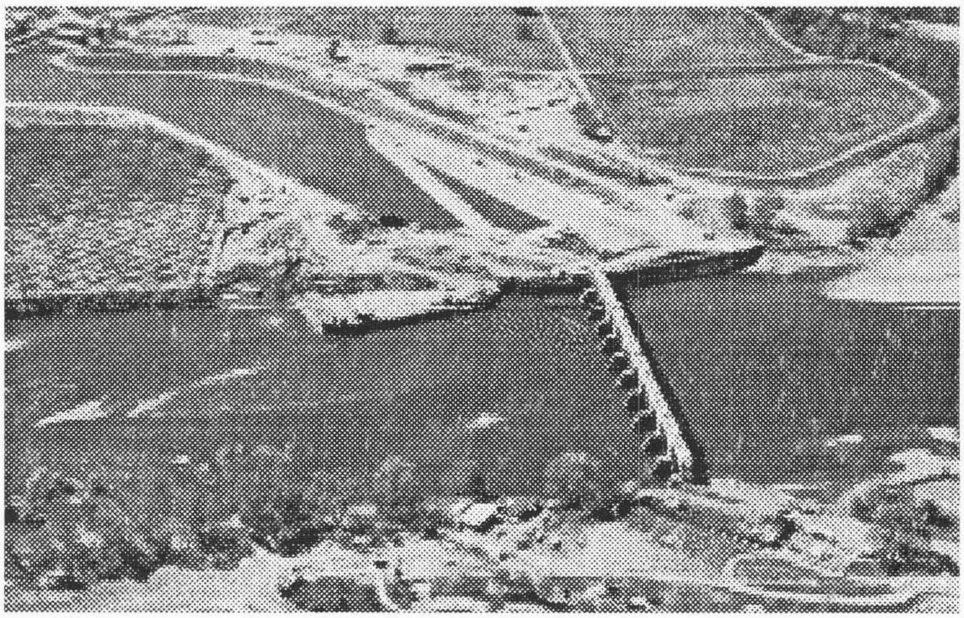
PAP-754

DRAFT

Hydraulic Field Evaluation of the Right Abutment Fish Ladder at Red Bluff Diversion Dam

Red Bluff Diversion Dam Fish Passage Program



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Water Resources Research Laboratory

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849
WATER RESOURCES MANAGEMENT ...FOR THE FUTURE
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

December 1996

United States Department of the Interior

BUREAU OF RECLAMATION
Reclamation Service Center
P.O. Box 25007
Building 67, Denver Federal Center
Denver, Colorado 80225-0007

IN REPLY REFER TO

December 23, 1996

MEMORANDUM

TO: Interagency Fisheries Work Group for Red Bluff Fish Passage Program

FROM: Max Stodolski, Program Manager, Red Bluff Fish Passage Program

SUBJECT: Quarterly Meeting

The next quarterly meeting of the IFWG is scheduled for Thursday, January 16, 1997. An agenda is attached. The draft report on the hydraulic field evaluation is also enclosed for your review. Results of this evaluation will be presented and discussed at the meeting. We anticipated having the draft enlarged ladder physical model study report available at this time. However, the large volume of data generated has delayed completion of the report. The report will be distributed at the meeting along with a discussion of the results. Copies will be distributed by mail for those IFWG Members not able to attend the meeting. We appreciate your participation.

AGENDA

Red Bluff Fish Passage Program
IFWG Information Session
January 16, 1997
Reclamation Administrative Office Conference Room - Red Bluff, CA

9:30	General Overview of Program Activities	Max Stodolski
9:40	Update on Pumping Plant Research Activities	Pumping Plant Evaluation Team
10:20	Modified Ladder Hydraulic Evaluation - Study Results	Joe Kubitschek
11:00	Break	
11:10	Enlarged Ladder Model Evaluation - Study Results	Joe Kubitschek
12:00	Lunch	
1:00	Discussion of Approach to Planning Program and Future Activities	Dave Robinson
2:00	Open Forum Discussions	Group
3:00	Adjourn	

Mailing List

California Department of Fish and Game:
George Heise
Harry Rectenwald
Paul Ward

U.S. Fish and Wildlife Service:
Steve Hirtzel
Jim Smith

Bureau of Reclamation:
Warren Frizell
Charles Liston
Steve Atkinson
Sandy Borthwick
Brent Mefford
Dave Robinson
Joe Kubitschek
Buford Holt
Cal McNab
Tracy Vermeyen

California Department of Water Resources:
Darryl Hayes
Ralph Hinton

National Marine Fisheries Service:
Chris Mobely
Marcin Whitman

Tehama-Colusa Canal Authority:
Art Bullock
Dave Vogel

Hydraulic Field Evaluation of the Right Abutment Fish Ladder at Red Bluff Diversion Dam

Red Bluff Diversion Dam Fish Passage Program

by

Brent Mefford,
Tracy Vermeyen,
David Robinson,
and
Joseph Kubitschek

Water Resources Research Laboratory
Technical Service Center
Denver, Colorado
August 1996

EXECUTIVE SUMMARY

Introduction

Under the Fish Passage Program, Reclamation's Water Resources Research Laboratory (WRRL) has been tasked with providing engineering support to further develop potential solutions for improving fish passage at RBDD. The WRRL current level of involvement consists of laboratory physical model and hydraulic field investigations. This report documents the results of the recent 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 of experts recommended that the right ladder regulating gate nearest to the bank be closed. The surface area of gate opening lost by this action would be replaced by modifying the left or river side ladder regulating gate. The shape of the opening was to be square which would provide a more compact jet 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.

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 of the orifice. Fish use of the orifice was recorded for 8 hour periods over a 14 day period. This data was to be compared to daily ladder count data taken at the ladder exit. Full coverage of the ladder entrance was not possible which prevented the comparison of ladder entrance and exit count data. However, the extent of use by fall chinook 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, there was extensive use of the orifice entrance by fall chinook salmon. The behavioral response of the fish was to enter the ladder and immediately turn 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 not conducive to passage in the lower portions of the ladder.

These observations and subsequent concerns provided the impetus for a detailed evaluation of the effects of orifice operation on hydraulic conditions. This report documents the results of these investigations. 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 these investigations indicate that the hydraulic performance of the existing right bank fish ladder at RBDD is less than optimum. Under current operating conditions for both pre and post modification configurations, diffuser flows strongly influence ladder pool velocity fields. Conclusions based on the results of this evaluation and the hydraulic characteristics of the right abutment ladder under pre and post modification conditions are:

- Diffuser velocities entering the downstream most ladder pools are non-uniform, are in excess of the 1.0-ft/s velocity criteria over part of the total diffuser area, and strongly influences ladder pool velocity fields. Crossing flow conditions are created which mask down ladder or pool to pool flows. These conditions 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 as compared to the original configuration. Results indicate that the orifice entrance modification has likely degraded performance within the ladder itself.

- Adverse crossing flow conditions exist for ladder pools 2-4, but are limited to elevations in the water column below the weir elevations of each ladder pool, respectively. However, good velocity field characteristics exist, in each case, 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 of the entrance orifice likely reduces entrance jet penetration by dissipating the energy of the impinging jet.

- Diffuser flows enter the ladder carrying 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 concerning both temporary and potential long term solutions for improving the right abutment ladder performance are presented as follows. These recommendations are based on WRRL experience, field observations, and the results of these investigations. Additional biological and hydraulic evaluations may be required before implementing any of the recommendations presented herein.

Operational Modifications

It is apparent from the results of these investigations and field observations that current ladder operation is less than optimal. The fact that the supplemental or diffuser flow head gate is operated in a full open position indicates that diffuser discharges are likely higher than design, creating diffuser exit velocities which exceed criteria. This condition is compounded by the fact that the diffusers are not baffled which allows for non-uniformity in velocity distributions. Furthermore, highly air entrained diffuser flows may potentially affect ladder performance by creating additional disorientation problems. Operational modifications should be investigated as a means of improving ladder performance with regard to diffuser flows. This 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 of the diffusers should also be investigated. This would improve the upstream to downstream flow conditions and reduce diffuser flow influences. Finally, baffling of diffusers should be considered to minimize diffuser flow influence on ladder pool velocity fields. Should this 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 recommendations represent the minimum efforts required to improve existing ladder performance.

Engineering Modifications

It may be desirable to invest in additional modifications to the existing right bank ladder in the short term. Certainly the design and implementation of a diffuser baffling scheme would help to improve ladder performance. 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. Other potential improvements regarding how diffuser flows are introduced into the last four ladder pools which are worth investigation as a temporary solution to improving ladder performance include:

- 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 increased diffuser flows resulting from full open head gate settings.
- Abandoning the existing diffusers (IE. Bulkheading the existing diffusers) in favor of a pipe diffuser concept or similar concept which supplies diffuser flows to ladder pools 1-6 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. The WRRL will prepare a feasibility or level of effort document which identifies those potential alternatives. This information is intended to assist in the selection of the best short term solution for optimizing the existing right bank ladder performance and will be available by February 1997. Should continued use of the entrance orifice modification be desired, the downstream obstruction should be removed in order to maximize the zone of attraction flow influence and satisfy the original intent of such modification. Finally, it should be noted that additional studies should be conducted to better define fish staging location below gate 11 as a function of gate setting and corresponding release discharge.

CONTENTS

FIGURES

ACKNOWLEDGMENTS

The Bureau of Reclamation, Red Bluff Field Office personnel provided critical Red Bluff Diversion Dam operational information for this study. Max Stodolski, Project Manager provided support for this study. Rich Johnson, U.S. Fish and Wildlife Service provided direction in establishing features of Red Bluff Diversion Dam associated with fish passage considerations. Marcin Whitman, National Marine Fisheries Service provide technical direction and valuable perspectives for this study. Perry Johnson provided peer review. And, Dave Robinson, Team Leader for the Red Bluff Fish Passage Program provided program management and coordinated all efforts between the Red Bluff Field Office and the Water Resources Research Laboratory.

INTRODUCTION

Red Bluff Diversion Dam (RBDD) is located on the Sacramento River, near the City of Red Bluff in north central California. Figure 1 is a general location map which identifies the project and those irrigation and water districts served.

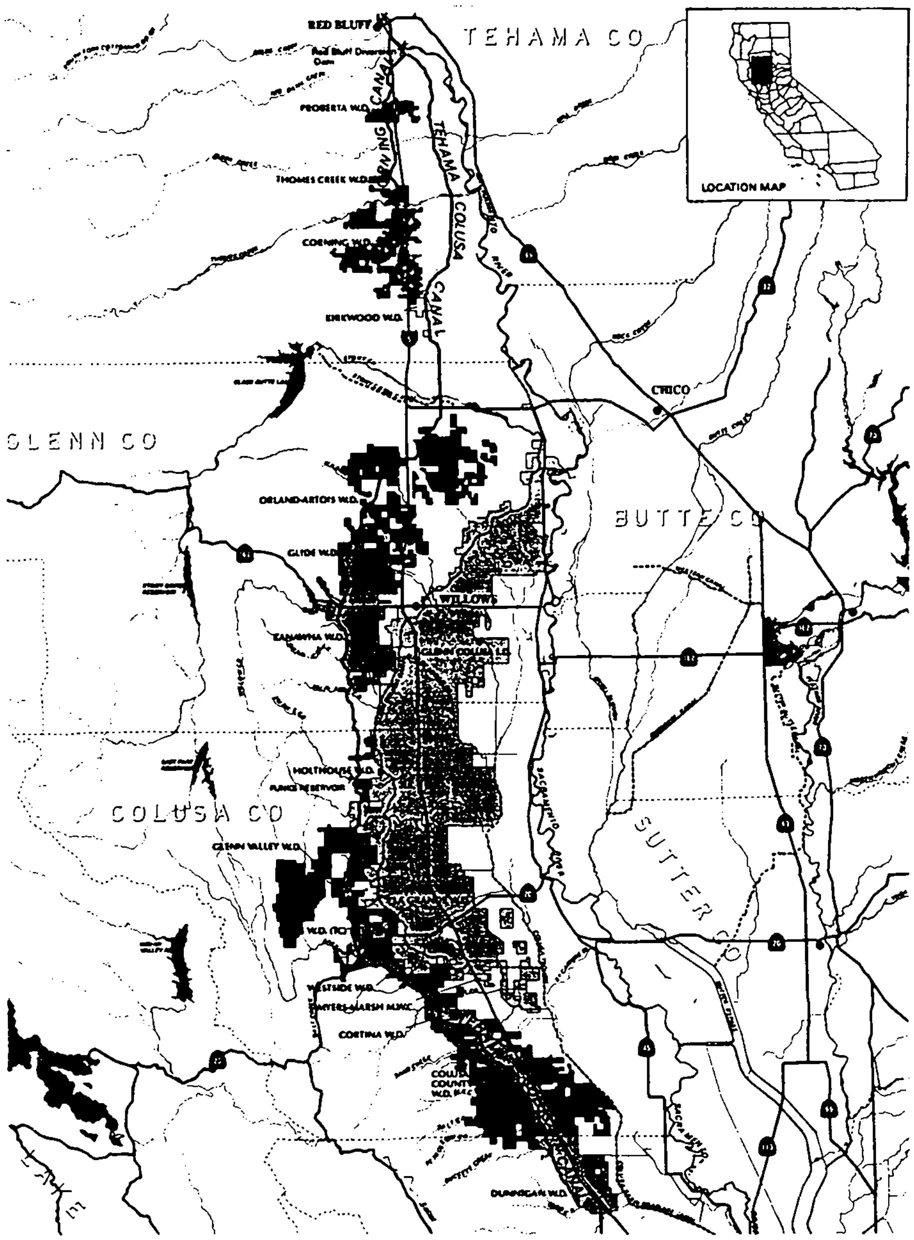


Figure 1. General location of RBDD. *Identifies irrigation and water districts served by the project.*

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 to the fish passage problems at RBDD. In 1992 Reclamation published an Appraisal Report which documents various alternatives for improving fish passage at RBDD. The scope of the Fish Passage Program was established such that alternatives to be considered will achieve the objectives while attempting to maintain current deliveries to the Tehama-Colusa and Corning Canals, maintain existing economic benefits of RBDD, and prevent 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 for improving fish passage at RBDD. 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 upon original design drawings. The existing diffusers are located in the four downstream most ladder pools. The diffuser for ladder pool 1 is 12-ft by 10-ft. For ladder pools 2-4, the diffuser sizes are 10-ft by 5-ft.

Both ladders were designed to operate at a discharge of 85-ft^3/s. Each ladder consist of a series of overflow weirs which contain submerged vertical slot orifices. Supplemental flows of approximately 265-ft^3/s (estimated based upon design data) are used to improve attraction flow conditions downstream of 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

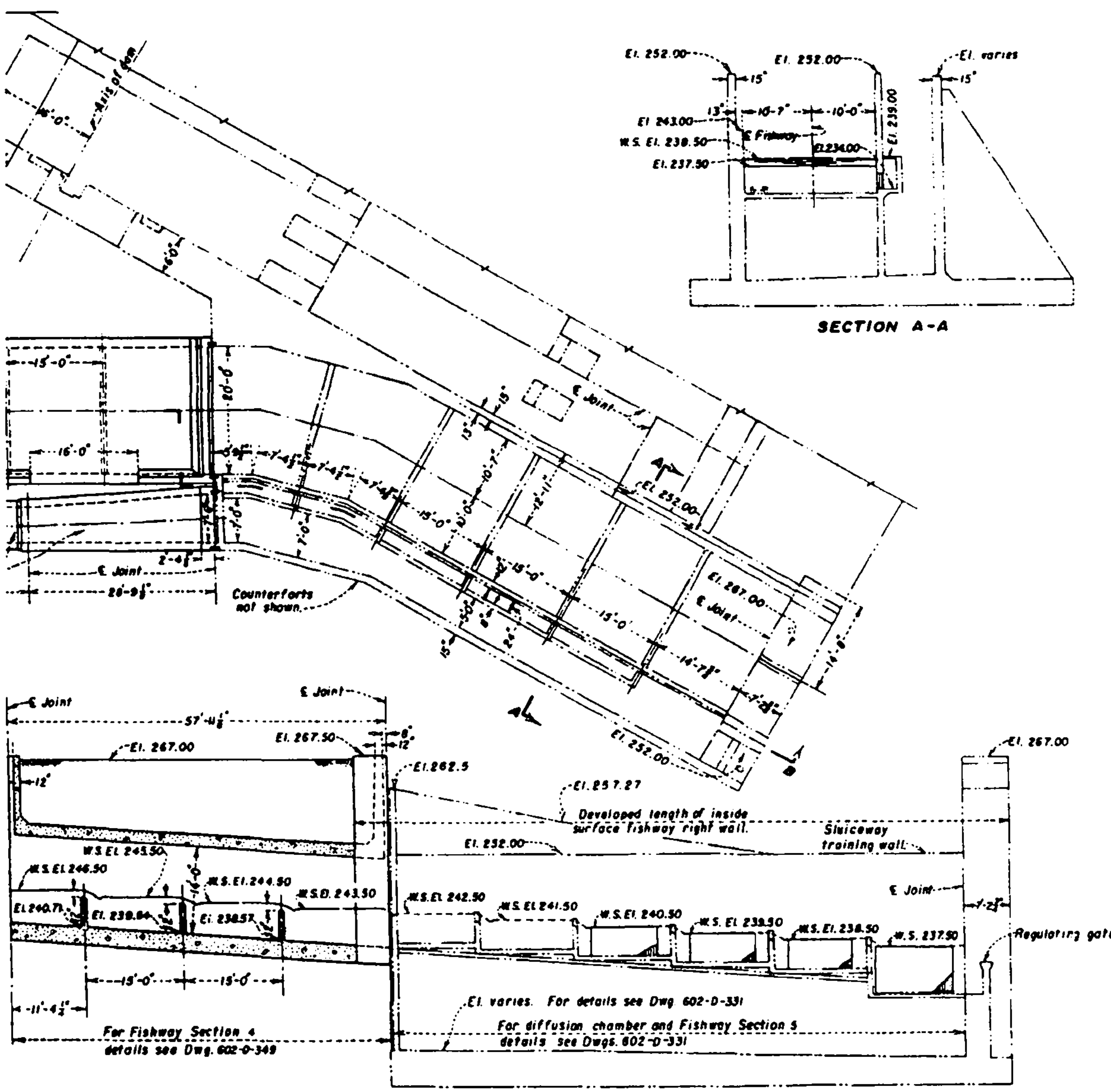


Figure 2. Plan and elevation details of right abutment fish ladder.

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 1-ft 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/tailwater elevations. These velocity criteria are designed to maintain effective attraction flow conditions in the tailrace so that fish can sense and locate ladder entrances.

The center ladder is somewhat similar in type to that of the right and left abutment ladders. It consists of a series weirs and slotted orifices. This ladder is temporary (ie. 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 of the center gate. The gate is then raised to provide flow to the ladder. The ladder was designed to operate at approximately 30 to 50-ft^3/s with supplemental flows of approximately 100-ft^3/s. However, this is somewhat speculative, since limited engineering and operational details are available. The supplemental flows for the center ladder are introduced into the downstream most pool via an overflow weir.

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 of experts recommended that the right ladder regulating gate nearest to the bank be closed. The surface area of gate opening lost by this action would be replaced by modifying the left or river side ladder regulating gate. The shape of the opening was to be square which would provide a more compact jet 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 made it necessary to have the ability to operate the ladder in an unmodified state. Use of an orifice plug (Figure 3) allowed return of the ladder to its original configuration.

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 of the orifice. Fish use of the orifice was recorded for 8 hour periods over a 14 day period. This data was to be compared to daily ladder count data taken at the ladder exit. Full coverage of the ladder entrance was not possible which prevented the comparison of ladder entrance and exit count data. However, the extent of use by fall chinook 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, there was extensive use of the orifice entrance by fall chinook salmon. The behavioral response of the fish was to enter the ladder and immediately turn 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 not conducive to passage in the lower portions of the ladder.

These observations and subsequent concerns provided the impetus for a detailed evaluation of the effects of orifice operation on hydraulic conditions. This report documents the results of these investigations. 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.

Figure 3. Photograph of orifice plug. *Installed to return ladder entrance to original (pre modified) condition.*

CONCLUSIONS

Results of these investigations indicate that the hydraulic performance of the existing right bank fish ladder at RBDD is less than optimum. Under current operating conditions for both pre and post modification configurations, diffuser flows strongly influence ladder pool velocity fields. Conclusions based on the results of this evaluation and the hydraulic characteristics of the right abutment ladder under pre and post modification conditions are:

- Diffuser velocities entering the downstream most ladder pools are non-uniform, are in excess of the 1.0-ft/s velocity criteria over part of the total diffuser area, and strongly influences ladder pool velocity fields. Crossing flow conditions are created which mask down ladder or pool to pool flows. These conditions 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 as compared to the original configuration. Results indicate that the orifice entrance modification has likely degraded performance within the ladder itself.

- Adverse crossing flow conditions exist for ladder pools 2-4, but are limited to elevations in the water column below the weir elevations of each ladder pool, respectively. However, good velocity field characteristics exist, in each case, 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 of the entrance orifice likely reduces entrance jet penetration by dissipating the energy of the impinging jet.

- Diffuser flows enter the ladder carrying 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 characteristics under pre and post modification operating conditions. Hydraulic performance, in this case, is characterized by velocity field patterns in each of the four ladder pools affected by diffuser flows and the RBDD tailrace field downstream of the ladder entrance. Velocity fields as well as other secondary hydraulic parameters (IE. turbulent intensity, air entrainment, acoustic, etc..) provide direct information regarding hydraulic performance since they elicit a biological response on the part of the fishery. Although it is arguable as to which parameter most influences ladder performance, it was reasoned that velocity in this case is most representative of the affect imparted by the ladder entrance modification. Thus, velocity field measurements were the focus of this evaluation.

The scope of this 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 near and far fields downstream of 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. However, hydro-acoustic data were not acquired due to problems associated with the instrumentation. It should be noted that in regards to the entrance modification, it is felt that the conditions associated with air entrainment and hydro acoustic characteristics, were not influenced significantly. That is, although there may be disorientation problems associated with the air entrainment and hydro acoustic conditions, these parameters are likely unchanged for both pre and post modification configurations.

The complete evaluation was segmented into two phases. Phase 1 represents investigations under pre modification conditions (ie. orifice plug installed) and phase 2 represents post modification investigations (ie. 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, due to 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 due to the air entrainment conditions which existed.

Phase 1 Testing

Phase 1 testing consisted of acquiring velocity data in order to characterize ladder hydraulic performance under pre modification (ie. 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 acquired at a distance, 1-ft downstream of each diffuser face. Four propeller type velocity sensors were mounted on a 1-in diameter stainless steel wading rod. Figure 4 is a photograph of velocity measurements being acquired along the diffuser wall of the right abutment fish ladder. This apparatus affords the ability of adjusting sensor locations on the wading rod to accomodate varying flow depth conditions. The sloping invert of the ladder created varying flow depths for each ladder pool of interest. In all cases, sensor elevations are given as the distance within the water column above

Figure 4. Photograph: Lower reach of right abutment fish ladder.
Diffuser velocity measurements being taken along diffuser wall.

the ladder invert. The diffusers along the right side of the ladder were identified as 1-4, such that the downstream most diffuser represented diffuser 1 and upstream diffusers were designated sequentially as 2-4, respectively. Diffuser 1 is the largest of the four diffusers and consists of a 12-ft wide by 10-ft high rectangular port. Diffusers 2-4 are similar in configuration but consist of 10-ft wide by 5-ft high openings for diffuser flows. 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 1-4, velocities were measured using the propeller meter setup along 2-ft station locations at four elevations in the vertical 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 wier of ladder pool 4. Diffuser 1 presented difficulties in acquiring velocity measurements along the downstream portion. High velocities accompanied with limited access resulted in the acquisition of data at four station locations only, which represented slightly more than half the diffuser area. In all cases, velocity measurements were acquired with the sensors oriented normal to the diffuser racks and parallel with the diffuser racks.

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 1-4, respectively. That is, ladder pool 4 contains diffuser 4, and so on. Although several pools exist upstream of the four pools where velocity data were acquired, the focus of these investigations was on those ladder pools affected by supplemental flows (ie. 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 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 to each pool cross section.

Air Concentration Measurements

As previously mentioned, air concentration profile measurements were acquired at each of the previously established station locations. Data were acquired using an air concentration probe which was 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 represents a photograph of of the air concentration probe setup used for air concentration measurements taken along the diffuser wall.

Near Field Tailrace Velocity Measurements

Velocity measurements were acquired just downstream of 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 1.5, 3, 4.5, and 6-ft. Velocities were measured along the center line of each ladder entrance gate at distances of 2, 30, and 50-ft downstream of the ladder entrance. Access was obtained using a jet boat to get as close to the ladder entrance as possible. The boat was tethered to eliminate any boat induced velocities. Figure 6 is a photograph of the jet boat which was employed for near field tailrace velocity measurments.

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 since the emphasis of this portion of the phase 2 testing was on velocity measurements which characterize the modified entrance configuration. That is, since 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 5. Photograph: Air concentration probe. *Setup used for taking air concentration measurements along diffuser wall.*

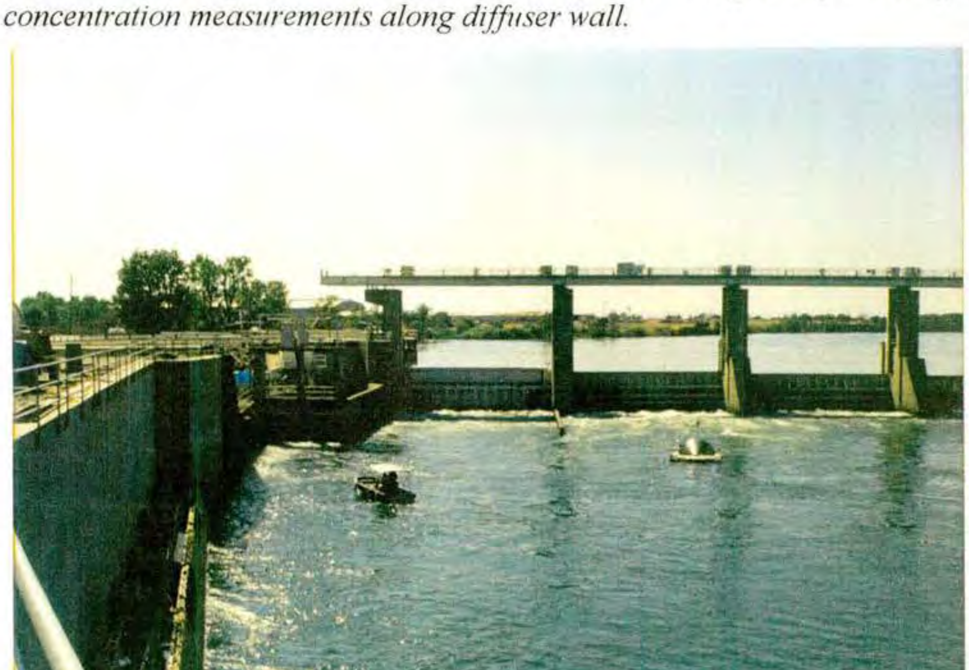


Figure 6. Photograph: Near field velocity measurments.

RESULTS

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

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 vector exiting the diffusers. As such, small changes in vector direction affect significant changes in the normal component magnitude. However, the results give a good indication of the two dimensional velocity distributions for each diffuser. Figures 7-10 are isovel plots for diffusers 1-4, respectively. Diffuser 1 (the downstream most diffuser located along the right side of ladder pool 1, which is just upstream of the ladder entrance) appears to indicate strong horizontal skewness with some vertical skewness in the velocity distribution (figure 7). It should be noted that because of access limitations, a limited amount of data were acquired along the downstream end of this diffuser. The data presentation represents only those results which were obtained from measurements acquired along the upstream portion of the screen. Diffuser 2 exhibits a similar skewness in the horizontal velocity distribution (figure 8) as diffuser 1. Velocities increase from upstream to downstream and indicate very little skewness in the vertical distribution. Again the velocity criteria is exceeded, in this case, over approximately 25 percent of the diffuser area. Diffuser 3 (figure 9) also demonstrates a horizontal skewness with some vertical skewness in velocity distribution. For this case, the velocity criteria is exceeded over approximately 25 percent of the area. Lastly, diffuser 4 results (figure 10) also indicate a horizontal skewness with some vertical skewness in velocity distribution. Furthermore, velocities increase from upstream to downstream. However, in this case, magnitudes are within the specified velocity criteria.

Ladder Pool Velocity Results

Ladder pool velocity results have been presented as plan view vector field plots. These vector field plots represent velocity results at a particular elevation 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 boundaries of each ladder pool. The coordinate axes represent physical dimensions of the ladder pools and are given in feet. 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. Particularly at lower elevations within the water column. Figures 11-14 represent the vector field plots for data acquired in each ladder pool at various sensor elevations. These results indicate strong crossing flows which appear to be maximum 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 are expected to become much more upstream to downstream as crossing flows are minimized with the reduced influence of diffuser flows and increased influence of sheet flows 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 results at an elevation of 6.0-ft above the invert. It should be noted that an elevation of 6.0-ft corresponds with the top elevation of the upstream weir for ladder pools 2-4. Thus, it is expected that diffuser flow influence is reduced given the sheet flow conditions in the water column at elevations above the top of the weirs. The results for pool 3 (figure 13) exhibit a similar trend compared with pools 1 and 2. Pool 4 data was not acquired at an elevation which is above its upstream weir elevation. However, similar results to those obtained for pools 1-3 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. However, vertical or up welling components of velocity likely exist. This is particularly true for the downstream portion of each ladder pool. 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. In addition, head differentials across the weirs are small. This is primarily due to the fact that as the diversion dam tailwater elevation rises, the downstream portion of the ladder is flooded, submerging those weirs which are influenced.

Air Concentration Results

The results of the air concentration profile measurements are given as figure 16. This color contour plot illustrates the volumetric concentration of air entrainment in diffuser flows. The maximum volumetric air concentration measured was on the order of 30 percent, with much of the diffuser flows carrying 2 to 5 percent air by volume. At these 2 to 5 percent levels, air is very visible and 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 operating conditions indicate sustained high velocities on the order of 7 to 8-ft/s for a distance of less than approximately 30-ft downstream of the ladder entrance. This result was confirmed by analysis of the ADCP data which indicated velocities began dropping at a distance of approximately 15-ft downstream of the ladder entrance. This is particularly true near the surface (IE. at higher elevations in the water column). Velocity magnitudes on the order of 3.3 ft/s appear to become relatively constant at a distance somewhere between 15 and 30-ft downstream of 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 approximately 15-ft downstream of the ladder entrance for the pre modified entrance configuration. Figure 15 represents near and far field data results acquired using the propeller meter and ADCP setups. Phases 1 and 2 results have been plotted 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 as previously indicated, are also summarized in the isovel plot shown in figure 15. The two sets of velocity data were combined for ease of comparison. 12 individual velocity profiles were collected along the centerline of the fish ladder gates downstream to the end of the research pumping plant trashrack structure. The total coverage was about 255-ft downstream of the fish ladder entrance gates. ADCP velocity profiles near the gates were not collected due to air entrainment conditions in the flow which attenuated the acoustic signal. However, ADCP data were collected to within 30-ft downstream of the ladder entrance.

The maximum far field velocities measured were about 4 to 5-ft/sec. For phase 1 data, velocities of 4-ft/sec 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 tests 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/sec velocities along the face of the trashrack structure. Although ladder releases contribute to these velocities, gate 11 releases are considered to contribute more significantly to these velocities. Based on transect data we estimated that the maximum downstream extent of the fish ladder jet was about 115-ft from the fish ladder entrance gates for phase 1 flow conditions.

Phase 2 Results

Diffuser Velocity Results

The data results for diffusers 1, 2, and 4 obtained during phase 2 testing illustrate similar velocity distribution characteristics as those obtained during phase 1 testing. Data for diffuser 3 was not acquired due to instrumentation problems. Figures 18-20 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 the substantial changes in normal component magnitudes presented here. It is felt that this is a result of the entrance modification which produces changes in the ladder flow patterns for all ladder pools of interest in this investigation. These changes produce slight changes in the diffuser resultant velocity direction and produces significant changes in the normal component magnitude. Comparison of diffuser 4 and ladder pool data from pool 4 for phases 1 and 2 demonstrate this condition. 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 appears to exceed the 1.0 ft/s velocity criteria. It should be noted that limited velocity data were acquired for this phase of testing. This was the result of attempting to obtain more velocity field detail at higher elevations within the water column. Thus, these results reflect the interpolated velocity data over the diffusers for fewer data points than those results presented under phase 1 of this evaluation. Care should be taken in the interpretation of these results and their comparison with phase 1 results. Nevertheless, the same general trends (i.e. Velocity distribution characteristics) 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

In similar fashion as the diffuser 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 are evident. While flow patterns above the top of the weirs can be seen as predominantly upstream to downstream with virtually no crossing flow characteristics. Figures 21-24 are the velocity field plots at various elevations within the water column for each ladder pool, respectively. The exception to the argument of similar velocity field characteristics between phases 1 and 2 is related to ladder pool 1. 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. As is evident, strong crossing flow conditions exist throughout the water column in ladder pool 1. This is likely due to 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

The post modification near filed velocity results are presented in the same fashion as phase 1 results (figure 25). Measurement locations for this phase of testing were limited to the left entrance gate (i.e. gate below which the orifice modification exists) centerline. The results indicate that high velocities on the order of 5.0-ft/s are sustained downstream for a distance of approximately 15-ft. Furthermore, velocity magnitudes on the order of 4.5-ft/s are sustained for a distance of approximately 30-ft downstream of the ladder entrance. Velocities appear to stabilize somewhere between 30 and 50-ft downstream of the ladder entrance. Thus, the zone of attraction flow influence is likely limited to 50-ft downstream of 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 of the ladder entrance. There is no doubt 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. Therefore, that the zone of influence would likely extend much farther downstream (as expected) should this obstruction be removed.

Far Field Velocity Results

The results of the phase 2 far field velocity measurements are summarized in the isovel plot shown in figure 25. Again, this plot is a compilation of phase 1 and phase 2 ADCP and propeller meter data collected downstream of 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 the centerline of the fish ladder gates downstream to the end of the research pumping plant trashracks. The total distance covered was about 255-ft downstream of the fish ladder gates. We attempted to collect velocity profiles near the gates, but air bubbles in the fish ladder releases attenuated the acoustic signal and no useful data were collected. However, near-field propeller meter data were included in figure 26 for completeness. The maximum far-field velocities measured were about 4 to 5-ft/sec. For phase 2 data, velocities of 4-ft/sec extended 230-ft downstream at a maximum depth of 13-ft. The extent of high velocities was increased over phase 1 conditions in that the 4-ft/sec velocities were maintained 40-ft further downstream. Whether this improvement was caused by the orifice modification or was related to increased flow through the Gate 11 (sluiceway) was not discernable from profile data. For phase 2 tests, the sluiceway gate was opened 2.3-ft or a 0.5-ft increase over the phase 1 gate setting which corresponds with an increased Gate 11 release of approximately 600-ft^3/s. The increased sluiceway flow is clearly shown by ADCP transect data presented in figure 25. Figure 27 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 the high velocity fish ladder flows near the right bank and how far jet extends downstream along the pumping plant trashracks. 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/sec) 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. The high velocities are caused by the convergence of the sluiceway and fish ladder flows. The two flows are forced together because the trashrack structure projects into the river channel and concentrates the two flow fields. Based on the transect data we estimated that the maximum downstream extent of the fish ladder jet was about 150-ft for phase 2 flow conditions.

DISCUSSION AND INTERPRETATION OF RESULTS

Fish Ladder Operation

It was noted initially upon arrival at RBDD 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 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 likely exceeds 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 flows is critical in provideing 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. This is due to the fact that the diversion dam tailwater elevation was approximately 240.8-ft. In order to maintain entrance velocity criteria of 8 to 10-ft/s, the ladder entrance gates are adjusted to achieve a 1-ft differential between the downstream most ladder pool and the diversion dam tailwater elevation. Thus, the water surface elevation in the downstream portion of the ladder was approximately 242.0-ft which resulted in this submergence.

Operation of Spillway Gate 11

The final discussion concerning operations is specifically related to the operation of Gate 11 which is located adjacent to the right abutment fish ladder. There seems to be a general consensus, although limited supporting data exists, that fish staging locations near the diversion dam are dependent on spillway gate settings and consequently spillway releases. As spillway releases are increased the turbulent intensity within the stilling basins increases. This consequently increased the degree of air entrainment which travels successively farther downstream of the stilling basin end sill. Fish staging locations seem to be consistently downstream of this "white water" zone (Fish Passage Action Program for Red Bluff Diversion Dam, 1988). This being the case, operation of Gate 11 has a significant impact on the performance of the right abutment fish ladder. Case in point, it was observed that for the release conditions existing during this evaluation, that when Gate 11 was set at 2.3-ft, the air entrainment zone extended downstream to the pumping plant. Applying the argument that fish are not likely to penetrate the air entrainment zone, operating Gate 11 in this manner would provide a barrier to the right abutment ladder. To further compound this argument, it should be realized that this air entrainment zone does not likely extend the full depth of the water column and is more realistically confined to the upper few feet. Thus, there may be some question 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 this condition 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 for the fish to sense and locate the ladder entrances. In all cases greater detail regarding the staging locations of fish in the vertical of the water column may provide further insight for establishing ladder and gate operations which optimizes fish passage potential at RBDD.

Diffuser Flow Air Entrainment

It is immediately obvious through observation of ladder operation, 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 air entrained or "white water" flows to the diffuser chimneys and subsequently into the ladder pools. However, there is insufficient settling time for the entrained air to rise out of the water column prior to entering the ladder. There is some question as to what degree this air entrainment may affect fish. In any case it seems logical to minimize the amount of this air entrainment, given the uncertainties regarding potential disorientation of fish. There are various techniques available for removing air entrainment from highly air entrained flows, the details of which have been included in the recommendations section of this report.

Diffuser Velocity Distributions

The results of the diffuser velocity distributions may be generalized to some degree, since 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 2-4 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. This non-uniformity in velocity distribution creates localized zones of velocity magnitudes which are in excess of the 1.0-ft/s velocity criteria. Such a criteria was established in order to minimize disorientation and delay on the part of the fishery. Thus, it is desirable to maintain strong upstream to downstream velocity field pattern such that the fishery will continue to move up the ladder. The skewness in the velocity distributions as seen by the diffuser velocity results is likely to confuse or disorient the fishery, creating excess delay and consequently poor ladder performance. In this regard, during testing, salmon were observed turning into diffuser 4 just upstream of the air entrainment zone. Further support for this perspective could be interpreted from the under water video observations obtained for ladder pool 1, under post modification conditions. Recall that these observations showed fish tended to turn immediately into diffuser 1 upon entering the ladder through the modified entrance orifice. This response is most likely related to the strong crossing flow patterns as seen by the phase 2, pool velocity field results.

Generalized Ladder Pool Flow Patterns

In similar fashion as the diffuser velocity distribution results of this evaluation, the pool velocity field or flow patterns may be generalized for pools 2-4. 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 wiers. At these elevations strong crossing flows exist. However, above the top of the weirs in the water column the velocity field is influenced only slightly by diffuser flows and exhibit flow orientation characteristics which are predominantly upstream to downstream.

Ladder Entrance Conditions

The observed ladder entrance conditions downstream of the right abutment ladder appear to change significantly 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 is bounded at the surface and appears to have a rather high turbulent intensity. The jets are somewhat 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 somewhat subjective. However, based on experience in the field of hydraulics and the results of near field velocity measurements, the modified entrance configuration likely represents improved hydraulic conditions from a fish passage standpoint, over the original gated entrance configuration. It is valid to state that the modified configuration will diffuse less quickly due to 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 draw back of this is that by modifying the entrance in such a way, the velocity field upstream of the ladder entrance in significantly influenced, as previously discussed. Thus, there is a good possibility that the deficiencies in fish passage associated with this ladder were merely displaced from the tailrace to ladder pool 1 instead of being eliminated.

Near Field and Far Field Attraction Flow Performance

The near field velocity results obtained for these investigations indicate improved attraction flow conditions for the modified ladder entrance configuration even with an obstruction located just downstream of the ladder entrance. This is evident in the fact that higher velocities are sustained further downstream than those obtained 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 limited.

The far field velocity measurements indicated that the fish ladder release flows were indistinguishable from sluiceway releases at distances greater than 115-ft downstream of the fish ladder gates. This distance corresponds to the beginning of the pumping plant trashracks. For distances less than 115-ft downstream, the fish ladder release velocities of 4 to 5-ft/sec were measured along the sheet pile retaining wall. Furthermore, phase 2 data showed improved jet penetration over phase 1 data, but this improvement was likely caused by increased flow through the sluiceway. Also, the relative magnitude of fish ladder releases (and corresponding zone of high velocity influence) is small compared with gate 11 releases. In the tailwater pool, ladder releases are significantly masked by gate 11 releases. To achieve effective guidance to the ladder entrance, it is critical that fish staging locations below gate 11 and the right abutment ladder entrance are compatible.

RECOMMENDATIONS

The following recommendations concerning both temporary and potential long term solutions for improving the right abutment ladder performance are presented as follows. These recommendations are based on WRRL experience, field observations, and the results of these investigations. Additional biological and hydraulic evaluations may be required before implementing any of the recommendations presented herein.

Operational Modifications

It is apparent from the results of these investigations and field observations that current ladder operation is less than optimal. The fact that the supplemental or diffuser flow head gate is operated in a full open position indicates that diffuser discharges are likely higher than design, creating diffuser exit velocities which exceed criteria. This condition is compounded by the fact that the diffusers are not baffled which allows for non-uniformity in velocity distributions. Furthermore, highly air entrained diffuser flows may potentially affect ladder performance by creating additional disorientation problems. Operational modifications should be investigated as a means of improving ladder performance with regard to diffuser flows. This 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 of the diffusers should also be investigated. This would improve the upstream to downstream flow conditions and reduce diffuser flow influences. Finally, baffling of diffusers should be considered to minimize diffuser flow influence on ladder pool velocity fields. Should this 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 recommendations represent the minimum efforts required to improve existing ladder performance.

Engineering Modifications

It may be desirable to invest in additional modifications to the existing right bank ladder in the short term. Certainly the design and implementation of a diffuser baffling scheme would help to improve ladder performance. 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. Other potential improvements regarding how diffuser flows are introduced into the last four ladder pools which are worth investigation as a temporary solution to improving ladder performance include:

- 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 (IE. bulkheading the existing diffusers) in favor of a pipe diffuser concept which supplies diffuser flows to ladder pools 1-6 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. The WRRL will prepare a feasibility or level of effort document which identifies those potential alternatives. This information is intended to assist in the selection of the best short term solution for optimizing the existing right bank ladder performance and will be available by February 1997. Should continued use of the entrance orifice modification be desired, the downstream obstruction should be removed in order to maximize the zone of attraction flow influence and satisfy the original intent of such modification. Finally, it should be noted that additional studies should be conducted to better define fish staging location below gate 11 as a function of gate setting and corresponding release discharge.

REFERENCES

Bureau of Reclamation. October 1991. *Appraisal Report - Red Bluff Diversion Dam Fish Passage Program.*

Bureau of Reclamation. January 1970. "Designer's Operating Criteria - Red Bluff Diversion Dam and Fish Passage Facilities." U.S. Department of the Interior.

Vogel, David A., Keith R. Marine, and James G. Smith. October 1988. "Fish Passage Action Program for Red Bluff Diversion Dam - Final Report on Fishery Investigations." U.S. Fish and Wildlife Service, Report No. FR1/FAO-88-19.

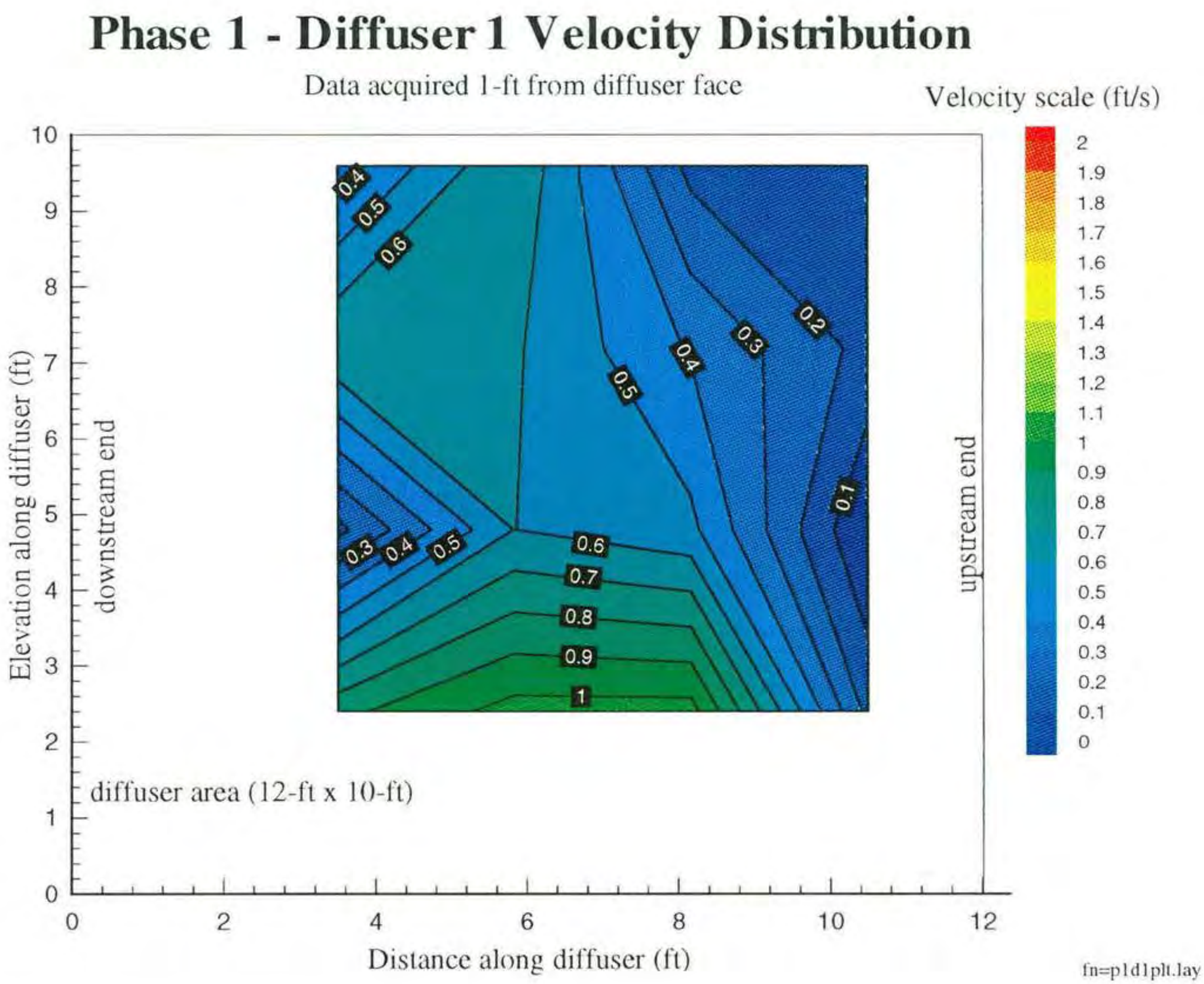


Figure 7. Diffuser 1 velocity contour plot. *Phase 1 testing.*

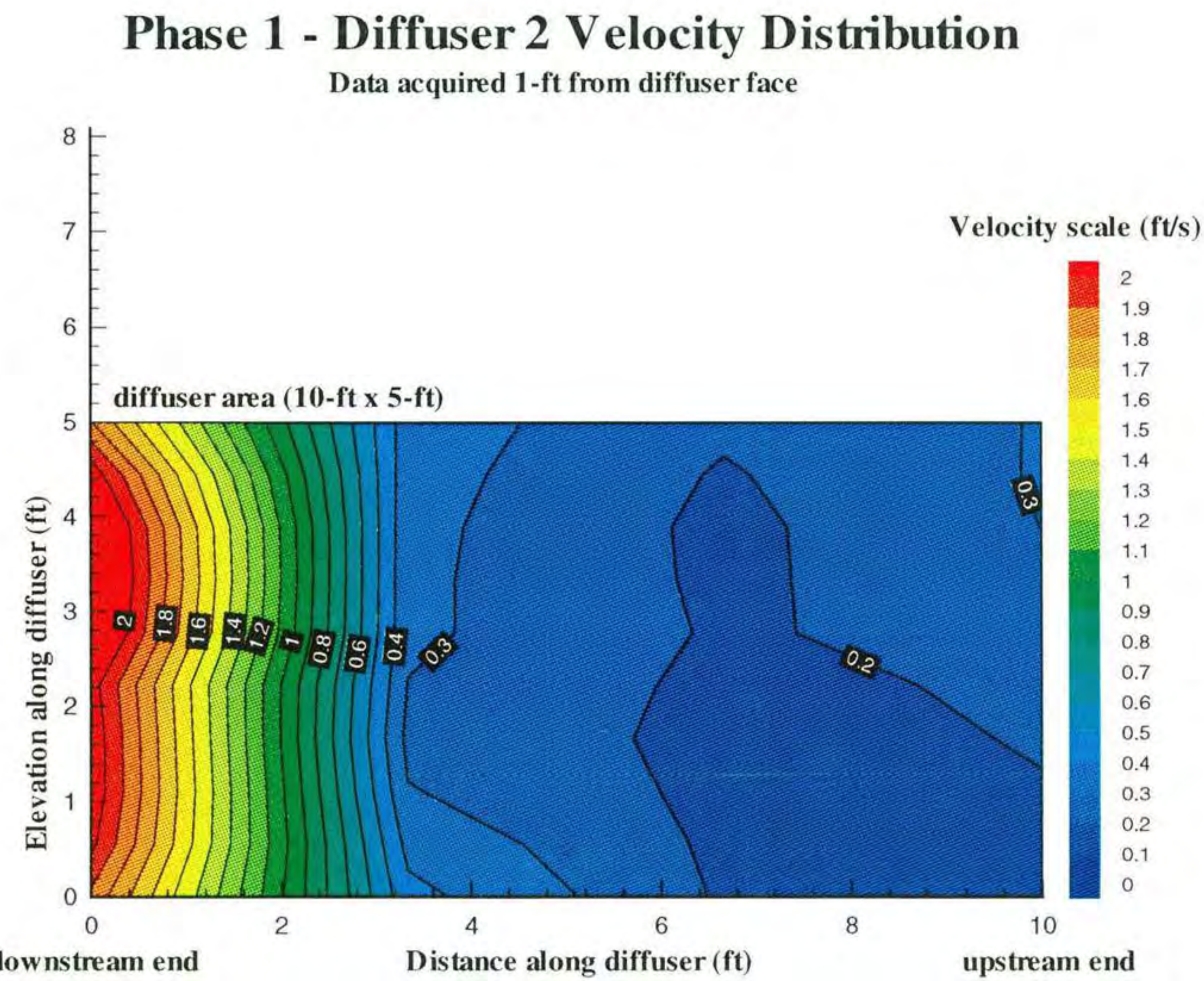


Figure 8. Diffuser 2 velocity contour plot.

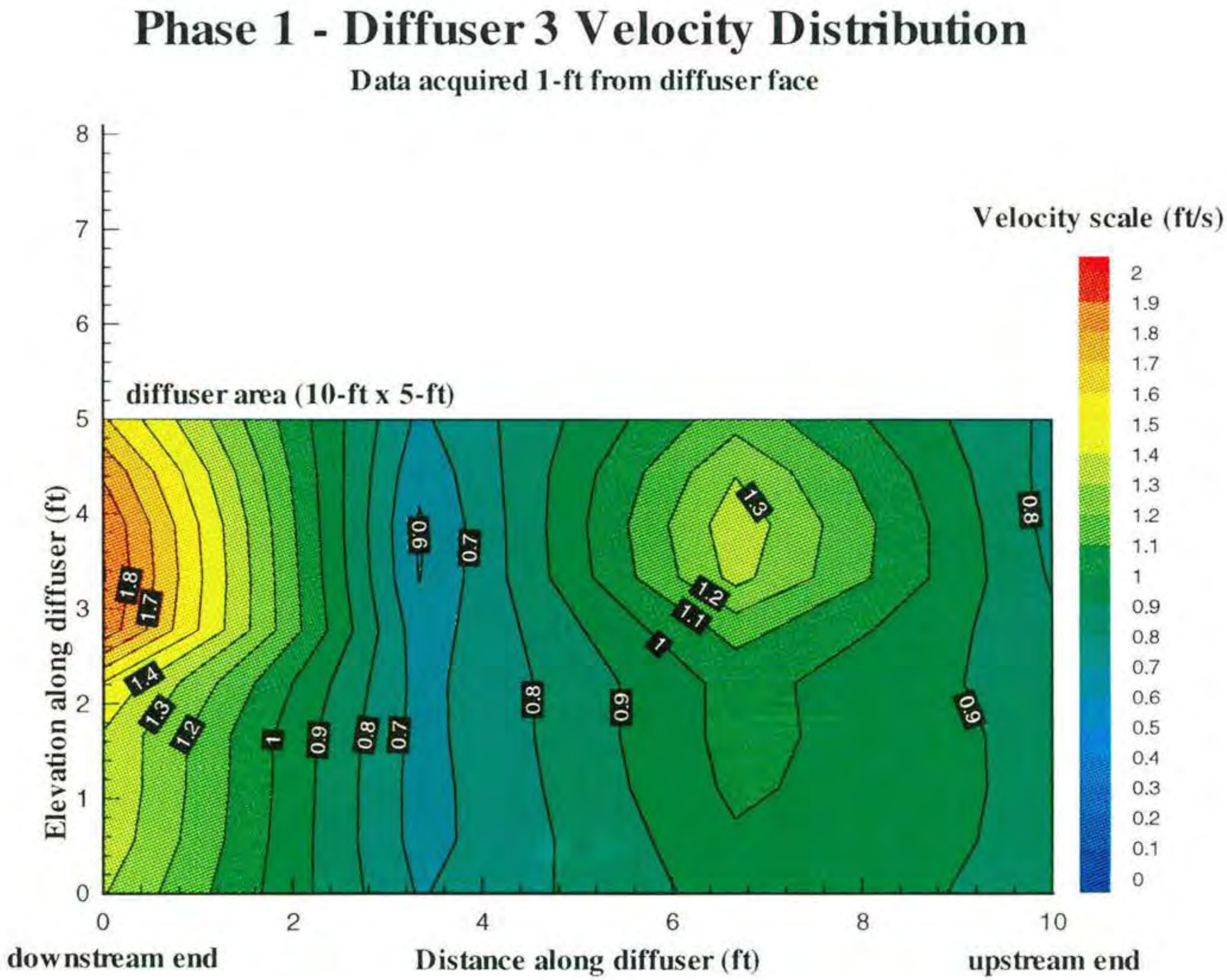


Figure 9. Diffuser 3 velocity contour plot. *Illustrates upstream to downstream skewness in velocity distribution.*

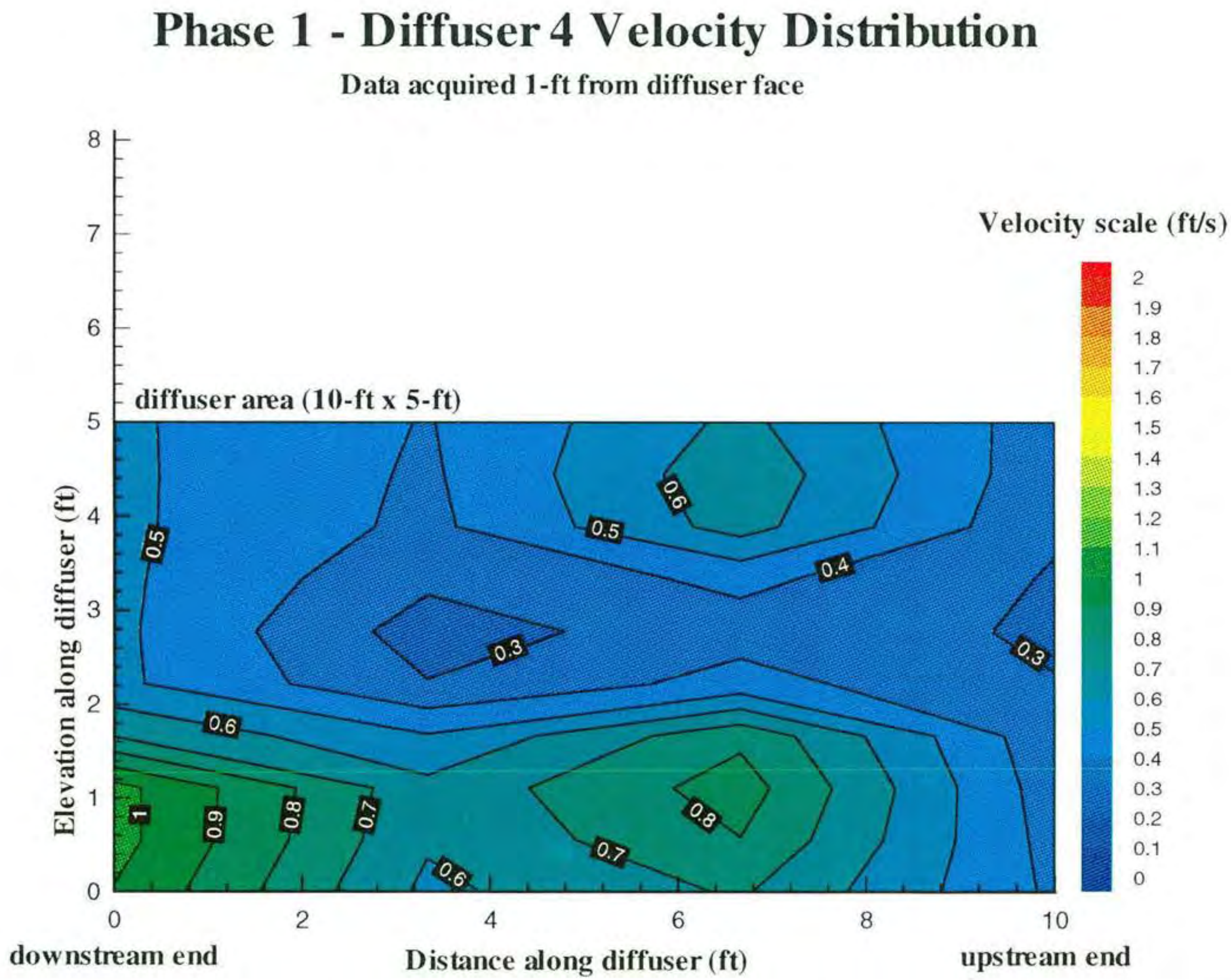


Figure 10. Diffuser 4 velocity contour plot. *Skewness in velocity distribution is less severe than those results obtained for diffusers 2 and 3.*

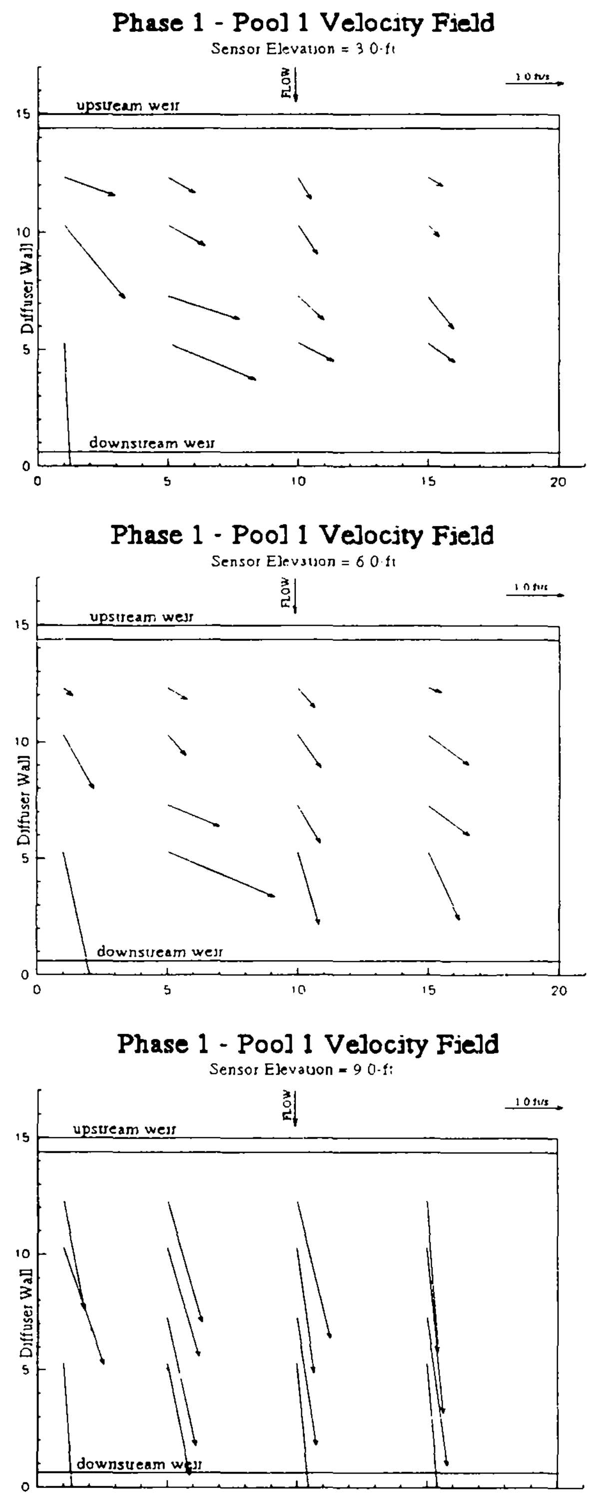
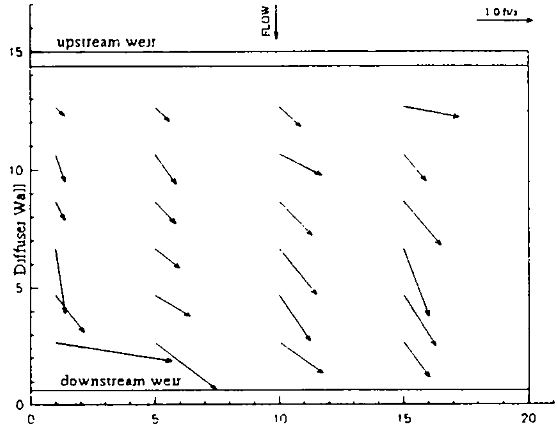


Figure 11. Ladder pool 1 velocity vector field data. *Phase 1 testing. Illustrates plan view vector field at various elevations within the water column.*

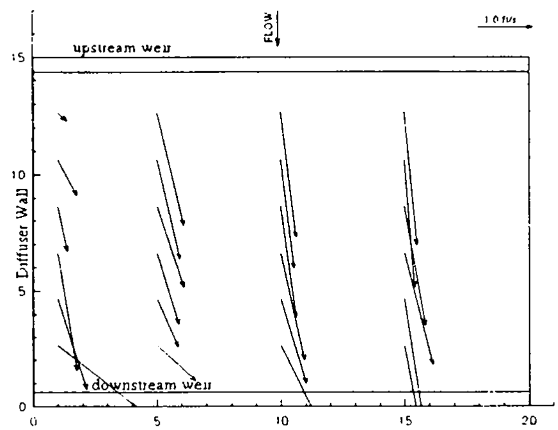
Phase 1 - Pool 2 Velocity Field

Sensor Elevation = 3.0-ft



Phase 1 - Pool 2 Velocity Field

Sensor Elevation = 6.0-ft



Phase 1 - Pool 2 Velocity Field

Sensor Elevation = 9.0-ft

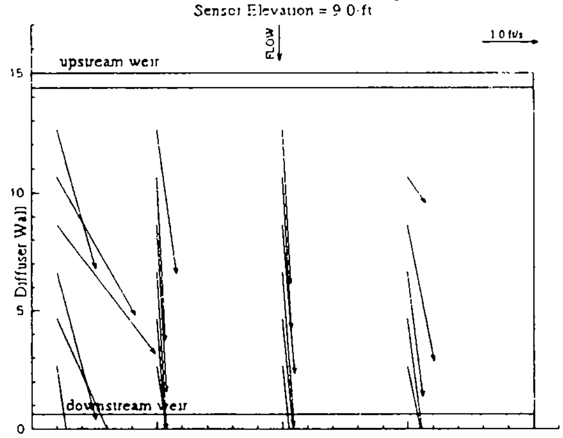


Figure 12. Ladder pool 2 velocity vector field plot. *Phase 1 testing.*

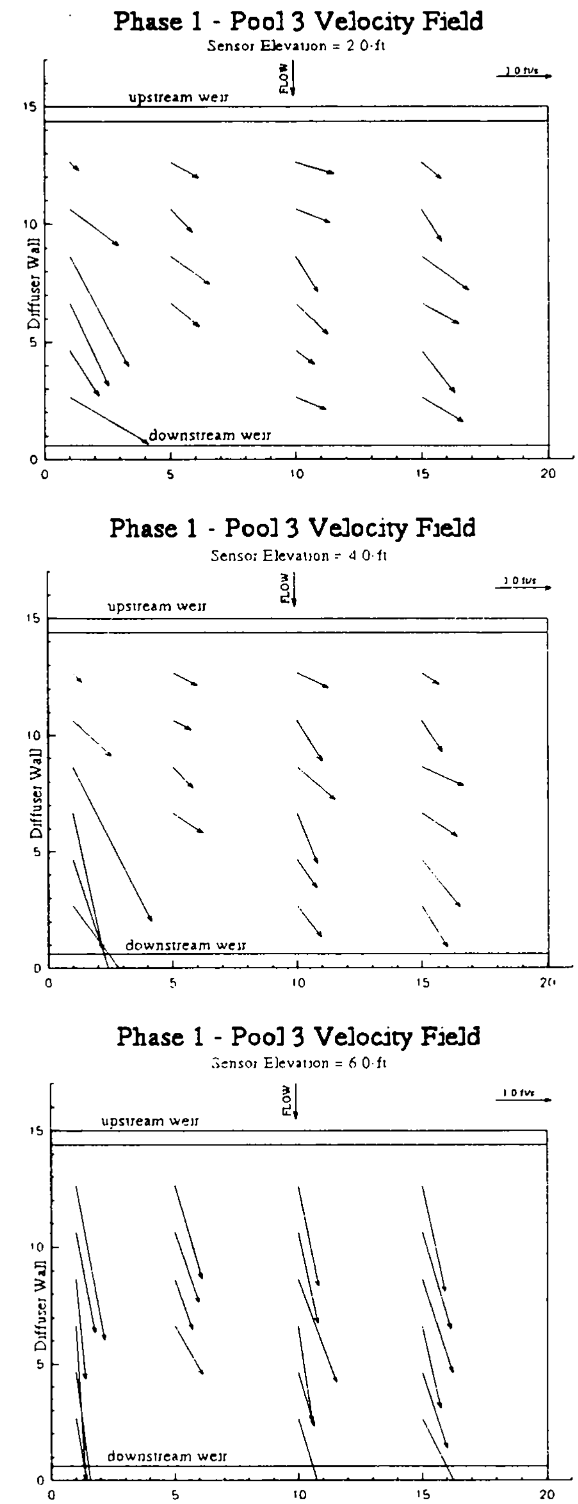


Figure 13. Ladder pool 3 velocity vector field plot. *Phase 1 testing.*

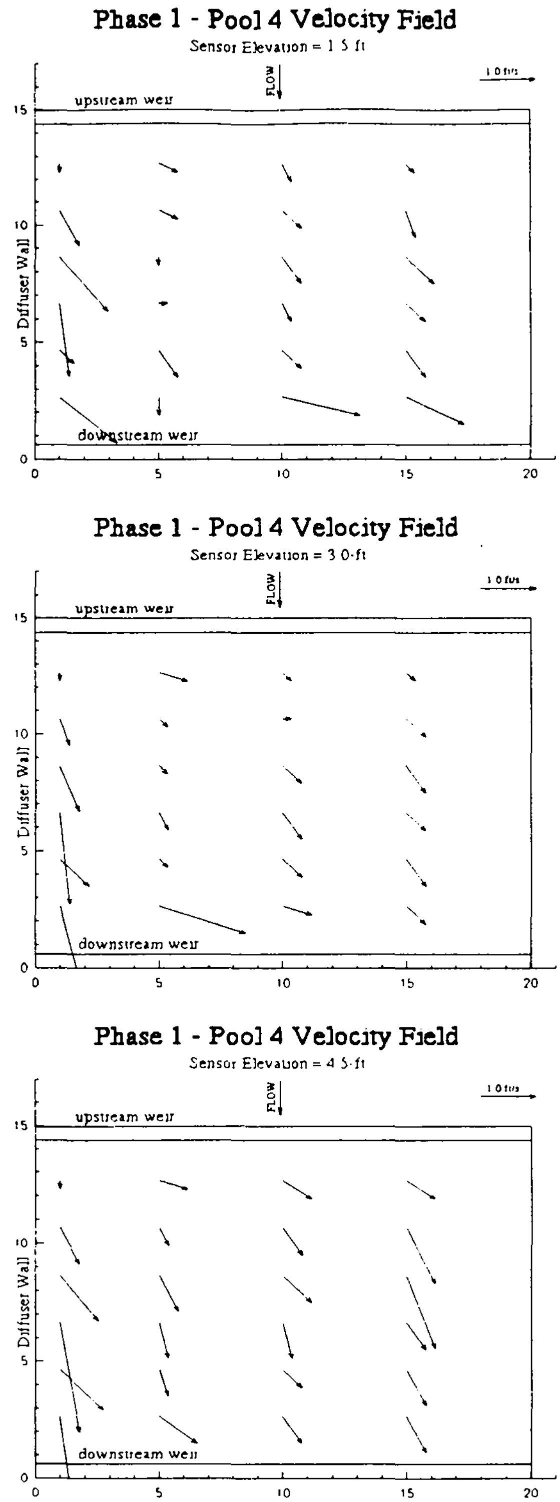


Figure 14. Ladder pool 4 velocity vector field plot. *Phase 1 testing.*

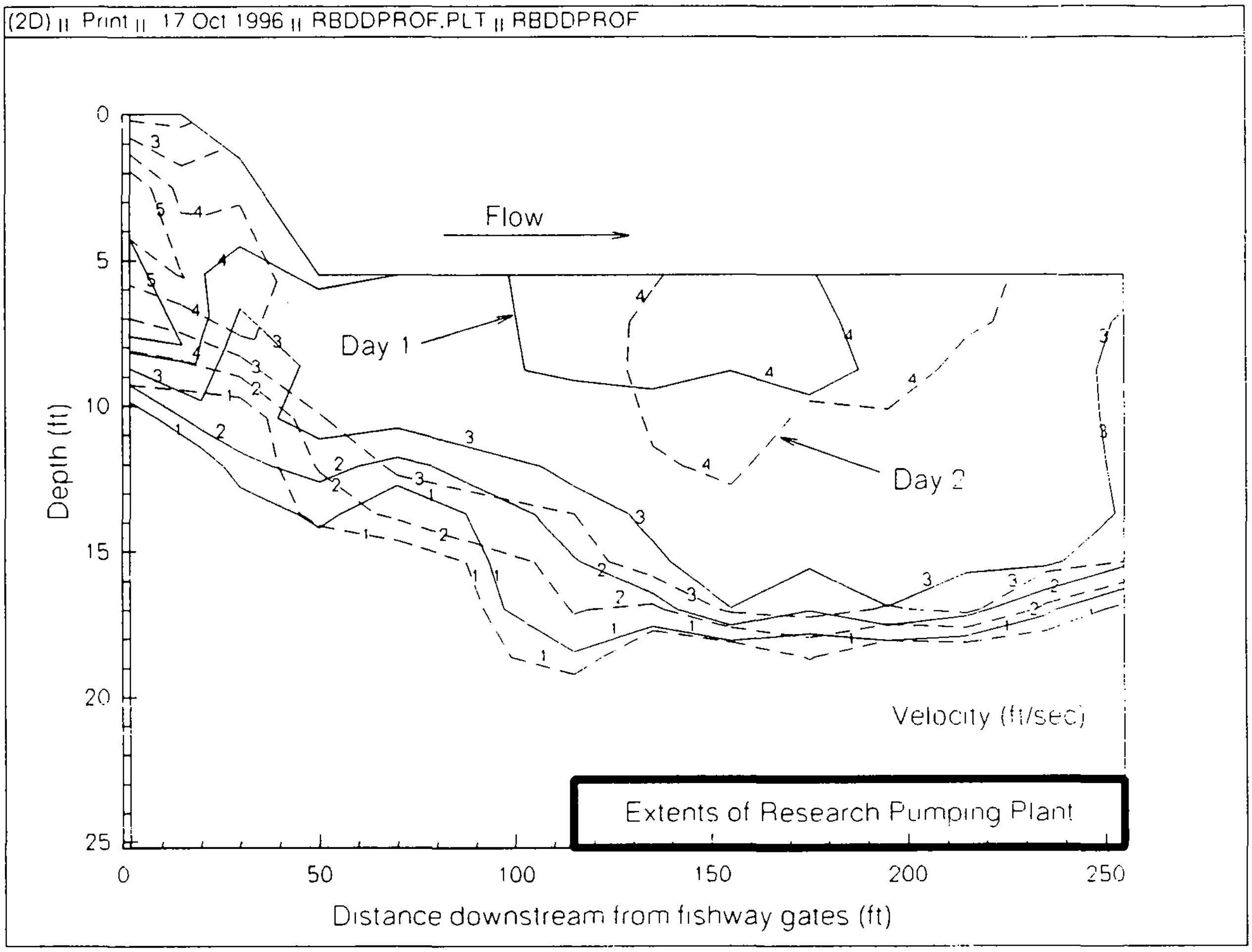


Figure 15. ADCP profile and current meter data collected downstream of right abutment fish ladder. *Contains data for phase 1 and phase 2 testing.*

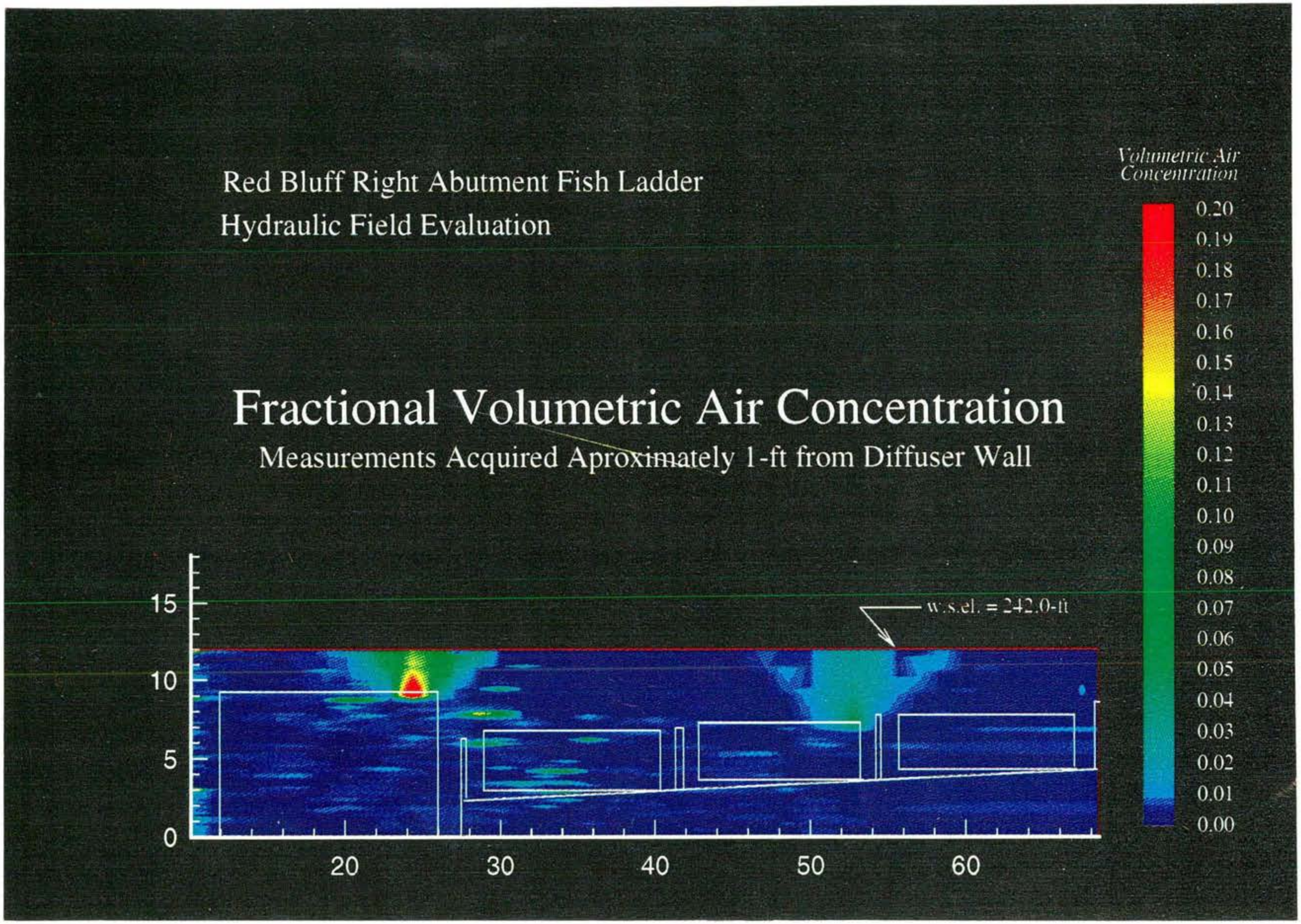


Figure 16. Air concentration contour plot. *Data acquired along diffuser wall side of fish ladder.*

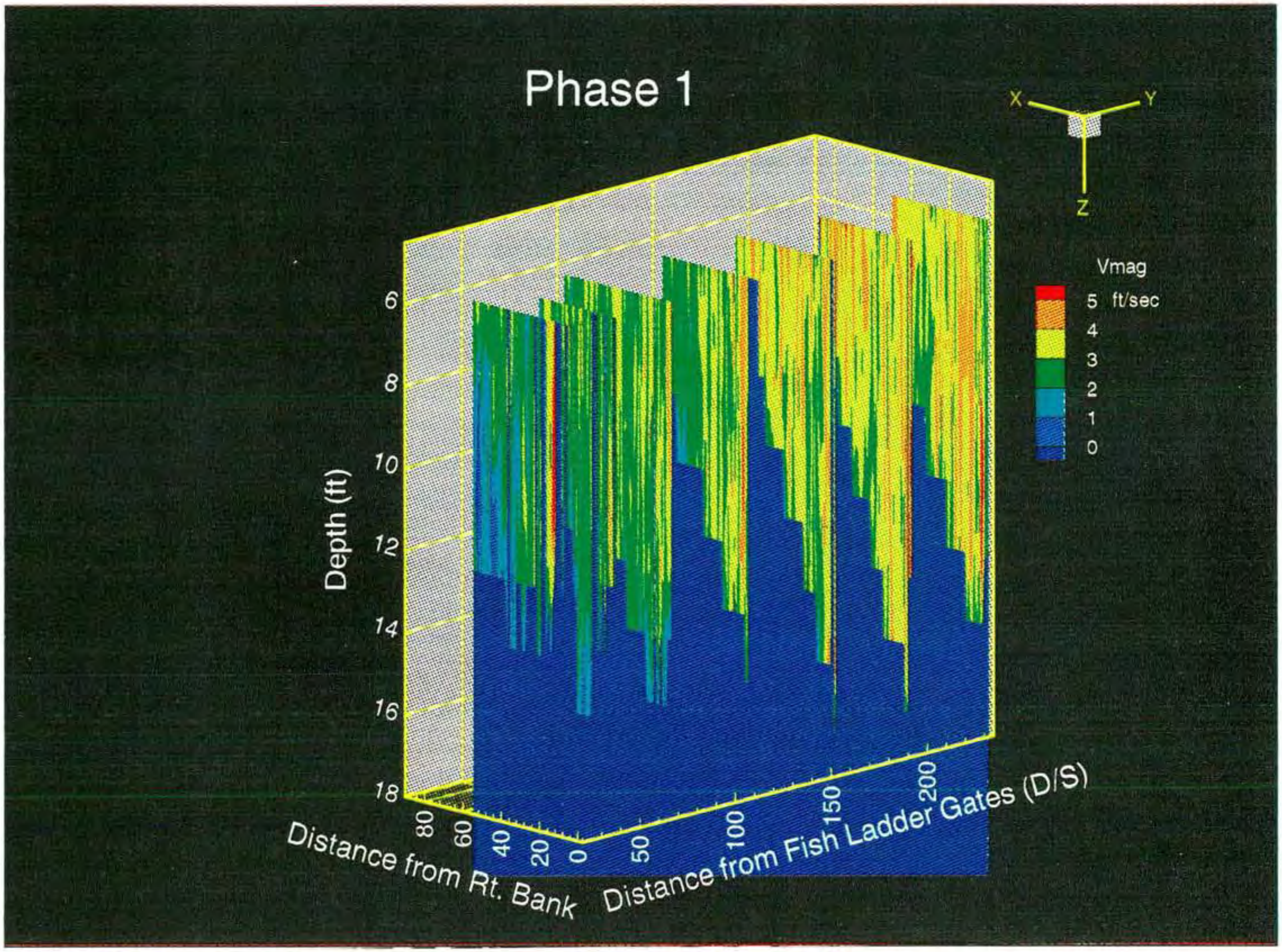


Figure 17. ADCP transect plots for several locations downstream from the fish ladder gates. *Phase 1 testing conditions. These transect plots show the high velocity jet exiting from the fish ladder gates in the near-field and the transition into a uniform velocity field in the far-field.*

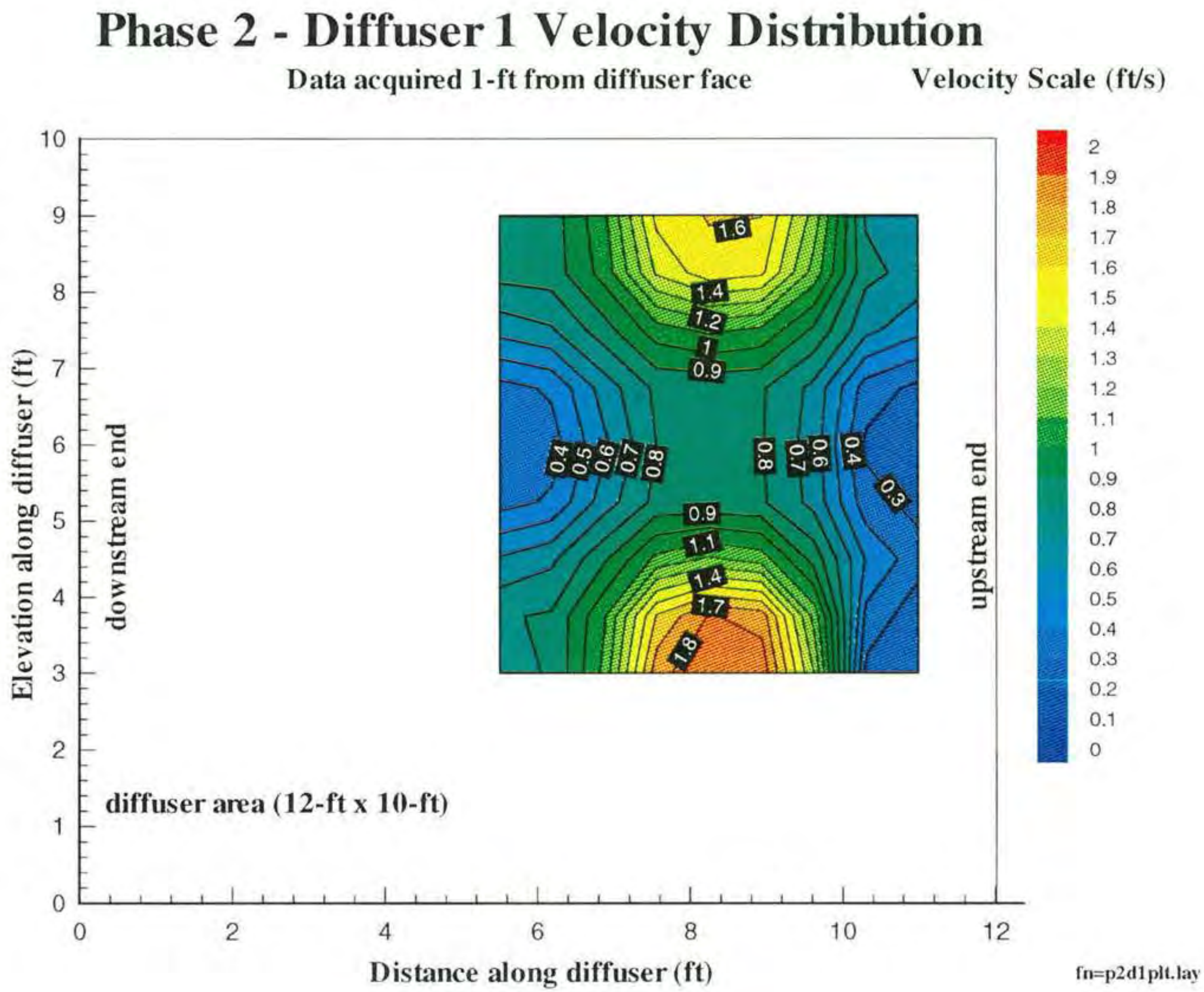


Figure 18. Diffuser 1 velocity contour plot. *Phase 2 testing.*

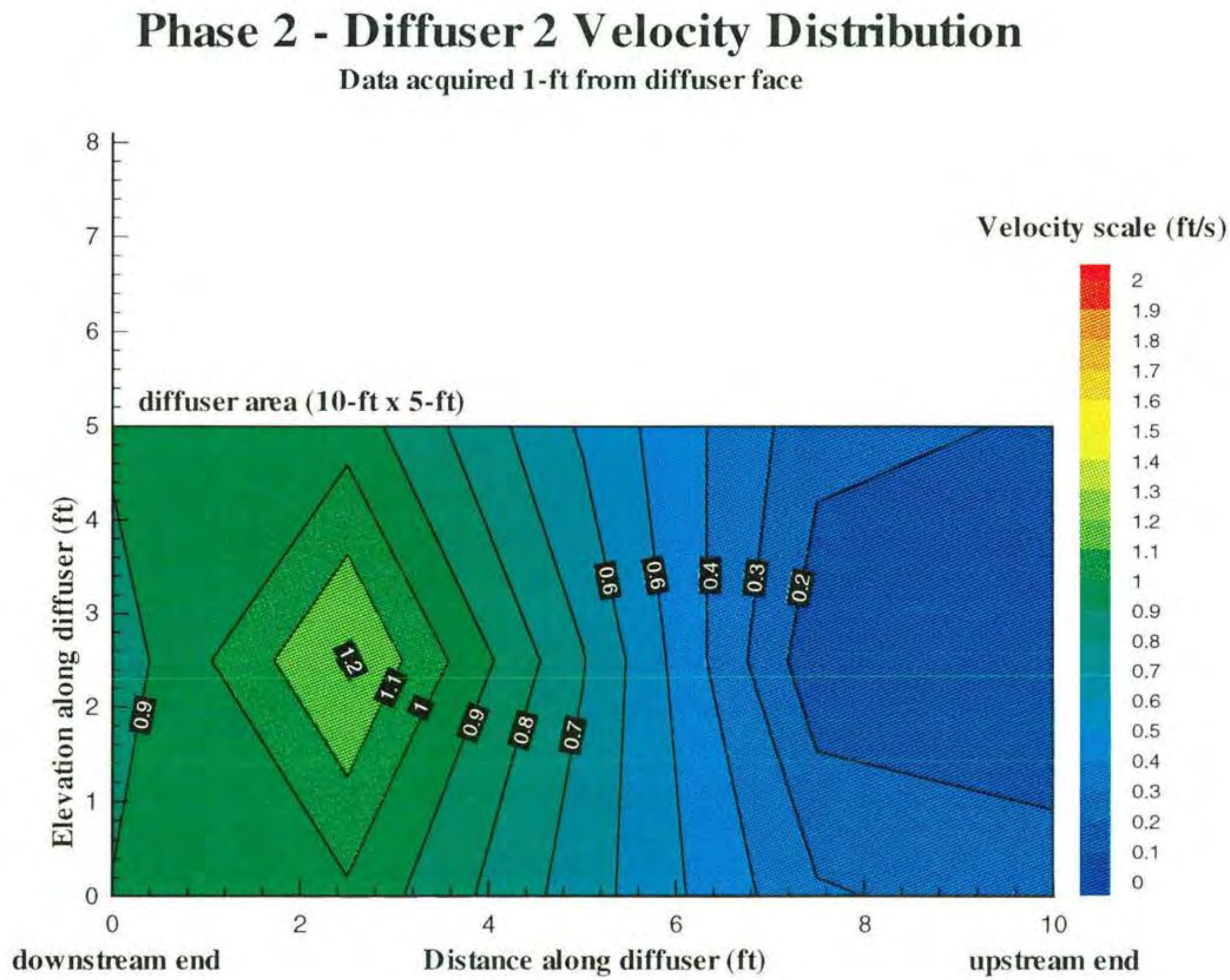


Figure 19. **Diffuser 2 velocity contour plot.** *Phase 2 testing.*

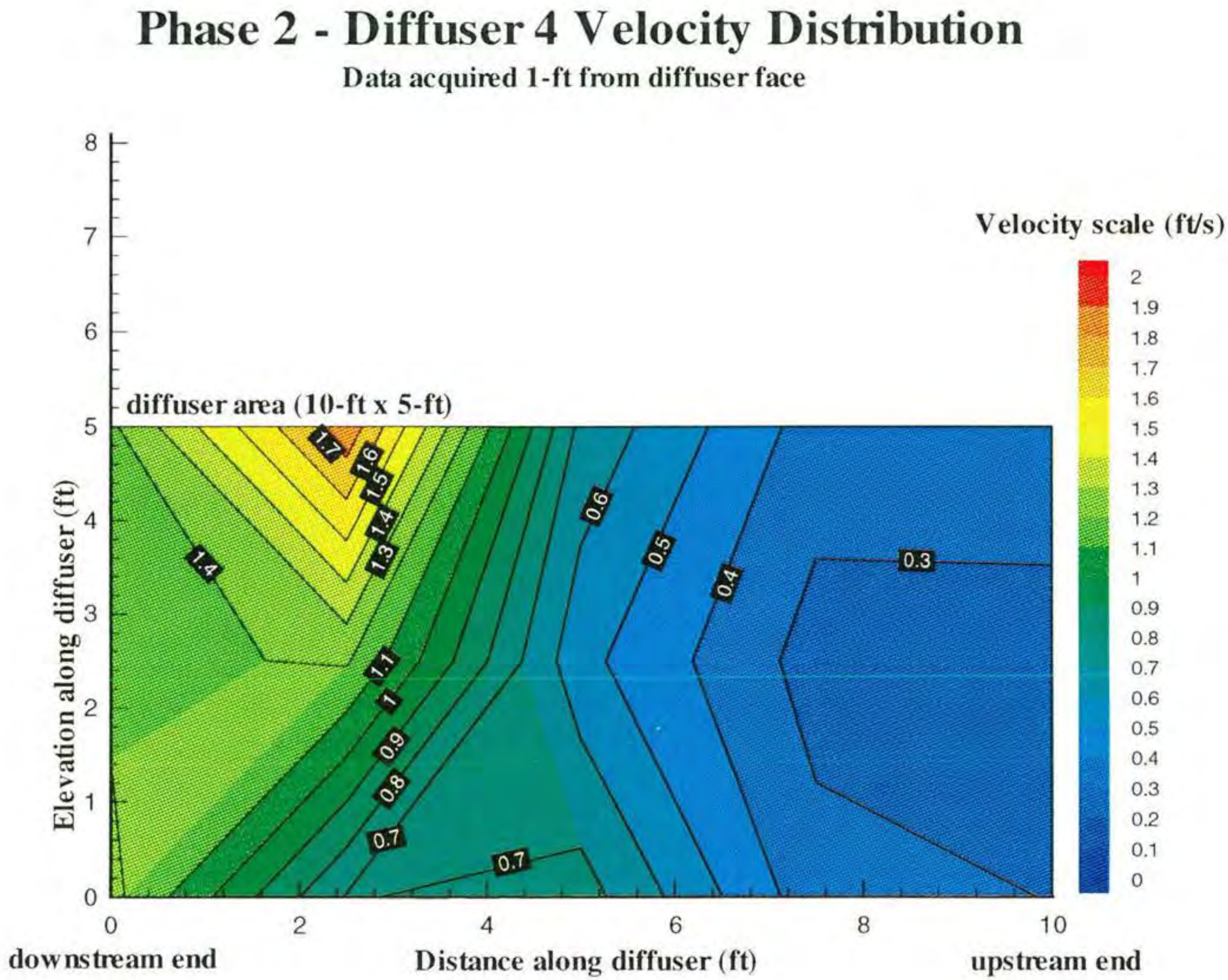


Figure 20. Diffuser 4 velocity contour plot. *Phase 2 testing.*

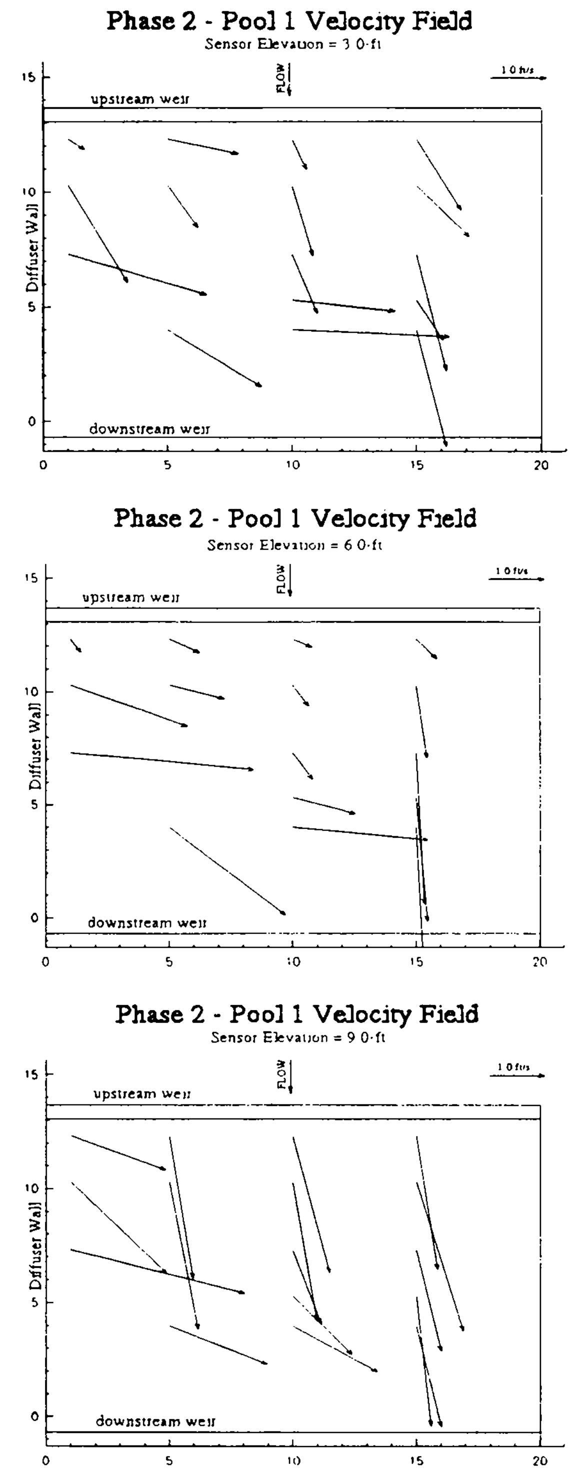
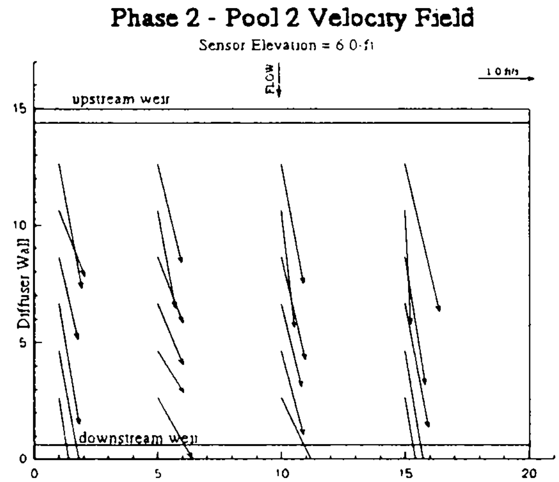


Figure 21. Ladder pool 1 velocity vector field plot. *Phase 2 testing. Note: severe crossing flow conditions.*



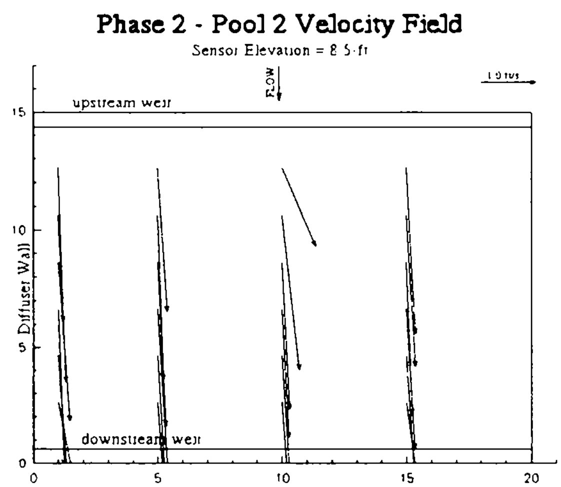
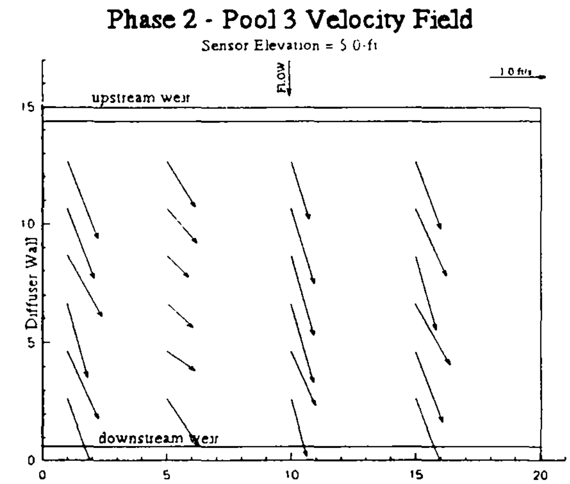


Figure 22. Ladder pool 2 velocity vector field plot. *Phase 2 testing.*



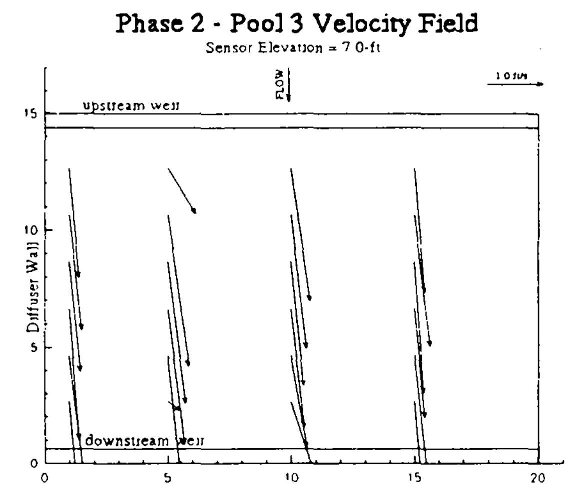


Figure 23. Ladder pool 3 velocity vector field plot. *Phase 2 testing.*

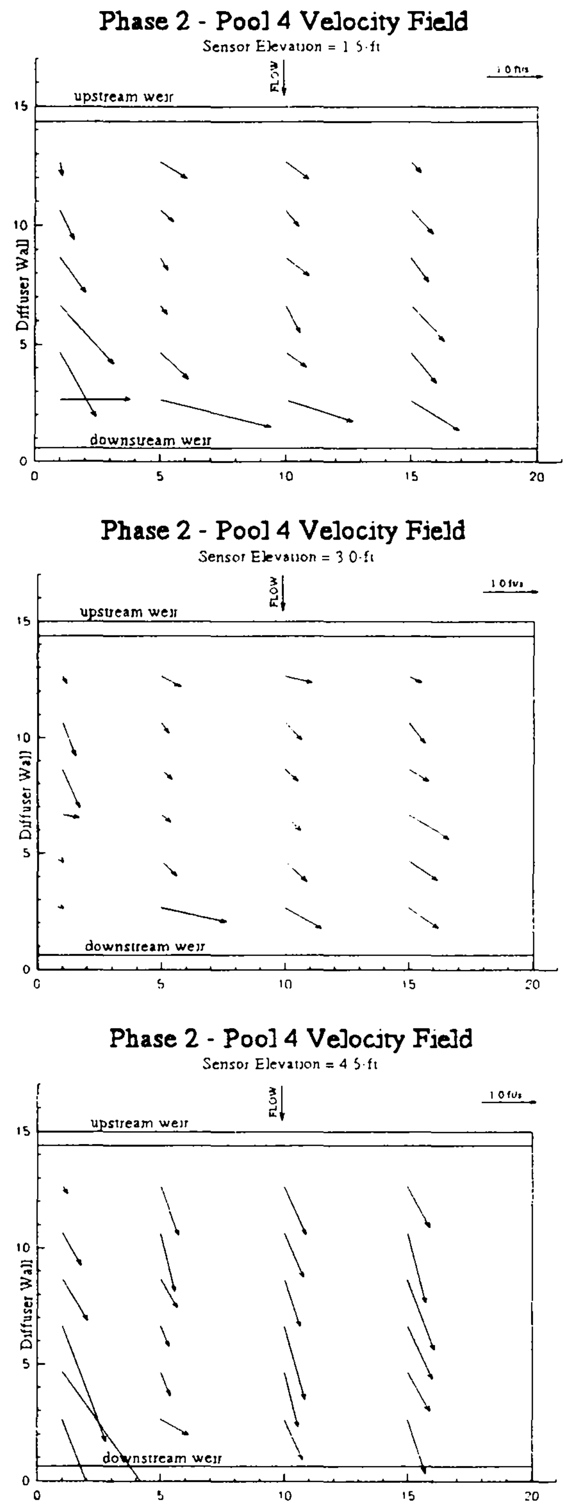


Figure 24. Ladder pool 4 velocity vector field plot. *Phase 2 testing.*

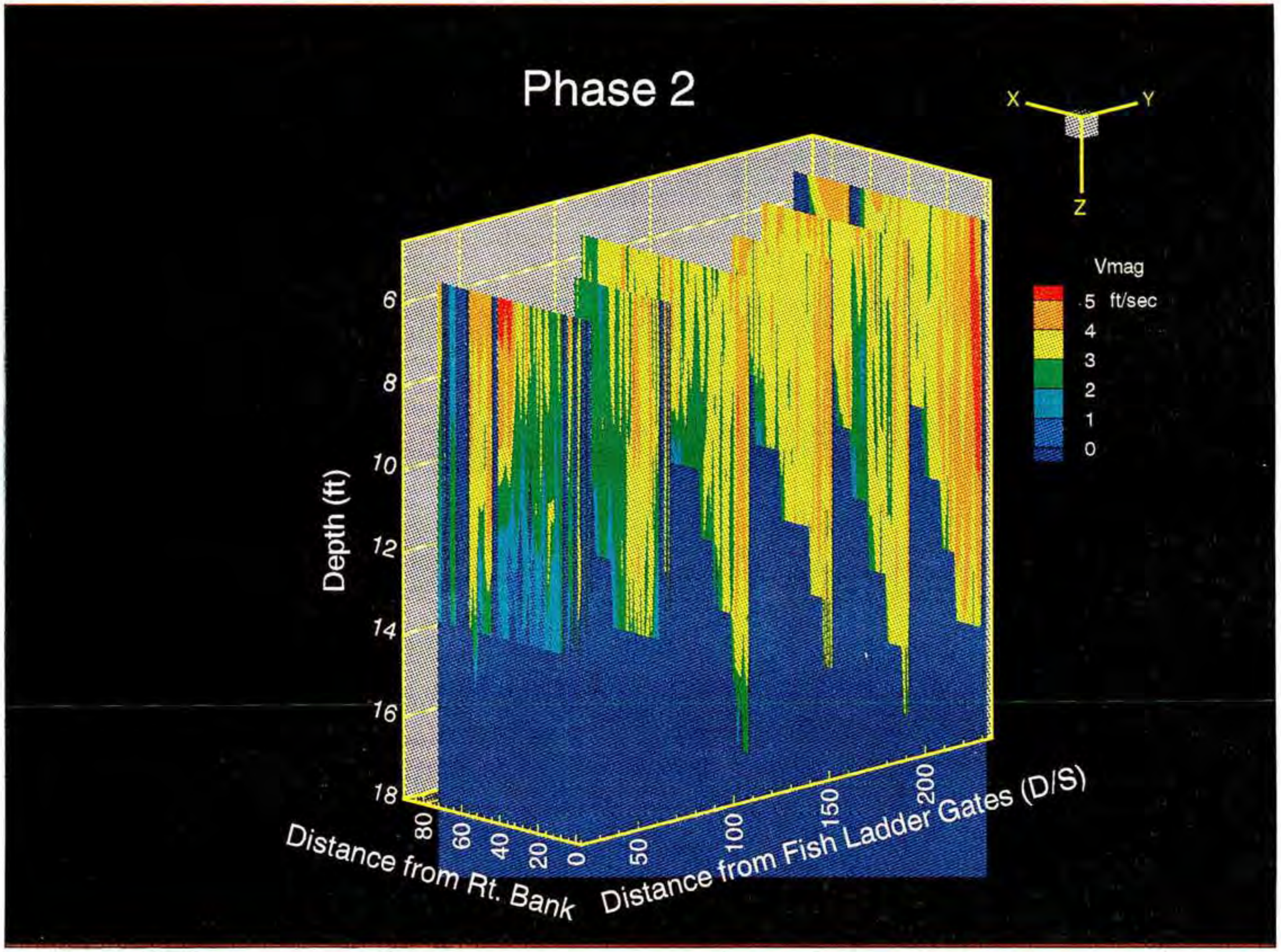


Figure 25. ADCP transect plots for several locations downstream from the fish ladder gates. *Phase 2 testing conditions. These transect plots show the high velocity jets exiting from the fish ladder gates and from Gate 11 in the nearfield, and the transition into a uniform velocity field in the far field. The high velocities measured 250 ft downstream are the result of increased flows through Gate 11.*

Appendix 1. Raw data: Diffuser, ladder pool, and near field velocities

C

RED BLUFF DIVERSION DAM
RECORD OF OPERATION

YEAR 1996

DATE	U/S ELEV 0001	U/S ELEV 0800	D/S ELEV 0001	D/S ELEV 0800	1	2	3	4	5	6	7	8	9	10	11	TOTAL OPEN	BASIN ELEV	CC CFS	TC CFS	KES.	CFS PASS 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	14,070
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	12,750
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]	240.86	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	13,350
8-7	252.48	252.51	241.17	241.19	1.5	1.0	1.0	1.0	0	0	1.0	1.0	1.0	2.0	1.2	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	15,390
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

RGA
1/23/89

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) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	Vavg (ft/s)	Vmin (ft/s)	Vmax (ft/s)
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) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	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) (corrected data)

Station	Sensor Orientation	Sensor Elevation	Vavg	Vmin	Vmax	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
August 6-9, 1996
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

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 4: Upstream most ladder pool containing diffuser flows.

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)	
17	parallel	1.5	564	30	1710	0.51	0.03	1.53	
		3	316	0	1050	0.28	0.00	0.94	
		4.5	345	0	930	0.31	0.00	0.83	
	perpendicular	1.5	2191	990	3150	1.96	0.89	2.82	
		3	1312	150	3130	1.18	0.13	2.80	
		4.5	564	30	1380	0.51	0.03	1.24	
15	parallel	1.5	570	30	1770	0.51	0.03	1.59	
		3	329	30	1050	0.29	0.03	0.94	
		4.5	499	30	1830	0.45	0.03	1.64	
	perpendicular	1.5	555	120	1350	0.50	0.11	1.21	
		3	315	0	1110	0.28	0.00	0.99	
		4.5	175	0	660	0.16	0.00	0.59	
13	parallel	1.5	197	0	600	0.18	0.00	0.54	
		3	153	0	510	0.14	0.00	0.46	
		4.5	462	0	1050	0.41	0.00	0.94	
	perpendicular	1.5	136	0	330	0.12	0.00	0.30	
		3	202	0	690	0.18	0.00	0.62	
		4.5	167	0	540	0.15	0.00	0.48	
11	parallel	1.5	266	0	630	0.24	0.00	0.56	
		3	239	0	600	0.21	0.00	0.54	
		4.5	624	90	1770	0.56	0.08	1.59	
	perpendicular	1.5	140	0	390	0.13	0.00	0.35	
		3	221	0	720	0.20	0.00	0.65	
		4.5	326	0	900	0.29	0.00	0.81	
9	parallel	1.5	254	0	510	0.23	0.00	0.46	sensor elevations moved to 1.5, 3, 5
		3	227	0	660	0.20	0.00	0.59	
		5	1266	60	3330	1.13	0.05	2.98	
	perpendicular	1.5	255	0	810	0.23	0.00	0.73	
		3	155	0	510	0.14	0.00	0.46	
		5	283	0	690	0.25	0.00	0.62	
7	parallel	1.5	332	30	660	0.30	0.03	0.59	flow depth over wier = 1.8 ft.
		3	230	0	660	0.21	0.00	0.59	
		5	1065	210	2490	0.95	0.19	2.23	
	perpendicular	1.5	524	150	900	0.47	0.13	0.81	
		3	402	0	750	0.36	0.00	0.67	
		5	362	30	1110	0.32	0.03	0.99	

Centerline of ladder.
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)
17	parallel	1.5	467	0	1230	0.42	0.00	1.10
		3	446	0	1410	0.40	0.00	1.26
		5	873	90	2190	0.78	0.08	1.96
	perpendicular	1.5	1325	360	2550	1.19	0.32	2.28
		3	753	60	1710	0.67	0.05	1.53
		5	372	0	930	0.33	0.00	0.83
15	parallel	1.5	311	30	840	0.28	0.03	0.75
		3	439	60	1388	0.39	0.05	1.24
		5	1175	120	2490	1.05	0.11	2.23
	perpendicular	1.5	416	0	1440	0.37	0.00	1.29
		3	448	0	1380	0.40	0.00	1.24
		5	273	30	930	0.24	0.03	0.83
13	parallel	1.5	578	0	1260	0.52	0.00	1.13
		3	342	0	960	0.31	0.00	0.86
		5	1575	330	2490	1.41	0.30	2.23
	perpendicular	1.5	280	30	720	0.25	0.03	0.65
		3	322	60	900	0.29	0.05	0.81
		5	415	30	870	0.37	0.03	0.78
11	parallel	1.5	382	0	780	0.34	0.00	0.70
		3	270	30	690	0.24	0.03	0.62
		5	1011	150	1950	0.91	0.13	1.75
	perpendicular	1.5	465	0	1080	0.42	0.00	0.97
		3	271	0	960	0.24	0.00	0.86
		5	296	30	1110	0.27	0.03	0.99
9	parallel	1.5	344	0	1050	0.31	0.00	0.94
		3	376	30	990	0.34	0.03	0.89
		5	958	180	2430	0.86	0.16	2.18
	perpendicular	1.5	270	0	720	0.24	0.00	0.65
		3	335	0	1050	0.30	0.00	0.94
		5	381	0	1050	0.34	0.00	0.94
7	parallel	1.5	357	0	840	0.32	0.00	0.75
		3	149	0	630	0.13	0.00	0.56
		5	1035	90	2550	0.93	0.08	2.28
	perpendicular	1.5	454	0	1140	0.41	0.00	1.02
		3	543	90	1140	0.49	0.08	1.02
		5	436	30	1770	0.39	0.03	1.59

Left of ladder 5-ft from left 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)
17	parallel	1.5	650	0	1800	0.58	0.00	1.61
		3	442	0	1200	0.40	0.00	1.08
		5	1165	210	2040	1.04	0.19	1.83
	perpendicular	1.5	948	0	2010	0.85	0.00	1.80
		3	604	30	2340	0.54	0.03	2.10
		5	355	60	1050	0.32	0.05	0.94
15	parallel	1.5	646	30	1740	0.58	0.03	1.56
		3	416	60	990	0.37	0.05	0.89
		5	830	30	2160	0.74	0.03	1.94
	perpendicular	1.5	501	30	1200	0.45	0.03	1.08
		3	578	30	2130	0.52	0.03	1.91
		5	440	60	1230	0.39	0.05	1.10
13	parallel	1.5	743	240	1440	0.67	0.22	1.29
		3	514	30	1620	0.46	0.03	1.45
		5	1153	60	2220	1.03	0.05	1.99
	perpendicular	1.5	654	60	1830	0.59	0.05	1.64
		3	813	30	1380	0.73	0.03	1.24
		5	486	0	1470	0.44	0.00	1.32
11	parallel	1.5	514	30	1710	0.46	0.03	1.53
		3	270	30	930	0.24	0.03	0.83
		5	1521	210	3150	1.36	0.19	2.82
	perpendicular	1.5	343	0	1260	0.31	0.00	1.13
		3	408	0	1620	0.37	0.00	1.45
		5	533	60	1350	0.48	0.05	1.21
9	parallel	1.5	499	30	1830	0.45	0.03	1.64
		3	430	30	1230	0.39	0.03	1.10
		5	1504	510	2730	1.35	0.46	2.45
	perpendicular	1.5	445	30	1050	0.40	0.03	0.94
		3	322	30	930	0.29	0.03	0.83
		5	353	0	1170	0.32	0.00	1.05
7	parallel	1.5	228	0	690	0.20	0.00	0.62
		3	143	0	360	0.13	0.00	0.32
		5	885	60	2190	0.79	0.05	1.96
	perpendicular	1.5	197	0	510	0.18	0.00	0.46
		3	263	0	690	0.24	0.00	0.62
		5	448	0	1260	0.40	0.00	1.13