RECLAMATION

Managing Water in the West

Centrifugal Separator Evaluation for Mussel Shell Debris Removal & Settlement Reduction

Research and Development Office Science and Technology Program (Final Report) ST-2017-8169-01

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Centrifugal separation technology was evaluated in both laboratory and field settings to assess performance capability for mussel settlement reduction and shell debris removal. The results of field testing showed that centrifugal separation did not significantly reduce downstream mussel settlement indicating that larval removal efficiencies are low. However, laboratory testing indicated 60-85% removal of mussel shell debris is possible. While this technology does not perform well for settlement reduction, the findings suggest it has significant promise as a low-maintenance means of mitigating shell debris impacts for cooling water systems. Additional field testing is recommended to confirm laboratory test results for shell debris separation efficiency.

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Executive Summary

The potential for quagga and zebra mussels to adversely affect Reclamation water and power facilities is significant and represents the likelihood for increased operation and maintenance (O&M) costs with the possibility for interrupted water delivery and power generation functions at facilities exposed to invasive mussel infestations. As such Reclamation is seeking and evaluating environmentally sound mitigation technologies of which centrifugal separation was identified as having potential. The centrifugal separation concept has been in use for many decades (more recently in the water treatment industry) to separate components of different densities in a heterogeneous mixture. This study explored the effectiveness of centrifugal separator technology to remove mussel larvae and shell debris for hydropower cooling water systems.

Objectives

The primary objective of this study was to evaluate the effectiveness of centrifugal separation for removal of mussel shell debris and reduction of mussel settlement in cooling water systems.

Approach

Laboratory testing was performed using a test facility constructed at Reclamation's Hydraulics Laboratory in Denver, Colorado to evaluate operational characteristics and shell debris removal performance. Field testing was conducted at Reclamation's Davis Dam to evaluate settlement reduction performance on a hydropower cooling water subsystem.

Conclusions

- The centrifugal separator concept is capable of removing 65-80% of mussel shells based on laboratory testing.
- The separator did not experience any malfunctions nor require any maintenance during the 6-month continuous field deployment.
- Mussel settlement was not reduced downstream of the separator during field testing indicating low separation efficiencies for mussel larvae.
- Only a small proportion of veligers from each size class were purged by the separator which is consistent with the lack of settlement reduction.

Recommendations

Additional field testing is recommended to confirm laboratory findings regarding effectiveness (efficiency) for shell debris removal. Doing so would require modifications to the field test facility at Davis Dam to quantify shell debris downstream of the separator for comparison with debris removed by the separator through the purge system.

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Introduction

The potential for quagga and zebra mussels to adversely affect Reclamation water and power facilities is significant and represents the likelihood for increased operation and maintenance (O&M) costs with the possibility for interrupted water delivery and power generation functions.

Depending on operating conditions and levels of infestation, impacts from mussel settlement and/or heavy shell debris loads drawn into various systems can be problematic. The following systems and equipment specific to most hydropower facilities have the potential to be adversely impacted by invasive mussels:

- Intakes and penstocks
- Gates and valves
- Bypasses and air vents
- Cooling water systems
- Raw water fire protection systems
- Service and domestic water systems
- Instrumentation
- Drainage and unwatering systems

The primary purpose of this study is to evaluate the effectiveness of centrifugal separation to remove mussel shell debris and possibly reduce mussel settlement in cooling water systems.

Centrifugal Separators

The centrifugal separation concept has been in use for many decades, to separate components of different densities in a heterogeneous mixture. The physical processes involve an imposed inertial force (often referred to as centrifugal force) that is directed radially away from an axis of rotation in a multi-constituent fluid. More recently, centrifugal separators (sometimes referred to as cyclone separators) have been used in water treatment processes for solids removal. The concept for such an application involves passing water through an upright or inclined cylinder containing an internal annulus and baffling components in such a manner as to create swirl. The swirling motion generates radial inertial forces by which particulates of larger density are separated from the primary flow and settle to the bottom of the cylinder for periodic purging. Recognizing that mussel shell debris has a greater density than water, it was postulated that such a system may be capable of shell debris removal without the need for system shutdown for manual cleanout.

Although various manufacturers of centrifugal separators exist, the Lakos system was selected for purchase and testing primarily due to cost and availability. Figure 1 is a schematic of the Lakos system tested during this study. Flow is introduced tangentially at the inlet from a pressurized pipe. As the flow enters the top of the separator, vertical vanes induce a rotational motion. This rotational motion creates centrifugal forces by which particulates with larger density than the surrounding fluid (in this case water) are transported radially outward. Near the bottom of the separator, the pickup tube drives the flow up to the outlet while the particles forced outward settle into the collection chamber at the bottom of the separator. The settled particles are then purged (either manually or automatically) with a small portion of the flow at desired intervals. The purge interval is generally dependent on the amount of particulates and rate of separation.

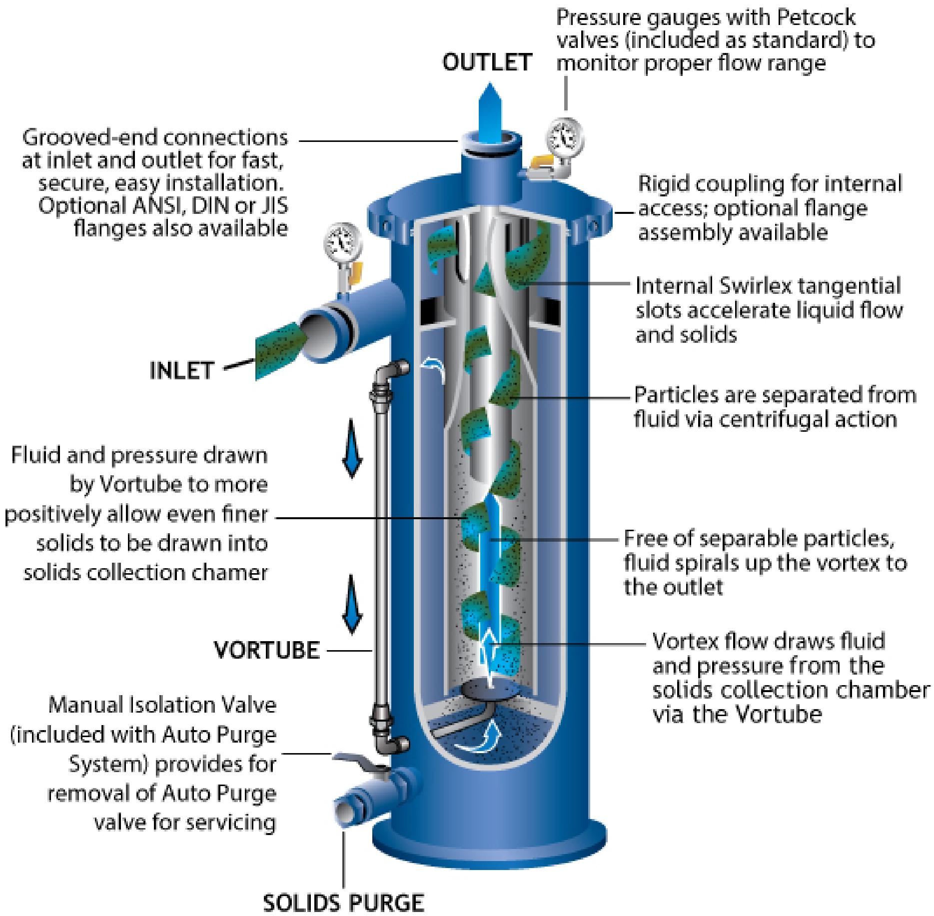

Figure 1. Schematic of centrifugal separator (Lakos – Lindsey Corp)

Methods

This study was conducted in two phases. The first phase involved laboratory testing to explore operational characteristics and evaluate, in a laboratory setting, the debris removal effectiveness. The approach allowed for shakedown of equipment and provided valuable insight into operational considerations for Phase 2 field testing. During Phase 2 the separator was installed on a branch of the cooling water subsystem that supplies the turbine packing and runner seals for Unit 2 at Reclamation’s Davis Dam.

Laboratory Testing Setup

Testing was performed using a test facility constructed at Reclamation's Hydraulics Laboratory in Denver, Colorado (Figure 2). Flow to the separator was supplied from the laboratory pump system to a head tank. Water was then drawn from the tank using a 3 HP centrifugal pump which charged the separator at the required operational flowrate. Treated water from the separator was discharged to a settling tank with an overflow weir to capture solids that were not removed by the separator. The setup included an automatic purge value at the bottom of the separator to purge separated debris. The flowrate for all tests was set at 0.40 ft^3/s (approximately 180 gal/min) within the separator design range of 130-225 gal/min.

Mesh bags were attached to the discharge side of the separator and on the discharge end of the purge system to capture debris. The total wet weight of debris collected from the discharge of the separator (not separated) and the purge (separated) were compared with the total wet weight of debris introduced to obtain separation efficiency.

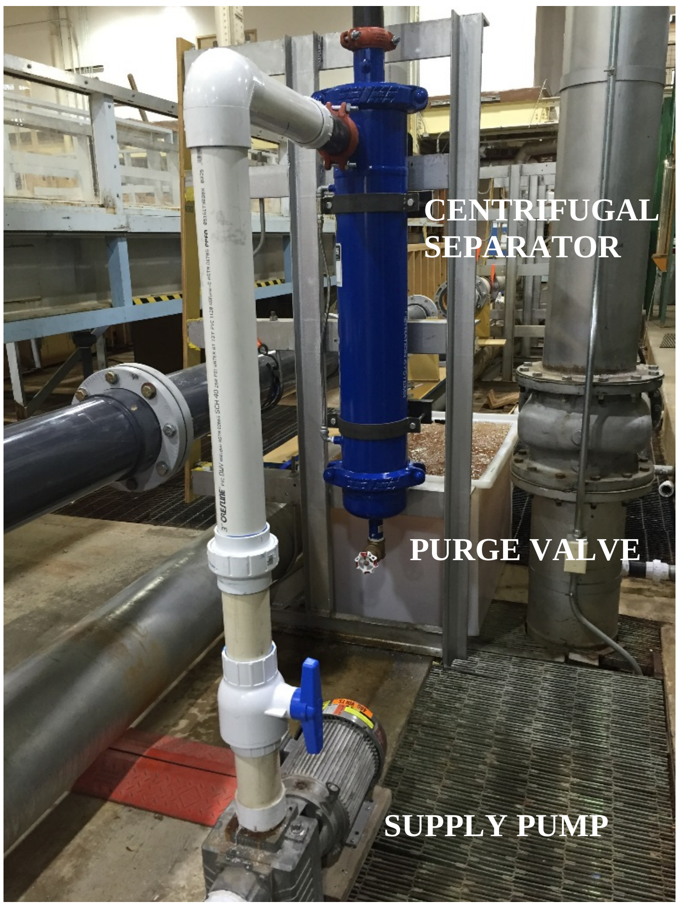

Figure 2. Photograph of laboratory setup for preliminary separator testing

Field Testing Setup

Following laboratory testing, the centrifugal separator was shipped to Davis Dam for installation. Figure 3 shows the as-installed setup on the test branch for the Unit 2 turbine packing and runner seals cooling water supply piping. The test branch is comprised of 3-in-dia steel piping which is interconnected with the 4-in cooling water supply piping and has a flow capacity of approximately 175 gpm. Figure 4 shows the flow directions for the inlet, outlet, and purge piping.

The separator was equipped with an automatic purge valve (ball valve) and controller with adjustable purge frequency and duration settings. A bag filter housing (Figure 5) with 800-micron filter media was installed on the purge line for collection of shell debris that was removed by the separator. Purged debris was collected from the bag filter housing monthly and dried in a 105°C oven for 24 hours to obtain a dry weight.

Finally, bioboxes were installed upstream and downstream of the separator for the control and treatment settlement evaluation. Biobox flowrates were monitored using a dual-channel ultrasonic flowmeter (Figure 6).

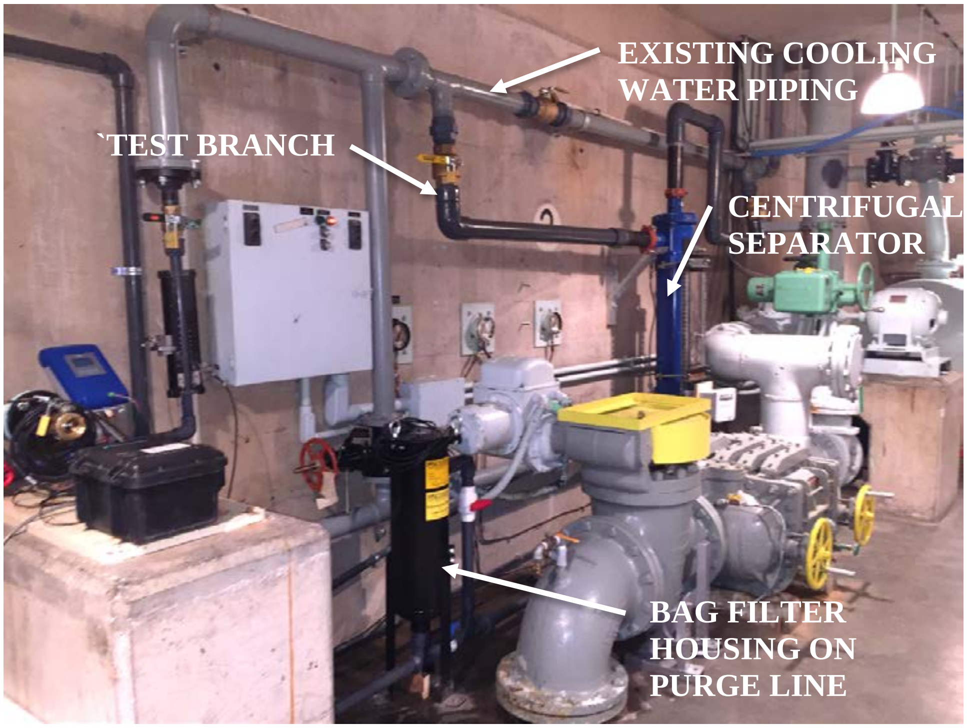

Figure 3. Field test setup on Unit 2 cooling water branch at Davis Dam

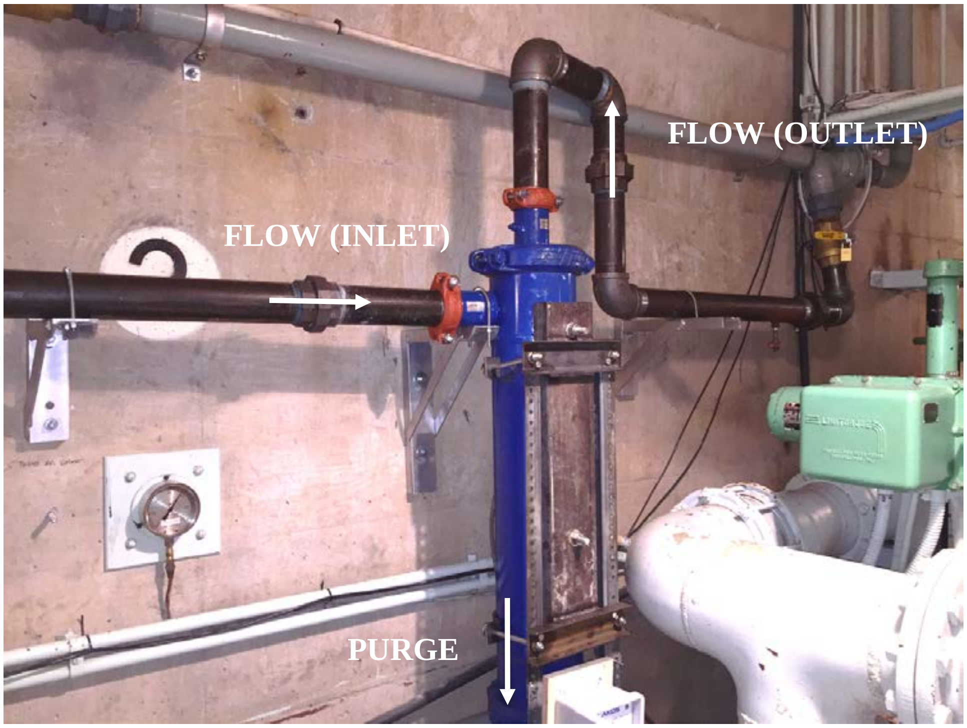

Figure 4. Centrifugal separator installed on test branch

Figure 5. Bag filter housing installed on purge line to collect debris removed by separator

Figure 6. Dual channel ultrasonic flow meter for monitoring bioboxes flowrates during testing

Mussel Settlement Analysis

Quagga mussel settlement was analyzed pre and post separation to determine if the separator was capable of removing pediveligers (the mussel larval stage which settles) from the cooling water. Sub-samples of water were diverted into bioboxes via branches from the main experimental pipe. The “control” biobox received a sub-sample of water from upstream of the separator, while the “treatment” biobox received a subsample of water downstream of the separator. The bioboxes were constructed from 10-gal coolers, which helped maintain a consistent water temperature, and provided a dark location for settlement (Figure 7). The coolers were modified with inflow and outflow ports to allow continuous water flow. The flow rate through each biobox was set at approximately 2 gal/min, to provide retention time for mussels to settle. Flowrates were recorded hourly using acoustic flowmeters to observe fluctuations in flow and to determine the total amount of water passing through each biobox.

Settlement plates (14.7 cm x 14.7 cm) were placed in each biobox to monitor mussel settlement (Figure 7). At the end of each one-month test the mussels which settled on both sides of each plate were collected and enumerated using cross polarized light microscopy. The total number of mussels settled in each biobox were compared to determine if the separator effectively removed pediveligers from the water resulting in reduced settlement.

Figure 7. Cooler biobox containing 10 settlement plates for monitoring mussel settlement

Mussel Larvae Separation

Veliger (mussel larvae) samples were collected to determine if the separator was capable of removing significant numbers of veligers of different size classes. Veliger samples were collected from sample ports located upstream and downstream of the separator using a 64-µm plankton tow net (Figure 8). Five replicates of a known concentration were collected from each location. Additional veliger samples were collected from the bag filter housing by placing a 64-µm cod-end filter inside the housing during the 30 second purge cycle. The cod-end filter was not large enough to filter all of the water during the purge cycle. Therefore the purge samples represent an unknown portion of the total amount of water and veligers purged. Eight purge samples were collected to determine if any veligers were purged.

The consolidated mussel samples were placed in bottles, preserved with 20 percent isopropanol alcohol, and buffered with 0.2 g of sodium bicarbonate (baking soda). Samples were sent to the Reclamation Detection Laboratory for Exotic Species where they were analyzed by microscopy. Mussels were enumerated based on size class (D-stage mussels between 50–100 µm, umbonal mussels between 100–200 µm, and pediveligers between 200–500 µm).

Figure 8. Collection of veliger sample using a 64-µm plankton tow net

Results

Laboratory Testing

Initial testing consisted of introducing two different types of debris to represent mussel shell debris sizes including sunflower seeds and pistachio shells. It quickly became apparent that the separator performed poorly for sunflower seed removal owing to the specific gravity of the seeds. While some of the seeds were removed, the majority of the seeds passed through the separator.

The second preliminary test using pistachio shells showed equally poor performance. However in this case, the shells quickly clogged the vertical slots just downstream of the inlet to the separator. The majority of shells that did pass through the vertical slots were separated, but the extent of clogging clearly demonstrated a limitation in the size and type of debris that can be removed.

The remaining tests involved the use of preserved dead mussel shell debris obtained from Lake Mohave, AZ. Results from this testing showed much greater promise with a significant portion of the shell debris removed by the separator. However, the purge value which was set on a 5-minute purge cycle became clogged, requiring disassembly and removal of debris.

Additional testing with shorter purge intervals improved the operating characteristics and resolved the issue. During the first test, the wet weight of mussel debris added was 259.86 g of which 13.21 g passed through the separator (was not separated), 181.65 g was removed through the purge valve, 2.06 g remained in the upstream tank and did not pass through the separator and 62.34 g was not recovered. This initial test indicates that 70% of the debris introduced was removed through the purge system of the separator. Table 1 summarizes the results of three laboratory tests for mussel debris removal efficiency.

Table 1. Laboratory separator efficiency test results

Test No.	Initial Wt (g)	Separated Wt (g)	Passed Wt (g)	Tank Wt (g)	Wt Lossed (g)	Passed (%)	Loss (%)	Efficiency (%)
1	259.86	181.65	13.21	2.06	62.34	5.08	23.99	70.46
2	419.55	267.58	17.26	8.43	126.28	4.11	30.10	65.09
3	261.14	212.94	13.79	0.47	33.94	5.28	13.00	81.69

It should be noted that lost weight is expected using the wet-weight method due to dislodging of mussel internals and fluids during testing. It was observed that most of the weight collected on the outlet (not separated) consisted of mussel tissue with very few shells passing through the separator (Figure 9). These results suggest that a centrifugal separator comparable to the Lakos design is capable of removing significant percentages (65-80%) of shell debris (Figure 10).

Figure 9. Mussel shell debris collected from the outlet (not separated) consistent primarily of mussel tissue

Figure 10. Mussel shell debris collected from the separator purge (separated) consisted primarily of mussel shells

Field Testing

Mussel Debris Separation

All samples collected from the bag filter housing contained mussel shells indicating the separator, as installed, is capable of removing mussel shell debris in the turbine packing and runner seals cooling water supply at Davis Dam. It was not possible to quantify the amount of debris entering the separator because of the installation location. Without this information shell removal efficiency could not be determined. The amount of debris purged monthly appeared to gradually increase from April-August (Table 2).

Table 2. Dry weights of debris separated during field testing at Davis Dam

Dates	Total Days	Purged Debris Dry Weight (g)
April 6th- April 27th	22	7.05
April 27th- May 23rd	27	6.86
May23rd- June 22nd	31	14.07
June 22nd- July 24th	33	17.09
July 24th- August 24th	32	20.23

Mussel Settlement Analysis

The results indicated no reduction in settlement downstream of the separator during three of five tests (Table 3). Mussel settlement is dependent upon the total amount of water passing through each biobox. If the separator was effectively removing pedi-veligers, settlement in the post-separation biobox would be consistently less than settlement in the control biobox, despite flow variations between the treatment and control bioboxes. Settlement in the treatment biobox was less than the control during Tests 1 and 2. However, the recorded flowrates indicate a 4-day period without flow to the treatment biobox during Test 1, and a 2-day period without flow to the treatment biobox during Test 2. The settlement reduction is likely due to these no-flow periods. When flow is stopped to the biobox for multiple days, new settlement is not occurring and already settled mussels may die due to increased water temperatures and decreased dissolved oxygen levels. After the first test, dead mussels were observed floating at the surface of the post-separator biobox.

Test 3 had the most consistent flow totals between bioboxes. More mussels were observed in the treatment biobox despite receiving 5,629 gal less than the control. More mussel settlement and flow was observed in the treatment biobox in Tests 4 and 5. Thus, the settlement tests do not indicate that downstream settlement is reduced by the separator.

Table 3. Biobox settlement and total flow during five seprator tests at davis Dam

Test	Dates	Total Days	Control		Post- Separator	
			Total Mussels	Total Gallons	Total Mussels	Total Gallons
1	April 6th- April 27th	22	6,050	45,627	893	29,182
2	April 27th- May 23rd	27	6,572	42,037	5,233	65,783
3	May23rd- June 22nd	31	4,789	42,683	5,475	37,054
4	June 22nd- July 24th	33	798	21,393	3,920	43,340
5	July 24th- August 24th	32	99	19,133	432	50,589

Mussel Larvae Separation

Veligers of each size class were found in samples collected from the separator purge (Table 4). It is difficult to determine the exact percent of veligers removed from the system because it was not possible to collect the entire purge sample. Approximately 1,750 gal of water passed through the separator between purge cycles, therefore at least 0.68 veligers/gal were purged. In comparison, an average of 128 veligers/gal were collected from upstream of the separator and 110 veligers/gal were collected downstream of the separator on the same days purge samples were collected. Although only an estimate, the veliger separation efficiency appears to be low, which would explain why downstream settlement was not reduced.

Similar numbers of veligers were collected from samples upstream and downstream of the separator, with slightly lower numbers seen in the post-separator samples (Table 5). One size class did not appear to be preferentially separated over another.

Table 4. Veliger counts from eight samples collected during separator purge cycle

Purge Sample	D-Stage	Umbonal	Pedi-veliger	Total Veligers
1	286	389	32	707
2	470	382	27	879
3	503	658	30	1,191
4	260	418	19	697
5	92	309	18	419
6	97	1,576	135	1,808
7	152	1,475	130	1,757
8	171	1,705	153	2,029
Average:	**253.9**	**864**	**68**	**1,185.9**

Table 5. Veliger counts from samples collected upstream and downstream of separator

Location-Rep	D-Stage	Umbonal	Pedi-veliger	Total Veligers
Upstream-1	779	1,352	100	2,231
Upstream-2	692	1,327	94	2,113
Upstream-3	815	2,204	184	3,203
Upstream-4	482	2,014	125	2,621
Upstream-5	821	2,319	55	3,195
Average:	**717.8**	**1,843.2**	**111.6**	**2,672.6**

Downstream-1	970	1,127	97	2,194
Downstream-2	419	1,895	168	2,482
Downstream-3	548	1,578	44	2,170
Downstream-4	401	1,751	57	2,209
Downstream-5	471	2,115	79	2,665
Average:	**561.8**	**1,693.2**	**89**	**2,344**

Mussel Shell Debris Removal

During field testing, shell debris removed by the separator through the purge system was collected using the bag filter housing installed on the purge line. Figure 11 shows the amount of debris collected during each of the five monthly tests (Tests 1-5 from left to right). Although the collected quantities are not large, it is important to note that this is debris which has either passed through the strainer on the cooling water takeoff or sluffed off from settlement in the piping downstream of the strainer. While it was not possible to quantify separation efficiency, these qualitative observations indicate the separator removed additional shell debris providing further protection of the cooling water system beyond that afforded by the strainer.

Figure 11. Shell debris collected from the separator purge system during field testing (Tests 1-5 from left to right)

Biobox Flowrates

Control of flowrates to the bioboxes was difficult throughout the course of testing, particularly for the treatment biobox. Project staff at Davis Dam attempted to adjust flowrates on a daily basis with little success. Flowrates to the treatment biobox varied widely during the first two tests (Figure 12) and actually dropped to zero over short periods of time. Following the initial tests, throttling was changed to use of the in-line ball valve instead of using the biobox supply takeoff gate valve. This change improved flowrates to the treatment biobox, but significant variability in comparison with the control biobox remained (Figures 13-15). It is unclear why the flowrates in all cases (particularly for the control) decreased during each of the tests. The most likely explanation is that the valves used for throttling slowly became obscured with debris resulting in reduced flowrates.

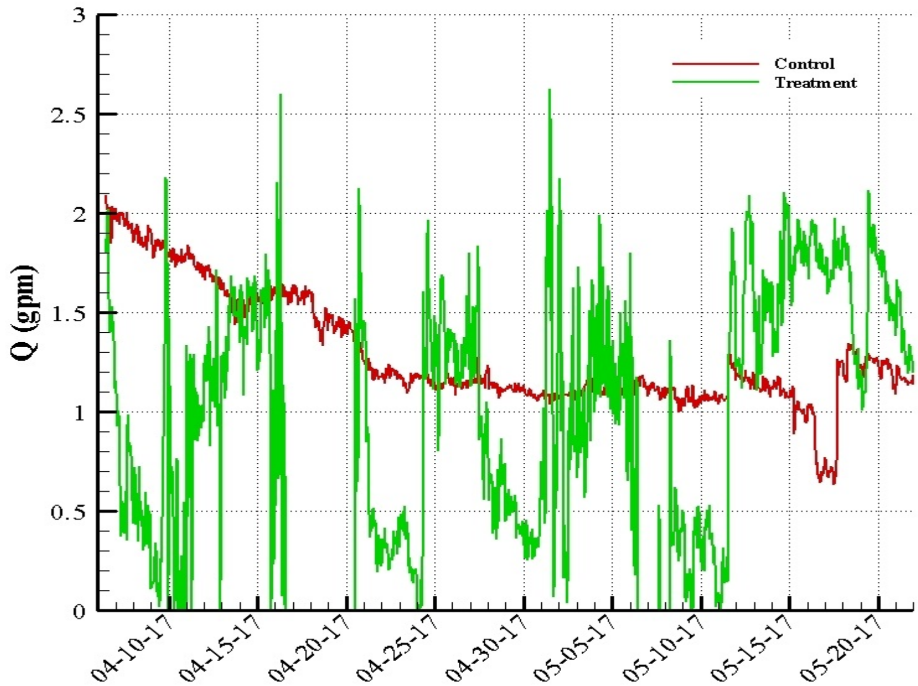

Figure 12. Control and treatment biobox flowrates during Tests 1 and 2

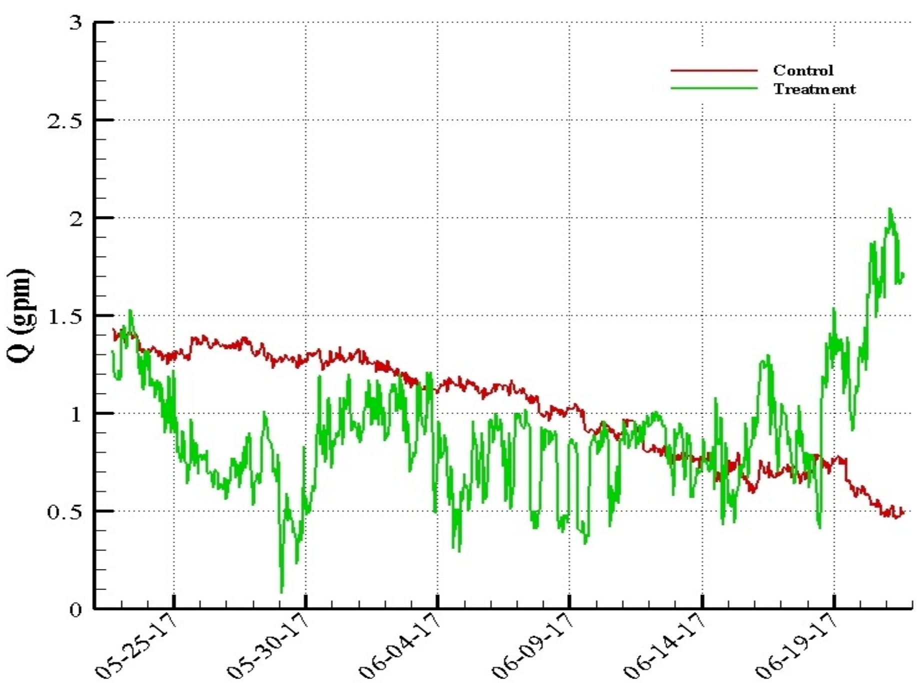

Figure 13. Control and treatment biobox flowrates during Test 3

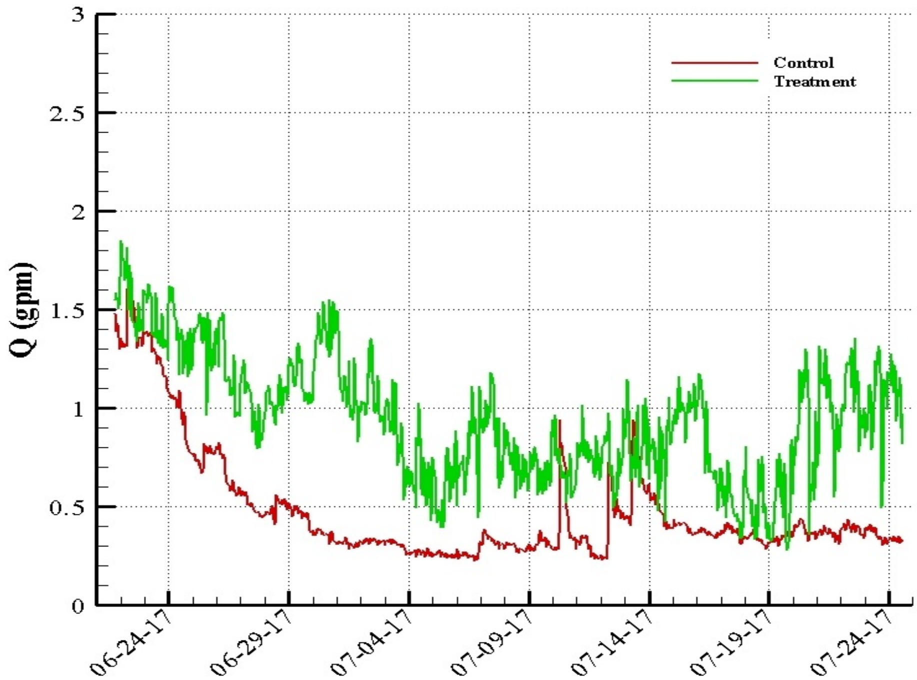

Figure 14. Control and treatment biobox flowrates during Test 4

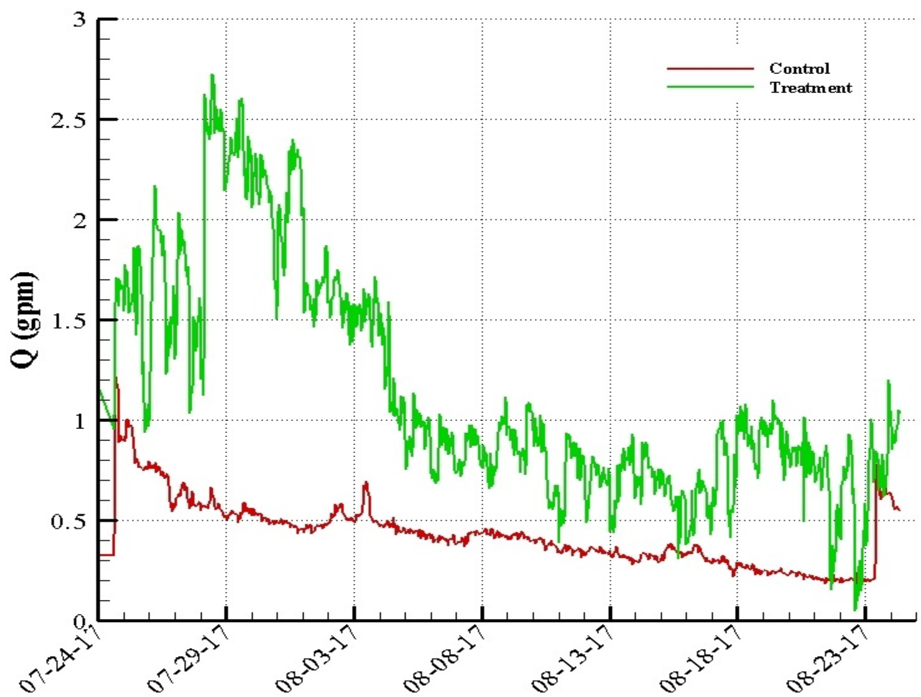

Figure 15. Control and treatment biobox flowrates during Test 5

Conclusions & Recommendations

Although the field test conditions with respect to bioboxes flowrates were not ideal, the performance of the separator for settlement reduction does not appear effective. However, performance regarding shell debris removal does appear promising. During the course of field testing, the separator operated continuously for the entire six months without requiring any maintenance. This operational characteristic, combined with shell debris removal, represents good potential as a low maintenance technology for mussel mitigation.

Typical cooling water systems are protected from debris using conventional strainers installed just downstream of supply piping takeoffs from penstocks or scroll cases. However, given typical cooling water system flowrate requirements (on the order of thousands of gpm), strainer media size is limited to about 1/8-in perforations. While this size removes a large portion of shell debris, is too large to prevent smaller shell debris from passing and impacting downstream systems. The use of centrifugal separation downstream of existing strainers may relax the 1/8-in strainer medial requirement such that improved (lower maintenance) shell debris removal could be possible with conventional 1/4-in media (i.e., without the need to reduce strainer media size as is commonly recommended for cooling water systems exposed to mussels). The following conclusions based on laboratory and field testing are summarized as

- Centrifugal separators, comparable to the Lakos design, are capable of removing 65-80% of mussel shells based on laboratory testing.
- The separator did not experience any malfunctions nor require any maintenance during the 6-month continuous field deployment.
- Mussel settlement was not reduced downstream of the separator during field testing suggesting low separator efficiencies for mussel larvae.
- Only a small proportion of veligers from each size class were purged by the separator which is consistent with the lack of settlement reduction.

Although settlement reduction performance was not favorable, shell debris removal performance appears to show promise. Additional field testing is recommended to confirm laboratory findings regarding effectiveness (efficiency) for shell debris removal. Doing so would require modifications to the field test facility at Davis Dam to quantify shell debris downstream of the separator for comparison with debris removed by the separator through the purge system.

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