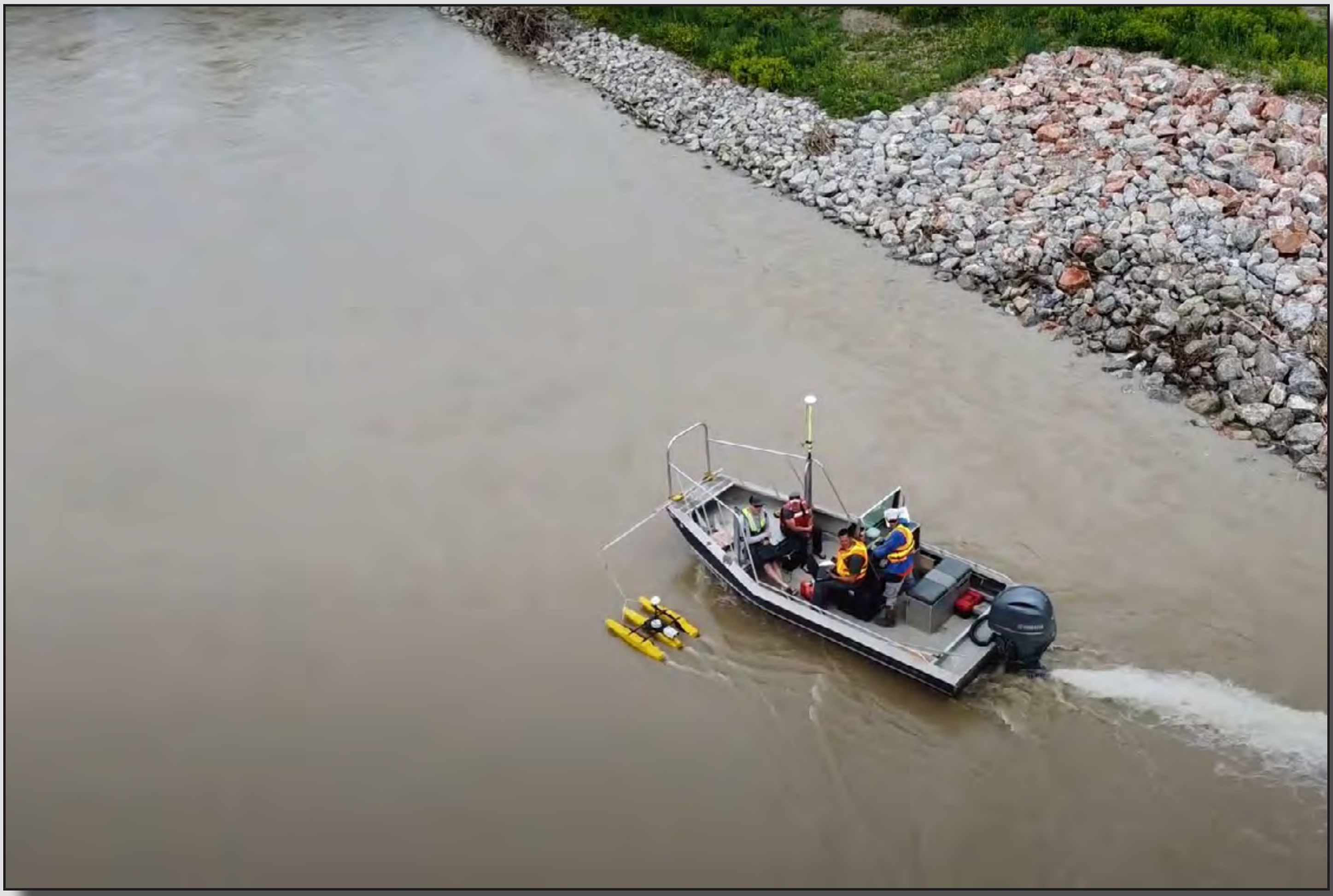
Prepared in cooperation with the Bureau of Reclamation

Yellowstone River Fish Bypass Channel Physical and Hydraulic Monitoring, Montana



Data Report 1189

U.S. Department of the Interior
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Cover. Photograph showing U.S. Geological Survey personnel collecting data in the Yellowstone River fish bypass channel, taken near the entrance of the channel on June 24, 2022, by James Brower of the Yellowstone Irrigation District.

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By J. Brooks Stephens, Jason S. Alexander, and Seth A. Siefken

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Contents

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Table

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Area	
acre	0.004047	square kilometer (km^2)
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Supplemental Information

Streamflow is given in cubic feet per second (ft^3/s).

Abbreviations

ADCP	acoustic Doppler current profiler
GPS	global positioning system
IDD	Intake Diversion Dam
Reclamation	Bureau of Reclamation
RSL	RiverSurveyor LIVE
RTK–GNSS	real-time kinematic global navigation satellite system
USGS	U.S. Geological Survey
VMT	Velocity Mapping Toolbox

Yellowstone River Fish Bypass Channel Physical and Hydraulic Monitoring, Montana

By J. Brooks Stephens,[1] Jason S. Alexander,[2] and Seth A. Siefken[1]

Abstract

The U.S. Geological Survey, in cooperation with the Bureau of Reclamation, began monitoring the Yellowstone River fish bypass channel according to the specifications of the Lower Yellowstone Adaptive Management and Monitoring Plan. The fish bypass channel was constructed to provide upstream migrating fish with a route around a diversion dam. The objective of this study is to monitor the physical and hydraulic characteristics of the bypass channel, including flow split, minimum depth for the deepest continuous 30 cross sectional feet, and mean channel velocity. Data are collected through several sets of measurements within the bypass channel at varying times during the field season. Physical and hydraulic data collected during this study can be used to ensure the hydraulic design criteria of the bypass channel are being met.

This report presents the methods used to monitor the physical and hydraulic characteristics of the bypass channel. Examples of the types of data collected and summarized as part of this study are provided using three figures and one table. Data collected for this study are summarized and published in an accompanying U.S. Geological Survey data release. The monitoring data can be used by the cooperating agencies to help describe the preferred hydraulic conditions for *Scaphirhynchus albus* (Forbes and Richardson, 1905; pallid sturgeon) passage.

Introduction

The Bureau of Reclamation (Reclamation) Lower Yellowstone Project was authorized in 1902 and provides irrigation water for about 58,000 acres in eastern Montana and western North Dakota (Bureau of Reclamation, 2021). The project includes the Intake Diversion Dam (IDD; fig. 1), a 12-foot (ft) high, 700-ft long wood and stone structure extending across the Yellowstone River channel, which raises the river elevation so water can be diverted into the Lower Yellowstone Project Main Canal (fig. 1). The diverted water is used to irrigate crops such as sugar beets, alfalfa, wheat, barley, and rye; however, the IDD is also a partial or total barrier to the movement upstream or downstream of some fish species and has been hypothesized to be a limitation to the recovery of the endangered *Scaphirhynchus albus* (Forbes and Richardson, 1905; pallid sturgeon; U.S. Fish and Wildlife Service, 2014). Monitoring of pallid sturgeon has indicated that these fish do not migrate beyond the IDD, and it is thought that the unimpeded river distance between the IDD and downstream reservoirs is not enough to allow free embryos of pallid sturgeon to naturally drift and mature (Bureau of Reclamation, 2021).

In 2019, construction began on a 2.1-mile-long bypass channel around the IDD (fig. 1) with the intention of allowing passage of pallid sturgeon and other fish. During construction of the bypass channel, Reclamation, in coordination with the U.S. Army Corps of Engineers and U.S. Fish and Wildlife Service, updated the Lower Yellowstone Adaptive Management and Monitoring Plan (Bureau of Reclamation, 2021) to specify monitoring criteria for the bypass channel. These criteria include the following:

1. Acoustic Doppler current profilers (ADCPs) are used to monitor the physical and hydraulic characteristics of the bypass channel at 14 permanent and 6 random cross sections, with potential for additional cross sections as needed.

2. Several sets of ADCP measurements are made at different times during the field season (April 1–October 31); each set of measurements includes all 20 cross sections measured on the same day and at the same streamflow for consistency.

3. The cross sections are measured at least twice during each of the following flow conditions:

    a. Prerunoff (April–May): 10,000–20,000 cubic feet per second (ft^3/s).

    b. Runoff (June–July): greater than 20,000 ft^3/s.

    c. Postrunoff or summer baseline (August–October): 5,000–10,000 ft^3/s.

[1]U.S. Geological Survey.

[2]Former U.S. Geological Survey employee.

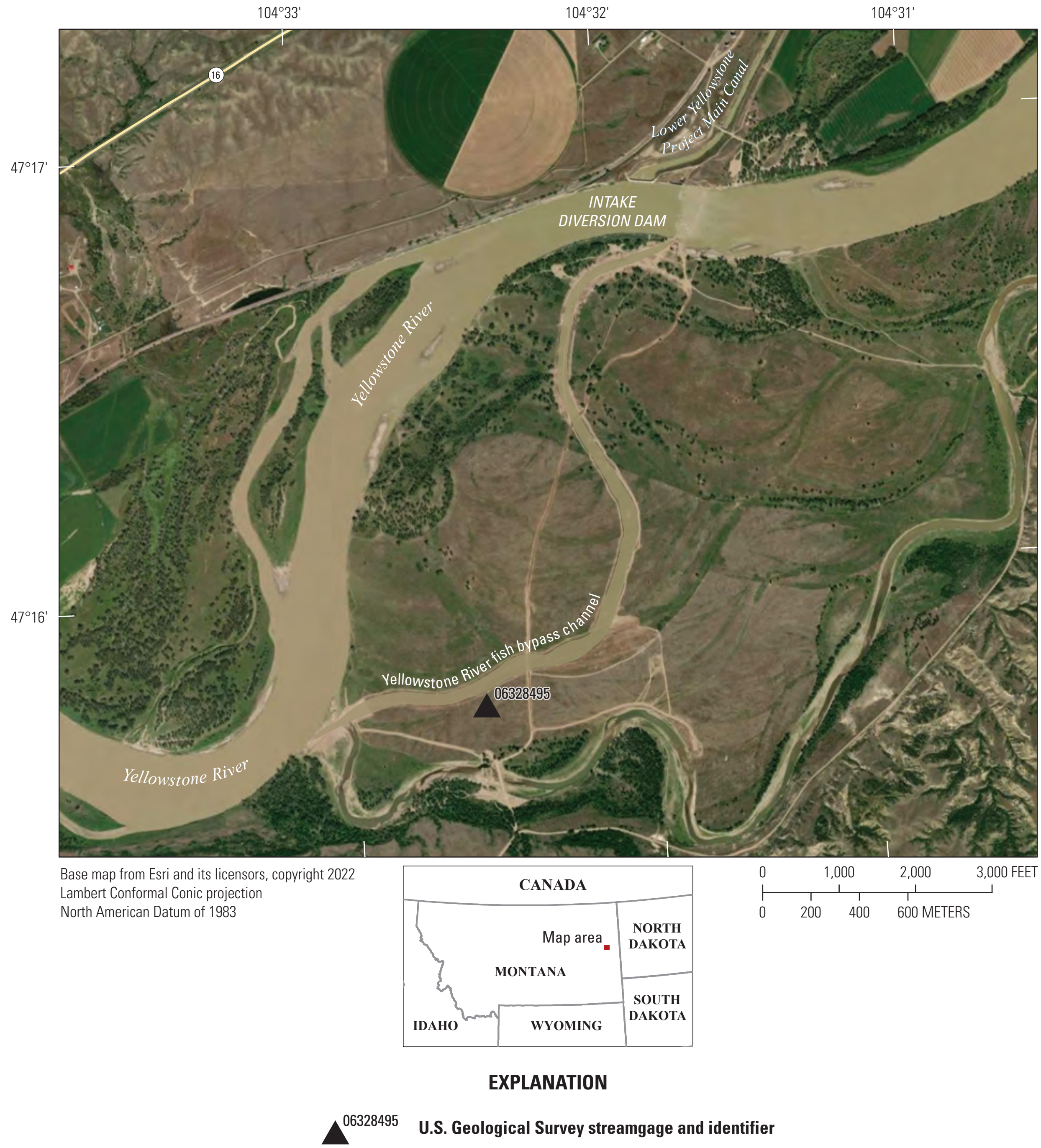

Figure 1. Location of the Yellowstone River fish bypass channel and Lower Yellowstone Project features in relation to the Yellowstone River, Montana.

The monitoring criteria also include the potential for directly monitoring bypass channel hydraulic characteristics in locations where telemetry data indicated congregations of pallid sturgeon.

In the spring of 2022, the U.S. Geological Survey (USGS), in cooperation with Reclamation, began monitoring the bypass channel according to the specifications of the Adaptive Management and Monitoring Plan. This report summarizes the general methods used by the USGS to monitor the physical and hydraulic characteristics of the bypass channel.

Purpose and Scope

The purpose of this report is to present methods used by the USGS to monitor hydraulic conditions in the bypass channel around the IDD on the Yellowstone River near Intake, Montana. Monitoring by the USGS began in 2022. Data collected from the 2022 and 2023 monitoring surveys are summarized and published in an accompanying USGS data release (Stephens and Siefken, 2024). This data release is planned to be updated annually as future data are collected. Data from the 2022 and 2023 monitoring surveys are used herein to illustrate how streamflow, channel geometry, and velocity data are collected and summarized in the data release.

Methods

Scientists and engineers use a variety of terms to describe characteristics of a river channel and its streamflow. In this report, the term “bathymetry” refers to the shape (topography) of a stream channel under the water surface and the term “hydraulics” refers to physical attributes of water flow in a stream channel. For monitoring cross sections in the bypass channel and the mainstem Yellowstone River, streamflow and water velocity are the primary measures used herein to describe hydraulic conditions; channel area, width, and depth are the primary measures used herein to describe channel bathymetry.

Acoustic Doppler Current Profiler Measurements

ADCPs were the primary instruments used to measure channel bathymetry and hydraulic conditions (Stephens and Siefken, 2024). ADCPs emit sound into the water column to measure water velocity via the Doppler effect (Mueller and others, 2013). The sound frequency emitted is dependent on the make and model of the ADCP, and different ADCP instruments are often designed for use in different river conditions (such as different depth, velocity, and clarity). Modern ADCP instruments can often measure velocity and direction of flow at multiple depths within the water column. These data are commonly averaged and binned over some user-defined width and depth interval.

ADCP measurements are typically made by suspending the instrument into the top of the water column and moving it across a span of the river channel in one or more passes perpendicular to the primary flow direction. Because channel hydraulic conditions are always changing, several passes are often made, and the measurements are postprocessed to produce an average of the conditions observed from each pass (Mueller and others, 2013). Additional details on methods used by the USGS to make ADCP measurements are provided in Mueller and others (2013). The USGS also uses a variety of software tools to postprocess ADCP measurement data including QRev (Mueller, 2016), RiverSurveyor LIVE (RSL; Xylem, 2023), and the Velocity Mapping Toolbox (VMT; Parsons and others, 2013). The end product is a rich dataset quantifying the shape of the channel and the spatial variation in flow velocity and direction at the channel cross section.

Cross Sections

ADCP measurements were made at the 14 permanent cross sections and 6 random cross sections. USGS station identifiers (table 1) were established for each cross section in the USGS National Water Information System (U.S. Geological Survey, 2023). The locations of the cross sections were preprogrammed as line features into a controller for a real-time kinematic global navigation satellite system (RTK–GNSS; fig. 2). This controller was then used to guide the location and direction of ADCP transect measurements at each cross section. Typical ADCP cross section measurements consisted of at least four passes and as many as six passes.

Velocity

Channel velocity characteristics are quantified and summarized using a combination of summary statistics and graphical depictions (Stephens and Siefken, 2024). The mean cross sectional water velocity (depth averaged velocity, table 1) of each surveyed cross section in the bypass channel and at the entrance and exit of the channel is determined from the QRev software as an average of all passes collected at each section. The VMT software was used to process RSL Microsoft Access table files and produce a heat map showing the average shape of the channel and spatial distribution of water velocities at each cross section (fig. 2).

The RSL Microsoft Access table files were also used to produce water velocity stick plan maps (fig. 3) in ArcGIS (Esri, 2023). These maps depict a plan view of the average velocity magnitude and direction within horizontally spaced samples at individual cross sections. Horizontal spacing is determined by applying an averaging time in the VMT Geographic Information System Export Tool. The averaging time to obtain 12–15 velocity vectors varies from survey to survey. The velocity vector sticks are useful for identifying the locations of the channel thalweg and changes in channel flow direction when compared with other surveys.

Table 1. Example of Yellowstone River fish bypass channel monitoring data provided in accompanying U.S. Geological Survey data release (Stephens and Siefken, 2024).

[U.S. Geological Survey station data from U.S. Geological Survey (2023). USGS, U.S. Geological Survey; NWIS, National Water Information System; ID, identifier; MDT, mountain daylight time; ft³/s, cubic foot per second; ft, foot; ft/s, foot per second; ift, international foot; NAD 83, North American Datum of 1983; HARN, High Accuracy Reference Network; NAVD 88, North American Vertical Datum of 1988; NA, not applicable]

Section	USGS NWIS station ID	Date (month/day/year)	Time (MDT)	Streamflow (ft^3/s)	Depth (ft; minimum depth of deepest continuous 30 ft)	Depth averaged velocity (ft/s)	Station (hundreds of feet)[1]
P14	06328480	08/31/2023	10:23	7,080	NA	1.73	NA
P13	471543104330201	08/31/2023	10:50	NA	2.8	3.52	109+00
P12	471545104325701	08/31/2023	11:01	1,150	5.9	2.01	105+00
P11	471546104324601	08/31/2023	11:17	1,110	2.8	3.35	97+00
F9150	471546104323901	08/31/2023	11:36	1,290	3.8	3.26	91+50
P10	471547104323201	08/31/2023	11:49	1,140	4.7	2.92	87+00
P9	471551104322101	08/31/2023	12:35	1,160	3.9	2.86	79+00
P8	471552104321101	08/31/2023	12:43	1,210	3.7	3.12	71+50
F6200	471600104320401	08/31/2023	12:54	1,140	4.5	2.45	62+00
P7	471605104320101	08/31/2023	13:02	1,160	3	3.09	56+00
F4900	471612104320301	08/31/2023	13:10	1,170	3.7	3.75	49+00
P6	471616104320501	08/31/2023	13:17	1,050	3.6	3.18	45+00
P5	471626104321301	08/31/2023	13:36	1,190	3.2	3.52	33+50
F3000	471629104321201	08/31/2023	13:41	1,330	3	3.73	30+00
P4	471636104321001	08/31/2023	13:48	1,210	3.3	3.49	23+00
P3	471642104320101	08/31/2023	13:59	1,140	3.9	3.93	13+00
F700	471643104315201	08/31/2023	14:04	1,150	4.5	2.78	7+00
P2	471644104314901	08/31/2023	14:10	1,060	4.9	2.5	4+50
P1	471645104314501	08/31/2023	14:26	NA	3.8	2.78	2+00
F000	471645104314201	08/31/2023	14:39	NA	10.2	1.43	0+00

Table 1. Example of Yellowstone River fish bypass channel monitoring data provided in accompanying U.S. Geological Survey data release (Stephens and Siefken, 2024).—Continued

[U.S. Geological Survey station data from U.S. Geological Survey (2023). USGS, U.S. Geological Survey; NWIS, National Water Information System; ID, identifier; MDT, mountain daylight time; ft^3/s, cubic foot per second; ft, foot; ft/s, foot per second; ift, international foot; NAD 83, North American Datum of 1983; HARN, High Accuracy Reference Network; NAVD 88, North American Vertical Datum of 1988; NA, not applicable]

Left edge northing (ift NAD 83 HARN State Plane Montana)	Left edge easting (ift NAD 83 HARN State Plane Montana)	Right edge northing (ift NAD 83 HARN State Plane Montana)	Right edge easting (ift NAD 83 HARN State Plane Montana)	Water surface elevation (ft above NAVD 88)	Flow split (percentage of bypass channel flow to total Yellowstone River flow)
1138000.75	3191049.72	1137472.36	3190617.08	1,996.17	15.68
1137005.41	3195842.82	1136783.98	3195943.18	1,994.17	NA
1137140.98	3196220.55	1136935.73	3196313.58	1,994.14	NA
1137327.13	3197034.11	1137113.8	3197021.25	1,993.55	NA
1137338	3197551	1137106	3197602	1,992.86	NA
1137505.01	3197920.97	1137329.21	3198038.24	1,992.65	NA
1137846.79	3198684.28	1137630.31	3198700.91	1,992.03	NA
1138041.74	3199311.84	1137849.19	3199470.09	1,991.37	NA
1138811	3199691	1138751	3199889	1,990.96	NA
1139389	3199844	1139327	3200063	1,990.61	NA
1139948	3199726	1140074	3199926	1,990.11	NA
1140298.94	3199532.53	1140408.37	3199706.13	1,989.76	NA
1141324.44	3198946.33	1141381.08	3199187.09	1,988.91	NA
1141712	3198947	1141678	3199171	1,988.45	NA
1142405.45	3199039.33	1142371.55	3199263.21	1,988.07	NA
1143188.39	3199742.7	1142952.96	3199808.4	1,987.01	NA
1143354	3200319	1143134	3200381	1,986.68	NA
1143410.35	3200532.09	1143190.04	3200593.57	1,986.64	NA
1143522.69	3200791.43	1143269.67	3200862.04	1,986.51	NA
1143604	3200977	1143241	3201078	1,985.88	NA

[1]Construction stationing in hundreds of feet. The relative position of the cross section along the centerline of the Yellowstone River fish bypass channel.

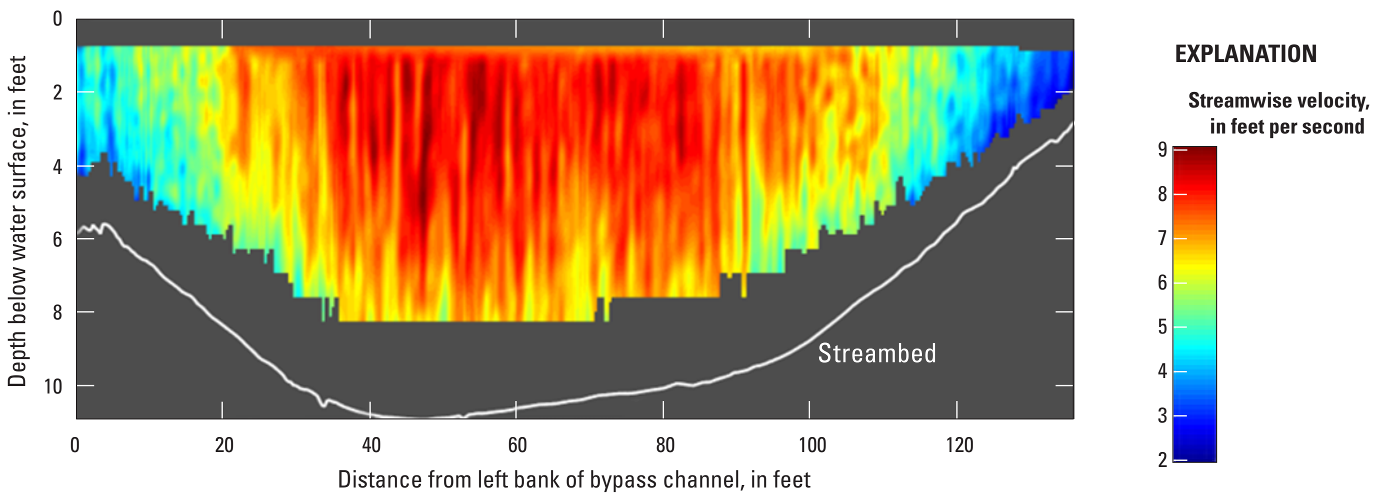

Figure 2. Example of water velocity heat map profile for the Yellowstone River fish bypass channel, Montana.

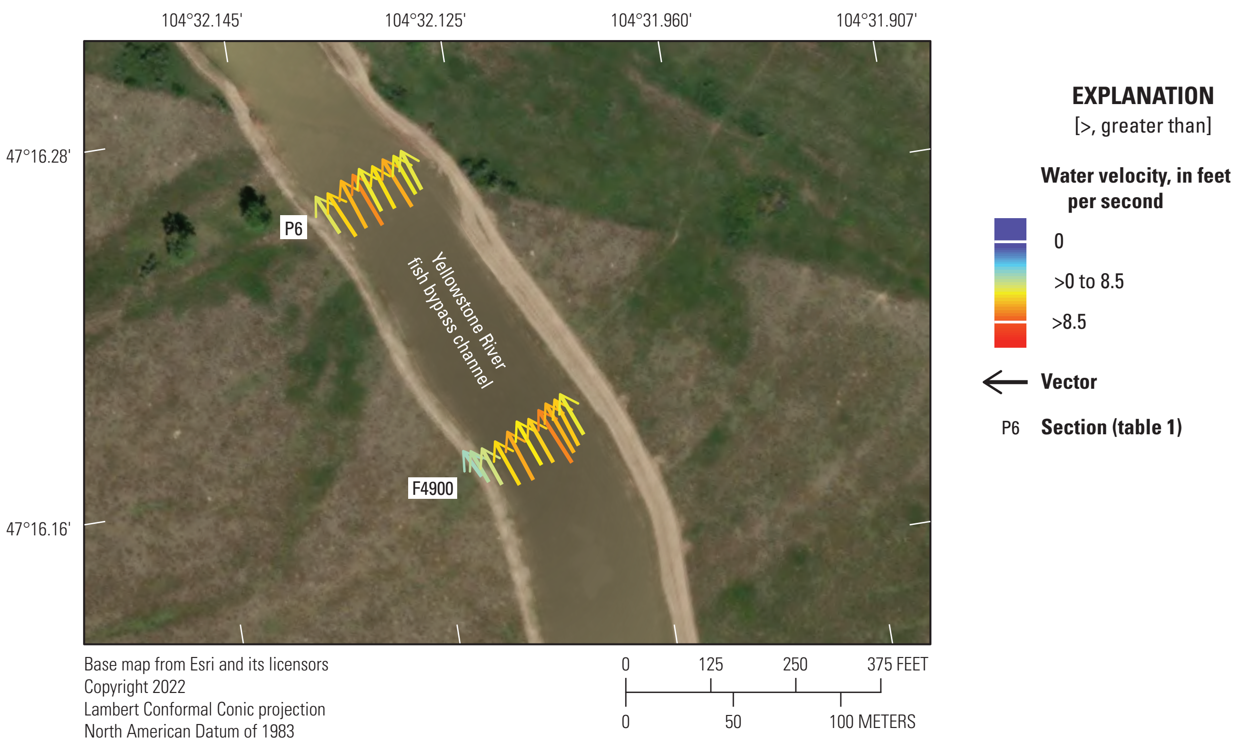

Figure 3. Example of georeferenced water velocity stick map for the Yellowstone River fish bypass channel, Montana. Warmer colors (red, orange, and yellow) and longer vectors (sticks) indicate higher water velocities than cooler colors (green and blue) and shorter vectors.

Streamflow

Streamflow (table 1) was computed for all surveyed cross sections except for those surveyed near the bypass channel entrance and exit. Streamflow was computed by postprocessing ADCP pass data in the QRev software (Mueller, 2016). The QRev software produces a final estimate of mean streamflow, as well as a measure of the uncertainty of the mean, depicted as the estimated 95-percent uncertainty. The estimated 95-percent uncertainty in the QRev software combines the random uncertainty, invalid data uncertainty, edge Q (cross section edge streamflow) uncertainty, extrapolation uncertainty, moving-bed test uncertainty, and systematic uncertainty (Mueller, 2016).

Flow Split

Flow split (table 1) was calculated as a percentage of the bypass channel streamflow to the total Yellowstone River streamflow. Total Yellowstone River streamflow was determined by the ADCP measurements collected at permanent cross section 14 at Yellowstone River mile 74 (Stephens and Siefken, 2024; fig. 3). The bypass channel streamflow was determined at the seasonal USGS streamgage located in the bypass channel (Yellowstone River fish bypass channel near Intake, Mont.; USGS station 06328495; fig. 1; U.S. Geological Survey, 2023) using the computed unit discharge value closest to the mean time of the measurement collected at Yellowstone River mile 74.

Bathymetry

The minimum depth (depth, table 1) for the deepest continuous 30-ft-wide stretch of surveyed cross section was determined from the most representative transect using the VMT Geographic Information System Export Tool with no averaging (Mueller, 2016) for each cross section. An algorithm was created using the R programming language (version 4.3.1; R Core Team, 2023) to determine the minimum depth for each 30-ft-wide section within the cross section starting with the first ADCP ensemble on the left bank. Four to six transects were collected with the ADCP at each cross section, each of which likely contains some random error; therefore, the representative transect used to determine bathymetry parameters is the transect that best represents the channel shape and velocity distribution as determined by the operator.

Water Surface Elevation

Water surface elevation (table 1) is the reference elevation for channel bathymetry measured at each cross section. This elevation is defined as the height of the water surface relative to the North American Vertical Datum of 1988. The water surface elevation for each cross section was determined by obtaining global positioning system (GPS) measurements with a survey rod along the edge of water or by using the height of the GPS antenna above the water surface elevation when using the GPS for ADCP navigation. The RTK–GNSS was used following USGS GPS survey techniques outlined in Rydlund and Densmore (2012). Control point 19, established by Reclamation, was used as vertical control for the RTK–GNSS surveys. All surveys were done using GEOID09 with Montana Federal Information Processing Standard 2500 State Plane coordinate projection.

Summary

In the spring of 2022, the U.S. Geological Survey, in cooperation with the Bureau of Reclamation, began monitoring the Yellowstone River fish bypass channel according to the specifications of the Adaptive Management and Monitoring Plan. The fish bypass channel was constructed to provide upstream migrating fish with a route around a diversion dam. The objective of this study is to monitor the physical and hydraulic characteristics of the bypass channel, including flow split, minimum depth for the deepest continuous 30 cross sectional feet, and the mean channel velocity. Data are collected through several sets of measurements at different times during the field season (April 1 to October 31). These data can be used to ensure that the hydraulic design criteria of the bypass channel are being met.

This report describes the methods used to monitor the physical and hydraulic characteristics of the bypass channel at 14 permanent and 6 random cross sections. Examples of the types of data collected and summarized for this study are described in the report, including a water velocity heat map profile, a georeferenced water velocity stick map, and a summary table of the hydraulic properties determined at all permanent and random cross sections. Data collected for this study are summarized and published in an accompanying U.S. Geological Survey data release. The monitoring data can be used by the cooperating agencies to help correlate hydraulic characteristics of the bypass channel to *Scaphirhynchus albus* (Forbes and Richardson, 1905; pallid sturgeon) passage.

Acknowledgments

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