RECLAMATION

*Managing Water in the West*

# Testing of Commonly used Fish Screens for Resistance to Invasive Mussel Fouling

**Research and Development Office**
**Science and Technology Program**
**Final Report ST-2016-5740-1**

**HL-2016-03**


**Josh Mortensen, Hydraulic Engineer, P.E.**
**Cathy Karp, Fisheries Biologist**



**Research and Development Office**
**Bureau of Reclamation**
**U.S. Department of the Interior**

**September 2016**

# Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

# PEER REVIEW DOCUMENTATION

## Project and Document Information

| | |
|---|---|
| Project: | Testing of Commonly used Fish Screens for Resistance to Invasive Mussel Fouling |
| WOID: | Z5740 |
| Document: | Final Report |
| Author: | Josh Mortensen, Cathy Karp |
| Date: | September 2016 |
| Reviewer: | Joe Kubitschek, PhD, PE |

## Review Certification

**Peer Reviewer:** I have reviewed the assigned items/sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy

Reviewer JOSEPH KUBITSCHEK Digitally signed by JOSEPH KUBITSCHEK Date: 2016.09.06 14:38:43 -06'00'

(Signature) Date

**Preparer:** I have discussed the above document and review requirements with the peer reviewer and believe that this review is completed, and the document will meet the requirements of the project.

Author JOSHUA MORTENSEN Digitally signed by JOSHUA MORTENSEN Date: 2016.09.06 14:30:13 -06'00'

(Signature) Date

**Preparer:** I have discussed the above document and review requirements with the peer reviewer and believe that this review is completed, and the document will meet the requirements of the project.

Author CATHERINE KARP Digitally signed by CATHERINE KARP Date: 2016.09.06 14:26:42 -06'00'

(Signature) Date

# Disclaimer

The information provided in this report is believed to be appropriate and accurate for the specific purposes described herein, but users bear all responsibility for exercising sound engineering judgment in its application, especially to situations different from those studied. References to commercial products do not imply endorsement by the Bureau of Reclamation and may not be used for advertising or promotional purposes.


# Acknowledgments

Many thanks go to the following:

- Brent Mefford for his enthusiasm and vision of this project
- Denver Hydraulics Laboratory Shop staff for their hard work constructing, modifying, and maintaining the floating test facility
- Intake Screens Inc. (ISI) and Hydrolox for providing their screen systems for testing
- Allen Skaja from Reclamation's Materials Engineering and Research Lab for help with the coatings

# Contents



# Tables



# Figures

# Executive Summary

This research project was conducted to better understand potential invasive mussel impacts to fish screens and cleaning systems that are in common use by Reclamation and our managing partners. Three fish screen systems (ISI Cylindrical screen with a brush cleaner, Hydrolox vertical traveling screen, and flat plate wedgewire screens with a brush cleaner) were tested using a floating test facility located in Lake Mead, NV from November 2011 through June 2016. The most significant finding from this study, common to all three screen types, is that existing cleaning systems were effective in preventing fouling of the fish screens provided they consistently operated as designed. Conclusions specific to each cleaning system are as follows:

- **Hydrolox Vertical Traveling Screen –** Operated for over 24 months with few problems and limited maintenance. While there was no mussel attachment to the main traveling screen, there was significant mussel settlement on the exterior and interior screen steel frame and supports. The main traveling screen remained mussel free as long as it stayed in motion, moving in and out of the water. In contrast, Hydrolox control screens that were continuously submerged (stationary or moving) became heavily fouled with mussels.

- **ISI Cylindrical Wedge-wire Screen –** Operated for over 24 months with few problems and limited maintenance. The main screen area remained free from mussel attachment as long as the brush cleaning system operated correctly and consistently. There was significant mussel settlement on the screen frame and edges of the screen where the brush could not reach. With the exception of a limited number of mussels attached to the inside of the screen, the main area of the screen that was regularly brushed remained clean with minimal impacts to flow through the screen.

- **Flat Plate Wedge-wire Screen –** Operated for about 21 months with few problems and limited maintenance. Results were similar to the cylindrical screen in that the main screen remained free from mussel attachment as long as the brush cleaning system operated correctly and consistently. The orientation of the wedgewire did change the effectiveness of the brushing. Wedgewires aligned with the brush (parallel with brushing motion) removed almost all live mussels, shell debris, and biofilm from the screen. However, wedgewires aligned perpendicular to the brushing motion prevented some of the shell debris from being removed which blocked a small portion of the screen area. The coating (Jotun SeaLion Resilient) that was applied to the flat plate screens showed no signs of damage or wear from the cleaning brushes and was successful in reducing mussel attachment on the screens within the test channel.

# Introduction

Quagga mussels (*Dreissena bugensis*) and to a lesser extent, zebra mussels (*D. polymorpha*) have become established in the Western United States. These fresh water invasive species are thought to have been transported from Eurasia to the Great Lakes Region and then migrated to other water systems throughout the U.S. (Figure 1). Quagga mussels were first discovered in Lake Mead, Lower Colorado River, in 2007, and are now widespread in the Lower Colorado River Basin, including water conveyance systems (i.e., canals and associated water resources infrastructure), and have been detected in other river basins in the west. Mussels can clog fish screens, trash racks, and intakes which then impedes water flow and impacts efficiency of fish diversion systems (Mackie & Claudi, 2010).

The threat of mussel impacts to fish protection systems is of particular concern for the west coast regions of the U.S. which contain numerous fish screening facilities. This is illustrated by the recent and growing presence of quagga mussels in southern California (Figure 1). The current research project tested fish screen systems in mussel-infested water to improve our understanding of the potential impacts of mussels on common fish screens and cleaning systems currently in use (Bureau of Reclamation, 2006).

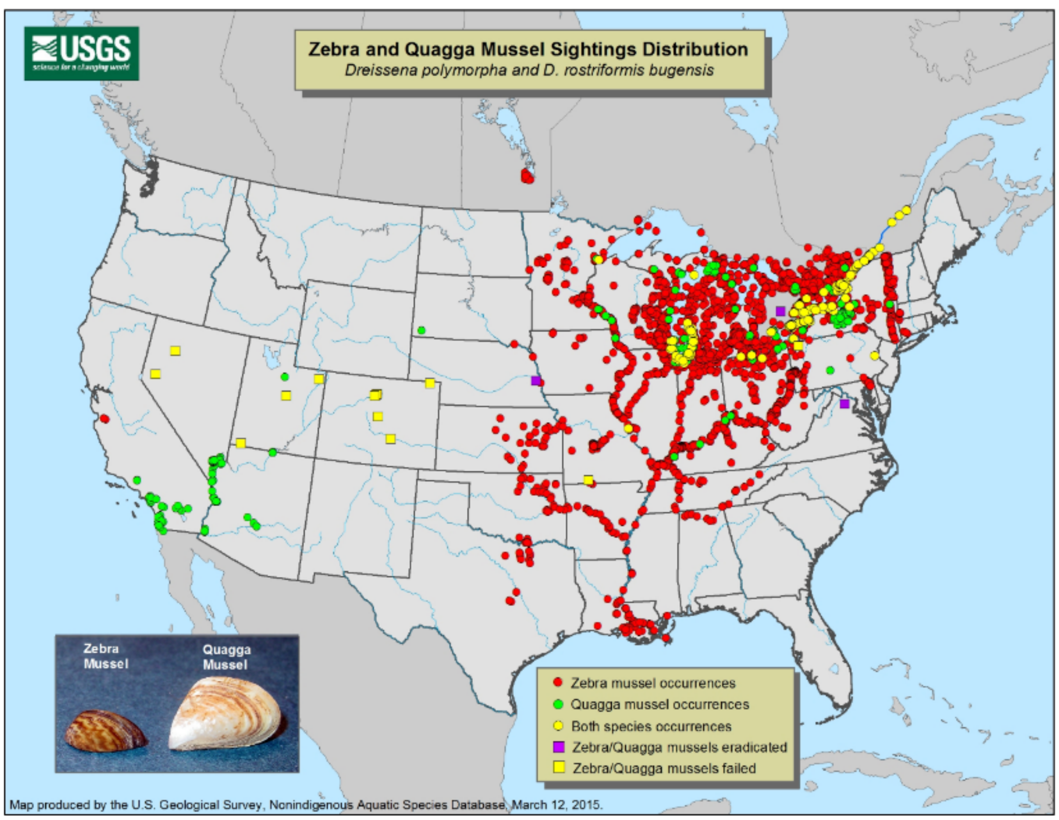



Figure 1 Map of quagga and zebra mussel distribution in the U.S. as of March 2015. (http://nas.er.usgs.gov/taxgroup/mollusks/zebramussel/maps/current_zm_quag_map.jpg)

# Objective

The main objective of this study was to determine the impacts of invasive mussels on commonly used fish screens and associated cleaning systems. Understanding fouling rates, impacts to operation and maintenance, and cleaning system performance is an important proactive step to maintain acceptable (i.e., within required criteria) screen hydraulic performance and effectiveness in the presence of invasive mussels.

# Testing Approach & Experimental Setup

Three common fish screen systems were tested using a floating test facility at Lake Mead Marina from November of 2011 to June of 2016 where quagga mussels are established and reproduce year round (Wong *et al*. 2012 and Holdren *et al*. 2012). The test facility consisted of a pontoon boat modified to pump lake water through the fish screen systems before returning it to the lake. The most valuable test method for this research was visual observations of the different screen systems compared to static screen samples that were continually submerged without cleaning. Visual comparisons were documented about every month for a period of about two years for each screen system. While these results were supplemented by some water quality and hydraulic measurements (water temperature, veliger counts and screen velocities & head loss) as well as maintenance records of each screen system, the most useful data were qualitative visual observations.

## Hydrolox Vertical Traveling Screen

Hydrolox™ traveling screens are common at many irrigation diversions and other intake structures throughout Reclamation (Figure 2). The screens, made of engineered polymer sections that interlock, continuously move in the vertical direction by rotating around a stationary bar submerged near the bottom and are driven by a motorized shaft at the top which is never submerged (see video demonstration in Figure 3). Hydrolox screens typically have a spray wash system to remove debris as the screen comes out of the water. Some locations apply pegs or bars to the polymer mesh that rotate with the screen for heavy debris applications. The Hydrolox tested in the floating test facility used neither the spray wash system nor pegs and was a single section of the S1800 Series screen that was approximately 40-inch wide and 60-inch tall.

Figure 2  Hydrolox screen at Reclamation's Shell Rock facility near Yakima, WA. (http://www.hydrolox.com/project.aspx?id=2147483694)

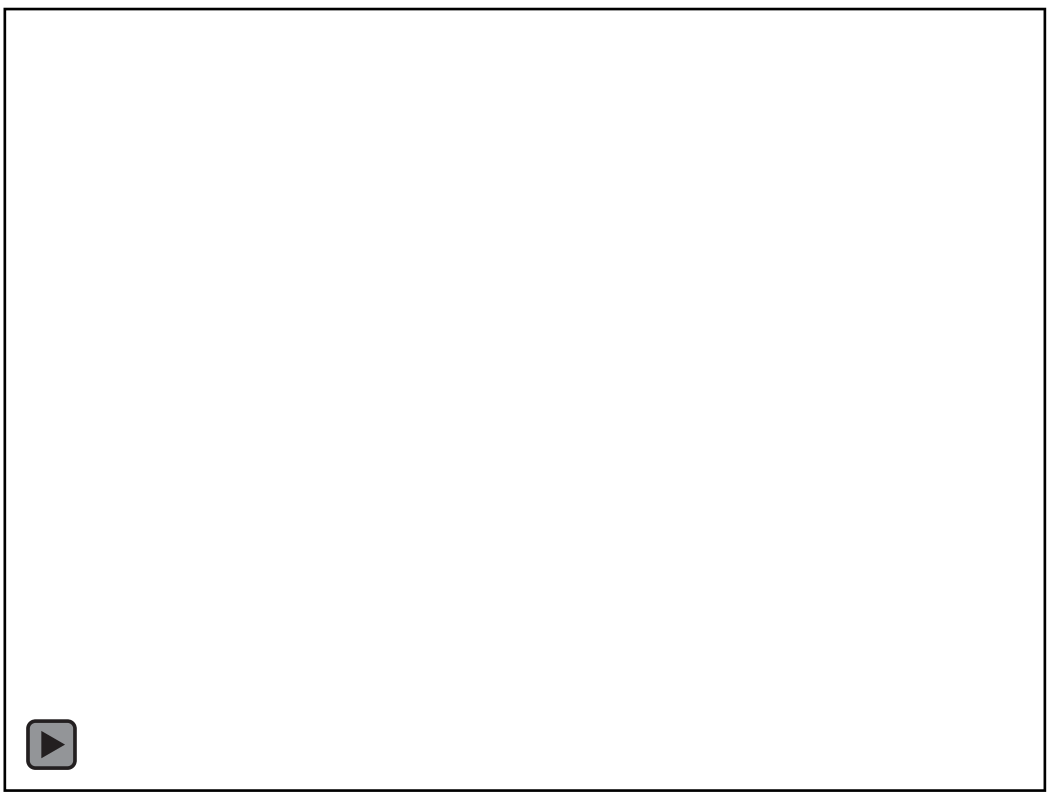


Figure 3  Video of Hydrolox screen operation in the floating test facility (looking upstream).

## ISI Cylindrical Screen

Intake Screens, Inc. (ISI) manufactures stationary cone and cylindrical shaped screens that have applications for low flow intakes or locations with heavy debris such as floating trees or ice. To avoid damage from ice or floating debris the cylindrical screens can be lifted out of the flow (Figure 4) or retrieved for maintenance. The screens are made of stainless steel wedgewire with interior supports. The cylindrical screen tested under this project was approximately 36-inch in length, 30-inch in diameter and had screen openings of 1.75 mm which were cleaned by rotating the screen through a stationary brush on both the outside and inside of the screen (Figure 5). Screen rotation was repeated in the opposite direction. A silicone foul release coating (Fuji) was applied to portions of the frame and internal flow baffle to reduce mussel settlement on those components.

Figure 4 ISI cylindrical screens at Reclamation's Lower Yellowstone Intake Canal headworks near Glendive, MT. (http://intakescreensinc.com/projects/intake-dam/)

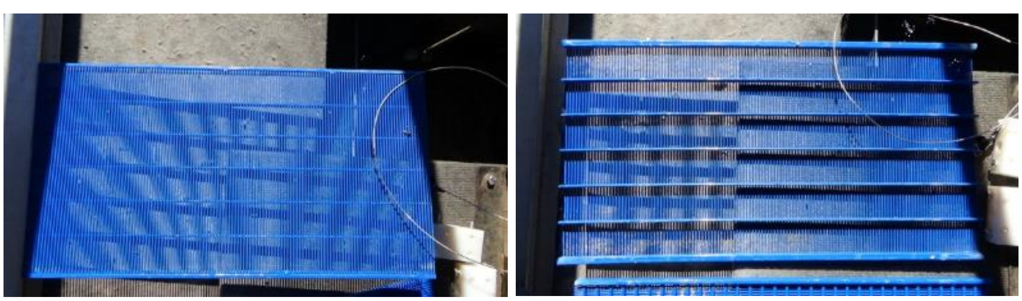

Figure 5 ISI cylindrical screen brush cleaning system at Lake Mead Marina test facility.

## Flat Plate Screen

Flat Plate fish screens are common for facilities that are required to screen large volumes of water such as the Red Bluff Pumping Plant Intake (Figure 6). These screens are made of stainless steel wedgewire typically with 1.75mm openings and brush cleaning systems similar to the ISI cylindrical screens.

Figure 6 Flat plate fish screen at Reclamation's Red Bluff Pumping Plant in Northern, CA. (http://agc-ca.org/uploadedImages/Spotlight/Photos/July_2013/Balfour_1.jpg)

Flat Plate test panels used for this study were approximately 12-inch-wide by 24-inch-tall with a vertical brush cleaning systems. With help from Reclamation's Materials Engineering and Research Lab (MERL), screens were coated with a Jotun SeaLion Resilient coating which the manufacturer claims to be both durable and mussel-resistant (Figure 7). Flat Plate screens with brush cleaners but without coatings were not tested during this project.



Upstream side Downstream side

Figure 7 Jotun SeaLion Resilient coating on a flat plate screen panel that was tested in the floating facility.

## Floating Test Facility (Pontoon Boat)

The three fish screen systems were installed on a pontoon boat that had been modified with a mixer propeller and rectangular test channel to pump flow through each fish screen system (drawings shown in Appendix A). The test facility required electric utilities available at the marina to power the mixer and screen cleaning systems (Figure 8). Several stainless steel and Hydrolox screen samples were hung off the boat at a depth of approximately 12 feet below the surface as well as in the test channel to serve as static screens for comparison.


Figure 8  The floating test facility (pontoon boat) moored at the Lake Mead Marina dock.

The ISI cylindrical screen and Hydrolox traveling screen systems were tested simultaneously. Figure 9 shows the ISI screen mounted just below (upstream) the mixer propeller (Figure 10) that pulls flow through the screen and into the test channel where it passes through the Hydrolox screen before returning to the lake out the rear of the boat (Figure 11). A rolling gantry hoist was used to position the screen systems and to retrieve the ISI screen for inspection and maintenance. The ISI screen was cleaned during three brushing cycles per day (every 8 hours) and the Hydrolox traveling system operated continuously.

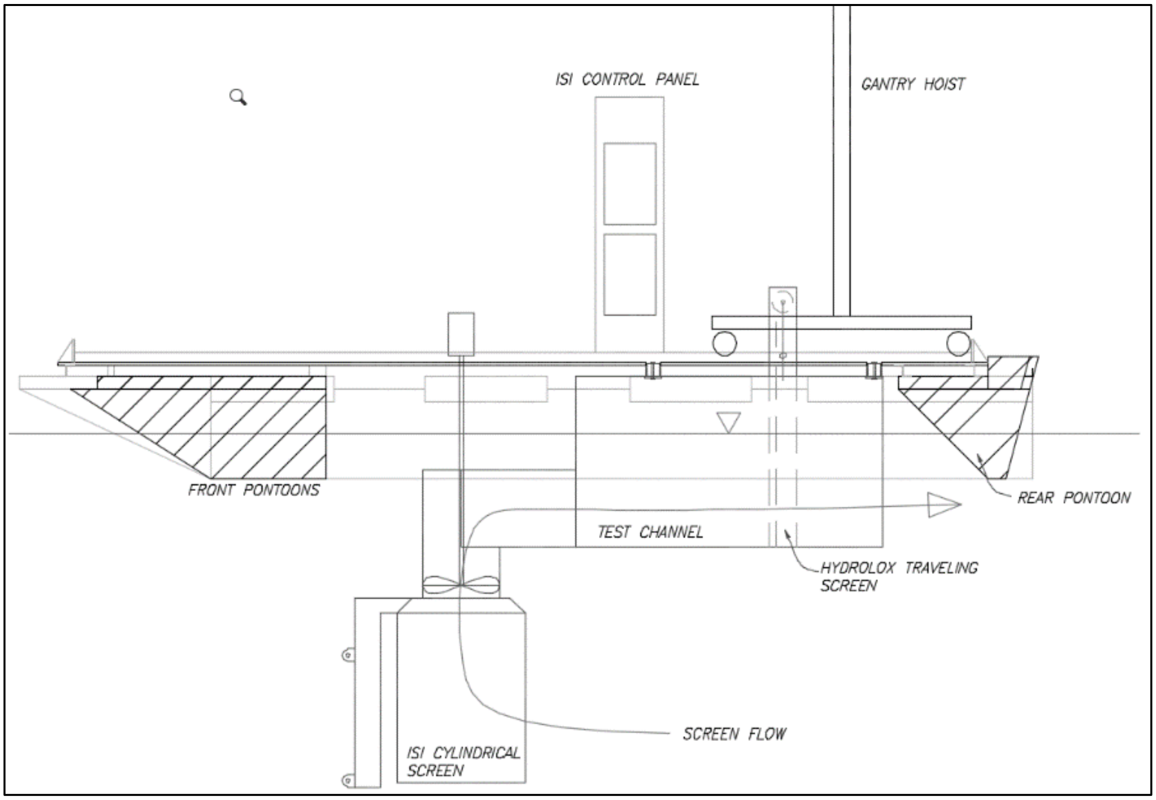



Figure 9  Schematic of the floating test facility with the ISI and Hydrolox screen systems.


Figure 10  Mixer propeller that drives flow through the ISI screen and into the test channel.


Figure 11 Hydrolox screen mounted in the downstream test channel near the rear of the pontoon boat (flow is right to left through test channel which is not visible in the photo).

Testing on the ISI and Hydrolox screens was completed in September 2014 and the test facility was modified to conduct testing on the flat plate screens with a combination brush cleaning system and new coating (Jotun SeaLion Resilient). Two rows of flat plate screens were installed in the downstream end of the test channel. The mixer provided flow into the test channel and through two rows of flat plate screens with three screen panels in each row (Figure 12). The 1st row had vertical wedgewire screens aligned parallel to the brushing motion while the 2nd row wedgewire was horizontal and perpendicular to the brushing. Table 1 shows how the six screens were configured and the variables that were tested with this setup. The center screens in both rows were cleaned with 2 brushing cycles per day (every 12 hours). Appendix A shows additional drawings of the modified test facility.

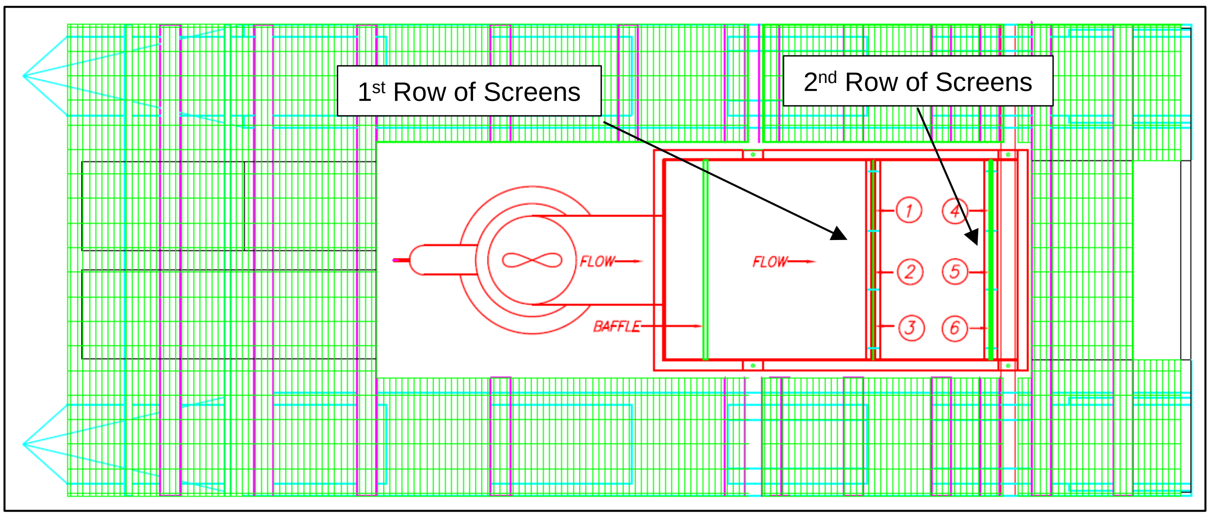



Figure 12 Plan view layout of modified test facility with two rows of flat plate test screens (Table 1). Water comes up through the mixer and flows left to right through the test channel and screens.

Table 1 Flat plate variable matrix.

| | **Left Screen** | **Center Screen** | **Right Screen** |
|---|---|---|---|
| **1st Row (upstream – vertical wedge-wires)** | Coated | Coated & Brushed | Stainless Steel Control, no coating, no brushing |
| **2nd Row (downstream – horizontal wedge-wires)** | Coated | Coated & Brushed | Stainless Steel Control, no coating, no brushing |

# Test Results and Discussion

Testing was conducted over approximately 4 ½ years (Figure 13) to observe mussel impacts on each fish screen system over multiple reproduction cycles. Quagga mussel reproduction typically increases in spring and fall at Lake Mead (Holdren *et al*, 2012) and a similar trend was found throughout the test period of the current study (Figure 14). Water temperature was monitored throughout the entire test period as very warm temperatures (approximately 86°F) may prevent mussel settlement (Wong *et al*, 2012). Figure 13 shows daily average water temperatures at 10 ft below the surface which approached that threshold every summer in the 4 ½ year test period. The summer of 2012 was especially warm which may have contributed to a mussel die-off observed at the test facility during that time. This die-off was also indicated by the noticeable drop in veliger counts during June of 2012 (Figure 14).

Also, to help assess mussel settlement, static screen samples were hung on the outside of the boat as well as within the test channel for comparison to the test screens. These static samples were most valuable in interpreting test results throughout the study (Figure 15).

Over the 4 ½ year period testing was conducted in three phases as shown in Figure 13. The test facility was installed at Lake Mead in November of 2011 with the intent to immediately begin testing the ISI and Hydrolox systems. However, continuous operation of active systems without fulltime attendance proved difficult as mechanical and electrical failures frequently prevented the systems from running continuously, especially during extremely warm outside temperatures which occur during the summer months. As such, November 2011 to about September 2012 involved a shakedown period when several minor modifications to the mechanical and electrical systems were made which helped resolve these issues. Successful testing of the ISI and Hydrolox screens was completed between about September 2012 and September 2014 with only a few minor interruptions in service. The ISI and Hydrolox systems were then removed and flat plate testing was conducted from September 2014 through June 2016 with only a few minor interruptions in service.

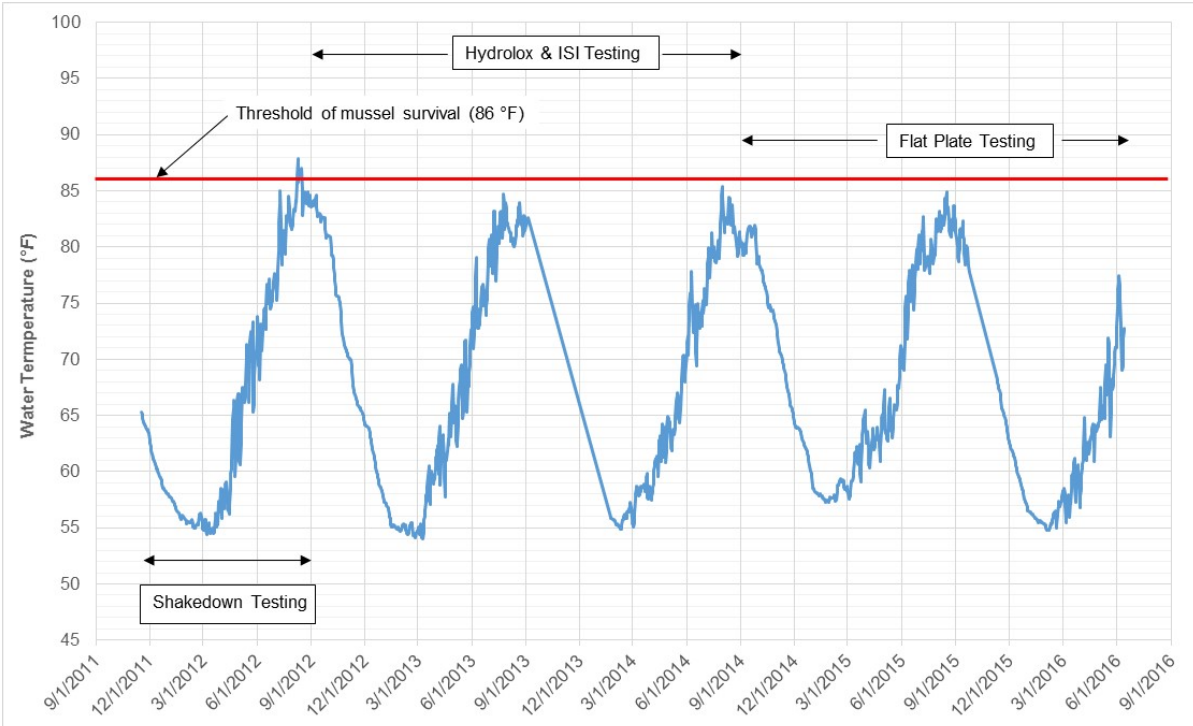



Figure 13 Water temperatures (10 ft below surface) and test periods of each system from November 2011 to June 2016.

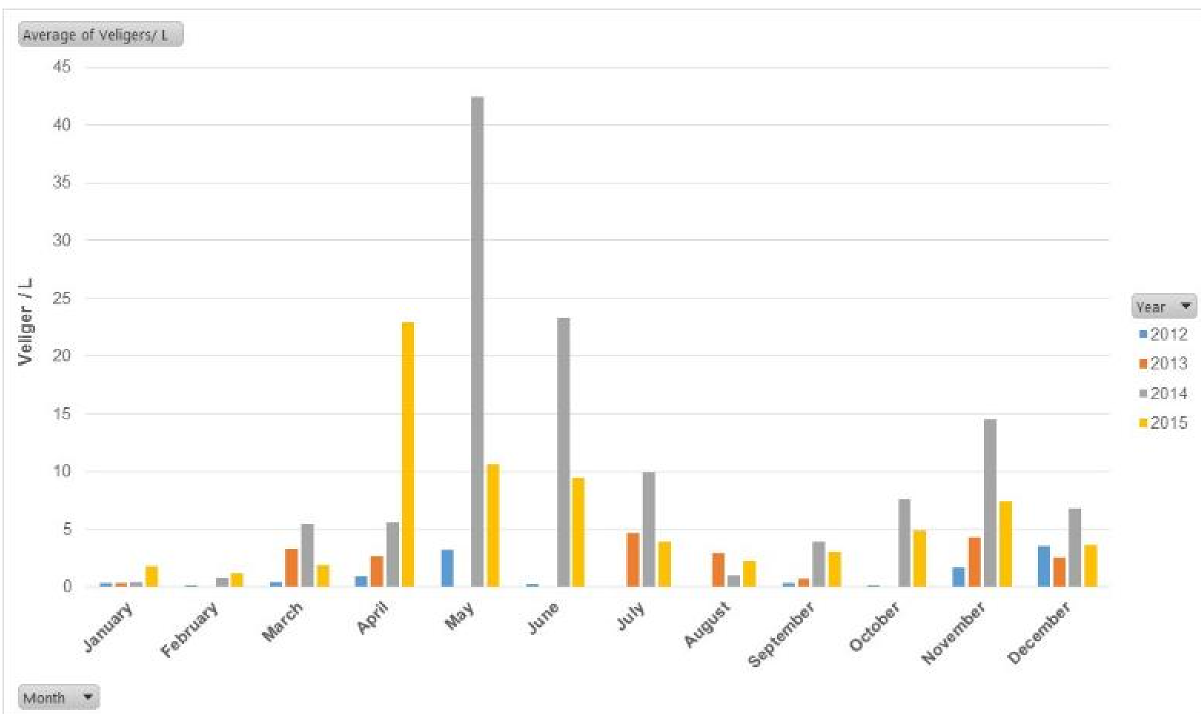



Figure 14 Veliger count data from 2012 to 2015 taken at the buoy line at Hoover Dam, not far from the test location (Reclamation Detection Laboratory for Exotic Species, Denver, CO).

Stainless Steel | Hydrolox | Hydrolox in test channel

Figure 15  Heavy mussel attachment on static screen samples that were submerged about 12 ft below the surface and a control Hydrolox sample submerged about 2 ½  ft below the surface in the test channel (Summer 2013).

## Hydrolox Vertical Traveling Screen

The Hydrolox screen operated continuously from the summer of 2012 to September of 2014. The screen traveled at a linear speed of approximately 1 in/sec which successively exposed a portion of the screen to air for 33 seconds over a rotation cycle (unsubmerged 43% of the time). The only maintenance required by the screen was occasional lubrication of the bearings supporting the rotating shaft at the top of the screen and replacement of the gear sprockets that drive the screen due to wear from the chain which had not been sufficiently tightened. As seen in Figure 16, there was no mussel attachment to the main screen while mussels heavily colonized on the screen frame and surrounding test channel. Two sections of Hydrolox static samples near the bottom of the test channel were also heavily fouled with mussels.

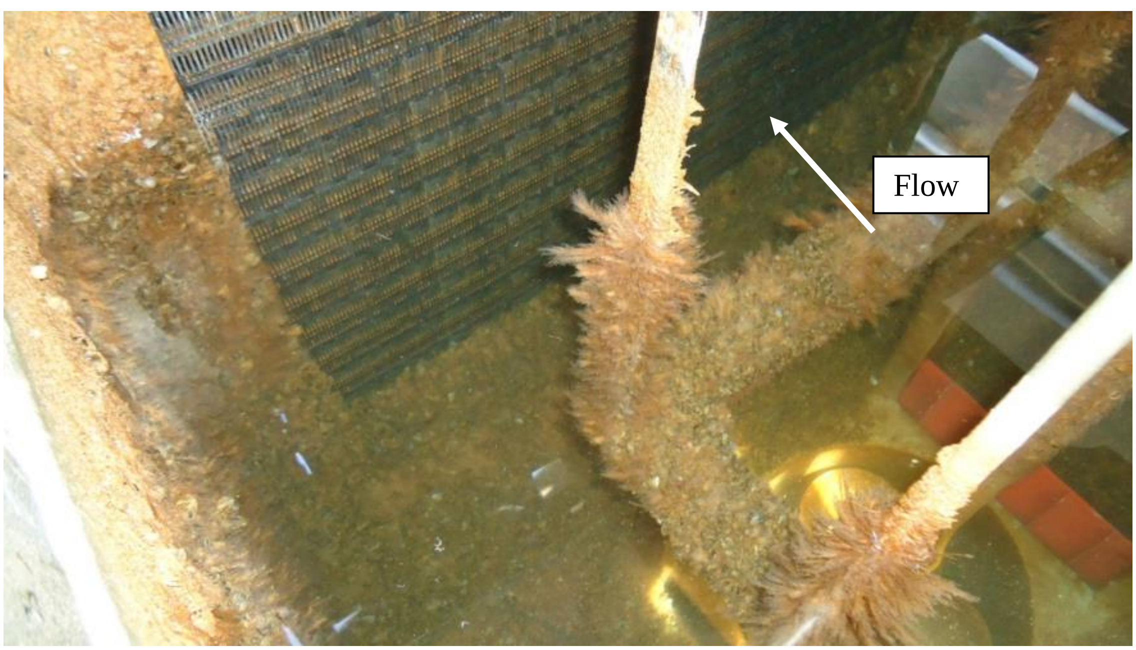



Figure 16  Heavy quagga mussel fouling on the floor and frame of the Hydrolox screen. The screen itself continuously cycled between submerged and unsubmerged and remained mussel-free.

The main Hydrolox screen was removed in September 2014 since it had operated continuously for over 2 years without major problems. Figures 17 and 18 show the inside of the Hydrolox screen and frame after it was removed and disassembled. While there was considerable mussel settlement on the interior frame there was no settlement to the screen itself. This was either due to the screen continually moving in and out of the water or to the stationary roller bar at the bottom of the frame that would scrape the mussels off as it contacted the screen as it moved (Figure 18).

Some biofilm that accumulated on both the outside and inside of the screen may have slightly increased head loss through the screen (see photos in Appendix B). The average velocity through the screen in September 2014 was 0.087 ft/s with a flow depth of approximately 2.8 ft. Unfortunately, there are no baseline data for comparison.

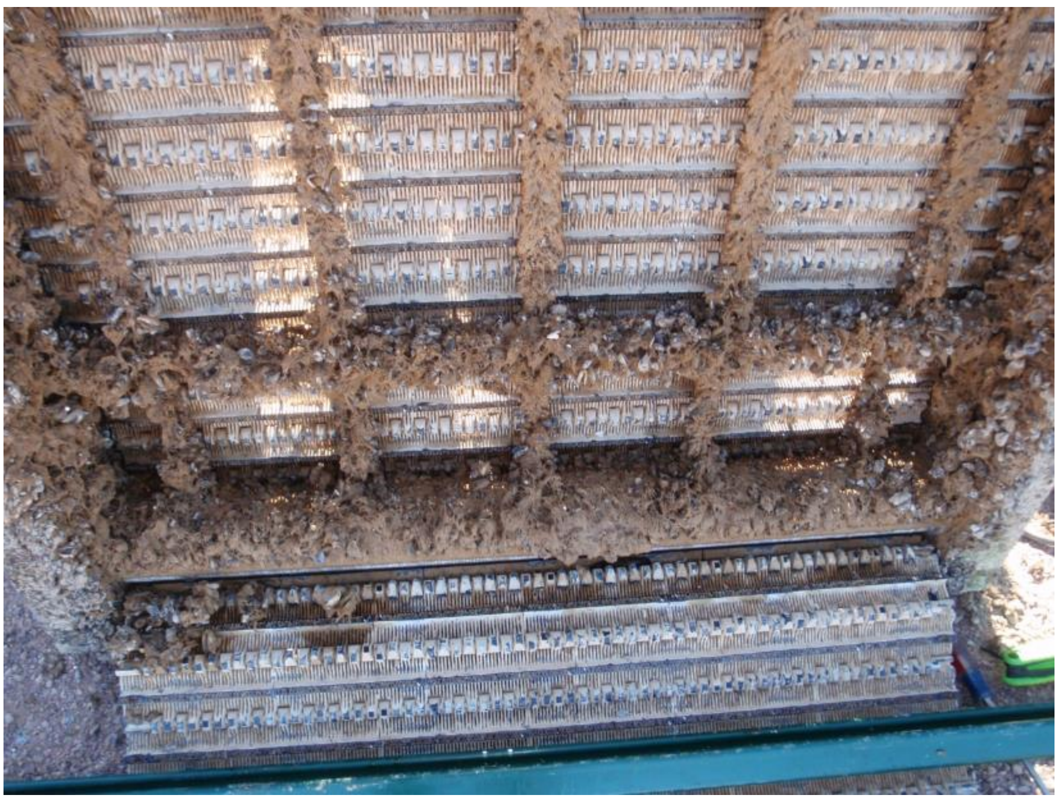


Figure 17 Inside of the Hydrolox traveling screen after 2 years of operation at Lake Mead.

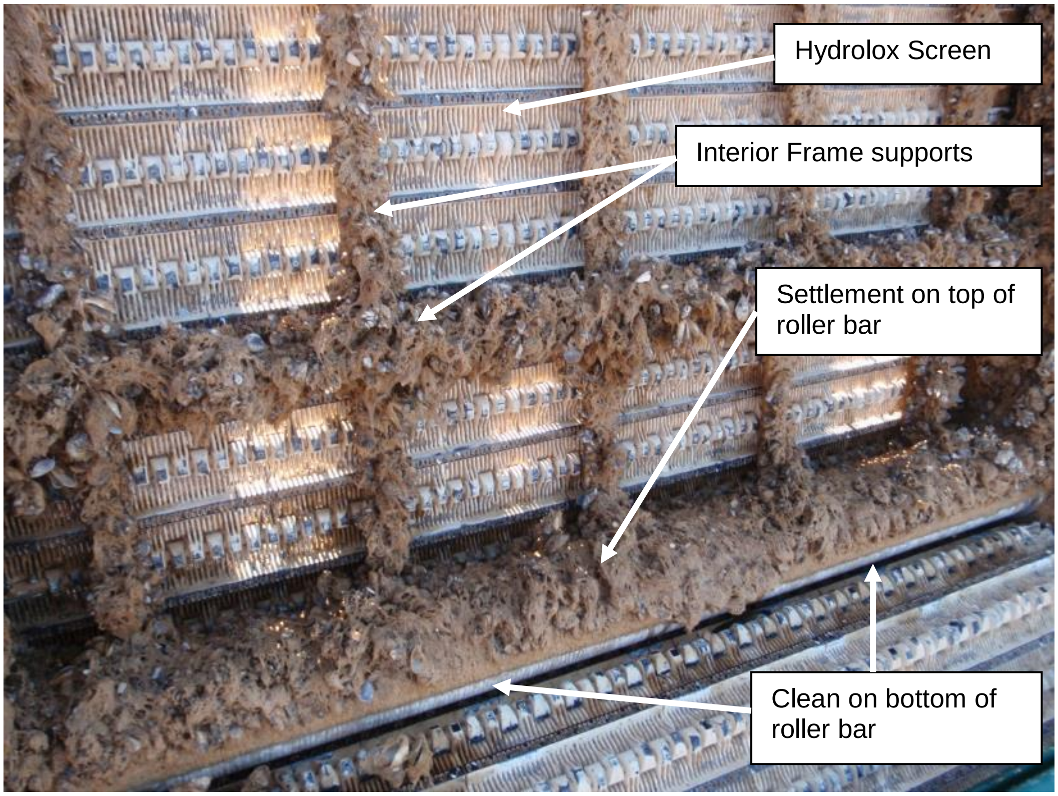


Figure 18  Mussel settlement on the inside of the Hydrolox screen frame.

To help understand what prevented mussels from attaching to the moving polymer sections of the Hydrolox, two separate sections of screen samples were mounted on a shaft which rotated the samples at approximately the same speed as the main Hydrolox screen. These samples were placed 12 ft below the water surface and stayed in continuous motion from September 2013 to July 2014. Figure 19 displays the growth of quagga mussels on these rotating control samples over time which shows that quagga mussels will attach and grow on an object in motion if continually submerged. If the roller bar is not the primary factor then the fact that there were no mussels on the main Hydrolox screen suggests that a screen that rotates up and out of the water surface will prevent mussel colonization and provide mussel-free operation on a long-term basis.


September 2013 January 2014 July 2014

Figure 19  Hydrolox sample sections that were mounted below the water surface and rotated at approximately the same speed as the main Hydrolox screen. Despite continuous motion, mussels attached to the samples.

To further test the hypothesis of mussel prevention by cycling a screen between submerged and unsubmerged a rotating system was added to the modified test facility in September 2014 after the main Hydrolox screen was removed. Two sections of Hydrolox polymer screen and two sections of stainless steel wedgewire screen were mounted on a shaft and rotated in and out of the water continuously. The video in Figure 20 demonstrates how this was done. This test was performed from September 2014 through May 2016 with no mussel attachment to either the Hydrolox or stainless steel screens, again showing that mussel settlement can be prevented by a screen that continuously moves in and out of the water.

In April 2016 a Hydrolox sample with mussel settlement was attached to the rotating screens to determine if mussels would come off after becoming settled due to cycling in and out of the water. Figure 21 shows that after 1 month of testing mussels appeared to be still alive and were well attached to the screen sample suggesting that mussel attachment may be very difficult to eliminate once they have already settled, even if the screen is continuously moving in and out of the water.

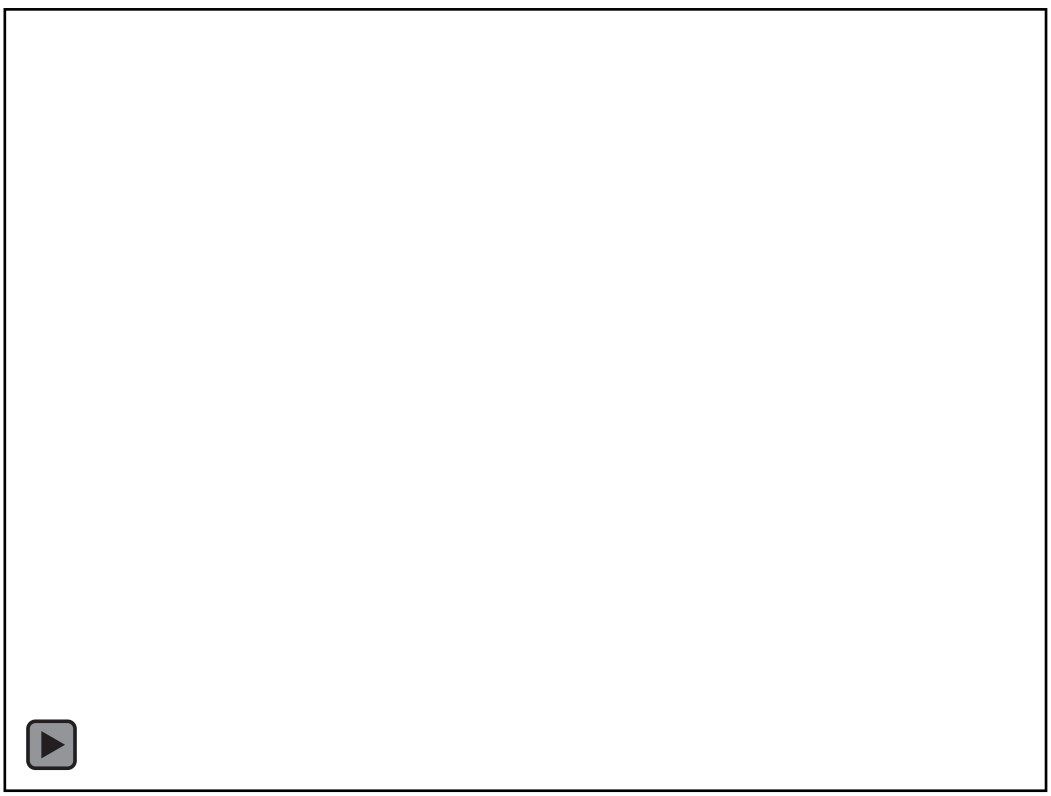


Figure 20  Video of rotating Hydrolox (left side) and stainless steel (right side) screen samples in and out of the water (flow is from top of screen to bottom).

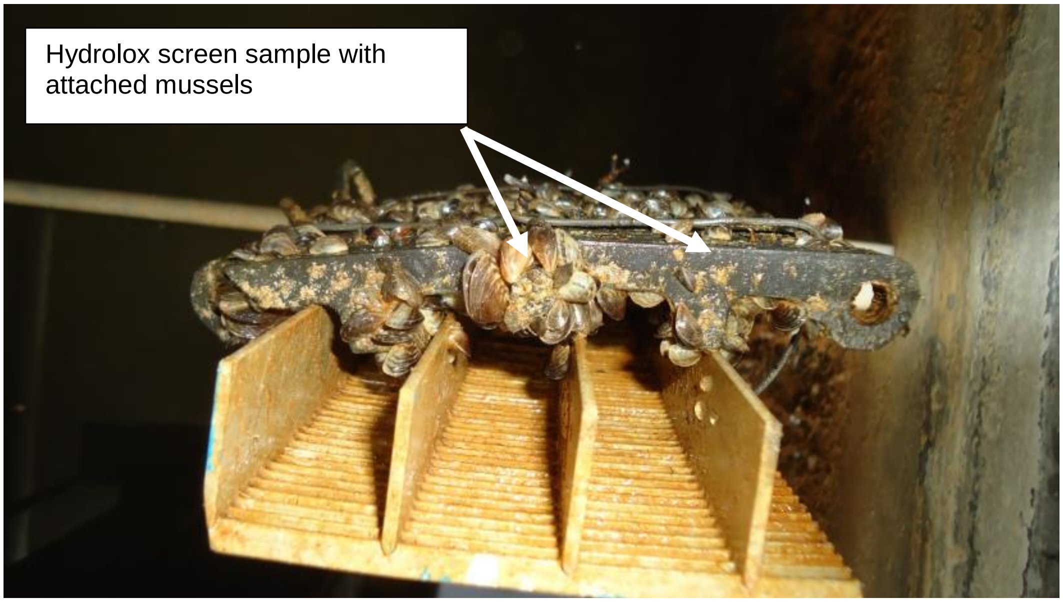



Figure 21  Mussels attached to Hydrolox screen sample (formed attachment while stationary and remained attached after rotation in and out of water for one month).

## ISI Cylindrical Screen

The brushing system on the ISI cylindrical screen operated continuously with cleaning every 8 hours from September 2012 to September 2014 with no problems. The only maintenance task that was performed was replacing one of the sacrificial anodes for cathodic protection of the screen structure which was done in April 2014. While static samples of stainless steel wedgewire were heavily fouled, the surface of the main screen that was brushed remained clean as long as the cleaning system operated as intended. If not, the screen was soon fouled with mussels and biofilm (Figure 22). The Fuji silicone coating was effective at preventing mussel settlement on the portions of the frame and internal flow baffle that were coated. Over time portions of the Fuji coating peeled off and allowed mussels to attach in those areas (see photos in Appendix B). Another concern is that mussels may clog the space between the wedgewires (visually observed in some locations on the screen) that cannot be removed by the brush. Photos were taken and velocity measurements around the outside of the screen were made to verify flow through the screen.

No brushing (2 months) 3 brush cycles per day (18 months)

Figure 22 Biofilm and mussel settlement on ISI screen structure. Screen clogged without brushing. No mussels were present on the exterior main screen that was brushed.

Acoustic Doppler Velocimetry (ADV) measurements were made around the outside circumference of the ISI screen to determine flow through the screen and identify areas that may have been clogged. Figure 23 shows approach velocities that were taken at four locations around the cylindrical screen in August 2014. The plot of the cylindrical screen is laid out linearly with four quadrants where measurements were made (circumferential length of 0 and 7.8 ft are the same location). While velocities were not perfectly uniform, they do show that the majority of the screen was not clogged as evidenced by approach velocities above 0.08 ft/s over the majority of the screen area. The average velocity was 0.096 ft/s which translates to a flowrate of approximately 1.9 $ft^3/s$. Again, there are no baseline data without mussels for comparison.

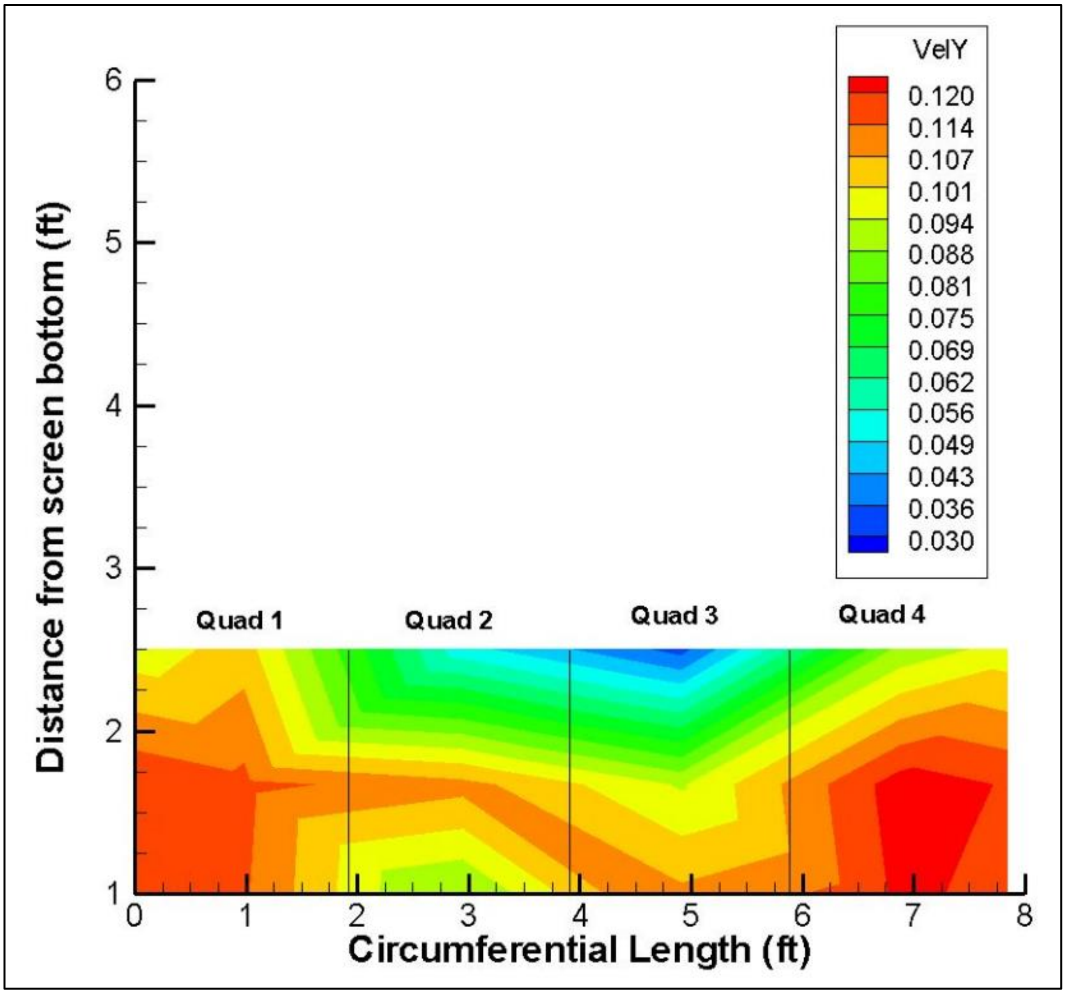



Figure 23 Interpolated contour plot of approach velocity data of the ISI cylindrical screen. Measurements were taken at 4 locations around the screen (3 depths per location, 12 measurements total).

The ISI screen and brushing system were removed and disassembled in September 2014 at test completion. Testing over the 2 year period has shown that the screen was generally protected from mussel settlement as long as the brush cleaning system operated correctly. When the inside of the screen was inspected for mussel settlement it appeared similar to the outside of the screen where there were no mussels on the part of the screen that was regularly brushed (Figures 24, 25, and 26). Biofilm accumulated on the inside of the screen even where it was brushed but did not seem to inhibit flow.

Figure 26 shows there was some mussel attachment in a few areas of the inside screen. These mussels seem to have been protected from the brush by the interior screen rib supports. However, mussel attachment to the inside of the screen was not common and did not seem to significantly reduce flow through the screen. Running the brush in both forward and reverse directions (which is already common practice) will help remove mussels in between the rib supports on the backside for the screen.

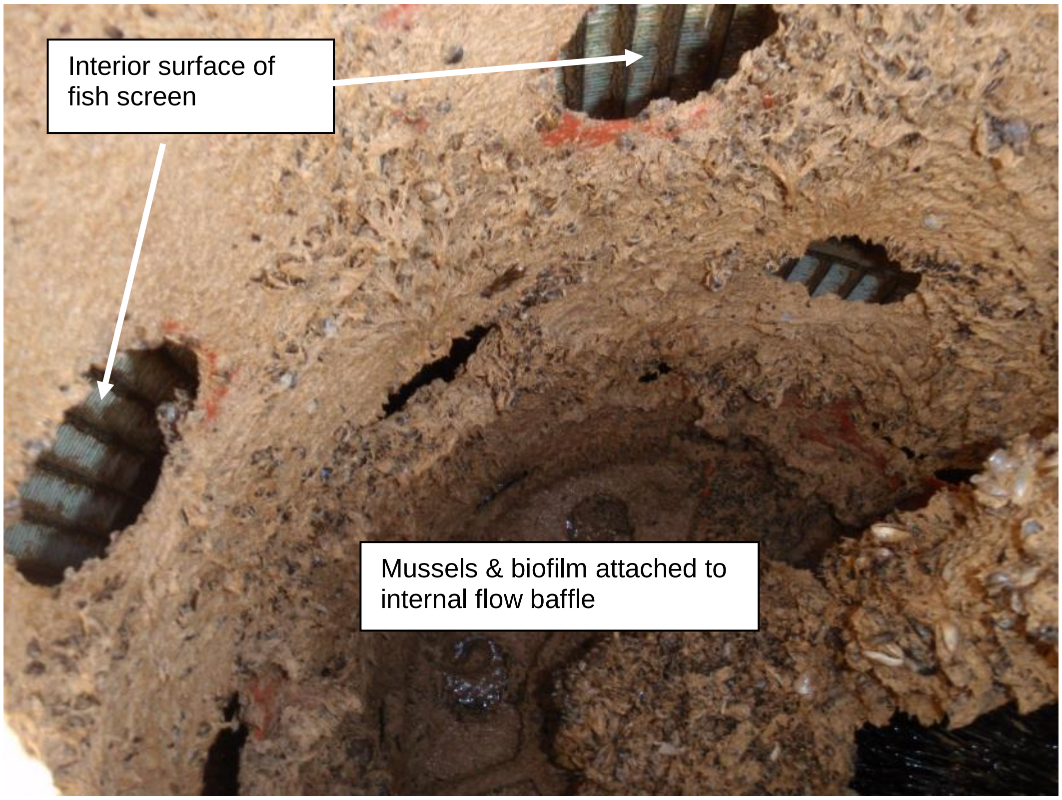


Figure 24 Inside of ISI cylindrical screen after over 2 years of operation. Mussels were attached basically everywhere except for the interior screen that had been continually brushed.

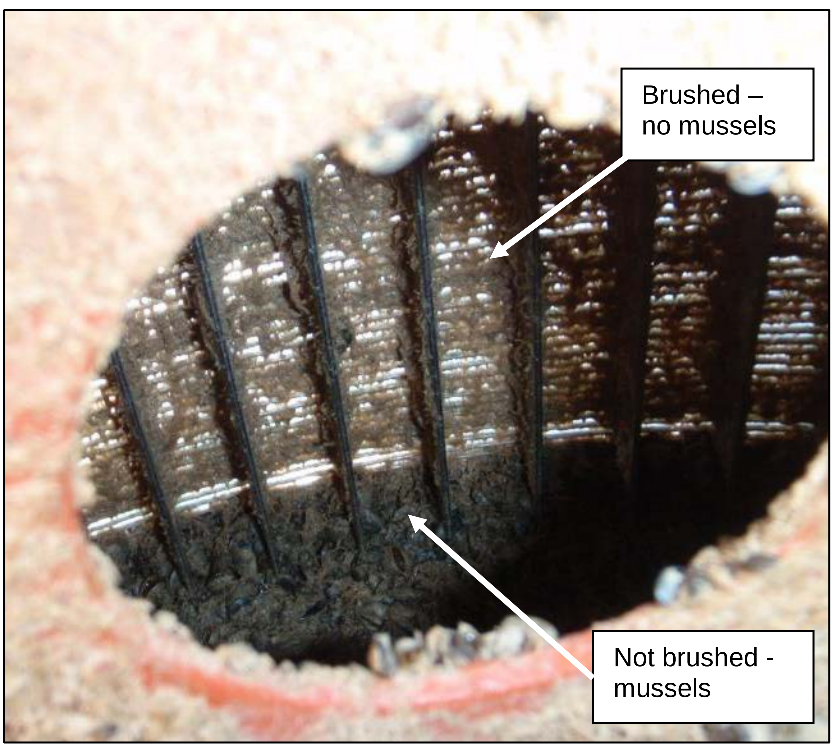


Figure 25 Mussel attachment to the inside screen surface where the brush did not extend.

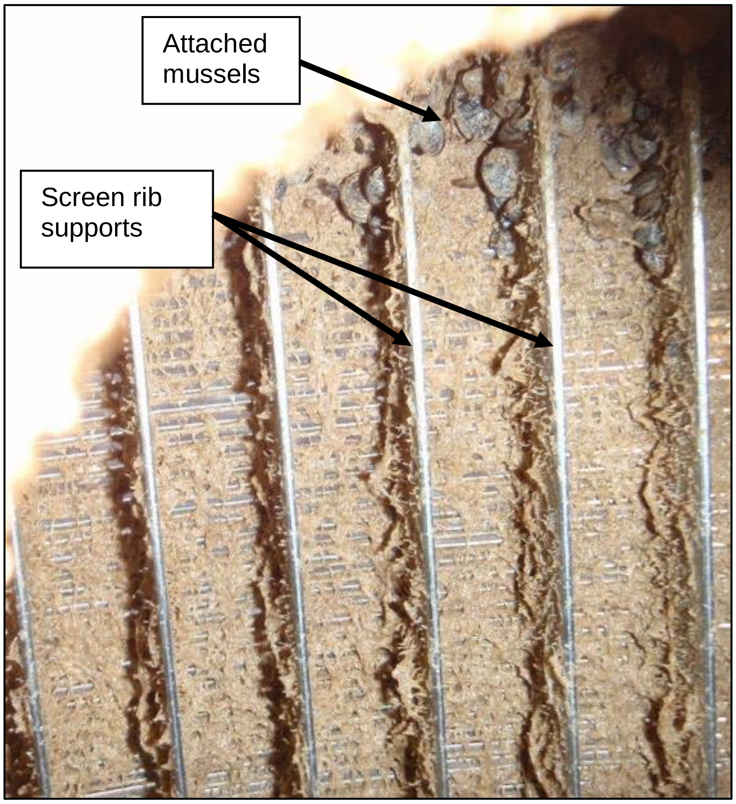



Figure 26  Biofilm and mussels attached to the interior ISI cylindrical screen behind the screen support ribs.

## Flat Plate Wedge-wire Screen

The flat plate wedgewire screen system operated intermittently from September 2014 to January 2015 due to mechanical problems with the mixer and then continuously from January 2015 through June 2016 with only a few minor interruptions in service. The center screens in each row were brush cleaned every 12 hours. Throughout the test period mussel attachment was observed only on the stainless steel static screens while debris from dead mussel shells (not live mussel attachment) was occasionally found on the screens with the Jotun SeaLion coating. Screens without the coating were not brushed as part of this testing as it was assumed that results would be similar to those obtained from the ISI testing.

Figure 27 shows the progression of biofilm and mussel attachment on the vertical wedgewire screens (upstream row) from December 2015 through June 2016. The control screen became almost completely covered after only 2 months and remained clogged throughout the test period. The screen with the Jotun coating that was not brushed performed better and was not significantly clogged until about May 2016. The Jotun coated screen that was brushed performed exceptionally well and visually appeared to be in the same condition (screen openings clear) throughout the entire test period. There were no signs of abrasion, wear, or other damage to the coating from the brushing.

The horizontal wedgewire screens (downstream row) produced similar results which are shown in Figure 28. The only difference was that the brushing motion, which was perpendicular to the wedgewire orientation, was not as effective. Starting in about April 2016 a few of the screen openings were visually clogged and some mussel shell debris remained on the screen even with brushing. Figure 29 presents a visual comparison of the difference in brushed screens with vertical and horizontal wedgewire orientation. Screens with wedgewires aligned with the brushing motion were more effective as the bristles from the brush were allowed to protrude into the screen openings as they passed over the screen.

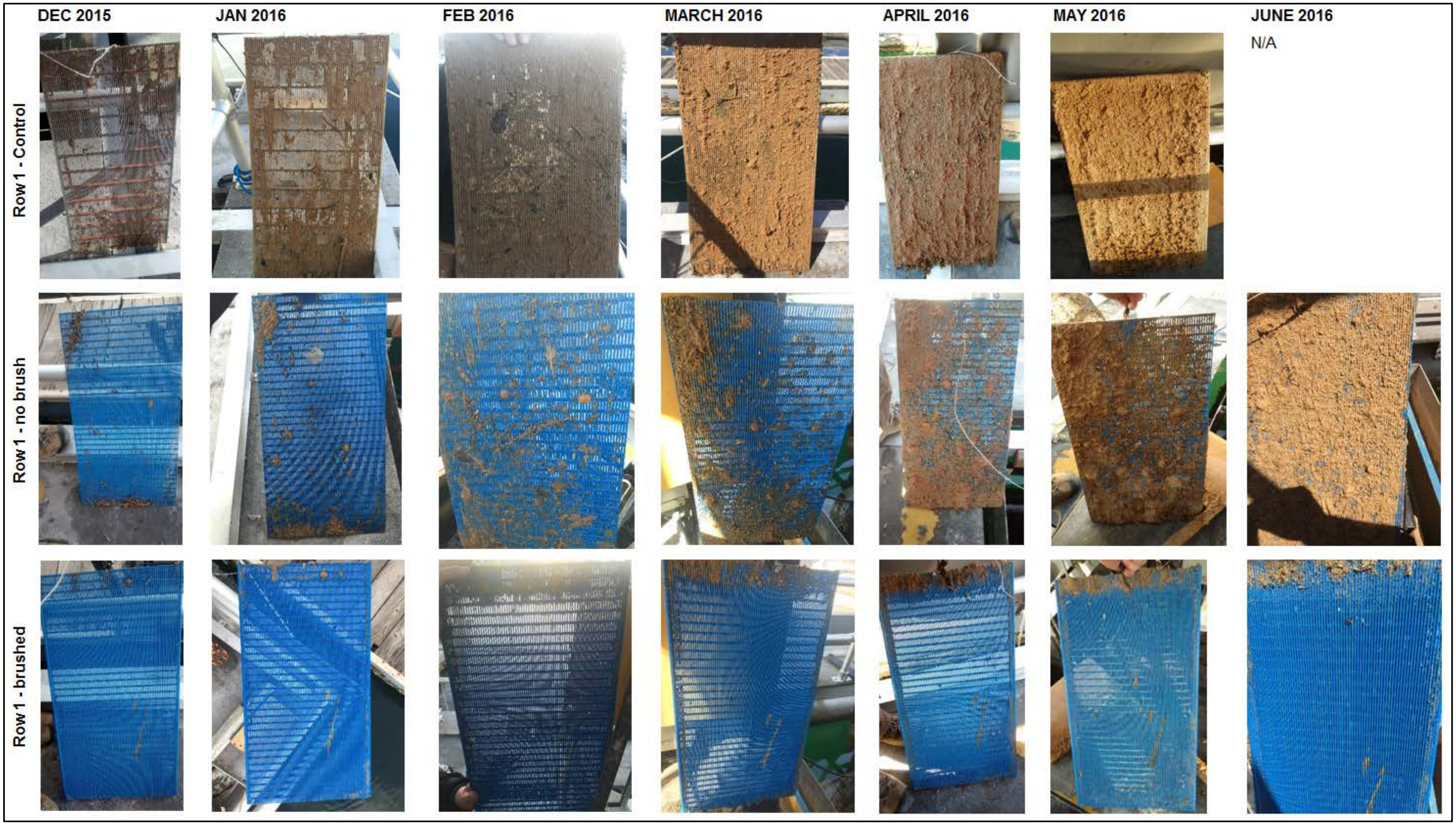



Figure 27  Time lapse photo comparison from Dec. 2015 through June 2016 of the first row of flat plate test screens (vertical wedgewire).


Figure 28  Time lapse photo comparison from Dec. 2015 through June 2016 of the second row of flat plate test screens (horizontal wedgewire).

Vertical (parallel to brushing)    Horizontal (perpendicular to brushing)

Figure 29 Vertical and horizontal wedgewire screens that were brushed. Brushing motion in the same wedgewire orientation was more effective, keeping screen openings clear.

Flow depths in the channel were measured upstream and downstream of each row of screens to determine the change in screen head loss over time. Figure 30 shows minimal head loss at baseline conditions and then a steady increase in head loss for both rows of screens through May for testing in 2015 and 2016. This trend is consistent with increasing veliger counts (Figure 14) through the spring months as well as visual observations.

Figure 31 compares velocities with clogged screens to their baseline condition. Velocities were measured approximately 3 inches upstream of the 1st row of screens and 4 inches downstream of the 2nd row of screens (space limitations prevented measurements upstream of the 2nd row). Despite having a baffle in the upstream test channel to help provide uniform flow, baseline velocities were skewed to the left side. Velocities measured in May show a decrease through the screens that were not cleaned (especially the control) and an increase through the center screen that had been consistently brushed. The 2nd row produced similar results with decreases in flow through the uncleaned screens and a significant increase through the brushed screen in the center. The flow reversal at the downstream control screen is likely a reverse eddy on the downstream side of the screen where the measurement was made and indicates that the screen was completely clogged.

Again, these results suggest that even in an environment of heavy biofilm and mussel fouling, screen operation can remain effective if the cleaning systems operate correctly and consistently as designed. However, screens will quickly become clogged and ineffective if cleaning is neglected.

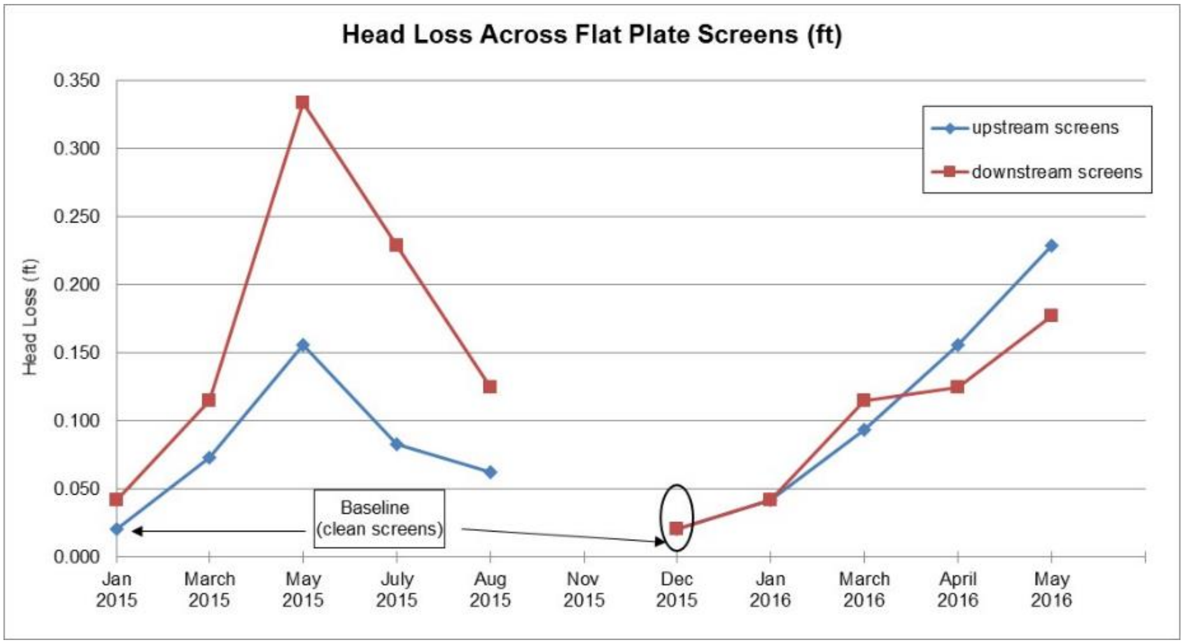



Figure 30  Head loss measurements across the 1st row (upstream) and 2nd row (downstream) of flat plate test screens from January 2015 through June 2016.

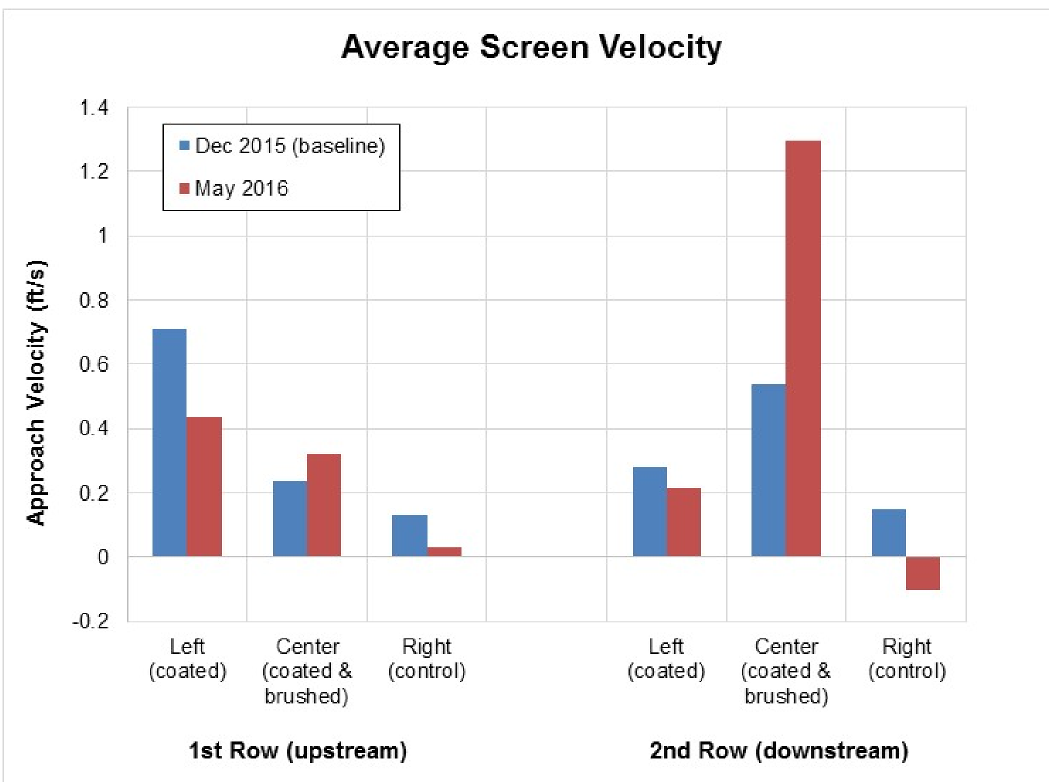



Figure 31 Comparison of average approach velocity measurements through the flat plate test screens from Dec. 2015 (baseline) to May 2016. Screen layout is shown in Figure 12

# Conclusions

The most significant finding from this study common to all three systems is that existing cleaning systems were effective in preventing clogging of the fish screens if consistently operated as designed. Conclusions specific to each cleaning system are as follows:

- **Hydrolox Vertical Traveling Screen –** Operated for over 24 months with few problems and limited maintenance. While there was no mussel attachment to the main traveling screen, there was significant mussel settlement on the exterior and interior screen frame and supports. Although not significant, there may have been some increased head loss across the screen caused by biofilm accumulated in the screen slots. A spray-wash cleaner, which was not included in this test, would probably help prevent this problem. The main traveling screen remained mussel free as long as it stayed in motion, moving in and out of the water. In contrast, Hydrolox control screens that were continually submerged (stationary or moving) became heavily fouled with mussels.

- **ISI Cylindrical Wedge-wire Screen –** Operated for over 24 months with few problems and limited maintenance. The main screen area remained free from mussel attachment as long as the brush cleaning system operated correctly and consistently. There was significant mussel settlement on the screen frame and edges of the screen where the brush could not reach. With the exception of a limited number of mussels attached to the inside of the screen, the main area of the screen that was regularly brushed remained clean with minimal impacts to flow through the screen.

- **Flat Plate Wedgewire Screen –** operated for 21 months with few problems and limited maintenance. Results were similar to the cylindrical screen in that the main screen remained free from mussel attachment as long as the brush cleaning system operated correctly and consistently. The orientation of the wedgewire did affect the effectiveness of the brushing. Wedgewires aligned with the brush (parallel with brushing motion) allowed almost all live mussels, shell debris, and biofilm to be removed from the screen. However, wedgewires aligned perpendicular to the brushing motion prevented some of the shell debris from being removed which blocked a small portion of the screen area. The coating (Jotun SeaLion Resilient) that was applied to flat plate screens showed no signs of damage or wear from the cleaning brushes and was successful in reducing mussel attachment to the screens within the test channel.

# References


Bureau of Reclamation. (2006). *Fish Protection at Water Diversions, a Guide for Planning and Designing Fish Exclusion Facilities. Water Resources Technical Publication.* Denver, CO: U.S. Department of Interior, Bureau of Reclamation.

Holdren, G. C., Horn, M. J., & Pucherelli, S. F. (2012). *The Limnology of Lake Mead, Arizona-Nevada, 2011 Report of Findings.* Denver, CO: U.S. Department of Interior, Bureau of Reclamation, Technical Service Center.

Mackie, G. L., & Claudi, R. (2010). *Monitoring and Control of Macrofouling Mollusks in Freshwater Systems.* New York: Taylor and Francis Group.

Wong, W. H., Gerstenberger, W. B., & Moore, B. (2012). Settlement and Growth of Quagga Mussels (Dreissena rostriformis bugensis Andrusov, 1897) in Lake Mead, Nevada-Arizona, USA. *Aquatic Invasions*, 7(1):7-19.

# Appendix A: Drawings of Original and Modified Floating Test Facility

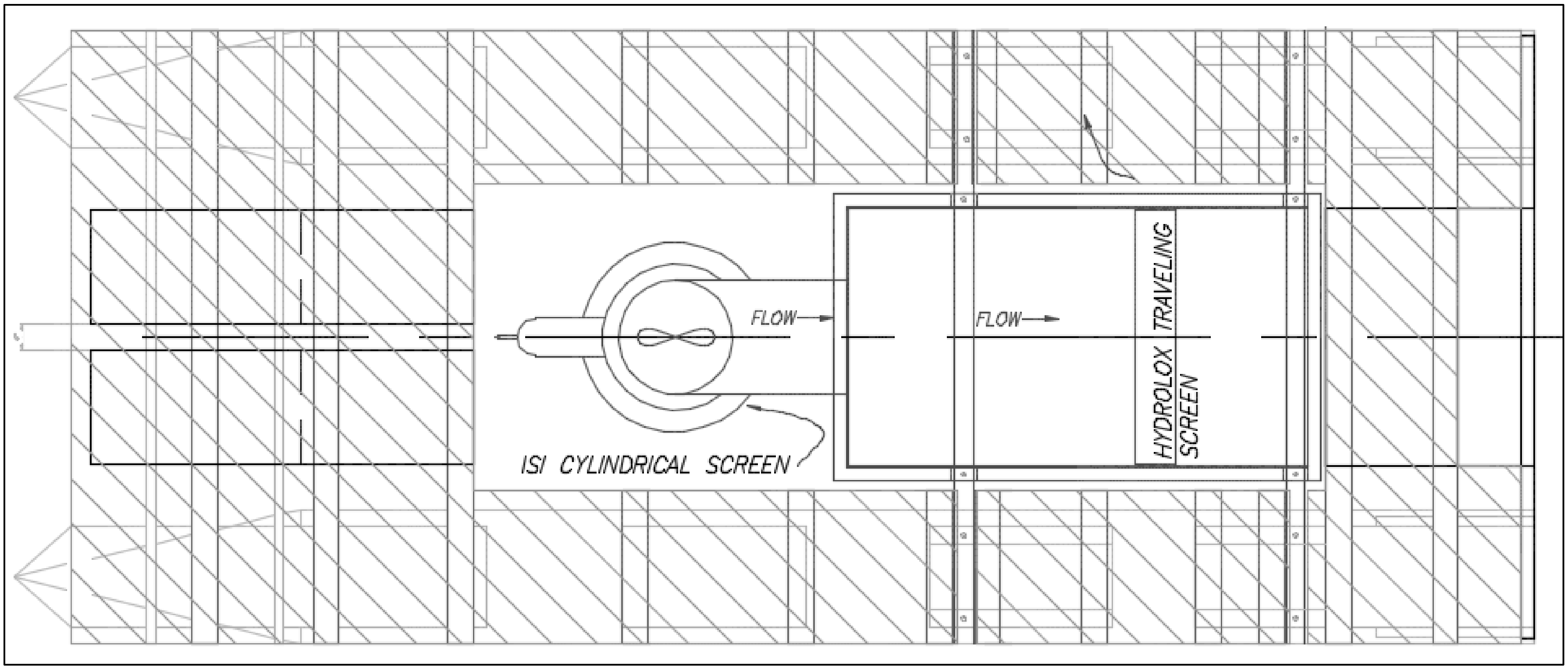



Figure 32 Plan view schematic of original floating test facility for ISI Cylindrical and Hydrolox Traveling screen testing.

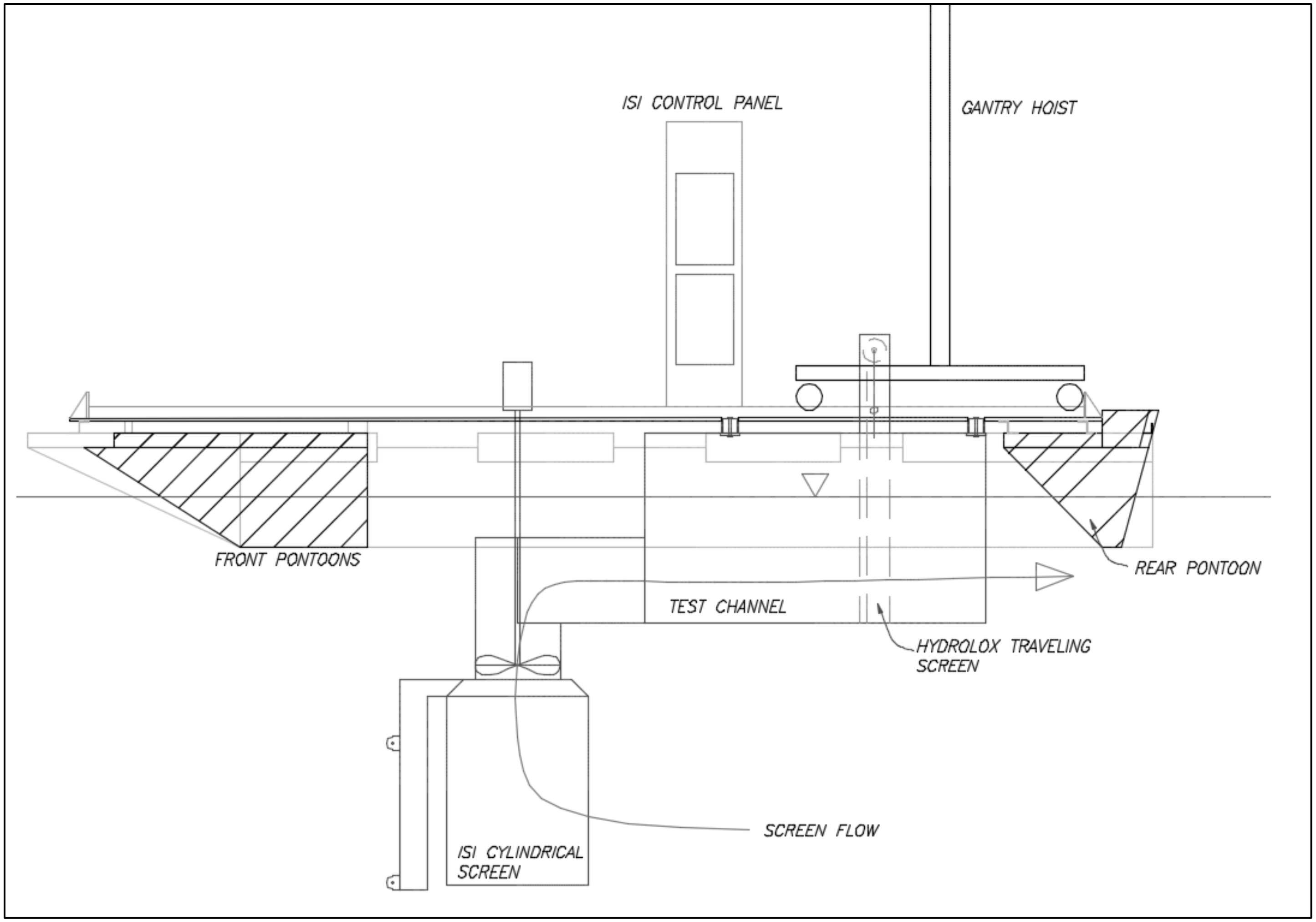



Figure 33 Profile view schematic of original floating test facility for ISI Cylindrical and Hydrolox Traveling screen testing.

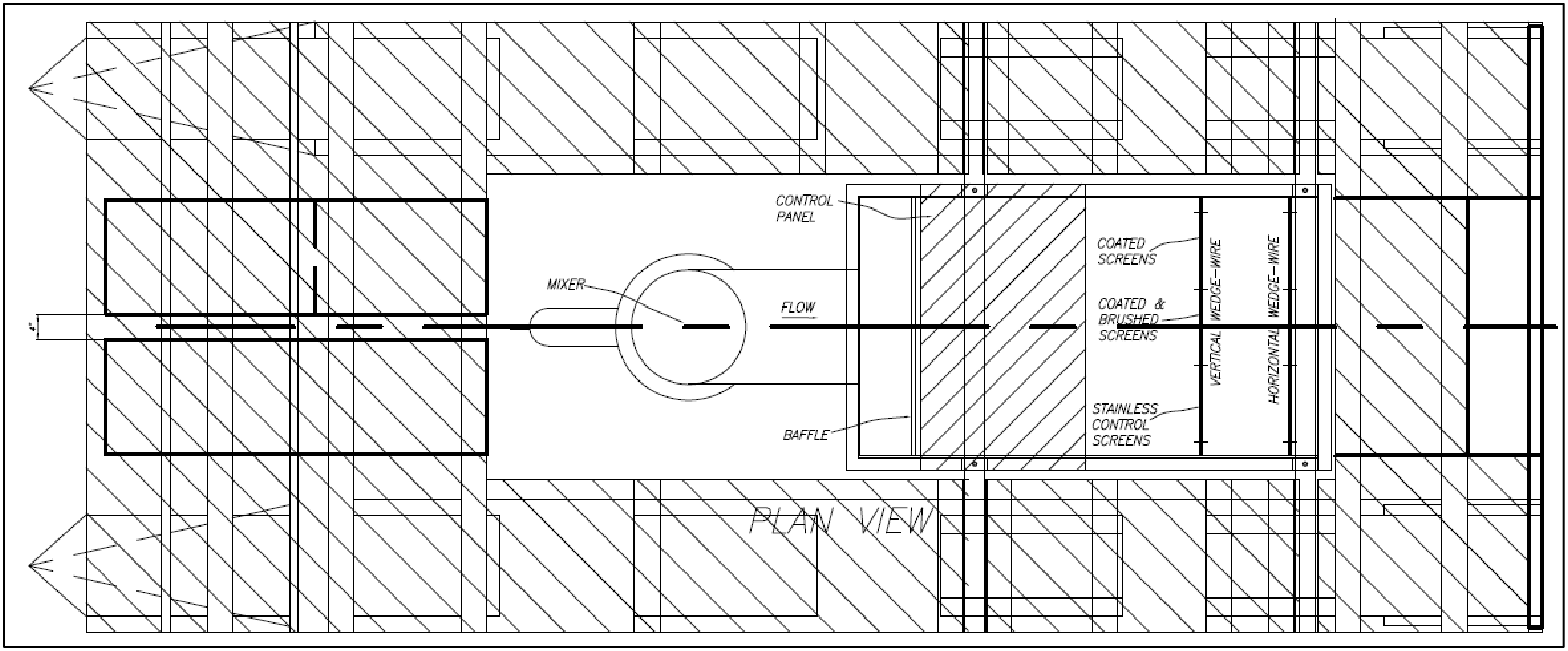



Figure 34 Plan View schematic of modified pontoon boat floating test facility for flat plate screen testing. Flow is supplied by a mixer that passes through the test channel, through both rows of flat plate screens, and out the back of the boat.

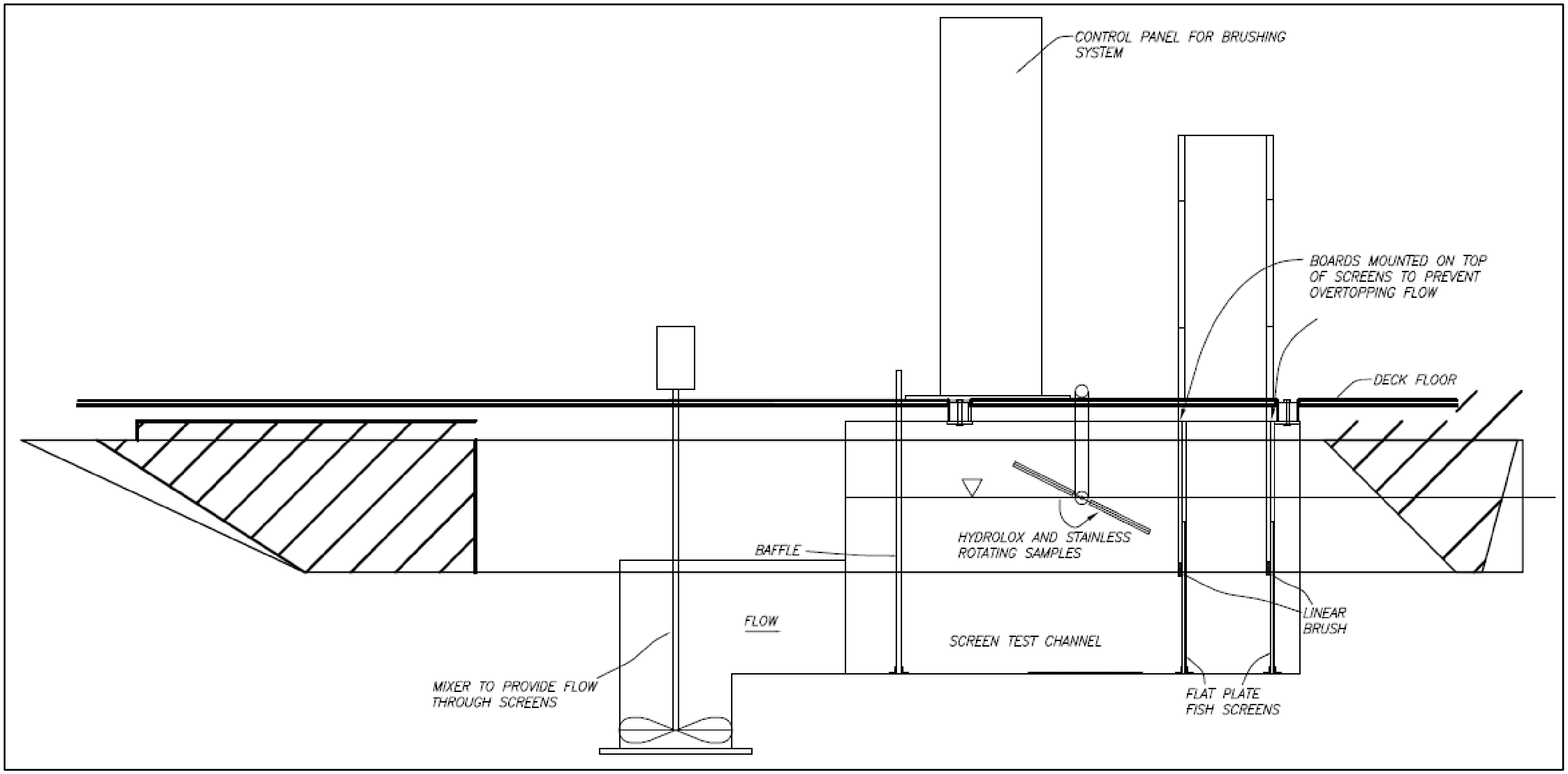



Figure 35 Profile View schematic of modified pontoon boat floating test facility for flat plate screen testing (flow is from left to right in the test channel).

# Appendix B: Photos of Hydrolox and ISI Cylindrical screen testing

Figure 36  Mussel settlement on Hydrolox frame and interior supports following testing (inside of Hydrolox screen).

Figure 37  Biofilm built up on the Hydrolox screen (inside of screen looking out).

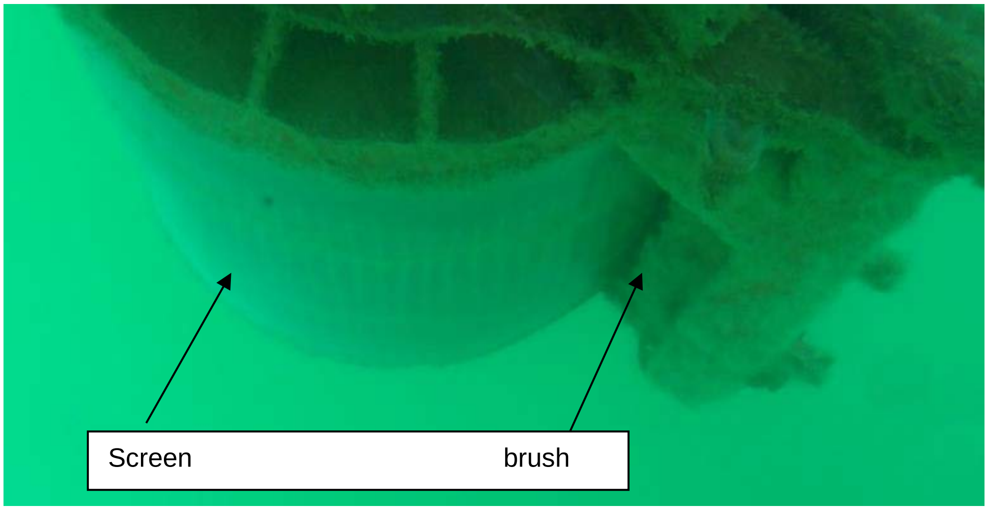



Figure 38  ISI screen and brush submerged below the surface.


Figure 39  Mussel settlement on ISI frame and screen edges. Mussels did not attach on areas coated with the Fuji Silicone coating. Mussels did attach to areas where the Fuji coating had peeled off.

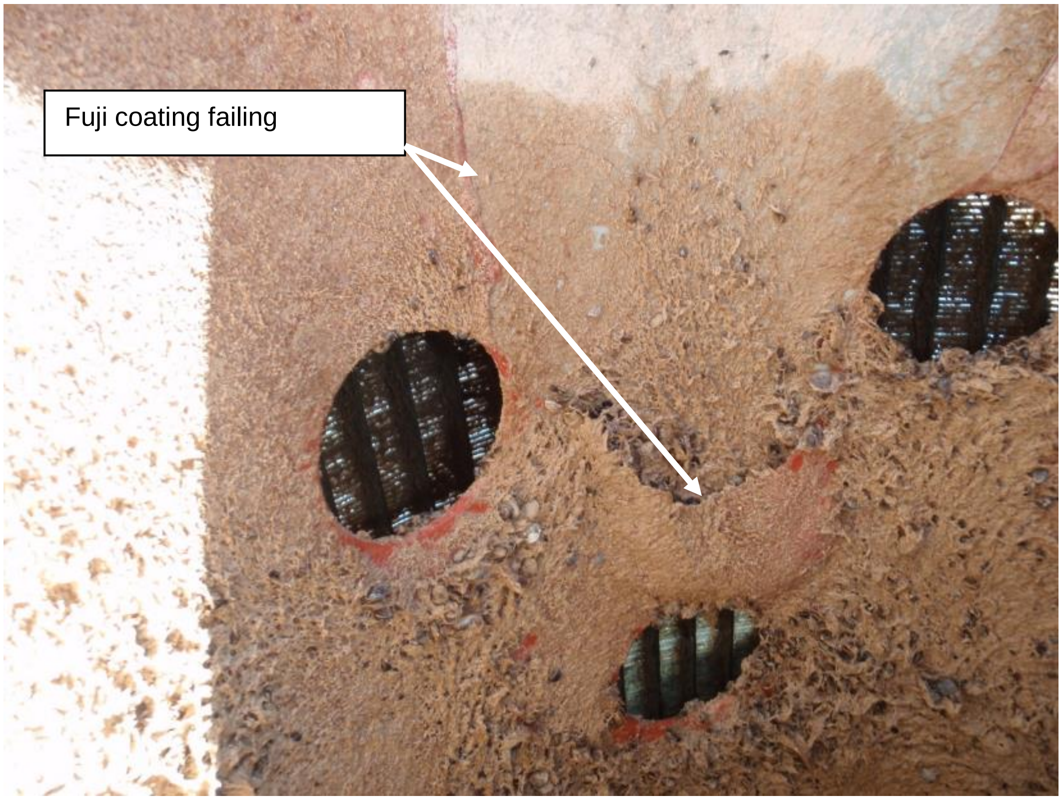


Figure 40  Mussel and biofilm attachment to the inside of the ISI internal flow baffle.