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Hydraulic Laboratory Report HL-2014-06

Lower Yellowstone River Intake Diversion Dam Fish Bypass Physical Model

Lower Yellowstone Project

Montana Area Office

U.S. Department of the Interior
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Hydraulic Investigations and Laboratory Services Group
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14. ABSTRACT
A physical model of the Lower Yellowstone Intake Diversion Dam fish bypass was evaluated at the Bureau of Reclamation's Hydraulic Laboratory. The model focused on the 3-D hydraulics that form at the downstream end or fish entrance of the bypass.

15. SUBJECT TERMS
Lower Yellowstone, Intake Dam, fish bypass, Pallid Sturgeon

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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.

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GLOSSARY OF SYMBOLS

ADV	Acoustic Doppler Velocimeter
BOR	U.S. Bureau of Reclamation
BRT	Lower Yellowstone River Biological Review Team
ft	Feet
ft^3/s	Cubic feet per second
FWS	U.S. Fish and Wildlife Service
USACE	U. S. Army Corps of Engineers
WSE	Water surface elevation

Project Background

Intake Dam is a Bureau of Reclamation (Reclamation) irrigation diversion dam on the Yellowstone River approximately 70 miles upstream from its confluence with the Missouri River. Construction of the irrigation project began in 1905 with a 12-ft-high diversion dam and a main canal. The Lower Yellowstone project can divert up to 1,374 ft^3/s and irrigates up to 57,000 acres in Montana and North Dakota. The diversion dam presents a barrier to pallid sturgeon migration up the Yellowstone River. The proposed project consists of a screened headworks structure that was completed in 2012, a new diversion weir, and a 250-ft-wide by approximately 2-milelong non-technical bypass channel around the dam.

This study provides a detailed evaluation of the flow conditions at the downstream confluence of the Yellowstone River and the bypass channel. The confluence area is vitally important to the success of the project because upstream migrating sturgeon have to “find” and navigate into the bypass to get around the dam. Water depths, velocity, and flow patterns were evaluated over a range of geometric and flow conditions.

Figure 1. Vicinity map showing the location of Lower Yellowstone Intake Diversion Dam.

Biological Criteria

Project biological performance objectives and design criteria have been established by the U.S. Fish and Wildlife Service (FWS) in conjunction with the

Lower Yellowstone Intake Project Biological Review Team (BRT) (FWS, 2014). The BRT is comprised of biologists and engineers who are experts in the field of pallid sturgeon and fish passage. The BRT recommended to FWS biological criteria that will provide the greatest opportunity for successful passage at the Lower Yellowstone Intake Diversion Dam site. Biological criteria are tabulated in Table 1.

Table 1. Tabular summary of design criteria for pallid sturgeon at Lower Yellowstone Intake Diversion Dam site.

Discharge at Sidney, Montana USGS Gauge	7,000 -14,999 ft^3/s	15,000-63,000 ft^3/s
Bypass Channel Flow Split	≥ 12%	13% to ≥ 15%
Bypass Channel cross-sectional velocities (measured as mean column velocity)	2.0 – 6.0 ft/s	2.4 – 6.0 ft/s
Bypass Channel Depth (minimum cross-sectional depth for 30 contiguous feet at measured cross-section)	≥ 4.0 ft	≥ 6.0 ft
Bypass Channel Fish Entrance (measured as mean column velocity at HEC-RAS station 136)	2.0 – 6.0 ft/s	2.4 – 6.0 ft/s
Bypass Channel Fish Exit (measured as mean column velocity)	≤ 6.0 ft/s	≤ 6.0 ft/s

Model Objectives

Objectives of the Lower Yellowstone River Intake Diversion Dam fish bypass physical model include:

- Evaluation of converging flow from the bypass channel and diversion weir for turbulent and shear zones
- Evaluation of existing conditions downstream of the existing dam (boulders, timbers, etc. in river immediately downstream of existing diversion) that may impact fish guidance into the bypass entrance
- Evaluation of attraction flow in the confluence area.

Model Description

Model Scale

A 1:16 scale physical hydraulic model of the confluence of the Lower Yellowstone River and the fish bypass was constructed in Reclamation's Hydraulics Laboratory in Denver, Colorado in 2014. In order to have a model with larger water depths so that the three-dimensional (3D) flow effects could be evaluated, only the right half of the river, proposed diversion weir, and bypass was modeled. The model included approximately 260 ft upstream of the diversion weir and 1,100 ft downstream (Figure 2). The existing dam, associated rock field, and topography were included in the model (Figure 3). The bypass cross sectional shape and design are based on the U.S. Army Corps of Engineers (USACE) 30% design report (USACE, 2012).

Similitude between the model and the prototype is achieved when the ratios of the major forces controlling the physical processes are kept equal in the model and prototype. Since gravitational and inertial forces dominate open channel flow, Froude-scale similitude was used to establish relationships between the model and the prototype parameters. The Froude number is described by:

$$Fr = \frac{v}{\sqrt{gd}}$$

where v = velocity, g = gravitational acceleration, and d = flow depth. When Froude-scale modeling is used, the following relationships exist between the model and prototype for the 1:16 geometric scale chosen:

Length ratio: $L_{p/m} = 16$

Velocity ratio: $V_{p/m} = (16)^{1/2} = 4$

Time ratio: $T_{p/m} = (16)^{1/2} = 4$

Discharge ratio: $Q_{p/m} = (16)^{5/2} = 1024$

Figure 2. Physical model extents overlaid on plan view photo.

Figure 3. Picture of physical model topography looking downstream. Note only ½ of the river channel and dam are in the model.

Model Setup

The model was constructed from plywood, concrete, sand, and rock. The topography was developed from LIDAR data flown in 2012, bathometry data collected in 2011, and the 30% design bypass alignment. The bypass alignment was cut out of the existing topography without any transition fill zones between the invert of the bypass and invert of the river. The width (upstream to downstream) of the crest of the diversion dam was reduced from the 30% design of 24 ft to 6ft. This change reflected the progressing design at the time the model was constructed. The new dam is to be built 40 ft upstream of the existing rock and timber dam. Both the LIDAR and the bathometry were unable to survey the rock field downstream of the existing dam. The topography of this area was estimated based on photos and eye witness accounts of the area.

Approximately 75% of the model topography was constructed from concrete and marine grade plywood, while the remaining 25% was constructed from sand. Areas near the interface between the bypass and the river were constructed with wood templates every 2 model foot and then filled in with sand. A soil stabilizer, DirtGlue, was sprayed on the sand to harden the surface and prevent it from erosion. The areas constructed with sand made it possible to alter the proposed topography with greater ease than concrete topography. The roughness of the existing rock field, and area between the existing dam and new dam, was simulated with gravel glued to the model topography.

Flow Measurement

A 250,000-gallon storage reservoir located under the laboratory floor supplied water for the hydraulic model through an automated flow delivery and measurement system. Water was delivered to the model using three 100-150 hp variable-speed permanent laboratory pumps and two temporary 40-60 hp auxiliary pumps located next to the model. A combination of these pumps provided the necessary flow rates for each flow scenario tested.

Model flow ranged from 3 to 32 cubic feet per second (ft^3/s). Flow from permanent laboratory pumps was measured using calibrated venturi meters. Four venturi sizes (4, 6, 8, and 12 inch diameter) were used according to the amount of flow through the pipe. A 44,000 pound volumetric/weigh tank facility is used to calibrate the laboratory venturi meters at regular intervals to an accuracy of 0.25%. Flow from the auxiliary pumps was measured using a Controlotron ultrasonic pipe flow meter on a 10-inch PVC pipe (accurate to ± 2.0%).

Water Surface Elevations

Water surface elevations were measured with piezometer taps and MassaSonic M-5000 Smart Ultrasonic Sensors. The MassaSonic units measure from 0.333 to

3.333 ft with an accuracy of ± 0.25 percent of maximum distance or 0.0083 ft at 3.333 ft and a resolution of 0.0008 ft. A sample rate of 100 Hz was used with the software displaying the average of 100 samples. Taking into account error that comes from the sensor, survey instrumentation, and human error, an uncertainty analysis showed that the uncertainty for water surface measurements is ± 0.074 ft prototype.

Water surface elevations (WSE) were measured in three places: forebay (230 ft upstream of the diversion dam), bypass (upstream in the bypass at USACE HecRAS station 400), and tailwater (1070 ft downstream of the dam in the river). The river WSEs were measured using a piezometer connected to a still well equipped with the ultrasonic level sensor. The bypass WSE was measured directly with an ultrasonic level sensor.

Velocity Measurement

Velocity data were collect with a handheld SonTek two-dimensional (2D) FlowTracker Acoustic Doppler Velocimeter (ADV). The SonTek FlowTracker ADV, mounted on a 6 ft wading rod, was used to collect velocity data upstream of the weir crest for approach conditions as well as in the bypass and confluence area. The FlowTracker is a side-looking instrument with a 10 cm (3.94 inch) sample distance. The instrument measures 3D velocity vectors in a small remote sampling volume (about 0.1 in^3) by emitting sound pulses (pings) at a specific frequency that reflect off of particles in the water. The FlowTracker has a sample rate of 1 Hz and an accuracy of ± 1.0% of the measured velocity. It operates within a range of 0.003 to 13.0 ft/s.

Boundary Conditions

Boundary conditions (flow, bypass flow split, WSEs, and approach velocity) for the physical model came from the USACE Adaptive Hydraulics Modeling system (ADH) 2D numerical model for the 30% design. The ADH model provided the amount of flow in the right half of the river as well as the amount of flow split in the bypass. Velocity profiles from the ADH model at the locations of the physical model boundaries were used to adjust and closely match the physical model approach conditions.

Data Acquisition

WSE measurements made with the MassaSonic sensors were recorded with a Measurement Computing USB-1616HS-4 data acquisition device. This unit collected the voltage output from the sensors and transferred it to a laptop computer running DASYLab v.12. This program would convert the voltage signal and scale it to prototype elevations. Data were then imported into a spreadsheet and formatted for analysis and presentation. All elevation, depth, velocity, and flow data in this report are listed in prototype units unless otherwise specified.

Investigation and Analysis

The majority of observations made during this study were qualitative in nature and consisted of setting up a flow condition and visually observing the flow patterns and conditions. During some tests WSE and velocity data were collected in target locations in or near the bypass. Seven different topography and flow split configurations were evaluated (Table 2).

Table 2. Topography and flow split configurations evaluated in the physical model.

Configuration	Bypass Invert (ft)	Bypass Flow split (% of total river flow)	Topography Adjustments
1	1983	~15%	
2	1981	~15%	
3	1981	~15%	Right bank (large)
4	1981	~15%	Right bank (large), Center
5	1981	~9%	Right bank (large), Center
6	1981	~15%	Right bank (small), River south abutment wall
7	1981	~15%	Right bank (small), River south abutment wall, 30-ft Notch

Configuration 1 represents the existing topography with the bypass channel excavated into the river channel with the bypass invert elevation at 1983 ft. This is 2 ft higher than the 30% design. Configuration 2 has the bypass invert elevation at 1981 ft, which is the 30% design elevation. Configuration 3 has the bypass invert at 1981 ft, but also includes increasing the height of the ground surface on the right bank of the river downstream of the dam (see Figure 10). Configuration 4 has the bypass invert at 1981 ft, the right bank topography adjustment, and a topography adjustment at the center apex of land at the convergence of the river and bypass (see Figure 15). Configuration 5 is the same as Configuration 4 but has bypass flow split of 9% of the total river instead of 15% like the other configurations. Configuration 6 has a smaller reduced right bank shoreline adjustment than configurations 3-5 and also includes the original dam south bank abutment concrete wall (see Figure 13). For most of the model study timeframe the existence and location of the south bank abutment wall was unknown. Configuration 7 is the same as configuration 6 and also includes a 30 notch on the river right side of the weir (see Figure 17).

Flow rates and boundary condition WSEs tested in the model are tabulated in Table 3 and Table 4. Table 3 flow rates assume a bypass flow spilt target of 15% of the total river. Table 4 flow rates assume a bypass flow split target of 9% of the total river. These tables assume a full irrigation diversion of 1,374 ft^3/s

Table 3. River and bypass flows and associated WSEs tested in the physical model. Target bypass flow split is 15% of the total river flow. Assumes an irrigation diversion of 1,374 ft^3/s.

Total River Flow (ft^3/s)	1/2 River ft^3/s model	Bypass ft^3/s model	1/2 River ft^3/s proto	Bypass ft^3/s proto	Upstream WSE (ft)	Bypass WSE (ft)	Downstream WSE (ft)
7,000	2.31	0.98	2,365	1,004	1992.8	1986.7	1986.3
10,000	3.53	1.42	3,619	1,450	1993.3	1987.6	1987.1
15,000	5.58	2.14	5,714	2,191	1994.2	1989.0	1988.4
24,000	9.26	3.37	9,482	3,451	1995.3	1990.9	1990.2
30,000	11.77	4.20	12,052	4,301	1996.0	1991.9	1991.2
45,300	17.96	6.22	18,391	6,369	1997.5	1994.1	1993.3
54,000	27.00	0.00	27,648	0	1998.8	na	1994.4
60,600	23.65	8.16	24,220	8,354	1999.8	1995.9	1995.2

Table 4. River and bypass flows and associated WSEs tested in the physical model. Target bypass flow split is 9% of the total river flow. Assumes an irrigation diversion of 1,374 ft^3/s.

Total River Flow (ft^3/s)	1/2 River ft^3/s model	Bypass ft^3/s model	1/2 River ft^3/s proto	Bypass ft^3/s proto	Upstream WSE (ft)	Bypass WSE (ft)	Downstream WSE (ft)
7,000	2.44	0.62	2,498	630	1992.8	1986.7	1986.3
10,000	3.77	0.88	3,863	900	1993.3	1987.6	1987.1
15,000	5.99	1.32	6,138	1,350	1994.2	1989.0	1988.4
24,000	9.99	2.11	10,233	2,160	1995.3	1990.9	1990.2
30,000	12.66	2.64	12,963	2,700	1996.0	1991.9	1991.2
45,300	19.46	3.98	19,925	4,077	1997.5	1994.1	1993.3
54,000	27.00	0.00	27,648	0	1998.8	na	1994.4
57,000	24.30	5.01	24,883	5,130	1999.8	1995.9	1994.7

Bypass Invert

In the 30% design the bypass invert elevation at the downstream end was 1981 ft. HEC-RAS numerical modeling showed that the Yellowstone River backwatered the lower portion of the bypass. The backwater effect in the bypass caused the water velocity in the lower portion of the bypass to be reduced. The reduced velocity did not meet the BRT criteria of > 2.4 ft/s and sediment modeling showed that this area would likely experience a significant amount of deposition (USACE 2014). To reduce the backwater effect, raising the invert of the lower portion of the bypass was considered.

The physical model evaluated a bypass invert of 1983 ft and 1981 ft (configurations 1 and 2, respectively). The target flow split of 15% remained constant. On average, the bypass velocity was about 1 ft/s faster with the invert at 1983 ft compared to 1981 ft (see Figure 4). Velocity measurements were taken in the bypass at station of 360 (30% design USACE HEC-RAS river stationing See Figure 2). Over the range of flow rates tested the maximum velocity was less than the BRT maximum velocity criteria of 6 ft/s. Flow patterns caused by the different bypass inverts were very similar (See Figure 5 and Figure 6).

It is recommended that the invert of the bypass be raised to provide faster water velocity in the bypass. Raising the invert will provide better fish attraction velocity and will reduce sedimentation. The amount of invert raise will depend on further numerical modeling. The two model configurations are intended to provide bounds on how a reasonable invert raise would affect the hydraulics of the confluence area. It is anticipated that a bypass invert elevation in-between 1981 ft and 1983 ft will result in similar flow patterns and water velocity interpolated between the two configurations.

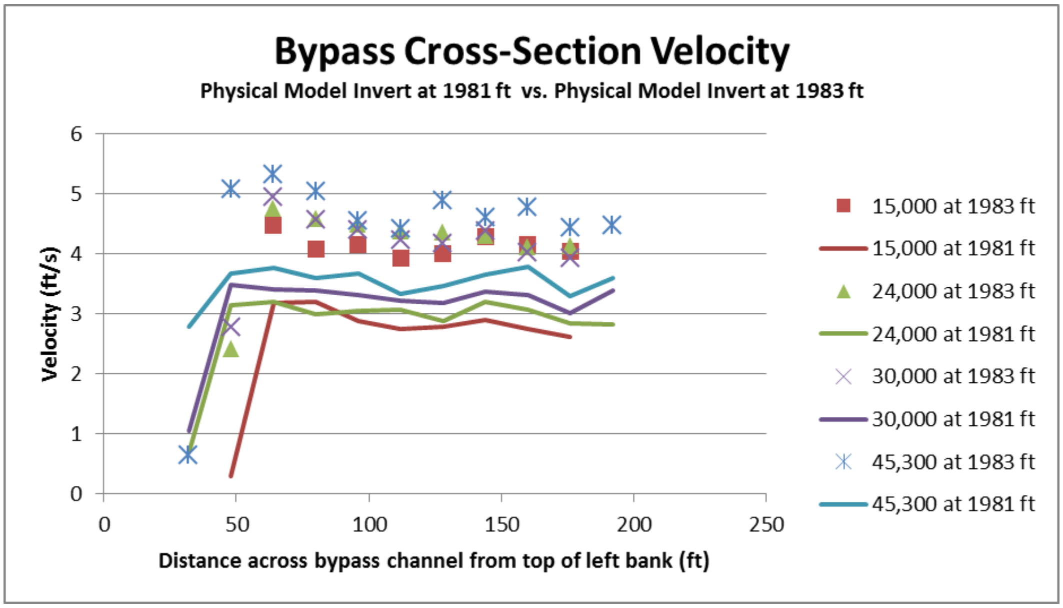

Figure 4. Bypass cross section velocity for bypass invert at 1983 ft and 1981 ft.

Figure 5. Fish bypass entrance flow patterns, configuration 1 (bypass invert 1983 ft), total river flow= 45,300 ft3/s.

Figure 6. Fish bypass entrance flow patterns, configuration 2 (bypass invert 1981 ft), total river flow= 45,300 ft3/s.

Right Bank Topography

On the Yellowstone River in the pre-project existing conditions there is a large eddy or flow recirculation that forms on the right side of the river just downstream of the dam. At high flows it is estimated that the eddy extends downstream approximately 850 ft from the dam and velocity in the eddy in the upstream direction can reach 4-5 ft/s (see Figure 7; Mike Backes, personal communication, October, 2014). A large flow recirculation located at the entrance of the fish bypass would hinder up migrating fish.

The physical model simulated this flow recirculation by “turning off” the flow in the bypass (see Figure 8). The topography on the river right bank in the physical model was different than the pre-project conditions because the bypass topography was constructed in the model. However, the flow recirculation zone was observed in the model. The length of the eddy and the velocity of the upstream moving water was similar to the prototype conditions.

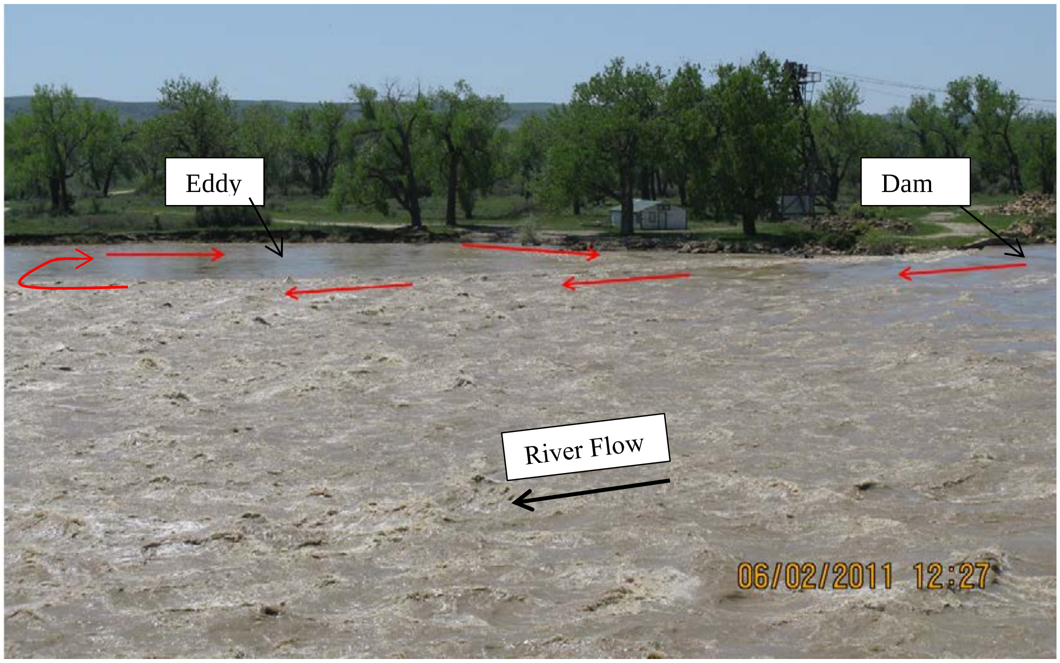

Figure 7. Existing conditions showing large eddy that forms on the river right side of river just downstream from the existing dam. Flow is 70,000 ft^3/s.

Figure 8. Physical model showing large eddy that forms on right side of river. No bypass flow. Flow is 54,000 ft^3/s

The flow effects of the bypass flow almost completely eliminate this eddy at low flow conditions, less than 24,000 ft^3/s. On the right bank there is a natural “shelf” in the topography with an approximate elevation of 1990 ft (see Figure 9). At flows less than 24,000 ft^3/s this area is out of the water and the downstream eddy is eliminated. This area starts to get inundated at flows greater than 24,000 ft^3/s and becomes a low velocity zone. The majority of the flow is still moving in the downstream direction, but velocities are less than 1 ft/s. There is a small amount of recirculation that does occur in this area (see Figure 6). As the flow expands onto this shelf, the velocity at the bypass entrance is reduced and does not converge with the main river as well as it does at lower flows.

Figure 9. Physical model showing right bank topography (green shaded area) at an approximate elevation of 1990 ft. Flow is 24,000 ft3/s.

In order to keep the momentum of the bypass flow moving out into the main river and eliminate the low velocity zone as seen in Figure 6 it is recommended that the elevation of the shelf on the right bank be raised. In the model sand bags were used to simulate this topography change (see Figure 10). With this topography adjustment, all the flow from the bypass channel quickly converged with the main river. The velocity in the bypass channel did not diminish as there is no place for the flow to expand, slow down, or recirculate. It is recommended that the elevation of the right bank be high enough (~1995 ft) so that it does not inundate over the range of flows prescribed by the BRT (7,000- 63,000 ft^3/s).

Figure 10. Fish bypass entrance flow patterns, configuration 3 (bypass invert 1981 ft, right bank topography adjustment), total river flow= 45,300 ft3/s.

A smaller, less intrusive topography adjustment was proposed in the USACE 60% design (USACE 2014). This configuration was also simulated and is labeled as configuration 6 (see Figure 11). This configuration performed better than without any right bank topography change; however it still allowed for flow to slow down especially in the shaded green area in Figure 11.

It is recommended that the larger right bank topography adjustment be included in the final design of the bypass channel to better direct bypass flow into the main body of the river.

Figure 11. Fish bypass entrance flow patterns, configuration 6 (bypass invert 1981 ft, small right bank topography adjustment, south river abutment wall) total river flow= 45,300 ft3/s. Shaded green area represents very slow velocity.

Center Point Eddy

During testing, a small eddy was observed at the center point between the river and the bypass channel. This eddy forms due to the expansion of flow downstream of this point (see Figure 14). It should be noted that at this time in the model study the location of the existing dam south abutment wall as seen in Figure 12 was unknown and was not included in previous configurations. Configurations 6 and 7 (Figure 11and Figure 19) incorporated the existing dam south abutment wall and showed the same small eddy formation as seen in configurations 1-5 (Figure 14).

Figure 12. Existing dam showing old headworks structure (foreground) and south abutment concrete wall.

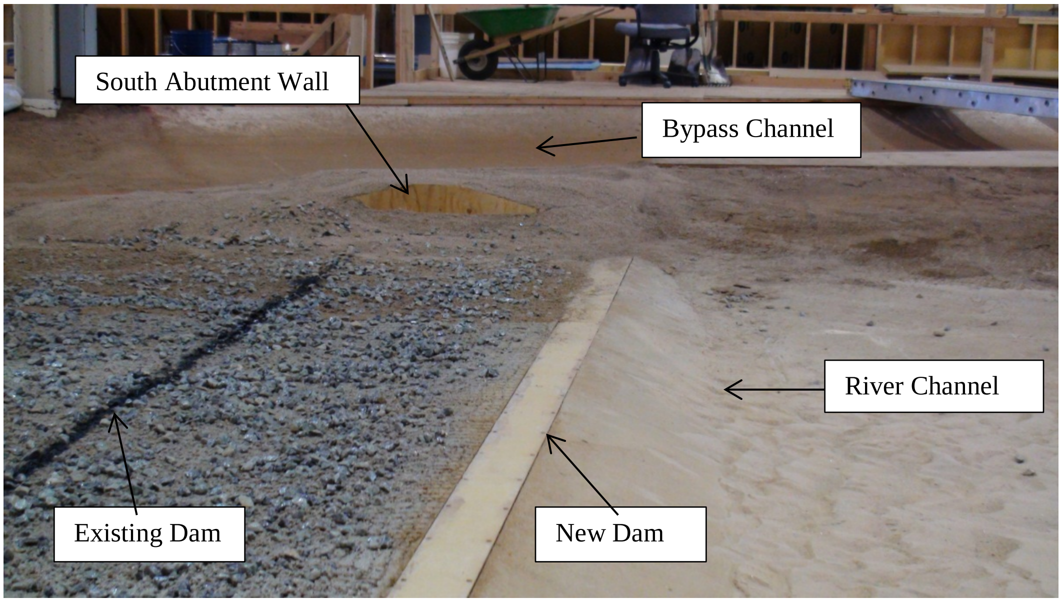

Figure 13. Physical model showing existing dam, new dam, and south abutment concrete wall.

Figure 14. Configuration 2, 45,000 ft^3/s in the river. The green area shows the location of a small eddy that forms at the center point of the river and bypass.

In configuration 4 part of the river side of the point of land was removed to streamline the flow (see Figure 15). This was successful in reducing the size of the eddy, but was not able to eliminate it. Excavating the river side of the point of land would require removal of the existing dam south abutment. It is unclear whether this would provide better fish passage conditions. The only reason to incorporate this change is for fish passage. It is recommended that the existing south dam abutment be kept in place and this configuration not be incorporated into the final design. If the formation of the small eddy is determined to hinder fish passage this topography change could be implemented at a later date as part of an adaptive management procedure.

Figure 15. Fish bypass entrance flow patterns, configuration 4 (bypass invert 1981 ft, right bank topography adjustment- large, center point topography adjustment), total river flow= 45,300 ft3/s

9% Flow Split

USACE's 30% design report states that a bypass flow of about 15% is the largest flow split that would still allow the main river channel to be hydraulically stable (USACE 2012). In the 30% design, the natural high flow channel around the south side of Joes Island is plugged. The plug keeps the bypass flow in the designed bypass channel. During the iterative design process one of the proposals was to keep the man-made channel and the natural high flow channel hydraulically separate and allow both to flow independently. Field measurements showed that the natural channel takes about 6% of the total river flow. That leaves 9% of the total river flow for the man-made bypass channel. Configuration 5 did not have any physical topography changes but rather changed the target flow split from 15% to 9% (see Figure 16).

If this proposal was considered further the bypass cross-sectional area would be reduced to keep the velocity in the recommended range (greater than 2.4 ft/s). In the physical model, however, the bypass geometry was not changed. A simplistic set of flow conditions were modeled to get a rough idea of how the reduced flow split would affect flow conditions. It should be noted that a fully designed configuration 5 would have higher velocities in the bypass channel than what was observed in the physical model. The 9% flow split was tested over the range of BRT prescribed flows. Over the range of flows tested the bypass flow did not merge with the main river as well for a 9% split compared to the 15% flow split.

There was also some flow recirculation that occurs along the zone in-between the river and bypass flows (see Figure 16). Initial testing indicates that a 9% flow split is not desirable for fish passage. If a 9% flow split is to be considered further the geometry of the bypass should be altered to represent a reduced cross-sectional area. It is recommended that the bypass target flow split be 15% of the total river flow.

Figure 16. Fish bypass entrance flow patterns, configuration 5 (bypass invert 1981 ft, right bank topography adjustment- large, center point topography adjustment, 9% bypass split), total river flow= 45,300 ft3/s

Weir Notch

A low flow notch in the diversion weir is being considered to help facilitate downstream passage of pallid sturgeon and larva and upstream and downstream passage of non-target species. During the design process 5 different notch designs and locations were developed (USACE 2013). “Notch 5” consisted of two notches; first is near the left descending bank with 10 ft bottom width at 1988 ft with 1V:10H slopes up to 1991 ft, second is near the right descending bank with 30 ft bottom width at elevation 1989 ft with 1V:10H slopes up to 1991 ft. This notch incorporates a 0.5 ft weir crest raise compared to the 30% design. As the physical model only covers the right half of the river, only the right bank notch was built into the model (see Figure 19). Velocity measurements and flow patterns were evaluated with and without the notch. On average the local velocity across the weir was about 1 ft/s faster with the notch than without the notch (see Figure 18). However, the general flow patterns that developed in the confluence area were unaffected by the addition of the notch (see Figure 17).

Figure 17. Low flow notch on right side of diversion weir.

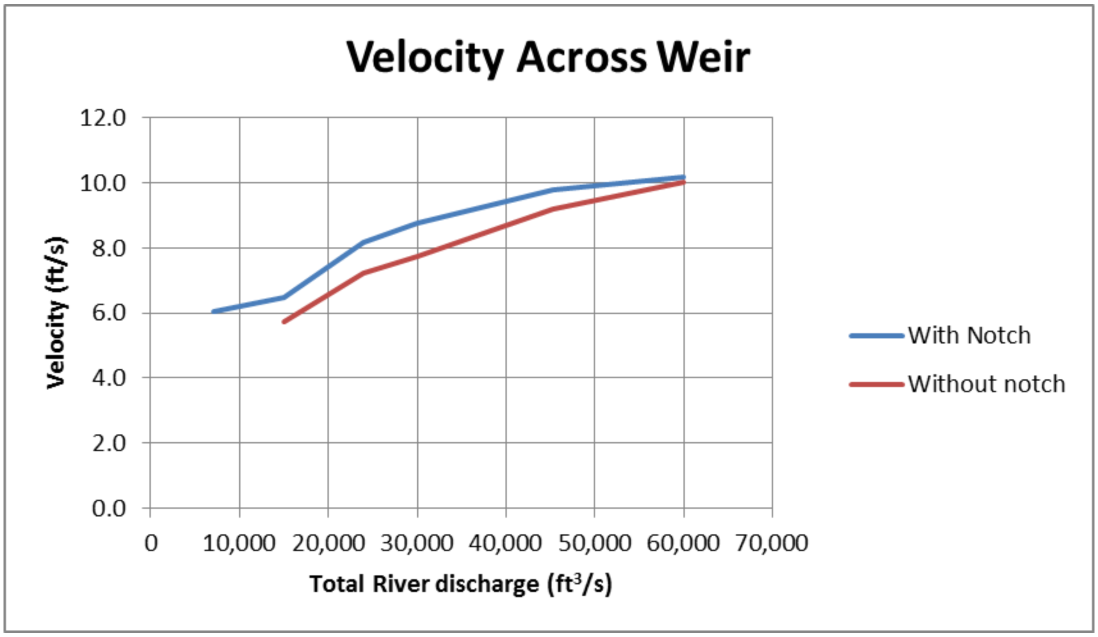

Figure 18. Velocity comparison with and without a notch.

Figure 19. Fish bypass entrance flow patterns, configuration 7 (bypass invert 1981 ft, right bank topography adjustment- small, south river abutment, and notch), total river flow= 45,300 ft3/s

Consideration should be given to whether or not flow velocity is too high for up-migrating fish and maintenance efforts related to the notch and the existing rock field. In preliminary discussions the notch shape would be excavated out of the existing rock field downstream of the dam. It is unlikely that the notch shape in the existing rock field will remain stable during high flows or ice flows.

Scour Hole Downstream of Existing Rock Field

There is a large scour hole on the river bottom on the right side of the river. This scour hole is immediately downstream of the existing rock field next to the downstream end of the bypass. The construction of the bypass calls for the bypass cross-sectional shape to be excavated out of the existing ground topography until it "day-lights" in the river bed. Extruding the bypass in to the area of the scour hole results in near vertical drop-offs into the scour hole. Estimated drop-off distances are detailed in Figure 20. It is uncertain how this will affect up-migrating fish. During the model study this area was filled in with movable sand to determine if this area would re-scour with the bypass flow entering the river (see Figure 21).

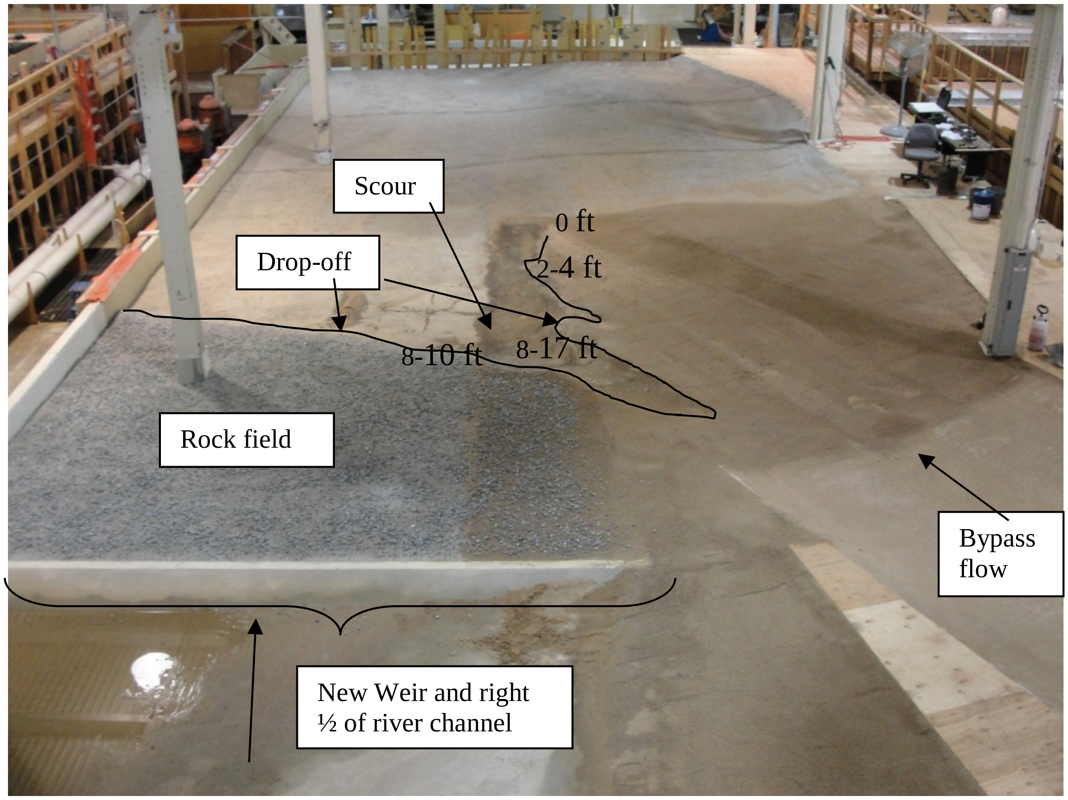

Figure 20. Model of the Yellowstone River and bypass topography detailing the vertical drop off downstream of the existing rock field. Note the large scour hole that forms downstream of the rock field with depths 8-17 ft deeper than the rock field.

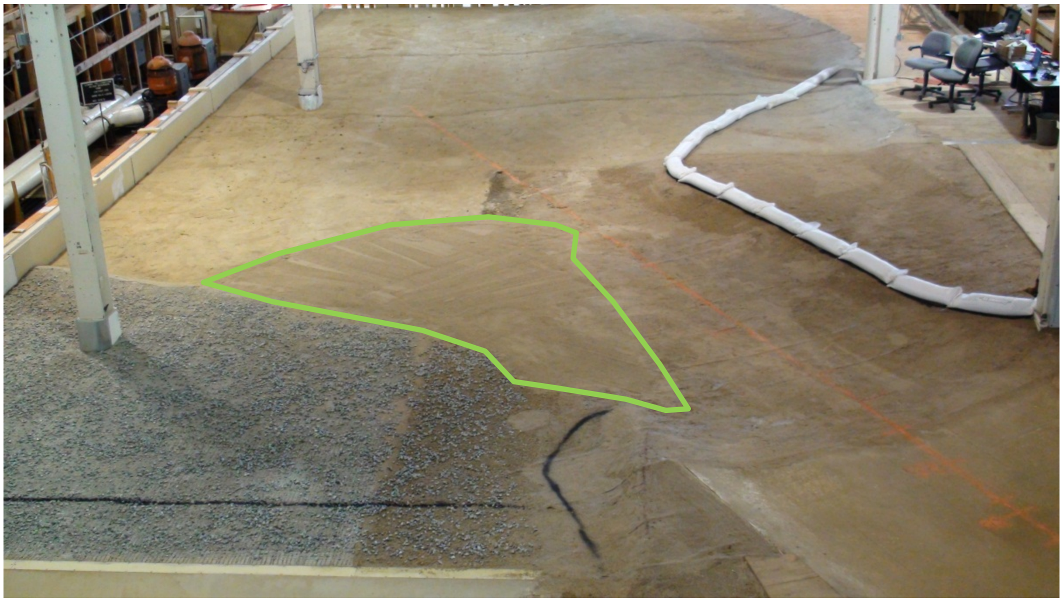

Figure 21. Model showing the large scour hole filled in (outlined in green).

It is noted that a full sediment analysis on the river bed load and movable sand was not completed. This simulation was preliminary in nature and should be only used to determine a general tendency for the region to scour or not with the additional flow from the bypass. After the scour hole was filled in to match the surrounding topography a flow of 30,000 ft^3/s was ran for 20 hours. This discharge was chosen because it is likely that sediments will be moving in the system, however it is less than the 2-year flow (45,300 ft^3/s) which is sometimes categorized as the “channel forming” discharge.   As seen in Figure 22, the area of the existing scour hole will continue to have a tendency to scour even with the addition of the bypass flow.

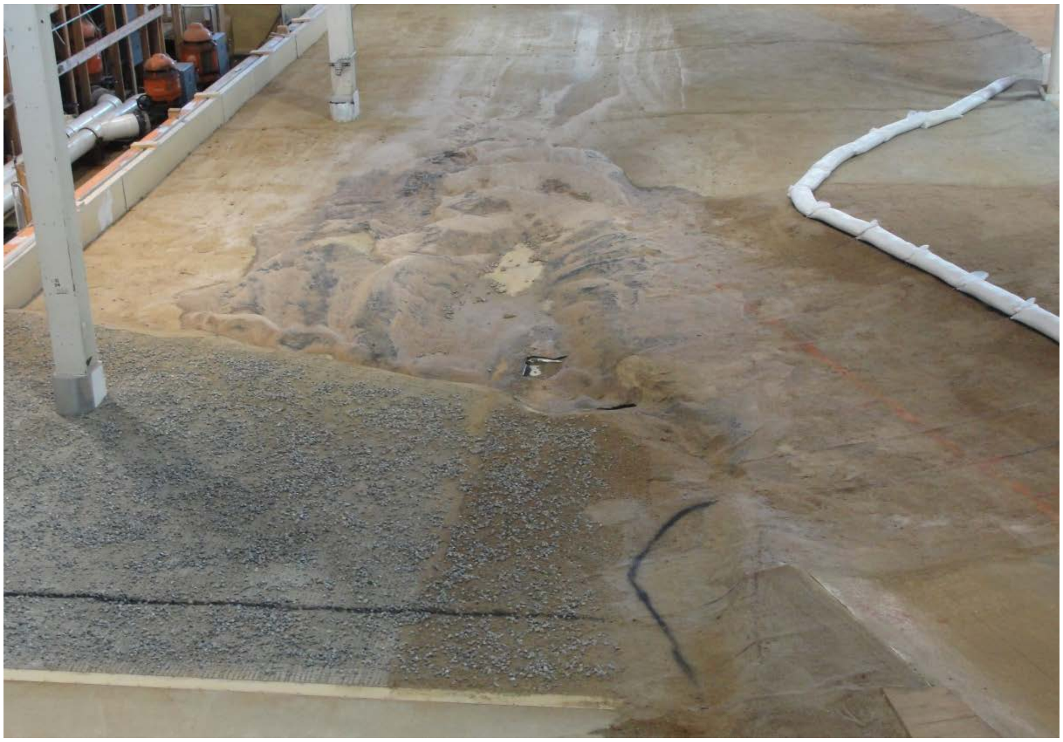

Figure 22. Sand scour after preliminary erosion test. It is likely that the existing scour hole will continue to scour in the future.

Recommendations

- It is recommended that the invert of the bypass be raised to provide faster water velocity in the bypass. It is recommended that the elevation of the right bank be high enough (~1995 ft) so that it does not inundate over the range of flows prescribed by the BRT (7,000- 63,000 ft^3/s). The amount of invert raise will depend on further numerical modeling. Raising the invert will provide better fish attraction velocity and will reduce sedimentation.
- It is recommended that the larger right bank topography adjustment be included in the final design of the bypass. The reason for this adjustment is to better direct bypass flow into the main body of the river.
- It is recommended that the existing south dam abutment be kept in place and the modeled topographic change not be incorporated into the final design. If the formation of the small eddy is determined to hinder fish passage, this topography change could be implemented at a later date as part of an adaptive management procedure.
- It is recommended that the bypass target flow split be 15% of the total river flow.

- Hydraulically a low flow notch similar in size as the notch modeled will not have a significant impact on the flow patterns in the confluence area. Consideration should be given to fish passage ability and maintenance.
- It is likely that the existing scour hole downstream of the rock field will continue to scour in the future.

References

U.S. Army Corp of Engineers (December 2012), “Intake Diversion Dam Modification Lower Yellowstone Project, Montana, Bypass Cannel 30% Design Documentation Report”.

U.S. Army Corps of Engineers (November 2013), “Lower Yellowstone- Intake Conceptual Notch Configurations for Proposed Weir Crest).

U.S. Army Corps of Engineers (August 2014), “Intake Diversion Dam Modification Loser Yellowstone Project, Montana, Bypass Channel 60% Design Report”.

U.S. Fish and Wildlife Service (March 19, 2014), “Letter to USACE From FWS stating revised biological criteria for the Intake project”.