PAP-1013

Nimbus Hatchery Fish Barrier Physical Model Study

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August 2002

DRAFT: Nimbus Hatchery Fish Barrier Physical Model Study – Floating Bar Rack Tom Gill, Water Resources Research Laboratory, USBR 2001

Introduction

A physical model study of the concept for a replacement fish barrier at Nimbus Fish hatchery was commissioned by the United States Bureau of Reclamation, (USBR), Mid-Pacific, (MP), Region "... to improve level of certainty associated with performance ..." of the proposed replacement structure design. The study was carried out at the USBR Technical Service Center, (TSC), by the Water Resources Research Laboratory, (WRRL) Group. This report has been prepared to document the model study.

Background

The Nimbus hatchery fish barrier is located on the American River a short distance downstream of Nimbus Dam. Construction of the fish barrier was completed in 1955. The structure angles downstream away from the fish ladder entrance on the left bank, making approximately a 55° angle with the stream banks. Figure 1 is an aerial view of the Nimbus fish barrier.



Figure 1: Nimbus fish barrier – flow direction is left to right. Note the fish ladder leading from the left side of the structure in the upper part of the photograph.

The structure features concrete abutments at the ends and concrete piers spaced 30 ft on center across the span of the structure. The piers rest on spread footers constructed several feet below the stream bed on bedrock. Figure 2 is a view from the left bank showing the piers of the existing structure that are spaced approximately 30 ft apart.



Figure 2: Existing Nimbus fish barrier piers, without walkway or pickets installed

Picket racks are installed by mid-September of each year for the spawning run then are removed in late December or early January. An overhead cableway is used to first install a walkway/support-rack atop the piers, then to install the picket racks which are supported by the walkway. When not in use, components are stored in an area beside the river under the cableway. Figure 3 shows the left side of the structure with walkway and picket racks installed.

Over the lifetime of the structure significant maintenance and repair issues have been encountered. When pickets are in place, it is necessary to manually remove debris twice weekly. At high discharges, it is necessary to raise or remove components of the barrier to prevent components from being damaged or destroyed. When flows exceed about 5000 ft³/s, pickets are raised, at a 10,000 ft³/s, the pickets are removed and at a

threshold of 15,000 ft³/s, the walkway/support-racks are removed. Removal of the support frames and pickets is approximately a three day task.



Figure 3: Section of the existing Nimbus fish barrier with walkway and pickets installed

USGS daily flow records posted on the internet for the Fair Oaks gage, located a short distance downstream from the fish barrier, were examined from 9/15 thru 12/30 for the years 1956 thru 1999. Over this period 5000 ft³/s discharge was exceeded during 20 years, 10,000 ft³/s was exceeded during 8 years and 15,000 ft³/s was exceeded during 7 years.

Bed scour has been another problem. Initially, a steel mat covered by bed material was placed across the stream bed to limit erosion underneath the pickets. This proved insufficient to control erosion, and fish were able to pass under pickets. Figure 4 shows construction of upgrades that were done during 1963. At that time, wire mesh screens were installed vertically along upstream and downstream piling rows. Large riprap was placed along the foundation to control scour. By the mid 1980's the wire mesh had apparently deteriorated and scour under the pickets was again a problem. Placement of cobbles to fill voids under the pickets has been performed repeatedly since that time.



FIGURE 4: 1963 foundation repairs – Wire mesh screens were installed and large riprap was placed between the screens and upstream of the barrier.

The magnitude of maintenance and repair issues associated with operation of the structure was such that in 1996 the Bureau of Reclamation assembled a concept study team to identify criteria and alternatives for upgrade or replacement of the structure.

Following the work of this group a Value Analysis, (VA), workshop was convened in June of 1999 to further analyze problems and alternatives for the fish barrier. The VA team included personnel form the Bureau of Reclamation, California Department of Fish and Game, U.S. Fish and Wildlife Service, Army Corps of Engineers, Save the American River Association and Surface Water Resources Inc.

Physical Model

The physical model was constructed on a 1:30 Froude-based scale. Model design was based on structural drawings and topographical contour data provided by the MP Regional office. A 900 ft reach of the American river ws modeled including topography up to an elevation of 102 ft. At the time the Service Agreement was completed,

(07/09/2001) concurrent construction of a full-scale sectional prototype model was planned for a 30 ft section of the existing structure. At the time of this writing, the full-scale model has not been built.

Two primary objectives were identified for the 1:30 scale model tests:

- Identify velocity fields and general flow patterns downstream of the fish barrier for evaluation of attraction and guidance performance potential.
- Develop general hydraulic performance characteristics of the proposed fish barrier for the range of hydraulic operating conditions expected.

Model tests were to be at discharge rates that span the anticipated operating range. Three discharges, representing low, nominal and high American River discharges were called for in the Service Agreement. From analysis of daily flow data from the Fair Oaks gage discussed above, and from practical limitations in the laboratory, the following discharge rates were identifieded for testing:

- Low flow 760 ft³/s (near the lower discharge limit that could be accurately measured and delivered in the lab – exceedence 88%)
- Nominal flow 2060 ft³/s (median flow exceedence 50%)
- High flow 5180 ft³/s (exceedence 5%)
- High flow 16000 ft³/s (exceedence 1%)
- Highest flow deliverable in lab 102,000 ft³/s (exceeded during one flow event in the 9/15 to 12/31 season during the 43 water years recorded)

(NOTE: Exceedence values calculated on the basis of daily reported discharge)

Plans for the replacement structure call for it to be built in the same location and orientation to the stream – angled at approximately 55 degrees with the channel centerline – as the current structure. In the drawings provided by the MP Region, the fish ladder entrance, at the left bank is unchanged. A 90 ft section adjacent to the right bank will become a gate controlled bypass section. The right bank abutment is raised and lengthened as the end wall of the bypass section, but remains in its present location.

Between the left bank and the bypass section, the structure features a vertical drop. It will consist of a 13 ft wide concrete sill on the upstream side. This width includes a 3 ft overhang extending in the downstream direction over a vertical concrete wall. Floating

bar racks will be hinged to the downstream edge of this overhang. A sheet pile cutoff wall will be installed below the upstream edge of the sill. A 28 ft wide concrete apron will extend from the base of the vertical wall on the downstream side. In the conceptual design supplied by the MP Region, the elevation of both the upstream sill and downstream apron would vary across the structure.

Beginning at the left side, the first 35 ft of the structure would have a sill elevation of 79 ft and an apron elevation of 73.5 ft. Over the 180 ft span between this 35 ft section and the bypass section, the sill would slope upward from the 79 ft elevation to an elevation of 80 ft next to the bypass. Over the same span, the apron would slope downward from an elevation of 73.5 ft to 72.5 ft next to the bypass. The objectives of the sloped sections are to increase the amount of flow on the fish ladder side approaching the structure when river discharge is low, and to enhance downstream attraction flows toward the fish ladder entrance. Figure 5 shows sketches of these cross sections.



Figure 5. Cross sections of the bypass (top) and drop (bottom) components of the conceptual design for the replacement structure.

Two types of control gates are under consideration for the bypass section. One option would be a rubber dam that would either stop all flow through the bypass in the inflated position, or would be completely deflated to bypass flow. A second option would be a bladder actuated overshot gate, (Obermeyer gate). A rubber dam would need to be high enough to act as a barrier to prevent fish from jumping over. It could not function to

simultaneously pass flow and impede upstream fish travel. If an Obermeyer gate were installed, floating racks could be attached to it to act as a fish barrier. The gate could be raised to the 80 ft elevation of the adjacent drop section during the time fish passage is being controlled, thus expanding the width of the structure which could function to pass flow while restricting upstream movement of fish.

A single component was used to model both gate types. A 10 ft by 90 ft overshot gate was installed. When raised to an elevation of 80 ft, the upper edge of the gate was in line with the trailing edge of the adjacent sill of the same elevation, modeling the Obermeyer gate. At this setting the gate was oriented approximately 49 degrees from horizontal. To model a rubber dam, the same gate was oriented vertically. The wall required for the left side of the rubber dam was modeled by inserting a sheet metal plate along the interior edge of the gate. Bypass flow for both types of gates was effectively modeled when the model gate was fully lowered.

Channel topography was simulated by placing concrete over a wire mesh supported by plywood. Plywood support shapes for contours above the elevation of 80 ft were cut by a computer controlled router reading data files converted from digital contour files supplied by the MP Region in Autocad format. Contour data provided by the MP Region as model construction was initiated included only elevations above 80 ft. Channel bottom contour data, (contour data below 80 ft elevation), that the MP Region later forwarded appeared to be of questionable accuracy. Prior to construction of the model, this concern was raised during a telephone conversation with Steven Lloyd, MP Region design engineer.

Steven concurred in our low confidence level in the quality of the stream bed data. He suggested that what appeared to be a plateau at 79 ft elevation with a mean width of 60 ft immediately upstream of the structure was probably a region lacking elevation data input when the contour map was generated. Beyond this region, the upstream bed elevation appeared to drop rapidly to below 65 ft, approximately 12 ft lower that the 77.5 ft crest elevation shown in 1954 construction drawings for the existing structure. In the downstream direction, the contour data indicates a rapid drop in bed elevation to below 65 ft. Approximately 150 ft downstream there appears to be a ridge at an elevation of about 70 ft, beyond which the elevation again drops off.

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Mr. Lloyd suggested that the downstream bed features indicated are not inconsistent with bed scour that has occurred below the structure, and a riprap-impregnated ridge that is located downstream of the scour hole.

The impact created by the uncertainty of the streambed elevation data is diminished by the fact that a significant amount of bed shaping and armoring will be require for the concept design in the vicinity of the structure. Using sill, apron and bypass elevations, a bed shape was developed to be consistent with the desired performance of the structure. Beyond the reshaped segment of the stream near the structure, the streambed was modeled in a shape similar to that indicated by the supplied contour data in both upstream and downstream directions. Figure 6 shows the topography of the model.



Figure 6. Model stream bank and bed elevation contours

Floating screens in the prototype drawings were to be constructed of ¾ in schedule 40 pipe with approximately a 54% open space. The concept design calls for screens 10 ft long by 4 ft wide. An unspecified type of floatation device was to be attached to the underneath side of the trailing end of the screens to attain the proper buoyancy. Screens for the model were machined from sheets of PVC plastic. At the small, (1:30), scale of the model, it was assumed that viscosity forces would have an increased impact. To compensate for this effect the model screens were designed with a larger 62% open space. Floats cut from Styrofoam material were attached to the underneath

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side of the downstream ends of the screens. Figure 7 shows the model screens with flow passing.



Figure 7. Floating screens under flow conditions—during this initial "wetting" of the model, styrofoam floats in the picture are held in place by rubber bands. They were subsequently attached using an adhesive. Note the debris hanging on the screens.

It should be noted that the 1:30 scale is too small to achieve a high degree of accuracy in modeling screen performance. Open space ratio of model screens and float apparatus design were selected to achieve reasonable similarity in performance, not with the expectations of evaluating design criteria for the screens or floats.

Data Acquisition

Data acquisition methodologies employed in the model tests included visual observations and two photographic methods. Surface velocity fields were documented using still photography with a one-second shutter opening. Additional documentation of the surface velocity field and of flow streamlines was provided through use of a video camera.

For the one-second exposure photographs, a Nikon F4 35mm camera with a 24 mm lens, (set on f-stop 8), that could be remotely operated was mounted approximately 15 ft above the model. A 2 ft by 2 ft (model scale) grid was created at the top of the model box using strings. Geo-reference grid points were translated down to the model surface using a plumb bob. Each grid point was then painted in fluorescent orange as a 3 in

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diameter circle or a 4 in by 4 in cross. At selected stream discharges, 1 in diameter styrofoam balls were scattered across the surface downstream of the fish barrier to create streaks in the one-second exposure photographs.

Color 400 film was developed as 4 in X 6 in prints from which bitmap images were scanned. The bitmap images were imported into an Autocad file which contained the model boundaries, the fish barrier footprint and the 2ft X 2 ft (model scale) grid. Using Autocad tools, the imported image could be scaled, rotated and moved to align the geo-reference points in the photo with those in the drawing. To account for optical distortion in the image, it was necessary to adjust scaling and position for different regions of the model. Figure 8 is a typical "streak" photograph.



Figure 8. A "streak" photograph taken at 2060 ft³/s discharge Note the geo-reference grid of circles and crosses, as well as the optical distortion.

A routine programmed in LISP was used for on-screen digitizing of the velocity vectors represented by the streaks in the photographs due to movement of styrofoam balls during the one-second exposure. Multiple photographs were taken at each selected discharge with additional styrofoam balls being scattered before each shot. In mapping the downstream velocity vector field, each of the images made for a discharge was imported in an attempt to obtain a comprehensive coverage of velocity "streaks". The

LISP routine recorded the digitized streaks with an arrow and a numeric value in ft/s. For streaks indicating a velocity less than 0.5 ft/s, the LISP routine enters a dot. Figure 9 shows a velocity field developed from streak photographs.



Figure 9. Vector diagram of the attraction flow velocity field for a 2060 ft³/s discharge

Video tape, taken from approximately 18 ft above the model with a Sony Hi-8 Handycam provides additional documentation of the attraction flow velocity field and of flow patterns as water moves across the fish barrier structure. Styrofoam balls were again scattered while video was being recorded. In addition, dye was injected into the flow at the fish ladder entrance and both immediately upstream and downstream of the structure. The video was reviewed in verifying flow direction for eddies in the downstream velocity field. An edited copy of the video from the tests in VHS format accompanies this report.

Results

Tests modeling an Obermeyer bypass gate raised to 80 ft elevation were performed for the selected discharges noted above up through 16,000 ft³/s. Velocity field maps developed from streak photographs are in Appendix A of this document. Subsequent to the initial tests with the Obermeyer gate, members of the planning team – Donna Garcia and Steven Lloyd of the Reclamation's MP Regional Office and Bruce Oppenheim,

Fishery Biologist with the Protected Resources Division of the National Marine Fisheries Service made a visit to observe the model in October, 2001 and to examine data acquired up to that time.

During the visit, the MP team requested additional tests be conducted for the discharges within the range the barrier would be functional modeling 1), a "rubber dam" control in the bypass section and 2), the Obermeyer gate in the bypass with no fish ladder discharge in the model. These tests have since been completed, and velocity field maps of flow for the selected discharges up through 5180 ft³/s. Velocity field maps developed from streak photographs for these test conditions are in Appendix A as well.

Current Project Status

During the October visit by members of the MP design team, changes to the abutments in the model were discussed as well as having TSC mechanical designers help with design specifications for the floating screens. Designs for desired model changes were to be supplied by the MP team. WRRL staff would contact TSC mechanical engineers to discuss developing specifications for the screens.

Members of TSC's Mechanical Equipment, (D-8410) and Hydraulic Equipment (D-8420) Groups have viewed the model and available literature for the floating screens, and feel that the concept is at present an experimental technology with insufficient data available to provide design specifications. Needed data would likely need to be obtained from an expanded modeling program on a larger scale to identify items such as satisfactory float design and the stresses various components will be subjected for the expected range of flow conditions.

Conference calls between MP team members and TSC personnel were held on 12/05/01 and on 12/14/01. During the first call, concerns regarding development of technology required for the floating screens were presented by engineers from the TSC equipment groups, along with their constraints on time available for design work. The MP team articulated their desire to have designs in place by January, 2002, in order to complete the first phase of construction prior to barrier installation in September of 2002.

In the 12/14 call, the MP team reiterated a strong desire to initiate construction during 2002 to preserve funding priority the project is now in line for. During the call, the MP team indicated given the need for coordination in the design process, it is interested in having the entire design be performed by TSC. Performance criteria for the structure – in particular maximum discharge at which the barrier is to remain functional, and bypass capacity – were discussed during the call. These parameters do not appear to be concrete at this time.

After the 12/14 conference call, TSC's Water Conveyance Group, (D-8140), was contacted about assuming the lead on design of the Nimbus fish barrier. Steve Robertson of that group was designated lead engineer for the project design. He met on 12/18 with the WRRL staff that had been involved in the physical model tests to become acclimated with the project. On 12/20, Mr. Robertson met with staff from WRRL and Equipment groups to discuss project concepts and alternatives that might the schedule of the design process.

A focus of discussion in the 12/20 meeting was time and resource requirements for development of the floating screen technology. The design process might be significantly streamlined if an alternative using existing technology or a simplified technology were employed. Concepts discussed include using a staggered configuration of Obermeyer gates/screens across the entire stream, and using a combination of Obermeyer gates/screens and a drop section with fixed declined bar rack, similar to the favored design from the VA study conducted in 1999. Discussion at this meeting included plans for a visit by TSC personnel is planned for early January, 2002 to observe the site and present alternatives to the MP team.