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16. Abstract

Scour at bridge substructure units can cause undermining of footings and exposure of piles, which can lead to bridge failure. Monitoring of the streambed elevations around a scour critical bridge to identify whether or not scour is occurring during a high-flow event is critical. Working on or near the water may be dangerous during these events.

The study investigated various techniques to monitor bridge scour during high-flow events.

Sonar has been the leading technique when completing underwater investigations. Different sonar devices were compared: single-beam echo sounder, multi-beam echo sounder, and side-scan. Based on parameters of cost, water depths less than 30 feet, data retrieval, processing, and quality, a single-beam echo sounder, side-scan, and the post-processing software SARHawk, was recommended.

Multiple access techniques were assessed based on personnel safety, ease of deployment, and efficient mobilization. Research concluded that a remotely operated unmanned surface vessel (USV) can best complete the following:

- Operate in turbulent waters with high current near substructure units or debris
- Obtain depth readings in water 3 to 30 feet deep
- Transmit real-time images and data to shore station
- Deploy rapidly and transport easily

Several USVs on the market were compared by means of a rating system and equipment testing. The USVs were rated on parameters outlined in specification sheets, in-person testing, and cost. The rating system identified the company and model of USV recommended.

The USV from Hydronalix called Sonar EMILY, equipped with single-beam sonar for water depths, side-scan sonar to obtain images of substructure units below water, topside camera to view the underside of bridges and performance characteristics to operate in turbulent waters with high current near substructure units or debris. The purchase cost for the USV, data acquisition laptop, and running gear is approximately \$50,000.

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Monitor, bridge, scour, countermeasure, footing, pile, sonar, side scan, drone, unmanned surface vessel, Hydronalix, EMILY, underwater, remote

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Unmanned Surface Vessels for Bridge Scour Monitoring

**Research of sonar applications for monitoring bridge
scour and performance of mitigation methods**

By Ayres Associates Inc

Prepared for:

The Michigan Department of Transportation

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Unmanned Surface Vessels for Bridge Scour Monitoring Sonar

**Research of sonar applications for monitoring bridge scour and
performance of mitigation methods**



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Introduction

Scour is the process of swift water flow removing sedimentation away from the bridge substructure causing large holes to form. These scour holes can cause undermining of the footings or exposure of piles, ultimately leading to bridge failure. Figure 1 shows a scour hole at a circular pile. Scour is most prominent during high flows caused by snowmelt, rain storms, spring run-off or combinations thereof. The most susceptible bridges that may incur scour problems are marked scour critical. For each scour critical bridge, a plan of action is written to deal with scour related problems. Part of the plan is to monitor the streambed elevations around a scour critical bridge to identify if scour is occurring and the corresponding magnitude. To conduct monitoring at the optimum time, water depth measurements and corresponding streambed elevations are identified during a high flow event. Monitoring the amount of scour is a difficult task because excessive undermining occurs at high water flows but can be filled back in with sedimentation at low water flows. To accurately evaluate the severity of scour, bridge substructure units need to be inspected at high flow events. The major concern while inspecting at these times is safety of personnel and ability of equipment to operate under high flow conditions. Ideal situations and access techniques involve unmanned procedures.

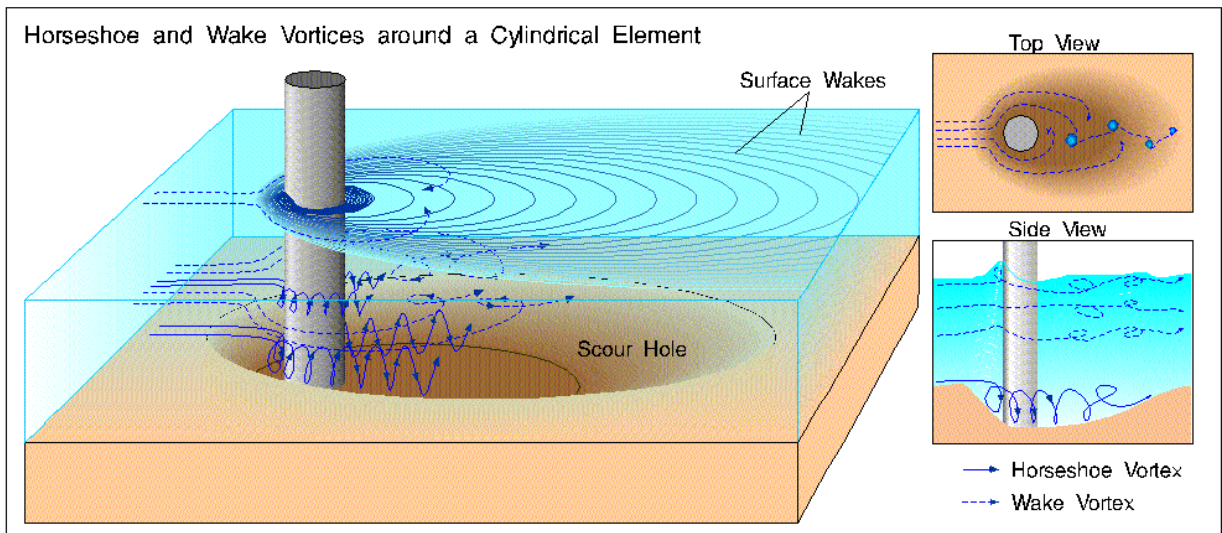


Figure 1: Scour Hole

Today, the most common manned and unmanned access techniques include the use of a bucket truck reaching over the edge of the bridge, a manned boat with survey equipment, or an unmanned remotely operated surface vessel, subsurface vessels and subsurface equipment. The access methods deploy acoustic or laser scanning equipment to survey the adjacent area underwater. These techniques were compared and evaluated to obtain a practice to evaluate bridge scour during high water flow the meet the Michigan Department of Transportation objectives.

Scope

Ayres Associates Inc is under contract with the Michigan Department of Transportation (MDOT) to research different techniques to monitor bridge scour.

The following objectives have been outlined by MDOT:

- Review and evaluate current and ongoing applicable research regarding scour monitoring.
- Identify procedure for objective research
- Evaluate different access techniques.
 - Bucket truck
 - Manned survey boat
 - Unmanned surface vessel
- Prepare list of equipment for a vessel that meets specific requirements set forth by the research panel.
 - Field test unmanned scour vessels for monitoring bridge scour
 - Produce hydrographic survey data to verify effectiveness of vessel
- Develop operating procedures for vessel and data processing for implementation of equipment at bridges and culverts.

The schedule for this project is in Appendix A.

Objective Research

MDOT mandates that scour critical bridges must be monitored to understand if scour is negatively affecting these bridges. Through awareness of industry practices, MDOT understands that equipment is available to obtain water surface elevations and water depth measurements to identify if scour is degrading a streambed at a scour critical bridge which could lead to catastrophic consequences.

To remain objective is to not be influenced by feelings, interpretations or prejudice rather base decisions on facts. The research conducted in this project is objective as it compares the facts of conditions and operation requirements known by MDOT to the facts of the performance of the equipment available to monitor scour. The research will conclude on equipment which performs under the conditions at scour critical bridges and satisfies the operation requirements of MDOT.

To identify the facts of the conditions at scour critical bridges and the operation requirements of MDOT an objective matrix was created by the research panel. The matrix is provided in Appendix B. The high priority requirements are below:

- Evaluate stream/river characteristics during storm events at bridge locations to determine real-time scour hole progression and thus determine when to close the bridge.
- Operable in turbulent waters, high current, and near substructure units or debris
- Bathymetric surveys of streambed and at bridge pier locations, typically 3 to 30 feet deep
- Topside camera to view underside of bridge
- Can be rapidly deployed

Various approaches to instrumentation gathering scour related data are available. The different approaches were outlined, and independent research was conducted by different research assistants. Upon the completion of the research of approaches, it was determined that a remotely controlled unmanned system would be most effective in meeting MDOT's requirements. Ayres Associates attended multiple site visits to see the capabilities of different unmanned vessels. The last step was to complete several iterations of training, in-house and with external clients, to evaluate the ease and use of the product. The instrumentation comparison and evaluation matrix is located in Appendix C.

Research was conducted by Ayres on available multi beam sonar systems. The research included online product evaluation and phone interviews with different vendors. A goal was implemented to complete all research independently so one investigator was not skewed by another investigator's discoveries. In addition, research was conducted by a variety of skill levels based on experience in the bridge scour field. Employee experience ranged from a water resource engineer who is proficient in hydrographic surveys, to a structural inspection staff member who has observed these deficiencies in the field, to a student intern with minor experience. Findings from all were then compiled and evaluated on one grading scale. It was from this scale that a vessel and list of equipment was chosen. The findings are summarized and rated in the USV comparison matrix in Appendix D.

There are disadvantages to online research only, such as, the lack of hands on evaluation. Observation of the machine in action gives a more true understanding for how it works. Site visits were conducted to multiple unmanned surface vendors from August 2017 to March 2019. During these site visits, a general questionnaire and data acquisition form was filled out regarding: ease of use, data collection, data processing, storage, machine capabilities, etc. Appendix E shows the field site visit forms.

The remaining step in this project's plan for objective research was to complete multiple iterations of training to evaluate the product. A user manual has been written to help facilitate this training. A total of three iterations are to be completed for Ayres and MDOT to be confident that any personnel with no prior knowledge could operate the vessel. A flow diagram of the training iteration process is shown in Figure 2.

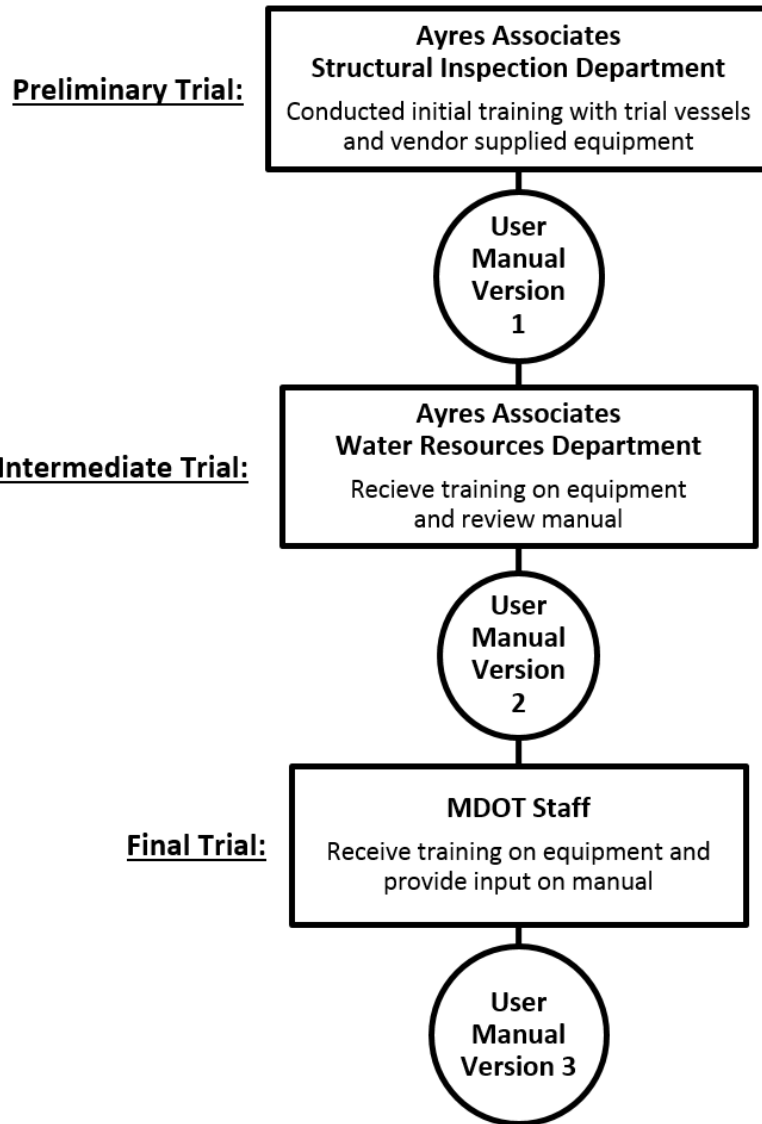


Figure 2: Vessel Operator Training Iteration Process

Ayres Associates Structural Inspection Department used bridge inspection experience and knowledge of accessing bridges to identify potential USVs. From research of USVs and field tests, a user manual was developed. Ayres Associates Water Resources Department then reviewed the manual and assisted with equipment demonstrations in preparation of training MDOT staff. Through training of MDOT staff, the final version of the User Manual including a list of equipment was generated.

Instrumentation

Modern hydrographic surveys utilize sonar for underwater investigation. Sonar is the act of measuring the time it takes for sound waves to travel in water. Many devices such as single and multi beam echo sounders, scanning sonar, and side scan emit sound waves through a transducer that are reflected off objects in the water. The sonar equipment works in conjunction with a Global Positioning System (GPS) to relay information to a data collection software. Locations of these objects and water depths result from data collected. Several sonar devices, data collection software programs, GPSs, and data acquisition laptops were researched through independent online research and conducting interviews with professionals and companies in the bathymetry survey industry.

Single Beam Sonar

Single beam sonar is the most common type of sonar and was the initial approach for hydrographic surveys. Single beam echo sounding emits one beam straight down through a single transducer and relies on the sound signal hitting the bed and reflecting back to the transducer. The degree at which a sound wave can be produced ranges from 3-30 degrees, depending on water depth.

Single beam echo sounders are easy to use and are relatively inexpensive. Due to their presence over the last 50 years, they have been engineered for the average person to use. They are ideal for obtaining very accurate water depths because the sound travels the shortest distance through the water column and reflects off a surface parallel with the transducer face. There is also no correction necessary for thermocline or water temperature. Shallow and narrow rivers have characteristics that require only a few passes and data points to map a hydrographic survey image. Post processing of data is made easy because there is no excess data produced and points are not laying on top of one another.

Depending on the quality and amount of data required, single beam echo sounders may not be able to efficiently cover large areas in great detail. For instance, different devices can obtain more data to a higher degree of accuracy at a faster rate.

Multi Beam Sonar

Current hydrographic surveys use multi beam sonar due to the advancement in accuracy and efficiency. Multi beam echo sounders are an evolution of single beam because they use anywhere from 128 to 512 transducers that emit sound waves all at different angles. The transducers can be oriented to form a swath ranging from 10-45 degrees. A plethora of accurate data points allows for a streambed to be mapped with only a few passes of the vessel. Depending on the device used, accuracy can be plotted to the centimeter.

A few disadvantages to using multi beam sonar are capital cost and data processing. Compared to single beam, a typical multi beam system will cost upwards of \$100,000. In addition to cost, the number of data points acquired can cause the post processing to be very difficult and time intensive. In shallow waters of 30 feet or less anticipated for this project, points may lay on top of one another due to the number of beams being transmitted and the small amount of surface area.

The following figures shows a visual representation of the swath and image obtained from single beam and multi beam echo sounders.

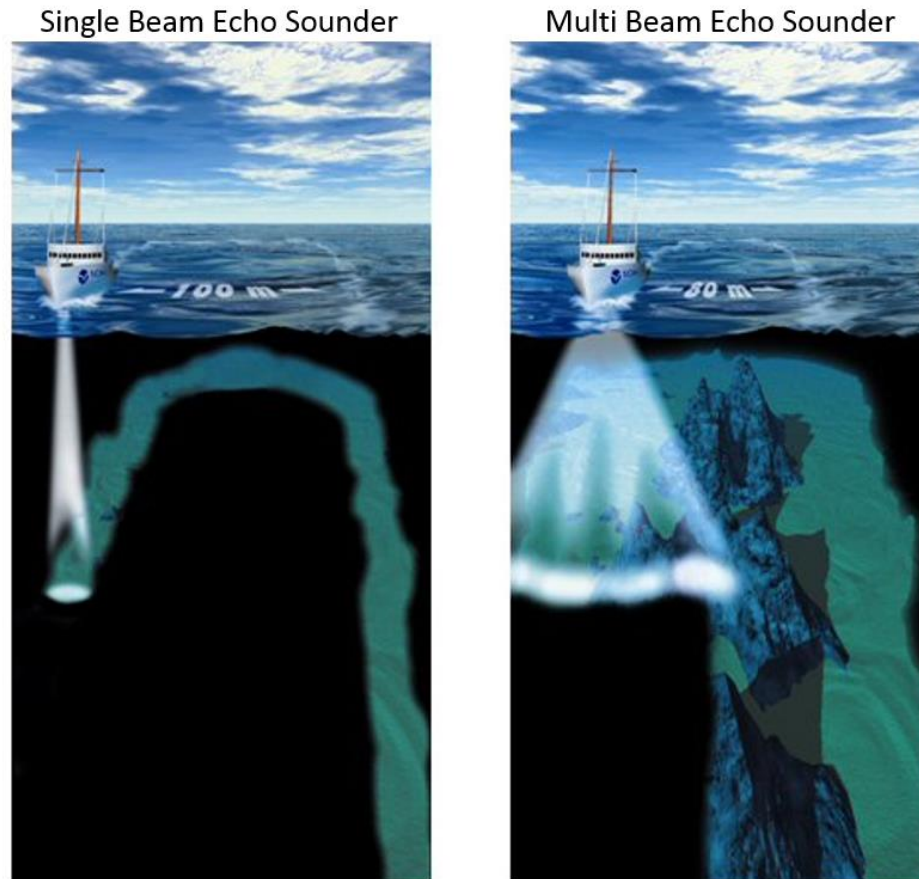


Figure 3: Single Beam versus Multi Beam Echo Sounders

With all the data acquired by multi beam sonar, there is potential some data is erroneous. Training and experience are required to understand what data is useful and erroneous. Filtering of data is best done in the office during processing of the hydro survey plots. Proficiency in filtering out erroneous data in hydro survey plots will take extensive experience and education.

Scanning Sonar

Scanning sonar produces a 2D or 3D underwater image. This can be done by either a single beam echo sounder or a multi beam echo sounder. The Blueview floor bed scanning system (Figure 4) is comprised of a sonar head mounted to a frame that is placed at the bottom of a river near a bridge pier. It collects data in a 3D form. The machine is moved to several locations around the pier to produce a complete image of the entire pier.



Figure 4: Stationary Blueview Scanning Sonar

Limitations were uncovered after interviewing professionals who currently use a Blueview system. The first and foremost is accessibility. The interviewee company utilizes a stationary mount that rests on the bottom of the riverbed. The instrumentation is susceptible to getting stuck due to debris and bed material. Timber debris is typically present at bridge pier noses and most likely during high flow events. A debris strike could endanger the equipment and the boat because of the cable connection between the two. In addition to debris, the bed material is a factor. The mount could sink into a sandy bed material. Another downfall to using a stationary scanning system is the requirement of personnel on the boat. As previously discussed, safety is the number one concern and having personnel on the water during high flow events is putting their safety at risk.

Side Scan

Side scan has the same principle as the stationary Blueview scanning sonar, however, it is attached to the vessel itself. The image produced in 2D or 3D provides more of an elevation view of the streambed banks or bridge piers. The 3D side scan is an excellent method of surveying deeper rivers where the boat drifts down the channel centerline with the current and the side scan beams travel bank to bank.

Figure 5 shows a raw 2D side scan image of a hydro facility. The image depicts a timber cofferdam from the logging era (upper middle), obscuring air bubbles and leaf litter (upper right), concrete piers (bottom), and upstream face of steel tainter gates (very bright lines in lower left).

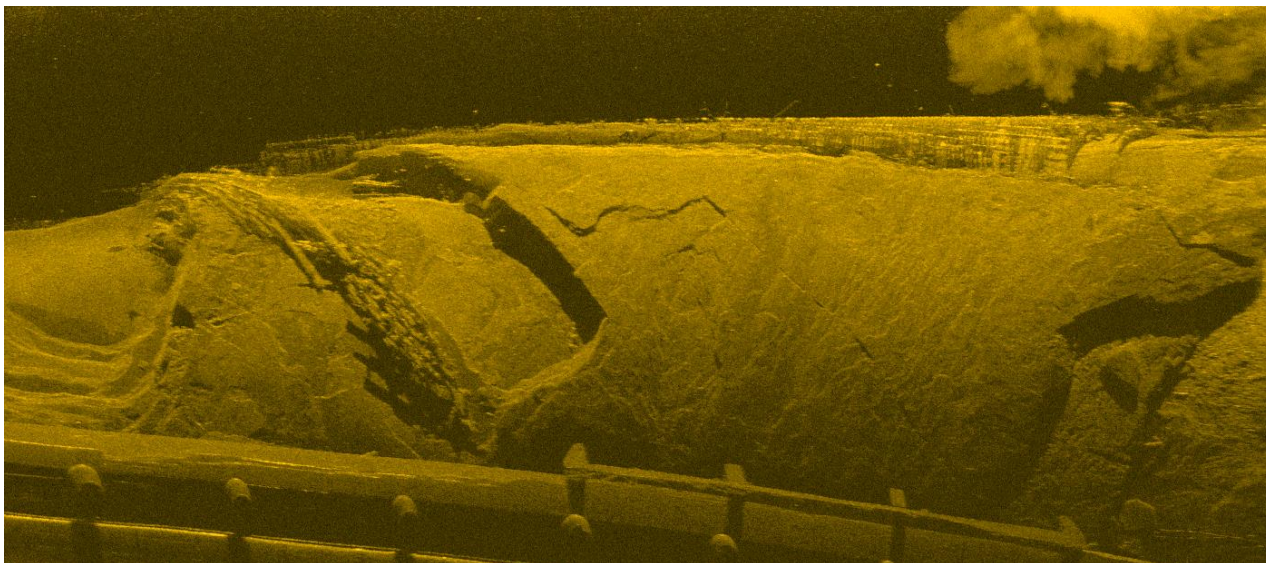


Figure 5: Raw 2D Side Scan Image

Some disadvantages to the side scan is the gap of data directly under the unit. Data under the boat is of poor quality because of the angle of incidence. Typically, the beams are pointed outward to capture the banks rather than straight down. Another concerning factor in shallow water is the possibility of hitting debris. The side scan must be submerged in the water and therefore limits how shallow the water can be to complete the survey. A downfall to utilizing a photograph, such as the one shown above, is the absent scale to quantify deficiencies.

Global Positioning System (GPS)

The sonar devices and data collection software require a GPS to transmit the location of the hydro survey system to the data collection software. A GPS device and GPS receiver work together to calculate exact locations. The GPS device generates the locations of satellites, and the receiver calculates the device's location based on the locations of three satellites provided by the device. All the information collected and calculated then can be displayed electronically. The GPS is important in order to ensure the data collected represents an accurate location. The more advanced GPS units that are used for hydro surveys output data

Data Acquisition Laptop

A computer with data processing software installed is necessary for data acquisition in the field. The sonar systems and GPS transmit information to the data collection software, and the computer stores the information so it can be post-processed and analyzed off-site. There are devices where a GPS has been integrated into a computer; however, the useful life of a GPS is greater than a computer since it has better endurance against the environment. Thus, in most hydrographic equipment setups, the two devices are kept independent of each other to eliminate purchasing both each time a combined device fails.

Accurate data acquisition relies on the choreographed process of vessel mobilization, gathering location data from GPS and water depth from the sonar unit. To reduce errors in the process, slow movements on flat water surfaces without obstruction to GPS satellites are required. Under the conditions MDOT expects to monitor bridge scour, it is likely that the water surface is not flat rather turbulent. For bridges with low vertical clearance, the GPS signal may be blocked. Therefore, the data acquisition system will need to clearly display real time water depths when the operator knows the location of the sonar even if GPS does not.

Data Processing Software

The industry standard for hydrographic survey is the software Hypack. It is widely used by academic, dredging, federal navigation, private hydro survey, and marine contractor representatives. Hypack satisfies the International Hydrographic Organization (IHO) standard requirements whereas other processing software may not meet the end user accuracy needs. Due to the speed of processing, Hypack can collect, monitor, process, and plot data internally and eliminate the need for multiple programs.

The user interface anticipates the issues faced by hydrographic surveyors: multiple instruments arranged on a highly mobile platform, accuracy and uncertainty limits, and file size. Hypack allows real-time monitoring of where survey points have been collected, how good the data is, and what areas need further investigation. If the data collected does not meet the design intent or purpose, real-time adjustments can be made to field survey techniques. This eliminates the need to take data blindly or downloading and processing data back at the office without first checking it in the field. The same software used to monitor data collection and quality in the field is also able to filter points, adjust incorrect field assumptions such as; water temperature profile, offset, and latency time, and re-process the data in the office to yield better accuracy. If a post-processing position correction is available, higher accuracy position data in the office can replace lesser quality field data. Hypack allows uncertainty computations (CUBE), filtering of data (reduction of points, averaging of nearby points, viewing point clouds, editing data points), and export to multiple other end use plotting programs.

To maintain accuracy, errors when collecting field data must be understood and monitored. For single beam data, the beam travels vertically so the depth error of any one measurement is related to the cosine of the angle error off vertical. Since most single beam surveys are completed looking downward on areas of relatively flat terrain, the vertical error is more detrimental than the horizontal error. For example, if the composite, meaning pitch and roll, angle error off vertical is 5 degrees, the depth reading will have an error of -0.07 feet in 20 feet. The horizontal error would be 1.8 feet in 20 feet of water, which may be considered acceptable if the survey is just monitoring general bridge scour. For multi beam data, up to 512 beams are sent at angles varying from 0 to 90 degrees off vertical. Small changes in position and angle error are extremely damaging to data quality. Using the above example, a 5 degree composite angle error in 20 feet of water for a beam at 45 degrees off vertical will introduce a vertical depth error of 1.3 feet (18 times the error of single beam equipment). If each of the 512 beams are offset 0.25 degrees from each other, the composite angle error must be less than 0.125 degrees to keep overlapping survey swaths from yielding points from one beam overlaid on a neighboring beam's points. In short, multi beam surveys must be able to resolve heave, pitch, roll, heading, and position to accuracies of 10 to 20 times better than single beam surveys just to yield the same data accuracy as a single beam survey.

Post processing speeds and data storage differ greatly between single beam data and multi beam data. Single beam data sets can be as simple as ascii text files less than a megabyte in size per hour of survey time. The key parameters with single beam are water surface (must be measured to accuracy better than transducer sounding accuracy), position of sounder (must be measured to accuracy better than point spacing), and transducer measurement (both draft of transducer face and depth to bed). For sounders that are integrated with a global positioning unit, Hypack may not be necessary to collect data. However, Hypack does allow real-time monitoring of where data was collected, the quality of data collected, and what underwater features might need more dense data to define for the survey intent. Multi beam data is far too complex to collect without a compilation, monitoring, and post-processing software program like Hypack. Data from 256 to 512 beams may arrive at the computer 10 to 20 times per second. Data from the real time kinetic survey system, compass, and motion sensor must arrive at the computer at speeds necessary to achieve the desired measurement position accuracy. Because the multi beam unit is underwater, the boat is rotating about a neutral axis elsewhere, the survey system is often high above water, the heading system is often as far fore and aft as possible, and the motion sensor is located in the bottom of the boat – all of these instruments must have their data corrected for the same latency time to the same axis and orientation as the multi beam soundings. Hypack computes the vertical, horizontal, and angular offset for each instrument and each beam for each data point at each point in time and presents the viewer with a real-time view of data. Accuracies that are worse than 0.5% in any one subsystem can prevent multi beam data from being useful to the end user. Therefore, the processing speeds and data storage required for multi beam data are 100 to 1000 times larger than those required for single beam data.

The amount of time required to conduct a survey and post process the data using single beam versus multi beam should be considered. The following example is based off a hydrographic surveyors' discussion at a Hypack conference. The typical bridge to be surveyed is three spans in water deeper than 8 feet. The table below shows the different tasks and amount of time required to complete the task in hours. As shown, using single beam would limit the time required to survey a bridge to half that of using multi beam.

Table 1: Survey Time Example for a Single Bridge Pier

Office		Single Beam	Multi Beam
Project Set Up:	Geospatial, planned lines, background images, added matrices, volume bounds, etc.	0.5	1
Data Preparation:	Filtering and quality control of data	0.5	4
Analyzing Data:	Creating contour lines	1	2
Plotting:	Hard copy and PDF document	1	1
Field			
Set up:	Equipment assembly, functionality tests, test measurements	0.5	1
Survey:	Acquiring data around bridge	1	2
Take down:	Data check and storage, equipment disassembly	0.5	1
Total Hours:		5	12

Result

The main instrumentation necessary to perform a thorough hydrographic analysis include: an echo sounder, side scan, data processing software, global positioning system (GPS), and computer. This combination of equipment can acquire a high volume of data. High volumes of data require extensive computer power to store and then process the data. The probability of acquiring erroneous data increases as more data is acquired. In water depths less than 30 feet as anticipated on this project, a multi beam echo sounder will gather more data than a single beam echo sounder but also gathers duplicate or erroneous points. Then filtering of the data will be required during post processing by an educated and experienced operator. Time for surveying with a multi beam echo sounder is greater than that for a single beam echo sounder. In summary, the benefits of a multi beam echo sounder do not outweigh the simplicity of a single beam echo sounder. To meet the objective of ease of use and rapid deployment, instrumentation including a single beam echo sounder, side scan, and GPS is recommended. The simplest and most compact design of the instrumentation will have the least impact on payload capacity of the access method.

Access Methods

In order to gain access to sites during storm events, three different approaches were evaluated and compared. The first is the under bridge inspection vehicle that reaches over the side of the bridge rail and down to the water surface. From this location, inspectors could use simple devices such as graduated probe rods or advanced devices such as tethered sonar devices to obtain underwater data. The second method of access involves manned vessels equipped with sonar that can be piloted under the bridge. The last method researched is the use of unmanned surface vessels that can be operated from the shore or bridge deck. The following approach methods were assessed in order to best fit the needs of the Michigan DOT.

Under Bridge Inspection Vehicle

The method of using under bridge inspection vehicle was evaluated because it has been a main method of access for structural inspection. Given the vehicle is in current operation by the Michigan DOT, it requires minimal training and can be deployed at low cost. The original thought behind this method is for inspectors to park the truck on the bridge above the pier during high water events and then be lowered down near the water surface. At this point, inspectors could evaluate underwater deficiencies with either a rod or a tethered surface vessel.



Figure 6: Under Bridge Inspection Vehicle

Disadvantages to this method include safety, ease of access, and inspection efficiency. Safety is the priority when inspecting bridges. Small local bridges, typically most susceptible to undermining, may be load posted and, therefore, a truck of this nature cannot be safely deployed due to the gross weight exceeding the structural capacity. If the structure is not posted and the truck can be deployed; the safety of the personnel in the bucket can be compromised due to fast moving current and heavy debris. In addition, the location of the truck on the bridge deck is of concern. If a pier is under investigation of being undermined, a heavy bucket truck parked on the edge of the bridge deck will cause high forces to be applied directly over the undermining which could cause more damage. Ease of access is considered because the bucket will only have access to one side of the pier at a time. The boom arms and/or truck will require repositioning before inspecting the other pier face. When using a tether device, inspection efficiency may be reduced due to the current dictating of the direction of data collection. For instance, the device would float with the current downstream while collecting data. Then, the inspector would drag the device upstream in order to make another pass downstream. Depending on the current speed and location of the bucket, a thorough inspection may require multiple passes. While it is possible to

automate the paying out and retrieval of the tag line between the tethered USV and the under bridge inspection vehicle bucket, generally this method is labor intensive to get this system in place to collect hydrographic survey data.



Figure 7: Tethered USV

Manned Vessel

Manned vessels can be comprised of inflatable, aluminum, or wood boats that range from 10 feet to 25 feet in length.

There are many advantages of using a manned vessel. First, the size of boat plays a major role in the data collection. For instance, storage room on the boat is ideal for more batteries, generators, and larger equipment. A manned boat is typically more stable and therefore less susceptible to heave, pitch, and roll movement so the data collected in moving water and inclement weather conditions generally has less “noise” causing the data to be cleaner in comparison to other methods. Moreover, manned boats sit high in the water and can adhere to the requirements of long radio antennas. Many manned boats can be outfitted with tilt-head multi beam units and deeper mounted units to avoid wave and surface debris interference.

Along with advantages, there are also many disadvantages to using a manned vessel. The first and most concerning is safety. The ideal time to survey scour is during high water flows which is also the most dangerous. Swift current and debris could cause the boat to tip or be pushed into the pier causing problematic scenarios. In addition to safety, mobilization is also an issue for operators. Some boats may require a trailer to transport it. If a trailer is needed, then a boat launch will also be needed which affects accessibility. Launching a boat may not be the fastest and safest task when the boat launch is impacted by a high flow event.

Examples of shallow water manned vessels are shown in Figures 8 and 9.



Figure 8: Manned Vessel



Figure 9: Inflatable Manned Vessel with Gasoline Motor

Both the manned vessel and under bridge inspection vehicle methods have difficulty accessing the bridge underside during a high flow event. Smaller structures may not have enough vertical space between the water surface and the superstructure low chord for a bucket or boat to access underneath the bridge. Figure 10 illustrates the lack of access under bridges during highwater events.



Figure 10: Minimal clearance between highwater surface and superstructure low chord

Unmanned Surface Vessel (USV)

Unmanned surface vessels are remotely operated vehicles that have been engineered to complete bathymetric surveys like that of a manned boat equipped with sonar instrumentation. Typical USV dimensions range from 1-3 feet wide by 4-6 feet long by 1-2 feet high. The hull shape is comprised of a catamaran style shown in Figure 11 or mono hull style shown in Figure 12. Payload platforms allow for different instruments to be attached directly to the machine.



Figure 11: Catamaran Type USV



Figure 12: Mono Hull Type USV

Unmanned surface vessels offer a plethora of advantages to completing underwater investigation. The first and most heavily weighed is safety. A remotely operated machine eliminates the need to have personnel on the water. This is crucial during high currents or when there is excessive debris in the water. The controller can remain safely on the shore or on the bridge deck.

Accessibility is another leading factor when using USVs. Due to the size and weight, these machines can be lifted and carried to the water by one or two people. The need for a boat launch can be eliminated as USVs can be loaded into the water from shore or dock directly at the bridge site. They also eliminate the larger equipment required by the other methods. With only a few feet of vertical clearance, these USVs can be deployed at smaller bridges that may experience high water flows near the superstructure low chord.

Site visit time can be reduced due to the elimination of boat launching, travel time, and set-up/break down times. The USV requires a one-time set up with the different sonar equipment. Once the USV is set up with the required instrumentation, it can remain setup during the inspection, while in transit to another site, and when in storage.

Limiting factors of USVs are the technology and cost. The generation of autonomous vehicles is in its beginning stages and have many software, data transmission, battery and reliability concerns to resolve. In addition, the cost is proportional to the quality of instrumentation accuracy; if one increases, so will the other.

To compare USVs that are currently available on the market, Ayres generated a matrix and rating scale. The matrix is populated with criteria to be compared, measured and evaluated. Data to fill the table was obtained from specification sheets, interviewing the company, and observing the USV in person. For each criteria a scale of effectiveness was generated to score the criteria. The vessel with the highest score will be the one researched further. The matrix is in Appendix D.

Bridge Location

Michigan is a large state. From Detroit to Houghton takes a day of driving. Figure 13 outlines the state of Michigan and the Department of Transportation’s seven regions. The access method chosen will need to be stationed at the various regions throughout the State not in one centralized location so that the system can be deployed in hours.

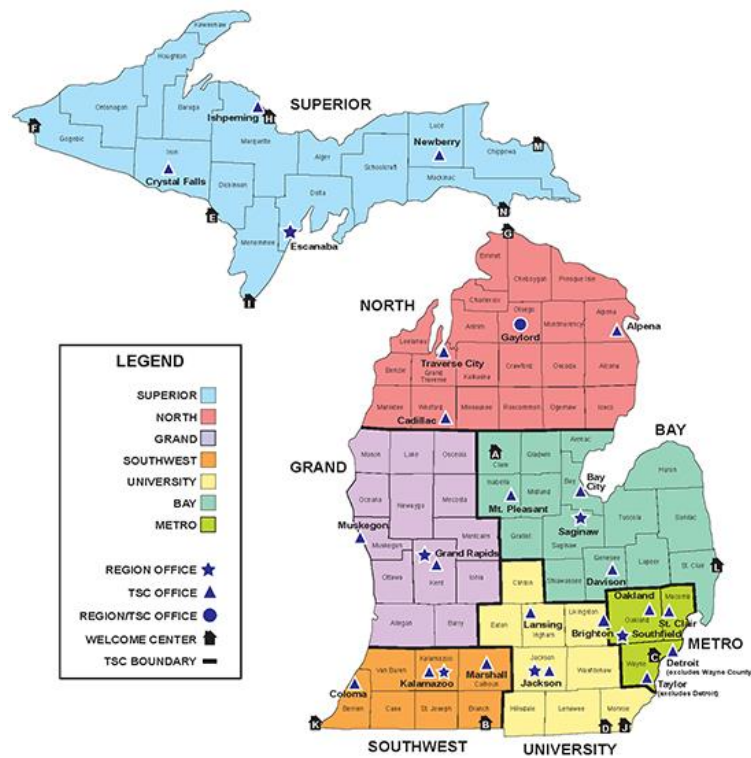


Figure 13 Michigan DOT Regions

Some Regions have numerous scour critical bridges that will be monitored using the chosen system. While a route between bridges will be determined and hence an order will be given to the bridges, no other priority system exists. All the scour critical bridges will need to be assessed. The chosen system will need to be portable and deployable with no more than 2 staff. Mobility is key to efficient operation of the inspection team monitoring scour critical bridges. As of May 2019, Figure 14 shows the number of scour critical bridges maintained by MDOT throughout the state and Figure 15 shows the scour critical bridges maintained by MDOT in the Bay Region alone.

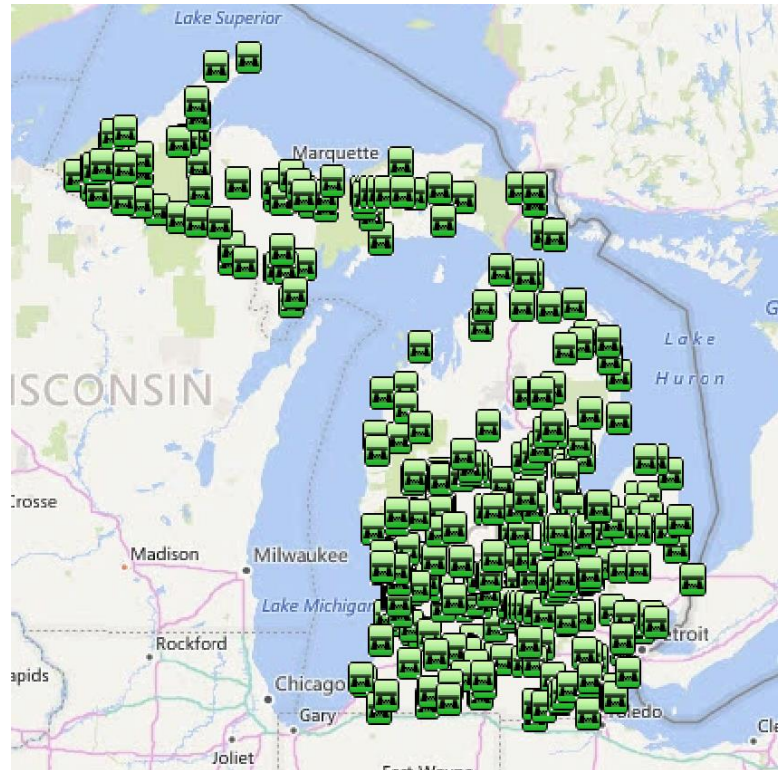


Figure 14 MDOT Scour Critical Bridges

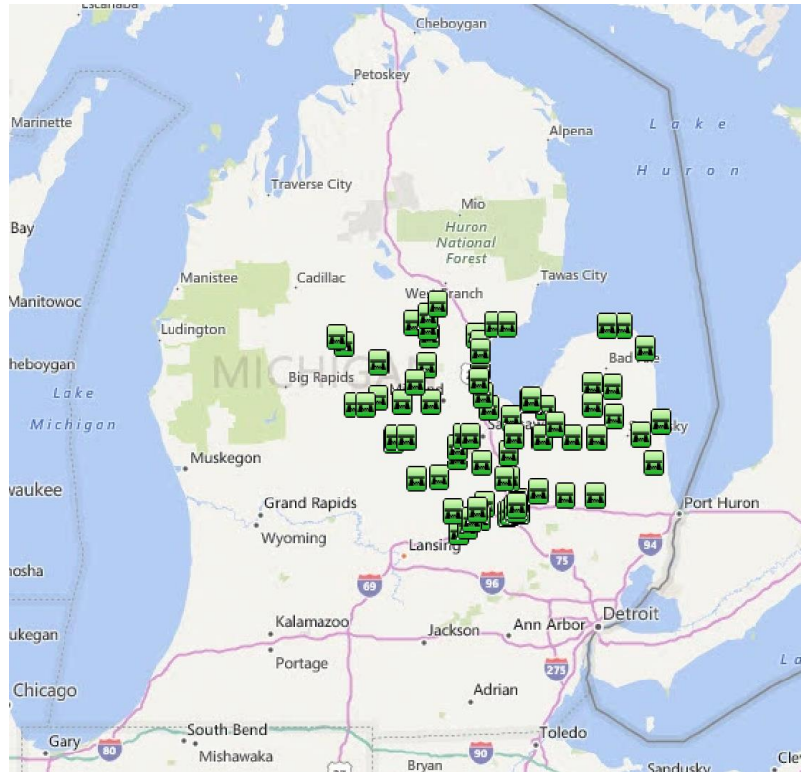


Figure 15 MDOT Bay Region Scour Critical Bridges

An access method that can be deployed within hours in multiple Regions is a requirement. By supplying several USVs that fit within MDOT’s financial budget, they can be located throughout the state to fulfill the coverage and deployment requirements.

Implementation

Monitoring scour critical bridges is the top priority of this research project. However, it should not be the only requirement. Other uses were considered for the available access methods. Other uses include but are not limited to observing performance of scour mitigation methods, inspection of culverts, inspection of bridges with limited clearance between the low chord and water surface, supplementing if not replacing underwater inspections and another tool in the inspection team’s tool box for routine inspections.

For culvert inspection, a USV with external camera can be a viable access method inside the culvert and bridges with shallow freeboard. From Ayres Associates experience with remotely operated vehicles in culverts, direct line of sight between camera transmitter and receiver are required to obtain a live first person view from the USV. It may also be prudent to have a tag line to the USV for retrieval from inside a culvert or sand bars around bridges.

For supplementing underwater inspections or potential replacement of divers, the access method will need to provide an image of the structure below water. A USV with side scan sonar can provide this image during a high water or high flow event. For images with greater detail of vertical surfaces, multi beam or scanning sonars could be deployed with the USV. While the imaging may not replace divers for underwater inspections at the 60-month frequency, a USV with side scan sonar may prove to be a cost-effective means of providing interim inspection of the underwater portion of a structure during or shortly after a high flow event. To expand the implementation of a USV to include underwater inspection to some degree, it should be outfitted with side scan sonar.

Modernization

From Ayres Associates experience and discussions with the research panel, two processes of modernization are possible. One process is to assemble pieces of equipment that can be replaced individually as more advanced technology becomes available. This requires operators of the equipment to have knowledge and technical capacity to remove and replace the equipment to be upgraded. As time passes, transfer of that knowledge and experience are required as operators depart.

Another process is to acquire equipment from a reputable manufacture that can provide replacement parts and upgrades. In the USV selection matrix located in Appendix D, company reputation measured by years in business is a rating factor.

Echo sounders and side scan sonar have useful life for the reasonably foreseeable future as they have been used for decades.

Result

After gathering information and comparing each access approach method, Ayres Associates believes that the Michigan DOT's needs will best be served by means of an unmanned surface vessel.

Several advantages for using USVs were previously mentioned. However, safety is the main concern when discussing bridge inspection during high flow events. Ayres believes that eliminating the need for personnel on the water is the controlling factor which the USV fulfills.

Instrumentation Selection

When it was determined that the best access method was a USV, several models from various companies were researched, and the sonar devices were compared to determine the best USV model that was already equipped with sonar. The sonar devices were determined by comparing the different instrumentation, their capabilities, and the typical bridge site characteristics that will be surveyed. Each piece of equipment was analyzed using a rating system which is in Appendix C. The categories in the rating system were selected to objectively compare the instrumentation while achieving MDOT's goals. Each category was weighted based on importance; categories with higher importance were worth more points than categories of lesser importance. Under each table, the categories are described briefly and point distinctions are provided. The various instrument models were given points based on their ability in each category. The total points for each model were summed and divided by the possible amount of points from all the categories then multiplied by 100 to compare each brand as a percent. The largest percent(s) is(are) highlighted in yellow for each table.

Echo Sounder

The echo sounder brands compared using the rating system were Seafloor Systems, R2Sonic, Teledyne, Echologger, CEE HydroSystems, Lowrance and Humminbird. Seafloor Systems featured the largest variety of echo sounders in comparison to Deep Ocean and Clearpath. The comparison matrix included the following categories: type, Hypack compatibility, GPS comparison, depth range, operating range, resolution, serviceability, and cost. From attribute ranking and field testing the echo sounder from the Helix unit by Humminbird meets the MDOT objectives.

Side Scan

Teledyne and Trittech, Lowrance and Humminbird were the side scan brands compared in the rating analysis. The categories used in the rating process were operating range, size, weight, depth rating, supported software programs, visibility, horizontal beam width, and cost. The side scan sonar with the best rating is Humminbird.

Global Positioning System (GPS)

Trimble, Lowrance, Humminbird, and Leica are a few brands that provide GPS units. Trimble is the main manufacturer of GPS devices and GPS receivers for the purpose of hydro survey data collection. It has various distributors throughout the world and in the state of Michigan.

Device type, GNSS Accuracy, environmental, durability, screen size and type, operating time, device connectivity, real-time corrections, processor, data storage, and cost were the categories used to research the models of GPS for the hydro survey data collection. The GPS affects the accuracy of the data and allows the operator to make real-time adjustments to the scour vessel's path if any data is missed; thus, GNSS accuracy was weighted significantly in comparison to the other categories.

Whereas the inspection team monitoring bridges for scour during high flow events does not have the objective of obtaining survey grade data, the GPS provided in a commercially available echo sounder used for fishing is an acceptable conclusion based on cost, accuracy, ease of use and size of equipment.

The GPS provided by the Humminbird device is acceptable.

Data Acquisition Laptop

The computer brands analyzed in the rating system include: Dell, Getac, and Panasonic. Categories used to compare the different brands were durability, hard drive, RAM, graphics card, display size, screen, keyboard, weight, and cost. Based on the rating system, the Latitude 7424 Rugged Laptop is the best option.

Data Processing Software

Hydrographic survey software packages collect and process data used to model terrain characteristics. Data is collected in real time producing an image of the stream bottom or scour hole. There are several hydrographic survey software packages on the market; a few include Hypack, SAR Hawk, EIVA, QINSy, Hydromagic, and Teledyne PDS. For the matrix comparison of the field software, the categories used include scope requirements, ease of use, compatibility with sonar instruments and other software, cost, and user-friendly interface.

From initial ratings and Ayres Associates experience, Hypack is known to be software of choice. However, during demonstrations and working with a computer running Hypack, communication between the echo sounder and GPS were troublesome. Consequently, Hypack received a low ease of use rating.

During testing of the Sonar EMILY by Hydronalix, the data recorded by the Humminbird unit was processed in the SAR Hawk software. SAR Hawk met the objective of ease of use and provided the images desired by MDOT.

Result

Various instruments are available to gather hydro survey data. To meet MDOT's objectives of ease of use and rapid deployment, a simple all-in-one instrument provides the most value. The sonar and GPS of commercially available fish finders meet these objectives.

MDOT and Ayres Associates have had some success with Lowrance products. From this success, a Lowrance unit was chosen by Ayres Associates for the RC Boat.

Hydronalix and SARHawk both use Humminbird products. The performance of the Humminbird Helix series of sonar and GPS meet MDOT's need for a simple all-in-one instrument and the objectives of the research. Hydronalix, SARHawk and Hummingbird all provide support for Helix instrumentation.

Ayres Associates believes that the Humminbird Helix provided with the Sonar EMILY will meet MDOT's objectives.

USV Selection

Similar to the comparison matrices created for the sonar instrumentation, one was created for the USV and is located in Appendix D. The comparison matrix includes factors that were necessary to meet MDOT's expectations for the USV. These factors included: hull shape, speed, battery life and chemistry, weight, payload capacity, boat clearance, instrumentation availability, demonstration, cost, and company-based factors. The data in the comparison matrix was collected from the company websites and discussions with company representatives. Based on the matrix, the top models were selected and scheduled for on-site demonstrations. Each site visit was summarized in a memorandum located in Appendix E. The purpose of the site visits was to determine if the advertised data accurately reflected the equipment's performance. Also, the ease of set-up and operation was an important aspect of the demonstrations.

Initially, research was focused on finding a vessel that was already equipped with the best sonar instruments as determined from the instrumentation section. Deep Ocean Engineering and SeaFloor Systems were selected as the top models based on the sonar instruments and advertised performance of the vessel. However, the vessels did not function as intended during the demonstrations. While researching for additional USVs, Ayres Associates assembled a vessel to create a more simplified approach to data collection than the initial models. The companies Martac and Hydronalix were discovered later based on the additional research. The following discussion provides reasoning behind the model selection.

Deep Ocean Engineering

Deep Ocean Engineering had three USV models that could potentially be used for scour analysis: I-980, I-1650, and H-1750. Model I-980 was eliminated first as it could not be equipped with sonar. The company recommended model I-1650 for use in scour analysis as it was already set up for bathymetry and lake and river surveys. Model I-1650 is a carbon fiber reinforced mono hull that measures 5.4 feet long and weighs 48 pounds by itself.

The demonstration of the model I-1650 occurred in a test tank in San Jose, California. The staff had difficulties setting up the boat and no sonar equipment was set up. USVs were fairly new to the company as they have only been developing them for 3 years. The model did not seem ready for on-site use based on the demonstration.

SeaFloor Systems

The SeaFloor Systems' models Echoboat and HyDrone-RCV seemed they would function best in scour analysis based on preliminary research. Of the two models, SeaFloor Systems recommended the Echoboat since it had better instrumentation capabilities than the HyDrone-RCV. The Echoboat has a mono hull and built from a high-density polyethylene (HDPE) plastic. The boat is about 5.5 feet long and weighs approximately 120 pounds when loaded with sonar equipment.

During the site visit in Falmouth, Massachusetts, the Echoboat performed well, and the data was collected with no issues. The day of the demonstration was rainy, but there was little current. To determine how well the Echoboat would operate during high flow events, another site demonstration was scheduled in Michigan.

The second demonstration was in Niles, MI. The St. Joseph River at the bridge site selected flowed at a current around five feet per second which simulated a high flow event. The Echoboat did not perform well during the second site demonstration. There were several difficulties setting up the equipment, and after it was assembled, it did not perform well in the current. The sonar equipment on the Echoboat provided water depths as desired. Durability was questioned when the antennae broke effectively ending the demonstration.

Ayres Associates

In an attempt to minimize costs and create a boat that functioned as intended, Ayres Associates equipped a remote control (RC) boat with basic sonar equipment. The boat is a carbon fiber mono hull and weighs 20 pounds with the sonar equipment. The RC boat uses a more simplified approach to data collection than the Deep Ocean Engineering and SeaFloor models. The sonar equipment consists of a GPS unit and transducer commonly used as a fish finder whereas the other models have a GPS unit and transducers typically used for bathymetric surveys. The RC Boat is depicted in Figure 16. A User Manual was developed as a precursor to the manual to be provided for the selected vessel.



Figure 16: Prototype USV

The RC boat is light weight and can be easily deployed into the water. Preparing the boat for data collection on-site takes 20 minutes. The Li-Po batteries must be charged prior to arriving on-site. The RC boat is equipped with a single beam echo sounder and maneuvers well in the water. However, with the addition of a side scan sonar at the rear of the vessel, the turning radius and maneuverability of the boat decreased. No reverse propulsion also limits maneuverability. The depth sounder can connect to a tablet to view data in real-time, and with a wi-fi extender, the boat can navigate further without losing connection between the two devices. The initial attempt at extending the wi-fi network on a bridge with a repeater was not successful. Further development of an extended wi-fi network at a bridge was not researched. The run time of one charge on the battery typically lasts from 20 to 30 minutes. Compared to the Sonar EMILY, the cost of the RC boat is approximately 20% the cost of the Sonar EMILY.

Martac

The models of USVs that could potentially be used for scour analysis were the MANTA T6, T8, and T12. Martac recommended MANTA T12 for multi-beam sonar as it was already equipped for it whereas the smaller models were not. The MANTA T12 is a 12-foot long carbon fiber catamaran boat which weighs approximately 350 pounds when fully equipped with sonar.

The site visit for Martac occurred at Bagnell Dam, Missouri. Martac was contracted by Ameren to collect the hydro survey data at the Bagnell Dam. The MANTA T12 performed well and was able to collect all the data with minor complications. The original battery lasted the entire survey. There was little current during this site visit as only the upstream side of the dam was completed and the downstream surveying was rescheduled. Thus, to determine the boat's capabilities in high flow flows, the details of the downstream surveying were collected from Ameren. According to Ameren, Martac made modifications to the MANTA T12 based on the upstream complications, and it performed well in the faster current. Despite the successful performance of the MANTA T12, the size and weight of the MANTA T12 requires a trailer for transportation. A smaller MANTA models would better meet MDOT's objectives as they weigh less and could fit in the back of a truck. However, equipping the smaller models with the sonar would require Martac to complete additional development to make this possible. Compared to the Sonar EMILY, the cost of the MANTA is approximately 300% the cost of the Sonar EMILY.

Hydronalix

The sonar Emergency Integrated Lifesaving Lanyard (EMILY) was the only model that Hydronalix offered with sonar capabilities. The sonar version of the EMILY is fairly new as its original use was for rescuing people caught in rip currents or offshore currents. The model is mono hull and constructed from Kevlar-reinforced fiberglass. It is approximately 4.3 feet in length and weighs approximately 40 pounds. The sonar system is simplified like the RC boat developed by Ayres Associates.

A site demonstration was completed in Baraga, Michigan. The EMILY performed well. It was easily deployed as it is light weight and a manageable size. The data collection process was simplified as compared to the Sea Floor Systems, only taking 10 minutes to set up. There were minor issues where the sonar unit lost communication with the Humminbird display. However, the radio control of the vessel did not have issues with communication.

A second site demonstration was completed in Niles, Michigan at the same location as the SeaFloor Systems demonstration. The intent of this demonstration was to see how well the boat would operate in a current faster than the first site and to learn more about the boat. The EMILY navigated the current easily, has a near zero turning radius due to the inboard jet drive and reverse enables retreat from an undesired location as well as adjustments to the vessels heading. The staff from Great Lakes Unmanned Systems Center were helpful in answering questions. There were minor complications with the battery initially, but after replacing the battery, the boat had no issues.

A third demonstration was conducted in Bay City, MI. This demonstration confirmed previous results and provided a side scan and down scan sonar image of an exposed footing.

Result

Each model has advantages and disadvantages and the site visits proved to provide valuable information as to how well each model would perform in high flow events. The models from Martac and Hydronalix provided better performance than the initial models researched from Deep Ocean Engineering and SeaFloor Systems.

For the comparison matrix of the USVs, ease of use, weight, cost, and speed had significant impact on the result. The vessel with the highest score is the Sonar EMILY developed by Hydronalix. Benefits of the EMILY are that it is light weight, maintains speed and maneuvers well in swift current with turbulent water, costs significantly less than other models, and it is easy to use. Even though the sonar equipment in the EMILY was not rated as well as other units in the instrumentation section, finding a boat that operated well was the priority. It is possible that components within the boat could be upgraded with more accurate equipment in the future or as the Humminbird technology develops, accuracy of the data may be improved.

Additionally, simpler sonar and GPS equipment makes the vessel more useful for many different operators with lower levels of operational and data interpretation training.

A final list and corresponding prices of the required instrumentation and equipment attached to the vessel is outlined in Appendix F. A user manual was generated for the Sonar EMILY and corresponding equipment.

Professional Surveying Licensure

Land surveying practice in the state of Michigan encompasses professional services that gather data about the earth and convey the results in some form (ASPRS 2012 State Surveying Regulations).

Land surveying can be done under a Professional Engineering (PE) license only if the person was certified before January 1, 1982 and are competent in land surveying. Otherwise, professional land surveying is a separate license that involves:

- 1) 4-year degree in Land Surveying or related field
- 2) Pass Fundamentals of Surveying (FS) and Principles & Practice of Surveying (PS) Exams
- 3) Most states require 4 years of experience under a Professional Land Surveyor
- 4) Online Application

Since hydrographic surveying is used solely to obtain water depths for scour observation, it is not included under the land surveying practice definition for Michigan. Thus, any bridge inspection team member who is competent in using the hydrographic survey equipment will be able to conduct the streambed profiling for water depths.

Conclusion

Ayres Associates was contracted to research different techniques to monitor bridge scour by fulfilling the following objectives:

- Review and evaluate current and ongoing applicable research regarding scour monitoring.
- Identify procedure for objective research
- Evaluate different access techniques.
 - Under bridge inspection vehicle
 - Manned survey boat
 - Unmanned surface vessel
- Prepare list of equipment for a vessel that meets the requirements set forth by the research panel.
 - Field test unmanned scour vessels for monitoring bridge scour.
 - Produce hydrographic survey data to verify effectiveness of vessel.
- Develop operating procedures for vessel and data processing
- Implement equipment at bridges and culverts.

Based on the research conducted, Ayres Associates believes the objectives outlined above will be best met by utilizing single beam sonar instrumentation on an unmanned surface vessel. To simplify the hydro survey process and best fit the needs outlined by MDOT, integrated sonar on the USV will comprise of a GPS unit and transducer.

Unmanned surface vessel research began by determining which USV models/companies would best meet the needs of MDOT. Some baseline factors that were compared are as follows:

- Evaluate stream/river characteristics during storm events at bridge locations to determine real-time scour hole progression and thus determine when to close the bridge.
- Rugged enough for high current or debris
- Bathymetric surveys of streambed and at bridge pier locations, typically 3 to 30 feet deep
- Topside camera to view underside of bridge
- Can be rapidly deployed

Ten different models were investigated by means of research, comparison matrix and rating system. Research was conducted online and in person. Online research was completed independently by Ayres Associates employees. Data including specification sheets, videos, and quotes were collected and used as input to the rating scheme. In addition to online research, companies offered field demonstrations of their products which allowed for hands on access to the machine and in person interaction with the companies. The USV comparison matrix in Appendix D outlines the available models and rating criteria. Using the USV comparison matrix and on-site testing, the vessel with the highest score is Hydronalix's Sonar EMILY.

Recommendation

Based on research of bridge scour monitoring techniques and available equipment, Ayres Associates recommends an unmanned surface vessel from the company Hydronalix and the model Sonar EMILY. Purchase of Sonar EMILY vessels will fulfill the objectives set forth by the research panel.

Operators of the Sonar EMILY should have hands on training with the vessel and the SAR Hawk post processing software. A training program is provided as part of the purchase of the Sonar EMILY and the content of the training program was provided to the Michigan DOT as a separate document.

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13. Map of MDOT Regions: Michigan Department of Transportation
14. Map of scour critical bridges from MiBRIDGE: Michigan Department of Transportation
15. Map of scour critical bridges from MiBRIDGE: Michigan Department of Transportation
16. Prototype RC boat: Ayres Associates, Inc.

Glossary

E

Echo sounder An echo sounder is a device that measures the depth of the streambed. It transmits sound echoes which bounce off the streambed and are received by the echo sounder. Also known as a transducer.

M

Manned vessel A boat, typically larger in size, that is operated by a person on board.

Multi beam sonar Echo sounders use anywhere from 128 to 512 transducers that emit sound waves at all different angles.

S

Side scan The images provide more of an elevation view of the streambed banks or bridge piers.

Single beam sonar The echo sounder emits one beam straight down through a single transducer and relies on the sound signal hitting the bed and reflecting back to the transducer.

U

Under bridge inspection vehicle The vehicle parks on the bridge deck and lowers a bucket with personnel under the bridge for inspection purposes.

Unmanned surface vessel A boat, typically smaller in size, that is operated remotely.

Appendix A
Project Schedule

SCHEDULE OF RESEARCH ACTIVITIES

An O, R, or X is used to indicate a month with activity or "O" = Original Schedule or "X" = Work Completed or "R" = Revised Schedule		Revision Date:	11/26/2018	Title:	Unmanned Multi Beam Sonar Vessel for Bridge Scour Monitoring																																							
		FY 2017													FY 2018													FY 2019																
		Research Activity	Estimated % of Total Project Budget	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept					
				Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept					
Task 1	Kickoff Meeting	1.2%	O	R	X																																							
Task 2	Current Research	5.1%	O	O	O	O	R																																					
Task 3	Best Practices	9.0%		O	O	O	O	O	O			R	R												R						R													
Task 4	Equipment List / Purchase Unit	34.6%	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O				R	R	R	R	R									
Task 5	Operating Procedures / Deliver Unit	24.4%								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					R	R	R	R	R	R									
Task 6	Spotlight Template	3.9%																					O	O	O											R	R	R						
Task 7	Project Review Sessions	5.1%											O																									R	R					
Task 8	Annual Interim Reports	2.6%																									O																	
Task 9	Final Report	11.5%																																				R	R	R	R	R		
Task 10	Project Wrap-Up Meeting	2.6%																																				O	O				R	R
Total (should = 100%)		100.0%																																								X	X	

Appendix B
Michigan DOT Objective Matrix

Applying Sonar to Monitor Bridge Scour and Performance of Scour Countermeasures
Report No. SPR-1682

Michigan Department of Transportation Objective Matrix

Category	Priority	Objective
Data	H	Confidence in the data provided to proceed with a plan of action
Data	H	Ability to generate data with little to no processing required <i>(for determining immediate scour conditions)</i>
Data	H	Companion processing software for quick field analysis and for (relatively) easy office post-processing / refinement and analysis. Capable of final outputs to non-proprietary formats such as .LAS, .LAZ, .E57, .TIN, .dxf, .dgn and/or comparable.
Equipment	H	Ability to accurately determine scour limits in high velocity flow
Equipment	H	Ability to respond with equipment to an extreme event within an expedited manner
Equipment	H	Determine location and size of scour holes
Equipment	H	Identify location of existing scour countermeasures
Equipment	H	Ability to develop a detailed elevation view of piers to determine/detect undermining (some type of side scan sonar?)
Equipment	H	Utilization of main-stream software with reputable / stable vendor history and support. (Think COTS solutions.) a. The research team should report on anticipated maintenance needs for the solution in terms of number of annual firmware, software upgrades anticipated etc.
Equipment	H	Modular component sets are desired to the extent possible to mitigate obsolescence.
Equipment	H	Computer must have MDOT Admin rights to meet their policy or otherwise stay separate of MDOT system
Operation	H	Data that can be analyzed by MDOT personnel immediately and on-site
Operation	H	Capable of being deployed under high velocity flows
Operation	H	Capable of being operated by MDOT Region staff
Operation	H	Able to operate field equipment with 2 inspectors or less at site
Operation	H	Recommended quality control and quality assurance functionality should be practical and reported on. Pole sounding intervals, overlapping passes, pass spread geometry etc.
Operation	H	Navigation without line of site
Operation	H	First person view from cameras on vessel
Equipment	L	Ability to inspect small culverts by mounting a GoPro camera or something equivalent
Equipment	M	Identify limits of equipment (i.e. water depth, velocity, vertical clearance, on-site vs off-site analysis, battery life, retrofits, limits/range of operation)
Equipment	M	Develop bathymetric contour maps of stream bottom <i>(for detailed channel bottom elevations)</i>
Equipment	M	Camera mounted to navigate areas where inspector cannot see (unmanned) vessel.
Equipment	M	IF autonomous multi-beam is feasible and IF it is economically compelling to procure an unit with design survey capabilities a platform capable of producing a tightly coupled trajectory processed solution is desirable with RTK GPS + IMU + Multibeam. This solution should have fixed "lever arms" in terms of known relations between sensors to the greatest extent possible to minimize set-up, measurement and calibration allowing for fast field deployment.
Equipment	M	Ability to determine condition of scour counter measures.

Appendix C
Instrumentation Comparison Matrix

Echo Sounder Rating System

Scale: See definitions below

Company	Brand	Model	Type	Software Compatibility	GPS Compatibility	Depth Range	Operating Range	Resolution	Serviceability	Cost	Echosounder's Total Points	Echosounder Score (percent of total points)
CEE HydroSystems	CEE HydroSystems	CEEPulse 100	0	1	3	2	1	2	2	3	14	66.67
Humminbird	Humminbird	XNT 9 20 T	1	1	3	2	4	0	2	3	16	76.19
Lowrance	Lowrance	HDI Skimmer	1	0	3	2	2	0	2	3	13	61.90
Seafloor Systems	Seafloor Systems	SEA 1102: SonarMite-DFX	0	1	5	0	3	0	2	3	14	66.67
		SEA 1020: SonarM8	0	0	0	2	0	1	2	3	8	38.10
		Hydrolite-TM	0	0	4	2	2	0	2	3	13	61.90
		Hydrolite-DFX Dual Frequency	0	1	5	0	0	0	2	3	11	52.38
	R2Sonic	2020 MB	1	1	0	2	0	3	1	0	8	38.10
		2024 MB	1	1	0	2	0	0	1	0	5	23.81
	Teledyne	Odom Echotrac MK III	0	0	0	2	0	1	1	0	4	19.05
		Odom Echotrac CV100	0	0	0	2	0	1	1	0	4	19.05
		Odom MB1	1	0	1	2	0	2	1	0	7	33.33
		Odom MB2	1	0	0	2	0	2	1	0	6	28.57
		RESON T50-P MB	1	0	1	2	0	3	1	0	8	38.10
		RESON T50-R Ultrahigh Resolution	1	0	1	2	0	3	1	0	8	38.10
		RESON T20-P MB	1	0	1	0	0	3	1	0	6	28.57
		RESON T20-R High Resolution	1	0	0	2	0	3	1	0	7	33.33
		RESON SeaBat 7101-ER	1	0	0	2	0	3	1	0	7	33.33
		RESON SeabBat 7111	1	0	0	2	0	2	1	0	6	28.57
		RESON SeaBat 7160	1	0	0	2	0	1	1	0	5	23.81
		RESON SeaBat 7125 SV2 Dual Frequency	1	0	0	2	0	0	1	0	4	19.05
	Echologger	ECS 400 Ultra/ECT 400 Ultra	0	1	1	2	3	0	1	0	8	38.10
AA400		0	0	0	2	1	0	1	0	4	19.05	
EU400 USB		0	1	1	1	3	0	1	0	7	33.33	
EA400 Autonomous		1	0	0	2	3	0	1	0	7	33.33	

Total possible points = 21

Rating Definitions and Scale

Type Multibeams provide a wider range of data points in one pass than single beams.
1 = Multibeam
0 = Single beam

Software Compatible Survey software collects data that is outputted by the echosounder.
1 = Compatible
0 = Not compatible

GPS Compatibility The Global Positioning System (GPS) will be used for navigation and depth location.
5 = Compatible with all GPS software.
4 = Compatible with more than 1 GPS software.
3 = Compatible with 1 GPS software.
1 = Not compatible with GPS.
0 = No data provided.

Depth Range The average depth the scour vessel will be operating in is 20 feet (6 meters).
2 = >/= 20 ft
1 = <20 ft
0 = No data provided.

Operating Range The average range the vessel will need to be operated from is 300 feet (91 m).
4 = >/= 300 ft max.
3 = < 300 ft max.
2 = < 90 ft max.
1 = < 60 ft max.
0 = No data provided.

Resolution The resolution that the echosounder provides will affect the quality of the hydrographic survey.
3 = >/= 0.001 m
2 = > 0.01 m
1 = > 0.1 m
0 = No data provided.

Serviceability The goal is to minimize the parties involved.
2 = Provider is same as the echosounder brand.
1 = Provider is not the same as the echosounder brand.
0 = No data provided.

Cost The budget amount for a fully equipped scour vessel is \$60,000. In order to meet the budget, approximately \$9,000 can be set aside for the echosounder.
3 = < \$ 9,000
2 = > \$ 12,000
1 = >/= \$15,000
0 = No data provided

GPS Rating System

Scale: See definitions below.

Brand	Model	GNSS Accuracy	Environmental	Durability	Screen Size	Screen Type	Sonar Compatibility	Operating Time	Device Connectivity	Real-time Corrections	Processor	Data Storage	Cost	Device's Total Points	Device Score (percent of total points)
Humminbird	Helix 12	0	3	0	2	2	3	2	2	0	0	0	5	19	55.88
Leica	Zeno 5	0	1	0	0	1	3	1	2	0	0	0	5	13	38.24
	CS10	0	4	1	0	1	3	1	2	0	0	0	5	17	50.00
	CS20	0	5	1	2	1	3	0	2	0	1	0	5	20	58.82
Lowrance	Elite 7 - Ti	1	0	0	2	2	3	0	2	0	0	0	5	15	44.12
Trimble	Geo 7x	5	2	2	1	1	3	0	2	2	1	1	2	22	64.71
	Juno 5	1	5	1	1	2	3	0	2	0	1	2	5	23	67.65
	Nomad 1050	1	5	1	0	1	3	2	2	0	1	1	5	22	64.71
	TDC100	1	4	0	2	2	3	2	2	0	2	1	5	24	70.59
Total possible points =														34	

Rating Definitions and Scale

GNSS Accuracy GNSS accuracy is a measurement of how close the field data is to the actual data. The accuracy of the field data affects post-processing time. Maximum GNSS accuracy:

- 5 = 1 cm
- 4 = 25 cm
- 3 = 50 cm
- 2 = 75 cm
- 1 = 1 m
- 0 = > 1 m

Environmental The GPS will constantly be exposed to various environmental conditions. IP tests evaluate how dust resistant and waterproof the device is.

- 5 = IP68 Rating
- 4 = IP67 Rating
- 3 = IPX7 Rating
- 2 = IP65 Rating
- 1 = IP54 Rating
- 0 = Not IP Rated

Durability The GPS will need to be durable to withstand the field conditions. The most common tests are: shock, drop, and vibration.

- 2 = Rated for all 3 tests
- 1 = Rated for 2 of 3 tests
- 0 = Rated for only 1 of 3 tests

Screen Size Information is easier to view with a larger screen. Screen height:

- 2 = >= 5 in.
- 1 = < 5 in.
- 0 = < 4 in.

Screen Type Is the screen in color or black and white? Multi-touch or touch only?

- 2 = Color, Multi-touch
- 1 = Color, Touch
- 0 = Touch

Sonar Compatibility Is the GPS unit compatible with single beam, multi beam, and side scan sonar?

- 3 = Compatible with single beam, multi beam, and side scan sonar
- 2 = Compatible with single and multi beam sonar
- 1 = Compatible with single beam sonar
- 0 = Incompatible

Operating Time Maximum time the device can operate.

- 2 = >= 12 hrs
- 1 = >= 10 hrs
- 0 = < 10 hrs

Device Connectivity The GPS has the ability to connect to other devices wirelessly.

- 2 = Bluetooth or cellular connectivity
- 1 = Unable to link to another device
- 0 = No information about device connectivity

Real-time Corrections Real-time corrections eliminates errors during data collection which allows the field crew to adjust the path of the sonar equipment to collect all the data they need. With this capability, less time is required for post-processing the data.

- 2 = VRS corrections
- 1 = Other real-time correction capabilities not including VRS
- 0 = No real-time corrections

Processor Ability to collect information

- 2 = > 1 GHz
- 1 = = 1 GHz
- 0 = < 1 GHz

Data Storage Maximum onboard storage

- 2 = > 16 GB
- 1 = <= 16 GB
- 0 = <= 1 GB

Cost The budget amount for a fully equipped scour vessel is \$60,000. To remain close to the budget, the GPS should be less than \$5,000.

- 5 = < \$5,000
- 4 = < \$6,000
- 3 = < \$7,000
- 2 = < \$8,000
- 1 = < \$9,000
- 0 = >= \$9,000

Side Scan Rating System

Scale: See definitions below

Company	Brand	Model	Operating Range	Size	Weight	Depth Rating	Software Compatibility	Visibility	Cost		Side Scan's Total Points	Side Scan Score (percent of total points)
Deep Ocean	Teledyne	M900-130	3	3	2	2	0	0	1		11	68.75
Humminbird	Humminbird	Helix 12	3	3	2	2	2	1	3		16	100.00
Lowrance	Lowrance	Elite 7 - Ti	1	3	2	2	1	1	3		13	81.25
Seafloor Systems	Teledyne	Benthos SIS-1624	3	0	0	0	2	0	0		5	31.25
	Tritech	Starfish 453 (Starfish AUV)	3	2	2	2	2	0	3		14	87.50
		Starfish 990F	3	2	2	2	2	1	3		15	93.75
Ocean Science	Tritech	Starfish 452F	3	2	2	2	1	1	3		14	87.50

Total possible points = 16

Rating Definitions and Scale

Operating Range The average range the vessel will need to be operated from is 300 feet (91 meters).

- 3 = > 300 ft
- 2 = < 200 ft
- 1 = < 100 ft
- 0 = Not specified

Size The size of the sidescan sonar will affect the amount of space the vessel has for other equipment.

- 3 = Compact
- 2 = Average
- 1 = Large
- 0 = No size specified.

Weight A lighter sidescan device is advantageous to minimize the total weight in the scour vessel.

- 2 = <= 5 lb
- 1 = > 5 lb
- 0 = Not specified

Depth Rating The average depth the scour vessel will be operating in is 20 feet (6 meters).

- 2 = >= 6 meters
- 1 = < 6 meters
- 0 = No data provided.

Software Compatibility All the equipment in the scour vessel will need to be compatible with the same software program.

- 2 = Compatible with hydro survey software
- 1 = Incompatible with hydro survey software
- 0 = Not specified

Visibility The color of the sidescan will affect how visible it is underwater.

- 1 = Sidescan sonar has a high visibility color such as yellow or red.
- 0 = Sidescan sonar is dark and less visible in water.

Cost The budget amount for a fully equipped scour vessel is \$60,000. A reasonable price for the side scan is \$10,000.

- 3 = < \$10,000
- 2 = < \$15,000
- 1 = \$15,000 or more
- 0 = Not specified

Software Rating System

Scale: See definitions below

Software Package	Satisfies Scope Requirements	Ease of Use	Instrument Compatibility	Software Compatibility	Brand Compatibility	License Type	License Cost per Seat	Marketing/Support Effort	Support Ease	Shelf Life/Update Frequency	Reviews/Recommendations	Company Headquarters	Total Points	Software (percent of total points)
HYPACK	4	1	4	5	5	0	4	5	5	3	2	1	39	75.00
EIVA	3	0	5	0	5	0	1	4	3	4	4	0	29	55.77
QINSy	4	0	1	0	5	1	0	3	3	0	3	0	20	38.46
Hydromagic	5	0	3	5	5	1	5	3	3	0	3	0	33	63.46
SAR HAWK	5	4	5	0	0	0	5	5	5	5	5	1	40	76.92
Teledyne PDS	3	0	0	5	5	1	0	3	4	0	5	0	26	50.00

Total possible points = 52

Rating Definitions and Scale

Satisfies Scope Requirements Is the software designed for bathymetric surveys? Is it geared towards shallow inland waters? Does it fulfill the scope requirements of accurately representing streambed profile data?
5 = 100% designed for shallow inland waters
4 = Not specifically designed for shallow waters, but has been proven to work via test case
3 = Geared towards large scale offshore exploration, but can be edited for shallow waters
2 = Geared towards large scale offshore exploration, but cannot be edited for shallow waters
1 = Only capable of large scale offshore exploration
0 = No bathymetric survey capabilities

Ease of use Online ratings or hands on experience
5 = Simple
4 = Self paced training with reference material
3 = Training required, occasional consultation of reference material
2 = Training required, consistent consultation of reference material
1 = Complex
0 = No data

Instrument Compatibility Is the software compatible for single beam, multibeam, and sides can instruments specifically designed for USV's?
5 = Can support 80-100% of instruments
4 = Can support 60%-79% of instruments
3 = Can support 40%-59% of instruments
2 = Can support 20%-39% of instruments
1 = Can support 5%-19% of instruments
0 = No information provided

Software Compatibility Is the software compatible with typical programs such as excel office and AutoCAD Civil 3D or Microstation?
5 = Yes, compatible
0 = No, not compatible. No information provided

Brand Compatibility Is the license compatible with various brands of sonar equipment?
5 = Compatible with more than one brand.
0 = Compatible with one brand.

License Type Is the license based on per-seat or concurrent user? For this scope, a concurrent user license would be more applicable than a per-seat license.
1 = Concurrent User
0 = Per-seat User

License Cost per Seat What is the license cost per seat?
5 = \$0 to \$5k
4 = \$5k to \$10k
3 = \$10k to \$15k
2 = \$15k to \$20k
1 = Greater than \$20k
0 = No data provided

Marketing/Support Effort Is the company actively trying to market their product? Do they provide enough support documentation of the software? Do they provide yearly conferences, troubleshooting support, or other resources?
5 = Good
4 = Satisfactory
3 = Fair
2 = Poor
1 = Critical
0 = Failing

Support Ease How easy is it to contact the software company for troubleshooting purposes?
5 = Effortless, call 24/7 and get support representative who represents your company
4 = Easy, call 24/7 and get random support representative
3 = Easy-to-Moderate, automated calls that require transferring departments/holding time
2 = Moderate, call/email where response rate is satisfactory
1 = Moderate-to-Difficult, contact information difficult to find, poor response time
0 = Difficult, no support provided

Shelf Life Update Frequency How long does the software last in the industry? How often are software updates? Are the updates made known to the users and are they easy to understand?
5 = Greater than 5yr
4 = 3-5 yr
3 = 1-3 yr
2 = 6 mo-1 yr
1 = 6 mo
0 = No data provided

Reviews Recommendations Has the software been recommended as the ideal software in the industry? How are the reviews from users?
5 = Good
4 = Satisfactory
3 = Fair
2 = Poor
1 = Critical
0 = Failing

Company Headquarters Where is the company located? Are they based in the United States? Factors to consider: language, currency type, time zone, ease of contacting, office location
1 = Based in U.S.
0 = Based outside U.S.

Data Acquisition Laptop Rating System

Scale: See definitions below

Company	Brand	Model	Durability	Hard Drive Capacity	RAM	Graphics Card	Display Size	Screen	Keyboard	Weight	Cost	Device's Total Points	Device Score (percent of total points)
Dell	Dell	Latitude 7424 Rugged Laptop	5	1	5	2	2	3	1	1	1	21	80.77
Getac	Getac	A140 Fully Rugged Tablet	2	1	3	2	2	2	1	1	1	15	57.69
		S410 Semi Rugged Notebook	3	1	3	3	2	1	1	2	3	19	73.08
		V110 Fully Rugged Notebook	3	1	3	2	0	0	1	2	0	12	46.15
Panasonic	Panasonic	Fully Rugged Toughpad FZ-A2	5	0	3	0	0	2	1	3	3	17	65.38
		Semi Rugged Toughbook 54 Touch	4	1	3	1	2	1	1	2	3	18	69.23
		Fully Rugged Toughbook 31	5	1	3	1	1	2	1	1	0	15	57.69
Seafloor Systems	Getac	S410 Semi Rugged Notebook	3	1	3	3	2	1	1	2	2	18	69.23

Total possible points = 26

Rating Definitions and Scale

Durability IP certification refers to the devices ability to withstand environmental conditions.

- 5 = IP65 certified and certified in 10 or more MIL-STD 810G tests
- 4 = IP65 certified and certified in 7 to 9 MIL-STD 810G tests
- 3 = IP65 certified and certified in 3 to 6 MIL-STD 810G tests
- 2 = IP65 certified and certified in 2 MIL-STD 810G
- 1 = Type of durability test not specified
- 0 = No testing performed

Hardrive Capacity Minimum capacity is the amount of data the device can store.

- 1 = 256 GB or more
- 0 = Less than 256 GB

RAM Minimum capacity is 16 GB

- 5 = 16 GB or more
- 3 = 8 GB
- 0 = < 8GB

Graphics Card The display screen output is generated by the graphics card.

- 3 = Intel HD Graphics 620
- 2 = Intel HD Graphics 520
- 1 = Intel HD Graphics 5500
- 0 = Not specified

Display Size The display size affects the ease of viewing the maps.

- 2 = 14" or larger
- 1 = > 12"
- 0 = > 10"

Screen Is the screen outdoor readable? Is it multi-touch, touch, or non-touch? Multi-touch screen allows finger, glove, or pen touch which is useful in undesirable weather conditions.

- 3 = Outdoor readable and multi-touch screen
- 2 = Multi-touch screen
- 1 = Touch screen
- 0 = Non-touch screen

Keyboard The keyboard will be exposed to environmental conditions so it is beneficial if it is water resistant.

- 1 = Water resistant
- 0 = No application applied for water resistance

Weight The weight of the notebook/tablet will affect how easy it is to transport and set-up.

- 3 = < 3 lb
- 2 = < 5 lb
- 1 = 5 lb or more
- 0 = Not specified

Cost The budget amount for a computer is \$5,000.

- 3 = < \$1,500
- 2 = \$1,500 to \$2,500
- 1 = \$2,501 to \$5,000
- 0 = > \$5,000

Appendix D
USV Comparison Matrix

USV Rating System

Scale: See definitions below

Company	Brand/Model	Hull Shape	Speed	Battery Life	Battery Chemistry	Weight	Payload Capacity	Boat Clearance Height	Instrumentation Availability	Demonstration Provided	Cost	Company Reputation	Company Recommendation	Current Relationship	USV's Total Points	USV Score (percent of total points)
ASV Global	C-Target 1	3	3	1	1	3	3	1	3	0	1	3	1	5	28	52.83
Clearpath Robotics	Heron	5	2	1	1	3	2	1	3	1	3	1	1	3	27	50.94
Deep Ocean	I-980	3	3	3	0	3	3	1	0	3	5	4	0	5	33	62.26
	I-1650	3	3	3	0	4	3	1	4	3	2	4	1	5	36	67.92
	H-1750	5	3	3	0	0	5	1	5	3	2	4	0	5	36	67.92
Hydronalix	EMILY	3	5	3	1	5	3	1	5	4	5	1	1	5	42	79.25
MARTAC	MANTA T8	5	5	5	1	2	3	1	3	4	1	1	0	5	36	67.92
	MANTA T12	5	5	5	1	2	5	1	5	4	1	1	1	5	41	77.36
SeaFloor Systems	EchoBoat	3	3	4	0	3	3	1	5	2	3	2	1	5	35	66.04
	HyDrone-RCV	5	4	4	0	5	5	0	3	1	5	2	0	5	39	73.58
Ocean Science	Z Boat 1800	3	3	1	1	3	4	1	3	1	4	2	1	2	29	54.72

Total possible points = 53

Rating Definitions and Scale

Hull Shape	Hull shape takes into account stability due to river current, waves, debris, weight of vessel, freeboard amount, etc. Typically, catamarans are more stable than planning (monohull). 5 = Catamaran 4 = Light weight catamaran or heavy monohull 3 = Monohull 2 = Light monohull 1 = Another hull design 0 = Wood Plank	Instrumentation Availability	Can the USV hold the desired instrumentation (single beam, multibeam, side scan, camera, etc.)? Can the specific USV be upgraded to a more advanced system (single beam to multi beam)? 5 = Completely compatible, can be upgraded with ease 4 = May require minor engineering to reconfigure mounting brackets 3 = Partly compatible, will take some engineering to reconfigure mounting brackets 2 = May require major overhaul/engineering to mount new instruments 1 = Minor adjustments available 0 = Unavailable
Speed	Max speed for use during high current. 5 = +25 fps 4 = 20-25 fps 3 = 15-20 fps 2 = 5-15 fps 1 = 0-5fps 0 = 0 fps	Demonstration Provided	Did the company provide a demo of the machine? Did they make themselves available? Did they sell the product to me? 5 = Demo provided, good experience 4 = Demo provided, satisfactory experience 3 = Demo provided, fair experience 2 = Demo provided, poor experience 1 = No demo provided, but was discussed 0 = No demo provided, no discussion
Battery Life	Total life time under survey speed (typical survey speed is 2m/s or 6.5 fps). 5 = > 5 hrs 4 = 4-5 hrs 3 = 4 hrs 2 = 3-4 hrs 1 = < 3 hrs 0 = < 0.5 hrs	Cost	Benchmark is budget amount of \$60,000 5 = Less than \$60,000 4 = \$60k to \$70k 3 = \$70k to \$90k 2 = \$90 k to \$120k 1 = Greater than \$120k 0 = No data provided
Battery Chemistry	Some batteries (Li) require more hassle to ship via air than others (NiMH). 1 = Other 0 = Li	Company Reputation	How long have the company been in the underwater exploration, surveying, or USV business? 5 = > 40 yrs 4 = 30-40 yrs 3 = 20-30 yrs 2 = 10-20 yrs 1 = 5-10 yrs 0 = < 5 yrs
Weight	Total weight of machine with all instruments attached. OSHA limits maximum weight a person can safely carry without leading to lower back damage to 51 lbs (see NIOSH). 5 = 1 person 4 = 1 person with trolley 3 = 2 people 2 = 2 people with trolley/trailer 1 = 3 people with or without trolley/trailer 0 = > 3 people	Company Recommendation	If a company has two models, which one would they recommend to best suit the needs of MDOT. 1 = Recommends 0 = Does Not Recommend
Payload Capacity	Allowable payload weight for additional instrumentation in the future. 5 = > 100 lbs 4 = 50-75 lbs 3 = 25-50 lbs 2 = 10-25 lbs 1 = 5-10 lbs 0 = < 5 lbs	Current Relationship	How current communications are going. Are they responsive to phone calls and/or emails? Do they check in on our process? 5 = Good 4 = Satisfactory 3 = Fair 2 = Poor 1 = Critical 0 = Failing
Boat Clearance Height	Total height of boat. 1 = < 2 ft 0 = >2 ft		

Appendix E
USV Field Visit Notes

MEMORANDUM

To: MDOT

From: CKJ

Date: July 24-25, 2017

Project No.: 63-0538.00

Re: MDOT Research Site Visit to MA July 24-25, 2017

MDOT Research Site Visit:

Date: 7/25/2017

Company: Seafloor Systems Inc.

Site Location: Falmouth, MA

Weather Conditions: Overcast 65-70° F

Machine Details: (Model, size, mobilization, storage, required hookups, etc.)

Model: EchoBoat

Size: 4.4ft x 3.2ft (plan)
Larger than originally assumed. Dimensions are true.

Storage: Typically stored assembled and resting on trailer.
Ports remain hooked up.
Can remove rack to reduce overall height.

Mobilization: Shipped in wooden crate, roughly 300lbs.
Generally can be shipped in one crate (boat, batteries, equipment, remote) unless there is excess equipment then may have two crates.
There are issues with air travel and lithium batteries. Ground transportation is easier.
Boat can fit in back of pickup truck or perhaps an SUV when traveling to site.
Recommends strapping boat down to homemade trailer.
Seafloor systems brought another crate for misc. demo gear (monitor, laptop, etc.)

Hookups/ports: Boat will come all hooked up for the most part.
Once hooked up, there shouldn't be much adjustment needed.

Weight: 120lbs when loaded with computer, GPS, autonav, batteries.
This was the most it would probably weigh for MDOT's purpose.

Equipment Details: (multibeam, GPS, camera, software, battery, laptop, typical replacement parts, etc.)

Equipment: Multibeam
 No real details were recorded.
 Will contact company via email/phone to obtain details

Typical Replacement Parts: Skeds and thrusters.
 Skeds wear out from being dragged during launch.
 Thrusters seem pretty cheap and can get caught on things below the water surface.

Cost: (overall, replacement parts, etc.)

Replacement Parts: Skeds and thrusters – couple hundred dollars.

Multibeam Set-Up: 120K
 Includes all equipment (boat, GPS, laptop, software, batteries, etc.).
 Includes 5 days of training.
 Seafloor Systems will come out to conduct the training.

Single Beam Set-Up: 30-40K
 Only for single beam.
 Need to contact company regarding total price that includes training.

Operation: (remote control, ease of use, etc.)

Remote Control: Typical remote control.
 Thrusters can be differential or the same.
 Easily toggles between autonomous or manual (1 switch).

Ease of Use: Seems easy to use.
 Can extend past line of sight (1,000ft).
 Seafloor Systems employee learned to operate in a day.

Data Processing:

Data Viewing: On laptop from shore.
 Real time plotting of depths.
 Did not see piles on screen when machine drove very close to them.
 Seafloor Systems will send raw data of site.

Misc. Notes: (speed, data collection under poor conditions, etc.)

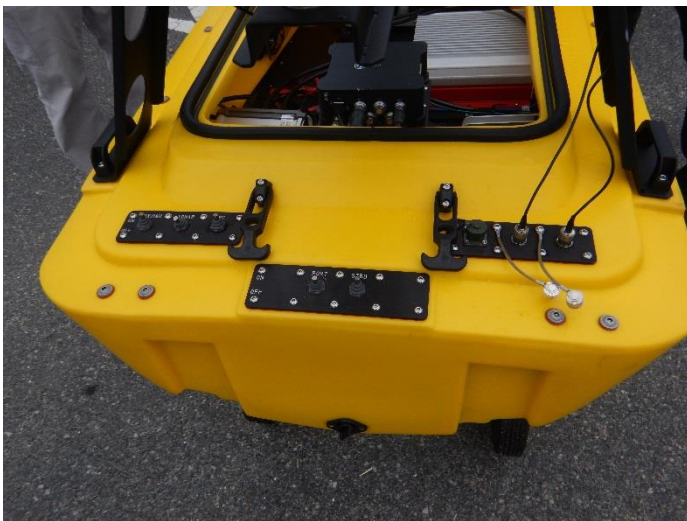
Speed: Survey Speed 2-3 knots
Max speed 6-8 knots

Current: When in auto mode, the current pushed the boat out of the outlined path and lost a section of data.

Poor Weather Conditions: 7/24/17 was raining all day.
Seafloor Systems confirms that data collection had no issues.
Boat did not take on water due to sealed cockpit (similar to a kayak).

MDOT Unmanned Scour Vessel Research

Site Visit to Seafloor Systems Inc. in Falmouth, MA



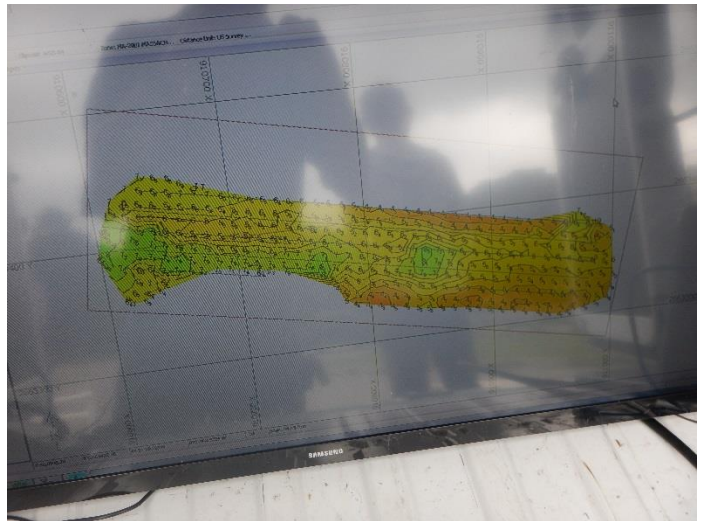
MDOT Unmanned Scour Vessel Research

Site Visit to Seafloor Systems Inc. in Falmouth, MA



MDOT Unmanned Scour Vessel Research

Site Visit to Seafloor Systems Inc. in Falmouth, MA



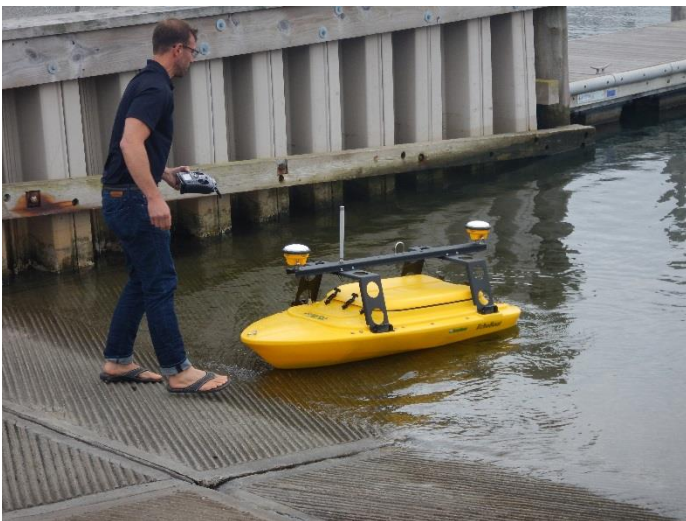
MDOT Unmanned Scour Vessel Research

Site Visit to Seafloor Systems Inc. in Falmouth, MA



MDOT Unmanned Scour Vessel Research

Site Visit to Seafloor Systems Inc. in Falmouth, MA



MEMORANDUM

To: MDOT

From: CKJ

Date: August 31, 2017

Project No.: 63-0538.00

Re: MDOT Research Site Visit to CA August 31, 2017

MDOT Research Site Visit:

Date: 8/31/2017

Company: Deep Ocean Engineering

Site Location: San Jose, CA

Weather Conditions: No Field Visit

Machine Details: (Model, size, mobilization, storage, required hookups, etc.)

Model: 1650 – Mono hull

- Wanted to see the 1750 (catamaran), but they don't have one available for demo purposes

Size: 4ft x 2.5ft x 1.5ft

Larger than originally assumed. Dimensions are true.

Storage:

1650

- Typically stored assembled and in crate
- 1 large crate for boat (6ft x 3ft)
- 1 crate for misc. instruments/controller/antenna

1750

- 3 large crates (1 for each hull and 1 for the center connecting piece)
- 1 crate for misc. instruments/controller/antenna

Mobilization:

- Didn't really discuss details, cost, weight
- Can be shipped via air or ground
- Batteries are NiMH (not Li) therefore they can be shipped air with less problems
- Didn't have a trailer or way to get it to the water from the truck without carrying it
- Requires two people to carry

Hookups/ports: Boat will come all hooked up for the most part.

Once hooked up, there shouldn't be much adjustment needed.

The staff was having issues hooking up the equipment... why? Shouldn't they be the experts? If they can't do it, can the average person?

The staff also had issues setting up the camera mounted on top of the boat.

Weight: Did not go over weight, assuming around 100lbs

Equipment Details: (multibeam, GPS, camera, software, battery, laptop, typical replacement parts, etc.)

Equipment: No real details were recorded.
The staff did not provide available instrumentation such as: single beam/multibeam/GPS/software/or a laptop
They provided batteries (4 packs) and a camera (China brand)
Will contact company via email/phone to obtain details
Emails are saved regarding specific instrumentation and quotes
The boat required 4 packs of batteries and they mentioned that you may need more.

Typical Replacement Parts: Thrusters, however, they seemed very robust and durable
See photos.

Cost: (overall, replacement parts, etc.)

Did not discuss because only the 1650 was present and not the 1750. See quotes in email obtained from Darrel Martin (Sales Rep.)

Operation: (remote control, ease of use, etc.)

Remote Control: Seems very basic (see photos)
Pros – easy to use, only two buttons
Cons – only two buttons, can only operate boat and nothing else

Ease of Use: Seems easy to use (only saw it in action in a test tank (12ft diameter x 6ft depth)
Can extend past line of sight (1,000ft).
Can use camera to operate.

Data Processing:

Did not go over data processing. Instead they showed multibeam images from the USS Arizona. These images are available in an email from Darrel.

Misc. Notes: (speed, data collection under poor conditions, etc.)

Customer Service:

-Sales Rep and VP called me day before the demo to tell me that the boat was not ready. I was already in CA before I got their message. They claimed that the batteries they ordered from the vendor came late. In addition, they could not provide a field visit to see the boat in action. Instead, they provided a test tank of water that measured 12ft in diameter by 6 ft deep. The boat barely fit in the diameter and could not move forward or backward very far.

-The staff could only show me the boat and a few instruments including the batteries and a camera. No other instrumentation was available.

-No post processing or software was shown or discussed.

-Overall feeling of the company was poor. They did not seem interested in selling the product and made little effort to talk to me or ask me questions.

-The staff was not prepared to have a "Demo". No batteries, no plan of action. The boat wasn't even ready to be shown.

Demo:

- Could not go see in boat in the field
- Instead the staff utilized a test tank
- I was not able to take photos or video during the test

Quality of Product:

- All of the products were well made
- Materials/configuration was ideal and seemed to have been through multiple iterations
- Hull was made from carbon fiber which was light and durable
- The hull was lined with a rubber strip which could be ideal for rubbing up against concrete piers

Misc. Notes:

-Their ROV's have been in service since the 80's. Their USV's have only been around for 3 years.

- Use 3rd party vendors for all their instruments

-Pros:

Flexibility with the boat configuration to be able to fit any type of instruments

As the technology advances the company doesn't have to keep up, they can just add the latest and greatest instrument

-Cons:

Have to rely on another companies product

- Camera on top was very nice and had a good quality image

-Batteries

- Use NiMH versus Li like other companies
- Can be shipped via air with less hassle than Li
- Not sure if there is a advantage/disadvantage to the chemistry type

-Room in the hull

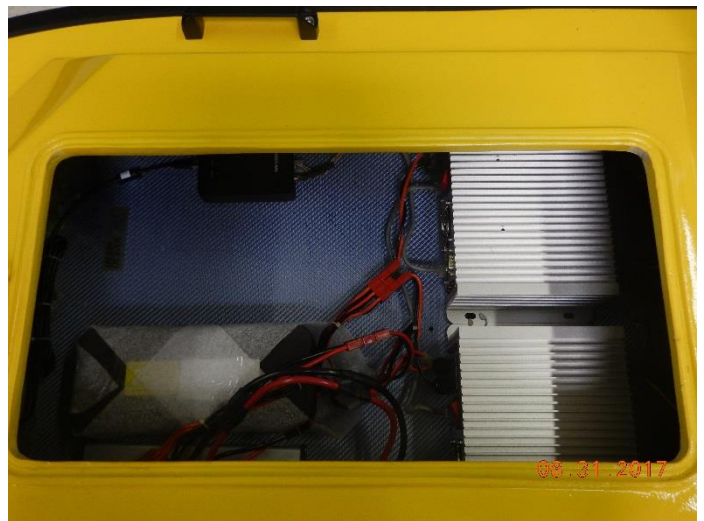
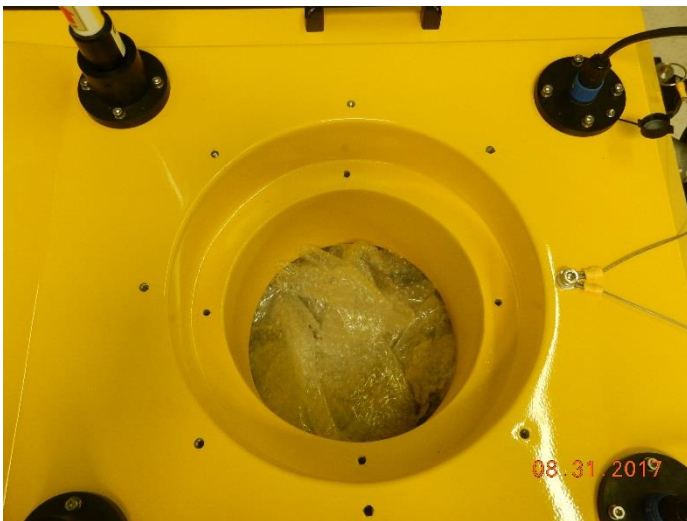
- with 4 battery packs, there wasn't a ton of room for any other instruments

-Thrusters

- Very impressed with the thrusters
- Durable and power efficient
- Had a quick release pin (ideal for shipping, see photos)

MDOT Unmanned Scour Vessel Research

Site Visit to Deep Ocean Engineering in San Jose, CA



MDOT Unmanned Scour Vessel Research

Site Visit to Deep Ocean Engineering in San Jose, CA



MEMORANDUM

To: File

From: Pete Haug

Date: April 30, 2018

Project No.: 63-0538.00

Re: Martac Mantas Demonstration at Bagnell Dam, MO

Arrived onsite at 0845 to meet Todd Meyer, Ameren's project manager for Keokuk Dam, Taum Sauk, and Bagnell Dam safety programs. Todd is a mechanical engineer by trade and licensure but has worked in hydropower relicensure for many years. He and another guy led the licensure efforts for Taum Sauk and Bagnell Dam.

Martac arrived at 0900. Co-founder and co-owner Tom Hanson led the team of three. The other two were Jeff and Shawn, two ex-SAR (search and rescue) Navy guys. Per Tom, Jeff had only been with the company for 6 weeks and Shawn only 10 days. Hydrographer Mike Muenscher from Seahorse Geomatics from Seattle was processing the data in real-time via phone connection with the boat operator Shawn. Jeff was the inflatable rib operator and safety tender.

We met Phil Thompson, plant manager, to do tailgate safety meeting. The river is not flowing – just minimum flow releases today. Wind was from the south at 10 to 13 mph. Water depth was 130 ft max and secchi clarity was about 6 feet.

Martac has three boats, a 6, 8, and 12 footer. They use the 12 footer for multibeam echsounder MBES surveys because of the payload requirement. The zer-payload top speed of their 6 footer is 120 knots and their 12 footer's top speed is 50 knots. This is their newest boat, and generation "three" per Tom with an upgraded powerplant. Their goal is to survey at 10-12 knots, but really they can only survey at 1-3 knots with MBES because of the data quality reduction at lower speeds. The boat did no more than 8 knots during the entire survey. With the MBES hanging in the water, Tom believes the boat could do 15 knots max.

The boat itself is amazing. Carbon fiber hull with twin catamaran bow that transitions to a performance boat at the stern. The propeller is a custom stainless steel prop that is 6DOF-CNC'd per Martac's design requirement. The shaft is rated for 50,000 RPM. The boat weighs 350 pounds but apparently most of this is battery. The payload hangs beneath the center. Martac says the next generation will have an actuated payload so it goes up and down rather than hanging always down.

Ameren paid more than \$40,000 for the upstream and downstream survey of this site. (Brennan in LaCrosse charges slightly more than half of that.)

Ameren said Martac completely failed the first time at Keokuk with battery and boat propulsion problems, but the second Keokuk trip was a good success on the upstream side of the dam. However, the boat has never been tested in high flows. The downstream side of Keokuk was to be the first real test for the boat but Ameren called it off.

Today, they are using an Applanix POSMV gyro with twin Trimble RTKGPS (VRS) and Teledyne Reson's T20 MBES head. They rent this equipment. Tom says he will next try the Norbit MBES because the head is much smaller and the Norbit processor is in the head so it does not generate as much heat.

Day 1:

9-11AM site safety and tour

11:45 retrieved trailer from hotel

12:00PM set up – The dam owner and I were not allowed to see inside the Mantas because “it is proprietary”

1:18PM – finished setting up and boat is in water. Boat is deployed on 8020 homemade aluminum strut trailer with 6” pneumatic tires and cargo net cradle

1:45PM after some trial operations, they had a connection problem and had to take boat back to shore

2:30PM – now taking data. They do not use Hypack so the processing software was unfamiliar to me. The data appears to be smooth and correct, but the onscreen plots were small.

Apparently Martac only collects data and does zero processing. Seahorse Geomatics does all the processing via overnight thumb drive delivery.

3:51PM now entering the spillway buoy system

4:30PM – now entering the powerhouse fish net system

4:50PM two runs along powerhouse are complete

5:30PM done inside powerhouse buoys

6:20PM back back on trailer. Tom says they will start at 6AM tomorrow so that they can be on the water by 7.

Day 2:

06:45AM – still no sign of Martac either upstream or downstream of dam

07:45AM – Martac comes onsite (boat ramp on downstream left bank) and starts to set up boat. They are really secretive about having me near the boat, so I stay on opposite side of parking lot.

08:10AM – Dave Koze from security stops by to check in and see how things are going. Martac is still loading gear into the boat.

08:33AM – the crew appears to be done loading the boat interior. They are pumping up the inflatable rib now.

08:45AM – break time for the crew, just waiting around (maybe for Todd?)

09:05AM – tailrace siren went off twice because fishermen entered the 75 yard no boating area. I went over to Martac to see if the control room was trying to hail them on the radio but they said the radio battery was dead this morning.

09:11AM – Todd arrived. He told me there is a radar detector that automatically detects boats that enter this 75 yard restricted area downstream of dam. The siren was just a warning to the fishermen.

09:30AM – Martac boat is downstream of dam, ready to survey. Today Jeff and Shawn are both in the rib on the water (not sure why) even though Todd is letting us walk on the draft tube deck right above the survey area.

11:15AM – finished spillway tailrace survey

11:30AM – connection problem with battery, so Jeff and Shawn head back to boat ramp to fix it. This is the second loose wire delay of this trip to Bagnell. Tom says they still have a few bugs to work out on the cables and communications...

11:43AM – back surveying now at the powerhouse

12:30PM – done with right units of powerhouse. I asked plant to switch station service unit off and they are now passing flow through unit 3.

1:30PM – done with powerhouse tailrace survey. Unfortunately, Tom is worried that they need more data on the upstream face so the crew is going to demob from the tailrace, travel up to the upper launch and remob for a second survey inside the buoy line. This is what happens when you don't use Hypack or a real-time processing software...

My thoughts:

1. Boat is very heavy but adequately powered. No boat battery changes were done throughout day. Tom says he would like to add solar film to top to charge battery during surveys.
2. Boat uses 4G radio comm and line of site comm – very efficient. We never lost comm from boat to operator. Near the powerhouse they switched from 4G to LOS because of the radio interference.
3. Boat is very low profile, only about 12" of draft and 4" above waterline. However the hatch leaked and the bilge pump had to run. Hatch was taped down. Tom says next generation will have gasketed hatch.
4. Boat is untested as a survey instrument in high flows. Really the boat is untested with regard to any survey... only Keokuk and Bagnell. The boat is really good in surf, but not tested with regard to instrumentation. This company does not have the depth to understand efficient survey methods, but they can build boats and control them.

END OF NOTES

MEMORANDUM

To: File

From: Pete Haug

Date: June 25, 2018

Project No.: 63-0538.00

Re: EMILY Demonstration at M-38 over Sturgeon River near Baraga MI

Arrived onsite at 1430hrs EDT on June 25, 2018. Andy Chosa (517-256-9149) and his partner (an ex-Navy diver named Jeffery Loman) had the EMILY unit in the back of a F-150. The vessel was about 60 to 70 inches long and powered by a single jet. The jet intake was a horizontal screen mounted flush with the boat hull on the underside. Andy said the hull was Kevlar-reinforced fiberglass and the screen was a custom metal fabrication (custom slot size). EMILY is owned by several local fire departments (Marquette, Manistique, and next will likely be the Pictured Pocks park. Primary use is retrieval of swimmers caught in rip currents or offshore currents.



EMILY has partnered with Humminbird (side scan supplier for commercial fishing vessels). The Humminbird system as demonstrated included the following:

- Real-time side scan sonar imaging (pixilation quality was less than our StarFish 990F but was sufficient to see 12 inch riprap and general bedforms)
- Real-time depth reports, displayed to 0.1 feet onscreen but probably no more accurate than 0.5 feet based on how the readings fluctuated on the screen.
- Overlaid inland river map (Navionics?)

The EMILY and Humminbird system was very easily deployed. From the back of truck, the EMILY was removed from a zippered red cushion case, the top vessel foam was removed, a single battery box was inserted and connected, the sonar system power cable was hooked up (one cable), the foam pad was replaced on top of the vessel, the Humminbird transducer was screwed into the back of the vessel (two ¼-28 NF socket cap screws?), and the vessel was launched.

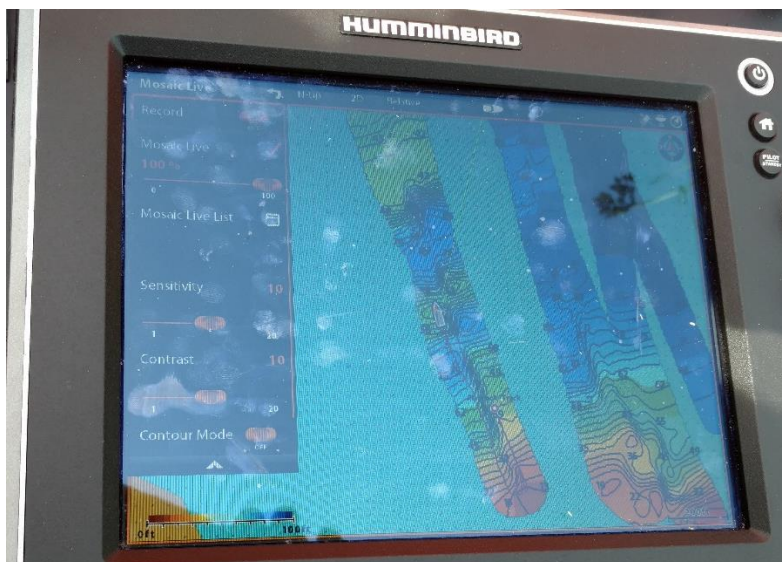
The weight of the vessel as tested was less than 40 pounds. The normal rescue version was 25 pounds, but the Humminbird, onboard GPS, oversized battery, and upsized motor weigh more. The vessel has nice straps that allow one person to carry it easily.

The unit has sufficient power to run 15 knots. It planed out in a half second, and the steering on this jet is remarkably agile. The 5 foot long vessel can travel in circles with a 10 foot diameter. Andy thinks the unit can go 25 miles per hour unloaded, but with the extra gear it is probably 15 knots of top speed. I witnessed it traveling at least 10 knots up on plane.

Communication was good. The transducer/gps unit lost communication with the Humminbird display about four times over two hours, but each outage was only for 10 seconds or so. Surprisingly the connection was not lost when the unit went behind the pier or far downstream, but rather the unit seemed to lose connection when it was right near the display (perhaps too close?). The radio control (jet motor and steering) never lost communication.

So far, since 2015 and these two guys started the EMILY sales, they have only had one cracked hull and that was apparently due to a fire department guy running the unit at top speed over a beaching wave and straight into a rocky shore. The unit has good padding all the way around. I would sooner think the side scan transducer would be damaged than the hull.

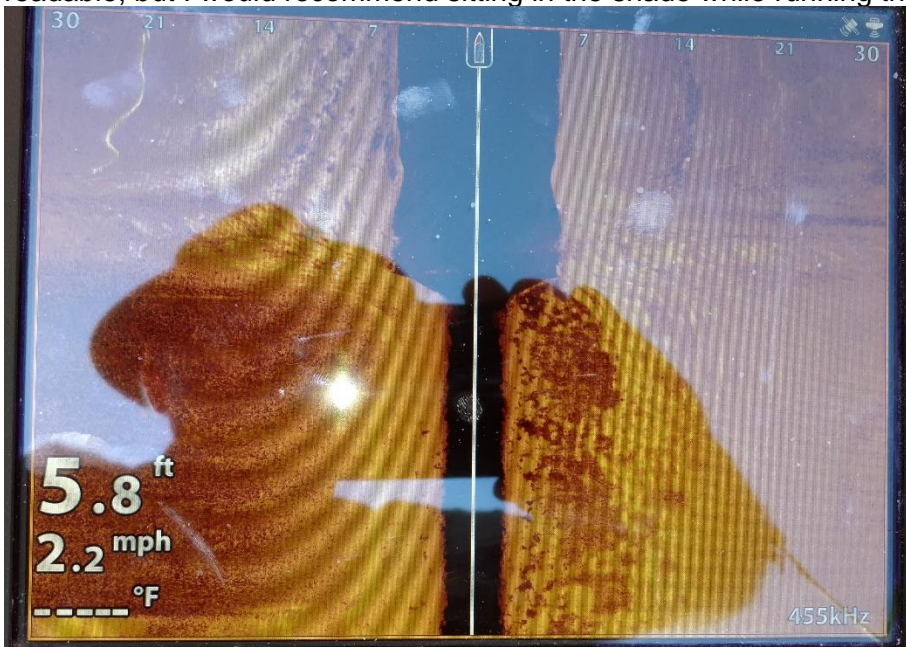
Humminbird does not have super great quality images, but they do make the operation of this vessel very easy. They apparently have a “mosaic function” that can piece all the data together in one image (below) and Andy believes Humminbird will provide a program to download the survey data in a xyz file.





Above is the control for the side scan and survey gear. It is simple – plug in the battery pack, plug in the antenna cable, hit the power button, learn the Humminbird menu options, survey.

You can see the side scan display barely in the above photo. The screen was daylight readable, but I would recommend sitting in the shade while running this.



All in all, this was the best value boat I have seen so far. Andy thinks the cost will be \$35k per boat and he is getting me a quote. I think the company is based in MI – that is a plus for long term support. Andy says they can supply parts and provide call service if field staff have operation issues or break something.

Videos and pictures are at:

Y:\Structural Inspection\MI\MDOT\Unmanned Vessel\Site Visit\EMILY - MI 2018\June 25 photos

Takeaways:

- 1) Vessel is easily deployed. Setup time was 10 minutes. I could see this system surveying six bridges a day if they were within 30 minutes of each other.
- 2) Humminbird is commercially available but it is not survey grade sonar. Pixel quality was about ¼ of the StarFish 990F quality. However, for a quick field assessment of bridge scour, the Humminbird might be good enough.
- 3) Humminbird has the best communication system I have seen so far – no externally exposed antenna and very little communication outages.
- 4) The propulsion system is light in weight but well-powered.
- 5) The hull is fiberglass but well-cushioned from pier strikes.
- 6) I am concerned that Humminbird is using a sportsman GPS (2m accuracy) and sportsman transducer (0.5 foot repeatability) but again, this might be good enough for a quick assessment of bridge scour potential.

END OF NOTES

MEMORANDUM

To: File

From: SAB

Date: September 27, 2018

Project No.: 63-0538.00

Re: EMILY Demonstration in Niles, MI

Contacts: Jeffery Loman, Hydronalix Representative

Location: West Main St/STH 139 over St. Joseph River in Niles, MI

Purpose: To determine how well the sonar EMILY would perform in a scenario that simulates the conditions in high flood events

Site Conditions: current was approximately 5 feet/second, debris was floating down the river, heavy weeds along east shoreline, sunny and 60 degrees Fahrenheit

Demonstration: Hydronalix set up all the equipment for the sonar EMILY, deployed it, and maneuvered it through the river to the bridge. The demonstration allowed MDOT staff to ask questions about the product and operate the boat. After the demonstration, the boat was disassembled for MDOT to view all the pieces of the EMILY and ask any additional questions. While the EMILY was in the water, Ayres Associates also had a remote controlled (RC) boat operating in the water.

Takeaways:

- 1) The EMILY demonstration was successful. The boat did not have trouble navigating through the river.
- 2) There were minor complications with the battery.
- 3) The Hydronalix staff were helpful in answering questions.

MEMORANDUM

To: File

From: Pete Haug

Date: October 26, 2018

Project No.: 63-0538.00

Re: EMILY demonstration near Bay City MI

Arrived at 0715 at Salzburg Avenue / Highway 13 / Lafayette Street Bridge over the Saginaw River near Bay City MI.

Starting at about 0740, Jeff Loman of Great Lakes Unmanned Systems and Paige Day of Hydronalix demonstrated the Sonar EMILY system. About eight MDOT staff, including Bridge Inspection Engineer Chad Skrocki, were present to witness the demonstration.

Setup was simple. The boat was unloaded from a ½-ton pickup and the radio antennas connected. Batteries were connected inside the hull. The foam top was latched onto the fiberglass hull, and the boat was ready to connect to the shore station. The shore station is a pelican case with a large Humminbird display (photo below) and several cable connections.



At 0750, the boat was connected via radio and line-of-sight (LOS) to the shore station. At 0752 the boat was placed in the water and operated per the photo below.



The above photo shows the western channel bridge is a single pile cap with four concrete columns reaching upward to support a single top header beam. With just the 2-inch tall antenna, the EMILY LOS kept disconnecting from the shore station, so at 0830 hrs the 4 foot antenna was attached and is slightly visible just over the pier wall in the photo below.



This too kept disconnecting, but eventually a loose coaxial cable was found and the EMILY then had far less connection issues. Generally, the EMILY could transmit the sonar image as long as the boat was not stationary behind a pier column. The data transmission range was later tested as 0.3 miles as long as LOS was maintained.

The observers noted that at Niles, the EMILY signal seemed to transmit to the shore station even when the boat was behind piers. Hydonalix could not explain what at the Lafayette bridge was the reason for the sonar transmission failure every time the boat spent more than 3 seconds behind a pier column.

The new thru-hull mount is neither a moon pool nor flush mount system, but more a hybrid. There is a 0.5 inch recess under the cut hull, and the sonar face sits in this recess. I speculated that air could be trapped in this area and distort the sonar image, but I did not see any field evidence that air pockets trapped in this area detracted from the image quality. Chad and I were able to “burp” the air pocket, but anytime the boat planes out then more air is introduced to this area again. Based on my field observations, I do not feel that this air pocket potential negatively impacts sonar performance.



EMILY is fast. Even with the larger Humminbird sonar unit, it immediately planed out when the trigger was depressed. Jeff Loman told me the trigger was set at a maximum less than the full throttle range, so he said the boat could go even faster. However, he said there is a significant loss of battery life when the boat is operated at full throttle, plus the added risk of boat impacts to structure and loss of control (rolling). The Saginaw was flowing at only 0.5 (west channel) to

1.5 (east channel) feet per second – and Jeff did say that for rivers at 6 feet per second he would recommend increasing the throttle range. Note that this observed configuration had 4 batteries, not 8 in the hull. MDOT wants the delivered version to have 8 batteries.

Water temp was 46F and air temp was 42F at 0715 and 53F at 1400 hrs.

At about 0900 hours, the observation team moved the shore station to the west bank because the bridge piers prevented signal transmission when the EMILY surveyed the westernmost span. LOS was nearly 100% when at the downstream left bank position in the park. At 1000 hrs the 4 pack of batteries was replaced in the boat and the crew moved to the eastern bridge section in the below photo.



The bascule bridge has an interior access walkway via the control tower (center of photo above) so the boat was hand carried by 2 staff down two stairways and lowered by rope 15 feet down to the water below. The staff appreciated that the boat was only 45 or 50 pounds, fully loaded.



The antenna from the shore station (on the deck where the above photo was taken) was draped downward and the boat did not lose signal that I witnessed thereafter.

Eventually the crew brought the shore station back to the bridge top deck and tested the max LOS range by running the boat downstream until the sidescan image disappeared. This was computed to be 0.31 miles from shore station at point of signal loss.

The boat ran until 1130 hrs and then the second 4 pack of batteries was depleted.

At 1340 hrs, the team met at the Saginaw regional office for MDOT and discussed the plan forward. MDOT would like a gopro on the boat (screw in mount provided by EMILY) and the signal transmitted to a handheld display for the boat operator. Ideally this would be a wide angle camera lens that is waterproof (display for operator, radio, camera on boat – all waterproof).

Hydronalix has teamed with Black Laser Learning to develop the SAR Hawk acquisition and processing software. It comes with the EMILY and the SAR Hawk creator Vince Capone is available for technical support (Paige calls him often she says). The SAR Hawk can export base maps to the Humminbird display and autonomous navigation in the EMILY is accomplished via a phone app that sends waypoints to the EMILY onboard nav system.

MDOT would like 3 double packs of batteries per boat (one to power the shore station, two to power the boat – swapped after 3 hrs). Paige says the shore station should run all day easily with 8 batteries and the boat should run 4 hours or more on an 8-pack.

MDOT would also like battery indicators somewhere – how much life is left in boat? Or voltage?

EMILY cost includes training but MDOT needs to account for travel if that is separate.

MDOT would like standalone computers for each boat to be separate from the MDOT system.

MDOT would like a longer antenna to hang off the bridge deck – maybe hang so antenna is 12 to 16 feet below top of parapet? Need a small secondary cable to prevent coax from taking all antenna whip load in wind under bridge.

MDOT would like the antenna on the boat to be about 2 foot tall antenna in addition to the 4 foot one for each boat. Some bridges are too close to water for a 4 foot antenna.

MDOT would like a spare part list and a set of commonly broke components

EMILY wants the MDOT logo to put on the fabric.

EMILY is warranted for parts and labor at 100% for one year. However they are sticking behind their quality and would likely assist as possible for future repairs.

I left MDOT's facility at 1435 to make my flight.

END OF NOTES

Appendix F
Equipment List

Equipment List

Sonar EMILY



Prepared for:

Michigan Department of Transportation

5/24/2019

Equipment List

Sonar EMILY



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www.AyresAssociates.com

Ayres Associates Project No. 63-0538.00

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1.0 Equipment for the Sonar EMILY Vessel

The following list is the equipment included with the Sonar EMILY vessel.

- Travel Stand
 - Figure 1
- Sonar EMILY with Flotation Device
 - Figure 2
- Sonar EMILY without flotation device
 - Figure 3
- Inside hull
 - Dual battery pack installed
 - Figure 4
- User Manual
 - Figure 5
- Sonar EMILY on stand
 - Flotation device and antenna installed
 - Figure 6
- Remote Control for Sonar EMILY
 - (8) AA Batteries
 - Storage Case
 - Figure 7
- Mini Toolbox
 - Waterproof grease
 - Silicone
 - Allen keys
 - Crescent wrench
 - Wire clippers
 - Screwdrivers
 - Superglue
 - Application brush
 - Multi-tool
 - Box cutter
 - Zip-ties
 - Cell meter
 - Cell meter instructions
 - Figure 8
- Batteries with Waterproof Case
 - (24) 3-cell batteries
 - (3) waterproof cases
 - Figure 9
- Battery Charging Set Up
 - (2) Charging ports
 - (1) Cell meter
 - Figure 10

- Above water cameras on top of EMILY
 - GoPro and charger
 - GoPro transmission and chargers
 - Rylo and chargers
 - GoPro footage viewer (EACHINE) and cables
 - Case for GoPro, Rylo, and screen
 - Micro SD cards for Rylo and GoPro
 - 2nd Battery for GoPro
 - 2nd Battery for Rylo
 - Figure 11
- Payload Station
 - Saw Hawk Software
 - USB drive containing software
 - USB software key
 - Display Screen
 - Travel case
 - Figure 12
- Yellow Pelican Case
 - Payload station
 - Remote carrying case
 - Figure 13
- Flag Antennas
 - (2) for Sonar set up
 - (1) for EMILY
 - Figure 14
- Bilge Pump
 - Figure 15
- Towels
 - (2) towels
 - Red or yellow
 - Figure 16
- Miscellaneous Spare Parts
 - (1) Inlet grate
 - (2) Steering arm boat seals
 - (1) Electrical anti-corrosion solution
 - (1) Impeller
 - (1) Lanyard
 - (1) Waterproof Spray
 - Figure 17
- Portable charger and USB wall charger
 - Pocket juice portable charger
 - USB wall charger for above water cameras
 - Figure 18
- Toolbox
 - Storage for spare parts, tools, batteries, and chargers
 - Figure 19

- Data acquisition laptop
 - Laptop and case shown
 - Power supply and mouse not shown
 - Figure 20
- Yellow Pelican Case before modification
 - Stores payload station, cameras, and EMILY remote
 - Figure 21
- Yellow Pelican Case after modification
 - One layer of foam removed from right side of case below slot for remote
 - Carrying case for above water cameras stored below remote where foam was removed
 - Figure 22
- Yellow Pelican Case after modification
 - Payload station and camera storage case in place
 - Figure 23
- Battery charging bags
 - From APEX RC Products
 - (4) total
 - Figure 24
- Lights and mounting bracket for GoPro Camera
 - From Lume Cube
 - Figure 25
- Additional parts not shown
 - AA batteries for EMILY remote (24 pack)
 - USB extension for SAR Hawk software key



Figure 1: Travel Stand Boat Resting Skids



Figure 2: Travel or Storage Mode



Figure 3: Sonar EMILY without Floatation Device

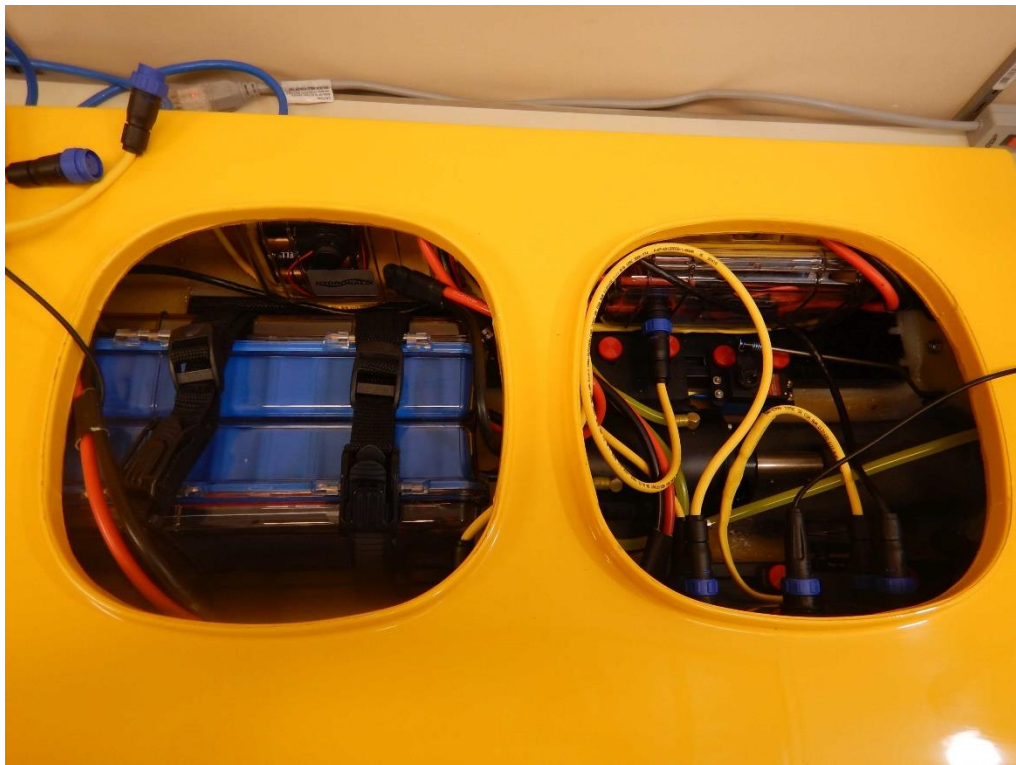


Figure 4: Dual Battery Pack Installed Inside Hull

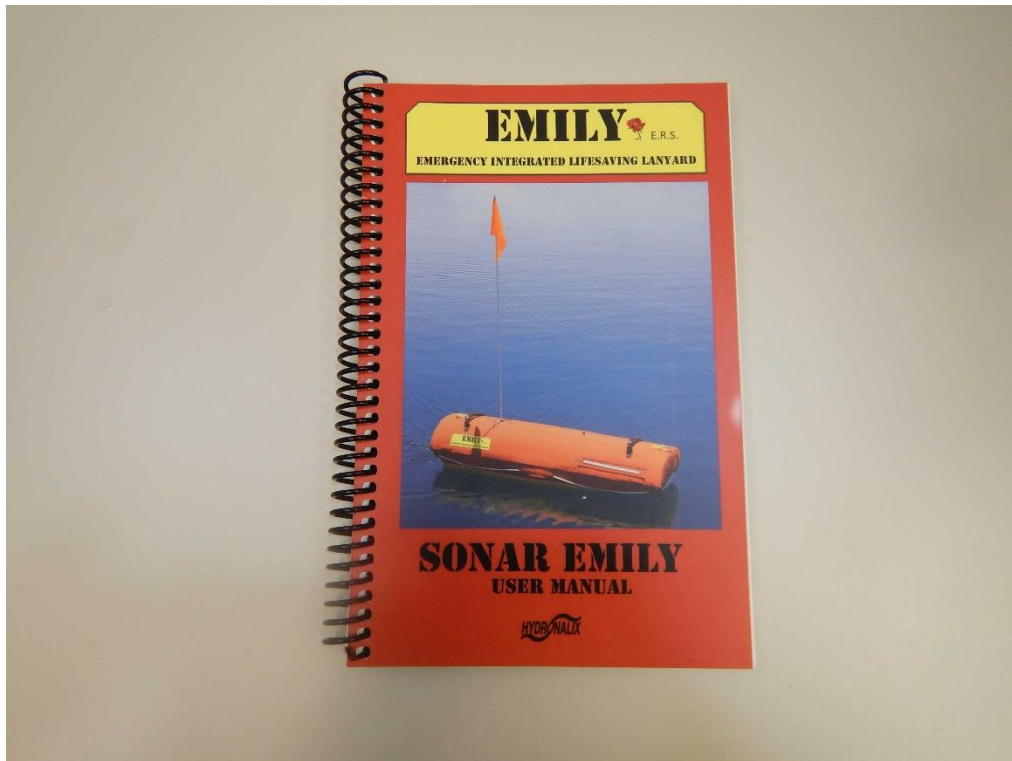


Figure 5: Owner's Manual



Figure 6: Sonar EMILY with float and antenna installed



Figure 7: Remote Control, Storage Case, and AA Batteries



Figure 8: Mini Toolbox



Figure 9: Batteries and Waterproof Case



Figure 10: Battery Charging Set Up



Figure 13: Yellow Pelican Case with Payload Station and Remote Storage Case

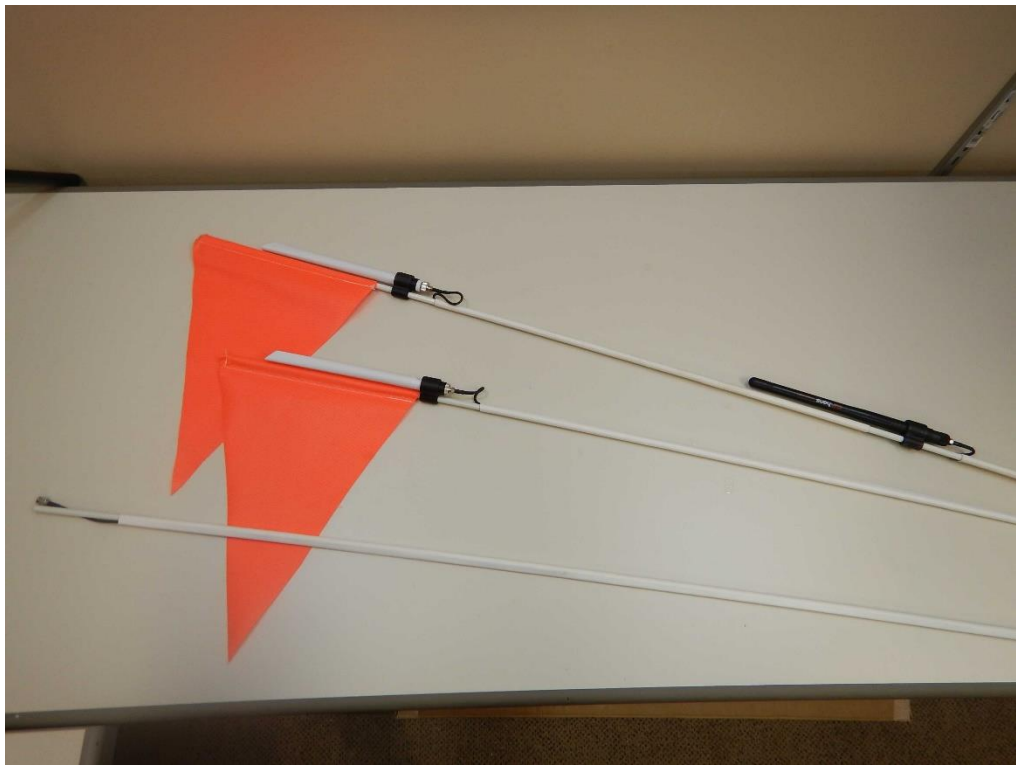


Figure 14: Flag Antennas



Figure 15: Bilge Pump



Figure 16: Towels (2)



Figure 17: Miscellaneous Spare Parts



Figure 18: Portable charger and USB wall charger



Figure 19: Toolbox



Figure 20: Data Acquisition Laptop and Case



Figure 21: Yellow Pelican Case Before Modification



Figure 22: Yellow Pelican Case After Modification



Figure 23: Yellow Pelican Case After Modification

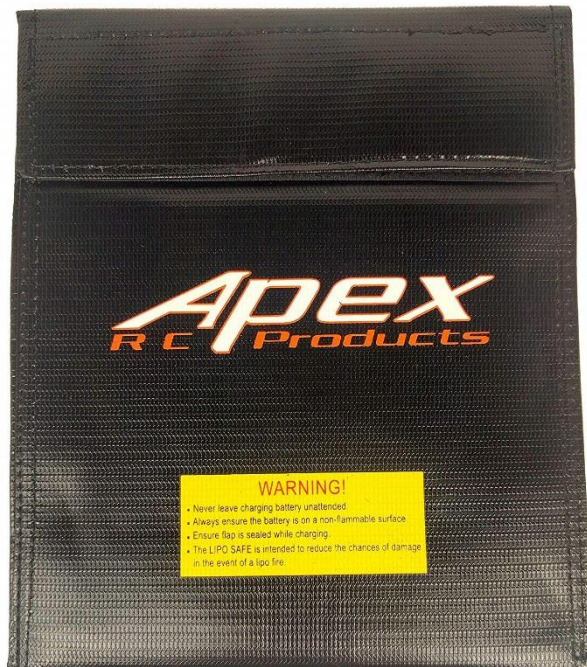


Figure 24: Battery charging bags from Apex RC Products



Figure 25: Lume Cube Lights and Bracket for GoPro Camera