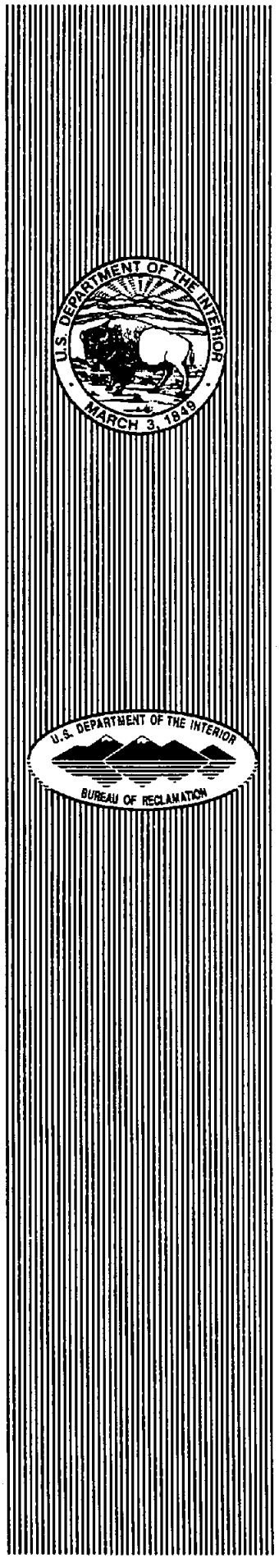

R-97-06

GRAND VALLEY IRRIGATION COMPANY DIVERSION DAM FISH PASSAGE PHYSICAL MODEL STUDY

September 1997

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

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by

Joseph Kubitschek and Brent Mefford

Water Resources Services
Water Resources Research Laboratory
Technical Service Center
Denver, Colorado

September 1997

UNITED STATES DEPARTMENT OF THE INTERIOR ★ **BUREAU OF RECLAMATION**

ABSTRACT

The U.S. Bureau of Reclamation, Water Resources Research Laboratory conducted a physical model study to evaluate and develop a fish passage concept for the Grand Valley Irrigation Company (GVIC) Diversion Dam. The project is located on the Colorado River near Palisade, Colorado. GVIC Diversion Dam has been identified as a barrier to upstream passage of endangered Colorado squawfish and razorback sucker native fish species. A low gradient riffle-pool concept was selected to provide passage for the range of river flow conditions corresponding to 740 ft^3/s to 12,000 ft^3/s. Results of the physical model study indicate that the proposed concept represents a viable means of providing upstream passage. The original concept was modified over the course of this study to optimize hydraulic performance. The final concept exhibited maximum riffle velocities of less than 4.0 ft/s. Design details and recommendations for implementation of this concept have been provided in accordance with the requirements of this project.

ACKNOWLEDGMENTS

The Implementation Program for Recovery of Endangered Colorado Fish Species provided funding for this study through the U.S. Bureau of Reclamation, Western Colorado Area Office (WCAO). FLO Engineering, Inc., under contract to WCAO, provided project information, conceptual design details, and hydraulic information for the Colorado River reach influenced by the Grand Valley Irrigation Company Diversion Dam. Manuel Flores, Warren King, Richard Cuny, and Herb Hanley were responsible for model construction. Rudy Campbell provided technician support. Tracy Vermeyen provided peer review.

Mission Statements

U.S. Department of the Interior

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

Bureau of Reclamation

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

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1 Velocity Data
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PURPOSE

This report documents the results of the physical model investigations associated with the Grand Valley Irrigation Company (GVIC) Diversion Dam fish passage concept. The purpose of the study was to evaluate and further develop the fish passage alternative selected for establishing upstream passage of endangered Colorado squawfish and razorback sucker native fish species at GVIC Diversion Dam.

APPLICATION

The information included in this report is intended for application at GVIC Diversion Dam and addresses site specific conditions. Design details and recommendations are provided for use by GVIC managers, Reclamation managers, and designers in the implementation of upstream fish passage at GVIC Diversion Dam.

INTRODUCTION

GVIC Diversion Dam is located on the Colorado River near Palisade, Colorado. The diversion dam is a concrete capped wood-cribbing structure with a varying crest elevation along the total crest length of approximately 1,400 feet. The structure is oriented such that it gradually traverses the river from the left bank at river mile 400.48 downstream to the GVIC canal headworks at river mile 400.24. Figure 1 is a general plan view layout of the GVIC diversion dam and appurtenances. The diversion dam has been identified as a barrier to upstream passage of endangered native fish species (Colorado squawfish and razorback sucker) for river flow conditions up to 12,000 ft^3/s. Above approximately 12,000 ft^3/s the diversion dam becomes sufficiently submerged and is no longer considered a barrier to passage.

Background

Under the *Recovery and Implementation Program for Endangered Colorado River Fish Species*, efforts have been initiated to establish fish passage at GVIC diversion dam. To date, various alternatives have been identified as a means of achieving this objective. These alternatives have been documented in the *Concept Development Report—Grand Valley Irrigation Company Diversion Dam Fish Passage Structure, Palisade, Colorado* (FLO Engineering, Inc., 1997). Of these alternatives, the concept designated 2A was selected for further development.

The U.S. Bureau of Reclamation (Reclamation), Water Resources Research Laboratory (WRRL) was tasked with conducting a physical model study for the purposes of evaluating and further developing the alternative 2A concept.

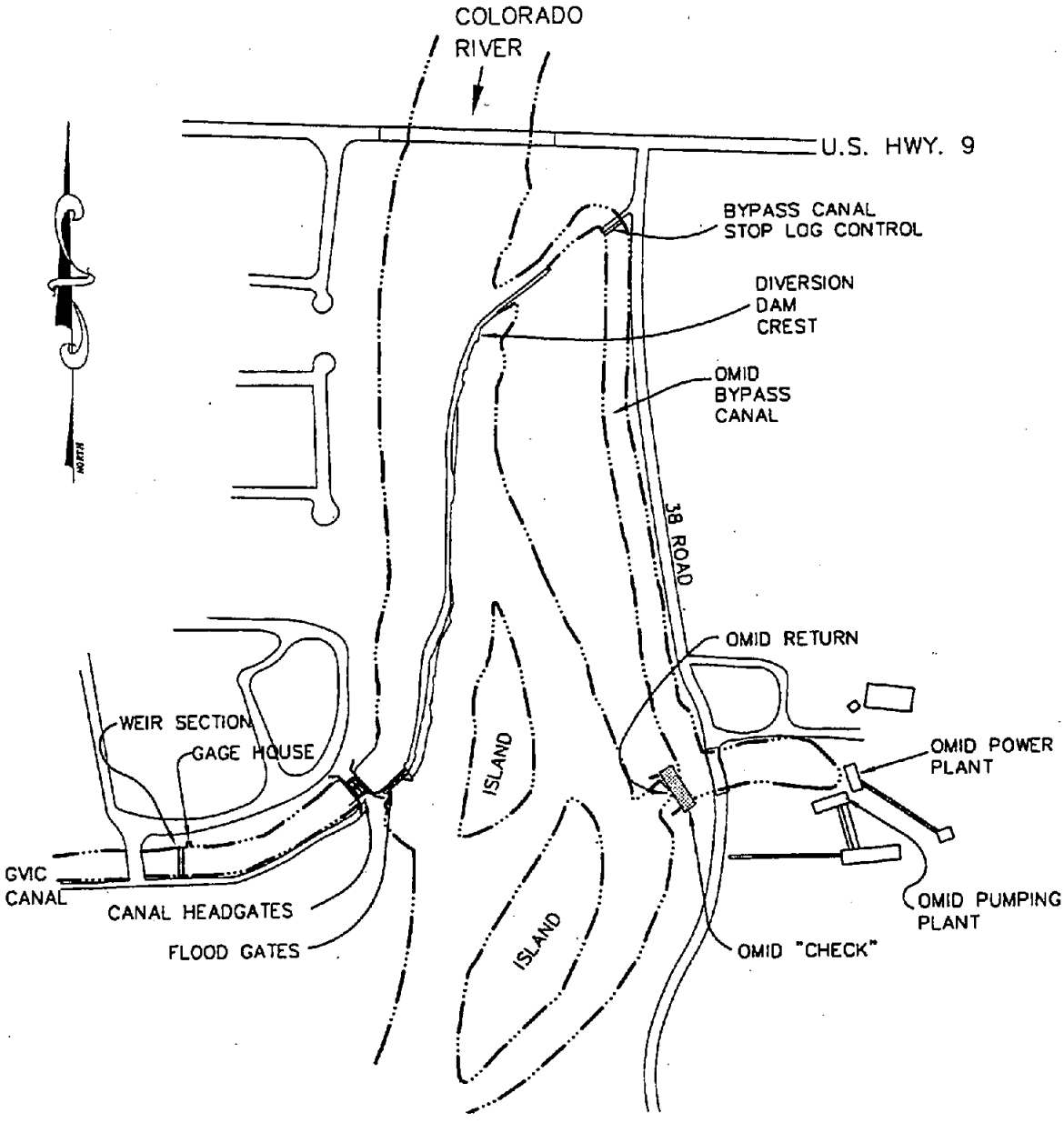

Figure 1.—Plan view layout of GVIC Diversion Dam and appurtenances (FLO Engineering, Inc., 1997).

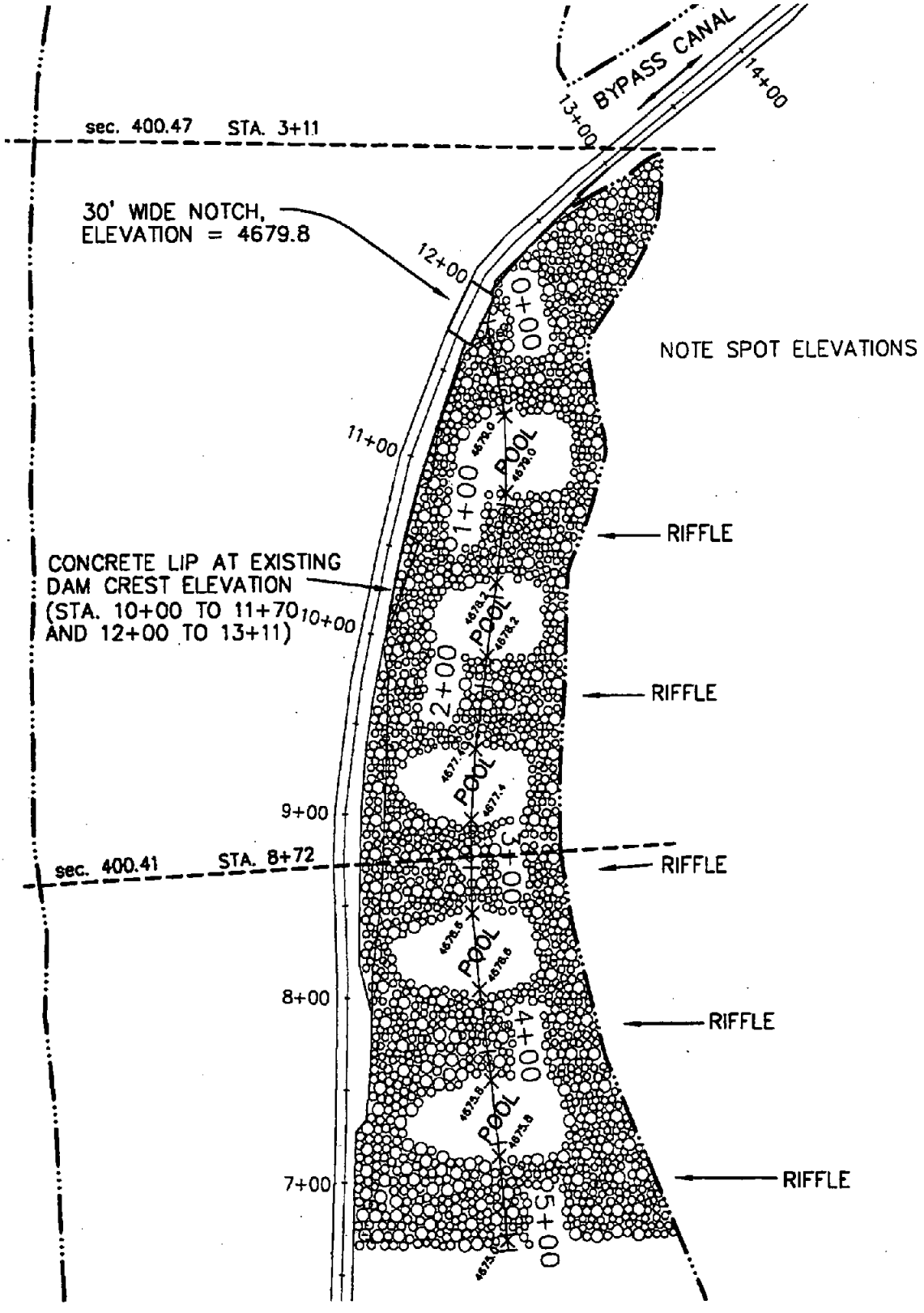

Figure 2.—Plan view schematic of alternative 2A fishpass concept (FLO Engineering, Inc., 1997).

Concept Description

The alternative 2A concept consists of a natural riffle and pool-type structure (fishpass) located immediately downstream from GVIC diversion dam. This concept is intended to provide hydraulic conditions suitable for upstream passage corresponding to river flow conditions between 740 and 12,000 ft^3/s. Figure 2 is a plan view schematic of this concept. The concept consists of five pool sections joined by six riffle sections. Typical riffle and pool section details are given as figures 3 and 4, respectively. The riffle segment lengths are 50 feet while the pool lengths are 40 feet, producing a total fishpass structure length of 500 feet. A 30-feet wide notch in the diversion dam is required to provide a discharge of 100 ft^3/s to the fishpass structure while maintaining the GVIC water right of 640 ft^3/s for minimum Colorado River flow conditions.

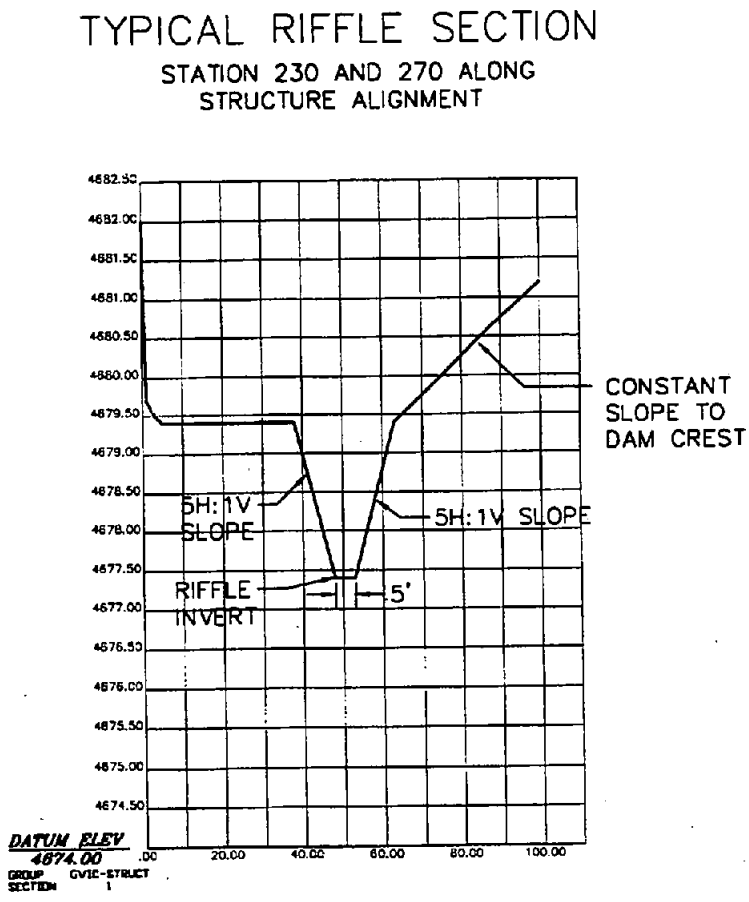

Figure 3.—Riffle section details (FLO Engineering, Inc., 1997).

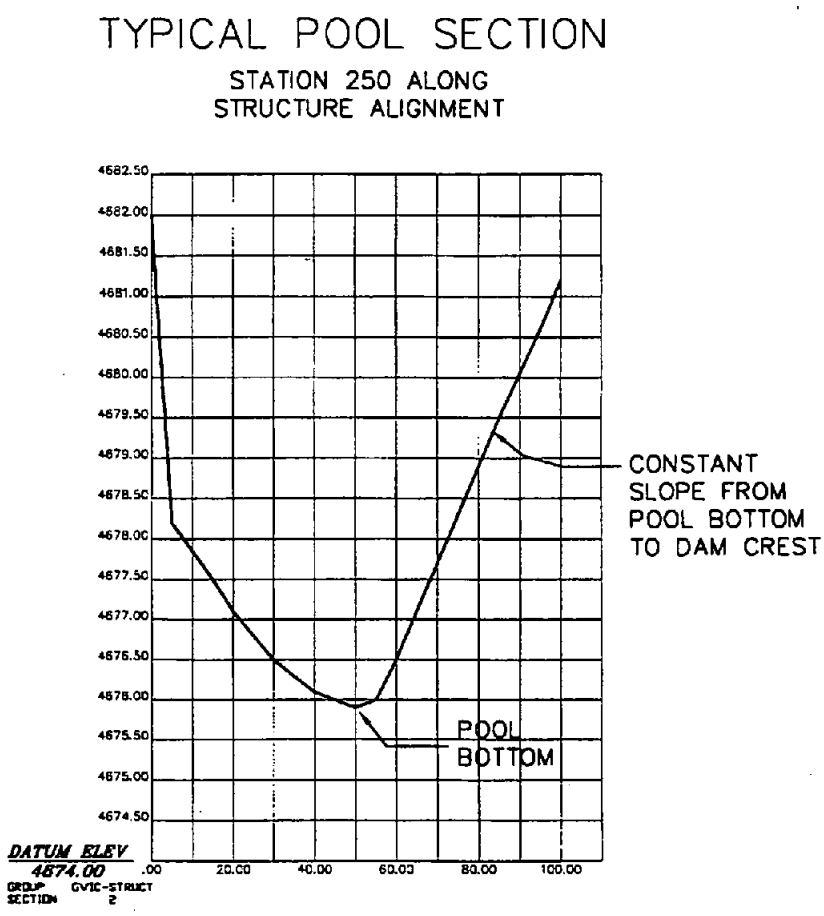

Figure 4.—Pool section details (FLO Engineering, Inc., 1997).

Biological and Hydraulic Considerations

To establish effective fish passage for GVIC Diversion Dam, hydraulic performance of any fishpass concept must be consistent with target species behavior and swimming strength. For the purposes of this study, swimming strength is critical in developing an effective fish passage concept because it provides a basis for hydraulic performance criteria. Swimming performance data are available for both Colorado squawfish and razorback sucker. Such data indicate that squawfish have stronger swimming ability than razorback sucker. Colorado squawfish have been found to exhibit sustained swimming speeds of 3.0 - 3.3 ft/s. In contrast, razorback sucker have exhibited sustained swimming speeds of 0.6 - 1.0 ft/s with burst speeds up to 2.0 ft/s. Based on these data, hydraulic performance of the GVIC fishpass concept must produce velocities less than 1.0 ft/s for effective upstream passage of both target species.

In addition to the fishpass velocity criteria, hydraulic characteristics of GVIC Diversion Dam must also be considered to establish effective upstream passage performance. The upper limit for which adequate passage performance is required corresponds with a Colorado River

discharge of 12,000 ft^3/s. Above this point, GVIC Diversion Dam becomes sufficiently submerged such that velocities passing over the crest become low enough for upstream passage of the target species. Below 12,000 ft^3/s velocities passing over the crest are too high for target species to negotiate. Thus, the objective of this study was to develop and demonstrate a viable fishpass concept which performs effectively for Colorado River flow conditions below 12,000 ft^3/s. In this respect there also exists a lower limit for which upstream fish passage is desired. The lower limit is established solely by the GVIC water right of 640 ft^3/s. Thus, for Colorado River flow conditions less than the combined GVIC water right and minimum fishpass design discharge, upstream passage will not be available. Given the minimum fishpass design discharge of 100 ft^3/s, the lower limit of operation is identified as approximately 740 ft^3/s. Below a Colorado River discharge of 740 ft^3/s, the fishpass must be shutdown to maintain the minimum GVIC diversion water right.

CONCLUSIONS

The following conclusions are based on the results of the physical model study:

- The modified alternative 2A riffle-pool concept demonstrates a viable means of providing suitable hydraulic conditions for efficient upstream fish passage at GVIC Diversion Dam.

- The location of the 30 foot notch in the diversion dam crest between STA 10+80 and STA 11+10 and subsequent location of the fishpass produces adverse hydraulic conditions for river discharges between 740 ft^3/s and 5,000 ft^3/s. Under these conditions, flow over the diversion dam between STA 6+50 and STA 7+50 is imparted to the fishpass and produces high velocity conditions on the order of 5.0 to 6.0-ft/s. Based on this result, the fishpass should be located as far upstream as possible to minimize the influence of flows over the diversion dam.

- Although maximum riffle velocities were found to be on the order of 3.0-4.0 ft/s for the final concept configuration, observations of the physical model indicate the existence of low velocity zones along riffle boundaries which are suitable for meeting fish passage velocity criteria.

- The riffle-pool configuration should be modified such that each riffle section traverses diagonally from pool to pool. This allows for a reduction of riffle gradients while maintaining the overall structure gradient and using the full width of the river channel downstream from the diversion dam. The physical model has shown that this modified riffle-pool configuration produces lower riffle velocities than the original concept.

- The physical model shows that hydraulic performance of this concept is critical for low end Colorado River flow conditions (e.g., 740 ft^3/s). In this case, the greatest water surface gradient exists along the fishpass. Thus, the highest fishpass velocity conditions are encountered.

PHYSICAL MODEL

Scale Considerations

The physical model for the alternative 2A fishpass concept was constructed at Reclamation's Water Resources Research Laboratory (WRRL) in Denver, Colorado. A 1:20 model scale was selected such that the entire width of the Colorado River reach which includes GVIC Diversion Dam and fishpass concept could be investigated. The total reach of the Colorado River included in the model corresponds to the upstream section of the GVIC Diversion Dam from river mile 400.50 downstream to approximately STA 6+25 along the diversion dam crest. Stationing for the diversion dam is designated from the downstream end, or right abutment (STA 00+00), located at the floodgates, to the upstream end, or left abutment (STA 13+00). The original concept design called for the 30-feet wide notch in the diversion dam to be located between STA 11+70 and STA 12+00. However, initial construction of the physical model placed the notch location between STA 10+80 and STA 11+10. This location was selected to make use of an existing low point in the diversion dam crest, thereby minimizing construction costs. Placing the notch approximately 100 feet downstream from the original location required a corresponding downstream shift of the entire fishpass structure. All other details were modeled according to the original concept design. The fishpass structure was constructed using ½-in rock material. Although not geometrically similar to the prototype riprap size expected, this size allows for adequate representation of prototype roughness. Figure 5 is a photograph of the physical model.

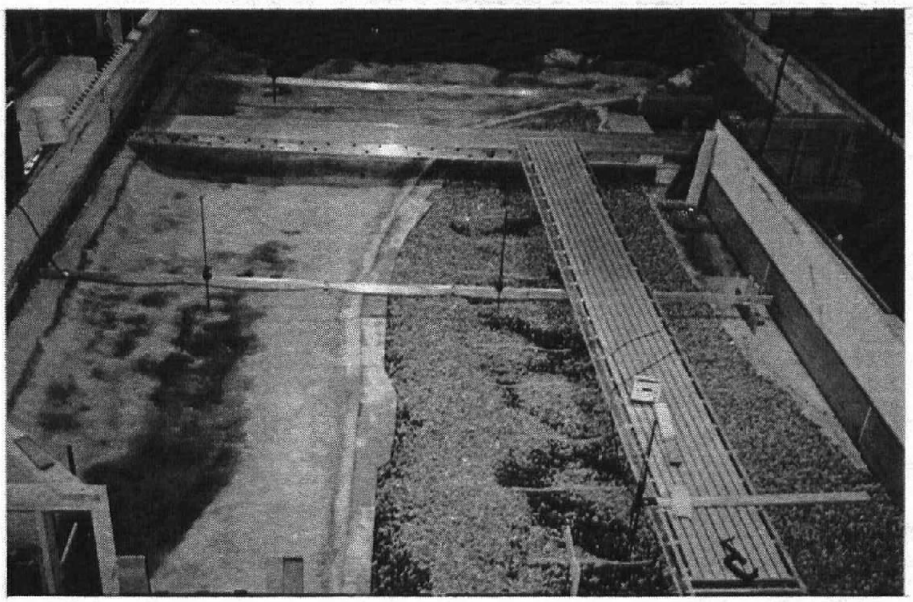

Figure 5.—Photograph of the physical model as constructed at the WRRL in Denver, Colorado.

Similitude

The physical model must be geometrically and kinematically similar to the prototype to predict performance under specified operating conditions (U.S. Bureau of Reclamation, 1986). Geometric similarity is achieved with the ratios of all geometric parameters between model and prototype being equal. Kinematic similarity is achieved with all ratios of model to prototype velocities being equal. For this study, kinematic similarity is achieved by Froude number (Fr) similitude. Froude number similitude was selected for this study because gravitational forces predominate. Thus, for the range of specified hydraulic conditions, the Froude number for both model and prototype are equal. The Froude number is a dimensionless parameter which defines the relationship between gravitational and inertial forces throughout the flow field and is defined as:

$$Fr = \frac{inertia\ force}{gravity\ force} = \frac{v^2}{Lg}$$

where,
v = characteristic velocity, [ft/s].
L = characteristic length, [ft].
g = gravitational acceleration, [ft/s^2].

Based on this approach, the geometric and kinematic scale relationships between model and prototype are determined as follows:

Geometric:
$L_r = L_p/L_m = 20$
$A_r = (L_r)^2 = 400$
$V_r = (L_r)^3 = 8{,}000$

where,
L_r = length ratio.
L_p = prototype characteristic length.
L_m = model characteristic length.
A_r = area ratio.
V_r = volume ratio.

Kinematic:
$t_r = (L_r)^{1/2} = 4.5$
$v_r = (L_r)^{1/2} = 4.5$
$a_r = 1.0$
$Q_r = (L_r)^{5/2} = 1{,}789$

where,
t_r = time ratio.
v_r = velocity ratio.
a_r = acceleration ratio.
Q_r = discharge ratio.

Methods

Velocity measurements and flow visualization techniques were used to evaluate the hydraulic performance of the alternative 2A fishpass concept. Velocity was considered to be the primary hydraulic parameter influencing upstream fish passage performance. Flow visualization techniques were used to further describe the hydraulic characteristics of the concept. Furthermore, flow visualization provided additional insight into interpretation of the results.

Velocities were measured along the fishpass centerline at the following locations:

- The entrance centerline at the crest of the diversion dam.
- The head and tail of each riffle section.
- The midpoint of each pool (i.e., deepest section).

Velocities were also measured at 50-feet STA locations along the diversion dam crest for river discharge conditions corresponding to 5,000 ft^3/s. These data were used in conjunction with flow visualization observations in the interpretation of results and provided additional insight into performance characteristics of the concept. Finally, velocities in all cases were measured at an elevation in the water column corresponding to1.0 foot above the invert.

Testing

Testing consisted of evaluating fishpass hydraulic performance for the original alternative 2A concept and two variations. Three phases of testing (each phase representing each concept variation) were completed. The first phase consisted of evaluating the original alternative 2A concept with the modified notch and fishpass structure locations. Subsequent modifications were made based on the results of phase one testing. Phase two testing consisted of evaluating the first variation of the original alternative 2A concept. Again, modifications were made based on phase two results. The final phase of testing consisted of evaluating the second variation of the original alternative 2A concept.

The first variation of the original alternative 2A concept consisted of modifying the riffle configuration such that each riffle segment traversed diagonally from pool to pool. This modification reduced the gradients for each riffle section while maintaining the overall fishpass structure gradient. The second variation consisted of moving the fishpass structure as far upstream as possible. In this case, the 30-feet notch was located between STA 11+80 and STA 12+10 along the diversion dam crest. The following list summarizes the conceptual details for each variation of the original alternative 2A concept.

Phase 1 Testing: Original Alternative 2A Concept - Straight Design

- Riffle Length = 50 feet
- Pool Length = 40 feet
- Riffle Slope = 1.6 feet per 100 feet = 1.6%
- Thalweg Slope = 1.6 feet per 180 feet = 0.9%
- Channel Slope = 0.9%
- Structure Length = 500 feet
- 30 feet notch centerline location at STA 10+95.

Phase 2 Testing: Variation No. 1 - Angled Riffle Design

- Riffle Length = 62 feet
- Pool Length = 52 feet
- Riffle Slope = 1.6 feet per 123.3 feet = 1.3%
- Thalweg Slope = 1.6 feet per 226 feet = 0.7%
- Channel Slope = 0.9%
- Structure Length = 500 feet
- 30 feet notch centerline location at STA 10+95.

Phase 3 Testing: Variation No. 2 - Angled Riffle with 20 feet Pool Lengths

- Riffle Length = 62 feet
- Pool Length = 20 feet
- Riffle Slope = 1.3%
- Thalweg Slope = 0.7%
- Channel Slope = 1.14%
- Structure Length = 400 feet
- 30 feet notch centerline location at STA 11+90.

Figures 6-8 represent schematics of the above configurations which were evaluated under each phase of testing.

Prior to testing, hydraulic information for the river reach influenced by GVIC Diversion Dam was required to establish operating conditions of the model consistent with the prototype. FLO Engineering, Inc., provided this information in the form of HEC-2 model results which identified stage-discharge relationships at various sections along the river reach in question (FLO Engineering, Inc., 1997). Table 1 identifies selected test conditions corresponding to HEC-2 data which were used for all three phases of testing. Since results of the shakedown testing indicated that fishpass performance does not change significantly above this point, 10,000 ft^3/s was selected as the maximum test condition . In fact, the results of this study indicate that higher Colorado River flow conditions (above 2,000 ft^3/s) produce more favorable fishpass performance. This feature is attributed to the water surface of energy gradient which decreases with increasing river discharge.

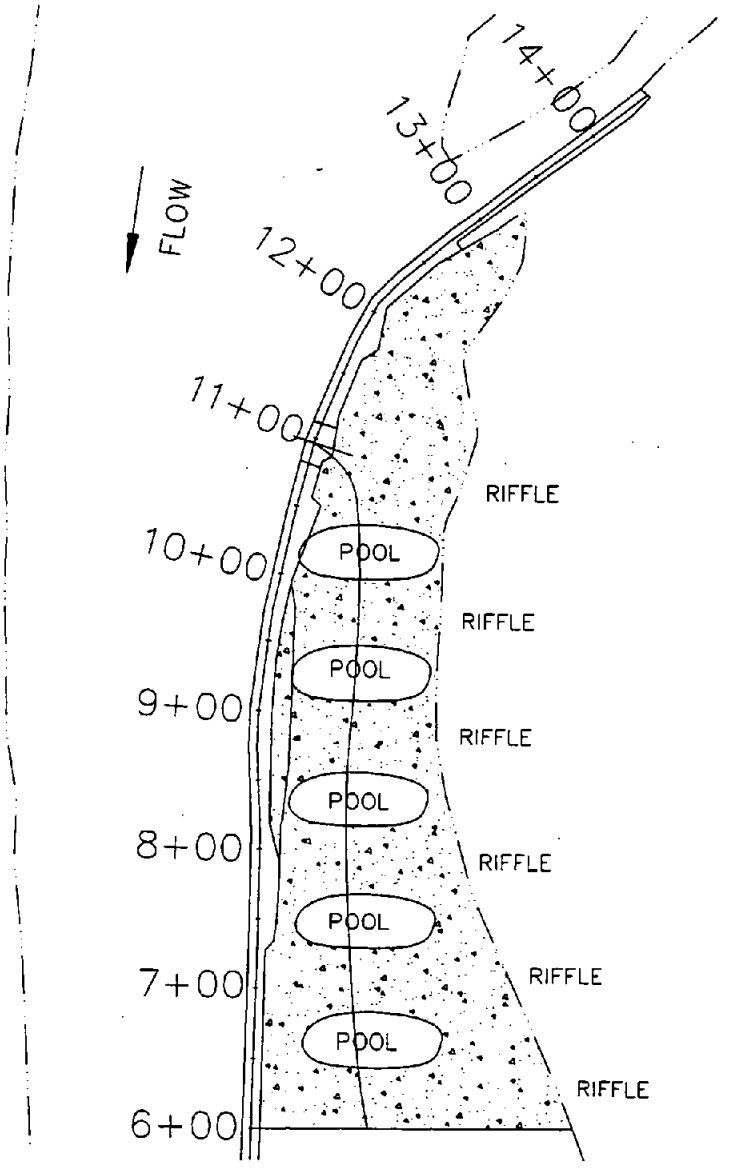

Figure 6.—Original alternative 2A configuration with fishpass located 100 feet downstream from original location.

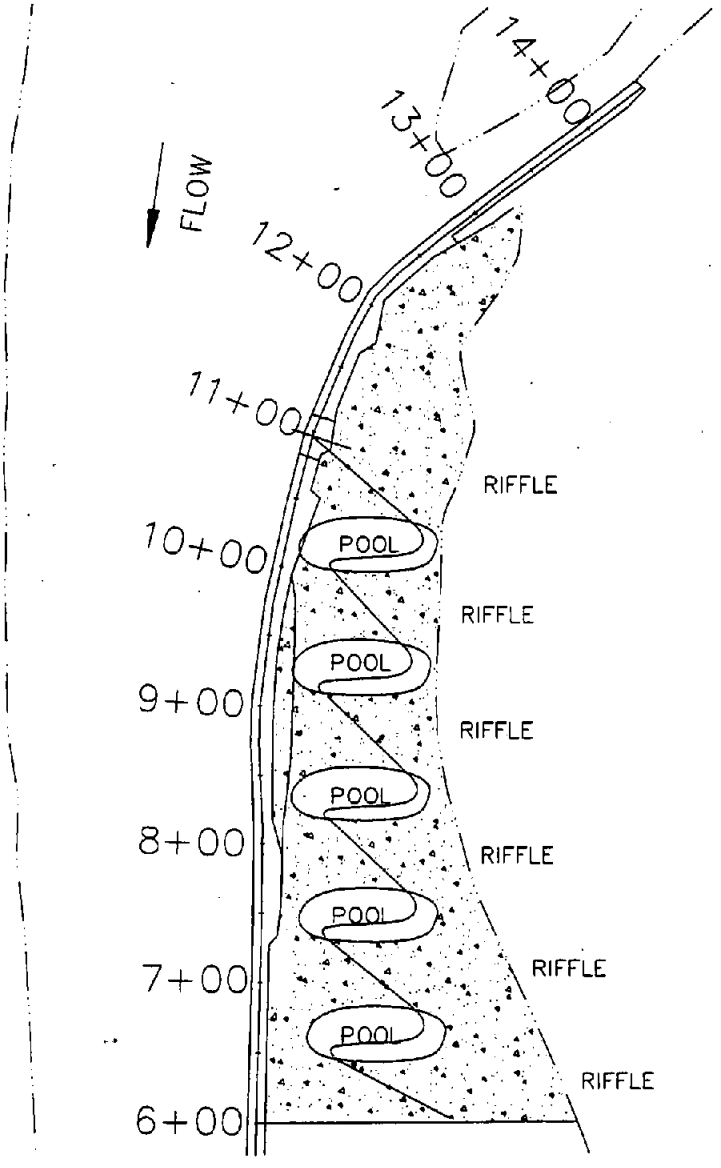

Figure 7.—Modified riffle configuration. Concept variation No. 1 - Phase 2 testing.

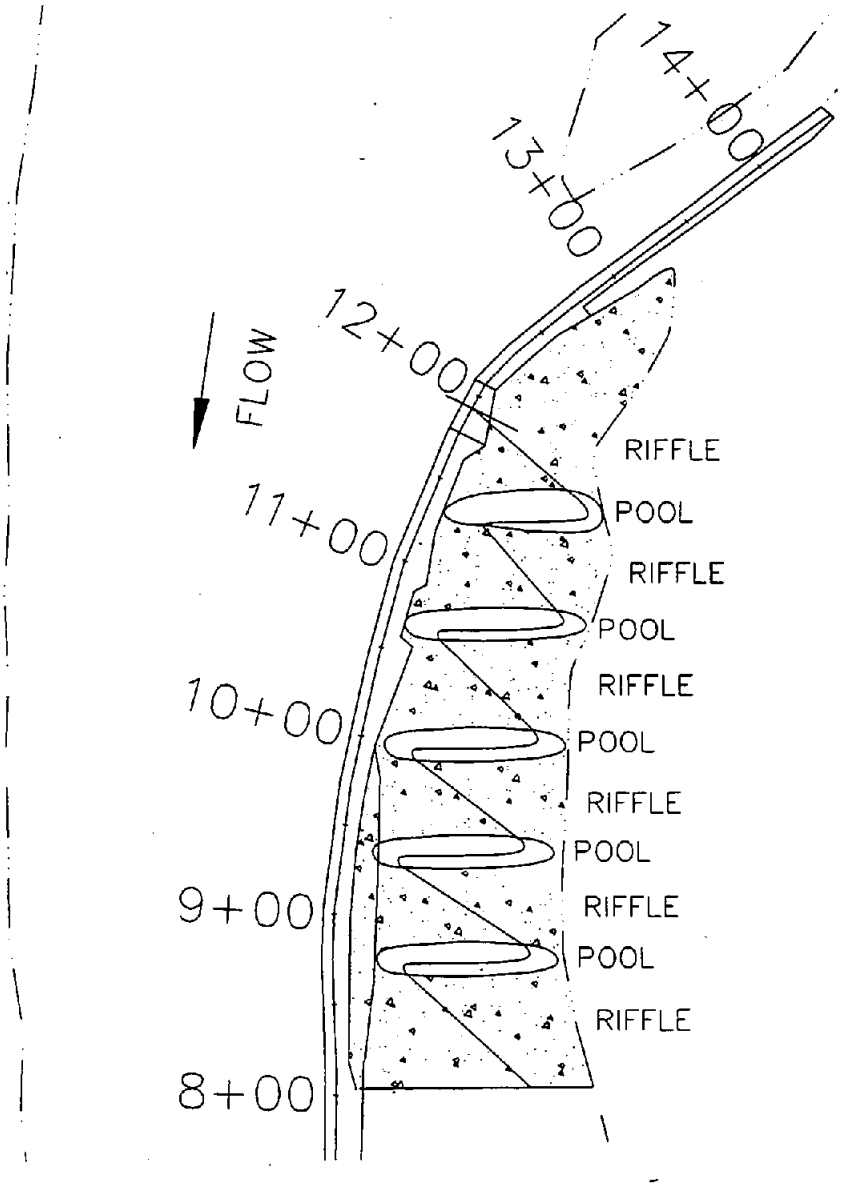

Figure 8.—Modified riffle concept located 100 feet upstream from original location. Pool lengths shortened to 20 feet. Concept variation No. 2 - Phase 3 testing.

Table 1.—Selected physical model test conditions for all three phases of testing

Physical Model Test Conditions					
River Discharge (ft^3/s)	w.s.el. @ river mile 400.47	Upstream w.s.el. @ river mile 400.41	Upstream w.s.el. @ river mile - STA 6+50	Fishpass w.s.el. @ river mile 400.41	Fishpass w.s.el. @ river mile - STA 6+50
740	4681.00	4681.00	4681.00	4677.75	4676.65
2,000	4681.80	4681.80	4681.70	4678.50	4678.40
5,000	4682.75	4682.50	4682.50	4680.70	4680.25
10,000	4684.00	4683.50	4683.00	4682.25	4681.90

Target water surface elevations (w.s.el.) were established upstream from the diversion dam for the respective river discharge conditions. The target w.s.el. for the fishpass at river mile 400.41 was set to correspond to the design flow depth of 2.0 feet. All other target w.s.el. for the remainder of test conditions (i.e., 5,000 to 10,000 ft^3/s) were set at the specified values based on HEC-2 data.

RESULTS

The results of the physical model study demonstrate that, with some modification, the original alternative 2A fishpass concept produces favorable velocity magnitudes for the range of Colorado River flow conditions tested. All results have been presented as velocity verses STA location along the fishpass structure. Tabulated velocity results are included in appendix 1. Photographs of the model and various modifications are included in appendix 2.

Phase 1 Test Results: Original Alternative 2A Concept

Phase 1 testing established hydraulic characteristics of the alternative 2A fishpass configuration located farther downstream from the originally specified location. The objective here was to use an existing low point in the diversion dam crest to minimize construction cost associated with the 30-feet notch. The notch design allows for a flow rate of 100 ft^3/s to be supplied to the fishpass while maintaining the 640 ft^3/s water right of GVIC under Colorado River flow conditions which produce a water surface elevation of 4681.00 upstream from GVIC Diversion Dam. Below this discharge, the fishpass will be considered inoperable due to flow limitations. Figure 6 shows the original alternative 2A concept configuration evaluated during this phase of testing.

Test No. 1.—This test consisted of evaluating the fishpass concept under river discharge conditions corresponding to 5,000 ft^3/s. A rock berm was constructed along the left side of the fishpass to represent the concept design information supplied by FLO Engineering, Inc.

(figure 4). The top of the berm was set at elevation 4682.00. The results indicate that the location of the berm creates adverse velocity conditions at higher river flow rates (i.e., 5,000 to 10,000 ft^3/s).

Figure 9 illustrates the velocity increase from upstream to downstream along the fishpass. Riffle velocities on the order of 4.0 to 5.0 ft/s were obtained along the downstream portion of the fishpass. Based on these results it was reasoned that the berm acts to channel flows over the diversion dam which are imparted to the fishpass. The berm was removed following this test. The left side ladder geometry was then blended with existing river channel topography in an attempt to spread flows along the downstream reach of the fishpass.

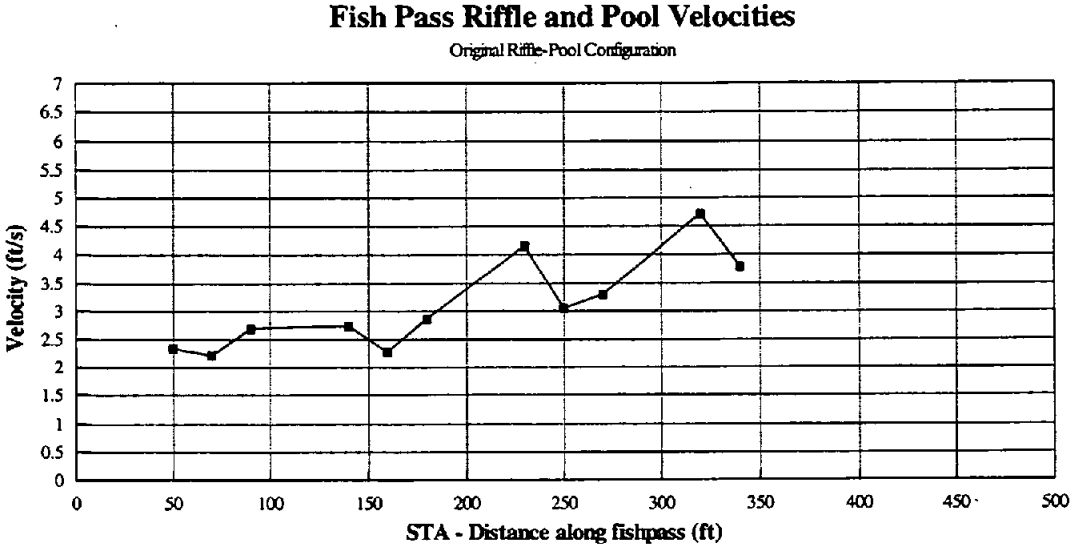

Figure 9.—Phase 1 - Test No. 1 velocity results. Q_{river} = 5,000 ft^3/s. *Original concept riffle configuration. Centerline of 30 feet notch located at STA 10+95 along diversion dam. Berm located along left side of fishpass.*

Test No. 2.—This test consisted of duplicating Test No. 1 without the left side berm configuration. The results indicate that velocities were effectively reduced along the downstream portion of the fishpass (figure 10). However, this appears to be at the expense of increased velocities along the upper portion of the fishpass. In this case, riffle velocities on the order of 4.0 to 4.5 ft/s were obtained along the entire fishpass reach. Although velocities were still somewhat higher than desirable, the remainder of flow conditions were tested to fully document the performance of this configuration.

Test No. 3.—This test consisted of evaluating minimum river flow conditions corresponding to 740 ft^3/s. Velocity data were acquired with no tailboard control at the downstream end of the model, on the downstream side of the diversion dam. Thus, flow depths along the fishpass were lower than the design depth of 2.0 feet. The results indicate high riffle velocities on the order of 5.0 to 6.5 ft/s (figure 11). This was attributed to two factors:

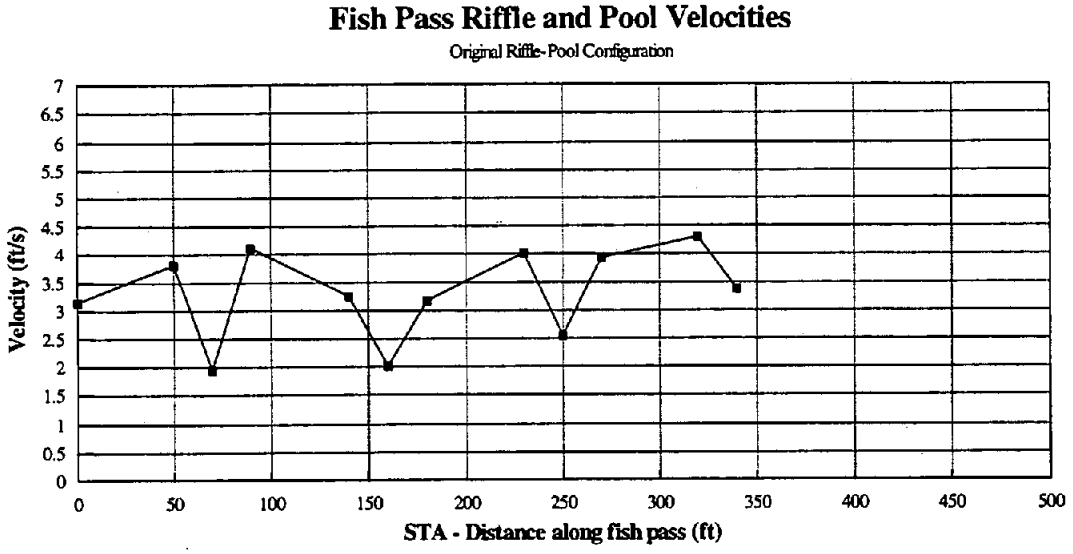

Figure 10.—Phase 1 - Test No. 2 velocity results. Q_{river} = 5,000 ft^3/s. *Original concept riffle configuration. Centerline of 30 feet notch located at STA 10+95 along diversion dam. Berm along left side of fishpass was removed.*

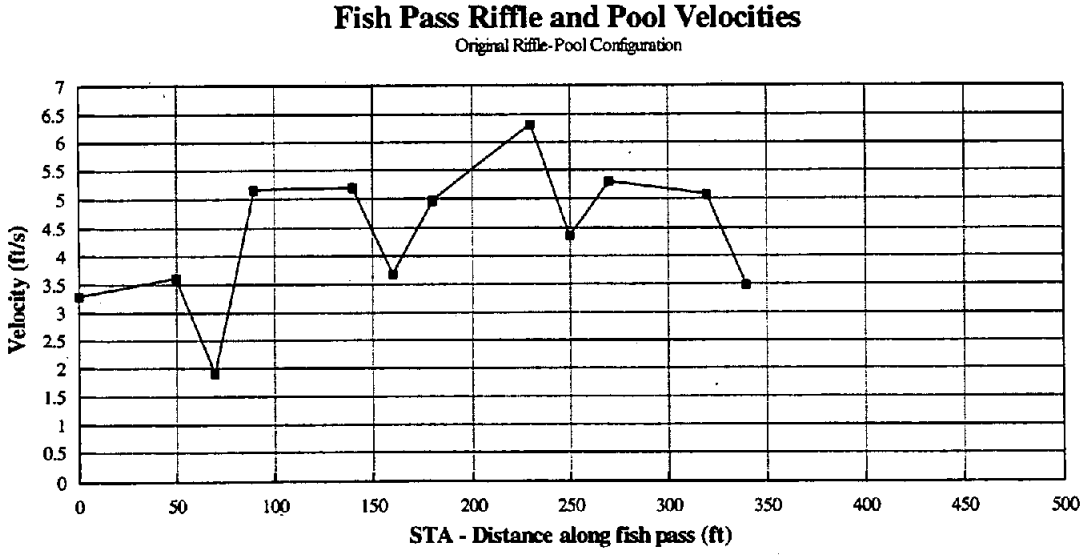

Figure 11.—Phase 1 - Test No. 3 velocity results. Q_{river} = 740 ft^3/s. *Original concept riffle configuration. Centerline of 30 feet notch located at STA 10+95 along diversion dam. No berm along left side of fishpass. Riffle flow depth < 2.0 feet.*

- The riffle gradient being steeper than required to maintain velocity magnitudes below 4.0 ft/s.

- The flow depth in the riffle sections being lower than the design depth of 2.0 feet. Thus, the diversion dam tailwater elevations were set to establish the design flow depth for the next test.

Test No. 4.—This test duplicated Test No. 3 conditions, with a w.s.el. which represented a 2.0-feet riffle flow depth for the STA corresponding to river mile 400.41 along the fishpass. The results of this test indicate some improvement in riffle velocity conditions (figure 12). Riffle velocity magnitudes on the order of 5.0 to 6.0 ft/s were obtained. Thus, a reduction of approximately 0.5 ft/s was realized with the 2.0 feet riffle section flow depth. However, it is apparent from the results of this test that the riffle gradients are too steep to produce the desired riffle velocities for effective upstream passage under minimum river flow conditions.

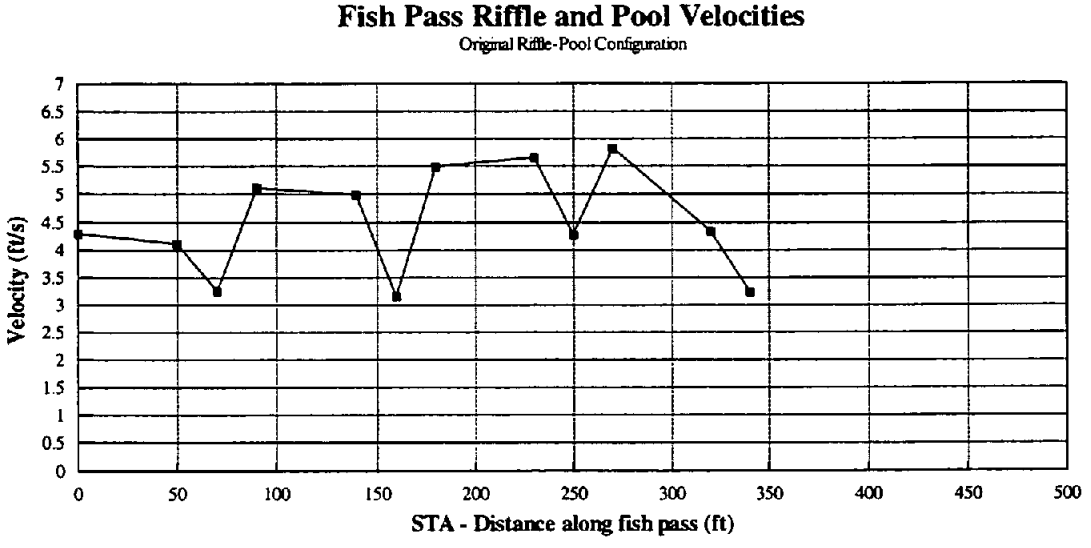

Figure 12.—Phase 1 - Test No. 4 velocity results. Q_{river} = 740 ft^3/s. *Original concept riffle configuration. Centerline of 30 feet notch located at STA 10+95 along diversion dam. No berm along left side of fishpass. Riffle flow depth = 2.0 feet.*

Test No. 5.—This test consisted of evaluating hydraulic performance for conditions corresponding to a river discharge of 10,000 ft^3/s. The results of this test demonstrate that fishpass riffle velocities on the order of 4.5 to 5.5 ft/s are achievable with this configuration (figure 13).

Following this phase of testing, the riffle configuration was modified to reduce riffle segment gradients. Figure 7 shows the modified riffle configuration. This modification consisted of riffle channel orientations which traverse diagonally from pool to pool. Such an arrangement allows for reduction of the riffle gradients by increasing riffle lengths between pools without affecting the overall fishpass gradient.

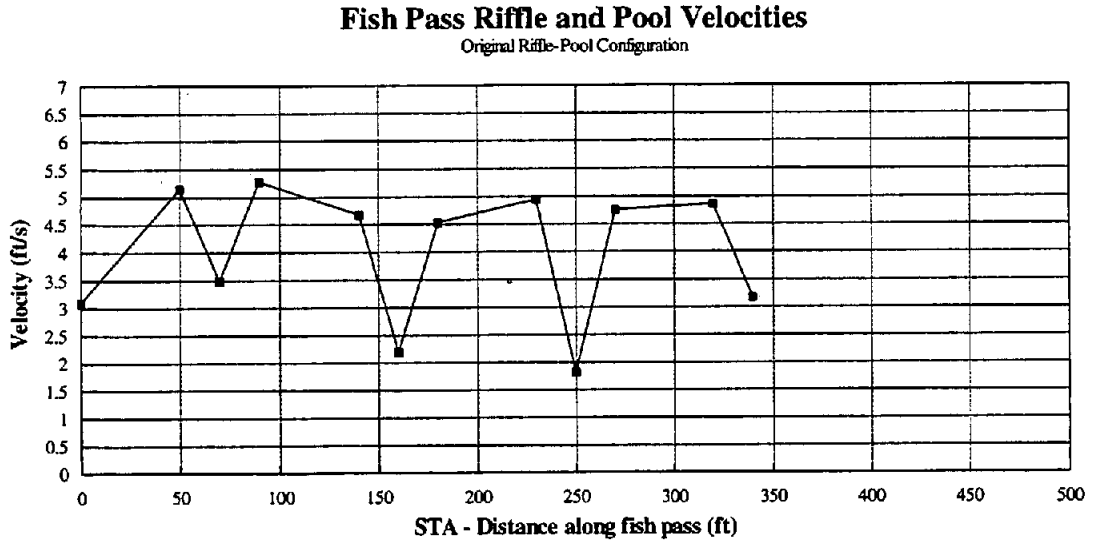

Figure 13.—Phase 1 - Test No. 5 velocity results. Q_{river} = 10,000 ft^3/s. *Original concept riffle configuration. Centerline of 30 feet notch located at STA 10+95 along diversion dam. No berm along left side of fishpass.*

Phase 2 Test Results: Variation No. 1

Phase 1 test conditions were duplicated to determine the effect of the modified riffle configuration over the critical range of river conditions.

Test No. 1 - This test consisted of evaluating the modified riffle configuration for conditions corresponding to a river discharge of 740 ft^3/s. Fishpass target w.s.el.s were set to maintain a riffle flow depth of 2.0 feet. The results indicate that the reduction of riffle gradients reduced riffle velocities along the upstream portion of the fishpass (figure 14). Riffle velocities on the order of 3.5 to 4.0 ft/s were obtained. However, riffle velocities along the downstream portion of the fishpass were still found to be higher than desirable. This was attributed to increased flow imparted to this reach of the fishpass.

Test No. 2 - This test consisted of evaluating the modified riffle concept for conditions corresponding to a river discharge of 5,000 ft^3/s. As previously observed during phase 1 testing, riffle velocities appear to increase from upstream to downstream along the fishpass (figure 15). These increased velocities are attributed to the increased flow over the diversion dam. Such flows accumulate from upstream to downstream and produce increased velocities. Results of Tests No. 1 and 2 provide a strong argument for moving the fishpass as far upstream as possible to minimize additional flows to the fishpass over the diversion dam crest.

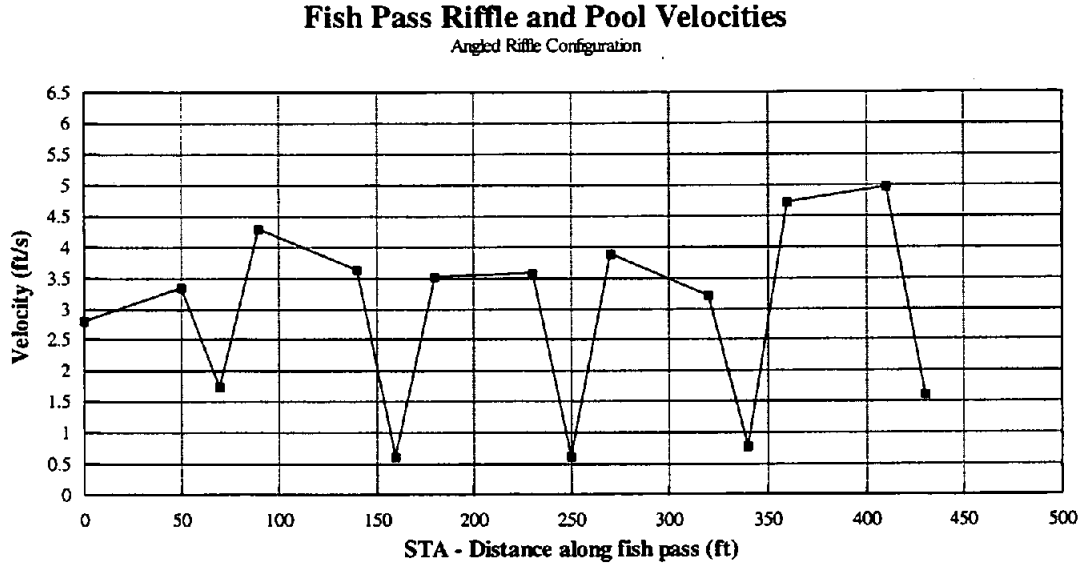

Figure 14.—Phase 2 - Test No. 1 velocity results. Q_{river} = 740 ft^3/s. *Angled riffle configuration. Centerline of 30 feet notch located at STA 10+95.*

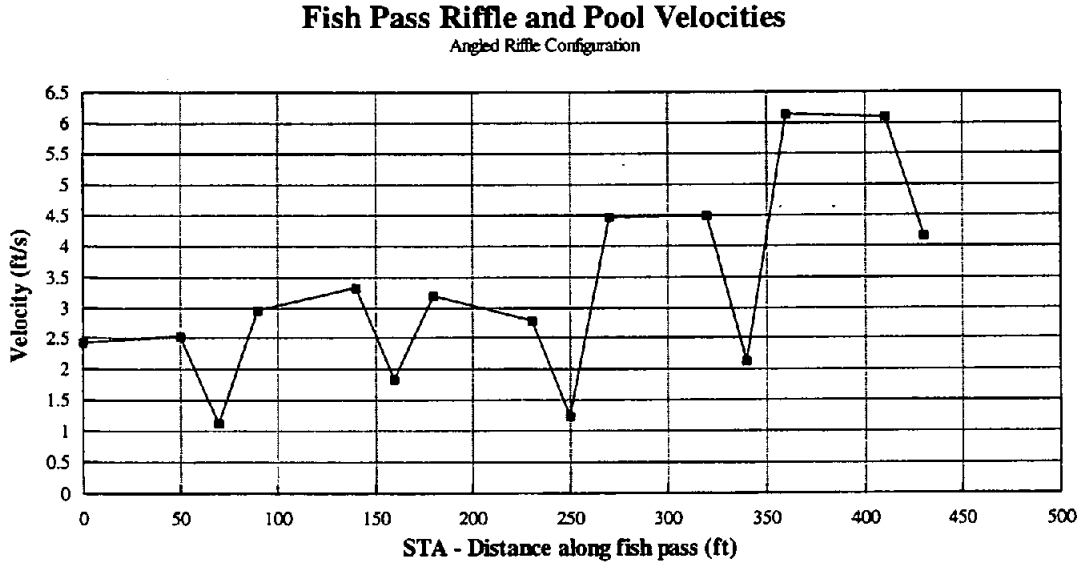

Figure 15.—Phase 2 - Test No. 2 velocity results. Q_{river} = 5,000 ft^3/s. *Angled riffle configuration. Centerline of 30 feet notch located at STA 10+95.*

Test No. 3 - This test consisted of evaluating the modified riffle concept for conditions corresponding with a river discharge of 10,000 ft^3/s. The results indicate favorable velocity conditions along the upstream portion of the fishpass (figure 16). Velocities on the order of 3.5 to 5.0 ft/s were obtained.

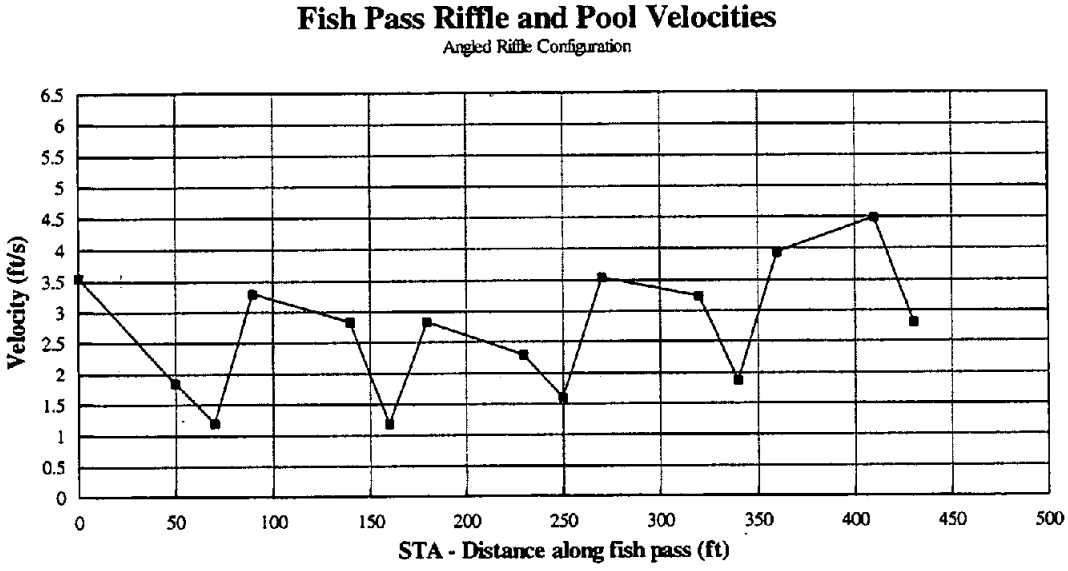

Figure 16.—Phase 2 - Test No. 3 velocity results. Q_{river} = 10,000 ft^3/s. *Angled riffle configuration. Centerline of 30 feet notch located at STA 10+95.*

Following this phase of testing, the fishpass concept was moved upstream in an attempt to minimize the influence of additional flows imparted to the fishpass over the diversion dam crest.

Phase 3 Test Results: Variation No. 2

The fish passage structure location was shifted upstream such that the diversion dam notch was located between STA 11+75 and STA 12+05. This represented an upstream shift of approximately 100 feet from the initial location. Figure 8 illustrates the modified location.

Test No. 1.—This test consisted of evaluating the modified concept for conditions corresponding to a river discharge of 740 ft^3/s. Velocities along the upstream portion of the fishpass were approximately 3.5 to 4.0 ft/s (figure 17). This represents an improvement over phase 2 testing. However, velocities along the last two riffle segments were found to be higher than expected, on the order of 4.5 to 5.0 ft/s. This was attributed to incorrect w.s.el test conditions which were slightly higher than the required set points upstream from the diversion dam. The conditions allowed a small amount of flow over the diversion dam, along the downstream reach of the fishpass, resulting in higher velocities.

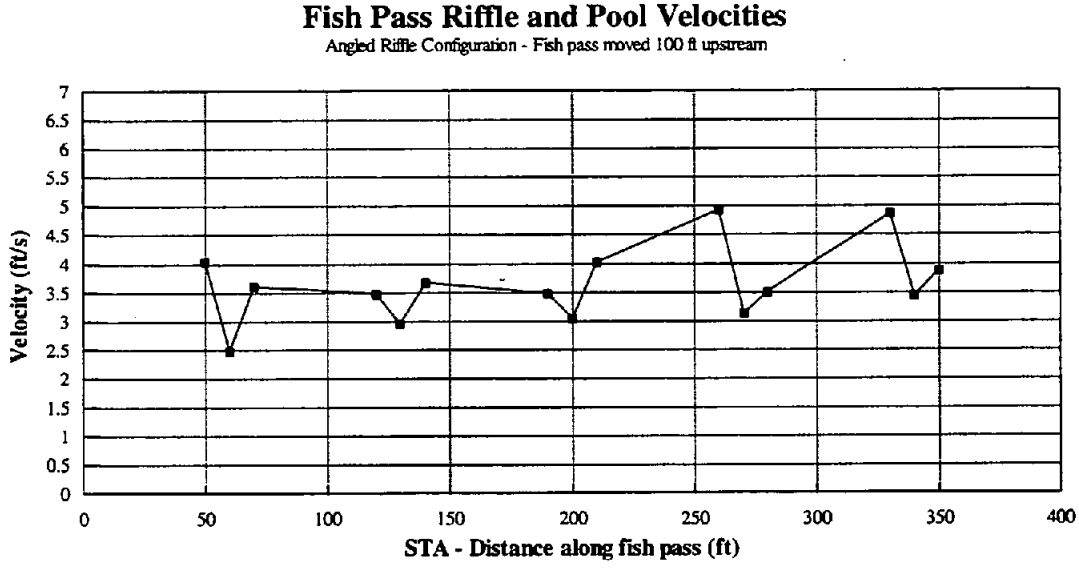

Figure 17.—Phase 3 - Test No. 1 velocity results. Q_{river} = 740 ft^3/s. *Angled riffle configuration. Fishpass structure located 100 feet upstream of original location. Centerline of 30 feet notch located at STA 11+95. Pool lengths reduced to 20 feet.*

Test No. 2.—This test consisted of evaluating the modified riffle concept for conditions corresponding to a river discharge of 2,000 ft^3/s. This test condition was selected to determine hydraulic performance between river flow conditions of 740 and 5,000 ft^3/s and to determine at which point flows over the diversion dam begin to influence fishpass velocities. Favorable hydraulic characteristics were exhibited with measured maximum riffle velocities of 3.5 ft/s (figure 18).

Test No. 3.—This test consisted of evaluating the modified riffle concept for conditions corresponding to a river discharge of 5,000 ft^3/s. Again, favorable hydraulic characteristics were obtained with measured maximum riffle velocities of less than 3.5 ft/s (figure 19).

Test No. 4.—This test consisted of evaluating the modified riffle concept for conditions corresponding to a river discharge of 10,000 ft^3/s. Riffle velocities increased slightly, but were still found to be less than 4.0 ft/s (figure 20).

Results Summary

Given the results of physical model testing, maximum riffle velocities of 3.5 to 4.0 ft/s can be achieved under minimum (worst case) river flow conditions, corresponding to a river discharge of 740 ft^3/s (i.e., 640 ft^3/s diversion and 100 ft^3/s down the fishpass) for the modified riffle configuration (variation no.2). In addition, the variation No. 2 fishpass configuration is capable of handling higher flow conditions up to the point at which the diversion dam is sufficiently submerged and blockage to upstream fish passage no longer exists (i.e., Colorado River discharge of 12,000 ft^3/s). It is important to note that velocities

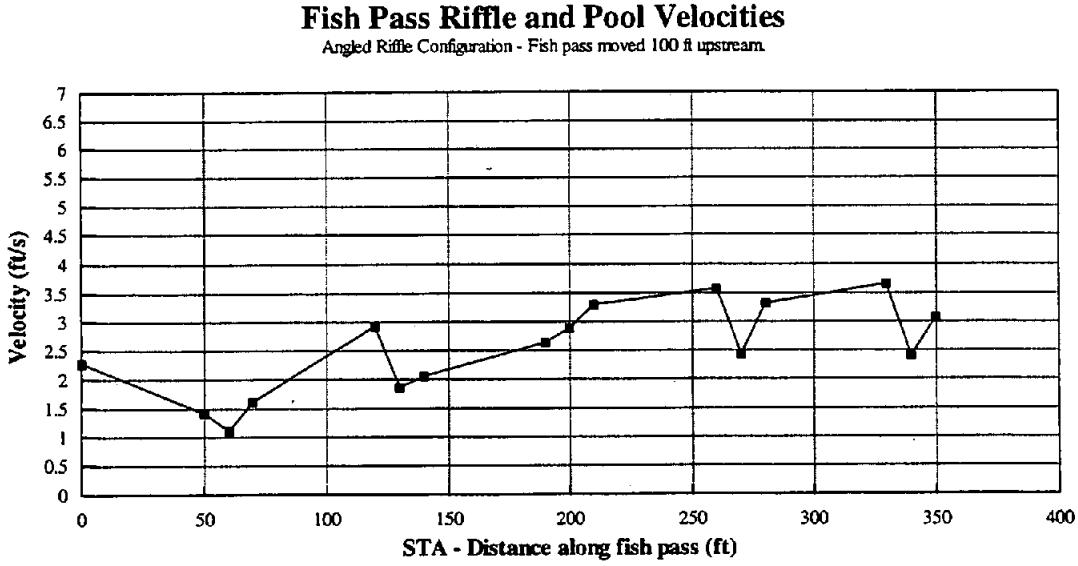

Figure 18.—Phase 3 - Test No. 2 velocity results. Q_{river} = 2,000 ft^3/s. *Angled riffle configuration. Fishpass structure located 100 feet upstream of original location. Centerline of 30 feet notch located at STA 11+95.*

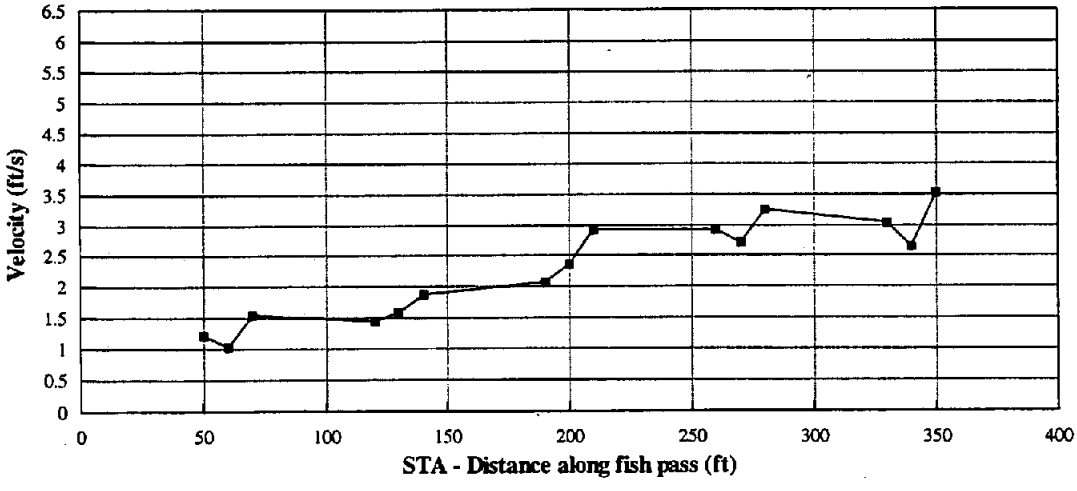

Figure 19.—Phase 3 - Test No. 3 velocity results. Q_{river} = 5,000 ft^3/s. *Angled riffle configuration. Fishpass structure located 100 feet upstream of original location. Centerline of 30 feet notch located at STA 11+95.*

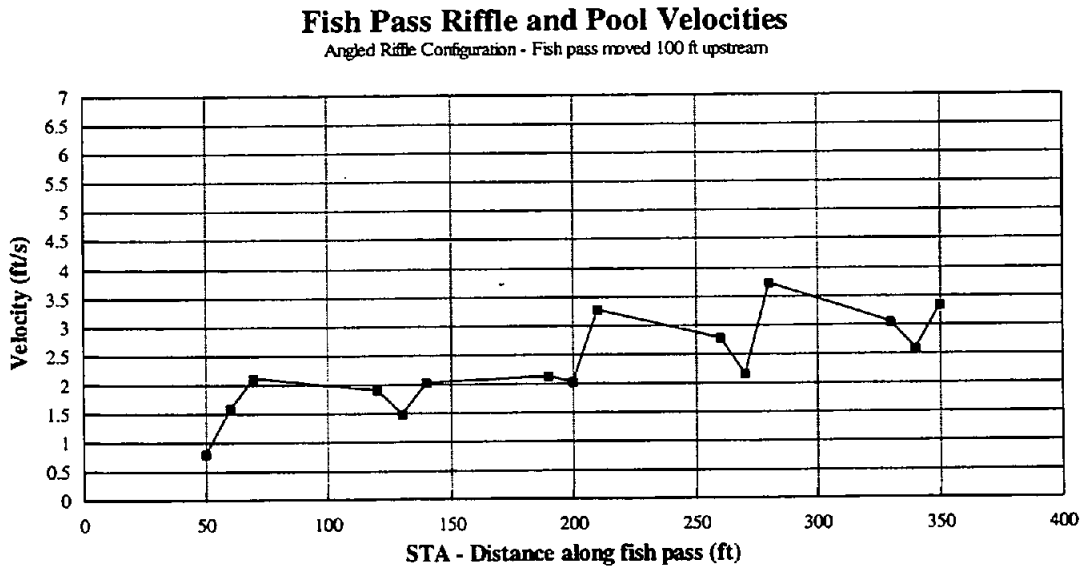

Figure 20.—Phase 3 - Test No. 4 velocity results. Q_{river} = 10,000 ft^3/s. *Angled riffle configuration. Fishpass structure located 100 feet upstream of original location. Centerline of 30 feet notch located at STA 11+95.*

obtained during this study were measured at maximum velocity locations. In fact, velocities are much lower at other locations along the fishpass structure. This is particularly true along the riffle channel boundaries, where eddies and boundary layer phenomena produce lower velocity magnitudes.

RECOMMENDATIONS

The model study results indicate that favorable hydraulic performance can be achieved with the modified alternative 2A fishpass concept (variation no.2). The following modifications to the original alternative 2A concept are recommended.

- The fishpass should be located as far upstream as possible, with the 30-feet notch in the diversion dam crest being located between STA 11+70 and STA 12+00. This is required to minimize the influence of flows over the diversion dam. Flows over the diversion dam adversely affect hydraulic performance.

- The riffle segments connecting each pool should be configured to traverse diagonally from pool to pool, with a maximum riffle gradient of 1.3 percent. This is required to maintain maximum riffle velocities below 3.5 ft/s.

- The riffle flats along the left side of the fishpass should run out with existing left bank topography downstream from GVIC Diversion Dam. This would allow for sufficient spreading of higher flows to minimize fishpass velocities.

BIBLIOGRAPHY

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

FLO Engineering, Inc., *Concept Development Report - Grand Valley Irrigation Company Diversion Dam Fish Passage Structure, Palisade, Colorado,* Prepared for the Bureau of Reclamation, Grand Junction Area Office, Contract No. 1425-6-CA-40-1730A, January 1997.

APPENDIX 1

Velocity Data

Phase 1 Testing - Original concept riffle configuration. Centerline of 30 ft notch at STA 10+95.

Test #1: Data Summary

Note: Berm located along left side of fish pass.

Qriver = 5,000 cfs Protoype

2.79 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.650	4673.35	1.120	4682.75	4682.75	sect. 400.47 u/s of diversion dam
PG#2	1.686	4670.95	2.264	4682.51	4682.50	sect. 400.41 u/s of diversion dam
PG#3	1.440	4671.75	1.978	4682.51	4682.50	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	2.061	4675.75	2.300	4680.53	4680.50	u/s fish pass - sect. 400.41
PG#5	0.330	4673.15	0.685	4680.25	4680.25	d/s fish pass - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
50	0.52	0.16	2.32	0.70
70	0.50	0.18	2.21	0.79
90	0.60	0.16	2.69	0.69
140	0.61	0.15	2.72	0.69
160	0.51	0.15	2.27	0.67
180	0.64	0.15	2.85	0.65
230	0.93	0.15	4.14	0.68
250	0.68	0.15	3.03	0.68
270	0.73	0.15	3.28	0.68
320	1.05	0.16	4.70	0.73
340	0.85	0.15	3.78	0.68

Phase 1 Testing - Original concept riffle configuration. Centerline of 30 ft notch at STA 10+95.

Test #2: Data Summary

Note: No berm located along left side of fish pass.

Qriver = 5,000 cfs Protoype

2.79 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.650	4673.35	1.12	4682.75	4682.76	sect. 400.47 u/s of diversion dam
PG#2	1.686	4670.95	2.264	4682.51	4682.50	sect. 400.41 u/s of diversion dam
PG#3	1.440	4671.75	1.978	4682.51	4682.50	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	2.069	4675.75	2.316	4680.69	4680.50	u/s fish ladder - sect. 400.41
PG#5	0.330	4673.15	0.685	4680.25	4680.25	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
0	0.70	0.16	3.13	0.71
50	0.85	0.15	3.81	0.67
70	0.44	0.16	1.95	0.72
90	0.92	0.15	4.10	0.66
140	0.73	0.16	3.25	0.73
160	0.45	0.16	1.99	0.73
180	0.71	0.15	3.16	0.66
230	0.89	0.15	4.00	0.65
250	0.57	0.15	2.53	0.65
270	0.88	0.16	3.92	0.70
320	0.96	0.15	4.30	0.67
340	0.75	0.15	3.37	0.69

Phase 1 Testing - Original concept riffle configuration. Centerline of 30 ft notch at STA 10+95.

Test #3: Data Summary

Note: No berm along left side of fish pass. Riffle flow depth < 2.0 ft.

Qriver = 740 cfs Protoype

0.41 cfs Model

Point Gage Data:						
	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.650	4673.35	1.033	4681.01	4681.00	sect. 400.47 u/s of diversion dam
PG#2	1.686	4670.95	2.189	4681.01	4681.00	sect. 400.41 u/s of diversion dam
PG#3	1.440	4671.75	1.903	4681.01	4681.00	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	2.069	4675.75	2.074	4675.85	4676.00	u/s fish ladder - sect. 400.41
PG#5	0.330	4673.15	0.473	4676.01	4676.00	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:				
	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
0	0.73	0.14	3.28	0.64
50	0.80	0.15	3.59	0.65
70	0.42	0.16	1.89	0.73
90	1.15	0.15	5.15	0.65
140	1.16	0.15	5.18	0.67
160	0.82	0.17	3.66	0.75
180	1.11	0.15	4.97	0.67
230	1.41	0.16	6.32	0.71
250	0.97	0.16	4.34	0.71
270	1.19	0.15	5.31	0.67
320	1.13	0.16	5.06	0.70
340	0.78	0.16	3.48	0.70

Phase 1 Testing - Original concpet riffle configuration. Centerline of 30 ft notch at STA 10+95.

Test #4 Data Summary

Note: No berm along left side of fish pass. Riflle flow depth set at 2.0 ft.

Qriver = 740 cfs Protoype

0.41 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.650	4673.35	1.033	4681.01	4681.00	sect. 400.47 u/s of diversion dam
PG#2	1.686	4670.95	2.189	4681.01	4681.00	sect. 400.41 u/s of diversion dam
PG#3	1.440	4671.75	1.903	4681.01	4681.00	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	2.061	4675.75	2.161	4677.75	4676.00	u/s fish ladder - sect. 400.41
PG#5	0.330	4673.15	0.505	4676.65	4676.00	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
0	0.96	0.17	4.28	0.76
50	0.92	0.15	4.10	0.66
70	0.73	0.15	3.25	0.66
90	1.14	0.15	5.11	0.65
140	1.12	0.17	5.00	0.76
160	0.70	0.18	3.13	0.80
180	1.23	0.15	5.48	0.66
230	1.26	0.15	5.65	0.68
250	0.95	0.16	4.26	0.70
270	1.30	0.15	5.81	0.68
320	0.96	0.16	4.31	0.71
340	0.72	0.16	3.23	0.71

Phase 1 Testing - Original concept riffle configuration. Centerline of 30 ft notch at STA 10+95.

Test #5: Data Summary

Note: No berm along left side of fish pass.

Qriver = 10,000 cfs Protoype

5.59 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.650	4673.35	1.183	4684.01	4684.00	sect. 400.47 u/s of diversion dam
PG#2	1.686	4670.95	2.314	4683.51	4683.50	sect. 400.41 u/s of diversion dam
PG#3	1.440	4671.75	2.003	4683.01	4683.00	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	2.061	4675.75	2.386	4682.25	4682.50	u/s fish pass - sect. 400.41
PG#5	0.330	4673.15	0.766	4681.87	4682.25	d/s fish pass - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
0	0.69	0.15	3.08	0.69
50	1.15	0.16	5.14	0.70
70	0.78	0.17	3.49	0.75
90	1.18	0.16	5.26	0.70
140	1.04	0.16	4.66	0.73
160	0.49	0.18	2.19	0.82
180	1.01	0.16	4.53	0.74
230	1.10	0.15	4.92	0.67
250	0.41	0.19	1.82	0.87
270	1.06	0.17	4.74	0.78
320	1.08	0.16	4.85	0.71
340	0.71	0.18	3.16	0.81

Phase 2 Testing - Angled riffle configuration. Centerline of 30 ft notch at STA 10+95.

Test #1: Data Summary

Qriver = 740 cfs Protoype
0.41 cfs Model

Point Gage Data:	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.658	4674.36	0.990	4681.00	4681.00	sect. 400.47 u/s of diversion dam
PG#2	1.698	4671.90	2.153	4681.00	4681.00	sect. 400.41 u/s of diversion dam
PG#3	1.439	4672.70	1.854	4681.00	4681.00	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	2.110	4677.50	0.000	4635.30	4676.00	u/s fish ladder - sect. 400.41
PG#5	0.370	4674.40	0.450	4676.00	4676.00	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
0	0.62	0.15	2.79	0.66
50	0.75	0.14	3.34	0.65
70	0.39	0.15	1.73	0.69
90	0.96	0.14	4.29	0.64
140	0.81	0.15	3.62	0.66
160	0.14	0.14	0.62	0.62
180	0.79	0.15	3.51	0.65
230	0.80	0.16	3.57	0.72
250	0.14	0.14	0.62	0.62
270	0.87	0.15	3.87	0.66
320	0.71	0.15	3.20	0.67
340	0.17	0.15	0.77	0.67
360	1.05	0.15	4.71	0.69
410	1.11	0.14	4.97	0.65
430	0.36	0.15	1.60	0.68

Phase 2 Testing - Angled riffle configuration. Centerline of 30 ft notch at STA 10+95.

Test #2: Data Summary

Qriver = 5000 cfs Protoype
2.8 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.658	4674.36	1.077	4682.74	4682.75	sect. 400.47 u/s of diversion dam
PG#2	1.698	4671.90	2.228	4682.50	4682.50	sect. 400.41 u/s of diversion dam
PG#3	1.439	4672.70	1.929	4682.50	4682.50	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	2.110	4677.50	2.295	4681.20	4680.50	u/s fish ladder - sect. 400.41
PG#5	0.370	4674.40	0.662	4680.24	4680.25	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	elocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
0	0.54	0.16	2.44	0.70
50	0.57	0.15	2.53	0.68
70	0.25	0.16	1.12	0.70
90	0.66	0.15	2.94	0.66
140	0.74	0.15	3.31	0.66
160	0.41	0.16	1.82	0.73
180	0.71	0.15	3.18	0.67
230	0.62	0.15	2.78	0.67
250	0.28	0.17	1.24	0.74
270	1.00	0.15	4.45	0.65
320	1.00	0.15	4.48	0.68
340	0.48	0.17	2.13	0.76
360	1.37	0.15	6.14	0.66
410	1.36	0.15	6.10	0.67
430	0.93	0.16	4.15	0.73

Phase 2 Testing - Angled riffle configuration. Centerline of 30 ft notch at STA 10+95.

Test #3: Data Summary

Qriver = 10000 cfs Protoype
5.59 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.658	4674.36	1.14	4684.00	4684.00	sect. 400.47 u/s of diversion dam
PG#2	1.698	4671.9	2.278	4683.50	4683.50	sect. 400.41 u/s of diversion dam
PG#3	1.439	4672.7	1.954	4683.00	4683.00	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	2.11	4677.5	2.339	4682.08	4682.50	u/s fish ladder - sect. 400.41
PG#5	0.37	4674.4	0.762	4682.24	4682.25	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	elocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
0	0.794	0.152	3.550	0.678
50	0.415	0.160	1.854	0.717
70	0.268	0.165	1.199	0.737
90	0.732	0.162	3.274	0.724
140	0.631	0.159	2.821	0.712
160	0.264	0.182	1.181	0.813
180	0.629	0.181	2.812	0.811
230	0.514	0.147	2.300	0.656
250	0.360	0.172	1.608	0.771
270	0.792	0.156	3.540	0.696
320	0.719	0.165	3.214	0.740
340	0.418	0.165	1.870	0.737
360	0.874	0.153	3.909	0.686
410	1.000	0.162	4.471	0.723
430	0.626	0.172	2.798	0.769

Phase 3 Testing - Angled riffle configuration. Centerline of 30 ft notch at STA 11+95.

Test #1: Data Summary

Notes:

* Fish passage structure was shifted upstream approximately 100-ft. The diversion dam notch centerline is located at STA 11+90.
* Fish pass bounded by existing river topography along left side.
* Total fish passage structure length is 400-ft from notch to tail of last riffle.
* Pool lengths were shortened to 20-ft.

Qriver = 740 cfs Protoype
0.42 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.760	4673.35	1.143	4681.01	4681.00	sect. 400.47 u/s of diversion dam
PG#2	1.706	4670.95	2.209	4681.01	4681.00	sect. 400.41 u/s of diversion dam
PG#3	1.437	4671.75	1.899	4680.99	4681.00	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	1.982	4674.11	2.082	4676.11	4675.85	u/s fish ladder - sect. 400.41
PG#5	0.440	4674.71	0.505	4676.01	4676.00	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
50	0.90	0.15	4.03	0.65
60	0.55	0.14	2.48	0.64
70	0.81	0.14	3.60	0.64
120	0.78	0.15	3.48	0.67
130	0.66	0.14	2.94	0.64
140	0.82	0.16	3.66	0.70
190	0.78	0.18	3.47	0.83
200	0.68	0.15	3.04	0.65
210	0.90	0.16	4.01	0.72
260	1.10	0.15	4.92	0.68
270	0.70	0.14	3.12	0.64
280	0.78	0.16	3.49	0.71
330	1.09	0.16	4.86	0.72
340	0.77	0.15	3.43	0.67
350	0.86	0.15	3.87	0.66

Phase 3 Testing - Angled riffle configuration. Centerline of 30 ft notch at STA 11+95.

Test #2: Data Summary

Notes:

* Fish passage structure was shifted upstream approximately 100-ft. The diversion dam notch centerline is located at STA 11+90.
* Fish pass bounded by existing river topography along left side.
* Total fish passage structure length is 400-ft from notch to tail of last riffle.
* Pool lengths were shortened to 20-ft.

Qriver = 2,000 cfs Protoype
1.12 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.760	4673.35	1.183	4681.81	4681.80	sect. 400.47 u/s of diversion dam
PG#2	1.706	4670.95	2.249	4681.81	4681.80	sect. 400.41 u/s of diversion dam
PG#3	1.437	4671.75	1.935	4681.71	4681.70	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	1.982	4674.11	2.280	4680.07	4678.50	u/s fish ladder - sect. 400.41
PG#5	0.440	4674.71	0.622	4678.35	4678.35	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
0	0.51	0.16	2.26	0.74
50	0.32	0.15	1.42	0.69
60	0.24	0.16	1.10	0.72
70	0.36	0.15	1.59	0.69
120	0.65	0.15	2.91	0.66
130	0.41	0.16	1.84	0.70
140	0.45	0.17	2.03	0.74
190	0.58	0.15	2.61	0.67
200	0.64	0.16	2.88	0.72
210	0.74	0.15	3.29	0.68
260	0.79	0.17	3.55	0.76
270	0.54	0.20	2.41	0.92
280	0.74	0.15	3.31	0.68
330	0.81	0.16	3.63	0.70
340	0.54	0.22	2.40	0.96
350	0.68	0.15	3.06	0.69

Phase 3 Testing - Angled riffle configuration. Centerline of 30 ft notch at STA 11+95.

Test #3: Data Summary

Notes:

* Fish passage structure was shifted upstream approximately 100-ft. The diversion dam notch centerline is located at STA 11+90.
* Fish pass bounded by existing river topography along left side.
* Total fish passage structure length is 400-ft from notch to tail of last riffle.
* Pool lengths were shortened to 20-ft.

Qriver = 5,000 cfs Protoype
2.79 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.760	4673.35	1.23	4682.75	4682.75	sect. 400.47 u/s of diversion dam
PG#2	1.706	4670.95	2.284	4682.51	4682.50	sect. 400.41 u/s of diversion dam
PG#3	1.437	4671.75	1.975	4682.51	4682.50	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	1.982	4674.11	2.345	4681.37	4680.50	u/s fish ladder - sect. 400.41
PG#5	0.440	4674.71	0.717	4680.25	4680.25	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
50	0.27	0.15	1.22	0.68
60	0.23	0.16	1.02	0.71
70	0.35	0.17	1.55	0.74
120	0.32	0.15	1.44	0.68
130	0.36	0.16	1.59	0.70
140	0.42	0.16	1.86	0.72
190	0.46	0.15	2.07	0.65
200	0.53	0.18	2.35	0.79
210	0.65	0.16	2.91	0.73
260	0.65	0.15	2.92	0.66
270	0.60	0.21	2.70	0.94
280	0.72	0.16	3.24	0.72
330	0.68	0.15	3.03	0.68
340	0.59	0.15	2.64	0.69
350	0.78	0.15	3.51	0.68

Phase 3 Testing - Angled riffle configuration. Centerline of 30 ft notch at STA 11+95.

Test #4: Data Summary

Notes:

* Fish passage structure was shifted upstream approximately 100-ft. The diversion dam notch centerline is located at STA 11+90.
* Fish pass bounded by existing river topography along left side.
* Total fish passage structure length is 400-ft from notch to tail of last riffle.
* Pool lengths were shortened to 20-ft.

Qriver = 10,000 cfs Protoype
5.59 cfs Model

Point Gage Data:

	Zero	Zero El.	PG reading	w.s.el.	Target El.	
PG#1	0.760	4673.35	1.293	4684.01	4684.00	sect. 400.47 u/s of diversion dam
PG#2	1.706	4670.95	2.334	4683.51	4683.50	sect. 400.41 u/s of diversion dam
PG#3	1.437	4671.75	1.999	4682.99	4683.00	sect. corresponding with STA 6+50 u/s of diversion dam
PG#4	1.982	4674.11	2.402	4682.51	4682.50	u/s fish ladder - sect. 400.41
PG#5	0.440	4674.71	0.817	4682.25	4682.25	d/s fish ladder - sect. corresponding with STA 6+50

Fish Pass Riffle and Pool Velocities:

	Model:		Prototype:	
STA	Velocity (ft/s)	Uncertainty	Velocity (ft/s)	Uncertainty
50	0.17	0.15	0.78	0.66
60	0.35	0.19	1.58	0.83
70	0.47	0.17	2.09	0.75
120	0.42	0.15	1.88	0.69
130	0.33	0.19	1.48	0.86
140	0.45	0.17	2.02	0.75
190	0.47	0.15	2.11	0.67
200	0.45	0.17	2.01	0.74
210	0.73	0.18	3.26	0.79
260	0.62	0.15	2.77	0.69
270	0.48	0.17	2.14	0.78
280	0.83	0.16	3.71	0.72
330	0.68	0.15	3.04	0.69
340	0.57	0.23	2.57	1.03
350	0.74	0.19	3.32	0.83

APPENDIX 2

Model Photographs

Figure 1.—Photograph of 1:20 scale physical model final concept.

Figure 2.—Photograph of Nixon-meter. Instrument used for acquiring fishpass velocity data during the physical model study.

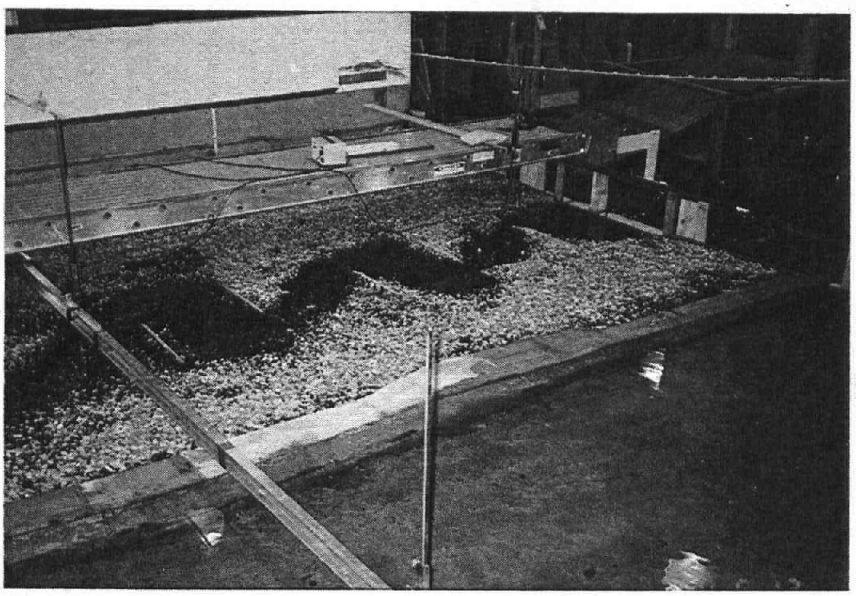

Figure 3.—Photograph of physical model. Test conditions corresponding with a Colorado River discharge of 740 ft^3/s.

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13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation, Water Resources Research Laboratory conducted a physical model study to evaluate and develop a fish passage concept for the Grand Valley Irrigation Company (GVIC) Diversion Dam. The project is located on the Colorado River near Palisade, Colorado. GVIC Diversion Dam has been identified as a barrier to upstream passage of endangered Colorado squawfish and razorback sucker native fish species. A low gradient riffle-pool concept was selected to provide passage for the range of river flow conditions corresponding to 740 ft^3/s to 12,000 ft^3/s. Results of the physical model study indicate that the proposed concept represents a viable means of providing upstream passage. The original concept was modified over the course of this study to optimize hydraulic performance. The final concept exhibited maximum riffle velocities of less than 4.0 ft/s. Design details and recommendations for implementation of this concept have been provided in accordance with the requirements of this project.

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