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HYDRAULIC FIELD EVALUATION OF THE RIGHT ABUTMENT FISH LADDER AT RED BLUFF DIVERSION DAM

RED BLUFF DIVERSION DAM FISH PASSAGE PROGRAM

September 1997

U.S. DEPARTMENT OF THE INTERIOR
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13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation, Water Resources Research Laboratory, conducted a detailed hydraulic field evaluation of the right abutment fish ladder at Red Bluff Diversion Dam in California. The purpose of this study was to investigate the influence on hydraulic performance of a recent modification to the ladder entrance. The results indicate that the modification, which consisted of incorporating a submerged entrance into the ladder end sill, has potentially degraded ladder performance. Diffuser velocities in many cases were found to exceed the 1.0-ft/s velocity criteria. In addition, significant crossing flow conditions exist. These combined results produce the potential for disorientation and delay to passage of the fishery. Recommendations based upon the findings of this study have been provided for improving hydraulic performance of the right abutment fish ladder.

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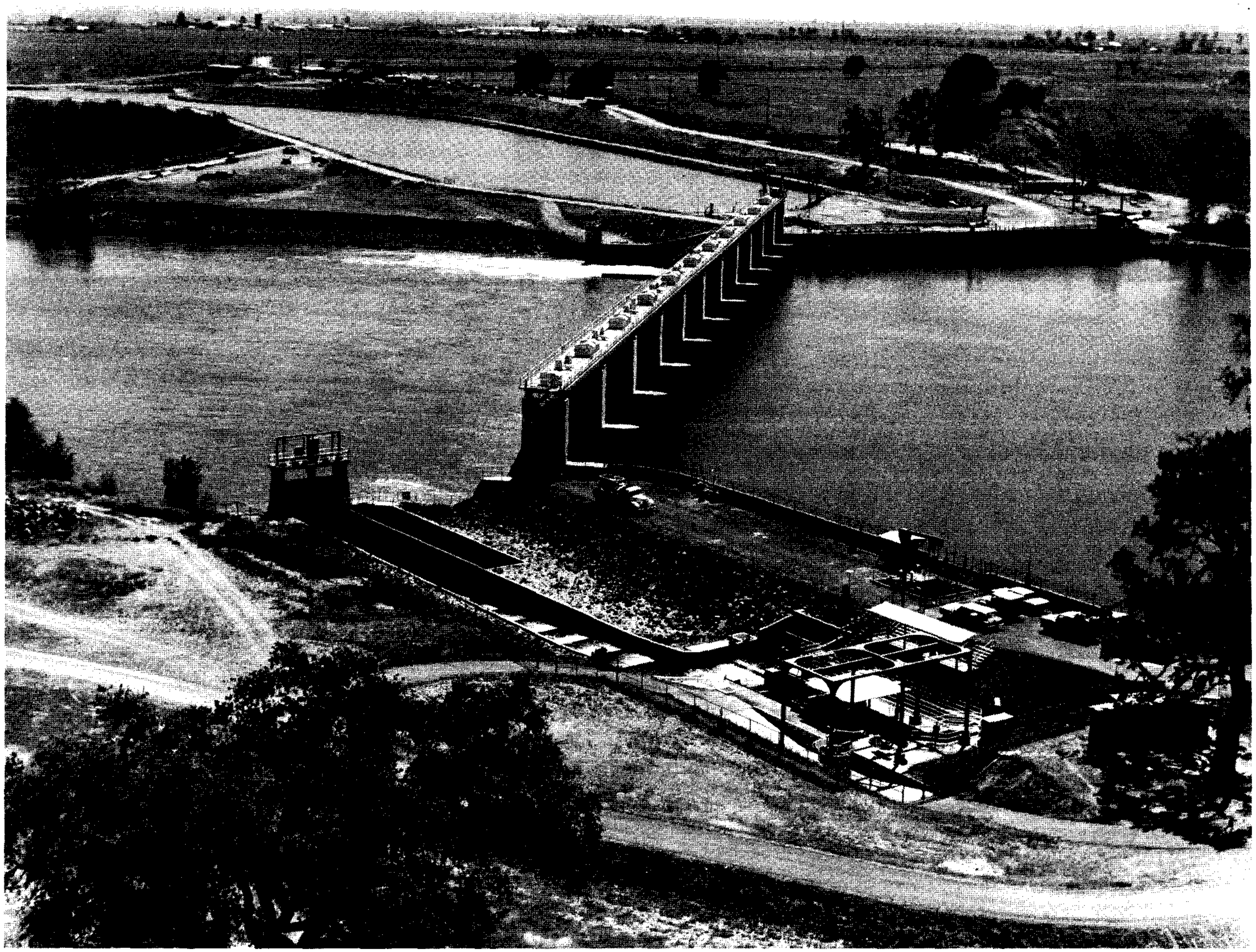

Aerial photograph of Red Bluff Diversion Dam and associated facilities.

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

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U.S. Department of the Interior
Mission Statement

The Mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

EXECUTIVE SUMMARY

Introduction

Under the Fish Passage Program, Reclamation's Water Resources Research Laboratory (WRRL) was tasked with providing engineering support to further develop potential solutions for improving fish passage at Red Bluff Diversion Dam (RBDD). The WRRL current level of involvement consists of laboratory physical model and hydraulic field investigations. This report documents the results of the right abutment fish ladder hydraulic field evaluation, which was completed in August 1996.

The right abutment fish ladder was modified in 1994 in an attempt to improve attraction flow conditions in the tailrace of RBDD. The conceptual approach called for modification of the existing ladder entrance geometry. An interdisciplinary group of experts concluded that the 3- by 18-ft configuration of the current ladder entrance contributed to early dissipation of the attraction jet in the tailrace. The group recommended that the right ladder regulating gate nearest to the bank be closed and an orifice entrance be incorporated into the ladder end sill immediately below the left side regulating gate. The shape of the orifice was to be square, which would provide a more compact jet geometry and consequently increase penetration into the downstream tailrace. A secondary benefit was that the entrance would be submerged, thus providing fish the opportunity to enter the ladder deeper in the water column.

Fish response to the orifice was monitored in August and September 1994 during the early portion of the fall chinook migration season. An underwater video camera was placed in the downstream-most pool of the ladder just upstream from the orifice. Fish use of the orifice was recorded for 8-hour periods over 14 days. Those data were to be compared with daily ladder count data taken at the ladder exit. However, full coverage of the ladder entrance was not possible, which prevented comparison of ladder entrance and exit count data. The use of the orifice and lower ladder pool was revealing. Despite relatively low ladder exit counts during the monitoring period, which ranged from 6 to 48 fish per day, fall chinook salmon made extensive use of the orifice entrance. The fish entered the ladder and immediately turned into the diffuser flow of the first ladder pool. Fish would typically hold in the lower pool and would often fall back out of the ladder. Although not definitive, this evidence suggested that the modifications to the ladder may have created hydraulic conditions that were less than optimum for efficient passage.

These observations and subsequent concerns provided the impetus for this study. Pre- and post-modification conditions were evaluated to: (1) determine the effects of ladder modification on hydraulic conditions in the lower portions of the ladder, and (2) characterize the effect of ladder modification on the attraction jet penetration into the tailrace. Concurrent biological evaluations were not performed.

Conclusions

Results of this investigation indicate that the hydraulic performance of the existing right bank fish ladder at RBDD is less than optimum. Conclusions based on the results of this evaluation are:

- Diffuser velocities entering the downstream-most ladder pools are non-uniform, exceed the 1.0-ft/s velocity criteria over part of the total diffuser area, and strongly influence ladder pool velocity fields. Crossing flow conditions are created which mask down-ladder or pool-to-pool flows. These conditions, in varying degrees, exist for both pre-and post-modification ladder entrance configurations.

- Crossing flow conditions in ladder pool 1 are more severe for the modified ladder entrance configuration compared to the original configuration, indicating that the orifice entrance modification has potentially degraded performance within the ladder itself.

- Adverse crossing flow conditions exist for ladder pools 2 through 4 but are limited to elevations in the water column below the weir elevations of each ladder pool. In contrast, favorable velocity field characteristics exist at elevations in the water column above the weir elevations for all ladder pools except pool 1. Velocity vector results acquired at these elevations are oriented primarily upstream to downstream with magnitudes which dominate the flow field.

- The modified entrance provides limited improvement of downstream attraction flow conditions. However, a large rock obstruction located immediately downstream from the entrance orifice likely reduces entrance jet penetration by dissipating the energy of the impinging jet.

- Diffuser flows entering the ladder carry significant entrained air (up to 19 percent by volume). This air entrainment potentially degrades ladder performance by compounding fish disorientation problems.

Recommendations

The following recommendations involving solutions for improving hydraulic performance of the right abutment ladder are based on WRRL experience, field observations, and the results of this study.

Operational Modifications

The results of this study and field observations show that current ladder operation is less than optimal. However, the as-built configuration of the diffusers represents sufficient area to accommodate diffuser flows. Thus, diffuser velocity criteria should be achievable. Operational modifications should be investigated as a means of improving ladder performance with regard to diffuser flows. This improvement includes reducing diffuser flows, which would also reduce air entrainment. However, the trade-off would be reduced attraction flow influence in the diversion dam tailrace. A means of increasing pool-to-pool ladder flows upstream from the diffusers should also be investigated. This flow increase would improve the upstream to downstream flow conditions and reduce diffuser flow influences. Should this improvement be achieved, the orifice modification to the ladder entrance would likely be more effective in improving ladder performance. As such, crossing flow conditions in ladder pool 1 would be minimized and likely result in less disorientation as fish enter the ladder. These recommendations represent the minimum efforts required to improve existing ladder performance.

Engineering Modifications

Additional modifications to the existing right bank ladder may be desirable. The design and implementation of a diffuser baffling scheme would improve ladder performance. However, maintenance and cleaning must be considered. In addition, an air stripping concept may be developed, designed, and installed in the diffuser channel to remove a large percentage if not all air entrainment prior to introducing supplemental flows into the ladder pools. The potential improvements regarding how diffuser flows are introduced into the last four ladder pools include:

- Installing diffuser baffles on each of the four existing diffusers.

- Incorporating floor diffusers into the current ladder configuration.

- Adding two additional diffusers to ladder pools 5 and 6 (which would represent the original design) to accommodate potential increased diffuser flows or reduce existing diffuser velocities.

- Abandoning the existing diffusers (i.e., bulkheading the existing diffusers) in favor of a pipe diffuser concept or similar concept which supplies diffuser flows to ladder pools 1 through 6 in a more uniform manner across the entire width of the fishway channel.

These engineering modifications represent only a few of the possible alternatives available for ladder performance improvement with respect to diffuser flows. A physical model study should be conducted prior to implementation of any engineering modification. In the case of existing diffuser baffling, a physical model study would facilitate the design and implementation process and ensure greater potential for success.

The information in this report is intended to assist in the selection of the best solution for optimizing the existing right bank ladder hydraulic performance. Should continued use of the entrance orifice modification be desired, the downstream obstruction should be removed to maximize the zone of attraction flow influence and satisfy that part of the original intent of such modification. Additional field studies should also be conducted to (1) better define fish staging location below gate 11 as a function of gate setting and corresponding release discharge and to (2) better define existing ladder deficiencies from a biological or fishery response standpoint with regard to these findings.

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FIGURES

PURPOSE

The purpose of this study was to evaluate the influence of a recent modification to the right abutment fish ladder entrance on hydraulic performance.

APPLICATION

The results of this study have direct application to the right abutment fish ladder at Red Bluff Diversion Dam (RBDD). Application elsewhere will require interpretation of results with consideration given to site specific conditions.

INTRODUCTION

Red Bluff Diversion Dam is located on the Sacramento River, near the City of Red Bluff in north central California. The project provides water to the west side of the river valley for irrigation purposes. Figure 1 is a general location map which identifies the project and those irrigation and water districts served.

Ineffective fish passage at RBDD has been identified as a contributing factor in the decline of the anadromous fishery resource along the upper Sacramento River basin. In 1991, the Bureau of Reclamation (Reclamation) initiated the RBDD Fish Passage Program to identify and recommend alternatives which represent potential solutions for improving fish passage at RBDD. In 1992, Reclamation published an Appraisal Report which documents various alternatives. The scope of the Fish Passage Program was established such that alternatives to be considered will achieve the objective of improving fish passage while maintaining current deliveries to the Tehama-Colusa and Corning Canals, maintaining existing economic benefits of RBDD, and preventing serious adverse impacts in other geographical areas.

Under the Fish Passage Program, Reclamation's Water Resources Research Laboratory (WRRL) has been tasked with providing engineering support to further develop potential solutions. The WRRL current level of involvement consists of laboratory physical model and hydraulic field investigations. This report has been peer reviewed by Perry Johnson, P.E., and documents the results of the recent right abutment fish ladder hydraulic field evaluation which was completed in August 1996.

BACKGROUND

Existing Fish Passage Facilities

The existing fish passage facilities at RBDD consist of two primary fish ladders located at the right and left abutments of the diversion dam and a temporary center ladder located in bay six of the diversion dam. Figure 2 represents plan and elevation details for the right abutment fish ladder, which is the focus of these investigations. The as-built condition of the right abutment ladder differs from the original design in respect to diffusers. Inspection prior to testing revealed that only four diffusers exist instead of the six which were previously thought to exist based on original design drawings. The existing diffusers are located in the four downstream-most ladder pools. The diffuser for ladder pool 1 measures 12 by 10 ft, and diffusers for ladder pools 2 through 4 measure 10 by 5 ft.

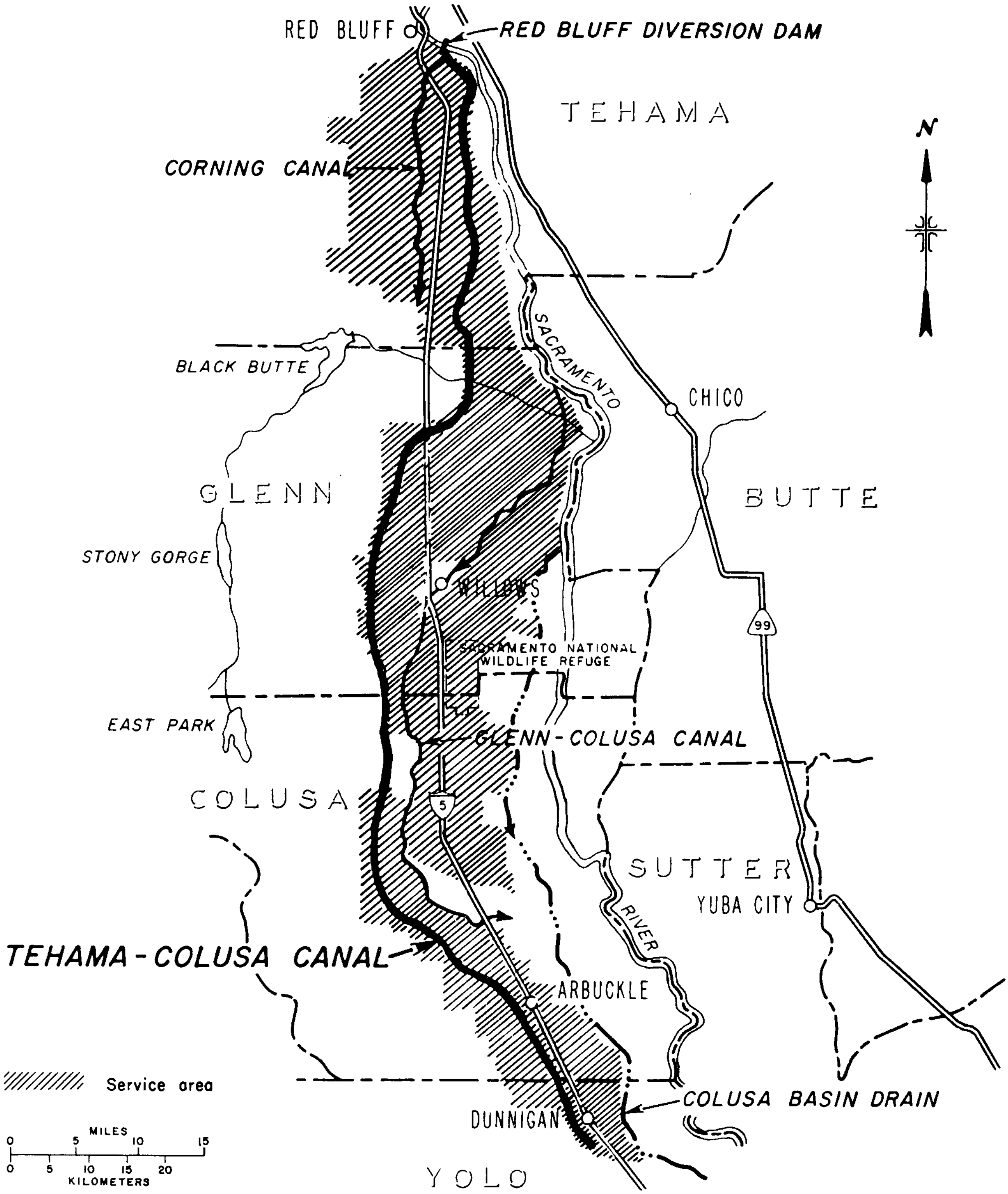


Figure 1. - General location of Red Bluff Diversion Dam.

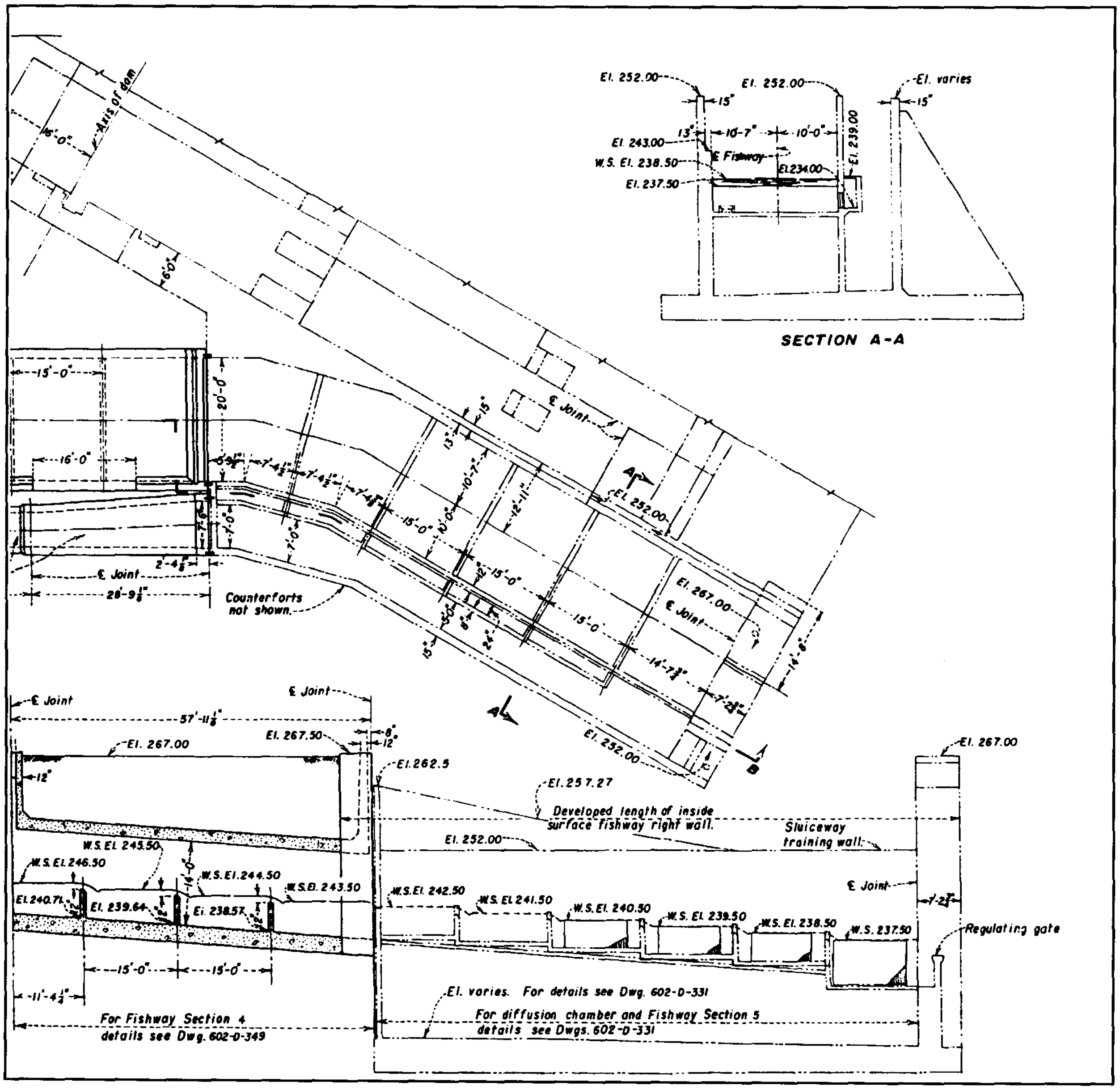


Figure 2. - Plan and elevation details of the right abutment fish ladder.

Both ladders were designed to operate at a discharge of 85 ft^3/s and consist of a series of overflow weirs which contain submerged vertical slot orifices. Supplemental flows of about 265 ft^3/s (estimated based on design data) are used to improve attraction flow conditions downstream from the ladder entrance in the diversion dam tailrace. These supplemental flows are introduced into the ladder via the four diffusers located on the right side of each ladder, one in each of the four downstream-most ladder pools. The diffusers are sized to comply with the maximum velocity criteria of 1.0 ft/s. These criteria are designed to minimize the disorientation and delay of fish by maintaining predominantly upstream to downstream velocity fields within the ladder pools affected by diffusers. The ladders are also equipped with two regulating gates atop the end sill. The space between the end sill and gates serves as the entrance to the ladder. The depth of the opening over the end sill normally ranges from 2.5 to 3 ft. The two 9-ft-wide regulating gates are automated to maintain a differential between the water surface elevations in the last ladder pool and the tailrace of the diversion dam. The differential is required to create entrance velocities of 8 to 10 ft/s over a range of river flows and corresponding tailwater elevations. These criteria have been established to maintain effective attraction flow conditions in the tailrace so that fish can sense and locate ladder entrances.

The center ladder is similar in type to that of the right and left abutment ladders. It consists of a series of weirs and slotted orifices. This ladder is temporary (i.e., installed at the beginning of the gates down period and removed at the end) and consists of a series of bulkheads which are placed downstream from the center gate. The gate is then raised to provide flow to the ladder. The ladder was designed to operate at about 30 to 50 ft^3/s with supplemental flows of about 100 ft^3/s. However, limited engineering and operational details are available.

Recent Modifications

The right abutment fish ladder was modified in 1994 in an attempt to improve attraction flow conditions in the tailrace of RBDD. The conceptual approach called for modification of the existing ladder entrance geometry. An interdisciplinary group of experts concluded that the 3- by 18-ft configuration of the current ladder entrance contributed to early dissipation of the attraction jet in the tailrace. The group recommended that the right ladder regulating gate nearest to the bank be closed and an orifice entrance be incorporated into the ladder end sill immediately below the left side regulating gate. The shape of the opening was to be square, which would provide a more compact jet geometry and consequently increase penetration into the downstream tailrace. A secondary benefit was that the end sill would be notched, thus providing fish the opportunity to enter the ladder deeper in the water column.

Creation of a square ladder entrance was not possible because of structural concerns with the end sill. Instead, a 6-ft-wide by 3-ft-high orifice was cut in the end sill just below the left side ladder regulating gate. Although not square, this configuration did provide a more compact geometry and deeper entrance. Concerns for endangered winter run chinook salmon required operation of the ladder in an unmodified state. Use of an orifice plug (fig. 3) allowed for return of the ladder to its original configuration.

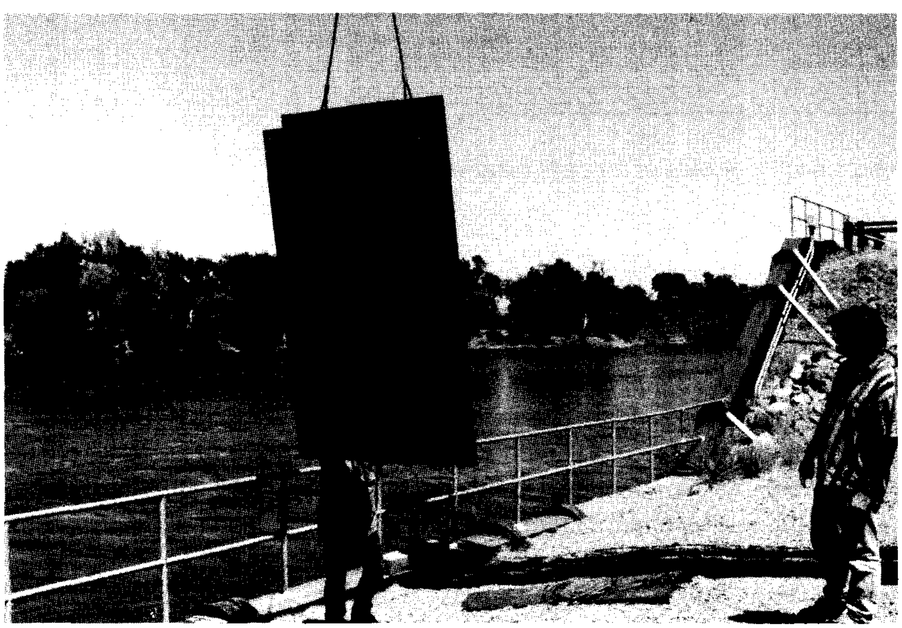


Figure 3. - Orifice plug installed to return ladder entrance to original (pre-modified) condition.

Fish response to the orifice was monitored in August and September 1994 during the early portion of the fall chinook migration season. An underwater video camera was placed in the downstream-most pool of the ladder just upstream from the orifice. Fish use of the orifice was recorded for 8-hour periods over 14 days. These data were to be compared to daily ladder count data taken at the ladder exit. However, full coverage of the ladder entrance was not possible, which prevented the comparison of ladder entrance and exit count data. The use of the orifice and lower ladder pool by fall-run chinook was revealing. Despite relatively low ladder exit counts during the monitoring period which ranged from 6 to 48 fish per day, extensive use of the orifice entrance occurred. The fish entered the ladder and immediately turned into the diffuser flow of the first ladder pool. Fish would typically hold in the lower pool and would often fall back out of the ladder entrance. Although not definitive, these observations suggested that the modification to the ladder may have created hydraulic conditions that were not optimum for efficient passage in the lower portions of the ladder.

These observations and subsequent concerns provided the impetus for a detailed evaluation of the effect of orifice operation on hydraulic performance. Pre- and post-modification conditions were evaluated to: (1) determine the effects of ladder modification on hydraulic conditions in the lower portions of the ladder, and (2) characterize the effect of ladder modification on the attraction jet penetration into the tailrace. Concurrent biological evaluations were not performed.

CONCLUSIONS

Results of this investigation indicate that the hydraulic performance of the existing right bank fish ladder at RBDD is less than optimum. Conclusions based on the results of this evaluation are:

- Diffuser velocities entering the downstream-most ladder pools are non-uniform, exceed the 1.0-ft/s velocity criteria over part of the total diffuser area, and strongly influence ladder pool velocity fields. Crossing flow conditions are created which mask down-ladder or pool-to-pool flows. These conditions, in varying degrees, exist for both pre- and post-modification ladder entrance configurations.

- Crossing flow conditions in ladder pool 1 are more severe for the modified ladder entrance configuration compared to the original configuration, indicating that the orifice entrance modification has potentially degraded performance within the ladder itself.

- Adverse crossing flow conditions exist for ladder pools 2 through 4, but are limited to elevations in the water column below the weir elevations of each ladder pool. In contrast, favorable velocity field characteristics exist at elevations in the water column above the weir elevations for all ladder pools except pool 1. Velocity vector results acquired at these elevations are oriented primarily upstream to downstream with magnitudes which dominate the flow field.

- The modified entrance provides limited improvement of downstream attraction flow conditions. However, a large rock obstruction located immediately downstream from the entrance orifice likely reduces entrance jet penetration by dissipating the energy of the impinging jet.

- Diffuser flows entering the ladder carry significant entrained air (up to 19 percent by volume). This air entrainment potentially degrades ladder performance by compounding fish disorientation problems.

SCOPE OF WORK

The hydraulic field evaluation, limited to the right abutment fish ladder, consisted of determining the hydraulic performance under pre- and post-modification operating conditions. Hydraulic performance is characterized by velocity magnitudes and field patterns in each of the four ladder pools affected by diffuser flows and the RBDD tailrace field downstream from the ladder entrance. Velocity fields as well as other secondary hydraulic parameters (i.e., turbulent intensity, air entrainment, acoustic, etc..) provide information regarding hydraulic performance because they elicit a response on the part of the fishery. Although the parameter that most influences ladder performance is difficult to determine, in this case, velocity appeared to be most representative of the effect imparted by the ladder entrance modification.

The evaluation included acquiring velocity data for the right abutment ladder in each of the four downstream-most ladder pools, along each of the diffusers, and in the tailrace near and far fields downstream from the ladder entrance. The original scope of work also contained provisions for acquiring air concentration and hydro-acoustic data in the downstream-most ladder pools. Air concentration data were acquired along each of the diffusers during phase 2 testing. However, hydro-acoustic data were not acquired because of problems with the instrumentation. It should be noted that although disorientation problems associated with air entrainment and hydro-acoustic conditions may have existed, these parameters were likely unchanged between pre-and post-modification configurations.

The evaluation was segmented into two phases. Phase 1 represents investigations under pre-modification conditions (i.e., orifice plug installed), and phase 2 represents post-modification investigations (i.e., orifice plug removed). Data for both phases were acquired at the same measurement locations for continuity and comparison purposes.

METHODS AND TESTING

All diffuser, ladder pool, and near field tailrace velocity measurements for phases 1 and 2 were acquired using a propeller type current meter. Originally, measurements were to be acquired using a three-dimensional acoustic Doppler velocimeter (ADV). However, because of the high degree of air entrainment, this approach was abandoned in favor of the backup propeller meters. Near and far field tailrace velocity measurements were acquired using a boat mounted acoustic Doppler current profiler (ADCP). Near field data were acquired with limited success, again because of the air entrainment conditions. ADCP data gaps were bridged using the propeller meter setup employed for ladder pool velocity measurements.

Phase 1 Testing

Phase 1 testing consisted of acquiring velocity data in order to characterize ladder hydraulic performance under pre-modification (i.e., orifice plug installed) operating conditions.

Diffuser Velocity Measurements.-Measurement locations were selected such that data were acquired along each of the four diffuser bays in the downstream-most ladder pools. Velocities were measured at a distance of 1.0 ft downstream from each diffuser face. Four propeller type velocity sensors were mounted on a 1.0-in-diameter stainless steel wading rod. Figure 4 shows velocity measurements being acquired along the diffuser wall of the right abutment fish ladder. This setup allowed for adjustability of sensor locations on the wading rod to accommodate varying flow depths. The sloping invert of the ladder created varying flow depths for each ladder pool of interest. In all cases, sensor elevations are

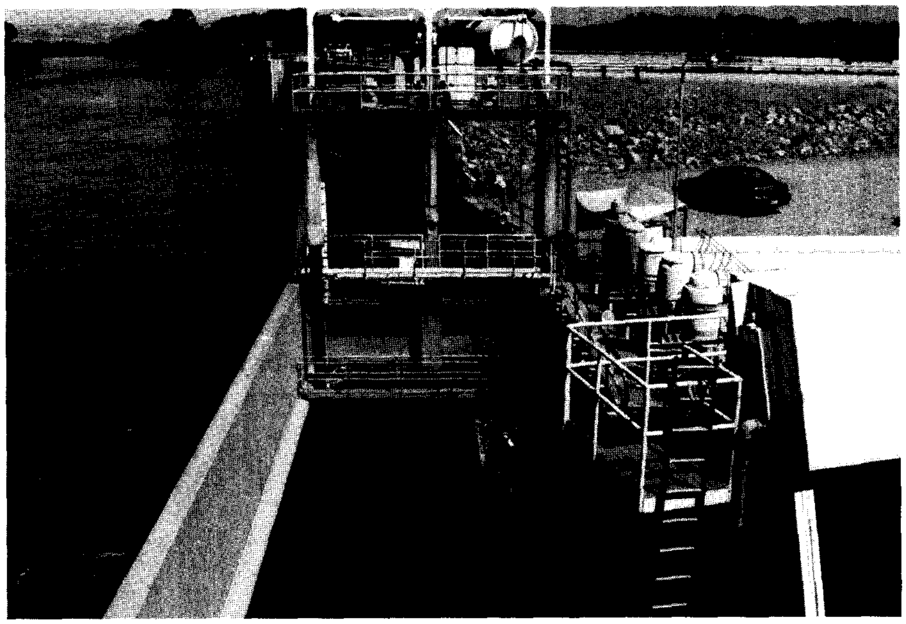


Figure 4. - Lower reach of right abutment fish ladder. Diffuser velocity measurements are being taken along the diffuser wall.

given as the distance within the water column above the ladder invert. The diffusers along the right side of the ladder were identified as 1 through 4, such that the downstream-most diffuser represented diffuser 1 and upstream diffusers were designated sequentially as 2 through 4. Diffuser 1 is the largest of the four diffusers and consists of a 12-ft-wide by 10-ft-high rectangular port. Diffusers 2 through 4 are similar in configuration but consist of 10-ft-wide by 5-ft-high rectangular ports. All diffusers contain bar racks on the upstream side with 1-in center spacings. Sensor elevations were adjusted for each diffuser to acquire velocities at fifth points in the vertical of the water column. For diffusers 1 through 4, velocities were measured using the propeller meter setup along 2-ft station locations and four elevations given as El. 2.4, 4.8, 7.2, and 9.6 ft for diffuser 1; El. 2, 4, 6, and 8 ft for diffusers 2 and 3; and El. 1.5, 3, 4.5, and 6 ft for diffuser 4. The stationing along the fish ladder was designated from upstream to downstream, starting at the upstream weir of ladder pool 4. Diffuser 1 presented difficulties in acquiring velocity measurements along the downstream portion. High velocities accompanied by limited access resulted in the acquisition of data at four station locations only, which represented slightly more than 50 percent of the total diffuser area. In all cases, velocity measurements were acquired with the sensors oriented normal to and parallel with the diffuser racks. This arrangement provided two components of the resultant velocity vectors in the horizontal plane.

Ladder Pool Velocity Measurements.-Pool velocity measurement locations were selected such that stationing along the ladder was consistent with diffuser velocity measurements. Thus, ladder pool traverses were made along those previously defined station locations, and velocities were measured at quarter points across the ladder. Ladder pool designations are consistent with diffuser designations of 1 through 4, respectively. That is, ladder pool 4 contains diffuser 4, and so on. Although several pools exist upstream from the four pools where velocity data were acquired, the focus of these investigations was on those ladder pools affected by supplemental flows (i.e., ladder pools for which diffusers exist). In similar fashion to the diffuser measurements, velocity sensors were set at three different elevations within the water column. It should be noted that following the phase 1 diffuser measurements, a sensor assembly was damaged and the propeller was lost. Thus, the remainder of testing for this evaluation contained only three measurement locations in the vertical. Given this limitation, the sensor elevations were adjusted and corresponded with El. 3, 6, and 9 ft for pool 1; El. 3, 6, and 9 ft for pool 2; El. 2, 4, and 6 ft for pool 3; and El. 1.5, 3, and 4.5 ft for pool 4. Again, data were acquired at each measurement location with sensors oriented normal to and parallel with each ladder pool cross section.

Air Concentration Measurements.-As previously mentioned, air concentration profile measurements were acquired along diffusers at each of the previously established station locations. Data were acquired using an air concentration probe developed by the WRRL in Denver, Colorado. The intent was to quantify the degree of air entrainment imparted to the ladder pools by diffuser flows. Figure 5 shows the air concentration probe setup used for air concentration measurements taken along the diffuser wall.

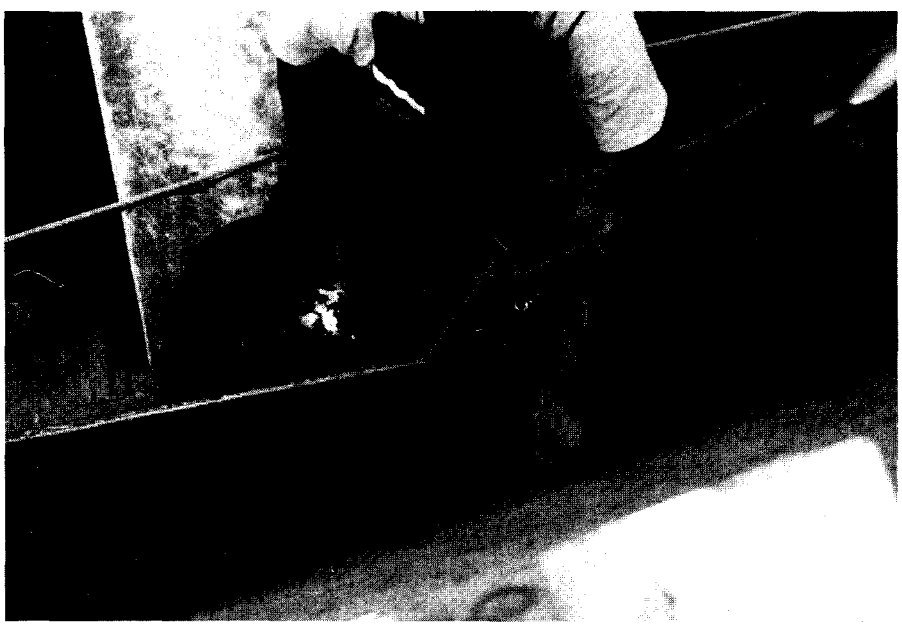


Figure 5. - Air concentration probe. Setup used for taking air concentration measurements along diffuser wall.

Near Field Tailrace Velocity Measurements.-Velocity measurements were acquired just downstream from the ladder entrance in the diversion dam tailrace using the same propeller meter setup as was used for ladder diffuser and pool velocity measurements. Sensor elevations were set at El. 1.5, 3, 4.5, and 6 ft. Velocities were measured along the centerline of each ladder entrance gate at distances of 2, 30, and 50 ft downstream from the ladder entrance. Access was obtained using a jet boat. The boat was tethered to minimize any boat-induced velocities. Figure 6 is a photograph of the jet boat employed for near field tailrace velocity measurements.

Far Field Tailrace Velocity Measurements.-The final component of the phase 1 investigations involved acquiring far field velocity data on the ladder side of the diversion dam tailrace. These measurements were acquired at the same time as the ladder diffuser and pool velocity measurements. A boat-mounted ADCP was employed for this purpose.

Phase 2 Testing

Phase 2 testing consisted of acquiring velocity data in order to characterize ladder hydraulic performance under post-modification (i.e., orifice plug removed) operating conditions. The phase 1 methods and procedures were duplicated for the phase 2 testing. However, near field velocity measurement locations differed from phase 1 testing because the emphasis of this portion of the phase 2 testing was on velocity measurements which characterized the modified entrance configuration. That is, because the right side ladder entrance regulating gate was closed for the modified entrance configuration, velocities were acquired only along the centerline of the left side regulating gate.

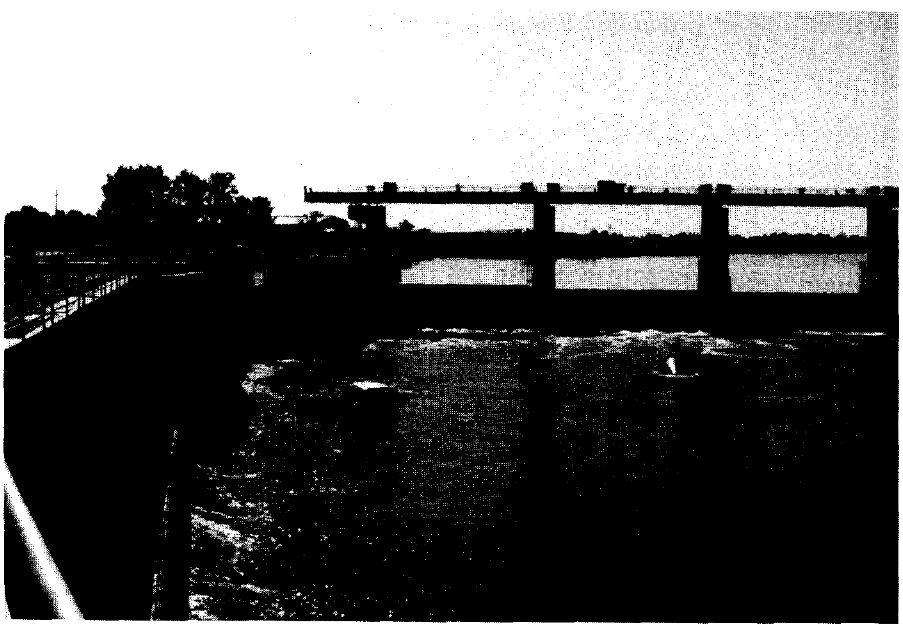


Figure 6. - Photograph of jet boat used for near field velocity measurements.

RESULTS

The raw data sets for phases 1 and 2, diffuser, ladder pool, and near field velocity measurements have been included in the appendix. Station designations and corresponding sensor elevations are presented with the velocity data for each diffuser and ladder pool, respectively. Also included are RBDD operating data for this test period.

Phase 1 Results

Diffuser Velocity Results.-Diffuser velocity distributions for the pre-modification testing (phase 1) are presented as isovel plots. The average velocities acquired at various points over each diffuser face were interpolated to generate a grid appropriate for constructing isovel contours. These velocities represent normal component measurements and do not reflect magnitude or direction of the resultant vector exiting the diffusers. Diffuser flows likely exit the diffusers at some orientation which has a downstream component. As such, small changes in the resultant vector direction cause significant changes in the normal component magnitude. Although presentation of data in this fashion does not give a complete description of resultant exit velocity magnitude or direction, the results give a good indication of the two-dimensional velocity distributions for each diffuser. Comparison of the normal component velocity data with the ladder pool velocity field data gives the complete description of exit velocity magnitude and direction along each of the diffusers. Figures 7 through 10 are isovel plots for diffusers 1 through 4, respectively. Diffuser 1 (the downstream-most diffuser located along the right side of ladder pool 1, which is located just upstream from the ladder entrance) appears to indicate horizontal skewness with some vertical skewness in the velocity distribution (fig. 7). Diffuser 2 exhibits skewness in the horizontal velocity distribution (fig. 8). Velocities increase from upstream to downstream and indicate very little skewness in the vertical distribution. The velocity criteria are exceeded, in this case, over about 25 percent of the diffuser area. Diffuser 3 (fig. 9) also demonstrates a horizontal skewness with some vertical skewness in velocity distribution. Again, the velocity criteria are exceeded over about 25 percent of the total area. Lastly, diffuser 4 results (fig. 10) indicate minimal horizontal skewness with some vertical skewness in velocity distribution. However, in this case, the diffuser velocities were found to be within criteria.

Ladder Pool Velocity Results.-Ladder pool velocity results have been presented as plan view vector field plots. These vector field plots represent velocity magnitude and direction at various elevations within the water column, consistent with the sensor elevation settings. Thus, for each pool, three plots are given representing the three different sensor elevations for which data were acquired. Vector lengths indicate velocity magnitudes and can be compared with the reference vector, which is equal to 1.0 ft/s. The upstream and downstream weir locations are also given to indicate the spatial extent of each ladder pool. The coordinate axes represent physical dimensions of the ladder pools and are given in feet (ft). The right and left boundaries indicated on the plot represent the right and left walls of the ladder. The results indicate that diffuser flows strongly influence the velocity field in each of the ladder pools. This influence is particularly evident at lower elevations within the water column. Figures 11 through 14 represent the vector field plots for data acquired in each ladder pool at various sensor elevations. Strong crossing flows exist which appear to peak near the diffuser side of the ladder and diminish across the ladder to the opposite wall. At higher elevations within the water column, velocity fields, as expected, become much more upstream to downstream oriented as crossing flows are minimized with the reduced influence of diffuser flows and increased influence of sheet flows passing over the weirs. In the upper portion of the water column, the results confirm that flow patterns are predominantly upstream to downstream with minimal crossing components. Pool 2 exhibits similar patterns at an elevation of 6.0 ft above the invert.

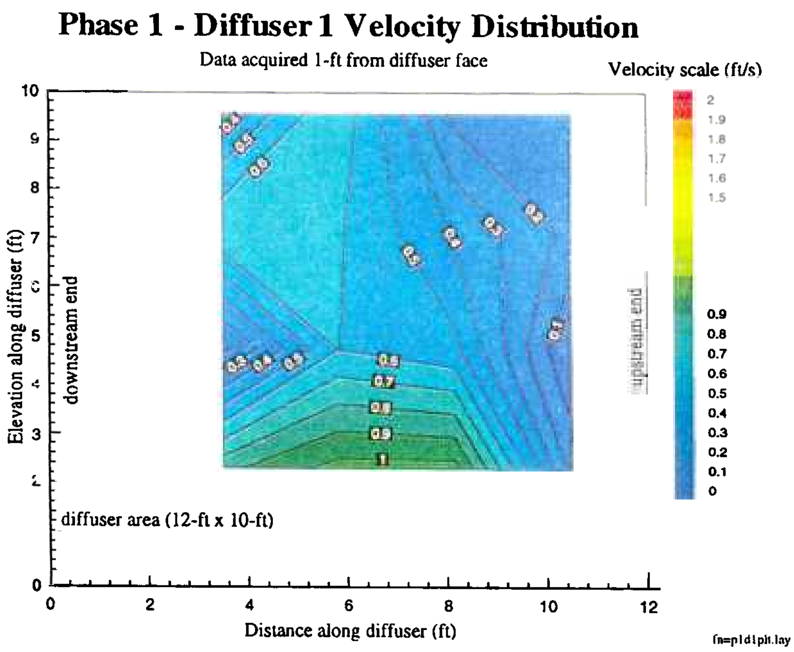


Figure 7. - Diffuser 1 velocity contour plot (phase 1 testing).

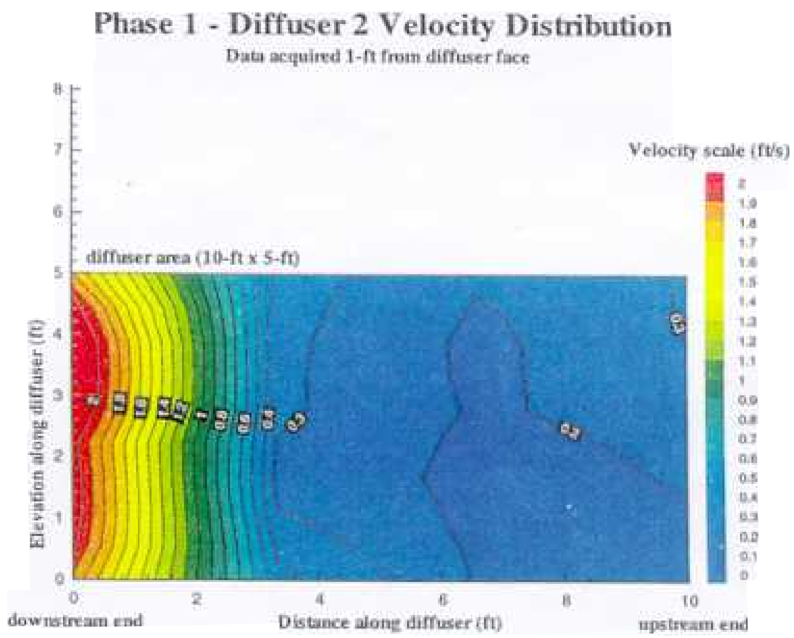


Figure 8. - Diffuser 2 velocity contour plot (phase 1 testing)

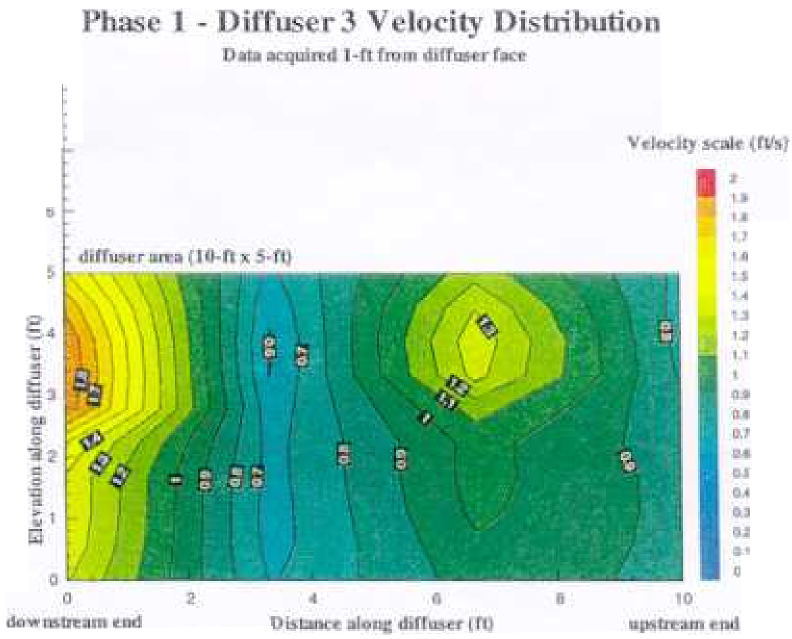


Figure 9. - Diffuser 3 velocity contour plot (phase 1 testing). Illustrates upstream to downstream skewness in velocity distribution.

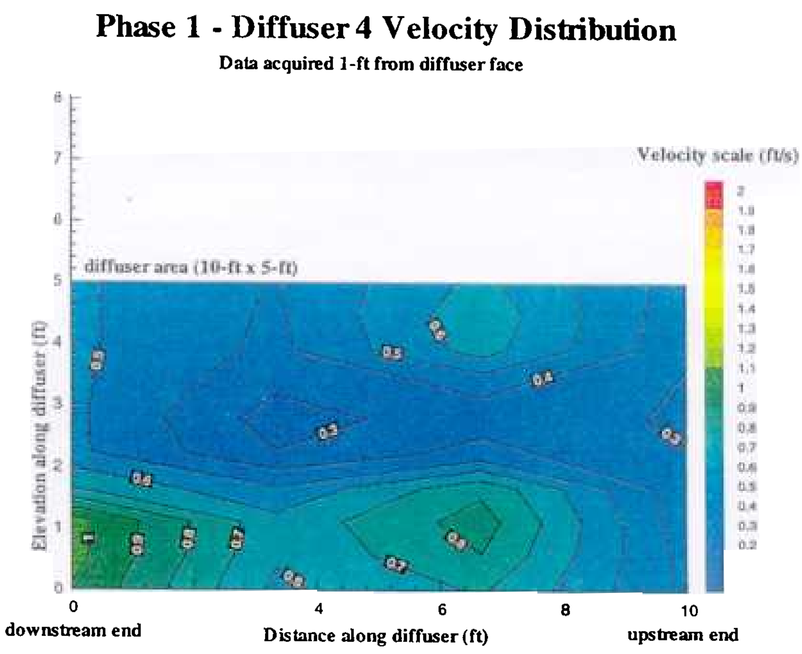


Figure 10. - Diffuser 4 velocity contour plot (phase 1 testing). Skewness in velocity distribution is less severe than those results obtained for diffusers 2 and 3.

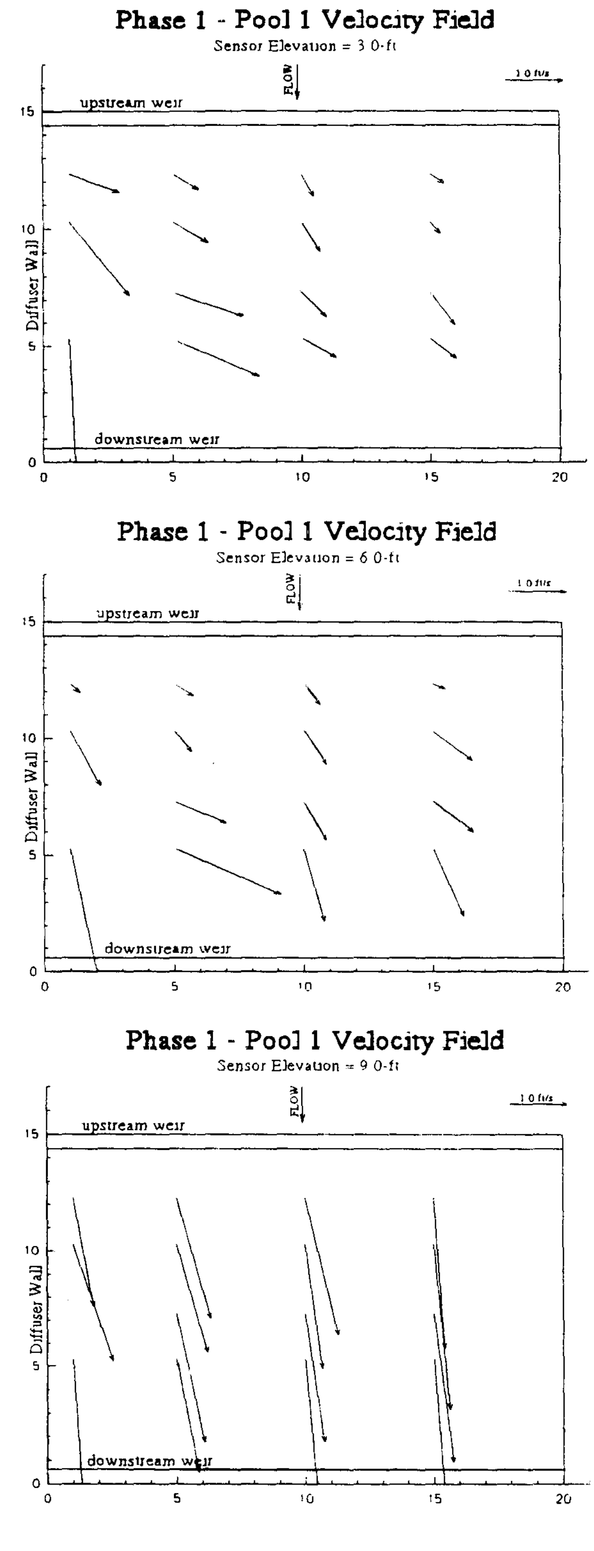


Figure 11. - Ladder pool 1 velocity vector field data (phase 1 testing). Illustrates plan view vector field at various elevations within the water column.

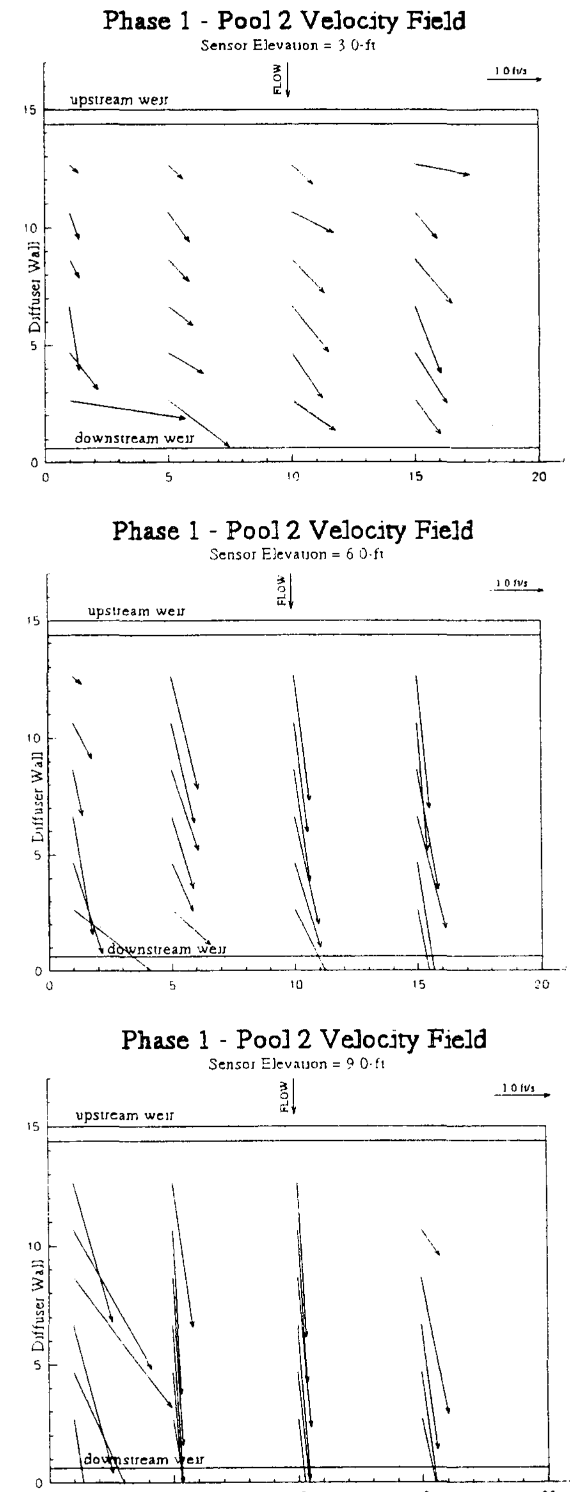


Figure 12. - Ladder pool 2 velocity vector field plot (phase 1 testing).

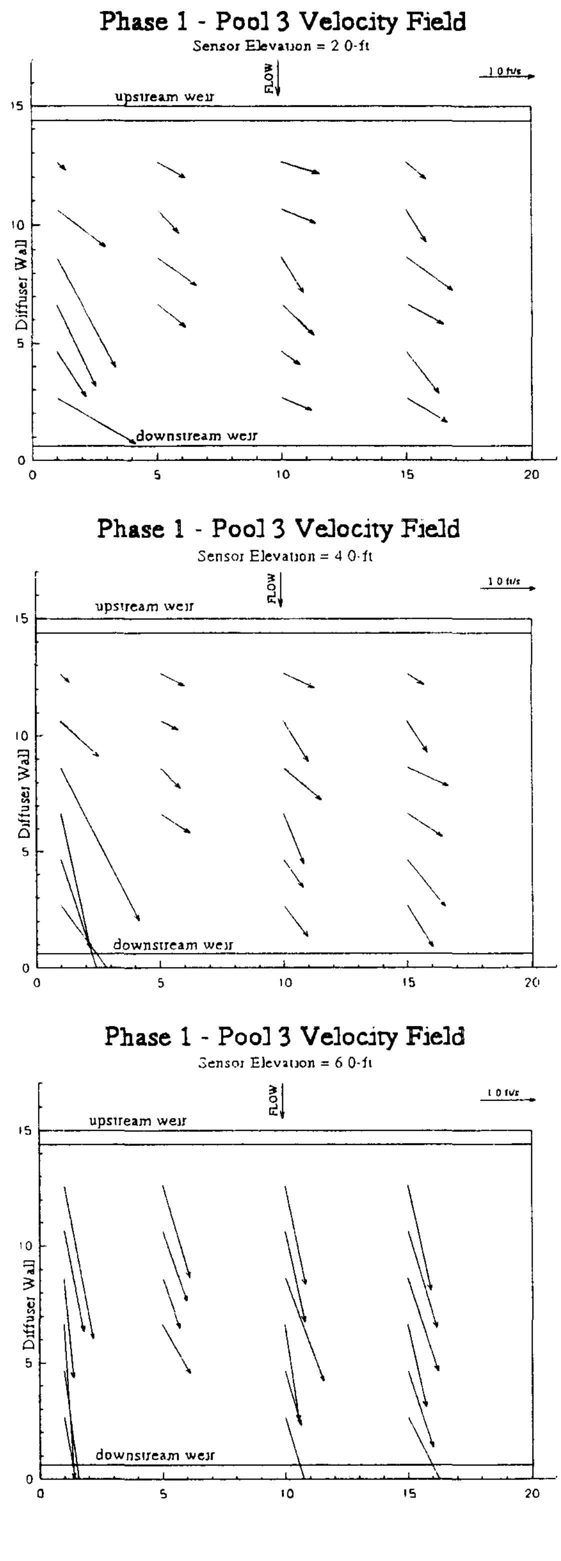


Figure 13. - Ladder pool 3 velocity vector field plot (phase 1 testing).

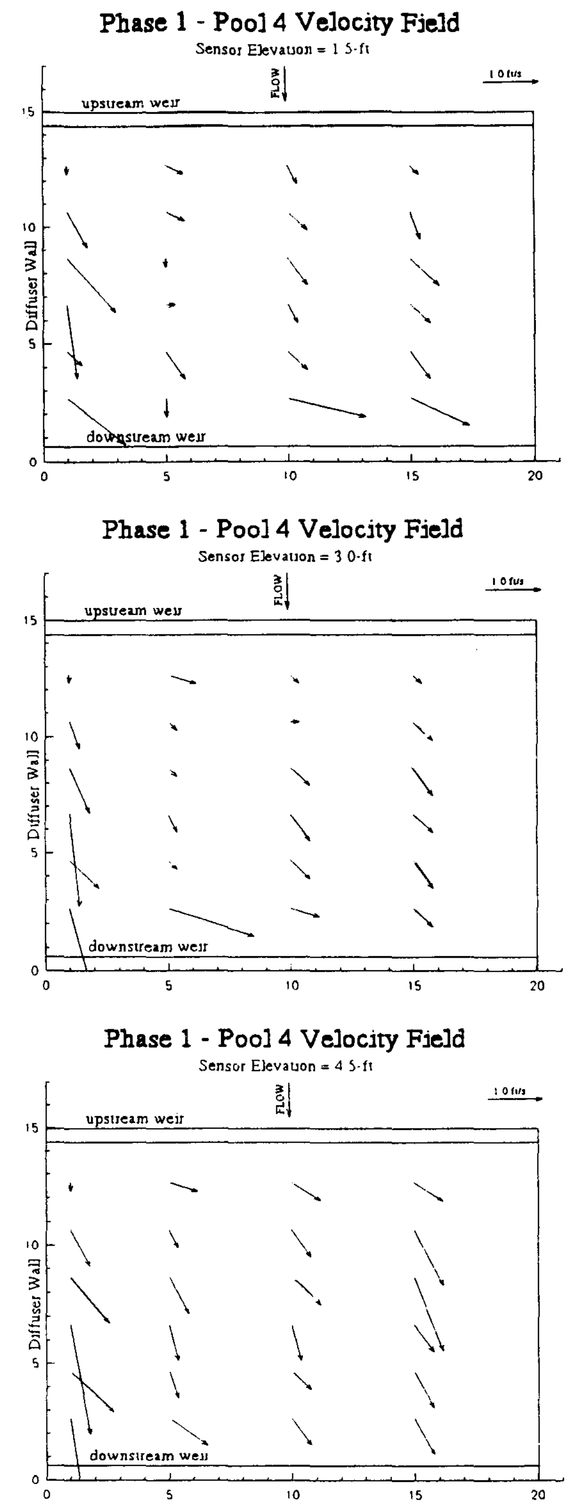


Figure 14. - Ladder pool 4 velocity vector field plot (phase 1 testing).

It should be noted that an elevation of 6.0 ft corresponds with the top elevation of the upstream weir for ladder pools 2 through 4 and is higher than the tops of each diffuser. Thus, diffuser flow influence is expected to be reduced given the sheet flow conditions in the water column at elevations above the top of the weirs. The results for pool 3 (fig. 13) show a similar trend compared with pools 1 and 2. Pool 4 data were not acquired at an elevation higher than the upstream weir elevation. However, similar results to those obtained for pools 1 through 3 are likely for this case as well. For all of these results, only two-dimensional velocity data were acquired and hence presented under the pool velocity measurements portion of this evaluation. Vertical or up welling components of velocity likely exist. As flow is imparted to the ladder pools by the diffusers, it must travel up and over the downstream weir to the next pool. Although vertical slotted orifices exist for each of the weirs separating the pools under investigation, flow through the orifices is limited by the relatively small cross sectional area. Nevertheless, some flow through the slotted orifices exists. In addition, head differentials across the weirs are small because of the diversion dam tailwater elevation, which floods the downstream portion of the ladder, submerging those weirs which are influenced by diffuser flows.

Air Concentration Results.-The results of the air concentration profile measurements are given as figure 15. This color contour plot illustrates the volumetric concentration of air in diffuser flows. The maximum air concentration measured was about 19 percent, with much of the diffuser flows carrying 2 to 5 percent. At these 2- to 5-percent levels, air is visible and likely generates significant acoustic noise, which may produce less than optimal passage conditions.

Near Field Velocity Results.-The results of the velocity field data acquired in close proximity to the ladder entrance using the propeller meter assembly for the original configuration (no orifice entrance) operating conditions indicated that high velocities of about 7 to 8 ft/s were sustained for a distance of less than about 30 ft downstream from the ladder entrance. This result was confirmed by analysis of the ADCP data, which indicated that velocities began dropping at a distance of about 15 ft downstream from the ladder entrance. This decrease is particularly true near the surface (i.e., at higher elevations in the water column). Velocity magnitudes of about 3.3 ft/s appear to become relatively constant at a distance between 15 and 30 ft downstream from the ladder entrance. Thus, the zone of high velocity attraction flow influence is certainly limited to 30 ft downstream and is more likely limited to 15 ft downstream from the ladder entrance for the pre-modified entrance configuration. Figure 16 represents near and far field data results acquired using the propeller meter and ADCP setups. The results of phases 1 and 2 have been presented together for comparison purposes. This plot demonstrates the fact that the near field zone of influence for the ladder under pre-modification conditions is limited to 15 ft.

Far Field Velocity Results.-The results of the far field velocity measurements are also summarized in the isovel plot shown on figure 16. The two sets of velocity data were combined for ease of comparison. Twelve individual velocity profiles were collected along the two tag lines extending from the centerline of each fish ladder entrance gate downstream to the end of the research pumping plant trashrack structure. The total coverage was about 255 ft downstream from the fish ladder entrance gates. ADCP velocity profiles near the gates were not collected because of air entrainment conditions in the flow which attenuated the acoustic signal. However, ADCP data were collected to within 30 ft downstream from the ladder entrance.

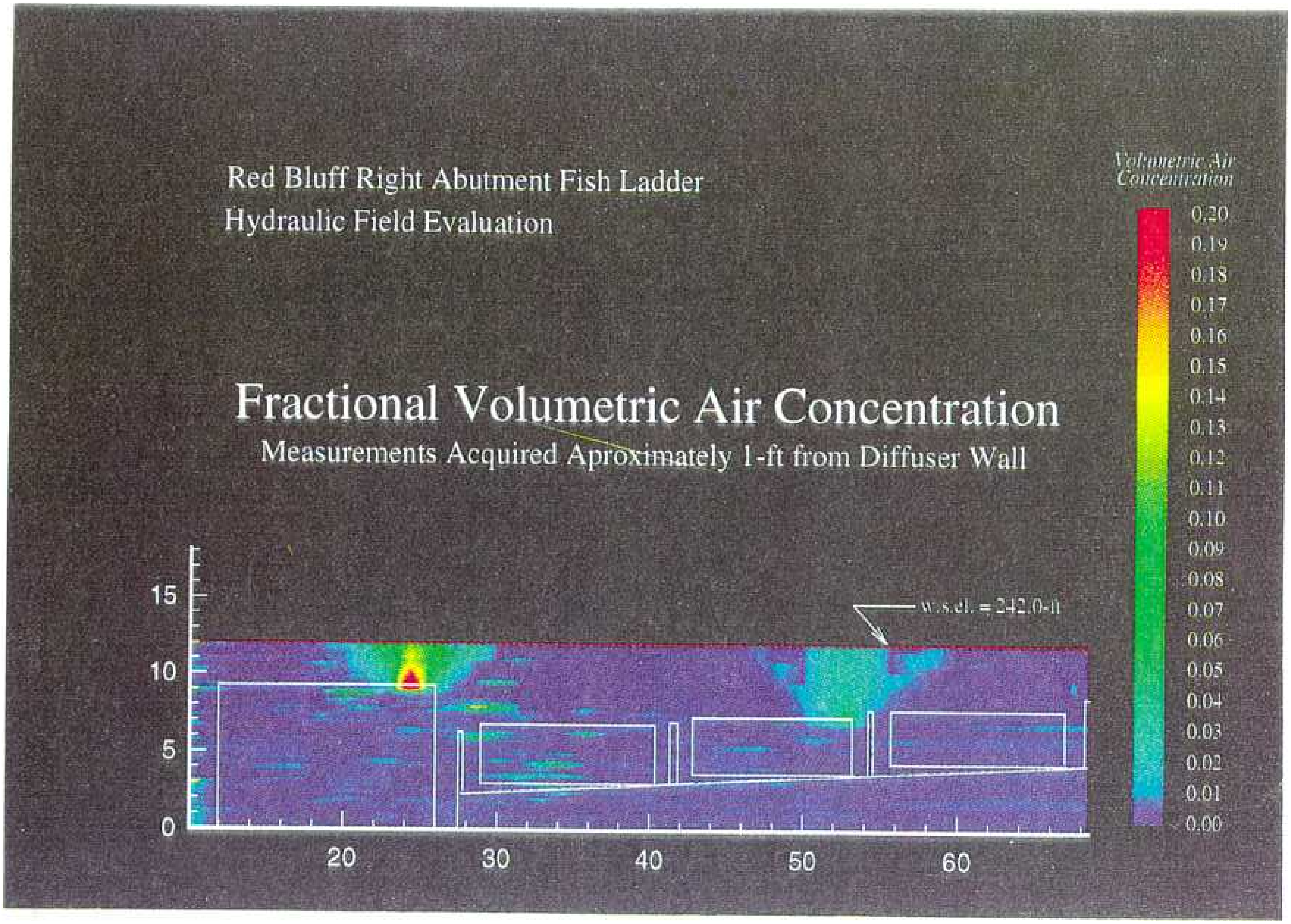
The maximum far field velocities were about 4 to 5ft/s. For phase 1 data, velocities of 4 ft/s extended 190 ft downstream at a maximum depth of 10 ft. However, for distances greater than 115 ft downstream, fish ladder releases were nearly indistinguishable from the flow field generated by gate 11 (sluiceway) releases. For phase 1 testing, the sluiceway gate was opened 1.8 ft. The lateral extent of the fish ladder jet was determined using a series of ADCP transects collected perpendicular to the research pumping plant trashrack structure. Figure 17 contains contour plots of the seven ADCP transects collected during phase 1 testing. The first three transects were collected perpendicular to the sheet pile retaining wall, and the next four were collected perpendicular to the research pumping plant trashrack structure. ADCP measurements collected 155 ft downstream from the fish ladder entrance gates show a relatively uniform velocity distribution over a transect covering a distance of 60-ft normal to the trashrack. However, transect data collected 115 ft downstream from the gates show 4 to 5 ft/s velocities along the face of the trashrack structure. Although ladder releases contribute to these velocities, gate 11 releases are considered to contribute more significantly. Based on transect data, the estimated maximum downstream influence of the fish ladder jet was about 115 ft from the fish ladder entrance gates for phase 1 conditions.

Phase 2 Results

Diffuser Velocity Results.-The data results for diffusers 1, 2, and 4 obtained during phase 2 testing illustrate velocity distribution characteristics similar to those obtained during phase 1 testing. Data for diffuser 3 were not acquired because of instrumentation problems. Figures 18 through 20 represent the isovel plots of the interpolated diffuser velocity data. Resultant velocity vector magnitudes are large. Consequently, normal component velocity magnitudes are very sensitive to vector direction. The resultant velocity vector magnitudes are similar for phases 1 and 2. However, minor changes in resultant vector directions produce changes in normal component magnitudes. These changes are felt to be a result of the entrance modification, which produces slight changes in the ladder flow patterns for all ladder pools of interest in this investigation. Comparison of diffuser and ladder pool velocity data for pool 4 during phases 1 and 2 demonstrates this feature. For all diffusers, the velocity distributions are skewed primarily in the horizontal with slight skewness in the vertical. Furthermore, velocities increase along the diffusers from upstream to downstream. However, under this phase of testing, only diffuser 1 velocities appear to exceed the 1.0-ft/s criteria. The same general trends (i.e., velocity distributions) are realized for both pre- and post-modification conditions with the exception of diffuser 1, which is directly influenced by the ladder entrance configuration.

Ladder Pool Velocity Results.-The ladder pool velocity field results exhibited the same characteristics for phase 2 as those of phase 1. The diffuser flow influence on pool velocity fields was confined to elevations below the top of the upstream and downstream weirs, where crossing flow characteristics were evident. Flow patterns above the top of the weirs can be seen as predominantly upstream to downstream with virtually no crossing flow characteristics. Figures 21 through 24 are the velocity field plots at various elevations within the water column for each ladder pool. The exception to the argument of similar velocity field characteristics between phases 1 and 2 is demonstrated by comparison of pool 1 velocity field results. As seen with the diffuser velocity results and the ladder pool velocity field results, ladder pool 1 is significantly affected by the ladder entrance configuration. Strong crossing flow conditions exist throughout the water column in ladder pool 1, probably because of the asymmetric geometry of the entrance modification and the location of the submerged orifice. In this case, diffuser flows imparted to ladder pool 1 must travel across the channel and out the orifice located on the left side of the fish ladder. In addition, sheet flows traveling over the upstream weir and along the right side of the ladder change direction, crossing over to the entrance orifice side of the ladder.

Near Field Velocity Results.-Post-modification near field velocity results are presented in the same fashion as phase 1 results (fig. 25). Phase 2 measurement locations were limited to the left entrance gate (i.e., gate below which the orifice modification exists) centerline. The results indicate that high velocities of about 5.0 ft/s were sustained downstream for a distance of about 15 ft. Furthermore, velocity magnitudes of about 4.5 ft/s were sustained for a distance of about 30 ft downstream from the ladder entrance. Velocities appear to stabilize somewhere between 30 and 50 ft downstream from the ladder


Red Bluff Right Abutment Fish Ladder
Hydraulic Field Evaluation
Fractional Volumetric Air Concentration
Measurements Acquired Aproximately 1-ft from Diffuser Wall
Volumetric Air Concentration
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
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0.02
0.01
0.00
w.s.el. = 242.0-ft
15
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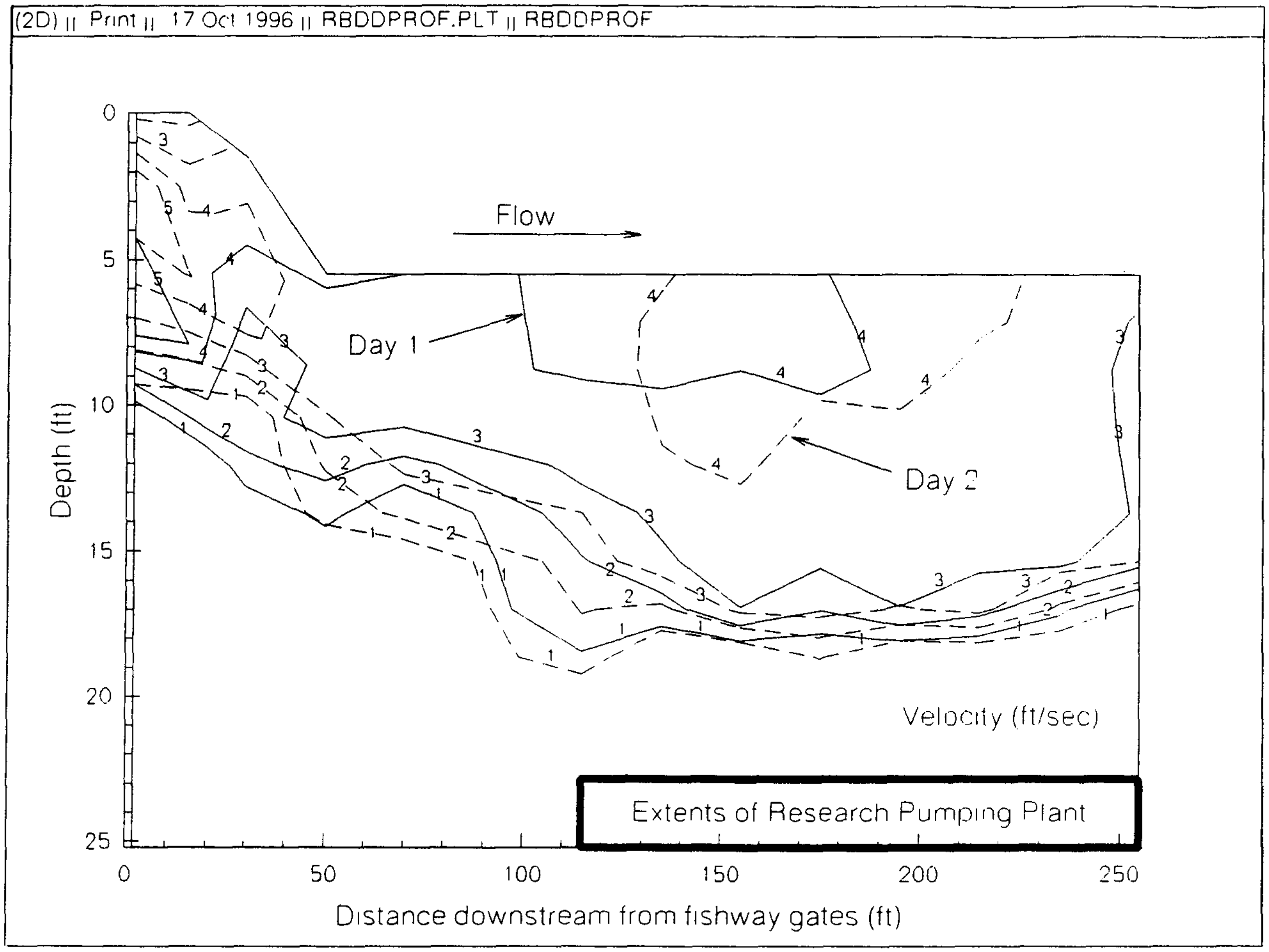


Figure 16. - ADCP profile and current meter data collected downstream from right abutment fish ladder. Contains data for phase 1 and phase 2 testing.

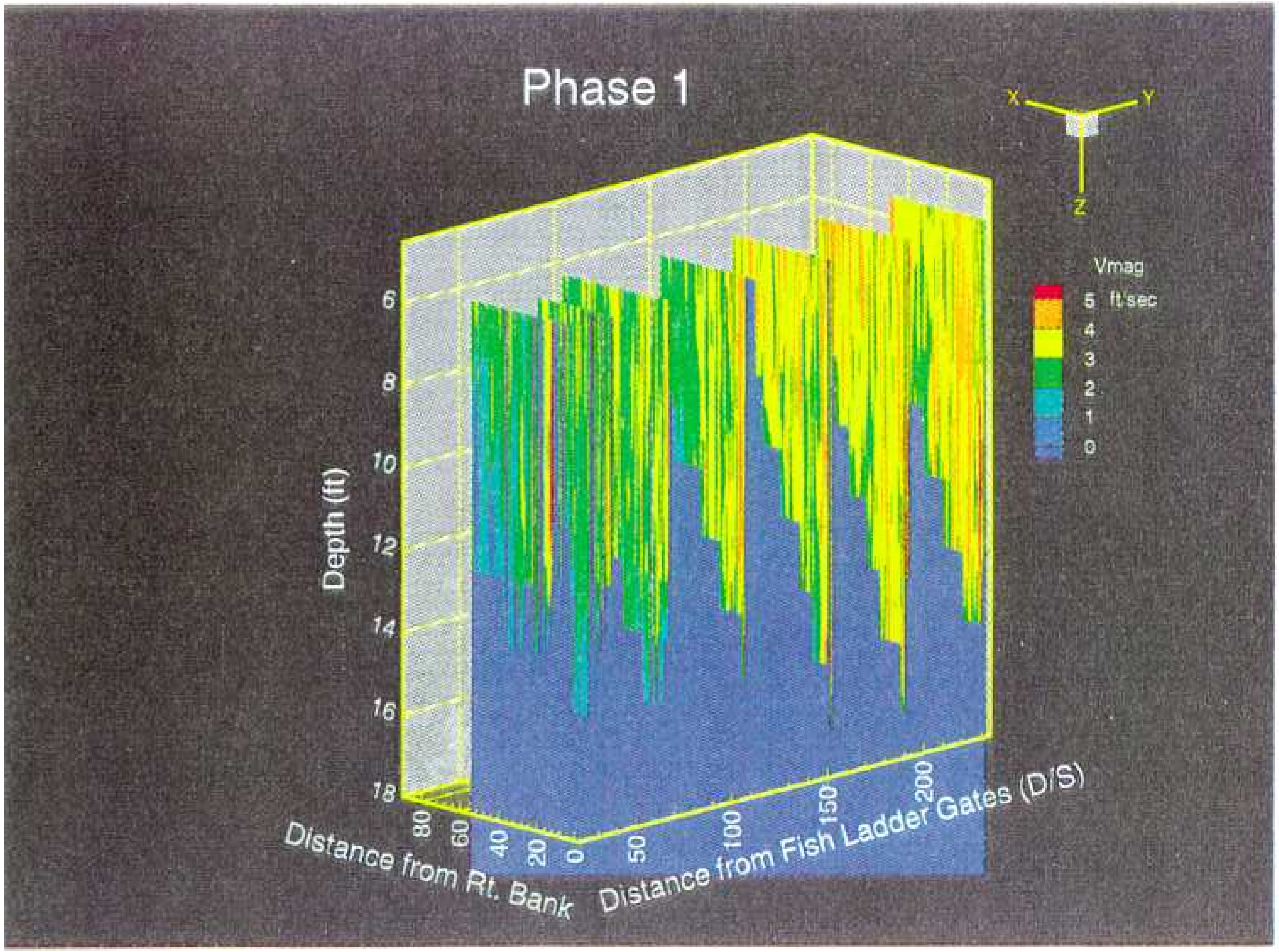


Figure 17. - ADCP transect plots for several locations downstream from the fish ladder gates (phase 1 testing conditions). These transect plots show the high velocity jet exiting from the fish ladder gates in the near field and the transition into a uniform velocity field in the far field.

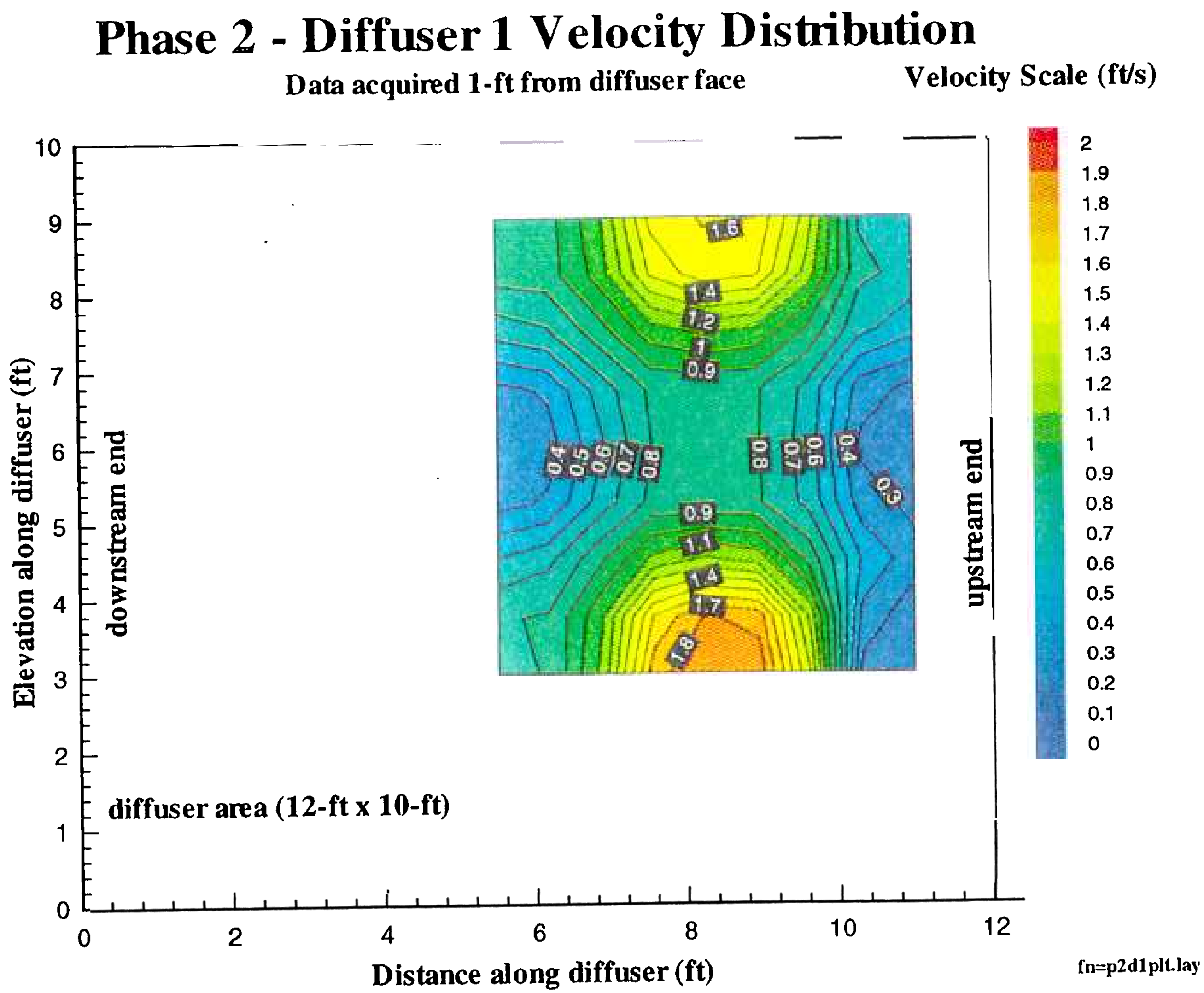


Figure 18. - Diffuser velocity contour plot (phase 2 testing).

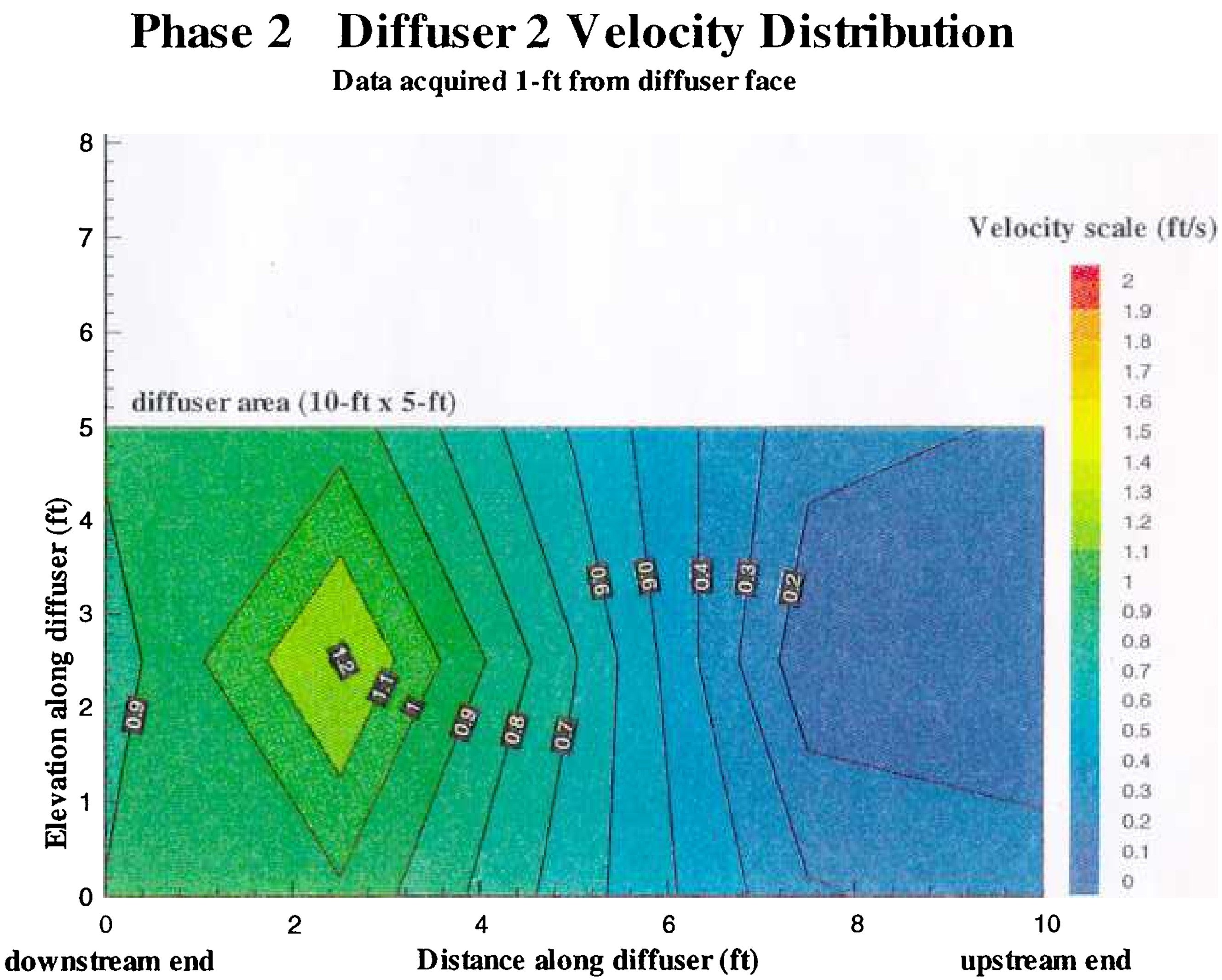


Figure 19. - Diffuser 2 velocity contour plot (phase 2 testing).

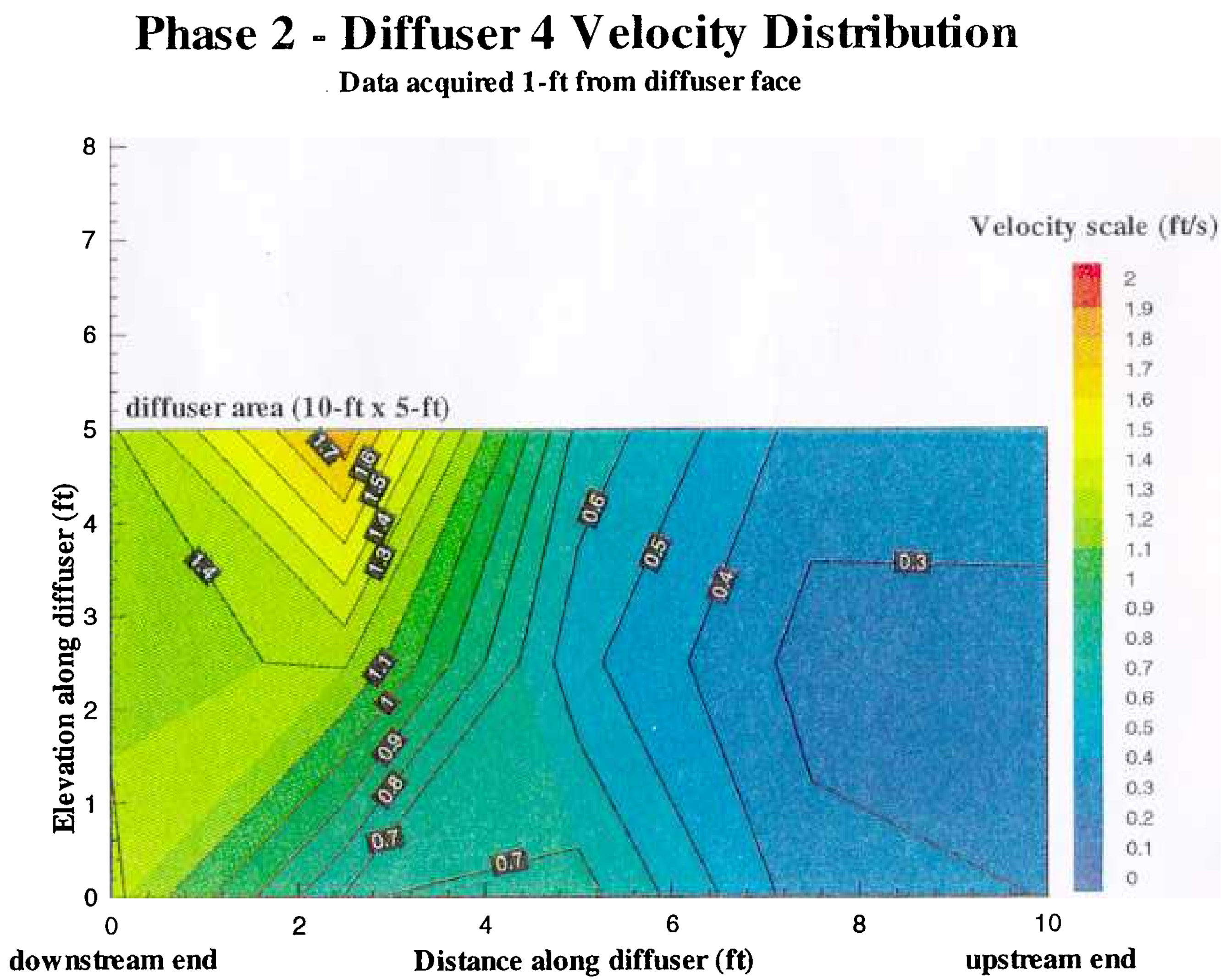


Figure 20. Diffuser 4 velocity contour plot (phase 2 testing).

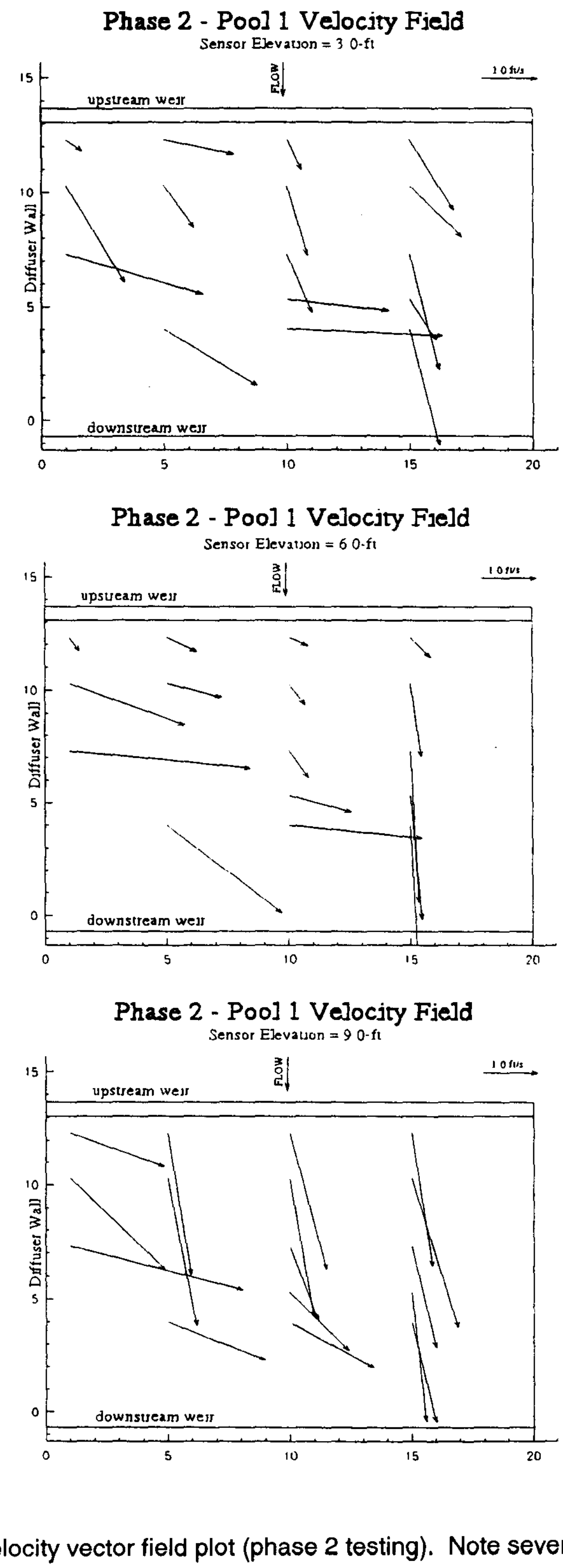
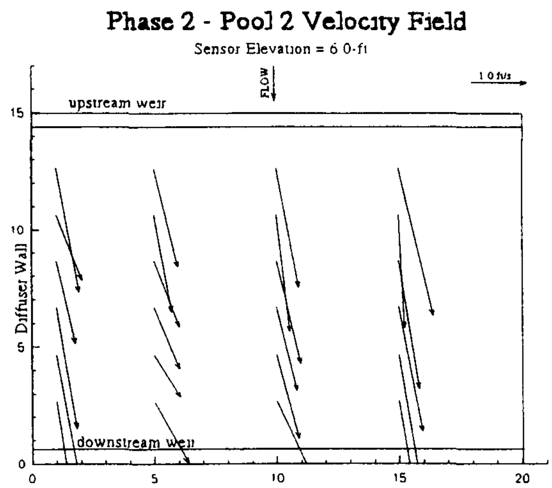


Figure 21. - Ladder pool 1 velocity vector field plot (phase 2 testing). Note severe crossing flow conditions.



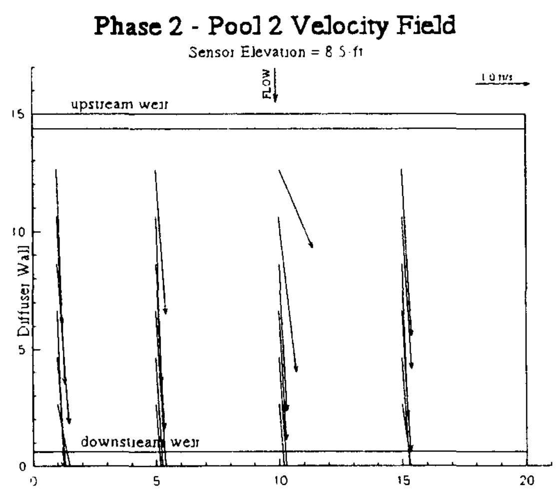
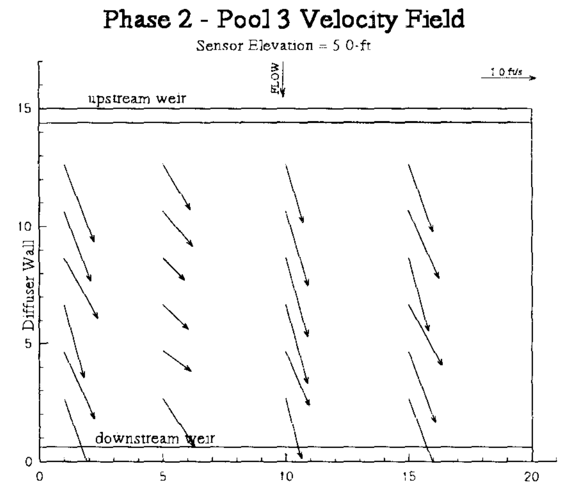


Figure 22. - Ladder pool 2 velocity vector field plot (phase 2 testing).



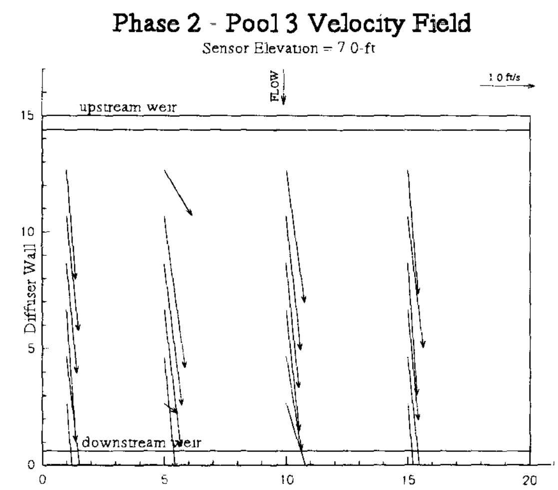
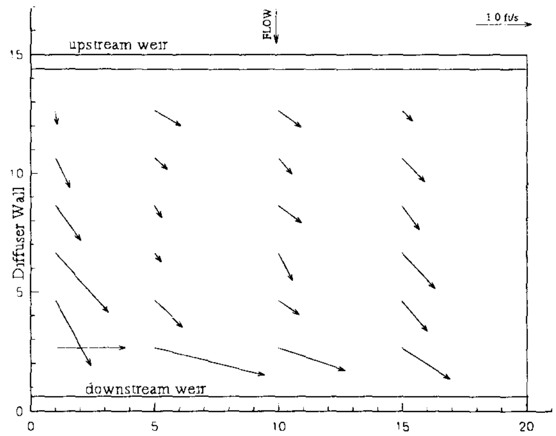
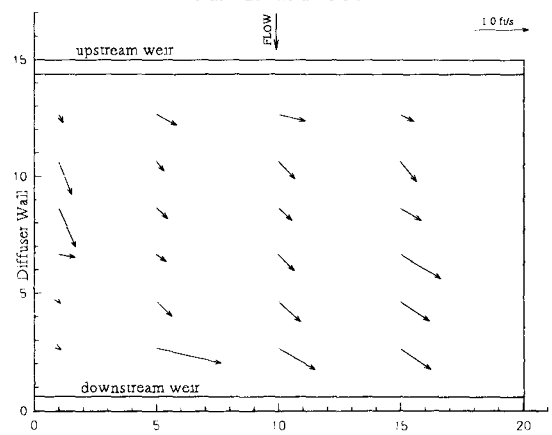


Figure 23. - Ladder pool 3 velocity vector field plot (phase 2 testing).

Phase 2 - Pool 4 Velocity Field



Phase 2 - Pool 4 Velocity Field



Phase 2 - Pool 4 Velocity Field

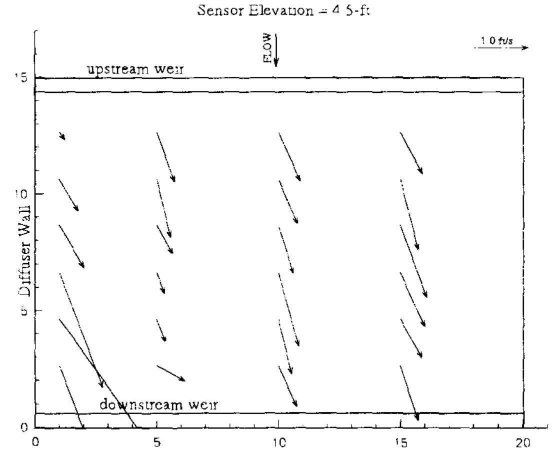


Figure 24. - Ladder pool 4 velocity vector field plot (phase 2 testing).

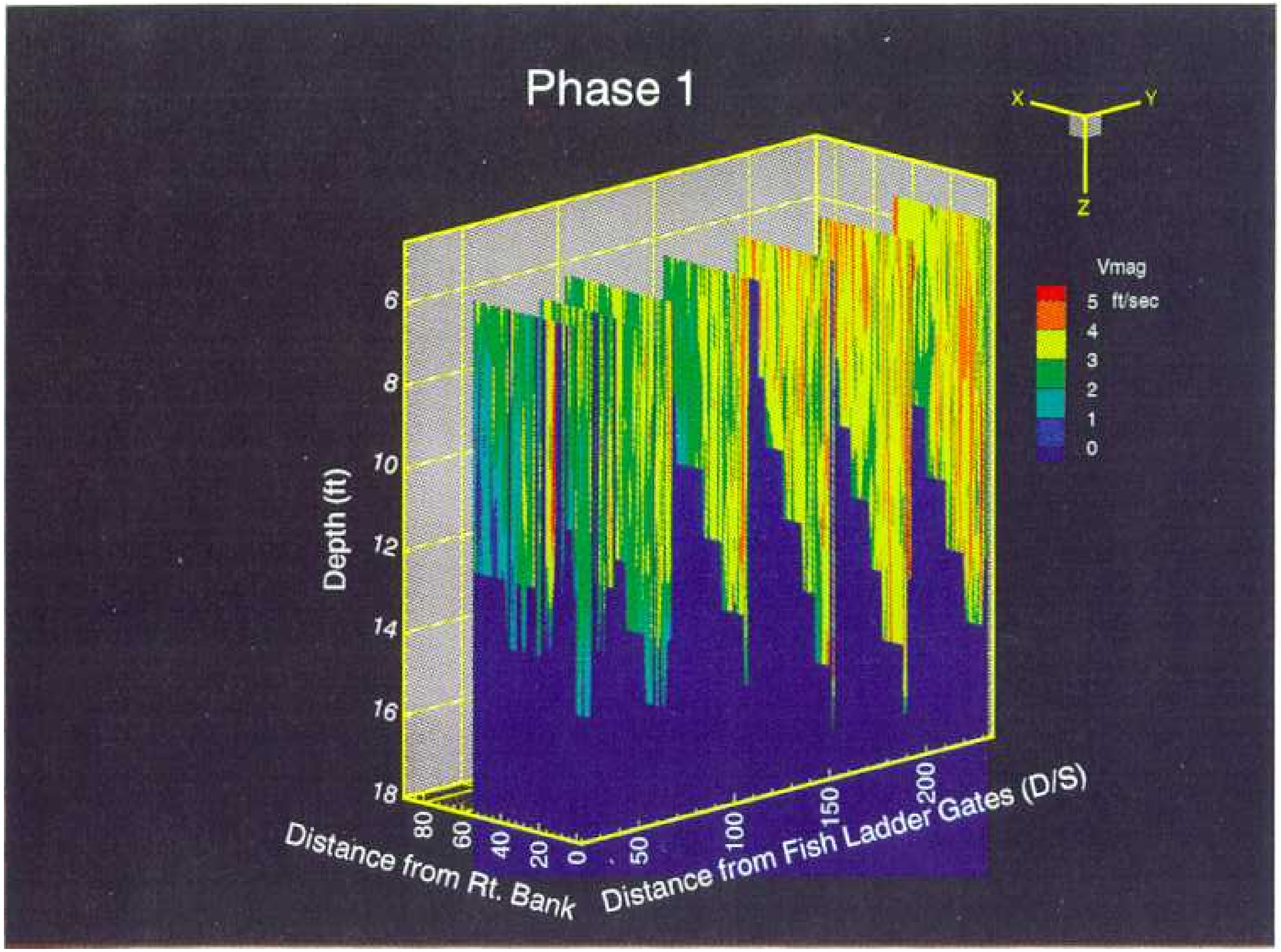


Figure 25. - ADCP transect plots for several locations downstream from the fish ladder gates for phase 1 testing conditions . These transect plots show the high velocity jets exiting from the fish ladder gates in the near field and the transition into a uniform velocity field in the far field.

entrance. Thus, the zone of attraction flow influence is likely limited to 50 ft downstream from the ladder entrance. It should be noted here that divers removing the orifice modification plug prior to phase 2 testing observed that a large bolder (riprap) was obscuring a portion of the orifice entrance, the result of which was noted during near field measurements as a surface boil just downstream from the ladder entrance. Little doubt exists that this obstruction has increased diffusion of the jet exiting the ladder entrance and impinging on the obstruction, consequently reducing the zone of attraction flow influence. The zone of influence would likely extend much farther downstream should this obstruction be removed.

Far Field Velocity Results.-The results of phase 2 far field velocity measurements are summarized in the isovel plot shown on figure 25. Again, this plot includes both phase 1 and phase 2 ADCP and propeller meter data collected downstream from the right abutment fish ladder entrance. The data were presented in this fashion such that a comparison between results for phases 1 and 2 could easily be achieved. ADCP velocity profiles were collected along a tag line extending from the centerline of the left ladder entrance gate downstream to the end of the research pumping plant trashracks. The total distance covered was about 255 ft downstream from the fish ladder gates. Attempts to collect velocity profiles near the gates were again unsuccessful because of air entrainment in the fish ladder releases which attenuated the acoustic signal. However, near-field data acquired by use of the propeller meter setup are included on figure 16 for completeness. The maximum far-field velocities measured were about 4 to 5 ft/s. For phase 2 data, velocities of 4 ft/s extended 230 ft downstream at a maximum depth of 13 ft. The extent of the high velocity zone was increased over phase 1 conditions in that 4-ft/s velocities were maintained 40 ft farther downstream. For phase 2 tests, the sluiceway gate was opened 2.3 ft, or a 0.5-ft increase from the phase 1 gate setting, which corresponds with an increased gate 11 release of about 600 ft^3/s . The increased sluiceway flow is clearly shown by ADCP transect data presented on figure 25. Figure 26 contains six ADCP transects collected downstream from the fish ladder gates. The first two transects were collected perpendicular to the sheet pile retaining wall, and the next four were collected perpendicular to the research pumping plant trashrack structure. The first four sets of transect data show high velocity fish ladder flows near the right bank. Likewise, the first transect shows the high velocities exiting the 60-ft-wide sluiceway. At about 115 ft downstream, the flow field was relatively uniform with slightly higher flows along the trashracks. However, the high velocities (4 to 5 ft/s) concentrated along the trashracks from 150 to 250 ft downstream are primarily a result of the increased flows through gate 11 and not the modification to the gate structure. These high velocities are caused by the convergence of the sluiceway and fish ladder flows. The two flows converge because the trashrack structure projects into the river channel and concentrates the two flow fields. Based on the transect data, the maximum downstream extent of the fish ladder jet was estimated to be about 150 ft for phase 2 flow conditions.

DISCUSSION AND INTERPRETATION OF RESULTS

Fish Ladder Operation

Initial observations upon arrival at RBDD noted that the right abutment fish ladder was operating such that the upstream supplemental flow head gate was set at full open, which is typical. However, this setting raised the question as to how much flow was actually being supplied to the ladder via the diffusers. Both the entrance conditions at the head gate and uncertainties regarding the entrance geometry make it difficult to estimate the discharge using empirical relationships. The actual discharge may exceed the original design discharge used to size diffusers to achieve the 1.0-ft/s velocity criteria. Diffuser velocities in excess of the 1.0-ft/s criteria may create disorientation problems for fish and consequently degrade ladder performance. However, it is recognized that maximizing diffuser flow is critical in providing sufficient attraction to ladder entrances. Additional observations prior to initiation of the testing for this evaluation revealed that the four downstream-most ladder pools and associated weirs were submerged because the diversion dam tailwater elevation was about 240.8 ft. To maintain entrance velocity criteria of 8 to 10 ft/s, the ladder entrance gates were adjusted to achieve the required differential between the downstream-most ladder pool water surface elevation and the diversion dam tailwater elevation. Thus, the water surface elevation in the downstream portion of the ladder was about 242.0 ft, which created this submergence.

Operation of Spillway Gate 11

Operational considerations associated with this investigation include gate 11, which is located adjacent to the right abutment fish ladder. The general consensus is that fish staging locations near the diversion dam depend on spillway gate settings and corresponding spillway releases. As spillway releases are increased, the turbulent intensity within the stilling basins increases. This turbulence increases the degree of air entrainment, which travels successively farther downstream from the stilling basin end sill. Fish staging locations appear to be consistently downstream from this "white water" zone (Vogel et al.,1988). Because of this location, operation of gate 11 likely has a significant impact on the performance of the right abutment fish ladder. Under the release conditions which existed during this evaluation, when gate 11 was set at 2.3 ft, the air entrainment zone extended well downstream to the pumping plant. Applying the argument that fish are not likely to penetrate the air entrainment zone and assuming this air entrainment extends to a significant depth in the water column, operating gate 11 in this manner could provide a barrier to the right abutment ladder. However, some question exists as to whether fish will negotiate the air entrainment zone at lower depths. In any case, the pre-modification ladder entrance configuration creates high velocity zones near the surface in the downstream tailrace. Thus, under these conditions, even if fish were inclined to negotiate the air entrainment zone at lower elevations within the water column, attraction flow conditions at those elevations would not likely be sufficient, making it difficult for fish to sense and locate the ladder entrance. In any case greater detail regarding the vertical distribution of fish staging may provide further insight for establishing ladder and gate operations which optimize fish passage potential at RBDD.

Diffuser Flow Air Entrainment

Observations of ladder operation show that supplemental flows supplied to the right abutment fish ladder are highly air entrained. After passing through the diffusers and into the ladder pools, these air entrainment zones extend the full width of each ladder pool for which diffuser flows are introduced. The source of this air entrainment is the plunging of the supplemental flow from the upstream head gate down into the diffuser channel. The diffuser channel conveys entrained air or "white water" flows to the diffuser chimneys and subsequently into the ladder pools. Insufficient settling time exists for the entrained air to rise out of the water column prior to entering the ladder, and some question exists as to what degree this air entrainment may affect fish. In any case, minimizing the amount of this air entrainment seems logical given the uncertainties regarding potential disorientation of fish, in that a simple alternative to do so likely exists.

Diffuser Velocity Distributions

Diffuser velocity distribution results may be generalized to some degree because similar characteristics were obtained for each of the diffusers, in many cases irrespective of pre- or post-modification conditions. The test results from phases 1 and 2 indicate that diffusers 2 through 4 strongly influence the velocity field within each respective ladder pool. In addition, velocities increase significantly from the upstream end of each diffuser to the downstream end. Strong upstream to downstream velocity field patterns are

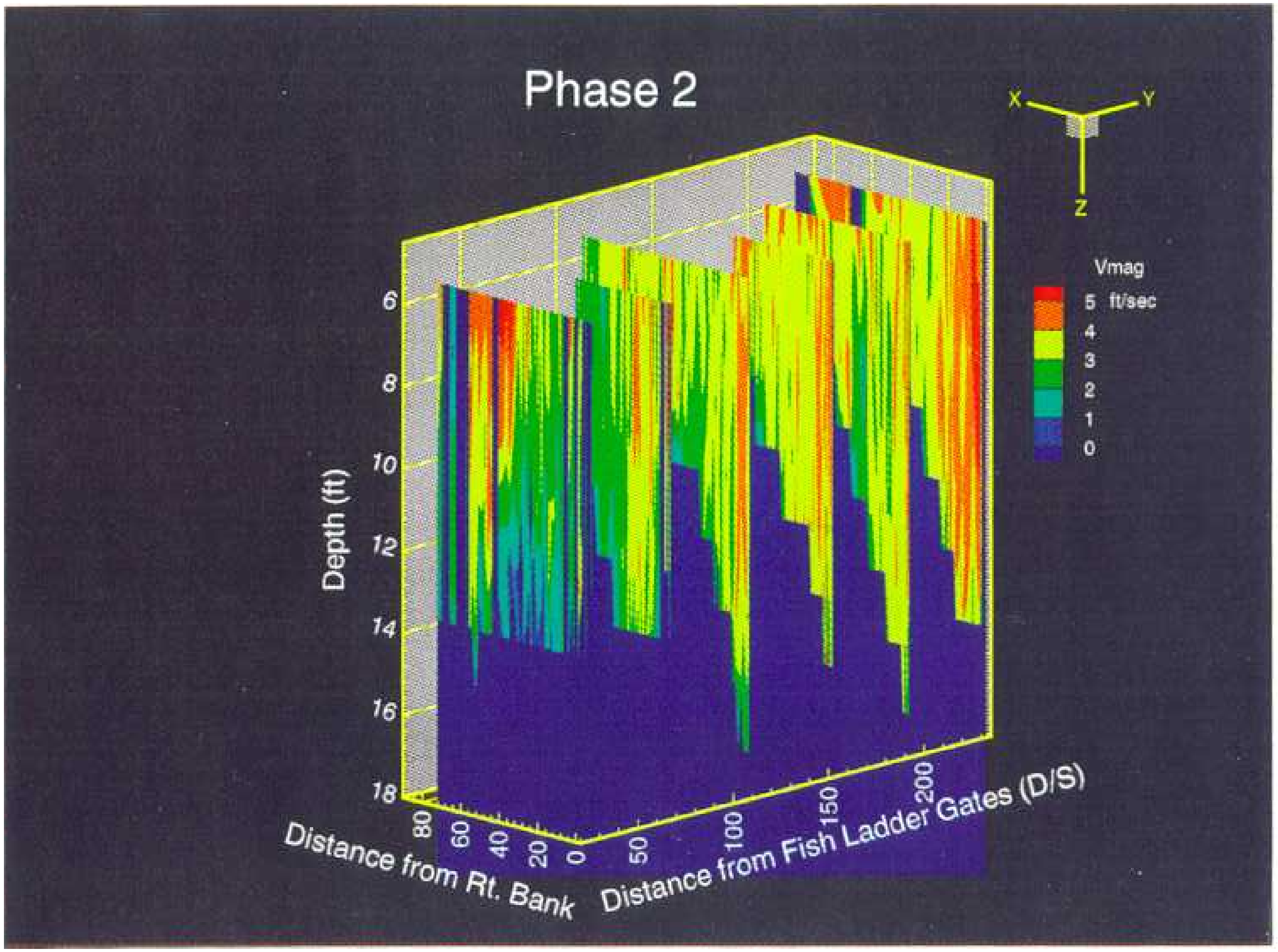


Figure 26. - ADCP transect plots for several locations downstream from the fish ladder gates for phase 2 conditions. These transect plots show the high velocity jets exiting from the fish ladder gates and from gate 11 in the near field, and the transition into a uniform velocity field in the far field. The high velocities measured 250 ft downstream are the result of increased flows through gate 11.

desirable such that fish will move quickly up the ladder. However, the non-uniformity in velocity distribution is represented by localized zones in which velocity magnitudes exceed the 1.0-ft/s velocity criteria and create crossing flow patterns which potentially cause delay.

Generalized Ladder Pool Flow Patterns

Similar to the diffuser velocity distribution results of this evaluation, the pool velocity field or flow patterns were found to be consistent for pools 2 through 4. As previously indicated, flow patterns are strongly influenced by diffuser flows at elevations in the water column which are below the respective weir elevations of the upstream and downstream ladder pool weirs. Strong crossing flows exist at these elevations. However, at elevations in the water column which are above the top of the weirs, the velocity field is influenced only slightly by diffuser flows and exhibits a flow pattern orientation which is predominantly upstream to downstream.

Ladder Entrance Conditions

The observed ladder entrance conditions downstream from the right abutment ladder appear to change from pre- to post-modification configurations. Visual inspection of surface conditions indicates that the pre-modification ladder entrance configuration produces two jets (one for each gated entrance), which are bounded at the surface and appear to have a high turbulent intensity. The jets are spread out and appear to diffuse quickly at the surface. In contrast, the modified entrance configuration produces surface conditions which appear to have smaller turbulent intensities. Realizing that these observations are confined to surface conditions, the interpretation of such is subjective. However, based on experience and the results of near field velocity measurements, the modified entrance configuration likely represents improved hydraulic conditions at the entrance, from a fish passage standpoint, over the original gated entrance configuration. The modified configuration will diffuse less quickly because of the geometry of the issuing jet and the fact that the surface does not present a boundary, at least in close proximity to the entrance. The near field velocity results of this evaluation support this position. The drawback of this position is that by modifying the entrance in such a way, the velocity field upstream from the ladder entrance is significantly influenced, as previously discussed. Thus, the deficiencies in fish passage associated with this ladder may have been merely displaced from the tailrace to ladder pool 1 instead of being improved.

Near Field and Far Field Attraction Flow Performance

The near field velocity results obtained for these investigations indicate slightly improved attraction flow conditions for the modified ladder entrance configuration even with an obstruction located just downstream from the ladder entrance. This improvement is evident in the fact that higher velocities are sustained for a greater distance downstream than those observed under the original gated entrance configuration. However, in both cases, ADCP transects show that good lateral penetration does not exist. Velocity data indicated that the fish ladder release flows are directed along the sheet pile retaining wall and the research pumping plant trashracks. This poor lateral penetration is solely a limitation of the ladder entrance orientation with respect to the diversion dam tailrace. This orientation is such that entrance jet penetration is primarily downstream. Thus, non-structural improvements to the existing right bank fish ladder with respect to lateral attraction flows are likely to provide limited improvement.

The far field velocity measurements indicated that the fish ladder release flows were indistinguishable from sluiceway releases at distances greater than 115 ft downstream from the fish ladder gates. This distance corresponds with the beginning of the pumping plant trashrack structure. For distances less than

115 ft downstream, fish ladder release velocities of 4 to 5 ft/s were measured along the sheet pile retaining wall. Furthermore, phase 2 data showed improved jet penetration over phase 1 data. In the tailwater pool, ladder releases have the potential of being significantly masked by gate 11 releases. To achieve effective guidance to the ladder entrance, fish staging locations below gate 11 and the right abutment ladder entrance must be compatible.

RECOMMENDATIONS

The following recommendations involving solutions for improving hydraulic performance of the right abutment ladder are based on WRRL experience, field observations, and the results of this investigation.

Operational Modifications

The results of this investigation and field observations show that current ladder operation is less than optimal. However, the as-built configuration of the diffusers represents sufficient area to accommodate diffuser flows. Thus, diffuser velocity criteria should be achievable. Operational modifications should be investigated as a means of improving ladder performance with regard to diffuser flows. This improvement includes reducing diffuser flows, which would also reduce air entrainment. However, the trade-off would be reduced attraction flow influence in the diversion dam tailrace. A means of increasing pool-to-pool ladder flows upstream from the diffusers should also be investigated. This flow increase would improve the upstream to downstream flow conditions and reduce diffuser flow influences. Should this improvement be achieved, the orifice modification to the ladder entrance would likely be more suited to improving ladder performance. In addition, crossing flow conditions in ladder pool 1 would be minimized resulting in less disorientation problems as fish enter the ladder. These operational recommendations represent the minimum efforts required to improve existing ladder performance.

Engineering Modifications

Additional modifications to the existing right bank ladder may be desirable. The design and implementation of a diffuser baffling scheme would improve ladder performance. However, maintenance and cleaning requirements should be considered. In addition, an air stripping concept may be developed, designed, and installed in the diffuser channel to remove a large percentage if not all air entrainment prior to introducing supplemental flows into the ladder pools. The potential improvements regarding how diffuser flows are introduced into the last four ladder pools include:

- Installing diffuser baffles on each of the four existing diffusers.

- Incorporating floor diffusers into the current ladder configuration.

- Adding two additional diffusers in ladder pools 5 and 6 (which would represent the original design) to accommodate increased diffuser flows resulting from full open head gate settings.

- Abandoning the existing diffusers (i.e., bulkheading the existing diffusers) in favor of a pipe diffuser concept which supplies diffuser flows to ladder pools 1 through 6 in a more uniform manner across the entire width of the fishway channel.

These engineering modifications represent only a few of the possible alternatives available for ladder performance improvement with respect to diffuser flows. A physical model study should be conducted prior to implementation of any engineering modification. In the case of implementing baffles along each of the existing diffusers, a physical model study would facilitate the design and ensure greater potential for success.

The information in this report is intended to assist in the selection of the best solution for improving performance of the existing right bank ladder. Should continued use of the entrance orifice modification be desired, the downstream obstruction should be removed to maximize the zone of attraction flow influence and satisfy that part of the original intent of such modification. Additional field studies should also be conducted to (1) better define fish staging locations along RBDD tailrace as a function of gate setting and corresponding release discharge and to (2) better define existing ladder deficiencies from a biological or fishery response standpoint with regard to these findings.

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APPENDIX

Raw Data: Gate Settings, Diffuser, Ladder Pool, and Near Field Velocity Results

RED BLUFF DIVERSION DAM
RECORD OF OPERATION

YEAR 1996

DATE	U/S 0001	ELEV 0800	D/S 0001	ELEV 0800	1	2	3	4	5	6	7	8	9	10	11	TOTAL OPEN	BASIN ELEV	CC CFS	TC CFS	KËS.	CFS PAS: DAM
8-1	252.49	252.53	241.25	241.34	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	2.4	11.9	250.5	102	1,333	15,000	15,150
8-2	252.51	252.57	241.30	241.28	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	2.1	11.6	250.5	84	1,400	13,500	14,790
8-3	252.43	252.46	241.20	241.13	1.5	1.0	1.0	1.0	0	0	1.0	0	1.0	2.0	2.5	11.0	250.5	73	1,400	13,500	14,07[illegible]
8-4	252.40	252.41	240.87	240.84	1.5	1.0	1.0	1.0	0	0	1.0	0	1.0	2.0	1.4	9.9	250.5	84	1,400	13,500	12,75[illegible]
8-5	252.50	252.45	240.80	240.78	1.5	1.0	1.0	1.0	0	0	1.0	0	1.0	1.5	1.7	9.7	250.5	63	1,542	13,500	12,510
8-6	[illegible]	[illegible]	240.80	240.97	1.5	1.0	1.0	1.0	0	0	1.0	0	1.0	2.0	1.7	10.4	250.5	71	1,467	14,500	13,35[illegible]
8-7	252.49	252.51	241.17	241.19	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	1.8	11.3	250.5	69	796	14,500	14,430
8-8	252.56	252.59	241.15	241.18	1.5	1.0	1.0	1.0	0	0	1.0	.5	1.0	2.0	2.1	11.1	250.5	70	1,123	14,500	14,190
8-9	252.57	252.59	241.26	241.29	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	2.3	11.8	250.5	69	1,367	15,000	15,030
8-10	252.48	252.56	241.20	241.26	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	2.0	11.5	250.5	87	1,400	15,000	14,670
8-11	252.52	252.56	241.26	241.29	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	2.1	11.6	250.5	67	1,329	15,000	14,790
8-12	252.60	252.55	241.31	241.40	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	2.6	12.1	250.5	76	1,158	15,000	15,390
8-13	252.45	252.60	241.36	241.39	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	2.6	12.1	250.5	85	1,033	15,000	15,39[illegible]
8-14	252.59	252.41	241.35	241.27	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	1.8	11.8	250.5	84	1,000	15,000	15,030
8-15	252.60	252.57	241.35	241.35	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	2.5	12.0	250.5	78	1,133	15,000	15,270

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
August 6-9, 1996
fn = rbelhfe1.wk4
Phase 1 Testing - Pre modification testing (orifice plug installed)
Scale = 0.000517 pls/m
Diffuser Wall Velocity Measurements (Raw data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s) (corrected data)	Vmin (ft/s) (corrected data)	Vmax (ft/s) (corrected data)
51.4	parallel	2.4	2	1	8	0.35	0.17	1.39
		4.8	1	0	4	0.17	0.00	0.69
		7.2	3	1	9	0.52	0.17	1.56
		9.6	12	2	19	2.08	0.35	3.30
	perpendicular	2.4	5	1	11	0.87	0.17	1.91
		4.8	1	0	5	0.17	0.00	0.87
		7.2	4	2	9	0.69	0.35	1.56
		9.6	2	0	5	0.35	0.00	0.87
53.4	parallel	2.4	8	2	14	1.39	0.35	2.43
		4.8	6	1	10	1.04	0.17	1.74
		7.2	9	1	15	1.56	0.17	2.60
		9.6	13	10	16	2.26	1.74	2.78
	perpendicular	2.4	6	2	12	1.04	0.35	2.08
		4.8	3	0	7	0.52	0.00	1.22
		7.2	6	1	11	1.04	0.17	1.91
		9.6	4	0	11	0.69	0.00	1.91
56.4	parallel	2.4	23	0	20	3.99	0.00	3.47
		4.8	23	0	20	3.99	0.00	3.47
		7.2	23	0	22	3.99	0.00	3.82
		9.6	22	0	22	3.82	0.00	3.82
	perpendicular	2.4	6	0	27	1.04	0.00	4.69
		4.8	10	2	27	1.74	0.35	4.69
		7.2	0	9	25	0.00	1.56	4.34
		9.6	1	0	27	0.17	0.00	4.69
58.4	parallel	2.4	20	20	26	3.47	3.47	4.52
		4.8	22	18	23	3.82	3.13	3.99
		7.2	21	13	22	3.65	2.26	3.82
		9.6	21	13	18	3.65	2.26	3.13
	perpendicular	2.4	1	0	3	0.17	0.00	0.52
		4.8	0	0	11	0.00	0.00	1.91
		7.2	1	0	2	0.17	0.00	0.35
		9.6	1	0	3	0.17	0.00	0.52
37	perpendicular	2	1	0	3	0.17	0.00	0.52
		4	1	0	2	0.17	0.00	0.35
		6	7	1	11	1.22	0.17	1.91
		8	4	0	9	0.69	0.00	1.56
	parallel	2	1	0	5	0.17	0.00	0.87
		4	1	0	4	0.17	0.00	0.69
		6	14	8	20	2.43	1.39	3.47
		8	15	13	19	2.60	2.26	3.30
39	perpendicular	2	1	0	4	0.17	0.00	0.69
		4	2	0	4	0.35	0.00	0.69
		6	5	0	11	0.87	0.00	1.91
		8	8	0	13	1.39	0.00	2.26
	parallel	2	3	1	8	0.52	0.17	1.39
		4	4	1	11	0.69	0.17	1.91
		6	10	3	16	1.74	0.52	2.78
		8	15	10	20	2.60	1.74	3.47
41	perpendicular	2	1	0	3	0.17	0.00	0.52
		4	1	0	5	0.17	0.00	0.87
		6	8	2	14	1.39	0.35	2.43
		8	10	4	15	1.74	0.69	2.60
	parallel	2	2	0	7	0.35	0.00	1.22
		4	5	2	9	0.87	0.35	1.56
		6	9	4	14	1.56	0.69	2.43
		8	14	9	19	2.43	1.56	3.30
43	perpendicular	2	1	0	8	0.17	0.00	1.39
		4	2	0	8	0.35	0.00	1.39
		6	2	0	5	0.35	0.00	0.87
		8	4	1	8	0.69	0.17	1.39
	parallel	2	7	2	15	1.22	0.35	2.60
		4	13	6	18	2.26	1.04	3.13
		6	13	9	18	2.26	1.56	3.13
		8	16	13	19	2.78	2.26	3.30
45	perpendicular	2	3	0	11	0.52	0.00	1.91
		4	1	0	11	0.17	0.00	1.91
		6	2	0	6	0.35	0.00	1.04
		8	6	1	12	1.04	0.17	2.08
	parallel	2	4	1	8	0.69	0.17	1.39
		4	10	3	15	1.74	0.52	2.60
		6	11	3	15	1.91	0.52	2.60
		8	14	8	17	2.43	1.39	2.95
47	perpendicular	2	12	8	15	2.08	1.39	2.60
		4	13	10	17	2.26	1.74	2.95
		6	5	0	9	0.87	0.00	1.56
		8	2	1	4	0.35	0.17	0.69
	parallel	2	2	0	7	0.35	0.00	1.22
		4	11	7	15	1.91	1.22	2.60
		6	11	7	15	1.91	1.22	2.60
		8	15	12	18	2.60	2.08	3.13
31.7	perpendicular	2	8	3	13	1.39	0.52	2.26
		4	11	0	17	1.91	0.00	2.95
		6	2	0	8	0.35	0.00	1.39
		8	2	0	4	0.35	0.00	0.69
	parallel	2	5	2	11	0.87	0.35	1.91

		4	16	5	20	2.78	0.87	3.47	
		6	13	6	18	2.26	1.04	3.13	
		8	15	12	18	2.60	2.08	3.13	
29.7	perpendicular	2	3	1	9	0.52	0.17	1.56	
		4	4	0	9	0.69	0.00	1.56	
		6	2	0	6	0.35	0.00	1.04	
		8	1	0	4	0.17	0.00	0.69	
	parallel	2	5	1	13	0.87	0.17	2.26	
		4	13	2	20	2.26	0.35	3.47	
		6	16	12	21	2.78	2.08	3.65	
		8	15	11	18	2.60	1.91	3.13	
27.7	perpendicular	2	4	0	11	0.69	0.00	1.91	
		4	3	0	10	0.52	0.00	1.74	
		6	1	0	5	0.17	0.00	0.87	
		8	1	0	3	0.17	0.00	0.52	
	parallel	2	9	2	15	1.56	0.35	2.60	
		4	15	9	21	2.60	1.56	3.65	
		6	17	11	22	2.95	1.91	3.82	
		8	16	12	20	2.78	2.08	3.47	
25.7	perpendicular	2	6	0	10	1.04	0.00	1.74	8.1-ft flow depth
		4	8	1	13	1.39	0.17	2.26	
		6	1	0	3	0.17	0.00	0.52	
		8	2	0	7	0.35	0.00	1.22	
	parallel	2	12	7	16	2.08	1.22	2.78	
		4	17	7	23	2.95	1.22	3.99	
		6	11	7	17	1.91	1.22	2.95	
		8	15	12	19	2.60	2.08	3.30	
23.7	perpendicular	2	5	1	12	0.87	0.17	2.08	
		4	4	1	10	0.69	0.17	1.74	
		6	2	0	5	0.35	0.00	0.87	
		8	4	0	9	0.69	0.00	1.56	
	parallel	2	4	11	0	0.69	1.91	0.00	
		4	4	1	8	0.69	0.17	1.39	
		6	11	6	17	1.91	1.04	2.95	
		8	14	10	18	2.43	1.74	3.13	
21.7	perpendicular	2	1	0	2	0.17	0.00	0.35	
		4	1	0	5	0.17	0.00	0.87	
		6	3	0	7	0.52	0.00	1.22	
		8	0	0	0	0.00	0.00	0.00	
	parallel	2	1	0	2	0.17	0.00	0.35	
		4	1	10	3	0.17	1.74	0.52	
		6	17	13	20	2.95	2.26	3.47	
		8	0	0	0	0.00	0.00	0.00	
17	perpendicular	1.5	6	3	9	1.04	0.52	1.56	
		3	3	0	8	0.52	0.00	1.39	
		4.5	3	0	9	0.52	0.00	1.56	
		6	2	0	7	0.35	0.00	1.22	
	parallel	1.5	5	1	13	0.87	0.17	2.26	
		3	12	3	18	2.08	0.52	3.13	
		4.5	22	16	27	3.82	2.78	4.69	
		6	11	5	19	1.91	0.87	3.30	
15	perpendicular	1.5	1.5	0	4	0.26	0.00	0.69	
		3	3	0	5	0.52	0.00	0.87	
		4.5	4.5	0	3	0.78	0.00	0.52	
		6	6	1	7	1.04	0.17	1.22	
	parallel	1.5	1.5	2	15	0.26	0.35	2.60	
		3	3	9	21	0.52	1.56	3.65	
		4.5	4.5	14	24	0.78	2.43	4.17	
		6	6	8	17	1.04	1.39	2.95	
13	perpendicular	1.5	1	0	5	0.17	0.00	0.87	
		3	1	0	5	0.17	0.00	0.87	
		4.5	2	0	4	0.35	0.00	0.69	
		6	4	0	8	0.69	0.00	1.39	
	parallel	1.5	8	2	13	1.39	0.35	2.26	
		3	10	2	17	1.74	0.35	2.95	
		4.5	12	6	19	2.08	1.04	3.30	
		6	11	7	15	1.91	1.22	2.60	
11	perpendicular	1.5	5	0	13	0.87	0.00	2.26	
		3	2	0	7	0.35	0.00	1.22	
		4.5	4	0	11	0.69	0.00	1.91	
		6	3	0	6	0.52	0.00	1.04	
	parallel	1.5	6	3	10	1.04	0.52	1.74	
		3	5	2	11	0.87	0.35	1.91	
		4.5	5	1	11	0.87	0.17	1.91	
		6	10	4	14	1.74	0.69	2.43	
9	perpendicular	1.5	2	0	6	0.35	0.00	1.04	
		3	1	0	4	0.17	0.00	0.69	
		4.5	2	0	8	0.35	0.00	1.39	
		6	1	0	4	0.17	0.00	0.69	
	parallel	1.5	4	1	7	0.69	0.17	1.22	
		3	3	0	9	0.52	0.00	1.56	
		4.5	4	0	9	0.69	0.00	1.56	
		6	7	3	12	1.22	0.52	2.08	
7	perpendicular	1.5	0	0	1	0.00	0.00	0.17	
		3	0	0	2	0.00	0.00	0.35	
		4.5	0	0	2	0.00	0.00	0.35	
		6	1	0	1	0.17	0.00	0.17	
	parallel	1.5	1	0	3	0.17	0.00	0.52	
		3	1	0	4	0.17	0.00	0.69	
		4.5	1	0	4	0.17	0.00	0.69	
		6	7	2	14	1.22	0.35	2.43	

Scale = 0.000517 pls/m

Downstream Near Field Velocity Measurements (Tailrace) (corrected data)

Distance Downstream	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)	Flow Depth
2-R	us	6	32	19	42	5.56	3.30	7.29	8.5
		4.5	42	30	51	7.29	5.21	8.86	
		3	14	6	32	2.43	1.04	5.56	
		1.5	1	0	7	0.17	0.00	1.22	
2-L	us	6	5	0	12	0.87	0.00	2.08	8.5
		4.5	25	10	35	4.34	1.74	6.08	
		3	50	36	57	8.68	6.25	9.90	
		1.5	2	1	4	0.35	0.17	0.69	
30-L	us	6	19	12	26	3.30	2.08	4.52	10.5
		4.5	19	10	26	3.30	1.74	4.52	
		3	15	8	24	2.60	1.39	4.17	
		1.5	1	0	4	0.17	0.00	0.69	
30-R	us	6	15	3	25	2.60	0.52	4.34	10.5
		4.5	18	5	26	3.13	0.87	4.52	
		3	19	7	24	3.30	1.22	4.17	
		1.5	2	1	4	0.35	0.17	0.69	
50-L	us	6	19	2	28	3.30	0.35	4.86	12
		4.5	19	10	29	3.30	1.74	5.04	
		3	18	5	24	3.13	0.87	4.17	
		1.5	3	1	5	0.52	0.17	0.87	
50-R	us	6	24	10	30	4.17	1.74	5.21	12
		4.5	22	15	29	3.82	2.60	5.04	
		3	19	9	25	3.30	1.56	4.34	
		1.5	0	0	0	Lost propeller on sensor 4			

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
August 6-9, 1996
fn = rbelhfe1.wk4
Phase 1 Testing - Pre modification testing (orifice plug installed)
Note: A sensor was lost during near field velocity measurments in downstream tailrace. Remainder of testing conducted with three sensors

POOL 1: Downstream most ladder pool, upstream of entrance gates.

Right side of ladder 5-ft from diffuser wall.
Scale = 1.0 pls/m
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
58.4	parallel	3	801	0	1980	0.72	0.00	1.77
		6	981	150	1830	0.88	0.13	1.64
		9	2372	990	3270	2.13	0.89	2.93
	perpendicular	3	1669	540	2970	1.50	0.48	2.66
		6	2045	570	3990	1.83	0.51	3.58
		9	435	0	1200	0.39	0.00	1.08
56.4	parallel	3	503	30	1620	0.45	0.03	1.45
		6	460	0	1470	0.41	0.00	1.32
		9	2750	1560	3990	2.46	1.40	3.58
	perpendicular	3	1361	240	2730	1.22	0.22	2.45
		6	1007	0	2790	0.90	0.00	2.50
		9	531	0	2070	0.48	0.00	1.85
53.4	parallel	3	425	30	1260	0.38	0.03	1.13
		6	442	0	1200	0.40	0.00	1.08
		9	2344	810	3840	2.10	0.73	3.44
	perpendicular	3	700	0	2130	0.63	0.00	1.91
		6	356	30	1080	0.32	0.03	0.97
		9	602	60	2130	0.54	0.05	1.91
51.4	parallel	3	320	0	1080	0.29	0.00	0.97
		6	253	60	600	0.23	0.05	0.54
		9	2591	510	3660	2.32	0.46	3.28
	perpendicular	3	521	120	990	0.47	0.11	0.89
		6	386	0	840	0.35	0.00	0.75
		9	653	60	2130	0.59	0.05	1.91

Centerline of ladder.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
58.4	parallel	3	398	0	1350	0.36	0.00	1.21
		6	1558	120	3060	1.40	0.11	2.74
		9	2768	1410	3660	2.48	1.26	3.28
	perpendicular	3	678	30	2400	0.61	0.03	2.15
		6	405	60	990	0.36	0.05	0.89
		9	222	0	780	0.20	0.00	0.70
56.4	parallel	3	528	150	1410	0.47	0.13	1.26
		6	823	90	2850	0.74	0.08	2.55
		9	2730	1170	3780	2.45	1.05	3.39
	perpendicular	3	507	30	1590	0.45	0.03	1.42
		6	436	0	1410	0.39	0.00	1.26
		9	364	0	930	0.33	0.00	0.83
53.4	parallel	3	630	120	1350	0.56	0.11	1.21
		6	709	0	2250	0.64	0.00	2.02
		9	2680	330	3690	2.40	0.30	3.31
	perpendicular	3	366	60	930	0.33	0.05	0.83
		6	444	0	1470	0.40	0.00	1.32
		9	326	0	720	0.29	0.00	0.65
51.4	parallel	3	468	60	1530	0.42	0.05	1.37
		6	435	0	900	0.39	0.00	0.81
		9	2942	1290	3930	2.64	1.16	3.52
	perpendicular	3	253	0	690	0.23	0.00	0.62
		6	340	60	750	0.30	0.05	0.67
		9	637	30	2010	0.57	0.03	1.80

Left of ladder 5-ft from left wall.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
58.4	parallel	3	412	0	1020	0.37	0.00	0.91
		6	1455	90	3150	1.30	0.08	2.82
		9	2960	990	3780	2.65	0.89	3.39
	perpendicular	3	508	30	1170	0.46	0.03	1.05
		6	604	30	2070	0.54	0.03	1.85
		9	227	0	990	0.20	0.00	0.89
56.4	parallel	3	689	0	1410	0.62	0.00	1.26
		6	655	90	2430	0.59	0.08	2.18
		9	3156	1770	4140	2.83	1.59	3.71
	perpendicular	3	483	0	1500	0.43	0.00	1.34
		6	789	60	1860	0.71	0.05	1.67
		9	375	0	1260	0.34	0.00	1.13
53.4	parallel	3	243	0	840	0.22	0.00	0.75
		6	624	60	1590	0.56	0.05	1.42
		9	3541	2970	4020	3.17	2.66	3.60
	perpendicular	3	209	0	750	0.19	0.00	0.67
		6	780	90	1350	0.70	0.08	1.21
		9	315	0	1770	0.28	0.00	1.59
51.4	parallel	3	190	0	570	0.17	0.00	0.51
		6	103	0	300	0.09	0.00	0.27
		9	3232	1230	4110	2.90	1.10	3.68
	perpendicular	3	289	0	1200	0.26	0.00	1.08
		6	269	30	750	0.24	0.03	0.67
		9	209	0	1110	0.19	0.00	0.99

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
August 6-9, 1996
fn = rbelhfe1.wk4
Phase 1 Testing - Pre modification testing (orifice plug installed)
Note: A sensor was lost during near field velocity measurments in downstream tailrace. Remainder of testing conducted with three sensors.

POOL 2:

Right side of ladder 5-ft from diffuser wall.
Scale = 1.0 pls/m
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
47	parallel	3	978	240	2040	0.88	0.22	1.83
		6	775	90	2880	0.69	0.08	2.58
		9	3246	1230	4080	2.91	1.10	3.66
	perpendicular	3	1226	90	2490	1.10	0.08	2.23
		6	765	120	2580	0.69	0.11	2.31
		9	468	0	1470	0.42	0.00	1.32
45	parallel	3	436	30	1410	0.39	0.03	1.26
		6	1023	0	2430	0.92	0.00	2.18
		9	2967	1950	3630	2.66	1.75	3.25
	perpendicular	3	717	30	2010	0.64	0.03	1.80
		6	426	30	1410	0.38	0.03	1.26
		9	217	0	840	0.19	0.00	0.75
43	parallel	3	416	60	1230	0.37	0.05	1.10
		6	1532	30	3180	1.37	0.03	2.85
		9	3312	2730	3900	2.97	2.45	3.49
	perpendicular	3	507	30	1680	0.45	0.03	1.51
		6	443	30	1470	0.40	0.03	1.32
		9	177	0	900	0.16	0.00	0.81
41	parallel	3	467	0	1200	0.42	0.00	1.08
		6	1725	60	3870	1.55	0.05	3.47
		9	3504	2700	3870	3.14	2.42	3.47
	perpendicular	3	419	0	1140	0.38	0.00	1.02
		6	531	30	1650	0.48	0.03	1.48
		9	178	0	330	0.16	0.00	0.30
39	parallel	3	623	90	1110	0.56	0.08	0.99
		6	2135	630	3510	1.91	0.56	3.15
		9	3431	2850	3930	3.07	2.55	3.52
	perpendicular	3	438	0	1260	0.39	0.00	1.13
		6	465	0	1350	0.42	0.00	1.21
		9	153	0	330	0.14	0.00	0.30
37	parallel	3	307	0	1080	0.28	0.00	0.97
		6	2395	690	4170	2.15	0.62	3.74
		9	3014	2370	4350	2.70	2.12	3.90
	perpendicular	3	302	0	870	0.27	0.00	0.78
		6	536	60	1230	0.48	0.05	1.10
		9	391	0	1650	0.35	0.00	1.48

Centerline of ladder.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
47	parallel	3	655	90	1710	0.59	0.08	1.53
		6	1459	120	2850	1.31	0.11	2.55
		9	2907	1410	3900	2.60	1.26	3.49
	perpendicular	3	882	30	2670	0.79	0.03	2.39
		6	669	0	1950	0.60	0.00	1.75
		9	276	30	1110	0.25	0.03	0.99
45	parallel	3	975	120	2160	0.87	0.11	1.94
		6	1818	450	2940	1.63	0.40	2.63
		9	3169	2430	3870	2.84	2.18	3.47
	perpendicular	3	628	60	1890	0.56	0.05	1.69
		6	512	30	1890	0.46	0.03	1.69
		9	275	0	1770	0.25	0.00	1.59
43	parallel	3	981	150	2010	0.88	0.13	1.80
		6	2300	840	3450	2.06	0.75	3.09
		9	3235	2490	3870	2.90	2.23	3.47
	perpendicular	3	750	180	1770	0.67	0.16	1.59
		6	480	0	1710	0.43	0.00	1.53
		9	221	0	780	0.20	0.00	0.70
41	parallel	3	729	90	1950	0.65	0.08	1.75
		6	2378	240	3810	2.13	0.22	3.41
		9	3136	1980	3810	2.81	1.77	3.41
	perpendicular	3	660	30	2010	0.59	0.03	1.80
		6	297	0	1860	0.27	0.00	1.67
		9	243	0	1710	0.22	0.00	1.53
39	parallel	3	446	0	1620	0.40	0.00	1.45
		6	2327	330	3390	2.09	0.30	3.04
		9	3175	2250	3900	2.84	2.02	3.49
	perpendicular	3	851	120	2190	0.76	0.11	1.96
		6	273	0	990	0.24	0.00	0.89
		9	173	0	690	0.16	0.00	0.62
37	parallel	3	427	0	1350	0.38	0.00	1.21
		6	2647	480	3660	2.37	0.43	3.28
		9	3221	2040	3720	2.89	1.83	3.33
	perpendicular	3	446	30	0	0.40	0.03	0.00
		6	315	0	1110	0.28	0.00	0.99
		9	167	0	990	0.15	0.00	0.89

Left of ladder 5-ft from left wall.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
47	parallel	3	745	30	1860	0.67	0.03	1.67
		6	2369	450	3450	2.12	0.40	3.09
		9	2768	1290	3990	2.48	1.16	3.58
	perpendicular	3	525	0	1470	0.47	0.00	1.32
		6	416	0	1890	0.37	0.00	1.69
		9	527	0	1830	0.47	0.00	1.64
45	parallel	3	1087	270	2490	0.97	0.24	2.23
		6	2738	660	3630	2.45	0.59	3.25
		9	3008	2520	3750	2.70	2.26	3.36
	perpendicular	3	644	30	1530	0.58	0.03	1.37
		6	435	0	1920	0.39	0.00	1.72
		9	351	30	1890	0.31	0.03	1.69
43	parallel	3	1435	90	2910	1.29	0.08	2.61
		6	2400	1140	3750	2.15	1.02	3.36
		9	2624	810	3690	2.35	0.73	3.31
	perpendicular	3	518	0	1350	0.46	0.00	1.21
		6	573	0	1770	0.51	0.00	1.59
		9	303	0	1620	0.27	0.00	1.45
41	parallel	3	938	90	2340	0.84	0.08	2.10
		6	2545	1350	3390	2.28	1.21	3.04
		9	2866	1830	3450	2.57	1.64	3.09
	perpendicular	3	745	60	1560	0.67	0.05	1.40
		6	423	0	1890	0.38	0.00	1.69
		9	520	30	2160	0.47	0.03	1.94
39	parallel	3	575	90	1410	0.52	0.08	1.26
		6	2725	1540	3720	2.44	1.38	3.33
		9	555	0	2820	0.50	0.00	2.53
	perpendicular	3	452	30	1620	0.41	0.03	1.45
		6	201	0	1320	0.18	0.00	1.18
		9	354	0	1860	0.32	0.00	1.67
37	parallel	3	239	239	930	0.21	0.21	0.83
		6	2820	2820	3690	2.53	2.53	3.31
		9	0	0	0	0.00	0.00	0.00
	perpendicular	3	1116	1116	2430	1.00	1.00	2.18
		6	250	250	1290	0.22	0.22	1.16
		9	0	0	0	0.00	0.00	0.00

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
August 6-9, 1996
fn = rbelhfe1.wk4
Phase 1 Testing - Pre modification testing (orifice plug installed)
Note: A sensor was lost during near field velocity measurments in downstream tailrace. Remainder of testing conducted with three sensors.

POOL 3:

Right side of ladder 5-ft from diffuser wall.
Scale = 1.0 pls/m
Ladder Pool Velocity Measurements (Raw data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	(corrected data) Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
31.7	parallel	2	no data					
		4						
		6						
	perpendicular	2	no data					
		4						
		6						
29.7	parallel	2	no data					
		4						
		6						
	perpendicular	2	no data					
		4						
		6						
27.7	parallel	2	487	0	2130	0.44	0.00	1.91
		4	428	90	930	0.38	0.08	0.83
		6	1058	240	2340	0.95	0.22	2.10
	perpendicular	2	569	30	1770	0.51	0.03	1.59
		4	598	0	2010	0.54	0.00	1.80
		6	569	60	1380	0.51	0.05	1.24
25.7	parallel	2	593	0	1410	0.53	0.00	1.26
		4	457	60	1350	0.41	0.05	1.21
		6	1079	150	2130	0.97	0.13	1.91
	perpendicular	2	797	120	1890	0.71	0.11	1.69
		4	410	0	1410	0.37	0.00	1.26
		6	360	30	690	0.32	0.03	0.62
23.7	parallel	2	495	0	990	0.44	0.00	0.89
		4	198	0	720	0.18	0.00	0.65
		6	1499	480	2910	1.34	0.43	2.61
	perpendicular	2	446	30	1080	0.40	0.03	0.97
		4	380	30	990	0.34	0.03	0.89
		6	491	30	1110	0.44	0.03	0.99
21.7	parallel	2	331	30	690	0.30	0.03	0.62
		4	272	0	1350	0.24	0.00	1.21
		6	1983	600	3510	1.78	0.54	3.15
	perpendicular	2	585	90	900	0.52	0.08	0.81
		4	500	30	990	0.45	0.03	0.89
		6	546	90	1350	0.49	0.08	1.21

Centerline of ladder.
Ladder Pool Velocity Measurements (Raw data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	(corrected data) Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
31.7	parallel	2	270	30	1080	0.24	0.03	0.97
		4	662	120	1770	0.59	0.11	1.59
		6	1557	540	2430	1.40	0.48	2.18
	perpendicular	2	604	0	1110	0.54	0.00	0.99
		4	478	60	1290	0.43	0.05	1.16
		6	434	30	1410	0.39	0.03	1.26
29.7	parallel	2	301	30	1350	0.27	0.03	1.21
		4	607	120	1590	0.54	0.11	1.42
		6	1174	150	2190	1.05	0.13	1.96
	perpendicular	2	367	0	1470	0.33	0.00	1.32
		4	387	30	1290	0.35	0.03	1.16
		6	311	0	1350	0.28	0.00	1.21
27.7	parallel	2	662	150	960	0.59	0.13	0.86
		4	1085	30	1890	0.97	0.03	1.69
		6	2048	960	2790	1.84	0.86	2.50
	perpendicular	2	633	90	1410	0.57	0.08	1.26
		4	398	60	1260	0.36	0.05	1.13
		6	274	30	780	0.25	0.03	0.70
25.7	parallel	2	759	120	1290	0.68	0.11	1.16
		4	708	60	1770	0.63	0.05	1.59
		6	2208	750	2880	1.98	0.67	2.58
	perpendicular	2	432	30	1470	0.39	0.03	1.32
		4	794	90	1530	0.71	0.08	1.37
		6	758	30	1590	0.68	0.03	1.42
23.7	parallel	2	293	0	1110	0.26	0.00	0.99
		4	886	120	1920	0.79	0.11	1.72
		6	1926	690	2970	1.73	0.62	2.66
	perpendicular	2	694	0	1320	0.62	0.00	1.18
		4	499	60	1350	0.45	0.05	1.21
		6	391	30	1470	0.35	0.03	1.32
21.7	parallel	2	257	0	1650	0.23	0.00	1.48
		4	299	30	690	0.27	0.03	0.62
		6	2142	570	3090	1.92	0.51	2.77
	perpendicular	2	762	150	1230	0.68	0.13	1.10
		4	636	30	1590	0.57	0.03	1.42
		6	406	30	840	0.36	0.03	0.75

Left of ladder 5-ft from left wall.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
31.7	parallel	2	510	0	1500	0.46	0.00	1.34
		4	879	30	2250	0.79	0.03	2.02
		6	1524	180	2760	1.37	0.16	2.47
	perpendicular	2	823	30	1770	0.74	0.03	1.59
		4	499	30	1050	0.45	0.03	0.94
		6	715	30	2130	0.64	0.03	1.91
29.7	parallel	2	899	90	2190	0.81	0.08	1.96
		4	1026	120	2400	0.92	0.11	2.15
		6	1634	180	3000	1.46	0.16	2.69
	perpendicular	2	658	0	1440	0.59	0.00	1.29
		4	761	60	1500	0.68	0.05	1.34
		6	499	60	1860	0.45	0.05	1.67
27.7	parallel	2	430	90	810	0.39	0.08	0.73
		4	498	0	1260	0.45	0.00	1.13
		6	1777	270	2820	1.59	0.24	2.53
	perpendicular	2	734	0	1800	0.66	0.00	1.61
		4	702	60	1620	0.63	0.05	1.45
		6	368	0	1530	0.33	0.00	1.37
25.7	parallel	2	713	60	1500	0.64	0.05	1.34
		4	416	0	870	0.37	0.00	0.78
		6	1998	180	3210	1.79	0.16	2.88
	perpendicular	2	938	60	1950	0.84	0.05	1.75
		4	841	30	2310	0.75	0.03	2.07
		6	614	30	1650	0.55	0.03	1.48
23.7	parallel	2	680	0	1950	0.61	0.00	1.75
		4	679	90	1710	0.61	0.08	1.53
		6	2070	840	3390	1.85	0.75	3.04
	perpendicular	2	399	30	1230	0.36	0.03	1.10
		4	414	30	1320	0.37	0.03	1.18
		6	576	30	1710	0.52	0.03	1.53
21.7	parallel	2	371	0	870	0.33	0.00	0.78
		4	233	0	870	0.21	0.00	0.78
		6	2261	840	3360	2.03	0.75	3.01
	perpendicular	2	407	60	1230	0.36	0.05	1.10
		4	360	0	810	0.32	0.00	0.73
		6	456	30	1200	0.41	0.03	1.08

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
August 6-9, 1996
fn = rbelhfe1.wk4
Phase 1 Testing - Pre modification testing (orifice plug installed)
Note: A sensor was lost during near field velocity measurments in downstream tailrace. Remainder of testing conducted with three sensors.

POOL 4: Upstream most ladder pool containing diffuser flows

Right side of ladder 5-ft from diffuser wall.
Scale = 0.00517 pls/m

Ladder Pool Velocity Measurements (Raw data)						(corrected data)		
Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
17	parallel	1.5	2	0	6	0.347309	0	1.041927
		3	3	0	9	0.520964	0	1.562891
		4.5	3	0	8	0.520964	0	1.389236
	perpendicular	1.5	0	0	0	0	0	0
		3	9	0	18	1.562891	0	3.125781
		4.5	4	0	13	0.694618	0	2.257509
15	parallel	1.5	3	0	6	0.520964	0	1.041927
		3	1	0	4	0.173655	0	0.694618
		4.5	3	0	7	0.520964	0	1.215582
	perpendicular	1.5	2	0	8	0.347309	0	1.389236
		3	1	0	6	0.173655	0	1.041927
		4.5	1	0	4	0.173655	0	0.694618
13	parallel	1.5	0	0	2	0	0	0.347309
		3	2	0	4	0.347309	0	0.694618
		4.5	4	0	11	0.694618	0	1.9102
	perpendicular	1.5	1	0	2	0.173655	0	0.347309
		3	1	0	3	0.173655	0	0.520964
		4.5	1	0	4	0.173655	0	0.694618
11	parallel	1.5	1	0	2	0.173655	0	0.347309
		3	1	0	4	0.173655	0	0.694618
		4.5	4	0	10	0.694618	0	1.736545
	perpendicular	1.5	0	0	2	0	0	0.347309
		3	1	0	2	0.173655	0	0.347309
		4.5	1	0	3	0.173655	0	0.520964
9	parallel	1.5	1	0	2	0.173655	0	0.347309
		3	1	0	3	0.173655	0	0.520964
		4.5	2	0	7	0.347309	0	1.215582
	perpendicular	1.5	0	0	1	0	0	0.173655
		3	1	0	3	0.173655	0	0.520964
		4.5	2	0	5	0.347309	0	0.868273
7	parallel	1.5	1	0	2	0.173655	0	0.347309
		3	1	0	2	0.173655	0	0.347309
		4.5	1	0	7	0.173655	0	1.215582
	perpendicular	1.5	1	0	2	0.173655	0	0.347309
		3	3	0	5	0.520964	0	0.868273
		4.5	3	0	7	0.520964	0	1.215582

Centerline of ladder.
Scale = 0.00517 pls/m

Ladder Pool Velocity Measurements (Raw data)						(corrected data)		
Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
17	parallel	1.5	2	0	6	0.347309	0	1.041927
		3	1	0	4	0.173655	0	0.694618
		4.5	3	0	9	0.520964	0	1.562891
	perpendicular	1.5	8	2	12	1.389236	0.347309	2.083854
		3	3	0	9	0.520964	0	1.562891
		4.5	2	0	5	0.347309	0	0.868273
15	parallel	1.5	2	0	8	0.347309	0	1.389236
		3	2	0	6	0.347309	0	1.041927
		4.5	2	0	6	0.347309	0	1.041927
	perpendicular	1.5	2	0	7	0.347309	0	1.215582
		3	2	0	8	0.347309	0	1.389236
		4.5	2	0	7	0.347309	0	1.215582
13	parallel	1.5	2	0	5	0.347309	0	0.868273
		3	3	0	9	0.520964	0	1.562891
		4.5	4	0	9	0.694618	0	1.562891
	perpendicular	1.5	1	0	6	0.173655	0	1.041927
		3	2	0	5	0.347309	0	0.868273
		4.5	1	0	5	0.173655	0	0.868273
11	parallel	1.5	3	0	7	0.520964	0	1.215582
		3	2	0	6	0.347309	0	1.041927
		4.5	3	0	9	0.520964	0	1.562891
	perpendicular	1.5	2	0	4	0.347309	0	0.694618
		3	2	0	5	0.347309	0	0.868273
		4.5	3	0	8	0.520964	0	1.389236
9	parallel	1.5	2	0	6	0.347309	0	1.041927
		3	0	0	2	0	0	0.347309
		4.5	3	0	6	0.520964	0	1.041927
	perpendicular	1.5	2	0	6	0.347309	0	1.041927
		3	1	0	2	0.173655	0	0.347309
		4.5	2	0	5	0.347309	0	0.868273
7	parallel	1.5	2	0	4	0.347309	0	0.694618
		3	1	0	3	0.173655	0	0.520964
		4.5	2	0	8	0.347309	0	1.389236
	perpendicular	1.5	2	0	6	0.347309	0	1.041927
		3	1	0	5	0.173655	0	0.868273
		4.5	3	0	8	0.520964	0	1.389236

Left of ladder 5-ft from left wall.

Scale = 0.00517 pls/m

Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
17	parallel	1.5	3	0	8	0.520964	0	1.389236
		3	2	0	6	0.347309	0	1.041927
		4.5	4	0	13	0.694618	0	2.257509
	perpendicular	1.5	6	1	15	1.041927	0.173655	2.604818
		3	2	0	10	0.347309	0	1.736545
		4.5	2	0	9	0.347309	0	1.562891
15	parallel	1.5	3	0	7	0.520964	0	1.215582
		3	3	0	9	0.520964	0	1.562891
		4.5	4	0	9	0.694618	0	1.562891
	perpendicular	1.5	2	0	7	0.347309	0	1.215582
		3	2	0	5	0.347309	0	0.868273
		4.5	2	0	6	0.347309	0	1.041927
13	parallel	1.5	2	0	5	0.347309	0	0.868273
		3	2	0	6	0.347309	0	1.041927
		4.5	3	0	7	0.520964	0	1.215582
	perpendicular	1.5	2	0	5	0.347309	0	0.868273
		3	2	0	8	0.347309	0	1.389236
		4.5	2	0	4	0.347309	0	0.694618
11	parallel	1.5	3	0	6	0.520964	0	1.041927
		3	3	0	7	0.520964	0	1.215582
		4.5	8	0	13	1.389236	0	2.257509
	perpendicular	1.5	3	0	6	0.520964	0	1.041927
		3	2	0	7	0.347309	0	1.215582
		4.5	3	0	7	0.520964	0	1.215582
9	parallel	1.5	3	0	6	0.520964	0	1.041927
		3	2	0	5	0.347309	0	0.868273
		4.5	6	0	15	1.041927	0	2.604818
	perpendicular	1.5	1	0	4	0.173655	0	0.694618
		3	2	0	6	0.347309	0	1.041927
		4.5	3	0	8	0.520964	0	1.389236
7	parallel	1.5	1	0	6	0.173655	0	1.041927
		3	1	0	4	0.173655	0	0.694618
		4.5	2	0	5	0.347309	0	0.868273
	perpendicular	1.5	1	0	6	0.173655	0	1.041927
		3	1	0	4	0.173655	0	0.694618
		4.5	3	0	6	0.520964	0	1.041927

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
August 6-9, 1996
fn = rbelhfe2.wk4
Phase 2 Testing - Post modification testing (orifice plug removed)
Scale = 1.0 pls/m
Diffuser Wall Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
51.4	perpendicular	3	332	0	990	0.30	0.00	0.89
		6	235	0	660	0.21	0.00	0.59
		9	1905	600	3120	1.71	0.54	2.80
	parallel	3	238	30	750	0.21	0.03	0.67
		6	290	30	630	0.26	0.03	0.56
		9	735	60	1830	0.66	0.05	1.64
53.4	perpendicular	3	1184	150	2460	1.06	0.13	2.20
		6	2348	1680	2880	2.10	1.51	2.58
		9	1920	930	2550	1.72	0.83	2.28
	parallel	3	2098	780	3150	1.88	0.70	2.82
		6	899	90	1710	0.81	0.08	1.53
		9	1995	1050	2490	1.79	0.94	2.23
56.4	perpendicular	3	2753	2100	3240	2.47	1.88	2.90
		6	3672	3390	4080	3.29	3.04	3.66
		9	3495	2910	3990	3.13	2.61	3.58
	parallel	3	883	180	2190	0.79	0.16	1.96
		6	376	0	1530	0.34	0.00	1.37
		9	937	0	1830	0.84	0.00	1.64
58.4	perpendicular	3	no data					
		6						
		9						
	parallel	3						
		6						
		9						
37	parallel	3	142	0	630	0.13	0.00	0.56
		6	2661	1290	4530	2.38	1.16	4.06
		8.5	3247	2550	3930	2.91	2.28	3.52
	perpendicular	3	114	0	420	0.10	0.00	0.38
		6	452	90	1770	0.41	0.08	1.59
		8.5	106	0	240	0.09	0.00	0.22
39	parallel	3	126	0	570	0.11	0.00	0.51
		6	1422	150	3330	1.27	0.13	2.98
		8.5	3535	2820	3990	3.17	2.53	3.58
	perpendicular	3	317	30	930	0.28	0.03	0.83
		6	519	30	1140	0.47	0.03	1.02
		8.5	152	0	480	0.14	0.00	0.43
41	parallel	3	2038	720	3480	1.83	0.65	3.12
		6	1757	750	2880	1.57	0.67	2.58
		8.5	3386	2460	4500	3.03	2.20	4.03
	perpendicular	3	922	60	1920	0.83	0.05	1.72
		6	383	0	1260	0.34	0.00	1.13
		8.5	219	0	1050	0.20	0.00	0.94
43	parallel	3	2362	450	3630	2.12	0.40	3.25
		6	2544	570	4170	2.28	0.51	3.74
		8.5	3329	2550	4050	2.98	2.28	3.63
	perpendicular	3	1356	360	2370	1.22	0.32	2.12
		6	412	0	1530	0.37	0.00	1.37
		8.5	116	0	360	0.10	0.00	0.32
45	parallel	3	1570	570	2610	1.41	0.51	2.34
		6	2616	1710	3510	2.34	1.53	3.15
		8.5	3143	2340	4140	2.82	2.10	3.71
	perpendicular	3	942	0	1680	0.84	0.00	1.51
		6	458	0	1380	0.41	0.00	1.24
		8.5	171	30	570	0.15	0.03	0.51
47	parallel	3	1715	570	2430	1.54	0.51	2.18
		6	2242	1470	3090	2.01	1.32	2.77
		8.5	3101	2250	3630	2.78	2.02	3.25
	perpendicular	3	502	30	1260	0.45	0.03	1.13
		6	331	0	960	0.30	0.00	0.86
		8.5	554	0	1530	0.50	0.00	1.37
31.7	parallel	2.5				Measurements taken @ 5' from diffuser		
		5	1638	390	2790	1.47	0.35	2.50
		7.5	2317	990	3240	2.08	0.89	2.90
	perpendicular	2.5						
		5	598	0	1920	0.54	0.00	1.72
		7.5	191	0	780	0.17	0.00	0.70
29.7	parallel	2.5						
		5	1484	90	2610	1.33	0.08	2.34
		7.5	2432	1290	3270	2.18	1.16	2.93
	perpendicular	2.5						
		5	535	0	1650	0.48	0.00	1.48
		7.5	247	30	1080	0.22	0.03	0.97
27.7	parallel	2.5						
		5	1279	60	2370	1.15	0.05	2.12
		7.5	2325	1290	3120	2.08	1.16	2.80
	perpendicular	2.5						
		5	683	30	1830	0.61	0.03	1.64
		7.5	217	0	990	0.19	0.00	0.89
25.7	parallel	2.5						8.1-ft flow depth
		5	1546	120	2970	1.39	0.11	2.66
		7.5	2783	1830	3630	2.49	1.64	3.25
	perpendicular	2.5						
		5	398	30	900	0.36	0.03	0.81
		7.5	189	0	810	0.17	0.00	0.73
23.7	parallel	2.5						

		5	1416	150	2670	1.27	0.13	2.39
		7.5	2765	1650	3780	2.48	1.48	3.39
	perpendicular	2.5						
		5	613	30	1680	0.55	0.03	1.51
		7.5	314	0	1380	0.28	0.00	1.24
21.7	parallel	2.5						
		5	1427	60	3030	1.28	0.05	2.72
		7.5	2634	1590	3720	2.36	1.42	3.33
	perpendicular	2.5						
		5	496	30	1290	0.44	0.03	1.16
		7.5	210	0	1230	0.19	0.00	1.10
17	parallel	1.5						
		3	33	0	120	0.03	0.00	0.11
		4.5	3497	2610	4620	3.13	2.34	4.14
	perpendicular	1.5	1391	270	2430	1.25	0.24	2.18
		3	48	0	270	0.04	0.00	0.24
		4.5	1265	0	2550	1.13	0.00	2.28
15	parallel	1.5	1360	180	2820	1.22	0.16	2.53
		3	45	0	180	0.04	0.00	0.16
		4.5	3250	2190	4350	2.91	1.96	3.90
	perpendicular	1.5	699	60	1710	0.63	0.05	1.53
		3	34	0	240	0.03	0.00	0.22
		4.5	2222	1410	2850	1.99	1.26	2.55
13	parallel	1.5	1250	60	2070	1.12	0.05	1.85
		3	65	0	270	0.06	0.00	0.24
		4.5	2450	630	3990	2.20	0.56	3.58
	perpendicular	1.5	1056	60	2190	0.95	0.05	1.96
		3	347	0	1530	0.31	0.00	1.37
		4.5	882	180	2250	0.79	0.16	2.02
11	parallel	1.5	741	210	1530	0.66	0.19	1.37
		3	849	150	1590	0.76	0.13	1.42
		4.5	897	210	1590	0.80	0.19	1.42
	perpendicular	1.5	506	0	1800	0.45	0.00	1.61
		3	350	30	1260	0.31	0.03	1.13
		4.5	497	120	1290	0.45	0.11	1.16
9	parallel	1.5	624	90	1230	0.56	0.08	1.10
		3	713	210	1380	0.64	0.19	1.24
		4.5	704	90	1380	0.63	0.08	1.24
	perpendicular	1.5	283	30	660	0.25	0.03	0.59
		3	258	0	930	0.23	0.00	0.83
		4.5	382	0	1170	0.34	0.00	1.05
7	parallel	1.5	301	0	630	0.27	0.00	0.56
		3	184	0	630	0.16	0.00	0.56
		4.5	181	0	630	0.16	0.00	0.56
	perpendicular	1.5	34	0	240	0.03	0.00	0.22
		3	92	0	300	0.08	0.00	0.27
		4.5	117	0	420	0.10	0.00	0.38

Scale = 1.0 pls/m

Downstream Near Field Velocity Measurements (Tailrace) (corrected data)

Distance Downstream	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)	Flow Deprth	
2-L	us	3	4798	3240	6150	4.30	2.90	5.51	8.5	
		6	6683	2970	9390	5.99	2.66	8.41		
		9	1810	600	3030	1.62	0.54	2.72		
15-L	us	3	4898	3000	6720	4.39	2.69	6.02	8.5	centerline of guidewall
		6	4905	3060	6630	4.40	2.74	5.94		
		9	3985	2460	5760	3.57	2.20	5.16		
15-L	us	3	5636	1950	7410	5.05	1.75	6.64	10.5	centerline of left gate
		6	3995	1620	6600	3.58	1.45	5.91		
		9	1875	630	3030	1.68	0.56	2.72		
30-L	us	3	4603	1440	6990	4.12	1.29	6.26	10.5	
		6	5031	3330	6930	4.51	2.98	6.21		
		9	3825	2130	5460	3.43	1.91	4.89		
50-L	us	3	3921	2430	5430	3.51	2.18	4.87	12	
		6	4207	3450	5580	3.77	3.09	5.00		
		9	3861	2910	4740	3.46	2.61	4.25		
20-DSB	us	3	1366	120	3090	1.22	0.11	2.77	12	20' downstream of shhet pile break angle
		6	3236	2010	4290	2.90	1.80	3.84		
		9	3750	2610	4710	3.36	2.34	4.22		
@ppuss	us	3	2978	1530	4290	2.67	1.37	3.84		@ upstream side of pumping plant structure
		6	4194	3450	5190	3.76	3.09	4.65		
		9	4434	3630	5130	3.97	3.25	4.60		

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
August 6-9, 1996
fn = rbelhfe2.wk4
Phase 2 Testing - Post modification testing (orifice plug removed)

POOL 1: Downstream most ladder pool upstream of entrance gates.

Right side of ladder 5-ft from diffuser wall.
Scale = 1.0 pls/m
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
58.4	parallel	3	no data					
		6						
		9						
	perpendicular	3						
		6						
		9						
56.4	parallel	3	no data					
		6						
		9						
	perpendicular	3						
		6						
		9						
53.4	parallel	3	924	120	1650	0.83	0.11	1.48
		6	299	0	1110	0.27	0.00	0.99
		9	3203	1980	4050	2.87	1.77	3.63
	perpendicular	3	606	30	1710	0.54	0.03	1.53
		6	1121	270	2040	1.00	0.24	1.83
		9	575	0	1590	0.52	0.00	1.42
51.4	parallel	3	327	0	900	0.29	0.00	0.81
		6	289	30	780	0.26	0.03	0.70
		9	3095	2280	3810	2.77	2.04	3.41
	perpendicular	3	1407	300	2400	1.26	0.27	2.15
		6	615	120	1890	0.55	0.11	1.69
		9	484	0	1140	0.43	0.00	1.02

Centerline of ladder.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
58.4	parallel	3	241	0	750	0.22	0.00	0.67
		6	358	0	1140	0.32	0.00	1.02
		9	1271	90	2130	1.14	0.08	1.91
	perpendicular	3	2055	1200	3270	1.84	1.08	2.93
		6	1276	390	2310	1.14	0.35	2.07
		9	1192	420	1950	1.07	0.38	1.75
56.4	parallel	3	1278	270	1950	1.15	0.24	1.75
		6	586	0	2430	0.53	0.00	2.18
		9	1593	240	2670	1.43	0.22	2.39
	perpendicular	3	503	60	1470	0.45	0.05	1.32
		6	409	90	1140	0.37	0.08	1.02
		9	574	0	1650	0.51	0.00	1.48
53.4	parallel	3	1516	690	2280	1.36	0.62	2.04
		6	468	30	1590	0.42	0.03	1.42
		9	3008	1200	4140	2.70	1.08	3.71
	perpendicular	3	408	30	1050	0.37	0.03	0.94
		6	335	0	990	0.30	0.00	0.89
		9	481	0	1710	0.43	0.00	1.53
51.4	parallel	3	663	0	1800	0.59	0.00	1.61
		6	184	0	720	0.16	0.00	0.65
		9	2973	1170	4170	2.66	1.05	3.74
	perpendicular	3	291	0	440	0.26	0.00	0.39
		6	398	30	1230	0.36	0.03	1.10
		9	751	150	2310	0.67	0.13	2.07

Left of ladder 5-ft from left wall.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
58.4	parallel	3	886	120	1890	0.79	0.11	1.69
		6	2701	420	3900	2.42	0.38	3.49
		9	2835	930	3690	2.54	0.83	3.31
	perpendicular	3	538	0	1770	0.48	0.00	1.59
		6	230	0	900	0.21	0.00	0.81
		9	302	0	1230	0.27	0.00	1.10
56.4	parallel	3	2522	1680	3210	2.26	1.51	2.88
		6	3323	2040	4200	2.98	1.83	3.76
		9	2194	510	3180	1.97	0.46	2.85
	perpendicular	3	601	0	1710	0.54	0.00	1.53
		6	166	0	1650	0.15	0.00	1.48
		9	507	0	1440	0.45	0.00	1.29
53.4	parallel	3	1114	180	2100	1.00	0.16	1.88
		6	1611	750	2880	1.44	0.67	2.58
		9	3234	2370	4230	2.90	2.12	3.79
	perpendicular	3	1045	270	1890	0.94	0.24	1.69
		6	226	0	1080	0.20	0.00	0.97
		9	953	30	1380	0.85	0.03	1.24
51.4	parallel	3	1529	960	2010	1.37	0.86	1.80
		6	428	0	1080	0.38	0.00	0.97
		9	2904	1530	3690	2.60	1.37	3.31
	perpendicular	3	898	300	2040	0.80	0.27	1.83
		6	433	30	1350	0.39	0.03	1.21
		9	423	0	1530	0.38	0.00	1.37

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
August 6-9, 1996
fn = rbelhfe2.wk4
Phase 2 Testing - Post modification testing (orifice plug removed)

POOL 1:

Upstream of ladder entrance.
Scale = 1.0 pls/m
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
4' upstream	parallel	3	141	0	660	0.13	0.00	0.59
centerline		6	265	0	1140	0.24	0.00	1.02
of		9	1008	100	1300	0.90	0.09	1.16
fishway	perpendicular	3	3136	1950	3870	2.81	1.75	3.47
		6	2707	1770	3780	2.43	1.59	3.39
		9	1707	270	2610	1.53	0.24	2.34
4' upstream	parallel	3	1232	150	2070	1.10	0.13	1.85
centerline		6	1920	390	3000	1.72	0.35	2.69
of		9	833	90	2310	0.75	0.08	2.07
right gate	perpendicular	3	1863	990	2700	1.67	0.89	2.42
		6	2337	1920	3270	2.09	1.72	2.93
		9	1966	780	3210	1.76	0.70	2.88
4' upstream	parallel	3	2522	1680	3210	2.26	1.51	2.88
centerline		6	3323	2040	4200	2.98	1.83	3.76
of		9	2194	510	3180	1.97	0.46	2.85
left gate	perpendicular	3	601	0	1710	0.54	0.00	1.53
		6	166	0	1050	0.15	0.00	0.94
		9	507	0	1440	0.45	0.00	1.29

Traverse across top of downstream most wier of fish ladder. Flow depth over wier = 4.6 ft.
Scale = 1.0 pls/m
Velocity Measurements (Raw data) (corrected data)

Location	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
36-in	parallel	1	1183	150	2970	1.06	0.13	2.66
from		2.3	1861	150	3450	1.67	0.13	3.09
left wall		3.7	1924	750	2970	1.72	0.67	2.66
70-in	parallel	1	1934	180		1.73	0.16	0.00
from		2.3	2502	150	3930	2.24	0.13	3.52
left wall		3.7	2972	1170	3630	2.66	1.05	3.25
centerline	parallel	1	2163	30	3930	1.94	0.03	3.52
of		2.3	2878	1590	3750	2.58	1.42	3.36
fishway		3.7	3046	1650	3840	2.73	1.48	3.44
92-in	parallel	1	1993	600	3030	1.79	0.54	2.72
from		2.3	2702	1470	3810	2.42	1.32	3.41
right wall		3.7	2934	1170	3690	2.63	1.05	3.31
58-in	parallel	1	2678	1740	3360	2.40	1.56	3.01
from		2.3	2597	1650	3870	2.33	1.48	3.47
right wall		3.7	3275	1770	3990	2.93	1.59	3.58
26-in	parallel	1	3240	2370	3960	2.90	2.12	3.55
from		2.3	2960	1500	3870	2.65	1.34	3.47
right wall		3.7	3137	2160	3690	2.81	1.94	3.31
12-in	parallel	1	1535	270	2790	1.38	0.24	2.50
from		2.3	2641	750	4170	2.37	0.67	3.74
rightwall		3.7	3200	2220	4050	2.87	1.99	3.63
					Vavg =	2.28		

Note: Sensor el's above top of wier.

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
August 6-9, 1996
fn = rbelhfe2.wk4
Phase 2 Testing - Post modification testing (orifice plug removed)

POOL 2

Right side of ladder 5-ft from diffuser wall.
Scale = 1.0 pls/m
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
47	parallel	3						
		6	1298	90	2100	1.16	0.08	1.88
		8.5	3081	1380	4140	2.76	1.24	3.71
	perpendicular	3						
		6	681	0	1260	0.61	0.00	1.13
		8.5	217	30	1080	0.19	0.03	0.97
45	parallel	3						
		6	889	180	1800	0.80	0.16	1.61
		8.5	3499	2550	4440	3.14	2.28	3.98
	perpendicular	3						
		6	529	90	1530	0.47	0.08	1.37
		8.5	174	30	450	0.16	0.03	0.40
43	parallel	3						
		6	1284	90	3030	1.15	0.08	2.72
		8.5	3470	2610	4350	3.11	2.34	3.90
	perpendicular	3						
		6	500	150	1170	0.45	0.13	1.05
		8.5	199	0	360	0.18	0.00	0.32
41	parallel	3						
		6	1394	30	3330	1.25	0.03	2.98
		8.5	3477	2190	4550	3.12	1.96	4.08
	perpendicular	3						
		6	501	120	1320	0.45	0.11	1.18
		8.5	155	0	600	0.14	0.00	0.54
39	parallel	3						
		6	2075	330	3510	1.86	0.30	3.15
		8.5	3491	2910	4110	3.13	2.61	3.68
	perpendicular	3						
		6	355	30	1200	0.32	0.03	1.08
		8.5	113	0	330	0.10	0.00	0.30
37	parallel	3						
		6	2120	30	4170	1.90	0.03	3.74
		8.5	3032	2100	3810	2.72	1.88	3.41
	perpendicular	3						
		6	481	0	1440	0.43	0.00	1.29
		8.5	191	0	960	0.17	0.00	0.86

Centerline of ladder.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)	
47	parallel	3							
		6	1558	270	3060	1.40	0.24	2.74	
		8.5	3026	1470	3750	2.71	1.32	3.36	
	perpendicular	3							
		6	689	90	2220	0.62	0.08	1.99	
		8.5	203	0	840	0.18	0.00	0.75	
45	parallel	3							
		6	1785	270	3320	1.60	0.24	2.97	
		8.5	2728	1890	3810	2.44	1.69	3.41	
	perpendicular	3							
		6	445	30	1350	0.40	0.03	1.21	
		8.5	172	0	420	0.15	0.00	0.38	
43	parallel	3							
		6	1767	12	3420	1.58	0.01	3.06	
		8.5	2742	1860	3420	2.46	1.67	3.06	
	perpendicular	3							
		6	417	0	1290	0.37	0.00	1.16	
		8.5	135	0	300	0.12	0.00	0.27	
41	parallel	3							
		6	2173	960	3750	1.95	0.86	3.36	
		8.5	3112	2430	3870	2.79	2.18	3.47	
	perpendicular	3							
		6	475	30	1110	0.43	0.03	0.99	
		8.5	153	0	360	0.14	0.00	0.32	
39	parallel	3							
		6	2496	96	3750	2.24	0.09	3.36	
		8.5	3286	1740	4110	2.94	1.56	3.68	
	perpendicular	3							
		6	264	0	780	0.24	0.00	0.70	
		8.5	350	0	1530	0.31	0.00	1.37	
37	parallel	3							
		6	2552	1530	3570	2.29	1.37	3.20	
		8.5	1663	0	3570	1.49	0.00	3.20	
	perpendicular	3							top sensor at w.s.el
		6	449	30	1740	0.40	0.03	1.56	
		8.5	665	0	1650	0.60	0.00	1.48	

Left of ladder 5-ft from left wall.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
47	parallel	3						
		6	2051	540	3210	1.84	0.48	2.88
		8.5	2355	420	3810	2.11	0.38	3.41
	perpendicular	3						
		6	326	0	1230	0.29	0.00	1.10
		8.5	290	0	1080	0.26	0.00	0.97
45	parallel	3						
		6	2866	870	3870	2.57	0.78	3.47
		8.5	3317	2790	4230	2.97	2.50	3.79
	perpendicular	3						
		6	450	60	1440	0.40	0.05	1.29
		8.5	203	0	690	0.18	0.00	0.62
43	parallel	3						
		6	2621	930	3870	2.35	0.83	3.47
		8.5	2996	1830	3990	2.68	1.64	3.58
	perpendicular	3						
		6	471	60	1560	0.42	0.05	1.40
		8.5	165	0	960	0.15	0.00	0.86
41	parallel	3						
		6	2699	1290	3630	2.42	1.16	3.25
		8.5	3224	1950	3990	2.89	1.75	3.58
	perpendicular	3						
		6	400	30	1320	0.36	0.03	1.18
		8.5	108	0	360	0.10	0.00	0.32
39	parallel	3						
		6	2406	990	3870	2.16	0.89	3.47
		8.5	3217	2130	3810	2.88	1.91	3.41
	perpendicular	3						
		6	117	0	540	0.10	0.00	0.48
		8.5	178	0	930	0.16	0.00	0.83
37	parallel	3						
		6	3148	2310	3930	2.82	2.07	3.52
		8.5	3493	2700	4170	3.13	2.42	3.74
	perpendicular	3						
		6	697	0	2160	0.62	0.00	1.94
		8.5	174	0	1020	0.16	0.00	0.91

Red Bluff Existing Right (West) Bank Fish Ladder Hydraulic Field Evaluation
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fn = rbelhfe2.wk4
Phase 2 Testing - Post modification testing (orifice plug removed)

POOL 3.

Right side of ladder 5-ft from diffuser wall.
Scale = 1.0 pls/m
Ladder Pool Velocity Measurements (Raw data)

						(corrected data)		
Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
31.7	parallel	2.5						
		5	1019	120	2070	0.91	0.11	1.85
		7.5	200	330	1450	0.18	0.30	1.30
	perpendicular	2.5						
		5	646	30	1890	0.58	0.03	1.69
		7.5	270	60	1020	0.24	0.05	0.91
29.7	parallel	2.5						
		5	417	60	870	0.37	0.05	0.78
		7.5	2399	600	3420	2.15	0.54	3.06
	perpendicular	2.5						
		5	568	30	1530	0.51	0.03	1.37
		7.5	225	30	660	0.20	0.03	0.59
27.7	parallel	2.5						
		5	516	0	1350	0.46	0.00	1.21
		7.5	2886	1830	3840	2.59	1.64	3.44
	perpendicular	2.5						
		5	530	60	1650	0.47	0.05	1.48
		7.5	340	0	1170	0.30	0.00	1.05
25.7	parallel	2.5						
		5	472	90	2010	0.42	0.08	1.80
		7.5	3018	1800	4230	2.70	1.61	3.79
	perpendicular	2.5						
		5	444	60	1260	0.40	0.05	1.13
		7.5	356	0	1740	0.32	0.00	1.56
23.7	parallel	2.5						
		5	749	30	2070	0.67	0.03	1.85
		7.5	3207	2370	3930	2.87	2.12	3.52
	perpendicular	2.5						
		5	605	0	1470	0.54	0.00	1.32
		7.5	420	30	1320	0.38	0.03	1.18
21.7	parallel	2.5						
		5	972	30	2040	0.87	0.03	1.83
		7.5	2166	1350	3840	1.94	1.21	3.44
	perpendicular	2.5						
		5	559	0	1560	0.50	0.00	1.40
		7.5	928	180	2430	0.83	0.16	2.18

Centerline of ladder.
Ladder Pool Velocity Measurements (Raw data)

						(corrected data)		
Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
31.7	parallel	2.5						
		5	1250	30	2730	1.12	0.03	2.45
		7.5	2326	780	3570	2.08	0.70	3.20
	perpendicular	2.5						
		5	311	0	1500	0.28	0.00	1.34
		7.5	689	30	2010	0.62	0.03	1.80
29.7	parallel	2.5						
		5	1146	90	2490	1.03	0.08	2.23
		7.5	1979	960	2700	1.77	0.86	2.42
	perpendicular	2.5						
		5	484	0	1500	0.43	0.00	1.34
		7.5	314	0	1230	0.28	0.00	1.10
27.7	parallel	2.5						
		5	1666	270	2640	1.49	0.24	2.37
		7.5	2545	1590	3270	2.28	1.42	2.93
	perpendicular	2.5						
		5	450	90	1200	0.40	0.08	1.08
		7.5	266	0	900	0.24	0.00	0.81
25.7	parallel	2.5						
		5	1678	90	2970	1.50	0.08	2.66
		7.5	2633	1890	3600	2.36	1.69	3.23
	perpendicular	2.5						
		5	449	30	1170	0.40	0.03	1.05
		7.5	257	30	900	0.23	0.03	0.81
23.7	parallel	2.5						
		5	1585	450	2400	1.42	0.40	2.15
		7.5	2829	1890	3750	2.53	1.69	3.36
	perpendicular	2.5						
		5	461	0	1110	0.41	0.00	0.99
		7.5	303	30	1290	0.27	0.03	1.16
21.7	parallel	2.5						
		5	1240	210	2640	1.11	0.19	2.37
		7.5	2816	1170	3450	2.52	1.05	3.09
	perpendicular	2.5						
		5	361	0	1200	0.32	0.00	1.08
		7.5	378	0	1320	0.34	0.00	1.18

Left of ladder 5-ft from left wall.
Ladder Pool Velocity Measurements (Raw data) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
31.7	parallel	2.5						
		5	1638	390	2790	1.47	0.35	2.50
		7.5	2317	990	3240	2.08	0.89	2.90
	perpendicular	2.5						
		5	598	0	1920	0.54	0.00	1.72
		7.5	191	0	780	0.17	0.00	0.70
29.7	parallel	2.5						
		5	1484	90	2610	1.33	0.08	2.34
		7.5	2432	1290	3270	2.18	1.16	2.93
	perpendicular	2.5						
		5	535	0	1650	0.48	0.00	1.48
		7.5	247	30	1080	0.22	0.03	0.97
27.7	parallel	2.5						
		5	1279	60	2370	1.15	0.05	2.12
		7.5	2325	1290	3120	2.08	1.16	2.80
	perpendicular	2.5						
		5	683	30	1830	0.61	0.03	1.64
		7.5	217	0	990	0.19	0.00	0.89
25.7	parallel	2.5						
		5	1546	120	2970	1.39	0.11	2.66
		7.5	2783	1830	3630	2.49	1.64	3.25
	perpendicular	2.5						
		5	398	30	900	0.36	0.03	0.81
		7.5	189	0	810	0.17	0.00	0.73
23.7	parallel	2.5						
		5	1416	150	2670	1.27	0.13	2.39
		7.5	2765	1650	3780	2.48	1.48	3.39
	perpendicular	2.5						
		5	613	30	1680	0.55	0.03	1.51
		7.5	314	0	1380	0.28	0.00	1.24
21.7	parallel	2.5						
		5	1427	60	3030	1.28	0.05	2.72
		7.5	2634	1590	3720	2.36	1.42	3.33
	perpendicular	2.5						
		5	496	30	1290	0.44	0.03	1.16
		7.5	210	0	1230	0.19	0.00	1.10

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.