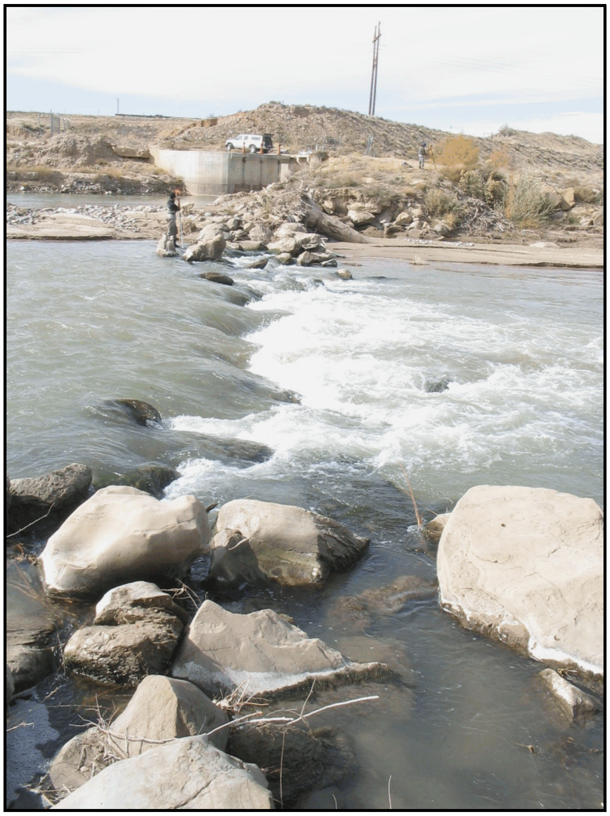
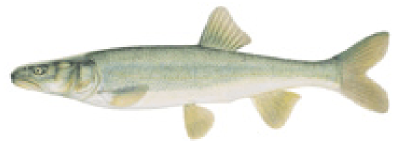
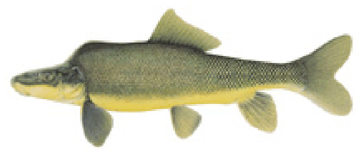
**FINAL REPORT**

# Evaluation of the Need for Fish Passage at the Arizona Public Service and Fruitland Irrigation Diversion Structures







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# 1. INTRODUCTION

## Purpose and Need

Efforts by the San Juan Basin Recovery Implementation Program (SJRIP) to recover the endangered Colorado pikeminnow (*Ptychocheilus lucius*) and the razorback sucker *(Xyrauchen texanus)* include habitat management, habitat development (e.g., fish ladders), nonnative species control, and native species augmentation (e.g., stocking of hatchery-reared Colorado pikeminnow and razorback sucker). In-stream diversion structures that affect upstream and downstream fish passage have the potential to inhibit the success of these recovery efforts. Understanding the effects that structures such as the Arizona Public Service Company (APS) and Fruitland diversions have on fish passage is essential to recovery efforts.

The Fruitland Diversion is located at River Mile (RM) 178.5 on the San Juan River, between the confluence of the Animas and the confluence of the La Plata River with the San Juan River near Farmington, New Mexico (Figure 1.1). The APS diversion - also known as the Four Corners Power Plant Diversion – is located at RM 163.3 (Figure 1.1). Both of these diversions are located within the designated critical habitat for Colorado pikeminnow and razorback sucker (USFWS 1994). Fish passage has already been provided at the two other diversion structures –Hogback Diversion and PNM Weir –located within the critical habitat. There is concern that the APS and Fruitland diversion structures may be affecting access to high quality spawning and rearing habitat upstream.

The extent to which the APS and Fruitland diversions are impediments to fish movement is currently unknown. Previous and ongoing SJRIP mark and recapture studies have demonstrated upstream movement of Colorado pikeminnow and razorback sucker past the Hogback and APS diversion structures, and upstream movement of flannelmouth (*Catostomus latipinnis*) and bluehead sucker *(C. discobolus*) past the Fruitland diversion (D. Ryden 2005, pers. comm.). However, the specific flows and operational conditions during which passage has been successful have not been documented. Although neither structure is a complete barrier to all fish at all times, the diversions may hinder passage for certain species/life stages under particular flow conditions.

## Goals and Objectives

The overall goal of the proposed study is to provide an accurate assessment of the need for fish passage at the APS and Fruitland diversion structures. This assessment will help the SJRIP determine whether to focus any future efforts and resources on providing fish passage at the APS and Fruitland diversion structures, and will ultimately assist in recovering the populations of Colorado pikeminnow and razorback sucker in the San Juan River.

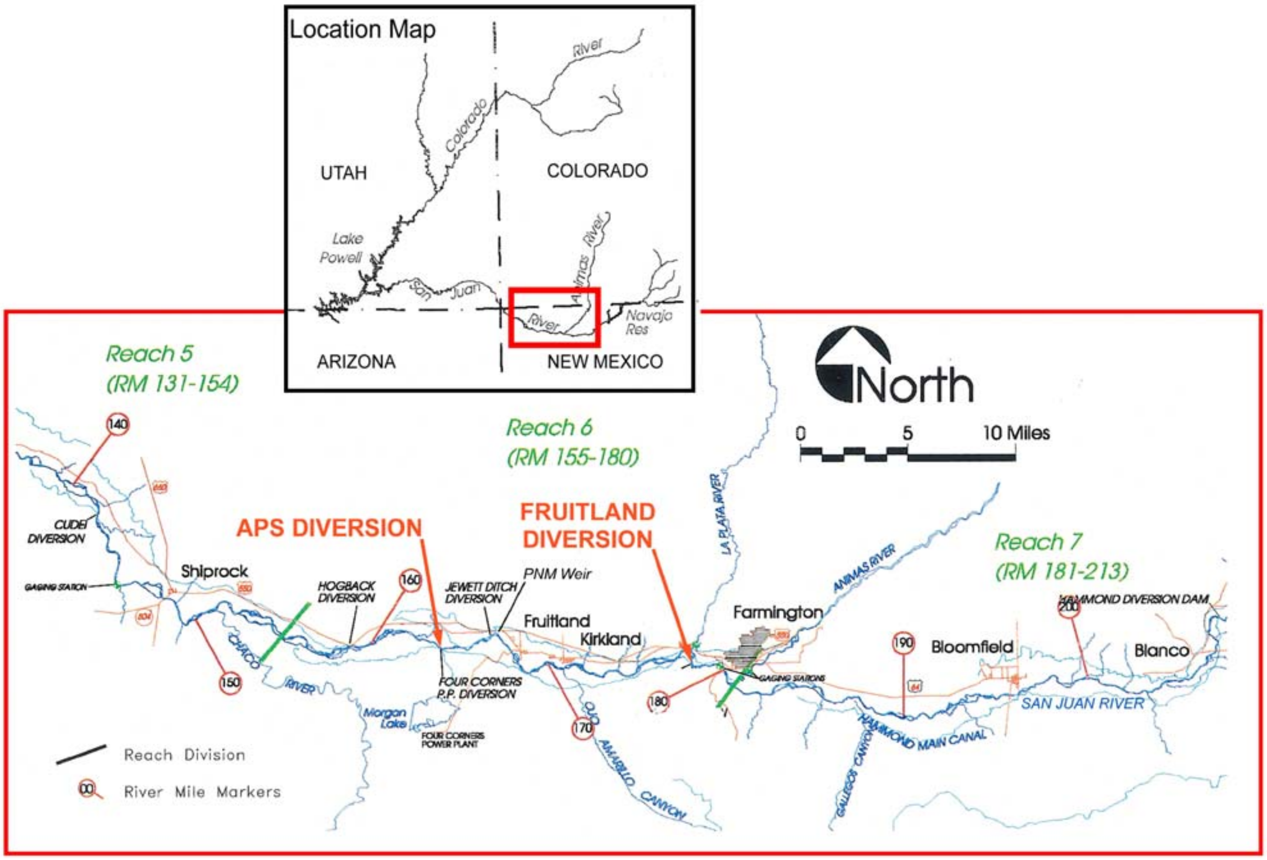


**Figure 1.1. Location map.**

In pursuit of this goal, three main objectives were established for this study:

1. Quantify the physical and hydraulic characteristics of the diversion structures and upstream and downstream channel segments.

2. Determine if and when the structures hinder or eliminate fish passage.

3. Assess the effect of diversion maintenance procedures on fish passage at the Fruitland structure.

# 2. METHODS

## Hydrodynamic Model Development

### Detailed Topographic Surveys

At each of the diversion sites, channel and floodplain topographic data were surveyed in the field using total station equipment (Figures 2.1 and 2.2). The diversion structures themselves were also surveyed to the extent feasible given safety constraints. Approximately 1,000 topographic data points were surveyed at each site. At the APS diversion, the topographic survey extended about 240 feet upstream from the weir and about 300 feet downstream from the weir. At the Fruitland diversion, the topographic survey extended about 370 feet upstream and about 400 feet downstream from the diversion structure. Survey data were reviewed for completeness (missing data, holes in the topography, etc.) during data collection to ensure that data density was adequate for accurate terrain model development. Field surveys were completed between November 3, 2004 -November 6, 2004. Flows at the U.S. Geological Survey (USGS) gage in Farmington (Gage #09365000 ) were between 783 and 804 cubic feet per second (cfs) during that time period (USGS 2004).

At the APS diversion, high water velocities prevented field surveys in the sluiceway and gate area for safety reasons. Therefore, original construction details obtained from the APS Company were used to determine the topography (elevations and dimensions) in that area and supplement the field-surveyed topographic data set. Similarly, at the Fruitland diversion, five data points from a 1996 survey of the sluiceway gate area were added to the data set. At both sites, the additional data points were added in the office using ArcView 3D Analyst and OrthoMax 3D visualization software. Where needed, additional terrain points and breaklines were added interactively to insure that the terrain interpolation algorithm (triangular irregular network [TIN] with break lines) accurately represented the site topography and produced appropriate hydrodynamic modeling results. These same techniques were used to "virtually adjust" the sluiceway gate heights to represent different operating conditions at each structure.

### Substrate and Riparian Mapping

For each site, substrate and vegetation information was gathered in order to provide hydraulic roughness information for modeling purposes. Specifically, substrate and riparian vegetation classifications throughout the study sites were hand-delineated in the field on prints of topographic survey maps. Substrate was delineated into visibly homogeneous substrate types based on dominant and subdominant particle sizes. Classification was based on a modified Wentworth scale (Table 2.1). Where water depth and turbidity were too great to determine substrate size visually, substrate was classified based on the "feel" of the material underfoot. Riparian vegetation was delineated into the categories based on species type (grass/herbaceous, tamarisk, Russian Olive, etc.) and approximate vegetation height. Substrate and riparian maps were digitized into a GIS layer using ArcView software.

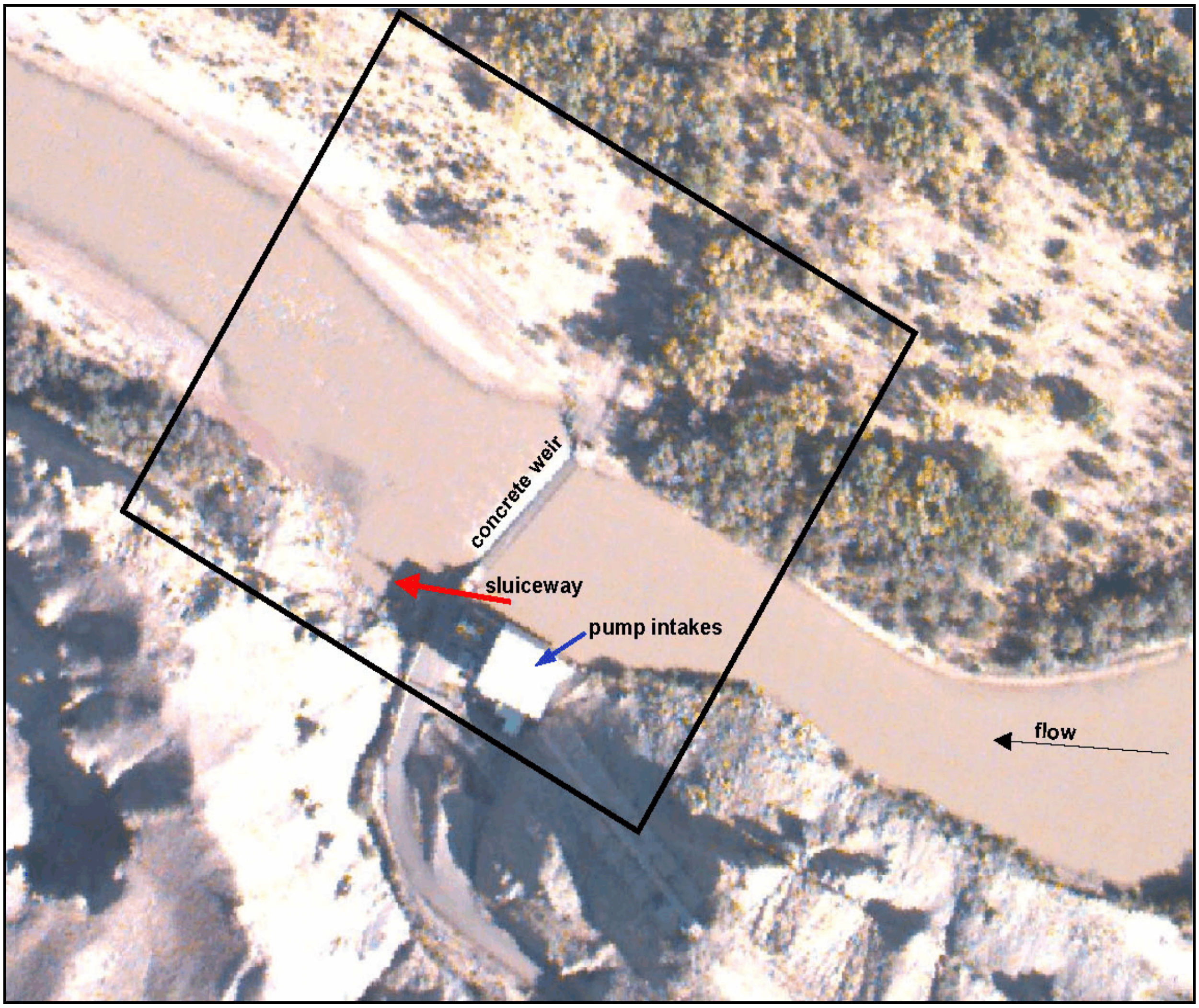


**Figure 2.1. Overview of the APS Weir Diversion structure. Black outline indicates approximate extent of topographic survey area.**

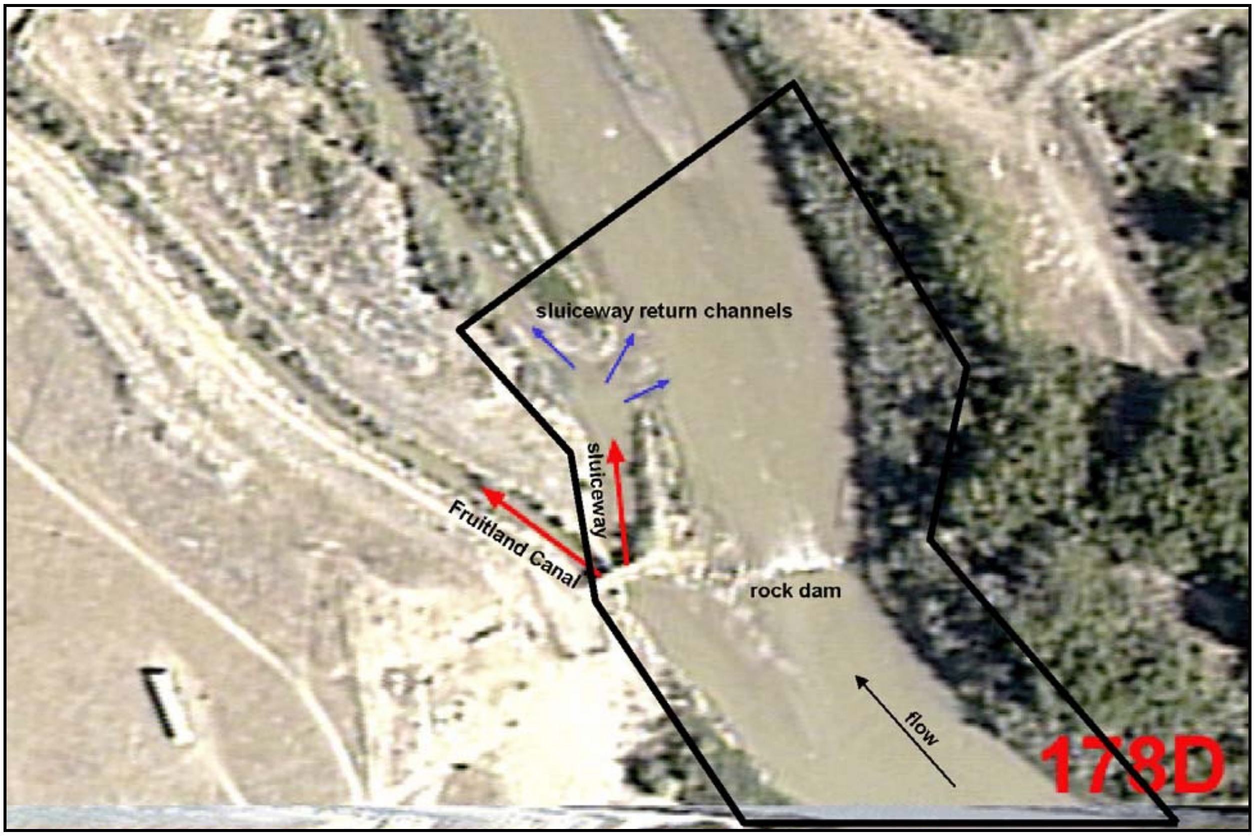


**Figure 2.2** **Overview of the Fruitland Diversion structure. Black outline indicates approximate extent of topographic survey area.**

**Table 2.1.** **Size classes used for substrate mapping. Size classes based on a modified Wentworth scale.**

| Size Class (mm) | Description |
| --- | --- |
| < 2 | sand/silt |
| 2-64 | gravel |
| 64-256 | cobble |
| > 256 | boulder |

## Water Surface Profile and Discharge Measurements

Field surveys of water surface profiles were completed in conjunction with the topographic surveys. At each site, profiles were surveyed along both the left edge of water (river left shoreline) and the right edge of water (river right shoreline) starting at the upstream boundary of the study site, proceeding through the diversion structure, and ending at the downstream boundary of the study site. A sufficient number of water surface elevation data points were collected to ensure that all significant breaks in slope (e.g., any abrupt drops in water surface elevation at the diversion structures) were well defined, and that average water surface slope conditions above and below the structures were also well defined. These water surface profile data were used to establish initial boundary conditions for the 2-D model and to calibrate roughness estimates.

Field measurements of discharge were also made at each site to determine the distribution of flow through the different components of the diversion structures. Measurements were made with a Marsh-McBirney flow meter and top-set rod using standard techniques. At the APS diversion, the flow passing over the concrete weir was measured and subtracted from the gaged flow at the Farmington USGS gage to determine the discharge passing through the sluiceway. At the Fruitland diversion, flow was measured in each of the three sluiceway return channels below the diversion. These measurements were used in conjunction with the gaged flow at Farmington to determine the discharge passing through the rock diversion and through the sluiceway gates (see Figure 2.2). For the APS Weir, the amount of flow being diverted through the pumps at the time of our field surveys was obtained from the APS Company and was subtracted from the Farmington gage value to further define the flow through the sluiceway. Adjustments were also made for the inflow from the La Plata River and for the flow diversion via the APS pumps. No flow was being diverted at the Fruitland structure at the time of our field surveys.

In order to improve model verification and calibration, a second set of field-surveyed water surface elevation data were collected in June 2005 during high-flow conditions. At the APS Diversion, a water surface profile was surveyed along the right edge of water (river right shoreline) between the upstream and downstream boundaries of the site. Data were collected between 10:00 AM and 1:00 PM on June 17, 2005, when the average river flow was 7,000 cfs. Because the APS Diversion is located about halfway between the Farmington and Shiprock USGS gages, the 7,000 cfs value was determined by averaging the recorded 15-minute gage values for the time period of the survey, factoring in the lag time between the two gages. Because the river was not wadeable at this flow, no field measurements of the discharge split between the weir and sluiceway were made at the APS Diversion during the June survey. The sluiceway gate was in the “full open” position at the time of the survey.

At the Fruitland Diversion, a water surface profile was surveyed along the left edge of water (river left shoreline) between the upstream and downstream boundaries of the study site. Data were collected between 4:30 PM and 6:30 PM on June 16, 2005, when the average river flow was 7,500 cfs at the nearby Farmington USGS gage. Because the river was not wadeable at this flow, detailed field measurements of the discharge splits between the rock dam, sluiceway, and canal were not made during the June survey. However, several spot measurements of velocity and depth were made in the sluiceway and canal. Based on these limited data, it was estimated that approximately 190 cfs were being diverted into the canal, approximately 1,000 to 1,500 cfs were passing through the sluiceway, and approximately 6,000 cfs were passing over the rock dam. Both sluiceway gates were fully open at the time of the survey.

## Water Surface and Velocity Modeling

Hydrodynamic modeling at the study sites was accomplished using the River2D model. The model is a two-dimensional, depth averaged hydrodynamic and fish habitat model developed specifically for use in natural streams and rivers. It is a Finite Element model, based on a conservative Petrov-Galerkin upwinding formulation. It features subcritical-supercritical and wet-dry area solution capabilities. It has been verified through a number of comparisons with theoretical, experimental and field results (Ghanem et al. 1995a; Waddle et al. 1996, Christison et al. 1999). A complete description of the formulation and implementation of the model is contained in Ghanem et al. (1995b). The model solves the two-dimensional vertically averaged flow equations using a spatially variable, scalar eddy viscosity (turbulence closure) that emphasizes vertical diffusion of momentum. The program utilizes spatially variable channel roughness. When supplied good data on topography and flow and stage boundary conditions, River2D will calculate velocities, water surface elevations and boundary shear stresses in the channel. It has been used in channels with or without islands.

### *Computational meshes*

Finite element meshes were generated at each of the study sites using the utilities in River2D. Meshes were refined as much as practical given the size of the study sites and limitations of computational time. Mesh density was maximized in the immediate vicinity of the diversion structures, with reduced resolution upstream and downstream from the structures where detail is not as critical.

### *Water surface modeling*

The two-dimensional model was calibrated to the measured water surface at the field-surveyed discharge by adjusting substrate and riparian vegetation roughness. The substrate maps at each site included an estimated hydraulic roughness height based on the size of the largest particle sizes in each substrate category. Approximate roughness was calculated for riparian vegetation types from standard Manning's "n" versus vegetation type references (e.g., Chow 1959; Arcement and Schneider 1989). Manning's "n" values for vegetation were converted to comparable roughness height. The roughness algorithm in the 2D model adjusts roughness as a function of relative depth (depth/roughness height). Thus, once roughness is calibrated in the model at one discharge, the same roughness can be used throughout the full range of discharge levels. Where water surface elevation data is available at additional flows, it can be used to validate the relative roughness algorithm. We have done this on many rivers and the accuracy is very good such that water surface elevations at flows other than the calibration flow are usually only minimally improved by making adjustments to the original calibrated roughness (Addley forthcoming).

During the calibration phase of the hydrodynamics modeling, the roughness heights across all substrate types were increased or decreased by a constant percentage until the modeled water surface matched the measured water surface. Within the digital terrain model (DTM), the sluiceway gate positions were also adjusted slightly to ensure that the modeled flow splits matched the field discharge measurements. Because a two-dimensional model cannot model a submerged gate we used a flow block on the bottom of the channel (gate extending up from the bed of the channel) to approximate the submerged gates. Nine to ten specific flows were modeled at each site.

At the APS Diversion study site, roughness heights were originally only calibrated to the low-flow water surface profile survey and then extrapolated to higher discharges. After collecting high-flow water surface elevation data in June 2005, roughness was increased slightly in order to minimize the differences between the modeled and measured water surface elevations for both the low (780 cfs) and high (7,000 cfs) calibration flows. One set of final roughness height values was used to model all flows. As seen in Figure 2.3 , the match for the 7,000 cfs flow level is quite good, except in the area immediately below the weir. At high flows, a significant hydraulic jump occurs along the lip of the weir, and the modeling discrepancy in this area is a function of the limitations of using a two-dimensional hydrodynamics model to represent the complex, three-dimensional hydraulics that develop in this area. However, the model does closely match measured values upstream and downstream of the weir lip, and the discrepancy at the weir lip is minor under low flow conditions (Figure 2.3).

At the Fruitland Diversion study site, roughness heights and the sluiceway gate settings (partially closed) were also originally calibrated to the low-flow water surface profile survey and extrapolated to the higher discharges. As seen in Figure 2.4, the modeled versus measured values match closely for the 790 cfs flow run. After collecting high-flow water surface elevation data in June, 2005, along the left side of the channel with the sluiceway gates completely open, we attempted to compare model results to the measured data. However, we were unable to model the site at high flow with the sluiceway gates wide open because the large velocities in the sluiceway prevented the model from numerically converging. The site was easily modeled at high flows with the gates partially closed, but closing the gates affected the flow and water surface elevations along the left side of the channel above the sluiceway and prevented a comprehensive comparison to the measured data. We were able to compare some of the field-measured elevations along the right side of the island below the rock dam with the modeled values, and generally found good agreement. We are confident that the solutions with the roughness calibrated at low flow and the gate partially closed provide an accurate representation of conditions at the rock dam and have no reservations using these solutions over the entire range of flows.

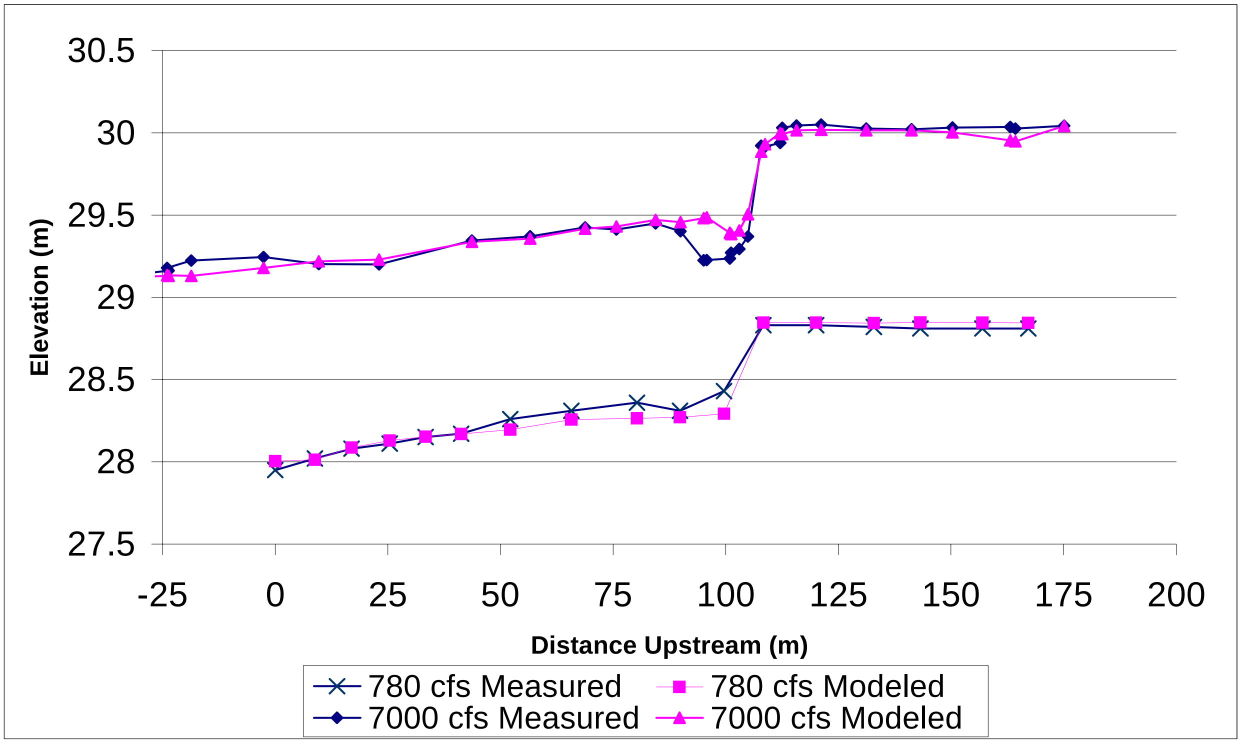


**Figure 2.3. Comparison plot of measured versus modeled water surface elevations at the APS Diversion for low- and high-calibration flows.**

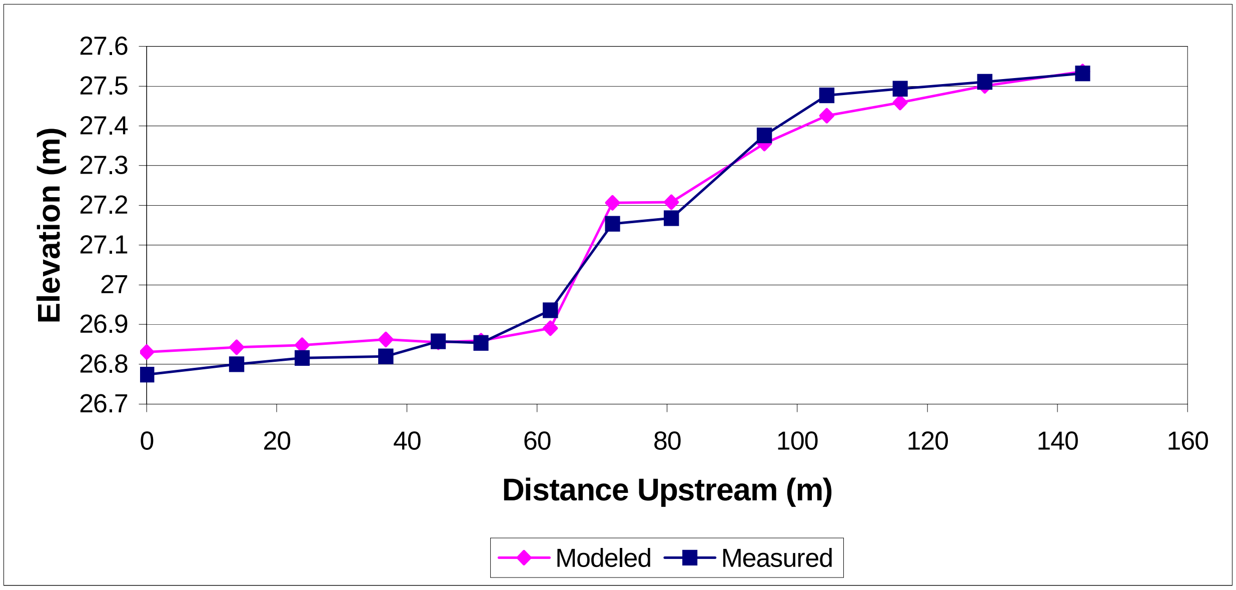


**Figure 2.4. Comparison plot of measured versus modeled water surface elevations at the Fruitland Diversion for the 790 cfs calibration flow.**

*Velocity modeling*
Vertically averaged velocities are generated during the solution of the two-dimensional hydrodynamics equations at each of the mesh nodes. No "calibration" of the velocity modeling is done. Accuracy of modeled velocities is primarily dependent on the accuracy of the channel topography, the accuracy of the channel roughness inputs, accuracy of the water surface elevations, and the hydrodynamics model itself (appropriateness of equations used in the model and the turbulence model used). In natural rivers, River 2D and other models like it such as the STAGR model written by Jonathan Nelson, both of which have been used extensively at Utah State University Water Research Laboratory, have been shown to generate accurate mean column velocities across the channel (e.g., Lisle et al. 2000, Nelson and Smith 1989, Shimizu et al. 1989, Addley forthcoming) and accurately model the size of recirculation zones (Nelson and McDonald, in Press; pers. observation).

## Fish Passage Criteria

A thorough literature search was completed to obtain information on passage criteria and swimming abilities of Colorado pikeminnow and razorback sucker. Because of the paucity of information available for Colorado pikeminnow and razorback sucker, information on congeneric species, and species thought to have similar swimming abilities were also obtained and reviewed. Specific information sought during the literature search included minimum water depth requirements, burst speed and sustained swimming speed data, and maximum passable vertical drop information. In addition to reviewing available literature, we also obtained input from various knowledgeable professionals who have been involved with native fish research and non-salmonid fish passageway designs.

We also obtained empirical data from mark-recapture studies that demonstrate movement through various diversion structures and engineered fishways. Where possible, information on the water velocities and depths that fish encountered during passage through these structures was reviewed to help define "passable" conditions.

The information from these various sources was used to define minimum depth, maximum velocity, and maximum vertical drop criteria. These criteria were used in conjunction with the hydrodynamic model outputs to identify passable and unpassable portions of the diversion structures at different flows.

## Hydrology

To place the passage conditions under different flow levels into a biological and temporal perspective, flow duration curves were developed using available hydrology data. Hydrology data were obtained from the San Juan Hydrology model developed by Keller-Bliesner Engineering. This model uses historical streamflow data in conjunction with projected "modern" operational conditions and water demands to simulate 65 years of flow data for the river. Modeled daily flows at the Farmington USGS gage node were used to represent flow conditions at the Fruitland diversion. Modeled monthly flows at the "Four Corners Power Plant Inflow" model node were used to represent flow conditions at the APS diversion. Modeled flow data for the Four Corners Power Plant Inflow node were only available as total monthly flow volumes; these volumes were converted into daily flow rates for duration analysis by assuming a constant daily rate for each month.

Monthly pumping records from 1985-2004 were provided by the APS Company, and these data were used to describe typical diversion conditions at the APS diversion. Diversion records for the Fruitland Canal are only available for 2003-2004; we reviewed these data and also spoke with Shiprock Irrigation Company staff to describe typical diversion conditions at the Fruitland diversion.

Fish passage conditions during the spawning periods for Colorado pikeminnow and razorback sucker are of particular interest. In the San Juan River, Colorado pikeminnow spawn on the descending limb of the hydrograph, typically in mid- to late-July (Holden 1999). Razorback sucker spawn on the ascending limb of the hydrograph, typically in April or May (Holden 1999). Therefore, in addition to analyzing flow duration using the full set of hydrology data, we also developed duration curves for July flows and April/May flows. For each of the three time frames analyzed, we determined the proportion of time that flows fall within the range represented by each modeled discharge.

## Fruitland Diversion Maintenance Information

Marlin Saggboy of the Shiprock Irrigation Company and Michael Isaacson of Keller-Bliesner Engineering were contacted to obtain information on typical maintenance and operation practices at the Fruitland Diversion structure.

# 3. RESULTS

## Description of APS Diversion

The APS diversion operates year round and provides water for use at the nearby Four Corners Power Plant. The structure consists of a concrete weir section across the river, with a gate and sluiceway assembly on river left. Together, the weir and sluiceway span the entire width of the river. The weir controls water surface elevation to provide water into pump intakes on river left (Figures 2.1 and 3.1). The sluiceway gate is 6 feet tall and opens from the bottom. The gate is operated to ensure adequate flow into the pumping station, and overall operations are varied based on river stage and pumping schedule. Based on monthly pumping records from 1985-2004, the average (and median) pumping rate is 41 cfs, with a minimum of 12 cfs and a maximum of 76 cfs (Figure 3.2).

According to the APS Company (B. Salisbury 2005a, pers. comm.), in a typical year the sluiceway gate is left completely open during April, May, and June while river flows are high. When flows drop in the beginning of July, the operators will partially close the gate (typically to the 50% closed position) to increase elevation and suction head for the pumps. The gate typically remains partially closed from July through March.

The concrete weir at the APS diversion is 10 feet thick and about 150 feet wide. The width of the sluiceway is 20 feet. Based on our 2004 survey, the average vertical drop in bed elevation from the top to the bottom of the concrete weir is about 8 feet, tapering to a 7 foot drop at the right and left edges of the weir. The drop from the downstream edge of the concrete sluiceway to the bottom of the scour pool below it is about 4 feet. According to the 1962 construction drawings of the APS facility, sloping rip rap aprons composed of 2' diameter rock were originally placed below the weir and below the concrete sluiceway. Apparently, considerable scour of the rip rap material and streambed has occurred since weir construction. At the time of our topographic survey, the water surface elevation drop over the weir was about 1.6 feet, the sluiceway gate was in the 80% closed position, and the diversion was running in single-train operation, pumping at a rate of 38 cfs.

## Description of Fruitland Diversion

### Physical Structure

The Fruitland diversion is operated seasonally for irrigation and is constructed of large boulders placed in the channel to divert water into a head gate assembly and sluiceway/canal on river left. The structure has three main components. The first component is a rock diversion dam composed of quarry rock material (3-4' diameter boulders) placed on the native streambed material. The rock dam spans most of the river width from the right bank to the edge of a high, narrow island (Figure 2.2). The dam is about 163 feet wide with a breadth of 20 feet in the

**Figure 3.1a.** **Photos of APS Weir. Top: Upstream view of concrete weir. Bottom: Upstream view of weir with pumphouse and sluiceway visible on the right side of the photo.**

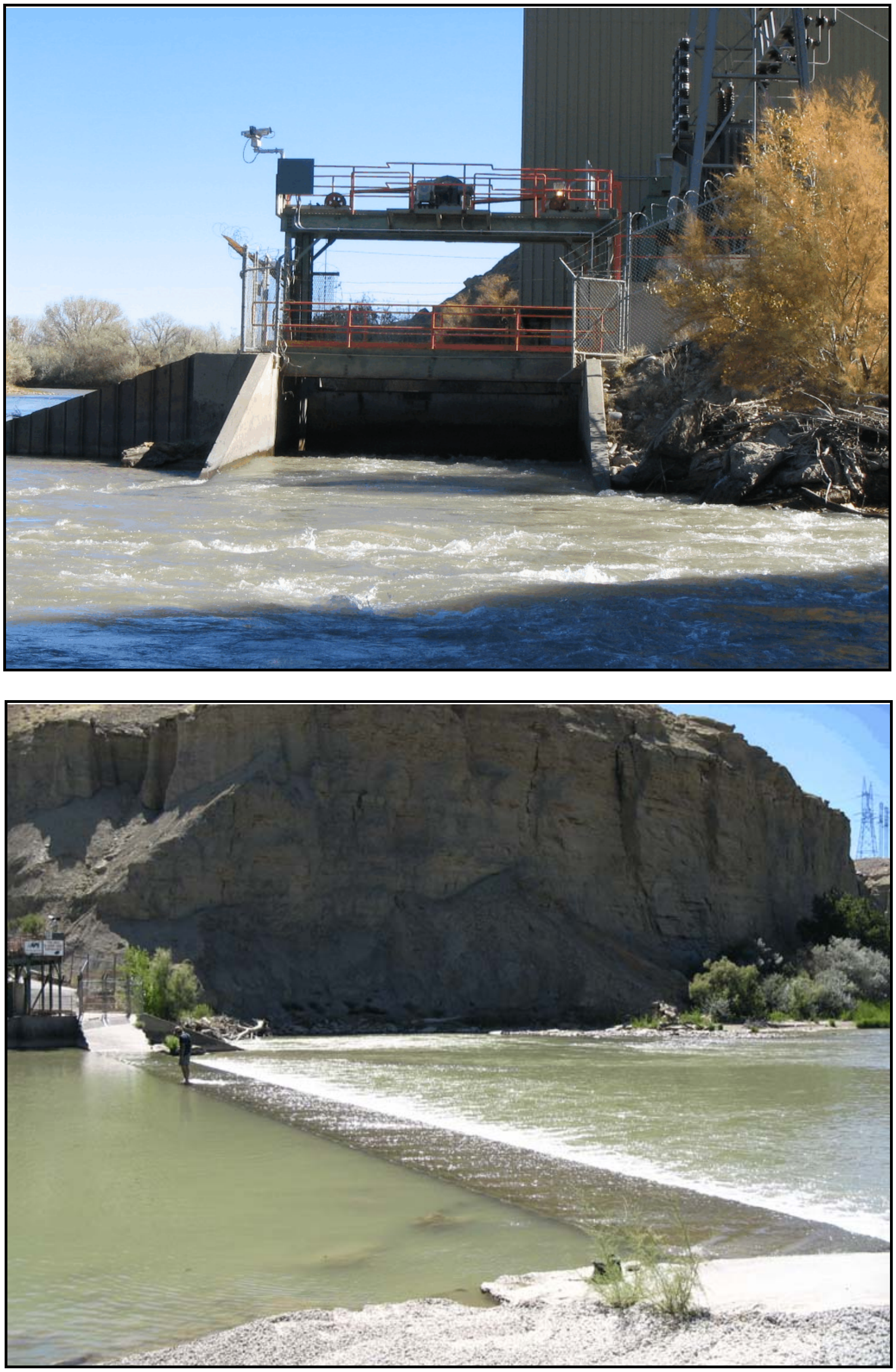

**Figure 3.1b. Photos of APS Weir. Top: Upstream close-up view of sluiceway gate. Bottom: View across concrete weir from river right to river left.**

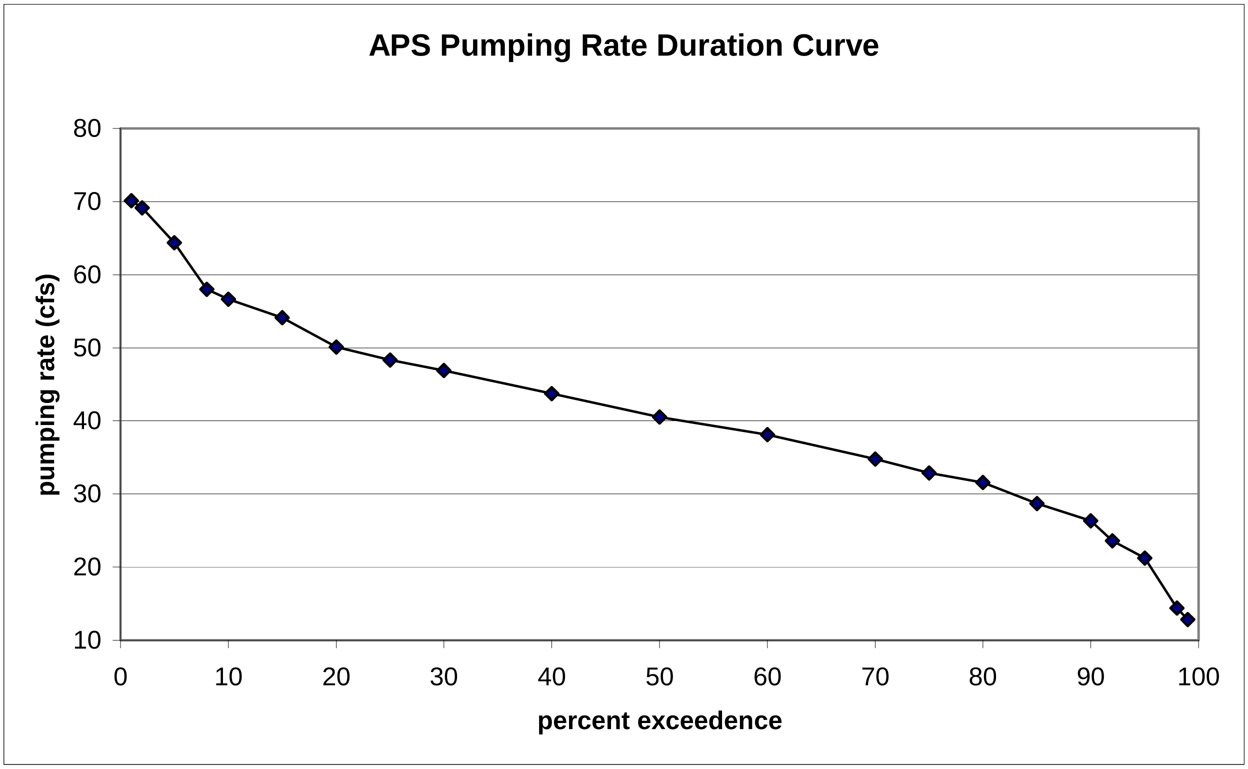


**Figure 3.2. Duration curve of pumping rates at the APS weir, based on monthly diversion records from 1985-2004.**

upstream-downstream direction. The vertical drop from the top of the boulders to the streambed below is about 4 to 6 feet, but this value varies considerably because the rock structure does not create a continuous elevational feature (Figure 3.3a). On average, the streambed gradient through the steepest part of the rock dam is 14 percent. At the time of our survey, the edges of the dam were at a somewhat higher elevation than the middle of the dam. The rock dam serves as a grade control structure to maintain an adequate water surface elevation for flow diversion into the sluiceway/canal facility on river left. The dam is periodically rebuilt by importing material or excavating bed material and placing it on the diversion structure to maintain flow into the diversion canal.

The second component of the Fruitland diversion is a sluiceway facility located between the island and the left bank of the river (Figure 2.2 and 3.3b). The sluiceway consists of two 10-foot wide steel radial headgates that open from the bottom. At the time of our topographic survey, which occurred after the end of the irrigation season, the right sluiceway gate was in the closed position and left sluiceway gate was open. This gate arrangement is typical of conditions during

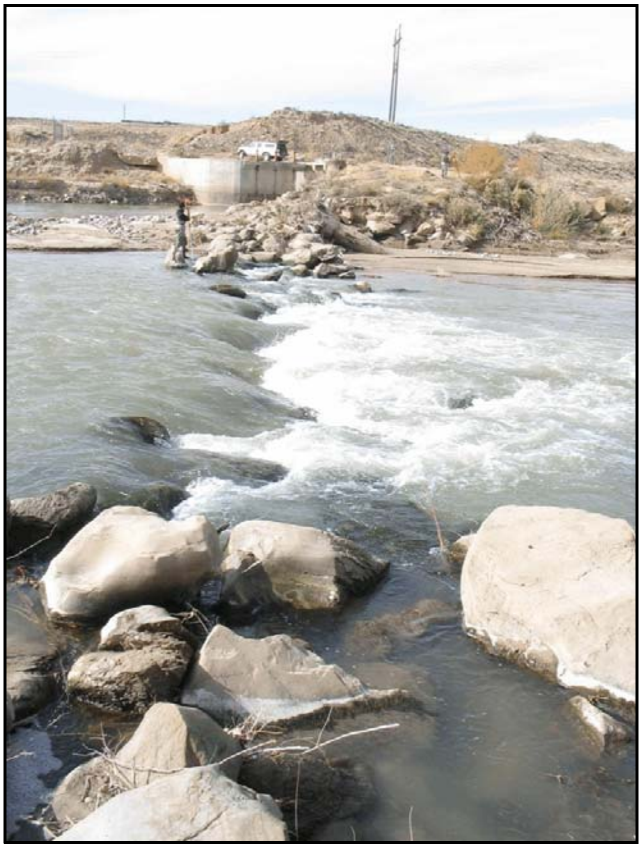

**Figure 3.3a. Photos of Fruitland Diversion. Top: View of rock dam looking towards river left. Bottom: View of rock dam looking towards river right.**

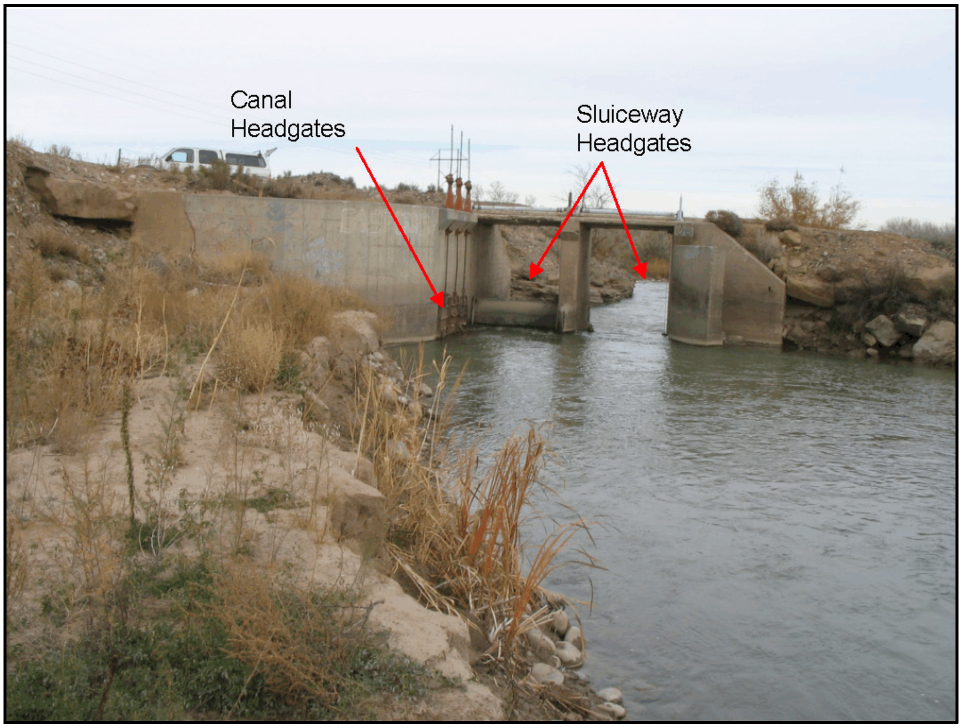


**Figure 3.3b. Photos of Fruitland Diversion. Top: Downstream view of sluiceway gates and canal headgates. Bottom: Upstream close-up view of sluiceway gates.**

the non-irrigation season, when one gate is left open to promote flushing of accumulated debris and sediment away from the canal headgates. During the irrigation season, both gates typically remain closed to help back up water and maintain head into the canal. A narrow bridge crosses the facility and provides vehicle access to a boat put-in at the downstream end of the island.

The third component of the Fruitland facility is the Fruitland Canal. Flow into the canal is controlled via three 4' by 4' steel headgates located in a concrete wall along the left bank of the river just upstream of the sluiceway headgates (Figure 3.3b). These gates open from the bottom, and are generally kept closed during the non-irrigation season (from November through March). During the irrigation season, they are opened to divert about 200 cfs into the canal. About 1 mile down the canal, a second set of headgates is operated to return half of the flow back into the San Juan River (M. Isaacson 2004, pers. comm.). This "double-control" of flow helps prevent excessive sediment accumulation in the canal, but it also means that more water than is actually used for irrigation is initially diverted out of the San Juan River.

## Maintenance Practices

Periodic maintenance of the rock diversion dam is needed when flood events cause the boulders to roll and shift, reducing the water surface elevation maintained by the dam. In general, maintenance procedures involve using heavy equipment to place new boulders on the structure and/or to move existing boulders that have rolled downstream back onto the structure (M. Saggboy 2004, pers. comm.). Rather than actually increasing the overall maximum height of the rock dam, these maintenance activities typically involve filling in gaps between the in-tact boulders. Also, when the structure is rebuilt, a lower-elevation notch in the dam is typically left to allow for boat passage. This type of maintenance work is usually completed in the springtime (early April), at the start of the irrigation season (M. Saggboy 2004, pers. comm.). Occasionally, if high spring runoff conditions substantially displace rocks, maintenance work may also be completed in late July after a high-flow event.

At the time of our survey in November 2004, no maintenance work had been performed on the Fruitland diversion dam since early spring, 2002 (M. Saggboy 2004, pers. comm.). Recent springtime flood magnitudes have been low on the San Juan River, and no difficulties with maintaining flow into the diversion headgates were reported during the 2004 irrigation season. Therefore, it is unlikely that significant shifting of the boulders within the rock dam had occurred prior to our November 2004 survey. Although no surveys of the structure immediately following maintenance work are available for comparison, we assume that the condition of the structure in November 2004 is a reasonable representation of the "average" condition and elevation of the dam. The existing condition of the structure appears similar to the condition seen in several photos of the rock dam taken by Shiprock Irrigation in July, 1991, further suggesting that conditions at the structure do not vary dramatically through time.

# Fish Passage Criteria

## Review of Literature on Swimming Abilities

*Colorado pikeminnow and surrogate species*
We found limited information on the sustained swimming abilities of Colorado pikeminnow, but no burst speed information specifically for Colorado pikeminnow. Childs and Clarkson (1996) calculated the 50% fatigue velocity (FV50) for larval and young-of-year (YOY) Colorado pikeminnow. The FV50 is the water velocity at which 50% of the fish can not continue swimming against the current, even with prodding using electrical current. Using hatchery-reared, unexercised fish, they found that the FV50 for YOY Colorado pikeminnow (average total length [TL] 27-28 mm) was 0.15 meters per second (m/s) in 30 minute trials at water temperatures of 14°C. The FV50 varied with temperature and was 0.14 m/s at 10°C and 0.19 m/s at 19°C. They also state that Beamish (1980) indicated that sustained swimming speeds for larger fish are ~ 80% of FV50 values obtained in 30 minute tests.

Berry and Pimenthal (1985) also calculated the FV50 for Colorado pikeminnow using hatchery-reared, unexercised fish. They found that the FV50 for Colorado pikeminnow with an average size of 432 mm was 1.04 - 1.08 m/s in 2 minute trials at temperatures of 14, 20 and 26°C. The FV50 for 120 minute trials with similar sized fish was 0.87 - 0.95 m/s at those temperature. Berry and Pimenthal (1985) found lower FV50s for smaller Colorado pikeminnow (average size 104 mm), during similar trials. The FV50 for the smaller Colorado pikeminnow was 0.50 m/s and 0.52 m/s in 2 minute trials at temperatures of 20°C and 26°C. However, when temperatures were lowered to 14°C, the FV50 decreased to 0.39 m/s. Similarly, in 120 minute trials the FV 50 for smaller Colorado pikeminnow at 20°C and 26°C was 0.47m/s, while the FV50 at 14°C was only 0.35 m/s.

Additionally, we also found information on the sustained and burst swimming speeds of several species congeneric to the Colorado pikeminnow, which may serve as surrogates for Colorado pikeminnow. Mesa and Olson (1993) determined prolonged swimming performance of two size-classes of northern pikeminnow (*Ptychocheilus oregonensis*). Using a swim tunnel they calculated the FV50 for fish after they swam the fish to exhaustion under a variety of water velocities and two temperature regimes. They found that in 20 minute trials at 12°C the FV50 was 1.05 m/s for northern pikeminnow at an average size of 435 mm (TL). At 18°C the FV50 for the same size fish was 1.15 m/s in 27 minute trials. Northern pikeminnow with a smaller average size (355mm TL) fatigued slightly faster at lower water velocities (the FV50 was 1.00 m/s in 20 minutes at 12°C and 1.07 m/s in 14.1 minutes at 18°C).

Kolok and Farrell (1994) measured the critical swimming speed for adult northern pikeminnow at 5°C and 16°C. Critical swimming speed is found by increasing the current velocity fish are swimming against every 20 minutes until fatigue is achieved. They found that northern pikeminnow with an average fork length of 305 mm had a critical swimming velocity of 0.73 m/s at 16°C. At 5°C critical swimming velocity for northern pikeminnow with an average fork length of 150 mm was 0.49 m/s. Myrick and Cech (2000) found that critical swimming velocities for Sacramento pikeminnow (*Ptychocheilus grandis*) were 0.40, 0.57, and 0.50 m/s at 10, 15, and 20ºC. Average total length of the fish were 229, 247, and 233 mm, respectively.

Froese and Pauly (2004) define burst speed as speeds that can be maintained for 5-10 seconds. While we did not find any information on burst speeds for Colorado pikeminnow, Froese and Pauly (2004) suggest that burst speed is about 10 times higher than sustained speed, but can only be sustained for a matter of seconds. If sustained speed is ~80% of FV50 values, and burst speed is ~ 10 times sustained speed, then we can estimate that burst speed for a Colorado pikeminnow near 400mm TL is approximately 7 m/s. Froese and Pauly (2004) listed burst speeds for Sacramento pikeminnow found by Bainbridge (1958), which were somewhat lower than this estimate. Bainbridge (1958) found burst speeds of 4.8 to 6.7m/s for Sacramento pikeminnow between 750 and 850mm TL.

In their bioenergetics model for northern pikeminnow feeding on juvenile salmonids, Peterson and Ward (1999) used average swimming speeds generated from radio telemetry contact data collected by Martinelli and Shively (1997). These average swimming speeds were substantially lower than "sustained speeds" seen in critical velocity and FV50 trials. In dam tailraces they used an average swimming speed of 0.09 m/s. Outside of tailrace areas they used a swimming velocity of 0.01 m/s. These speeds were calculated as the straight line distance between radio telemetry contacts divided by time.

#### *Razorback sucker and surrogate species*

We found no published information on the sustained swimming abilities or burst speeds of the razorback sucker. However, some published data were available for the Sacramento sucker (*Catostomus occidentalis*). Myrick and Cech (2000) found that critical swimming velocities for Sacramento sucker were 0.47, 0.48, and 0.51 m/s at 10, 15, and 20ºC. Average total length of the fish were 191, 200, and 209 mm, respectively. Substituting the critical swimming velocity for an FV50 value and using the formula outlined above for estimating the burst speeds of Colorado pikeminnow, we can estimate burst speeds for Sacramento sucker may be between 3.76-4.08 m/s. However, critical swimming velocities for northern pikeminnow were lower than FV50 velocities, so this may be a conservative estimate.

#### *Summary of swimming ability information*

A summary of the swimming ability information described above is provided in Table 3.1. For simplicity and for comparison purposes, only data for the larger (200mm length and greater) life stages are included, and only values for water temperatures between 16 and 20ºC are included. The San Juan River is typically within this temperature range from June through September. Water temperatures are somewhat cooler – between 11 and 13ºC – during April and May, when razorback sucker typically spawn (Holden 1999). Therefore, the values listed in Table 3.1 may be somewhat greater than the true swimming speeds for razorback sucker during their spawning period. However, since no swimming ability information was specifically found for razorback sucker, it is difficult to know how significantly temperature would affect their swimming speed.

Table 3.1. Summary of swimming ability information available in the literature.

| | Colorado Pikeminnow | | Northern Pikeminnow | | Sacramento Pikeminnow | Sacramento Sucker |
|---|---|---|---|---|---|---|
| **Fish Length (mm)** | 432 | | 435 | 305 | 235 | 200 |
| **Speed (m/s)** | 1.06 | 0.91 | 1.15 | 0.73 | 0.50 | 0.51 |
| **Type of Trial** | FV50 | FV50 | FV50 | Critical swimming velocity | Critical swimming velocity | Critical swimming velocity |
| **Length of Trial (min)** | 2 | 120 | 27 | n/a | n/a | n/a |
| **Citation** | Berry & Pimenthal '85 | | Mesa & Olson '93 | Kolok & Farrell '94 | Myrick & Cech '00 | Myrick & Cech '00 |
| **Burst Speed Estimate** | 7.0 m/s (Froese & Pauly '04) | | | | 4.8 to 6.7 m/s (Bainbridge '58; 750-850 mm long fish) | 4.0 m/s (Froese & Pauly '04) |

The results of the studies described above indicate that adult-sized (400mm long and greater) pikeminnow are capable of maintaining speeds of about 1.0 m/s for sustained time periods (Table 3.1). Available information applicable to razorback sucker is very limited and relatively inconclusive; however, the sustained speed data reported for Sacramento sucker is essentially the same as that reported for Sacramento pikeminnow (Table 3.1), suggesting that the sustained speed capabilities for razorback sucker may be fairly comparable to Colorado pikeminnow. Burst speed information is not well-established for either species.

## Recapture Data

Since information on the swimming abilities of Colorado pikeminnow and razorback sucker is limited, we also reviewed documented instances of these species passing through various instream structures on the San Juan River and through Redlands fish ladder on the Gunnison River to help define "passable" conditions.

*PNM Weir*

In 2003, the fish passage facility at the PNM Weir on the San Juan River (located between Fruitland Diversion and the APS Weir - see Figure 1.1) began operation in June and remained open until November. During this time period, eight individual Colorado pikeminnow and four razorback sucker used the fish passage facility. Seven of the Colorado pikeminnow were captured in late June-early July. The Colorado pikeminnow ranged in size from 520 mm - 640 mm total length (TL). The razorback sucker ranged in size from 400 mm - 460 mm. Additionally, 6,193 flannelmouth suckers and 10,076 bluehead suckers used the fish passage facility in 2003. In 2004, the PNM fish passage facility operated from June through October.

During that time, five Colorado pikeminnow and seven razorback sucker used the passage facility. The Colorado pikeminnow ranged from 185-643 mm TL, and the razorbacks ranged from 435-480 mm TL (A. Lapahie 2005, pers. comm.).

The PNM fish passage facility consists of an artificial "side channel" with boulder (rip-rap) bed material that leads to a gate area where fish are collected and sorted (Figure 3.4). Native fishes are returned to the river above the diversion structure. The fishway is about 350 feet long. Although detailed information on the flow velocities and depths within the PNM fishway was not readily available, the weir was designed to meet some general criteria used by the Bureau of Reclamation (BOR) when designing fishways for native sucker species. Velocities are kept below a maximum of 1.2 m/s (4 ft/s); vertical drops are avoided or kept to a height of 0.12 m (0.4 ft) or less; and water depths are kept to a minimum of 0.9 m (3 ft) to provide cover and reduce predation risk (B. Mefford 2005, pers. comm.). The successful use of the PNM facility by both adult Colorado pikeminnow and razorback sucker provides evidence that these fish are capable of sustained swimming speeds of up to 1.2 m/s, at least in channels where boulders provide velocity refuge zones.

**Figure 3.4. Photo of fish passage facility at PNM weir. Photo by William Miller, Miller Ecological Consultants; photo obtained from San Juan Recovery Program web site at http://www.fws.gov/southwest/sjrip/.**

All four razorback sucker collected in the PNM fish ladder in 2003 had been stocked downstream of the Hogback Diversion and recollected upstream of the APS Diversion (D. Ryden 2005, pers. comm.). Additional fish sampling in the San Juan River by SJRIP cooperators showed that at least three additional razorback suckers that were stocked below the Hogback Diversion have been collected above the APS diversion. One of the Colorado pikeminnow collected in the PNM fish ladder in 2003 had also been previously captured below the APS diversion. Additional fish sampling in the San Juan River by SJRIP cooperators documented an additional Colorado pikeminnow that was captured below the APS diversion, and subsequently recaptured above the APS diversion.

Most of these recaptures were separated by hundreds of days, so it is not possible to know the specific flow conditions under which the Colorado pikeminnow and razorback sucker were able to swim past the APS diversion. However, in 2002, one stocked Colorado pikeminnow (TL 521 mm) was collected below the APS diversion on 10/11/2002 and recollected above it on 10/22/2002 (D. Ryden 2005, pers. comm.). During this time, flows at the Farmington USGS gage were between 671 and 741 cfs. The APS sluiceway gate was set at the 50% closed position throughout this time period, and the pumps were diverting at a rate of 38 cfs every day except October 20, when the pumps were off (B. Salisbury 2005b, pers. comm.). These conditions are similar to the conditions we experienced during our topographic and water surface surveys at the APS site in November 2004. During our survey, it was unsafe to closely approach the sluiceway gate area due to the extremely high water velocities passing under the gate. The drop in water surface elevation over the weir was 1.6 feet, and water depths in the weir area were only about 6 inches or less. The fact that an adult Colorado pikeminnow was able to migrate past the diversion during these conditions suggests that the APS Diversion is not a complete barrier to certain Colorado pikeminnow, even when conditions are less than ideal.

The New Mexico Fisheries Resource Office has seen movement of other species of fish past the APS diversion during their nonnative removal efforts between PNM Weir and Hogback Diversion. Below Hogback Diversion, they tagged 3,361 fish in 2003 and 2004, including the following species: channel catfish (*Ictalurus punctatus*), common carp (*Cyprinus carpio*), flannelmouth sucker, bluehead sucker, flannelmouth x bluehead sucker hybrids (*Catotomus* spp.), and flannelmouth x white sucker hybrids. They have subsequently found ten of those fish above the APS diversion (5 flannelmouth sucker, 3 common carp,and 2 channel catfish).

One tagged flannelmouth sucker and one tagged bluehead sucker have been documented to pass the Fruitland Diversion (D. Ryden 2005, pers. comm.). The bluehead sucker also passed several diversions on the lower Animas River. Flannelmouth sucker are probably similar to razorback sucker in terms of swimming ability, so the fact that flannelmouth sucker have successfully navigated the Hogback Diversion fish passage facility, the APS Diversion, the PNM Weir fish passage facility, and Fruitland Diversion adds further evidence that these structures are not complete barriers to native and endangered fishes. Unfortunately, the recaptures described for these other species did not occur close enough together in time to be able to determine the specific flow conditions that were present when successful upstream passage was made.

*Redlands Diversion*

The Redlands Diversion on the Gunnison River has a fish ladder that has passed both Colorado pikeminnow and razorback sucker (Burdick 2001). The fish passage is a 107 m long vertical slot/orifice passageway. The final bottom slope of the passage is 3.75%. Approximately 25 cfs runs down the passageway. Velocities measured near the top middle and bottom of the passageway ranged from 0.70 - 1.07 m/s (U.S. Bureau of Reclamation, unpublished data). The depths measured in the passageway were 1.8 m at the entrance and 1.07 m in the forebay at the top of the ladder. Burdick (2001) indicated that while the depths in the ladder may vary by river stage, the hydraulics remain the same. He found that between 1996 and 2000, 51 Colorado pikeminnow negotiated the fish ladder at the Redlands Diversion. The Colorado pikeminnow ranged in size from 383 - 765 mm. The Colorado pikeminnow utilized the fish ladder almost exclusively in July and August. Additionally, Burdick (2001) listed several instances where the same fish used the ladder in multiple different years. The timing of Colorado pikeminnow use, combined with collecting several of the same fish in multiple years, suggests that these movements were probably associated with spawning migrations.

Burdick (2001) did not see any of the over 40,000 razorback suckers stocked through July 2001 in the Gunnison and Upper Colorado Rivers use the fish trap. However, they enclosed 6 razorback sucker in the bottom of the fish trap, and two successfully navigated the fish ladder. Additionally, over 14,000 flannelmouth sucker and over 22,000 bluehead sucker used the passageway between 1996 and 2001. Additionally, from July 2001-December 2004 16 Colorado pikeminnow and 9 razorback sucker ascended the passageway (B. Burdick 2005, pers. comm.).

## Depth and Vertical Drop Data

We found little information related to depths associated with velocities for different swimming performances. The only detail we were able to find relative to depth was that the swimming chamber used by Berry and Pimenthal (1985) in their trials with Colorado pikeminnow had a diameter of 20 cm. This suggests that adult Colorado pikeminnow can sustain speeds of about 1 m/s in fairly shallow water.

We did not find any quantitative information related to the leaping abilities of any species of *Ptychocheilus* or any Catostomid species. We did find several reports stating that northern pikeminnow were not known for their leaping ability.

Regardless of physical leaping ability (or a lack thereof), there is evidence that vertical drops in the streambed can present a behavioral passage impediment to bottom-oriented sucker species. When the height of a vertical drop approaches the fork length of the fish, the eddy forces/hydraulic alterations associated with the drop can cause orientation problems for the fish that may prevent it from even attempting to swim up over the drop (B. Mefford 2005, pers. comm.).

# 4. MODELING RESULTS

## Fruitland Diversion

### Analysis Techniques

The topographic mesh (DTM) used to model the Fruitland site is shown in Figure 4.1, and Table 4.1 lists the specific flows modeled for the Fruitland site. Because flows during the winter (non-irrigation) season are typically low, inflows of 1,500 cfs and lower were modeled with one of the sluiceway gates in the "open" position. Flows of 2,000 cfs and greater were modeled with both sluiceway gates in the "closed" position, as if active flow diversion were occurring. Although additional combinations of inflow values and sluiceway gate positions are possible, they were not specifically modeled because the major issue of concern is passage conditions through the rock dam portion of the Fruitland structure. Closing or opening a sluiceway gate simply alters the proportion of the total inflow that runs through the rock dam area. For example, if the sluiceway gates were closed when the total inflow to the site was 790 cfs, a greater proportion of the flow would run through the rock dam, and conditions in that area would be more similar to the model run for 1,000 cfs total inflow. Therefore, the model runs that were completed provide an adequate representation of the range of conditions within the rock dam area.

**Table 4.1. Modeled flows and sluiceway conditions for Fruitland Diversion.**

| Modeled Discharge (cfs) | Discharge Through Rock Dam (cfs) | Discharge Through Sluiceway Area (cfs) | Modeled Sluiceway Gate Position |
|---|---|---|---|
| 500 | 305 | 195 | one gate open |
| 790 | 519 | 271 | one gate open |
| 1,000 | 689 | 311 | one gate open |
| 1,500 | 1,112 | 388 | one gate open |
| 2,000 | 1,797 | 203 | both gates closed |
| 3,000 | 2,704 | 296 | both gates closed |
| 5,000 | 4,547 | 453 | both gates closed |
| 8,000 | 7,331 | 669 | both gates closed |
| 10,000 | 9,196 | 804 | both gates closed |

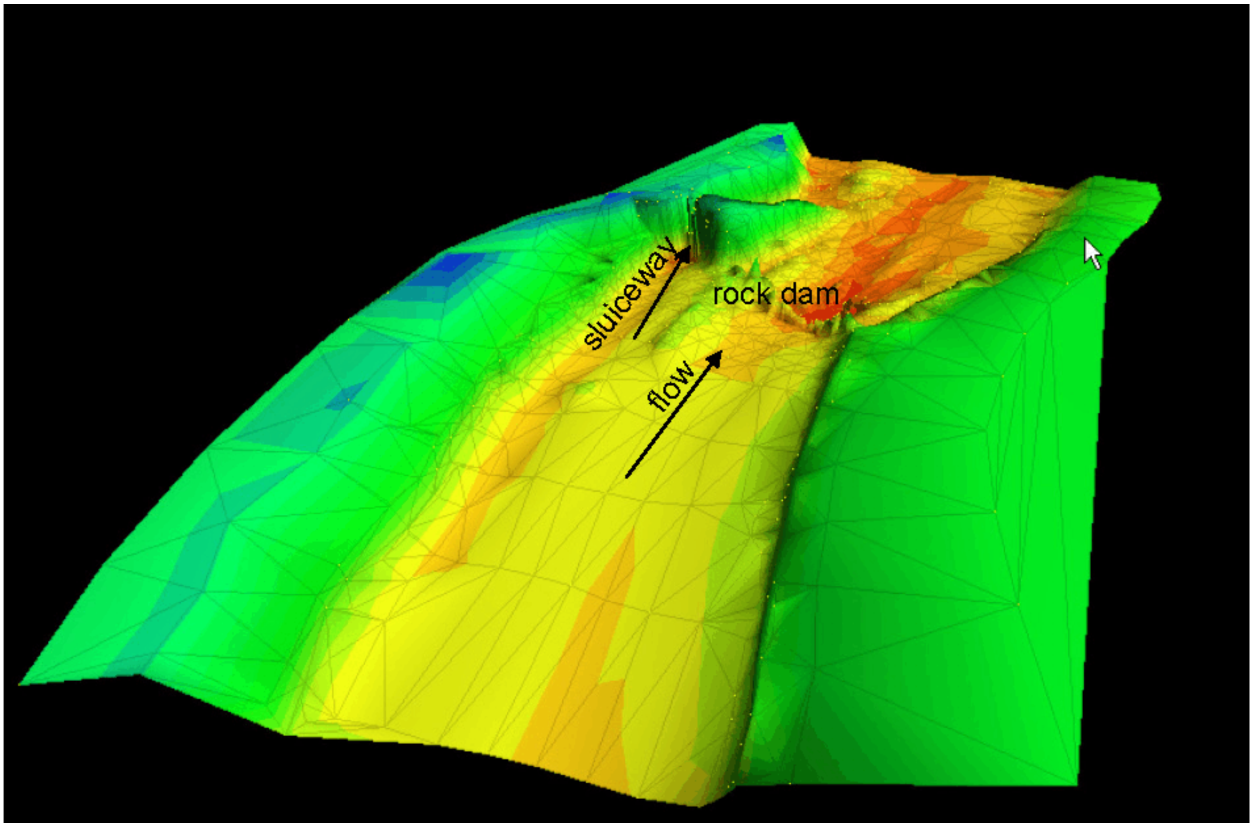


**Figure 4.1. Three-dimensional view of topographic mesh used to model Fruitland diversion.**

The sluiceway channel and gate area were not analyzed in detail. At the time of our survey, the vertical drop in water surface elevation between the upstream and downstream sides of the closed gate was 2 feet, and velocities in the vicinity of the gates were high. While it may be possible for a fish to swim underneath a gate (when open) or leap over a gate (when closed) , these conditions are not ideal for passage, and would likely constitute an impediment to passage. Therefore, our modeling efforts focused primarily on providing an accurate representation of conditions that would be encountered by an upstream-migrating fish within the main channel rock dam area.

To examine passage conditions within the rock dam area, a subset of model nodes were extracted from the overall model for detailed analysis (Figure 4.2). At total of 425 nodes were extracted, each representing a “pixel” size of about 4 feet by 4 feet. This subset was used to examine the proportion of nodes meeting various depth and velocity criteria relevant to fish passage.

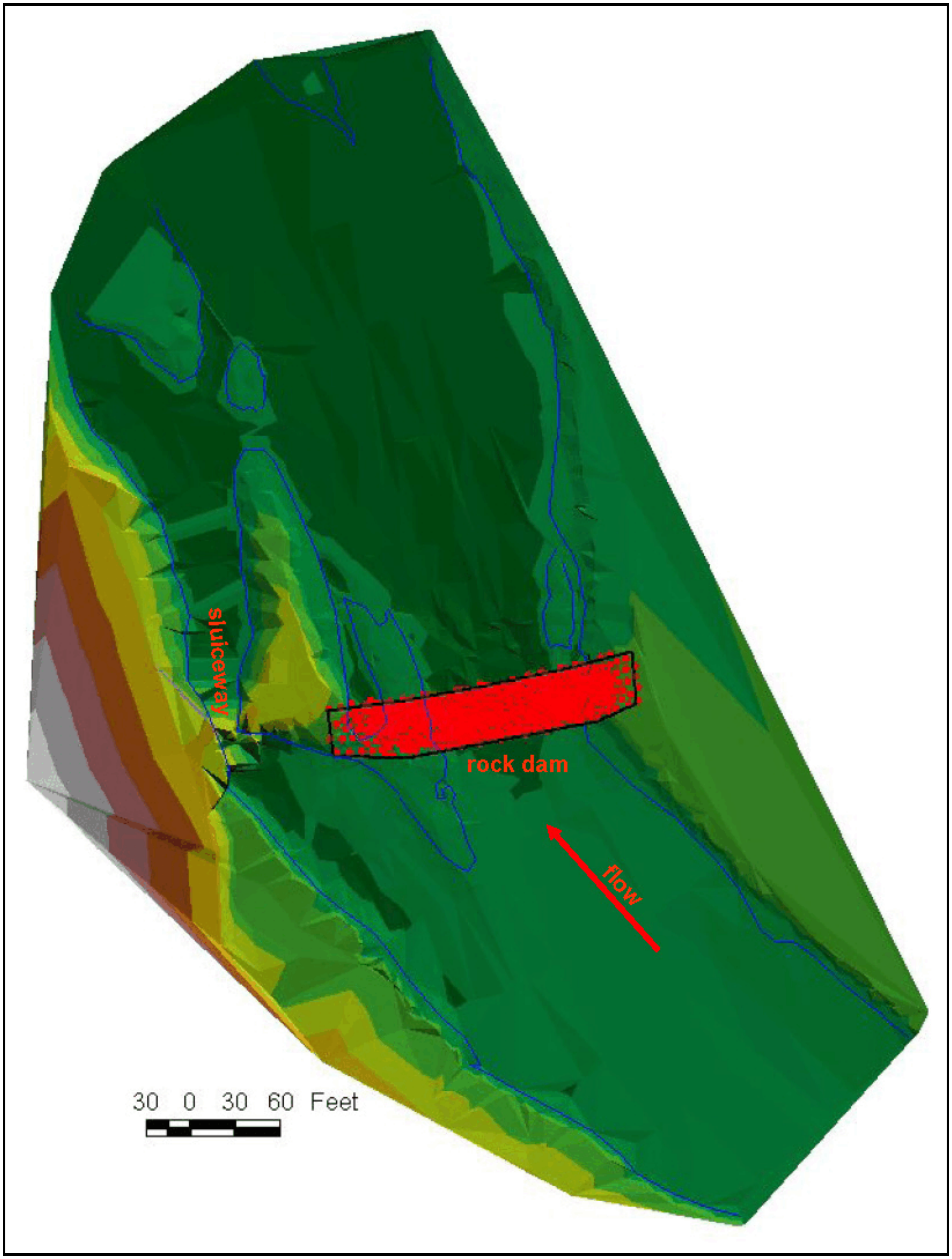


**Figure 4.2. Fruitland model site. Bright red area indicates model nodes in vicinity of rock dam extracted for passage analysis.**

## Depth and Velocity Conditions

Because the specific depth and velocity criteria for Colorado pikeminnow and razorback sucker are not definitively established, model results are presented for a variety of depth and velocity combinations. Two specific minimum depth criteria were analyzed: a depth of 0.30 m (1 foot), and a depth of 0.15 m (6 inches). The 0.30 m value was selected because this depth would probably provide adequate "wetted cover" for the largest size classes of Colorado pikeminnow and razorback sucker. The 0.15 m value was selected as a less restrictive criteria that would provide cover for all but the largest size classes of fish. Additionally, the 0.15 m value is closer to the 20 cm swimming chamber depth (diameter) used by Berry and Pimenthal (1985) in their trials with Colorado pikeminnow.

For each of these two minimum depth criteria, we determined the proportion of nodes meeting various maximum velocity criteria. Specifically, maximum velocity increments of 1, 2, 4, 6, and 8 m/s were analyzed. The minimum value of 1 m/s was selected because the literature indicates that this is a good approximation of the swimming speed that can be sustained for an extended period of time by adult Colorado pikeminnow and razorback sucker. However, the use of a burst speed estimate may also be relevant because the rock dam structure at Fruitland Diversion only spans a river length of about 6 meters (20 feet). Therefore, higher velocity threshold values up to 8 m/s were also examined.

Model results within the rock dam area for the various depth and velocity criteria are presented in Tables 4.2 and 4.3. For modeled flows of less than 3,000 cfs, depth is an important factor. At these flows, a substantially greater proportion of nodes meet the minimum depth value of 0.15 m than meet the minimum depth value of 0.30 m, and many nodes do not meet either value (Figure 4.3). Once flows entering the site reach 3,000 cfs or greater, depth becomes less of an issue (Figure 4.3) and velocity becomes a more important variable.

At flows of 1,500 cfs and less, our model results indicate that at least one third of the wetted portion of the rock dam meets the most restrictive depth and velocity criteria of 0.30 m minimum depth and 1 m/s maximum velocity (Table 4.2). If the criteria are relaxed to 0.15 minimum depth and 2 m/s maximum velocity, only the 8,000 cfs and 10,000 cfs model runs show less than one third of the wetted nodes meeting the criteria (Table 4.3). For all of the modeled flows, at least 67% or more of the wetted notes have velocities of 4 m/s or less and meet the indicated depth criteria (Tables 4.2 and 4.3).

**Table 4.2. Fruitland Diversion results using 0.30 m (1 foot) minimum depth criteria.**

| Discharge (cfs) | Total # of Wetted Model Nodes | % of Wetted Nodes ≥0.3 m Deep With Velocities Less Than or Equal To Indicated Values | | | | |
|---|---|---|---|---|---|---|
| | | 1 m/s | 2 m/s | 4 m/s | 6 m/s | 8 m/s |
| **500** | 204 | 56 | 69 | 70 | 70 | 70 |
| **790** | 234 | 45 | 67 | 69 | 69 | 69 |
| **1,000** | 256 | 36 | 61 | 67 | 67 | 67 |
| **1,500** | 302 | 33 | 61 | 71 | 71 | 71 |
| **2,000** | 341 | 28 | 65 | 79 | 80 | 80 |
| **3,000** | 365 | 22 | 63 | 87 | 87 | 87 |
| **5,000** | 388 | 14 | 45 | 91 | 94 | 94 |
| **8,000** | 404 | 6 | 23 | 82 | 95 | 95 |
| **10,000** | 409 | 4 | 15 | 80 | 97 | 97 |

**Table 4.3. Fruitland Diversion results using 0.15 m (6 inch) minimum depth criteria.**

| Discharge (cfs) | Total # of Wetted Model Nodes | % of Wetted Nodes ≥0.15 m Deep With Velocities Less Than or Equal To Indicated Values | | | | |
|---|---|---|---|---|---|---|
| | | 1 m/s | 2 m/s | 4 m/s | 6 m/s | 8 m/s |
| **500** | 204 | 65 | 78 | 81 | 81 | 81 |
| **790** | 234 | 55 | 78 | 83 | 83 | 83 |
| **1,000** | 256 | 50 | 76 | 84 | 84 | 84 |
| **1,500** | 302 | 46 | 74 | 86 | 86 | 86 |
| **2,000** | 341 | 36 | 74 | 90 | 91 | 91 |
| **3,000** | 365 | 25 | 69 | 95 | 96 | 96 |
| **5,000** | 388 | 15 | 47 | 94 | 97 | 97 |
| **8,000** | 404 | 6 | 24 | 84 | 97 | 97 |
| **10,000** | 409 | 5 | 16 | 82 | 98 | 98 |

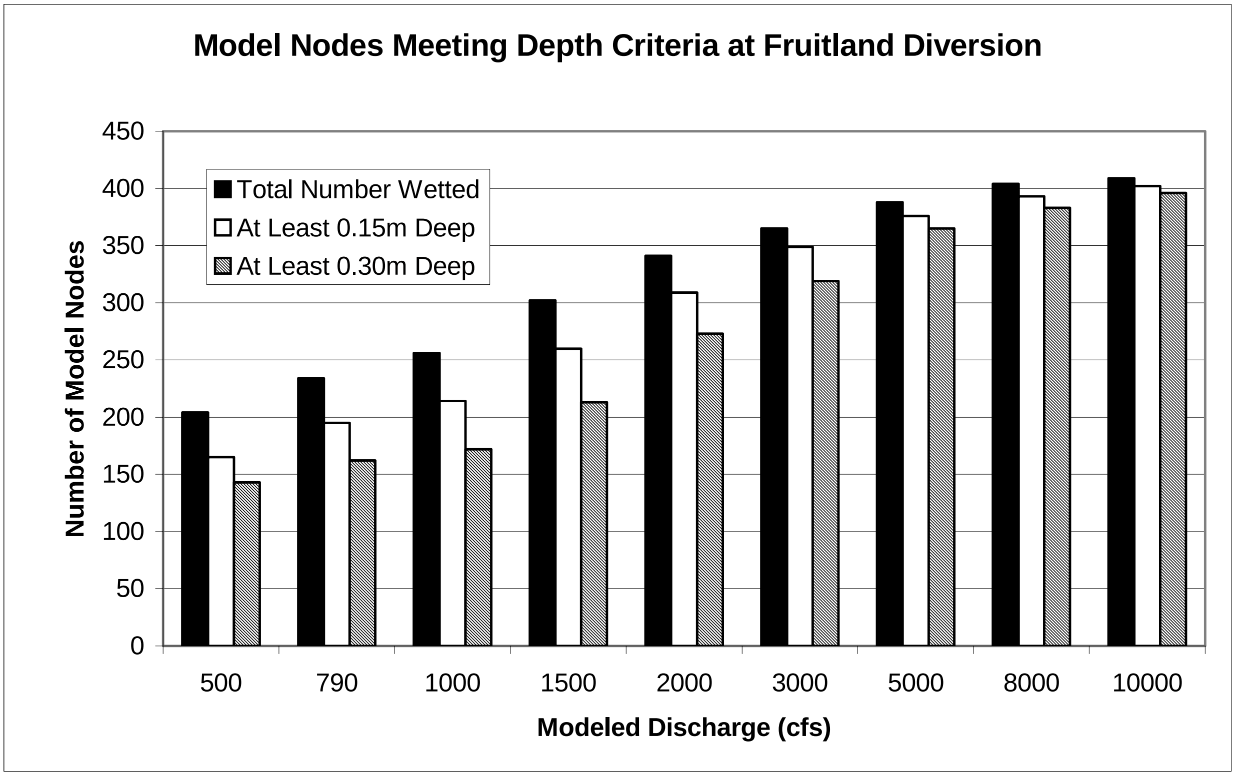


**Figure 4.3. Number of model nodes meeting depth criteria within rock dam area at Fruitland Diversion.**

Because migrating fish need to be able to navigate the rock dam in a continuous manner, the distribution of "passable" nodes within the rock dam area is perhaps more important than the simple percentage of nodes meeting specific depth and velocity criteria. Figure 4.4 shows the distribution of model nodes meeting versus not meeting two different sets of depth and velocity criteria. Results are shown for the most restrictive depth/velocity criteria evaluated (depth $\geq$0.30 m and velocity $\leq$1 m/s), and for a less restrictive set of criteria (depth $\geq$0.15 m and velocity $\leq$2 m/s). Because the majority of nodes at any flow have velocities less than 4 m/s, results are not shown for these higher maximum velocity levels.

As seen in Figure 4.4a, the nodes that meet the depth and velocity criteria under the lowest modeled flows (discharge 1,000 cfs and less) are primarily located near the central section of the rock dam. Conditions along the right and left edges of the dam are too swift and shallow to meet the criteria. The model results indicate that no fully continuous path of "suitable" nodes through the rock dam exists at the 500 cfs, 790 cfs, or 1,000 cfs flow levels using the most restrictive depth and velocity criteria (Figure 4.4a). However, an upstream-migrating fish would only need to swim through a short (5- to 10-foot long) stretch of shallower/faster water in the middle of the dam to successfully pass the structure under these low flow conditions. When the model criteria are relaxed to the less-restrictive depth ( $\geq$0.15 m) and velocity ($\leq$2 m/s) criteria, one or more

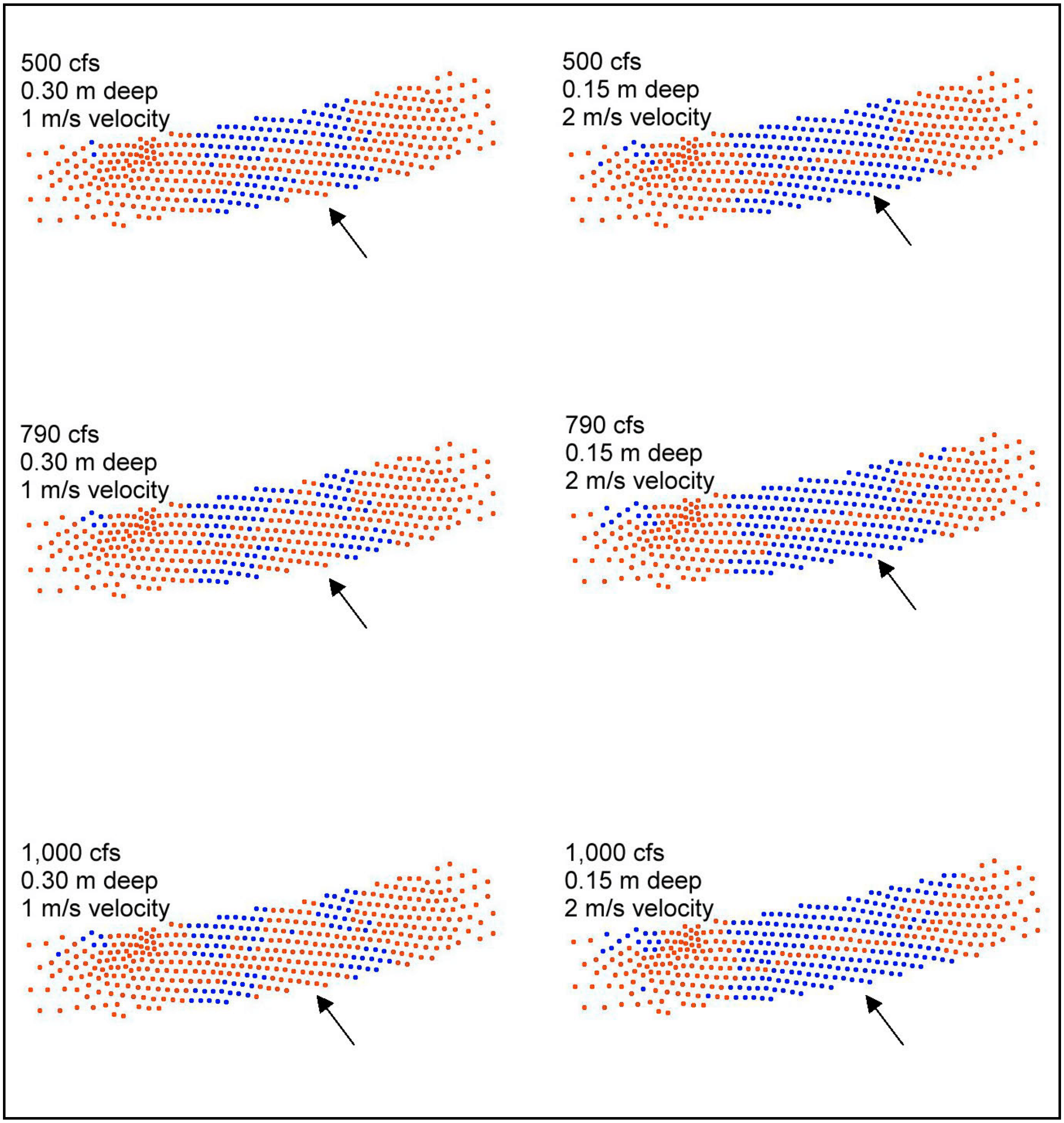


**Figure 4.4a. Fruitland model results for nodes in vicinity of rock dam. Blue-colored dots indicate nodes that are greater than or equal to indicated depth and less than or equal to indicated velocity; red-colored dots do not meet criteria. Arrows indicate flow direction.**

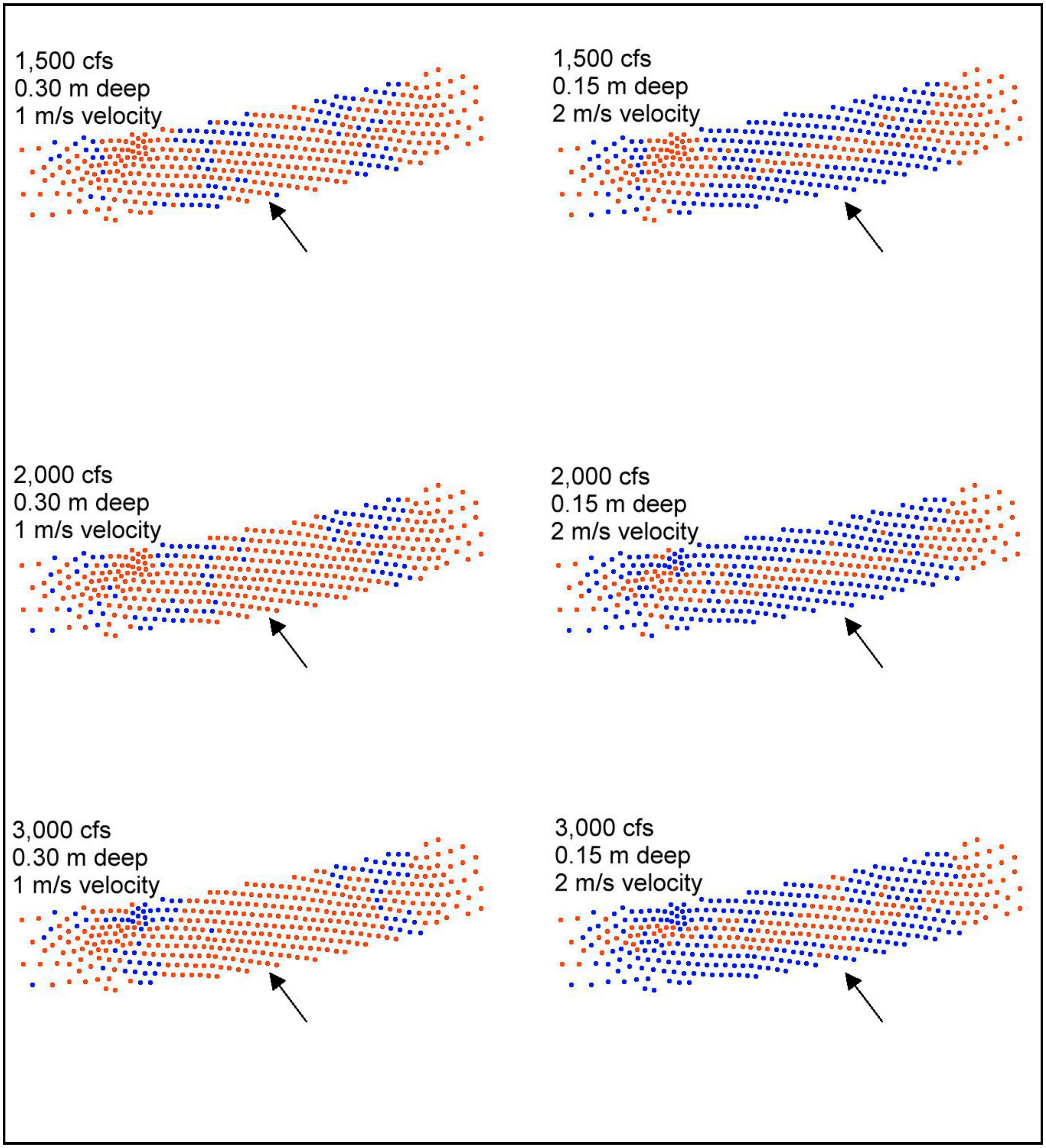


**Figure 4.4b. Fruitland model results for nodes in vicinity of rock dam. Blue-colored dots indicate nodes that are greater than or equal to indicated depth and less than or equal to indicated velocity; red-colored dots do not meet criteria. Arrows indicate flow direction.**

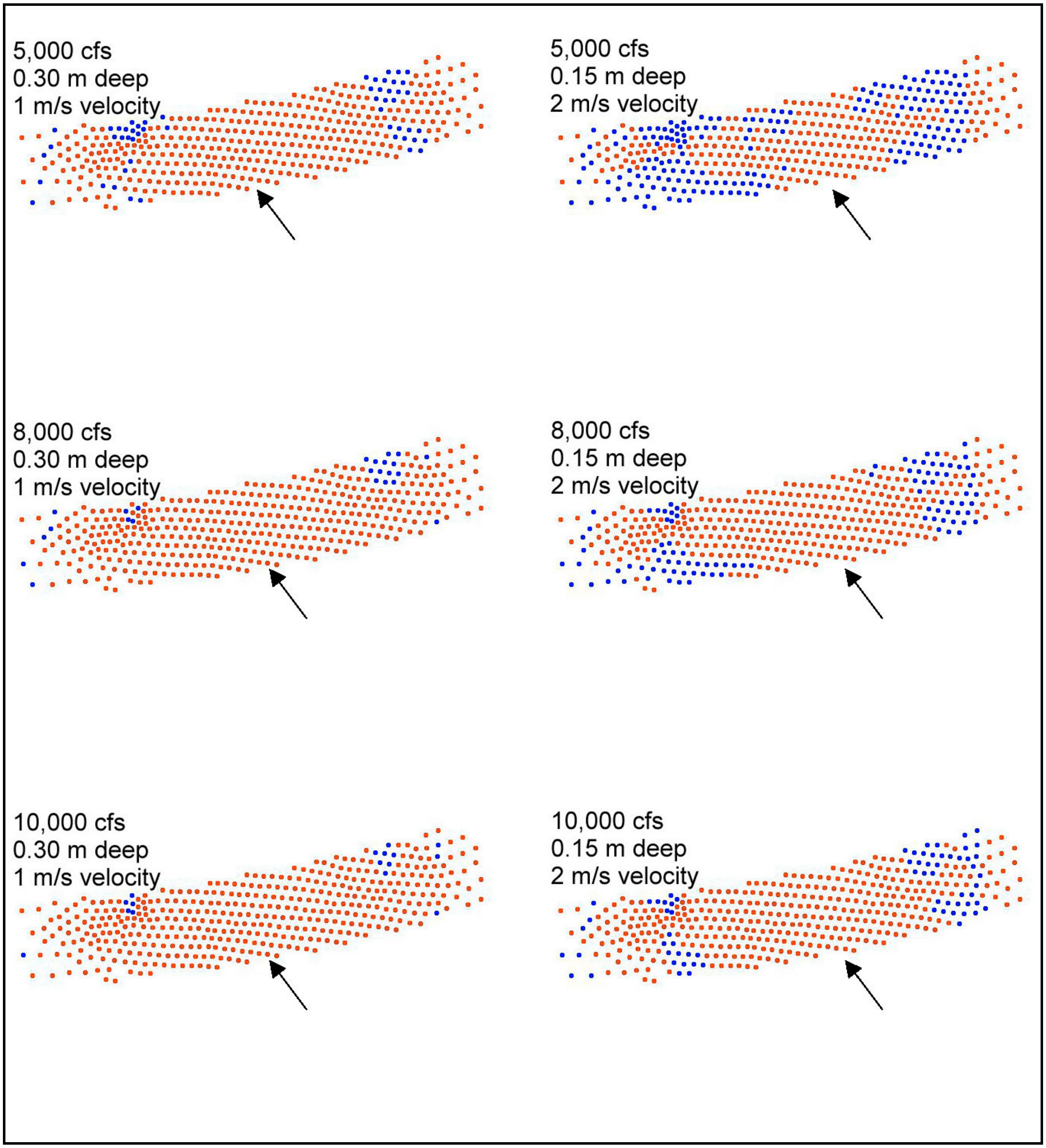


**Figure 4.4c. Fruitland model results for nodes in vicinity of rock dam. Blue-colored dots indicate nodes that are greater than or equal to indicated depth and less than or equal to indicated velocity; red-colored dots do not meet criteria. Arrows indicate flow direction.**

continuous paths of "suitable" nodes are available for migrating fish at the 500 cfs, 790 cfs, and 1,000 cfs flow levels (Figure 4.4a).

Results are fairly similar for the moderate flow levels that were modeled, but the locations of the "suitable" nodes begin to shift farther towards the edges of the rock dam (Figure 4.4b). As with the low flow results, a short gap in "suitable" nodes exists at the 1,500 cfs and 2,000 cfs flow levels when the most restrictive criteria are used. At 3,000 cfs, one continuous path of suitable nodes exists near the right side of the dam, even when the most restrictive criteria are used (Figure 4.4b). When the criteria are relaxed to 0.15 minimum depth and 2 m/s maximum velocity, continuous paths of suitable nodes are available at all three flow levels (Figure 4.4b). At 3,000 cfs, the far left portion of the rock dam becomes more completely inundated and an additional continuous suitable path becomes available in this area (Figure 4.4b).

Model results for the 5,000 cfs flow level are similar to the results for the 3,000 cfs flow level for the less restrictive depth/velocity criteria (Figures 4.4b and 4.4c). However, at 5,000 cfs, short gaps in suitable nodes appear when the most restrictive criteria are used (Figure 4.4c). For the 8,000 cfs and 10,000 cfs model runs, very few nodes meet the restrictive criteria, particularly within the upstream portion of the rock dam (Figure 4.4c). At these high discharge levels, flow velocities are high throughout the main river channel, and exceed 1 m/s in the main channel areas above and below the rock dam (Figure 4.5). However, even at these high flow levels, narrow continuous suitable paths are available along the far right side of the dam when the less restrictive depth/velocity criteria are used (Figure 4.4c). Observations of the rock dam during the high-flow (7,500 cfs) survey in June 2005 confirm that conditions along the far right side of the dam appear to meet the less restrictive passage criteria. In this area, a large eddy develops immediately below the rock dam, and velocities just above the rock dam are slowed by inundated vegetation (Figure 4.6).

In summary, all the modeled flows have at least one continuous path of suitable model nodes that meet the less restrictive criteria of 0.15 m minimum depth and 2 m/s maximum velocity. Only the 3,000 cfs model run shows a continuous path of suitable nodes when the most restrictive criteria (0.30 m minimum depth and 1 m/s maximum velocity) are used; however, all modeled discharges except 8,000 cfs and 10,000 cfs show nearly continuous paths of suitable nodes even when the most restrictive criteria are used. Based on duration analysis of the full year's hydrology, the flow ranges represented by the 8,000 and 10,000 cfs model runs only occur about 5 percent of the time (Figure 4.7, Table 4.4).

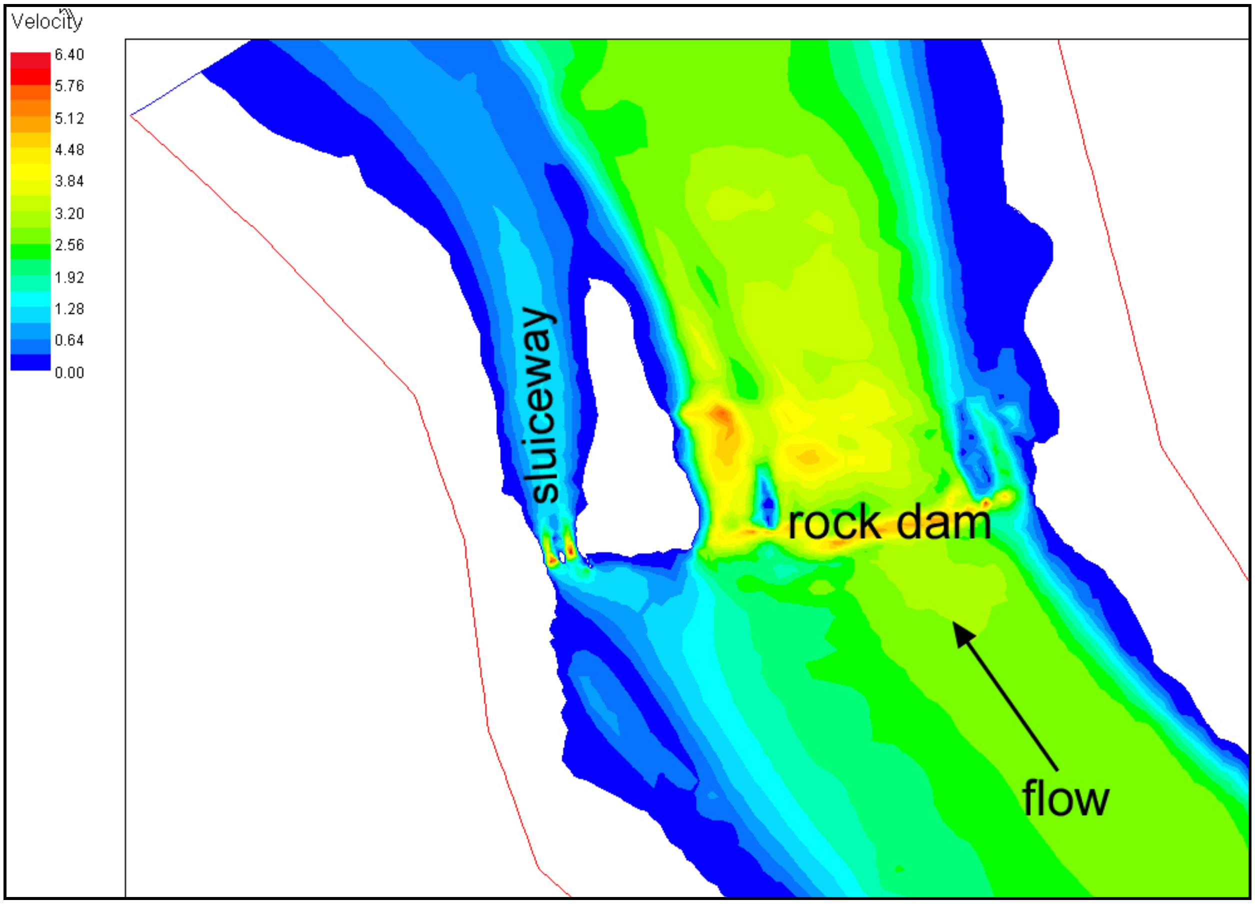


**Figure 4.5. Image of modeled velocities at Fruitland diversion at the 10,000 cfs flow level. Blue areas indicate velocities of about 2 m/s and less; green, yellow, and red areas indicate velocities greater than 2 m/s.**

**Figure 4.6. Photo showing upstream view of the right side of the Fruitland diversion rock dam at 7,500 cfs.**

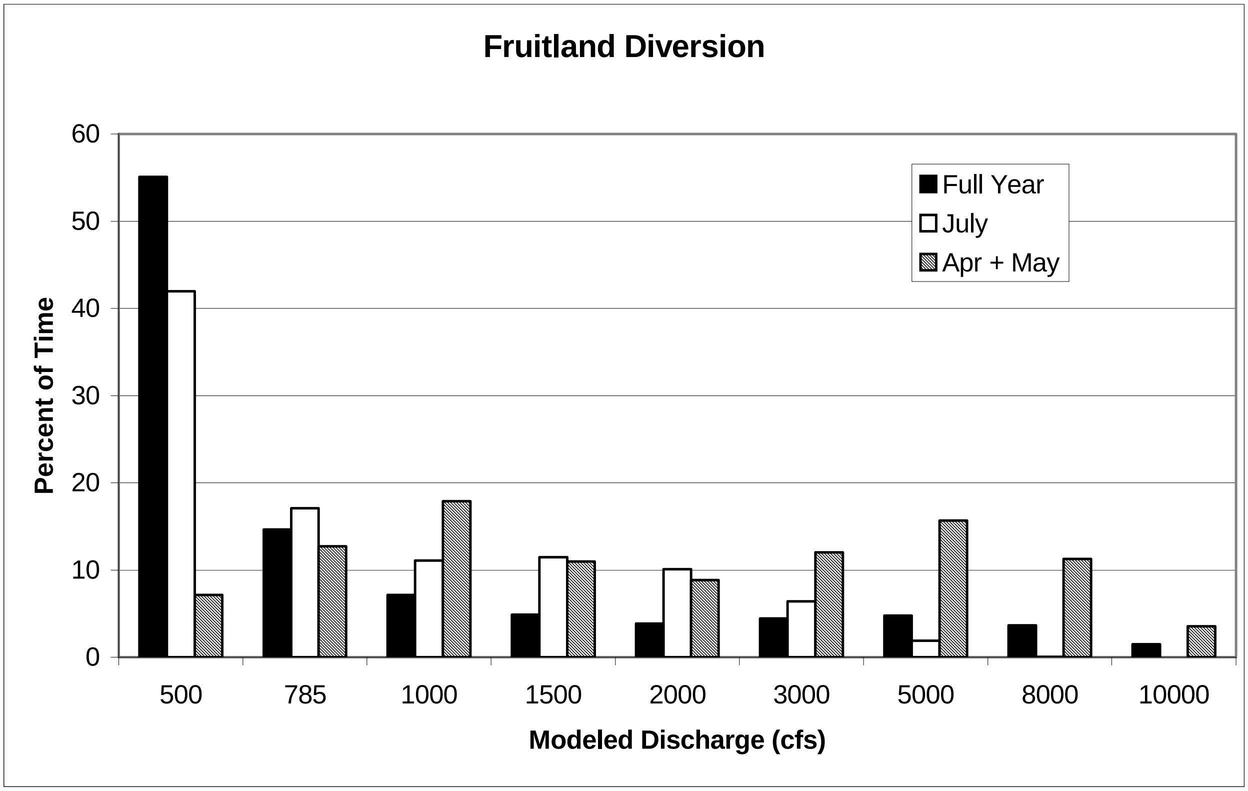


**Figure 4.7. Percent of time flows fall within ranges represented by modeled discharges at Fruitland Diversion.**

**Table 4.4. Percent of time flows fall within ranges represented by modeled discharges.**

| Modeled Discharge (cfs) | Flow Range Represented by Modeled Discharge (cfs) | Percent of Time at Fruitland Diversion | | | Percent of Time at APS Diversion | | |
|---|---|---|---|---|---|---|---|
| | | Full Year | July | April + May | Full Year | July | April + May |
| 500 | 1 - 640 | 55.1 | 42.0 | 7.1 | 49.0 | 33.8 | 6.1 |
| 780/790 | 641 - 890 | 14.7 | 17.1 | 12.7 | 17.9 | 23.1 | 7.6 |
| 1,000 | 891 - 1,250 | 7.1 | 11.1 | 17.9 | 7.8 | 9.2 | 16.8 |
| 1,500 | 1,251 - 1,750 | 4.9 | 11.5 | 11.0 | 5.7 | 15.4 | 15.4 |
| 2,000 | 1,751 - 2,500 | 3.9 | 10.1 | 8.9 | 4.6 | 10.8 | 10.0 |
| 3,000 | 2,501 - 4,000 | 4.5 | 6.4 | 12.0 | 4.2 | 6.2 | 11.6 |
| 5,000 | 4,001 - 6,500 | 4.8 | 1.9 | 15.7 | 5.9 | 1.5 | 19.3 |
| 8,000 | 6,501 - 9,000 | 3.7 | 0.0 | 11.2 | 4.2 | 0.0 | 10.9 |
| 10,000 | > 9,000 | 1.5 | 0.0 | 3.5 | 0.6 | 0.0 | 2.3 |

Assuming that adult Colorado pikeminnow and razorback sucker are capable of swimming at speeds greater than their sustained swimming speed for short distances, the rock dam at the Fruitland diversion does not appear to be a significant impediment to upstream migration. Literature-based burst speed estimates for various pikeminnow and sucker species range from 4 to 7 m/s (Table 3.1). The majority of model nodes within the rock dam have velocities less than these values at all modeled discharge levels (Tables 4.2 and 4.3). In addition, the individual boulders that comprise Fruitland dam create numerous "pockets" of lower-velocity habitat where migrating fish may be able to rest while navigating the structure. The diversity of boulder sizes and heights across the rock dam also means that the potential for orientation problems associated with large vertical drops in bed elevation is low at Fruitland diversion. For these reasons, we conclude that there does not appear to be a need to provide fish passage at Fruitland diversion.

### Potential Effects of Maintenance Practices

As discussed previously, the condition of the rock dam during our topographic survey appears to be a reasonable representation of the average condition and elevation of the dam. Thus, it is assumed that the depths and velocities shown in the hydrodynamics model outputs represent passage conditions for the rock dam in its typical state. When individual rocks shift or tumble downstream during flood flows, the gradient and elevation of the structure would be reduced, reducing flow velocities and improving passage conditions. As long as rock material is used to repair the structure, the elevation of the dam remains varied, and the maximum height of the structure is not substantially increased, we assume that normal maintenance activities at Fruitland diversion would not negatively affect fish passage. However, in order to help confirm that this assumption is valid, we recommend that photographs be taken of the rock dam immediately after maintenance/repair work is next performed.

## Model Results: APS Weir

### Analysis Techniques

The topographic mesh (DTM) used to model the APS diversion is shown in Figure 4.8, and Table 4.5 lists the specific flows modeled for the APS site. At the APS diversion, fish may be able to swim upstream either over the concrete weir or through the sluiceway. As described previously, the sluiceway gate is most commonly operated in either the fully-open or 50% closed position. In order to assess passage conditions within the sluiceway, we ran the APS diversion model with the gate in the fully open position for all discharges. Preliminary model runs indicated that the presence or absence of an obstruction (gate) within the sluiceway did not substantially affect the flow distribution between the weir and sluiceway; therefore, conditions at the weir are adequately represented by the model runs completed assuming an open sluiceway gate.

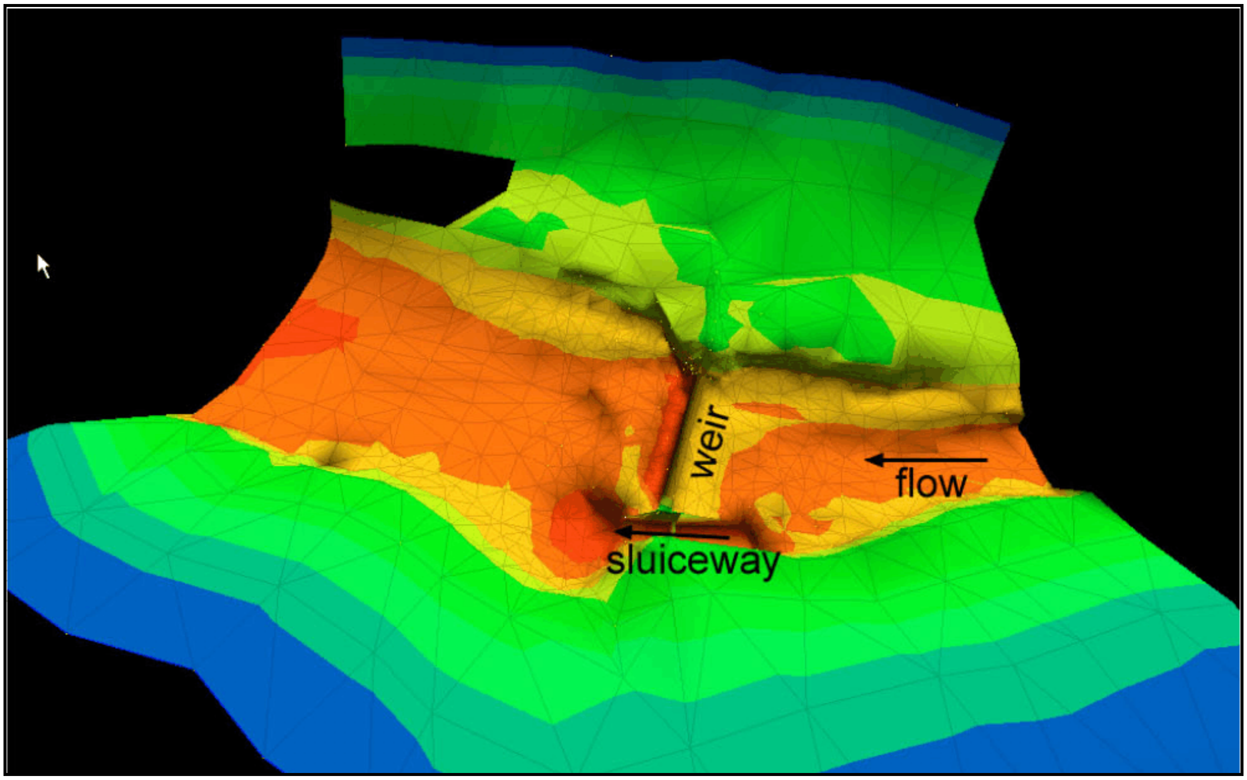

**Figure 4.8. Three-dimensional view of topographic mesh used to model APS diversion.**

**Table 4.5. Modeled flows for APS Diversion.**

| Modeled Discharge (cfs) | Discharge Through Sluiceway (cfs) | Discharge Over Concrete Weir (cfs) |
|---|---|---|
| 500 | 475 | 25 |
| 780 | 644 | 136 |
| 1,000 | 717 | 283 |
| 1,500 | 848 | 652 |
| 2,000 | 959 | 1041 |
| 3,000 | 1108 | 1892 |
| 5,000 | 1424 | 3576 |
| 7,000 | 1695 | 5305 |
| 8,000 | 1842 | 6158 |
| 10,000 | 2109 | 7891 |

To assess passage conditions at the concrete weir, a subset of model nodes forming a transect across the weir was extracted for analysis (Figure 4.9). Average water depth and velocity along the wetted portion of this transect was determined for each modeled discharge. In addition, the water surface elevation at the upstream edge of the weir was compared to the water surface elevation below the weir. Because a hydraulic jump develops along the downstream edge ("lip") of the weir which causes a localized depression in water surface elevation, a point about 10 feet below the downstream edge of the weir was used to represent the water surface elevation downstream of the weir. The total downstream distance between the upstream and downstream points examined is 20 feet. We also compared the downstream water surface elevation to the elevation of the concrete weir itself as an additional indicator of the magnitude of the vertical drop that exists at the weir at different discharges.

To examine passage conditions within the sluiceway, a subset of model nodes located within the sluiceway was extracted for analysis (Figure 4.9). Because the sluiceway is fairly narrow, with vertical walls and a flat concrete bottom, depths exceed 0.60 m (2 feet) throughout the sluiceway even at the lowest modeled discharge. Since depth does not limit passage through the sluiceway, only velocity distributions within the extracted subset of model nodes were examined to evaluate passage conditions.

## Depth and Velocity Conditions : Weir

Conditions across the concrete weir are summarized in Table 4.6. At the modeled discharges below 2,000 cfs, a vertical drop exists between the top of the weir and the downstream water surface. Although the leaping ability (or lack thereof) of Colorado pikeminnow and razorback sucker is not well documented, the literature states that northern pikeminnow are not known for their leaping ability. Razorback sucker are considered to be less athletic than Colorado pikeminnow (B. Mefford 2005, pers. comm.). Based on this limited information, we assume that the need to leap over a vertical drop of any size would constitute an impediment to upstream migration by either species. Therefore, even though average depth and velocity across the middle portion of the weir may be within a "suitable" range (depth > 0.15 m; velocity < 2 m/s), passage at the weir is considered potentially impeded at flows of 1,500 and 1,000 cfs. Passage is also impeded at flows below 780 cfs due to the lack of depth across the weir as well as the presence of a vertical drop (Table 4.6).

At flows greater than 2,000 cfs, the downstream water surface elevation becomes high enough to begin to shallowly inundate the weir. Depths across the middle of the weir are adequate (> 0.30 m), and velocities are within the range of burst speed estimates for pikeminnow and sucker species (Table 4.6, Table 3.1). However, the presence of an 8 foot drop in streambed elevation at the weir creates a strong potential for orientation problems that have been observed for razorback sucker when vertical drops exceed the length of the fish (B. Mefford 2005, pers. comm.). The large vertical drop at the weir also creates a localized depression (hydraulic jump) in the water surface along the downstream lip of the weir at flows greater than 2,000 cfs. This

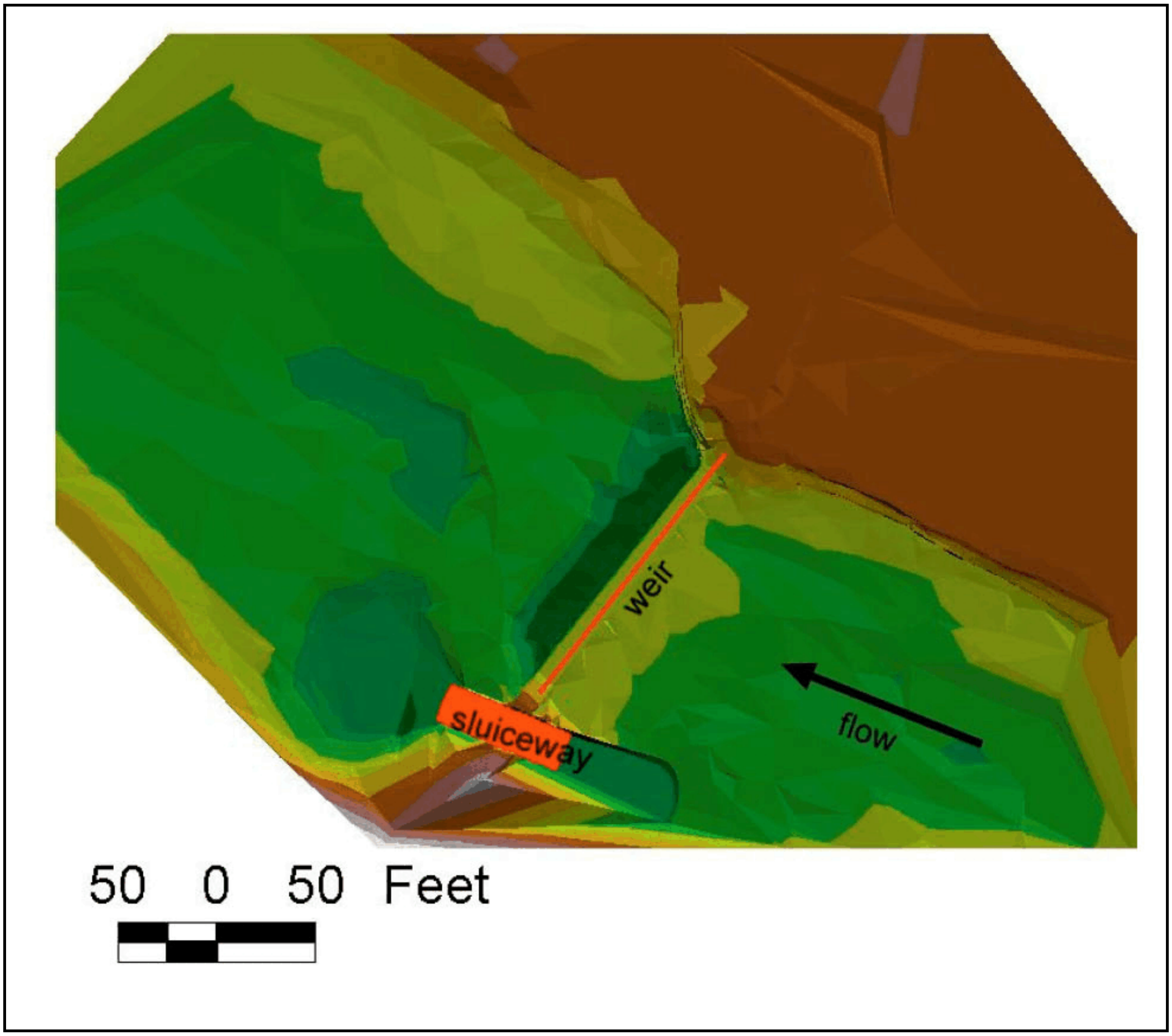


**Figure 4.9. APS model site. Bright red area indicates model nodes in sluiceway extracted for analysis; bright red line indicates weir transect extracted for analysis.**

Table 4.6. Depth and velocity conditions across the concrete weir at APS diversion.

| Modeled Discharge (cfs) | Average Depth Across Weir (m) | Average Velocity Across Weir (m/s) | Difference Between Water Surface Elevation Upstream and Downstream of Weir (m) | Water Surface Elevation Downstream of Weir Relative to Top of Weir |
|---|---|---|---|---|
| 500 | 0 | 0 | 0.45 | 0.52 m lower than weir |
| 780 | 0.12 | 0.6 | 0.52 | 0.38 m lower than weir |
| 1,000 | 0.20 | 0.8 | 0.50 | 0.29 m lower than weir |
| 1,500 | 0.26 | 1.3 | 0.46 | 0.13 m lower than weir |
| 2,000 | 0.35 | 1.7 | 0.41 | same height as weir |
| 3,000 | 0.50 | 2.2 | 0.29 | 0.28 m higher than weir |
| 5,000 | 0.75 | 2.7 | 0.27 | 0.55 m higher than weir |
| 7,000 | 0.95 | 3.2 | 0.17 | 0.89 m higher than weir |
| 8,000 | 1.04 | 3.3 | 0.17 | 0.97 m higher than weir |
| 10,000 | 1.29 | 3.8 | 0.14 | 1.24 m higher than weir |

effect reduces depths and increases velocities beyond the average values listed for the middle portion of the weir in Table 4.6. Strong vertical velocities, eddies, and turbulent currents occur in this location. Therefore, conditions along the downstream edge of the weir are not ideal for passage under any of the modeled flow conditions.

At flows of 5,000 cfs and greater, the sloped abutment to the right (facing downstream) of the flat portion of the concrete weir begins to be substantially inundated, providing a potential pathway for upstream migration that avoids the intense hydraulics at the lip of the weir (Figure 4.10). This right bank area has a smaller vertical drop in bed elevation, reducing the likelihood of fish orientation problems (right bank area adjacent to weir can be seen in top photo, Figure 3-1a). At flows of 5,000 and greater, a narrow pathway with suitable depth and velocity conditions (depth > 0.15 m, velocity < 2 m/s) emerges in this area. Assuming that adult Colorado pikeminnow and razorback sucker are capable of swimming at speeds somewhat greater than their sustained swimming speed for short distances of about 4 m (13 ft), the right side of the APS weir would most likely be passable during high flow conditions (5,000 cfs and greater).

**Figure 4.10. Photo of the APS diversion at 7,000 cfs. Photo taken from the right bank looking across the weir to the sluiceway. Note the strong hydraulic jump across middle portion of weir and the more moderate hydraulics towards the right edge of water.**

## Depth and Velocity Conditions: Sluiceway

As described previously, depth is not a limiting factor within the sluiceway area. Velocity distributions within the extracted sluiceway nodes are shown in Figure 4.11. Images of model outputs for velocity at three flows are shown in Figure 4.12. For all model runs except the 500 cfs run, the majority of nodes in the sluiceway have velocities greater than 2 m/s (Figure 4.11). In general, the lowest -velocity nodes occur along the right and left edges of the sluiceway. At high flows, lower-velocity nodes also develop in the left (facing downstream) side of the entrance to the sluiceway due to an eddy that develops along the left bank above the diversion. This effect is most apparent in the results for the 7,000, 8,000, and 10,000 cfs flow levels (Figure 4.11).

At discharges of about 2,000 cfs and less, the highest velocities occur at the downstream edge of the sluiceway, where the concrete pad ends and the bed drops into the scour hole below. A hydraulic jump develops at this location. Once flows reach about 3,000 cfs, this feature becomes less pronounced, and velocities become more consistently high throughout the middle section of the sluiceway (Figure 4.11).

Based on the model outputs, no continuous pathways with velocities less than 1 m/s are present at any of the modeled discharges. Therefore, passage through the sluiceway would require Colorado pikeminnow or razorback sucker to be able to exceed their sustained swimming speed (estimated at 1 m/s for adults) for the majority of the trip up the sluiceway. At flows of 780 cfs and greater, velocities throughout the sluiceway exceed 1 m/s everywhere or nearly everywhere. However, for all the flows modeled, 84 to 100% of the sluiceway nodes have velocities less than or equal to 4.0 m/s, which is the low-end burst speed estimate we found in the literature for adult sucker or pikeminnow. Assuming that Colorado pikeminnow and razorback sucker can swim at burst speed for distances of about 50-70 feet (15-21 m), the sluiceway may be passable at the modeled flows. However, since burst speeds can generally be maintained for only 5-10 seconds (Froese and Pauly 2004), the length of the sluiceway may present a challenge depending on the true maximum burst speed of the fish.

Although velocities within the sluiceway may be within the burst speed capabilities of Colorado pikeminnow and razorback sucker, the physical conditions within the structure are not ideal for passage. The vertical walls and smooth concrete bottom mean that no micro-habitats or potential resting areas are available for upstream-migrating fish, and velocity gradients along the edges of the structure are very sharp. This makes swimming conditions more challenging than in a channel with natural bed and bank material. Without more definitive biological data on the swimming abilities of Colorado pikeminnow and razorback sucker, it is difficult to conclusively determine whether or not the sluiceway at the APS diversion would impede passage.

As described previously, the sluiceway gate at the APS diversion is typically kept open during April, May, and June, and then partially closed when flows drop in July. Based on average monthly flow data, the gate would typically be in the fully open position when flows are greater than 2,000 cfs and in the 50% closed position when flows are less than 2,000 cfs (Figure 4.13).

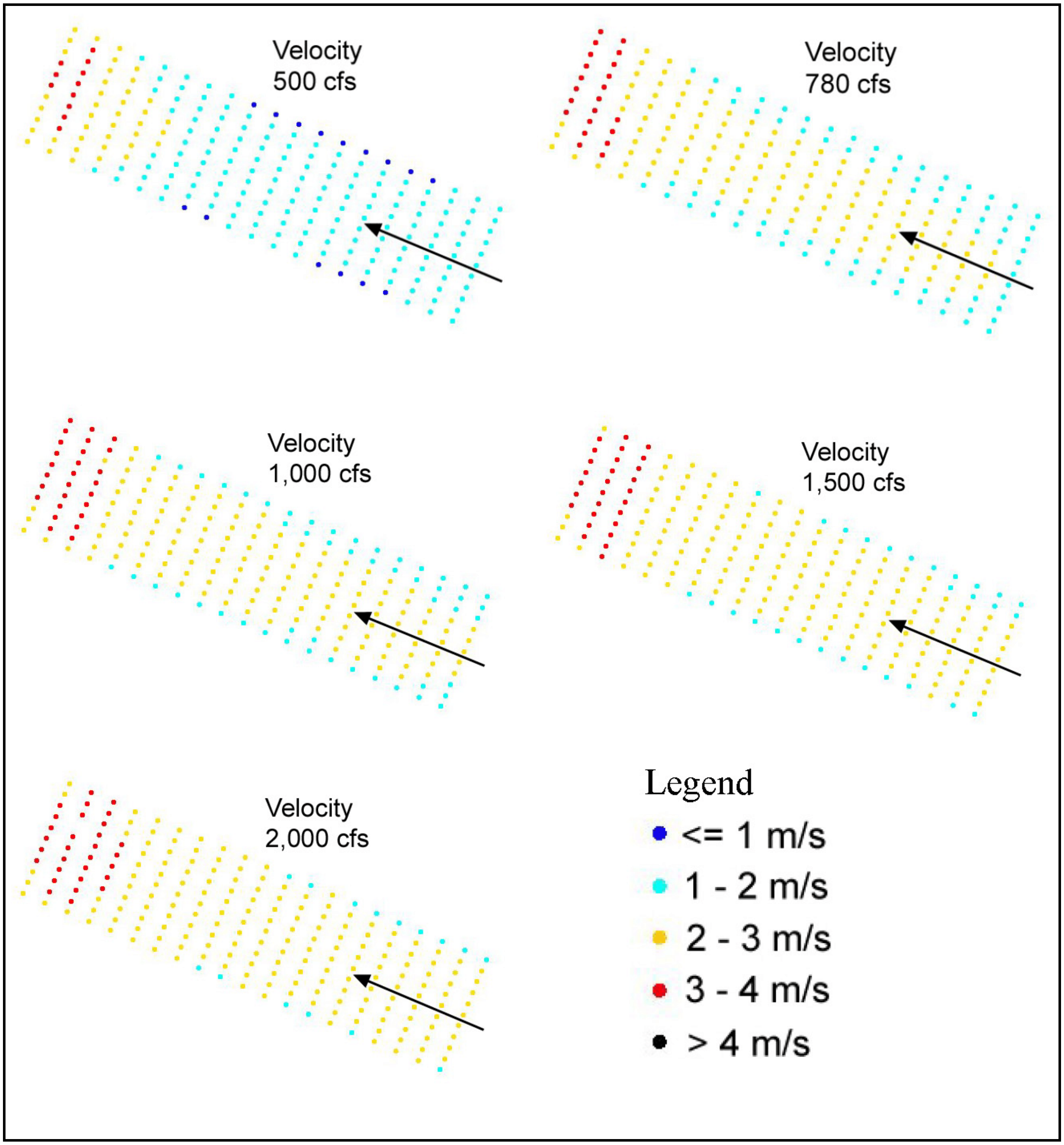


**Figure 4.11a. Velocity distributions within sluiceway at APS Diversion. Arrows indicate flow direction.**

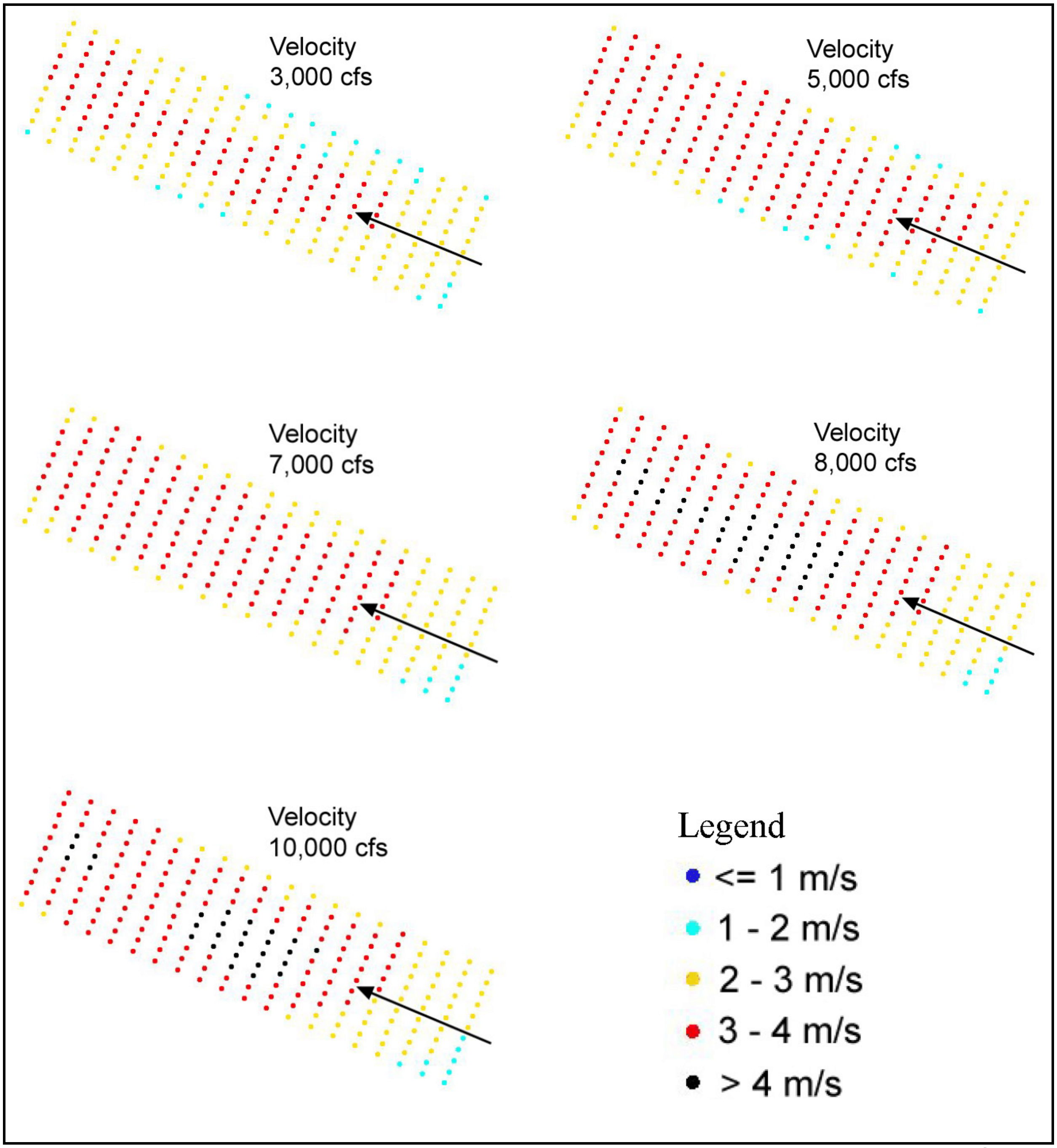


**Figure 4.11b. Velocity distributions within sluiceway at APS Diversion. Arrows indicate flow direction.**

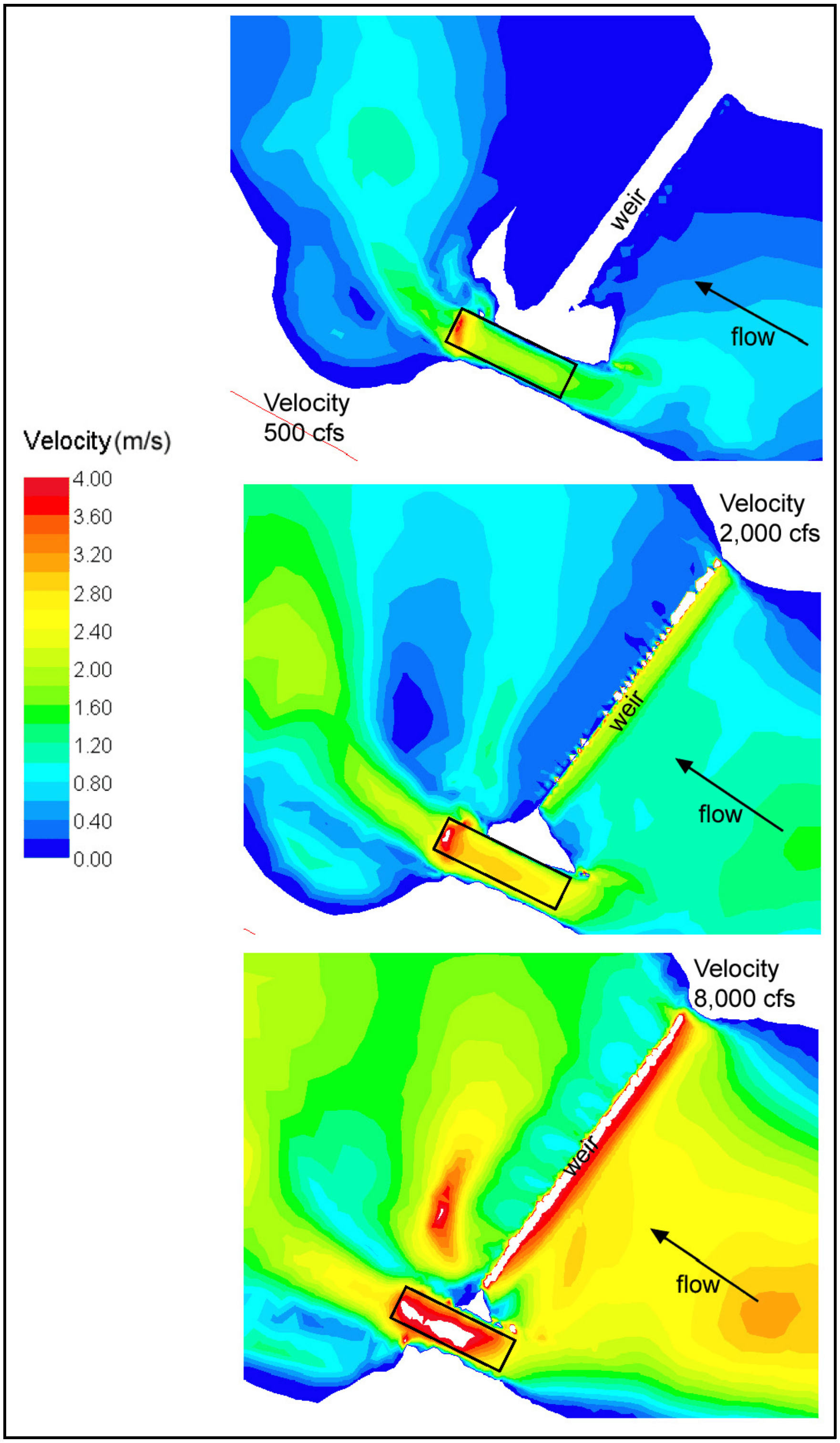


**Figure 4.12. APS diversion model outputs of velocity for the 500, 2,000, and 8,000 cfs model runs. Outlined areas indicate approximate boundary of model nodes extracted to examine conditions within the sluiceway.**

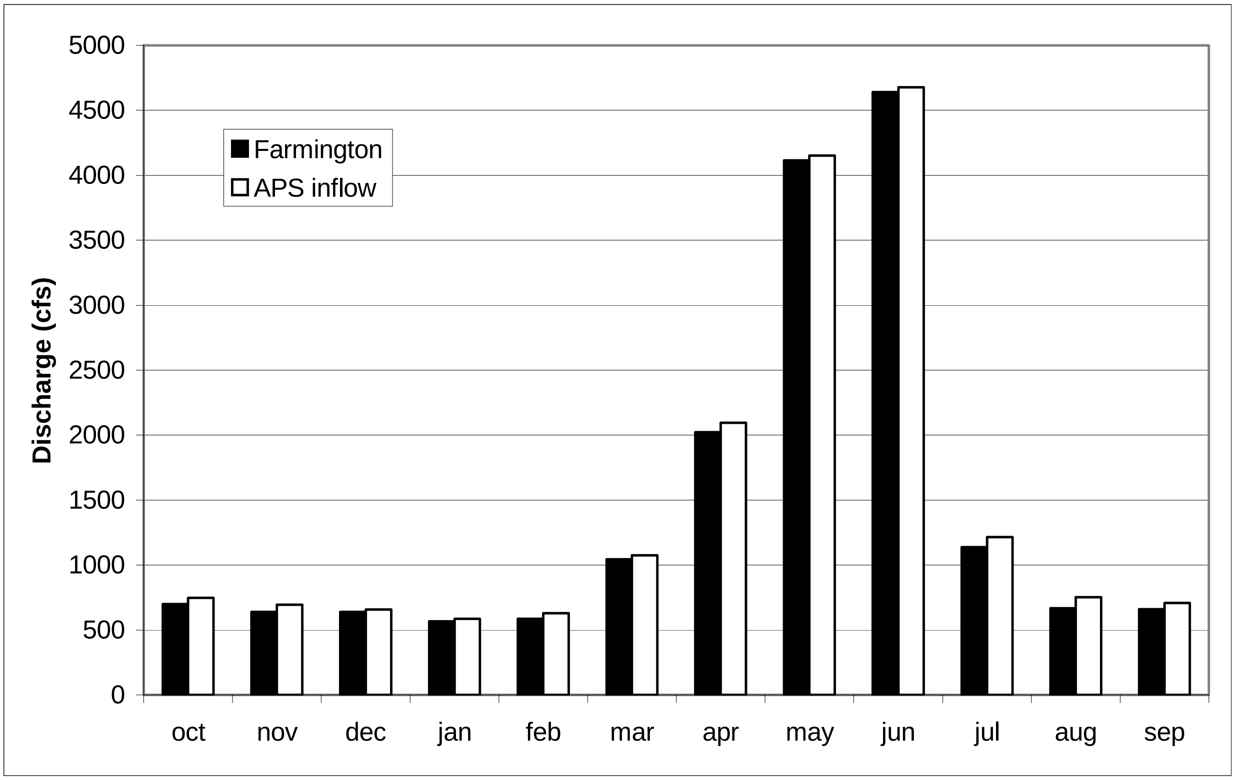


**Figure 4.13. Modeled average flows by month at the Farmington and APS inflow model nodes.**

Although detailed modeling of the sluiceway with the gate partially closed was not performed, some simple discharge calculations were completed to assess the extent to which velocities would increase if flow depth was constrained. When the gate is 50% closed, the height of the opening between the bottom of the gate and the floor of the sluiceway is 3 feet (0.91 m). For flows of 2,000 cfs and less, average velocity conditions within the central 5 meters of the sluiceway were calculated for both the open and partially-closed gate scenarios (Table 4.7). At the 1,000, 1,500, and 2,000 cfs discharge levels, velocities in the sluiceway gate area nearly double when the gate is partially closed. At these discharge levels, velocities exceed 4 m/s, which is the low-end burst speed estimate found for adult sucker or pikeminnow species. At the 780 and 500 cfs flow levels, sluiceway velocities also increase significantly when flow depth is constrained by the gate, but remain below 4 m/s (Table 4.7). Occasionally during low flow conditions, the gate is dropped below the 50% closed position, which would further compress flow depth and increase velocities under the gate. Specifically, if the gate were 80% closed, velocities under the gate would exceed 4 m/s at the 500 and 780 cfs flow levels. Therefore, depending on the specific gate position and the true burst speed capabilities of Colorado pikeminnow and razorback sucker, the sluiceway may hinder passage when the gate is partially closed.

Table 4.7. **Sluiceway velocities for different gate positions.**

| Modeled Discharge (cfs) | Average Velocity Within Central Portion of Sluiceway (m/s) | |
|---|---|---|
| | Gate Open | Gate 50% Closed |
| 500 | 1.72 | 2.92 |
| 780 | 2.06 | 3.78 |
| 1,000 | 2.22 | 4.21 |
| 1,500 | 2.50 | 4.87 |
| 2,000 | 2.64 | 5.53 |

## Summary

At flows of 5,000 cfs and greater, model results indicate that passage would be possible along the sloping right abutment of the weir (Table 4.8). This conclusion is based on the assumption that fish would be able to swim at speeds of 2 m/s (i.e., double their sustained swimming speed) for a short distance. At flows of 500 cfs and less, the dry conditions across the top of the weir would most likely impede passage, even if fish were able to leap up over the vertical drop at the lip of the weir (Table 4.8). For all other discharge levels, it is difficult to make definitive conclusions about fish passage at the weir given the lack of biological information about the leaping abilities of Colorado pikeminnow and razorback sucker. If the assumption that neither species is able to leap over a vertical drop is valid, then passage at the weir would be impeded at the 1,500, 1,000, and 780 cfs flow levels. However, the fact that in October, 2002 a Colorado pikeminnow was documented to have passed the APS Diversion when flows were in the range of 700 cfs may suggest that Colorado pikeminnow do have some leaping ability – but, there is no way to know whether that particular fish passed over the weir or through the sluiceway. If the assumption that the 8 foot vertical drop in the streambed at the weir causes orientation problems is valid, then passage at the weir would also be impeded at the 2,000 and 3,000 cfs discharge levels. However, while these orientation problems have been observed in bottom-oriented sucker species, it is not known to what extent Colorado pikeminnow would be affected. Again, the fact that a Colorado pikeminnow has been documented to have passed the APS Diversion under low flow conditions suggests that the vertical drop in the bed may not prevent passage – but again, there is no way to know whether that particular fish passed over the weir or through the sluiceway. Basically, for discharge levels greater than 500 cfs and less than 5,000 cfs, the only thing that can be definitively stated about passage at the weir is that conditions are not ideal for passage. Specifically, conditions at the weir do not match the criteria used to design passable fishways for native species. Those criteria specify that vertical water surface drops be avoided; that vertical drops in bed elevation not exceed 0.12 m (0.4 ft); and that velocities not exceed 1.2 m/s (5 ft/s) (B. Mefford 2005, pers. comm.).

**Table 4.8. Summary of passage conditions within the weir area at APS Diversion.**

| Modeled Discharge (cfs) | Passage Conditions at Weir | | |
|---|---|---|---|
| | **Passage Condition** | **Reason(s)** | **Biological Assumption(s)** |
| 500 | impeded | 1. no flow depth across weir<br>2. vertical drop<br>3. vertical drop in bed | 1. lack of ability to leap across dry weir<br>2. lack of vertical leaping ability<br>3. orientation problems |
| 780 | may be impeded | 1. vertical drop<br>2. vertical drop in bed | 1. lack of vertical leaping ability<br>2. orientation problems |
| 1,000 | may be impeded | 1. vertical drop<br>2. vertical drop in bed | 1. lack of vertical leaping ability<br>2. orientation problems |
| 1,500 | may be impeded | 1. vertical drop<br>2. vertical drop in bed | 1. lack of vertical leaping ability<br>2. orientation problems |
| 2,000 | may be impeded | 1. vertical drop in bed | 1. orientation problems |
| 3,000 | may be impeded | 1. vertical drop in bed<br>2. velocities at weir lip exceed low-end burst speed estimate (4 m/s) | 1. orientation problems<br>2. lack of ability to swim faster than 4 m/s |
| 5,000 | passable | 1. passable depth and velocity conditions along right bank | 1. ability to swim at 2x sustained speed for brief (4m) distance |
| 8,000 | passable | 1. passable depth and velocity conditions along right bank | 1. ability to swim at 2x sustained speed for brief (4m) distance |
| 10,000 | passable | 1. passable depth and velocity conditions along right bank | 1. ability to swim at 2x sustained speed for brief (4m) distance |

Similarly, the only thing that can be definitively stated about passage through the sluiceway is that conditions are not ideal for passage at any discharge level (Table 4.9). To navigate the sluiceway with the gate open, fish would need to swim at velocities between 2 and 4 times greater than their sustained swimming speed for a distance of 15 to 21 meters. Although these velocities are within the burst speed estimates for Colorado pikeminnow and Sacramento sucker, the estimates were made by applying a general mathematical formula to limited sustained speed information (Table 3.1). Without more information on the true burst speeds and burst speed endurance of Colorado pikeminnow and razorback sucker, it is difficult to know to what degree passage may be impeded (or not) within the sluiceway. The documented October 2002 passage by a Colorado pikeminnow suggests that passage is possible – but it is unknown whether the fish navigated the weir or the sluiceway. In addition, even if adult Colorado pikeminnow are able to navigate the sluiceway during low flow it is unknown whether passage would be possible for razorback sucker or for Colorado pikeminnow of a different size or gender. Studies have found

Table 4.9. **Summary of passage conditions within the sluiceway at APS Diversion.**

| Modeled Discharge (cfs) | Gate Position | Passage Conditions in Sluiceway | | |
|---|---|---|---|---|
| | | Passage Condition | Reason | Biological Assumption |
| 500 | open or 50% closed | may be passable | velocities less than low-end burst speed estimate (4 m/s) | ability to swim at burst speed for moderately long (15-21 m) distance |
| 780 | open or 50% closed | may be passable | velocities less than low-end burst speed estimate (4 m/s) | ability to swim at burst speed for moderately long (15-21 m) distance |
| 1,000 | open | may be passable | velocities less than low-end burst speed estimate (4 m/s) | ability to swim at burst speed for moderately long (15-21 m) distance |
| | 50% closed | may be impeded | velocities at gate exceed low-end burst speed estimate (4 m/s) | lack of ability to swim faster than 4 m/s |
| 1,500 | open | may be passable | velocities less than low-end burst speed estimate (4 m/s) | ability to swim at burst speed for moderately long (15-21 m) distance |
| | 50% closed | may be impeded | velocities at gate exceed low-end burst speed estimate (4 m/s) | lack of ability to swim faster than 4 m/s |
| 2,000 | open | may be passable | velocities less than low-end burst speed estimate (4 m/s) | ability to swim at burst speed for moderately long (15-21 m) distance |
| | 50% closed | may be impeded | velocities at gate exceed low-end burst speed estimate (4 m/s) | lack of ability to swim faster than 4 m/s |
| 3,000 | open | may be passable | velocities less than low-end burst speed estimate (4 m/s) | ability to swim at burst speed for moderately long (15-21 m) distance |
| | 50% closed | may be impeded | velocities at gate exceed low-end burst speed estimate (4 m/s) | lack of ability to swim faster than 4 m/s |
| 5,000 | open | may be passable | velocities less than low-end burst speed estimate (4 m/s) | ability to swim at burst speed for moderately long (15-21 m) distance |
| 8,000 | open | may be passable | velocities less than low-end burst speed estimate (4 m/s) | ability to swim at burst speed for moderately long (15-21 m) distance |
| 10,000 | open | may be passable | velocities less than low-end burst speed estimate (4 m/s) | ability to swim at burst speed for moderately long (15-21 m) distance |

considerable variability in swimming ability based on age and gender (B. Mefford 2005, pers. comm.). In summary, based on our modeling results, it appears that passage up the sluiceway would be the most likely to be impeded under a high discharge/partially closed gate scenario, and passage would be the least likely to be impeded under a low discharge/open gate scenario.

During April and May, when razorback sucker typically spawn, flows equal or exceed 5,000 cfs more than 30% of the time (Figure 4.14). Therefore, spawning razorback sucker would be able to successfully pass around the right side of the weir every one out of three years, on average. In addition, since the sluiceway gate is typically kept open in April and May, spawning razorback sucker may be able to pass through the sluiceway even if passage is impeded at the weir, if the 4 m/s burst speed estimate is accurate and can be maintained through the length of the sluiceway. However, during the remainder of the year when flows are lower and the sluiceway gate is kept partially closed, conditions may impede passage by razorback sucker (Table 4.8).

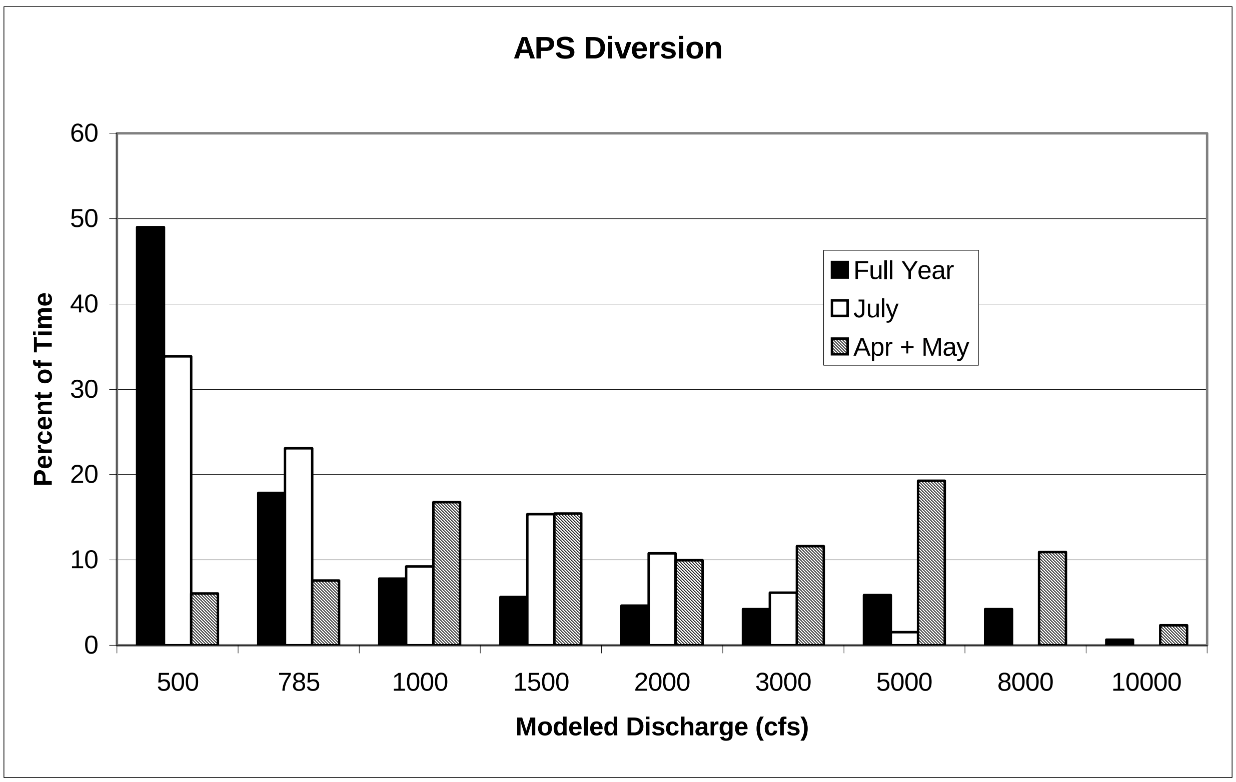


**Figure 4.14. Percent of time flows fall within ranges represented by modeled discharges at APS Diversion.**

During July, which is the typical spawning period for Colorado pikeminnow, the average flow is 1,250 cfs. Flows are only in the 5,000 cfs and greater range 1.5% of the time, and the sluiceway gate is typically partly closed (Figure 4.13, Figure 4.14). Therefore, in most years, the conditions at the APS Diversion have the potential to impede spawning Colorado pikeminnow from reaching 16 miles of potentially high quality habitat upstream of the diversion and within the species' designated critical habitat (Table 4.8).

# 5. DISCUSSION

## Interpretation of Model Results

### Two-Dimensional Modeling

There are limitations to using a two-dimensional hydrodynamics model to represent hydraulic conditions where substantial vertical velocity patterns occur, such as flow at the crest and immediately downstream of a weir (e.g., flow over APS weir) and flow through a submerged gate (e.g., the sluiceway gates at both APS and Fruitland Diversions). However, at the APS Diversion the model did a good job of matching measured water surface elevations upstream and downstream of the weir at both low (780 cfs) and high (7,000 cfs) flow conditions. This provides some assurance that the model results are accurate throughout the range of modeled discharges. We were also able to model the sluiceway with the gates open and provide velocities through the open sluiceway.

Although conditions within the sluiceway at the APS Diversion were not modeled under the partially closed (submerged) gate scenario using the two-dimensional model, the sluiceway and gate dimensions are known, along with the total sluiceway discharge. Therefore, the velocity estimates in Table 4.7, which are based on the standard continuity equation (flow = width x depth x velocity) should provide a reasonably accurate representation of average velocity conditions in the gate area.

The rock dam at the Fruitland Diversion provides less difficulty for a two-dimensional model as flows through the rock dam are primarily two-dimensional. The Fruitland Diversion site was calibrated (roughness calibration) to low flow (790 cfs) conditions with a partial flow block in the sluiceway to simulate the typical gate settings. Water surface elevations over the rock dam accurately matched the measured data. Flow was simulated over the range of discharges using this model setup. The Fruitland Diversion sluiceway, however, proved to be difficult to model at high flows with the gates fully open. Therefore, comparison of the measured high flow water surface data with modeled values was limited to the area along the right side of the island below the rock dam, and agreement was generally good. We are confident that the model results generated at the rock dam over the range of discharges is a good representation of depths and velocities experienced by fish.

### Biological Interpretation

The greatest hindrance to interpreting the model results is the fact that the swimming abilities of Colorado pikeminnow and razorback sucker are not definitively established. No literature was found specifically documenting the burst speeds, minimum depth requirements, or leaping abilities of either species. No published swimming ability information of any kind was found for razorback sucker. Because of the paucity of biological data, determination of the flow conditions that hinder or allow passage must rely on a number of assumptions.

At the Fruitland Diversion, model results suggest that the rock dam structure does not significantly hinder fish passage, expect perhaps at very high discharges (8,000 cfs and greater). This conclusion is based on the assumption that Colorado pikeminnow and razorback sucker are able to swim at speeds of up to 2 m/s for brief distances. This assumption seems reasonable, especially given the fact that the boulder material would provide some small velocity refuges within the structure.

At the APS Diversion, model results suggest that passage would be possible along the right bank side of the weir during high flows (5,000 cfs and greater). As with Fruitland Diversion, this conclusion is based on the assumption that adult Colorado pikeminnow and razorback sucker are able to swim at speeds of up to 2 m/s for brief distances. At flows less than 5,000 cfs, conditions at the APS Diversion do not match the vertical drop and velocity criteria known to be passable (i.e., used in designing fishways for native species), but it is uncertain to what extent the conditions would impede passage. It is not possible to resolve this uncertainty without more definitive biological data on the swimming ability, leaping ability, and orientation behavior of different ages and genders of Colorado pikeminnow and razorback sucker. In the absence of these data, it can only be concluded that the APS Diversion has the potential to impede passage at flows less than 5,000 cfs. This means that in most years, there is the potential for spawning Colorado pikeminnow to be impeded by the APS Diversion and unable to access 16 miles of upstream habitat. Similarly, in years with low spring runoff, there is the potential for spawning razorback sucker to be impeded by the APS Diversion and unable to access upstream habitat.

## Recommendations

If it is a priority for the SJRIP to eliminate the concern over fish passage at the APS Diversion, then steps should be taken to improve passage conditions at the structure. One possible option could involve re-installing a sloping rip-rap apron along the downstream edge of the weir. This would reduce the vertical drop in bed elevation and the vertical water surface drop that currently exists at flows below 2,000 cfs. This measure would improve passage conditions under moderate flow conditions; however, at flows below 780 cfs, passage would still be impeded by the lack of flow depth across the weir (unless a notch were also cut into the weir). Because flows are in this low range nearly 50% of the time (Figure 4.14), passage would still potentially be hindered during much of the year. In addition, a very large amount of rock would be needed to convert the existing 8 foot drop into a slope flat enough to meet passable fishway criteria, which require slopes of 5:1 or flatter (B. Mefford 2005, pers. comm.). The rip-rap would also be susceptible to future scour, and would likely require some maintenance over time. It may be possible to selectively rip-rap only a portion of the weir to help limit costs.

Other possible options for improving passage could involve constructing an artificial "side channel" around the weir (similar to the PNM fishway), or using a combination of notching the existing weir and providing a rip-rap ramp at the notch to eliminate the low-flow vertical drop in water surface elevation. If passage improvements are pursued, we recommend that a variety of options be explored in more detail, and that they be evaluated in terms of short- and long-term costs, feasibility (i.e., would a particular option be compatible with the APS diversion facility and pumping needs), and relative passage benefits.

Additional biological studies would be helpful in determining the validity of the various assumptions listed in Tables 4.8 and 4.9. Laboratory experiments in swimming tubes or flumes could be conducted to better determine the swimming abilities (sustained speed, burst speed, burst speed endurance) of Colorado pikeminnow and razorback sucker. Ideally, experiments should be conducted in a variety of water temperatures with both female and male fish, as well as with fish of different sizes and ages. Studies to evaluate whether Colorado pikeminnow experience orientation problems at vertical drops in bed elevation could also be pursued. Results from these studies may allow for more definitive conclusions to be made about whether or not the velocities within the APS sluiceway hinder passage. However, if it is a priority for the SJRIP to eliminate the concern over passage at the APS Diversion, we recommend that studies to explore the feasibility of various passage improvement options be pursued without delay. Biological studies would provide helpful information, but should not be considered a prerequisite for pursuing passage improvements.

At this time, we do not recommend that additional modeling or field velocity measurements be pursued in the sluiceway gate area. Although such measurements may improve the accuracy of the existing velocity estimates, the results would still not be conclusive given the absence of biological data. If and when reliable burst speed and endurance estimates become available, it may be useful at that time to pursue more detailed sluiceway velocity measurements. If this is pursued, a combination of empirical velocity measurements and 3D flow modeling and/or scale modeling could be used to obtain very accurate velocity data

At the Fruitland Diversion, there does not appear to be a need to provide improved fish passage. However, we recommend that the rock dam be visited and photographed immediately after maintenance work is next performed on the structure to confirm that the maintenance activities do not substantially alter the height or composition of the dam relative to the conditions documented in this study.

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