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Hydraulic Laboratory Report HL-2010-04

Summary of Hydraulic Studies for Ladder and Flume Fishway Design-Nimbus Hatchery Fish Passage Project

American River Division – Folsom Unit
Central Valley Project, CA

U.S. Department of the Interior
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14. ABSTRACT
Nimbus Fish Hatchery was built below Nimbus Dam to mitigate for lost spawning habitat by construction of Folsom and Nimbus Dams. The barrier weir, required to guide fish into the hatchery ladder, has experienced major, costly damage over the years. The goal of the project is to replace the existing in-river weir with a flume and ladder that will meet hatchery goals for fish, open up more river habitat, reduce operation and maintenance costs, and enhance the overall environment.
This report documents the many previous designs, including in-river designs, and the decisions made that accompany the final design of the flume, ladder, and rock weir entrance channel for the Nimbus Fish Hatchery. Results of hydraulic studies that were conducted to support the fisheries needs are given.

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

Acknowledgments

I would like to acknowledge the contributions of the Project Manager, Mr. David Robinson of Reclamation's Central California Area Office for his tireless efforts in coordinating all the many facets of the design and providing funding. Mr. Robinson's skills brought a lengthy project to completion by leading the design data collection and environmental process effort, and forming the TSC design team and the Interagency Fish Passage Technical Team (IFPTT). Mr. Steven Robertson led the TSC design team and always provided support to the fisheries needs and timely designs. The participants of the IFPTT provided much needed input during the design process, ensuring that the fishway design would be appropriate. In particular, I would like to thank Mr. George Heise, California Department of Fish and Game, for providing great insight based upon his broad experience. Mr. James Higgs provided the Flow 3D numerical modeling efforts discussed in this report and documented as a draft report in the reference section. Mr. Brent Mefford provided invaluable consultation on the fishway designs.

Hydraulic Laboratory Reports

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Executive Summary

This report summarizes the designs from many years of work that have occurred in the effort to determine the best way to replace the aging Nimbus Fish Hatchery Barrier Weir. The existing weir is a rock foundation angled across the American River below Nimbus Dam. The barrier is formed by adding a metal framework and pickets atop the rock foundation during Chinook season to guide the fish to a ladder for entry to the hatchery.

Many planning and engineering studies have been completed [1, 2, 6, 7, 8, and 9]. Some of the early ideas led to physical hydraulic model studies [3, 4] and a specification and drawings for a new in-river structure [5] that was later determined to not meet resource agency goals.

The final design for the ladder and flume fishway was completed through a collaborative effort that included Reclamation's Central California Area Office (CCAO), Denver Technical Services Center (TSC), Mid-Pacific Regional Office, and the Interagency Fish Passage Technical Team (IFPTT) comprised of State and Federal Fisheries Resource Agencies. The goal of the final design was to meet the fish hatchery targets for gathering fish while providing a safe, low maintenance structure that minimally impacted the river. This goal was accomplished with collaborations between the IFPTT and the Reclamation design team as the design progressed from the Project Alternative Solutions Study (PASS) [6], through the Value Engineering Studies [7, 8], numerical hydraulic studies [11, 12] to the final issuance of the Specifications and Drawings for the Ladder and Flume Fishway [10]. Final design information is summarized in the body of this report with additional meeting notes, discussions, and design trail, documented in detail in the appendices.

Background

Nimbus Fish Hatchery, figure 1, is located on the American River approximately 1/4 mile downstream of the Nimbus Dam, in Fair Oaks, California. The facilities were built in the 1950's to compensate for spawning areas of salmon that were blocked by construction of the Folsom and Nimbus Dams. The barrier weir is shown in figures 1 and 2 with the piers standing above the rock weir without the pipe racks and pickets that form the existing barrier.

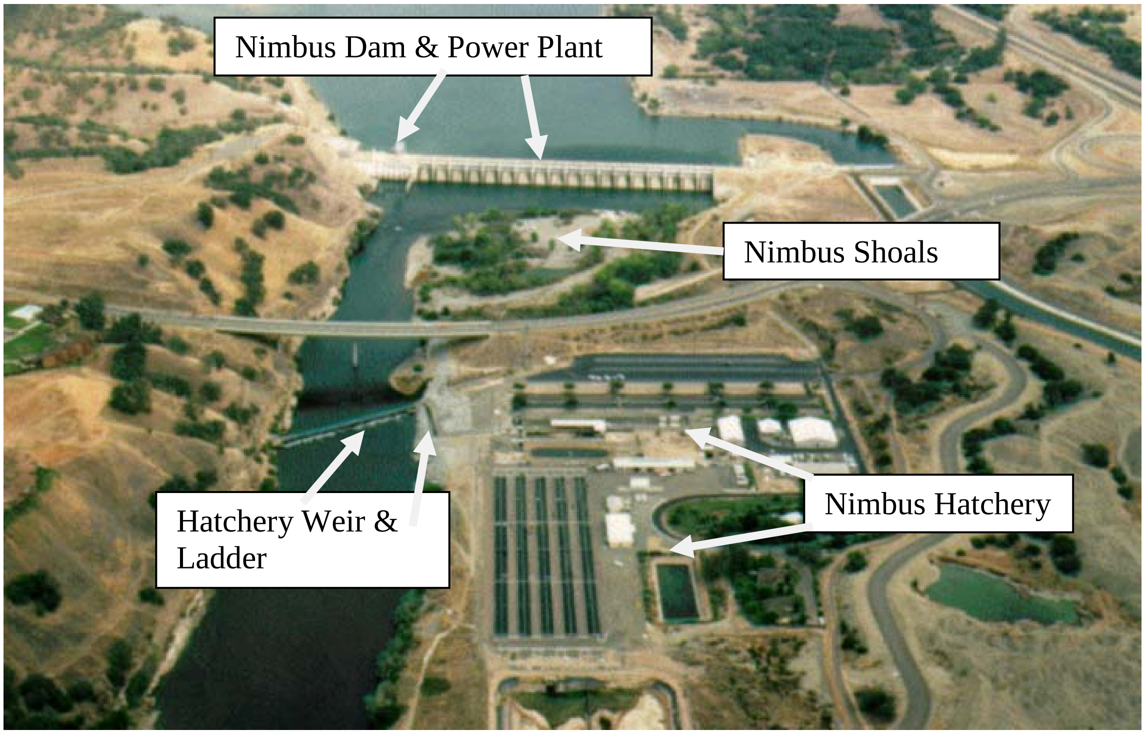

Figure 1. - Overall view of Nimbus Dam with the existing hatchery weir and facilities. Nimbus Shoal area below the dam is a predominant feature formed by a relatively flat rock outcropping.

The Nimbus Hatchery Barrier Weir is an aging structure that has often needed repairs to the foundation, figure 3, and requires annual flow reductions that impact Endangered Species Act (ESA) listed fish to install and remove the support structure and pickets that provide the seasonal barrier. There are also worker and public safety issues associated with the operations and maintenance of the structure. The potential solutions to the problems have been extensively evaluated and analyzed in a series of planning efforts.

The goal of the project is to replace the existing in-river rock weir with something that will meet the needs of the fish hatchery target goals, be safe, have limited O&M, and meet as many of the other agency and community needs as possible.

Year 1996 - Concept study performed to modify the existing hatchery rock barrier weir [1].

Year 1999 – Value Analysis Workshop performed to revisit alternatives for modifying or replacing the existing in-river hatchery rock barrier [2].

Year 2001 – Physical hydraulic model study performed of the floating bar rack from the 1999 Value Analysis Workshop report [3].

Year 2002 – Designed the "In-River Weir with Bypass and New Entrance" [4, 5]. Many issues including cost, complexity, and upstream passage of juveniles caused the project to be shelved.

Year 2003 – New alternatives presented to extend a flume and ladder fishway from the hatchery to the base of Nimbus Dam and Environmental Assessment started.

Year 2006 - Project Alternative Solutions Study (PASS) performed to collaboratively select with the stakeholders an alternative to take to final design [6].

The preferred alternative "Rectangular Flume with Standard Ladder Entrance, (Alternative 1B PASS meeting notes [6]" was approved by Reclamation's Central California Area Office for design.

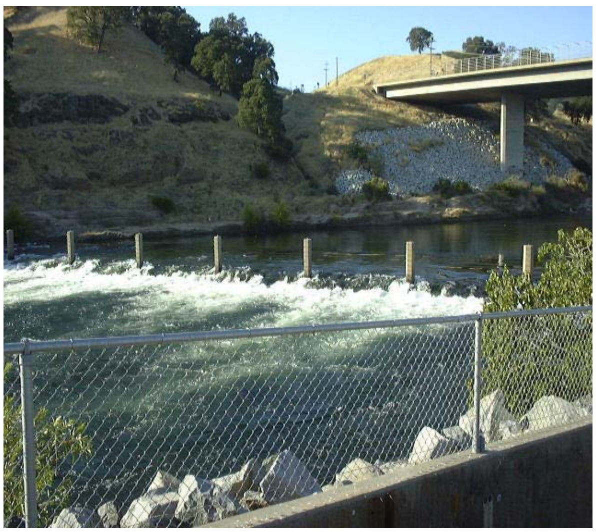

Figure 2. - Existing Nimbus Hatchery in-river rock weir at the base of the concrete ladder into the hatchery. The weir is shown operating under a typical flow rate without the picket barrier installed. In the background is the Hazel Ave. Bridge.

Figure 3. - Damage to the Nimbus hatchery rock weir after a flood event. This is costly and requires emergency action to get it repaired in time for spawning season. (Note: Flow is from left to right.)

Interagency Fish Passage Technical Team Charter

David Robinson, CCAO, was the project Leader for the Nimbus Hatchery Fish Passage Project below Nimbus Dam on the American River near Sacramento, CA. One portion of the project was to provide oversight and coordination between the Design Team and the Resource Agencies to ensure that the facilities designed would meet project goals. An Interagency Fish Passage Technical Team (IFPTT) was developed and successfully provided guidance at key points throughout the project according to the following charter:

"An Interagency Fish Passage Technical Team (IFPTT) will be assembled that will be used by the project team to discuss and resolve any fish passage technical issues related to the design. The Design Team will utilize the Interagency Team to conduct independent review of designs as part of the project quality management plan at key points throughout the schedule. The Interagency Team will include technical experts by invitation from the National Marine Fisheries Service, California Department of Fish and Game, U.S. Fish and Wildlife Service, and California Department of Water Resources. Kathy Frizell, Technical Services Center, Denver, CO, email khfrizell@usbr.gov *will be the IFPTT coordinator and has the responsibility to assist in planning, conducting, and closing out the design review process by the team.*

The technical review team will be asked to help review the fish passage criteria used in the design, assist in identifying modifications or measures to maximize passage and fish use, and to work with biologists and hatchery personnel to ensure that an effective and efficient structure is constructed. We expect that this team will meet 3-5 times over the course of the next year for half day meetings. We will be providing the team with design criteria, drawings, and other material ahead of the meetings that will require some additional time for review. We appreciate your support for this effort to ensure our mutual interests in managing the hatchery and lower American River fish resources are met.

The objective of the first meeting of the IFPTT is to provide input and come to a consensus on the design criteria for the proposed fishway from the hatchery with a concrete flume with ladder entrance near the base of Nimbus Dam as outlined in the PASS notes. This important meeting will provide design data for the final design phase in order to assure that the designed fishway will meet the stakeholder and agency requirements prior to taking the design from the concept phase into final design."

The IFPTT members were:

Reclamation

David Robinson, Project Manager, drobinson@usbr.gov, (916) 989-7179
Kathy Frizell, Hydraulic Engineer, khfrizell@usbr.gov, (303) 445-2144
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California Department of Fish and Game

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U.S. Fish and Wildlife Service

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Other parties occasionally met with the group; however, the base team's participation was consistent throughout the project.

The baseline concept that the IFPTT started with was a result of the PASS study [6] developed in July 2006 after many different attempts over the years to find an adequate solution for maintaining, rehabilitating, or replacing the existing Nimbus Hatchery weir [1, 2, 3, 4 ,and 5].

The VE Team, required by Reclamation policy to review any design over a certain cost, also provided comments about the baseline design in July 2008 [7]. These comments were then presented to the IFPTT for review and discussion, Appendix A. Reclamation's Design Team then produced an Accountability report [8] to address the VE team's recommendations that also included concurrence by the IFPTT.

The results of discussions and suggestions made by collaborations with the IFPTT are summarized in this report with the detailed meeting notes provided in Appendix A.

Introduction

Reclamation's CCAO and the TSC staff developed a project management plan in 2007 to perform design phases in an organized manner with active participation by all concerned stakeholders. A major component of the design was the formation of the Interagency Fish Passage Technical Team (IFPTT) to provide design suggestions and oversight throughout the project.

The baseline design involved abandoning the in-river structure and replacing it with a rectangular flume with standard ladder entrance that extended from the existing Nimbus Hatchery, underneath Hazel Ave Bridge, and across the Nimbus Shoals to the tailwater pool at the base of the dam. The concept design phase continued through FY08 and a Value Engineering Study (VE) was performed that proposed moving the concrete ladder upstream and adding a rock fishway at the downstream end for the entrance [7]. The IFPTT was asked to comment on VE proposal No. 5 or the fishway entrance channel throughout the summer of 2008 and into February 2009 when the concept design phase was completed (Appendix A).

Final design started in May 2009 and the VE accountability report [8] and Design, Estimating, and Construction (DEC) review [9] completed. Final design was completed in spring 2010 with review and finalizing of specifications. Construction of the project will depend upon available funding. After construction of the new fishway a year or two of evaluation will be performed by the hatchery personnel and Reclamation as agreed to during the final meeting of the IFPTT in February 2010 (Appendix A). After operation is deemed successful, the existing barrier weir will be removed under separate contract.

This project has been ongoing for years and many decisions have been made along the way. The intent of this document is to compile the many planning efforts, hydraulic model studies, meeting and teleconference notes, decisions, collaborations, and design suggestions that have occurred relating to the fisheries and hydraulic aspects of the project. The body of the report summarizes the hydraulic and fisheries-based design features and provides appropriate references. Appendix A contains the detailed documentation of the design process. Appendix B contains output from HEC-RAS modeling of the flume and weirs. Structural design details will be covered separately in other documentation.

Objective

The objective of this report is to summarize the hydraulic and fisheries designs and the communications between the CCAO, the TSC, Mid-Pacific Regional Office, and agency members of the IFPTT during the course of the final design effort for the Ladder and Flume Fishway - Nimbus Fish Hatchery Project. The project has been a collaborative effort between engineering and fisheries disciplines to achieve the best possible structure that will meet the needs of the project. The hydraulic design features for the flume, weirs, conventional concrete ladder, and rock ramp design with auxiliary and fish attraction flow, are provided under various river discharges and subsequent water surface elevations at the toe of Nimbus Dam.

Description of the Final Fishway Design

Figure 4 shows a plan view of the final design layout and elements of the fishway as of April 2010. The general description of the fishway is a rectangular concrete flume with traditional weir and pool ladder to drop elevation onto the Nimbus Shoals area with a rock channel entrance. All elevations are given in NAVD88 datum.

The fishway begins with a tie-in to the existing hatchery flume leading to a rectangular concrete flume (approximately 1,200-foot-long) from the hatchery to the east side of the existing Nimbus Shoals access road. The flume will be 6 feet wide with 6 foot high walls. A flow rate of about 25 ft^3/s will produce a velocity of about 1.0 ft/s with a flow depth of about 4 feet in the flume section.

The first 300 ft of the flume across the hatchery yard will have a slope of 0.001 and run by the planned visitor center. Minimal provisions will be designed for a future visitor's plaza near the flume tie-in location in the hatchery yard area. Three stoplog weirs will control the flow depth. This will lead to about another 400 foot long flume portion through the remainder of the hatchery yard and under Hazel Avenue Bridge with a flat gradient. The next approximately 500 feet long portion will be a series of 100 feet long pools with a 0.5 foot drop (0.005 feet/foot gradient). The flume section will be broken into pools by overtopping flow weirs with bottom orifices formed to 1.25-ft-wide by 1.5-ft-high with stoplog boards. Additional angles could be installed to make 50-ft-long pools. The flume section will be covered with fencing for public safety.

A bridge deck section and roadway will be constructed across the flume to allow maintenance equipment access to the existing hatchery ladder entrance and public access to the Nimbus Shoals area.

A conventional concrete fish ladder exactly like the existing ladder, with a 12:1 slope, 9-ft-wide with 4-ft-high stoplog weirs without orifices, is located at the end of the flume. The ladder entrance is at invert El. 80.2 ft with the top of the walls at the entrance at El 90.7 ft. A pipe gate with dimensions of 24 inches wide by 18 inches high will be located at the ladder entrance to allow regulation of the numbers of fish into the hatchery as is done now. Once the ladder walls are submerged the fishway is non-functional.

Auxiliary flow will be supplied to the rock channel in a rock-lined transition area between the entrance to the concrete ladder and the top of the rock channel. An existing, but unused, 42-inch concrete pipeline from Lake Natoma to the Nimbus Fish Hatchery will be tapped to provide between 10 and 40 ft^3/s additional flow. Flow will enter through a diffuser located on an angled wall that will produce flow velocities less than 1 ft/s.

An approximately 300-ft-long rock lined channel will be excavated from the transition area to the Nimbus tailwater pool at El. 76 ft. The channel will begin with a trapezoidal crest section at El. 84 ft that will control the elevation of the water in the transition pool. The rock channel will have a trapezoidal shape with 4 ft bottom width and 2:1 side slopes on a 2.5 percent slope. A total flow (flume plus auxiliary) of 25-65 ft^3/s will be available. The channel will be lined with 6 inch to 12 inch rock (ungrouted) and pools for fish passage will be formed with six boulder chevron weirs at 40 foot spacing. Large rock bollards will be located along the channel to prevent vehicle access into the rock channel.

A concrete structure foundation will be constructed along the perimeter and near the end or entrance of the trapezoidal rock channel. This will accommodate a lower pipe gate structure and access steps, grating, and a guardrail if deemed necessary at a future date.

An 18 inch attraction pipe will be embedded in the south embankment of the rock channel to provide potential attraction flow amounts of 5 – 20 ft^3/s if needed. The pipe end will be set at centerline El 82.1 ft and upturned by 5 degrees with flow control by manual insertion of orifice plates.

The final drawings of the design are contained in the final specification for the Ladder and Flume Fishway [10].

Figure 4. - Final layout of the Ladder and Flume Fishway – Nimbus Fish Hatchery Project, April 2010.

Design Flows and Tailwater Pool Elevations

Design flows were determined from the PASS team to be from 500-5000 ft^3/s during the seasons Chinook and Steelhead would be migrating upstream and then be kept in river until they are ready to spawn [6]. The Chinook season is from approximately September 15 through December with Steelhead season starting in January and extending until through April. The IFPTT thought it would be best to expand the capability of the facility to get fish to the hatchery under somewhat higher flows, given that once the concrete weir and pool ladder walls are submerged the ladder is “non-functional”. The ladder walls will begin submerging once the water level exceeds El. 90.7 ft.

The discussion centered on under what flow the Nimbus Shoals, thus structures, would inundate and what was the corresponding flow exceedence? This led to an investigation of the USGS gage data, the tailrace data collected near the power plant by CCAO, the elevation of the Shoals, and the datum under which the data were reported. The other complicating factor is that the new fishway would be built and need to operate for at least one, maybe two, seasons before the existing weir in the river would be removed. This meant determining the effect of weir removal on the upstream water surface elevations to ensure adequate depth of pool at the new fish entrance.

Flow Exceedences

Design flow exceedences for fish passage structures are generally determined based upon National Oceanic and Atmospheric Agency criteria for exceedence during upstream migration periods. The Nimbus fishway is not leading to spawning habitat but to the hatchery; therefore, this criteria did not necessarily need to be met, but provided guidance for decision-making. In addition, structural survival of the fishway structures was needed during flood stage. These two project goals led to potentially selecting different design flow exceedences. Flow for structural survival was addressed separately from fishway criteria using safe levee capacity and alignment of the fishway to avoid high flow velocities.

Fishway design flows are usually based upon available USGS records for the migrating seasons of interest based upon the species. In this case the Fair Oaks gage, No. 11446500, located just downstream from the weir was used to obtain monthly and daily values for the entire year on the American River below Nimbus Dam. The monthly flow exceedences for 5, 50, and 95 percent were determined from the data set as shown in figure 5. Several different data sets were used with varying lengths of record. This is because the American River flows are highly regulated and changes have been made over the years regarding operations. This includes the adoption of a minimum stream flow requirement for the American River below Nimbus Dam of 250 ft^3/s.

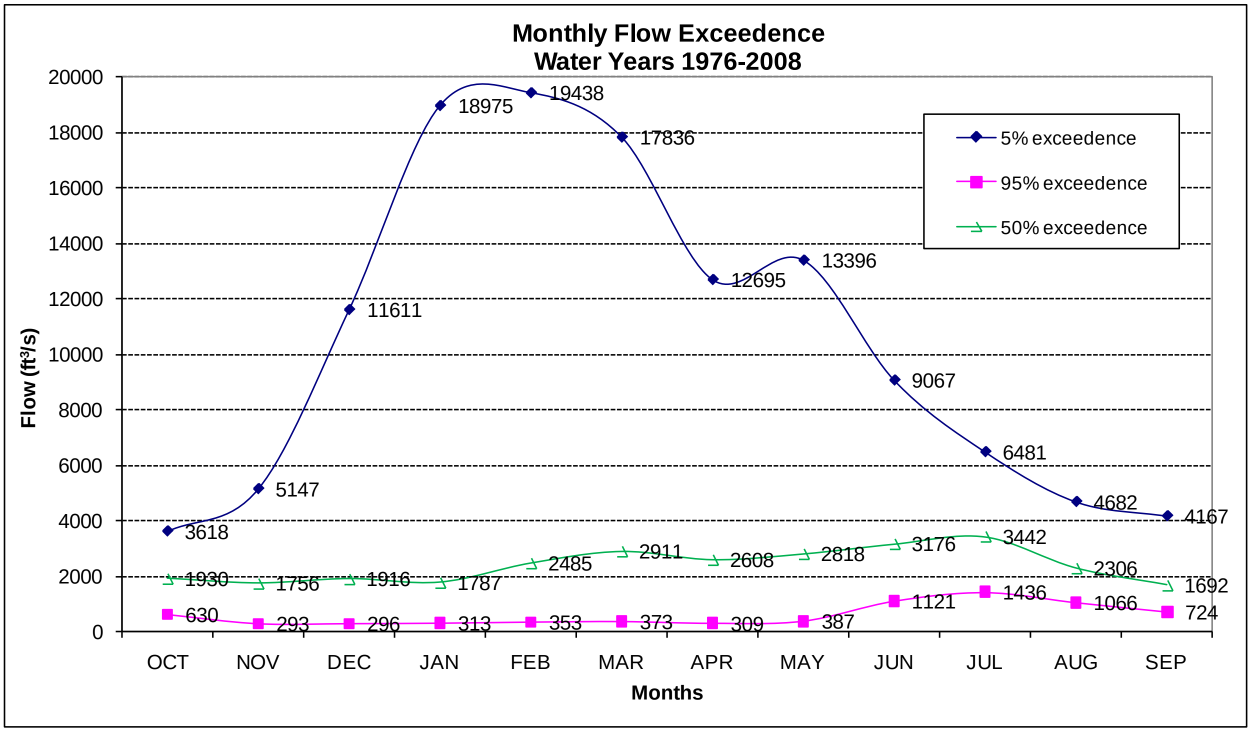

Figure 5. - Monthly flow exceedence for the American river below Nimbus Dam.

Table 1 shows the final design values chosen for each season with additional discussions and data given in documents in Appendix A. The months of September, November and December were used in the computation of exceedences for the Chinook season. The months of January through April were used in the computation of exceedences for the Steelhead season. The minimum stream flow value of 250 ft^3/s was used for the 95 percent exceedence, not the monthly flow data due to the minimum flow requirement. This value would produce a conservatively low water surface elevation at the fishway entrance.

Table 1. - Design flow values for the fishway based upon monthly flows.

Flow Exceedences	Discharge (ft^3/s) Chinook season	Discharge (ft^3/s) Steelhead season	Discharge (ft^3/s) Design values
Highest monthly 5%	11,611	19,438	20,000
Highest monthly 50%	1,930	2,911	1,930
Lowest monthly 95%	293	309	250*

*CCAO reported as minimum stream flow requirement

The design flow selections were based on the best available data at the time and input from all parties. The IFPTT did not think that NMFS criteria for fish ladder design needed to be strictly followed because this was not a ladder providing passage beyond a dam. Central California Area Office provided data on minimum stream flow requirements that might be instilled in the future, even though historically flows this low in the river have not occurred. It was felt that the normal flow during the Chinook period should be used for the basic design. The higher flow of nearly 20,000 ft^3/s would provide adequate Steelhead passage after partial inundation of the Shoals. As such this was a well thought out effort that should provide adequate numbers of fish to the hatchery throughout the entire length of both Chinook and Steelhead seasons.

Tailwater Pool Elevation Investigations

With the design flow values specified, the next phase was to determine under what discharges various key design conditions would occur. The design concerns are centered around water surface elevations in the tailwater pool and over Nimbus Shoals both for the current operation with the existing weir and then after weir removal post construction and evaluation of the new fishway.

The design issues included:

- Depth at the fishway entrance
  - Potentially greater depth with the weir, but concern about being too shallow after weir removal.
- Submergence of the fishway during large flow events
  - Higher likelihood with the weir, lower likelihood without the weir in the long term
- Power production
  - Potentially reduced depth at the tailrace with weir removal

The target depth at the rock fishway entrance is 4 ft after weir removal. Flows causing submergence of the Shoals leading to partial then full submergence of the rock fishway, then submergence of the concrete ladder walls must be determined. Submergence of the concrete ladder walls would make the ladder non-functional. The target discharge for submergence of the concrete ladder walls would be near that of the highest expected flows during the Steelhead season. Hopefully, submergence of the concrete ladder would occur after the target flow of 20,000 ft^3/s. Finally, power production could be affected, by potentially increasing maintenance if cavitation is caused with low tailrace water surfaces after weir removal.

The current operation with the existing hatchery weir is considered temporary, with emphasis placed on the long-term affect of water surfaces and depths on the fishway operation after weir removal of primary importance. To address these water surface elevation design issues knowledge of several items is required for the current operating condition with the existing hatchery weir including:

- USGS data from the river gage below the weir,
- Tailrace data from the power plant operators
- Datum information and the necessary conversion to NAVG88

Information required after removal of the weir:

- Tailwater and tailrace pool water surface information

- Bathymetry in the river upstream from the existing weir

Datum Conversion

The USGS gage below the hatchery weir and the power plant tailrace data is based upon NGVD29 datum which is1929 survey data. Gage datum is 71.53 feet above sea level NGVD29. The design data and construction drawings for the dam and power plant utilized the 1929 datum also. A new project datum was established in 1988. Topography was given in 1988 elevations, but there has been great confusion about how elevations are being reported. The conversion from the 1929 datum to the 1988 datum is equal to:

$$NAVD88 = NGVD29 + 2.34$$

All data for this project are now referenced using the 1988 datum including elevations of the topography, existing and the new fishway structures, the USGS gage data, and the tailwater and tailrace pool water surface elevations.

Bathymetry Upstream from the Existing Weir

Bathymetry was obtained in April 2008 [11] for use as design data and construction of the fishway entrance, figure 6. The fishway entrance would need to be excavated through the higher contours on the bank, but it does appear that adequate depth would then be attainable depending upon the minimum flow. These data also turned out to be useful in determining a high point in the river channel topography located below the power plant. Figure 6 shows the high contours in yellow and orange below the power plant at an elevation of about 78.5 ft. These data were used in the numerical modeling effort to determine water surfaces in the tailrace pool, after weir removal, and potential velocity patterns in the pool near the fishway entrance.

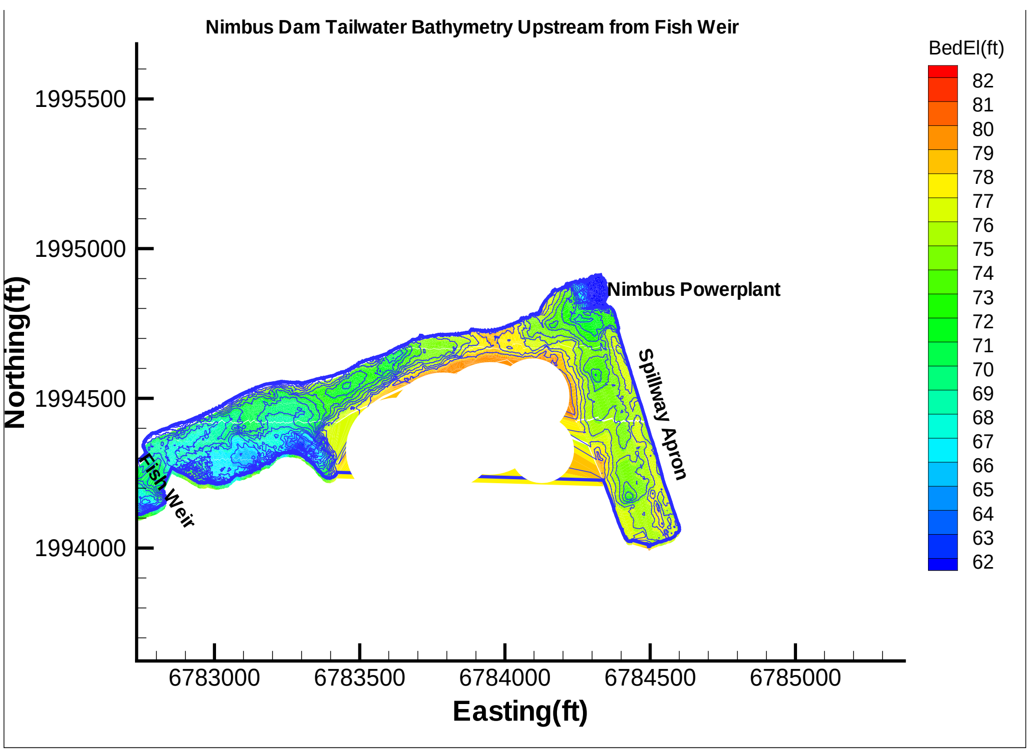

Figure 6. - Bathymetry below Nimbus Dam upstream from the existing hatchery weir, April 2008.

Resulting Water Surface Elevations

The USGS gage location is downstream from the discovered high bathymetry elevations below the power plant tailrace, the narrow river section under Hazel Ave Bridge, and the existing weir. Therefore, this section measures and shows only the influence from wherever the control is downstream and does not reflect any of the localized flow phenomena upstream. These data have been converted to NAVG88 datum, but it is difficult to draw any conclusions from the USGS gage data that are useful upstream near the power plant tailrace or the fishway entrance. However, the gage data is clearly several feet lower than the tailrace data gathered with the weir in the river. Figure 7 shows a drop across the existing hatchery weir even under a flow rate of 35,000 ft3/s which indicates a downstream controlling feature below Nimbus Dam for flows up to at least this level.

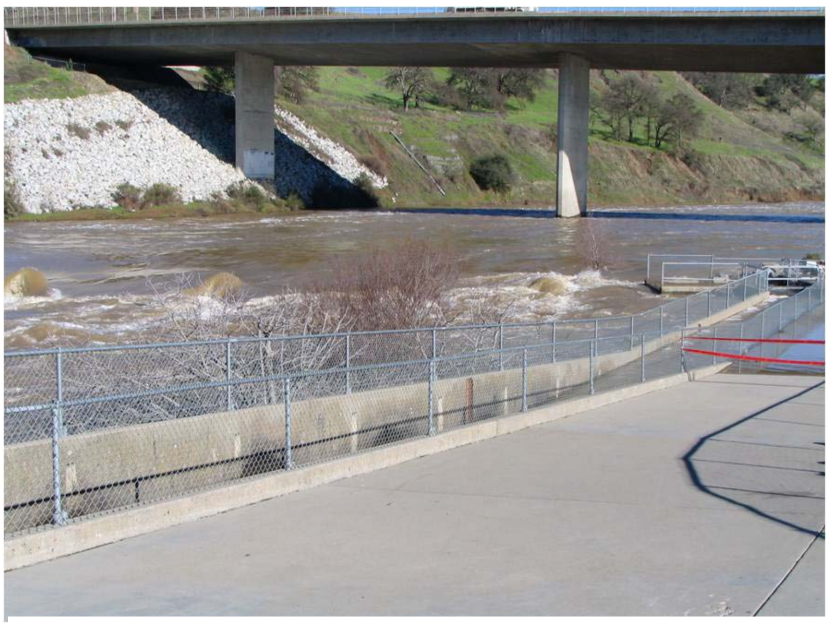

Figure 7. - Photo of 35,000 ft^3/s passing over the existing hatchery weir. A portion of the walkway and ladder are submerged to the right of the photo. Hazel Ave. Bridge is shown in the background.

The power plant needs appropriate water surface elevations very near the draft tube release in the tailrace. There is concern that once the existing weir is removed, the draft tubes might not be submerged enough to provide smooth operation or cavitation may occur [email from John Brooks to Steve Robertson, 5/20/08, Appendix A]. The values from the original turbine specification, pre-weir, compared to the post weir water surface elevations show about a 2 ft increase in water surface elevation is needed for appropriate operation.

Flow 3D numerical modeling was conducted to assist with determining tailwater pool elevations after removal of the existing hatchery weir. The weir was removed and the topography input to the model elevation 74 ft. The elevation of 74 ft was selected by the design team because it appeared to match existing topography and be appropriately low enough to provide adequate depth in the river. (The final elevation for grade after weir removal will be determined under a later design effort looking specifically at weir removal post construction and operation of the new fishway.) Numerical modeling was performed for the six flow rates corresponding to:

- Minimum river releases from an operational standpoint or 250 ft^3/s,
- Normal flow expected during the Chinook season or 50 percent exceedence level of 1,930 ft^3/s,
- Maximum flow expected during Steelhead season or 95 percent exceedence level of 20,000 ft^3/s,
- Three cases of high flow, 66,667, 115,000, and 160,000 ft^3/s for investigation of structural survival.

Figures 8-13 show the numerical modeling results with water surface elevations. The areas where the water surface elevations show a large change, represented by significant color boundaries, are the areas of flow control change for the various flow rates investigated. The tailrace data points were selected from the results of these simulations.

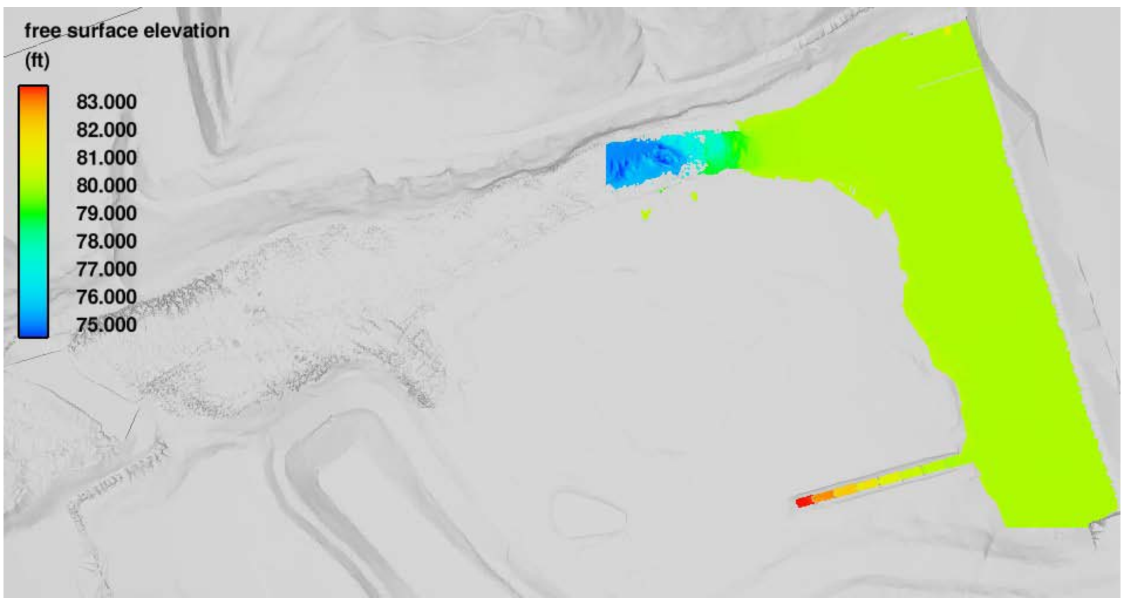

Figure 8. - Water surface elevation map at a river flow of 250 ft^3/s. The water surface elevation at the tailrace is 79.8 ft. Froude numbers indicated control in the area of high river contours just below the power plant tailrace. (Note: The dam is on the right side of the map with the power plant tailrace in the top right corner. The walls of the tailrace area are just visible.)

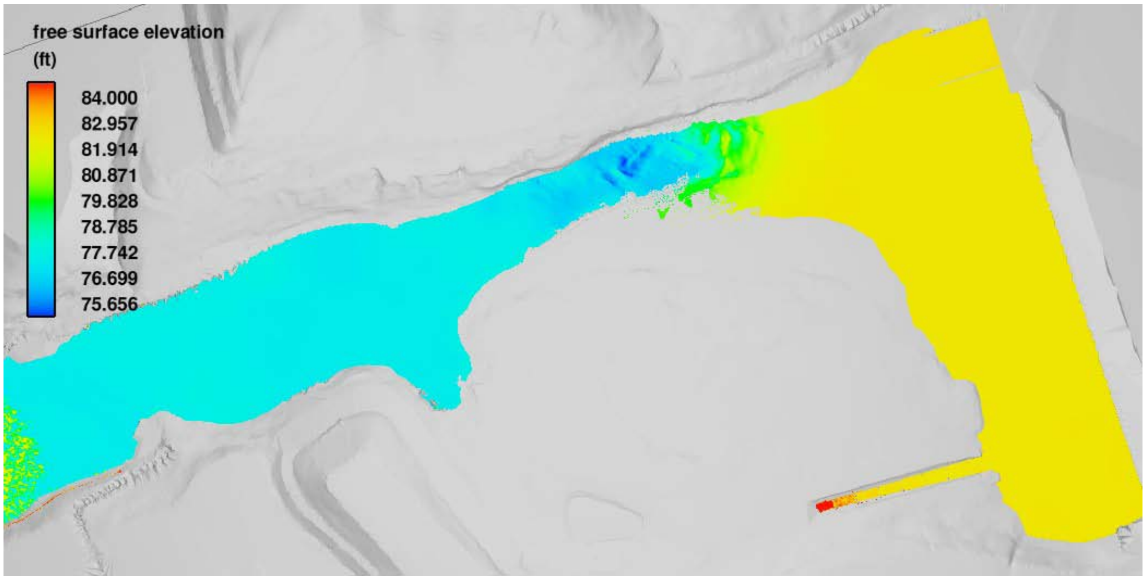

Figure 9. - Water surface elevation map at a river flow of 1,930 ft^3/s. The water surface elevation at the tailrace is 82.1 ft. Froude numbers indicated control in the river section upstream from the Hazel Ave. Bridge. (Note: The dam is on the right side of the map with the power plant tailrace in the top right corner. The walls of the tailrace area are just visible.)

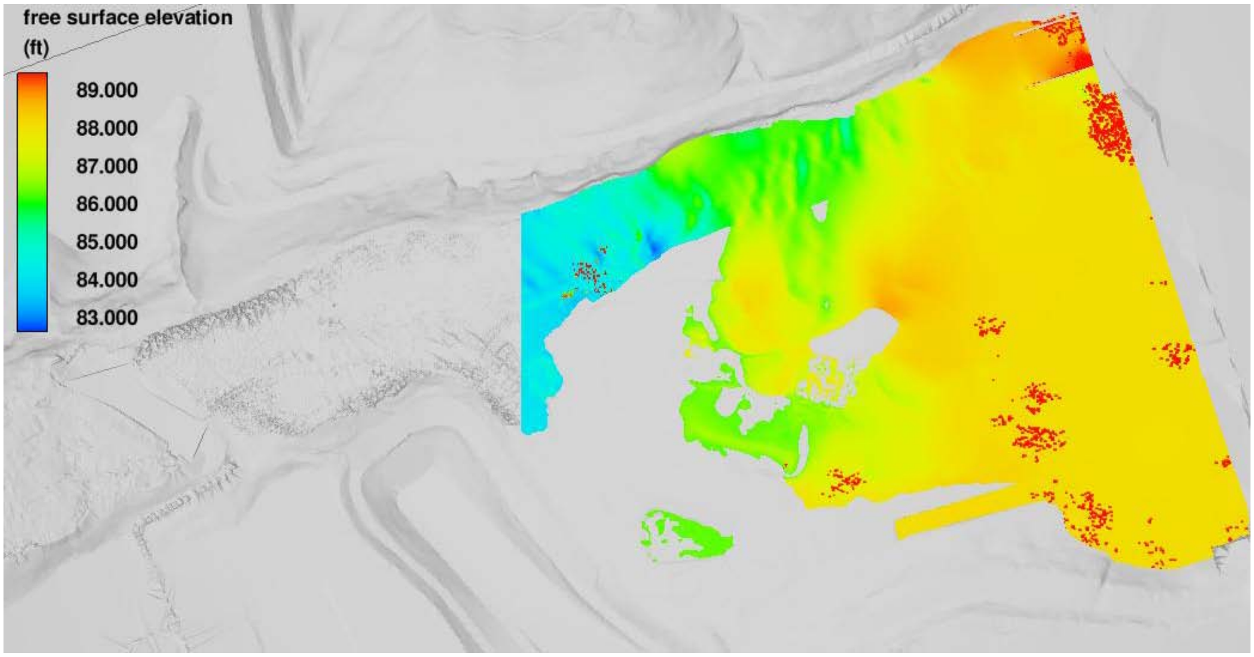

Figure 10 - Water surface elevation map at a river flow of 20,000 ft^3/s. The water surface elevation at the tailrace is 88.2 ft. Froude numbers near critical, from another plot, indicated control in the river section with water surface El. 84 to 85 ft. (Note: The dam is on the right side of the map with the power plant tailrace in the top right corner. The walls of the tailrace area are just visible.)

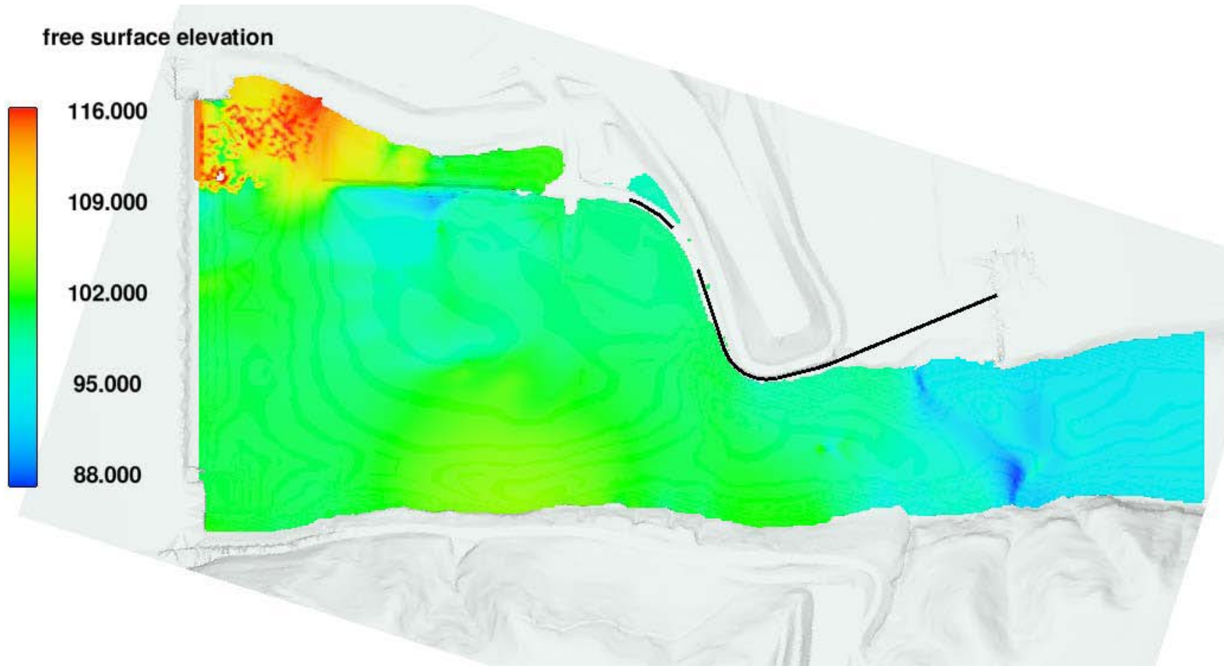

Figure 11. - 66,677 ft^3/s water surface elevation map. The water surface elevation at the tailrace is 101.2 ft. (Note: The dam is on the left side of the map with the power plant tailrace in the bottom left corner.)

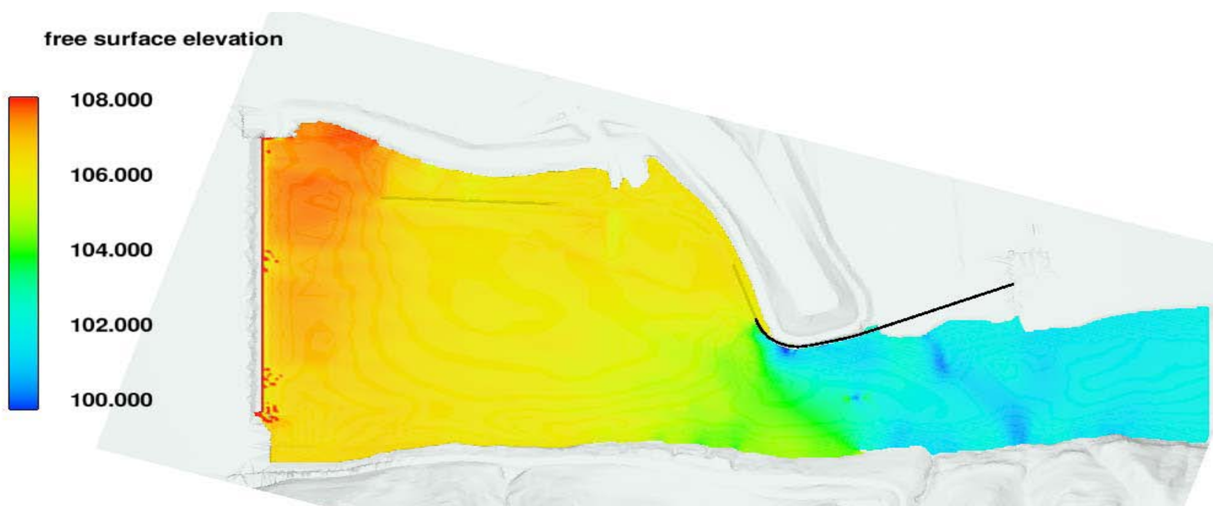

Figure 12. - 115,000 ft^3/s water surface elevation map. The water surface elevation at the tailrace is 106.4 ft. (Note: The dam is on the left side of the map with the power plant tailrace in the bottom left corner.)

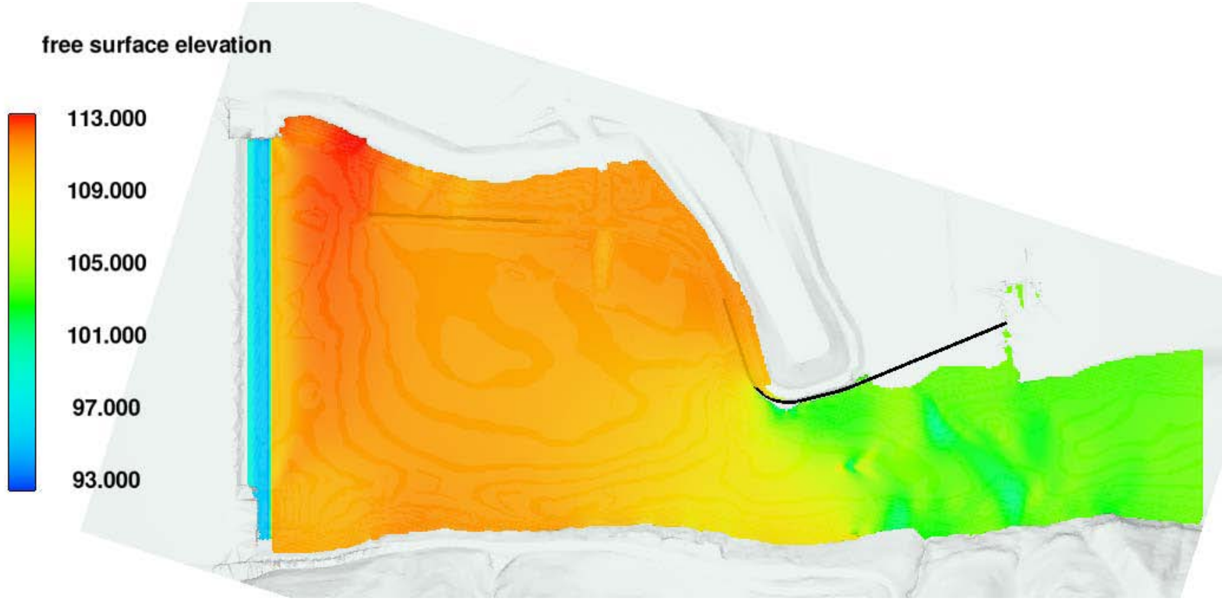

Figure 13. - 160,000 ft^3/s water surface elevation map. The water surface elevation at the tailrace is 111.0 ft. (Note: The dam is on the left side of the map with the power plant tailrace in the bottom left corner.)

Table 2 is a summary of the numerical model results for the water surfaces below Nimbus Dam with the weir removed.

Table 2. - Summary of water surface elevations predicted by the numerical model for the weir removed to El. 74 ft.

Discharge (ft^3/s)	Elevation (ft)
250	79.8
1,930	82.1
20,000	88.2
66,667	101.2
115,000	106.4
160,000	111.0

These numerical data for the water surfaces for each river discharge from the numerical model were then compared to the NAVD88 converted data for the USGS gage location, the powerplant tailrace provided by CCAO personnel with the weir, and the power plant tailrace original design elevations, on figures 14 and 15. Also, shown in figures 14 and 15 are the wall elevation for the concrete fish ladder and the invert for the rock fishway entrance. The power plant tailrace data includes the influence of the existing hatchery weir. All other values are given assuming the existing weir is removed to El. 74 ft, including the power plant design data.

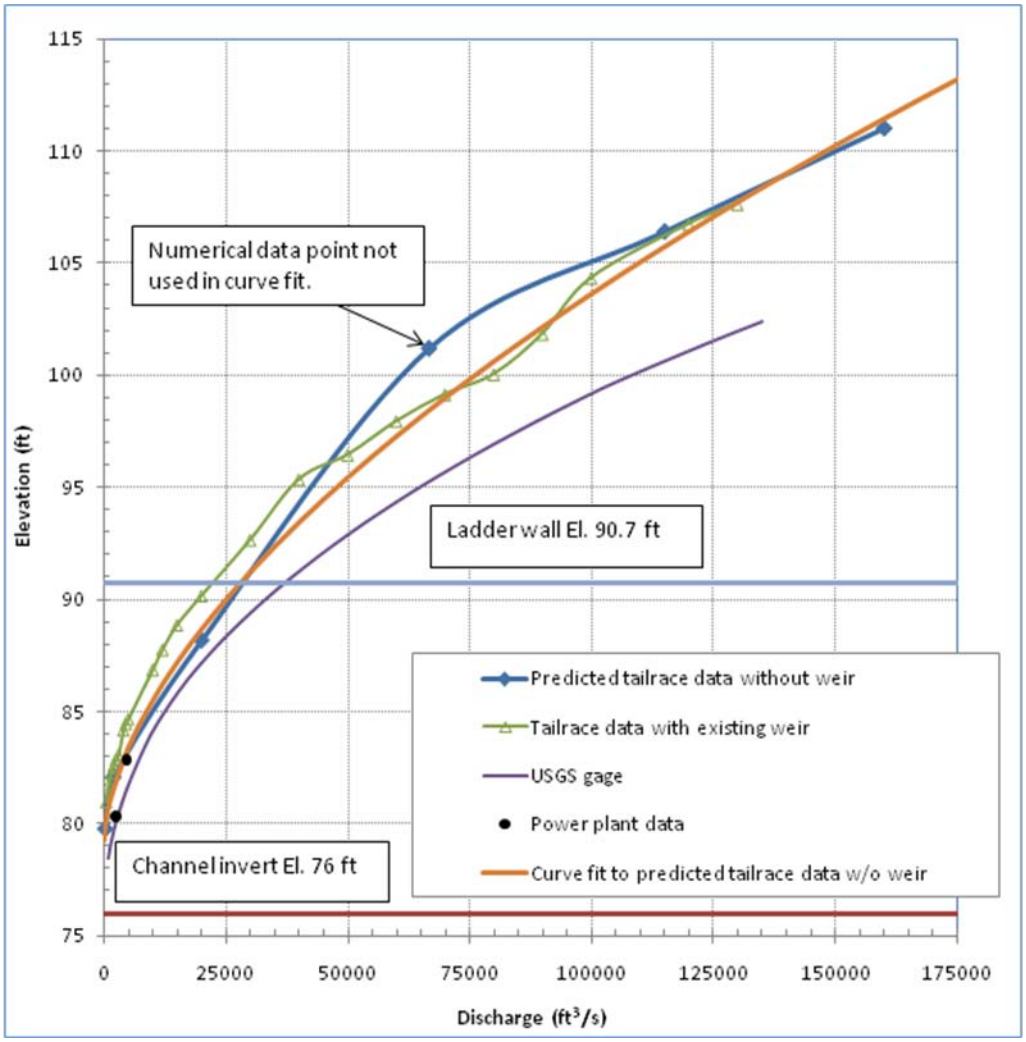

Figure 14. - USGS gage data and Nimbus tailrace and tailwater pool elevations from the existing data and the numerical model results over the full range of river flows. The numerical model results are shown as predicted tailrace data without the weir and then were used in the curve fit equation. (Note: All data given in NAVD88).

The power plant tailrace curve and numerical modeling results over the range of flows from 250 to 160,000 ft^3/s require interpretation based upon the geometry of the Nimbus Shoal area, narrow river section beneath the bridge, and the USGS gage measurement location. The existing *measured* power plant tailrace data, provided by Reclamation's CCAO, shows various flow conditions occurring and what seem to be various changes in flow control up to a discharge of 130,000 ft^3/s with the weir in the river. Understanding the reason for the shape of this curve could lead to insight of the numerical modeling results. For flows up to about 40,000 ft^3/s, it appears that the high points in the river channel or the weir are controlling and backwatering the tailrace area, even though some flow has submerged the Shoals. As the flow increases to between about 40,000 and 80,000 ft^3/s and significant flow over Nimbus Shoals occurs, the rating curve flattens with little head increase. The tailrace curve then increases significantly, implying a control shift which would seem to be the constriction in the river at the Hazel Ave Bridge crossing.

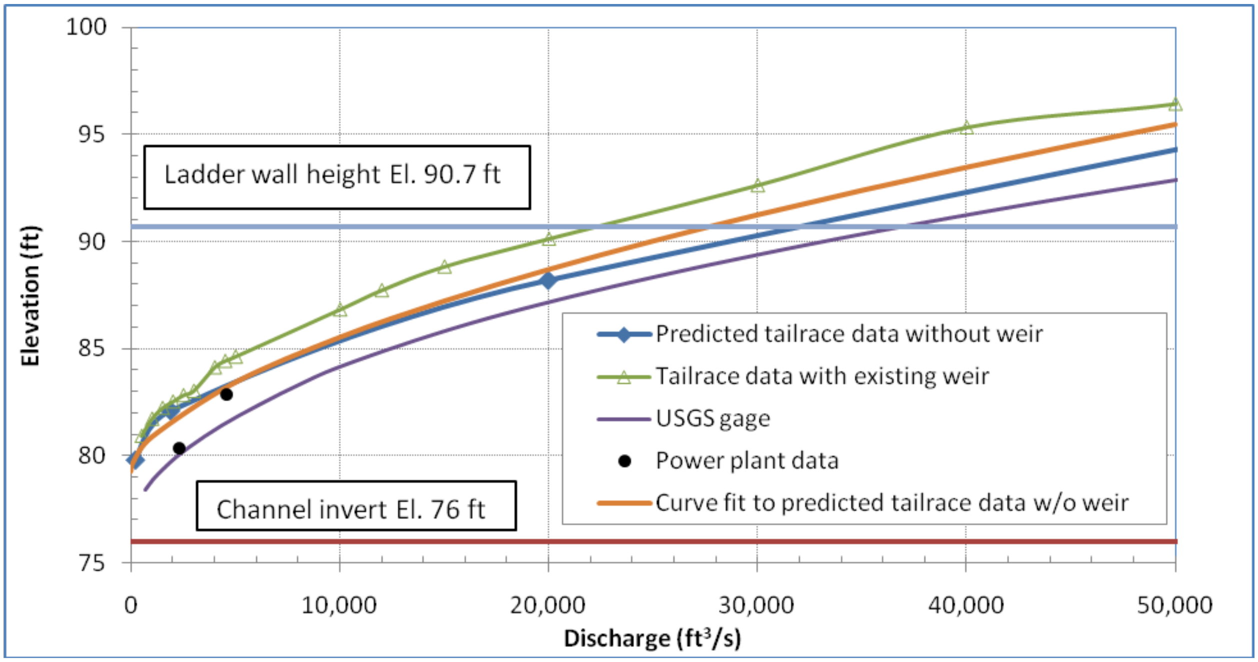

Figure 15. - USGS gage data and Nimbus tailrace and tailwater pool elevations from the existing data and the numerical model results over the full range of river flows. (Note: All data given in NAVD88).

Numerical model results, with the weir removed to El. 74 ft shows that under low flows the high topography in the river below the power plant will control the water levels upstream. Power plant tailrace water levels similar to those with the existing weir will be produced and should provide adequate depth when compared to the original design values, figure 15.

The numerical model at a flow of 20,000 ft^3/s resulted in a water surface quite a bit lower than the existing tailrace data and approached that of the USGS gage site. This implies that the flow is no longer controlled by the high topography in the river but has changed to a downstream location that is controlling but not as much as the existing weir. Figure 7 shows a flow rate of 35,000 ft^3/s with a drop still existing over the weir which would indicate that the water surface value for 20,000 ft^3/s might be reasonable.

Numerical model results for a flow of 66, 667 ft^3/s produced a water surface at the power plant tailrace that was higher than with the in-river weir. This did not make physical sense, because the water surface could not be greater than that with the weir; therefore; this data point was not used in the analysis. The problem could have been shallow flow over the Shoal area not being modeled correctly. At 115,000 ft^3/s and 160,000 ft^3/s the numerical model indicated similar water surfaces between the power plant tailrace with or without the weir in the river.

Therefore, it seems that the river channel topography below the power plant controls for small flows, and the constriction in the river below Hazel Ave Bridge controls for higher flows. It would appear that the new power plant tailrace rating curve will be lower once the high topography below the power plant is inundated through the intermediate river discharges until the narrow river section will control for flows of about 75,000 ft^3/s or more. The shift in control from downstream of the weir to the narrow river section under Hazel Ave will still occur, but is not well defined and time could not be spent running numerous additional discharges in flow 3D. To provide a tailrace rating curve for the weir after removal, the numerical data was fit to the following equation:

$$El. = 79.29 + 0.027Q^{0.591}$$

Table 3 shows the river discharge and water surface elevations reported at the tailrace with the existing weir and the values computed with the equation fit to the numerical model data. Because it is expected that the tailrace elevations will follow the existing tailrace elevations once a river discharge of about 75,000 ft^3/s is exceeded, the elevations shown in the last column of Table 3 are shown as matching those of the existing tailrace condition above that elevation.

Table 3. - Discharge rating table for the power plant tailrace. (Note: All elevations given in NAVD88.)

River Discharge	Tailrace El. With Existing Weir*	Tailrace El. With Weir Removed (equation fit)	Tailrace El. With Weir Removed (matching with existing tailrace above 75, 000 ft^3/s)
(ft^3/s)	(ft)	(ft)	(ft)
500	80.94	80.35	80.35
1000	81.74	80.89	80.89
1500	82.24	81.32	81.32
2000	82.54	81.70	81.70
2500	82.84	82.04	82.04
3000	83.04	82.35	82.35
4000	84.14	82.92	82.92
4500	84.44	83.18	83.18
5000	84.64	83.43	83.43
10000	86.84	85.53	85.53
12000	87.74	86.24	86.24
15000	88.84	87.22	87.22
20000	90.14	88.69	88.69
30000	92.64	91.24	91.24
40000	95.34	93.46	93.46
50000	96.44	95.45	95.45
60000	97.94	97.29	97.29
70000	99.14	99.01	99.01
80000	100.04	100.63	100.04
90000	101.84	102.17	101.84
100000	104.34	103.64	104.34
120000	106.74	106.41	106.74
130000	107.64	107.72	107.64

*Supplied by CCAO

Submergence of the rock fishway length will gradually occur as releases from the dam increase. The walls in the concrete fish ladder at El. 90.7 ft will begin to submerge about 27,500 ft^3/s if based on using the equation fit to the numerical model data as shown in figure 15. The 95 percent exceedence flow is 20,000 ft^3/s; therefore, the ladder should be operational throughout the Steelhead season most of the time.

Additional documentation for this modeling may be found in the draft report by Higgs [12] and discussions in Appendix A.

Velocities and Depths in River Low Flow Control Reach

Another benefit of the numerical modeling was the information provided about flow depths and velocities in the low flow river control reach of high topography downstream from the power plant. This area is currently backwatered by the existing hatchery weir a majority of the time. Plots of the flow depths and velocities through this reach of about 500 ft are found in Higgs [12]. To summarize, the following results were determined of interest for upstream fish passage during low flows:

- It is possible to have ½ to 1 ft depths for a short distance in this area under the minimum flow of 250 ft^3/s. Velocities in the river channel approached 12 ft/s in the center, but reduced to 5 ft/s along the edges of the channel. The contour maps developed from the numerical modeling do not have adequate resolution to say whether or not a continuous passageway for fish will occur.
- Under the normal river flow of 1,930 ft^3/s, flow depths in the river control section were 2 to 3 ft. Velocities up to 17 ft/s in the center of the channel were computed, but flow along the edges produced velocities of about 5 ft/s.
- A flow rate of 20,000 ft^3/s produced at least 4 ft of flow depth throughout this river section. Velocity patterns were similar to those of the 1,930 ft^3/s flow rate.

Velocities near Flume Embankments

Initial numerical modeling was requested to provide design information regarding velocities near the fishway structures, particularly near the entrance and through the river constriction under Hazel Ave. Bridge. The flow rates selected corresponded to a design flood for Folsom Dam, 115,000 ft^3/s, the maximum levied channel capacity, 160,000 ft^3/s, and a “worst case” failure of three gates near the fishway entrance, 67,667 ft^3/s. The entire fishway flume and ladder will be exposed to high releases from the dam during flooding and must survive and be operational to provide fish to the hatchery without interruption during their seasons.

The preliminary fishway design, often referred to as the baseline design, was used in the numerical modeling with a gently-sloping concrete flume from the hatchery leading to the concrete weir and pool ladder forming the fishway entrance, figure 16. The baseline design included high concrete walls extending about 30 ft above the elevation of the Shoals. There were significant changes to the end of the fishway, in particular, during the design process. During the Value Engineering Study and final design, the flume length was shortened, the concrete weir and pool ladder was moved upstream, a rock fishway entrance was added, and the alignment changed. The upstream portion of the flume and ladder fishway alignment remained very similar in final design. The concrete flume and ladder structures are supported by sloping embankments protected by riprap. A comparison in the plan views of the designs may be made by reviewing figures 4 and 16.

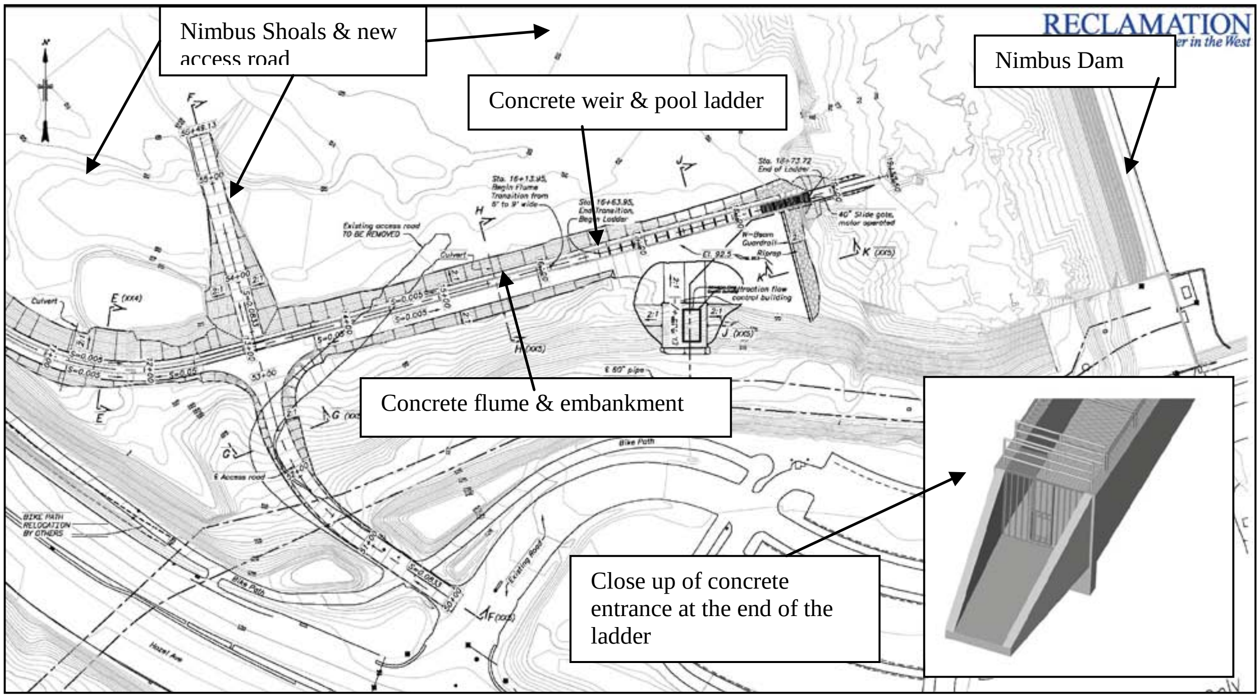

Figure 16. - Plan view of the end of the baseline fishway flume and traditional concrete ladder entrance across the Shoals. A close up of the ladder entrance with a pipe gate that would be used limit the number of fish entering the fishway for the baseline design, prior to the VE study is included.

Velocities near the concrete flume embankment should provide good design information as the embankment slope did not change even though the flume was widened from 4 to 6 ft after the modeling was complete. Velocity results were obtained from the numerical model upstream (probe 4) and downstream (probe 3) from the bend. A maximum average velocity of 18 ft/s should be used to design the embankment protection near the river bend under Hazel Ave. This would be conservative as velocities decreased with depth. Sweeping velocities were high along the flume embankment slope as the flow from the Shoals turned to go downstream in the river under the bridge. After the flow turned, the velocities were higher in the downstream direction parallel to the river flow. Other portions of the embankment were not subjected to high velocities; however, data were not extracted from the model at all points along the flume and the flume, ladder, and the Shoal access road layout changed in final design. Detailed locations and velocity magnitudes with depth are given in Higgs [12] and are summarized in Table 4.

The extensive changes to the ladder entrance and alignment during final design mean that the velocities reported near the baseline entrance, at probe 8 in table 4, are most likely not valid for the rock channel entrance. As seen in the comments of table 4, the high wall of the concrete flume most likely significantly influences the velocities. However, velocities were quite low for evenly distributed flow releases from the dam and could possibly be considered of the same magnitude as those with a rock fishway following the contours of the Shoals. When the flow was concentrated in the four gates farthest to the left, the flow clearly exited across the entrance walls to reach the river channel producing no reasonable way to access results for the new rock channel geometry and alignment.

Table 4. - Average velocities along the flume embankment at the river bend under Hazel Ave Bridge and near the fishway entrance. (Note: x is in the downstream direction and y is parallel to the dam.)

	Q = 160,000 ft^3/s		Q = 115,000 ft3/s		Q = 66667 ft3/s	
Location	Velocity (ft/s)	Comments	Velocity (ft/s)	Comments	Velocity (ft/s)	Comments
upstream of bend, probe 4	18.1	flow has turned corner & sweeping x velocity is about three times y or normal velocity	16.5	flow has turned corner and mostly sweeping x or downstream velocity		less than other velocities
downstream of bend, probe 3	13.6	normal x velocity is equal to sweeping y velocity	11.9	sweeping y velocity equal in magnitude to the normal x downstream velocity		less than other velocities
fishway entrance*, probe 8	6.2	velocity magnitudes are increasing with depth, particularly in the downstream direction	5.4	perhaps downstream direction is OK?, Y direction probably affected by structure because increasing with depth, Z insignificant but also increasing near bottom	11.9	magnitudes increasing near surface but odd individual components, Y ≥ X, probably influenced by structure

Flume and Concrete Ladder Water Surface Profile

The geometry of the flume and concrete ladder were designed to meet criteria from the IFPTT and also minimize excavation, exposure to flow releases from the dam, and allow expansion of the existing visitor center. The ladder flow rate was initially thought to be closer to 40 ft^3/s; however, the CCAO made flow measurements in the existing ladder and determined that the flow rate is usually 25 ft^3/s (per phone conversation with David Robinson, CCAO, and Project Manager). The final criteria from the IFPTT were:

- 6-ft-wide flume
- Velocity of 1 ft/s in the flume
- 4 ft flow depth under existing 25 ft^3/s flow from the hatchery
- Weirs with orifices every 100 ft through steeper sloped sections of the flume
- 3 weirs through the new visitor viewing area
- Acceptable to use same ladder design as the existing facility

The hydraulics of the flume and ladder where modeled using the USACOE HEC-RAS program [13]. With subcritical flow, the downstream weir at the top of the concrete ladder will control the upstream water levels. Survey information about the concrete flume invert elevation and water depth at the existing entrance to the hatchery was received late in the design process. The invert elevation obtained was significantly higher than the design team had assumed. Therefore, a portion of the slope of the flume across the hatchery yard had to be significantly steepened to lessen design impacts along the full length of the flume at this late date. The water surface elevation was also computed from the survey data. The target elevation for the design is 103.27 ft to match the existing water level entering the hatchery.

The flume slope begins at 0.01 at the juncture with the existing hatchery flume at El. 99.42 ft. The slope changes after about 150 ft to 0.00028 (the existing slope across the hatchery yard) and continues around the bend under Hazel Ave for about 525 ft with a drop of only 0.14 ft. The slope then steepens again to 0.005 for about 545 ft to El. 94.58 ft at the flat-bottomed expansion from 6 to 9 ft at the top of the weir and pool ladder. The ladder is on a 12: 1 slope down to elevation 80.2 ft. The existing weirs in the concrete ladder are 4 ft high with no orifices, but removable plates to allow drainage of water and fish when the ladder is shut down for the season. The weir at the top of the ladder was set at station 14+77 which was 2 ft down the ladder slope. *(Note: final design drawing has the top of the ladder at station 14+57.64 and the first weir 2 ft downstream at station 14+55.64).*

Three profiles were run with 25 ft^3/s always in the flume and another 20 and then 40 ft^3/s added below the ladder and upstream from the rock channel control weir. The flume weirs were designed to be 3 ft high with 1.5-ft-high by 1.25-ft wide orifice openings. This was the minimum size recommended in Bell's Handbook [14]. A weir coefficient of 1.6 was selected to be used in HEC-RAS. The placement of the weirs in the flume was made as per drawing number 485-D-3781[10]. Figure 17 shows the water surface schematic from HEC-RAS for the three profiles run. At the hatchery tie-in, of course, the downstream tailwater did not have an influence. The resulting water surface elevation at the junction with the existing hatchery flume was 103.13 ft or 0.14 ft low, but certainly acceptable. The flow depth in the flume, with Manning's "n" value of 0.01, averaged just less than 4 ft with velocities at about 1.1 ft/s. The drop across the weirs did not exceed 0.5 ft in the flume section and was often less. There was little drop in the weirs just upstream from the expansion in the 0.005 sloping section. The drop in the concrete ladder was 1 ft, the same as reported for the existing ladder, with greater than 4 ft of flow depth in each pool. The HEC-RAS output of the water surface profile for a tailwater elevation of 82.1 ft and 25 ft^3/s through the ladder is shown in Appendix B. *(Note: stationing is slightly off from the final specification drawings. For example the weirs in the visitor viewing plaza are now at stations 1+50, 2+00, and 2+50 instead of as modeled at 1+40, 1+90, and 2+240.)* There is plenty of flexibility to change the weir height and location, but the initial placement and height of weirs is considered adequate and meets the IFPTT criteria for the design.

A pipe gate, designed after the one used at the existing ladder entrance, is located at the entrance to the ladder. The pipe gate will be used to control fish numbers coming into the ladder and flume to the hatchery. The transition area from the rock channel to the entrance to the concrete ladder was investigated closely. Skimming flow from was requested from the last weir in the ladder to the pool upstream from the rock channel. This area is discussed in the following section.

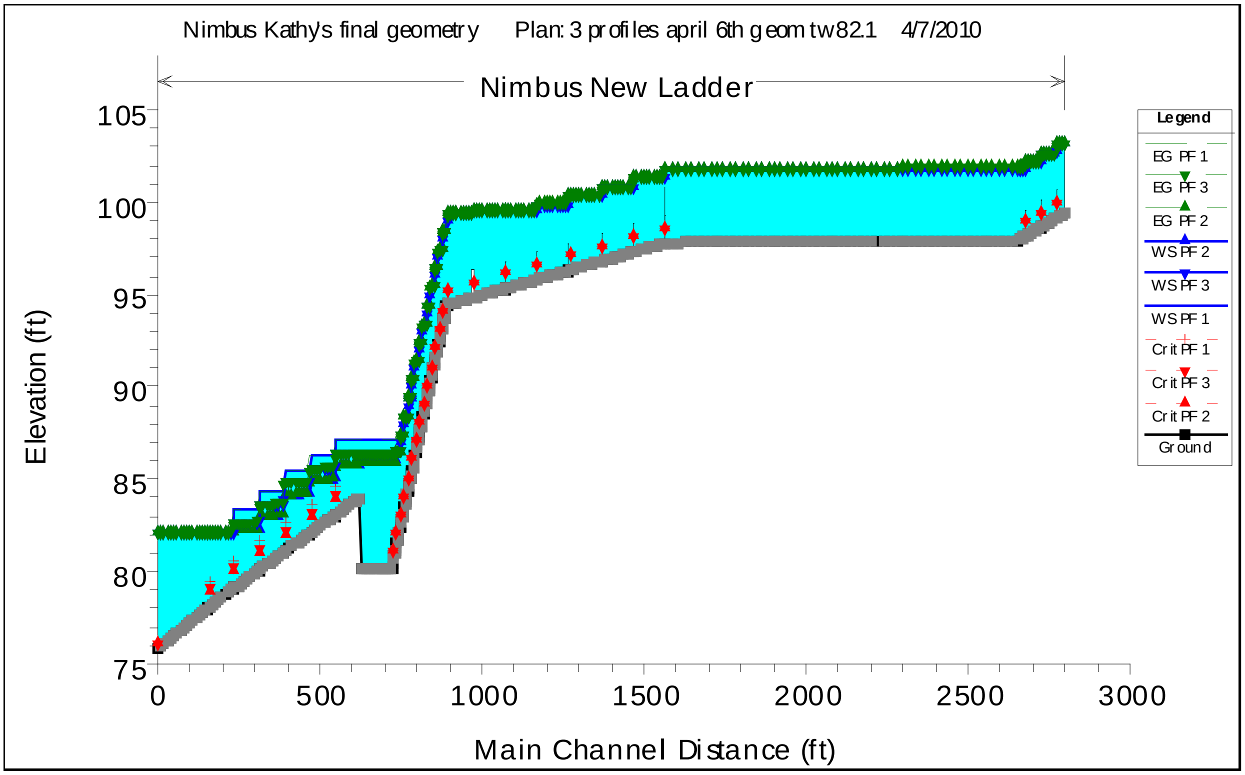

Figure 17. - HEC-RAS output showing the water surface elevations throughout the fishway.

Nimbus Rock Weir Designs

The chevron rock weirs for the Nimbus hatchery rock channel need to be designed to function from 25 to 65 ft^3/s under various river flow and tailwater pool conditions. The operation of the fishway is meant to be flexible. The auxiliary flow was added to the system to support depth in the rock fishway channel and will be able to provide up to an additional 40 ft^3/s flow in the transition area between the entrance to the concrete ladder and the top of the rock channel. The objectives of the rock fishway are:

- To provide an entrance to the fishway with adequate depth and velocity for passage
- To provide noise and turbulence to attract fish to the entrance
- To provide backwater for the concrete ladder with acceptable depth
- To provide a structurally stable and aesthetically pleasing structure across the Shoals

To meet these objectives several different geometries and combinations of flows and tailwater elevations were investigated using basic guidelines for boulder weir fishways, Flow 3D, and HEC-RAS.

Initially, the numerical model, Flow 3D, was used to determine if the VE study concept geometry for the rock fishway would provide acceptable results. The slope from El. 80.2 ft at the base of the ladder to the tailwater pool below the dam at El. 76 ft was 0.0125.+ The trapezoidal channel with 4-ft bottom width and 2:1 side slopes was modeled with spherical objects representing nine boulder weirs arranged in chevron patterns of five boulders each along the slope. A flow of 25 ft^3/s with a tailwater El. 80 ft was modeled.

The slope of the fishway channel and placement of weirs is determined by the need to keep connectivity between the entrance to the concrete ladder and the water surface at the top of the rock channel and to provide noise, via drops, for fish attraction. The weir at the entrance to the concrete ladder was modeled at 85.6 ft. The original slope of the channel began at the invert of the transition and the boulder weirs did not produce enough backwater to ensure fish could easily pass into the concrete ladder. A 2.1 ft differential in water surfaces resulted from this initial geometry under flow rate of 25 ft^3/s and tailwater of El. 80 ft, figure 18. Additional plots are given by Higgs [12].

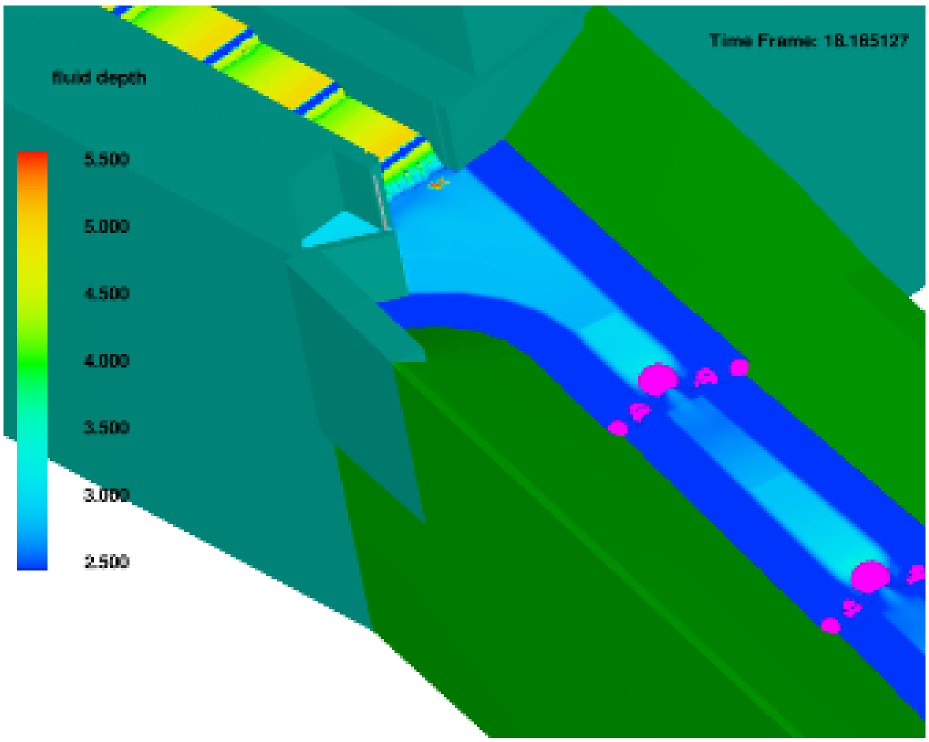

Figure 18. Result from the numerical model showing the excessive drop from last weir in the concrete ladder to the transition zone upstream from the rock channel entrance for the original fishway slope of 0.0125 and no auxiliary fishway flow.

A couple of additional geometries were investigated using the numerical model with the same rock channel slope and six boulder chevron-shaped weirs. These were attempts to provide more backwater into the transition area by adding sills of 1 ft and 2 ft heights between the rock chevrons to reduce the flow area and thus increase the flow depths. However, these geometries did not produce a significant improvement in the water surface differential in the transition area [12].

Therefore, the upstream end of the rock fishway was raised to El. 84.7 ft and the rock fishway slope steepened to 0.025 or doubled. The geometry of the weirs remained the same inside the trapezoidal channel with 4-ft bottom width and 2:1 side slopes, and the number of weirs in the fishway remained at six. The raised crest produced a pool situation that backwatered the bottom of the concrete ladder that indicated the weir crest was probably a little too high. Figure 19 shows the centerline water surface profiles through the transition area and rock channel boulder weirs for the three flow rates investigated, under the minimum tailwater situation. This initial look at the flow through the sloping rock channel with weirs spaced at 40 ft showed promise. Figures 20 and 21 show the flow depths and velocities through the fishway from the transition pool through the boulder weirs in the fishway to the tailwater pool.

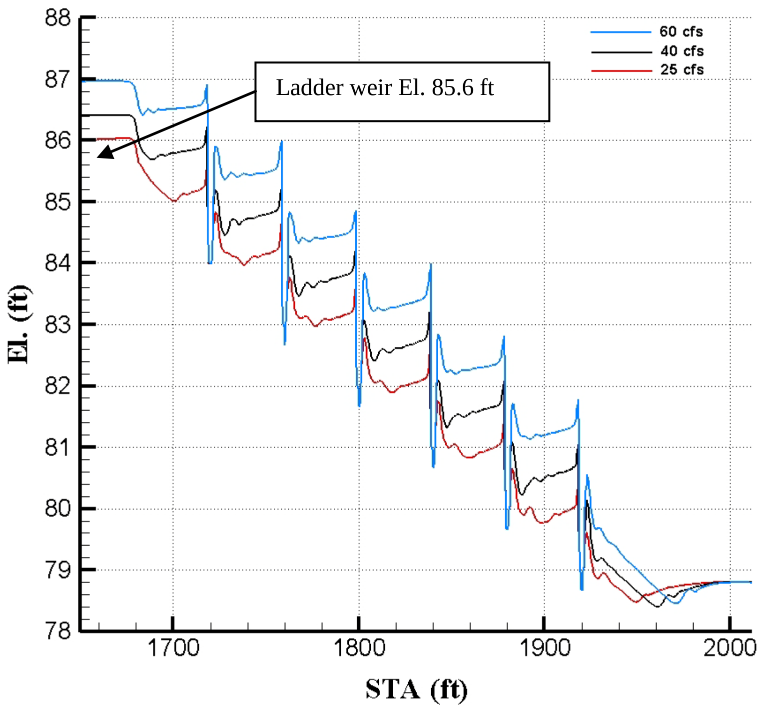

Figure 19. - Water surface profiles through the transition area and rock ramp with the ramp crest at El. 84.7 ft. (Note: the bottom weir in the ladder was modeled at El. 85.6 ft.)

The color plots from Flow 3D show that there is a lot of diversity in the flow depth and velocity throughout the pools, thus providing for flexibility in passage opportunity. The results of this were promising as the transition area depth was actually a little deeper than needed and approximately 1 ft drops existed between rock weirs. Flow 3D numerical simulations of the fishway were ended with the production of this geometry.

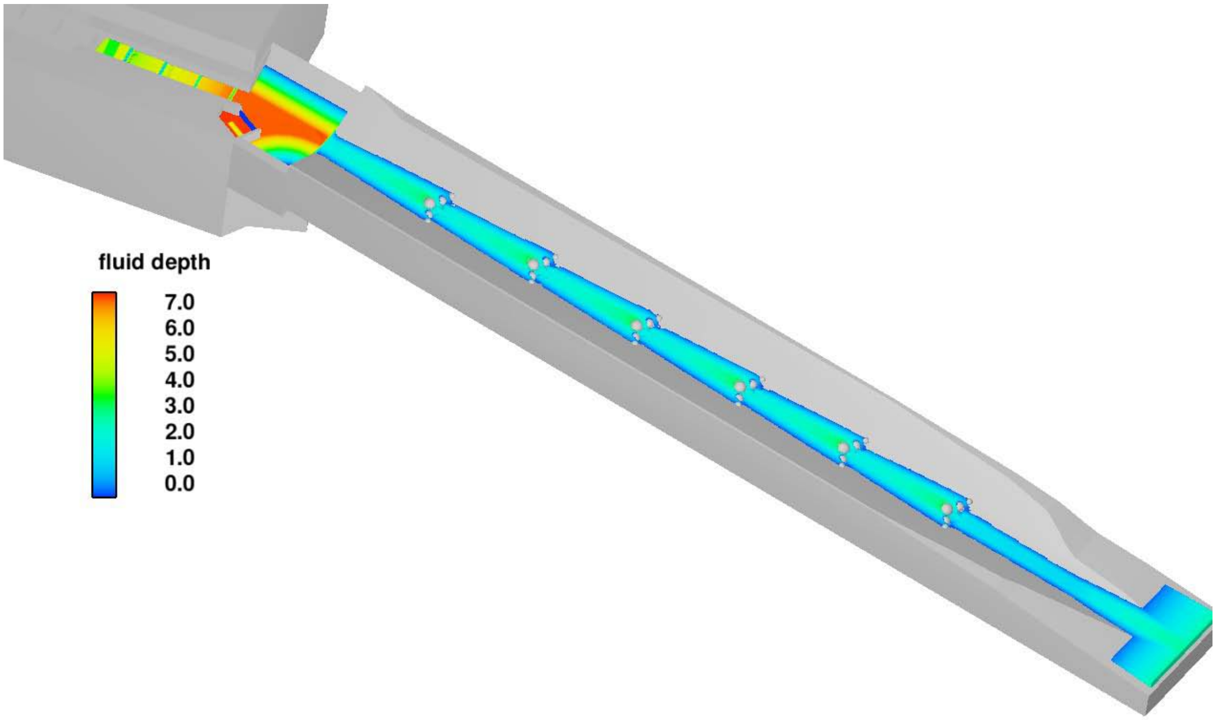

Figure 20. - Flow of 65 ft^3/s in the rock channel with ramp crest El. 84.7 ft. Depths are shown in the bottom of the ladder, the transition area and the rock channel with a minimum tailwater pool El. 79.8 ft.

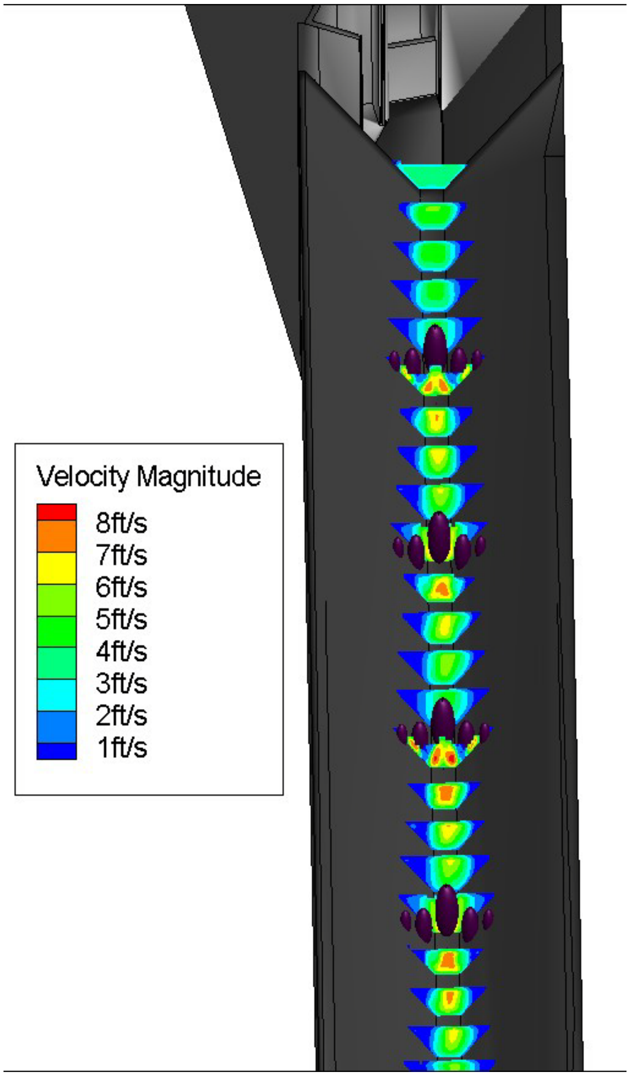

Figure 21. - View is looking upstream along the rock fishway with the concrete fish ladder shown at the top. Flow velocities through the rock weirs are stronger in the center and less near the edges. A flow of 65 ft^3/s is shown for a rock ramp crest of 0.7 ft higher than the final design.

Any fishway design is undertaken by looking at the slope, total length, total drop, pool length, number of pools, head differential, thus velocity between slots and pools and resulting flow area between the rocks leading to projected flow depth in the pools [15]. The slope is usually adjusted to match the topography in addition to matching velocity criteria for the species of interest. Table 5 shows the computations for various flows, tailwater elevations, and assumed number of weirs for the Nimbus fishway based upon the slope of 0.025 developed from the previous Flow 3D modeling effort. The total head is the difference between the water surfaces at the upstream and downstream end of the rock fishway. The head differential between pools is determined by dividing the total head available by the number of pools assumed. The slot velocity is then estimated by $\sqrt{(2g\Delta H)}$. The slot velocity could be as high as burst speeds for steelhead and Chinook or at least 20 ft/s from Bell [14]. During discussions with the IFPTT it was determined that the fish swimming speed for design should not be burst speed, but a reduced sustained swimming speed because the fish are at the end of a long journey. Sustained speeds of 4-10 ft/s for Chinook salmon are reported in Bell [14], so using 7-8 ft/s for design should be reasonable. The area is assumed to be that of the two openings on either side of the large center boulder in the weir (often called the tuning rock) and of 1 to 1.5 ft width. In this case, the flow is small in the channel and the openings between the tuning rock and the next rocks should be kept as close to 1 ft as possible. The depth is then estimated based upon two 1-ft-wide slots with larger areas flowing between the rocks on the side slopes and over the rocks.

A goal of the rock channel was to provide noise and turbulence over to the rock channel from the river channel and power releases. Therefore, as large a drop as possible, or as few weirs as possible, given velocity criteria, was attempted in the design. Table 5 shows the results for an assumed number of weirs from 6 to 12 and the range of head differences, velocities, and depths. The depths are somewhat shallow for the 25 ft^3/s flow range, but improve with an additional 15 ft^3/s added from the auxiliary flow pipe and again with the full 40 ft^3/s added to total 65 ft^3/s in the fishway.

Table 5. - Computations for possible rock channel designs for the fishway.

Fishway	River	tailwater	upstream	# of weirs	pool length	total head	delta H	velocity	area	depth
Discharge	Discharge	El.	El.	N	PL	HT		V	A	
(ft^3/s)	(ft^3/s)	(ft)	(ft)		(ft)	(ft)	(ft)	(ft/s)	(ft^2)	(ft)
25	250	79.8	84.97	6	40	5.17	0.86	7.45	3.36	1.68
				8	30	5.17	0.65	6.45	3.88	1.94
				10	24	5.17	0.52	5.77	4.33	2.17
				12	20	5.17	0.43	5.27	4.75	2.37
	1290	82.1	84.97	6	40	2.87	0.48	5.55	4.50	2.25
				8	30	2.87	0.36	4.81	5.20	2.60
				10	24	2.87	0.29	4.30	5.82	2.91
				12	20	2.87	0.24	3.92	6.37	3.19
	20000	88.2	88.2	6	40	0	0.00	0.00		
				8	30	0	0.00	0.00		
				10	24	0	0.00	0.00		
				12	20	0	0.00	0.00		
40	250	79.8	85.3	6	40	5.5	0.92	7.68	5.21	2.60
				8	30	5.5	0.69	6.65	6.01	3.01
				10	24	5.5	0.55	5.95	6.72	3.36
				12	20	5.5	0.46	5.43	7.36	3.68
	1290	82.1	85.4	6	40	3.3	0.55	5.95	6.72	3.36
				8	30	0	0.00	0.00		
				10	24	0	0.00	0.00		
				12	20	0	0.00	0.00		
	20000	88.2	88.2	6	40	0	0.00	0.00		
				8	30	0	0.00	0.00		
				10	24	0	0.00	0.00		
				12	20	0	0.00	0.00		
65	250	79.8	85.51	6	40	5.71	0.95	7.83	8.30	4.15
				8	30	5.71	0.71	6.78	9.59	4.79
				10	24	5.71	0.57	6.06	10.72	5.36

Fishway	River	tailwater	upstream	# of weirs	pool length	total head	delta H	velocity	area	depth
Discharge	Discharge	El.	El.	N	PL	HT		V	A	
(ft^3/s)	(ft^3/s)	(ft)	(ft)		(ft)	(ft)	(ft)	(ft/s)	(ft^2)	(ft)
				12	20	5.71	0.48	5.54	11.74	5.87
	1290	82.1	85.55	6	40	3.45	0.58	6.09	10.68	5.34
				8	30	3.45	0.43	5.27	12.33	6.17
				10	24	3.45	0.35	4.71	13.79	6.89
				12	20	3.45	0.29	4.30	15.11	7.55
	20000	88.2	88.2	6	40	0	0.00	0.00	submerged	
				8	30	0	0.00	0.00	submerged	
				10	24	0	0.00	0.00	Submerged	
				12	20	0	0.00	0.00	submerged	

Three flows were modeled in HEC-RAS at the beginning of the rock fishway, 25, 40 and 65 ft^3/s. The geometry for the rock ramp from table 5 and the Flow 3D preliminary studies was used in the HEC-RAS modeling effort. The geometry was a 5 ft long crest at El. 84 ft leading to the rock ramp with 2.5 percent slope down to El. 76 ft in the tailwater pool. There are six weirs designed spanning a length of 240 ft for a pool length of 40 ft with 1 ft vertical slots. A manning's "n" of 0.05 was used in the model for roughness of the general rock bed. Upstream head values over the crest were obtained from HEC-RAS runs with no weirs along the rock channel but the tailwater imposed.

The following results were obtained from HEC-RAS for the rock fishway:

- The tailwater associated with 20,000 ft^3/s in the river, El. 88.2 ft, submerges the entire rock channel; therefore, the rock channel design is not a factor.
- Five rock weirs will be exposed to provide fish attraction under the normal river flow of 1930 ft^3/s and tailwater El. 82.1 ft, table 6 and figure 22.
    - Maximum drop across the weirs occurs at the juncture with the tailwater and is 1.1-1.2 ft under the minimum river flow of 250 ft^3/s and tailwater El. 79.8 ft.
    - Minimum pool depths are about 2 ft for all fishway flows.
- All six rock weirs will be exposed to provide fish attraction under the minimum river flow of 250 ft^3/s and tailwater El. 79.8 ft, table 7 and figure 23.
    - Maximum drop across the weirs occurs at the juncture with the tailwater and is 1.2, 1.5, and 2.1ft for 25, 40, and 65 ft^3/s fishway flows, respectively, under the minimum river flow of 250 ft^3/s and tailwater El. 79.8 ft.
    - Minimum pool depths are about 2 ft for all fishway flows.

Table 6. - HEC-RAS output for the rock channel entrance starting at the crest through the tailwater pool for flow rates of 25, 40 and 65 ft^3/s in the channel and tailwater El. 82.1 ft corresponding to a river discharge of 1,930 ft^3/s. *(Note: stationing is slightly different than the final stationing).*

Structure Station	Min Ch El	Q=25 ft^3/s, TW=82.1 ft				Q=40 ft^3/s, TW=82.1 ft				Q=65 ft^3/s, TW=82.1 ft			
		W.S. El	Vel Chnl	Depth	Drop	W.S. El.	Vel Chnl	Depth	Drop	W.S. El	Vel Chnl	Depth	Drop
(ft)	(ft)	(ft)	(ft/s)	(ft)	(ft)	(ft)	(ft/s)	(ft)	river sta	(ft)	(ft/s)	(ft)	(ft)
1672.64	84	85.77	1.88	1.77		86.42	1.87	2.42		87.11	2.04	3.11	
1682.64	83.75	85.77	1.2	2.02		86.43	1.21	2.68		87.13	1.32	3.38	
1707.64	83.12	85.74	0.85	2.62		86.4	0.94	3.28		87.1	1.1	3.98	
1712.64	83	84.97	1.37	1.97	0.77	85.68	1.34	2.68	0.72	86.33	1.51	3.33	0.77
1747.64	82.12	84.93	0.86	2.81		85.64	0.95	3.52		86.29	1.16	4.17	
1752.64	82	84.16	1.32	2.16	0.77	84.94	1.29	2.94	0.7	85.47	1.6	3.47	0.82
1787.64	81.12	84.12	0.84	3		84.9	0.92	3.78		85.42	1.2	4.3	
1792.64	81	83.02	1.54	2.02	1.1	83.72	1.56	2.72	1.18	84.36	1.8	3.36	1.06
1827.64	80.12	82.97	0.89	2.85		83.67	1	3.55		84.32	1.23	4.2	
1832.64	80	82.28	1.26	2.28	0.69	82.72	1.53	2.72	0.95	83.35	1.77	3.35	0.97
1867.64	79.12	82.25	0.75	3.13		82.67	0.98	3.55		83.31	1.21	4.19	
1872.64	79	82.11	0.76	3.11	0.14	82.17	1.17	3.17	0.5	82.3	1.79	3.3	1.01
1910.29	78.06	82.11	0.4	4.05		82.15	0.63	4.09		82.26	0.98	4.2	
1915.82	77.92	82.1	0.36	4.18	0.01	82.1	0.58	4.18	0.05	82.1	0.95	4.18	0.16
1998.74	75.85	82.1	0.04	6.25		82.1	0.07	6.25		82.1	0.11	6.25	

Table 7. - HEC-RAS output showing flow depths through the fishway of 25, 40, and 65 ft^3/s under the tailwater pool El. 79.8 ft corresponding to the minimum river flow of 250 ft^3/s. *(Note: stationing is slightly different than the final stationing).*

Structure Station	Min Ch El	Q=25 ft^3/s, TW=79.8 ft				Q=40 ft^3/s, TW =79.8 ft				Q=65 ft^3/s, TW =79.8 ft			
		W.S. El	Vel Chnl	Depth	Drop	W.S. El	Vel Chnl	Depth	Drop	W.S. El	Vel Chnl	Depth	Drop
(ft)	(ft)	(ft)	(ft/s)	(ft)	(ft)	(ft)	(ft/s)	(ft)	(ft)	(ft)	(ft/s)	(ft)	(ft)
1672.64	84	85.77	1.88	1.77		86.42	1.87	2.42		87.11	2.04	3.11	
1682.64	83.75	85.77	1.2	2.02		86.43	1.21	2.68		87.13	1.32	3.38	
1707.64	83.12	85.74	0.85	2.62		86.4	0.94	3.28		87.1	1.1	3.98	
1712.64	83	84.97	1.37	1.97	0.77	85.68	1.34	2.68	0.72	86.33	1.51	3.33	0.77
1747.64	82.12	84.93	0.86	2.81		85.64	0.95	3.52		86.29	1.16	4.17	
1752.64	82	84.16	1.32	2.16	0.77	84.94	1.29	2.94	0.7	85.47	1.6	3.47	0.82
1787.64	81.12	84.12	0.84	3		84.9	0.92	3.78		85.42	1.2	4.3	
1792.64	81	83.02	1.54	2.02	1.1	83.72	1.56	2.72	1.18	84.36	1.8	3.36	1.06
1827.64	80.12	82.97	0.89	2.85		83.67	1	3.55		84.32	1.23	4.2	
1832.64	80	82	1.54	2	0.97	82.69	1.56	2.69	0.98	83.36	1.77	3.36	0.96
1867.64	79.12	81.95	0.89	2.83		82.65	0.99	3.53		83.31	1.21	4.19	
1872.64	79	80.78	1.8	1.78	1.17	81.42	1.81	2.42	1.23	82.1	1.98	3.1	1.21
1910.29	78.06	80.71	0.83	2.65		79.86	2.11	1.94		82.05	1.08	3.99	
1915.82	77.92	79.82	1.36	1.9	0.89	79.8	0.11	3.95	1.5	79.95	3.19	2.03	2.1
1998.74	75.85	79.8	0.07	3.95		79.8	0.11	79.8		79.8	0.18	3.95	

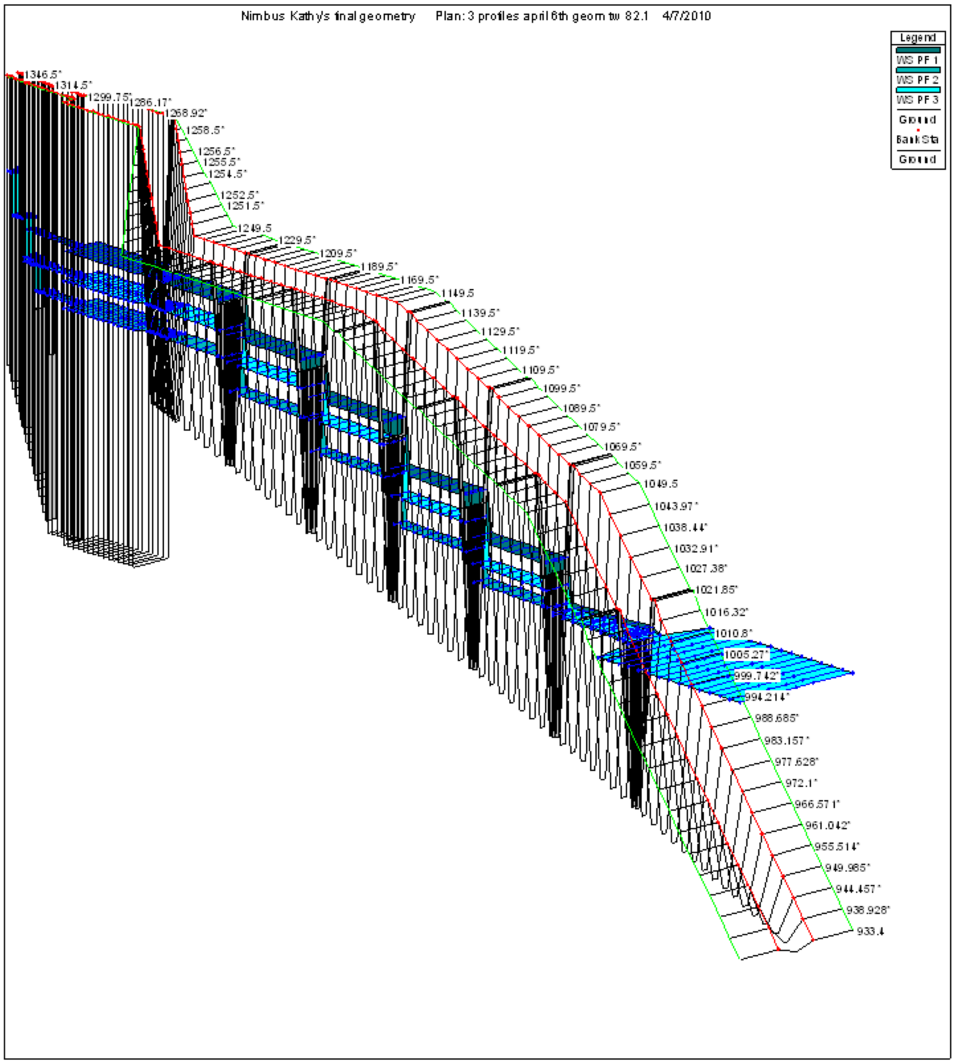

Figure 22. HEC-RAS output for 25, 40, and 65 ft^3/s through the rock fishway with the tailwater pool at El. 82.1 ft corresponding to the normal river flow of 1,930 ft^3/s. -

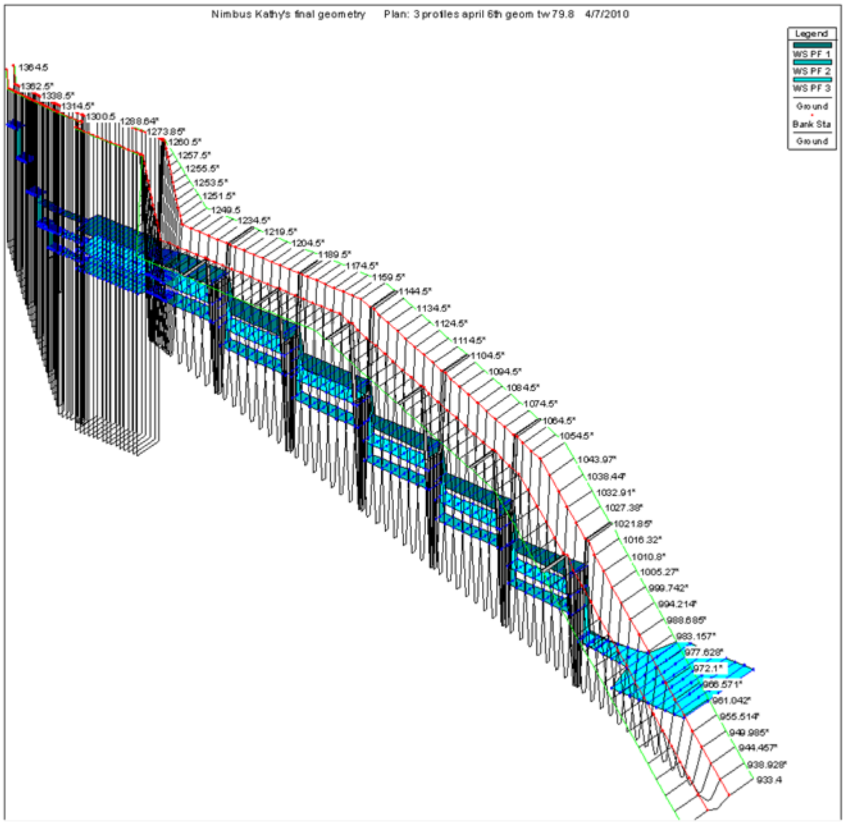

Figure 23. - HEC-RAS output showing flow depths through the fishway of 25, 40, and 65 ft^3/s under the tailwater pool El. 79.8 ft corresponding to the minimum river flow of 250 ft^3/s.

The results obtained from Flow 3D with the higher rock fishway crest were very similar to those from HEC-RAS with slightly shallower flow depths reported in the fishway, but very similar drops between weirs.

The crest elevation at 84 ft at the top of the rock fishway will submerge the first and possibly the second weir at the entrance to the concrete ladder. This should ensure connectivity when the prototype is built. The recommended operation of the rock channel would be to provide at least 15 ft^3/s auxiliary flow through the fishway to increase flow depths and noise in the channel.

Both HEC-RAS and Flow 3D were run with six boulder weirs in the fishway to look at the weir geometry and spacing that would meet criteria. In Flow 3D the weir boulders were modeled as perfect spheres and in HEC-RAS the weirs were constructed using vertical slots between obstructions. Both used 1 ft spacing. The reality probably is the actual boulders that would be used for construction are somewhere in between both geometries. Therefore, it is expected that the fishway will operate somewhere between that predicted by the Flow 3D and the HEC-RAS results. A benefit of using boulder weirs in a rock fishway is that it allows for flexibility in the final arrangement of the boulders. The large center boulder is not set into the rock bed but left on the surface so that the drop between weir pools can be adjusted as necessary. Therefore, results from idealized spherical objects or vertical slots that are used for ease of design are not the final answer, but provide for an initial layout for the pools that can be "tweaked" during construction.

Fish Attraction

The entrance to the rock fishway is located over near the left abutment of Nimbus Dam. The location, and whether or not fish attraction from the ladder entrance will be adequate, has been discussed throughout the design process. Only a certain number of fish are needed to meet the hatchery requirements, therefore, full passage is not needed. The criteria of 10 percent flow ratio of the ladder to the river flow for ladder attraction also did not need to be met, because this is not actually passage beyond the dam upstream to spawning habitat. Nevertheless, enough flow, noise, turbulence, or velocity and depth were still needed for the Chinook to find the ladder entrance. Steelheads are looking for tributary flow so their ability to find the entrance did not seem to be quite as much of an issue for the IFPTT.

Early on in the project, Reclamation's CCAO performed two tests to see if introduction of other flow and noise to the quiet tailwater pool below the dam would attract fish to the area from the power plant tailrace where flow is released the majority of the time. These tests are described in the following per David Robinson, Project Team Leader, and CCAO: *"Two tests were performed in the fall of 2003 after the weir was installed. There were a lot of Chinook salmon in the river that year and many had gotten past the weir before it went in. We were making normal releases through the power plant and nothing over the spillway. The first test started by opening gate 16 (opposite side of Nimbus Dam from the power plant) to a flow of approximately 100 cfs. Fish immediately were attracted to the gate flow in significant numbers. Upon further review, a second test was performed that was designed to ramp flow up until fish arrived to try and get an idea of the minimum required to attract fish. This test started with a minimal release that was ratcheted up in increments. By the time we had an estimated 50 cfs flowing over the gate, fish arrived in significant numbers."*

The observations from the tests were discussed with the IFPTT during the first meeting in February 2008 [Appendix A]. It was explained that the flows were estimated but hopefully within the target range of ±10 percent of the power plant flow. It was recognized that a small flow from the gates had more velocity, thus noise, than flow exiting a ladder entrance. IFPTT seemed encouraged with the response of the fish in the tests and thought that any noise or turbulence would bring Chinook over to the area. It was agreed that noise and turbulence for attraction should be incorporated into the final design of the fishway entrance.

One of the reasons the rock fishway entrance was selected over the concrete weir and pool entrance was to help provide noise and turbulence for attraction. The auxiliary flow will provide additional flow in the rock channel, up to a total of 65 ft^3/s, to enhance hydraulic performance of the rock channel, but also to assist with attraction velocities exiting the entrance. Early phases of numerical modeling used a rough rock fishway design with the baseline orientation and 65 ft^3/s figure 24. The intent of the numeric modeling effort was to determine the water surface elevations without the hatchery weir, but it also does provide some insight into the flow patterns and velocities in the tailwater pool that might be considered for fish attraction from the rock fishway. The final design of the fishway is oriented 15 degrees farther away from the power plant and river channel. Figures 25-28 show the baseline orientation of the fishway. As expected, for small river flows the percentage of flow from the fishway causes a larger influence in the flow pattern. The final design may not be adequately represented by these results; and caution should be used about drawing conclusions for the final design.

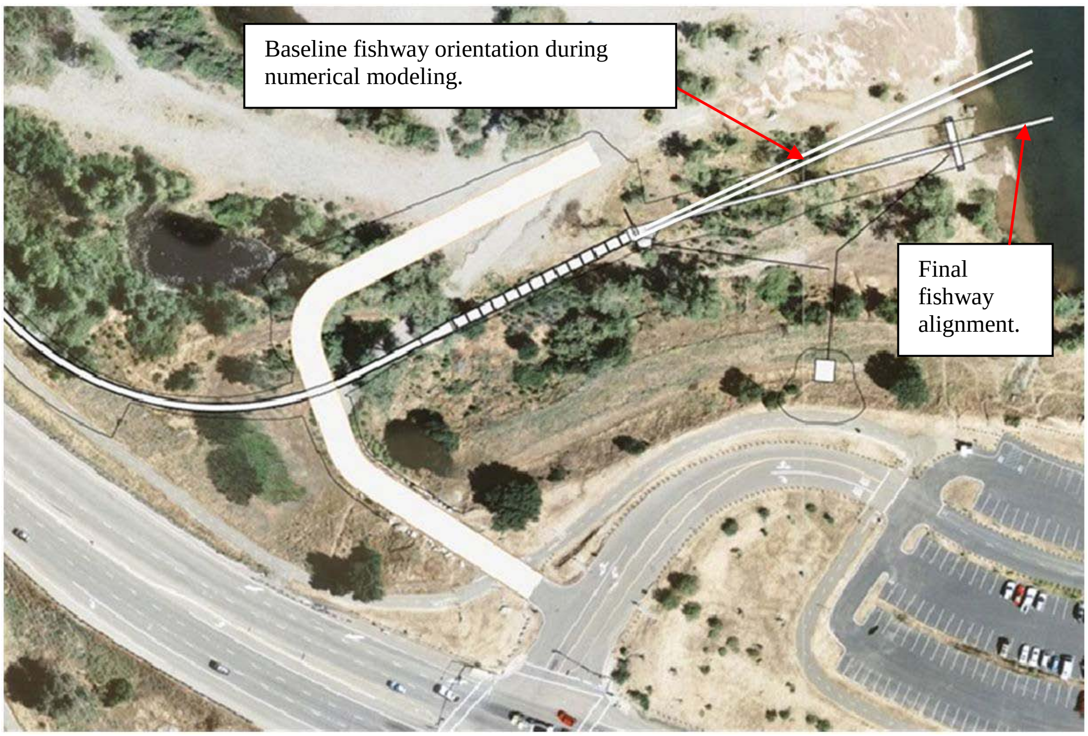

Figure 24. - The baseline orientation was used in the numerical modeling and intuitively seems more favorable for attraction, so results may only be viewed as providing insight and may not be similar to the actual attraction.

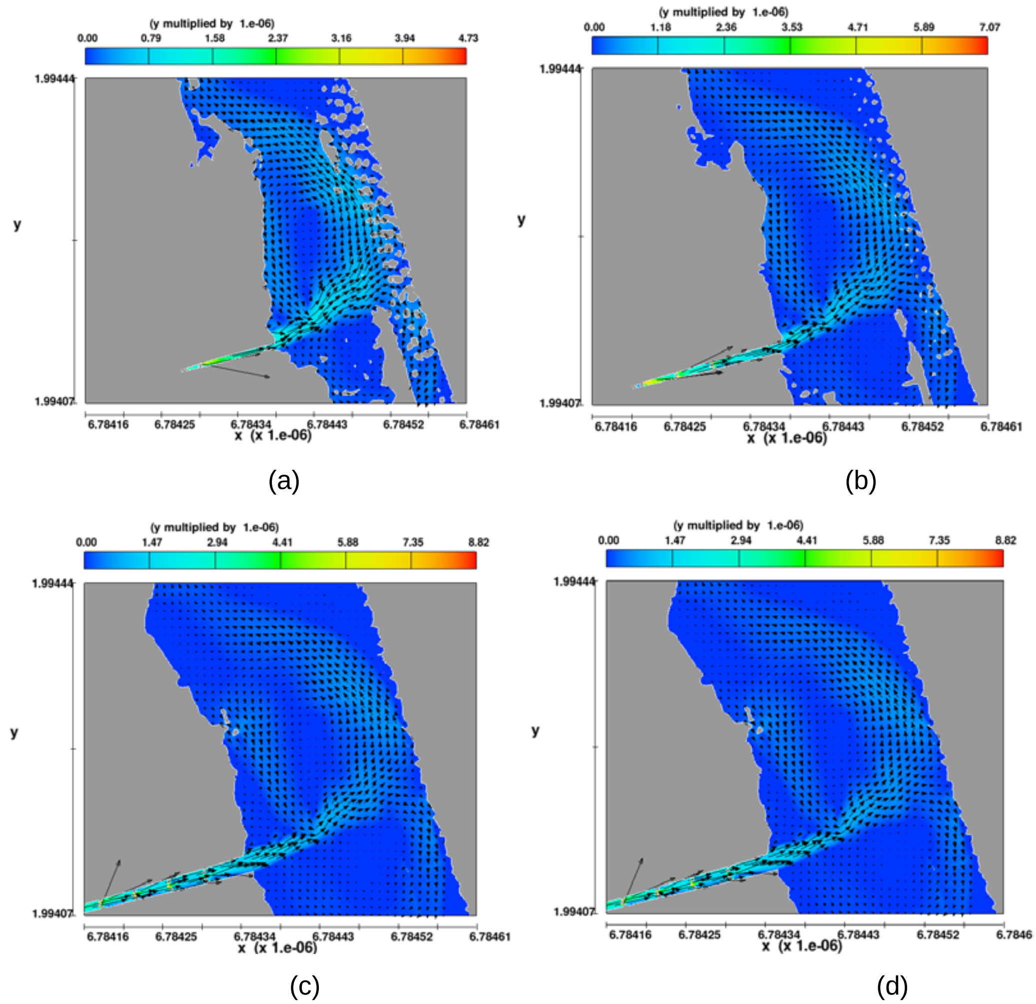

Figure 25. - Potential fishway entrance attraction velocities for various water surface elevations in the tailwater pool. All graphs are for a river release of 250 ft^3/s with 185 ft^3/s through the power plant and 65 ft^3/s through the fishway with the baseline, not final, fishway design orientation: a) El. 76.5 ft or 1/2 ft above channel bottom, b) El. 77.5 ft or 1 1/2 ft above, c) El. 78.5 ft or 2 ½ ft above, and d) El. 79.5 ft or 3 1/2 ft above.

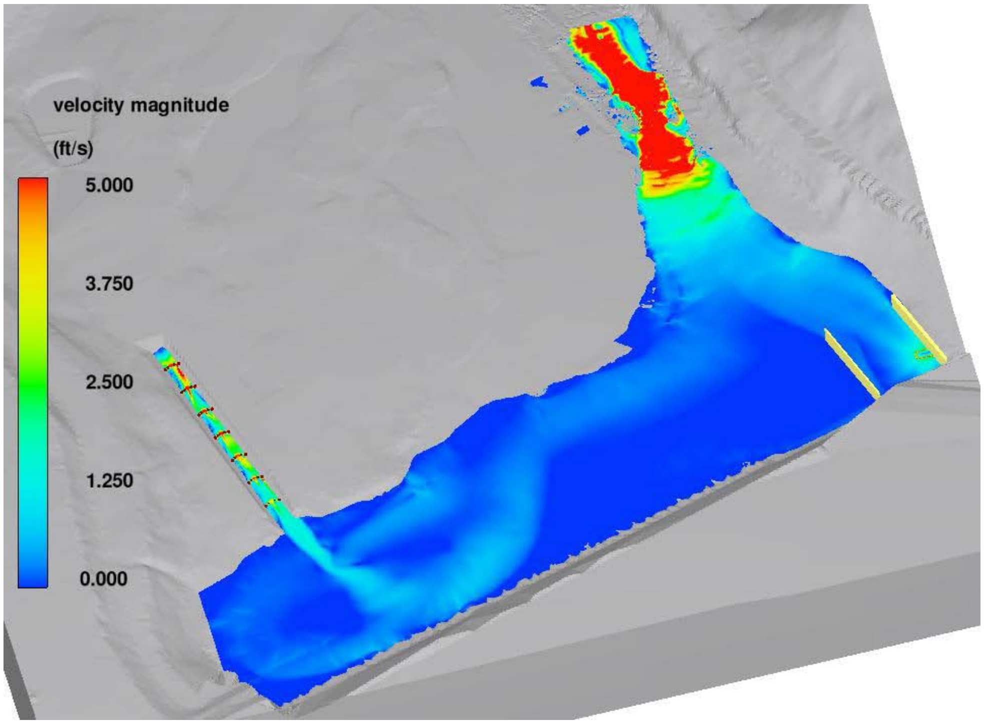

Figure 26. - Overall schematic of the velocities at the pool surface with 185 ft^3/s from the power plant and 65 ft^3/s from the fishway at the surface of the tailrace El. 79.8 ft. The river channel topography controls at the high point below the power plant with higher velocities in this short reach. There still appears to be some attraction influence from the fishway entrance across the tailwater pool with the baseline, not final, fishway design.

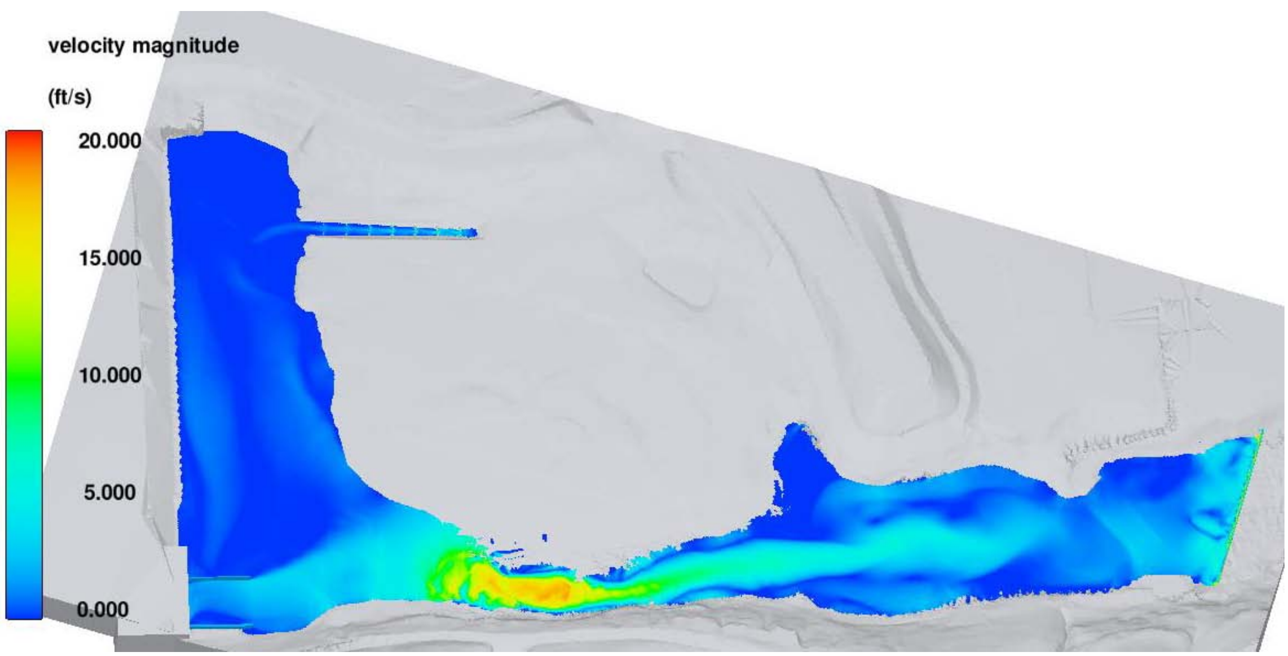

Figure 27. - Overall schematic of the velocities at the pool surface with 1,930 ft^3/s from the power plant and 65 ft^3/s from the fishway at the surface of the tailrace El. 79.8 ft. The river channel controls at the high point below the power plant with higher velocities in the short reach but there still appears to be some minor eddying produced by the fishway entrance across the tailwater pool with the baseline, not final, fishway design.

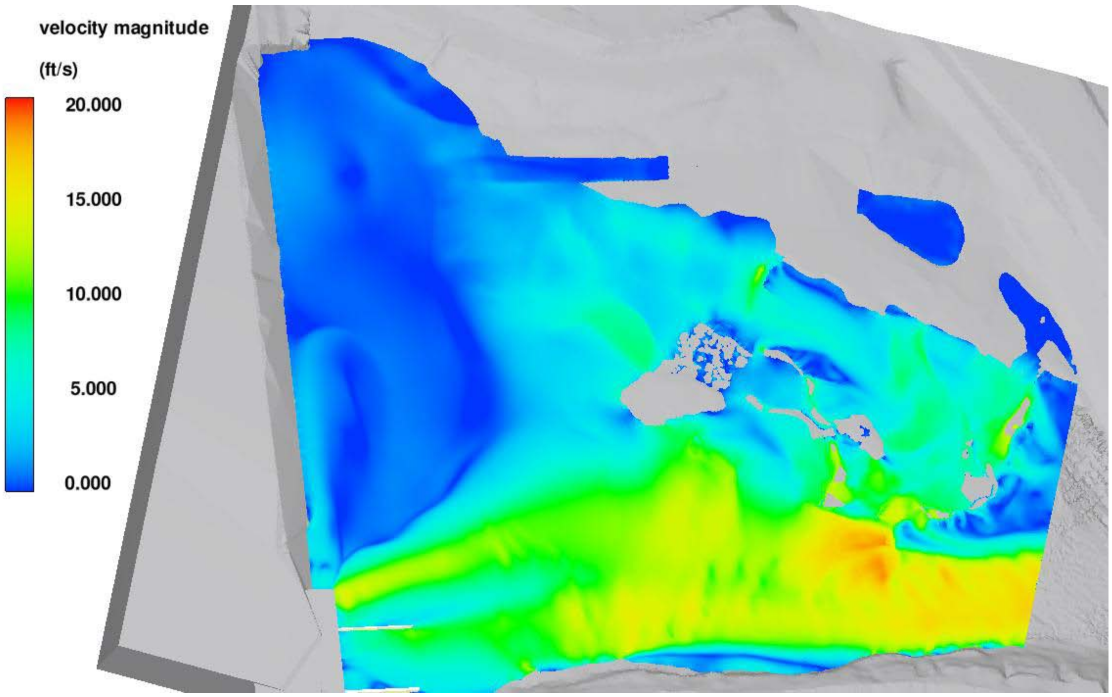

Figure 28. - Overall schematic of the velocities at the pool surface with 10,000 ft^3/s from the power plant, 5,000 ft^3/s from each of the two gates adjacent to the power plant and 65 ft^3/s from the fishway at the surface of the tailrace El. 79.8 ft. It is difficult to say if there is specific attraction influence from the fishway entrance but upstream opportunities may exist.

Fish Attraction Pipe

The purpose for the fish attraction pipe was to provide flexibility to the design of the fishway entrance by providing more flow skimming the surface of the pool for attraction. The attraction pipe idea came from the Healdsburg, California site as discussed in Appendix A.

The flow for the 18inch fish attraction pipe will come from the existing abandoned 42 inch pipeline from Nimbus Dam. The plan view of the valve vault and pipeline location is shown on figure 4. The pipeline will parallel the fishway on the right, or east, side and daylight out of the topography near the end of the fishway as shown in the sectional end view on figure 29. The end view shows the concrete foundation that will be constructed for the hatchery staff to add a pipe gate to control the numbers of fish entering the rock channel in the future. The elevation of the pipe is fixed with a centerline elevation at the end of El. 82.1 ft or the water surface elevation associated with the normal river discharge. There is a 5 degree upturn at the end of the pipe to keep the flow near the surface as the tailwater increases. The pipeline is designed to have a maximum flow of 20 ft^3/s and be controlled by manually placed orifices as needed. Table 8 shows the expected flow rates under a range of reservoir elevations for given orifice sizes. The attraction flow pipe will share flow from the 42 inch pipeline with the auxiliary flow for the rock fishway, thus is limited to 20 ft^3/s. It will most likely not be needed for routine operation of the fishway and usually the rock fishway will take the majority of the flow to provide depth and velocity in the rock channel.

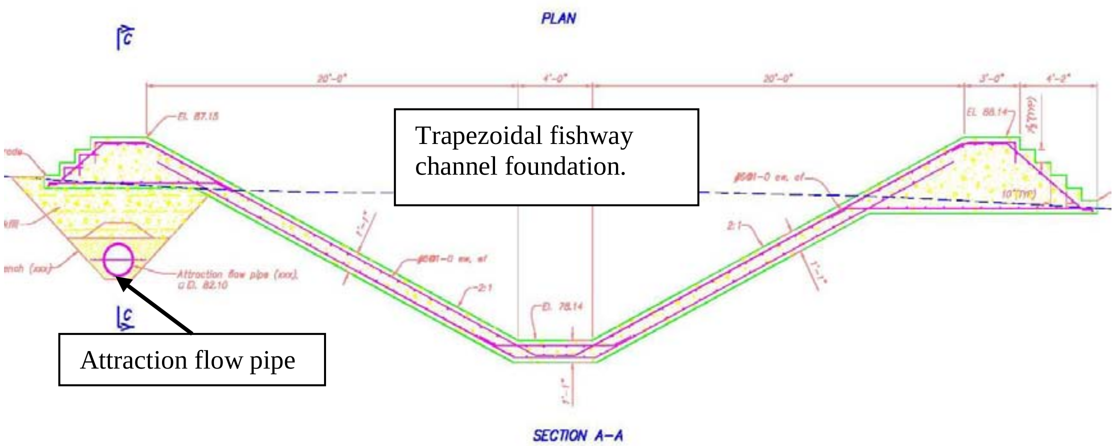

Figure 29. - Cross section showing the trapezoidal shape of the rock channel at the embedment point of the foundation for future features and the location of the attraction pipe.

Table 8. - Orifice sizes needed to provide flow under the range of available head at Nimbus Dam.

Orifice Diameter (Inches)	Flow (ft^3/s)	
	Low Reservoir	High Reservoir
5.49	4.6	5
8.86	9.1	10
9.89	13.5	15
10.9	17.6	20

Conclusions

The design for the Nimbus Hatchery Fish Passage Project flume and ladder fishway has evolved over many years and provides the features desired by the resource agencies today. The primary features are the flume of relatively flat slope to transport the fish from the weir and pool ladder and the rock channel entrance to the hatchery.

The key to the flume and ladder design is to have a flexible operational system that will provide the necessary numbers of fish to the hatchery each season, whether a high or low run is expected, and structurally survive floods during releases from Nimbus Dam. There is always uncertainty in designing for fish passage, even in this case where the fish are not passing upstream but into a hatchery. To lessen the impact of potential uncertainty in fish behavior, as many facilities with as much operational flexibility as possible were provided in the design. The following conclusions were reached in the design:

Flows and Water Surfaces

The fishway flume and ladder will function from September through April for flows between 250 and 20,000 ft^3/s. Normal flow in this well regulated system is about 1,930 ft^3/s and was the focus of the design.

The rating curve for the pool at the base of Nimbus Dam is given in figure 14 and table 5. Water surface levels in the power plant tailrace and fishway entrance should provide adequate depth under low flows. Some boulder weirs in the rock channel will be exposed to provide noise during normal operation, even as the Shoals begins inundating. It also shows that the fishway will become non-functional at about 27,500 ft^3/s when the walls of the concrete ladder become submerged.

Flume

The discharge into the flume is fairly well-known and specified at 25 ft^3/s. The following features were designed:

- The water surface at the tie-in with the hatchery flume is El.103.13 ft,
- A six foot flume width with resulting flow depth of just under 4 ft and velocity of 1.1 ft/s,
- Varied slopes to match connection to the existing hatchery flume and topography,
- Three-ft high weirs were placed on 100 ft centers with provision for additional weirs at 50 ft intervals. The drop across the flume weirs was 0.5 ft or less,
    - Orifices were placed in the weirs to allow both streaming and diving flow,
- Weirs and viewing windows were placed for future visitor center improvements,
- Riprap protection on flume embankment slopes for protection under flood events.

The fishway design starts at the connection with the existing hatchery. The existing water surface was computed from survey information. Water surfaces, depths and velocities were computed in HEC-RAS to ensure the design would meet the requirements. Uncertainty exists with the survey information, and the selected roughness values and weir coefficients used in the HEC-RAS modeling.

Weirs may be added or locations adjusted in the flume section if there is too little or too much head throughout the flume for the fish to progress upstream.

Concrete Ladder

The final flume length was shortened and the ladder attached where the drop could be provided from the hatchery to the Shoals while minimizing exposure of the concrete walls. An expansion section was designed from the flume to the 9-ft-wide ladder. The existing functioning weir and pool ladder design was simply transferred to the end of the flume and a pipe gate added at the end of the ladder to restrict fish entry as necessary to meet hatchery requirements. HEC-RAS computations showed 1 ft of drop across the weirs and greater than 4 ft of flow depth in the pools.

Rock Channel Entrance

Features of the rock channel entrance design included:

- Connectivity between the end of the concrete ladder and the top of the rock channel by setting the rock channel crest at El. 84 ft. This crest elevation will submerge the first and probably the second weir at the concrete ladder entrance,
- Uniform geometry of the transition between the concrete ladder and the rock channel where the addition of 20 to 40 ft^3/s auxiliary flow through a diffuser produces exit velocities of 1 ft/s or less,
- Small sized trapezoidal-shaped channel with a 4-ft-bottom width and 2:1 side slopes. Slope of the rock channel was set at 0.025 and was steepened to produce some noise and drop between weir pools,
- Six chevron-shaped boulder weirs to produce depths and velocities for fish passage and noise for fish attraction,
    - A concrete foundation added near the end of the rock channel in case another pipe gate might be added in the future,
- Fish attraction pipe exiting near the end of the rock fishway to provide additional skimming flow for attraction, if necessary,

During construction of the rock ramp, the center boulder of the chevron weir, or tuning boulder, will be placed on the surface of the rock foundation. This rock can then be moved upstream or downstream to enlarge or reduce the openings between boulders, thus increasing or reducing flow, and conversely reducing or increasing head between weir pools.

Overall drop is critical to the fishway entrance design. It was critical to the design to know the flow depths at the entrance after the existing weir removal. The water surfaces were developed in Flow 3D after field data were collected of the bathymetry in the river that will play a role in low flow conditions. Modeling with both HEC-RAS and Flow 3D produce uncertainties with results. Exactness of tailwater elevations, rock roughness selection, modeling of the flow area between boulders using perfect spheres or vertical slots can all contribute to uncertainty in the design. In addition, the overall channel roughness often varies during construction. However, the final channel will lend itself to easy modifications as felt necessary. In the rock channel entrance additional weirs could be installed if the resource agencies feel that less drop per weir pool is desired.

The recommended operation of the rock channel would be to provide at least 15 ft^3/s auxiliary flow through the fishway to increase flow depths and noise, and reduce velocities in the channel,

Monitoring

Resource agencies felt that monitoring could provide valuable information prior to removal of the existing in-river weir. The hatchery has goals for the numbers of and times that fish are collected. Most agencies are fairly certain that the these goals will be met, but monitoring must be done to ensure goals are met. In addition, more would like to be known about fish behavior as the fish approach the Nimbus tailrace pool, enter the fishway, and arrive at the hatchery. Resource agencies would be looking for impediments to timely passage of the fish and operational improvements that could be made to the system. For instance, adding or removing weirs in the flume, adjusting the auxiliary flow amount, adding the fish attraction pipe flow. It is recommended that monitoring take place for two seasons, if possible. Removal of the existing weir would then take place and habitat improvements made as warranted.

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