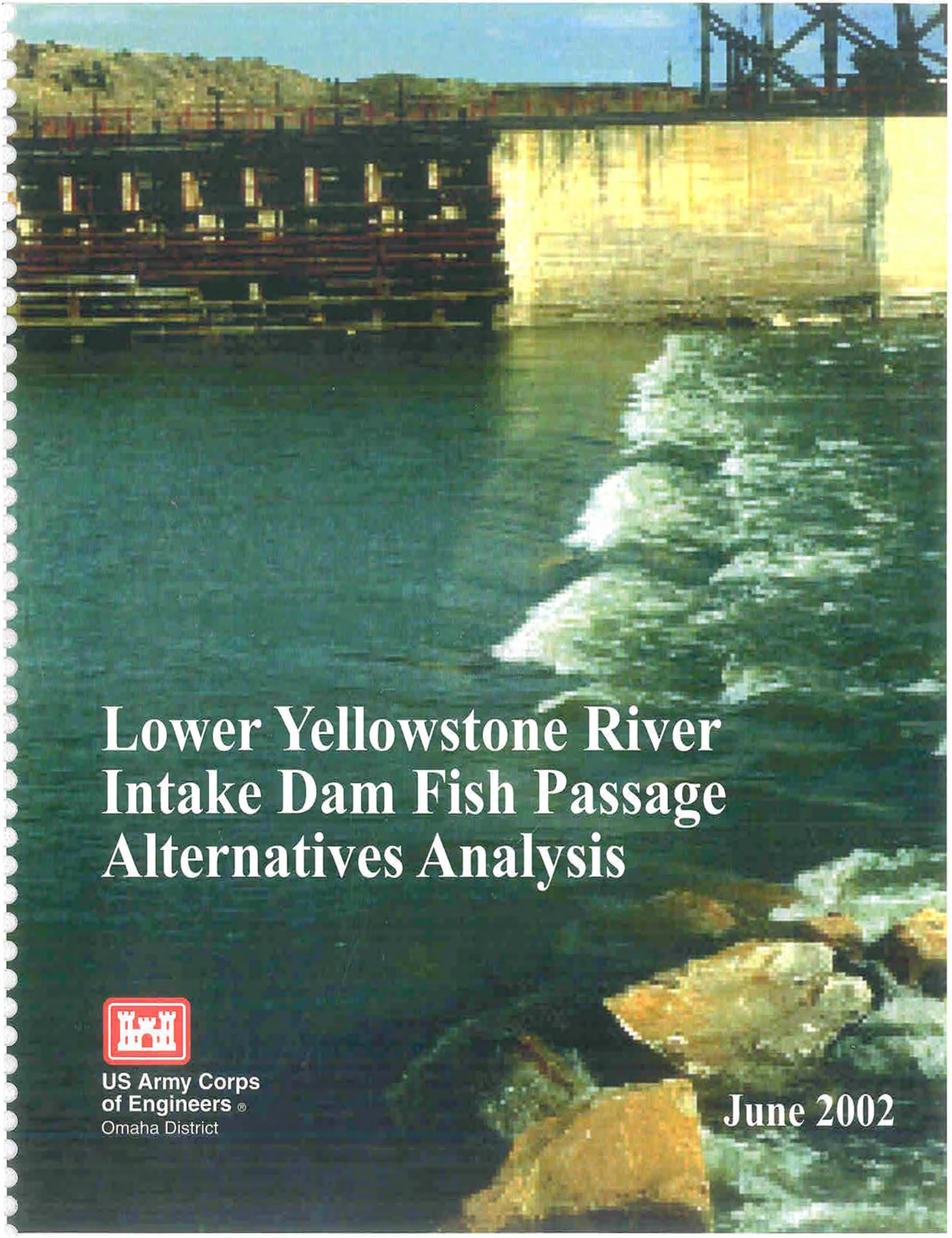

Lower Yellowstone River Intake Dam Fish Passage Alternatives Analysis

US Army Corps
of Engineers ®
Omaha District

June 2002

LOWER YELLOWSTONE RIVER

INTAKE DAM FISH PASSAGE

ALTERNATIVES ANALYSIS

June, 2002

Prepared by:

U.S Army Corps of Engineers,
Omaha District
106 S. 15th St.
Omaha, NE 68102

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* Only in the CD version of the report

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Executive Summary

The Omaha District Corps of Engineers (Corps) has completed an Alternatives Analysis for fish passage at the Intake Diversion Dam on the Yellowstone River (Intake Dam) using Congressionally added funding from the fiscal year 2001 Energy and Water Development Appropriations Act. A study approach was developed in coordination with the Bureau of Reclamation, the Lower Yellowstone Irrigation Districts, the U.S. Fish and Wildlife Service, and the Montana Department of Fish, Wildlife, and Parks. Using available information, a supplemented with information from other studies, the Corps developed recommendations with regard to fish passage at Intake Dam. In addition, further data needs and compliance actions required prior to construction have been identified.

As a result of this funding, the following tasks were completed:

- a flow duration analysis for the Yellowstone River
- a hydraulic analysis of various fish passage options
- a preliminary (10%) design for various fish passage options
- an engineering comparison of the alternatives
- a biological comparison of the alternatives
- five meetings, including a site visit, held in Montana visit
- one site visit held at the fish lab in Denver
- a literature review
- report development and reproduction
- a table of contacts and technical experts
- a preliminary list of data needs and tasks needed prior to construction

In addition, the Omaha District utilized Corps' pallid sturgeon funding for the following parallel studies:

- a sturgeon behavior and swim study (by contract with the Bureau of Reclamation - Water Resources Research Laboratory; White and Mefford)
- a shovelnose sturgeon / pallid sturgeon swim comparison study (by contract with the USGS - S.O. Conte Anadromous Fish Research Center; Kynard et al)

The Bureau of Reclamation's Water Resources Research Laboratory also contributed funding to support the sturgeon behavior and swim study.

Lower Yellowstone River
Intake Dam Fish Passage
Alternatives Analysis

Four basic types of fish passage concepts were considered for this study:

- Nature-like Fishways
- Baffled Fishways
- Elevator Fishways
- Dam Removal / Replacement

Within those four groupings, various alternatives were considered, and some were investigated further. A total of seven alternatives were investigated for this study.

Based on the information in this report, all alternatives could potentially support adult pallid sturgeon passage to some extent during certain Yellowstone River discharges. Alternatives are discussed for pallid sturgeon passage potential only (without regard for cost and other benefits), as well as in conjunction with other issues such as the construction cost and the cost for the operation and maintenance of a given alternative (overall alternative analysis). The overall alternatives analysis focused on predicting which alternatives would allow for the **greatest likelihood of pallid sturgeon passage**, with the **lowest construction cost, lowest operational and maintenance cost,** as well as the greatest potential for **other benefits** such as passage of other species or sizes of fish, and recreational use.

The result of this study effort is a coordinated and multi-purpose approach to fish passage issues and options at the Intake Dam. **The Corps recommends that a nature-like fish passage structure alternative (such as the riprap fish ladder with boulder weirs) would best meet the need for pallid sturgeon passage for the least cost, and provide for multi-species passage, and also provide recreational boat passage.**

This report should not be considered as an exhaustive review of existing literature. Additional literature was provided to the Corps as a result of the circulation of the draft report. However, funding and time constraints limited our review of additional literature and incorporation of that information into this report. Appendix I consists of additional literature that should be considered prior to the development of a final design.

Background

Project Authorization and Study Approach

The Corps received funding (but no language) for this effort in the fiscal year 2001 Energy and Water Development Appropriations Act. After the bill was enacted into law under the President's signature, the Corps used its inherent authority to utilize the funding to conduct coordination activities with the Bureau of Reclamation (Bureau) in anticipation of future Economy Act work. Based on coordination with the Bureau, the funding was needed in order to provide assistance to the Bureau in the development of design alternatives for a fish passage structure at the Intake Dam.

The Bureau drafted a fish passage report in January 2000 in which a rock channel was considered for fish passage. The Corps was to expand on other alternative designs for fish passage, based primarily on the information in the Bureau's report.

The $100,000 allocated to the Corps was used to develop fish passage alternatives at the Intake Dam on the Yellowstone River. Due to a scarcity of specific information on the swimming capabilities of the pallid sturgeon, the Corps and the Bureau determined that additional information was needed before a design could be recommended. Rather than proceed with the limited information available, additional Corps funding was used for studies providing useful sturgeon swim information. The results of these contracted study efforts can be found in Appendix A and Appendix B.

The goal of this study effort was to facilitate discussion among the agencies and the irrigation district, and to recommend a plan that would meet the needs of the irrigation district and the environmental agencies. This study effort also supports Conservation Measure 1 for Pallid Sturgeon in U. S. Fish and Widlife Service's 2000 Biological Opinion for the Current Operation of the Missouri River Main Stem System (Opinion). It is anticipated that the Bureau will develop the detailed design for construction with future appropriations.

Five coordination meetings and a site visit in Denver were held in support of this project. The first, a "kick-off" meeting, was held in Glendive, Montana on January 17, 2000. The purpose of this meeting was to discuss the Corps' scope of work for this study and to visit the Intake Dam site. A second meeting was held in Glendive, Montana on March 15, 2001 to review and discuss the preliminary draft engineering report. A third meeting was held in Glendive, Montana on May 10, 2001 to discuss the draft engineering report and initial biological information. One decision of this meeting was to fund additional sturgeon studies. It was agreed to do additional fish studies using a shovelnose sturgeon as a surrogate for the pallid sturgeon. A site visit to the sturgeon testing facilities was made on November 5, 2002 in Denver, Colorado. A fourth meeting was held January 9, 2002 in Billings, Montana to

discuss the preliminary results of the sturgeon studies. A fifth meeting was held in Sidney, Montana on March 7, 2002 to review and discuss the preliminary final alternatives analysis report.

The Bureau of Reclamation provided staff for meetings and document review, as well as assisted in funding the shovelnose sturgeon swim study. The U.S. Fish and Wildlife Service, Lower Yellowstone Irrigation Project, and the Montana Game, Fish and Parks also provided staff for meetings and document review.

Project Location and Description

The Intake Dam study area is located along the Yellowstone River in southeastern Montana approximately 17 miles downstream from Glendive, Montana (See Figure 1). The purpose of the study is to assist the Bureau of Reclamation in exploring alternatives for fish passage at the Intake Dam. The Intake Dam is used to divert flows from the Yellowstone River for irrigation purposes.

The Lower Yellowstone Irrigation Project was constructed by the Bureau of Reclamation between 1905 and 1909 to provide irrigation for northeastern Montana and western North Dakota. The diversion dam is a low-head structure constructed of timber and rock placed to elevations ranging from elevation 1989 to 1987 feet mean sea level (National Geodetic Vertical Datum – NGVD) across the Yellowstone River from left bank to right bank (looking downstream). The dam is subject to extreme wear at times due to the tremendous ice load in the river that can occur in the spring. A fish passage structure constructed at Intake Dam would modify this federal project, which is owned by the Bureau of Reclamation and operated by the irrigation districts of the Lower Yellowstone Project

The Biological Assessment on the Operation of the Yellowstone Diversion Dam concluded that the dam, in its current configuration, is blocking the upstream migration of pallid sturgeon (Bureau of Reclamation, 2001). By providing fish passage through the Intake Dam, the Bureau and the irrigation districts could assist in the recovery of the pallid sturgeon.

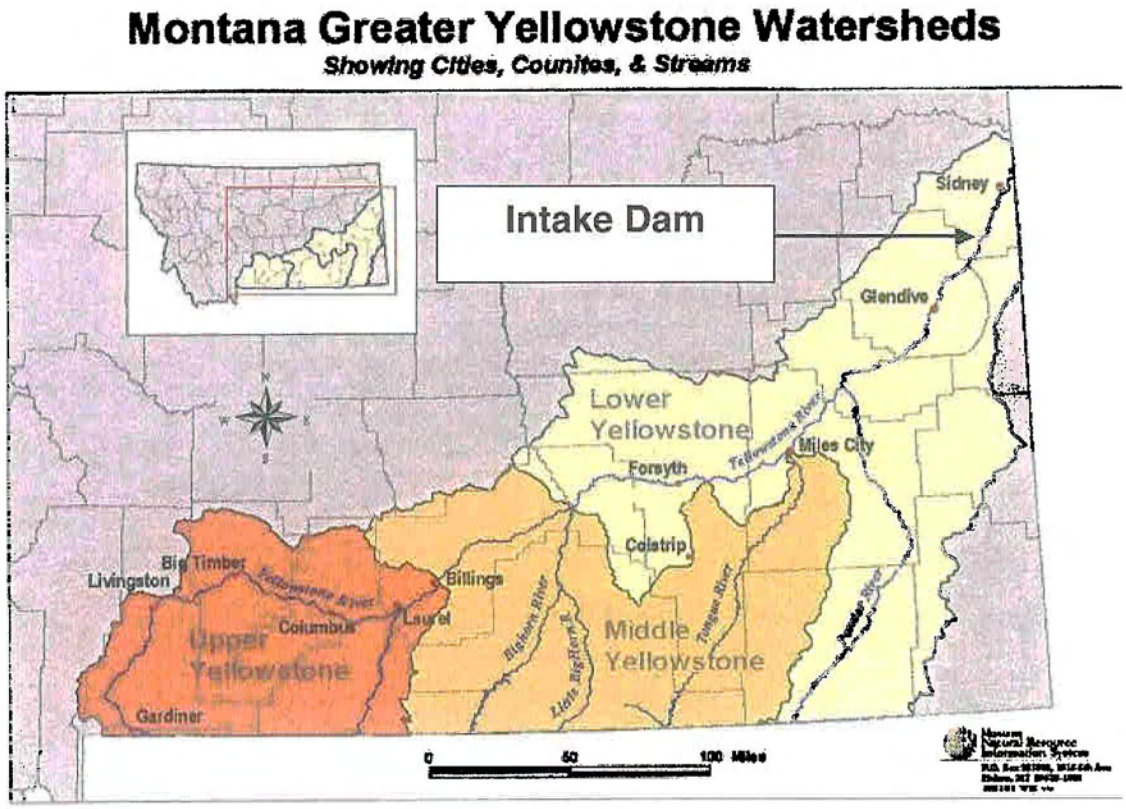


Figure 1 Project Location

Project Data and Operational Constraints

The project data received from the Bureau for the study included the HEC-RAS model used in the report entitled, "Intake Diversion Dam, Yellowstone River, Montana, Fish Protection and Passage Concept Study Report" dated January 2000 (Bureau of Reclamation, 2000). The HEC-RAS model did match the runs used in the Bureau's 2000 report and was accepted as reflecting existing conditions. The HEC-RAS data modeled the existing dam, which extends about 700 feet across the Yellowstone River channel. Intake Dam rises approximately 8 to 10 feet above the channel bed. The crest of the dam varies from elevation 1989 at the left (north) channel bank (looking downstream) to elevation 1987 at the right (south) channel bank. 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 100-foot long 1:10 downstream slope.

Figure 2 shows the comparison of upstream and downstream water surface elevations at the Intake Dam under a typical range of flow conditions. This chart

represents the difference between the upstream and downstream water surface conditions that must be accounted for by each alternative. The alternatives must be able to work with a head differential ranging from 2 to 6 feet. Note that under low flow conditions associated with lower velocities most conducive to fish migration, the dam crest is believed to obstruct fish passage (Bureau of Reclamation, 2001). The pallid sturgeon, however, are migratory spawners that typically migrate during higher velocities associated with spring flow events.

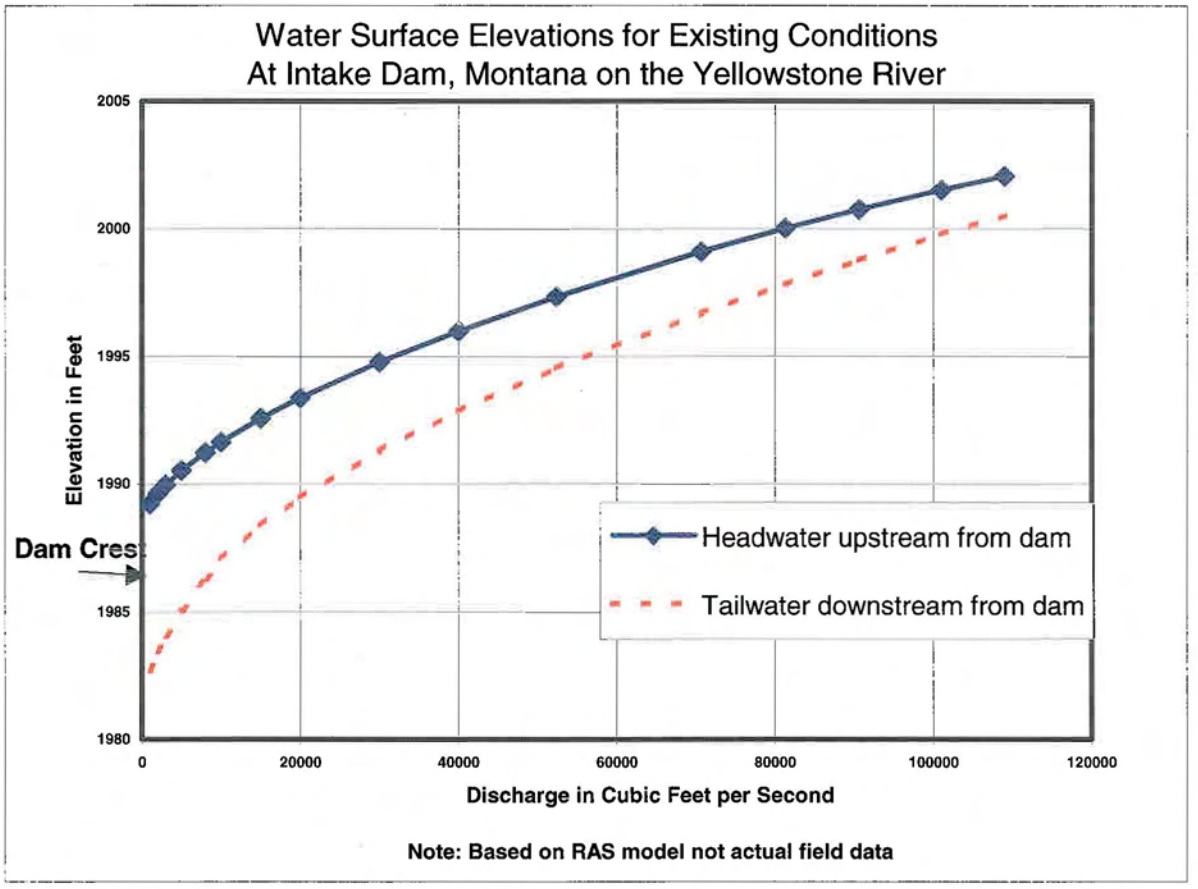


Figure 2 Intake Dam Water Surface Elevations

In reviewing the information provided, there appears to be two primary operational constraints to consider with regard to the design of the fish passage structure:

- Head Elevation. The purpose of the Intake Dam is to divert water into a canal for irrigation purposes. In order for the canal to have sufficient water during the irrigation season, a minimum river elevation difference ("head") is needed to divert the 1400 cfs allotted for the intake canal. The fish passage structure should be designed to operate while ensuring that enough head remains to meet the purpose of the intake structure.

- Resistance to Ice Damage. The Yellowstone River is known for its winter ice cover, as well as the dramatic spring break-up of the ice and resulting ice flows. (See Figure 3) Currently, these ice flows result in an annual maintenance need at the Intake Dam. The fish passage structure should be designed to withstand ice flows to the greatest extent possible so as not to incur a heavy maintenance burden on the Bureau or on the irrigation districts.

Figure 3 Yellowstone River at Ice-Out (Bureau of Reclamation photo)

Pallid Sturgeon Background Information

Pallid Sturgeon Overview

Like many other species, the decline of pallid sturgeon (*Scaphirhynchus albus*) populations can be attributed to massive habitat alterations (Bramblett, 1996). Dams, such as those found on the Yellowstone and Missouri Rivers, create barriers for pallid sturgeon migrating into spawning environments. Pallids move out of the Missouri River and up the Yellowstone River as the photoperiod and discharge of the Yellowstone is increasing (Bramblett, 1996). During this time of high discharge, the pallids spawn in the Yellowstone River where they reside until photoperiod and discharge decrease in late summer (Bramblett, 1996). They then move back into the Missouri River.

Pallid sturgeons are non-guarders (they don't actively guard their eggs) and are open water/substratum egg scatterers with an adhesive egg. The eggs must be scattered over an adequate substrate that would allow the egg to adhere to and stay in the appropriate habitat. After 3-8 days, the eggs hatch and the sack fry are carried downstream by the current until they reach suitable rearing habitat. The further upstream the pallids spawn, the longer the larval fish will have to drift downstream before reaching impounded waters without riverine conditions. This gives them more time to develop and select the appropriate habitat necessary for their survival (Krentz, 1999). The ability of pallid sturgeon to move far upstream is considered critical for the survival of their species (Bureau of Reclamation, 2001).

Pallids have historically been found in large, turbid riverine habitat with a firm sandy or gravelly substrate (Bramblett, 1996). Pallids are typically found in areas with velocity breaks from linear flows such as downstream island tips or on or near the bottom of the channel. These areas allow the pallids to use their body morphology to its full advantage (Bureau of Reclamation, 2001). Pallids are not adapted to navigate turbulent waters and are not very strong swimmers (Bramblett, 1996). Over the years, the displacement of rocks by ice and the periodic addition of new riprap have created a rocky river bed that extends downstream from the dam. This rocky substrate, along with turbulent flows, make passage at the dam difficult for these sturgeon.

Sturgeon Use of Fishways

Sturgeon in North America consist of two primary groups; the *Acipenser* genus and the *Scaphirhynchus* genus. The pallid and shovelnose sturgeon are river sturgeon of the *Scaphirhynchus* genus. All sturgeon have the same basic shape and physical structure; a flattened body with barbels and bony scutes.

Sturgeon have been documented as passing through fishways, although most fishways to date have not been designed specifically for sturgeon. Table 1 summarizes fish passage information from a PowerPoint presentation by Dr. Boyd Kynard.

Table 1 Sturgeon Passage through Fishways

SPECIES	RIVER	LOCATION	FISHWAY TYPE	OTHER
white sturgeon *Acipenser transmontanus*	Columbia River	Dalles Dam	pool and weir	3181 sturgeon passed in 6 years
white sturgeon	Columbia River	Bonneville Dam	ladder and orifice fish elevator	141 sturgeon in 31 years 4570 sturgeon in 31 years
white sturgeon	Otter Tail River	Breckenridge Dam	riffle - pool	April upstream movement
shortnose sturgeon *Acipanser brevirostrum*	Connecticut River	Holyoke Dam	fish elevator	97 sturgeon in 22 years
lake sturgeon *Acipenser fulvescens*	Menominee River	unnamed	side-baffle spiral starcase	in development

To the best of our knowledge, there are no fishways currently operating that have been designed specifically for sturgeon (any species), although at least one structure for the lake sturgeon is in development. There are no structures designed, or in progress, specifically for *Scaphirhynchus* species. The design of a fish passage structure for the pallid sturgeon, a rare species for which little specific life history information is known, will likely need to rely somewhat on swimming capability and behavior information from the closely-related shovelnose sturgeon, other sturgeon species, and other warm-water fishes.

Fish Passage Considerations

General Considerations

Perhaps the most important feature of a fish passage structure is its ability to attract fish to use it. The entrance of the fish passage must be located where flows will attract the fish without excessive velocities that would force the fish away (USACE, 1996). Sustained speeds are generally attractive to fish while the upper limits of burst speeds are barriers to fish (U.S. Army Corps of Engineers, 1991). This attraction water should not be highly aerated or turbulent. The location of the entrance should be as close as possible to the area which the migrating fish penetrate farthest upstream at an obstruction (Clay, 1995). This minimizes the risk of the fish not finding the fishway. Telemetry information can be used to see where the sturgeon concentrate below the dam (Whelan, 2001).

Within the fish passage, the water velocities need to be kept well below the burst speeds for general passage. Blind corners, especially with 90-degree angles, should be avoided, as fish tend to accumulate at such points and may jump, with possible injury (U.S. Army Corps of Engineers, 1991). The large size of pallid sturgeon needs to be kept in mind when designing any fishway for them to use. They need to feel safe enough to use the passage (Whelan, 2001). Fishway exits are usually placed well away from strong currents. However, a slight positive downstream current for leading can be advantageous. The fish must be kept moving away from the fishway so that they aren't swept back to the tailwater (U.S. Army Corps of Engineers, 1991). Additionally, we want to ensure that fish continue to move upstream in the Yellowstone River rather than become entrained into the irrigation canal.

Pallid Sturgeon Considerations

Different species of fish pass river obstructions differently. Salmonid species jump over small obstructions while pallid sturgeon remain close to the channel bottom and have to work their way through gaps in obstructions (U.S. Army Corps of Engineers, 1996). This should be taken into consideration when developing a fish passage facility for sturgeon.

Since pallid sturgeon are not strong swimmers (Adams et al, 1997, Adams et al, 1999), they remain close to the channel bottom, and do not jump over obstacles, therefore only a few fish passage designs can be considered for their use. Benthic (bottom-dwelling fish) such as pallid sturgeon could use certain baffle-type passages. The weir and orifice design facilitates the upstream movement of fish that prefer to move along the bottom, rather than leaping over obstacles (USACE, 1996).

Some wild shovelnose sturgeon were able to navigate vertical slot and dual slot fishways, although the fish appeared disoriented and passage success was poor (White and Mefford, 2002).

Another consideration when designing a fish passage is the swimming speed of the species that needs to utilize it. Swim speeds are split into three categories: burst speeds, which are maintained for 15 seconds or less; prolonged speeds, which have a duration of up to 200 minutes; and sustained speeds, which can be maintained for more than 200 minutes (Tunink, 1977). Sustained speeds have also been described as movement at or less than one body length per second (Viedler, 1993) A successful fish passage must not exceed the speed capabilities of the targeted species.

Adams et al (1999) identified 70 cm/sec (2.3 ft/sec) burst speeds for 20 cm (7.8 inch) long fork-length pallid sturgeon, or about 3.5 body lengths / second. If this relationship is similar for larger fish, then our target length for pallid sturgeon (3 to 5 feet total length) would result in approximate burst speeds of around 9 to 16 ft/sec. This result is similar to the calculated burst speeds in Table 2, using another method.

Studies on microhabitat selection of pallid sturgeon in Montana found that they are most often associated with water velocities ranging from 1.3 to 2.9 ft/sec (Dryer and Sandvol, 1993). According to a study performed by Bramblett (1996), pallids use bottom current velocities ranging from 0 to 4.5 ft/sec.

The above velocity ranges are similar to those velocities (2.0 - 3.0 ft/sec) that resulted in 100% successful passage by wild Yellowstone River shovelnose sturgeon during laboratory flume tests using a range of velocities and substrates (White and Mefford, 2002). Additionally, between 81% and 97% of shovelnose sturgeon successfully negotiated all ranges of velocities (0.8 - 4.0 ft/sec) tested over multiple substrates (smooth, sand, gravel, cobble). The conclusion of the White and Mefford study is that **2.0 - 4.0 ft/sec is a good range for optimum movement success, although all velocities tested were easily negotiated by motivated fish (ibid).** Prolonged swim speeds (2.7 body lengths / second at 65 cm/sec (2.1 ft/sec) velocities) were also used by pallid and shovelnose sturgeon to swim side-baffle structures (Kynard et al, 2002). The Kynard study concluded that **current velocity in fish ladders or rock ramps that enable fish to swim in prolonged mode and do not require the burst swim mode seem preferable for these species.**

These data can be used to estimate the prolonged and sustained speed types for pallid sturgeon (see Table 2). The prolonged speeds average 25% to 67% higher than sustained speeds and are 20% to 30% of maximum burst speeds (Jones et al., 1974). From this information, the burst speeds can be calculated as being 9.6 to 15 ft/sec (see Table 2). However, Boyd Kynard (2001), has indicated that the true burst

speed of pallid sturgeon may not be this fast. Data specific to burst speeds was not collected as part of the White and Mefford tests, nor the Kynard tests, however it was noted that **sturgeon maintained position with little apparent effort at facing velocities as high as 7.8 ft/sec.** The draft White and Mefford study can be found in Appendix A.

Table 2 Swimming speeds as applied to pallid sturgeon

Calculated values for fish 3 - 5 ft in length are in italics

Actual measured values (from studies) are in bold

SPEED TYPE	SPEED DESCRIPTION	SWIM SPEED
Burst	<20 second duration	*9.6 – 15.0 ft/sec* **3.5 body lengths / second[1] - juvenile** **3.2 - 4.2 body lengths / second [2] - juveniles**
Prolonged	up to 200 minute duration 25-67% higher than sustained speed / 20-30% of max. burst speed	*2.9 - 4.5 ft/sec* **<4 ft/sec [3] (10 minutes) - adult shovelnose** **2.1 - 3.8 ft/sec (15 minutes) – adults [4]** **0.9 - 2.0 body lengths / sec [5] - adults** **0.6 - 0.9 body lengths / sec [6] - adult shovelnose**
Sustained	>200 minute duration	**< 1 ft/ sec [7] (480 minutes) - juveniles** *1.3 - 2.9 ft/sec*

1 Adams et al, 1999
2 Hoover and Kilgore
3 White and Mefford, 2002
4 Hoover and Kilgore
5 Kynard et al, 2002
6 Kynard et al, 2002
7 Hoover and Kilgore

In a study conducted in a swim tunnel, the swim speeds of juvenile pallid sturgeon (5.1 - 7.9 inches, fork length) were measured. Burst speeds of 1.8 - 2.3 ft/sec and prolonged speeds from 1.0 – 1.6 ft/sec were observed. Juvenile pallids were able to swim up to 480 minutes at speeds less than 1.0 ft/sec. The sustained and

prolonged speeds of juvenile pallid sturgeon are comparable to speeds reported for similar sized lake sturgeon, but pallids demonstrated a higher capacity for burst swim speeds. In a similar study using adult shovelnose sturgeon (22 - 27 inches fork length), it was found they have a 15-minute swimming speed of 2.1 – 3.8 ft/sec. These shovelnose sturgeons swam actively at low speeds (0.2 – 1.0 ft/sec), but at higher speeds (3.9 – 1.3 ft/sec), they alternated between active swimming and pressing themselves to the bottom of the tunnel (Hoover and Kilgore).

A second study compared the swim capabilities of the shovelnose sturgeon, which were used as a surrogate species for the Mefford and White study, with swim capabilities of the target species, the pallid sturgeon. Unlike the fish used in the White and Mefford study, the fish in this study were hatchery-raised fish acclimated to laboratory conditions, so the results cannot necessarily be used to predict the swim capabilities of wild fish. However, the Kynard study concluded that wild fish should easily navigate complex flow regimes in baffle sections, based on the information gathered on hatchery fish (Kynard et al, 2002). Additionally, the study results implied that the travel time of the two species are comparable for the distance tested (7.5 feet) and if anything, the pallid sturgeon showed more motivation to move upstream than did the shovelnose sturgeon. (e.g. didn't have to be prodded, ibid) The rate of travel (body lengths per second) was not significantly different between pallid and shovelnose sturgeon for laminar flows. In turbulent flows, the movement rate for pallid sturgeon was slightly faster. Therefore, use of shovelnose sturgeon as a surrogate, based on this study, is considered appropriate, although it would be desirable to repeat the study with a larger sample size. The Kynard study can be found in Appendix B.

Table 3 Shovelnose and Pallid Sturgeon Swim Comparison

species	age	length	weight	number studied	swim rate - laminar	swim rate - turbulent
pallid	4 yrs	45.6 cm average (18 in) 35 - 52.5 cm (13.8 - 20.7 in)	308 g average (10.9 oz) 130 - 500 g (4.6 - 17.6 oz)	22	1 bl/sec*	0.9 - 2.0 bl/sec
shovelnose	3 yrs	39.2 cm average (15.4 in) 33.5 - 46.1 cm (13.2 - 18.1 in)	200 g average (7 oz) 100 - 320 g (3.5 - 11.3 in)	3	1 bl/ sec	0.6 - 0.9 bl/sec

* body length per second

Four important steps should be followed in developing fishways regardless of which type is selected:

1) identifying the species and life stages (and sizes) that are migrating;
2) testing these fish in an experimental fishway;
3) designing the fishway;
4) quantitatively assessing the fishway (Odeh, 1999).

The scope of this document involves primarily items 1 and 2 above. Items 3 and 4 are outside the scope of this study.

Item 1 - Identify the species and life stages (and sizes) that are migrating.
The Bureau is awaiting a Biological Opinion from the U.S. Fish and Wildlife Service (USFWS) in response to their Biological Assessment on the operation of the dam, so specific requirements are not yet known. However, the Biological Assessment indicates that pallid sturgeon are the target species for this effort, primarily sexually mature pallid sturgeon. These fish are assumed to be 3 to 5 fee in length, based on information from local fisheries biologists. Although the pallid sturgeon is the target species, movement of other native fish (and other sizes of pallid sturgeon) would be desirable, based on discussions at meetings held in association with this project. The Biological Opinion may contain specific information on the timing required for passage, as well as the targeted size of pallids for which passage is required. This information would make for a more meaningful document and assist in the alternatives analysis to determine which alternative could best meet these requirements. **The passage requirements, especially with regard to the seasonal timing of those requirements, is needed prior to the final design for the fish passage structure in order to ensure that the passage structure meets the needs of the Biological Opinion.**

Item 2 - Testing these fish in an experimental fishway. After the release of the draft of this document, a meeting was held with representatives from the U.S. Fish and Wildlife Service and the Montana State Game, Fish, and Parks Department. Three primary questions with regard to sturgeon capabilities came up repeatedly at this meeting:

- **Laminar versus turbulent flows.** Do pallid sturgeon tolerate turbulent flows such as those within a baffled fish pass system? What laminar flow velocities can pallid sturgeon tolerate?

- **Navigational capabilities.** Could pallid sturgeon find a structure entrance (fish pass, rock ramp, or elevator opening) that is only a fraction of the length of the dam? Could pallid sturgeon navigate through a baffled passage?

- **Attraction to structure**. Would the location of a structure entrance (fishway, rock ramp, or elevator) at a large scour hole be an attracting feature

encouraging upstream fish movement through the structure? Would attractant flows or guidance assist in pallid sturgeon use and the success of the structure in passing pallid sturgeon?

It was these unanswered questions that prompted the development of the scope of work that was ultimately awarded to the Bureau of Reclamation - Water Resources Research Laboratory (the White and Mefford study). The group decided that shovelnose sturgeon could be used as a surrogate species for the pallid sturgeon for this effort.

The results of the White and Mefford study, and a parallel study by Kynard et al with regard to the three primary questions above are as follows:

Laminar vs. turbulent flows.

Velocities between 2 and 4 feet per second were recommended for fishway attraction velocities. In velocities of less than 4 fps, sturgeon were able to actively swim for more than ten minutes. This velocity range would be a useful criteria to use for fishway options requiring sustained swimming (White and Mefford). Surprisingly, sturgeon were able to hold a position with little apparent effort ("facing" velocity) in flow velocities as high as 7.8 ft/sec. Many of the sturgeon (47%) were able to successfully negotiate a channel with velocities as high as 6 ft/sec. Although sturgeon could successfully move through high velocities, they were not able to "hold" for very long, and would not be expected to maintain their position at high velocities for extended periods. This supports the theory that a shorter fishway length would be advantageous.

In a separate study, Kynard et al (2002) indicated that average swim speed for sturgeon (pallid and shovelnose) in laminar flows within a circular test flume were 1 body length per second. In turbulent flows, pallid sturgeon had slightly higher swim speeds (0.9 - 2.0 body lengths / second) than shovelnose sturgeon (0.6 - 0.9). Sturgeon in all tests in laminar flows corresponding from zero to 67 cm/sec (2.2 ft/sec) velocities utilized sustained swim speeds. See Table 3 and Appendix B.

Turbulent flows, as suspected, did pose a hazard for upstream navigation. Both horizontal turbulence and vertical turbulence were tested by White and Mefford (see Appendix A). Although both types of turbulence ("eddies") were able to be negotiated, larger eddies tended to cause delays in upstream movement. As eddy size increased, passage success decreased. Eddy size is a function of baffle size and velocity. Even high baffles (22.5 inch) could be navigated successfully at low velocities (1.6 ft/sec). Since baffle size and placement function to slow the current to within acceptable velocities for the targeted fish, care must be taken to avoid development of large eddies if the passage structure is to function successfully.

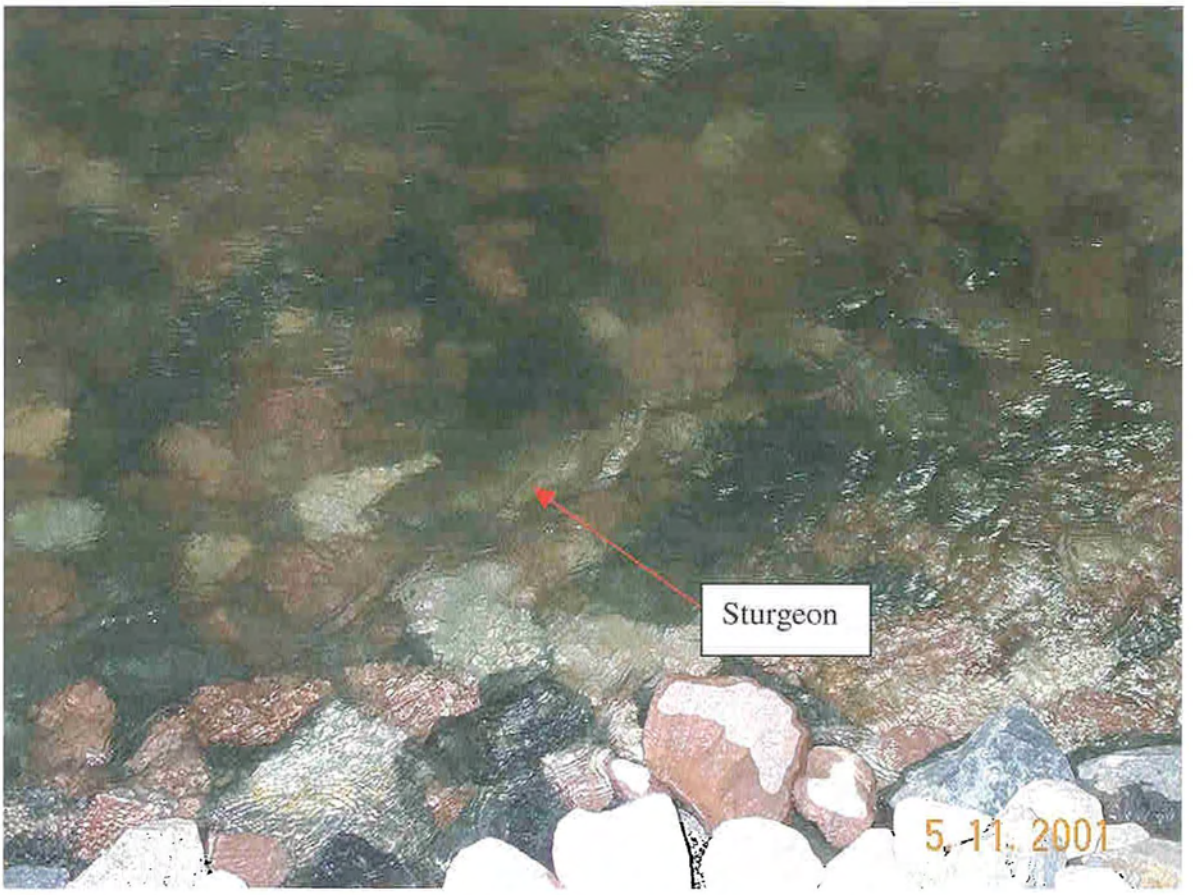


Figure 4 Shovelnose Sturgeon swimming upstream through constructed boulder weirat the Bureau's Water Resources Research Laboratory in Denver (Corps of Engineers photo)

Navigational Capabilities

The wild Yellowstone shovelnose sturgeon showed a surprising ability to navigate vertical slot fishways and rock ramp fishways during the White and Mefford tests. However, as eddy size increased (representing turbulence), success in passage decreased. This pattern was seen in the standard vertical slot and the duel slot prototype fishways. Flow velocities of at least 2 ft/sec were needed to properly orient the fish for passage through the structure. Even during fall testing (post-October, 2001) when fish appeared to be less motivated to move, some shovelnose sturgeon successfully maneuvered all three fishways tested (two baffled fishways and the rock fishway).

The White and Mefford study reinforced concerns about turbulence and the avoidance of large eddy development in the design of structures to be navigated. In addition, this study tested fishway navigation capabilities for three types of fishways: a standard vertical slot fishway, a duel slot fishway, and a rock ramp fishway. These

tests were performed during the fall when the fish may have had motivational problems, however they still provide some useful information. Only about 25% of the fish passed all slots, and that occurred when slot velocities ranged from 3 to almost 4 ft/ sec. However, 62.5% of the fish passed through the rock fishway, also during fall testing, so of the three structures tested, the rock fishway was the most successful. See Appendix A for the details of the testing.

In the 2002 study by Kynard et al, hatchery-raised pallid and shovelnose sturgeon were tested in a circular half-meter wide flume with a 6% slope (see Appendix B). Flow was provided using a water pump. Upstream progress was monitored visually and using information from transmitters attached to each fish and receivers placed along the flume. One section of the circular flume contained baffles, which were negotiated by both the pallid and shovelnose sturgeon , however the rate of travel was greater for pallids than for shovelnose. Both species of fish avoided baffle-formed eddies and continued swimming within the main current

Attraction to Structure

While the White and Mefford study didn't specifically address this aspect, it appears as though providing laminar flows within the range of velocities already described, along with the fishes' instinctive urge to move upstream during certain months of the year may provide enough attraction for the sturgeon to move up and into a structure. Since this aspect is not fully developed, it would be advantageous to develop a prototype structure for on-site testing with pallid sturgeon. This structure should have enough initial flexibility that could be adapted as needed, based on the results of the testing.

The use of the scour hole location as the downstream end of a fishway was discussed briefly and informally with Dr. White, and was thought to be an acceptable, if not preferred, location. The scour hole is commonly fished successfully, indicating that fish have a tendency to congregate at that location.

Description of Alternatives

Four basic types of fish passage concepts were considered for this study:

- Nature-like Fishways
- Baffled Fishways
- Elevator Fishways
- Dam Removal / Replacement

Within those four groupings, various alternatives were considered, and some were investigated further. A total of seven alternatives were investigated for this study.

Nature-like Fishways

These passage concepts consist of a "nature-like" stream with or without strategically placed rocks and / or depressions to control flow velocities. Within this basic concept, this report investigated three design alternatives:

1) the grouted riprap fish ladder (with options of a concrete wall or earthen berm, and either depressions or boulders for resting)

2) a modified version of the Bureau of Reclamation's riprap fish ladder with boulder weirs

3) a dredged bypass through an existing dry channel

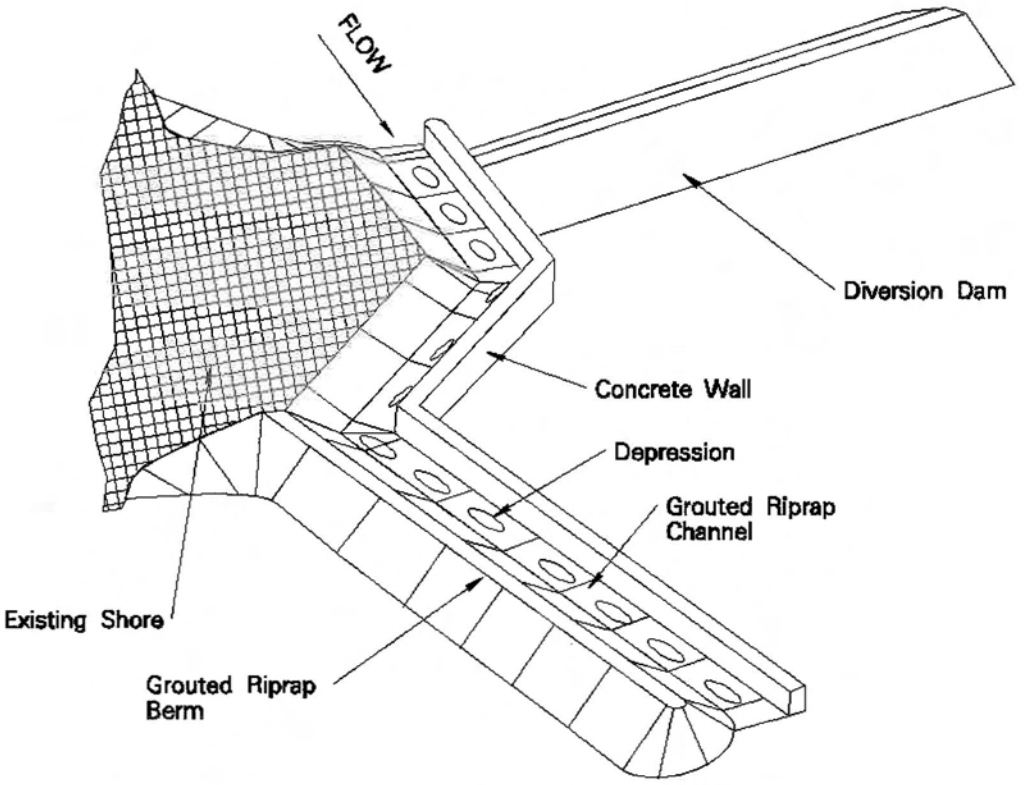
1) Grouted Riprap Fish Ladder

This alternative was originally based on a J-Hook, which is a rock dike placed in the stream in the form of a small "j" to create fish habitat. The purpose of the structure is to concentrate flows through the unobstructed portion of the stream at low flow and to force water over the structure at higher flows. The "j" portion concentrates flows over the rock in the area of the "j" to create a water plunge that creates a scour hole in the stream bed for fish habitat. For this study, the alternative was modified since the concentration of flows caused velocities that exceeded the design criteria and the scour hole would cause vertical turbulence.

During the development of initial concepts, two factors were analyzed to maintain low average velocities. These two factors were the upstream channel area and the slope of the channel itself. A trade-off between the elevation of the upstream inlet and the slope forced the alternative to have a long length in order to keep the average velocity in the acceptable range. A larger upstream area would allow more

water to enter the alternative and increase velocities. A higher upstream inlet elevation would restrict the amount of inflowing water but would increase average velocities by increasing the slope of the channel. Later this alterative was modified to incorporate shallow depressions or weirs to allow the fish to rest before darting upstream, but the length was not adjusted.

Two options were prepared for this alternative, one with an earthen berm separating the river and the grouted fish ladder and another with a concrete wall forming this separation. Figure 5 displays an isometric view (three-dimensional sketch of the concrete wall option with depressions. Figure 6 is a plan view (viewed from above) of this option. Figure 7 is an isometric view of the earthen berm option with boulder weirs. Figure 8 is a plan view of this option.



GROUTED RIPRAP FISH LADDER PASSAGE WITH CONCRETE WALL
No Scale

Figure 5 Isometric View of Grouted Riprap Fish Ladder with Concrete Wall

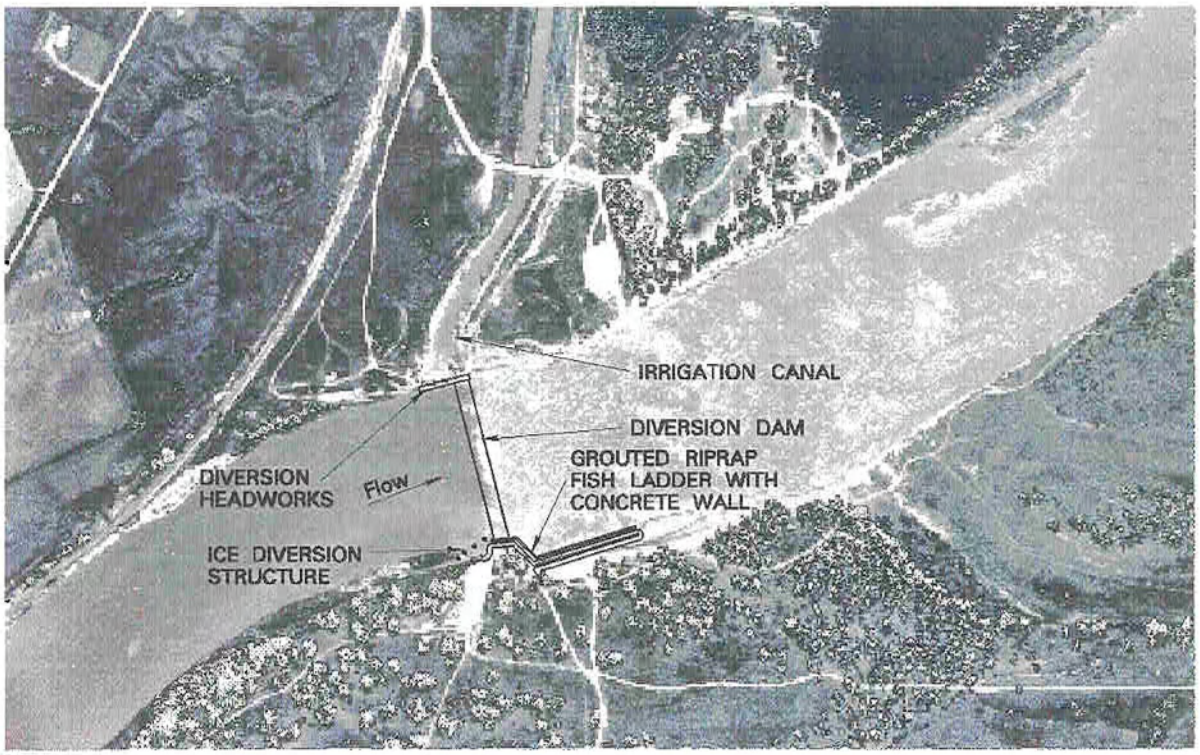
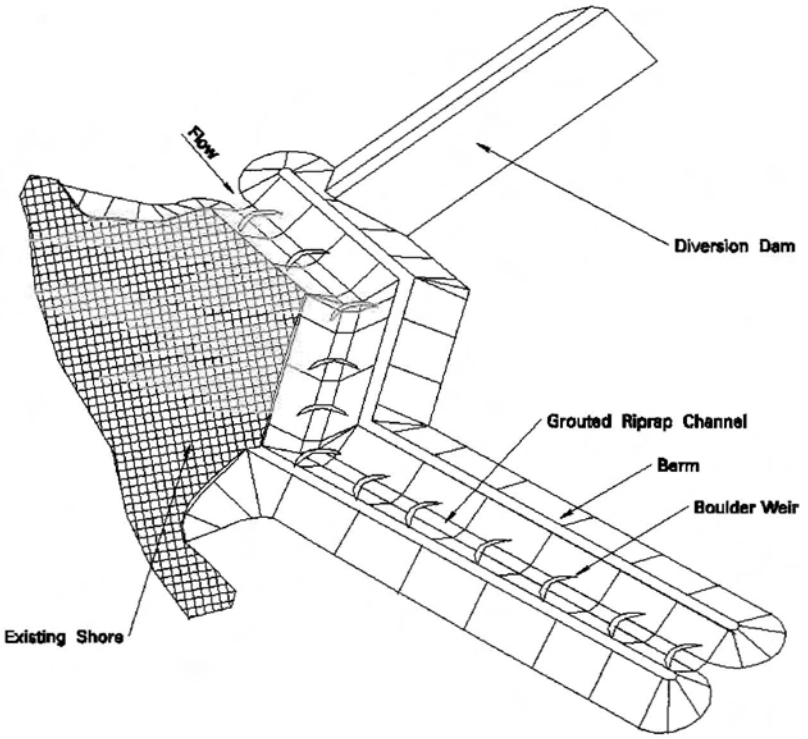


Figure 6 Plan View of Grouted Riprap Fish Ladder with Concrete Wall



GROUTED RIPRAP FISH LADDER PASSAGE
WITH RIPRAP BERM AND BOULDER WEIRS

Figure 7 Isometric View of Grouted Riprap Fish Ladder with Berm and Boulder Weirs

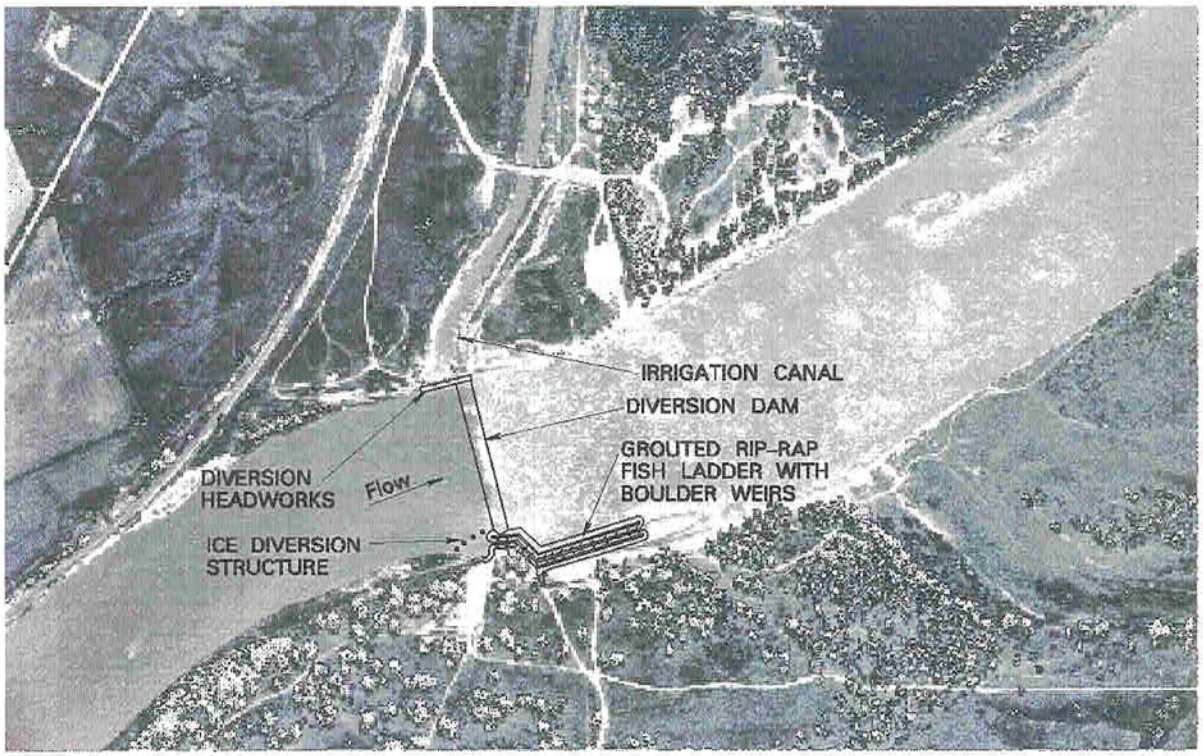


Figure 8 Plan View of Grouted Riprap Fish Ladder with Earthen Berm and Boulder Weirs

2) Riprap Fish Ladder with Boulder Weirs

This alternative is similar to the grouted riprap fish ladder, but is a modified version of the riprap fish ladder discussed in the Bureau's January 2000 report, but with a slope change from 2.5% to 2.0% based on study data. A prototype of this structure was one of the structures tested in the fish tests described in Appendix A. There are two primary differences between the riprap fish ladder (nature-like fishway 2) and the grouted riprap fish ladder (nature-like fishway 1). The riprap fish ladder (2) is about 200 feet long compared to 600 feet for the grouted riprap ladder (1), and the riprap fish ladder (2) is about one-half the total width of the grouted riprap ladder (1). As explained in the description of the grouted riprap ladder, initial concepts for the grouted fish ladder assumed a longer channel with a lower slope would be required to maintain acceptable average velocities for fish passage.

The riprap fish ladder (2) did not initially include grouting of the boulders, but further discussions with the Bureau indicated that grouting was a possibility once the boulders were "fine tuned" (Mefford, personal communication).

Figures showing this alternative are 9 and 10. Again this alternative may have an option of either an earthen berm (as shown) or concrete wall (that is not shown) to separate the passage flows from the Yellowstone River.

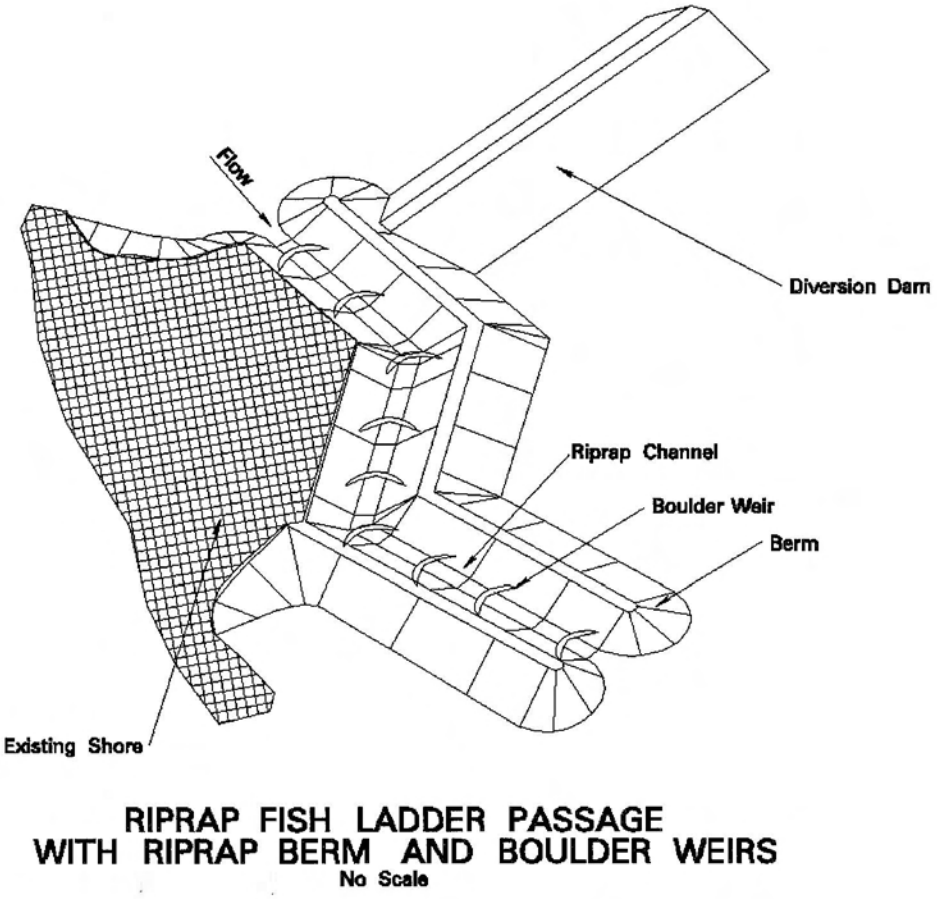


Figure 9 Isometric View of Riprap Fish Ladder with Boulder Weirs

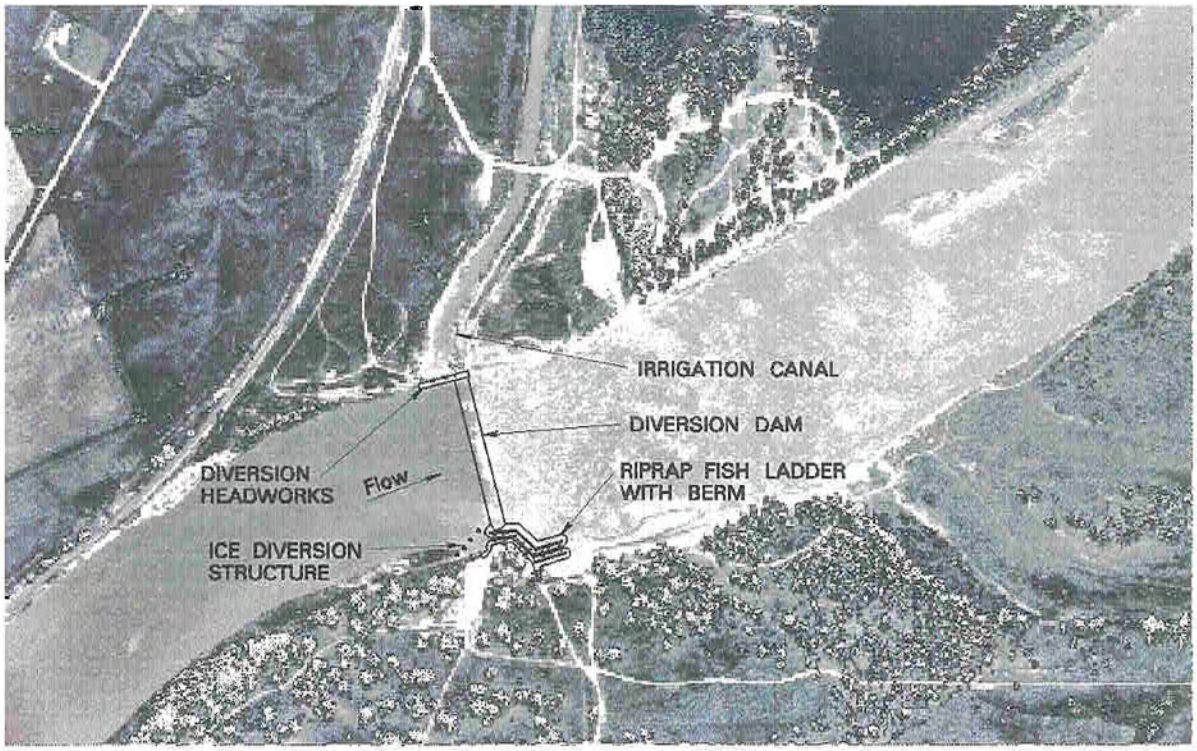


Figure 10 Plan View of Riprap Fish Ladder with Boulder Weirs

3) Bypass Channel

This alternative would use the overflow side channel (high flow channel) to the south of the existing rock dam to bypass fish. The concept would involve construction of a structure at the mouth of the abandoned river chute to allow water to pass through the chute for low flows. The length of the bypass channel was about 6000 feet matching the length of the abandoned river channel. The alternative has reasonable average velocities, but the lack of survey information in the area left the cost of this alternative in doubt. A shorter bypass chute may be possible at this site, and may warrant additional study. Maintenance of the channel after high Yellowstone River flows was a concern. The Yellowstone River routinely uses this side channel during high flow periods flushing sediment and debris through the channel. Figures were not prepared for this alternative. The Bureau of Reclamation has done a more detailed study of this alternative, which can be consulted for more information on this alternative.

Although the 6000 foot length of this alternative poses some concern, many fish species would likely move upstream through such a channel if sufficient attraction flow were provided. The provision of attraction flow, however, could be challenging due to the length of the alternative. An alternative of shorter length could have merit

if sufficient attraction flows were achievable. The effect of the volume of flow through such a long channel should be modeled to determine the effect on the head needed for the irrigation intake.

Baffled Fishways

This alternative used data obtained during the literature search to design a fish bypass ladder. The concept is sometimes referred to as a fish baffle, since walls or intrusions into the flow are used to baffle or slow the water to allow for fish passage. For this alternative, the concept of the Denil Fish baffle was used since the literature search indicated this type of fish structure worked the best for non-salmonid species. The baffle concept assumed a 600-foot long concrete structure 10-foot wide and rectangular in shape. For the concept, the channel roughness was estimated at 0.060 for the concrete structure with the vertical baffles accounting for the additional roughness. The baffle slope was set at 0.08% to try to reduce velocities in the baffle.

As explained in the description of the grouted riprap ladder, initial concepts for the baffle fishway assumed a longer channel with a lower slope would be required to maintain acceptable average velocities for fish passage. Since the concept placed the baffle fishway in the center of the Yellowstone River channel, the longer baffle fishway also provided a downstream exit that was past the existing rock rapids that might prevent pallid sturgeon attraction. Later investigation indicated the length could be reduced while maintaining a suitable average velocity, but the changes were not made for the conceptual analysis. It is recommended that more study be done for this concept if it is selected for fish passage at Intake Dam. This concept is shown in Figures 11 and 12.

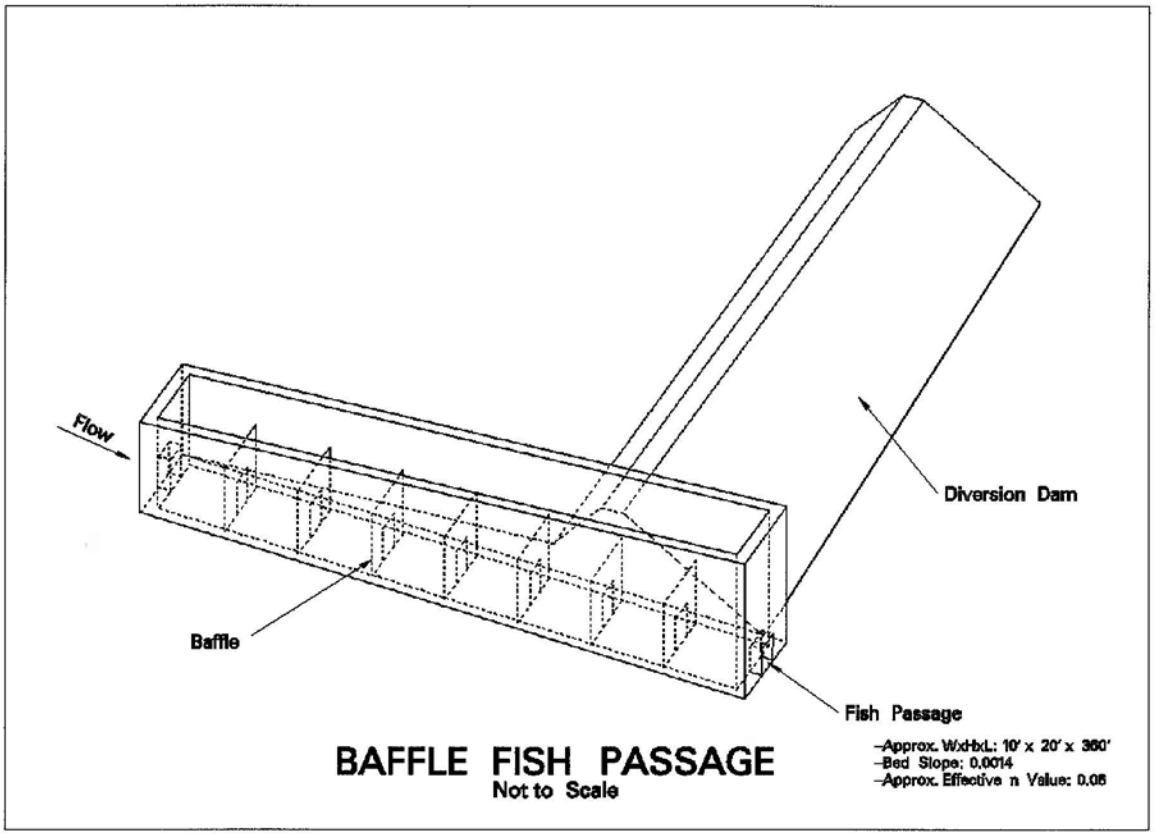


Figure 11 Isometric View of Concrete Fish Baffle

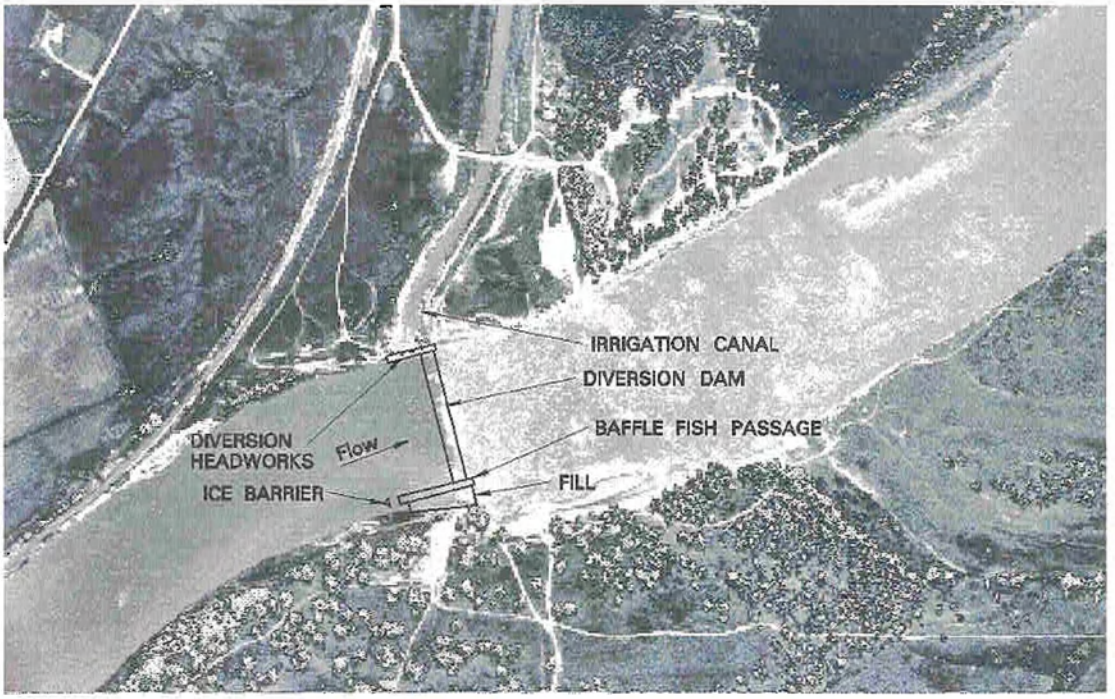


Figure 12 Plan View of Concrete Fish Baffle

Figure 13 Wild Shovelnose Sturgeon from the Yellowstone River Negotiating Horizontal Baffle at the Bureau's Water Resources Research Laboratory in Denver (Corps of Engineers photo)

Elevator Fishways

The fish elevator is a concept that allows fish to pass through the dam via a concrete lock or elevator using attraction flows. Once fish have been attracted into the structure, the opening is closed and water is either pumped or released through a valve into the structure to raise the water surface elevation to that on the upstream side of the structure. Once the water surface is equalized, an upstream door is opened and the fish are allowed to swim out.

The elevator was a rectangular concrete structure about 10 feet wide and 180 feet long. As with the baffle fishway concept, additional length was added to allow the downstream exit to be placed downstream from the existing rock rapids. The concept is shown on Figures 14 and 15.

Two concerns for this alternative were how to attract and automate the fish passage structure and the potential annual maintenance costs from normal operation given the number of moving parts. Attractant flows are achieved by opening valves or gates at the upstream end of the elevator. However, it is uncertain what attraction would be needed to get the fish to exit the elevator above the dam. In addition, the method of detecting the fish to automate the valve system to lock the fish through the structure was not examined. The maintenance costs were not estimated for this concept, but could be potentially expensive, depending on the period of use for the structure (during high spring flows or all year round),.

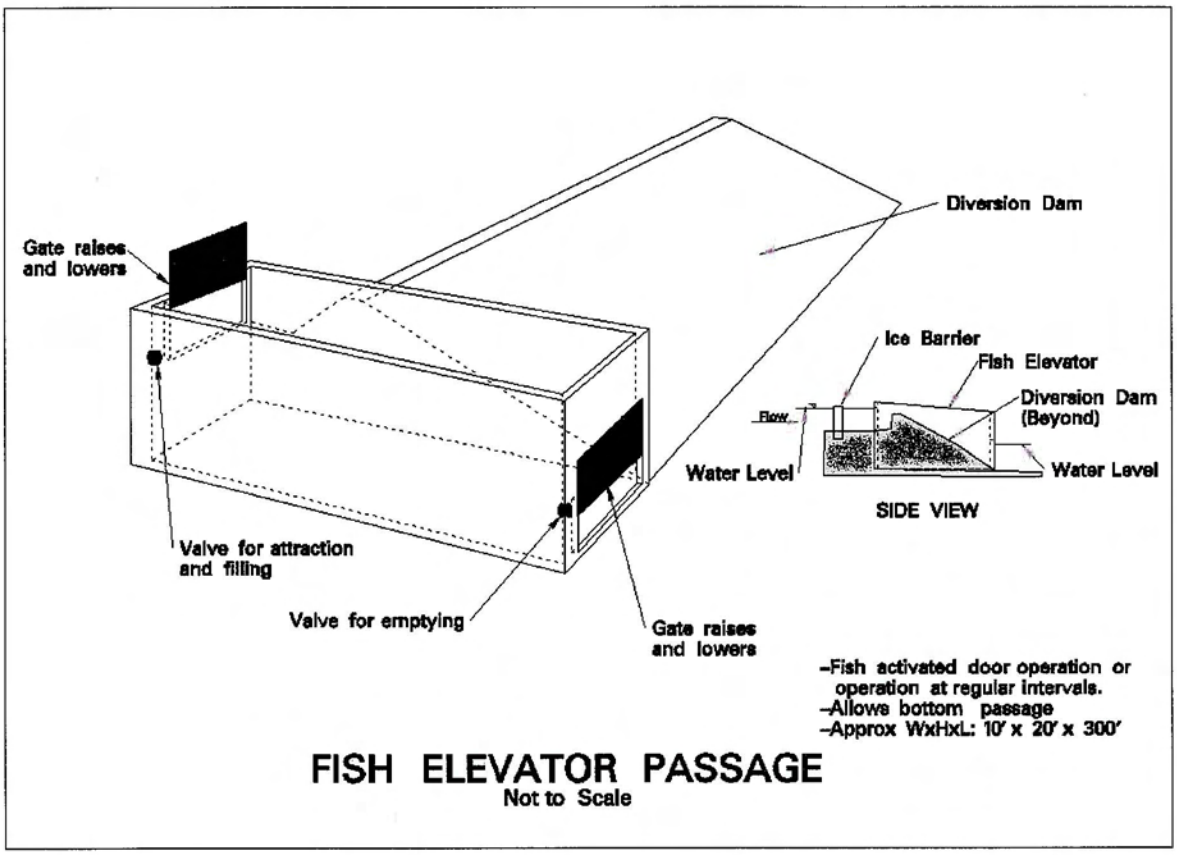


Figure 14 Isometric of Fish Elevator

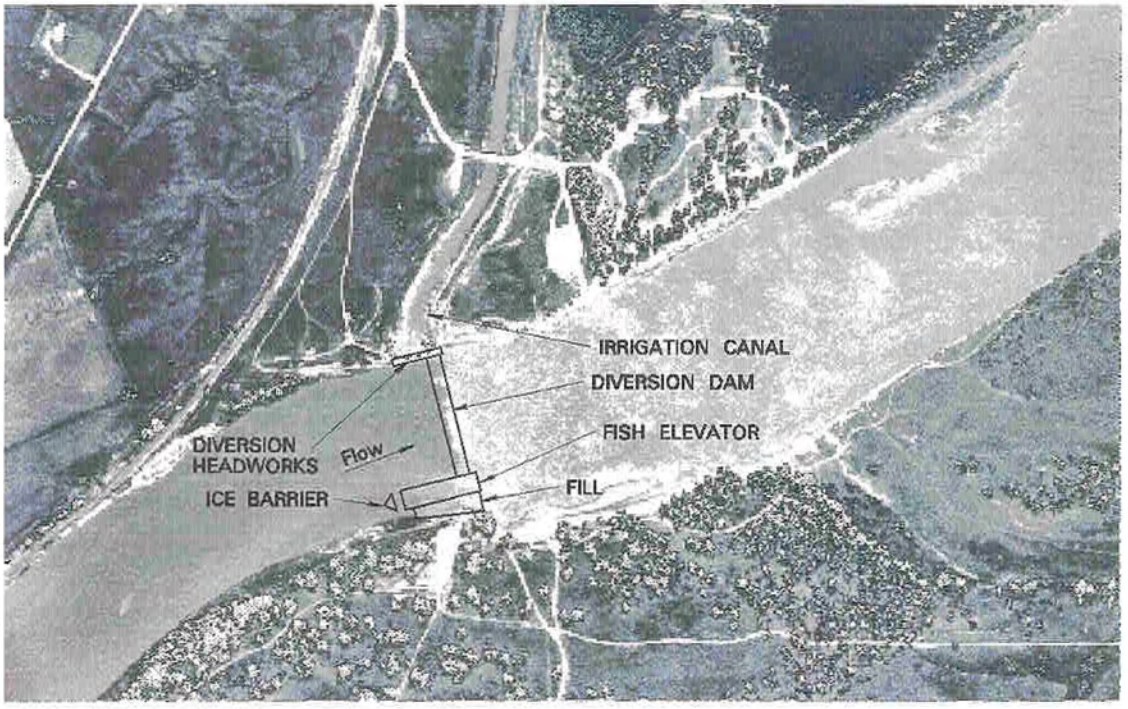


Figure 15 Plan View of Fish Elevator

Dam Removal or Replacement

Dam Removal with Infiltration Gallery

This alternative would remove the rock dam and replace it with an infiltration gallery below the bed of the Yellowstone River. The infiltration gallery would allow water to seep through the bed of the Yellowstone River and enter the gallery to be pumped to the diversion canal. Preliminary investigations indicate that numerous large pumps and the gradation and sediment load of the Yellowstone River bed would potentially make this a high maintenance alternative. Figures were not prepared for this alternative.

This alternative would consist of twelve 56,100 gallon-per-minute irrigation pumps, assuming back-up pumps would not be needed. Using estimated permeabilities for the Yellowstone River bed, about one mile of infiltration gallery would need to be constructed in the bed of the Yellowstone River to allow the peak flow of 1400 cfs to infiltrate into the gallery. Yellowstone River sediment might interfere with the ability of the river water to percolate into the infiltration gallery, requiring routine

maintenance. This alternative includes the complete removal of Intake Dam, therefore the operation and maintenance costs associated with Intake Dam would no longer be needed. After dam removal, the next upstream impediment to fish migration would be Cartersville Dam.

Dam Replacement with Collapsible Gate System

This alternative would replace all or a portion of the existing rock dam structure with a new gate structure that could be collapsed when not in use. An example of this type of structure would be Obermeyer gates. Before and after the irrigation season, the gates would be lowered to allow the river to run without impedance. During the irrigation season, one or more gates would be lowered to allow fish passage through the gate opening(s). This alternative includes complete removal of Intake Dam, installation of a cement footing, and temporary dewatering during construction. Since Intake Dam would be removed, future operation and maintenance costs associated with Intake Dam would no longer be needed.

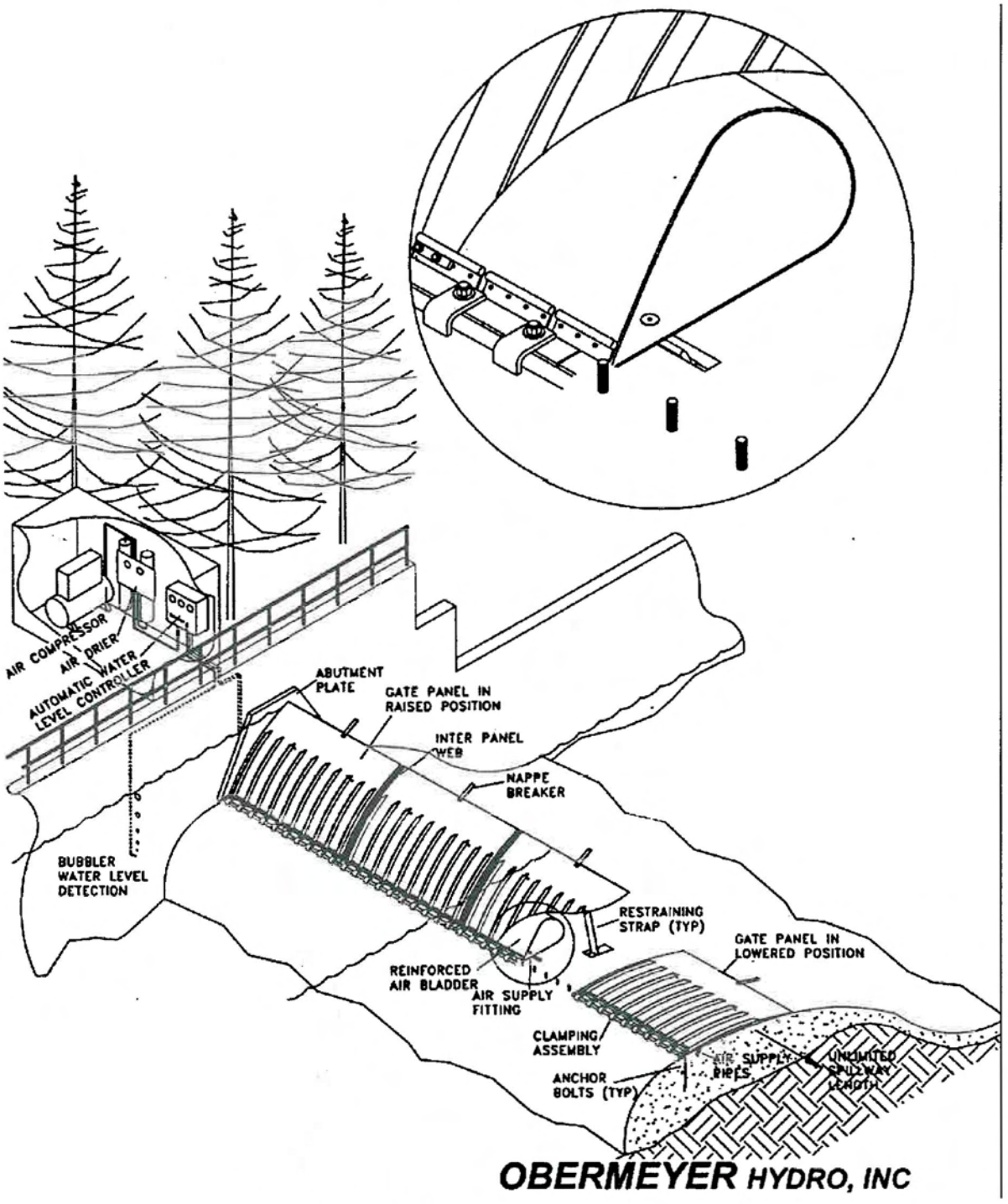
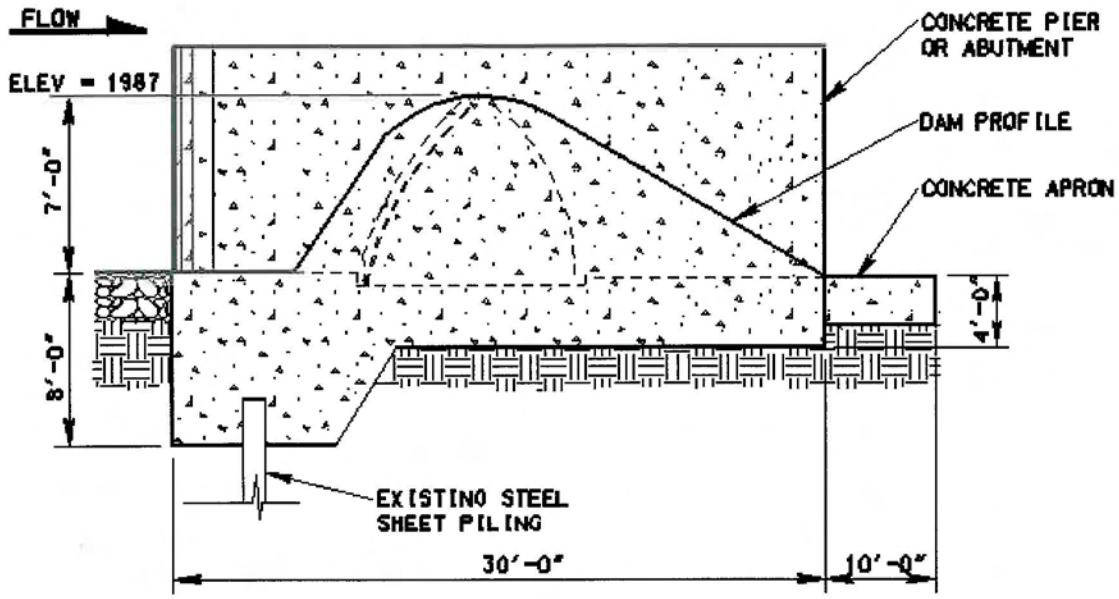


Figure 16 Isometric of Obermeyer Weir



NEW DAM DETAIL

NO SCALE

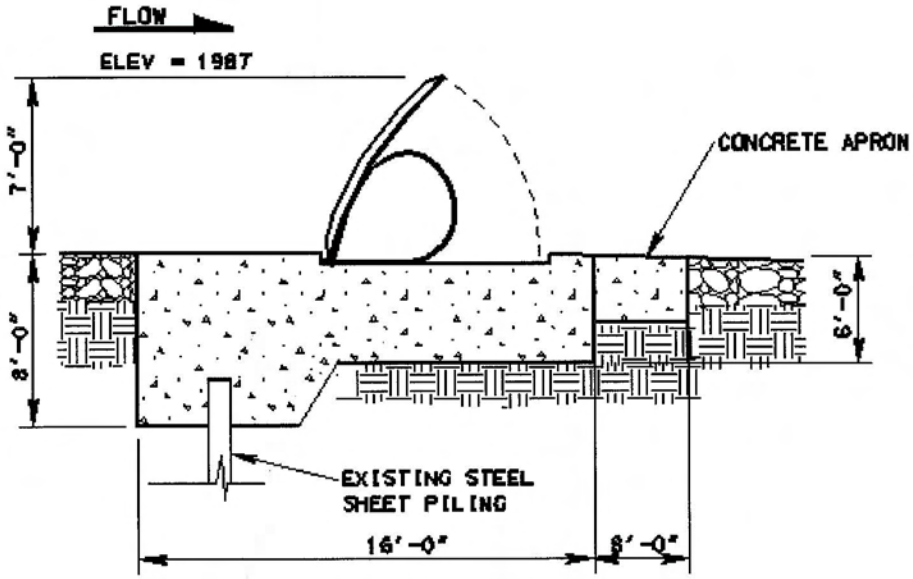


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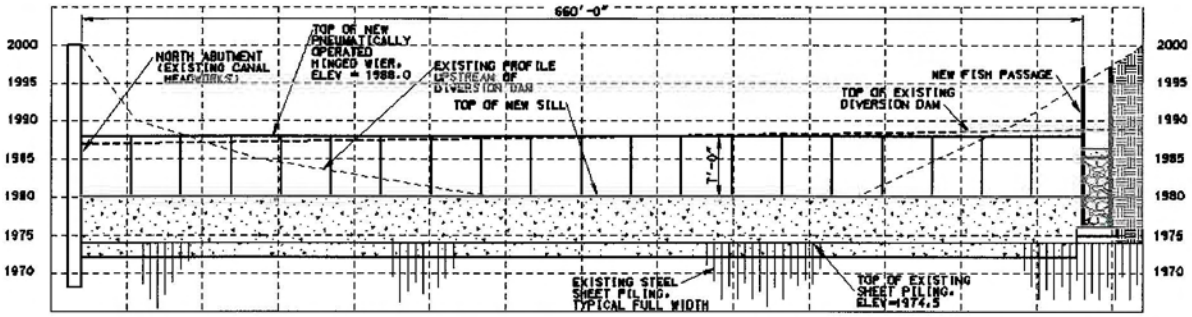
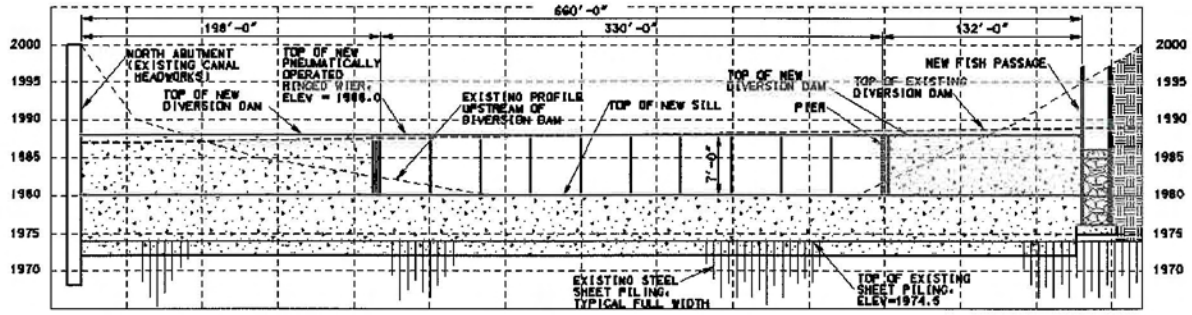
Figure 17 Collapsible Gate Details



DIVERSION DAM PROFILE (ALTERNATIVE 1)

NOTE: VERTICAL SCALE = 5 x HORIZ SCALE



DIVERSION DAM PROFILE (ALTERNATIVE 2)

NOTE: VERTICAL SCALE = 5 x HORIZ SCALE

Figure 18 Collapsible Gate Profiles

Engineering Analyses

Flow Duration Analysis

Flow duration relationships are used to define the percent of time that a given discharge is equaled or exceeded. Duration curves represent the cumulative distribution function of all data recorded at the site and can be based on monthly, seasonal or annual periods. Duration curves are not to be used for assessing future probabilities of infrequent events.

Flow duration curves for the Yellowstone River near Intake, Montana were developed for use in optimizing stream flows for endangered fish spawning runs. The nearest stream gage to the project reach is the Yellowstone River near Sidney, Montana USGS gage number 06329500. This stream gage is located on the left bank at Montana-Dakota Utilities Company power plant, 0.2 miles downstream from the bridge on State Highway 23, located 2.5 miles south of the town of Sidney, Montana, at river mile 29.2. The drainage area at the gage site is 69,103 square miles. Discharge records for the Yellowstone River near Sidney gage are available back to 1911. Daily discharge records from 1911 through 1999 were used in the analysis to develop flow duration curves representing existing conditions.

Annual, seasonal and monthly flow duration curves were created using HEC-STATS, a statistical analysis program. Computed flow duration relationships are summarized in Table 4.

Table 4 Flow Duration

YELLOWSTONE RIVER AT SIDNEY, MONTANA

DAILY DISCHARGE VALUES IN CUBIC FEET PER SECOND

PERCENT TIME FLOW EXCEEDED OR EQUALLED	MAY	JUNE	JULY	MAY-JULY	ANNUAL
0	106000	143000	113000	143000	143000
0.01	104000	142000	112000	142000	118000
0.5	63400	96500	79500	88000	75000
1	53300	90800	73500	79600	66000
2	48300	82500	67400	71400	55800
5	39900	72500	56400	60200	41300
10	32700	63500	43700	51200	28700
15	28100	57800	38300	45300	21200
20	24800	54100	34900	40400	16300
30	21000	47100	29000	32900	11500

Table 4 Flow Duration

YELLOWSTONE RIVER AT SIDNEY, MONTANA

DAILY DISCHARGE VALUES IN CUBIC FEET PER SECOND

PERCENT TIME FLOW EXCEEDED OR EQUALLED	MAY	JUNE	JULY	MAY-JULY	ANNUAL
40	18000	41500	24900	27400	9490
50	15700	36500	21000	22700	8220
60	13800	32000	17100	18600	7240
70	12100	28800	13700	15200	6270
80	10300	23300	10100	12100	5350
85	9150	20700	8270	10500	4930
90	7840	17400	6470	8590	4210
95	6540	13900	4460	6440	3300
98	5440	10700	2860	4450	2350
99	4420	9370	2350	2960	1870
99.5	2190	8000	1880	2150	1570
100	570	6240	1200	570	570

To demonstrate the flow duration concept, actual recorded discharges for the Sidney gage for the May through July time frame for the calendar years 1997 and 2000 are shown in Figures 19 and 20. The 1997 period shown in Figure 19 was considered a "wet" year. Here the 50% flow duration values were easily exceeded by the recorded flows for the three-month period. The 2000 period shown in Figure 20 was considered a "dry" period. Here the recorded flows were less than the 50% flow duration values. The flow duration values indicate that on average, the flows will be exceeded 50 % of the time during the specified flow period. The flow duration values do not indicate anything about the frequency of large floods or droughts.

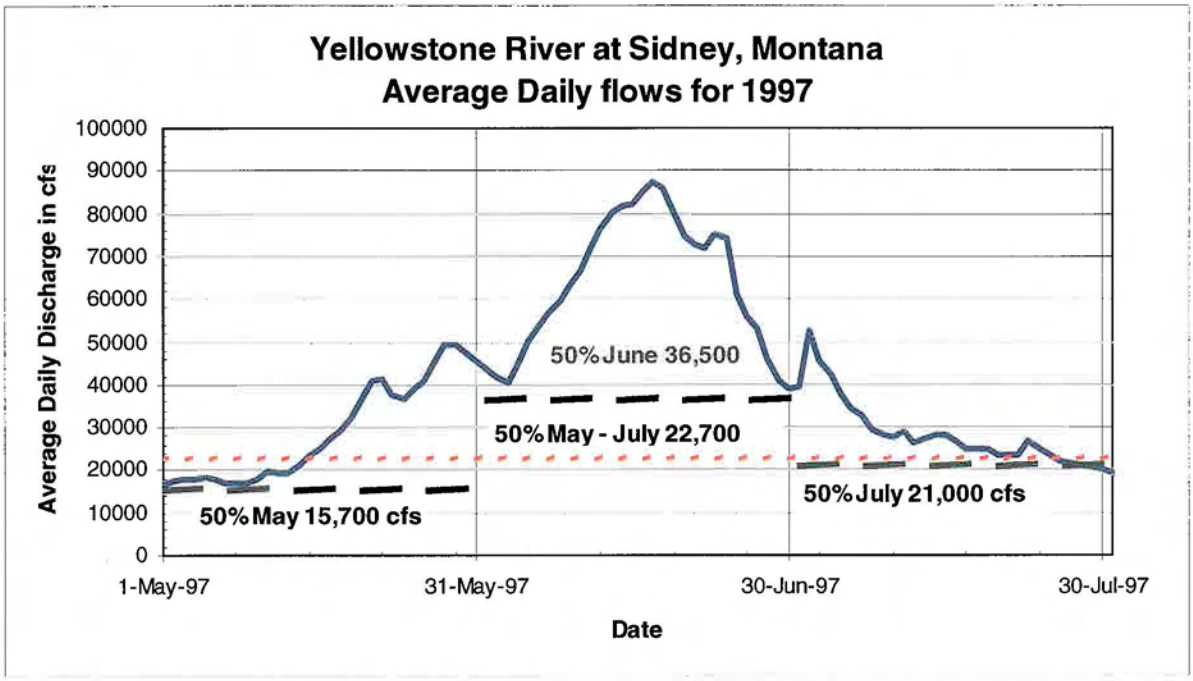


Figure 19 Average Daily flows for May through July in 1997

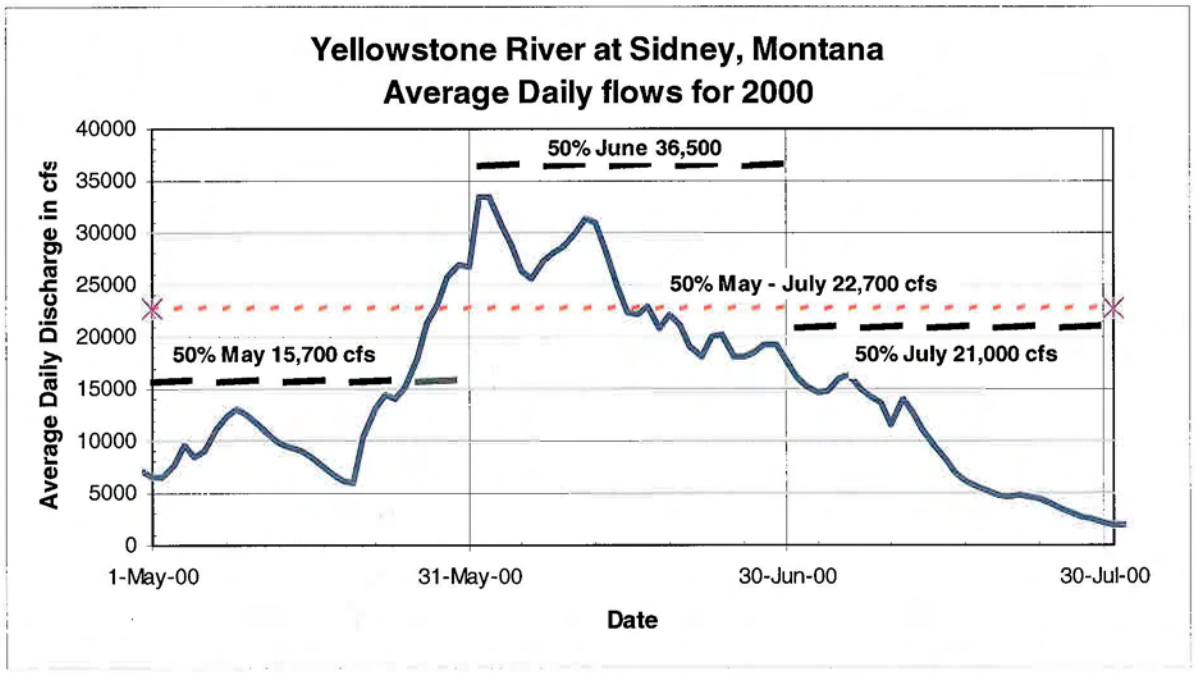


Figure 20 Average Daily flows for May through July in 2000

Hydraulic Analysis

Purpose

The purposes of the hydraulic analysis are threefold. The primary purpose is to assess the impact of any fish passage alternative on the diversion of flow to the irrigation canal. The second purpose was to calculate the amount of water entering the fish passage structure. The final purpose was to calculate an estimate of the flow velocity and flow depth for the fish passage alternatives.

Model Assumptions

The alternatives were modeled using HEC-RAS 3.0 released in May 2001. HEC-RAS is a one-dimensional standard step backwater simulation model assuming steady state, uniform flow. The program is used to calculate water surface elevations along a stream for single discharge regardless of time. The model requires input of the stream geometry, roughness values, and other variables. As a one-dimensional model, it is limited to simulating flows in one-dimension and will not be able to calculate spot velocities (a specific velocity at a specific flow depth and location) in the riprap channel, fish baffle, or channel bypass. Velocities and depths that are calculated are averaged across the entire section or subsection. The model cannot accurately compute velocity and depth changes across a cross section nor can it compute turbulence or the velocity in naturally occurring flow eddies. A two- or three-dimensional model would be needed to compute changes in flow direction or vertical turbulence.

HEC-RAS version 3.0 included a flow optimization procedure. This procedure allows the quasi-simulation of two-dimensional flow at flow splits and islands. By creating separate flow paths and junctions, the model can calculate the flow among the individual flow channels. For this study these channels would include the irrigation canal, the Yellowstone River, and the fish passage alternative. The model uses initial estimates of flow diversions to calculate water surface elevations for the fish passage alternatives, irrigation canal, and the Yellowstone River and then iterates until all three energy grade elevations are within an acceptable tolerance at the flow junction. This procedure proved to be very useful in calculating the flows leaving the Yellowstone River and entering the fish passage option and the Intake Dam canal. This allowed the actual Yellowstone River tailwater to be used in calculating the backwater profiles for the fish passage alternatives and for calculating the flow into the canal through the diversion gate structure as well as the required gate openings.

All fish passage alternatives modeled with HEC-RAS were located along the right channel bank with the downstream end located just upstream from the scour hole area near the right channel bank, which is 5 to 10 feet deep. Although located at the

downstream end of the dam, it is believed that this location would best serve to attract the fish into a passage.

Model Development

The HEC-RAS model used in the Bureau report entitled: ***Intake Diversion Dam, Yellowstone River, Fish Protection and Passage Concept Study Report***, dated January 2000 was used as the base model for this analysis effort. This report describes the details of the model, which will only be summarized here. The survey data was obtained in April of 1999. The model was calibrated to the water surface elevations measured at the time of the survey. The model received did accurately reproduce the results shown in the subject report. All modifications made to the model were done to reflect changes in flow conditions as a result of the alternative being studied.

Four discharges were modeled for the Yellowstone River. These are shown in Table 5 with the target flows for the diversion channel. It was quickly noted while running existing conditions (before any fish alternatives were added), that the target diversion flow of 1400 cfs could not be accomplished for a Yellowstone River flow of 5000 cfs. The target was then reduced to 1170 cfs as computed by the HEC-RAS model. The flows used for the Yellowstone River, as shown in Table 5, were those used in the January 2000 Bureau of Reclamation report for consistency. The flows also represent the wide range of flow conditions possible in the study area.

Table 5 HEC-RAS Model Flows and Intake Gate Openings

Computed Canal Discharge for Existing Conditions

Yellowstone River Discharge In cfs	Target Canal Discharge In cfs	Gate Openings for existing conditions	Computed Canal Discharge In cfs	Exceedance Frequency for May to July Time Period
5000	1400	11 open 5 feet	1170*	97%
15,000	1400	11 open 3.3 feet	1410	70%
29,500	1400	11 open 1.7 feet	1400	35%
38,800	1400	11 open 1.6 feet	1400	22%

* This was the maximum discharge computed to be diverted to the irrigation canal for existing conditions and was below the target discharge. This 1170 cfs discharge will be the target for all the alternatives.

Alternatives Analysis

Of the seven alternatives being considered to provide fish passage at the dam, only five were modeled in the hydraulic analysis. The fish elevator and infiltration gallery were not modeled. The fish elevator uses a locking system that would not be suitable for a steady state model. The infiltration gallery would remove the dam and was not hydraulically modeled. Descriptions of the five remaining alternatives that were modeled are described in the following paragraphs.

During the development of initial concepts, two factors were analyzed to maintain low average velocities. These two factors were the upstream channel area and the slope of the channel itself. These factors were calculated by normal depth in the initial concept phase. A trade-off between the elevation of the upstream inlet and the slope forced the alternative to have a long length in order to keep the average velocity in the acceptable range. A larger upstream area would allow more water to enter the alternative and increase velocities. A higher upstream inlet elevation would restrict the amount of inflowing water but would increase average velocities by increasing the slope of the channel. Later the alterative were modeled using HEC-RAS but the lengths were not changed. In addition, features such as boulder weirs, baffles, and depression were not incorporated in the model since they cannot be adequately modeled using a one-dimensional model,

As such, the purpose of the one-dimensional HEC-RAS model was to calculate average velocities and the distribution of flows for comparison purposes in the alternative evaluation. Therefore there is more confidence in the distribution of discharges than for average velocities. The models cannot identify spot velocities or vertical or horizontal turbulence. It is recommended that physical model studies be used if such data is required, since they provide the most accurate and meaningful data.

The design of the fish passage structures need to balance the energy from the differential water surface elevation across the dam structure with the length of the passage structure itself. With a short passage structure, the area at the upstream end of the structure, invert (channel bed) elevation, and water surface differential over the dam control the amount and the velocity of water passing through the structure. For longer structures, the length of the structure helps dissipate the energy difference from the water surface differential across the dam. The slope of the structure and the downstream water surface elevation control the velocity and the amount of water passing through the structure. To assess the flow conditions for these situations the alternatives were modeled using HEC-RAS.

For the HEC-RAS model, average roughness values for the structures were used to help model the wide range in discharges. Channel roughness actually depends on the size of the rock in the channel and the flow depth. Given the range of flows being considered there will be a large variation in the channel roughness, especially at lower flows (higher roughness values). Therefore, the roughness values were selected to err with calculating higher velocities at lower river flows.

Pre-Dam Conditions

To provide a comparison for the alternatives, the dam and canal diversion were removed from the HEC-RAS to compute flow velocities prior to the dam construction. It is recognized that the dam would have influenced the bed geometry and elevation, but it was assumed the resulting flows in area away from the dam would not be significantly impacted. The results of this model indicated the pre-dam velocities ranged between 2 and 5 feet per second, representing flow velocities ranging from 5,000 to 38,800 cfs, with the largest velocities occurring during the higher discharge events.

Grouted Riprap Fish Ladder

For the grouted riprap fish ladder, two options were modeled for the alternative to show this trade off in upstream invert elevation and structure slope. Both options used a 600-foot long structure with a 10-foot channel bottom and 1 vertical on 3 horizontal side slopes. Both used a downstream invert elevation of 1981.0. The first option used an upstream invert elevation of 1981.8 (channel slope of 0.13%) and the second option used an upstream invert elevation of 1984.6 (channel slope of 6%). Therefore the only difference between these options was the upstream invert elevation and the slope of the channel bottom. A channel Manning's "n" value roughness of 0.040 was applied to reflect the large rock to be used in the grouted riprap fish ladder. The results of these models are shown in Table 6.

Depressions were added to the alternative to provide places for fish to rest. The depressions were not modeled since the one-dimensional model cannot adequately address the vertical and horizontal turbulence. However, experience indicates that such depressions may induce vertical turbulence near the depression.

Table 6 Grouted Riprap Fish Ladder

For a 600-foot long structure with a 10-foot bottom width and 1 vertical on 3 horizontal side slopes. Roughness = 0.040 and downstream elevation of 1981.0.

Upstream Invert Elev.	Yellowstone River Discharge (cfs)	Fish Ladder Discharge (cfs)	Average Velocity at Upstream End (fps)	Flow Depth Upstream End (feet)	Average Velocity at Downstream End (fps)	Flow Depth Downstream End (feet)
1981.8 20' upstream	5,000*	1210	4.6	7.8	***10.0*** 7.5	4.9 5.8
1981.8 20' upstream	15,000	2150	6.0	9.8	***11.3*** 8.8	6.5 7.5
1981.8 20' upstream	29,500	3400	7.3	11.8	***12.9*** 10.5	7.9 9.0
1981.8 20' upstream	38,800	4180	7.9	12.9	11.9 11.2	9.6 10.0
Raised upstream channel invert to decrease velocities						
1984.6 20' upstream	5,000**	700	6.0	4.9	***8.9*** 6.9	3.7 4.4
1984.6 20' upstream	15,000	1410	8.0	6.6	***8.9*** 8.3	5.8 6.0
1984.6 20' upstream	29,500	2400	10.2	8.3	7.5 7.6	9.0 8.9
1984.6 20' upstream	38,800	2950	10.9	9.3	7.4 7.5	10.5 10.4

Italics and bold numbers indicate critical depth or highly turbulent flow conditions exist
* With all gates open – 1091 cfs passes to the diversion canal
** With all gates open – 1135 cfs passes to the diversion canal

Riprap Fish Ladder with Boulder Weirs

A model for the riprap ladder with boulder weirs was developed. Options for higher and lower bed elevations in the passage structure (invert) were also modeled. The length was set at 200 feet to parallel the layout shown in the January 2000 Bureau of Reclamation report on fish passage at Intake Dam. The slope was decreased to 2% from 2.5% based on comments received during the fish testing studies. The channel roughness value of 0.035 used by the Bureau of Reclamation was also used in this analysis. The results of the HEC-RAS model are shown in Table 7.

Table 7 Riprap Fish Ladder with Boulder Weirs

For a 200-foot long structure with a 8-foot bottom width and 1 vertical on 2 horizontal side slopes. Roughness = 0.035 and downstream elevation of 1981.0.

Upstream Invert Elev.	Yellowstone River Discharge (cfs)	Fish Ladder Discharge (cfs)	Average Velocity at Upstream End (fps)	Flow Depth Upstream End (feet)	Average Velocity at Downstream End (fps)	Flow Depth Downstream End (feet)
.						
1987.0	5,000*	220	7.5	2.3	***7.4***	2.3
1987.0	15,000	580	9.3	4.0	7.6	4.5
1987.0	29,500	1200	10.8	5.7	6.6	7.8
1987.0	38,800	1640	11.5	6.7	6.7	9.3
Raised upstream channel invert to decrease velocities						
1985.0	5,000**	540	9.1	3.8	***9.1***	3.8
1985.0	15,000	1090	10.5	6.5	***8.1***	6.4
1985.0	29,500	1930	12.0	7.2	***7.5***	9.6
1985.0	38,800	2500	12.7	8.1	***7.8***	11.2

Italics and bold numbers indicate critical depth or highly turbulent flow conditions exists
* With all gates open – 1160 cfs passes to the diversion canal
** With all gates open – 1140 cfs passes to the diversion canal

Baffled Fishway

The baffle fish passage was analyzed for various geometries. Again the sole difference was the upstream invert and slope of the structure. To reflect the addition of vertical slot baffles in the concrete structure, a Manning's roughness value of 0.060 was used for the channel. The results of the models are shown in Table 8.

Table 8 Baffle Fish Passage

For a 600-foot long structure with a 10-foot bottom width with vertical walls. Roughness = 0.060 and downstream elevation of 1981.0.

Upstream Invert Elev.	Yellowstone River Discharge (cfs)	Fish Baffle Discharge (cfs)	Average Velocity at Upstream End (fps)	Flow Depth Upstream End (feet)	Average Velocity at Downstream End (fps)	Flow Depth Downstream End (feet)
1981.5 20' upstream	5,000*	280	3.3	8.5	***9.7*** 6.2	2.9 4.4
1981.5 20' upstream	15,000	390	3.7	10.6	6.3 6.0	6.2 6.6
1981.5 20' upstream	29,500	510	3.9	13.0	5.5 5.4	9.2 9.4
1981.5 20' upstream	38,800	560	3.9	14.2	5.2 5.1	10.8 11.0

Table 8 Baffle Fish Passage

For a 600-foot long structure with a 10-foot bottom width with vertical walls. Roughness = 0.060 and downstream elevation of 1981.0.

Upstream Invert Elev.	Yellowstone River Discharge (cfs)	Fish Baffle Discharge (cfs)	Average Velocity at Upstream End (fps)	Flow Depth Upstream End (feet)	Average Velocity at Downstream End (fps)	Flow Depth Downstream End (feet)
Raised upstream channel invert to decrease velocities						
1984.6 20' upstream	5,000**	200	3.7	5.4	***8.0*** 5.7	2.5 3.5
1984.6 20' upstream	15,000	310	4.1	7.5	4.8 4.8	6.4 6.5
1984.6 20' upstream	29,500	420	4.3	9.8	4.5 4.5	9.4 9.4
1984.6 20' upstream	38,800	490	4.4	11.0	4.5 4.5	10.9 10.9

Italics and bold numbers indicate critical depth or highly turbulent flow conditions exists

* With all gates open – 1150 cfs passes to the diversion canal

** With all gates open – 1160 cfs passes to the diversion canal

Bypass Channel

A HEC-RAS model was developed for the Bypass Channel alternative to the South of Intake Dam. Please note the only available topography for this option is the U.S.G.S. 7.5 minute Quadrangle Map with a contour interval of 20 feet. Therefore it is unknown if the slopes examined for the channel will require substantial fill, excavation, or are physically possible. The model also does not include any information on the entrance structure. It is assumed a sizeable structure will be required to prevent the Yellowstone River from capturing the channel bypass and making it the main Yellowstone River channel. Variables examined in the hydraulic analysis included the channel roughness and channel bottom width. A channel roughness value of 0.040 reflects a rock-lined channel while a roughness value of 0.028 reflects an earthen channel with some grassy vegetation. Table 9 shows the model results for the 6000-foot bypass channel. All options used a channel slope of 0.15%. The bypass channel alternative was assumed to be along the right channel bank about 6000 feet long with its flow entrance approximately 4,500 feet upstream from the dam and its flow outlet about 1,300 feet downstream from the dam.

Table 9 Bypass Channel to the South of Intake Dam

For a 6000-foot long channel with a 20-foot bottom width with 1 vertical on 3 horizontal side slopes. Roughness = 0.040 and downstream elevation of 1981.0.

Upstream Invert Elev.	Yellowstone River Discharge (cfs)	Fish Baffle Discharge (cfs)	Average Velocity at Upstream End (fps)	Flow Depth Upstream End (feet)	Average Velocity at Downstream End (fps)	Flow Depth Downstream End (feet)
1990.0	5,000	30	1.2	0.9	0.3	3.2
1990.0	15,000	280	2.7	3.4	1.2	6.2
1990.0	29,500	850	3.6	6.1	2.0	9.1
1990.0	38,800	1,280	4.0	7.5	2.4	10.7
Roughness value lowered to n=0.028						
1990.0	5,000	40	1.7	0.9	0.4	3.3
1990.0	15,000	370	3.7	3.3	1.6	6.2
1990.0	29,500	1120	5.0	5.9	2.6	9.0
1990.0	38,800	1690	5.6	7.2	3.2	10.6
Channel bottom width increased to 40 feet and n=0.028						
1990.0	5,000	70	1.8	0.9	0.4	3.2
1990.0	15,000	640	4.0	3.2	1.8	6.2
1990.0	29,500	1760	5.4	5.7	2.9	9.0
1990.0	38,800	2550	6.0	7.0	3.5	10.5

Dam Replacement with Collapsible Gates

A HEC-RAS model was developed for the collapsible gate alternative. A collapsible gate is a regulation gate that uses a mechanism to lift the gate from a horizontal position to a more vertical position to control the flow. An example of such a gate is the Obermeyer gate shown in Figure 16. These gates use a inflatable bladder (air pressure) under the gate to raise and lower the gate. The gates can be set at the same elevation or different elevations depending on the required flow over the gate, etc.

The HEC-RAS model was developed to determine the average velocity through a gate(s) lowered to allow fish passage and to determine the impact on flow diversion to the canal. The original-RAS model obtained from the Bureau of Reclamation used an inline weir structure to model the flow over the rock dam. This geometry was altered to reflect the lowering of collapsible gates. For this study, it was assumed the gates would be 20 feet wide and about 9 feet high. To determine the average velocity through the gate(s) opening, a second model was developed by replacing the inline weir geometry with four sections reflecting the geometry of the dam. A comparison of the two models revealed differences in the upstream water surface elevations and the amount of flow diverted to the canal. For this effort these differences were considered negligible.

Once the cross sectional geometry or inline weir geometry was modified to reflect one or more gates being in the totally lowered position, the diversion gate openings to the canal were altered until meeting the minimum irrigation flow requirement of 1400 cubic feet per second (cfs) for river flow above 5000 cfs and 1170 cfs for flows at 5000 cfs. (Note: This was the maximum flow achievable with all gates open for 5000 cfs in the Yellowstone River). Table 10 shows the results of the flow and gate openings.

Table 10 Collapsible Gate Modeling Results

Yellowstone River Discharge	Number of gates and opening in feet	Flow to canal in cfs	Average Velocity through lowered gate(s) in feet per second - *flow depth (in feet) italicized*
		1 Gate completely lowered	
5000	11 – 5.0	1150	5.6 *(9.7)*
15000	11 – 3.2	1400	8.6 *(11.0)*
29500	11 – 1.7	1410	10.8 *(2.4)*
38800	11 – 1.6	1400	11.9 *(13.1)*
		2 Gates completely lowered	
5000	11 – 5.0	1020	14.5* *(6.6)*
15000	11 – 3.69	1400	8.7 *(10.7)*
29500	11 – 1.73	1410	10.8 *(12.1)*
38800	11 – 1.62	1400	11.9 *(12.9)*
		3 Gates completely lowered	
5000	11 – 5.0	840	13.2* *(5.4)*
15000	11 – 4.6	1400	8.5 *(10.5)*
29500	11 – 1.76	1410	10.8 *(11.9)*
38800	11 – 1.65	1410	12.0 *(12.6)*
		4 Gates completely lowered	
5000	11 – 5.0	620	12.2* *(4.5)*
15000	11 – 5.0	1360	8.8 *(10.1)*
29500	11 – 1.78	1400	10.9 *(11.6)*
38800	11 – 1.67	1410	11.8 *(12.4)*
		5 Gates completely lowered	
5000	11 – 5.0	480	11.5* *(4.1)*
15000	11 – 5.0	1320	16.3* *(8.2)*
29500	11 – 1.92	1400	10.9 *(11.4)*
38800	11 – 1.69	1410	11.9 *(12.1)*
		10 Gates completely lowered	
5000	11– 5.0	50	5.0* *(4.9)*
15000	11 – 5.0	980	9.4* *(7.5)*
29500	11 – 3.3	1410	10.1 *(10.4)*
38800	11 – 1.78	1400	9.2 *(12.1)*

Table 10 Collapsible Gate Modeling Results

Yellowstone River Discharge	Number of gates and opening in feet	Flow to canal in cfs	Average Velocity through lowered gate(s) in feet per second - *flow depth (in feet) italicized*
15 Gates completely lowered			
5000	11 – 5.0	20	3.3* *(5.1)*
15000	11 – 5.0	810	5.9* *(8.0)*
29500	11 – 3.3	1400	6.9 *(10.9)*
38800	11 – 1.78	1400	7.2 *(12.4)*
20 Gates completely lowered			
5000	11 – 5.0	10	2.5* *(5.1)*
15000	11 – 5.0	770	4.3* *(8.2)*
29500	11 – 4.69	1401	5.6 *(11.0)*
38800	11 – 2.17	1400	6.1 *(12.6)*

* Indicates flow is confined entirely to the gate opening(s)

The results of the modeling indicated that all flows to the irrigation canal could be maintained until 3 gates were placed in the fully lowered position, except at the 5000 cfs flow. With two gates down the flow would drop from 1170 cfs to 1020 cfs and to 840 cfs with three gates down. Opening four gates begins to impact the 15,000 cfs flow lowering the irrigation canal diversion to 1360 cfs. For flows at 30,000 cfs and higher, as many as 20 gates could be lowered without impacting the irrigation canal flow.

Ice Issues

Ice is a consistent wintertime presence on the Yellowstone River. The proposed fish passage at the Intake Dam could be impacted by ice covers and by ice jams. There are 93 entries for the Yellowstone River listed in the Ice Jam Data Base (US Army 2002). It is important that the fish passage either be constructed to resist the ice forces or be protected from ice action. In either case, the Ice Engineering Group of ERDC/CRREL could assist characterizing the ice conditions in the Lower Yellowstone and estimating the maximum ice forces that may be expected, and in selecting an appropriate plan for protecting the fish passage structure from ice.

A row of piers or dolphins, extending from the riverward side of the entrance of the fish passage to the upstream shore, could provide protection for the fish passage structure from direct ice action. (See Figure 6 for an approximate representation or pier placement.) The row of piers would meet the shore at a small angle so that moving ice would tend to shear along the piers and not impact them directly. Each pier would be an independent structure, and should have minimal impact on sediment and fish passage. The actual size and shape of the piers would depend on the expected ice forces and the required foundation. Similar circular piers were designed for an ice control structure to be built by the Buffalo District of the Corps (Lever, Gooch and Daly 2000). Circular piers are often used for bridges and are relatively inexpensive to construct. A good overview of structural ice control methods, including the use of piers, can be found in "Structural Ice Control, Review of Existing Methods." (Tuthill 1995).

The installation of gates to control the upstream water levels is contemplated in the modification to the Lower Yellowstone Diversion Dam. The Obermeyer-type gates consist of individual steel panels that are raised and lowered by individual air bladders. It would also be worth considering a Bridgestone-type inflatable dam. This structure is simpler in design than the Obermeyer system, consisting of a long (up to about 300 ft) air-filled tube clamped to a prepared concrete sill. Filling and emptying the air bladder regulates the upstream water level, without the use any mechanical parts on the dam itself. Inflatable dams have shown considerable promise in severe ice environments of the upper Missouri, and the Susquehanna Rivers, as well as rivers in northern New England and Quebec. (Tuthill 2001). They are much less prone to the icing problems experienced by mechanical gates (Haynes et al 1997, Tuthill 2002). The Bridgestone-type structures are also conformable to sloping side abutments, which might reduce the required alterations to the existing dam or riverbed.

Information from the meeting held in conjunction with the Lower Yellowstone Diversion Project indicated that the island to the east of the proposed location for fish passage has had ice and flow cover it during winter months. The piers to deflect

ice may need to be altered into a "v' shape to reflect this circumstance, thereby preventing this ice to enter the fish passage.

Construction Costs

Construction costs were estimated from the conceptual drawings made for each plan. All costs include engineering and design and administration of the construction contract (9% and 6% respectively) were added to the costs. A contingency of 35% was added to the cost to address uncertainties associated with conceptual design. Detailed listings of the costs are shown in Appendix E. Costs (rounded) for each alternative are shown in Table 11.

Annual operation and maintenance costs related to the Intake Dam would not be needed for alternatives involving the removal of Intake Dam, but would need to be included for the remaining alternatives. These annual costs, however, were not provided by the irrigation district so are not included in this report. Annual operation and maintenance costs were not estimated for the alternatives, but relative costs (in terms of "high," "moderate," and "low") were estimated for the basis of the alternatives matrix.

Table 11 Estimate Construction Costs for Conceptual Alternatives

Alternative	Base Cost	Contingency 35%	Engineering and Design (9%)	S&A during Construction (6%)	Total
Grouted Riprap Fish Ladder (Concrete Wall)	$1,050,000	$350,000	$80,000	$130,000	$1,610,000
Grouted Riprap Fish Ladder (Berm Wall)	$600,000	$190,000	$50,000	$70,000	$910,000
Riprap Fish Ladder with Boulder Weirs	$370,000	$110,000	$30,000	$40,000	$550,000
Bypass Channel to the South of Intake Dam	Not available	Not available	Not available	Not available	Not available
Baffle Fish Passage	$830,000	$260,000	$60,000	$100,000	$1,250,000
Fish Elevator	$640,000	$210,000	$50,000	$100,000	$1,000,000
Infiltration Gallery\Pumping	Not available	Not available	Not available	Not available	Likely greater than $5 million
Collapsible gates (Full Length)	$3,560,000	$1,210,000	$280,000	$450,000	$5,500,000

Table 11 Estimate Construction Costs for Conceptual Alternatives

Alternative	Base Cost	Contingency 35%	Engineering and Design (9%)	S&A during Construction (6%)	Total
Collapsible gates (Half Length is gated, one-half concrete)	$3,480,000	$1,180,000	$280,000	$440,000	$5,380,000
Full length Concrete Dam*	$3,640,000	$1,220,000	$280,000	$450,000	$5,590,000

* Please note the concrete dam cost was added to allow calculation of either partial or full replacement of the rock dam with a concrete dam to preclude the need for future maintenance or introduction of rock into o the riverine area.

Alternative Comparison

For comparison purposes the alternatives were placed in a matrix format in Table 12. The alternatives were then compared based on five criteria:

- Velocity range
- Pallid sturgeon passage potential
- Construction cost
- Maintenance cost
- Other benefits (e.g. recreational use, non-sturgeon fish passage)

All alternatives investigated could provide fish passage to some extent, depending on the volume of water in the Yellowstone. Therefore, the comparative analysis is primarily to formulate the most "bang for the buck" with regard to anticipated costs, pallid sturgeon passage, and other benefits. Costs and maintenance provide a relative comparison for long-term viability. Before the overall matrix could be determined, however, the alternatives were compared for pallid sturgeon passage potential alone, without regard for cost or other benefits. This comparison is outlined in the section below. After the pallid comparison, the alternatives were compared for operational considerations, including maintenance costs and other benefits.

Comparison of Pallid Sturgeon Passage Potential

The alternatives were compared for pallid sturgeon passage potential by looking at predicted velocities within the alternative, the potential for turbulence, the presence of resting areas, the potential attraction to the structure, and the number of "unknown" parameters or uncertainty. The general thought process used was as follows:

- slower velocities are better than faster velocities
- attraction flows are needed
- low turbulence is better than moderate or high turbulence
- horizontal turbulence is preferable to vertical turbulence
- resting areas are beneficial
- proven methods have lower risk than experimental methods (lower uncertainty)

The length of the structure would normally be a criteria for fish passage, however not all of the lengths for the alternatives considered (e.g. the bypass channel and some of the grouted riprap alternatives) were calculated using the final HEC-RAS model. Some were initially estimated using other methods and were not later refined. Therefore, length is not a good screening criterion for this effort. If the alternatives

are refined and analyzed in later studies, we recommend that the structure lengths be recalculated for any alternative comparison.

If additional analyses are done with these alternatives at a later date, and length criteria are standardized, then "shorter length is better than longer length" should be added into consideration.

The pallid sturgeon ranking exercise did not take into account cost, operation and maintenance concerns, or any recreational benefits. Those considerations are discussed under the section called "Operational Considerations," and are also included in the overall alternatives matrix.

Grouted Riprap Fish Ladder
(concrete wall and berm options)

There doesn't appear to be any difference in velocity or depth between the wall and berm options within the grouted riprap design, so pallid sturgeon considerations should not be the determining factor between these options.

(depression and boulder options)

Use of depressions or scour holes as resting areas within this fishway should result in a range of velocity options. The scour holes should provide "rest" areas, possibly allowing for upward movement at or below "burst" speed velocities for numerous species and sizes of fish. This type of design would allow for downstream passage of young-of-year and adult fish as well. Modeled average flow velocities exceed sustained swim speeds. However, if the depressions function as resting areas passage is possible. The use of depressions to provide rest areas would be experimental, since we have no examples of these types of resting structures in other designs. The current models could not determine velocity or turbulence conditions within the depressions. There is a possibility that the depressions could contain "vertical" turbulence as the water column plunges downward. If depressions are going to be used for resting areas, a physical model should be tested with fish to ensure that the depressions function as rest areas.

Use of boulders as resting areas would also result in a wide range of velocity options within the fishway. The boulders would provide "rest" areas, allowing for upward movement at or below "burst" speed velocities for numerous species and sizes of fish. This type of design would also allow for downstream passage of young-of-year and adult fish as well. While grouting and articulated matting are nice from a construction and maintenance perspective, interstitial spaces and soft substrate are nice from a biological perspective and may provide higher passage success for smaller fishes (Cornish, personal communication). Additional thought should go into the benefits and impacts of grouting the boulders prior to final design, if this option is

pursued. This option received a higher ranking than the "depressions" option because of the uncertainty associated with the use of depressions for resting areas.

Riprap with Boulder Weirs

This fishway is very similar to the "grouted riprap option with boulders" option above, and would also include a wide range of velocity options due to the presence of boulders, The boulders would provide "rest" areas, allowing for upward movement at or below "burst" speed velocities for numerous species and sizes of fish. This type of design would also allow for downstream passage of young-of-year and adult fish as well. While grouting and articulated matting are nice from a construction and maintenance perspective, interstitial spaces and soft substrate are nice from a biological perspective and may provide higher passage success for smaller fishes (Cornish, personal communication). Additional thought should go into the benefits and impacts of grouting the boulders prior to final design, if this option is pursued.

Wild shovelnose sturgeon navigated a test boulder design and performed well (White and Mefford, 2002), and boulders have been used in other designs for fish passage. This alternative received a higher ranking than the "grouted riprap with depressions" alternative because of the uncertainty with the use of depressions for resting areas. There are other boulder passage designs used in other parts of the country (e.g. Aadland) and in Europe that were not considered in this report, but should be considered prior to the development of a final design.

Bypass Channel

Flow velocities are predicted to be low, which is good since the design currently has no provision for resting areas such as boulders or depressions. These structures could be added into the design if needed, however.

There is no identified method for adding attraction flows to this alternative. It is uncertain how fish would find this channel. The existing design is excessively long (6000 feet), however, shorter design options are likely possible. Due to the uncertainty of attraction flows, passage through this alternative is uncertain. However, bypass channels are used with great success in Europe in passing sturgeon *(Acipenser sturio)* (Cornish, personal communication). A shorter bypass channel with attraction flows could work for fish passage at Intake Dam, but was not included in this report.

Baffle Fish Passage

Baffled fishways were tested as part of the White and Mefford contract, using shovelnose sturgeon, to determine the sturgeon's tolerance to eddies (horizontal and vertical) formed by baffles of various sizes over a range of flows.

Fish negotiated all vertical baffles tested, but the percent success declined with baffle height (see Appendix A, Table 8). For 3, 6, and 12-inch vertical baffles, success ranged between 75% and 100% at all velocities tested between 2 and 4 ft/sec (White and Mefford, 2002). Figure 13 shows a shovelnose sturgeon negotiating a horizontal baffle during these tests.

Prototype fishway tests were conducted using shovelnose sturgeon, however the timing of the testing (October) likely affected these fishes' motivation to move upstream through the structures. Sturgeon moved through the vertical slot and the dual slot fishways, however success (upstream movement) was below that in the rock fishways using the same fish (also in October).

This type of fishway may present a greater challenge for downstream passage, if required, since baffled structures are often uni-directional. The White and Mefford study indicated that for many velocities, sturgeon were able to float back downstream (head facing upstream) through the baffles. At very high flows velocities, sturgeon didn't maintain the "head upstream" position and seemed to become disoriented. The Kynard et al study, 2002, investigated downstream movement through a channel with side baffles. Out of 47 total fish observations of downstream movement, 68% had the head pointing upstream, 92% remained more than two body depths off the bottom, and all drifted slowly with little body movement, using their pectoral fins to maintain orientation. The downstream movement behavior of these pallid and shovelnose sturgeon was similar to that observed for lake and shortnose sturgeon (Kynard et al, 2002).

The designed structure is long (600 ft), but further study may show that a shorter structure may also function as designed. The modeled flow velocities are slightly better than the riprap structures, however the potential for turbulence is greater. This alternative is ranked below the riprap alternatives due to turbulence potential, although fish passage may be adequate. Baffle-type structures are also more "species" or "size" specific than the boulder ramp or the bypass channel alternatives.

Fish Elevator

Fish elevators rely only on attracting fish into confined pools. Swim capabilities and other fish behavior therefore are not critical. Elevators often use low barrier dams to direct the fish into the concentration pools. Such dams could also be useful in directing fish into other fishways (USACE, 1996). The fish elevator could provide successful fish passage based on previous success of elevators in sturgeon passage (Kynard, 2001), however bottom-dwelling fish may have difficulty overcoming vertical barriers such as the sill at the upstream outlet of most elevators (Cornish, personal communication).

Velocities and length are not an issue with this alternative, however there are other unanswered questions. Although fish attraction flows are not designed into this

structure currently, they could be added. However, it is unknown what flows (or other factors) would entice fish to leave the elevator once opened above the dam. Fish elevators are not species-specific and have been used successfully in other areas, so passage using this option would be possible.

Infiltration Gallery

In this alternative, the problems associated with attracting the fish, swim capabilities, and other fish behavior would be eliminated. Since this option would be the most like the pre-dam Yellowstone River (no river structures to pass through or around) with regard to river velocities, fish passage should be highly successful. Velocities with this alternative, which involves the removal of the dam, would revert to those within the Yellowstone River away from the dam (2 - 5 ft/sec).

Collapsible Gates

If fish passage is only required for pallid sturgeon passage from late April until June, and if the irrigation bypass flows don't begin until June or July, then potentially all of the gates could be lowered until irrigation flows are needed. Additional information is needed on the timing of passage requirements for the structure, as well as the timing of irrigation flows.

In the portions of the river where the gates are lowered, fish would have attraction flow, but may need to use "burst" speeds in order to pass the approximately 30 feet of high velocities during most years (depending on Yellowstone River discharges). During low flows, the discharge would be confined only to the lowered area (rather than over the top of the gates), resulting in high velocities. However, it is not known whether pallid sturgeon passage would be required during low (or very high) discharge events. The number of gates to be lowered, and associated velocities, would vary by year depending on the flow in the Yellowstone River.

An operational scheme would need to be developed that indicates the number of gates needed to be lowered for fish passage for a range of Yellowstone River discharges while allowing the irrigation canal to meet its targeted flows. Turbulence is likely where flow overtops gates, but laminar flows should be present where gates are lowered (and where fish would pass). Burst speeds would be needed, but passage is possible. If the relationship between pallid sturgeon body length and burst speed (Adams et al, 1999) holds true for larger pallid sturgeon, then mature 3 to 5 foot long fish would use about a 9 to 16 ft/sec burst speed.

Comparison of Operational Considerations

For all alternatives except dam removal alternatives, there will be some operational constraints. Currently rock for the dam is loaded and cabled to the dam from the

east bank. This operation would need to be shifted away from the channel bank and there is likelihood that rock could accidentally be dropped into the alternative while traveling over it. This concern will need to be examined in more detail once an alternative is selected.

Grouted Riprap Fish Ladder

The alternative would require debris removal and regular maintenance. If not constructed properly, the grouted riprap may require additional maintenance. The row of ice deflecting piers should reduce the ice forces on the structure, but may catch debris potentially obstructing fish passage and requiring removal during the summer months. Maintenance costs for the Intake Dam structure would continue.

Aesthetically, this type of passage can be designed to appear quite natural, and could be designed to allow for canoe and kayak passage during years of sufficient flows

(concrete wall and berm options)

The earthen berm option is lower in cost than the concrete wall option, however it may be more susceptible to ice damage.

(depression and boulder options)

The depressions may be better suited to survive ice movement, however the inclusion of ice deflection structures should minimize ice-related maintenance of the boulders. The boulders could be "fine tuned" after initial construction, unlike the depressions. The boulders have less uncertainty surrounding the velocities, since boulder options have been modeled.

The boulders may require debris removal. Since the riprap and boulders would be grouted, regular maintenance of the rock may not be required. The boulder weirs may need to be monitored to provide the best location for fish passage. The row of ice deflecting piers should reduce the ice forces on the structure, but may catch debris requiring removal during the summer months. Maintenance costs for the Intake Dam structure would continue.

Riprap with Boulder Weirs

The alternative would also require debris removal and regular maintenance. If the riprap is not grouted, regular maintenance of the rock would also be required. The boulder weirs may need to be monitored to provide the best location for fish passage. The row of ice deflecting piers should reduce the ice forces on the structure, but may catch debris requiring removal during the summer months. Maintenance costs for the Intake Dam structure would continue.

Aesthetically, this type of passage can be designed to appear quite natural, and could be designed to allow for canoe and kayak passage during years of sufficient flows. Examples of other rock and boulder fish passage designs can be found in Appendix F.

Bypass Channel

The entrance structure would require regular maintenance to prevent the Yellowstone River from capturing this channel. After high flows the channel may need to have debris and sediment removed to restore fish passage. The stability of this channel would need to be studied in more detail to ensure that sediment would not need to be removed on a regular basis. The maintenance of the Intake Dam structure would continue.

Aesthetically, this alternative would have a good chance to be designed to look like a natural side channel, and could also be designed for use by canoes and kayaks.

Baffle Fish Passage

The alternative would require debris removal and regular maintenance. Recent history with these structures indicates they are highly susceptible to debris plugging the structure and altering the flow conditions. The row of ice deflecting piers should reduce the ice forces on the structure, but may catch debris requiring removal during the summer months. This may alleviate some of the debris entering the structure. Maintenance of the Intake Dam structure would continue.

The baffled fishway would not look as "natural" as the rock or channel passage structures, and would not provide for the passage of recreational canoes or kayaks.

Fish Elevator

This alternative would require debris removal and regular maintenance. The working gates and valves or pumps would require regular maintenance to maintain the functional operation of the structure. The row of ice-deflecting piers should reduce the ice forces on the structure, but may catch debris requiring removal during the summer months. Maintenance of the Intake Dam structure would continue.

The elevator structure need not necessarily be a lengthy structure, so aesthetically it may be better than a baffled structure. The fish elevator would not be designed to pass recreational boats such as canoes and kayaks.

Infiltration Gallery

The area required for an infiltration bed would be extremely large to be able to divert 1400 cfs. The suitability of the bed material for infiltration gallery was a concern for this alternative. The Yellowstone River has a significant sediment load that may also impact the infiltration and the overall viability of this alternative. The number and size of pumps required to discharge 1400 cfs would require frequent maintenance and would be costly to operate with either electricity or diesel fuel. If the entire rock dam is removed the current maintenance activity of placing rock on the dam would be eliminated. This would include rock acquisitions, hauling, and placing of the rock as well as the maintenance of the cabling system to place the rock. There would be a savings from this that would potentially offset the maintenance costs for the pumping. In addition, the Lower Yellowstone Diversion Irrigation Projects would have new pumps and piping to replace a 100-year old structure.

Aesthetically, this option would look the most natural, and would also allow for passage of recreational canoes and kayaks.

Collapsible Gates

The gates, bladder or lifting mechanism, and air compressor would require maintenance to ensure their proper operation. Maintaining the bladder or gates would probably require a temporary river diversion. In addition, the bladders may be susceptible to vandalism when inflated. If the entire rock dam is removed for a structure of all gates or one-half gates and one-half concrete dam, the current maintenance activity of placing rock on the dam would be stopped. This would include acquisitions, hauling, and placing of the rock as well as the maintenance of the cabling system to place the rock. There would be a savings from this that would potentially offset the maintenance costs for the gates. In additions, the Lower Yellowstone Diversion Irrigation Projects would have a new structure to replace a 100-year old structure.

Aesthetically, the gates would not be noticeable when lowered, but would be more noticeable than the current dam when up. Recreational boats could pass through the lowered gates if needed

Table 12 Alternatives Comparison

Alternative	Range of Velocity, Depth, Bottom Width	Potential For Turbulent Flows	Burst Lengths	Swim Potential	Attraction Flow	Resting Features	Passage Potential	Relative Construction Cost	Relative Maintenance Cost	Other	Overall Rating
grouted riprap fish ladder with concrete wall	7 - 12 fps 4 to 10 feet deep 10 ft bottom width	low - no eddy-forming structures	adjustable	burst speeds needed between resting areas	yes	depressions or boulders	moderate-high (length can be shortened)	$1,600,000 moderate	Low to Moderate	recreational passage	2 (boulder option)
grouted riprap fish ladder with earthen berm	7 - 12 fps 4 to 10 feet deep 10 ft bottom width	low - no eddy-forming structures	adjustable	burst speeds needed between resting areas	yes	depressions or boulders	moderate-high (length can be shortened)	$910,000 Low	Low to Moderate	recreational passage	1 (boulder option)
riprap fish ladder with boulders	7 - 12 fps 2 to 9 feet deep 8 ft bottom width	moderate - eddy formation related to boulder placement	adjustable	burst speeds needed between resting areas	yes	boulders	moderate-high	$550,000 Low	Low to Moderate	recreational passage	1
bypass channel	1 - 6 fps 3 to 10 feet deep 20 ft bottom width	low - no eddy-forming structures in design	N/A	sustained speeds	no; a weakness in this design	none in design, but could be added	low as designed, but not eliminated as an option to consider	High at existing length No estimate	High at existing length	recreational passage	7 potential for higher ranking with shorter (less costly) design
baffle fish passage	5 - 11 fps 2 to 11 feet deep 10 ft bottom width	can be designed to minimize, but higher than riprap ladders	adjustable	sustained to burst speeds needed	yes	behind baffles	moderate - low	$1,250,000 moderate	High	High Debris Potential	4
fish elevator	N/A 20 ft deep 10 ft bottom width	low - no eddy-forming structures in design	N/A	sustained speeds	possibly; could be added using a pipe through the elevator	not needed	low	$1,000,000 low	High	High Debris Potential	
Infiltration gallery with pumping	2 - 5 fps[1] river depths 700 ft wide (full river)	low - no constructed eddy-forming structures	N/A	sustained speeds can be used	N/A	naturally-occurring rocks	high	>$8,000,000 High	High Costs to operate pumps would be high	recreational passage	5
collapsible gates (can replace all or just one-half of the existing rock dam)	6 - 12 fps 5 to 13 feet deep 20 ft to 700 ft wide, depending on number of gates	low - moderate turbulence through lowered gates; high below overtopped gates	30 ft	burst speeds	yes	30 ft downstream from structure	potentially high; dependent on irrigation operational plan	$5,500,000 High	Medium Replace 100-year old structure Prevent or lower need for annual rock maintenance	possible recreational passage	6

[1] based on HEC-RAS model for pre-dam Yellowstone River conditions, 5 – 38,800 cfs

Table 12 Alternatives Comparison

Alternative	Range of Velocity, Depth, Bottom Width	Potential For Turbulent Flows	Burst Lengths	Swim Potential	Attraction Flow	Resting Features	Passage Potential	Relative Construction Cost	Relative Maintenance Cost	Other	Overall Rating
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grouted riprap fish ladder with earthen berm	7 - 12 fps 4 to 10 feet deep 10 ft bottom width	low - no eddy-forming structures	adjustable	burst speeds needed between resting areas	yes	depressions or boulders	moderate-high (length can be shortened)	$910,000 Low	Low to Moderate	recreational passage	1 (boulder option)
riprap fish ladder with boulders	7 - 12 fps 2 to 9 feet deep 8 ft bottom width	moderate - eddy formation related to boulder placement	adjustable	burst speeds needed between resting areas	yes	boulders	moderate-high	$550,000 Low	Low to Moderate	recreational passage	1
bypass channel	1 - 6 fps 3 to 10 feet deep 20 ft bottom width	low - no eddy-forming structures in design	N/A	sustained speeds	no; a weakness in this design	none in design, but could be added	low as designed, but not eliminated as an option to consider	High at existing length No estimate	High at existing length	recreational passage	7 potential for higher ranking with shorter (less costly) design
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fish elevator	N/A 20 ft deep 10 ft bottom width	low - no eddy-forming structures in design	N/A	sustained speeds	possibly; could be added using a pipe through the elevator	not needed	low	$1,000,000 low	High	High Debris Potential	
Infiltration gallery with pumping	2 - 5 fps[1] river depths 700 ft wide (full river)	low - no constructed eddy-forming structures	N/A	sustained speeds can be used	N/A	naturally-occurring rocks	high	>$8,000,000 High	High Costs to operate pumps would be high	recreational passage	5
collapsible gates (can replace all or just one-half of the existing rock dam)	6 - 12 fps 5 to 13 feet deep 20 ft to 700 ft wide, depending on number of gates	low - moderate turbulence through lowered gates; high below overtopped gates	30 ft	burst speeds	yes	30 ft downstream from structure	potentially high; dependent on irrigation operational plan	$5,500,000 High	Medium Replace 100-year old structure Prevent or lower need for annual rock maintenance	possible recreational passage	6

[1] based on HEC-RAS model for pre-dam Yellowstone River conditions, 5 – 38,800 cfs

Summary

Seven alternatives were investigated for this study:

- Grouted Riprap Fish Ladder (wall and berm options; depression and boulder options)
- Riprap Fish Ladder with Boulder Weirs
- Bypass Channel to the South of Intake Dam
- Baffle Fish Passage
- Fish Elevator
- Infiltration Gallery\Pumping
- Collapsible gates

Each of these alternatives has been investigated as far as possible with the information available. At this time none of the alternatives should be eliminated since each has its advantages and disadvantages based on the preliminary analysis.

Based on the information used for this document, **the alternatives with the greatest potential for pallid sturgeon passage are the dam removal options (infiltration gallery alternative and collapsible gate alternative) and the riprap fish passage options with boulders.** Fish passage alternatives with high flows were undesirable, but some alternatives had resting areas that addressed this concern. The extremely high construction cost of dam removal options The extremely high construction cost of dam removal options essentially remove those options as viable, from a funding standpoint. After consideration of cost and other factors, **the nature-like (especially rock ramp alternatives) are recommended.**

While the ranking reflects the information from the boulder weir design used by the Bureau of Reclamation in the sturgeon swim study (White and Mefford), and the Corps, it should be noted that there are other boulder weir designs that should also be considered. Due to time and funding constraints, these designs were not included as part of this alternatives analysis.

Recommendations

Based on the information in this document, and the assumption that construction funding is a factor in design selection, **the Corps recommends the nature-like fishways, especially riprap fish ladder with boulder weirs**. The group of nature-like fishways are robust alternatives that rank high even with considerable cost variation. Upon closer examination, all of the alternatives considered could be adjusted to the needs of the targeted fish size identified in the Biological Opinion for passage.

General considerations evolved though the alternative comparison within the nature-like fishway group and cost estimating process:

- boulder resting areas are preferable to depressions due to vertical eddies, and the potential for depressions to collect sand
- a berm is better than a cement wall to separate the fishway from the river, due to cost
- large pallid sturgeon may need a wide (10') bottom width to account for the space that the boulders occupy
- large pallid sturgeon would benefit from a deep depth
- a higher discharge through the fishway results in a greater attraction flow, but may be harder for juvenile fish to pass, and could draw more water away from the irrigation intake
- boulders can be "fine tuned" to achieve desired flow velocities within the structure
- relatively low construction costs for all nature-like options
- moderate maintenance cost
- natural appearance
- recreational boat passage potential

Further consideration should be given to the bypass channel option, since a viable alternative may be possible by shortening the length of the channel.

If funding sources are unlimited, then a dam removal option should be considered, especially the collapsible gate option. Construction costs for the collapsible gate option are less than the infiltration gallery option, and the maintenance costs of the new structure would be moderate.

Additional Data Needs / Tasks

Two options exist for proceeding with the design and construction of fish passage for Intake Dam.

- The first would be to do more detailed hydraulic modeling such a two- or three dimensional modeling or even physical modeling (like that in Appendix A and B) to refine the selected alternative before it is built. It is recommended that the physical model be pursued with actual fish to verify that fish could swim through the structure.

- Construct the selected alternative and use adaptive management techniques to alter the structure. This option could not be used with all alternatives. It would be best suited to the rock bypass structures where it would be easier to reconfigure the boulder weirs or the channel configuration (although somewhat more expensive).

There is much work remaining to get from this document to a constructed project. Pre-construction engineering and design tasks that remain are itemized below. There may be other data needs, or compliance requirements that have yet to be discovered, so this is not an exhaustive list.

Data Needs

Before the final design can be completed, the following data is needed from other agencies / groups:

- **Pallid sturgeon passage requirements from the FWS Biological Opinion on the transfer of the Intake Dam to the irrigation districts.** The current recommendations involve assumptions with regard to the timing of passage, (May - June) as well as the size of fish that would be passed (3 - 5 feet). If year-round passage is required, or if passage of all sizes of pallid sturgeon is required, the alternatives should be re-evaluated for compliance with these requirements.

- **Operation and maintenance costs for the Intake Dam should be provided by the irrigation districts in order to better determine cost savings for dam replacement alternatives.** Current operation and maintenance costs are relative (low, moderate, high) and are only for the fish passage structure, not the operation and maintenance of the Intake Dam. With most structures, the dam will remain in place and operation and maintenance costs will continue, and may even change with the fish passage

structure in place. For dam removal alternatives, those costs will no longer be incurred.

- **The operational timing of the irrigation canal (an operational plan) should be provided in order to determine the viability of the collapsible gate alternative.** Can an operational plan be developed to meet both the needs of the irrigation district as well as the needs of the pallid sturgeon? Currently, the assumption is that both needs could be met, but without the finalized Biological Opinion for the transfer of Intake Dam, and without the operational plan from the irrigation district, this is still somewhat uncertain.

Tasks

In addition to the above data needs, there are additional tasks to be undertaken prior to construction of a fish passage facility:

- Value Engineering Study
  - consider shorter bypass channel alternative
  - consider alternative boulder weir design alternatives
  - resolve timing issues (fish passage vs irrigation needs)
- gather additional survey data
  - sufficient survey data for 2-dimensional modeling or physical modeling (if needed)
  - Sufficient surveys to allow design of the selected fishway alternative
- pallid sturgeon flume tests "on site"
- soil borings for geotechnical analysis
- canoe / kayak passage criteria (if desired)
- detailed design
- detailed construction cost estimate
- Section 10 / 404 permit
- Environmental Assessment by lead federal agency
- Section 401 water quality certification from State DEQ
- Investigation of condition or existing sheet piles if to be reused
- Availability of power and communications for collapsible gates

Surveys

The surveys for this project would consist of 1 inch = 30 feet, 1-foot contour interval mapping. The mapping would be provided in a digital format and would involve some hydrographic mapping methods. The total area of coverage would be 11 acres. The extent of the survey would include the area of the existing diversion dam and portions of the bank line and underwater topography. The cost of the survey would be approximately $, 40,000.

Subsurface Investigation

The investigation would consist of borings mainly for the design and construction of the Obermeyer gate structure, baffle structure and fish elevator. Borings would be drilled to a depth of 25 feet below the channel invert. The approach would be to install one hole with either CPT or SPT methods, and use hollow-stem augering on the remaining two holes to obtain undisturbed samples for evaluation. The cost of the field investigation plus soil testing was included in the cost estimate. The investigation is limited to the banks of the Yellowstone. The flowing water makes any investigation difficult and relates to a high cost. Therefore, borings will not be obtained in river.

Riprap (Stone) Material

Any new stone of an angular surface would be quarried rock that would have to be obtained from western North Dakota or areas near Billings, Montana. If rounded surfaces would be acceptable, possible sources of field stone are located between Glasgow, Montana and the North Dakota border.

Collapsible Gates

More computer modeling may be required for this alternative to refine the operational schemes for various Yellowstone River flow conditions. This work would require close coordinated with the Bureau of Reclamation, the U.S. Fish and Wildlife Service, the Montana Department of Fish, Wildlife, and Parks, and the Lower Yellowstone Irrigation Districts to make sure the schemes meet both fish and irrigation needs. The modeling should include any head-losses anticipated from the screening facility planned in the diversion channel as this could impact the flows estimated for the collapsible gates entering into the diversion channel.

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APPENDIX A

Assessment of Behavior and Swimming Ability of Yellowstone River Sturgeon for Design of Fish Passage Devices

ASSESSMENT OF BEHAVIOR AND SWIMMING ABILITY OF YELLOWSTONE RIVER STURGEON FOR DESIGN OF FISH PASSAGE DEVICES

BY:

ROBERT G. WHITE, PH.D.
MONTANA COOPERATIVE FISHERY RESEARCH UNIT
MONTANA STATE UNIVERSITY-BOZEMAN
BOZEMAN, MONTANA 59717

AND

BRENT MEFFORD, P.E.
WATER RESOURCES RESEARCH LABORATORY
BUREAU OF RECLAMATION
DENVER, COLORADO 80225-0007

Jan 10, 2002

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Background

Intake Dam was originally constructed as a rock-filled timber crib weir about 12 ft high and 700 ft long, containing 23,000 cubic yards of material. The dam raises the upstream water elevation from about 3 to 5 feet depending on river flows. Since construction, the structure has required frequent repair to maintain the needed upstream head to divert flow into the Main Canal. Heavy ice and large flood flows work to progressively move riprap material from the dam downstream. A cableway that crosses the river over the crest of the dam is used to place riprap along the dam crest when repairs are required. Over the years, large quantities of rock have been added to the dam to replace rock displaced by the river. Riprap now extends a considerable distance downstream of the dam altering the natural form of the river.

Fish population studies conducted by Montana Fish, Wildlife and Parks (Stewart, 1986, 1988, 1990, 1991) indicate the dam is a partial barrier to many species and likely a total barrier to some species. Passage of endangered pallid sturgeon is of particular importance at Intake Dam. Backes and Gardner (1994) found no pallids and significantly larger shovelnose sturgeon upstream of Intake Dam. There is little question that Intake Dam is a substantial barrier to the upstream movement of sturgeon species. However, the question remains as to the best method of attracting and passing sturgeon at Intake. The behavior of sturgeon found in the Yellowstone and Missouri River systems has been the subject of several field studies. These studies provide insight into the sturgeon's preferences of flow regime (Bramblett 1996, Backes and Gardner 1994, Erickson 1992, Peterman and Haddix 1975), channel shape (Bramblett 2001, Elser 1977, Peterman and Haddix 1975,) and channel substrate (Bramblett 1996, Backes and Gardner 1994, Baily and Cross 1954). However, when confronted by a barrier, the hydraulic conditions which are favorable to attraction and passage of sturgeon are not thoroughly understood. Little is documented about the ability of sturgeon to negotiate the combination of flow depth, velocity and turbulence.

The research study was developed in response to a request for proposals (RFP) issued by the US Army Corps of Engineers (COE) via electronic mail on May 16, 2001. The study was designed to investigate the interaction between flow conditions and the behavior and swimming ability of pallid sturgeon for use in the design of fish passage structures. Wild adult shovelnose sturgeon from the Yellowstone River were used as a surrogate species as recommended in the RFP. Results of habitat use studies conducted by Bramblett (1996) comparing pallid and shovelnose sturgeon were used in experimental design and evaluation of test data.

Study Participants and Facilities

The study was conducted at Reclamation's Water Resources Research Laboratory (WRRL) in Denver, Colorado. Montana State University (MSU) and Reclamation jointly participated in the research study. Montana State University provide the lead for permitting, biological testing and assessment. Reclamation provided the lead for designing and constructing test apparatus at WRRL and conducting hydraulic evaluations of test conditions.

Fish Collection and Handling

Adult shovelnose sturgeon used in the study were collected from the Yellowstone River by Montana Fish, Wildlife and Parks (MFWP) personnel. Twenty six shovelnose sturgeon were collected July 17, 2001 and 14 October 16, 2001. Dr. Dave Erdahl at the USFWS Bozeman Fish Technology Center and MFWP were consulted on captive handling, transport and maintenance of shovelnose sturgeon. Both groups of fish were transported to Reclamation's Water Resources Research Laboratory (WRRL) in Denver, Colorado shortly after being collected. Fisheries biologist from Reclamation's Fisheries Application Group in Denver transported the fish by vehicle in aerated tanks. The fish were iced down during transport and arrived in Denver in good condition. Upon arrival water temperature was tempered and fish were placed in two 9 foot diameter by 2.5 foot deep circular plastic tanks at WRRL and given a mild salt treatment (Figure 1). Water was continuously circulated through the fish holding tanks from the laboratory's water supply reservoir located beneath the laboratory floor. Water quality within the WRRL water supply reservoir is maintained by an ozonation system. No additional water treatment was required. The water temperature of the supply reservoir was 64 F ± 2 throughout the testing. These water temperatures were typical of Yellowstone River temperatures during spawning (Bramblett 1996) and considered adequate for all tests. Water temperature in the fish holding tanks was cooled to 62 F based on recommendations offered by Dr. Erdahl. His experience with holding Yellowstone River sturgeon for extended periods has shown fish survival is best at water temperatures about 60 F. Fish were fed both commercial trout diet and live night crawlers.

Test sturgeon in group 1 ranged in fork length from 25.2 inches (the 24.6 inch fish had a damaged tail and was not used) to 35.8 inches (mean 31.8) (Figure 2) and weighed 3.1 to 10.6 pounds (mean 6.7) (Figure 3). Group 2 fish ranged in fork length from 28.5 inches to 31.5 inches (mean 30.4)

Figure 1 - View of sturgeon in circular holding tank.

Study Scope

The study was divided into two experimental phases. The first phase focused on identifying the behavior of sturgeon exposed to a combination of flow depth, velocity, and turbulence. These parameters are important in the design of effective fishway attraction and passage conditions. After preliminary testing, we determined that the series of depths tested had no observable influence on sturgeon behavior and depth was eliminated as a test veriable (depth remained constant). The second phase observed the response of shovelnose sturgeon to three types of fishways: a standard vertical slot baffled fishway, a duel-vertical slot baffled fishway and a rock channel with boulder weirs. We planned to conduct both day and night tests,

but since sturgeon movement in preliminary tests was good during light periods, night tests were not conducted.

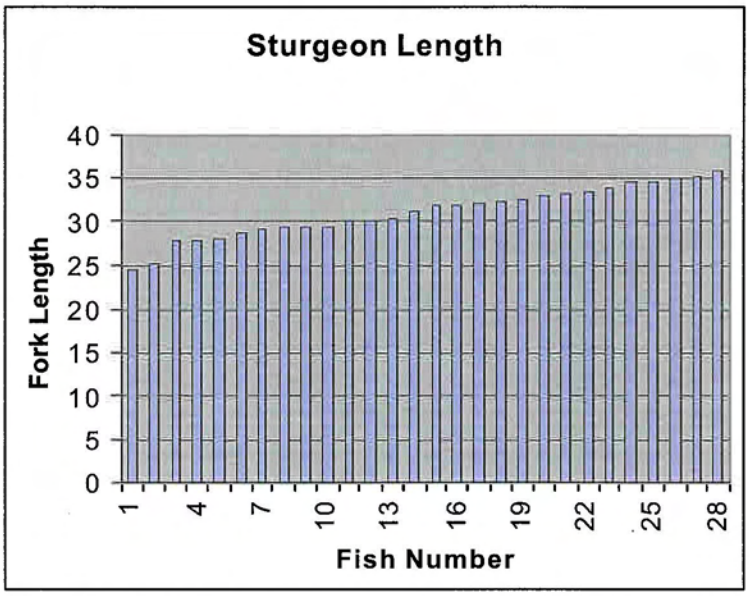


Figure 2 - Fork length of shovelnose sturgeon in test group 1.

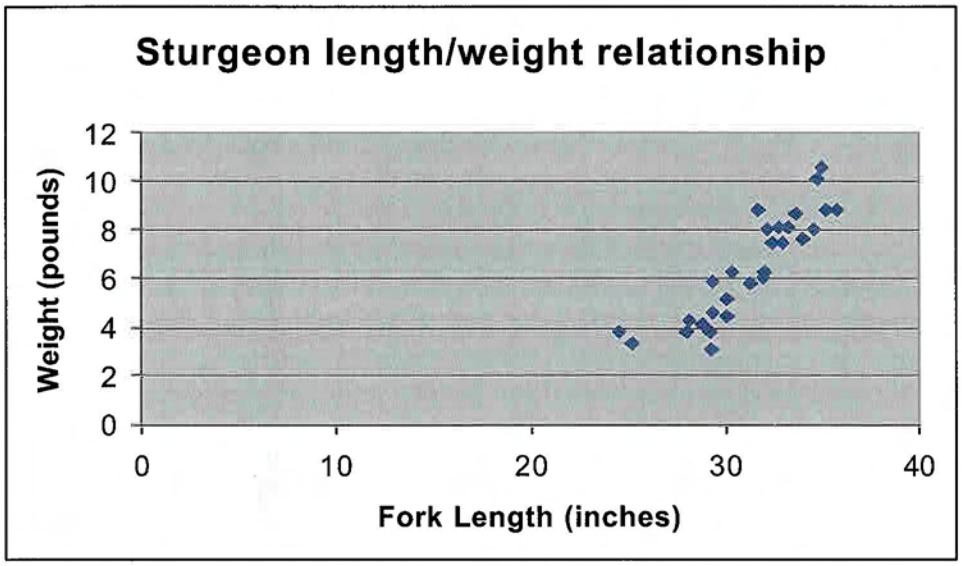


Figure 3 - Weight versus fork length of shovelnose sturgeon in test group 1.

Sturgeon Response to Flow Velocity, Channel Bed Roughness and Flow Turbulence

Flow Velocity and Bed Roughness

Experimental Apparatus

Two flumes were used during velocity and substrate tests. A 3 ft wide by 30 ft long by 5 ft deep horizontal flume was used to observe fish behavior and movement for tests of average flow velocity up to 4.0 ft/s (Figure 4). A second adjustable slope flume was used to test fish at velocities above 4.0 ft/s. The sloping flume is 3 ft wide by 60 ft long by 1.5 ft deep (Figure 5). The flume's slope can be adjusted from -0.5 degrees to 8 degrees. Both flumes have glass walls allowing visual observation of fish behavior.

Test Procedure

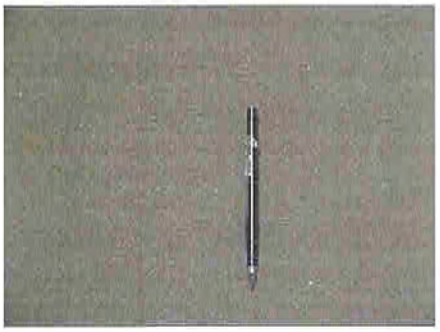
Bed roughness and velocity ranges were selected based on field data of sturgeon habitat preferences summarized in Table 1. Tests were conducted using four bed roughnesses at nine flow velocities (Table 2). Bed roughnesses tested were fine sand, course sand, gravel and cobble (Figure 6). Tests of sand and gravel beds were conducted by placing sheets of marine plywood coated with each roughness on the flume floor. A cobble bed was created by placing a layer of tightly packed cobbles within the flume.

Table 1 - Summary of shovelnose and pallid sturgeon habitat preferences identified in available literature.

Study Author	Depth		Velocity		Substrate	
	Pallid	Shovelnose	Pallid	Shovelnose	Pallid	Shovelnose
Bramblett, 1996, Yellowstone River	2 to 23 ft	3 to 29 ft	0.4 to 4.33 ft/s	0.1 to 6.0 ft/s	>90 % sand bed, <5% gravel	26 % sand, 69% gravel
Erickson, 1992, Lake Sharpe, SD.	13 to 20 ft	NA	0 to 2.4 ft/s	NA	All	NA
Schmulbach et al., 1982 experimental data	NA	NA	NA	2.5 ft/s ± 1.5 ft/s (critical velocity)	NA	NA
Peterman and Haddix, 1975, Tongue River	NA	1.4 to 3 ft	NA	NA	NA	NA

Figure 4 - View of 3 ft wide by 30 ft long by 5 ft deep horizontal flume.

Figure 5 - View looking downstream in the 3 ft wide by 60 ft long by 1.5 ft deep adjustable slope flume.



Fine Sand Bed Roughness

Course Sand Bed Roughness

Gravel Bed Roughness

Cobble Bed Roughness

Figure 6 - Photographs of bed roughness materials used for sturgeon swimming tests.

At the initiation of a test, water velocity and depth were set at 0.8 ft/s and 18 inches, respectively. Two sturgeon were netted from the holding tank based on size (one longer than the other) or color (light /dark) so fish-specific observations could be made. Fish were placed in a large water-filled cooler and lifted by overhead crane (30 ft flume) or transported by dolly (adjustable slope flume) and released into the bottom of the flume. Observations of fish movement were recorded throughout 20 or 30 minute trials. At the end of a trial, velocity was increased by increasing discharge while keeping depth constant. Average velocities tested were 0.8 ft/s, 1.2 ft/s, 1.6 ft/s, 2.0 ft/s, 2.5 ft/s, 3.0 ft/s, 3.5 ft/s, 4.0 ft/s and 6.0 ft/s (adjustable slope flume). At the end of a test series or when a fish became impinged on the bottom screen, fish were removed and fork length measured. Handling, was kept to a minum to minimize stress. To avoid reusing the fish until all fish had been tested, each sturgeon was marked with a numbered strip of duck tape loosely secured around the caudal peduncle.

Table 2. Test variables - Bed roughness and flow velocity

Fine Sand, <0.01 in diameter
Course Sand, 0.1 in- 0.25 in diameter
Gravel, 0.5 in - 1.0 in diameter
Cobble, 2 in - 8 in diameter

Average Velocity, ft/s	Depth, ft
0.8	1.5
1.6	1.5
2.0	1.5
2.5	1.5
3.0	1.5
3.5	1.5
4.0	1.5
6.0	0.7

Adjustable Slope Flume Tests - Bramblett (1996) documented sturgeon in current velocities up to about 6.0 ft/s. Average velocities greater than 4.0 ft/s were not attainable in the 30 foot flume. Therefore, a similar series of tests were conducted in the adjustable slope flume to observe behavior and movement at velocities in the range of 6 to 6.5 ft/s. Bottom substrates tested were smooth bed, coarse sand, gravel and cobble. A smooth bed (plywood flume floor) was substituted for the fine sand bed substrate during the sloping flume tests to observe behavior on a channel bed similar in roughness to a trowel finished concrete surface. The downstream one-third of the channel length was backwatered to provide a method of exposing the fish to an increasing velocity with time. Velocity at the downstream end of the flume was increased in steps similar to tests conducted in the 30 ft flume. Upstream of the backwater zone, flow approached normal depth. It was desired to have a similar velocity at mid-depth for each bed roughness. To achieve similar velocities, flume slope was varied between tests of different bed roughness (Figure 7). A temporary net was inserted 20 feet up from the bottom of the flume to hold fish in the backwater zone as velocity was stepped up (see figure 5). This allowed the flume slope to be held constant during trails at a fixed bed roughness and did not require fish to be moved down for each velocity trial. Test duration was a maximum of 30 minutes but shorter if both fish had moved to the temporary net.

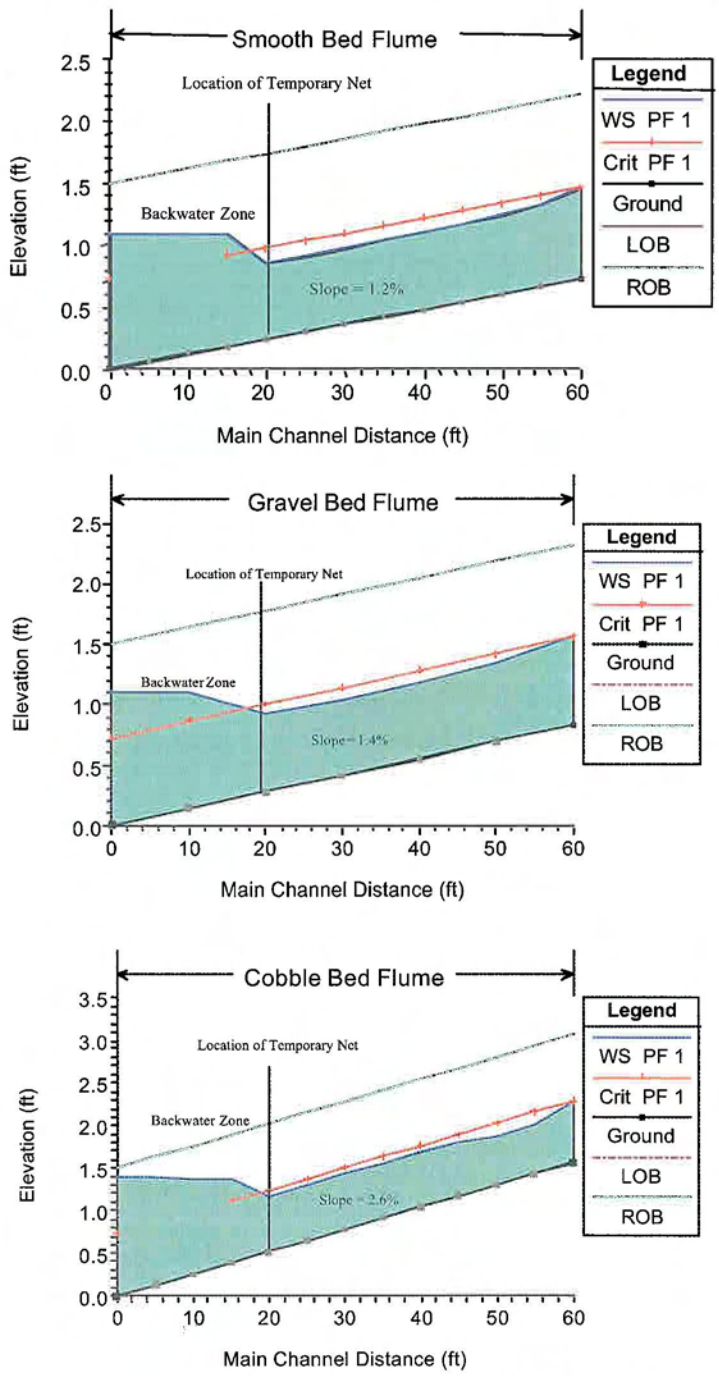


Figure 7 - Watersurface profiles predicted for sloping flume tests using smooth, gravel and cobble bed roughness, HEC-RAS numerical model.

Velocity and Bed Roughness Test Results

Thirty-Foot-Flume Tests - As part of our examination of the influence of velocity and substrate type on sturgeon behavior, we conducted 6 tests consisting of 46 trials in the 30 foot flume. Each test evaluated the behavior of two sturgeon at seven or eight average velocities (trials) ranging from 0.8 ft/s to 4.0 ft/s, and one of four substrate types (fine sand, coarse sand, gravel, and cobble, see Table 2). Vertical velocity profiles are presented in Figures 8 to15 showing the average downstream velocity component (V_x) and the fluctuation of the vertical velocity component expressed as an root-mean-squared-value (V_z rms). Velocity is plotted as a function of distance above the bed. Due to the high irregularity of the gravel and cobble beds a virtual zero bed datum was established based on near bed velocity. The virtual datum was established as the lowest point of continuously positive downstream flow. The velocity profiles show a sharp velocity reduction of V_x for increasing bed roughness. The velocity reduction (boundary layer) is most apparent in the first 4 inches above the bed. In the near bed zone, V_z rms increases with bed roughness. The increase is most pronounced for the cobble bed where the maximum V_z rms values were found to be about 10 percent of V_x max.

Sturgeon successfully negotiated the range of velocities tested, over all substrates. Success was defined as moving from the bottom of the flume to the top within a 30 minute period. Although there were small differences in success associated with substrate type, with cobble being the poorest, small sample size and high individual variation precluded conclusive determination of the influence of substrate. However, pattern of success related to velocity was consistent among substrates. The lowest overall percent success occurred at 0.8 ft/s (67%), increasing to 83% at 1.2 ft/s and 1.6 ft/s, and to 100% at velocities of 2.0 ft/s, 2.5 ft/s, and 3.0 ft/s (Table 3). Success dropped to 92% and 87% at 3.5 ft/s and 4.0 ft/s, respectively. This indicates that attraction velocity becomes strong at 2.0 ft/s and remains high up to 4.0 ft/s.

General fish behavior associated with substrate was also similar among types and movement patterns related to velocity. Sturgeon moved most at low and high velocities (Table 4). At low velocities, fish were less oriented to flow and milled around, moving up and down channel. Up and down movement averaged 4.08 and 4.90 per fish at 0.8 ft/s and 1.2 ft/s, respectively; and movement was throughout the channel. Seventy-six and 18% percent of down-channel movement was head first, suggesting low orientation to flow. Total movement was less at velocities between 1.6 ft/s and 3.5 ft/s and all down-channel movement was tail first, suggesting strong flow orientation. At high velocities, up and down movement increased, with an average total up and down movement of 4.17 trips at 3.5 ft/s and 4.38 trips at 4 ft/s. However, most movement at high velocities was near the upper end of the channel and all down-channel movement was tail first, indicating high orientation to flow. Average time required to first reach the top was slowest at 0.8 ft/s (8.8 minutes) and fastest at 4.0 ft/s (0.8 minutes).

Table 3. Comparison of the number of sturgeon successfully negotiating the 30 foot flume (number to top / number tested) at eight velocities (0.8 - 4.0 ft/s) tested with three substrate types (12 fish), two vertical barrier widths (8 fish), and four horizontal baffle heights (14 fish).

	VELOCITY							
	SUBSTRATE TESTS							
Velocity	0.8	1.2	1.6	2.0	2.5	3.0	3.5	4.0
Sand	3 / 4	3 / 4	3 / 4	4 / 4	4 / 4	4 / 4	4 / 4	-
Gravel	3 / 4	4 / 4	4 / 4	4 / 4	4 / 4	4 / 4	4 / 4	4 / 4
Cobble	2 / 4	3 / 4	3 / 4	4 / 4	4 / 4	4 / 4	3 / 4	3 / 4
Total	8 / 12	10 / 12	10 / 12	12 / 12	12 / 12	12 / 12	11 / 12	7 / 8
%	67	83	83	100	100	100	92	87
	VERTICAL BAFFLE TESTS							
Baffle Width								
15.5 inch	1 / 2	-	2 / 4	1 / 2	3 / 3	3 / 3	2 / 3	2 / 3
22.5 inch	-	-	3 / 4	0 / 2	2 / 4	-	0 / 2	1 / 3
Total	1 / 2	-	5 / 8	1 / 4	5 / 7	3 / 3	2 / 5	3 / 6
%	50	-	63	25	71	100	40	50
	WEIR BAFFLE TESTS							
Baffle Height								
3 inch	1 / 4	2 / 4	3 / 4	4 / 4	4 / 4	4 / 4	2 / 2	2 / 2
6 inch	1 / 4	2 / 4	4 / 4	3 / 4	3 / 4	3 / 4	3 / 3	3 / 3
12 inch	0 / 4	3 / 4	2 / 4	3 / 4	3 / 4	1 / 3	1 / 1	1 / 1
21 inch	0 / 2	1 / 2	0 / 2	0 / 2	0 / 2	1 / 2	0 / 2	0 / 2
Total	2 / 14	8 / 14	9 / 14	10 / 14	10 / 14	9 / 13	6 / 8	6 / 8
%	14	57	64	71	71	69	75	75
Overall Total	11 / 28	18 /26	24 / 34	23 / 30	27 / 33	24 / 28	19 / 25	16 / 22
Overall %	39	69	71	77	82	86	76	73

Table 4. Average movement of 12 shovelnose sturgeon in the 30 foot flume at velocities ranging from 0.8 ft/s to 4.0 ft/s, over sand, gravel and cobble substrate.

Velocity, (ft/s)	Time to Top (minutes)	Number of Times Fish Moved to Top	Number of Times Fish Moved Up	Number of Times Fish Moved Down	Total Movement U+D	Moved Downstream Head First (Percent)
0.8	8.8	1.00	2.67	1.42	4.08	76
1.2	3.2	1.10	2.78	2.12	4.90	18
1.6	2.3	0.75	1.42	1.83	3.25	0
2.0	2.0	1.08	1.92	1.67	3.59	0
2.5	2.2	1.17	1.83	1.75	3.58	0
3.0	2.2	1.08	1.25	1.50	2.75	0
3.5	2.8	1.67	2.00	2.17	4.17	0
4.0	0.8	1.38	2.50	1.88	4.38	0

Sloping Flume Tests - We tested a maximum of five velocity ranges for each substrate type, for a total of 61 trials (Table 5). Because the flume was tilted, within the backwater zone (below the removable net), depth decreased and flow velocity increased moving up the flume. For a distance of about 20 ft upstream of the net location flow conditions were nearly constant (fully developed flow) for coarse sand, gravel and cobble substrates. Between the upstream end of the flume and the onset of fully developed flow, was a length of channel in which flow accelerated as it moved down the flume. Flow in the smooth bed flume accelerated down the entire flume upstream of the backwater zone. Fish were allowed to move to the top of the flume during the tests of highest velocity. Velocity was measured at the downstream end of the flume, at the temporary net and 20 ft upstream of the temporary net. These velocities are denoted herein by the subscripts *d* (downstream), *n* (net) and *u* (upstream). Vertical velocity profiles for each substrate measured 40 ft upstream of the flume's downstream end are given in Figure 16. In the smooth channel, average flow velocity 20 ft upstream of the temporary net was similar to the roughened bed channels, however the average velocity increased to about 6.8 ft/s at entry to the backwater zone.

At lower velocity ranges, fish movement and behavior was similar to that observed at comparable velocities in the 30 foot flume. At the 0.8_d -1.1_n ft/s velocity range fish milled around in the channel and did not actively try to pass beyond the removable net. As velocities were increased, sturgeon became more flow oriented and when down-channel movement occurred it was primarily tail first compared to a mix of head first and tail first movement at the low velocities. Also, as velocity increased fish spent considerable time nosing the removable net in an attempt to pass.

Overall movement success was 57 % at the 0.8_d -1.1_n ft/s velocity test, increasing to 70% and 81 % at the 1.6_d -2.5_n ft/s and 2.0_d -3.3_n ft/s velocity tests, respectively, then declining to 47% at the 2.2_n-6.0_u ft/s velocity tests (Table 5). Movement success was best over smooth bottom (60-90%), followed by coarse sand (50-66%), gravel (33-80%), and cobble (25-50%). When the net was removed for the 2.2_n -6.0_u ft/s velocity test, fish holding at the net usually moved up immediately and reached the top in less than 6 minutes. Unlike the "crawling" behavior at lower velocities, fish actively swam at the high velocity. Although some fish sprinted the entire distance without stopping, most moved up in three or four spirts, resting apparently effortlessly in the high velocity flow. Maximum facing velocity, measured adjacent to the nose of resting fish (about 4 inches off the bed), ranged from 6.5-7.8 ft/s and was unrelated to fish size (Table 6). Fish usually rested no more than 3 minutes between sprints. This suggests that, although adult shovelnose sturgeon can successfully move through these high velocities, they are not likely to maintain position for an extended period. On several occasions motivated fish were moved to the bottom and they immediately returned to the top.

Table 5. Comparison of movement success over four substrates at average velocities ranging from 0.8 to 6.0 ft/s in the adjustable slope flume.

Number reaching top/number tested

Velocity (ft/s)	0.8_d-1.1_n	1.2_d-2.0_n	1.6_d -2.5_n	2.0_d -3.3_n	2.2_n-6.0_u
Smooth	7/10	3/4	9/10	9/10	6/10
Coarse Sand	3/6	-	4/6	4/6	4/6
Gravel	4/6	2/6	5/6	-	2/6
Cobble	2/6	4/8	3/8	-	2/8
TOTAL	16/28	9/18	21/30	13/16	14/30
Percent	57	50	70	81	47

Table 6. Facing velocities of resting shovelnose sturgeon in the 30 foot flume and adjustable slope flume associated with test velocity. (Location of measurements varied along the flume.)

Velocity Test (ft/s)	Facing Velocity, (ft/s)	Fork Length (inches)
30 foot flume		
0.8 (smooth)	1.49	28
1.6 (sand)	1.48	31
2.0 (sand)	2.22	30
2.5 (sand)	2.75	30
2.5 (gravel)	3.05	31.5
3.5 (sand)	4.08	31
Adjustable slope flume		
2.2_n-6.0_u (smooth)	7.5	28
	7.8	31.5
	6.5	30.0
	7.6	33.5
coarse sand / gravel	6.6	35.0
cobble	>6.4	32.5

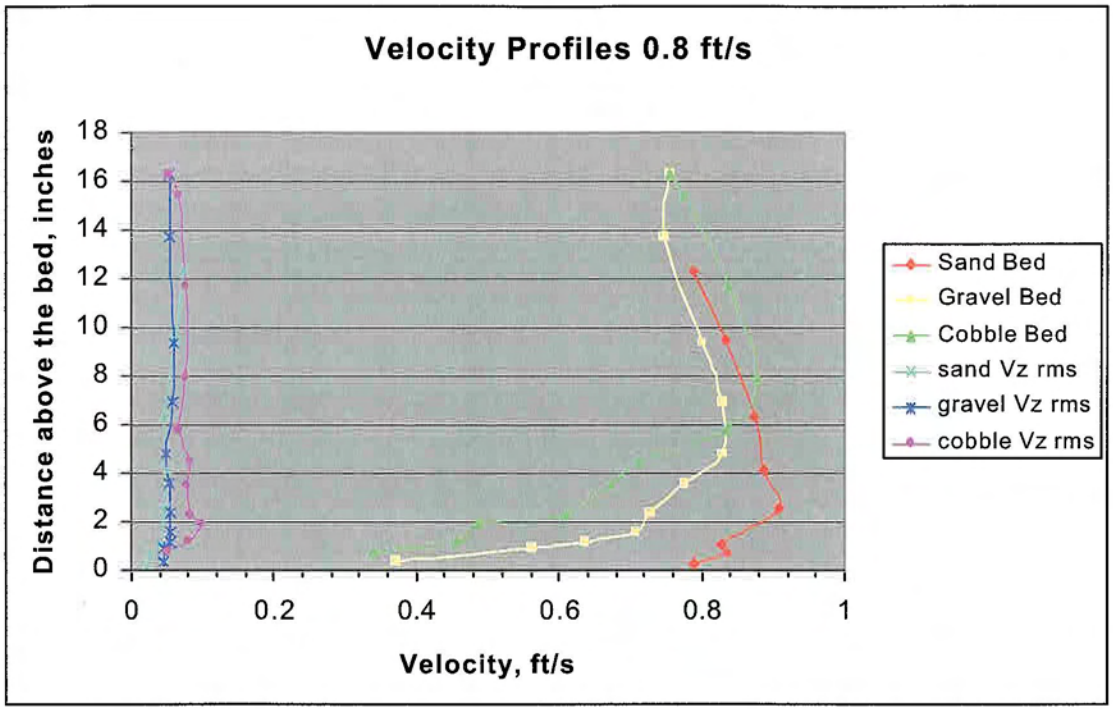


Figure 8 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 0.8 ft/s.

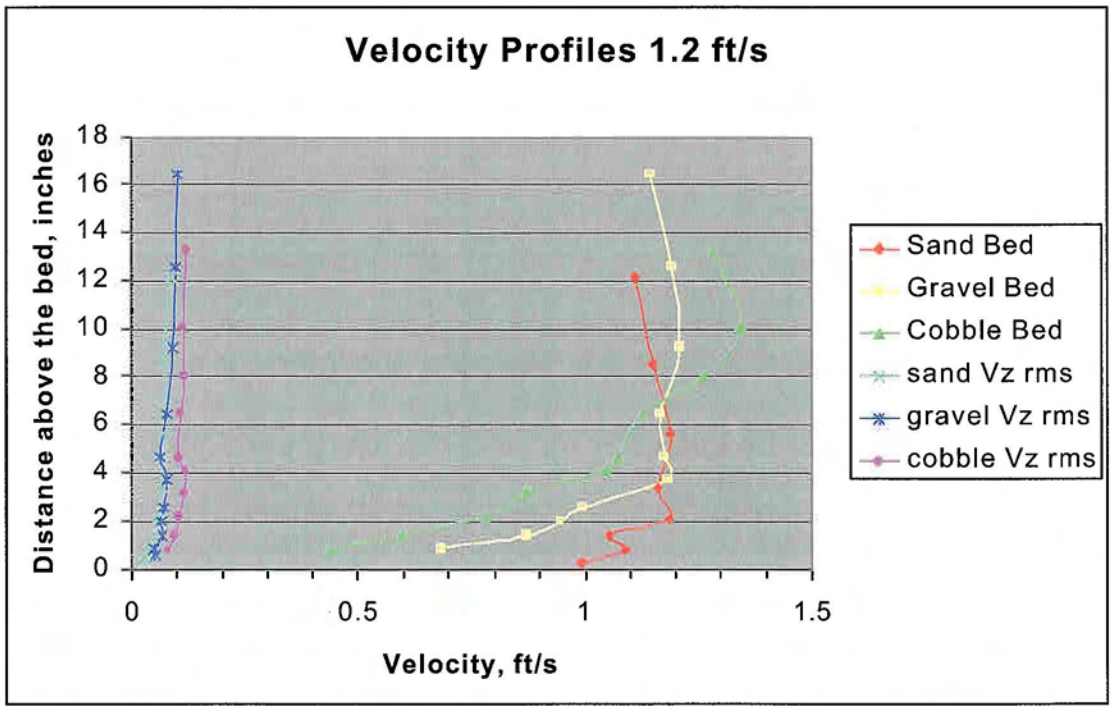


Figure 9 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 1.2 ft/s.

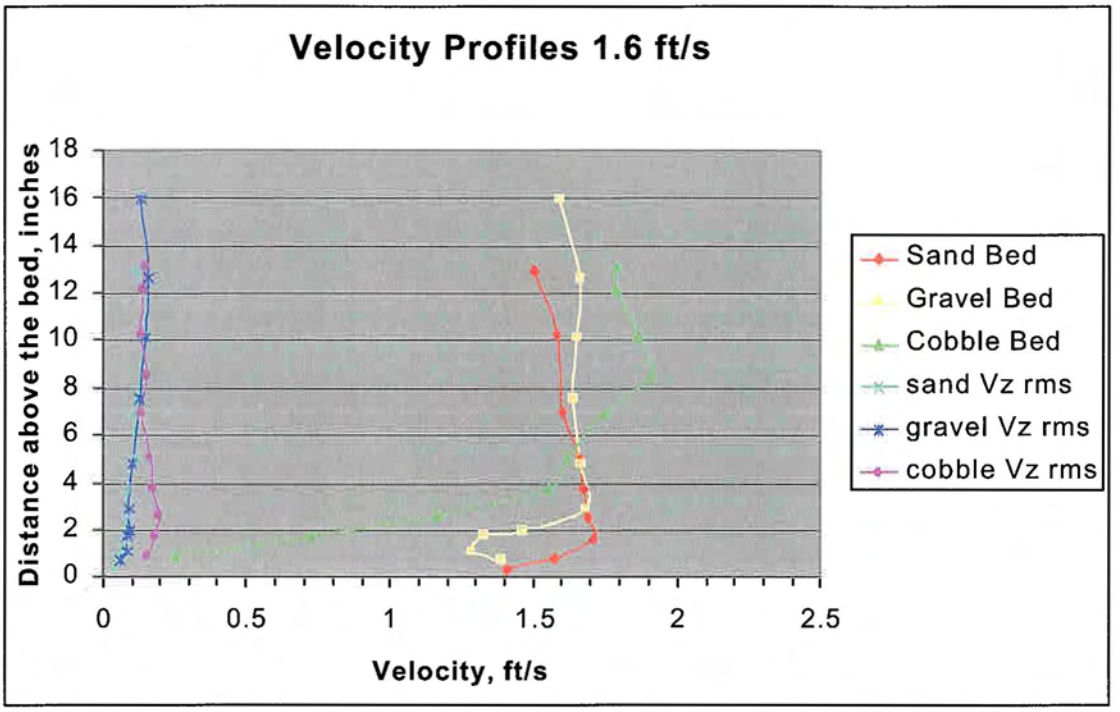


Figure 10 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 1.6 ft/s.

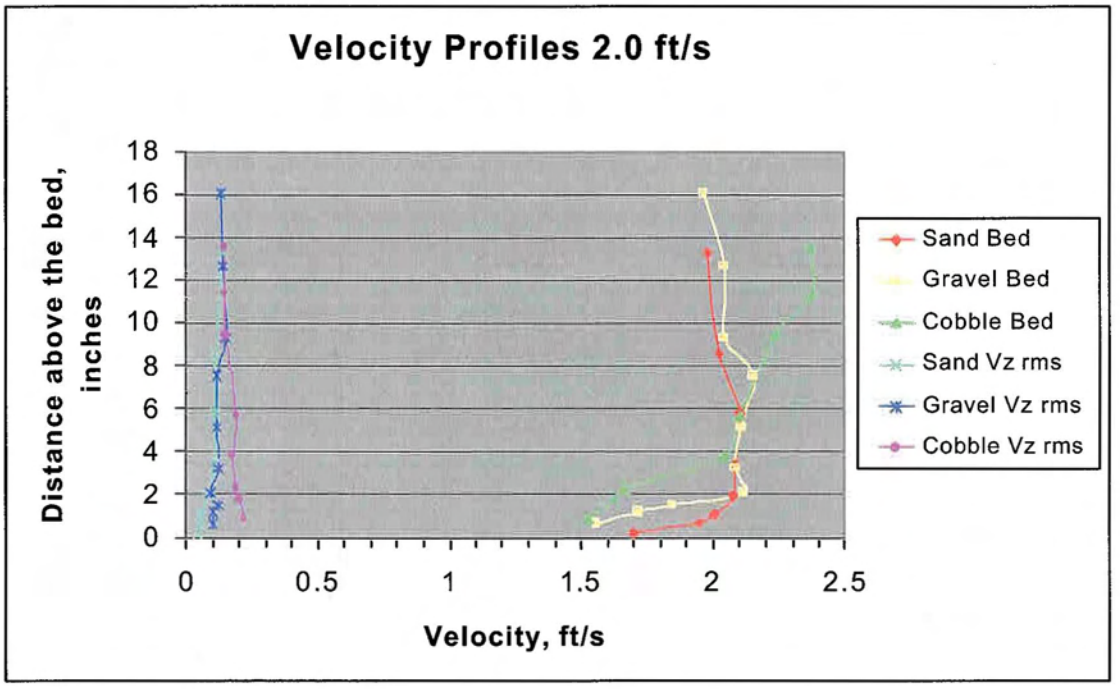


Figure 11 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 2.0 ft/s.

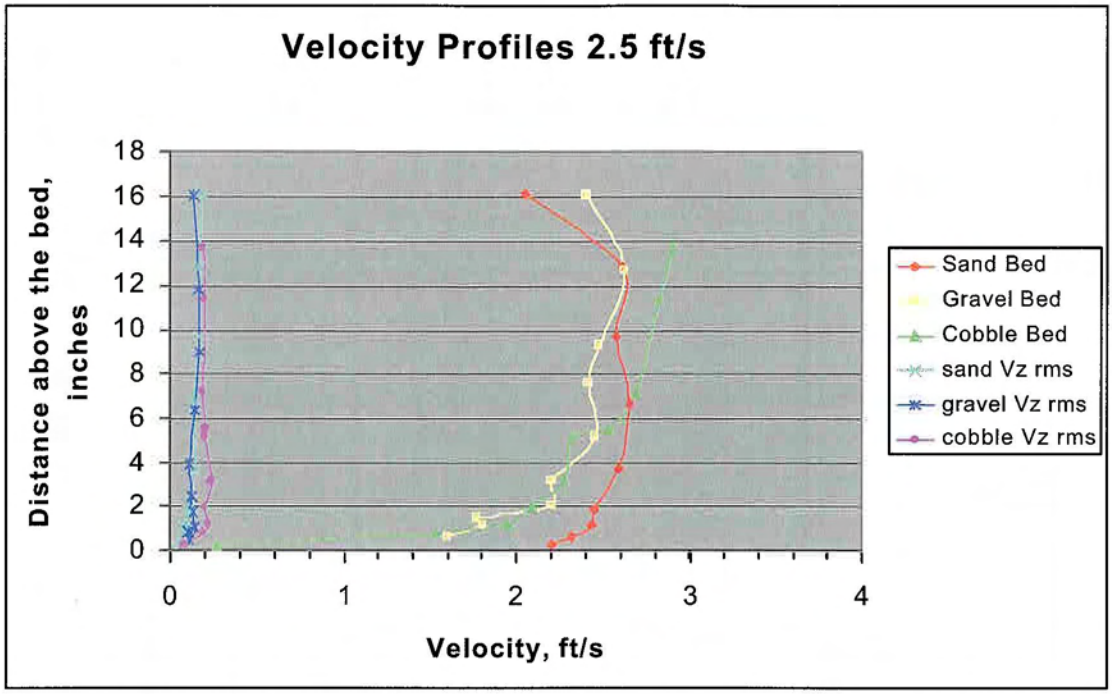


Figure 12 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 2.5 ft/s.

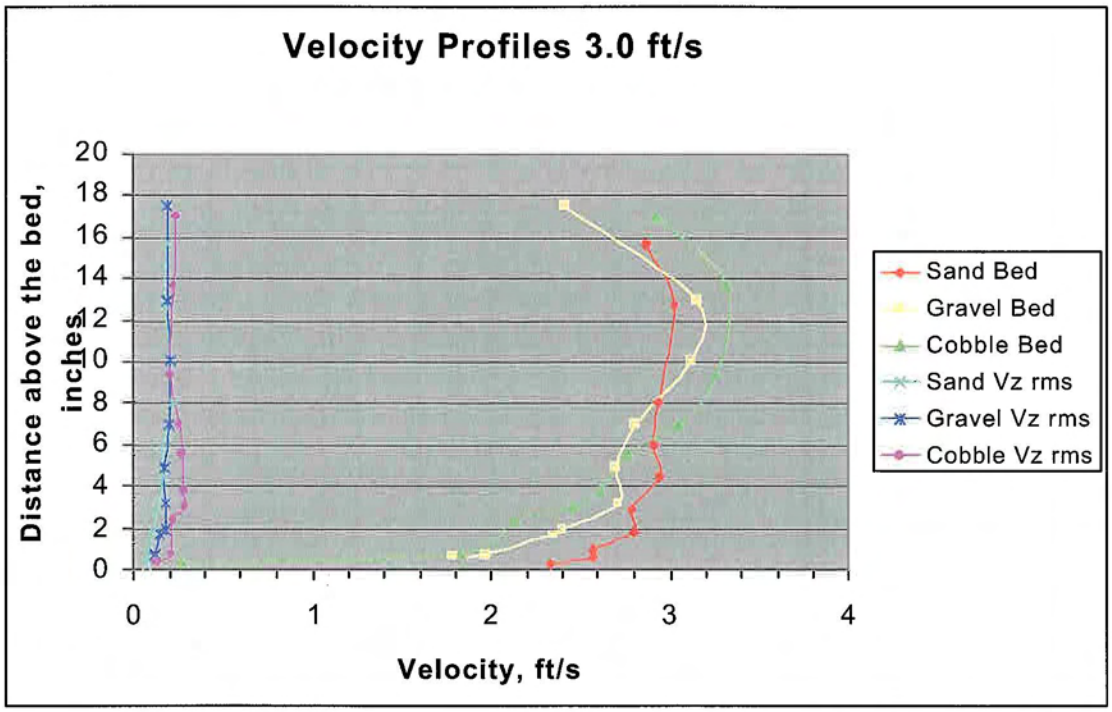


Figure 13 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 3.0 ft/s.

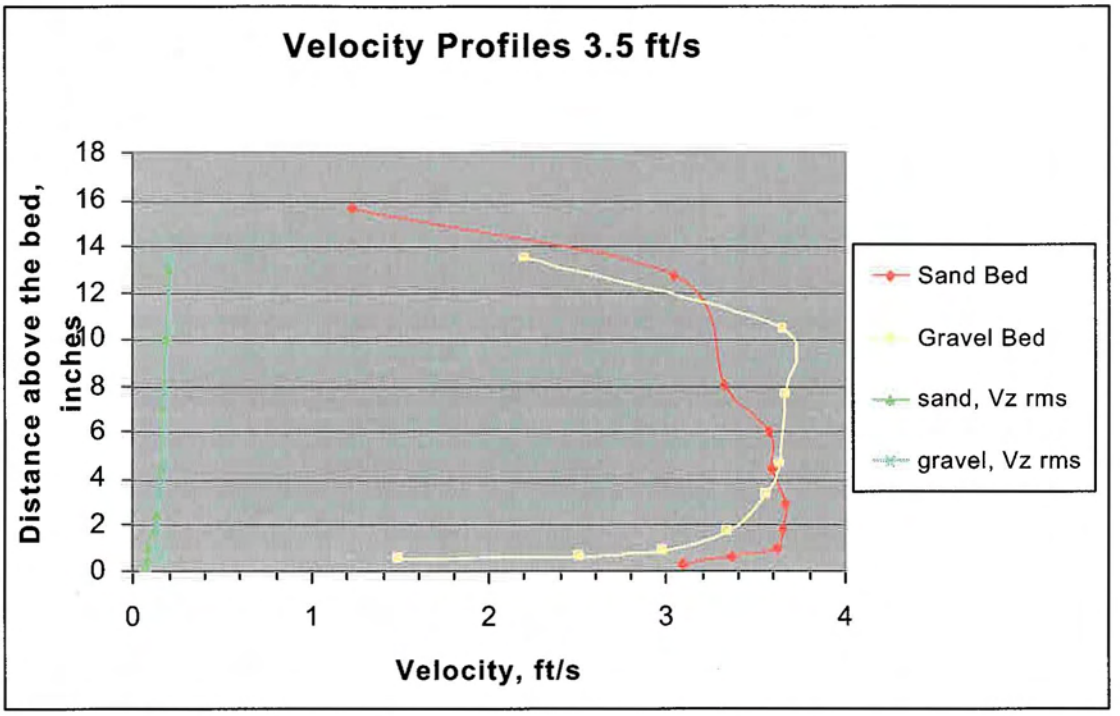


Figure 14 - Vertical velocity profiles measured over coarse sand and gravel beds for flume tests with an average flow velocity target of 3.5 ft/s.

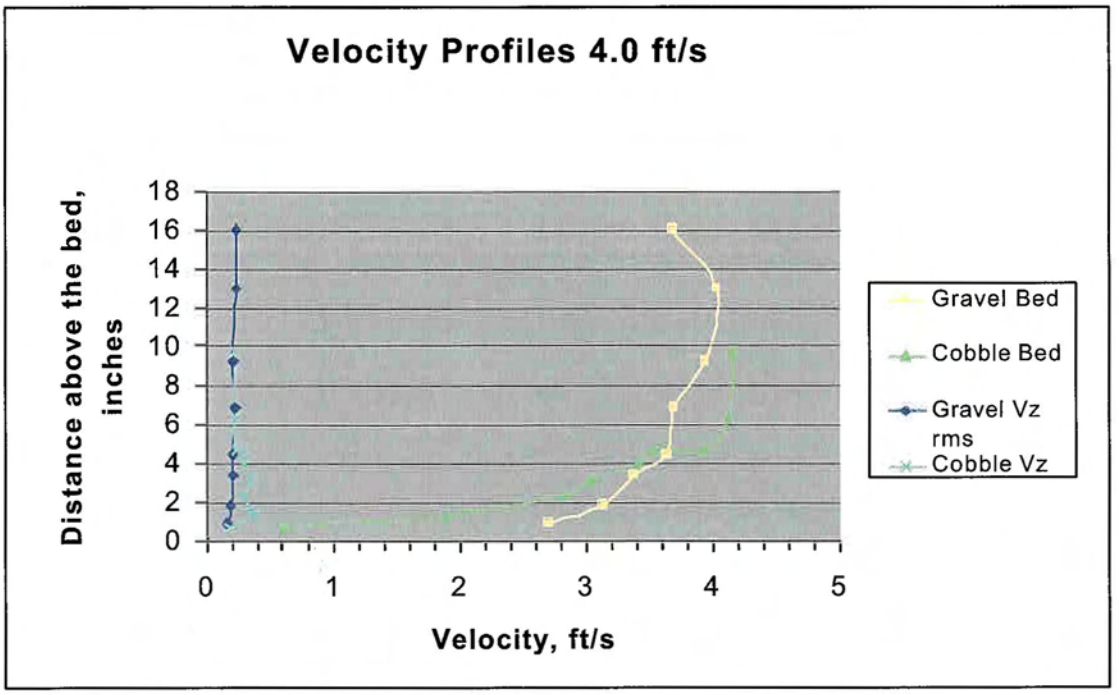


Figure 15 - Vertical velocity profiles measured over gravel and cobble beds for flume tests with an average flow velocity target of 4.0 ft/s.

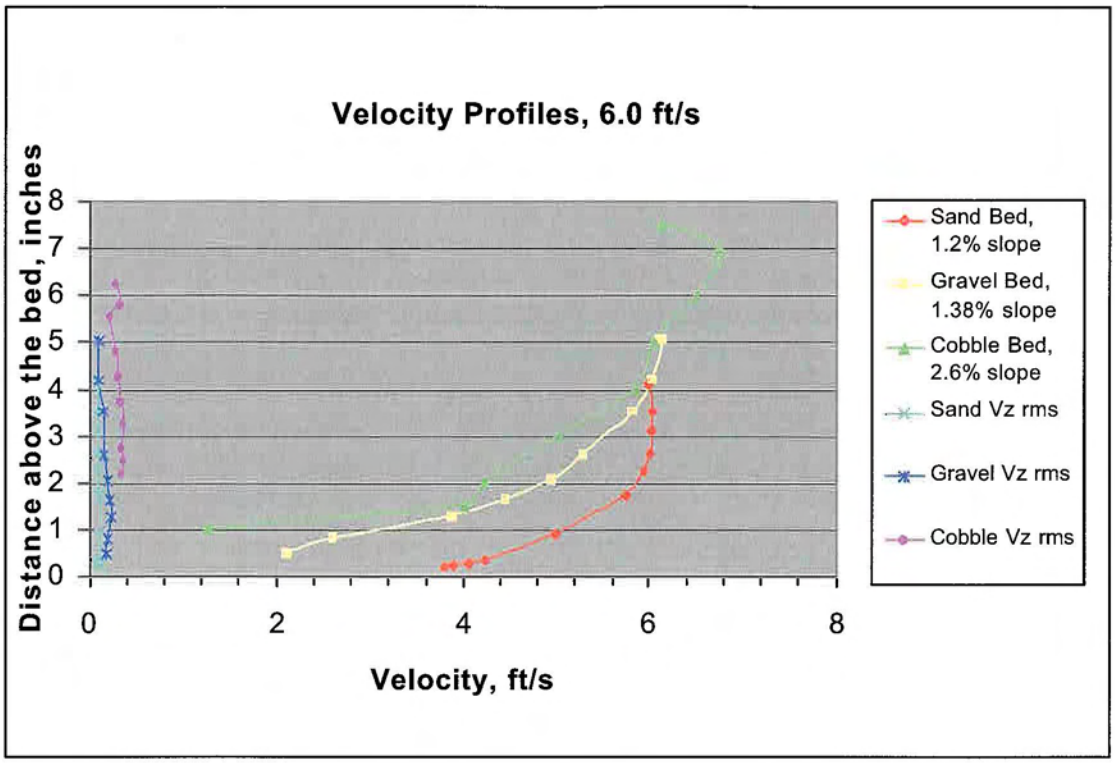


Figure 16 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with a target average flow velocity of 6.0 ft/s.

Flow Turbulence

Vertical Baffles - Large Scale Horizontal Eddies

The importance of flow direction in the horizontal plane in relation to upstream fish movement was evaluated using vertical baffles of two different widths. Baffles were placed in the flume perpendicular to the back channel wall at a 6 ft spacing (Figure 17). Flow past each baffle was similar to that found in vertical slot fishways. Flow velocity accelerates through the slot then slows again in the downstream pool. Downstream and behind each vertical baffle, flow forms a large horizontally aligned eddy.

Test Procedure - Fish disorientation in relation to horizontal eddy scale was investigated using 4 tests of 2 vertical baffle widths. Baffle widths were chosen to represent about 50 percent and 75 percent of the average fish's body length. Tests were conducted for each baffle width using a range of average velocities (through slot velocity) of 0.8 ft/s to 4.0 ft/s. For these tests, flow depth was set at 18 inches and discharge

was adjusted to achieve the target slot velocity. Test procedures were identical to those in velocity/substrate tests except fish were moved to the downstream end of the flume at the beginning of each velocity trial.

Horizontal Eddy Test Results - Fish used in the tests resulted in baffle width to mean fish length ratios, (R_h) of 0.49 and 0.71 for the 15.5 inch and 22.5 inch wide baffles, respectively. Hydraulic conditions for each test are given in Table 7. Water surface differentials presented were measured using piezometer taps located near the flume floor between each baffle. The flow pattern encountered by fish downstream of each baffle is shown in Figure 18 for the maximum slot velocity tested. The velocity vector field was mapped for a distance of twice the baffle width downstream by measuring two dimensional point velocities on a horizontal grid. All velocities were measured at mid-depth. Flow through the vertical slot drives the circulation of the horizontal eddy. Behind the vertical baffles flow moves upstream along the back wall. For each baffle width, upstream flow extended out from the wall about two-thirds of the baffle width.

In tests of both baffle widths, at velocities below 2.5 ft/s there was considerable up and down movement within the pools between baffles, often circling in the area below the first baffle. In the tests of the 15.5 inch baffle (2 series of tests, $R_h = 0.49$) 66-75% of the fish moved to the top at velocities of 2.5 ft/s and above. At these velocities, fish that had moved to the top in the previous trial resisted being moved down-channel between trials and fish that moved up did so immediately when flow was increased. Fish that passed the first slot usually continued to the top without holding. Tests of the 22.5 inch wide baffle (2 series of tests, $R_h = 0.71$), showed that fish navigated the channel successfully at low velocity (1.6 ft/s) but displayed considerable upstream disorientation at 3 ft/s and higher velocities (see Table 3). Fish often moved upstream between baffles in the upstream eddy current. The current would propel the fish suddenly upstream resulting in the fish striking the upstream baffle or turning and swimming vertical along the downstream baffle face then circling downstream.

Table 7. Test variable - Ratio of baffle width to mean fish length, (R_h).

Slot Flow Velocity Target, ft/s (Average)	Measured Flow, ft^3/s		Measured Water Surface Differential between Baffles, ft	
	15.25 inch Wide Vertical Baffle, $R_h = 0.49$	22.5 inch Wide Vertical Baffle, $R_h = 0.71$	15.25 Inch Wide Vertical Baffle, $R_h = 0.49$	22.5 inch Wide Vertical Baffle, $R_h = 0.71$
0.8	2.08	1.94	0.01	0.015
1.6	4.15	2.97	0.04	0.04
2.0	6.48	3.7	0.06	0.07
3.0	9.08	4.9	0.14	0.12
3.5	11.67	5.8	0.21	0.18
4.0	NA	6.6	NA	0.27

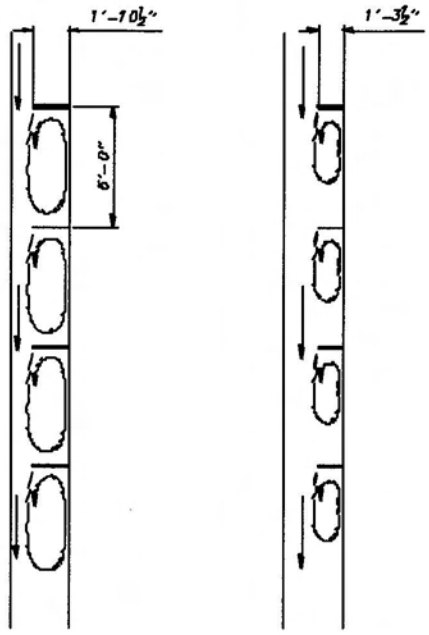


Figure 17 - Plan view of flow past vertical baffles in test flume.

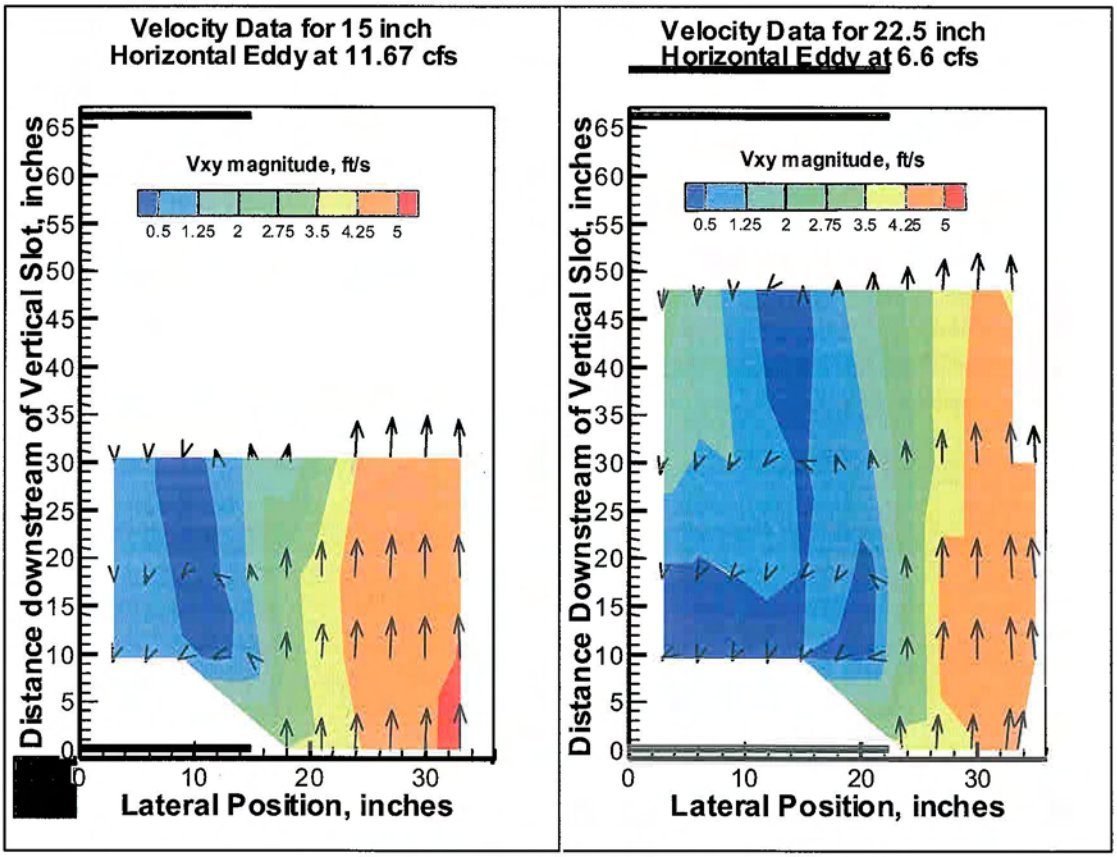


Figure 18 - Plan view of the velocity vector field measured downstream of vertical baffles.

Weir Baffles - Large Scale Vertical Eddies

The importance of flow direction in the vertical plane in relation to upstream fish movement was evaluated using baffles installed as weirs at four different heights. Baffles were mounted on the floor of the flume at a 6 ft spacing (Figure 19). Flow past each baffle was similar to that found in pool and weir fishways. Flow velocity accelerates across the weir then slows again in the downstream pool. Downstream and behind each baffle, flow forms a large vertical eddy. Flow circulates within the eddy with flow above the baffle (weir crest) moving downstream and flow behind the baffle moving upstream (Figure 20).

Figure 19 - View of 6 inch high weirs used to induce large scale vertical oriented eddies in the flow along the invert of the test flume.

Test Procedure - To evaluate the influence of large scale vertical turbulence, we examined sturgeon behavior related to 3, 6, 12, and 21 inch cross channel baffles, at eight velocities over sand substrate. The flow depth over each baffle was held constant at 18 inches. Fish used in the tests resulted in baffle height to mean fish length ratios, (R_v) of 0.09, 0.19, 0.38 and 0.67 for the 3 inch, 6 inch, 12 inch and 21 inch high baffles, respectively. Two fish were used in each of seven tests (52 trials); each velocity trial was 20 minutes duration. Sturgeon that successfully negotiated the flume (made it to the top) were moved to the bottom before the next velocity increase.

Vertical Eddy Test Results - Water surface differentials measured upstream to downstream across the baffles are given in Table 8. The flow pattern encountered by fish downstream of 3 inch, 6 inch and 12 inch baffles is shown in Figures 21 to 23 for weir velocities of 1.6 and 3.0 ft/s. The velocity vector field was mapped over a vertical plane downstream of a baffle. All velocities were measured at mid-channel. Behind the baffles flow moves upstream from the channel floor to about the height of the baffle crest.

Table 8. Test variable - Ratio of baffle height to mean fish length ratio,(R_v)

Flow Velocity Target over the Weir, ft/s (Average)	Depth Above Weir, ft	Measured Flow, ft^3/s	Measured Water Surface Differential Across Weir, ft			
			3 inch High Weir, $R_v = 0.09$	6 inch High Weir, $R_v = 0.19$	12 inch High Weir, $R_v = 0.38$	21 inch High Weir, $R_v = 0.67$
0.8	1.5	3.6	0.01	0.015	0.015	0.01
1.2	1.5	5.0	0.015	0.02	0.02	0.015
1.6	1.5	6.9	0.02	0.03	0.03	0.025
2.0	1.5	8.5	0.03	0.035	0.03	0.04
2.5	1.5	11.0	0.045	0.05	0.07	0.07
3.0	1.5	13.5	0.06	0.10	0.10	0.14
3.5	1.5	16.0	0.08	0.13	0.13	0.17
4.0	1.5	17.5	0.10	0.25	NA	NA

Fish negotiated all baffles tested, but percent success declined with baffle height (see Table 3, Weir Baffle Tests). The two fish in the 21 inch baffle test did not pass the first baffle 78% of the time; each reached the top only once (at 1.2 ft/s and 3 ft/s). Overall passage success (all baffle tests) increased with increasing velocity up to 2 ft/s, then leveled off at about 70%; if the results from the 21 inch baffle are excluded, success levels off at about 83%. For 3, 6 and 12 inches baffles, success was 75-100% at all velocities tested between 2.0 and 4 ft/s. The lowest overall success rate was 14% at 0.8 ft/s. At this velocity, 8 of 14 fish tested did not pass the first baffle. Milling behavior was common at 0.8 ft/s and 1.6 ft/s and nearly all down-channel movement was head first suggesting poor flow orientation. At 2.0 ft/s and above, most down-channel movement was tail first suggesting much stronger flow orientation. Another indication of flow attraction is how quickly fish moved to the top. Excluding the 21 inch baffle data, at velocities of 1.6, 2.0, 2.5, 3.0, 3.5, and 4 ft/s, 3 of 12 (25%), 6 of 12 (50%), 8 of 12 (67%), 8 of 11 (73%), 6 of 6 (100%), 6 of 6 (100%), respectively, moved up immediately when velocity was increased. Once a fish immediately moved to the top, it almost always moved up immediately in subsequent velocities tested. No fish in the 21 inch baffle tests moved up immediately, as well as two fish in the 12 inch baffle test. These two fish were impinged and removed during the 3.0 ft/s test.

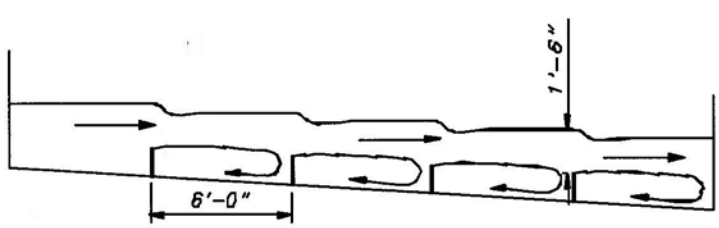


Figure 20 - Elevation view of flow over weir baffles in the test flume.

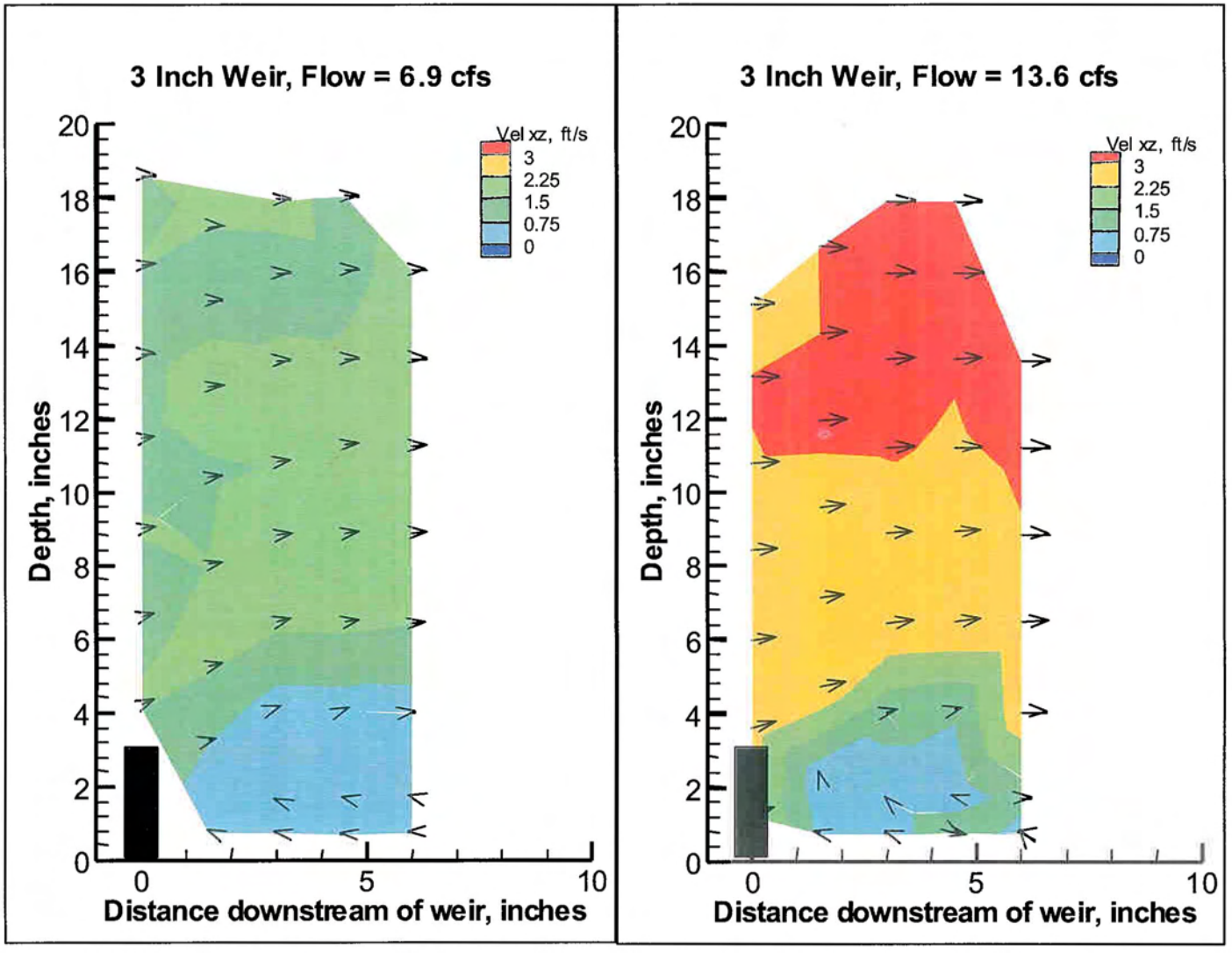


Figure 21 - Elevation view of measured velocity vector field downstream of 3 inch high weir baffles.

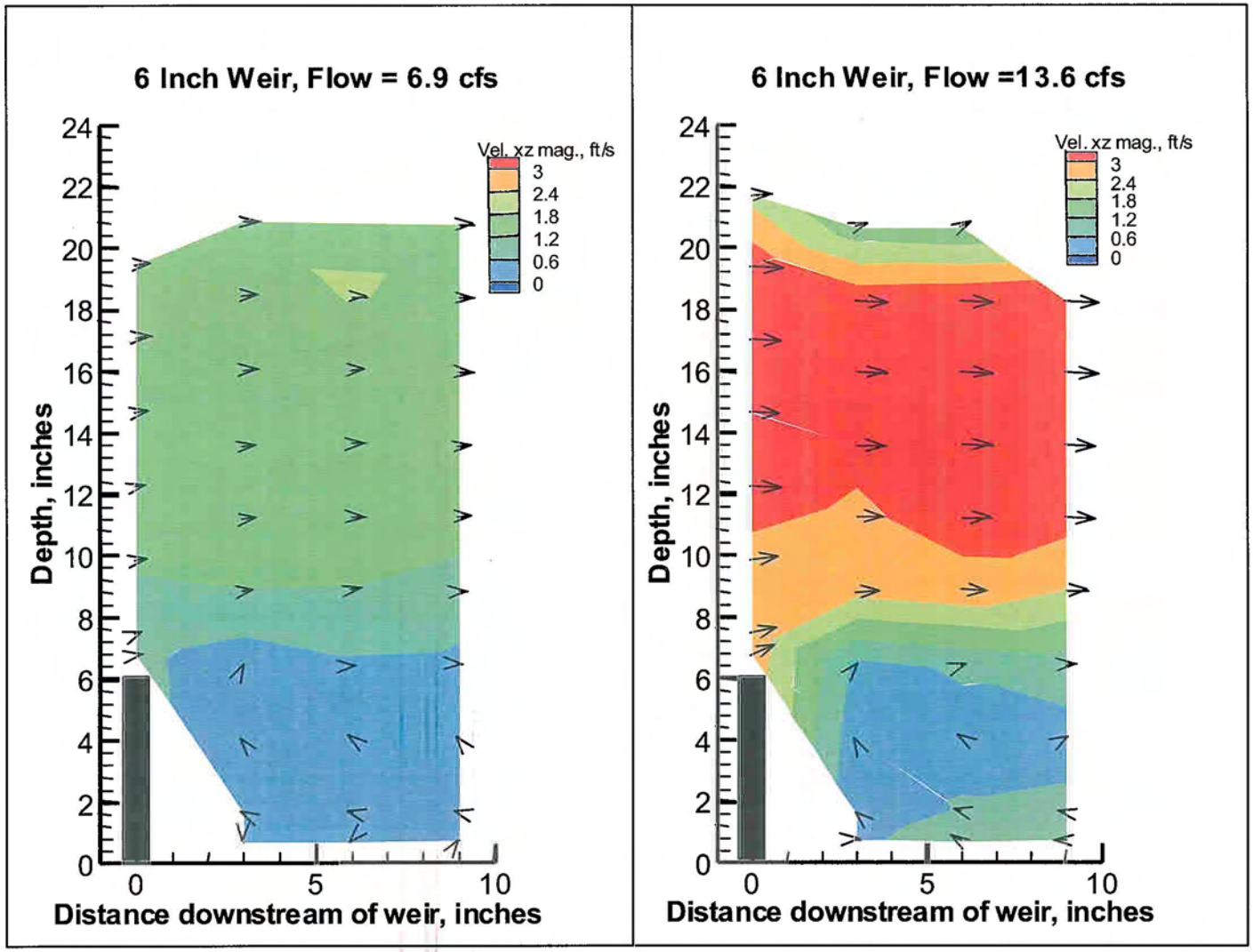


Figure 22 - Elevation view of measured velocity vector field downstream of 6 inch high weir baffles.

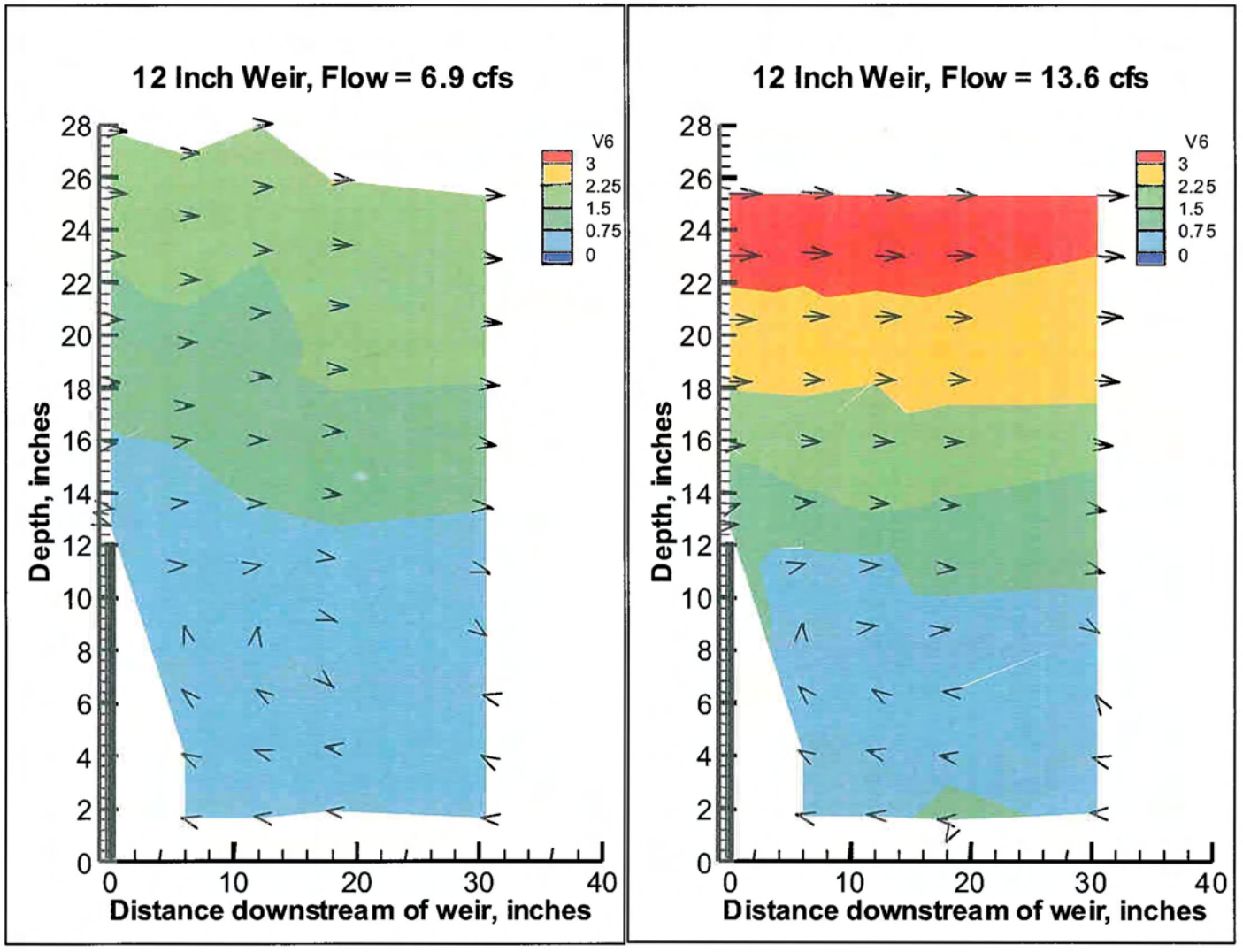


Figure 23 - Elevation view of measured velocity vector field downstream of 12 inch high weir baffles.

Fishway Studies

The U.S. Bureau of Reclamation, Water Resources Research Laboratory, maintains three prototype scale test fishways for evaluating passage of non-salmonids native to the western United States. During the sturgeon study these fishways were used to observe sturgeon passage and behavior in response to fishway flow conditions of different fishway geometries. All fishway tests were conducted at similar flow depths and passage velocities.

Test Apparatus

Two of the fishways are used for testing different baffle designs for flume type fishways. For the sturgeon studies, two different forms of vertical slot fishway baffles were tested in the flumes. The flumes are 5.5 ft wide by 5.5 ft deep by 30 ft long with a 5 % bottom slope. A standard vertical slot baffle design (FWS, 1997) was placed in one fishway and a Reclamation designed chevron shaded duel-vertical-slot baffle was tested in the second. Vertical slot baffle is a generic term that refers to a flow baffle that has full depth openings (slots) that allow fish passage at any depth. Different vertical slot baffle designs create different flow patterns within the pools between baffles. The vertical slot baffle designs tested are shown in Figures 24 and 25. In the laboratory tests, all baffles were spaced 6 ft apart.

The third fishway is a 70 ft long section of a rock lined bypass channel with boulder weirs (Figure 26). The fishway is designed to test fish passage through a rock fishway with different configurations of rock baffles. The fishway is a trapezoidal channel at a 2.0% slope with a 4 ft wide bottom, 2:1 side slopes 4 ft deep. The channel is constructed of riprap with a gradation of 15 percent (D_{15}) smaller than 5 inches and 85 percent (D_{85}) smaller than 15 inches. Two foot to 3.5 ft diameter boulders are placed in the flow to form control sections. Boulders are placed with a 2 ft wide space between boulders in a upstream pointing chevron pattern. The boulder pattern is designed to create a flow pattern of highest velocity in the center of the channel and lowest velocities along the banks, giving fish a choice of flow conditions. In the model, artificial boulders are use to facilitate placement. The model boulders are constructed of concrete mortar placed over wire lath.

Test Procedure

All fishway tests were conducted with the second group of fish which were collected from the Yellowstone River on October 16, 2001. In general, these fish were less motivated to move than the group of fish collected in July. Fish were handled as in other tests. Fish were released at the bottom of the fishway and movement behavior recorded. Fish behavior at two velocities (2.5 - 4.0 ft/s) and associated differentials across slots (0.12- 0.35 ft) was evaluated in each test. Velocity was altered by manipulating tail boards.

View of standard vertical slot baffle fishway looking downstream.

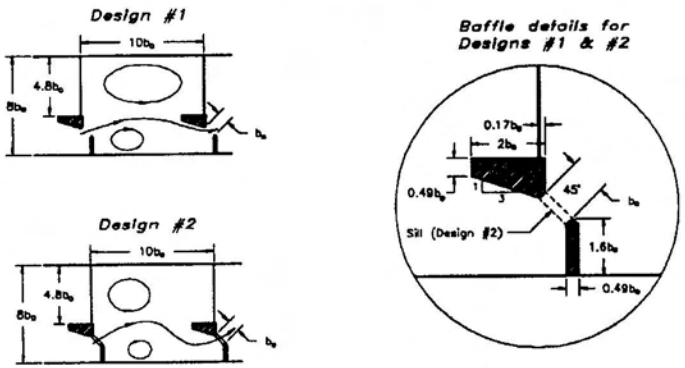


Figure 24 - Standard vertical slot fishway baffle design, FWS, 1997.

View of chevron shaped duel-vertical slot baffle fishway looking downstream.

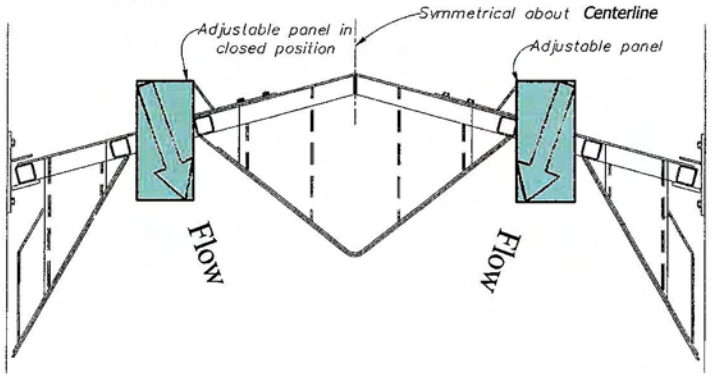


Figure 25 - Reclamation chevron shaped duel-vertical slot baffle design.

Fishway Test Results

Standard Vertical Slot Fishway - Only two of eight fish tested (four tests) in the standard vertical slot fishway were successful in passing all four slots (Table 9). One passed when slot velocity was 2.99 ft/s with a differential water surface between pools of 0.26 ft and the other when slot velocity was 3.8 ft/s with a differential of 0.31ft. In general, as velocity was increased, fish activity increased. At the lowest velocities tested, all fish typically circled both counterclockwise and clockwise. At higher velocities, most movement was counterclockwise. When stationary, fish were typically located at the bottom net on the slot side with the tail in the corner and the body at a 45 degree angle or holding parallel to the slot wall with the tail near the slot opening. One fish passed all four slots in 4 minutes once passage was initiated. This fish stayed mostly on the slot side and out of the eddy. The second successful fish took 30 minutes to pass all four slots once passage began. Passage began soon after slot velocity was increased to 3.8 ft/s (differential 0.31 ft). The fish passed the first two slots in succession, then circled in the eddy and held with the body about 3/4 through slot 2. Then moved up and held parallel to slot 3 wall facing away from the slot. Movement through slots 3 and 4 was not observed but occurred in less than 5 minutes.

Table 9. Evaluation of passage success of eight shovelnose sturgeon in the standard vertical slot fishway.

Date	Flow (ft^3/s)	Velocity (ft/s) (Measured point velocity in slot)	Average Differential, (ft)	Fork length, (in)	Passage Time, Minutes (after passing first baffle)
10/29/01	3.43	---	0.20	31.5	---
				35.5	---
		2.99	0.26	31.5	4
				35.5	---
		3.9	0.33	31.5	---
				35.5	---
	3.31	2.6	0.15	31.0	---
				28.5	---
		3.3	0.24	31.0	---
				28.5	---
		3.8	0.31	31.0	30
				28.5	---
	3.32	2.5	0.12	30.0	---
				33.5	---
		3.7	0.24	30.0	---
				33.5	---
11/05/01	3.37	---	0.14	31.5	---
				33.0	---
		---	0.26	31.5	---
				33.0	---
		---	0.31	31.5	---
				33.0	---

Duel Slot Fishway - The duel vertical slot fishway baffle was developed to minimize large scale eddies within a fishway and maximize the cross sectional area of downstream flow. The objective was to improve streamwise fish orientation within the fishway. Flow through the duel slot baffle forms slender eddies (horizontal) along the flume walls bracketing a wide center area of downstream flow. We conducted five tests of the duel slot fishway. Although fish were more motivated to move in this fishway compared to the standard slot fishway, only 2 of the 10 sturgeon tested successfully negotiated the 4 sets of duel slots. One reached the top in 16 minutes and the other in 53 minutes (Table 10). Four others moved past the first duel slot (two up to slot 2, one up to slot 3 and one to slot 4). Fish tended to be bounced around quite a lot below the first set of slots. When fish were stationary, they generally held in the middle of the channel between the slots, facing into the flow. Four of the 10 fish either did not move or moved very little. Others showed considerable up and down channel movement and circling clockwise between sets of slots. Down channel movement was mostly tail first, but not always.

Table 10. Evaluation of passage success of 10 shovelnose sturgeon in the duel slot fishway.

Date	Flow (ft^3/s)	Velocity (ft/s)	Differential (ft)	Fork Length (inches)	Minutes (after passing first baffle)
10/30/01	5.75			29.5	---
				33.0	---
	5.75			30.5	---active below 3
				31.5	---active below 4
	5.75			31.5	---
				35.5	53
11/02/01	6.25	2.8	0.13	31.5	---
		2.8	0.14	30.0	---
11/05/02	6.0	2.8	0.13	30.5	16
		2.9	0.14	28.5	Active below 2
		3.5	.18		

Rock Fishway - We conducted 12 tests of the rock fishway. Hydraulic conditions within the fishway were similar for all tests. Fishway flow depth was varied during some tests to improve observation of fish from the surface. Of the three fishways tested, passage success was much superior in this fishway. Fifteen of the 24 fish tested (62.5%) successfully negotiated the fishway (Table 11). Passage time ranged from 14 to 83 minutes (mean 38.9 minutes). Motivated fish had no difficulty negotiating the rock fishway. Movement was usually up channel and movement pattern was very consistent. Fish typically moved up the left side of the channel into the turbulence, then moved across the channel and held briefly. This position was very consistent, with nearly all fish holding in the same area. The fish would then move up into the turbulence in the middle of the channel, then gradually move over below boulders 1 and 2 (right) and pass through the gap between these boulders, holding just above them, often with the tail just above or in the gap. The velocity in the gap was 4 ft/s. The pattern of passage through each boulder group was very predictable and consistent. Fish appeared to search for the best hydraulic conditions available for passage. Only two fish that passed the first boulder group did not pass the other two. Seven fish were not motivated to move and remained near the bottom net throughout the tests.

Figure 26 - View looking downstream at rock lined fishway channel with boulder weirs.

Table 11. Evaluation of passage success of 24 shovelnose sturgeon in the rock fishway.

Date	Flow (ft^3/s)	Velocity (ft/s) (flow velocity between boulders)	Differential (pool to pool) ft	Fork length inches	Minutes
10/29/01	16.0	---	---	31.5	70
				29.5	---
	16.0	---	---	31.0	18
				30.5	25
	16.0	---	---	28.5	14
				30.5	---
11/01/01	14.6	3.3 - 4.4	2.2	32.5	83
				30.0	50
	14.6	3.3 - 4.4	2.3	30.0	---
				28.5	---
	13.0	---	---	29.5	33
				34.5	69
	14.0	---	---	30.0	---
				31.5	---
11/02/01	14.1	3.7 - 4.2	.19	31.5	15
				28.5	23
	14.1	3.5 - 4	.17	31.5	45
				30.0	48
	14.1	3.7 - 4.2	.19	31.0	31
				28.5	---
	14.1	3.5 - 4.1	.19	30.0	---
				32.5	---
	14.0	---		35.5	30
				31.0	30

Summary/Discussion

Fifty three tests and 204 trials (Table 12) to evaluate the behavioral response of adult shovelnose sturgeon to velocity, substrate, horizontal turbulence, vertical turbulence, and three prototype fishways were conducted during the study for a total of approximately 71 hours of observations. Test fish were obtained from the Yellowstone River, Montana in July and October 2001. Fork length ranged from 25.2 to 35.5 inches and weight ranged from 3.1 to 10.6 pounds. Tests were conducted July 24-31 (30 ft flume), August 1-3 (Adjustable slope, sand and gravel bed), August 27-31 (horizontal and vertical baffles), September 25-29 (adjustable slope, cobble bed); and Oct. 29 -Nov. 7 in the three fishway models.

Test fish were very docile and showed no apparent response to observers, simplifying experimental concerns. The only observable stress experienced by test fish occurred when a fish either got tangled in the up- or down-channel netting by its scutes or when it collided with a baffle. In both cases, fish would return to or stay at the bottom of the channel and remain there for the remainder of the test. Forceful collisions with baffles were not uncommon and these, as well as apparent lack of response to light suggest that eye sight is of little important in sturgeon navigation. Preliminary tests holding velocity constant and varying depth revealed that velocity, rather than depth was important in attraction and orientation so depth was eliminated as a test variable.

Sturgeon successfully negotiated the range of average velocities tested (0.8-6.0) over all substrates (smooth, fine sand, coarse sand, gravel and cobble) evaluated. As substrate grain size increased, movement success declined, but relatively small sample size and large variability precluded definitive conclusions. However, general trends were similar in both the 30 foot flume and the adjustable slope flume, with poorest movement success over cobble.

Pattern of successful movement related to velocity was consistent among substrates and among all test conditions. Flow orientation and attraction became strong at about 2 ft/s and remained strong at higher velocities tested. At velocities of 0.8 and 1.6 ft/s, fish showed poor orientation to flow as indicated by milling behavior, downstream head first movements and longest average time to reach the top of the channel. At velocities of 2 - 6 ft/s, strong flow orientation was apparent and down-channel movement was nearly always tail first. Average percent success in negotiating the channel at the highest velocities tested dropped from 81-87% at 4 ft/s, to 47% at 6 ft/s. Although adult shovelnose sturgeon could successfully move through and hold in high velocities, they did not hold long and would not be expected to maintain position at these velocities for extended periods.

Although sturgeon were able to negotiate horizontal and vertical eddies tested, larger eddies tended to cause delays. Generally, as eddy size increased, success in passage decreased. This pattern was also seen in the standard vertical slot and the duel slot prototype fishways. Velocity orientation in horizontal and vertical eddy tests was similar to other tests. At velocities below 2 or 2.5 ft/s, orientation was poor and fish tended to be less flow oriented. At higher velocities, undirected movement declined.

All prototype fishway tests were conducted using shovelnose sturgeon collected in October 2001. These fish appeared to be less motivated to move. However, fishway tests were instructive. Some shovelnose sturgeon successfully maneuvered all three fishways tested. In both the vertical slot and duel slot fishways, fish appeared disoriented and passage success was poor. In the rock fishway, passage success was much improved, with 62.5% of the 24 fish tested reaching the top. In an effort to determine if poor success in the other fishways was due to using fish not motivated to move, we tested two fish in both fishways that had successfully negotiated the rock fishway. Only one of these four fish negotiated the fishway (duel slot).

Fishway Design Recommendations

Fishway Attraction Flow

Fishway attraction velocity should be between 2 to 4 ft/s. Ideally, these velocities should be sustained to the thalweg of the river. In the study, flow depth was not found to alter shovelnose sturgeon behavior in the range tested (0.7 ft to 4.5 ft). However, there are many attraction and predator avoidance benefits to having flow depths of about 4 ft or more when flow does not limit fishway operation. The studies of large scale eddies show attraction flow should provide a uniform transition between the fishway and the downstream river flow. Large eddies created by structures in the flow or poor alignment of merging flows may mask the fishway attraction flow.

Fishway Passage Velocity

The shovelnose sturgeon showed strong upstream movement at flow velocities of between 3.0 to 4.0 ft/s. In this velocity range, many test fish were able to actively swim for periods of 10 minutes or more. We recommend maximum fish passage velocities for design conditions be in the range of 3.0 to 4.0 ft/s.

Fishway Type

Based on our tests, we recommend a natural channel or rock channel fishway design for passage of sturgeon at Intake Diversion. In addition to positive results with sturgeon, this fishway provides a diversity of velocities and would better accommodate other fish species using the pass. Due to the significant river ice that forms near the dam, alternative construction techniques to riprap should be considered such as fabricated cable tied mats. These types of lining materials may provide cost effective low maintenance alternatives to a riprap lined fishway structure.

Table 12. Summary of tests conditions evaluated, number of sturgeon tested, number of tests conducted, and number of trials completed. (Each test used 2 fish and consisted of up to eight trials (velocities)).

Experimental condition	# Fish	# Tests	# Trials
30 foot flume			
Sand	4	2	14
Gravel	4	2	16
Cobble	4	2	16
Adjustable slope flume			
Smooth	10	5	22
Coarse gravel	6	3	12
Gravel	6	3	12
Cobble	8	4	15
Vertical baffles			
15.5 inch	4	2	11
22.5 inch	4	2	6
Horizontal baffles			
3 inch	4	2	14
6 inch	4	2	16
12 inch	4	2	14
21 inch	2	1	8
Vertical slot fishway	8	4	11
Duel slot fishway	10	5	5
Rock fishway	24	12	12
TOTAL	106	53	204

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APPENDIX B

Preliminary Comparison of Pallid and Shovelnose Sturgeon for Swimming Ability and Use of Fish Passage Structures

FINAL REPORT

TO

U. S. Army Corps of Engineers
Omaha District
Omaha, NE

PRELIMINARY COMPARISON OF PALLID AND SHOVELNOSE STURGEON FOR SWIMMING ABILITY AND USE OF FISH PASSAGE STRUCTURE

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PI - BOYD KYNARD
STAFF - DON PUGH, ERIKA HENYEY & TIM PARKER

S.O. CONTE ANADROMOUS FISH RESEARCH CENTER
U. S. GEOLOGICAL SURVEY
BIOLOGICAL RESOURCES DIVISION
ONE MIGRATORY WAY
TURNERS FALLS, MA 01376

BACKGROUND

This project gathered information in an experimental flume on the swimming ability and behavior of pallid sturgeon S*caphirhynchus albus* and shovelnose sturgeon *S. platorynchus* in two different water flow regimes: laminar and turbulent flows. Previous studies of pallid and shovelnose sturgeon in swimming tunnels found they had a weak swimming ability (Adams et al. 1997, Adams et al. 1999). Also, pallid sturgeon are believed to be poor swimmers in highly turbulent water (Bramblett 1996; S. Krentz personal communication). Swimming of shovelnose sturgeon is likely similar to pallid sturgeon, but differences in swimming ability (or swimming motivation) between closely related *Acipenser spp.* occur (B. Kynard unpublished data). Life history of both species indicates they likely move long distances, and thus in natural rivers, must pass fast flowing riffle reaches. Fish with this life history must be able to negotiate fast turbulent flows. Further, pallid sturgeon eat fish and must swim well enough to catch prey.

The difficulty that fish have swimming upstream through natural channels or fishways depends on their swimming ability and behavioral response to the structural configuration and flow conditions (Kynard 1993; Clay 1995). Thus, if swimming of fish is being studied for development of fish passage, it is important to study both swimming ability and behavior of fish. This is best done in experimental flumes or in fishways.

Stamina studies of swimming fish in swim tunnels reflect only the basic physiological stamina of a fish swimming in the water column, not their actual ability to move upstream in the complex flows of natural streams or technical fish ladders. The discrepancy between performance observed in a swim tunnel and flumes or natural channels should be greatest with bottom species, like pallid sturgeon, that are prevented in swim tunnels from using all their behavioral and morphological swimming adaptations. Thus, results of swimming stamina studies of pallid sturgeon may not provide appropriate information on their swimming ability that is needed to design fishways. This situation was found during design of fish ladders for Australian fishes (Malin-Cooper 1992). For sturgeons and perhaps for all fish, the best information on swimming for use in designing upstream fishways (technical or semi-natural) will likely result from free-swimming fish in flumes equipped with natural or fishway structures that provide complex velocity situations and turbulence, as occurs in rivers.

Our objective was to determine the swimming ability and behavior of pallid and shovelnose sturgeon in two types of flow environments: a laminar flow and a complex turbulent flow created by passage structure. We documented the success and behavior of fish moving upstream in both reaches. We also observed how sturgeon moved downstream past structure in fast turbulent flow. This information is useful when designing passage environments and understanding the potential sources of damage to sturgeon that move downstream in a fish ladder. We were also interested in identifying the passage routes that sturgeon use in complex currents.

METHODS

We tested 22 pallid sturgeon and 3 shovelnose sturgeon for swimming performance in laminar flow and for the ability to move upstream in complex currents. Because of the few

shovelnose sturgeon available, most testing focused on characterization of pallid sturgeon. Pallid sturgeon were 4-year-old fish (Missouri River stock) that were obtained as 3-month-old fingerlings from the Gavins Point National Fish Hatchery (USFWS), Yankton, SD in September 1997. Shovelnose sturgeon were 3-year-old (Yellowstone River stock) that were obtained as fertilized eggs from the Bozeman Fish Technology Center, Bozeman, MT in June 1998. We reared all test fish at the Conte Anadromous Fish Research Center (USGS, BRD), Turners Falls, MA on ambient Connecticut River water and a natural photoperiod for that geographic location.

Test pallid sturgeon (n=22) had a mean fork length of 45.6 cm (range, 35.0 – 52.5 cm) and a mean weight of 308.0 g (range, 130.0 – 500.0 g). Shovelnose sturgeon (n=3) had a mean fork length of 39.2 cm (range, 33.5 – 46.1 cm) and a mean weight of 200.0 g (range, 100.0 – 320.0 g; Table 1). Thus, pallid sturgeon were larger than shovelnose sturgeon, but several pallid sturgeon were small, like shovelnose sturgeon.

The test flume was 4.26 m in diameter with a circular wall in the middle that created a 0.50 m wide channel for testing fish (Fig. 1). The floor of the experimental flume had a 6 % (1:16.5) slope. Water was supplied to the experimental tank from the Connecticut River at ambient temperature. A large motor and pump withdrew water (5 cfs) from the center drain of the tank and pumped it into the head of the experimental flume. An adjustable weir at the head of the flume controlled the amount of water flow that passed down the test flume (Fig.1). The most downstream 6.65 m long section of the flume was the experimental section. Fish were kept within this section with plastic mesh barriers at the up- and downstream ends and were not allowed to swim all the way around the tank. The downstream 3.45 m of the flume was divided longitudinally to create a narrow 0.28 m wide channel with laminar flow. The upstream 2.96 meters of the flume contained three side baffles, 0.99 m apart and alternated on the inside and outside walls of the channel (Fig. 1). The bottom of the test flume had small baffles (5 cm high x 5 cm wide, spaced 15 cm apart on center) at a right angle to flow to create uniform bottom roughness. We used a Marsh-McBirney 2-Dimension probe of 2.54 mm diameter (model 523 M) to make all hydraulic measurements. A 60-sec logging period was used during each hydraulic measurement of current velocity and vector (direction).

Test fish had been reared in a circular tank and had no prior experience with turbulence or fast velocity. To give fish some experience with complex flows and structure, two weeks prior to testing, all were held in a common tank with faster than normal velocities and several bottom structures.

We monitored fish movement up and down the flume with a TIRIS PIT tag and antenna-detector system (Fig.1). TIRIS antenna 1 was placed 0.92 m from the downstream fish barrier to monitor fish presence in the introduction area. Antenna 2 was 0.53 m downstream of the upstream end of the divider that created the narrow laminar channel. It monitored fish presence at the upstream end of the laminar reach. Antenna 3 was 0.30 m upstream of side baffle C. It monitored fish presence at the end of the baffle reach. TIRIS antennae were small coils of wire located on the bottom between two bottom baffles and did not affect water flow or fish behavior.

In the short 30-cm long reach downstream of baffle A, we video recorded each fish's movements as they approached and passed the baffle going up- and downstream. The transect

across the slot entrance was designated transect C, the next downstream bottom baffle as transect B, and the next bottom baffle as transect A Fig. 1). A camera suspended over the flume recorded an overhead view of fish and was used to determine the number of tailbeats/s and swim speed (number of body lengths per second = L/s). A second camera viewed fish from the side through a clear panel on the inside wall of the flume and showed the distance that fish swam above the bottom. The formula used to calculate L/s was [distance traveled (cm) / time (s)] + current velocity (cm/s) / fish length (cm fork length). We used fork length, not total length, because the tail beyond the fork length contributed little to thrust during swimming and yet, could be several cm long. We also used video recordings to determine the behavior of fish as they approached the fast water in the baffle slot, the spatial route used to pass the slot, and the route relative to current velocity and vector. Ribbon tail-tells to show current direction were spaced 10 cm apart along the top of A, B, and C bottom baffles (each 15 cm apart on center). To mark swimming distance and route of fish we used each ribbon location as a station on the transect to record fish crossing and water velocity and vector. To show the route of fish, we recorded each station where the pointed snout of fish crossed the transect line or crossed over ribbon locations. Previously, Webb (1986) used video recording of lake sturgeon movements to determine swimming performance in a small flume.

All tests were conducted during the day and fish were not fed within 24 hours of testing, similar to methods of Farlinger and Bemish (1977) and Webb (1986). The flume was inside a weakly lighted building. Prior to testing, each fish was immobilized using electrical narcosis (constant current of 30 VDC total impressed voltage or about 0.7V/cm fish fork length. This procedure is similar to chemical anesthetics, only faster, cheaper, with quick recovery and less deleterious effects on fish (Kynard and Lonsdale 1975, Henyey et al. 2002). We attached a TIRIS PIT tag with a fish hook to the side of an immobilized fish above and behind the right pectoral fin. The tag was oriented vertically to the body axis. Tagging took less than 1 min and fish recovered quickly, as indicated by their rapid return to an upright position and escape response. Fish recovered from immobilization and tagging for 5 min before being placed in the test flume. The tag and hook combination weighed 0.96 g, less than 1% of the smallest fish (100 g) body weight. The tagging procedure and tag weight did not appear to interfere with fish swimming or behavior.

After test fish were removed from the flume at the completion of tests, we immobilized them as described previously, removed the tag, measured and weighed each fish, and returned them to a common holding tank. Additionally, all fish had been individually marked with a long-term mark (non-toxic acrylic paint) in their fins; thus, we were able to ensure that each fish carried the same TIRIS tag when it was tested individually and later, as one member of a group.

Fish were initially tested individually and later in groups of three. In the first set of tests, single fish were tested for 6-8 hours or until they passed upstream of baffle C. In a second set of tests, the same fish were tested in groups of three, some for 6 hours, others for 2 hours (Table 2). Most long trials began in the morning about 0800-1000 hours. During the 2-hour trials of fish groups, the first trial was done in the morning and the second was done in the afternoon. Tank water was changed between morning and afternoon trials so that all trials began at ambient temperature. We did not observe any obvious effect of time-of-day on performance of fish.

We provided motivation to most fish to get them to move from the introduction area. This is not surprising because fish had spent their entire life in circular rearing tanks. After about 1 hour during long trials and 30 min during short trials, we motivated fish in the introduction area by making the near-field environment undesirably noisy (rapping on the side of the tank or on the bottom near the fish) and, if this did not produce movement, by probing the fish's caudal peduncle with a dowel. Similar motivation to swim was provided by other researchers of sturgeon swimming in flumes (Peake et al. 1997).

RESULTS AND DISCUSSION

Temperature of water increased during tests due to heat generated by the motor/water pump in the water system, which was closed (Tables 3 and 4, Figs. 2 and 3). During single fish tests, temperature increase during daily trials was from initial temperatures of 14.3 to 19.9 °C to final temperatures of 23.7 to 26.9 °C; and during group fish trials daily temperature increase was from 12.6 to 15.2 to 14.1 to 20.8 ° C. The increase in temperature during tests was gradual (mean, 0.27° C per hour; maximum, 0.34° C per hour; Tables 3 and 4). Level of dissolved oxygen was at saturation when most tests began, and was higher than saturation (maximum, 122 %) when five tests began (Fig. 4). The supersaturated condition quickly returned to saturation after a few minutes of normal pumping operation because much of the flow was spilled and aerated as it passed over the regulating weir at the head of the flume (Fig. 1).

We did not observe any obvious abnormal behavior (swimming or opercular movements) of fish that would indicate a stress induced effect of temperature or DO levels. However, the test procedures were not designed to evaluate the effects of these factors on fish movements. While increasing temperature (range, 7-21 C) has been related to increased swimming endurance of lake sturgeon (23-55 cm TL) swimming in a prolonged mode (Peake et al. 1997), we could find no comparative information on pallid or shovelnose. One possible effect of the colder temperature could have been to reduce the motivation of pallid sturgeon to swim upstream. The effect of temperature on performance of pallid sturgeon is discussed later.

Laminar Reach

Velocities in the laminar section ranged from 2.5 to 65.1 cm/sec, mean 31.2 cm/sec (Fig. 5). We visually observed that fish swam upstream just above the bottom. Thus, we believe that the velocities and vectors at 5 cm above the bottom baffles in the center of the channel (equidistance side to side) best reflect the velocity route used by fish. Current vectors in the channel at 5 cm above the bottom baffles show that flow was mainly laminar with similar velocities across the channel except for the most upstream reach, where velocity was higher at some cross section transects on the outside of the channel (Fig. 5).

The mean time (all individual movements) for fish to move from antenna 1-2 was 3:20 min (single fish trials) and 3:16 min (group fish trials; Table 5). The mean times of the two groups of fish were not significantly different (Mann-Whitney test, alpha >0.05). This result suggests that neither "group effect" nor water temperature (warmer in single fish tests than in group trials) had a significant effect on swimming performance of fish in the laminar reach. While increasing temperature improved the swimming performance of juvenile lake sturgeon

swimming in the prolonged mode (Peake et al. 1997) and lower water temperature causes reduced swimming performance in most fishes (Videler 1993), pallid sturgeon did not show an effect of temperature. Pallid sturgeon (45.6 mean FL) were swimming in an average velocity of 31.2 cm/s, so swimming was the sustained mode of about 1 L/s or less. One body length/s is within the sustained range of fish (Viedler 1993). Perhaps, pallid sturgeon must be exercised in faster velocity (prolonged swim mode) to show an effect of temperature.

One shovelnose sturgeon (fish 419), tested singly, moved to antenna 2 four times (Table 5). Even with prodding, the other two shovelnose sturgeon would not move upstream. This fish moved to antenna 2 in a mean time of 49 min 19 s (the longest mean time of any fish tested). When tested in groups, 2 of 3 shovelnose sturgeon moved to antenna 2 (Table 5). Fish 335 moved once in a time of 2:17 min and fish 419 moved two times, taking 2:24 and 5:06 min. Although the data are few, the shovelnose sturgeon tested in a group had similar swim times as many pallid sturgeon and fish 419 swam to antenna 2 much faster than it did earlier.

Baffle Reach

Frequency of test pallid sturgeon that swam to antenna 3 differed between single fish tests (9 of 22, 41%) and group tests (3 of 17, 18%; Table 5). This difference could be related to water temperature (warm during single fish tests, cool during group fish tests) that could affect motivation to swim, or to a group fish effect. Because the present tests were not designed to separate the effects of these factors, either factor or a combination of the two could be responsible for the change in behavior. We suspect that water temperature was the important factor because we have noted that when water temperature in holding tanks decreases to about 12 °C, fish activity greatly decreases and fish begin to rest on the bottom in an aggregation facing into the current. However, both group and temperature may have combined to reduce motivation of pallid sturgeon during tests.

Profiles of water flow in the baffle section are shown in Figs. 6, 7 and 8. Movement of water down the baffle section was a narrow side to side flow with a maximum velocity of 65 cm/s that occurred at each baffle slot. Most fish moved upstream near, but above, the bottom, so flow conditions at 5 cm above the bottom baffles best reflect the flow that fish used. At 5 cm above the bottom, similar velocity and vector profiles occurred at both inside and outside side baffles (Fig. 6). Directly downstream and behind each baffle, the velocity was slower and flow vectors show this was an eddy. The eddy extended farther downstream at outside side baffles than at inside side baffles. Some fish stopped in this outside eddy before moving upstream through a baffle slot.

Of the 22 pallid sturgeon tested singly, 9 fish (40.9 %) reached antenna 3; whereas, only 3 of 17 (17.6 %) reached antenna 3 when tested in groups. Mean time for fish to pass from antenna 2 to 3 for fish in single trials (n=9) was 2:41 min and for fish tested in groups, mean time was 1:04 min (n=4 observations from a 3 fish trial). Thus, once pallid sturgeon began to ascend the baffles, they made rapid progress passing the three baffles. Although fish moved individually up the flume whether tested singly or in groups, possibly the group affected speed of fish movement up the baffles. Also possible, is that the faster mean time of fish in groups was a result of the small sample size (n=3). It is interesting that the three fish in group trials that moved upstream to antenna 3 were not the same fish that had moved to antenna 3 during single

fish trials, thus the faster time of fish in groups was not due to prior experience. The few fish that moved to antenna 3 in group tests compared to single fish tests could have been due to the colder water during group tests, or a group effect. None of the three shovelnose sturgeon tested during single-fish trials moved to antenna 3, but one tested in group trials swam there (Table 5). Fish 419 (38 cm FL) moved from antenna 2 to 3 two times: taking 55 s and 28:06 min. The 28:06 min time was twice as long as the longest time required by any pallid sturgeon. Perhaps, shovelnose sturgeon were less motivated, at least when tested singly (and in warm water) to swim upstream than pallid sturgeon. Also, shovelnose sturgeon may be poorer at navigating complex structure/flow environments than pallid sturgeon. These questions cannot be answered by the present study.

Swim Speed

Swim speed (body length per sec=L/s) of the 22 pallid sturgeon with the fastest swim time from antenna 1 to 2, at mean water velocity of 31.2 cm/s, is the best estimate of swim speed in laminar flow (Fig. 9). These pallid sturgeon swam at 0.9-2.0 L/s, e.g., in the sustained to prolonged swim modes. Most fish demonstrated this swim mode for many hours during tests, much longer than the usual 200 min that defines the lower limit of sustained swimming (Peake et al. 1997).

Swim speed of the two shovelnose sturgeon that swam from antenna 1 to 2 was similar or slightly less than for pallid sturgeon (Fig. 9). Swim speed was between 0.6 and 0.9 L/s. The performance of these two fish, while slightly less than for pallid sturgeon, did not show a clear difference between the two species.

Swim speed of the five sturgeon with the highest L/s shows they swam at 2.2-2.7 L/s while passing the baffle velocity of about 65 cm/s. Burst speed (the swim speed fish can maintain for 20 s; Peake et al. 1997) of a 20 cm FL pallid sturgeon tested by Adams et al. (1999) was 70 cm/s (about 3.5 L/s). This data on burst swim speed supports the conclusion that our test fish, which passed the baffle slot swimming 2.7 or less body lengths/s, were swimming in the prolonged swim mode. The 2 min critical swim speed of a 16 cm TL lake sturgeon at 15 °C was 2.5 L/s (Webb 1986). As shown below (section on Swimming Behavior at Baffle A), fish only took about 2 s (maximum, 4 s) to pass through the fast velocity of the baffle, so the pallid and shovelnose sturgeon had the ability to swim past the baffle quickly without using burst speed.

Shovelnose sturgeon 419 swam at a similar speed as the fastest pallid sturgeon at baffle A. This fish moved at 2.8 L/s (Fig. 9). The swim speed of this fish suggests a similar thrust capability as pallid sturgeon, as would be expected with fish of similar size and similar body/fin morphology (Videler 1993).

The swim speed of pallid and shovelnose sturgeon tested in the flume will be less than one would observe from testing wild fish. Jones et al. (1974) found that swim performance of hatchery trout was only about 80% of wild trout performance. Observations on lake sturgeon swimming (Kynard et al. unpublished data) suggest that not only is the swim speed of hatchery

fish less than wild fish, but hatchery fish must learn to control their body orientation in turbulent flow. Wild fish should easily navigate complex flow regimes like those in the baffle section.

Swimming Behavior at Baffle A

Exposing fish to increased water velocity and structure prior to tests gave fish some experience moving around structure, but it did not likely greatly improve their swimming fitness or give them the experience to optimally navigate in complex flows. Fish in the holding tank did not spend more time swimming in fast velocity, but they did move more around the tank and encounter structure. So, there was likely some increase in general fitness and ability to control body orientation in complex flows. In other tests with lake sturgeon, we encountered the same situation. The only way we improved lake sturgeon swimming fitness was to give them a daily period of exercise in a flume where they had to swim (Kynard et al. unpublished data).

Fish that approached baffle A did not rest long there, but moved directly upstream. The maximum time that a fish used the eddy area behind the baffle was 1:30 min. However, some fish remained for many minutes behind baffle C, an outside baffle which has more eddy space. The eddy downstream of the side baffles provided resting conditions and space for several, not just one fish. Unfortunately, during group tests two fish did not simultaneously occur at baffle A, so we were unable to document this interaction. During tests in a similar ladder, two lake sturgeon did occur together behind baffles and did not interfere with each other (Kynard et al. unpublished data).

The mean time and tailbeats/s that pallid sturgeon (n=17) and shovelnose sturgeon (n=1) used to pass baffle A are shown in Table 6. Fish spent a mean time of 2 s (range, 1-4 s) passing upstream and the mean tailbeats/s of all fish was 3.6. Shovelnose 419, which was shorter than most pallid sturgeon, took 4 s and a mean of 3.6 tailbeats/s (n=2 observations) to pass baffle A (Table 6). The tailbeats/s of both species were similar, but the sample size of shovelnose is too small for conclusions on this species.

Sturgeon used eight routes to pass the baffle slot (Fig. 10). Only 10 of 43 fish trips resulted in fish swimming through the eddy behind the baffle. Most fish avoided the eddy and continued swimming in the fast current. Also, fish had no problem maintaining a strong directional propulsion through the slightly complex slot currents. Some fish moved laterally when they encountered the lateral flow at the slot, but they recovered and continued upstream. Thus, for fish with little experience with complex currents, a flat head that would seem difficult to control when swimming through fast complex currents, and only a moderate level of fitness, pallid sturgeon were quite adept at controlling their orientation and direction while swimming.

The probability of occurrence of fish at each station across the three transects at side baffle A is shown in Fig. 11. The pattern of sturgeon swimming through the area was to remain away from the wall on either side and use the fast current in the center one-third. This enabled them to keep both or at least one pectoral fin erect and useful for orientation. Fish distribution was normal in transects A and C, but skewed to the right in transect B. This may reflect the avoidance of the eddy in transect B and preference for the dominant flow with fast velocity.

Downstream Movement

When sturgeon that moved to antenna 3 moved downstream, the TIRIS system recorded the time for passage to antenna 1 and video recorded their movement at baffle A. The mean time for pallid sturgeon to move from antenna 3-2 (the baffle section) was 10:38 min (n=6 observations).

Video observations showed that most fish (68 %) did so with their bodies oriented head upstream (30 of 47 observations). Fish also remained more than two body depths off the bottom (34 of 37 observations, 91.9 %). Typically, fish drifted slowly using pectoral fins to maintain body orientation in a "dead-fish condition", i.e., just enough fin motion to maintain body orientation. This behavior facilitated downstream movement pass baffles without causing injury to fish. We also observed this behavior during downstream movement of lake and shortnose sturgeon (Kynard et al. unpublished data), so it may be typical of all sturgeon.

Conclusions and Recommendations

All test fish swam in the 35 cm/s mean velocity of the laminar flow reach at 1 L/s in a sustained swim mode.

Pallid sturgeon demonstrated the swimming ability to navigate complex currents in a side-baffle fish ladder at 6 % slope and similarly, should be able to swim upstream in complex flows in other passage situations, like rock ramps, as long as velocities are appropriate.

Pallid and shovelnose sturgeon swam through the side-baffle section off the bottom in a prolonged swim mode at 2.7 L/s, passing quickly through 65 cm/s velocity in only 1-2 s using about 2 tailbeats/s. Current velocity in fish ladders or rock ramps that enable fish to swim in the prolonged mode, and do not require the burst swim mode, seems preferable for these species.

The small sample size of shovelnose sturgeon make the results for this species only preliminary. Additional study is needed to compare swimming of pallid and shovelnose sturgeon. The available data from our test shovelnose sturgeon suggests that shovelnose sturgeon have similar swimming ability as pallid sturgeon, but may have less motivation. Shovelnose sturgeon may be more motivated to move when crowded or in a group. This could reflect an aspect of the early aggregation behavior described by Kynard et al (2002) for both species.

Temperature variation of 13 to 27 °C did not have an obvious effect on swimming performance in the sustained or prolonged modes of pallid sturgeon.

Pallid and shovelnose sturgeon have appropriate behaviors that facilitate moving downstream in a side-baffle fish ladder without causing injury.

The side-baffle fish ladder design has promise for passing pallid and shovelnose sturgeon upstream of barriers.

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Table 1. Fish code, species (pallid=P, shovelnose=S), weight, and fork length for fish in trials, fall 2001.

Fish Code	Species	Weight (gm)	FL (cm)
329	P	180	38.5
330	P	280	46.5
348	P	160	39.5
351	P	400	50.2
353	P	500	51.7
360	P	430	52
363	P	280	43.7
370	P	480	51.5
372	P	300	46.5
373	P	280	46.5
392	P	280	46
393	P	420	52.5
396	P	320	46.5
402	P	130	35
403	P	170	39.5
405	P	230	41
406	P	240	41.5
407	P	430	49.5
411	P	310	46.5
414	P	245	43.5
416	P	380	48.5
418	P	330	46.5
335	S	320	46.1
409	S	100	33.5
419	S	180	38

Pallid	
Mean Wt	308.0
St Dev Wt	104.6
Median Wt	290.0
Min Wt	130.0
Max Wt	500.0
Mean FL	45.6
StDev FL	4.8
Median FL	46.5
Min FL	35
Max FL	52.5

Shovelnose	
Mean Wt	200.0
St Dev Wt	111.4
Median Wt	180.0
Min Wt	100.0
Max Wt	320.0
Mean FL	39.2
StDev FL	6.4
Median FL	38
Min FL	33.5
Max FL	46.1

Table 2. Dates, species (pallid=P, shovelnose=S), fish code, and start, end and total time for single and group trials, fall 2001.

			Time (hh:mm)		
Date	Species	Fish Code	Start	End	Total
9/24/01	P	372	12:14	16:55	04:41
9/25/01	P	393	12:54	17:00	04:06
9/26/01	P	373	09:06	15:50	06:44
9/27/01	P	330	08:43	11:18	02:35
9/27/01	P	411	12:27	17:57	05:30
9/28/01	P	360	08:54	17:12	08:18
10/1/01	P	418	08:57	17:02	08:05
10/2/01	P	416	08:49	14:54	06:05
10/3/01	P	407	09:18	16:17	06:59
10/4/01	P	392	09:25	16:27	07:02
10/5/01	P	329	08:41	15:59	07:18
10/9/01	S	409	10:13	16:21	06:08
10/10/01	S	419	10:10	16:21	06:11
10/11/01	P	353	07:57	14:20	06:23
10/12/01	S	335	08:39	15:04	06:25
10/13/01	P	414	08:21	14:26	06:05
10/15/01	P	351	10:03	16:06	06:03
10/16/01	P	370	09:16	15:17	06:01
10/17/01	P	406	09:06	15:06	06:00
10/18/01	P	402	09:19	15:50	06:31
10/19/01	P	363	10:10	16:12	06:02
10/22/01	P	405	09:12	14:05	04:53
10/23/01	P	348	08:45	14:50	06:05
10/24/01	P	403	08:55	15:00	06:05
10/25/01	P	396	09:19	12:40	03:21
10/26/01	S	335, 409, 419	09:27	15:57	06:30
10/29/01	P	360, 370, 373	09:46	16:13	06:27
10/30/01	P	348, 396, 414	12:15	14:28	02:13
10/31/01	P	330, 392, 393	09:22	11:25	02:03
10/31/01	P	353, 416, 418	13:00	15:02	02:02
11/1/01	P	363, 407, 411	09:48	11:50	02:02
11/1/01	P	351, 372, 402	13:30	15:33	02:03
11/2/01	P	329, 403, 405, 406	09:59	12:02	02:03

Table 3. Date, species, fish code, mean, median, standard deviation of the mean, minimum and maximum temperatures during pallid and shovelnose trials, fall 2001.

			Temperature - C				
Date	Species	Fish Code	Mean	Median	StDev	Minimum	Maximum
9/24/01	P	372	25.4	25.4	1.0	23.7	26.9
9/25/01	P	393	24.8	24.9	1.5	22.2	26.9
9/26/01	P	373	24.0	24.1	1.8	20.8	26.8
9/27/01	P	330	20.8	20.8	0.7	19.7	21.9
9/27/01	P	411	23.9	23.9	1.3	21.6	25.9
9/28/01	P	360	23.6	23.8	2.0	20.2	26.6
10/1/01	P	418	22.5	22.6	2.2	18.6	25.9
10/2/01	P	416	21.6	21.6	2.3	18.0	25.2
10/3/01	P	407	22.8	22.7	2.7	18.4	27.1
10/4/01	P	392	23.0	23.2	2.8	18.3	27.1
10/5/01	P	329	23.0	23.1	2.7	18.6	27.1
10/9/01	S	409	18.3	18.3	2.1	14.9	21.6
10/10/01	S	419	20.1	20.2	2.3	16.3	23.6
10/11/01	P	353	19.6	19.4	2.3	16.0	23.4
10/12/01	S	335	20.5	20.5	2.2	16.9	24.0
10/13/01	P	414	20.6	20.5	2.6	16.6	24.7
10/15/01	P	351	20.3	20.5	2.2	16.6	23.7
10/16/01	P	370	19.2	19.2	2.1	15.9	22.6
10/17/01	P	406	19.2	19.2	1.8	16.2	21.9
10/18/01	P	402	17.9	18.0	1.9	14.9	20.8
10/19/01	P	363	17.5	17.5	1.9	14.5	20.5
10/22/01	P	405	17.7	17.7	1.8	14.6	20.3
10/23/01	P	348	17.2	17.1	1.8	14.3	20.0
10/24/01	P	403	18.7	18.8	2.5	14.6	22.7
10/25/01	P	396	17.6	17.5	1.5	15.2	19.9
10/26/01	S	335, 409, 419	18.2	18.3	1.8	14.9	20.8
10/29/01	P	360, 370, 373	17.1	17.1	1.9	13.9	20.0
10/30/01	P	348, 396, 414	15.2	15.3	0.8	14.0	16.3
10/31/01	P	330, 392, 393	13.9	14.0	0.8	12.7	15.2
10/31/01	P	353, 416, 418	14.4	14.5	0.6	13.5	15.4
11/1/01	P	363, 407, 411	14.0	14.1	1.0	12.6	15.4
11/1/01	P	351, 372, 402	14.8	14.8	0.9	13.5	16.2
11/2/01	P	329, 403, 405, 406	14.4	14.3	0.9	13.0	15.7

Table 4. Date, species, fish code, mean, median, standard deviation of the mean, minimum and maximum quarter hourly changes in temperatures for pallid and shovelnose sturgeon trials, fall 2001.

Date	Species	Fish Code	Mean	Median	StDev	Minimum	Maximum
9/24/01	P	372	0.27	0.30	0.11	0.1	0.4
9/25/01	P	393	0.28	0.30	0.12	0.1	0.4
9/26/01	P	373	0.22	0.20	0.09	0.1	0.4
9/27/01	P	330	0.22	0.20	0.10	0.1	0.4
9/27/01	P	411	0.20	0.20	0.07	0.1	0.3
9/28/01	P	360	0.19	0.20	0.10	0	0.4
10/1/01	P	418	0.23	0.20	0.10	0.1	0.4
10/2/01	P	416	0.29	0.30	0.07	0.1	0.4
10/3/01	P	407	0.31	0.30	0.08	0.1	0.5
10/4/01	P	392	0.31	0.30	0.09	0.2	0.5
10/5/01	P	329	0.29	0.30	0.06	0.2	0.4
10/9/01	S	409	0.28	0.30	0.06	0.1	0.4
10/10/01	S	419	0.30	0.30	0.12	0.1	0.5
10/11/01	P	353	0.30	0.30	0.09	0.1	0.5
10/12/01	S	335	0.28	0.30	0.11	0.1	0.5
10/13/01	P	414	0.32	0.30	0.10	0.1	0.5
10/15/01	P	351	0.30	0.30	0.09	0.1	0.5
10/16/01	P	370	0.28	0.30	0.08	0.1	0.4
10/17/01	P	406	0.24	0.30	0.10	0.1	0.4
10/18/01	P	402	0.23	0.25	0.10	0	0.4
10/19/01	P	363	0.25	0.30	0.08	0.1	0.4
10/22/01	P	405	0.30	0.30	0.09	0.1	0.5
10/23/01	P	348	0.24	0.30	0.10	0.1	0.4
10/24/01	P	403	0.34	0.30	0.10	0.1	0.5
10/25/01	P	396	0.34	0.30	0.10	0.1	0.5
10/26/01	S	335, 409, 419	0.23	0.20	0.10	0.1	0.5
10/29/01	P	360, 370, 373	0.23	0.30	0.09	0.1	0.4
10/30/01	P	348, 396, 414	0.26	0.30	0.10	0.1	0.4
10/31/01	P	330, 392, 393	0.28	0.30	0.08	0.1	0.4
10/31/01	P	353, 416, 418	0.24	0.25	0.07	0.1	0.3
11/1/01	P	363, 407, 411	0.31	0.30	0.03	0.3	0.4
11/1/01	P	351, 372, 402	0.34	0.30	0.07	0.3	0.5
11/2/01	P	329, 403, 405, 406	0.34	0.30	0.11	0.2	0.5

Table 5. Mean, minimum and maximum upstream passage times for individual pallid and shovelnose sturgeon in single and group trials and summary statistics for single and group trials, fall 2001.

Pallid Single Trials

Date	Fish Code	Species	Logged at Antenna 3	Count 1 to 2	Count 2 to 3	Mean (h:mm:ss)	Min	Max
9/24/01	372	P	yes	12		0:03:13	0:00:16	0:11:44
					2	0:00:39	0:00:38	0:00:41
9/25/01	393	P	yes	10		0:01:35	0:00:12	0:05:05
					1	0:02:44	0:02:44	0:02:44
9/26/01	373	P	no	2		0:00:25	0:00:24	0:00:27
9/27/01	330	P	no	1		0:02:16	0:02:16	0:02:16
9/27/01	411	P	no	5		0:03:23	0:00:13	0:14:43
9/28/01	360	P	no	3		0:00:25	0:00:19	0:00:36
10/1/01	418	P	no	8		0:03:14	0:00:18	0:10:18
10/2/01	416	P	yes	6		0:08:07	0:00:30	0:29:59
					1	0:00:48	0:00:48	0:00:48
10/3/01	407	P	no	13		0:02:47	0:00:21	0:07:54
10/4/01	392	P	no	12		0:03:44	0:00:13	0:16:25
10/5/01	329	P	no	14		0:04:23	0:00:09	0:42:28
10/11/01	353	P	no	5		0:05:14	0:00:19	0:23:21
10/13/01	414	P	yes	16		0:02:49	0:00:14	0:27:23
					1	0:02:03	0:02:03	0:02:03
10/15/01	351	P	no	9		0:09:27	0:00:17	1:06:03
10/16/01	370	P	no	9		0:00:52	0:00:18	0:02:17
10/17/01	406	P	no	12		0:01:51	0:00:15	0:08:17
10/18/01	402	P	yes	13		0:05:01	0:00:08	0:48:15
					2	0:09:14	0:00:35	0:17:52
10/19/01	363	P	yes	6		0:00:32	0:00:20	0:01:15
					1	0:01:24	0:01:24	0:01:24
10/22/01	405	P	yes	1		0:00:57	0:00:57	0:00:57
					1	0:00:46	0:00:46	0:00:46
10/23/01	348	P	no	3		0:00:38	0:00:26	0:00:59
10/24/01	403	P	yes	4		0:00:41	0:00:16	0:01:44
					1	0:00:44	0:00:44	0:00:44
10/25/01	396	P	yes	2		0:00:26	0:00:20	0:00:33
					1	0:01:14	0:01:14	0:01:14

Single Trial Pallid			
	Count	22	9
	Sum	166	11
	Mean*	0:03:20	0:02:41
	Minimum	0:00:08	0:00:35
	Maximum	1:06:03	0:17:52

* mean times are calculated using all records

Table 5 (con't)

Pallid Group Trials

Date	Fish Code	Species	Logged at Antenna 3	Count 1 to 2	Count 2 to 3	Mean (h:mm:ss)	Min (h:mm:ss)	Max (h:mm:ss)
10/29/01	360	P	no	1		0:42:19	0:42:19	0:42:19
	370	P	no	4		0:00:36	0:00:13	0:01:32
	373	P	no	1		0:00:09	0:00:09	0:00:09
	414	P	no	4		0:05:06	0:00:35	0:15:32
10/31/01	330	P	no	1		0:00:07	0:00:07	0:00:07
	393	P	no	2		0:04:57	0:00:22	0:09:32
	353	P	yes	4		0:00:19	0:00:11	0:00:34
					2	0:00:57	0:00:33	0:01:21
	418	P	yes	2		0:04:22	0:00:24	0:08:19
					1	0:00:22	0:00:22	0:00:22
11/1/01	363	P	no	4		0:02:12	0:00:39	0:06:08
	407	P	yes	2		0:06:47	0:00:37	0:12:56
					1	0:00:55	0:00:55	0:00:55
	351	P	no	4		0:00:32	0:00:16	0:00:55
	372	P	no	4		0:02:51	0:00:19	0:09:42
	402	P	no	8		0:01:21	0:00:21	0:03:51
11/2/01	329	P	no	5		0:03:31	0:00:14	0:12:17
	403	P	no	1		0:00:31	0:00:31	0:00:31
	405	P	no	5		0:02:17	0:00:04	0:09:58
	406	P	no	2		0:19:59	0:12:45	0:27:13

		1 to 2	2 to 3
Group Trial Pallid	Count	17	3
	Sum	54	4
	Mean*	0:03:32	0:01:04
	Minimum	0:00:04	0:00:22
	Maximum	0:42:19	0:01:21
All Pallid	Count	39	12
	Sum	220	15
	Mean*	0:03:24	0:02:00
	Minimum	0:00:04	0:00:22
	Maximum	0:42:19	0:01:21

* mean times are calculated using all records

Table 5 (con't)

Shovelnose Single Trials

Date	Fish Code	Species	Logged at Antenna 3	Count 1 to 2	Count 2 to 3	Mean	Min	Max
10/10/01	419	S	no	4		0:49:19	0:00:39	2:58:50

Shovelnose Group Trials

Date	Fish Code	Species	Logged at Antenna 3	Count 1 to 2	Count 2 to 3	Mean	Min	Max
10/26/01	335	S	no	1		0:02:17	0:02:17	0:02:17
	419	S	yes	2		0:03:45	0:02:24	0:05:06
					2	0:14:31	0:00:55	0:28:06

Group Trial Shovelnose			
	Count	2	0
	Sum	3	2
	Mean*	0:03:16	
	Minimum	0:02:17	0:00:55
	Maximum	0:05:06	0:28:06

* mean times are calculated using all records

Table 6. Mean, minimum, and maximum time (min:s) and number of tailbeats/sec of seventeen pallid and one shovelnose sturgeon swimming upstream from Transect A to C through baffle slot A.

			Time			Tailbeats/s		
Fish	Species	Count	Mean	Minimum	Maximum	Mean	Minimum	Maximum
329	P	2	0:02	0:01	0:03	2.8	2.7	3.0
351	P	3	0:02	0:01	0:03	3.6	2.7	5.0
353	P	6	0:01	0:01	0:02	3.3	2.5	5.0
363	P	3	0:01	0:01	0:01	3.7	3.0	5.0
370	P	1	0:02	0:02	0:02	3.0	3.0	3.0
372	P	2	0:02	0:01	0:03	3.0	3.0	3.0
373	P	1	0:01	0:01	0:01	4.0	4.0	4.0
393	P	1	0:01	0:01	0:01	3.0	3.0	3.0
396	P	1	0:01	0:01	0:01	5.0	5.0	5.0
402	P	6	0:02	0:01	0:04	4.1	3.0	7.0
403	P	2	0:01	0:01	0:01	3.5	3.0	4.0
405	P	3	0:02	0:01	0:03	4.0	3.0	5.0
406	P	3	0:01	0:01	0:02	4.2	3.0	5.0
407	P	1	0:01	0:01	0:01	4.0	4.0	4.0
411	P	2	0:02	0:01	0:04	2.5	2.0	3.0
414	P	3	0:02	0:02	0:02	3.0	2.5	4.0
418	P	1	0:01	0:01	0:01	4.0	4.0	4.0
419	S	2	0:04	0:01	0:07	3.6	2.1	5.0

Table 7. Mean, minimum and maximum downstream passage times from antenna 3 to 2 for individual pallid and shovelnose sturgeon in single and group trials and summary statistics for single and group trials, fall 2001.

Single Pallid Trials

Date	Fish Code	Species	3 to 2	Mean	(h:mm:ss) Min	Max
9/24/01	372	P	2	0:01:27	0:01:07	0:01:47
10/2/01	416	P	1	0:00:12	0:00:12	0:00:12
10/13/01	414	P	1	0:16:34	0:16:34	0:16:34
10/18/01	402	P	1	0:43:18	0:43:18	0:43:18
10/25/01	396	P	1	0:00:52	0:00:52	0:00:52

Single Trial Pallid	Count	5
	Sum	6
	Mean*	0:10:38
	Minimum	0:00:12
	Maximum	0:43:18

Group Pallid Trials

Date	Fish Code	Species	3 to 2	Mean	(h:mm:ss) Min	Max
10/31/01	353	P	2	0:01:06	0:00:30	0:01:43
10/31/01	418	P	1	0:00:52	0:00:52	0:00:52
11/1/01	407	P	1	0:02:35	0:02:35	0:02:35

Group Trial Pallid	Count	3
	Sum	4
	Mean*	0:04:06
	Minimum	0:00:30
	Maximum	0:02:35

All Pallid		
	Count	8
	Sum	10
	Mean*	0:07:40
	Minimum	0:00:12
	Maximum	0:43:18

Table 7 (con't)

Group Shovelnose Trials

Date	Fish Code	Species	2 to 3	Mean	Min	Max
10/26/01	419	S	2	0:09:08	0:00:22	0:17:55

Group Trial Shovelnose		
	Count	1
	Sum	2
	Mean*	0:09:08
	Minimum	0:00:22
	Maximum	0:17:55

* mean times are calculated using all records

Figure 1. Experimental flume with different flow conditions (up- to downstream): structure/turbulent flow within the baffle area, then laminar flow with decreasing velocity to the acclimation area.

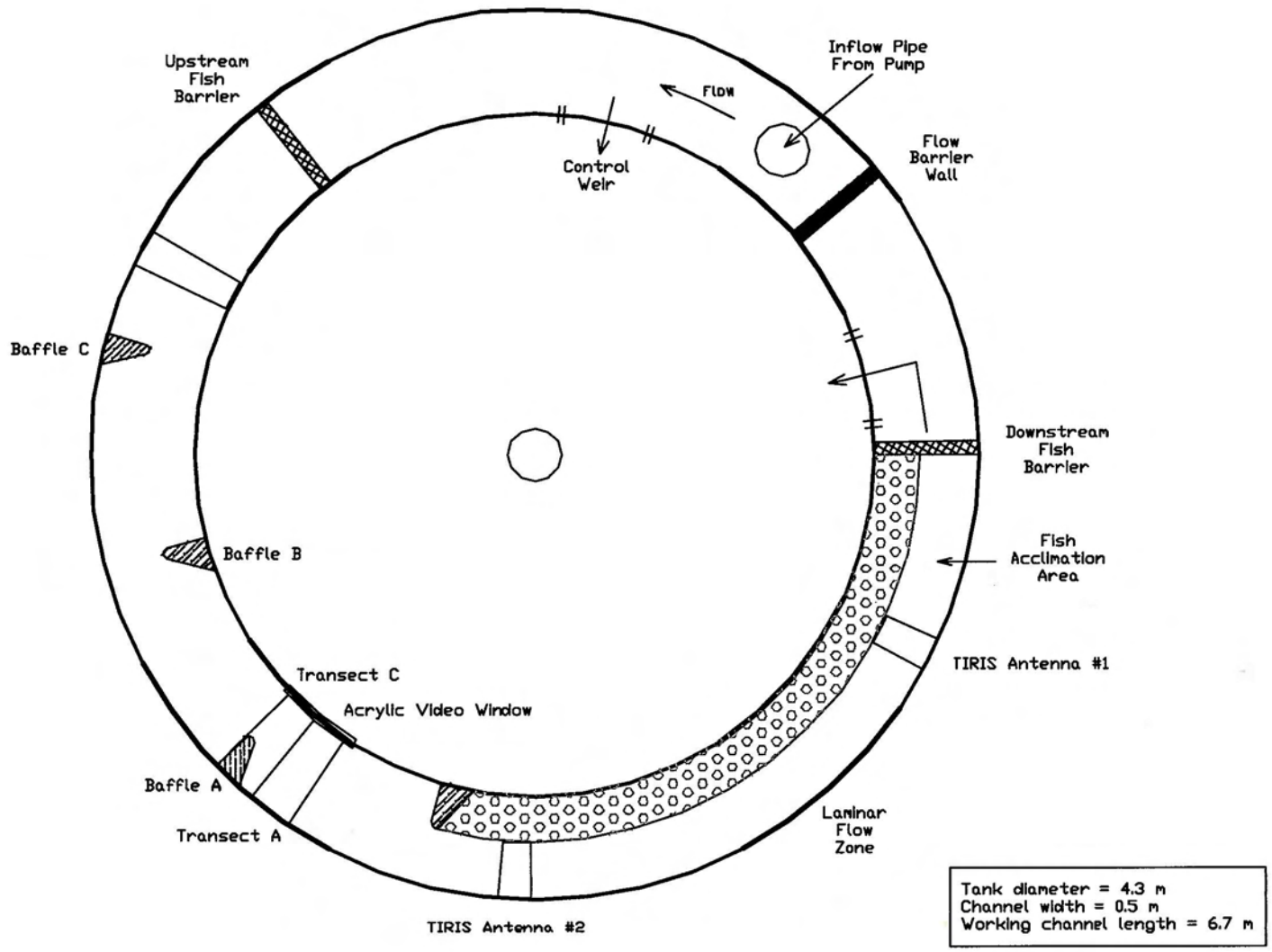


Figure 2. Temperature [C] during single fish pallid and shovelnose sturgeon trials, fall 2001.

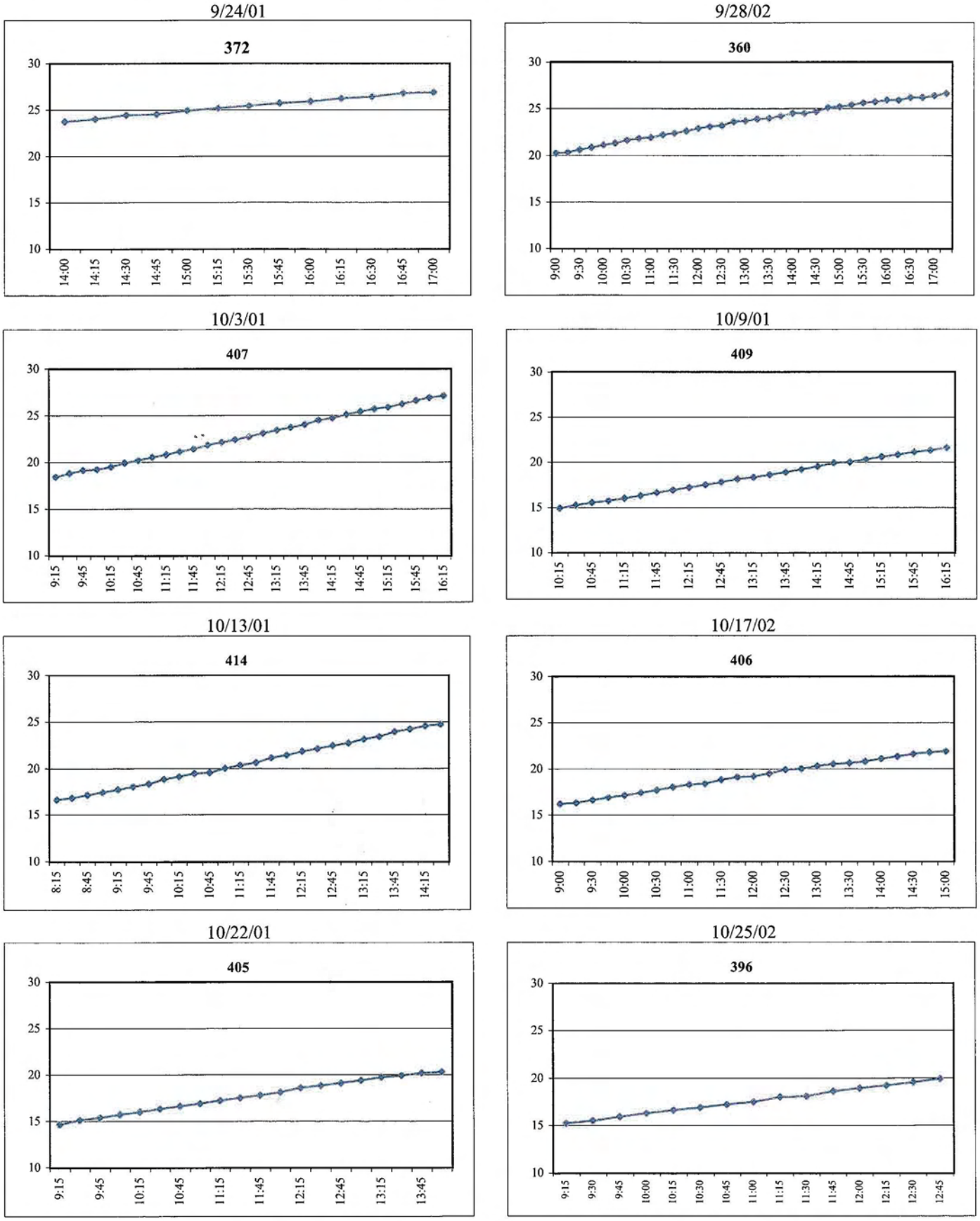
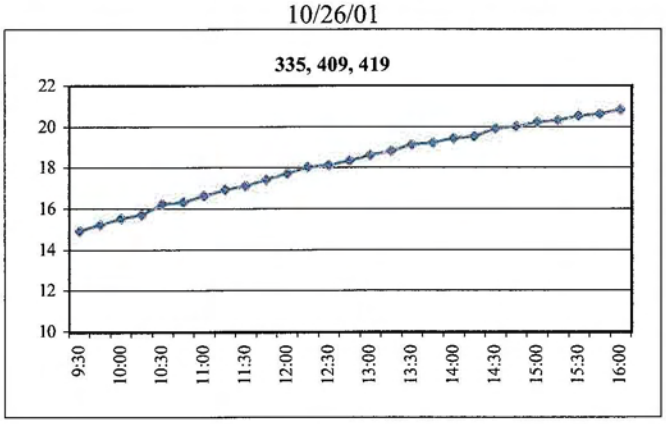
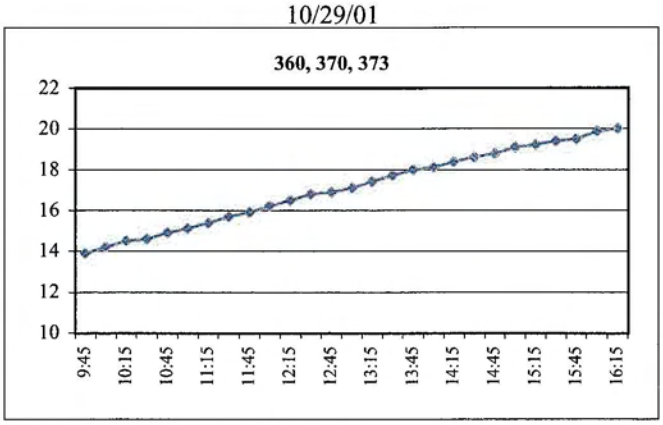


Figure 3. Temperature [C] during group pallid and shovelnose sturgeon trials, fall 2001.

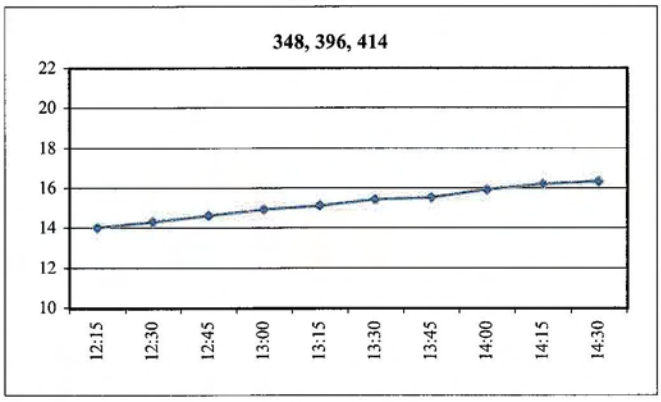
10/26/01



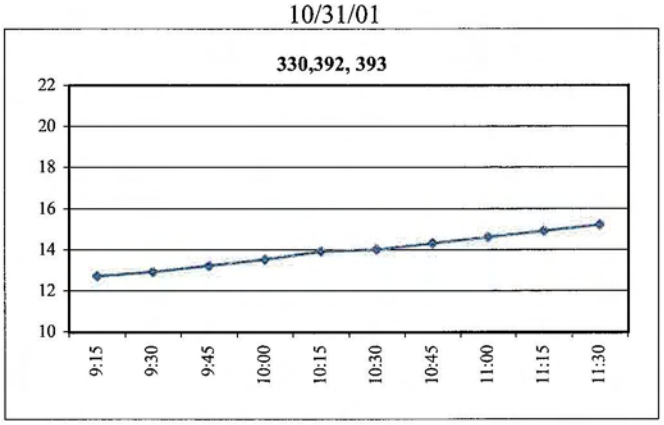
10/29/01



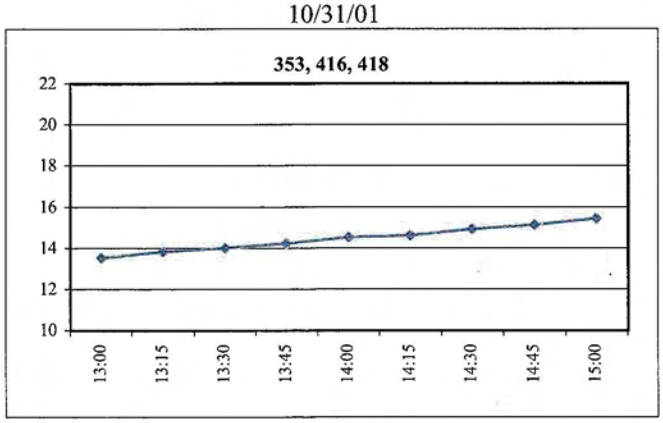
10/30/01



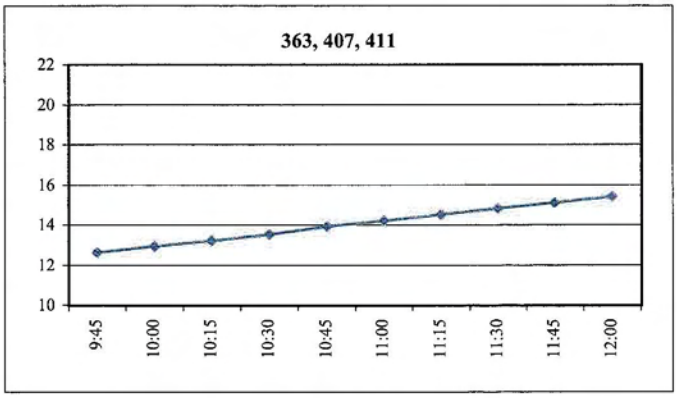
10/31/01



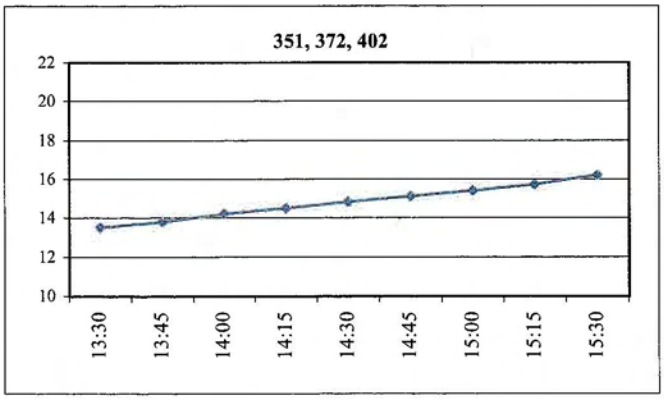
10/31/01



11/1/01



11/1/01



11/2/01

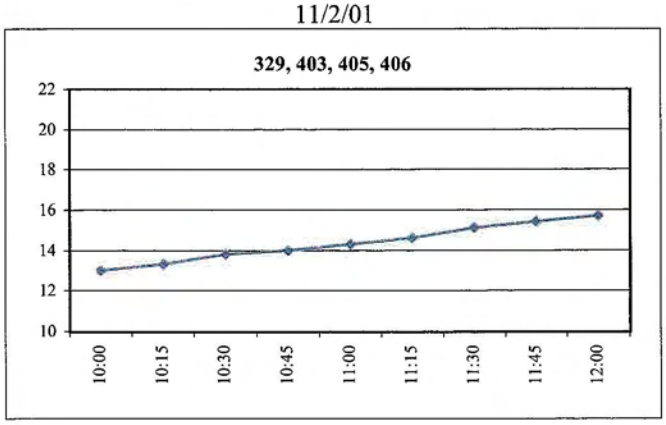


Figure 4. Temperature and percentage dissolved oxygen at the start and end of pallid and shovelnose sturgeon trials.

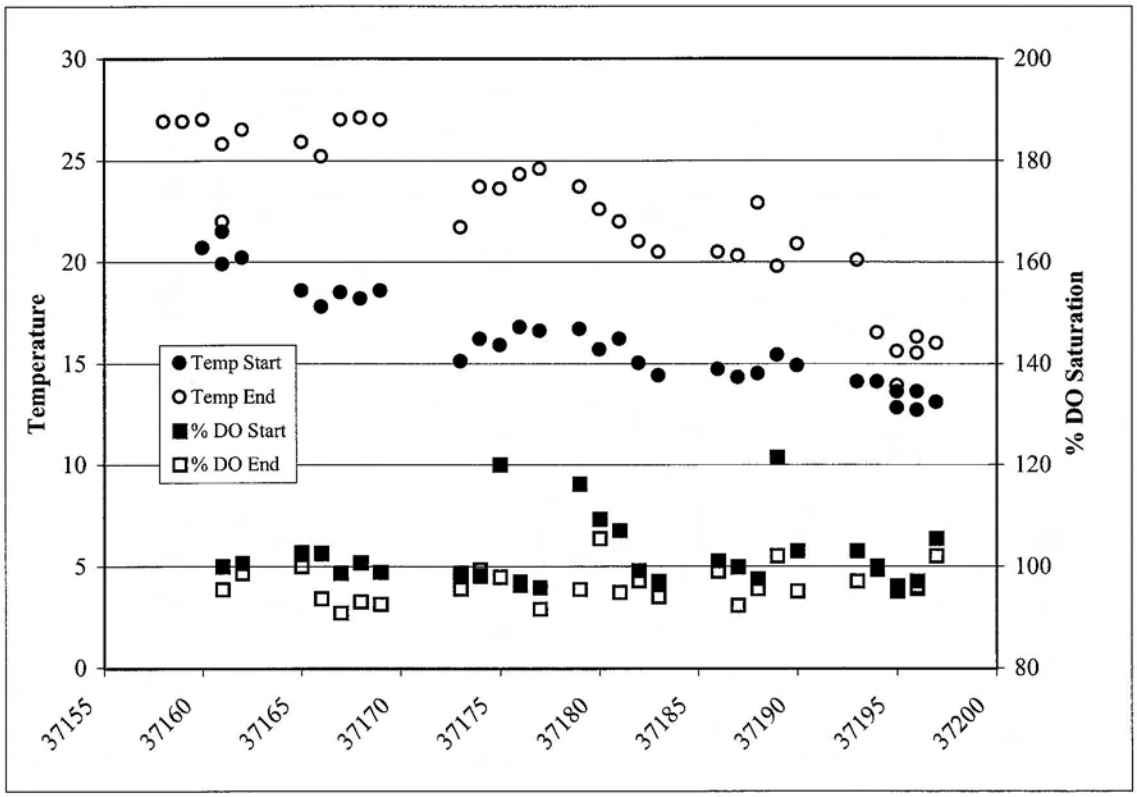


Figure 5. Velocity vectors for the straight channel section of the experimental flume for pallid and shovelnose sturgeon tests, fall 2001.

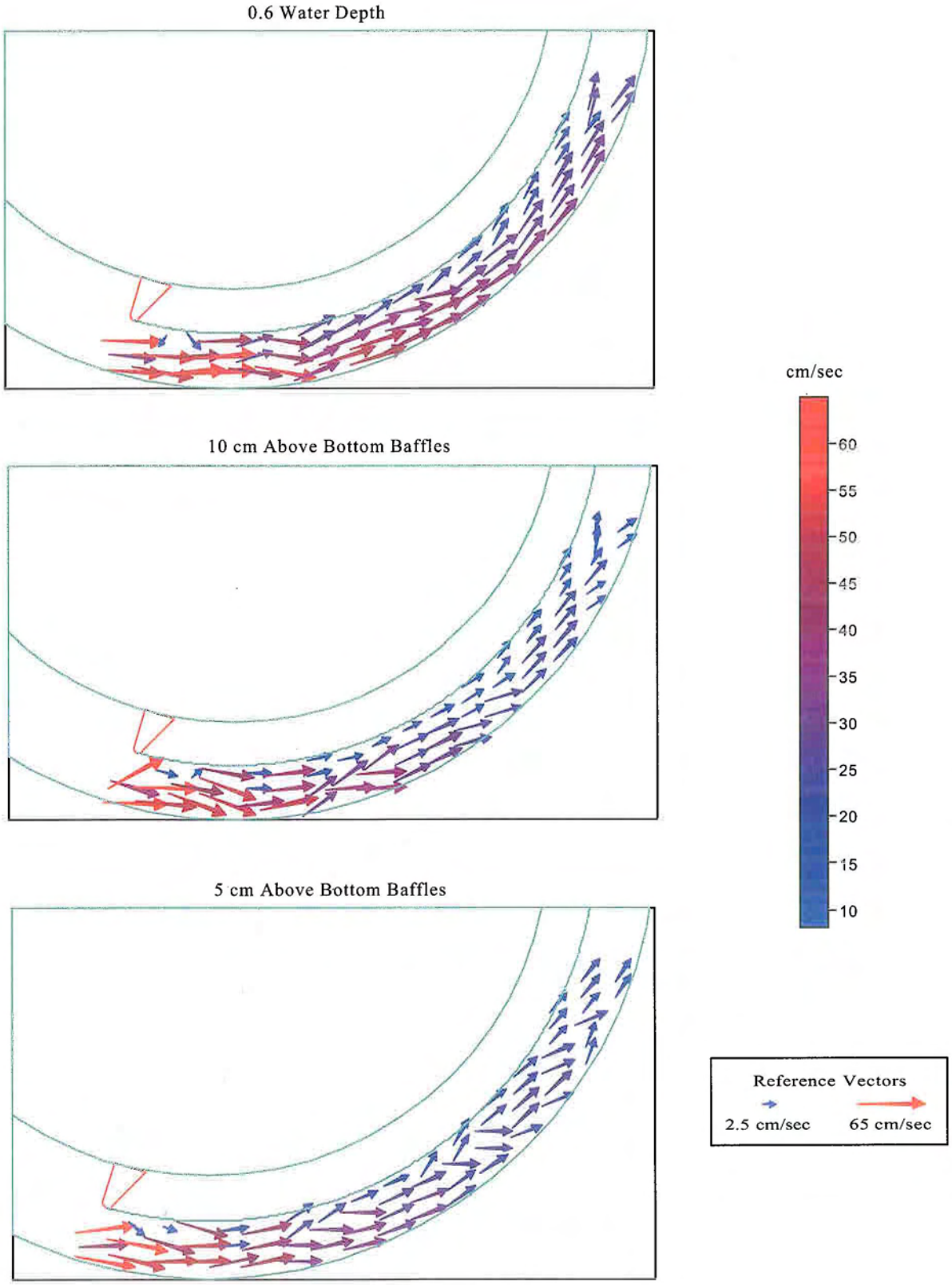


Figure 6. Velocity vectors in the baffle zone at 5 cm above the bottom baffles of the experimental flume for pallid and shovelnose sturgeon trials, fall 2001.

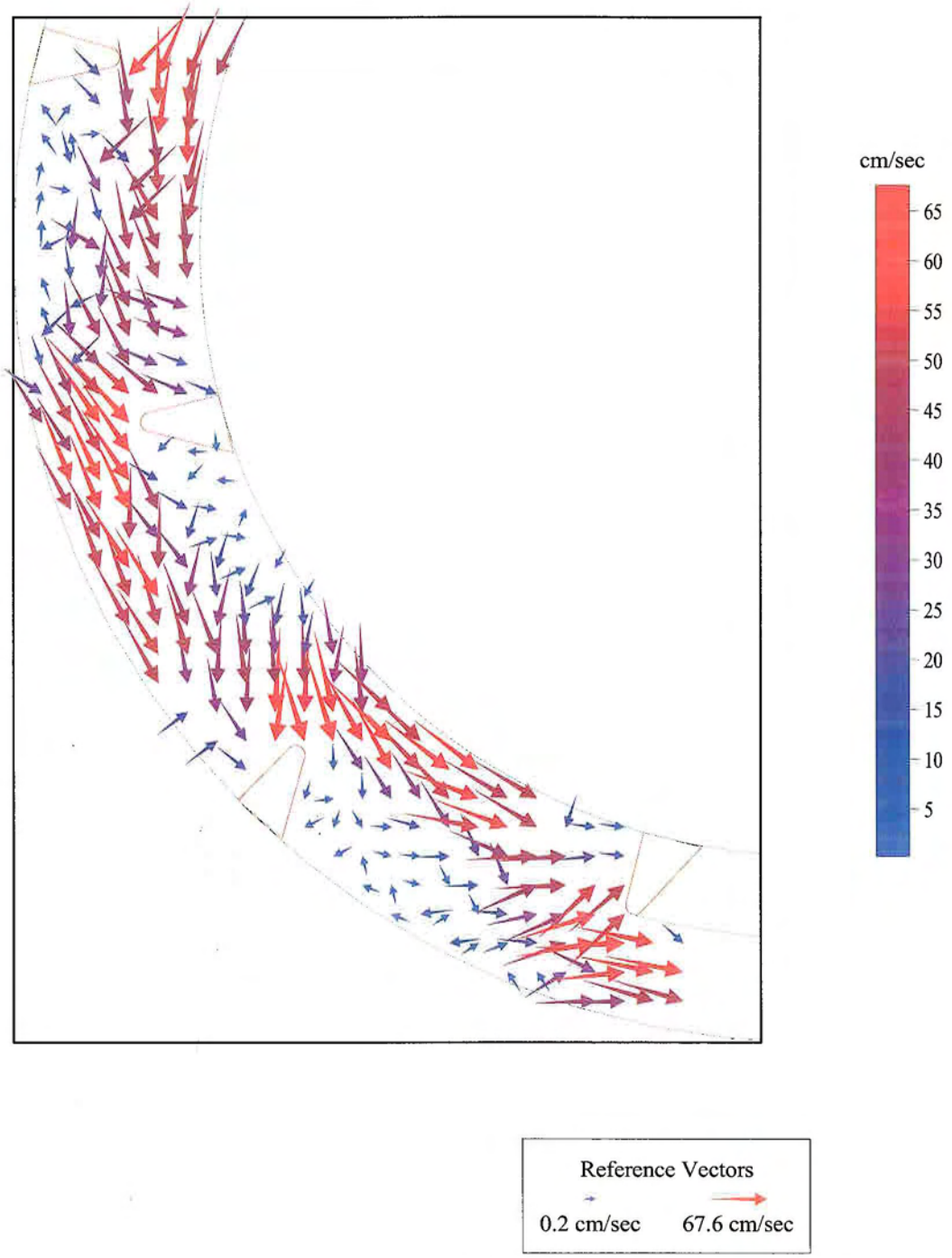


Figure 7. Velocity vectors in the baffle zone at 10 cm above the bottom baffles of the experimental flume for pallid and shovelnose sturgeon trials, fall 2001.

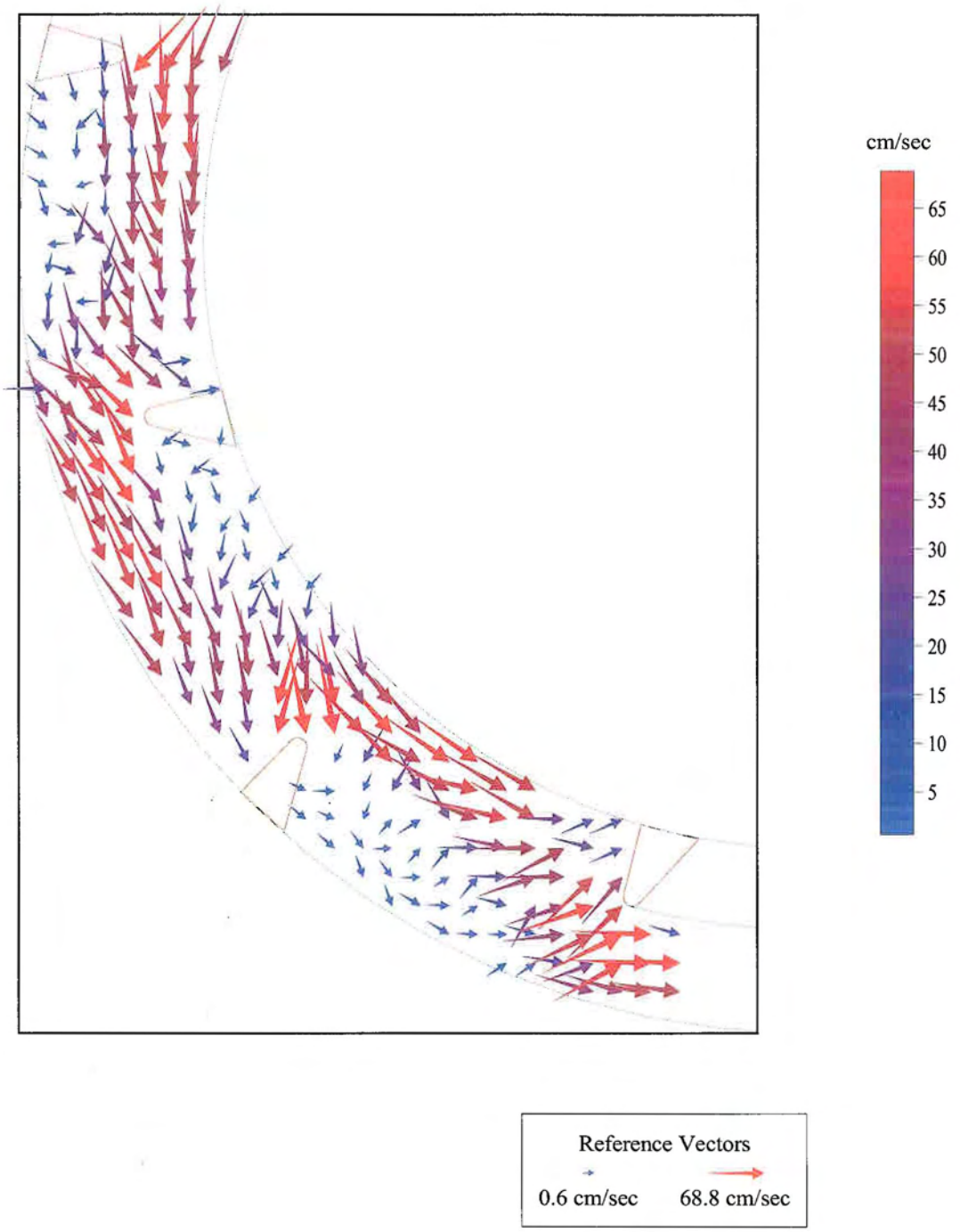


Figure 8. Velocity vectors in the baffle zone at 0.6 depth in the experimental flume for pallid and shovelnose sturgeon trials, fall 2001.

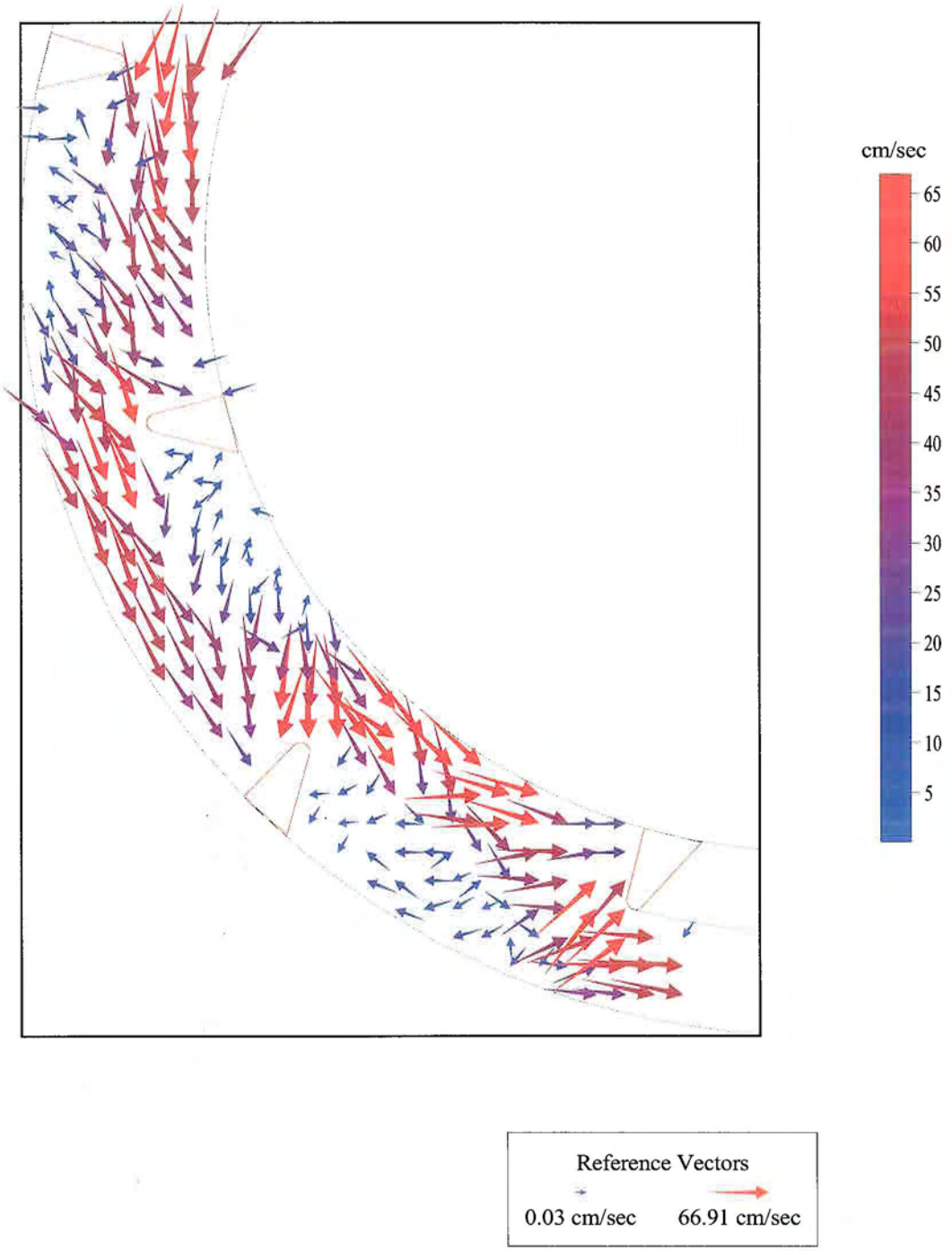
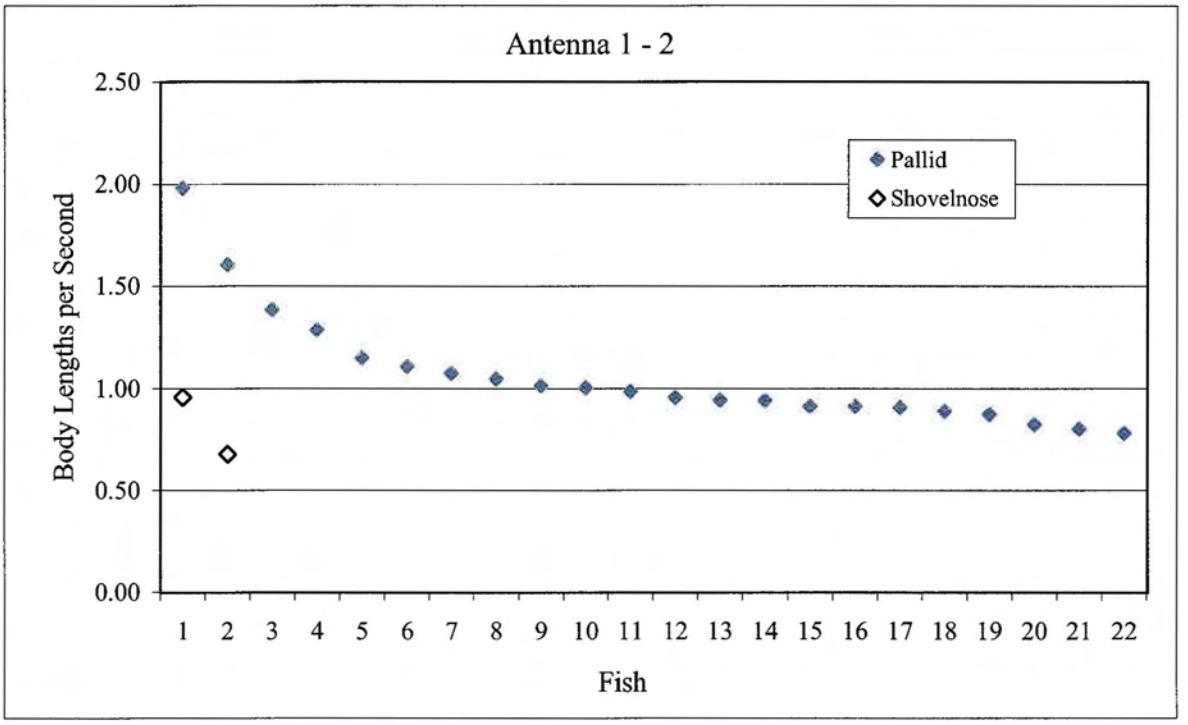


Figure 9. Body lengths per second for the best record of each pallid and shovelknose sturgeon swimming from antenna 1 to 2 (laminar flows) and from transect A to C (baffled flow) in the 'video zone'.



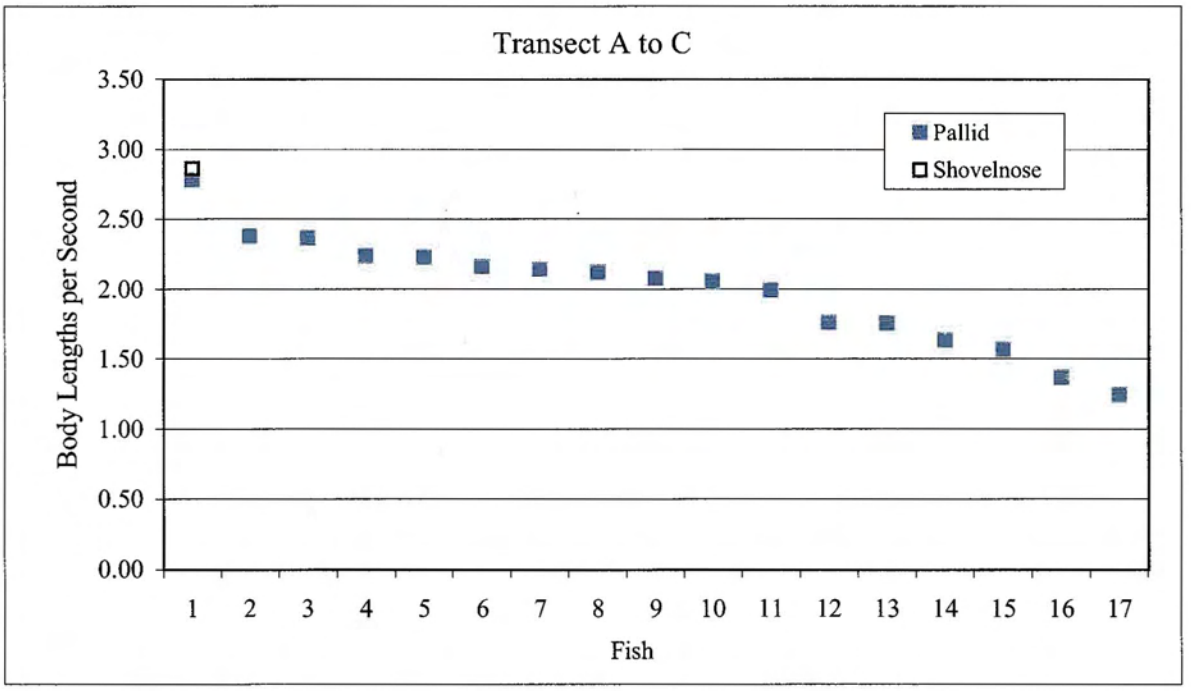
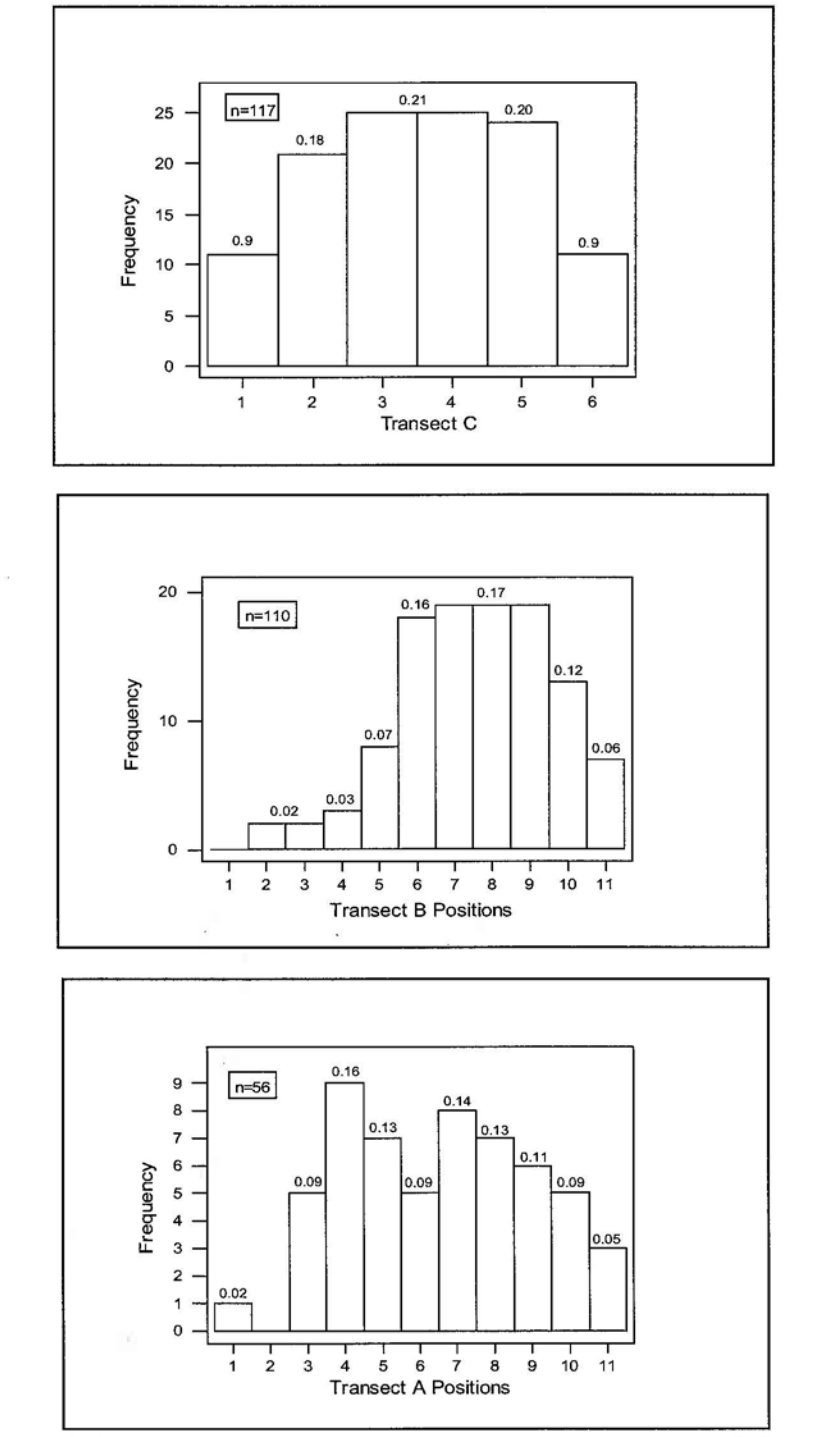


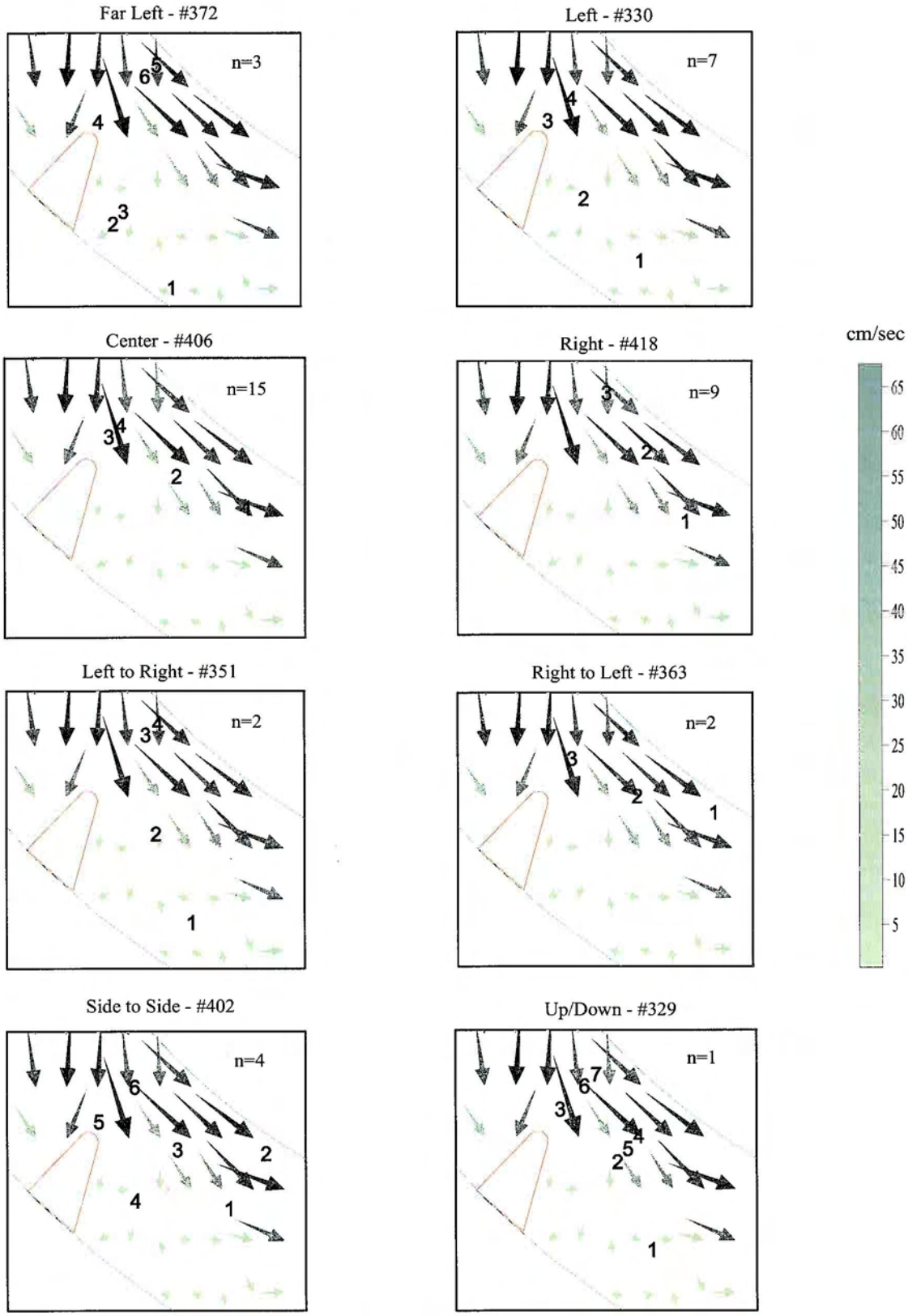
Figure 11. Movement of fish passing through the "video zone" as shown by the frequency of occurance of fish passing across transects A-B (downstream of baffle slot) and transect C (baffle slot). Probability of occurance is above each bar; n = total number of observations of all fish and all trips. Position 1 is on outside wall, position 6 and 11 are on inside wall.



outside flume *inside flume*

Looking Up-fishway

Figure 10. Eight movement routes through the baffle slot as shown by a typical fish (numbered). Total number of fish trips with each route (n) shown inside figure.



APPENDIX C

Literature Search Results

Warm Water Fish Passage References

(not an exhaustive list)

Attracting pallid sturgeon to the fishway

U.S. Bureau of Reclamation. 2001. Current operation of the Lower Yellowstone project at Intake, Montana. Draft biological assessment. Montana Area Office, Billings.

- typically found in areas with velocity breaks from linear flows such as areas with "sand dune" substrate, downstream island tips, or on or near the bottom of the channel that allow them to use their body shape & morphology to its full advantage
- move upstream during periods of high flow when passage over the low-head diversions may be easiest. Therefore, the coarse, rocky substrate & turbulent flows are the likely impediments

U.S. Army Corps of Engineers. 1996. Feasibility of establishing upstream fish passage at Gavins Point dam. Omaha District preliminary report, Omaha.

- the entrance of the fishway needs to be located where flows will attract the fish without excessive velocities that would force the fish away
- the water surface elevation at the entrance must be within a narrow range for the fishway to retain optimum effectiveness
- once the fish have progressed to the lake pool, measures should be in place at the exit to keep them moving away from the fishway so that they aren't swept back to the tailwater
- elevators often use low barrier dams, to direct the fish into the concentration pools; such barrier dams also could be effective for standard (non-mechanical) fishways
- weir & orifice design facilitates the upstream movement of fish that prefer to move along the bottom, rather than leaping over obstacles

Clay, C.H. 1995. Design of fishways and other fish facilities. Lewis Publishers, Boca Raton. pp. 57-127.

- the entrance to a fishway should be as close as possible to the point or line to which the migrating fish penetrate farthest upstream at an obstruction

- reasons for attraction/auxiliary water: 1) to extend the area of intensity of velocity of outflow from the fish entrances to attract more fish 2) to provide velocities in fish transportation channels of sufficient magnitude to encourage the migrating fish to keep moving in the required direction
- attraction water should not be highly aerated or turbulent

U.S. Army Corps of Engineers. 1991. Fisheries handbook of engineering requirements and biological criteria. Fish passage development and evaluation program. North Pacific Division, Portland. pp. 6.1-6.9, 26.1, 33.1- 34.41.

- upstream migrants will seek the farthest upstream point; as a general rule, this results in guidance & indicates a good location for entrances
- blind corners, particularly with 90 degree angles, should be avoided as fish tend to accumulate at such points & may jump, with subsequent injury
- as swimming ability is a function of length, ambient temperature & oxygen level, such factors must be measured & the guidance velocities used must be within the allowable parameters
- cruising speeds (a speed that can be maintained for hours) generally are attractive, & the upper limits of darting speeds (sprint/burst speeds), a barrier
- sturgeon have not been passed successfully in pool type fishways, but lock passage is possible (no citation)
- large fish (over 20 lbs) may hesitate to use shallow over-flows
- fishway exits (both ends to accommodate both upstream & downstream movement) are customarily placed well above any possible drawdown effect, or away from strong currents; a slight positive downstream current for leading is advantageous
- adults frequently seek higher velocities at obstructions, which may be utilized to attract them to fishway entrances
- in the design of upstream facilities, velocities must be kept well below the darting speeds for general passage

Pallid Sturgeon (*Scaphirhynchus albus*) Information

U.S. Bureau of Reclamation. 2001. Current operation of the Lower Yellowstone project at Intake, Montana. Draft biological assessment. Montana Area Office, Billings.

Migration:

- move up & down the lower Yellowstone River both daily & seasonally
- can move as much as 13 miles a day at a rate as fast as 6mph
- home range greatest during spring & could be as large as 198 miles
- discharge & photoperiod might be environmental cues for timing of migration & other movements; move out of lower Missouri River in early spring during increased photoperiod & relatively low discharge. They enter & move into the lower Yellowstone River as photoperiod & discharge of the Yellowstone is increasing
- reside & possibly spawn in lower Yellowstone River during times of relatively high discharge
- as photoperiod & discharge decrease in late summer, they move back into the Missouri River
- potential influence of water temperature & turbidity on movements are not known

Reproduction:

- low reproductive success throughout its range
- nonguarders & are open water/substratum egg scatterers with an adhesive egg. This requires eggs to be scattered over an appropriate substrate that would allow the egg to adhere to & remain in the appropriate habitat
- eggs hatch from 3-8 days later & the sack fry are carried downstream by the current into suitable rearing habitat
- the further upstream they spawn, the longer the drifting larval fish have to develop & select habitat before they drift into impounded waters without riverine conditions. This suggests that the ability to move upstream may be critical to the development & survival of larval & immature fish & the entire species
- in culture conditions, it was observed that the larvae are poor swimmers that swim up the water column until exhaustion, then settle out & drift, then repeat. This study indicated that the minimum drift distance needed for pallid larvae to develop is about 55-89 kilometers (34-55 miles)

Morphology & Navigation:

- morphologically adapted to live in swift water on the bottom of large, turbid, free-flowing rivers
- are not as capable of navigating turbulent waters & are not as strong as swimmers as salmonids or suckers
- typically found in areas with velocity breaks from linear flows such as areas with "sand dune" substrate, downstream island tips, or on or near the bottom of the channel that allow them to use their body shape & morphology to its full advantage

- move upstream during periods of high flow when passage over the low-head diversions may be easiest. Therefore, the coarse, rocky substrate & turbulent flows are the likely impediments
- passage of the dam has been made more difficult with the displacement of the rocks & periodic addition of new riprap

U.S. Army Corps of Engineers. 1996. Feasibility of establishing upstream fish passage at Gavins Point dam. Omaha District preliminary report, Omaha.

- show a probable size range of 15-45 pounds
- a highly mobile species with a strong seasonal migration urge
- migrations of 50-100 miles are typical, in the absence of major obstructions
- the entrance of the fishway needs to be located where flows will attract the fish without excessive velocities that would force the fish away
- the water surface elevation at the entrance must be within a narrow range for the fishway to retain optimum effectiveness
- once the fish have progressed to the lake pool, measures should be in place at the exit to keep them moving away from the fishway so that they aren't swept back to the tailwater
- elevators often use low barrier dams, to direct the fish into the concentration pools; such barrier dams also could be effective for standard (non-mechanical) fishways
- weir & orifice design facilitates the upstream movement of fish that prefer to move along the bottom, rather than leaping over obstacles

Bramblett, R.G. 1996. Habitats and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri rivers, Montana and North Dakota. Doctorate thesis. Montana State University, Bozeman.

- habitat mostly limited to turbid waters
- not described until 1905 (by Forbes & Richardson)
- decline attributed to massive habitat alterations; 51% of the total range has been channelized for barge navigation & 28% has been impounded; the remaining 21% is below dams, & therefore has altered temp., flow, & sediment dynamics
- reduction in habitat diversity & quantity may effectively remove habitat-related reproductive isolating mechanisms, thereby leading to hybridization between pallid & shovelnose sturgeon
- bioaccumulates pollution because of long life span & diet of other fishes & insects
- require large, turbid riverine habitat with a firm sandy or gravelly substrate
- movement was greater at night & was positively correlated with water temperatures & discharge (in Lake Sharpe)

- aging of sturgeon is based on pectoral fin annuli
- adult shovelnose sturgeon appear to be of limited utility as an adult pallid sturgeon surrogate because of the differences in habitat use & movements between the 2 species
- pallid & shovelnose sturgeon used bottom current velocities ranging from 0-1.37 m/s (0-4.5 ft/s), & 0.02-1.51 m/s, respectively (see attached table 1)

Odeh, M. 1999. Innovations in fish passage technology. American Fisheries Society, Bethesda. pp. 173-195.

- 4 important steps in developing fishways: 1) identifying the species & life stages (& sizes) that are migrating 2) testing these fish in an experimental fishway 3) designing & building the fishway 4) quantitatively assessing the fishway (see page 191)
- at least 2 native species (perch) could ascend the vertical-slot fishway if water velocities were less than typical velocities for salmonid designs
- for 3 species (perch & herring), there were some low-velocity trials where less than 100% of fish negotiated the fishway baffle even though 100% had negotiated a higher velocity
- one measure of the effectiveness of a fishway is the relative density of fish in the river immediately downstream, compared to the number of fish passing through the fishway
- the fishway needs to be able to pass at least 95% of the size range of each migratory life stage of each species
- to accurately assess the performance of a fishway it would seem essential to have quantitative measures of the migratory fish community as it approaches, enters, & ascends the fishway
- assessment is an essential component of developing fishways for migratory species where there is little knowledge of the behavior of these fishes in fishways
- if fish were handled in any way, they stopped migrating upstream & some moved back downstream
- an experimental fishway or baffle is particularly useful to initially determine whether the design suits the behavior of the fish
- the velocity criteria of a fishway should not be solely a function of the swimming ability of fish; diel movement patterns, ascent time, & the length of the fishway should also be considered
- avoiding tunnels when developing fishways for nonsalmonid fishes would appear to be an appropriate cautious measure (Denil design)

Clay, C.H. 1995. Design of fishways and other fish facilities. Lewis Publishers, Boca Raton. pp. 57-127.

- the entrance to a fishway should be as close as possible to the point or line to which the migrating fish penetrate farthest upstream at an obstruction
- 2 reasons for attraction water (auxiliary water): 1) to extend the area of intensity of velocity of outflow from the fish entrances to attract more fish 2) to provide velocities in fish transportation channels of sufficient magnitude to encourage the migrating fish to keep moving in the required direction
- attraction water should not be highly aerated or turbulent
- a low pressure system can supply auxiliary water to the fishway, but no air should be permitted to enter the system; this auxiliary water system might also need to be screened to prevent injury to small downstream migrant fish

U.S. Army Corps of Engineers. 1991. Fisheries handbook of engineering requirements and biological criteria. Fish passage development and evaluation program. North Pacific Division, Portland.

- upstream migrants will seek the farthest upstream point; as a general rule, this results in guidance & indicates a good location for entrances
- blind corners, particularly with 90 degree angles, should be avoided as fish tend to accumulate at such points & may jump, with subsequent injury
- as swimming ability is a function of length, ambient temperature & oxygen level, such factors must be measured & the guidance velocities used must be within the allowable parameters
- cruising speeds (a speed that can be maintained for hours) generally are attractive, & the upper limits of darting speeds (sprint/burst speeds), a barrier
- sturgeon have not been passed successfully in pool type fishways, but lock passage is possible
- large fish (over 20 lbs) may hesitate to use shallow over-flows
- fishway exits are customarily placed well above any possible drawdown effect, or away from strong currents; a slight positive downstream current for leading is advantageous
- Adults frequently seek higher velocities at obstructions, which may be utilized to attract them to fishway entrances
- In the design of upstream facilities, velocities must be kept well below the darting speeds for general passage

Tunink, D.H. 1977. The swimming performance of fishes endemic to the middle Missouri River. Masters thesis. The University of South Dakota. pp. 5-7, 43.

- critical velocity = the highest current velocity at which fish can maintain their position in the current for a 10 minute interval
- the spring or burst speed is the highest activity level & is usually maintained for < 15 seconds (see attached table 1)
- the prolonged or steady swimming speed is an activity level maintained between 200 minutes & 15 seconds (see attached table 1)
- the cruising or sustained speed level includes all locomotor activities maintained for longer than 200 minutes (see attached table 1)
- Jones et al. (1974) reported that prolonged swimming speeds, which include critical velocity estimates, averaged 25-67% higher than sustained speeds & were 20-30% of maximum burst speeds (see attached table 1)

Dryer, M.P., and A.J. Sandvol. 1993. Pallid sturgeon recovery plan. U.S. Fish & Wildlife Service, Denver. pg. 7.

- Studies on microhabitat selection of pallid sturgeon in Montana found that they are most frequently associated with water velocity ranging from 40 to 90 cps (1.3 to 2.9 ft/sec) (see attached table 1)

Helfrich, L.A., C. Liston, S. Hiebert, M. Albers, and K. Frazer. 1999. Influence of low-head diversion dams on fish passage, community composition, and abundance in the Yellowstone River, Montana. Rivers 7 (1): 21-32.

- migrating fish may use a natural channel on the south side of the river during high water events
- certain species, including shovelnose sturgeon were collected only downstream at Cartersville & Intake dams
- fish size was unrelated to passage
- no pallid sturgeon were caught during this study
- results indicate that Huntley, Cartersville, & Intake dams did not represent complete barriers to the passage of certain fish species, especially at high flows in wet years
- fish passage either over the dams or in the natural bypass channels was feasible, expecially for strong-swimming species during high flows
- from September to March of each year the natural bypass channels were dry & impassable
- shovelnose sturgeon were not collected at Huntley Dam, were rare upstream of Cartersville Dam, but were common at Intake Dam; their upstream

distribution may be restricted by the combined impacts of the diverison dams, especially during low-water (drought) years

- alternative passages to (natural or artificial) that extend fish passage to periods beyond high flows may greatly benefit fish populations during times when adults migrate upstream to spawning habitats & juveniles move to nursery areas & overwintering habitats
- swimming ability may be related to fish passage, because strong swimming species (10) exhibited dam passage in this study, whereas 27 other species did not
- dams create good habitat for predators
- alternatives for fish passage mitigation at low-head dams include: 1) adding artificial riffles, although the efficacy of these on native fishes is unknown; 2) including conventional fish ladders, elevators, or locks, although these may prove to be inefficient for nonsalmonids; & 3) completing dam removal, although downstream sedimentation & other issues are concerns

McLeod, A.M., and P. Nemenyi. 1939-1940. An investigation of fishways. Iowa Institution of Hydraulic Research. pgs. 5

The study of fishways from the point of view of the effort required of the fish may be approached by 2 methods:

- First, gather empirical data at actual fishways with satisfactory entrance conditions, as to the passage of the fish; the % of fish failing to pass; & the apparent effort of those which complete the passage
- The 2nd approach consists of 3 phases – a) a study of the hydraulic properties of various fishways by measurements & observations on small models as well as on full-scale fishways with application of the general laws of fluid mechanics; b) a study of the relation of fish effort to the properties of the flow; and c) determination of the limit of effort of which each different species is normally capable
- If the size of the cross section of a fishway is increased, other conditions remaining the same, the velocity would increase & the fishway would become more difficult to pass. By a proper reduction of the slope, the increase in size can be compensated.

Additional Useful Literature

Bunt, C.M. 1999. Fishways for warmwater species: Utilization patterns, attraction efficiency, passage efficiency, and relative physical output. PhD Dissertation, University of Waterloo, Ontario, Canada. (also see http://www.biotactic.com/newpage1.htm)

Colt, J. and R.J. White, editors. 1991. Fisheries Bioengineering Symposium. American Fisheries Society Symposium 10.

Bruch, R. and M. Endris. 1989. Use of Eureka fishway, Fox River, WI by warmwater fish populations. Spring 1989 Wisconsin DNR Report.

http://www.fisheries.org/Meetings/Recent_AFS_Annual_Mtgs/annual98/program/monday12.htm#5

APPENDIX D

Additional Details from Hydraulic Analysis

Purpose of Appendix

The purpose of the appendix is to supplement data presented in the main report. General modeling procedures and assumptions not found in the main report will be presented as well as output from the model itself. Data from the existing conditions, riprap fish ladder, grouted riprap fish ladder, and the collapsible gate alternatives will be presented in this appendix. The results from the modeling ofa all of the alternatives are on file with the Omaha District Corps of Engineers.

Project Data

The project data received from the Bureau for the study included the HEC-RAS model used in the report entitled, "Intake Diversion Dam, Yellowstone River, Montana, Fish Protection and Passage Concept Study Report" dated January 2000 (Bureau of Reclamation, 2000). The HEC-RAS model did match the runs used in the Bureau of Reclamation's 2000 report and was accepted as reflecting existing conditions. The HEC-RAS data modeled the existing dam, which extends about 700 feet across the Yellowstone River channel. The dam rises approximately 8 to 10 feet above the channel bed. The crest of the dam varies from elevation 1989 at the left (north) channel bank (looking downstream) to elevation 1987 at the right (south) channel bank. 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 100-foot long 1:10 downstream slope. No additional survey data was obtained or used in this analysis.

Various alternatives were examined using the HEC-RAS model. Use of the 3.0 version of HEC-RAS allowed the use of the flow optimization procedure at reach or stream junctions. This was used for the existing conditions model to determine the gate openings required in the diversion dam structure while maintaining the diversion flows in the Bureau model.

In order to further utilize the flow optimization for HEC-RAS, all the alternatives modeled were developed as separate stream or flow reaches to allow the model to use the Yellowstone River elevations to determine the flow in the alternative as well as the downstream water surface elevation.

The flows used in the Bureau's HEC-RAS model, were also used when modeling all alternatives. The flows ranged from 5,000 cfs to 38,800 cfs, providing for a wide range of flow conditions on the Yellowstone River.

Model Layout

Examples of the model layout for existing conditions is shown in Figure 1. The results of the flow optimization are shown in the Table 1 and were copied directly from the HEC-RAS program. The gate openings were set as shown in Table 2 to achieve the required discharges in the irrigation canal.

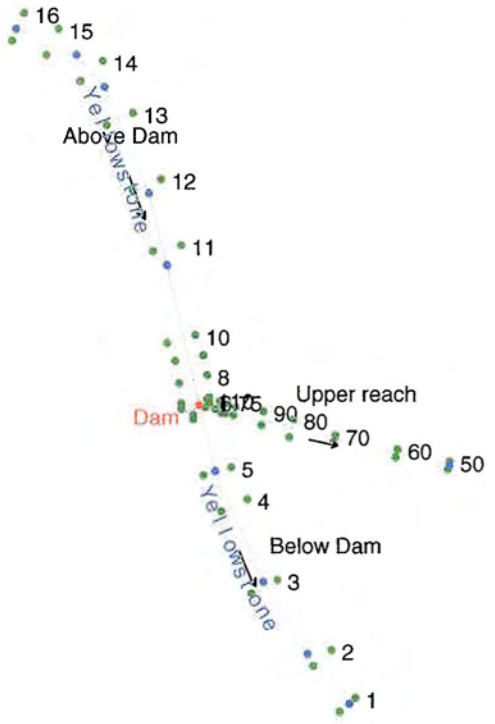


Figure 1 Model Layout for Existing Conditions

Table 1 Flow Optimization Results
Existing Conditions

RAS Plan: rpt flow disRiver	Reach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Yellowstone	Above Dam	6.75	1990.22	1990.23	5000.00
Yellowstone	Above Dam	6.75	1992.33	1992.40	15000.00
Yellowstone	Above Dam	6.75	1994.53	1994.73	29500.00
Yellowstone	Above Dam	6.75	1995.69	1995.97	38800.00
Junction:	Dam				
Yellowstone	Below Dam	6.6	1990.21	1990.22	3830.82
Yellowstone	Below Dam	6.6	1992.32	1992.39	13588.41
Yellowstone	Below Dam	6.6	1994.53	1994.71	28099.16
Yellowstone	Below Dam	6.6	1995.68	1995.94	37398.11
Intake Canal	Upper reach	110	1990.17	1990.20	1169.18
Intake Canal	Upper reach	110	1992.35	1992.38	1411.59
Intake Canal	Upper reach	110	1994.67	1994.69	1400.84
Intake Canal	Upper reach	110	1995.94	1995.96	1401.89

These results represented existing conditions. To obtain these flows the following gate openings were used:

Table 2
Gate Openings for Existing Conditions

Yellowstone River Discharge	Number of Gates Opened	Gate Opening In feet
5,000 cfs	11	5.0
15,000 cfs	11	3.3
29,500 cfs	11	1.7
38,800 cfs	11	1.6

Riprap Fish Ladder with Boulder Weirs

The riprap fish ladder was also modeled. As explained in the main report it is very similar to the Bureau of Reclamations plan presented in their January 2000 report, except the slope was increased. A schematic of the model layout is shown in Figure 2. The results of the flow optimization are show in Table 3. A typical ladder section is shown in Figure 3.

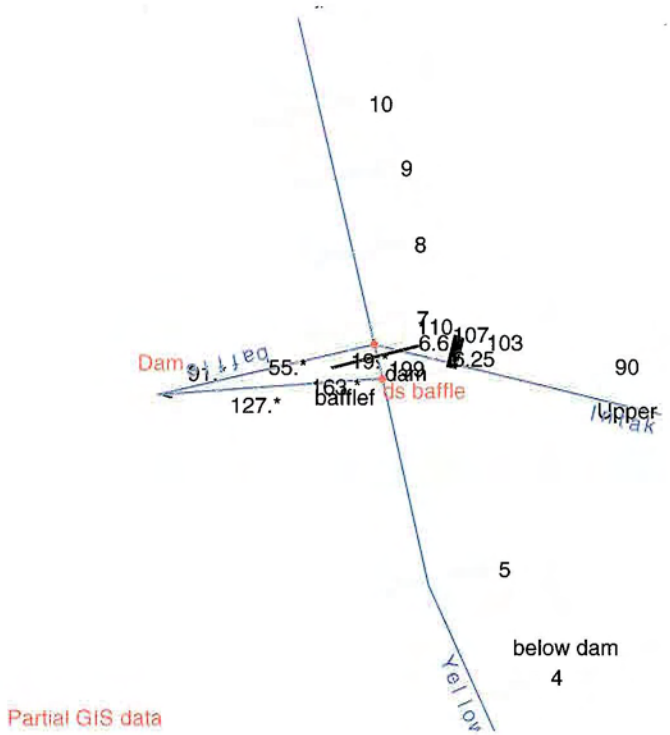


Figure 2 Model Layout of Riprap Fish Ladder Model

Table 3 Flow Optimization Results
Riprap Fish Ladder Conditions

RAS Plan: BOR PassageReach	River Sta	W.S. Elev	E.G. Elev	Q Total
		(ft)	(ft)	(cfs)
Above Dam	6.75	1990.15	1990.16	5000.00
Above Dam	6.75	1992.21	1992.29	15000.00
Above Dam	6.75	1994.36	1994.56	29500.00
Above Dam	6.75	1995.48	1995.77	38800.00
Junction:	Dam			
dam	6.6	1990.15	1990.16	3622.28
dam	6.6	1992.22	1992.28	13020.23
dam	6.6	1994.37	1994.53	26894.02
dam	6.6	1995.49	1995.73	35755.63
Upper reach	110	1990.14	1990.17	1161.39
Upper reach	110	1992.25	1992.27	1399.74
Upper reach	110	1994.52	1994.54	1405.76
Upper reach	110	1995.71	1995.73	1404.50
bafflef	199	1989.29	1990.17	216.33
bafflef	199	1990.94	1992.28	580.03
bafflef	199	1992.72	1994.53	1200.23
bafflef	199	1993.67	1995.73	1639.87

Table 3 Flow Optimization Results
Riprap Fish Ladder Conditions

RAS Plan: BOR PassageReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
dam	6.25	1984.48	1984.50	3622.28
dam	6.25	1988.08	1988.17	13020.23
dam	6.25	1991.11	1991.30	26894.02
dam	6.25	1992.68	1992.92	35755.63
bafflef	1	1985.31	1986.17	216.33
bafflef	1	1987.51	1988.40	580.03
bafflef	1	1990.75	1991.42	1200.23
bafflef	1	1992.34	1993.03	1639.87
Junction:	ds baffle			
below dam	6	1984.48	1984.49	3838.61
below dam	6	1988.09	1988.15	13600.26
below dam	6	1991.12	1991.26	28094.24
below dam	6	1992.69	1992.87	37395.50

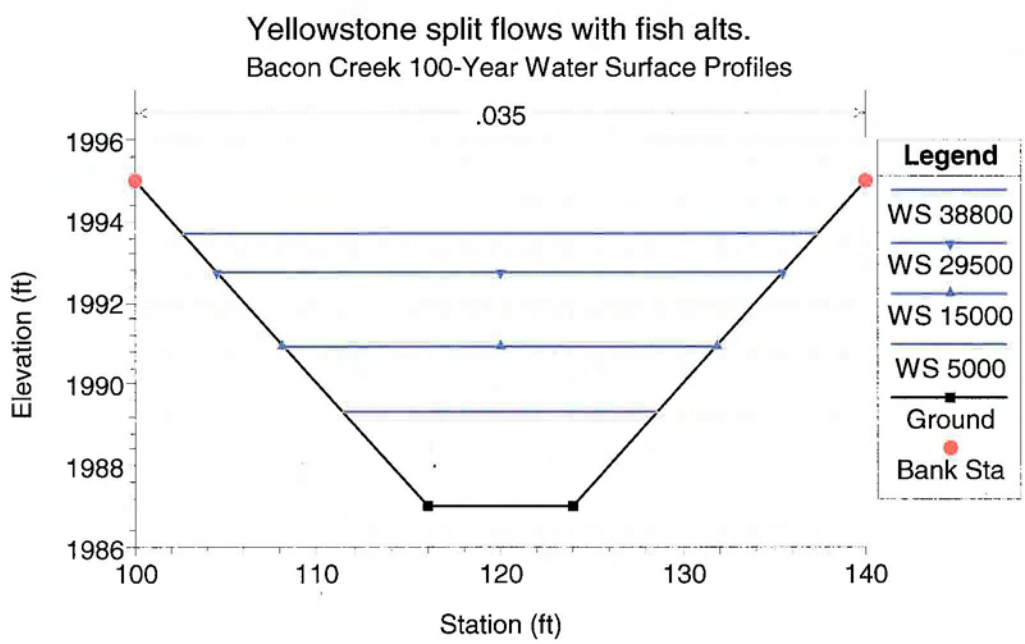


Figure 3 Typical Section from Riprap Fish Ladder Model

Grouted Riprap Fish Ladder

The grouted riprap fish ladder was also modeled. As explained in the main report, during the development of initial concepts, two factors were analyzed to maintain low average velocities. These two factors were the upstream channel area and the slope of the channel itself. These factors were calculated by normal depth in the initial concept phase. A trade-off between the elevation of the upstream inlet and the slope forced the alternative to have a long length in order to keep the average velocity in the acceptable range. A larger upstream area would allow more water to enter the alternative and increase velocities. A higher upstream inlet elevation would restrict the amount of inflowing water but would increase average velocities by increasing the slope of the channel. Later the alterative were modeled using HEC-RAS but the lengths were not changed. In addition, features such as boulder weirs, baffles, and depression were not incorporated in the model since they cannot be adequately modeled using a one-dimensional model. A schematic of the model layout is shown in Figure 4. The results of the flow optimization are show in Table 4. A typical ladder section is shown in Figure 5.

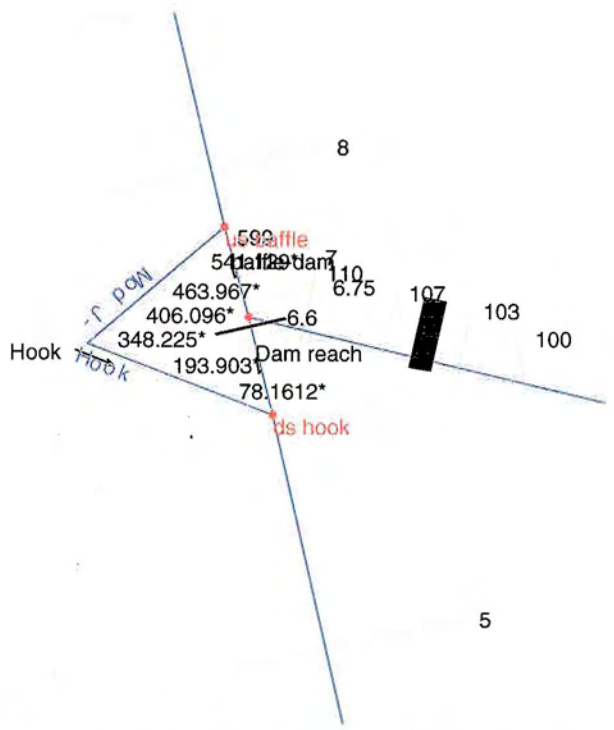


Figure 4 Model Layout of Grouted Riprap Fish Ladder Model

Table 4 Flow Optimization Results
Grouted Riprap Fish Ladder Conditions

RAS Plan: trapus91.4Reach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
baffle-dam	6.75	1989.86	1989.87	3709.52
baffle-dam	6.75	1991.96	1992.04	14548.41
baffle-dam	6.75	1994.14	1994.34	28759.68
baffle-dam	6.75	1995.30	1995.59	38288.71
Junction:	Dam			
Dam reach	6.6	1989.86	1989.86	2623.44
Dam reach	6.6	1991.97	1992.02	11326.80
Dam reach	6.6	1994.16	1994.31	24547.11
Dam reach	6.6	1995.33	1995.55	33070.31
Upper reach	110	1989.83	1989.86	1086.08
Upper reach	110	1991.99	1992.02	1421.60
Upper reach	110	1994.28	1994.30	1412.57
Upper reach	110	1995.53	1995.55	1418.40
Above Dam	8	1989.86	1989.88	5000.00
Above Dam	8	1992.02	1992.12	15000.00
Above Dam	8	1994.29	1994.52	29500.00
Above Dam	8	1995.50	1995.82	38800.00
Junction:	us baffle			
baffle-dam	7	1989.86	1989.87	3709.52
baffle-dam	7	1991.97	1992.05	14548.41
baffle-dam	7	1994.18	1994.37	28759.68
baffle-dam	7	1995.35	1995.63	38288.71
Hook	599	1989.52	1989.88	1290.48
Hook	599	1991.46	1992.04	2251.59
Hook	599	1993.54	1994.39	3540.32
Hook	599	1994.65	1995.65	4311.28
Dam reach	6	1984.47	1984.47	2623.44
Dam reach	6	1988.03	1988.07	11326.80
Dam reach	6	1991.01	1991.12	24547.11
Dam reach	6	1992.55	1992.70	33070.31
Hook	1	1985.76	1987.38	1290.48
Hook	1	1987.34	1989.40	2251.59
Hook	1	1988.82	1991.47	3540.32
Hook	1	1990.57	1992.77	4311.28
Junction:	ds hook			
Below dam	5	1983.94	1984.30	3913.92
Below dam	5	1987.49	1987.71	13578.40
Below dam	5	1990.35	1990.64	28087.44

Table 4 Flow Optimization Results
Grouted Riprap Fish Ladder Conditions

RAS Plan: trapus91.4Reach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Below dam	5	1991.86	1992.20	37381.60

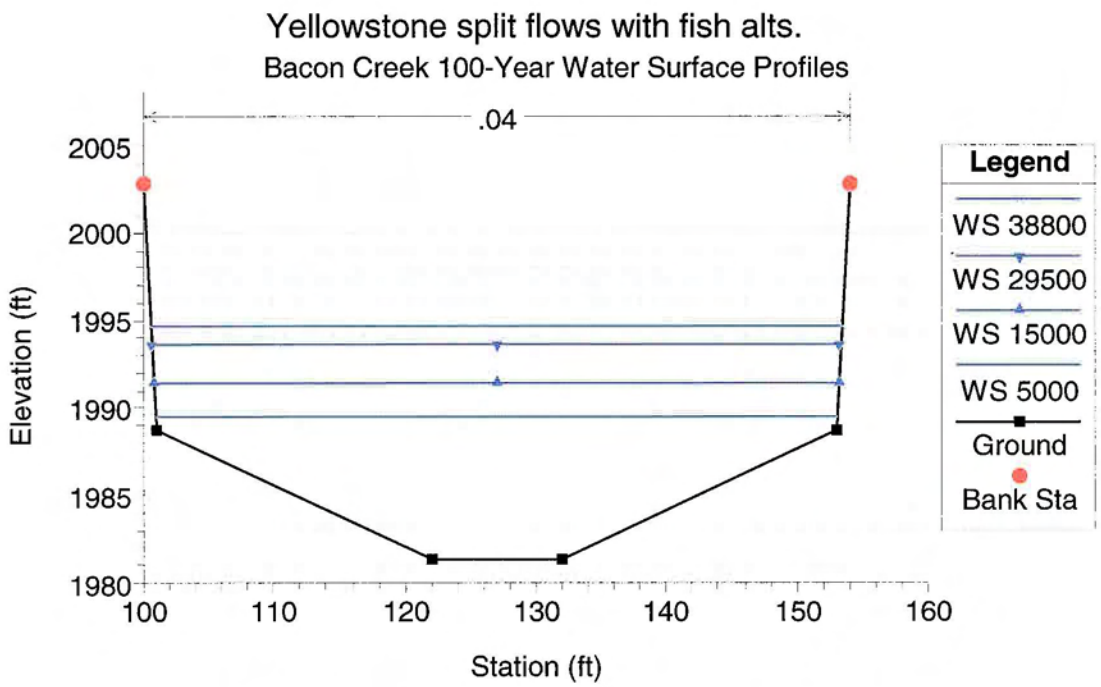


Figure 5 Typical Section from Riprap Fish Ladder Model

Collapsible Gates

The collapsible gate alternatvie was also modeled. The gates were modeled using two methods. The first method was to use the existing HEC-RAS model where the dam was modeled as an inline weir (The Bureau's model used the inline weir option). HEC-RAS would use the weir equation but would account for submergence from the downstream tailwater. The weir crest was edited for the various gate opening to reflect the lowering of the gates. This model was used to set the flow distribution, etc. To calculate velocities, the inline weir was converted to an embankment (inline weir removed). Initial comparison of the results showed they were not the same, but similar. This procedure was the selected to provide an indication of velocities in the "gate opening". A schematic of the model layout using the inline weir is shown in Figure 6. The results of the flow optimization and intake canal gate openings for various collapsible gate openings are show in Tables 5, 6, 7, 8, 9, 10, 11, and 12. A typical section showing several gate openings are shown in Figures 7, 8, 9, and 10.

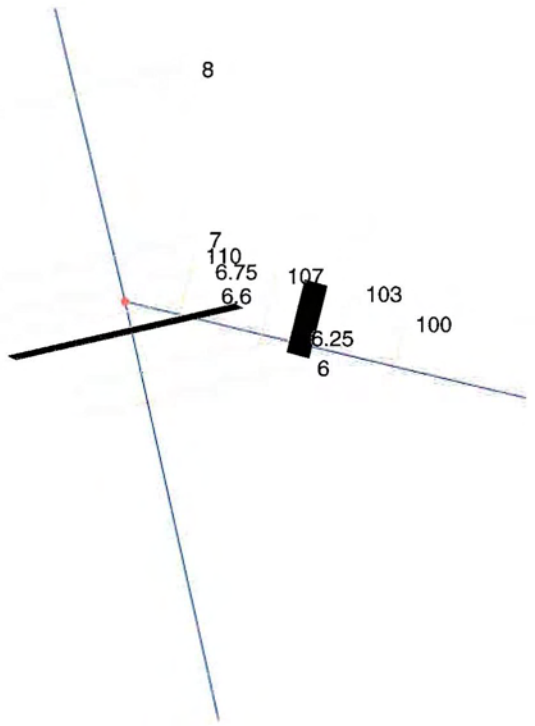


Figure 6 Model Layout for Collapsible Gates using Inline Weir

Table 5 Flow Optimization Results
Collapsible Gates with One Gate Fully Lowered

RAS Plan: 1 inline rgReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Above Dam	6.75	1990.12	1990.13	5000.00
Above Dam	6.75	1992.34	1992.42	15000.00
Above Dam	6.75	1994.58	1994.77	29500.00
Above Dam	6.75	1995.76	1996.03	38800.00
Junction:	Dam			
Below Dam	6.6	1990.12	1990.12	3849.42
Below Dam	6.6	1992.34	1992.40	13595.73
Below Dam	6.6	1994.57	1994.75	28094.31
Below Dam	6.6	1995.75	1996.00	37396.35
Upper reach	110	1990.09	1990.13	1150.59
Upper reach	110	1992.38	1992.40	1404.27
Upper reach	110	1994.74	1994.76	1405.69
Upper reach	110	1995.97	1995.98	1403.65

These results represented the flow discharges for collapsible gate conditions with one gate lowered using the inline weir model. To obtain these flows the following gate openings were used:

Table 6 Gate Openings for Gate Openings for Collapsible Gates with One Gate Fully Lowered		
Yellowstone River Discharge	**Number of Gates Opened**	**Gate Opening In feet**
5,000 cfs	11	5.0
15,000 cfs	11	3.2
29,500 cfs	11	1.7
38,800 cfs	11	1.6

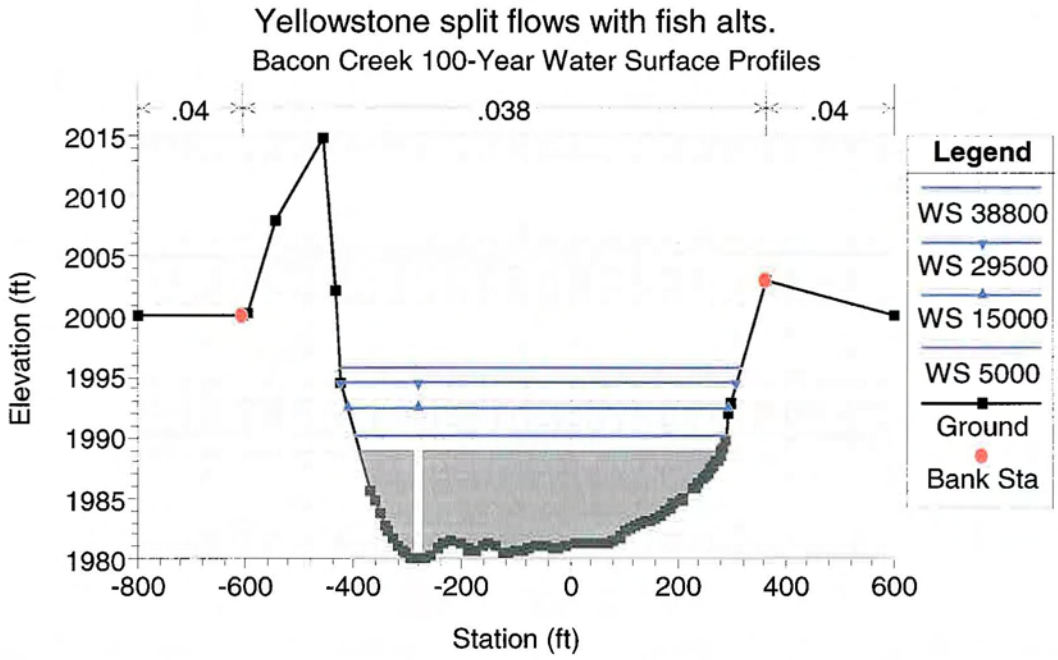


Figure 7 Cross Section at the Inline Weir for Collapsible Gates with One Gate Fully Lowered

Table 7 Flow Optimization Results
Collapsible Gates with Three Gate Fully Lowered

RAS Plan: 3 inline rgReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Above Dam	6.75	1988.84	1988.86	5000.00
Above Dam	6.75	1991.58	1991.67	15000.00
Above Dam	6.75	1993.91	1994.13	29500.00
Above Dam	6.75	1995.13	1995.43	38800.00
Junction:	Dam			
Below Dam	6.6	1988.84	1988.85	4156.73
Below Dam	6.6	1991.58	1991.65	13595.92

Table 7 Flow Optimization Results
Collapsible Gates with Three Gate Fully Lowered

RAS Plan: 3 inline rgReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Below Dam	6.6	1993.91	1994.11	28093.15
Below Dam	6.6	1995.12	1995.40	37390.04
Upper reach	110	1988.82	1988.84	843.27
Upper reach	110	1991.60	1991.63	1404.08
Upper reach	110	1994.10	1994.12	1406.85
Upper reach	110	1995.40	1995.42	1409.96

These results represented the flow discharges for collapsible gate conditions with three gates lowered using the inline weir model. To obtain these flows the following gate openings were used:

Table 8
Gate Openings for Gate Openings for Collapsible Gates with Three Gate Fully Lowered

Yellowstone River Discharge	Number of Gates Opened	Gate Opening In feet
5,000 cfs	11	5.0
15,000 cfs	11	4.6
29,500 cfs	11	1.76
38,800 cfs	11	1.65

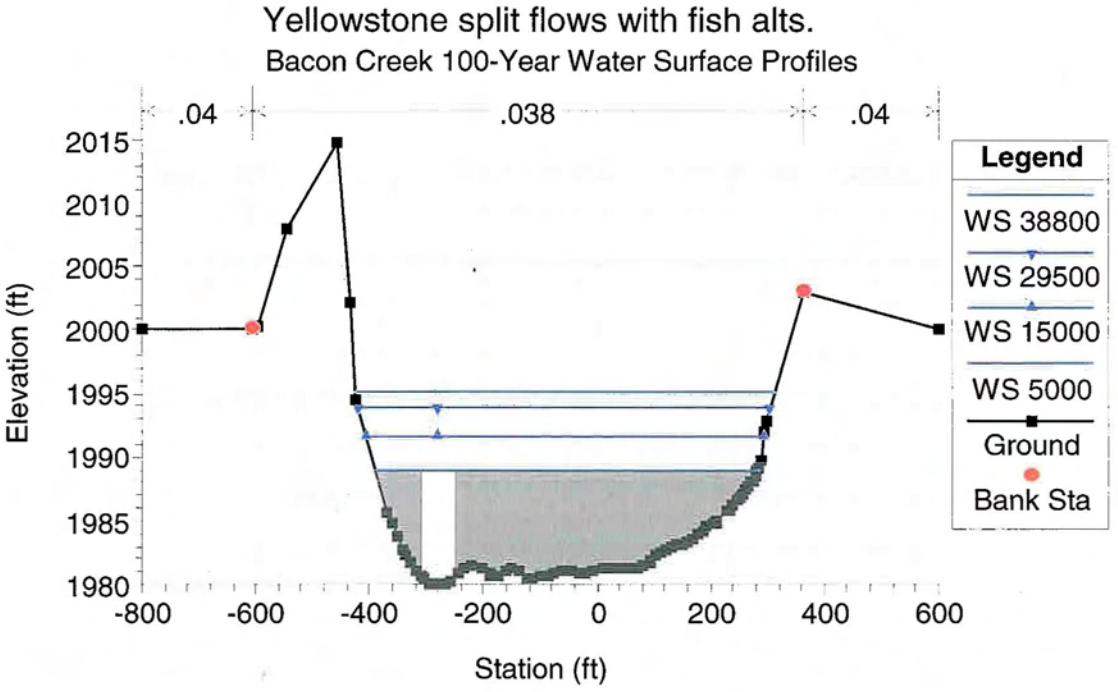


Figure 8 Cross Section at the Inline Weir for Collapsible Gates with Three Gates Fully Lowered

Table 9 Flow Optimization Results
Collapsible Gates with Five Gate Fully Lowered

RAS Plan: 5 inline rgReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Above Dam	6.75	1987.07	1987.11	5000.00
Above Dam	6.75	1990.95	1991.05	15000.00
Above Dam	6.75	1993.36	1993.60	29500.00
Above Dam	6.75	1994.60	1994.93	38800.00
Junction:	Dam			
Below Dam	6.6	1987.07	1987.10	4519.22
Below Dam	6.6	1990.94	1991.03	13677.08
Below Dam	6.6	1993.35	1993.57	28095.73
Below Dam	6.6	1994.59	1994.89	37393.02
Upper reach	110	1987.10	1987.11	480.78
Upper reach	110	1991.00	1991.04	1322.93
Upper reach	110	1993.55	1993.57	1404.27
Upper reach	110	1994.87	1994.89	1406.98

These results represented the flow discharges for collapsible gate conditions with five gates lowered using the inline weir model. To obtain these flows the following gate openings were used:

Table 10
Gate Openings for Collapsible Gates with Five Gate Fully Lowered

Yellowstone River Discharge	Number of Gates Opened	Gate Opening In feet
5,000 cfs	11	5.0
15,000 cfs	11	5.0
29,500 cfs	11	1.92
38,800 cfs	11	1.69

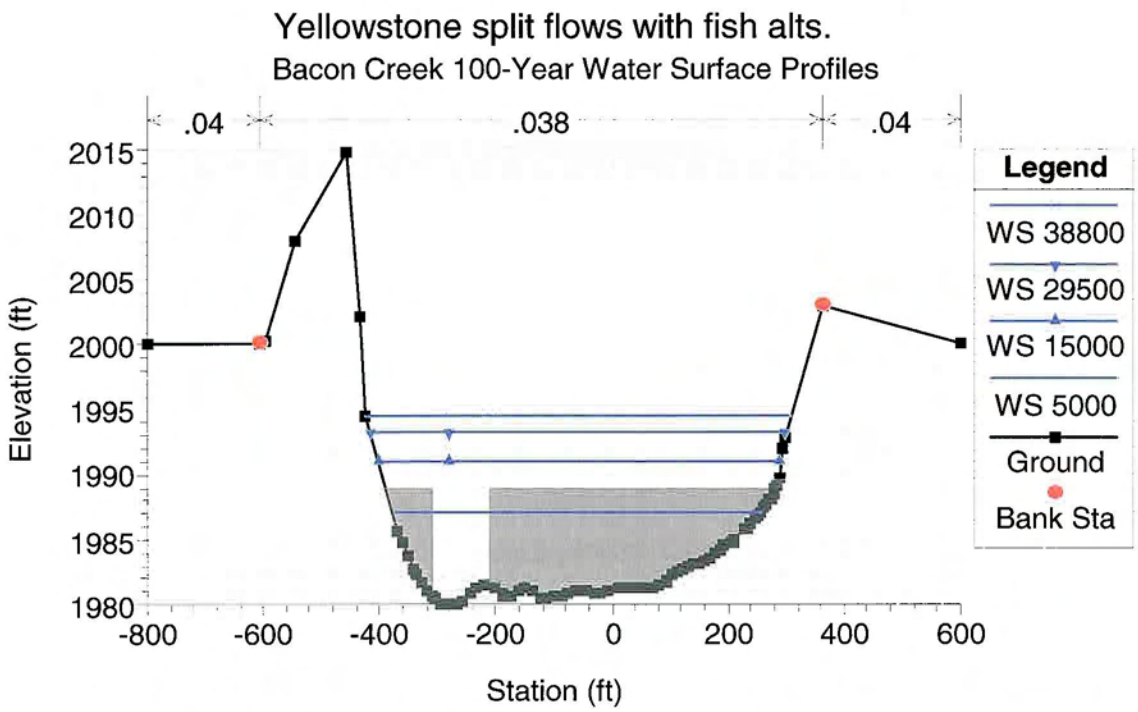


Figure 9 Cross Section at the Inline Weir for Collapsible Gates with Five Gates Fully Lowered

Table 11 Flow Optimization Results
Collapsible Gates with Ten Gate Fully Lowered

RAS Plan: 10 inline rgReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Above Dam	6.75	1985.40	1985.48	5000.00
Above Dam	6.75	1989.34	1989.50	15000.00
Above Dam	6.75	1992.08	1992.39	29500.00
Above Dam	6.75	1993.49	1993.90	38800.00
Junction:	Dam			
Below Dam	6.6	1985.37	1985.45	4955.10
Below Dam	6.6	1989.33	1989.47	14015.64
Below Dam	6.6	1992.07	1992.35	28094.16
Below Dam	6.6	1993.47	1993.85	37398.58
Upper reach	110	1985.43	1985.43	44.90
Upper reach	110	1989.42	1989.45	984.36
Upper reach	110	1992.32	1992.35	1405.84
Upper reach	110	1993.83	1993.85	1401.42

These results represented the flow discharges for collapsible gate conditions with ten gates lowered using the inline weir model. To obtain these flows the following gate openings were used:

Table 12 Gate Openings for Collapsible Gates with Ten Gate Fully Lowered		
Yellowstone River Discharge	**Number of Gates Opened**	**Gate Opening In feet**
5,000 cfs	11	5.0
15,000 cfs	11	5.0
29,500 cfs	11	3.3
38,800 cfs	11	1.78

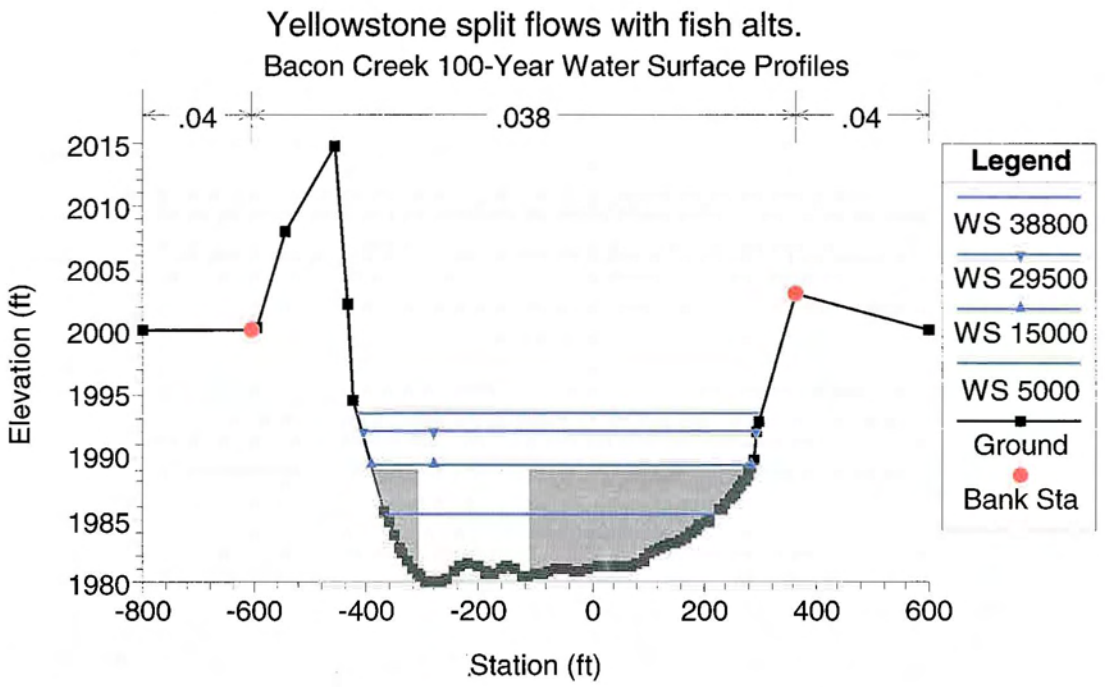


Figure 10 Cross Section at the Inline Weir for Collapsible Gates with Ten Gates Fully Lowered

A schematic of the collapsible model layout without the inline weir (the dam and gates were modeled as an embankment) is shown in Figure 11. The results of the flow optimization for various gate openings are show in Tables 13, 14, 15, 16, 17, 18, 19, and 20. A typical section showing several gate openings are shown in Figures 12, 13, 14, and 15.

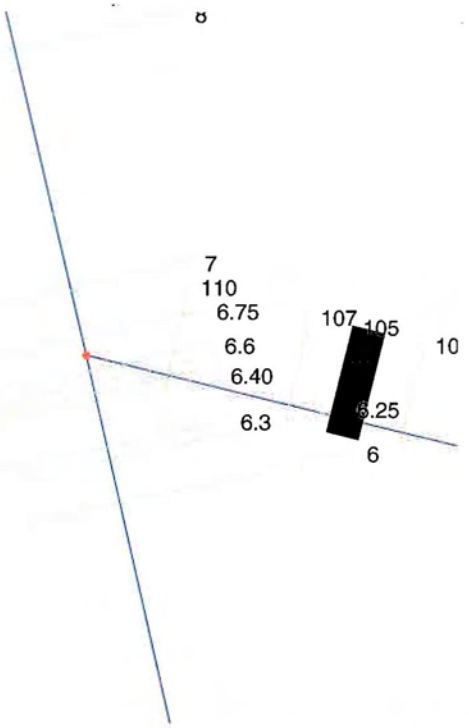


Figure 11 Model Layout for Collapsible Gates modeled as an Embankment

Table 13 Flow Optimization Results
Collapsible Gates with One Gate Fully Lowered
Gates/Dam modeled as an Embankment

RAS Plan: 1 oberReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Above Dam	6.75	1990.39	1990.40	5000.00
Above Dam	6.75	1992.32	1992.40	15000.00
Above Dam	6.75	1994.32	1994.52	29500.00
Above Dam	6.75	1995.42	1995.71	38800.00
Junction:	Dam			
Below Dam	6.6	1990.38	1990.39	3789.79
Below Dam	6.6	1992.32	1992.38	13599.38
Below Dam	6.6	1994.31	1994.50	28114.64
Below Dam	6.6	1995.41	1995.67	37416.57
Upper reach	110	1990.35	1990.39	1210.21
Upper reach	110	1992.36	1992.38	1400.62
Upper reach	110	1994.46	1994.48	1385.36
Upper reach	110	1995.65	1995.67	1383.43

These results represented the flow discharges for collapsible gate conditions with one gate lowered using the embankment model. To obtain these flows the following gate openings were used:

Table 14 Gate Openings for Collapsible Gates with One Gate Fully Lowered (Embankment Model)		
Yellowstone River Discharge	**Number of Gates Opened**	**Gate Opening In feet**
5,000 cfs	11	5.0
15,000 cfs	11	3.2
29,500 cfs	11	1.7
38,800 cfs	11	1.6

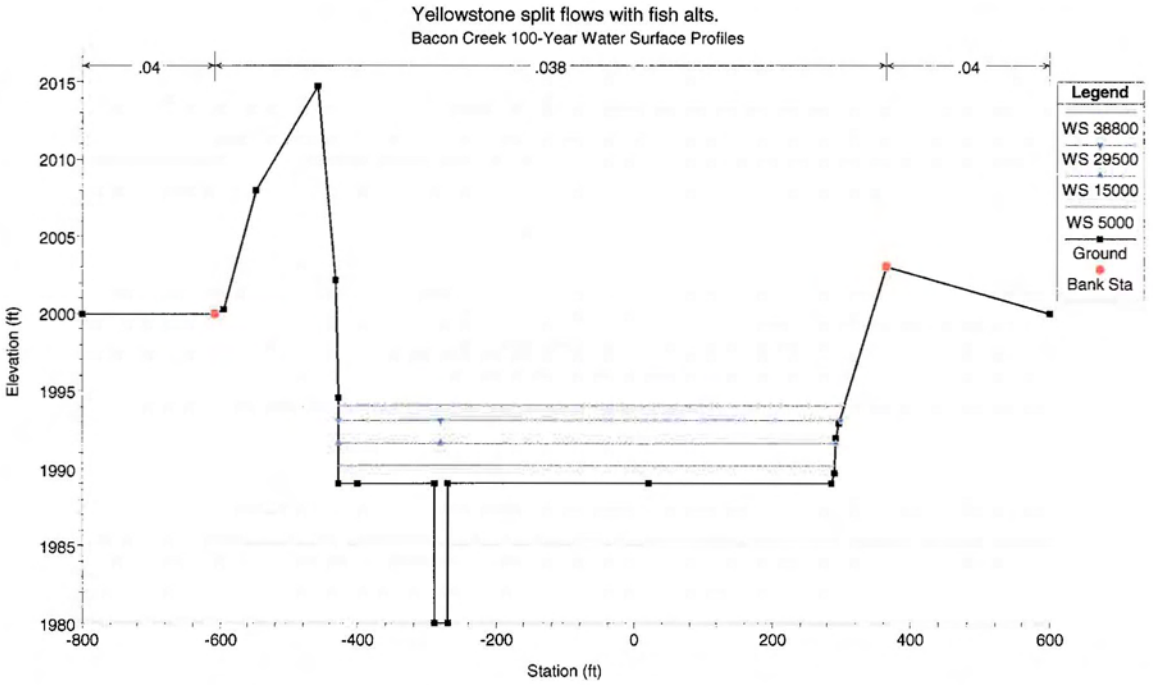


Figure 12 Cross Section at Embankment for Collapsible Gates with One Gate Fully Lowered

Table 15 Flow Optimization Results
Collapsible Gates with Three Gate Fully Lowered
Gates/Dam modeled as an Embankment

RAS Plan: 3 oberReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Above Dam	6.75	1988.48	1988.50	5000.00
Above Dam	6.75	1991.80	1991.88	15000.00
Above Dam	6.75	1993.81	1994.03	29500.00
Above Dam	6.75	1994.91	1995.23	38800.00
Junction:	Dam			
Below Dam	6.6	1988.48	1988.49	4234.82
Below Dam	6.6	1991.79	1991.86	13543.80
Below Dam	6.6	1993.81	1994.01	28102.03
Below Dam	6.6	1994.90	1995.19	37404.44
Upper reach	110	1988.46	1988.49	765.18
Upper reach	110	1991.84	1991.87	1456.20
Upper reach	110	1993.98	1994.00	1397.97
Upper reach	110	1995.19	1995.21	1395.56

These results represented the flow discharges for collapsible gate conditions with three gates lowered using the embankment model. To obtain these flows the following gate openings were used:

Table 16
Gate Openings for Collapsible Gates with Three Gate Fully Lowered (Embankment Model)

Yellowstone River Discharge	Number of Gates Opened	Gate Opening In feet
5,000 cfs	11	5.0
15,000 cfs	11	4.6
29,500 cfs	11	1.76
38,800 cfs	11	1.65

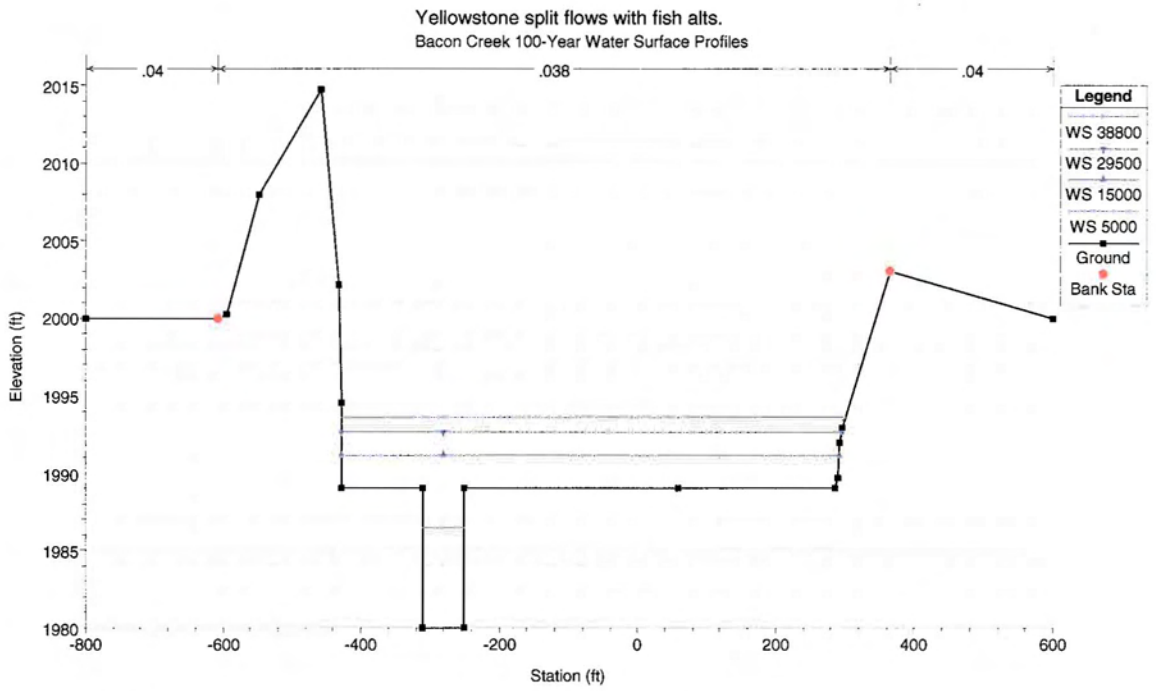


Figure 13 Cross Section at Embankment for Collapsible Gates with Three Gate Fully Lowered

Table 17 Flow Optimization Results
Collapsible Gates with Five Gate Fully Lowered
Gates/Dam modeled as an Embankment

RAS Plan: 5 oberReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Above Dam	6.75	1986.47	1986.52	5000.00
Above Dam	6.75	1992.70	1992.77	15000.00
Above Dam	6.75	1993.31	1993.55	29500.00
Above Dam	6.75	1994.38	1994.72	38800.00
Junction:	Dam			
Below Dam	6.6	1986.46	1986.50	4691.53
Below Dam	6.6	1992.70	1992.75	13313.55
Below Dam	6.6	1993.30	1993.52	28108.87
Below Dam	6.6	1994.36	1994.69	37407.44
Upper reach	110	1986.51	1986.52	308.47
Upper reach	110	1992.70	1992.73	1686.45
Upper reach	110	1993.48	1993.50	1391.13
Upper reach	110	1994.67	1994.69	1392.56

These results represented the flow discharges for collapsible gate conditions with five gates lowered using the embankment model. To obtain these flows the following gate openings were used:

Table 18 Gate Openings for Collapsible Gates with Five Gate Fully Lowered (Embankment Model)		
Yellowstone River Discharge	**Number of Gates Opened**	**Gate Opening In feet**
5,000 cfs	11	5.0
15,000 cfs	11	5.0
29,500 cfs	11	1.92
38,800 cfs	11	1.69

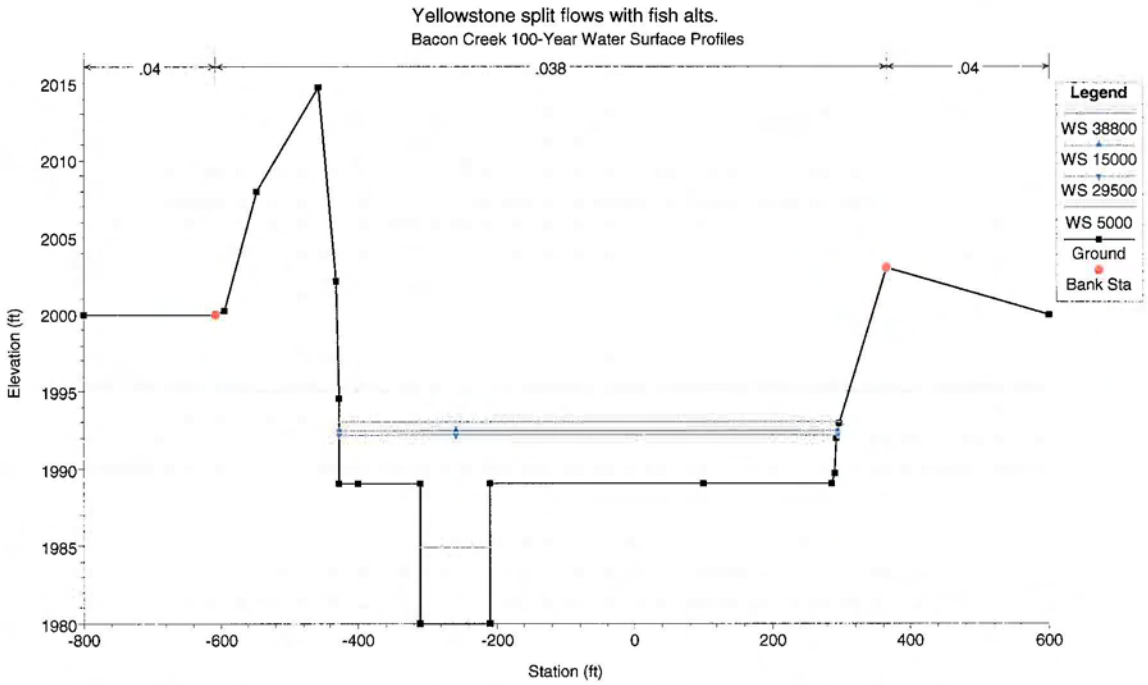


Figure 14 Cross Section at Embankment for Collapsible Gates with Five Gate Fully Lowered

Table 19 Flow Optimization Results
Collapsible Gates with Ten Gate Fully Lowered
Gates/Dam modeled as an Embankment

RAS Plan: 10 oberReach	River Sta	W.S. Elev (ft)	E.G. Elev (ft)	Q Total (cfs)
Above Dam	6.75	1985.38	1985.46	5000.00
Above Dam	6.75	1988.95	1989.13	15000.00
Above Dam	6.75	1991.99	1992.31	29500.00
Above Dam	6.75	1993.33	1993.74	38800.00
Junction:	Dam			
Below Dam	6.6	1985.34	1985.42	4954.58
Below Dam	6.6	1988.93	1989.09	14099.43
Below Dam	6.6	1991.97	1992.26	28113.27
Below Dam	6.6	1993.29	1993.68	37415.34
Upper reach	110	1985.43	1985.43	45.42
Upper reach	110	1989.07	1989.09	900.57
Upper reach	110	1992.22	1992.25	1386.73
Upper reach	110	1993.66	1993.68	1384.66

These results represented the flow discharges for collapsible gate conditions with ten gates lowered using the embankment model. To obtain these flows the following gate openings were used:

Table 20
Gate Openings for Collapsible Gates with Ten Gate Fully Lowered (Embankment Model)

Yellowstone River Discharge	Number of Gates Opened	Gate Opening In feet
5,000 cfs	11	5.0
15,000 cfs	11	5.0
29,500 cfs	11	3.3
38,800 cfs	11	1.78

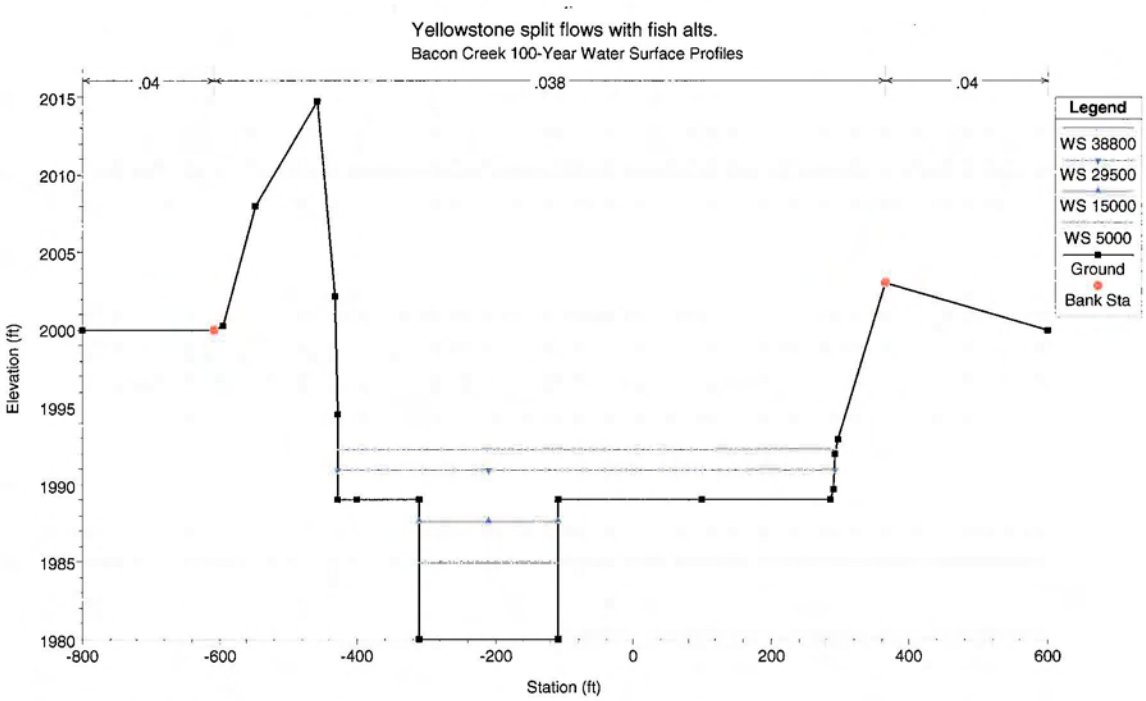


Figure 15 Cross Section at Embankment for Collapsible Gates with Ten Gate Fully Lowered

APPENDIX E

Construction Estimate Cost Details and Assumptions

Structural Assumptions

The concepts for the structures in the draft Preliminary Fish Passage Alternatives were reviewed and found adequate for the 10% design stage. The concept drawings were revised to more accurately reflect the concepts and to improve readability. The original estimates for the concepts were reviewed by Cost Branch and revised as appropriate. (See attached.) The estimate format was modified to allow adjustment for variations of the configuration shown.

In addition to a review of the original concepts, new concepts were developed for a grouted rip-rap fish ladder and a collapsible dam. Drawings and estimates for these alternatives were added to the original concepts.

The cost for the fish ladder structure may be reduced by making certain modifications, such as using a berm instead of a concrete wall adjacent to the dam or by changing the structure's length. The slope should not be increased, but it may be possible to truncate the ladder as long as sufficient depth is maintained over the discharge end.

The estimate for the collapsible gate structure assumes only a limited amount of work for modification of the streambed. If the collapsible gates are extended for the full width of the stream, it may be necessary to remove a significant amount of rocks both upstream and downstream of the dam in order to obtain the necessary streambed profile. Extending the gates only partially across the river will minimize the amount of streambed work and reduce the cost of the dam. The remainder of the width can be closed with a new concrete spillway (as assumed in the estimate) or the existing rock dam can be rebuilt. If the existing rock dam is rebuilt, consideration should be given to embedding a sheetpile or concrete wall within it to help reduce displacement of the rocks by water and ice. This would also help maintain the proper crest elevation and reduce the transport of rock downstream of the dam.

Using a partial width collapsible gate instead of full width would provide a deeper flow of water through the dam when the gates are lowered. This may be advantageous for boat and fish passage if the stream velocity through the gates is not too great. (Since the gates would not necessarily be lowered during the fish migration period, they would not serve as a substitute for the fish passage structures.) With either the partial or full width collapsible gate alternatives, erosion of the dam would be reduced or eliminated. However periodic maintenance would be required to remove rocks which could interfere with operation of the gates.

The collapsible gate concept assumes that the existing sheet piles are in good condition and are in such a location that they can be reused. Although the sheet piles are approximately 90 years old, they have not been exposed to the atmosphere and therefore should still be serviceable. This would need to be verified during the design. If they are not serviceable or are not in the proper location, the dam foundation would need to be resized or new piles driven as required to provide the necessary stability. (Geotechnical Section has indicated that the existing subgrade has characteristics that should prevent excessive seepage and provide adequate bearing capacity to directly support the dam structure, therefore sheet piles may not be required.)

The collapsible gate structure requires a building to house the compressor and controls for the gate operators. The building should be of secure construction to prevent unauthorized access and minimize potential damage from vandalism. Power for the compressor and controls is assumed to be available in the area. Remote monitoring of the gates would be possible with the addition of sensors and transmission equipment.

The air bladders which operate the gates are of a reinforced high strength material which is resistant to abrasion as well as to deterioration by the elements and sunlight. The bladders can be damaged by vandalism, however they can sustain several bullet-sized punctures without becoming unserviceable. The bladders should have a service life of 20 years or more and should require minimal maintenance.

YELLOWSTONE RIVER DIVERSION DAM
Glendive, MT

Designed By: COE - Omaha District
Estimated By: CENWO-ED-CC

Prepared By: Gary Norenberg

Preparation Date: 05/16/02
Effective Date of Pricing: 03/01/02

Sales Tax: 0.00%

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ESTIMATE ASSUMPTIONS:

1. Estimate is does not include real estate costs.

2. Engineering and Design - 9%

3. Supervision and Administration - 6%

4. Contingencies - 35%

5. Assume construction of a coffer dam so that half of the new structure can be constructed. This coffer dam is removed and a new cofferdam is constructed for the remaining half. Assume that most of the cofferdam material cannot be reused for the second portion. Riprap is placed on the outside bank of the coffer dams. This riprap is salvaged from the existing rock dam or from rock washed downstream of the dam.

6. Random fill is obtained on site at no cost for the material.

7. New quarried riprap is imported, by truck or rail depending on the quantity needed, for down stream of the dam structure and for the fish ladder. Quarried stone is required from a durability requirement compared to field stone. Streambank protection riprap is salvaged from on site.

8. Operation of the irrigation canel is from April to October. With the construction of coffer dams the irrigation season should not be impacted and construction could take place year round on the new structures.

** PROJECT OWNER SUMMARY - CONTRACT **

		QUANTY	UOM	CONTRACT	CONTINGN	E&D	S&A	TOTAL COST	UNIT
01	Full Length Hinged Weir	700.00	LF	3,554,457	1,209,013	279,800	444,882	5,488,153	7840.22
02	Partial Length Hinged Weir	350.00	LF	3,476,465	1,181,716	273,483	434,838	5,366,501	15333
03	Full Length Concrete Dam	700.00	LF	3,644,155	1,218,233	281,934	448,275	5,592,597	7989.42
04	Fish Baffle	1.00	EA	828,340	254,873	58,985	93,786	1,235,983	1235983
05	Fish Elevator	1.00	EA	642,242	207,261	47,966	76,266	973,736	973736
06	Riprap Fish Ladder, Conc Wall	600.00	LF	1,044,177	347,939	80,523	128,032	1,600,671	2667.78
07	Riprap Fish Ladder, Earth Berm 1	600.00	LF	599,388	192,262	44,495	70,747	906,892	1511.49
08	Riprap Fish Ladder, Earth Berm 2	200.00	LF	371,615	112,542	26,045	41,412	551,615	2758.07

	QUANTY UOM	CONTRACT	CONTINGN	E&D	S&A	TOTAL COST	UNIT
01 Full Length Hinged Weir							
01_ 1 Mobilization		16,214	5,675	1,313	2,088	25,291	
01_ 2 Diversion of Water		640,653	189,182	43,782	69,614	943,230	
01_ 3 Stripping	5.00 ACR	15,409	5,393	1,248	1,984	24,034	4806.89
01_ 4 Foundation Excavation	5885.00 CY	9,327	3,265	755	1,201	14,548	2.47
01_ 5 Rock Excavation	9733.00 CY	39,710	13,899	3,217	5,114	61,940	6.36
01_ 6 Backfill Walls	2084.00 CY	7,915	2,770	641	1,019	12,346	5.92
01_ 7 Wing Walls	106.00 CY	42,441	14,854	3,438	5,466	66,200	624.53
01_ 8 Wing Wall Footing Slab	42.00 CY	24,690	8,641	2,000	3,180	38,511	916.92
01_10 Foundation Slab	4221.00 CY	804,932	281,726	65,199	103,667	1,255,524	297.45
01_11 Hinged Weir	700.00 LF	1,665,176	582,812	134,879	214,458	2,597,325	3710.46
01_12 Compressor Building	1.00 EA	54,669	19,134	4,428	7,041	85,273	85273
01_14 Restoration	7.00 ACR	38,306	13,407	3,103	4,933	59,749	8535.58
01_16 Riprap, Channel	2613.00 TON	125,232	43,831	10,144	16,129	195,335	74.76
01_17 Riprap, Streambank	75.00 TON	3,594	1,258	291	463	5,607	74.76
01_20 Subsurface Investigation	1.00 EA	66,188	23,166	5,361	8,524	103,240	103240
TOTAL Full Length Hinged Weir	700.00 LF	3,554,457	1,209,013	279,800	444,882	5,488,153	7840.22
02 Partial Length Hinged Weir							
02_ 1 Mobilization		16,214	5,675	1,313	2,088	25,291	
02_ 2 Diversion of Water		640,653	189,182	43,782	69,614	943,230	
02_ 3 Stripping	5.00 ACR	15,409	5,393	1,248	1,984	24,034	4806.89
02_ 4 Foundation Excavation	2943.00 CY	4,664	1,633	378	601	7,275	2.47
02_ 5 Rock Excavation	4867.00 CY	19,857	6,950	1,608	2,557	30,973	6.36
02_ 6 Backfill Walls	2084.00 CY	7,915	2,770	641	1,019	12,346	5.92
02_ 7 Wing Walls	106.00 CY	42,441	14,854	3,438	5,466	66,200	624.53
02_ 8 Wing Wall Footing Slab	42.00 CY	24,690	8,641	2,000	3,180	38,511	916.92
02_10 Foundation Slab	2111.00 CY	402,561	140,896	32,607	51,846	627,911	297.45
02_11 Hinged Weir	350.00 LF	832,588	291,406	67,440	107,229	1,298,663	3710.46
02_12 Compressor Building	1.00 EA	54,669	19,134	4,428	7,041	85,273	85273
02_14 Restoration	7.00 ACR	38,306	13,407	3,103	4,933	59,749	8535.58
02_16 Riprap, Channel	2613.00 TON	125,232	43,831	10,144	16,129	195,335	74.76
02_17 Riprap, Streambank	75.00 TON	3,594	1,258	291	463	5,607	74.76
02_20 Subsurface Investigation	1.00 EA	66,188	23,166	5,361	8,524	103,240	103240
02_22 Foundation Excavation	3513.00 CY	5,568	1,949	451	717	8,685	2.47
02_23 Rock Excavation	4867.00 CY	19,857	6,950	1,608	2,557	30,973	6.36
02_24 Dam Foundation Slab	2823.00 CY	654,630	229,121	53,025	84,310	1,021,086	361.70
02_25 Conc Dam	2311.00 CY	501,427	175,499	40,616	64,579	782,121	338.43
TOTAL Partial Length Hinged Weir	350.00 LF	3,476,465	1,181,716	273,483	434,838	5,366,501	15333
03 Full Length Concrete Dam							
03_ 1 Mobilization		16,214	5,675	1,313	2,088	25,291	
03_ 2 Diversion of Water		941,424	272,277	63,013	100,190	1,376,903	

	QUANTY UOM	CONTRACT	CONTINGN	E&D	S&A	TOTAL COST	UNIT
03_ 3 Stripping	5.00 ACR	15,409	5,393	1,248	1,984	24,034	4806.89
03_ 6 Backfill Walls	2084.00 CY	7,915	2,770	641	1,019	12,346	5.92
03_ 7 Wing Walls	106.00 CY	42,441	14,854	3,438	5,466	66,200	624.53
03_ 8 Wing Wall Footing Slab	42.00 CY	24,690	8,641	2,000	3,180	38,511	916.92
03_14 Restoration	7.00 ACR	38,306	13,407	3,103	4,933	59,749	8535.58
03_16 Riprap, Channel	2613.00 TON	125,232	43,831	10,144	16,129	195,335	74.76
03_17 Riprap, Streambank	75.00 TON	3,594	1,258	291	463	5,607	74.76
03_19 Subsurface Investigation	1.00 EA	66,188	23,166	5,361	8,524	103,240	103240
03_20 Foundation Excavation	7026.00 CY	11,136	3,897	902	1,434	17,369	2.47
03_21 Rock Excavation	9733.00 CY	39,710	13,899	3,217	5,114	61,940	6.36
03_22 Dam Foundation Slab	5646.00 CY	1,309,259	458,241	106,050	168,620	2,042,170	361.70
03_23 Conc Dam	4621.00 CY	1,002,637	350,923	81,214	129,130	1,563,903	338.43
TOTAL Full Length Concrete Dam	700.00 LF	3,644,155	1,218,233	281,934	448,275	5,592,597	7989.42
04 Fish Baffle							
04_ 1 Mobilization		16,214	5,675	1,313	2,088	25,291	
04_ 2 Diversion of Water		370,393	94,591	21,891	34,807	521,681	
04_ 3 Stripping	2.00 ACR	6,164	2,157	499	794	9,614	4806.89
04_ 4 Foundation Excavation	948.00 CY	1,903	666	154	245	2,969	3.13
04_ 5 Rock Excavation	800.00 CY	3,264	1,142	264	420	5,091	6.36
04_ 8 Basin Slab	490.00 CY	136,854	47,899	11,085	17,625	213,464	435.64
04_ 9 Basin Walls	582.00 CY	104,176	36,462	8,438	13,417	162,493	279.20
04_14 Backfill Walls	23148 CY	87,916	30,771	7,121	11,323	137,130	5.92
04_15 Restoration	7.00 ACR	38,306	13,407	3,103	4,933	59,749	8535.58
04_17 Ice Diversion Pilings	7.00 EA	20,529	7,185	1,663	2,644	32,021	4574.41
04_18 Riprap, Streambank	220.00 TON	10,544	3,690	854	1,358	16,446	74.76
04_20 Subsurface Investigation	1.00 EA	32,077	11,227	2,598	4,131	50,034	50034
TOTAL Fish Baffle	1.00 EA	828,340	254,873	58,985	93,786	1,235,983	1235983
05 Fish Elevator							
05_ 1 Mobilization		16,214	5,675	1,313	2,088	25,291	
05_ 2 Diversion of Water		140,063	31,499	7,290	11,591	190,442	
05_ 3 Stripping	2.00 ACR	6,164	2,157	499	794	9,614	4806.89
05_ 4 Foundation Excavation	948.00 CY	1,903	666	154	245	2,969	3.13
05_ 5 Rock Excavation	800.00 CY	3,264	1,142	264	420	5,091	6.36
05_ 8 Basin Slab	490.00 CY	136,854	47,899	11,085	17,625	213,464	435.64
05_ 9 Basin Walls	582.00 CY	80,862	28,302	6,550	10,414	126,128	216.71
05_10 Gates & Valves	1.00 EA	63,418	22,196	5,137	8,168	98,918	98918
05_14 Backfill Walls	23148 CY	87,916	30,771	7,121	11,323	137,130	5.92
05_15 Restoration	7.00 ACR	38,306	13,407	3,103	4,933	59,749	8535.58
05_16 Riprap	220.00 TON	10,544	3,690	854	1,358	16,446	74.76
05_17 Ice Diversion Pilings	7.00 EA	20,529	7,185	1,663	2,644	32,020	4574.33
05_18 Riprap, Streambank	75.00 TON	3,594	1,258	291	463	5,607	74.76
05_20 Subsurface Investigation	1.00 EA	32,611	11,414	2,642	4,200	50,867	50867

	QUANTY	UOM	CONTRACT	CONTINGN	E&D	S&A	TOTAL COST	UNIT
TOTAL Fish Elevator	1.00	EA	642,242	207,261	47,966	76,266	973,736	973736
06 Riprap Fish Ladder, Conc Wall								
06_ 1 Mobilization			16,214	5,675	1,313	2,088	25,291	
06_ 2 Diversion of Water			140,063	31,499	7,290	11,591	190,442	
06_ 3 Stripping	2.00	ACR	6,164	2,157	499	794	9,614	4806.89
06_ 4 Foundation Excavation	3123.00	CY	6,270	2,194	508	807	9,779	3.13
06_ 5 Rock Excavation	800.00	CY	3,264	1,142	264	420	5,091	6.36
06_ 8 Diversion Wall Footing	1227.00	CY	227,141	79,499	18,398	29,254	354,293	288.75
06_ 9 Diversion Walls	728.00	CY	275,268	96,344	22,297	35,452	429,360	589.78
06_13 Backfill Walls	3055.00	CY	11,603	4,061	940	1,494	18,098	5.92
06_14 Diversion Earth Berm	3200.00	CY	13,853	4,849	1,122	1,784	21,608	6.75
06_15 Riprap, Grouted	2560.00	TON	163,421	57,197	13,237	21,047	254,902	99.57
06_16 Riprap	1803.00	TON	86,411	30,244	6,999	11,129	134,783	74.76
06_17 Ice Diversion Pilings	7.00	EA	20,529	7,185	1,663	2,644	32,020	4574.33
06_18 Restoration	7.00	ACR	38,306	13,407	3,103	4,933	59,749	8535.58
06_19 Riprap, Streambank	75.00	TON	3,594	1,258	291	463	5,607	74.76
06_20 Subsurface Investigation	1.00	EA	32,077	11,227	2,598	4,131	50,033	50033
TOTAL Riprap Fish Ladder, Conc Wall	600.00	LF	1,044,177	347,939	80,523	128,032	1,600,671	2667.78
07 Riprap Fish Ladder, Earth Berm 1								
07_ 1 Mobilization			16,214	5,675	1,313	2,088	25,291	
07_ 2 Diversion of Water			140,063	31,499	7,290	11,591	190,442	
07_ 3 Stripping	2.00	ACR	6,164	2,157	499	794	9,614	4806.89
07_ 4 Foundation Excavation	3123.00	CY	6,270	2,194	508	807	9,779	3.13
07_ 5 Rock Excavation	800.00	CY	3,264	1,142	264	420	5,091	6.36
07_10 Diversion Earth Berm, River Side	12000	CY	51,948	18,182	4,208	6,690	81,028	6.75
07_11 Riprap, Berm	1493.00	TON	21,884	7,659	1,773	2,818	34,135	22.86
07_12 Riprap, Grouted	2560.00	TON	163,421	57,197	13,237	21,047	254,902	99.57
07_14 Diversion Earth Berm	3200.00	CY	13,853	4,849	1,122	1,784	21,608	6.75
07_16 Riprap	1803.00	TON	86,411	30,244	6,999	11,129	134,783	74.76
07_17 Ice Diversion Pilings	7.00	EA	19,513	6,830	1,581	2,513	30,437	4348.10
07_18 Restoration	7.00	ACR	38,306	13,407	3,103	4,933	59,749	8535.58
07_20 Subsurface Investigation	1.00	EA	32,077	11,227	2,598	4,131	50,033	50033
TOTAL Riprap Fish Ladder, Earth Berm 1	600.00	LF	599,388	192,262	44,495	70,747	906,892	1511.49
08 Riprap Fish Ladder, Earth Berm 2								
08_ 1 Mobilization			16,214	5,675	1,313	2,088	25,291	
08_ 2 Diversion of Water			140,063	31,499	7,290	11,591	190,442	
08_ 3 Stripping	2.00	ACR	6,164	2,157	499	794	9,614	4806.89
08_ 4 Foundation Excavation	1041.00	CY	2,090	731	169	269	3,260	3.13
08_ 5 Rock Excavation	266.66	CY	1,088	381	88	140	1,697	6.36
08_10 Diversion Earth Berm, River Side	4000.00	CY	17,316	6,061	1,403	2,230	27,009	6.75

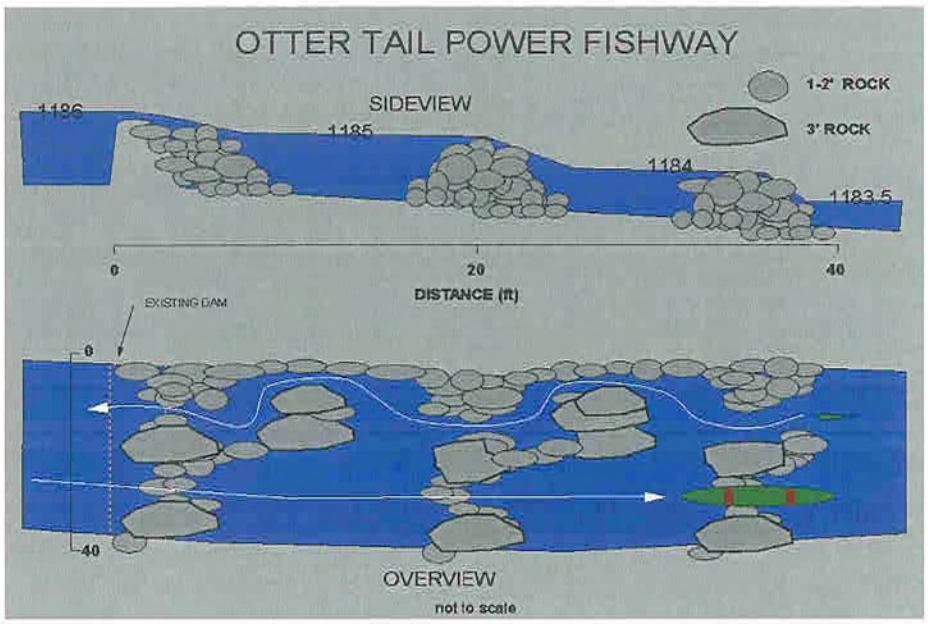
** PROJECT OWNER SUMMARY - FEATURE **

		QUANTY UOM	CONTRACT	CONTINGN	E&D	S&A	TOTAL COST	UNIT
08_11	Riprap, Berm	497.66 TON	7,295	2,553	591	939	11,378	22.86
08_12	Riprap, Grouted	853.34 TON	54,474	19,066	4,412	7,016	84,968	99.57
08_14	Diversion Earth Berm	1066.66 CY	4,618	1,616	374	595	7,202	6.75
08_16	Riprap	601.00 TON	28,804	10,081	2,333	3,710	44,928	74.76
08_17	Ice Diversion Pilings	7.00 EA	19,513	6,830	1,581	2,513	30,437	4348.10
08_18	Restoration	7.00 ACR	38,306	13,407	3,103	4,933	59,749	8535.58
08_19	Riprap, Streambank	75.00 TON	3,594	1,258	291	463	5,607	74.76
08_20	Subsurface Investigation	1.00 EA	32,077	11,227	2,598	4,131	50,033	50033
TOTAL	Riprap Fish Ladder, Earth Berm 2	200.00 LF	371,615	112,542	26,045	41,412	551,615	2758.07

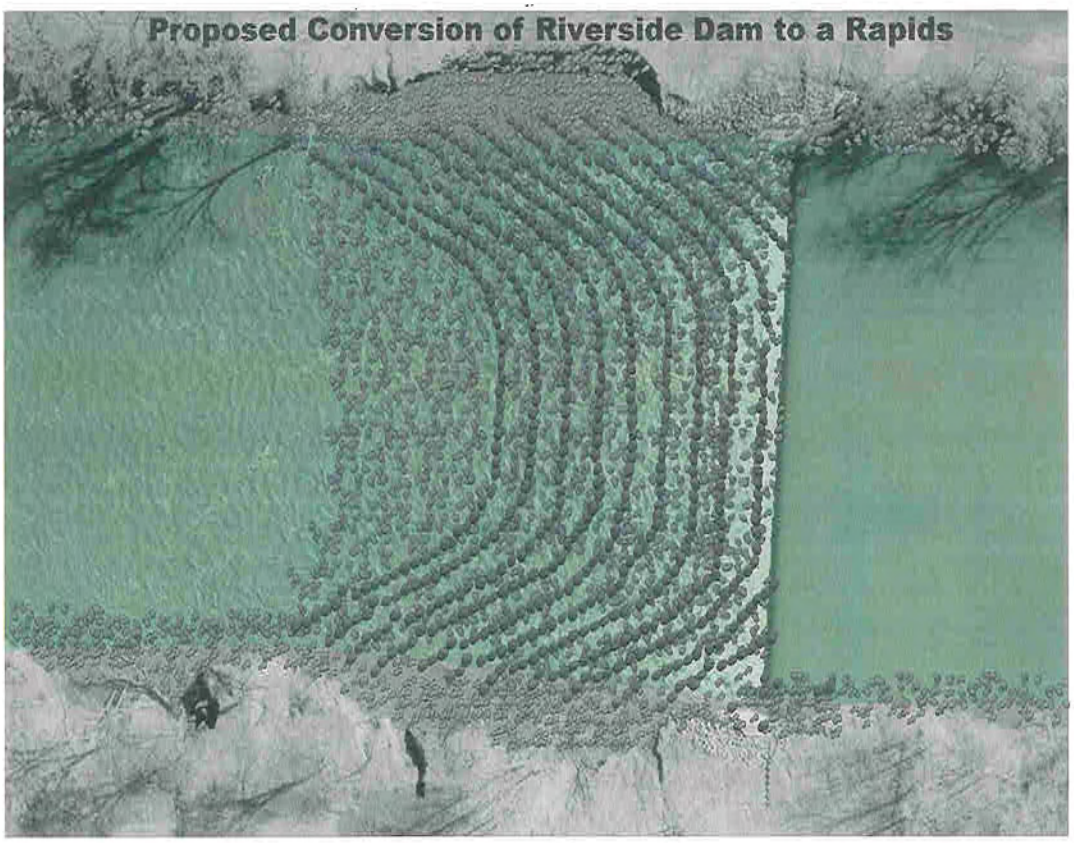
APPENDIX F

Rock Ramp Examples

Point of Contact: Luther Aadland



Minnesota Department of Natural Resources



The dam needed repair and all alternatives were expensive. I presented a rapids design similar to the Midtown Project and worked with the Army Corps of Engineers to further refine the rapids design for Riverside Dam. The project is presently under construction and is expected to be completed by 2001. Total construction cost is about $3.5 million.

APPENDIX G

Technical Contacts and Expertise

TECHNICAL CONTACTS AND EXPERTISE
(not an exhaustive list - only a beginning)

Name & Address	Warmwater Passage	Sturgeon Passage	Rock Ramp Design	Fish Elevators	Baffle Structures	Canoe Passage	Other
Dr. Luther Aadland Department of Natural Resources 1221 East Fir Ave. Fergus Falls, MN 56537 (218) 739-7449 luther.aadland@dnr.state.mn.us	X		X				
Dr. Marcelo H. Garcia, Director Ven Te Chow Hydraulics Lab University of Illinois, Champaign 205 North Mathews Ave Urbana, Illinois 61801 (217) 244-4484 mhgarcia@uiuc.edu			X			X	
Dr. Boyd Kynard S.O. Conti Lab 1 Migratory Way Turner Falls, MA (413) 863-9475, ext. 42 kynard@forwild.umass.edu	X	swim speeds					spiral passage

Name & Address	Warmwater Passage	Sturgeon Passage	Rock Ramp Design	Fish Elevators	Baffle Structures	Canoe Passage	Other
Mark Cornish Corps of Engineers Rock Island District (309) 794-5385 mark.a.cornish@mvr02.usace.army.mil							disc of fish passage reports
Brett Mefford Bureau of Reclamation Water Resources Research Laboratory Bureau of Reclamation Denver, Colorado (303) 475-2149 bmefford@do.usbr.gov		baffle / rock ramp passage	X				engineering analyses
Glenn R. Parsons Dept. of Biology University of Mississippi (601) 232-7479		swim speeds					
Jan Hoover and Jack Kilgore Environmental Research Development Center (formerly Waterways Experiment Station) Vicksburg, Mississippi (601) 634-3996 jan.j.hoover@wes02.usace.army.mil		swim speeds					

Name & Address	Warmwater Passage	Sturgeon Passage	Rock Ramp Design	Fish Elevators	Baffle Structures	Canoe Passage	Other
Gary Whelan Michigan DNR Fisheries Division P.O. Box 30446 Lansing, MI 48909 (517) 373-6948 whelang@state.mi.us		lake sturgeon www.gift.org pool - weir	pool - weir				
Chuck Surprenant U.S. Fish and Wildlife Service Carterville Fishery Resources Office 9053 Route 148 Marion, IL 62959 (618) 997-6869		lake sturgeon					
Reid Adams Southern Illinois University (618) 453-4113 adamsr@siu.edu		juvenile pallid swim speeds					
Dan Wilcox Corps of Engineers St. Paul District	fish passage at Lock and Dam 7, Mississippi River						compiled a matrix of warmwater fish swimming capabilities, based on literature

Name & Address	Warmwater Passage	Sturgeon Passage	Rock Ramp Design	Fish Elevators	Baffle Structures	Canoe Passage	Other
Ben Rizzo Supervisory Hydraulic Engineer US Fish and Wildlife Service, Region5 Engineering Field Office Suite 612 One Gateway Center Newton Corner, MA 02458-2802 (617) 244-1368	X			X			serpintine vertical slot fishway