGen® device.

Figure 2.2. Location of the RivGen® device near Igiugig, Alaska.

Five video cameras were attached to the ORPC RivGen® device to monitor fish upstream and downstream of the turbine foils. While the system was deployed, LGL Alaska (LGL) monitored the video for fish-turbine interactions, subsampling 10 minutes per hour (at the top of the hour) (LGL 2015). After the deployment was completed, the raw data, metadata, and a spreadsheet with processed events were released to PNNL for further analysis. Specifically, this was to develop automated algorithms that detected fish within the frames so that manual analysis could focus only on times when fish were present. To do this, manual analysis was required to annotate the video so that it could inform the algorithm development.

3.0 Manual Analysis

3.1 Methods

The development of tidal current and in-stream river current turbines as an industry is relatively new. It is in the early research and development stages that require testing to determine ideal technology and resource choices. The required technologies for monitoring fish interactions around turbine installations have the same early research stage limitations. This project used an underwater optical camera data set that captured numerous instances of fish and a turbine in the same field of view. Cameras and lights were manufactured by IAS systems. Cameras were customized SeeMate™ color to monochrome units with a F2.9 angle lens. Lights were SeeBrite™ omnidirectional model 24L-SS-LED-350. Power came from shore

and data were stored on digital video recorders. Manual processing of the data provided a baseline for software algorithm development as well as qualitative comparisons of fish behavior near the device.

3.1.1 Data Set

The data set comprised underwater video data from five cameras aligned on one side of the RivGen® device (Figure 3.1)—two upstream of the rotor and three downstream—recording 24 hours per day from 19–26 July and 19–28 August. Illumination from two artificial light sources was used between approximately 2300 and 0600 each night. PNNL received the raw video data (6,418 files; 368 hours), along with supplemental reports from LGL in December 2015. LGL had previously processed the first 10 minutes of certain hour blocks of the data, typically coincident with the turbine spinning; observed events were recorded in a spreadsheet that was provided to PNNL with the data set.

For PNNL, the first step was to determine whether the data quality was good enough for the proposed analysis. The research team needed to be able to visually observe fish presence, behavior, species, and any adverse impacts. In February 2016, the data quality was deemed satisfactory, but not suitable for species determination/identification. For additional information regarding the usability and overall quality of the video, see the Quality Check Summary Report (Trostle 2016).

In this study, "collision" refers to when a fish swims into a static object, and "strike" refers to a moving part hitting a fish.

During an Advisory Committee meeting (including participants from ORPC, PNNL, the University of Washington, and the University of Maine) held in March 2016, it was decided that the data set should be manually processed giving priority to nighttime segments (00:00 – 06:00 and 23:00 – 00:00) from July, for which previously subsampled data from LGL showed the highest frequency of fish interactions with the turbine. Additionally, camera 2 (Figure 3.1) was given priority because it showed the upstream view of the rotor. This meant that it:

- could show potential fish collision or strike interactions with the turbine,
- could show near-field avoidance behavior,
- had a sufficient light source, and
- could be used to coarsely estimate the size and distance of fish relative to the turbine and supporting structures.

As data processing progressed, team members realized that full manual analysis of both July and August nighttime video data would be excessively time-consuming. For every 1 hour of raw video data, it took reviewers approximately 13 to 15 hours to manually review and annotate the video. Due to the amount of time it took for manual review, only part of the July Nighttime Data (July 19, 20, 21, and some of July 23), all of the July 22 Data, none of the August data, and the data required for the test bed development were reviewed (see Section 4.1). Of 18 days of video data recorded by LGL, PNNL was able to review 1 full day, 3 nighttime segments, 4 half-hour blocks on July 23, and 16 five-minute sections for the test bed—a total of 42.33 hours. The PNNL team decided to concentrate on particular subsets of data that would allow for meaningful comparisons. Statistical analysis was not performed on any of the manual review data because of the relatively short period analyzed. Therefore, all uses of the term compare/comparison regarding manual processing for this report refer to qualitative, non-statistical assessment of the data. These comparisons have been grouped into four categories:

- July 22 Data: A full day, July 22 (hereafter referred to as July 22 Data), was analyzed because it was important to include a full day inclusive of daytime data for preliminary comparisons of the first 10 minutes of each hour to the full 60 minutes of each hour. This also allowed for diel differences to be qualitatively compared.

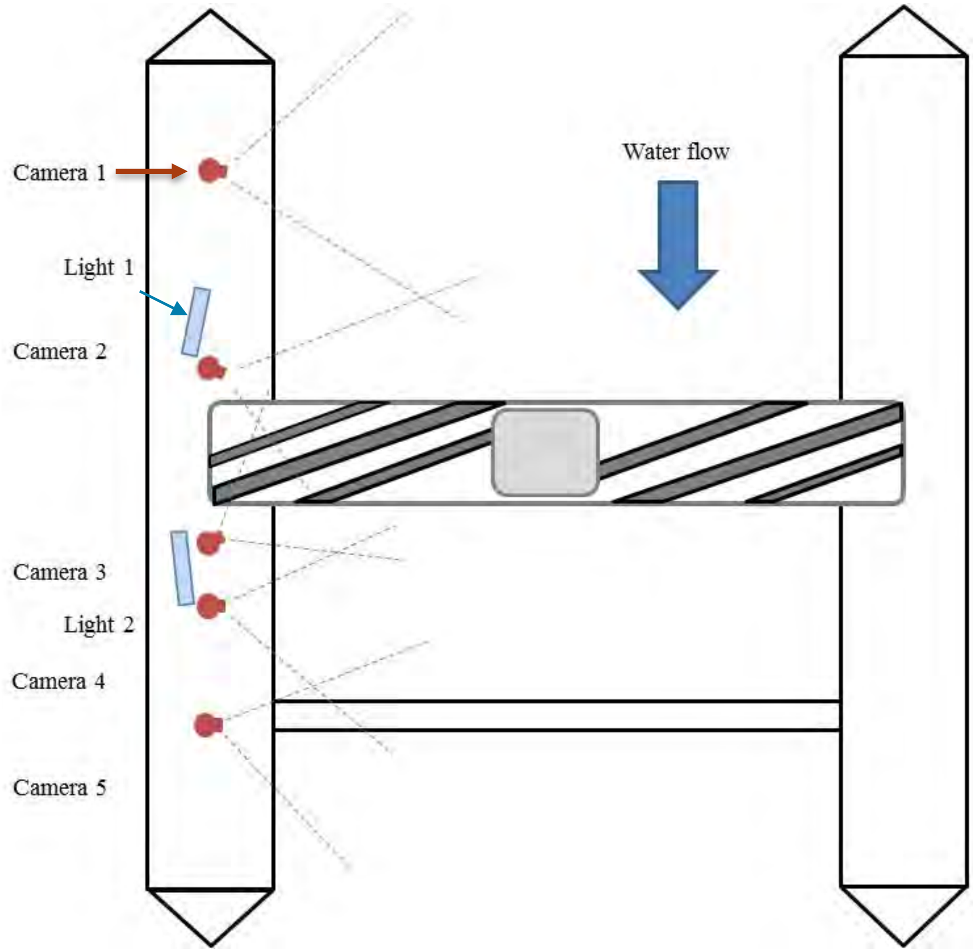


Figure 3.1. Schematic showing approximate locations and views of cameras by number on the RivGen® device.

Lights are represented by blue rectangles. (Not to scale. The pontoon structure is 19.8 m long, 11.5 m wide and 1.7 m high. The turbine [TGU] is 10.4 m long, 1.5 m wide, and 1.5 m high.) (Figure courtesy of LGL and ORPC.)

- Nighttime Data: Nighttime only (00:00 – 06:00 and 23:00 – 00:00) data from July 19, 23:00 to July 23, 03:00 (hereafter referred to as Nighttime Data) were processed as mentioned in the bulleted paragraph. The data from July 23 Nighttime Data consist of only the first half-hour of each hour block (e.g., 01:00 to 01:30). These data represent the majority of the processing effort for this study. The first night (July 19) of data collection had technical issues with the lighting system and data were collected without a light source.
- Light Effects Data: The hour block from 23:00 – 00:00 for July 19–22 were processed with varying artificial light operations to gain a preliminary understanding of any effect lights may have on fish detection probability and fish behavior.
- Collision/Strike Data: Events with fish interactions where possible collision or strike occurred were separated into a small subset and further analyzed. Reviewers observed a total of 20 events that had possible collision or strike interactions. These events were separated for further comparisons.

3.1.2 Manual Processing

The data were provided in a proprietary format that was difficult to manipulate for the proposed processing and analysis procedures. Data files were changed to .mp4 format for ease of use with minimal

change in data quality. Two reviewers worked together to establish processing protocols and definitions for parameters annotated for each event. A subsample of data was processed by each reviewer and compared for similarity to ensure data processing would be consistent and accurate throughout the analysis.

The reviewers visually processed the data in half-hour blocks using Media Player Classic-Home Cinema (MPC-HC). Reviewer 1 processed the first half-hour and Reviewer 2 the second half-hour. Whenever a reviewer visually assessed a fish or an object that had characteristics different from the surrounding water column debris (i.e., shiny and/or non-passive movement) that was present in the field of view for more than one frame, it was deemed an event. For each event, the numerical annotation method explained in the *Igiugig Video Analysis – FY16 Progress Report* (Avila et al. 2016) was used to describe the event characterizations. Parameters for these characterizations are described in Appendix A. Manual review did not distinguish between the terms "avoid" and "evade" throughout this report. Because the reviewers were unaware of the exact distance of the objects from the turbine, and because they did not use the behavioral responses of the objects and fish to decide between the two terms, "avoid" was used in all instances to describe behaviors that showed some form of active change assumed to be related to the turbine. Important classification annotations referenced throughout this report are whether or not an event was a Fish Event or a Maybe Event. A Fish Event meant that the reviewer was positive the object was a fish, whereas a Maybe Event meant the reviewer was not sure (hereafter referred to as Fish or Maybe Events, respectively). The designations between these two annotation descriptions are important for comparison and analysis purposes, as well as for informing the algorithm development.

Objects that were not definitively defined as fish were still deemed events and recorded as Maybe Events. It was important to include these for two reasons. First, video quality could possibly affect the reviewer's determination of whether or not an event contained a fish, and erring on the side of capturing all events with some false positives was preferable to missing some Fish Events. Second, software and automated algorithm development was a major objective of this research. Objects often had characteristics similar to fish and could be identified as events by the automated algorithms. This again allows more confidence in capturing all Fish Events at the cost of some additional false positives.

To keep the reviewers calibrated during review, both started with a training period to go over the parameters and define characterizations. They separately reviewed the same video and compared results for 2–3 weeks, addressing any discrepancies in annotations. As the reviewers began processing the data individually, they kept in regular contact, went over interesting or questionable interactions, reviewed each other's annotations, and discussed methods to ensure calibration at bi-weekly meetings.

Even with these checks, during analysis, an inconsistency was discovered between reviewers. While both reviewers saw a similar number of events, meaning they were stopping for the same objects, the distinction between calling an object a Fish Event or Maybe Event did not always correspond. This meant that some of the objects one reviewer deemed as a Fish, the other reviewer deemed as a Maybe fish.

Comparisons were made using the July 22 Data to show any similarities that exist in event occurrence and fish count estimates between processing of the first 10 minutes per hour, and processing of the full hour. Additionally, figures for visualization were also made to display

- differences between definite Fish Events and objects with non-passive behavior,
- fish count differences between day and night, and
- fish count differences between when the device was spinning and static.

For the Nighttime Data, the behavior types that are associated with different categories of events were compared. This categorization of events was based on the Appendix A annotation, "Fish?". This annotation was simply a question to the reviewer about whether the object observed during a designated event was definitely a Fish or a Maybe. Initially, All Events that included Fish and Maybe Events were considered. Categories separated All Events into Fish and Maybe Events. Fish Events were further

categorized by annotations from Appendix A designating the fish as juvenile (likely a salmon smolt), adult (likely a salmon), or unidentifiable as determined by the reviewer. The category separation flow chart is shown in Figure 3.2. After behavior types were attributed to the categories of events by percentage (Figures 3.4–3.10), behavior types were coarsely grouped. Each of the behavior types the reviewers used for the annotation description was designated as either Avoidance, Passive, or Other (Table 2).

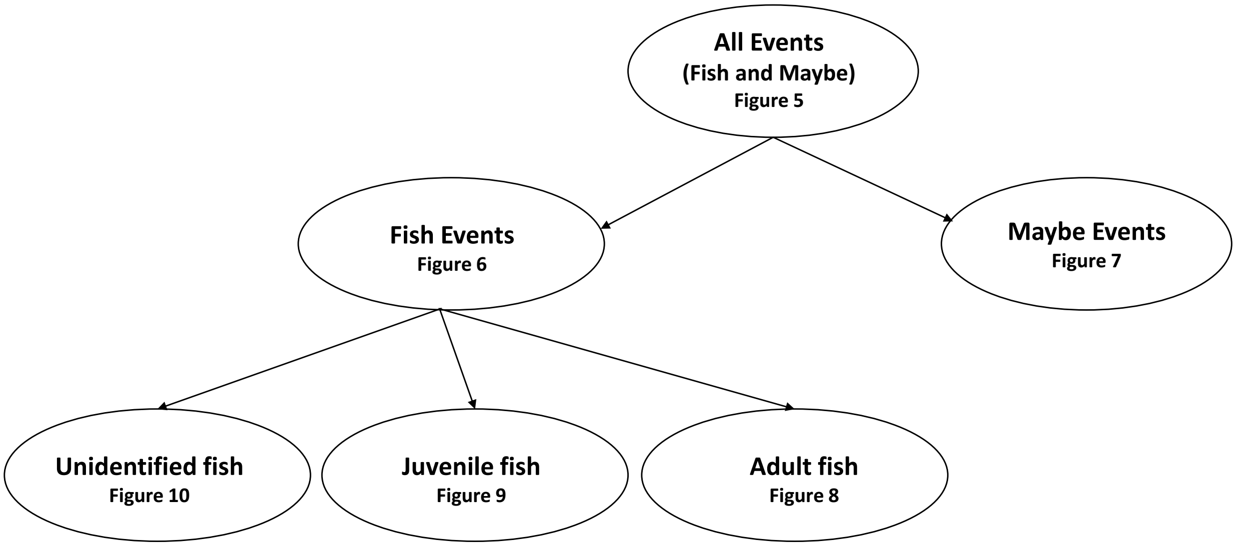


Figure 3.2. Flow chart showing the different categories of events used to visualize behavior types (Figures 3.4–3.9) attributed by data processing reviewers. All events that had potential fish collision or strike were placed in a separate subset (3.10).

Table 3.1. Grouping of annotated behavior types into Avoidance, Passive, and Other.

Avoidance	Passive	Other
Milling	Straight across (above or below)	Unable to tell
Pause	Through turbine	Other
Against current	Toward static parts	
Avoid reverse	Face first	
Avoid below		
Avoid above		
Avoid around		

A simple comparison of the Lights Effects Data was to determine whether more events were observed when the lights were on or off during varied light operations from July 19–22. This was possible because on July 19 the lights were off due to technical difficulties. The lights were turned on the next day and they were used for the remainder of Nighttime Data collection.

The last subset of data comparisons were the events when fish collision or strike may have occurred in the Nighttime Data. This data set includes only events that were positively determined by both data reviewers to be Fish and excludes the Maybe Events; hence, there is no disparity between reviewer determinations.

3.2 Results

Currently, no established video data analysis techniques exist for assessing fish interactions. Using the above methods, qualitative comparisons were made with the data set to highlight differences in 1) subsampling of the first 10 minutes of each hour and the entire hour; 2) nighttime behavior types; 3) possible collision and strike events; and 4) the effects of nighttime illumination. The data were further summarized between whether an object was a Fish or Maybe Event, and the categorical groupings associated with the observed behaviors.

3.2.1 Fish Presence/Behavior

3.2.1.1 July 22 Data Subsampling Comparisons

For the July 22 subset of data there were 2,538 events: 260 were Fish Events, 2,256 were Maybe Events, and 22 Events were a combination of Fish and Maybe occurrences. The majority (81%) of events occurred during nighttime hours. Only one Fish Event occurred during daytime—in hour 19 in the processed data. Fish abundance or frequency of events does not appear to be related to whether the turbine was spinning (hours 1–2) or static (hours 3–6), but does seem to coincide with low light levels (hours 1–6 and hour 24). To compare the 10-minute sampling regime with full analysis, the 10-minute counts were multiplied by six to produce an hour estimate. This assumes that the first 10 minutes is representative of the subsequent five 10-minute blocks. The comparison between these processing methods shows that when the first 10 minutes is subsampled and multiplied by 6 to approximate an hourly estimate the numbers are inflated for hours 3–6. Hour 1 is underestimated, for hour 2 the estimates are similar, and hours 3–6 are over-estimated for both the number of Fish and number of events (Figure 3.3).

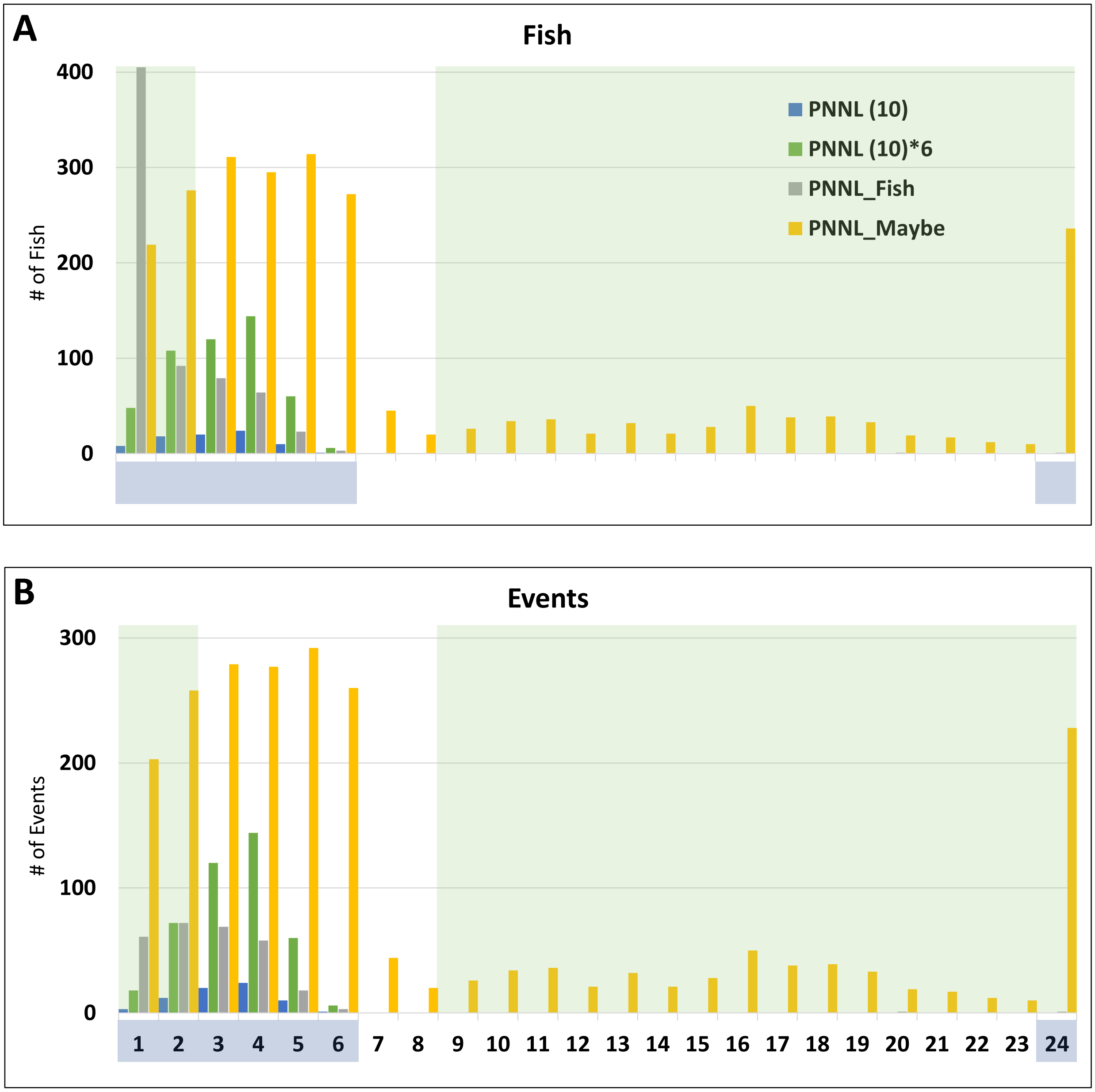


Figure 3.3. Bar graphs showing processed data for July 22, 2015.
*The horizontal axis represents each hour block for both graphs and the dark shaded numbers represent hour blocks that are after sunset and before sunrise (Nighttime Data). The green shaded background of the plot areas show when the RivGen® was spinning. Graph A displays Fish and Maybe counts as observed during manual processing by hour blocks. Graph B displays the number of events. The blue bar, "PNNL (10)", represents the estimates from PNNL's processing of the first 10 minutes of each hour. The orange bar, "PNNL (10)*6", represents PNNL's estimate multiplied by 6 to be an approximation for the full hour. The gray bar, "PNNL_Fish", represents PNNL's count of "Fish" for Graph A or "events" for Graph B for the full hour. The yellow bar, "PNNL_Maybe", represents the count of objects (Graph A) or events (Graph B) with non-passive behavior but not determined to be fish.*

3.2.1.2 Nighttime Data Behavior Types

Other than processing the July 22 Data, PNNL only processed Nighttime Data. For the category that includes both Fish and Maybe Events, there were 629 Fish Events, 4,149 Maybe Events, and 51

combination events that included both Fish and Maybe occurrences. Each event was broken down into the described behavior specific to the annotation list found in Appendix A. Grouping all of these described behaviors by annotation behavior type (e.g., avoid around, avoid above—see Appendix A) provides some evidence of what the dominant behaviors are within the camera field of view in front of the RivGen® during nighttime hours. The dominant behavior for Fish and Maybe Events was "through turbine", followed by "straight across", followed by "toward static parts" (Figure 3.4). Note that this comparison is not separated by Fish or Maybe Events or any other qualifier, and the Passive behavior group dominates with 80% of the behavior, compared to ~19% for the Avoidance group.

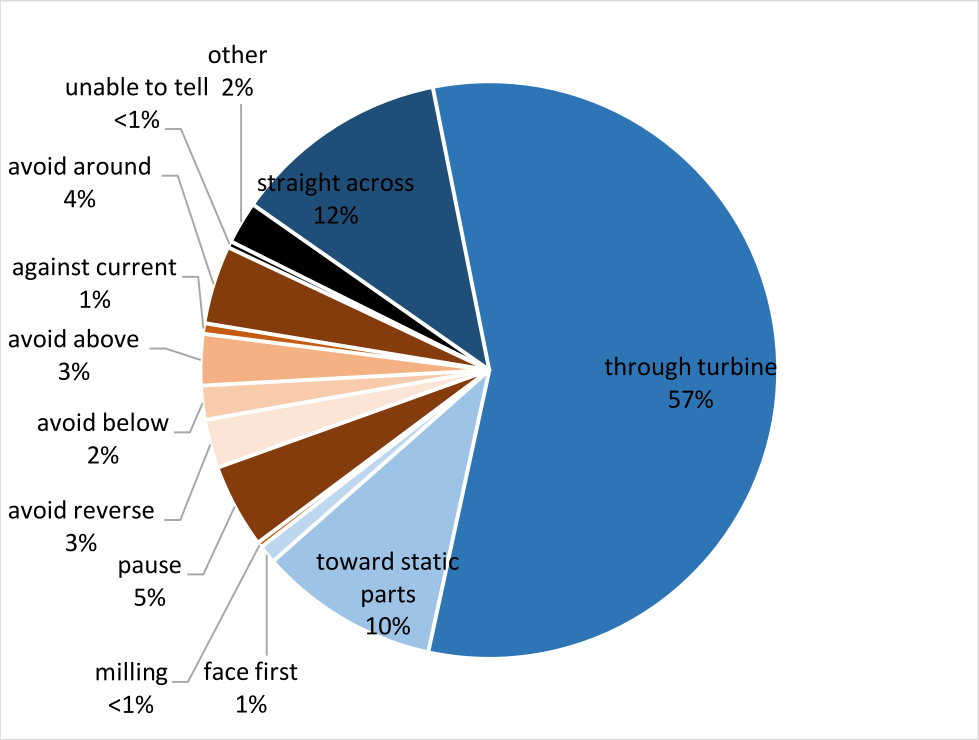


Figure 3.4. Behavior types recorded by reviewers for Nighttime Data. Data included are both Fish and Maybe Events for all sizes; n = 4,829.

The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

The Nighttime Data were separated into Fish and Maybe Events to visualize how reviewer-described behaviors may be different for each. Combination events (n = 51) that had both Fish and Maybe Events were removed because it was impossible to separate behavior annotations associated with a Fish object or a Maybe object during the event. For Fish Events the top three dominant behaviors were "through turbine", "avoid around", and "pause" (Figure 3.5), and for Maybe Events the top three behaviors were "through turbine", "straight across", and "into static parts" (Figure 3.6). There is a distinct qualitative difference in behavior types (Avoidance vs. Passive) between the Fish Events and Maybe Events. Figure 3.5 shows Fish Events dominated by the Avoidance group of behaviors (62%) and Figure 3.6 shows Maybe Events dominated by the Passive group of behaviors (80%). This abundance of passive behaviors is expected, because one of the qualifiers when distinguishing between Fish and Maybe Events was how the objects moved. It is important to note that there was some disparity between what the two reviewers designated as a Fish or Maybe Event as described in "Manual Processing."

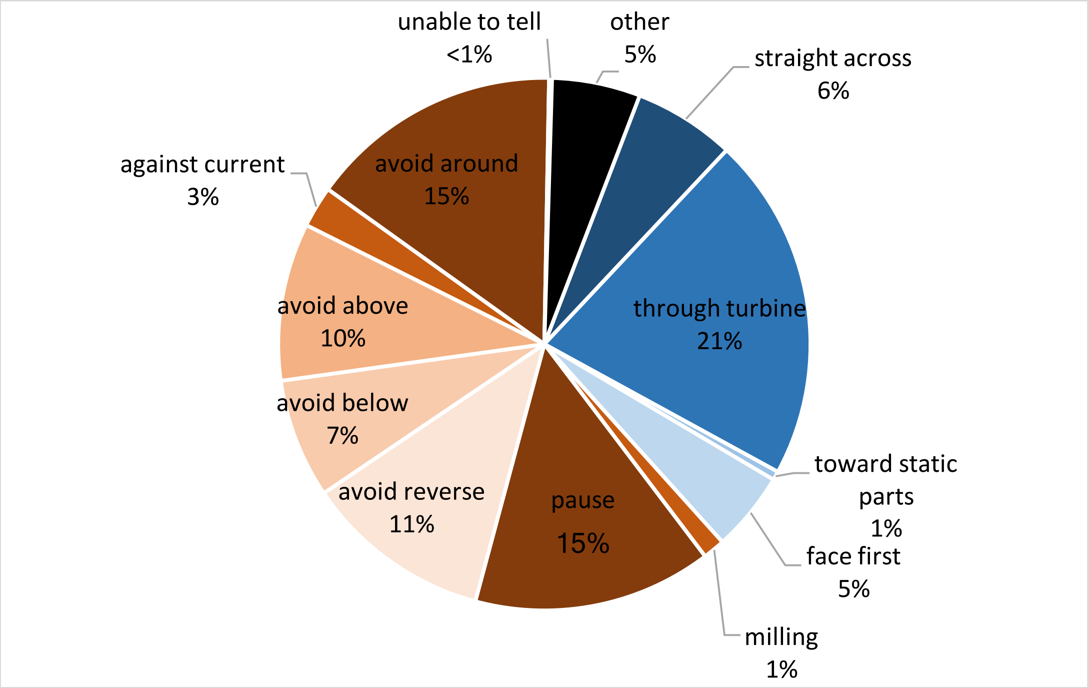


Figure 3.5. Behavior types recorded by reviewers for Fish Events in Nighttime Data for all sizes (n = 618).

Maybe and Combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

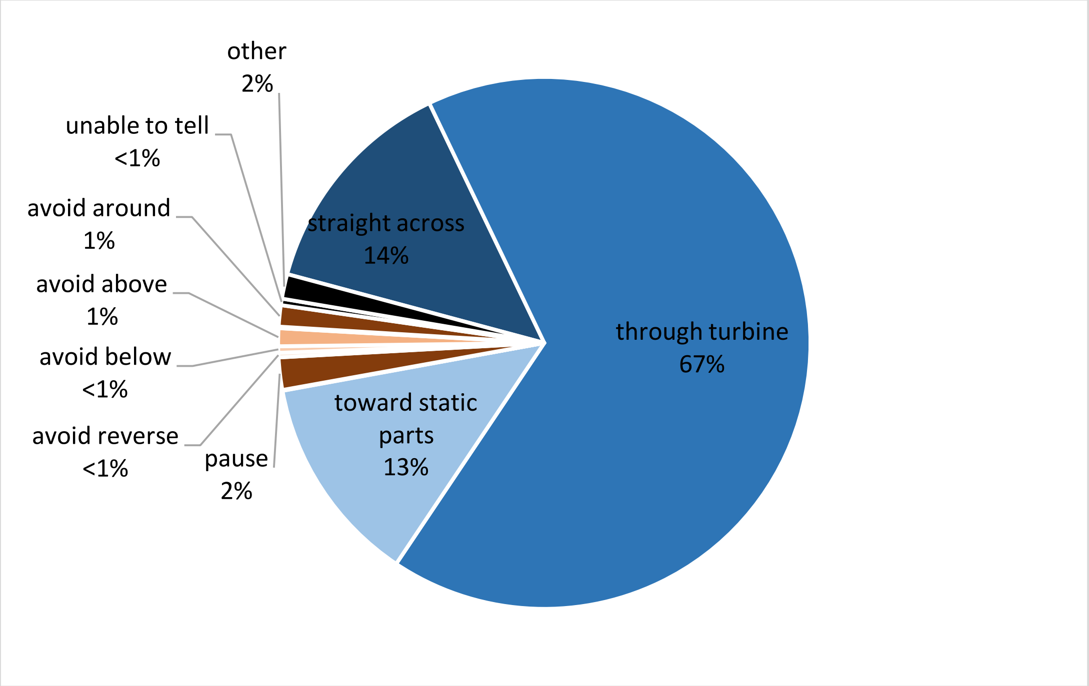


Figure 3.6. Behavior types recorded by reviewers for Maybe Events in Nighttime Data for all sizes (n = 4,149).

Fish and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

Within the Fish Events category, a separation was made to categorize juvenile, adult, and unidentifiable fish. Eleven Fish Events had a combination of adult, juvenile, or unidentifiable Fish Events that were removed from these comparisons. There were 174 adult Fish Events for which the dominant behaviors were “pause”, “avoid around”, and “avoid reverse” (Figure 3.7). There were 259 juvenile Fish Events, for which the dominant behaviors were “through turbine”, “avoid around”, and “pause” (Figure 3.8). Determining whether it was an adult or juvenile was sometimes impossible. This created the category of an unidentified Fish Event of which there were 185. The dominant behavior was “through turbine”, “avoid around”, and “pause” (Figure 3.9). Adult fish displayed Avoidance behavior 82% of the time compared to only 14% passive behavior. The behavior groups for juveniles were split, showing 50% Avoidance behaviors and 44% Passive behaviors. And the fish that were unidentifiable demonstrated dominant Avoidance behavior 57% of the time and Passive behavior 36% of the time.

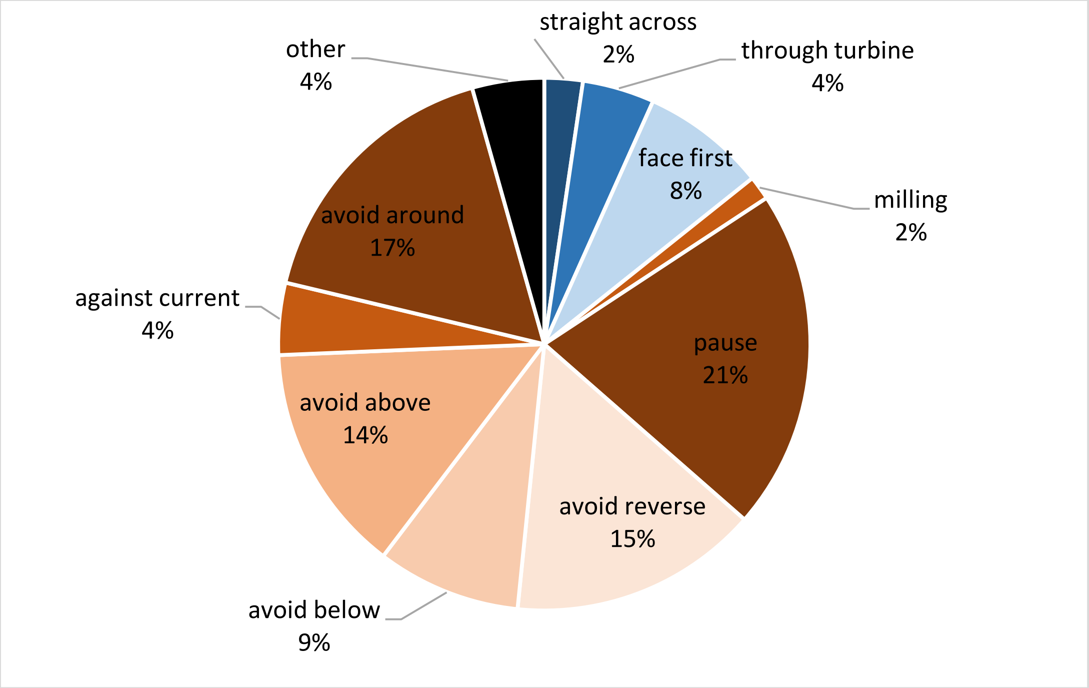


Figure 3.7. Behavior types recorded by reviewers for adult Fish Events in Nighttime Data (n = 174). *Juvenile and unidentified Fish Events, Maybe Events, and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.*

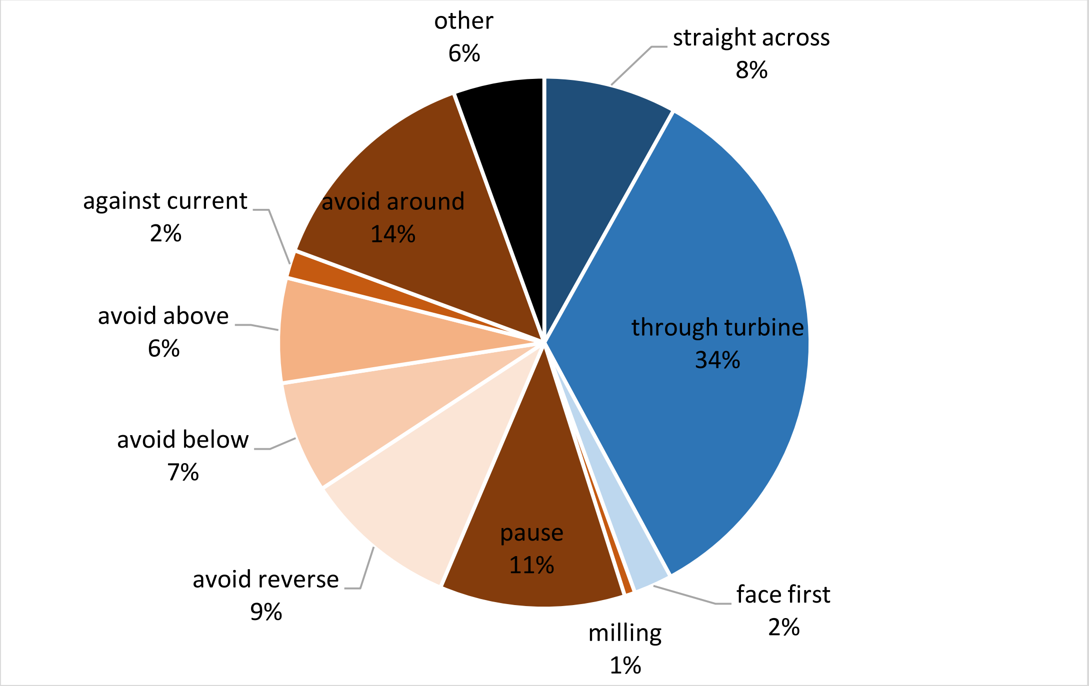


Figure 3.8. Behavior types recorded by reviewers for juvenile Fish Events in Nighttime Data. (n = 259).

Adult and unidentified Fish Events, Maybe Events, and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

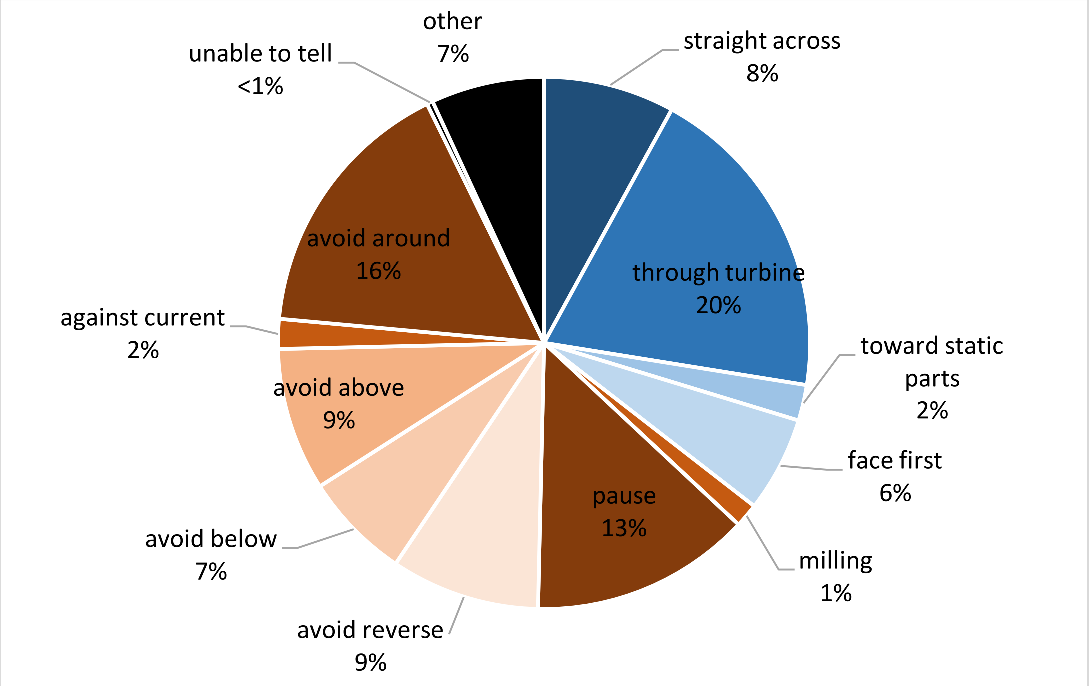


Figure 3.9. Behavior types recorded by reviewers for unidentified Fish Events in Nighttime Data (n = 185).

3.2.1.3 Fish Collision and Strike

Reviewers found a total of 20 events involving possible collision or strike (12 strike and 8 collision). All strike events in this data set refer to moving parts of the turbine hitting an object or fish, while collision refers to an object or fish coming into contact with a static part of the device (this could include the blade when it is not turning). Of these 20 potential events, 17 were Fish Events and 3 were Maybe Events. Of the 17 Fish Events, juveniles made up 12 of the events and adults made up 5 events. All but one of the juvenile Fish Events had multiple fish in the field of view, up to ~50. All of the adult events were single fish. All juvenile Fish Events occurred between 00:00 and 01:00, except two which occurred at 01:03 and 03:02. The turbine was spinning for all but one of the juvenile Fish Events and none of the adult Fish Events. Juveniles made up 11 of the strike events, while the remaining strike occurrence was a Maybe Event. No adults were involved in any of the strike events. Of the 8 collision events, adults made up 5, a single juvenile made up 1, and the rest were Maybe Events. The one juvenile collision and 4 of the 5 adult collision events occurred with a static blade. The last adult collision occurred with the camera and was the only confirmed collision. Behavior for these events was dominated by Avoidance group behaviors "through turbine", "avoid around", and "pause" (Figure 3.10).

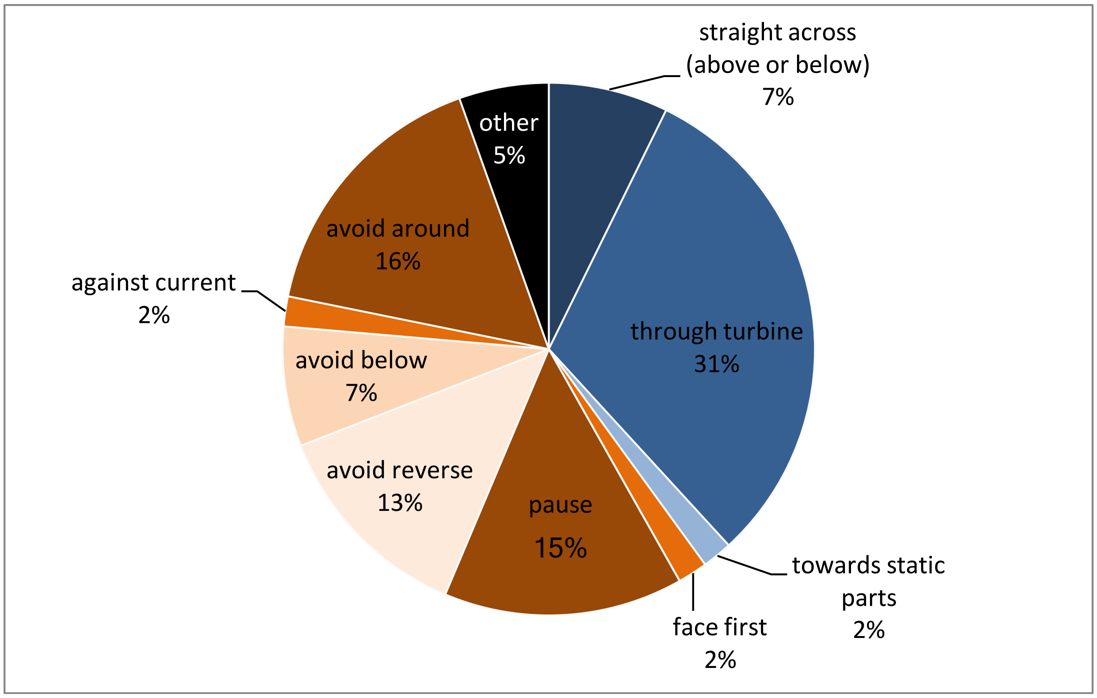


Figure 3.10. Behavior types recorded by reviewers for potential collision or strike Fish Events in Nighttime Data (n = 17).

The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

3.2.1.4 Light Effects

On July 19, the lights remained off through the night, while on every other night the lights turned on as it became dark. A light operations record was not kept during deployment, so manual reviewers at PNNL watched the video and estimated the operational status of the lights (Figure 3.11). Events observed over four nights during hour block 23 (23:00–00:00) when light operations varied were compared to show fish presence while the lights were on and off (Table 3.2). Over the four-night comparison of hour block 23 (a total of 4 hours), the lights were off 45% and on 55% of the total time.

Only 5 events were recorded by the reviewers on July 19 when the lights remained off the entire hour. All 5 events on July 19 occurred in the first 9 minutes of the hour block, and they were all Maybe Events. On July 20, 1 Maybe Event occurred while the lights were off during the first 34 minutes of hour block 23, and 144 events (1 Fish Event, 143 Maybe Events) occurred while the lights were on in the last 26 minutes of hour block 23. On July 21, 2 Maybe Events occurred while the lights were off during the first 14 minutes of hour block 23, and 65 events (2 Fish Events, 63 Maybe Events) occurred while the lights were on during the last 46 minutes of hour block 23. On July 22, 135 Maybe Events were recorded by reviewers when the lights remained on during hour block 23. Over the four-night comparison, approximately 2% of the total events occurred while the lights were off, and 98% occurred while the lights were on.

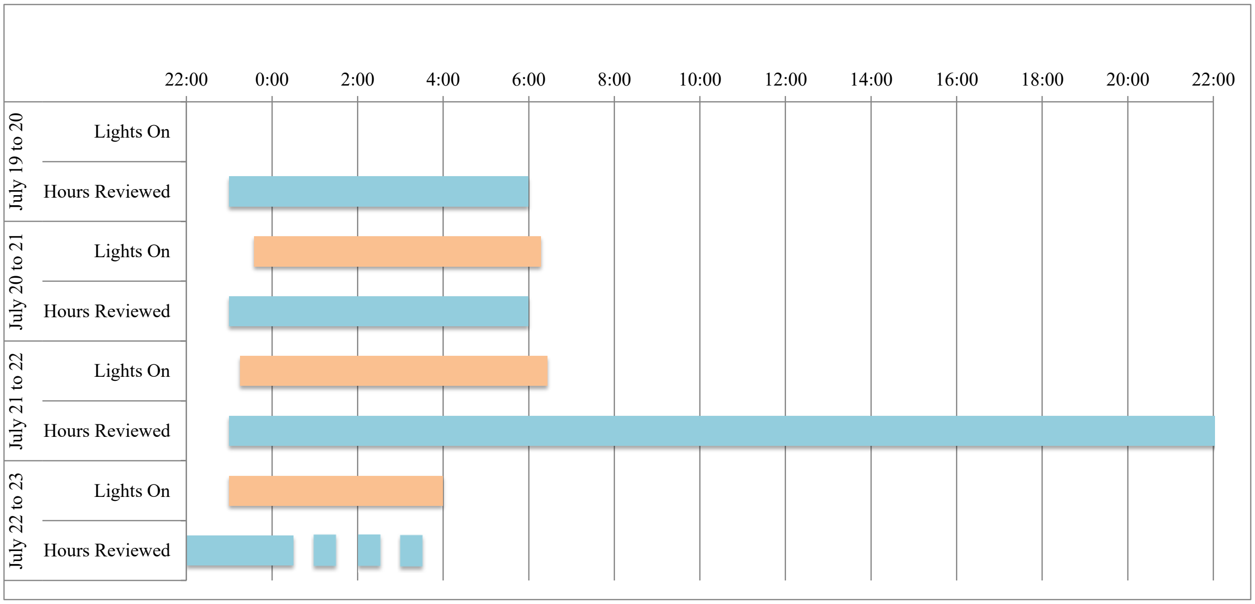


Figure 3.11. Visual approximation of light operations determined by watching the video data and noting when the turbine and objects began to look brighter (lights on), or when the turbine and objects began to look darker (lights off).

Although a light operations record was not kept, PNNL staff watched the video data to estimate when the lights came on and turned off. The orange bars represent the duration of time the lights were estimated to be on, while the blue bars represent the duration of time manually reviewed by the two reviewers. The x-axis on Figure 3.11 shows a total range of 24 hours, from hour 22:00 on one day and up to hour 22:00 of the next day. This was done to show the light operations and review effort in a more continuous manner. The major y-axis labels list the dates reviewed with minor label divisions of when the lights were on and the hours reviewed on those dates. From the night of July 19 to the morning of July 20, the lights remained off, and the reviewers manually processed video data from 23:00–06:00, although only part of hour blocks 23 and 5 were visible. From the night of July 20 to the morning of July 21, the lights were estimated to be on from 23:35–06:17 and the reviewers manually processed video data from 23:00–06:00. From the night of July 21 to the morning of July 22, the lights were estimated to be on from 23:15–06:26 and the reviewers manually processed video data from 23:00–22:00. From the night of July 22 to the morning of July 23, the reviewers manually processed video data from 23:00–00:30, 01:00–01:30, 02:00–02:30, and 03:00–03:30. The lights were estimated to turn on at 23:00 and remained on during all of the manual review effort on July 23, but an estimation of when the lights turned off that day was not done.

Table 3.2. Comparison of the number of events recorded by reviewers during hour block 23 (23:00–00:00) over four nights when the lights were on and off, including the duration of light operation status and totals.

Hour Block 23	Lights Off		Lights On		Total
Date	Duration	Number of Events	Duration	Number of Events	Number of Events
7/19/2015	60 minutes	5	0 minutes	No data	5
7/20/2015	34 minutes	1	26 minutes	144	145
7/21/2015	14 minutes	2	46 minutes	65	67
7/22/2015	0 minutes	No data	60 minutes	135	135
Total	108 minutes	8	132 minutes	344	352

3.3 Discussion

Perceived risk and shortage of empirical data about fish interactions with tidal and in-stream turbines like ORPC's RivGen® means that monitoring is required during turbine deployment. For near-field interactions, optical cameras are the ideal choice because acoustic devices are limited at such close ranges because of transmitted sound scattering from the turbine blades. For this research, the use of cameras provided a useful data set that allowed the capture of hundreds of fish interactions with an operational commercial-scale device. These interactions included 17 possible collisions with static components and possible strike with dynamic components of the device. These 17 events accounted for 2.75% of all Nighttime Fish Events and 0.07 % of total hours processed. Only through intense manual processing effort was it possible to find the extremely rare events of collisions and possible strikes that were observed. These processed data also allowed comparison of a complete manually processed data set to the same subsampled processed data set. Of the 17 possible collision or strike events, only 1 was in the first 10 minutes of the hour. This means that 16 of the events would have been missed, pointing to the importance of full data set processing to ensure these rare events are observed. While strike and collision are of major concern, the behaviors used by fish as they approach these devices are important for continued research and to determine the need for monitoring around turbines. The types of behavior provide input parameters to models as well as identifying differences that may exist between different species or age classes of fish.

The previous analysis by LGL primarily processed data to coincide with times that the RivGen® device was spinning, which was typically during daylight hours. The PNNL research team concentrated on nighttime because 66% of all fish observed by LGL were observed during nighttime even though this time composed less than 10% of their total processed data.

3.3.1.1 July 22 Data Subsampling Comparisons

PNNL processed the first 10 minutes of each hour, illustrating the difference between subsampling and full analysis. Processing sub sets of data is common for researchers faced with the daunting task of large data sets, and it is considered a valid way to process large amounts of data. In this instance, when subsampled data [(10)*6] were compared to the fully processed (all 60 minutes of each hour) 24 hours of data on July 22, the number of Fish Events per hour was the same for hour 2, less for hour 1, and more for hours 3, 4, 5, and 6 (Figure 3.3B). While there was some discrepancy between the two, a larger sample size for comparison would be required for validation. The number of fish (counts) had similar results with the (10)*6 estimates being larger than the actual 60-minute counts for hours 2–6 (Figure 3.3A). Counts be skewed if large schools of fish are present. The first hour block in the July 22 fish count data (Figure 3.3A) is a good example of this; the full hour count data are more than four times the (10)*6 estimate. This was simply a case of several schooling Fish Event occurrences that were made up of tens of juvenile fish observed from minute 10 to 60. Subsampling may provide a valid estimate of Fish Events but fish counts may be biased low if events with large schools of fish are missed.

Having the entirety of the July 22 video processed provided evidence that the majority of Fish Events occur during nighttime. For this single day, it also indicated that the number of Fish Events did not dramatically increase or decrease based on whether the turbine was static or spinning. For the total data manually reviewed by PNNL, the turbine was spinning for 44% of the time, and not spinning for 56% of the time. After the RivGen® spinning ceased (typically around 01:00), the number of Fish Events decreased from then until 06:00. The occurrence of Fish Events is more likely to be related to light levels because Fish Events decrease temporally as sunrise approaches. If the driver for frequency of Fish Events is light levels, then use of artificial lighting to increase detection probability at night introduces a possible complication.

3.3.1.2 Nighttime Data Behavior Types

Describing the behavior of Fish and Maybe Events captured from a single camera is subjective for most of the descriptions (see Appendix A). While an observed movement upstream or downstream is definitive in nature, movement toward or away from the camera or attempting to use depth of field to describe an event is difficult and accuracy is impossible. Nevertheless, behavior was described for all Fish and Maybe Events during PNNL processing of the data. An extensive list of behavior types that described in detail the majority of observed fish behavior was used. Additionally, specific behaviors were qualified as being Avoidance or Passive behaviors (Table 3.1). For the manually processed data set, the extent to which behavior is addressed for each processed event is important to understand fish behavior in general as well as differences between behaviors of fish based on their size or age class.

The binary grouping of all specific behaviors into Avoidance and Passive behavior groups provided evidence of two important findings:

- First, the amounts of Avoidance and Passive behavior differ between Maybe and Fish Events. During the PNNL processing, both reviewers agreed that movement or behavior of the object during an event had a strong bearing on whether or not it was deemed to be a Maybe or Fish Event. More movement, especially those representing non-passive examples, typically led to classification as a Fish Event. The Avoidance group of behaviors is therefore important for separating Fish Events from Maybe Events. However, not all fish entering the field of view will necessarily change their behavior before exiting. Fish already in line to avoid the turbine may not change their trajectory and thus fall under one of the Passive group's behaviors.
- Second, the amount of Avoidance/Passive behavior differs between adult and juvenile Fish Events. Fish Events that consisted of adult fish had only 17% Passive behavior and of this amount only 4% were specifically "through turbine" (Figure 3.7). In contrast, juvenile Fish Events had a 50/50 split between Avoidance and Passive behavior and 34% of the Passive behavior was "through turbine". This comparison shows evidence that adult fish are better at avoiding the turbine than juvenile fish. Although juvenile fish behavior may consist of Avoidance behaviors, the juveniles tended to be less successful in actually avoiding the device and often went "through the turbine" even after attempting an Avoidance behavior.

Behavior types or groups may play an important role in algorithm development in the future. A variety of qualifiers are used in algorithm development, and behavior or movement is an important one for animal detection algorithms used with remote sensing devices and specifically optical cameras. Often, threshold metrics are used for initial investigations into automating an animal being in a frame. However, if this is successful and a variety of animal types have potential for being detected, then the next step is grouping them by some qualifying characteristic. Often size is the first characteristic for grouping followed by movement or behavior. Knowing the movements and behavior associated with the fish detected in these data has the potential to further general knowledge or inputs for modeling. Improved automated analysis to decrease the effort required to process and analyze these types of data and ultimately create cost-

effective methods. Use of these methods by developers and researchers can provide meaningful data accepted by regulatory bodies that require monitoring.

3.3.1.3 Fish Collision and Strike

As fish collision, strike, and near-miss events are generally accepted to be rare at marine and hydrokinetic (MHK) installations, it is important to process most, if not all, of the data collected to ensure these events are not missed. If an entire data set is not to be processed, then large-scale time blocks likely to coincide with the highest probability event occurrences, decided upon with expert opinion or existing empirical data and statistical analysis, should be processed. The sequence of the processing steps used for camera data set described herein is a good example of efficient gathering of useful information. The initial subset processing performed by LGL for the first 10 minutes of certain hour blocks made it clear that most Fish Events occurred during nighttime. This is a highly productive first step for a large data set for which no established processing methods exist, except for manually reviewing the data. As a logical first step, it saved time and provided the foundation for taking the next step to gather meaningful results. PNNL followed up and concentrated processing effort on nighttime hour blocks based on the LGL information that indicated more events occurred at night. This concentration on the Nighttime Data provided more meaningful comparisons of a variety of fish behaviors showing differences in adult and juvenile behaviors. The processed data also captured 17 events, out of a total of 618 Fish Events, with possible collision and strike between fish and a commercial-scale device, indicating how rare these events are and the difficulty associated with observing them. Even with capturing the events with possible collision or strike, actual contact is difficult to verify because uncertainty remains based mostly on the data quality specific to camera selection, lighting, placement, and field of view. Collision was only confirmed in one instance when an adult fish collided with the camera. Additionally, it is important to note that the outcome of a collision, strike, or near-miss event was not possible to determine because of data quality and the short duration that a fish was in the actual field of view.

Camera selection for underwater fish observations is not a trivial matter. The field of view, resolution, low light capacity, and frame rate are just a few of the parameters that are crucial to gathering high-quality, meaningful data. After data have been collected, the file type becomes important for effective processing that leads to useful analysis. The cameras used to collect the data presented in this report were customized SeeMate ™ color to monochrome units with a F2.9 wide angle lens, manufactured by IAS systems (North Vancouver, British Columbia). The images had a resolution of 352 × 240 pixels. Each camera had a variable frame rate (less than 10 per second), and a field of view of "approximately one-third of the area between the pontoons and the left (portside) one-third of the TGU"[1] (LGL 2015). Pixel resolution, field of view, and light capturing ability created limitations in the data set, and complications continued because the output files were of a proprietary format. Significant amounts of unplanned time and resources were required for file conversion to a non-proprietary format, followed by testing several video-file viewers to determine the one best suited for this analysis, which included requirements like moving forward and backward through each frame capture without skipping or freezing up. Based on this work, literature review, and discussions with other researchers, a brief set of guidelines for camera selection for future applications is given in the Recommendations section.

3.3.1.4 Light Effects

On every night except July 19 the lights turned on as natural light levels decreased to illuminate continued monitoring fish presence and interaction. A comparison was done to better understand the potential impact of artificial lights during this environmental monitoring effort during hour block 23 from July 19

---

[1] LGL Alaska Research Associates, Inc., 2015 *Fish and Wildlife Monitoring Plan for RivGen® Testing on the Kvichak River, Alaska in 2015*

to 22. As it became dark on July 19, the field of view began to fade into a grainy, grayscale image with portions of it becoming black over time. If fish were present during the last 15 minutes of hour 23:00 on July 19, it would have been very difficult for the reviewer to see or document their presence. When comparing the first half of hour 23:00 on July 19 to the same hour on July 20, the images of both nights seem similar, but when the lights appear to turn on at approximately 23:35 on July 20, the turbine is illuminated, potentially creating an opportunity for light to reflect off fish and be visible to the camera, as well as make the image sharper and clearer. In contrast, on July 19 the image degrades over time. Nighttime illumination probably affects the detection probability of fish by the reviewers, and may alter an avoidance/attraction response by the fish.

The number of events that occurred when the lights were on was considerably higher than when the lights were off (344 compared to 8, respectively), and with a similar operation duration (55% compared to 45%, respectively). The number of events when comparing lights on and off differs considerably, yet the reason for this in this application is not well understood. Artificial lights may have attracted fish, thereby causing more events, or more fish may have been present during the last half of hour 23 when the lights were generally on every night except July 19; the data from July 22 when the lights were on for the full hour show more fish during the second half hours (135 vs 94), but this does not account for the extreme difference observed overall. Alternatively, fish presence may be similar on all nights, but the artificial light provides the source needed to make them visible to the optical cameras and in turn, reviewers. Additionally, on July 22 when all 24 hours were reviewed, Nighttime events (when the lights were on from 00:00–06:26, and 23:00–00:00) made up 99.9% of the total events for that day, with only 1 daytime Fish Event overall (although 436 Maybe Events during the daytime). Due to this clear difference and the lack of baseline understanding of fish attraction or deterrence related to this variable, the role of artificial lights during environmental monitoring needs to be further investigated.

4.0 Automated Analysis

Automated analysis was investigated to develop algorithms for detecting fish presence in the video, so that an entire video data set could feasibly be analyzed automatically without the need for manual sampling. Reducing the volume of data to just those video segments during which fish were present would optimize human labor time, and the reduced-volume approach could also be used to perform a quick preliminary analysis of the data. Ultimately, the system could be fully automated, and the software optimized to run in real time as part of an underwater observation system for long-term monitoring of the effects of MHK devices on animal populations.

The vision for an automated video processing system consists of three main components: preprocessing, detection, and classification (Figure 4.1). The preprocessing component filters the raw video frame to improve its quality in terms of contrast, color balance, and smoothness. The detection component identifies objects that might be fish, and the classification component classifies the detections to filter out false positives such as kelp, shadows, or other objects that are not of interest. These three components interact, and each requires many design decisions in order to realize an effective system. Under this project, candidate algorithms were investigated for each of the components, and an infrastructure was developed to tie the components together into a web-based application developed by PNNL called EyeSea.

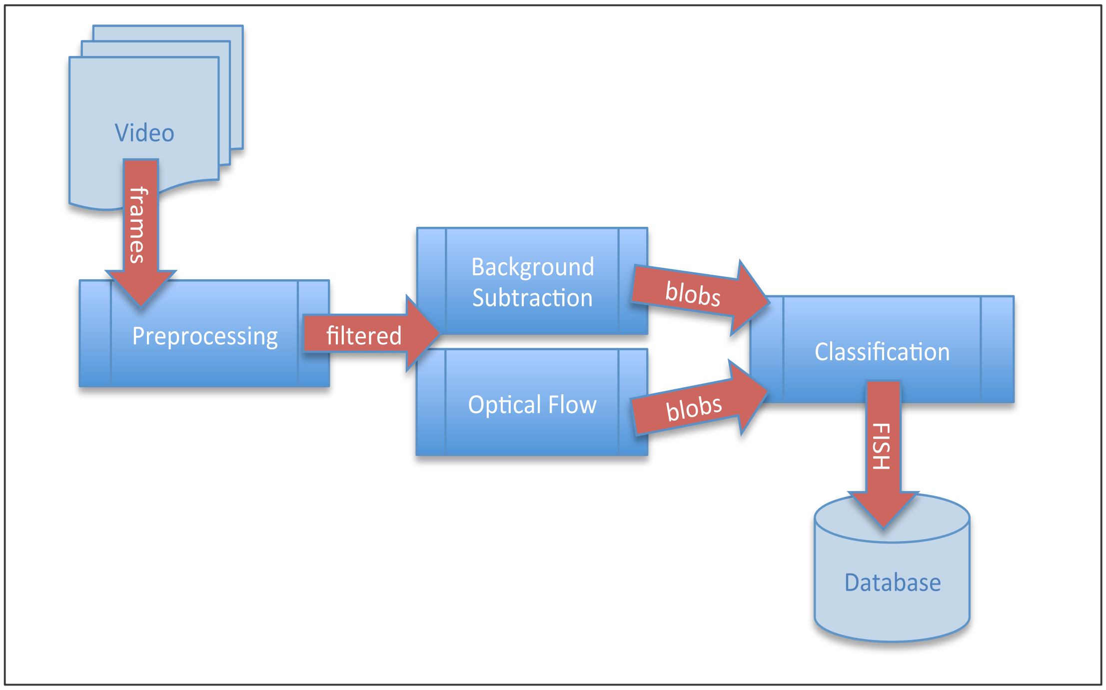


Figure 4.1. The automated processing chain.

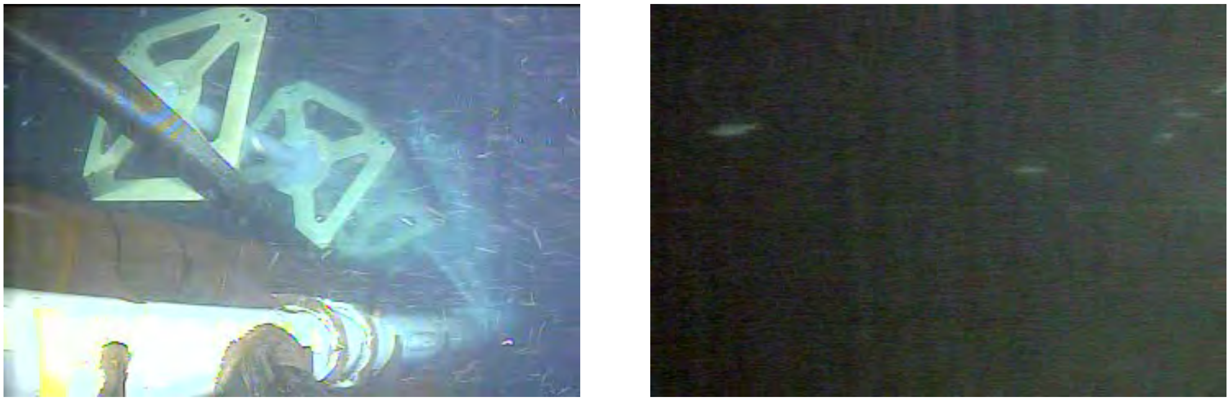
4.1 Methods

A testbed was developed to evaluate the performance of different algorithms; it consisted of a development data set and a processing pipeline. This meant that algorithms could be evaluated in a consistent, reproducible manner. A development data set was assembled from a subset of the full Igiugig data set consisting of 16 five-minute video segments containing Fish Events (Appendix B). The video segments were selected to represent different lighting conditions, different camera views and different sizes of fish, individuals and schools (Figure 4.2). Each video consisted of a total of 7500 frames, and even though the segments were chosen to include fish, only 6% of the total frames did in fact contain fish (the presence of fish is not a common event). The data were annotated as described in the Manual Analysis section. The processing pipeline was adapted from the Fish4Knowledge (Boom et al. 2014) code[2] for fish detection with custom code. The pipeline was used to batch process all the development videos using a particular detection algorithm, and to calculate the resulting detection rate and false positive rate by comparing the detections to the manual analysis annotations (Figure 4.3).

---

[2] http://groups.inf.ed.ac.uk/f4k/

a) Camera 1, daylight b) Camera 1, night



c) Camera 3, night illuminated d) Camera 4, night illuminated

Figure 4.2. Example images of fish in the different cameras with different illumination.

For the detection algorithms, background subtraction and optical flow were investigated. Three different background subtraction techniques were evaluated: Robust Principal Components Analysis (RPCA) (Candès et al. 2011), Gaussian Mixture Model (GMM) (Lee 2005) and Video Background Extraction (ViBE) (Barnich and Van Droogenbroeck 2009). The optical flow analysis consisted of a dense optical flow calculation using the Farnebäck algorithm (Farnebäck 2003) and a sparse feature-based flow calculation using the Lucas-Kanade method (Lucas and Kanade 1981), both as implemented in OpenCV.[3] For classification, models were developed using forward-stepping linear discriminant analysis (Lotlikar and Kothari 2000) on the detected objects to distinguish between fish and non-fish objects. The features used for classification were object size, intensity, shape, and motion.

---

[3] http://opencv.org

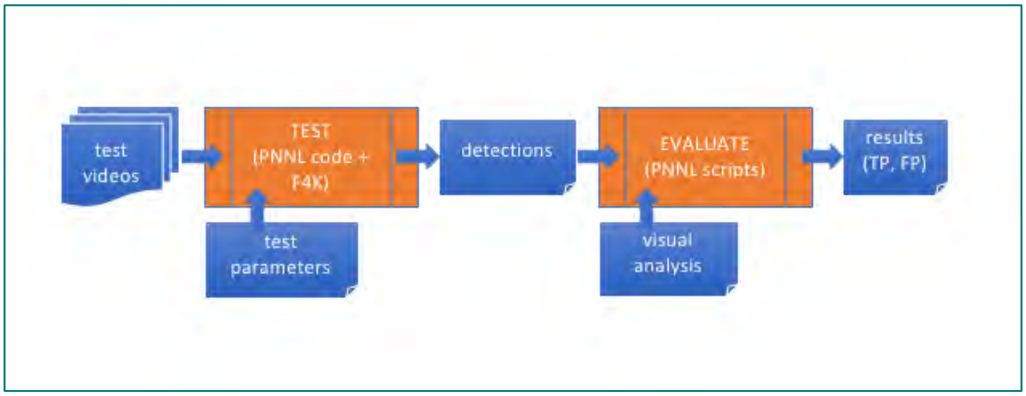


Figure 4.3. The developed testbed pipeline for evaluating different detection algorithms.

Background subtraction is a computer vision technique that is used to separate an image (or video frame) into background and foreground, where foreground means objects or regions of interest and is application-dependent. In this study, foreground is defined as fish and everything else is considered background, even other objects that might be moving such as the turbine itself and floating debris. This is a challenging data set for background subtraction because of the low quality of the video and the highly dynamic background. RPCA, GMM, and ViBE algorithms were selected based on recommendations from researchers at the University of Washington and the Fish4Knowledge project (Boom et al 2014) as being robust relative to background motion. The recommended parameter values for each algorithm were used.

The foreground images resulting from the background subtraction were further processed to group connected pixels of similar intensity into “blobs”. These objects were then classified as fish or non-fish. The blob size was highly variable ranging from 1 pixel to over 10,000 pixels, so the blobs were divided into five size groups and classification models for each group were developed separately.

The motivation for including optical flow is the hypothesis that fish motion is different than other motion in the scene, such as the motion of objects drifting with the current and the motion of the turbine foils turning. The researchers who performed the manual analysis said that one of the features they used to recognize fish was directed motion. Optical flow is the motion (spatial displacement) of light intensity from one video frame to the next. It is calculated for video by matching regions in one frame with regions in the subsequent frame, where the matching is based on edges and gradients of light intensity, and the flow is the displacement. There are several algorithms for calculating optical flow in the literature. For this application, the Farnebäck algorithm was chosen to calculate a dense optical flow over the entire image. Initial tests of both the sparse and the dense optical flow methods indicated that the sparse method was not effective when analyzing the raw video because of the lack of strong gradient features that could be tracked from one frame to the next. Dense methods are more robust relative to some changes in object intensity and shape because dense methods use more surrounding context for matching features.

In a parallel effort, a Deep Learning model was applied to the development data set. The open-source machine learning library TensorFlow was used to build a convolution neural network and train it on a portion of the data set. This type of neural network must be trained on labeled data to generate a model for classifying new data. For this video analysis, the inputs to the network were the individual video frames, labeled as “fish” or “no fish”. A subset of the labeled data (video frames) was selected at random to train the network and the resulting model was tested on the remaining data. This process was repeated over multiple iterations, where a new subset of the data was selected for training at each iteration. This iterative process is necessary to find the subset of the data that produces the best model.

4.2 Results and Discussion

One project goal was to reduce human labor time, hence the performance objectives were a 90% detection rate and a 30% false positive rate. The detection rate is the percentage of actual fish present that are detected, and the false positive rate is the percentage of reported detections that are not fish. It was important to detect most of the fish at the cost of some false positives because the false positives could be sorted out by human analysts, but too many false positives would reduce the benefit of the automation.

For an initial comparison of the background subtraction algorithms, the recommended parameter values for each algorithm were used (Table 4.1). The algorithms were evaluated for how well they correctly identified which frames contained fish. A frame was classified as "fish" if it contained one or more detections (foreground objects). The algorithms all performed similarly on the test bed data set (Table 4.2). The best detection rate was 67.51% (ViBE), which was much lower than the goal of 90%. The false positive rate was high, but the best true negative rate was better than 57%, which means that over 57% of the frames containing no fish were correctly labeled as such.

Table 4.1. Background subtraction algorithm parameters.

RPCA	ViBE	GMM
Window size = 50 Interval = 10 Threshold = 50	History = 20 Learning = 50 Radius = 20 Match criteria = 2 Update probability = 1/8	alpha = 0.02 threshold = 0.7 upper difference = 220 lower difference = 30

Table 4.2. Background subtraction frame classification results.

Algorithm	Percent of Fish Frames Correctly Detected	Percent False Positives	Percent True Negatives
RPCA	57.45	92.18	**57.60**
ViBE	**67.51**	**91.51**	54.48
GMM	63.79	92.29	52.19

The figures in bold indicate the best performance between the algorithms.

The background subtraction alone is not sufficient to meet the performance objectives, but the results offer valuable insight into the effects of night and day, the use of lights, and camera placement (see Section 7.0 for specific recommendations). The individual videos were analyzed to better characterize the algorithm performance under different conditions (Figure 4.4). All algorithms performed best on the videos from camera 1 at night, where there was no turbine in view and lights were on but angled away from the camera's field of view. All algorithms performed poorly in terms of false positives on the video from cameras 3 and 4 at night. The turbine was in view in both these cameras and the lights were aimed at the turbine. All algorithms performed worst on the video from camera 1 during the day, when most of the reported detections were false positives and most of the actual fish present were not detected. During the day, the fish were in low contrast with the background, so they were more difficult to detect. The lights at night reflected off the fish, increasing the fish's contrast with the background, so they were easier to

detect. Floating debris that was similar in size to small fish also reflected the light causing false positives (Figure 4.5).

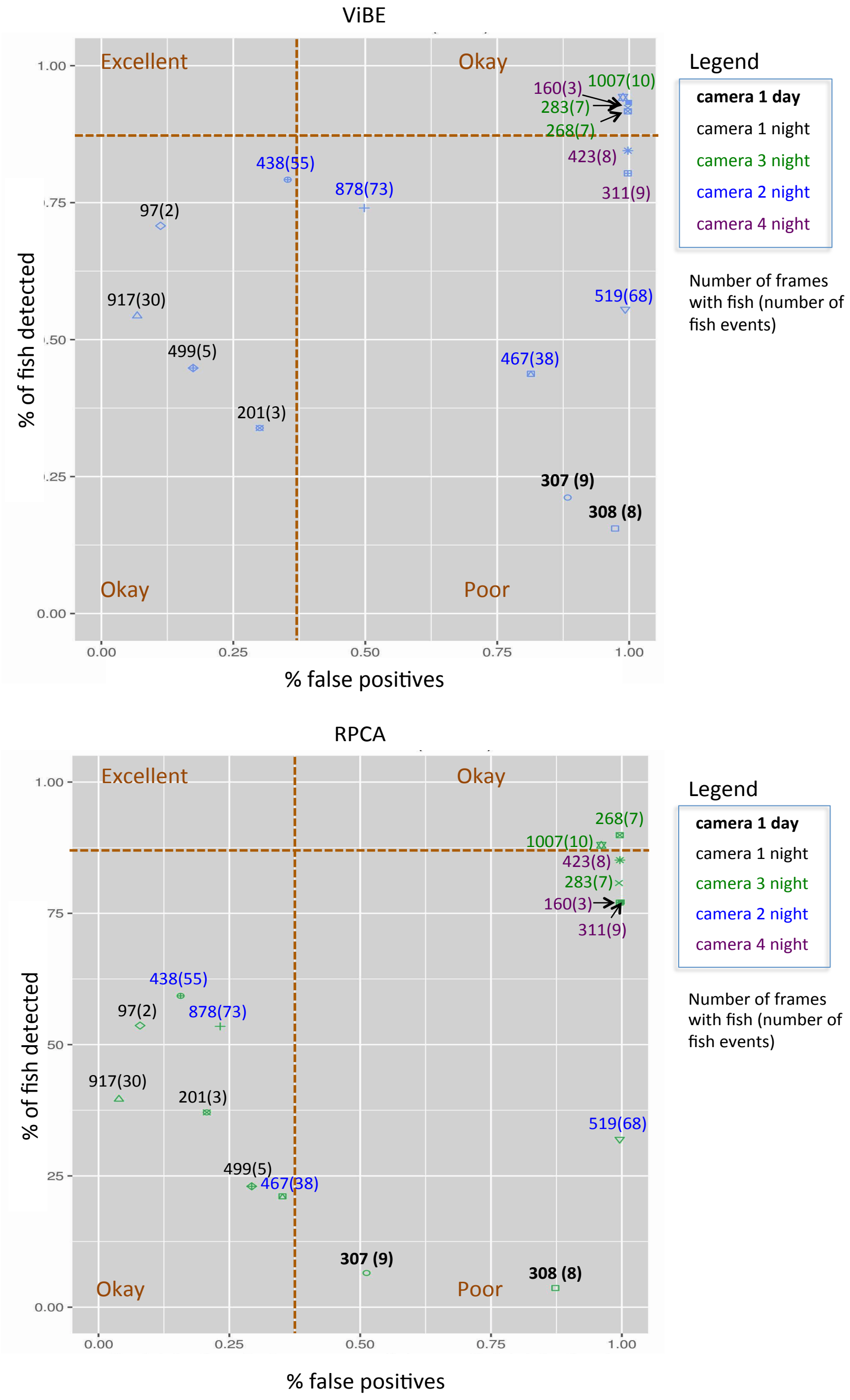


Figure 4.4. The detection rate and false positive rate by test video for RPCA (top) and ViBE (bottom). *The numbers on the scatter plots indicate the number of frames (out of 7500 per video) that contained fish and the number in parentheses is the number of Fish Events. A Fish Event is when a particular fish is in view; an event usually spans multiple consecutive frames.*

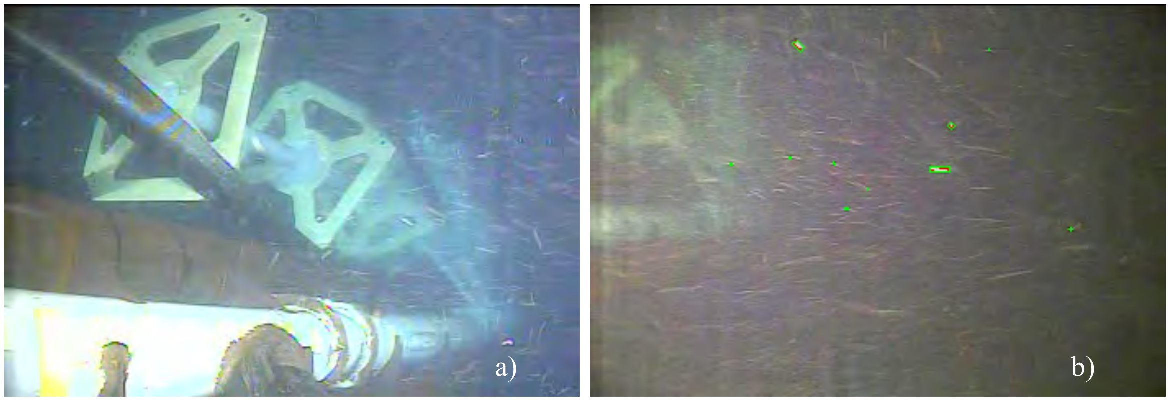


Figure 4.5. Example frame from camera 4 at night with small fish (a) and the detected objects from ViBE (b). The small fish are detected but there are also some false positives from the illuminated debris. These false positives were eliminated during post-processing.

Using the results of the initial evaluation as a baseline, preprocessing techniques were evaluated. The two techniques included with the Fish4Knowledge code were histogram equalization and contrast stretch. The preprocessing did not add significant computation time, but neither technique improved the performance and in some cases had a negative effect. A bilateral filter (Tomasi and Manduchi 1998) is often used in photographic applications, and this technique was tested on two of the videos, one from camera 3 and one from camera 4. Only two videos were processed because the computation was extremely slow on a desktop computer, but the results were promising (Figure 4.6).

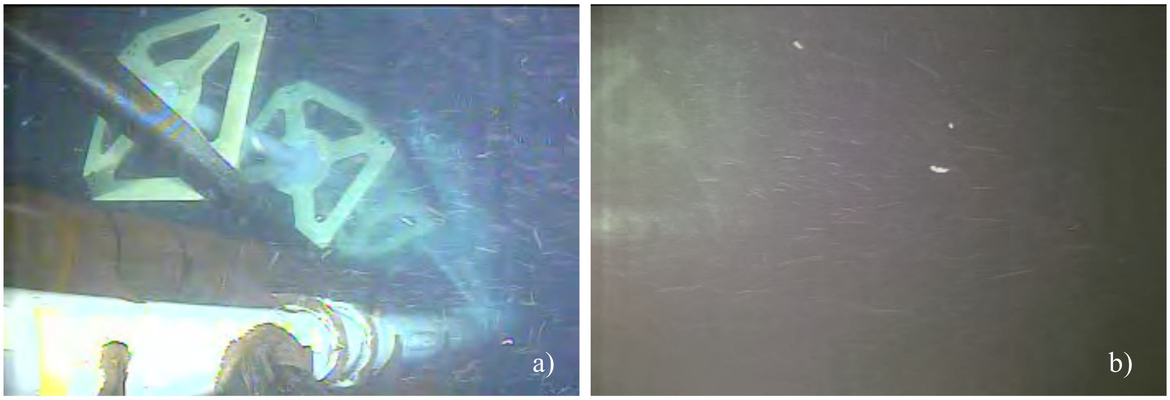


Figure 4.6. The raw frames (a) are preprocessed with a bilateral filter to reduce the clutter from debris (b).

The parameters of the best performing algorithm, ViBE, were varied to find the optimal values for the Igiugig data set. An exhaustive search for the optimal values of all five parameters was beyond the scope of this project, so two parameters with a strong influence on performance, the radius and the match criteria, were varied. The radius is the relative difference in intensity between background and foreground; a higher value will reduce the sensitivity and a lower value will reduce the precision (more false positives). Because detecting all the fish was more important than eliminating false positives, the radius was reduced and values of 20, 18, and 16 were evaluated. The match criterion is the minimum number of historical values that must fall within a current pixel's radius to consider the pixel to be background. A lower value will reduce sensitivity and a higher value will increase false positives and processing time. Values of 2 and 4 were evaluated. The best combination of values was radius = 16 and match criterion = 4 (Table 4.3).

Table 4.3. ViBE parameter tuning results.[(a)]

	Match = 2	Match = 4
Radius = 18	52% / 39%	70% / 54%
Radius = 16	55% / 42%	**74% / 59%**

(a) The first number in each cell is the true positive rate and the second number is the false positive rate. The figures in bold indicate the best combination of values.

A classification model for the detected objects significantly improved the performance by reducing the number of false positives. The detected objects were classified as "fish" or "non-fish" based on human analysis, and were divided into five size categories. A random sample of approximately 50 of each class (~100 observations) in each size category was used to develop a linear discriminant model for each category. For each size class, forward-stepping linear discriminant analysis followed by canonical analysis was used to determine the best model. Variables considered for the model included the blob size, blob solidity, blob eccentricity, and blob intensity. The models were tested on the remaining blobs that were not used for model development and the results are shown in Table 4.4. The larger blobs were classified most accurately; the accuracy decreased with decreasing blob size. The size of fish that can be accurately classified is dependent on their distance from the camera (the same size blob could be a large fish further away vs. a small fish close to the camera), and having the capacity to judge distance more effectively is discussed further in the Recommendations.

Table 4.4. Detected object classification results.

	Fish		Non-Fish		
Object Size in Pixels (number of fish objects)	True Positive	False Negative	True Negative	False Positive	Percent Correct
200+ (549)	533	16	3753	63	**98.2**
100 – 200 (320)	290	30	12,715	22	**99.6**
5 – 100 (2805)	2281	524	61,356	10,369	85.4
2 – 5 (2114)	1485	629	109,995	23,365	66.3
Total	4589	1199	187,819	33,819	84.6

The optical flow was calculated to generate a displacement in the horizontal and vertical dimensions for each pixel in the video frames, dx and dy, respectively. The displacements were then used to calculate the direction and magnitude of the motion from frame to frame. Direction was defined with 0 being toward the right and 180 toward the left. Five points in different regions of the frame were selected, and the motion was characterized at those points for one of the videos from camera 4 at night (Figure **4.7**). The direction of the motion appeared to be uniformly distributed across all directions and the magnitude appeared to follow a Weibull distribution (Figure 4.8). Due to the flow of the current from left to right in the video, the direction of motion was expected to be concentrated around 0 degrees. The uniform distribution that was observed may be due to the small, random motion of the floating debris. It may also indicate that the optical flow algorithm was not accurately matching points from one frame to points in the subsequent frame, due to the lack of distinctive features in the scene and the algorithm's bias toward small motion. The distribution of the magnitude of the motion shows that most of the calculated motions were small, with some outliers. The small motions may be due to debris and noise in the images, and the

outliers may indicate darting fish. The results are inconclusive and indicate a more in-depth investigation is needed, including testing the use of the bilateral filter for preprocessing to reduce the clutter in the scene.

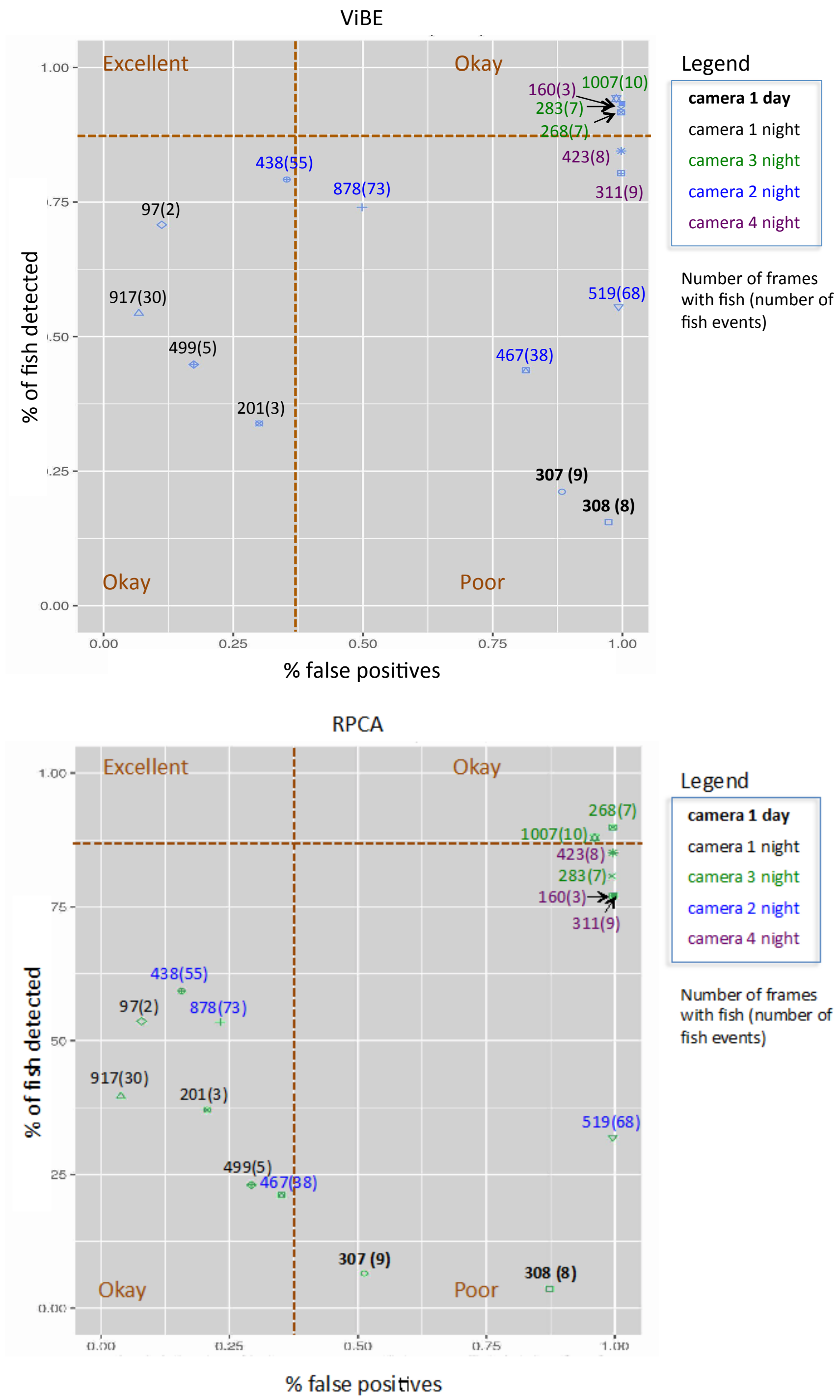
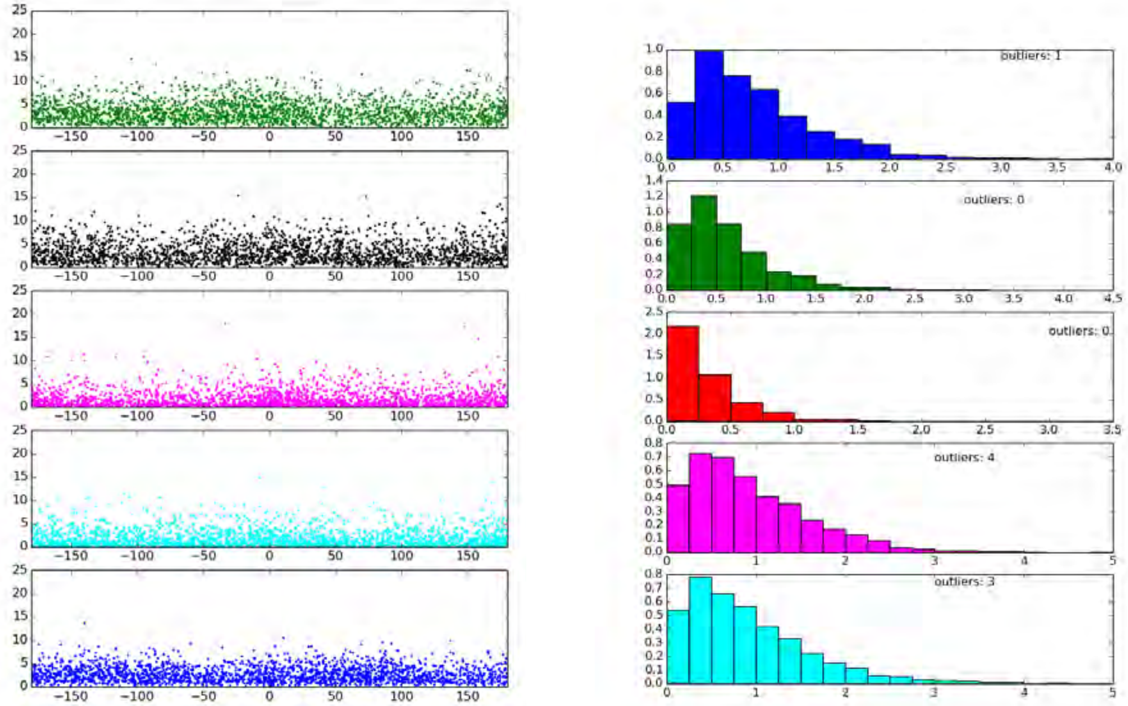


Figure 4.7. The detection rate and false positive rate by test video for RPCA (top) and ViBE (bottom). *The numbers on the scatter plots indicate the number of frames (out of 7500 per video) that contained fish and the number in parentheses is the number of Fish Events. A Fish Event is when a particular fish is in view; an event usually spans multiple consecutive frames.*



a) Magnitude vs. Direction

b) Magnitude Distribution

Figure 4.8. The magnitude and direction of motion at five points in the video were characterized using optical flow. The direction appeared to be uniformly distributed across all directions (a), and the magnitude appeared to follow a Rayleigh distribution that implies the motion in the x and y directions are independent (b).

The best Deep Learning model developed over the iterative learning process achieved 79% correct classification of both “fish” and “no fish” frames. This result is promising and on par with the background subtraction/blob classification results. This approach could be suitable for batch processing a large volume of recorded data, like the Igiugig data set, especially if the processing can be done on a high-performance computing system of parallel nodes. However, this approach would not be suitable for a real-time system because of the computational intensity, and the requirement for training data that is specific to the location being monitored.

5.0 Software

5.1 Need and Requirements

EyeSea is a web application that was developed by PNNL to meet the need for a central repository for accessing and analyzing the terabytes of video data from the Igiugig project. During the manual analysis of the video data it was found that the proprietary format of the video data required the use of the vendor’s specific software, which ultimately did not meet the requirements of the analysis team. Fortunately, an open-source video encoder (https://ffmpeg.org/) enabled the transcoding of the video data to the standard h264 format. This allowed the analysis team to use other more feature-rich software to perform the analysis of the video data. There was still the issue of how to make the h264 encoded video data available to the analysis team and also how to store results of the video analysis. To solve this issue a database-driven web site was designed, called “EyeSea”. This web-based application was developed in

parallel with the algorithm development, and was envisioned as the framework for ultimately providing a user-friendly front-end to the automated analysis, combining all the analysis tools into one comprehensive "human-in-the-loop" system for video analysis.

5.2 Functionality

The database was designed to store video metadata (e.g., date, time, location, timezone), analysis results (e.g., fish detected, species of fish, location of fish in video frame), and site-specific data (e.g., log-in information, batch processing information). Figure 5.1 shows the schema of the database that was ultimately implemented in MySQL.

Once the database had been designed the next step was to implement the web application. Bottle (https://bottlepy.org), a web framework for Python, was used to implement the web site. An asynchronous architecture was designed to allow users to query video data and later return and view the transcoded results. This was necessary to enable users to query videos encompassing large amounts of time without causing a browser timeout. Although the website was designed to play back the video inside the web browser, an option was added to allow users to download the video to their local machine for later offline playback. The website was later extended to allow for in-browser analysis of video. Figure 5.2 shows a screen capture example of the in-browser video playback.

EyeSea was also designed to facilitate batch processing and analysis of video. A set of scripts were written that could be deployed on a cluster of servers for parallel processing of multiple videos. The servers query the database for jobs to process and communicate to the database the status of the job as they are completed. The batch processing feature of EyeSea was used to extract Fish Events for later use in the analysis algorithm development testbed.

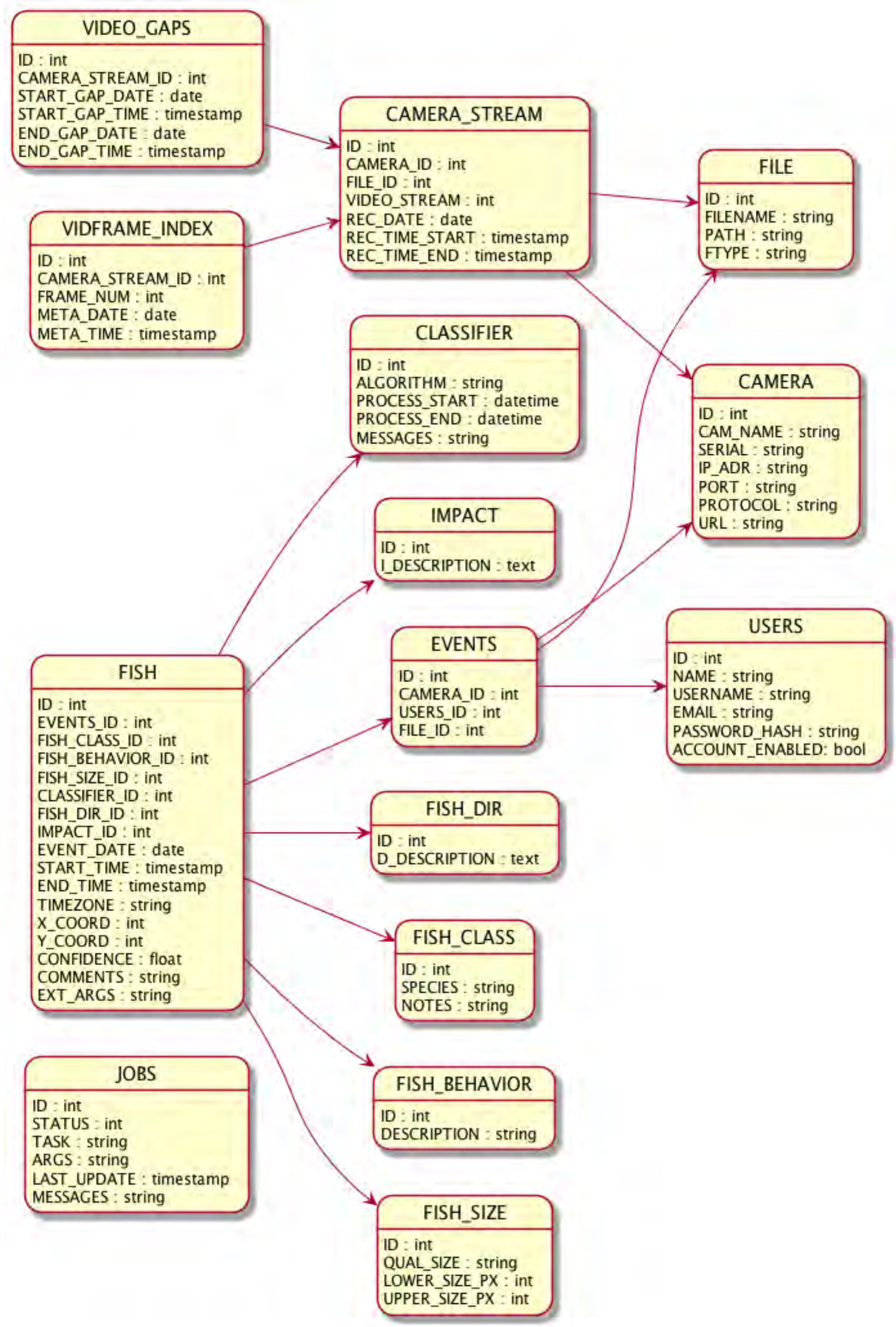


Figure 5.1. EyeSea database schema.

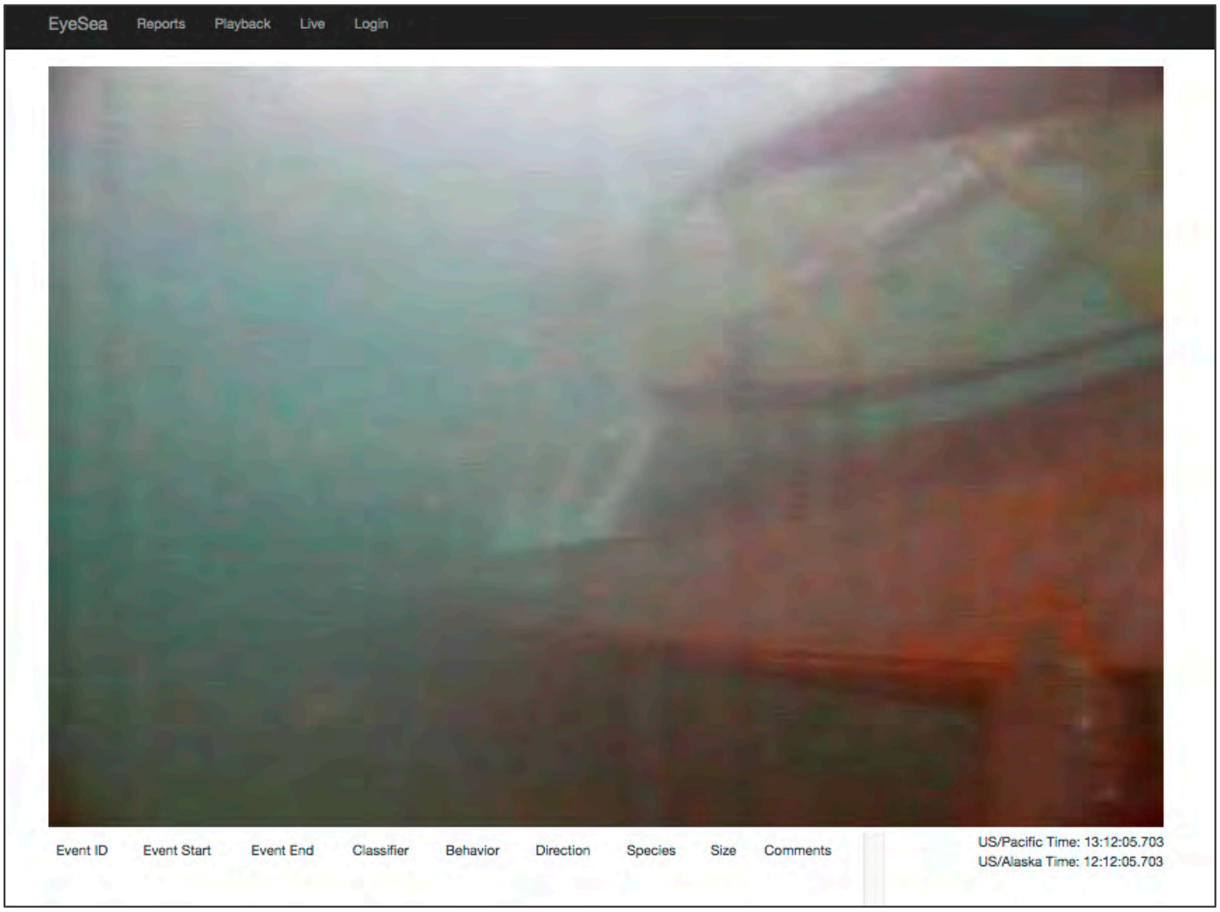


Figure 5.2. The EyeSea web application in playback mode.

6.0 Conclusions

6.1 Manual Analysis

The main points derived from the manual analysis of the data are as follows:

- Manual review of low-quality data is time-consuming. In this data set it took approximately 13–15 hours to manually review and annotate 1 hour of raw video data.
- Most interactions between the fish and the turbine occur at night.
- The frequency of fish interactions does not appear to be affected by whether the turbine is spinning or static.
- Processing subsamples (10 minutes) is likely effective for capturing unbiased event counts, but may not be effective for individual fish counts.
- Reviewer interpretation of Fish and Maybe Events in this data set is similar across two reviewers (qualitative analysis), but care is needed when assigning the designation of objects to introduced categories (quantitative analysis).
- Adult fish are qualitatively more likely to avoid collision or strike than juvenile fish.
- Adult fish are qualitatively more likely to show avoidance behavior as opposed to passive behavior relative to juveniles.

- More events occur when lights are on than when lights are off. Fish may be attracted to lights, lights may increase detection probability, or both.
- These data demonstrate the use of optical cameras for observing fish interactions with a deployed device in an underwater setting; however, improvements could be made with camera specifications and lighting parameters to increase the detection probability of fish, in both manual and automated review. Doing so may significantly decrease the manual and automated processing time.
- Observing "definite" vs. "probable" strike or collision is still extremely difficult and more research needs to be done to develop technologies or combine multiple technologies to gain confidence in determining actual contact with the device.

6.2 Automated Analysis

The main conclusions of the automated analysis effort were as follows:

- Tools available for detecting and tracking fish and other animals in underwater video are lacking. It was necessary to develop a new framework for semi-automated, human-in-the-loop analysis of underwater video. This framework can be used to test new algorithms and refine existing algorithms for automated fish detection and characterization, as well as support human expert analysis and standardized, reproducible information reporting.
- Reducing data volume is the first issue to address with automated processing. Large volumes of data are difficult to work with in terms of transferring, storing, and searching. A computationally simple background subtraction algorithm (ViBE) detected 74% of the human-identified Fish and Maybe fish, and is suitable for use in a real-time system to reduce data volume by saving only video that might contain fish.
- Reducing false positives is the second issue to address with automated processing. A statistical model can be used to classify detections as fish or not-fish, such as the one reported here that achieved a correct classification rate of 85% overall, and 92% for detections larger than 5 pixels. However, the statistical model required labeled training data that took time to assemble from the data and the model may not be transferable to other data sets. A classification model based on motion characteristics would potentially be more effective over a wider range of data.
- Underwater video recorded in energetic locations present challenges to automated processing that require algorithms specifically designed for this purpose. "Out of the box" algorithms such as those provided in the openCV library exhibited limited effectiveness, especially the optical flow techniques. Parameter tuning of the background subtraction algorithms did improve performance.

A combination of the automated detection developed under this project and human analysis could provide more accurate Fish Event information than the current practice of sampling, and with less labor time and cost than full analysis. Human analysis is currently the "gold standard" for accuracy, but it is very time-consuming so labor costs can be high and there may be long delays between collecting data and generating results. Sampling the video for analysis, e.g. analyzing 10 minutes of every hour reduces the labor time but sacrifices accuracy and increases the risk of missing rare events. The automated fish detection algorithms developed under this project can be completed quickly, but the resulting information is not as nuanced as that provided by human analysts and the detection accuracy is not yet sufficient so a "human-in-the-loop" approach is recommended. The automated detection software can be used to eliminate most of the video that does not contain fish, and the ensuing human analysis can be limited to those segments most likely to contain fish. With the developed processing system, this approach would reduce labor time by half over the full analysis, and would improve the reporting accuracy over sampling-based methods.

The performance of the automated processing can be further improved, based on the promising results demonstrated here. Future work should include incorporating computationally efficient bilateral filtering as a preprocessing stage, an intelligent scheme for parameter selection based on environmental conditions and video quality, and the integration of motion features. Further development of the EyeSea software should include a learning mode for tuning algorithm parameters using annotations provided by human experts.

7.0 Recommendations

The analysis of the Igiugig video data, both human/manual and automated, provided valuable insight into how to improve underwater video deployments in the future.

Since PNNL's review of the video data incorporated different approaches and anticipated outcomes than those of the original monitoring plan, recommendations arose regarding the monitoring process and methods for making project development and analysis more efficient in future studies. The water in the Kvichak River was described as being very clear compared to other rivers in the original monitoring report, yet the video data were described in PNNL's Quality Check Summary Report (Trostle 2016) as being "usable", in that the reviewers would be able to describe fish presence. The declaration of "usable" embodies the overall quality of the video data, including the following factors: resolution, frame rate, the placement of the cameras and light sources, the field of view, and the settings of the digital video recorder camera system. Careful consideration of the anticipated review and analysis objectives should be applied when making a camera selection. Those who will be reviewing the data should consider the questions they would like to answer and make sure that their camera selection, settings, and placement have the potential to address those questions.

To increase the quality of the video, future studies should use a low lux camera with a higher resolution and faster, even frame rate, but be aware that this will increase data accumulation because the files will be larger. Higher resolution video data would increase the likelihood that the manual reviewers could decipher between Maybe and Fish Events, identify taxonomic classification, and have more confidence regarding strike and collision. An increase in frame rate will improve the ability to detect actual strike because there would be more frames to describe the interaction around the turbine. It would also allow the reviewer, and possibly the algorithm, to use behavior as a qualifier, because sometimes the object would move significantly between frames, making behavior difficult to determine. Additionally, in some cases an object would only be in the field of view for one or two frames, making it difficult to determine if the object was a fish or not. In this study, objects that were only in one frame were not recorded as an event, because there was insufficient information to describe or categorize the object. With a more frequent frame rate and higher resolution, those objects could be included and give the study a broader picture, because the probability of missed events would be lower.

During manual video review, the reviewers realized that full manual analysis was too time-consuming. For this data set it took manual reviewers approximately 13–15 hours to process 1 hour of raw video data. A number of factors affect this approximation of time, including light operations, whether it was day or night, the number of fish, the behavior(s) of the fish, the amount of debris, the quality of the video, and whether or not the turbine was spinning. No 1-hour segment was identical to another in terms of time spent by manual reviewers due to the variability in the factors listed above, making the time spent extremely inconsistent. For this reason, future studies should be cautious when developing a timeframe estimate for manual processing, and reviewers should be wary that the anticipated estimation of time spent may change.

As described in the Quality Check Summary Report, a great deal of work and time was put into understanding the methods and settings implemented throughout the study, and converting the video from

a propriety format (.par), which was designed to be tamperproof, to a more appropriate format for the development of automated processing and analysis (.mp4). A more accessible format, such as .mp4 or .avi could be used for ease of use and to enable automated analysis before manual review.

As PNNL reviewers sifted through the video data, they noticed a variation in the light operations. In general, the lights seemed to be on at night and off during the day, with at least one exception on July 19, but a light operation record was not maintained during the study. Because there were many more Fish Events at night, it is important to get a better understanding of the effect artificial lights have on fish behavior (e.g., whether lights attract or repel fish). It is also important to quantify the difference the lights make to the physical parameters of detection (e.g., define more robust limits of detection, and define optimal placement and settings of light sources and cameras to increase manual and automated detection potential).

Recommendations for future underwater environmental monitoring are listed below:

- **General setup.** Include an indication of range within the field of view to help reviewers distinguish size and location in relation to the turbine. Also, aim the camera so the field of view is aligned with particular turbine components, possibly in combination with sensors on the turbine foils to increase the detectability potential and promote a higher level of confidence during potential strike and collision events. The aiming of each camera will likely require an iterative process of viewing early data and making adjustments to achieve ideal viewings for manual processors as well as ideal background for algorithm applications.
- **Video format**. A standard format (e.g., .avi, .mp4) should be used, rather than a proprietary format. When the video is in a standard format, researchers have a wide array of existing tools that they can use for analysis and processing. A proprietary format restricts researchers to using vendor-supplied software that often is not designed for the type of analysis required.
- **Camera type.** Choose a camera that has underwater capability with high pixel resolution in low light conditions, the capability to mount and adjust placement settings, appropriate data storage and transmission, and a suitable field of view range for the study area.
- **Camera resolution and placement.** The camera resolution will determine the size of objects in pixels at a given distance from the camera. Objects that are less than five pixels in total size are difficult to detect, both algorithmically and visually. Higher resolution will increase the volume of data, but low resolution will restrict the size of fish that can be reliably detected. The size of a fish in pixels, along the horizontal dimension, is

  length of fish in meters / meters per pixel

  The meters per pixel is

  $$\frac{2r\tan\frac{\alpha}{2}}{n}$$

  where r is the distance to the fish in meters, α is the horizontal camera field of view angle, and n is the number of pixels in the horizontal dimension. For example, a 10 cm (4 in.) fish would be 10 pixels long at 10 m from a 320 × 240 pixel camera with a 20 degree horizontal field of view. This calculation will also help determine how far from the turbine to locate the camera. Test the placement of the cameras and lights to optimize manual and automated detection probability. Note where the sun will be throughout the study and test different angles to avoid glare.

- **Frame rate.** Ideally, the frame rate should be constant, meaning that there is a fixed interval of time between frames. The Igiugig video had a variable frame rate that resulted in uneven motion of objects from frame to frame. Higher frame rates increase the volume of data, but if the frame rate is too low the number of frames in which a fish may be in the field of view is decreased, decreasing the

probability of detection. A rate of 30 frames per second is a reasonable choice to balance data volume with detection likelihood.

- **Lighting**. Fish specific to this study are typically more active at night, so some sort of illumination is needed if video is the only monitoring technique used. The light also generated more false positives from reflecting debris. An indirect light source, like the lighting viewed from camera 1 in the Igiugig video may be the best choice. If lights are to be used, the lights should be on throughout the study to maintain a more controlled environmental setup, and increase light sources with more angles of incidence to prevent fish from disappearing when they turn at an angle that does not reflect light from a single source. However, while improving the detection of fish and debris, this practice may also introduce possible bias because of the lights themselves increasing detection probability or attracting fish, both of which complicate comparisons when lights are turned off or confounded by diel differences.
- **Detailed record keeping**. The following aspects should be recorded:
  - all monitoring operations, including camera operation, light operation, power operation, turbine status, and any other introduced monitoring systems.
  - water flow, weather conditions and any significant events that occurred during the study.
  - any maintenance issues or disruptions throughout the study.
  - review efforts.
- **Other monitoring**. Consider adding other monitoring technologies to help determine whether actual collision or strike occurred and to have a backup technology for behavioral monitoring. Strain gauges or other devices physically attached to the blades of a turbine could be used to complement the video data for those times when a collision or strike is possibly seen. Having coincident data sets providing evidence of collision or strike would be better than just one. For instance, if a reviewer thinks a strike was seen on the video data, the same timestamp could be searched for blade-attached strain gauges to see if there was a spike. If there was an anomaly on the strain gauge, then that is more evidence of a strike. The absence of strain gauge data would be evidence that the interaction was more likely a near-miss.

To inform future studies, additional research into specific aspects would also be useful, in particular a study to assess the effects of lights on fish, in conjunction with an evaluation of light and camera placement and settings toward the optimization of detection probability to find an ideal experimental design for manual and automated detection. The study would record details of the placement, including heading, pitch and roll of both the lights and the cameras, light operations, intensity, wavelength, exact range in relation to the device and cameras, as well as camera operations, range, resolution, frame rate, and settings. For algorithm development, further research is recommended into different optical flow techniques, and the refinement of parameters for the background subtraction. Each of these aspects would improve the results derived from future monitoring. Each study site will have specific physical characteristics that will affect underwater video camera data collection. However, as research continues on future data sets, general application principles will arise that can be applied to most situations.

8.0 References

Avila A, Hull R, Matzner S, Staines G, Trostle C, and Harker- Klimeš G. 2016. *Igiugig Video Analysis – FY16 Progress Report* PNNL-25909 Pacific Northwest National Laboratory, Richland, WA.

Barnich O and Van Droogenbroeck M. 2009. ViBe: a powerful random technique to estimate the background in video sequences. In proceedings of *Acoustics, Speech and Signal Processing, 2009.*

ICASSP 2009. IEEE International Conference on Acoustics, Speech and Signal Processing (pp. 945–948). IEEE.

Boom BJ, He J, Palazzo S, Huang PX, Beyan C, Chou H-M, Lin F-P, Spampinato C, and Fisher RB. 2014. A research tool for long-term and continuous analysis of fish assemblage in coral-reefs using underwater camera footage. *Ecological Informatics*, 23:83–97.

Candès EJ, Li X, Ma Y, and Wright J. 2011. Robust principal component analysis? *Journal of the ACM (JACM) 58*(3), 11.

Farnebäck G. 2003. Two-frame motion estimation based on polynomial expansion. In proceedings of *Scandinavian Conference on Image Analysis* (pp. 363–370). Springer Berlin Heidelberg.

Lee DS. 2005. Effective Gaussian mixture learning for video background subtraction. *IEEE transactions on pattern analysis and machine intelligence 27*(5), 827–832.

LGL Alaska Research Associates, Inc. 2015. *Fish and Wildlife Monitoring Plan for RivGen® Testing on the Kvichak River, Alaska in 2015*.

Lotlikar R and Kothari R. 2000. Fractional-step dimensionality reduction. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 22(6): 623–627.

Lucas BD and Kanade T. 1981. An iterative image registration technique with an application to stereo vision. *International Joint Conferences on Artificial Intelligence (IJCAI)* 81: 674–679.

Tomasi C and Manduchi R. 1998. Bilateral filtering for gray and color images. In *Computer Vision, 1998. Sixth International Conference on Computer Vision* (pp. 839–846). IEEE.

Trostle C. 2016. *Igiugig Fish Video Study– Quality Check, Summary Report*. Pacific Northwest National Laboratory, Richland, WA.

Appendix A

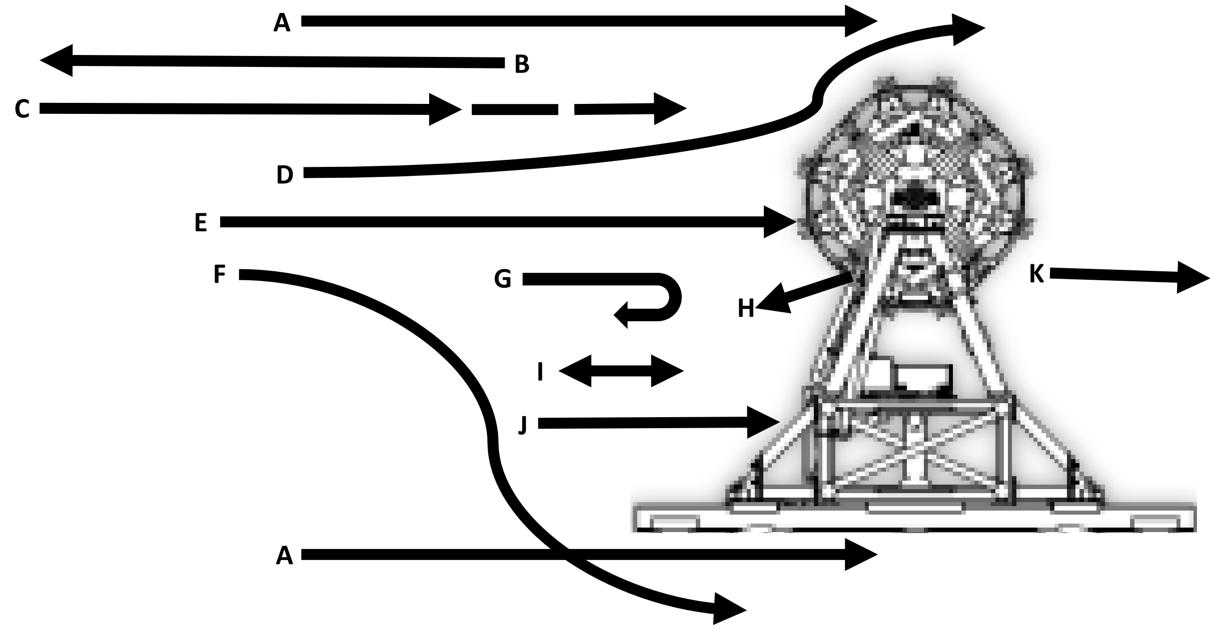
Manual Annotation

Appendix A

Manual Annotation

Annotation	Description of Annotation
Event	Reference number per event; restarting for each half-hour block of data
Date	Day video data was collected; yyyy/mm/dd
File	Filename given to each half-hour block of data; includes day and time
FileStartTime	Time that file starts on the given day it was collected
StartTime	Time that an event begins; begins 00:00:000 per half-hour block of data
EndTime	Time that an event ends; ends 29:59:999 per half-hour block of data
Lights	Either on or off; binary
Spinning	Either yes or no; binary
Camera	Designated number of camera; these data only include Camera 2
Fish?	Is the event triggering object a fish; yes, no, maybe
Number	How many objects or fish occur during an event
Size	Size of objects or fish seen during an event; measured as length on computer monitor; unidentifiable, small (<0.5 in), medium (0.5–3.0 in), large (>3.0 in.); was adjusted relative to monitor screen sizes
Species	Visually identifiable relative size designation or salmon; unidentifiable, juvenile, salmon, adult
VideoQuality	Relative anecdotal comparison of each event relative to others based on clarity of event triggering object in field of view; horrible, bad, okay, good, excellent
Notes	To clarify any previous annotation categories
Location	Where the event triggering object is in the water column; based on computer monitor divided into thirds; bottom, middle, top
Direction	All observed directions of the event triggering objects or fish; downstream, upstream, cross river toward, cross river away
Behavior	Reviewer description of all object or fish behaviors observed during an event. • straight across • against current • pause • avoid above • through turbine

	• avoid below • avoid reverse • out of turbine • milling • toward static parts • through wake • avoid around • unable to tell • other
Impact	Reviewer determination if there was collision or strike during an event
Comments	To clarify any previous categories since “Notes”



A- straight across
B- against current
C- pause
D- avoid above
E- through turbine
F- avoid below
G- avoid reverse
H- out of turbine
I- milling
J- toward static parts
K- through wake
L- unable to tell (not shown)
M- other (not shown)

Appendix B

Video Data Set Used for Algorithm Development

Video Data Set Used for Algorithm Development

Video File (Date, time, camera)	Day | Appendix BLights	Turbine | Spinning | None	Fish Events	Fish Frames
`20150719_175830-1.mkv`	Day	None	7	308
`20150720_110030-1.mkv`	Day	None	9	307
`20150722_030200-1.mkv`	Lights	None	30	917
`20150722_030200-2.mkv`	Lights	Turbine	72	878
`20150722_030200-3.mkv`	Lights	Turbine	7	283
`20150723_000330-1.mkv`	Lights	None	2	97
`20150723_000330-2.mkv`	Lights	Spinning	68	519
`20150723_000330-3.mkv`	Lights	Spinning	7	268
`20150723_000330-4.mkv`	Lights	Spinning	8	423
`20150724_000000-1.mkv`	Lights	Turbine	5	499
`20150724_000000-2.mkv`	Lights	None	53	438
`20150724_000000-3.mkv`	Lights	Turbine	10	1007
`20150724_000000-4.mkv`	Lights	Turbine	9	311
`20150825_040330-1.mkv`	Lights	None	3	201
`20150825_040330-2.mkv`	Lights	Turbine	38	467
`20150825_040330-4.mkv`	Lights	Turbine	3	160
Total			**334**	**7569 (6%)**

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT OF
ENERGY

Proudly Operated by **Battelle** *Since 1965*

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

www.pnnl.gov

Attachment 3

Igiugig Hydrokinetic Project: Fish Monitoring Plan

ORPC
OCEAN RENEWABLE
POWER COMPANY

FISH MONITORING PLAN

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511-002

November 15, 2018

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613-4008
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 GENERAL DESCRIPTION OF THE IGIUGIG HYDROKINETIC PROJECT

Igiugig Village Council (IVC) is applying to the Federal Energy Regulatory Commission (FERC) for an original hydrokinetic pilot project license for the Igiugig Hydrokinetic Project (Project), P-13511-001. The Project is located in the Kvichak River at Igiugig, Alaska (Figure 1). The Project will be carried out in two separate phases over an expected ten-year pilot project license term. In Phase I, IVC will install and monitor a single-device Ocean Renewable Power Company, Inc. (ORPC) RivGen® Power System for an initial period of 12 months (Figure 2). In Phase II, after operating and monitoring this initial power system for one year, IVC will decide whether to install the second RivGen® device to create a two-device RivGen® Power System. Electricity generated by the Project will be delivered by an underwater power cable to a shore station in Igiugig, Alaska, where it will be power-conditioned and connected to the power plant owned by the Igiugig Electric Company.

The Project will deploy the ORPC RivGen® Power System, the proprietary energy power system designed to generate electricity at river sites with water depths of 5 m (16.4 ft) or more and to connect directly into an existing diesel-powered micro-grid (Figure 2 and Figure 3). The RivGen® Power System is powered by the turbine generator unit (TGU).

Figure 1. The Project layout showing the location of the RivGen® Power System (Phase I) and the addition of the second RivGen® device (Phase II).

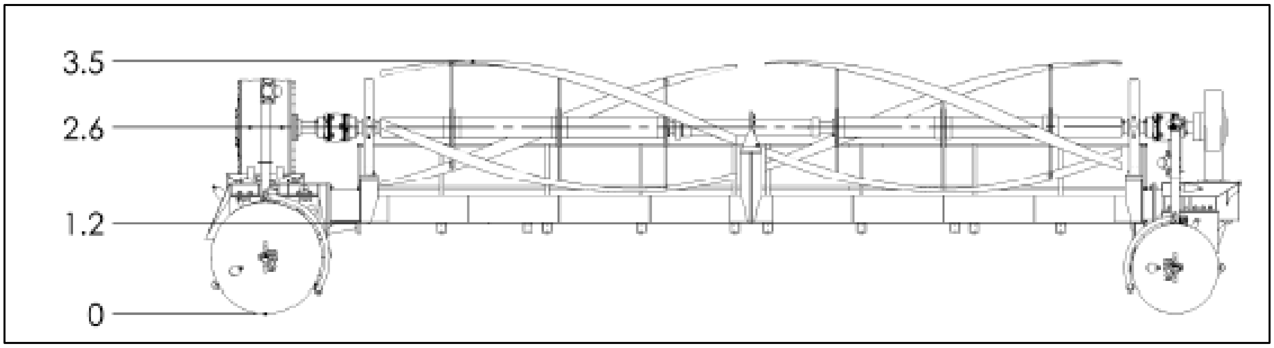


Figure 2: RivGen® device (profile view). Dimensions in meters. Source: ORPC

ORPC designed the RivGen® Power System to generate electricity at river sites with water depths of 5 m (16.4 ft) or more and connect directly into an existing diesel-powered microgrid. The RivGen® Power System is powered by the TGU. The TGU rests on a buoyant pontoon support structure frame, allowing the RivGen® Power System to be floated to the project site. Once anchored at the Project site, the RivGen® device is ballasted so that it submerges and settles on the river bottom. As a result, the RivGen® Power System is essentially self-deploying, and installation requires only commonly available vessels and minimal construction equipment. All components of the RivGen® Power System are compactly sized to travel to remote sites where they can easily be assembled on shore near the Project site.

ORPC power systems are designed around the proprietary turbine generator unit, or TGU. The TGU is made up of ORPC's proprietary advanced design cross-flow (ADCF) turbines, with slowly rotating foils that extract energy from moving water to power a central underwater permanent magnet generator. The ADCF turbines are fabricated to resist corrosion. The TGU includes a fairing system to increase the overall capture area of the RivGen® turbines and accelerate the flow entering the power generating portion of a foil's rotation.

The TGU has a rated capacity of 35 kW at 2.25 meters per second (m/s). ORPC has used empirical data and existing literature data of the annual flows in the Kvichak River to estimate the Project's annual electrical generation. The methods used for estimating annual generation are described in Section A.1.5. Exhibit F drawings (F-1 through F-6) show the placement of the TGU on the pontoon support structure, the dimensions of the TGU, and the height of the TGU above the riverbed. In addition, Exhibit F includes construction drawings, which include existing Project structures, including the shore station, buried transmission cable between the shore station and diesel microgrid, and the associated step-up transformer.

The RivGen® device measures approximately 15.8 m (51.8 ft) long x 3.5 m (11.5 ft) high x 14.4 m (47 ft) wide. The chassis sits on the pontoon structure of the TGU which is 1.2 m (4 ft) off the river bottom. The total weight of the TGU is approximately 26,000 kg (57,320 lbs).

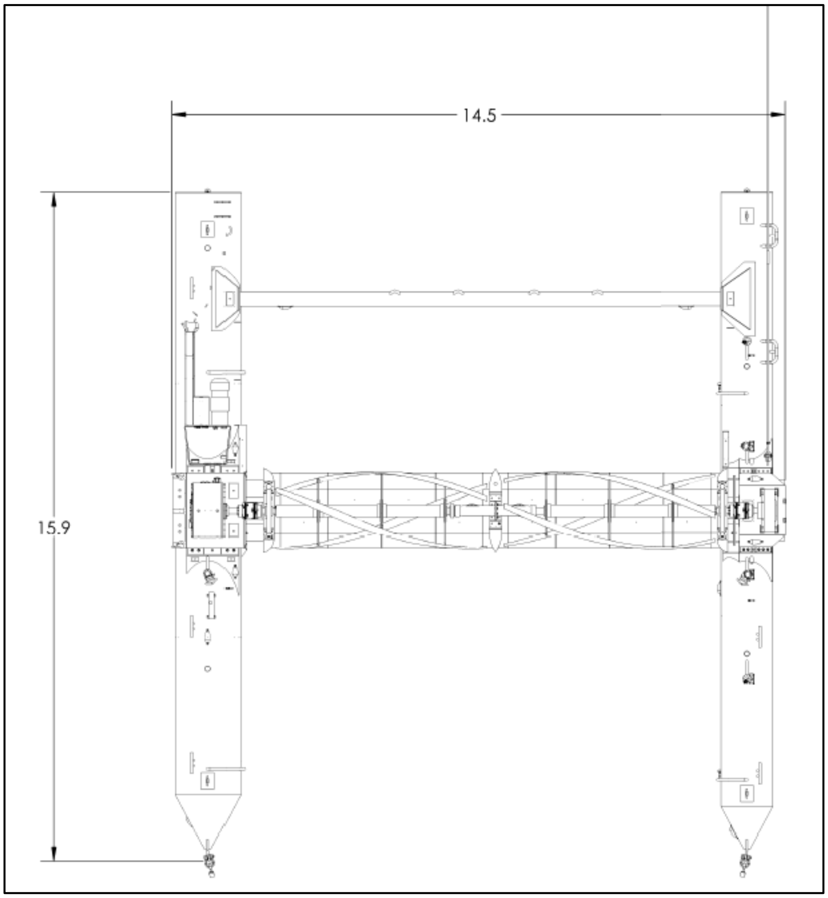


Figure 3. RivGen® device (top view). Dimensions in meters. Source: ORPC

1.2 PILOT LICENSING PROCESS

The purpose of the Project is to study the installation of ORPC's RivGen® Power System and its effect on the Kvichak River environment. FERC's pilot licensing program has been designed to support the advancement and orderly development of innovative hydrokinetic technologies for projects that are small, short-term, removable and carefully monitored. The purposes of FERC's pilot license program are to test new hydrokinetic technologies, determine the appropriate sites for hydrokinetic projects, and collect information on the environmental and other effects of these new generating devices.

The concept of adaptive management is foundational to ORPC's study plan development. As stated by FERC (2006), "adjustments to measures required during the license term will be based on information gleaned from ongoing monitoring or other post-license studies." ORPC believes that given the uncertainty associated with the relatively new pilot project process, the ability to adjust monitoring studies through adaptive management, based on experienced gained through the Project, allows for more effective studies. ORPC is proposing the adaptive management approach as the most responsible path forward for this Project, considering the available ecological and environmental data. This approach is also more appropriate to the pilot project license program's goals and objectives than attempting to finalize each study plan prior to deploying the Project's first phase. A Project Adaptive Management Plan is included in Appendix A of the final pilot license application (FPLA).

For the purposes of monitoring fish interactions with the RivGen® Power System, the proposed video monitoring system was developed under guidance from researchers at the Pacific Northwest National Laboratory (PNNL), University of Alaska Fairbanks (UAF), and University of Washington (UW). It was informed by previous monitoring work performed by LGL Alaska Research Associates, Inc. (LGL). Fish presence, behavior, and potential effects from the devices will be evaluated. Monitoring will be implemented with consideration of the anticipated fish species, specifically, sockeye salmon smolt, and the unique physical characteristics of the device to ensure adequate monitoring.

2.0 GOALS AND OBJECTIVES

The Project will install a two-device RivGen® Power System in phases at the same site on the Kvichak River where RivGen® Power Systems were installed in 2014 and 2015. Installation entails deploying the device(s) on the river bed, where water current will rotate a pair of turbines to generate hydroelectric power. This is a relatively new technology that is still in the demonstration phase, with few comparable attempts in Alaska. LGL reported results of the fish and wildlife monitoring conducted during the 2014 demonstration season and 2015 operations (Attachment 1). The Pacific Northwest National Laboratory also conducted data analysis on the video collected in 2015 (Attachment 2).

The overall goal of this Plan is to monitor the RivGen® device for potential fish interactions for one year to inform the regulatory process and provide the basis for future modifications based on observed effects. After collecting monitoring data for a year, IVC will convene a meeting with the Adaptive Management Team (outlined in the Adaptive Management Plan) to collectively evaluate fish monitoring data and adjust future monitoring efforts based on known effects. The specific objectives are as follows:

1. Document the presence and timing of fishes at the RivGen® device by species and life stage
2. Characterize salmon movements past the RivGen® device during migration periods
3. Describe the behavioral response of salmon that come into the vicinity of the RivGen® device
4. Describe any observable acute effects from contact with the RivGen® device, including disorientation, injury, or mortality during salmon migrations

3.0 STUDY AREA

The RivGen® Power System will be deployed on the Kvichak River near the village of Igiugig, Alaska. Igiugig is at the outlet of Lake Iliamna, approximately 60 river miles upstream from where the Kvichak River empties into Bristol Bay. The RivGen® Power System will operate at the site of previous deployments, with coordinates of -155.9150 and 59.3247. At this site, water depth is approximately 5 m, the river width is approximately 128 m, substrate is scoured cobbles and gravel, and the maximum current velocity in the center of the channel is approximately 2.5 m/s (Thomson, Kilcher, & Polagye, 2014). The site is just downstream from Fly Island and about 100 ft from the right bank (facing downstream) in a part of the river that is deep and has high water velocity. The selected site is near Site 10 as described by TerraSond in 2011, whose surveys included measurements of hydrology characteristics, including bathymetry and current velocities throughout the immediate area (Figure 1).

4.0 BACKGROUND AND RELEVENT INFORMATION

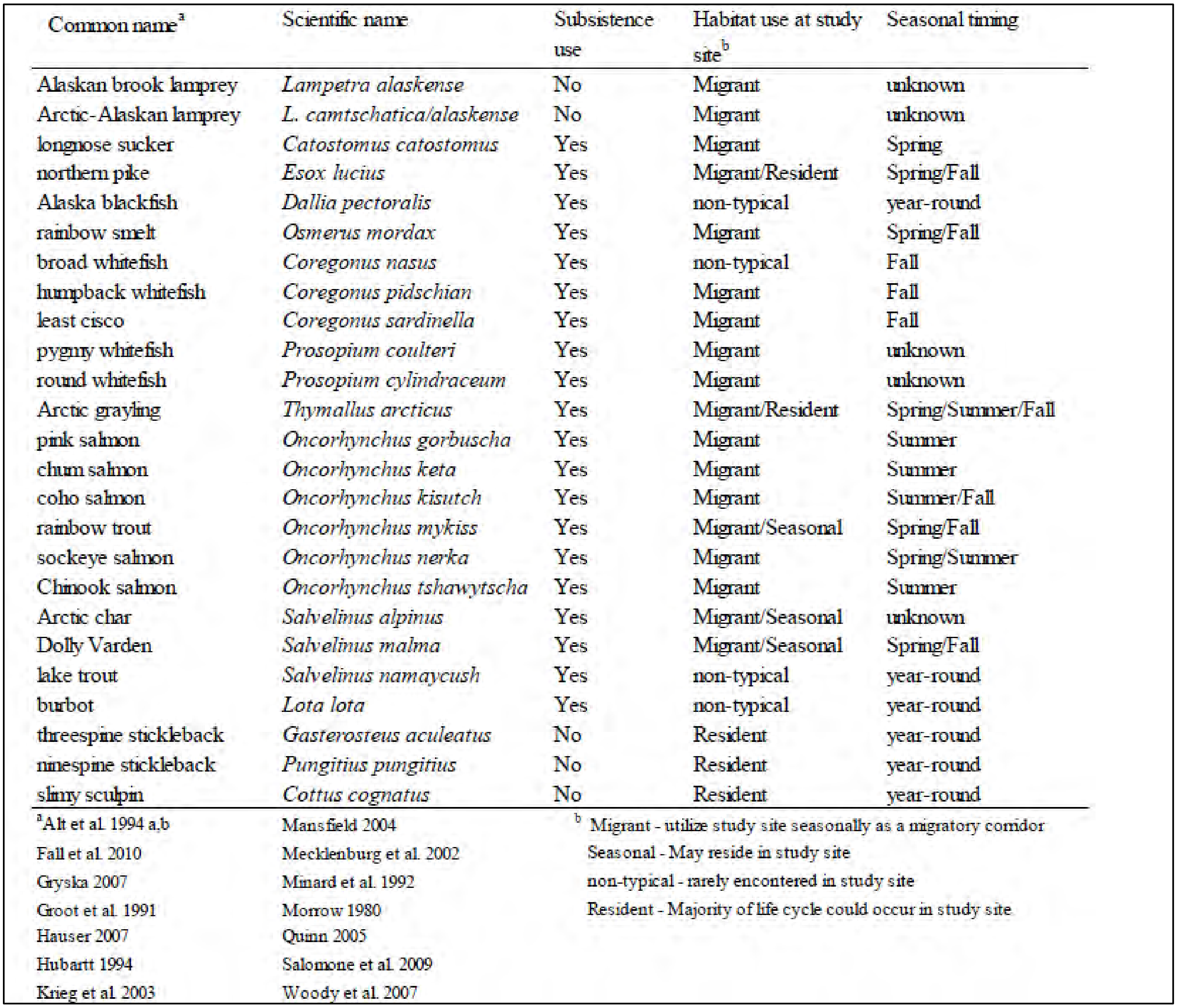
4.1 RESOURCE DISCUSSION

Fish Species Composition

Approximately 25 species of fish are known to inhabit the Kvichak River, including all five species of Pacific salmon (*Oncorhynchus* spp.) found in Alaska (Table 1). Most, though likely not all, are present near Igiugig at some point during the year, either as year-round resident species or as migratory species that pass through seasonally en route to spawning or feeding locations. Many species are harvested in two Igiugig fisheries (subsistence and recreational); salmon may also be harvested in a third fishery (commercial) downstream in Bristol Bay. The Alaska Department of Fish and Game (ADF&G) manages all fish species taken in each of these three fisheries.

Fish species in the Kvichak River that have the potential to be observed near Igiugig are presented in Table 1. Each species has its own unique aspects of timing and behavior that influence the likelihood for encountering or being affected by the RivGen® device(s). Table 2 shows anticipated seasonal presence of selected fish species near Igiugig. In general, fishes that are found in the study area use this stretch of river as a corridor for migration among over-wintering, feeding and spawning grounds. Fishes locate themselves in the river according to preferred habitat characteristics such as water flow and food availability. Adult and juvenile fishes tend to be located in environments where they have relatively low energy expenditure and high food intake. Therefore, typical preference in a river for holding or migrating is near the bottom, along the shores, and behind relatively large structures such as boulders. In this regard, adult fishes are expected to avoid the higher energy portion of the river. Juvenile salmon migrating downstream to the ocean, conversely, often choose the high energy environments (surface, thalweg, and no structure) where they can swim with the water flow and conserve internal energy. Therefore, the location of the RivGen® device(s) in the thalweg of the river makes it more likely to encounter downstream-migrating fish (such as juvenile sockeye salmon) than upstream-migrating fish (such as adult salmon). Further details are provided in subsequent parts of this section for high priority species.

Table 1. *List of Fish Species in the Kvichak River*



Common name[a]	Scientific name	Subsistence use	Habitat use at study site[b]	Seasonal timing
Alaskan brook lamprey	*Lampetra alaskense*	No	Migrant	unknown
Arctic-Alaskan lamprey	*L. camtschatica/alaskense*	No	Migrant	unknown
longnose sucker	*Catostomus catostomus*	Yes	Migrant	Spring
northern pike	*Esox lucius*	Yes	Migrant/Resident	Spring/Fall
Alaska blackfish	*Dallia pectoralis*	Yes	non-typical	year-round
rainbow smelt	*Osmerus mordax*	Yes	Migrant	Spring/Fall
broad whitefish	*Coregonus nasus*	Yes	non-typical	Fall
humpback whitefish	*Coregonus pidschian*	Yes	Migrant	Fall
least cisco	*Coregonus sardinella*	Yes	Migrant	Fall
pygmy whitefish	*Prosopium coulteri*	Yes	Migrant	unknown
round whitefish	*Prosopium cylindraceum*	Yes	Migrant	unknown
Arctic grayling	*Thymallus arcticus*	Yes	Migrant/Resident	Spring/Summer/Fall
pink salmon	*Oncorhynchus gorbuscha*	Yes	Migrant	Summer
chum salmon	*Oncorhynchus keta*	Yes	Migrant	Summer
coho salmon	*Oncorhynchus kisutch*	Yes	Migrant	Summer/Fall
rainbow trout	*Oncorhynchus mykiss*	Yes	Migrant/Seasonal	Spring/Fall
sockeye salmon	*Oncorhynchus nerka*	Yes	Migrant	Spring/Summer
Chinook salmon	*Oncorhynchus tshawytscha*	Yes	Migrant	Summer
Arctic char	*Salvelinus alpinus*	Yes	Migrant/Seasonal	unknown
Dolly Varden	*Salvelinus malma*	Yes	Migrant/Seasonal	Spring/Fall
lake trout	*Salvelinus namaycush*	Yes	non-typical	year-round
burbot	*Lota lota*	Yes	non-typical	year-round
threespine stickleback	*Gasterosteus aculeatus*	No	Resident	year-round
ninespine stickleback	*Pungitius pungitius*	No	Resident	year-round
slimy sculpin	*Cottus cognatus*	No	Resident	year-round

[a] Alt et al. 1994 a,b
Fall et al. 2010
Gryska 2007
Groot et al. 1991
Hauser 2007
Hubartt 1994
Krieg et al. 2003
Mansfield 2004
Mecklenburg et al. 2002
Minard et al. 1992
Morrow 1980
Quinn 2005
Salomone et al. 2009
Woody et al. 2007

[b] Migrant - utilize study site seasonally as a migratory corridor
Seasonal - May reside in study site
non-typical - rarely encontered in study site
Resident - Majority of life cycle could occur in study site

Table 2. Anticipated seasonal presence of selected fish species near Igiugig. Light gray – run duration, gray – run peak (Source: LGL)

Species	Jan-Mar	April	May	June	July	Aug	Sept	Oct	Nov-Dec
Sockeye salmon (smolt)			░▓	▓░					
Sockeye salmon (adult)				░	░▓░	░			
Chinook salmon				░	░	░			
Pink salmon					░	░▓░	░		
Chum salmon					░	░▓░	░		
Coho salmon					░	░▓	▓		
Rainbow trout		░	▓	▓░			░▓	▓░	░

Subsistence Fish Harvest

For the communities within the Kvichak River watershed, the subsistence way of life is a fundamental part of their cultural and physical wellbeing. Each year residents harvest, distribute, and consume many fish species found in the river. Historically, salmon have been the mainstay for subsistence, but a considerable portion of the subsistence take is also comprised of non-salmon species that can be harvested year-round. Recent studies estimate that greater than 18,000 lbs of non-salmon fish are harvested regionally on an annual basis (Krieg et al., 2005). Several different harvest techniques, including angling and nets, are employed as the fish move seasonally from their over-wintering grounds to summer spawning and feeding habitats (Fall, Holen, Davis, Krieg, & Koster, 2006).

Of the 16 different non-salmon fish used by the people of Igiugig, seven are estimated to be harvested by greater than 25 percent of the households in the village (Kreig et al., 2003). Rainbow trout, Dolly Varden, and northern pike comprise the species of greatest subsistence harvest (besides salmon), in descending order (Kreig et al., 2005). A summary of these seven species is provided as well as descriptions of how they use the habitat near the outlet of Lake Iliamna downstream to Kaskanak Creek.

Rainbow trout (*Oncorhynchus mykiss*) are the freshwater resident form of this species found in the Kvichak River watershed. The anadromous form (steelhead) has not been documented in the Bristol Bay region. During the spring, rainbow trout will congregate between the outlet of Lake Iliamna and

Kaskanak Flat; these fish will include both spawners and nonspawners. ADF&G conducted abundance studies from 1986 through 1991 near Igiugig (Minard et al., 1992). Much of the sampling for these studies was conducted immediately below Igiugig, in the braided portions of the river where the fish gathered in shallow, low velocity areas. The authors noted that rainbow trout gathered in large numbers at these sites during April and May. By mid-June, they disperse into Lake Iliamna to spend the summer months before migrating to tributaries of the lake and to the Kvichak River in the fall. Abundance estimates in 1988, 1989, and 1990 were 2,038 (SE=1,252), 2,912 (775), and 4,460 (1,441), respectively. Annual survival ranged from 28 percent to 30 percent, and average age was six years (Krieg et al., 2003, Mecklenburg et al., 2002, Minard et al., 1992, and Morrow, 1980).

Rainbow trout support a substantial sport fishing industry that is managed by ADF&G. In addition to being economically valuable to the residents of Igiugig, rainbow trout are also a highly regarded subsistence resource. Krieg et al. (2003) reported that 100 percent of the households in Igiugig will include rainbow trout in their annual subsistence harvest. Local fishing guides indicate that rainbow trout can be located anywhere in the river, but that fishermen tend to drift “lines” down the channel that are most productive (Brian Kraft, personal communication, Alaska Sportsman’s Lodge). These lines are defined by bathymetry, water flows, and food characteristics that are the most energetically beneficial to the rainbow trout. Observations during 2014 and 2015 showed that the lines drifted by sport fisherman were inshore of the device towards the eastern bank of the river and that there was no observed interference between trout sport fishing practices and the RivGen device whether it was deployed on the river bed or on the surface during maintenance events. It is possible that the RivGen® Power System structure may provide some preferred habitat (e.g., shelter or cover) for rainbow trout. This condition may encourage them to come in close proximity with the device even though the high-power density region of the channel is not usually preferred. Overall, it is anticipated that adult rainbow trout may encounter the device(s) and any in-water mooring or electrical cables running to shore.

Arctic grayling (*Thymallus arcticus*) are found throughout the Kvichak drainage. During the winter months, Arctic grayling will be found in lakes or larger rivers that provide sufficient habitat while frozen. During the spring, they will migrate up streams to their spawning and feeding grounds, so the Kvichak River at Igiugig is likely used only as a migration corridor rather than an area of residence. Arctic grayling will spawn in low energy portions of the streams; this is also where the fry will rear before heading to the overwintering grounds. Arctic grayling have been caught in the Kvichak at Igiugig, but the majority of this species is harvested further downstream near the outlet of Pecks, Ole and Kaskanak Creeks (Gryska, 2007, Krieg et al., 2003, and Morrow, 1980). No information on population abundance or cross-channel distribution at Igiugig is available but based on their preferred habitat it is not anticipated that adult or juvenile grayling will encounter the RivGen® device(s). However, they will likely encounter moorings and electrical cables running to shore.

Northern pike (*Esox lucius*) are found in the lakes and rivers throughout southwest Alaska, including the Kvichak River. These fish will overwinter in the slower water of large rivers and deeper lakes, and then migrate to their summer spawning and feeding grounds in slow moving streams, sloughs, and along the lake shore. The Kvichak River at Igiugig is likely used only as a migration corridor rather than an area of residence because of predominant high-water velocity. Igiugig residents harvest pike during the spring and fall in the Kvichak River (Alt, 1994a, Krieg et al., 2003, and Mecklenburg et al., 2002), Kvichak tributaries of Ole and Pecks Creeks, and Lake Iliamna tributaries of Upper and Lower Talarik Creeks (Ida Nelson, personal communication, Igiugig resident). No information on population abundance or cross-channel distribution at Igiugig is available but based on their preferred habitat it is not anticpated that adult or juvenile pike will encounter the hydrokinetic device. However, they will likely encounter any in-water mooring and electrical cables running to shore.

Humpback whitefish (*Coregonus pidschian*) can take advantage of many different freshwater and marine habitats and are found in freshwater residential and anadromous forms. These fish are found throughout the Kvichak River watershed and make up a large component of the subsistence fishery. Despite the relative importance of this fish, little is known of its life history or population size. A recent study by Woody and Young (2007) examined strontium concentrations in humpback whitefish taken from Lake Clark and found no definitive evidence that those fish migrated to and from saltwater. It is known that spawning occurs during the fall and takes place in the upper reaches of streams, or the littoral zones of lakes. Based on harvest records for Igiugig residents, humpback whitefish are caught near the village as they migrate to or from their spawning grounds located in the tributaries of the Kvichak River (Alt, 1994b, Fall et al., 2010, Woody and Young, 2007, and Krieg et al., 2003). Residents fish for humpback whitefish in October and November (Ida Nelson, personal communication, Igiugig resident). At Igiugig, the Kvichak River is likely used only as a migration corridor rather than an area of residence by the humpback whitefish. No information on population abundance or cross-channel distribution at Igiugig is available but based on their preferred habitat it is not anticipated that adult or juvenile humpback whitefish will encounter the RivGen® device(s). However, they will likely encounter any in-water mooring and electrical cables running to shore.

Dolly Varden (*Salvelinus malma*) in the Kvichak River watershed exist in anadromous and freshwater resident forms. Generally, the freshwater residents will be in the upper reaches of the streams that drain into Lake Iliamna, and the anadromous form is found in the mainstem and larger tributaries of the Kvichak River. Resident Dolly Varden will rear in slow moving water on the stream bottoms and then move to stream pools or eddies once they are large enough. Anadromous forms will spawn in the summer and fall and may remain in the streams up to 20 months before migrating back to sea. The juvenile anadromous form will remain in the freshwater 2 to 4 years using the stream bottom for cover and feeding. Once large enough, they make the transformation into smolts and migrate to sea around May and June (Hubartt, 1994, Kreig et al., 2003, Mecklenburg et al., 2002, and Morrow, 1980). The anadromous form of this species is harvested January through April in the Kvichak (Kreig et al., 2005) via ice fishing. Local fishing guides indicate that Dolly Varden are caught incidentally when targeting rainbows, but are uncommon (Brian Kraft, personal communication, Alaska Sportsman's Lodge). Overall, it is anticipated that adult Dolly Varden may encounter the RivGen® device(s) and moorings or electrical cables running to shore, but it would be a rare occurrence due to their low abundance in the Project area.

Longnose suckers (*Catostomus catostomus*) are harvested by Igiugig residents during the spring, usually in late May and early June. These fish reside in lakes or stream pools and will migrate to gravel sections of streams in the spring for spawning. Based on the harvest records, Igiugig residents harvest these fish in the feeder streams of the upper Kvichak River, namely Pecks and Ole Creeks, in addition to the Kaskanak Flats area (Krieg et al., 2003, Mansfield, 2004, Mecklenburg et al., 2002, and Morrow, 1980). No information on population abundance or cross-channel distribution at Igiugig is available but based on their preferred habitat it is not anticipated that adult or juvenile longnose suckers will encounter the RivGen® device(s). However, they will likely encounter in-water moorings and electrical cables running to shore.

Rainbow smelt (*Osmerus mordax*) are anadromous fish that migrate up the Kvichak River each spring from the ocean and are thought to spawn in the tributaries of Lake Iliamna. Little is known about their life history or population size. However, based on traditional ecological knowledge, the rainbow smelt are only present from spring to early fall (Gotthardt & McClory, 2006, Mecklenburg et al., 2002, and Kreig et al., 2003). The Kvichak River at Igiugig is likely used only as a migration corridor rather than an area of residence. No information on population abundance or cross-channel distribution at Igiugig is available, but based on their preferred habitat, it is anticipated that out-migrating adult or juvenile rainbow smelt will encounter the RivGen® device(s) and in-water mooring or electrical cables running to shore.

Adult Sockeye Salmon

Socioeconomic Importance

Bristol Bay, Alaska, produces the greatest number of sockeye salmon (*Oncorhynchus nerka*) in the world. During 1991-2010, the region produced an average annual sockeye salmon run of 38 million (SD 12 million); the Kvichak stock represented 21 percent of this average. Bristol Bay sockeye have been intensively harvested since the early 1900s, mostly in commercial fisheries located in marine waters near river confluences (Clark et al., 2006). Commercial harvest from 1991 to 2010 averaged 26 million for Bristol Bay as a whole, and 4 million for the Kvichak River.

Subsistence fishing for sockeye salmon in Bristol Bay has occurred since inhabitance and continues to be an important source of protein for local residents (Morstad, Jones, Sands, Salomone, Buck, & West, 2010). In 2009, the subsistence harvest of sockeye for the Kvichak River/Iliamna Lake sub-district totaled 46,772 from 187 permits, and in the Igiugig region totaled 1,071 from 5 permits (Salomone, Morstad, Sands, Jones, Baker, Buck, West, & Kreig, 2011). In addition to the subsistence fishery, sockeye salmon have been an essential segment of the sport fishing industry for that region. From 1997 through 2008 the annual sport fish harvest of sockeye salmon in the Kvichak River averaged 1,860 fish (Dye& Schwanke, 2009).

Management

To manage and sustain the fisheries, federal and state agencies have collected detailed records of catch, spawning escapement, and age composition for the nine major Bristol Bay sockeye salmon stocks (including the Kvichak River) since 1952. The Bristol Bay region remains relatively pristine, biodiversity of salmon remains high (Hilborn et al., 2003), and salmon populations have not been influenced by hatcheries. Therefore, Bristol Bay provides a unique long-term history of wild salmon population dynamics, largely unaffected by alterations to habitat or genetics.

ADF&G's salmon management objectives include managing for sustained yield (largely accomplished by adhering to escapement goals), maintaining genetic diversity and overall health of the escapement (the number of fish that spawn each year), providing for an orderly fishery, helping to ensure high quality fishery products, and harvesting fish consistent with regulatory management plans. The Commissioner delegates management authority to Area Management Biologists, who regulate time and area openings for otherwise closed fisheries.

ADF&G's fishery biologists develop escapement goals for salmon based on the sustained yield principle, in accordance with the Policy for the Management of Sustainable Salmon Fisheries (5 AAC 39.222) and the Policy for Statewide Salmon Escapement Goals (5 AAC 39.223). Typically, the relationship between escapement levels and subsequent adult salmon returns is an important part of escapement goal development.

Timing

Average run timing (2000-2010) shows that 25 percent of Kvichak River spawners return by June 30, 50 percent by July 5, and 75 percent by July 10 (Figure 4). During this period, run timing ranged plus or minus three days, with the earliest having 50 percent return by July 2 and the latest by about July 8 (based on combined catch and escapement). Sockeye salmon usually take two to four days to travel from the fishing district upstream to the counting tower at Igiugig (T. Baker, personal communication, research biologist, ADF&G).

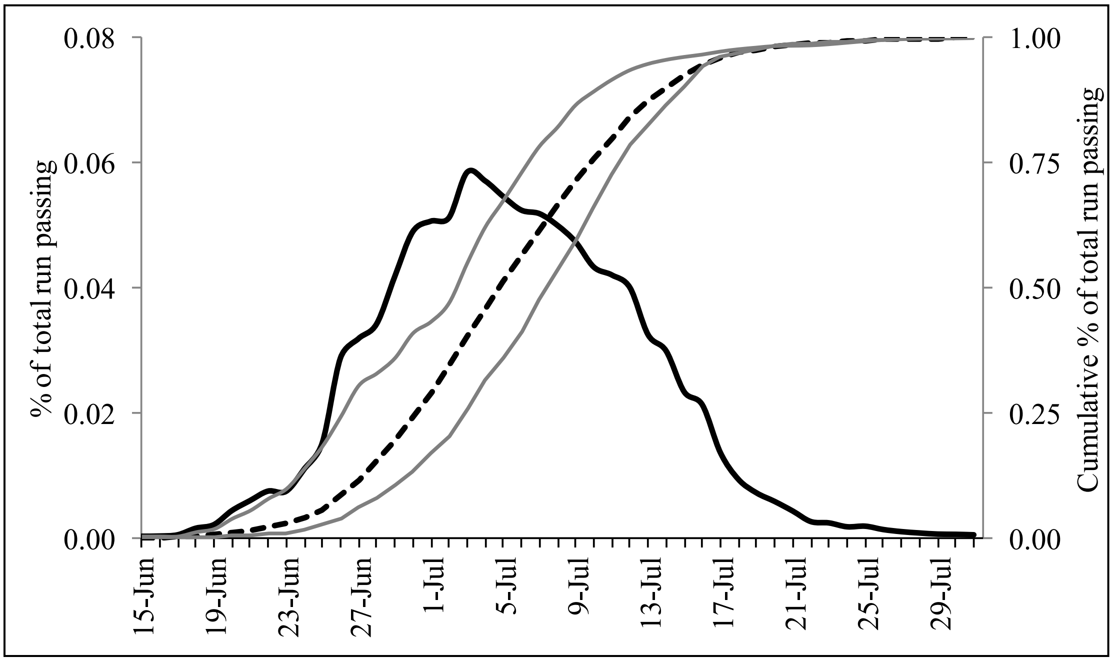


Figure 4. Run timing curves for Kvichak River sockeye salmon. The average run timing from 2000 to 2010 are indicated by thick black lines (daily=solid line and cumulative=dashed line). The earliest and latest cumulative curves during this time period are indicated by gray lines. Source: LGL

Distribution

When current velocities in the thalweg are high, sockeye salmon are extremely bank-oriented while migrating upriver due to the energetic gain in swimming against slower waters near the bank (Woody, 2007, and Anderson, 2000). Taking advantage of this life history trait, W. F. Thompson (1962) developed the tower counting system for Bristol Bay in 1953. When tower counts were compared to weir counts (assumed to be a complete census) on the Egegik River, relative error was -7.4 percent (Rietze, 1957; Spangler & Rietze, 1958). Therefore, we can assume that most sockeye were visible from the counting towers and not swimming in the thalweg; otherwise, the observed relative error would have been much greater. At Igiugig, Anderson (2000) found nearly all sockeye passed 3.0 - 9.1 m from the left bank (facing upstream) and 3.7 - 9.1 m from the right bank. Igiugig was chosen for the enumeration project because current velocities in the thalweg likely preclude adult salmon swimming across or through the middle of the river in this area. It is anticipated that adult sockeye salmon encounters with the RivGen® device(s) will be minimized by device placement in the river thalweg. Adult salmon are expected to encounter moorings and electrical cables running to shore.

Abundance

Total abundance of adult sockeye salmon returning to individual Bristol Bay rivers is calculated from catch and escapement estimates. Escapement of sockeye salmon to the Kvichak River is estimated with a counting tower operated by ADF&G near Igiugig. Commercial catch of Kvichak River sockeye salmon happens downstream, in Bristol Bay saltwater; catch of fish bound for the Kvichak River is estimated based on age-specific stock composition methods. From 2006 through 2010, the estimated Kvichak River sockeye salmon run averaged 6.1 million total fish, with a range of 4.2 to 9.2 million fish (Table 3). Kvichak River sockeye salmon vary among four main age classes: 1.2, 1.3, 1.4, and 2.3 (European notation—1st number=freshwater age, 2nd=ocean age, Table 4). On average, 60 percent return 5 years after the year in which they were spawned, as Age-2.2s or Age-1.3s (return time is calculated by adding the freshwater and ocean ages plus one year for overwinter incubation of the eggs). Age-2 fish are usually the most abundant and exert strong influence on total run size.

Table 3. *Historical catch and escapement of Kvichak River sockeye salmon.*

Year	Catch	Escapement	Total
1956	4,168,343	9,443,318	13,611,661
1957	3,540,189	2,842,810	6,382,999
1958	549,396	534,785	1,084,181
1959	281,930	673,811	955,741
1960	7,976,500	14,602,360	22,578,860
1961	6,863,814	-	6,863,814
1962	1,833,401	2,580,884	4,414,285
1963	223,459	338,760	562,219
1964	763,486	957,120	1,720,606
1965	17,785,664	24,325,926	42,111,590
1966	4,168,575	3,755,185	7,923,760
1967	1,800,652	3,216,208	5,016,860
1968	387,565	2,557,440	2,945,005
1969	3,760,565	8,394,204	12,154,769
1970	16,581,224	13,935,306	30,516,530
1971	3,764,861	2,387,392	6,152,253
1972	342,150	1,009,962	1,352,112
1973	21,791	226,554	248,345
1974	148,595	4,433,844	4,582,439
1975	1,605,407	13,140,450	14,745,857
1976	1,458,180	1,965,282	3,423,462
1977	739,464	1,341,144	2,080,608
1978	3,815,636	4,149,288	7,964,924
1979	13,418,829	11,218,434	24,637,263
1980	12,743,074	22,505,268	35,248,342
1981	5,234,733	1,754,358	6,989,091
1982	1,858,475	1,134,840	2,993,315
1983	16,534,901	3,569,982	20,104,883
1984	12,523,803	10,490,670	23,014,473
1985	6,183,103	7,211,046	13,394,149
1986	787,303	1,179,322	1,966,625
1987	3,526,824	6,065,880	9,592,704
1988	2,654,364	4,065,216	6,719,580
1989	11,456,509	8,317,500	19,774,009
1990	10,551,217	6,970,020	17,521,237
1991	3,808,873	4,222,788	8,031,661
1992	5,718,947	4,725,864	10,444,811
1993	5,287,523	4,025,166	9,312,689
1994	13,893,613	8,355,936	22,249,549
1995	17,391,906	10,038,720	27,430,626
1996	1,983,269	1,450,578	3,433,847
1997	179,480	1,503,732	1,683,212
1998	1,072,760	2,296,074	3,368,834
1999	6,663,209	6,196,914	12,860,123
2000	1,033,814	1,827,780	2,861,594
2001	330,538	1,095,348	1,425,886
2002	-	703,884	703,884
2003	34,244	1,686,804	1,721,048
2004	2,163,318	5,500,134	7,663,452
2005	532,450	2,320,332	2,852,782
2006	2,687,895	3,068,226	5,756,121
2007	1,420,384	2,810,208	4,230,592
2008	2,873,889	2,757,912	5,631,801
2009	3,297,344	2,266,140	5,563,484
2010	5,018,048	4,207,410	9,225,458
10 yr avg.	3,967,974	3,552,998	7,322,573

Table 4. *Age composition of Kvichak River sockeye salmon, in percentages*

Year	Age 1.2	Age 1.3	Age 2.2	Age 2.3	2-ocean	3-ocean	Total run (millions)
1990	4	7	75	14	79	21	18
1991	51	13	17	19	68	32	8
1992	23	23	41	12	65	35	11
1993	22	25	45	7	67	33	10
1994	7	7	83	2	90	10	23
1995	9	4	75	12	84	16	28
1996	12	35	20	33	32	68	4
1997	47	12	31	9	78	22	2
1998	51	26	18	4	69	31	4
1999	58	9	28	4	87	13	13
2000	12	60	20	8	32	68	3
2001	9	84	1	5	10	90	1
2002	45	15	37	2	83	17	1
2003	64	17	15	4	79	21	2
2004	23	3	73	1	96	4	8
2005	18	41	32	9	50	50	3
2006	45	31	17	7	62	38	6
2007	63	18	3	16	66	34	4
2008	73	25	1	0	74	26	6
2009	18	40	40	2	57	43	6

Sockeye salmon abundance in Bristol Bay has fluctuated significantly during the past century (Figure 5). Two notable aspects of the Kvichak River sockeye salmon are a historic 5-year cyclic pattern in abundance, and an overall decline in abundance beginning in the mid-1990s. Reasons for the cycle are unclear and the subject of much discussion. Some data indicate an interaction of marine and freshwater processes, reinforced by historical fishing patterns and escapement goal policy. Ruggerone and Link (2006) provided evidence that the cyclic abundance of Kvichak sockeye salmon was maintained by dispensatory fishing mortality, density-dependent interactions between brood lines, low productivity of the Kvichak River watershed, and the relatively stable 5-year life cycle of Kvichak River salmon rather than natural dispensatory mortality caused by predators or marine derived nutrients. Whatever the cause, the cycle began to change during the mid-1990s and the Kvichak River stock has failed to dominate the Bristol Bay run since. Speculation about factors causing the Kvichak River stock collapse grew as the series of low runs continued from 1996 through 2005.

The history and accuracy of tower counting systems in Bristol Bay is described by Woody (2007), while methods for efficiently estimating sampling error (precision) can be found in Reynolds et al. (2007).

Towers are constructed on clear streams such as the Kvichak River at sites amenable to sampling, which is circumscribed by a set of guidelines (Woody, 2007). As previously mentioned, tower counts were very close to weir counts on the Egegik River (relative error was -7.4 percent), (Rietze, 1957; Spangler & Rietze, 1958). The sources of error counting include observer variability, aspects of migration, weather conditions, and sampling error due to subsampling (Woody, 2007).

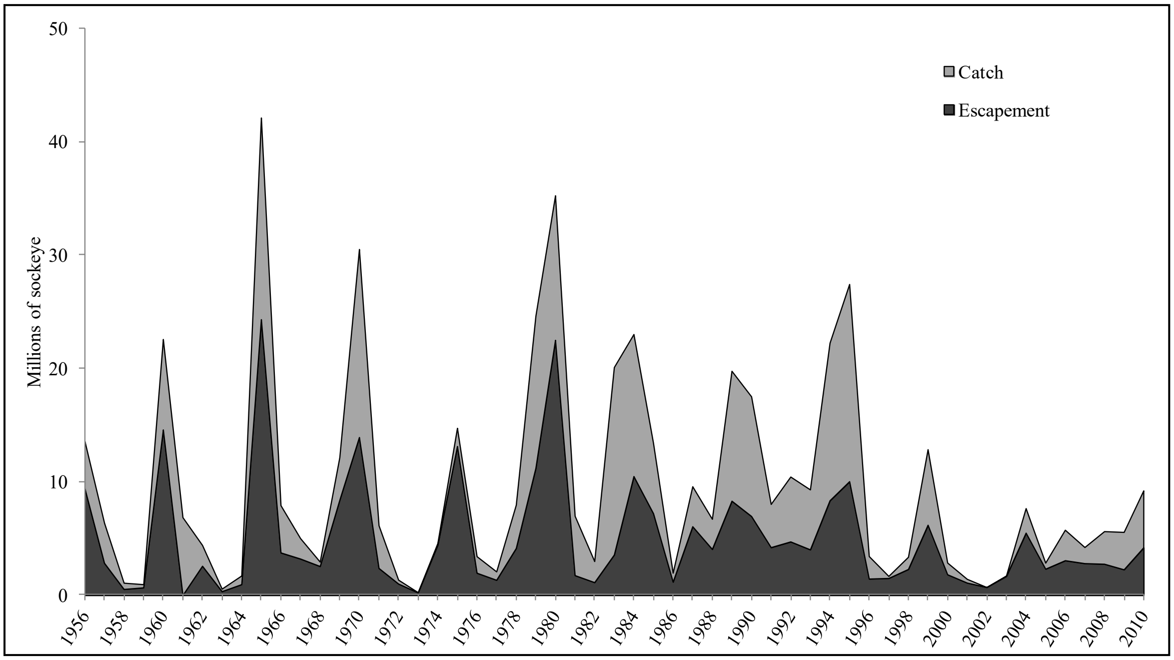


Figure 5. Catch and escapement trends for Kvichak River sockeye salmon. Source: LGL

Juvenile Sockeye Salmon

As Pacific salmon complete the fresh water stage of their life cycle, they undergo physiological changes to make the transition to salt water. This parr-smolt transformation includes changes in morphology and behavior that favors increased survival at sea (Groot and Margolis, 1991). In the early 1950s, fisheries scientists from the University of Washington and U.S. Fish and Wildlife Service started collecting biological data from the out-migrating sockeye salmon smolts in the Bristol Bay region (LGL, unpublished data). Smolts were first monitored from the Kvichak River near the village of Igiugig in 1957. ADF&G became the lead organization in 1961 and has collected smolt data annually since then (e.g., Crawford, 2001).

Biological data collected from the Kvichak River smolt studies usually include age, length, and weight, along with some information on smolt run timing and relative abundance. Fyke nets were used from 1956 through 1970 to capture smolts, so relative abundance estimates were based on catch per unit effort. In 1971, hydroacoustics were first tested on the Kvichak River to determine if total smolt abundance could be estimated. The results were rigorous enough that this method was used by ADF&G through 2000 (Crawford & West, 2001). Due to problems with aging sonar equipment and budget cuts, ADF&G sonar portion of smolt monitoring on the Kvichak River was discontinued in 2001; biological data continued to be gathered annually (Crawford and Fair, 2003). In 2007, the Bristol Bay Science and Research Institute (BBSRI) designed and built a new sonar system to estimate smolt outmigration in the rivers of Bristol Bay. This was first tested on the Kvichak River in 2008 and has operated annually since then, concurrent with ongoing biological data collected by ADF&G (Wade, Degan, Link, & Nemeth, 2013.).

Sockeye salmon smolt behavior on the Kvichak River has been characterized over the years using fyke net catches and sonar data. Across years, smolts tend to follow the same general behavior patterns in regard to run timing and distribution in the water column (Wade et al., 2013). These behaviors are thought to be driven in part driven by the evolutionary pressure for survival (Groot & Margolis, 1991).

Timing

Interactions between growth rate, body size, and environmental conditions are the primary factors that trigger the parr-smolt transformation. Photoperiod appears to drive this transformation, but water temperature also influences the timing of the annual outmigration (Groot & Margolis, 1991; Quinn, 2005). On the Kvichak River, outmigration generally coincides with the melting of ice on Lake Iliamna (mid-May) and is the timing for smolt sampling projects (Crawford, 2001). The length of the outmigration for sockeye salmon is somewhat compressed relative to other species of Pacific salmon

(Quinn, 2005). On the Kvichak River, the entire duration of the run is 2 to 3 weeks long, with the majority of fish out-migrating in the last week of May. From 2008 through 2012, greater than 85 percent of total smolts were detected in a period of 9 days, with 4-day peaks during this time accounting for > 50 percent (Wade, Degan, Link, & Raborn, 2010a, Wade, 2010b, Wade, 2011, Wade, 2012; and Wade et al., 2013), (Figure 6 and Figure 7).

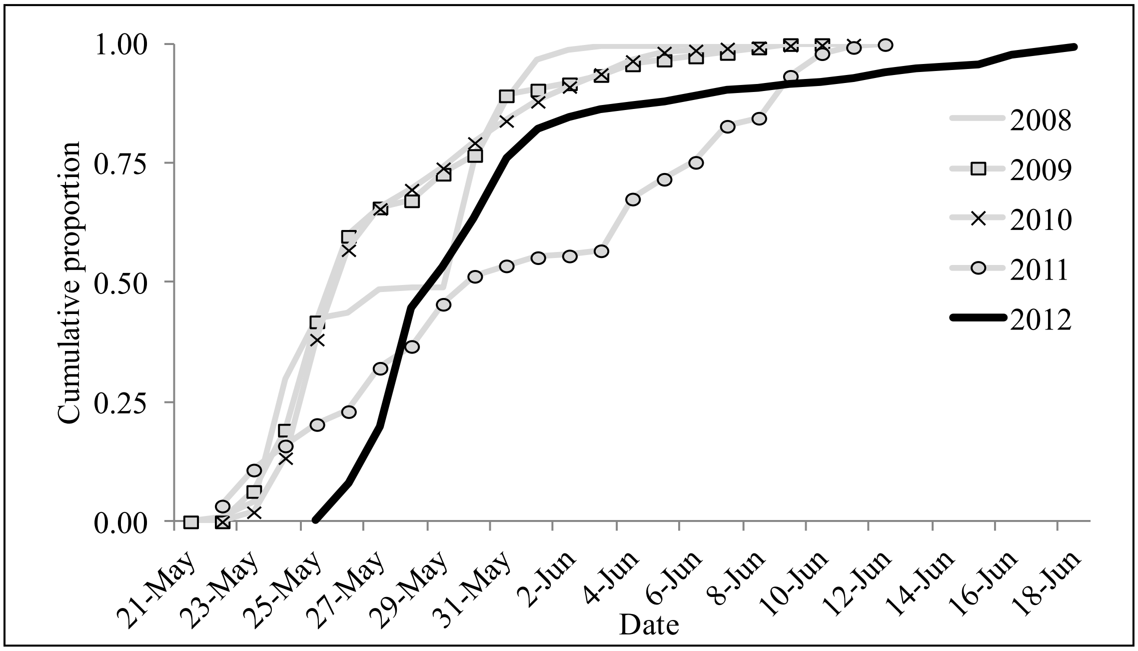


Figure 6. Run timing of sockeye salmon smolt out-migration, Kvichak River, 2008-12. Source: LGL

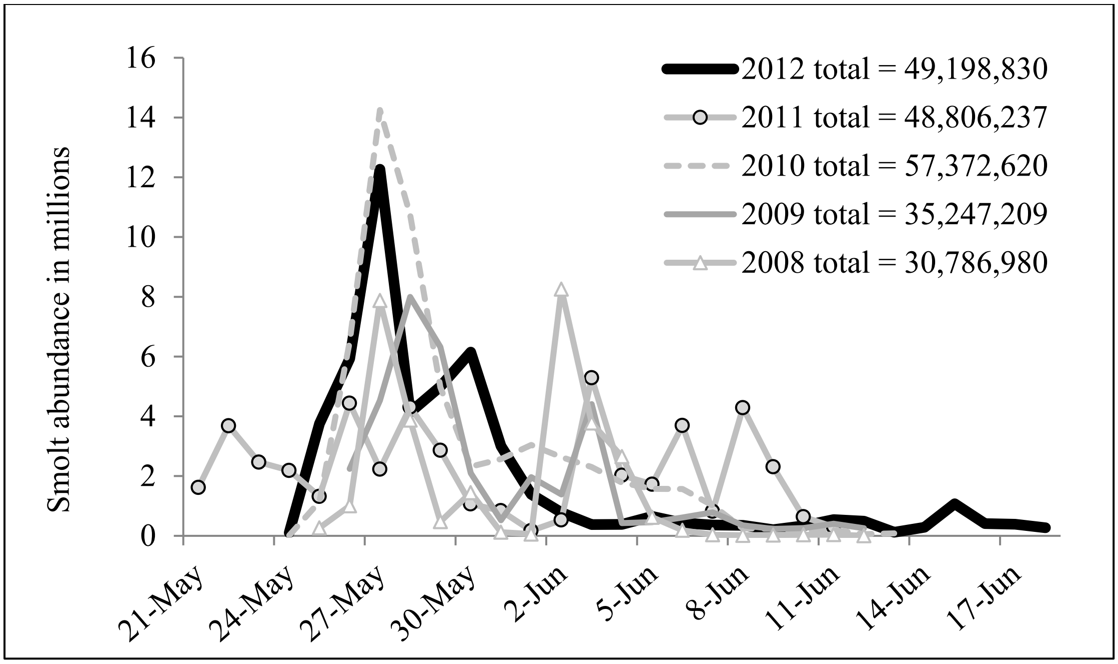


Figure 7. Estimated daily sockeye salmon smolt abundance, Kvichak River, 2008 – 2012. Source: LGL

Distribution

Past studies of sockeye salmon smolt behavior on the Kvichak River have indicated the majority of out-migrating smolts will migrate in the upper portion of the water column. Using video (from 2000) and acoustic data (2000 and 2001), Maxwell, Mueller, Degan, Crawford, McKinley and Hughes (2009) found that all smolts traveled in the top 1.0 m of water, and the majority of smolts were in the top 0.3 m. The Bristol Bay Science and Research Institute (BBSRI) study (2008-2012) characterized vertical distribution down to 2.5 m in depth, and then divided these data into two categories (dark, daylight) to check for diel differences in distribution. On the Kvichak River, the smolt vertical distribution was consistent across years for both periods of daylight and darkness (Figure 8). During the periods of darkness > 90 percent of smolts were detected in the upper 1.0 m and on average > 80 percent were found in the upper 0.5 m. Daylight distribution tended to be a little deeper, but in all cases > 81 percent were found in the 0.0 to 1.5 m strata. By utilizing the upper portion of the water column, smolts travel in the higher velocity water and therefore reduce the amount of energy expended to reach the sea.

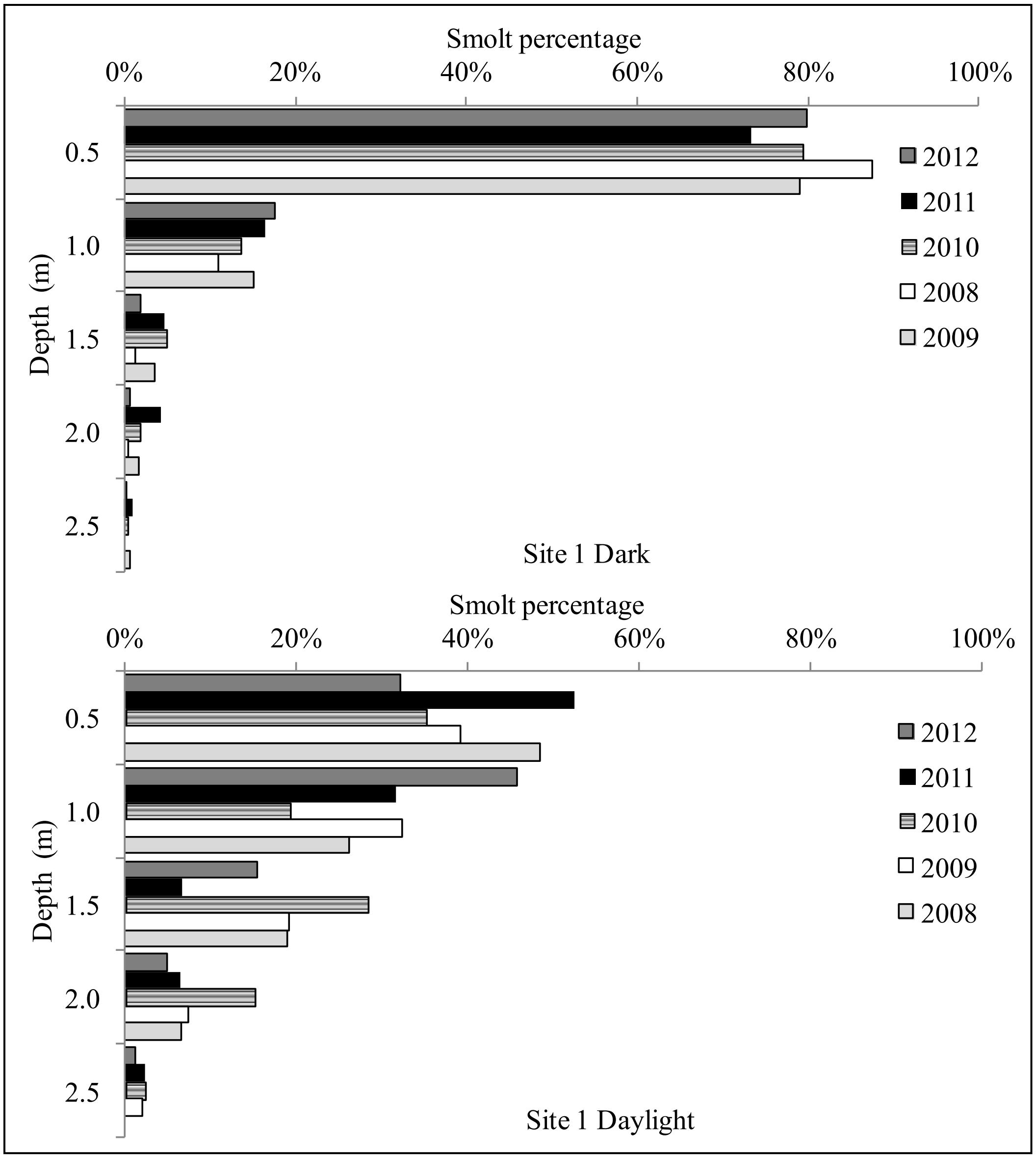


Figure 8. Vertical distribution of out-migrating sockeye salmon smolts, Kvichak River, 2008 – 2012.

Source: LGL

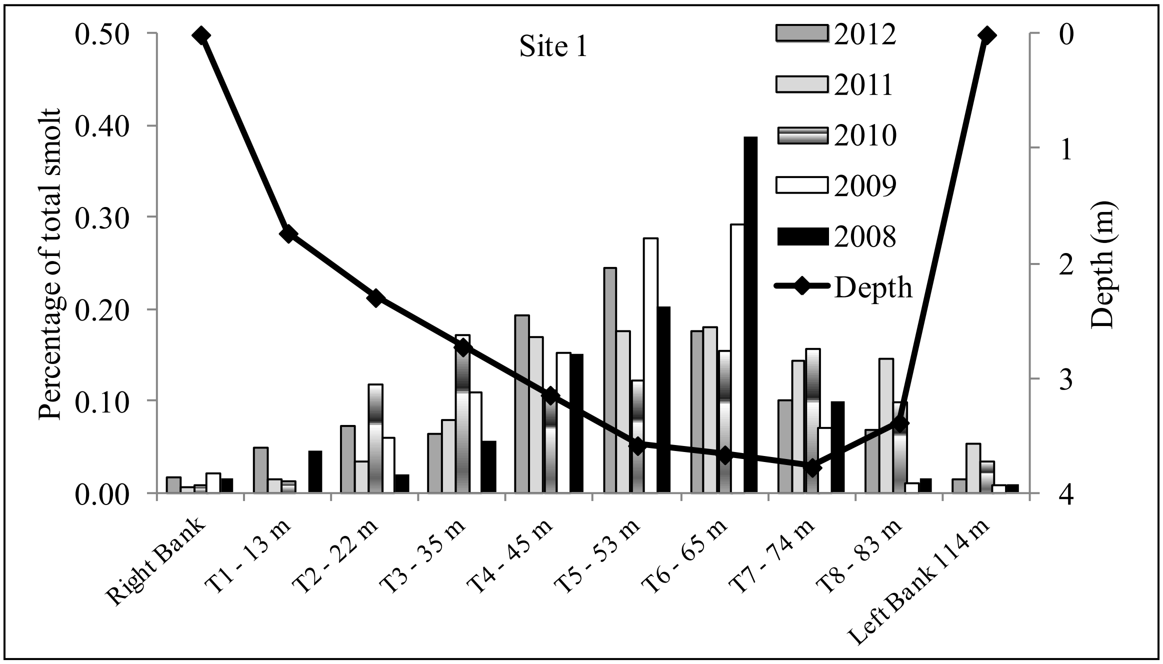


Figure 9. Cross-river distribution of sockeye salmon smolt, Kvichak River, 2008 – 2012. Source: LGL

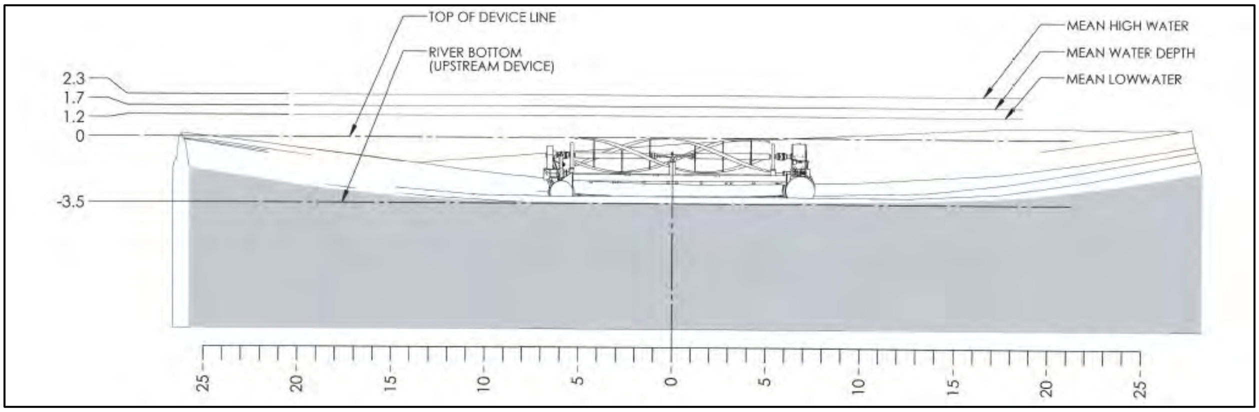


Figure 10. Cross section of RivGen® device from downstream, looking upstream. Generic river bed profile using 1:200 scale.

Abundance

Sockeye salmon smolt abundance on the Kvichak River was estimated annually from 1957 to 2001 by ADF&G, then annually since 2008 by BBSRI (Wade et al., 2013). Methods to estimate smolt abundance have gone through three fundamentally different changes since inception (LGL, unpublished data), so comparison of absolute numbers across eras is not valid. It is believed that estimates from hydroacoustics more accurately reflect the actual number of fish. During the period of time when the ADF&G sonar was thought to be operating correctly (1972-1992), annual estimates varied from 15 to 342 million smolts. The BBSRI estimates for Site 1 on the Kvichak River have ranged from 30-57 million smolts. Given the short duration of the smolt outmigration, it is possible that more than 20 million smolts move down the river in a 24-hour period.

Other Salmon

The Kvichak River is home to all five species of Pacific salmon in Alaska (sockeye, Chinook, coho, chum, and pink salmon), all of which are fished commercially and for subsistence (Table 5). There are also in-river sport fisheries for Chinook, coho, and sockeye salmon. Pacific salmon are anadromous and share similar life histories with respect to spawning migration. In general, pink and chum spawn in the lower reaches of rivers while sockeye, Chinook, and coho salmon will travel further up the basin to preferred spawning and rearing habitat. Juvenile pink and chum salmon typically migrate downstream immediately after hatching (Groot & Margolis, 1991).

Table 5. *Historical salmon harvest in the Kvichak River region.*

Naknek/Kvichak Harvest - 20 Year Average[a]	Sockeye	Chinook	Coho	Chum	Pink
Commercial (1990 - 2010)[b]	8,238,895	2,816	4,436	255,487	73,661
Subsistence (1989 - 2009)	77,653	1,323	1,218	844	957

[a] Morstad et al. 2010, Salomone et al. 2011

[b] Commercial fishing is limited to Kvichak Bay (i.e., no commercial fishing occurs in the Kvichak River).

Although extensive research has been conducted on sockeye salmon in the Kvichak River, little effort has been dedicated to the study of the other four species of salmon near the Project. ADF&G conducts annual spawning ground surveys in the Naknek/Kvichak drainage, but the majority of the effort is in the Naknek River and its tributaries (Salomone, et al. 2009), which are downstream of Igiugig and the Project. According to the ADF&G Anadromous Waters Catalog, several streams above the Village of Igiugig support spawning populations of sockeye, Chinook, and coho salmon, whereas pink and chum salmon are rarely found (Table 6).

Table 6. *Distribution of salmon in tributaries of the Kvichak River by life stage.*

	Species/Lifestage[a]				
Location	Sockeye	Chinook	Coho	Pink	Chum
Kaskanak Creek	p	s	s	s	s
Ole Creek	s	p	p		p
Pecks Creek	s	p	p		s
Belinda Creek	s	s			
Dennis Creek	s				
Gibraltar Creek	s				s
Kakhonak River	s				
Copper River	s	s			
Tommy Creek	s				
Iliamna River	s	p	p	p	p
Pile River	s				
Knutson Creek	s				
Canyon Creek	s				
Chekok Creek	s		p		
Chekok Bay Creek	s		p		
Stonehouse Creek	s				
Eagle Bay Creek East	s				
Eagle Bay Creek West	s				
Roadhouse Creek	s		s		
Newhalen River	s	s	p		
Pete Andrews Creek	s				
Upper Talarik Creek	s, r	s	s, r	p	s
Lower Talarik Creek	s	p	s		
324-10-10150-2155	s		p		

[a] p - present, m - migration, r - rearing, s - spawning. Alaska Department of Fish and Game (2011). Anadromous Waters Catalog Overview.

Aside from sockeye salmon, little is known about the age and run timing of juvenile salmon upstream of Igiugig (ADF&G, 2011). ADF&G records incidental non-sockeye salmon catch that occurs during the sockeye salmon smolt project on the Kvichak River, but abundance and run timing are not estimated using these data (Crawford, 2001). Regardless, the out-migrating smolts from these other species could encounter the RivGen® device(s) (Quinn, 2005; Groot & Margolis, 1991). The age at which Chinook and coho will smolt varies from system to system but ranges from 0 to 2 years for Chinook and 0 to 4 years for coho (Morrow, 1980; Quinn, 2005; Groot & Margolis, 1991). Age-1 and older Chinook and coho smolts are larger than the respective aged sockeye smolts, so they may be better able to avoid the RivGen® device(s).

Chum and pink salmon usually out-migrate immediately after emergence from the gravel (Groot & Margolis, 1991); therefore, juvenile chum and pink salmon originating upstream of Igiugig would likely have already migrated past the Project site by the time of redeployment in late June.

4.2 RESULTS OF PREVIOUS MONITORING

4.2.1 2015 MONITORING

Fish and wildlife monitoring was performed by LGL in 2015, in accordance with the 2015 Monitoring Plan and ADF&G Fish Habitat Permit FH 15-II-0038. Data was collected around the RivGen® 1.F Power System deployed in the Kvichak River in July and August 2015. The RivGen® was deployed from approximately July 10 through September 15 in 2015, which overlapped with part of the migration of adult salmon and rainbow trout, among other species (Table 2). This time period did not overlap with the main migration timing of juvenile sockeye salmon, which migrate downstream from approximately May 21 through June 10 (Figure 6).

Fish movements at the RivGen® device were described using video footage collected from five underwater cameras mounted to the pontoons of the power system. Video footage was collected 24 hours/day July 19–25 and again August 19–27, 2015; review was done by watching the first 10 minutes of a selected hour from each of the four primary cameras (the fifth camera was a backup). Spatially, the camera field of view captured the port side of the RivGen® device, including upstream and downstream views of the port side turbine (only, due to reduced visibility from variable river turbidity of the starboard side turbine). In accordance with the 2015 Monitoring Plan, footage was reviewed to achieve partial temporal coverage during different categories of turbine operating status and daytime/nighttime conditions. At night, two underwater lights lit the viewing area. In addition, bird and marine mammal surveys were conducted for 15 minutes each morning of monitoring. Methods and the overall approach were similar to those described for the demonstration study conducted at the same site in 2014.

Blocks of video footage from portions of 238 different hours were reviewed in season in 2015. There were 359 events with fish, composed of approximately 1,202 individual fish from at least six species. The majority of fish observations were of solitary fish; the largest school was approximately 100 fish. Species composition varied from July to August and also from day to night. In particular, salmon smolt were almost exclusively seen at night, and were more prevalent in July than August. Several instances of fish moving through the RivGen® turbine were noted and reported in season as part of the Project's adaptive management process. LGL did not detect any obvious physical injuries to fish and saw no altered behavior by wildlife near the RivGen® device. Cameras, lights, and power system components all operated reliably. All video footage was archived. The LGL monitoring report in included as Attachment 1 to this Plan. (LGL 2015)

4.2.2 PNNL DATA ANALYSIS

Video data collected as part of the 2015 RivGen® Power System monitoring provided a valuable opportunity for further analysis to better quantify interactions between fish and the turbine. As a result, the U.S. Department of Energy commissioned PNNL to conduct data analysis and to develop potential automation techniques for future monitoring. The goal of PNNL's analysis of video data collected around ORPC's RivGen® device deployed in the Kvichak River during July and August 2015 was to gain an understanding of the implications of using underwater video cameras as a fish monitoring technique. The data were analyzed manually and used to develop automated algorithms for detecting fish in the video frames and describing their interaction behavior relative to the device. In addition, PNNL researchers developed a web application, EyeSea, to combine manual and automated processing, so that ultimately the automated algorithms could be used to identify where human analysis was needed (i.e., when fish are present in video frames). The EyeSea software is discussed further in Section 6.3.1 of this Plan.

The manual analysis began to look at all data from the start of deployment of the RivGen® device, primarily using video from Camera 2 that looked directly at the upstream side of the turbine, so any interaction could be identified; this was to ensure rare events were seen, and initially focused on nighttime data when more fish were present. This process highlighted the amount of time it takes to identify fish, and ultimately only 42.33 hours of video were reviewed because of the time-consuming analysis. The data were classified as "Fish" when the reviewer was confident it was a fish, and "Maybe" is defined by an object that during manual analysis is deemed to possibly be a fish, but not a definite identification. The two classes were distinguished based on the movement, shape, and color characteristics. Fish Events were further classified by "adult", "juvenile", or "unidentifiable" age. Behavioral attributes were noted and were broadly divided into Passive and Avoidance activities. In over 42 hours of the data reviewed, there were 20 potential contact interactions, of which 3 were "Maybe" classifications, 12 were juveniles, and 5 were adults. While only 11.5% of the video data were analyzed from Camera 2, these results are from the time when most fish were present over the turbine deployment period (ADF&G data) and provide preliminary evidence that fish strike or collision of fish in the Kvichak River with an instream turbine is rare.

On only one occasion was an actual contact confirmed, and this was an adult fish that contacted the camera, not the turbine itself. This experience highlights the difficulties associated with confirming a strike or collision event as either having occurred or having been a near-miss. More interactions were detected at night; this was probably biased by nighttime use of artificial light, which may have attracted fish, but also could have increased detection probability because light is reflected from the fish itself.

The full PNNL report (Matzner, et al. 2017) is included as Attachment 2.

4.3 BEST AVAILABLE SCIENCE

As an emerging industry, development of marine and hydrokinetic projects has been hampered by a lack of best available science that demonstrates environmental interactions with power systems. However, results of LGL fish and wildlife monitoring in 2014 and 2015 as well as analysis completed by PNNL in 2015 were consistent with a growing global knowledge base of recently published data that indicates negligible environmental effects from hydrokinetic turbines. Many of the global studies associated with marine energy project are accessible on the Tethys website managed by PNNL: https://tethys.pnnl.gov/

Detailed environmental studies have been conducted around ORPC power systems in both tidal and river environments. ORPC's TidGen® Power System was used for the Cobscook Bay Tidal Energy Project in Maine. The TidGen® device is comprised of the same core technology as the RivGen® device but on a larger scale. In Cobscook Bay, researchers have an understanding of changes in fish density over time. Monitoring recorded little interactions between fish and turbine foils and revealed that small fish move through the turbines. Side-looking sonar revealed some deflections or avoidance behavior occurring in the range of seven to fifteen meters from the turbine. Mobile transects indicated fish responded further away from the device, in the range of 10 to 140 meters from the device. The behavioral effect footprint around device may be within ten to one hundred and forty meters, and it has been observed that once fish move past the device, direction of movement was with the water current as shown in Figure 11. It should be noted that the TidGen® device is over twice the size of the RivGen® device.

Additional resources for best available science are included in Section 11, References of this Plan.

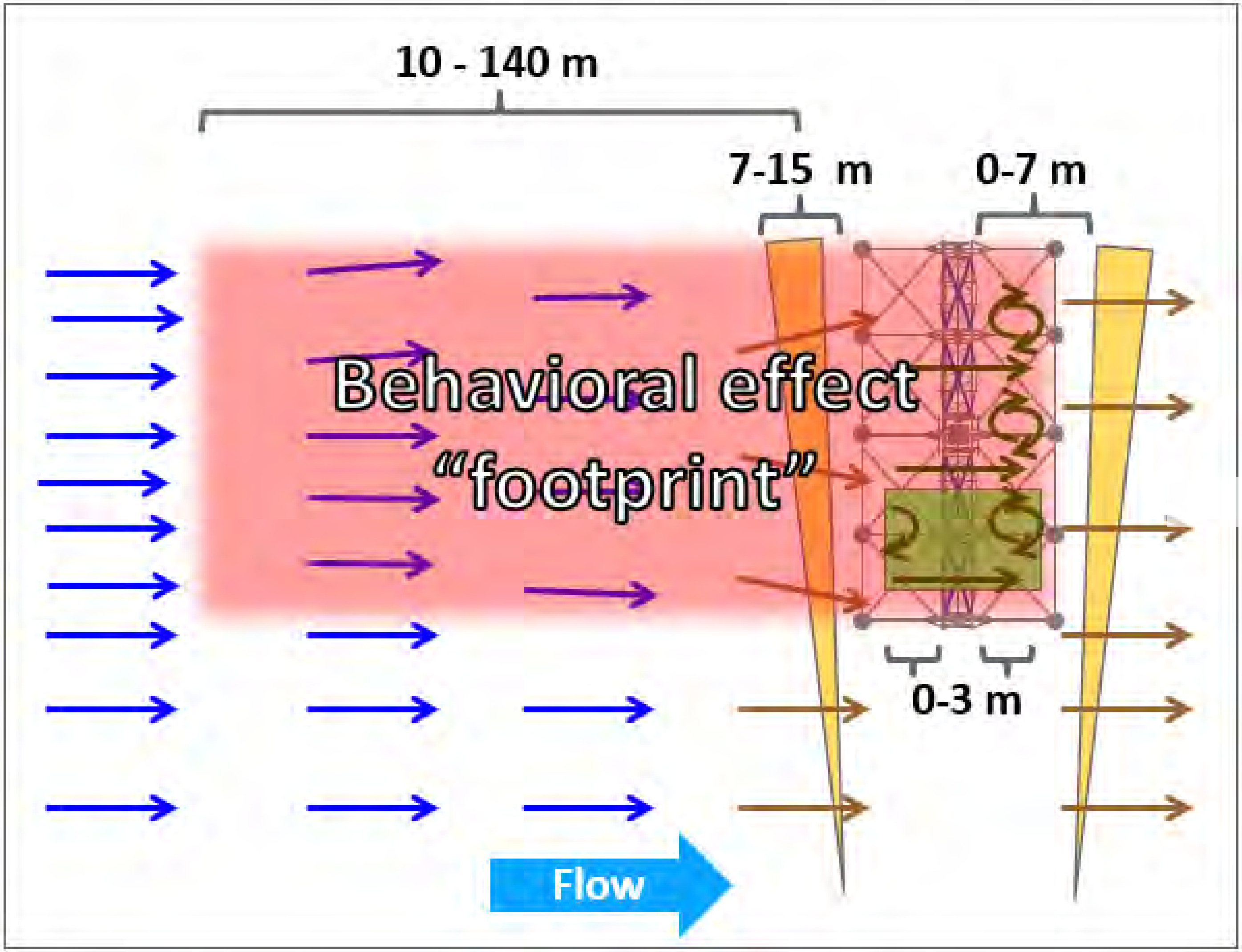


Figure 11.Synthesis of fish studies for ORPC's Cobscook Bay Tidal Energy Project (Source: University of Maine)

5.0 PROJECT NEXUS

The Fish Monitoring Plan prepared by ORPC and UAF describes a rationale for preparing the monitoring plan, objectives, and how the objectives will be achieved. The issues, observations, and data required for this process are based on content as per FERC regulations §5.6(d)(3)(i), §5.6(d)(3)(iv), §5.11, §5.18(b)(5)(ii)(B), and §5.18(b)(5)(ii)(C). In addition, the information needs of ADF&G to prepare a Fish Habitat Permit (FHP, Title 16 Permit) are considered as based on Durst (2011). The primary objective of the monitoring program is to document how migrating fish interact with and pass the RivGen® device(s).

6.0 METHODOLOGY

The Fish Monitoring Plan has been developed to incorporate lessons learned from 2014 and 2015 testing of the RivGen® Power System at the Project location in the Kvichak River at Igiugig and an adaptive management process. Faculty and staff of UAF College of Fisheries and Ocean Sciences and Alaska Hydrokinetic Energy Research Center (AHERC) will work with the Project lead, IVC, and Project partner, ORPC, to monitor interactions between fishes and a hydrokinetic turbine in the Kvichak River, near Igiugig, Alaska.

6.1 OVERVIEW

The Fish Monitoring Plan has been prepared by ORPC and UAF with input from Project partners at UW and PNNL. The issues, observations, and data required for the Fish Monitoring Plan are based on content required by FERC regulations §5.6(d)(3)(i), §5.6(d)(3)(iv), §5.11, §5.18(b)(5)(ii)(B), and §5.18(b)(5)(ii)(C). In addition, the information needs of ADF&G to prepare a Fish Habitat Permit (FHP, Title 16 Permit) were considered as based on Durst (2011).

Monitoring results and lessons learned from the 2014 and 2015 RivGen® Power System testing at the Project location has informed the Fish Monitoring Plan. This Plan will include monitoring equipment, operation schedule, and revised monitoring costs.

6.2 EQUIPMENT

It is recommended that two pairs of underwater stereo cameras (two cameras per stereo pair for a total of four cameras) will be mounted on the port pontoon of the pontoon support structure to record fish behavior. Forward camera(s) will be placed so that the field of view (FOV) includes both the upstream end and the side of the devices. Aft camera(s) will be placed so that the FOV include the downstream end and the side of the devices. Cameras will be mounted in a way that most effectively captures the intended FOVs (Figures 12 and 13).

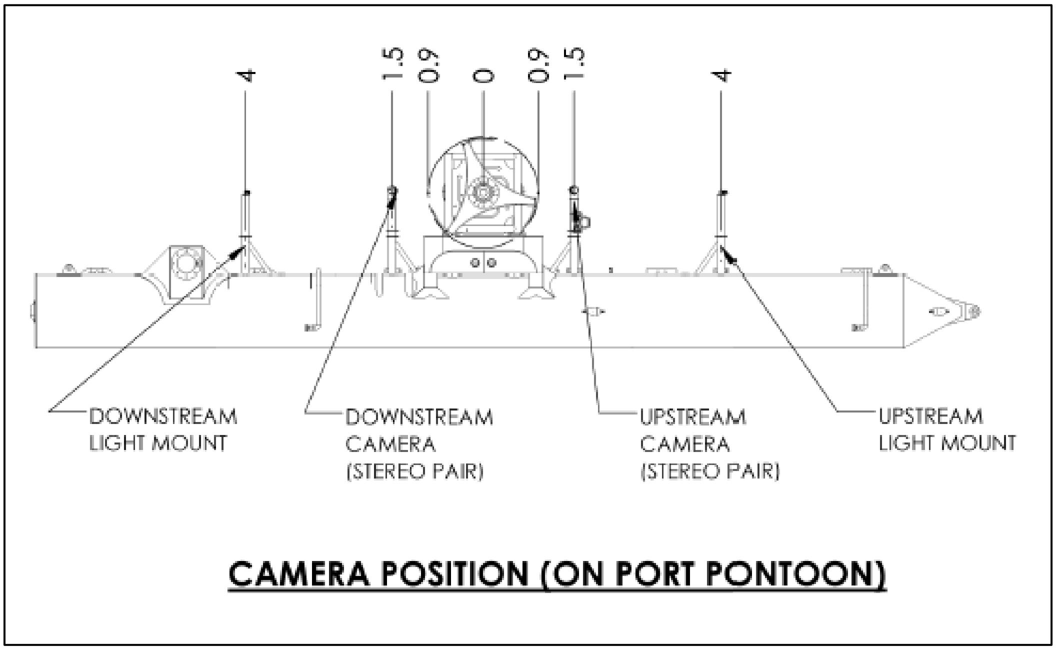


Figure 12. Cross-section view of RivGen® device environmental monitoring system. River flow from right to left. Dimensions in meters. (Source: ORPC)

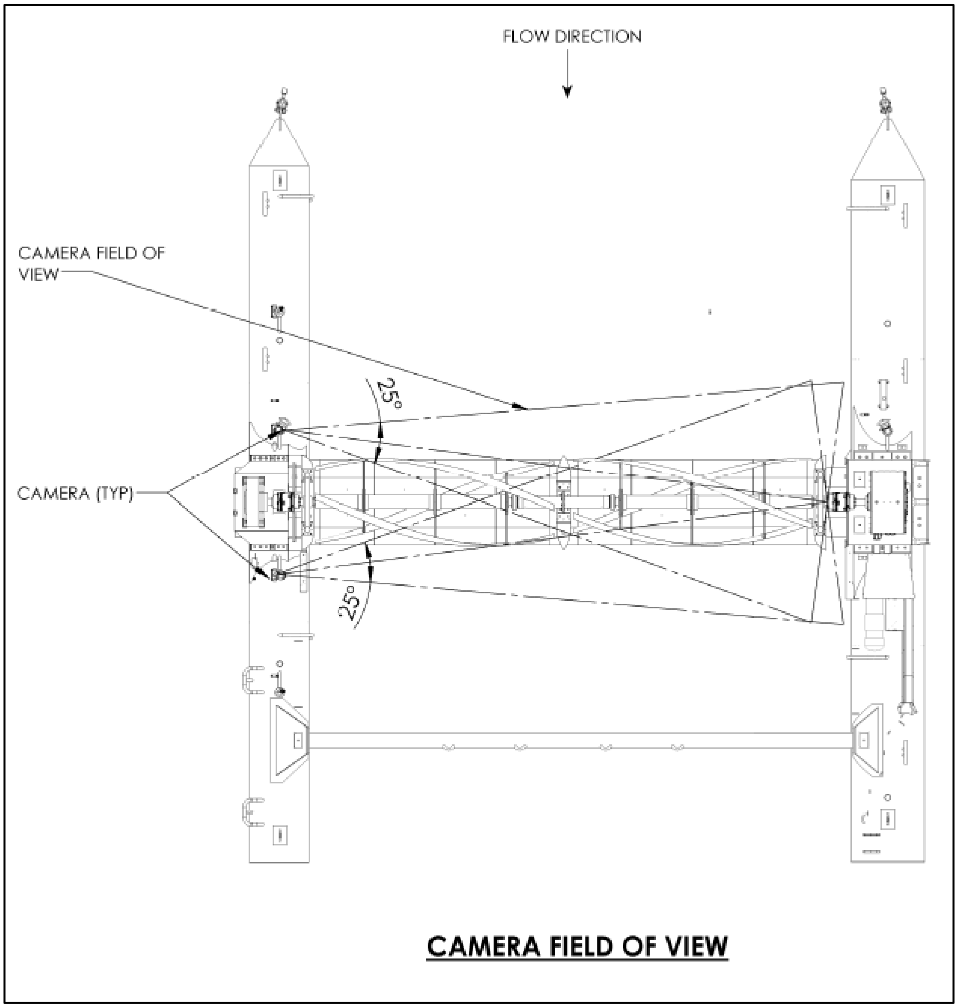


Figure 13. Plan view of RivGen® device environmental monitoring system showing camera beam angles. River flow from top to bottom.

6.2.1 CAMERAS

Cameras will be high resolution (600 TV Line) monochrome cameras capable of operating in low light conditions (0.01 lux). Cameras will have a wide-angle lens with a 25° FOV and an operating distance of 18 m (Table 7). Upstream and downstream cameras will be set in a stereo-optic configuration within a marine science grade acrylic enclosure with clear wide-angle dome ports and wet-mateable connectors. A polyurethane-jacketed data/power cable will run from each camera to the environmental monitoring module located on the device. Specifications for the camera and associated accessories are included in Attachment 3.

Table 7. *Environmental Monitoring Cameras. Source: ORPC*

Lens focal length	Minimum Camera Resolution	Estimated total pixels on target at Minimum resolution	Uncompressed data rate (MB per frame)
16 mm	800x600	25	0.96

6.2.2 LIGHTS

The environmental monitoring system will include lights to provide better illumination of the video field of view during night time monitoring. Because a sonar camera (e.g., DIDSON or ARIS) will not be included in the environmental monitoring system, it will not be possible to assess the effects of the lights on fish behavior, specifically whether the lights are an attractant or repellent to fishes. Generally, it is thought that lights are an attractant, so behavioral analyses conducted while the lights are on 10 minutes of each hour will be considered to represent the upper bound in number of fish/turbine interactions. During time periods when fish behavior will not be observed (50 minutes of each hour), lights will be turned off. Light specifications are included in Table 8 and Attachment 3.

Table 8. *Environmental Monitoring Lights. Source: ORPC*

Typical Lumen Output (Flood)	Efficacy	Color	Beam Angle
0-10,000 dimmable	94 lm/w[1]	Daylight White (5,000 k ~ 6,000 k)	Spot: 35 degrees

6.3 DATA ANALYSIS

During initial deployment of the Phase I RivGen® device (Summer 2019), UAF personnel will be present onsite in Igiugig for deployment of cameras and initial video collection. While onsite, UAF personnel will evaluate video to ensure that the collected footage is appropriate for monitoring interactions between fishes and the turbine. Additionally, UAF personnel will work with PNNL personnel and project partners to design the most feasible method for delivering recorded video footage to the UAF campus for subsequent analyses of potential fish/turbine interactions. Once the Project lead and partners are comfortable with the camera set up and method of video footage delivery, UAF personnel will conduct video analyses, in consultation with PNNL, at the UAF campus (approximately July 2019-May 2020). Video captured by cameras deployed at the base of the turbine will be analyzed to identify interactions between fishes and the turbine, including strikes, avoidance behavior, and lack of reaction utilizing the EyeSea software developed by PNNL. For each interaction between fishes and the turbine, species will be identified, and size will be estimated.

Should the turbine be deployed in late Spring 2020 it will likely be before or during the peak of the sockeye salmon smolt outmigration. Sockeye salmon smolt typically emigrate from Lake Iliamna to the Bering Sea, via the Kvichak River in a large pulse lasting <4 weeks (last two weeks of May and first two weeks of June) and consisting of 10s of millions of individuals (Nemeth et al. 2014). Because of the socioeconomic importance of sockeye salmon coupled with the short, intense emigration through the Kvichak River, this has been identified as ADF&G's priority monitoring period due to the elevated potential for fish/turbine interactions. As a result, UAF personnel will be on-site at all times while the turbine is deployed during the sockeye smolt outmigration from May 21 through June 10, 2020 and will conduct video analyses, as requested by ADFG. The adult sockeye salmon migration (25 June to 15 July) has also been identified as a priority time period. During priority time periods, 10 minutes of every hour around the clock will be recorded. The video collected will be run through supervised analysis each afternoon by EyeSea software, in which the software will identify fish interaction events and UAF fish biologists will classify the events after identification. After daily video review, daily summaries of fish/turbine interactions will be provided to IVC, ORPC, ADFG and interested parties as part of the adaptive management plan. Additionally, once every three days, validation of EyeSea software will be accomplished by comparing results of identification of fish interactions by EyeSea software and UAF fish biologists. During this validation, one total hour of randomly chosen 10-minute video segments (6 total segments x 10 minutes each segment = 1 total hour) will be reviewed by both EyeSea software and visually by UAF fish biologists, and the number of fish interactions will be compared. As the rigor the EyeSea software in reliably detecting fish events is validated intervals between groundtruthing events will be extended based on input from the AMT. Finally, during non-priority time periods, video recording duration will be reduced as part of the AMP. For example, during winter, video of 10 minutes of every 3 hours will be recorded and run through supervised analysis.

6.3.1 EYESEA SOFTWARE

In parallel to PNNL's analysis of the 2015 video data collected around the RivGen® device, EyeSea was developed to convert the video data to a usable form and to enable manual and automated analysis of the data that would have a standardized output. The project goal was to develop software algorithms that could identify video frames with fish present to inform and accelerate manual analysis. To achieve this, independent manual analysis was completed for specific video clips (i.e., visual analysis and annotation by a human observer was the standard for assessing the algorithms). The analysis process indicated that some confounding aspects of the algorithm development could potentially be solved with recommended improvements in the initial camera data collection methods.

For the algorithm development, background subtraction, optical flow, and Deep Learning techniques were considered. The Deep Learning approach was determined to need too much training data for this application, so its use was not continued. The optical flow analysis was considered promising, but did not give immediate results, so it needs further investigation. Therefore, background subtraction was the primary focus in algorithm development. Three methods of background subtraction were tried: Robust Principal Components Analysis (RPCA), Gaussian Mixture Model (GMM), and Video Background Extraction (ViBE). A classification technique was then applied to the foreground images to determine fish presence. Using this combination, fish could be accurately identified when occupying a higher number of pixels (>200 pixels, 98.2 percent correct; 100–200 pixels, 99.6 percent correct; 5–100 pixels, 85.4 percent correct; 2–5 pixels, 66.3 percent correct).

ORPC and UAF are collaborating with PNNL to use the EyeSea software as a tool for analyzing data collected as part of this Project. As part of this collaboration, video collected during the Project will be used to further refine the software for the future. Additionally, it is anticipated that PNNL will continue to make improvements to the software prior to implementation in 2019. The full PNNL report (Matzner, et al. 2017), including both data analysis and algorithm development, is included as Attachment 2.

6.3.2 DATA STORAGE

Data Storage will include mention of the following:

- Data will be stored on two separate Tb-sized Raid Hardrives or similar.
- Data will be accessed daily when UAF personnel are in field and a minimum of bi weekly when UAF personnel are reviewing data remotely.

6.3.3 SAMPLE RATE

Due to data volume and hard drive storage constraints, ten minutes of each hour throughout a 24 hour period will be recorded by video cameras regardless of whether the turbine is spinning or not, during priority periods. For this study, priority periods are defined as the sockeye smolt outmigration (May 21-June 10) and the adult sockeye salmon migration (25 June to 15 July). These video recordings will be stored on hard drives. Each afternoon, video footage will be run through supervised analysis by UAF personnel. In this supervised analysis, EyeSea software will identify fish interactions and these will subsequently be classified by UAF fish biologists. During expected migratory periods of smolts and adults, we will start by running four hours of video per day through supervised analysis and interaction classification. After a week of daily summaries are produced and sent to ADFG, IVC will consult with ADF&G to confirm the sampling rate is adequate to assess fish interactions and if necessary make adjustments through the adaptive management process. For example, if fish interactions are relatively common and/or fish interactions are difficult to visually classify, the amount of recorded video could be increased (for example, to 15 min of each hour). In contrast, if fish interactions are extremely rare and there are no documented turbine-fish collisions, the amount of recorded video could be decreased, with the concurrence of ADF&G and the Adaptive Management Team, to wisely use staff and equipment resources. During non-priority time periods, such as winter, video of 10 minutes of every 3 hours will be recorded and run through supervised analysis. Reporting to ADF&G during these non-priority time periods will initially occur on a bimonthly basis but may be reduced to monthly summary reports if fish interactions are extremely rare and non-consequential. During shoulder seasons between priority and non-priority time periods, video sampling rate will be gradually scaled back at a rate with which IVC, ORPC, UAF and ADFG are comfortable.

6.4 FIELD VERIFICATION

UAF personnel will be onsite during initial deployment in 2019 and any operations that overlap with the main migration timing of juvenile sockeye, which migrate downstream from approximately May 21 through June 10 annually (Figure 6). UAF personnel will adjust camera settings and operational modes, and review data acquired through different settings to optimize data acquisition during these sensitive periods. Furthermore, they will process and review data on a daily basis, perform manual groundtruthing checks to ensure EyeSea software is adequately identifying fish events within a reasonable margin of error, and report any fish events that reveal likely impacts to ADF&G. Manual groundtruthing will initially occur once every three days during priority periods. To accomplish this validation of EyeSea software, one total hour of randomly chosen 10 minute video segments (6 total segments x 10 minutes each segment = 1 total hour) will be reviewed by both EyeSea software and visually by UAF fish biologists, and the number of fish interactions will be compared. As the rigor the EyeSea software in reliably detecting fish events is validated intervals between groundtruthing events will be extended based on input from the AMT.

6.5 ADAPTIVE MANAGEMENT

The project team will implement an adaptive management approach that has proven valuable in previous projects implemented by ORPC. ORPC has demonstrated that through an engaging and open adaptive management process, project license conditions can be modified to keep levels of monitoring proportional to measured environmental risk. Adaptive management is a structured, iterative process of scientific decision making in the face of uncertainty with an aim to reducing uncertainty over time via system monitoring.

ORPC developed an Adaptive Management Plan as a condition of its FERC pilot project license for the Cobscook Bay Tidal Energy Project in Maine. The plan and the project's adaptive management team have been touted in the industry as a model based on its transparency and demonstrated actions. Key elements of the Plan's success include the following:

- Strong relationships built on integrity and trust
- Science-based data collection by respected technical advisors
- Initiating adaptive approach in the pre-consent phase and continuing through project operation
- Building an environmental interaction knowledge base of ORPC power systems deployed at other sites and pertinent global industry information

ORPC has developed monitoring plans for the Igiugig Hydrokinetic Project that will advance the Project in an environmentally responsible manner and build on lessons learned from past renewable energy projects and data gathered around its power systems, including 2014 and 2015 testing of the RivGen® Power System at the Project location. An Adaptive Management Plan is included in Appendix A of the FPLA.

7.0 REPORTING

IVC will file full summary reports with the regulatory agencies annually. These reports, authored by UAF fisheries personnel, will describe analyses conducted on video footage collected by cameras deployed on the turbine. The results of these analyses will directly address the four study objectives:

1. Document the presence and timing of fish at the RivGen® device by species and life stage
2. Characterize fish movements past the RivGen® device during the sockeye salmon smolt out migration
3. Describe the behavioral response of sockeye salmon smolt that comes into contact with the RivGen® device
4. Describe any observable acute effects from contact with the RivGen® device, including disorientation, injury, or mortality during the sockeye salmon smolt out migration

Should altered fish activity be noted at any time during the observations, the appropriate federal and state resource agencies will be notified for consultation. This is particularly important during the sockeye salmon smolt outmigration, when analyses will be conducted daily.

8.0 SCHEDULE

Pending receipt of the FERC pilot license, monitoring will be performed around the single-device RivGen® Power System beginning in 2019. UAF will review and certify all data collected, and IVC will issue reports on monitoring progress to the appropriate regulatory agencies for technical review biannually. Monitoring methods and frequency will be reviewed by IVC and its partners with appropriate regulatory agencies and modifications made as appropriate through an adaptive management process. This process will inform continued monitoring for Phase I as well as be used to determine appropriate levels of monitoring for Phase II prior to the installation of the second RivGen® device. All data collected in this monitoring effort will be in the public domain, in accordance with the public nature of the FERC pilot license process.

9.0 BUDGET

IVC is targeting an average annual environmental monitoring cost of approximately $30,000 over the course of the ten-year pilot license. It is anticipated that levels of annual monitoring, and associated costs, costs will be higher during the first several years of the Project when initial monitoring efforts will cost approximately $175,000 and be reduced in accordance with protocols established in the Project Adaptive Management Plan.

10.0 DISCUSSION OF ALTERNATIVE APPROACHES

IVC believes the Project has little potential to affect fish and wildlife. ORPC has been testing hydrokinetic power devices in field environments since 2007, and during this time, has not observed any negative environmental effects of these devices. In addition, the Project is small relative to the available habitat in the Kvichak River and will be monitored for direct interaction with aquatic life. IVC believes that the Fish Monitoring Plan, in conjunction with the Adaptive Management Plan, is sufficient to inform licensing decisions, that it is appropriate to the size and scope of the Project, and that the approaches proposed in the study are in general accordance with those recommended by the resource agencies.

11.0 REFERENCES

Bevelhimer, M., Scherelis, C., Colby, J., Tomichek, C., and Adonizio, M.A. 2015. Fish behavioral response during hydrokinetic turbine encounters based on multi-beam hydroacoustics results. In Proceedings of the 3rd Marine Energy Technology Symposium (METS), April 27–29, 2015, Washington, D.C.

Broadhurst, Melanie, Sue Barr, and C. David L. Orme. 2014. “In-Situ Ecological Interactions with a Deployed Tidal Energy Device; an Observational Pilot Study.” Ocean & Coastal Management, vol. 99, 31-38. doi:10.1016/j.ocecoaman.2014.06.008

Durst, J. (2011). Fish population concerns related to hydrokinetic development and permit requirements in state waters. ADF&G. Presented at the Alaska Hydrokinetics Technical Conference, Dena’ina Center, Anchorage, AK.

Hammar, Linus, Sandra Andersson, and Linda Eggertsen. 2013. "Hydrokinetic Turbine Effects on Fish Swimming Behaviour." PLoS ONE, vol. 8(12), 1- 12. http://dx.doi.org/10.1371/journal.pone.0084141

LGL (2015). LGL Alaska Research Associates, Inc. Fish and Wildlife Monitoring Plans and Reporting for RivGen® Power System testing, Igiugig, Alaska, 2014 and 2015.

LGL Alaska Research Associates, Inc. (unpublished data). An historical review of the Bristol Bay smolt monitoring program and recommendations for future smolt sampling. Unpublished report prepared by the Bristol Bay Science and Research Institute, Dillingham, AK.

Matzner, S.; Trostle, C.; Staines, G.; Hull, R.; Avila, A.; Harker-Klimes, G. (2017). Triton: Igiugig Fish Video Analysis. Report by Pacific Northwest National Laboratory (PNNL). pp 60.

Nemeth, M. J., Priest, J.T. and Patterson, H.M., 2014. Assessment of fish and wildlife presence near two river instream energy conversion devices in the Kvichak River, Alaska in 2014. Final report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, for Gray Stassel Engineering, Anchorage, AK. 28 pp. + appendices.

Nemeth, M. J., G. D. Wade, D. J. Degan, and M. R. Link. 2014. Sockeye salmon smolt abundance and inriver distribution in Bristol Bay, Alaska: results from the Kvichak, Ugashik, and Egegik rivers in 2013. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK, 55 pp. + appendices.

Shen, H., Zydlewski, G.B., Viehman, H.A., Staines, G. 2016. Estimating the probability of fish encountering a marine hydrokinetic device. Renewable Energy 97: 746-756.

TerraSond (2011). Kvichak River RISEC Project. Resource reconnaissance and physical characterization. Final Report. Prepared by TerraSond Ltd., Palmer, AK for Dept. of Community and Economic Development, AIDEA/AEA, Rural Energy Group, Anchorage, AK

Thomson, J., Kilcher, L. and Polagye, B. (2014). Flow measurements during RivGen® deployment Igiugig, AK. 2014. U.S. Department of Energy, DE-EE0006397.

Viehman, H. 2012. Fish in a tidally dynamic region in Maine: Hydroacoustic assessments in relation to tidal power development. Master's thesis. University of Maine, Orono, Maine, USA.

Viehman, H., Zydlewski, G.B., McCleave, J., and Staines, G .2014. Using acoustics to understand fish presence and vertical distribution in a tidally dynamic region targeted for energy extraction. Estuaries and Coasts. Doi:10.1007/s12237-014-9776-

Viehman, H., and Zydlewski, G.B .2014. Fish interaction with a commercial-scale tidal energy device in a field setting. Estuaries and Coasts. doi:10.1007/s12237-014-9767-8

Viehman, H., Zydlewski, G.B., McCleave, J., Staines, G. 2015. Using acoustics to understand fish presence and vertical distribution in a tidally dynamic region targeted for energy extraction. Estuaries and Coasts. 38(S1): 215-226.

Viehman, H., Zydlewski, G.B. 2015. Fish interaction with a commercial-scale tidal energy device in a field setting. Estuaries and Coasts. 38(S1): 241-252.

Viehman, H. 2016. Hydroacoustic analysis of the effects of a tidal power turbine on fishes. PhD Dissertation. University of Maine, Orono, Maine, USA.

Viehman H, Zydlewski GB. 2017. Multi-scale temporal patterns in fish passage in a high-velocity tidal channel. PLoS ONE.12(5), e0176405.

Attachment 1

Data Analysis for Monitoring of the RivGen® in the Kvichak River, 2015
LGL Alaska Research Associates, Inc., November 11, 2015

Alaska Research Associates, Inc.

LGL Alaska Research Associates, Inc.
2000 W International Airport Road Suite C1
Anchorage, Alaska 99502 USA
Tel: (907) 562-3339 Fax: (907) 562-7223

To: Nate Johnson and Monty Worthington, Ocean Renewable Power Company
From: Justin Priest and Matt Nemeth, LGL Alaska Research Associates, Inc.

Re: Data Analysis for Monitoring of the RivGen® in the Kvichak River, 2015

Date: November 11, 2015

This memo summarizes the preliminary data analyses from fish and wildlife monitoring at the RivGen® Power System, a submerged hydrokinetic device operated by the Ocean Renewable Power Company (ORPC) in the Kvichak River in July and August 2015. Monitoring was performed by LGL Alaska Research Associates, Inc., in accordance with the 2015 Monitoring Plan developed in March 2015 and Alaska Department of Fish and Game (ADF&G) Fish Habitat Permit FH 15-II-0038. Data presented here are preliminary and may change after final QA/QC. Interim results and figures were also presented in monthly progress reports at the end of July and August.

Fish movements at the RivGen® device were described using video footage collected from five underwater cameras mounted to the pontoons of the power system. Video footage was collected 24 hours/day July 19–25 and again August 19–27, 2015; review was done by watching the first 10 minutes of a selected hour from each of the four primary cameras (the fifth camera was a backup). Spatially, the camera field of view captured the port side of the RivGen® device, including upstream and downstream views of the port side turbine (only). In accordance with the Monitoring Plan, footage was reviewed to achieve partial temporal coverage during different categories of turbine operating status and daytime/nighttime conditions (Figure 1). At night, two underwater lights lit the viewing area. In addition, bird and marine mammal surveys were conducted for 15 minutes each morning of monitoring. Methods and the overall approach were similar to those described for the demonstration study conducted at the same site in 2014.

Blocks of video footage from portions of 238 different hours were reviewed inseason in 2015. There were 359 events with fish, composed of approximately 1,202 individual fish from at least six species. The majority of fish observations were of solitary fish; the largest school was approximately 100 fish. Species composition varied from July to August and also from day to night. In particular, salmon smolt were almost exclusively seen at night, and were more prevalent in July than August. Several instances of fish moving through the RivGen® turbine were noted and reported inseason as part of the Adaptive Management Plan. We did not detect any obvious physical injuries to fish, and saw no altered behavior by wildlife near the RivGen® device. Cameras, lights, and power system components all operated reliably. All video footage has been archived.

Preliminary results are presented in more detail below, organized by each Objective from the 2015 Monitoring Plan. Where appropriate, data are also presented in Tables and Figures below.

Data analyses listed by 2015 monitoring objective:

1) Summary of monitoring effort.
    a) Video review effort, by RivGen® device status and time group.
        (1) Table 1. Review effort by RivGen® device status and month.
        (2) Figure 1. Daily schedule of RivGen® device operations and data review effort.

2) Presence and timing of fish and wildlife at the RivGen® device (Objective 1 from Monitoring Plan).
    a) Fish monitoring observations.
        (1) Table 2. Number of fish observation events and number of fish, by month, day/night status, and RivGen® device operating status.
        (2) Table 3. Species and number of fish observed, by month and day/night status.
        (3) Table 4. Fish per reviewed hour block, by species, month, and day/night status.
        (4) Figure 2. Hourly summary of review effort, raw observations, and observations standardized by review effort for fish.
    b) Wildlife monitoring observations.
        (1) Table 5. Bird and wildlife observations by species group.

3) Characterize fish movements past the RivGen® device (Objective 2).
    a) Basic movement type.
        (1) Table 6. Movement classification/direction by species, day/night, and RivGen® status.
    b) Movements in relation to the RivGen® device.
        (1) Table A (to be determined): Movement of fish under, over, or through the turbine area.
        (2) Evidence of passage delay: We saw no obvious evidence of passage delay. Adult salmon were clearly able to move around the device, both going upstream (mostly in the daytime), or downstream (mostly at night). Adult salmon also showed general milling behavior that did not appear to be repeated attempts to move past the device. Finally, juvenile salmon were seen transiting past the device, usually travelling downstream. Juvenile salmon sometimes held downstream of the turbine briefly.

4) Describe the behavioral response of fish or wildlife contacting the RivGen® device (Objective 3).
    a) Table B (to be determined): Number of fish showing obvious attraction to, avoidance of, or sheltering at the RivGen® device in 2015, by species and day/night status.

b) Evidence of avoidance or attraction by fish: We saw no obvious evidence of attraction to the RivGen® device. Any such attraction would likely have only been detected as fish markedly altering course to move directly towards the RivGen® device; we saw no instances of this. We did see instances of avoidance by fish moving downstream, which sometimes altered course to move either over or under the turbine. Avoidance by upstream-moving fish (i.e., fish that avoided the RivGen® device altogether by moving away from it before coming into camera view) would not be easily detectable because the fish would have already altered their course before being able to be observed.

c) Evidence of avoidance or attraction by wildlife: There was no evidence of attraction or avoidance by wildlife during the study; all animals observed showed no behavioral changes near the RivGen® device. No marine mammals were observed in 2015.

5) Describe any acute effects from contact with the RivGen® device (Objective 4).

a) Evidence of disorientation, injury, or mortality: Acute effects of fish moving through the RivGen® device, including any potential adverse effects were documented and reported in four Adaptive Management Reports delivered within 48 hours of the incident. We saw no obvious indication of moribund or inert behavior that might indicate injury or mortality. We did see some potential disorientation by juvenile salmon moving downstream. In these events, schools of fish dispersed as they approached the RivGen® device from upstream; afterwards, downstream of the RivGen® device, these fish milled or moved around abruptly in the eddy behind the turbines, before resuming downstream movement.

Table 1. Summary of the review effort during all RivGen® device operational statuses, 2015. “Partial” hours were when turbines only operated during part of an hour block. “Spinning Whole Hour (Stbd turbine only)” hours were operations when only the starboard turbine was operational.

	July		August		Total	
Device Status	Not Reviewed	Reviewed	Not Reviewed	Reviewed	Not Reviewed	Reviewed
Day						
Not Spinning	26	39	25	11	51	50
Partial	1	16		4	1	20
Spinning Whole Hour		44		69	0	113
Spinning Whole Hour (Stbd turbine only)				17	0	17
Day Subtotal	*27*	*99*	*25*	*101*	*52*	*200*
Night						
Not Spinning	32	6	24	3	56	9
Partial		3			0	3
Spinning Whole Hour		1	20	18	20	19
Spinning Whole Hour (Stbd turbine only)			2	7	2	7
Night Subtotal	*32*	*10*	*46*	*28*	*78*	*38*
Total	59	109	71	129	130	238

Table 2. Summary of the total number of fish events and individuals during all device statuses, 2015. A “Fish Event” is defined as an observation of at least one fish during subsampling review. “Spinning Whole Hour (Stbd turbine only)” was when only the starboard turbine was operational.

	July			August			Total	
Device Status	# Fish Events	Total Fish Seen		# Fish Events	Total Fish Seen		# Fish Events	Total Fish Seen
Day								
Not Spinning	17	26		2	3		19	29
Partial	16	39		1	1		17	40
Spinning Whole Hour	57	196		19	19		76	215
Spinning Whole Hour (Stbd turbine only)				10	10		10	10
Day Subtotal	*90*	*261*		*32*	*33*		*122*	*294*
Night								
Not Spinning	150	736		5	5		155	741
Partial	16	75					16	75
Spinning Whole Hour	4	15		49	64		53	79
Spinning Whole Hour (Stbd turbine only)				13	13		13	13
Night Subtotal	*170*	*826*		*67*	*82*		*237*	*908*
Total	260	1,087	0	99	115	0	359	1,202

Table 3. Total number of fish by species during day/night and month, 2015.

	July		August			
Species	Day	Night	Day	Night	Total	Total %
Chum salmon (adult)			14	12	26	2.2%
Coho salmon (adult)			5	2	7	0.6%
Pink salmon (adult)				2	2	0.2%
Sockeye salmon (adult)	259	51	1	1	312	26.0%
Unidentified adult salmon			9	8	17	1.4%
Unidentified juvenile salmonid		773	1	52	826	68.7%
Rainbow trout			1		1	0.1%
Lamprey spp.	1		1	1	3	0.2%
Unknown species	1	2	1	4	8	0.7%
Total	261	826	33	82	1,202	100.0%

Table 4. Number of fish detected per reviewed hour block by species, 2015. Data are standardized to 10-minute review blocks.

	July		August		
Species	Day	Night	Day	Night	Total
Chum salmon (adult)	-	-	0.1	0.4	0.1
Coho salmon (adult)	-	-	0.0	0.1	0.0
Pink salmon (adult)	-	-	0.0	0.1	0.0
Sockeye salmon (adult)	2.6	5.1	0.0	0.0	1.3
Unidentified adult salmon	-	-	0.1	0.3	0.1
Unidentified juvenile salmon	0.0	77.3	0.0	1.9	3.5
Rainbow trout	-	-	0.0	0.0	0.0
Lamprey spp.	0.0	0.0	0.0	0.0	0.0
Unidentified species	0.0	0.2	0.0	0.1	0.0
Total	2.6	82.6	0.3	2.9	5.1

Table 5. Summary of bird and wildlife observations near the RivGen® device, 2015. Data are standardized to the 15-minute sampling periods.

Taxonomic Group	Sightings	Number of individuals sighted	Number of individuals within 15 m of device	Number of individuals per sample period
Passerines	34	41	4	2.7
Bald Eagles	6	7	0	0.5
Other Raptors	1	1	0	0.1
Waterfowl and Loons	8	11	0	0.7
Gulls, Jaegers, and Terns	53	133	0	8.9
Corvids	3	3	0	0.2
Shorebirds	10	12	0	0.8
Terrestrial mammals	0	0	0	0
Marine mammals	0	0	0	0

Table 6. The number of fish events classified by movement type for each species, 2015. Proportions are per subtotaled day and night.

Movement Type	Chum salmon (adult)	Coho salmon (adult)	Pink salmon (adult)	Sockeye salmon (adult)	Unidentified adult salmon	Unidentified juvenile salmon	Rainbow trout	Lamprey spp.	Unidentified species	Total	Subtotal %
Day											
Milling	5	3		33	5				1	47	38.5%
Travel down	4			8	4	1		2	1	20	16.4%
Travel up	2	1		33			1			37	30.3%
Travel, other	2	1		12						15	12.3%
Undetermined				3						3	2.5%
Day Subtotal	*13*	*5*	*0*	*89*	*9*	*1*	*1*	*2*	*2*	*122*	*100.0%*
Night											
Milling	2	1	2	6	2	20			1	34	14.3%
Travel down	9	1		30	6	142		1	4	193	81.4%
Travel up				3		2				5	2.1%
Travel, other						1				1	0.4%
Undetermined				2		2				4	1.7%
Night Subtotal	*11*	*2*	*2*	*41*	*8*	*167*	*0*	*1*	*5*	*237*	*100.0%*
Total	24	7	2	130	17	168	1	3	7	359	100.0%

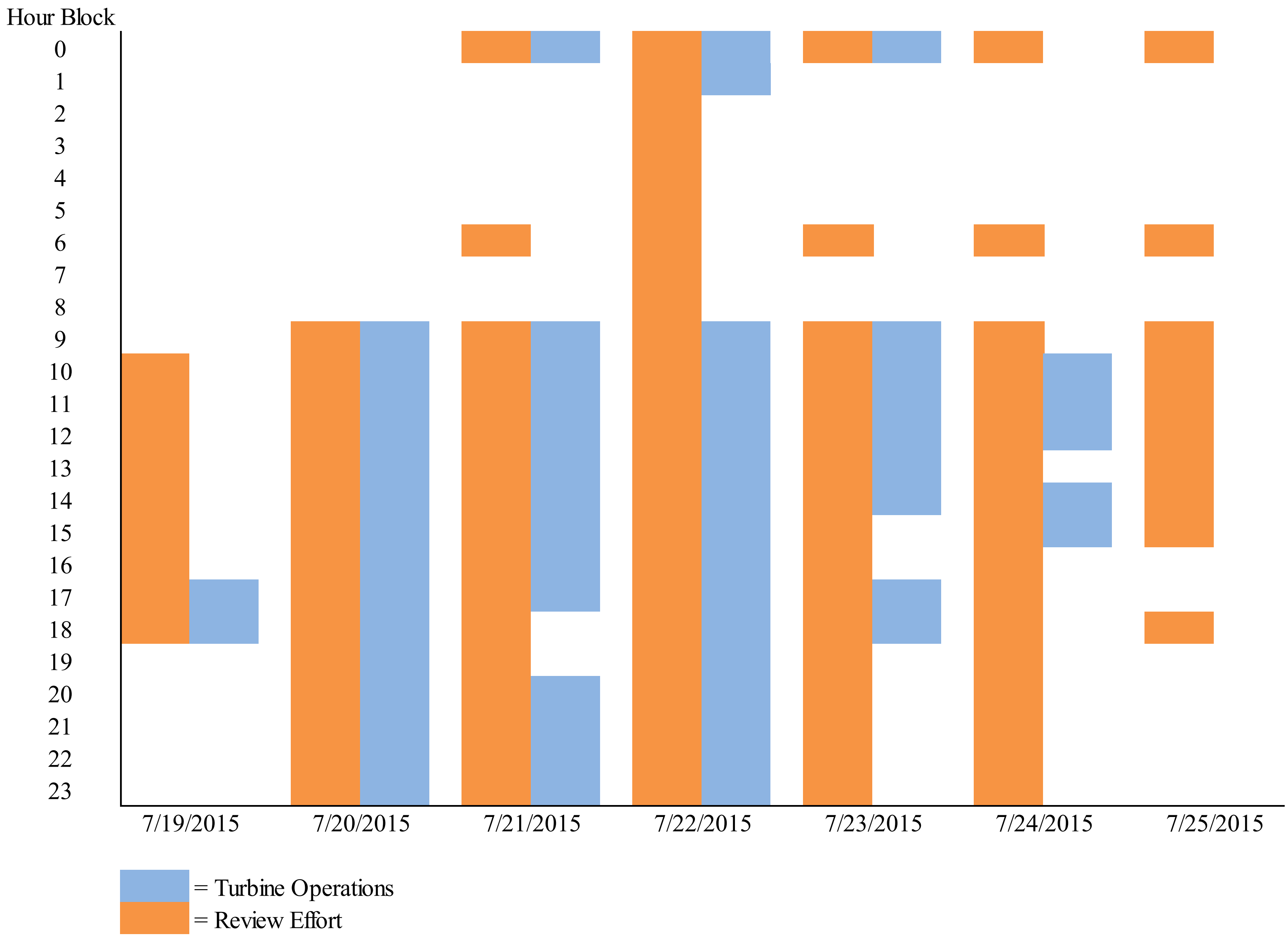


Figure 1A. Summary of turbine operations and review effort of the video system, July 2015. “Half” hours were operations when only one of the two turbine sides was operational.

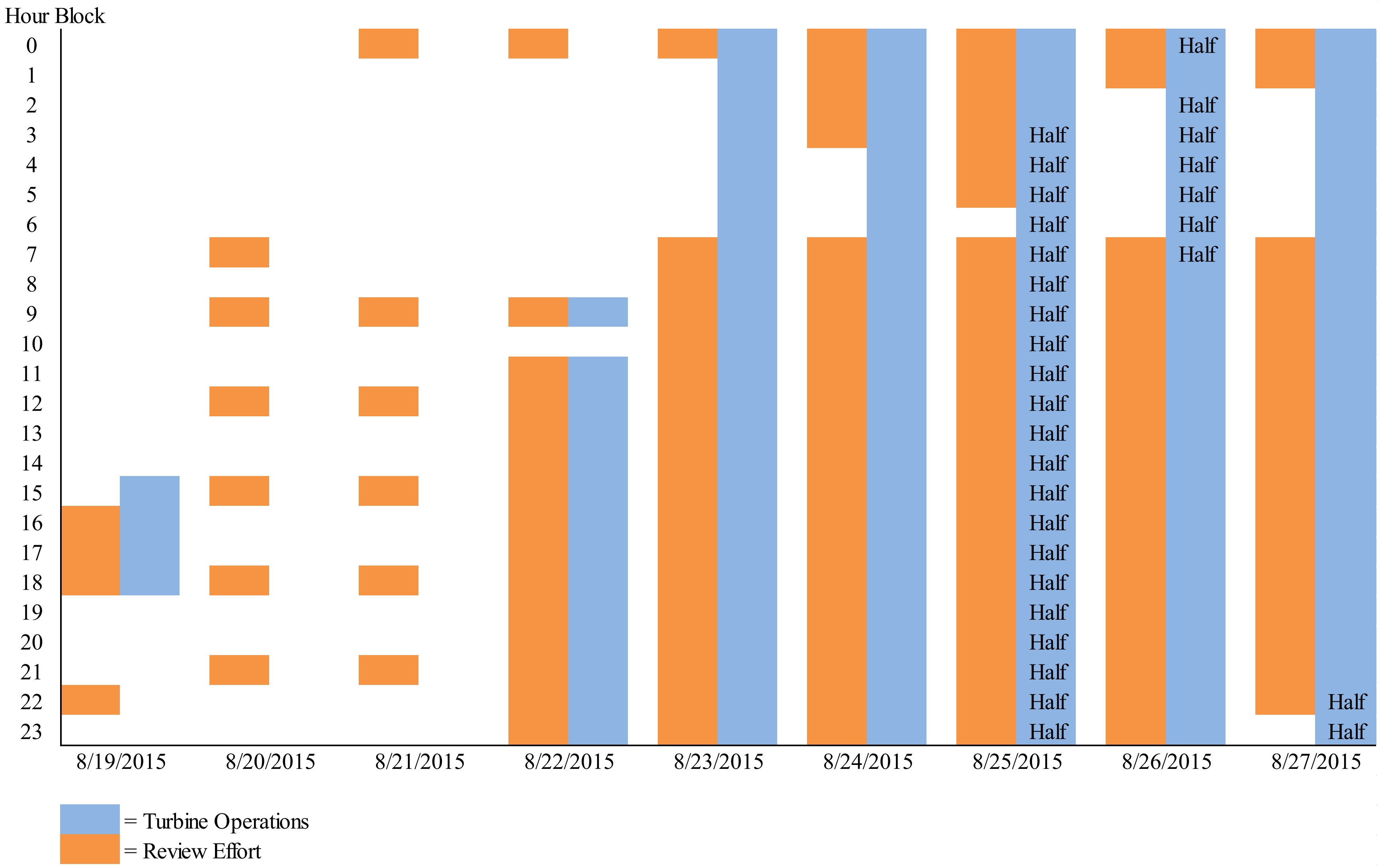


Figure 1B. Summary of turbine operations and review effort of the video system, August 2015. “Half” hours were operations when only the starboard turbine was operational.

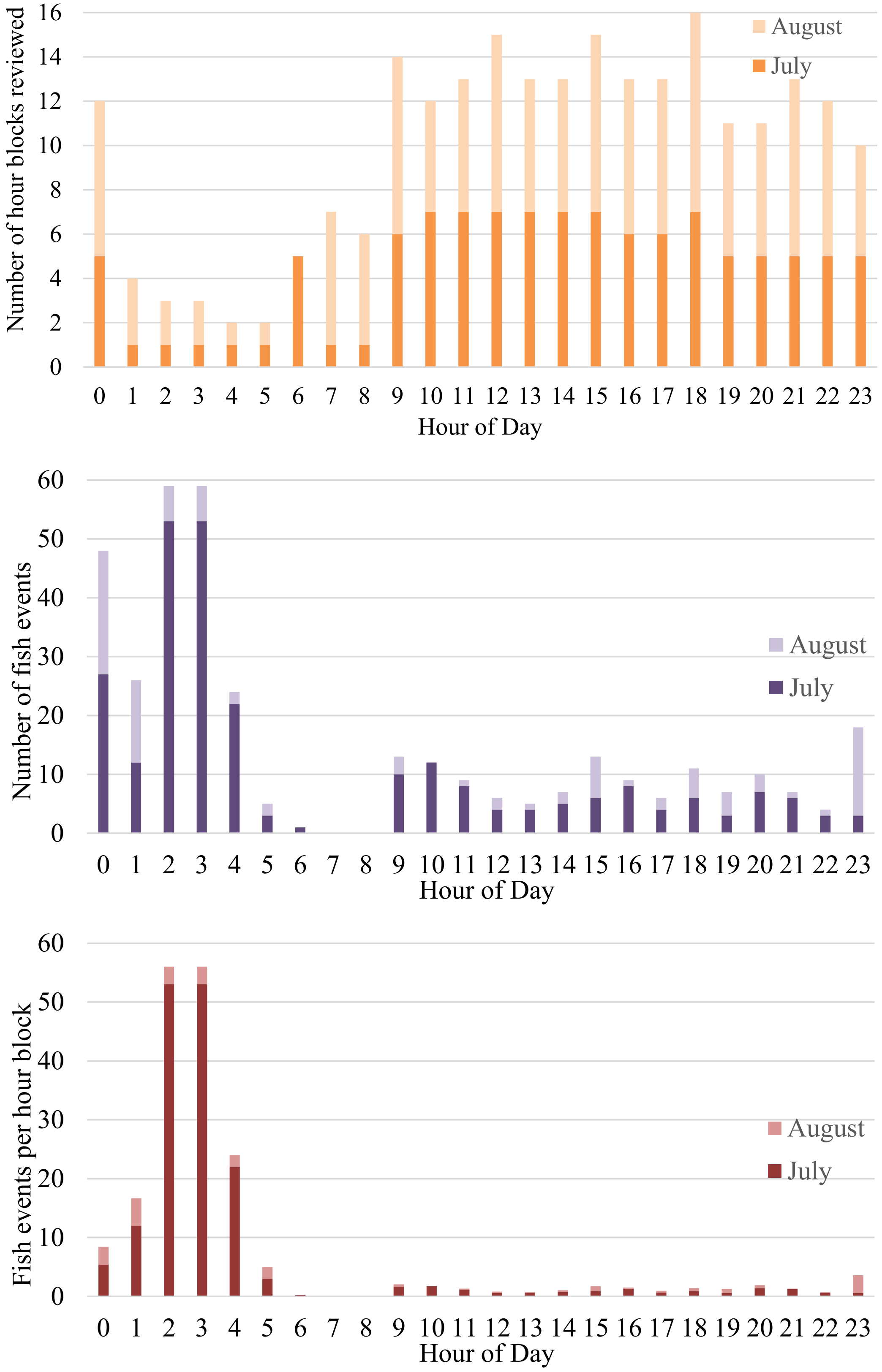


Figure 2A, 2B, 2C. Review effort by hour of day, number of fish events by hour of day, and fish events per hour, by hour of day.

Attachment 2

Triton: Igiugig Fish Video Analysis
PNNL, August 2017

PNNL-26576

Pacific Northwest
NATIONAL LABORATORY

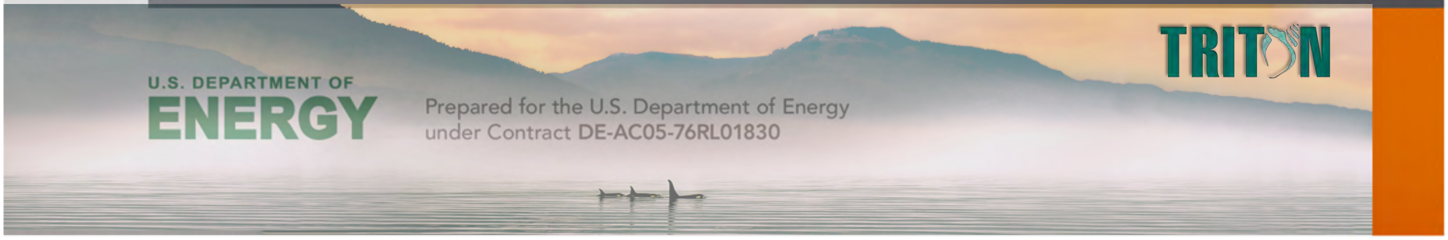
Proudly Operated by Battelle Since 1965

Triton: Igiugig Fish Video Analysis

Project Report

August 2017

S Matzner
C Trostle
G Staines
R Hull
A Avila
GEL Harker-Klimeš



U.S. DEPARTMENT OF ENERGY

TRITON

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

This document was printed on recycled paper.
(8/2010)

Triton: Igiugig Fish Video Analysis

Project Report

August 2017

S Matzner
C Trostle
G Staines
R Hull
A Avila
GEL Harker-Klimeš

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Tidal and instream turbine technologies are currently being investigated for power generation in a variety of locations in the US. An environmental permitting and consenting requirement parallels this exploration generating the need to ensure little or no harm, in the form of strike or collision, befalls marine animals from device deployments. Monitoring methods (e.g., underwater cameras, active acoustics, passive acoustics) around turbine deployments provide empirical data allowing regulators and other stakeholders to assess risk. At present, there is a high level of concern and limited data precluding robust conclusions, which creates a challenge to regulators who must make decisions based on perceived risk versus actual risk. However, the data that are currently available to the scientific community for analysis indicate the issue to be of low risk to date, and strike or collision to be rare events. One such dataset that provides insight to the rarity of strike and collision risk to fish came from an instream turbine deployment in Alaska that used underwater video as the monitoring method.

This document describes the analysis of video data collected around the Ocean Renewable Power Company's RivGen® device deployed in the Kvichak River during July and August 2015 to gain an understanding of the implications of using underwater video cameras as a fish monitoring technique. The data were analyzed manually and used to develop automated algorithms for detecting fish in the video frames and describing their interaction behavior relative to the device. In addition, Pacific Northwest National Laboratory (PNNL) researchers developed a web application, EyeSea, to combine manual and automated processing, so that ultimately the automated algorithms could be used to identify where human analysis was needed (i.e., when fish are present in video frames).

The goal of the project was to develop software algorithms that could identify video frames with fish present to inform and accelerate manual analysis. To achieve this, independent manual analysis was completed for specific video clips (i.e., visual analysis and annotation by a human observer was the standard for assessing the algorithms). The analysis process indicated that some confounding aspects of the algorithm development could potentially be solved with recommended improvements in the initial camera data collection methods.

The manual analysis began to look at all data from the start of deployment of the RivGen® device, primarily using video from Camera 2 that looked directly at the upstream side of the turbine so any interaction could be identified; this was to ensure rare events were seen, and initially focused on Nighttime Data when more fish were present. This process highlighted the amount of time it takes to identify fish, and ultimately only 42.33 hours of video were reviewed because of the time-consuming analysis. The data were classified as "Fish" when the reviewer was confident it was a fish, and "Maybe" fish when it was difficult to distinguish. The two classes were distinguished based on the movement, shape, and color characteristics. Fish Events were further classified by "adult", "juvenile", or "unidentifiable" age. Behavioral attributes were noted and were broadly divided into Passive and Avoidance activities. In over 42 hours of the data reviewed, there were only 20 potential contact interactions, of which 3 were Maybe classifications, 12 were juveniles, and 5 were adults. While only 11.5% of the video data were analyzed from Camera 2, these results are from the time when most fish were present over the turbine deployment period (from Alaska Department of Fish and Game data) and provide preliminary evidence that fish strike or collision of fish in the Kvichak River with an instream turbine is rare.

On only one occasion was an actual contact confirmed, and this was an adult fish that contacted the camera, not the turbine itself. This experience highlights the difficulties associated with confirming a strike or collision event as either having occurred or having been a near-miss. More interactions were

detected at night; this was probably biased by nighttime use of artificial light, which may have attracted fish, but also could have increased detection probability because the light is reflected from the fish itself.

For the algorithm development, background subtraction, optical flow, and Deep Learning techniques were considered. The Deep Learning approach was determined to need too much training data for this application, so its use was not continued. The optical flow analysis was considered promising, but did not give immediate results, so it needs further investigation. Therefore, background subtraction was the main focus in algorithm development. Three methods of background subtraction were tried: Robust Principal Components Analysis (RPCA), Gaussian Mixture Model (GMM), and Video Background Extraction (ViBE). A classification technique was then applied to the foreground images to determine fish presence. Using this combination, fish could be accurately identified when occupying a higher number of pixels (>200 pixels, 98.2% correct; 100–200 pixels, 99.6% correct; 5–100 pixels, 85.4% correct; 2–5 pixels, 66.3% correct).

In parallel, EyeSea was developed to convert the video data to a usable form and to enable manual and automated analysis of the data that would have a standardized output.

Recommendations for further research, and optimizing methods for enhancing data collection and analysis include the following:

- Research
  - Conduct more studies of the effect of lights on fish behavior.
  - Investigate the use of low light video applications as an alternative to using lights.
  - Further investigate optical flow techniques and their applicability for automated analysis.
  - Further refine the parameters for background subtraction in automated analysis.
- Standardized techniques
  - Include markings on the turbines to determine relative range and size of fish within the field of view.
  - Use a standardized (non-proprietary) video format that has a consistent frame rate of at least 25 frames per second.
  - Use a scientific camera designed for underwater measurement in low light environments that has a field of view appropriate for the observations and a pixel resolution high enough to determine fish within the given range.
  - Carefully consider the use of lights and how they illuminate the areas of interest.
  - Standardized and detailed record keeping and metadata collection
  - Use other monitoring technologies (e.g., strain sensors on turbine blades) to determine actual collision or strike events.

Acknowledgments

The authors thank the invaluable contribution of the Advisory Committee members who steered how the data were analyzed, and provided input for solutions: Nathan Johnson (Ocean Renewable Power Company), Steve Brunton (University of Washington), Gayle Zydlewski (University of Maine) and Andrea Copping (Pacific Northwest National Laboratory). PNNL also thanks the Ocean Renewable Power Company team in Alaska who provided information about the deployment, and Justin Priest and the team from LGL Alaska who provided information about the initial processing techniques.

PNNL also thanks the U.S. Department of Energy for funding this project and providing ongoing advice.

Acronyms and Abbreviations

DOE	U.S. Department of Energy
FY	fiscal year
GMM	Gaussian Mixture Model
MPC-HC	Media Player Classic-Home Cinema
MHK	marine and hydrokinetic
LGL	LGL Alaska
ORPC	Ocean Renewable Power Company
PNNL	Pacific Northwest National Laboratory
RPCA	Robust Principal Components Analysis
TRL	Technology Readiness Level
ViBE	Video Background Extraction

Glossary

Term	Definition
asynchronous architecture	A system that does not depend on strict arrival times of signals for operation.
avoidance	Used in all instances to encompass behaviors that showed some form of active change; no attempt was made to distinguish between avoidance and evasion.
background subtraction	A computer vision technique used to separate an image (or video frame) into background and foreground, where foreground means objects or regions of interest and is application-dependent.
bilateral filter	A non-linear, edge-preserving, and noise-reducing smoothing filter for images.
“blobs”	Groups of connected pixels of similar intensity.
canonical analysis	A method of regression analysis to determine relationships between a predictor variable and a criterion variable.
collision	When a fish swims into a static object.
compare/ comparison	Qualitative, nonstatistical assessment of the project video data.
contrast stretch	An image enhancement technique that improves the contrast in an image by increasing the range of intensity values.
Deep Learning	Application of learning tasks to artificial neural networks.
directed motion	Motion that demonstrated intended movement; used in this report to describe fish-like movement
EyeSea	A database-driven website for accessing video data files and analysis data.
Event	A place in time during manual video processing marked by a reviewer as having a fish-like object or fish in two or more frames
false positive	Detection of a fish by the algorithm when there was not a fish
Fish	An object that is deemed to be a fish during a manual analysis event
Fish Event	An event deemed to contain a fish during manual analysis
forward-stepping linear discriminant analysis	A method for finding a combination of features that characterizes two or more classes of objects.
histogram equalization	A technique for adjusting image intensities to enhance contrast.
July 22 Data	The full 24-hour manual analysis data of July 22, 2015.
Maybe	An object that during manual analysis is deemed to possibly be a fish, but not a definite identification.
Maybe Event	An event that during manual analysis is deemed to contain an object that could possibly be a fish
MySQL	An open-source relational database management system.
near-field	Relative term referring to an object or fish being relatively close the turbine within the video camera field of view.

neural network	A computer system based on how networks within biological brains work, which “learns”, i.e., improves its performance, by considering examples that have been labeled with key parameters.
Nighttime Data	Data from hours 00:00 – 06:00 and 23:00 – 00:00 from July 19, 23:00 to July 23, 03:00
OpenCV	Open Source Computer Vision Library
optical flow	An image processing technique used to compute motion of an object based on changes in the individual pixels in an image.
Rayleigh distribution	A continuous probability distribution characterized by a shape parameter used to model the magnitude of a multi-component vector.
strike	When a fish is hit by a moving part of the turbine
true negative	An object classified as non-fish by automated analysis that was deemed to be a non-fish by a human reviewer, or a frame classified by automated analysis as containing no fish that was not included in the frames containing fish noted by human analysts.

Contents

Figures

Tables

1.0 Introduction

The Triton initiative is a U.S. Department of Energy (DOE)-funded capability at the Pacific Northwest National Laboratory's (PNNL's) Marine Sciences Laboratory in Sequim, Washington. It aims to support DOE-funded projects that are developing technologies for measuring and monitoring the environment around marine energy devices through the mid- to high-level Technology Readiness Levels (TRLs). Ultimately, the initiative is intended to facilitate the permitting process and reduce the overall cost of marine renewable energy.

As part of the initiative, the Igiugig Fish Video Analysis project described herein used video data collected by LGL Alaska around an Ocean Renewable Power Company (ORPC) RivGen® device deployed in Alaska. The data on fish interactions around the operating device were made available to PNNL for further manual/human processing and use in developing automated processing software.

This final report summarizing the project tasks and results follows two previous reports: a data quality report (Trostle 2016) and a project progress report (Avila et al. 2016). The ensuing sections of this report briefly describe the project, the manual analysis of the video data, development of an automated algorithm for detecting fish presence in video frames, development of the software to enable data processing, and finally present conclusions and recommendations for future projects. Appendices A and B, respectively, contain manual annotations and the video data set used to develop the algorithm.

2.0 Description of Project

The ORPC RivGen® device (Figure 2.1) was deployed in the Kvichak River (Figure 2.2) from 19 to 25 July and 19 to 28 August in 2015. The device's two-turbine turbine generator unit (TGU) is supported by a chassis incorporating a pontoon support structure. The structure acts as a foundation when the device is deployed on the riverbed and gives it self-deployment and retrieval capabilities. The system is designed to generate reliable, renewable electricity in rivers near remote communities that have no access to large, centralized power grids.

Figure 2.1. Photograph of the ORPC RivGen® device.

Figure 2.2. Location of the RivGen® device near Igiugig, Alaska.

Five video cameras were attached to the ORPC RivGen® device to monitor fish upstream and downstream of the turbine foils. While the system was deployed, LGL Alaska (LGL) monitored the video for fish-turbine interactions, subsampling 10 minutes per hour (at the top of the hour) (LGL 2015). After the deployment was completed, the raw data, metadata, and a spreadsheet with processed events were released to PNNL for further analysis. Specifically, this was to develop automated algorithms that detected fish within the frames so that manual analysis could focus only on times when fish were present. To do this, manual analysis was required to annotate the video so that it could inform the algorithm development.

3.0 Manual Analysis

3.1 Methods

The development of tidal current and in-stream river current turbines as an industry is relatively new. It is in the early research and development stages that require testing to determine ideal technology and resource choices. The required technologies for monitoring fish interactions around turbine installations have the same early research stage limitations. This project used an underwater optical camera data set that captured numerous instances of fish and a turbine in the same field of view. Cameras and lights were manufactured by IAS systems. Cameras were customized SeeMate™ color to monochrome units with a F2.9 angle lens. Lights were SeeBrite™ omnidirectional model 24L-SS-LED-350. Power came from shore

and data were stored on digital video recorders. Manual processing of the data provided a baseline for software algorithm development as well as qualitative comparisons of fish behavior near the device.

3.1.1 Data Set

The data set comprised underwater video data from five cameras aligned on one side of the RivGen® device (Figure 3.1)—two upstream of the rotor and three downstream—recording 24 hours per day from 19–26 July and 19–28 August. Illumination from two artificial light sources was used between approximately 2300 and 0600 each night. PNNL received the raw video data (6,418 files; 368 hours), along with supplemental reports from LGL in December 2015. LGL had previously processed the first 10 minutes of certain hour blocks of the data, typically coincident with the turbine spinning; observed events were recorded in a spreadsheet that was provided to PNNL with the data set.

For PNNL, the first step was to determine whether the data quality was good enough for the proposed analysis. The research team needed to be able to visually observe fish presence, behavior, species, and any adverse impacts. In February 2016, the data quality was deemed satisfactory, but not suitable for species determination/identification. For additional information regarding the usability and overall quality of the video, see the Quality Check Summary Report (Trostle 2016).

During an Advisory Committee meeting (including participants from ORPC, PNNL, the University of Washington, and the University of Maine) held in March 2016, it was decided that the data set should be manually processed giving priority to nighttime segments (00:00 – 06:00 and 23:00 – 00:00) from July, for which previously subsampled data from LGL showed the highest frequency of fish interactions with the turbine. Additionally, camera 2 (Figure 3.1) was given priority because it showed the upstream view of the rotor. This meant that it:

In this study, "collision" refers to when a fish swims into a static object, and "strike" refers to a moving part hitting a fish.

- could show potential fish collision or strike interactions with the turbine,
- could show near-field avoidance behavior,
- had a sufficient light source, and
- could be used to coarsely estimate the size and distance of fish relative to the turbine and supporting structures.

As data processing progressed, team members realized that full manual analysis of both July and August nighttime video data would be excessively time-consuming. For every 1 hour of raw video data, it took reviewers approximately 13 to 15 hours to manually review and annotate the video. Due to the amount of time it took for manual review, only part of the July Nighttime Data (July 19, 20, 21, and some of July 23), all of the July 22 Data, none of the August data, and the data required for the test bed development were reviewed (see Section 4.1). Of 18 days of video data recorded by LGL, PNNL was able to review 1 full day, 3 nighttime segments, 4 half-hour blocks on July 23, and 16 five-minute sections for the test bed—a total of 42.33 hours. The PNNL team decided to concentrate on particular subsets of data that would allow for meaningful comparisons. Statistical analysis was not performed on any of the manual review data because of the relatively short period analyzed. Therefore, all uses of the term compare/comparison regarding manual processing for this report refer to qualitative, non-statistical assessment of the data. These comparisons have been grouped into four categories:

- July 22 Data: A full day, July 22 (hereafter referred to as July 22 Data), was analyzed because it was important to include a full day inclusive of daytime data for preliminary comparisons of the first 10 minutes of each hour to the full 60 minutes of each hour. This also allowed for diel differences to be qualitatively compared.

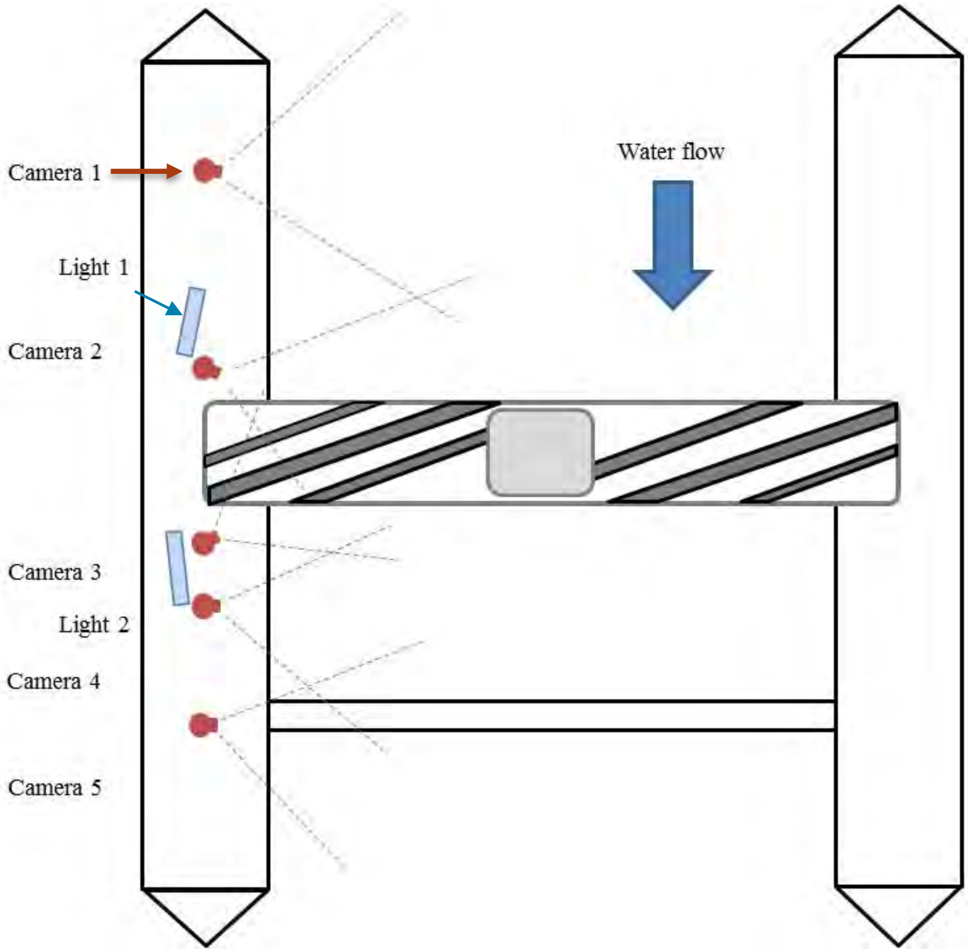


Figure 3.1. Schematic showing approximate locations and views of cameras by number on the RivGen® device.

Lights are represented by blue rectangles. (Not to scale. The pontoon structure is 19.8 m long, 11.5 m wide and 1.7 m high. The turbine [TGU] is 10.4 m long, 1.5 m wide, and 1.5 m high.) (Figure courtesy of LGL and ORPC.)

- Nighttime Data: Nighttime only (00:00 – 06:00 and 23:00 – 00:00) data from July 19, 23:00 to July 23, 03:00 (hereafter referred to as Nighttime Data) were processed as mentioned in the bulleted paragraph. The data from July 23 Nighttime Data consist of only the first half-hour of each hour block (e.g., 01:00 to 01:30). These data represent the majority of the processing effort for this study. The first night (July 19) of data collection had technical issues with the lighting system and data were collected without a light source.
- Light Effects Data: The hour block from 23:00 – 00:00 for July 19–22 were processed with varying artificial light operations to gain a preliminary understanding of any effect lights may have on fish detection probability and fish behavior.
- Collision/Strike Data: Events with fish interactions where possible collision or strike occurred were separated into a small subset and further analyzed. Reviewers observed a total of 20 events that had possible collision or strike interactions. These events were separated for further comparisons.

3.1.2 Manual Processing

The data were provided in a proprietary format that was difficult to manipulate for the proposed processing and analysis procedures. Data files were changed to .mp4 format for ease of use with minimal

change in data quality. Two reviewers worked together to establish processing protocols and definitions for parameters annotated for each event. A subsample of data was processed by each reviewer and compared for similarity to ensure data processing would be consistent and accurate throughout the analysis.

The reviewers visually processed the data in half-hour blocks using Media Player Classic-Home Cinema (MPC-HC). Reviewer 1 processed the first half-hour and Reviewer 2 the second half-hour. Whenever a reviewer visually assessed a fish or an object that had characteristics different from the surrounding water column debris (i.e., shiny and/or non-passive movement) that was present in the field of view for more than one frame, it was deemed an event. For each event, the numerical annotation method explained in the *Igiugig Video Analysis – FY16 Progress Report* (Avila et al. 2016) was used to describe the event characterizations. Parameters for these characterizations are described in Appendix A. Manual review did not distinguish between the terms "avoid" and "evade" throughout this report. Because the reviewers were unaware of the exact distance of the objects from the turbine, and because they did not use the behavioral responses of the objects and fish to decide between the two terms, "avoid" was used in all instances to describe behaviors that showed some form of active change assumed to be related to the turbine. Important classification annotations referenced throughout this report are whether or not an event was a Fish Event or a Maybe Event. A Fish Event meant that the reviewer was positive the object was a fish, whereas a Maybe Event meant the reviewer was not sure (hereafter referred to as Fish or Maybe Events, respectively). The designations between these two annotation descriptions are important for comparison and analysis purposes, as well as for informing the algorithm development.

Objects that were not definitively defined as fish were still deemed events and recorded as Maybe Events. It was important to include these for two reasons. First, video quality could possibly affect the reviewer's determination of whether or not an event contained a fish, and erring on the side of capturing all events with some false positives was preferable to missing some Fish Events. Second, software and automated algorithm development was a major objective of this research. Objects often had characteristics similar to fish and could be identified as events by the automated algorithms. This again allows more confidence in capturing all Fish Events at the cost of some additional false positives.

To keep the reviewers calibrated during review, both started with a training period to go over the parameters and define characterizations. They separately reviewed the same video and compared results for 2–3 weeks, addressing any discrepancies in annotations. As the reviewers began processing the data individually, they kept in regular contact, went over interesting or questionable interactions, reviewed each other's annotations, and discussed methods to ensure calibration at bi-weekly meetings.

Even with these checks, during analysis, an inconsistency was discovered between reviewers. While both reviewers saw a similar number of events, meaning they were stopping for the same objects, the distinction between calling an object a Fish Event or Maybe Event did not always correspond. This meant that some of the objects one reviewer deemed as a Fish, the other reviewer deemed as a Maybe fish.

Comparisons were made using the July 22 Data to show any similarities that exist in event occurrence and fish count estimates between processing of the first 10 minutes per hour, and processing of the full hour. Additionally, figures for visualization were also made to display

- differences between definite Fish Events and objects with non-passive behavior,
- fish count differences between day and night, and
- fish count differences between when the device was spinning and static.

For the Nighttime Data, the behavior types that are associated with different categories of events were compared. This categorization of events was based on the Appendix A annotation, "Fish?". This annotation was simply a question to the reviewer about whether the object observed during a designated event was definitely a Fish or a Maybe. Initially, All Events that included Fish and Maybe Events were considered. Categories separated All Events into Fish and Maybe Events. Fish Events were further

categorized by annotations from Appendix A designating the fish as juvenile (likely a salmon smolt), adult (likely a salmon), or unidentifiable as determined by the reviewer. The category separation flow chart is shown in Figure 3.2. After behavior types were attributed to the categories of events by percentage (Figures 3.4–3.10), behavior types were coarsely grouped. Each of the behavior types the reviewers used for the annotation description was designated as either Avoidance, Passive, or Other (Table 2).

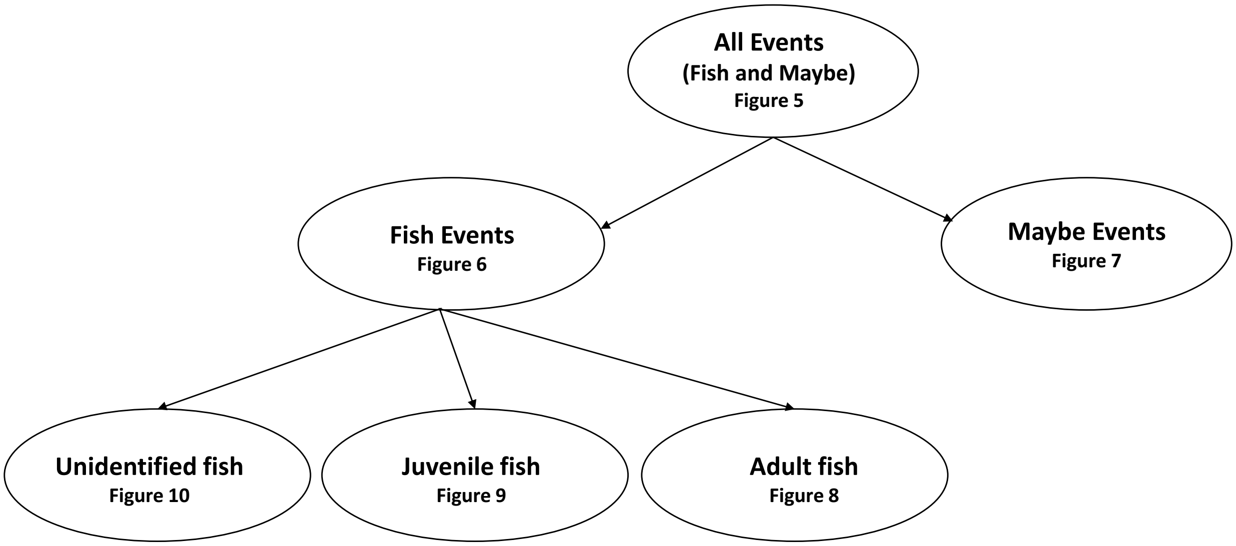


Figure 3.2. Flow chart showing the different categories of events used to visualize behavior types (Figures 3.4–3.9) attributed by data processing reviewers. All events that had potential fish collision or strike were placed in a separate subset (3.10).

Table 3.1. Grouping of annotated behavior types into Avoidance, Passive, and Other.

Avoidance	Passive	Other
Milling	Straight across (above or below)	Unable to tell
Pause	Through turbine	Other
Against current	Toward static parts	
Avoid reverse	Face first	
Avoid below		
Avoid above		
Avoid around		

A simple comparison of the Lights Effects Data was to determine whether more events were observed when the lights were on or off during varied light operations from July 19–22. This was possible because on July 19 the lights were off due to technical difficulties. The lights were turned on the next day and they were used for the remainder of Nighttime Data collection.

The last subset of data comparisons were the events when fish collision or strike may have occurred in the Nighttime Data. This data set includes only events that were positively determined by both data reviewers to be Fish and excludes the Maybe Events; hence, there is no disparity between reviewer determinations.

3.2 Results

Currently, no established video data analysis techniques exist for assessing fish interactions. Using the above methods, qualitative comparisons were made with the data set to highlight differences in 1) subsampling of the first 10 minutes of each hour and the entire hour; 2) nighttime behavior types; 3) possible collision and strike events; and 4) the effects of nighttime illumination. The data were further summarized between whether an object was a Fish or Maybe Event, and the categorical groupings associated with the observed behaviors.

3.2.1 Fish Presence/Behavior

3.2.1.1 July 22 Data Subsampling Comparisons

For the July 22 subset of data there were 2,538 events: 260 were Fish Events, 2,256 were Maybe Events, and 22 Events were a combination of Fish and Maybe occurrences. The majority (81%) of events occurred during nighttime hours. Only one Fish Event occurred during daytime—in hour 19 in the processed data. Fish abundance or frequency of events does not appear to be related to whether the turbine was spinning (hours 1–2) or static (hours 3–6), but does seem to coincide with low light levels (hours 1–6 and hour 24). To compare the 10-minute sampling regime with full analysis, the 10-minute counts were multiplied by six to produce an hour estimate. This assumes that the first 10 minutes is representative of the subsequent five 10-minute blocks. The comparison between these processing methods shows that when the first 10 minutes is subsampled and multiplied by 6 to approximate an hourly estimate the numbers are inflated for hours 3–6. Hour 1 is underestimated, for hour 2 the estimates are similar, and hours 3–6 are over-estimated for both the number of Fish and number of events (Figure 3.3).

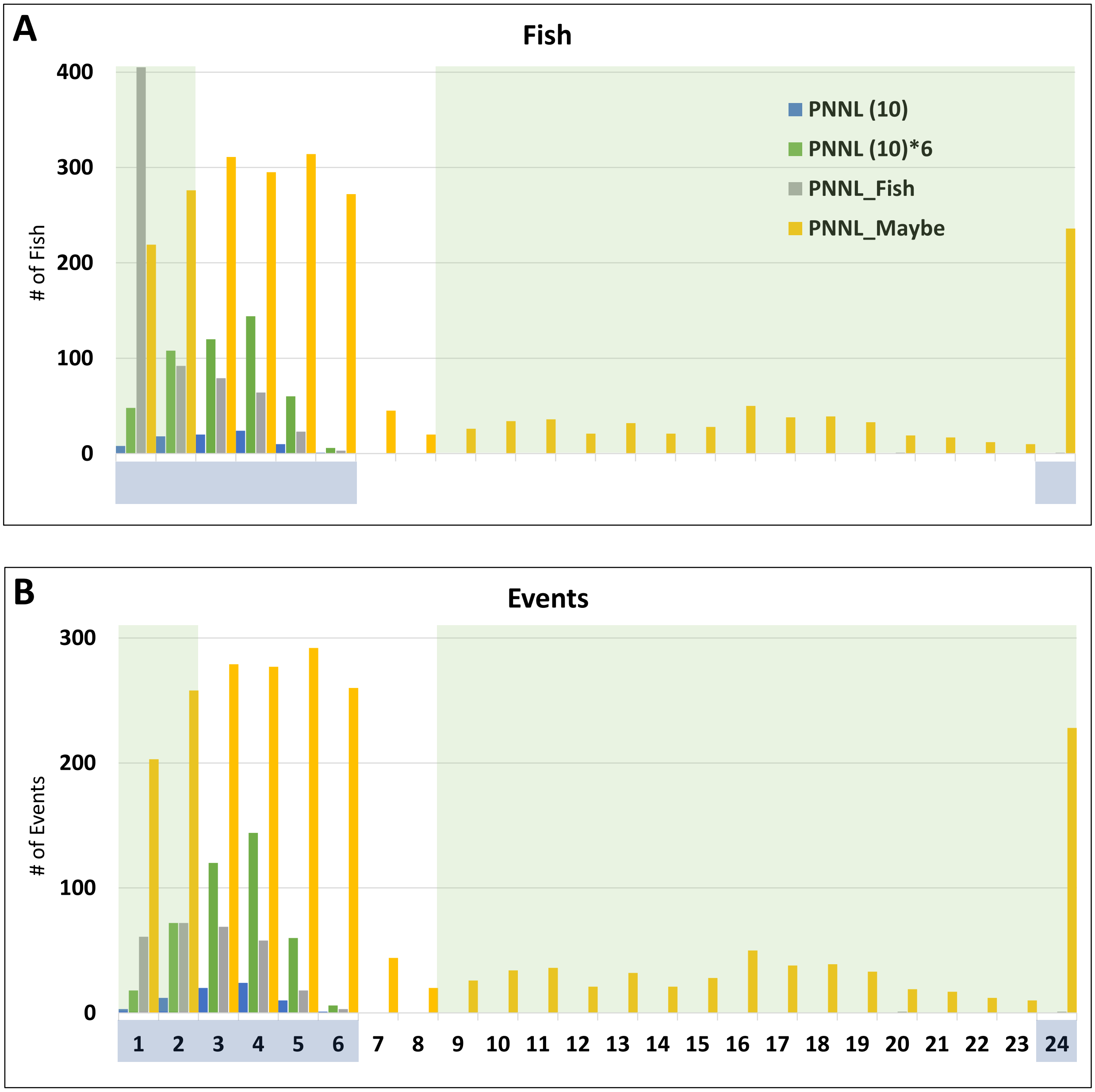


Figure 3.3. Bar graphs showing processed data for July 22, 2015.
*The horizontal axis represents each hour block for both graphs and the dark shaded numbers represent hour blocks that are after sunset and before sunrise (Nighttime Data). The green shaded background of the plot areas show when the RivGen® was spinning. Graph A displays Fish and Maybe counts as observed during manual processing by hour blocks. Graph B displays the number of events. The blue bar, "PNNL (10)", represents the estimates from PNNL's processing of the first 10 minutes of each hour. The orange bar, "PNNL (10)*6", represents PNNL's estimate multiplied by 6 to be an approximation for the full hour. The gray bar, "PNNL_Fish", represents PNNL's count of "Fish" for Graph A or "events" for Graph B for the full hour. The yellow bar, "PNNL_Maybe", represents the count of objects (Graph A) or events (Graph B) with non-passive behavior but not determined to be fish.*

3.2.1.2 Nighttime Data Behavior Types

Other than processing the July 22 Data, PNNL only processed Nighttime Data. For the category that includes both Fish and Maybe Events, there were 629 Fish Events, 4,149 Maybe Events, and 51

combination events that included both Fish and Maybe occurrences. Each event was broken down into the described behavior specific to the annotation list found in Appendix A. Grouping all of these described behaviors by annotation behavior type (e.g., avoid around, avoid above—see Appendix A) provides some evidence of what the dominant behaviors are within the camera field of view in front of the RivGen® during nighttime hours. The dominant behavior for Fish and Maybe Events was "through turbine", followed by "straight across", followed by "toward static parts" (Figure 3.4). Note that this comparison is not separated by Fish or Maybe Events or any other qualifier, and the Passive behavior group dominates with 80% of the behavior, compared to ~19% for the Avoidance group.

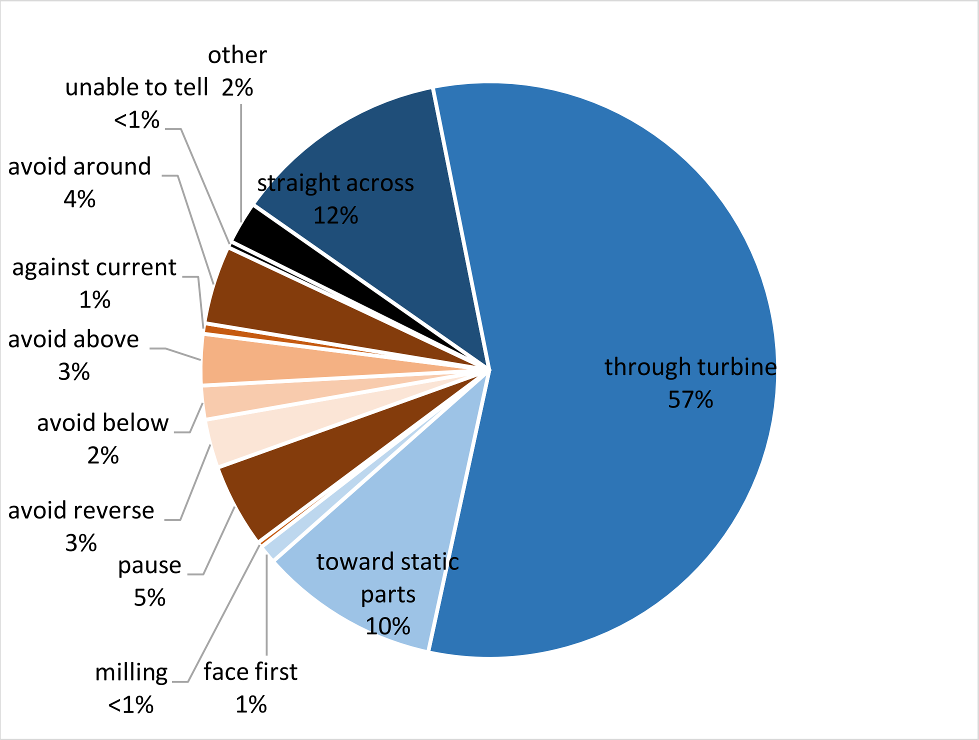


Figure 3.4. Behavior types recorded by reviewers for Nighttime Data. Data included are both Fish and Maybe Events for all sizes; n = 4,829.

The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

The Nighttime Data were separated into Fish and Maybe Events to visualize how reviewer-described behaviors may be different for each. Combination events (n = 51) that had both Fish and Maybe Events were removed because it was impossible to separate behavior annotations associated with a Fish object or a Maybe object during the event. For Fish Events the top three dominant behaviors were "through turbine", "avoid around", and "pause" (Figure 3.5), and for Maybe Events the top three behaviors were "through turbine", "straight across", and "into static parts" (Figure 3.6). There is a distinct qualitative difference in behavior types (Avoidance vs. Passive) between the Fish Events and Maybe Events. Figure 3.5 shows Fish Events dominated by the Avoidance group of behaviors (62%) and Figure 3.6 shows Maybe Events dominated by the Passive group of behaviors (80%). This abundance of passive behaviors is expected, because one of the qualifiers when distinguishing between Fish and Maybe Events was how the objects moved. It is important to note that there was some disparity between what the two reviewers designated as a Fish or Maybe Event as described in "Manual Processing."

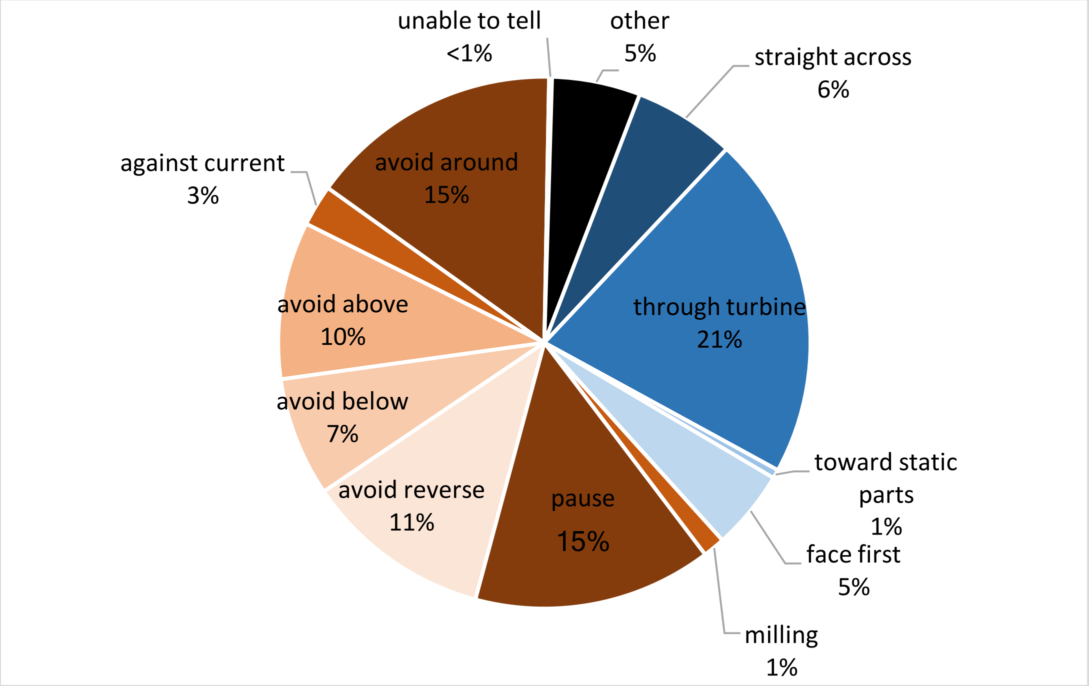


Figure 3.5. Behavior types recorded by reviewers for Fish Events in Nighttime Data for all sizes (n = 618).
Maybe and Combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

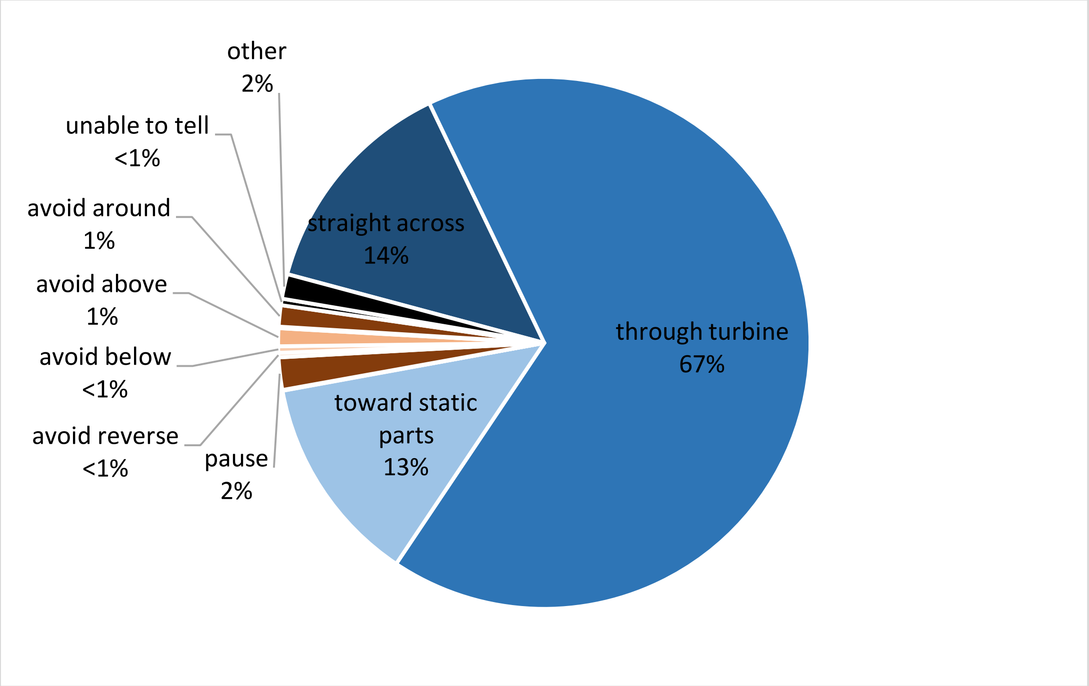


Figure 3.6. Behavior types recorded by reviewers for Maybe Events in Nighttime Data for all sizes (n = 4,149).
Fish and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

Within the Fish Events category, a separation was made to categorize juvenile, adult, and unidentifiable fish. Eleven Fish Events had a combination of adult, juvenile, or unidentifiable Fish Events that were removed from these comparisons. There were 174 adult Fish Events for which the dominant behaviors were “pause”, “avoid around”, and “avoid reverse” (Figure 3.7). There were 259 juvenile Fish Events, for which the dominant behaviors were “through turbine”, “avoid around”, and “pause” (Figure 3.8). Determining whether it was an adult or juvenile was sometimes impossible. This created the category of an unidentified Fish Event of which there were 185. The dominant behavior was “through turbine”, “avoid around”, and “pause” (Figure 3.9). Adult fish displayed Avoidance behavior 82% of the time compared to only 14% passive behavior. The behavior groups for juveniles were split, showing 50% Avoidance behaviors and 44% Passive behaviors. And the fish that were unidentifiable demonstrated dominant Avoidance behavior 57% of the time and Passive behavior 36% of the time.

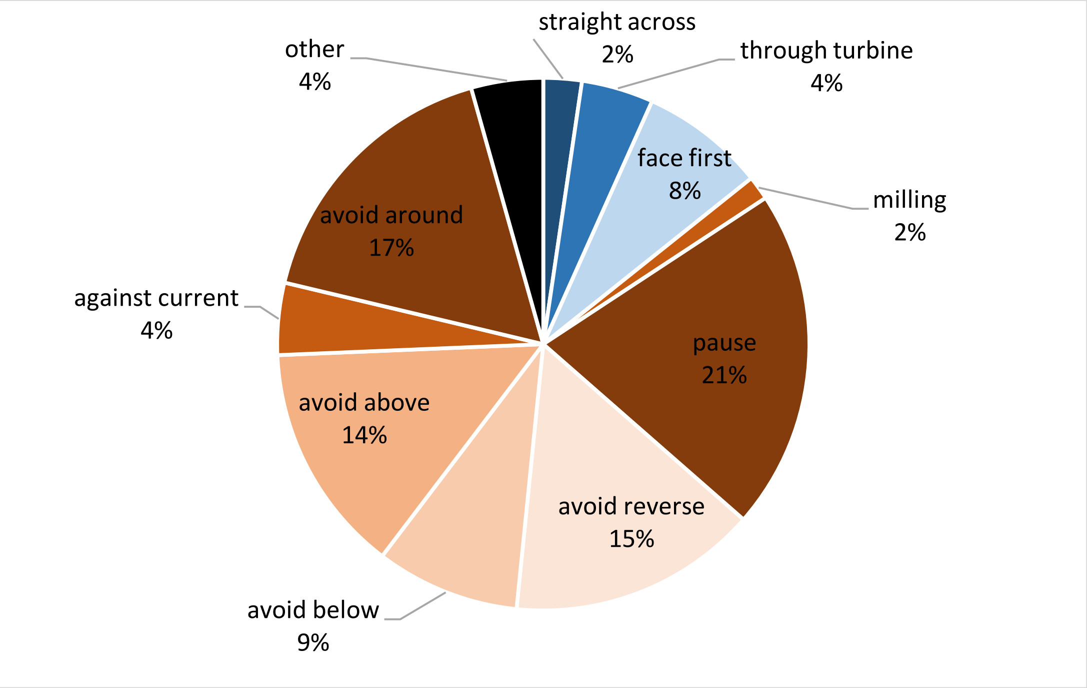


Figure 3.7. Behavior types recorded by reviewers for adult Fish Events in Nighttime Data (n = 174). *Juvenile and unidentified Fish Events, Maybe Events, and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.*

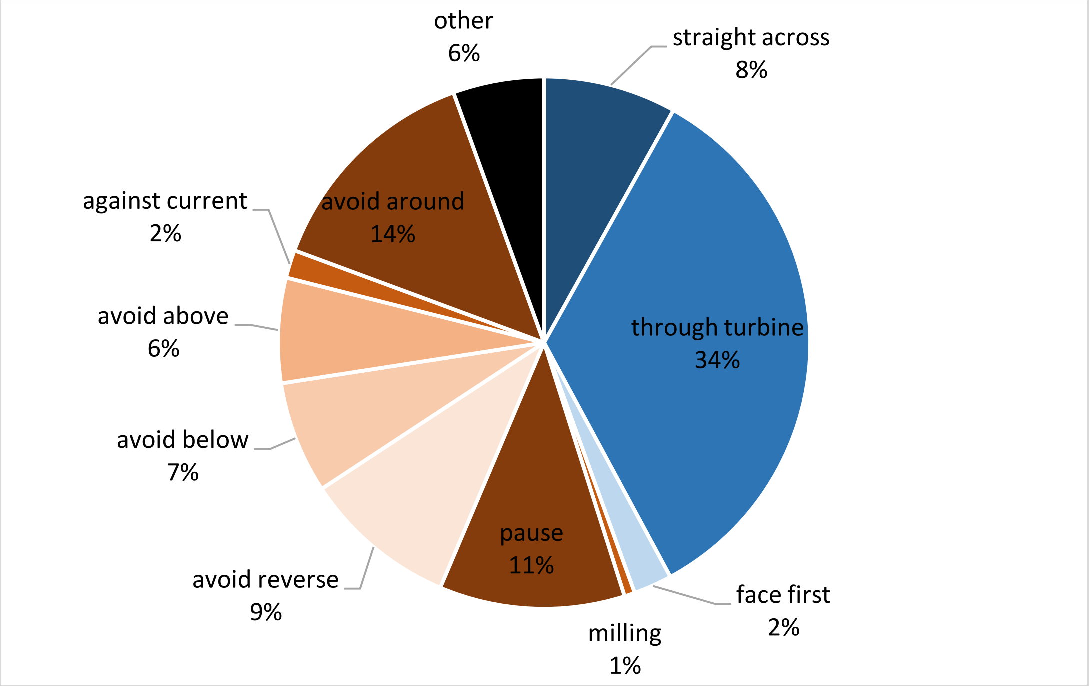


Figure 3.8. Behavior types recorded by reviewers for juvenile Fish Events in Nighttime Data. (n = 259).

Adult and unidentified Fish Events, Maybe Events, and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

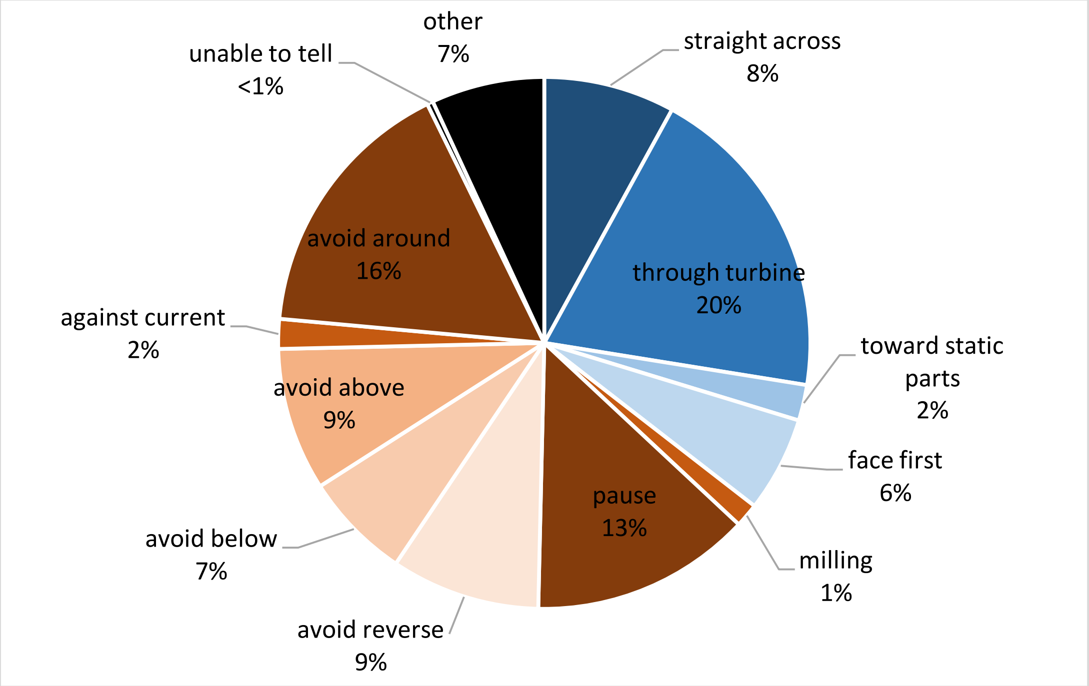


Figure 3.9. Behavior types recorded by reviewers for unidentified Fish Events in Nighttime Data (n = 185).

3.2.1.3 Fish Collision and Strike

Reviewers found a total of 20 events involving possible collision or strike (12 strike and 8 collision). All strike events in this data set refer to moving parts of the turbine hitting an object or fish, while collision refers to an object or fish coming into contact with a static part of the device (this could include the blade when it is not turning). Of these 20 potential events, 17 were Fish Events and 3 were Maybe Events. Of the 17 Fish Events, juveniles made up 12 of the events and adults made up 5 events. All but one of the juvenile Fish Events had multiple fish in the field of view, up to ~50. All of the adult events were single fish. All juvenile Fish Events occurred between 00:00 and 01:00, except two which occurred at 01:03 and 03:02. The turbine was spinning for all but one of the juvenile Fish Events and none of the adult Fish Events. Juveniles made up 11 of the strike events, while the remaining strike occurrence was a Maybe Event. No adults were involved in any of the strike events. Of the 8 collision events, adults made up 5, a single juvenile made up 1, and the rest were Maybe Events. The one juvenile collision and 4 of the 5 adult collision events occurred with a static blade. The last adult collision occurred with the camera and was the only confirmed collision. Behavior for these events was dominated by Avoidance group behaviors "through turbine", "avoid around", and "pause" (Figure 3.10).

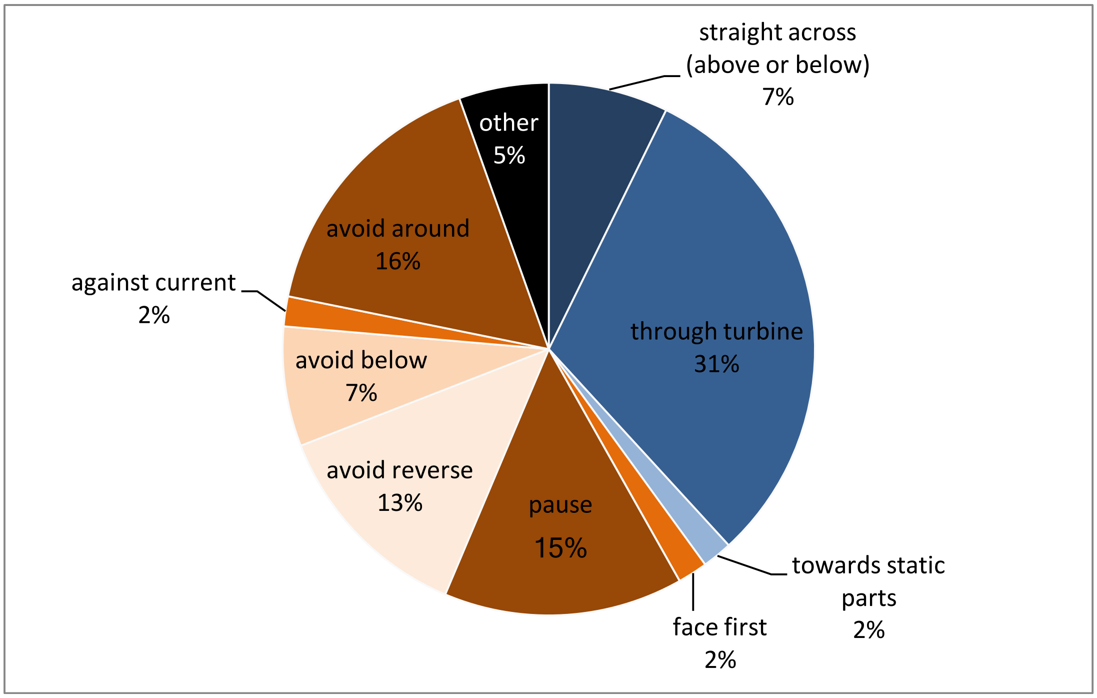


Figure 3.10. Behavior types recorded by reviewers for potential collision or strike Fish Events in Nighttime Data (n = 17).

The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

3.2.1.4 Light Effects

On July 19, the lights remained off through the night, while on every other night the lights turned on as it became dark. A light operations record was not kept during deployment, so manual reviewers at PNNL watched the video and estimated the operational status of the lights (Figure 3.11). Events observed over four nights during hour block 23 (23:00–00:00) when light operations varied were compared to show fish presence while the lights were on and off (Table 3.2). Over the four-night comparison of hour block 23 (a total of 4 hours), the lights were off 45% and on 55% of the total time.

Only 5 events were recorded by the reviewers on July 19 when the lights remained off the entire hour. All 5 events on July 19 occurred in the first 9 minutes of the hour block, and they were all Maybe Events. On July 20, 1 Maybe Event occurred while the lights were off during the first 34 minutes of hour block 23, and 144 events (1 Fish Event, 143 Maybe Events) occurred while the lights were on in the last 26 minutes of hour block 23. On July 21, 2 Maybe Events occurred while the lights were off during the first 14 minutes of hour block 23, and 65 events (2 Fish Events, 63 Maybe Events) occurred while the lights were on during the last 46 minutes of hour block 23. On July 22, 135 Maybe Events were recorded by reviewers when the lights remained on during hour block 23. Over the four-night comparison, approximately 2% of the total events occurred while the lights were off, and 98% occurred while the lights were on.

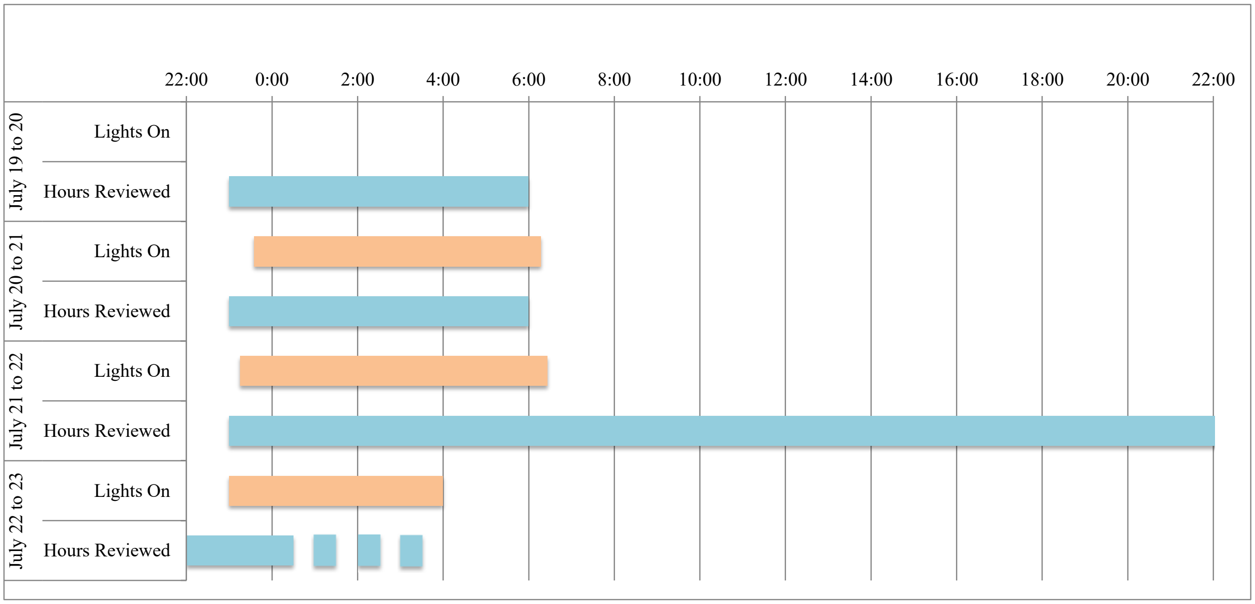


Figure 3.11. Visual approximation of light operations determined by watching the video data and noting when the turbine and objects began to look brighter (lights on), or when the turbine and objects began to look darker (lights off).

Although a light operations record was not kept, PNNL staff watched the video data to estimate when the lights came on and turned off. The orange bars represent the duration of time the lights were estimated to be on, while the blue bars represent the duration of time manually reviewed by the two reviewers. The x-axis on Figure 3.11 shows a total range of 24 hours, from hour 22:00 on one day and up to hour 22:00 of the next day. This was done to show the light operations and review effort in a more continuous manner. The major y-axis labels list the dates reviewed with minor label divisions of when the lights were on and the hours reviewed on those dates. From the night of July 19 to the morning of July 20, the lights remained off, and the reviewers manually processed video data from 23:00–06:00, although only part of hour blocks 23 and 5 were visible. From the night of July 20 to the morning of July 21, the lights were estimated to be on from 23:35–06:17 and the reviewers manually processed video data from 23:00–06:00. From the night of July 21 to the morning of July 22, the lights were estimated to be on from 23:15–06:26 and the reviewers manually processed video data from 23:00–22:00. From the night of July 22 to the morning of July 23, the reviewers manually processed video data from 23:00–00:30, 01:00–01:30, 02:00–02:30, and 03:00–03:30. The lights were estimated to turn on at 23:00 and remained on during all of the manual review effort on July 23, but an estimation of when the lights turned off that day was not done.

Table 3.2. Comparison of the number of events recorded by reviewers during hour block 23 (23:00–00:00) over four nights when the lights were on and off, including the duration of light operation status and totals.

Hour Block 23	Lights Off		Lights On		Total
Date	Duration	Number of Events	Duration	Number of Events	Number of Events
7/19/2015	60 minutes	5	0 minutes	No data	5
7/20/2015	34 minutes	1	26 minutes	144	145
7/21/2015	14 minutes	2	46 minutes	65	67
7/22/2015	0 minutes	No data	60 minutes	135	135
Total	108 minutes	8	132 minutes	344	352

3.3 Discussion

Perceived risk and shortage of empirical data about fish interactions with tidal and in-stream turbines like ORPC's RivGen® means that monitoring is required during turbine deployment. For near-field interactions, optical cameras are the ideal choice because acoustic devices are limited at such close ranges because of transmitted sound scattering from the turbine blades. For this research, the use of cameras provided a useful data set that allowed the capture of hundreds of fish interactions with an operational commercial-scale device. These interactions included 17 possible collisions with static components and possible strike with dynamic components of the device. These 17 events accounted for 2.75% of all Nighttime Fish Events and 0.07 % of total hours processed. Only through intense manual processing effort was it possible to find the extremely rare events of collisions and possible strikes that were observed. These processed data also allowed comparison of a complete manually processed data set to the same subsampled processed data set. Of the 17 possible collision or strike events, only 1 was in the first 10 minutes of the hour. This means that 16 of the events would have been missed, pointing to the importance of full data set processing to ensure these rare events are observed. While strike and collision are of major concern, the behaviors used by fish as they approach these devices are important for continued research and to determine the need for monitoring around turbines. The types of behavior provide input parameters to models as well as identifying differences that may exist between different species or age classes of fish.

The previous analysis by LGL primarily processed data to coincide with times that the RivGen® device was spinning, which was typically during daylight hours. The PNNL research team concentrated on nighttime because 66% of all fish observed by LGL were observed during nighttime even though this time composed less than 10% of their total processed data.

3.3.1.1 July 22 Data Subsampling Comparisons

PNNL processed the first 10 minutes of each hour, illustrating the difference between subsampling and full analysis. Processing sub sets of data is common for researchers faced with the daunting task of large data sets, and it is considered a valid way to process large amounts of data. In this instance, when subsampled data [(10)*6] were compared to the fully processed (all 60 minutes of each hour) 24 hours of data on July 22, the number of Fish Events per hour was the same for hour 2, less for hour 1, and more for hours 3, 4, 5, and 6 (Figure 3.3B). While there was some discrepancy between the two, a larger sample size for comparison would be required for validation. The number of fish (counts) had similar results with the (10)*6 estimates being larger than the actual 60-minute counts for hours 2–6 (Figure 3.3A). Counts be skewed if large schools of fish are present. The first hour block in the July 22 fish count data (Figure 3.3A) is a good example of this; the full hour count data are more than four times the (10)*6 estimate. This was simply a case of several schooling Fish Event occurrences that were made up of tens of juvenile fish observed from minute 10 to 60. Subsampling may provide a valid estimate of Fish Events but fish counts may be biased low if events with large schools of fish are missed.

Having the entirety of the July 22 video processed provided evidence that the majority of Fish Events occur during nighttime. For this single day, it also indicated that the number of Fish Events did not dramatically increase or decrease based on whether the turbine was static or spinning. For the total data manually reviewed by PNNL, the turbine was spinning for 44% of the time, and not spinning for 56% of the time. After the RivGen® spinning ceased (typically around 01:00), the number of Fish Events decreased from then until 06:00. The occurrence of Fish Events is more likely to be related to light levels because Fish Events decrease temporally as sunrise approaches. If the driver for frequency of Fish Events is light levels, then use of artificial lighting to increase detection probability at night introduces a possible complication.

3.3.1.2 Nighttime Data Behavior Types

Describing the behavior of Fish and Maybe Events captured from a single camera is subjective for most of the descriptions (see Appendix A). While an observed movement upstream or downstream is definitive in nature, movement toward or away from the camera or attempting to use depth of field to describe an event is difficult and accuracy is impossible. Nevertheless, behavior was described for all Fish and Maybe Events during PNNL processing of the data. An extensive list of behavior types that described in detail the majority of observed fish behavior was used. Additionally, specific behaviors were qualified as being Avoidance or Passive behaviors (Table 3.1). For the manually processed data set, the extent to which behavior is addressed for each processed event is important to understand fish behavior in general as well as differences between behaviors of fish based on their size or age class.

The binary grouping of all specific behaviors into Avoidance and Passive behavior groups provided evidence of two important findings:

- First, the amounts of Avoidance and Passive behavior differ between Maybe and Fish Events. During the PNNL processing, both reviewers agreed that movement or behavior of the object during an event had a strong bearing on whether or not it was deemed to be a Maybe or Fish Event. More movement, especially those representing non-passive examples, typically led to classification as a Fish Event. The Avoidance group of behaviors is therefore important for separating Fish Events from Maybe Events. However, not all fish entering the field of view will necessarily change their behavior before exiting. Fish already in line to avoid the turbine may not change their trajectory and thus fall under one of the Passive group's behaviors.
- Second, the amount of Avoidance/Passive behavior differs between adult and juvenile Fish Events. Fish Events that consisted of adult fish had only 17% Passive behavior and of this amount only 4% were specifically "through turbine" (Figure 3.7). In contrast, juvenile Fish Events had a 50/50 split between Avoidance and Passive behavior and 34% of the Passive behavior was "through turbine". This comparison shows evidence that adult fish are better at avoiding the turbine than juvenile fish. Although juvenile fish behavior may consist of Avoidance behaviors, the juveniles tended to be less successful in actually avoiding the device and often went "through the turbine" even after attempting an Avoidance behavior.

Behavior types or groups may play an important role in algorithm development in the future. A variety of qualifiers are used in algorithm development, and behavior or movement is an important one for animal detection algorithms used with remote sensing devices and specifically optical cameras. Often, threshold metrics are used for initial investigations into automating an animal being in a frame. However, if this is successful and a variety of animal types have potential for being detected, then the next step is grouping them by some qualifying characteristic. Often size is the first characteristic for grouping followed by movement or behavior. Knowing the movements and behavior associated with the fish detected in these data has the potential to further general knowledge or inputs for modeling. Improved automated analysis to decrease the effort required to process and analyze these types of data and ultimately create cost-

effective methods. Use of these methods by developers and researchers can provide meaningful data accepted by regulatory bodies that require monitoring.

3.3.1.3 Fish Collision and Strike

As fish collision, strike, and near-miss events are generally accepted to be rare at marine and hydrokinetic (MHK) installations, it is important to process most, if not all, of the data collected to ensure these events are not missed. If an entire data set is not to be processed, then large-scale time blocks likely to coincide with the highest probability event occurrences, decided upon with expert opinion or existing empirical data and statistical analysis, should be processed. The sequence of the processing steps used for camera data set described herein is a good example of efficient gathering of useful information. The initial subset processing performed by LGL for the first 10 minutes of certain hour blocks made it clear that most Fish Events occurred during nighttime. This is a highly productive first step for a large data set for which no established processing methods exist, except for manually reviewing the data. As a logical first step, it saved time and provided the foundation for taking the next step to gather meaningful results. PNNL followed up and concentrated processing effort on nighttime hour blocks based on the LGL information that indicated more events occurred at night. This concentration on the Nighttime Data provided more meaningful comparisons of a variety of fish behaviors showing differences in adult and juvenile behaviors. The processed data also captured 17 events, out of a total of 618 Fish Events, with possible collision and strike between fish and a commercial-scale device, indicating how rare these events are and the difficulty associated with observing them. Even with capturing the events with possible collision or strike, actual contact is difficult to verify because uncertainty remains based mostly on the data quality specific to camera selection, lighting, placement, and field of view. Collision was only confirmed in one instance when an adult fish collided with the camera. Additionally, it is important to note that the outcome of a collision, strike, or near-miss event was not possible to determine because of data quality and the short duration that a fish was in the actual field of view.

Camera selection for underwater fish observations is not a trivial matter. The field of view, resolution, low light capacity, and frame rate are just a few of the parameters that are crucial to gathering high-quality, meaningful data. After data have been collected, the file type becomes important for effective processing that leads to useful analysis. The cameras used to collect the data presented in this report were customized SeeMate ™ color to monochrome units with a F2.9 wide angle lens, manufactured by IAS systems (North Vancouver, British Columbia). The images had a resolution of 352 × 240 pixels. Each camera had a variable frame rate (less than 10 per second), and a field of view of "approximately one-third of the area between the pontoons and the left (portside) one-third of the TGU"[1] (LGL 2015). Pixel resolution, field of view, and light capturing ability created limitations in the data set, and complications continued because the output files were of a proprietary format. Significant amounts of unplanned time and resources were required for file conversion to a non-proprietary format, followed by testing several video-file viewers to determine the one best suited for this analysis, which included requirements like moving forward and backward through each frame capture without skipping or freezing up. Based on this work, literature review, and discussions with other researchers, a brief set of guidelines for camera selection for future applications is given in the Recommendations section.

3.3.1.4 Light Effects

On every night except July 19 the lights turned on as natural light levels decreased to illuminate continued monitoring fish presence and interaction. A comparison was done to better understand the potential impact of artificial lights during this environmental monitoring effort during hour block 23 from July 19

---

[1] LGL Alaska Research Associates, Inc., 2015 *Fish and Wildlife Monitoring Plan for RivGen® Testing on the Kvichak River, Alaska in 2015*

to 22. As it became dark on July 19, the field of view began to fade into a grainy, grayscale image with portions of it becoming black over time. If fish were present during the last 15 minutes of hour 23:00 on July 19, it would have been very difficult for the reviewer to see or document their presence. When comparing the first half of hour 23:00 on July 19 to the same hour on July 20, the images of both nights seem similar, but when the lights appear to turn on at approximately 23:35 on July 20, the turbine is illuminated, potentially creating an opportunity for light to reflect off fish and be visible to the camera, as well as make the image sharper and clearer. In contrast, on July 19 the image degrades over time. Nighttime illumination probably affects the detection probability of fish by the reviewers, and may alter an avoidance/attraction response by the fish.

The number of events that occurred when the lights were on was considerably higher than when the lights were off (344 compared to 8, respectively), and with a similar operation duration (55% compared to 45%, respectively). The number of events when comparing lights on and off differs considerably, yet the reason for this in this application is not well understood. Artificial lights may have attracted fish, thereby causing more events, or more fish may have been present during the last half of hour 23 when the lights were generally on every night except July 19; the data from July 22 when the lights were on for the full hour show more fish during the second half hours (135 vs 94), but this does not account for the extreme difference observed overall. Alternatively, fish presence may be similar on all nights, but the artificial light provides the source needed to make them visible to the optical cameras and in turn, reviewers. Additionally, on July 22 when all 24 hours were reviewed, Nighttime events (when the lights were on from 00:00–06:26, and 23:00–00:00) made up 99.9% of the total events for that day, with only 1 daytime Fish Event overall (although 436 Maybe Events during the daytime). Due to this clear difference and the lack of baseline understanding of fish attraction or deterrence related to this variable, the role of artificial lights during environmental monitoring needs to be further investigated.

4.0 Automated Analysis

Automated analysis was investigated to develop algorithms for detecting fish presence in the video, so that an entire video data set could feasibly be analyzed automatically without the need for manual sampling. Reducing the volume of data to just those video segments during which fish were present would optimize human labor time, and the reduced-volume approach could also be used to perform a quick preliminary analysis of the data. Ultimately, the system could be fully automated, and the software optimized to run in real time as part of an underwater observation system for long-term monitoring of the effects of MHK devices on animal populations.

The vision for an automated video processing system consists of three main components: preprocessing, detection, and classification (Figure 4.1). The preprocessing component filters the raw video frame to improve its quality in terms of contrast, color balance, and smoothness. The detection component identifies objects that might be fish, and the classification component classifies the detections to filter out false positives such as kelp, shadows, or other objects that are not of interest. These three components interact, and each requires many design decisions in order to realize an effective system. Under this project, candidate algorithms were investigated for each of the components, and an infrastructure was developed to tie the components together into a web-based application developed by PNNL called EyeSea.

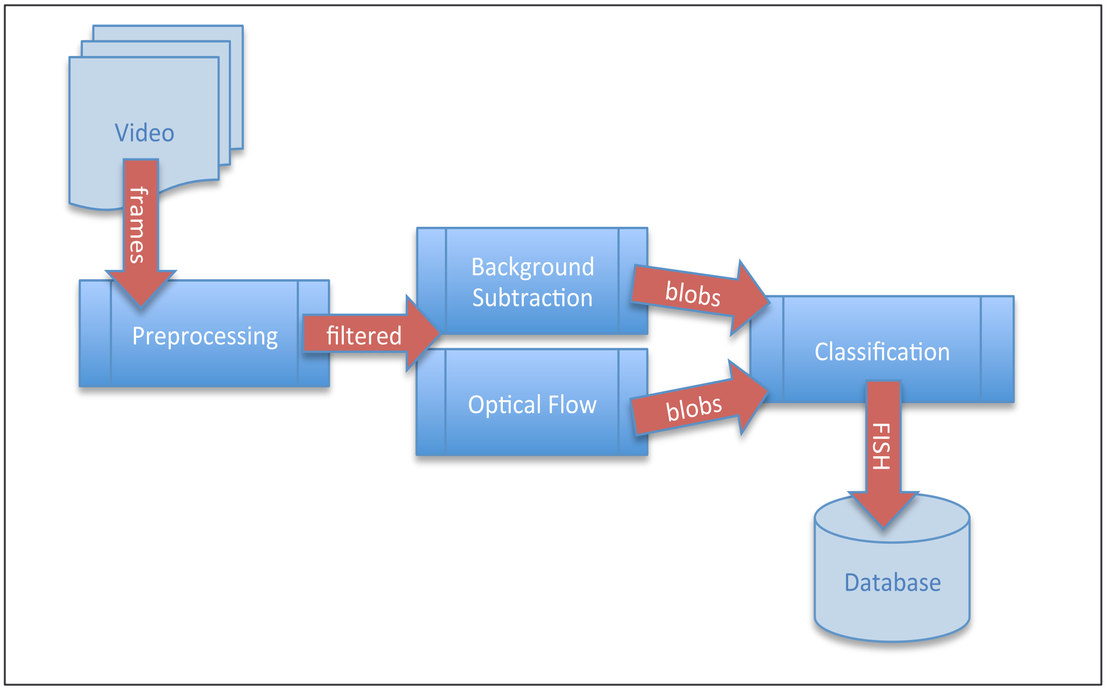


Figure 4.1. The automated processing chain.

4.1 Methods

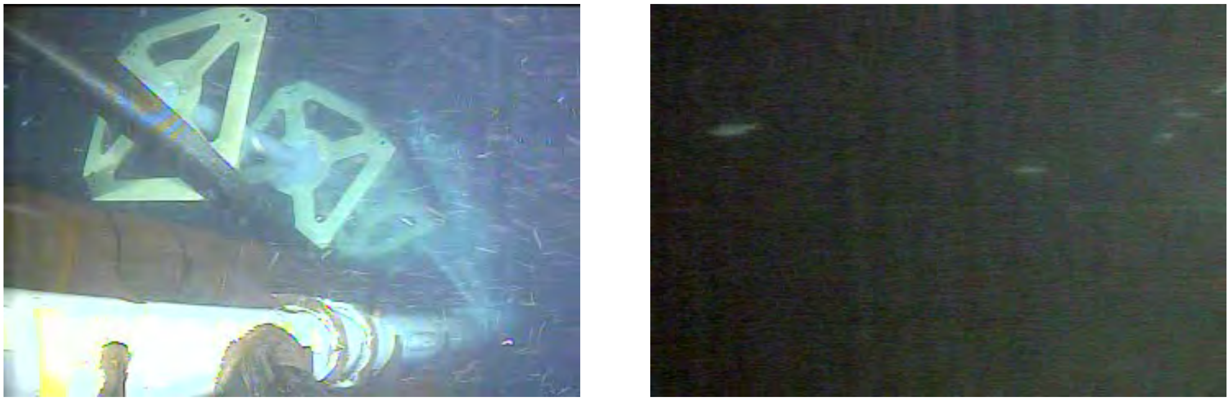
A testbed was developed to evaluate the performance of different algorithms; it consisted of a development data set and a processing pipeline. This meant that algorithms could be evaluated in a consistent, reproducible manner. A development data set was assembled from a subset of the full Igiugig data set consisting of 16 five-minute video segments containing Fish Events (Appendix B). The video segments were selected to represent different lighting conditions, different camera views and different sizes of fish, individuals and schools (Figure 4.2). Each video consisted of a total of 7500 frames, and even though the segments were chosen to include fish, only 6% of the total frames did in fact contain fish (the presence of fish is not a common event). The data were annotated as described in the Manual Analysis section. The processing pipeline was adapted from the Fish4Knowledge (Boom et al. 2014) code[2] for fish detection with custom code. The pipeline was used to batch process all the development videos using a particular detection algorithm, and to calculate the resulting detection rate and false positive rate by comparing the detections to the manual analysis annotations (Figure 4.3).

---

[2] http://groups.inf.ed.ac.uk/f4k/

a) Camera 1, daylight

b) Camera 1, night



c) Camera 3, night illuminated

d) Camera 4, night illuminated

Figure 4.2. Example images of fish in the different cameras with different illumination.

For the detection algorithms, background subtraction and optical flow were investigated. Three different background subtraction techniques were evaluated: Robust Principal Components Analysis (RPCA) (Candès et al. 2011), Gaussian Mixture Model (GMM) (Lee 2005) and Video Background Extraction (ViBE) (Barnich and Van Droogenbroeck 2009). The optical flow analysis consisted of a dense optical flow calculation using the Farnebäck algorithm (Farnebäck 2003) and a sparse feature-based flow calculation using the Lucas-Kanade method (Lucas and Kanade 1981), both as implemented in OpenCV.[3] For classification, models were developed using forward-stepping linear discriminant analysis (Lotlikar and Kothari 2000) on the detected objects to distinguish between fish and non-fish objects. The features used for classification were object size, intensity, shape, and motion.

---

[3] http://opencv.org

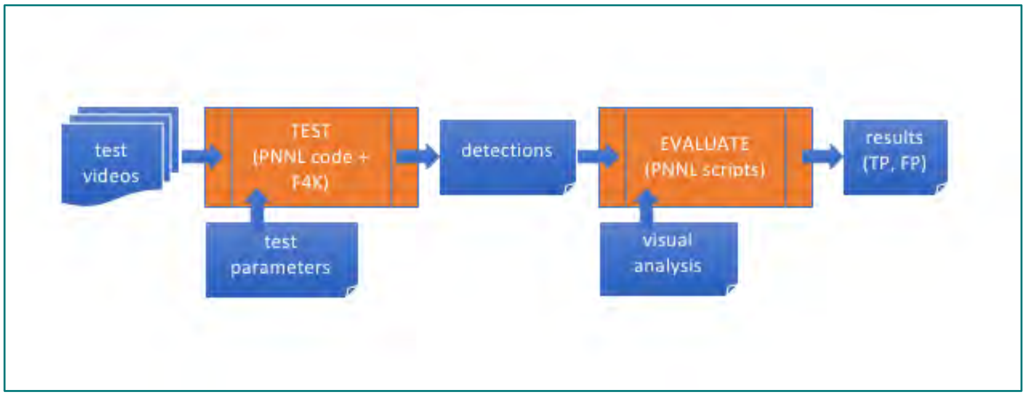


Figure 4.3. The developed testbed pipeline for evaluating different detection algorithms.

Background subtraction is a computer vision technique that is used to separate an image (or video frame) into background and foreground, where foreground means objects or regions of interest and is application-dependent. In this study, foreground is defined as fish and everything else is considered background, even other objects that might be moving such as the turbine itself and floating debris. This is a challenging data set for background subtraction because of the low quality of the video and the highly dynamic background. RPCA, GMM, and ViBE algorithms were selected based on recommendations from researchers at the University of Washington and the Fish4Knowledge project (Boom et al 2014) as being robust relative to background motion. The recommended parameter values for each algorithm were used.

The foreground images resulting from the background subtraction were further processed to group connected pixels of similar intensity into “blobs”. These objects were then classified as fish or non-fish. The blob size was highly variable ranging from 1 pixel to over 10,000 pixels, so the blobs were divided into five size groups and classification models for each group were developed separately.

The motivation for including optical flow is the hypothesis that fish motion is different than other motion in the scene, such as the motion of objects drifting with the current and the motion of the turbine foils turning. The researchers who performed the manual analysis said that one of the features they used to recognize fish was directed motion. Optical flow is the motion (spatial displacement) of light intensity from one video frame to the next. It is calculated for video by matching regions in one frame with regions in the subsequent frame, where the matching is based on edges and gradients of light intensity, and the flow is the displacement. There are several algorithms for calculating optical flow in the literature. For this application, the Farnebäck algorithm was chosen to calculate a dense optical flow over the entire image. Initial tests of both the sparse and the dense optical flow methods indicated that the sparse method was not effective when analyzing the raw video because of the lack of strong gradient features that could be tracked from one frame to the next. Dense methods are more robust relative to some changes in object intensity and shape because dense methods use more surrounding context for matching features.

In a parallel effort, a Deep Learning model was applied to the development data set. The open-source machine learning library TensorFlow was used to build a convolution neural network and train it on a portion of the data set. This type of neural network must be trained on labeled data to generate a model for classifying new data. For this video analysis, the inputs to the network were the individual video frames, labeled as “fish” or “no fish”. A subset of the labeled data (video frames) was selected at random to train the network and the resulting model was tested on the remaining data. This process was repeated over multiple iterations, where a new subset of the data was selected for training at each iteration. This iterative process is necessary to find the subset of the data that produces the best model.

4.2 Results and Discussion

One project goal was to reduce human labor time, hence the performance objectives were a 90% detection rate and a 30% false positive rate. The detection rate is the percentage of actual fish present that are detected, and the false positive rate is the percentage of reported detections that are not fish. It was important to detect most of the fish at the cost of some false positives because the false positives could be sorted out by human analysts, but too many false positives would reduce the benefit of the automation.

For an initial comparison of the background subtraction algorithms, the recommended parameter values for each algorithm were used (Table 4.1). The algorithms were evaluated for how well they correctly identified which frames contained fish. A frame was classified as "fish" if it contained one or more detections (foreground objects). The algorithms all performed similarly on the test bed data set (Table 4.2). The best detection rate was 67.51% (ViBE), which was much lower than the goal of 90%. The false positive rate was high, but the best true negative rate was better than 57%, which means that over 57% of the frames containing no fish were correctly labeled as such.

Table 4.1. Background subtraction algorithm parameters.

RPCA	ViBE	GMM
Window size = 50 Interval = 10 Threshold = 50	History = 20 Learning = 50 Radius = 20 Match criteria = 2 Update probability = 1/8	alpha = 0.02 threshold = 0.7 upper difference = 220 lower difference = 30

Table 4.2. Background subtraction frame classification results.

Algorithm	Percent of Fish Frames Correctly Detected	Percent False Positives	Percent True Negatives
RPCA	57.45	92.18	**57.60**
ViBE	**67.51**	**91.51**	54.48
GMM	63.79	92.29	52.19

The figures in bold indicate the best performance between the algorithms.

The background subtraction alone is not sufficient to meet the performance objectives, but the results offer valuable insight into the effects of night and day, the use of lights, and camera placement (see Section 7.0 for specific recommendations). The individual videos were analyzed to better characterize the algorithm performance under different conditions (Figure 4.4). All algorithms performed best on the videos from camera 1 at night, where there was no turbine in view and lights were on but angled away from the camera's field of view. All algorithms performed poorly in terms of false positives on the video from cameras 3 and 4 at night. The turbine was in view in both these cameras and the lights were aimed at the turbine. All algorithms performed worst on the video from camera 1 during the day, when most of the reported detections were false positives and most of the actual fish present were not detected. During the day, the fish were in low contrast with the background, so they were more difficult to detect. The lights at night reflected off the fish, increasing the fish's contrast with the background, so they were easier to

detect. Floating debris that was similar in size to small fish also reflected the light causing false positives (Figure 4.5).

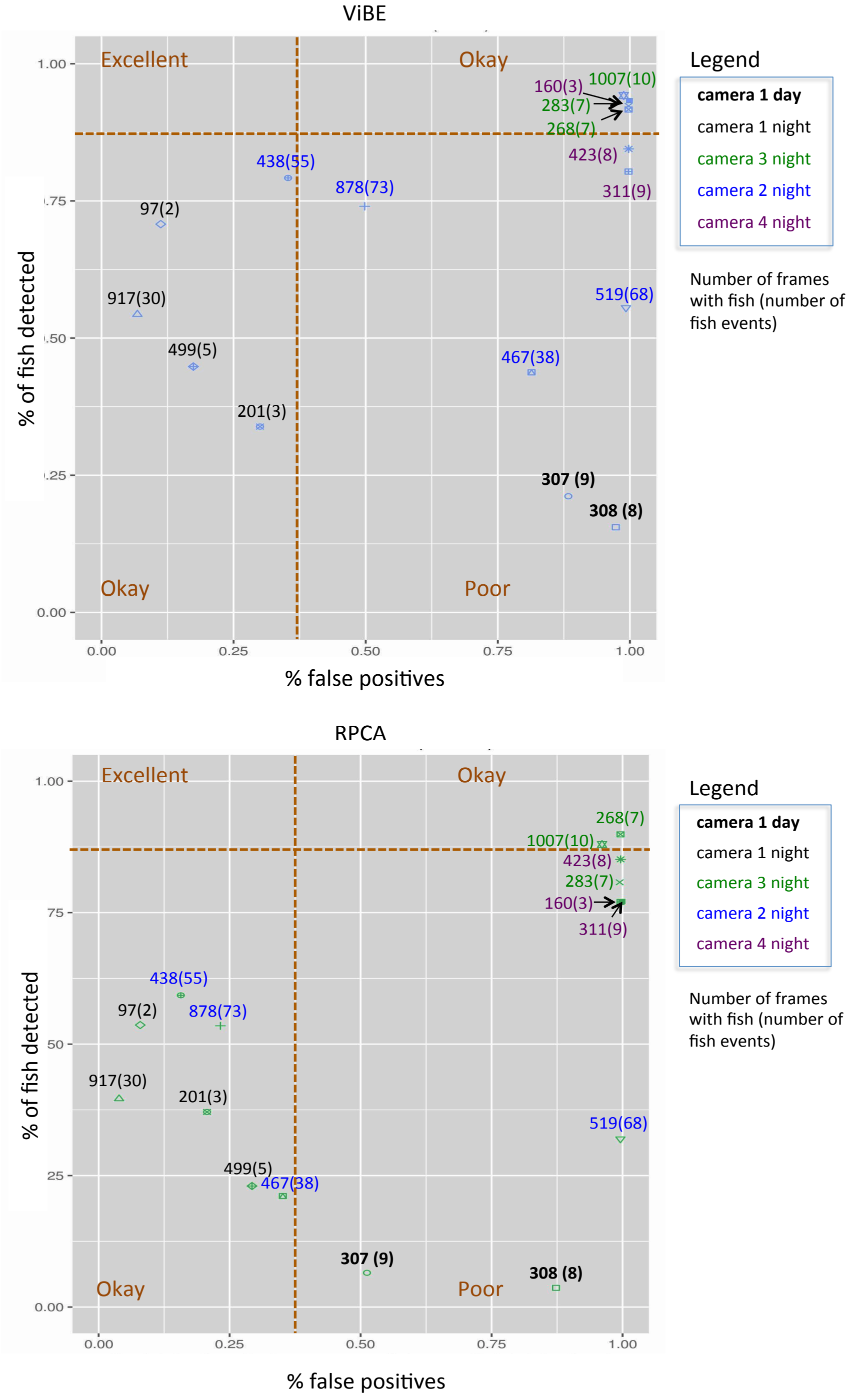


Figure 4.4. The detection rate and false positive rate by test video for RPCA (top) and ViBE (bottom). *The numbers on the scatter plots indicate the number of frames (out of 7500 per video) that contained fish and the number in parentheses is the number of Fish Events. A Fish Event is when a particular fish is in view; an event usually spans multiple consecutive frames.*

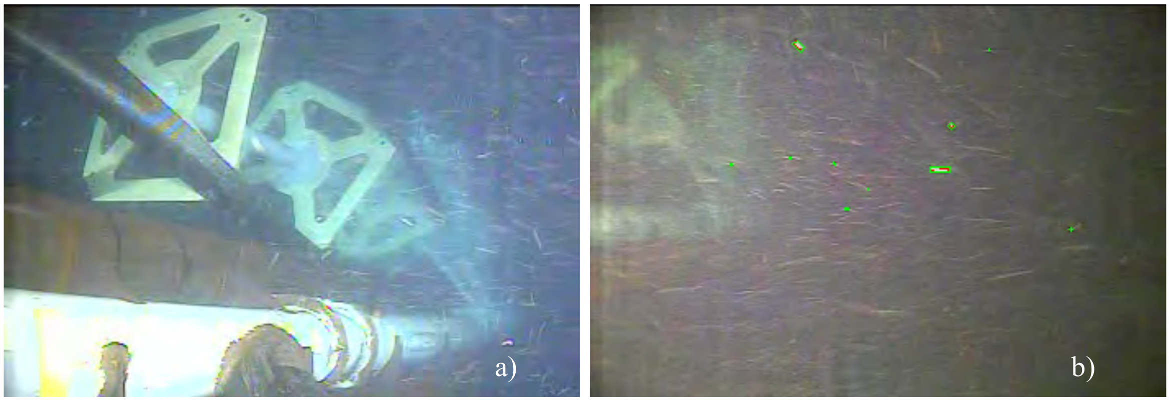


Figure 4.5. Example frame from camera 4 at night with small fish (a) and the detected objects from ViBE (b). The small fish are detected but there are also some false positives from the illuminated debris. These false positives were eliminated during post-processing.

Using the results of the initial evaluation as a baseline, preprocessing techniques were evaluated. The two techniques included with the Fish4Knowledge code were histogram equalization and contrast stretch. The preprocessing did not add significant computation time, but neither technique improved the performance and in some cases had a negative effect. A bilateral filter (Tomasi and Manduchi 1998) is often used in photographic applications, and this technique was tested on two of the videos, one from camera 3 and one from camera 4. Only two videos were processed because the computation was extremely slow on a desktop computer, but the results were promising (Figure 4.6).

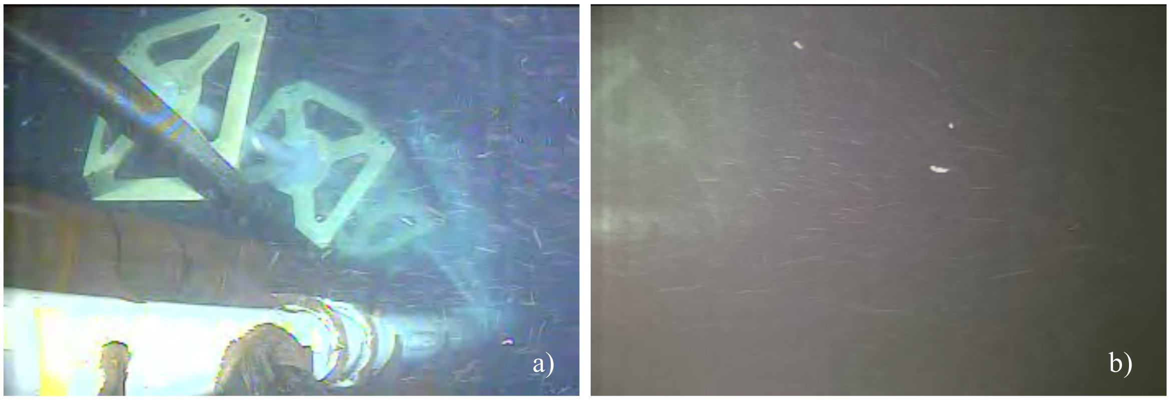


Figure 4.6. The raw frames (a) are preprocessed with a bilateral filter to reduce the clutter from debris (b).

The parameters of the best performing algorithm, ViBE, were varied to find the optimal values for the Igiugig data set. An exhaustive search for the optimal values of all five parameters was beyond the scope of this project, so two parameters with a strong influence on performance, the radius and the match criteria, were varied. The radius is the relative difference in intensity between background and foreground; a higher value will reduce the sensitivity and a lower value will reduce the precision (more false positives). Because detecting all the fish was more important than eliminating false positives, the radius was reduced and values of 20, 18, and 16 were evaluated. The match criterion is the minimum number of historical values that must fall within a current pixel’s radius to consider the pixel to be background. A lower value will reduce sensitivity and a higher value will increase false positives and processing time. Values of 2 and 4 were evaluated. The best combination of values was radius = 16 and match criterion = 4 (Table 4.3).

Table 4.3. ViBE parameter tuning results.[(a)]

	Match = 2	Match = 4
Radius = 18	52% / 39%	70% / 54%
Radius = 16	55% / 42%	**74% / 59%**

(a) The first number in each cell is the true positive rate and the second number is the false positive rate. The figures in bold indicate the best combination of values.

A classification model for the detected objects significantly improved the performance by reducing the number of false positives. The detected objects were classified as "fish" or "non-fish" based on human analysis, and were divided into five size categories. A random sample of approximately 50 of each class (~100 observations) in each size category was used to develop a linear discriminant model for each category. For each size class, forward-stepping linear discriminant analysis followed by canonical analysis was used to determine the best model. Variables considered for the model included the blob size, blob solidity, blob eccentricity, and blob intensity. The models were tested on the remaining blobs that were not used for model development and the results are shown in Table 4.4. The larger blobs were classified most accurately; the accuracy decreased with decreasing blob size. The size of fish that can be accurately classified is dependent on their distance from the camera (the same size blob could be a large fish further away vs. a small fish close to the camera), and having the capacity to judge distance more effectively is discussed further in the Recommendations.

Table 4.4. Detected object classification results.

	Fish		Non-Fish		
Object Size in Pixels (number of fish objects)	True Positive	False Negative	True Negative	False Positive	Percent Correct
200+ (549)	533	16	3753	63	**98.2**
100 – 200 (320)	290	30	12,715	22	**99.6**
5 – 100 (2805)	2281	524	61,356	10,369	85.4
2 – 5 (2114)	1485	629	109,995	23,365	66.3
Total	4589	1199	187,819	33,819	84.6

The optical flow was calculated to generate a displacement in the horizontal and vertical dimensions for each pixel in the video frames, dx and dy, respectively. The displacements were then used to calculate the direction and magnitude of the motion from frame to frame. Direction was defined with 0 being toward the right and 180 toward the left. Five points in different regions of the frame were selected, and the motion was characterized at those points for one of the videos from camera 4 at night (Figure **4.7**). The direction of the motion appeared to be uniformly distributed across all directions and the magnitude appeared to follow a Weibull distribution (Figure 4.8). Due to the flow of the current from left to right in the video, the direction of motion was expected to be concentrated around 0 degrees. The uniform distribution that was observed may be due to the small, random motion of the floating debris. It may also indicate that the optical flow algorithm was not accurately matching points from one frame to points in the subsequent frame, due to the lack of distinctive features in the scene and the algorithm's bias toward small motion. The distribution of the magnitude of the motion shows that most of the calculated motions were small, with some outliers. The small motions may be due to debris and noise in the images, and the

outliers may indicate darting fish. The results are inconclusive and indicate a more in-depth investigation is needed, including testing the use of the bilateral filter for preprocessing to reduce the clutter in the scene.

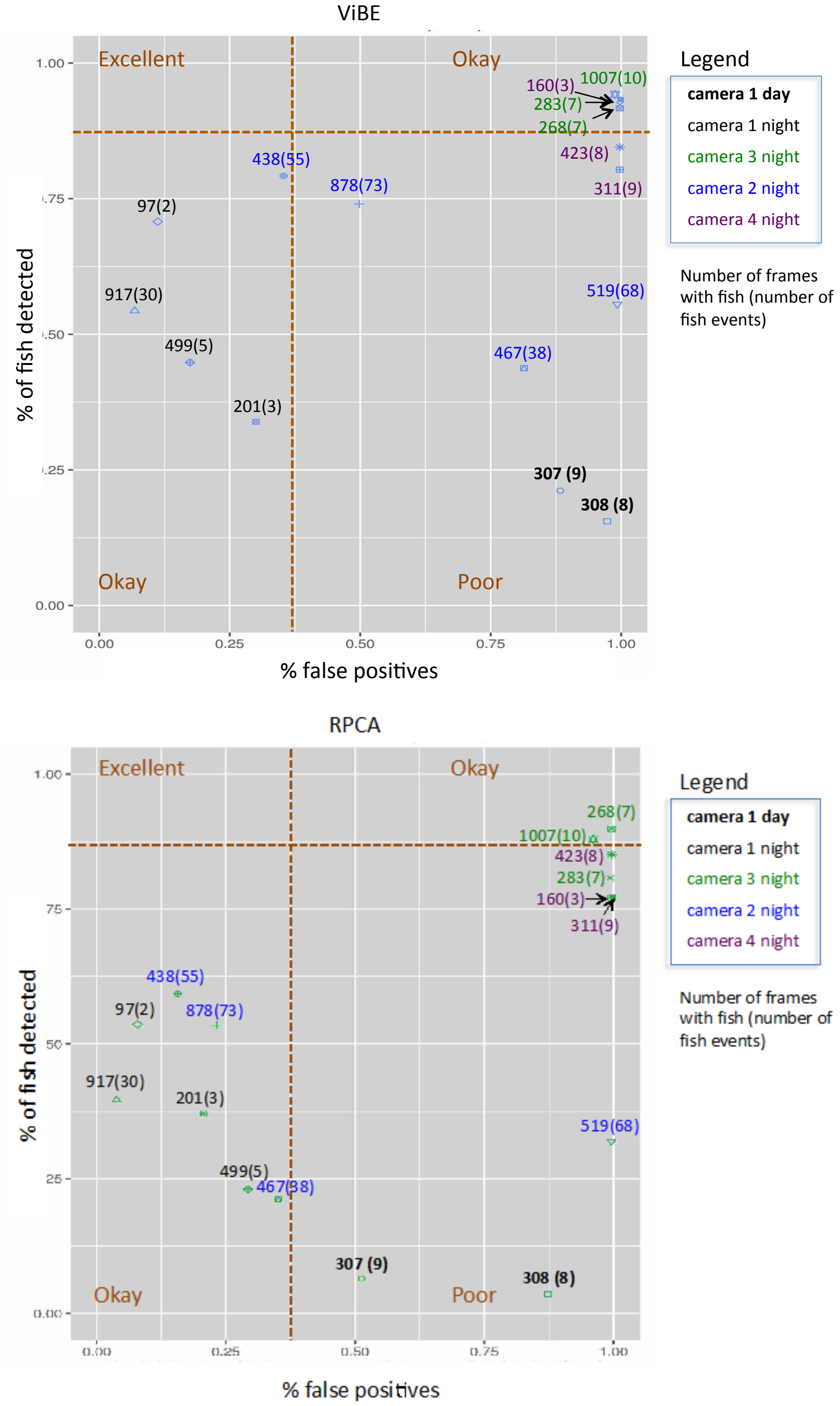
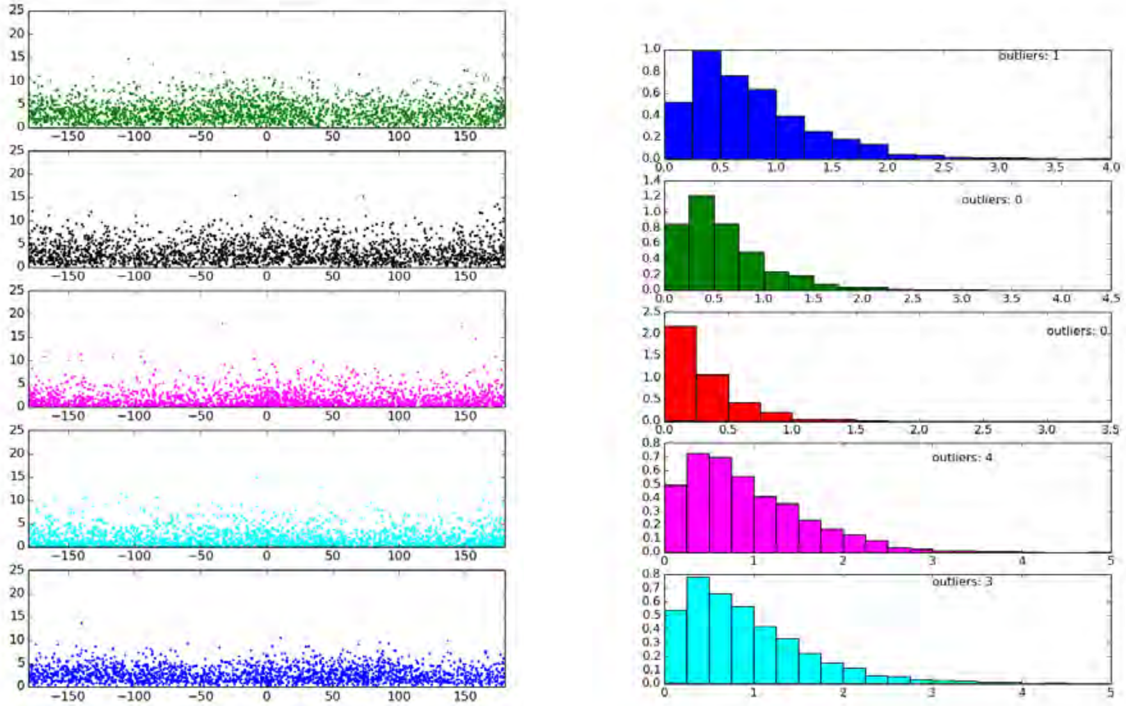


Figure 4.7. The detection rate and false positive rate by test video for RPCA (top) and ViBE (bottom). *The numbers on the scatter plots indicate the number of frames (out of 7500 per video) that contained fish and the number in parentheses is the number of Fish Events. A Fish Event is when a particular fish is in view; an event usually spans multiple consecutive frames.*



a) Magnitude vs. Direction

b) Magnitude Distribution

Figure 4.8. The magnitude and direction of motion at five points in the video were characterized using optical flow. The direction appeared to be uniformly distributed across all directions (a), and the magnitude appeared to follow a Rayleigh distribution that implies the motion in the x and y directions are independent (b).

The best Deep Learning model developed over the iterative learning process achieved 79% correct classification of both “fish” and “no fish” frames. This result is promising and on par with the background subtraction/blob classification results. This approach could be suitable for batch processing a large volume of recorded data, like the Igiugig data set, especially if the processing can be done on a high-performance computing system of parallel nodes. However, this approach would not be suitable for a real-time system because of the computational intensity, and the requirement for training data that is specific to the location being monitored.

5.0 Software

5.1 Need and Requirements

EyeSea is a web application that was developed by PNNL to meet the need for a central repository for accessing and analyzing the terabytes of video data from the Igiugig project. During the manual analysis of the video data it was found that the proprietary format of the video data required the use of the vendor’s specific software, which ultimately did not meet the requirements of the analysis team. Fortunately, an open-source video encoder (https://ffmpeg.org/) enabled the transcoding of the video data to the standard h264 format. This allowed the analysis team to use other more feature-rich software to perform the analysis of the video data. There was still the issue of how to make the h264 encoded video data available to the analysis team and also how to store results of the video analysis. To solve this issue a database-driven web site was designed, called “EyeSea”. This web-based application was developed in

parallel with the algorithm development, and was envisioned as the framework for ultimately providing a user-friendly front-end to the automated analysis, combining all the analysis tools into one comprehensive "human-in-the-loop" system for video analysis.

5.2 Functionality

The database was designed to store video metadata (e.g., date, time, location, timezone), analysis results (e.g., fish detected, species of fish, location of fish in video frame), and site-specific data (e.g., log-in information, batch processing information). Figure 5.1 shows the schema of the database that was ultimately implemented in MySQL.

Once the database had been designed the next step was to implement the web application. Bottle (https://bottlepy.org), a web framework for Python, was used to implement the web site. An asynchronous architecture was designed to allow users to query video data and later return and view the transcoded results. This was necessary to enable users to query videos encompassing large amounts of time without causing a browser timeout. Although the website was designed to play back the video inside the web browser, an option was added to allow users to download the video to their local machine for later offline playback. The website was later extended to allow for in-browser analysis of video. Figure 5.2 shows a screen capture example of the in-browser video playback.

EyeSea was also designed to facilitate batch processing and analysis of video. A set of scripts were written that could be deployed on a cluster of servers for parallel processing of multiple videos. The servers query the database for jobs to process and communicate to the database the status of the job as they are completed. The batch processing feature of EyeSea was used to extract Fish Events for later use in the analysis algorithm development testbed.

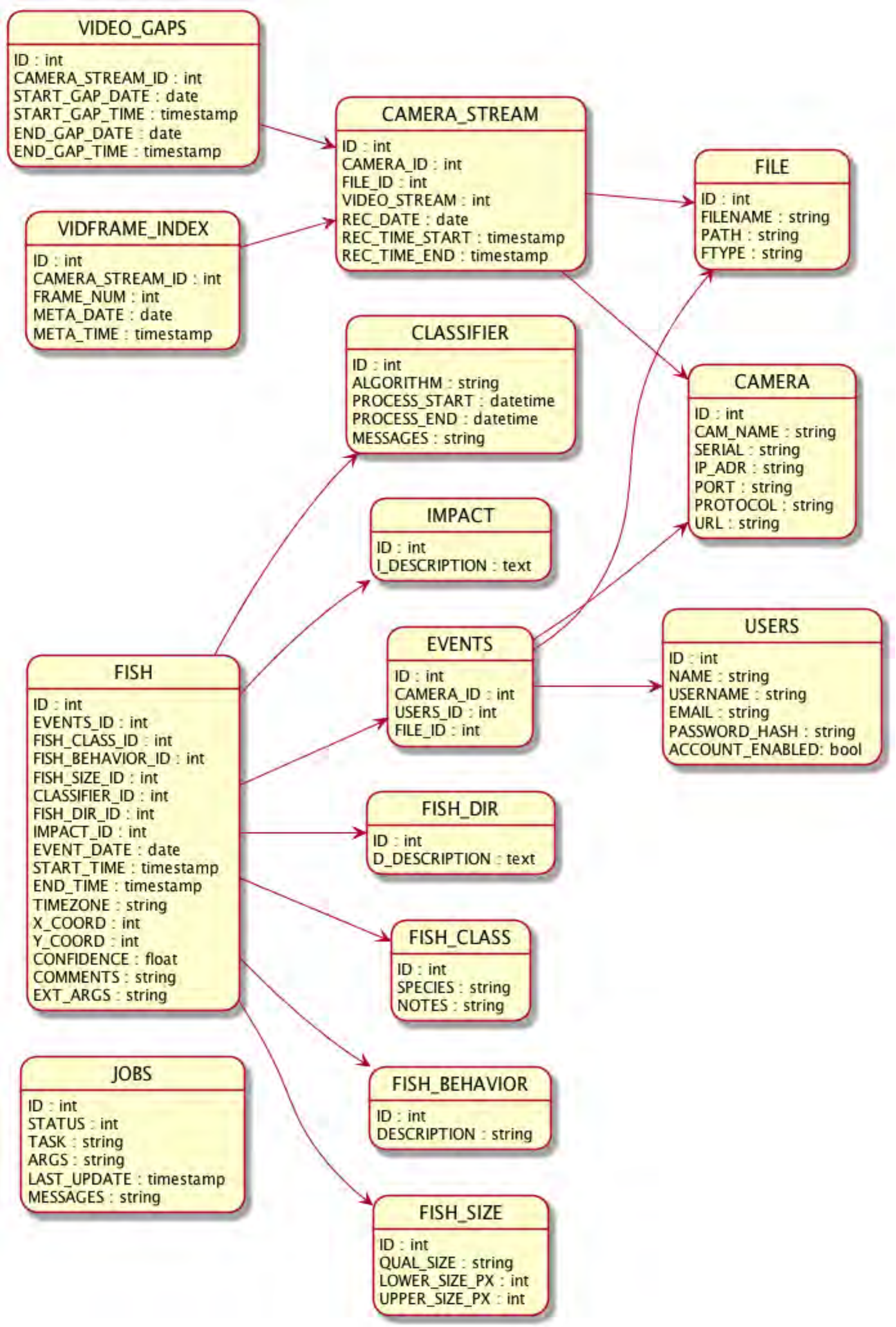


Figure 5.1. EyeSea database schema.

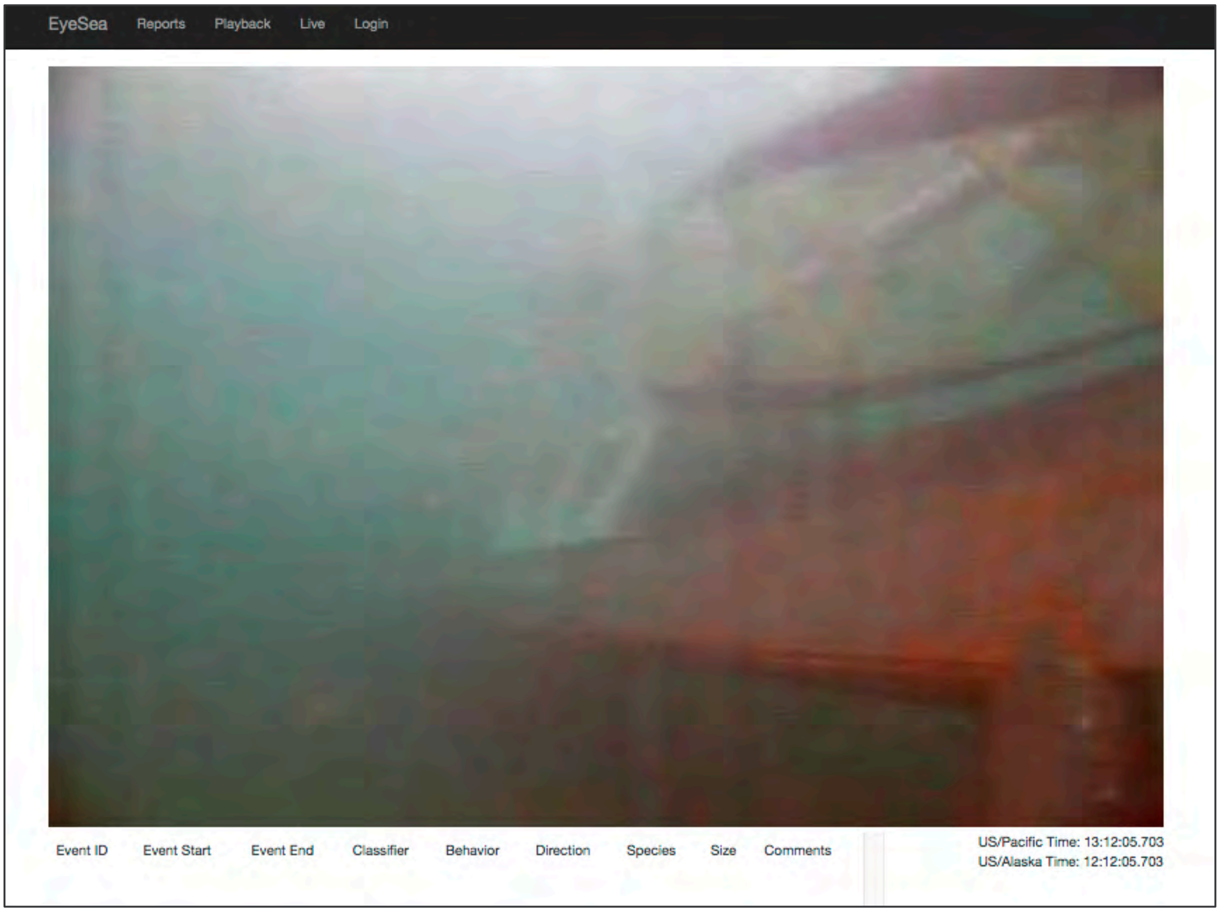


Figure 5.2. The EyeSea web application in playback mode.

6.0 Conclusions

6.1 Manual Analysis

The main points derived from the manual analysis of the data are as follows:

- Manual review of low-quality data is time-consuming. In this data set it took approximately 13–15 hours to manually review and annotate 1 hour of raw video data.
- Most interactions between the fish and the turbine occur at night.
- The frequency of fish interactions does not appear to be affected by whether the turbine is spinning or static.
- Processing subsamples (10 minutes) is likely effective for capturing unbiased event counts, but may not be effective for individual fish counts.
- Reviewer interpretation of Fish and Maybe Events in this data set is similar across two reviewers (qualitative analysis), but care is needed when assigning the designation of objects to introduced categories (quantitative analysis).
- Adult fish are qualitatively more likely to avoid collision or strike than juvenile fish.
- Adult fish are qualitatively more likely to show avoidance behavior as opposed to passive behavior relative to juveniles.

- More events occur when lights are on than when lights are off. Fish may be attracted to lights, lights may increase detection probability, or both.
- These data demonstrate the use of optical cameras for observing fish interactions with a deployed device in an underwater setting; however, improvements could be made with camera specifications and lighting parameters to increase the detection probability of fish, in both manual and automated review. Doing so may significantly decrease the manual and automated processing time.
- Observing "definite" vs. "probable" strike or collision is still extremely difficult and more research needs to be done to develop technologies or combine multiple technologies to gain confidence in determining actual contact with the device.

6.2 Automated Analysis

The main conclusions of the automated analysis effort were as follows:

- Tools available for detecting and tracking fish and other animals in underwater video are lacking. It was necessary to develop a new framework for semi-automated, human-in-the-loop analysis of underwater video. This framework can be used to test new algorithms and refine existing algorithms for automated fish detection and characterization, as well as support human expert analysis and standardized, reproducible information reporting.
- Reducing data volume is the first issue to address with automated processing. Large volumes of data are difficult to work with in terms of transferring, storing, and searching. A computationally simple background subtraction algorithm (ViBE) detected 74% of the human-identified Fish and Maybe fish, and is suitable for use in a real-time system to reduce data volume by saving only video that might contain fish.
- Reducing false positives is the second issue to address with automated processing. A statistical model can be used to classify detections as fish or not-fish, such as the one reported here that achieved a correct classification rate of 85% overall, and 92% for detections larger than 5 pixels. However, the statistical model required labeled training data that took time to assemble from the data and the model may not be transferable to other data sets. A classification model based on motion characteristics would potentially be more effective over a wider range of data.
- Underwater video recorded in energetic locations present challenges to automated processing that require algorithms specifically designed for this purpose. "Out of the box" algorithms such as those provided in the openCV library exhibited limited effectiveness, especially the optical flow techniques. Parameter tuning of the background subtraction algorithms did improve performance.

A combination of the automated detection developed under this project and human analysis could provide more accurate Fish Event information than the current practice of sampling, and with less labor time and cost than full analysis. Human analysis is currently the "gold standard" for accuracy, but it is very time-consuming so labor costs can be high and there may be long delays between collecting data and generating results. Sampling the video for analysis, e.g. analyzing 10 minutes of every hour reduces the labor time but sacrifices accuracy and increases the risk of missing rare events. The automated fish detection algorithms developed under this project can be completed quickly, but the resulting information is not as nuanced as that provided by human analysts and the detection accuracy is not yet sufficient so a "human-in-the-loop" approach is recommended. The automated detection software can be used to eliminate most of the video that does not contain fish, and the ensuing human analysis can be limited to those segments most likely to contain fish. With the developed processing system, this approach would reduce labor time by half over the full analysis, and would improve the reporting accuracy over sampling-based methods.

The performance of the automated processing can be further improved, based on the promising results demonstrated here. Future work should include incorporating computationally efficient bilateral filtering as a preprocessing stage, an intelligent scheme for parameter selection based on environmental conditions and video quality, and the integration of motion features. Further development of the EyeSea software should include a learning mode for tuning algorithm parameters using annotations provided by human experts.

7.0 Recommendations

The analysis of the Igiugig video data, both human/manual and automated, provided valuable insight into how to improve underwater video deployments in the future.

Since PNNL's review of the video data incorporated different approaches and anticipated outcomes than those of the original monitoring plan, recommendations arose regarding the monitoring process and methods for making project development and analysis more efficient in future studies. The water in the Kvichak River was described as being very clear compared to other rivers in the original monitoring report, yet the video data were described in PNNL's Quality Check Summary Report (Trostle 2016) as being "usable", in that the reviewers would be able to describe fish presence. The declaration of "usable" embodies the overall quality of the video data, including the following factors: resolution, frame rate, the placement of the cameras and light sources, the field of view, and the settings of the digital video recorder camera system. Careful consideration of the anticipated review and analysis objectives should be applied when making a camera selection. Those who will be reviewing the data should consider the questions they would like to answer and make sure that their camera selection, settings, and placement have the potential to address those questions.

To increase the quality of the video, future studies should use a low lux camera with a higher resolution and faster, even frame rate, but be aware that this will increase data accumulation because the files will be larger. Higher resolution video data would increase the likelihood that the manual reviewers could decipher between Maybe and Fish Events, identify taxonomic classification, and have more confidence regarding strike and collision. An increase in frame rate will improve the ability to detect actual strike because there would be more frames to describe the interaction around the turbine. It would also allow the reviewer, and possibly the algorithm, to use behavior as a qualifier, because sometimes the object would move significantly between frames, making behavior difficult to determine. Additionally, in some cases an object would only be in the field of view for one or two frames, making it difficult to determine if the object was a fish or not. In this study, objects that were only in one frame were not recorded as an event, because there was insufficient information to describe or categorize the object. With a more frequent frame rate and higher resolution, those objects could be included and give the study a broader picture, because the probability of missed events would be lower.

During manual video review, the reviewers realized that full manual analysis was too time-consuming. For this data set it took manual reviewers approximately 13–15 hours to process 1 hour of raw video data. A number of factors affect this approximation of time, including light operations, whether it was day or night, the number of fish, the behavior(s) of the fish, the amount of debris, the quality of the video, and whether or not the turbine was spinning. No 1-hour segment was identical to another in terms of time spent by manual reviewers due to the variability in the factors listed above, making the time spent extremely inconsistent. For this reason, future studies should be cautious when developing a timeframe estimate for manual processing, and reviewers should be wary that the anticipated estimation of time spent may change.

As described in the Quality Check Summary Report, a great deal of work and time was put into understanding the methods and settings implemented throughout the study, and converting the video from

a propriety format (.par), which was designed to be tamperproof, to a more appropriate format for the development of automated processing and analysis (.mp4). A more accessible format, such as .mp4 or .avi could be used for ease of use and to enable automated analysis before manual review.

As PNNL reviewers sifted through the video data, they noticed a variation in the light operations. In general, the lights seemed to be on at night and off during the day, with at least one exception on July 19, but a light operation record was not maintained during the study. Because there were many more Fish Events at night, it is important to get a better understanding of the effect artificial lights have on fish behavior (e.g., whether lights attract or repel fish). It is also important to quantify the difference the lights make to the physical parameters of detection (e.g., define more robust limits of detection, and define optimal placement and settings of light sources and cameras to increase manual and automated detection potential).

Recommendations for future underwater environmental monitoring are listed below:

- **General setup.** Include an indication of range within the field of view to help reviewers distinguish size and location in relation to the turbine. Also, aim the camera so the field of view is aligned with particular turbine components, possibly in combination with sensors on the turbine foils to increase the detectability potential and promote a higher level of confidence during potential strike and collision events. The aiming of each camera will likely require an iterative process of viewing early data and making adjustments to achieve ideal viewings for manual processors as well as ideal background for algorithm applications.
- **Video format**. A standard format (e.g., .avi, .mp4) should be used, rather than a proprietary format. When the video is in a standard format, researchers have a wide array of existing tools that they can use for analysis and processing. A proprietary format restricts researchers to using vendor-supplied software that often is not designed for the type of analysis required.
- **Camera type.** Choose a camera that has underwater capability with high pixel resolution in low light conditions, the capability to mount and adjust placement settings, appropriate data storage and transmission, and a suitable field of view range for the study area.
- **Camera resolution and placement.** The camera resolution will determine the size of objects in pixels at a given distance from the camera. Objects that are less than five pixels in total size are difficult to detect, both algorithmically and visually. Higher resolution will increase the volume of data, but low resolution will restrict the size of fish that can be reliably detected. The size of a fish in pixels, along the horizontal dimension, is

  length of fish in meters / meters per pixel

  The meters per pixel is

  $$\frac{2r\tan\frac{\alpha}{2}}{n}$$

  where r is the distance to the fish in meters, α is the horizontal camera field of view angle, and n is the number of pixels in the horizontal dimension. For example, a 10 cm (4 in.) fish would be 10 pixels long at 10 m from a 320 × 240 pixel camera with a 20 degree horizontal field of view. This calculation will also help determine how far from the turbine to locate the camera. Test the placement of the cameras and lights to optimize manual and automated detection probability. Note where the sun will be throughout the study and test different angles to avoid glare.

- **Frame rate.** Ideally, the frame rate should be constant, meaning that there is a fixed interval of time between frames. The Igiugig video had a variable frame rate that resulted in uneven motion of objects from frame to frame. Higher frame rates increase the volume of data, but if the frame rate is too low the number of frames in which a fish may be in the field of view is decreased, decreasing the

probability of detection. A rate of 30 frames per second is a reasonable choice to balance data volume with detection likelihood.

- **Lighting**. Fish specific to this study are typically more active at night, so some sort of illumination is needed if video is the only monitoring technique used. The light also generated more false positives from reflecting debris. An indirect light source, like the lighting viewed from camera 1 in the Igiugig video may be the best choice. If lights are to be used, the lights should be on throughout the study to maintain a more controlled environmental setup, and increase light sources with more angles of incidence to prevent fish from disappearing when they turn at an angle that does not reflect light from a single source. However, while improving the detection of fish and debris, this practice may also introduce possible bias because of the lights themselves increasing detection probability or attracting fish, both of which complicate comparisons when lights are turned off or confounded by diel differences.
- **Detailed record keeping**. The following aspects should be recorded:
  - all monitoring operations, including camera operation, light operation, power operation, turbine status, and any other introduced monitoring systems.
  - water flow, weather conditions and any significant events that occurred during the study.
  - any maintenance issues or disruptions throughout the study.
  - review efforts.
- **Other monitoring**. Consider adding other monitoring technologies to help determine whether actual collision or strike occurred and to have a backup technology for behavioral monitoring. Strain gauges or other devices physically attached to the blades of a turbine could be used to complement the video data for those times when a collision or strike is possibly seen. Having coincident data sets providing evidence of collision or strike would be better than just one. For instance, if a reviewer thinks a strike was seen on the video data, the same timestamp could be searched for blade-attached strain gauges to see if there was a spike. If there was an anomaly on the strain gauge, then that is more evidence of a strike. The absence of strain gauge data would be evidence that the interaction was more likely a near-miss.

To inform future studies, additional research into specific aspects would also be useful, in particular a study to assess the effects of lights on fish, in conjunction with an evaluation of light and camera placement and settings toward the optimization of detection probability to find an ideal experimental design for manual and automated detection. The study would record details of the placement, including heading, pitch and roll of both the lights and the cameras, light operations, intensity, wavelength, exact range in relation to the device and cameras, as well as camera operations, range, resolution, frame rate, and settings. For algorithm development, further research is recommended into different optical flow techniques, and the refinement of parameters for the background subtraction. Each of these aspects would improve the results derived from future monitoring. Each study site will have specific physical characteristics that will affect underwater video camera data collection. However, as research continues on future data sets, general application principles will arise that can be applied to most situations.

8.0 References

Avila A, Hull R, Matzner S, Staines G, Trostle C, and Harker- Klimeš G. 2016. *Igiugig Video Analysis – FY16 Progress Report* PNNL-25909 Pacific Northwest National Laboratory, Richland, WA.

Barnich O and Van Droogenbroeck M. 2009. ViBe: a powerful random technique to estimate the background in video sequences. In proceedings of *Acoustics, Speech and Signal Processing, 2009.*

ICASSP 2009. IEEE International Conference on Acoustics, Speech and Signal Processing (pp. 945–948). IEEE.

Boom BJ, He J, Palazzo S, Huang PX, Beyan C, Chou H-M, Lin F-P, Spampinato C, and Fisher RB. 2014. A research tool for long-term and continuous analysis of fish assemblage in coral-reefs using underwater camera footage. *Ecological Informatics*, 23:83–97.

Candès EJ, Li X, Ma Y, and Wright J. 2011. Robust principal component analysis? *Journal of the ACM (JACM) 58*(3), 11.

Farnebäck G. 2003. Two-frame motion estimation based on polynomial expansion. In proceedings of *Scandinavian Conference on Image Analysis* (pp. 363–370). Springer Berlin Heidelberg.

Lee DS. 2005. Effective Gaussian mixture learning for video background subtraction. *IEEE transactions on pattern analysis and machine intelligence 27*(5), 827–832.

LGL Alaska Research Associates, Inc. 2015. *Fish and Wildlife Monitoring Plan for RivGen® Testing on the Kvichak River, Alaska in 2015*.

Lotlikar R and Kothari R. 2000. Fractional-step dimensionality reduction. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 22(6): 623–627.

Lucas BD and Kanade T. 1981. An iterative image registration technique with an application to stereo vision. *International Joint Conferences on Artificial Intelligence (IJCAI)* 81: 674–679.

Tomasi C and Manduchi R. 1998. Bilateral filtering for gray and color images. In *Computer Vision, 1998. Sixth International Conference on Computer Vision* (pp. 839–846). IEEE.

Trostle C. 2016. *Igiugig Fish Video Study– Quality Check, Summary Report*. Pacific Northwest National Laboratory, Richland, WA.

Appendix A

Manual Annotation

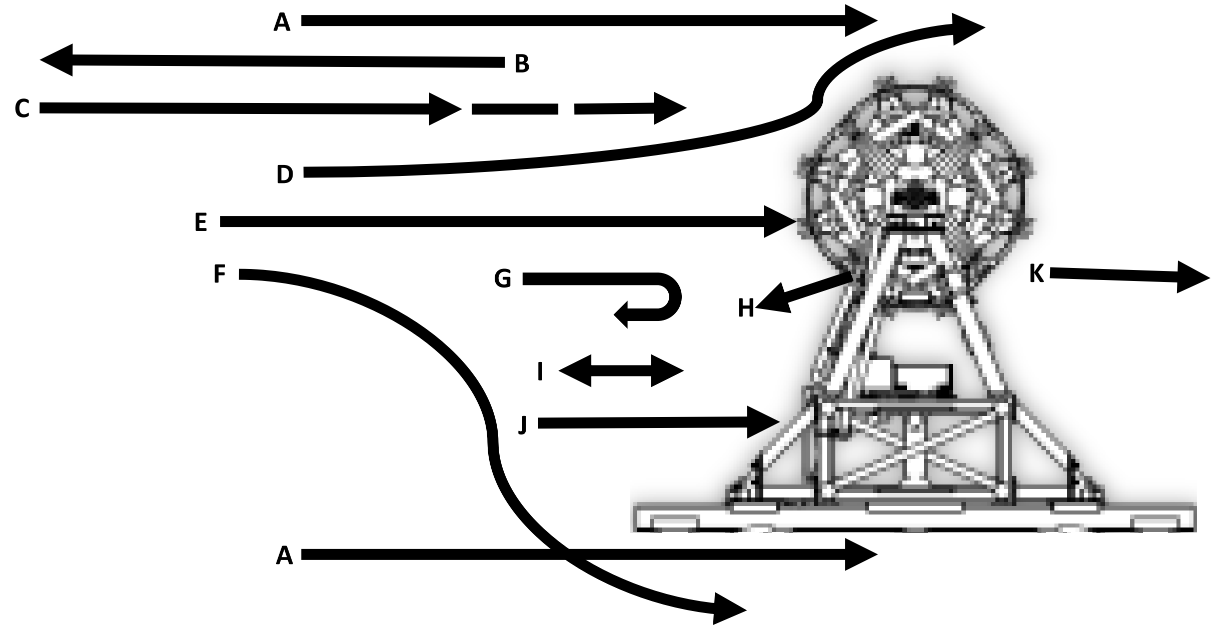
Appendix A

Manual Annotation

Annotation	Description of Annotation
Event	Reference number per event; restarting for each half-hour block of data
Date	Day video data was collected; yyyy/mm/dd
File	Filename given to each half-hour block of data; includes day and time
FileStartTime	Time that file starts on the given day it was collected
StartTime	Time that an event begins; begins 00:00:000 per half-hour block of data
EndTime	Time that an event ends; ends 29:59:999 per half-hour block of data
Lights	Either on or off; binary
Spinning	Either yes or no; binary
Camera	Designated number of camera; these data only include Camera 2
Fish?	Is the event triggering object a fish; yes, no, maybe
Number	How many objects or fish occur during an event
Size	Size of objects or fish seen during an event; measured as length on computer monitor; unidentifiable, small (<0.5 in), medium (0.5–3.0 in), large (>3.0 in.); was adjusted relative to monitor screen sizes
Species	Visually identifiable relative size designation or salmon; unidentifiable, juvenile, salmon, adult
VideoQuality	Relative anecdotal comparison of each event relative to others based on clarity of event triggering object in field of view; horrible, bad, okay, good, excellent
Notes	To clarify any previous annotation categories
Location	Where the event triggering object is in the water column; based on computer monitor divided into thirds; bottom, middle, top
Direction	All observed directions of the event triggering objects or fish; downstream, upstream, cross river toward, cross river away
Behavior	Reviewer description of all object or fish behaviors observed during an event. • straight across • against current • pause • avoid above • through turbine

- avoid below
- avoid reverse
- out of turbine
- milling
- toward static parts
- through wake
- avoid around
- unable to tell
- other

Impact	Reviewer determination if there was collision or strike during an event
Comments	To clarify any previous categories since “Notes”



A- straight across
B- against current
C- pause
D- avoid above
E- through turbine
F- avoid below
G- avoid reverse
H- out of turbine
I- milling
J- toward static parts
K- through wake
L- unable to tell (not shown)
M- other (not shown)

Appendix B

Video Data Set Used for Algorithm Development

Video Data Set Used for Algorithm Development

Video File (Date, time, camera)	Day | Appendix BLights	Turbine | Spinning | None	Fish Events	Fish Frames
`20150719_175830-1.mkv`	Day	None	7	308
`20150720_110030-1.mkv`	Day	None	9	307
`20150722_030200-1.mkv`	Lights	None	30	917
`20150722_030200-2.mkv`	Lights	Turbine	72	878
`20150722_030200-3.mkv`	Lights	Turbine	7	283
`20150723_000330-1.mkv`	Lights	None	2	97
`20150723_000330-2.mkv`	Lights	Spinning	68	519
`20150723_000330-3.mkv`	Lights	Spinning	7	268
`20150723_000330-4.mkv`	Lights	Spinning	8	423
`20150724_000000-1.mkv`	Lights	Turbine	5	499
`20150724_000000-2.mkv`	Lights	None	53	438
`20150724_000000-3.mkv`	Lights	Turbine	10	1007
`20150724_000000-4.mkv`	Lights	Turbine	9	311
`20150825_040330-1.mkv`	Lights	None	3	201
`20150825_040330-2.mkv`	Lights	Turbine	38	467
`20150825_040330-4.mkv`	Lights	Turbine	3	160
Total			**334**	**7569** **(6%)**

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT OF
ENERGY

Proudly Operated by **Battelle** *Since 1965*

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

www.pnnl.gov

Attachment 3

Monitoring Equipment Specifications

FLIR BLACKFLY® S

P/N: BFS-PGE-31S4, GIGE VISION

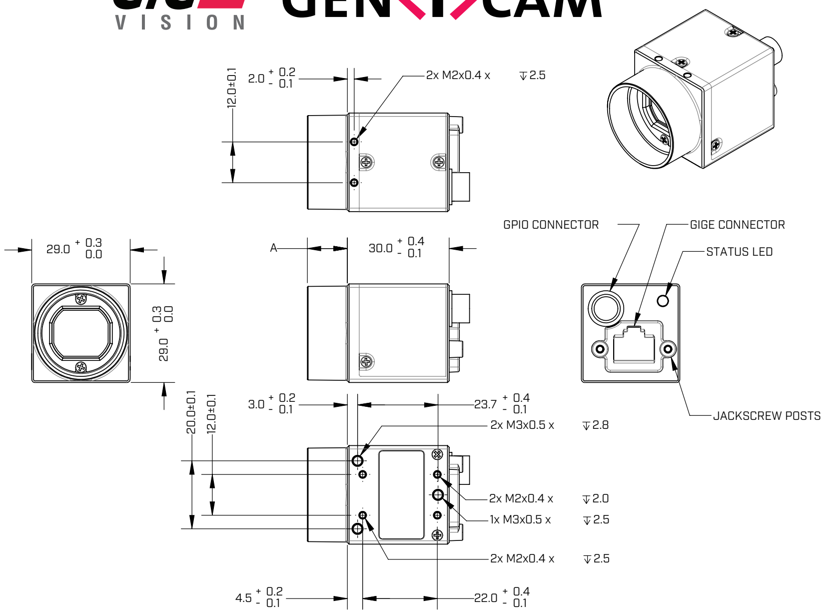
SMALL PACKAGE, POWERFUL RESULTS

The Blackfly S combines the newest CMOS image sensors with our new and intuitive Spinnaker software development kit. The many new advanced camera features are designed to meet your complex imaging needs and speed up development time.

KEY FEATURES

- Leverage the latest **CMOS sensors** and new on-camera image processing features. Harness increased **binning** flexibility, powerful **auto-exposure** controls and robust **color transformation** tools.
- Improve cycle time using advanced camera controls and programmable logic Utilize **sequencer, chunk data, event notification, counters, timers** and **logic blocks**.
- Accelerate your time to market using our **GenICam3 API, GUI API library**, detailed **API logging** and comprehensive **documentation**.
- IEEE 1588 Precision Time Protocol for **accurate clock synchronization** with no user oversight.

GiGE VISION GEN<i>CAM



Specifications

	BFS-PGE-31S4M	BFS-PGE-31S4C
Resolution	2048 x 1536	
Frame Rate*	35 FPS	
Megapixels	3.1 MP	
Chroma	Mono	Color
Sensor	Sony IMX265, CMOS, 1/1.8"	
Readout Method	Global shutter	
Pixel Size	3.45 µm	
Lens Mount	C-mount	
ADC	12-bit	
Minimum Frame Rate**	1 FPS	
Gain Range**	0 to 48 dB	
Exposure Range**	11 µs to 30 s	
Acquisition Modes	Continuous, Single Frame, Multi Frame	
Partial Image Modes	Pixel binning, decimation, ROI	
Image Processing	Gamma, lookup table, and sharpness	Color correction matrix, gamma, lookup table, hue, saturation, and sharpness
Sequencer	Up to 8 sets using 2 features, exposure and gain	
Image Buffer	240 MB	
User Sets	2 user configuration sets for custom camera settings	
Flash Memory	6 MB non-volatile memory	
Opto-isolated I/O	1 input, 1 output	
Non-isolated I/O	1 bi-directional, 1 input	
Auxiliary Output	3.3 V, 120 mA maximum	
Interface	GigE PoE	
Power Requirements	Power over Ethernet (PoE), or 12 V nominal (8 - 24 V) via GPIO	
Power Consumption	3 W maximum	
Dimensions/Mass	29 mm x 29 mm x 30 mm / 36 g	
Machine Vision Standard	Gige Vision v1.2	
Compliance	CE, FCC, KCC, RoHS, REACH. The ECCN for this product is: EAR099.	
Temperature	Operating: 0°C to 50°C Storage: -30°C to 60°C	
Humidity	Operating: 20% to 80% (no condensation) Storage: 30% to 95% (no condensation)	
Warranty	3 years	

*Frame rates are measured with Device Link Throughput Limit of 380 MBps and Acquisition Frame Rate disabled. Values are rounded down to whole numbers.

**Values are the same in binning and no binning modes.

FLIR Integrated Imaging Solutions

CANADA
12051 Riverside Way
Richmond, BC, Canada
V6W 1K7
T: +1 866.765.0827 (toll free)
T: +1 604.242.9937
F: +1 604.242.9938
E: mv-sales@flir.com
www.flir.com/mv

USA
T: +1 866.765.0827 (toll free)
E: mv-na-sales@flir.com

EUROPE
T: +49 7141 488817-0
F: +49 7141 488817-99
E: mv-eusales@flir.com

CHINA
T: +86 10 8215 9938
F: +86 10 8215 9936
E: mv-chinasales@flir.com

ASIA
E: mv-asiasales@flir.com

For a full list of international distributors and offices visit www.flir.com/contact-us

Tamron M118FM16, 16mm, 1/1.8", C mount Lens

HOME / MACHINE VISION CAMERAS / ACCESSORIES / LENSES / TAMRON M118FM16, 16MM, 1/1.8", C MOUNT LENS

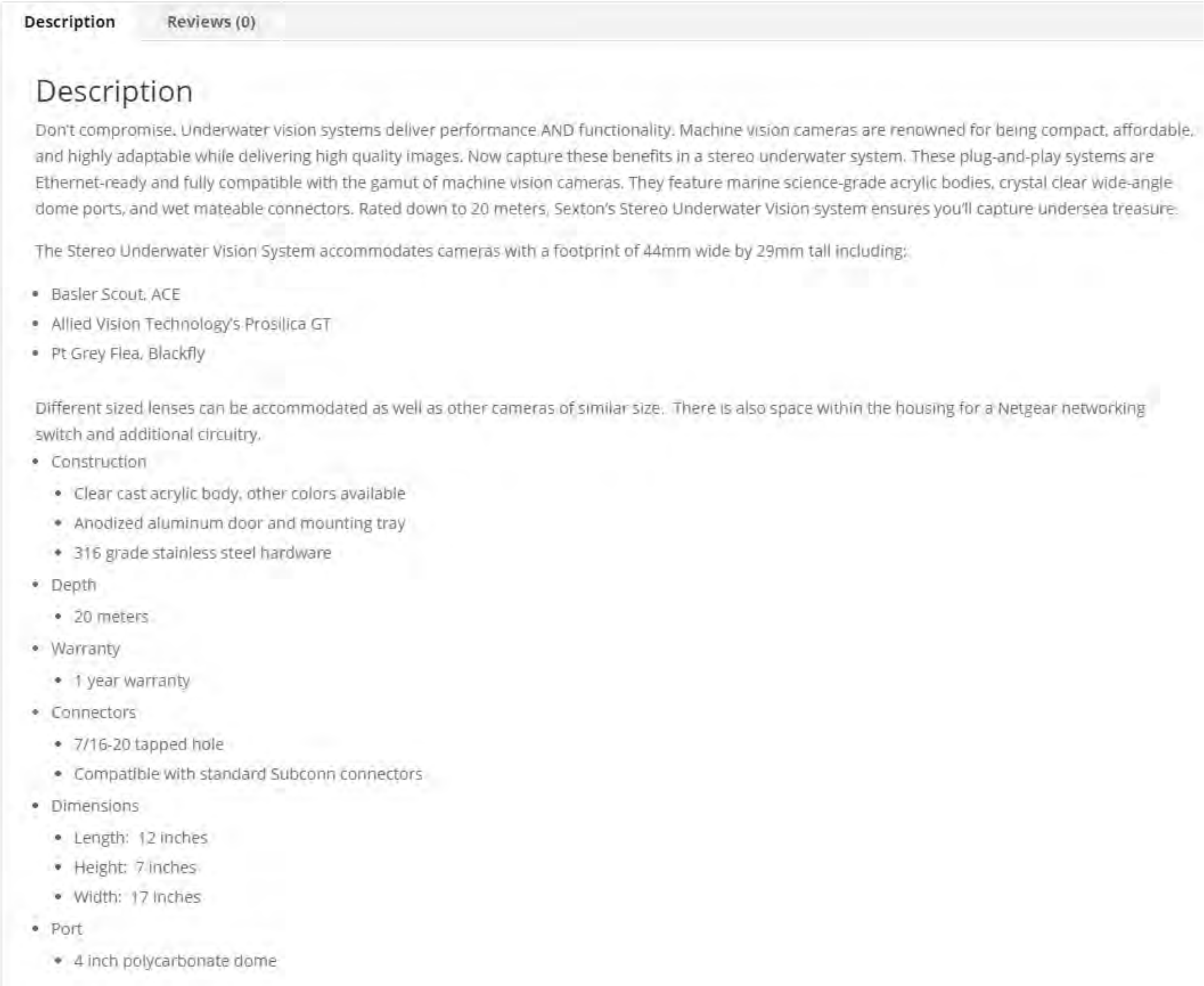
Specifications

Documents

Manufacturer Part Number	Tamron M118FM16;
Focal Length	16mm;
Optical Format	1/1.8";
Lens Mount	C Mount;

Stereo Underwater Vision System

Categories: Camera Enclosures, Instrument Enclosures, Networking



Description

Don't compromise. Underwater vision systems deliver performance AND functionality. Machine vision cameras are renowned for being compact, affordable, and highly adaptable while delivering high quality images. Now capture these benefits in a stereo underwater system. These plug-and-play systems are Ethernet-ready and fully compatible with the gamut of machine vision cameras. They feature marine science-grade acrylic bodies, crystal clear wide-angle dome ports, and wet mateable connectors. Rated down to 20 meters, Sexton's Stereo Underwater Vision system ensures you'll capture undersea treasure.

The Stereo Underwater Vision System accommodates cameras with a footprint of 44mm wide by 29mm tall including:

- Basler Scout, ACE
- Allied Vision Technology's Prosilica GT
- Pt Grey Flea, Blackfly

Different sized lenses can be accommodated as well as other cameras of similar size. There is also space within the housing for a Netgear networking switch and additional circuitry.

- Construction
  - Clear cast acrylic body, other colors available
  - Anodized aluminum door and mounting tray
  - 316 grade stainless steel hardware
- Depth
  - 20 meters
- Warranty
  - 1 year warranty
- Connectors
  - 7/16-20 tapped hole
  - Compatible with standard Subconn connectors
- Dimensions
  - Length: 12 inches
  - Height: 7 inches
  - Width: 17 inches
- Port
  - 4 inch polycarbonate dome

DEEPSEA® Power & Light®

LED SeaLite®

Patents Pending

FEATURES

Wide, Flood, Spot, or Switchable Dual Beam Configurations

Up to 10,000 Lumens

4,000 m, 6,000 m, and 11,000 m Depth Rated Options

Flicker-Free Digital and Analog Dimming Interfaces

Customer Serviceable

SeaSense™ Protocol

T: 858-576-1261
F: 858-576-0219

4033 Ruffin Road
San Diego, CA
92123-1817 USA

www.deepsea.com
sales@deepsea.com

LED SeaLite®

	LSL-1000	LSL-2000	LSL-2025
Optical Specifications			
Typical Lumen Output (Flood)	10,000		See www.deepsea.com/multiray for sample configuration specifications.
Efficacy	63 lm/w[1]	94 lm/w[1]	
Lux at 1 m	Wide[2]: 2,300 lx Flood: 5,600 lx Spot: 14,000 lx		
Color	Day Light White 5000 K ~ 6500 K Warm White 2600 K ~ 3700 K Contact Sales for Color Options		
CRI	Day Light White: 70 Warm White: 80		
Beam Angle (HPFW)	Wide[2]: 115° Flood: 75° Spot: 35°		Wide[2]: 115° Flood: 75° Spot: 40°
Environmental Specifications			
Depth Rating	4,000 m Acrylic Port 6,000 m or 11,000 m Sapphire Port		
Thermal Protection	Intelligent Thermal Rollback		
Operational Temperature	-10°C to 40°C [14°F to 104°F][3]		
Storage Temperature	-40°C to 100°C [-40°F to 212°F]		
Electrical Specifications			
Voltage	90~140 VAC 50/60 Hz 110~160 VDC	10~48 VDC[1]	
Power	160W @ 120 VAC 60 Hz	106W @ 24 VDC	
Dimming	RS232[4], RS485[4], Phase/Triac	RS232[4], RS485[4], 0~5V, 0~10V, 4~20mA	
Mechanical Specifications			
Housing	Hard Anodized 6013 Aluminum Titanium		
Port	Standard: Sapphire Optional: Acrylic		
Outer Diameter	63.0 mm [2.48 in]		
Overall Length (Without Connector)	Acrylic Flood/Wide: 95.9 mm [3.77 in] Sapphire Flood: 93.3 mm [3.67 in] Acrylic/Sapphire Spot: 99.6 mm [3.92 in]		
Weight in Air[5]	Sapphire Flood: 490 g Sapphire Spot: 510 g	Sapphire Flood: 450 g Sapphire Spot: 470 g	
Weight in Water[5]	Sapphire Flood: 240 g Sapphire Spot: 260 g	Sapphire Flood: 200 g Sapphire Spot: 220 g	
Connector[6]			
Default	SEACON MCBHMP SS Please contact sales for more options.		

[1] 100% output available above 20 VDC. 50% output from 10~20 VDC due to input current limits.
[2] Wide beam angle only available on Acrylic port 4,000 m depth rating.
[3] For 120 VAC versions, thermal rollback may reduce light output in water temperatures exceeding 25° C [77° F]. See Manual for additional information.
[4] For RS232 and RS485, see Manual.
[5] Nominal values are measured with MCBHMP connector and aluminum housing.
[6] Ensure that ampacity ratings for interconnect system are suitable for your operating conditions. See Manual for more information.

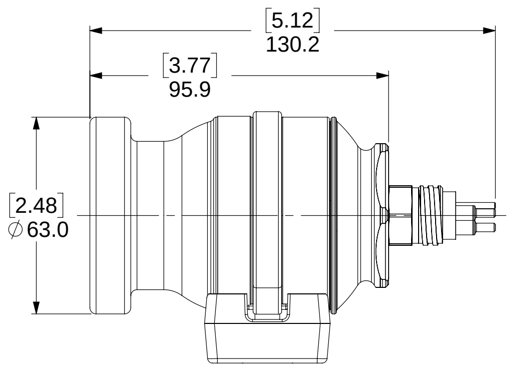
DEEPSEA Power & Light®

**Specifications subject to change without notice.*

LED SeaLite®

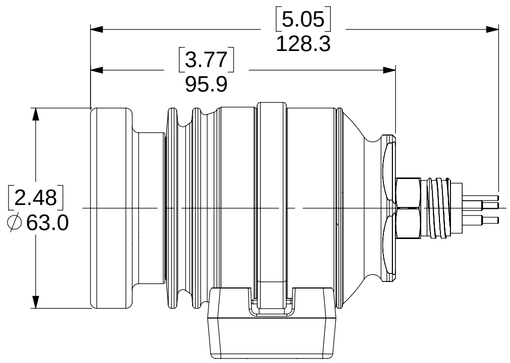
Dimensions

Flood Beam Acrylic Port



FLOOD/WIDE ACRYLIC ALUMINUM

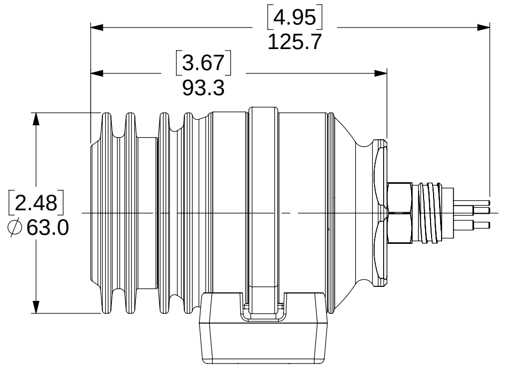
mm [inch]



FLOOD/WIDE ACRYLIC TITANIUM

mm [inch]

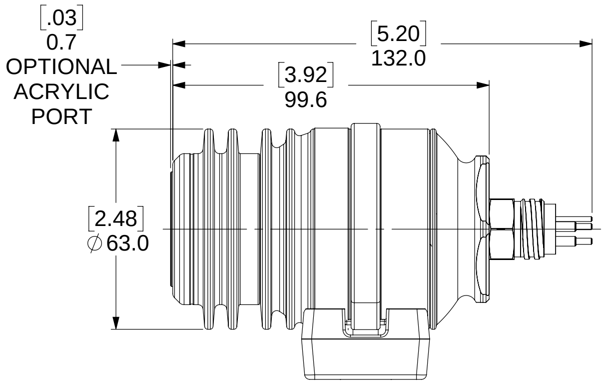
Flood Beam Sapphire Port



FLOOD SAPPHIRE

mm [inch]

Spot Beam

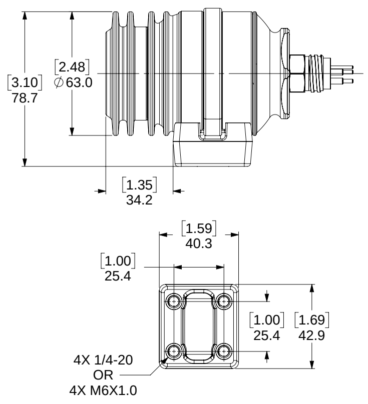


SPOT ACRYLIC/SAPPHIRE

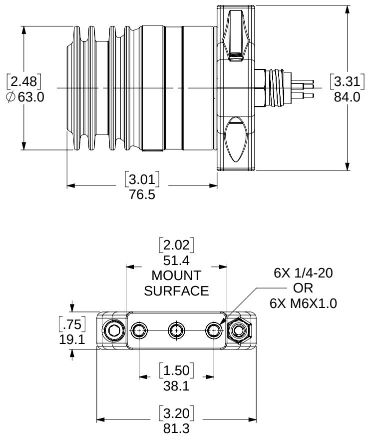
mm [inch]

Bracket

SADDLE BRACKET



COLLAR BRACKET



mm [inch]

IGIUGIG HYDROKINETIC PROJECT

APPENDIX C: STUDY REPORTS AND ASSESSMENTS

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511-002

November 15, 2018

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613-4008
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

Appendix C: Study Reports and Assessments includes the following documents:

Igiugig Village Council, Documentation of River Ice Conditions, 2015 and 2017

Kasper, J. L., P. Duvoy and N. Konefal, Kvichak River Frazil Ice Study Final Report, September 2017, Fairbanks, AK.

Matzner, S., Trostle, C., Staines, G., Hull, R., Avila, A., & Harker-Klimes, G. (2017). Triton: Igiugig Fish Video Analysis

Murphy, Paul G. (2015). Estimation of Acoustic Particle Motion and Source Bearing Using a Drifting Hydrophone Array Near a River Current Turbine to Assess Disturbances to Fish, University of Washington

TerraSond (2011). Kvichak River RISEC Project. Resource reconnaissance and physical characterization. Final Report. Prepared by TerraSond Ltd., Palmer, AK for Dept. of Community and Economic Development, AIDEA/AEA, Rural Energy Group, Anchorage, AK

Thomson, J., Kilcher, L. & Polagye, B. (2014). Flow measurements during RivGen® deployment Igiugig, AK. 2014. U.S. Department of Energy, DE-EE0006397.

Thomson, J., Guerra, M. (2018). ORPC RivGen Wake Characterization. U.S. Department of Energy, DE-EE0006397.

ICE PHOTOS

KVICHAK RIVER, IGIUGIG. ALASKA

Source: Igiugig Village Council

January 22, 2015 - Kvichak River, Igiugig: Shard ice and small bergs floating downriver

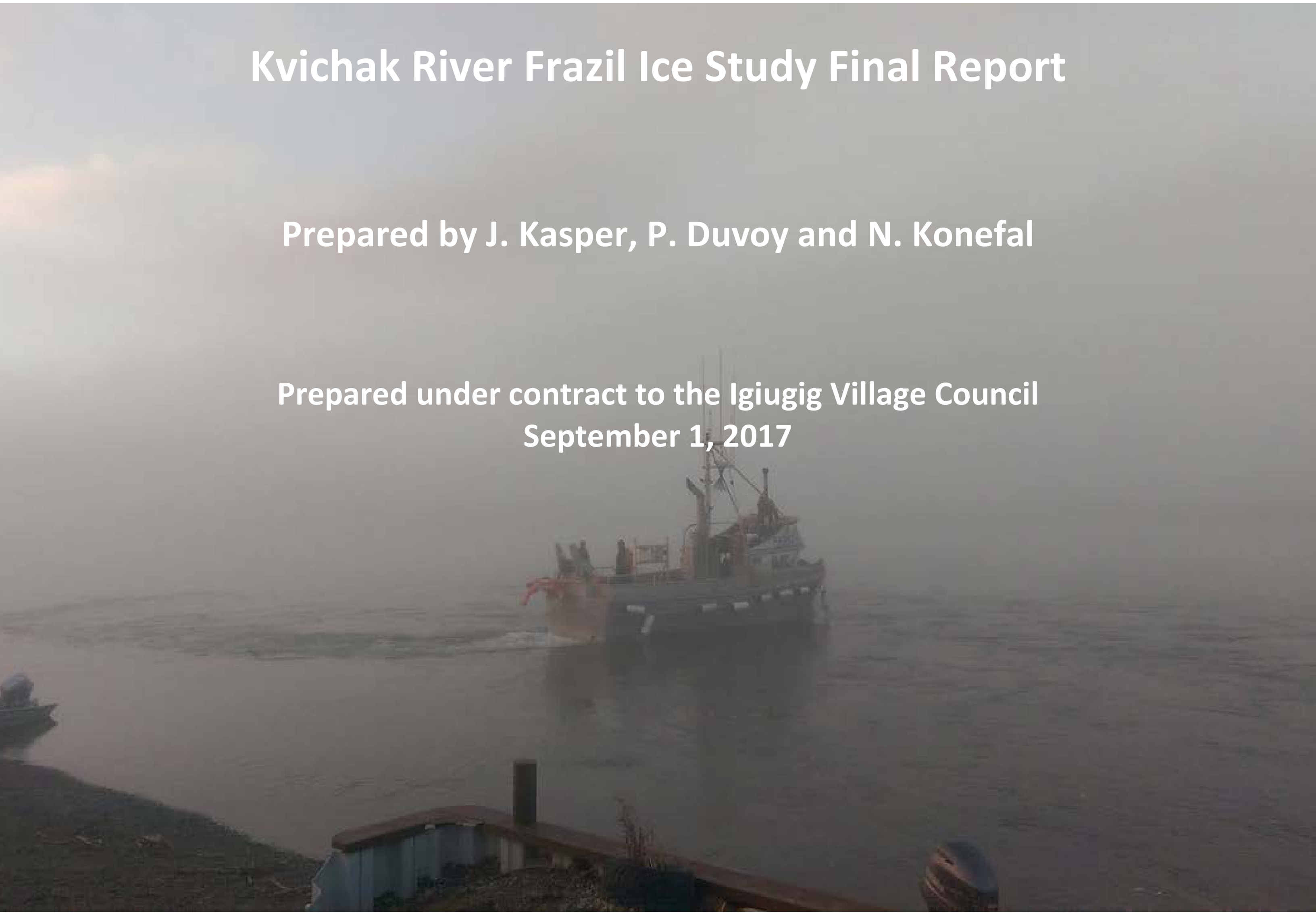

January 27, 2015 – Kvichak River, Igiugig: Temperatures dropped, causing ice to jam and river to freeze over

February 12, 2015 – Kvichak River, Igiugig: After a warm spell the river started to open again

February 18, 2015 – Kvichak River, Igiugig: river partially open

March 13, 2015 – Kvichak River, Igiugig: Temperatures dropped below zero again this week

May 10, 2017. Surface ice in approximate Project location. (Drone photo)



Kvichak River Frazil Ice Study Final Report

Prepared by J. Kasper, P. Duvoy and N. Konefal

Prepared under contract to the Igiugig Village Council
September 1, 2017

Suggested Citation: Kasper, J. L., P. Duvoy and N. Konefal, Kvichak River Frazil Ice Study Final Report, September 2017, Fairbanks, AK.

1 Table of Contents

2 List of Figures

3 List of Tables

4 Summary

The University of Alaska Fairbanks (UAF) Alaska Hydrokinetic Energy Research Center was tasked with developing a real-time data telemetry / remote power generation system to monitor frazil ice conditions in the Kvichak River in support of the U.S. Department of Energy funded “Next Generation MHK River Power System Optimized for Performance, Durability and Survivability” project. A real-time telemetry system was requested because of the short time span between the end of the frazil ice season when the instruments would be recovered, limited vessel availability and the project end-date.

To meet the project objectives, UAF designed and assembled a remote power/real-time data telemetry system that included an auto start propane generator, a small PV array, a small battery bank and line-of-sight radios as well as two sonar systems to monitor river velocity and water column acoustic backscatter strength. Both sonars included internal batteries for powering the instruments in case of failure of the shore based power system. The sonars, deployed in ~5 m of water on the bed of the Kvichak River, adjacent to the Village of Igiugig, Alaska were tethered to shore via a waterproof armored cable that conveyed power to the subsurface instruments and data from the instruments to the shore based telemetry system. The instruments were programmed to record data internally as well as to transmit data serially over the cables to the shore based system.

The system was in-place between November, 2016 and June, 2017. While the real-time data telemetry system was not successful and the remote power generation power system was only partially successful, the system design included sufficient redundant power in the form of internal instrument batteries to enable the collection of nearly three months of overlapping velocity and backscatter data (from November through February) and a record of acoustic backscatter strength spanning the entire ~150 day frazil ice season between November, 2016 and ~April, 2017.

The acoustic Doppler current profiler (ADCP) ceased recording data during a site visit in February during which communication to the ADCP was lost when personnel on-site were midway through re-programming the ADCP after the failure of the shore based remote power system. Based on battery bank voltages and ambient temperatures recorded by an on-site data logger, the remote power system functioned until mid-February just prior to the arrival of UAF personnel on-site, when very cold air temperatures (< -30 ^{o}C) caused the battery bank voltage to drop. An accumulation of ice from an icing event earlier in the deployment appeared to interfere with the generators ability to self-start and thus the generator was unable to recharge the battery bank. In addition, solar panels at the site were iced over and solar insolation was insufficient to clear the panels and/or deliver sufficient power to recharge the battery bank. While the generator was able to be restarted, UAF personnel on-site were not equipped to deal with the frozen batteries.

The results of the monitoring are summarized as follows: briefly, the sonars captured multiple time periods when frazil ice was present at the deployment site. Frazil was detected at the site beginning in early December when water temperatures first dipped below -0.1 deg. C. There is a ~2 week period in the record (from ~1/7/2017-1/22/2017) when frazil ice was continuously detected. Outside of this two week period, frazil is intermittently present. Later in the season, in late February, there appears to be enough solar gain during the day to warm water temperatures above the cutoff for frazil (~-0.2 deg. C) and there is a distinct diurnal signal in the backscatter and water temperature records. While the sonars are unable to definitively identify the presence of frazil ice, the increase in acoustic backscatter strength is correlated with periods when super cooled water was present at the site (temperatures below zero degrees Celsius). Both the ADCP and the Shallow Water Ice Profiler (SWIP) record water temperature. Note that video or physical sampling would be required confirm that the increase in acoustic backscatter is indeed frazil as well as to determine the accumulation rates of frazil on any submerged infrastructure to determine the risk frazil poses to hydrokinetic energy converters in this environment.

5 Monitoring Frazil Ice in the Kvichak River

5.1 Methods

5.1.1 River bed mooring, remote power / data telemetry system

A bottom mounted mooring was deployed on the bed of the Kvichak River from a ~10 m Bristol Bay fishing vessel, the F/V EG on November, 4, 2016 and recovered on June 24, 2017. The mooring was located at 59.32493 N, 155.91515 W (Figure 1). The shore based remote power / real-time data telemetry system was located on the river bank immediately adjacent to the mooring (Figure 1).

Figure 1. Location of Power System, Mooring, Igiugig School, ILC Office.

The mooring is shown in Figure 3. The ORPC owned ASL Shallow Water Ice Profiler (SWIP) is the rectangular, aluminum case on the side of the orange fiberglass mooring frame. The transducers of both the SWIP and the ADCP were 0.5 m above the bed. The University of Alaska (UAF) owned 1200 kHz Teledyne RD Sentinel acoustic Doppler current profiler (ADCP) used in the study is visible in the center of the frame. UAF provided the fiberglass Sea Spider mooring frame for this project. Figure 2 is a picture of the mooring when it was deployed in the Kvichak River. The image was taken from a drone equipped with a camera.

Figure 2. A picture of the remote power / data telemetry system and the mooring taken from a drone in May, 2017. The mooring location is circled in red. Floating ice is visible in the image flowing downstream.

Figure 3 . UAF personnel with the ADCP and SWIP mounted on an orange fiberglass "Sea Spider" frame. The instruments ready for loading on the F/V EG in Igiugig in November, 2016.

The remote power /real-time data telemetry is described in detail in Appendix B through D. Briefly, it consisted mainly of equipment that UAF already owned, including a 2,500W LP remote start generator, 2-80W solar panels, a 12V, 416A battery bank, power conditioning electronics and protection. The real-time data telemetry system consisted of a shore-based unit on the Kvichak River bank (a UAF owned 900 MHz Zlink Xtreme transmit radio and power electronics) and a local unit initially located at the Iliamna Lake Contractor's (ILC) office in Igiugig (a 900 Mhz Zlink Xtreme radio configured as a receiver). A laptop computer synced to a cloud based, Google drive and configured with a remote management application was meant to receive the data and then provide remote access to the laptop to researchers at UAF. The on-shore unit was meant to transfer data from the riverbank to the ILC office using a 900 Mhz line-of-site radio. Initial efforts in November 2016 to establish communication between the shore based transmit radio and the receive radio failed.

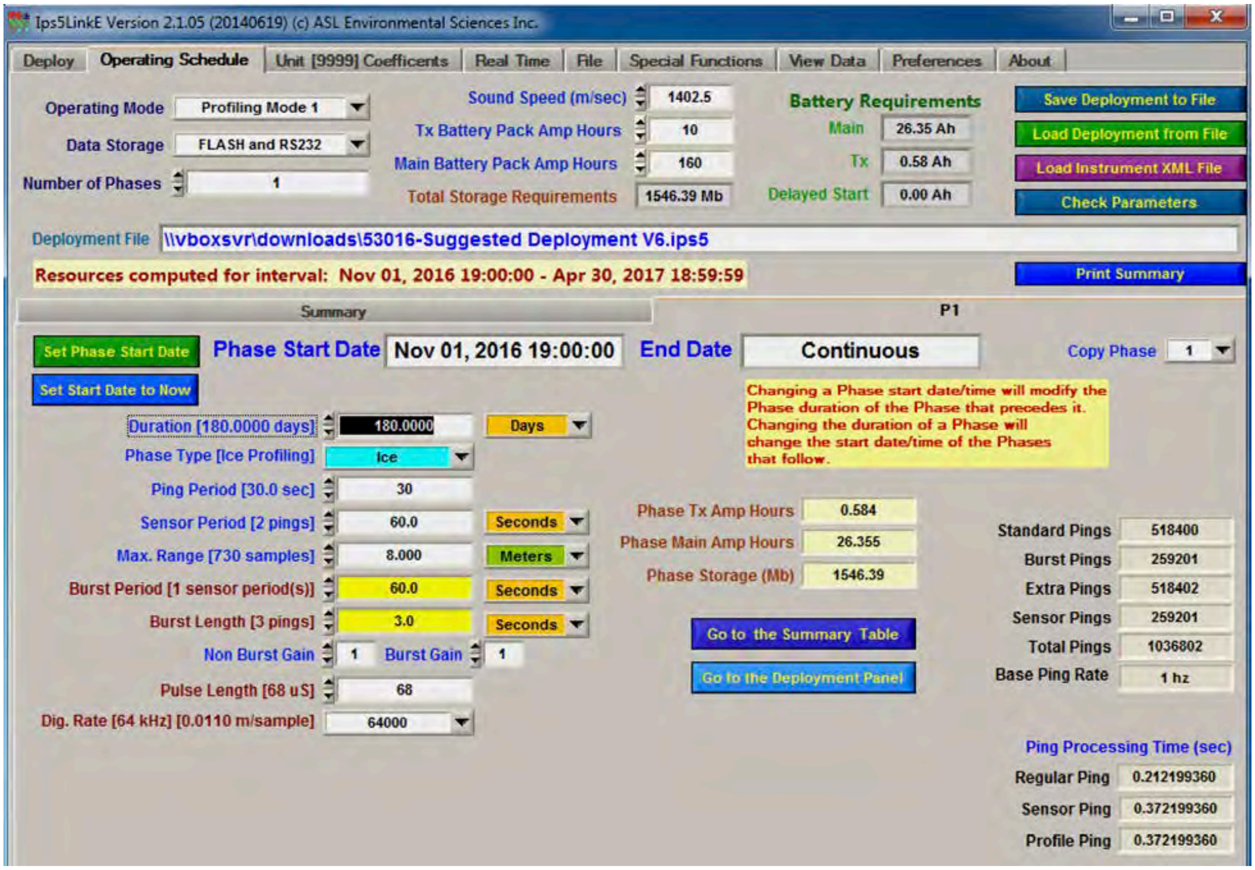
Between November and February, UAF purchased a Moxa NPort IA5450AI-T 4-port serial server and a Digi Xpress XEB09-CIPA 900 MHz Wireless Ethernet bridge with high gain antennae, to increase data throughput. UAF then assembled and tested a weather proof, protected, power electronics system that incorporated these two additional pieces of hardware. The Moxa serial server was meant to allow the Ethernet bridge to transfer data from both the ADCP and the SWIP over its wireless link. (The original system was not capable of transferring data from both sensors since it lacked the hardware required to host and aggregate data streams from the multiple serial devices on site, the ADCP, SWIP and Campbell Scientific datalogger.) The system was tested in Fairbanks with a second Teledyne ADCP and Campbell data logger and it performed well. Data was meant to be received at the Igiugig School with a second-high gain antenna and Ethernet bridge and stored on a laptop computer attached to the local network. Data would then be accessed and downloaded from any location with a network connection. The Igiugig School was chosen because it was closer to the river bank site than the ILC office, it was located on higher ground and there were fewer obstructions between the school and the telemetry system than between the telemetry system and the ILC office.

UAF personnel traveled to Igiugig in February, 2017 but before they were able to put the new system in place, they discovered that the power system had failed several days prior to their arrival.

5.2 Sampling Schemes

The SWIP was configured for 1 ping every 30 seconds; then 1 burst of 3 pings, 1 second each one. Each ping had 730 samples corresponding to 8 meters depth (Figure 4). This sampling scheme was developed by UAF with assistance from ASL. The SWIP ceases collecting data when its memory is full, thus the duty cycle was dictated by available memory (2 GB), predicted battery life and frazil ice behavior (ASL, pers. comm., 2016).

The ADCP was configured for 1 ping every 15 seconds where every ping was comprised of 23 depth cells of 0.25 m from 0.8 m to 6.30 m depth (Figure 5). Similar to the SWIP, the ADCP's sampling was dictated by available memory (4 GB) and predicted battery life. Note, UAF utilized 1- Teledyne RD alkaline battery pack and 2-Lithium battery packs purchased for a completed project (but that were never used). The Lithium batteries were housed in an external battery case and the Alkaline battery pack was utilized as the internal battery. External lithium batteries were necessary to enable the ADCP to collect data for the full length of the anticipated ~6 month deployment.



Operating Mode: Profiling Mode 1
Data Storage: FLASH and RS232
Number of Phases: 1
Sound Speed (m/sec): 1402.5
Tx Battery Pack Amp Hours: 10
Main Battery Pack Amp Hours: 160
Total Storage Requirements: 1546.39 Mb

Battery Requirements
Main: 26.35 Ah
Tx: 0.58 Ah
Delayed Start: 0.00 Ah

Deployment File: \\vboxsvr\downloads\53016-Suggested Deployment V6.ips5

Resources computed for interval: Nov 01, 2016 19:00:00 - Apr 30, 2017 18:59:59

Phase Start Date: Nov 01, 2016 19:00:00
End Date: Continuous
Copy Phase: 1

Changing a Phase start date/time will modify the Phase duration of the Phase that precedes it. Changing the duration of a Phase will change the start date/time of the Phases that follow.

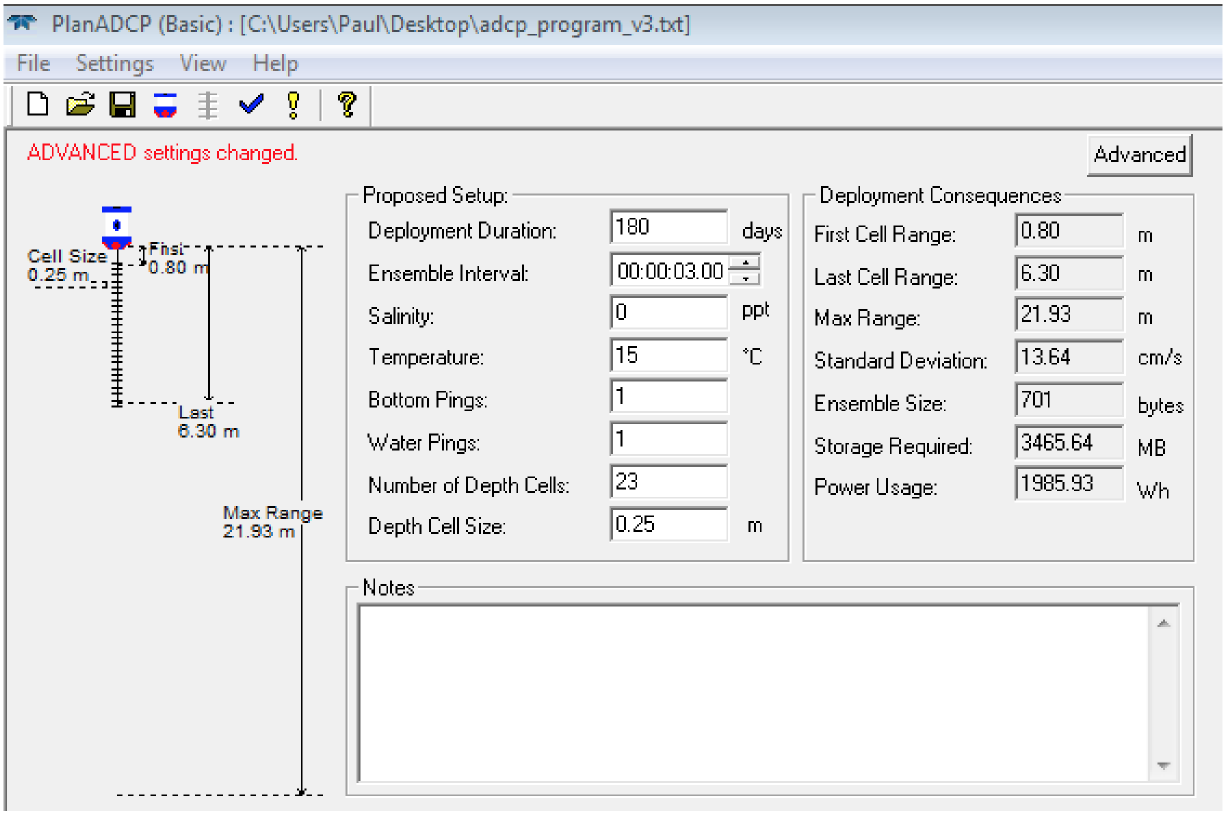
Duration [180.0000 days]: 180.0000 Days
Phase Type [Ice Profiling]: Ice
Ping Period [30.0 sec]: 30
Sensor Period [2 pings]: 60.0 Seconds
Max. Range [730 samples]: 8.000 Meters
Burst Period [1 sensor period(s)]: 60.0 Seconds
Burst Length [3 pings]: 3.0 Seconds
Non Burst Gain: 1
Burst Gain: 1
Pulse Length [68 uS]: 68
Dig. Rate [64 kHz] [0.0110 m/sample]: 64000

Phase Tx Amp Hours: 0.584
Phase Main Amp Hours: 26.355
Phase Storage (Mb): 1546.39

Standard Pings: 518400
Burst Pings: 259201
Extra Pings: 518402
Sensor Pings: 259201
Total Pings: 1036802
Base Ping Rate: 1 hz

Ping Processing Time (sec)
Regular Ping: 0.212199360
Sensor Ping: 0.372199360
Profile Ping: 0.372199360

Figure 4. Screenshot of SWIP Sampling Configuration.



ADVANCED settings changed.

Proposed Setup:

Deployment Duration:	180	days
Ensemble Interval:	00:00:03.00	
Salinity:	0	ppt
Temperature:	15	°C
Bottom Pings:	1	
Water Pings:	1	
Number of Depth Cells:	23	
Depth Cell Size:	0.25	m

Deployment Consequences

First Cell Range:	0.80	m
Last Cell Range:	6.30	m
Max Range:	21.93	m
Standard Deviation:	13.64	cm/s
Ensemble Size:	701	bytes
Storage Required:	3465.64	MB
Power Usage:	1985.93	Wh

Figure 5. Screenshot of ADCP Sampling Configuration.

The SWIP records acoustic backscatter strength in counts. The SWIP used for this study is owned by ORPC and was used by UAF in a previous study in the Tanana River (J. Schmid, R. Tyler, pers. comm.). The conversion of the sonar signal from analog to digital and the characteristics of the SWIP's A/D board means the count scale ranges from 0 to 65536.

5.3 Results

5.3.1 Shallow Water Ice Profiler

Upon retrieval of the full data set from the SWIP's internal memory card in June, 2017, the SWIP data was converted to a Matlab compatible format using ASL's IPS5 software program. The data were then analyzed and plotted using Matlab routines developed by UAF.

Plots of acoustic backscatter strength measured in counts by the SWIP through time by month are shown in the following figures. Plots of temperature recorded by the SWIP for the same time periods are included as well.

In the following plots, acoustic backscatter strength measured by the SWIP is presented as color contours through time (x-axis) versus distance from the transducer (y-axis). The surface of the water is marked by high backscatter counts, exceeding 60,000 counts at a distance of ~5 m from the transducer. This is because the water-air as well as the water-ice interfaces strongly reflect the acoustic signals from the SWIP and the ADCP. This change in the location of the strong surface reflection is at least in part due to presence of ice at the surface over the mooring as well as the seasonally declining water levels. Note, the water depth begins at 5 m and drops to ~3.75 m at the end of the deployment in April. Average water depth over at the mooring during the deployment was 4.55 m while the max water depth was 5.3 m and the minimum depth was 3.6 m.

Early in the record when the water temperature is above freezing, periods of increased backscatter are attributed to turbulence (and air bubbles entrained at the surface by this turbulence) as well as by the resuspension of particles from the bed (e.g. Figure 6). Beginning in December (Figure 7), intermittent periods when frazil ice is present are marked by an increase in backscatter in the water column when the water temperature is below zero degrees Celsius. Frazil is present at the site beginning in early December through late January. In late January when water temperatures increase to greater than ~-0.2 deg. C, frazil is nearly absent until ambient temperatures drop again in mid-February (2/10-2/13 and 2/19-2/22).

Beginning in late February, there is a diurnal signal (day-night) in both the temperature and backscatter data (i.e. frazil ice presence). When the water temperature dips below zero beginning in December, the slight daytime warming is apparently enough to lead to a decrease in frazil ice. Note, that when the water temperature is low enough (-0.2 ^{O}C), this diurnal variation does not lead to a decrease in frazil (Figure 8); there is a ~2 week period during January, 2017 when the water temperature is low enough that frazil is present through the entire 2-week period. Just after this period, there is a thickening of the area of strong surface reflection indicating the presence of thickening surface ice cover (ADCP "bottom track" data corroborates this interpretation). The surface ice cover thickness abruptly changes on 1/26/2017.

The diurnal temperature/backscatter signal is especially prominent beginning in February (Figure 9) when day-time warming of the water due to solar insolation leads to periodic variations in the presence and concentration of frazil ice.

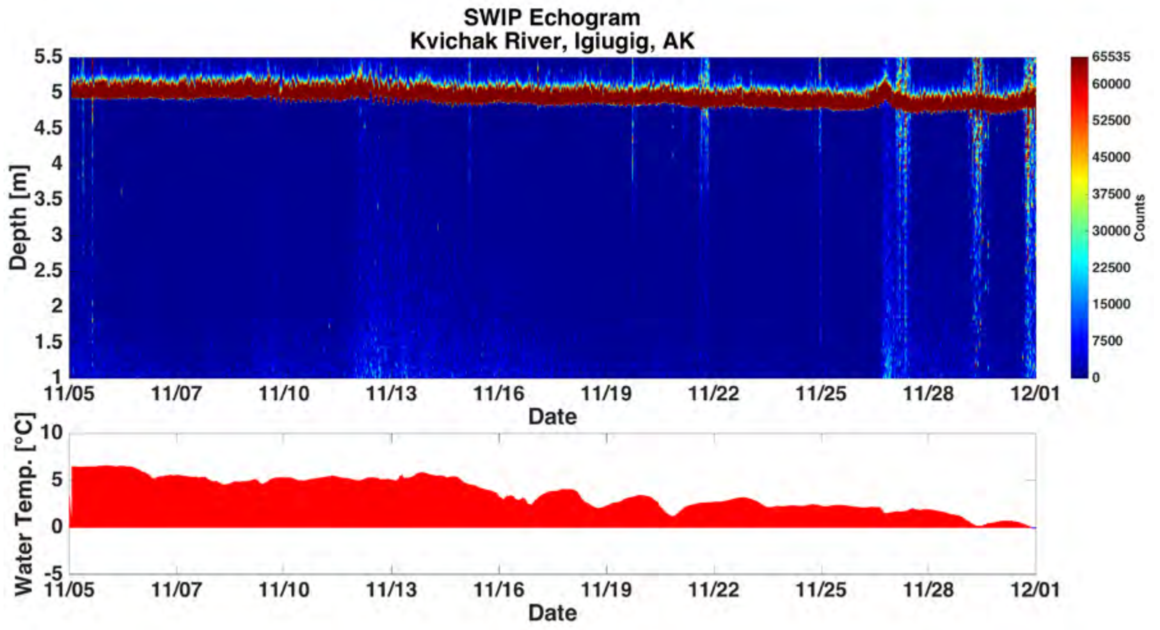


Figure 6. Top: acoustic backscatter strength in counts (color) through time versus distance from the SWIP transducer (y-axis) and Bottom: water temperature (degrees Celsius) for the period from 11/05/2016-12/01/2016.

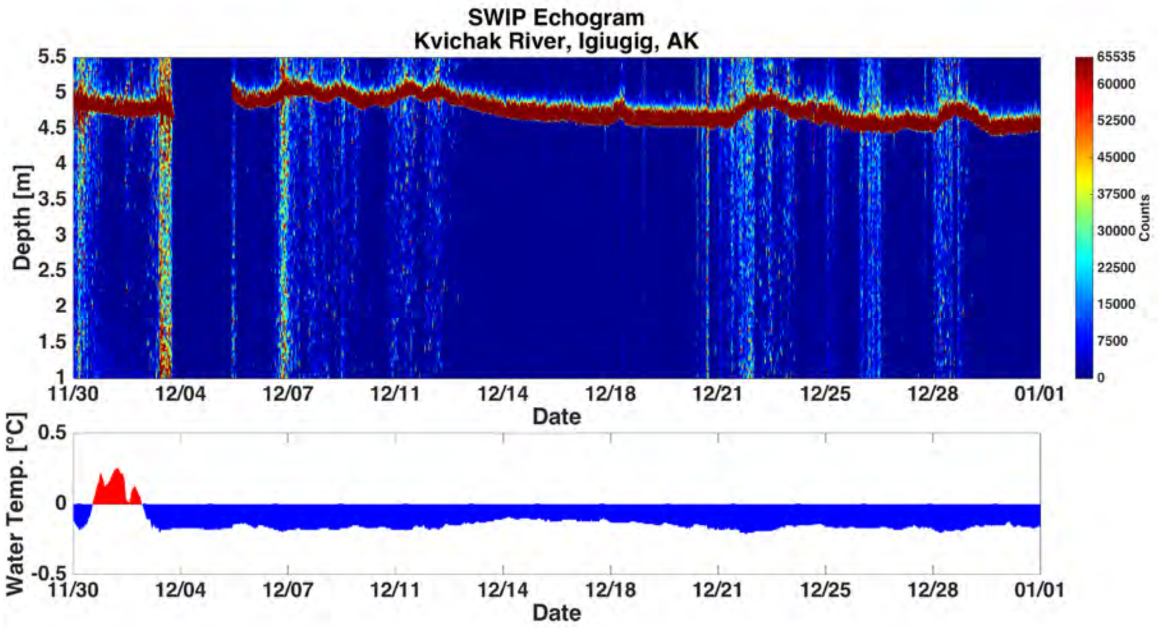


Figure 7. Top: acoustic backscatter strength in counts (color) through time versus distance from the SWIP transducer (y-axis) and Bottom: water temperature (degrees Celsius) for the period from 11/30/2016-01/01/2017.

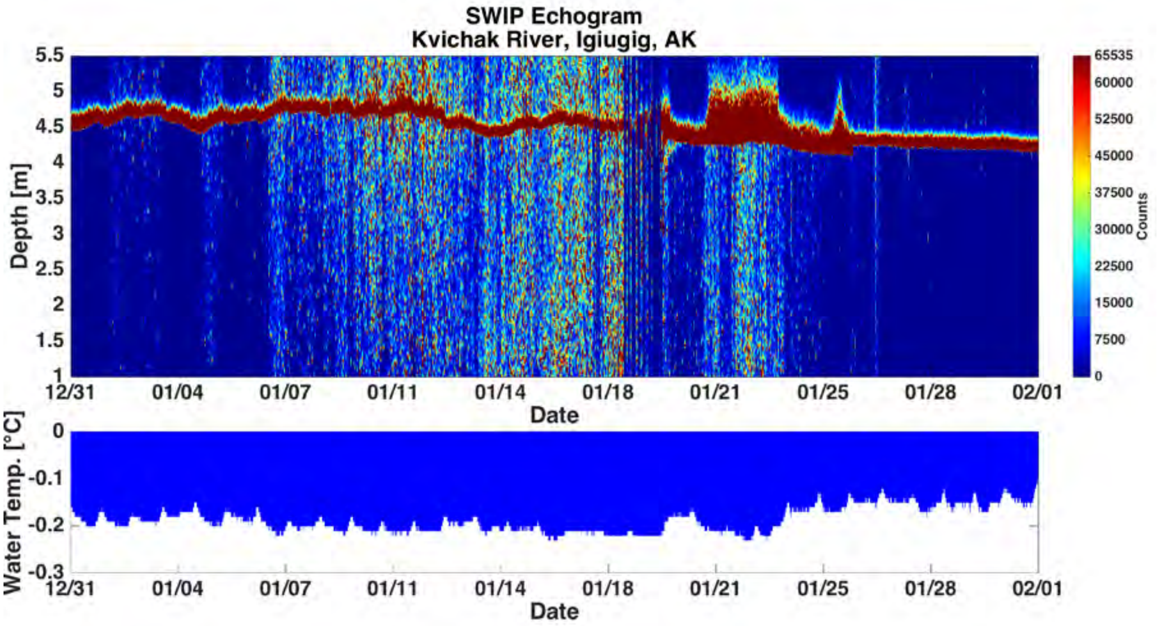


Figure 8. Top: acoustic backscatter strength in counts (color) through time versus distance from the SWIP transducer (y-axis) and Bottom: water temperature (degrees Celsius) for the period from 12/31/2016-02/01/2017.

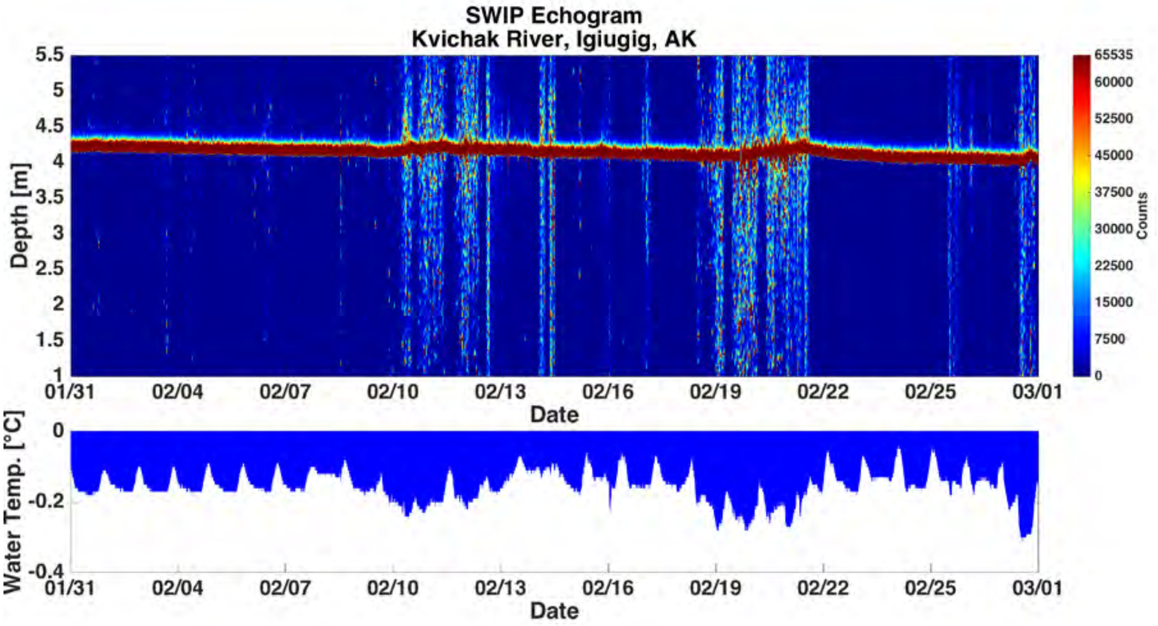


Figure 9. Top: acoustic backscatter strength in counts (color) through time versus distance from the SWIP transducer (y-axis) and Bottom: water temperature (degrees Celsius) for the period from 01/31/2016-03/01/2017.

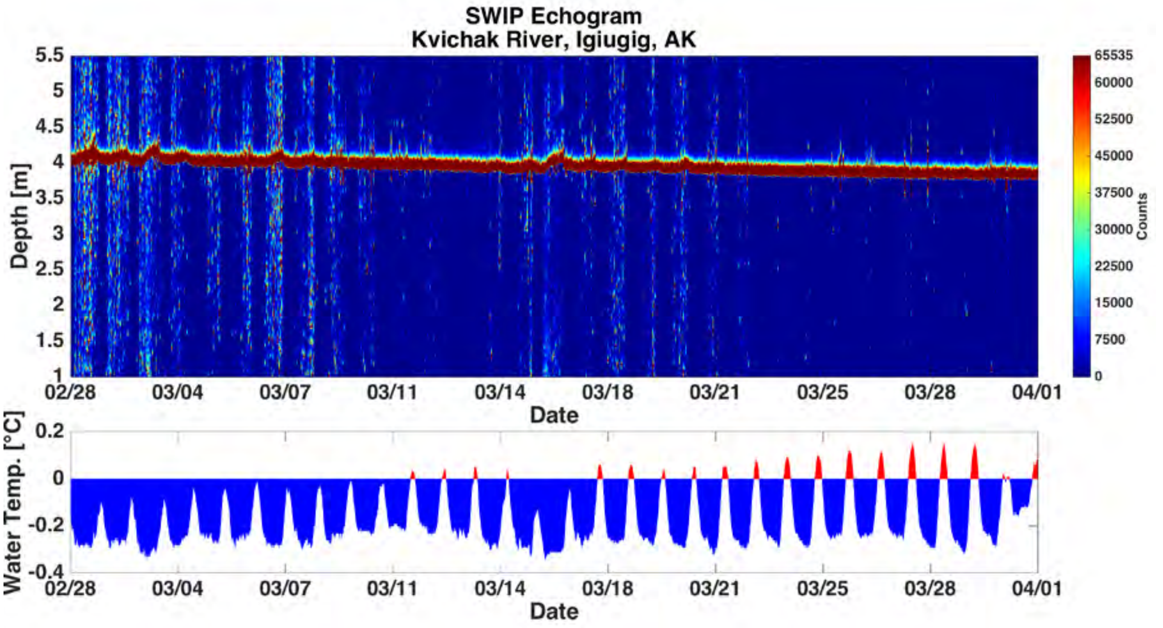


Figure 10. Top: acoustic backscatter strength in counts (color) through time versus distance from the SWIP transducer (y-axis) and Bottom: water temperature (degrees Celsius) for the period from 02/28/2017-04/01/2017.

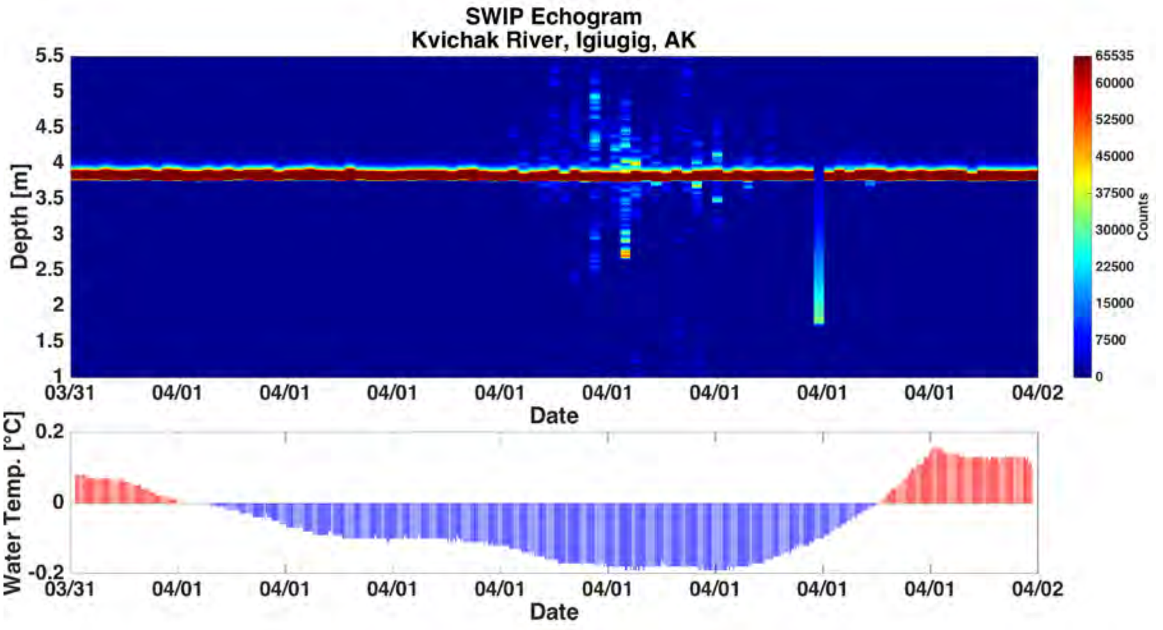


Figure 11. Top: acoustic backscatter strength in counts (color) through time versus distance from the SWIP transducer (y-axis) and Bottom: water temperature (degrees Celsius) for the period from 03/31/2017-04/02/2017.

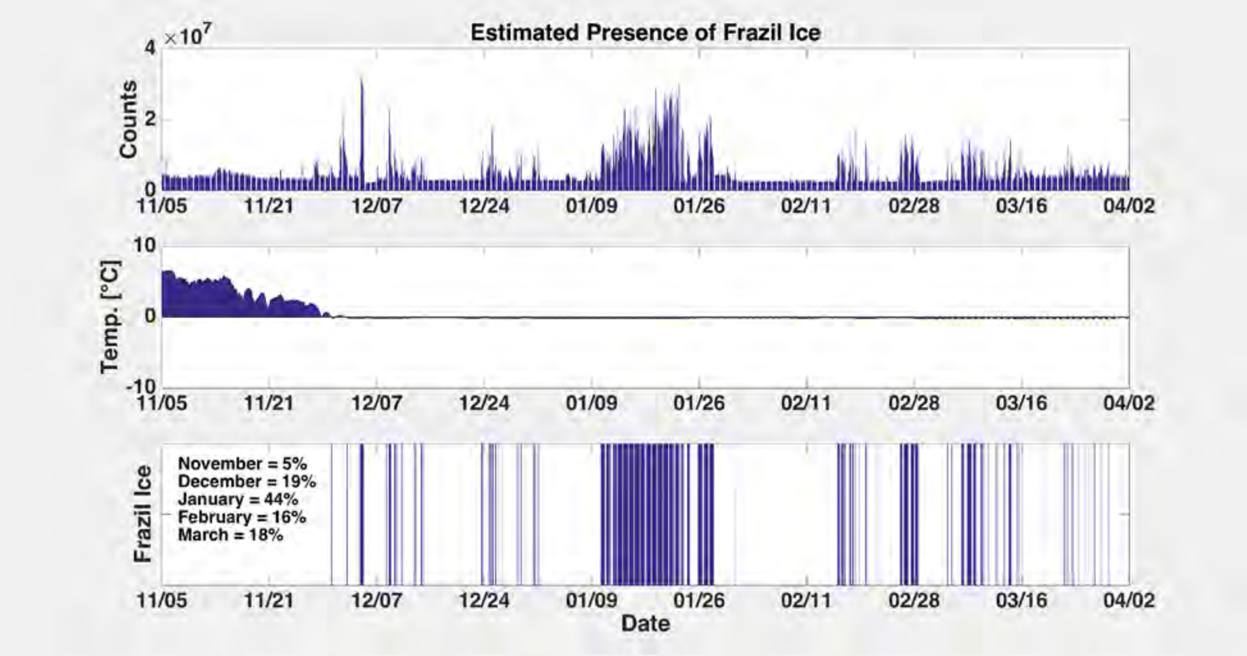


Figure 12. Summary of the presence/absence of frazil ice based on the SWIP measurements.

Figure 12 summarizes the presence of frazil ice over the deployment period based on the SWIP backscatter count and water temperature. Frazil is considered to be present at the site when water temperatures are below zero degrees Celsius and when the backscatter count exceeds the mean of the backscatter. Frazil was present for 5% of November, 19% of December, 44% of January, 16% of February and 18% of March (a total of 20% of the 6 month record).

5.3.2 Acoustic Doppler Current Profiler

Data from the acoustic Doppler current profiler is shown in Figure 13 through Figure 15 and described briefly here. At the beginning of the record the southward velocity is ~3 m/s and decreases to ~2 m/s in the latter part of the record. Vertical velocities at the site are smaller and average to ~0 m/s. Velocity at the deepest bin (1.5 m above the bottom averaged 1.24 m/s (191 deg. from North, T). At 3.5 m above the bottom (the shallowest bin for which there is a continuous record), the velocity averaged 1.4 m/s (184 T). The average vertically averaged velocity for the length of the ADCP record is 1.36 m/s (186 T). The vertically averaged velocity including the magnitude of the velocity are shown in Figure 14.

The ADCP was configured to measure the surface ice velocity using the bottom track feature. Ice velocities are only reported where the error velocity magnitude was less than 0.5 m/s. When error velocities exceed this threshold, it is unlikely that the ADCP is reporting valid velocities. Ice velocities during the period when the ADCP returned valid returns (late January through mid-February) was ~1.5 m/s. Based on the standard deviation of the velocity (Figure 5), ice velocities below 0.136 m/s are indistinguishable from zero and the ice is considered immobile. The ADCP returned valid ice velocities for 333 hours (13 days) during the deployment. There was immobile, anchor ice over the mooring for ~37 hours (~1.5 days). The presence of this immobile anchor (shorefast) ice over the mooring was intermittent and on average lasted for 22 seconds and the longest time that anchor ice was over the mooring was 20 minutes.

The ADCP also records acoustic backscatter strength (Figure 15). Additionally, we calculated the magnitude of the turbulent kinetic energy at a depth of 1.5 m. The water depth above the mooring drops throughout the ADCP record as does the magnitude of the velocity and TKE consistent with the trend towards decreasing water levels above the ADCP.

Surface ice thickness as measured by the SWIP for the period where the ADCP returned valid ice velocities are shown in Figure 15.

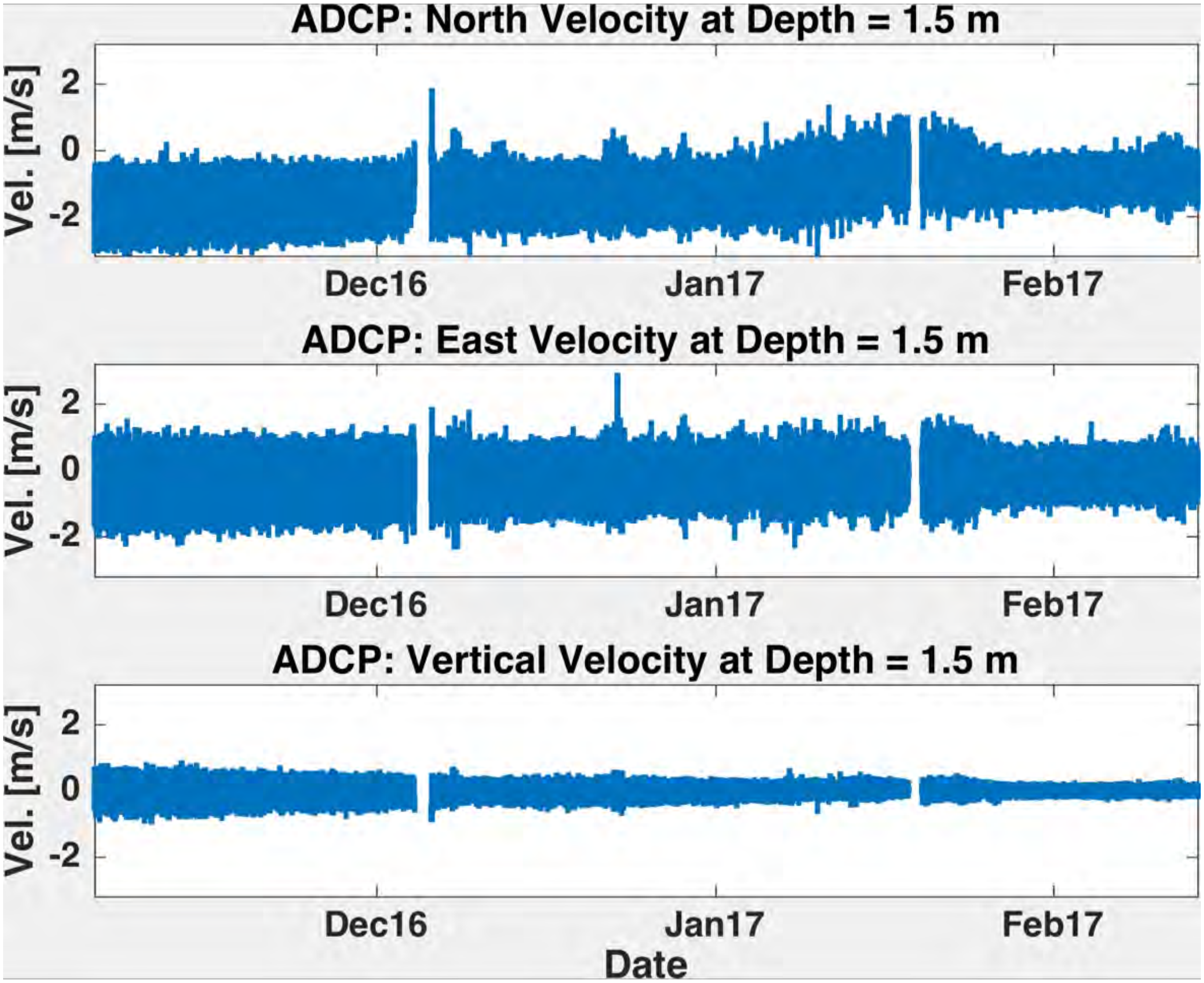


Figure 13. Water Velocity from the ADCP.

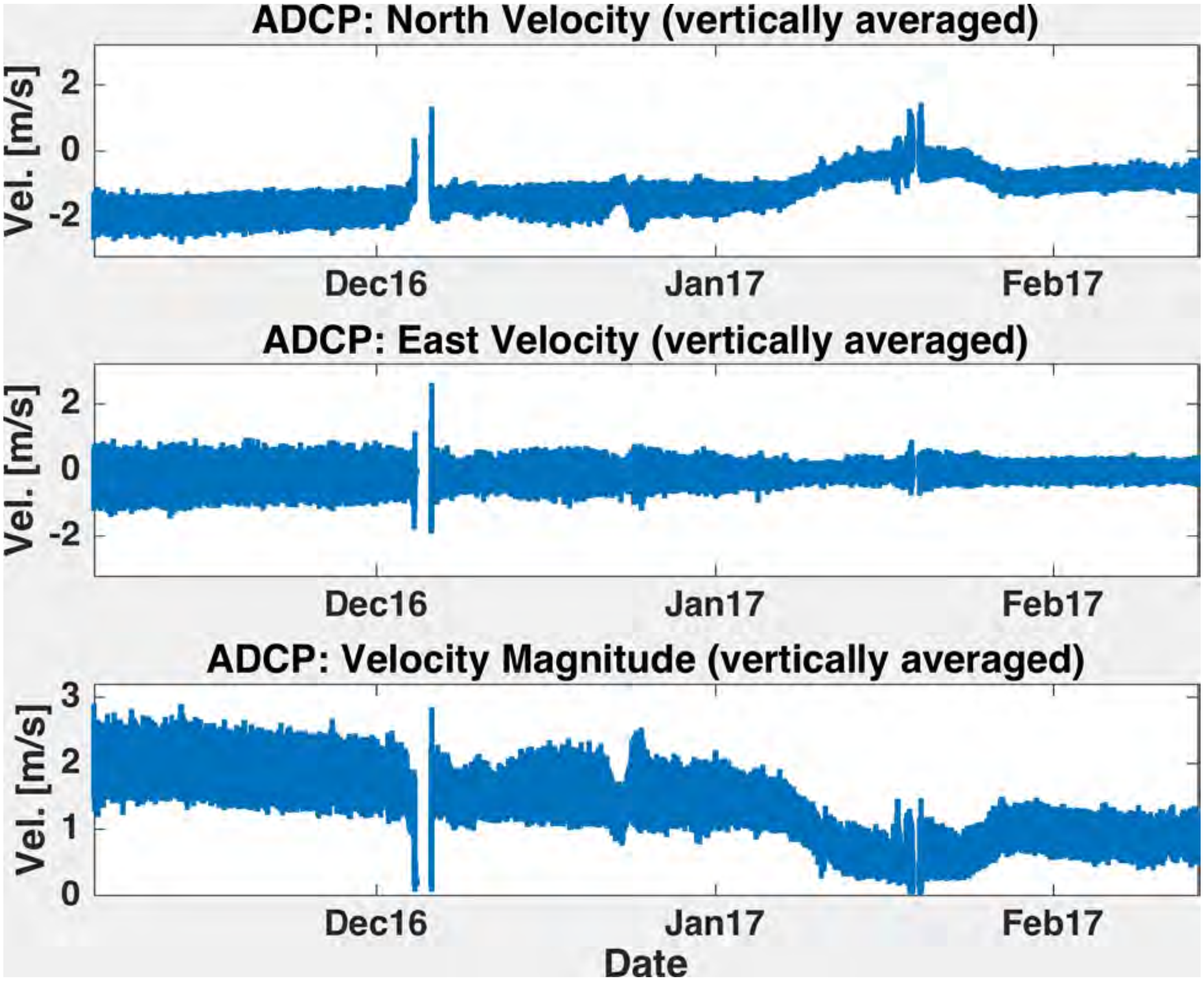


Figure 14. Vertically averaged velocities from the ADCP.

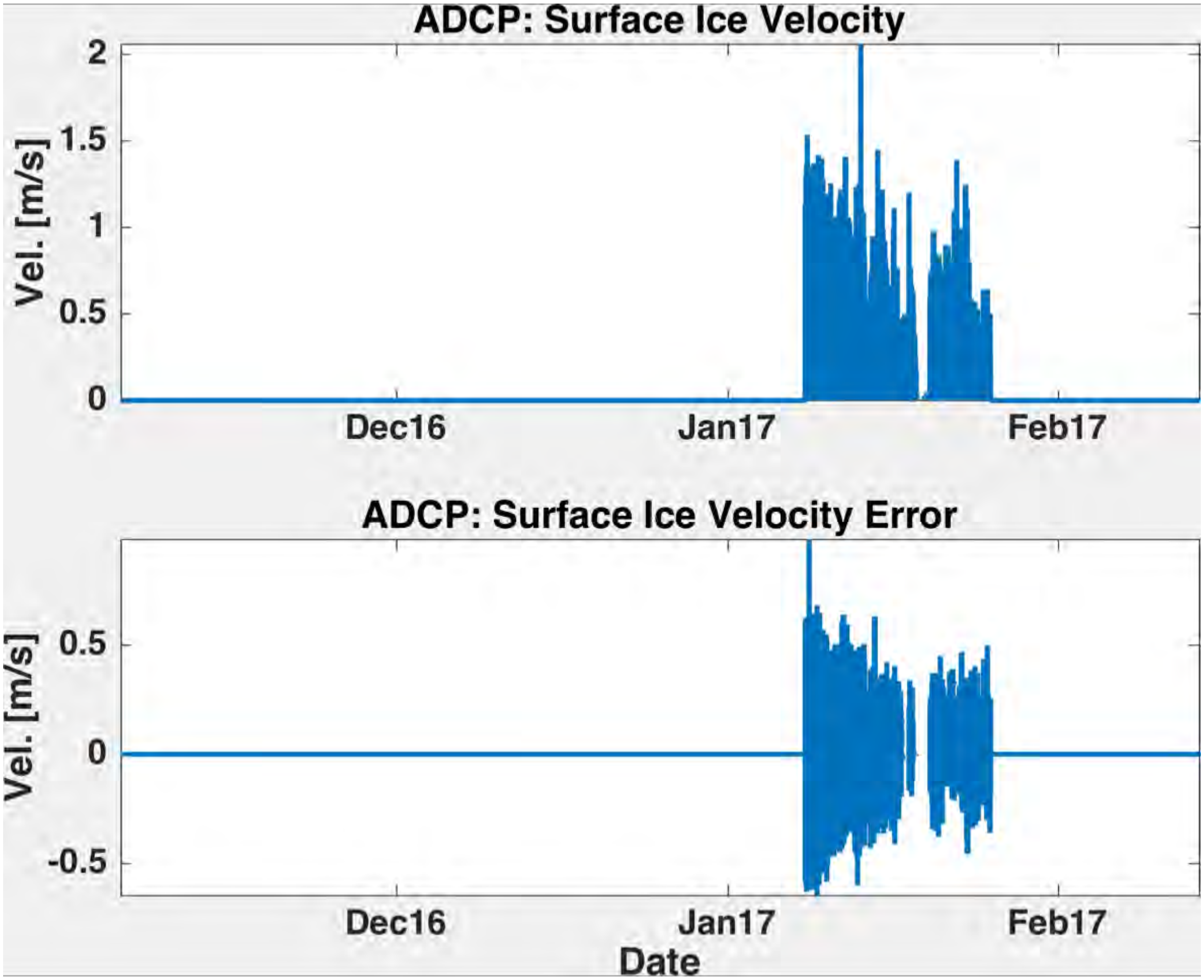


Figure 15. Surface Ice Velocity (top) from the ADCP Bottom Track and (Bottom) Bottom Track Error Velocity.

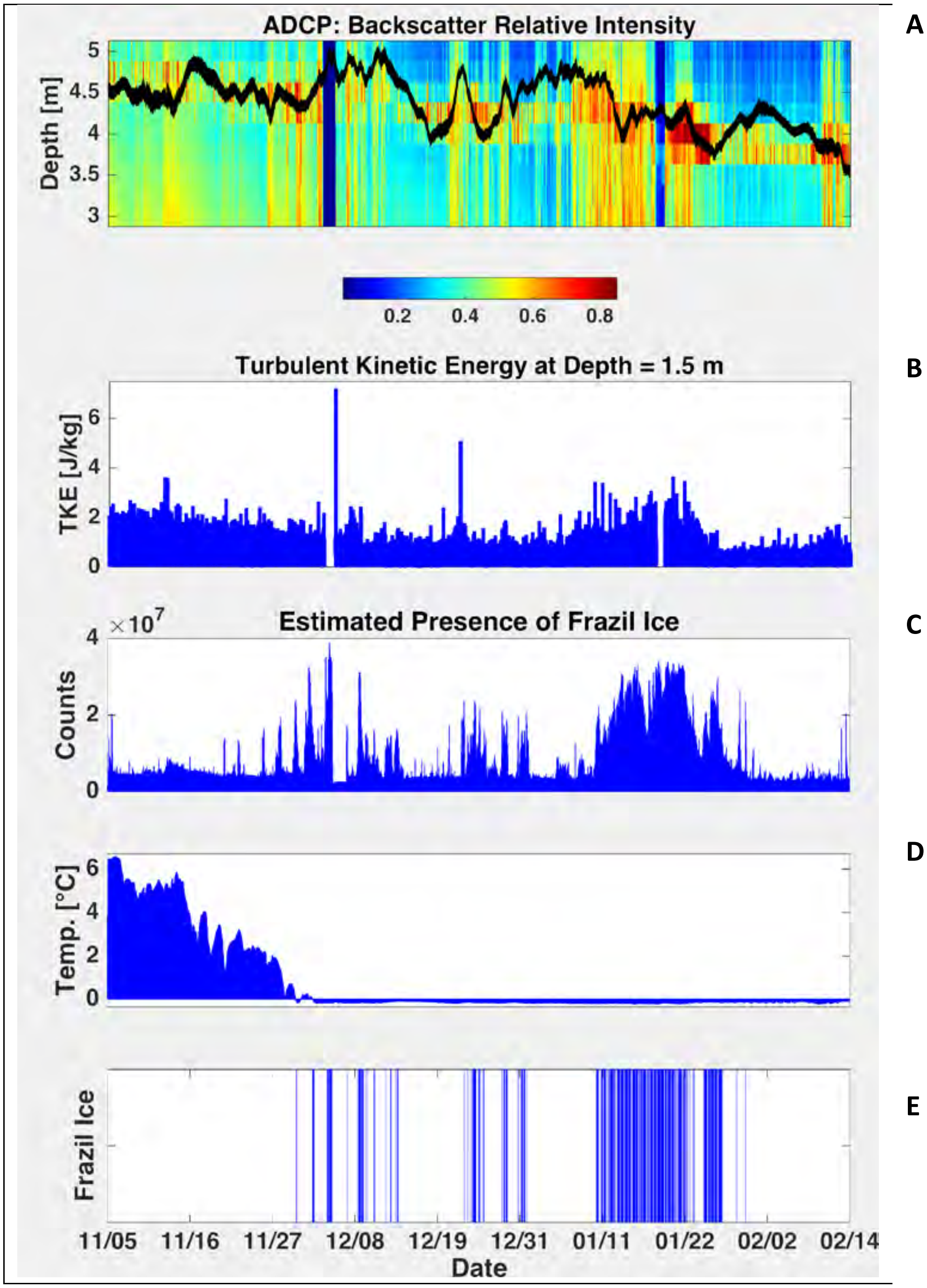


*Figure 16. **A)** Acoustic backscatter and **B**) turbulent kinetic energy from the ADCP. **C)** Frazil ice; **D)** Water temperature and **E)** presence of frazil ice from the SWIP. The distance to the surface based on the ADCP pressure record is shown in figure **A** as a black line.*

5.3.3 Power System

An onsite data logger (a UAF-owned Campbell CR6) recorded ambient temperature and battery bank voltage at the remote power system. Battery bank voltages are shown in Figure 17 while ambient temperatures logged by the CR6 are shown in Figure 18. Note the logger only measured temperatures through mid-February after which, the logger and power system were not operational.

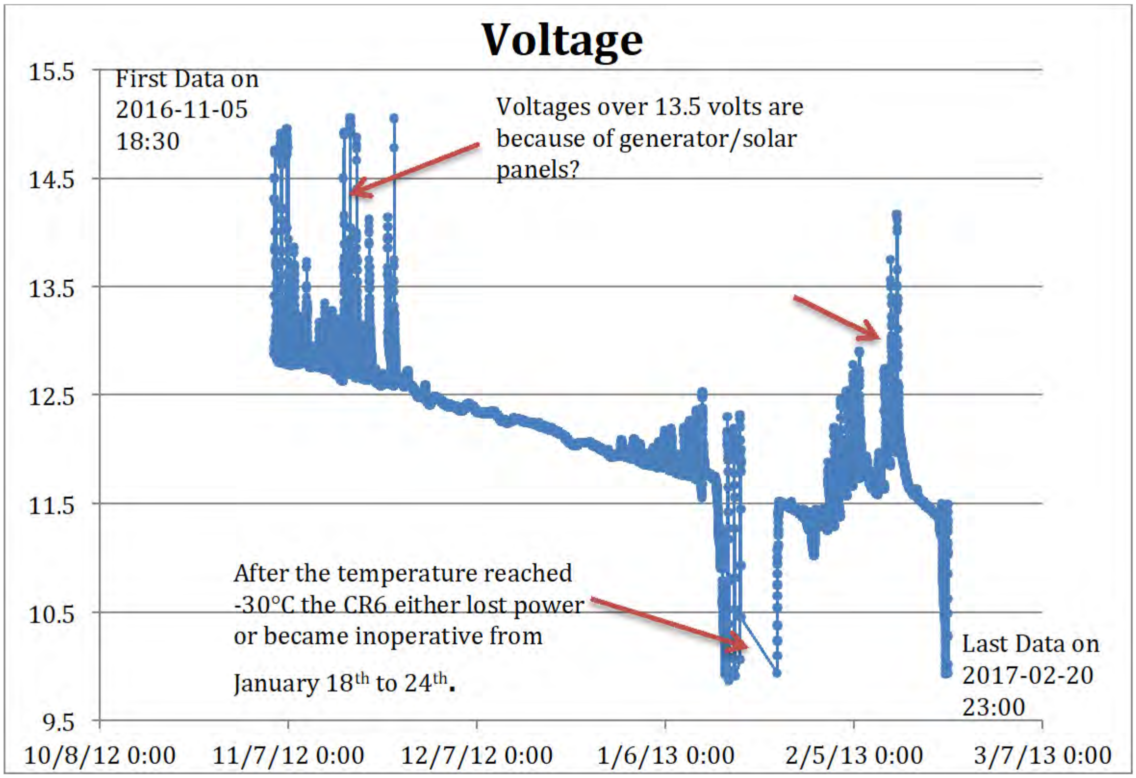


Figure 17. Battery Bank Voltage (V, y-axis) versus time (x-axis) recorded by the data logger.

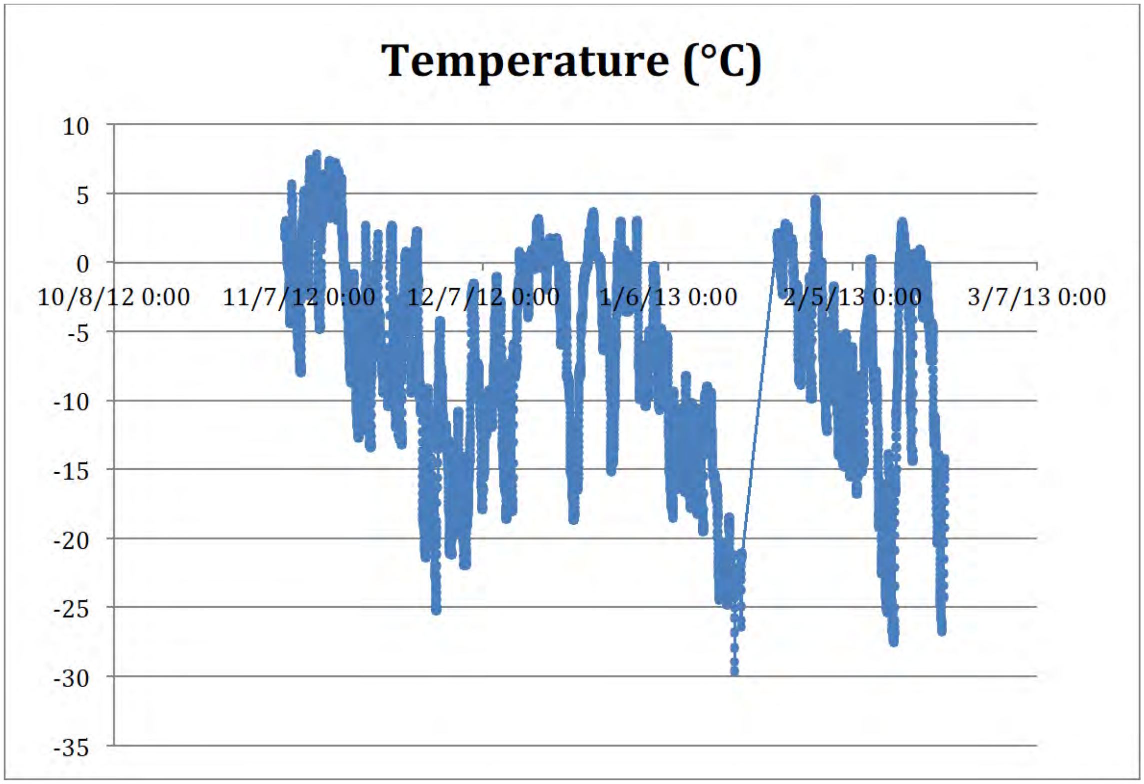


Figure 18. Ambient temperature (deg. C, y-axis) versus time (x-axis) recorded by the datalogger.

The battery bank voltage time series shows that the generator failed to start when required; the voltage set point for the generator to start was 11.5VDC and the battery bank was not depleted to that voltage until 1/15/2017 (72 days into the deployment). The contribution of solar early in the deployment before the dark days of December resulted in the battery bank voltage staying above the generator start voltage. Solar contribution was zero from 11/24-12/29/2016 possibly due to solar panel icing. When the battery bank voltage reached the generator start voltage for the first time it was accompanied by temperatures reaching -30°C as shown in Figure 18. This resulted in the generator not starting and battery bank voltage dropping under 10VDC. This was followed by three days of minimal solar contributions and then five days of the voltage being too low for the data logger to continue to operate (1/19-1/23/2017). On January 24, 2017 after temperatures rose above freezing, the battery bank voltage appeared to recover--most likely due to the solar panels--and the battery bank voltage settled at ~11.5VDC. Although this was the generator start voltage, the generator failed to start. After another warm temperature day of +5°C on 1/30/2017, the voltage increased again. It is assumed that the warm temperatures at this point allowed solar panels to de-ice and battery to resume charging. Solar charging continued from 1/30-2/11/2017 before another cold snap most likely caused icing on the solar panels and damage to the batteries that prevented charging. After 2/11/2017, battery voltage continued to decline until another cold snap was encountered on 2/19/2017 that put the power system fully out of commission.

5.4 Summary and Conclusions

Two acoustic instruments, an ASL Shallow Water Ice Profiler and a Teledyne RD Instruments 1200 kHz Workhorse acoustic Doppler current profiler provide a ~6 month record between Nov. 2016 and April 2017 of acoustic backscatter and water temperature from the Kvichak River adjacent to the Village of Igiugig. The temperature and backscatter data indicate frazil ice was present at the site beginning in December. The final episode of super cooled water and frazil ice was recorded in late March, 2017. Water temperatures in January were low enough that there is a ~2 week period when frazil ice was present at the site continuously (and throughout the water column). Beginning in late January, day-night variations in water temperature lead to decreased frazil during the warmer days. Frazil is present during 20% of the 6-month record.

Water velocities (and water level) at the site gradually declined over the deployment period to minimums in mid-February, 2017 at which time the ADCP stopped logging data. Turbulent kinetic energy at the site also declined throughout the deployment along with the seasonal changes in water velocities and water level. While the real-time data telemetry and remote power systems were not entirely successful, the overall data return from the instruments on the river bed was quite good and the instruments provided a robust record of conditions at the site during the periods when frazil was expected to be present.

6 Acknowledgements

Funding for this project was provided by the U.S. Department of Energy through the Igiugig Village Council. Additional funding for this project came from University of Alaska Fairbanks, Alaska Center for Energy and Power. This work would not have been possible without the support of the Igiugig Village Council and the residents of the Village of Igiugig. We also appreciate ORPC’s understanding of the challenges faced while working in remote Alaska communities

7 Appendix A: IVC River Ice Study Plan

Prepared by Dr. J. Kasper, Mr. N. Konefal and Mr. A. Cannavo, University of Alaska Fairbanks for ORPC, Inc.
October 11, 2016

As part of the US Department of Energy (DOE) funded Igiugig Village Council (IVC)-led project, the University of Alaska Fairbanks (UAF) will perform a study of over winter ice conditions in the Kvichak River at Igiugig, Alaska. UAF will deploy a mooring equipped with sensors to measure water column and surface ice velocities (a 1200 kHZ Teledyne RDI Workhorse Sentinel Acoustic Doppler Current Profiler) as well water column frazil ice and surface ice thickness (an ASL Environmental Sciences, Inc. Shallow Water Ice Profiler, or SWIP, owned by ORPC, Inc.). These sensors will be deployed by the first week of November 2016 and will be retrieved in May 2017.

1. Instrumentation:

The sensors will be mounted on an Ocean Science, Inc. “sea spider” fiberglass tripod and deployed on the river bottom in ~16 ft of water facing upwards. The instruments will be deployed near the location shown in Figure 19. The ADCP transmits sound at 1.2 MHz while the SWIP transmits a sound pulse at 542 kHz. The instruments and frame are shown in Figure 20.

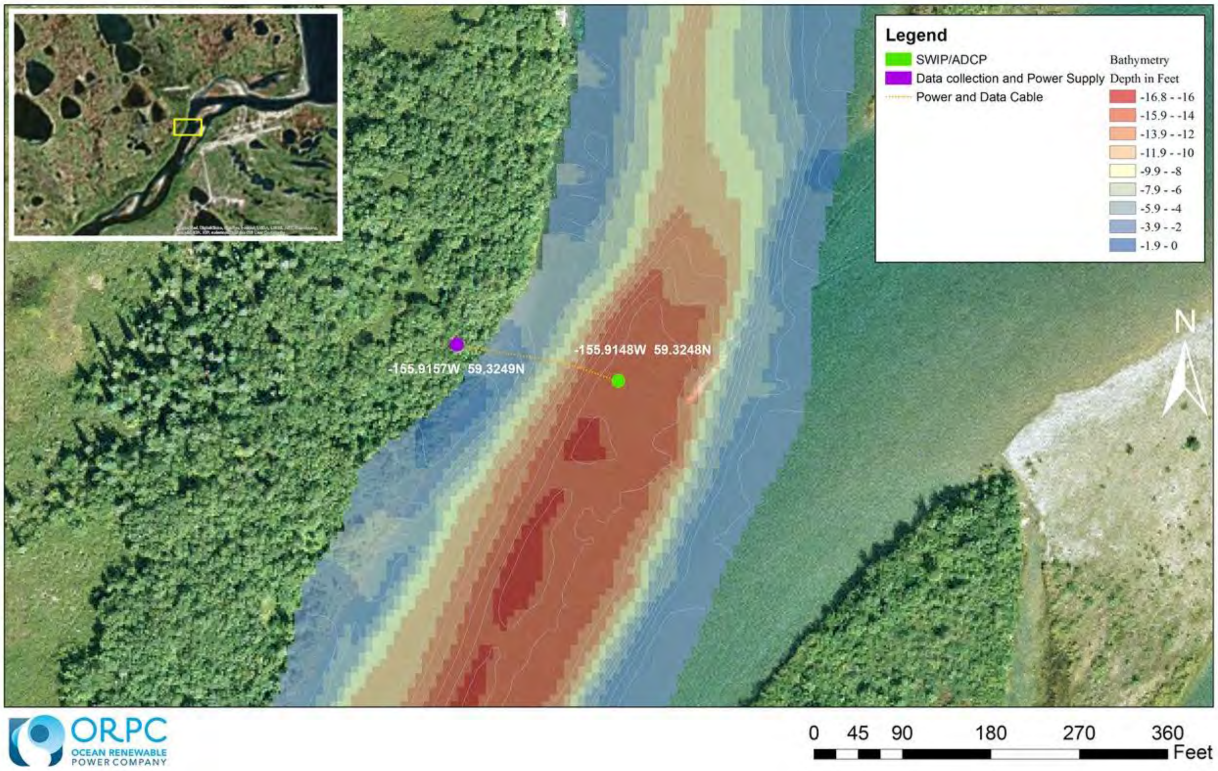


Figure 19 Map of SWIP/ADCP deployment in Igiugig on the Kvichak River.

The ADCP will be programmed to sample continuously at the maximum sampling rate (~1 Hz with ice tracking on, dependent on the water depth). Single ping data will be collected in beam coordinates and transformed to earth coordinates (N-S, E-W and vertical) during post processing. Collecting single ping data and applying coordinate transformations and ensemble averaging after the fact, allows the most flexibility in collecting and analyzing the data.

Ideally, the SWIP would be configured to burst sample at 1 Hz in profiling mode for 10 minutes at the start of every hour. This sampling rate is subject to change based on the throughput of the radio modem. Data throughput of the system will be verified prior to deployment.

Figure 20. Top Leftt: a TRDI Workhorse Sentinel ADCP. Image courtesy of TRDI, Inc. Top Right: An Ocean Science “sea spider” mooring frame. Bottom: An ASL Environmental Sciences SWIP with extended battery case. The Sea Spider frame will be equipped with 150 lbs of lead weights (50 lbs on each tripod leg) to keep the package moored to the river bed.

2. Data collection and power supply:

The shore based data and communication package will consist of a propane fueled autostart generator and two 80W solar panels with sufficient fuel to power the entire 6 month deployment. Propane is available locally in Igiugig and UAF owns an autostart propane generator. A small battery bank will be installed as well to allow for time to service the power system in case of failure. The power system design was carried out by Mr. Andrew Cannavo, an undergraduate mechanical engineering student from Bucknell University and an intern with UAF from May-August 2016. Mr. Cannavo’s report is included as Appendix B. Instrument data, battery bank voltage and generator output will be logged on-site using a Campbell Scientific, Inc. datalogger. Additionally, a radio modem will be used to transmit the data in real time to a laptop computer located inside a nearby IVC facility, ~0.5 miles distant. The laptop will be synced to a cloud service. Data will be available in near real time for quality control, analysis and for monitoring the operation of the instruments. Estimated power usage are shown in Table 1. Estimated power usage for the instrumentation. The ADCP and radio modem are 24V instruments while the SWIP and data logger operate on 12V.. Note solar, wind and hydrokinetic generation were considered as well to power the instrumentation system. However, the solar resource during winter was too small to be economic similarly while the small design loads and variable winds in the region made finding a suitable, cost effective wind turbine for the system problematic. While a small hydrokinetic system was considered, since we have no experience operating commercially available units such as Ampair 100W Water Turbine from ABS Alaska, Inc. we did not consider this a reliable solution.

Table 1. Estimated power usage for the instrumentation. The ADCP and radio modem are 24V instruments while the SWIP and data logger operate on 12V.

Watt Calculation (24V instruments)		
Estimated Watt Demand	18.1	Watt-hrs
Hours expected to run	24	hour/day
Total daily usage	434.4	Watt-hrs/day
Amp-Hour Calculation		
Battery loss correction (static average loss)	443.088	Watt-hrs/day
System Voltage (DC)	24	Volts
Amp-hours per day	18.462	Amp-hrs/day
Watt Calculation (12V instruments)		
Estimated Watt Demand	5	Watt-hrs
Hours expected to run	24	hour/day
Total daily usage	120	Watt-hrs/day
Amp-Hour Calculation		
Battery loss correction (static average loss)	122.4	Watt-hrs/day
System Voltage (DC)	12	Volts
Amp-hours per day	10.2	Amp-hrs/day
Total Amp-Hours per day	28.662	Amp-hrs/day

The number of 20 Amp-hour batteries required for 7 days of power to allow for time to service the system in case of a failure is estimated as 3. Calculations for this are shown in **Error! Reference source not found.**.

Table 2. . Estimate of the number of batteries necessary for backup power.

Battery Bank Calculation		
Approximate backup power required	7	days
Amp-hour storage required	200.634	Amp-hrs
Assume 50% depth of discharge	0.5	
Required Amp backup	401.268	Amp-hrs
20 Hr battery amp rating (needed)	64	fraction
Number of Batteries (parallel)	6.2698125	
Number of Batteries (series)	2	
Rounded number of Batteries Needed	3	

3. In field Operations:

   a) Personnel:

At least two personnel plus a vessel operator will be on site for deploying the instrumentation. All personnel on the vessel deck participating in the deployment will have appropriate safety equipment including safety shoes and personal flotation devices, at a minimum. Before the deployment operation begins on-site personnel will perform a job safety analysis, i.e. they will walk through the deployment in order to identify and mitigate any safety risks.

   b) Deployment Equipment:

The instrument package will be deployed in early November from an IVC chartered vessel (Figure 6). The vessel will be equipped with a davit to aid in safely hoisting the ~200 lb mooring package (~1.2 m x ~1.2 m x ~0.7 m high) over the side of the vessel and for lowering the package to the river bed.

Figure 21. 22 IVC Chartered vessel for deploying the monitoring, package and data and communications packages

c) Operations:

In preparation for deployment the mooring, its cable and chain bundle, and a temporary surface float attached to the deployment line will be laid out on the vessel deck and prepped for deployment. The SWIP cable is reinforced, jacketed and weighted while the RDI ADCP cable is a standard neoprene data and communication cable. Both are equipped with waterproof, impulse-type connectors suitable for long-term underwater deployment. The RDI cable will be jacketed in a nylon sleeve for additional protection. The cable bundle will be wrapped with chain to provide weight as well strain relief.

The Vessel will transit to the deployment location and hold position based on GPS coordinates of the desired deployment location. Once the crew is ready deployment operations will commence by lowering the mooring with its temporary surface float and cable and chain bundle attached to the river bed. Once it has settled into position, the deployment location and time will be recorded using a handheld GPS unit. After the placement of the mooring package on the riverbed, power and data cables bundled with the chain will be run from the vessel to shore. The chain will be connected to a temporary ground anchor where the cable bundle makes landfall. After running the cable to shore, the surface float will be replaced with a large chain link which will be lowered to the riverbed downstream of the mooring package. This line will provide a safe means of dragging for the mooring during recovery if it is not possible to retrieve the mooring using the chain alone.

The data collection and power supply equipment will then be installed on shore and the system will be commissioned, with successful data collection confirmation.

At the conclusion of the study in May 2017, all equipment will be removed including the temporary ground anchor. This primary means to accomplish this will be by retrieving the chain at the shore and using it to pull the mooring from the riverbed and into the vessel.

4. Data Collection and Analysis:

Since the data will be available in near real time, data will be monitored daily to ensure the equipment is operating continuously. Plots of time series of velocity, suspended ice acoustic return strength (in counts), temperature, surface ice draft (calculated as the acoustically measured distance between the ADCP and the water surface minus the height of the water column as measured by the ADCP's pressure sensor) and surface ice velocity will be updated at least monthly. Data will be summarized in the final deployment month so that when the equipment is removed the data analysis will be complete as well. A draft report summarizing the results of the ice study will be delivered to IVC in early June allowing a final version to be complete by June 30, 2017.

8 Appendix B: Design of the shore power system

MEMO

To: Director Jeremy Kasper, AHERC
From: Intern Andrew Cannavo, AHERC
Subject: Design of a system for powering instrumentation for measuring river ice and velocities
Date: 15 July, 2016

Assignment (from Scope of Work):

"As part of the Igiugig Village Council led DOE project to deploy ORPC's Rivgen® hydrokinetic turbine in the Kvichak River near Lake Iliamna, AHERC is funded to complete a frazil ice study of the deployment site. The study requires the deployment of an Acoustic Doppler Current Profile (ADCP), a Shallow Water Ice Profiler (SWIP) and possibly an underwater time lapse camera system. Before deployment of these instruments, the costs associated with deploying the instruments in real time (preferred) versus in autonomous, internally logging mode need to be quantified."

Considerations (from Scope of Work):

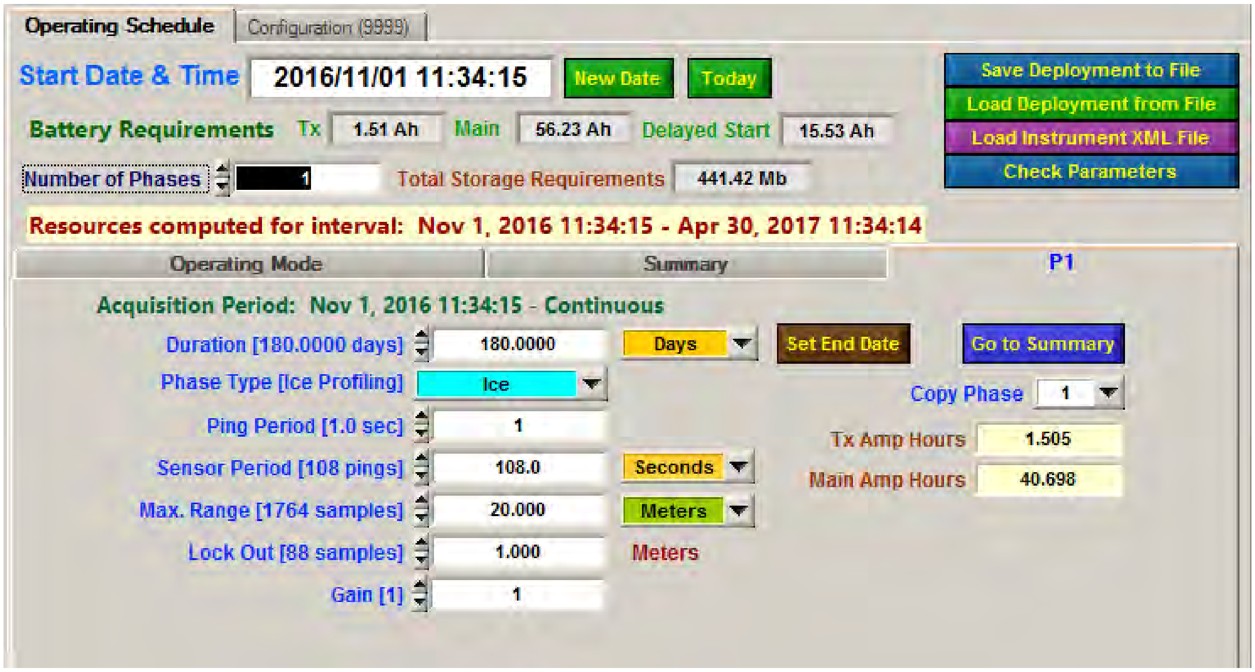
"Deployment in real time mode requires the purchase of a serial cable for conveying power from shore and data transfer from the bottom mounted ADCP to shore. (The SWIP is already equipped with the necessary cabling.) Additionally, the electrical load of each instrument needs to be quantified in order to determine the design of the power system. The electrical load will be determined by the sampling scheme of each instrument. Additionally, real time mode will require the use of a pair of radio modems to transmit data from where the instrument cables make landfall to an IVC owned building 0.5 miles distant from the site."

Scenario 1:

Both the ADCP and SWIP are capable of being deployed with internal data logging and operating in battery powered mode. The period of the study however is long, about 6 months, and being able to support the power and data loads for this length of a period will require the right sampling schemes and external batteries to supplement the internal battery pack of each instrument. While the sampling schemes can be made to fit both requirements of power and data for the intended time period, the amount of data they collect may not be optimal due to the infrequency of measurements.

Shallow Water Ice Profiler:

Using the IPS5Link River software that is used to deploy the SWIP, it was shown that using the standard sampling scheme for the instrument meets both our power and data requirements for a 180 study. It can be seen in Figure 1 that over the 180 day period 441 MB of data will be collected using only 56 amp hours of power. The typical internal battery used to deploy with the SWIP has about 120 amp hours. Of the estimated 56 Ah use, this leaves a considerable margin of unused power. If deploying the SWIP at the start study is done, an additional 15 Ah of power will not be used in delaying the start of data collection, reducing power needs even more.



Start Date & Time 2016/11/01 11:34:15

Battery Requirements Tx 1.51 Ah Main 56.23 Ah Delayed Start 15.53 Ah

Number of Phases 1 Total Storage Requirements 441.42 Mb

Resources computed for interval: Nov 1, 2016 11:34:15 - Apr 30, 2017 11:34:14

Acquisition Period: Nov 1, 2016 11:34:15 - Continuous

Duration [180.0000 days] 180.0000 Days

Phase Type [Ice Profiling] Ice

Copy Phase 1

Ping Period [1.0 sec] 1

Tx Amp Hours 1.505

Sensor Period [108 pings] 108.0 Seconds

Main Amp Hours 40.698

Max. Range [1764 samples] 20.000 Meters

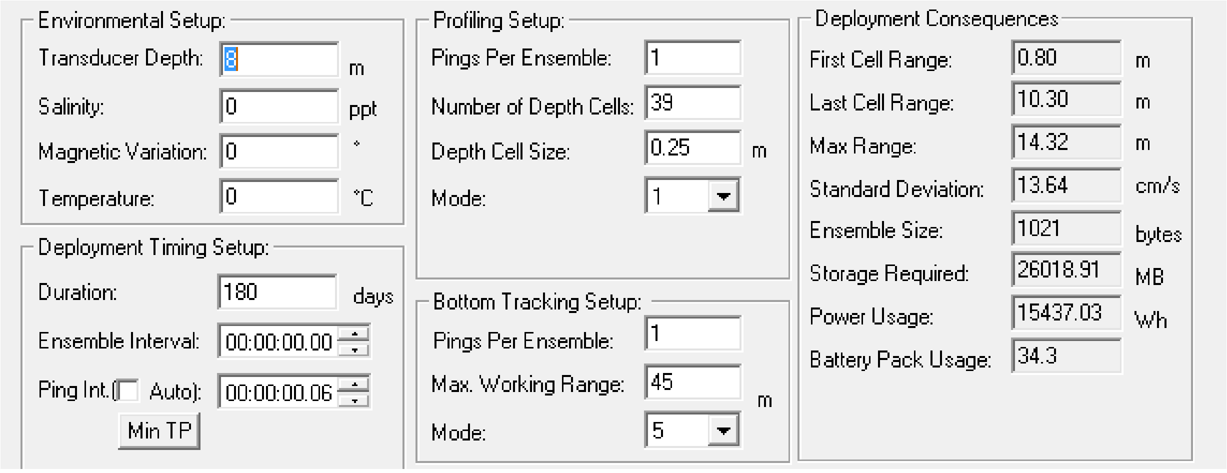
Lock Out [88 samples] 1.000 Meters

Gain [1] 1

Figure 23. *Example sampling scheme for the SWIP*

Acoustic Doppler Current Profiler:

The software used to program the ADCP for deployment, PlanADCP, allows full user control over the conditions it will see and characteristics necessary for the deployment. For a deployment of six months, the time period of the intended frazil ice study, a measurement of 1 ping at a frequency of 10 Hz will provide more than sufficient data. This amounted to a power usage of about 85 Wh per day and 26 GB of data over the course of the 180 days. Using this amount of data and power means the ADCP could not be deployed internally with the current settings, but for the purpose of the study this frequency of measurements is required. A hybrid between internal and externally driven will have to be created for a successful deployment.



Environmental Setup:
Transducer Depth: 8 m
Salinity: 0 ppt
Magnetic Variation: 0 °
Temperature: 0 °C

Deployment Timing Setup:
Duration: 180 days
Ensemble Interval: 00:00:00.00
Ping Int.(☐ Auto): 00:00:00.06

Profiling Setup:
Pings Per Ensemble: 1
Number of Depth Cells: 39
Depth Cell Size: 0.25 m
Mode: 1

Bottom Tracking Setup:
Pings Per Ensemble: 1
Max. Working Range: 45 m
Mode: 5

Deployment Consequences
First Cell Range: 0.80 m
Last Cell Range: 10.30 m
Max Range: 14.32 m
Standard Deviation: 13.64 cm/s
Ensemble Size: 1021 bytes
Storage Required: 26018.91 MB
Power Usage: 15437.03 Wh
Battery Pack Usage: 34.3

Figure 24. Example sampling scheme for deployment scenario.

Scenario 1 Summary:

While the data collection schemes for the instruments being internally logged are not be ideal for the intention of the study, they do show that it is at least plausible to deploy them for the 180 day period and to be both internally powered and store data. While this would be good for the independence of the study, there are some other considerations. Internally logging the data would mean it would not be accessible until the end of the study. This could mean that if something would to happen that would hinder or stop data collection altogether, it would not be known until the data was retrieved. The potential loss of data is great since it would not be monitored remotely. Remote monitoring of the data could recognize a problem with the data after only a few days and address the issue. The frequency of data required for the purpose of the study is also large, especially for the ADCP. The sampling scheme shown above for the ADCP showed that it was not possible to internally manage the instrument for the course of the 180 day period. Thus, a hybrid plan must be achieved between internally and externally powering the system.

Scenario 2:

Analysis:

In order to deploy this system in real time mode, meaning constant data collection over the designated period of study, there are two main considerations. These being how to power the system during this time period and how to effectively transmit the collected data. Through the use of a power system consisting of a battery bank and some sort of recharge device (i.e. solar array, wind turbine, hydrokinetic turbine, or generator) the instruments can be powered. The use of cabling, Campbell data logger, and radio modem will transmit data from the SWIP and ADCP to shore, couple the data, and then transmit it the half mile from the site through the radio and to an offsite computer.

Power Calculations:

In order to determine the power required to run the instruments and associated system, estimates were made for individual device's consumption based on the maximum possible usage for the radio modem and data logger. The estimates for each instrument were the power each would draw due to a sampling scheme that allowed for maximum data collection. **Error! Reference source not found.** shows the calculated power demands for both the 24 V powered devices (ADCP and radio modem) and the 12 V devices (SWIP and data logger).

Table 3. Power Demand of Instruments

Watt Calculation (24V instruments)		
Estimated Watt Demand	9.37	Watt-hrs
Hours expected to run	24	hour/day
Total daily usage	224.88	Watt-hrs/day
Amp-Hour Calculation		
Battery loss correction (static average loss)	229.3776	Watt-hrs/day
System Voltage (DC)	24	Volts
Amp-hours per day	9.5574	Amp-hrs/day
Watt Calculation (12V instruments)		
Estimated Watt Demand	0.568	Watt-hrs
Hours expected to run	24	hour/day
Total daily usage	13.632	Watt-hrs/day
Amp-Hour Calculation		
Battery loss correction (static average loss)	13.90464	Watt-hrs/day
System Voltage (DC)	12	Volts
Amp-hours per day	1.15872	Amp-hrs/day
Total Amp-Hours per day	10.71612	Amp-hrs/day

While these power requirements are larger estimates for the instruments they are still relatively low in terms of daily usage. Ideally, a renewable device would be able to power the system continuously with a battery bank used as backup power. Taking a look at the number of batteries required for a given number of days of sufficient power (**Error! Reference source not found.**) gives a safe working power allowance for the system in the case something the bank isn't able to be continuously powered.

Table 4. Examining the number of batteries necessary for sufficient power

Battery Bank Calculation		
Approximate backup power required	7	days
Amp-hour storage required	229.37	Amp-hrs
Assume 50% depth of discharge	0.5	
Required Amp backup	458.74	Amp-hrs

20 Hr battery amp rating (needed)	85	fraction
Number of Batteries (parallel)	6	
Number of Batteries (series)	2	
Rounded number of Batteries Needed	3	Series/parallel

Power Recommendations:

Based on power requirements of about 300 W-h/day for the system in question

Battery Bank:

The battery bank will be made up of 8 12V batteries connected in series/parallel to make the bank 24V. It was decided to increase the number of batteries from the calculated 6 (Table 4) to 8 in order to account for the lower power availabilities from the cold temperatures likely to be encountered. This bank is thus made up of 8 batteries connected in series in pairs of 2 to create the 24 V power. These 4 pairs are then connected in parallel to increase the available power of the battery bank to about 400 Ah based on standard 12 V battery ratings (Table 5).

Table 5. Determining the power of the battery bank

Battery Bank Capacity		
Number of 12 V Batteries	8	batteries
Batteries in Series/Parallel configuration	4	pairs
Battery Bank Voltage	24	Volts
Available Power (20 hr)	85	Amp-hrs
Current	4.25	Amps
Current used daily	102	Amp-Hours
Power of Bank	408	Amp-Hours

Solar:

Having two 80W solar panels available, powering the instruments with solar energy is the first thing to examine. These power ratings given by the manufacturer for the panels were from testing of sun conditions at 1 kW/m^2 test conditions. For Igiugig however, these conditions are often unlikely. Because the test period for these instruments occurs in the winter, the limitation for this power option is already cut to about 4 hours of sun per day (Figure 3). Based on preliminary power calculations, this could still provide the necessary power for all the instruments. However, examining the solar irradiance data for the area around Igiugig, found from the National Renewable Energy Lab's NSRDB Data Viewer, the average direct solar irradiance averages to about 2.5 kWh/m^2/day (Figure 26). This translates to only about 1/10 of the available power, 100 W/m^2, that the panels are rated for.

Based on this data it seems that solar will not be an adequate stand-alone power source for the instrumentation required in this system. There is also about 50% cloud cover in the winter time when the study is to be conducted and snow is prevalent. This would require the panels to be swept off if covered, reducing the independence of a solar system even further.

However, since the study is over the course of 6 months, the last half of the study could provide adequate sun to offset the overall power consumption of the system. Since the solar panels and equipment are already available to us they should be incorporated into the power system to be created in order to help offset power needs when the sun increases later in the study. The low power requirements of the devices should make any solar production relatively significant though later in the study. Even at a tenth of the available power production of the panels due to the low solar irradiance, 16W of power for a couple hours a day could provide the required 10W/hr for the instruments. The remaining 6W of power could be used, while minimally, to recharge the battery bank and offset propane use.

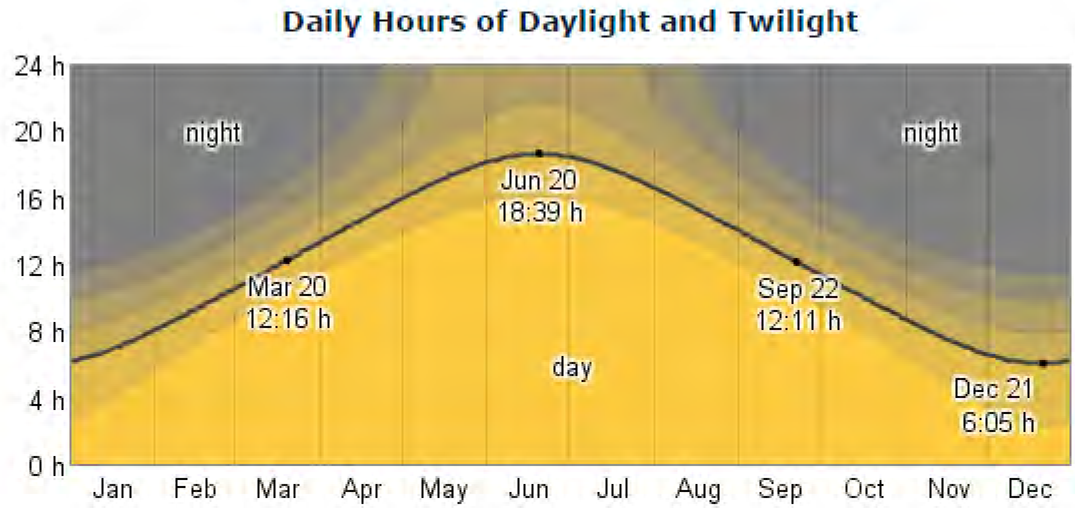


Figure 25. . (https://weatherspark.com/averages/32974/Igiugig-Alaska-United-States)

PSM Direct Normal Irradiance 4 nearby results

Result 1 of 4

Average DNI: 2.6330762

Result 2 of 4

Average DNI: 2.6042829

Result 3 of 4

Average DNI: 2.6259134

Result 4 of 4

Average DNI: 2.6166127

SUNY India Direct Normal Irradia... 0 nearby results

Figure 26 . (https://maps.nrel.gov/nsrdb-viewer/)

Wind:

The winter time is the peak of the year for wind speeds. Igiugig sees its highest average wind speeds at this time when the study is to be conducted. As seen in Figure 5, the average daily wind speed is about 10 mph, with a range from 2 – 17 mph during the winter months. With this large range of wind speeds a turbine with a low cut in speed would be required to ensure reliable power throughout the range of velocities. Not already having a turbine that fits these requirements would mean one would have to be purchased and installed. One such turbine that fits these requirements is the Bergey XL 1, offered from Remote Power Inc; it has a cut in speed of 5.6 mph and a power rating of about 1300 Watts. The price of the turbine itself is about $4,250 not including the cost of the tower or installation costs. For the purpose of this study, these costs seem high and unnecessary expenses to complete it effectively.

Given the high cost of having to buy new equipment to power the system and the general unreliability of wind, using it as an effective resource to meet the power needs of the system during the course of the study seem unlikely.

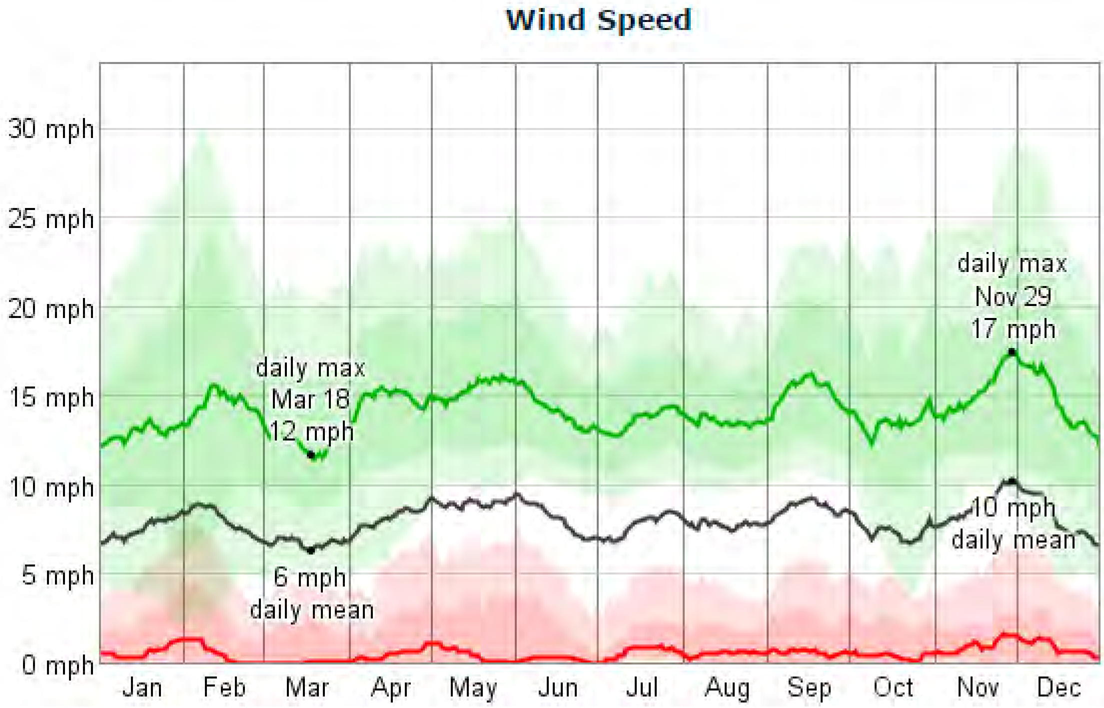


Figure 27 . *(https://weatherspark.com/averages/32974/Igiugig-Alaska-United-States)*

Hydro:

Being at the mouth of the river leading from Lake Iliamna, the use of a hydrokinetic turbine could be significant. One such turbine is the Ampair 100W Water Turbine from ABS Alaska, Inc. This 100 Watt turbine can provide up to 4 amps per hour. The amp requirement of our system is only about 1.25 amps per hour, but the 4 amp rating is the maximum it can produce. There is a recommendation for the turbine that water speed be at least 1.8 m/s and be at a depth of at least 16 inches or else the power production of the turbine will be negligible. Not knowing the conditions for the river at Igiugig leaves the question of whether these requirements can be met.

Given the troubles encountered at Nenana with the 5kW New Energy turbine these minimal requirements, especially velocity, seem like they could be a problem. The small amount of power the turbine is rated for could conceptually meet our consumption needs, but that was for ideal conditions at the turbine, something we most likely will not have. Since the system will be deployed over the winter, water velocities will likely be reduced and the introduction of frazil ice could introduce other problems to the performance of the small turbine. With a cost of $2,200 and the associated risks of unreliability, using a marine turbine such as this one from ABS does not seem like an effective, independent solution to powering the system.

Autostart Generator:

The most reliable of the options available to us to power the system would be through the use of an autostart generator. Recommendations from Greg Egan of Remote Power Inc. suggested this course of action due to the low power requirements of our system. Through the use of a battery bank, needed regardless of the power option chosen, the generator would only need to be turned on every 4 or 5 days for about 5 hours (**Error! Reference source not found.**) in order to recharge the batteries spent. This interval could be set and then the only involvement necessary would be someone needed to refill the propane tanks every few months depending on the size of the tank. Through the use of a propane autostart generator and tanks storing propane onsite, there is the possibility of the system still being able to sustain itself throughout the testing.

Using the generator as the means to power the system seems to be the most reliable of the power methods stated, as it does not have to rely on unsteady environmental conditions for power production. The cost would be minimal as we already have the autostart generator and the system for the instruments would be greatly simplified down to only distribution boxes and a DC-DC converter for the two different power requirements of the two instruments. The battery bank will no longer be used for backup power, but for powering the instruments with the generator recharging the bank periodically. While the cost is reduced and the system is greatly simplified, the power source is not renewable. However, in the interest of completing the study and having reliable and consistent data throughout the test period, this method seems like the most reasonable option.

Table 6. Amount of fuel needed for 180 day study.

Depletion and Charging		
Available Power (60% availability)	244.8	Amp-hrs
Amp-Hours per day Used	10.71612	Amp-hrs/day
Assume 40% Depth of Discharge	0.4	
Days before depletion	9.137635637	days
Power of Bank	9792	Watts
Charging Capacity of Generator	2500	Watts/hr

Assume 80% efficiency	2000	Watts/hr
Full capacity recharge time	4.896	Hours
Fuel Consumption Rate	2.3	lb/hr
Fuel used per recharge	11.2608	lbs
Number of Recharges over 180 day study	19.69875	recharges
Fuel used over 180 day study	221.823684	lbs

After considering the inclusion of the solar panels into the system, the power consumption calculations were redone (Table 7). Assuming only a tenth of the rated power production of the panels and only an average of 3 hours of operation per day over the course of the 180 day period reduced fuel consumption of propane to about 180 lbs (Table 8)This means that coupling two 100 lb propane tanks would give enough fuel to power the system throughout the whole study.

Table 7. Power consumption after considering production from solar panels

Corrected Power Consumption (with Solar Panels)		
Estimated Solar Production	16	Watt
Average Hours of Sun over 180 days	3	hour/day
Daily Solar Production	48	Watt-hrs/day
Voltage	24	Volts
Amp-Hours per day	2	Amp-hrs/day
Total Amp-Hours per day (original - solar power produced)	8.71612	Amp-hrs/day

Table 8. Fuel Consumption after considering offset power produced from solar panels.

Corrected Depletion and Charging (with Solar Panels)		
Available Power (60% availability)	244.8	Amp-hrs
Amp-Hours per day Used	8.71612	Amp-hrs/day
Assume 40% Depth of Discharge	0.4	
Days before depletion	11.2343566	days
Power of Bank	9792	Watts
Charging Capacity of Generator	2500	Watts/hr
Assume 80% efficiency	2000	Watts/hr
Full capacity recharge time	4.896	Hours
Fuel Consumption Rate	2.3	lb/hr
Fuel used per recharge	11.2608	lbs
Number of Recharges over 180 day study	16.0222794	recharges
Fuel used over 180 day study	180.423684	lbs

System Diagram:

The diagram shown in Figure 28 is the system design for use with the autostart generator and integrated solar panels. The generator is connected to the 24V battery bank and recharges it at set intervals as it is depleted. Using at most 15 Ah of power a day and assuming 60% of available power due to the cold temperatures means the bank could power the instruments 9 days before having to be recharged by the generator.

From the bank the instruments are connected as the load. There is a fuse and switch on the positive power cable for protecting the instruments and the DC-DC converter converts the power from the 24V of the battery bank down to 12V for the SWIP and Campbell logger. The rest of the instruments can be powered directly with 24V.

The incorporation of the solar panels was done due to the fact that the panels and associated equipment are already available to us. The panels may not provide considerable power until later in the deployment when daily sun increases. However, since the power requirements of our system are so low, they could offset the amount of propane used to run the generator considerably as the daily sun increases. With two 100 pound tanks of propane onsite and the addition of the solar panels to supplement the generator, the whole 180 day deployment could be achieved without having to have any tanks refilled or replaced.

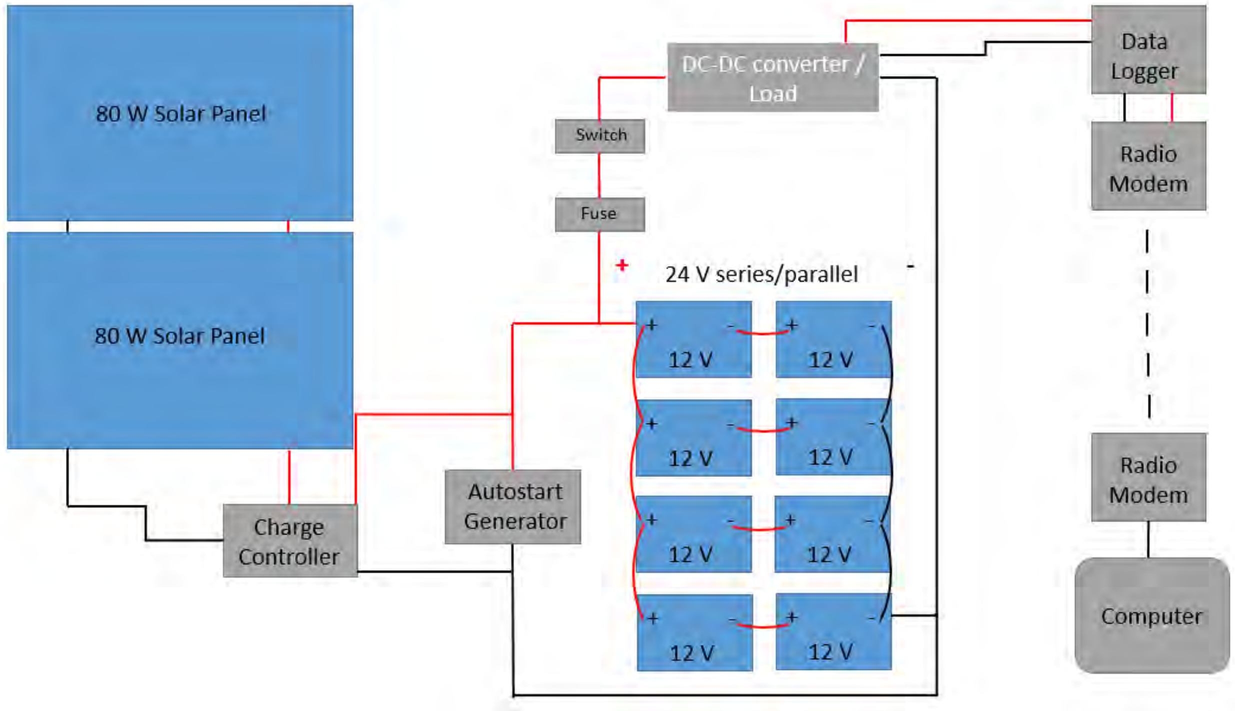


Figure 28. System Diagram for system with autostart generator supplemented with solar panels

Recommendation:

Adjusting the sampling scheme so that less frequent measurements are made by the instruments could reduce the power demands of the system from the max estimated in scenario 2. Since the time period of the study is so long, less frequent measurements would have significant impact on the power, but coupling the system with the external battery bank should reconcile this issue. However, the purpose of the study requires a larger sampling scheme for both instruments.

Externally powering the instruments and offloading the data through the use of the data logger and modem to a computer is thus necessary.

To get the most reliable system and thus the highest possibility of complete data over the course of the 180 day study it is recommended to use the propane autostart generator system with onsite propane storage tanks to externally power the instruments and offload data to the offsite computer. Coupling this power source with the two available solar panels will allow for offset power production from the generator later in the term of the study, as more sun becomes available. Installing internal battery packs to the instruments can also be done in order to provide backup power if required in the case of a drained or malfunctioned battery bank. Both instruments are cabled with RS422 connections, allowing simultaneous power and data transmission. The use of this external powered system allows the data collected from the instruments to be coupled through the use of the Campbell data logger and transmitted with a radio modem offsite. The use of the data logger will also allow the monitoring of the power and charging of the battery bank. Overall, this system seems to be the most efficient and independent of all the options examined while still providing the large amount of data required for the purpose of studying the frazil ice in the river.

.

9 Appendix C: Power Calculations

Table 9. Power calculations for the remote power/real-time data telemetry ice monitoring system.

Watt Calculation (24V instruments)		
Estimated Watt Demand	9.37	Watt
Hours expected to run	24	hour/day
Total daily usage	224.88	Watt-hrs/day
Amp-Hour Calculation		
Battery loss correction (static average loss)	229.3776	Watt-hrs/day
System Voltage (DC)	24	Volts
Amp-hours per day	9.5574	Amp-hrs/day
Watt Calculation (12V instruments)		
Estimated Watt Demand	0.568	Watt
Hours expected to run	24	hour/day
Total daily usage	13.632	Watt-hrs/day
Amp-Hour Calculation		
Battery loss correction (static average loss)	13.90464	Watt-hrs/day
System Voltage (DC)	12	Volts
Amp-hours per day	1.15872	Amp-hrs/day
Total Amp-Hours per day	10.71612	Amp-hrs/day

Battery Bank Capacity		
Number of 12 V Batteries	8	batteries
Batteries in Series/Parallel configuration	4	pairs
Battery Bank Voltage	24	Volts
Available Power (20 hr)	85	Amp-hrs
Current	4.25	Amps
Current used daily	102	Amp-Hours
Power of Bank	408	Amp-Hours

Depletion and Charging		
Available Power (60% availability)	244.8	Amp-hrs
Amp-Hours per day Used	10.71612	Amp-hrs/day
Assume 40% Depth of Discharge	0.4	
Days before depletion	9.137635637	days
Power of Bank	9792	Watts
Charging Capacity of Generator	2500	Watts/hr
Assume 80% efficiency	2000	Watts/hr
Full capacity recharge time	4.896	Hours
Fuel Consumption Rate	2.3	lb/hr
Fuel used per recharge	11.2608	lbs
Number of Recharges over 180 day study	19.69875	recharges
Fuel used over 180 day study	221.823684	lbs

24 V Instruments Usage		
ADCP	3.57	Watt-hrs
RF Modem	5.8	Watt-hrs
12 V Instruments Usage		
SWIP	0.232	Watt-hrs
Campbell Logger	0.336	Watt-hrs

Corrected Depletion (with Solar Panels)		
Estimated Solar Production	16	Watt
Average Hours of Sun over 180 days	3	hour/day
Daily Solar Production	48	Watt-hrs/day
Voltage	24	Volts
Amp-Hours per day	2	Amp-hrs/day
Total Amp-Hours per day	8.71612	Amp-hrs/day

Battery Bank Capacity		
Number of 12 V Batteries	8	batteries
Batteries in Series/Parallel configuration	4	pairs
Battery Bank Voltage	24	Volts
Available Power (20 hr)	85	Amp-hrs
Current	4.25	Amps
Current used daily	102	Amp-Hours
Power of Bank	408	Amp-Hours

Depletion and Charging		
Available Power (60% availability)	244.8	Amp-hrs
Amp-Hours per day Used	8.71612	Amp-hrs/day
Assume 40% Depth of Discharge	0.4	
Days before depletion	11.2343566	days
Power of Bank	9792	Watts
Charging Capacity of Generator	2500	Watts/hr
Assume 80% efficiency	2000	Watts/hr
Full capacity recharge time	4.896	Hours
Fuel Consumption Rate	2.3	lb/hr
Fuel used per recharge	11.2608	lbs
Number of Recharges over 180 day study	16.0222794	recharges
Fuel used over 180 day study	180.423684	lbs

10 Appendix D: System Block Diagram

A block diagram of the remote power / data telemetry system and sonars is shown below (Figure 29).

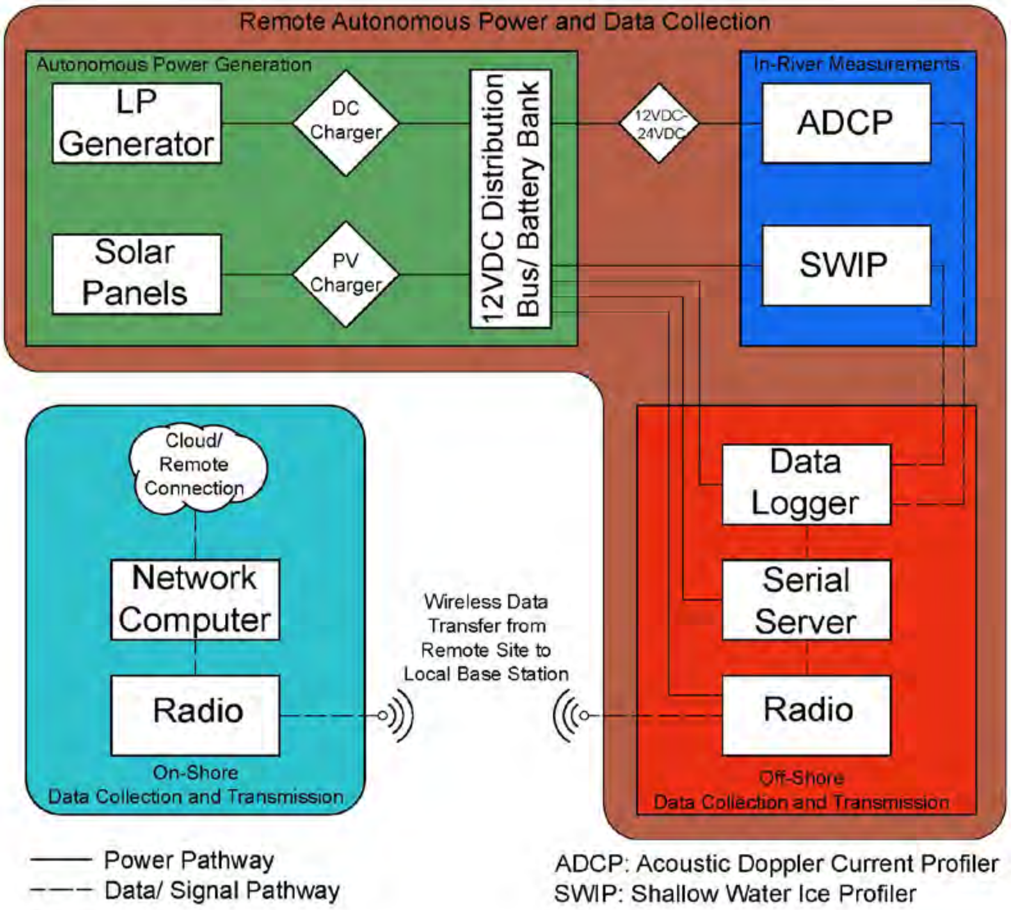


Figure 29. Block diagram of the remote power / data telemetry system.

11 Appendix E: June, 2017 Recovery Plan

Igiugig Recovery Plan

Dates: 6/23-6/25/2017
Location: Igiugig, AK
Participants: Nick Konefal and Jeremy Kasper

Overview:

UAF researchers Nick Konefal and Jeremy Kasper will travel to Igiugig, AK to recover a mooring from the Kvichak River. An ADCP and SWIP are mounted to the mooring and are being removed as the project has ended and data needs to be recovered. In addition to the mooring, on shore equipment will be retrieved and all equipment will be prepped for shipping back to Fairbanks.

Recovery Plan

6/23/2017

- Travel to Anchorage via Alaska Airlines (~9am) and then Anchorage to Igiugig (~1pm) arriving in Igiugig around 2:30pm
- Once Karl's boat has been launched and he is ready we will start the process for removing the mooring

1) Safety talk and plan overview with recovery crew
2) Load necessary recovery equipment on boat (See attached list)
3) Drag grapple for mooring drag line
    a) Attach one side of line to the grappling hook and the other to a cleat on the boat.
    b) Attach davit hook/ shackle to grappling hook
    c) Position boat to the side of the expected drag line position (side will depend on which side of the boat the davit is on
    d) Use davit to lift grappling hook and swing over side of the vessel
    e) With one person on the davit remote and the other letting out the grapple line, lower the grappling hook into the water until the hook is on the bottom of the river
    f) Move boat perpendicular to drag line/river and drag grapping hook over the dragline. Continue until the grapple has passed the dragline areas by ~20'-30'.
    g) Pull up in the grapple using the davit and determine if the dragline has been successfully grabbed. If it has not repeat step f and g.
    h) Once the dragline has been brought above water with the use of the grapple and davit, tie a line through the shackle at the end of dragline and secure to the boat making the

   line tight. This will allow the tension on the davit line to be released and grapple to be removed from the drag line
   - i) Swing the davit back over the boat and release the grapple from the davit hook
   - j) Tie a slipknot around the dragline at the lowest point possible
   - k) Connect the davit to the slipknot and lift the dragline using the davit
   - l) Tie off the new slack in the dragline to the cleat to secure the load
   - m) Lower the davit to release tension on the davit line
   - n) Remove slipknot from dragline
   - o) Repeat steps j-n until mooring is out of the water
   - p) If possible, swing mooring on to the deck of the boat
4) Once the mooring has been brought onboard/ out of the water, work the boat back to shore pulling in the armored cable. This should be able to be done by hand using two bodies.
5) Once the boat has reached the shore where the armored cable lands, detach the cable from the shore and bring the rest of the cable on the boat.
6) While on the far bank, recover the rest of the equipment. The wooden frame should be light enough that we don't need to take it apart at this point and can lift it on to the boat.
7) Once all equipment is recovered from the far side of the river, return to the Igiugig side and unload the equipment
8) Once all the equipment is on shore it can be disassembled and prepped for shipping.

6/24/2017

- Disassemble equipment and prep for shipping

6/25/2017

- Depart Igiugig around ~2:30pm on Dena'ina Air, arriving Anchorage around 4pm. Depart Anchorage ~6PM arriving into Fairbanks around 7pm.

Recovery Equipment

1) Davit
2) Davit Adapter
3) 2- 12V Batteries for Davit
4) Battery connections
5) Davit control box/ remote
6) Grapple
7) Large shackle for grapple
8) Line for grapple
9) Shackle for davit
10) Smaller line segments for making slipknots
11) Socket set

12) Electric Drill+ spare batteries+ charger

13) ADCP CASE?? (May be in Igiugig already)

Shipping Materials

1) 2x Empty action packers for equipment
2) Tape
3) Sharpies for labeling

Items to be shipped back

1) Davit	SHIP
2) Davit Adapter	SHIP?
3) Grappling Hook	SHIP
4) 3x-40lb propane tanks	LEAVE?
5) Wooden stand	LEAVE
6) Z-link antenna	SHIP
7) Inverter Box	SHIP
8) Generator	SHIP
9) Power supply box	SHIP
10) Spider frame	SHIP
11) ADCP	SHIP
12) SWIP	SHIP to ORPC
13) ADCP Cable	SHIP
14) SWIP Armored Cable	SHIP to ORPC
15) 2 Float Coats	SHIP
16) Propane hoses/accessories	SHIP
17) Wires/ accessories	SHIP

12 Appendix G: Pictures from the Field

Figure 30. The F/V EG ready to deploy the instruments in the Kvichak River.

Figure 31. UAF personnel with the remote power/data telemetry riverl ice monitoring system on the bank of the Kvichak River, downstream of the Village of Igiugig, Alaska, November, 2016.

Figure 32. View of the remote power/real-time data telemetry river ice monitoring system from the Kvichak River, November, 2016.

Figure 33. Power System with Solar Panels, November, 2016.

Figure 34. Remote power and data telemetry system, November, 2016.

Figure 35.Equipment packaged for initial shipment to Igiugig prior to the November, 2016 deployment.

Figure 36. Approaching the site of the remote power/real-time data telemetry river ice monitoring system from downstream in February, 2017. A shelf of shorefast ice extends from the bank.

Figure 37. Looking downstream on the Kvichak River from the remote power/data telemetry system, February, 2017.

Figure 38. UAF personnel working on the remote power/real-time data telemetry system in February, 2017.

PNNL-26576

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

Triton: Igiugig Fish Video Analysis

Project Report

August 2017

S Matzner
C Trostle
G Staines
R Hull
A Avila
GEL Harker-Klimeš

U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

TRITON

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

Triton: Igiugig Fish Video Analysis

Project Report

August 2017

S Matzner
C Trostle
G Staines
R Hull
A Avila
GEL Harker-Klimeš

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Tidal and instream turbine technologies are currently being investigated for power generation in a variety of locations in the US. An environmental permitting and consenting requirement parallels this exploration generating the need to ensure little or no harm, in the form of strike or collision, befalls marine animals from device deployments. Monitoring methods (e.g., underwater cameras, active acoustics, passive acoustics) around turbine deployments provide empirical data allowing regulators and other stakeholders to assess risk. At present, there is a high level of concern and limited data precluding robust conclusions, which creates a challenge to regulators who must make decisions based on perceived risk versus actual risk. However, the data that are currently available to the scientific community for analysis indicate the issue to be of low risk to date, and strike or collision to be rare events. One such dataset that provides insight to the rarity of strike and collision risk to fish came from an instream turbine deployment in Alaska that used underwater video as the monitoring method.

This document describes the analysis of video data collected around the Ocean Renewable Power Company's RivGen® device deployed in the Kvichak River during July and August 2015 to gain an understanding of the implications of using underwater video cameras as a fish monitoring technique. The data were analyzed manually and used to develop automated algorithms for detecting fish in the video frames and describing their interaction behavior relative to the device. In addition, Pacific Northwest National Laboratory (PNNL) researchers developed a web application, EyeSea, to combine manual and automated processing, so that ultimately the automated algorithms could be used to identify where human analysis was needed (i.e., when fish are present in video frames).

The goal of the project was to develop software algorithms that could identify video frames with fish present to inform and accelerate manual analysis. To achieve this, independent manual analysis was completed for specific video clips (i.e., visual analysis and annotation by a human observer was the standard for assessing the algorithms). The analysis process indicated that some confounding aspects of the algorithm development could potentially be solved with recommended improvements in the initial camera data collection methods.

The manual analysis began to look at all data from the start of deployment of the RivGen® device, primarily using video from Camera 2 that looked directly at the upstream side of the turbine so any interaction could be identified; this was to ensure rare events were seen, and initially focused on Nighttime Data when more fish were present. This process highlighted the amount of time it takes to identify fish, and ultimately only 42.33 hours of video were reviewed because of the time-consuming analysis. The data were classified as "Fish" when the reviewer was confident it was a fish, and "Maybe" fish when it was difficult to distinguish. The two classes were distinguished based on the movement, shape, and color characteristics. Fish Events were further classified by "adult", "juvenile", or "unidentifiable" age. Behavioral attributes were noted and were broadly divided into Passive and Avoidance activities. In over 42 hours of the data reviewed, there were only 20 potential contact interactions, of which 3 were Maybe classifications, 12 were juveniles, and 5 were adults. While only 11.5% of the video data were analyzed from Camera 2, these results are from the time when most fish were present over the turbine deployment period (from Alaska Department of Fish and Game data) and provide preliminary evidence that fish strike or collision of fish in the Kvichak River with an instream turbine is rare.

On only one occasion was an actual contact confirmed, and this was an adult fish that contacted the camera, not the turbine itself. This experience highlights the difficulties associated with confirming a strike or collision event as either having occurred or having been a near-miss. More interactions were

detected at night; this was probably biased by nighttime use of artificial light, which may have attracted fish, but also could have increased detection probability because the light is reflected from the fish itself.

For the algorithm development, background subtraction, optical flow, and Deep Learning techniques were considered. The Deep Learning approach was determined to need too much training data for this application, so its use was not continued. The optical flow analysis was considered promising, but did not give immediate results, so it needs further investigation. Therefore, background subtraction was the main focus in algorithm development. Three methods of background subtraction were tried: Robust Principal Components Analysis (RPCA), Gaussian Mixture Model (GMM), and Video Background Extraction (ViBE). A classification technique was then applied to the foreground images to determine fish presence. Using this combination, fish could be accurately identified when occupying a higher number of pixels (>200 pixels, 98.2% correct; 100–200 pixels, 99.6% correct; 5–100 pixels, 85.4% correct; 2–5 pixels, 66.3% correct).

In parallel, EyeSea was developed to convert the video data to a usable form and to enable manual and automated analysis of the data that would have a standardized output.

Recommendations for further research, and optimizing methods for enhancing data collection and analysis include the following:

- Research
  - Conduct more studies of the effect of lights on fish behavior.
  - Investigate the use of low light video applications as an alternative to using lights.
  - Further investigate optical flow techniques and their applicability for automated analysis.
  - Further refine the parameters for background subtraction in automated analysis.
- Standardized techniques
  - Include markings on the turbines to determine relative range and size of fish within the field of view.
  - Use a standardized (non-proprietary) video format that has a consistent frame rate of at least 25 frames per second.
  - Use a scientific camera designed for underwater measurement in low light environments that has a field of view appropriate for the observations and a pixel resolution high enough to determine fish within the given range.
  - Carefully consider the use of lights and how they illuminate the areas of interest.
  - Standardized and detailed record keeping and metadata collection
  - Use other monitoring technologies (e.g., strain sensors on turbine blades) to determine actual collision or strike events.

Acknowledgments

The authors thank the invaluable contribution of the Advisory Committee members who steered how the data were analyzed, and provided input for solutions: Nathan Johnson (Ocean Renewable Power Company), Steve Brunton (University of Washington), Gayle Zydlewski (University of Maine) and Andrea Copping (Pacific Northwest National Laboratory). PNNL also thanks the Ocean Renewable Power Company team in Alaska who provided information about the deployment, and Justin Priest and the team from LGL Alaska who provided information about the initial processing techniques.

PNNL also thanks the U.S. Department of Energy for funding this project and providing ongoing advice.

Acronyms and Abbreviations

DOE	U.S. Department of Energy
FY	fiscal year
GMM	Gaussian Mixture Model
MPC-HC	Media Player Classic-Home Cinema
MHK	marine and hydrokinetic
LGL	LGL Alaska
ORPC	Ocean Renewable Power Company
PNNL	Pacific Northwest National Laboratory
RPCA	Robust Principal Components Analysis
TRL	Technology Readiness Level
ViBE	Video Background Extraction

Glossary

Term	Definition
asynchronous architecture	A system that does not depend on strict arrival times of signals for operation.
avoidance	Used in all instances to encompass behaviors that showed some form of active change; no attempt was made to distinguish between avoidance and evasion.
background subtraction	A computer vision technique used to separate an image (or video frame) into background and foreground, where foreground means objects or regions of interest and is application-dependent.
bilateral filter	A non-linear, edge-preserving, and noise-reducing smoothing filter for images.
“blobs”	Groups of connected pixels of similar intensity.
canonical analysis	A method of regression analysis to determine relationships between a predictor variable and a criterion variable.
collision	When a fish swims into a static object.
compare/ comparison	Qualitative, nonstatistical assessment of the project video data.
contrast stretch	An image enhancement technique that improves the contrast in an image by increasing the range of intensity values.
Deep Learning	Application of learning tasks to artificial neural networks.
directed motion	Motion that demonstrated intended movement; used in this report to describe fish-like movement
EyeSea	A database-driven website for accessing video data files and analysis data.
Event	A place in time during manual video processing marked by a reviewer as having a fish-like object or fish in two or more frames
false positive	Detection of a fish by the algorithm when there was not a fish
Fish	An object that is deemed to be a fish during a manual analysis event
Fish Event	An event deemed to contain a fish during manual analysis
forward-stepping linear discriminant analysis	A method for finding a combination of features that characterizes two or more classes of objects.
histogram equalization	A technique for adjusting image intensities to enhance contrast.
July 22 Data	The full 24-hour manual analysis data of July 22, 2015.
Maybe	An object that during manual analysis is deemed to possibly be a fish, but not a definite identification.
Maybe Event	An event that during manual analysis is deemed to contain an object that could possibly be a fish
MySQL	An open-source relational database management system.
near-field	Relative term referring to an object or fish being relatively close the turbine within the video camera field of view.

neural network	A computer system based on how networks within biological brains work, which “learns”, i.e., improves its performance, by considering examples that have been labeled with key parameters.
Nighttime Data	Data from hours 00:00 – 06:00 and 23:00 – 00:00 from July 19, 23:00 to July 23, 03:00
OpenCV	Open Source Computer Vision Library
optical flow	An image processing technique used to compute motion of an object based on changes in the individual pixels in an image.
Rayleigh distribution	A continuous probability distribution characterized by a shape parameter used to model the magnitude of a multi-component vector.
strike	When a fish is hit by a moving part of the turbine
true negative	An object classified as non-fish by automated analysis that was deemed to be a non-fish by a human reviewer, or a frame classified by automated analysis as containing no fish that was not included in the frames containing fish noted by human analysts.

Contents

Figures

Tables

1.0 Introduction

The Triton initiative is a U.S. Department of Energy (DOE)-funded capability at the Pacific Northwest National Laboratory's (PNNL's) Marine Sciences Laboratory in Sequim, Washington. It aims to support DOE-funded projects that are developing technologies for measuring and monitoring the environment around marine energy devices through the mid- to high-level Technology Readiness Levels (TRLs). Ultimately, the initiative is intended to facilitate the permitting process and reduce the overall cost of marine renewable energy.

As part of the initiative, the Igiugig Fish Video Analysis project described herein used video data collected by LGL Alaska around an Ocean Renewable Power Company (ORPC) RivGen® device deployed in Alaska. The data on fish interactions around the operating device were made available to PNNL for further manual/human processing and use in developing automated processing software.

This final report summarizing the project tasks and results follows two previous reports: a data quality report (Trostle 2016) and a project progress report (Avila et al. 2016). The ensuing sections of this report briefly describe the project, the manual analysis of the video data, development of an automated algorithm for detecting fish presence in video frames, development of the software to enable data processing, and finally present conclusions and recommendations for future projects. Appendices A and B, respectively, contain manual annotations and the video data set used to develop the algorithm.

2.0 Description of Project

The ORPC RivGen® device (Figure 2.1) was deployed in the Kvichak River (Figure 2.2) from 19 to 25 July and 19 to 28 August in 2015. The device's two-turbine turbine generator unit (TGU) is supported by a chassis incorporating a pontoon support structure. The structure acts as a foundation when the device is deployed on the riverbed and gives it self-deployment and retrieval capabilities. The system is designed to generate reliable, renewable electricity in rivers near remote communities that have no access to large, centralized power grids.

Figure 2.1. Photograph of the ORPC RivGen® device.

Figure 2.2. Location of the RivGen® device near Igiugig, Alaska.

Five video cameras were attached to the ORPC RivGen® device to monitor fish upstream and downstream of the turbine foils. While the system was deployed, LGL Alaska (LGL) monitored the video for fish-turbine interactions, subsampling 10 minutes per hour (at the top of the hour) (LGL 2015). After the deployment was completed, the raw data, metadata, and a spreadsheet with processed events were released to PNNL for further analysis. Specifically, this was to develop automated algorithms that detected fish within the frames so that manual analysis could focus only on times when fish were present. To do this, manual analysis was required to annotate the video so that it could inform the algorithm development.

3.0 Manual Analysis

3.1 Methods

The development of tidal current and in-stream river current turbines as an industry is relatively new. It is in the early research and development stages that require testing to determine ideal technology and resource choices. The required technologies for monitoring fish interactions around turbine installations have the same early research stage limitations. This project used an underwater optical camera data set that captured numerous instances of fish and a turbine in the same field of view. Cameras and lights were manufactured by IAS systems. Cameras were customized SeeMate™ color to monochrome units with a F2.9 angle lens. Lights were SeeBrite™ omnidirectional model 24L-SS-LED-350. Power came from shore

and data were stored on digital video recorders. Manual processing of the data provided a baseline for software algorithm development as well as qualitative comparisons of fish behavior near the device.

3.1.1 Data Set

The data set comprised underwater video data from five cameras aligned on one side of the RivGen® device (Figure 3.1)—two upstream of the rotor and three downstream—recording 24 hours per day from 19–26 July and 19–28 August. Illumination from two artificial light sources was used between approximately 2300 and 0600 each night. PNNL received the raw video data (6,418 files; 368 hours), along with supplemental reports from LGL in December 2015. LGL had previously processed the first 10 minutes of certain hour blocks of the data, typically coincident with the turbine spinning; observed events were recorded in a spreadsheet that was provided to PNNL with the data set.

For PNNL, the first step was to determine whether the data quality was good enough for the proposed analysis. The research team needed to be able to visually observe fish presence, behavior, species, and any adverse impacts. In February 2016, the data quality was deemed satisfactory, but not suitable for species determination/identification. For additional information regarding the usability and overall quality of the video, see the Quality Check Summary Report (Trostle 2016).

In this study, “collision” refers to when a fish swims into a static object, and “strike” refers to a moving part hitting a fish.

During an Advisory Committee meeting (including participants from ORPC, PNNL, the University of Washington, and the University of Maine) held in March 2016, it was decided that the data set should be manually processed giving priority to nighttime segments (00:00 – 06:00 and 23:00 – 00:00) from July, for which previously subsampled data from LGL showed the highest frequency of fish interactions with the turbine. Additionally, camera 2 (Figure 3.1) was given priority because it showed the upstream view of the rotor. This meant that it:

- could show potential fish collision or strike interactions with the turbine,
- could show near-field avoidance behavior,
- had a sufficient light source, and
- could be used to coarsely estimate the size and distance of fish relative to the turbine and supporting structures.

As data processing progressed, team members realized that full manual analysis of both July and August nighttime video data would be excessively time-consuming. For every 1 hour of raw video data, it took reviewers approximately 13 to 15 hours to manually review and annotate the video. Due to the amount of time it took for manual review, only part of the July Nighttime Data (July 19, 20, 21, and some of July 23), all of the July 22 Data, none of the August data, and the data required for the test bed development were reviewed (see Section 4.1). Of 18 days of video data recorded by LGL, PNNL was able to review 1 full day, 3 nighttime segments, 4 half-hour blocks on July 23, and 16 five-minute sections for the test bed—a total of 42.33 hours. The PNNL team decided to concentrate on particular subsets of data that would allow for meaningful comparisons. Statistical analysis was not performed on any of the manual review data because of the relatively short period analyzed. Therefore, all uses of the term compare/comparison regarding manual processing for this report refer to qualitative, non-statistical assessment of the data. These comparisons have been grouped into four categories:

- <u>July 22 Data</u>: A full day, July 22 (hereafter referred to as July 22 Data), was analyzed because it was important to include a full day inclusive of daytime data for preliminary comparisons of the first 10 minutes of each hour to the full 60 minutes of each hour. This also allowed for diel differences to be qualitatively compared.

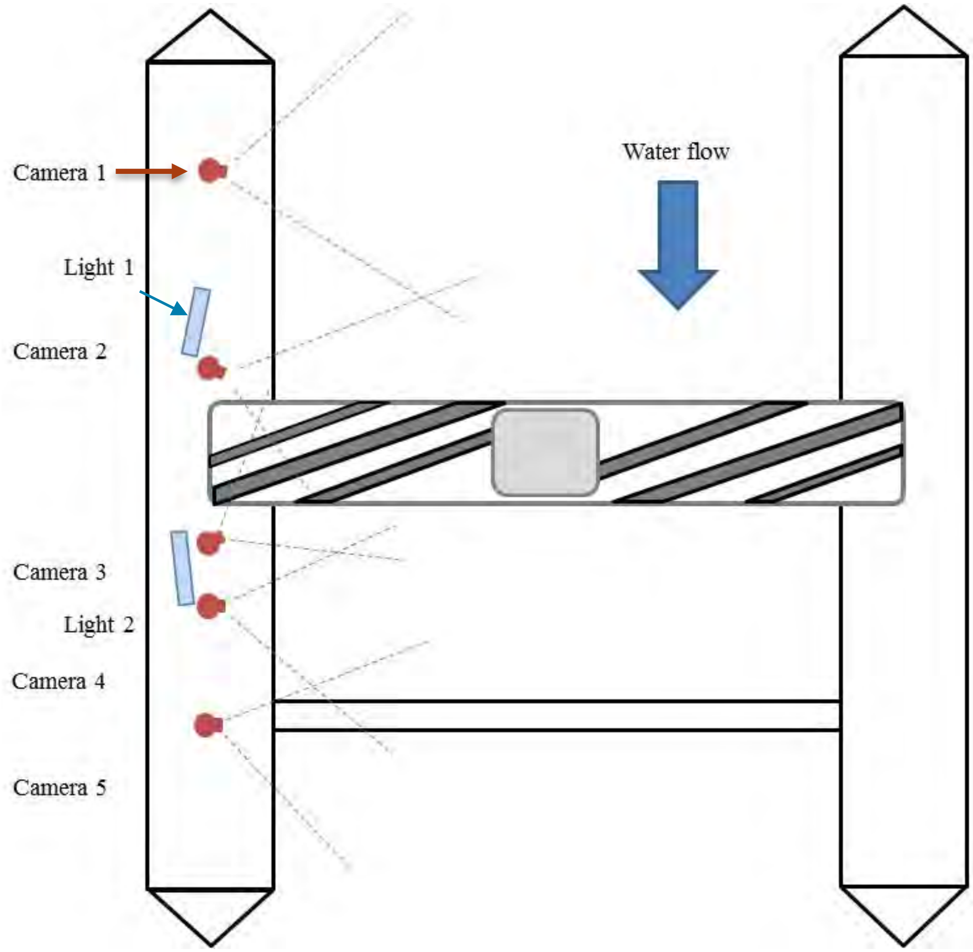


Figure 3.1. Schematic showing approximate locations and views of cameras by number on the RivGen® device.

Lights are represented by blue rectangles. (Not to scale. The pontoon structure is 19.8 m long, 11.5 m wide and 1.7 m high. The turbine [TGU] is 10.4 m long, 1.5 m wide, and 1.5 m high.) (Figure courtesy of LGL and ORPC.)

- Nighttime Data: Nighttime only (00:00 – 06:00 and 23:00 – 00:00) data from July 19, 23:00 to July 23, 03:00 (hereafter referred to as Nighttime Data) were processed as mentioned in the bulleted paragraph. The data from July 23 Nighttime Data consist of only the first half-hour of each hour block (e.g., 01:00 to 01:30). These data represent the majority of the processing effort for this study. The first night (July 19) of data collection had technical issues with the lighting system and data were collected without a light source.
- Light Effects Data: The hour block from 23:00 – 00:00 for July 19–22 were processed with varying artificial light operations to gain a preliminary understanding of any effect lights may have on fish detection probability and fish behavior.
- Collision/Strike Data: Events with fish interactions where possible collision or strike occurred were separated into a small subset and further analyzed. Reviewers observed a total of 20 events that had possible collision or strike interactions. These events were separated for further comparisons.

3.1.2 Manual Processing

The data were provided in a proprietary format that was difficult to manipulate for the proposed processing and analysis procedures. Data files were changed to .mp4 format for ease of use with minimal

change in data quality. Two reviewers worked together to establish processing protocols and definitions for parameters annotated for each event. A subsample of data was processed by each reviewer and compared for similarity to ensure data processing would be consistent and accurate throughout the analysis.

The reviewers visually processed the data in half-hour blocks using Media Player Classic-Home Cinema (MPC-HC). Reviewer 1 processed the first half-hour and Reviewer 2 the second half-hour. Whenever a reviewer visually assessed a fish or an object that had characteristics different from the surrounding water column debris (i.e., shiny and/or non-passive movement) that was present in the field of view for more than one frame, it was deemed an event. For each event, the numerical annotation method explained in the *Igiugig Video Analysis – FY16 Progress Report* (Avila et al. 2016) was used to describe the event characterizations. Parameters for these characterizations are described in Appendix A. Manual review did not distinguish between the terms “avoid” and “evade” throughout this report. Because the reviewers were unaware of the exact distance of the objects from the turbine, and because they did not use the behavioral responses of the objects and fish to decide between the two terms, “avoid” was used in all instances to describe behaviors that showed some form of active change assumed to be related to the turbine. Important classification annotations referenced throughout this report are whether or not an event was a Fish Event or a Maybe Event. A Fish Event meant that the reviewer was positive the object was a fish, whereas a Maybe Event meant the reviewer was not sure (hereafter referred to as Fish or Maybe Events, respectively). The designations between these two annotation descriptions are important for comparison and analysis purposes, as well as for informing the algorithm development.

Objects that were not definitively defined as fish were still deemed events and recorded as Maybe Events. It was important to include these for two reasons. First, video quality could possibly affect the reviewer’s determination of whether or not an event contained a fish, and erring on the side of capturing all events with some false positives was preferable to missing some Fish Events. Second, software and automated algorithm development was a major objective of this research. Objects often had characteristics similar to fish and could be identified as events by the automated algorithms. This again allows more confidence in capturing all Fish Events at the cost of some additional false positives.

To keep the reviewers calibrated during review, both started with a training period to go over the parameters and define characterizations. They separately reviewed the same video and compared results for 2–3 weeks, addressing any discrepancies in annotations. As the reviewers began processing the data individually, they kept in regular contact, went over interesting or questionable interactions, reviewed each other’s annotations, and discussed methods to ensure calibration at bi-weekly meetings.

Even with these checks, during analysis, an inconsistency was discovered between reviewers. While both reviewers saw a similar number of events, meaning they were stopping for the same objects, the distinction between calling an object a Fish Event or Maybe Event did not always correspond. This meant that some of the objects one reviewer deemed as a Fish, the other reviewer deemed as a Maybe fish.

Comparisons were made using the July 22 Data to show any similarities that exist in event occurrence and fish count estimates between processing of the first 10 minutes per hour, and processing of the full hour. Additionally, figures for visualization were also made to display

- differences between definite Fish Events and objects with non-passive behavior,
- fish count differences between day and night, and
- fish count differences between when the device was spinning and static.

For the Nighttime Data, the behavior types that are associated with different categories of events were compared. This categorization of events was based on the Appendix A annotation, “Fish?”. This annotation was simply a question to the reviewer about whether the object observed during a designated event was definitely a Fish or a Maybe. Initially, All Events that included Fish and Maybe Events were considered. Categories separated All Events into Fish and Maybe Events. Fish Events were further

categorized by annotations from Appendix A designating the fish as juvenile (likely a salmon smolt), adult (likely a salmon), or unidentifiable as determined by the reviewer. The category separation flow chart is shown in Figure 3.2. After behavior types were attributed to the categories of events by percentage (Figures 3.4–3.10), behavior types were coarsely grouped. Each of the behavior types the reviewers used for the annotation description was designated as either Avoidance, Passive, or Other (Table 2).

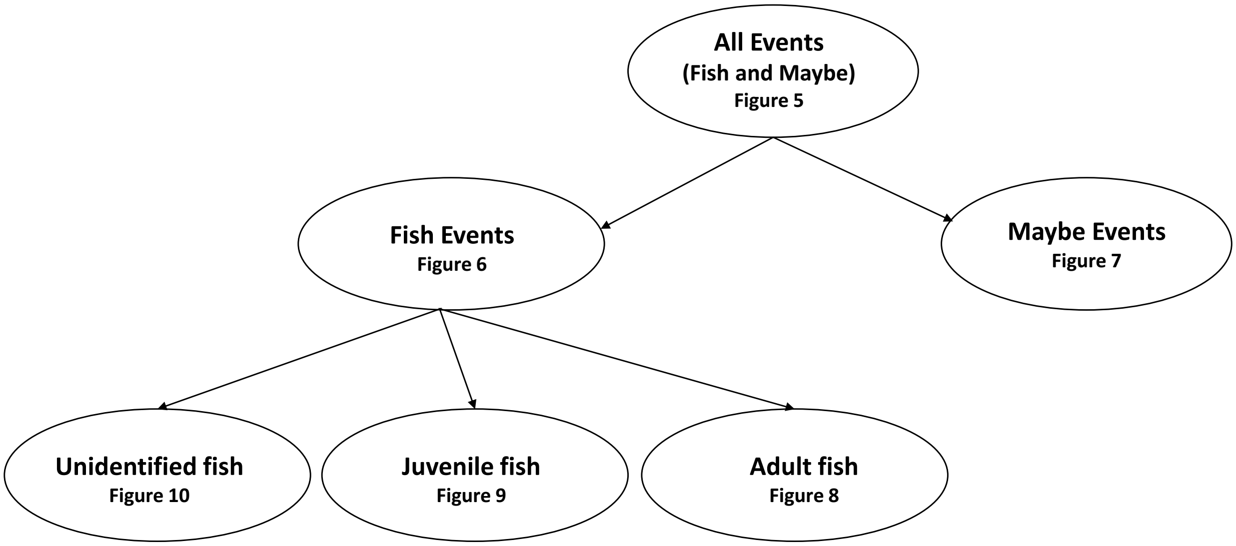


Figure 3.2. Flow chart showing the different categories of events used to visualize behavior types (Figures 3.4–3.9) attributed by data processing reviewers. All events that had potential fish collision or strike were placed in a separate subset (3.10).

Table 3.1. Grouping of annotated behavior types into Avoidance, Passive, and Other.

Avoidance	Passive	Other
Milling	Straight across (above or below)	Unable to tell
Pause	Through turbine	Other
Against current	Toward static parts	
Avoid reverse	Face first	
Avoid below		
Avoid above		
Avoid around		

A simple comparison of the Lights Effects Data was to determine whether more events were observed when the lights were on or off during varied light operations from July 19–22. This was possible because on July 19 the lights were off due to technical difficulties. The lights were turned on the next day and they were used for the remainder of Nighttime Data collection.

The last subset of data comparisons were the events when fish collision or strike may have occurred in the Nighttime Data. This data set includes only events that were positively determined by both data reviewers to be Fish and excludes the Maybe Events; hence, there is no disparity between reviewer determinations.

3.2 Results

Currently, no established video data analysis techniques exist for assessing fish interactions. Using the above methods, qualitative comparisons were made with the data set to highlight differences in 1) subsampling of the first 10 minutes of each hour and the entire hour; 2) nighttime behavior types; 3) possible collision and strike events; and 4) the effects of nighttime illumination. The data were further summarized between whether an object was a Fish or Maybe Event, and the categorical groupings associated with the observed behaviors.

3.2.1 Fish Presence/Behavior

3.2.1.1 July 22 Data Subsampling Comparisons

For the July 22 subset of data there were 2,538 events: 260 were Fish Events, 2,256 were Maybe Events, and 22 Events were a combination of Fish and Maybe occurrences. The majority (81%) of events occurred during nighttime hours. Only one Fish Event occurred during daytime—in hour 19 in the processed data. Fish abundance or frequency of events does not appear to be related to whether the turbine was spinning (hours 1–2) or static (hours 3–6), but does seem to coincide with low light levels (hours 1–6 and hour 24). To compare the 10-minute sampling regime with full analysis, the 10-minute counts were multiplied by six to produce an hour estimate. This assumes that the first 10 minutes is representative of the subsequent five 10-minute blocks. The comparison between these processing methods shows that when the first 10 minutes is subsampled and multiplied by 6 to approximate an hourly estimate the numbers are inflated for hours 3–6. Hour 1 is underestimated, for hour 2 the estimates are similar, and hours 3–6 are over-estimated for both the number of Fish and number of events (Figure 3.3).

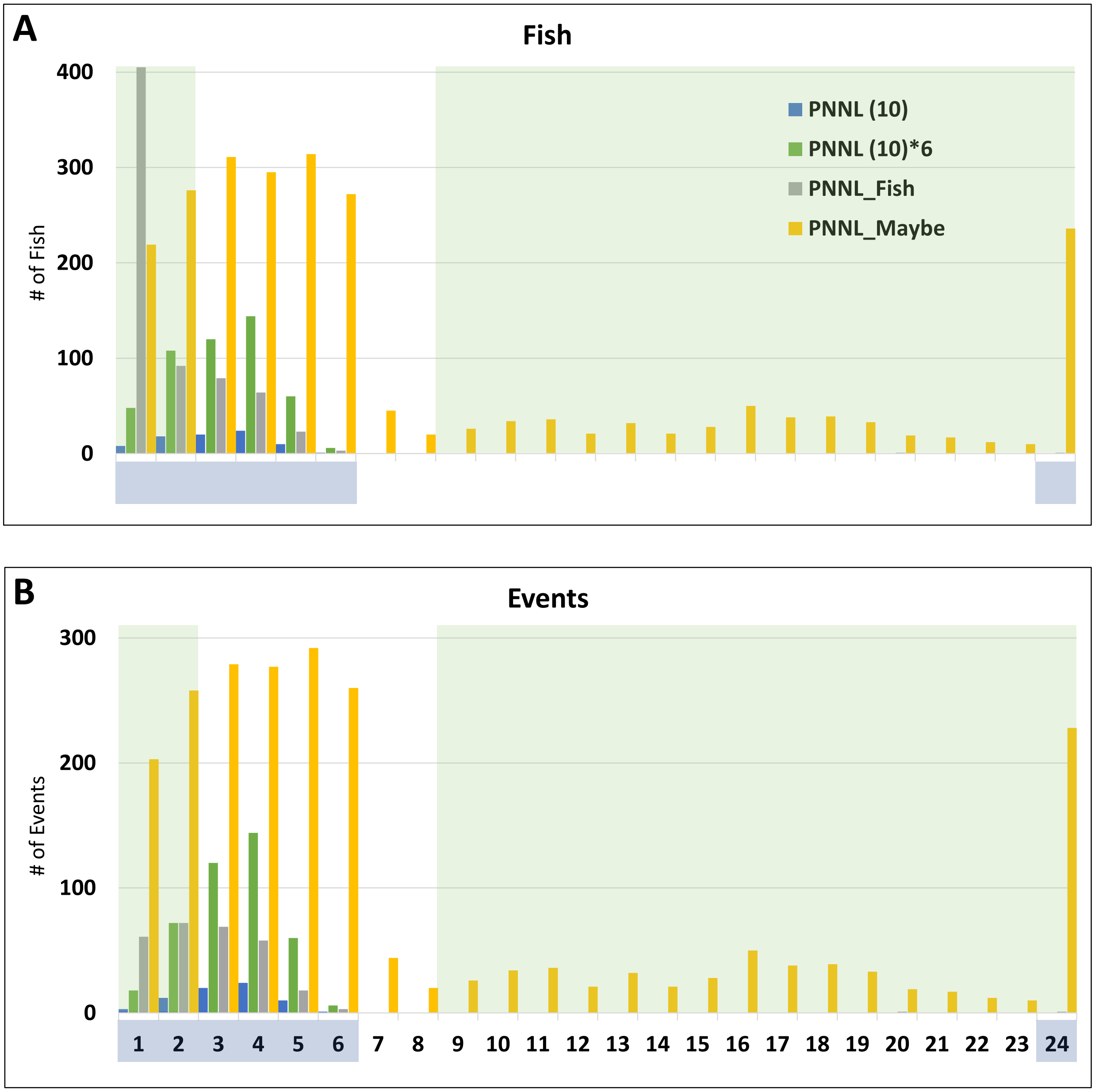


Figure 3.3. Bar graphs showing processed data for July 22, 2015.
*The horizontal axis represents each hour block for both graphs and the dark shaded numbers represent hour blocks that are after sunset and before sunrise (Nighttime Data). The green shaded background of the plot areas show when the RivGen® was spinning. Graph A displays Fish and Maybe counts as observed during manual processing by hour blocks. Graph B displays the number of events. The blue bar, "PNNL (10)", represents the estimates from PNNL's processing of the first 10 minutes of each hour. The orange bar, "PNNL (10)*6", represents PNNL's estimate multiplied by 6 to be an approximation for the full hour. The gray bar, "PNNL_Fish", represents PNNL's count of "Fish" for Graph A or "events" for Graph B for the full hour. The yellow bar, "PNNL_Maybe", represents the count of objects (Graph A) or events (Graph B) with non-passive behavior but not determined to be fish.*

3.2.1.2 Nighttime Data Behavior Types

Other than processing the July 22 Data, PNNL only processed Nighttime Data. For the category that includes both Fish and Maybe Events, there were 629 Fish Events, 4,149 Maybe Events, and 51

combination events that included both Fish and Maybe occurrences. Each event was broken down into the described behavior specific to the annotation list found in Appendix A. Grouping all of these described behaviors by annotation behavior type (e.g., avoid around, avoid above—see Appendix A) provides some evidence of what the dominant behaviors are within the camera field of view in front of the RivGen® during nighttime hours. The dominant behavior for Fish and Maybe Events was "through turbine", followed by "straight across", followed by "toward static parts" (Figure 3.4). Note that this comparison is not separated by Fish or Maybe Events or any other qualifier, and the Passive behavior group dominates with 80% of the behavior, compared to ~19% for the Avoidance group.

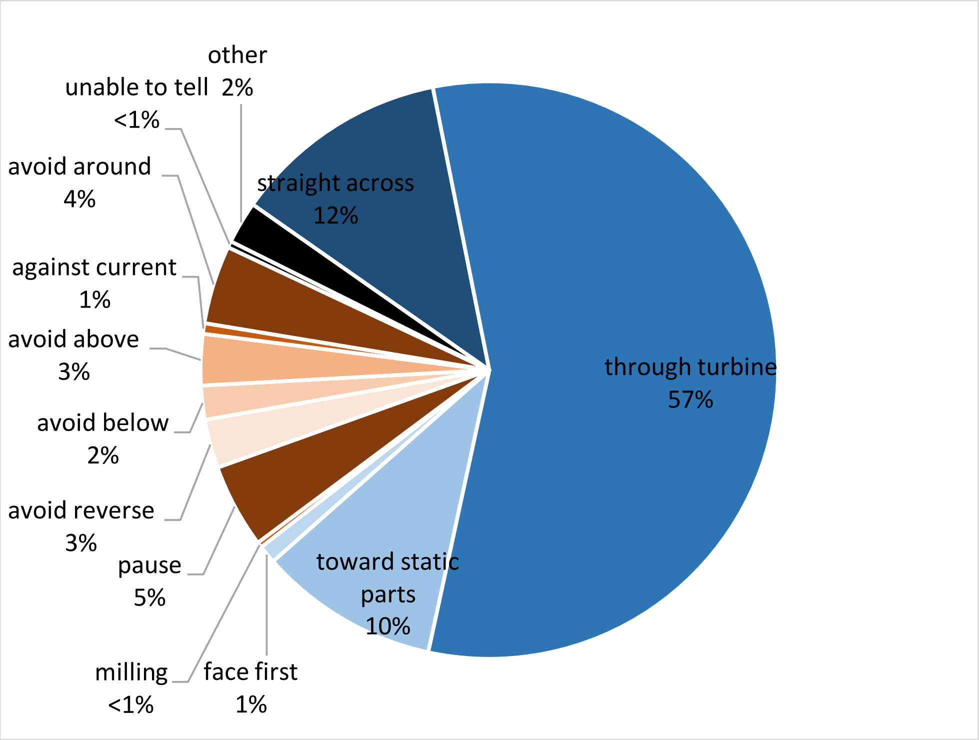


Figure 3.4. Behavior types recorded by reviewers for Nighttime Data. Data included are both Fish and Maybe Events for all sizes; n = 4,829.

The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

The Nighttime Data were separated into Fish and Maybe Events to visualize how reviewer-described behaviors may be different for each. Combination events (n = 51) that had both Fish and Maybe Events were removed because it was impossible to separate behavior annotations associated with a Fish object or a Maybe object during the event. For Fish Events the top three dominant behaviors were "through turbine", "avoid around", and "pause" (Figure 3.5), and for Maybe Events the top three behaviors were "through turbine", "straight across", and "into static parts" (Figure 3.6). There is a distinct qualitative difference in behavior types (Avoidance vs. Passive) between the Fish Events and Maybe Events. Figure 3.5 shows Fish Events dominated by the Avoidance group of behaviors (62%) and Figure 3.6 shows Maybe Events dominated by the Passive group of behaviors (80%). This abundance of passive behaviors is expected, because one of the qualifiers when distinguishing between Fish and Maybe Events was how the objects moved. It is important to note that there was some disparity between what the two reviewers designated as a Fish or Maybe Event as described in "Manual Processing."

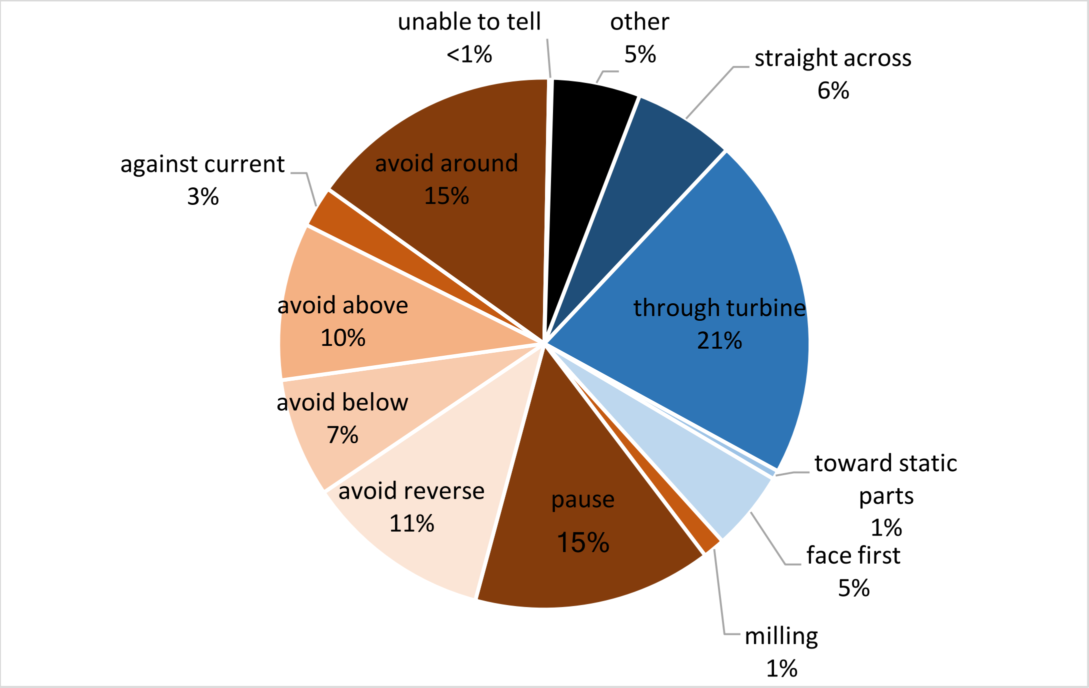


Figure 3.5. Behavior types recorded by reviewers for Fish Events in Nighttime Data for all sizes (n = 618).

Maybe and Combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

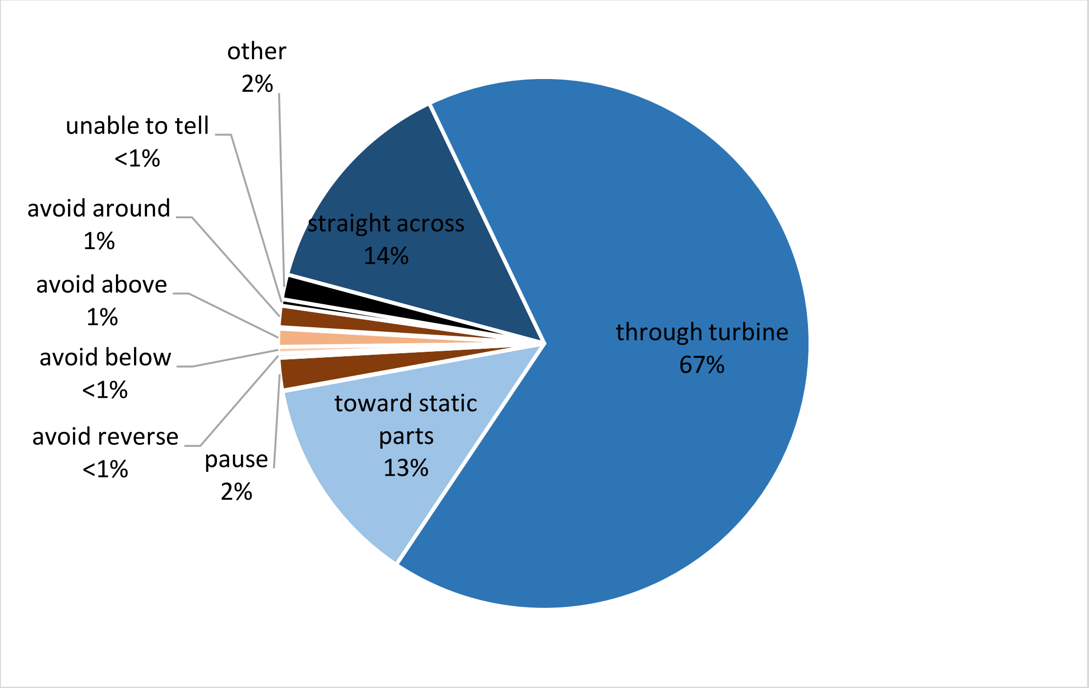


Figure 3.6. Behavior types recorded by reviewers for Maybe Events in Nighttime Data for all sizes (n = 4,149).

Fish and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

Within the Fish Events category, a separation was made to categorize juvenile, adult, and unidentifiable fish. Eleven Fish Events had a combination of adult, juvenile, or unidentifiable Fish Events that were removed from these comparisons. There were 174 adult Fish Events for which the dominant behaviors were "pause", "avoid around", and "avoid reverse" (Figure 3.7). There were 259 juvenile Fish Events, for which the dominant behaviors were "through turbine", "avoid around", and "pause" (Figure 3.8). Determining whether it was an adult or juvenile was sometimes impossible. This created the category of an unidentified Fish Event of which there were 185. The dominant behavior was "through turbine", "avoid around", and "pause" (Figure 3.9). Adult fish displayed Avoidance behavior 82% of the time compared to only 14% passive behavior. The behavior groups for juveniles were split, showing 50% Avoidance behaviors and 44% Passive behaviors. And the fish that were unidentifiable demonstrated dominant Avoidance behavior 57% of the time and Passive behavior 36% of the time.

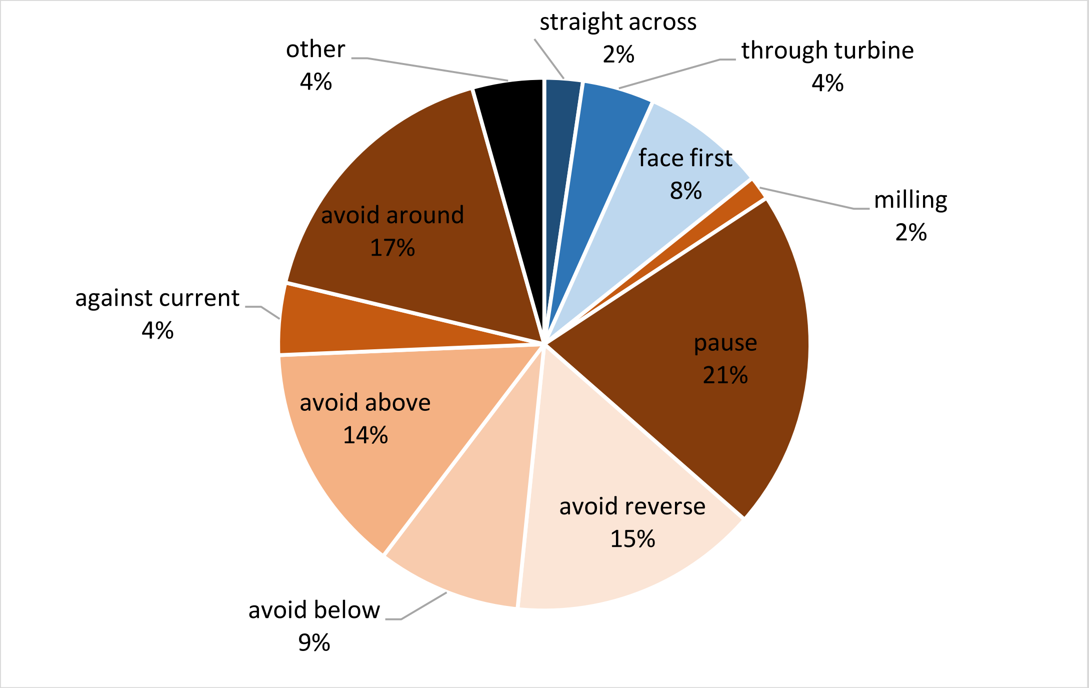


Figure 3.7. Behavior types recorded by reviewers for adult Fish Events in Nighttime Data (n = 174). *Juvenile and unidentified Fish Events, Maybe Events, and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.*

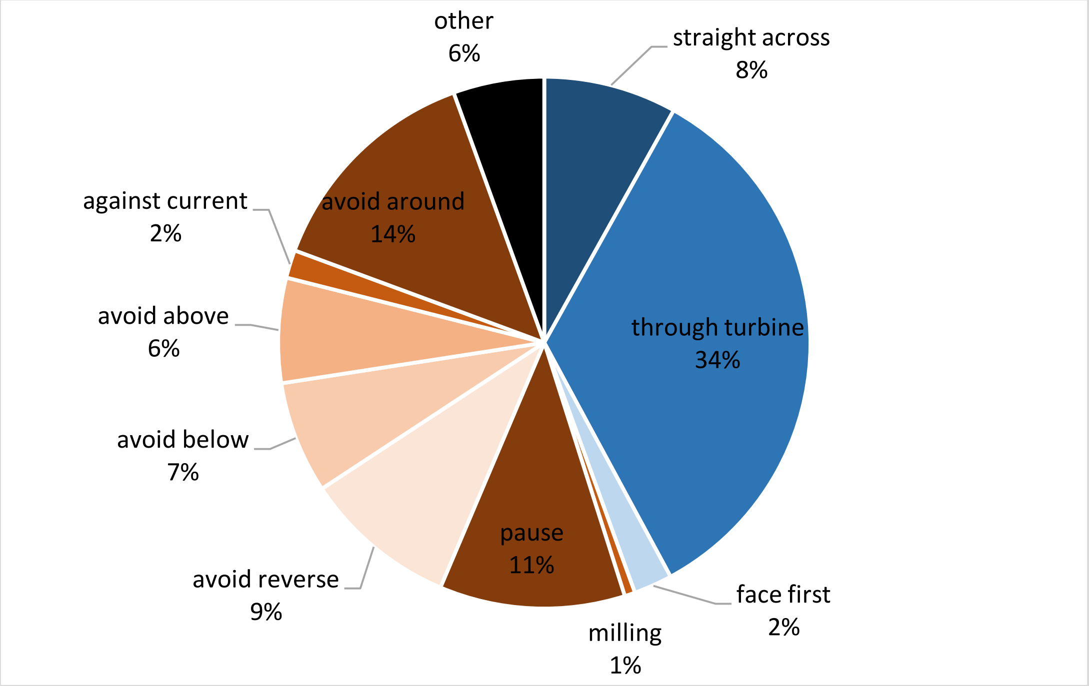


Figure 3.8. Behavior types recorded by reviewers for juvenile Fish Events in Nighttime Data. (n = 259).

Adult and unidentified Fish Events, Maybe Events, and combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

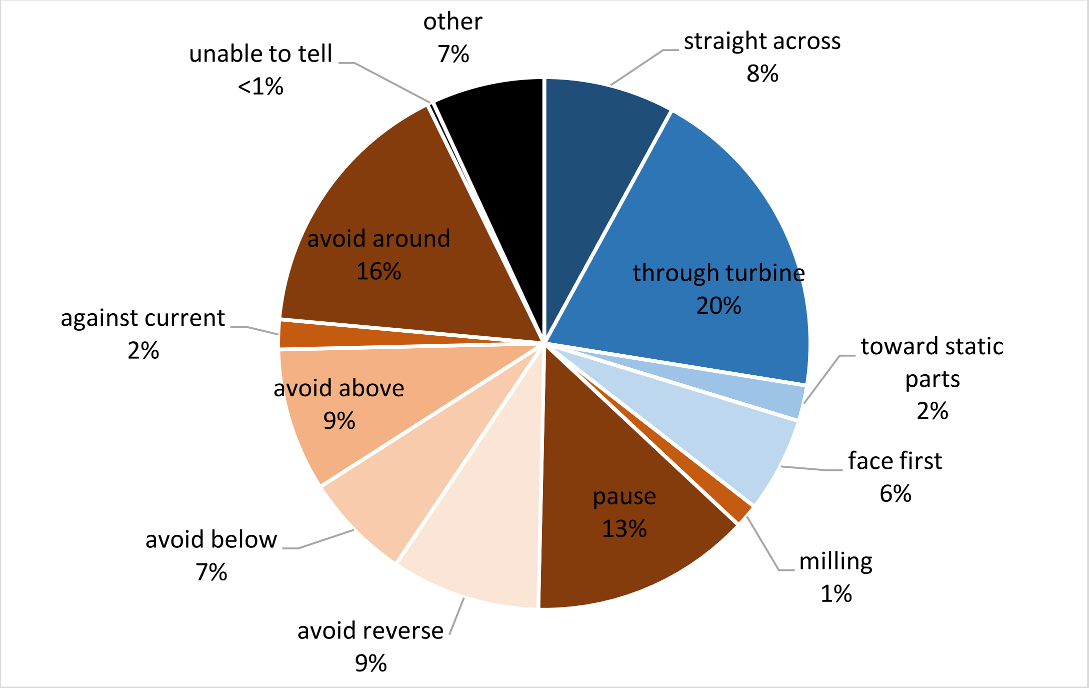


Figure 3.9. Behavior types recorded by reviewers for unidentified Fish Events in Nighttime Data (n = 185).

3.2.1.3 Fish Collision and Strike

Reviewers found a total of 20 events involving possible collision or strike (12 strike and 8 collision). All strike events in this data set refer to moving parts of the turbine hitting an object or fish, while collision refers to an object or fish coming into contact with a static part of the device (this could include the blade when it is not turning). Of these 20 potential events, 17 were Fish Events and 3 were Maybe Events. Of the 17 Fish Events, juveniles made up 12 of the events and adults made up 5 events. All but one of the juvenile Fish Events had multiple fish in the field of view, up to ~50. All of the adult events were single fish. All juvenile Fish Events occurred between 00:00 and 01:00, except two which occurred at 01:03 and 03:02. The turbine was spinning for all but one of the juvenile Fish Events and none of the adult Fish Events. Juveniles made up 11 of the strike events, while the remaining strike occurrence was a Maybe Event. No adults were involved in any of the strike events. Of the 8 collision events, adults made up 5, a single juvenile made up 1, and the rest were Maybe Events. The one juvenile collision and 4 of the 5 adult collision events occurred with a static blade. The last adult collision occurred with the camera and was the only confirmed collision. Behavior for these events was dominated by Avoidance group behaviors "through turbine", "avoid around", and "pause" (Figure 3.10).

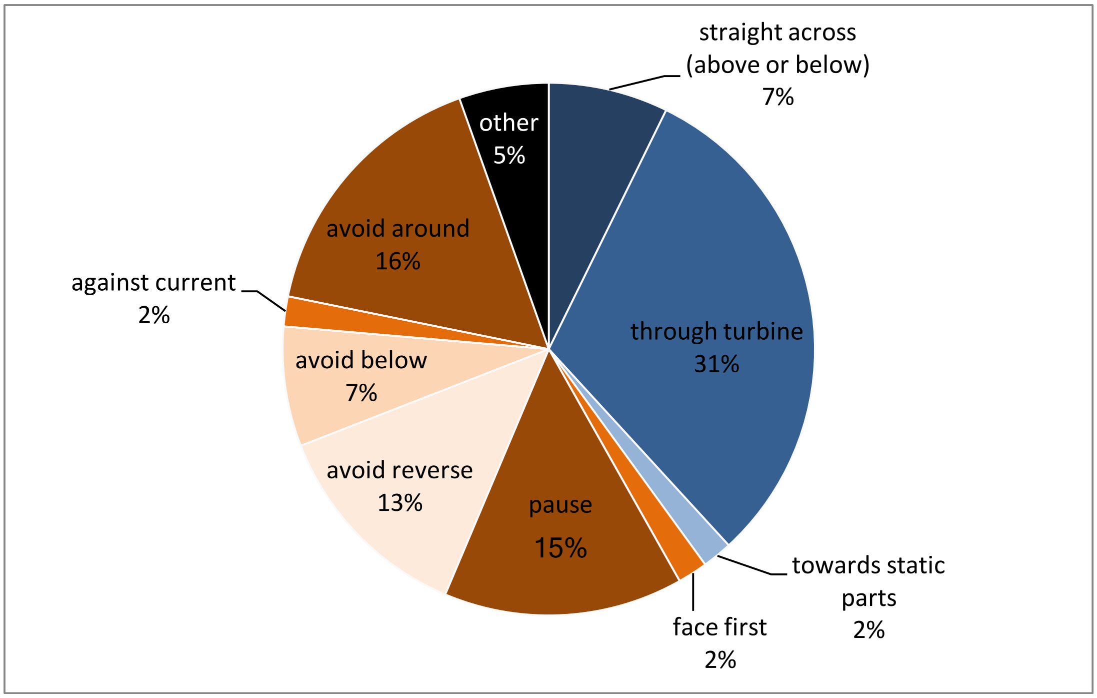


Figure 3.10. Behavior types recorded by reviewers for potential collision or strike Fish Events in Nighttime Data (n = 17).

The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

3.2.1.4 Light Effects

On July 19, the lights remained off through the night, while on every other night the lights turned on as it became dark. A light operations record was not kept during deployment, so manual reviewers at PNNL watched the video and estimated the operational status of the lights (Figure 3.11). Events observed over four nights during hour block 23 (23:00–00:00) when light operations varied were compared to show fish presence while the lights were on and off (Table 3.2). Over the four-night comparison of hour block 23 (a total of 4 hours), the lights were off 45% and on 55% of the total time.

Only 5 events were recorded by the reviewers on July 19 when the lights remained off the entire hour. All 5 events on July 19 occurred in the first 9 minutes of the hour block, and they were all Maybe Events. On July 20, 1 Maybe Event occurred while the lights were off during the first 34 minutes of hour block 23, and 144 events (1 Fish Event, 143 Maybe Events) occurred while the lights were on in the last 26 minutes of hour block 23. On July 21, 2 Maybe Events occurred while the lights were off during the first 14 minutes of hour block 23, and 65 events (2 Fish Events, 63 Maybe Events) occurred while the lights were on during the last 46 minutes of hour block 23. On July 22, 135 Maybe Events were recorded by reviewers when the lights remained on during hour block 23. Over the four-night comparison, approximately 2% of the total events occurred while the lights were off, and 98% occurred while the lights were on.

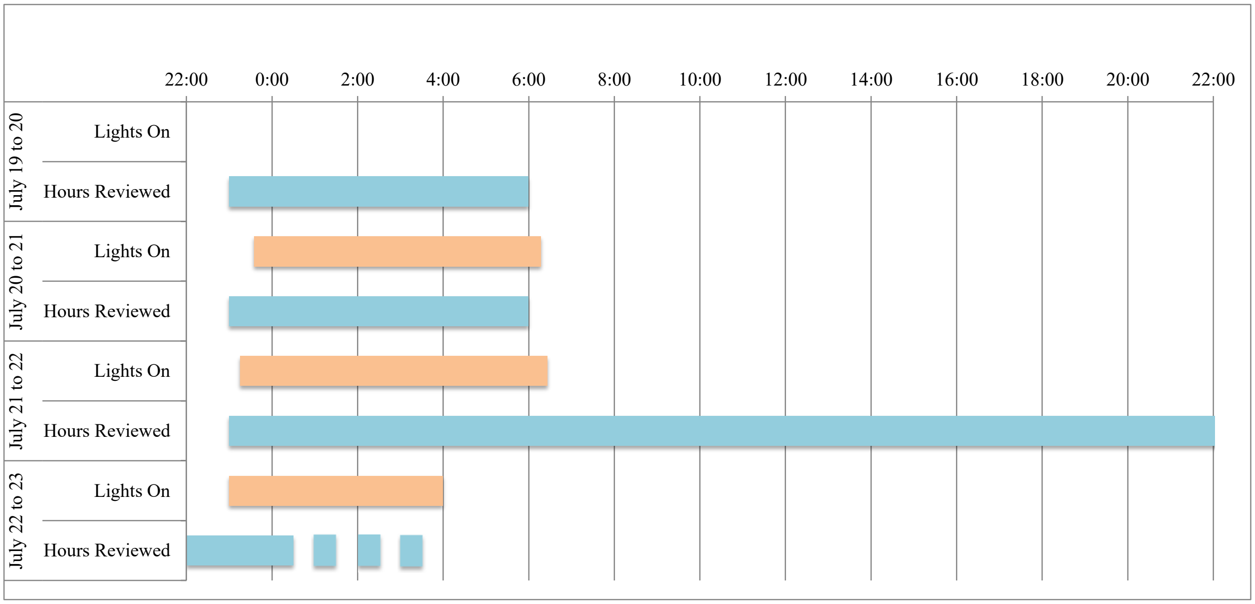


Figure 3.11. Visual approximation of light operations determined by watching the video data and noting when the turbine and objects began to look brighter (lights on), or when the turbine and objects began to look darker (lights off).

Although a light operations record was not kept, PNNL staff watched the video data to estimate when the lights came on and turned off. The orange bars represent the duration of time the lights were estimated to be on, while the blue bars represent the duration of time manually reviewed by the two reviewers. The x-axis on Figure 3.11 shows a total range of 24 hours, from hour 22:00 on one day and up to hour 22:00 of the next day. This was done to show the light operations and review effort in a more continuous manner. The major y-axis labels list the dates reviewed with minor label divisions of when the lights were on and the hours reviewed on those dates. From the night of July 19 to the morning of July 20, the lights remained off, and the reviewers manually processed video data from 23:00–06:00, although only part of hour blocks 23 and 5 were visible. From the night of July 20 to the morning of July 21, the lights were estimated to be on from 23:35–06:17 and the reviewers manually processed video data from 23:00–06:00. From the night of July 21 to the morning of July 22, the lights were estimated to be on from 23:15–06:26 and the reviewers manually processed video data from 23:00–22:00. From the night of July 22 to the morning of July 23, the reviewers manually processed video data from 23:00–00:30, 01:00–01:30, 02:00–02:30, and 03:00–03:30. The lights were estimated to turn on at 23:00 and remained on during all of the manual review effort on July 23, but an estimation of when the lights turned off that day was not done.

Table 3.2. Comparison of the number of events recorded by reviewers during hour block 23 (23:00–00:00) over four nights when the lights were on and off, including the duration of light operation status and totals.

Hour Block 23	Lights Off		Lights On		Total
Date	Duration	Number of Events	Duration	Number of Events	Number of Events
7/19/2015	60 minutes	5	0 minutes	No data	5
7/20/2015	34 minutes	1	26 minutes	144	145
7/21/2015	14 minutes	2	46 minutes	65	67
7/22/2015	0 minutes	No data	60 minutes	135	135
Total	108 minutes	8	132 minutes	344	352

3.3 Discussion

Perceived risk and shortage of empirical data about fish interactions with tidal and in-stream turbines like ORPC's RivGen® means that monitoring is required during turbine deployment. For near-field interactions, optical cameras are the ideal choice because acoustic devices are limited at such close ranges because of transmitted sound scattering from the turbine blades. For this research, the use of cameras provided a useful data set that allowed the capture of hundreds of fish interactions with an operational commercial-scale device. These interactions included 17 possible collisions with static components and possible strike with dynamic components of the device. These 17 events accounted for 2.75% of all Nighttime Fish Events and 0.07 % of total hours processed. Only through intense manual processing effort was it possible to find the extremely rare events of collisions and possible strikes that were observed. These processed data also allowed comparison of a complete manually processed data set to the same subsampled processed data set. Of the 17 possible collision or strike events, only 1 was in the first 10 minutes of the hour. This means that 16 of the events would have been missed, pointing to the importance of full data set processing to ensure these rare events are observed. While strike and collision are of major concern, the behaviors used by fish as they approach these devices are important for continued research and to determine the need for monitoring around turbines. The types of behavior provide input parameters to models as well as identifying differences that may exist between different species or age classes of fish.

The previous analysis by LGL primarily processed data to coincide with times that the RivGen® device was spinning, which was typically during daylight hours. The PNNL research team concentrated on nighttime because 66% of all fish observed by LGL were observed during nighttime even though this time composed less than 10% of their total processed data.

3.3.1.1 July 22 Data Subsampling Comparisons

PNNL processed the first 10 minutes of each hour, illustrating the difference between subsampling and full analysis. Processing sub sets of data is common for researchers faced with the daunting task of large data sets, and it is considered a valid way to process large amounts of data. In this instance, when subsampled data [(10)*6] were compared to the fully processed (all 60 minutes of each hour) 24 hours of data on July 22, the number of Fish Events per hour was the same for hour 2, less for hour 1, and more for hours 3, 4, 5, and 6 (Figure 3.3B). While there was some discrepancy between the two, a larger sample size for comparison would be required for validation. The number of fish (counts) had similar results with the (10)*6 estimates being larger than the actual 60-minute counts for hours 2–6 (Figure 3.3A). Counts be skewed if large schools of fish are present. The first hour block in the July 22 fish count data (Figure 3.3A) is a good example of this; the full hour count data are more than four times the (10)*6 estimate. This was simply a case of several schooling Fish Event occurrences that were made up of tens of juvenile fish observed from minute 10 to 60. Subsampling may provide a valid estimate of Fish Events but fish counts may be biased low if events with large schools of fish are missed.

Having the entirety of the July 22 video processed provided evidence that the majority of Fish Events occur during nighttime. For this single day, it also indicated that the number of Fish Events did not dramatically increase or decrease based on whether the turbine was static or spinning. For the total data manually reviewed by PNNL, the turbine was spinning for 44% of the time, and not spinning for 56% of the time. After the RivGen® spinning ceased (typically around 01:00), the number of Fish Events decreased from then until 06:00. The occurrence of Fish Events is more likely to be related to light levels because Fish Events decrease temporally as sunrise approaches. If the driver for frequency of Fish Events is light levels, then use of artificial lighting to increase detection probability at night introduces a possible complication.

3.3.1.2 Nighttime Data Behavior Types

Describing the behavior of Fish and Maybe Events captured from a single camera is subjective for most of the descriptions (see Appendix A). While an observed movement upstream or downstream is definitive in nature, movement toward or away from the camera or attempting to use depth of field to describe an event is difficult and accuracy is impossible. Nevertheless, behavior was described for all Fish and Maybe Events during PNNL processing of the data. An extensive list of behavior types that described in detail the majority of observed fish behavior was used. Additionally, specific behaviors were qualified as being Avoidance or Passive behaviors (Table 3.1). For the manually processed data set, the extent to which behavior is addressed for each processed event is important to understand fish behavior in general as well as differences between behaviors of fish based on their size or age class.

The binary grouping of all specific behaviors into Avoidance and Passive behavior groups provided evidence of two important findings:

- First, the amounts of Avoidance and Passive behavior differ between Maybe and Fish Events. During the PNNL processing, both reviewers agreed that movement or behavior of the object during an event had a strong bearing on whether or not it was deemed to be a Maybe or Fish Event. More movement, especially those representing non-passive examples, typically led to classification as a Fish Event. The Avoidance group of behaviors is therefore important for separating Fish Events from Maybe Events. However, not all fish entering the field of view will necessarily change their behavior before exiting. Fish already in line to avoid the turbine may not change their trajectory and thus fall under one of the Passive group's behaviors.
- Second, the amount of Avoidance/Passive behavior differs between adult and juvenile Fish Events. Fish Events that consisted of adult fish had only 17% Passive behavior and of this amount only 4% were specifically "through turbine" (Figure 3.7). In contrast, juvenile Fish Events had a 50/50 split between Avoidance and Passive behavior and 34% of the Passive behavior was "through turbine". This comparison shows evidence that adult fish are better at avoiding the turbine than juvenile fish. Although juvenile fish behavior may consist of Avoidance behaviors, the juveniles tended to be less successful in actually avoiding the device and often went "through the turbine" even after attempting an Avoidance behavior.

Behavior types or groups may play an important role in algorithm development in the future. A variety of qualifiers are used in algorithm development, and behavior or movement is an important one for animal detection algorithms used with remote sensing devices and specifically optical cameras. Often, threshold metrics are used for initial investigations into automating an animal being in a frame. However, if this is successful and a variety of animal types have potential for being detected, then the next step is grouping them by some qualifying characteristic. Often size is the first characteristic for grouping followed by movement or behavior. Knowing the movements and behavior associated with the fish detected in these data has the potential to further general knowledge or inputs for modeling. Improved automated analysis to decrease the effort required to process and analyze these types of data and ultimately create cost-

effective methods. Use of these methods by developers and researchers can provide meaningful data accepted by regulatory bodies that require monitoring.

3.3.1.3 Fish Collision and Strike

As fish collision, strike, and near-miss events are generally accepted to be rare at marine and hydrokinetic (MHK) installations, it is important to process most, if not all, of the data collected to ensure these events are not missed. If an entire data set is not to be processed, then large-scale time blocks likely to coincide with the highest probability event occurrences, decided upon with expert opinion or existing empirical data and statistical analysis, should be processed. The sequence of the processing steps used for camera data set described herein is a good example of efficient gathering of useful information. The initial subset processing performed by LGL for the first 10 minutes of certain hour blocks made it clear that most Fish Events occurred during nighttime. This is a highly productive first step for a large data set for which no established processing methods exist, except for manually reviewing the data. As a logical first step, it saved time and provided the foundation for taking the next step to gather meaningful results. PNNL followed up and concentrated processing effort on nighttime hour blocks based on the LGL information that indicated more events occurred at night. This concentration on the Nighttime Data provided more meaningful comparisons of a variety of fish behaviors showing differences in adult and juvenile behaviors. The processed data also captured 17 events, out of a total of 618 Fish Events, with possible collision and strike between fish and a commercial-scale device, indicating how rare these events are and the difficulty associated with observing them. Even with capturing the events with possible collision or strike, actual contact is difficult to verify because uncertainty remains based mostly on the data quality specific to camera selection, lighting, placement, and field of view. Collision was only confirmed in one instance when an adult fish collided with the camera. Additionally, it is important to note that the outcome of a collision, strike, or near-miss event was not possible to determine because of data quality and the short duration that a fish was in the actual field of view.

Camera selection for underwater fish observations is not a trivial matter. The field of view, resolution, low light capacity, and frame rate are just a few of the parameters that are crucial to gathering high-quality, meaningful data. After data have been collected, the file type becomes important for effective processing that leads to useful analysis. The cameras used to collect the data presented in this report were customized SeeMate ™ color to monochrome units with a F2.9 wide angle lens, manufactured by IAS systems (North Vancouver, British Columbia). The images had a resolution of 352 × 240 pixels. Each camera had a variable frame rate (less than 10 per second), and a field of view of "approximately one-third of the area between the pontoons and the left (portside) one-third of the TGU"[1] (LGL 2015). Pixel resolution, field of view, and light capturing ability created limitations in the data set, and complications continued because the output files were of a proprietary format. Significant amounts of unplanned time and resources were required for file conversion to a non-proprietary format, followed by testing several video-file viewers to determine the one best suited for this analysis, which included requirements like moving forward and backward through each frame capture without skipping or freezing up. Based on this work, literature review, and discussions with other researchers, a brief set of guidelines for camera selection for future applications is given in the Recommendations section.

3.3.1.4 Light Effects

On every night except July 19 the lights turned on as natural light levels decreased to illuminate continued monitoring fish presence and interaction. A comparison was done to better understand the potential impact of artificial lights during this environmental monitoring effort during hour block 23 from July 19

---

[1] LGL Alaska Research Associates, Inc., 2015 *Fish and Wildlife Monitoring Plan for RivGen® Testing on the Kvichak River, Alaska in 2015*

to 22. As it became dark on July 19, the field of view began to fade into a grainy, grayscale image with portions of it becoming black over time. If fish were present during the last 15 minutes of hour 23:00 on July 19, it would have been very difficult for the reviewer to see or document their presence. When comparing the first half of hour 23:00 on July 19 to the same hour on July 20, the images of both nights seem similar, but when the lights appear to turn on at approximately 23:35 on July 20, the turbine is illuminated, potentially creating an opportunity for light to reflect off fish and be visible to the camera, as well as make the image sharper and clearer. In contrast, on July 19 the image degrades over time. Nighttime illumination probably affects the detection probability of fish by the reviewers, and may alter an avoidance/attraction response by the fish.

The number of events that occurred when the lights were on was considerably higher than when the lights were off (344 compared to 8, respectively), and with a similar operation duration (55% compared to 45%, respectively). The number of events when comparing lights on and off differs considerably, yet the reason for this in this application is not well understood. Artificial lights may have attracted fish, thereby causing more events, or more fish may have been present during the last half of hour 23 when the lights were generally on every night except July 19; the data from July 22 when the lights were on for the full hour show more fish during the second half hours (135 vs 94), but this does not account for the extreme difference observed overall. Alternatively, fish presence may be similar on all nights, but the artificial light provides the source needed to make them visible to the optical cameras and in turn, reviewers. Additionally, on July 22 when all 24 hours were reviewed, Nighttime events (when the lights were on from 00:00–06:26, and 23:00–00:00) made up 99.9% of the total events for that day, with only 1 daytime Fish Event overall (although 436 Maybe Events during the daytime). Due to this clear difference and the lack of baseline understanding of fish attraction or deterrence related to this variable, the role of artificial lights during environmental monitoring needs to be further investigated.

4.0 Automated Analysis

Automated analysis was investigated to develop algorithms for detecting fish presence in the video, so that an entire video data set could feasibly be analyzed automatically without the need for manual sampling. Reducing the volume of data to just those video segments during which fish were present would optimize human labor time, and the reduced-volume approach could also be used to perform a quick preliminary analysis of the data. Ultimately, the system could be fully automated, and the software optimized to run in real time as part of an underwater observation system for long-term monitoring of the effects of MHK devices on animal populations.

The vision for an automated video processing system consists of three main components: preprocessing, detection, and classification (Figure 4.1). The preprocessing component filters the raw video frame to improve its quality in terms of contrast, color balance, and smoothness. The detection component identifies objects that might be fish, and the classification component classifies the detections to filter out false positives such as kelp, shadows, or other objects that are not of interest. These three components interact, and each requires many design decisions in order to realize an effective system. Under this project, candidate algorithms were investigated for each of the components, and an infrastructure was developed to tie the components together into a web-based application developed by PNNL called EyeSea.

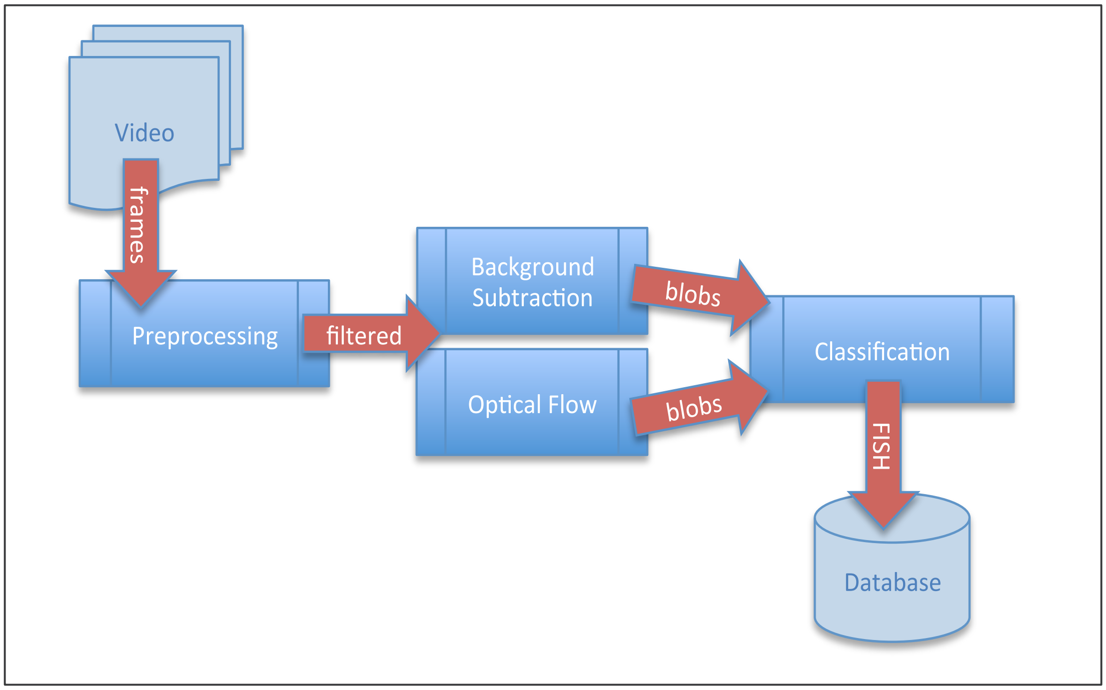


Figure 4.1. The automated processing chain.

4.1 Methods

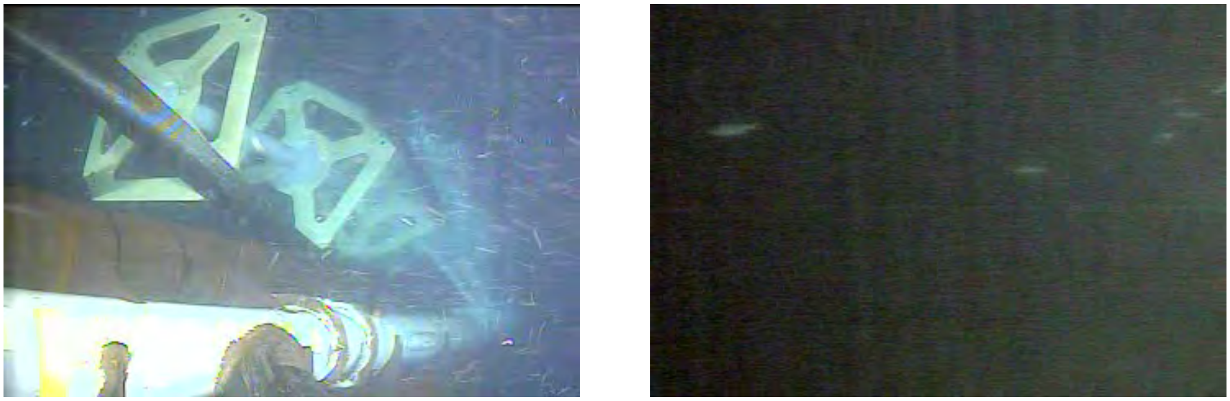
A testbed was developed to evaluate the performance of different algorithms; it consisted of a development data set and a processing pipeline. This meant that algorithms could be evaluated in a consistent, reproducible manner. A development data set was assembled from a subset of the full Igiugig data set consisting of 16 five-minute video segments containing Fish Events (Appendix B). The video segments were selected to represent different lighting conditions, different camera views and different sizes of fish, individuals and schools (Figure 4.2). Each video consisted of a total of 7500 frames, and even though the segments were chosen to include fish, only 6% of the total frames did in fact contain fish (the presence of fish is not a common event). The data were annotated as described in the Manual Analysis section. The processing pipeline was adapted from the Fish4Knowledge (Boom et al. 2014) code[2] for fish detection with custom code. The pipeline was used to batch process all the development videos using a particular detection algorithm, and to calculate the resulting detection rate and false positive rate by comparing the detections to the manual analysis annotations (Figure 4.3).

---

[2] http://groups.inf.ed.ac.uk/f4k/

a) Camera 1, daylight

b) Camera 1, night



c) Camera 3, night illuminated

d) Camera 4, night illuminated

Figure 4.2. Example images of fish in the different cameras with different illumination.

For the detection algorithms, background subtraction and optical flow were investigated. Three different background subtraction techniques were evaluated: Robust Principal Components Analysis (RPCA) (Candès et al. 2011), Gaussian Mixture Model (GMM) (Lee 2005) and Video Background Extraction (ViBE) (Barnich and Van Droogenbroeck 2009). The optical flow analysis consisted of a dense optical flow calculation using the Farnebäck algorithm (Farnebäck 2003) and a sparse feature-based flow calculation using the Lucas-Kanade method (Lucas and Kanade 1981), both as implemented in OpenCV.[3] For classification, models were developed using forward-stepping linear discriminant analysis (Lotlikar and Kothari 2000) on the detected objects to distinguish between fish and non-fish objects. The features used for classification were object size, intensity, shape, and motion.

---

[3] http://opencv.org

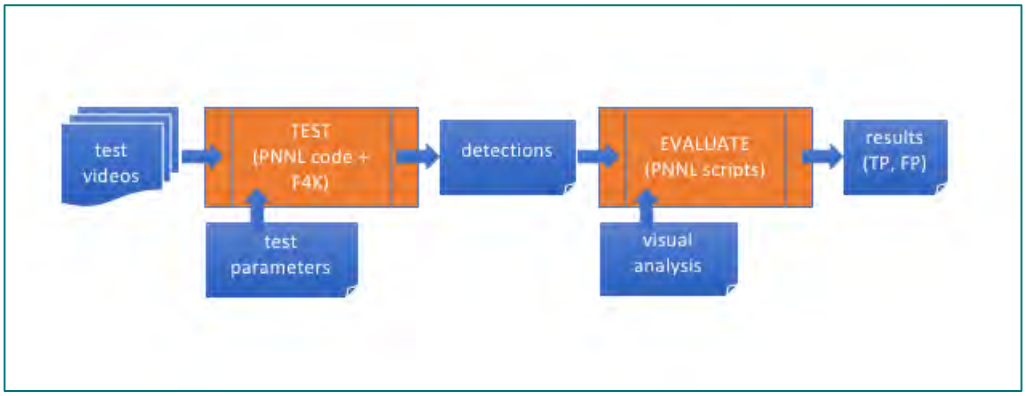


Figure 4.3. The developed testbed pipeline for evaluating different detection algorithms.

Background subtraction is a computer vision technique that is used to separate an image (or video frame) into background and foreground, where foreground means objects or regions of interest and is application-dependent. In this study, foreground is defined as fish and everything else is considered background, even other objects that might be moving such as the turbine itself and floating debris. This is a challenging data set for background subtraction because of the low quality of the video and the highly dynamic background. RPCA, GMM, and ViBE algorithms were selected based on recommendations from researchers at the University of Washington and the Fish4Knowledge project (Boom et al 2014) as being robust relative to background motion. The recommended parameter values for each algorithm were used.

The foreground images resulting from the background subtraction were further processed to group connected pixels of similar intensity into “blobs”. These objects were then classified as fish or non-fish. The blob size was highly variable ranging from 1 pixel to over 10,000 pixels, so the blobs were divided into five size groups and classification models for each group were developed separately.

The motivation for including optical flow is the hypothesis that fish motion is different than other motion in the scene, such as the motion of objects drifting with the current and the motion of the turbine foils turning. The researchers who performed the manual analysis said that one of the features they used to recognize fish was directed motion. Optical flow is the motion (spatial displacement) of light intensity from one video frame to the next. It is calculated for video by matching regions in one frame with regions in the subsequent frame, where the matching is based on edges and gradients of light intensity, and the flow is the displacement. There are several algorithms for calculating optical flow in the literature. For this application, the Farnebäck algorithm was chosen to calculate a dense optical flow over the entire image. Initial tests of both the sparse and the dense optical flow methods indicated that the sparse method was not effective when analyzing the raw video because of the lack of strong gradient features that could be tracked from one frame to the next. Dense methods are more robust relative to some changes in object intensity and shape because dense methods use more surrounding context for matching features.

In a parallel effort, a Deep Learning model was applied to the development data set. The open-source machine learning library TensorFlow was used to build a convolution neural network and train it on a portion of the data set. This type of neural network must be trained on labeled data to generate a model for classifying new data. For this video analysis, the inputs to the network were the individual video frames, labeled as “fish” or “no fish”. A subset of the labeled data (video frames) was selected at random to train the network and the resulting model was tested on the remaining data. This process was repeated over multiple iterations, where a new subset of the data was selected for training at each iteration. This iterative process is necessary to find the subset of the data that produces the best model.

4.2 Results and Discussion

One project goal was to reduce human labor time, hence the performance objectives were a 90% detection rate and a 30% false positive rate. The detection rate is the percentage of actual fish present that are detected, and the false positive rate is the percentage of reported detections that are not fish. It was important to detect most of the fish at the cost of some false positives because the false positives could be sorted out by human analysts, but too many false positives would reduce the benefit of the automation.

For an initial comparison of the background subtraction algorithms, the recommended parameter values for each algorithm were used (Table 4.1). The algorithms were evaluated for how well they correctly identified which frames contained fish. A frame was classified as "fish" if it contained one or more detections (foreground objects). The algorithms all performed similarly on the test bed data set (Table 4.2). The best detection rate was 67.51% (ViBE), which was much lower than the goal of 90%. The false positive rate was high, but the best true negative rate was better than 57%, which means that over 57% of the frames containing no fish were correctly labeled as such.

Table 4.1. Background subtraction algorithm parameters.

RPCA	ViBE	GMM
Window size = 50 Interval = 10 Threshold = 50	History = 20 Learning = 50 Radius = 20 Match criteria = 2 Update probability = 1/8	alpha = 0.02 threshold = 0.7 upper difference = 220 lower difference = 30

Table 4.2. Background subtraction frame classification results.

Algorithm	Percent of Fish Frames Correctly Detected	Percent False Positives	Percent True Negatives
RPCA	57.45	92.18	**57.60**
ViBE	**67.51**	**91.51**	54.48
GMM	63.79	92.29	52.19

The figures in bold indicate the best performance between the algorithms.

The background subtraction alone is not sufficient to meet the performance objectives, but the results offer valuable insight into the effects of night and day, the use of lights, and camera placement (see Section 7.0 for specific recommendations). The individual videos were analyzed to better characterize the algorithm performance under different conditions (Figure 4.4). All algorithms performed best on the videos from camera 1 at night, where there was no turbine in view and lights were on but angled away from the camera's field of view. All algorithms performed poorly in terms of false positives on the video from cameras 3 and 4 at night. The turbine was in view in both these cameras and the lights were aimed at the turbine. All algorithms performed worst on the video from camera 1 during the day, when most of the reported detections were false positives and most of the actual fish present were not detected. During the day, the fish were in low contrast with the background, so they were more difficult to detect. The lights at night reflected off the fish, increasing the fish's contrast with the background, so they were easier to

detect. Floating debris that was similar in size to small fish also reflected the light causing false positives (Figure 4.5).

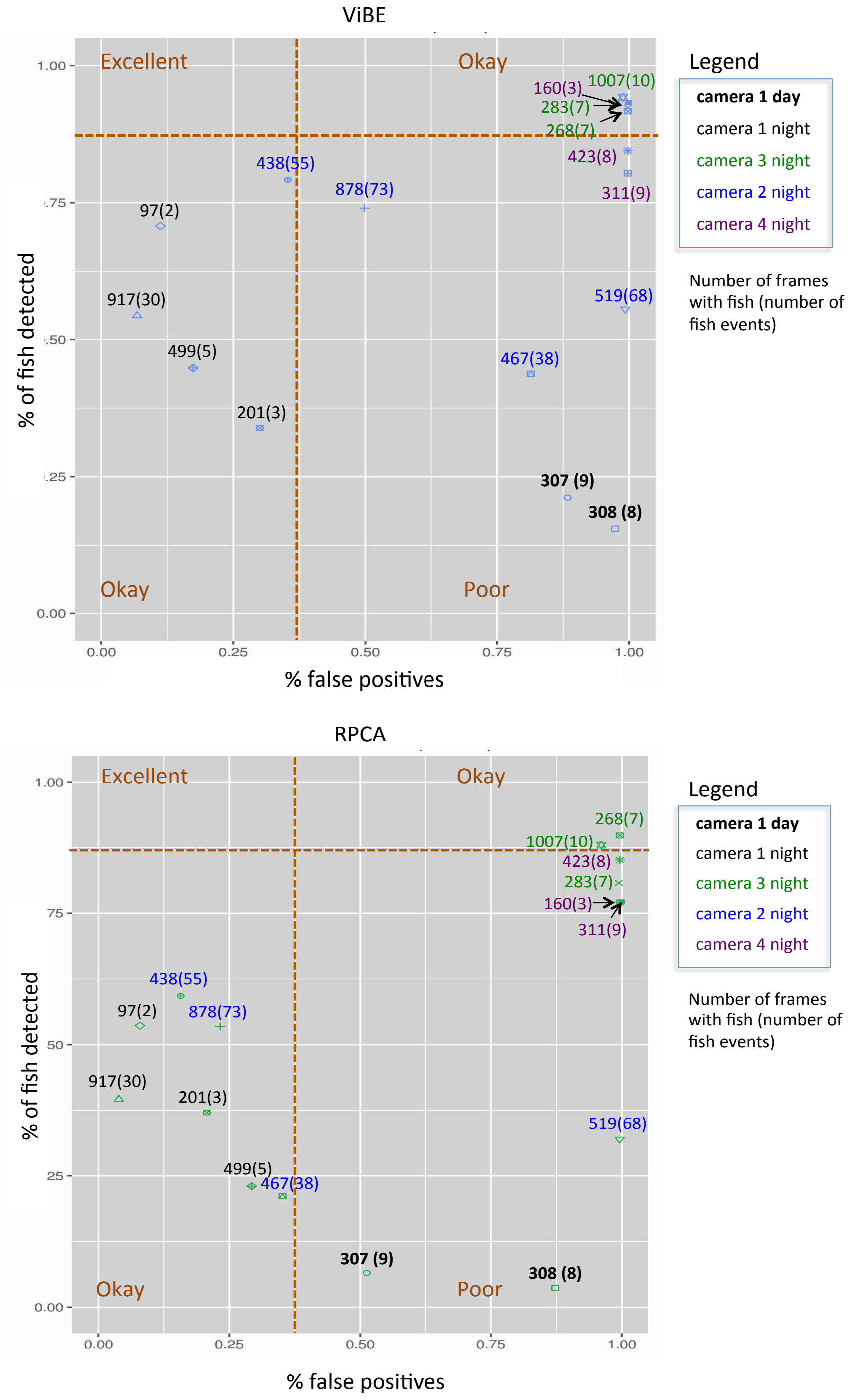


Figure 4.4. The detection rate and false positive rate by test video for RPCA (top) and ViBE (bottom). *The numbers on the scatter plots indicate the number of frames (out of 7500 per video) that contained fish and the number in parentheses is the number of Fish Events. A Fish Event is when a particular fish is in view; an event usually spans multiple consecutive frames.*

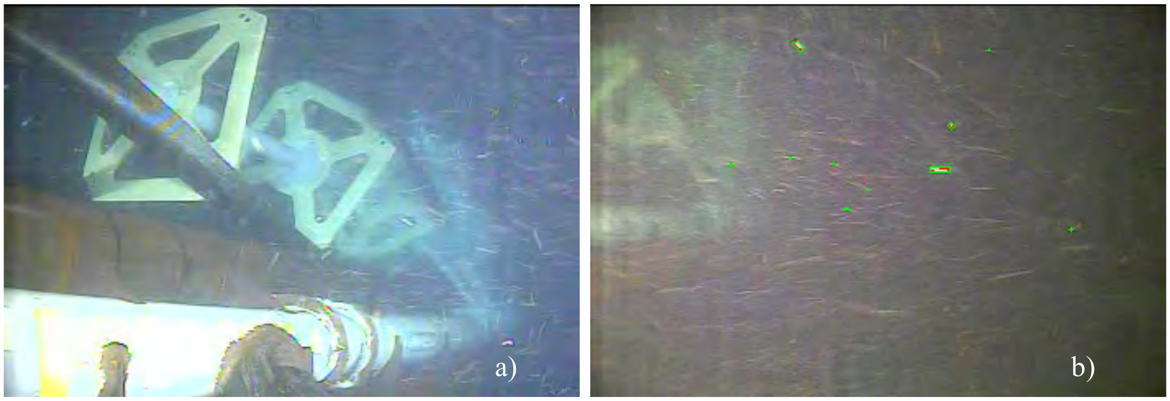


Figure 4.5. Example frame from camera 4 at night with small fish (a) and the detected objects from ViBE (b). The small fish are detected but there are also some false positives from the illuminated debris. These false positives were eliminated during post-processing.

Using the results of the initial evaluation as a baseline, preprocessing techniques were evaluated. The two techniques included with the Fish4Knowledge code were histogram equalization and contrast stretch. The preprocessing did not add significant computation time, but neither technique improved the performance and in some cases had a negative effect. A bilateral filter (Tomasi and Manduchi 1998) is often used in photographic applications, and this technique was tested on two of the videos, one from camera 3 and one from camera 4. Only two videos were processed because the computation was extremely slow on a desktop computer, but the results were promising (Figure 4.6).

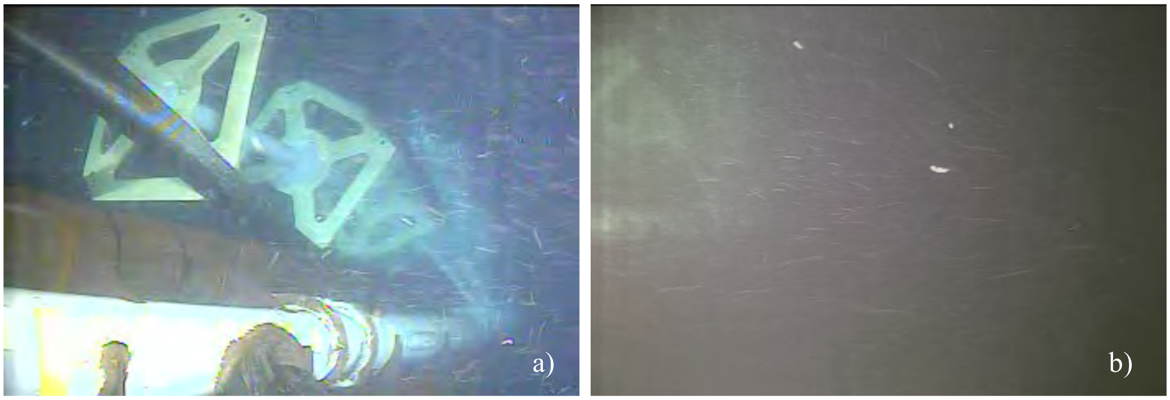


Figure 4.6. The raw frames (a) are preprocessed with a bilateral filter to reduce the clutter from debris (b).

The parameters of the best performing algorithm, ViBE, were varied to find the optimal values for the Igiugig data set. An exhaustive search for the optimal values of all five parameters was beyond the scope of this project, so two parameters with a strong influence on performance, the radius and the match criteria, were varied. The radius is the relative difference in intensity between background and foreground; a higher value will reduce the sensitivity and a lower value will reduce the precision (more false positives). Because detecting all the fish was more important than eliminating false positives, the radius was reduced and values of 20, 18, and 16 were evaluated. The match criterion is the minimum number of historical values that must fall within a current pixel's radius to consider the pixel to be background. A lower value will reduce sensitivity and a higher value will increase false positives and processing time. Values of 2 and 4 were evaluated. The best combination of values was radius = 16 and match criterion = 4 (Table 4.3).

Table 4.3. ViBE parameter tuning results.[(a)]

	Match = 2	Match = 4
Radius = 18	52% / 39%	70% / 54%
Radius = 16	55% / 42%	**74% / 59%**

(a) The first number in each cell is the true positive rate and the second number is the false positive rate. The figures in bold indicate the best combination of values.

A classification model for the detected objects significantly improved the performance by reducing the number of false positives. The detected objects were classified as "fish" or "non-fish" based on human analysis, and were divided into five size categories. A random sample of approximately 50 of each class (~100 observations) in each size category was used to develop a linear discriminant model for each category. For each size class, forward-stepping linear discriminant analysis followed by canonical analysis was used to determine the best model. Variables considered for the model included the blob size, blob solidity, blob eccentricity, and blob intensity. The models were tested on the remaining blobs that were not used for model development and the results are shown in Table 4.4. The larger blobs were classified most accurately; the accuracy decreased with decreasing blob size. The size of fish that can be accurately classified is dependent on their distance from the camera (the same size blob could be a large fish further away vs. a small fish close to the camera), and having the capacity to judge distance more effectively is discussed further in the Recommendations.

Table 4.4. Detected object classification results.

	Fish		Non-Fish		
Object Size in Pixels (number of fish objects)	True Positive	False Negative	True Negative	False Positive	Percent Correct
200+ (549)	533	16	3753	63	**98.2**
100 – 200 (320)	290	30	12,715	22	**99.6**
5 – 100 (2805)	2281	524	61,356	10,369	85.4
2 – 5 (2114)	1485	629	109,995	23,365	66.3
Total	4589	1199	187,819	33,819	84.6

The optical flow was calculated to generate a displacement in the horizontal and vertical dimensions for each pixel in the video frames, dx and dy, respectively. The displacements were then used to calculate the direction and magnitude of the motion from frame to frame. Direction was defined with 0 being toward the right and 180 toward the left. Five points in different regions of the frame were selected, and the motion was characterized at those points for one of the videos from camera 4 at night (Figure **4.7**). The direction of the motion appeared to be uniformly distributed across all directions and the magnitude appeared to follow a Weibull distribution (Figure 4.8). Due to the flow of the current from left to right in the video, the direction of motion was expected to be concentrated around 0 degrees. The uniform distribution that was observed may be due to the small, random motion of the floating debris. It may also indicate that the optical flow algorithm was not accurately matching points from one frame to points in the subsequent frame, due to the lack of distinctive features in the scene and the algorithm's bias toward small motion. The distribution of the magnitude of the motion shows that most of the calculated motions were small, with some outliers. The small motions may be due to debris and noise in the images, and the

outliers may indicate darting fish. The results are inconclusive and indicate a more in-depth investigation is needed, including testing the use of the bilateral filter for preprocessing to reduce the clutter in the scene.

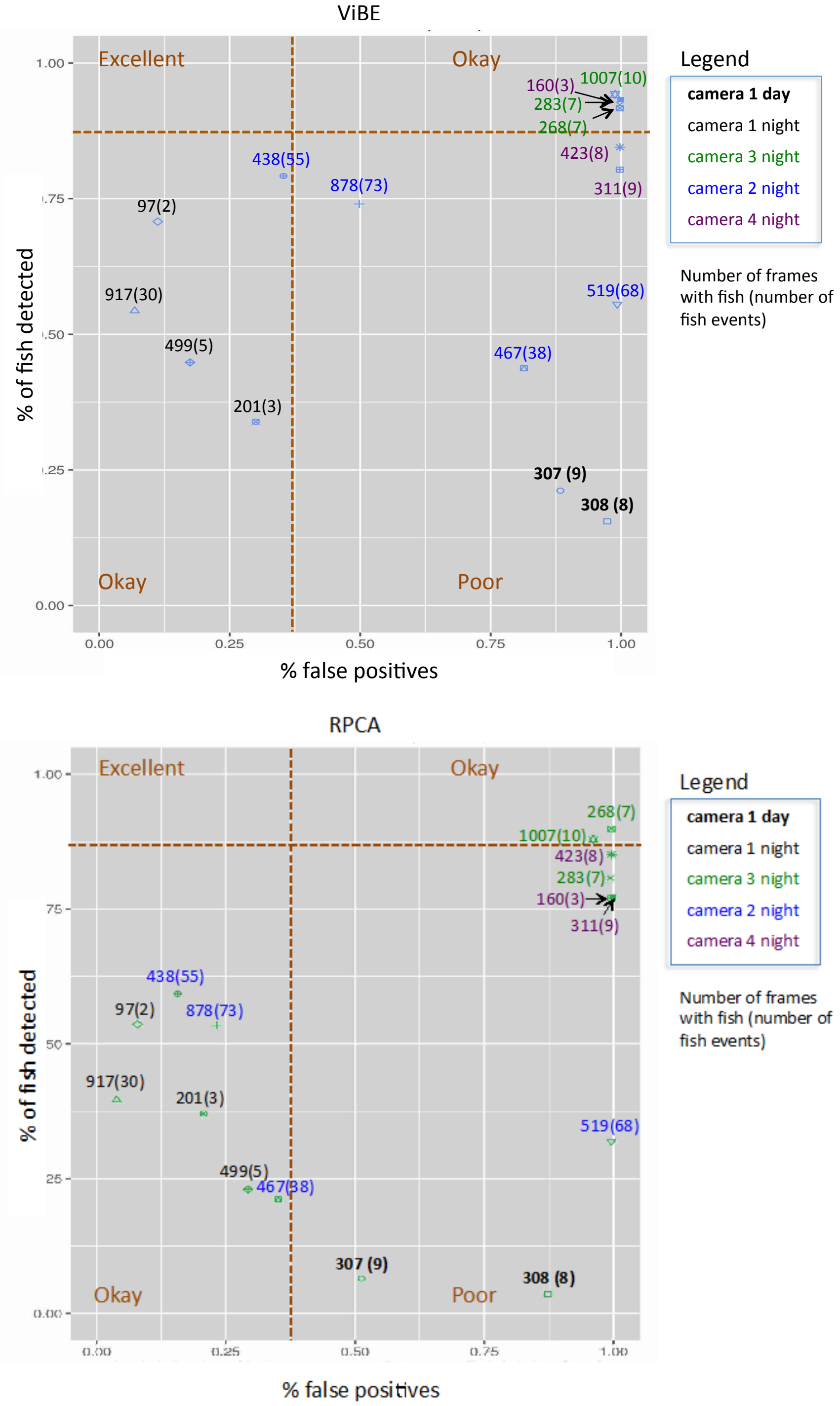
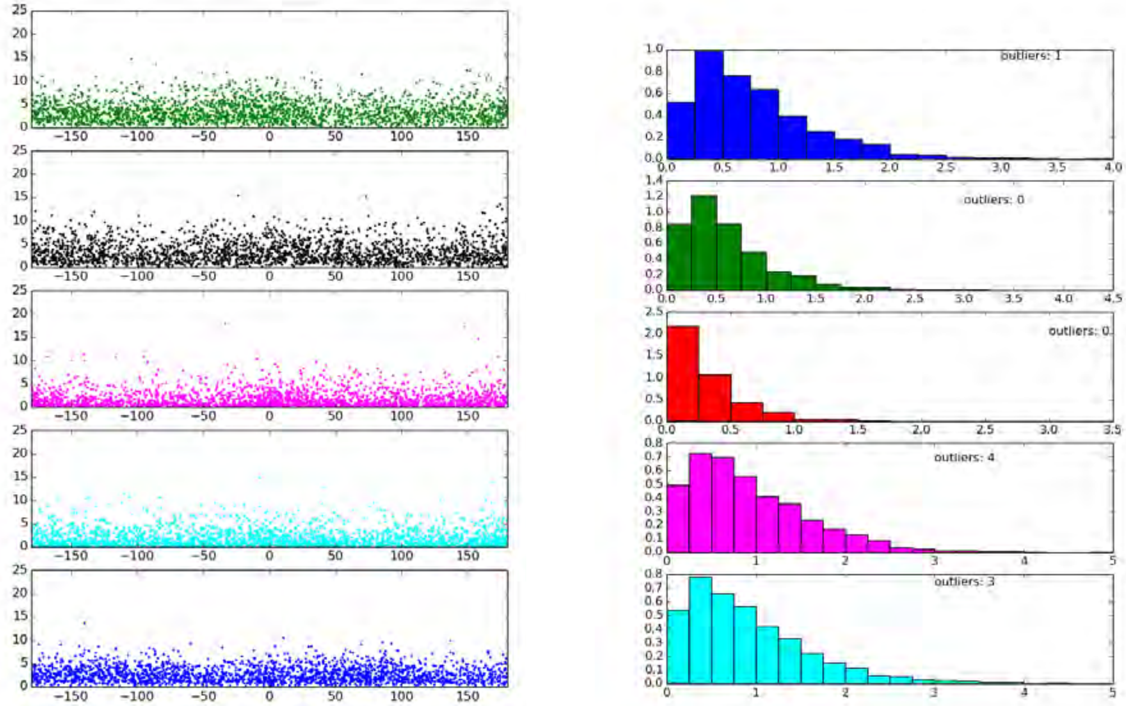


Figure 4.7. The detection rate and false positive rate by test video for RPCA (top) and ViBE (bottom). *The numbers on the scatter plots indicate the number of frames (out of 7500 per video) that contained fish and the number in parentheses is the number of Fish Events. A Fish Event is when a particular fish is in view; an event usually spans multiple consecutive frames.*



a) Magnitude vs. Direction

b) Magnitude Distribution

Figure 4.8. The magnitude and direction of motion at five points in the video were characterized using optical flow. The direction appeared to be uniformly distributed across all directions (a), and the magnitude appeared to follow a Rayleigh distribution that implies the motion in the x and y directions are independent (b).

The best Deep Learning model developed over the iterative learning process achieved 79% correct classification of both "fish" and "no fish" frames. This result is promising and on par with the background subtraction/blob classification results. This approach could be suitable for batch processing a large volume of recorded data, like the Igiugig data set, especially if the processing can be done on a high-performance computing system of parallel nodes. However, this approach would not be suitable for a real-time system because of the computational intensity, and the requirement for training data that is specific to the location being monitored.

5.0 Software

5.1 Need and Requirements

EyeSea is a web application that was developed by PNNL to meet the need for a central repository for accessing and analyzing the terabytes of video data from the Igiugig project. During the manual analysis of the video data it was found that the proprietary format of the video data required the use of the vendor's specific software, which ultimately did not meet the requirements of the analysis team. Fortunately, an open-source video encoder (https://ffmpeg.org/) enabled the transcoding of the video data to the standard h264 format. This allowed the analysis team to use other more feature-rich software to perform the analysis of the video data. There was still the issue of how to make the h264 encoded video data available to the analysis team and also how to store results of the video analysis. To solve this issue a database-driven web site was designed, called "EyeSea". This web-based application was developed in

parallel with the algorithm development, and was envisioned as the framework for ultimately providing a user-friendly front-end to the automated analysis, combining all the analysis tools into one comprehensive "human-in-the-loop" system for video analysis.

5.2 Functionality

The database was designed to store video metadata (e.g., date, time, location, timezone), analysis results (e.g., fish detected, species of fish, location of fish in video frame), and site-specific data (e.g., log-in information, batch processing information). Figure 5.1 shows the schema of the database that was ultimately implemented in MySQL.

Once the database had been designed the next step was to implement the web application. Bottle (https://bottlepy.org), a web framework for Python, was used to implement the web site. An asynchronous architecture was designed to allow users to query video data and later return and view the transcoded results. This was necessary to enable users to query videos encompassing large amounts of time without causing a browser timeout. Although the website was designed to play back the video inside the web browser, an option was added to allow users to download the video to their local machine for later offline playback. The website was later extended to allow for in-browser analysis of video. Figure 5.2 shows a screen capture example of the in-browser video playback.

EyeSea was also designed to facilitate batch processing and analysis of video. A set of scripts were written that could be deployed on a cluster of servers for parallel processing of multiple videos. The servers query the database for jobs to process and communicate to the database the status of the job as they are completed. The batch processing feature of EyeSea was used to extract Fish Events for later use in the analysis algorithm development testbed.

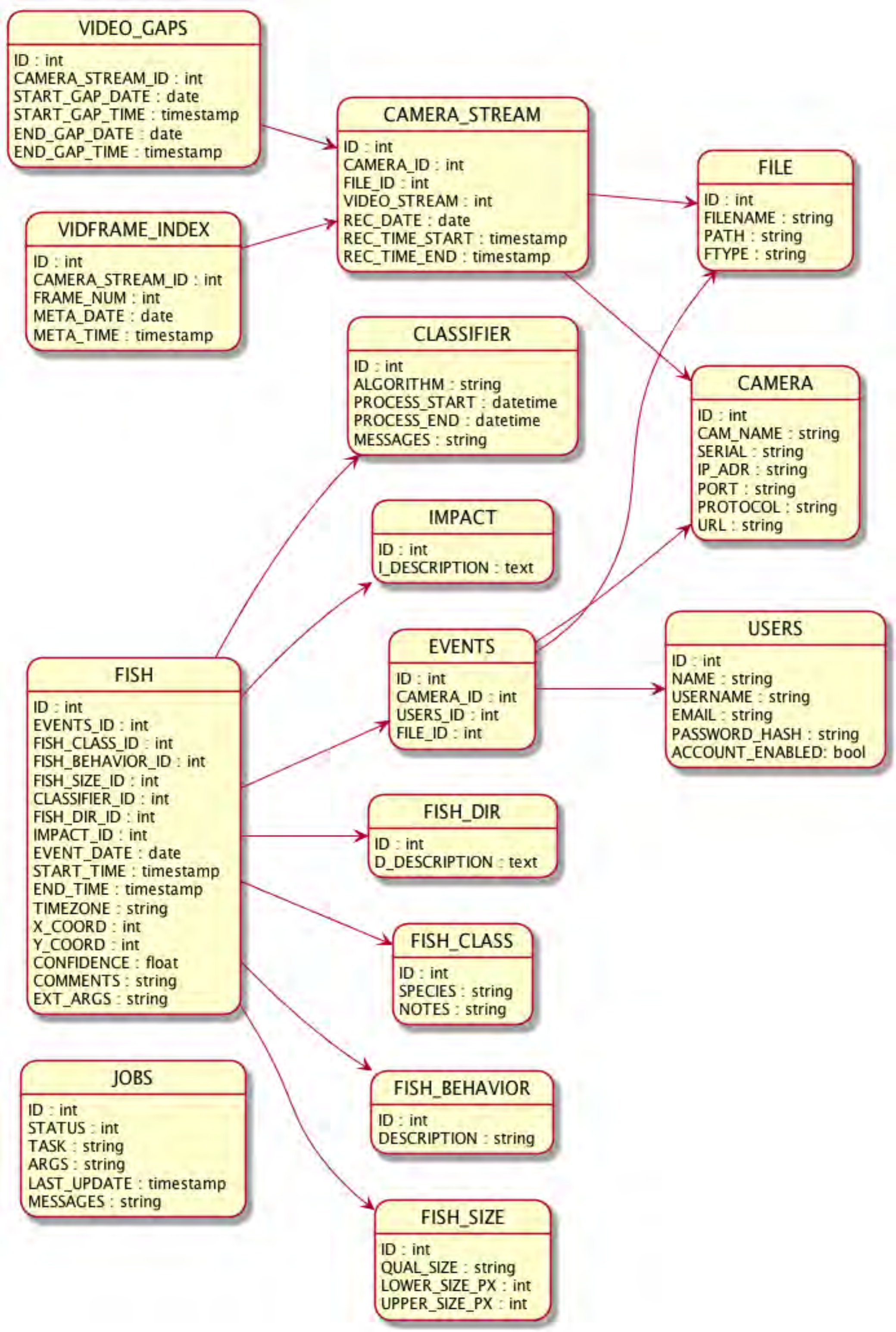


Figure 5.1. EyeSea database schema.

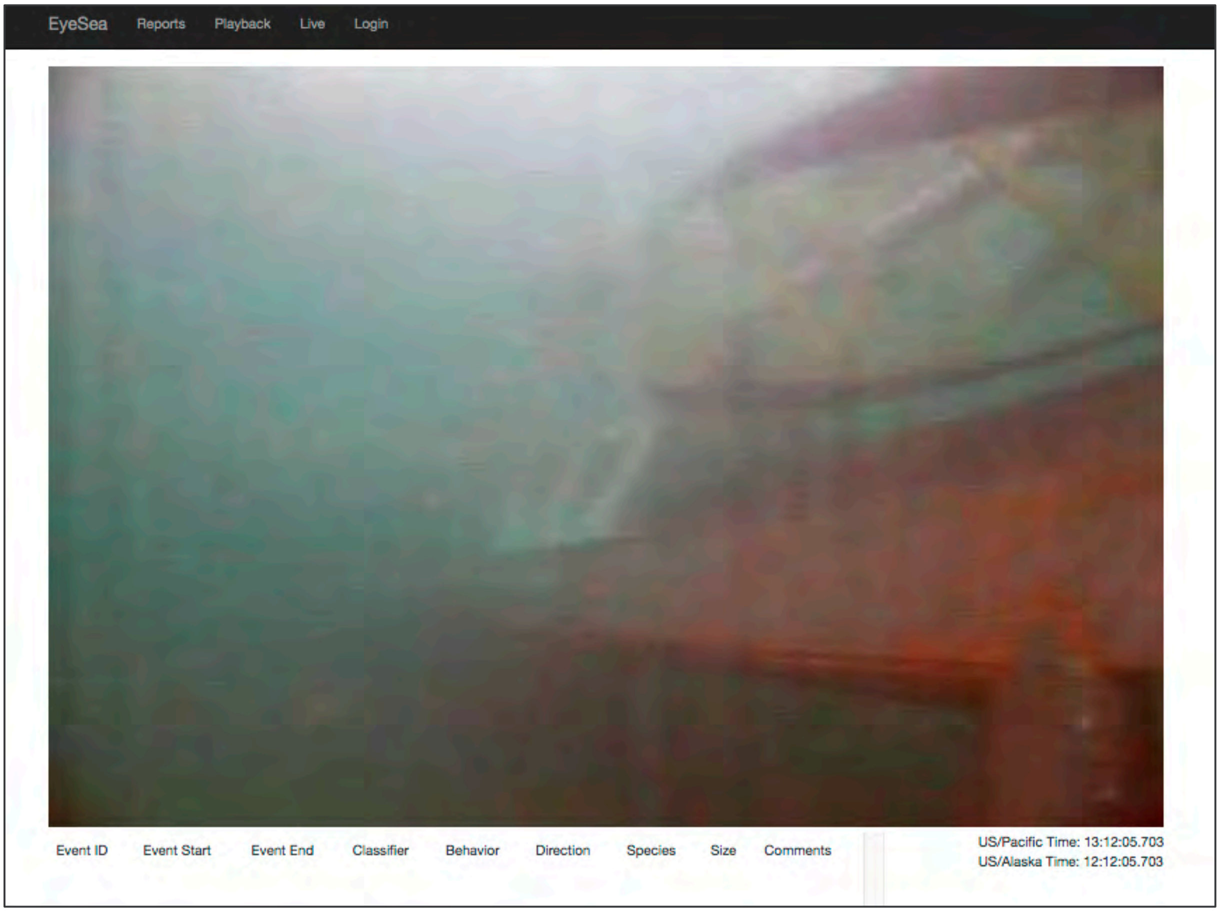


Figure 5.2. The EyeSea web application in playback mode.

6.0 Conclusions

6.1 Manual Analysis

The main points derived from the manual analysis of the data are as follows:

- Manual review of low-quality data is time-consuming. In this data set it took approximately 13–15 hours to manually review and annotate 1 hour of raw video data.
- Most interactions between the fish and the turbine occur at night.
- The frequency of fish interactions does not appear to be affected by whether the turbine is spinning or static.
- Processing subsamples (10 minutes) is likely effective for capturing unbiased event counts, but may not be effective for individual fish counts.
- Reviewer interpretation of Fish and Maybe Events in this data set is similar across two reviewers (qualitative analysis), but care is needed when assigning the designation of objects to introduced categories (quantitative analysis).
- Adult fish are qualitatively more likely to avoid collision or strike than juvenile fish.
- Adult fish are qualitatively more likely to show avoidance behavior as opposed to passive behavior relative to juveniles.

- More events occur when lights are on than when lights are off. Fish may be attracted to lights, lights may increase detection probability, or both.
- These data demonstrate the use of optical cameras for observing fish interactions with a deployed device in an underwater setting; however, improvements could be made with camera specifications and lighting parameters to increase the detection probability of fish, in both manual and automated review. Doing so may significantly decrease the manual and automated processing time.
- Observing “definite” vs. “probable” strike or collision is still extremely difficult and more research needs to be done to develop technologies or combine multiple technologies to gain confidence in determining actual contact with the device.

6.2 Automated Analysis

The main conclusions of the automated analysis effort were as follows:

- Tools available for detecting and tracking fish and other animals in underwater video are lacking. It was necessary to develop a new framework for semi-automated, human-in-the-loop analysis of underwater video. This framework can be used to test new algorithms and refine existing algorithms for automated fish detection and characterization, as well as support human expert analysis and standardized, reproducible information reporting.
- Reducing data volume is the first issue to address with automated processing. Large volumes of data are difficult to work with in terms of transferring, storing, and searching. A computationally simple background subtraction algorithm (ViBE) detected 74% of the human-identified Fish and Maybe fish, and is suitable for use in a real-time system to reduce data volume by saving only video that might contain fish.
- Reducing false positives is the second issue to address with automated processing. A statistical model can be used to classify detections as fish or not-fish, such as the one reported here that achieved a correct classification rate of 85% overall, and 92% for detections larger than 5 pixels. However, the statistical model required labeled training data that took time to assemble from the data and the model may not be transferable to other data sets. A classification model based on motion characteristics would potentially be more effective over a wider range of data.
- Underwater video recorded in energetic locations present challenges to automated processing that require algorithms specifically designed for this purpose. “Out of the box” algorithms such as those provided in the openCV library exhibited limited effectiveness, especially the optical flow techniques. Parameter tuning of the background subtraction algorithms did improve performance.

A combination of the automated detection developed under this project and human analysis could provide more accurate Fish Event information than the current practice of sampling, and with less labor time and cost than full analysis. Human analysis is currently the “gold standard” for accuracy, but it is very time-consuming so labor costs can be high and there may be long delays between collecting data and generating results. Sampling the video for analysis, e.g. analyzing 10 minutes of every hour reduces the labor time but sacrifices accuracy and increases the risk of missing rare events. The automated fish detection algorithms developed under this project can be completed quickly, but the resulting information is not as nuanced as that provided by human analysts and the detection accuracy is not yet sufficient so a “human-in-the-loop” approach is recommended. The automated detection software can be used to eliminate most of the video that does not contain fish, and the ensuing human analysis can be limited to those segments most likely to contain fish. With the developed processing system, this approach would reduce labor time by half over the full analysis, and would improve the reporting accuracy over sampling-based methods.

The performance of the automated processing can be further improved, based on the promising results demonstrated here. Future work should include incorporating computationally efficient bilateral filtering as a preprocessing stage, an intelligent scheme for parameter selection based on environmental conditions and video quality, and the integration of motion features. Further development of the EyeSea software should include a learning mode for tuning algorithm parameters using annotations provided by human experts.

7.0 Recommendations

The analysis of the Igiugig video data, both human/manual and automated, provided valuable insight into how to improve underwater video deployments in the future.

Since PNNL's review of the video data incorporated different approaches and anticipated outcomes than those of the original monitoring plan, recommendations arose regarding the monitoring process and methods for making project development and analysis more efficient in future studies. The water in the Kvichak River was described as being very clear compared to other rivers in the original monitoring report, yet the video data were described in PNNL's Quality Check Summary Report (Trostle 2016) as being "usable", in that the reviewers would be able to describe fish presence. The declaration of "usable" embodies the overall quality of the video data, including the following factors: resolution, frame rate, the placement of the cameras and light sources, the field of view, and the settings of the digital video recorder camera system. Careful consideration of the anticipated review and analysis objectives should be applied when making a camera selection. Those who will be reviewing the data should consider the questions they would like to answer and make sure that their camera selection, settings, and placement have the potential to address those questions.

To increase the quality of the video, future studies should use a low lux camera with a higher resolution and faster, even frame rate, but be aware that this will increase data accumulation because the files will be larger. Higher resolution video data would increase the likelihood that the manual reviewers could decipher between Maybe and Fish Events, identify taxonomic classification, and have more confidence regarding strike and collision. An increase in frame rate will improve the ability to detect actual strike because there would be more frames to describe the interaction around the turbine. It would also allow the reviewer, and possibly the algorithm, to use behavior as a qualifier, because sometimes the object would move significantly between frames, making behavior difficult to determine. Additionally, in some cases an object would only be in the field of view for one or two frames, making it difficult to determine if the object was a fish or not. In this study, objects that were only in one frame were not recorded as an event, because there was insufficient information to describe or categorize the object. With a more frequent frame rate and higher resolution, those objects could be included and give the study a broader picture, because the probability of missed events would be lower.

During manual video review, the reviewers realized that full manual analysis was too time-consuming. For this data set it took manual reviewers approximately 13–15 hours to process 1 hour of raw video data. A number of factors affect this approximation of time, including light operations, whether it was day or night, the number of fish, the behavior(s) of the fish, the amount of debris, the quality of the video, and whether or not the turbine was spinning. No 1-hour segment was identical to another in terms of time spent by manual reviewers due to the variability in the factors listed above, making the time spent extremely inconsistent. For this reason, future studies should be cautious when developing a timeframe estimate for manual processing, and reviewers should be wary that the anticipated estimation of time spent may change.

As described in the Quality Check Summary Report, a great deal of work and time was put into understanding the methods and settings implemented throughout the study, and converting the video from

a propriety format (.par), which was designed to be tamperproof, to a more appropriate format for the development of automated processing and analysis (.mp4). A more accessible format, such as .mp4 or .avi could be used for ease of use and to enable automated analysis before manual review.

As PNNL reviewers sifted through the video data, they noticed a variation in the light operations. In general, the lights seemed to be on at night and off during the day, with at least one exception on July 19, but a light operation record was not maintained during the study. Because there were many more Fish Events at night, it is important to get a better understanding of the effect artificial lights have on fish behavior (e.g., whether lights attract or repel fish). It is also important to quantify the difference the lights make to the physical parameters of detection (e.g., define more robust limits of detection, and define optimal placement and settings of light sources and cameras to increase manual and automated detection potential).

Recommendations for future underwater environmental monitoring are listed below:

- **General setup.** Include an indication of range within the field of view to help reviewers distinguish size and location in relation to the turbine. Also, aim the camera so the field of view is aligned with particular turbine components, possibly in combination with sensors on the turbine foils to increase the detectability potential and promote a higher level of confidence during potential strike and collision events. The aiming of each camera will likely require an iterative process of viewing early data and making adjustments to achieve ideal viewings for manual processors as well as ideal background for algorithm applications.
- **Video format**. A standard format (e.g., .avi, .mp4) should be used, rather than a proprietary format. When the video is in a standard format, researchers have a wide array of existing tools that they can use for analysis and processing. A proprietary format restricts researchers to using vendor-supplied software that often is not designed for the type of analysis required.
- **Camera type.** Choose a camera that has underwater capability with high pixel resolution in low light conditions, the capability to mount and adjust placement settings, appropriate data storage and transmission, and a suitable field of view range for the study area.
- **Camera resolution and placement.** The camera resolution will determine the size of objects in pixels at a given distance from the camera. Objects that are less than five pixels in total size are difficult to detect, both algorithmically and visually. Higher resolution will increase the volume of data, but low resolution will restrict the size of fish that can be reliably detected. The size of a fish in pixels, along the horizontal dimension, is

  length of fish in meters / meters per pixel

  The meters per pixel is

  $$\frac{2r\tan\frac{\alpha}{2}}{n}$$

  where r is the distance to the fish in meters, α is the horizontal camera field of view angle, and n is the number of pixels in the horizontal dimension. For example, a 10 cm (4 in.) fish would be 10 pixels long at 10 m from a 320 × 240 pixel camera with a 20 degree horizontal field of view. This calculation will also help determine how far from the turbine to locate the camera. Test the placement of the cameras and lights to optimize manual and automated detection probability. Note where the sun will be throughout the study and test different angles to avoid glare.

- **Frame rate.** Ideally, the frame rate should be constant, meaning that there is a fixed interval of time between frames. The Igiugig video had a variable frame rate that resulted in uneven motion of objects from frame to frame. Higher frame rates increase the volume of data, but if the frame rate is too low the number of frames in which a fish may be in the field of view is decreased, decreasing the

probability of detection. A rate of 30 frames per second is a reasonable choice to balance data volume with detection likelihood.

- **Lighting**. Fish specific to this study are typically more active at night, so some sort of illumination is needed if video is the only monitoring technique used. The light also generated more false positives from reflecting debris. An indirect light source, like the lighting viewed from camera 1 in the Igiugig video may be the best choice. If lights are to be used, the lights should be on throughout the study to maintain a more controlled environmental setup, and increase light sources with more angles of incidence to prevent fish from disappearing when they turn at an angle that does not reflect light from a single source. However, while improving the detection of fish and debris, this practice may also introduce possible bias because of the lights themselves increasing detection probability or attracting fish, both of which complicate comparisons when lights are turned off or confounded by diel differences.
- **Detailed record keeping**. The following aspects should be recorded:
  - all monitoring operations, including camera operation, light operation, power operation, turbine status, and any other introduced monitoring systems.
  - water flow, weather conditions and any significant events that occurred during the study.
  - any maintenance issues or disruptions throughout the study.
  - review efforts.
- **Other monitoring**. Consider adding other monitoring technologies to help determine whether actual collision or strike occurred and to have a backup technology for behavioral monitoring. Strain gauges or other devices physically attached to the blades of a turbine could be used to complement the video data for those times when a collision or strike is possibly seen. Having coincident data sets providing evidence of collision or strike would be better than just one. For instance, if a reviewer thinks a strike was seen on the video data, the same timestamp could be searched for blade-attached strain gauges to see if there was a spike. If there was an anomaly on the strain gauge, then that is more evidence of a strike. The absence of strain gauge data would be evidence that the interaction was more likely a near-miss.

To inform future studies, additional research into specific aspects would also be useful, in particular a study to assess the effects of lights on fish, in conjunction with an evaluation of light and camera placement and settings toward the optimization of detection probability to find an ideal experimental design for manual and automated detection. The study would record details of the placement, including heading, pitch and roll of both the lights and the cameras, light operations, intensity, wavelength, exact range in relation to the device and cameras, as well as camera operations, range, resolution, frame rate, and settings. For algorithm development, further research is recommended into different optical flow techniques, and the refinement of parameters for the background subtraction. Each of these aspects would improve the results derived from future monitoring. Each study site will have specific physical characteristics that will affect underwater video camera data collection. However, as research continues on future data sets, general application principles will arise that can be applied to most situations.

8.0 References

Avila A, Hull R, Matzner S, Staines G, Trostle C, and Harker- Klimeš G. 2016. *Igiugig Video Analysis – FY16 Progress Report* PNNL-25909 Pacific Northwest National Laboratory, Richland, WA.

Barnich O and Van Droogenbroeck M. 2009. ViBe: a powerful random technique to estimate the background in video sequences. In proceedings of *Acoustics, Speech and Signal Processing, 2009.*

ICASSP 2009. IEEE International Conference on Acoustics, Speech and Signal Processing (pp. 945–948). IEEE.

Boom BJ, He J, Palazzo S, Huang PX, Beyan C, Chou H-M, Lin F-P, Spampinato C, and Fisher RB. 2014. A research tool for long-term and continuous analysis of fish assemblage in coral-reefs using underwater camera footage. *Ecological Informatics*, 23:83–97.

Candès EJ, Li X, Ma Y, and Wright J. 2011. Robust principal component analysis? *Journal of the ACM (JACM) 58*(3), 11.

Farnebäck G. 2003. Two-frame motion estimation based on polynomial expansion. In proceedings of *Scandinavian Conference on Image Analysis* (pp. 363–370). Springer Berlin Heidelberg.

Lee DS. 2005. Effective Gaussian mixture learning for video background subtraction. *IEEE transactions on pattern analysis and machine intelligence 27*(5), 827–832.

LGL Alaska Research Associates, Inc. 2015. *Fish and Wildlife Monitoring Plan for RivGen® Testing on the Kvichak River, Alaska in 2015*.

Lotlikar R and Kothari R. 2000. Fractional-step dimensionality reduction. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 22(6): 623–627.

Lucas BD and Kanade T. 1981. An iterative image registration technique with an application to stereo vision. *International Joint Conferences on Artificial Intelligence (IJCAI)* 81: 674–679.

Tomasi C and Manduchi R. 1998. Bilateral filtering for gray and color images. In *Computer Vision, 1998. Sixth International Conference on Computer Vision* (pp. 839–846). IEEE.

Trostle C. 2016. *Igiugig Fish Video Study– Quality Check, Summary Report*. Pacific Northwest National Laboratory, Richland, WA.

Appendix A

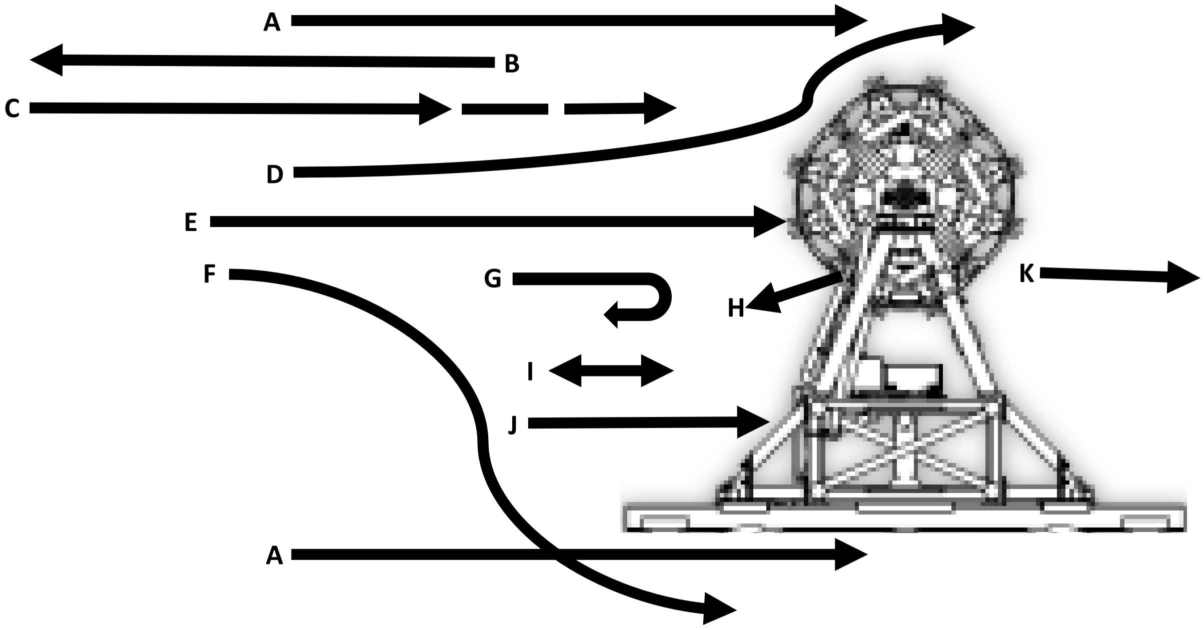
Manual Annotation

Appendix A

Manual Annotation

Annotation	Description of Annotation
Event	Reference number per event; restarting for each half-hour block of data
Date	Day video data was collected; yyyy/mm/dd
File	Filename given to each half-hour block of data; includes day and time
FileStartTime	Time that file starts on the given day it was collected
StartTime	Time that an event begins; begins 00:00:000 per half-hour block of data
EndTime	Time that an event ends; ends 29:59:999 per half-hour block of data
Lights	Either on or off; binary
Spinning	Either yes or no; binary
Camera	Designated number of camera; these data only include Camera 2
Fish?	Is the event triggering object a fish; yes, no, maybe
Number	How many objects or fish occur during an event
Size	Size of objects or fish seen during an event; measured as length on computer monitor; unidentifiable, small (<0.5 in), medium (0.5–3.0 in), large (>3.0 in.); was adjusted relative to monitor screen sizes
Species	Visually identifiable relative size designation or salmon; unidentifiable, juvenile, salmon, adult
VideoQuality	Relative anecdotal comparison of each event relative to others based on clarity of event triggering object in field of view; horrible, bad, okay, good, excellent
Notes	To clarify any previous annotation categories
Location	Where the event triggering object is in the water column; based on computer monitor divided into thirds; bottom, middle, top
Direction	All observed directions of the event triggering objects or fish; downstream, upstream, cross river toward, cross river away
Behavior	Reviewer description of all object or fish behaviors observed during an event. • straight across • against current • pause • avoid above • through turbine

	• avoid below • avoid reverse • out of turbine • milling • toward static parts • through wake • avoid around • unable to tell • other
Impact	Reviewer determination if there was collision or strike during an event
Comments	To clarify any previous categories since “Notes”



A- straight across
B- against current
C- pause
D- avoid above
E- through turbine
F- avoid below
G- avoid reverse
H- out of turbine
I- milling
J- toward static parts
K- through wake
L- unable to tell (not shown)
M- other (not shown)

Appendix B

Video Data Set Used for Algorithm Development

Video Data Set Used for Algorithm Development

Video File (Date, time, camera)	Day | Appendix BLights	Turbine | Spinning | None	Fish Events	Fish Frames
20150719_175830-1.mkv	Day	None	7	308
20150720_110030-1.mkv	Day	None	9	307
20150722_030200-1.mkv	Lights	None	30	917
20150722_030200-2.mkv	Lights	Turbine	72	878
20150722_030200-3.mkv	Lights	Turbine	7	283
20150723_000330-1.mkv	Lights	None	2	97
20150723_000330-2.mkv	Lights	Spinning	68	519
20150723_000330-3.mkv	Lights	Spinning	7	268
20150723_000330-4.mkv	Lights	Spinning	8	423
20150724_000000-1.mkv	Lights	Turbine	5	499
20150724_000000-2.mkv	Lights	None	53	438
20150724_000000-3.mkv	Lights	Turbine	10	1007
20150724_000000-4.mkv	Lights	Turbine	9	311
20150825_040330-1.mkv	Lights	None	3	201
20150825_040330-2.mkv	Lights	Turbine	38	467
20150825_040330-4.mkv	Lights	Turbine	3	160
Total			**334**	**7569** **(6%)**

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT OF
ENERGY

Proudly Operated by **Battelle** *Since 1965*

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

www.pnnl.gov

Estimation of Acoustic Particle Motion and Source Bearing Using a Drifting Hydrophone Array Near a River Current Turbine to Assess Disturbances to Fish

Paul G. Murphy

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science in Mechanical Engineering

University of Washington
2015

Program Authorized to Offer Degree: Mechanical Engineering

University of Washington
Graduate School

This is to certify that I have examined this copy of a doctoral dissertation by

Paul G. Murphy

and have found it complete and satisfactory in all respects,
and that any and all revisions required by the final
examining committee have been made.

Co-Chairs of Supervisory Committee:

____
[Committee Co-Chair]

____
[Committee Co-Chair]

Reading Committee:

____
[Committee member]

Date: _________________

In presenting this dissertation in partial fulfillment of the requirements for a doctoral degree at the University of Washington, I agree that the Library shall make its copies freely available for inspection. I further agree that extensive copying of this dissertation is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Any other reproduction for any purposes or by any means shall not be allowed without my written permission.

Signature________________________________

Date____________________________________

University of Washington

Abstract

Estimation of Acoustic Particle Motion and Source Bearing Using a Drifting Hydrophone Array Near a River Current Turbine to Assess Disturbances to Fish

Paul G. Murphy

Co-Chair of the Supervisory Committee:
Professor Peter Dahl
Mechanical Engineering

Co-Chair of the Supervisory Committee:
Professor Brian Polagye
Mechanical Engineering

River hydrokinetic turbines may be an economical alternative to traditional energy sources for small communities on Alaskan rivers. However, there is concern that sound from these turbines could affect sockeye salmon (*Oncorhynchus nerka*), an important resource for small, subsistence based communities, commercial fisherman, and recreational anglers. The hearing sensitivity of sockeye salmon has not been quantified, but behavioral responses to sounds at frequencies less than a few hundred Hertz have been documented for Atlantic salmon (*Salmo salar*), and particle motion is thought to be the primary mode of stimulation. Methods of measuring acoustic particle motion are well-established, but have rarely been necessary in energetic areas, such as river and tidal current environments. In this study, the acoustic pressure in the vicinity of an operating river current turbine is measured using a freely drifting hydrophone array. Analysis of turbine sound reveals tones that vary in frequency and magnitude

with turbine rotation rate, and that may sockeye salmon may sense. In addition to pressure, the vertical components of particle acceleration and velocity are estimated by calculating the finite difference of the pressure signals from the hydrophone array. A method of determining source bearing using an array of hydrophones is explored. The benefits and challenges of deploying drifting hydrophone arrays for marine renewable energy converter monitoring are discussed.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

This work was funded by the National Science Foundation through the NNMREC grant and by the Department of Energy though the Sustainability of Tidal Energy grant.

Chapter 1. INTRODUCTION

At present, many riverine villages in remote areas of Alaska receive most of their power from diesel generators. The lack of a road network requires fuel to be delivered by barge or air, resulting in high energy costs. Consequently, there is interest in developing turbines to harness the kinetic energy from the currents of nearby rivers, much in the same manner that wind turbines harness the kinetic energy in atmospheric winds.

An evaluation of the economic utility of river turbines to riverine communities should include an assessment of the effects of turbine presence and operation on fishes, particularly sockeye salmon (*Oncorhynchus nerka*), a vital resource for residents of subsistence based villages. The salmon population is similarly essential to the economic health of the commercial fishing and sport fishing industries. For these reasons, assessing risk to fish is a necessary step in evaluating the environmental and social compatibility of river turbines.

Sound is a pressure wave which generates minute motion in the fluid medium through which it propagates. Movement of the medium when disturbed by sound waves can be described in terms of discrete fluid particle motion, wherein fluid particles are defined as the smallest volume over which a calculation of density would still equal the average density of the fluid [1]. This acoustic particle motion is thought to be the primary mode of acoustic stimulation in many species of fishes, including sockeye salmon (*Oncorhynchus nerka*) [2]. Although it is unlikely that sound from turbines will be intense enough to cause physical harm to individual fish, behavioral changes that result in a decrease in the overall fish population (e.g., by discouraging the regular migration of salmon to spawning locations) are conceivable [3]. The effects of sound on fish behavior is an active area of research in the biological research community and this paper focuses primarily on quantification of turbine sound.

In this study, acoustic pressure is measured near a river current turbine, and properties of the turbine-generated sound are analyzed and discussed. Pressure measurements are made using vertically separated and temporarily coherent hydrophones deployed from a drifting platform, from which the vertical components of acoustic particle velocity and acceleration are also estimated.

1.1 ACOUSTICS OF RIVER ENVIRONMENTS

The domain of a river, as it pertains to sound propagation, may be described quite generally as a depth varying channel with the average depth (*D*) usually small relative to the average width (*W*), and the average width small compared to the river length (*L*). For our frequencies of interest, of order 10-1000 Hz, a river can be considered a shallow water environment bounded by a pressure release surface above (air) and a sediment bottom characterized by higher density and sound speed than water. (An exception being very mud-like sediments found in slow moving rivers although such systems are of less relevance in energy conversion). Depth variation in a river occurs in both the across-channel and along-channel directions, which can have a strong effect on sound propagation. The term "along-channel" is used to describe a plane parallel to the bulk fluid motion, and "across-channel" to describe a plane perpendicular to the bulk fluid motion.

Sound emitted from a sound source in shallow water, at mid-water depth, will spread spherically until the wavefront reaches the top and bottom boundaries. Within this region, defined roughly by the water depth (*H*), the sound intensity will decrease in proportion to the inverse of r^2 (spherical spreading) where r is the range from the source. For ranges beyond H, roughly speaking, intensity falls with the inverse of r (cylindrical spreading), a result of reflection from the surface and bottom. In a river, the width (*W*) is generally greater than depth, but of a similar order; therefore, beyond the region of spherical spreading, an assumption of azimuthally symmetric (cylindrical) spreading is invalid.

Because a river environment is generally shallow relative to the acoustic wavelengths of interest (*O* 15 m for 100 Hz), sound propagation is best described in the context of normal modes. Normal mode solutions to the acoustic wave equation in shallow water consist of a finite sum of trapped normal modes and an infinite (continuous) sum of untrapped modes [4]. The latter (or "leaky") modes leak energy into the bottom and thus experience a high loss during propagation, while the trapped modes can propagate over longer distances as the sound field is more effectively confined within the surface and bottom boundaries. An approximate rule for sound being trapped in the waveguide (i.e., for trapped modes to exist) is that the frequency satisfies $\frac{2H}{\lambda} > 1$, where λ is the wavelength of sound. Frequencies for which this ratio is < 1 are said to be below modal cutoff. In the along-channel direction, river depth may vary considerably over short distances. As a result, a sound field generated in deeper regions of the river and consisting of trapped modes may be subject to modal cutoff as the field propagates into shallower regions. In the across-channel direction, the river bottom generally slopes upward towards the shore on either side, resulting in modal cutoff at higher frequencies nearer to the shore.

Although modal cutoff and depth variation can limit the propagation of low frequency sounds, migratory fish may have no alternative but to travel through ensonified areas. Furthermore, since the width and depth of the channel in the vicinity of a sound source may be small relative to the wavelengths of sound produced by the source, it is important to quantify sound levels in the near field to fully assess the exposure of migrating fish.

Prior investigations have shown that the highest noise levels (measured in 1/3 octave bands) in rivers with no major obstructions to the flow and limited surface agitation (i.e., “runs”) occur at low frequencies (< 50 Hz) [5]. Noise levels can be expected to decrease with a slope of approximately 30 dB/decade until around 250 Hz before increasing again with an average slope of approximately 6 dB/decade until 16 kHz. In addition to the general trends, a slight increase in level is expected from 500 Hz – 2 kHz.

1.2 RIVER TURBINE SOUND MECHANISMS

Data on sound from hydrokinetic (river, tidal, or ocean current) turbines is scarce, and there are no known measurements of particle motion near operating hydrokinetic turbines. However, one can draw on experience with analogous technology to anticipate possible sound sources. Much like wind turbines, periodic blade passage by stationary objects can create pressure minima and maxima during each revolution, which may generate propagating sound [6]. Sound generated in this way would be at frequencies directly related to the fundamental rotation rate of the turbine, with harmonics at higher frequencies. Broadband levels are also expected to vary with inflow velocity.

The generator used to convert mechanical to electrical power can also produce noise. The primary mechanism of sound generation from AC generators is vibration of the stator and foundation by periodically varying magnetic forces, which are caused by the generator's rotating magnetic field [7]. The number of magnetic pole pairs on the rotor or stator affects the forcing function, so sounds from generator vibration are related to both the rate of rotation and the particular number of pole pairs in a generator's design. Excitation of vibrational modes in the generator stator and foundation can significantly increase the amplitude of radiated sound. Gearboxes and vibration in the turbine foundation or rotation of shaft bearings may also produce sound.

While sound from turbulence generated by the rotation of the turbine or from vortices shed from the frame are also possible, the effectiveness of turbulent sources to radiate sound is weak owing to the quadrapole nature of such sources [8]. However, turbulent excitation of the blades can radiate sound more efficiently as a dipole source. The frequencies of this radiated sound would be expected to match the modes of blade vibration [9]. Finally, cavitation is well known to be a powerful radiator of sound as a monopole source, but hydrokinetic turbines are designed to avoid operating in a manner that promotes cavitation.

1.3 METRICS RELEVANT TO FISH HEARING RISK ASSESSMENT

Recent reports on fish hearing recommend the inclusion of particle motion measurements when assessing the risk that anthropogenic sound sources pose to fishes [3]. Behavioral audiograms, which show an animal's auditory threshold at a range of frequencies, have been developed for at least four species of fish, including Atlantic cod (*Gadus morhua*), Atlantic herring (*Clupea harengus*), Atlantic salmon (*Salmo salar*), and dab (*Limanda limanda*). While a high degree of caution has been advised in interpreting these data, they have provided some insight into fish hearing, and suggest the sensitivity of fish to lower frequency sounds of order 100-1000 Hz [3].

Although many fish species are sensitive to acoustic pressure, the majority exploit and are sensitive to the particle motion aspect of sound [2]. Located in the inner ear, the otolith has been identified as the principle organ responsible for sensation of particle motion and is thought to perform the function of an inertial sensor [2]. Fishes with a swim bladder or other gas filled sac may be capable of sensing sound pressure, provided the organ is located in close proximity to the ear. Salmon and trout, for example, do have a swim bladder, but it is not located close to the ear and therefore they are thought to be primarily sensitive to particle motion [3].

Although there is not an accepted standard for which quantity of particle motion should be reported, particle acceleration has been suggested as an appropriate metric given the current understanding of the otolith's function [2] [3].

1.4 SOURCE LOCALIZATION

Source localization by time delay of arrival estimation is a method of determining the angle of incidence of plane waves by examining the time that wavefronts arrive at adjacent hydrophones in an array. Source localization has been successfully used to track marine mammals, notably whales, by their vocalizations [10], and is of particular interest in marine energy converter monitoring studies because, unlike active acoustic methods, it does not introduce a loud source into the marine environment. As loud sources may change the behavior of marine mammals, it is preferable to use passive methods of tracking when possible. In addition, real-time passive monitoring of marine energy sites (via communication cables) would consume significantly less bandwidth than active acoustic or video monitoring.

Chapter 2. METHODOLOGY

This section will describe in detail the basics of sound, the measurement theory utilized, the 'RivRaft' drifting platform and its instrumentation, the turbine site characteristics, and the specifics of deployment on the Kviachak River.

2.1 BASIC PROPERTIES OF WAVES AND SOUND

Waves are, in the most general sense, transitory disturbances caused by the movement of energy and information. When a wave interacts with a system, the state of the system is temporarily altered, but after the wave has passed, the system returns to its original state, although perhaps slightly altered by the wave's passing [1].

Waves are characterized by several principal properties. Frequency (f) describes the number of full oscillations of a wave as measured by a stationary observer over a period of time. The conventional unit of measurement of frequency is the Hertz (Hz), which has units of $1/s$. The inverse of frequency is known as the wave period (T), which is the number of seconds that elapse per oscillation. The wavelength (λ) of a wave is the distance from crest to crest of a wave.

Sound is a compressional wave that propagates through a material. The speed of sound, *c*, is set by the properties of the medium, and is related to frequency and wavelength by Eq. 2.1.1 [1], such that

$$\lambda f = c \,. \qquad 2.1.1$$

Typical sound speeds in air are approximately 343 m/s, while speeds in water are around 1500 m/s. The significant difference in speed is, primarily, a result of the higher density of water. Underwater sound speed also varies as a function of temperature, depth, and salinity. In the ocean, spatial variations in these parameters cause sound to propagate in fascinating ways, making the *sound speed profile* an important property to characterize. Relationships between temperature, depth, and salinity typically take forms similar to [11]

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S - 35) + 0.016z \ . \quad 2.1.2$$

2.2 SOURCE BEARING ESTIMATION BY TIME-DELAY OF ARRIVAL ESTIMATION

A method to determine the bearing of an acoustic source relative to an array of hydrophones is described by Wahlberg [10]. For two or more hydrophones coherently measuring incoming sound, the time delay of arrival (TDOA) of each wave-front will differ with hydrophone position. Provided the distance from the source to the hydrophone pair is long relative to the spacing between hydrophones, L_{mn}, wave-fronts can be approximately as plane waves. This assumption, in combination with knowledge of the TDOA, denoted τ_d, allows calculation of the angle of incidence of the arriving plane wave (Eq. 2.3.1 and Figure 1), given by

$$\cos(\alpha_{mn}) = \frac{c\tau_d}{L_{mn}} \ . \qquad 2.2.1$$

In Eq. 2.2.1, c is the speed of sound and α_{mn} is the angle between an arriving plane wave and the axis of the receiver pair. A complex solution arises for values of $c\tau_d / L_{mn}$ exceeding a magnitude of 1. In practice, this can occur if the $r >> L$ assumption is not valid, implying non-planar wavefronts. Error in TDOA estimation, which may result from noise or receiver motion and orientation changes, can also result in complex results. Time delay of arrival can be estimated by examining the cross-correlation $R_{ab}(\tau)$ between two signals $a(t)$ and $b(t)$, (Eq. 2.3.2)

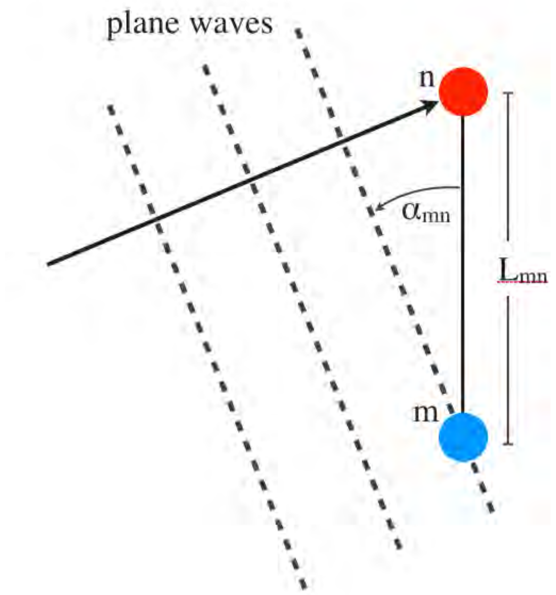


Figure 1: Source Localization Theory. Angle of incidence is calculated from the time delay of arrival of plane waves at spatially separated coherent hydrophones.

$$R_{ab}(\tau) = E\left[a(t)b(t+\tau)\right] \tag{2.2.2}$$

where E is the expected value function. The index of the maximum of the cross-correlation function provides an estimate of the time delay of arrival between two hydrophones. In this case, the hydrophone producing signal b is assumed to be further from the source. As seen in Figure 2, lag at the maximum cross correlation can take on small values for two closely spaced hydrophones,

Higher resolution in source localization measurements can be achieved by changing one of the three parameters on the right hand side of Eq. 2.2.1. Increasing L_{mn} generally results in a larger time delay of arrival at adjacent hydrophones. However, increasing L_{mn} increases the minimum range for which a wave can be assumed to be planar. Alternatively, increasing τ_d by means of using measuring at higher sample rates can easily increase resolution. Finally, using multiple hydrophone pairs can increase accuracy substantially.

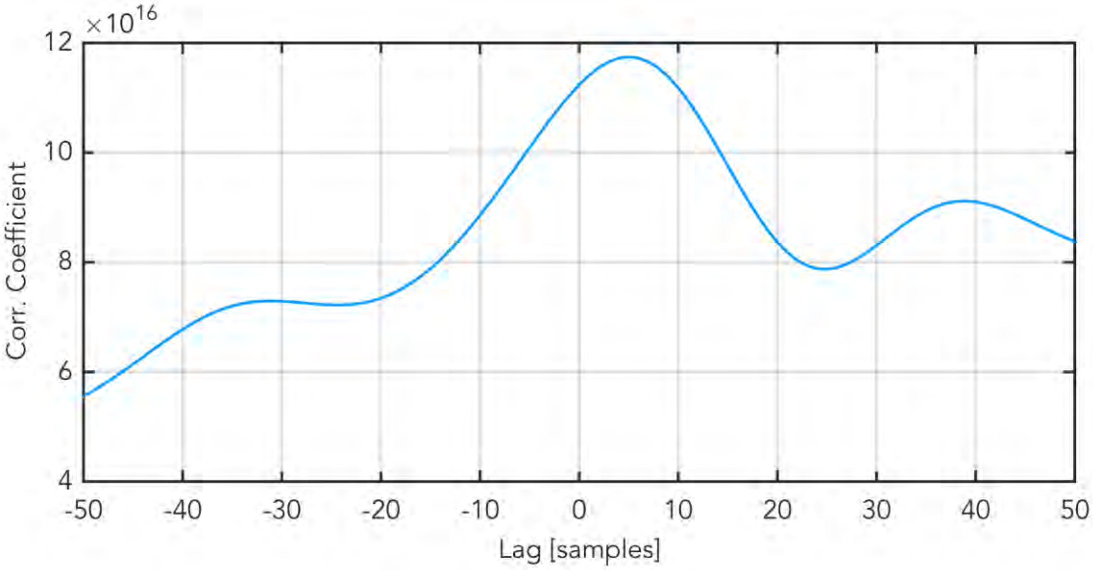


Figure 2: Example cross-correlation from closely spaced hydrophones.

Calculation of the bearing angles for a multiple receiver array goes as (Eq. 2.3.3) [10]

$$(r_x(i)-s_x)^2+(r_y(i)-s_y)^2+(r_z(i)-s_z)^2=c^2(T_1+t(i))^2 \qquad 2.2.3$$

where the coordinates $r_x(i)$, $r_y(i)$, and $r_z(i)$ correspond to the position of each receiver. The coordinates s_x, s_y, and s_z correspond to the position of the source. The bearing angles relative to the Cartesian axes can be calculated by solving a system of equations based on Eq. 2.2.3 (Eqs. 2.3.4 through 2.3.8) [10],

$$(\vec{r}_i-\vec{r}_j\ )\cos\left(\theta_{ij}\right)=c\tau_{ij} \qquad 2.2.4$$

$$Ax=b \qquad 2.2.5$$

$$A^T Ax=A^T b \qquad 2.2.6$$

$$(A^T A)^{(-1)} A^T Ax=(A^T A)^{(-1)} A^T b \qquad 2.2.7$$

$$x = (A^T A)^{(-1)} A^t b \tag{2.2.8}$$

where x is a vector of cosines of the bearing angles. The bearing angles can be determined by taking the inverse cosine of x, such that

$$\alpha = \cos^{-1}(x_1) \tag{2.2.9}$$

$$\beta = \cos^{-1}(x_2) \tag{2.2.10}$$

$$\gamma = \cos^{-1}(x_3). \tag{2.2.11}$$

Finally, the azimuth and elevation angles can be calculated (Eqs. 2.3.12 and 2.3.13) as

$$\theta = \tan^{-1}\left(\frac{\beta}{\alpha}\right) \tag{2.2.12}$$

$$\varphi = \tan^{-1}\left(\frac{\left(\alpha^2 + \beta^2\right)^{\frac{1}{2}}}{\gamma}\right). \tag{2.2.13}$$

Where θ is the azimuth angle and ϕ is the elevation angle.

2.3 SITE CHARACTERISTICS

The Kviachak River flows from Lake Iliamna to Bristol Bay in southwest Alaska (Figure 3). The village of Igiugig sits at the headwaters of the Kviachak River and currently generates most of its electricity from diesel generators. Near the site river currents often exceed 2 m/s, turbidity is low, and the river is largely free of debris, making it a particularly good candidate for hydrokinetic power generation.

At the turbine deployment site, the river bed is predominantly small cobbles (less than 10 cm diameter), overlying gravel and coarse sand. Based on the shoreline composition, the cobble layer likely overlays fine, unconsolidated sediments. Closer to the river mouth, the bottom was composed of much finer sand and little cobble, while downstream of the turbine site the bottom composition varied between regions primarily composed of coarse sand and gravel and regions dominated by small cobbles. The average water temperature in the vicinity of the turbine was 16 °C, measured at a depth of 1 m on August 21 and 24, which, with zero salinity (freshwater), results in a sound speed of approximately 1469 m/s [11].

There are abundant fish in the Kviachak River, most notably sockeye salmon. Each year, these salmon migrate up the Kviachak to Lake Iliamna to spawn. Adult salmon typically swim upstream through the shallow edges of the Kviachak, where flow rates are lower to conserve energy for spawning, while juvenile salmon outmigrating to the ocean are found to swim through the generally faster and deeper channels near the middle of the river.

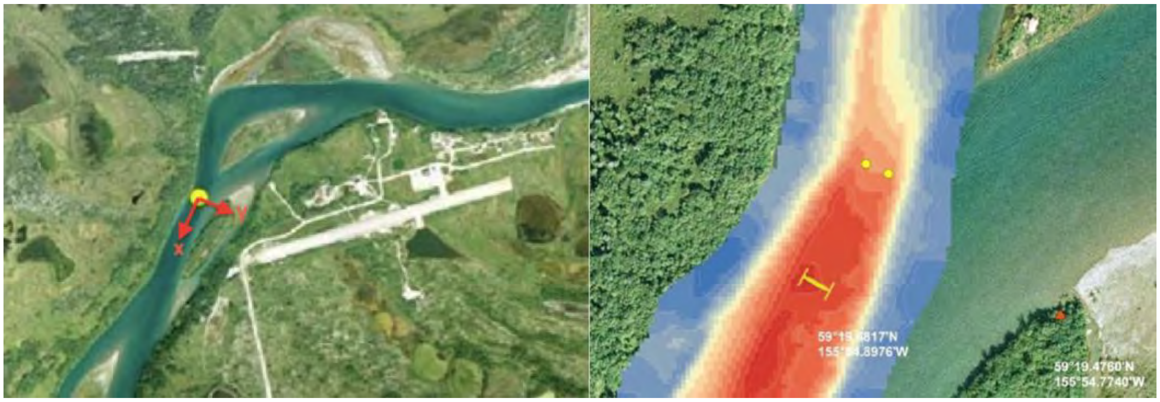


Figure 3: RivGen Site. The village of Igiuig on the Kviachak River, flowing from Lake Iliamna (left, out of frame). The turbine location and coordinate system are shown with satellite view of the village of Igiugig (left). Local bathymetry and locations of upstream anchors can be seen (right). Position of turbine is approximate.

2.4 RIVER TURBINE

A RivGen river current turbine, developed by the Ocean Renewable Power Company (ORPC), was installed on the Kviachak River in August 2014. The RivGen (Figure 4) turbine is a helical, cross-flow turbine (horizontal orientation) designed to produce power from river currents. The RivGen turbine has five principal components: turbine rotor, generator, support frame, pontoons, and power export cable to a shore station. During deployment, the turbine is towed to location and moored to upstream anchors. The generator is a 3-phase AC direct drive design (no gearbox), and, for initial characterization testing, rotation rate is varied by application of a resistive load at a shore station. When the applied resistive load results in a rotation rate that maximizes power output, the turbine is said to be operating optimally. At low resistance, the generator approaches a short-circuit operating condition and produces enough opposition torque to bring the turbine to a stop. In a commercial operation, the power delivered to shore would connect with the local electricity grid.

The RivGen turbine is submerged in an area with an average depth of 5 meters. Because of the height of the turbine foundation, the rotational-axis depth is approximately 2.5 meters.

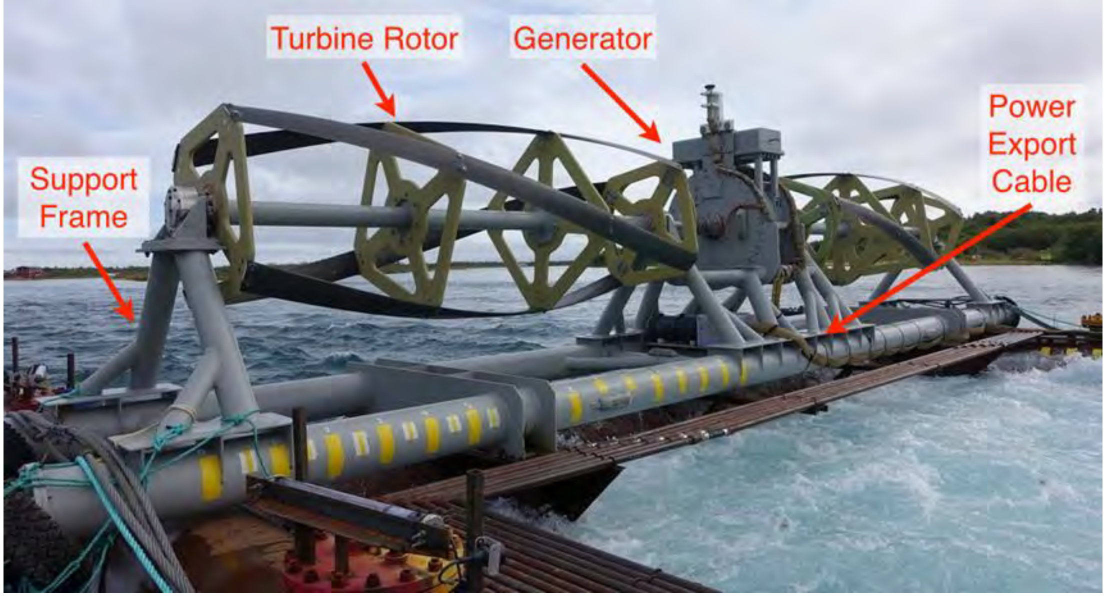


Figure 4: RivGen Turbine. The ORPC RivGen turbine moored and floating on the surface of the Kviachak River during maintenance.

2.5 'RIVRAFT' DRIFTING HYDROPHONE ARRAY

As sound waves pass through a medium, fluid particles are disturbed in an oscillatory manner that is well described by the Navier-Stokes equations [1]. Because viscous effects are neglected, it is common to see the Euler equations referenced instead. It is convenient in underwater acoustics to linearize the Euler equations, thus reducing their complexity without a significant loss of accuracy. Estimation of particle motion follows from a substitution in the linearized Euler equations.

In this study, we estimate particle acceleration using a finite difference approximation for the pressure gradient from coherent and spatially separated hydrophones [12]. Beginning with the linearized Euler equation [13]

$$\nabla p(t) = -\rho_0 \vec{a}(t), \tag{2.5.1}$$

where $\nabla p(t)$ is the pressure gradient, $\vec{a}(t)$ is the particle acceleration, and is the density of the fluid, the approximation for particle acceleration given by the finite difference approximation becomes

$$a_{21}(t) = -\frac{\left(p_2(t) - p_1(t)\right)}{\rho_0 \; d}, \tag{2.5.2}$$

where $p_1(t)$ and $p_2(t)$ are the pressures at hydrophones 1 and 2, respectively, and d is the separation distance between hydrophones. To estimate particle acceleration for sound with wavelength λ with a maximum plane wave systematic intensity error of -0.5 dB, a hydrophone spacing of satisfying $d < \lambda/8$, is required [13]. An increase in bandwidth is afforded by decreasing *d*, however this results in higher phase errors at low frequencies, where the pressure field can take on smaller values at adjacent points. Therefore, it is advantageous to choose d such that only the highest frequencies (smallest wavelengths) of interest can be measured, as any additional reduction in *d* will result in increased error.

Particle velocity can be estimated by cumulatively integrating both sides of Eq. 2.5.2, such that

$$v_{21}(t) = -\int_{-\infty}^{t} \frac{\left(p_2(t) - p_1(t)\right)}{\rho_0 \; d} d\tau. \tag{2.5.3}$$

The physical environment of the acoustic near field of a hydrokinetic turbine complicates instrument deployment (currents on the order of a few meters per second). Freely drifting systems equipped to measure acoustic pressure around tidal turbines have been successfully deployed and are effective at minimizing contamination by “flow noise”, which arises from differential velocity between hydrophone elements and water currents [14] [15]. The RivRaft (Figure 5) is a rigid and freely drifting platform that minimizes net fluid flow over the face of mounted hydrophones, thereby greatly reducing flow noise.

2.5.1 *Platform Design*

Because of the remoteness of the study site, the RivRaft was designed to ship disassembled be assembled on site, and be deployed/recovered by a small crew with minimal mechanical assistance. The RivRaft frame was constructed of 80/20 15-series ultra-lite extruded aluminum (Figure 5). The 80/20 frame permitted reconfiguration when necessary and was both lightweight and stiff. Buoyancy was provided by four 91 cm x 15 cm outer diameter pontoons (foam-core schedule 40 PVC). The overall weight of the instrumented system in air was approximately 72 kg, and its reserve buoyancy was approximately 20 kg. The measurement array was at the base of a “chandelier” (Figure 6), a retractable, vertically oriented aluminum spar, which could be raised fully above the water line or lowered to a depth of up to 1.6 m. It was

Figure 5: The RivRaft during deployment on the Kviachak, chandelier submerged (left). The chandelier with hydrophones and Doppler velocimeter in lowered position (right).

desirable for hydrophones to be positioned at moderate depth in the water to avoid close proximity with the water-air interface where the sound field vanishes. The chandelier supported up to four hydrophones (icListen HF, Ocean Sonics) in a tetrahedral arrangement, and the probe for an acoustic Doppler velocimeter (Nortek Vector). The spacing between hydrophones was originally set at 0.6 m, allowing estimation of particle velocity and acceleration up to 400 Hz, and was chosen based on the approximate hearing range of salmon. Following damage incurred to three hydrophones on August 18, a two-hydrophone vertical array was fabricated on site. In order to ensure that both hydrophones were as deep in the water as possible, a separation distance of 15.24 cm was used, allowing estimation of vertical particle velocity and acceleration up to 1200 Hz. Four lines (not pictured) tensioned the submerged chandelier to the surface frame to reduce vibrations. Hydrophones were shielded with cylindrical plastic guards made of perforated PVC. An in-water calibration (conducted in October, following deployment) revealed that overall voltage sensitivity and directional response of the hydrophones were not affected by shielding of this type at frequencies less than 6 kHz.

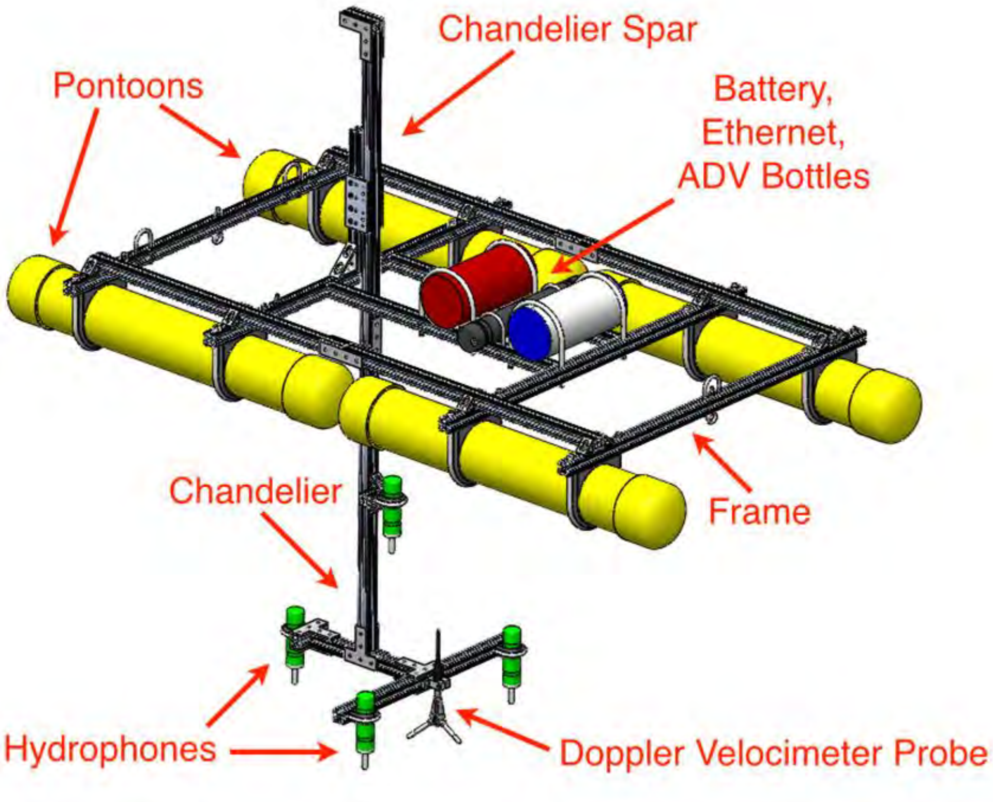


Figure 6: The RivRaft Design: Instrument cables, tensioning lines, and hydrophone flow

shields not shown.

2.5.2 *Instrumentation*

The icListen HF hydrophones have a measurement bandwidth of 10 Hz – 200 kHz, a nominal sensitivity of -168 V/µPa, onboard A/D converter, internal storage, and onboard power. Prior to and following deployment, each hydrophone was calibrated using a M351 field calibrator (GeoSpectrum), which can produce traceable calibration tones at 10, 26, 70, 100, and 250 Hz. A pressure vessel containing an Ethernet switch was used to synchronize hydrophone signals in a master-slave configuration. The Ethernet switch and hydrophones were powered by an external battery pack in a second pressure housing. The Nortek Vector included an integrated inertial motion unit (IMU), allowing measurement of relative motion between the raft and river and changes to orientation. The ADV probe was attached to the bottom of the chandelier to measure relative velocity as close to the array centroid as possible and, therefore, identify the potential for flow noise contamination. A GPS position logger (QStarz BT-Q1000eX) sampling at 1 Hz resolution was used to record raft position. Finally, two cameras (GoPro Hero 3) were included for video documentation. The first was fixed on the top of the chandelier post facing the bow, and the second submerged and fixed at the bottom of the chandelier post, facing the bow but angled downwards for a view of the river sediment.

2.6 FIELD MEASUREMENTS

Acoustic experiments were conducted from August 14 through August 25, 2014. Sound from nearby fishing boats and rain were the primary sources of anthropogenic noise in the measurements and care was taken to document the occurrence of both.

A typical drift configuration is presented in Figure 7, showing the approximate scale of the turbine and nominal distance between the raft and turbine. The turbine location on the river was marked by several surface floats, such that the raft was consistently deployed at a lateral offset to limit the risk of entanglement. Several initial drifts were conducted on August 16 to determine best practices for working on the river. A location to the lee of a small island upstream of the turbine was identified as a suitable deployment site: sheltered from the high velocities in the river, close enough to shore to load and unload the raft from the skiff, and deep enough to lower the hydrophone chandelier while close to shore. From here, the raft was guided into faster currents using a boat hook and allowed to drift. After travelling at least 100 meters past the turbine, the raft was recovered by the skiff crew, the chandelier was retracted, and the raft was then towed to an area of slow flow downstream. At this location, the raft was loaded on to the skiff and returned to the upstream location for subsequent drifts.

Sound pressure and particle motion were measured with the turbine in one of two operational states: "braked" and "optimal". When operating in "braked" mode, the turbine was not rotating or generating power. When operating in "optimal" mode, a turbine rotated at a rate of approximately 50 rpm, which coincided with the optimal tip speed ratio [16].

During the preliminary drifts on August 16, three hydrophones were submerged with the lowest hydrophone 0.76 m below surface, but the raft was not equipped with a GPS tracker, ADV, or IMU. Following reconfiguration after hydrophone damage on August 18, measurements resumed on the 22, 24, and 25 with the reconfigured vertical orientation 2-hydrophone array. The analysis presented here focuses on data from August 25, on which total of five drifts were conducted. On August 25, hydrophone 1 was deployed at a depth of 0.61 m, and hydrophone 2 at a depth of 0.47 m (for a mean array depth of 0.53 m). For simplicity, the three braked cases will be referred to as Braked 1-3, and the two optimal cases as Optimal 1-2.

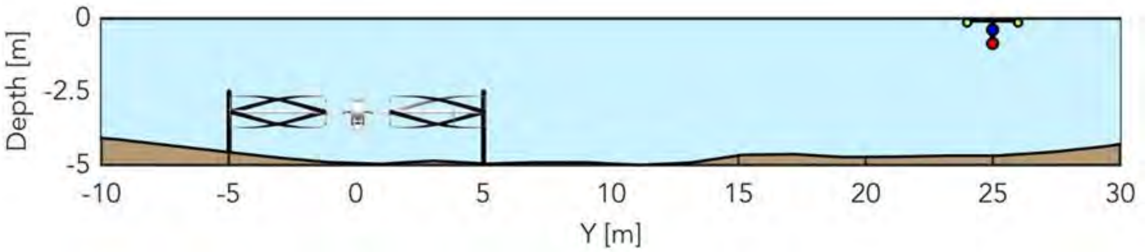


Figure 7: Cross-section of typical drift configuration. Raft shown with two element vertical array: hydrophone 1 (red), hydrophone 2 (blue).

2.7 DATA PROCESSING

2.7.1 *Sound Pressure Level and Pressure Spectral Density*

Sound pressure level and pressure spectral density are standard measures of sound are merit description. The sound pressure level (SPL),

$$SPL = 10log_{10}\left(\frac{p_{rms}^{2}}{p_{0}^{2}}\right) \tag{2.6.1}$$

is a ratio of the square of root mean square pressure, p_{rms}, to the square of a standard pressure, p_0, expressed logarithmically in units of decibels (dB) (Eq. 2.6.1). Because of the large dynamic range in acoustic measurements, logarithmic measures of magnitudes are particularly convenient. The pressure spectral density, given by

$$S_p\left(f\right) = \frac{2\left|\mathrm{F}\ \left\{x\left(t\right)\right\}\right|^2}{Nf_s} \tag{2.6.2}$$

is a measure of the distribution of variance in a pressure time series over frequency. Practically, pressure spectral density can be calculated only up to a maximum frequency, called the Nyquist frequency, which is equivalent to half of the sampling frequency used to measure the pressure time series. The pressure spectral density, $S_p\left(f\right)$, can be calculated by Eq. 2.6.2, where $\mathrm{F}\ \left\{x\left(t\right)\right\}$ is the Fourier transform of the pressure time series, N is the number of samples, and f_s is the sampling frequency.

The spectrum is calculated over discrete windows, or regularly sized segments, of the pressure series. Windows are averaged to produce the final spectrum. Because the FFT algorithm assumes periodic signals (a measured pressure time series is unlikely to be perfectly periodic), tapered windows help to reduce spectral leakage. A taper, such as a cosine taper, creates an artificially periodic signal. Windows are overlapped to compensate for the loss of information at the edges of each tapered window. Computationally, this requires the calculation of a higher number of FFTs, but overlaps of 50% are usually enough to provide an accurate measure of spectral distribution. Spectrograms are a way of viewing the change in pressure spectral density over time and are constructed by calculating the pressure spectral density in regular windows.

2.7.2 *Hydrophone Array*

The recorded voltage data are band-pass filtered in the time domain using a phase preserving method to exclude frequencies below 30 Hz and above 1200 Hz (where particle motion measurements are not accurate), except for general considerations of broadband sound production by the turbine, for which the high pass filter is extended to 10 kHz. Recorded voltage data were sampled at 256 kHz, but subsequently down-sampled (after filtering) by a factor of 10 to reduce file size. The effective hydrophone sample rate after down-sampling is 25.6 kHz.

The recorded voltage time series are converted to pressure by first calculating the fast Fourier transform of the data, then multiplying by frequency dependent calibration curves obtained from the M351 field calibrator. After converting from complex voltage spectra to complex pressure spectra, an inverse Fourier transform is used to return to the time domain for further processing (such as time-domain calculation of particle motion). Frequency-dependent sensitivity curves are approximated by a cubic spline interpolation between discrete calibration frequencies (10, 26, 70, 100, 250 Hz). In general, hydrophone sensitivity varied between instruments at the same frequency by no more than 1 dB re 1 V/µPa and was flat above 250 Hz for individual instruments.

Time-domain pressure measurements and particle motion estimates are demeaned where appropriate and prior to subsequent spectral processing. Pressure spectral densities and spectrograms are calculated from the average of the pressure signals from hydrophones 1 and 2, such that pressure and motion spectra are presented for the same depth (~0.53 m).

Pressure spectrograms for analyzing low frequency sounds are produced using quarter second window (6400 samples) with cosine tapers (hamming) and 50% overlap. On occasion, transient “clicking” sounds were heard, and for these short duration signals pressure spectrograms are created using 1/16th second windows (1600 samples) with a cosine taper (hamming) and 50% overlap. Pressure and particle acceleration spectral densities are calculated using MATLAB’s “pwelch” function using quarter second windows (6400 samples) with cosine tapers (hamming) and 50% overlap, and are presented with 95% confidence intervals generated by the pwelch function.

As will be shown (Results, Acoustic Particle Motion), distinct spectral peaks are apparent in the “optimal” spectra and denoted H1, H2, and H3. The frequency of the H1 tone, which oscillates during a drift, is calculated by identifying the frequency with the maximum spectral level in the 90-110 Hz band. Here, pressure spectral densities are calculated for 1.5 s long intervals. Each interval is assigned a location in the along-stream direction (x) corresponding to the raft position at the temporal mid-point of the interval. Each interval is demeaned and windowed into intervals with 6400 points with a cosine taper (hamming) and 50% overlap. RMS pressure for each tone is determined by integrating the spectra over a 5 Hz band centered at the peak frequency, and then calculating the square root of the result.

A result presenting the decay of the 1/3 octave band centered on 100 Hz with range for the Optimal 1 drift will be shown (Results). Calculations of 1/3 octave band levels are done in the frequency domain by integrating over calculated pressure spectral densities within the lower and upper limits of each band. Here, PSDs are calculated using half second windows over segments of 1.5 seconds. Range from the turbine is determined using the approximate raft position at the midpoint of each time segment. Maximum and minimum values of the braked data within a region without boat noise provide a measure of the ambient conditions on the river in the same band.

2.7.3 *ADV*

Relative velocity was measured in three directions, and the norm is calculated. The relative velocity between the raft and the current can be used to determine the spectral contamination from flow noise.

2.7.4 *GPS*

GPS data was recorded in degrees latitude and longitude, and is converted to Cartesian coordinates with the origin located at the turbine centroid (59.3247°N and -155.9151°W). The Cartesian coordinate system is rotated 107 degrees clockwise such that the turbine's rotational axis is oriented along the y-axis, and the river currents are approximately along the x-axis. Cubic interpolation from GPS data (sampled at 1 Hz) is used to approximate the raft position at any time, though GPS measurements are likely accurate to 5 meters at best.

2.7.5 *Correlation with Turbine Performance*

The turbine rotation rate (sampled at 1 Hz) was provided by Ocean Renewable Power Company. As with GPS data, cubic interpolation was used to approximate the velocity between sampled points to correlate turbine rotation rate with acoustic measurements. We note that this process involves three, asynchronous clocks: the clock on the master hydrophone (synchronized before deployment to the clock on a PC synchronized using Network Time Protocol), the clock on the Ocean Renewable Power Company data acquisition system (synchronized daily using Network Time Protocol), and the GPS logger (GPS time information). Consequently, the difference between clocks is likely to be much less than the 1 second time basis for which GPS and rotation rate information is available.

Chapter 3. RESULTS

3.1 RIVRAFT PERFORMANCE

The RivRaft's heading, pitch, and roll time series are indicative of the platform's stability (Figure 8). Similarly, the relative velocity between the river current and raft is indicative of the probable contamination by flow noise.

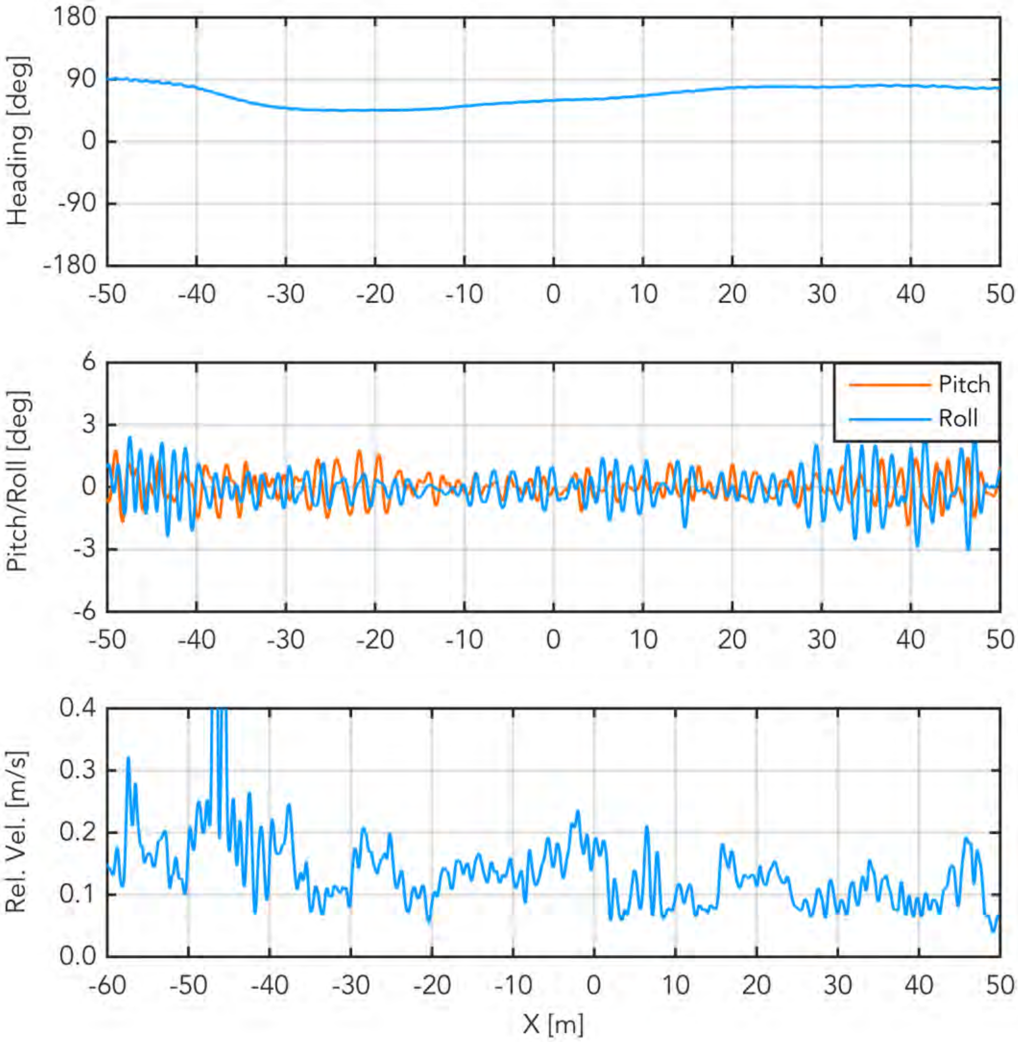


Figure 8: RivRaft Stability. Characteristic heading, pitch, roll, and relative velocity.

For relative velocities less than 0.5 m/s, flow noise is not expected to mask propagating sound at frequencies higher than order 10 Hz [14]. Because relative velocities were typically less than 0.3 m/s for RivRaft drafts, flow noise contamination is likely to be minimal.

3.2 DRIFT PATHS

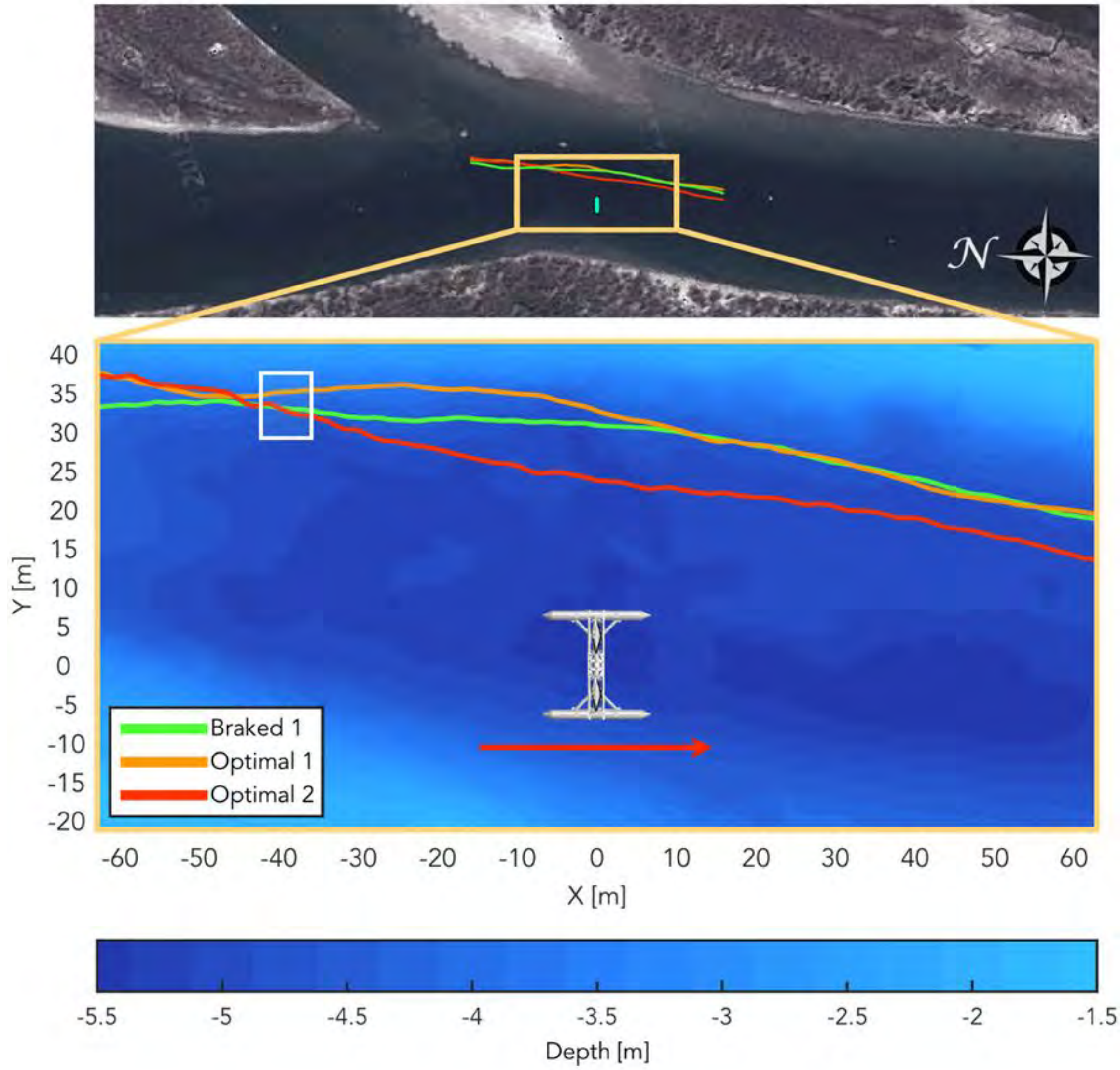


Figure 9: Bathymetry and Drift Paths. The bathymetry of the measurement area is shown with drift paths and turbine overlaid. The red arrow indicates flow direction. The white box denotes the region presented in Figure 13 and Figure 14.

The path taken by the RivRaft varied from drift to drift for the five cases considered (two "optimal", three "braked"). While two of the braked drifts are severely contaminated by significant boat noise from fishing vessels and not discussed here, the remaining braked drift and both optimal drifts are relatively uncontaminated. These are overlaid on a plot of site bathymetry (Figure 9). The red arrow indicates the flow direction. The depths along the drift trajectories are typically 1-2 meters (20-40%) shallower than at the turbine deployment site (5 m depth).

3.3 ACOUSTIC PRESSURE

A spectrogram of the averaged pressure between both hydrophones from Optimal 1 (orange drift in Figure 10) reveals a tone centered at 100 Hz (Fig. 8).

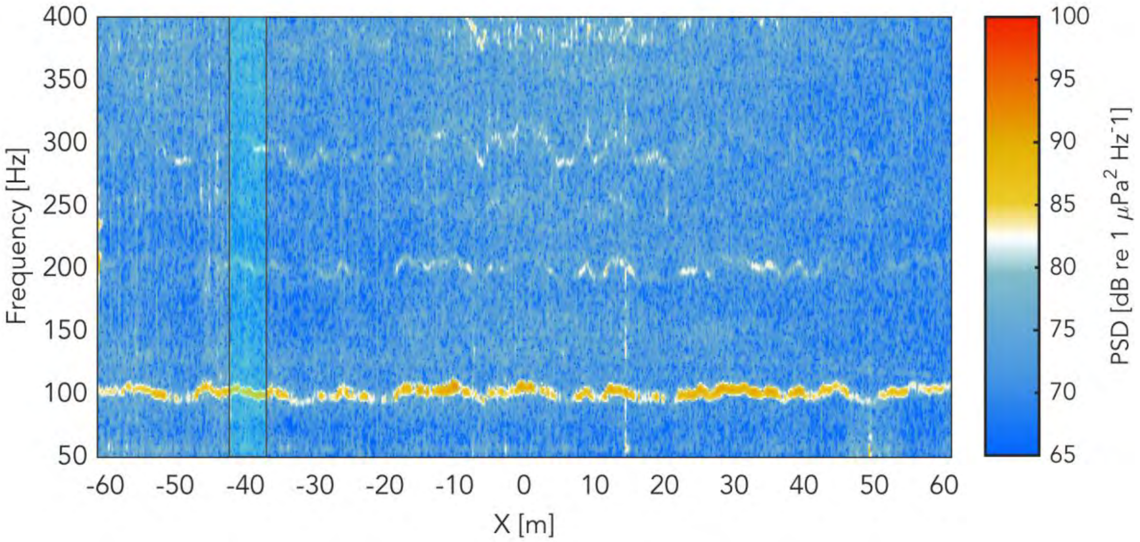


Figure 10: Pressure Spectrogram, Braked 1. A spectrogram of pressure from Braked 1 is shown. Boat noise contaminates the region of measurement from -20 m downstream of the turbine to approximately 50 m upstream of the turbine. The blue highlighted region denotes the area of analysis that corresponds to Figure 13 and Figure 14.

The center frequency of the 100 Hz tone appears to vary either in time or with distance from the turbine (a distinction that is not immediately clear because of the motion of the RivRaft during measurements). Tones at 200, 250, and 300 Hz with similar fluctuations in frequency are also visible, and tones centered at frequencies near 400 and 500 Hz may also be present, but are more difficult to distinguish from ambient noise.

Measurements while the turbine was braked contain boat noise from sport fishing traffic during portions of all drifts, which rendered braked drifts 2 and 3 unusable. A long period without boat noise from Braked 1 reveals that the 100 Hz and higher tones are not present while braked (Figure 11). It is notable that boat noise (occurring while the raft was between x = -20 m and x = 50 m, relative to the turbine), is similar in frequency and level to turbine sound for the 100 Hz harmonic, but without knowledge of the boat's position as a function of time, a direct comparison between sound produced by the turbine and fishing vessels is not possible.

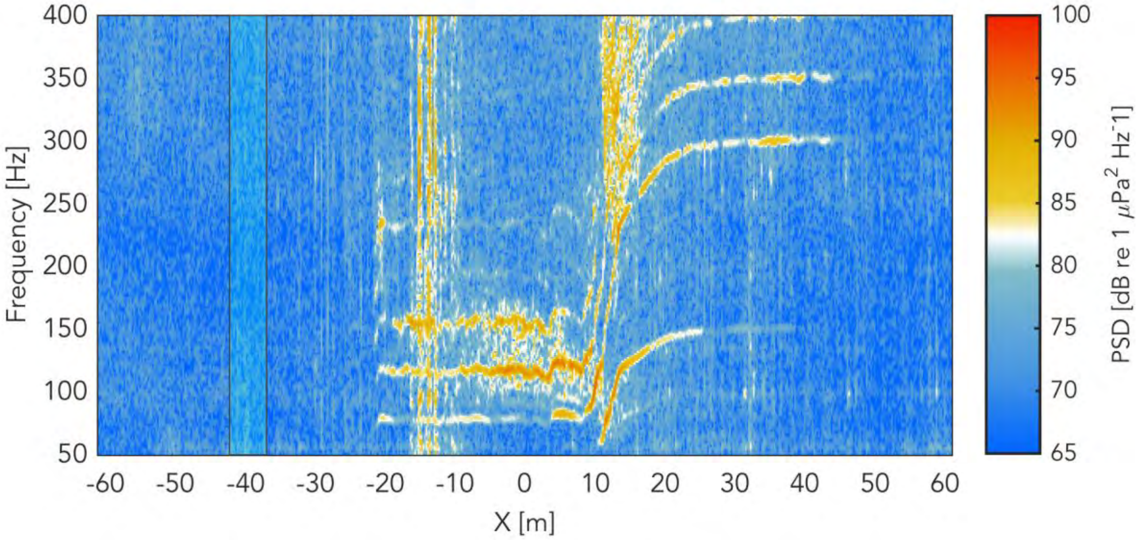


Figure 11: Pressure Spectrogram, Braked 1. A spectrogram of pressure from Braked 1 is shown. Boat noise contaminates the region of measurement from -20 m downstream of the turbine to approximately 50 meters upstream of the turbine. The blue highlighted region denotes the area of analysis that corresponds to Figure 13 and Figure 14.

In addition to the low frequency tones, a periodically occurring short duration broadband sound can be seen in the spectra at higher frequencies (Figure 12). This sound is audible in recordings and may be described qualitatively as a "clicking" sound. The "click" appears only when the turbine is operating.

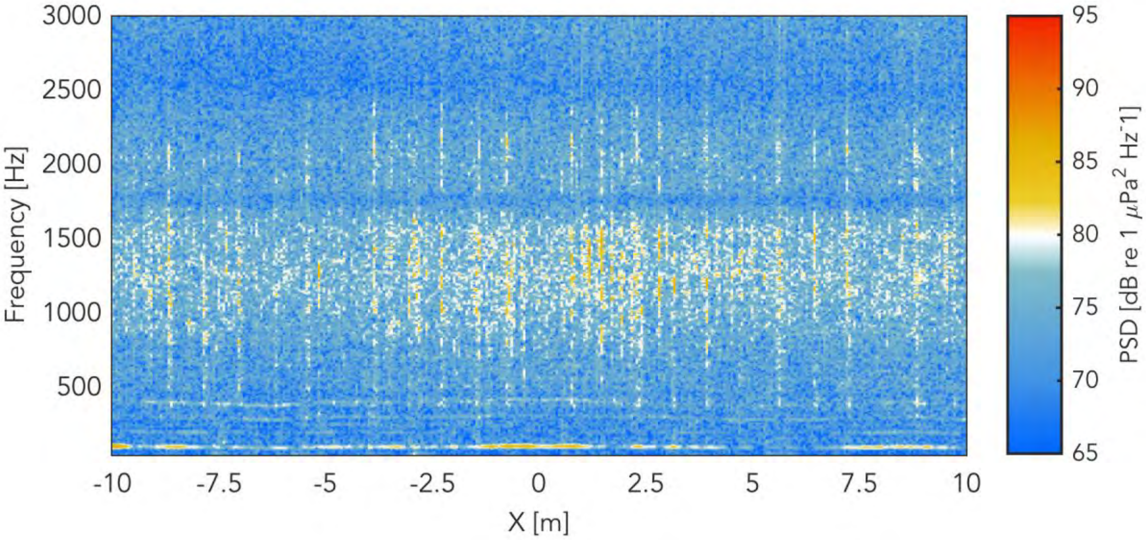


Figure 12: Clicking Noise. The broadband "clicking" noise is most visible in the 1000-2000 Hz band. Low frequency tones discussed previously are visible below 500 Hz.

A comparison of average pressure spectral density from Optimal 1 and Braked 1 over the region from *x* = -42 m to *x* = -38 m upstream of the turbine shows that the peak received level for the 100 Hz tone from the Optimal case can exceed the braked level (as close to a measure of background noise as is possible for this study) by as much as 30 dB re 1 µPa2 Hz-1 (Figure 13). Peak received levels for the 200 and 300 Hz tones can exceed braked levels by as much as 10 dB re 1 µPa2 Hz-1. In general, received levels above 100 Hz are higher for the optimally operating turbine than braked turbine.

The 100, 200, and 300 Hz tones are the most noticeable features of the optimal case spectra, and are present only during turbine operation. Because of their regular spacing and similar frequency fluctuations, it is plausible that they are harmonics. For clarity throughout the following sections, the tones appearing near 100, 200, and 300 Hz are denoted H1, H2, and H3, respectively.

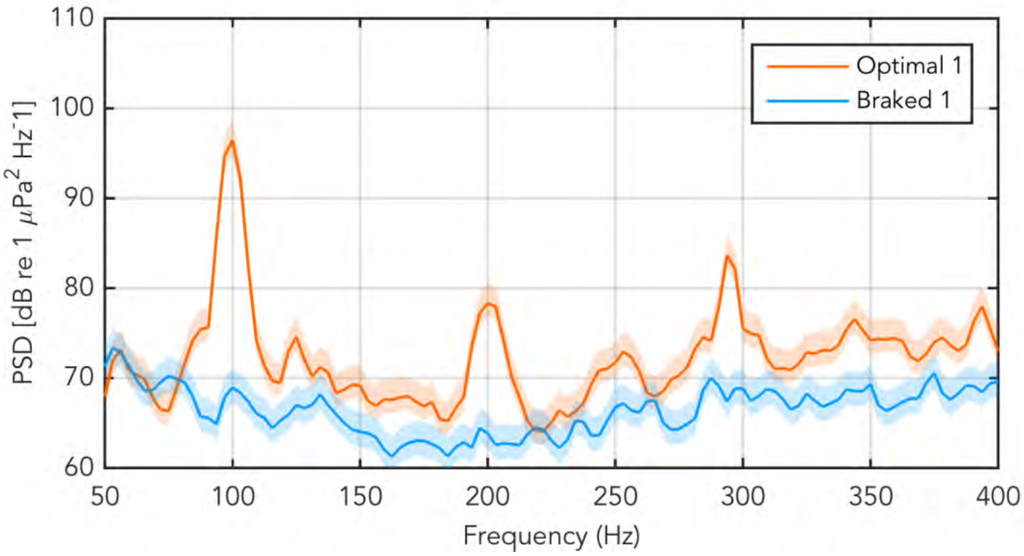


Figure 13: Pressure Spectral Densities of Braked 1 and Optimal 1. PSD for Braked 1 and Optimal 1 over the period when the raft was between *x* = -42 m to *x* = -38 m. The shaded regions show the boundaries of 95% confidence intervals.

3.4 ACOUSTIC PARTICLE VELOCITY AND ACCELERATION

The tones in the pressure spectra are not clearly distinguishable in the vertical acceleration spectra (Figure 14).

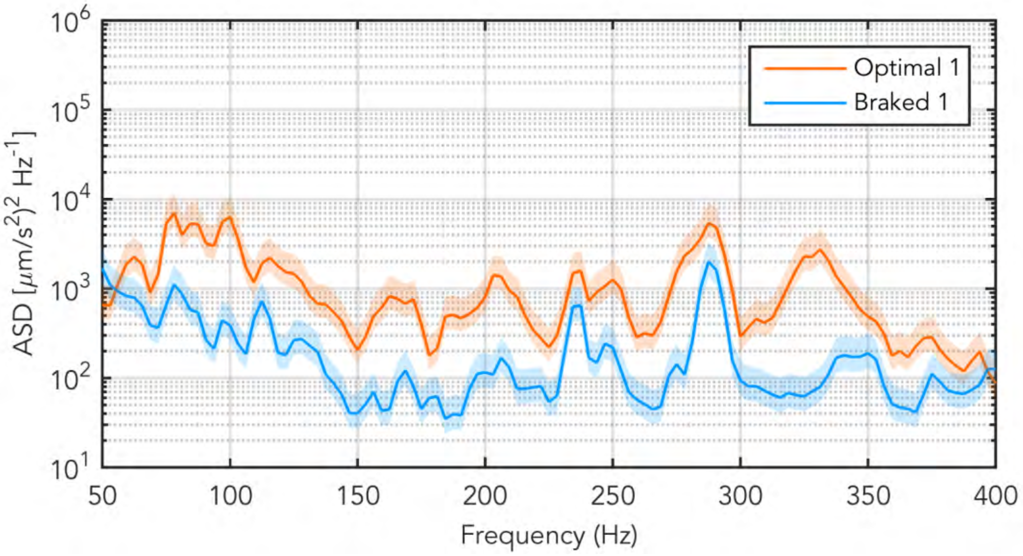


Figure 14: Acceleration spectral densities of Braked 1 and Optimal 1. ASD for Braked 1 and Optimal 1 over the period when raft was between *x* = -42 m to *x* = -38 m. The orange shaded region shows the boundaries of a 95% confidence interval.

The measured pressure spectral density can be compared to a prediction of the particle velocity by assuming that the measured sound propagates as a plane wave at all frequencies (Figure 15). Here, the left y-axis shows the measured pressure spectral density (Optimal 1, *x* = -40 m), and the right y-axis shows the predicted particle velocity spectral density based on the measured pressure. The measured particle velocity spectra density is plotted, which shows that the plane wave assumption is not valid at lower frequencies (at least less than 500 Hz).

An analysis of the river in the context of normal modes may explain this lack of agreement. Generally, the pressure field rolls off with decreasing distance from the air-water interface, while the particle velocity and acceleration take on their greater magnitudes. This effect is evident at greater depths from the air-water interface for lower frequencies, but is less significant for higher frequencies. Therefore, it is plausible that the vertical components of particle velocity and acceleration at 100 Hz are masked by other particle motion in the river at this depth (0.53 m).

Predicted particle velocity is near in value to the measured vertical particle velocity at frequencies above 500 Hz, indicating that the plane wave assumption is more accurate. Interestingly, between 750 and 1250 Hz, vertical particle velocity is less than the expected plane wave value, which may indicate that the horizontal component is more significant, while the vertical and component is approximately equal to the predicted particle velocity above 1250 Hz, indicating that most of the sound may be propagating vertically at these frequencies.

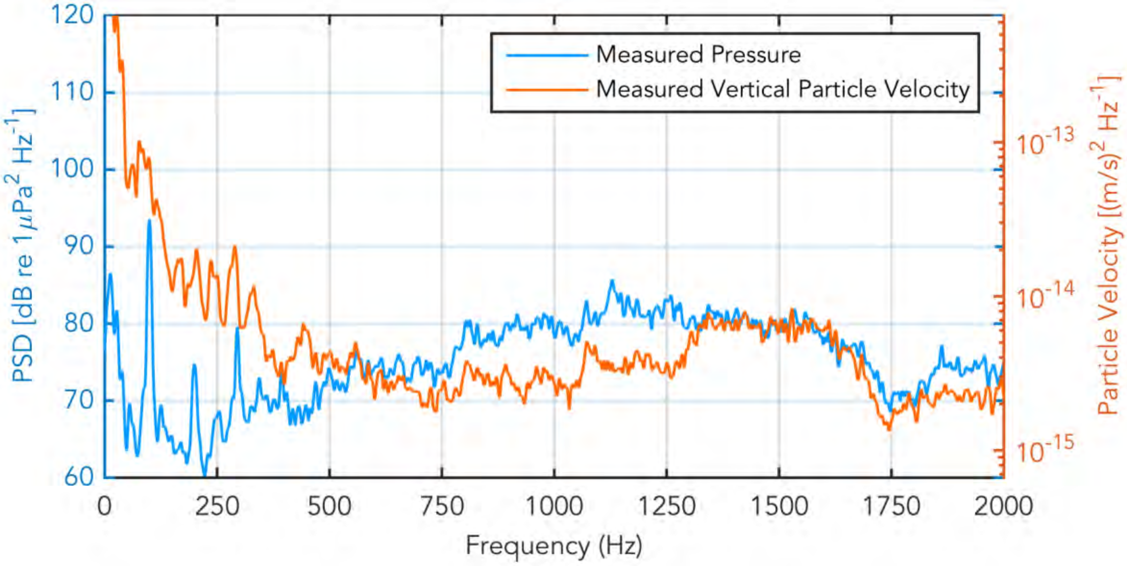


Figure 15: Measured pressure and particle velocity for Optimal 1 over the period when the raft was between x = -42m and x = -38 m. Using right axis, pressure may be interpreted as the predicted value of particle velocity following a plane wave assumption.

3.5 MAGNITUDE AND FREQUENCY VARIATION IN THE H1 TONE

A comparison of the time series of the RMS pressure of the H1 (Optimal 1) tone to the angular velocity of the RivGen turbine shows these quantities are correlated in time (Figure 16). Similarly, the center frequency of the H1 tone also exhibits a strong correlation with turbine rotation rate. The variations in rotation rate are likely the effect of riverine turbulence applied against a constant generator resistance (time-varying generator voltage and current) [17].

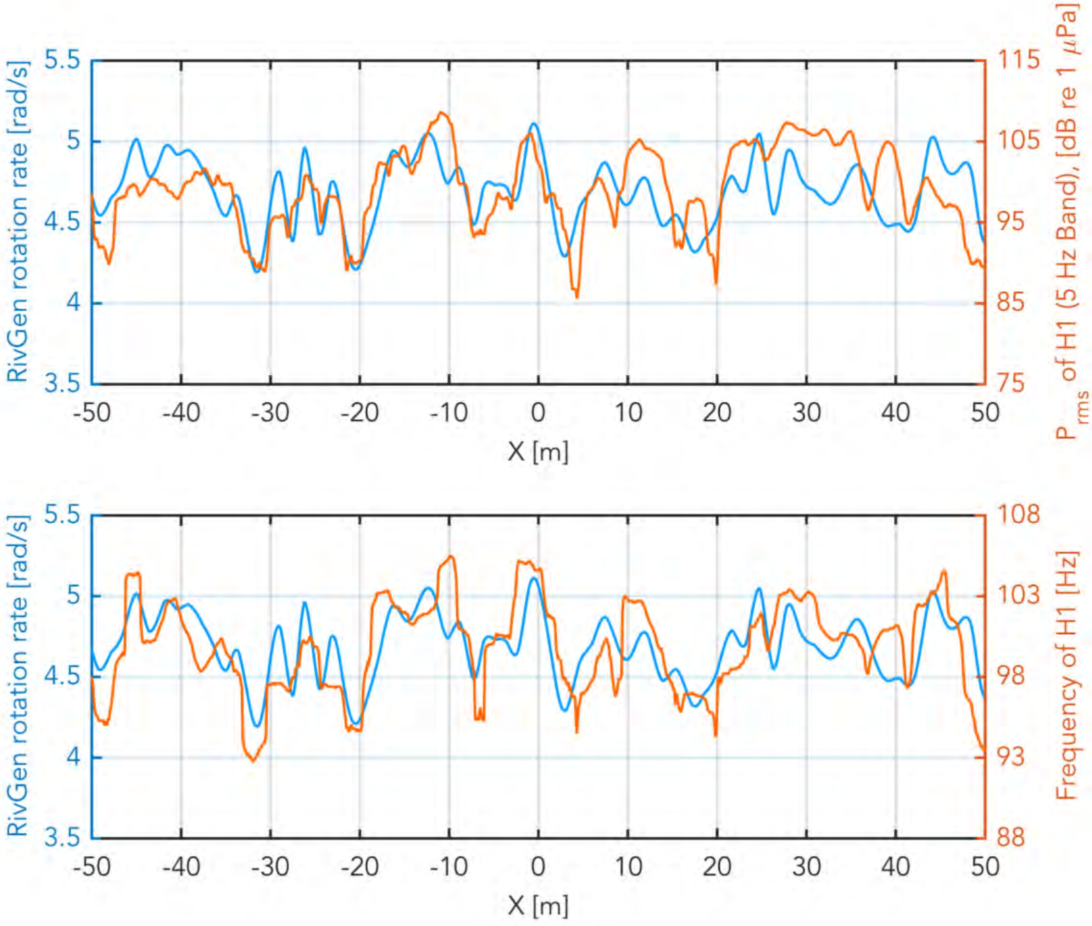


Figure 16: Turbine Rotation Rate, P_{rms} (integrated over 5 Hz band) and Frequency of H1 Tone (Optimal 1).

3.6 1/3 OCTAVE BAND LEVEL CONTAINING H1 TONE WITH RANGE

An analysis of the level of the 1/3 octave band centered on 100 Hz reveals that the 100 Hz tone for Optimal Drift 1 decays to within ambient levels within 125 m downstream of the turbine (Figure 17). Here, the shaded blue region is bounded on top and bottom by the maximum and minimum values of the braked data in the same band.

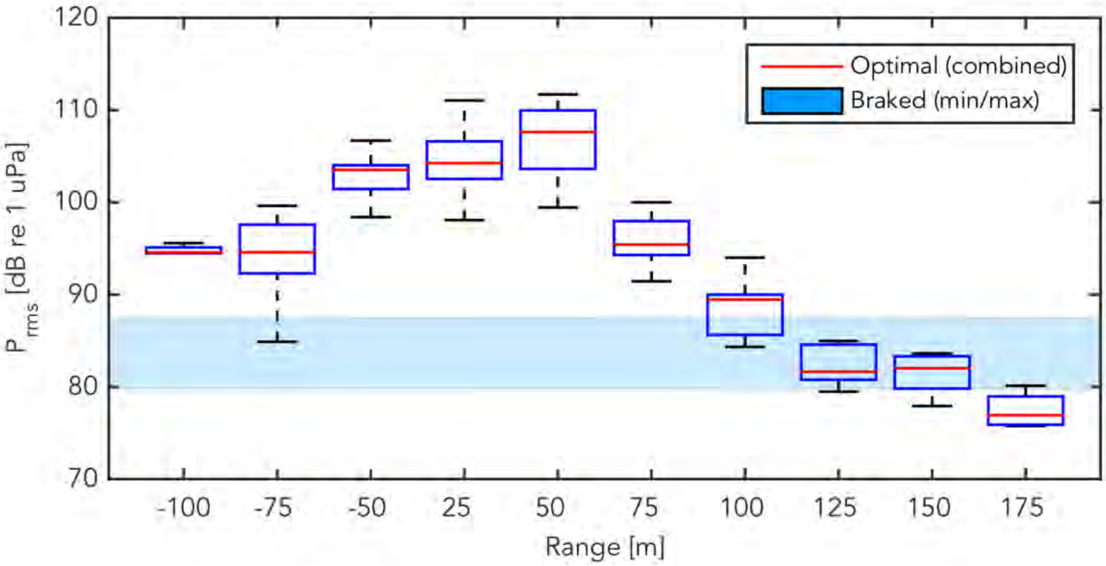


Figure 17: 1/3 Octave Band Level (centered at 100 Hz) of Optimal 1 with range. Negative ranges correspond to upstream positions, positive to downstream. The maximum and minimum values in the same band as measured when the turbine was braked provide a measure of the background levels.

3.7 SOURCE LOCALIZATION

The RivRaft was deployed from the R.V. Robertson for testing in Admiralty Inlet, Puget Sound, Washington on June 18th, 2014. At the time, the raft was equipped with a four hydrophone array with 0.6 m spacing between hydrophone elements and an array centroid depth of 1.3 m. During tests of the source localization methods, the raft was allowed to drift freely during a period of slack tide, and the R.V. Robertson remained with 30 meters of the raft at all times Figure 18.

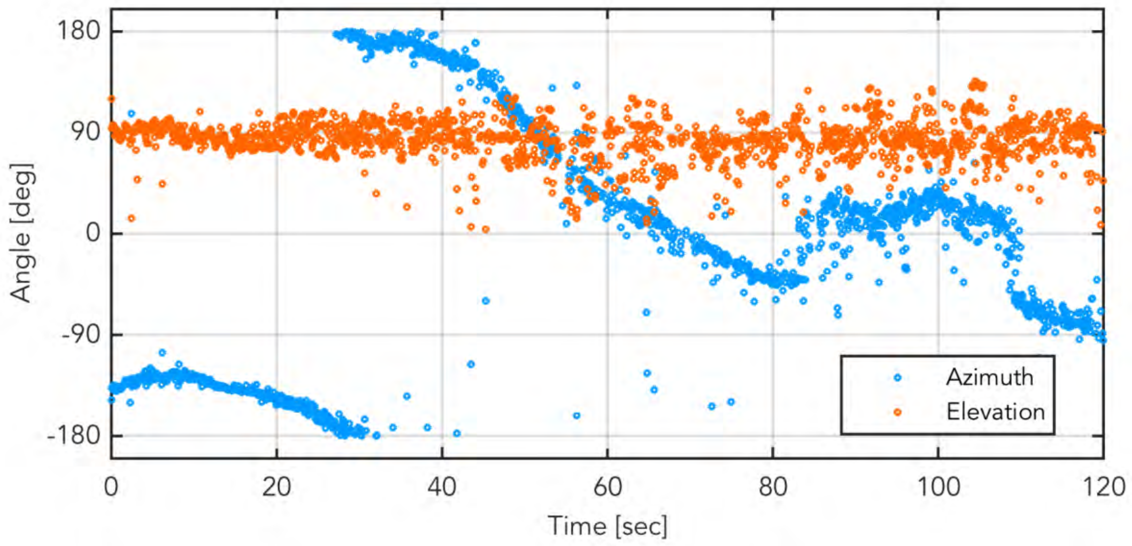


Figure 18: Bearing of R.V. Robertson over a 2 minute period on 6/18/2014.

The primary source of sound was the Robertson's engines. As can be seen in Figure 18, estimates of source elevation remain around 90 degrees. The Raft proceeded to rotate over the 2 minute period, which is visible in the azimuth angle of incoming sound from the Robertson.

Because only two hydrophones were intact during the deployment on 8/25 on the Kviachak River, the resolution of the source localization calculation is significantly less fine (Figure 19). Furthermore, it was only possible to estimate the elevation of incoming plane waves from the vertically oriented hydrophone pair.

Because the horizontal displacement between the RivRaft and RivGen is much greater than their vertical displacement, elevation angles near 90 degrees are not surprising. However, the variation in angle with longshore position, and particularly the abrupt change in angle from -20 m to -10 m, are peculiar.

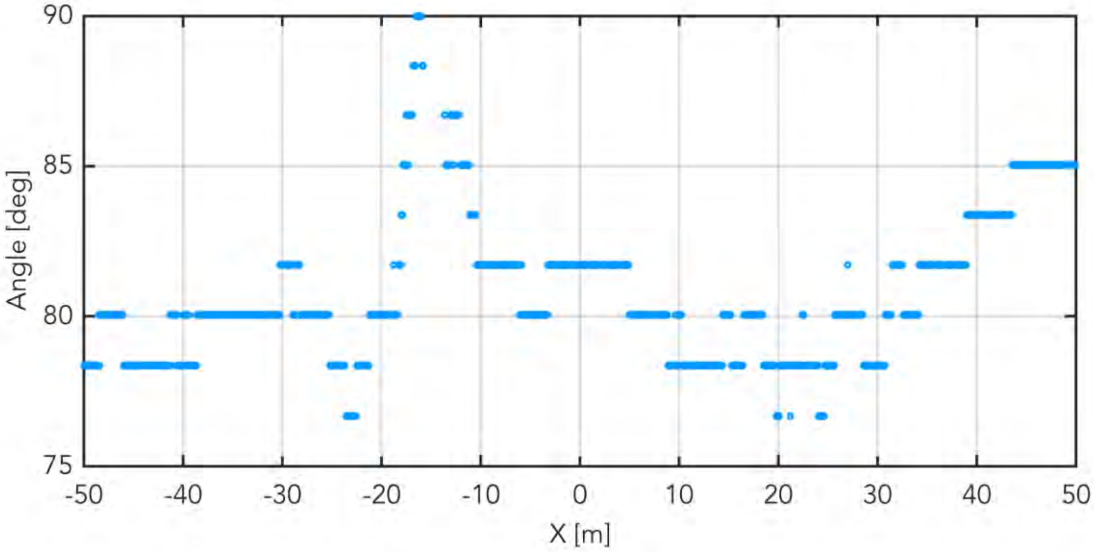


Figure 19: Elevation of incoming plane waves, Optimal 1.

Chapter 4. DISCUSSION

4.1 SOUND CHARACTERISTICS AND POTENTIAL SOURCES

The tones centered around 100, 200, and 300 Hz (H1, H2, and H3, Figure 13), appear only during turbine operation, with magnitude and frequency correlated with the turbine rotation rate (Figure 16). More information would be required to definitively identify the source of the sounds, but the hypothesis that the sounds are related to generator operation is consistent with both their harmonic structure and the expected fundamental frequency of vibration of the generator (personal communication, Ocean Renewable Power Company).

Another possible explanation is turbine blade vibration. Effort has been made to model blade vibration in hydrokinetic turbines, though this work has focused mostly on horizontal axis turbines, and not cross flow designs [9]. Tones from blade vibration would be expected to occur at particular modes and would not be expected to vary with rotation rate. Furthermore, RivGen's blades are not cantilevered, as in a horizontal axis turbine, but supported at both ends and at intermediate points along their length, resulting in a higher overall stiffness that would be less likely to vibrate at the observed frequencies. Consequently, while blade vibration due to turbulence is likely to contribute to both optimal and braked levels, blade vibration is unlikely to be the source of the observed tones.

In addition to the distinct tones, a broadband "clicking" sound is noted and audible (Figure 12). This sound occurs once per rotation of the turbine. Most of the acoustic energy in these "clicks" is spread across higher frequencies, from 1 to 10 kHz. The source of this sound is unknown, but might be associated with a misaligned bearing and, therefore, not a typical feature of turbine operation.

4.2 SOUND PROPAGATION

The water depth at the location of RivGen is approximately 5 m. At this depth, a 100 Hz tone is not expected to excite a proper normal mode, but the higher frequency tones at 200 and 300 Hz are not below the modal cutoff and thus would be expected to propagate over longer distances, albeit with lower initial intensity. Higher frequencies, such as those associated with the broadband “clicking” sound, may continue to travel with minimal attenuation (indeed, the “clicking” sound was still audible in water depth less than 0.5 m at a distance of over 150 meters from the turbine). Variation in river depth in the along-channel direction may cause similar losses, thus localizing lower frequency sounds in both along- and across-channel directions. Though this may limit the region ensonified by low frequency sound, the nearfield of a 100 Hz tone (O 30 m) is on the same order as the river width (O 150 m).

4.3 DETECTION OF TURBINE SOUND BY FISHES

While it is beyond the scope of this paper to consider the behavioral effects that turbine sound might have on fishes, as this remains an active area of research in the biological research community, there are characteristics of turbine sound and river bathymetry that may be of interest were one to attempt a study of behavioral changes of Kviachak River fishes.

It is not clear whether the observed tones would be detectable by fishes at the ranges that measurements were undertaken. The level of the 1/3 octave band containing the H1 tone (100 Hz) decays to near ambient conditions within 100 m downstream of the source (Figure 17), which provides rough boundaries to the ensonified region. Additionally, the low frequency tones seen in the pressure spectra were not clearly distinguishable in the vertical particle acceleration spectra. The vertical particle acceleration associated with the tones may be masked by the higher accelerations near the water surface. Additionally, the three-dimensional particle acceleration vector was not measured and may be greater in magnitude. Though a suitable audiogram for sockeye salmon (Oncorhynchus nerka) is unavailable, the observed tones are within the approximate hearing range of Atlantic salmon at [2].

Aside from the low frequency tones, particle acceleration associated with other sources of turbine sound is not likely to be detectable by sockeye salmon at similar ranges (e.g., the broadband “clicking” is above the upper hearing limit for these fish). Notably, the acoustic pressure levels associated with recreational fishing traffic occurs at similar frequencies to turbine operation, so a thorough accounting of contextual sources of sound during the fish migration up and down river would be required as part of a behavioral study.

4.4 PERFORMANCE OF 'RIVRAFT' SYSTEM

Deployment and recovery of the RivRaft were difficult because of the raft's size and weight. At least three operators were required to deploy the raft safely and efficiently, and a team of four was preferable. High drag made towing the raft upstream after each drift nearly impossible, and it was found to be easier to ferry the raft atop the skiff between deployments.

The shape of the "chandelier" increased the risk of entanglement with objects in the current, and indeed three hydrophones were damaged while attempting to deploy the raft. Because of the damage to hydrophones, it was not possible to measure the pressure gradient in three dimensions as originally intended. Instead, a 2-hydrophone array was deployed to measure the pressure gradient in the vertical direction.

Vibration of the chandelier spar and the taut lines supporting it may have contributed to recorded low frequency noise (below 10 Hz). Doppler shift caused by the movement of the RivRaft was assessed and found to contribute on the deci-Hertz scale (i.e., negligible effect), and would be expected for any drifting system, but is not significant.

For future measurements of particle motion using coherent, spatially distributed hydrophones, a lighter and more compact design is recommended. A spar buoy (e.g., SWIFT drifter [18]) could be deployed by an individual from the bow of a skiff, and it would not be unreasonable to outfit a similar design with an accelerometer based sensor or hydrophone array with a smaller hydrophone separation.

Chapter 5. CONCLUSIONS

Sound with strong tonal peaks and a harmonic structure at frequencies less that 500 Hz was measured near an operating river hydrokinetic turbine. The frequency and level of the fundamental tone (approximately 100 Hz) were found to vary with the rotation rate of the turbine, suggesting that generator "cogging" is the source of the tones. The level of the fundamental was also found to decay to near ambient levels within 100 m of the turbine (downstream direction). A broadband clicking sound was also measured and seen to occur approximately once per turbine rotation.

Sounds originating from the turbine were shown to be within the frequency range to which sockeye salmon (*Oncorhynchus nerka*) are most sensitive. However, it was not possible clearly distinguish acoustic particle acceleration from background noise at the measurement depth. To do so, it may be necessary to measure at greater depths, where neither particle motion nor pressure take on extreme values. Because salmon are primarily sensors of particle motion, not pressure, it is unclear if they would be capable of detecting turbine sound based on measurement of turbine sound in the form of pressure alone.

Source bearing estimations were conducted using the same array used for particle motion estimation. Though the 4-element array performed well in trials, damage was incurred to hydrophones during deployment on the Kviachak River, leaving only two hydrophones for bearing estimation. Because measurements conducted on the Kviachak River were lower in resolution (owing to the single pair of hydrophones), source bearing estimation was inconclusive.

Finally, the drifting RivRaft platform was stable and seemed to minimize the relative fluid velocity over it hydrophone array. As a result, flow noise was not detectable at frequencies higher than 30 Hz. In spite of this success, the difficult deployment and recovery of the RivRaft severely limited measurement opportunities. Smaller and lighter systems are advised for future measurements of acoustic particle motion.

BIBLIOGRAPHY

[1] D. T. Blackstock, Fundamentals of Physical Acoustics, John Wiley & Sons, Inc, 2000.

[2] A. N. Popper and R. R. Fay, "Rethinking sound detection by fishes," *Hearing Research,* vol. 273, pp. 25-36, 2009.

[3] A. D. Hawkins, A. N. Popper, R. R. Fay, D. A. Mann, S. Bartol, T. J. Carlson, S. Coombs, W. T. Ellison, R. L. Gentry, M. B. Halvorsen, S. Lokkeborg, P. H. Rogers, B. L. Southall, D. G. Zeddies and W. N. Tavolga, "Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report," Springer and ASA Press, Cham, Switzerland, 2014.

[4] G. V. Frisk, Ocean and Seabed Acoustics: A Theory of Wave Propagation, Prentice-Hall Inc., 1994.

[5] D. Tonolla, V. Acuna, M. S. Lorang, K. Heutschi and K. Tockner, "A field-based investigation to examine underwater soundscapes of five common river habitats," *Hydrological Processess,* vol. 24, pp. 3146-3156, 29 May 2010.

[6] H. Hubbard and K. Shepherd, "Aeroacoustics of large wind turbines," *J. Acoust. Soc. Am.,* vol. 89, p. 2495, 1991.

[7] G. H. Jang and D. K. Lieu, "The effect of magnet geometry on electric motor vibration," *IEEE Transactions on Magnetics,* vol. 27, no. 6, pp. 5202-5204, November 1991.

[8] M. J. Lighthill, "On sound generated aerodynamically II. Turbulence as a source of sound," *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences,* 23 February 1954.

[9] M. Jonson, J. Fahnline, E. Johnson, M. Barone and A. Fontaine, "Influence of blade solidty on marine hydrokinetic turbines," in *Internoise 2012/ASME NCAD Meeting*, New York City, 2012.

[10] M. Wahlberg, B. Mohl and P. T. Madsen, "Estimating source position accuracy for a large-aperture hydrophone array for bioacoustics," *J. Acoust. Soc. Am.,* vol. Vol 109, no. No. 1, January 2001.

[11] K. V. Mackenzie, "Nine-term equation for sound speed in the oceans," *J. Acoust. Soc. Am.,* vol. 70, no. 3, September 1981.

[12] D. R. Dall'Osto, P. H. Dahl and J. W. Choi, "Properties of the acoustic intensity vector field in a shallow water waveguide," *J. Acoust. Soc. Am.,* vol. Vol 131, no. No. 3, 2012.

[13] F. J. Fahy, Sound Intensity, Elsevier Science Publishers LTD, 1989.

[14] C. Bassett, J. Thomson, P. H. Dahl and B. Polagye, "Flow-noise and turbulence in two tidal channels," *j. Acoust. Soc. Am.,* vol. 135, no. No. 4, p. 1764, April 2014.

[15] B. Wilson, "Rethinking Underwater Sound-Recording Methods to Work at Tidal-Stream and Wave-Energy Sites," in *Marine Renewable Energy Technology and Environmental Interactions*, Dordrecht, Springer Netherlands, 2014, pp. 111-126.

[16] T. Burton, D. Sharpe, N. Jenkins and E. Bossanyi, Wind Energy Handbook, 2nd ed., Wiley, 2011.

[17] D. Forbush, B. Polagye, J. Thomson, B. Fabien, J. Donegan and J. McEntree, "Characterization and control of cross-flow turbine in shear flow," in *3rd Marine Energy Technology Symposium*, Washington D.C., 2015.

[18] J. Thomson, "Wave Breaking Dissipation Observed with "SWIFT" Drifters," *Journal of Atmospheric and Oceanic Technology,* vol. 29, May 2012.

TERRASOND
PRECISION GEOSPATIAL SOLUTIONS®

KVICHAK RIVER RISEC PROJECT

Resource Reconnaissance & Physical Characterization

Final Report

Kvichak River, Vicinity of Igiugig, Alaska

December 9, 2011

Prepared for:

State of Alaska
Department of Community and Economic Development
AIDEA/AEA
Rural Energy Group
813 West Northern Lights Blvd.
Anchorage, Alaska 99503

ALASKA ENERGY AUTHORITY

Prepared by:

TerraSond Ltd.
1617 S. Industrial Way, Suite 3
Palmer, AK 99645
Phone: (907) 745-7215

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES (Included on CD and FTP Site)

Appendix 1 – Map Sheets and CAD Files
Appendix 2 – ADCP Profiles and Data
Appendix 3 – USGS Gage Data
Appendix 4 – Bathymetric Data Products
Appendix 5 – Survey Control
Appendix 6 – Prior Surveys
Appendix 7 – Fledermaus Scene
Appendix 8 – Manufacturer's Specification Sheets

1.0 EXECUTIVE SUMMARY

1.1 Introduction

During the summer and fall of 2011 TerraSond Ltd. (TerraSond) completed a bathymetric survey and hydrokinetic energy assessment of the Kvichak River at Igiugig, Alaska. The purpose of this work was to characterize the initial site conditions for the design and installation of a hydrokinetic turbine to provide electric power for the village.

There were six distinct phases of work for this project. The first was a literature review and investigation of prior surveys and hydrologic studies done in the area. This included collection of Alaska State Land Surveys, data sheets for existing National Geodetic Survey, (NGS) control, and Alaska Community Development Maps. The primary source for surface water hydrology was the USGS Water Resources Office in Anchorage, Alaska. The USGS operated a gaging station on the Kvichak River at Igiugig from 1967 to 1987. They provided copies of the discharge measurement field notes, rating curves, and original descriptions of the gage site. There was also a hydrologist on staff at the Anchorage office that operated and maintained the original USGS gage. He was generous with his time and was able to provide excellent firsthand accounts of the gage operations methods.

The second, third, fourth, and fifth phases consisted of four field expeditions conducted over the summer and fall of 2011. The first expedition was from 9 to 13 June 2011. The purpose of this trip was to do an initial area reconnaissance for future hydrographic surveys, establish a local control network, and attempt to recover existing monumentation that might be useful for the planned hydrographic surveys. The second expedition spanned 17 to 26 June 2011. During this trip the field crew completed the first multibeam bathymetric survey, 10 flow velocity measurements, one discharge measurement, and a survey of water levels along the river to determine the water surface slope. The third expedition was from 26 August to 2 September 2011. During this trip the crew did a second bathymetric survey, completed 11 flow velocity measurements, and a discharge measurement. They also collected 10 sediment samples from the river bed. The fourth expedition was from 11 to 14 October 2011. The main purpose of Expedition IV was to complete detailed flow velocity studies. The field crew completed 35 velocity profiles and one discharge measurement. The final phase of the project was complete data reduction, and preparation of this report with its accompanying map sheets and data packages.

1.2 Synopsis of Findings

1.2.1 Control

During the first expedition a local control network consisting of five monuments was established. Three Continuously Observed Reference Stations, (CORS) were included in the final network adjustment. This network was the basis of control for all of the future survey activities. TerraSond also developed a provisional water level datum for this project based on current discharge measurements, Global Positioning System, (GPS) water level surveys, and the USGS stage and discharge record. The new datum is called the Kvichak River Igiugig Provisional Datum of 2011, (KRIGIPVD11).

An attempt was made to recover any existing NGS monuments in the area. These monuments were placed in1946. After an extensive search using GPS and a magnetometer the crew was unable to locate any of these monuments. The crew also tried to locate remnants of the USGS gage station and reference monuments. No confirmed remains of the gage station could be found.

1.2.2 Bathymetry

The data from the first bathymetric survey was not satisfactory. Therefore, it was discarded and the data acquired on Expedition III was used for preparation of the bathymetric surface and analysis of the river bed.

The Kvichak River bed is comprised mainly of gravel and cobbles. There is little sand or silt. There are also occasional boulders with a volume of one cubic meter or greater. Inspection of the bathymetric surface reveals 44 dangers to navigation and 10 hazards for construction in the project area. There are also a few areas of shoaling that pose a danger to navigation. The locations and coordinates of these features are given in the accompanying map sheets in Appendix 1. The river bathymetry varies considerably from the mouth to the downstream extent of the project area. At the mouth there is a small field of sand waves to the left and a shoal on the right. The shoal continues downstream to the vicinity of the Fish and Game Boat Landing. Over this same stretch the main channel forms a well defined thalweg in the middle. About half way downstream in the project site by the Fish and Game Boat Landing the channel bifurcates around the first island. The right channel narrows and forms a sharp central thalweg as part of an inverted triangular profile. The bed drops rapidly through this area. Then the central part of the channel fills and a trapezoidal profile emerges. This profile continues for the remainder of the project area. Consideration of the moving bed tests and the sampled bed materials indicate that the river bed is quite stable. Nonetheless it should not be considered immutable. Movement of small material below the limit of instrument detection as well as localized scour patterns that develop around various fixed objects can cause some bed load transport.

1.2.3 Hydrokinetic Energy

Analysis of the Acoustic Doppler Current Profiler, (ADCP) data from Expeditions II and III indicates that there are three areas of the river that offer the most potential for development of a hydrokinetic facility. These areas are designated as Site 6, 9, and 10. Their locations are depicted on the accompanying map sheets in Appendix 1. All three locations have a well defined and stable zone of high energy density the ranges between 4.5 to 7 kW/ m^2. Site 6 has shown the most promise for immediate development. This site has a good zone of energy density. The channel is large and can thus accommodate a turbine while leaving ample room for navigation. It is also close to the current generator facility. This reduces the cost and effort required to connect to the power grid. Sites 9 and 10 have excellent energy density characteristics. However, the channel at site 9 is less accommodating to a turbine and navigation. Further, they are up to 1 km downstream from the electric power facility and nearly 150 meters from the village side shore.

1.2.4 Recommendations

Site 6, 9, and 10 show the most promise for future hydrokinetic development. Presently Site 6 offers the best constellation of features. There is good energy density. The site is close the power generation facility. The channel dimensions are generous and the zone of high energy density is offset from the thalweg. However, there appears to be more seasonal variability of energy density at this site compared to the other sites. Its proximity to the river mouth also makes it susceptible to problem with floating debris and ice. Site 9 has a very high energy density that appears more stable. However, the channel is smaller and the high energy density zone is centered in the thalweg. The channel morphology may also be more dynamic at this site. It is further away from the power generation facility. Thus connection to the existing power infrastructure is more difficult and expensive. Site 10 has a large and deep channel. This site could accommodate multiple turbines on the surface as well as the bottom. The energy characteristics of the river are very favorable. The only drawback to this site is its distance from the existing power infrastructure.

The work presented in this report is the first detailed field investigation for a future hydrokinetic facility in Igiugig. More investigation is required to help ensure the success of this effort. There is a need for more detailed studies of flow dynamics. These studies would increase the knowledge of temporal and spatial flow patterns in the river. They would also determine the stability of the flow patterns and determine if there is migration of the thalweg. Installation of a new gage station is crucial to future planning and design of a turbine system for this river. Quality gage data will provide timely information of flow velocities and discharge. It will be invaluable for assessment, and operation of any turbine system. A gage station should be established in the vicinity of the planned turbine trial site. It should be installed before the turbine is placed in the river.

A good qualitative and quantitative assessment of the ice condition on the river is crucial to the future success of this endeavor. Currently there are only limited anecdotal accounts of ice conditions. Every effort should be made to establish an ice observation system in Igiugig as soon as possible.

2.0 SITE DESCRIPTION

2.1 Introduction

Igiugig, Alaska is located on the left bank of the Kvichak River, (N59^{o} 19’, W155^{o} 54’). It is situated at the mouth of the river, Figures 1, 2. The year round population is about 50 people. It is not on the road system. Normal access is by plane or boat. There is no rail service. Goods and fuel are brought to the village by barge and plane.

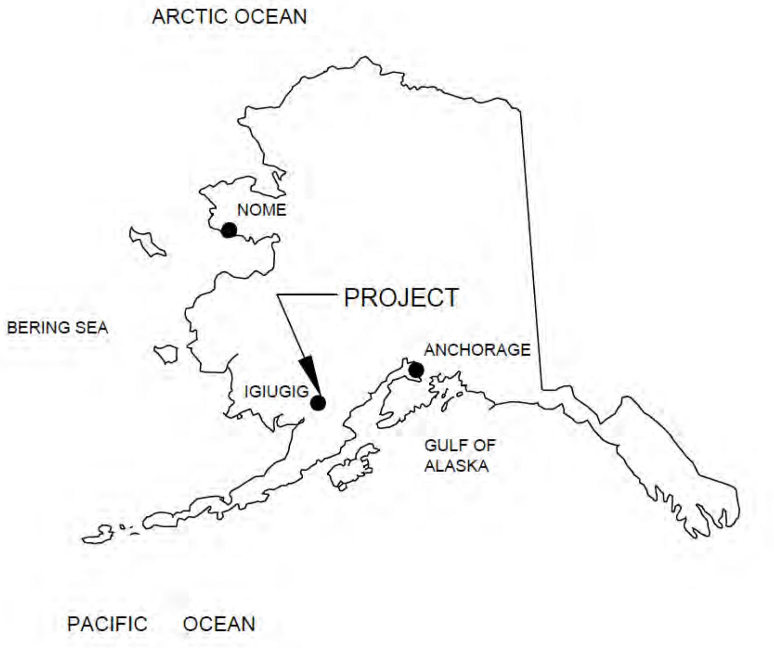


Figure 1 – Igiugig project location map.

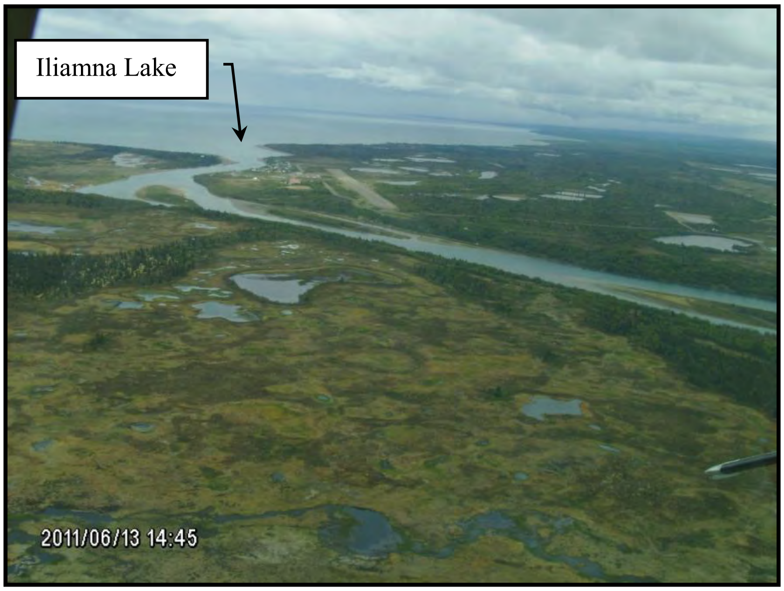


Figure 2 – Aerial view of the project site from the west.

2.2 Kvichak River

The main source for the Kvichak River is drainage from Iliamna Lake. In the vicinity of Igiugig there are no other significant tributaries or diversions to the river. The river flows past Igiugig and continues on for 110 km to its outlet in Kvichak Bay. The total drainage basin for the river is 16,835 km^2 and it has a mean elevation of 546 meters. Approximately 20% of the basin is storage in the form of lakes and ponds. Transitional forest comprises about 64% of the basin, and the remainder it primarily wetlands. The average annual precipitation is 101.6 cm. Average annual snowfall in the basin is 178 cm. The record high and low temperatures for Igiugig are 31^o C and -42^o C. The average annual high and low temperatures are 26^o C and -33^o C. Typical summer temperatures range from -1^o C to19^o C. Winter temperatures are between -16^o C and -1^o C.

The average flow velocity is 1.37 m/s (σ = 0.26 m/s). In some particularly fast reaches the surface velocity can approach 3.0 m/s in the central channel. The river level can rise and fall over a range of two meters. The average annual range of water levels is 1.1 meters. The smallest and larges annual ranges are 0.59 and 1.48 meters. Peak stages and discharges occur in the fall during September and October. The lowest stages and discharges are in the spring during April and May. The average annual high discharge rate in the USGS gage data for this site is 815 m^3 /s, (σ = 213 m^3 / s). And the average reported low discharge is 293 m^3 /s, (σ = 81 m^3 / s). The daily average discharge rate from the USGS data is 500 m^3 /s, (σ = 201 m^3 / s).

The water is extremely clear. During most of the year the bed can be seen at depths to 5 meters. However, there are some times when the sediment load increases and visibility drops. This is typically during periods of high wind from the east and extended duration rain. The surrounding area is transitional forest and tundra. There are few large trees. Thus there is rarely any substantial amount of drifting materials in the water. The river usually does not experience a major freeze. However, some ice may form from November to February. The mild climate and rapid flow normally prevent persistence of the ice. During break up in March to May ice from the lake is driven into the river by wind. This ice is typically about 1 meter thick. It can be present in the river for two to three weeks.

2.2 Infrastructure

Igiugig may be reached by boat and plane. There is no rail or road access. The village has a good local network of improved dirt and gravel roads. The state of Alaska maintains a 3000 foot x 75 foot gravel runway. Adjacent to the runway is a generous apron and a hangar with three large bay doors. The Federal Aviation Administration maintains a weather station with two web cameras at the airport. The lake and river offer ample opportunities for float plane operations. Large goods including construction equipment and materials can be brought to the village by cargo planes and barges, Figure 3, 4. There is regular air taxi service from Anchorage.

Full service lodging for work crews is available at a work camp that is owned and operated by Iliamna Lake Contractors, (ILC). ILC can also provide four-wheelers, Jon boats, pickup trucks, gasoline, and diesel fuel, an assortment of heavy construction equipment, barge service, and basic mechanic support.

Figure 3 – Flexibarge on the Kvichak River near the Fish and Game boat landing.

Figure 4 – FAA weather station with webcams.

3.0 SURVEY ACTIVITIES

3.1 Introduction

Prior to commencing field activities TerraSond completed a detailed study of existing land survey data, USGS stream gage records, prior hydrokinetic energy assessments and the community profile. This preparatory research was used to plan the subsequent field expeditions. These expeditions took place on 9 to 13 June 2011, 17 to 26 June 2011, 26 August to 2 September 2011, and 11 to 14 October 2011.

3.2 Literature Research

Several literature resources were obtained by TerraSond for the purpose of planning and executing the survey activities presented in this report. The land survey data assembled consisted of Alaska State Land Surveys, (ASLS), and Easement Vacations, (EV), National Geodetic Survey, (NGS) control monuments, GPS sites in the NGS Continuously Observed Reference Stations, (CORS), system, Alaska State Community Development Maps, USGS 15 minute topographic maps, and a site specific digital orthorectified image. Stream gage data was collected by the USGS in the vicinity of the project site from 1967 to 1987. Prior hydrokinetic assessments were published by the Electric Power Research Institute, (EPRI), and the Alaska Center for Energy and Power, (ACEP).

TerraSond obtained digital copies of ASLS AS91-111, AS91-111A, and EV EV - 2-541. These documents were used to identify property boundary lines and status as well existing monuments in the area. These surveys were not used for any of the hydrographic analysis in this report. Digital copies of these surveys were placed in Appendix 6 of this report.

The NGS online database was searched for control monuments within a radius of five miles, (8 km) from the approximate center of the project site. Three records were returned. The PID's were UV7630, UV7631, and UV 7632. Horizontal orders for these monuments were First, Third, and Second respectively. No vertical order was reported for these monuments in the NGS database. An attempt was made to recover these monuments during Expedition I. Unfortunately they could not be located. All of these monuments were set in1946. In light of their age and the manner of placement it is believed that they have been lost. Current copies of the NGS datasheets for the monuments were placed in Appendix 5 of this report.

Three Continuously Observed Reference Stations (CORS) stations were identified within 100 km of the project site. The CORS ID's for these stations were AB22, AC24, and AC27. The sites were located in the vicinity of Iliamna, King Salmon, and the McNeil River Game Refuge respectively. These stations were used as fixed control for the adjustment of the local control network established by TerraSond for this project. The data sheets for these CORS sites were placed in Appendix 5 of this report.

Digital copies of the Alaska State Community Development Maps were obtained from the Alaska Department of Commerce, Community, and Economic Development Community and Regional Affairs. These maps were used to gain an initial impression of the river dynamics on a decadal scale. They were also used to identify land status and village infrastructure. Copies of these maps are in Appendix 6 of this report.

A USGS digital raster graphic of the Iliamna B-8 15 minute topographic map and a site specific orthorectified image were used to do the initial planning of survey efforts. Comparison of the USGS map and the orthorectified image was also used to gain an indication of river morphodynamics on a decadal scale. The digital orthorectified image was used as a background in final map sheets.

An extensive investigation of the USGS historical gage data for this site was completed. This included a visit to the USGS Water Resources Office in Anchorage, Alaska. Copies of the original USGS records for the station were obtained. The following documents were obtained: USGS Gage Station Descriptions, USGS Discharge Measurement Notes, Rating Curve Plots. All of the online gage data for the gaging site was downloaded from the USGS web page. Personal interviews were also conducted with a member of the USGS staff that operated the gage site for a portion of the time that it was active. This data was used to assess historic discharge, flow velocities, and approximate times of peak and minimum discharge. The collected data items were placed in Appendix 3 of this report.

The Electric Power Research Institute, (EPRI) completed two assessments of the hydrokinetic potential for the Kvichak River. The first was *System Level Design, Performance, Cost and Economic Assessment – Alaska In-Stream Power Plants*, and the other was *River In-Stream Energy Conversion (RISEC) Characterization of Alaska Sites.* These reports were used for an initial estimate of the river's potential for development of a hydrokinetic power generation facility. Their assessment was based on the historical record from USGS Gage Site 15300500. The information contained in these reports was one source of guidance for the planning of the field surveys completed this year.

3.3 Field Expeditions

Four field survey expeditions were completed for this project. The goals of the first expedition were to complete an initial site reconnaissance and establish a local control network. The three subsequent expeditions were used to complete a multibeam bathymetric survey, and progressively develop a detailed assessment of hydrokinetic energy potential.

3.3.1 Field Expedition I

Expedition I spanned 9 to 13 June 2001. During this expedition five control monuments were set and surveyed with multiple static GPS sessions. The static GPS session data was then post processed and adjusted with a precise ephemeris to determine the final adjusted coordinates for the control network. In addition to the GPS survey a detailed site reconnaissance was completed. This included a general tour of the village and introductions to members of the village council and the village corporation. The field team also dedicated approximately 1 ½ days to locating USGS reference monuments, and NGS control monuments. The team searched using the available descriptions from the respective agencies, GPS coordinates, and local inquiries. None of the monuments could be recovered. During this field expedition the team also completed an initial boat transit of the proposed hydrographic study area.

3.3.2 Field Expedition II

Expedition II was conducted on 17 to 26 June 2011. The primary activity during this trip was the completion of the first hydrographic surveys. These included a multibeam bathymetric survey, 10 ADCP transects, an ADCP discharge measurement, four ADCP moving bed tests, and a water line survey with RTK GPS to estimate the water surface slope of the river.

3.3.3 Field Expedition III

Expedition III spanned 26 August to 2 September 2011. During this trip the crew completed one ADCP moving bed test, an ADCP discharge measurement, 10 ADCP transects, and collected 10 bottom grab samples. They also completed a second multibeam survey. Six of the ADCP transects were completed in the extended project area. This expanded area reached down stream an additional 1.3 km beyond the original proposed project boundary. Near surface flow velocity measurements were made at select points along each of the ADCP transects.

3.3.4 Field Expedition IV

Expedition IV started on 11 October 2011 and ended on 14 October 2011. During this time 34 ADCP transects, an ADCP discharge measurement, and four moving bed tests were completed. Near surface flow velocity measurements were made at select points along each of the ADCP transects. The ADCP transects were positioned to develop detailed estimates of energy density at Sites 5, 6, 9, and 10. An additional transect was also run on Station 17.

4.0 SURVEY CONTROL

4.1 Introduction

During Expedition I TerraSond established a control network for the project site. This network consisted of five monuments that were set and surveyed using static GPS methods. Several redundant occupations were made using Leica 1200+ series dual frequency GPS GNSS units. The collected occupation data for the network was then adjusted using Trimble Geomatics Office Version 1.63. Three CORS stations were included in the network adjustment. All monuments were set on the left bank of the river. The monument locations and coordinates have been depicted on the accompanying map sheets in Appendix 1.

ADCP river discharge measures and RTK GPS Surveys of the water level collected during Expedition II, III, and IV were used to determine the water level datum. The discharge measurements were referenced to the USGS rating curves for the site. This provided a coarse basis for comparison of the current river stage with the historical record. This was then used to estimate where the current stage was compared to the recorded lowest stage. The water surface ellipsoid height that was slightly below the corresponding ellipsoid height of the estimated historical low ellipsoid height was selected. This chosen value was 25.00 meters.

4.2 Control Network Establishment

After assessing the field site the survey crew determined that the best location for the primary control monument was in the vicinity of the Fish and Game Boat Landing. This location was selected because of its central location in the project area, ease of access, good line of site for broadcast of RTK correction signals, and stable soils. Two monuments were set at this location. The first monument was designated "*HK-1*." It was a 36 inch x ¾ inch piece of rebar with a domed 3 ¼ inch aluminum cap stamped "*IGIUGIG HK-1 TERRASOND 2011*." The selected location was a grassy section on the side of a knoll between the upper parking area and the boat landing. The final set was 0.4 feet below grade. Figures 5, 6. The second monument was set for vertical reference. It has been designated as "*HK-V*". It was comprised of four sections of ½ inch x 4 foot steel drive rod with a bullet head center threaded at the top. The rod was driven until met with refusal at approximately 16 feet. This monument was set 0.2 feet below grade at the top of the hill on the east shoulder of the road leading from the school to the boat landing, Figure 7, 8. A group of small sized cobbles with one large cobble were set around and over both monuments for protection.

Figure 5 – Monument HK-1.

3 ¼ inch aluminum cap on rebar.

Figure 6 – View across the Kvichak River from HK-1.

Figure 7 – Monument HK-V.

Figure 8 – View from HK-V.

View to the northwest across the road toward the Fish and Game boat landing and HK – 1.

Three additional monuments were set for the purpose of monitoring the river water level and as possible base station locations. Monument "*HK-2*" was established with a 3¼ inch domed aluminum cap marked "*IGIUGIG HK-2 TERRASOND 2011*" on 36 inch x ¾ inch rebar. It was set three quarters of the way down the bank from the west fence corner of the fuel tank containment by the electric generation plant, Figures 9, 10. Sloughing of the bank that occurred between 2 September and 11 October 2011 has destroyed this monument.

Figure 9 – Monument HK-2.

3 ¼ inch aluminum cap on rebar. (Destroyed.)

Figure 10 – View to the northwest across the Kvichak River from HK-2.

(HK-2 was Destroyed.)

Monument "*HK-3*" was placed on a level spot at the base of a 3 meter bluff of moderate repose on the left bank in the vicinity of the Kvichak River mouth. It was topped with a 3 ¼ inch aluminum cap that was stamped "*IGIUGIG HK-3 TERRASOND 2011*" The final placement was 0.4 feet below grade. It was concealed under several medium cobbles, Figures 11, 12.

Figure 11 – Monument HK-3.

3 ¼ inch aluminum cap on rebar.

Figure 12 – View toward downstream witness tree from HK-3.

The final monument was placed near the downstream extent of the initial project area. Two pieces of ½ inch x 4 foot drive rod were driven and topped with a bullet head. It has been designated "*HK-4*". The monument was established in a small level clearing approximately 35 feet shoreward of the left bank. Figure 13, 14.

Figure 13 – Monument HK-4.

½ inch x 8 foot steel rod with bullet top.

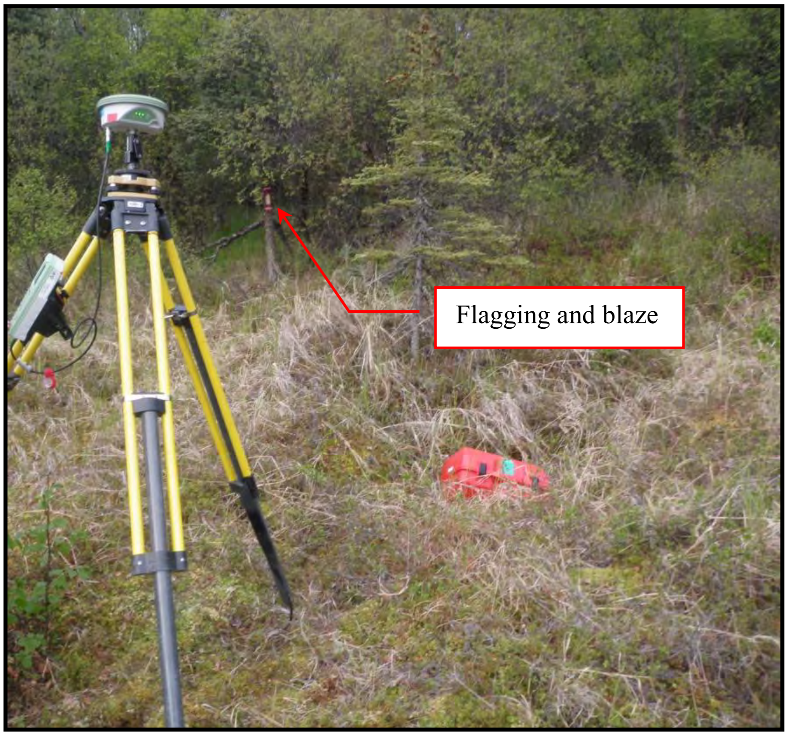


Figure 14 – View of upstream bearing tree from monument HK-4.

4.3 Network Adjustment

Trimble Geomatics Office (TGO) version 1.63 was used to process the static GPS data and adjust the control network. Three CORS sites were included in the network adjustment, Table 1. These stations were held fixed and the newly placed control monument locations were adjusted horizontally and vertically.

CORS ID	PID	Latitude	Longitude	Ellipsoid Ht. (m)	Geoid Ht. (m)
AB22	DL6678	N 59° 53' 57.55673"	W 154° 41' 53.64393"	199.318	13.03
AC24	DL7656	N 58° 40 53.66665	W 156° 39' 09.83425"	35.814	13.72
AC27	DM7487	N 59° 15' 09.03078"	W 154° 09' 46.28667"	417.006	12.36
Datum NAD 83 Geoid heights based on the NGS 2009 geoid model GEOID09 AK					

Table 1 – CORS used for Kvichak River control network adjustment.

Preliminary processing was done in June 2011. Final coordinate processing with precise ephemeris files was completed in October 2011. The TGO project coordinate system was set to UTM AK Zone5 NAD 83 and used the NGS 2009 Geoid model for Alaska, (GEOID09 AK). Final project coordinates were transformed to Alaska State Plane Coordinate System Zone 5. (Note: The horizontal datum for this system is NAD 83, and the horizontal units are U.S. Survey Feet). The final adjusted coordinates have been given on the included map sheet and in Table 2.

Monument	Latitude	Longitude	Northing	Easting	Ellipsoid Ht.	Orthometric Ht.
HK-1	N 59° 19' 40.20931"	W 155° 54' 06.65546"	1951306.55	1285272.68	102.46	57.58
HK-V	N 59° 19' 39.97861"	W 155° 54' 05.33396"	1951281.18	1285340.55	107.15	62.28
HK-2*	N 59° 19' 38.96916"	W 155° 53' 53.47837"	1951161.19	1285952.49	93.14	48.27
HK-3	N 59° 19' 42.64454"	W 155° 53' 12.33824"	1951473.56	1288096.69	95.14	50.26
HK-4	N 59° 19' 10.74202"	W 155° 55' 00.87362"	1948396.64	1282374.74	93.96	49.08
Datum NAD 83, Alaska State Plan Coordinate System Zone 5 US Survey feet. Orthometric height is based on NGS geoid model of 2009 GEOID09 AK *HK-2 was destroyed						

Table 2 – Final adjusted values for Kvichak River RISEC local control network.

4.4 Establishment of the Project Water Level Datum

Water levels are constantly changing. Therefore, establishment of a water level datum can be problematic. Nonetheless it is necessary to establish a reasonable and useful datum from which water depth may be reckoned. The choice of a water level datum is particularly difficult for inland waters. These water bodies lack the stabilizing influence of the ocean reservoir with its regular and predictable tide cycles. A three month water level record at a coastal tide station is typically sufficient to obtain the requisite knowledge of water level extremes and sinusoidal constituents for the determination of the station datum and prediction of future water levels. Water level fluctuations on inland water bodies do not behave in a manner that is sufficiently regular and predictable for the development of dependable water level models analogous to those used for tide predictions. Inland waters levels are subject to any manner of seasonal and secular fluctuations. In some cases years of observation may be required to determine a suitable datum level for a particular river or lake.

For non-tidal water the vertical datum, should be selected such that at least 95% of the time the water is above this level. Ideally no single daily mean water level should ever fall more than about 0.2 meters below the datum level. Further, the water level datum for a river must recognize that the surface of the water is sloped. Therefore, a series of water levels must be measured along the many reaches of the river to determine an appropriate water surface level slope. Then the datum level is adjusted with respect to this slope along the course of the river. In this manner the water level datum will always appropriately reflect the state of the river during its usual low stages.

A fully developed water level datum has not been established for the Kvichak River. TerraSond has created a provisional water level datum to meet the needs of this project. The Kvichak River Igiugig Provisional Datum of 2011 has been designated as KRIGIPVD11. The datum definition and description given in this report and its accompanying map sheets supersede all other datum descriptions previously issued for this project. In particular it supersedes the description given for 11 RISECVD that was issued in the interim report dated 3 October 2011and its associated documents and map sheets.

TerraSond did not have a long term river gage record that was tied to a true vertical datum. The USGS gage data record was referenced to an arbitrary height. It was not determined with respect to any accepted vertical reference. All of the RM's for the USGS gage station have been lost. Therefore, it was impossible to make a physical tie of the current water level data to the USGS record. However, it was possible to make some coarse but reasonable assumptions in the pursuit of a suitable selection for the KRIGIPVD11 water level datum.

The datum level for the KRIGIPVD11 datum was established by referencing a current discharge measurement and RTK GPS water level measurement to the original USGS rating curve. The USGS gage data for this site indicated that the lowest annual river stages typically occur between the second week of March and the second week of April. Using their rating curve the USGS estimated that the lowest discharge for the recorded history was 181 m^3/s (6400 ft^3/s). This discharge corresponded to a USGS gage height of 15.10 ft. (4.60 m). On 21 June 2011 an ADCP discharge measurement was made in the approximate location of the previous USGS discharge measurements. The total discharge was 335 m^3/s, (11,830 ft^3/s). This discharge would correspond with a USGS gage height of 16.95 ft. (5.17 m). The river water level at the Fish and Game Boat Landing, (the origin of the KRIGIPVD11 datum) was measured using RTK GPS at about the same time that the discharge measurement was made. The water level ellipsoid height was found to be 25.90 m, (84.97 ft.). Using the USGS rating curve as a basis for comparison reveals that the difference in gage height for these two discharges would have been about 1.85 feet, (0.56m). Thus a rough assumption could be made that the corresponding ellipsoid height of the water surface at the origin of KRIGIPVD11 for the USGS's historical low discharge would have been about 25.34 meters, (83.14 ft). Based on this rough correspondence between the USGS gage height and the measured ellipsoid height, it was determined that an ellipsoid height of 25.00 meters would be a reasonable value for the provisional datum. This value makes allowance for some extra range in the water levels to ensure that the river does not drop to a stage that is below the established datum for determining water depth, Figure 15.

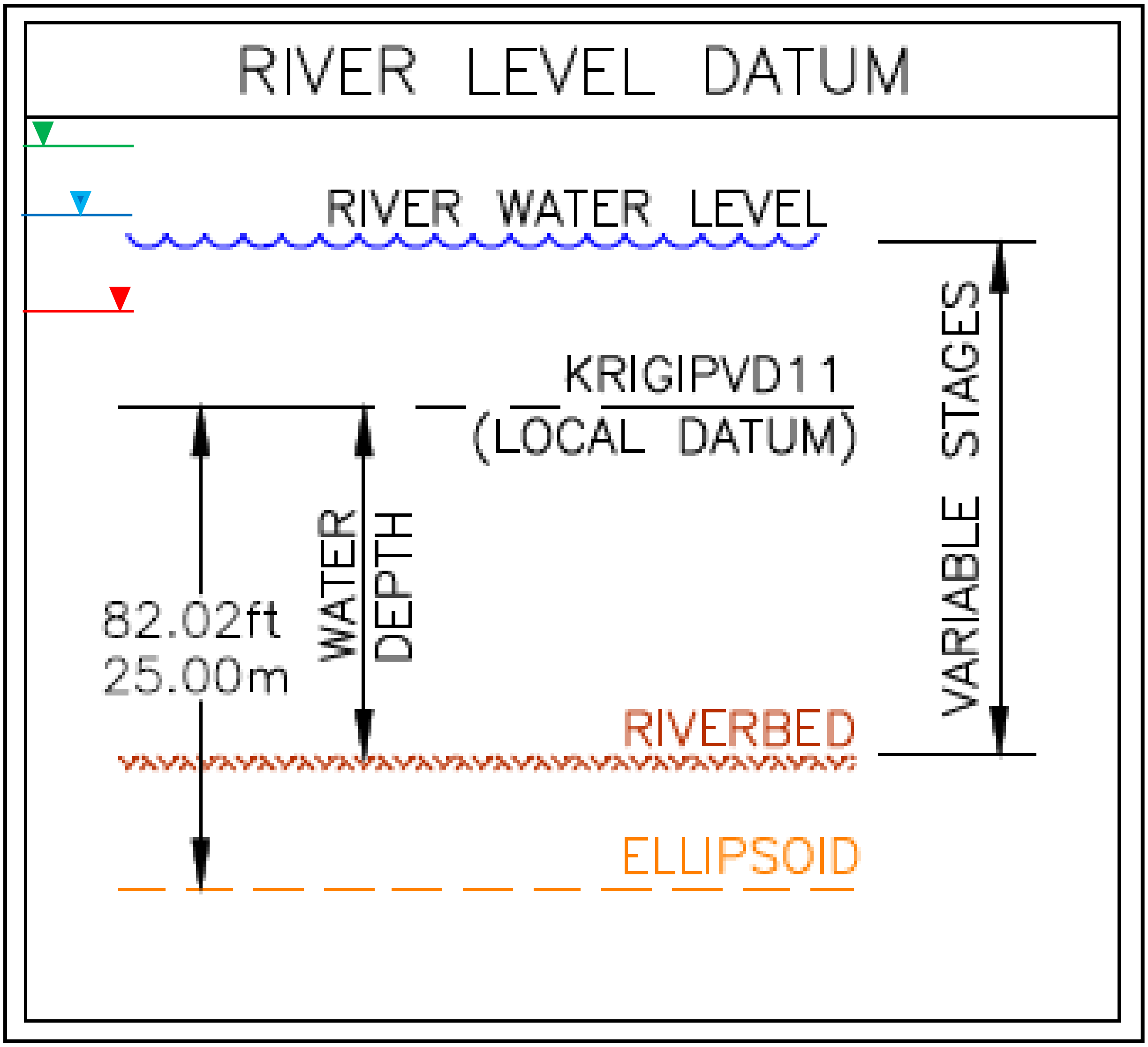


Figure 15 – Relationships of the KRIGIPVD11 datum.

(NOT TO SCALE)

— Mean annual high water height (1.86 m above KRIGIPVD11)
— Mean daily water height (1.27 m above KRIGIPCD11)
— Mean annual low water height (0.79 m above KRIGIPVD11)

The KRIGIPVD11 datum is used for the bathymetric surface presented in this report. The depths represented on this surface are the distance in feet from the level of the KRIGIPVD11 datum to the river bed. Because KRIGIPVD11 was selected to be slightly below an estimated extreme of low water, the given depths should be a rather conservative estimate. Further, the water depths given on this surface have not been adjusted for the slope of the river surface. Given the close proximity of the project area to the origin of the KRIGIPVD11 datum, and the provisional status of this datum it was determined that such a fine adjustment was premature.

It is important to remember that the KRIGIPVD11 datum was selected to represent a water level that is extreme for the river. This level was chosen because it is unlikely that the river stage would drop below this datum. Therefore, water depths that are referenced to this datum can be considered a worst case shallow water situation. This convention for depth determination gives a conservative view with respect to navigational considerations.

Water depth must never be confused with river stage. River stage refers to the vertical movement of the water surface. The river stage is continuously changing. The established datum is fixed and by implication the surveyed depth of the river is also fixed. Further, the river stage can be given with respect to any reference. The reference may have specific physical significance or it can be arbitrary. The river stage is the basis for discharge estimates, and flood potential. Ideally the river should not drop to a stage that is below the level of KRIGIPVD11. It is also prudent to bear in mind that the KRIGIPVD11 datum is provisional. The depths referenced to this datum should not be considered definitive for purposes of navigation.

Levels and values for Mean Annual High water level, Mean Daily Water Level, and Mean Annual Low Water Level are given in Figure 15. The methods used to establish these values are given in section 10.4.

5.0 MONUMENT RECOVERY

5.1 Introduction

Approximately 1½ days of Expedition I were dedicated to locating existing monuments. There was particular interest in locating USGS reference monuments, (RM) that were associated with the gage station. An effort was also made to recover NGS survey monuments that were located on the right bank of the river.

5.2 USGS Gage 15300500 Reference Monuments

The USGS operated a gaging station on the Kvichak River from June 1967 to September 1987. It was designated as USGS Gage Site 15300500. The associated RM's were referenced to an arbitrary datum. The USGS determined water level with respect to this datum by leveling from the RM to the water. Recovery of these RM's was necessary to establish a physical tie from the current survey to the historical USGS gage record. An attempt was made to locate the RM's and any other items associated with this gaging station. TerraSond obtained the online record for this gage from the USGS web site. A visit was also made to the USGS Water Resources Office in Anchorage, Alaska. During this visit the USGS provided copies of the original gage descriptions, discharge notes and the rating curves. There was also a hydrologist on staff at this office that was responsible for operation and maintenance of the gage when it was active. He was able to answer questions about the gage's operational methods, and the locations of its associated RM's.

The field crew used the USGS descriptions and coordinates to locate any features of the original USGS gage that might have remained at the site. Inquiries were also made with local people in Igiugig. The local people had little recollection of the gage. No reference monuments were located by the field crew. The crew found some items that they thought may have been associated with the gage's bubbler system. However, after consultation with the USGS it was determined that the items found were not associated with the gage. After this investigation it was concluded that any items from the gage station that could be used to establish a sound physical tie to the original gaging data have been lost.

The documents copied from the USGS and the data obtained from the USGS web sites are included in Appendix 3 of this report.

5.3 NGS Control Monuments

There were three NGS monuments recorded within a radius of five miles from the approximate center of the project site, Table 3, the current NGS data sheets for these monuments were included in Appendix 5 of this report.

PID	Designation	Latitude (NAD 83)	Longitude (NAD 83)
UV7631	IGIUGIG POST OFFICE E GABLE	N 59° 19’ 46.49301”	W 155° 54’ 00.67627”
UV7630	IGIUGIG	N 59° 19’ 58.06078”	W 155° 53’ 13.86006”
UV7632	IGIUGIG 1946 AZ MK	N 59° 19’ 50.43518”	W 155° 53’ 13.88539”

Table 3 – NGS control monuments recorded in the project area.

The monuments were set in 1946. The field crew made an attempt to locate all of these monuments. They used GPS positioning, in conjunction with a magnetometer. They were able to get to the reported locations and identify many of the references given in the NGS data sheets. However, none of the monuments were recovered. It would have been good to occupy one or more of these monuments with static GPS sessions and tie the project control network to existing monumentation. However, the lack of ability to do this was not deleterious to the final accuracy and precision of the surveys completed for the project.

6.0 MULTIBEAM HYDROGRAPHIC SURVEY

6.1 Introduction

TerraSond performed two multibeam echosounder (MBES) surveys for this project. The first one was completed during Expedition II. When the data from this survey was analyzed and processed in the office it was found to be unsatisfactory. Therefore, it was decided to discard this data and conduct a second survey during Expedition III. The second survey was conducted over 27 to 29 August 2011. The area of coverage started on Iliamna Lake about 0.12 km prior the mouth of the Kvichak River and extended downstream about 2.7 km of reach distance. The total area covered was approximately 0.8 km^2. The cleaned survey data was used to create two interpolated bathymetric surfaces with 0.5 and 1.0 meter cell size.

6.2 Instrumentation

All bathymetric data was acquired with an R2Sonic 2024 MBES equipped with a Valeport acoustic velocimeter to measure the speed of sound at the sonar face. An Odom Digibar Pro acoustic velocimeter was used to measure the speed of sound throughout the water column. Vessel position and attitude were determined with a Coda Octopus F-180 inertial motion unit, (IMU). The F-180 received RTK GPS correction messages from a Leica GPS 1200+ series base station located on HK-1. Bathymetric data acquisition, vessel position and navigation were managed with HYPACK MAX 2011. All software for the bathymetric survey was running on a Panasonic Toughbook model CF 30 field computer with Windows XP Professional. The survey platform for the bathymetric surveys was an 18 foot Lowe Jon boat with a 25 hp outboard engine. The MBES was mounted on a vertical pole off the port side of the boat The F-180 and its GPS antennas were mounted on the same pole directly above the MBES. The draft of the MBES head was 0.44 meters.

6.2 Instrument Calibration

All calibrations and checks were done according the specifications provided in the respective manufacturer's technical manuals. The detailed steps required for each procedure may be obtained from the appropriate manuals. The MBES and the F-180 were calibrated on Iliamna Lake. Two sets of MBES calibration data (commonly called a "Patch Test") were acquired for this survey. One patch test was done on 27 August 2011 and the other on 29 August 2011. The data was processed with the Caris HIPS and SIPS calibration routines. The calibration results were then applied to the vessel configuration file. Comparison of the two patch test results confirmed that the MBES head position remained constant throughout the survey.

6.3 Hydrographic Data Acquisition and Processing

Hydrographic data acquisition was managed with HYPACK MAX 2011. HYPACK received data streams from the F-180 and the MBES. The sound velocity at the MBES head was supplied by the Valeport velocimeter. Daily sound velocity profiles were collected with the Odom DigiBar Pro. Vessel navigation was also managed with HYPACK MAX. Raw survey data was then post processed using Caris HIPS and SIPS 7.1.

The Expedition III MBES acquisition was accomplished on 27 to 29 August 2011. TerraSond acquired a precise high density bathymetric data set that could be used as a base DEM surface for multiple products. The project goals for the MBES data set were to determine the geomorphology of the riverbed, a reference baseline surface for future comparisons, a surface for 1D - 3D numerical modeling, and an obstruction detection program. Geologic interpretation was beyond the scope of this project, however, the data set is informative for geologic interpretation and the dataset should be referenced when this interpretation is required.

MBES data was acquired in all locations of the project area that permitted safe operation of the vessel and equipment. The MBES physical dimensions, sensor capabilities and boat maneuverability were the main factors that determined which areas of the river could be safely surveyed. The combination of instrument draft and minimum sensor range dictated a minimum operational water depth of at least 1.5 meters. At this depth the river bed was about 1 meter below the MBES head. The survey lines were run such that there was always significant swath overlap with the adjacent line. This overlap increases point density and ensures full coverage of the river bed. HYPACK displayed the swath coverage on the navigation monitor in real time. The real time display allowed the survey crew to verify full bottom coverage while still on the water.

During post processing Caris HIPS and SIPS is used to apply vessel offsets, sound velocity, vessel position and attitude to the raw MBES data. Application of these values orthorectifies the sounding to water surface. Because of the high data rate and constant vessel movement there is a large amount of noise in all of the data streams. The data streams are inspected and cleaned of noise and spurious values. Then the soundings are adjusted to the project vertical datum. The final step is to inspect the corrected sounding that will be used to create the base surface. In this step the entire set of soundings is carefully checked to insure that they are actually bottom soundings. Spurious values that resulted from noise or environmental interference with the MBES beam are removed from the final data set. The average horizontal and vertical total propagated uncertainty of the soundings used to prepare the final surface is 0.25, and 0.1 meters respectively. This cleaned data set is then used to interpolate a final bathymetric surface with a cell size of 0.5 meters.

Every effort has been made to insure the accuracy and precision of the bathymetric data products for this report. However, the purpose of this survey was to prepare a data product for use in the design and placement of an in stream turbine. It was not prepared to be a navigation product. It should not be used for vessel navigation.

There were a few locations where small gaps exist in the sounding data. None of them posed a critical problem for the overall quality of the bathymetric surface. The interpolation functions of Caris HIPS and SIPS were used to fill the gaps. The locations of these gaps have been depicted as white polygons in Figure 16.

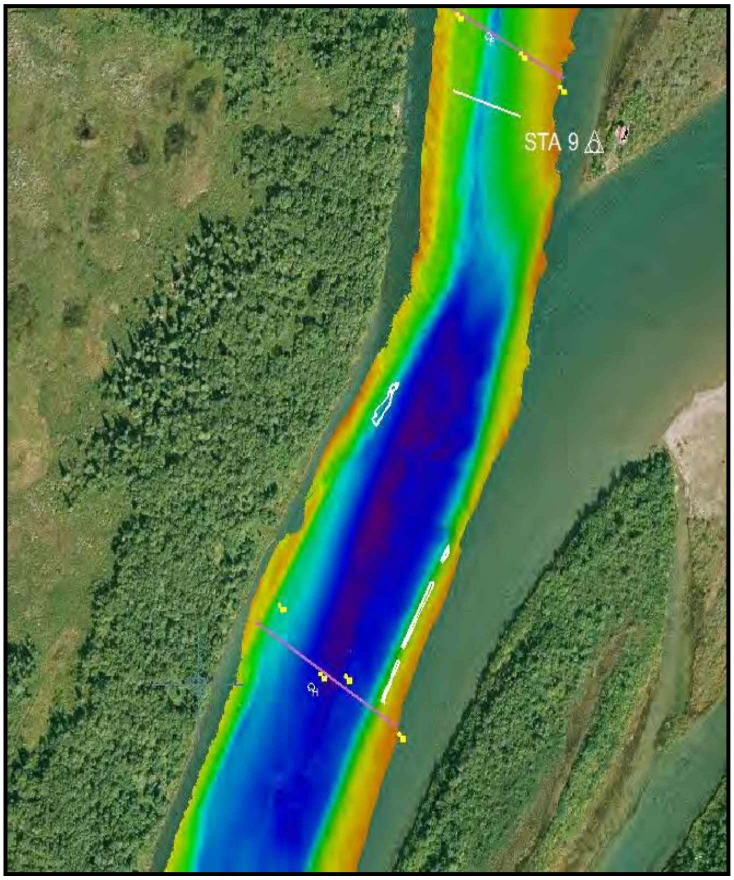


Figure 16 – Minor data gaps depicted in white.

7.0 ACOUSTIC DOPPLER CURRENT PROFILING

7.1 Introduction

The principle aim of this study was to characterize the hydrokinetic energy of the Kvichak River. TerraSond used a Workhorse Sentinel 1200kHz acoustic Doppler current profiler, (ADCP) to survey flow velocities and estimate discharge. The instrument was manufactured by Teledyne RD Instruments, (TRDI) of San Diego, California. ADCP studies were completed during Expedition II, III, and IV. On each of these expeditions the ADCP was used to test for a moving bed, estimate river discharge, and survey flow velocity across select transects.

7.2 ADCP Methods

7.2.1 Instrumentation

All ADCP measurements were done with a Teledyne RD Instruments 1200 kHz Workhorse Sentinel. It was equipped with a thermistor to measure water temperature, a flux gate compass tilt sensor, and Doppler bottom tracking. The same instrument was used for the entire study. ADCP data was collected using TRDI WinRiver II Version 2.07 running on a Dell Latitude E6400 XFR laptop computer with Windows XP professional operating system. The ADCP was powered by an external AC power source. Real time horizontal position and heading were supplied to WinRiver II by a Coda Octopus F-180 inertial motion unit. The F-180 received RTK GPS correction messages from a Leica 1200+ series base station located on monument HK-1. WinRiver II received the instrument’s roll and pitch from the ADCP’s internal flux gate compass tilt sensor. HYPACK MAX 2011 was used to manage boat navigation and mark key target points. HYPACK MAX received its horizontal positions from the F-180. The survey platform for the ADCP system was an 18 foot Lowe Jon boat. The ADCP was mounted vertically on the port side of the boat using a pole mount. The F-180 and its GPS antennas were mounted on the same pole directly above the ADCP. The transducer head of the ADCP was 0.5 meters below the water line. The instrument was programmed with a 25 cm blanking distance and 25 cm bins. The ping rate was 1 Hz and each ensemble consisted of a single ping. Flow data was collected using GPS and bottom tracking simultaneously. The speed of sound in water was computed by WinRiver II using the ADCP measured water temperature and a salinity of 0 ppt.

7.2.2 Instrument Calibration

All calibrations and checks were done according the specifications provided in the respective manufacturer’s technical manuals. The detailed steps required for each procedure may be obtained from the appropriate manuals.

Prior to starting the ADCP surveys the instrument’s flux gate compass was calibrated for hard and soft iron on shore in the vicinity of the project site. The ADCP was then installed on the boat pole mount. The boat transited to the lake and the remaining calibrations and checks were completed. On the lake the ADCP compass calibration was verified, and the head misalignment was determined. The F-180 was also calibrated on the lake. Prior to each survey session on the river the compass calibration was verified, head misalignment was determined, and the F-180 was calibrated.

7.2.3 Moving Bed Test

Moving bed tests were done at several locations in the project site. All of the tests were done using the stationary method as outlined in the USGS and TRDI methods. For each test the boat was held for a minimum of 10 minutes as close to a single point as possible using visual references and HYPACK MAX positioning. The boat movement as determined by bottom tracking was recorded during the session. The boat position and indicated upstream progress were then evaluated to assess the potential for the existence of a moving bed. Over the three expeditions a total of nine moving bed tests were completed. One moving bed test was done in conjunction with each of the discharge measurements. The additional tests were located at select points of interest in the study area. These locations were chosen based on their proximity to prospective turbine sites as well as changes in bed morphology and water flow that indicated a potential for the existence of a moving bed. All of the moving bed tests indicated that any bed movement that might be present was below the limit of detection for the instrument and method. Further, the use of RTK GPS for positioning of the ADCP obviated any potential bias in the discharge measurement that would have been introduced by a moving bed if bottom tracking was used. The locations of all moving bed tests have been depicted on the accompanying map sheets in Appendix 1.

7.2.4 Discharge Measurements

A discharge measurement was completed on Expeditions II, III, and IV. These measurements were done at Station 5. This location was selected for several reasons. First, it was in the same area that the USGS did their discharge measurements. This would allow the current discharge to have a reasonable basis for comparison to the USGS's data collection. Station 5 is located upstream from the first bifurcation in the river channel. There were no significant tributaries upstream of Station 5. Thus there was no division of flow or addition of flow associated with this station. Therefore, the discharge measurements represent the river flow that is received from the lake. Station 5 was also close to the current electric power generation facility. It was also thought to be a location with high energy density.

Discharge measurements were completed using the protocols recommended by the USGS and TRDI. A minimum of four transects consisting of two matched left - right pairs were run for each discharge measurement. The discharge values were computed by WinRiver II. The discharge of the individual transects was compared to the mean discharge for the set. None of the individual discharge values differed from the mean discharge by more than 5%.

7.2.5 ADCP Velocity Transects

Single transect velocity measurements were made at numerous locations on Expeditions II, III, and IV. There was a total of 54 transects completed over the three expeditions. Single transects were run at stations 1 to 4, and 6 to 12 on Expedition II. On Expedition III single transects were run at stations 6, 9 to 11, and 13 to 18. After evaluating the data from Expeditions II and III it was determined that the ADCP transects for Expedition IV should focus on areas in the vicinity of Stations 5, 6, 9, 10, 11, and 17. These areas were then designated as sites 5, 6, 9, 10, 11, and 17. The discharge measurement at Site 5 was used to fulfill the requirement for the single Site 5 velocity transect. Eleven transects were completed at Site 6. The first transect was located approximately 30 meters downstream of Station 5. The remaining 10 transects were the spaced at

20 meter intervals downstream. The eleventh transect was located about 120 meters downstream of Station 6. The Site 9 transects started about 90 meters upstream of Station 9. From this point a total of 10 transects were placed at approximately 20 meter intervals downstream. The Site 10 transects started about 20 meters downstream of the last transect of Site 9. The remaining 10 transects were then placed at successive 30 meter intervals downstream. Single transects were run at Site 11 and 17. Both of them were located at the respective stations. The locations of these transects have been depicted on the map sheets in Appendix 1.

Because of the instrument draft and blanking distance the first measurement bin spanned a zone that was between 75 and 100 cm below the surface. WinRiver II used an extrapolation algorithm to estimate the velocity and flow in the zone between the first bin and the surface. Nonetheless it was determined that there would be some value to measuring the flow speed in the zone above the first bin. A Marsh-McBirney FlowMate 2000 portable velocity flow meter was used to make a series of water speed measurement in this zone on all of the transects surveyed during Expeditions III and IV. The flow mate was placed on a vertical pole and fixed at a depth of 61 cm. The boat was held at select points on the transects by means of visual reference and GPS positioning using HYPAK MAX and the F-180. The positions and water speeds were compiled in a spreadsheet. The Marsh-McBirney sample positions and velocities collected during Expedition IV were depicted on the map sheets in Appendix 1. A spreadsheet with the measured velocities and positions was places in Appendix 2.

8.0 RIVER SLOPE ESTIMATE

8.1 Introduction

On 18 June 2011 a set of water level measurements were made using a Leica 1200+ series RTK GPS rover unit. The water levels and horizontal positions were placed in an Excel 2010 spread sheet and the ellipsoid heights were regressed to a line with respect to reach distance, Figure 17.

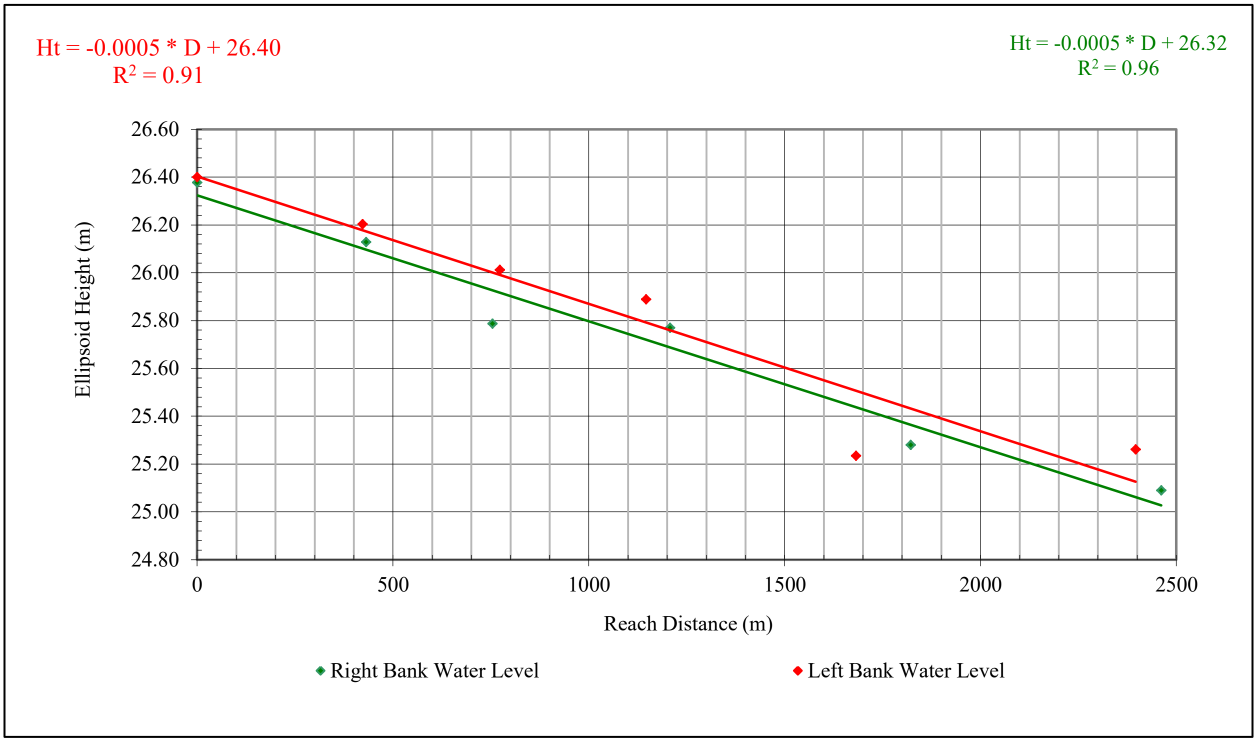


Figure 17 – Linear regression of water level slope.

8.2 Water Surface Level Slope Estimate

Corresponding left and right bank water levels were measured on 18 June 2011. These measurements were done using a Leica 1200+ series RTK GPS rover unit that was receiving correction messages from an RTK GPS base station set on HK-1. Measurements were made in the vicinity of Stations 1,3,5,8,9, and 12. The reach distance along each bank between points was computed. The ellipsoid heights with respect to the computed reach distances were then regressed to a line using Microsoft Excel 2010. This regression gave an estimated water surface slope of -0.0005 for both banks. The R^2 regression coefficients were 0.91 and 0.96 for the left and right banks respectively, Figure 17.

EQN 8.1 $Ht = S_{WL} * D + b$

Where: Ht = Ellipsoid height of the water surface in meters
S_{WL} = Water level slope
b = Height of the vertical intercept of the regression line at the putative river mouth

9.0 RIVER BED MATERIALS

9.1 Introduction

During the third expedition to Igiugig ten sediment samples were collected from the Kvichak River bed and Iliamna Lake. The collection dates were 27 and 30 August 2011. These samples were collected by dragging a cylindrical bed sampler several meters on the bottom. One drag was made for each sample. This yielded approximately four liters of bed material per sample. The sampled materials were classified by size using the scheme of Lane et. al as presented in Sediment Transport Theory and Practice by Yang (1996). This was a coarse characterization of materials based on simple inspection and measurement using calipers and the American Association of Petroleum Geologist's sedimentary size graph by George V. Chilingar. It was not intended to replace a more rigorous analysis using appropriate methods with standard sieves and hydrometry. The locations of the bed samples are depicted on the accompanying map sheets in Appendix 1.

9.2 Bed Samples

Sample	***Description***
A.	The material is exclusively sand. The majority is coarse sand. The remainder consists of medium and fine sand. There is no frank presentation of gravel, cobbles, silt or clay.
B.	There are some small cobbles. The predominant material is gravel. The full spectrum of gravel sizes is present. However, most of it is in the medium and fine range. Some sand is present in sizes from 0.25 to 2 mm. The majority of the sand is 0.5 to 1.0 mm. (coarse sand). There is a minor amount of clay/silt material. The sample has a pronounced odor of organic decay.
C.	This material is substantially dominated by small cobbles. The small remainder consists of gravel and sand. The majority of the gravel is coarse and medium with a very small amount of fine gravel. The sand is mostly coarse. There are trace amounts of fine and very fine sand. There is no frank evidence of silt or clay. The sample has a mild aroma of organic decay.
D.	This material is predominantly small cobbles and gravel. There is some very coarse and coarse gravel. The sample is dominated by medium and fine gravel. A small amount of very coarse sand is present. There is no obvious presence of material smaller than coarse sand.
E.	The bed is predominantly gravel. The full spectrum of gravel sizes is present. There are some small cobbles. The minimal amount of sand present is primarily very coarse and coarse.
F.	This sample is primarily medium and fine gravel. However, the full spectrum of gravel sizes is present. There are some small cobbles. The small amount of sand present is primarily coarse and very coarse. There is no clear evidence of finer sands, silt or clay.

G. The bed material is small cobbles and very coarse gravel. There are no significant amounts of any smaller materials.

H. The majority of material is small cobbles and very coarse gravel. The small remainder is coarse, medium and fine gravel. There is no evidence of finer material.

I. There are some small cobbles. The primary gravel is very coarse, and coarse. Some medium, fine, and very fine gravel is present. Finer material does not appear.

J. The material is small cobbles with very coarse, coarse, and medium gravel. There are no significant amounts of finer material.

Iliamna Lake and the Kvichak river waters are exceptionally clear. On the lake the bottom can be easily seen to a depth of five meters. In the general vicinity of the river mouth the lake bottom appears to be scattered cobbles, and small boulders on top of coarse sand. The river the bed is visible in almost all of the study area. The central part of the channel appears to be small to large cobbles and the occasional small boulder. At the water line by the mouth of the river the gravel and cobbles diminish and the beach consists primarily of fine and medium sands. There are occasional small areas with substantial silt or clay material. Further downstream the shore line presents infrequent small and medium boulders. The primary materials are large and small cobbles, with an assortment of gravel, and sand. There is relatively little organic material in the shoreline bed.

10.0 FINDINGS

10.1 Introduction

ADCP surveys were completed on Expeditions II, III, and IV. The effort had three primary goals. The first goal was to obtain discharge measurements at low medium and high stages. The second goal was to determine if there was a detectable moving bed at select points in the river. The final goal was to develop a detailed picture of the flow velocities and distribution of hydrokinetic energy density in the river.

A multibeam bathymetric survey was completed on Expedition II and III. The data from Expedition II was not satisfactory. It was discarded and a second survey was completed on Expedition III. The results of the second survey were the only ones included in this report. The purpose of the multibeam survey was to develop a detailed digital elevation model (DEM) of the river bed. Second, it established a baseline state of river bathymetry. It created a detailed 3-D data set suitable for future modeling requirements. Finally, the bathymetric survey was also used to identify dangers to navigation, and hazards for construction.

Ten bed samples were collected on Expedition III. These samples were intended to give a preliminary view of the typical bed material in the project site. They were not intended to be suitable for a detailed sediment study for the purpose of making a definitive assessment of bed stability and bed load transport.

None of the RM’s from the USGS gaging station were recovered. Nonetheless some coarse relationships were established. This was done by referencing current discharge measurements to the original USGS rating curve and then relating the gage heights to an ellipsoid height. This was then used to make some estimates of return even parameters, and extremes of flow and height conditions. These findings should be accepted with great caution. The river has changed over the decades since the USGS operated its gaging station. No physical tie to the USGS RM’s was possible. Therefore, the relationships established are based only on a rough estimate of water levels using a rating curve that is over two decades old.

10.2 ADCP Findings

TerraSond did ADCP surveys on Expeditions II, III, and IV. On each expedition a discharge measurement was completed at Station 5 in the vicinity of the electric power generator facility. A moving bed test was done in conjunction with each of these discharge measurements. On each occasion no moving bed was detected. Over the three expeditions a total of eight more moving bed tests were completed at other locations in the river. No moving bed was detected at any of these locations. The locations of the moving bed tests have been depicted on the accompanying map sheets. Fifty four single transects were completed over the course of the three expeditions. Nine single transects were done on Expedition II. The first of these was at the mouth of the river and the last was in the vicinity of the downstream extent of the original proposed survey area. This was about 2.5 km downstream. On Expedition III ten single transects were completed The first was at Station 5 and last was at Station 18. The transect at Station 18 was about 1.5 km downstream from Station 12. The total downstream extent of ADCP surveys was nearly 4 km of reach distance. After examination of the ADCP transects from Expeditions II and III it was decided that the best areas for further study were in the vicinity of Stations 5, 6, 9, 10, and 17. The area surrounding each of these stations was expanded to a study site. The sites were given a numerical designation that corresponded with the station that was the basis of the expanded area. ADCP efforts for Expedition IV aimed to develop a more detailed picture of the flow characteristics in these sites. The locations of the sites and the individual transects surveyed at each of these sites are depicted in the accompanying map sheets.

10.2.1 Discharge Measurements

A discharge measurement was done at Station 5 during each expedition. TerraSond attempted to time the discharge measurements to coincide with a low, medium, and high discharge. The first measurement was done on 21 June 2011. The second and third measurements were done on 27 August and 12 October 2011. The results of these measurements are in tables 4, 5, and 6.

21-Jun-11

Expedition II Discharge at Station 5

Transect	Total Q	Delta Q	Width	Total Area	Q/Area	Flow Speed
	m³/s	%	m	m²	m/s	m/s
PH3C002	334	-0.18	123	225	1.5	1.6
PH3C003	334	-0.13	124	222	1.5	1.6
PH3C004	337	0.78	127	227	1.5	1.6
PH3C005	333	-0.47	126	225	1.5	1.5
Average	335	0	125	225	1.5	1.6
Std Dev.	2	0.54	2	2	0.0	0.0

Table 4 – Expedition II ADCP discharge.

29-Aug-11

Expedition III Discharge at Electric Power Station

Transect	Total Q	Delta Q	Width	Total Area	Q/Area	Flow Speed
	m³/s	%	m	m²	m/s	m/s
PWRHSEDIS002	548	0.72	156	327	1.7	1.8
PWRHSEDIS003	540	-0.79	159	330	1.6	1.8
PWRHSEDIS004	544	-0.04	158	326	1.7	1.7
PWRHSEDIS005	545	0.11	158	327	1.7	1.8
Average	544	0	158	327	1.7	1.8
Std Dev.	3	0.62	2	2	0.0	0.0

Table 5 – Expedition III ADCP discharge.

12-Oct-11

Expedition IV Discharge at Electric Power Station

Transect	Total Q	Delta Q	Width	Total Area	Q/Area	Flow Speed
	m³/s	%	m	m²	m/s	m/s
SITE5-1001	548	0.47	170	334	1.6	1.7
SITE5-1002	548	0.55	167	330	1.7	1.7
SITE5-1003	552	1.24	170	333	1.7	1.8
SITE5-1004	533	-2.26	166	329	1.6	1.6
Average	545	0	168	332	1.6	1.7
Std Dev.	8	1.55	2	2	0.0	0.0

Table 6 – Expedition IV ADCP discharge.

The USGS operated a gaging station on the Kvichak River at this location from 1967 to 1987. It was designated Site 15300500. During this time they completed 39 discharge measurements and developed two rating curves. This rating curves were used by the USGS to make daily estimates of discharge. The USGS published these estimates from 1 January 1967 to 1 January 1987. Unfortunately the original RM's for the gaging station have been lost. Further, the river channel has experienced some changes in dimension and flow pattern over the last 24 years. Nonetheless the USGS gaging data has been of some utility in characterizing the current discharge. This data set shows that the typical low discharges have occurred between the middle of March and the middle of April, Figure 18. The high discharges have usually occurred between late August and early October.

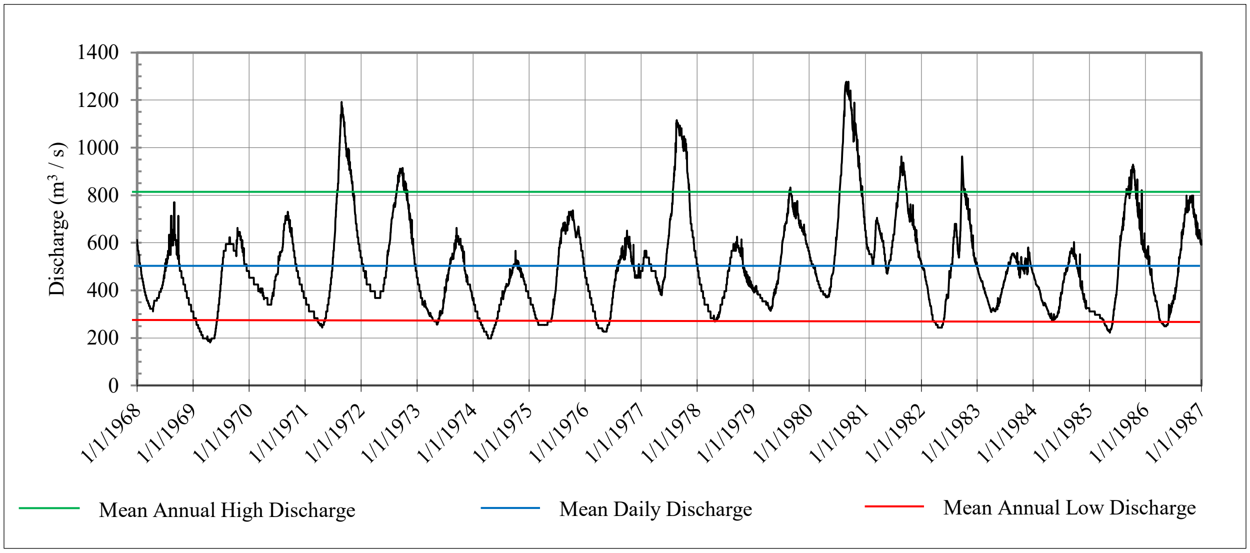


Figure 18 – USGS Site 15300500 daily discharge.

The USGS normally used a river year that corresponds with the U.S. fiscal year to define the period for selecting annual descriptive statistics. This approach was not useful for current analysis because it resulted in annual extremes being designated within weeks of each other in the same calendar year. Therefore it was decided to use the calendar year for river analysis in this report. The annual peak and minimum discharges that have been presented in Figure 19 were determined from the USGS gage data for the respective calendar years.

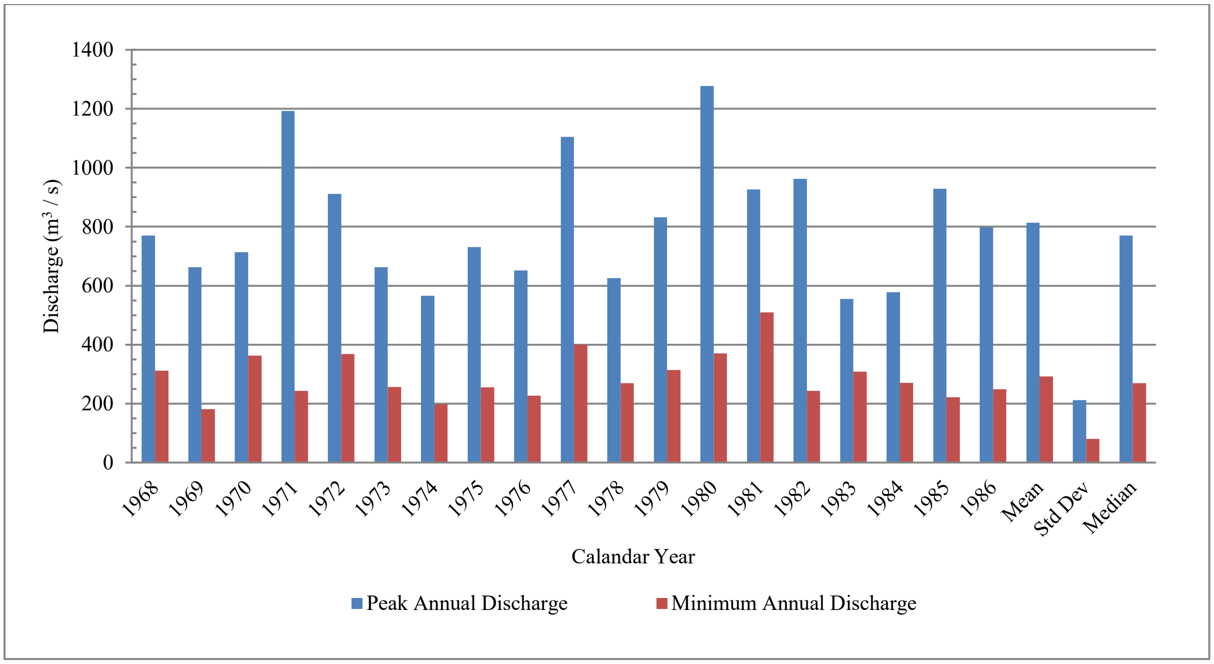


Figure 19 – USGS Site 15300500 annual maximum and minimum discharge.

The average daily discharge for the USGS record was 500 m^3/s (σ = 201 m^3/s). The maximum and minimum daily discharges reported were 1277 m^3/s and 181 m^3/s respectively. The average annual minimum and peak reported discharges were 293 m^3/s, (σ = 81 m^3/s), and 813 m^3/s, (σ = 212 m^3/s). The ADCP measured discharge on 21 June 2011 was 335 m^3/s. This value would have fallen in the 21st percentile of the USGS data set. The other two discharges measured on 27 August and 12 October 2011 were 544 and 545 m^3/s. These measurements fell into the 65th percentile of the USGS record. The USGS reported mean discharge for all of the June months was 405 m^3/s, (σ = 90 m^3/s). The minimum and maximum discharges reported in the USGS data set for the June months were 394 m^3/s and 524 m^3/s. The USGS reported daily mean discharge for all of the August months was 693 m^3/s, (σ = 199 m^3/s). The reported mean discharge for the October months was 699 m^3/s, (σ = 181 m^3/s). The minimum and maximum USGS discharge values October were 510 m^3 / s and 1189 m^3 /s. These parameters have been summarized in table 7. Several community members observed that this year seemed to have some of the lowest water levels that had been seen in the last 15 years. Comparison of the current ADCP discharge measurement to the USGS record has corroborated these observations.

Characteristic	Discharge (m^3/s)	Standard Deviation (1σ m^3/s)
USGS Mean Daily Discharge	500	201
USGS Maximum Daily Discharge	1277	****
USGS Minimum Daily Discharge	181	****
USGS Mean Annual Minimum Discharge	293	81
USGS Mean Annual Maximum Discharge	813	212
USGS Mean Daily Discharge June	405	90
USGS Maximum Discharge June	524	****
USGS Minimum Discharge June	394	****
USGS Mean Daily Discharge August	693	199
USGS Maximum Discharge August	1277	****
USGS Minimum Discharge August	413	****
USGS Mean Daily Discharge October	699	181
USGS Minimum Discharge October	510	****
USGS Maximum Discharge October	1189	****
RISEC Expedition II Discharge	335	2
RISEC Expedition III Discharge	544	3
RISEC Expedition IV Discharge	545	8

Table 7 – Summary discharge statistics.

10.2.2 Moving Bed Tests

Nine moving bed tests were done over the course of the three expeditions. One was done in conjunction with each of the discharge measurements at Station 5. The remaining ones were done at select points of interest in the river. None of these tests detected a moving bed.

The lack of a positive result for a moving bed does not mean that the bed is completely stable. There may be enough movement of the bed at rates below the instrument detection level to cause long term changes in the bed morphology. Further, modifications to flow patterns caused by objects place on the bed may cause substantial localized changes in the bed morphology.

10.2.3 Energy Density

ADCP velocity magnitude values were exported from WinRiver II for further evaluation using MatLAB Version 2008b. The velocity magnitude values were smoothed with a 3 x 3 ensemble average over the entire profile. The total hydrokinetic power density was computed by the following.

EQN 10.1 $P = 0.5 * \rho * V^3$

Where: P = Power density
ρ = Density of fresh water
V = water velocity magnitude

Images depicting the distribution of flow and hydrokinetic power were produced for every transect. The full collect has been placed in Appendix 2 of this report. The highlights of transects collected at Sites 5, 6 9 and 10 have been selected for discussion because they show the most promise for future development.

The depth shown in all of the ADCP transect graphics are those measured by the ADCP at the time of the survey. They have not been adjusted to the KRIGIPVD11 datum. The physical dimensions and acoustic properties of the ADCP prevent direct measurement of the entire channel. The TRDI WinRiver II software applies a series of extrapolation algorithms to estimate current velocities and discharge in the omitted areas. The results of these extrapolations are then added to the actual measured portion of the channel to determine the total discharge of the channel.

The TRDI WorkHorse Sentinel 1200 kHz ADCP used for this project was mounted vertically on a pole with the transducer head 0.5 meters below the water surface. When the transducers ping the sound is emitted in all directions. Thus there is a simultaneous return from the water column and the instrument housing. Because of this the instrument cannot distinguish between returns in the first 0.25 meters in front of the transducer head and the returns from the housing. Therefore no measurements are recorded for the region that extends from the transducer head to a point 0.25 meters distant. This distance is known as the blanking distance. The combined draft and blanking distance for the data presented here is 0.75 meters, (2.46 ft.). Therefore there are no direct measurements of current velocity recorded for the first 0.75 meters of the water column. A small portion of the bottom of the water column does not have direct current velocity measurements. This is due to issues with backscatter from the bottom and the need to use bottom tracking to determine vessel movement. In the data presented here the bottom gap is 0.75 m, (2.46). However, the ADCP does measure the actual depth to the river bed. Due to the instrument draft and blanking distance the ADCP cannot be maneuvered all the way to the shore. There must always be at least 0.75m (2.46) between the transducer heads and the river bed. Therefore, the profiles presented in this report represent the portion of the channel that was surveyed directly by the ADCP. There is a small sliver on each side of the channel that is omitted. In order to make an extrapolation to compute the discharge in the side slivers the ADCP is held in position for about 10 seconds as close as possible to the bank while also maintaining at least two good measurement bins below the instrument. Thus the shallowest water that this instrument configuration can measure is 1.30 m (4.26 ft). While holding position near the bank the distance from the instrument to the bank is measured and recorded in the data record. The sampled bins and the bank distance are used to extrapolate a value for discharge in the omitted sliver at each bank, Figure 20.

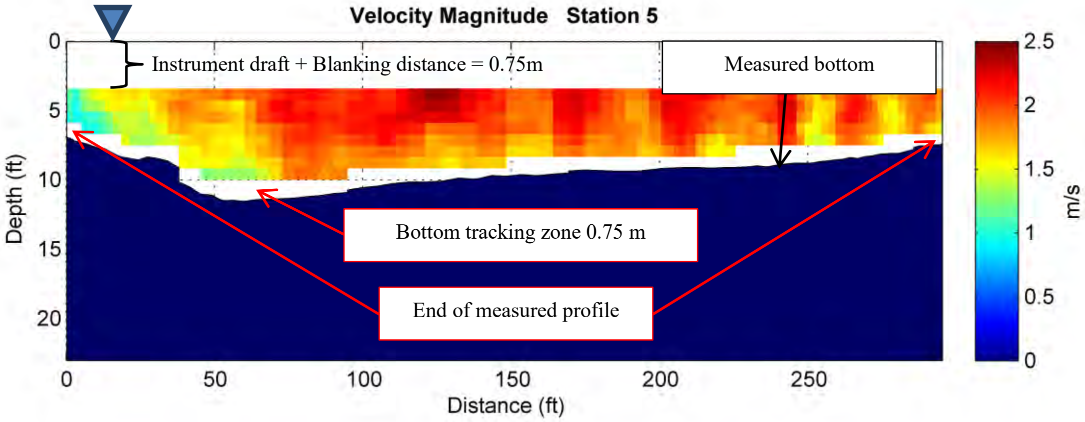


Figure 20 – Omitted zones of ADCP profiles.

10.2.3.1 Station 5

The June ADCP transect at Station 5 exhibits a zone of low to moderate power density that is centrally located in the channel. Its left extent is offset to the right of the thalweg by about 10 meters. From there it extends to the right of the channel such that it ultimately occupies the central two thirds of the river. The overall distribution of power at this station appears to remain the same at the higher discharge rates. Average velocity magnitude at Station 5 was 1.6 m/s on 21 June 2011, 1.8 m/s on 27 August 2011, and 1.7 on 12 October 2011. At the lower discharge the power density ranges from about 2 to 4 kW/m^2. At the higher discharge the range energy density in this zone is from approximately 4 to 6 kW/m^2 Figures 21, 22, 23.

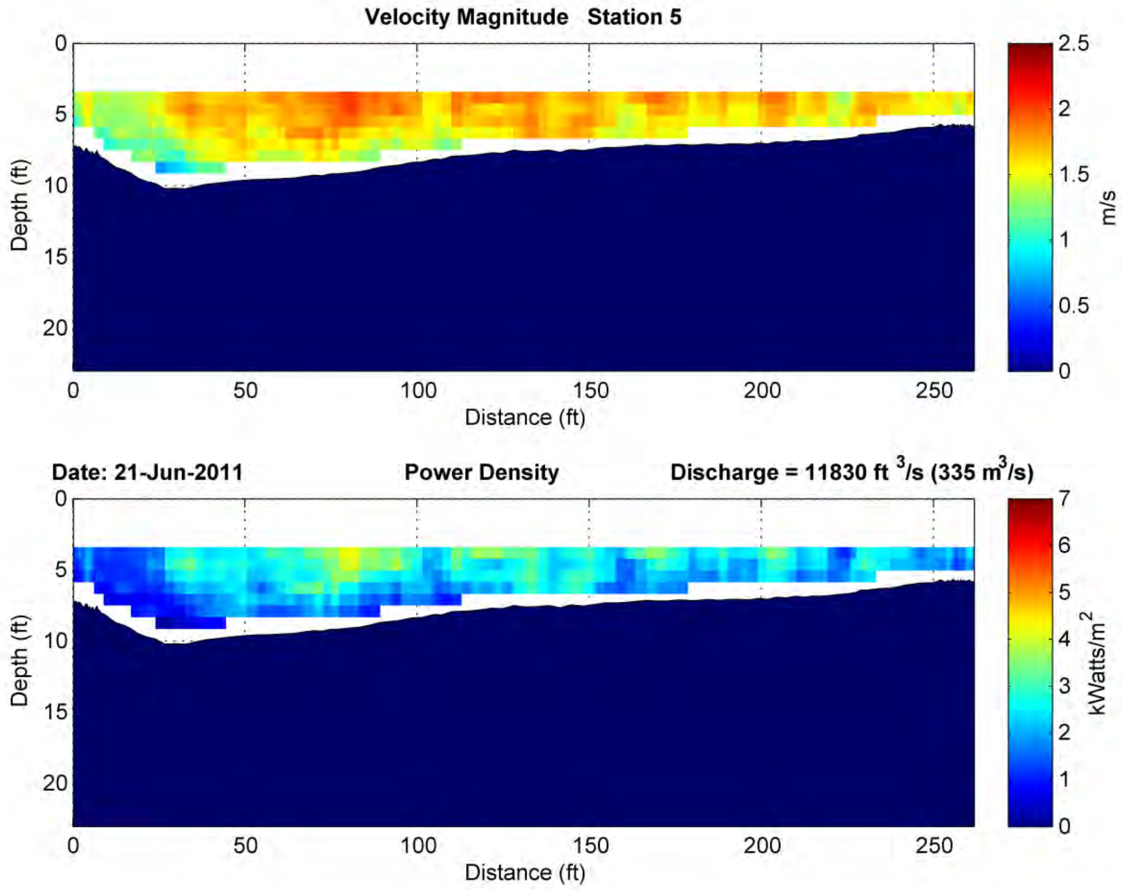


Figure 21 – ADCP transect at Station 5 Expedition II.

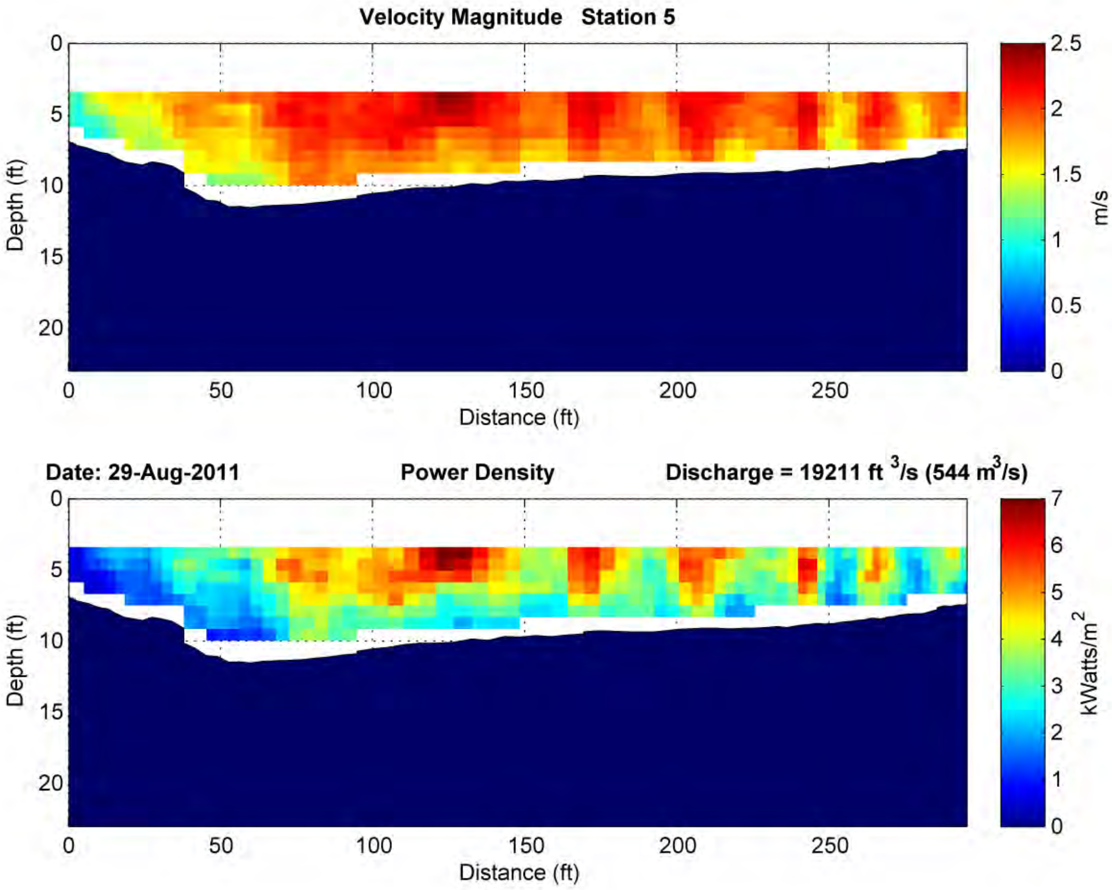


Figure 22 – ADCP transect at Station 5 Expedition III.

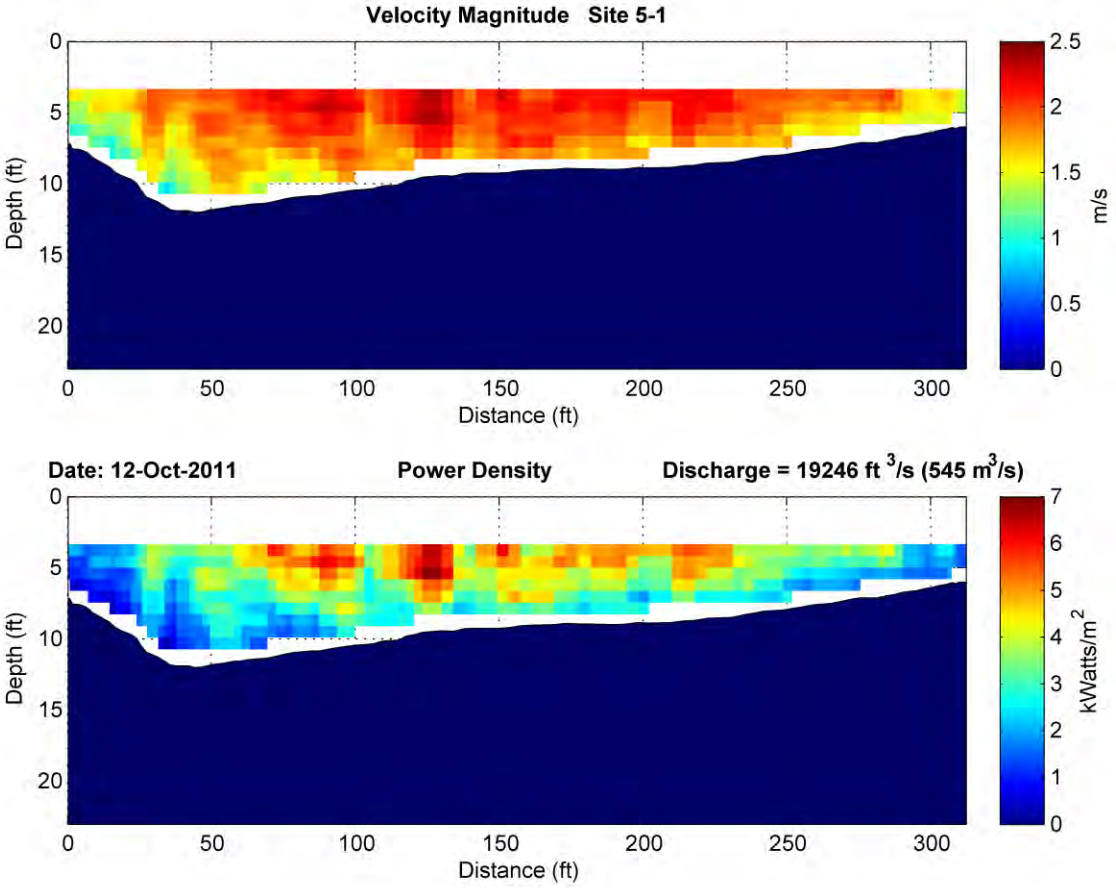


Figure 23 – ADCP transect at Station 5 Expedition IV.

10.2.3 Station 6

The energy is concentrated in the left half of the river at Station 6. In June it is at a moderate level of about 3.5 to 4.5 kW/m^2 Figure 22. The power increases considerably in August and October. At this higher discharge the power range in the left half of the channel is 5 to 7 kW/m^2, Figures 24, 25, 26. The average velocity magnitude at Station 6 for Expeditions II, III, and IV was 1.3, 1.6, and 1.9 m/s respectively. The overall distribution of power remains consistent through the seasons. At this station the power zone is wide. The thalweg is broad and less pronounced compared to other reaches. This location offers a wide high power zone while maintaining good depth and breadth for navigation.

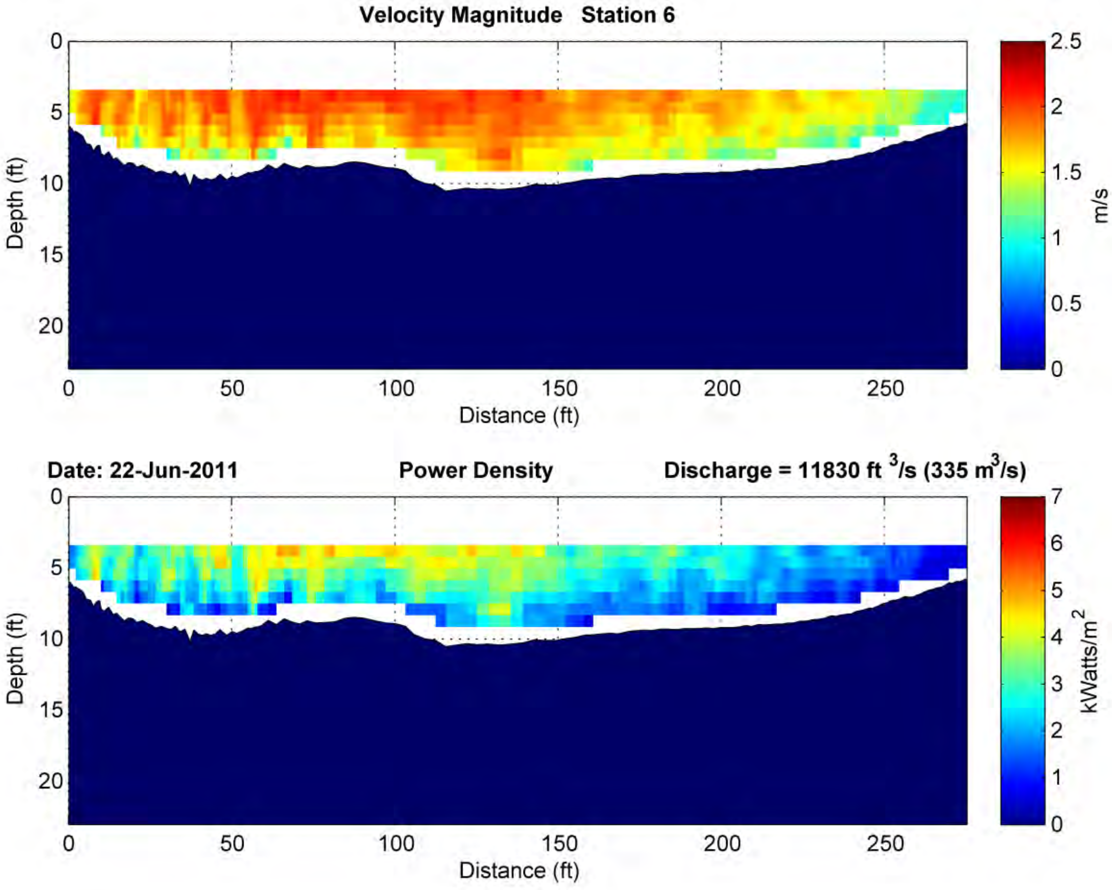


Figure 24 – ADCP transect at Station 6 Expedition II.

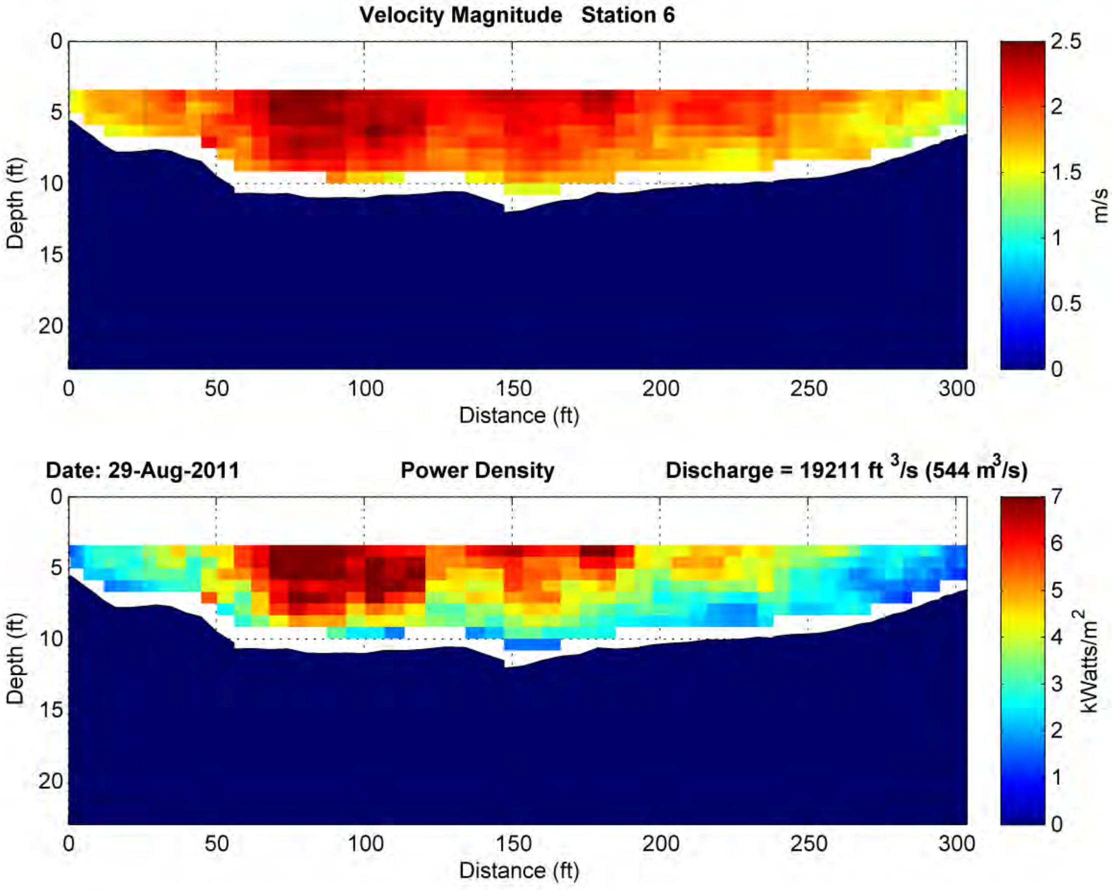


Figure 25 – ADCP transect at Station 6 Expedition III.

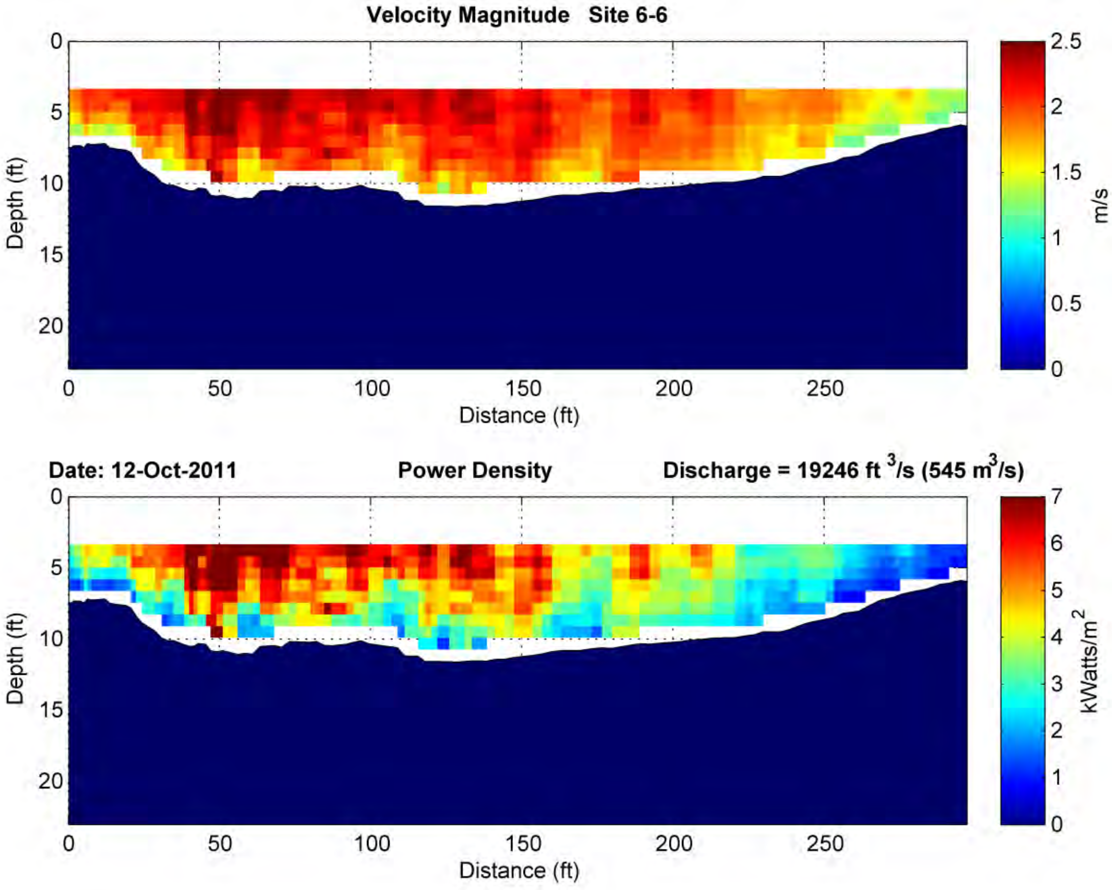


Figure 26 – ADCP transect at Station 6, (Site 6-6) Expedition IV.

10.2.3.1 Site 6

The initial ADCP data from Station 6 indicated that it would be one of the more favorable locations for a turbine. Therefore the scope of investigation was expended about this station. The expanded zone was designated as Site 6. A total of 11 ADCP transects were completed at this site during Expedition IV. The first was placed about 120 meters upstream of the original transect for Station 6. The remaining 10 transected were placed at 20 meter intervals downstream.

At Site 6 the power density distribution changes with the river morphology. From Site 6-1 to 6-2 the thalweg is expanded to the left and becomes less pronounced Figures 26, 27. Two zones of slightly elevated power density start to form at Site 6-2. At Site 6-3 some of the material returns to the left side of the thalweg and the right side is extended and widened, Figure 29.

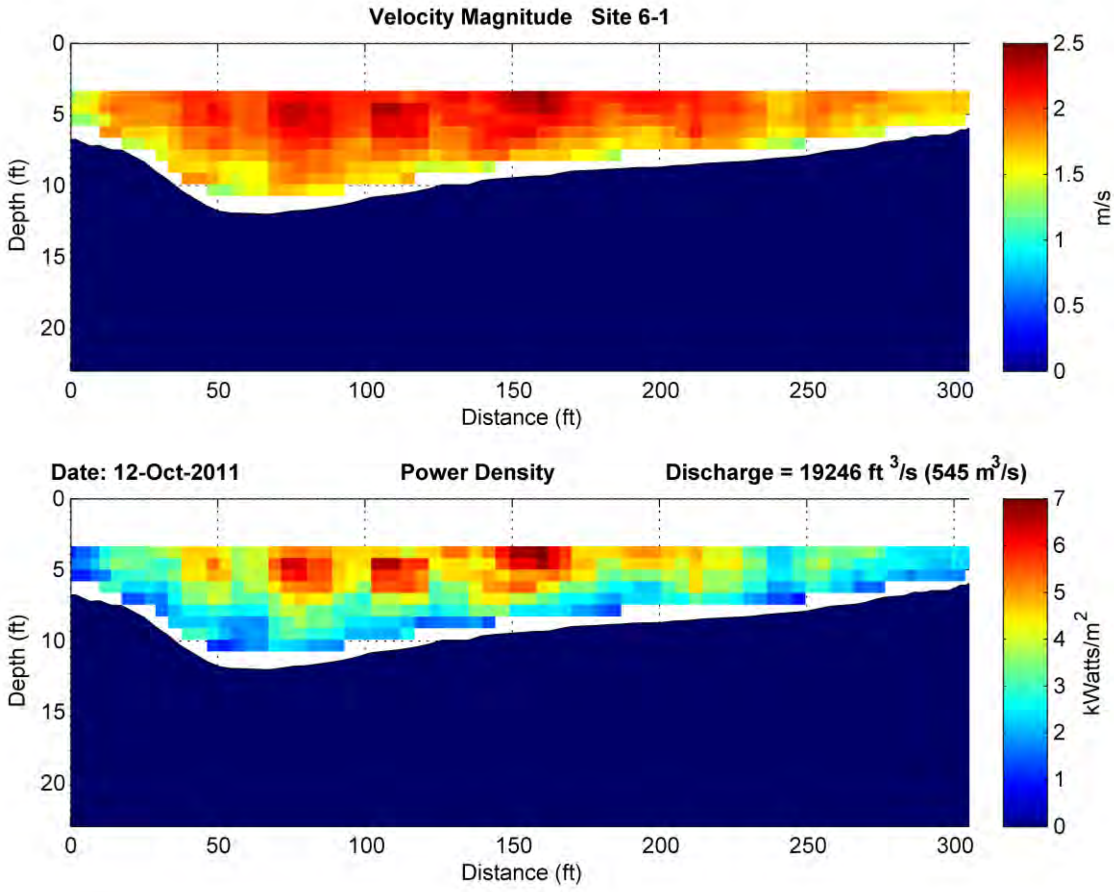


Figure 27 – ADCP transect Site 6-1.

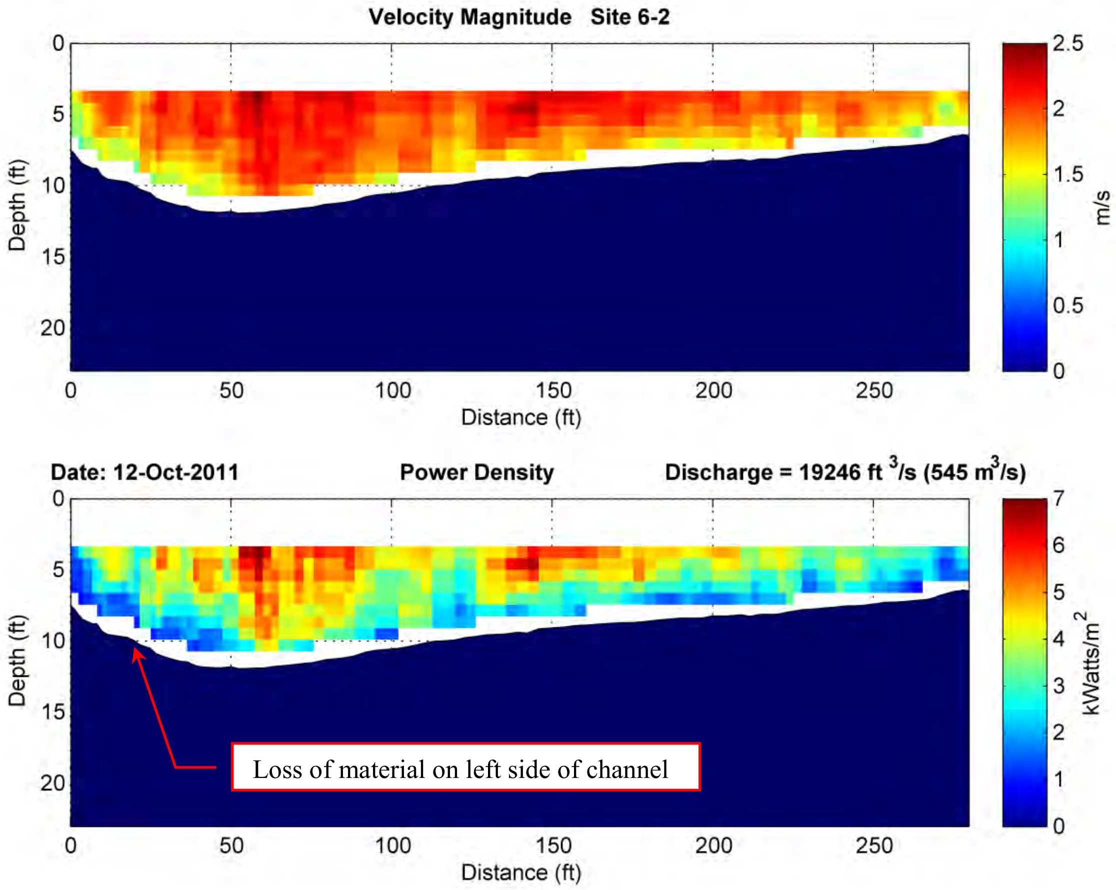


Figure 28 – ADCP transect Site 6-7.

A second zone of elevated energy density develops to the right of the thalweg.

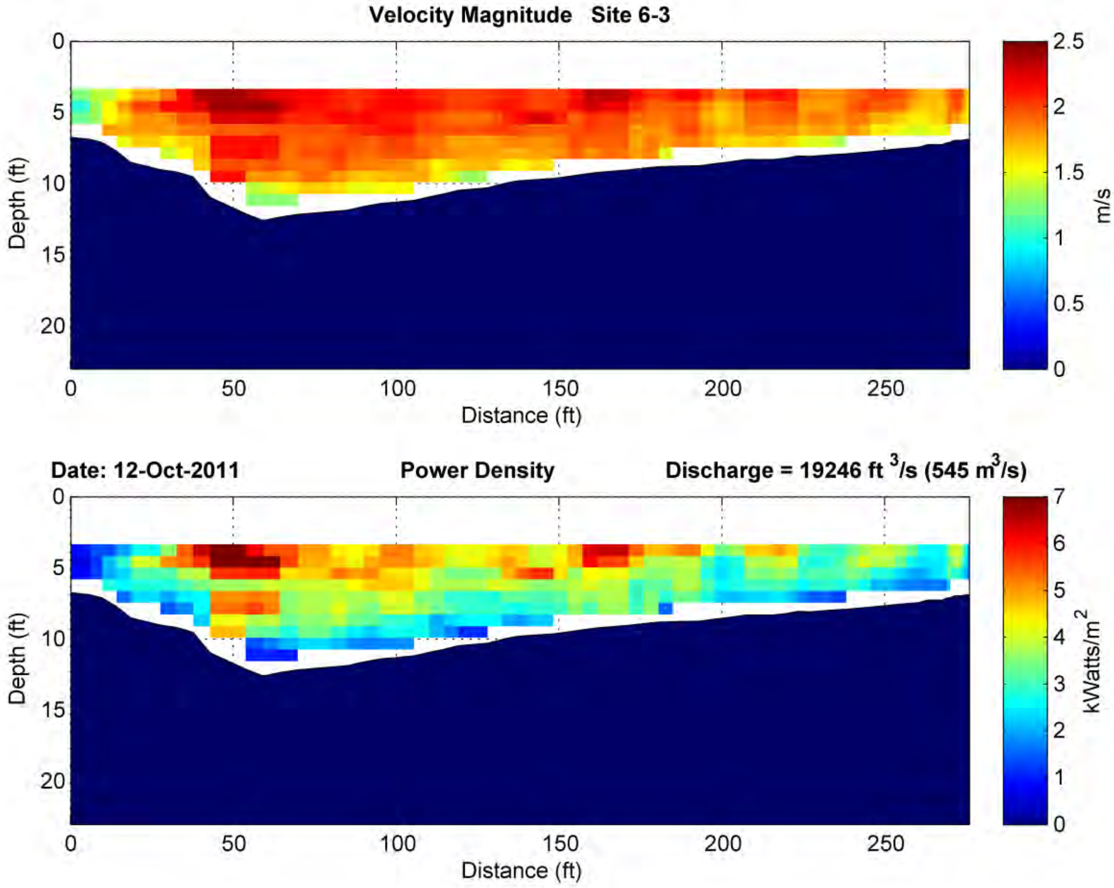


Figure 29 – ADCP Transect Site 6-3.

Some material returns on the left side and the right side continues to expand.

From Site 6-3 to Site 6-6 the thalweg expands to the right and the channel starts to develop a profile that has a steep slope from the left to a low point at 15 meters from the left bank. Then there is a gradual slope up to the right bank. A zone of elevated energy density develops on the left side of the river, Figures 29, 30, 31.

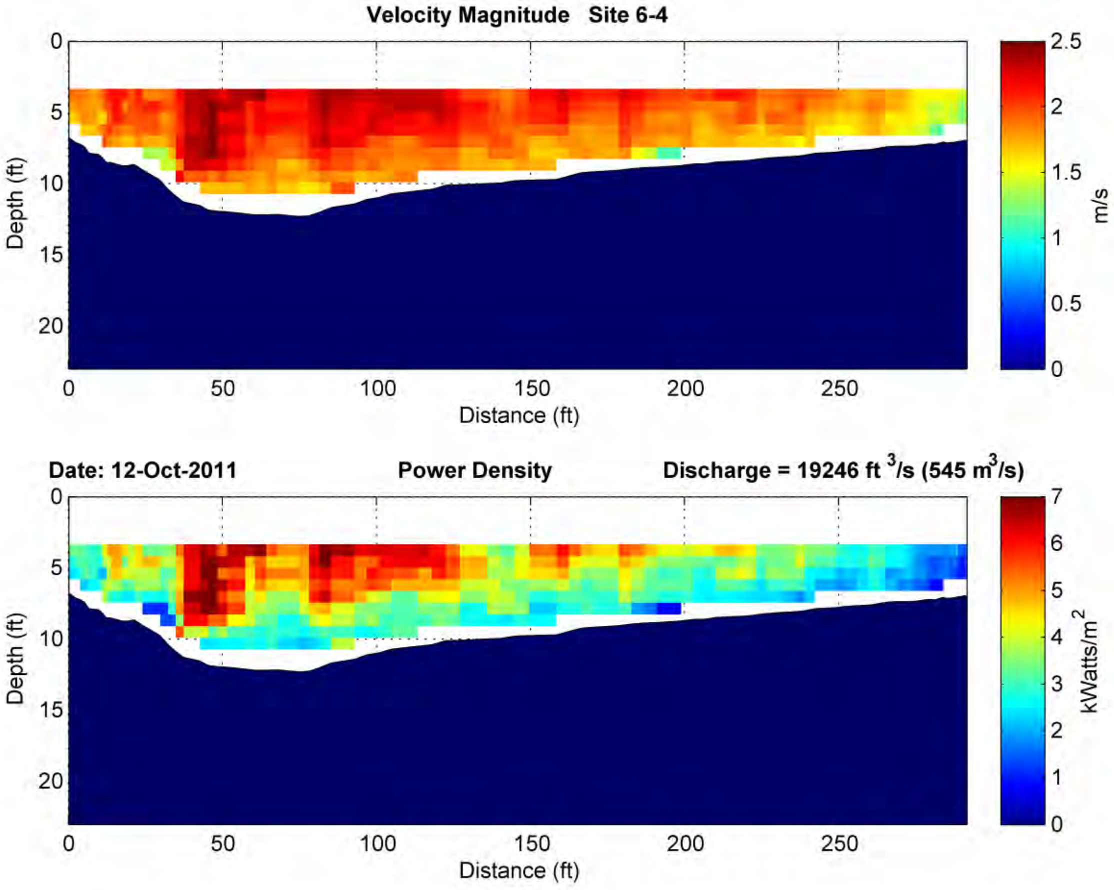


Figure 30 – ADCP transect Site 6-4.

The channel expansion continues and a zone of higher energy density develops in the vicinity of the thalweg.

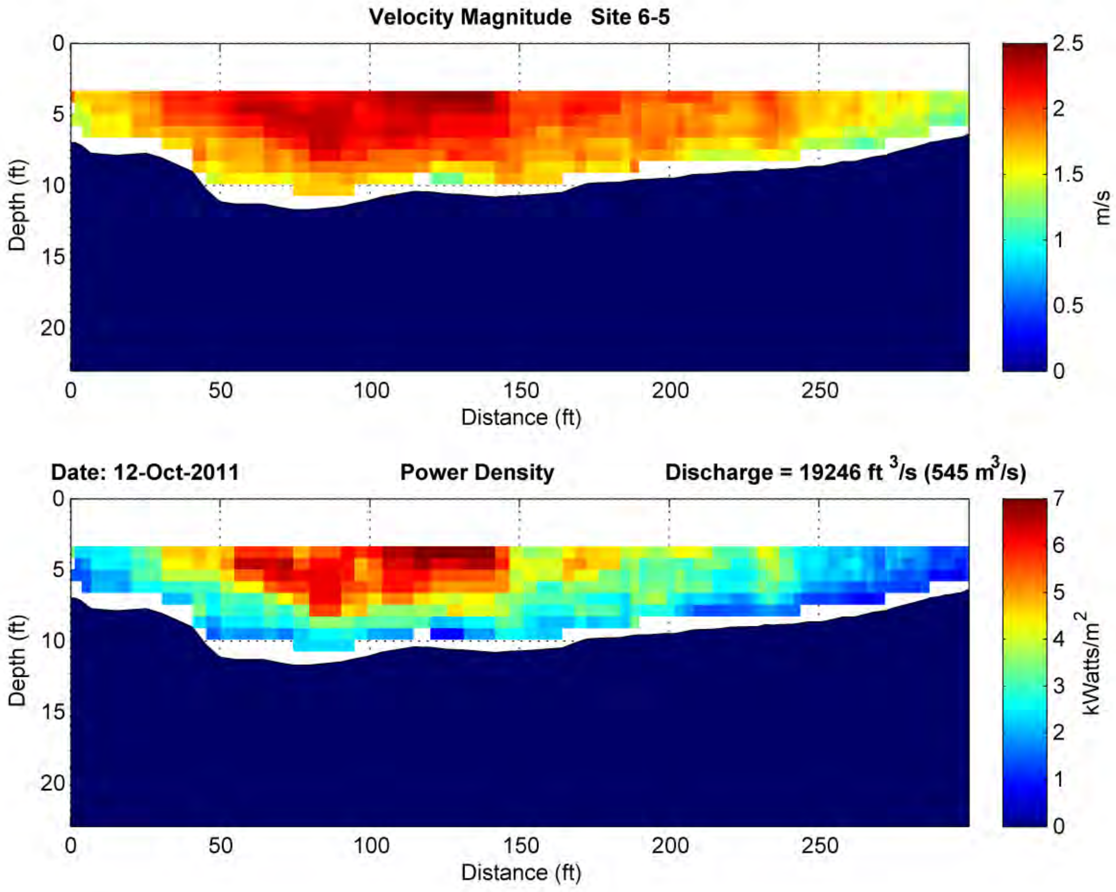


Figure 31 – ADCP transect Site 6-5.

Channel expansion continues and the zone of higher energy density consolidates in the vicinity of the thalweg.

At Site 6-6 the channel expands on the left and right side. The high energy density increases intensity and expands to occupy the majority of the left half of the channel. At Site 6-7 the channel is filled in on the left and continues to excavate on the right. The zone of elevated energy density remains largely the same as in the upstream transect. At Site 6-8 the left side is excavated again and the right side continues to be excavated. The overall profile has moderately steep slopes on the left and right with a flat bottom that comprises the central half of the channel. The elevated energy density persists to the left half of the channel, Figures 32, 33, 34.

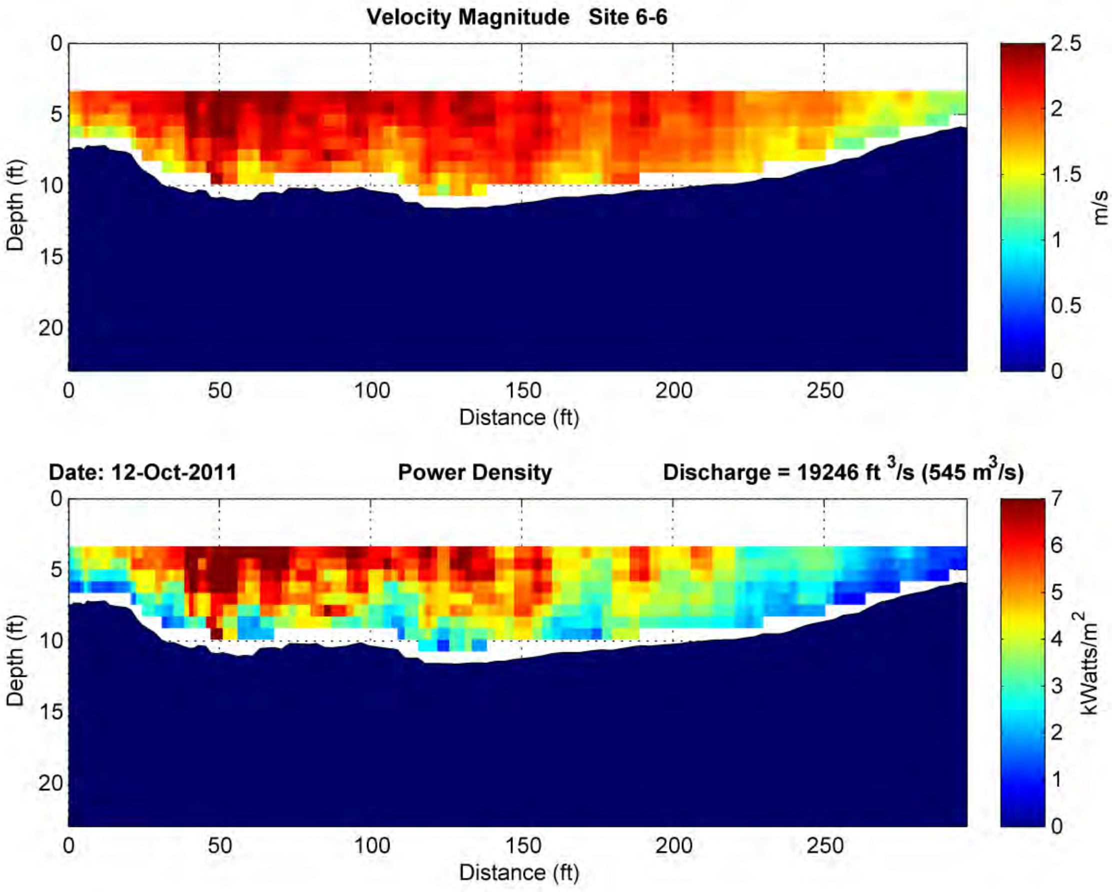
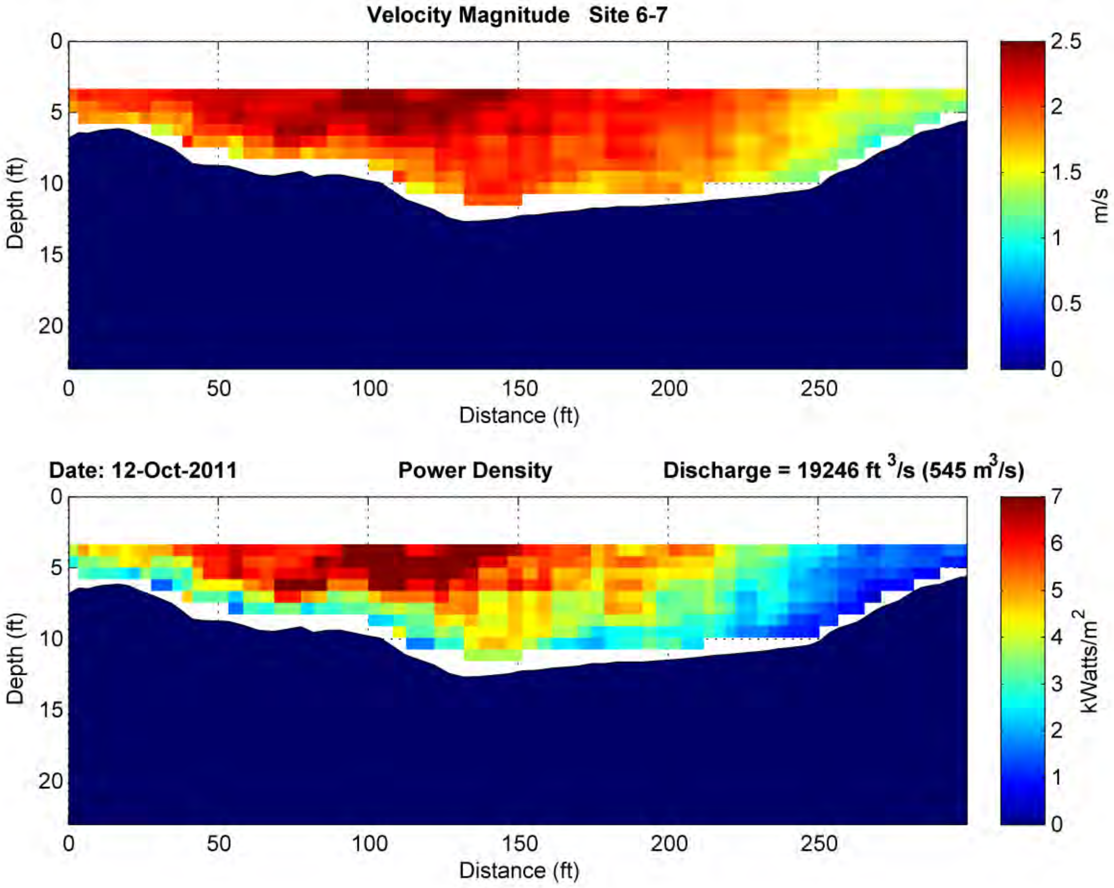


Figure 32 – ADCP transect Site 6-6.

The channel expansion continues and the zone of higher energy density expands to occupy the left half of the channel.


Velocity Magnitude Site 6-7

Date: 12-Oct-2011 Power Density Discharge = 19246 ft ^{3}/s (545 m^3/s)

Figure 33 – ADCP transect 6-7.

At Site 6-7 the channel is filled in on the left and continues to be excavated on the right.

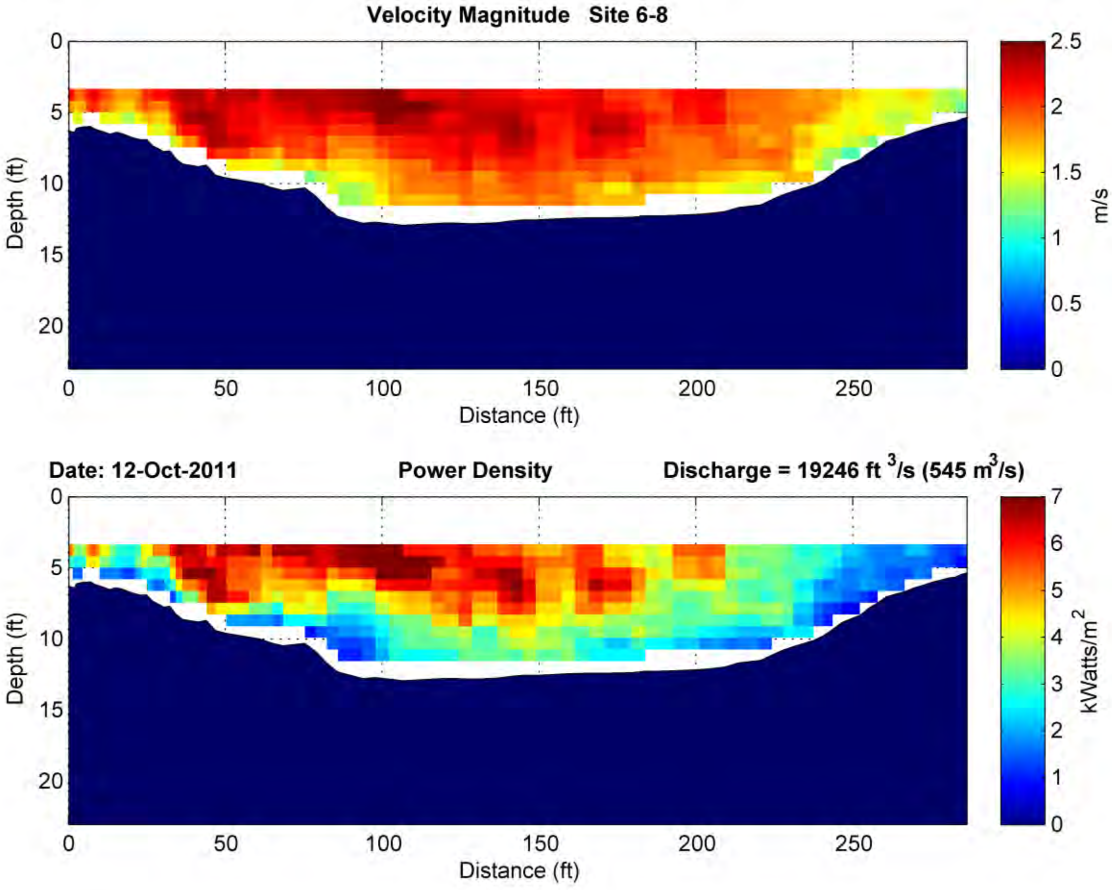


Figure 34 – ADCP transect 6-8.

At Site 6-8 the left side is excavated again and the right side continues to be excavated.

At Site 6-9 the left portion of the channel is filled again and the right side is still excavated. The flat portion of the channel is shifted slightly to right. The elevated energy density still trends to the left of the channel. However it has moved slightly to the right in response to the fill on the left, Figure 35.

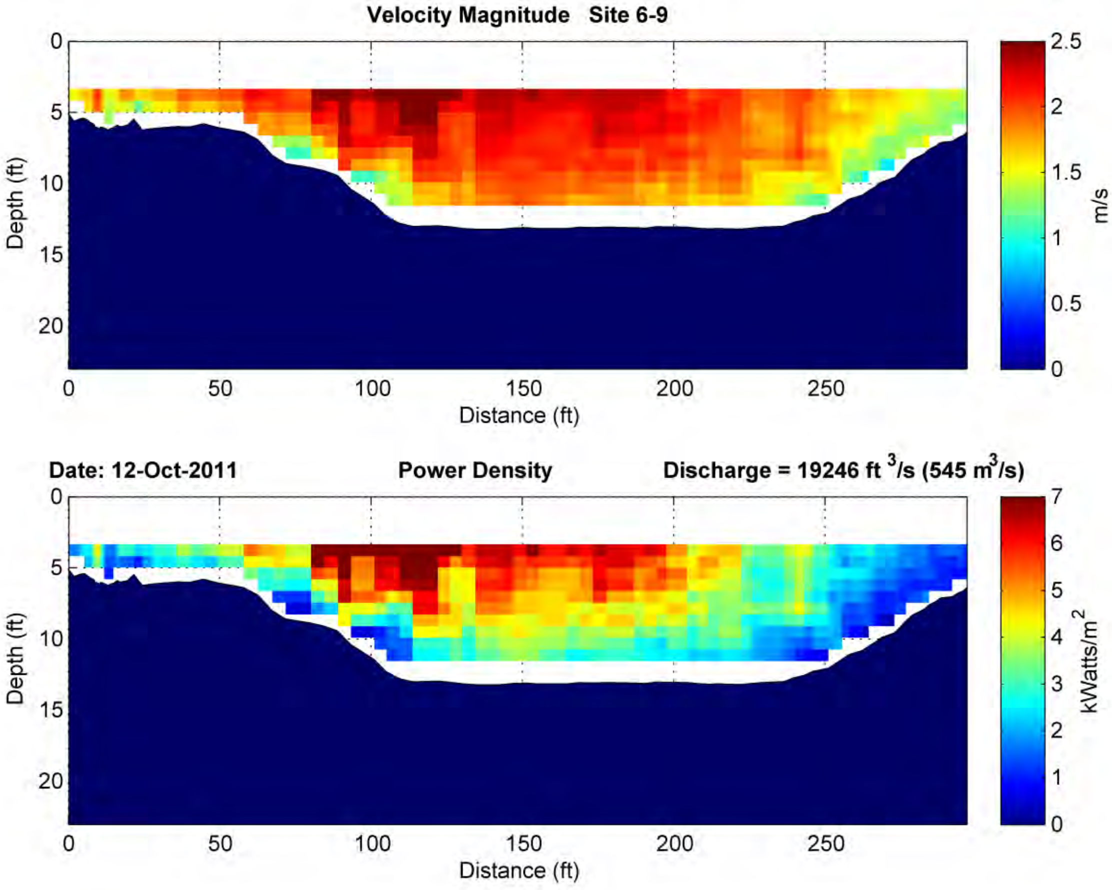


Figure 35 – ADCP Transect Site 6-10.

At Site 6-9 a trapezoidal profile starts to emerge.

The profile at Site 6-10 exhibits a reversal of the previous excavation and fill trend. The left side is substantially excavated and has a very short steep profile. The right side is filled in slightly. The channel profile is dominated by a broad flat section that favors the left side and has a slight dip to the right side. The high energy density zone is expanded over the majority of this broad flat portion of the channel, Figure 36.

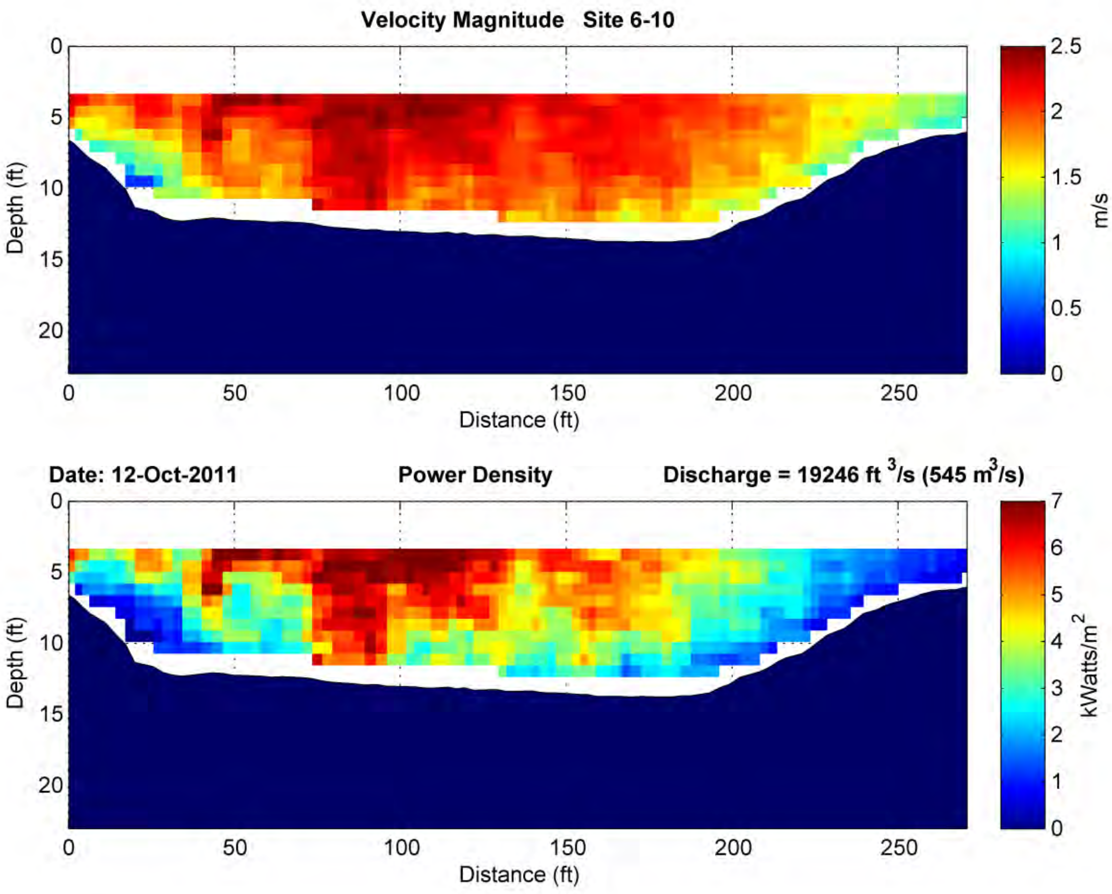


Figure 36 – ADCP transect Site 6-10.

The left side of the channel continues to fill at site 6-11. The channel is developing a profile that has a gradual slope from the left to a low point about 75 m from the left bank. Then there is a steep slope up to the left bank. A more clearly defined thalweg is starting to form on the right side. The elevated energy density zone is in the center of the channel. It appears to be less dense than it was in the upstream profiles, Figure 37.

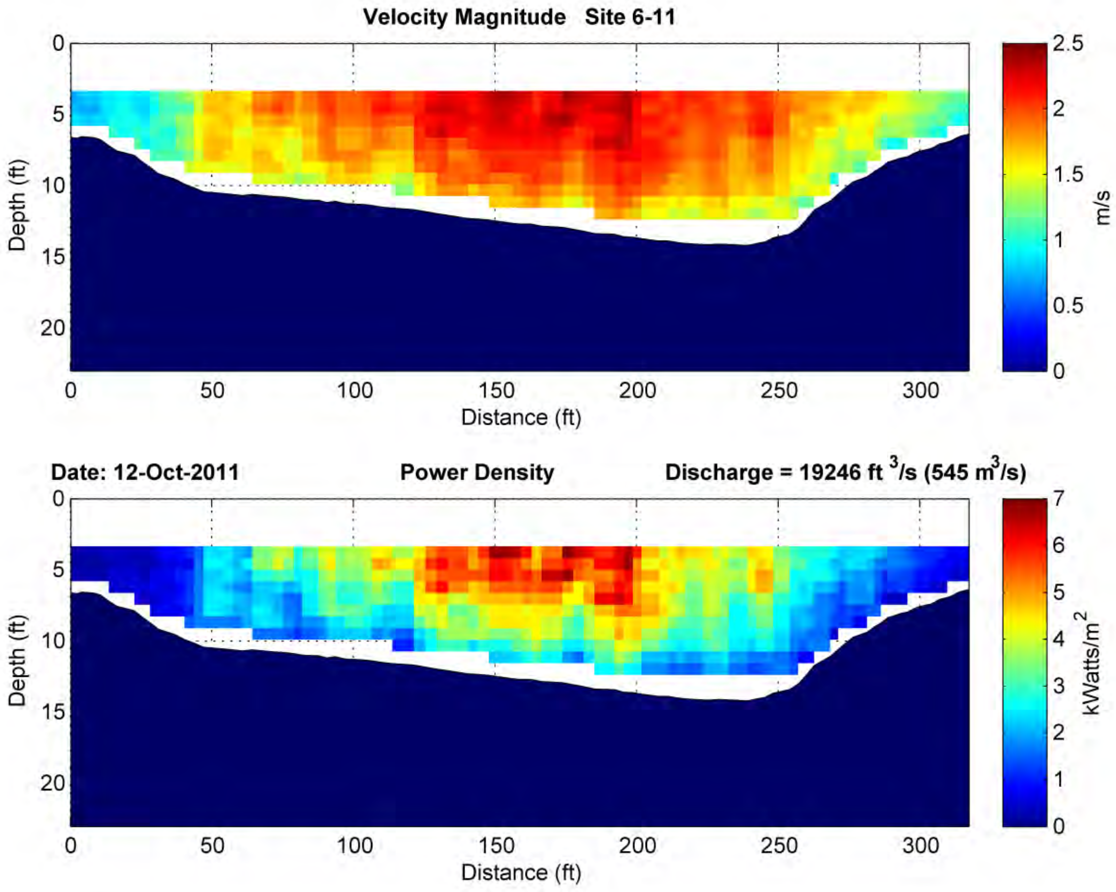


Figure 37 – ADCP transect Site 6-11.

At Site 6-11 the left side starts to fill. This is a harbinger to the inverted profile that emerges in Site 9.

Overall Site 6 offers a stable zone of elevated energy density. The channel is primarily broad and deep. It is close to the current power generation facility and the Fish and Game Boat landing. All three of these features make it a prime candidate site for an electric turbine.

10.2.3.2 Station 9

Station 9 exhibits a stable zone of high energy density that is located in the center of the channel. Even at the lower discharge rate the energy density is between 5 and 7 kW/m^2. The average flow velocities for Station 9 are 1.9, 1.4, 2.0 m/s for each of the successive expeditions, Figures 38, 39, 40.

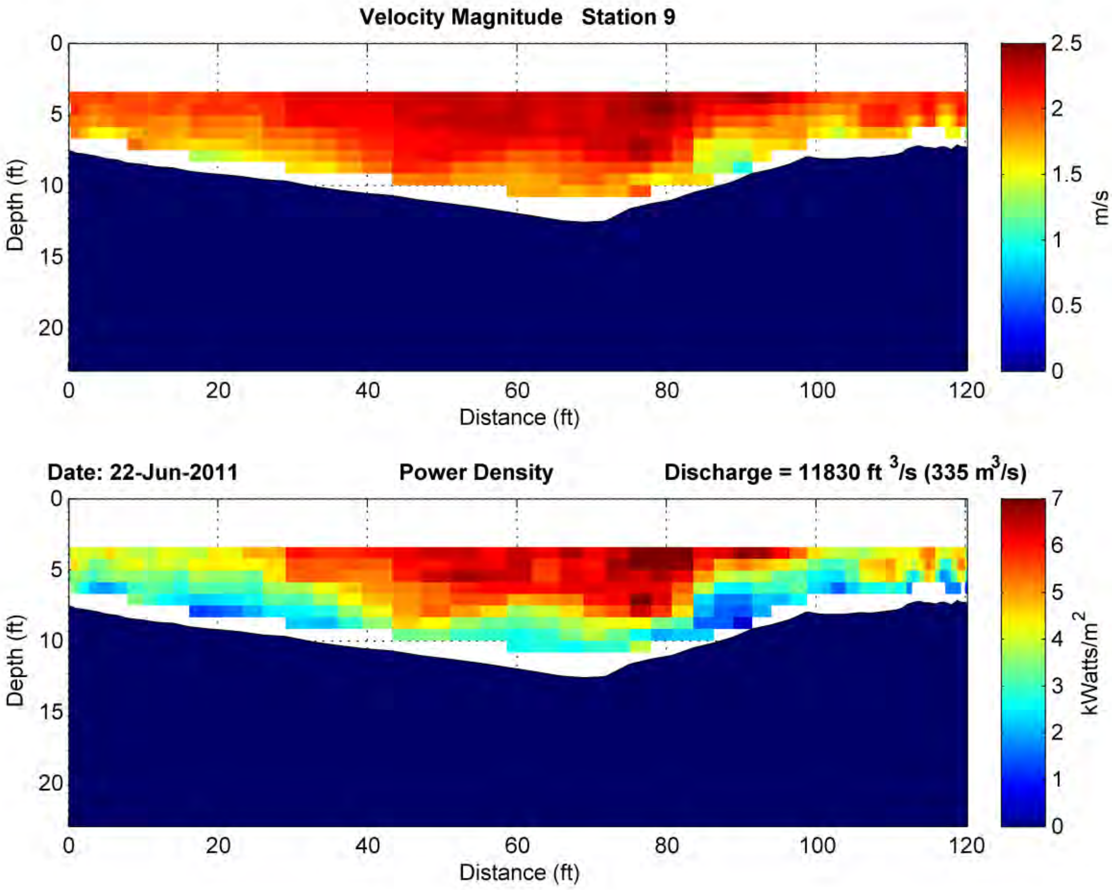


Figure 38 – ADCP transect Station 9 Expedition II.

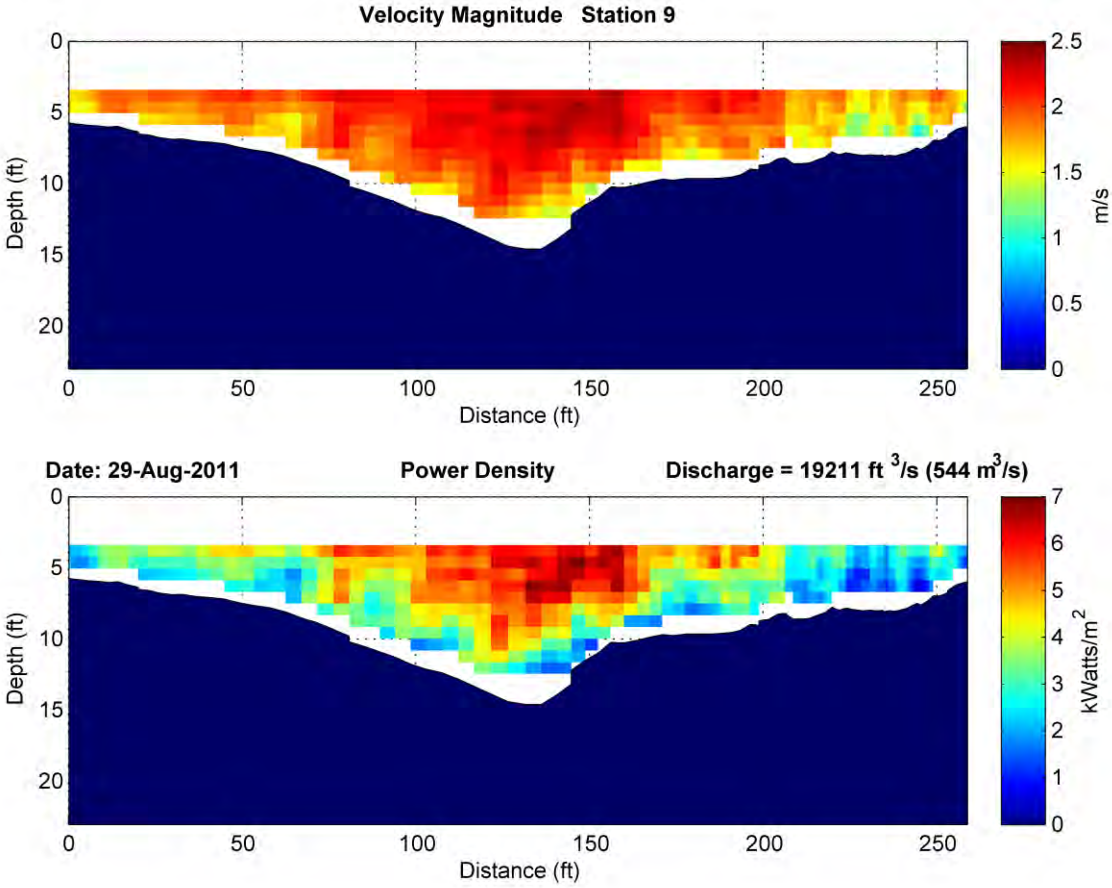
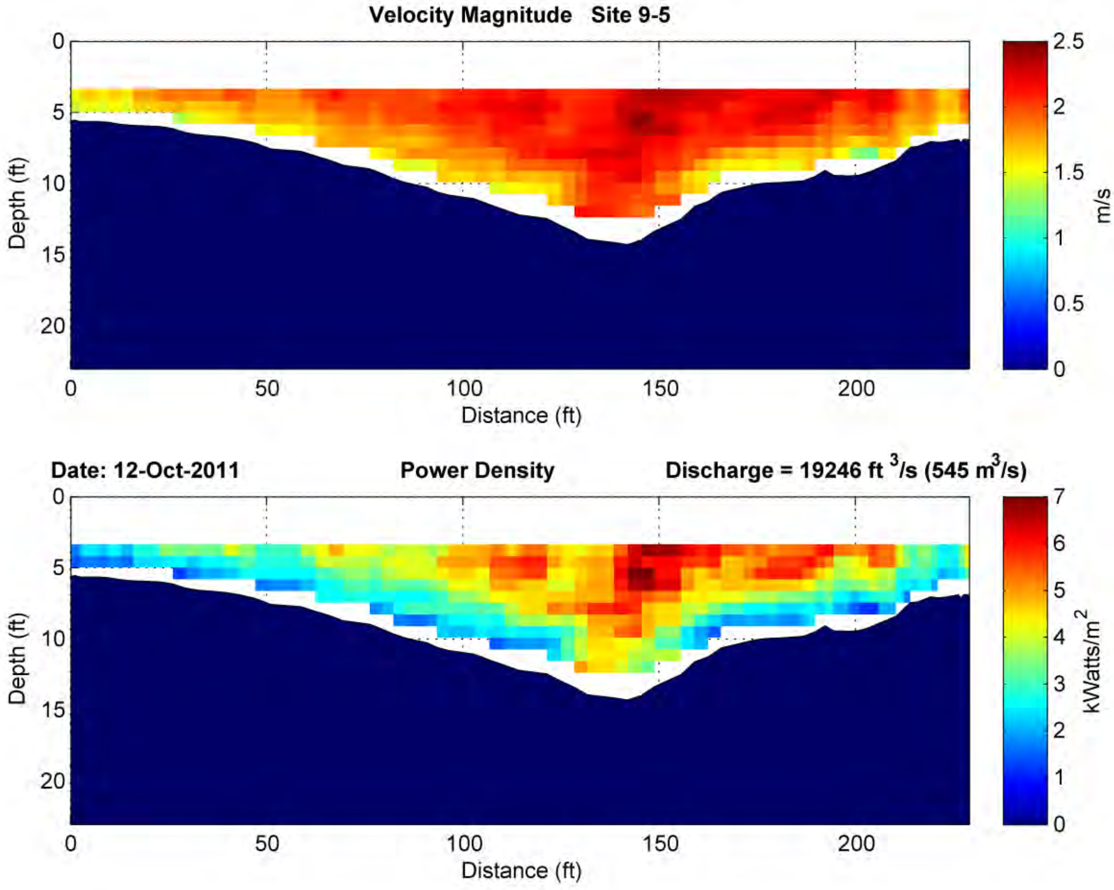


Figure 39 – Station 9 Expedition III.


Velocity Magnitude Site 9-5

Date: 12-Oct-2011 Power Density Discharge = 19246 ft ^{3}/s (545 m^3/s)

Figure 40 – ADCP Transect Station 9 Expedition IV.

10.2.3.3 Site 9

The reach in the vicinity of Station 9 exhibited a very high energy density at its downstream end. Therefore it was also selected for more detailed ADCP profiling on Expedition IV.

At the upstream end of the reach the thalweg is well defined and roughly centered in the channel. The overall profile of the channel is an inverted triangle, Figures 41, 42, 43. At site 9-1 there is a small elevation of energy density slightly to the right of the thalweg. The channel is progressively excavated on both sides as it goes down stream.

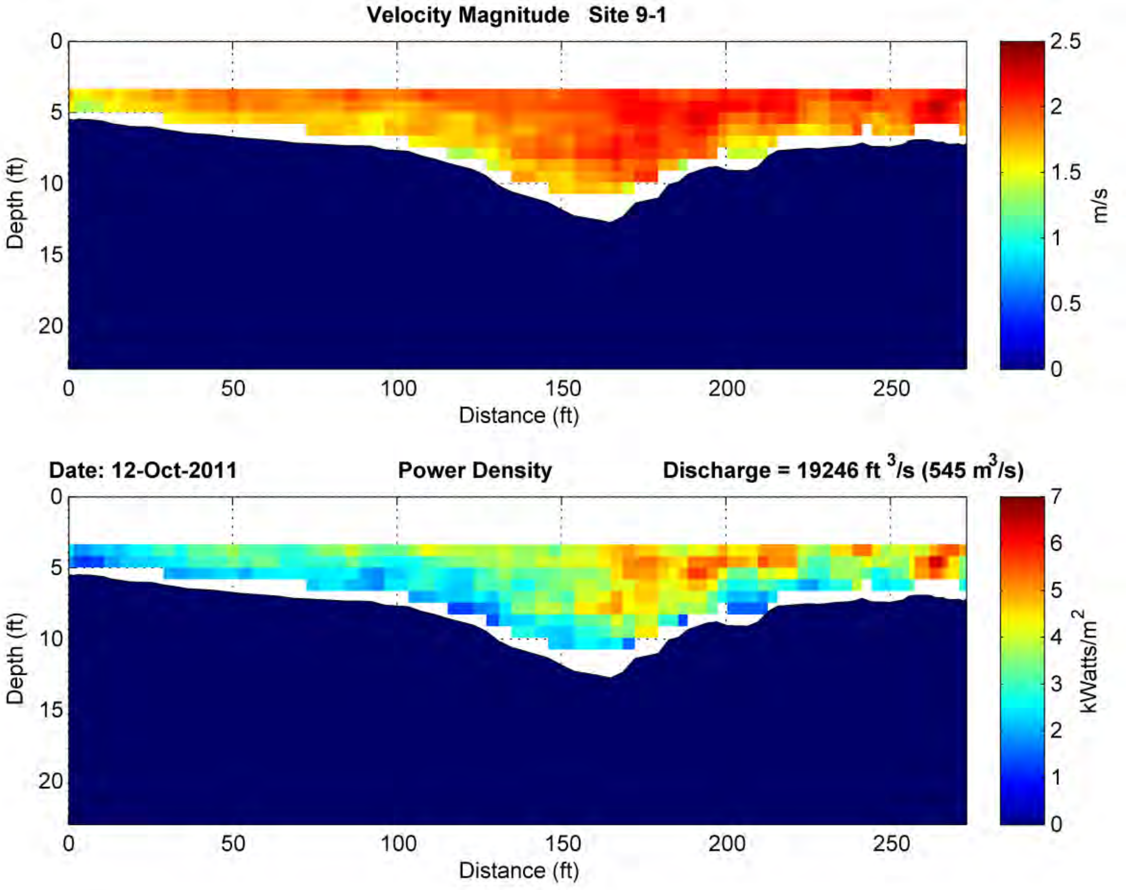


Figure 41 – ADCP transect Site 9-1.

The inverted triangular profile with a central well defined thalweg continues for the first portion of Site 9.

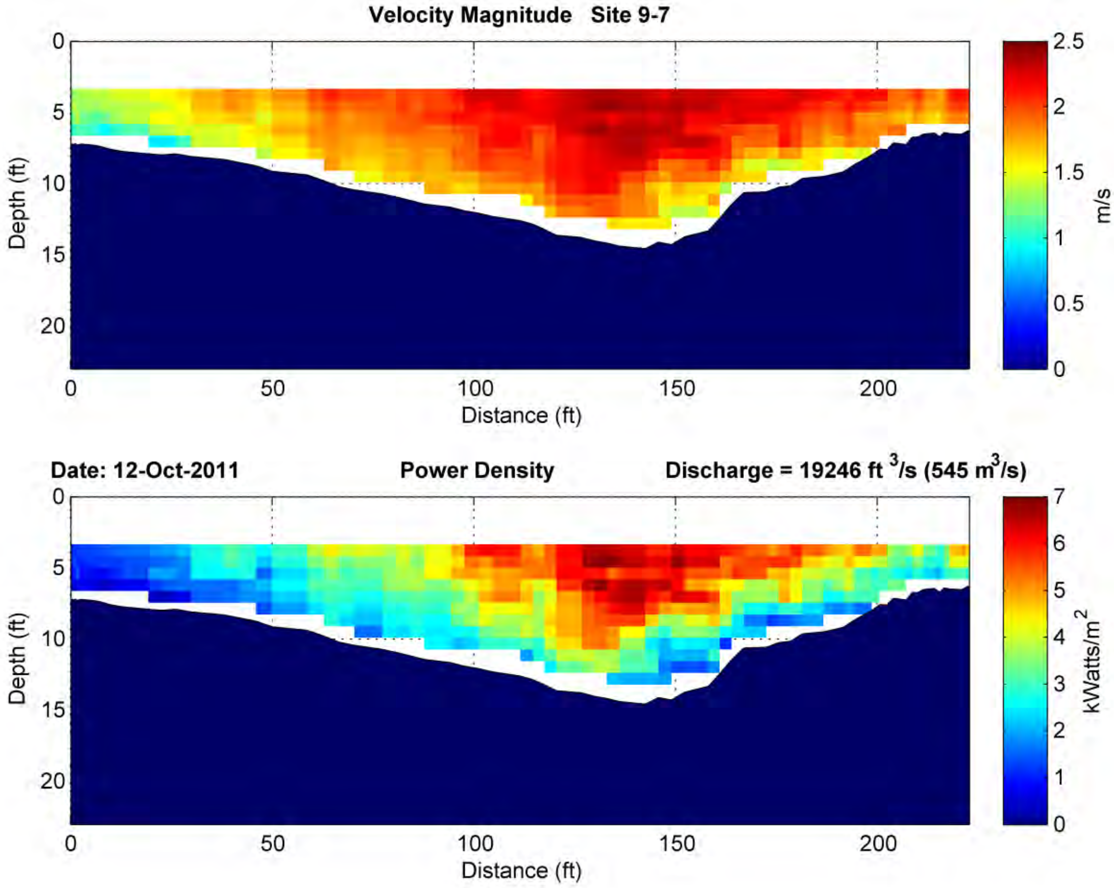


Figure 42 – ADCP transect Site 9-7.

At Site 9-7 the channel begins to open up and move toward a trapezoidal profile.

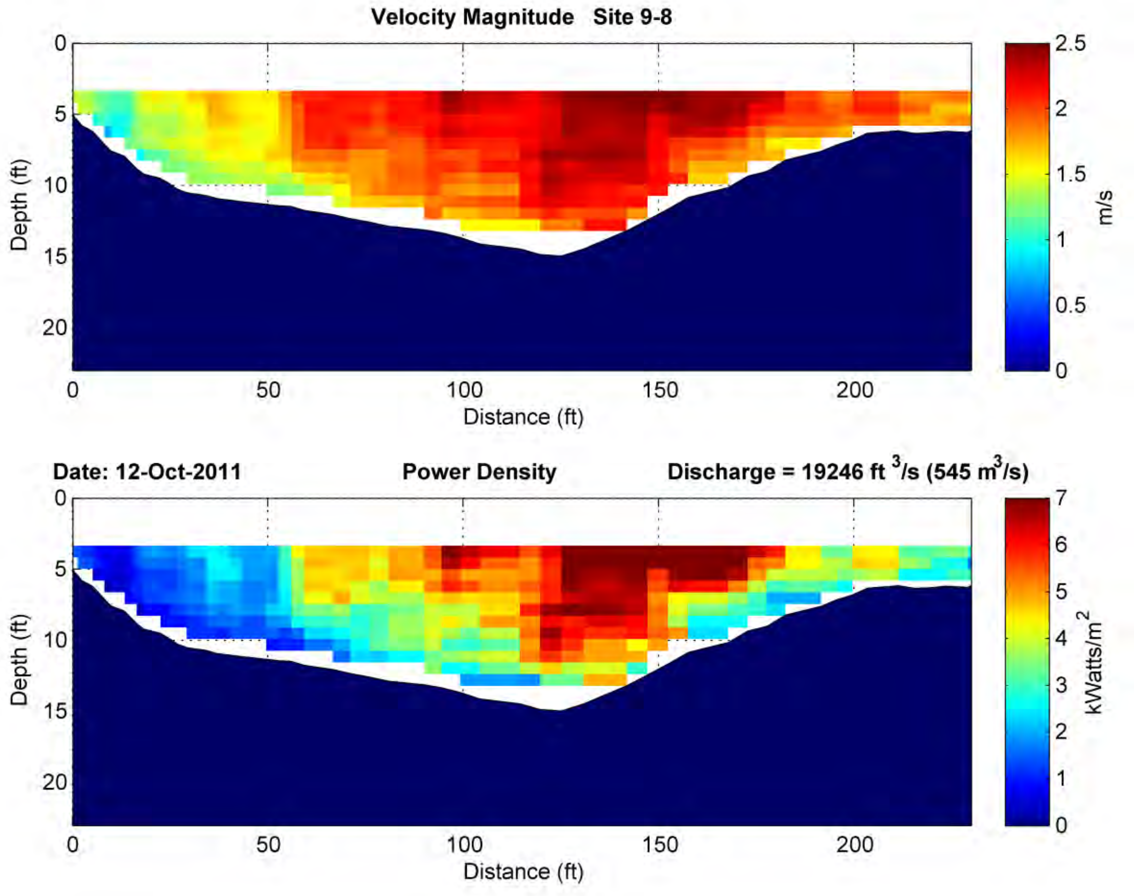


Figure 43 – ADCP transect Site 9-8.

By Site 9-8 the well defined central thalweg starts to give way to a broad flat bottom that rises with steep slopes to the left and right banks, Figure 43. With further progress downstream this zone tends to align with the thalweg and the energy density rises. As the thalweg becomes wider the high energy density zone expands and becomes more intense, Figure 44. By Site 9-10 the high energy zone dominates the right side of the channel. The energy density in the zone is between 5.5 kW/m^2 to 7 kW/m^2, Figure 44.

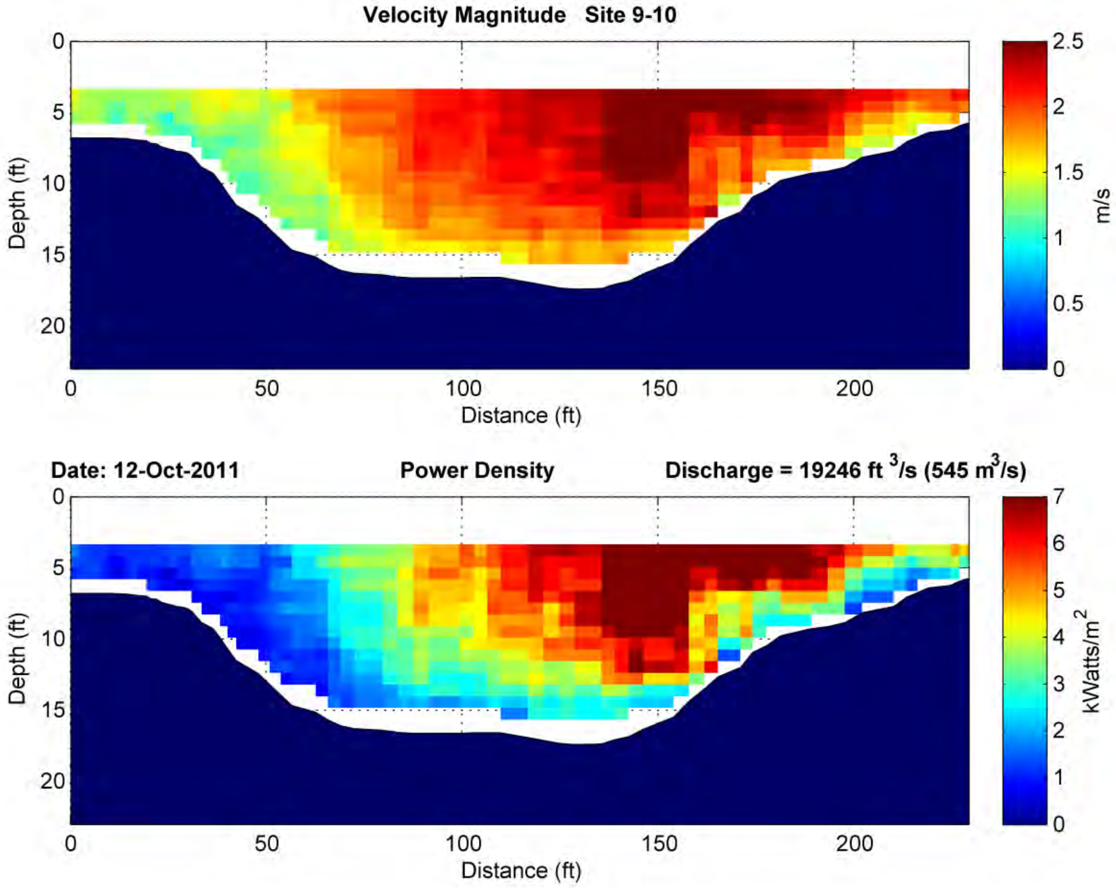


Figure 44 – ADCP transect Site 9-10.

The downstream end of Site nine presents a well-defined zone of high energy density. This zone favors the right bank. The channel is moderately broad. However, it is not as spacious as Site 6.

10.2.3.4 Sites 10 and 11

Site 10 is immediately downstream of Site 9. The first transect of Site 10 is 20 meters downstream of the last transect for Site 9. The transect spacing at Site 10 is 30 meters. There are 11 transects at this site. There is only one transect at Site 11. The characteristics of this transect are not very different from the last transects of Site 10. Indeed it appears to be an additional increment of a trend that started at the end of Site 9 and continues through Site 10.

The morphodynamic and hydrokinetic trends that started at the end of Site 9 continue at Site 10. The channel becomes progressively wider and develops a more open parabolic form. Likewise the zone of high energy density remains in the center and continues to increase, Figures 45, 46. The central zone of high energy density appears to peak between Site 10-3 and 10-5, Figure 46, 47 At Site 10-7 the channel begins to change shape. For the rest of the reach it starts to form a trapezoidal profile.

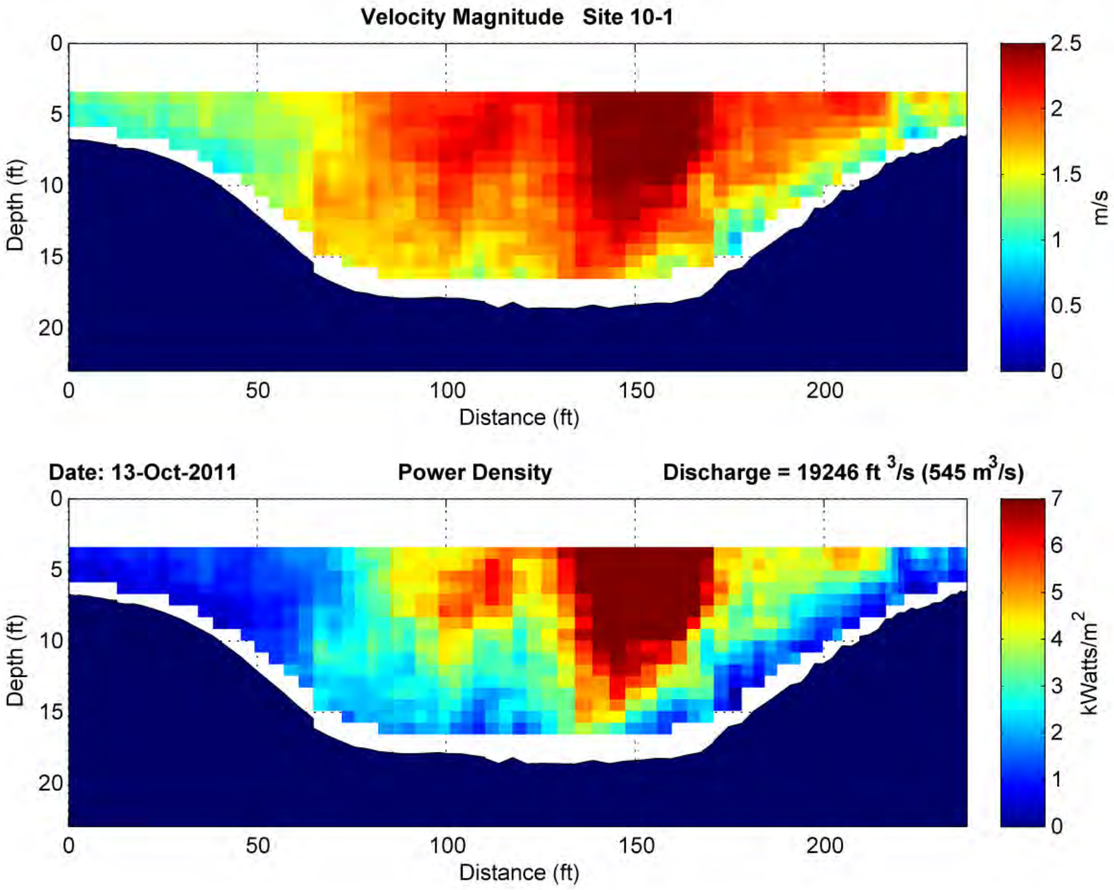


Figure 45 – ADCP transect Site 10-1.

At Site 10-1 the trapezoidal profile is frank.

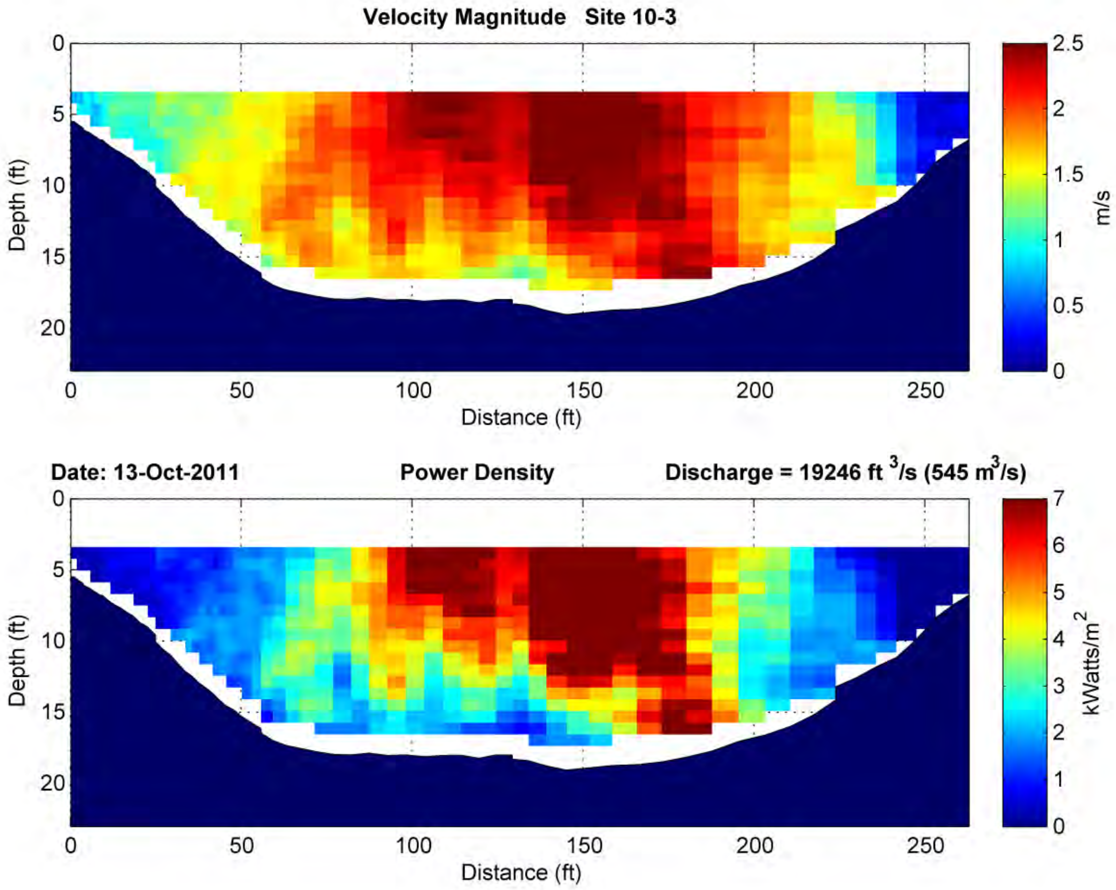


Figure 46 – ADCP transect Site 10-3.

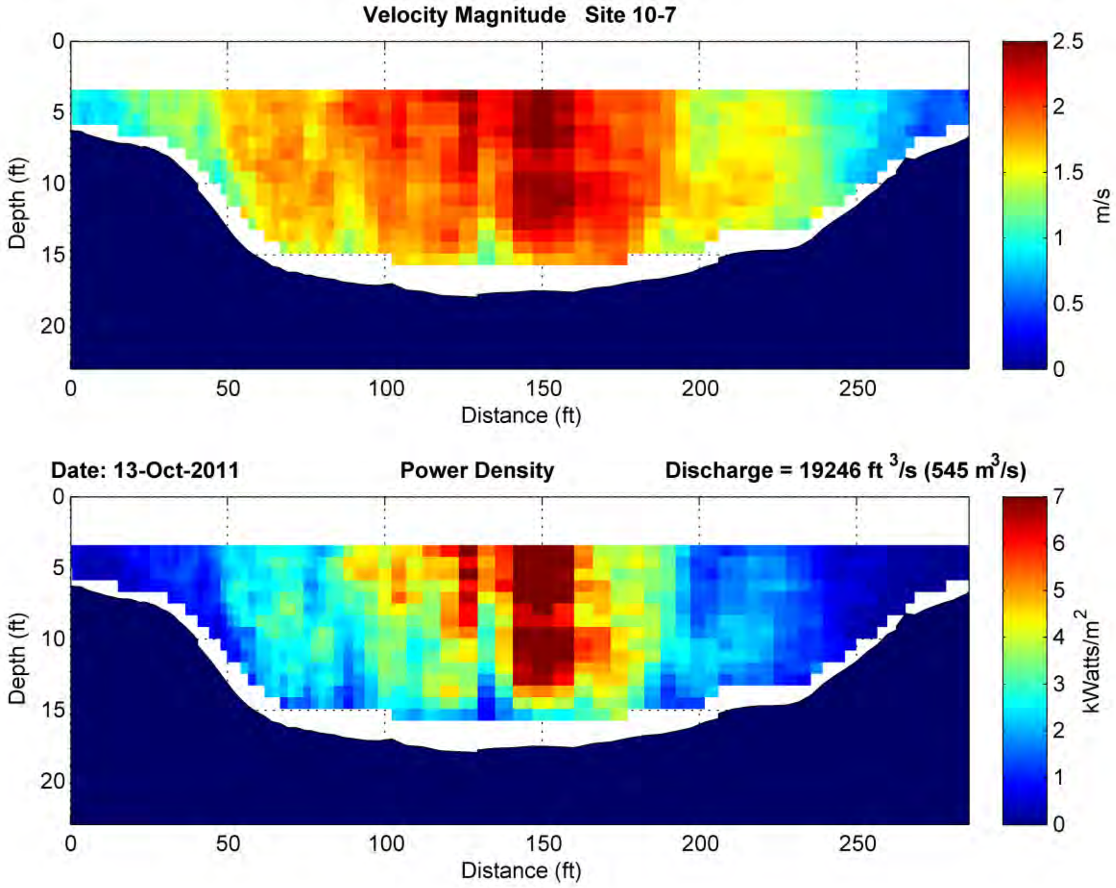


Figure 47 – ADCP transect Site 10-7.

From Site 10-7 to 11-1 there is a gradual filling of the channel coupled with a flattening of the center. At Site 10-8 a trapezoidal profile begins to emerge, Figure 48. By Site 10-10 the channel is a well formed trapezoid, Figure 49. This profile remains to Site 11-1 figure 50. Along this extent of the river the zone of elevated energy density remains in the center of the channel. However, it is diminished.

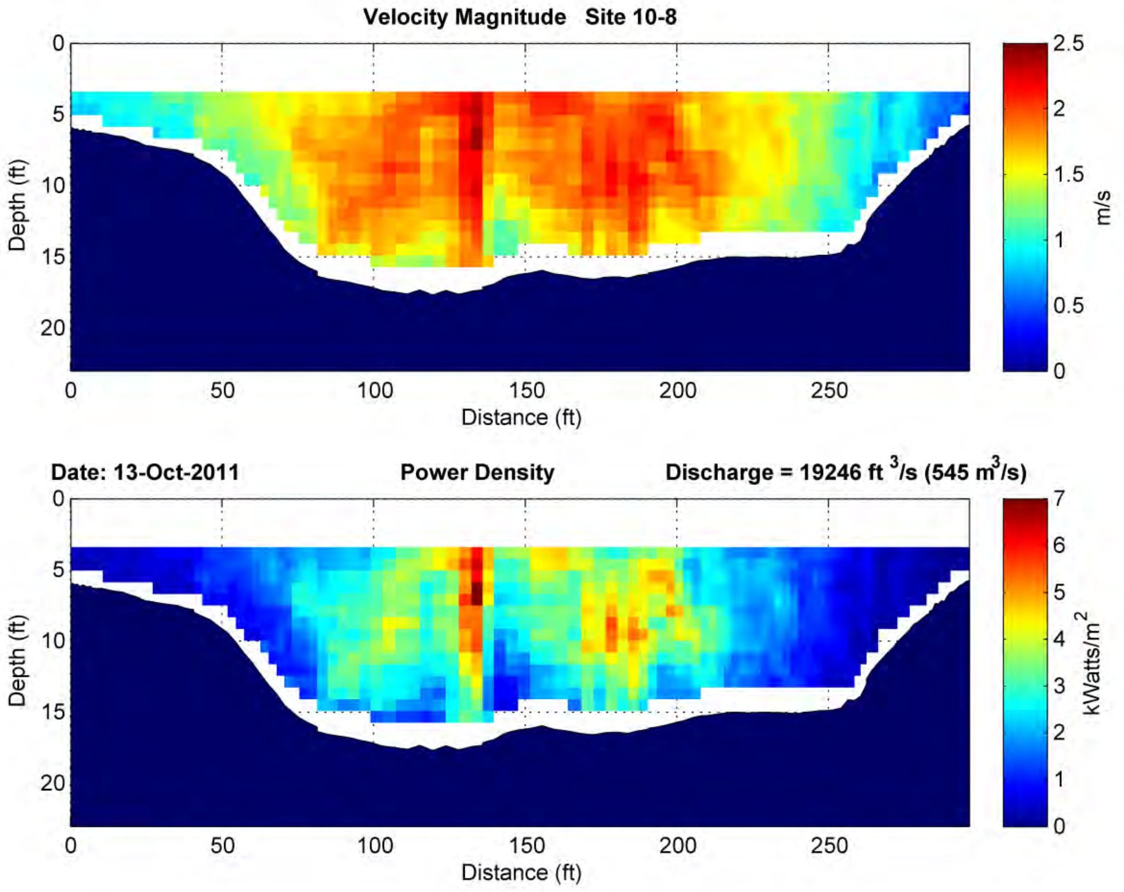


Figure 48 – ADCP transect Site 10-8.

At Site 10-8 the trapezoidal profile remains, however the zone of high energy density is waning.

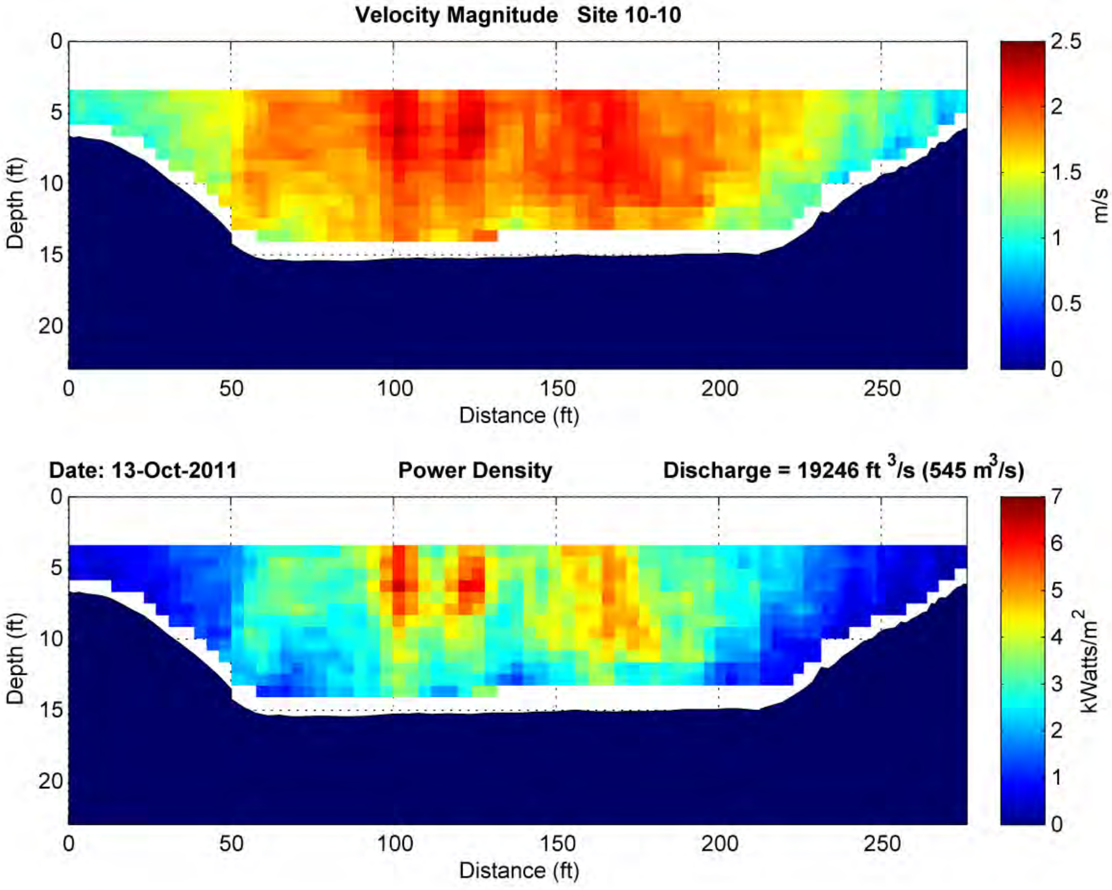


Figure 49 – ADCP transect Site 10-10.

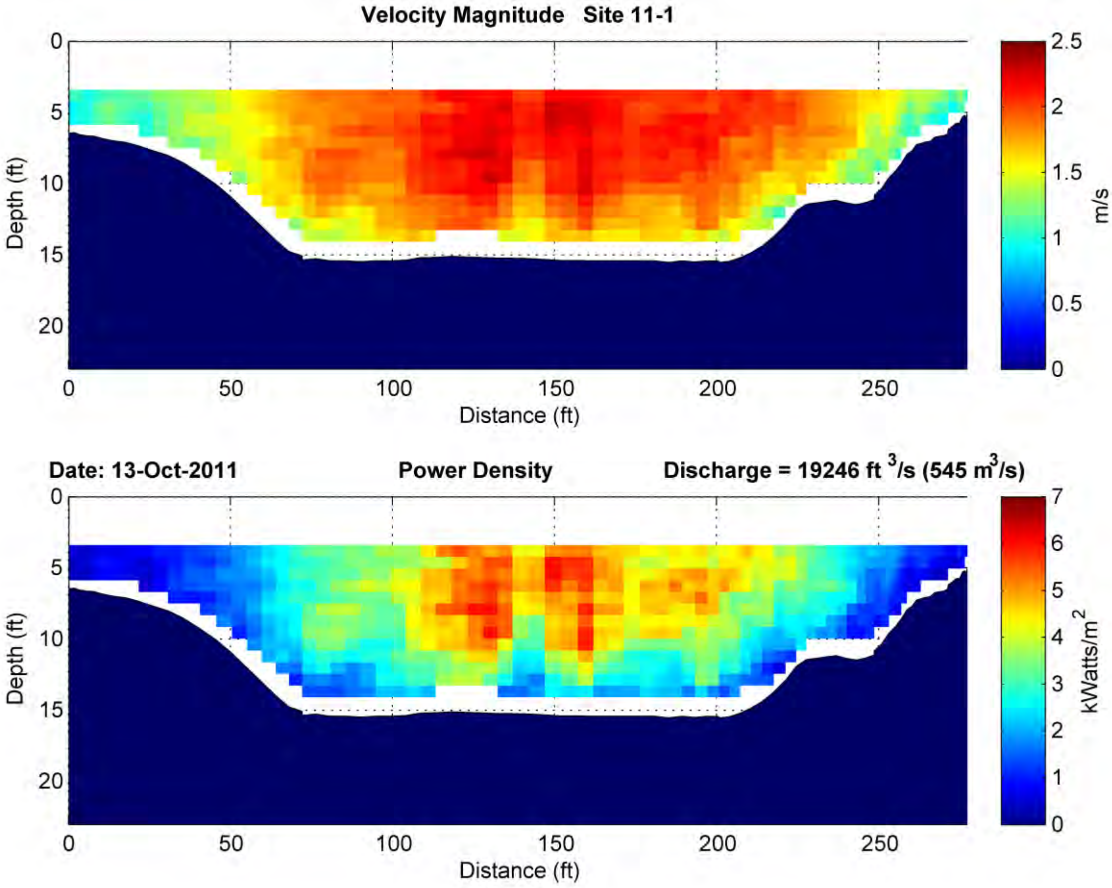


Figure 50 – ADCP transect Site 11-1.

10.2.3.5 Top Section Flow Velocity

The first ADCP measurement bin starts at 75 cm below the surface. This leaves a gap to the surface from the first bin where no velocity data is collected. TRDI's WinRiver II software uses an extrapolation algorithm to estimate the velocity in this area for the purpose of measuring discharger. However, it does not report an estimated flow velocity.

Therefore it was decided to make some measurement of flow velocity in this area with a Marsh-McBirney Flowmate 2000 flow meter. The flow meter was pole mounted on the port side of the boat. The sensor head was placed 61 cm below the water. The boat was navigated across the ADCP transects and held at select positions across the river. Four to five measurements were taken at even spacing across the channel.

The measurements taken during expedition IV are depicted on the map sheets in Appendix 1. The surface velocities were typical for this type of river. Near the banks the velocities tended to be slower than in the middle channel. The values that were reported are roughly the same as those observed in the top bins of the ADCP profile. On some of the transects at Site 10 there is a back eddy by the right bank. At these locations the river flow is reversed. These velocities are reported on the map sheets as (-) values.

10.3 River Bed Findings

An R2Sonic 2024 MBES was used to do a bathymetric survey from about 0.12 km above the mouth to a downstream extend of about 2.7 km. This survey was used to identify dangers to navigation, hazards for construction, and give a detailed picture of the shape of the river bed. The surveyed has been depicted on the included map sheets in Appendix 1

Immediately before the mouth of the river there is a small field of sand waves that tend toward the left bank. On the right a shoal extends from shore into the lake and then continues along the right bank downstream to the vicinity of the Fish and Game Boat Landing. The thalweg develops quickly at the mouth and descends to a depth of about 14 feet. About 1000 feet downstream there is an abrupt rise to 8 feet which is followed a quick drop to 12 feet. The bed slowly rises again to 5 feet in the vicinity of Station 5. Then the river starts a bend to the right and the bed drops once more near Station 6. This time it forms a 10 foot deep thalweg on the right side and there is a shoal that forms on the left by the Fish and Game Boat Landing. The shoal remains on the left and extends into the channel on the left side of the first island. On the right side the bed rises again to 2 feet and starts to curve left. At the approach to Site 9 the river narrows and a sharp central thalweg forms. In the downstream half of Site 9 there is rapid drop to 18 feet. This feature has come to be called "*The Chute.*" *The Chute* opens into Site 10. Here the channel fills and takes on a trapezoidal profile. It continues downstream with the same profile as the bed slowly rises to 10 feet just beyond Site 11.

Numerous dangers to navigation, (DtoN) and hazards for construction, (HforC) have been identified in the bathymetric surface. In this report a DtoN is defined as any object with a volume greater than 1 m^3 that rises to within 4 feet, (1.22 m) of the water surface. The DtoN's in the Kvichak River include numerous boulders and the various shoals. The DtoN's are depicted on the accompanying map sheet in Appendix 1. The map sheet also has a table of coordinates for all of the DtoN's. The HforC's are presented on the accompanying map sheets. There is also a table of coordinates for the HforC's. In this report a HforC is defined as any bottom object that is greater than 1 m^3, and extends more than 3.3 feet, (1 m) feet above the bed.

The bed materials of the Kvichak River appear to be quite stable with respect to the short term. No moving bed was detected with the ADCP. The collected bed samples consisted primarily of larger forms that were predominantly in the range of gravel and cobbles. Nonetheless this does not obviate the fact that the river is very energetic. It also has a constant source of material in the lake and along the banks. Further, ice enters the river from the lake each year. This ice could dislodge bed material and create strong localized areas of scour. Therefore, while the river bed may appear more stable than many other rivers, it is still important to keep all manners of sediment transport in mind when considering construction designs for the banks and the river bed.

The river morphology of the Kvichak was well characterized by the 2011 bathymetric survey. The upper Kvichak River along the Village of Igiugig has a significant bend (approximating a 90º bend) in the river with a non-uniform alveus for most of the range along the project area. Statements from village residents and evaluation of historical maps and aerial photographs indicate that the Kvichak River has experienced significant change within recent recorded history. Of particular note, the zone constituting the bend in the river across from the Fish and Game Boat Landing has changed dominant flow regimes several times within the last 70 years. The cross-sectional peak flow within the river may also shift significantly throughout this portion of the river. TerraSond interprets that the thalweg is not stable, particularly distinct, nor well confined geomorphologic body within this river structure. Persistent geologic formations are not constraining this river, and it is believed that the Kvichak River can be expected to demonstrate change over time. Several areas of the river appear to be more static and persistent than the bend noted above. In particular, the opening to Lake Iliamna and the stretch after the bend appear to demonstrate more persistent behavior.

10.4 Tie of Current Survey Data to USGS Gage

The field crew could not locate any of the USGS gaging station RM's or associated equipment. Given the field search, and consultation with the USGS and the local community it is highly probable that all of these items have been lost. Therefore, it is not possible to make a sound physical tie to the original USGS gaging station. Nonetheless a coarse relationship has been established using current ADCP discharge measurements, RTK GPS water level observations, and the USGS rating curves. The USGS data is several decades old. However, it is the best data record available for this site. The river dimensions and climatology have changed. The relationships that are developed in the following sections are at best tenuous extrapolations. These relationships are not intended to replace a current and complete hydrologic study. They are an attempt to use past data as a means to gain insight into the hydrologic characteristics of the river. Great care should be exercised if this data is used for any design development and analysis.

The USGS Gaging Site 15300500 was established at Igiugig on the Kvichak River on 15 June 1967. It was operational until 1987. The methods used at the time were published in Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter A8, *Discharge Measurements at Gaging Stations*, Book 3, Applications of Hydraulics, 1969. During this time they did 39 discharge measurements. The USGS used these measurements to establish a set of rating curves for the site. There were two sets of RM's used for the river gage height. Both sets of RM's originated from an assumed arbitrary value. By coincidence the values selected for both references were close. The first set was used for measurements 1 to 16. Measurements 17 to 39 were completed using the second set of RM's. The exact date that the USGS switched RM's is not certain. It was most likely sometime between discharge measurement 16 and 17. These measurements took place on 28 September 1970, and 24 March 1971. There was no mention in the USGS station records of a level loop being done to tie the two sets of RM's together. Nonetheless the USGS appears to have adjusted the gage heights for discharge measurements 8 to 16 and carried them forward to the later rating curves, Figure 51.

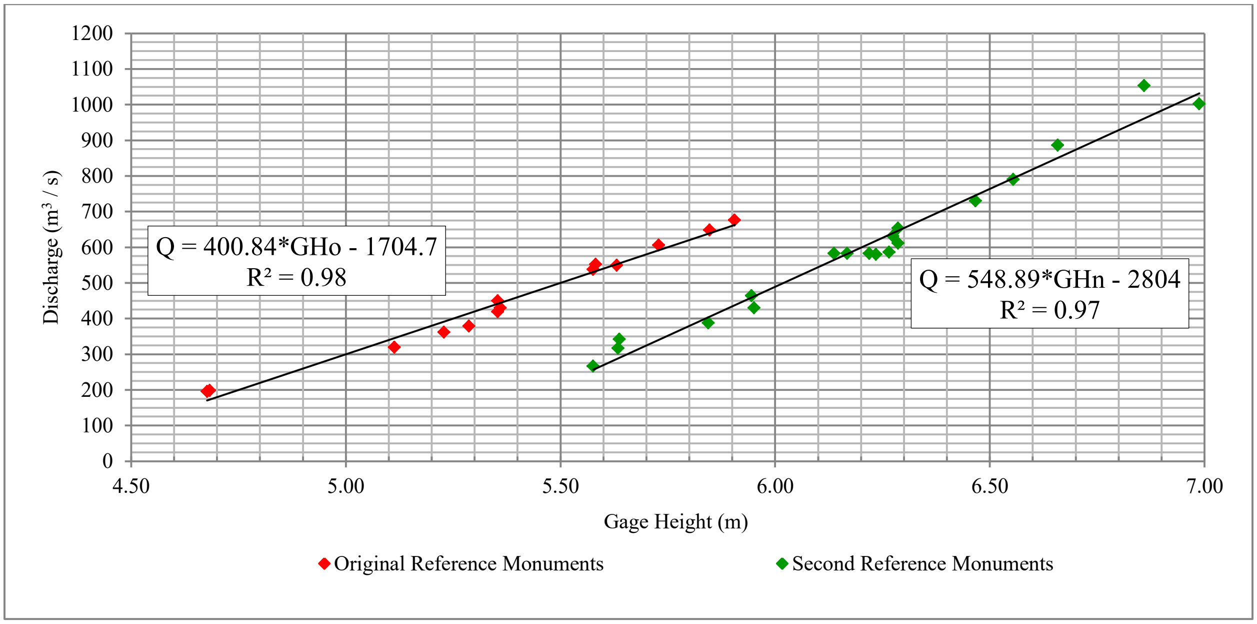


Figure 51 – USGS discharge versus gage height with respective regressions.

A relationship between the KRIGIPVD11 datum and the original USGS rating curve was established using two current river levels and ADCP discharge measurements. Three ADCP discharge measurements were completed for this project. RTK GPS observations were made in close temporal proximity to the ADCP discharge measurements. The timing of these measurements was sufficiently close to allow a reasonable assumption to be made that the river level was not significantly changed from the level at the exact time of the ADCP discharge measurements. The first ADCP discharge that was used for establishing the relationship to the USGS rating curve was done on 21 June 2011, and the second was done on 12 October 2011. The measured discharge on 21 June was 335 m^3/s and the observed ellipsoid height of the water surface was 25.90 m. On 12 October the measured discharge was 545 m^3/s, and the ellipsoid height of the water surface was 26.44 m. These discharges were plotted on the original USGS rating curve to determine the corresponding USGS gage heights. The USGS gage heights for the two discharge values were 16.95 feet, (5.17 m), and 18.50 feet, (5.64 m). The offsets between the report USGS stages and the ellipsoid height of the water were 20.73 meters, and 20.78 meters, respectively. The average of these two values was taken to be a standard offset between a given ellipsoid height and the USGS gage height for the original set of RM's. This value was 20.76 meters. Thus the corresponding current ellipsoid height for any given USGS gage height value on the original curve was estimated by adding 20.76 meters to the gage height. This sum was compared to 25.00 meters to determine where the particular stage was with respect to the KRIGIPVD11 datum. For example, an original USGS gage height of 6.00 m would correspond to a water surface ellipsoid height of 26.76 m. The water surface level would be 1.76 m above the KRIGIPVD11 datum.

Discharge measurements 1 to 16 tended to cover the lower discharge values. The higher discharges were covered by the later measurements that used the second set of RM's. Slightly less than 1/5 of the USGS measured discharges overlapped. These values were clustered around the overall average measured discharge, Figure 51. Therefore, if the analysis of stage and discharge required for this report was going to be based on a complete range of reported discharges a means of referencing the two sets of measurements had to be developed. This was done by applying a conformal transformation to map gage heights from the domain used for the second set of measurements to the domain used for the original set of measurements.

Six of the USGS discharge measurements were omitted from the calculations to reference the two sets of measurements. Measurement two was removed because the USGS did not use it for the development of their original rating curve. This measurement appeared to be an erroneous outlier. Measurement three was also an apparent outlier. Measurements 23, 24, 35, and 39 did not have complete information in the USGS field notes. The remaining measurements were used as reported by the USGS.

The second set of gage heights were transformed to correspond with the first set. This was done by first determining a linear regression model for each set of values. Then the two regression models were set equal to each other, Figure 51, equations 10.1a, b, c.

EQN 10.1a $Qo = Mo\ GHo + Io$

EQN 10.1b $Qn = Mn\ GHn + In$

EQN 10.1c $\mathrm{Mo} * \mathrm{GHo} + \mathrm{Io} = \mathrm{Mn} * \mathrm{GHn} + \mathrm{In}$

Where: Qo and Qn = respective river discharges in m^3/s.

Mo and Mn = the slope of the regression line for the original gage and the second gage heights.

GHo and GHn = the original and second reported gage heights in meters.

Io and In = the intercept values for the original and second gage heights.

Equation 10.1c was manipulated to derive an expression that transposed the second set of gage heights to the regression of the original gage heights, equation 10.1d.

EQN 10.1d $\Delta \mathrm{GHi} = \frac{\mathrm{Mn} * \mathrm{GHn} - \mathrm{Io} + \mathrm{In}}{\mathrm{Mo}} - \mathrm{GHn}$

Where: ΔGHi = the i^{th} gage height shift from the second set of gage heights to the gage heights with respect to the regression equation for the original set of gage heights.

The slopes of the two regression lines are not parallel. It was desirable to retain the full character of the second set of discharge measurements after they were transformed. Simply applying Equation 10.1d would not have accomplished this. It would have only expressed the transformed gage heights as dictated by the regression equation of the original discharge data. In order to preserve the full character of the second set of discharge measurements the mean of all values given by Equation 10.1d was computed. This mean shift was applied to the gage heights reported for the second set of discharge measurements. Thus the gage heights were transformed conformally. This is confirmed by demonstrating that the slope of the regression for the transformed discharge data is parallel to the first regression, Figure 52.

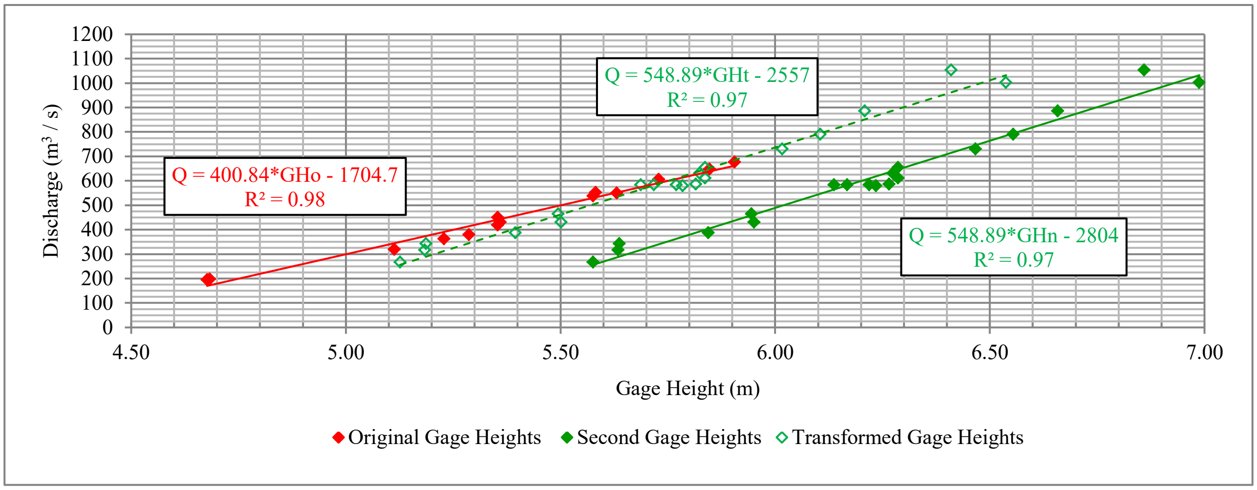


Figure 52 – Regression of USGS discharge measurements.

The USGS gage heights of the first discharge measurements and transformed gage heights were unioned to form a single set. This set was then regressed with respect to the gage heights, Figures 52, 53.

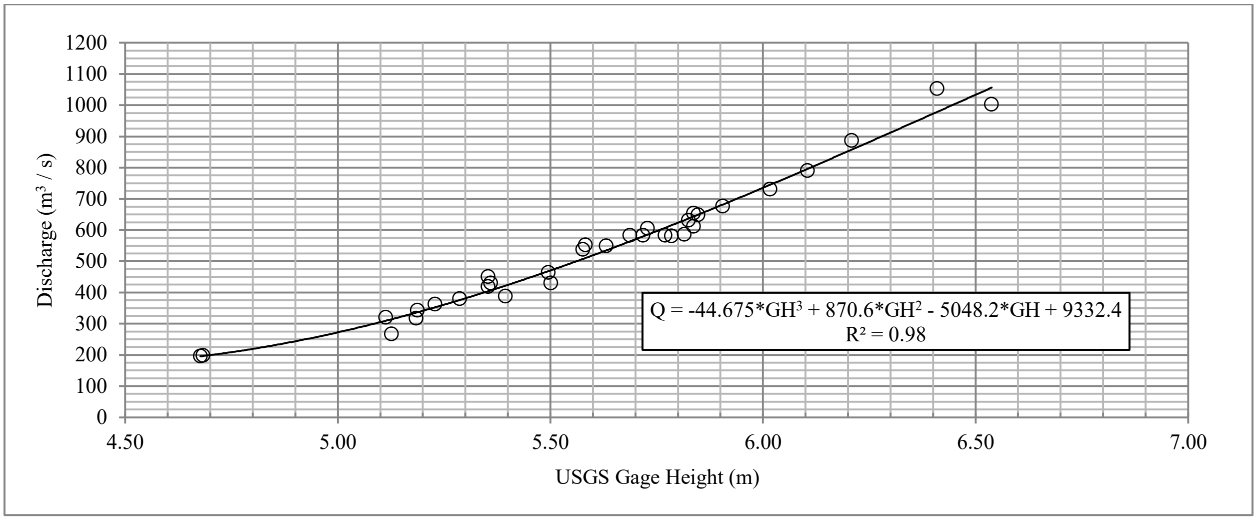


Figure 53 – Regression of combined and transformed USGS discharge measurements.

The combined data was regressed to several forms. The best fit was achieved with a third order polynomial, Equation 10.2.

EQN 10.2 $Q = -44.675*GH^3 + 870.6*GH^2 - 5048.2*GH + 9332.4.$

The relationship between the USGS gage height and the KRIGIPVD11 datum was derived from the comparison of discharge measurements and the USGS original rating curve. This was applied to the combined gage height data set to develop a regression of discharge as a function of height above the KRIGIPVD11 datum, Figure 54.

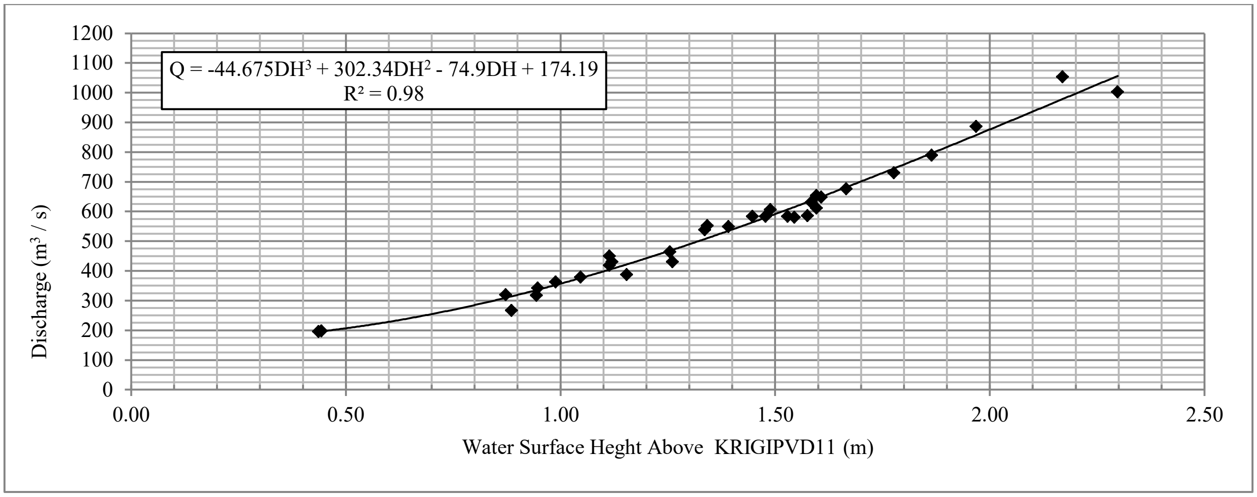


Figure 54 – Regression of discharge with respect to water surface height above the KRIGIPVD11 datum.

This regression gave the following polynomial equation.

EQN10.3 $Q = -44.675*DH^3 + 302.34*DH^2 - 74.9*DH + 174.19$

Where: DH = water surface height above the KRIGIPVD11 datum

The USGS estimated the average flow velocity for the channel cross section as part of their discharge measurements. This data was regressed to an exponential form that expressed discharge as a function of velocity, Figure 55 Equation 10.4.

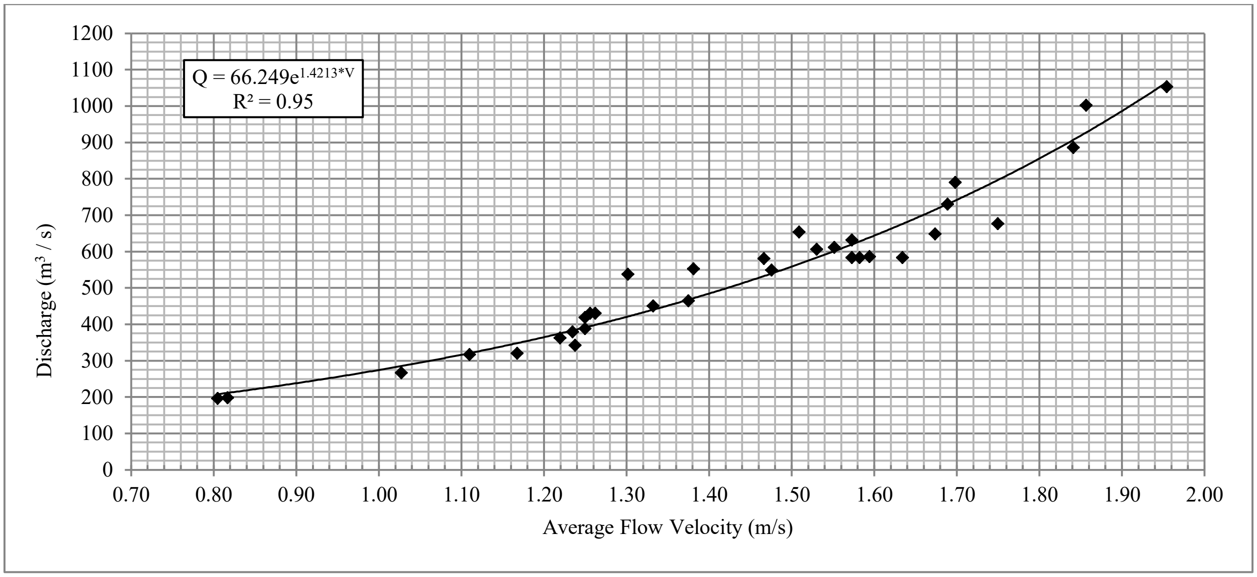


Figure 55 – Regression USGS discharge with respect to average cross section flow velocity.

EQN 10.4 $Q = 66.249*e^{1.4213*V}$

Where: e = base of the natural logarithm

V = average cross sectional flow velocity in m/s

The relationship between height above the KRIGIPVD11 datum and discharge was used for a regression to a power law equation to express average flow velocity as a function of height above the datum, Figure 56, Equation 10.5.

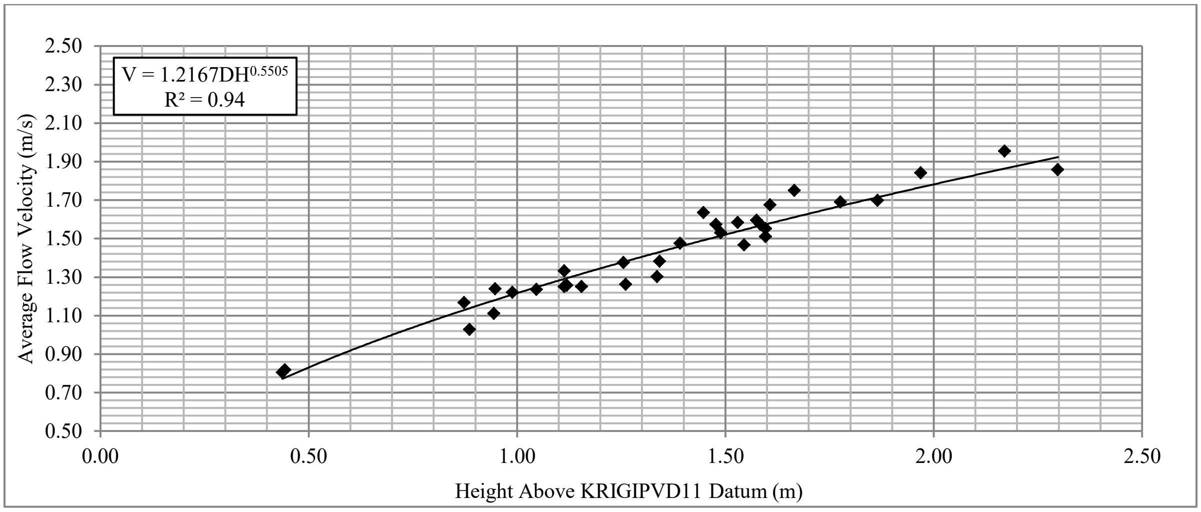


Figure 56 – Regression of flow velocity with respect to height above the KRIGIPVD11 datum.

EQN 10.5 $V = 1.216*DH^{0.5505}$

The USGS used their rating curve and gage height to produce daily estimates of discharge. They issued values for everyday from 1 January 1968 to 1 January 1987. The above regression equations were applied to this data to produce plots of discharge versus flow velocity, and height above the KRIGIPVD11 datum, Figures 57, 58.

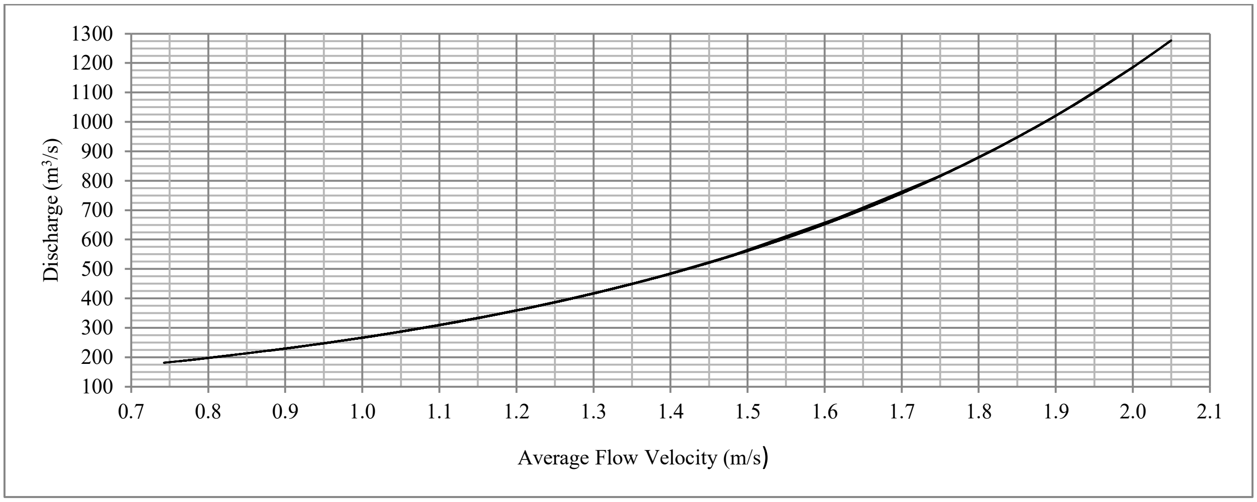


Figure 57 – Full record plot of USGS discharge as a function of mean flow velocity.

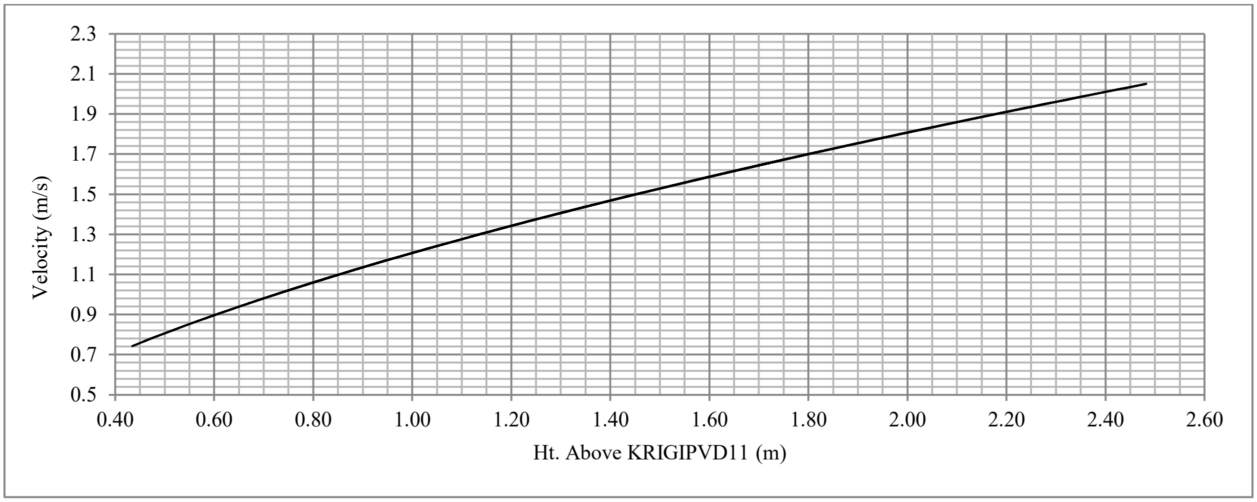


Figure 58 – Full record plot of USGS flow velocity and a function of height above the KRIGIPVD11 datum.

The published USGS discharge data was used to complete a return period analysis using the Log-Pearson Type III distribution as outlined in *Guidelines For Determining Flood Flow Frequency,* Bulletin #17B of the Hydrology Subcommittee, Interagency Advisory Committee on Water Data, USGS, 1982. Once the discharge return events were determined the relationships between discharge, and flow velocity and height above the KRIGIPVD11 datum developed for this report were used to create an expression for the corresponding return periods with respect to these parameters, Figure59, Equations 10.6a, 10.6b.

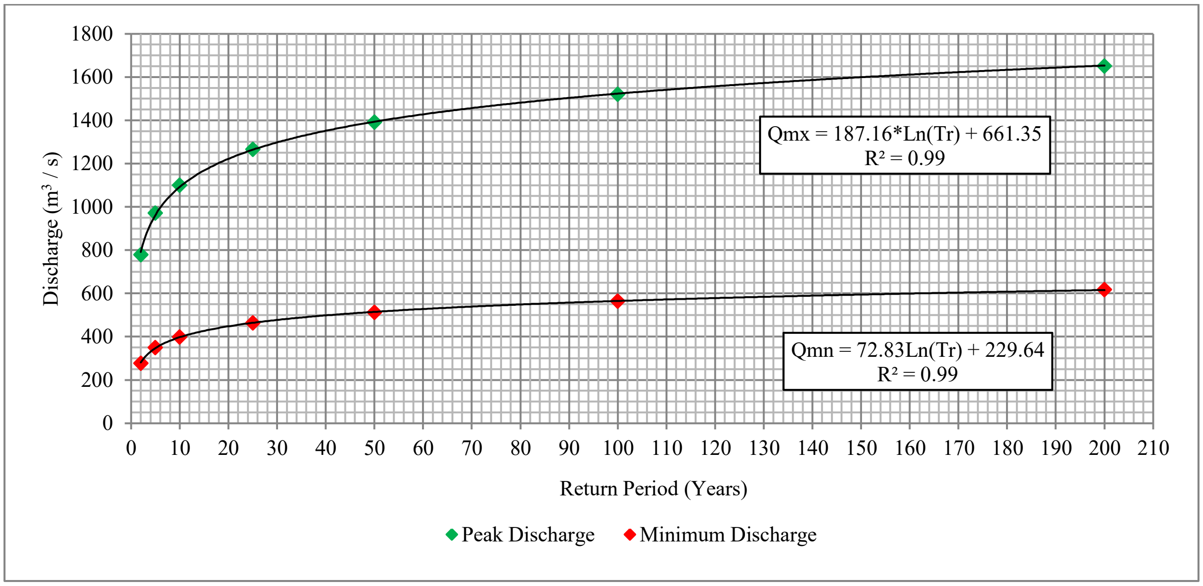


Figure 59 – Plot of discharge return period for the Kvichak River at Igiugig.

Equation 10.6a and 10.6b give an empirical expression for the discharge as a function of return period.

EQN 10.6a Return period for annual maximum discharge

$$Qmx = 187.16 * Ln(Tr) + 661.35$$

EQN10.6b Return period for annual minimum discharge

$$Qmn = 72.83 Ln(Tr) + 229.64$$

Where:
Qmx = annual maximum discharge for a given return period
Qmn = annual minimum discharge for a given return period
Tr = return period in years

A return frequency analysis was developed for height above the KRIGIPVD11datum and average flow velocity. These were computed by applying the previously developed relationships to the discharge return analysis, Figures 60, 61.

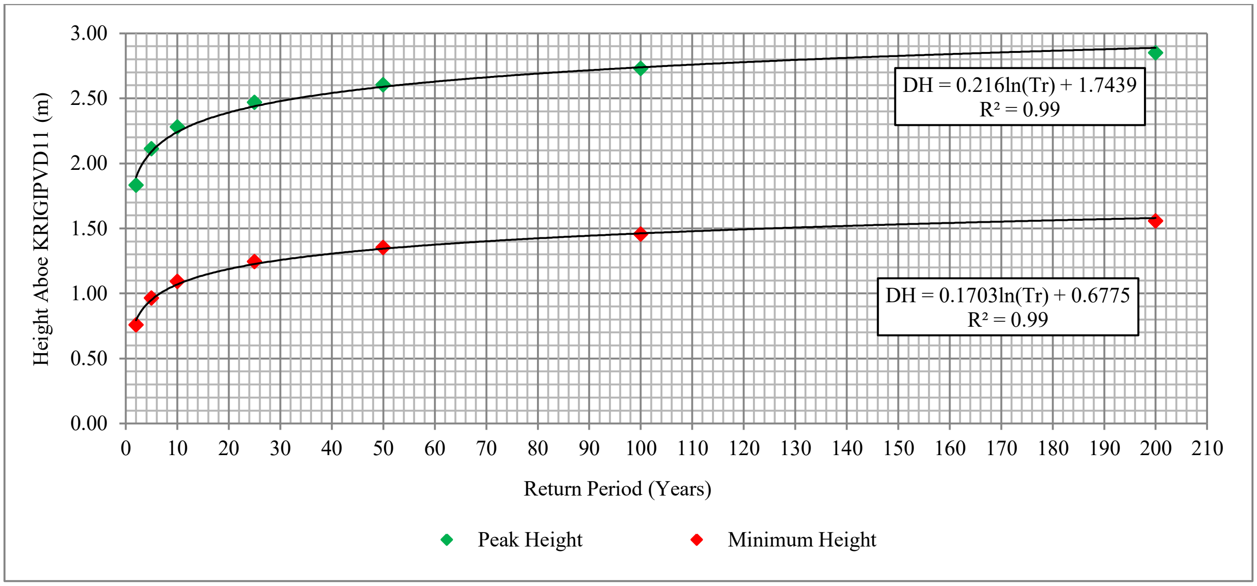


Figure 60 – Plot of return period for height above the KRIGIPVD11 datum the Kvichak River at Igiugig.

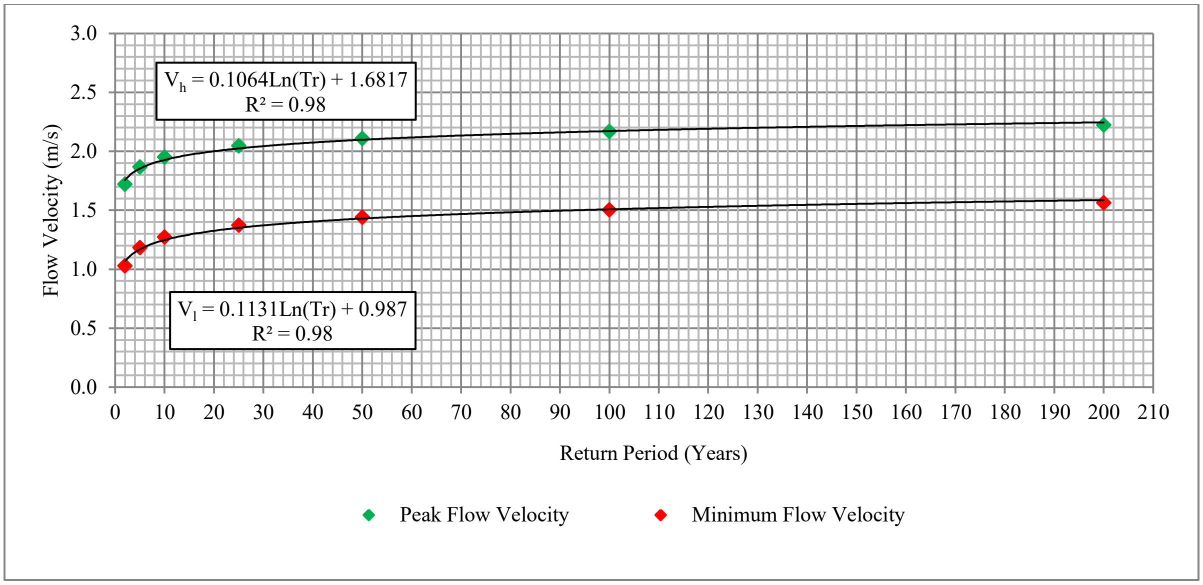


Figure 61 – Plot of the return period for mean flow velocity for the Kvichak River at Igiugig.

The following regression equations give an expression height above the KRIGIPVD11 datum and flow velocities for a given return period.

EQN 10.7a $DH_h = 0.216*Ln(Tr) + 1.7439$

EQN 10.7b $DH_l = 0.1703*Ln(Tr) + 0.6775$

EQN 10.7c $V_h = 0.1064 * \mathrm{Ln}(Tr) + 1.6817$

EQN 10.7d $V_l = 0.1131 * \mathrm{Ln}(Tr) + 0.987$

Where: The subscripts h and l refer to the respective high or low of the given parameter.

Figures 62 and 63 depict the flow velocities and height above datum as determined by applications of the respective regressions to the full record of USGS daily discharge values.

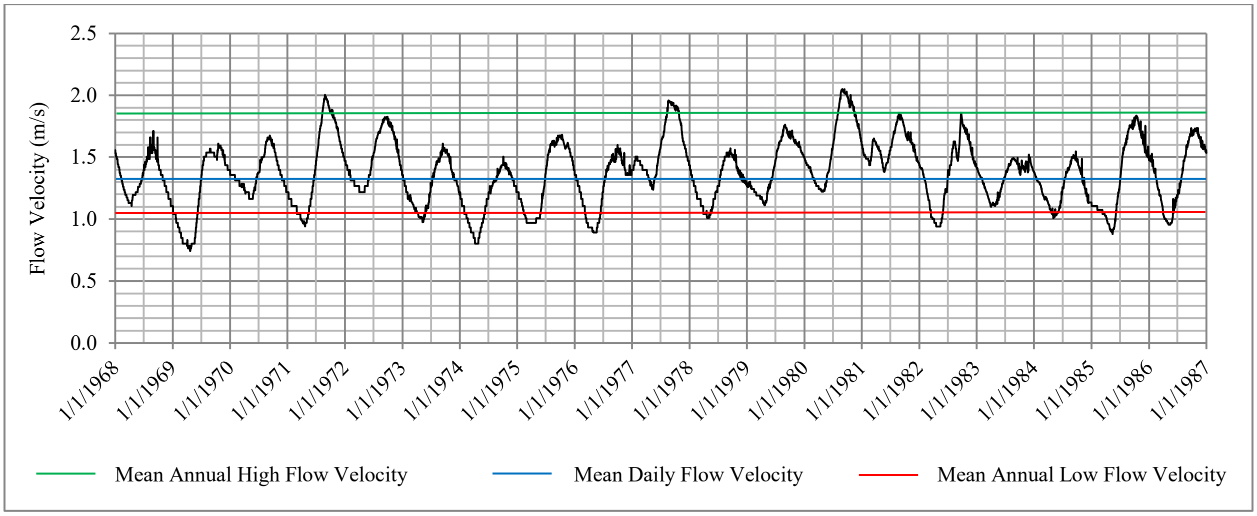


Figure 62 – Daily flow velocities.

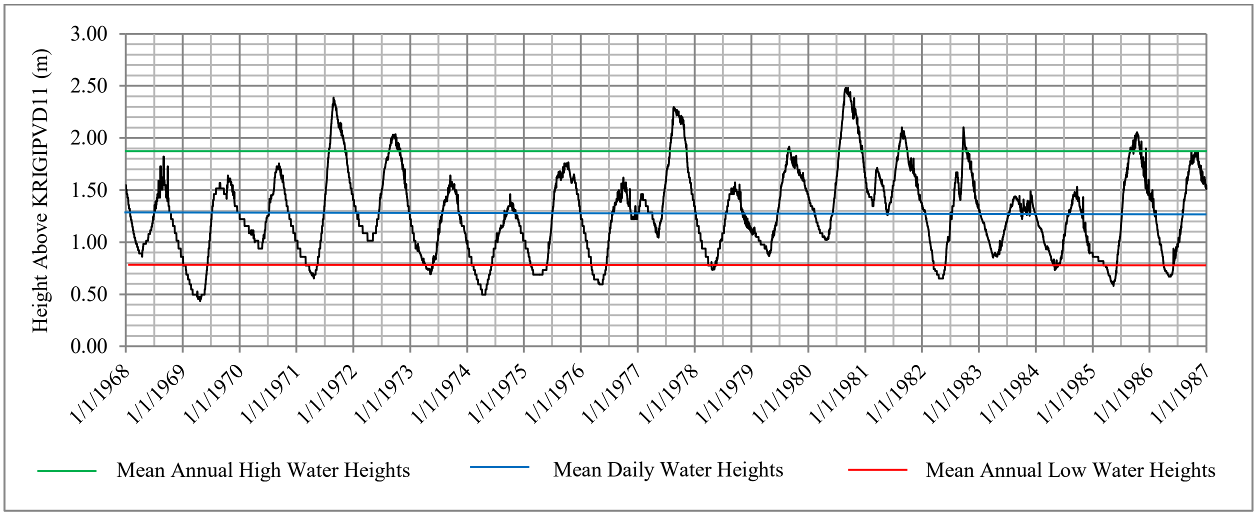


Figure 63 – Average Daily height above KRIGIPVD11 Datum.

Some key parameters that were determined from the preceding regressions are summarized in the following tables.

Year	Date	Q (m^3/s)	V (m/s)	Ht. (m)	Rank	Exceedance Probability
1981	2/21/1981	510	1.43	1.35	1	0.05
1977	4/26/1977	399	1.27	1.09	2	0.10
1980	4/19/1980	371	1.22	1.02	3	0.15
1972	4/21/1972	368	1.22	1.01	4	0.20
1970	5/27/1970	362	1.21	1.00	5	0.25
1979	4/23/1979	314	1.11	0.87	6	0.30
1968	4/14/1968	311	1.11	0.86	7	0.35
1983	4/2/1983	309	1.10	0.85	8	0.40
1984	5/4/1984	271	1.01	0.74	9	0.45
1978	4/25/1978	269	1.01	0.73	10	0.50
1973	5/9/1973	256	0.97	0.69	11	0.55
1975	4/9/1975	255	0.97	0.69	12	0.60
1986	5/17/1986	249	0.96	0.67	13	0.65
1971	4/22/1971	244	0.94	0.65	14	0.70
1982	5/15/1982	244	0.94	0.65	15	0.75
1976	5/1/1976	227	0.89	0.59	16	0.80
1985	5/14/1985	222	0.88	0.58	17	0.85
1974	4/27/1974	198	0.80	0.50	18	0.90
1969	4/21/1969	181	0.74	0.43	19	0.95
	Mean	293	1.04	0.79		
	Std Dev 1σ	81	0.17	0.23		
	Median	269	1.01	0.73		

Table 8 – Summary of annual minimum discharge.

Summary of USGS annual minimum discharge and computed flow velocity, Water level height above KRIGIPVD11, and exceedance probabilities. Q = discharge, V = mean flow velocity, Ht = height above KRIGIPVD11 datum.

Return Period (Years)	Q (m^3 / s)	V (m/s)	Ht (m)
2	278	1.03	0.76
5	350	1.18	0.97
10	399	1.27	1.09
25	463	1.37	1.24
50	513	1.44	1.35
100	564	1.50	1.46
200	617	1.56	1.56

Table 9 – Summary of minimum discharge return periods.

Summary of return periods for annual minimums for Kvichak River at Igiugig. Q = discharge, V = mean flow velocity, Ht = height above KRIGIPVD11 datum.

Year	Date	Q (m^3/s)	V (m/s)	Ht (m)	Rank	Exceedence Probability
1980	9/12/1980	1277	2.05	2.48	1	0.05
1971	8/27/1971	1192	2.00	2.39	2	0.10
1977	8/27/1977	1104	1.95	2.28	3	0.15
1981	8/24/1981	963	1.86	2.10	4	0.20
1982	9/24/1982	963	1.86	2.10	5	0.25
1985	10/12/1985	929	1.84	2.06	6	0.30
1972	9/23/1972	912	1.82	2.03	7	0.35
1979	8/31/1979	833	1.76	1.92	8	0.40
1986	11/8/1986	799	1.74	1.87	9	0.45
1968	8/29/1968	770	1.71	1.82	10	0.50
1975	9/17/1975	731	1.68	1.76	11	0.55
1970	9/15/1970	714	1.66	1.73	12	0.60
1969	10/17/1969	663	1.61	1.64	13	0.65
1973	9/14/1973	663	1.61	1.64	14	0.70
1976	9/30/1976	651	1.60	1.62	15	0.75
1978	9/17/1978	626	1.57	1.57	16	0.80
1984	9/7/1984	578	1.52	1.48	17	0.85
1974	10/4/1974	566	1.51	1.46	18	0.90
1983	8/24/1983	555	1.49	1.44	19	0.95
	Mean	815	1.73	1.86		
	Std Dev 1σ	213	0.17	0.31		
	Median	770	1.71	1.82		

Table 10 – Summary of annual maximum discharge.

Summary of USGS annual maximum discharge and computed flow velocity, Water level height above KRIGIPVD11, and exceedance probabilities. Q = discharge, V = mean flow velocity, Ht = height above KRIGIPVD11 datum.

Return Period (Years)	Q (m^3/s)	V (m/s)	Ht (m)
2	778	1.72	1.83
5	971	1.87	2.11
10	1101	1.95	2.28
25	1266	2.04	2.47
50	1392	2.11	2.60
100	1520	2.17	2.73
200	1651	2.22	2.85

Table 11 – Summary of maximum discharge return periods.

Summary of return periods for annual maximums for Kvichak River at Igiugig. Q = discharge, V = mean flow velocity, Ht = height above KRIGIPVD11 datum.

11.0 RECOMMENDATIONS

11.1 Turbine Site Recommendations

TerraSond has analyzed the collected data during the four Expeditions in 2011. These recommendations are based on interpretation of the alveus, bathymetry, the power density magnitude, the power density stability, and knowledge of the vessel traffic requirements. Specific bathymetry requirements were unavailable during this site selection due to still undetermined project plans. The candidate site recommendation were based on criteria provided by AEA, AE&E. and turbine designs which were under consideration for this project at the time of this report.

No specific turbine design and installation method have been selected this time. Therefore it is important to recognize that all recommended candidate sites presented here may not be appropriate for all turbine configurations and design methodologies. However, all candidate sites presented within this report are appropriate for at least one construction methodology or turbine configuration.

This study has identified several locations that may be well suited for power conversion. Three candidate site areas are recommended for perspective RISEC development. The sites are designated as Site 6, Site 9, and Site 10. These designations are based on the proximity to the original ADCP transect station determined during Expeditions II and III. The exact turbine location is not recommended in this report. These site recommendations are only intended to provide guidance for the direction of future studies of a more detailed nature.

11.1.2 RISEC Site Six

The area of Site 6 is recommended as the best suited for power production using shallow water power conversion systems. This is the closest site to the village power generation facility. It presents the lowest cost and effort for connection to the existing grid. The peak power density is most frequently located outside the thalweg. Thus the site is well suited to simultaneous use for power generation and vessel navigation. It has not been determined if this site offers a longer power production season or a larger diesel offset, however, the potential for less operational maintenance effort from offline turbine moves is a possibility for this site, Figure 46.

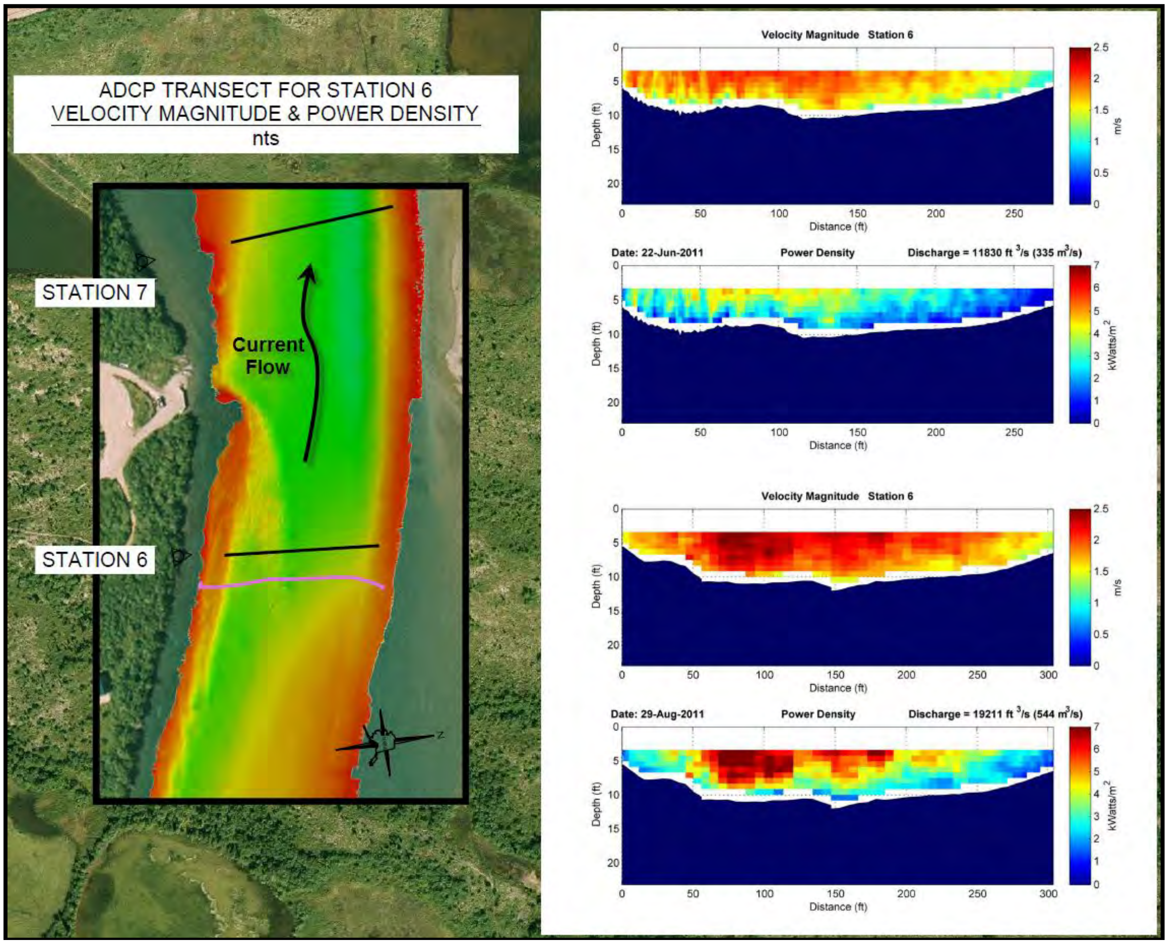


Figure 64 – Site 6 candidate site.

Several items must be considered prior to construction of an in water turbine system at this site.

1. Is the power cross sectional regime stable enough during peak discharge periods?

2. This area is likely to offer little opportunity for debris shedding. The river may guide debris directly into the turbine and create an accumulation point between the turbine and the left bank. Debris will need to be directed into the thalweg by engineering efforts.

3. The bathymetry for this site is shallower than other sites recommended within this study. Also, there is a naturally occurring sandbar directly below this site. Future operations will need to monitor the development of this accretion zone to insure that it does not interfere with turbine performance or significantly alter river flow.

11.1.3 RISEC Site Nine

Site 9 is also well suited for in water turbine construction Figure 65. It exhibits a peak power regime that should be more stable through the season that the one at Site 6. The alveus appears to be constant with slow cycles for change. This portion of the river appears to contain the most significant gradient along the thalweg. The flow is predictable and consistent through the *Chute*. The power density reaches deep into the water column and offers the ability to product power at deeper levels within the river than at Site 6. This site may offer the ability for surface and subsurface power production.

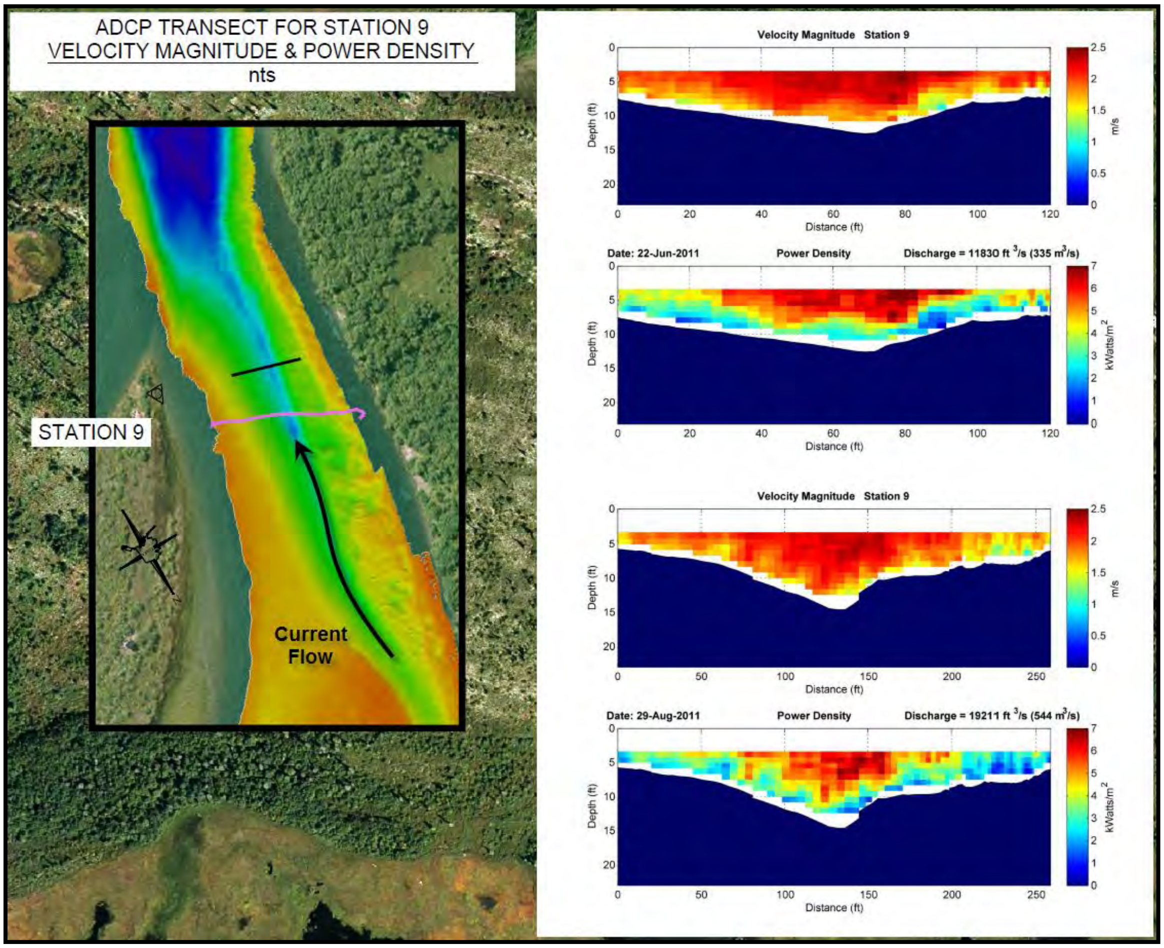


Figure 65 – Candidate Site 9.

Site 9 is a narrow channel. Navigability needs to be carefully considered at this site. The river, particularly at lower river stages, will experience significant spatial constraint. It is not known at this time if any turbine design modifications will be required to satisfy the navigational constraints it this site. Comments from the community and discussions with AE&E indicate that vessel traffic may not require many shutdown periods during a season. Although currently uncalculated, this site may require the highest transmission infrastructure cost.

Significant considerations still remain prior to construction at Site 9.

1. Cost for connection to the grid is potentially very expensive compared to Site 6.

2. Sediment transport issues may exist for this site based upon alveus morphology and should be monitored through time. Property issues will need to be sorted out for this site prior to construction.

3. A Vessel traffic plan will need to be established for total operation and maintenance costs to be well understood.

4. Debris and hazard evaluations will be required prior to project construction. This area is likely to offer little opportunity for debris shedding during low river stages due to the horizontal constraint of the channel. The river is likely to direct debris into the vicinity of the turbine. Detailed understanding of debris episodes, debris momentum, and the general path of debris through this channel will be needed to develop mitigation options.

11.1.4 RISEC Site Ten

The third potential location is Site 10 This site offers the best location for deployment of multiple turbines. This site is attractive as an adaptable and expansive project site that offers opportunity to produce a substantial portion of the power for the Igiugig. This site has the deepest bathymetry of the candidate sites. This stretch of river could accommodate an array of turbines to be placed on the bed or floating. The high energy density zone is long and stable.

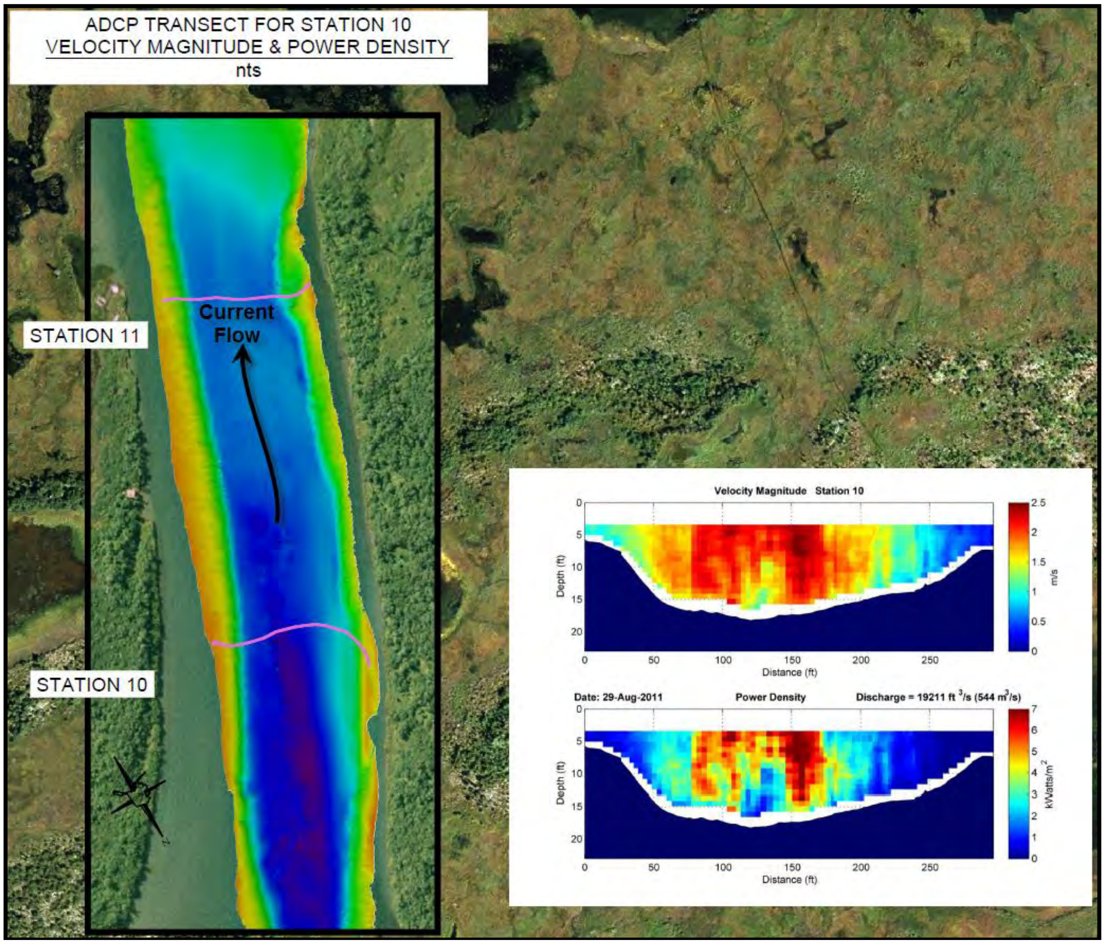


Figure 66 – RISEC Site 10.

RISEC Site 10 has a channel that is broad and deep. This gives the site 10 the best potential for power generation while minimizing interference with navigation. However, the distance from the generation facility and the left bank increases the cost and effort required to connect to the power grid.

Significant considerations still remain prior to construction at Site 10.

1. Can the cost for transmission infrastructure to Site 10 be offset by increased power production from multiple turbines?

2. The length of river appropriate for construction will require additional measurements which have not been accomplished in this study. If bottom mounted turbine configurations are considered, detailed bethymetry will be required to identify suitable bed locations. The extent of the area presented in this report has not been identified at this time and it should not be assumed that the entire length of river presented in the figure is appropriate for turbine installation.

3. A Vessel traffic plan will need to be established for proper estimation of operation and maintenance cost.

4. This site demonstrates significant power low in the water column which appears to result from the significant drop in elevation from RISEC Site 9. This could indicate that an area of increased turbulence may exist throughout RISEC Site 10 and may affect the range for potential construction.

5. Debris and hazard evaluations will be required prior to construction. The river is likely to bring debris into the turbine. Debris will need to be directed away from the turbines.

11.2 Future Studies

The results reported in this document represent the first field investigation for the design and construction of an in water turbine facility in the Kvichak River at Igiugig. The prior assessments presented have relied on historical data. The bulk of the site characterization was based on USGS gage data from Site 15300500. This data was 24 years old. Even a cursory inspection of USGS topographic maps, Community Development Maps, and aerial photography revealed that the river has experienced significant changes over the past three decades.

The MBES survey completed this year is thought to be the only one of its kind done in this area of the river. It has given a tremendous view of the current river bed condition. However, it is only a baseline study. Future MBES surveys should be done at locations considered favorable for a turbine site. These surveys should be scheduled for a high flow river state. This would offer an opportunity to maximize bottom coverage. Detailed MBES surveys should be done at any turbine location before and after placement. These studied should be planned with consideration for detection of changes in bed morphology.

The ADCP data collected to date gives a good initial description of the flow velocities and energy density in the river. However, they only represent three limited views in time. True high and low flow conditions have not been captured. Further, the stability of flow could not be adequately assessed with the three data sets. There is a need for long term current monitoring at the potential turbine sites. This is the best way to determine the nature of the flow regime. In particular it is important to assess the level of turbulence in the river and determine the long term stability of the thalweg and the zones of high energy density. The most suitable means of doing this would be an ADCP moored on the bottom of the river for up to one year.

In spite of the fact that it was over 24 years old the USGS gage data was still of some use for the present work. However, in the decades since this gage was operational there have been changes in the river climatology and morphology. Further there are no features remaining from the original USGS installation that may be used to establish a physical tie to their data set. Any relationships between current observations and the USGS record presented in this report are tenuous and should be used with caution. Long term automated monitoring of the river's water level is important for the future success of any turbine project. Even though the results of this year's efforts are considered successful, they would have been better if a gaging station had been placed at the start of the work. This station would have provided a continuous record of water level. It would have made it easier to estimate the right time to do discharge measurements for peak flows. And the initial data for the creation of a new rating curve could have been obtained. The gage could have been left in place for the foreseeable future. Thus there would be a dependable record of river stage leading up to the placement of a pilot project. With regard to the hydrologic aspects of this project a solid record of river stage is of paramount importance. Every effort should be made to establish a new gaging station at Igiugig and develop a current rating curve. A good record of river stage and discharge will be invaluable for the monitoring and assessment of turbine operation and performance.

The stability of the river bed is only given light consideration if this report. Prior to any turbine placement the prospective site should receive a detailed assessment. This assessment should include determination of sub bottom conditions, and proper sieve analysis of bed material. Near bottom flow velocities should be measured and used to determine the threshold for insipient movement of the bed materials. ADCP profiles and channel profiles should be used to optimize Manning’s equation for the select section of river.

There is no detailed knowledge of ice conditions on the river. Numerous accounts of ice conditions have been received from the USGS and the community. However, there is no solid quantitative data on ice dimension, composition, disposition and seasonality. Such information is crucial to the construction and operation of a turbine in this river. The collection of a solid data record for the river ice should be started as soon as possible. An excellent first step would be to start a local observer program that involves the local school. This could be augmented with the installation of game cameras to capture regular images of river ice. These first steps are simple and inexpensive. With respect to data quality they offer an excellent value.

TerraSond looks forward to assisting with these studies and remains available to AEA, AE&E, and the Village of Igiugig as they develop the industry capability, instrumentation, methodologies, and future techniques needed by the emerging in - stream hydrokinetic industry.

Flow measurements during RivGen deployment Igiugig, AK – Summer 2014

Jim Thomson, Levi Kilcher, and Brian Polagye

revision: November 4, 2014

Abstract

Velocity measurements during the Ocean Renewable Power Company's 'RivGen' Turbine deployment at Igiugig, AK, are used to assess the variability of the river flow. The first objective is to understand the spatial variability of the inflow velocities for RivGen, in particular the strong spanwise shear that occurs at the RivGen location. The second objective is to understand the time variability of inflow velocities, in particular the streamwise coherence of the inflow velocities. Results suggest that the river flow is approximately steady, in the mean sense, at any particular location in the river, with random turbulent fluctuations that are around 10% of the mean flow. The mean flow in the center channel of the river is 2.5 m/s, with reductions near the riverbanks and in the shallows. As the flow is quasi-steady, the data from various stations can be gridded to a synoptic flow map around the turbine. A cross-section of this flow map immediately upstream of the turbine shows strong inflow velocity gradients across the turbine. Spectral analysis and lagged correlation results indicate that temporal fluctuations at a given point are dominated by large scale fluctuations (> 10 s), such that measurements at the turbine location are just as useful for inflow control implementation as upstream measurements.

1 Site description

The ORPC deployment site on the Kvichak River is just downstream of the village of Igiugig, AK. A local coordinate system is defined in Figure 1, with $+x$ downstream (u component of velocity), $+y$ cross-river towards the village (v component of velocity), and $+z$ upwards (w component of velocity). The origin is at the nominal center of the turbine (59.324745° N, 155.915092° deg W) and the rotation from an east-north-up (true) coordinate system is 107° deg clockwise.

The river is approximately 5 m deep and 150 m wide at the deployment site, and the turbine hub-height is approximately 2 m below the surface. The turbine is 1.5 m in diameter. The flow is maximum $u \approx 2.5$ m/s in the center of the river.

2 Data collection & Analysis

Inflow velocities were measured upstream of the RivGen turbine in Iguigig, AK, from Aug 15 to 25, 2014. Measurements were made with six Nortek Aquadopp profilers deployed in a down-looking orientation from surface catamaran platforms (Doppcats, see Figure 2). The platforms were towed

Figure 1: RivGen deployment location and local coordinate system at Igiugig, AK.

Figure 2: Doppcat platform for down looking Nortek Aquadopp velocity profiler (left) and sounding weight platform for Nortek Vector velocimeter (right) at Igiugig, AK.

on tethers at 10 m spacing astern of small skiffs, which held station and sampled at 1 Hz for 10 minutes at a variety of locations upstream of the turbine. The station-holding approach was adopted when the anchors for the Doppcats did not hold sufficiently in the strong river flows and cobbled riverbed. Locations were recorded at 5 Hz using Qstarz BT-Q1000 receivers, and this information was merged with the velocity measurements in post-processing.

Two additional measurements were made. First, a Nortek Vector velocimeter was deployed on a “turbulence torpedo lowered from a davit at the stern of the skiff to provide high-fidelity turbulence measurements at 16 Hz. Second, a Nortek Signature profiler (a new 5-beam instrument) was deployed down-looking on a Doppcat and released to freely drift over the turbine and observed flow patterns at 8 Hz. The data return was 100% from all instruments, and the resulting cumulative sampling time (sum of all instruments) is about 300 hours of river velocity data.

The velocity measurements, which vary in space and time, are subject to measurement uncertainties which are predominantly the Doppler noise Δu_n of the instruments. The streamwise flow u, for example, is decomposed as

$$u(x, y, z, t) = \bar{u}(x, y, z) + u'(x, y, z, t) \pm \Delta u_n \pm \Delta u_{sk}, \tag{1}$$

where $\bar{u}$ is the mean flow calculated from 10 minutes of data and Δu_n is estimated as a constant noise level of 0.04 m/s for the 2 MHz aquadopps and 0.01s m/s for the 1 MHz aquadopps. There are additional uncertainties resulting from imperfect station keeping, measured via GPS as $\Delta u_{sk} \approx$ 0.1 m/s.

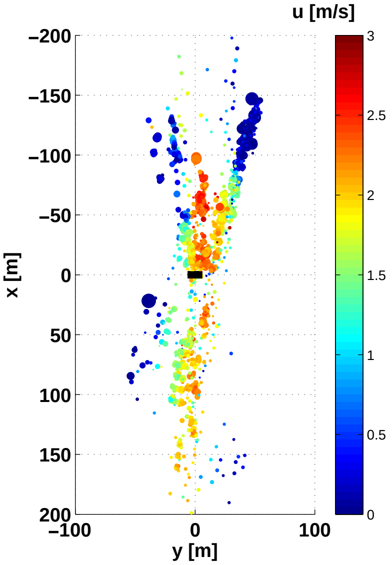


Figure 3: All mean streamwise flow results from the Doppcat station keeping measurements. Points are colored by flow speed and sized by number of observations. The turbine location is shown by a thick black line at the origin.

The space and time variables also have uncertainties,

$$x = x \pm \Delta x_{gps} \pm \Delta x_{bs} \pm \Delta x_{sk}, \qquad t = t \pm \Delta t_{cd}, \tag{2}$$

which are the result of GPS errors ($\Delta x_{gps} \approx 5$ m), beam spreading of the down looking Aquadopps ($\Delta x_{bs} \approx 3$ m), imperfect station keeping ($\Delta x_{sk} \approx 5$ m), and clock drift ($\Delta t \approx 1$ s).

These uncertainties are assumed to be uncorrelated, and averaging of results significantly reduces the uncertainty, such that robust estimates of the mean flow $\bar{u}(x, y, z)$ at a given position are repeatable. However, spatial gradients of the mean flow will be smoothed over scales finer than the uncertainties Δx. Beyond the mean estimates, robust estimates of the turbulence intensity TI are possible if the additional sources of variance from uncertainties are removed following *Thomson et al.* (2012),

$$TI(x, y, z) = \frac{\sqrt{\langle u'(x, y, z, t)^2 \rangle - \Delta u_n^2 - \Delta u_{sk}^2}}{\bar{u}(x, y, z)}, \tag{3}$$

where $\langle u'(x, y, z, t)^2 \rangle$ indicates an ensemble value over 10 minutes of observations at a particular (x, y) station.

3 Results

The river velocity measurements show robust spatial pattern in the mean streamwise flow $\bar{u}(x, y, z)$, with random turbulent fluctuations in time that are approximately $TI \approx 10\%$ of the mean flow at any given location. Figure 3 shows all the $\bar{u}$ observations collected with the Doppcats over 10 days. The temporal and spatial variations are separated by binning individual 10-minute ensembles into 5-m resolution grid cells (using the local coordinate system) and assessing sensitivity. The spatial

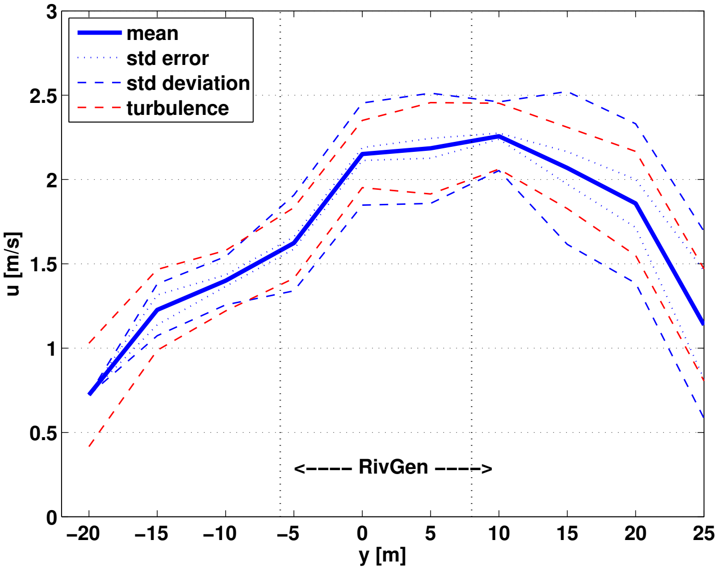


Figure 4: Lateral shear shown as the streamwise flow u versus cross-river dimension y. Results are the average from 338 stations lasting at least 10 minutes each, collected at positions immediately upstream of the turbine ($-20 < x < 0$ m). The blue dotted line is the standard error in determining the mean flow at each y. The blue dashed line is the standard deviation of individual stations. The red dashed line is variation expected from the measured turbulence intensity. The RivGen turbine cross-section is shown as a black line ($-6 < y < 8$) m.

variations in the mean flow are extreme, and in many cases the uncertainty in position Δx is a greater source of velocity changes than the $TI \approx 10\%$ turbulence intensity at any given point.

In the following subsections, the spatial patterns are addressed are: cross-river y (i.e., lateral shear of inflow velocities), depth profiles z (i.e., vertical shear of inflow velocities), and streamwise x (i.e., inflow turbulence and wake deficit). For each axis investigated, the robustness of the spatial pattern is quantified with the standard error and standard deviation of the gridded mean velocity result and this is compared with velocity fluctuations expected from the average turbulence intensity TI in each grid cell.

In a final subsection, temporal variability is examined using frequency spectral and coherence metrics.

3.1 Lateral shear

The lateral shear of inflow velocities across the turbine (i.e., from port to starboard) is the most striking spatial pattern. As shown in Figure 4, the mean inflow velocity varies from 1.6 m/s at the port side of the turbine ($y = -6$ m) to 2.3 m/s at the starboard side of the turbine ($y = 8$ m). This 44% increase in speed is a 200% increase in the power density of the flow and likely has profound impacts on the performance of the turbine. This mean flow pattern is robust, as shown by the standard error lines in Figure 4. However the individual ensembles have significant scatter, as by the standard deviation lines in Figure 4. In fact, the standard deviations obtained from the uncertainties in spatial binning are similar, and generally exceed, the velocity fluctuations attributed to turbulence within each ensemble.

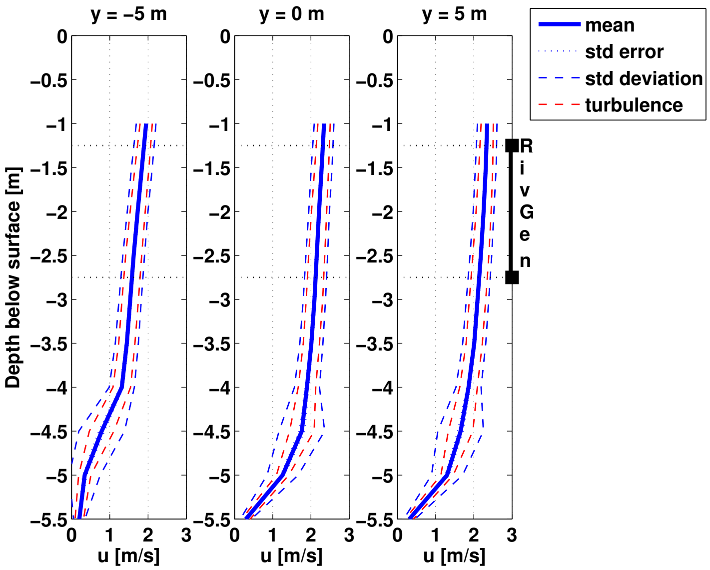


Figure 5: Vertical shear shown as the streamwise flow u versus depth below the surface at three positions in the cross-river direction: nominally turbine port ($y = -5$ m), turbine center ($y = 0$ m) and turbine starboard ($y = +5$ m). Results are the average from 338 stations lasting at least 10 minutes each, collected at positions immediately upstream of the turbine ($-20 < x < 0$ m). The blue dotted line is the standard error in determining the mean flow at each y. The blue dashed line is the standard deviation of individual stations. The red dashed line is variation expected from the measured turbulence intensity. The RivGen rotor sweep is shown as a black line ($-2.75 < z < -1.25$) m.

The observed shear is expected given the proximity to a river bend and the ADCP surveys complete the previous year by Terrasonde. It appears that deployment of the RivGen turbine a few meters farther east, at approximately $0 < y < 12$ m, would have provided a much more uniform inflow condition. Although a few meters may seem an extreme sensitivity in a river that is 150 m wide, the deep region near the river bend is a much smaller feature and clearly controls the flow.

3.2 Vertical shear

There is minimal vertical shear in the streamwise inflow velocities upstream of the turbine. As shown in Figure 5, RivGen is sufficiently far above the riverbed and sufficiently small in diameter relative to the river depth that vertical variations are typically less than 10% of the mean flow value at hub height $z = -2$ m below the surface. Vertical shear is assessed at three locations in cross-river dimension y, nominally turbine port ($y = -5$ m), turbine center ($y = 0$ m) and turbine starboard ($y = +5$ m). The pattern from these three profiles is consistent with the lateral shear result, in which flow is strongest at the starboard side of the turbine and in which spatial uncertainties of exceed turbulent fluctuations.

3.3 Streamwise variations (inflow and wake)

The alongstream pattern of the streamwise mean flow shown in Figure 6 is dominated by the presence of the RivGen turbine and the reduction in flow immediately downstream of the turbine

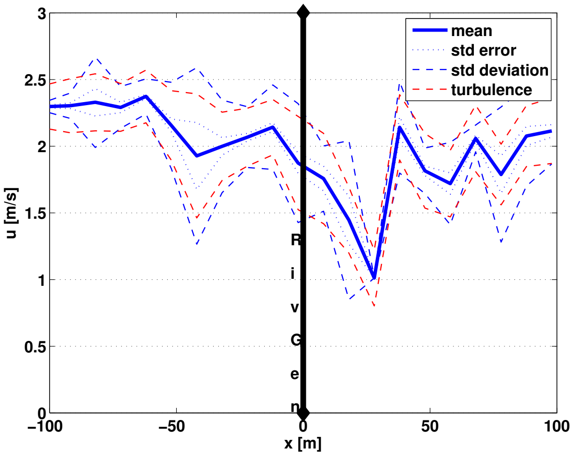


Figure 6: Streamwise flow u upstream and downstream of the turbine ($-6 < y < 8$ m). Results are the average from 563 stations lasting at least 10 minutes each. The blue dotted line is the standard error in determining the mean flow at each y. The blue dashed line is the standard deviation of individual stations. The red dashed line is variation expected from the measured turbulence intensity. The turbine location is shown by the black line ($x = 0$ m).

($0 < x < 20$ m). The reduction in the mean flow is significant, from 2 m/s to 1 m/s, and is consistent with momentum deficit expected from energy extraction. Curiously, an increase in turbulence intensity, as expected for wake-added turbulence, is not observed. The wake results are poorly constrained, because only a few stations were collected in this region (see Figure 3), and thus should be interpreted with some skepticism. Furthermore, these results are confounded by the strong lateral shears across the turbine (i.e., Figure 4), such that any non-uniformity in sampling with bias particular x slices. For example, the upstream measurement have shown a reduction in flow and in increase in the variability around $x = -50$ m, which is coincident with a gap in the stations (see Figure 3) and biased sampling towards the negative y.

Despite the caveats in the streamwise pattern, it is worth nothing that the velocity deficit recovers around $x = 30$ m, which is 20 turbine diameters downstream.

3.4 Turbulence spectra and coherence

The temporal variability in the velocity components for a given location is shown in Figure 7 as the turbulent kinetic energy (TKE) spectra upstream ($x \approx -75$ m) and downstream ($x \approx 50$ m) of the turbine. Spectral are calculated using 10-minutes of motion-corrected velocity data from a Nortek Vector mounted on a 'turbulence torpedo' (see Figure 2) hanging from a davit at turbine hub height ($z = -2$ m). Motion-compensated spectra have been demonstrated by *Thomson et al.* (2013); *Kilcher et al.* (2014), and the methods herein are the same. The corrections are minor, because the 'turbulence torpedo' is fared and does not introduce much motion. Spectral are similar up and downstream of the turbine, other than some elevation in the v component at mid-frequencies. This is most likely because the downstream measurement was beyond the region of significant wake (see Figure 6).

The spectra of all components show an expected $f^{-5/3}$ power law at high frequencies, consistent with the isotropic cascade of energy from large scales to small scales through the inertial range.

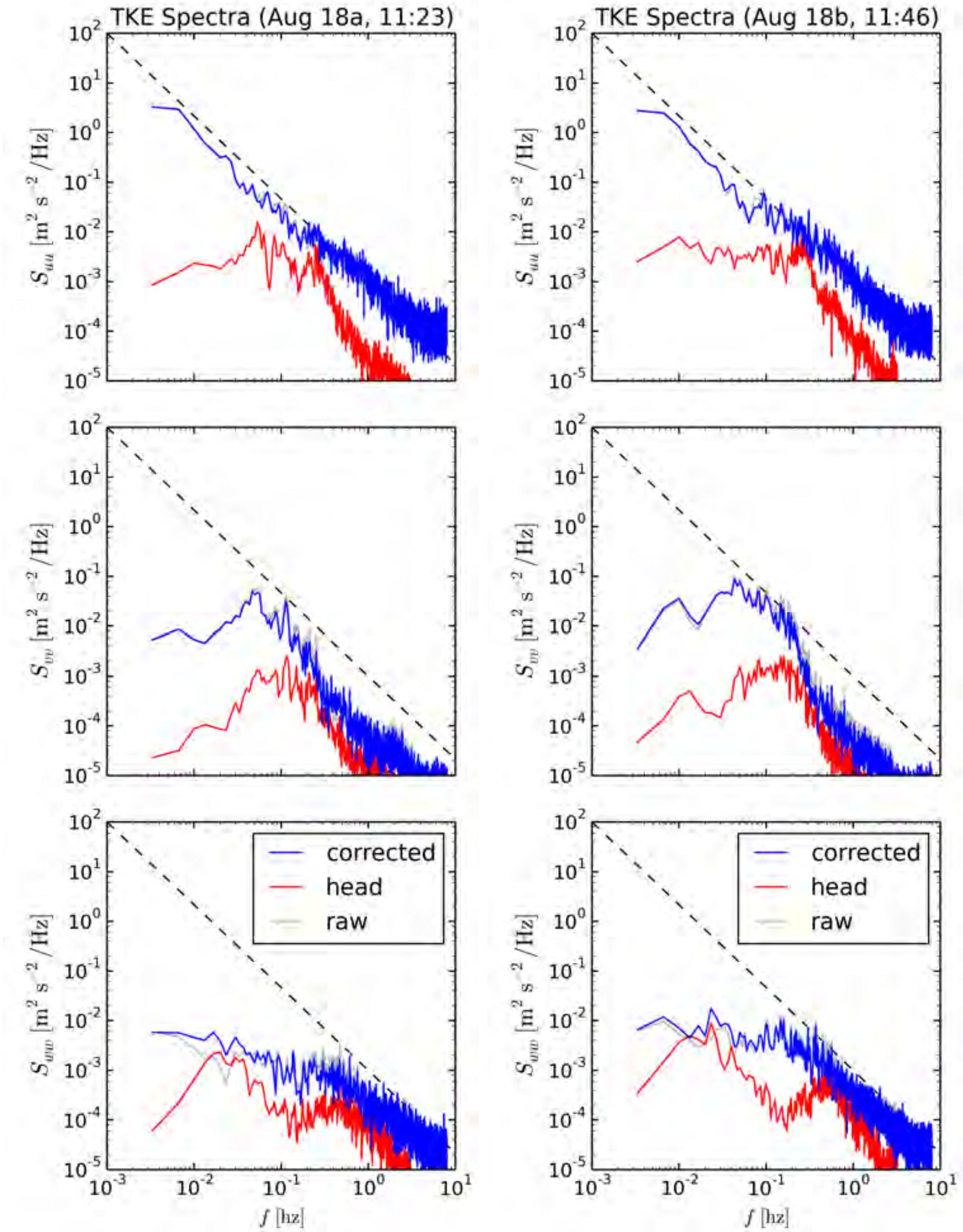


Figure 7: Turbulent kinetic energy spectra density versus frequency for the different velocity components (top is u, middle is v, bottom is w) measured upstream (left) and downstream (right) of the turbine. Corrected spectra (blue lines) use the motion of the instrument head (red) to remove motion from the raw spectra (grey lines). Spectral are calculated using 10-minutes of motion-corrected velocity data from a Nortek Vector mounted on a ‘turbulence torpedo’ hanging from a davit at turbine hub height ($z = -2$ m).

At lower frequencies, the u components continue the power law, but the v and w components have maxima at $f \approx 0.06$ Hz and $f \approx 0.2$ Hz, respectively. Assuming that the eddies are 'frozen' as they advect with the mean flow (i.e., Taylor's hypothesis), time and length scales are related as

$$2\pi l = \frac{\bar{u}}{f}, \tag{4}$$

where f is the cyclic frequency in a TKE spectrum. Thus, the length scales of the maxima in v and w are $l_v \approx 6$ m and $l_w \approx 2$ m. These length scales are consistent with the expectation that the 6 to 7 m depth of the main river channel limits the scale of 3D isotropic turbulence and that vertical motions w' are further limited by the distance from the measurement volume to the nearest boundary (here, the surface, which is 2 m away).

More puzzling is the lack of a maxima in the u component spectra, which would be expected to be similar to the v component. This may be related to leakage at low frequencies, where subtle changes in station keeping of the boat against the river flow may add additional variance. Alternatively, the low frequency energy in the u component could be contaminated by deviations from the frozen field approximation, which are expected for the large scales that take a relatively long time (> 10 s) to advect past the instrument. Although the physical reason and relation to $f^{-5/3}$ is unclear, the empirical result is useful: the temporal variations in the flow are dominated by large fluctuations over long time scales (> 10 s).

The turbulence spectrum is equivalent to the lagged auto-correlation of a given velocity time series. Figure 8 shows this calculation for a doppcat measurement upstream of the turbine, as well as the lagged correlation *between* two simultaneous doppcat measurements separated by 10 m in x. Consistent with the upstream TKE spectrum, the auto-correlation result shows significant correlations on time lags of up to ±40 s. The correlation between two simultaneous independent measurements shows almost an identical result. This is contrary to the expectation of a distinct, sign-definite lag between the two measurements, as would be expected if the flow was truly a frozen signal advecting along or was wave-like. Such a flow would be the ideal case for implementing feed-forward control in a turbine, because an upstream measurement could be projected to the turbine with a known time lag.

Despite the general lack of coherent lags in simultaneous flow measurements at various separation distances (other examples are similar to Figure 8), the inflow at the site RivGen is still amenable to control strategies. The streamwise flow appears to be coherent at large space and time scales. On short space and time scales (i.e., small eddies), the turbulence likely evolves too quickly to observe lags, and on longer time scales the lags are essentially zero for separations of O(10 m). The zero lag result dominates because the longer scales contain the most energy. Thus, at any individual fixed point, such as the turbine location, the most robust preview of the flow would be the previous 10 to 30 s of flow *at that location.* An upstream measurement would have no increased skill relative to this self-forecast, because the only thing different at the upstream measurement location would be the small, incoherent eddies. Restated: the large velocity fluctuations tend to last at least 10 s, and on those time scales localized measurements are equivalent to any upstream measurement. (This is akin to the famous 'dummy' forecast in meteorology: synoptic weather patterns last longer than one day, and thus a simple forecast that tomorrow's weather will be like today's weather is quite skillful.)

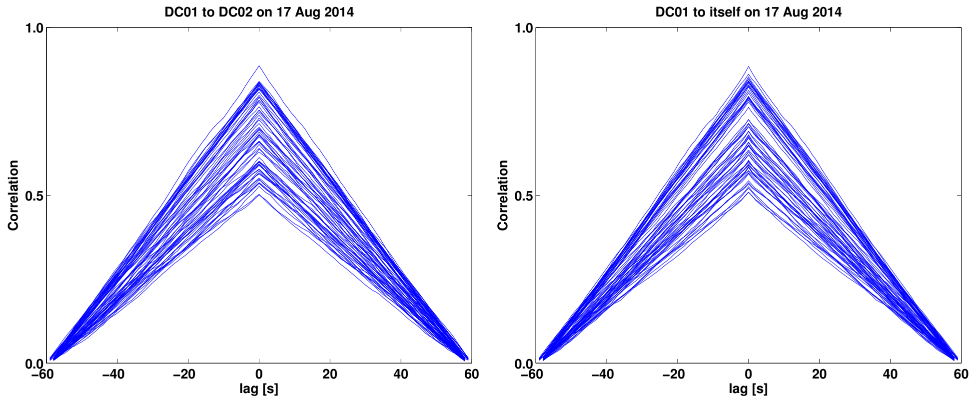


Figure 8: Lagged correlations between two upstream doppcat velocity measurements separated by 10 m (left) and the same calculation for single doppcat measurement (right). Correlations are calculated using raw velocity data (1 Hz) in one-minute ensembles, after correction for platform motion using the GPS data.

4 Conclusions

At this site, and likely at many other river sites, flow is generally steady at a given location, but flow varies dramatically between locations, particularly across the river. The primary result here is that 1) a lateral change in position of a few meters results in changes to flow speed that far exceed the turbulence fluctuations at any given location and 2) the turbulence is dominated by long time scales. Simply put, this is a site for which it is more important to know where you are than to know what time it is.

5 Acknowledgements

Joe Talbert, Alex deKlerk, and Curtis Rusch provided excellent technical support in the field. Funded by the US Dept of Energy.

References

Kilcher, L., J. Thomsoon, and J. Colby, Determing the spatial coherence of turbulence at MHK sites, in *Proceedings of the 2nd Marine Energy Technical Symposium (METS)*, edited by ‘, 2014.

Thomson, J., B. Polagye, V. Durgesh, and M. Richmond, Measurements of turbulence at two tidal energy sites in Puget Sound, WA, *J. Ocean. Eng.*, *37*(3), 363–374, 2012.

Thomson, J., et al., Tidal turbulence spectra from a compliant mooring, in *Proceedings of the 1st Marine Energy Technical Symposium (METS)*, 2013.

ORPC RivGen Wake Characterization

Maricarmen Guerra Paris*
University of Washington
Seattle, WA, USA

Jim Thomson
University of Washington
Seattle, WA, USA

*Corresponding author: mguerrap@uw.edu

ABSTRACT

Baseline and post-deployment flow conditions were measured at the ORPC RivGen turbine site on the Kvichak river in the vicinity of Igiugig village, Alaska. Mean surface flow and turbulence measurements were collected from a drifting platform equipped with a Nortek Signature 1000Hz five beam AD2CP. Baseline measurements indicate a maximum flow of 2.5 m/s and a 10% turbulent intensity in the turbine vicinity. Measurements after turbine deployment and grid connection show a significant decrease in surface velocity up to 200 m downstream from the turbine and an increase in turbulence intensity up to 20% that extends about 75 m downstream of the turbine. The turbulent kinetic energy dissipation rate is also increased immediately downstream of the turbine.

1. INTRODUCTION

The extraction of hydrokinetic energy from rivers and tidal currents requires the installation of marine hydrokinetic turbines facing the flow field, as for any perturbation in the river medium, environmental effects are expected to occur [1, 2, 3]. Such environmental effects pose a challenge to the development of hydrokinetic energy extraction projects at all scales and must be carefully analyzed.

The study of the wake behind a turbine is essential in the characterization of hydrodynamic effects. Wake analysis reveals changes to the mean flow and mixing behind the turbine, as well as how long it takes to return to the natural flow conditions. The length of the wake and its features also affect the downstream distribution of additional devices and their performance [4].

Much of the research on hydrokinetic turbine wakes has been carried out numerically [5, 6, 7], and at the laboratory scale under controlled conditions [8, 4, 9], differing mainly on how detailed the turbine and the energy extraction are represented [10]. At the field scale, towing experiments of a vertical crossflow turbine were conducted in an unconfined environment in [11]. In general, the wake of the turbine is characterized by: i) a deficit in the mean flow that might persist beyond several turbine diameters downstream [12]; ii) an increase in turbulence due to eddies shed by turbine blades; and iii) complex interactions between natural and turbine induced turbulent structures [6].

In this investigation we assess the wake formed behind a horizontal cross-flow turbine installed on the Kvichak river in southwest Alaska, USA, just downstream of the village of Igiugig. The small village is home to 70 people and its electricity source currently depends on an isolated power grid fed by diesel generators. The Ocean Renewable Power Company (ORPC) has set a pilot hydrokinetic energy project on the Kvichak river stream to provide Igiugig with a renewable and locally produced source of energy.

ORPCs RivGen turbine was successfully deployed, tested and connected to the local power grid during the summers of 2014 and 2015. During each deployment a team from the University of Washington Applied Physics Laboratory performed several measurements of pre and post-deployment river flow conditions. Here, analysis focuses on the turbine wake observed during deployment in summer 2015.

The characterization of the wake requires the ability to capture, in space and time, the complex three dimensional nature of the flow in the vicinity of the turbine [12]. In this case, the turbine's wake was captured using a drifting approach. A freely drifting platform instrumented to measure flow velocity at high frequency through the water column was released at different locations along a cross-section upstream the turbine location and let flow along river streamlines. This repetitive process allowed us to cover a large portion of the river in the turbine vicinity before and after turbine deployment without interfering with turbine operations and without deploying an array of instruments on the riverbed.

The use of repeated drifts is only possible because the river flow has strong stationarity, and thus drifts from different times can be merged to get a complete picture of the river flow state. Data from before and after turbine deployment can then be organized into horizontal grids in order to obtain a map of river flow conditions and further elucidate the turbine effects in the flow. As noted in [12], the mean flow and turbulence do not recover at the same rate in a turbine wake, thus the wake extension and recovery to an undisturbed state are analyzed using both mean flow and turbulence statistics.

Figure 1: Kvichak river near Igiugig, Alaska, and local coordinate system. X-axis corresponds to main flow direction. Basemap was taken from Google Earth.

2. DATA COLLECTION

Surface velocity and velocity variations along the water column were collected from a moving platform around the turbine deployment site on the Kvichak river. Figure 1 shows a plan view of the river and turbine location. Measurements took place prior to and after the deployment (and grid connection) of ORPC's RivGen hydrokinetic turbine in order to analyze the effects of turbine rotation and energy extraction in the river flow conditions.

Site and Turbine Description

The ORPC deployment site is on the Kvichak River, just downstream of the village of Igiugig in southwest Alaska. The Kvichak river flows southwest from Iliamna Lake to Bristol Bay. At the deployment site, the river is approximately 5 m deep and 150 m wide. The flow is at is maximum, $u \sim 2.5$ m/s, in the center of the river.

RivGen is a crossflow horizontal turbine, approximately 12 m wide and 1.5 m in diameter. Turbine hub-height is approximately 2.5 m below the river free surface when the turbine is submerged and resting on the riverbed. Turbine blockage in the Kvichak river was estimated to be 10% when considering the turbine swept area plus the turbine's support structure area over the area of the river cross-section at the turbine location (obtained from a previous bathymetric survey conducted by ORPC).

2.1 Drifting Platform Description

Flow velocities throughout the water column were collected using a drifting Nortek Signature 1000Hz five beam AD2CP. The Signature was mounted looking downward on a disk buoy equipped with two Qstarz GPS data receivers measuring geographic position and drifting velocity at 10 Hz with a 5 m accuracy in position and 0.05 m/s in drifting velocity (using a phase-resolving GPS antenna). The platform is shown in Figure 2.

The Signature was set up to measure velocities in its 5 BEAM coordinates at an 8 Hz sampling rate (continuous). The blanking size was set to 0.5 m and cell size to 0.5 m, with a 7.5 range to cover the entire water column.

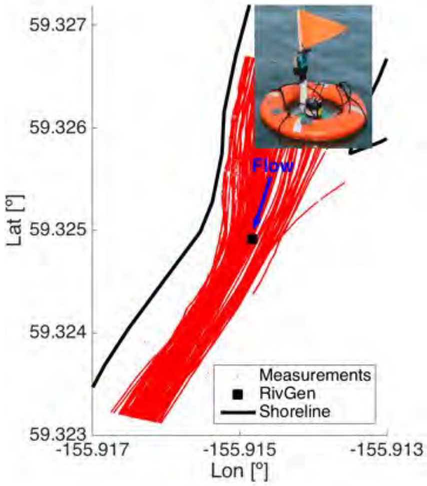


Figure 2: Instrumented drifting platform and drifts path in red. Black lines represent the river shoreline and black square defines turbine location

2.2 Measurement Procedure

Drifts began $\sim$ 200 m upstream of the turbine position by directly dropping the drifter buoy from a small vessel. The cross-sectional river span was covered by releasing the drifter at seven different (estimated) positions across the river. Each drift was recovered $\sim$ 200 m downstream of the turbine. Figure 2 shows location and direction of drifts.

Two sets of drifts were conducted: before and after turbine deployment. The first set was conducted in order to characterize the river in its natural state and the inflow conditions for the turbine. This data set consisted of $\sim$ 150 drifts between July 8th and July 13th, 2015. A portion of the drifts (15) were set-up to measure altimetry (bathymetry) and due to an instrument restriction, could only measure along beam velocities at 4 Hz (instead of 8 Hz).

The second set of drifts took place after turbine deployment, from July 19th to July 21st, 2015. This data set consisted of $\sim$ 190 drifts covering the same longitudinal river span, but concentrated over and next to the turbine to evaluate the turbine wake. As for the first set, 25 drifts were taken in altimeter mode, measuring 5 beam velocities at 4 Hz.

3. ANALYSIS

3.1 Data organization

A local coordinate system was defined for all flow measurements, with positive x downstream (u component of velocity), positive y cross-river towards the village (v component of velocity), and positive z upwards (w com-

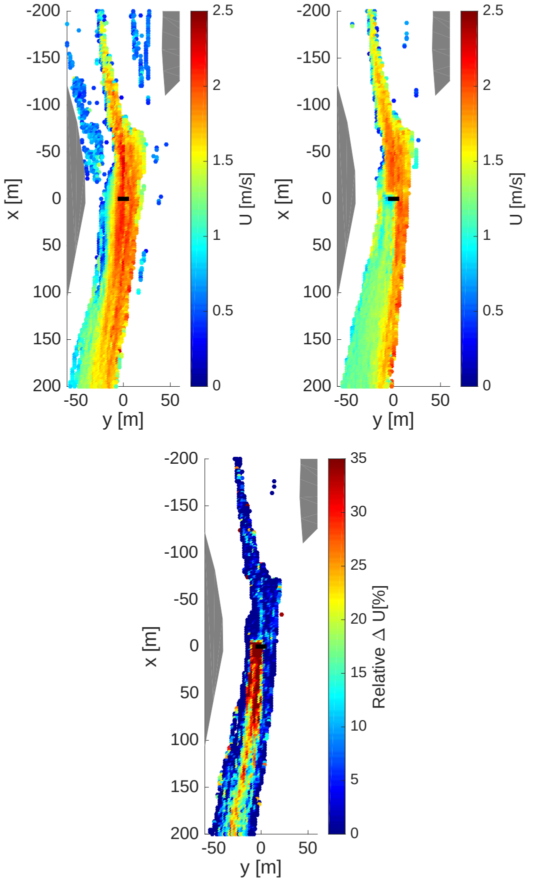


Figure 3: Hub-height velocity measurements maps: baseline (top left), post-deployment (top right) and relative difference (lower). Grey areas represent river banks and black square defines turbine location.

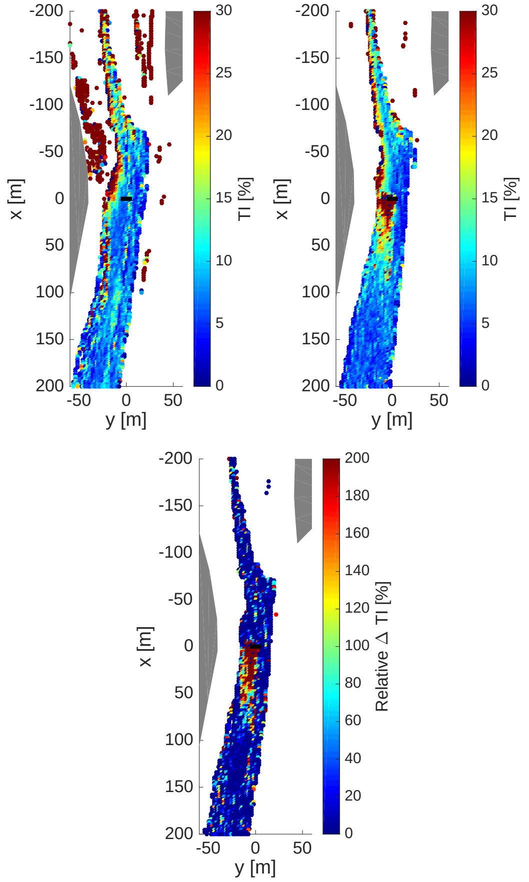


Figure 4: Pseudo-Turbulence intensity measurements maps: baseline (top left), post-deployment (top right) and relative difference (lower). Grey areas represent river banks and black square defines turbine location.

ponent of velocity). The origin is at the nominal center of the turbine (59.324916 °N; 155.914828 °W) and the rotation from an east-north-up (true) coordinate system is 107° clockwise. The system is shown in Figure 1.

Collected data was organized into a $2x2$ m^2 horizontal grid defined in the local coordinate system which covers 400 m in the along river direction and 60 m in the cross-river direction; the center of the grid is at the center of the turbine. The grid organization results in a map of surface velocities and a set of velocity variations at different depths where significant differences can be observed between before and after turbine deployment.

3.2 Horizontal Velocity

Surface flow velocity was obtained from platform drifting velocities recorded by the GPS receivers. Horizontal velocity magnitude profiles through the water column were estimated from the surface flow velocity and the horizontal velocity measured by the drifting Nortek Signature as:

$$U(x, y, z, t) = U_d(x, y, t) - U_{ad2cp}(x, y, z, t) \qquad (1)$$

where U_d is the drifting horizontal velocity and U_{ad2cp} represents the horizontal velocity magnitude estimated from the Nortek Signature measurements.

Grid averaged hub-height velocity magnitude maps are shown in Figure 3. Maximum hub-height velocity is at the main channel center, reaching $\sim$ 2 m/s just upstream of the turbine; the velocity magnitude distribution agrees with the shape and bathymetry of the river. Post-deployment measurements show a decrease in hub-height flow velocity magnitude towards mid-river, observable immediately downstream of the turbine. The velocity decrease was also observed in the surface flow velocity, beginning about 25 m downstream the turbine (not shown). This distance indicates how long it takes for the water column to mix behind the turbine for the wake effects to be observable at the free surface.

The relative velocity change map, shown in the lower panel of Figure 3, indicates a strong hub-height velocity change beginning right downstream the turbine location. The velocity change reaches a maximum of 35% and extends for more than 200 m downstream the turbine. The persistence of the wake in terms of mean flow velocity is an indicator of energy extraction.

3.3 Turbulence

Flow turbulence is spatially characterized by two parameters: turbulence intensity and the rate of turbulent kinetic energy (TKE) dissipation. These two parameters provide key information on the turbine's turbulent wake, describing how much river turbulence is increasing, and how does the river flow recovers downstream the turbine.

A pseudo-turbulence intensity (TI) is estimated using the 5 beam raw velocity measurements from the Signature relative to the mean surface velocity of the flow. This pseudo-TI is defined as:

$$TI(x, y, z, t) = \frac{\sqrt{\frac{1}{5}\sum_{i=1}^{5} u_i^2(x, y, z, t) - \Delta u_n^2}}{U_{ad2cp}(x, y, z, t)} \tag{2}$$

where u_i represents each along beam velocity from the Nortek Signature, u_n is the along beam velocity error and U_ad2cp is the horizontal velocity magnitude. This assumes that the platform is drifting with the mean flow and that the fluctuations are all independent realizations of the turbulent field, though there are only three independent components of velocity. The along-beam measurements have independent noise errors, u_n, and thus the use of all 5 beams is preferred to estimate the velocity variations at each point along a drift track. By only using the along beam velocities, pseudo-TI only captures the turbulent length scales similar to the beam separations. This spatial definition is uniformly biased low compared to the usual temporal definition of turbulent intensity $\sigma_u/\bar{u}$, where σ_u is the standard deviation of along channel velocity and $\bar{u}$ corresponds to the mean flow.

Stationary measurements of turbulence using Accoustic Doppler Velocimeters at the turbine site show the existence of a cascade of isotropic turbulence in the Kvichak river [13, 14], which allows for the estimation of the rate at which turbulent kinetic energy is dissipated.

Here, we instead use a spatial method for the TKE dissipation rate. Dissipation rates of TKE are calculated using the spatial structure functions of the along-beam turbulent fluctuations $D(z, r)$ [15, 16], defined as:

$$D_i(z, r) = \langle (u_i(z) - u_i(z + r))^2 \rangle \tag{3}$$

where u_i corresponds to each along beam velocity, z is the along beam measurement location, and r the distance between velocity measurements; the angle brackets denote a time average. It is important to note that the spatial structure function captures a wider range of turbulent length scales than the pseudo-TI, as it incorporates the velocity fluctuations differences along the entire water column. At the inertial subrange of isotropic turbulence, the dissipation rate ϵ is obtained from the following relation [16]:

$$D_i(z, r) = C_v^2 \epsilon^{2/3} r^{2/3} \tag{4}$$

where C_v^2 is a constant equal to 2.1.

The structure function was estimated using all instantaneous profiles within each grid cell (about 8 instantaneous profiles for each drift that passed through a grid cell). TKE dissipation rate was estimated from the time averaged structure function estimate at different depths by linearly fitting $D_i(z, r)$ to $r^{2/3}$ as:

$$D_i(z, r) = A(z) r^{2/3} + N(z) \tag{5}$$

where $A(z)$ is the slope of the linear fitting defined as $A(z) = C_v^2 \epsilon(z)^{2/3}$ and $N(z)$ represents uncertainties related to Doppler noise [15]. TKE dissipation rate at each depth of each grid cell is estimated from $A(z)$. For the calculations, r values ranged between 1 m and 2.5 m.

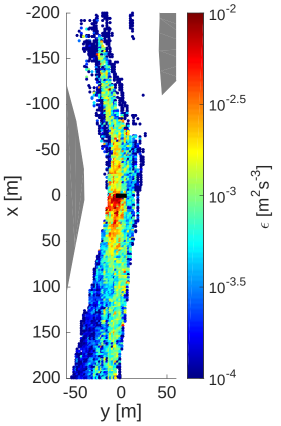


Figure 5: Turbulent kinetic energy dissipation rate map from turbulent structure function along vertical beam after turbine deployment and grid connection. Grey areas represent river banks and black square defines turbine location.

Baseline, post-deployment, and relative change of pseudo-turbulence intensity maps are shown in Figure 4. All maps correspond to hub-height measurements, 2.5 m below free surface. Baseline ambient turbulence at hub height is about 10% around the turbine location, increasing near the river boundaries as the water depth decreases. This value is consistent with stationary measurements using ADVs at the site. When the turbine is operational, at hub height, there is approximately a doubling of pseudo-TI, extending from just upstream of the turbine to ∼ 75 m downstream the turbine.

A plan view of TKE dissipation rate for a fully operational turbine is shown in Figure 5. A region of higher TKE dissipation rate is observed immediately downstream of the turbine extending about 50 m downstream, consistent with the increase in turbulence intensity and its recovery extension.

4. CONCLUSIONS AND FUTURE WORK

Spatial measurements of mean flow and turbulence in the vicinity of the ORPC RivGen power system site in the Kvichak river in Alaska reveal the impact of a hydrokinetic turbine on flow conditions. The repetitive drifting approach at a high sampling rate has proven to be effective in capturing the natural flow conditions and the averaged effects of turbine rotation and energy extraction in the flow, showing a turbulent wake that extends more than 50 m downstream of the turbine location and a larger effect in the mean flow extending more than 200 m downstream.

Future work includes the study of turbine operation and wake relation, the analysis of free surface variations upstream and downstream of the turbine from a longitudinal array of pressure gages installed under the turbine, the analysis of the spatial scales of the turbulence, and the analysis of momentum balance measured upstream and downstream of the turbine.

5. ACKNOWLEDGMENTS

The authors are grateful for the help and support during field measurements of Joe Talbert, Alex deKlerk, Dylan Dubuque from APL-UW, Sam Harding from PNNL, Eric Nelson from NREL, Ryan Tyler, James Donegan and Monty Worthington from ORPC, and the people from the village of Igiugig. The authors also thank the Ocean Renewable Power Company for their support and collaboration in this project. The authors acknowledge US Naval Facilities Engineering Command (NAVFAC) for acquisition and testing of the Nortek Signature AD2CP. This investigation is supported by the US Department of Energy. Maricarmen Guerra also thanks the support of Fulbright and the Becas Chile - Conicyt doctorate fellowship program.

6. REFERENCES

[1] Cada, G., Ahlgrimm, J., Bahleda, M., Bigford, T., Stavrakas, S., Hall, D., Moursund, R., and Sale, M., 2007. “Potential impacts of hydrokinetic and wave energy conversion technologies on aquatic environments”. *Fisheries,* ***32***(4), pp. 174–181.

[2] Boehlert, G., and Gill, A., 2010. “Environmental and ecological effects of ocean renewable energy development: a current synthesis”. *Oceanography,* ***23***(2), pp. 68–81.

[3] Polagye, B., Van Cleve, B., Copping, A., and Kirkendall, K., 2011. Environmental effects of tidal energy development: Proceedings of a scientific workshop march 22-25, 2010. Tech. rep., US National Oceanographic and Atmospheric Administration.

[4] Myers, L., and Bahaj, A., 2012. “An experimental investigation simulating flow effects in first generation marine current energy converter arrays”. *Renewable Energy,* ***37***(1), pp. 28 – 36.

[5] Kang, S., Borazjani, I., Colby, J. A., and Sotiropoulos, F., 2012. “Numerical simulation of 3d flow past a real-life marine hydrokinetic turbine”. *Advances in Water Resources,* ***39***, pp. 33–43.

[6] Kang, S., Yang, X., and Sotiropoulos, F., 2014. “On the onset of wake meandering for an axial flow turbine in a turbulent open channel flow”. *Journal of Fluid Mechanics,* ***744***, pp. 376–403.

[7] Blackmore, T., Batten, W., and Bahaj, A., 2014. “Influence of turbulence on the wake of a marine current turbine simulator”. In Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, Vol. 470, The Royal Society, p. 20140331.

[8] Myers, L., and Bahaj, A., 2007. “Wake studies of a 1/30th scale horizontal axis marine current turbine”. *Ocean Engineering,* ***34***(5), pp. 758–762.

[9] Chamorro, L. P., Troolin, D. R., Lee, S.-J., Arndt, R., and Sotiropoulos, F., 2013. “Three-dimensional flow visualization in the wake of a miniature axial-flow hydrokinetic turbine”. *Experiments in Fluids,* ***54***(2), pp. 1–12.

[10] Day, A., Babarit, A., Fontaine, A., He, Y.-P., Kraskowski, M., Murai, M., Penesis, I., Salvatore, F., and Shin, H.-K., 2015. “Hydrodynamic modelling of marine renewable energy devices: A state of the art review”. *Ocean Engineering,* ***108***, pp. 46 – 69.

[11] Polagye, B., Cavagnaro, R., Niblick, A., Hall, T., Thomson, J., and Aliseda, A., 2013. “Cross-flow turbine performance and wake characterization”. In Proceedings of the 1st Marine Energy Technology Symposium (METS13), Washington, DC.

[12] Chamorro, L., Hill, C., Morton, S., Ellis, C., Arndt, R., and Sotiropoulos, F., 2013. “On the interaction between a turbulent open channel flow and an axial-flow turbine”. *Journal of Fluid Mechanics,* ***716***, pp. 658–670.

[13] Forbush, D., Polagye, B., Thomson, J., Fabien, B., Donegan, J., and McEntee, J., 2015. “Characterization and control of cross-flow turbine in shear flow”. In Proceedings of the 3rd Marine Energy Technology Symposium (METS15), Washington, DC.

[14] Forbush, D., Polagye, B., Thomson, J., Kilcher, L., Donegan, J., and McEntee, J., Forthcoming. “Performance characterization of a river current turbine in shear flow”.

[15] Wiles, P. J., Rippeth, T. P., Simpson, J. H., and Hendricks, P. J., 2006. “A novel technique for measuring the rate of turbulent dissipation in the marine environment”. *Geophysical Research Letters,* ***33***(21).

[16] Thomson, J., Polagye, B., Durgesh, V., and Richmond, M., 2012. “Measurements of turbulence at two tidal energy sites in Puget Sound, WA”. *Journal of Oceaninc Engineering,* ***37***(3), pp. 363–374.

IGIUGIG HYDROKINETIC PROJECT

EXHIBIT D: ADDITIONAL INFORMATION REQUESTS

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511-002

November 15, 2018

Prepared for:
Igiugig Village Council
#1 Airport Way
Igiugig, Alaska 99613-4008
Phone (907) 533-3211
www.igiugig.com

Prepared by:
ORPC, Inc
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

Appendix D: Additional Information Requests includes the following document:

- Igiugig Village Council response to Additional Information Requests

ORPC
OCEAN RENEWABLE
POWER COMPANY

Nathan E. Johnson
DIRECTOR- ENVIRONMENTAL AFFAIRS

66 Pearl Street, Suite 301
Portland, ME 04101

DIRECT 207 221 6254
CELL 207 712 2927
OFFICE 207 772 7707

njohnson@orpc.co

August 5, 2015

Ms. Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street NE
Washington, DC 20426

Subject: **Submittal of Igiugig Hydrokinetic Project (FERC Project No. 13511-002) Draft Application Deficiencies and Requests for Additional Information**

Dear Ms. Bose:

On behalf of the Igiugig Village Council, Ocean Renewable Power Company is pleased to submit the attached responses to the Federal Energy Regulatory Commission's (Commission) Draft Application Deficient and Request for Additional Information for the Igiugig Hydrokinetic Project (Project) dated June 5, 2015. The information requested in Schedules A and B is submitted in accordance with the Commission's 60 day time frame for responses.

If you have any questions regarding this submission, please contact me by telephone at 207/221-6254 or by email, njohnson@orpc.co.

Sincerely,

Nathan E. Johnson
Director - Environmental Affairs

cc: AlexAnna Salmon, Igiugig Village Council

Enclosure: Draft Application Deficiencies and Requests for Additional Information

IGIUGIG HYDROKINETIC PROJECT

DRAFT APPLICATION DEFICIENCIES AND REQUESTS FOR ADDITIONAL INFORMATION

DRAFT PILOT LICENSE APPLICATION, P-13511-002
BEFORE THE UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

August 5, 2015

Prepared for:
Igiugig Village Council
P.O. Box 4008
Igiugig, Alaska 99613
Phone (907) 533-3211
www.igiugig@bristolbay.com

Prepared by:
ORPC Solutions, LLC
66 Pearl St., Suite 301
Portland, Maine 04101
Phone (207) 772-7707
www.orpc.co

TABLE OF CONTENTS

SCHEDULE A

Deficiencies

Exhibit E

Deficiency 1
Exhibit E does not conform to section 5.18(b)(1) because it does not identify the project's river mile designation or other reference point. Please revise Exhibit E to include the project's river mile designation.

Response
The Kvichak River does not have designated river miles. The Project site is approximately 1.20 miles downstream (southwest) from the outlet of Lake Iliamna (main channel) as shown below.

Measure the distance between multiple points on the ground

Length: 1.20 Miles

☑ Mouse Navigation

Deficiency 2
Exhibit E does not conform to section 5.18(b)(4) because it does not include:

(a) *the number, type, and minimum and maximum hydraulic capacity and installed (rated) capacity of existing and proposed turbines or generators to be included as part of the project; and* *(b) an estimate of the dependable capacity and average annual production in kilowatt hours (or mechanical equivalent).*

Response
Hydraulic capacity is not applicable to the proposed RivGen® Power System technology since it does not impede or block natural water flow.

In Phase 01, IVC will deploy, monitor and test a single-device RivGen® Power System for one year within the Project boundary. In Phase 02, IVC will install an additional RivGen® device to the power system, for a total of two devices. Each RivGen® device has a rated capacity of 20kW at 2.25 m/s (Exhibit E, page 18 of 151).

The proposed Project will significantly impact the existing energy resource by displacing diesel fuel at Igiugig, where the estimated annual output from a 40kW project is 409,504kWh (Exhibit E, page 4 of 151).

Deficiency 3
Exhibit E does not conform to section 5.18(b)(5)(E) because it does not include:

(a) an estimate of the cost of construction, and operation and maintenance of the proposed project;

Response
See Exhibit A, Table 3 (Page A-1, 2):

(ix) The estimated cost of the project	$2.7 million capital costs
(x) The estimated capital costs and estimated annual operation and maintenance expense of each proposed environmental measure	$2.7 million capital costs $120,000 annual operating expenses, including environmental measures

(b) an estimate of the cost of each proposed resource protection, mitigation, or enhancement measure; and

Response

This information appears in Exhibit E, E.4.3. Cost of Environmental Measures (Page 133 of 151):

E.4.3 COST OF ENVIRONMENTAL MEASURES
ORPC has estimated the average annual cost to implement the Fish and Wildlife Plan to be approximately $50,000 over the course of the ten-year pilot license. It is anticipated that levels of annual monitoring, and associated costs, costs will be higher during the first several

years of the Project and be reduced in accordance with protocols established in the Project Adaptive Management Plan (Appendix B).

(c) an estimate of the value of the developmental resources for the proposed project.

Response
This information was included in Exhibit E as follows:

Exhibit E, E.1.2.2 Need for Power (Page 3 of 151):

The proposed Project will significantly impact the existing energy resource by displacing diesel fuel at Igiugig, where the estimated annual output from a 40kW project is 409,504kWh. Based on IVC's existing generation at 11.7kWh per gallon of diesel, the corresponding annual fuel displacement of the power from the Project would be 35,000 gallons per year. The anticipated cost savings to the electric utility based on an adjusted avoided cost of fuel published in the Alaska Energy Authority (AEA) Power Cost Equalization Report ($7.58 gallon[1]) amounts up to $265,300 per year.

Exhibit E, E.4.1.5 Electric Power Benefits (Page 132 of 151):

E.4.1.5 Electric Power Benefits
Output from the RivGen® Power System will directly offset the use of diesel fuel for electrical generation, providing a stably priced alternative renewable energy source. The Project will also continue the community's efforts toward environmental sustainability by producing power with zero carbon emissions.

A successful commercial Project and corresponding decrease in local electricity rates would encourage both public and private facilities to increase the use of electric heat pumps in the future, potentially increasing peak demand and further increasing annual generation requirements.

---

[1] This amount is based on the average fuel cost for next ten years ($6.58 gallon) as reported by AEA (2013), plus the difference between 2014 actual cost ($7.96 gallon) and AEA (2013).

SCHEDULE B

Additional Information Request

General

Comment 1

The consultation record and reference material attached to the draft license application is substantial. Since this material is now in the record, you do not need to resubmit these documents with your final license application. However, any required plans, appendices, or new information (e.g., revised exhibits, recent consultation, etc.) pertinent to the proposed project should be included with your final application.

Response

So noted.

Comment 2

The consultation record does not indicate that you have consulted with federal or state park and recreation agencies. Please add the Alaska Region of the National Park Service and the Department of Natural Resources Division of Parks and Outdoor Recreation to your distribution list.

Response

IVC has corrected the consultation record to include the Alaska Region of the National Park Service and Department of Natural Resources Division of Parks and Outdoor Recreation. This information has been added to our distribution list in Exhibit E, Section E.5.0 and stakeholder list.

We note that the National Park Service was contacted during the licensing process and attach correspondence from Cassie Thomas, Program Analyst, Wild and Scenic River Specialist, Park Planning & Special Studies Division, Washington DC, and Alaska Coordinator, Hydropower Assistance Program, from January 25, January 26, and January 31, 2012 (attached). Ms. Thomas stated “Placement of the devices near Igiugig under a FERC pilot license appears to be unlikely to create unacceptable recreational or aesthetic impacts, provided the array is safely moored, tethered or anchored, and its location properly marked for navigational safety, as may be required by other agencies (e.g. Coast Guard).” When referencing the 2012 correspondence, Ms. Thomas reiterates, “My comments still stand, and none of our fisheries staff at Lake Clark or Katmai National Parks were concerned about the project's potential to affect park resources (Email correspondence to Monty Worthington and Nathan Johnson, Ocean Renewable Power, June 5, 2015).

Exhibit E

Navigation Safety Plan

Comment 3

On page SP-13 of the Navigation Plan, you indicate that the height of the device will be 12 feet. On page SP-10, you indicate that a variety of boats (i.e., fishing boats to barges) pass the project, with a potential draft depth of 5 feet. On page A-29, you indicate river depths range from 12 to 22 feet at the project site, and on page SP-13 you state that the river depths range from 15 to 20 feet. On page SP-13, you state that there will be at least 5 feet of water between the device and the water surface and that this is acceptable to the local waterway users. You propose to mark each device with three buoys and to mark shore-side exit of the power cable with signs.

Regardless of which minimum river depth is correct, it appears that there may not be enough depth to safely accommodate both the devices and larger vessel traffic during the low flow conditions. Further, the draft application and Navigation Plan do not provide sufficient information for our analysis of potential navigation conflicts. An additional purpose of the plan is to define steps to prevent entanglement with fishing gear and anchors, which is also not adequately described in the Navigation Plan.

Therefore, please provide the following:

(a) Please clarify the nearest locations to the project where boats could be expected to anchor, and whether larger craft will generally avoid anchoring or deploying gear near the proposed underwater devices. Please explain the basis of your answer.

Response

Boats do not typically anchor near the project site as the river is fast moving and would be an exceptionally challenging place for a vessel to anchor. Vessels in general do not anchor in the river but rather tie off to trees or bushes on shore or pull their anchors up on to the river bank. The nearest locations where vessels typically moor in this fashion are on the Northern bank of the river directly across from the "Fish and Game" boat landing in Igiugig, approximately 0.5 miles upstream from the project site.

(b) Please clarify the expected clearances between boats and the devices at high, medium and low flows and how your proposed measures safely mitigate navigational risks at lower water levels. For example, please explain why additional warning signs for boat traffic are not needed upstream or downstream of the devices, or how warning signs might be fitted to the buoys to warn mariners of the navigation hazard and precisely where such signs would be installed.

Response

Terrasond performed survey activities at potential hydrokinetic deployment locations, including Site 10 (RivGen® Power System location) in 2011 (included in Appendix C of the Draft Pilot License Application). Below is an excerpt from their report regarding establishment of site control:

> *For non-tidal water the vertical datum, should be selected such that at least 95% of the time the water is above this level. Ideally no single daily mean water level should ever fall more than about 0.2 meters below the datum level. Further, the water level datum for a river must recognize that the surface of the water is sloped. Therefore, a series of water levels must be measured along the many reaches of the river to determine an appropriate water surface level slope. Then the datum level is adjusted with respect to this slope along the course of the river. In this manner the water level datum will always appropriately reflect the state of the river during its usual low stages.*

The Terrasond datum established for Site 10, the location of the proposed RivGen® deployments, is estimated to be 16 ft. ORPC has used this conservative depth for planning purposes and navigation. The University of Washington, using the altimeter mode on a Nortek Signature instrument, measured the depth at the site as 5.5 meters (18.04 ft) in July 2015. Figure A-1 shows the proposed RivGen® device locations with the Terrasond datum water depths (95% of the time water is above the level depicted).

The assembled 2015 RivGen® device has a total height of 12.5 ft. From the bottom of the pontoon support structure to the top of the turbines is 11.5 ft. An electrical cabinet on top of the generator protrudes approximately 1 ft above the top of the turbines. The height of the commercial RivGen® device planned for this Project will not exceed 12 feet. Table A-1 below summarizes site water depths at various river stages and the corresponding navigational clearance over the commercial RivGen® device. Figure A-2 depicts various water stages over the device.

Table A-1. Kvichak River depth and navigational clearance

River Stage	Estimated Depth at Site (ft)	Navigational Clearance (ft) over RivGen® Device (12.0 ft high)
Terrasond Datum (95% of time water is above this level)	16.0	4.0
July 2015 measured depth	18.0	6.0
Mean Annual Low Water Height	18.0	6.0
Mean Annual High Water Height	22.0	10.0

The proposed RivGen® devices will be located in the deepest stretch of the Kvichak River, which should allow a minimum of 3 ft of navigational clearance over the device during the navigation season on the Kvichak River. It should be noted that shallower portions of the river both upstream and downstream of the deployment location prevent vessels with drafts greater than 3 ft from passing. Therefore a vessel with a draft over 3 ft encountering a deployed RivGen® device is highly unlikely. Furthermore, signs warning of the submerged turbine and electrical cable will be posted both upstream and downstream of the turbine on either side of the Kvichak River.

To further mitigate the potential of mariners encountering deployed RivGen® devices IVC has worked with ORPC to develop a detailed Notice to Mariners and Aviators informing of device presence and navigational clearance. This notice has been distributed throughout the Village, in local media and with navigational users to make them aware of the device presence.

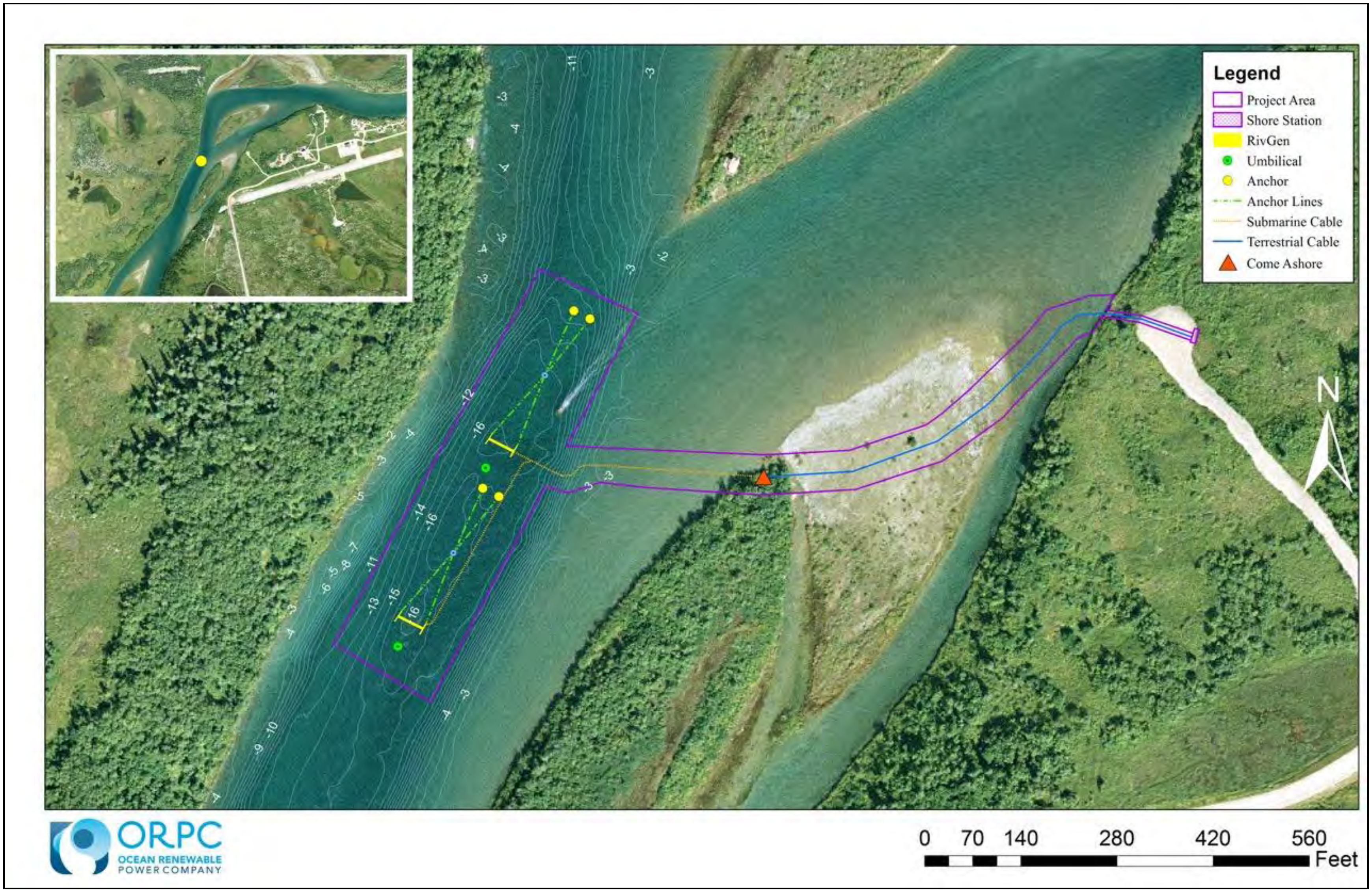


Figure A-1. Water depth at proposed RivGen® device locations. Based on Terrasond datum (95% of the time water is above the level depicted).

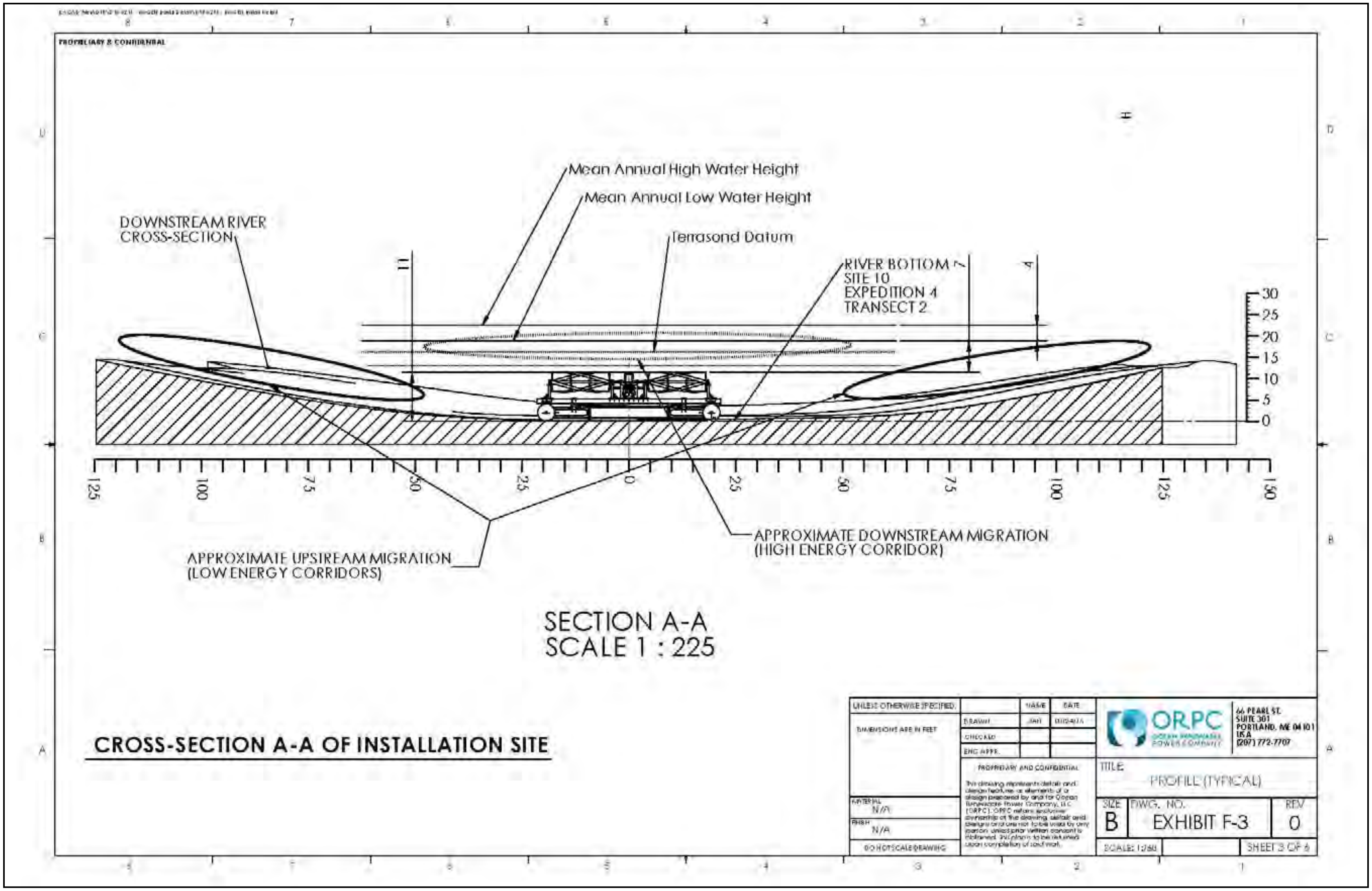


Figure 2. Cross-section of installation site

Comment 4

You indicate that floatplanes are known to use the river near Igiugig. Please indicate where floatplanes are known to land and take off from, in relation to the proposed project.

Response

In Exhibit E, Section E.3.2.1, it states "Float-equipped airplanes land on the river."

Float equipped airplanes land in the Kvichak River in the vicinity of the project site. The taxiways used include the river reach in which the project is located and the stretch of river around the bend and upstream of the project location. There is ample distance in the river reach occupied by the RivGen® device(s) for floatplanes to continue to use this stretch of river as a taxiway. A Notice to Mariner and Aviators will be sent out as well as directly contacting air charter companies that utilize this reach of the river to ensure they are aware of the presence of the RivGen® devices in the Project location in order to adjust their flight plan to safely land and take off in its vicinity. This approach was utilized during the demonstration phase of the project in 2014 and 2015 with no known adverse effects to aviation in the Project area.

*Figure A-3.*Areas of Kvichak River in the vicinity of the Project that are utilized as taxiways.

Comment 5

You state that a navigation safety plan was prepared for the Anchorage Waterways Division of the US Coast Guard for system testing in 2014. It is unclear how the navigation plan filed with the draft application compares with the one filed with the Coast Guard and whether the Coast Guard agrees with the provisions of your proposed navigation plan. Therefore, please consult the Coast Guard on your proposed plan. Allow the Coast Guard at least 30 days to file comments. In your response, please file documentation of the consultation with the Coast Guard, a copy of any comments you receive, and explain how you addressed any comments on the plan. If needed to address our concerns or those raised by the Coast Guard, please file a revised navigation plan.

Response

The Navigation Safety Plan included in the draft application was submitted to the U.S. Coast Guard on July 1, 2015 as directed by this additional information request. A follow up email was sent to the U.S. Coast Guard on August 3 requesting their input. In addition, a phone message was left on August 5, 2015 seeking their input. No response was received.

Recreation

Comment 6

Please clarify whether the 2013 sport fishing data provided applies to the entire river, the upper river, or another reach.

Response

The 2013 sportfishing included in the draft application is for the main stem of the Kvichak River and does not include other tributaries in the Kvichak River drainage area. The data is available on the following website: http://www.adfg.alaska.gov/sf/sportfishingsurvey/index.cfm?ADFG=area.results

Aesthetics

Comment 7

Photographs included with the draft license application suggest that the shore station may be highly visible to boaters and recreation users in the project area. Please clarify whether you propose any measures to reduce the visual effect of the shore station (e.g., vegetative screening, using colors that blend in with the natural surroundings, etc.)

Response

The Shore Station was sited, designed and installed in 2014. There have been no negative comments from the community regarding aesthetic impacts. IVC would prefer not to paint the Shore Station to blend in because it may result in the risk of getting bumped into as it is adjacent to a small turn around.

The area adjacent to the Shore Station has already been developed, and most of the shoreline which runs parallel to the runway has been developed with residential and commercial uses (i.e. bulk fuel farm, water treatment plant and tank, public boat landings, barge ramps, and private homes). The Shore Station has limited visibility from the river since the adjacent channel is too shallow to accommodate boats and vegetation exists between the Shore Station and riverbank.

Therefore, mitigation measures to minimize visual impacts such as vegetative barriers or natural paint colors are not proposed.

Seasonal Project Removal

Comment 8

The draft license application indicates that the generating devices will be removed during the winter. The application does not indicate where the generating devices would be stored when not deployed. Please describe how and where the devices will be stored when not deployed, including the storage location in relation to the project boundary. Additionally, there is no description of how the devices will be re-attached to the power cable when they are re-installed at the beginning of the generating season. Please provide this information.

Response

Project Operations

The RivGen® Power System(s) will only be scheduled to be removed during Lake Iliamna ice out periods as described in Exhibit E, page 50 of 151:

> The Kvichak River at the Project site is relatively debris and ice free for the majority of the year (TerraSond, 2011). However, break up of ice in Lake Iliamna and its subsequent movement through the Kvichak River poses a potential risk to the Project infrastructure. An operation and maintenance schedule therefore has been developed to remove the RivGen® device(s) from the Project prior to ice out. Based on historical records, significant ice out typically occurs in May. During this period the RivGen® device will be relocated to Igiugig near the existing concrete boat ramp for routine annual inspection and maintenance. IVC anticipates that the RivGen® devices will be removed annually May 1 and redeployed on June 15. An adaptive management process, in accordance with the Project Adaptive Management Plan (Appendix C), will be implemented to modify the annual maintenance period based on seasonal fluctuations in ice.
>
> When the RivGen® devices are removed for the ice out events the power cables will also be removed, the power cables will be redeployed and interconnected to the devices after the devices are reattached to their mooring systems, but before redeployment to the riverbed.

The proposed location for annual inspection and maintenance of the RivGen® devices is adjacent to the existing concrete boat ramp on Lake Iliamna in Igiugig as shown in Figure A-4. This location was used in 2014 and 2015 for assembly, launching and disassembly operations associated with RivGen® device deployments (Figure A-5). It also is easily accessible to other town facilities and barge shipments.

In the event that the Lake Iliamna location is not accessible due to ice the RivGen® device(s) will be staged on the northern tip of the unnamed island to the east of the Project site (Figure x). This also the location of the power and data cable come ashore and is accessible to the Shore Station at the end of the sportfish access trail.

Figure A-4. RivGen® Annual Inspection and Maintenance (I&M) locations

Figure A-5. RivGen staging on Lake Iliamna, July 2015.