DESIGN FOR FISH PASSAGE ON THE YELLOWSTONE RIVER AT INTAKE DAM USING NUMERICAL AND PHYSICAL MODELING

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Abstract The Lower Yellowstone Project at Intake is a Bureau of Reclamation irrigation project located on the Yellowstone River. The Intake Diversion Dam modification will provide fish passage and prevent entrainment while maintaining the irrigation diversion project function. The fish passage design was based on ADH two-dimensional modeling and a physical model. Criteria for the fish passage was developed from available fish swim studies and surveys of existing river riffles. Performance was scored using computed hydraulic parameters. The presentation will discuss numerical and physical model results, design innovations, and predicted fish passage performance.

INTRODUCTION

WRDA 2007 authorized the U.S. Army Corps of Engineers (Corps) to assist the U.S. Department of the Interior Bureau of Reclamation (Reclamation) with design and construction of the Lower Yellowstone Project for the purpose of ecosystem restoration. The Corps and Reclamation are working collaboratively to complete an Environmental Assessment (EA) in compliance with NEPA. Engineering analysis includes the construction of numerical models and a physical model. Construction is planned for fiscal year 2010 with a total project cost estimated at $40 to $50 million.

Project Purpose The proposed project is a high priority for recovery of pallid sturgeon in the Upper Missouri River Basin. Providing fish passage at Intake Diversion Dam would open up a minimum of 165 river miles of additional habitat that pallid sturgeon could utilize for spawning and other purposes. The natural condition of the Yellowstone River and its natural flow hydrograph suggest to biologists that this river reach is critical to the recovery of pallid sturgeon on the Missouri River System between Ft. Peck Dam and Lake Sakakawea.

Existing Project Description Intake Dam is a Reclamation irrigation diversion dam on the Yellowstone River 70 miles upstream from the mouth. Intake Dam was originally constructed as a rock-filled timber crib weir with a height of 12 feet in 1906. The diversion dam crest becomes fully submerged at river flows above about 20,000 cubic feet per second (cfs), however, the dam continues to produce some head drop to flows in excess of 100,000 cfs.The dam spans across the Yellowstone River channel for a width of 700 feet. The dam extends about 135 feet longitudinally along the channel and consists of a 1 vertical on 2 horizontal (1:2) upstream slope, a 15-foot wide crest, and a varying degree downstream slope. Since the construction of the dam, the structure has required frequent repair to maintain the upstream Yellowstone River water surface elevation required for irrigation flow diversion. In the current condition, the dam crest elevation varies as ice and flood flows progressively displace riprap material from the crest. Current practice is to maintain the water surface a minimum of one foot above the wooden structure to provide enough head for the maximum irrigation flow diversion rate of 1,374 cfs.

The repetitive placement of loose rock riprap has created a debris field downstream of the dam crest. A photo of the dam crest at low flow is included in Figure 1.

Figure 1 Intake Dam at Low Flow.

Proposed Project Features The proposed project consists of a new headworks structure, revised diversion weir, and a full channel rock ramp downstream of the weir. The new headworks structure includes a screen structure on the canal to prevent fish including pallid sturgeon from entering the canal. The revised diversion weir will be designed to maintain the required head for irrigation diversion, allow fish passage at the crest, and facilitate sediment passage. The rock ramp will be designed to meet biologic criteria across the entire river channel to allow upstream fish migration. Project features are illustrated in Figure 2.

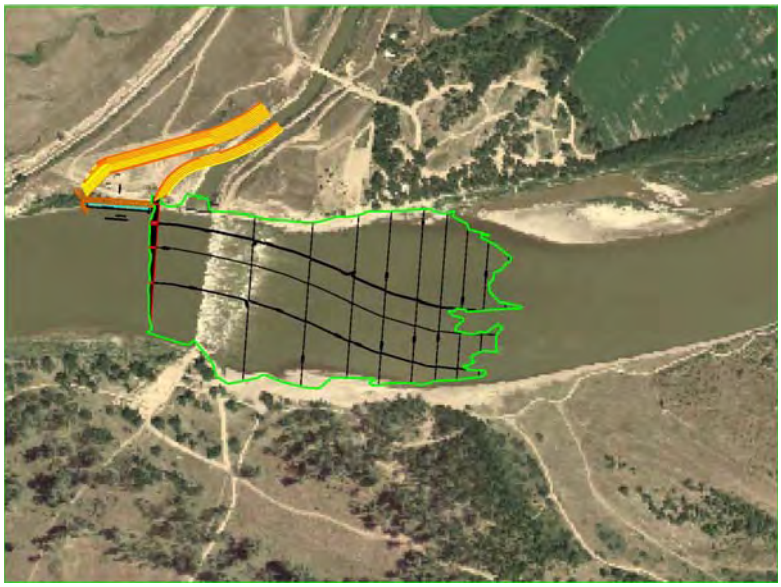

Figure 2 Proposed Project Features.

Design Overview Both numerical and physical modeling is included in design of project features. Numerical modeling consists of HEC-RAS one-dimensional and ADH two-dimensional modeling. A physical model has also been constructed. Primary modeling objectives are to evaluate the ability of the proposed project to:

- Maintain the irrigation diversion capability at a full range of flow conditions without dam crest maintenance.
- Provide a durable project that withstands Yellowstone River debris and ice forces.
- Prevent entrainment of fish in the canal and meet NOAA fish screen design criteria.
- Maintain Yellowstone River sediment passage without any sediment removal issues.
- Provide fish passage by assessing performance with biologic design objectives for the ramp and diversion weir.

PROJECT PERFORMANCE EVALUATION

Fish passage is a critical aspect of the project. A range of performance values were determined by a Biologic Review Team (BRT) to establish metrics for use with evaluating project performance. Evaluation was performed using a variety of tools to classify project performance using depth and velocity. Acres of habitat were tallied according to the various categories and converted to be expressed as a percentage of the total area of interest. The classification ranges selected by the BRT are shown in Table 1.

Table 1 Hydraulic Classification Ranges.

Depth Ranges (ft)
0 to 1.64
1.64 to 3.28
> 3.28

Velocity Ranges (ft/s)
0 to 2
2 to 4
4 to 6
6 to 8
8 to 12

Hydraulic Strain Classification In addition to depths and velocities, turbulence through a reach can greatly affect fish passage. To address this part of the evaluation, computations were performed to determine the spatial distribution of total hydraulic strain within the bend. Hydraulic strain is a representation of the spatial derivative of velocity. It is a measure of flow field distortion which can be easily calculated from a velocity dataset and can be shown to be a precursor to turbulence. Hydraulic strain is at its greatest when changes in velocity occur over a short distance. These areas would also be noted as edge or high shear areas.

Fish can efficiently swim through a complex flow field if they swim away from any source of relative high total hydraulic strain and in the direction of high velocity not associated with high total hydraulic strain (ERDC, 2009). The numeric value at which this variable becomes prohibitive to Pallid Sturgeon passage has not been extensively studied, but the variable still

serves as an indicator of likely paths to be taken through a reach and is useful for comparison between bends. The concept of hydraulic strain is illustrated in the Figure 3 (ERDC, 2009).

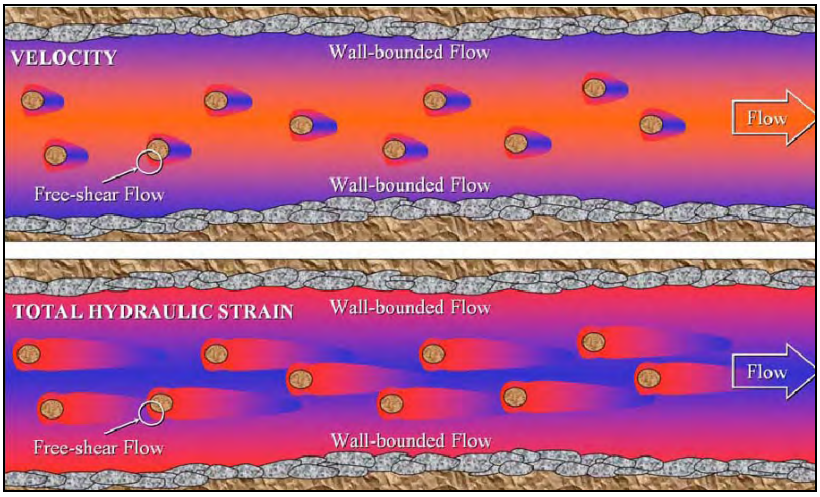

Figure 3 Hydraulic Strain in a Linear Channel with Obstructions.

NEW HEADWORKS STRUCTURE

The headworks structure is designed to provide an irrigation diversion of 1,374 cfs from the Yellowstone River at a river flow of 3,000 cfs. A separate project will include the construction of a new Yellowstone River diversion weir and associated features. Significant project features and design considerations include:

- The new headworks structure consists of removable fish screens, gate structures, downstream energy dissipation features, and a short segment of new canal that joins with the existing irrigation canal.
- Design criteria for the fish screen are to meet NOAA National Marine Fisheries Service screen criteria for juvenile salmonids. Design criteria for salmonids are considered conservative with respect to fish passage and is used because no guidance is available for Pallid Sturgeon.
- Due to the extreme ice conditions, removal of the fish screens is required during the winter non-irrigation season to prevent screen damage.
- Flow through each screen is controlled by a slide gate so that each screen can be operated individually.

Headworks Structure The preliminary design of the in-channel fish screen determined that eleven (11) cylindrical screens would be required to continue to provide the diversion capacity of the existing headworks and canal. However, twelve (12) screens are proposed in the design to allow more flexibility in operations and to provide redundancy to the system. The design team determined that a new headworks structure and canal inlet would best accommodate these screens rather than retrofitting these screens to an expansion of the existing headworks. The new headworks structure is sited immediately upstream of the existing structure. The cylindrical fish screens will be installed on the river side of the new gated headworks structure. The new headworks structure will require excavating a new transition section from the new headworks

structure to the existing canal. The existing headworks openings will be plugged, and the channel immediately behind the existing headworks will be filled.

Cylindrical Fish Screen The preliminary fish screen concept design is summarized as:

- The required 1,374 cubic feet per second diversion capacity can be provided with 11 operational screen units, each with an approximate capacity of 125 cubic feet per second.
- Each screen until would be a 78-inch diameter cylindrical unit with two screen cylinders 100 inches long attached on either end of the manifold for a total length of 24 feet and a screen area of 340 square feet per unit.
- The screens are constructed of #69 wedge wire (width of 0.069 inches) and a slot opening of 0.069 inches which produces a 50% open area.
- Screen approach velocity is 0.4 ft/sec over the screen area (i.e. a slot velocity of 0.8 ft/sec) which meets fisheries criteria proposed for this project.
- Each unit would be installed on the river side of the headworks structure. A slide gate, integrated into the screen manifold/track system, would be used to help regulate flow imbalance and to allow a single unit to be taken out of service for maintenance or repair.
- The screens would roll on a recessed track to allow raising the screens out of the river when the canal is not operating to prevent damage from large debris and ice.
- The portal where the screen connects to the headworks structure is a 4-foot wide by 6-foot high opening.
- The screens are cleaned by stationary brushes on both inside and outside while the screen rotates. Timing of cleaning can be a preset schedule, or when sensors detect a preset amount of head loss across a screen.

Design Analysis Design of the headworks structure included HEC-RAS and ADH modeling. A rating curve was developed from staff gage data at the site to determine the minimum operating level for diversion. Additional head losses due to the fish screens were added to the current operating level. An HEC-RAS model was developed to evaluate the Yellowstone River, the irrigation canal, and the proposed headworks structure. Headworks structure and coffer dam elevations were developed using an uncertainty evaluation.

The discharge of 3,000 cfs was selected by the project team as the minimum Yellowstone River flow at which the full diversion flow of 1374 cfs must be delivered to the irrigation district. This flow was selected based on flow-duration curves developed from the Sidney, MT gaging station. The 90% and 95% flows during August (low flow month) are 2710 cfs and 1770 cfs, respectively. If one assumes full diversion at Intake and no irrigation return, then 3000 cfs corresponds roughly to the 95% exceeded flow. If one assumes full diversion at Intake and irrigation return of about 1000 cfs, 3000 cfs corresponds roughly to the 90% exceeded flow.

The target water surface elevation of 1991.4 ft NAVD88 for a discharge of 3,000 cfs was selected based on water surfaces produced by the existing dam and the expected headloss through the screens.

Critical elevations determined from the HEC-RAS model in conjunction with HEC-FDA are summarized below:

- Top of headworks elevation = 2012.5 ft NAVD. This elevation was selected because it provides >95% assurance that it will contain the 100-yr ice jam event as well as <10% chance of being exceeded over 50 years.
- Bottom of headworks (not including structural foundation) = 1981.4 ft NAVD88 based on the target water surface of 1991.4 ft NAVD88 minus 10 ft. The value of 10 ft is based on the 6.5 ft diameter cylindrical screens, and approximately 1/3 of screen diameter of clearance below the screen.
- Canal invert = 1980 ft NAVD88 (similar in elevation to existing). Water surface elevation in canal for 1,374 cfs = 1990.1 ft NAVD88, resulting in approximately 1.3 ft head differential between riverside and canal during most extreme condition (3,000 cfs in river, 1,374 cfs in canal)
- Coffer dam top elevation of 2004 ft NAVD88. Provides 90% assurance of containing the 10-year ice jam event and about 5% annual exceedance probability. Further analysis may be conducted to determine if it would be economical to require construction only during low flow/no ice jam months with a reduced coffer dam height.

ADH RESULTS: DIVERSION DAM AND ROCK RAMP

The proposed Diversion Dam and Rock Ramp is designed to maintain sufficient water levels upstream to provide diversion at flows as low as 3,000 cfs, as well as provide suitable velocities and depths through the rock ramp to facilitate fish passage.

- The face of the dam will be a concrete weir with a 3:1 face slope.
- The crest of the dam will vary in elevation as shown in Figure 4.
- The gradient of the ramp steepens as it proceeds downstream. Proceeding from the crest, the ramp is at a 0.0 ft/ft gradient for the first ten feet, 0.002 ft/ft for the next 500 feet, 0.004 ft/ft for the next 400 feet, 0.006 ft/ft for the next 400 feet, and 0.008 ft/ft to ground. This results in an approximate total length of 1600 ft from the crest.
- The two-dimensional hydraulic model, ADH (ADaptive Hydrodynamics/Hydrology), was used to model the rock ramp.
- Results of the ADH model give depth-averaged velocities at nodes in a mesh/network.
- Multiple ramp configurations were modeled. Results from the configurations were evaluated for performance using biologic criteria.

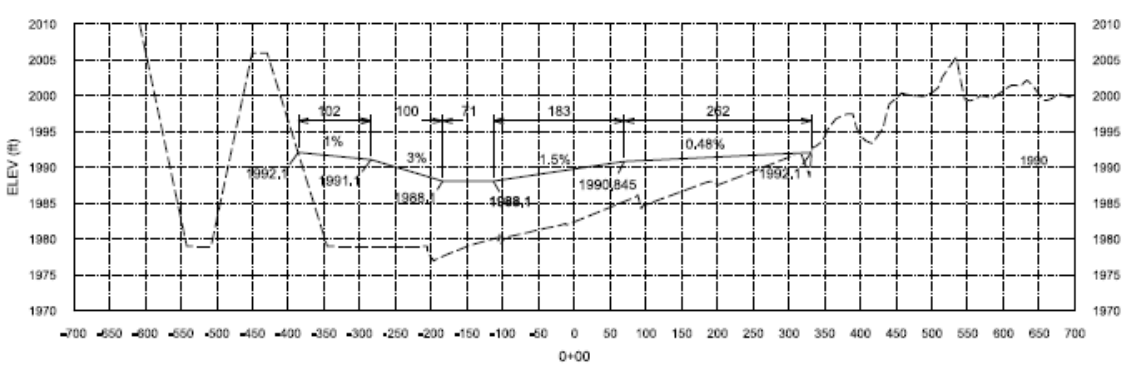

Figure 4 Proposed Weir Crest.

Design Analysis The proposed project numerical analysis was performed with HEC-RAS and ADH. The HEC-RAS model was used to perform a preliminary evaluation of ramp configuration. The two-dimensional ADH model was used to refine the ramp geometry and assess model performance with respect to the BRT criteria shown in Table 1.

Velocity magnitudes for a discharge of 30,000 cfs as computed by the ADH model for the proposed ramp are illustrated in Figure 5.

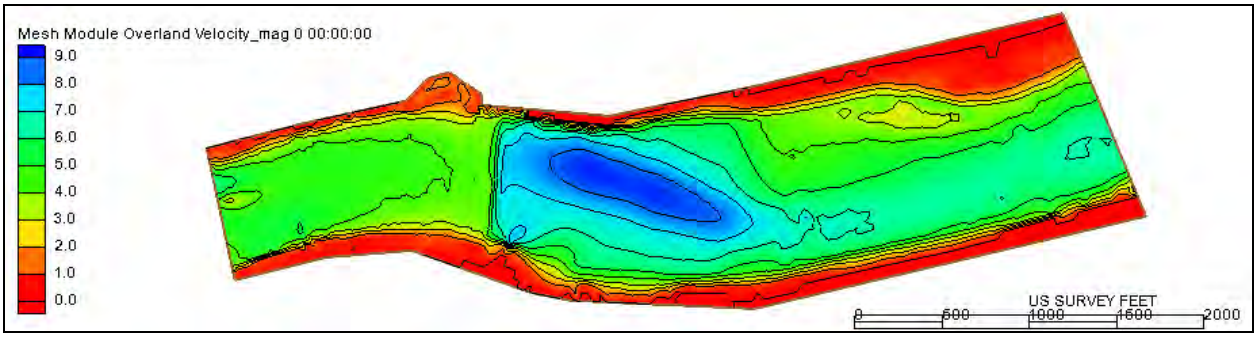

Figure 5 ADH Computed Ramp Velocity.

FUTURE EFFORTS AND TECHNICAL FOCUS

Future efforts consist of:

- Verifying consistency of numerical and physical models
- Evaluating sediment transport using ADH
- Evaluating debris/ice protection using ADH and the physical model

REFERENCES

BRT. (2009). Biological Review Team. “Lower Yellowstone River Irrigation Project Fish Passage and Screening Alternatives and Alternative Scoring Criteria.” Prepared by U.S. Fish and Wildlife Service.

Goodwin, et al. (2009). USACE Engineering Research and Development Center. “Candidate Hydraulic Variables to Characterizing Habitat Value of Bends in the Missouri River.”

USACE 2009. Omaha District U.S. Army Corps of Engineers. “Lower Yellowstone Project Fish Passage and Screening, Preliminary Design Report. Appendix A-2, Hydraulics.”