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PHYSICAL MODEL STUDIES OF THE GCID PUMPING PLANT FISH SCREEN STRUCTURE ALTERNATIVES

PROGRESS REPORT NO. 1

1:30 SCALE MODEL INVESTIGATIONS: ALTERNATIVE D

December 1995

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Technical Service Center
Water Resources Research Laboratory (WRRL)

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by

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PURPOSE

This report presents the results of the D alternative, positive barrier fish screen physical model investigations for Glenn-Colusa Irrigation District (GCID). The study was performed to evaluate, improve, and document the viability of the concept as a means to protect the fishery resource.

APPLICATION

The information included in this report is provided to the GCID Technical Advisory Group to assist in the evaluation of proposed screen alternatives and to provide design data for the selected alternative.

INTRODUCTION

The Glenn-Colusa Irrigation District Pumping Plant is located in north-central California, approximately 100 miles north of Sacramento, on an oxbow of the Sacramento River. Figure 1 is a general location map. The pumping plant exports water from the Sacramento River to the west side of the Sacramento River Valley for irrigation purposes.

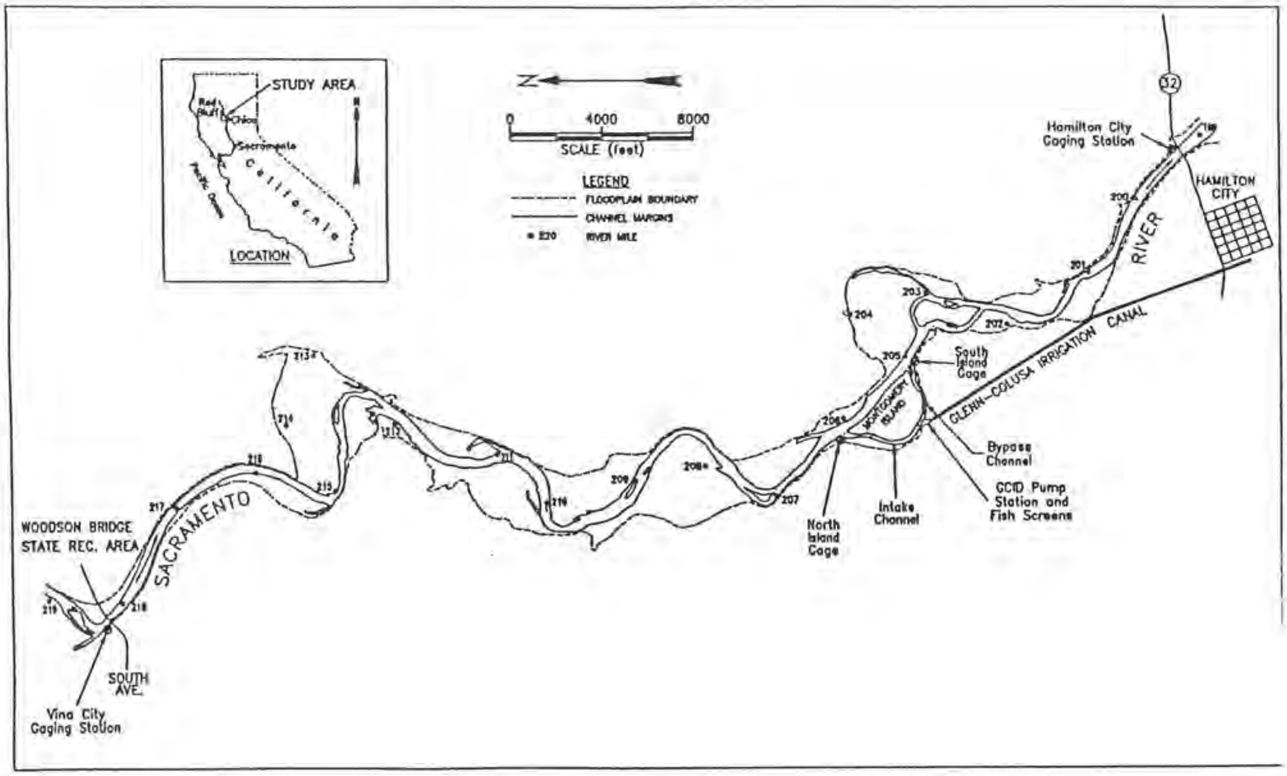

Figure 1 General location map of GCID pumping plant and existing fish screen facilities. (Extracted from report 4.)

In 1972, a rotary drum screen facility was constructed to provide fish protection from pumping plant entrainment. The facility originally consisted of 40 drum screens 8-ft wide and 17-ft in diameter. In 1970 the Sacramento River experienced the largest flooding since the construction of Shasta Dam. The result was a meander cutoff downstream of Montgomery Island which caused a decrease in river length of almost 1-1/2 miles. The implications of this meander cutoff have been a drop in water surface elevations of approximately 3 ft at the north end of Montgomery Island. These changes occurred over several years as the river stabilized. Lower water surface elevations resulted in lower than desired water depths in front of the drum screens. As a result, through-screen velocities exceeded resource agency fish screening criteria during high diversions. In 1991 the National Marine Fisheries Service (NMFS) filed an injunction against the irrigation district to restrict pumping during the peak winter-run Chinook salmon downstream migration period.

An aggressive program was initiated by the district in conjunction with resource agencies to identify options for both short- and long-term resolutions of the screening problem. To improve interim screen performance, flat panel wedge wire screens were placed in front of the drum screens in 1993. In 1995 the drum screens were removed from service.

Pursuit of a long-term solution has generated a number of screening alternatives which have, in turn, been subjected to detailed evaluation. In 1994, HDR Engineering, Inc. prepared a draft feasibility report which reviewed eight alternatives for replacement or modification of the existing screen facilities. Since then, these alternatives have been reduced to two.

The two remaining alternatives, labeled "A" and "D" are shown as figures 2 and 3, respectively.

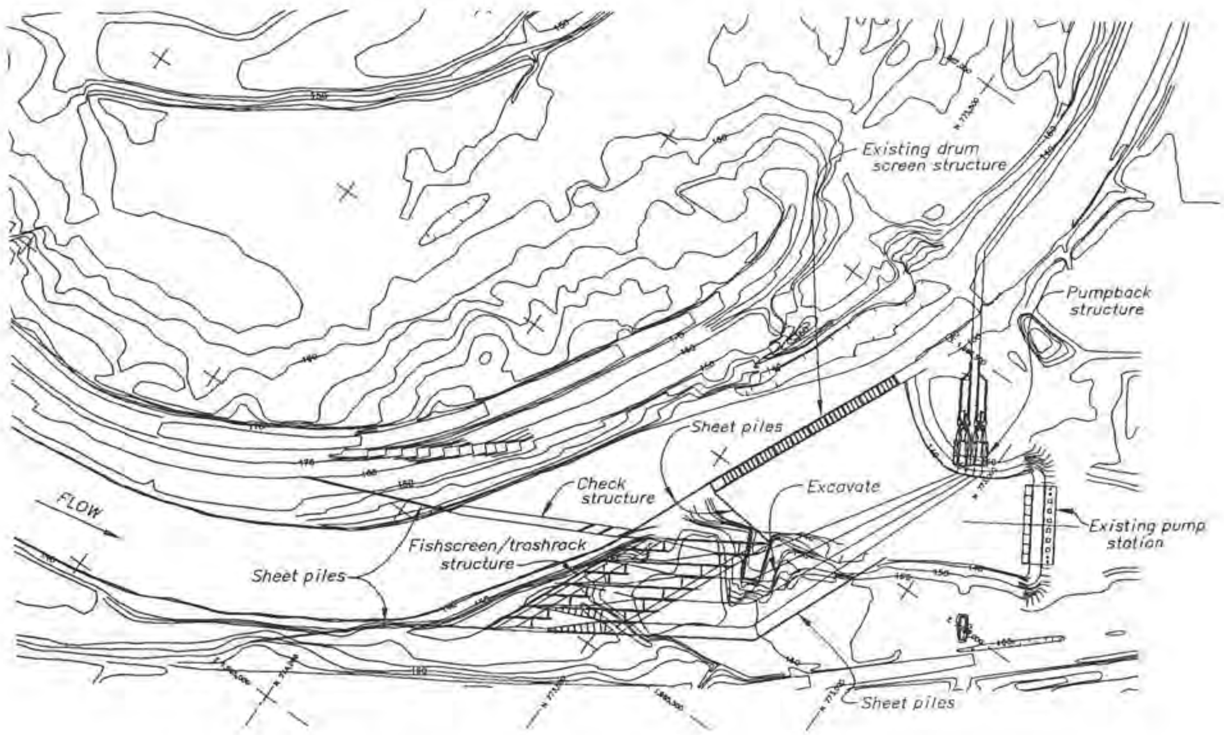

Figure 2 Conceptual layout: Plan view of proposed A alternative.

Both of these alternatives are to be investigated under this study. Alternative A consists of a new screen facility located just upstream of the existing facility. The A screen concept is a four-bay-multiple-V structure with bypass and evaluation facilities. Screen alternative D consists of modifying the existing screen facilities by increasing the length of the flat panel screen structure. The proposed screen is about 1,000 ft long, extending approximately 500 ft upstream of the existing structure.

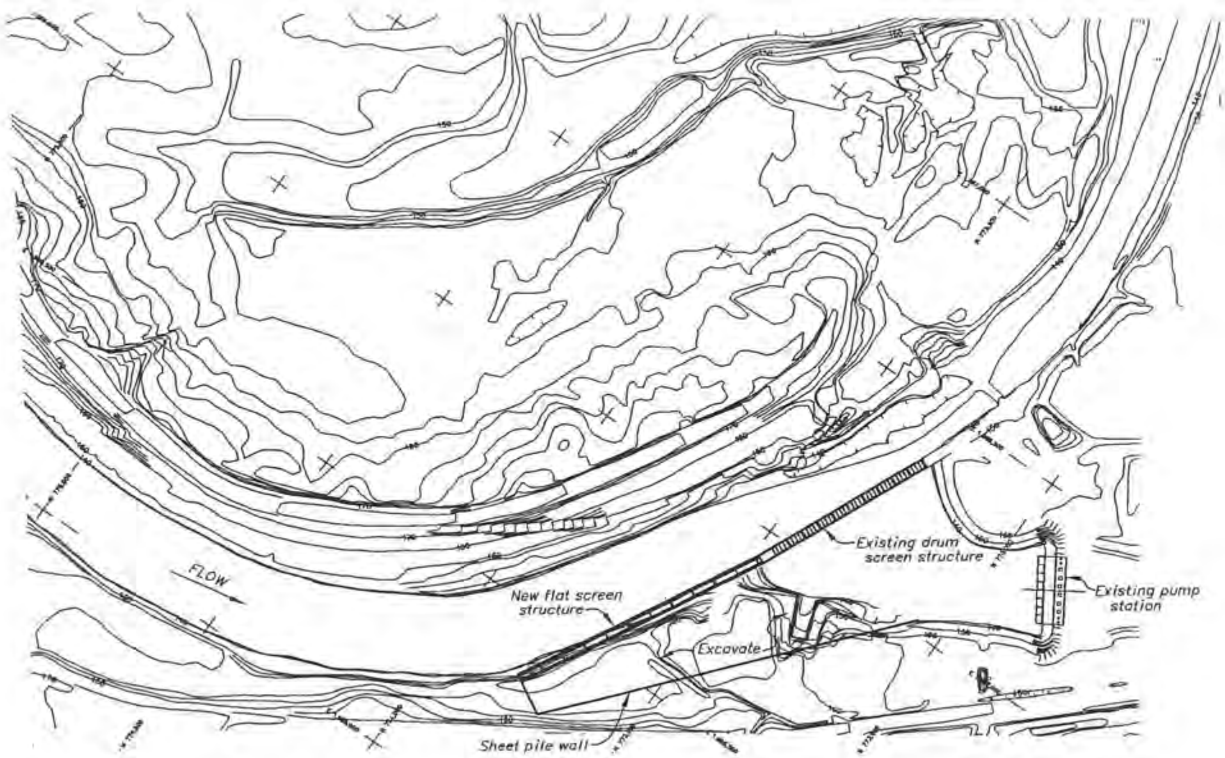

Figure 3 Conceptual layout: Plan view of proposed D alternative.

Both of the previously described alternatives will initially be evaluated and optimized using a 1:30 scale physical model. It is anticipated at this time that upon completion of these investigations, one or both alternatives will be modeled at a smaller scale to provide design and operation data for the prototype facility. A report series will be generated for documentation of the physical modeling of the screen alternatives. This report covers the 1:30 scale model investigations of the D alternative and constitutes the first report in the series.

OBJECTIVES OF THE MODEL STUDIES

Prior to designing a fish screening facility, the objectives and operational constraints of the facility must be established. This requires identifying applicable state and Federal resource agency fish screening criteria and objectives specific to the site. This process was conducted through the GCID screen replacement Technical Advisory Group (TAG). The following organizations participate on the TAG:

Glen-Colusa Irrigation District
California Department of Fish and Game
Fish and Wildlife Service

California Department of Water Resources
U.S. Corps of Engineers
National Marine Fisheries
Bureau of Reclamation

In conjunction with these organizations several consultants to them also participate as members of the TAG. These consultants provide biological, engineering, and legal expertise.

Through this process the following major objectives were identified for the D alternative screen concept.

- The screen design shall allow diversion of up to 3,000 ft^3/s of flow.

- The approach channel shall provide a nearly linear distribution of flow to the screen face.

- For all flow conditions, the normal velocity to the screen face measured 3 inches in front of the screen shall not exceed 0.33 ft/s. This is a State of California fish screening requirement.

- The flow velocity component parallel to the screen face, termed sweeping velocity, must be twice the normal component. This is also a State specified design criteria. However for the D alternative, it was determined by the TAG that high sweeping velocities would be desirable for the long flat plate screen design. A design objective of 2 ft/s sweeping velocity was chosen.

- The terminal open channel bypass should provide a minimum of about 500 ft^3/s of flow at an average velocity of 2 ft/s.

- The oxbow channel, bypass channel, and screen facility should be designed to minimize or eliminate areas of reverse flow or slack water. These areas are considered predator habitat.

- The structure must allow for upstream migrants to move through the oxbow should they enter the bypass channel.

Not present in the objectives for the 1:30 model are evaluation of: operating criteria, intermediate screen bypasses, and screen baffling. These topics were not included for the following reasons.

Operating criteria are dependent on the flow split at the north end of Montgomery Island. This relationship is affected by changes in the river gradient along either path around the island. Changes in the river gradient can occur during major flow events and due to activities like oxbow dredging or channel stabilization efforts. For the purposes of the model, the river gradient as of a 1991 U.S. Corps of Engineers survey was used as the baseline for river hydraulics. The 1991 river channel survey likely represents the historic minimum gradient at the site. Since the 1991 survey was conducted, several significant flood events have occurred on the river. In 1995 a limited survey of the channel bottom conducted by Ayers and Associates for the Corps of Engineers revealed the main stem river gradient along Montgomery Island has changed. The survey shows a riffle, located roughly 2,800 ft upstream of the south gauge, has aggraded as much as 2 ft since 1991, figure 4. Due to present uncertainty as to the appropriate river gradient for the site, 1991 river conditions were modeled. Using 1991 river topography in the model allows for screen size and diversion limitations to be identified for worst case river conditions. The model screen performance data can be applied to other than 1991 river conditions by comparing model data based on similar water surface elevations at the fish screen.

National Marine Fisheries screen criteria specify intermediate fish bypasses should be used to limit time of screen exposure to $\leq$ 60 seconds. The passage time in front of the D-alternative screen, assuming a sweeping velocity of 2 ft/s, is about 500 seconds. The original D-alternative screen concept as presented to the TAG recognized this limitation of the concept. However, it was decided the concept had sufficient merit to initially pursue a model investigation of the screen structure without intermediate bypasses. Hydraulic data obtained from the model will be used to assess the need for, or spacing of, intermediate bypasses at a future time. Bypass designs will then be tested in the subsequent smaller scale (larger size) model of the D-alternative.

Baffling of screen bays was not including in the scope of these investigations. Although baffling may be pursued in future investigations to further improve and maintain good velocity distributions under changing hydraulic conditions, this effort focuses on minimizing the need for screen baffling.

CONCLUSIONS

The results of these investigations demonstrate that the D-alternative is a viable design. The study results show the long flat plate screen concept can be designed to meet the listed objectives. A series of modifications to the screen design was identified and instituted through the model study to improve performance. These screen modifications and the final design are shown in figure 8. A brief summary of screen performance versus objectives for the final D-alternative screen configuration is given below.

- Diversion capacity - The minimum screen area required to comply with the 0.33 ft/s maximum average velocity approaching the screen is 9,091 ft^2. Assuming the existing screen invert elevation of 127.3, the following screen lengths are required for 3,000 ft^3/s diversion:

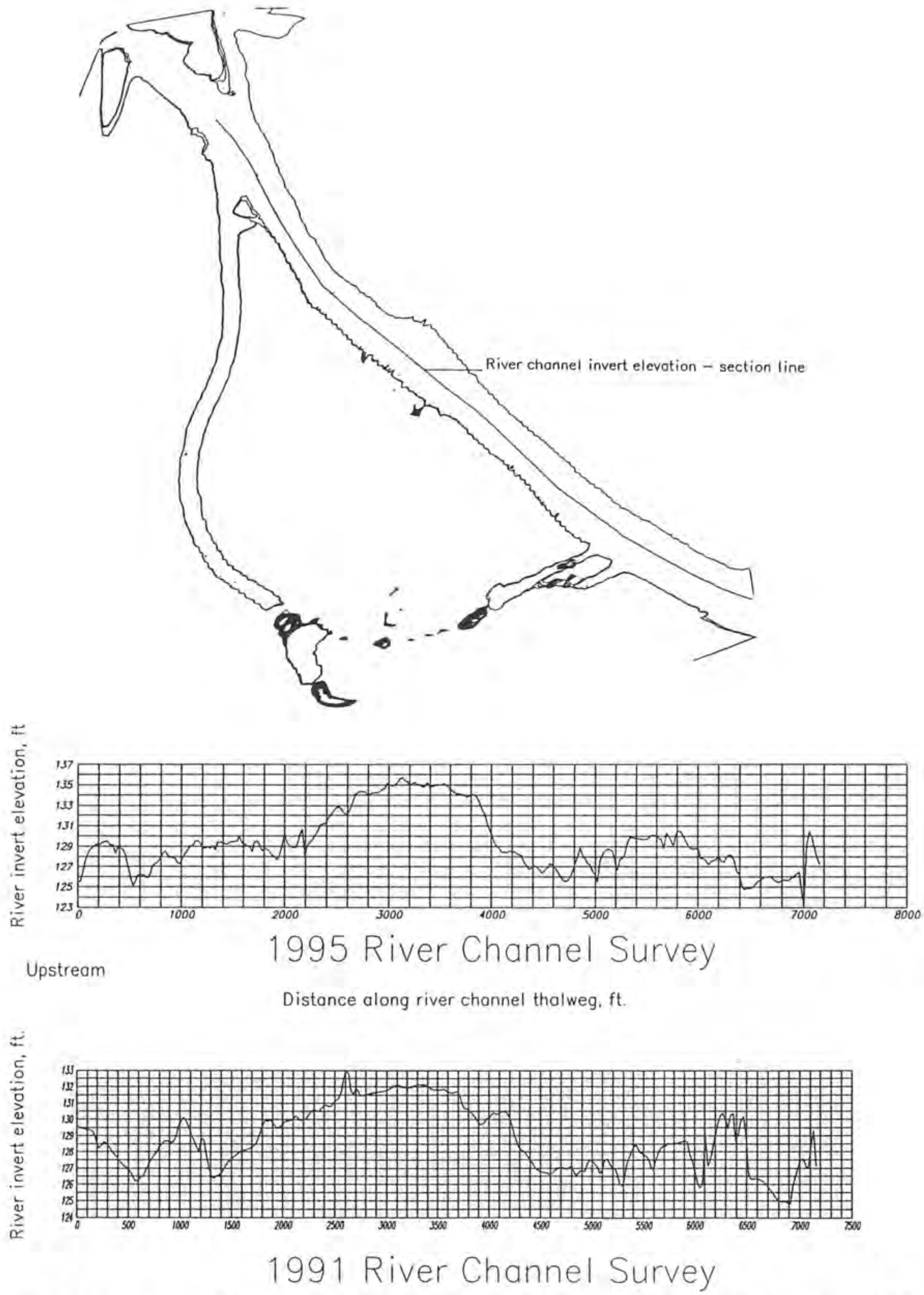

Figure 4 - Sacramento River main channel invert elevations at Montgomery Island for the years 1991 and 1995.

Screen Length (ft)	Screen Water Surface (ft)	River Flow - North gauge (Based on 1991 river topography) (ft^3/s)
1,123	135.4	9,000
1,057	135.9	10,000

The final screen length chosen may be longer or shorter depending on the final elevations selected for the screen invert and water surface. Increasing the water surface elevation (requires constructing a gradient control structure on the river main stem) will also lower the river flow for which 3,000 ft^3/s can be diverted. The upstream extent of the screen should be limited to about 530 ft upstream of the existing structure. This allows the flow to turn through the upstream bend before encountering the screen structure. If required, a longer screen can be achieved by also extending downstream of the existing structure.

• Approach flow conditions - A good distribution of flow to the screen face is achieved by adding an opposite bank guide wall and providing two 4° bends in the screen alignment, see figure 8.

• Screen approach velocity - The good uniformity of velocity along the length of the screen documented in the model testing indicates the D-alternative screen concept can be designed to meet the 0.33 ft/s approach velocity criteria for nearly all operating conditions. However, under high river flow and peak pumping unfavorable conditions can occur. During high river conditions, excess flow passes through the upstream end of the screen and reverse flow passes out the downstream end. This can result in approach velocities near the upstream end of the screen exceeding the 0.33 ft/s approach velocity criteria, see figure 24. Screen baffling will be needed to improve this condition.

• Screen sweeping velocity - Sweeping velocity in front of the screen exceeds twice the approach velocity for all conditions. Depending on river and pumping combinations, sweeping velocities range from about 0.75 ft/s to over 3.0 ft/s. Low pumping and low river conditions yield the lowest sweeping velocities. Sweeping velocities of between 1.5 and 2.0 ft/s were achieved for most flow combinations.

• Bypass flow - For the 1991 river conditions, the 500 ft^3/s bypass flow objective requires a trapezoidal channel (2:1 side slopes) with a bottom width of 14 ft at an invert elevation of 127.0. For this channel, bypass flows in excess of 500 ft^3/s can be attained when pumping 3,000 ft^3/s for north gauge river elevations higher than about 136.5. At lower river elevations the target bypass flow can be achieved under reduced pumping.

• Predator habitat - Transitions upstream and downstream of the screen structure were added to the design to eliminate reverse flow and slack water zones. Under weak pumping conditions or high river conditions, reverse flow conditions do occur near the downstream end of the screen. This condition occurs when flow in excess of pumping demand moves through the upstream portion of the screen. However, this condition does not create likely predator habitat. Flow exiting the screen merges smoothly with flow entering the bypass channel.

- Fish passage - The open channel bypass design allows for free upstream and downstream movement of fish.

SIMILITUDE

The physical model of the D-alternative screen configuration must be geometrically and kinematically similar to the prototype to adequately predict prototype performance under specified operating conditions (3). Geometric similarity is achieved with the ratios of all prototype to model geometric parameters being equal. Kinematic similarity is achieved with the ratios of all prototype to model velocities being equal. Froude law similitude is employed to establish the kinematic relationship between model and prototype. This similitude is based on maintaining model and prototype Froude numbers which are equal in all cases. The required geometric and kinematic ratios for this 1:30 Froude scale model are as follows:

Geometric

$L_r = L_p/L_m = 30$

$A_r = (L_r)^2 = 900$

$V_r = (L_r)^3 = 2,700$

Where,

L_p = Prototype characteristic length,

L_m = Model characteristic length,

L_r = Length ratio,

A_r = Area ratio, and

V_r = Volume ratio.

Kinematic

$t_r = (L_r)^{1/2} = 5.48$

$v_r = (L_r)^{1/2} = 5.48$

$a_r = 1$

$Q_r = (L_r)^{5/2} = 4{,}930$

Where,

t_r = Time ratio,

v_r = Velocity ratio,

a_r = Acceleration ratio, and

Q_r = Discharge ratio.

PHYSICAL MODEL

The fish screen model was constructed at Reclamation's Water Resources Research Laboratory in Denver, Colorado. The 1:30 scale model included approximately 3,000-ft of the oxbow channel, the D alternative screen structure, the pumping plant, and a portion of the downstream bypass channel. The scale was chosen to achieve the objectives of the study and yield efficiency of model operation. Froude number similitude criteria were used to establish kinematic similarity between model and prototype. Figure 5 is a photograph of the river model for the D alternative, as constructed in the laboratory.

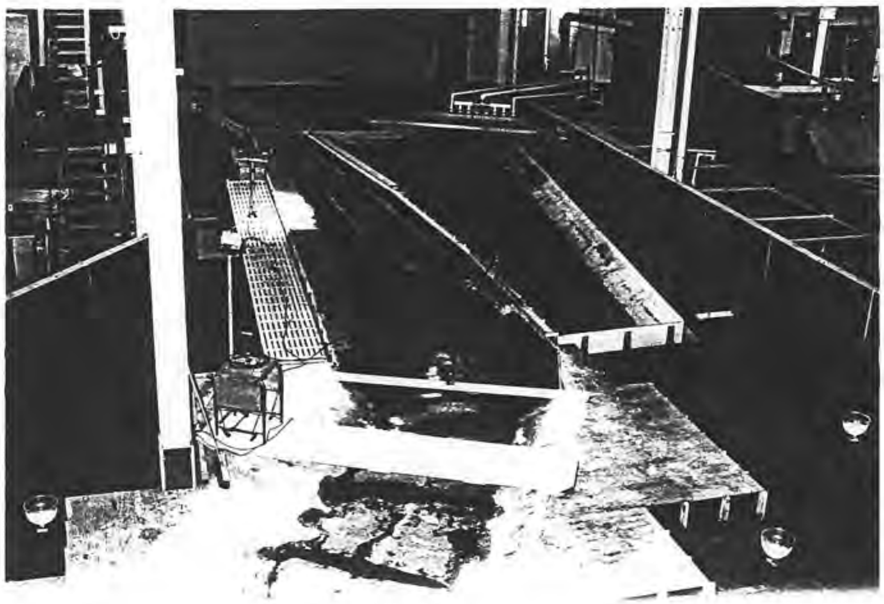

Figure 5 Photograph of the D-alternative physical model as constructed in the laboratory.

Some important considerations should be realized concerning modeling of the screen under this investigation. The prototype screen is sized such that it consists of 0.071-in wedge wire on 0.164-in centers representing a 3/32-in slot opening, which yields an open area of approximately 55 percent. Due to the size of the prototype screen it would be highly impractical to attempt to model this detail at a 1:30 scale. However, for the modeling purposes of this application it is important only to represent the resistance characteristics of the screen. The resistance characteristics of the prototype, which are defined by the headloss verses discharge relationship, can be adequately modeled, provided the Reynolds number (Re) of the through-screen flow regimen is sufficiently high. Previous work performed by Yeh, et al., (2) in this area has indicated that for Re $\geq$ 250, the screen headloss coefficient is not significantly sensitive to large changes in velocities. Figure 6 illustrates the headloss verses Re relationship for a screen of this type under similar application. However, the Re used for these analyses was based on the average channel approach velocity. Further analysis of these results and additional testing conducted in the WRRL indicate that a minimum through-screen Reynolds number of 80 based on the through-screen velocity is adequate for representing the prototype screen resistance. The through-screen Reynolds number for 3/16-in perforated aluminum plate having a 56 percent open area used in the model is about 120 and adequately represents prototype screen resistance characteristics.

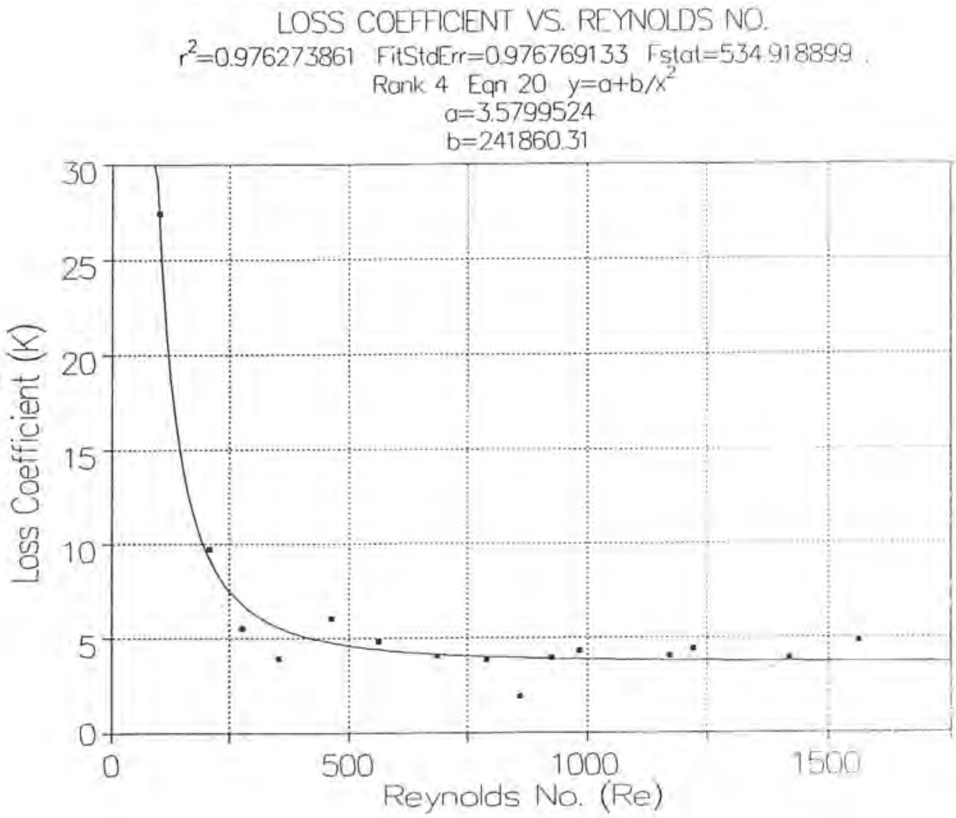

Figure 6 Headloss coefficient verses Reynolds number relationship for an angled, vertical wedge-wire, screen configuration.

NUMERICAL MODEL

The hydraulics of the river system near GCID were estimated using the hydrodynamic model RMA2[1]. RMA2 is a two-dimensional depth averaged finite element model developed by the Corps of Engineers. The numerical modeling was performed under contract by Ayers Associates. Much of the model development had previously been conducted by Ayers (1, formally RCE) as part of an effort to study options for a gradient restoration structure.

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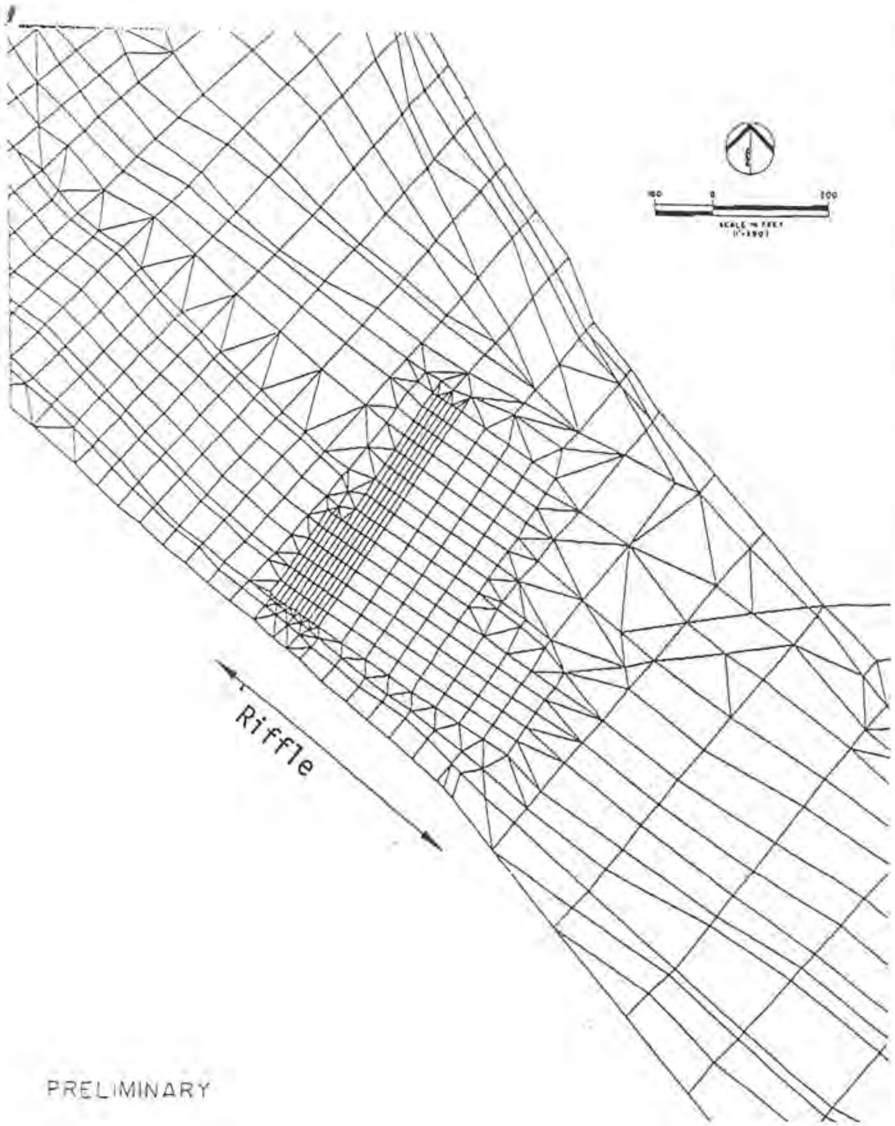
[1] RMA2 is marketed under the name Boss FastTabs by Boss International.

Numerical flow simulations were conducted to provide hydraulic data on river flow splits around Montgomery Island and determine estimated water surface elevations within the oxbow channel. These data were needed to establish entrance and exit boundary conditions for operation of the physical model. A total of 15 flow scenarios were run for the D-alternative screening concept. Of these, 13 flow combinations were identified to establish the system (river and pumping plant) hydraulics assuming no gradient restoration structure in the main river channel. Table 1 lists the flow combinations modeled and the major hydraulic data derived for each. These simulations were conducted using 1991 river and bank topography data. These data are considered to represent recent historic low river gradient conditions at Montgomery Island. Simulations 1 to 11, were each repeated using three values of channel rugosity corresponding to Mannings "n" values of 0.02, 0.025 and 0.03. These roughness values cover the expected range of uncertainty in channel conditions and, therefore, give the likely range of hydraulic parameters.

To assess the impact of the riffle aggregation identified in the 1995 main channel survey on the system hydraulics, two additional simulations were conducted. The riffle was modeled as a broad-crested weir placed at the location of the natural riffle. The simplified riffle was depicted as a rock structure with a 20-ft-wide (streamwise direction) crest and a 1:100 downstream slope. The riffle was superimposed on the 1991 river topography as shown in figure 7. Weir crest elevations of 133 and 134 were run for the condition of 7,000 ft^3/s river (north gauge) and 3,000 ft^3/s pumping at GCID. Table 2 gives the major hydraulic parameters with the simplified riffle in the main channel.



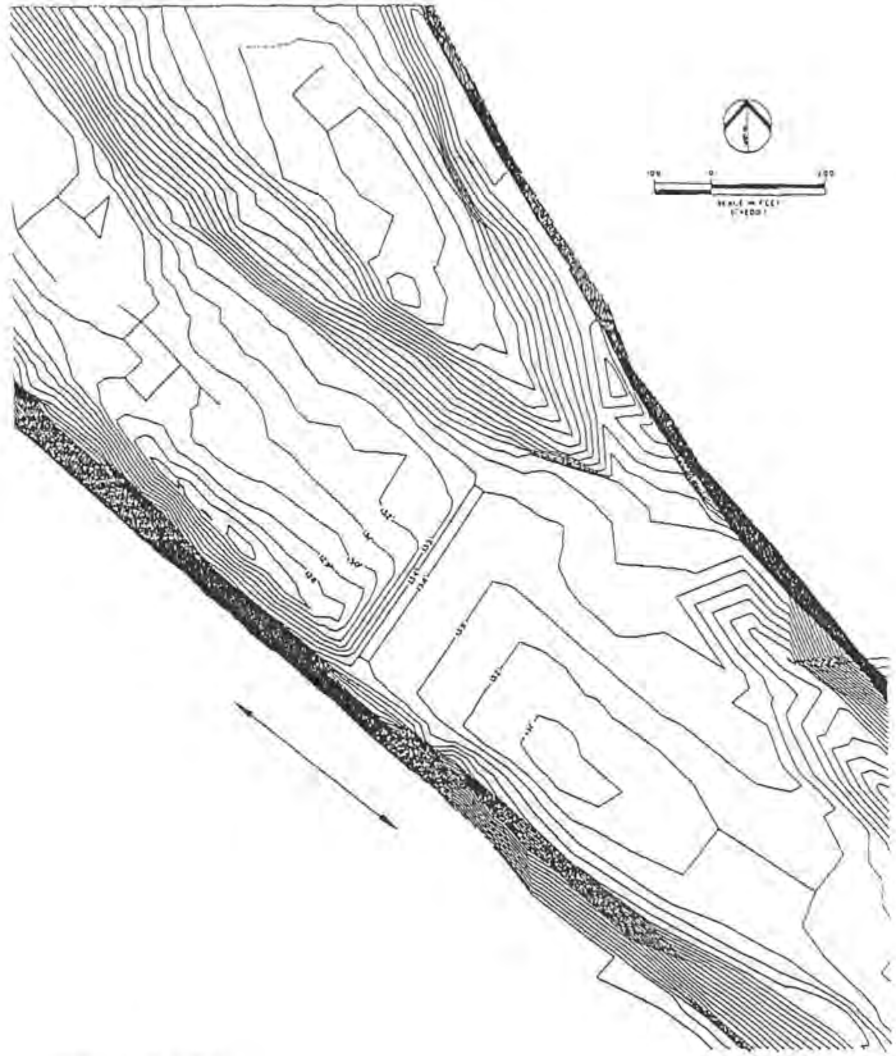


Figure 7 - RMA2 numerical simulation of a simplified riffle in the main river channel along Montgomery Island. Riffle location and size are based on 1995 channel survey data. Simulation conducted by Ayers Associates.

Table 1

GCID Screening Option D-3

2D Simulation Results

n=.025 for the River Channel

Run No.	Q_{river}	Q_{pump}	$Q_{Hamilton\ City}$	Manning "n" (Bypass channel)	Q_{intake}	Q_{bypass}	Water Surface Elevation (ft)		
							North Gage	South Gage	GCID Screens
		(Input)					*(Output)*		
1	7,000	2,000	5,000	0.03	2,534	534	135.9	134.5	135.4
				0.025	2,578	578	135.9	134.5	135.3
				0.02	2,629	629	135.9	134.5	135.3
2	7,000	2,500	4,500	0.025	2,914	414	135.8	134.4	134.9
				0.02	2,945	445	135.8	134.4	134.9
3	8,000	2,400	5,500	0.03	2,928	528	138.2	134.8	135.5
				0.025	2,970	570	136.2	134.8	135.5
				0.02	3,018	618	136.2	134.8	135.4
4	8,000	2,850	5,150	0.025	3,262	412	138.1	134.6	135.1
				0.02	3,292	442	136.0	134.6	135.0
5	8,000	2,750	8,250	0.03	3,285	535	136.5	135.0	135.7
				0.025	3,325	575	136.5	135.0	135.6
				0.02	3,376	624	136.5	135.0	135.6
6	9,000	3,000	8,000	0.025	3,480	480	138.4	134.9	135.4
				0.02	3,520	520	138.4	134.9	135.4
7	10,000	3,000	7,000	0.03	3,570	570	136.8	135.2	135.9
				0.025	3,615	615	136.8	135.2	135.9
				0.02	3,665	665	136.8	135.2	135.8
8	12,000	3,000	9,000	0.03	3,800	800	137.5	135.8	136.7
				0.025	3,872	872	137.5	135.8	136.7
				0.02	3,948	948	137.4	135.8	138.8
9	20,000	3,000	17,000	0.03	4,652	1,852	139.9	138.2	139.5
				0.025	4,793	1,793	139.9	138.2	138.4
				0.02	4,950	1,950	138.9	138.2	139.4
10	40,000	3,000	37,000	0.03	7,230	4,240	144.5	142.8	144.2
				0.025	7,404	4,415	144.5	142.8	144.2
				0.02	7,572	4,584	144.5	142.8	144.1
11	50,000	1,000	58,000	0.03	9,080	8,088	148.5	146.7	148.3
				0.025	9,255	8,275	148.5	146.7	148.3
				0.02	9,427	8,440	148.5	146.7	148.2
12	8,000	300	7,700	0.02	1,474	1,174	136.9	135.4	136.8
13	5,000	1,000	4,000	0.02	1,670	670	135.4	134.2	136.1

Table 2

GCID Screening Option D-3

2D Simulation Results
Simulated Riffle
n=.025 for the River Channel

Run No.	Q_{river}	Q_{pump}	$Q_{Hamilton\ City}$	Manning "n" (Bypass channel)	Riffle Crest Elev.	Discharge: Intake Channel	Discharge: Bypass Channel	Water Surface Elevation (ft): Upstream of GMF	Water Surface Elevation (ft): Downstream of GMF	Water Surface Elevation (ft): North Gage	Water Surface Elevation (ft): South Gage	Water Surface Elevation (ft): GCID Screens
14	7,000	3,000	4,000	0.025	134	3,612	612	136.2	134.3	136.3	134.2	135.2
15	7,000	3,000	4,000	0.025	133	3,420	420	135.8	134.3	136.9	134.2	134.8

TEST SETUP

Water is supplied to the model from a 250,000-gallon sump via the laboratory pumping system. Discharge delivered to the model is measured using a permanent bank of laboratory venturi meters. The system is equipped with a flow controller to maintain the desired flow rate. Model tailwater elevations are maintained using stoplogs at the downstream end of the bypass channel. Water surface elevations are monitored throughout the model using point gages set at specific locations of interest (i.e., intake channel, screen structure forebay, and bypass channel entrance). The pumping plant was simulated using three separate pump and manifold systems in the model. Pump intakes 1 and 2, 3 to 8, and 9 and 10 were manifolded to separate pumps. Pumped discharges were measured using a Controlotron ultrasonic flowmeter for pumps 3-8, and paddle wheel type flowmeters for pumps 1 and 2 and pumps 9 and 10. The bypass discharge was measured using a 12.5° v-notch weir. Model velocities were measured using an acoustic doppler velocimeter (ADV) which is capable of acquiring continuous three-dimensional velocity measurements at a resolution of 0.001 ft/s with an accuracy of 0.5 percent of full scale. Figure 8 is a photograph of the ADV setup used for acquiring velocity measurements along the screen for this investigation.

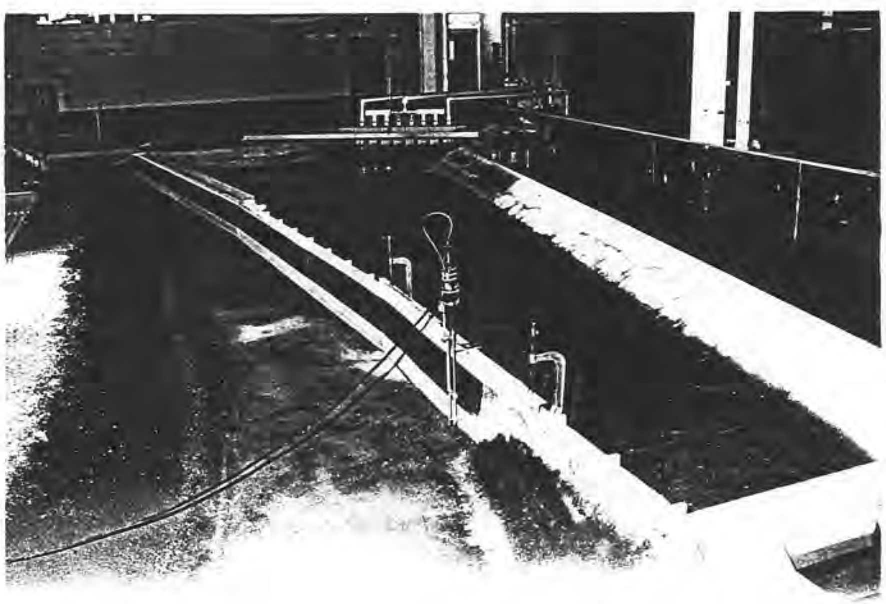


Figure 8 Photograph of the ADV setup for velocity measurements along the screen.

TESTING

Testing under this phase of the hydraulic model study has been consistent with achieving the required objectives. Both dye and confetti tests were performed for flow visualization purposes to determine general flow patterns associated with this alternative. Velocity measurements were conducted to quantify near-screen hydraulic conditions. The results of these flow visualization and velocity measurement tests lead to modifications improving performance of the D-alternative screen.

Flow Visualization

Flow visualization tests were conducted to evaluate the upstream transition from the channel to the screen structure, the opposite bank guidewall orientation, and the downstream transition from the screen structure to the bypass channel. These tests employed both confetti and dye to establish surface and sub-surface flow patterns, respectively. Tests were documented using video and photographs.

Velocity Measurements

Velocity measurements were acquired along the screen structure for two baseline flow simulations prior to and after each successive modification to the model. Baseline flow simulations consisted of pumping plant discharges of 2,000 ft^3/s and 3,000 ft^3/s, both with bypass discharges of 500 ft^3/s. Minimum water surface elevations and corresponding river flows were estimated for these pumping conditions using available numerical data from the Gradient Restoration Feasibility study, (1). Estimated values used for the physical model are given in table 3. Better estimates of the river flows for these conditions were obtained following completion of RMA2 numerical modeling. These values are shown in parentheses below the estimated values in table 3. For consistency in comparison of modifications, the river values given in table 3 were carried through the model study. The simulation number given in table 3 corresponds to the sequencing of numerical simulations of table 1.

Table 3. Initial testing flow simulation set points.

Simulation No.	Q_{river} (ft^3/s)	$Q_{pumping}$ (ft^3/s)	Q_{intake} (ft^3/s)	Q_{bypass} (ft^3/s)	w.s.el.$_{screens}$ (ft)
1	7,000 (7,500)	2,000	2,500	500	135.5
7	10,000 (12,000)	3,000	3,500	500	136.7

Velocities were measured at the centerline of each 40-ft-wide bay for the new screen structure and at the centerline of every fifth bay along the existing structure. Point velocities were measured at the 0.6-ft depth thus representing the approximate vertical average velocity.

Evaluation of flow visualization and velocity data guided modifications tested in the model. This approach resulted in tests of:

- The original screen configuration,
- An expanded opposite bank guidewall,
- A 4° bend in the upstream screen orientation,
- Reduced pumping plant forebay area,
- Reduced screen length, and
- Transitions to the bypass channel entrance.

Each of these modifications were developed based upon the results of previous tests. Again, screen velocity measurements were used to identify possible causes of poor screen performance. Figure 9 is a conceptual layout identifying the associated modifications.

The final screen concept configuration was tested under a wide range of flow conditions. These hydraulic conditions tested are included as Table 4.

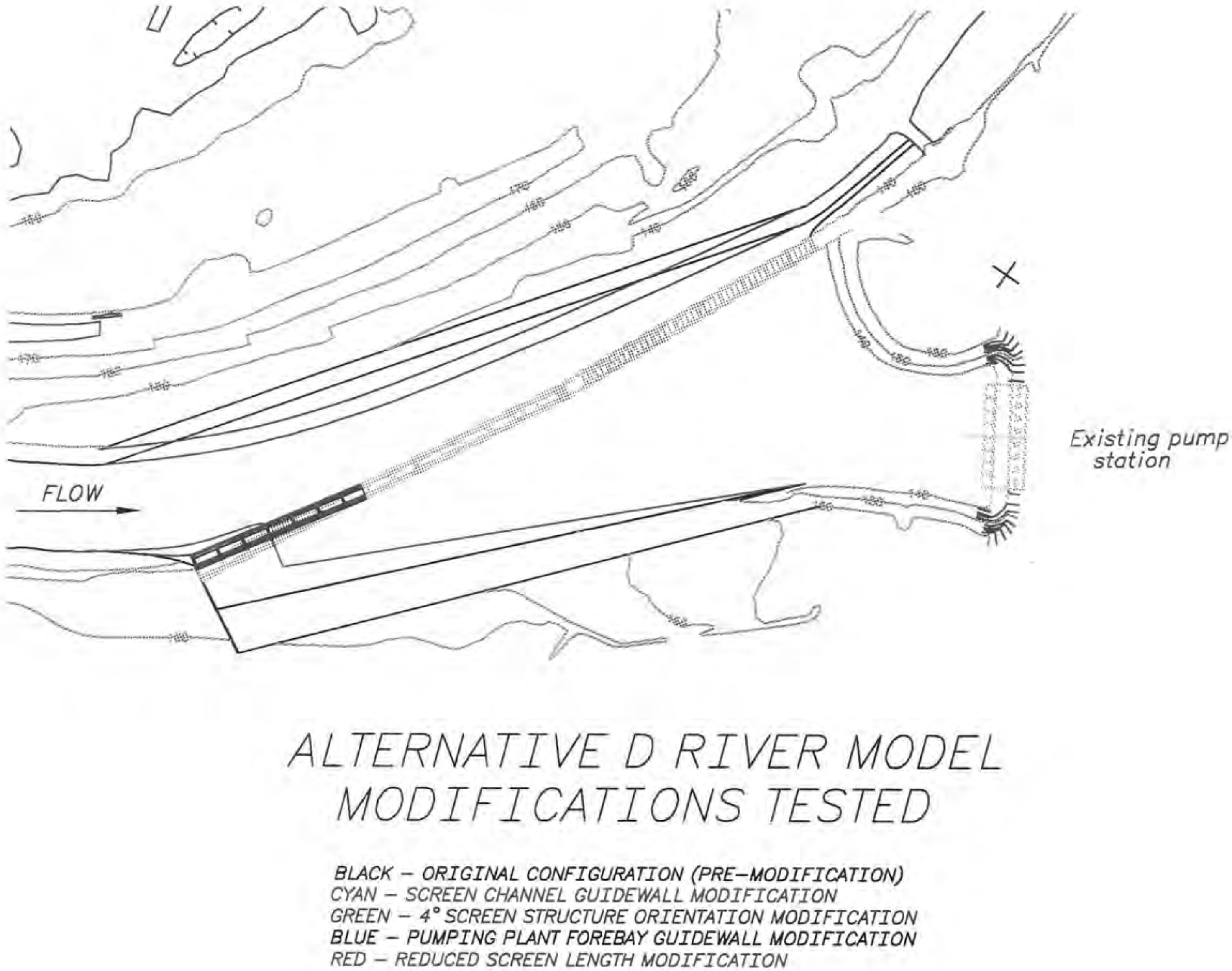


Figure 9 Conceptual layout of the D-alternative screen configuration and associated modifications.

Table 4. Expanded testing program for the final screen concept design.

Simulation No. (reference Table 1)	Q_{river} (ft^3/s)	$Q_{pumping}$ (ft^3/s)	Q_{intake} (ft^3/s)	Q_{bypass} (ft^3/s)	w.s.el.$_{screens}$ (ft)
1	7,000	2,000	2,500	500	135.5
7	10,000	3,000	3,500	500	136.7
9	20,000	3,000	5,029	2,029	139.6
10	40,000	3,000	8,090	5,090	144.7
11	60,000	1,000	10,350	9,350	148.7
12	4,000	500	1,100	600	135.1
13	5,000	1,000	1,650	650	135.3
14	8,000	300	1,400	1,100	136.9

RESULTS

The primary result of the testing is the realization of improved screen performance for the D-alternative screen. This improved performance is demonstrated by the increase in screen effectiveness for the upstream 300 ft of screen area, the elimination of eddy zones on both sides of the channel transition to screen forebay, and the establishment of near-uniform screen velocity distributions under non-baffled conditions.

The major results of the model study are presented as X-Y velocity plots for each configuration tested. The dependent variable is given as the measurement location along the screen structure and the independent variable represents the magnitude of velocity at each measurement location. Both sweeping and normal components of velocity have been presented on the same plot for each test. In addition, complete tabular data for each test are included in appendix A.

Test results

The original D-alternative screen configuration was tested under flow simulation 7. Figure 10 represents the results of test No. 1. As shown, the normal component screen velocity distribution is non-uniform. Negative sweeping and normal component velocities existed along the first upstream bay. Dye tests indicated that this condition was a result of a large eddy zone generated by the upstream channel transition to the screen structure. Flow visualization tests also showed approach flow separated from the opposite bank at the upstream end of the screen structure and impinged largely on the upstream one-third of the screen. As a result, a large eddy zone existed along the opposite bank guidewall.

The opposite bank guidewall was extended into the channel and shaped to turn the approach flow and align it with the screen structure. The guidewall was shaped until dye traces indicated approach flow remained attached along its full length. The reshaped guidewall provided good uniformity of approach channel flow along the screen. Dye injected into the oxbow channel upstream of the screen at three points across the channel tracked nearly parallel along the screen length. Near-bank flow entered the screen within the first quarter of the screen length, midchannel flow entered the screen over the middle half of the screen, and opposite-bank flow moved parallel to the opposite bank entering the screen along the downstream one-quarter of its length.

The modified opposite bank guidewall was then tested under flow simulations 1 and 7. Figures 11 and 12 represent the results of each of these tests, respectively. Approach and sweeping velocities improved as a result of the guidewall changes. However, poor flow conditions persisted near the upstream transition to the screen.

To improve flow conditions at the screen's upstream end, the leading 300 ft of screen structure was angled 4° into the approach flow, see figure 9. This improved the alignment of the approach channel and screen. Figures 13 and 14 show the effects of this modification. The screen realignment eliminated the eddy present in front of the first bay. However, screen approach velocities on the first two screen bays exceeded allowable criteria. These high velocities were caused by the close proximity of the upstream bend in the oxbow channel. Flow leaving the channel bend approached the upstream end of the screen before completing the turn. This caused the angle of attack on the screen to be significantly larger near the upstream end of the screen.

Two modifications were tested to further improve screen approach velocities. First, the pumping plant forebay guidewall was moved closer to the screen structure, thus reducing the forebay area particularly at the upstream end of the screen structure, see figure 9. Figure 15 shows the resulting screen velocity distribution for flow simulation 1. Reducing the forebay area improved the overall uniformity of approach flow along the screen but fell short of achieving the uniformity of approach velocity needed at the upstream end of the screen. The testing clearly showed the screen had to be shortened or moved downstream to avoid the direct influence of the channel bend. To test this assumption, the screen length was reduced by 150 ft, figure 9. This resulted in a screen length of 1,003 ft and a screen area of about 9,100 ft^2 at a water surface elevation of 136.4. Figures 16 and 17 show the improvement in the screen velocity distribution obtained.

The final modification to the D-alternative screen tested in the 1:30 scale model consisted of changing the bypass channel entrance geometry. This effort was undertaken to increase sweeping velocity on the downstream most screen bays. A submerged berm was placed along the opposite bank guidewall near the entrance to the bypass channel. The berm was designed to reduce the channel area and provide a smooth transition to the bypass channel. The berm tested increased near-screen sweeping velocities by about 30 percent, figure 18. Additional efforts in this area were not considered warranted for the objectives of the 1:30 model. Final geometry of the bypass intake will depend on the final screen length chosen for the design.

Final concept testing

Upon completion of the initial modifications, tests were conducted to document screen performance for a wide range of river and pumping flow combinations. The flow combinations tested are listed in table 4. Figures 19-26 show the results of these tests. Of special note are the reverse flow conditions that occur under low pumping conditions, figures 21-23, and also under high river flow conditions, figures 24-26. Reverse flow conditions occur when flow in excess of pumping demand moves through the upstream portion of the screen. This condition is accentuated by the curvature of the oxbow channel. Figure 27 shows velocities measured at several cross sections along the oxbow channel. Flow is directed into the near bank as it moves around the bend upstream of the screen structure. The angle at which flow approaches the screen, and therefore flow, is greatest at the upstream end. Flow combinations that result in large bypass flows will likely result in some reverse flow at the lower end of the screen structure. Dye was injected in the regions of reverse flow to determine if the condition created eddies or slack water conditions in front of the screen that might favor predators. The reverse flow through the screen was found to merge smoothly with flow entering the bypass channel moving continuously downstream.

Prior to completion of model testing, a final test was conducted to verify repeatability of the data. The final configuration was again tested under flow simulation 7 conditions. Figure 28 represents the results of this test. These results were then compared with the results obtained for test No. 10. Figure 29 represents the comparison plot of these two tests. The results show a satisfactory agreement of data.

An uncertainty analysis for these tests has also been performed and is included as appendix B. The results of this analysis indicate that the fractional uncertainty of the measured averaged normal velocity component is on the order of $\pm$ 0.11. This result is considered good given the low magnitude of velocities and the large difference between normal and sweeping velocity components.

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4) Resource Consultants & Engineers (RCE), Inc., *Riverbed Gradient Restoration, Sacramento River Mile 206, California, Advanced Data and Topography for the Design Memorandum*, U.S. Army Corps of Engineers, December 1992.

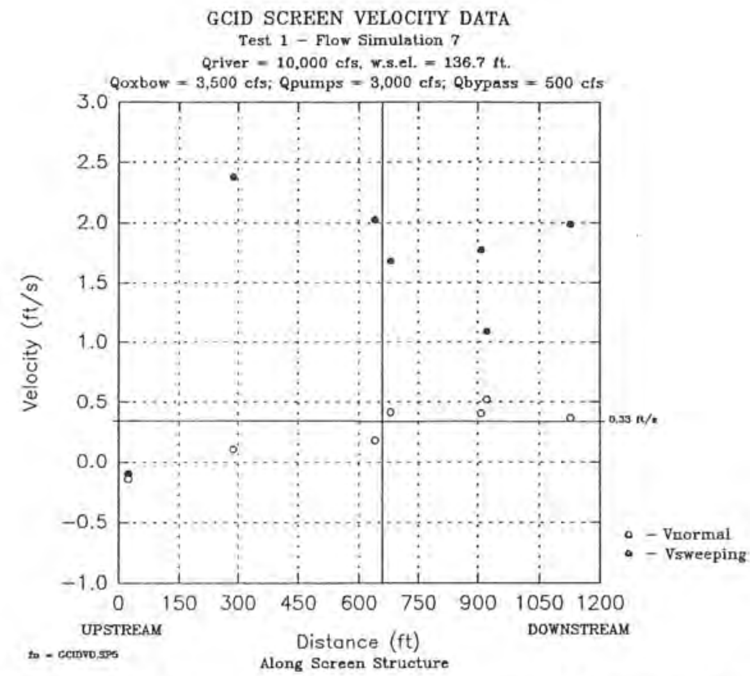

Figure 10. - Original D-alternative screen configuration test results, flow simulation 7.

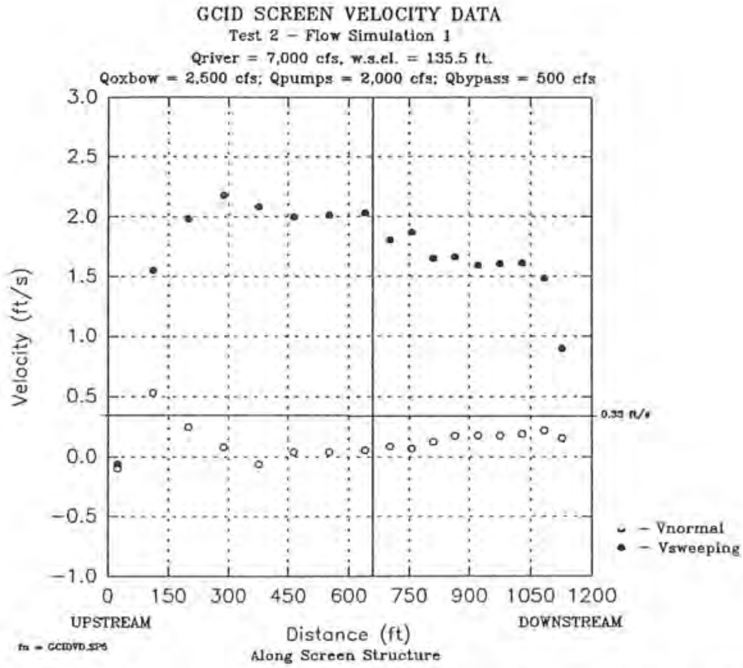

Figure 11. - Opposite bank guidewall modification test results, flow simulation 1.

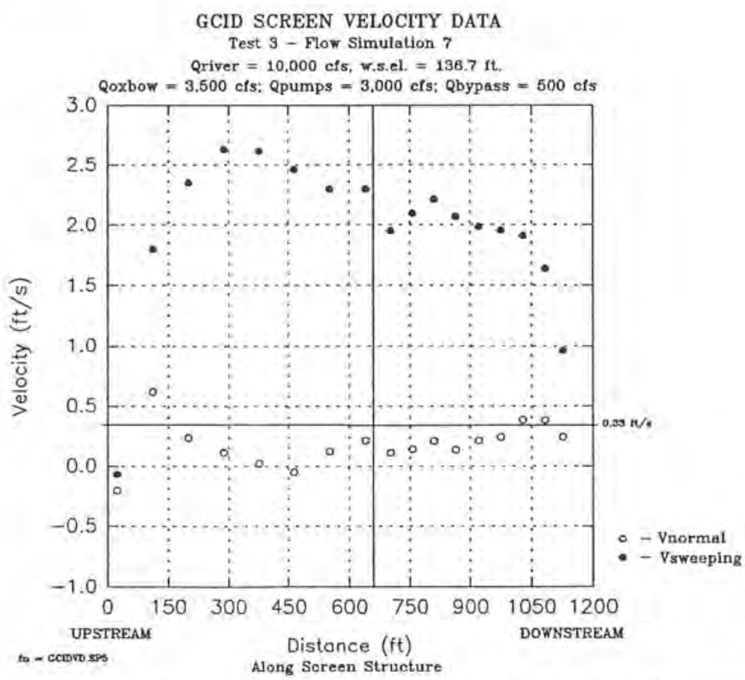

Figure 12. - Opposite bank guidewall modification test results, flow simulation 7.

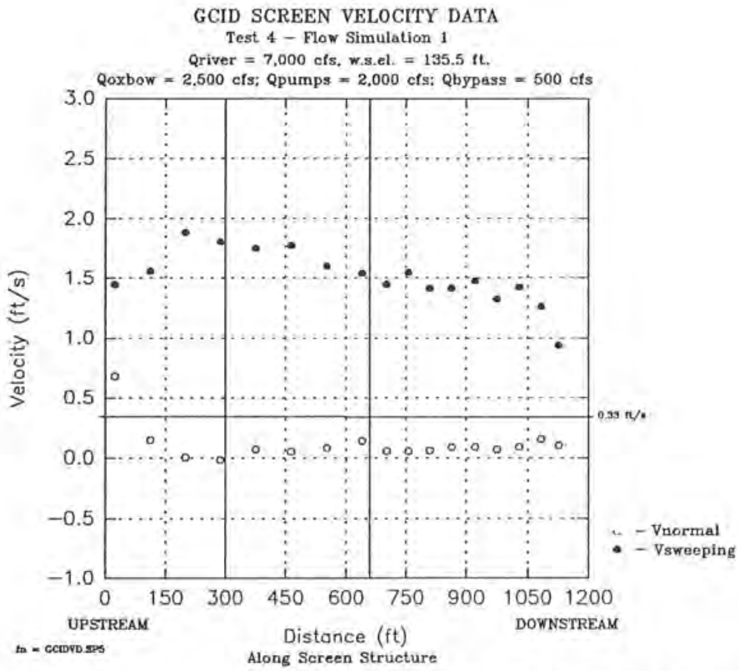

Figure 13. - 4° screen orientation modification test results, flow simulation 1.

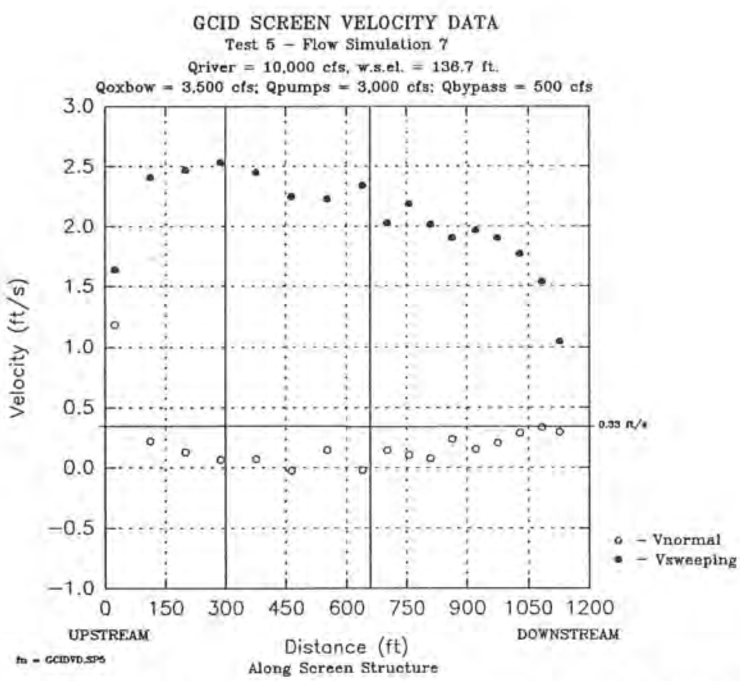

Figure 14. - 4° screen orientation modification test results, flow simulation 7.

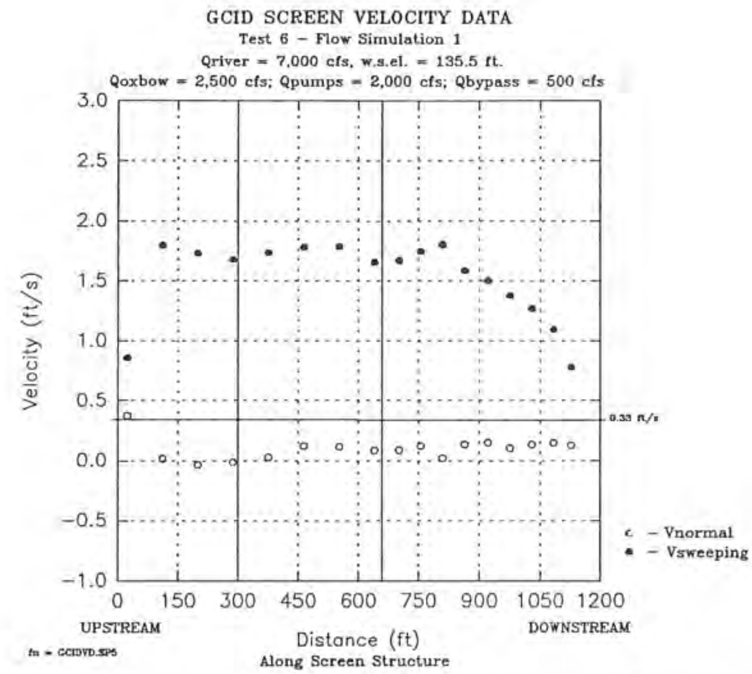

Figure 15. - Pumping plant forebay guidewall modification test results, flow simulation 1.

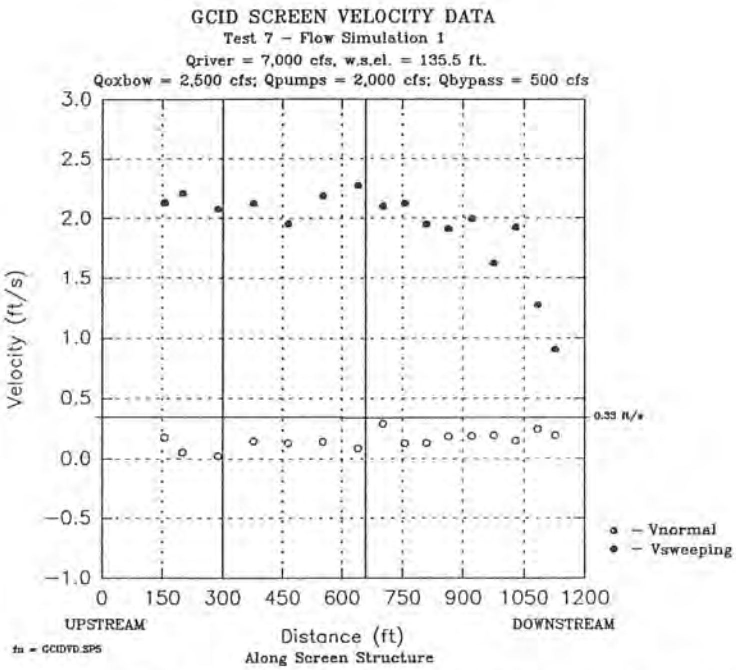

Figure 16. - Reduced screen length modification test results, flow simulation 1.

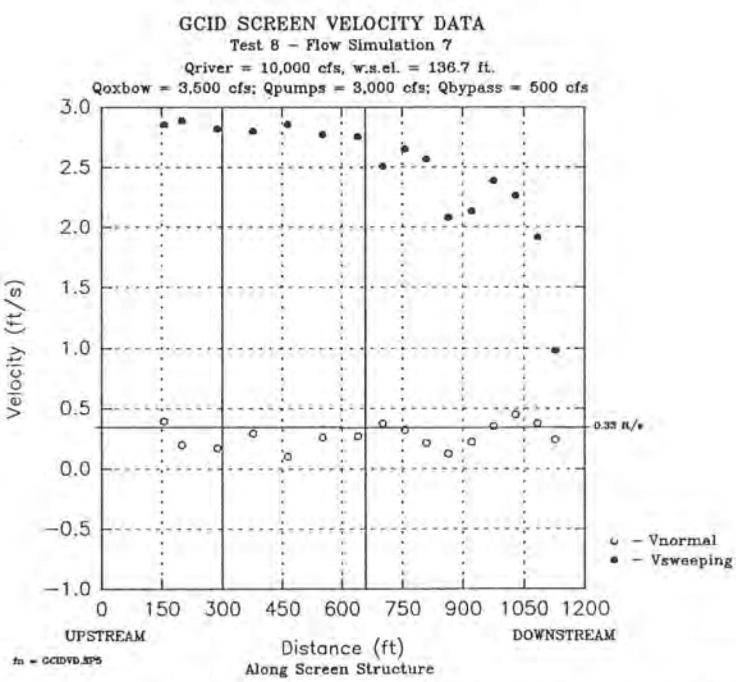

Figure 17. - Reduced screen length modification test results, flow simulation 7.

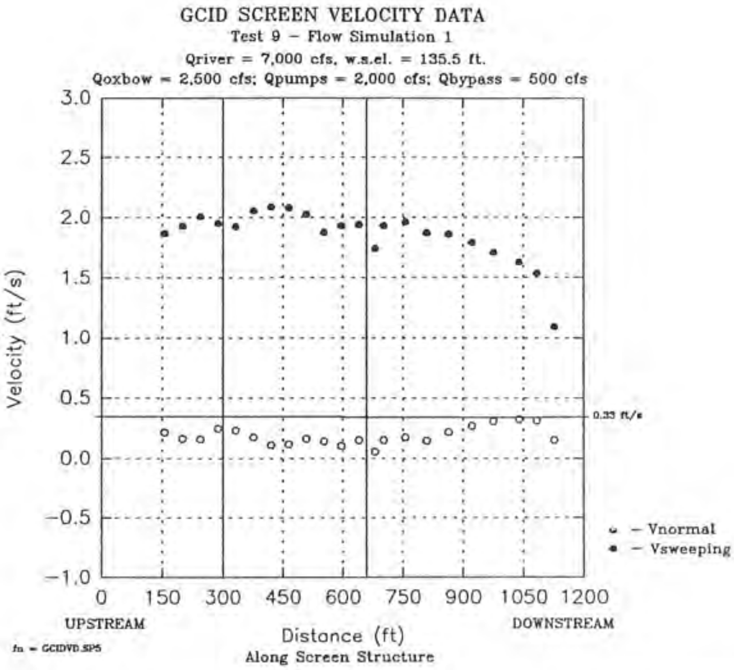

Figure 18. - Bypass channel entrance modification test results, flow simulation 1.

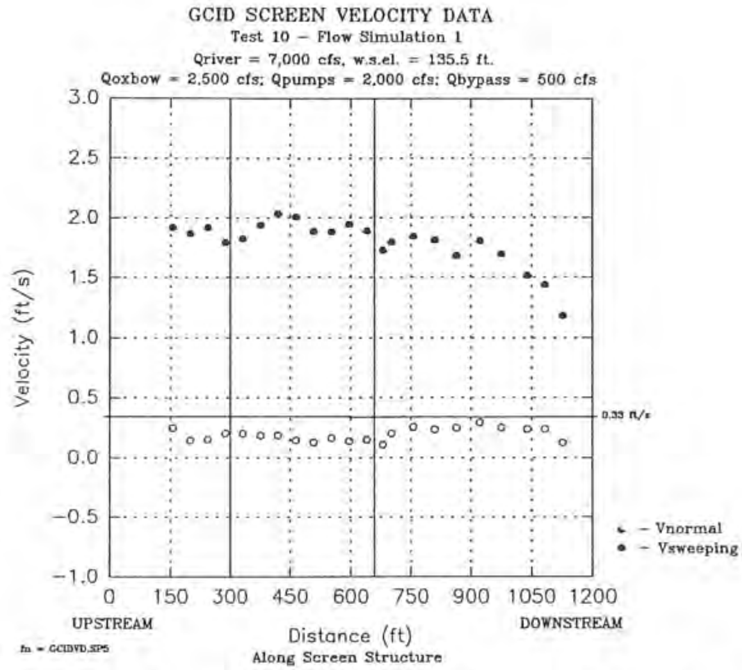

Figure 19. - Final test results, flow simulation 1.

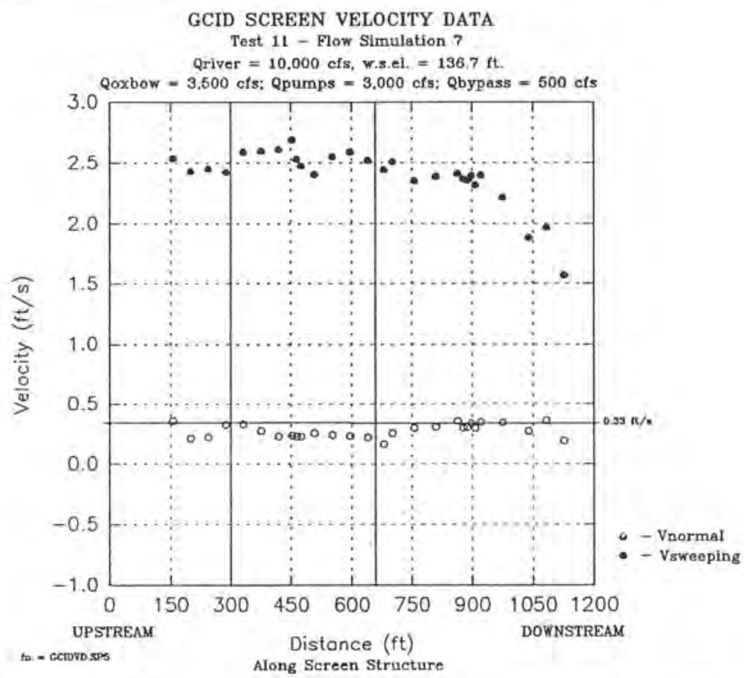

Figure 20. - Final test results, flow simulation 7.

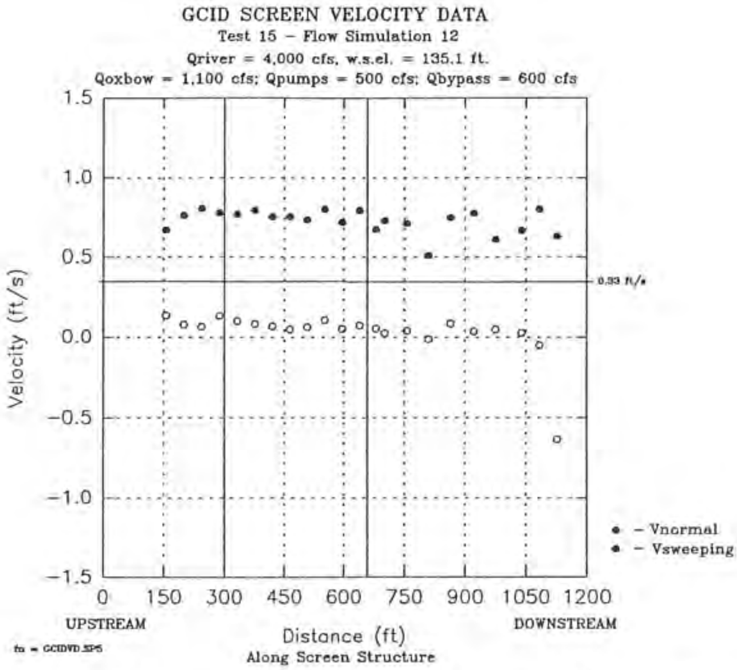

Figure 21. - Final test results, flow simulation 12.

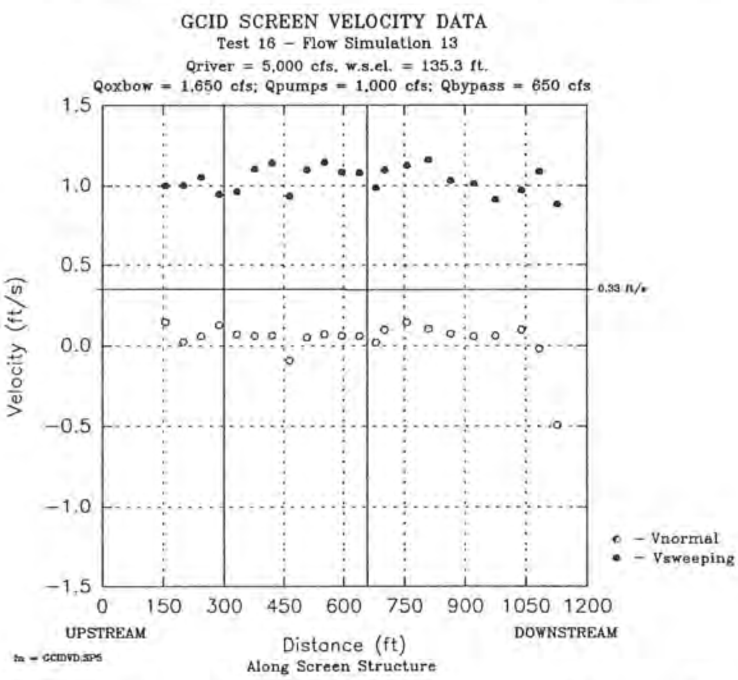

Figure 22. - Final test results, flow simulation 13.

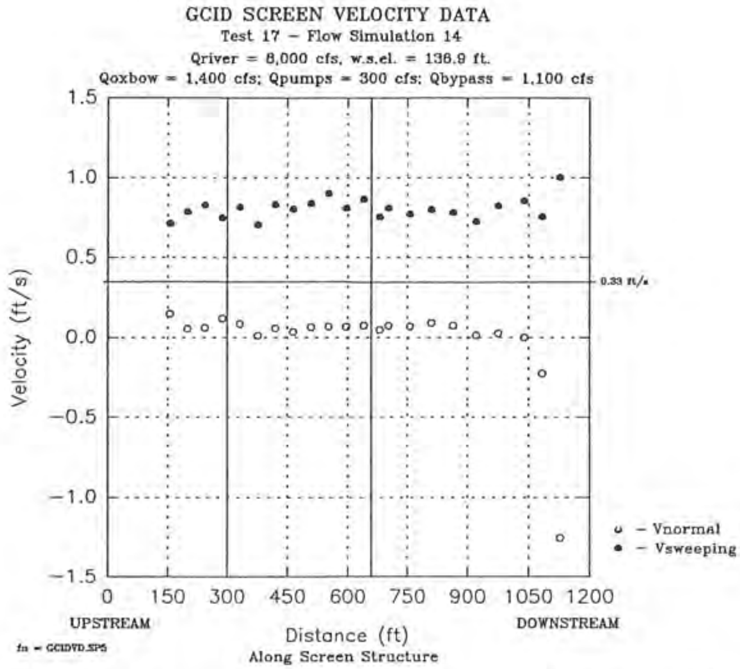

Figure 23. - Final test results, flow simulation 14.

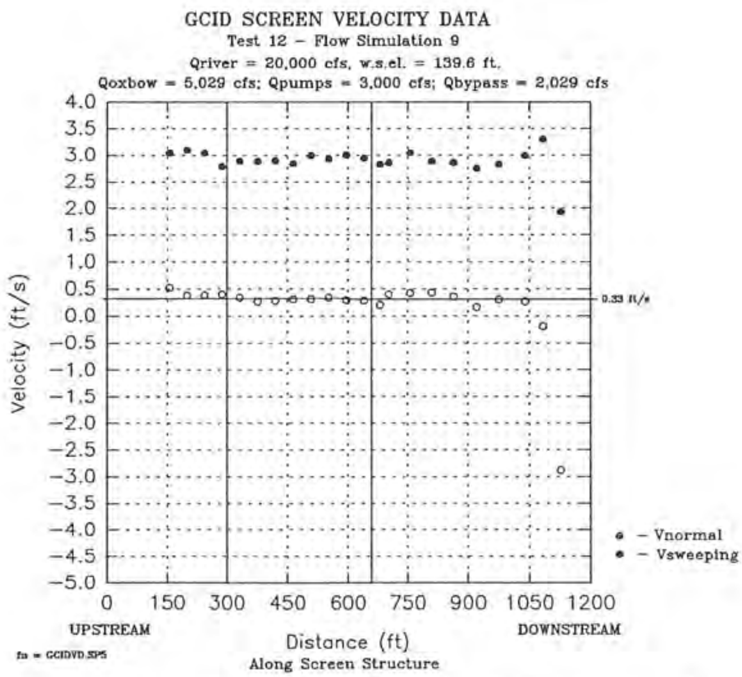

Figure 24. - Final test results, flow simulation 9.

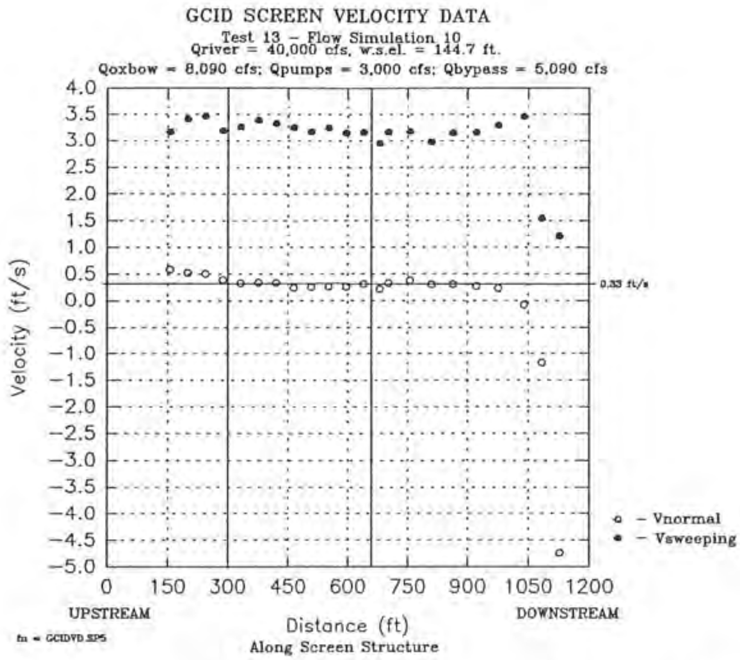

Figure 25. - Final test results, flow simulation 10.

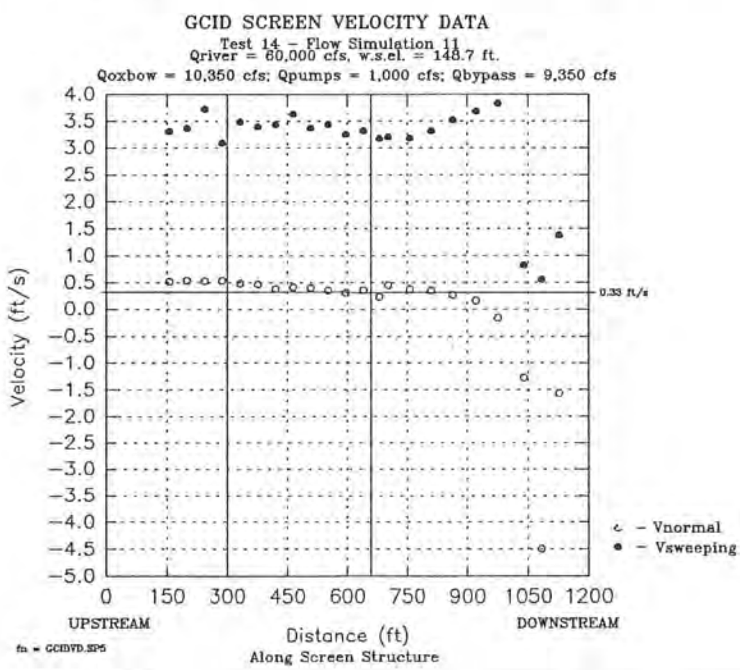

Figure 26. - Final test results, flow simulation 11.

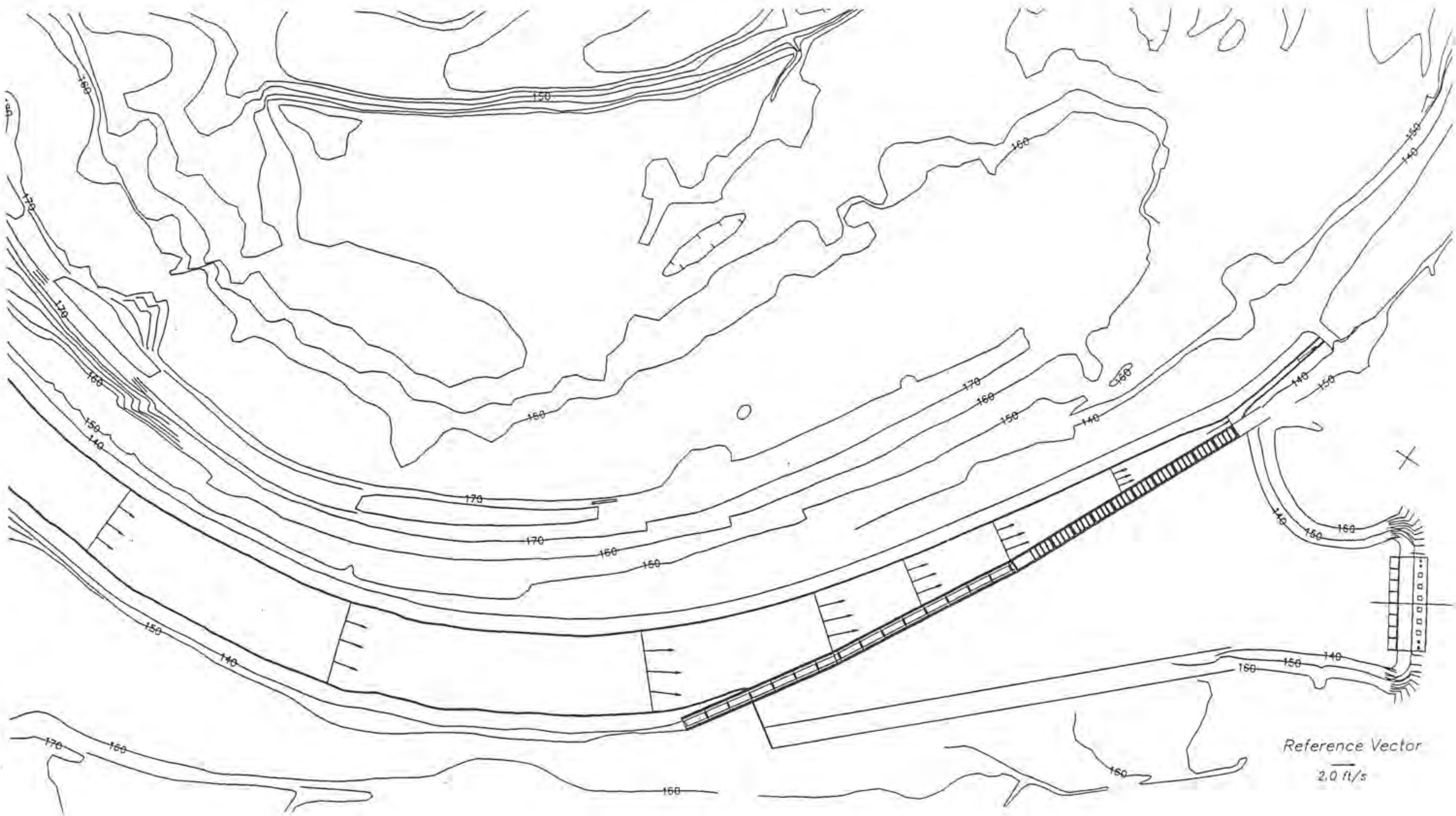

Figure 27 - Plan view of the D alternative fish screen showing oxbow channel flow velocity vectors in the vicinity of the screen.

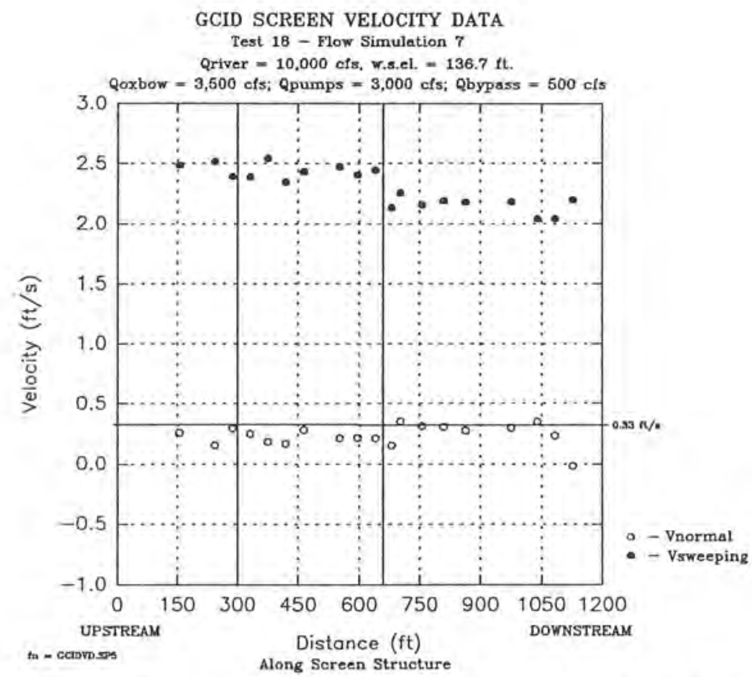

Figure 28. - Repeatability verification results, flow simulation 7.

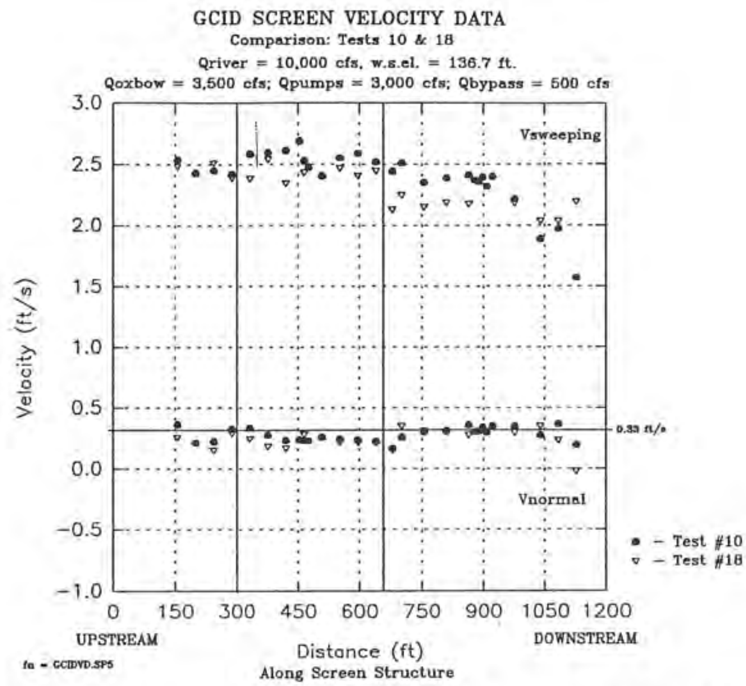

Figure 29. - Repeatability verification results. Comparison between results obtained from test #10 and test #18.

APPENDIX A : Screen Velocity Data

TEST #1 – Original Screen Configuration (Pre-modification)

Flow Simulation 7:

Qriver = 10,000 ft3/s w.s.el. = 136.7 ft

Qapproach = 3,500 ft3/s

Qpump = 3,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
55	-0.14202	-0.097	1747	n/a	n/a
50	0.105127	2.375459	928	n/a	n/a
45	0.180942	2.020794	1210	n/a	n/a
44	0.41537	1.68083	984	n/a	n/a
25	0.403079	1.772908	813	n/a	n/a
24	0.521713	1.08785	747	n/a	n/a
2	0.36486	1.985771	843	n/a	n/a

fn = gcidrsum.wk3

TEST #2 – Screen Guidewall Modification

Flow Simulation 1:

Qriver = 7,000 ft3/s   w.s.el. = 135.5 ft

Qapproach = 2,500 ft3/s

Qpump = 2,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
b55	−0.09923	−0.05919	1530	16.66667	99.93468
b53	0.528402	1.552762	808	18.23762	99.01961
b51	0.248571	1.983628	796	19.09925	99.62453
b49	0.082917	2.179227	1546	22.79862	99.67763
b47	−0.06113	2.085447	818	15.69764	99.63459
b45	0.039685	1.999272	798	15.05221	100
b43	0.041139	2.012633	773	22.16602	100
b41	0.05668	2.032505	746	20.05049	100
b40	0.088005	1.80238	809	17.14915	98.53837
b35	0.069297	1.868629	774	15.59087	100
b30	0.126607	1.649357	1197	16.17349	92.07692
b25	0.175565	1.661973	754	18.64545	99.6037
b20	0.177997	1.593407	759	19.03294	99.86842
b15	0.176908	1.606008	733	19.04275	98.92038
b10	0.190015	1.611881	680	18.95049	100
b5	0.219024	1.483078	760	18.48377	100
b1	0.155392	0.894295	780	16.50769	99.87196

fn = gcidrsum.wk3

TEST #3 – Screen Guidewall Modification

Flow Simulation 7:

Qriver = 10,000 ft3/s w.s.el. = 136.7 ft

Qapproach = 3,500 ft3/s

Qpump = 3,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
b55	−0.20278	−0.06932	618	18.78047	99.83845
b53	0.617229	1.799615	400	19.72917	99.50249
b51	0.236224	2.348678	488	20.02732	99.59184
b49	0.112305	2.629403	429	18.81507	99.53596
b47	0.021606	2.614951	482	16.58714	98.36735
b45	−0.04788	2.462296	480	16.26181	100
b43	0.122308	2.296343	403	15.48553	99.75247
b41	0.213353	2.297189	597	16.70184	99.5
b40	0.110012	1.951702	375	16.48267	96.40103
b35	0.141399	2.094591	405	15.73333	95.74468
b30	0.209407	2.213149	437	14.6537	99.31818
b25	0.133754	2.066713	568	14.13556	99.1274
b20	0.211301	1.981706	433	19.66667	100
b15	0.242315	1.952854	399	19.6934	100
b10	0.385905	1.909851	426	17.60955	100
b5	0.38213	1.639108	426	16.90767	100
b1	0.241907	0.957619	400	15.43167	99.25558

fn = gcidrsum.wk3

TEST #4 – 4 Degree Screen Orientation Modification

Flow Simulation 1:

Qriver = 7,000 ft3/s w.s.el. = 135.5 ft

Qapproach = 2,500 ft3/s

Qpump = 2,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
b55	0.682013	1.44615	814	20.87346	99.02676
b53	0.149536	1.5595	788	27.71489	100
b51	0.004035	1.883972	824	23.40696	100
b49	−0.0151	1.805282	846	15.89362	99.76415
b47	0.071198	1.751235	871	20.32147	99.7709
b45	0.05193	1.772667	844	16.65758	100
b43	0.083188	1.59908	855	17.26628	100
b41	0.141512	1.539664	795	18.22809	100
b40	0.055688	1.447412	779	16.549	99.8718
b35	0.054143	1.546885	791	17.86304	99.7478
b30	0.05909	1.413079	832	17.07131	100
b25	0.087352	1.413215	853	18.23017	100
b20	0.090249	1.475065	772	19.43739	100
b15	0.069781	1.325382	843	13.56544	98.94366
b10	0.089827	1.423868	826	18.91606	100
b5	0.155262	1.259595	1011	15.06001	100
b1	0.104051	0.937091	806	12.30686	99.87608

fn = gcidrsum.wk3

TEST #5 – 4 Degree Screen Orientation Modification

Flow Simulation 7:

Qriver = 10,000 ft3/s   w.s.el. = 136.7 ft

Qapproach = 3,500 ft3/s

Qpump = 3,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
b55	1.183399	1.637491	744	30.30645	99.86577
b53	0.219076	2.408302	738	28.46658	99.86469
b51	0.127577	2.468447	752	27.11702	100
b49	0.065743	2.532138	726	24.86272	99.45206
b47	0.072	2.451172	738	26.53659	99.86469
b45	–0.02461	2.248526	731	23.21478	100
b43	0.145492	2.228945	743	22.38044	100
b41	–0.02148	2.340355	760	22.12149	100
b40	0.142651	2.027954	752	18.77526	99.73475
b35	0.105196	2.186984	720	17.7537	99.72299
b30	0.077334	2.013735	744	16.8293	100
b25	0.237079	1.902756	719	23.20167	100
b20	0.151754	1.965907	732	14.40483	99.59184
b15	0.203436	1.903862	732	18.02778	99.86357
b10	0.285747	1.769437	745	20.61835	100
b5	0.333808	1.53909	746	23.28239	100
b1	0.294061	1.044911	775	19.01677	100

fn = gcidrsum.wk3

TEST #6 – Pumping Plant Forebay Guidewall Modification

Flow Simulation 1:

Qriver = 7,000 ft3/s w.s.el. = 135.5 ft

Qapproach = 2,500 ft3/s

Qpump = 2,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
b55	0.375456	0.858158	962	19.25398	100
b53	0.015184	1.792834	817	16.94818	99.7558
b51	−0.034	1.726636	834	17.29296	100
b49	−0.01237	1.673491	821	17.47016	100
b47	0.028437	1.733303	967	15.38366	99.69072
b45	0.121229	1.780534	776	18.4317	100
b43	0.113838	1.787014	800	16.05292	100
b41	0.083518	1.653122	791	17.73536	100
b40	0.086705	1.666092	775	16.65591	100
b35	0.119909	1.744038	725	18.90253	100
b30	0.019062	1.80041	794	16.54576	100
b25	0.134877	1.58453	587	15.63146	100
b20	0.149472	1.501062	637	15.24019	100
b15	0.102765	1.377777	448	14.16741	98.89625
b10	0.133398	1.267162	409	13.8044	99.27184
b5	0.147167	1.092834	404	13.15512	99.75309
b1	0.126044	0.777165	418	11.64513	99.76134

fn = gcidrsum.wk3

TEST #7 – Reduced Screen Length Modification

Flow Simulation 1:

Qriver = 7,000 ft3/s w.s.el. = 135.5 ft

Qapproach = 2,500 ft3/s

Qpump = 2,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD	R
b52	0.176582	2.127625	732	19.04053	100	2.13494
b51	0.052368	2.204948	725	21.33103	100	2.20557
b49	0.02169	2.076452	717	14.56392	97.81719	2.076566
b47	0.144119	2.12371	748	19.77451	100	2.128595
b45	0.130844	1.95621	749	18.76903	100	1.960581
b43	0.141768	2.186348	744	16.89023	100	2.19094
b41	0.085063	2.273448	760	15.4636	100	2.275039
b40	0.288564	2.100503	736	18.74819	99.59405	2.120232
b35	0.128439	2.123903	733	15.27876	100	2.127783
b30	0.131355	1.949214	723	14.08437	99.86188	1.953635
b25	0.185299	1.910649	751	13.35242	100	1.919613
b20	0.189694	1.993389	740	13.13604	100	2.002394
b15	0.192391	1.624046	721	11.50763	97.43243	1.635402
b10	0.149434	1.923832	728	11.78388	99.04762	1.929626
b5	0.244584	1.277332	744	10.78943	99.2	1.300538
b1	0.192467	0.90244	733	9.603911	97.99465	0.922736

fn = gcidrsum.wk3

TEST #8 – Reduced Screen Length Modification

Flow Simulation 7:

Qriver = 10,000 ft3/s   w.s.el. = 136.7 ft

Qapproach = 3,500 ft3/s

Qpump = 3,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD	R
b52	0.393692	2.857026	864	15.48611	98.63013	2.884024
b51	0.19787	2.888992	1257	11.2803	95.08321	2.89576
b49	0.17295	2.824328	478	12.27894	56.30153	2.829618
b47	0.293241	2.803112	763	13.51464	94.08138	2.818408
b45	0.102118	2.858828	903	20.27907	99.77901	2.860651
b43	0.262064	2.775813	841	16.09592	99.29162	2.788156
b41	0.270213	2.756781	810	14.5214	98.18182	2.769993
b40	0.375358	2.509373	786	12.50891	94.01914	2.537291
b35	0.323049	2.653456	783	17.3461	99.74522	2.673049
b30	0.212435	2.566119	816	17.13276	97.95918	2.574897
b25	0.124797	2.08055	482	12.80774	58.85226	2.084289
b20	0.2217	2.132474	334	8.568863	42.38579	2.143967
b15	0.350647	2.388681	787	19.63659	99.11839	2.41428
b10	0.449601	2.263097	872	19.1594	99.88545	2.307325
b5	0.375776	1.91501	811	16.57008	99.754	1.951531
b1	0.2409	0.977665	2172	16.44659	96.49045	1.006907

fn = gcidrsum.wk3

TEST #9 – Modified Bypass Entrance Testing.

Flow Simulation 1:

Qriver = 7,000 ft3/s   w.s.el. = 135.4 ft (@entrance to screen forebay)

Qapproach = 2,500 ft3/s   w.s.el. = 135.2 ft (@bypass channel entrance)

Qpump = 2,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
B52	0.215675	1.869272	731	19.80438	100
B51	0.16292	1.92768	781	16.86855	99.87212
B50	0.15828	2.006923	721	18.70365	100
B49	0.247943	1.951005	745	18.28322	100
B48	0.230476	1.925676	737	18.27001	100
B47	0.17472	2.054477	720	22.14445	100
B46	0.110876	2.086223	741	17.83941	99.59677
B45	0.117527	2.080796	740	17.89054	100
B44	0.16145	2.027155	743	16.90623	100
B43	0.140526	1.875985	729	17.62963	99.7264
B42	0.104579	1.931371	738	16.5953	100
B41	0.150589	1.940649	781	15.27956	100
DB	0.054615	1.744418	868	15.61367	98.97378
B40	0.150578	1.931037	731	19.83767	100
B35	0.174582	1.961815	732	19.57058	100
B30	0.145713	1.871985	735	19.04445	100
B25	0.216197	1.860003	747	17.78983	99.73298
B20	0.267012	1.792767	742	17.15948	99.73119
B15	0.307838	1.709526	835	14.03234	98.81657
B10	0.32271	1.629869	729	21.09831	100
B5	0.310649	1.536829	721	21.72631	100
B1	0.150219	1.092006	744	20.33423	100

TEST #10 – Final Testing.

Flow Simulation 1:

Qriver = 7,000 ft3/s w.s.el. = 135.4 ft (@entrance to screen forebay)

Qapproach = 2,500 ft3/s w.s.el. = 135.2 ft (@bypass channel entrance)

Qpump = 2,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
B52	0.249899	1.919732	729	15.16964	99.3188
B51	0.146925	1.865928	726	17.32599	100
B50	0.153601	1.918749	729	15.60311	100
B49	0.206401	1.793132	714	14.44958	98.21183
B48	0.204276	1.823632	707	13.73692	96.32153
B47	0.187647	1.938978	754	20.33687	100
B46	0.189629	2.034569	725	21.63356	100
B45	0.147933	2.007598	746	18.32261	100
B44	0.128567	1.882463	754	16.76304	100
B43	0.167915	1.88101	728	14.85028	99.5896
B42	0.138862	1.943884	759	17.12165	100
B41	0.152779	1.886623	722	15.5374	100
DB	0.109214	1.727243	726	18.42929	100
B40	0.203559	1.794762	771	15.96152	100
B35	0.257178	1.841619	713	14.44647	97.13896
B30	0.235192	1.810226	747	20.05712	100
B25	0.249507	1.6811	750	19.90711	100
B20	0.293723	1.80234	746	19.31903	100
B15	0.252433	1.693969	743	17.28892	100
B10	0.239143	1.515432	752	16.53059	97.66234
B5	0.239286	1.43797	736	19.601	100
B1	0.124163	1.182485	753	18.01815	100

TEST #11 – Final Testing.

Flow Simulation 7:

Qriver = 10,000 ft3/s w.s.el. = 136.3 ft (@entrance to screen forebay)

Qapproach = 3,500 ft3/s w.s.el. = 136.2 ft (@bypass channel entrance)

Qpump = 3,000 ft3/s

Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
T8B52	0.36002	2.537566	1104	12.74668	98.57143
T8B51	0.213375	2.428089	866	14.17321	99.88466
T8B50	0.221382	2.450326	725	11.81287	99.86226
T8B49	0.325303	2.421763	727	14.53829	99.72565
T8B48	0.332338	2.587328	801	14.03329	99.50311
T8B47	0.275128	2.596258	730	13.98402	98.78214
T8B46	0.229826	2.610425	726	12.93159	99.72527
T8B45	0.21378	2.544453	735	11.88844	99.72863
T8B45-1	0.236474	2.690005	730	20.34794	100
T8B45-2	0.229562	2.529372	748	16.01471	99.86649
T8B45-3	0.22839	2.473914	744	15.39964	100
T8B44	0.256594	2.404639	735	14.68299	100
T8B43	0.240961	2.550923	777	14.45989	98.47909
T8B42	0.232293	2.588638	748	14.39528	99.86649
T8B41	0.219987	2.518435	744	14.26568	99.86577
T8DB	0.334133	2.442687	747	13.82151	98.67899
T840	0.255352	2.510185	749	11.82466	99.07407
T8B35	0.299355	2.352596	716	10.3487	99.16898
T8B30	0.308067	2.386965	731	16.54902	100
T8B25	0.355591	2.409957	743	16.24675	99.73154
T8B24	0.30128	2.369221	736	20.43433	100
T8B23	0.305851	2.353853	740	19.76216	100
T8B22	0.336658	2.393599	735	19.33333	100
T8B21	0.297356	2.317401	762	18.43963	100
T8B20	0.348598	2.398138	724	17.0198	100
T8B15	0.344424	2.215211	750	15.20667	99.86684
T8B10	0.273434	1.883769	724	13.98435	96.79144
T8B5	0.36406	1.967556	722	15.54663	95.62914
T8B1	0.195037	1.57048	746	20.86595	100

TEST #12 – Final Testing.
Flow Simulation 9:
Qriver = 20,000 ft3/s w.s.el. = 139.8 ft (@bypass channel entrance)
Qapproach = 5,029 ft3/s
Qpump = 3,000 ft3/s
Qbypass = 2,029 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
B52	0.5208	3.036447	547	8.747715	74.72678
B51	0.380468	3.095407	720	16.47268	96.77419
B50	0.383612	3.038584	741	17.47099	98.1457
B49	0.394657	2.787752	700	16.3919	96.15385
B48	0.340701	2.891733	591	15.35364	79.6496
B47	0.268232	2.886008	714	11.85574	98.75519
B46	0.276745	2.897617	714	9.910831	96.35628
B45	0.304387	2.843118	364	5.322344	48.99058
B44	0.314772	2.990014	739	14.71764	99.73009
B43	0.339785	2.928736	689	14.72666	92.1123
B42	0.288602	3.003753	740	15.68288	99.86504
B41	0.28293	2.943159	742	13.12713	99.86541
DB	0.399922	2.810953	709	11.11707	95.94046
B40	0.399595	2.857473	707	9.5686	93.89111
B35	0.42351	3.042788	596	14.10123	81.30968
B30	0.428618	2.888389	398	16.05863	53.63881
B25	0.356822	2.860237	746	14.12288	96.50712
B20	0.158755	2.750353	701	12.9339	95.24457
B15	0.300693	2.831081	699	13.36719	93.32443
B10	0.264456	2.989843	676	11.10503	89.89362
B5	−0.19072	3.29984	695	10.61966	92.05298
B1	−2.87576	1.929515	463	12.04824	62.31494

fn = gcidrsum.wk3

TEST #13 – Final Testing.

Flow Simulation 10:

Qriver = 40,000 ft3/s w.s.el. = 144.7 ft (@bypass channel entrance)

Qapproach = 8,090 ft3/s

Qpump = 3,000 ft3/s

Qbypass = 5,090 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
B52	0.586416	3.165857	621	11.03382	84.95212
B51	0.523481	3.411979	733	12.9186	98.38926
B50	0.508617	3.465357	648	12.20833	87.68607
B49	0.389638	3.188827	718	15.4935	98.08743
B48	0.328391	3.261216	717	15.25802	99.17013
B47	0.338214	3.382517	511	8.532942	68.49866
B46	0.330911	3.324683	708	7.753296	98.60724
B45	0.238292	3.250559	675	8.402964	93.75
B44	0.252443	3.164709	863	9.235226	91.80851
B43	0.258385	3.244985	707	9.066478	97.11539
B42	0.258052	3.149014	656	9.799289	89.3733
B41	0.305157	3.16158	712	9.869382	95.95687
DB	0.417604	2.925801	832	10.54647	96.40788
B40	0.327198	3.16729	704	10.35417	95.78231
B35	0.378342	3.174953	609	10.32841	80.76923
B30	0.303673	2.975526	677	9.662235	93.76731
B25	0.299391	3.147048	626	9.6459	85.75343
B20	0.262872	3.157248	770	10.66191	97.8399
B15	0.229738	3.29295	696	10.52874	95.7359
B10	−0.08062	3.458553	686	11.32264	90.98143
B5	−1.16723	1.542286	728	11.63507	98.37838
B1	−4.73697	1.212677	29	8.229885	3.934871

fn = gcidrsum.wk3

TEST #14 – Final Testing.

Flow Simulation 11:

Qriver = 60,000 ft3/s w.s.el. = 148.7 ft (@bypass channel entrance)

Qapproach = 10,350 ft3/s

Qpump = 1,000 ft3/s

Qbypass = 9,350 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
B52	0.513983	3.30769	623	12.21027	86.64812
B51	0.536616	3.363465	706	12.322	97.24518
B50	0.529446	3.724796	805	12.59006	95.37915
B49	0.535139	3.084885	727	13.75424	99.4528
B48	0.482042	3.480753	721	13.89829	100
B47	0.466744	3.391343	750	13.54311	100
B46	0.37739	3.4323	742	13.55975	99.73119
B45	0.41076	3.62865	727	12.41311	98.77718
B44	0.396022	3.366173	682	12.5479	93.29685
B43	0.348603	3.432609	732	12.50729	99.72752
B42	0.30631	3.248921	732	12.45173	99.59184
B41	0.357476	3.315133	731	15.93844	99.72715
DB	0.451996	3.14471	732	15.67851	98.25504
B40	0.447659	3.199208	731	14.76425	99.45578
B35	0.378494	3.176466	730	14.29178	99.8632
B30	0.34977	3.310798	744	13.72043	99.86577
B25	0.269699	3.516612	628	13.44214	85.32609
B20	0.160711	3.6866	672	13.27232	89.12467
B15	−0.16001	3.824609	731	13.52668	99.86339
B10	−1.27606	0.819727	741	17.00765	99.06417
B5	−4.48928	0.556188	732	13.15437	100
B1	−1.56046	1.375411	28	12.77381	3.753351

fn = gcidrsum.wk3

TEST #15 – Final Testing.
Flow Simulation 12:
Qriver = 4,000 ft3/s w.s.el. = 135.1 ft (@bypass channel entrance)
Qapproach = 1,100 ft3/s
Qpump = 500 ft3/s
Qbypass = 600 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
B52	0.13593	0.668377	799	19.01627	100
B51	0.077819	0.760917	836	21.02991	100
B50	0.065899	0.804773	760	23.08904	100
B49	0.133596	0.776434	726	19.26446	100
B48	0.100605	0.769368	730	20.06849	100
B47	0.082534	0.793272	745	20.36331	100
B46	0.067581	0.753759	733	16.48658	99.05405
B45	0.04768	0.75251	729	15.01006	97.98387
B44	0.061797	0.733695	736	14.62726	97.74236
B43	0.106005	0.801685	665	11.94436	91.09589
B42	0.050866	0.717929	601	11.33777	80.99731
B41	0.072289	0.792518	652	8.900307	88.34689
DB	0.099741	0.666029	597	8.543272	81.11413
B40	0.025347	0.727104	722	14.11865	95.75597
B35	0.0409	0.710914	564	10.91135	75.60322
B30	–0.01278	0.5078	647	9.787223	88.02721
B25	0.084835	0.747631	752	19.082	100
B20	0.036241	0.775915	695	18.69736	94.55782
B15	0.048536	0.608912	779	18.26829	100
B10	0.026595	0.665546	740	17.83558	100
B5	–0.0513	0.800084	710	16.51596	97.93104
B1	–0.63518	0.631037	871	16.10371	99.88532

fn = gcidrsum.wk3

TEST #16 – Final Testing.
Flow Simulation 13:
Qriver = 5,000 ft3/s w.s.el. = 135.3 ft (@bypass channel entrance)
Qapproach = 1,650 ft3/s
Qpump = 1,000 ft3/s
Qbypass = 650 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
B52	0.143425	0.998537	488	11.48224	64.89362
B51	0.022082	0.999743	714	15.27031	94.82072
B50	0.05762	1.050505	742	19.06828	99.86541
B49	0.125381	0.944153	810	20.71029	99.631
B48	0.070018	0.961611	746	20.01921	100
B47	0.05932	1.101169	724	22.37385	100
B46	0.062287	1.139766	721	24.454	100
B45	−0.0901	0.933608	571	5.03561	75.62914
B44	0.049807	1.09485	654	7.287462	87.66756
B43	0.069491	1.144416	597	9.807928	78.55264
B42	0.059262	1.082696	675	11.96346	94.14226
B41	0.058668	1.077193	735	13.89388	99.0566
DB	0.086486	0.981899	712	15.57069	96.34641
B40	0.096765	1.095894	746	16.09875	100
B35	0.14143	1.123484	727	17.94406	100
B30	0.102024	1.158327	745	18.64698	100
B25	0.073197	1.028901	720	18.63472	98.09264
B20	0.0569	1.010204	728	17.98397	99.72603
B15	0.059561	0.91024	722	17.26547	99.5862
B10	0.095999	0.967432	731	15.63064	99.45578
B5	−0.019	1.086502	735	14.99093	98
B1	−0.49274	0.881681	730	16.12238	99.45504

fn = gcidrsum.wk3

TEST #17 – Final Testing.

Flow Simulation 14:

Qriver = 8,000 ft3/s w.s.el. = 136.9 ft (@bypass channel entrance)

Qapproach = 1,400 ft3/s

Qpump = 300 ft3/s

Qbypass = 1,100 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
B52	0.146846	0.710643	465	11.11183	50.16181
B51	0.053324	0.782713	800	12.28417	98.03922
B50	0.060785	0.825368	838	14.75338	93.94619
B49	0.117104	0.746299	820	13.96829	99.27361
B48	0.08475	0.814094	1165	15.19828	97.57119
B47	0.009883	0.702368	768	14.16059	97.58577
B46	0.055168	0.828324	780	13.34359	95.70552
B45	0.034116	0.800617	769	16.62115	96.36591
B44	0.064378	0.837405	801	15.64919	99.37965
B43	0.067038	0.900723	695	14.56067	86.65836
B42	0.06689	0.806942	819	13.82011	97.96651
B41	0.073376	0.86324	915	12.34171	94.62254
DB	0.099167	0.745566	776	18.80026	97.85624
B40	0.07226	0.80744	746	10.89231	95.03185
B35	0.067686	0.768786	639	8.434533	84.07895
B30	0.090738	0.798036	756	19.79938	99.47369
B25	0.073588	0.778816	788	19.11421	98.74686
B20	0.012031	0.720861	794	17.233	99.00249
B15	0.024557	0.820962	794	17.1314	99.62359
B10	–0.00087	0.852943	746	16.67292	98.1579
B5	–0.22589	0.754194	788	16.40059	98.87077
B1	–1.25689	1.001416	1329	16.3085	99.92481

fn = gcidrsum.wk3

TEST #18 – Final Testing.
Flow Simulation 7:
Qriver = 10,000 ft3/s w.s.el. = 136.2 ft (@bypass channel entrance)
Qapproach = 3,500 ft3/s
Qpump = 3,000 ft3/s
Qbypass = 500 ft3/s

Bay No.	Vnormal	Vsweeping	SAMPLES	SNR AVG	% GOOD
B52	0.260215	2.485709	1444	8	100
B51					
B50	0.154914	2.516052	1136	12	99.56179
B49	0.295114	2.391886	1176	15	88.15592
B48	0.25005	2.388837	876	17	100
B47	0.184526	2.54198	865	18	99.88453
B46	0.166555	2.343992	899	13	99.88889
B45	0.28268	2.434304	988	15	100
B44					
B43	0.213911	2.472211	838	16	100
B42	0.216068	2.407372	912	5	100
B41	0.213481	2.448122	912	6	100
DB	0.224524	2.132772	836	13	100
B40	0.352996	2.254178	879	16	98.98649
B35	0.313826	2.154105	836	18	100
B30	0.306283	2.188491	836	19	100
B25	0.277024	2.178768	825	19	98.68421
B20					
B15	0.297862	2.182892	855	19	100
B10	0.351758	2.03833	912	18	100
B5	0.234872	2.037275	878	19	100
B1	-0.01868	2.195381	899	20	99.55703

fn = gcidrsum.wk3

APPENDIX B : Velocity Measurement Uncertainty Analysis

Velocity Measurement Uncertainty Analysis

An error analysis of a typical data set has been performed to determine the estimated uncertainty associated with those results presented in this report.

All velocity measurements were acquired using a Sontek Acoustic Doppler Velocimeter (ADV). This instrument has the capability of measuring local velocities in water to a resolution of 0.001 ft/s with a maximum sampling rate of 200 Hz and an accuracy of $\pm$0.5 percent of the measured value. The high rate of sampling has the advantage that a large number of samples can be acquired over a short period of time. From a statistical standpoint, this advantage translates into a better estimate of the uncertainty associated with the reported results.

For the application of this physical model study, consider the data presented as Table B2.

Table B2. - Typical normal component velocity data set.

Time (sec)	u (ft/s)
0.02	-0.0342
0.06	-0.0296
0.1	0.0404
0.14	0.0105
0.18	0.0579
0.22	0.0362
0.26	0.0667
0.3	0.0592
0.34	0.0447
0.38	0.0605
0.42	0.0447
0.46	0.0536
0.5	0.0671
0.54	0.0565
0.58	0.0128
0.62	0.0164
0.66	0.1575
0.7	0.074
0.74	0.0243
0.78	0.073

Table B2. - Typical normal compenent velocity data set.	
Time (sec)	u (ft/s)
0.82	0.0174
0.86	0.0615
0.9	0.1279
0.94	0.0204
0.98	-0.024

These data represent a typical velocity data set and were extracted from an actual test run described in the body of the report. Here, a total of 50 separate velocity measurements were acquired over a 2-second time period at a sampling rate of 25 Hz. From these data, the mean value or best estimate for the measured velocity can be determined as:

$$\bar{u}=(u_i+.....+u_N)/2$$

where,

$\bar{u}$ = The mean value of n measurements,
u_i = The values of the measured x-component of velocity,
n = The number of measurements of u.

For this case, the mean is determined as;

$$\bar{u}=$$

This mean value represents the best estimate of the measured value u for this data set. Given this result, the average uncertainty can be characterized by the standard deviation which is defined as:

$$\sigma_u=\sqrt{(u_i-\bar{u})^2/(n-1)}$$

where,

σ_u = The standard deviation of n measurements of u,
ui = The measured values of u,

$\bar{u}$ = The mean value of n measurements of u,
n = The number of measurements of u.

Although the standard deviation represents the average uncertainty of the separate measurements of $u_1,\ldots,u_n$, a more precise means of stating the uncertainty exists. Since, $\bar{u}$ is comprised of all n measurements of u, it can be considered more reliable than any one measurement considered separately. Thus, the uncertainty in any set of n measurements is defined as the standard deviation of the mean which is defined as:

$$\sigma_{\bar{u}}=\sigma_u/\sqrt{n}$$

The important point here is the square root of the number of samples in the denominator. This indicates that the more measurements acquired, the more certain the mean value becomes. Consequently, the smaller the uncertainty of the mean becomes. For this case the standard deviation of the mean is determined as:

$$\sigma_{\bar{u}}=$$

Thus, the best estimate of u is reported as the mean, $\bar{u}$ $\pm$ the standard deviation of the mean, $\sigma_{\bar{u}}$. Which is given for this case as $\pm$ ft/s.

This same analysis can be applied to all of the results presented in this report. Consequently, from this analysis, it can be seen that a high degree of precision for these velocity measurements is realized. This is especially appreciated since the flow regime is turbulent. Therefore, assuming that the length of time over which the measurements are acquired is sufficiently long, the reported mean values of the velocity measurements may be accurately stated as indicated in this analysis.