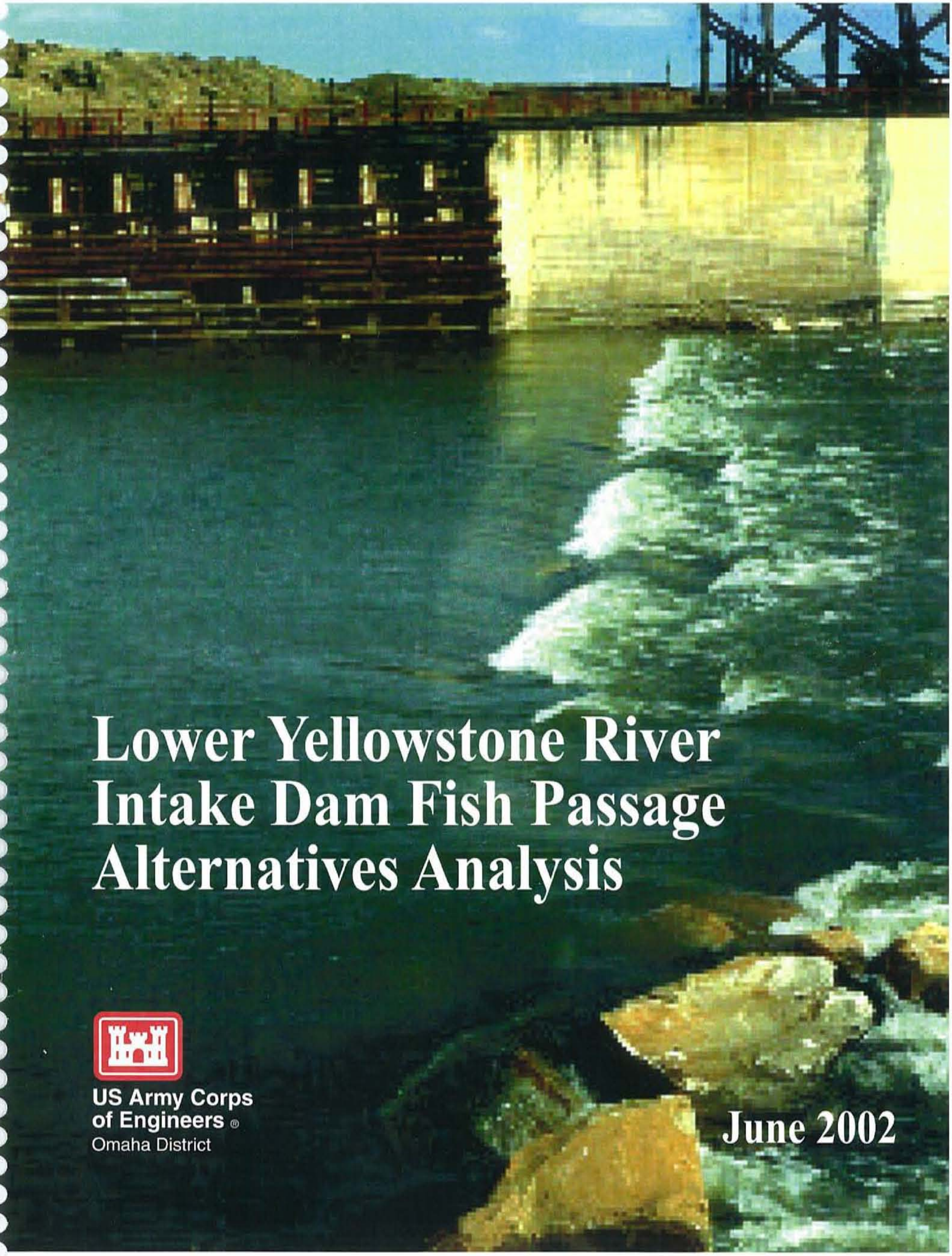

Lower Yellowstone River Intake Dam Fish Passage Alternatives Analysis

US Army Corps of Engineers ®
Omaha District

June 2002

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.

Literature Cited

Adams, S.R., J.J. Hoover, and K.J. Killgore. 1999. Swimming endurance of juvenile pallid sturgeon *Scaphirhynchus albus*. Copeia 1999:802-807.

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

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

Cornish, Mark A. Personal communication (e-mail). Warm water fish passage expert, Rock Island District, Corps of Engineers

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

Haynes, F.D, R. Haehnel, C. Clark, and L. Zabilansky (1997) Ice Control Techniques for Corps Projects. Technical Report REMR-HY-14. US Army Corps of Engineers Waterways Experiment Station.

Jones, D.R., O.S. Banford, and J.W. Kiceniuk. 1974. An evaluation of the swimming performance for several fish species from the Mackenzie River. Mimmeo report: Department of the Environmental Fisheries and Marine Service. Central Region, Winnepeg, Manitoba, Canada. 69 pp.

Kynard, B., Pugh, D., Henyey, E. and Parker, T. Draft Report: Preliminary Comparison of Pallid and shovelnose sturgeon for swimming ability and use of fish passage structure. February 2002.

Krentz, S. 1999. Personal communication. U.S. Fish and Wildlife Service, Bismarck ND.

Kynard, B. 2001. Personal communication. Conte ARFC, Turner Falls MA.

Lever, James H, Gordon Gooch, and Steven F. Daly (2000) Cazenovia Creek Ice-Control Structure ERDC/CRREL Technical Report 00-14. http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/TR00-14.pdf

McLeod, A.M., and P. Nemenyi. 1939-1940. An investigation of fishways. Iowa Institution of Hydraulic Research. pp. 14,15,50.

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

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.

Tuthill, A. (1995) Structural Ice Control, Review of Existing Methods. CRREL Special Report 95-18. US Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, NH http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/SR95_18.pdf

Tuthill, A. (2001) Performance Survey of Inflatable Dams in Ice-Affected Waters. Ice Engineering Information Exchange Bulletin US Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, NH http://www.crrel.usace.army.mil/ierd/tectran/IERD30.pdf

Tuthill A. (2002) Ice-Affected Components of Locks and Dams. ERDC/CRREL TR-02-4 US Army Corps of Engineers ®Engineer Research and Development Center

U.S. Army (2002) Ice Jam Database. http://www.crrel.usace.army.mil/ierd/ijdb/

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.

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

U.S. Bureau of Reclamation, 2000. Intake Diversion Dam, Yellowstone River, Montana. Fish Protection and Passage Concept Study Report. Water Resources Research Laboratory, Denve. Prepared for the Montana Area Office, USBOR, January 2000.

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

Whelan, G. 2001. Personal communication. Michigan Department of Natural Resources, Lansing MI.

White, R.G. and B. Mefford. 2002. Assessment of behavior and swimming ability of Yellowstone River sturgeon for design of fish passage devices. Montana Cooperative Fishery Research Unit, Montana State University; and Water Resources Research Laboratory, Bureau of Reclamation, Denver. Prepared for the Omaha District Corps of Engineers, January 2002.

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

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We wish to thank the United States Army Corps of Engineers, Omaha District and Reclamation's Science and Technology Program for funding this project. We also thank the Montana Department of Fish, Wildlife and Parks (FWP) who collected wild fish for use in the experiments, the Bureau of Reclamation Montana Area Office for providing coordination and technical data on Intake Diversion Dam, Glendive, Montana and Reclamation's Fisheries Application Group in Denver who provided great assistance in the transport and holding of test fish.

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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.

Figure 1 - View of sturgeon in circular holding tank.

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)

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.

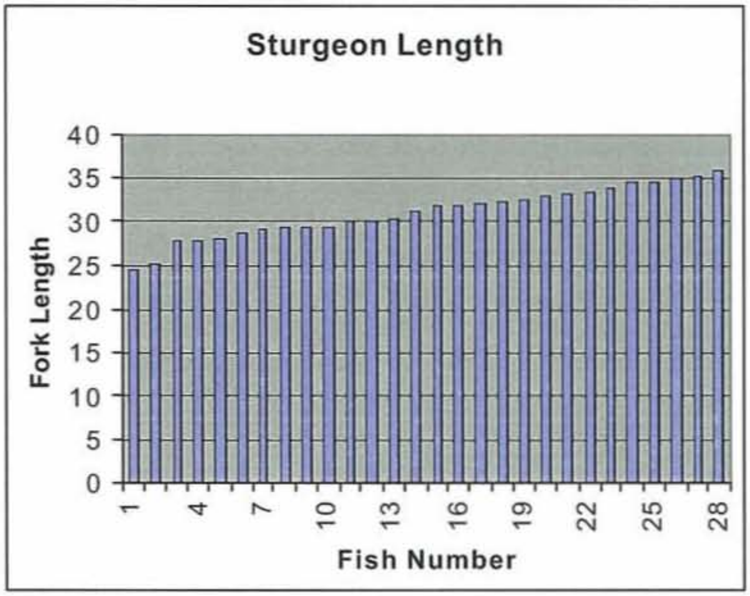

Figure 2 - Fork length of shovelnose sturgeon in test group 1.

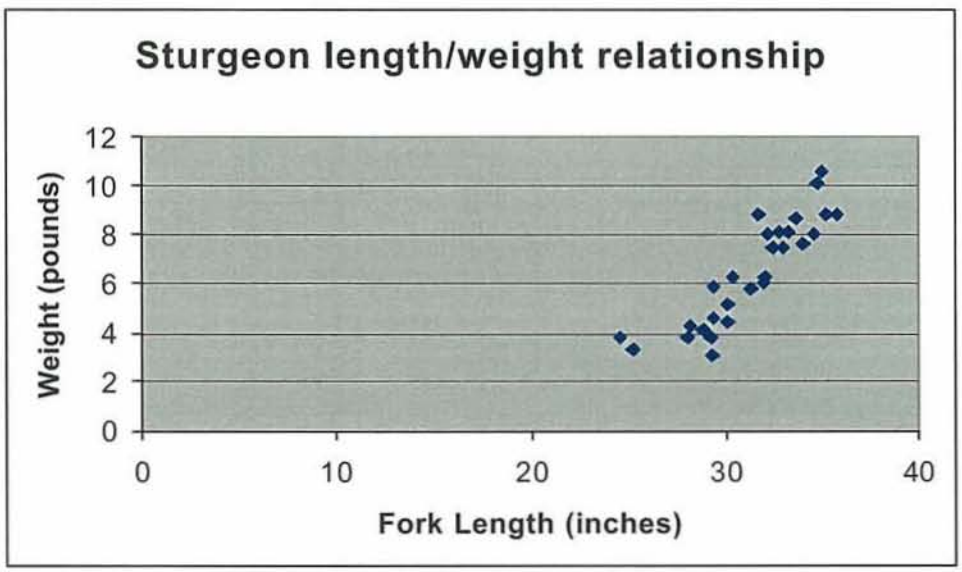

Figure 3 - Weight versus fork length of shovelnose sturgeon in test group 1.

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.

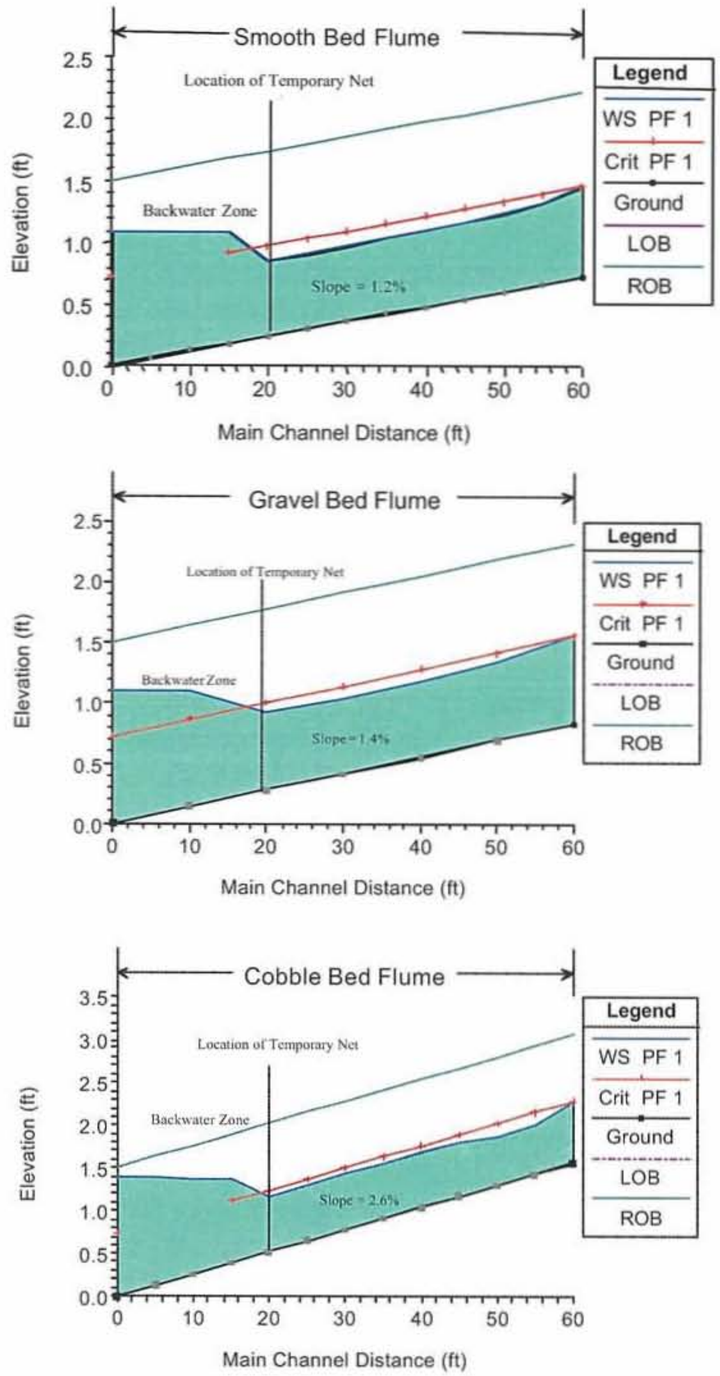

Figure 7 - Watersurface profiles predicted for sloping flume tests using smooth, gravel and cobble bed roughness, HEC-RAS numerical model.

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

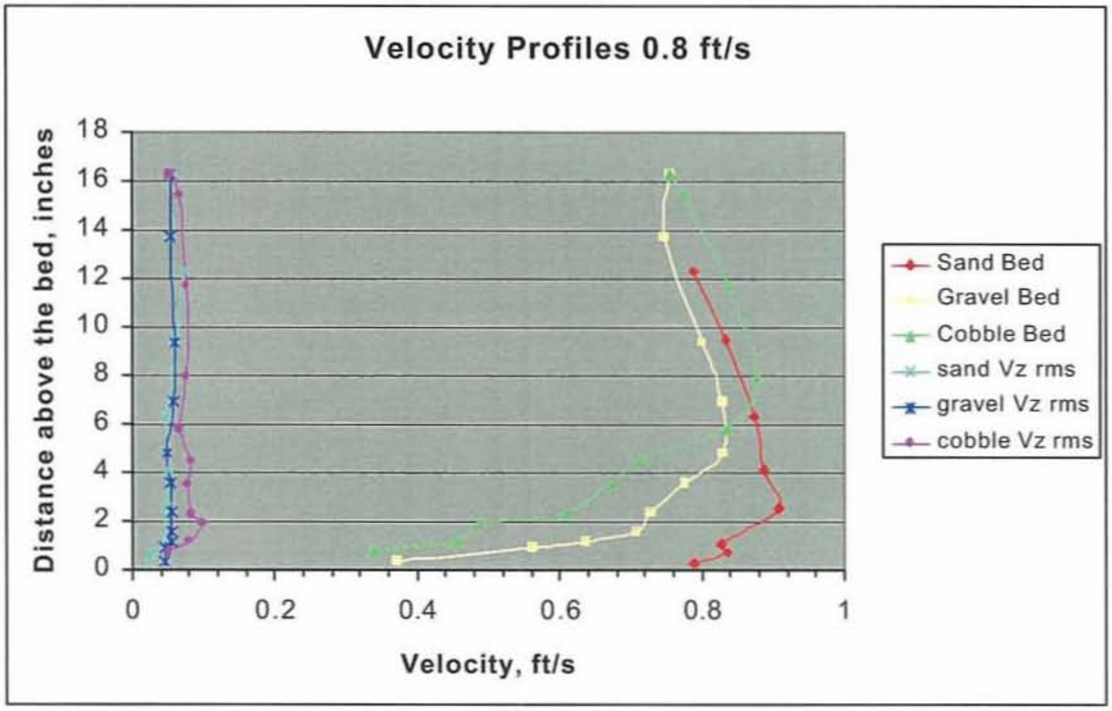

Figure 8 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 0.8 ft/s.

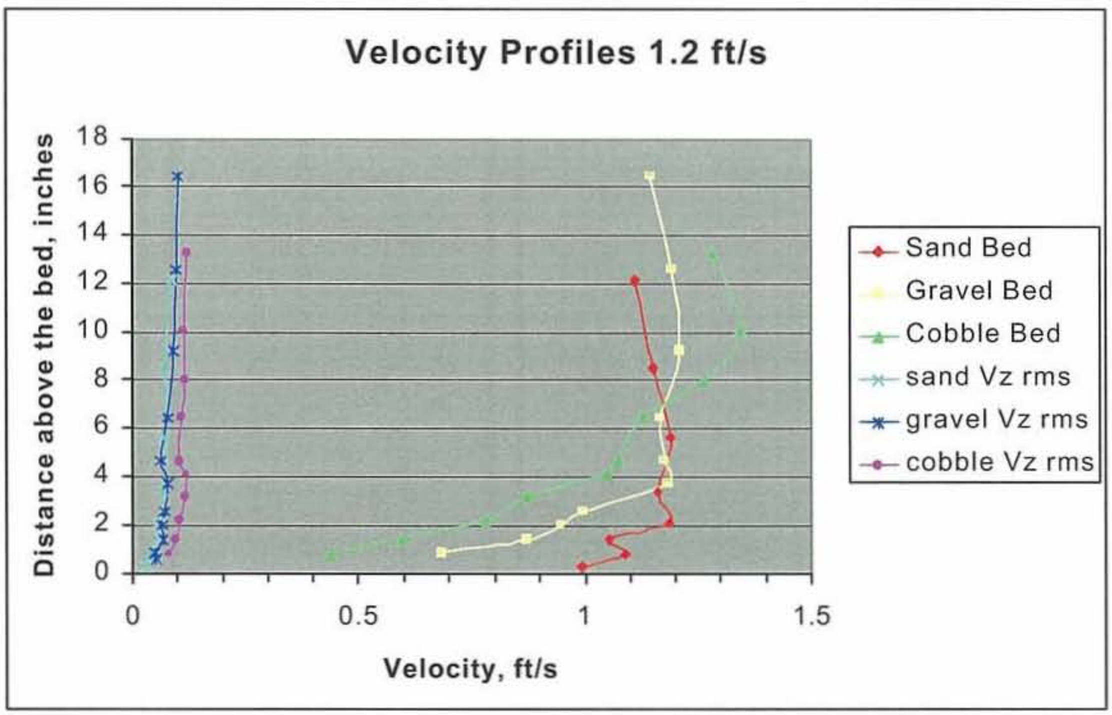

Figure 9 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 1.2 ft/s.

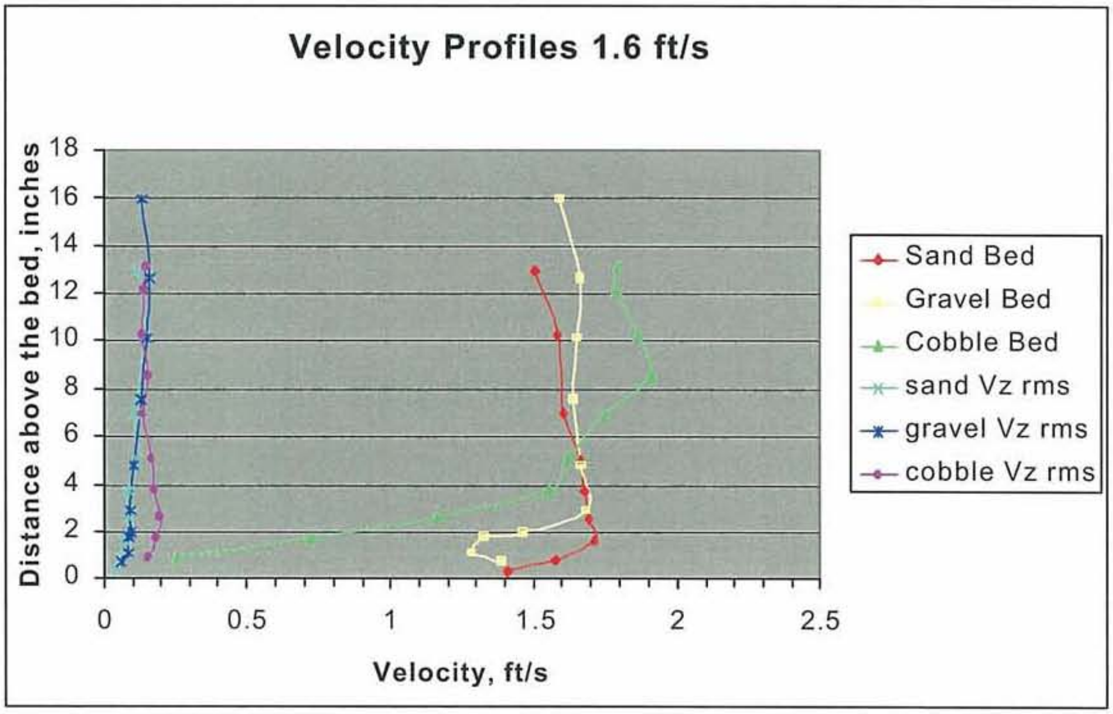

Figure 10 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 1.6 ft/s.

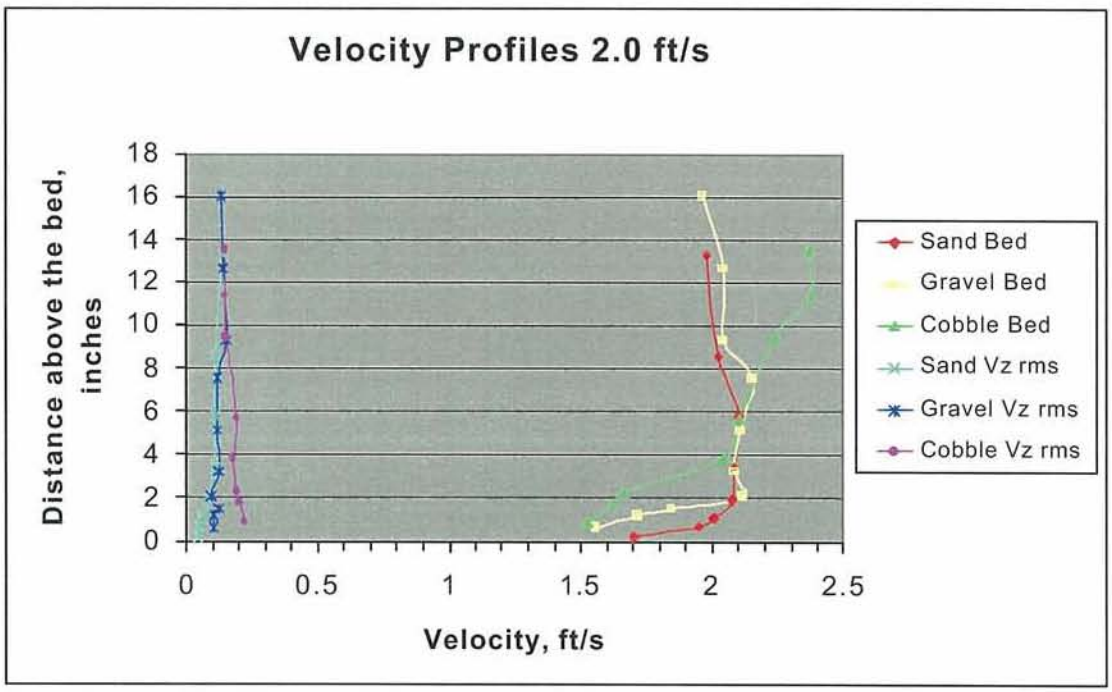

Figure 11 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 2.0 ft/s.

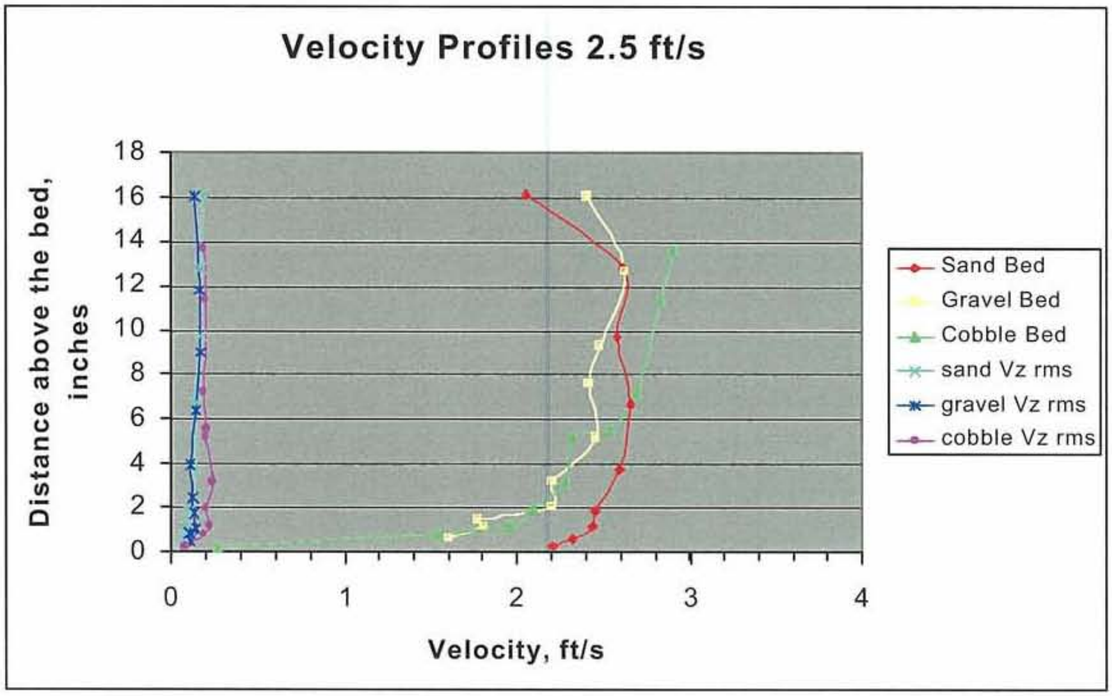

Figure 12 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 2.5 ft/s.

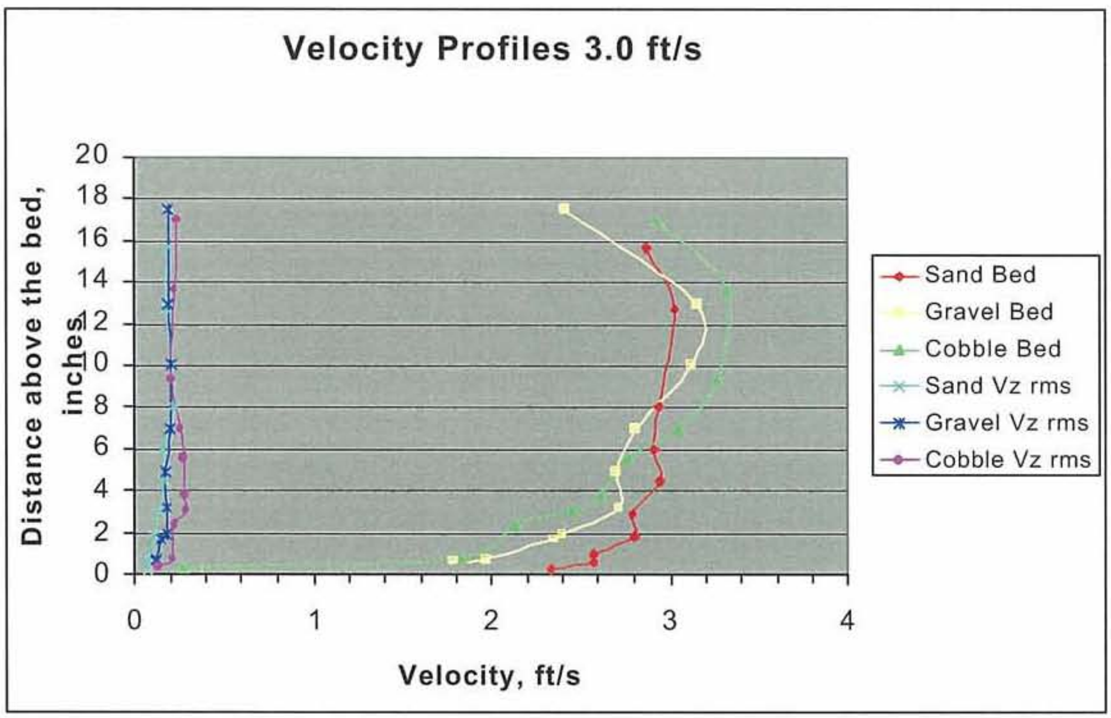

Figure 13 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with an average flow velocity target of 3.0 ft/s.

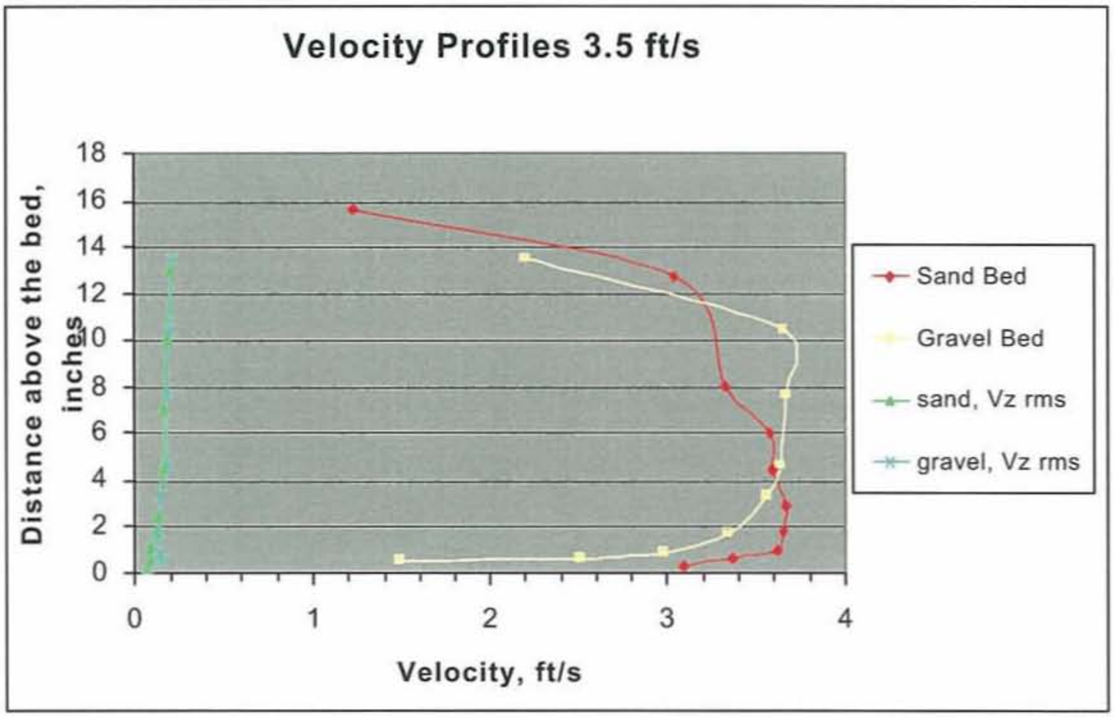

Figure 14 - Vertical velocity profiles measured over coarse sand and gravel beds for flume tests with an average flow velocity target of 3.5 ft/s.

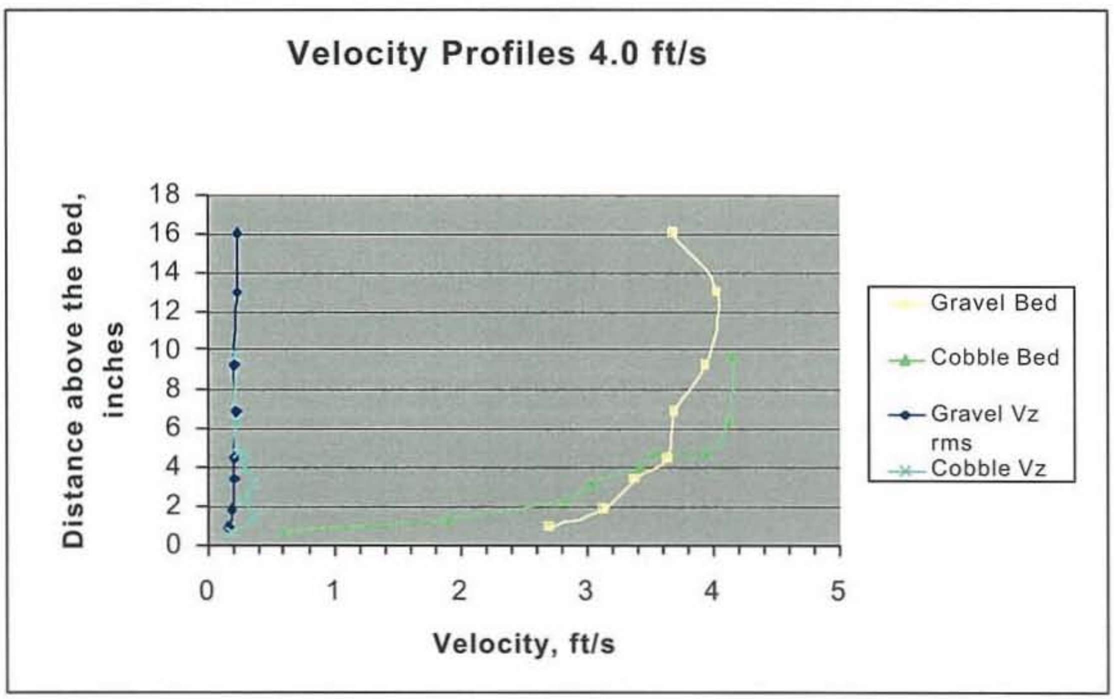

Figure 15 - Vertical velocity profiles measured over gravel and cobble beds for flume tests with an average flow velocity target of 4.0 ft/s.

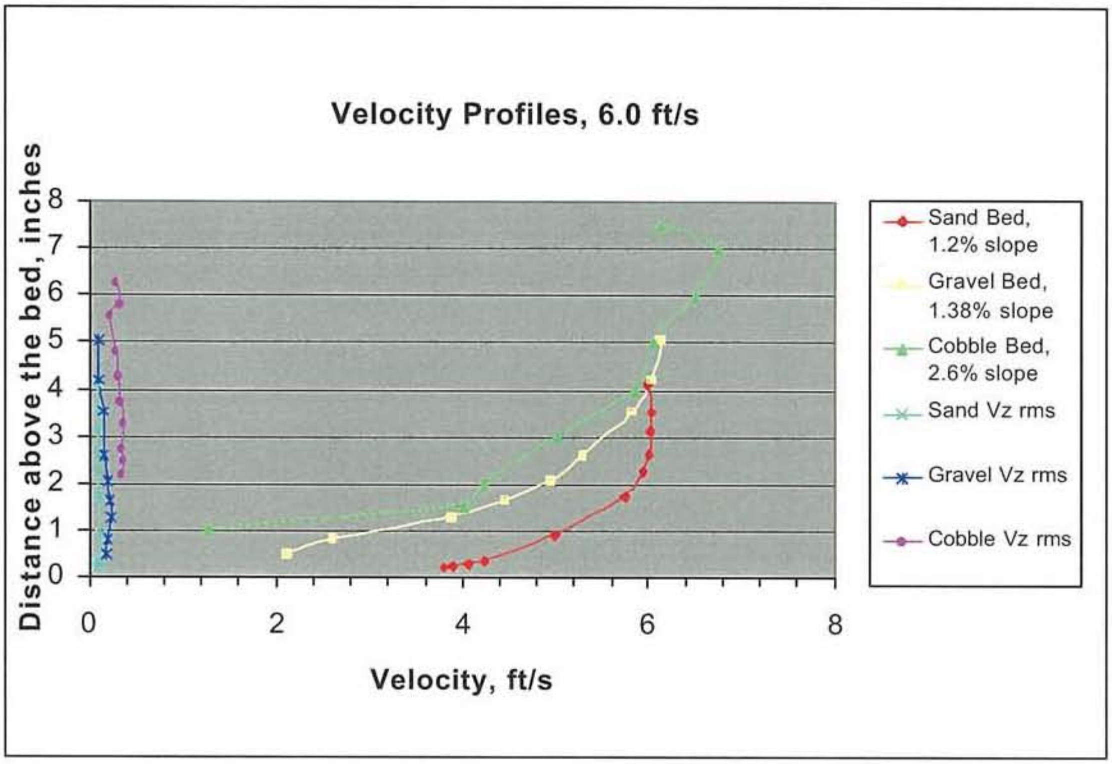

Figure 16 - Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with a target average flow velocity of 6.0 ft/s.

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

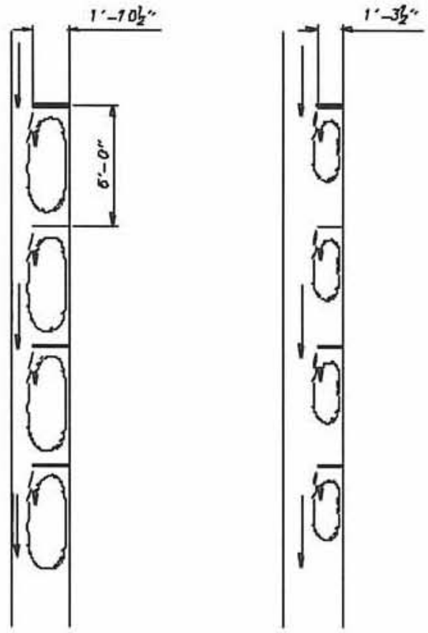

Figure 17 - Plan view of flow past vertical baffles in test flume.

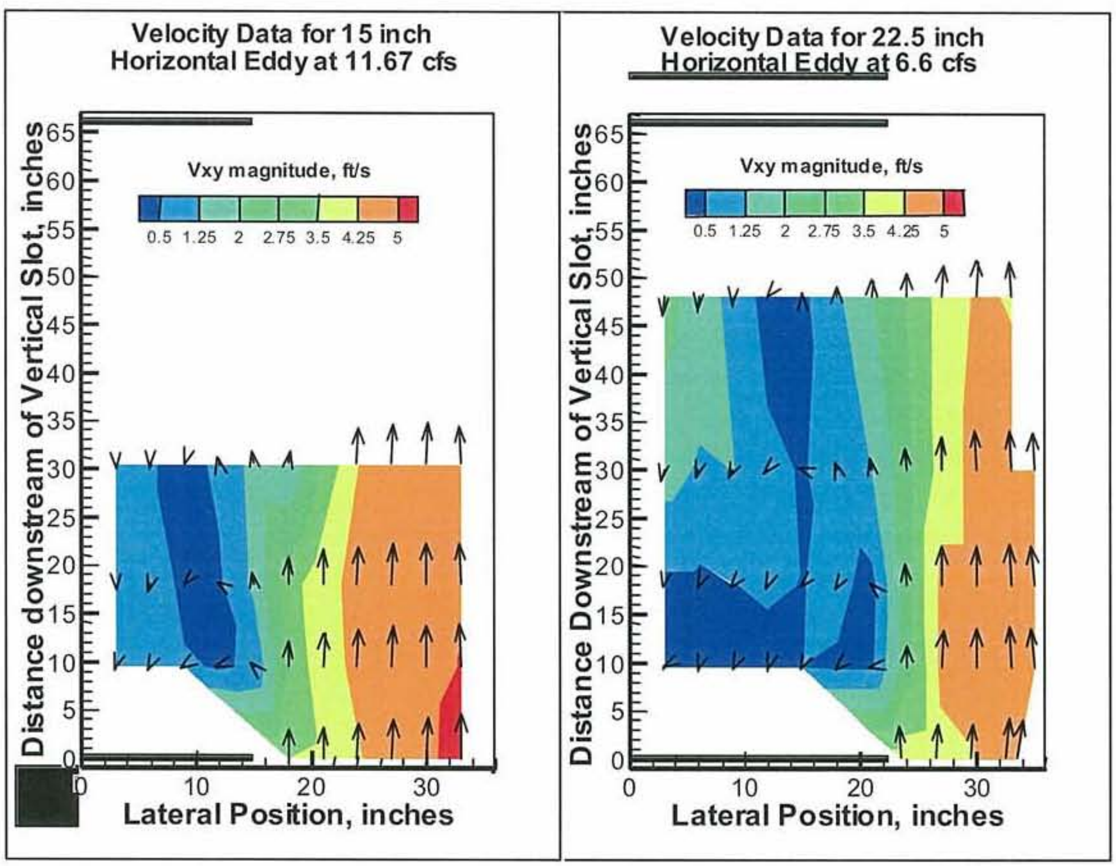

Figure 18 - Plan view of the velocity vector field measured downstream of vertical baffles.

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, ft³/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.

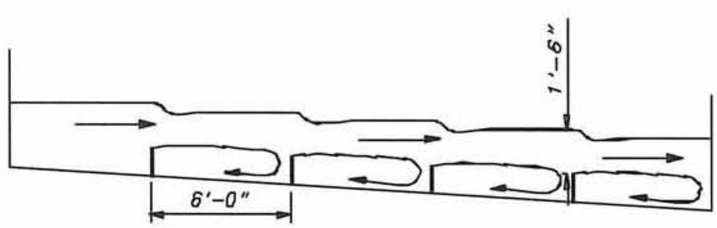

Figure 20 - Elevation view of flow over weir baffles in the test flume.

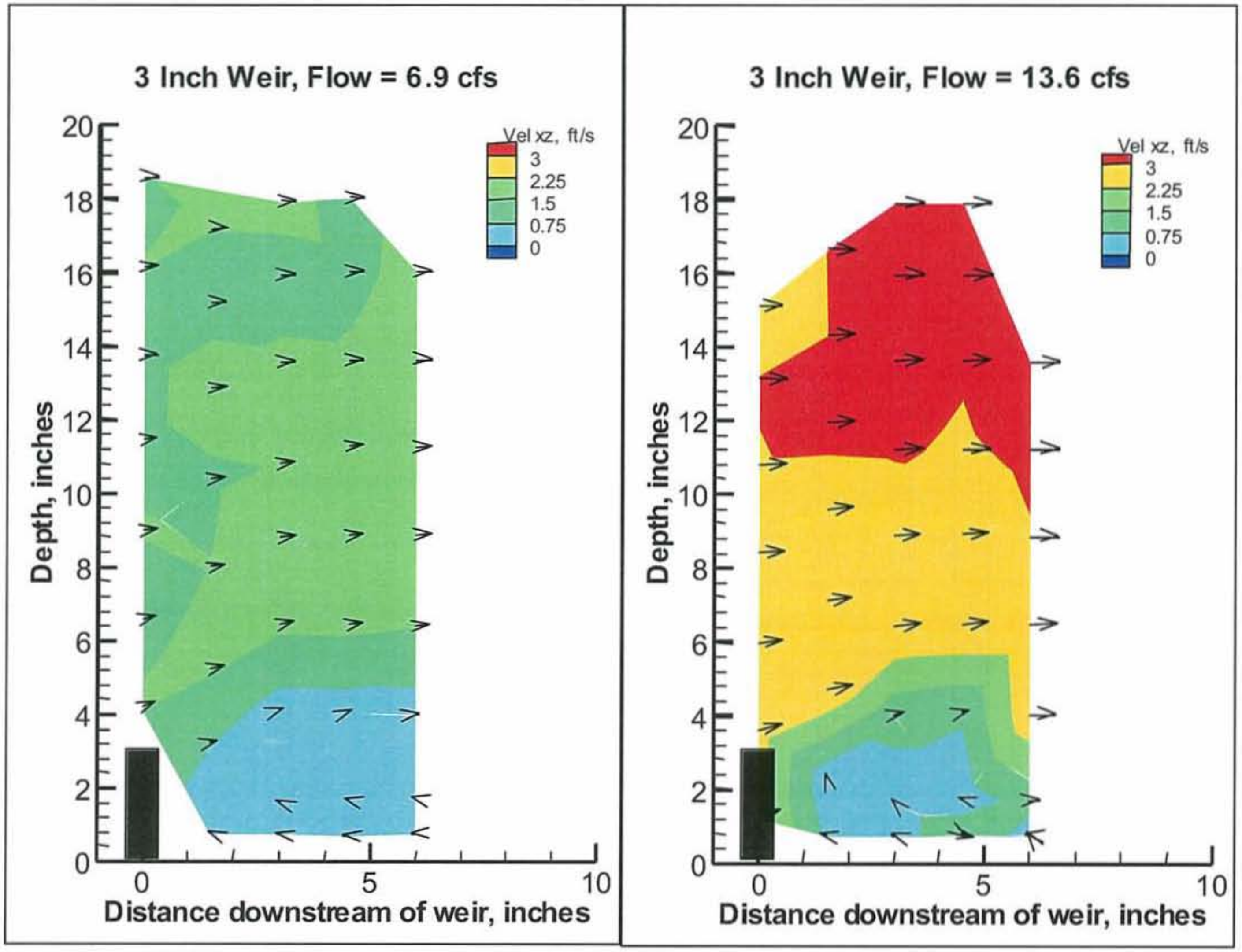

Figure 21 - Elevation view of measured velocity vector field downstream of 3 inch high weir baffles.

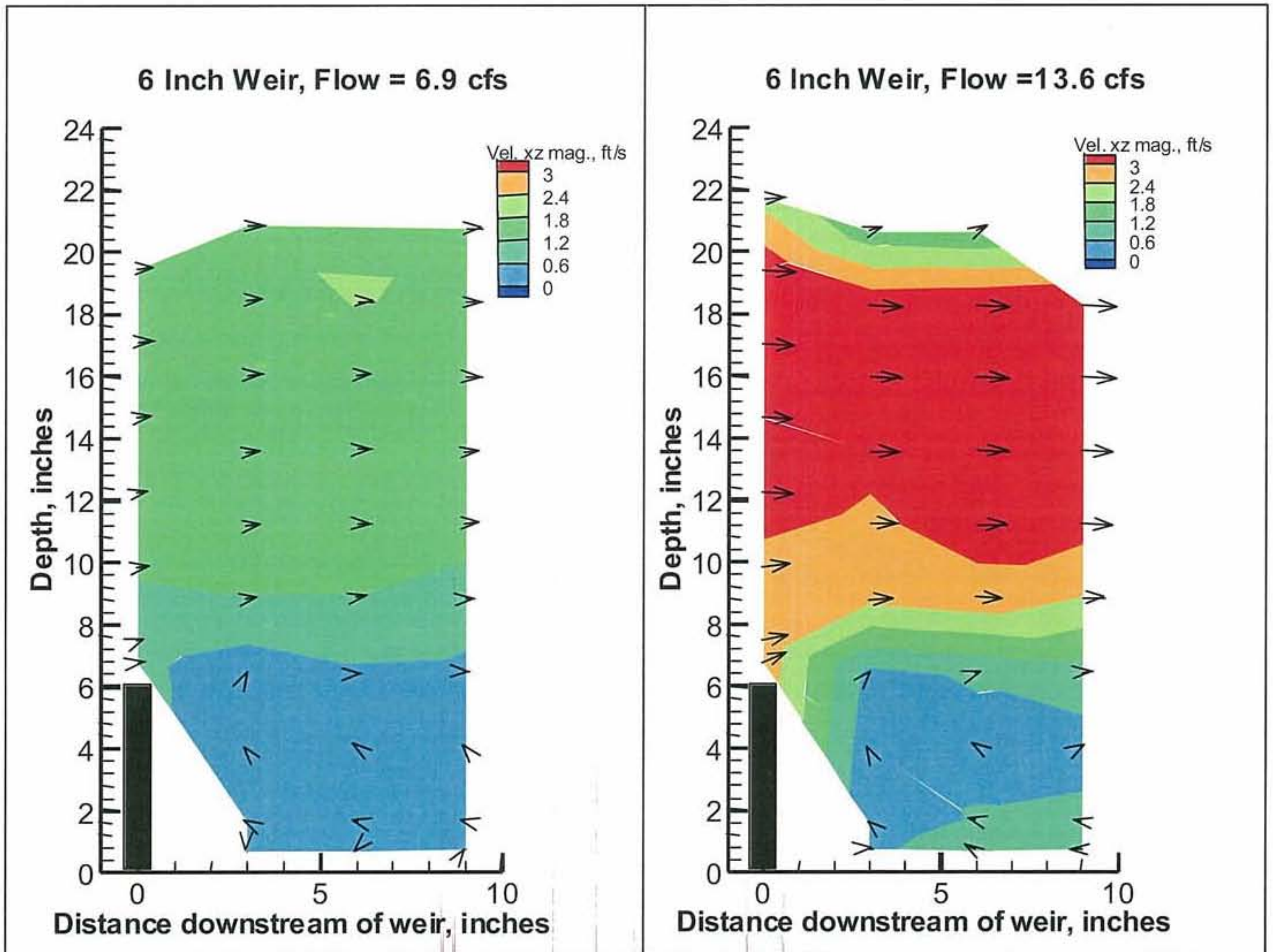

Figure 22 - Elevation view of measured velocity vector field downstream of 6 inch high weir baffles.

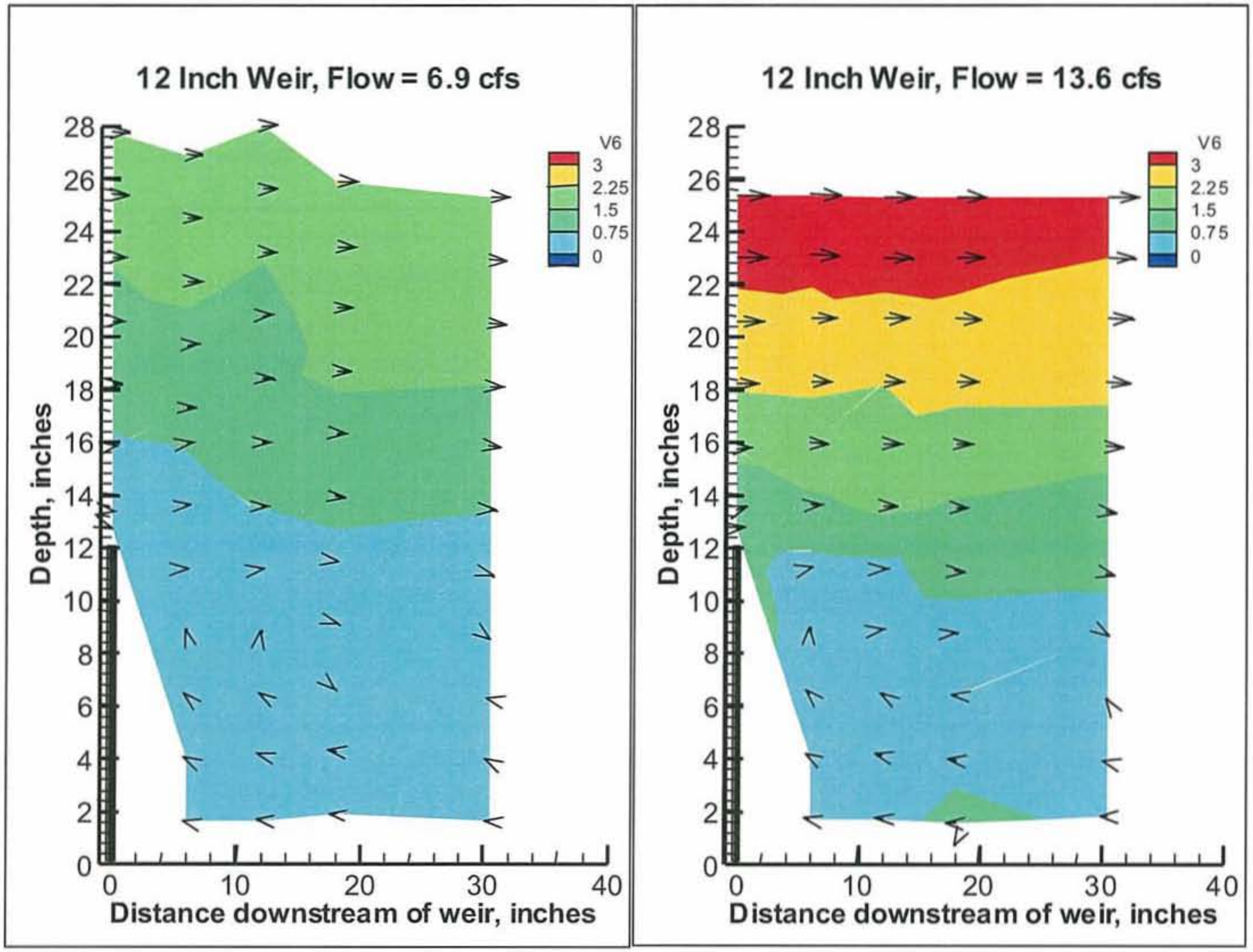

Figure 23 - Elevation view of measured velocity vector field downstream of 12 inch high weir baffles.

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.

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

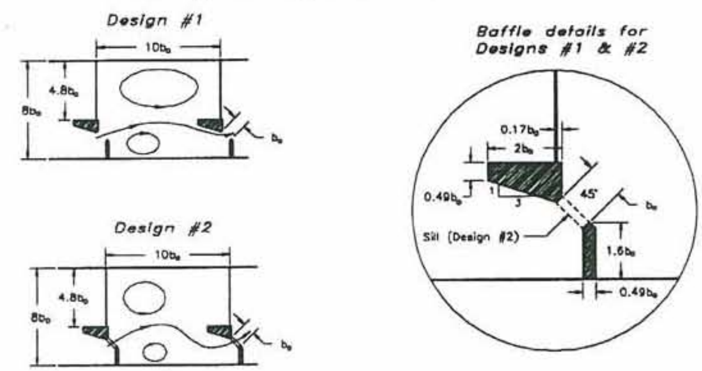

Figure 24 - Standard vertical slot fishway baffle design, FWS, 1997.

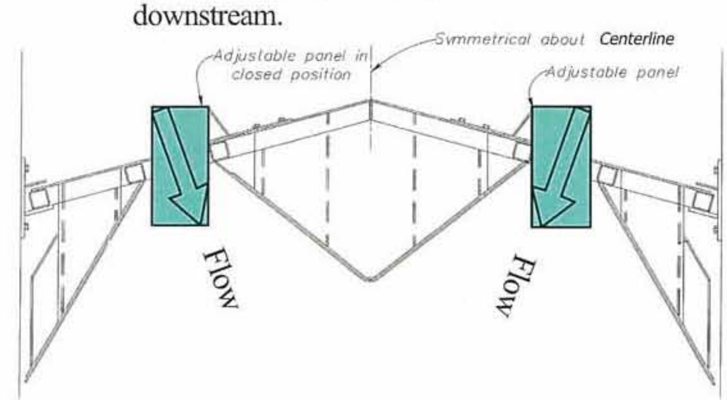

Figure 25 - Reclamation chevron shaped duel-vertical slot baffle design.

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

References

Backes, K.M. and W. M. Gardner. 1994. Lower Yellowstone pallid sturgeon study III and Missouri River pallid sturgeon creel survey. Montana Fish, Wildlife and Parks, USBR contract NO. 2-FG-60-01840, January 1994.

Bramblett, R.G. 1996. Habitats and movement of pallid and shovelnose sturgeon in the Yellowstone and Missouri rivers, Montana and North Dakota. Ph.D. Dissertation. Montana State University – Bozeman.

Bailey R.M. and F. B. Cross. 1954. River sturgeons of the American genus *Scraphirhynchus*: Characters, distribution and synonymy. Papers of the Michigan Academy of Science, Arts and Letters: 39:169-209, 1954.

Elser A.A. 1977. The effect of altered streamflow on the fish of the Yellowstone and Tongue rivers, Montana. Technical Report No. 8, Yellowstone Impact Study, July 1977.

Erickson, J.D., Habitat selection and movement of Pallid sturgeon in Lake Sharpe, South Dakota, Masters thesis, South Dakota Stat University, Brookings, 1992.

Peterman, L.G. and M. J. Haddix. 1975. Lower Yellowstone River fishery study progress report No. 1. Montana Department of Fish, Wildlife and Parks, Helena, 1975.

Stewart, P.A. 1986, 1988, 1990, 1991. Fish management surveys. Federal Aid in Fish Restoration, Project F-30-R-22. Montana Department of Fish, Wildlife and Parks, Helena.

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

April 5, 2002

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BACKGROUND

This project gathered information in an experimental flume on the swimming ability and behavior of pallid sturgeon *Scaphirhynchus 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.

<u>Baffle Reach</u>

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.

References

Adams, S.R., G.R. Parsons, J.J. Hoover & K.J. Killgore. 1997. Observations of swimming ability in shovelnose sturgeon, (*Scaphirhynchus platorynchus*). J. Fresh. Ecol. 12:631-633.

Adams, S.R., J.J. Hoover & K.J. Killgore. 1999. Swimming endurance of juvenile pallid sturgeon, *Scaphirhynchus albus*. Copeia 1999:802-807.

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

Clay, C.H. 1995. Design of fishways and other fish facilities. Lewis Publishers, Boca Raton, Fl.

Farlinger, S. & F.W.H. Beamish. 1977. Effects of time and velocity increments on the critical swimming speed of largemouth Australian bass (*Micropterus salmoides*). Trans. Amer. Fish. Soc. 106:436-439.

Henyey, E., B. Kynard, and P. Zhuang. 2002. Use of electrical narcosis to immobilize juvenile shortnose and lake sturgeon for handling. 4th Int. Sturgeon Symp, Oshkosh, WI.

Jones, D.R., J.W. Kiceniuk and O.S. Bamford. 1974. Evaluation of the swimming performance of several fish species from the Mackenzie River. J. Fish. Res. Board Can. 31:1641-1647.

Kynard, B. 1993. Fish behavior important for fish passage. Pages. 129-134 in K. Bates, ed., Fish passage policy and technology, American Fisheries Society, Bioengineering Section, Bethesda, Maryland.

Kynard, B. and E. Lonsdale. 1975. Experimental study of galvanonarcosis for rainbow trout (*Salmo gairdneri*) immobilization. J. Fish. Res. Bd. Canada 32:300-302.

Kynard, B., E. Henyey, and M. Horgan. 2002. Ontogenetic behavior and migration of pallid and shovelnose sturgeon with a note on adaptive significance of body color. Env. Biol. Fish. In Press.

M. Malen-Cooper. 1992. Swimming ability of juvenile Australian Bass, *Macquarianove maculeata* (Steindachner), and juvenile barramundi, *Lates calearlfer* (Bloch), in an experimental vertical-slot fishway. Aust. J. Mar. Freshwater Res.43:823-834.

Peake, S, F.W.H. Beamish, R. S. McKinley, D.A. Scruton, and C. Katopodis. 1997. Relating swimming performance of lake sturgeon, *Acipenser fulvescens*, to fishway design. Can. J. Fish. Aquatic Sci. 54: 1361-1366.

Videler, J.J. 1993. Fish swimming. Chapman & Hall, London.

Webb, P.W. 1986. Kinematics of lake sturgeon, *Acipenser fulvescens*, at cruising speeds. Can. J. Zool. 64: 2137-2141.

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 (h:mm:ss)	Max (h:mm:ss)
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		1 to 2	2 to 3
	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				
	Fish		Logged at	Count			(h:mm:ss)	
Date	Code	Species	Antenna 3	1 to 2	2 to 3	Mean	Min	Max
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

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 (h:mm:ss)	Max (h:mm:ss)
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 (h:mm:ss)	Max (h:mm:ss)
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

<u>Group Trial Shovelnose</u>	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.

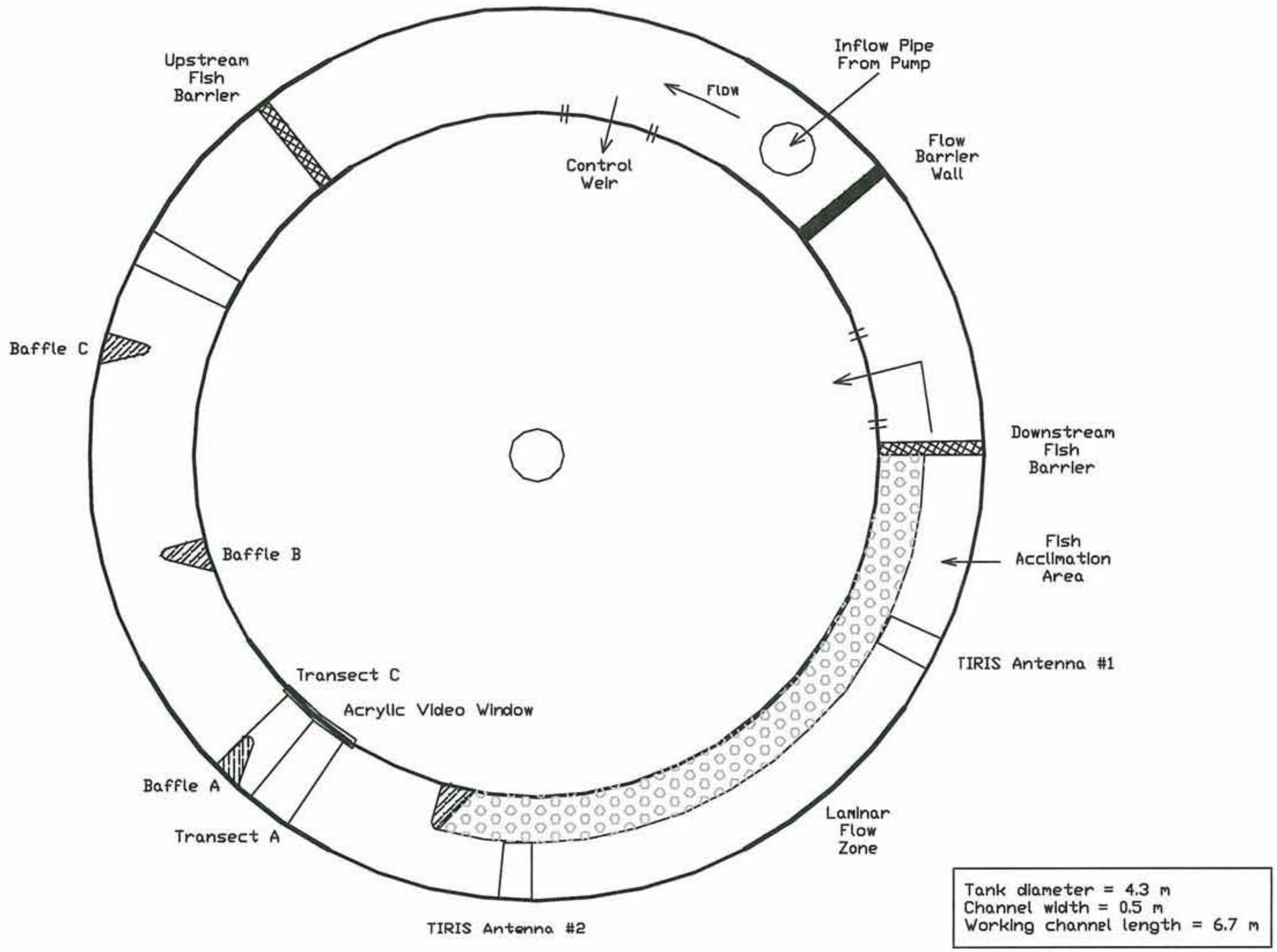


Figure 2. Temperature [C] during single fish pallid and shovelnose sturgeon trials, fall 2001.

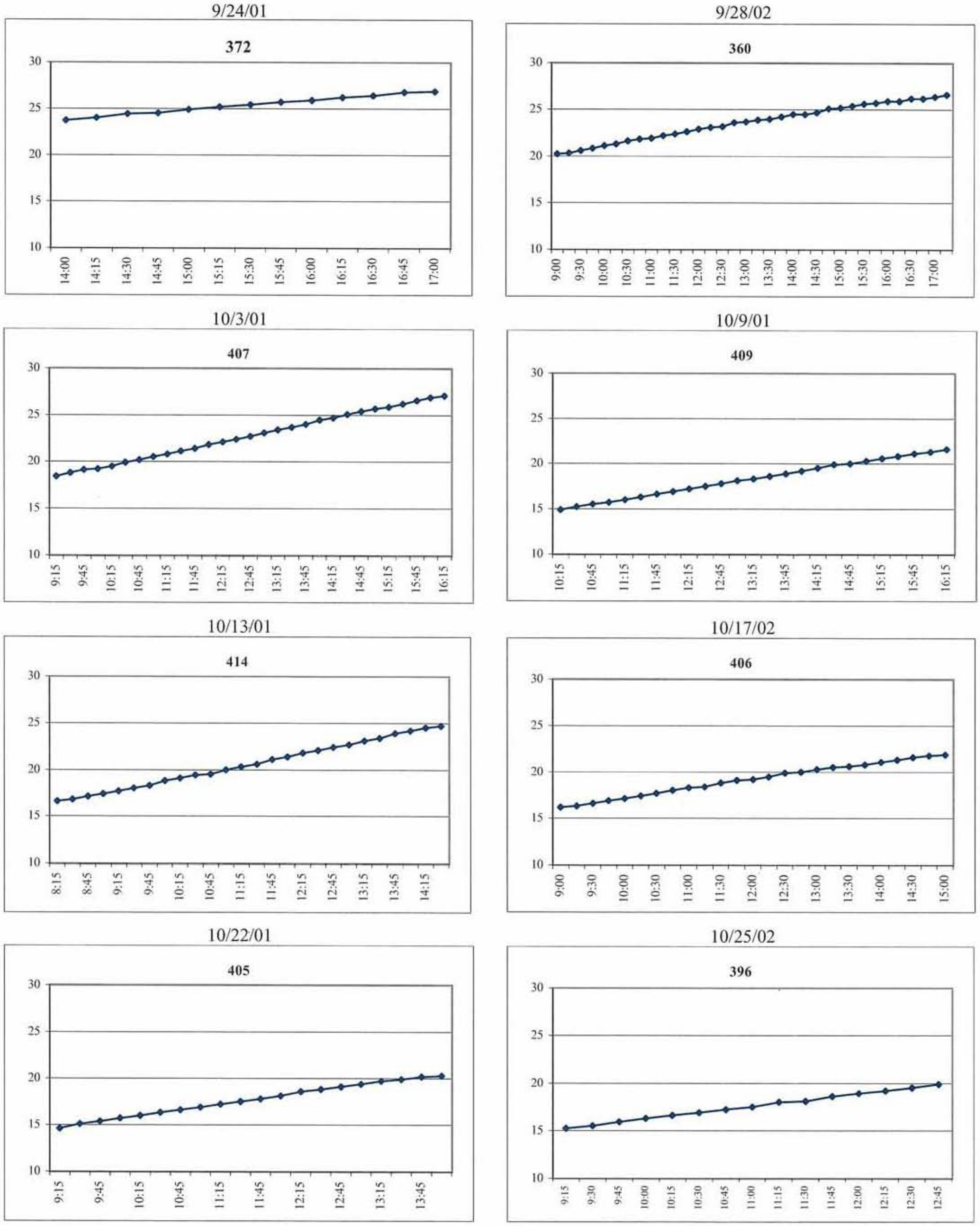
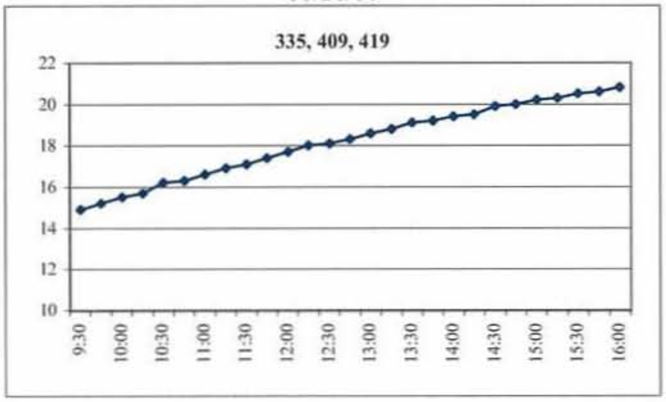
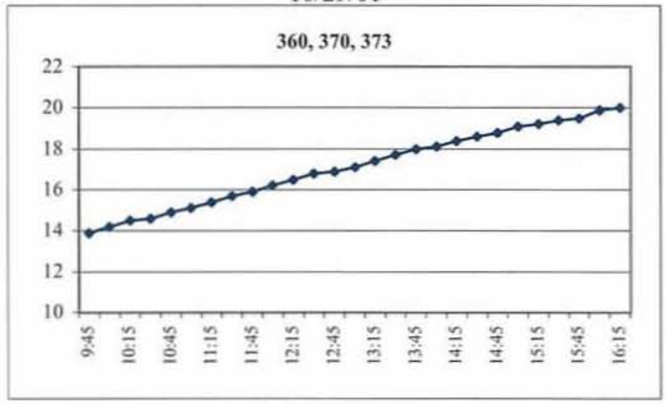


Figure 3. Temperature [C] during group pallid and shovelnose sturgeon trials, fall 2001.

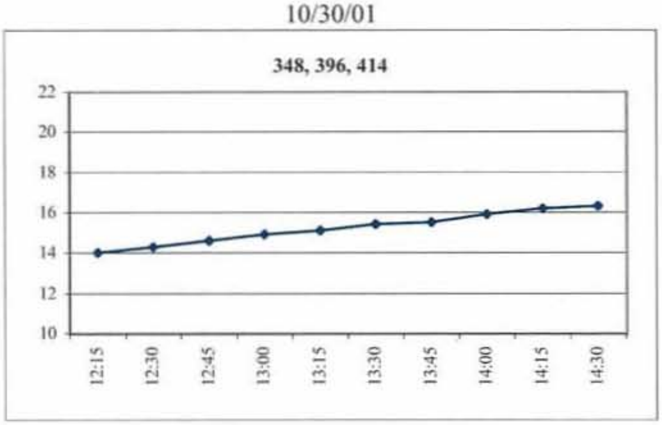
10/26/01



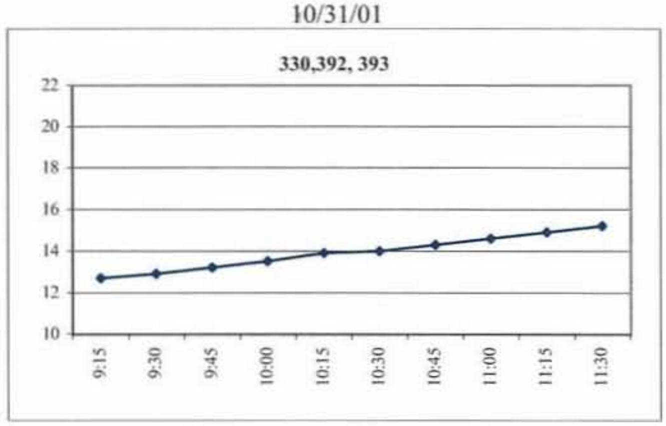
10/29/01



10/30/01

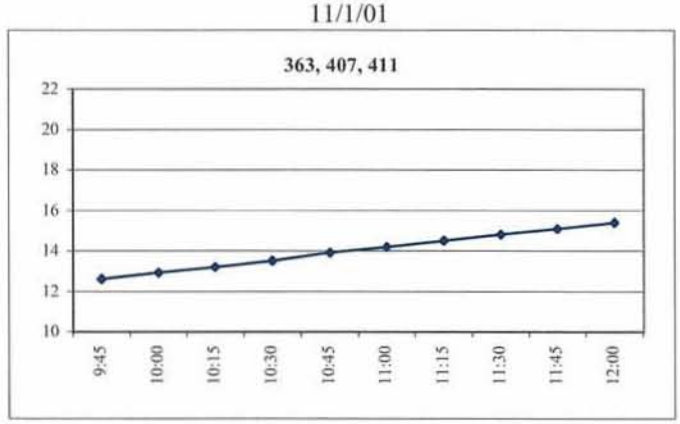


10/31/01

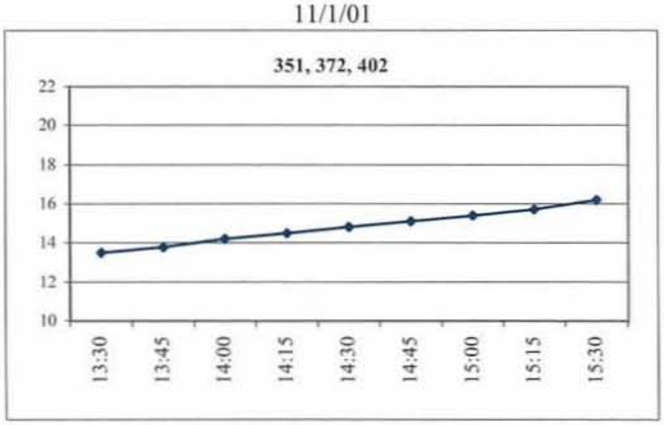


10/31/01

11/1/01



11/1/01



11/2/01

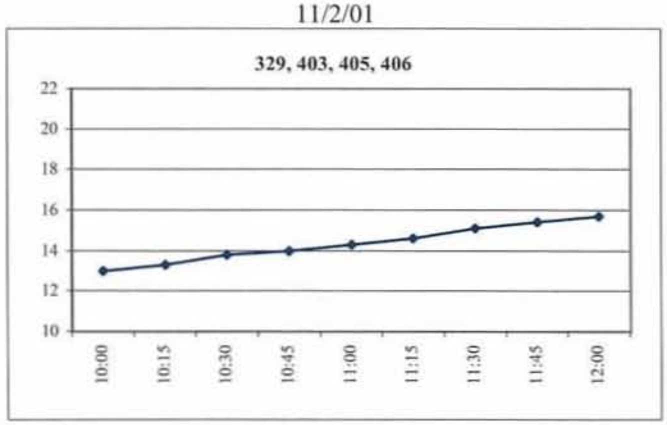


Figure 4. Temperature and percentage dissolved oxygen at the start and end of pallid and shovelnose sturgeon trials.

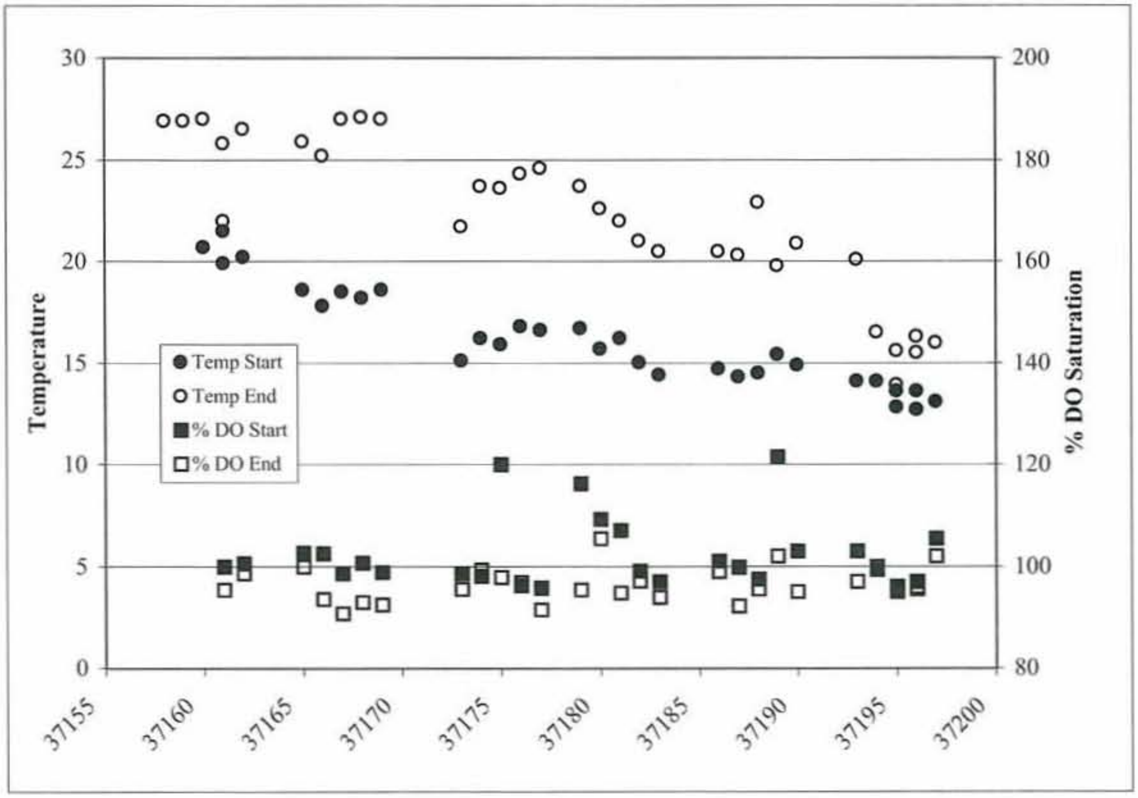


Figure 5. Velocity vectors for the straight channel section of the experimental flume for pallid and shovelnose sturgeon tests, fall 2001.

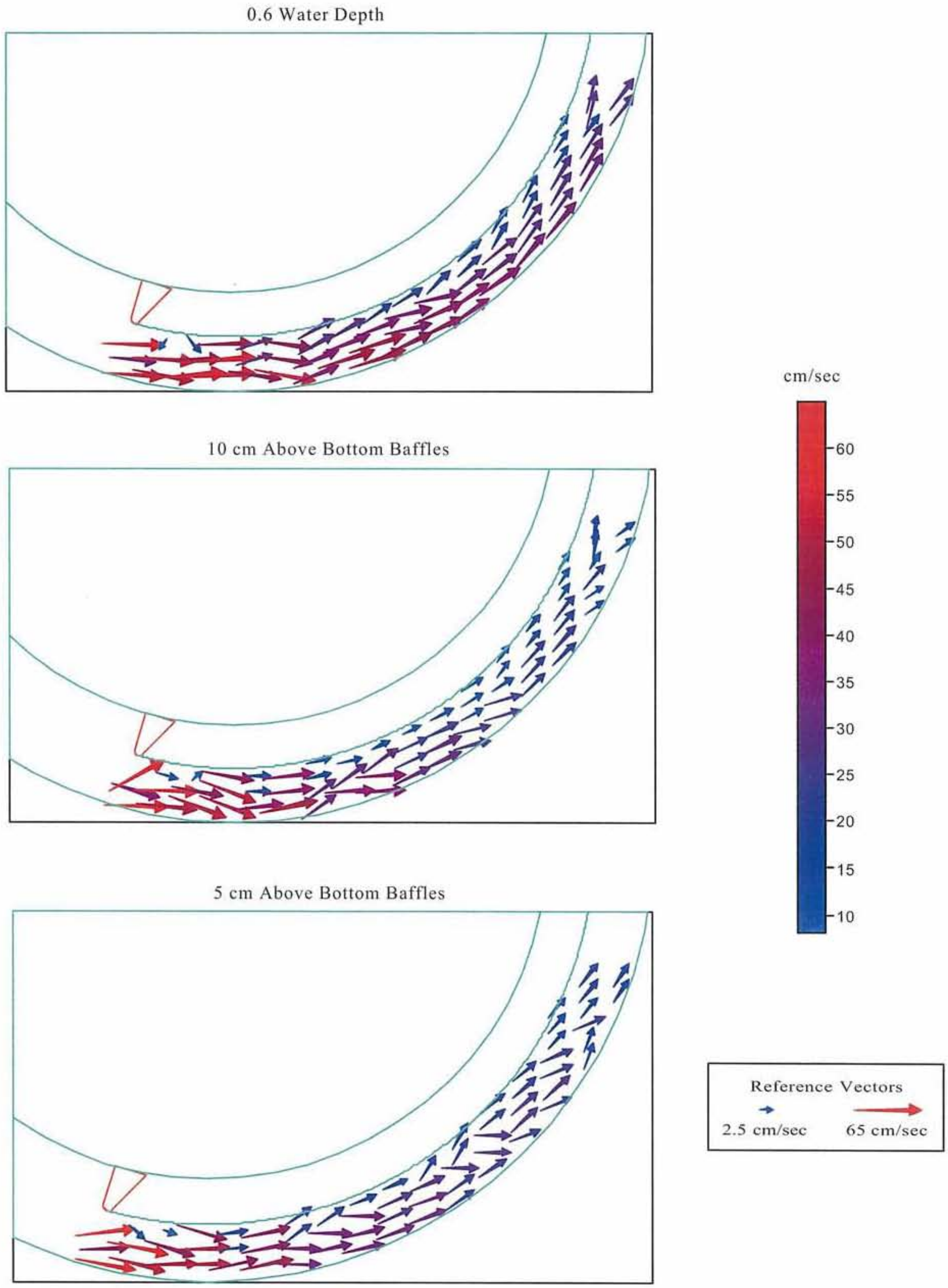


Figure 6. Velocity vectors in the baffle zone at 5 cm above the bottom baffles of the experimental flume for pallid and shovelnose sturgeon trials, fall 2001.

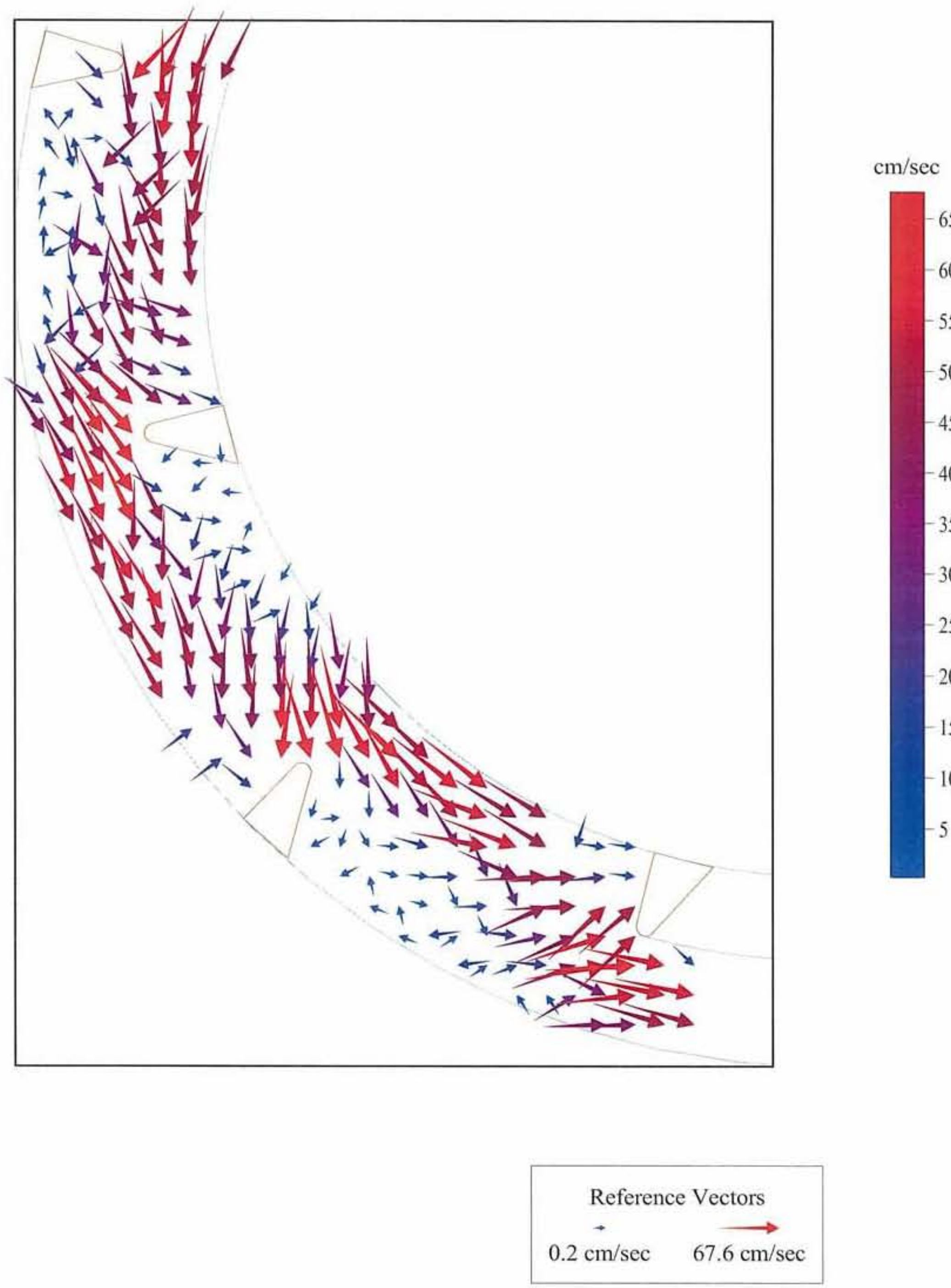


Figure 7. Velocity vectors in the baffle zone at 10 cm above the bottom baffles of the experimental flume for pallid and shovelnose sturgeon trials, fall 2001.

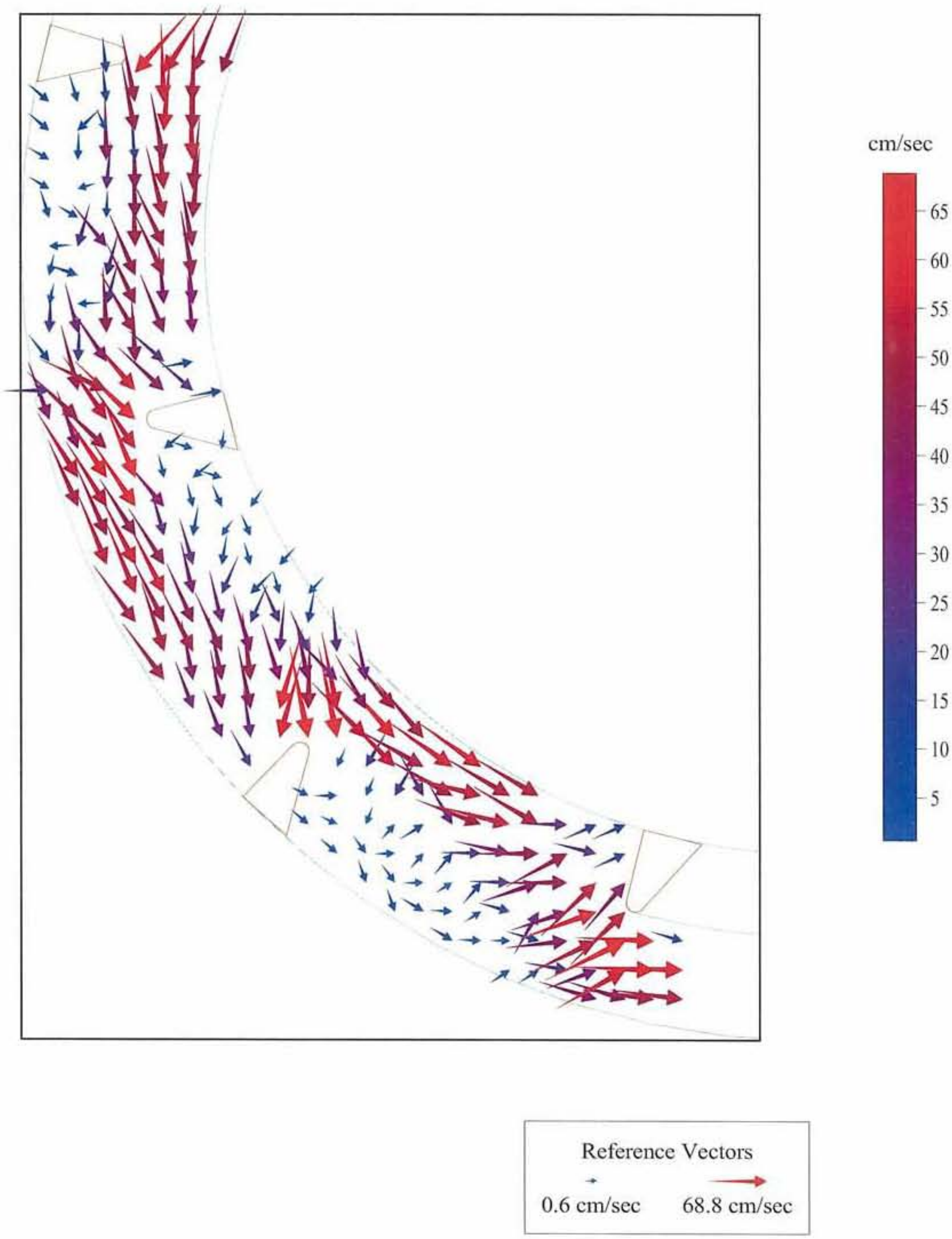


Figure 8. Velocity vectors in the baffle zone at 0.6 depth in the experimental flume for pallid and shovelnose sturgeon trials, fall 2001.

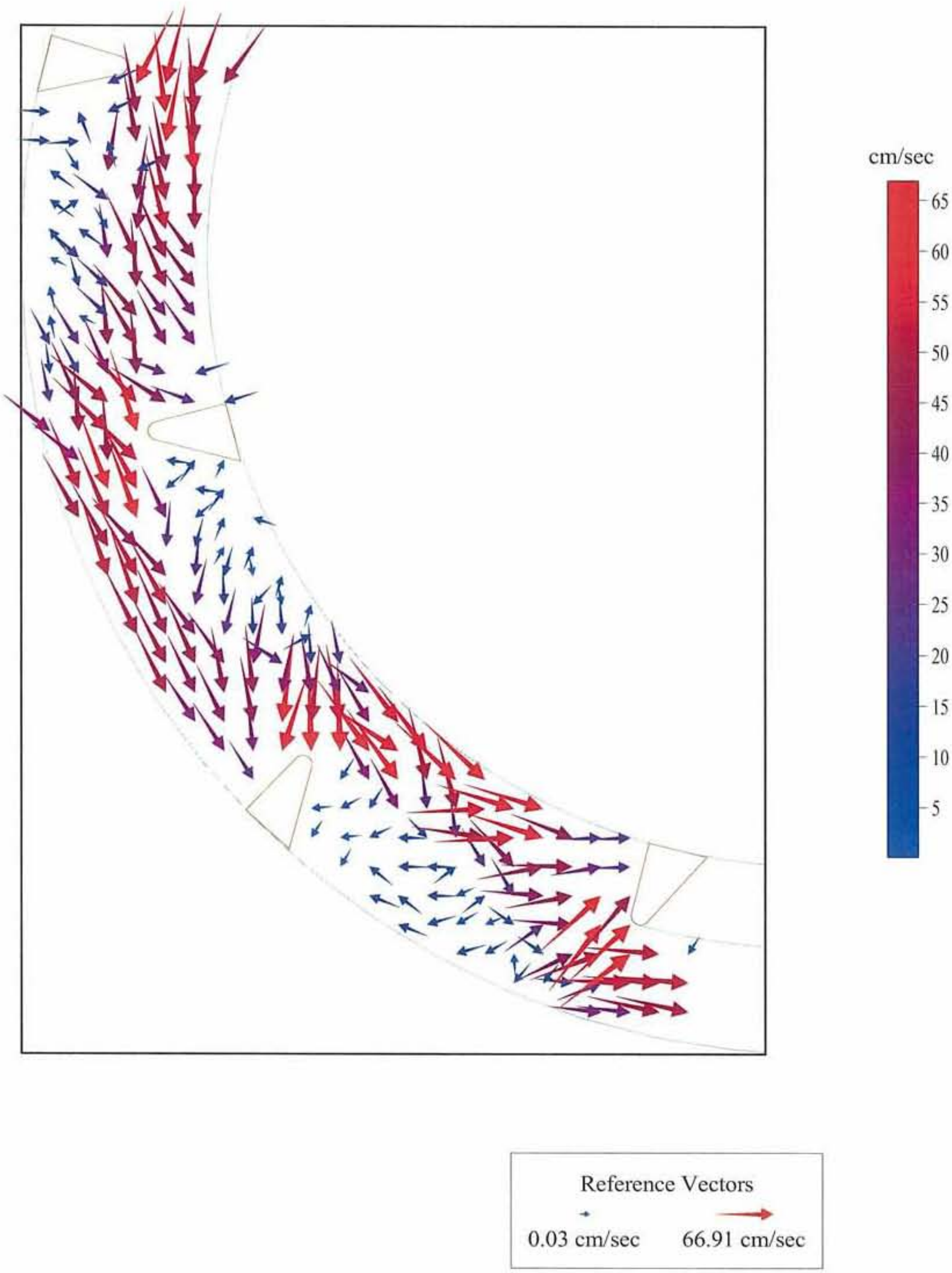
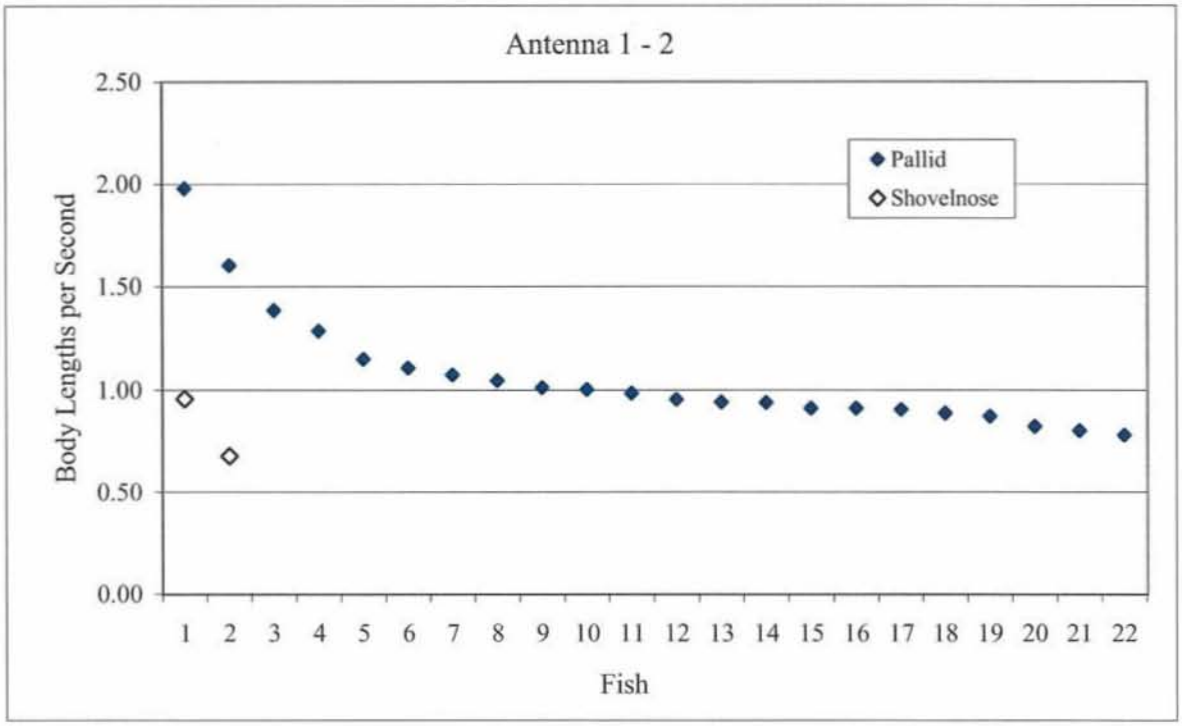


Figure 9. Body lengths per second for the best record of each pallid and shovelknose sturgeon swimming from antenna 1 to 2 (laminar flows) and from transect A to C (baffled flow) in the 'video zone'.



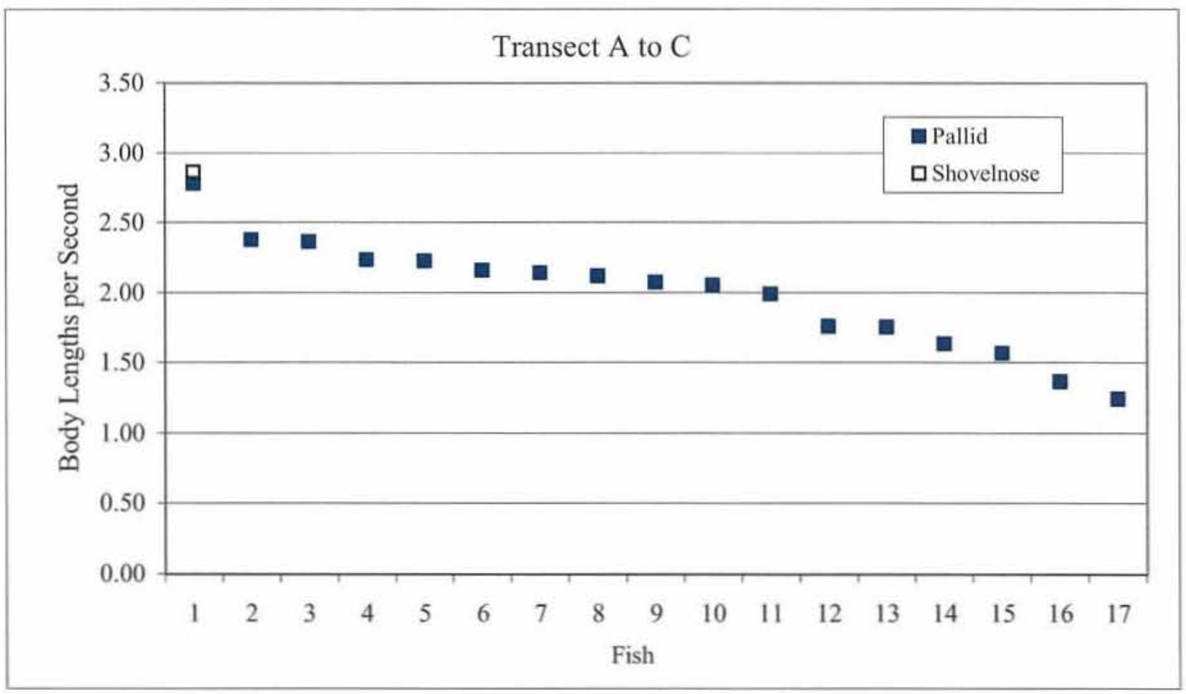
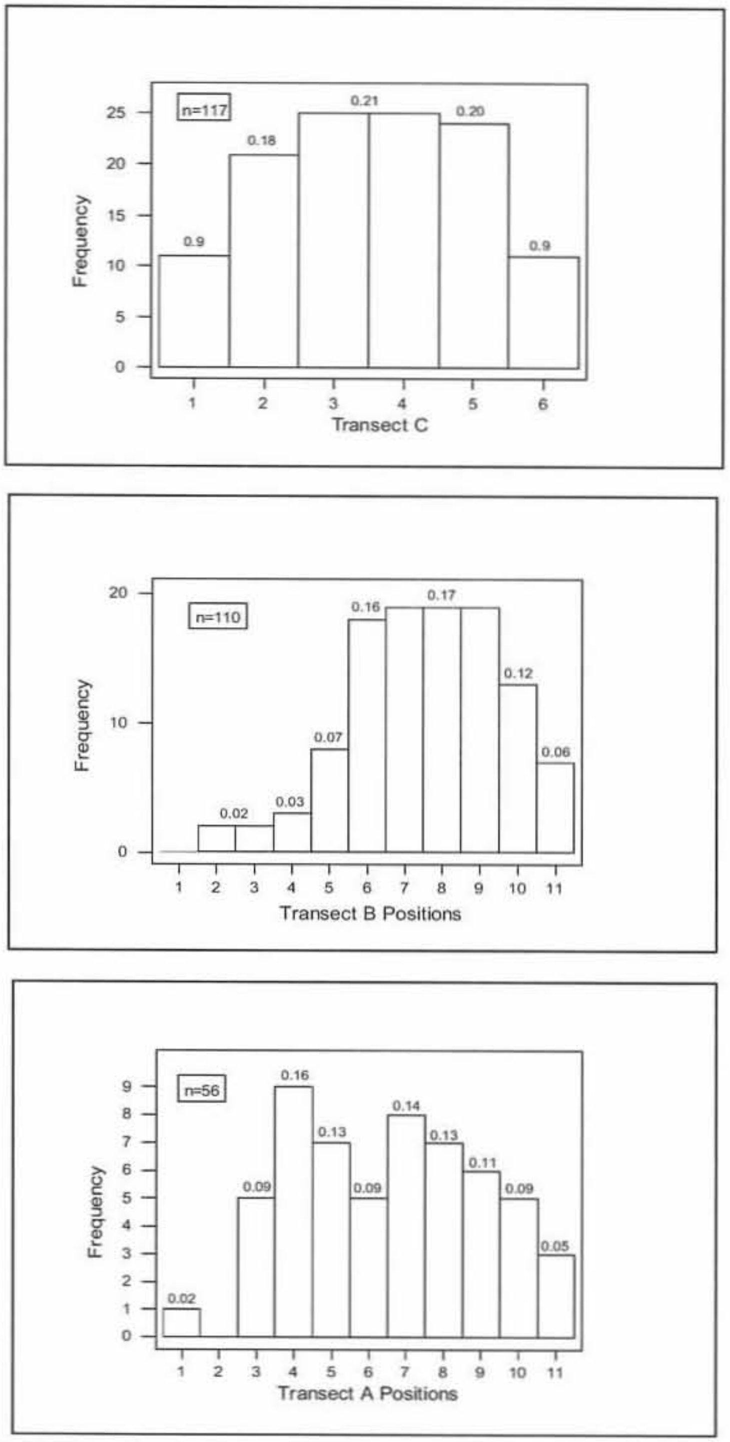


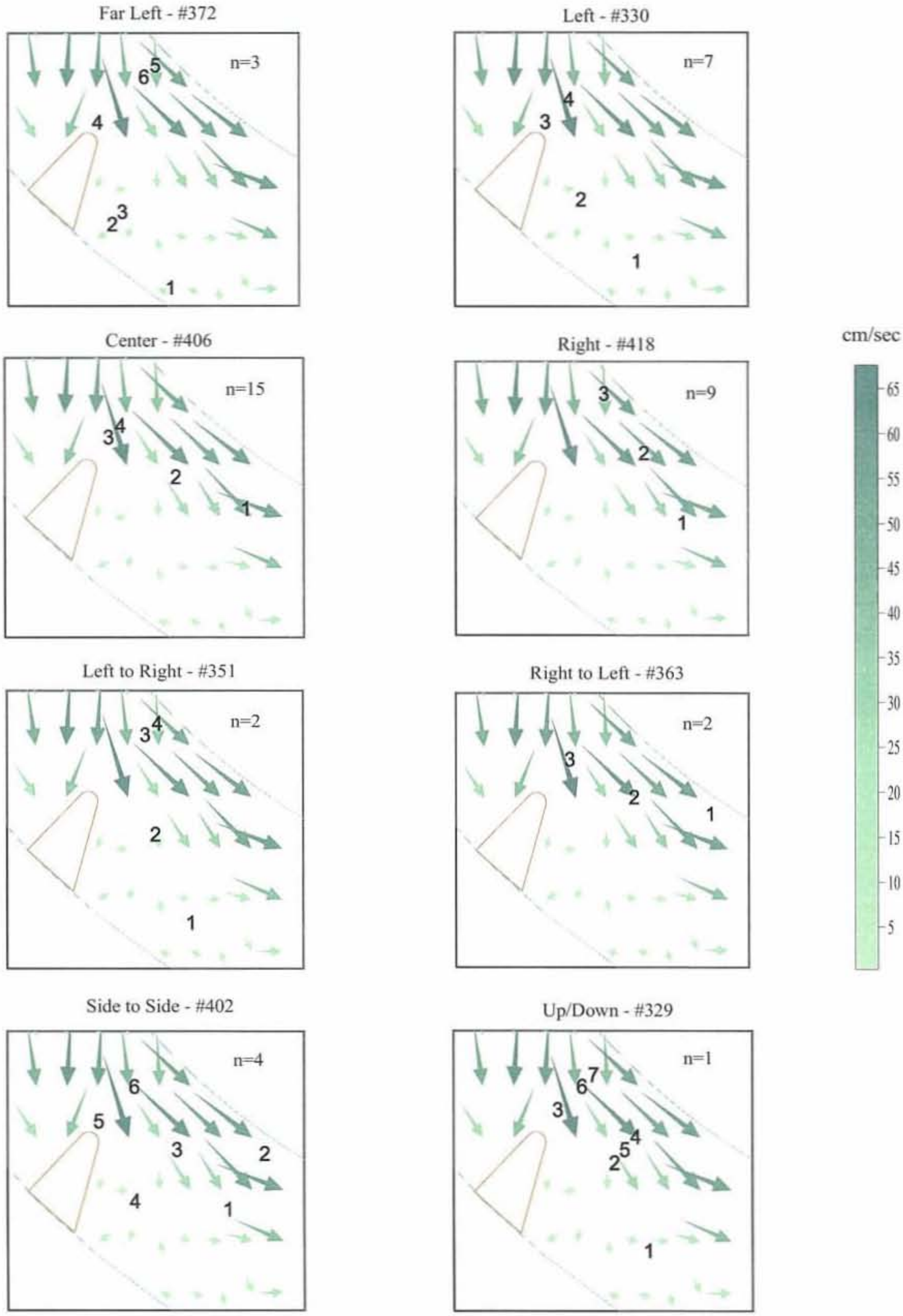
Figure 11. Movement of fish passing through the "video zone" as shown by the frequency of occurance of fish passing across transects A-B (downstream of baffle slot) and transect C (baffle slot). Probability of occurance is above each bar; n = total number of observations of all fish and all trips. Position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

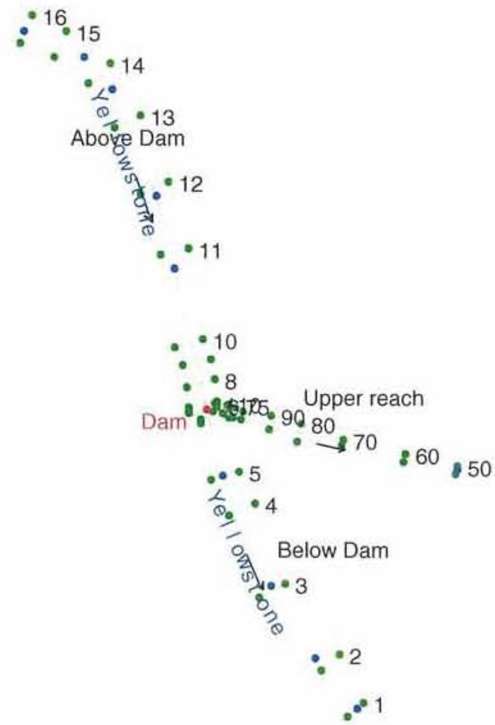


Figure 1 Model Layout for Existing Conditions

Table 1 Flow Optimization Results
Existing Conditions

RAS Plan: rpt flow disRiver	Reach	River Sta	W.S. Elev	E.G. Elev	Q Total
			(ft)	(ft)	(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.

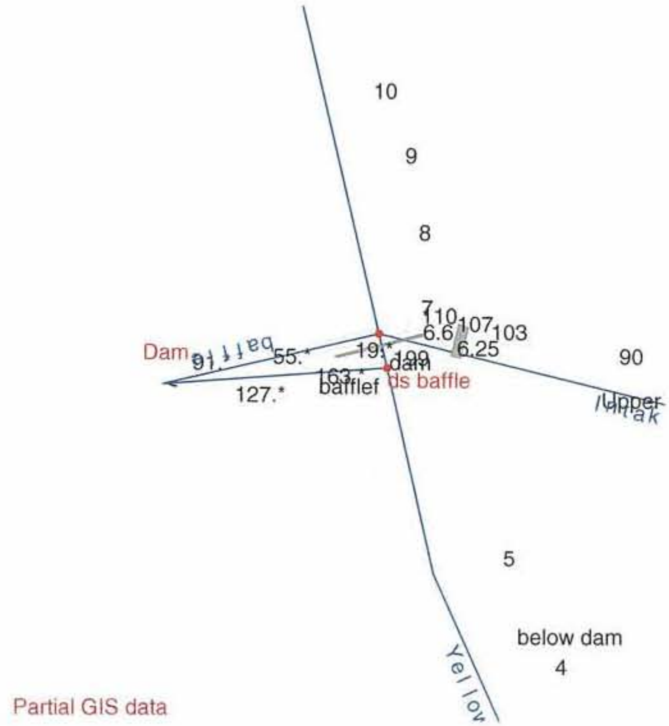


Figure 2 Model Layout of Riprap Fish Ladder Model

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	E.G. Elev	Q Total
		(ft)	(ft)	(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

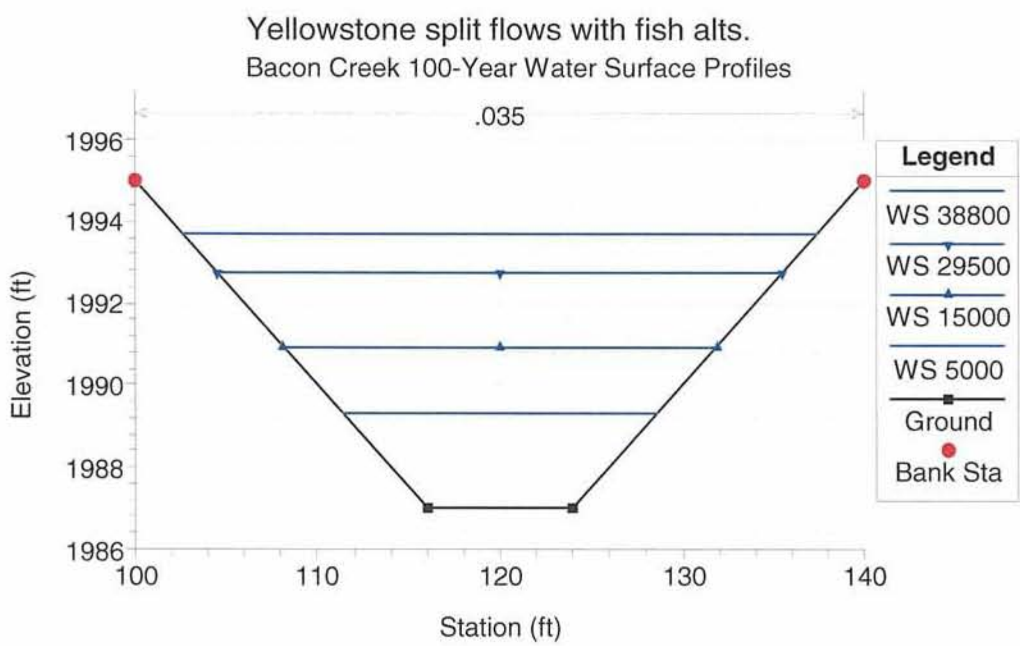


Figure 3 Typical Section from Riprap Fish Ladder Model

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.

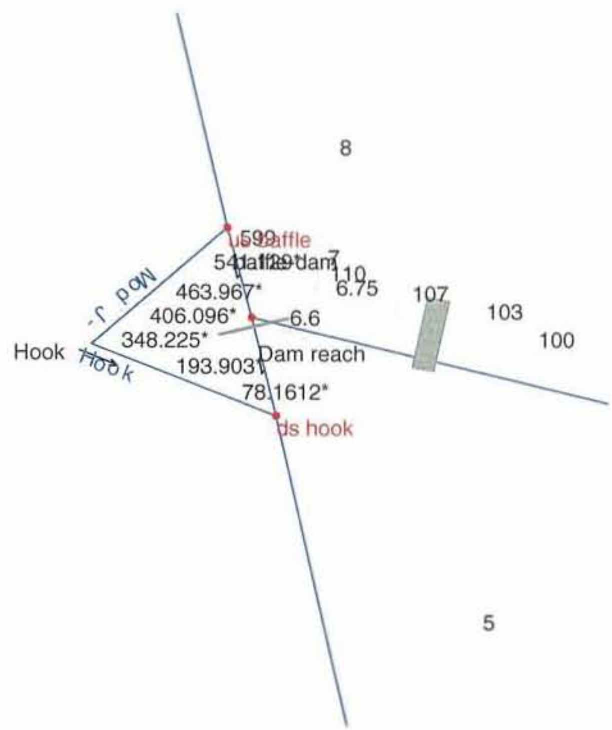


Figure 4 Model Layout of Grouted Riprap Fish Ladder Model

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

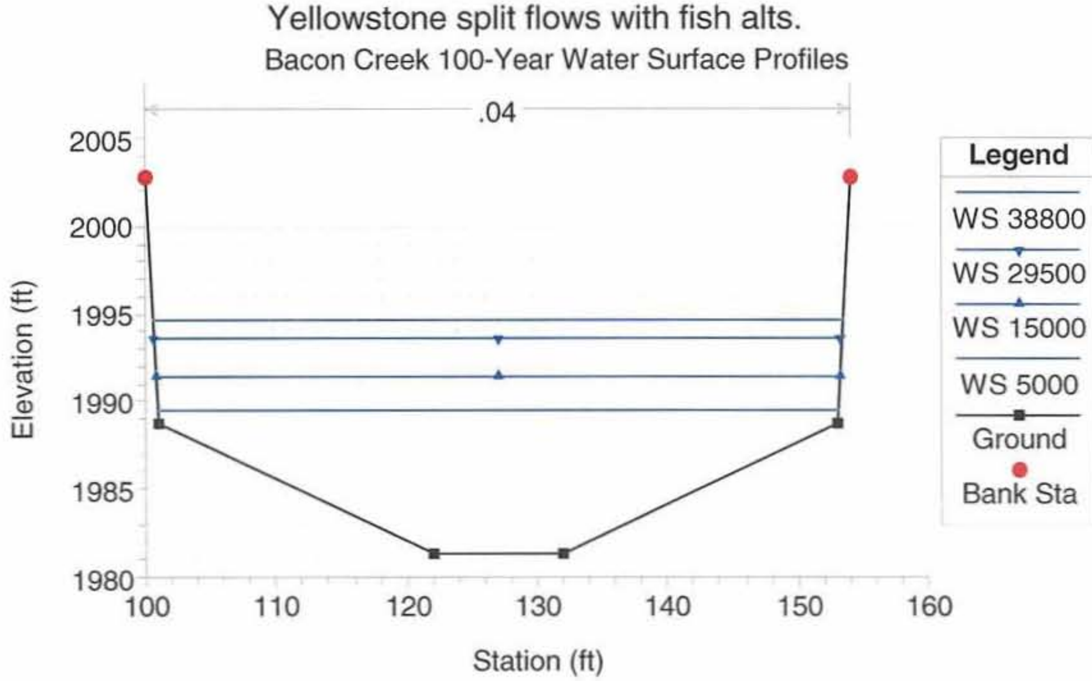


Figure 5 Typical Section from Riprap Fish Ladder Model

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.

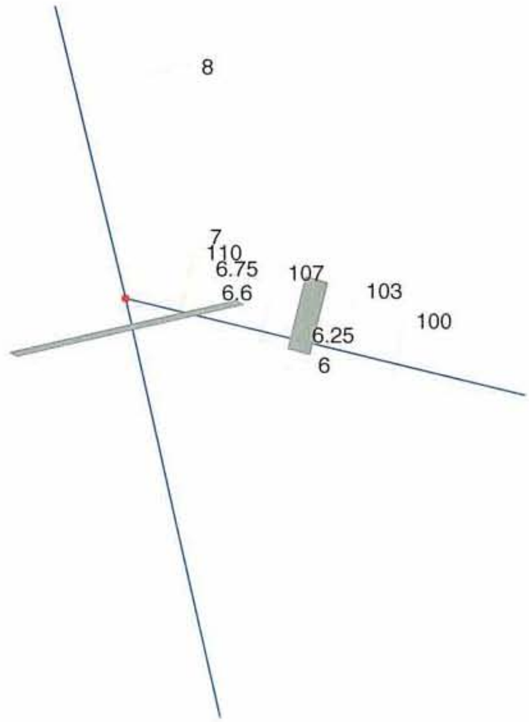


Figure 6 Model Layout for Collapsible Gates using Inline Weir

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

RAS Plan: 1 inline rgReach	River Sta	W.S. Elev	E.G. Elev	Q Total
		(ft)	(ft)	(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

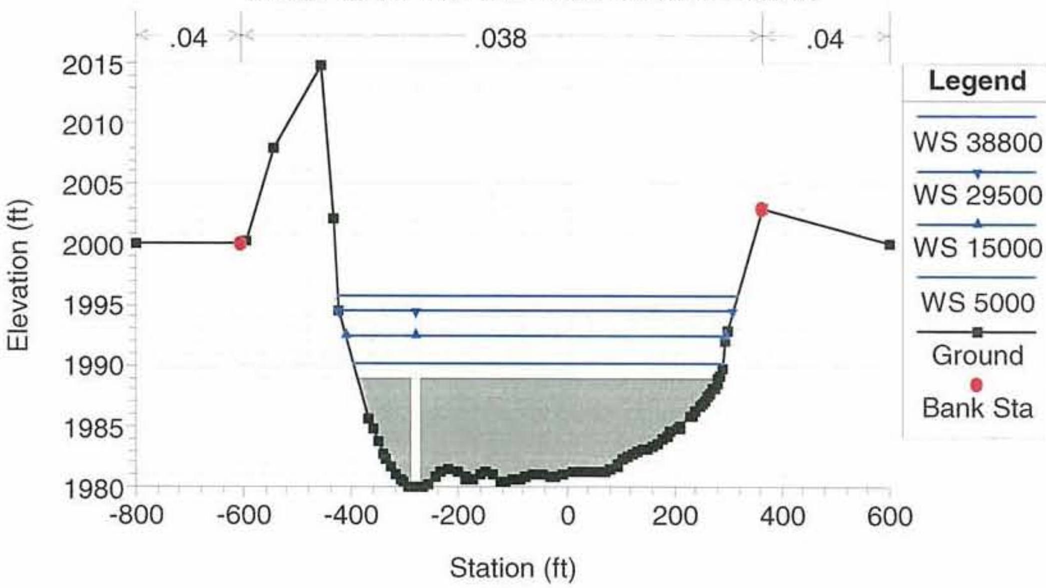


Figure 7 Cross Section at the Inline Weir for Collapsible Gates with One Gate Fully Lowered

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

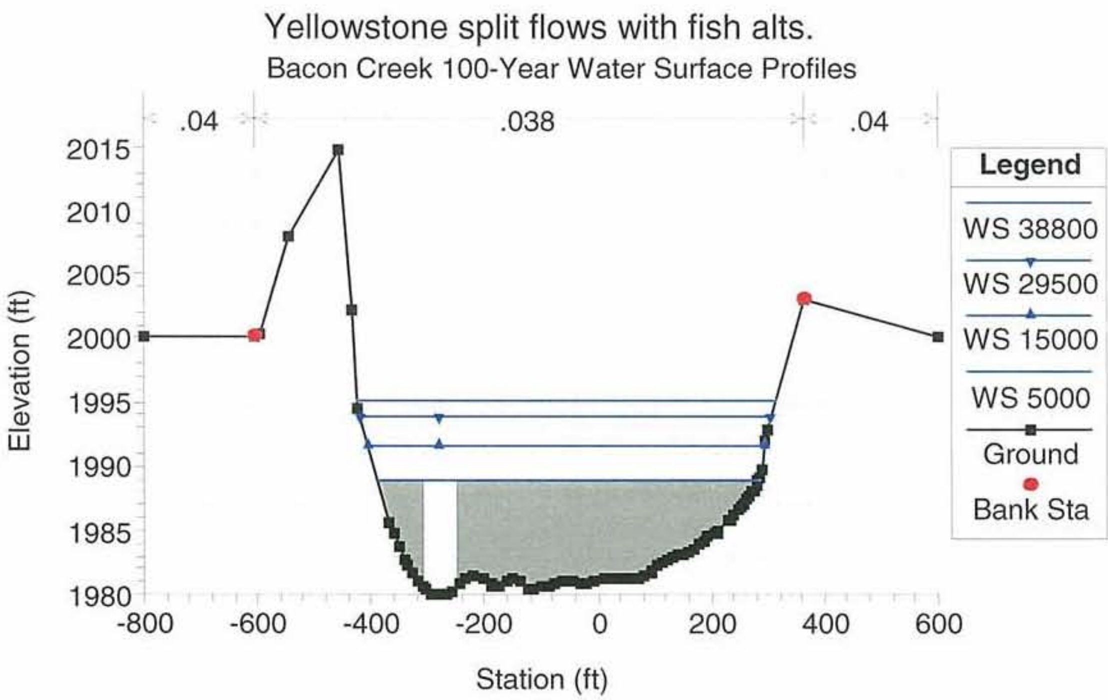


Figure 8 Cross Section at the Inline Weir for Collapsible Gates with Three Gates Fully Lowered

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

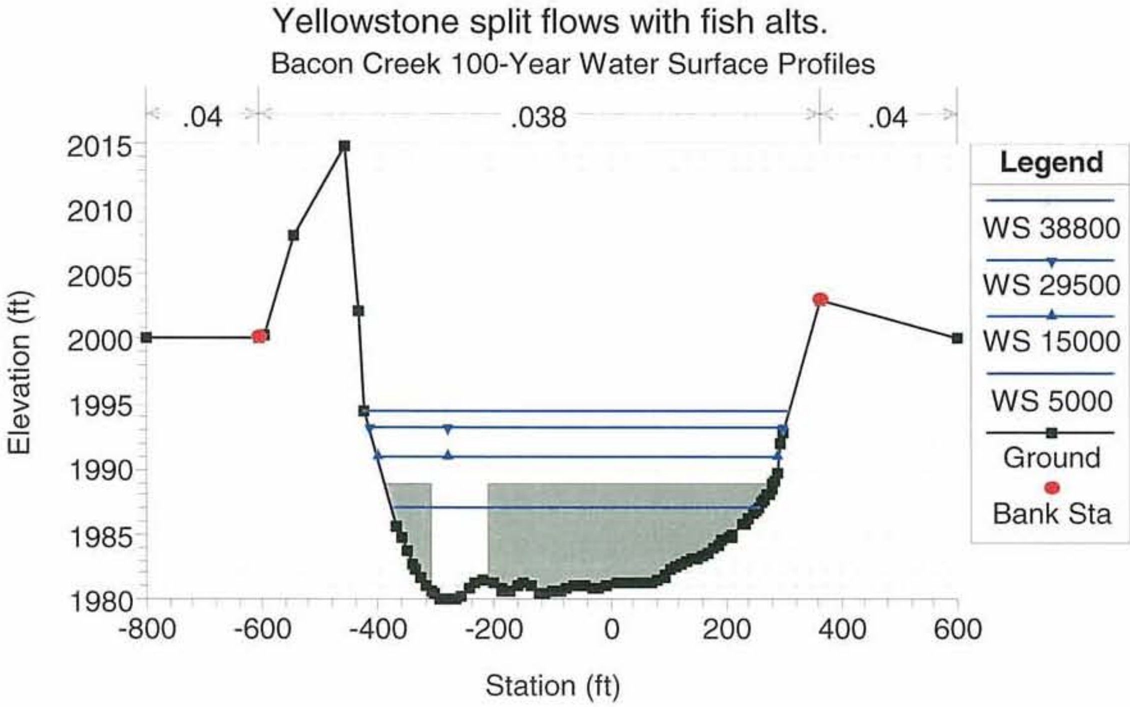


Figure 9 Cross Section at the Inline Weir for Collapsible Gates with Five Gates Fully Lowered

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

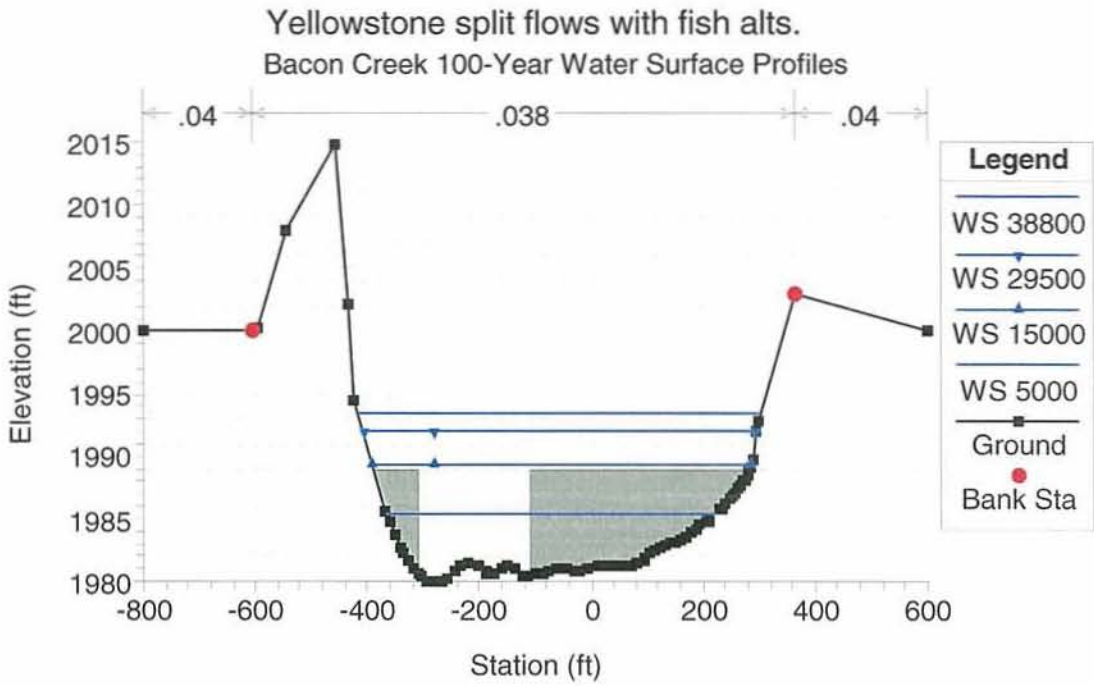


Figure 10 Cross Section at the Inline Weir for Collapsible Gates with Ten Gates Fully Lowered

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.

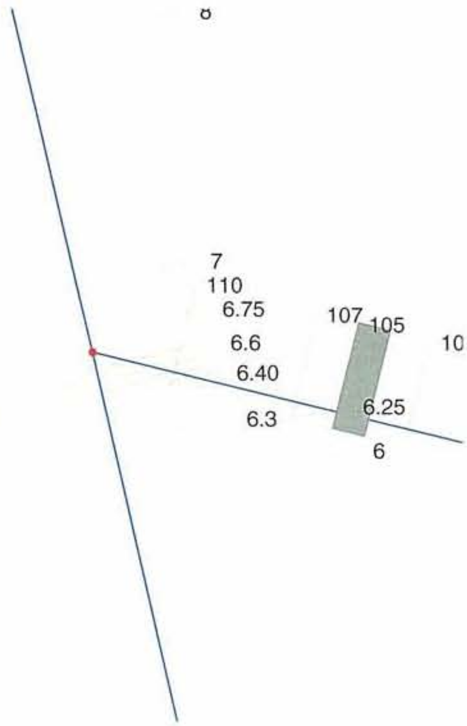


Figure 11 Model Layout for Collapsible Gates modeled as an Embankment

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	E.G. Elev	Q Total
		(ft)	(ft)	(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

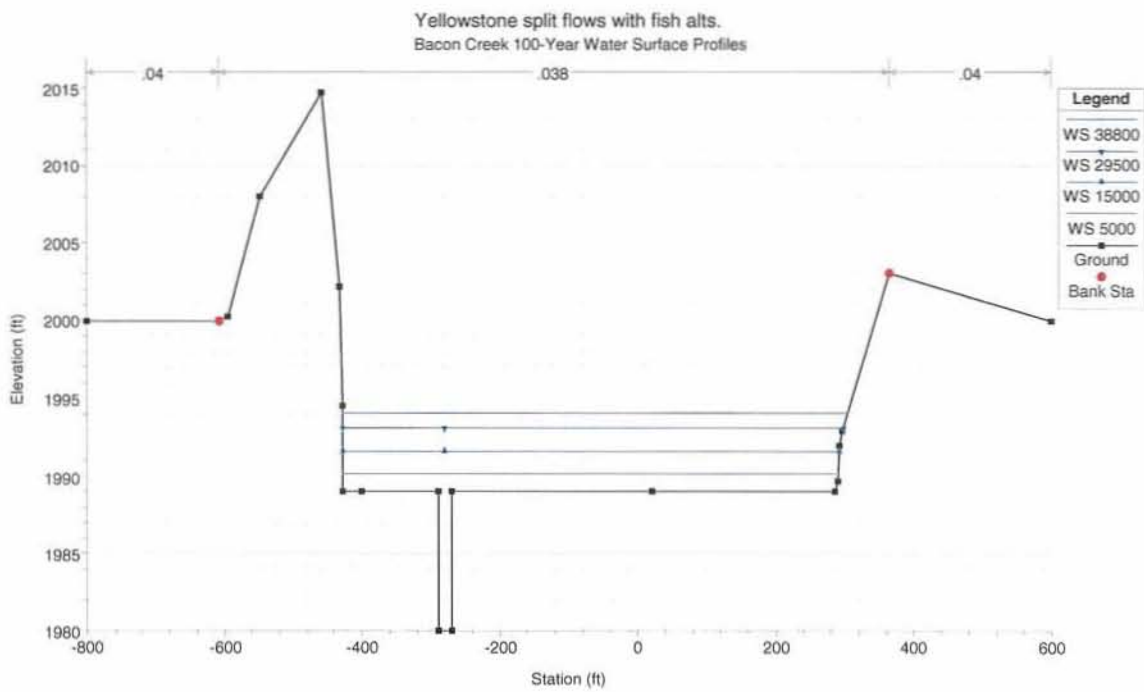


Figure 12 Cross Section at Embankment for Collapsible Gates with One Gate Fully Lowered

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:

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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

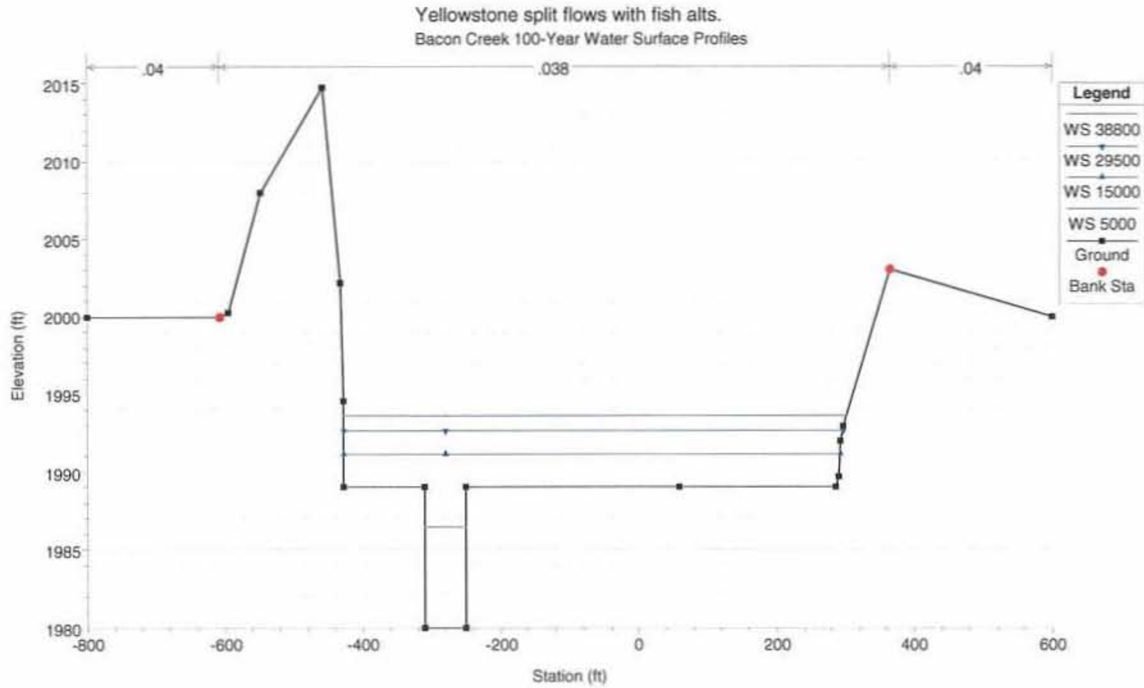

Figure 13 Cross Section at Embankment for Collapsible Gates with Three Gate Fully Lowered

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	E.G. Elev	Q Total
		(ft)	(ft)	(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

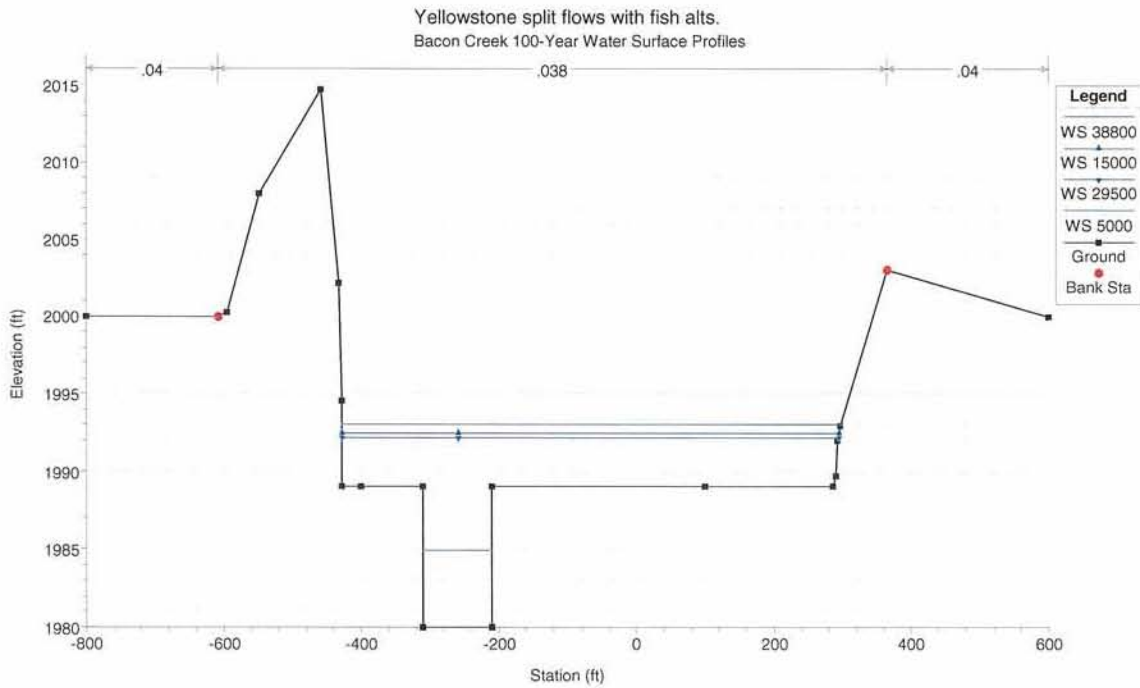

Figure 14 Cross Section at Embankment for Collapsible Gates with Five Gate Fully Lowered

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	E.G. Elev	Q Total
		(ft)	(ft)	(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

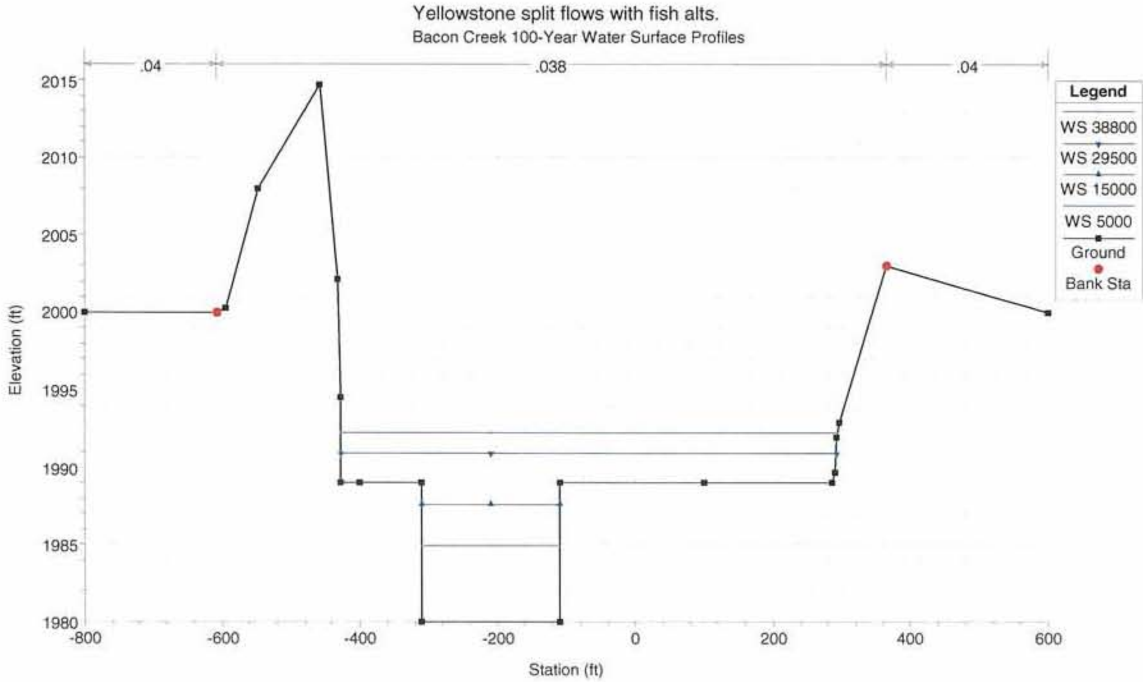

Figure 15 Cross Section at Embankment for Collapsible Gates with Ten Gate Fully Lowered

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.

Thu 16 May 2002 Tri-Service Automated Cost Engineering System (TRACES) TIME 14:39:22
Eff. Date 03/01/02 PROJECT RV0610: YELLOWSTONE RIVER DIVERSION DAM - Glendive, MT
Option Feasibility Estimates SUMMARY PAGE 1
** 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

LABOR ID: CI0610 EQUIP ID: MR0059 Currency in DOLLARS CREW ID: CREW00 UPB ID: UPBE00

	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

	QUANTY UOM	CONTRACT	CONTINGN	E&D	S&A	TOTAL COST	UNIT
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

	QUANTY UOM	CONTRACT	CONTINGN	E&D	S&A	TOTAL COST	UNIT
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

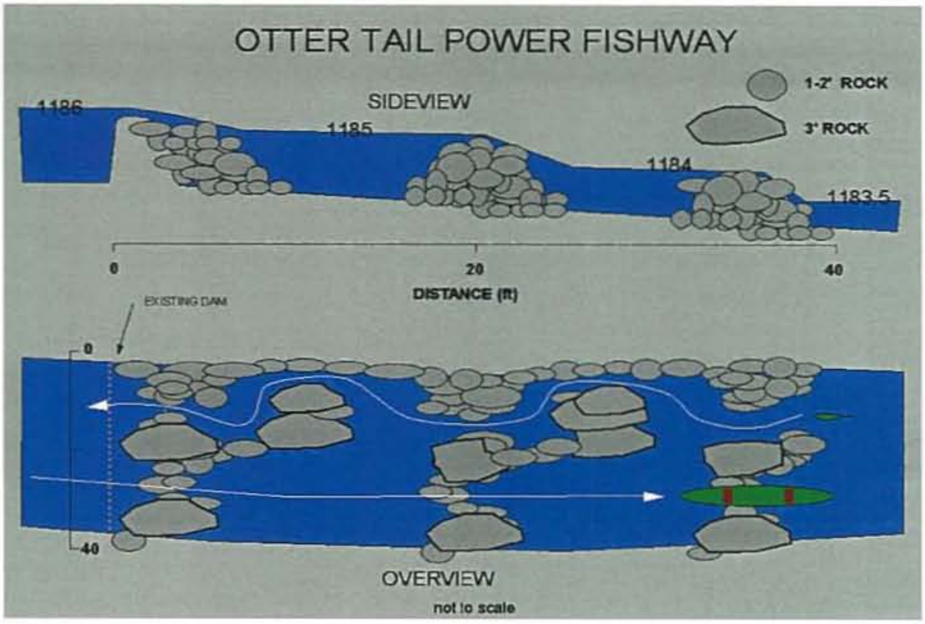
** PROJECT OWNER SUMMARY - FEATURE **

		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

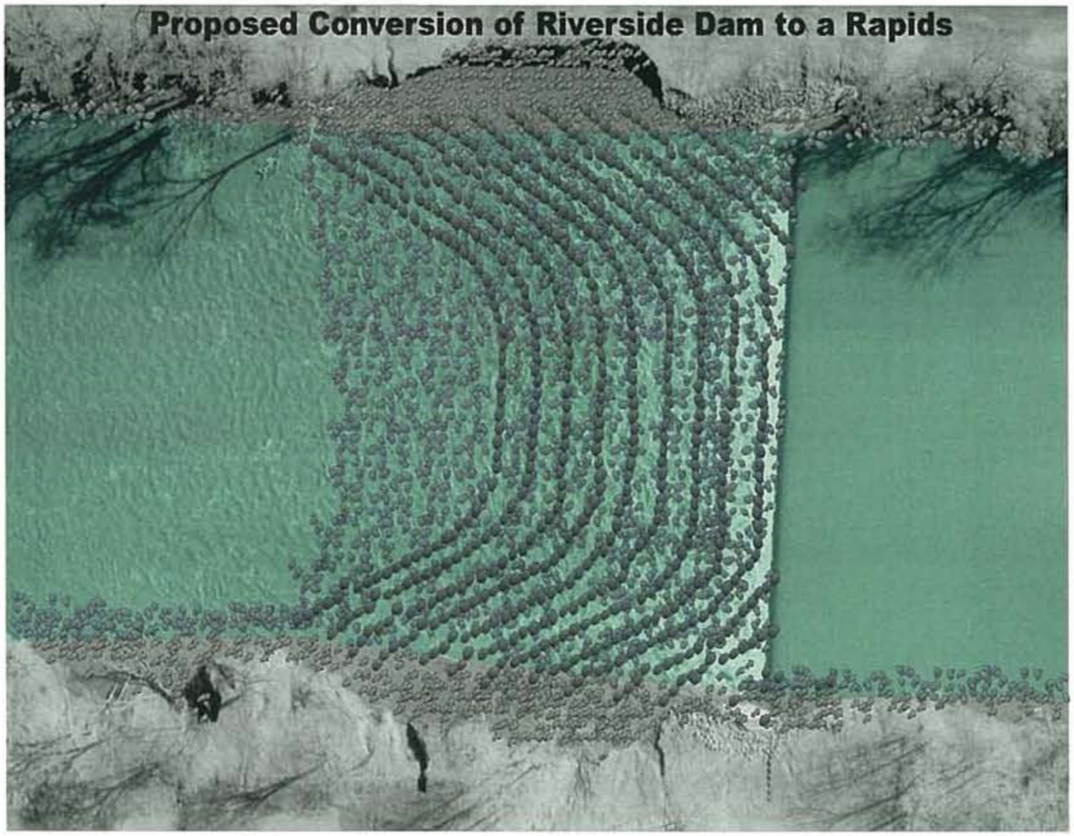
APPENDIX F

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