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Physical Model Study of a Primary Bypass Intake With Louvers at the Tracy Fish Collection Facility, Tracy, California

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by

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EXECUTIVE SUMMARY

A 1:6 scale physical model and a computational model of a Tracy Fish Collection Facility (TFCF) primary bypass intake with approach louvers were studied to refine bypass approach velocity distributions. The TFCF functions to prevent fish entrainment at the Tracy Pumping Plant. The TFCF collects fish that are then returned to the San Joaquin River. To achieve efficient fish collection, velocity fields should be generated that are uniform and that supply well directed guidance to the bypass entrance. In the first phase of this study, modeling was used to develop low maintenance internal features of the bypass entrance that generated near-uniform internal velocity distributions (Kubitschek, 2003). This second phase study focused on extending the 1:3 model findings to the approach flow. Study findings show that velocity distributions in the vicinity of the bypass entrance are influenced by approach flow velocity distributions. This may imply that the TFCF trashracks and louvers should be maintained clean to sustain uniform velocity fields approaching and entering the intakes. Findings also show that by adding a minor flow restriction to the backside of the louver immediately adjacent to the bypass entrances, a local through-louver high velocity zone can be eliminated. Elimination of the high velocity zone should improve fish guidance to the bypass intake. Finally, findings show that acceptable passing flow and bypass entrance hydraulics can be maintained with the bypass guide wall removed. This supports possible future guide wall removal that could lead to application of improved louver cleaning techniques (i.e., eliminate the need for removal of the louver panels during cleaning).

INTRODUCTION

This report is the second in a series of two reports describing hydraulic investigations of the primary bypasses at the Tracy Fish Collection Facility (TFCF) developed under the Tracy Fish Facilities Improvement Program. The TFCF is located at the entrance to the Delta-Mendota Intake Channel on the south side of the Sacramento-San Joaquin Delta (the Delta), near Tracy, California. The Delta-Mendota Intake Channel supplies water from the Delta to the Tracy Pumping Plant (TPP), which in turn supplies water to the Delta–Mendota Canal for delivery to the San Joaquin Valley and Southern California. The TFCF, constructed in the 1950s, functions to remove fish from the intake flow and transport them back to Delta locations that are remote from the pumping influences (Liston et al., 1993). Efficient collection performance must be maintained to minimize fish losses to the pumped diversion. The primary bypass entrance transition structures of the TFCF have deteriorated through corrosion and will be replaced in the near future. These studies were conducted to guide development of the replacement design.

The TFCF uses a louver and bypass system to collect fish. Louvers consist of a series of vertical slats placed in a line with the slats oriented normal to the flow (figure 1). Except for large fish, louvers are not a positive barrier to fish passage. The 1-in spacing between louver slats is large enough to allow many small fish to pass. However, fish sweeping along the louver face in the passing flow encounter the flow disturbance created by the louver slats that appears to the fish to be a barrier. Fish tend to guide along the louver line with the flow. Bypass entrances with guide walls (figure 2) are placed at the quarter points and at the terminal end of the louver-line in the TFCF. The fish that guide along the louver are directed to, and collected by, these bypasses.

Fish may avoid rapid changes or discontinuities in the velocity field. Generating uniform velocity fields that guide fish into the bypass entrances at all elevations in the water column contributes to optimizing fish collection efficiencies. Criteria and hydraulic operating objectives require vertically uniform entrance velocity distributions within the bypass and well-directed approach velocity distributions that guide the fish to the bypass entrances without generating excessive flow accelerations or decelerations. If the passing fish encounter flow or structural features that cause avoidance responses, the fish may stop and hold their position instead of sweeping along the louver face. This can cause the louvers to lose their fish exclusion effectiveness and fish can be passed through the louvers as a result. Field observations indicate that significant fish losses through the

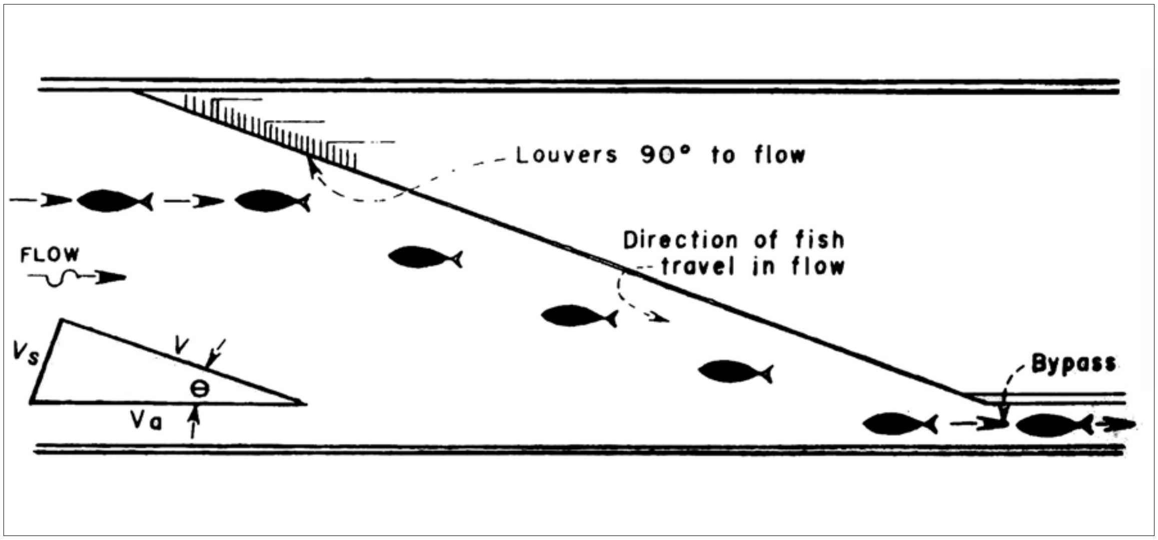


FIGURE 1.—Schematic of louver concept.

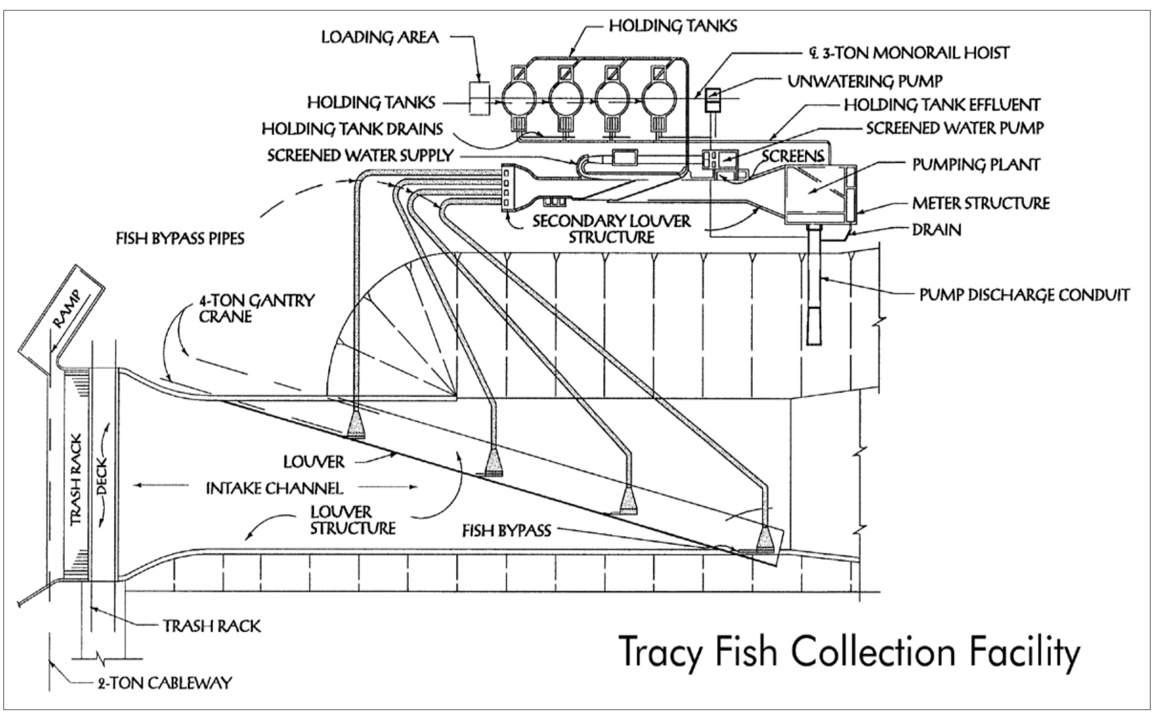


FIGURE 2.—Plan view of the TFCF showing the four primary bypasses leading to the secondary louver structure and fish holding facility.

louvers may be occurring immediately upstream from the bypass entrances and, consequently, improvement of approach flow distributions and patterns in this zone may be beneficial.

The original bypass entrance design generated near uniform internal vertical velocity distributions through use of an internal vane system (figure 3). These vanes, which were developed through a physical model study (McBirney, 1956), forced equal withdrawal of water from near the surface and near the bottom. However, these vanes were not accessible for maintenance and they fouled with debris (and could not be cleaned), and with time, they corroded and some failed. The first phase of this study (Kubitschek, 2003) focused on development of an alternative design that would continue to generate uniform internal vertical velocity distributions without the use of vanes. This Phase 1 study was conducted using a 1:3 scale model, which allowed detailed investigations of the internal geometry and flow patterns within the intake. A computational fluid dynamics (CFD) model was also developed and applied. An internal tapered choke or throat treatment (figure 4) was developed that created increased flow resistance at deeper elevations in the intake and, thus, caused a balanced flow to be drawn from the shallower, near surface, portions of the intake. The Phase 1 model was also used to investigate alternative end plate treatments that helped reduce observed eddy and slack-water zones within the bypass for certain operations. Because of the eddy reduction benefits, a concept with a modified end plate was selected for final design (figure 4). However, the 1:3 scale model did not include louver flow and, thus, could not be used to evaluate approach and passing flow velocity influences and the approach velocity field between the bypass guide wall and the louver face (figure 4).

Objectives

The objectives of this Phase 2 study are to evaluate the bypass entrance approach flow velocity field and develop design features that will improve fish guidance characteristics to the bypass entrances. The study also considers the influence of approach flow distributions on the velocities in the bypass entrance and transition box. This Phase 2 study used a 1:6 scale model, which allowed inclusion of louver flow. Thus, the effects of flow passing the bypass entrance and the bypass approach velocity field in the wedge-shaped section included between the louver face and the guide wall were represented. The model was developed to establish conditions required to optimize velocity field influences for fish guidance to the bypass entrances.

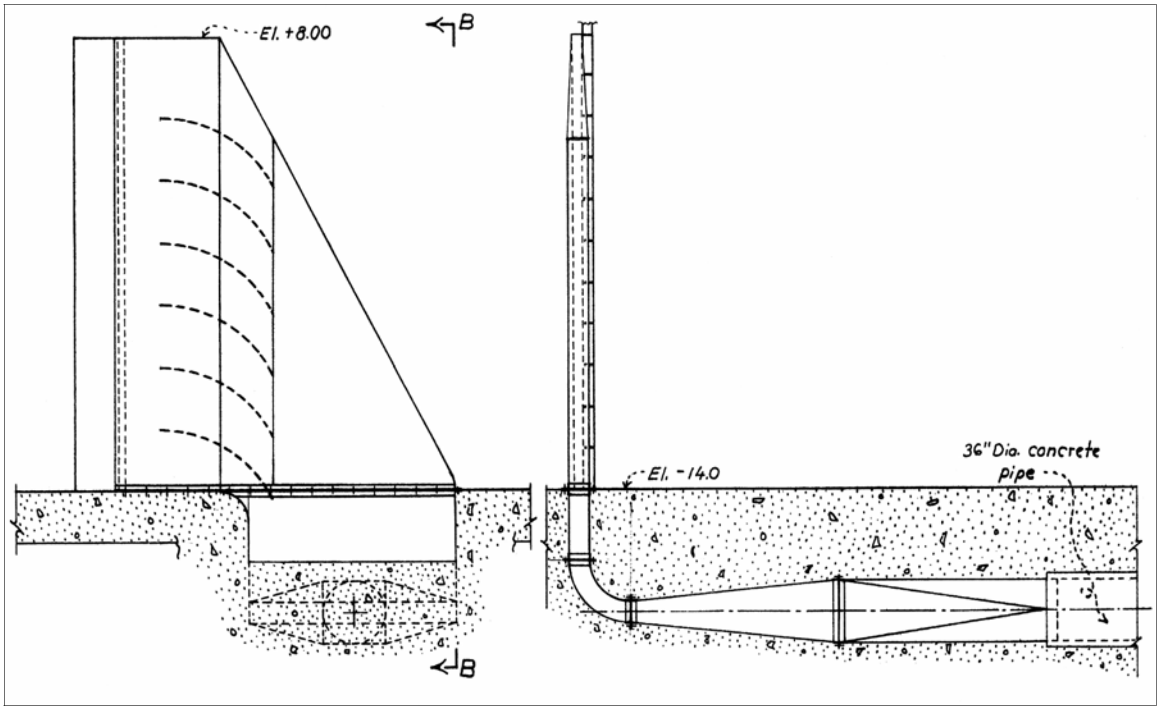


FIGURE 3.—Elevation and section views of original as-built primary bypass at the TFCF showing basic turning vane and transition geometry.

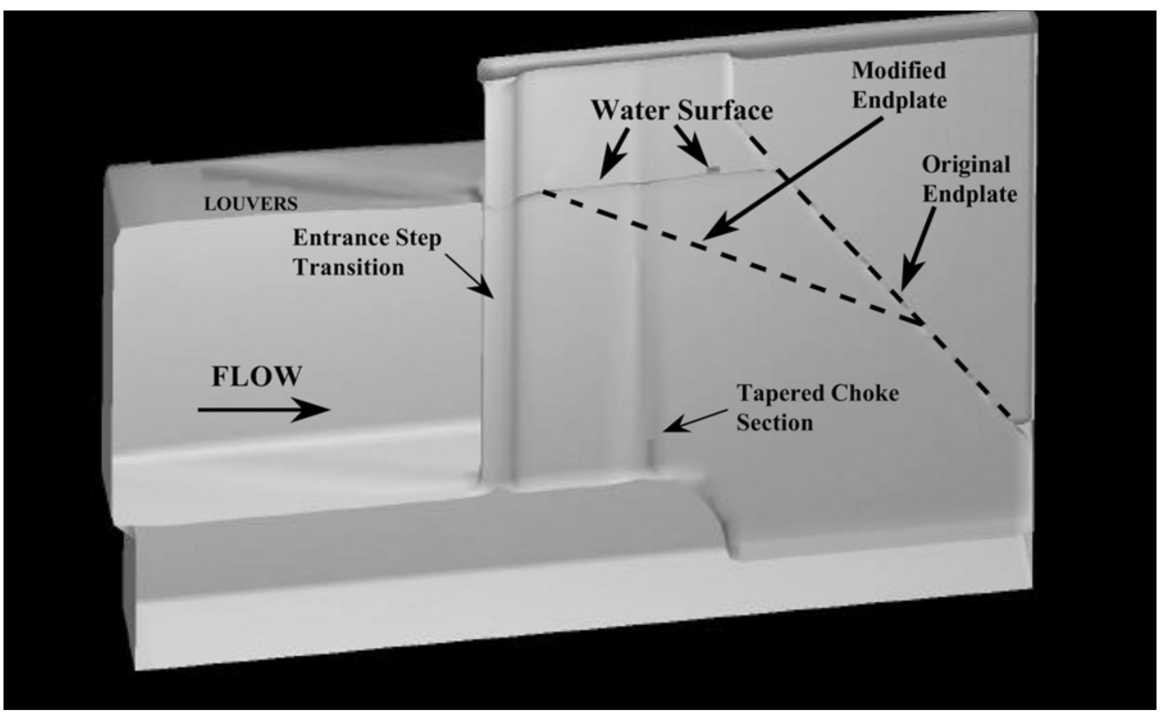


FIGURE 4.—Elevation view of the Phase 1 developed bypass showing the developed tapered choke.

The Phase 1 study and report (Kubitschek, 2003) address physical and computational model studies conducted to establish internal bypass structure modifications that generate uniform velocity distributions within the bypass intake. Other than verifying the first phase study findings with approach flow influences included, no additional studies were conducted in Phase 2 addressing refinement of the internal features of the bypass intake.

All evaluations were conducted with the bypass operating in compliance with current TFCF operating criteria. The bypass entrance for all tests was 6-in wide and extended the full height of the water column (the same configuration and size as the existing entrances). The model bypass was operated with bypass ratios (the ratio of mean bypass entrance velocity to primary channel transport velocity) of 1.2 and 1.6. These bypass ratios bracket the established criteria for bypass operation.

METHODOLOGY

Physical Model Description

A 1:6 Froude-scale physical model of a single primary bypass intake with approach louver line was constructed at Reclamation's Water Resources Research Laboratory in Denver, Colorado. Because the flow in the approach channel is nearly parallel and similar over the length of the primary louver, approximately a quarter of the facility was modeled (this yielded a larger size model that could be more accurately evaluated). Figure 5 displays details of the physical model showing the basic layout. Figure 6 shows a photograph of the physical model as constructed in the laboratory. The model layout and scale were selected to generate representative flow field and approach flow influences on the bypass entrance and the immediate bypass approach. Efforts were made to maximize flow section sizes to allow accurate velocity measurements and minimize viscous effects by providing sufficiently large Reynolds numbers. A maximum deliverable model flow of approximately 14 cubic feet per second (ft^3/s) limited the model size.

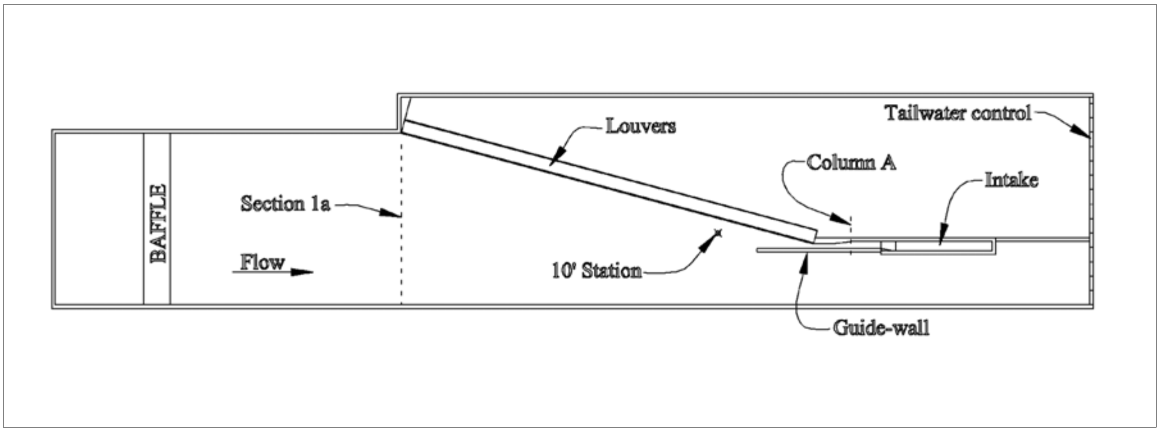


FIGURE 5.—Plan view layout of 1:6 Froude-scale physical model of a single TFCF primary bypass with an approach louver line.

FIGURE 6.—Photograph of 1:6 Froude-scale physical model of a single TFCF primary bypass with an approach louver line.

The Reynolds number provides an indication of the relative influences of viscous forces in a fluid flow field and is defined here as R_e = UL/í, where U is a characteristic velocity (the velocity through the section of interest), L is a characteristic length (in this case the bypass width or spacing between louver slats), and í is the kinematic viscosity of water. Provided R_e is sufficiently large, gravitational forces will predominate and, hence, Froude-scale similitude achieves adequate similarity between model and prototype and thus produces acceptable modeling accuracy. The Froude number provides an indication of the relative influence of gravitational forces that typically predominate for open channel or free surface flows and is defined as $F_r = U/(gL)^{½}$, where U is a characteristic velocity, L is a characteristic length, and g is the gravitational acceleration. Thus, Froude model similitude between model and prototype is achieved by the following relationships.

Geometric length ratio, L_r	=	6.0
Area ratio, $A_r = L_r^2$	=	36.0
Volume ratio, $V_r = L_r^3$	=	216.0
Kinematics		
Time ratio, $t_r = L_r^{1/2}$	=	2.45
Velocity ratio, $u_r = L_r^{1/2}$	=	2.45
Acceleration ratio, a_r	=	1.0
Discharge ratio, $Q_r = L_r^{5/2}$	=	88.2

The 1:6 Froude-scale physical model (figure 5) included a single primary bypass intake with the tapered choke developed in the Phase 1 study installed. The model also included 44.4-ft (prototype) of louver line converging at 15º to the approach channel. This corresponds to approximately half the length of the louver line between each of the bypass intakes in the existing structure (figure 2). Louver slat spacing was maintained at 1-in because of constructability and modeling distortion concerns. As a consequence, general flow patterns are correctly modeled but details of flow patterns on and through the louvers were not represented in the physical model. The length of louver included was considered adequate to establish louver influences on bypass approach flow distribution. The model also included a 5.5-ft-wide (prototype) channel passing the bypass structure on the approach channel side and a 15-ft-wide (prototype) channel passing the bypass on the exit channel side. These channels were sized and configured to represent passing flow influences on the energy field across the louver line.

Model Verification Data

Field and model data collected for the TFCF were available and were used to guide the model setup and to supply verification of model operating conditions. Where appropriate, these data are presented with model findings in this report to display comparisons. Available data included:

- **Bypass Entrance –** Field data documenting velocity distributions at the existing bypass entrances were collected by Kubitschek (2001). The evaluated bypass intakes originally included flow distribution control vanes. The actual condition of the intakes and turning vanes at the time of evaluation is uncertain. These intakes did not include the recently developed tapered choke. The field data tend to show non-uniform vertical velocity distributions that likely result from debris fouled vanes or from failed and missing vanes. Consequently, these data were not useful in guiding setup or validation, but highlight existing problems with the existing bypass performance.

  Hydraulic laboratory model studies by McBirney (1956) of the original design with turning vanes and by Kubitschek (2003) in the Phase 1 study (that developed the tapered choke velocity distribution control treatment) provide data on the vertical velocity distributions in the bypass entrance. Both studies indicate the vertical velocity uniformity that is desired. It should be recognized that these model studies did not include approach flow that could have an influence.

- **Primary Louver and Bypass Approach Flow –** Vertical velocity profiles were evaluated at various locations in the primary louver and bypass approach channel of the TFCF (Marsden and Frizell, 2001). The specific operating conditions (specific flow rates, the extent of debris fouling of the trashracks and louvers) that were evaluated were not documented by Marsden and Frizell, as they intended to demonstrate the capabilities of an Acoustic Doppler Profiler. These data cannot be referenced to supply profile magnitude and distribution specifics but they do supply general indications of the main channel approach velocity distributions that can be expected.

Physical Model Testing

Testing consisted of refining and verifying model setup and then evaluating and refining the bypass approach velocity characteristics of the design. These evaluations were conducted over the full range of potential TFCF primary system operation. Flow depths and transport velocities in the TFCF approach channel are influenced by tidal effects and TPP operation. The minimum primary channel depth is approximately 16 ft, while the maximum flow depth is approximately 21 ft. Primary louver bypass flows are governed by head differential between the primary channel and the secondary louver channel (figure 2). Pumping from the secondary channel at its downstream end controls the water surface elevation in the secondary channel. Depending on the time of the year and the fish species present, the bypasses are operated to comply with established criteria bypass ratios (the ratio of the mean bypass entrance velocity to the mean approach channel transport velocity, U_{bypass} / $U_{transport}$). The bypass entrance velocity is adjusted to compensate for changing velocities in the approach channel (to sustain constant bypass ratios) by turning off or on secondary channel control pumps. The bypasses are operated to generate bypass ratios that range from 1.2 to 1.6, although facility limitations at times restrict operating capacity.

The flows evaluated were turbulent. Levels of turbulence intensity as measured by the magnitudes of velocity fluctuations were not determined. All velocities presented in this report are time-averaged means.

The testing process consisted of:

1. Validation and refinement of model setup to insure proper approach flow conditions.—An Acoustic Doppler Velocimeter (ADV) was used to evaluate velocity distributions in the approach and exit channels. Selective flow resistance was applied to flow entering the entrance channel from the model head-box to generate vertical velocity distributions in the approach channel that generally correspond to those presented in Marsden and Frizell (2001).

2. Validation of the velocities in the bypass intake.—A two- dimensional Laser Doppler Anemometer (LDA) was used to evaluate velocity distributions in the bypass intake structure. Velocity measurement locations were selected to correspond to measurement locations used in the previous model studies (McBirney, 1956; Kubitschek, 2003) to allow direct comparison between findings. Figure A1-1 in appendix 1 shows a cross section of the bypass and measurement vectors for the laser anemometer, denoted as Columns A-E. Velocities were evaluated at the extreme limits for bypass operation to generally bracket and verify that velocity distributions predicted from the Phase 1 model occur with the

included approach velocity influences. This work was intended as a validation of the Phase 1 findings and of the Phase 2 model setup. Prototype operating conditions evaluated were:

Channel Depth	Bypass Discharge	Bypass Ratio	Approach Velocity	Bypass Velocity
16 ft	40 ft^3/s	1.2	4.17 ft/s	5.0 ft/s
20 ft	20 ft^3/s	1.2	1.67 ft/s	2.0 ft/s

3. Validation of velocity distributions across the louver line face.—Velocity distribution across the louver line face was evaluated with a flow depth of 16 ft, a bypass discharge of 40 ft^3/s, and a bypass ratio of 1.2. This approximately corresponds to an operating condition evaluated by Marsden and Frizell on August 16, 2001. This, again, was evaluated to supply confirmation of model setup and to confirm that the reduced length of louver line included was sufficient to establish representative bypass approach velocity distributions.

4. Evaluation of velocity distributions in the bypass entrance approach wedge.—Digital tracking of surface floats and CFD modeling were used to evaluate velocity distributions in the approach wedge contained within the volume defined by the louver face and the bypass guide wall (figure 5). With this evaluation, typical flow patterns that occur in this zone were evaluated to determine if modifications should be made to the structure or operations to improve fish guidance characteristics to the bypass entrance. Conditions evaluated were:

Channel Depth	Bypass Discharge	Bypass Ratio	Approach Velocity	Bypass Velocity
16 ft	40 ft^3/s	1.2	4.17 ft/s	5.0 ft/s
20 ft	20 ft^3/s	1.2	1.67 ft/s	2.0 ft/s

These conditions were selected for the evaluation to generally bracket the potential ranges of operation.

Based on the initial findings, two alternative modifications were made that generated additional back pressure over the last reach of louvers (immediately upstream from the bypass entrance), thus, reducing velocities through that reach of louvers. The influence of these modifications was evaluated using the CFD model. The developed concept represents the recommended design.

5. Evaluation of bypass entrance performance without the guide wall.—To explore the implications of a possible future modification to the TFCF that could include guide wall removal to allow louver cleaning without louver panel removal, hydraulic performance of the bypass intake without the guide wall was evaluated. Approaching and passing velocities were evaluated at stations located 20 ft and 10 ft upstream from the leading edge of the bypass entrance, at the leading edge of the entrance, at the trailing edge of the entrance, and 4 ft downstream from the trailing edge. Velocity profiles were also evaluated at quarter points across the bypass entrance.

   These evaluations were conducted for the following operating conditions:

Channel Depth	Bypass Discharge	Bypass Ratio	Approach Velocity	Bypass Velocity
16 ft	40 ft^3/s	1.2	4.17 ft/s	5.0 ft/s
20 ft	20 ft^3/s	1.2	1.67 ft/s	2.0 ft/s

Computational Fluid Dynamics Model Description

Flow-3D®, a CFD software package from Flow Science, Inc., was used to develop a full-scale, two-dimensional, fully turbulent, viscous computational model of a single primary bypass intake with a length of approach louvers. The CFD model allowed detailed evaluation of flow conditions through the louvers (between louver slats) and along the louver face. The required level of hydraulic documentation resolution could not be achieved using the physical model. Geometry for the CFD model was generated using the Flow 3-D solids modeler. The geometry and CFD models were meshed using a non-uniform grid to obtain sufficient flow structure resolution within the relatively small sections between louvers. The boundary conditions used for the CFD model were based on mid-depth conditions with the bypass operating with a 20-ft flow depth, 20-ft^3/s bypass discharge, and a 1.2 bypass ratio. Boundary conditions used consisted of a:

1. Constant velocity (1.7 ft/s) at the inflow boundary as established by laboratory measurements

2. “Sink” near the end of the bypass that produced a constant outflow velocity (1.62 ft/s) as established by laboratory measurements.

3. Constant pressure boundary downstream from the louvers that allowed for natural fluctuations of the flow field downstream from the louvers.

4. Wall boundary at the sides of the model.

Simplifications included in the CFD model were use of 2-D modeling to represent the flow field and rectangular shaped turning vanes behind the louvers instead of the curved turning vanes as used in the actual TFCF louvers. These simplifications were applied to expedite modeling and reduce computer run times.

A 2-D analysis was considered applicable because we were looking for changes in the flow field’s X-Y plain and all boundaries and the louver section are vertical. The simplified vane geometry generates representative flow field and energy control with respect to both control uniformity and magnitude of the potential field across the louver. The simplified vane geometry would not affect the occurrence of localized high velocity zones both upstream from the louver face and between the louver slats. Localized high-velocity zones and, thus, design and regulation issues could be identified.

Computational Fluid Dynamics Model Testing

The CFD model was applied to specifically evaluate the near field velocities approaching the bypass intake. The model included approximately 6 ft of approach louver, the 6-in-wide bypass intake, the guide wall, and approach and exit channels that allowed establishment and representation of the influences of approach, passing, and exiting flow.

The model was evaluated with an approach transport velocity of 1.7 ft/s and a bypass entrance velocity of 1.62 ft/s. This corresponds to the facility operating with a bypass ratio of approximately 1.0 (this was the documented mid-depth operating condition for the 20-ft depth, 20-ft^3/s operation). It should be noted that for this operating condition, even though the average bypass ratio was 1.2, actual bypass ratios varied vertically across the entrance. The study focused on evaluating lateral velocity magnitudes (velocity components normal to the approach channel and parallel to the louver slats). The lateral velocity is the most sensitive component and a direct indication of velocity attractions to the louver face.

The model was initially evaluated based on the existing and proposed replacement bypass intake structure and louver design. Alternative treatments that modified local high velocity zones through the louver were then evaluated.

RESULTS AND DISCUSSION

Bypass Entrance Velocities – Physical Model

Initial velocities in the bypass intake and transition box were evaluated in the physical model. This evaluation was conducted to validate the Phase 1 findings with the included influence of approach and passing flow. As previously noted, because of the large size of the Phase 1 model, sufficient flow could not be supplied to that model to represent the passing and approach flow influences.

Velocity distributions within the bypass intake were evaluated with and without the modified end plate treatment (figure 4). The modified end plate treatment was developed in the Phase 1 study as a way to reduce an eddy/slack-water zone that was observed in the upper portion of the intake and transition box. Because of the flow improvements displayed in the Phase 1 model, the bypass intake structure with the modified end plate was selected for the TFCF replacement structure design. Performance of the bypass with the modified bypass end plate was evaluated with a 16-ft depth, a 40-ft^3/s bypass discharge, and a 1.2 bypass ratio and with a 20-ft depth, a 20-ft^3/s bypass discharge, and a 1.2 bypass ratio. These conditions generate extremes in velocity magnitudes approaching and passing through the bypass, and bracket the range of the possible prototype operating conditions. After validating the model setup, establishing the approach flow velocity distributions that corresponded to those observed by Marsden and Frizell (2001), and refining the approach flow velocity field, velocities within the bypass were evaluated. Figure 7 shows approach channel velocity distributions evaluated by Marsden and Frizell at a station 10 ft upstream from the bypass entrance (figure 5) near the louver line and corresponding velocities evaluated in the model. Note that the field and model vertical velocity distribution patterns are similar. This implies that the model setup and the approach flow distributions are representative of conditions that have been documented in the field at the TFCF.

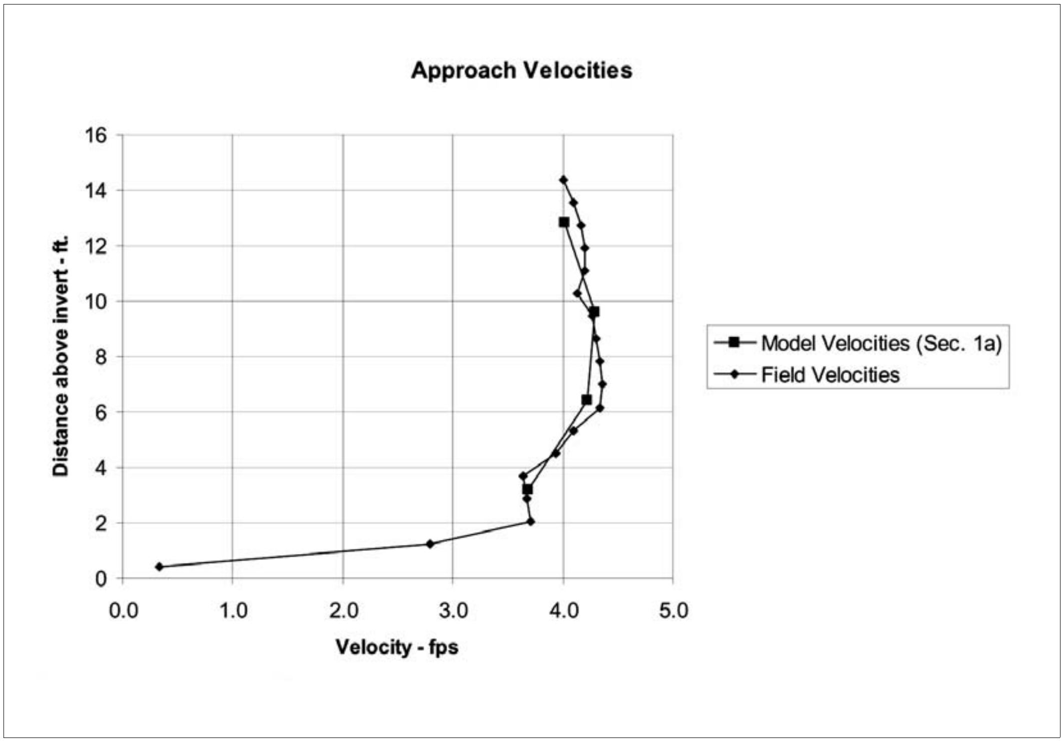


FIGURE 7.— Comparison of Model and prototype (Marsden and Frizell, 2001) approach velocity distributions with a 16-ft primary channel flow depth, a 40-ft^3/s bypass discharge, and a 1.2 bypass velocity ratio.

The velocity distributions observed at the bypass entrance with the 16-ft flow depth and 40-ft^3/s bypass discharge, are shown in figure 8. This displays bypass performance with high-velocity operation. Documented velocity distributions observed at other sections throughout the bypass structure are shown in figures A1-1 through A1-6 (in appendix 1). Included in figure 8 are the bypass entrance velocity distributions evaluated for the bypass with the existing end plate treatment and the bypass entrance velocity distribution evaluated with the modified end plate.

Figure 9 shows the bypass entrance velocity distribution evaluated for the intake structure with a modified end plate operating with a 20-ft depth, a 20-ft^3/s bypass discharge, and a 1.2 bypass ratio. This displays performance with low velocity operation. Combined with the evaluation displayed in figure 8, the evaluations bracket the typical range of bypass operations. Also included in figure 9 is the corresponding approach velocity distribution applied. Velocity distributions evaluated at other sections throughout the bypass structure for this operation are shown on figures A1-7 through A1-11 in appendix 1.

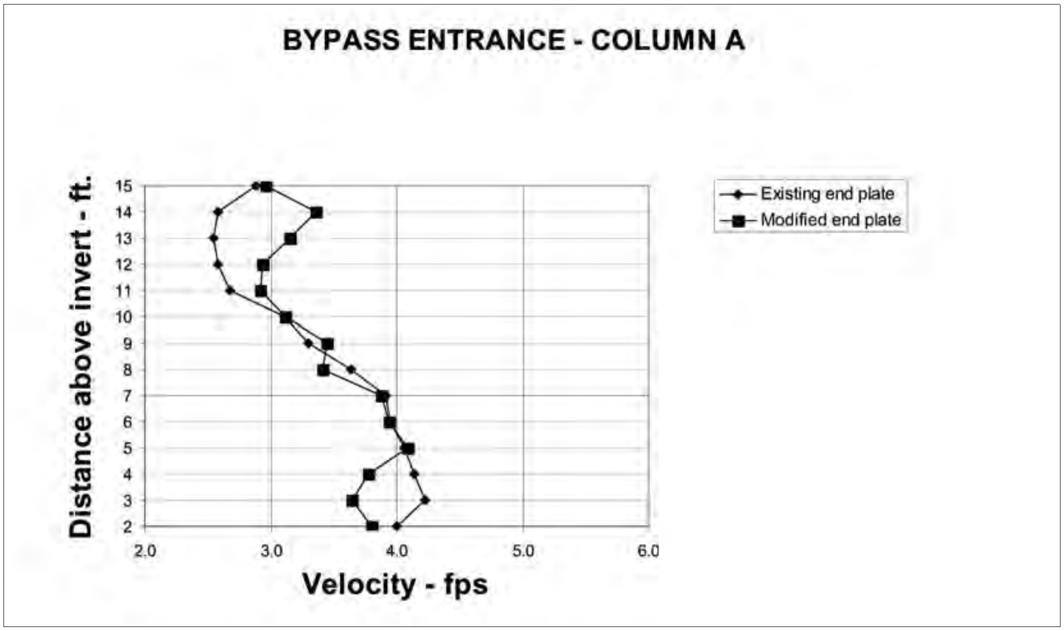


FIGURE 8.— Bypass entrance velocity distribution (centerline) with a 16-ft primary channel flow depth, a 40-ft^3/s bypass discharge, a 1.2 bypass ratio, existing and modified end plate treatments, and a near field approach velocity distribution that has been physically adjusted to correspond to field observed conditions.

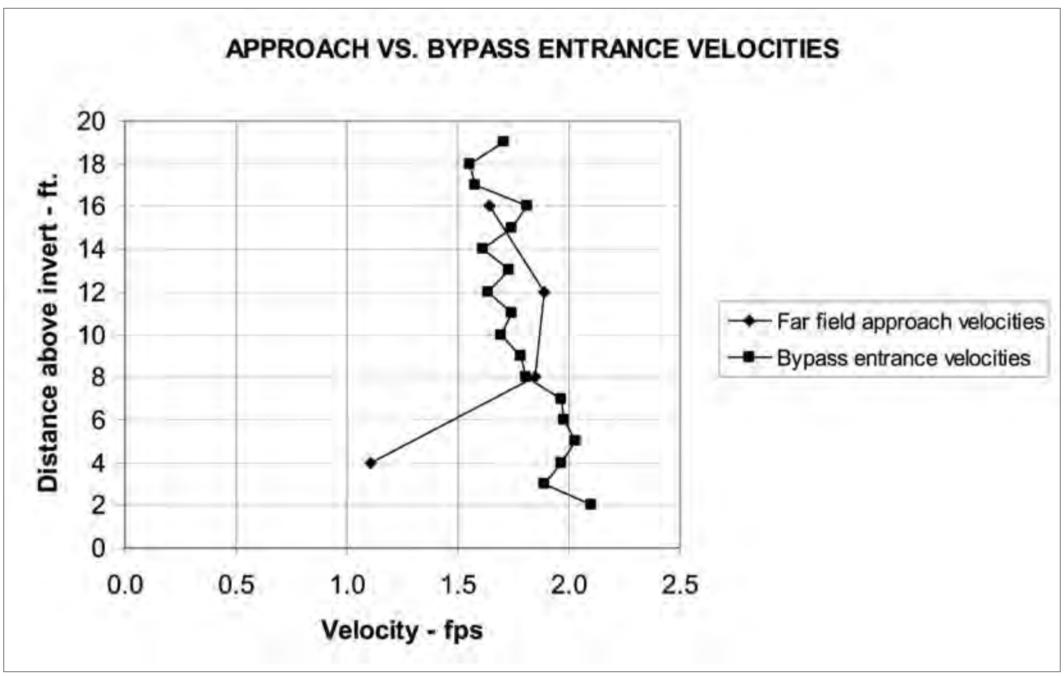


FIGURE 9.— Bypass entrance centerline velocity distribution with a 20-ft depth, a 20-ft^3/s bypass discharge, a 1.2 bypass ratio, a modified end plate, and an approach velocity distribution that has been physically adjusted to correspond to field observed conditions. (The applied velocity distribution at a station 10 ft upstream from the bypass entrance is shown.)

A byproduct of the initial model setup investigation was a demonstration of the influences of approach velocity distribution on velocity distributions within the bypass. The effects of approach velocity distribution on the bypass entrance velocity distribution were demonstrated early in the study. Velocities within the bypass were evaluated operating with a 20-ft flow depth, a 20-ft^3/s bypass discharge, a 1.2 bypass ratio, and two different approach flow distributions. Figure 9 displays one approach velocity distribution and figure 10 displays the other. Corresponding observed bypass entrance velocity distributions are shown in each figure. The approach distribution in figure 9 corresponds to velocity distributions documented by Marsden and Frizell (2001), while the distribution shown in figure 10 includes reduced surface velocities and velocity maximums at mid-depth. With all other operating conditions being the same, a comparison of observed entrance velocity distributions shows that the modified approach velocity distribution (figure 10) can yield severe vertical velocity gradients at the bypass entrance.

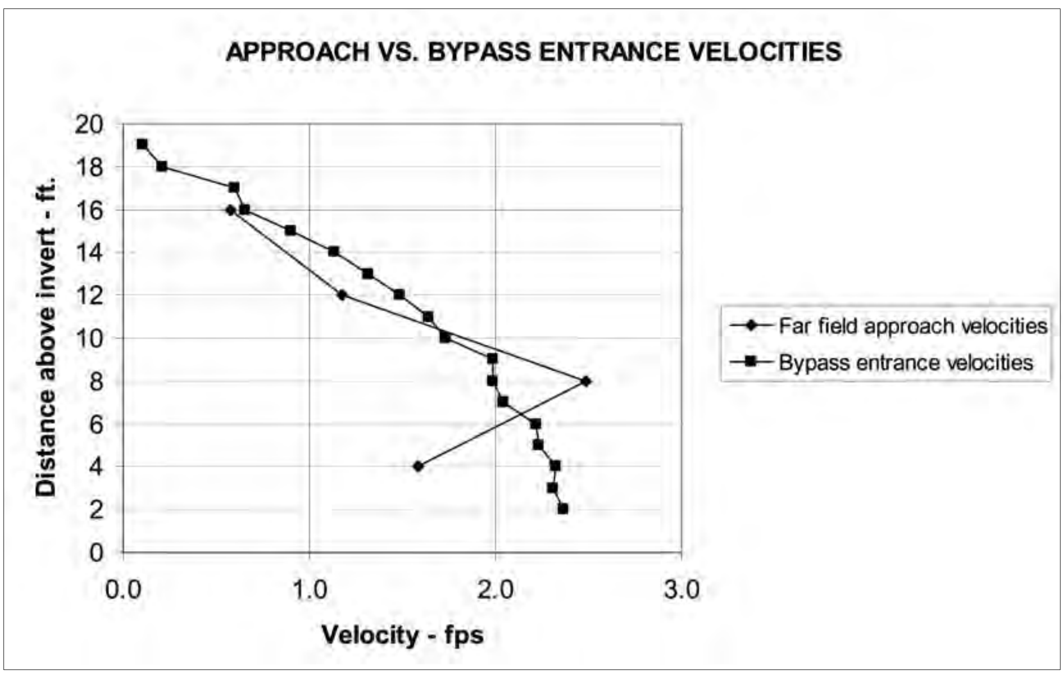


FIGURE 10.— The bypass entrance centerline velocity distribution observed with a 20-ft depth, a 20-ft^3/s bypass discharge, a 1.2 bypass ratio, and an alternative approach velocity distribution. (The alternative distribution at a station 10 ft upstream from the bypass intake is shown.)

The lesson to learn from this is that both near-field and far-field approach velocity distributions can significantly influence the bypass entrance velocity distribution. Non-uniform fouling of the trashrack or louver might generate distorted vertical velocity profiles that in turn would generate non-uniform far-field and bypass entrance velocity distributions. These findings may indicate the importance of maintaining clean louvers and trashracks that would sustain approach flow distributions that correspond to those that the bypass system was developed to operate with.

Near Field Bypass Approach Velocities – Physical Hydraulic Model

Initially, efforts were made to use an electromagnetic velocity meter to evaluate near field resultant velocities in the wedge contained between the louver face and guide wall (figure 11). The electromagnetic meter was applied because it offered the best available instrumentation for application in the confined space. The drawback of the electromagnetic meter is that it evaluates a mean velocity that occurs in a volume and thus it indicates general velocity trends but does not supply detailed resolution. Figure 12 shows results obtained from the electromagnetic meter study with the intake operating with the 20-ft flow depth and 20-ft^3/s bypass discharge. The vector orientation presented in figure 12 is representative of vector fields observed over a range of operations in this phase of the study. In general, it was concluded that velocities were well oriented and supplied good general guidance to the bypass entrance. Unfortunately, it was also concluded that the electromagnetic meter did not supply sufficient resolution to document localized high velocity zones along the louver face.

Efforts were then made, using the physical hydraulic model, to evaluate the near field velocities in the wedge with emphasis on identifying pronounced velocity features that might guide fish to and through the louver, diverting them from guidance to the bypass entrance. Again, observations were that high velocity attraction zones to the louver were very localized and that detailed evaluation resolution would be required to adequately document them. Again, limitations with conventional instrumentation and difficult access prevented obtaining detailed and well-resolved evaluations using the physical model.

A technique that used digitized video tracking of small surface floats was found most effective in generating detailed vector fields. Products that this technique generated include:

1. Flow paths of individual floats that, when combined through multiple tracking, displayed the large-scale turbulence and the variability that are present in the flow fields.

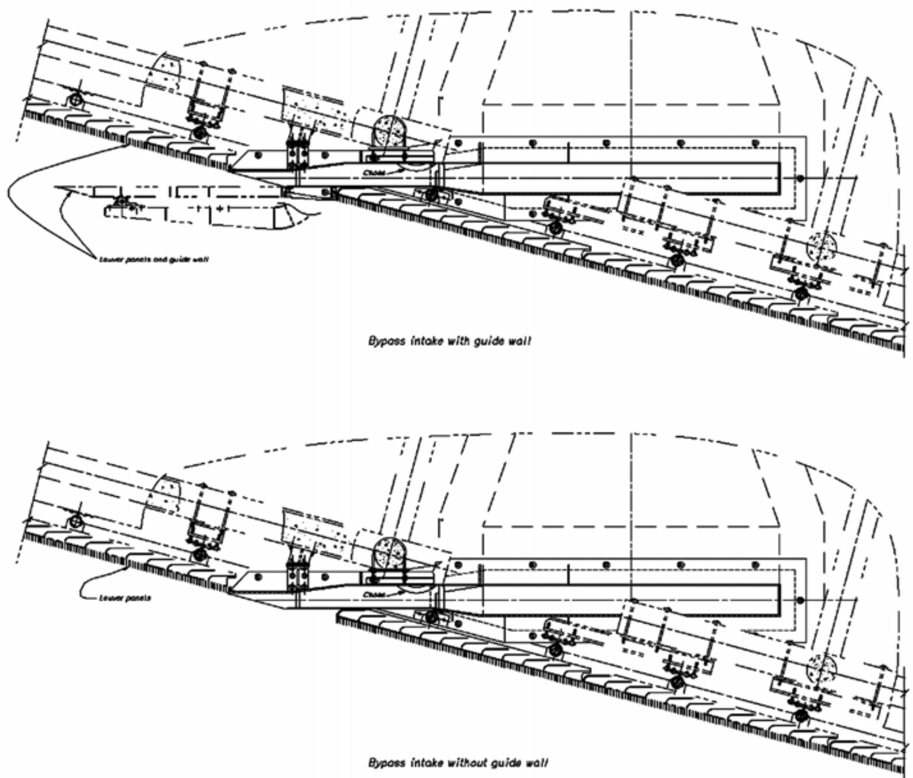


FIGURE 11.—Bypass intake with and without guide wall.

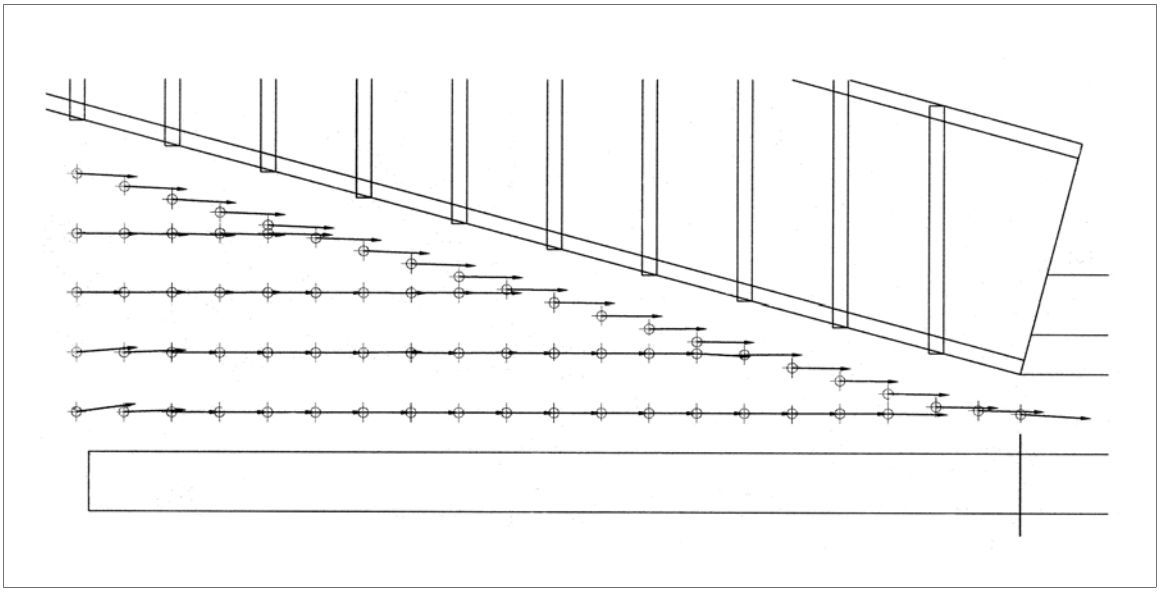


FIGURE 12.— Representative electromagnetic meter evaluations of near field approach velocities – intake operating with a 20-ft depth, 20-ft^3/s bypass discharge, and 1.2 bypass ratio.

2. Evaluation(s) of grid based vectors based on mean values obtained from multiple float trackings in localized zones. On average, four vectors obtained from the trackings (both magnitudes and flow direction) were averaged at each grid node. These vectors supply a representation of mean flow conditions.

Limitations of float tracking evaluation technique include:

1. The technique is limited to the evaluation of surface flow conditions. The surface flow conditions are strongly influenced by local, near-surface velocities entering the bypass entrance and by wave action and flow deflection that are generated off structural features (in particular the leading edge of the guide wall). These conditions likely are not fully representative of the detailed velocities throughout the water column.

2. Flow conditions through the louver and between the louver slats were not readily visible using the video tracking technique. Also, the narrow spacing between the slats and model simplifications of the slat array (a coarser spacing between slats was used to simplify model construction and reduce potential viscosity related modeling distortions) prevented detailed documentation of flow conditions through the louver.

Findings from the digitized tracking studies are presented in figures 13 through 16. Figures 13 and 14 display the video float trackings obtained with a 20-ft flow depth, 20-ft^3/s bypass discharge, and 1.2 bypass ratio and with a 16-ft flow depth, 40-ft^3/s bypass discharge, and 1.2 bypass ratio. Figures 15 and 16 display the computed grid based vector fields generated for the same operating conditions. Both trackings display general guidance along the guide wall to the bypass entrance, although deflections of flow towards the louver do occur off the guide wall nose with the higher velocity. Both tracking sets also show float deflection and guidance along the louver face. The general documented trend is float guidance along the louver face and through the wedge to the bypass entrance. The vector fields display fairly uniform velocities through the wedge and to the bypass. There is a tendency with the 16-ft-deep, high-velocity condition (figures 14 and 16) for increased louver passage to occur at a location approximately mid-way down the wedge. This may, in part, be caused by wave or wake flow disturbances initiated by flows past the guide wall nose that locally deflect flow towards the louver face.

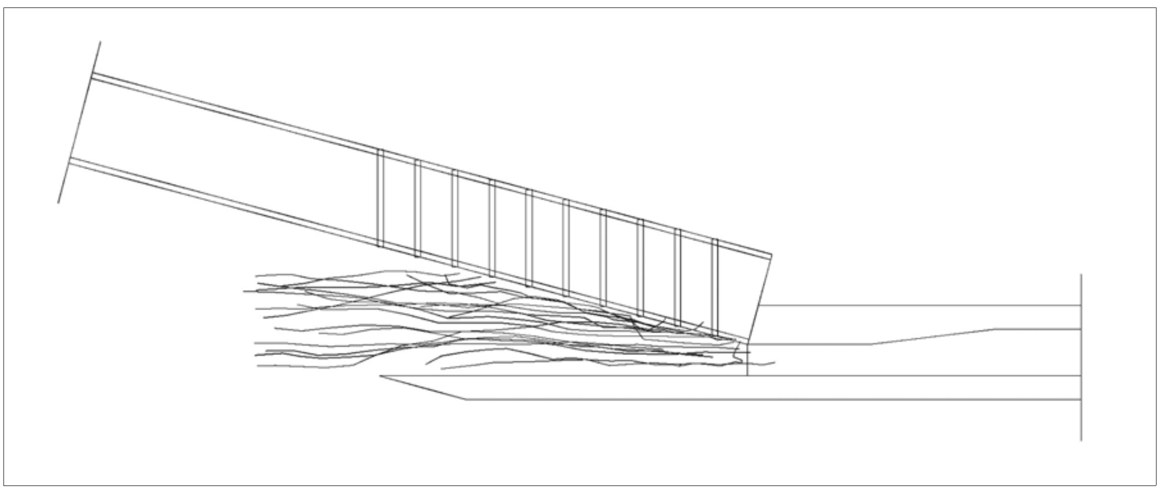


FIGURE 13.—Near field approach flow patterns – individual float trackings with a 20-ft flow depth, a 20-ft^3/s bypass discharge, and a 1.2 bypass ratio.

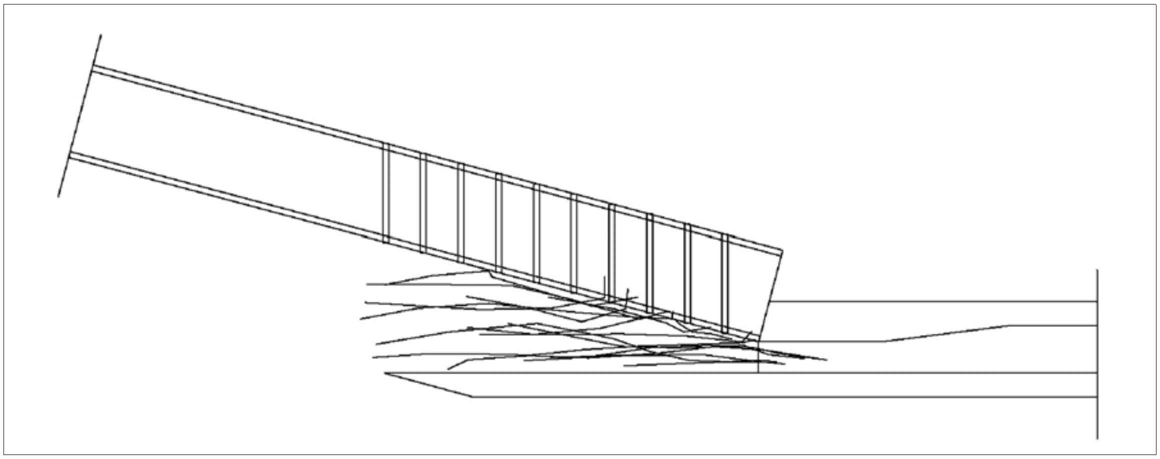


FIGURE 14.—Near field approach flow patterns – individual float trackings with a 16-ft flow depth, a 40-ft^3/s bypass discharge, and a 1.2 bypass ratio.

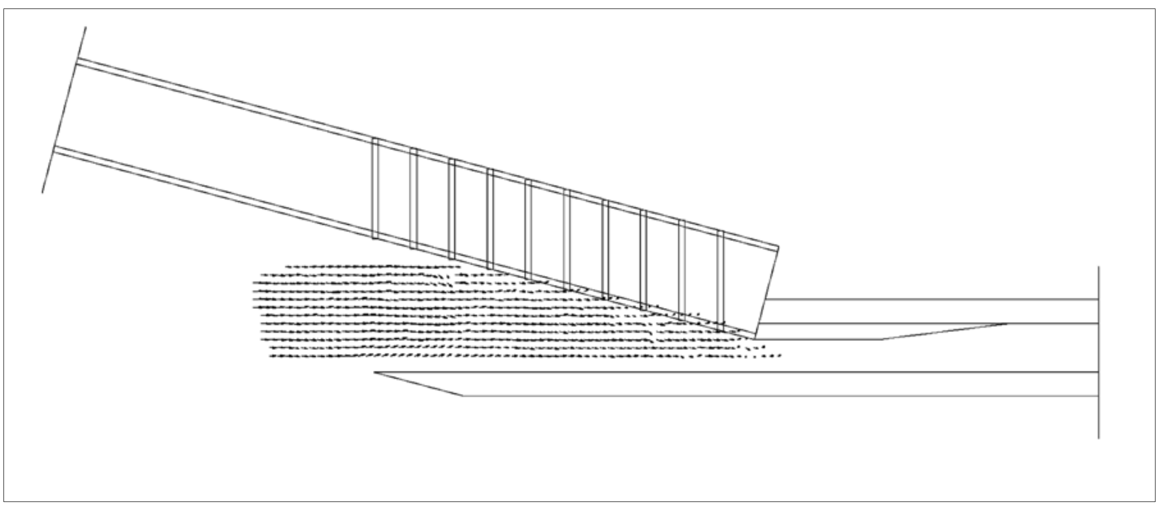


FIGURE 15.—Near field computed vector field – with a 20-ft flow depth, a 20-ft^3/s bypass discharge, and a 1.2 bypass ratio.

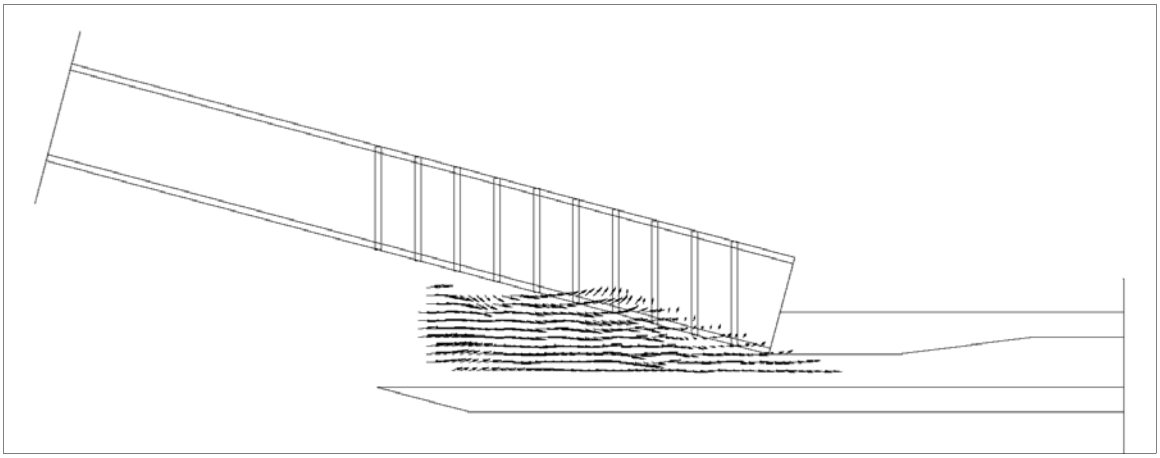


FIGURE 16.—Near field computed vector field – with a 16-ft flow depth, a 40-ft^3/s bypass discharge, and a 1.2 bypass ratio.

Near-Field Bypass Approach Velocities – Computational Fluid Dynamics Model

To better quantify and evaluate through-louver flow distributions in greater detail, modeling of the near-field bypass approach velocity was pursued using the CFD model. Limited initial studies were conducted evaluating longitudinal velocities or velocity components that are parallel to the approach channel and guide wall. These evaluations showed small accelerations in the channel velocity as the flow approached the bypass entrance and a small resulting increase in longitudinal approach velocity magnitude (approximately 0.1 ft/s) across the last approximately 0.75 ft of louver length (figure 17). Because of the relatively small variations displayed, evaluation efforts then focused on the lateral velocity component (the velocity component normal to the approach channel and guide wall and parallel to the louver slats). The lateral velocity components would more sensitively display velocity influences that could attract fish to the louver.

The CFD model was initially used to evaluate near-field lateral approach velocities that occur with the proposed replacement design (figure 11). This design included details of the louver configuration and louver transition to the bypass entrance that are the same as those present in the existing TCFC facility. The results of this evaluation are shown in figure 18. Note that the flow passing between louver slats concentrates on the downstream side of the openings causing local high velocity areas across the face of the downstream slat. Velocity magnitudes tend to increase across each cycle of louver length (as defined by the length of louver face influenced by each turning vane), with the greatest velocities occurring across the last louver face of the cycle. Note in figures 17, 18, and 19 that these local higher velocities occur primarily between the louver slats and extend, at most, 2.0 in out from the louver face.

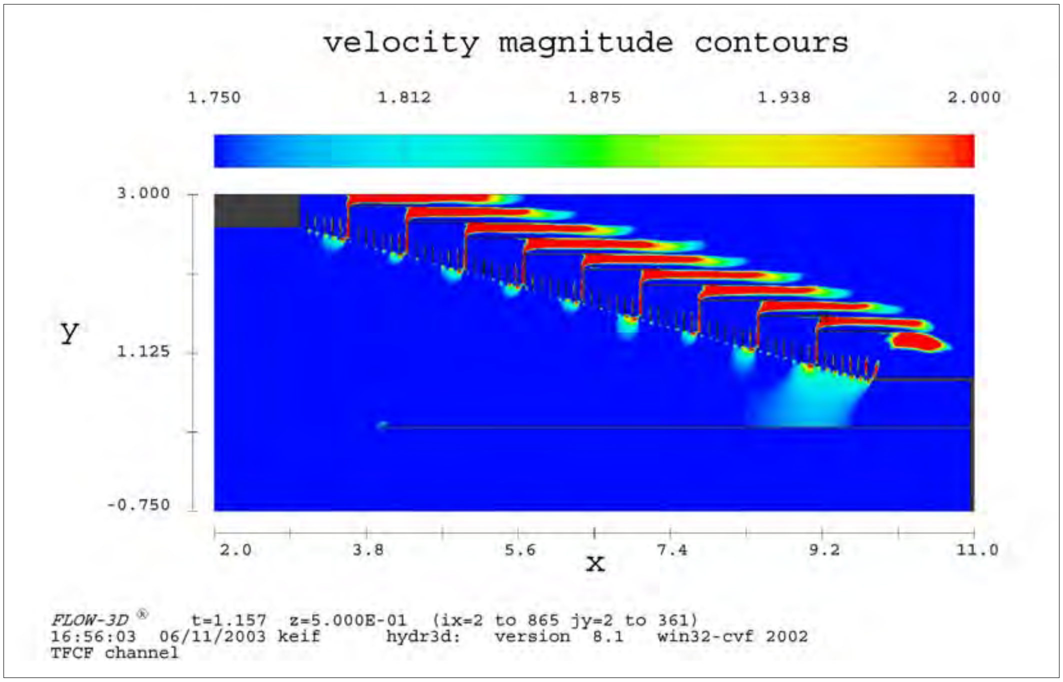


FIGURE 17.—CFD simulated resultant velocities produced by the initial design.

Figure 18 also shows that, with the existing design (and the proposed replacement design), the highest lateral velocities occur over the last cycle (as defined by the louvers influenced by the last turning vane) of the louver face immediately upstream from the bypass entrance. These high velocities occur at the critical location, just before the bypass entrance, where fish likely hold trying to avoid entering the narrow and dark bypass. If fish hold, louver guidance characteristics are reduced and fish passage through the louvers may increase.

It was noted that the high velocities result from less constriction of the flow path exiting the last louver cycle. The absence of a turning vane at the downstream end of the louver adjacent to the bypass results in approximately twice the perpendicular flow area exiting the louvers immediately downstream from the louver slats (figure 18). As a result, the back pressure on the last louver cycle is greatly reduced and flow rates through the last cycle are increased.

To reduce velocities through the last cycle, alternative elements were applied that mimic the exit section control of the over lapping turning vanes. Initially, the influence of just the lateral leg of the turning vane was evaluated. This was followed by evaluation of the influence of the full turning vane. Figures 19 and 20 show the corresponding evaluated lateral velocities. The findings indicate that either control option generates appropriate back pressure and velocity reductions. It appears that a simplified element that generates an exit section width that is comparable to the width between overlapped turning vanes supplies acceptable control.

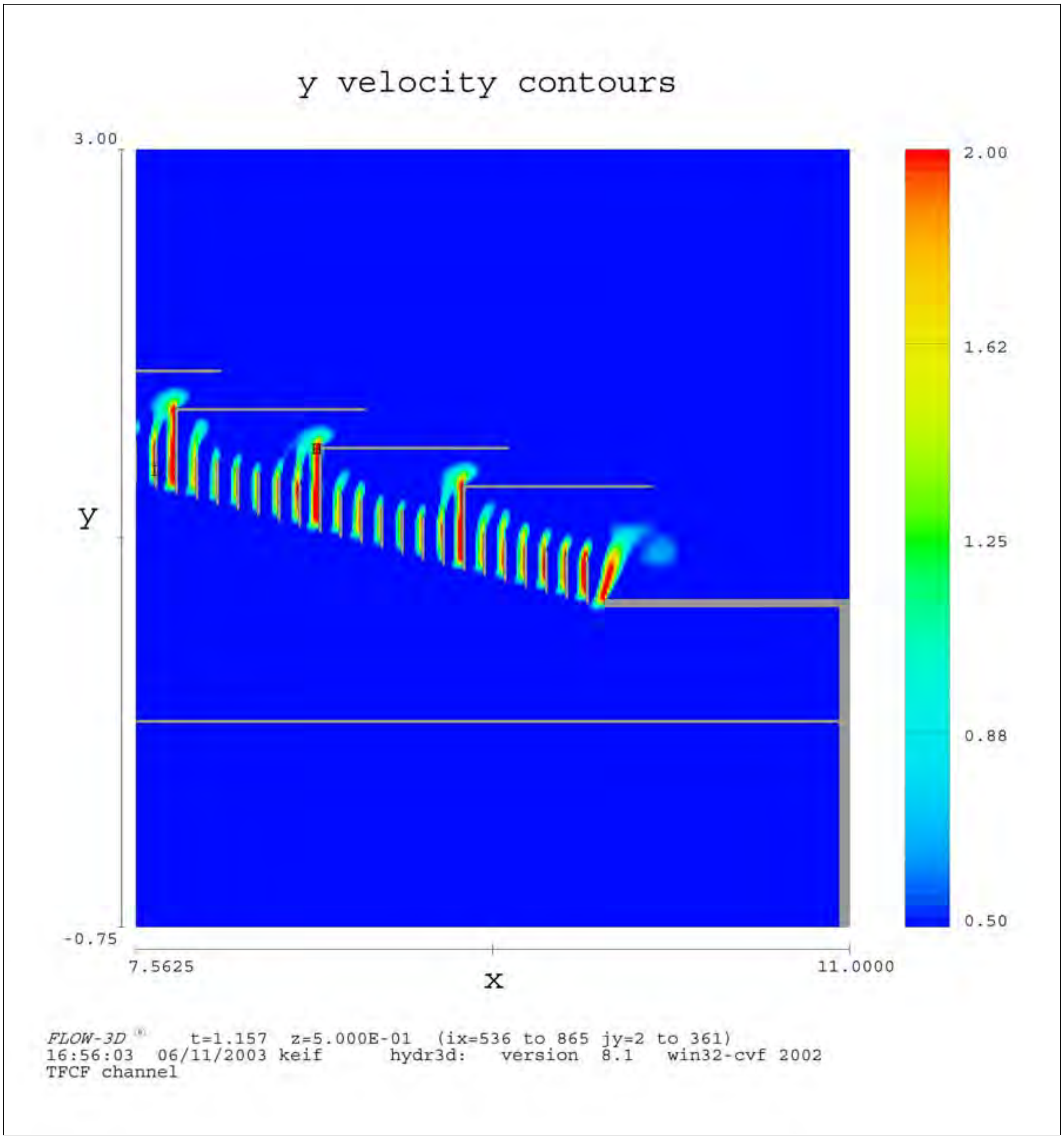


Figure 18.—CFD simulated lateral velocities produced by the initial design.

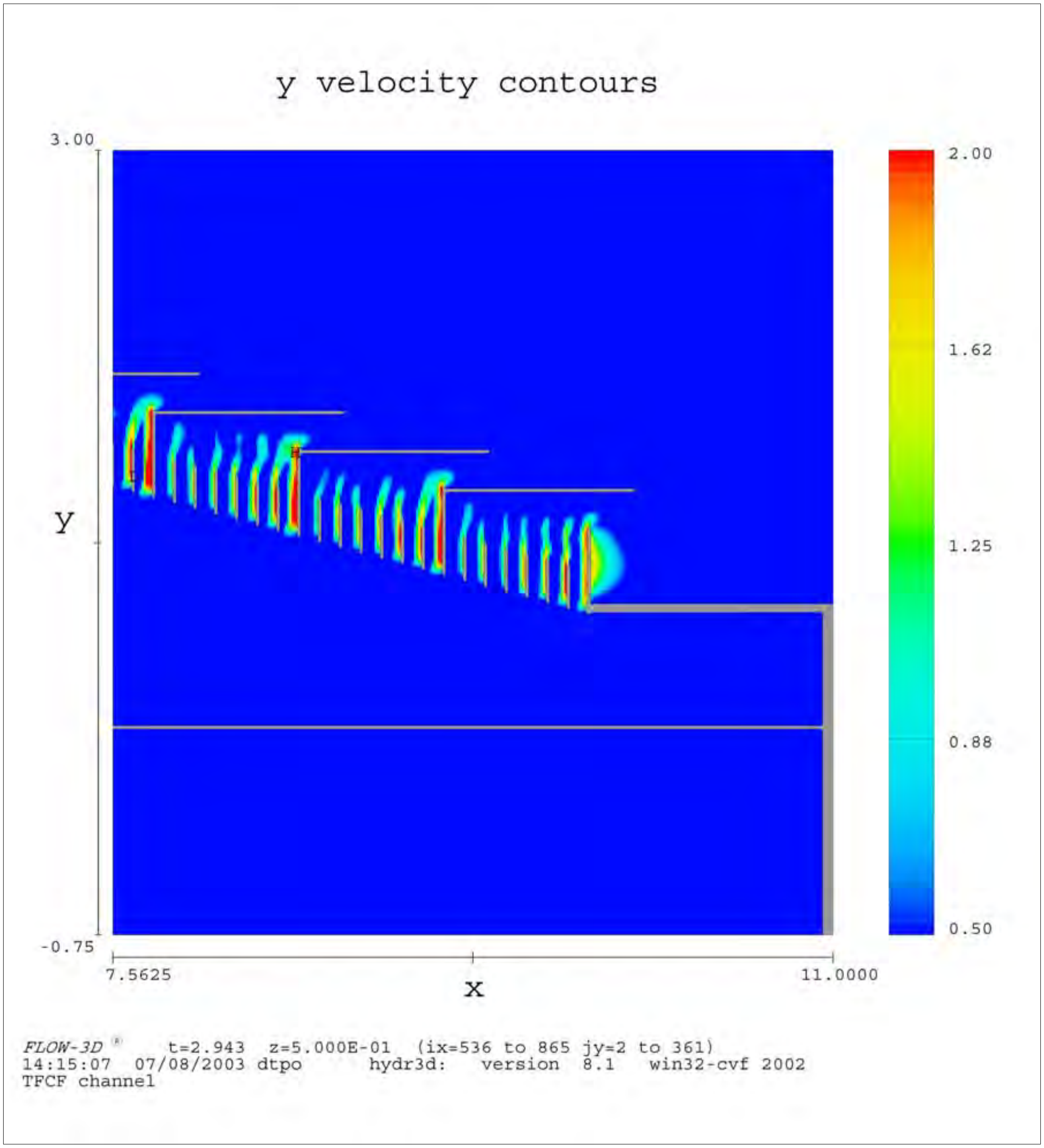


FIGURE 19.—CFD simulated lateral velocities produced by the initial design with a partial vane treatment.

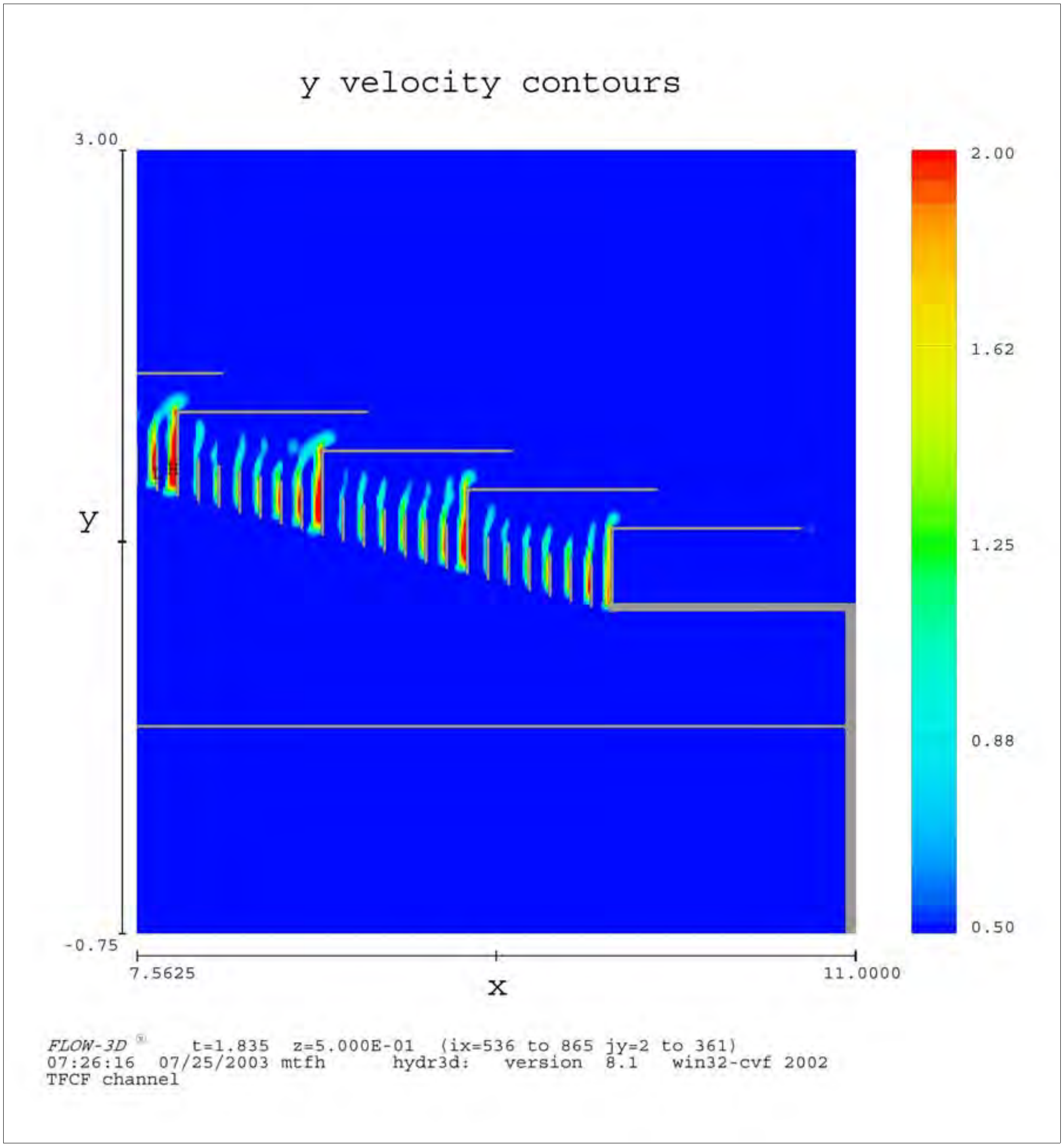


FIGURE 20.—CFD simulated lateral velocities produced by the initial design with a full turning vane treatment.

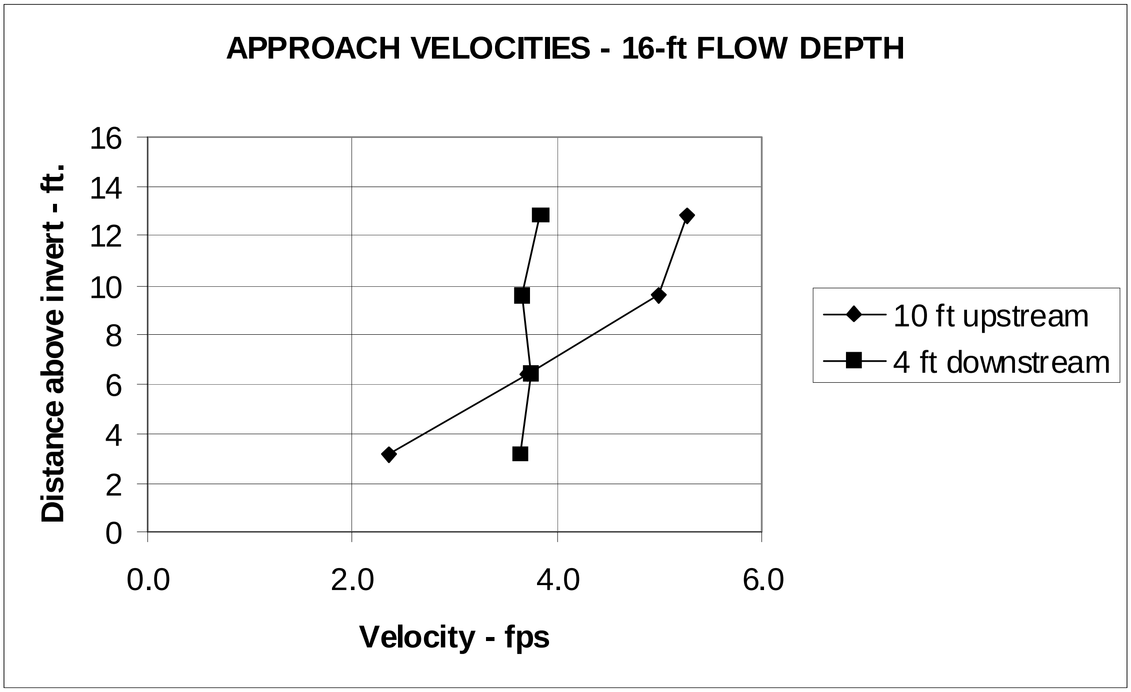
Bypass Performance Without Guide Wall

As this study progressed, it was pointed out that a major deficiency with the existing TFCF is the need to remove louver panels for cleaning. Louver fish exclusion efficiencies could be substantially improved by developing an effective louver cleaning system that would leave the louvers in place. This might constitute a facility improvement or upgrade effort for the future. One obstacle to in-place louver cleaning is the guide walls. Spacing between the guide walls and the louvers does not allow access with cleaning equipment in these critical locations where both debris and fish are concentrated. It was proposed that facility operation without guide walls be considered. Because both the physical and CFD models were available, an opportunity existed to evaluate the hydraulic implications of guide wall removal.

The bypass entrance velocity distributions and the surrounding flow field were evaluated again with a 20-ft flow depth, 20-ft^3/s bypass discharge, and 1.2 bypass ratio and with a 16-ft flow depth, 40-ft^3/s bypass discharge, and 1.2 bypass ratio. For these operating conditions, velocities were evaluated at sections positioned 20 ft and 10 ft upstream from the leading edge of the bypass intake, at the leading edge, at the trailing edge, and 4 ft downstream from the trailing edge of the intake. Without the guide wall, the bypass intake becomes a diagonal section across a rectangular conduit with leading and trailing vertical edges (figure 11). At each section, velocity profiles were evaluated at stations 1.0, 1.5, and 3.0 ft in front of the louver face.

Figure 21 shows velocity profiles evaluated at the stations 10 ft upstream and 4 ft downstream, which display changes in the bypass entrance passing profiles that occur with the 16-ft-deep high-velocity flow and the 20-ft-deep low-velocity flow. Note that for both operations, the upstream profiles display gradients that indicate bottom and boundary (louver) influences. Note that because of instrumentation limitations, near bottom velocities were not evaluated. For both operations, the bypass entrance appears to slice off the near boundary profiles. Vertical gradients generate more vertically uniform velocity profiles that continue on past the entrance. The complete sets of evaluated approach and passing velocity profiles are displayed in figures A2-1 through A2-10 of appendix 2.

Profiles evaluated at the station 10 ft upstream from the bypass entrance with the guide wall in place are shown in figures 7 and 9. Observed profiles at this station with and without the guide wall are similar.



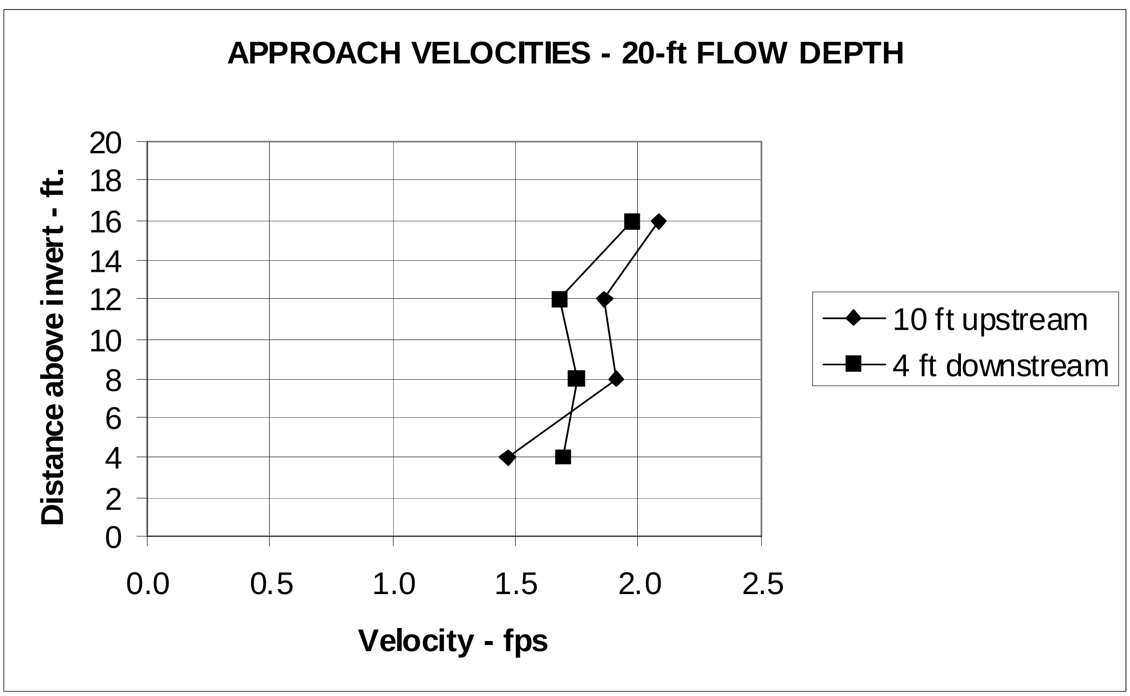


FIGURE 21.—Approach and passing velocity profiles without guide wall (velocities evaluated 1.0 ft from louver face).

Figure 22 displays velocity profiles evaluated at the bypass entrance (Column A, seen in the upper diagram of figure A1-1) for the above operating conditions. As with the previous evaluations, these velocities were determined using the LDA. Presented velocities were measured at quarter points across Column A. Comparison of these velocity profiles with those evaluated for the bypass intake with guide wall (figures 8, 9, A1, and A6) shows that bypass entrance velocity profiles without the guide wall are comparable or more vertically uniform.

In general, it appears that operation of the bypass intake without the guide wall will continue to yield good bypass entrance velocity distributions and continuity in the approach and passing flow field that should sustain fish guidance along the louver face.

CONCLUSIONS

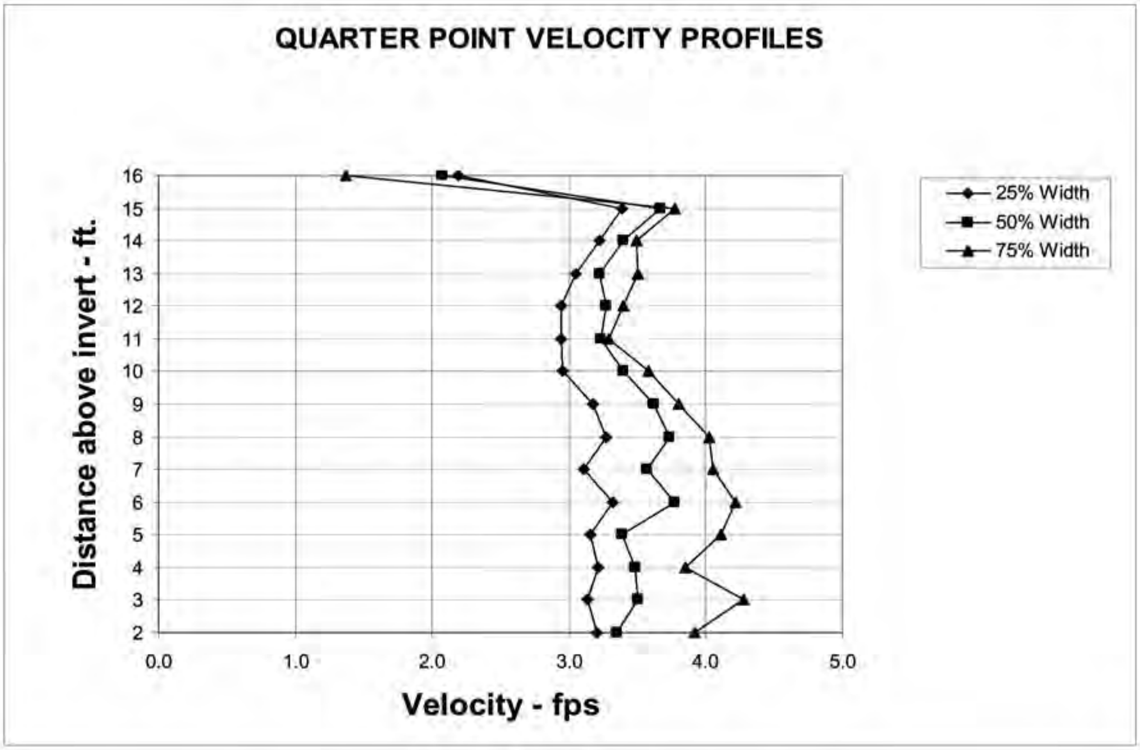
The following conclusions were achieved from the Phase 2 study:

1. Approach flow velocity distributions will influence velocity distributions at the bypass entrance. As a consequence, debris fouling of the trashracks and louvers in the TFCF may modify vertical approach velocity distributions that, in turn, can modify vertical velocity distributions in the bypass intake.

2. With approach flow velocity distributions that are comparable to distributions documented in the field at the TCFC primary louver, near uniform vertical velocity distributions will be generated at the bypass entrance if the tapered choke treatment developed in Phase 1 of this study is used.

3. In general, near-field bypass entrance approach velocities are well directed, supplying good guidance between the louver face and guide wall to the bypass entrance.

4. The existing facility design and the initially proposed replacement design lack flow back pressure control over the last cycle of louver length. Lack of back pressure control generates higher through-louver velocities over the last louver cycle. The generated higher velocities do not extend out substantially from the louver face. Nevertheless, the higher velocities may yield fish attraction and fish leakage through the louver that would reduce louver fish exclusion efficiency.



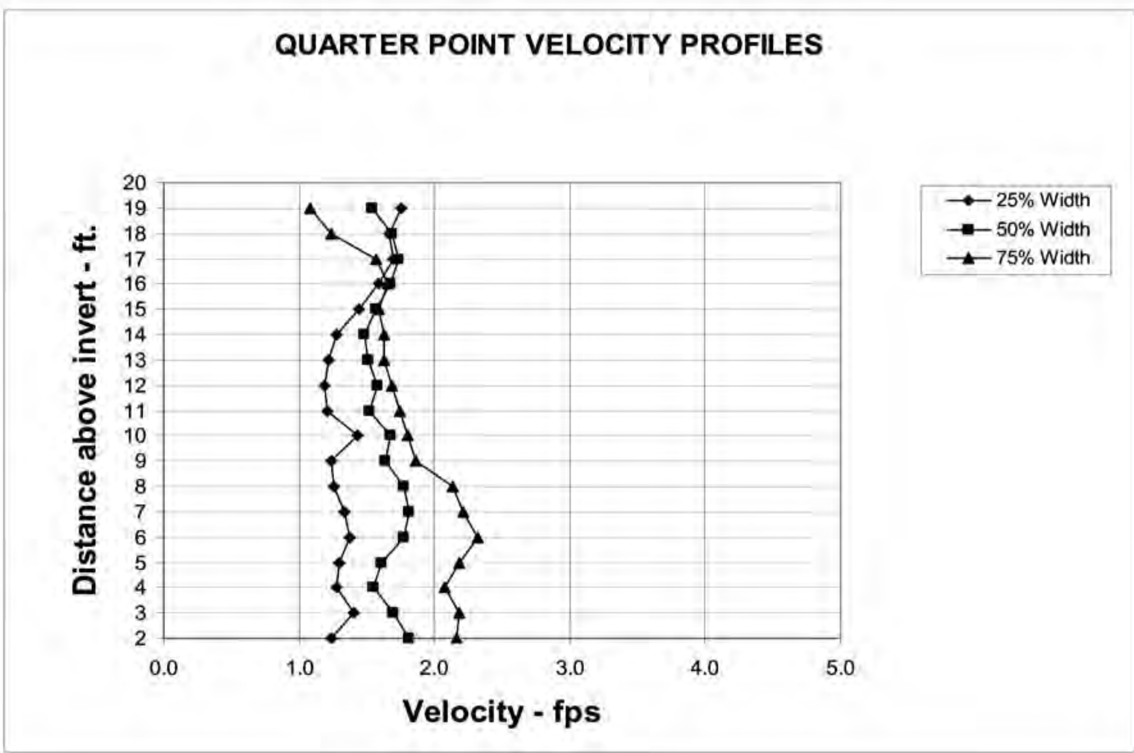


FIGURE 22.—Velocity profiles at quarter points across the bypass entrance (section A), bypass operating without a guide wall.

5. A geometrically simplified element added to the exit section from the last cycle of the louver that constricts the exit flow path in a similar manner to overlapping turning vanes will reduce velocities through the last louver cycle, generating velocity distributions that are comparable with those through the remainder of the louver face.

6. Bypass entrances operated without guide walls can sustain both uniform entrance velocity distributions and continuous, well-directed sweeping flow past the bypass and on down the louver face. From a hydraulic perspective, it appears that operation of the bypass entrances without guide walls is a valid alternative. Vertical velocity distributions will be a function of approach velocity distributions and potentially a function of debris fouling.

RECOMMENDATIONS

Recommendations resulting from the above conclusions include:

1. Whenever bypass entrance velocity distributions are evaluated in the field, vertical approach flow velocity distributions should also be evaluated. The two are strongly related. It is a mistake to evaluate bypass entrance velocity distributions without considering approach flow distribution and its possible influence.

2. The effect of trashrack and louver debris fouling on approach flow distributions and in turn on bypass entrance velocity distributions should be evaluated in the field. It may be found that non-uniform fouling leads to severe velocity variations at the bypass entrance that could reduce fish collection efficiencies. This could imply that more frequent cleaning is necessary. It might also be found that debris fouling has minimal influence on velocity distributions and that the current cleaning schedule is adequate.

3. Elements should be added to the backside of the bypass intake and transition boxes that generate a flow constriction and back pressure on each of the terminal louver cycles (as established by the zone of control of the last turning vane) immediately upstream from each bypass entrance. The element should be sized to generate a comparable exit flow section width restriction to that generated by the overlapping turning vanes. The need for this modification and alternative constriction designs has been discussed with Reclamation's mechanical designers.

ACKNOWLEDGMENTS

The funding for the second phase study was provided through the Tracy Fish Facilities Improvement Program (TFFIP) under the Central Valley Projects Improvement Act (CVPIA). Morris "Rudy" Campbell, Hydraulic Engineering Technician, provided physical model design drawings, instrumentation setup, and data collection and reduction for this study. Jim Higgs, Hydraulic Engineer, developed the CFD model and was responsible for identifying and demonstrating the final concepts viability through CFD model results. Perry Johnson, P.E., provided general study oversight and direction and developed much of the report text. The general concept for this study and the roles of the Phase 1 and Phase 2 studies were developed with direction from Joe Kubitschek, Hydraulic Engineer.

Peer Review This report was peer reviewed by Charles Liston, Research Aquatic Scientist; Brent Mefford, Hydraulic Engineer; and Leslie Hanna, Hydraulic Engineer, all with the U.S. Department of the Interior, Bureau of Reclamation.

REFERENCES

Babb, A.F. 1968. Hydraulic Model Studies of the Bypass Intake Structures for the Delta Fish Protection Facilities, University of California Department of Water Science and Engineering Paper No. 1019.

Kubitschek, J.P. 2001. Field Evaluation of Primary Bypass Performance at Tracy Fish Collection Facilities, California, U.S. Department of the Interior, Bureau of Reclamation, Water Resources Research laboratory Travel Report, TR-01-08.

Kubitschek, J.P. 2003. Physical and Computational Model Studies to Improve Hydraulic Performance at the Primary Bypasses at Tracy Fish Collection Facility, Tracy, California. Tracy Fish Collection Facility Studies, California, Volume 19.

Liston, C., R. Brockman, G. Sackett, C. Karp, L. Hess, P. Johnson, S. Hiebert, and G. Mueller. 1993. Improvements in Fish Collection Facilities at the Federal Pumping Plant in the South Delta, California. Proceedings of the American Fisheries Society Fish Passage Symposium, Portland, Oregon. September 1993.

McBirney, W.B. 1956. Hydraulic Studies of Fish Collecting Facilities B Delta-Mendota Intake Canal, Central Valley Project, California, U.S. Department of the Interior, Bureau of Reclamation, Hydraulic Laboratory Report Hyd-410.

Marsden, R., and W. Frizell. 2001. Current Measurements at the Bureau of Reclamation Tracy Fish Facility. August 15-16, 2001.

Appendix 1

Velocity Profiles within the Bypass Entrance and Bypass Transition Structure

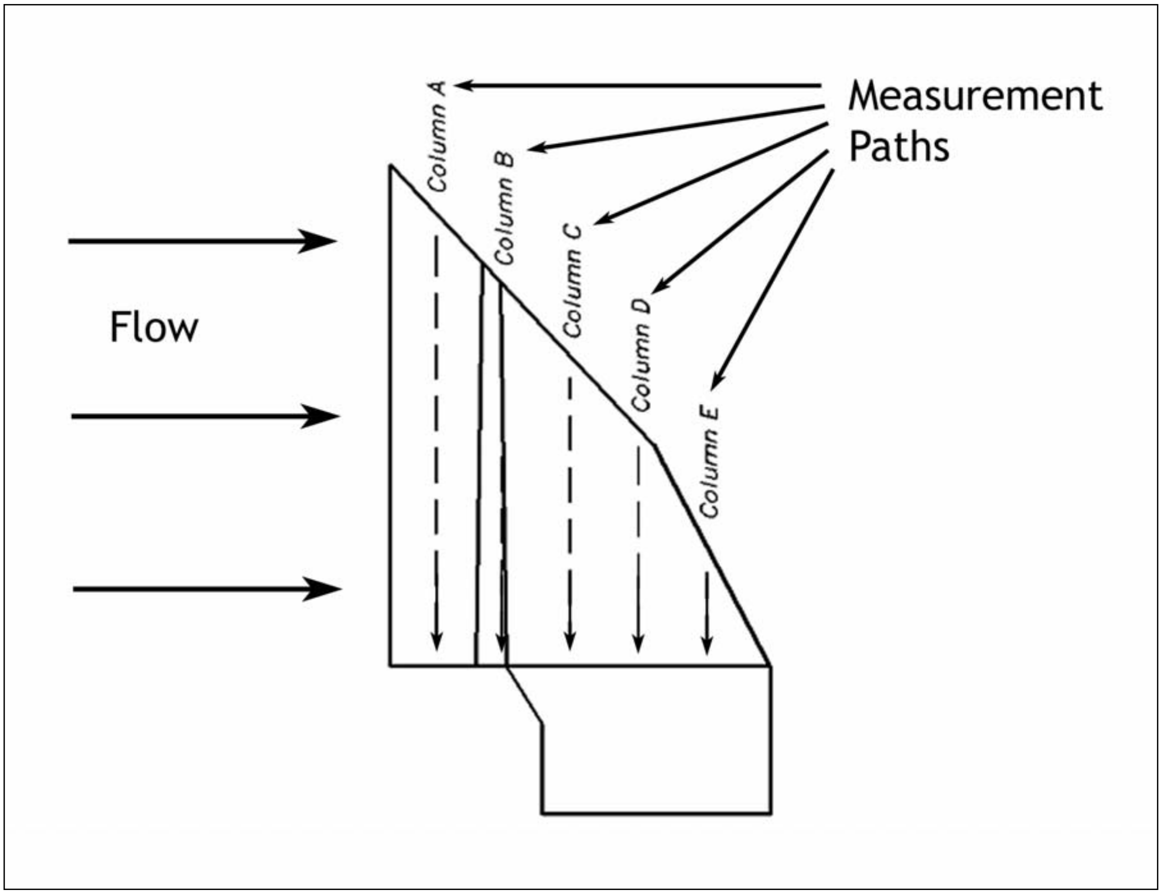


FIGURE A1-1.—Cross section rendering of the bypass intake showing laser anemometer measurement paths and orientation used in this study. Paths are called Columns A-E.

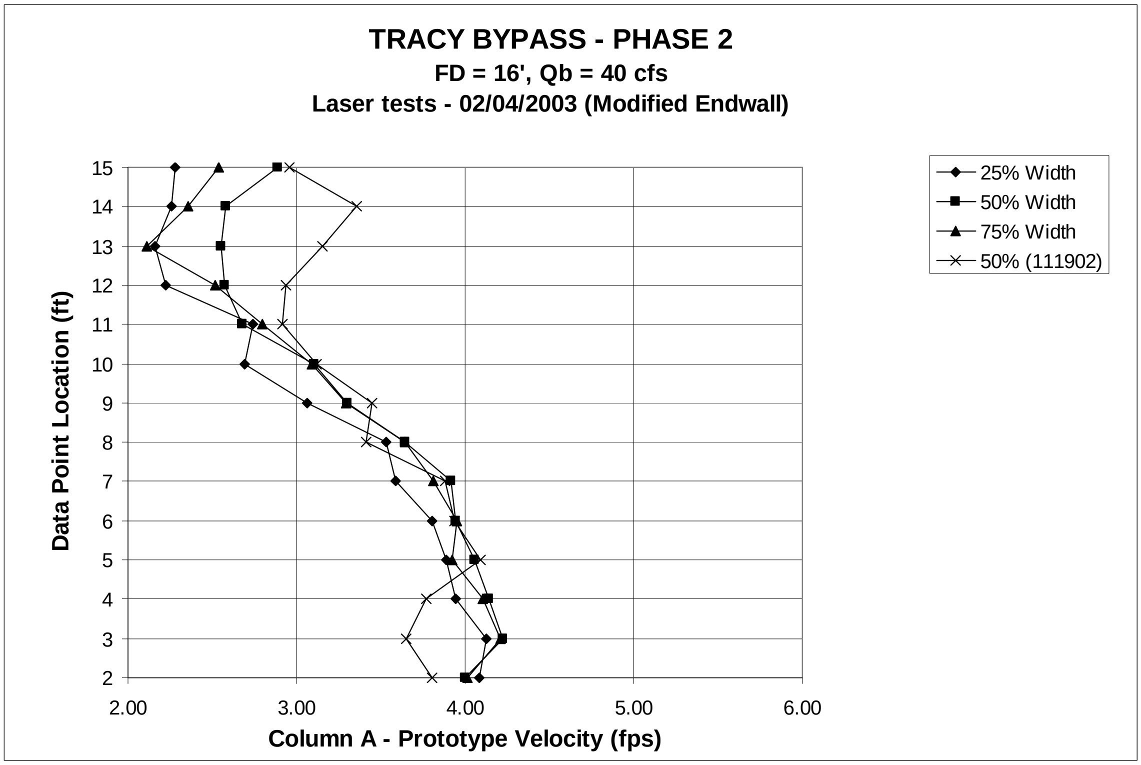


FIGURE A1-2.—Velocity profile for Column A with modified endwall, at FD =16’ and Q_b = 40 cfs.

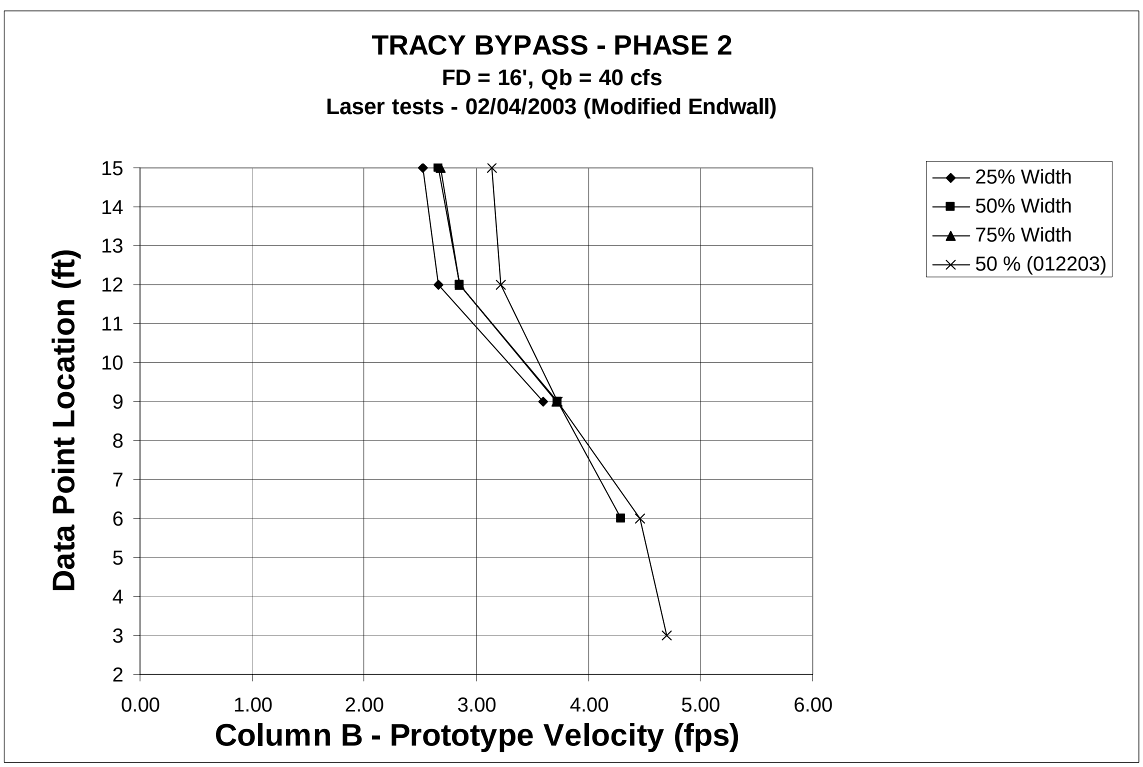


FIGURE A1-3.—Velocity profile for Column B with modified endwall, at FD =16’ and Q_b = 40 cfs.

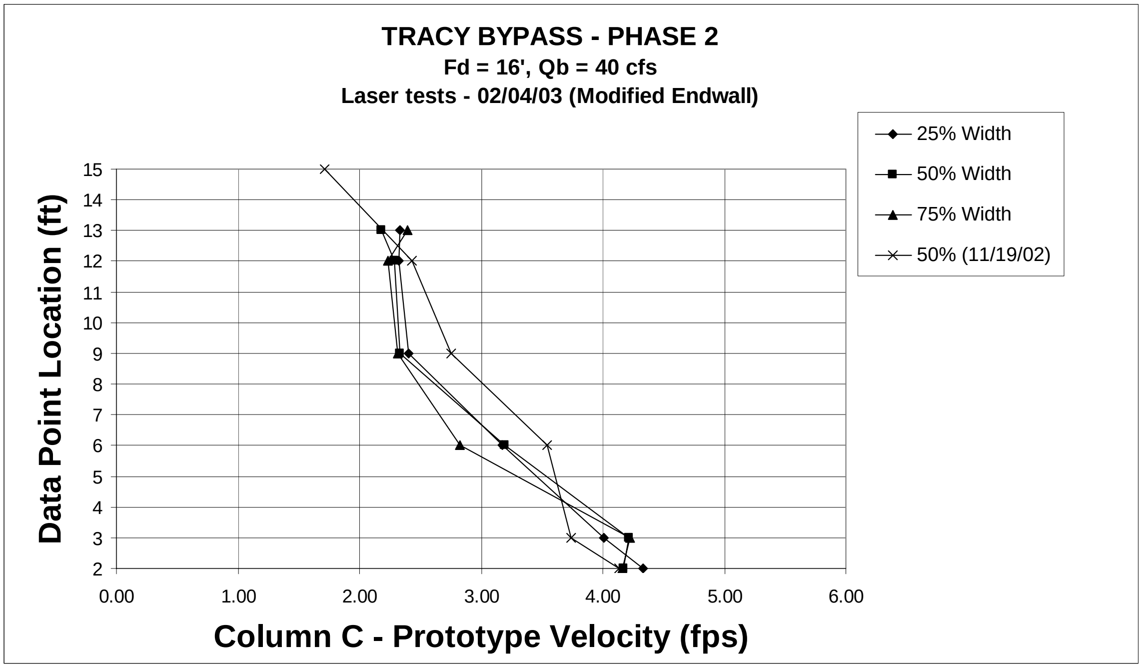


FIGURE A1-4.—Velocity profile for Column C with modified endwall, at FD =16' and Q_b = 40 cfs.

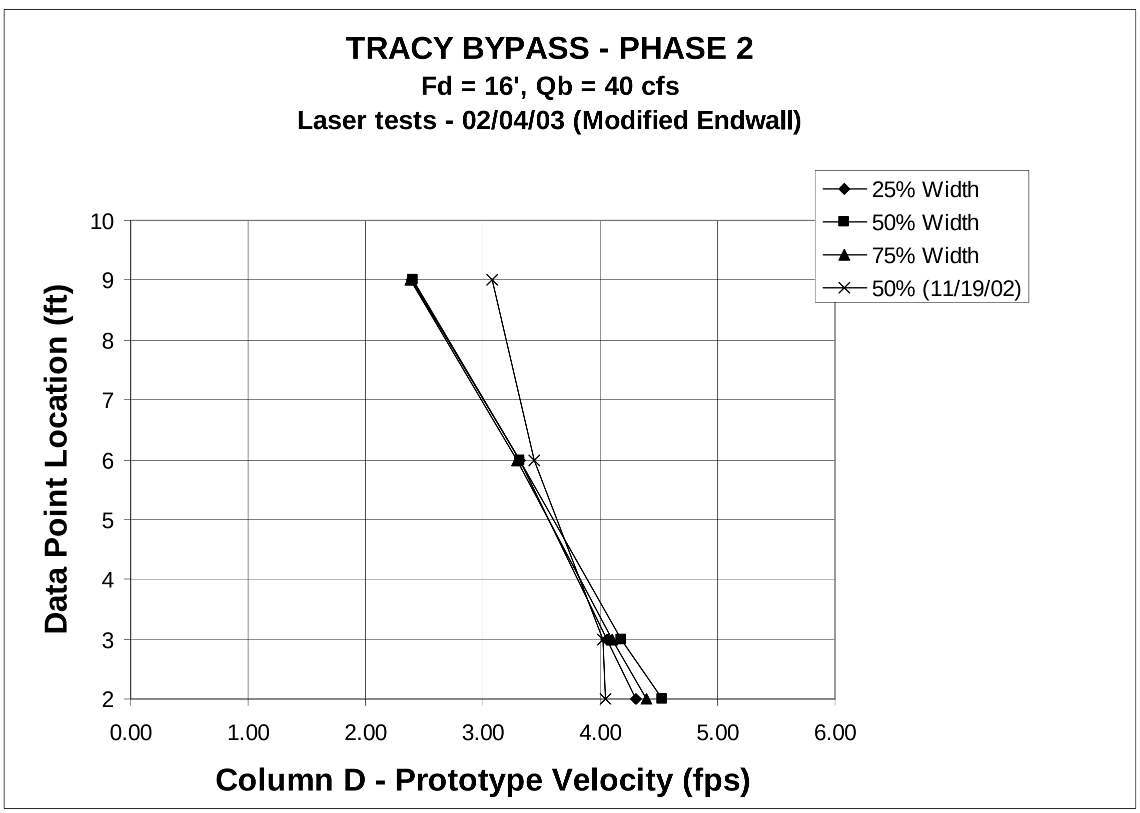


FIGURE A1-5.—Velocity profile for Column D with modified endwall, at FD =16' and Q_b = 40 cfs.

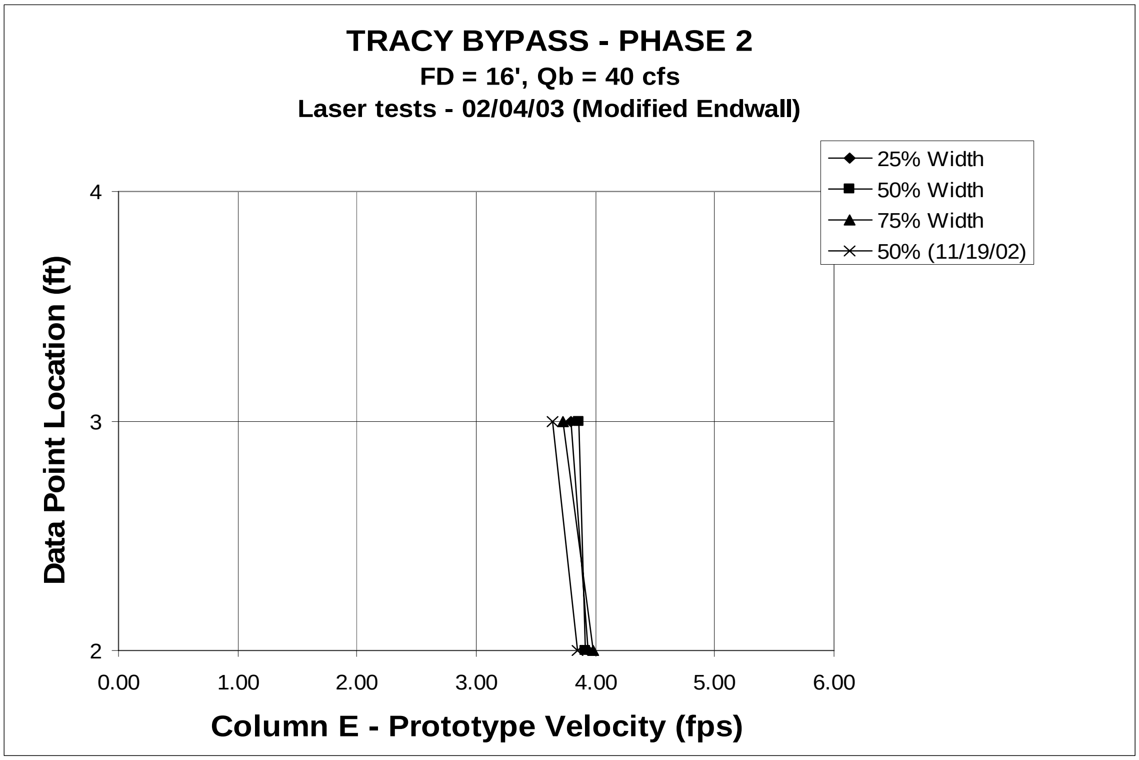


FIGURE A1-6.—Velocity profile for Column E with modified endwall, at FD =16' and Q_b = 40 cfs.

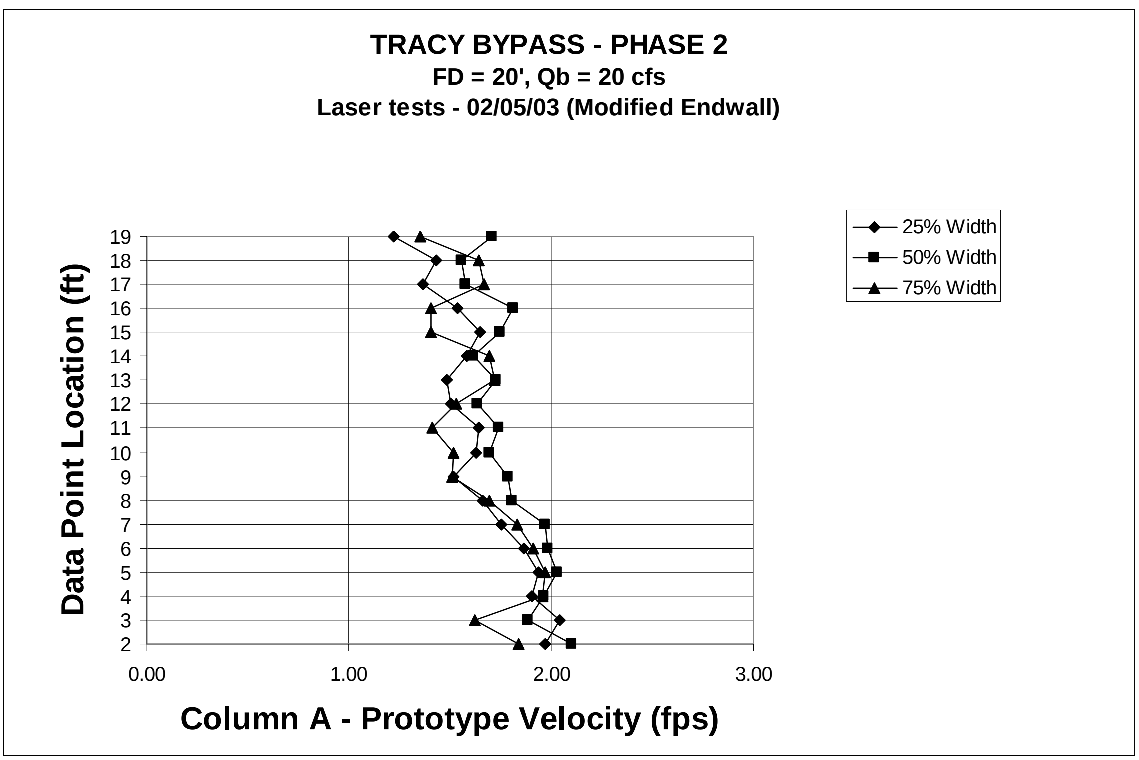


FIGURE A1-7.—Velocity profile for Column A with modified endwall, at FD =20' and Q_b = 20 cfs.

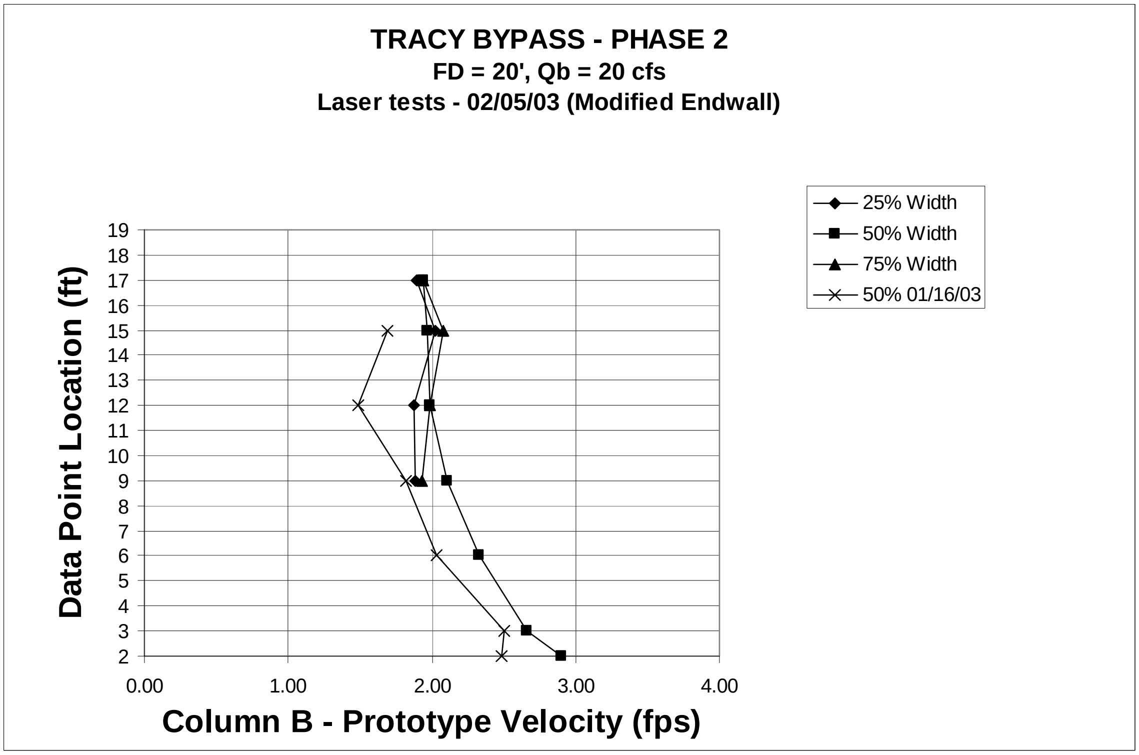


FIGURE A1-8.—Velocity profile for Column B with modified endwall, at FD =20' and Q_b = 20 cfs.

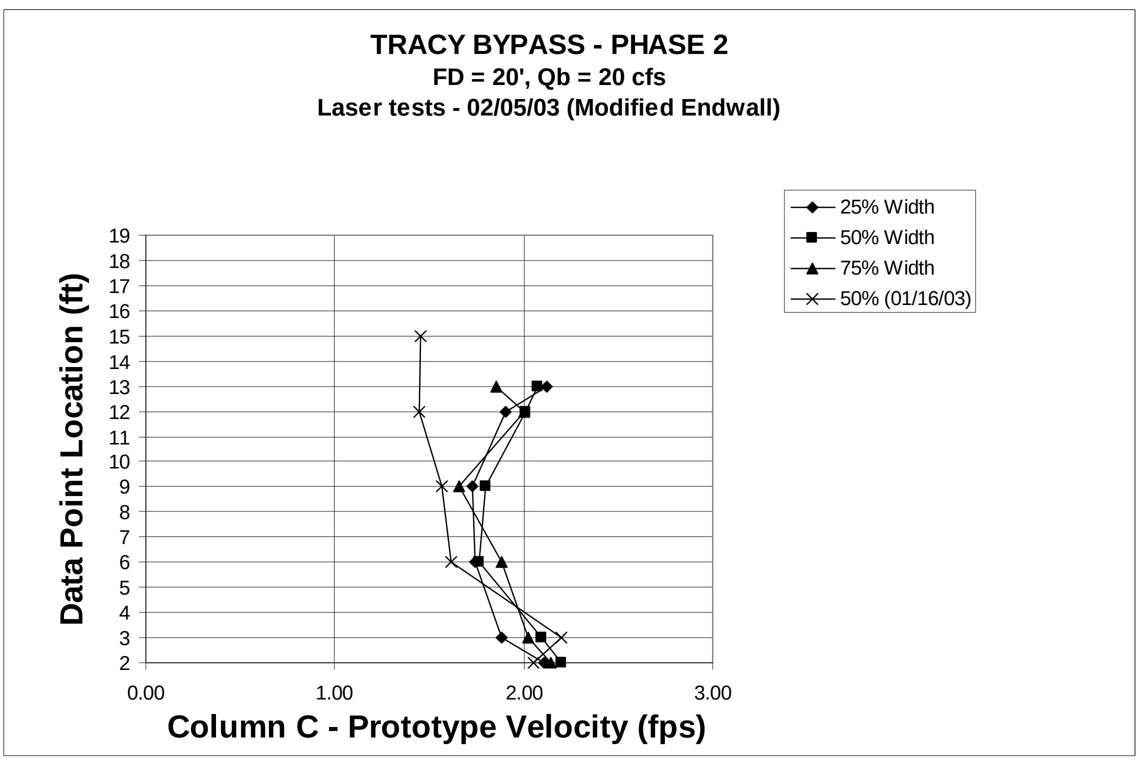


FIGURE A1-9.—Velocity profile for Column C with modified endwall, at FD =20' and Q_b = 20 cfs.

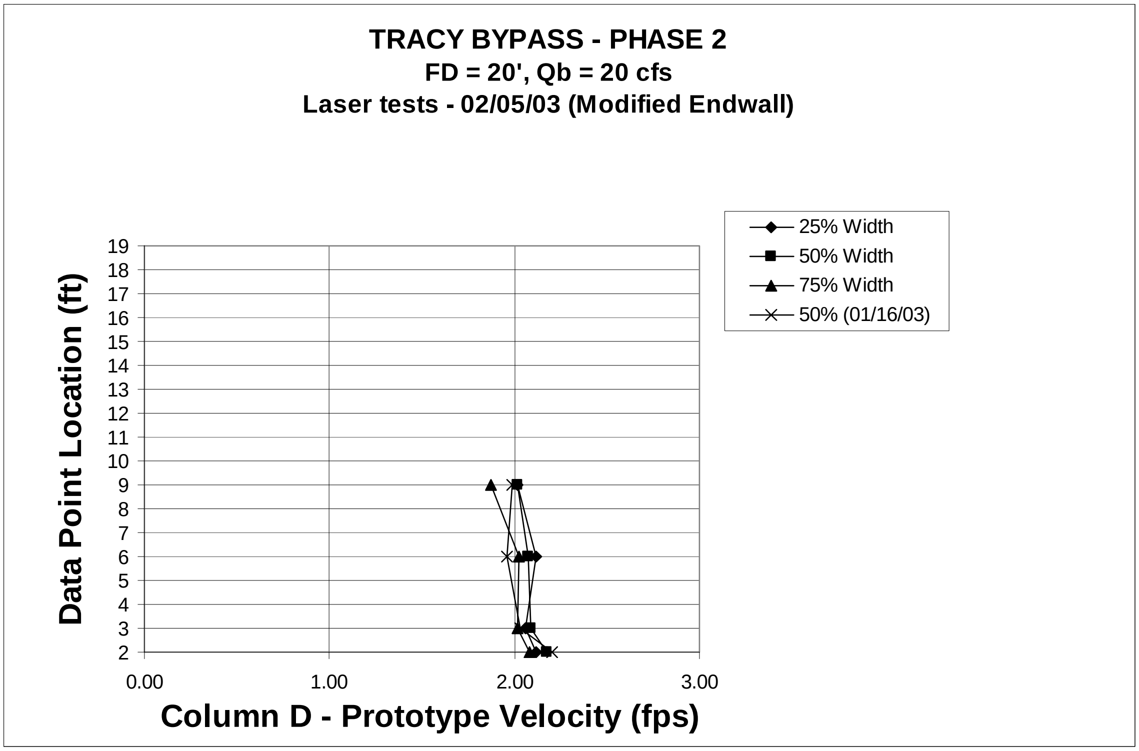


FIGURE A1-10.—Velocity profile for Column D with modified endwall, at FD =20’ and Q_b = 20 cfs.

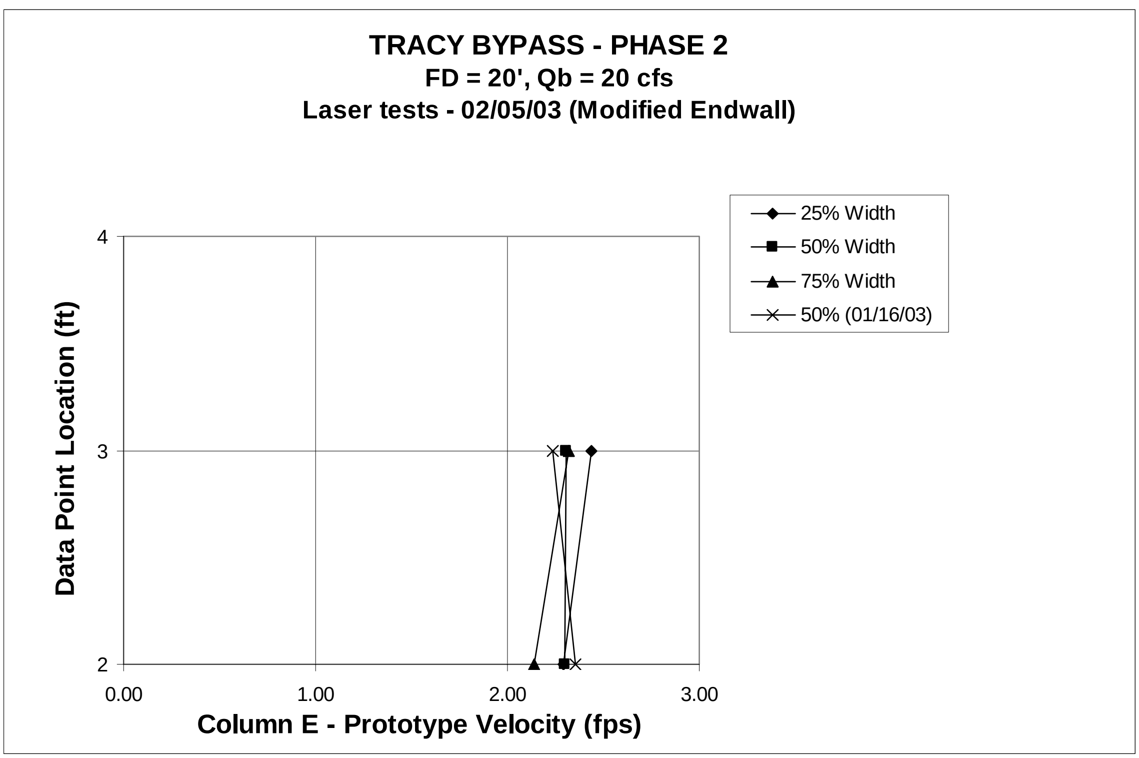


FIGURE A1-11.—Velocity profile for Column E with modified endwall, at FD =20’ and Q_b = 20 cfs.

APPENDIX 2

Approach and Passing Velocity Profiles for the Bypass Entrance without a Guide Wall

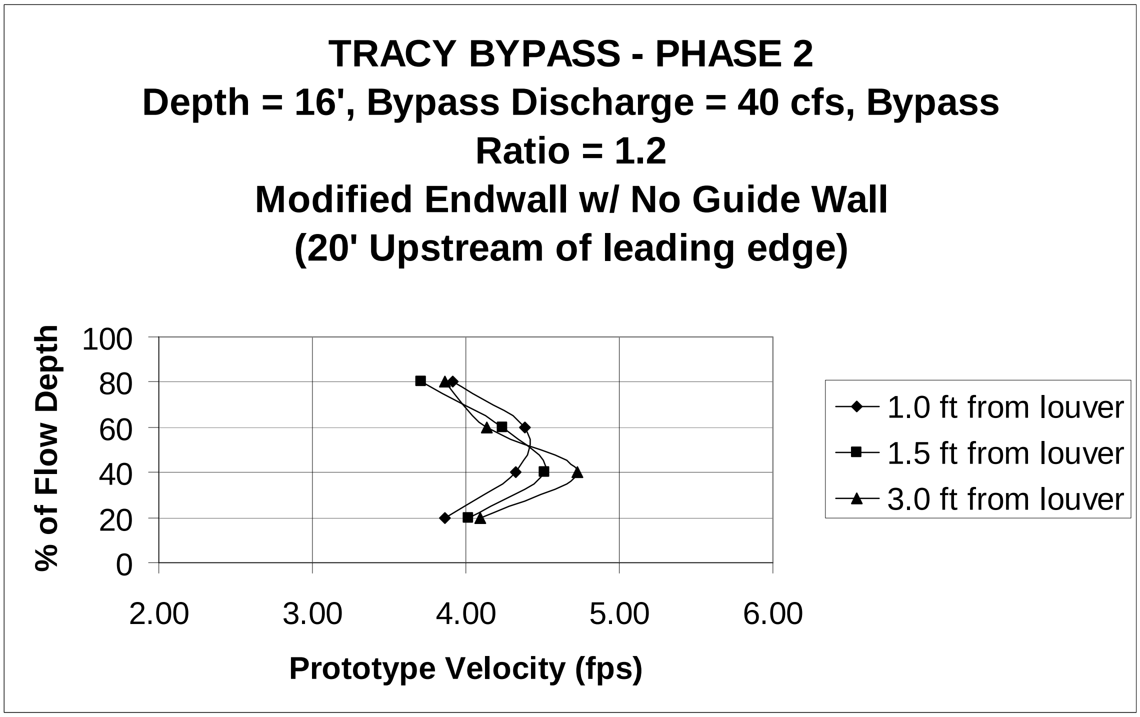


FIGURE A2-1.—Velocity profile 20 ft upstream from leading edge with no guide wall on modified endwall, at FD =16’ and Q_b = 40 cfs (bypass ratio = 1.2).

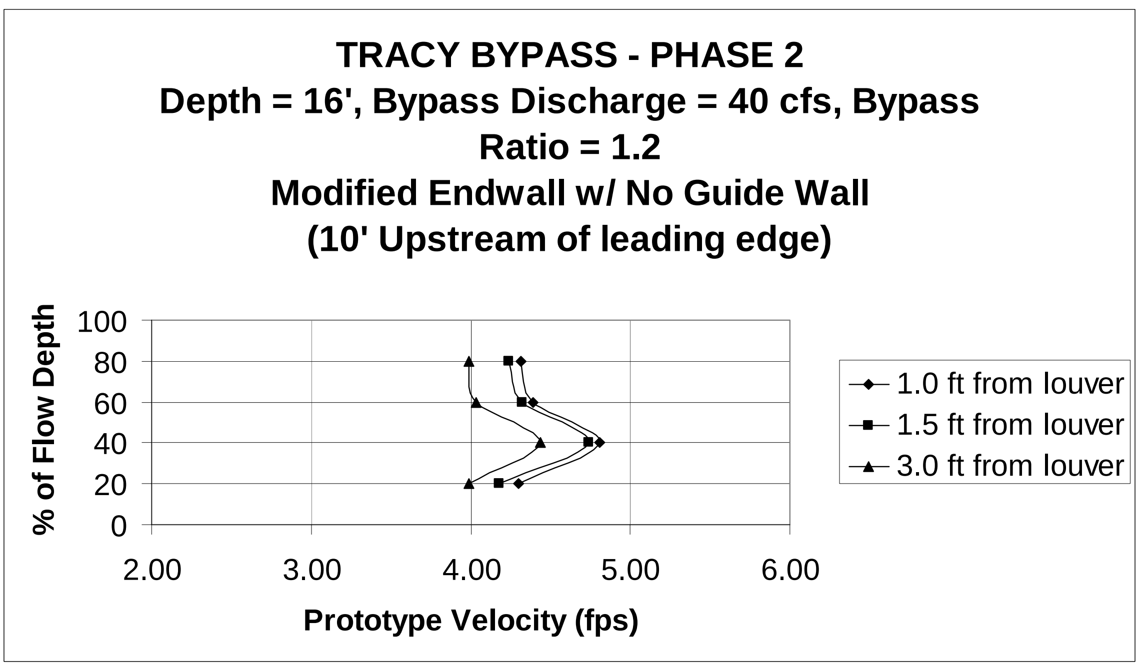


FIGURE A2-2.—Velocity profile 10 ft upstream from leading edge with no guide wall on modified endwall, at FD =16’ and Q_b = 40 cfs (bypass ratio = 1.2).

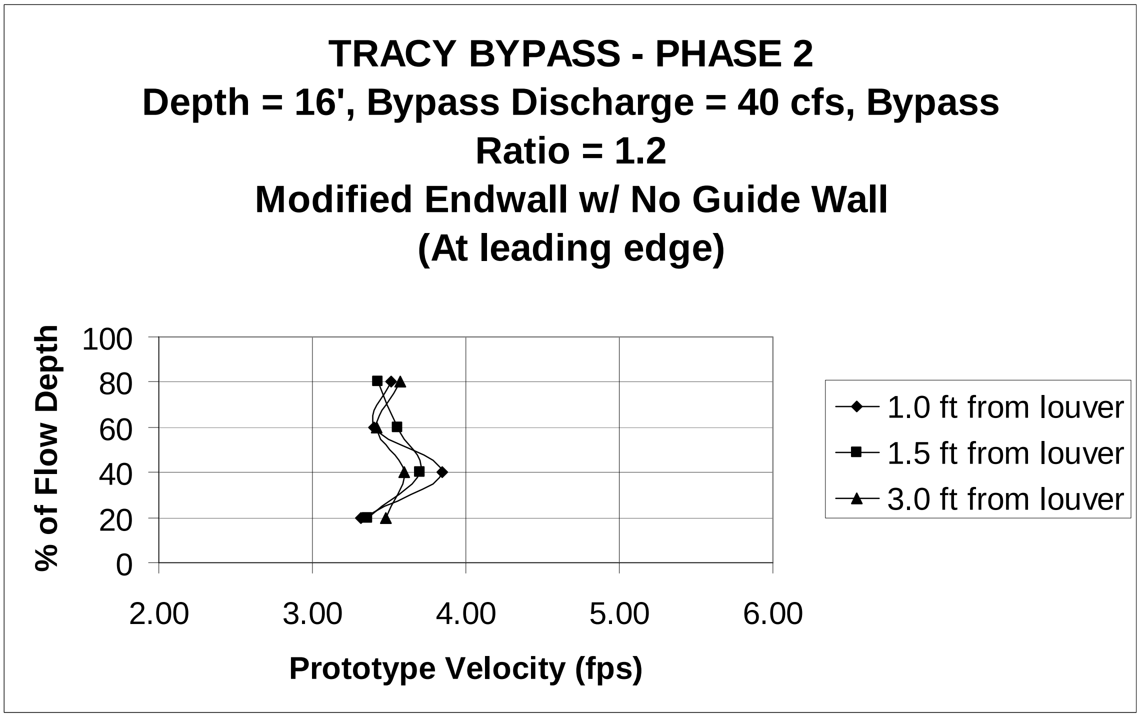


FIGURE A2-3.—Velocity profile at leading edge with no guide wall on modified endwall, at FD =16' and Q_b = 40 cfs (bypass ratio = 1.2).

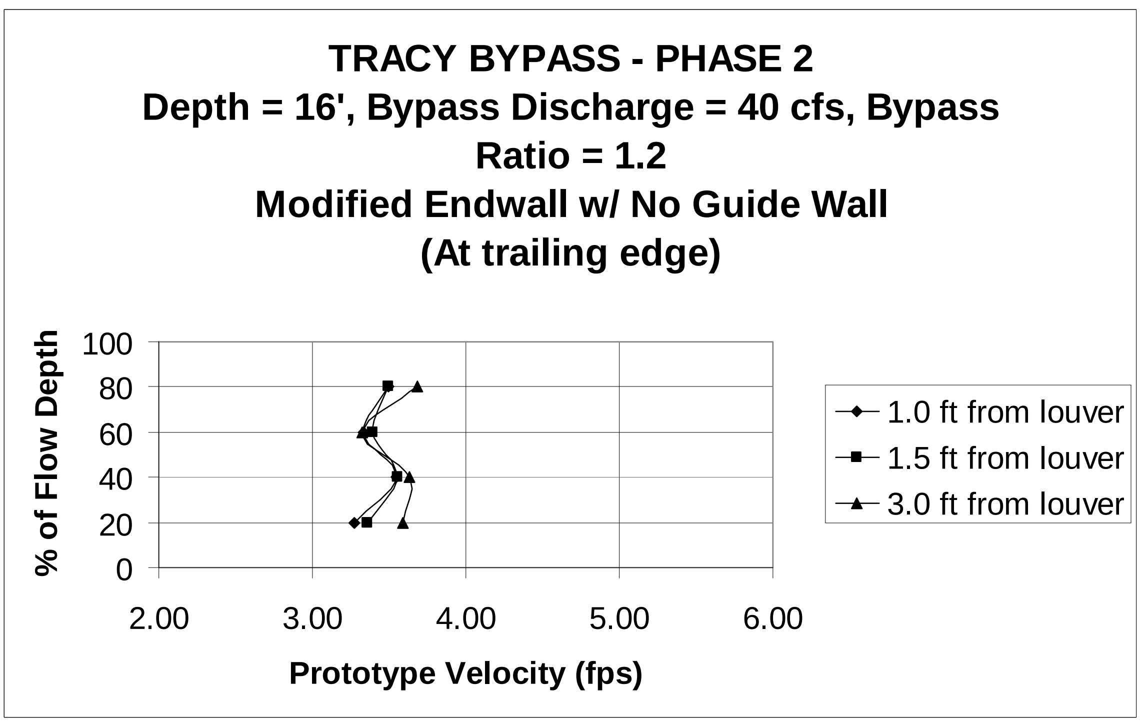


FIGURE A2-4.—Velocity profile at trailing edge with no guide wall on modified endwall, at FD =16' and Q_b = 40 cfs (bypass ratio = 1.2).

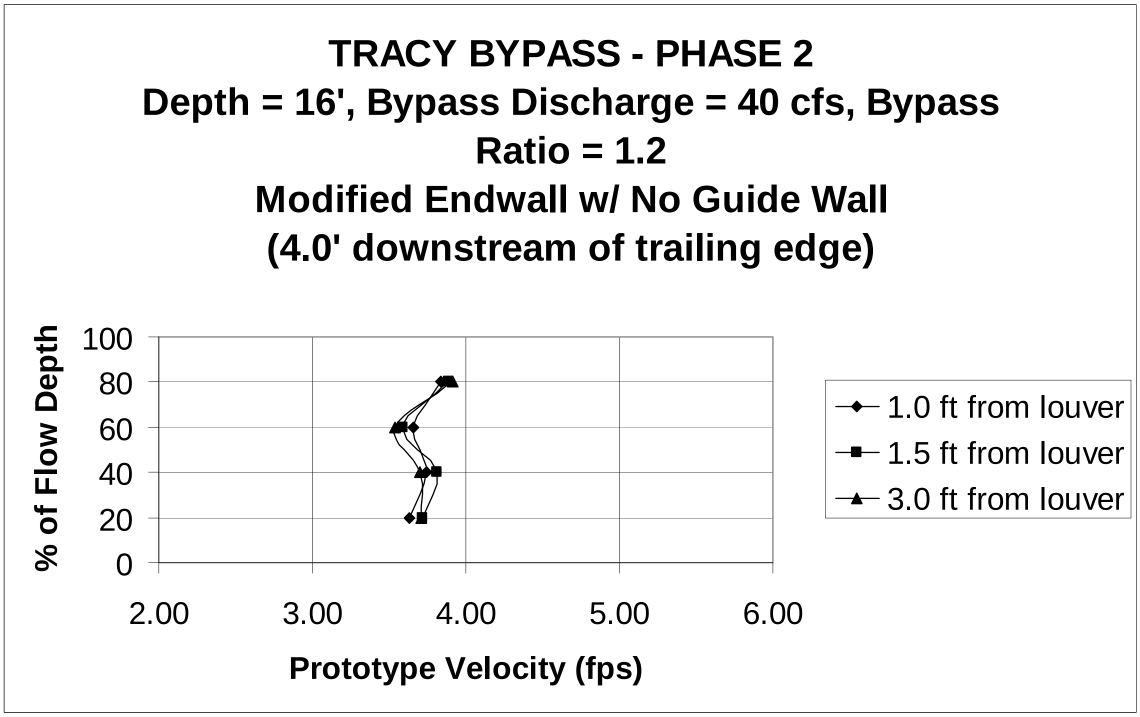


FIGURE A2-5.—Velocity profile 4.0 ft downstream from trailing edge with no guide wall on modified endwall, at FD =16’ and Q_b = 40 cfs (bypass ratio = 1.2).

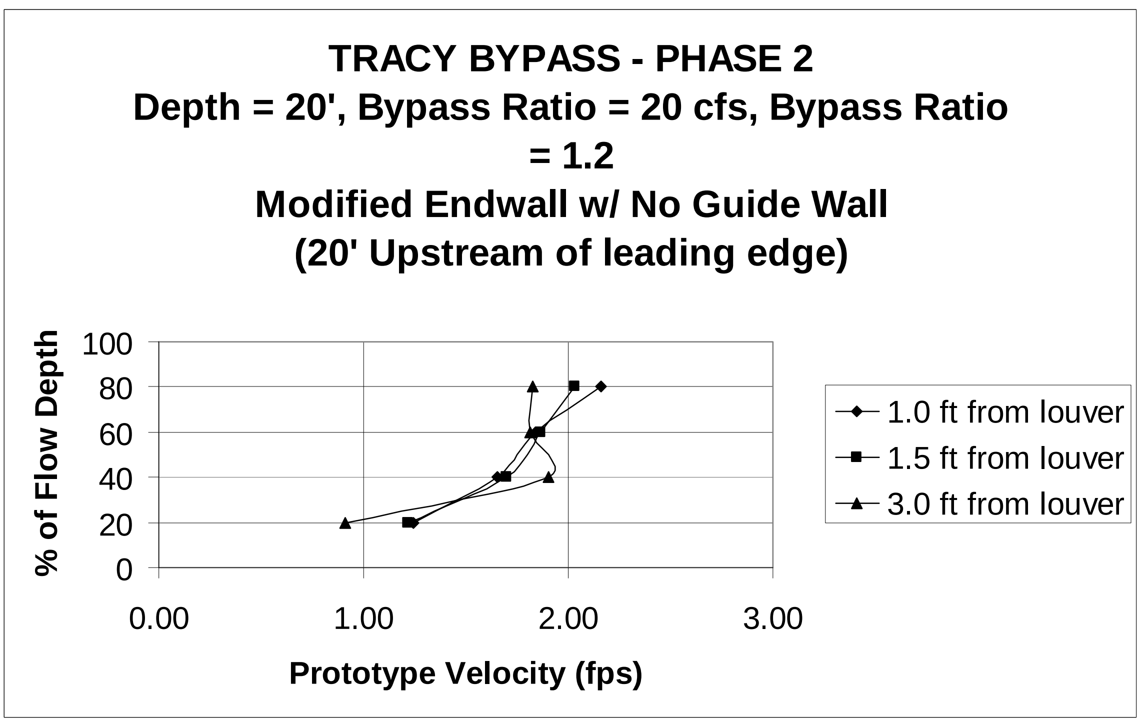


FIGURE A2-6.—Velocity profile 20 ft upstream from leading edge with no guide wall on modified endwall, at FD =20’ and Q_b = 20 cfs (bypass ratio = 1.2).

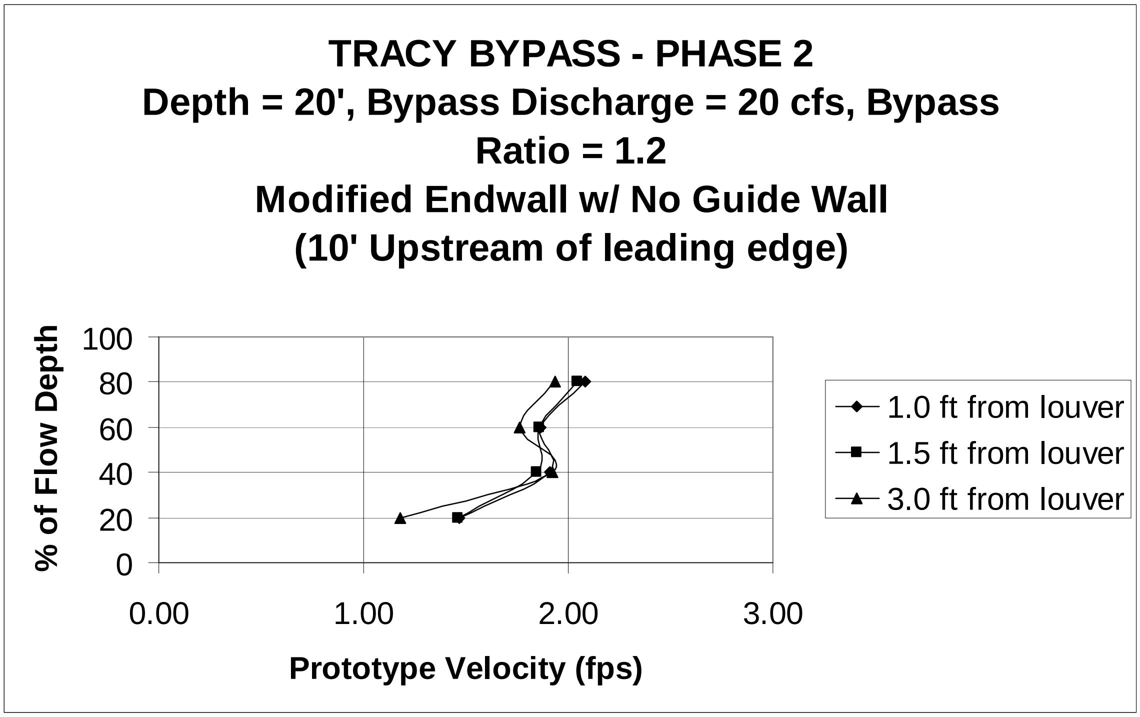


FIGURE A2-7.—Velocity profile 10 ft upstream from leading edge with no guide wall on modified endwall, at FD =20' and Q_b = 20 cfs (bypass ratio = 1.2).

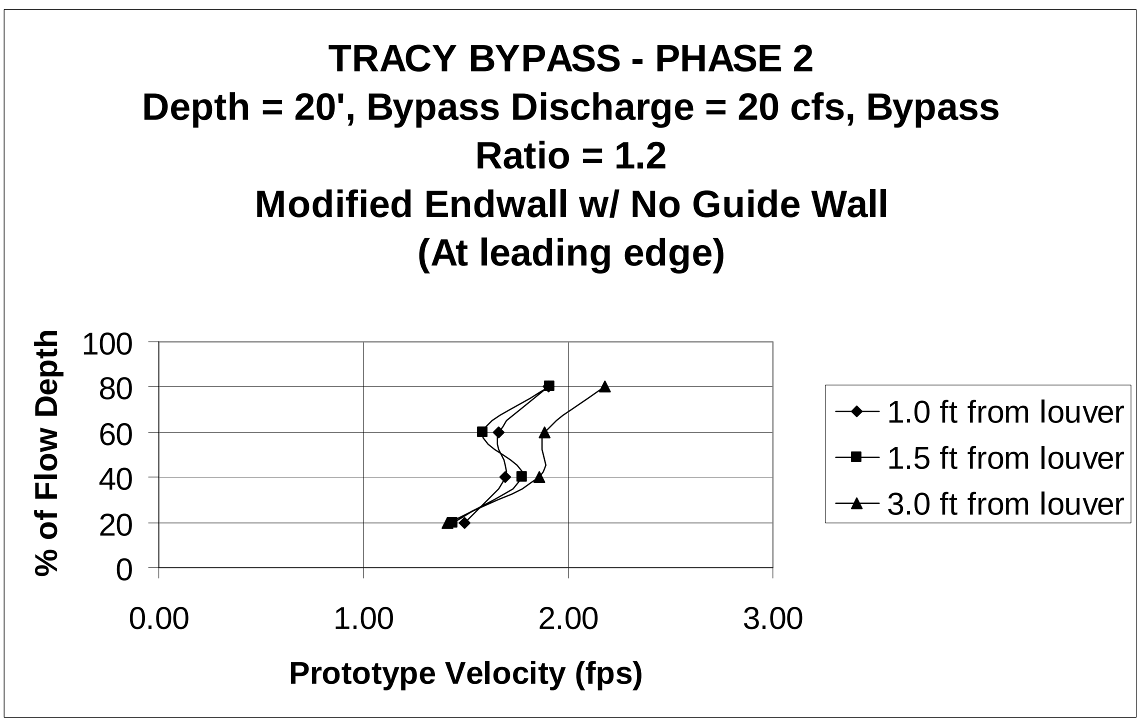


FIGURE A2-8.—Velocity profile at leading edge with no guide wall on modified endwall, at FD =20' and Q_b = 20 cfs (bypass ratio = 1.2).

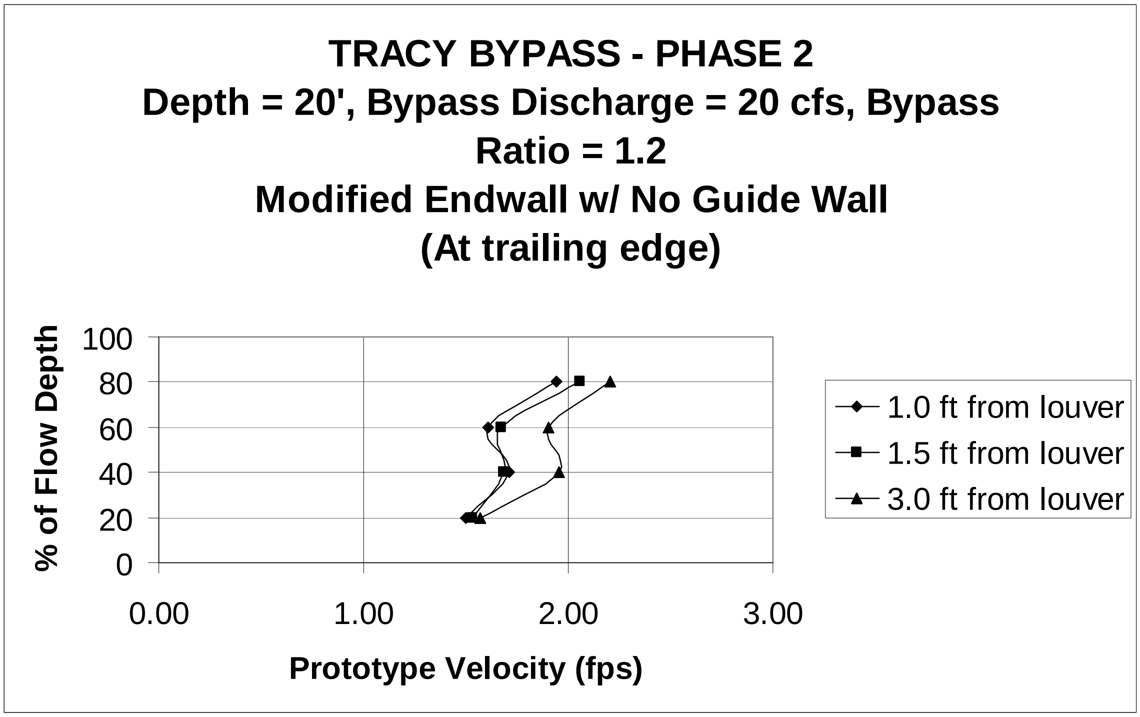


FIGURE A2-9.—Velocity profile at trailing edge with no guide wall on modified endwall, at FD =20' and Q_b = 20 cfs (bypass ratio = 1.2).

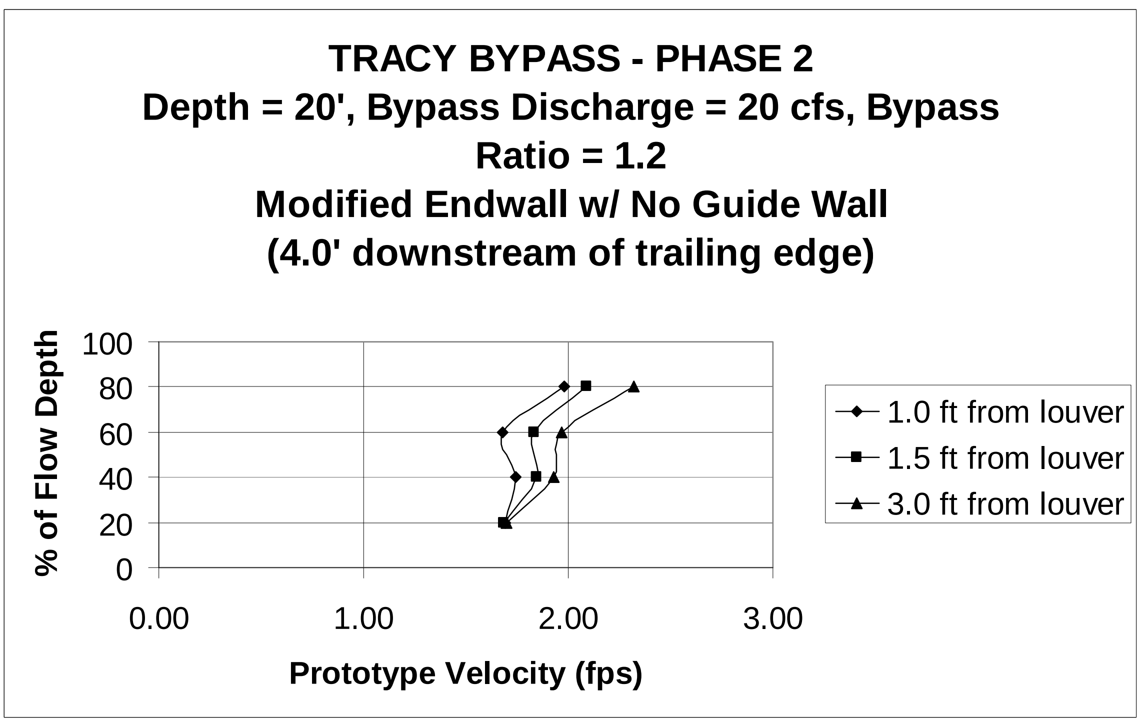


FIGURE A2-10.—Velocity profile 4 ft downstream from trailing edge with no guide wall on modified endwall, at FD =20' and Q_b = 20 cfs (bypass ratio = 1.2).