PAP- 859

TECHNICAL SERVICE CENTER
Denver, Colorado

MODULAR FISH SCREEN HYDRAULIC MODEL STUDY

Prepared by
Joseph Kubitschek

Water Resources Research Laboratory

U.S. Department of the Interior
Bureau of Reclamation

January 1995

RECLAMATION'S MISSION

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.

DEPARTMENT OF THE INTERIOR'S MISSION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering wise use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

CONTENTS

Page

Introduction 1
Conclusions 3
Similitude 3
Physical model 4
Test setup 5
Model tests 6
    Theory 6
        Diffuser plate analysis 6
        Head loss determination 7
    Submergence 10
    Orientation 10
    Modifications 11
    Head loss 13
Results 13
    Submergence 14
    Orientation 26
    Modification 28
    Head loss 36
Bibliography 38

TABLES

Table

1 Modular screen configurations tested 13
2 Head loss results for all tests conducted 37

FIGURES

Figure

1 Conceptual layout 2
2 Photograph #1: Test setup 5
3 Photograph #2: Test setup 6
4 Photograph #3: Original baffling configuration 8
5 Perforated plate diffuser design details 9
6 Photograph #4: Alternate Orientation 11
7 Photograph #5: Ramp structure modification 12
8 Photograph #6: Flow plate modification 12
9 Isovel plot of normal component velocities: S = 5.36 ft 15
10 Velocity surface plot of normal component velocities: S = 5.36 ft 15
11 Isovel plot of normal component velocities: S = 4.88 ft 16
12 Velocity surface plot of normal component velocities: S = 4.88 ft 16
13 Isovel plot of normal component velocities: S = 4.36 ft 17

14 Velocity surface plot of normal component velocities: S = 4.36 ft 17
15 Isovel plot of normal component velocities: S = 3.88 ft 18
16 Velocity surface plot of normal component velocities: S = 3.88 ft 18
17 Isovel plot of normal component velocities: S = 3.40 ft 19
18 Velocity surface plot of normal component velocities: S = 3.40 ft 19
19 Isovel plot of normal component velocities: S = 2.96 ft 20
20 Velocity surface plot of normal component velocities: S = 2.96 ft 20
21 Isovel plot of normal component velocities: S = 2.24 ft 21
22 Velocity surface plot of normal component velocities: S = 2.24 ft 21
23 Vector field plot of sweeping velocities: S = 5.36 ft 23
24 Vector field plot of sweeping velocities: S = 4.88 ft 23
25 Vector field plot of sweeping velocities: S = 4.36 ft 24
26 Vector field plot of sweeping velocities: S = 3.88 ft 24
27 Vector field plot of sweeping velocities: S = 3.40 ft 25
28 Vector field plot of sweeping velocities: S = 2.96 ft 25
29 Vector field plot of sweeping velocities: S = 2.24 ft 26
30 Isovel plot of normal component velocities: Orientation 27
31 Velocity surface plot of normal component velocities: Orientation 27
32 Vector field plot of sweeping velocities: Orientation 28
33 Isovel plot of normal component velocities: Ramp mod 1 29
34 Velocity surface plot of normal component velocities: Ramp mod 1 29
35 Vector field plot of sweeping velocities: Ramp mod 1 30
36 Isovel plot of normal component velocities: Ramp mod 2 31
37 Velocity surface plot of normal component velocities: Ramp mod 2 31
38 Vector field plot of sweeping velocities: Ramp mod 2 32
39 Isovel plot of normal component velocities: Plate mod 1 33
40 Velocity surface plot of normal component velocities: Plate mod 1 33
41 Vector field plot of sweeping velocities: Plate mod 1 34
42 Isovel plot of normal component velocities: Plate mod 2 35
43 Velocity surface plot of normal component velocities: Plate mod 2 35
44 Vector field plot of sweeping velocities: Plate mod 2 36

INTRODUCTION

Protection of fisheries resources from diversion or pump entrainment has become increasingly important as more species are being protected under the endangered species act. It is anticipated that in the future, water users (primarily agricultural) will be required to provide fish protection from entrainment. Typically, these water users function with limited budgets and maintenance capabilities. Existing screen technology, although adequate in many cases, presents the opportunity for improvement. Particularly for this application.

Improvements from both performance and cost standpoints are thought to be achievable. An alternative development or feasibility study was conducted by members from Reclamation's Technical Service Center (TSC), Water Resources Research Laboratory (WRRL) and the Shasta Area Office. Perry Johnson, Research Hydraulic Engineer (D-8560), Joe Kubitschek, Hydraulic Engineer (D-8560), Rick Christensen, Mechanical Engineer (D-8420) and Greg O'Haver, Mechanical Engineer (NC-651), participated in this study. The objectives of this study were to identify potential improvements over existing technology, to identify concerns associated with the proposed concept, and to identify those developmental tasks critical for demonstrating acceptable performance of this concept. Verifying concept competitiveness with existing technology was a first priority. Thus, a cost review and comparison was conducted (Appendix A, Memorandum dated March 3, 1994: Cost Comparison). This document demonstrates the potential for the modular screen concept to be competitive with, or potentially less expensive than existing screen technology. The realization of the cost competitive potential justified proceeding with the laboratory investigations detailed in this report.

The investigations detailed in this report include a series of tests conducted to demonstrate and refine the hydraulic characteristics of this concept. A 1:4 scale, Froude-based hydraulic model of the 100 ft^3/s unit concept (Figure 1) was constructed and tested at Reclamation's WRRL in Denver. The objectives of this study were to establish acceptable uniform normal component velocities while maintaining sufficient sweeping component velocities over the screen face, to establish submergence limits, and to determine the influence of orientation on concept performance. Due to the supply discharge limits of the laboratory, approach velocities for all tests were set at the maximum attainable velocity of 0.5 ft/s for a flow depth of 3.0 ft. This corresponds with 1.0 ft/s for a flow depth of 12.0 ft in the prototype based on Froude law similitude between model and prototype.

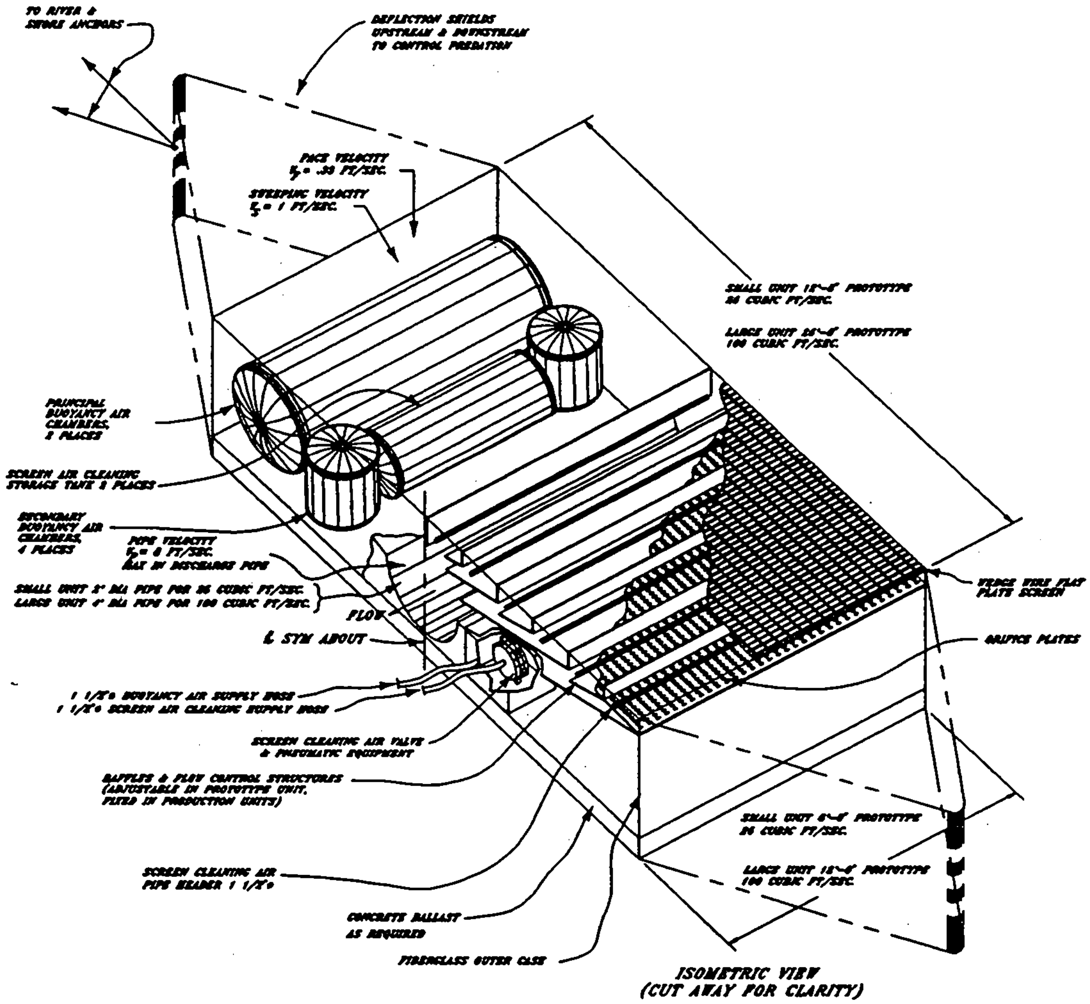


Figure 1. - Conceptual layout of modular fish screen unit.

To date no biological investigations have been conducted. Biological evaluations would best be conducted using a full size modular unit. This would eliminate entrainment and impingement uncertainties associated with scale. Except for loss of influential parameter control and more difficult monitoring logistics, biological evaluation might best be conducted in the field using a full size modular screen. Evaluation of fish entrainment and impingement will be required to obtain resource agency endorsement of this concept for field applications. Extensive field testing would also be required to determine hydraulic, biological, and operational characteristics under site-specific conditions. Thus, laboratory studies are a preliminary evaluation and refinement of screen performance and do not constitute a completion of the performance documentation process.

CONCLUSIONS

The following may be deduced from the results of the hydraulic investigations conducted in the laboratory:

- Uniform normal component velocities are attainable over the screen face by application of a perforated orifice plate diffuser for the hydraulic conditions tested.

- Sufficient sweeping component velocities can be maintained for submergences greater than 3.5 ft for the 100 ft^3/s and 1.75 ft for the 25 ft^3/s over the range hydraulic conditions tested.

- The normal component velocity criteria of 0.33 ft/s can be met at the design discharge of 100 ft^3/s for the hydraulic conditions tested.

- 20^o orientation of the unit with respect to the approach flow will influence screen performance particularly in maintaining sweeping velocity components. Sweeping velocity breakdown occurs at the corners of the unit under this condition.

- Overall system head loss will not be greater than 1.6 ft, prototype at the design discharge of 100 ft^3/s under clean screen conditions. This loss is expected to increase with degree of screen fouling.

- This concept demonstrates adequate hydraulic performance by meeting the velocity criteria established by resource agencies within submergence and orientation limits and without regard to biological performance or site specific conditions.

SIMILITUDE

The 1:4 Froude scale model of the 100 ft^3/s modular screen concept must be geometrically and kinematically similar to the prototype to adequately predict prototype performance under tested operating conditions. Froude law similitude was selected since gravitational effects predominate for free surface flows. Geometric similarity is achieved with the ratios of all geometric parameters between model and prototype being equal. This similarity is represented by the length ratio, $L_r = L_p/L_m$. Where, L_p = representative length in the prototype and L_m = representative length in the model. The geometric and kinematic ratios for the 1:4 Froude scale model are given as follows:

Geometric:

$L_r = L_p/L_m = 4$

$A_r = L_r^2 = 16$

$V_r = L_r^3 = 64$

where,

A_r = area ratio

V_r = volume ratio

Kinematic:

$t_r = L_r^{1/2} = 2$

$v_r = L_r^{1/2} = 2$

$a_r = 1$

$Q_r = L_r^{5/2} = 32$

where,

t_r = time ratio

v_r = velocity ratio

a_r = acceleration ratio

Q_r = discharge ratio

PHYSICAL MODEL

The physical model is a 1:4 Froude scale model of the 100 ft^3/s unit concept. The scale was selected as the largest scale possible to minimize through screen Reynolds distortion while being within the maximum discharge capacity of the laboratory for the flow depths and velocities required. Head loss coefficients across the screen and thus, potential screen influence on through screen flow distribution are dependent on the through screen Reynolds number. A prototype size screen was used in the model because it supplied the correct geometry and flow resistance while having large enough member sizes to maintain adequate Reynolds numbers. That is, provided the Reynolds number is high enough, no change in head loss across the screen will be realized between model and prototype. Previous work has shown that through screen Reynolds numbers greater than approximately 200 exhibit a constant head loss coefficient for this type of screen. The screen Reynolds number for this testing was on the order of 220. Discharge capacity was an issue in that both through-screen and passing flow discharge must be supplied to the test flume and required passing flows were selected to minimize the near boundary (ie. flume wall) influences on screen performance.

TEST SETUP

An existing 11.667 ft wide X 3 ft deep flume was modified to accept installation of this model. The length of the flume is approximately 50 ft. Figures 2 and 3 are photographs showing the modular screen laboratory set-up. Figure 2 is a post construction photograph of the hydraulic model taken prior to testing. Figure 3 is a test run photograph representing the maximum flow depth attainable in the laboratory. A three-dimensional, acoustic doppler velocimeter (ADV) was employed for all screen face measurements. Point velocities were measured at an elevation 1 in. above the screen surface. Nine traverses across the screen, each consisting of twelve point velocity measurements along the screen, were conducted, resulting in 108 velocity measurements over the screen face. An ultrasonic transit time flowmeter was employed for measurement of diversion discharge. This flowmeter consisted of a clamp-on type and was located on the discharge pipe. Flow depth upstream of the modular screen was monitored using a laboratory hook gage. This is achieved by relating the elevation of the hook gage zero to the channel invert elevation. Finally, a piezometer ring was installed on the discharge pipe, outside of the flume, in connection with a pressure transducer to determine system head loss. Total discharge supplied to the flume was measured using the laboratory venturi measurement system. Stop logs were used on the downstream end of the channel to regulate flow depth.

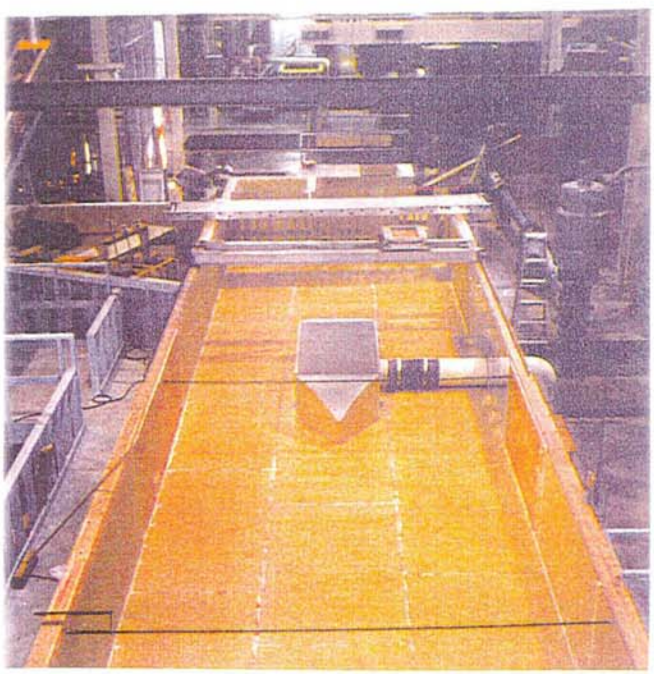


Figure 2. - Photograph #1 - Laboratory test setup - Post construction.

Figure 3. - Photograph #2 - Laboratory test setup - Test run.

MODEL TESTS

The primary objective of this testing was first to generate uniform normal component velocity distributions over the screen face for the range of hydraulic parameters to be tested. As indicated previously, a fair degree of effort was required to obtain uniform normal component velocity distributions over the screen face. This was achieved by application of the following theoretical development.

Theory

Diffuser plate analysis

Design of the perforated diffuser plate required an analytical approach based on empirical results of perforated orifice plate research. This was necessary to determine the design (ie. orifice sizes and locations) most appropriate for this application The empirical discharge equation for a perforated orifice plate is given as (Brater and King):

$$Q = N\ C_d\ a\ (2gh)^{1/2}$$

where,

Q = discharge [ft^3/s].
N = number of orifices [dimensionless].
C_d = discharge coefficient [dimensionless].
a = orifice area [ft^2].
h = pressure drop across orifice [ft].
g = gravitational acceleration [ft/s^2].

Application of this equation to baseline normal component velocity data allowed for the determination of orifice sizes and locations required for uniform Q and consequently uniform normal component velocities over the entire screen face. Once this result was realized, concept performance could be evaluated over a range of hydraulic conditions.

Head loss determination

Application of the Bernoulli equation along a streamline is required to determine the total head loss associated with the modular screen system. This equation is given as:

$$z_1 + P_1/\gamma + v_1^2/2g = z_2 + P_2/\gamma + v_2^2/2g + h_L$$

where,

z_1 = channel water surface EL. [ft].
z_2 = piezometer ring EL. [ft].
v_1 = channel approach velocity [ft/s].
v_2 = discharge pipe avg. velocity [ft/s].
P_1/γ = pressure head at channel water surface EL. [ft].
P_2/γ = pressure head at piezometer ring [ft].
h_L = total head loss [ft].
g = gravitational acceleration [ft/s^2]

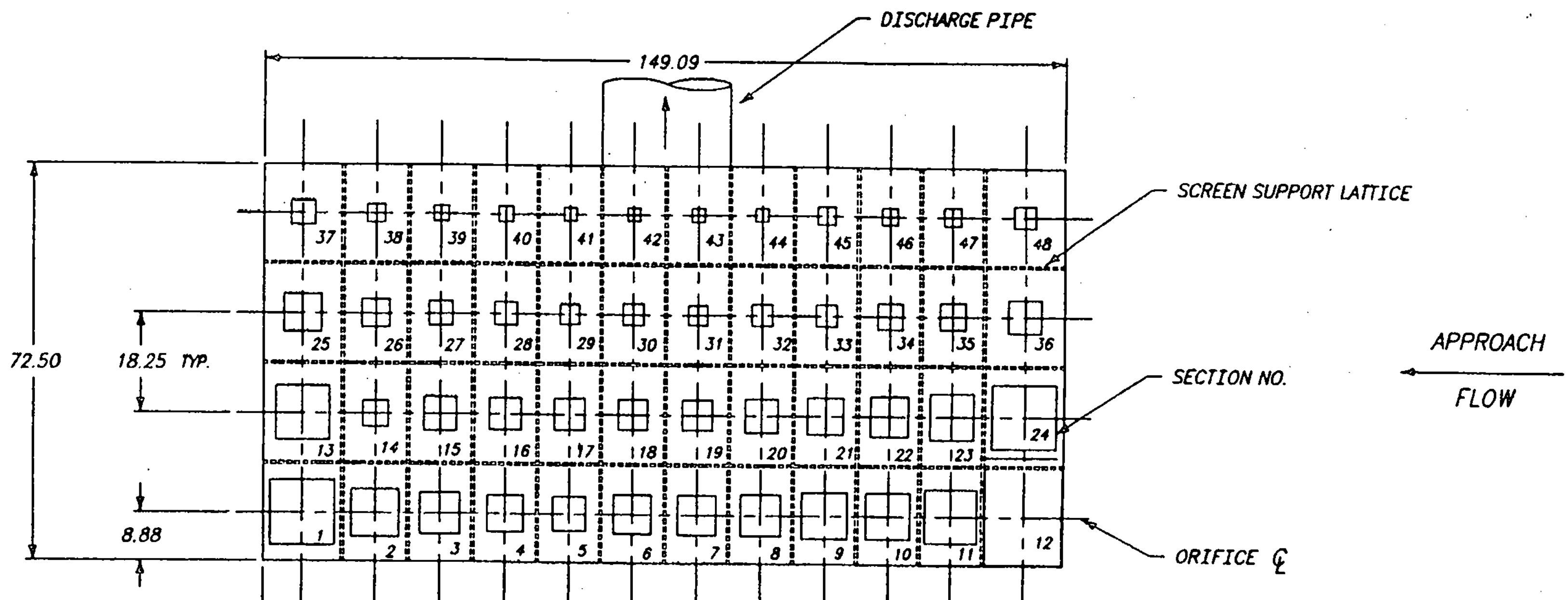
Solving for h_L in the above equation, assuming P_1/γ is zero gives:

$$h_L = (z_1 - z_2) - P_2/\gamma + (v_1^2 - v_2^2)/2g$$

Thus, knowing the test channel flow depth, the channel approach velocity, the discharge pipe velocity, the pressure head at the piezometer ring, and the required elevation of the piezometer ring with respect to the channel invert elevation, the head loss may be computed using the above equation. Sources of head loss include open channel flow losses, screen and baffle passage losses, entrance losses, and friction losses in the discharge pipe (typically assumed negligible). The significance of the various losses and their influence on flow distributions varies with flow path.

Preliminary tests were conducted to determine the original concept baffle settings required to generate uniform normal component velocities over the screen face. Figure 4 is a photograph of the original baffle concept as constructed in the model. The degree of complexity inherent in this baffle concept is evident. Approximately fifteen tests were conducted to determine baffle settings. These tests demonstrate that the original baffle concept has the potential to produce uniform velocities. However, it was felt that the complexity of this configuration could likely be reduced and improved flow distribution control achieved with the use of a simple orifice plate positioned behind the screen. Three additional tests were conducted to determine the orifice plate configuration required. Figure 5 represents the perforated orifice diffuser plate design details as obtained from this study. Because of fabrication simplicity, all further tests were conducted using the orifice plate for flow distribution control.

Figure 4. - Photograph #3 - Original baffle configuration.



Perforated Orifice Plate Diffuser

Design Details

MODEL ORIFICE DIMENSIONS:

SECTION NO.	SQ. DIMENSION	SECTION NO.	SQ. DIMENSION	SECTION NO.	SQ. DIMENSION	SECTION NO.	SQ. DIMENSION
1	5.9375	13	4.9375	25	3.4375	37	2.1875
2	4.3125	14	2.3750	26	2.5000	38	1.6250
3	3.7500	15	3.0625	27	2.2500	39	1.4375
4	3.3750	16	2.9375	28	2.1250	40	1.3750
5	3.1250	17	2.8750	29	1.8125	41	1.1875
6	3.5625	18	2.7500	30	1.9375	42	1.1875
7	3.6250	19	2.8125	31	1.8125	43	1.2500
8	3.7500	20	3.0625	32	1.9375	44	1.1875
9	4.2500	21	3.3125	33	1.9375	45	1.6250
10	3.3750	22	3.6250	34	2.3750	46	1.5625
11	4.9375	23	4.1875	35	2.4375	47	1.6875
12	FULL OPEN	24	5.8750	36	3.0000	48	2.0000

NOTES:
1. ALL ORIFICES SHALL BE SQUARE-TYPE TO MAXIMIZE AREA WITHIN EACH SECTION.
2. ORIFICE ℄ INTERSECTIONS SHOULD USED TO LOCATE ALL ORIFICES.
3. SCREEN SUPPORT LATTICE SHALL BE USED AS NATURAL SECTION BOUNDARIES (AS SHOWN).
4. ORIENTATION OF DIFFUSER PLATE WITHIN MODULAR UNIT IS CRITICAL. THE DIFFUSER PLATE SHALL BE POSITIONED WITH RESPECT TO THE DISCHARGE PIPE AND THE FLOW DIRECTION AS SHOWN.

ALWAYS THINK SAFETY

MODULAR FISH SCREEN STUDY
Perforated Orifice Plate Diffuser
Design Details

ALL DIMENSIONS INCHES

Figure 5. - Perforated orifice plate diffuser details.

Submergence testing

The first series of tests were conducted to establish submergence limits for the new diffuser configuration. The submergence limit is established at that submergence where sweeping component velocities begin to breakdown. Point velocities were acquired at 108 locations over the screen face for various submergences tested. Submergence here is defined as the depth of flow over the unit. That is the channel flow depth less the modular screen height. The maximum flow depth attainable in the laboratory comprises the first test in this series. This submergence was obtained as 5.3 ft. The flow depth was then reduced in seven increments over the submergence range available in the laboratory. The seventh test represents the minimum submergence. This submergence was obtained as 2.2 ft. The minimum submergence available is by virtue of the fact that the ADV requires this flow depth in order that the entire probe head be submerged. During these tests the approach velocity was held at approximately 1.0 ft/s while the diversion discharge was held at the design discharge of 100 ft^3/s.

Orientation testing

A single test was conducted at the maximum submergence to identify the influence of screen orientation with respect to the approach flow direction on screen performance. The modular unit was rotated in the horizontal plane to 20^0 out of alignment with respect to the approach flow direction (ie. 20^0 from the axis of the test channel). Figure 6 is a photograph of this orientation as tested in the hydraulic model. Point velocities were acquired at 108 locations over the screen face. Here, as in previous testing, the approach velocity was held at 1.0 ft/s with the diversion discharge being maintained at 100 ft^3/s.

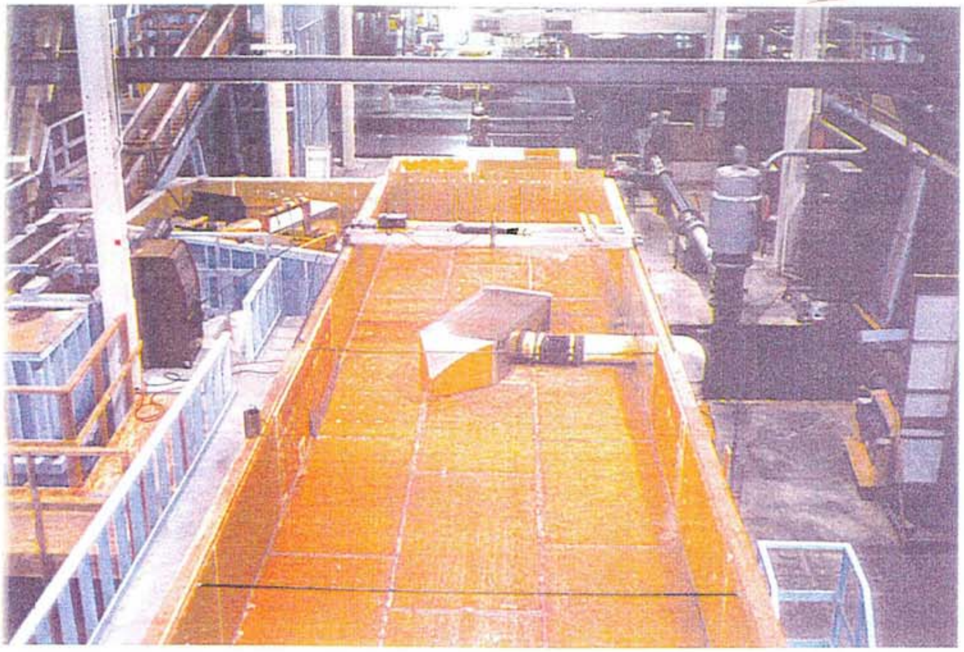


Figure 6. - Photograph #4 - 20° misalignment orientation.

Modifications testing

Review of the submergence results indicated that sweeping velocities along the discharge side of the unit were not being maintained. This disturbance was reasoned to be a result of the combined influence of the discharge pipe cross section and the withdrawal characteristics of the unit. The profile of the discharge pipe exhibits substantial blockage to flow on that side of the unit causing an up-welling effect at the leading edge and a stagnation zone downstream These effects in combination with the sink characteristics of the screen resulted in a breakdown of sweeping velocities along this side of the unit. Four additional tests were conducted to address this problem. The first two tests evaluated a 1:2 slope ramp structure that was 2 ft wide, at the maximum and minimum submergences (ie. 5.3 ft and 3.9 ft respectively). The remaining two tests evaluated the flat plate modification which was 2 ft wide and runs the entire length of the screen, at the maximum and minimum submergences (ie. 5.3 and 3.9 ft respectively). Figures 7 and 8 are photographs of these modifications as constructed and tested in the model. Figure 7 being the ramp structure modification and figure 8, the flow plate modification.

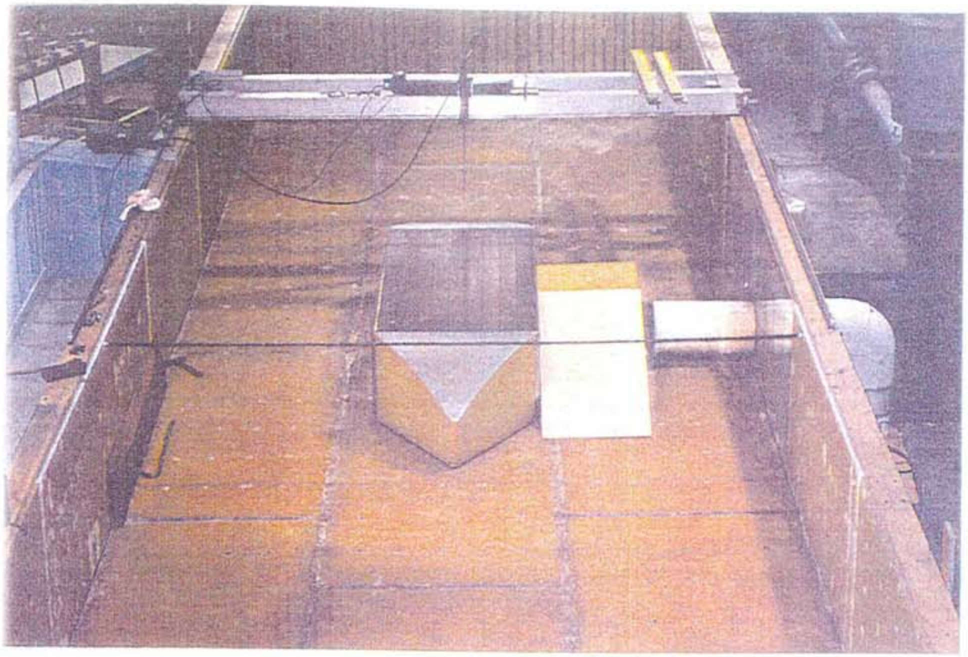


Figure 7 - Photograph #5 - Ramp structure modification.

Figure 8. - Photograph #6 - Flow plate modification.

The following table identifies the hydraulic parameters for each of the tests conducted as identified above:

Table 1: Modular screen configurations tested.

Test No.	Submergence (ft)	$v_{approach}$ (ft/s)	Q_{unit} (ft^3/s)
MFSS37 - Submergence	5.36	1.10	100
MFSS38 - Submergence	4.88	1.12	100
MFSS39 - Submergence	4.36	1.04	100
MFSS40 - Submergence	3.88	1.16	100
MFSS41 - Submergence	3.40	1.10	100
MFSS42 - Submergence	2.96	1.10	100
MFSS43 - Submergence	2.24	1.16	100
MFSSA1 - Orientation	5.28	0.92	100
MFSSR1 - Ramp mod.	5.24	1.16	100
MFSSR2 - Ramp mod.	3.96	1.06	100
MFSSP1 - Plate mod.	5.00	1.16	100
MFSSP2 - Plate mod.	3.68	1.16	100

Head loss testing

During each of the previously described tests, total system head loss was measured . These data were obtained by application of the Bernoulli equation along a streamline from the water surface elevation in the channel at a location upstream of the modular screen unit, to the piezometer ring located out side of the channel on the discharge pipe.

RESULTS

The previously described tests were conducted and the results for each test are presented as velocity surface plots and isovels for the normal component velocities over the screen face, and vector field plots for the sweeping component velocities over the screen face. The velocity surface plots were generated as an additional means for flow visualization of normal component velocity distributions over the screen face. As previously identified, these velocity measurements were acquired at a distance of 1 in. off of the screen face in the model. This corresponds with 4 in. for the prototype. This was as reasonably close to the screen that measurements could be taken using the ADV equipment. Total system head loss was measured during each of the previously described tests. These results are presented as Table 2.

Submergence results

As previously mentioned the objective of these series of tests was to establish submergence limits for this concept. However, these tests also further demonstrate system performance and typical hydraulic characteristics of the concept. The important aspect to realize is that the sink characteristics of this concept remain unchanged over the range of submergences tested. That is the normal component velocity characteristics are consistent for all submergences tested. This result is demonstrated by Figures 9-22. Figures 9, 11, 13, 15, 17, 19 and 21 represent isovel plots of the normal component data for decreasing submergences. Figures 10, 12, 14, 16, 18, 20 and 22 represent the same data plotted as the velocity surface over the screen face. The coordinate system is set up such that the approach flow is from right to left and the discharge pipe is located on the right side of the unit looking downstream.

The normal component velocity magnitudes for the velocity surface plots are indicated by the vertical axis. The negative sign indicates a downward direction. The x and y axes composing the horizontal plane represent the spatial coordinates over the screen face. The approach flow direction for all plots is from right to left. The discharge pipe exits from the right side of the modular screen unit looking downstream. Thus, the origin of each of the plots presented represents the downstream corner of the screen opposite the discharge pipe side. Similitude between model and prototype requires a velocity ratio of 1:2, model to prototype (see Similitude). This means that the 0.33 ft/s normal component velocity criteria, established for the prototype, becomes 0.167 ft/s in the model. Resource agencies allow a $\pm$ 10% variation in this target value over the entire screen. Thus, to be in compliance, maximum normal component velocities for the prototype must be at or below 0.36 ft/s and normal component velocities for the model must be at or below 0.18 ft/s. This criteria was achieved to a reasonable degree. However, fine tuning is required to improve these results.

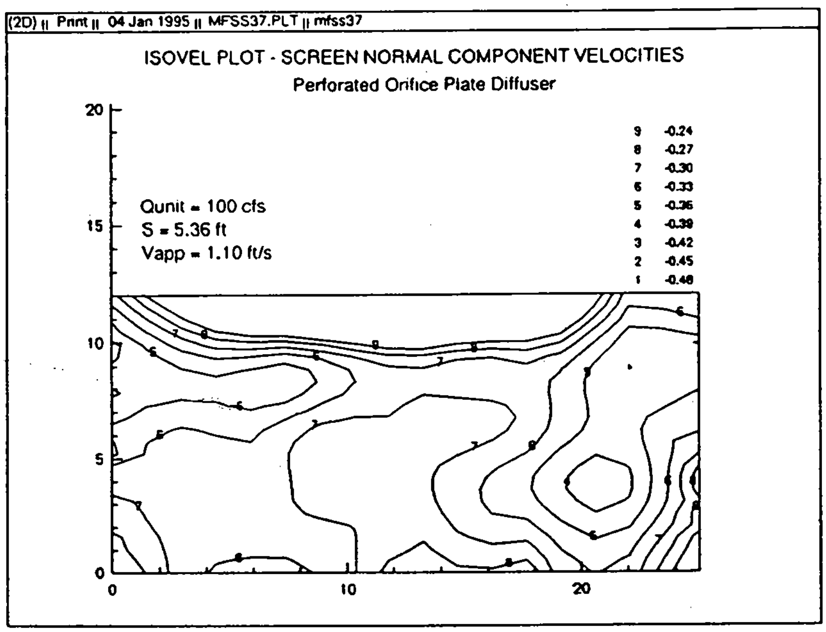


Figure 9. - Isovel plot of normal component velocities. Submergence = 5.36 ft.

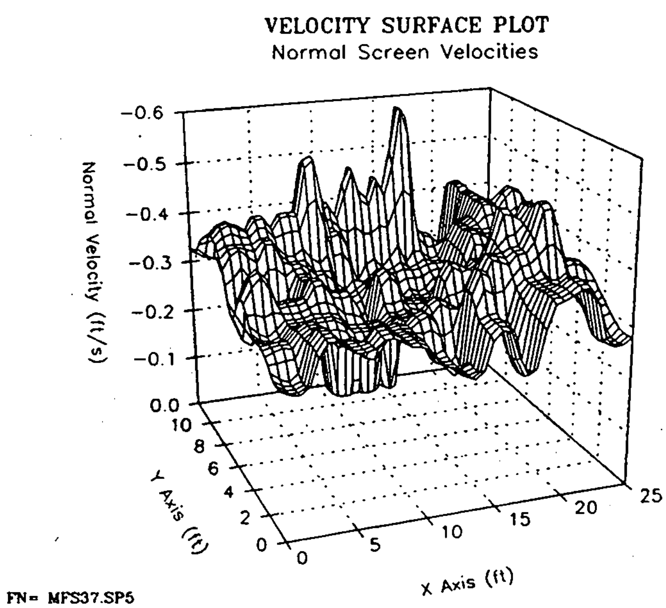


Figure 10. - Normal component velocity surface plot. Submergence = 5.36 ft.

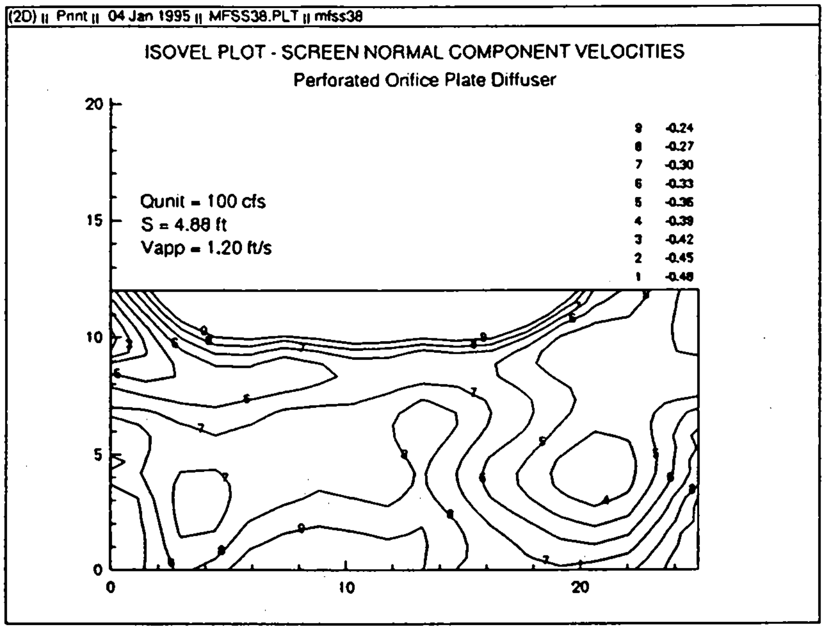


Figure 11. - Isovel plot of normal component velocities. Submergence = 4.88 ft.

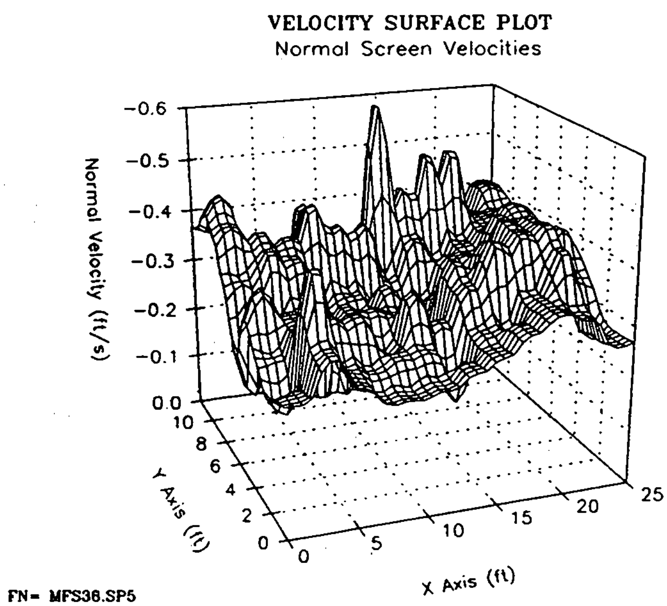


Figure 12. - Normal component velocity surface plot. Submergence = 4.88 ft.

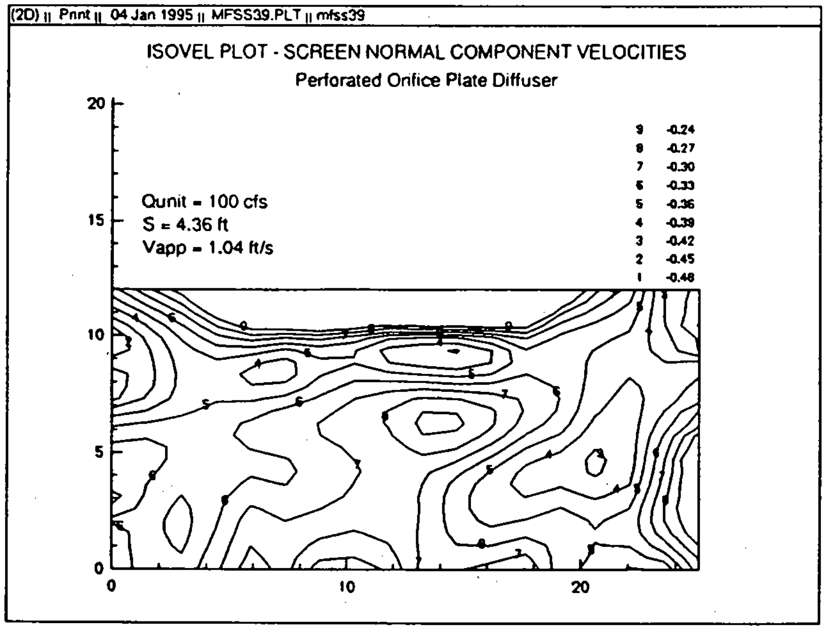


Figure 13. - Isovel plot of normal component velocities. Submergence = 4.36 ft.

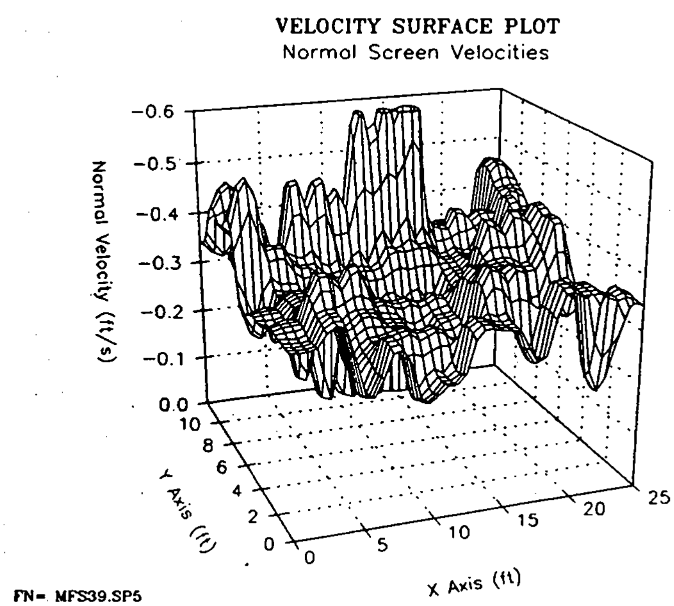


Figure 14. - Normal component velocity surface plot. Submergence = 4.36 ft.

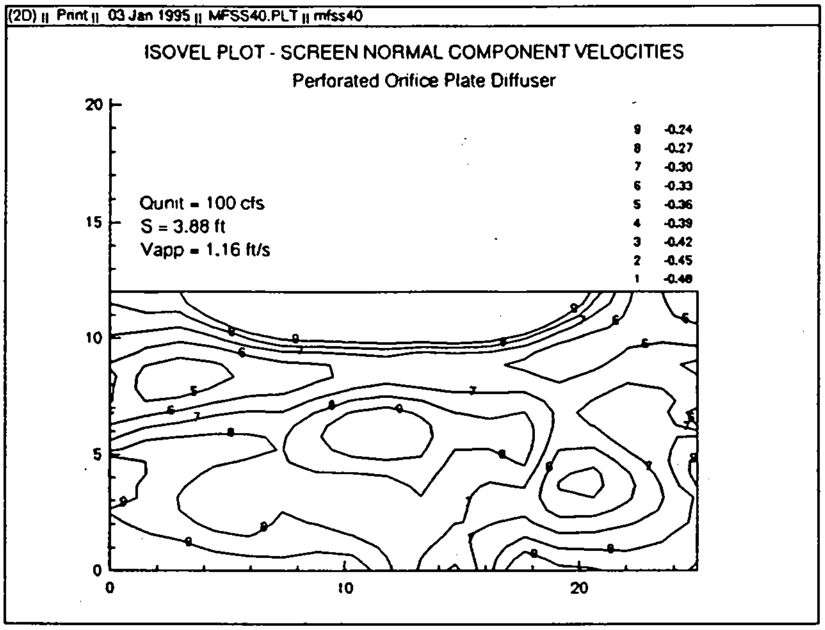


Figure 15. - Isovel plot of normal component velocities. Submergence = 3.88 ft.

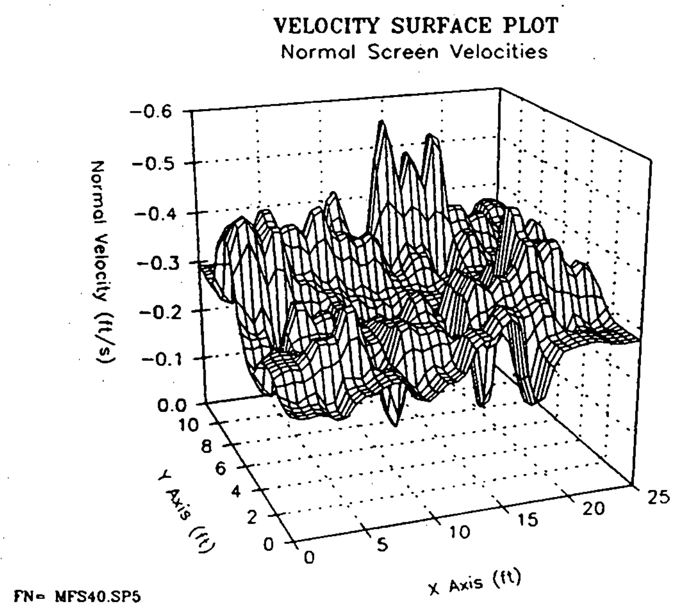


Figure 16. - Normal component velocity surface plot. Submergence = 3.88 ft.

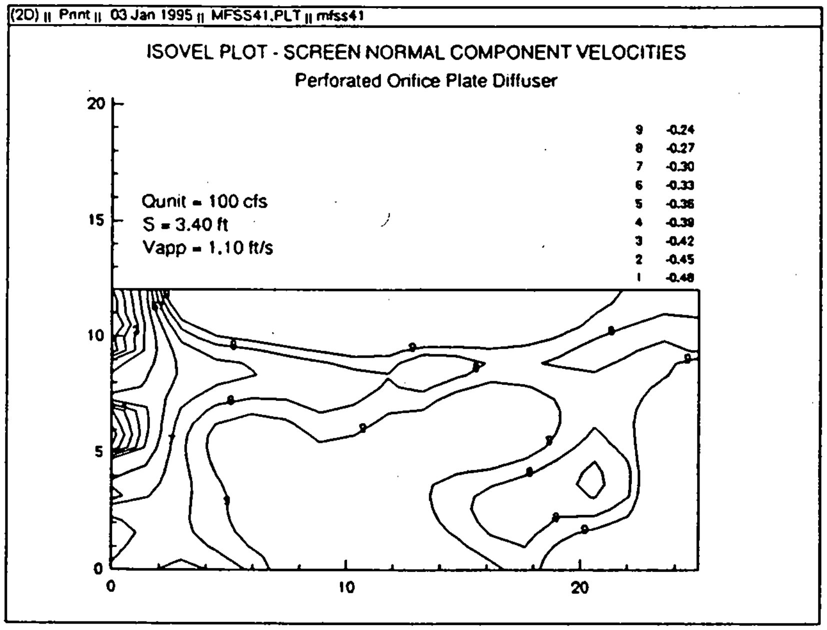


Figure 17. - Isovel plot of normal component velocities. Submergence = 3.40 ft.

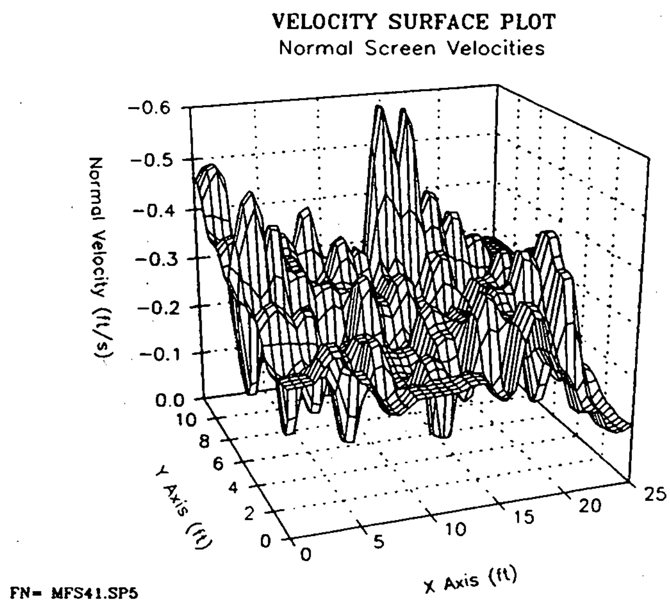


Figure 18. - Normal component velocity surface plot. Submergence = 3.40 ft.

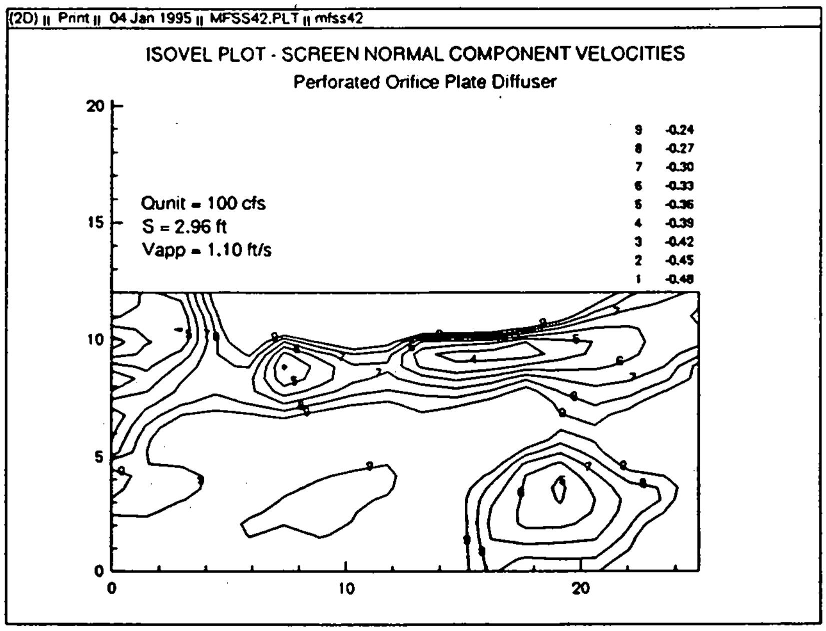


Figure 19. - Isovel plot of normal component velocities. Submergence = 2.96 ft.

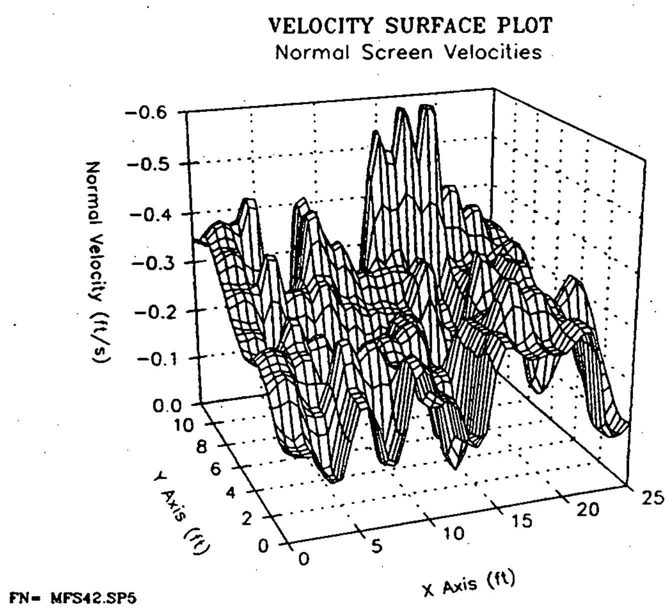


Figure 20. - Normal component velocity surface plot. Submergence = 2.96 ft.

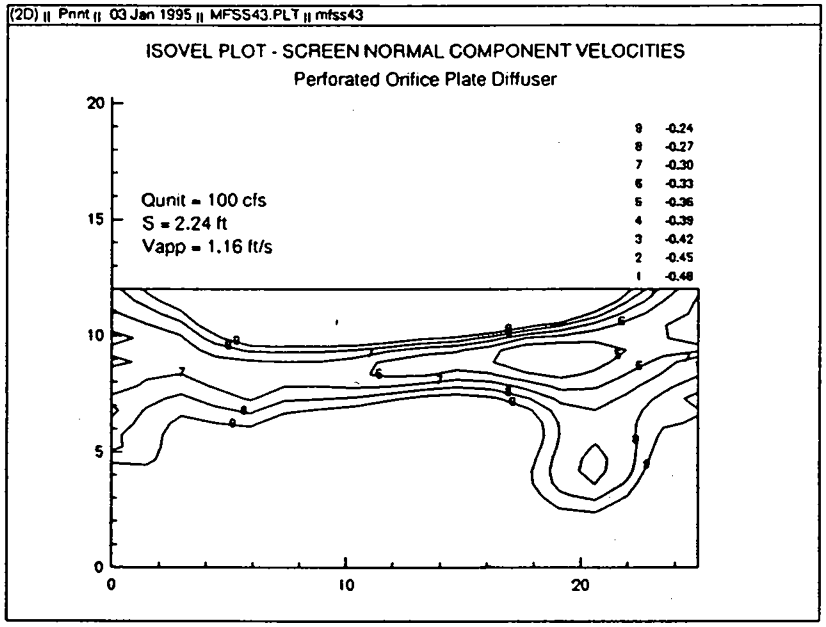


Figure 21. - Isovel plot of normal component velocities. Submergence = 2.24 ft.

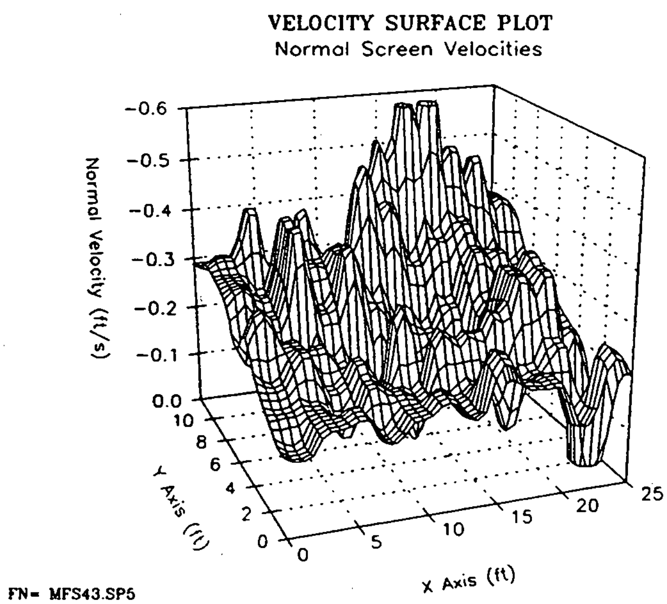


Figure 22. - Normal component velocity surface plot. Submergence = 2.24 ft.

Since, it is apparent from these results that, the normal component velocities remain virtually unchanged over the range of submergences tested, another means of establishing a submergence limit was required. Figures 23-29 represent the sweeping component velocity vector field plots for each submergence point tested. From these results it is realized that as submergence is reduced, sweeping velocities begin to breakdown. Thus, the criteria for establishing submergence limits becomes the ability to maintain sweeping component velocities over the screen face. This means that a submergence limit exists at that depth of flow over the unit in which sweeping velocity magnitudes and directions can no longer be sustained. The point at which this breakdown is most discernable was selected as the submergence limit for hydraulic conditions under which these tests were conducted. This submergence limit is demonstrated by Figure 25. Therefore for a model submergence of 0.85 ft, we can expect a submergence limit of approximately 3.5 ft to be realized in prototype scale.

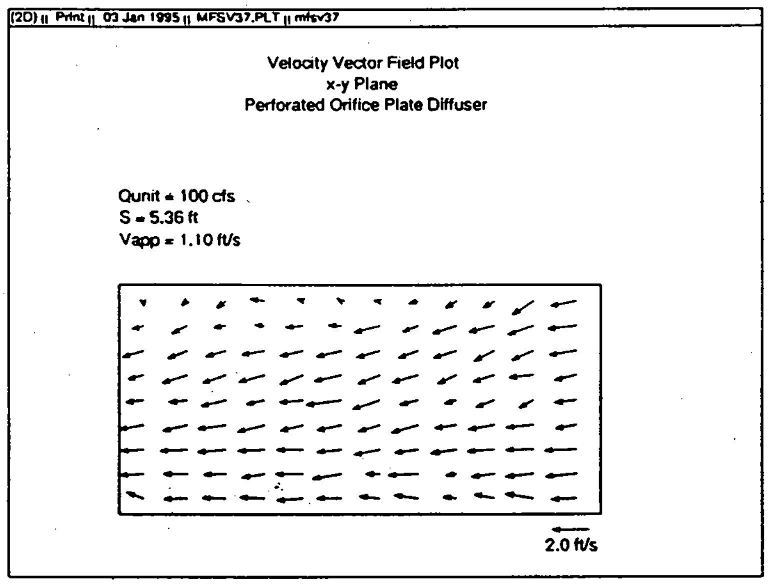


Figure 23. - Vector field plot of sweeping component velocities. Submergence = 5.36 ft.

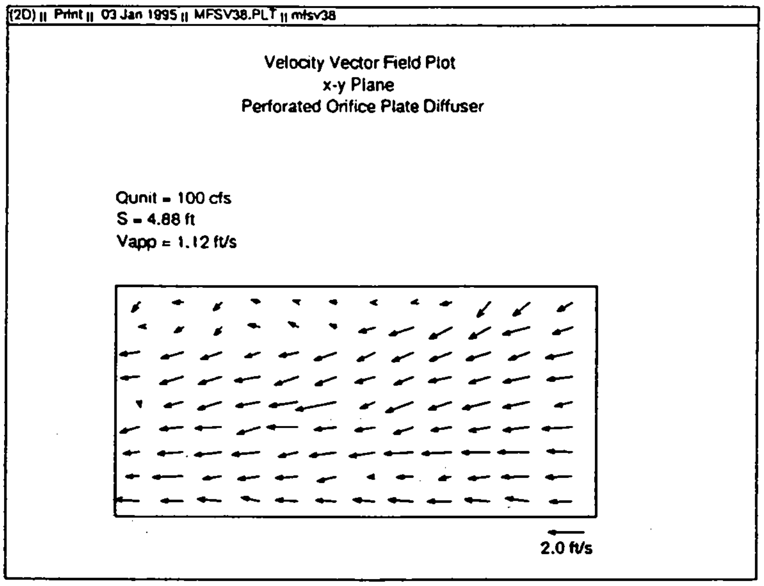


Figure 24. - Vector field plot of sweeping component velocities. Submergence = 4.88 ft.

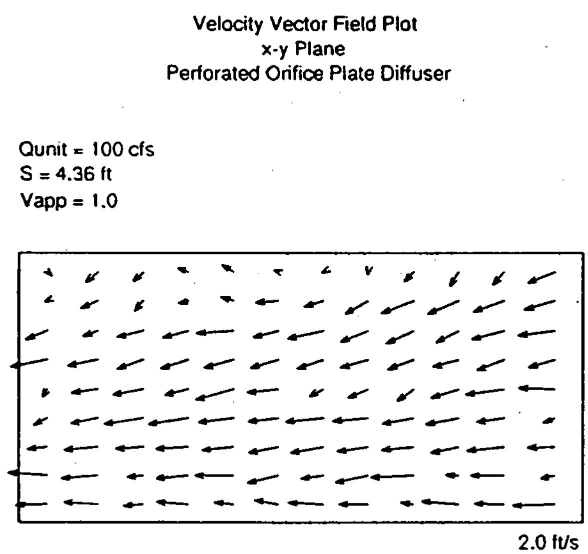


Figure 25. - Vector field plot of sweeping component velocities. Submergence = 4.36 ft.

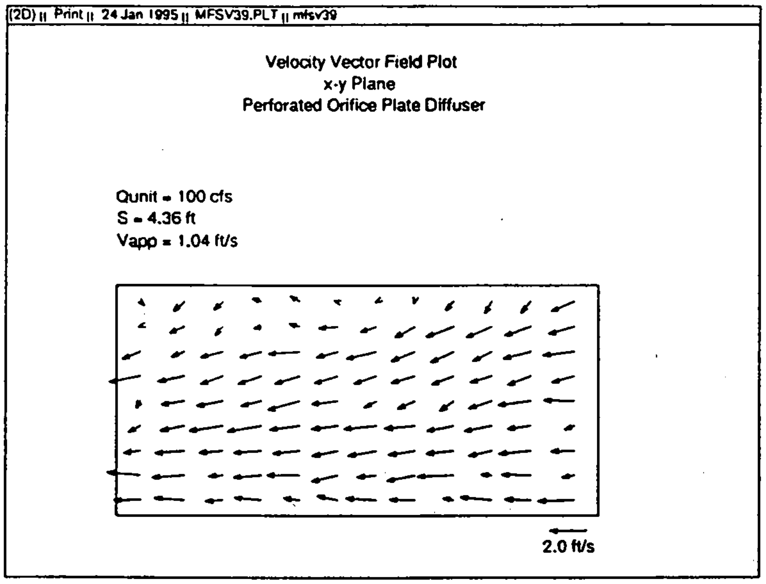


Figure 26. - Vector field plot of sweeping component velocities. Submergence = 3.88 ft.

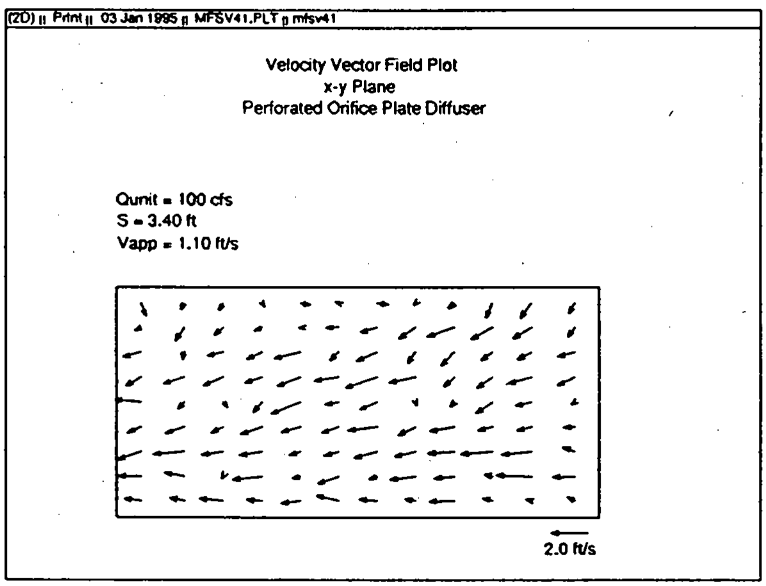


Figure 27. - Vector field plot of sweeping component velocities. Submergence = 3.40 ft.

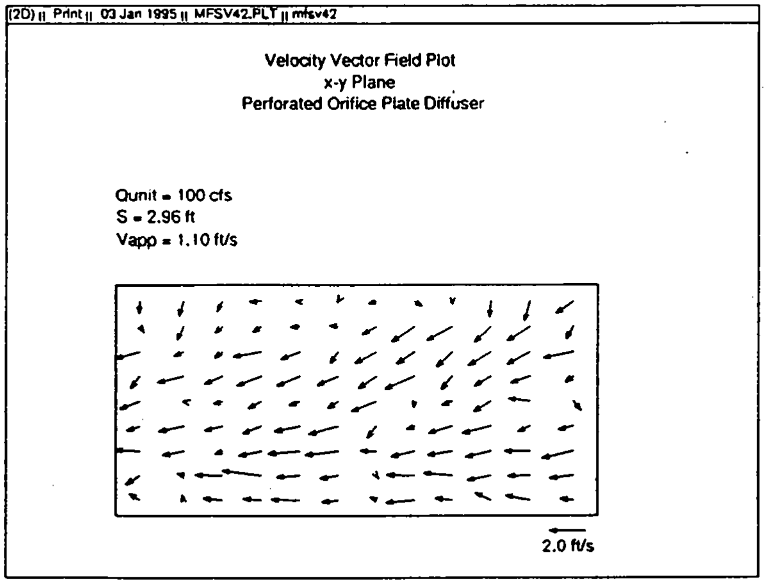


Figure 28. - Vector field plot of sweeping component velocities. Submergence = 2.96 ft.

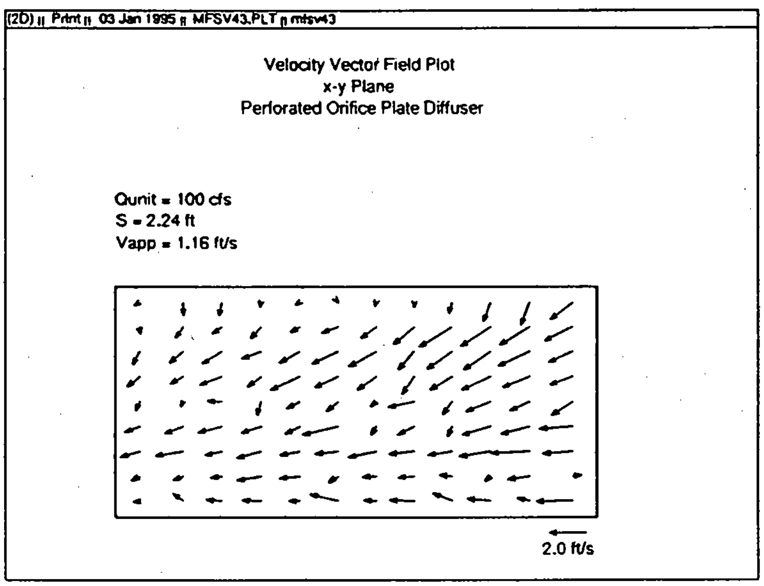


Figure 29. - Vector field plot of sweeping component velocities. Submergence = 2.24 ft.

Orientation results

A single test was conducted to demonstrate the influence of the modular unit orientation with respect to approach flow direction. The unit was rotated in the horizontal plane to 20^o out of alignment with the axis of the laboratory channel. This test was conducted at the maximum submergence available in the laboratory setup. The approach velocity was set at approximately 0.84 ft/s. The through unit discharge was set at 100 ft^3/s. Figures 30 - 32 represent the results of this test. Although it appears that the normal component velocity criteria can be achieved, the sweeping velocities cannot be maintained over the entire screen area. Figure 30, the sweeping component vector field plot, demonstrates this result. Therefore, orientation of the unit certainly influences performance with the 20 degree misalignment appearing to be excessive. Further testing will be required to establish these limits.

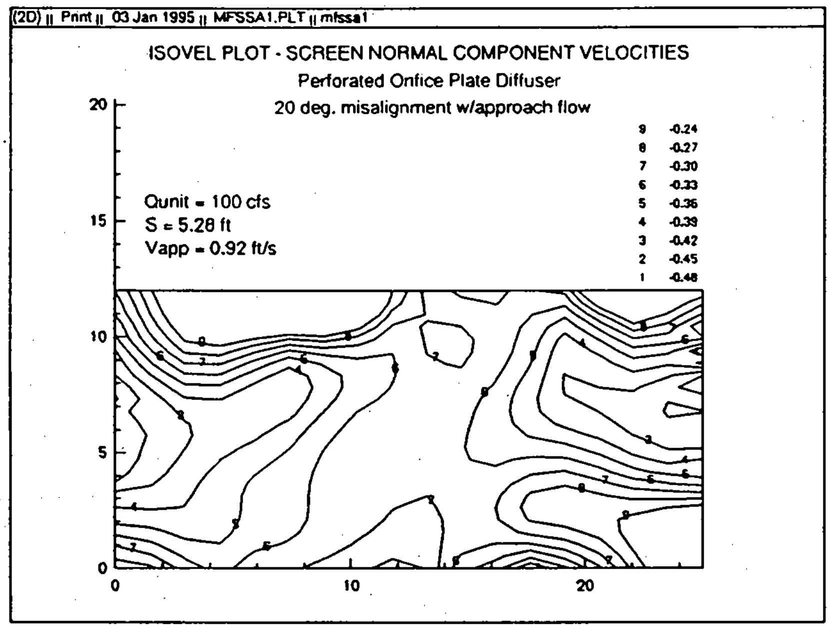


Figure 30. - Isovel plot of normal component velocities. 20^o misalignment. Submergence = 5.28 ft.

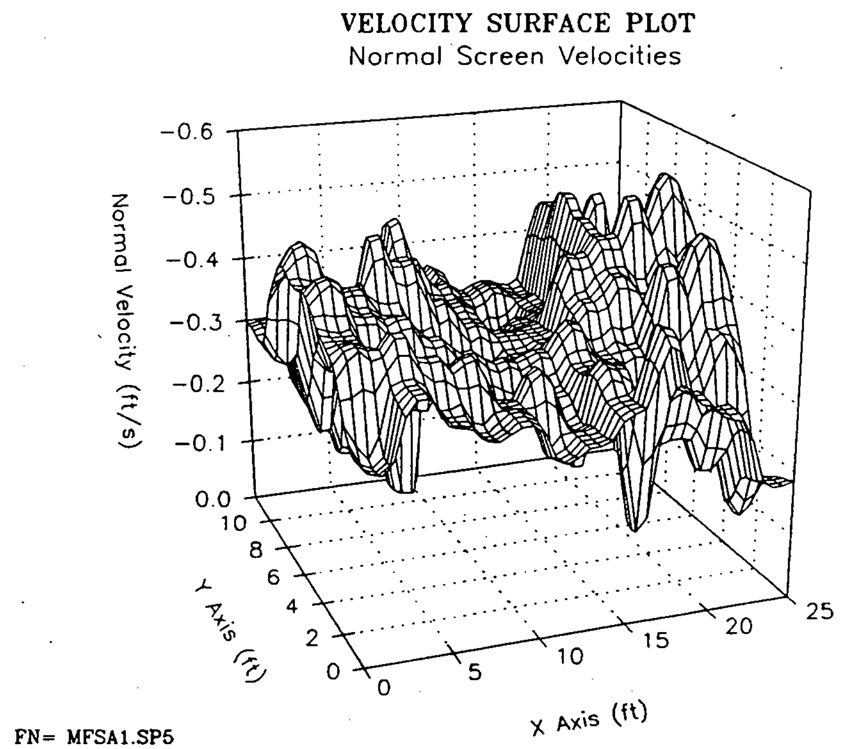


Figure 31. - Normal component velocity surface plot. 20^{o} misalignment. Submergence = 5.28 ft.

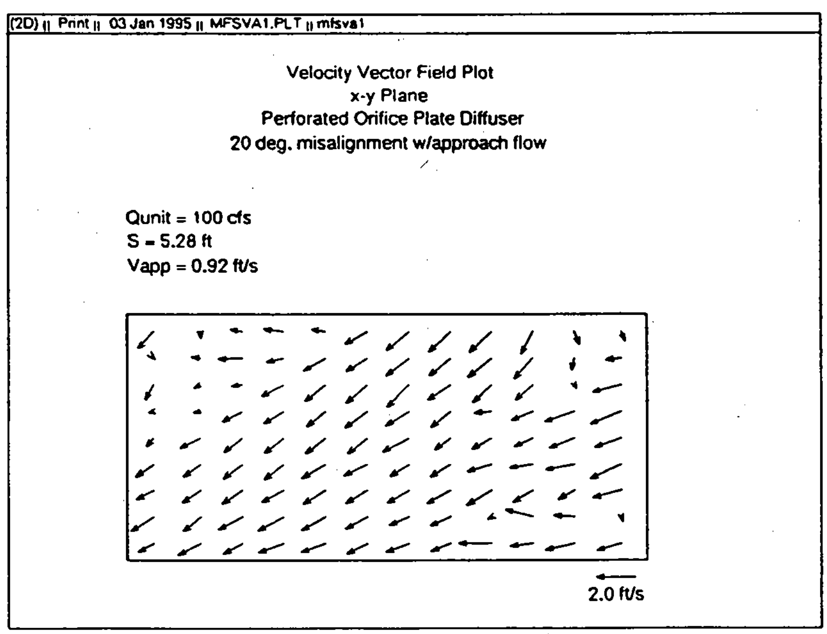


Figure 32. - Vector field plot of sweeping component velocities. 20^{o} misalignment. Submergence = 5.28 ft.

Modification results

As mentioned previously, submergence results revealed a defect in the general characteristics of this concept. Sweeping velocities could not be maintained along the discharge pipe side of the unit. It was reasoned that this was a combined affect of the discharge pipe profile and the sink characteristics of the unit. The discharge pipe profile being a substantial barrier to flow. Thus, creating a stagnation zone downstream giving the sink greater potential to draw flow up and over the side of the unit. Two modifications were developed to solve this problem. The first, a ramp structure 2 ft wide with a 1:2 slope upstream and downstream of the discharge pipe. The second modification consisted of a flat plate 2 ft wide extending the entire length of the screen. Both modifications were evaluated at the maximum submergence and at the submergence limit previously established. Figures 33 - 38 represent the results of the ramp structure modification. Figures 39 - 44 represent the results obtained from the plate modification. Both modifications demonstrated sweeping velocity improvements. However, the flat plat demonstrated the greatest improvement giving strong sweeping component velocities along the length of the screen with the exception of a small breakdown at the leading edge. This result is seen by comparison of Figures 35 and 38 with Figures 41 and 44. Although the flat plate appears to demonstrate potential, more comprehensive evaluations should be conducted before including this feature in the design.

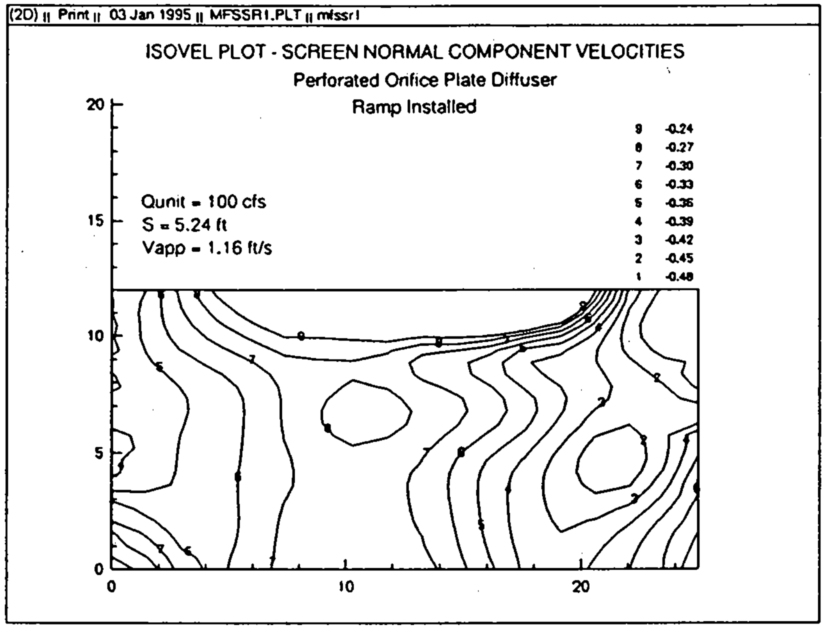


Figure 33. - Isovel plot of normal component velocities. Ramp structure modification. Submergence = 5.24 ft.

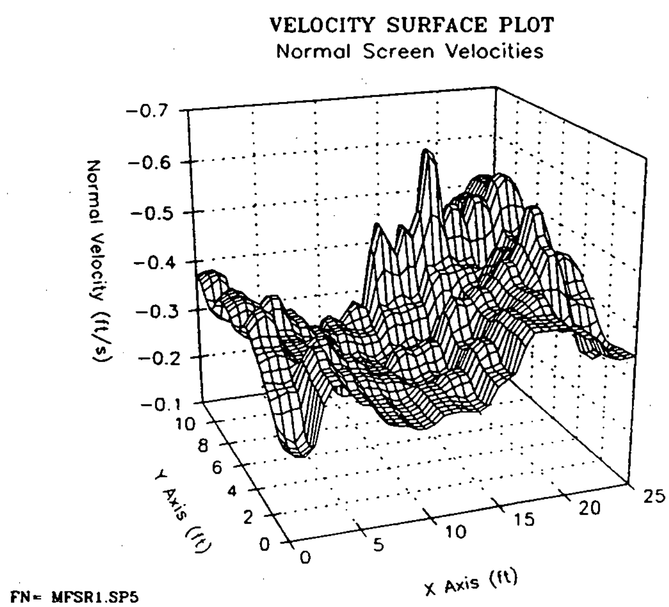


Figure 34. - Normal component velocity surface plot. Ramp structure modification. Submergence = 5.24 ft.

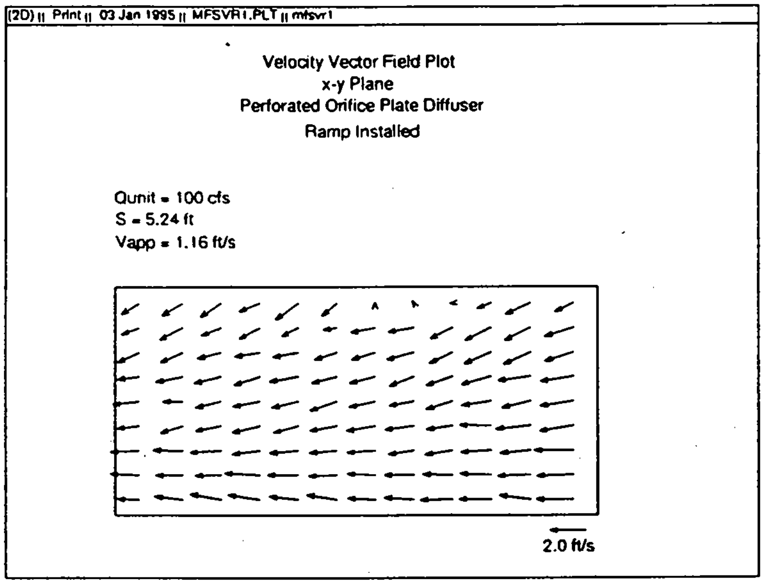


Figure 35. - Vector field plot of sweeping component velocities. Ramp structure modification. Submergence = 5.24 ft.

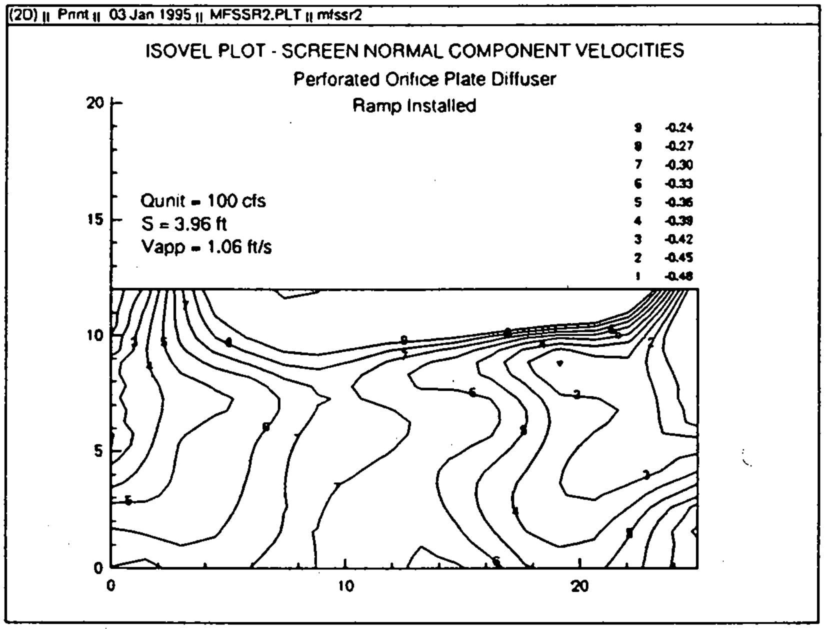


Figure 36. - Isovel plot of normal component velocities. Ramp structure modification. Submergence = 3.96 ft.

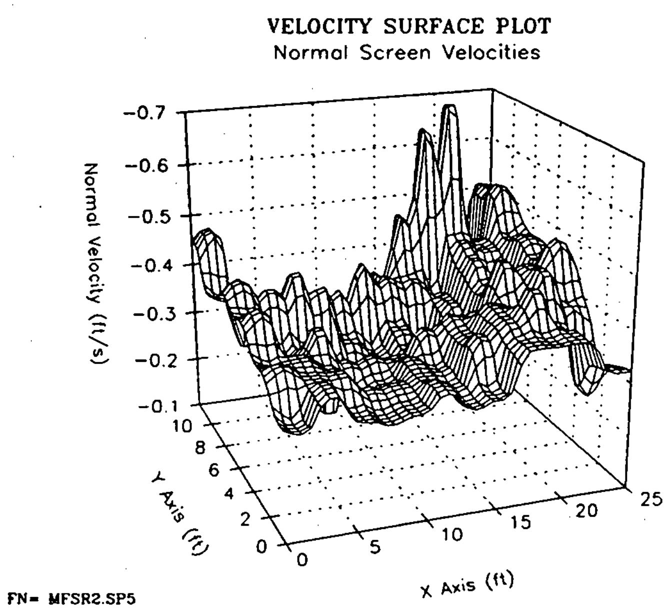


Figure 37. - Normal component velocity surface plot. Ramp structure modification. Submergence = 3.96 ft.

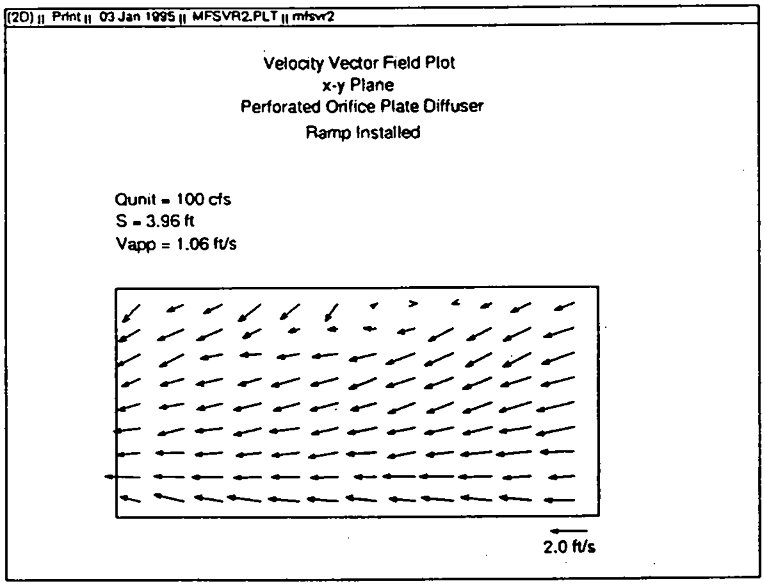


Figure 38. - Vector field plot of sweeping component velocities. Ramp structure modification. Submergence = 3.96 ft.

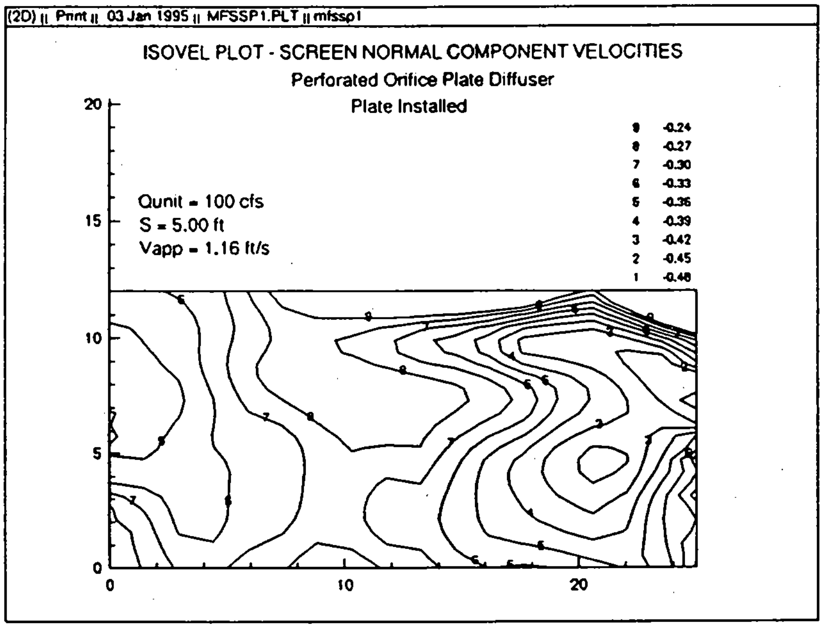


Figure 39. - Isovel plot of normal component velocities. Flow plate modification. Submergence = 5.00 ft.

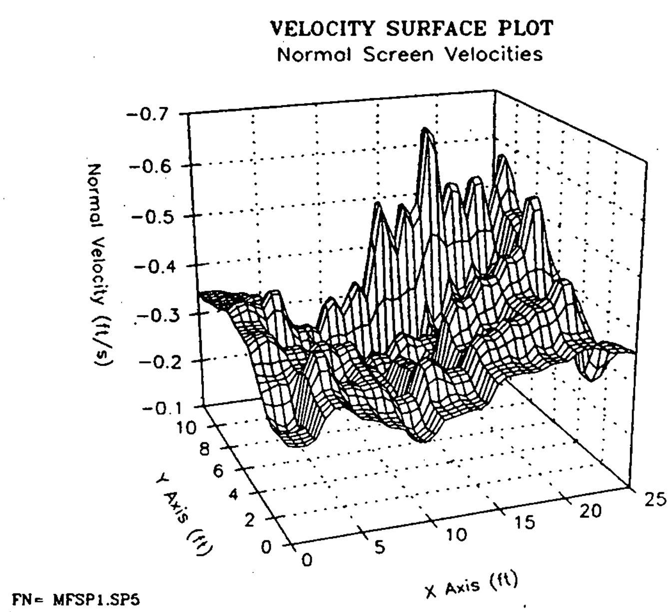


Figure 40. - Normal component velocity surface plot. Flow plate modification. Submergence = 5.00 ft.

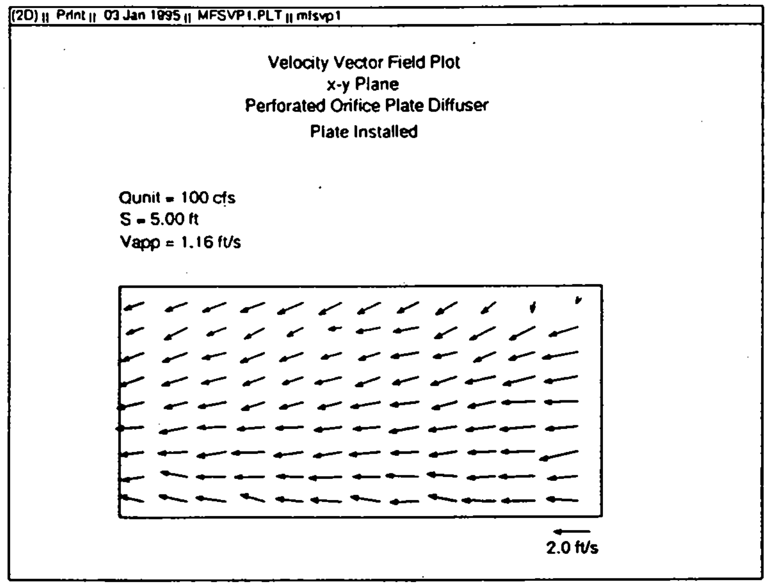


Figure 41. - Vector field plot of sweeping component velocities. Flow plate modification. Submergence = 5.00 ft.

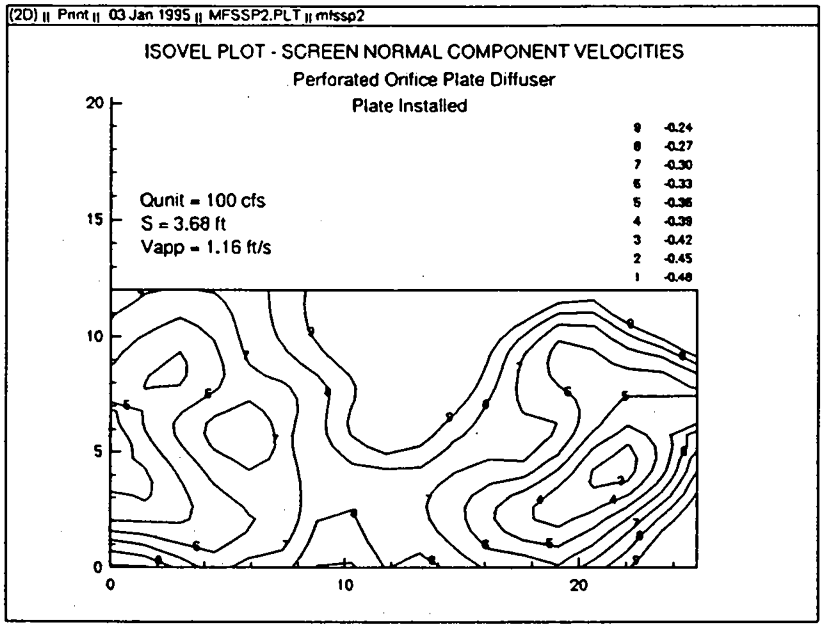


Figure 42. - Isovel plot of normal component velocities. Flow plate modification. Submergence = 3.68 ft.

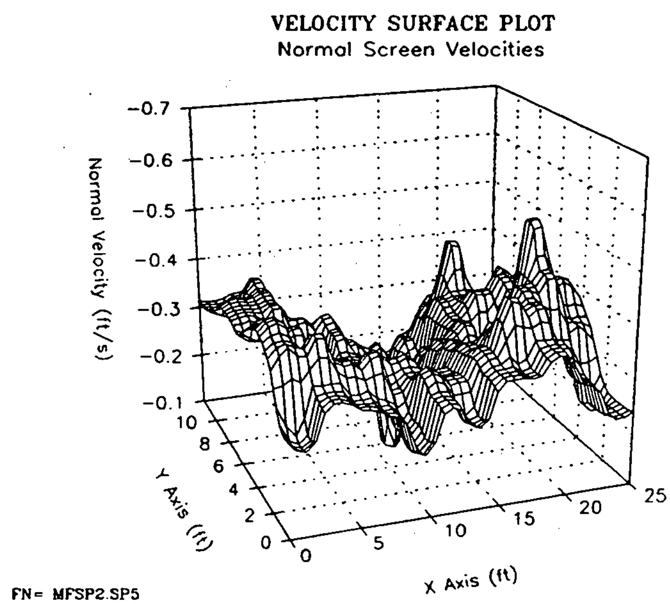


Figure 43. - Normal component velocity surface plot. Flow plate modification. Submergence = 3.68 ft.

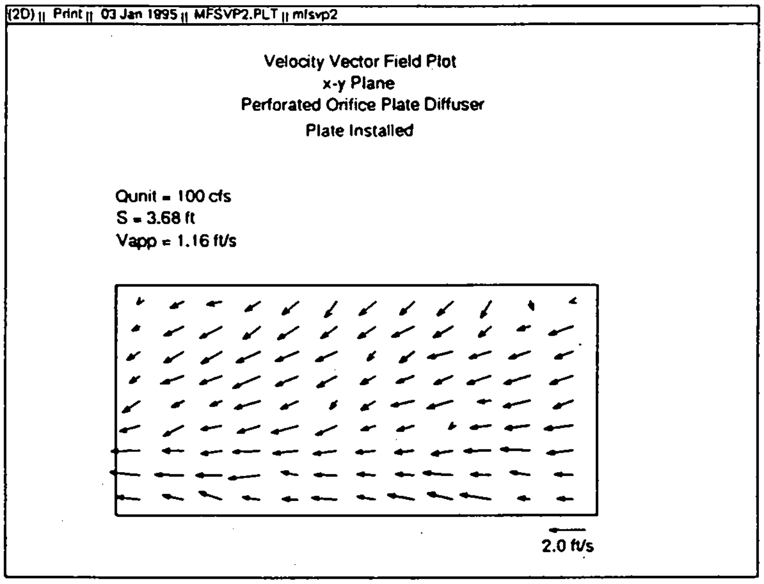


Figure 44. - Vector field plot of sweeping component velocities. Flow plate modification. Submergence = 3.68 ft.

Head loss Results

As previously described, total system head loss was measured for each of the tests conducted. These results were obtained by measuring the static pressure in the discharge pipe using the piezometer ring and pressure transducer. Bernoulli's equation was employed to compute system head loss as described in the theory section. The following table indicates measured head loss for each of the tests presented in this report.

Table 2: Head loss results for all tests conducted.

Test No. - Type	Head loss (ft)
MFSS37 - Submergence	1.17
MFSS38 - Submergence	1.16
MFSS39 - Submergence	1.32
MFSS40 - Submergence	1.35
MFSS41 - Submergence	1.18
MFSS42 - Submergence	1.20
MFSS43 - Submergence	1.08
MFSSA1 - Orientation	1.56
MFSSR1 - Ramp mod.	1.60
MFSSR2 - Ramp mod.	1.48
MFSSP1 - Plate mod.	1.47
MFSSP2 - Plate mod.	1.52

There does not appear to be any discernable variation in measured head loss with submergence over the range tested. Taking the maximum value acquired for all tests, 1.6 ft becomes a conservative estimate of system head loss for the conditions tested in the laboratory.

The extent of these hydraulic investigations were limited by available funding. However, the hydraulic features of this concept have been developed through this effort. Limited additional studies, which would confirm the performance characteristics of the recommended design, should be conducted prior to a prototype field installation. Of particular concern is the velocity distribution sensitivity to modular unit alignment in pitch, roll, and yaw. Further evaluations of this concept with the plate modification would be prudent.

BIBLIOGRAPHY

Yeh, Harry H. and Shresta, Mandira, Free Surface Flow Through a Screen, FX-10, Dept. of Civil Engineering, Univ. of Washington.

Brater, Ernest F. and King, Horace Williams, Handbook of Hydraulics, 6th Edition, McGraw-Hill, Inc., 1976.

Bureau of Reclamation, Hydraulic Laboratory Techniques, U.S. Department of the Interior, 1980, Reprinted 1986.

D-3751
RES-3.50

3 1994

MEMORANDUM

To: Project Superintendent, Redding CA
Attention: SO-305 (O'Haver)

From: Philip H. Burgi
Chief, Hydraulics Branch

Subject: Cost Comparison Between the Reclamation Modular Fish Screen and Existing Fish Screen Technology

Introduction

During preliminary review of the proposed Reclamation Modular Fish Screen concept, many concerns were identified. The primary concern was whether this concept has potential to offer any new or beneficial features relative to existing screen concepts or technology. Thus, it was important to identify those features that could potentially improve existing screen technology, prior to any development or design efforts.

A meeting was held on October 26, 1993, to address many of the concerns associated with the proposed Reclamation Modular Fish Screen concept. A value engineering (VE) approach was used to identify those features that have the potential to enhance existing screen technology. The meeting was attended by Greg O'Haver (SO-305), concept originator; Perry Johnson (D-3751), hydraulic engineer; Rick Christensen (D-3423), mechanical engineer; and Joe Kubitschek (D-3751), hydraulic engineer. During this meeting existing screen concepts were evaluated from a performance standpoint; identification of strengths and weaknesses of specific concepts was achieved (see attached memorandum from Joe Kubitschek, dated October 27, 1993, - Modular Fish Screen Developmental Meeting). The proposed Reclamation Modular Fish Screen concept was then evaluated in the same manner. Upon completion of these evaluations, critical developmental tasks, which specifically addressed many of the concerns associated with the proposed concept, were identified. A detailed study plan is being prepared.

It was realized at this point that cost savings may be this concepts greatest strength. Thus, a cost survey of existing screen technology was conducted, and is presented as follows.

Cost Comparison

A survey of competitive, physical barrier concepts was conducted to determine associated costs. The process reviewed proven and developmental fish exclusion concepts to determine those features with major cost contributions.

Total costs were then determined and divided by the system capacity or discharge to yield cost per cubic foot per second. This cost per cubic foot per second could then be used as a basis for comparison of the various concepts available.

The Eicher screen is a fish exclusion concept particularly well suited for closed conduit and hydroelectric applications. Figure 1, represents a basic schematic for a typical Eicher screen installation. Three separate Eicher screen installations were used for comparison with other available screen concepts. These were the installations at Elwha, Puntledge, and Blue River; all of which are hydroelectric facilities. From table 1, it can be seen that the average cost per cubic foot per second for these installations is approximately $2,175. This cost is relatively high considering these are high capacity installations. This is due primarily to the fact that this concept requires a bypass and, in some cases, costly modifications to existing civil works.

The modular inclined screen (MIS), although it has not yet been installed at any field location, exhibits promising potential for a wide range of applications. The Alden Research Laboratory has conducted extensive evaluations (both hydraulic and biological) to verify performance under current fish agency criteria. Figure 2 is a basic schematic of the MIS. Cost information for this concept is presented graphically using figure 3. As illustrated by figure 3, the cost per cubic foot per second for the MIS decreases, not only with approach velocity, but depth of installation also. If a mean cost was selected from figure 3, the cost per cubic foot per second for the MIS could be expressed as approximately $3,000. Again, this is relatively high due to bypass requirements and structural aspects of the concept. It is important to note foundation preparation, civil works, and excavation can add to this cost.

A large source of cost information was obtained via the Bonneville Power Administration (BPA) Planning Report for the Yakima River Basin (reference 2). The projects identified from this source are considered small installations as is apparent from the capacities shown in table 1. Figure 4 shows a typical drum screen installation, similar to those currently in wide use at many fish exclusion facilities. Average costs for small screen installations of this type are on the order of $6,400 per cubic foot per second. However, this cost may climb to over $10,000 per cubic foot per second. As can be seen from table 1, these costs vary substantially. This is due primarily to the degree of effort required for each of these installations. In other words, the lower cost sites represent rework of existing installations to update their operation. Conversely, those sites which reflect higher cost per cubic foot per second represent installations which require entire screen replacement or are new locations proposed for screen installations. Regardless of the above, these costs are high when compared with large screen installations of this type. It is important to realize that based on this fact, a very good opportunity exists to develop a competitive concept, particularly for small installations or facilities of the type proposed for the Yakima River Basin.

A survey of manufacturers was also conducted to cost prefabricated fish exclusion concepts which are available. Some different concepts available are given as figures 5-6. The cost associated with these products reflect fabrication and material costs only (table 1). Additional costs would be incurred for installation of system and piping.

Figure 7 is a typical perforated plate screen installation. This is another common exclusion concept. The Idaho Department of Fish and Game has additional information on this type of installation.

The last concept to be considered is that which was designed, fabricated, and installed for the temporary pumps at Red Bluff. This installation is a box type screen with an internal angled perforated plate screen. Information obtained from the regional office indicates that two, 55-ft^3/s (maximum) screens were designed, fabricated, and installed for approximately $110,000. It is important to note that this cost, $1,000 per cubic foot per second, includes installation.

The latest engineering estimate identifies the proposed Reclamation Modular Fish Screen cost to be on the order of $25,000 for the 25-$ft^3$/s capacity unit, resulting in a cost of approximately $1,000 per cubic foot per second. This cost does not include development or design, only materials and fabrication. Other costs would be incurred for installation of the unit and any associated piping required. A total of $500,000 has been budgeted for development and design of this proposed concept. However, this cost has not been included in the comparison because it represents an initial or fixed cost. Thus, as more units are fabricated and installed this cost will become less significant.

The cost information for all of the above-described concepts has been presented in cost per cubic foot per second as table 1.

It should be understood that unit cost (cost per cubic foot per second) is not only influenced by the particular device or concept being applied, but also by site-specific considerations, overall capacity, and any associated civil works required. For example, some particular concepts such as the MIS and Eicher screens require bypasses, while others may require extensive civil works or excavation. In contrast, some concepts require no civil works or bypass installations (i.e., prefabricated screen installations, Reclamation Modular Fish Screen, etc.) but may require some type of buried pipe or manifold.

Many of the above concepts vary in extent of use. Some of the newer concepts, although extremely promising as effective exclusion techniques, have not been fully accepted for use in a wide variety of applications. Angled, rotary drum screen technology has been widely accepted as indicated by its extensive use. Alternately, the MIS has yet to be installed for a specific application or site, although extensive developmental (laboratory) work has been conducted.

The following conclusions may be developed based on this analysis.

Conclusions

- Pursuit of developmental work for this concept in the laboratory and the field is warranted due to the obvious opportunity to produce a low cost modular screen concept that meets current criteria as guided by the various fish agencies.

- This cost comparison indicates that the proposed Reclamation Modular Fish Screen is very competitive for small screen applications. Yet, it should be realized, this concept appears to be less competitive for those larger installations where cost per cubic foot per second tends to be less, as indicated by some of the typical installations surveyed herein.

- The greatest competition is from those prefabricated concepts presently available. As developmental work progresses, improvements may be made to increase competitiveness of the Reclamation Modular Fish Screen in this area.

- Maintenance costs have not been included is this comparison, but will certainly affect the cost per cubic foot per second for various concepts. Those with mechanical components and complex systems will obviously incur higher maintenance costs than the more basic concepts.

Philip H Burgi

Attachments

cc: Regional Director, Sacramento CA, Attention: MP-200
(w/attachments)

bc: D-3750
D-3751
D-3751 (Kubitschek)
(w/attachments to each)

WBR:JPKubitschek:flh:3/1/94:236-200, ext. 455)
(c:\wp\d3751\msccmemo.wpl)

References:

1.) Guidelines for applying Fish Protection/Passage Technologies at Hydroelectric Projects and Other Water Intakes, Review Team Draft, 11/12/93, Stone & Webster Environmental Technology and Services.

2.) Planning Report to Bonneville Power Administration, Fish Passage & Protective Facilities, Phase II, Yakima River Basin, Washington, DOI, BOR, PN Region, June 1990.

3.) Assessment of Downstream Migrant Fish Protection Technologies for Hydroelectric Application, Stone & Webster Engineering Corp., EPRI, AP-4711, Project: 2694-1, Final Report, Sept. 1986.

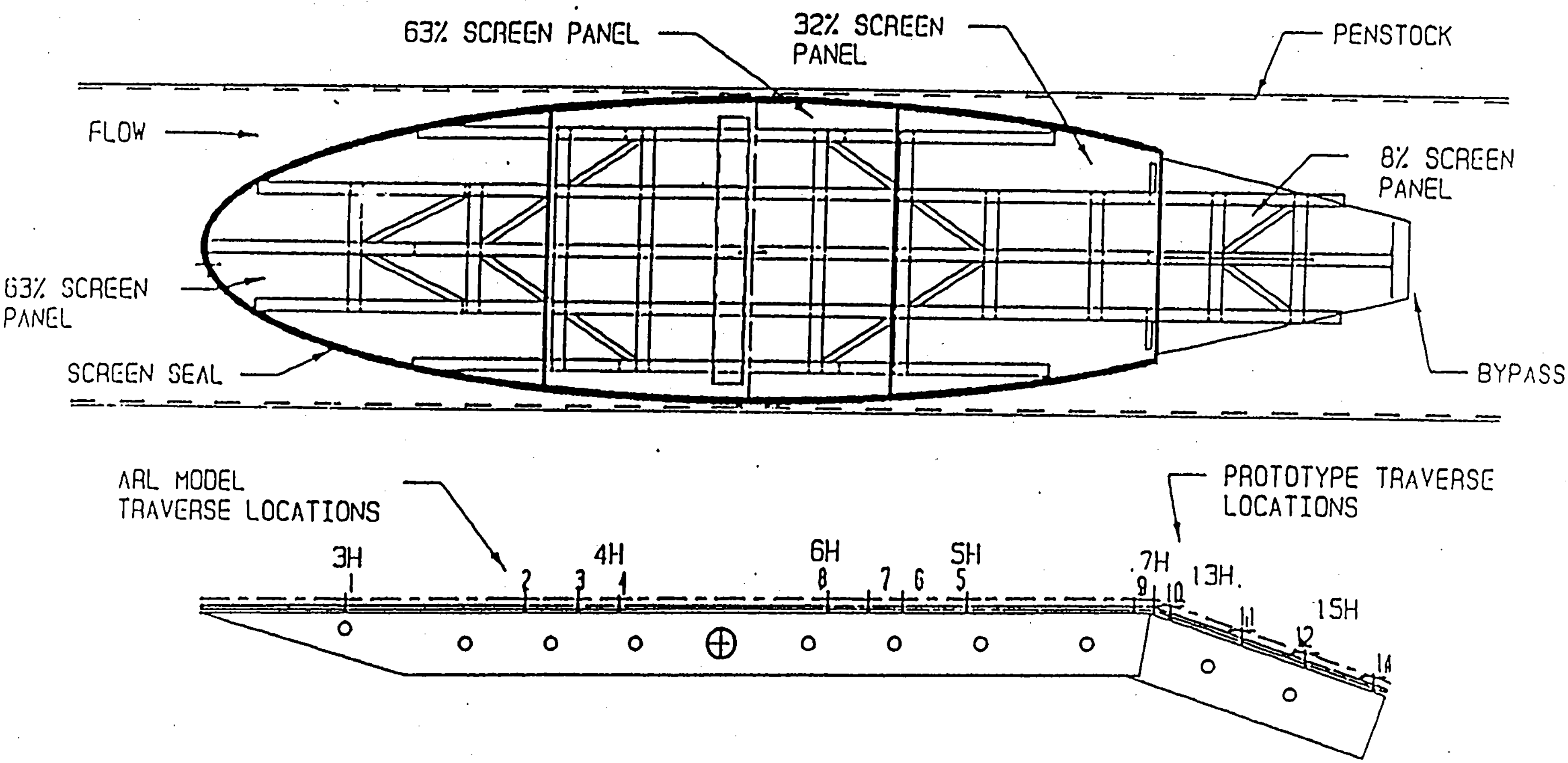


Figure 1: Plan and Section Views of typical Eicher Screen Structure.

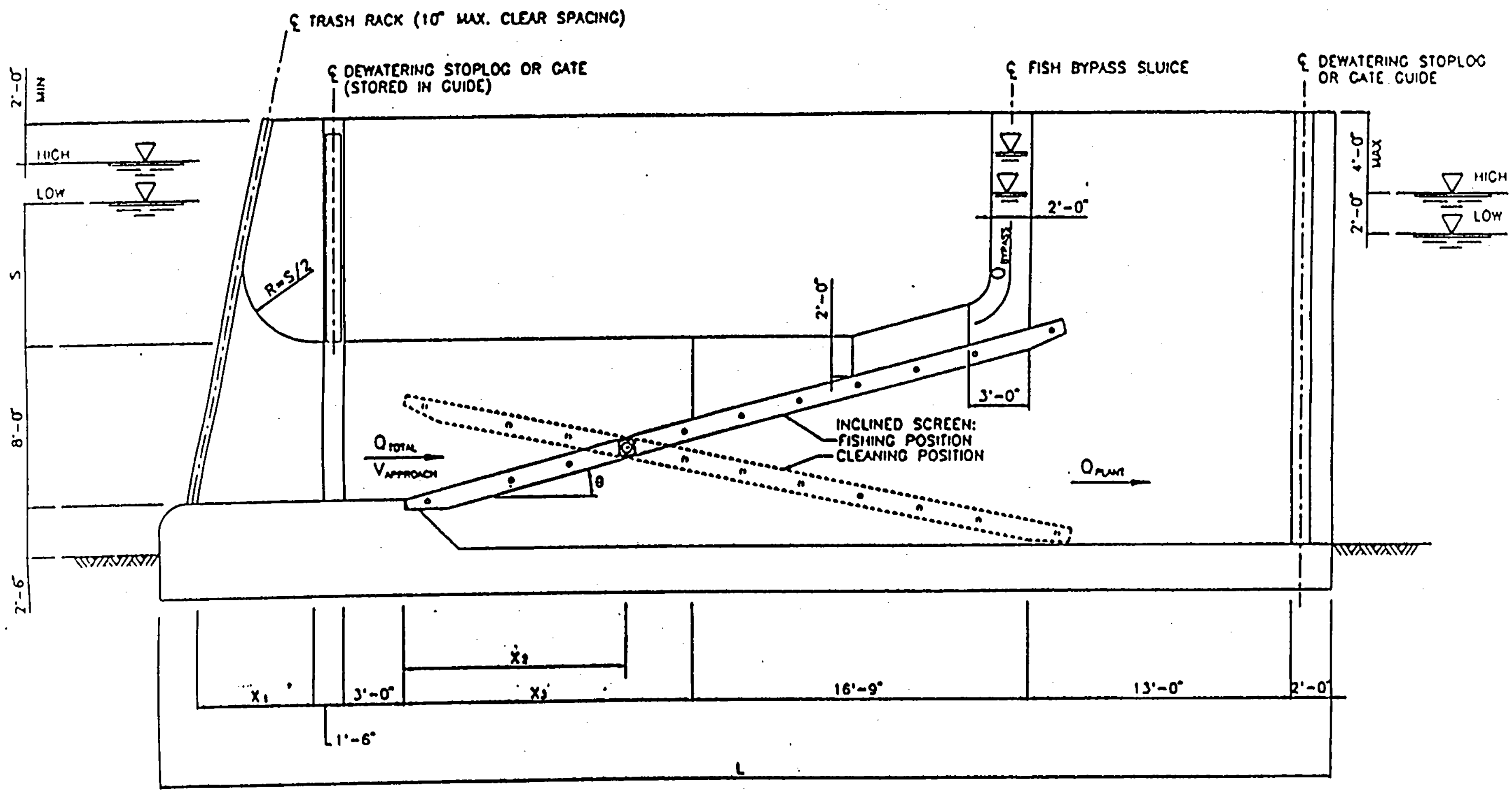


Figure 2: Profile of Modular Inclined Screen as Conceptually Designed.

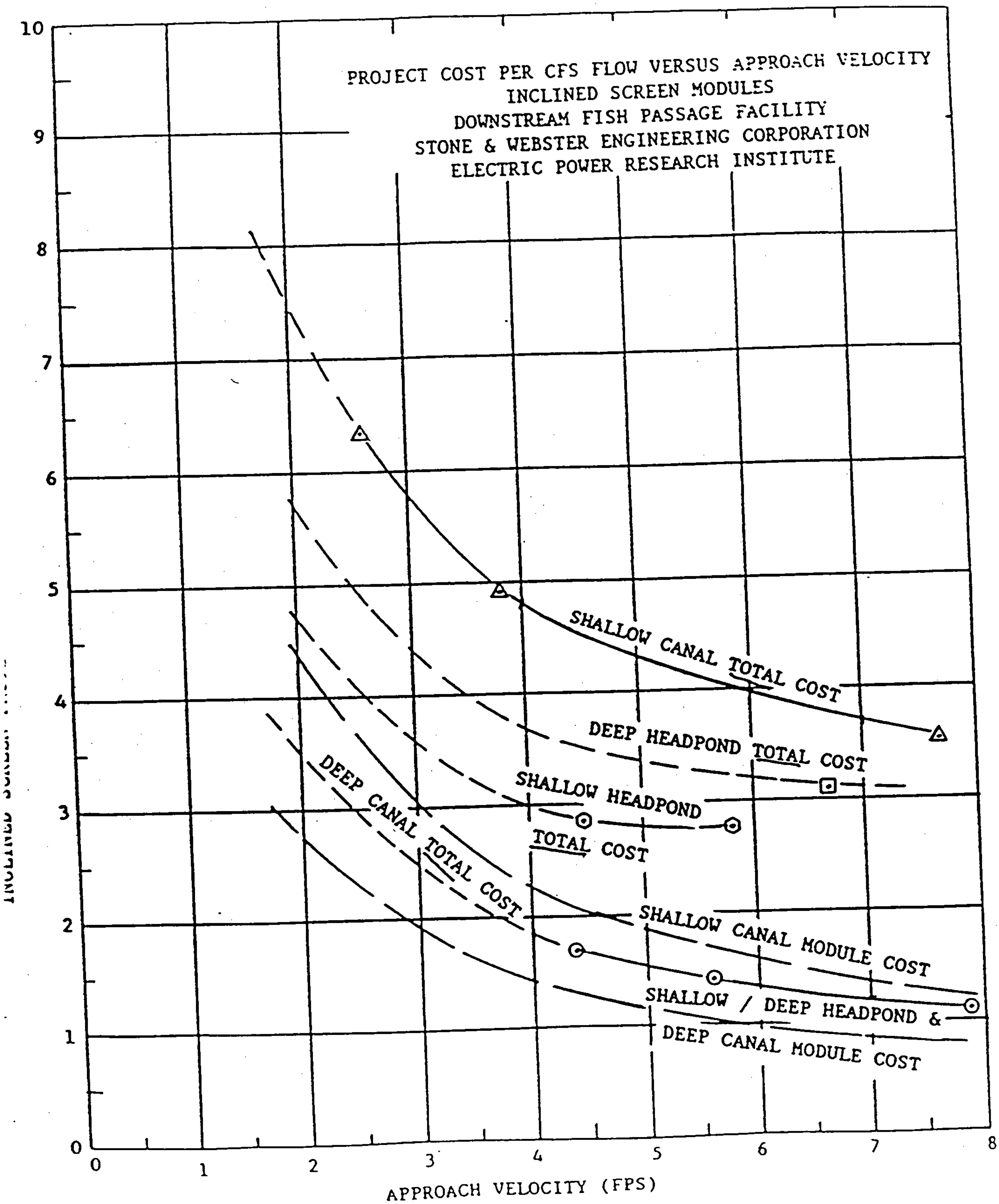


Figure 3: Order of Magnitude Cost Estimates for MIS Screening Facilities (Reference 1).

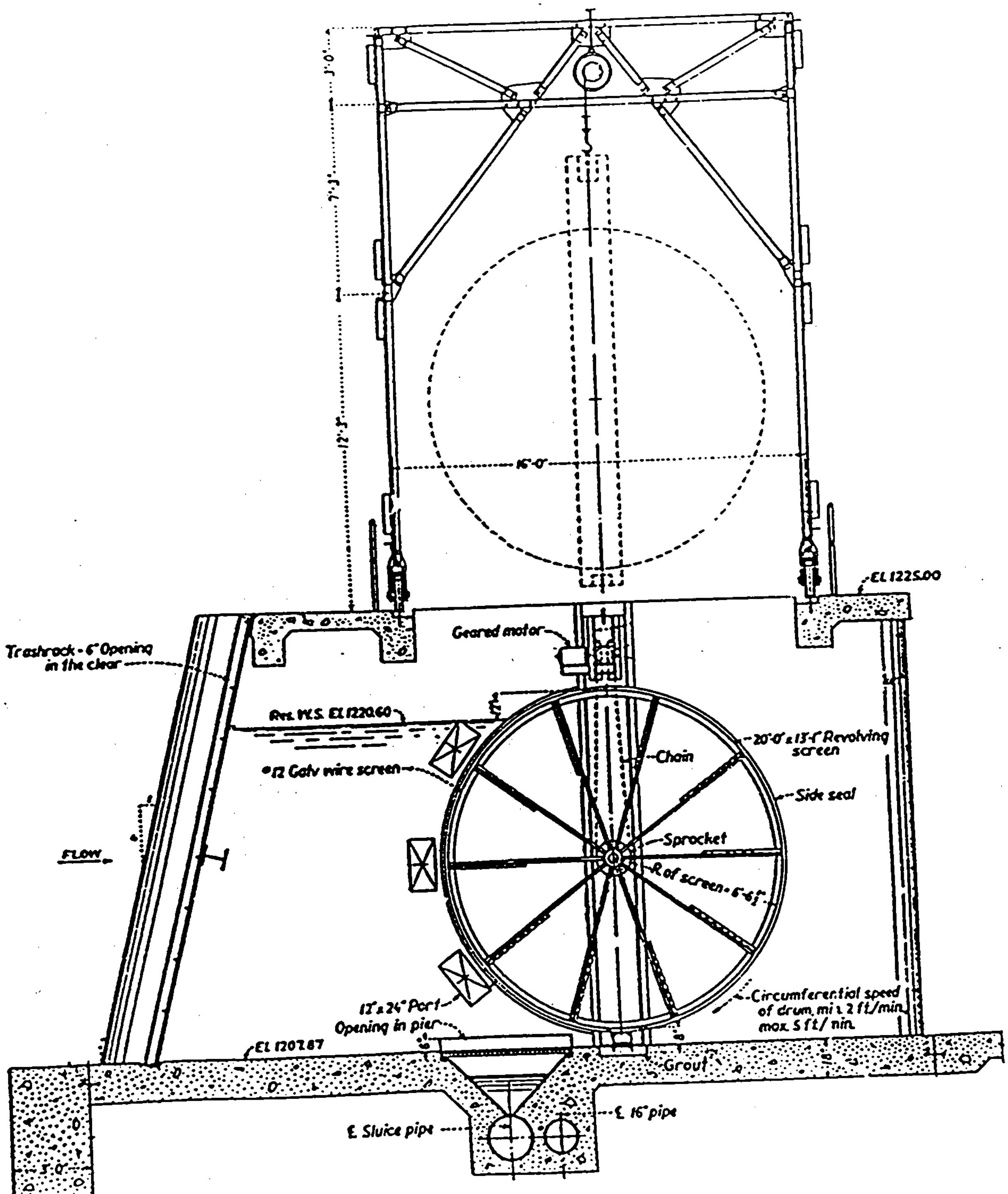


Figure 4: Typical Rotary Drum Screen Installation.

Johnson screens in surface water intake systems

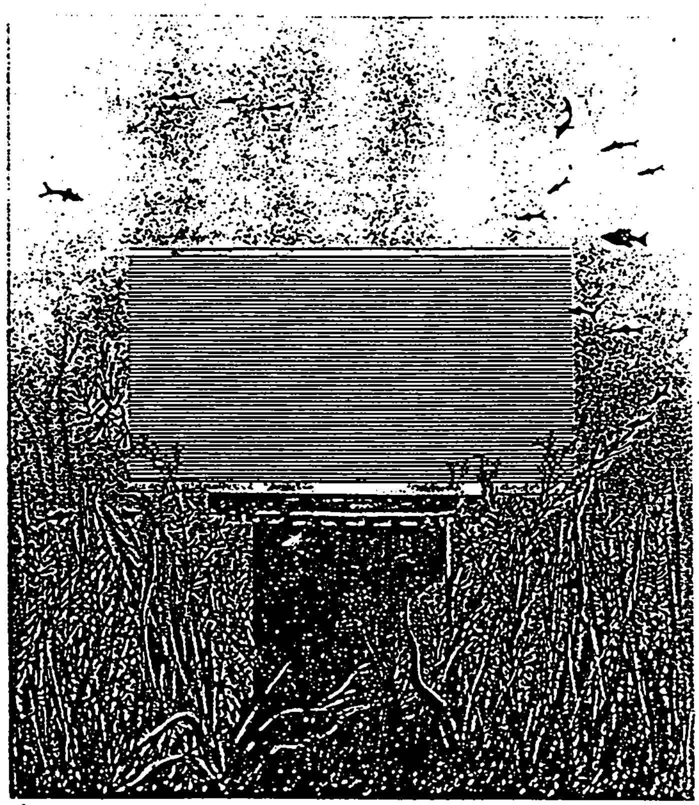


Figure 5: Johnson Intake Screen System.

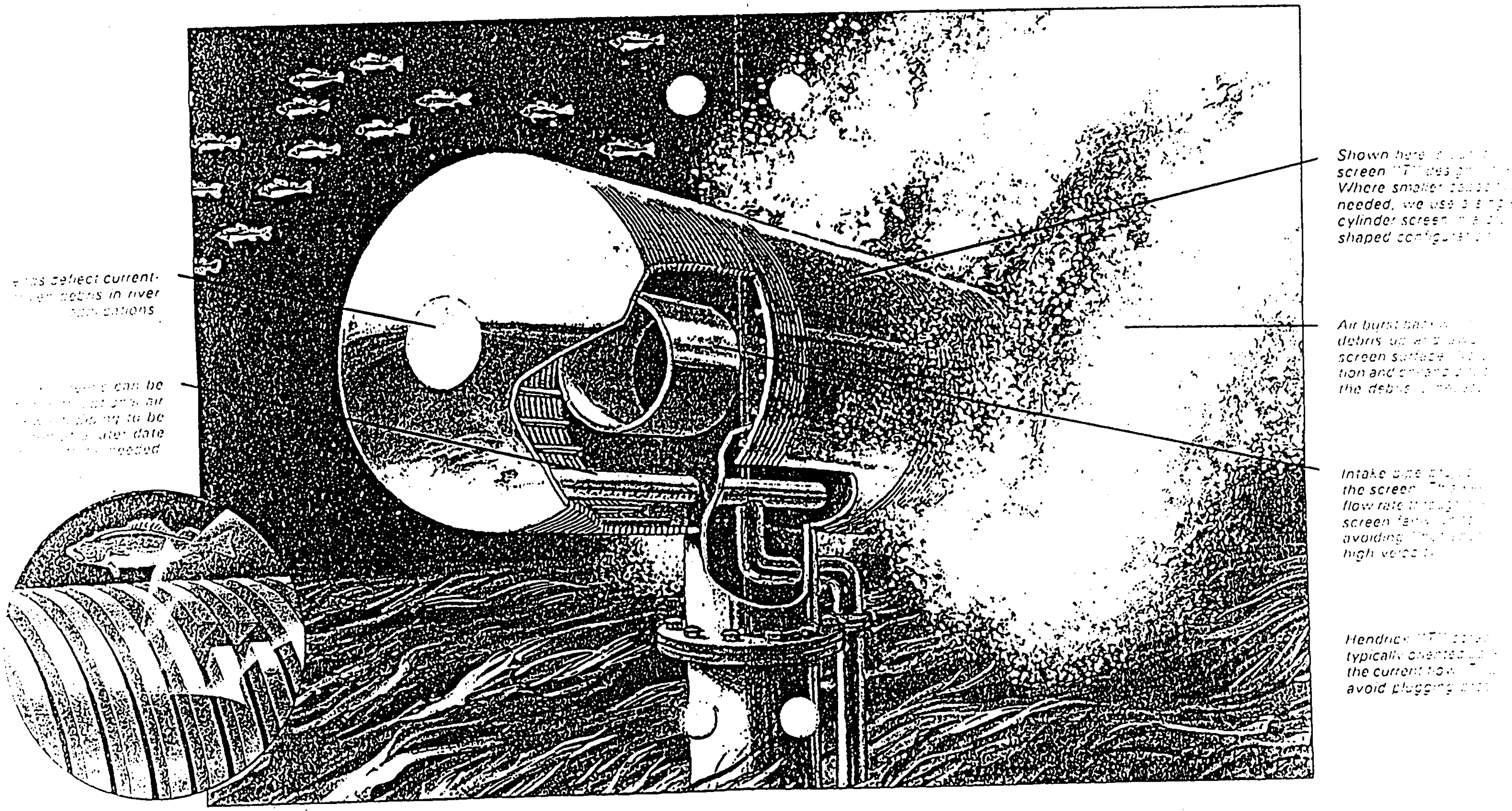


Figure 6: Hendrick Intake Screen System.

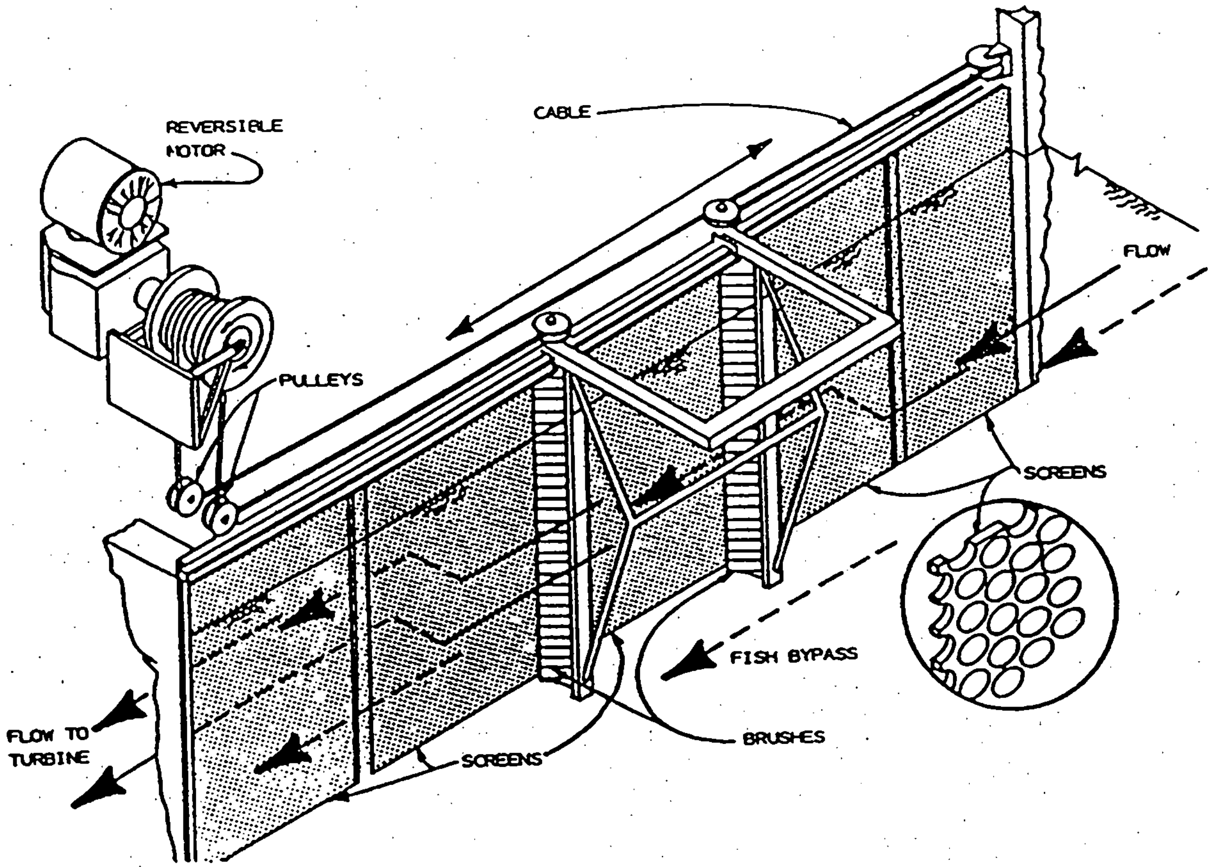


Figure 7: Typical Stationary Perforated Plate Screen Installation.

.ABL_ . Cos. ..npa.. Sul , f Ex .. Sci Tec gle

15 February 1994

SITE	Description	Q (cfs)	Est. cost $ Million	$ cost/cfs
LARGE SCREEN INSTALLATIONS:				
N/A	USBR Modular Fish Screen	25	0.025	1000
Elwha	Eicher Screens	2000	3.04	1520
	Eicher Screens–Low Velocity Alternative	2000	7.12	3560
Puntledge	Eicher Screens	1000	4	4000
Blue River	Eicher Screens	1000	1	1000
Glenn–Colusa	MIS	3000	11.9	3966.67
Leaburg Canal	Angled Screen Facility – Wedge (profile) wire	2500	2 (1984–85)	800.00
Glenn–Colusa	Rotary Drum Screen	3000	2.6 (1972)	866.67
Tehama–Colusa	Angled Drum Screen Facility			
Sunnyside Canal	Angled Drum Screen Facility	1300	5	3846.15
Wapato	Angled Drum Screen Facility	2000	5.8	2900.00
Toppenish	Angled Drum Screen Facility	650	1.6	2461.54
Chandler	Angled Drum Screen Facility (includes juvenile eval. facility)	1500	7.7	5133.33
Rosa	Angled Drum Screen Facility	2200	13.9	6318.18
Easton	Angled Drum Screen Facility (includes juvenile eval. and counting fac.)	1170	7.8	6666.67
Boswell	Angled Perforated Plate	1200	1.2	1000.00
SMALL SCREEN INSTALLATIONS:				
Horn Rapids: Richland Canal Screen	Angled Drum Screen	80	0.4	5000.00
Westside Screen	Angled Drum Screen	114	0.6	5263.16
Savage Rapids	Rotary Drum Screen	100	0.01	100.00
T.W. Sullivan	Inclined Plane Screens	500	1.07	2140.00
North Fork Project	Angled Screen Facility	500	3.9 (1956–74)	7800.00

South Cow Creek	Angled Perforated Plate Screen Facility	50	0.393	7860.00
YAKIMA RIVER BASIN:				
Kiona	Rotary Drum Screen	26	0.3	11538.46
Snipes & Allen	Rotary Drum Screen	30	0.31	10333.33
Boise Cascade	Rotary Drum Screen	5	0.04	8000.00
Moxee	Rotary Drum Screen	10	0.08	8000.00
Union Gap	Rotary Drum Screen	50	0.4	8000.00
Hubbard	Rotary Drum Screen	50	0.31	6200.00
Taylor	Rotary Drum Screen	10	0.08	8000.00
Selah – Moxee	Rotary Drum Screen	100	0.53	5300.00
Vertrees No. 2	Rotary Drum Screen	20	0.15	7500.00
Vertrees No. 1	Rotary Drum Screen	5	0.05	10000.00
Fogarty	Rotary Drum Screen	20	0.15	7500.00
Bull	Rotary Drum Screen	14	0.11	7857.14
Ellensburg Mill	Rotary Drum Screen	25	0.18	7200.00
New Cascade	Rotary Drum Screen	120	0.54	4500.00
Packwood	Rotary Drum Screen	30	0.02	666.67
Old Cascade	Rotary Drum Screen	30	0.08	2666.67
O'Connor	Rotary Drum Screen	2	0.01	5000.00
Younger	Rotary Drum Screen	10	0.08	8000.00
Old Union	Rotary Drum Screen	20	0.01	500.00
Fruitvale	Rotary Drum Screen	30	0.09	3000.00
WIP – Toppenish Pump Site	Rotary Drum Screen	120	0.53	4416.67
Naches – Cowiche	Rotary Drum Screen	60	0.24	4000.00
Chapman – Nelson	Rotary Drum Screen	5	0.04	8000.00
Cogdon	Rotary Drum Screen	65	0.38	5846.15
Gleed	Rotary Drum Screen	25	0.19	7600.00
Powell	Rotary Drum Screen	30	0.2	6666.67
Lewis (Mill)	Rotary Drum Screen	10	0.08	8000.00
LaFortune	Rotary Drum Screen	30	0.2	6666.67
Ireland	Rotary Drum Screen	5	0.01	2000.00
Scott	Rotary Drum Screen	40	0.26	6500.00
Kelly	Rotary Drum Screen	25	0.16	6400.00
Lowery	Rotary Drum Screen	25	0.16	6400.00
Clark	Rotary Drum Screen	6	0.06	10000.00
Foster – Natches	Rotary Drum Screen	3	0.03	10000.00
John Cox	Rotary Drum Screen	10	0.07	7000.00
Natches – Selah	Rotary Drum Screen	150	0.72	4800.00
Carmack	Rotary Drum Screen	4	0.01	2500.00
Holwenger	Rotary Drum Screen	5	0.03	6000.00
Lindsey	Rotary Drum Screen	15	0.12	8000.00
Emerick	Rotary Drum Screen	5	0.05	10000.00
Anderson	Rotary Drum Screen	7	0.06	8571.43

Ter[illegible]	[illegible]		[illegible]		[illegible]
Sinclair – Cobb	Rotary Drum Screen	5	0.07		14000.00
Gnavaugh	Rotary Drum Screen	1.3	0.01		7692.31
Beck	Rotary Drum Screen	3	0.03		10000.00
Seaton	Rotary Drum Screen	8	0.06		7500.00
Copper – Masterson	Rotary Drum Screen	10	0.08		8000.00
Peterson	Rotary Drum Screen	10	0.05		5000.00
Mussetti	Rotary Drum Screen	20	0.15		7500.00
Ballard	Rotary Drum Screen	3	0.03		10000.00
Contratto	Rotary Drum Screen	2	0.02		10000.00
Giustetti – Contrato	Rotary Drum Screen	2	0.02		10000.00
Giustetti – Bussoli	Rotary Drum Screen	1	0.01		10000.00
Bossoli	Rotary Drum Screen	12	0.09		7500.00
Brockbank	Rotary Drum Screen	5	0.05		10000.00
Contratto – Banchi	Rotary Drum Screen	4	0.04		10000.00
Yakima – Tieton	Rotary Drum Screen	250	1.05		4200.00
(Upper & Lower Site)	Rotary Drum Screen	30	0.27		9000.00
WIP – Upper Site	Rotary Drum Screen				
McAusland	Vertical Traveling Screen	10	0.02		2000.00
Red Bluff	Box Screens – Temp. Pumps Angled Perforated Plate	110	0.11		1000.00
PRE – FABRICATED SCREEN SYSTEMS:					
Johnson Filtration Systems, Inc.	Intake Screen System w/ Air Scour System	50	0.057		1140.00
Hendrick Screen Co.	Intake Screen System w/ Air Scour System &	25	0.032		1280.00
Plum Creek Mfg.	Rotary Intake Screens	3	0.0009	(1985)	300.00

Memorandum

27 October 1993

To: Greg O'Haver (SD-305)
Perry Johnson (D-3751)
Rick Christensen (D-3423)

From: J. Kubitschek (D-3751)

Subject: Modular Fish Screen Development Meeting Summary.

Modular Fish Screen Development Meeting

26-27 October 1993

Attendance: Greg O'Haver/Mechanical Engineer, SD-305
Perry Johnson/Hydraulic Research Engineer, D-3751
Rick Christensen/Mechanical Engineer, D-3423
Joe Kubitschek/Mechanical-Hydraulic Engineer, D-3751

Agenda:

1. Introduction: Overview of Modular Screen Concept.

2. Survey of Available Screen Concepts.

3. Weaknesses of Available Screen Concepts .

4. Brainstorm possible problems and concerns associated with the original USBR Modular Screen concept.

5. Identification of Initial Developmental Tasks.

Discussion:

1. Introduction - Focused on design features and criteria for the proposed USBR modular fish screen concept. Possible application limitations were discussed along with innovative features of the concept.

2. A survey of commercially available fish screen concepts was conducted. Based on the experience of those involved in this meeting, possibilities for improvement to these existing concepts were identified. Existing screen concepts were broken down into large and small screen concepts as follows:

FISH SCREEN CONCEPTS:

Large Screen Options:

- Drum Screens
- Vertical Wedge-wire Screens

Small Screen Options:

- Drum Screens (paddle wheel or power)
- Vertical Wedge-wire
- Wedge-wire Cylinders (air burst or water spray cleaned)
- Wedge-wire Ogee
- Infiltration Gallery
- Perforated Plate
- Inclined Screens

3. Weaknesses of Existing Concepts were identified and listed as follows:

Large Screen Concepts -

Drum:
- Regulated w.s.el. required.
- Passes debris which must be handled eventually.
- Seals are difficult to maintain.
- Mechanical elements req. extensive maintenance.
- Low % screen use.
- Siltation due to low through screen velocities.
- Req's bypasses.
- Cost tends to be high (approx. $2,000-4,000/cfs).
- Limited flexibility w/changing conditions.
- Inspection and maintenance difficult.
- Sizing due to limited flexibility req's over design.
- Retrofit may be costly and difficult.
- Predation criteria req's 2 ft/s min. forebay velocities.
- Ice formation and blockage may be a problem in some cases.

Vertical Wedge-wire:
- Submergence requirements contribute to over design.
- Sedimentation due to low through screen velocities.
- Cleaning requirements are extensive.
- Effective cleaning methods are typically mechanical.
- Debris removal and handling is difficult.
- Permanent structure -> Limited flexibility.
- Length of structure is extensive with no w.s.el. control.
- Not easily modified.
- Forebay predation is a problem.
- Requires bypass.

Small Screen Concepts -

General:
- For drum and vertical screens, same problems as above.
- Submergence requirements may limit installation to deep water.
- Sedimentation fouling can be a problem.
- Substantial head loss associated with some concepts.
- Remote cleaning may be ineffective.
- Debris removal and handling may be difficult.
- Ice jamming may occur in some cases.
- Creation of slack water zones may result in predation.
- Access, inspection, and maintenance may be difficult.
- Cost tends to be high (approx. $4,000-20,000/cfs).

4. Concerns identified during discussion of Original USBR Modular Fish Screen Concept:

- Generating uniform velocity distributions that satisfy resource agency criteria.
- Identifying submergence influences on velocity distributions and establishing minimum submergence criteria.
- Identifying and eliminating secondary flow features (caused by nose and side influences) that could cause fouling or fish impingement.
- Performance in a multiple array-creation of separation zones that produce predation habitat or variations in screen alignment that could cause cleaning or impingement problems.
- Potential for internal sediment deposition.
- Structural adequacy (in particular, when heavily fouled).
- Cleaning - development of controls and effective back-flushing design.
- Fish avoidance characteristics - vertical velocities may increase impingement.
- Stability and local foundation scour (similar problem to bridge pier scour). In particular, under high velocities or flood events.
- Ice jamming or ice loading potential.
- Handling/Removal for maintenance or prior to flood events.
- Competitiveness (cost, serviceability) with other available screening options.

5. Developmental Tasks:

Hydraulics Laboratory -
- Determine appropriate model scale.
- Design model.
- Develop internal baffling that generates uniform velocity distributions.
- Establish submergence criteria.
- Insure no potential internal deposition.
- Evaluate flow acceleration and foundation scour potential.
- Minimize adverse secondary flows.
- Evaluate multiple screen array.
- Evaluate structural adequacy (Loading potential).
- Evaluate/Develop air burst control.
- Confirm competitiveness of concept.

Field -
- Develop effective back-flush design.
- Confirm fish avoidance characteristics.
- Develop floatation/handling features.
- Confirm general design effectiveness - Field prototype study.