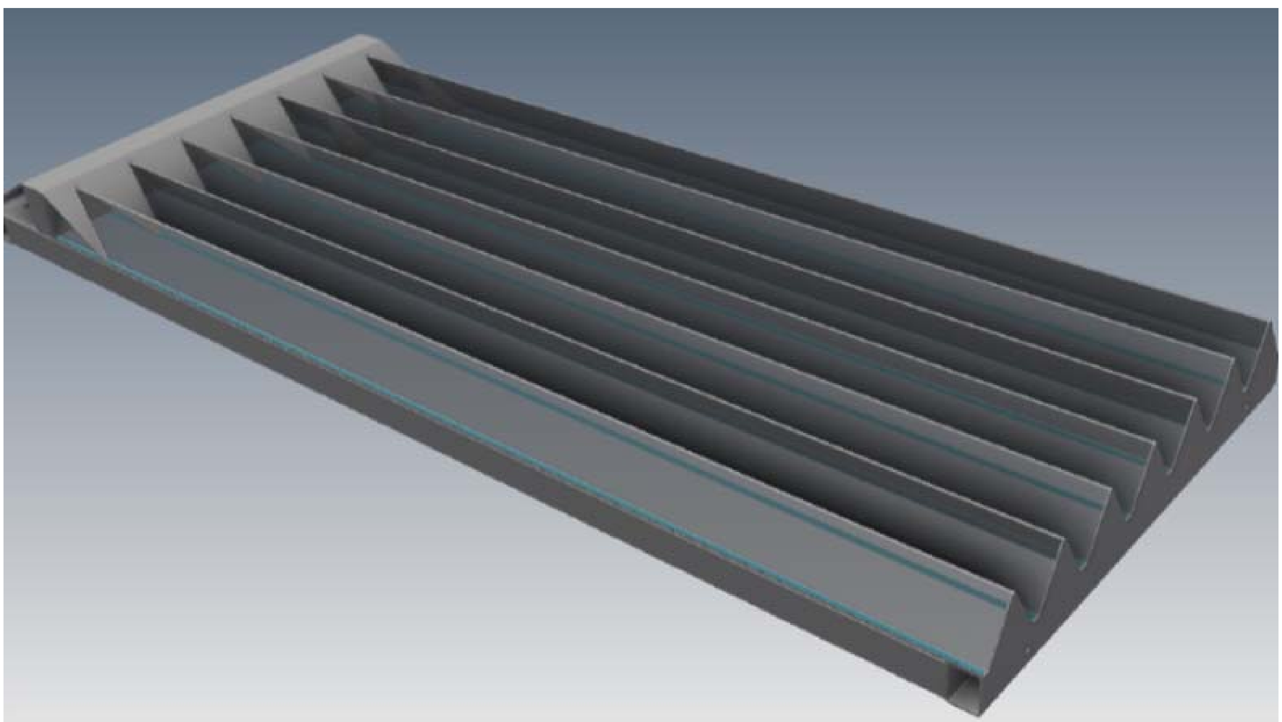
Hydraulic Laboratory Technical Memorandum PAP-1157

Laboratory Tests of a Corrugated Water Screen for Screening Fish from Irrigation Water Diversions



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Denver, Colorado

December 2016

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Laboratory Tests of a Corrugated Water Screen for Screening Fish from Irrigation Water Diversions

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Date

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Introduction

Reclamation is interested in applying passive style fish screens with low operation and maintenance costs to protect native species from entrainment into irrigation canals. Many rural screening sites would benefit by implementing a passive style screen. Passive style screens are designed to minimize the need for mechanical cleaners to clean debris off the screen surface. Corrugated Water Screens (CWS) are a new style of fish and debris screen that uses perforated plate corrugated into a series of trapezoidal shaped channels on the screening surface. The screen can be mounted as an overshot style screen with good passive cleaning characteristics or as a more traditional vertical screen with brush cleaner.

Summary

Hydraulic evaluation tests of the Corrugated Water Screen (CWS) screen were conducted in Reclamation's Hydraulics Laboratory. The testing mainly focused on the screen's hydraulic performance when mounted in an overshot ramp orientation. Several tests were also conducted with the screen mounted as a vertical screen with the corrugations running parallel to the flow. Tests of the vertically mounted screen were conducted to investigate flow capacity, flow uniformity and measure screen plus baffle headloss.

In the overshot orientation the screen is designed to provide a high ratio between sweeping and screen approach velocity which promotes good passive cleaning characteristics. Clear water and debris tests were conducted of the screen operating under free flow and partially submerged conditions at different ramp slopes. Partially submerged describes the screen operating when the water surfaces in the fish bypass channel and/or the downstream canal and are raised above the screen toe. A 5-ft-long by 2.1-ft-wide screen module was used for these tests.

Overshot Screen Tests

The major findings of the overshot screen tests are summarized below. Findings for operating the screen under free flow and partially submerged conditions are presented.

Under free flow and partially submerged operation:

• Screen slopes between 0.85 and 4.0 degrees were tested. Varying screen slope within this range was not found to significantly affect screening capacity.

• The head to flow relationship for the screen crest is given by $Q_C=8.05*H^{1.5}$.

Under Free Flow Operation:

• The screen module tested passed a flow of 4 ft^3/s through the screen with 0.7 ft of head on the crest.

• The screen headloss was found to vary with screen slope. Screening a flow of 4.0 ft^3/s required about 0.9 ft of head at a 0.85 degree slope and 1.25 ft of head at a 4 degree slope.

Partially Submerged Flow Operation:

• The flow split between screened flow and bypass flow can be altered by submerging a length of the downstream end of the screen. This can be done by either raising the bypass water level and/or raising the downstream canal water level.

• Raising the bypass water level above the screen toe and downstream canal water level increases screened flow, decreases bypass flow, and forces a hydraulic jump on the screen. The screen was operated in the model under partially submerged conditions with screened flow capacities reaching about 8 ft^3/s.

• Raising the downstream canal water surface level above the screen toe increases bypass flow and reduces screen headloss. When the canal water surface is higher than the bypass water surface some screened flow will flow out the toe of the screen as bypass flow.

Debris Tests

• The overshot screen displayed very little debris impingement during multiple debris tests for both free flow and partially submerged operation.

• Air burst cleaning was effective for up to 0.5 ft of head on the screen crest. Air burst cleaning effectiveness decreases at higher heads due to the development of negative pressures on the downstream crest face.

• Brush cleaning (conducted manually in the tests) was very effective under free flow and submerged operation.

• Creating a hydraulic jump on the screen by raising the bypass channel water level was also found to remove impinged debris from the screen.

Vertical Screen Tests

Dye injection tests on the screen mounted vertically showed good uniformity of flow through the screen surface indicating the same baffle plate used for the overshot orientation provides good flow control for the vertically mounted screen. The screen module passed 5 ft^3/s flow or 0.47 ft^3/s per sq. ft. of vertical surface area with a headloss of 0.28 ft. Larger flows could be passed by adding additional screen panels vertically and horizontally.

Screen Components and Attributes

The screen contains several features unique to fish screens that may improve operation and fish protection.

• The invert of each corrugation consists of a solid channel fish trough. The solid troughs provide multiple fish passage channels improving protection for small bodied fish and provide for movement of sediment over the screen away from the porous screen.

• Corrugating the screen fabric adds increased screen area yielding lower through screen velocity and increased structural stiffness when compared to a similar flat plate screen. The screen is mounted directly above a flow control baffle composed of a varying porosity plate. The baffle plate controls flow uniformity and velocity through screen without blocking screen area.

The screen's corrugation pattern, baffle plate and support frame is shown in figure 1. The screen has a crest plate that transitions flow onto the screen and causes the flow to accelerate. The screen fabric is stainless steel perforated plate. The screen tested in this study contained 3/32 inch round holes staggered on 5/16 inch centers with a 33 percent open area. The screen corrugation provides 1.42 times more perforated screen area compared to a flat surface after subtracting out the solid channel fish troughs. The crest ramp and screen are mounted on a stainless steel porosity (baffle) plate. The plate tested had three sections containing porosities of 4, 8, and 15 percent open area. The screen and baffle plate are supported on a stainless steel tubular frame that does not block any screen area. The frame was equipped with air release ports in the center of each corrugated channel to allow compressed air to be released to supplement mechanical screen cleaning.

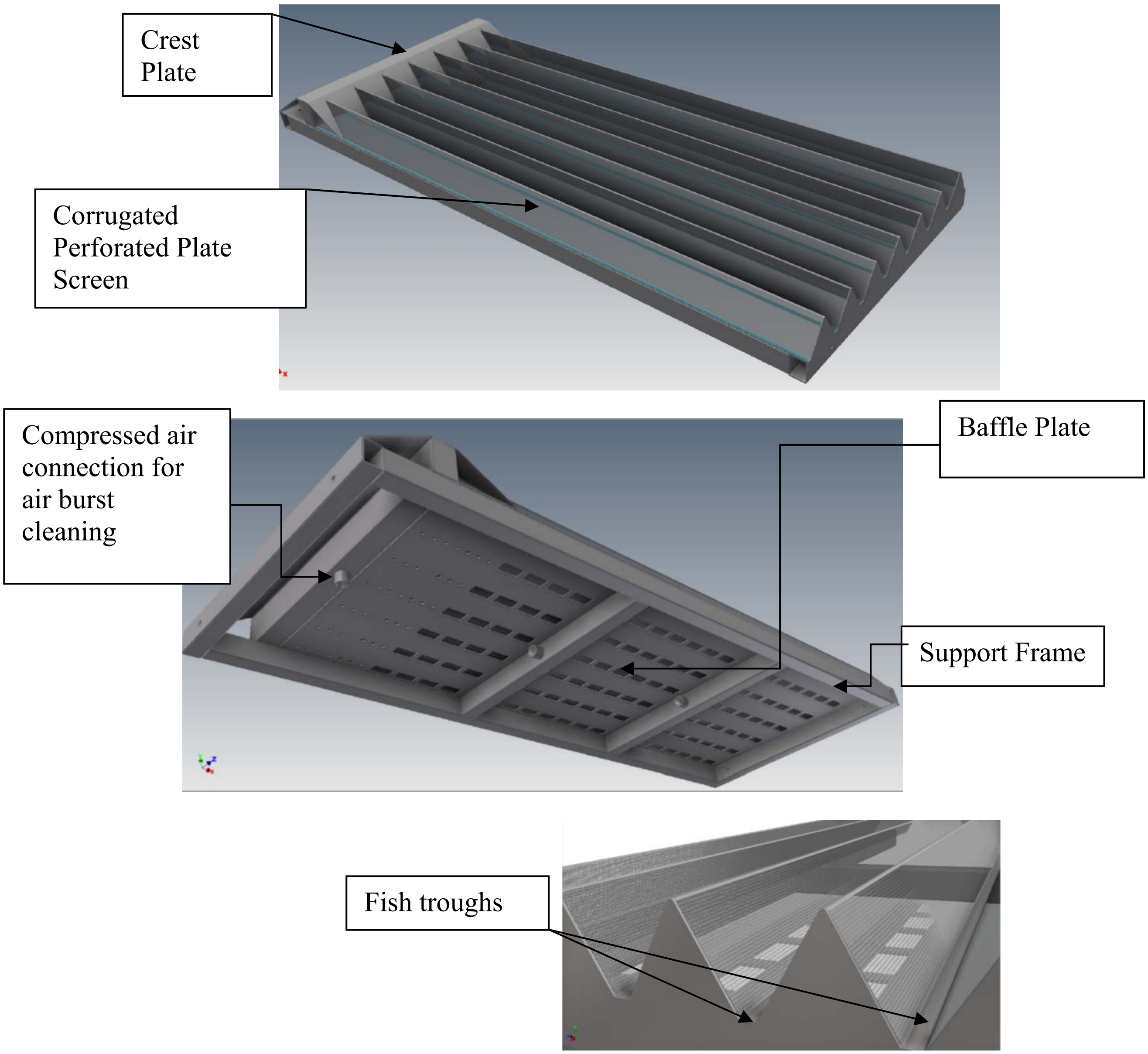

Figure 1. Three dimensional CAD renderings showing the screen, baffle plate, support frame and fish troughs.

Model Tests

An existing model box in the hydraulics laboratory was modified to accommodate the CWS testing, figures 2 and 3. A 5-ft-long by 2.1-ft-wide prototype screen module was installed in a laboratory flume for testing, see figure 3. The screen was tested to evaluate its performance when mounted both as an overshot down ramp and a vertical screen. Upstream of the screen the model consisted of a head box with gravel baffle and a transition section to a 2.1-ft-wide rectangular screen channel.   The-2.1-ft wide channel continued about 20 ft downstream from the screen where an adjustable height sharp-crested weir was installed to measure bypass flow and adjust the downstream water level. Beneath the screen (overshot orientation) or behind the screen (vertical orientation) an opening was provided through the channel wall to allow screened flow to pass out the side and into a parallel screened flow channel.   Near the downstream end of the screened flow channel an adjustable width sharp- crested weir was used to measure screen flow and adjust backwater depth on the screen. Flow to the model was supplied using the laboratories' permanent pumping and water measurement system.   Flow was pumped into the headbox upstream of a gravel baffle used to remove excessive turbulence. Flow then moved downstream through the model as open channel flow and discharged into the laboratory sump where it was recirculated.

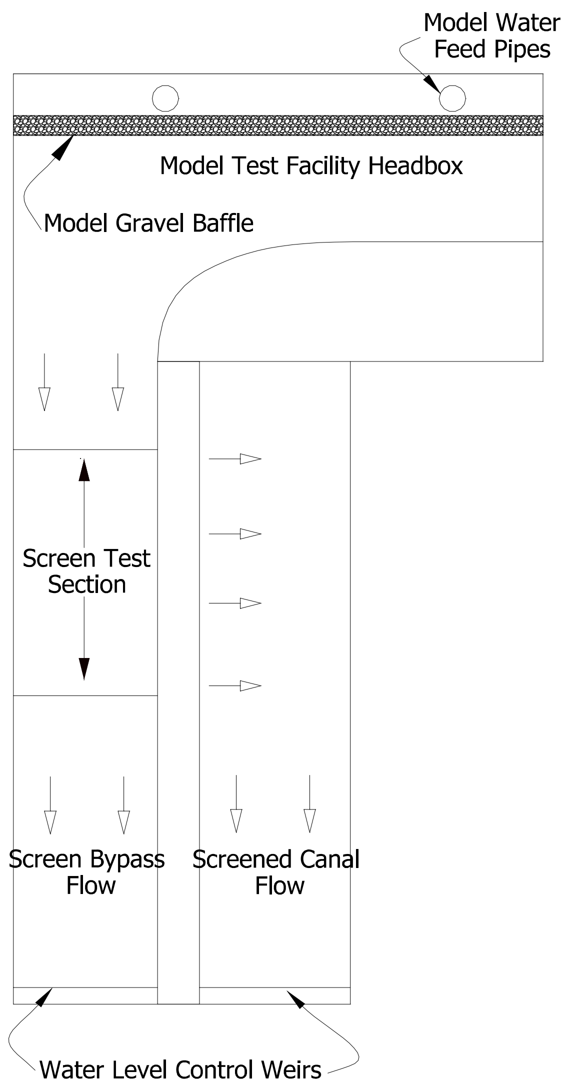

Figure 2. Plan view drawing of model test facility

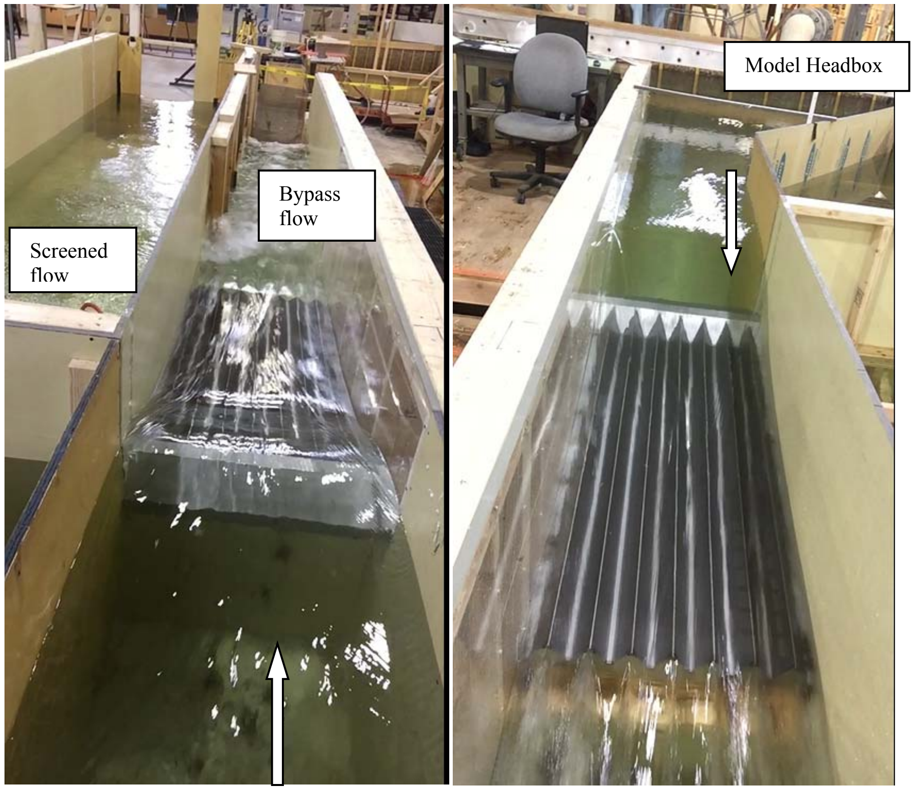

Figure 3. Views of the model looking downstream (left) and upstream (right) at the screen channel. The screened flow channel is shown on the left side of the left photograph.

Overshot Screen Configuration

The screen was mounted in the channel with the corrugations running in the direction of flow. The screen crest (upstream end of the screen) was supported on a 1.5-ft-high sill wall. The downstream screen toe was mounted on an adjustable sill wall to permit different screen slopes to be evaluated.

Vertical Screen Configuration

The model used for the overshot tests was modified for the vertical screen tests by removing the weir walls that supported the overshot screen. The screen was installed with the corrugations running in the flow direction. The screen was mounted on its side on a 1.5-inch-high sill plate at an angle of 17 degrees to the flow. The angle of the screen in the channel was chosen to achieve a 4-inch-wide flow bypass slot at the end of the screen. The screen crest plate, now vertical, was mounted flush to the channel wall with a short transition wedge added upstream to smooth flow onto the crest plate (see figure 25).

Overshot Screen Tests

In the overshot configuration the screen crest is mounted on a horizontal sill with the screen sloping downward at a shallow slope in the flow direction. Flow passes over the screen crest ramp where flow accelerates prior to passing onto the screen. The majority of the flow reaching the screen gradually passes through the screen and baffle plate as it flows downstream over the screen. The remaining flow, termed bypass flow carries fish and debris past the screen where it can be directed back to the stream. The overshot CWS screen with the flow control baffle plate beneath the screen maximizes debris passage by creating a high sweeping velocity across the screen surface and a low through screen flow velocity.

Test Objectives

The screen tests were conducted to gather hydraulic performance data on the screen and obtain experience related to the passive cleaning characteristics of the screen under different hydraulic conditions. The primary hydraulic performance data collected were screen headloss and flow capacity under free and submerged flow conditions for different screen slopes. As an overshot screen the CWS is designed to operate under free flow or partially submerged conditions.

Test Setup and Data Collection

Screen slopes between 0.85 and 4 degrees (1.5 to 7.0 percent) were tested. Measurements recorded in the model (see figure 4) included:

- Upstream head on screen crest (H)
- Water surface elevation in the downstream canal (screened water, H_C)
- Water surface elevation in the bypass flow channel (unscreened water containing fish and debris, H_{BP})
- Upstream canal flow, Q_C
- Downstream canal flow (screened water, Q_S)
- Bypass flow, Q_{BP}

Many test runs also included visual observations of debris movement past the screen.

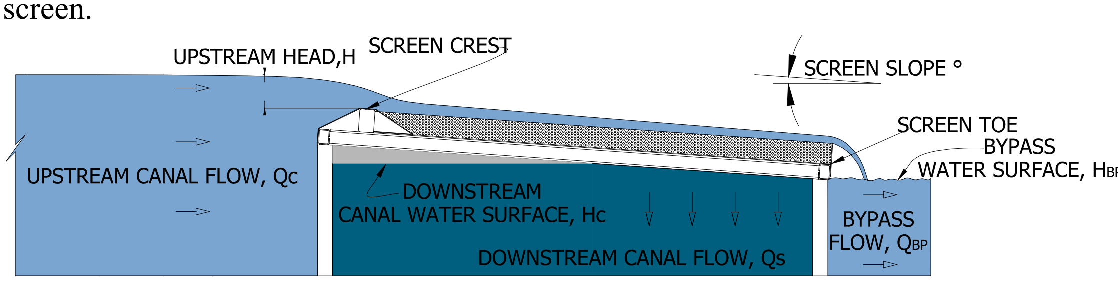

Figure 4. Schematic showing terms used for describing the screen measurements.

Overshot Screen Operation

The overshot screen crest acts as a weir controlling flow passing downstream onto the screen. The screen was not tested under high submergence levels that would alter the crest discharge relationship.

Overshot screens can operate under a range of different conditions depending on the water surface elevations upstream and downstream of the screen. Downstream water levels include both canal and bypass water surfaces. Possible screen operating conditions can be best described using a four quadrant diagram, figure 5. These operating conditions can occur for any type of sloping overshot style screen. Quadrant I represents free flow conditions with no tailwater submergence of the screen and screen performance is highly predictable. Because the screen slopes, only Quadrant I is defined by a single type of flow over the entire screen.

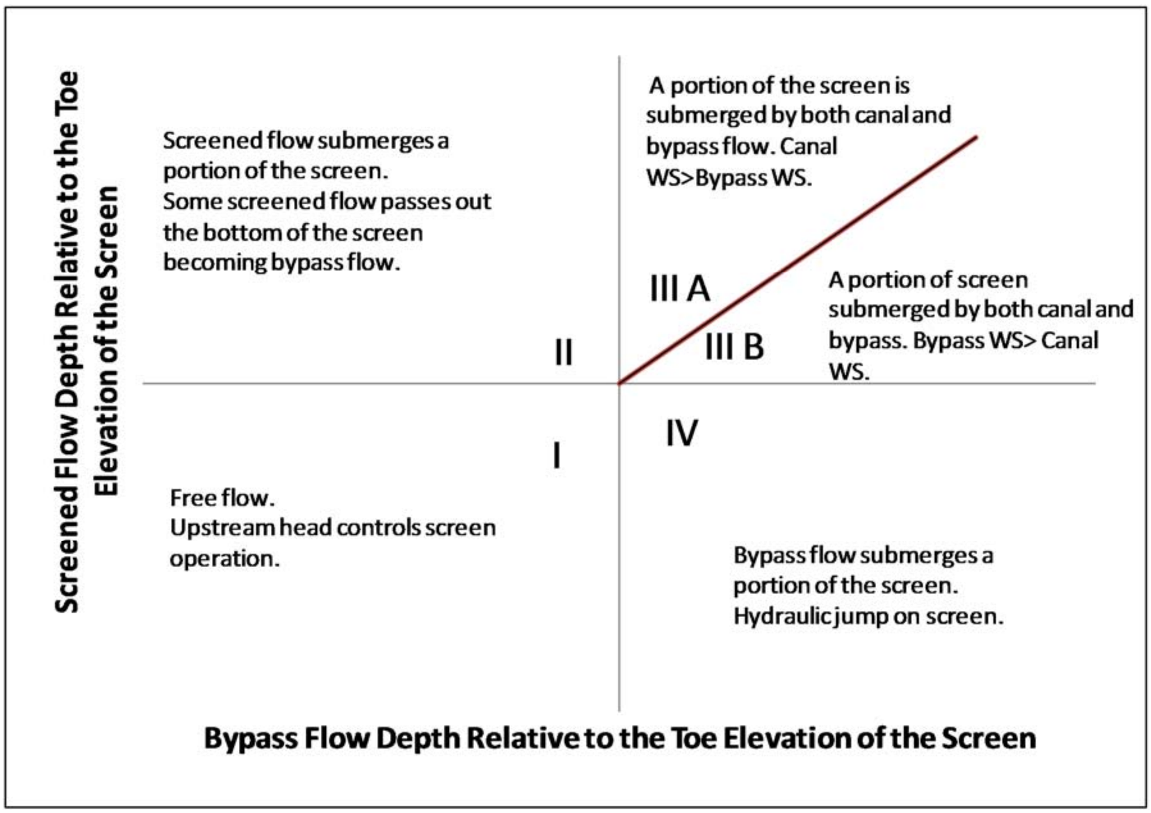

Figure 5. Four quadrant diagram of screen operation for a sloping overshot screen.

Quadrants II-IV depict different operating conditions combining free flow on upstream unsubmerged portions of the screen with tailwater submergence affecting flow through the lower portion of the screen. For all tests, crest flow (Q_C) was not affected by partial submergence of the screen. Therefore, changes in Q_S and Q_{BP} that occur in Quadrants II-IV reflect a shift in the percent of Q_C split between Q_S and Q_{BP}. Quadrant II represents a condition where the downstream canal water surface is higher than both the screen toe and bypass water surface. For this scenario, a portion of the screened water passes out the screen toe, adding to Q_{BP} and reducing the screen efficiency. This condition would occur when the downstream canal water surface was checked up abnormally high.

Quadrant III represents conditions where both downstream canal flow and the bypass flow submerge a portion of the screen. Equal canal and bypass water surface elevations are represented by the 45 degree line shown splitting the quadrant. Above the line the canal water surface is higher than the bypass water surface causing some screened flow to pass back out of the screen becoming bypass flow similar to Quadrant II. This region is identified as Quadrant III-A on figure 5. Below the line is Quadrant III-B where the bypass flow water surface is higher than the canal water surface impeding backflow of screened water through the submerged screen toe. Operating in Quadrant III-B provides control of screened and bypass flow percentages with the ability to also reduce screen headloss in contrast to Quadrant I. Operating in Quadrant III could occur if the bypass water surface is raised above the screen toe to reduce bypass flow and the increased canal flow raises the canal water surface above the toe of the screen.

Quadrant IV represents partial screen submergence by the bypass water surface while the canal water surface is below the screen toe. Operation in this quadrant allows the flow split between screened flow and bypass flow to be altered in favor of greater screened flow and smaller bypass flow. This operation allows increased screened flow compared to Quadrant I operation. Operating in Quadrant IV is the recommended operating condition for partially submerged operation. Diagrams showing operating conditions for each quadrant are shown in figure 6.

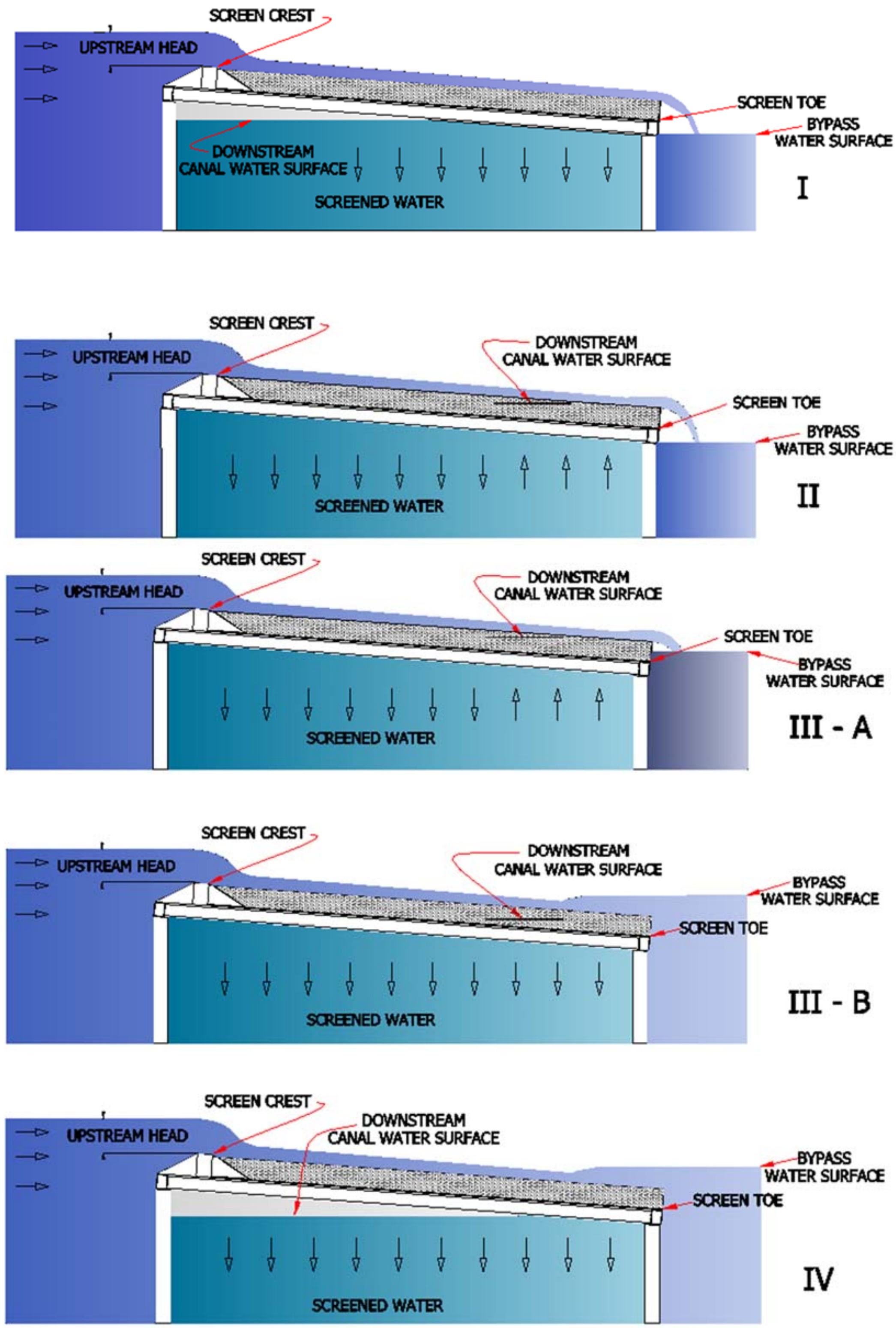

Figure 6. Diagrams showing water surface levels for the four quadrants of screen operation.

Overshot Screen Test Results

One hundred eight tests were conducted with the screen mounted in an overshot configuration. All test conducted are shown on a four quadrant chart in figure 7. Testing focused largely on screen performance in Quadrants I and III-B. A high canal backwater condition in the model test facility limited the range of tests that could be conducted in Quadrant IV. The time the model facility was available for the testing prohibited modifying the model to allow expanded testing in Quadrant IV. The screen module was installed and tested at slopes of 4.0, 3.7, 2.2 and 0.85 degrees. Screen slope was varied to obtain data on the influence of slope on screen diversion capacity, headloss and debris passage. Visual observations were used to identify notable changes in debris passage.

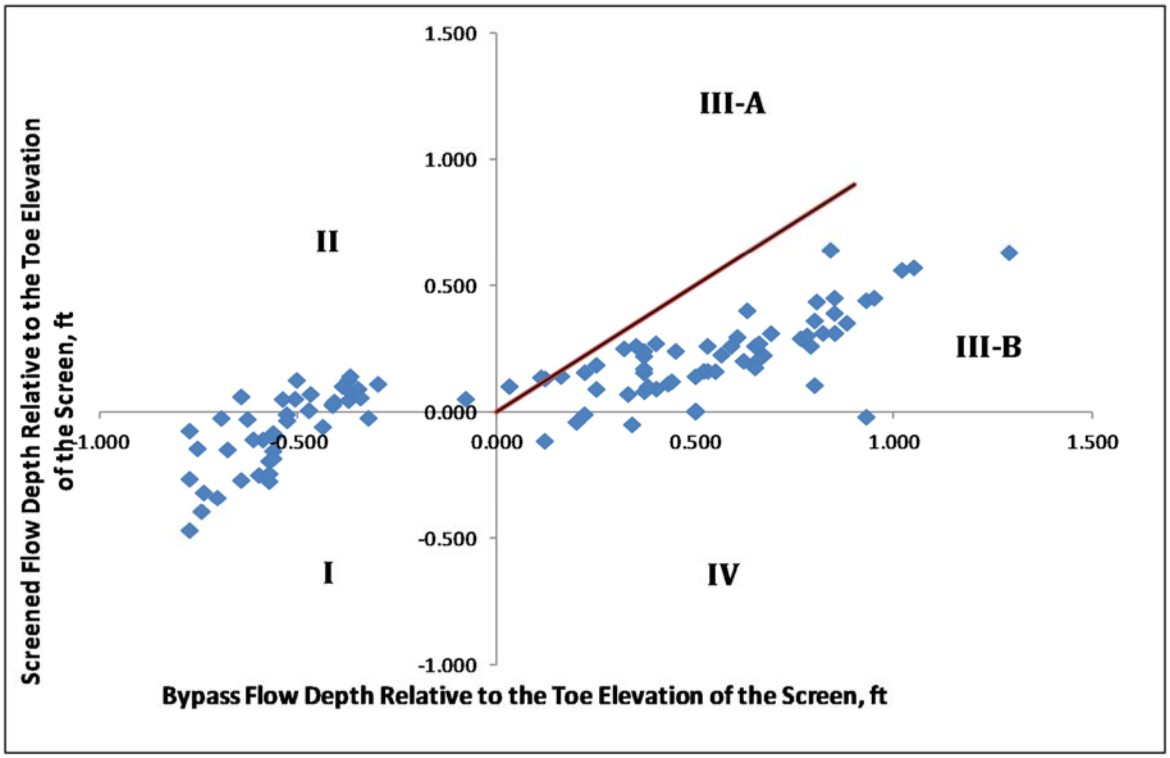

Figure 7. Plot showing all overshot test data on a four quadrant diagram.

Quadrant I - Free Flow Operation

Bypass water surface elevation and screened canal water surface elevation below the toe of the screen. The CWS was installed in the model in an overshot orientation operating under free flow conditions as shown in figure 8. Flow over the screen crest either passes through the screen and baffle becoming screened canal flow or passes off the downstream end of the screen as bypass flow.

Figure 8. Side and upstream looking views of the screen in an overshot orientation while operating at 3 ft^3/s under free flow conditions.

A discharge rating curve for the CWS crest is given in figure 9. Screen slope within the range tested was not found to significantly affect the crest discharge (Q_C) and a single rating curve is shown for all screen slopes tested. The screened flow (Q_S) versus upstream head relationship is presented in figure 10. The rating curve shown applies to all slopes tested for upstream heads up to 0.7 ft. The screen became fully wetted at a head of about 0.7 ft or a Q_S of 4 ft^3/s. Again, the free flow tests show no discernible difference between screen slopes tested. For upstream heads greater than 0.7 ft the screen is fully wetted and the rate of increase in screened flow (Q_S) declines sharply.

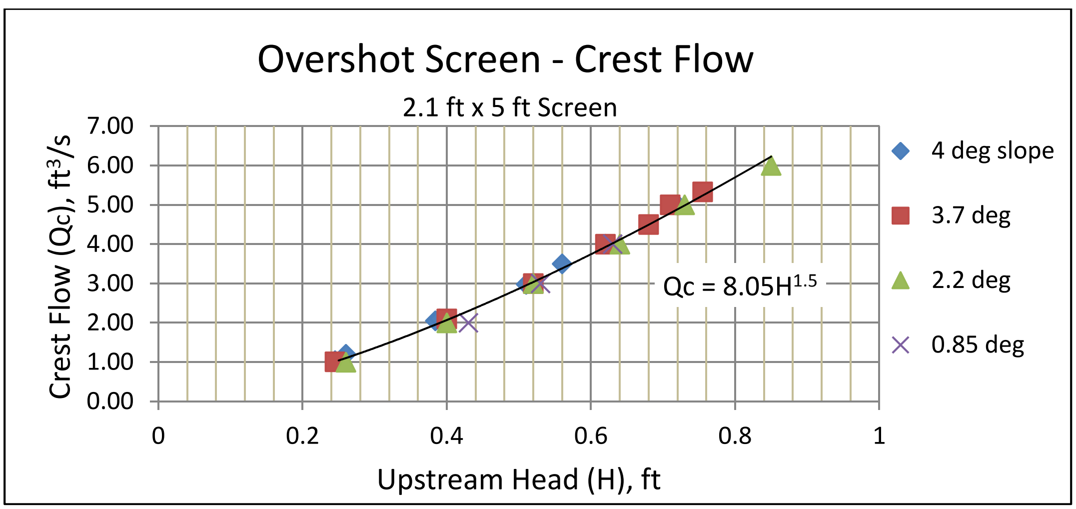

Figure 9. Plot of Crest Flow (Q_C) versus Upstream Head (H). Upstream head is referenced to the screen crest.

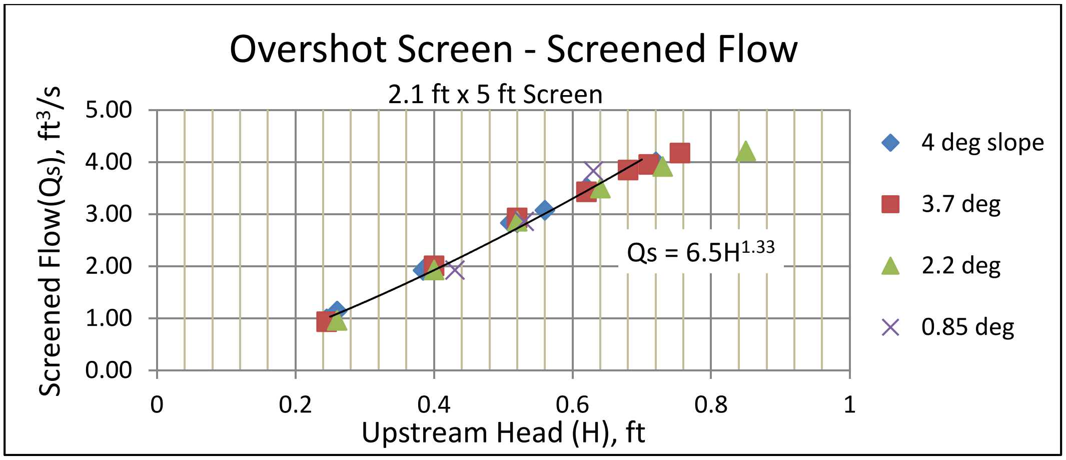

Figure 10. Test data for Screened Flow (Qs) versus Upstream Head (H) shown for each screen slope tested. The best-fit line is based on data for all screen slopes operating under partially wetted screen conditions.

Screening headloss (H_L) is defined as the elevation difference between the upstream water surface and the downstream canal water surface. During free flow operation the minimum headloss occurs when the downstream canal water surface is level with the screen toe. The minimum headloss associated with free flow conditions is the summation of three components: 1) the upstream head on the crest as given in Figure 9, 2) the headloss due to water passing through the screen as shown in Figure 11, and 3) the vertical drop of the sloped screen. Figure 11 gives headloss for free flow operation when the downstream canal water surface (H_C) was within a 0.1 ft of the screen toe. It shows that steeper screen slopes produce greater headloss. This is largely due to the vertical drop of the screen which increases with larger slopes. By definition of free flow, the downstream canal water surface is located at or below the screen toe, thus increasing screen slope increases headloss.

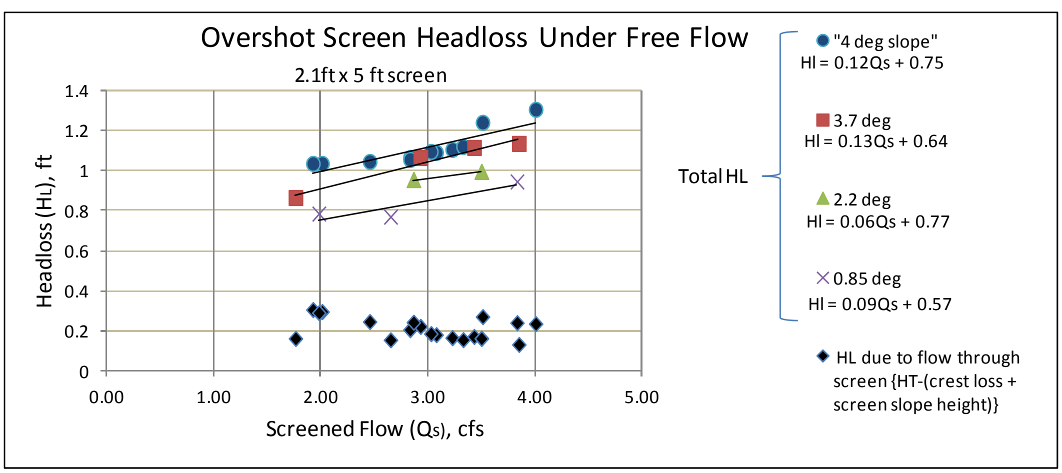

Figure 11. Test data of total Screen Headloss (H_L) versus Screened Flow (Qs) as a function of screen slope. The headloss component due to flow through the screen and baffle is shown along the bottom of the plot. (Does not include losses associated with flow over the crest and screen slope height).

During free flow operation, the percent of crest flow passed downstream as bypass flow (Q_{BP}) is given in figure 12. Two regimes of bypass flow operation were noted during the testing. Under conditions of small crest flows which were not sufficient to fully wet the entire length of the screen, approximately 5 percent of the flow was bypassed via the fish troughs for all slopes tested. The screen module became fully wetted (flow over the entire screen surface) between heads of 0.6 to 0.7 ft depending on screen slope. Flatter screen slopes became fully wetted at higher crest flows than did steeper screen slopes. Increasing crest flow above the point at which the screen becomes fully wetted causes a sharp increase in the percent of bypass flow ($\%Q_{BP}$). The percent bypass flow for a fully wetted screen can be estimated using the best-fit equation:

$$\%Q_{BP} = 9.35Q_C - 26.6, \text{ for } Q_C > 4 \text{ ft}^3\text{/s for this CWS test}$$

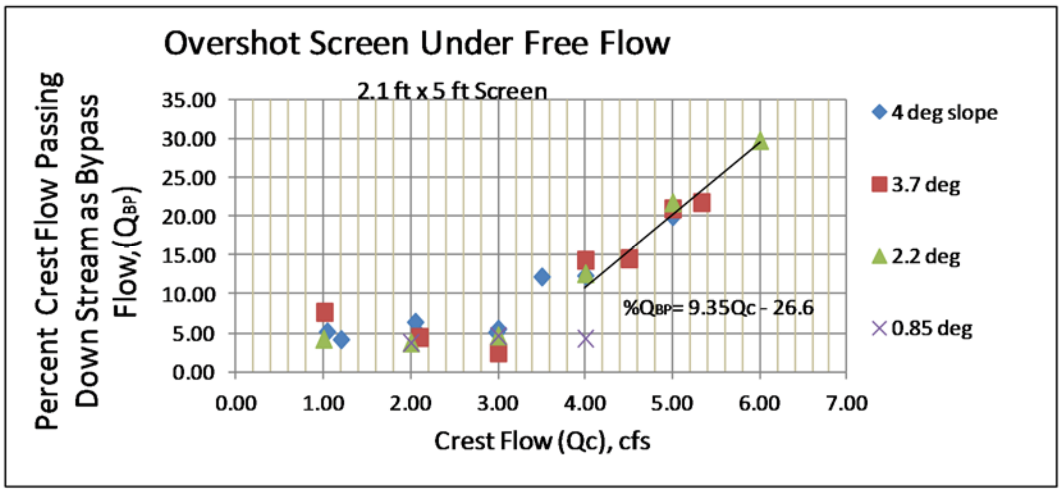

Figure 12. Plot of the percent of crest flow passing downstream as Q_{BP} for free flow conditions.

Quadrant II – Partial Screen Submergence by Downstream Canal Water Surface.

In Quadrant II the screen toe is submerged by the water surface of the downstream canal and the bypass water surface is lower than the screen toe (see figure 6). Figure 13 is a photograph of the CWS operating in Quadrant II. Flow near the screen toe is flowing from beneath the screen and back through the screen adding to the bypass flow. This condition would most likely occur if the downstream canal water surface was checked up higher than normal. Figure 14 compares Quadrant II data with that of predicted free flow equation shown on figure 10. The Quadrant II data falls below the predictive free flow line indicating a decrease in Q_S and an increase in Q_{BP} compared to free flow.

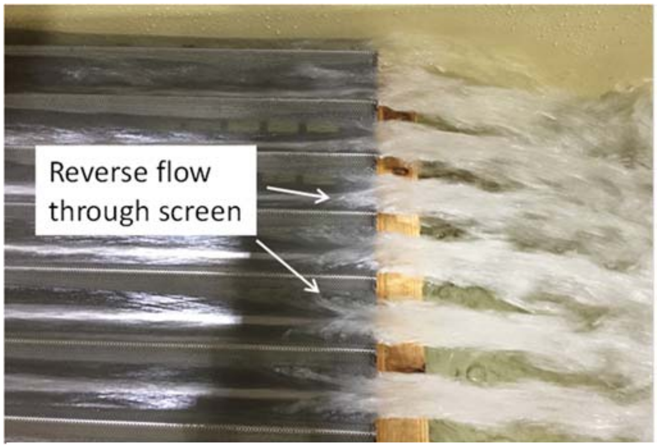

Figure 13. Photograph of Quadrant II operations showing screened flow passing out the screen when the screen toe is submerged by the canal water level

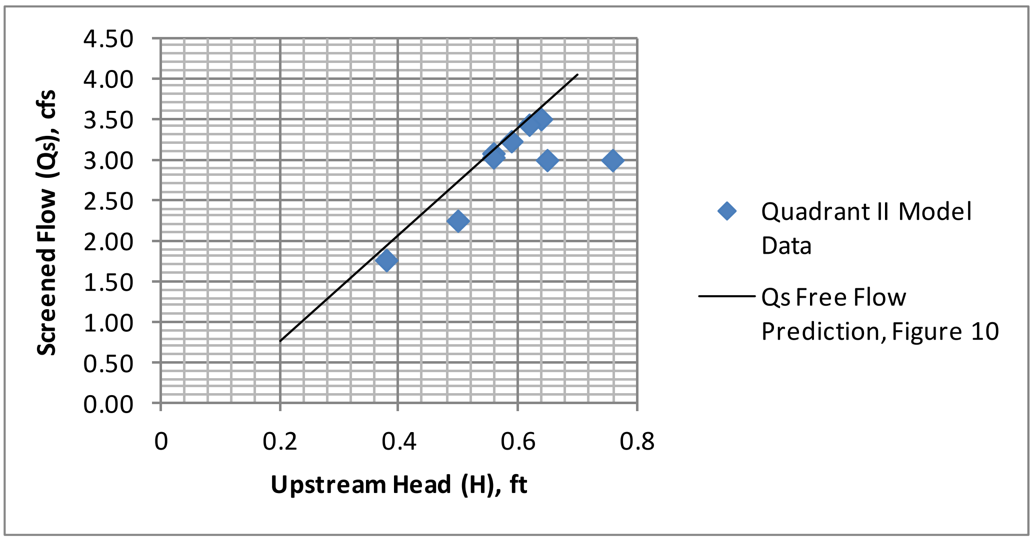

Figure 14. Plot of Screened Flow (Q_S) versus Upstream Head (H) measured for model operation in Quadrant II.

Quadrant III – Partial Screen Submergence by Both Downstream Screened Canal Flow and the Bypass Flow.

Submerging the screen toe by raising the bypass water surface above the screen toe results in a hydraulic jump forming downstream of the toe and gradually moving upstream onto the screen as the bypass water surface elevation is increased. Operating with a jump on the screen was found to be an effective method of changing the flow split between screened flow and bypass flow, however predicting bypass flow when the toe of the screen is submerged is difficult due to the many parameters involved. Trial and error was used to adjust the flow split when partially submerging the screen. The following discussion of operating in Quadrants III and IV is given to illustrate general flow trends.

Quadrant III operation is defined by both downstream canal and bypass water surfaces being higher than the screen toe (see figure 6). Quadrant III is shown in figure 5 divided in half by a 45 degree line which defines when downstream canal and bypass water surfaces are equal. Flow conditions above the line (Quadrant III-A) are similar to Quadrant II. Operating below the line (Quadrant III-B) results in a hydraulic jump over the submerged portion of the screen and an increase in Q_S, figure 15.

Figure 15. Photographs of tests in Quadrant III-B showing a hydraulic jump on the screen. The left photo shows the jump covering about 30 percent of the screen length. The right photo shows the screen with the toe of the jump located just downstream from the crest.

Figure 16 shows data measured while operating in Quadrant III-B. These data include testing for screen slopes of 0.85, 2.2 and 3.7 degrees. The data in each plot is sorted by percent bypass flow to illustrate the variability in Q_s and Q_{BP} that were achieved for similar upstream head conditions. Quadrant III-B data are plotted in figure 16 as H versus Q_S giving a comparison with free flow data plotted in figure 10. Data plotted above the free flow line shows Q_S can be substantially increased and Q_{BP} decreased by raising the bypass water surface elevation. When the screen is not fully wetted, bypass flows are about 5 percent of Q_C. Increasing the net head on the screen toe shows a general increase in Q_S. However, other factors including the length of screen submergence and upstream head also affect Q_S resulting in scatter in the test data. The model configuration limited testing to a maximum bypass submergence depth of 1.08 ft in and a canal submergence depth of 0.64 ft.

A feature of Quadrant III-B operation is the ability to reduce screen headloss compared to free flow conditions by checking both the canal and bypass water levels above the screen toe. Submergence of the screen toe by the canal water surface results in a direct reduction in the screen headloss. The headloss reduction that can be achieved is limited to the vertical height of the sloping screen.

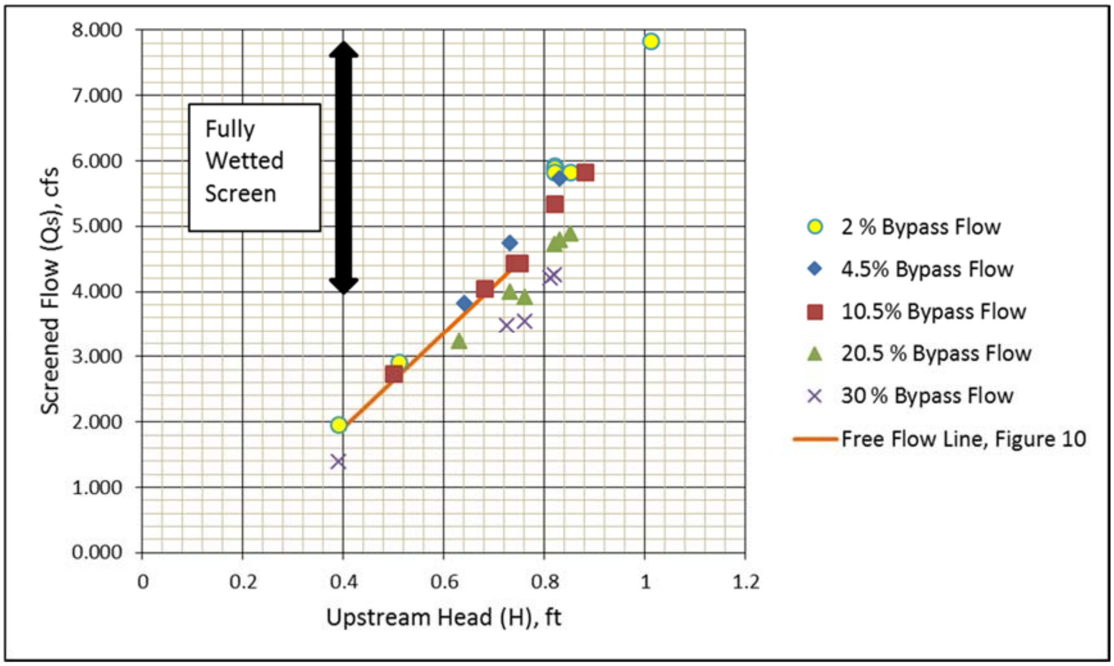

Figure 16. Plot of screened flow, (Q_S) versus upstream head, (H) for the screen operating in Quadrant III-B.

Quadrant VI – Partial Screen Submergence by the Bypass Flow

Quadrant VI operation is defined by a bypass water surface checked up to submerge the screen toe, forcing a hydraulic jump on the screen and a canal water surface below the screen toe. Similar to operating in Quadrant III-B, checking the bypass water elevation allows the flow split between diversion and bypass flow to be shifted in favor of screened flow. This shift is most evident when the screen is fully wetted. Because the canal water surface is below the screen toe, headloss is similar to free flow conditions. As shown in figure 7, few tests were conducted in Quadrant IV. This was a limitation of the model test facility that could not be rectified due to the limited time available to test the CWS.

To expand the Quadrant IV data set, Quadrant III tests conducted with the downstream canal water surface less than 0.1 ft above the screen toe and bypass water surfaces greater than 0.1 ft above the screen toe were included in Quadrant IV data plotted in figure 17. The data for screened flows less than 4 ft^3/s fall close to the free flow prediction line plotted on figure 17. This result is expected as the screen was not fully wetted and the ratio of screened flow to bypass flow is high. At flows greater than 4 ft^3/s the Quadrant IV data show an increase in screened flow compared to that predicted for free flow conditions.

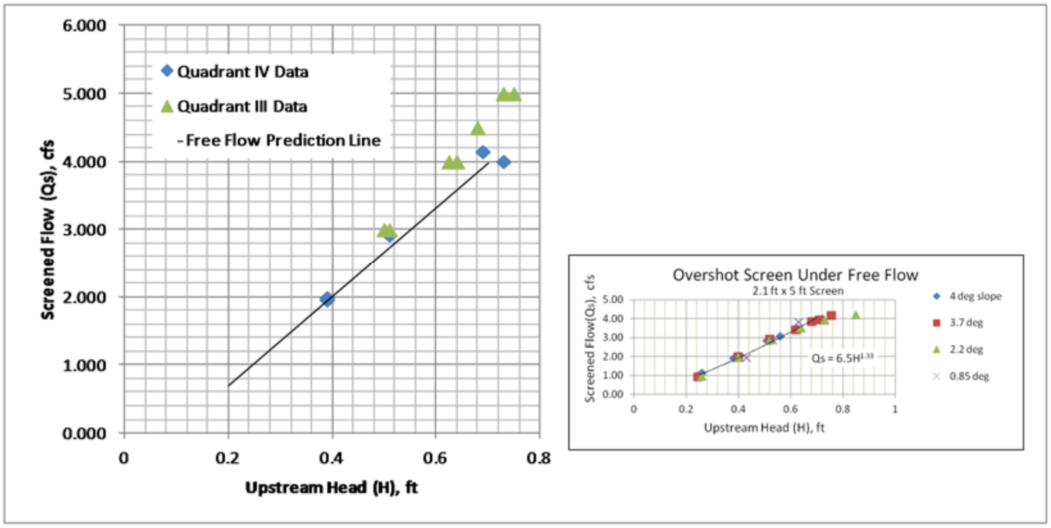

Figure 17. Plot of Screened Flow (Q_S) versus Upstream Head (H) for tests in Quadrant IV. Figure 10 is shown in the lower right corner of the plot for comparison.

Observations from Debris Tests

Model debris consisted of a mixture of paper punch, shredded paper and tree moss. Approximately one cubic foot of dry moss and one half cubic foot of paper punch material were mixed together. The material was saturated in water until it was close to neutrally buoyant. The tree moss was a dried natural material used commercially for floral decoration. The material was composed of fine flexible strands up to about 0.5 ft in length. The material was placed in the model headbox upstream from the screen crest and allowed to disperse through the water column before reaching the screen. Debris was captured downstream of the bypass channel weir using a fine vertical screen across the channel. The material was then reused. Debris tests often included repeated applications of debris taken from the capture screen. This recycling of the debris material during a test allowed tests to be performed with the screen exposed to large quantities of debris. The CWS is designed to provide a high sweeping velocity parallel to the screen surface and a low approach velocity normal to the screen. These flow conditions have been demonstrated by previous researchers to promote passage of debris along the screen with minimal impingement and plugging of debris on the screen. Debris tests were conducted for approximately half of all test runs and under free flow and partially submerged screen operations. The results of debris testing consisted of photographs, video records, and visual observations. No quantitative debris test data were recorded.

Quadrant I Free Flow Debris Tests

The upstream 0.5 ft of the screen showed the greatest impingement of debris during free flow debris tests. Impinged debris consisted of limited quantities of small pieces of the saturated paper strips shown in figure 18. Very little impingement of tree moss was observed during all the debris tests. Impingement of debris further down the screen was little to none. The flow transition from crest flow to screen flow is largely responsible for elevated debris impingement immediately downstream of the crest. The crest serves to accelerate flow and rapidly transition the flow onto the screen where it flows nearly parallel to the screen. The transition from crest flow to screen causes a downward curvature of the flow over approximately the leading 0.5 ft of screen, see figure 19. The transition zone produces reduced pressure as flow leaves the crest followed by elevated pressure on the upper end of the screen where flow is turned downstream along the screen. The zone of elevated pressure on the screen produces a zone of reduced sweeping to approach velocity. Downstream of the transition zone water flows nearly parallel to the screen surface with lower through screen velocity and increased sweeping velocity. To compensate for the curvilinear flow downstream of the crest, the percent open area in the screen's underlying baffle plate is set at 4 percent for the first 5 inches of screen followed by sections of the baffle plate with 8 and 15 percent open area. Dye was injected above the screen face along its length to visualize the strength of flow entering the screen. The pull of dye through the screen appeared to be uniform with the exception of the first couple of inches of screen where dye appeared to move directly into the screen rather than following a shallow angle as viewed over downstream portions of the screen. This indicates reducing the percent opening of the baffle plate near the head of the screen may be needed.

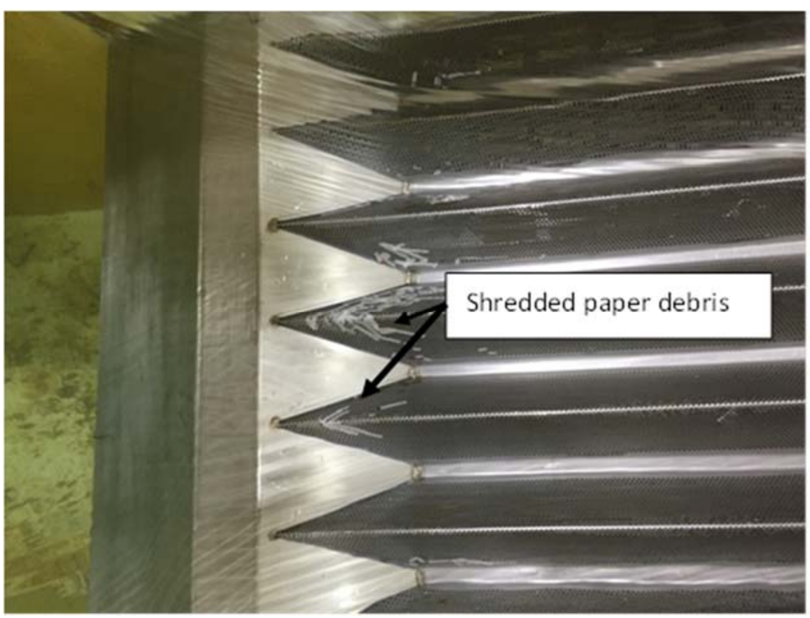

Figure 18. Photograph of debris impinged downstream from the screen crest. Flow is from left to right.

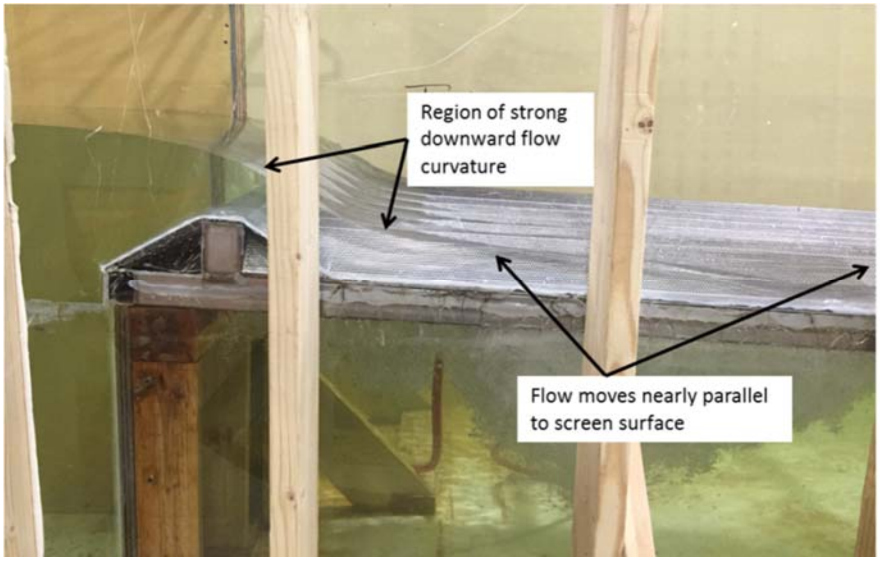

Figure19. Photograph showing the curvature of flow as it transitions from the crest onto the screen.

Operation of the screen at flows where the screen was not fully wetted resulted in larger debris occasionally becoming high centered on the top of screen corrugations near the downstream end of the screen. The debris was not impinged on the screen but was simply left behind where the screen became dry as flow passed through the screen. Increased crest flow quickly moved the debris downstream and off the screen.

Quadrant III-B Submerged Flow Debris Tests

The screen retained good debris passage characteristics when operating in Quadrant III-B with a hydraulic jump on the screen. When bypass flow was greater than about 5 percent, sweeping flow remained on the screen surface below the recirculation zone of the hydraulic jump for the full length of the screen. Some debris that was swept past the screen was pulled upstream into the jump, see figure 20. This material was again swept downstream when it was entrained into the sweeping flow above the screen face. Under high submergence levels with high screen flow and low bypass flow material was observed moving about the toe of the screen with little material impinged on the screen. Material would settle on the screen for a short time before being swept downstream.

The high turbulence under the toe of the hydraulic jump appeared to have a positive cleaning action on the screen. When the jump was swept up and down the screen by raising and lowering the bypass water surface, any debris that had accumulated was dislodged and swept downstream. This operation was found to provide an effective cleaning action on the screen. This is characteristic is thought to be due to dynamic pressure fluctuations on the screen near the toe of the jump.

Figure 20. Photographs of debris being pulled into the hydraulic jump on the screen.

Observations of Air Burst Cleaning

The screen frame is designed for injecting compressed air through air manifolds in the tubular support frame. The three upstream cross supports contain 5/16 inch diameter holes located below the peak of each screen corrugation, see figure 21. During this study, the laboratory compressed air supply system was used to provide compressed air at about 100 psi. Air bursts were controlled by manually opening and closing a ¼ turn valve connected to the air supply line for each cross member.

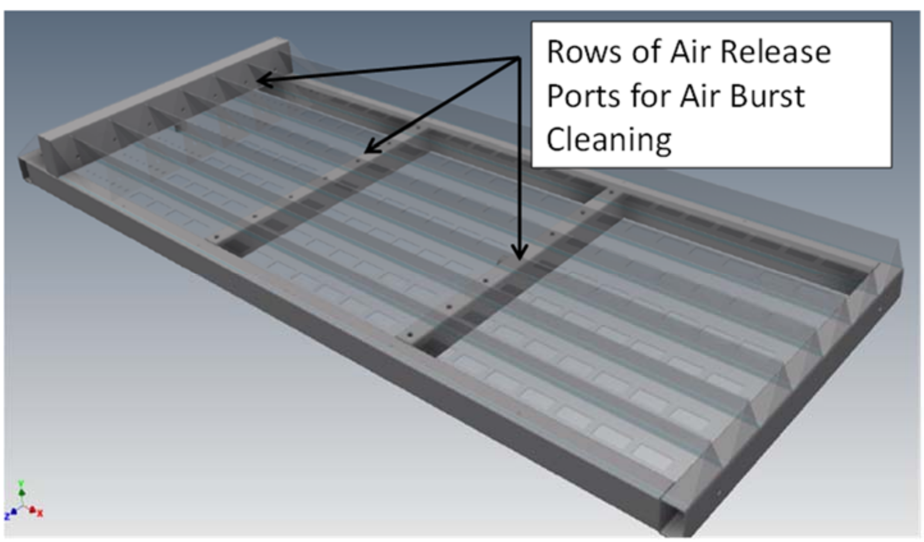

Figure 21. CAD drawing showing compressed air release ports in each tubular cross member. Baffle plate, screen, and crest are shown partially transparent for visual clarity.

Air bursts of between 2 and 10 seconds were found to be effective for removing debris impinged on the screen surface. Air bursts were less effective at removing fine debris that appeared to be partially protruding through the holes in the screen surface. The air manifold beneath the screen crest plate was found to provide effective cleaning of the entire screen under low head conditions. Downstream release port locations were difficult to evaluate as little debris was typically impinged on the lower three-quarters of the screen. At crest heads under about 0.5 ft, an air burst from the upstream row produced flow turbulence that was effective at removing debris the full length of the screen, see figure 22. As head increased, the effectiveness of air bursts from the upstream air manifold decreased. This was likely due to the development of a negative pressure zone on the downstream crest face as head over the crest increased. A portion of the air released from the upstream manifold was drawn to the crest rather than moving downstream through the screen.

Figure 22. Photograph of air burst cleaning of the screen.

Brush Cleaning the Screen

The screen can also be cleaned using a brush specially designed for the corrugated screen surface. For these tests, manual brushing was performed using the brush shown in figure 23. The brush is custom made with a row of 2 inch long by 3.5 inch diameter cylindrical shaped brushes that are aligned to pass down each corrugation much like a bottle brush. A single pass of the brush along the screen was found effective for cleaning the screen.

Figure 23. Photograph of a custom-made corrugated screen brush head showing cylindrical brushes.

General Design and Operation Guidelines for CWS Overshot Screens

A single CWS screen module was tested in this laboratory study. Additional modules can be mounted side by side to increase screening capacity. For screening large flows the screen length can also be increased. The screen could be located either in-stream or in-canal provided the head required to move flow over the screen surface is available.

Prior to designing a screen facility, the canal design flow to be screened (Qs) and the head available at the site for screening must be determined. Available screening head is defined as the amount the upstream water surface can be raised at the screen location without reducing flow or exceeding canal freeboard requirements. Or if conveyance improvements can be made to the downstream canal, it may be possible to provide operational head by making those improvements. An available head of one foot is recommended for operating the CWS screen in the overshot orientation.

The screen design process is summarized as follows:

1. Design the screen facility to operate under free flow conditions. Screen slope and the change in head due to the screen called headloss can be determined from figure 11. To maximize the passive cleaning capability of the screen, select the largest screen slope the available head allows.

2. Determine the number of screen modules needed by dividing the maximum screened flow (Q_S) by the screen capacity from figure 10, rounding up to obtain the number of complete modules. Note: it is recommended that the screen area be increased by at least 15 percent to account for screen fouling between cleaning cycles. As shown in figure 10, a maximum Q_S of 4 ft^3/s for a 5 ft screen module should be used. Lower Q_S values can be selected to lower headloss and bypass flow requirements

3. Check the amount of bypass flow delivered using figure 12. Convert the bypass flow from percent to ft^3/s and add the bypass flow and screened flow to determine the total upstream flow (Q_C) required. For fish screening applications, a minimum of 10 percent bypass flow is recommended for normal screen operation.

4. Set the screen's toe elevation (invert of corrugations) at the canal's downstream water surface elevation for the canal design flow.

5. Determine the upstream crest elevation by adding the screen's slope height to the screen's toe elevation from step 4. The screen slope height in feet is equal to $5.0*\sin\theta$, where θ is the screen angle above horizontal in degrees.

6. Check the required upstream water surface elevation by selecting H from figure 9 using Q_C from step 3 and adding H to the screen crest elevation from step 5. The resulting elevation is the minimum upstream water surface elevation needed for the screen. If the minimum elevation is higher than the available head try reducing the screen slope, lowering the screen to partially submerge the screen toe below the canal and bypass water surfaces or increase the screen width to reduce the head required to pass the design flow.

7. Placing a gated structure in the downstream bypass channel that allows the bypass water surface to be raised up to 1 ft above the screen toe is recommended for operating in Quadrants III-B and IV.

8. In conjunction with the screen's debris passage ability, occasional manual brushing, air burst cleaning with manual brushing, or installing a mechanical brush system may be required for locations with high debris loads.

Vertical Screen Tests

The primary objective of the model study was to investigate operation of the CWS as a passive style overshot screen. To take full advantage of the model facility, limited testing of a CWS mounted in a vertical orientation was also conducted to determine flow capacity, headloss characteristics, and baffle effectiveness. The model facility was modified to install the screen is a vertical orientation similar to a vertical flat plate screen, figure 24. The weir walls that supported the overshot screen were removed. The screen was installed with the corrugations running in the flow direction. The screen module was mounted on its side on a 1.5 inch high sill plate at an angle of 17 degrees to the flow direction. The angle of the screen in the channel was chosen based on model limitations and to achieve a minimum of a 4 inch wide flow bypass slot at the end of the screen. The screen crest plate, now vertical, was mounted flush to the channel wall with a short transition wedge added upstream to transition flow onto the crest plate. Screened and bypass flow were conveyed away from the screen similar to that used for the overshot tests. Screened flow as measured using a rectangular weir. In the vertical orientation the water surface slope along the screen is typically much smaller than in the overtopping orientation. Therefore, sweeping velocity is typically lower on a vertical screen and the flushing of debris past the screen by sweeping flow is less pronounced. Corrugating the screen fabric does help reduce debris impingement by increasing the screen's wetted area and lowering the through screen velocity compared to a flat screen of similar screen fabric. For most CWS vertical installations a mechanical sweep style brush should be used to clean the screen. However, no mechanical brush was tested in the model study.

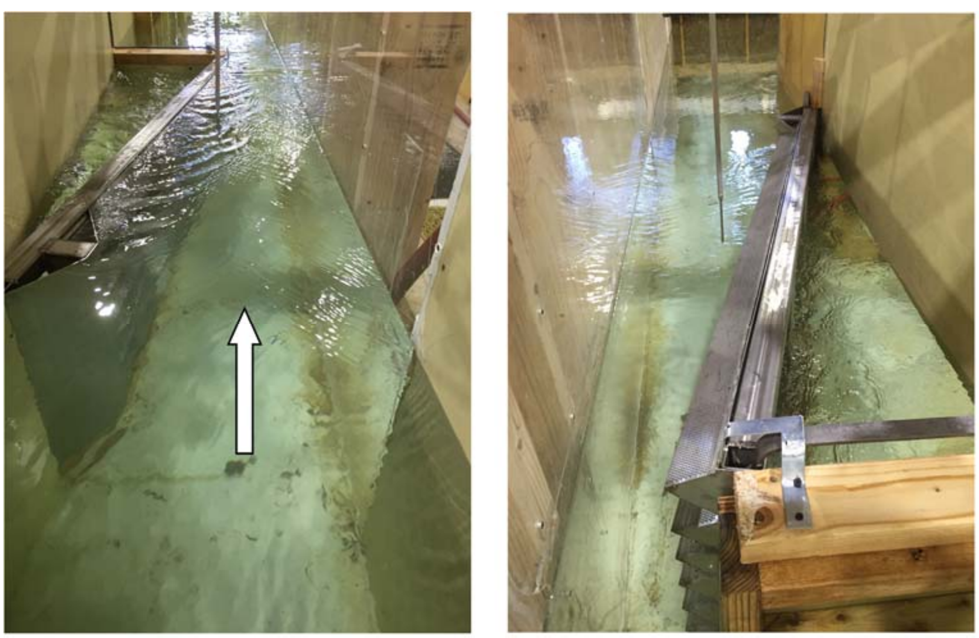

Figure 24. Photographs looking downstream (left panel) and upstream (right panel) of the screen installed vertically.

Test data for screened flow versus headloss are presented in figure 25. The 2.1-ft-high by 5-ft-long screen with baffle plate was capable of passing a maximum of 5 ft^3/s or 0.47 ft^3/s per sq. ft. of vertical surface area (projected surface area) with a headloss of 0.28 ft. At maximum flow, the calculated approach velocity to the screen was 0.33 ft/s. Dye was injected across the channel upstream from the screen, along the screen crest and across the corrugated screen surface. The flow of dye to the screen and on the screen surface showed good flow uniformity passing through the screen indicating the baffle plate designed for the overshot orientation also works well for a vertically mounted screen.

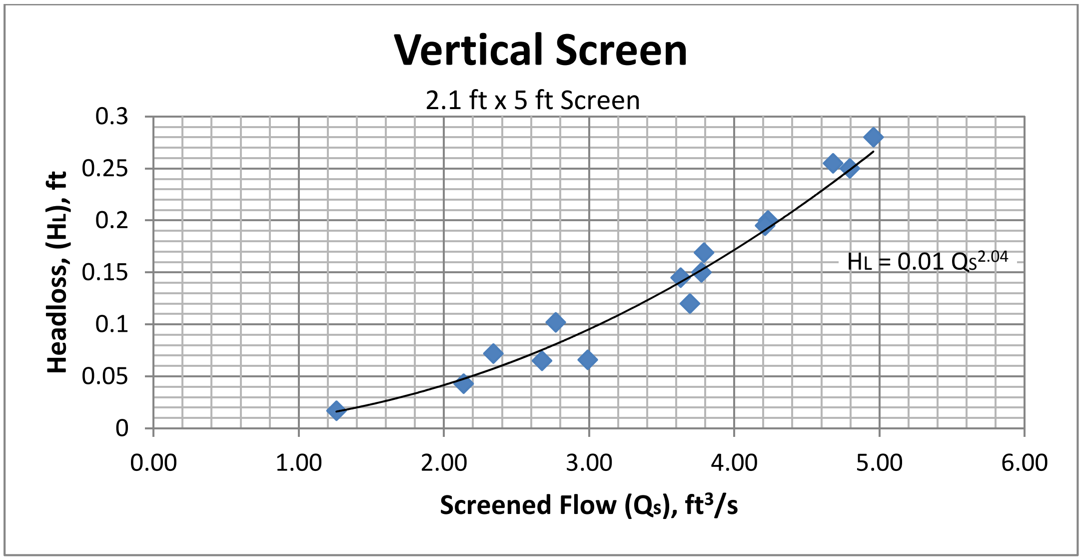

Figure 25. Plot of Screen Headloss (H_L) versus Screened Flow (Q_S) for a vertically mounted screen. Screen headloss includes the losses for the screen and baffle plate.