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AQUATIC STUDIES OF THE YELLOWSTONE RIVER

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by
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On November 6, 1979, the Bureau of Reclamation was renamed the Water and Power Resources Service in the U.S. Department of the Interior. The new name more closely identifies the agency with its principal functions - supplying water and power.

The text of this publication was prepared prior to adoption of the new name; all references to the Bureau of Reclamation or any derivative thereof are to be considered synonymous with the Water and Power Resources Service.

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SUMMARY

This study was initiated on the lower Yellowstone River to quantify effects of streamflow alterations on selected sport fish. Efforts were concentrated on sauger (*Stizostedion canadense*) and walleye (*Stizostedion vitreum vitreum*) and effects of in-stream irrigation diversions on their movements, particularly during the spawning season, were assessed. Walleye migrated upstream from Garrison Reservoir to the lowermost diversion (Intake), spawned, and most returned to the reservoir during spring. Sauger also concentrated below the lower diversion and the next diversion 267 km upstream (Forsyth). Sauger movement as determined by tag returns, was extensive over the Intake diversion during spring. Few sauger and no walleye migrated over the Forsyth diversion which created a 0.5-m vertical drop in the river in contrast to a turbulent slope created by boulders forming the Intake diversion.

A comparison of the average length of sauger collected in three sections of the lower Yellowstone River revealed that sauger in the upstream section were significantly longer than fish in the lower section, due largely to a larger proportion of older fish in the upper section. Sauger were least abundant in the upper section and progressively more abundant in downstream sections. Growth rates and condition factors for sauger were similar in all three sections of the river. Movement and growth data indicate that a general upstream movement of mature sauger occurred after spawning.

Initial combined spawning criteria for sauger and walleye were determined by egg abundance on the spawning grounds downstream from Intake diversion. Expected range of depths for eggs at the 90-percent confidence level was from 0.46 to 1.04 m. The upper limit was biased because sampling could not be accomplished in water deeper than 0.9 m. Expected range of velocities for eggs at a 90-percent confidence level was from 0.72 to 0.96 m/s. Spawning substrate was 89 percent loose cobble and pebble. Using these criteria and excluding maximum depth, the midrange of flows which maximized suitable spawning area was similar to the historical median flow during the spawning season, 240 and 260 m^3/s, respectively.

The relatively high flow velocities, turbid water conditions, and diverse fish fauna of the lower Yellowstone River required adaptation of equipment and fish collecting techniques to accommodate these conditions. One method was by electrofishing, for which a 5.2- by 1.5-m flat-bottomed aluminum boat powered by a 6.3 X 10^4-W jet outboard motor was used. Detailed descriptions of this boat and the specialized electrofishing equipment developed for this study are described in appendix B, Electrofishing Large Rivers - The Yellowstone Experience.

The unique physical and hydraulic characteristics of the river also presented problems in collecting WSP (water surface profile) data. A crew of two people surveyed transects across the river with a constant-recording depth sounder mounted in a boat, a rangefinder, and standard surveying equipment. This method was relatively efficient considering the distances and depths involved. Accuracy of hydraulic predictions from the WSP program increased with an increased number of known water surface elevations at various discharges. Straight, island, and braided stream sections were surveyed. The WSP program did not accurately predict hydraulic conditions for a braided section of river. Limitations and possible improvements in data collection and analysis are discussed.

PURPOSE AND OBJECTIVES

This study was a continuation of earlier studies conducted on the lower Yellowstone River which included distribution, abundance, and some life history aspects of various fish species (Peterman and Haddix [1][1], Haddix and Estes [2]). These studies were part of a large-scale effort by the Bureau of Reclamation to determine the availability of water resources of the Yellowstone River and tributaries for the development of coal resources in southeastern Montana.

The objectives of this study were: (1) to assess effects of irrigation diversion structures at Forsyth and Intake on upstream migration of spawning fish, (2) to gather life history information on game fish in the river, and (3) to develop a rapid and accurate method for collecting stream profile cross sections in a deep, turbid river.

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[1] Numbers in brackets refer to items in the bibliography.

Walleye and sauger were selected for study during this phase of the project because they are important game fish and have a wide range. Movement of fish has been correlated to spawning, feeding, over-wintering and other biological activities. For this reason, any diversion dam which impedes movement may restrict biological activities necessary for the continued survival or abundance of a species. It, therefore, is necessary to know: (1) how the dam affects movement, (2) important biological activities of the species both above and below the diversion, and (3) if movement is restricted, how this is affecting the population in question. Life history information is generally lacking for these two species in a free-flowing river system.

DESCRIPTION OF STUDY AREA

The Yellowstone River is one of this country's few remaining free-flowing rivers. The Yellowstone is described in terms of stream gradients, flow regimes, major tributaries, fish distribution, etc. by Peterman and Haddix [1], and Haddix and Estes [2]. Newell [3] and Schwehr [4] described distribution and composition of the major aquatic insect populations.

The Yellowstone River drainage contains approximately 182 336 square kilometers, 92 982 of which lie in Montana (fig. 1). It originates in the mountains of northwestern Wyoming and flows in a

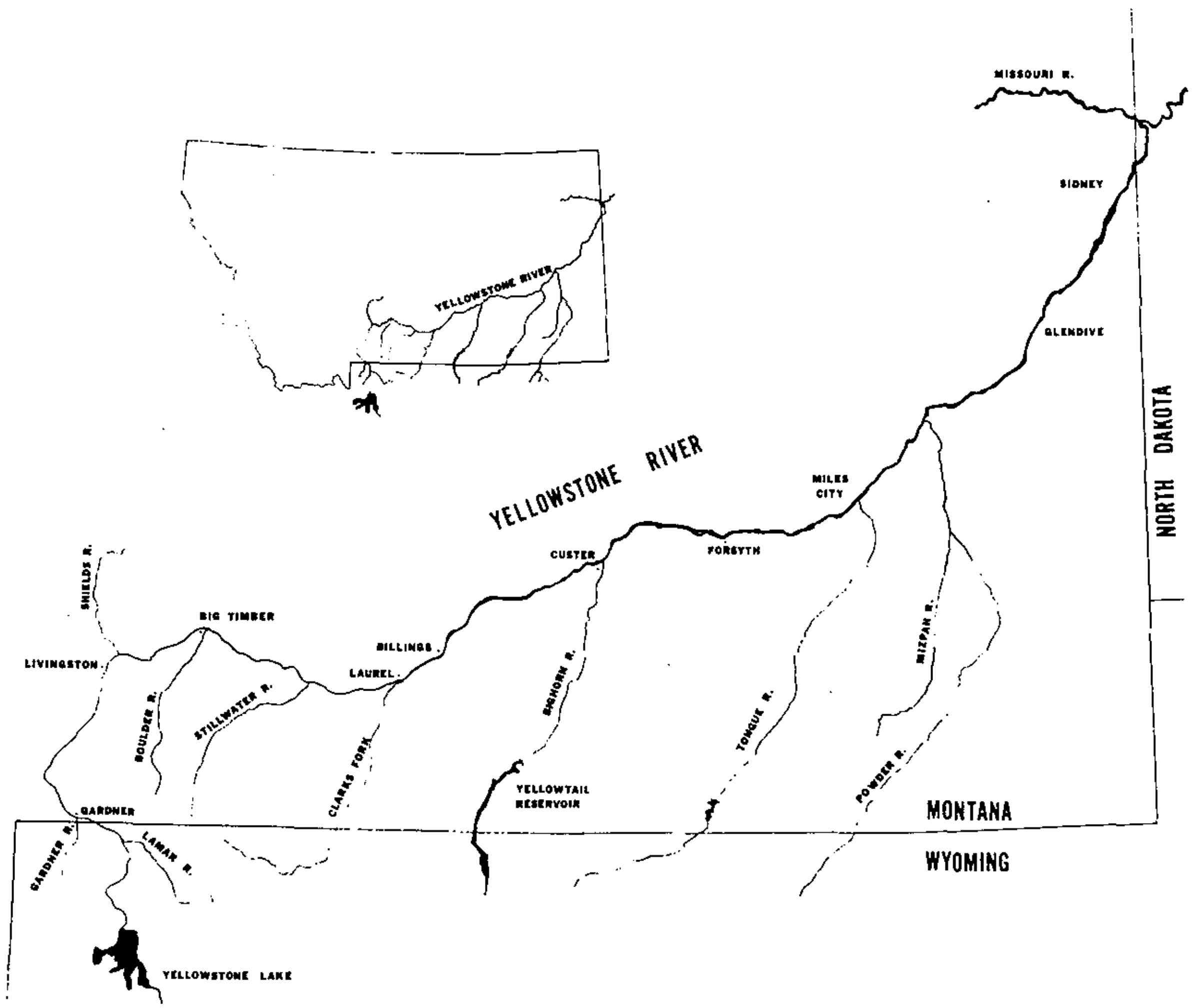


Figure 1.—Map of the Yellowstone River drainage.

general northeasterly direction to its confluence with the Missouri River in North Dakota, 1091 km downstream. Approximately 885 km of the Yellowstone River are in Montana. Average gradient is 2.44, 1.53, and 0.53 m/km for the upper, middle, and lower reaches, respectively. Mean annual discharge based on a minimum of 45 years' data was 107, 200, 328, and 373 m^3/s at Livingston, Billings, Miles City, and Sidney, respectively. Turbidity is seasonally high in the lower river. Based on 14 samples taken by the U.S. Geological Survey [5] from March through September 1975, turbidity averaged 83, 110, and 129 JTUs (Jackson Turbidity Units) at Huntley, Miles City, and Sidney, respectively. Turbidity increases in the Yellowstone River downstream from the Powder River. In the lower Powder River, turbidity averaged 714 JTUs for seven samples taken from March through September 1975.

The Yellowstone River supports a trout fishery in the upper reach and a warm-water fishery in the lower reach. Diversity of species increases progressively downstream. Eleven fish species (5 families) have been recorded in the upper Yellowstone River in Montana, 20 species (8 families) were collected in the middle river, and 46 species (12 families) were collected in the lower river. A species list was compiled by Peterman and Haddix [1].

Newell [3] determined that a rich aquatic invertebrate population is present in the Yellowstone River with both number of species and standing crop decreasing from the upper to the lower river. Mayflies (Ephemeroptera), caddisflies (Trichoptera), and true flies (Diptera) dominated the bottom fauna. The stonefly fauna (Plecoptera) was diverse but not abundant and decreased in number of species downstream.

This study encompassed the lower half of the Yellowstone River from the mouth of the Big Horn River (river km 476) downstream to the North Dakota border (approximately river km 18). Major tributaries along the lower river are the Big Horn River (river km 476), Tongue River (river km 298), and Powder River (river km 240). Two major diversions were present in the study area. Forsyth (Cartersville or Rosebud) diversion is located at river km 382 and Intake diversion is located at river km 114.

Forsyth diversion is a concrete structure extending 230 m across the entire width of the Yellowstone River (fig. 2) and diverts water for irrigation along the north side of the river. During intermediate to low flows the structure created approximately a 0.5-m vertical drop. During high spring flows and when ice jams form below the diversion the difference between water elevations immediately upstream and downstream from the diversion is less pronounced.

Intake diversion extends 219 m across the main channel of the Yellowstone River (fig. 3) and provides water for irrigation along the north side of the Yellowstone River. This diversion provides water for users from river km 114 downstream to near the confluence with the Missouri River. A side channel, which begins to flow at a total discharge of 650 m^3/s, bypasses Intake diversion to the south. The head and tail are approximately 3 km upstream and 3 km downstream from the diversion. The diversion is a wooden structure which has been covered by large boulders to raise the head. New boulders are placed on the diversion every few years to replace boulders which are pushed downstream by ice and high water. The diversion does not form a sharp vertical drop. The downstream drop is approximately 1.2 m in 30 m and is characterized by very turbulent water. The structure can divert a maximum of 34 m^3/s.

Major habitat components of the lower Yellowstone River are main channel pools, runs and riffles, side channels or chutes, and backwaters. Pools are generally 1.5 to 3.0 m deep, although some are at least 5.5 m deep during low summer flows. Backwaters, an integral part of the river ecosystem, are much more common in island or braided sections of the Yellowstone River. In addition, the amount of gradually sloping gravel bars is larger in these sections.

The lower Yellowstone River contains many islands and braided areas with the exception of the reaches from Miles City (river km 306) to Cedar Creek (river km 172) and Sidney (river km 40) to the mouth. The Miles City to Cedar Creek section runs through several bedrock outcrops. Near the mouth, the Yellowstone widens and has a shifting sand and silt bottom.

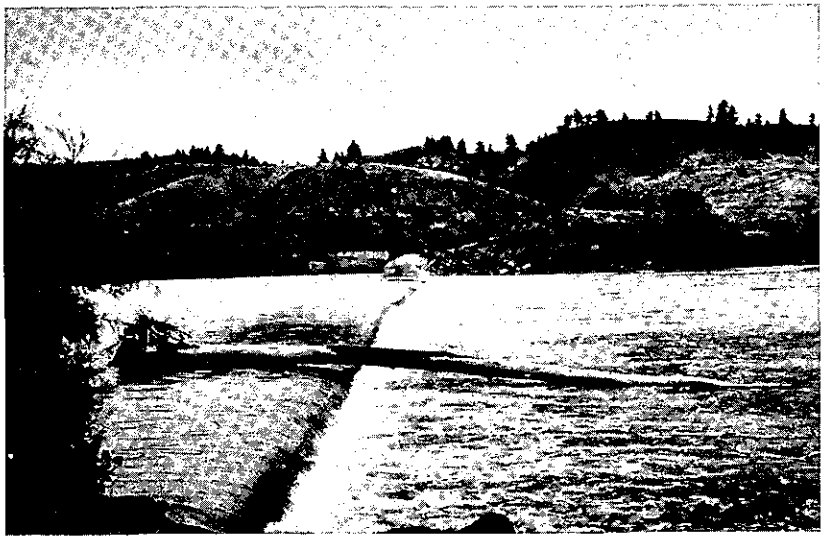


Figure 2.-Forsyth or Cartersville diversion is a concrete structure which creates approximately a 0.5-m drop in the Yellowstone River during normal summer flows. Photo P1279-D-79151

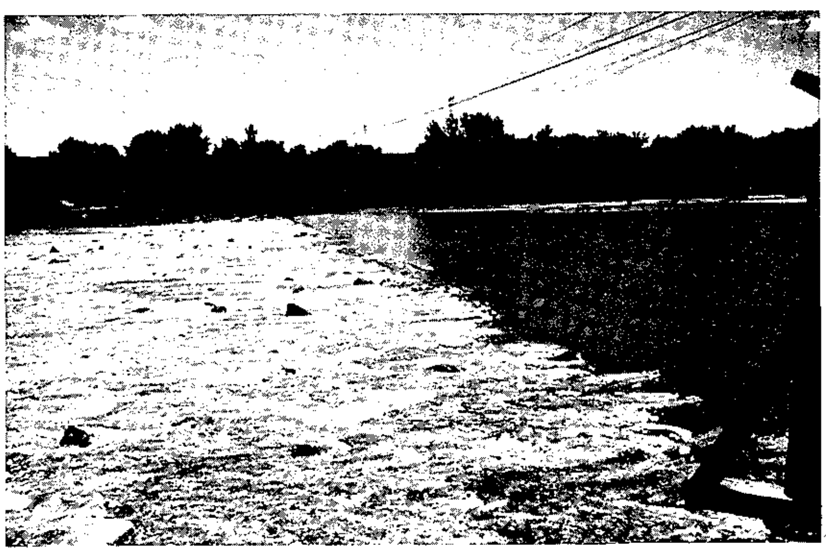


Figure 3.-Intake diversion is a submerged, wooden-framed structure covered with large boulders. Photo P1279-D-79150

EFFECTS OF DIVERSION ON UPSTREAM FISH MIGRATION

INTRODUCTION

The objective of this phase of study was to determine the effects of diversion structures at Forsyth and Intake on upstream migration of spawning fish. Diversions may directly affect sauger and walleye survival because of their wide-ranging movements which have been documented in several studies (Eschmeyer [6], Forney [7], Wolfert [8], Schoumacher [9], Nelson [10]. Low-head diversion structures, which span the entire width of the river, have been constructed to divert water into canals for irrigation use. Intake diversion, constructed in 1907, and Forsyth diversion, constructed in 1904, are two such structures located at river km 114 and 381, respectively. In previous studies on the Yellowstone River, concentrations of walleye and sauger were found below diversion dams, particularly during the spring spawning season (fig. 4) (Peterman and Haddix [1], Haddix and Estes [2]). Both walleye and sauger are considered as prize sport fish in the lower Yellowstone River.

Figure 4.-Adult walleye on their spawning migration below Intake diversion occasionally exceeded 3.2 kg. Photo P1279-D-79149

METHODS

Fish were collected by boom electrofishing in a 5.2- by 1.5-m flat-bottomed aluminum boat powered by a 6.3 X 10^4-W motor equipped with a jet foot (fig. 5). The two positive electrodes were copper tubes shaped like spheres. Four negative electrodes constructed of 1.2-m lengths of aluminum or steel conduit were suspended along each side of the boat (see appendix B). Amount and type of electrical output from a 4500-W generator was regulated by a Variable Voltage Pulsating Unit (Coeffelt VVP-10). Usually, a pulsating direct current, at 10 A, 150 to 250 V, 50-percent pulse width, and a frequency of 80 to 100 pulses per second was used (Novotony and Priegel [11]).

Figure 5.-Electrofishing collections were made from this 5.2-m-long aluminum boat. Photo P1279-D-79147

To determine their relative abundance and monitor their movements, walleye and sauger were collected at four sections along the Yellowstone River both up and downstream from Intake diversion in the spring of 1977 (fig. 6). Total length and mass of individual fish were measured to the nearest 2.5 mm and 5 grams, respectively; sex for mature fish in ripe or nearly ripe condition was determined. Walleye and sauger were tagged with consecutively numbered blue floy anchor tags at the posterior base of the anterior dorsal fin. Fish were released near the middle of each section, and samples taken on the north and south sides of each section independently. Sections 1, 2, and 3 were 0.4, 7.7, and 15.4 km downstream from the Intake diversion and were 2.6, 1.9, and 2.2 km long, respectively. The upstream end of section 4 was 4.5 km upstream from Intake diversion and was 3.4 km long. Only section 1 was sampled in 1976. Fish were collected during daylight hours in 1976 prior to and including April 21. During the remainder of

1976 spring sampling, fish were collected at night because larger sample sizes were obtained (Haddix and Estes [2]). Fish were collected only during daylight hours in 1977 because maneuverability to sections 2, 3, and 4 was difficult and dangerous at night. For comparison of fish abundance between 1976 and 1977, only data collected during daylight hours were used.

Walleye and sauger were collected and tagged at three locations on the Yellowstone River during the spring from 1974 through 1977. These areas were (1) downstream from the Forsyth diversion (river km 381), (2) near Miles City (river km 298), and (3) downstream from Intake diversion (river km 114). Biologists also tagged sauger upstream from the Forsyth diversion in 1974. Fish were also collected from August through October in 1977 at 13 locations from river km 553 downstream to river km 13. North Dakota Game and Fish personnel cooperated by collecting walleye and sauger near river km 13 in April 1977.

Fish tag return data were broken down into three groups: (1) fish recaptured during the same year they were tagged, (2) fish recaptured during the year following tagging and during the same season they were tagged, and (3) fish recaptured during the following year, but during a season other than the one they were tagged. All but one fish fit into one of these three groups. Most returns were from anglers, although some returns were from Fish and Game personnel. Returns by Fish and Game personnel were not included if the fish was caught within 5 km of the tagging site during the same season and year that it was tagged in. All angler returns were used. A difference of at least 5 km between the release and recapture location of the fish was necessary before it was considered movement.

RESULTS

Walleye and sauger migrated to an area below Intake diversion during the spring of 1977 for the purpose of spawning. Spring densities of both species were highest in section 1 (fig. 7).

Species abundance decreased as the distance downstream from the dam increased; i.e., densities of both sauger and walleye were second and third largest, respectively, in sections 2 and 3, the two sections fartherest downstream. Densities of sauger were 6.1, 3.6, 1.1, and 0.4 fish per kilometer in sections 1, 2, 3, and 4, respectively (fig. 7). Densities of walleye were 3.1, 1.1, 0.4, and 0.0 fish per kilometer for sections 1, 2, 3, and 4, respectively.

During 1977 the chronology of peak walleye abundance in the three sections below the dam appeared to depict the migration of fish upstream (fig. 8). The peak abundance in section 3 occurred at least 9 days prior to the peak in section 2 while the number of walleye peaked 8 days earlier in section 2 than section 1. Sections 3 and 2 and sections 2 and 1 were approximately equal distances apart; 7.7 and 7.3 km, respectively. The peak in section 1 occurred on May 23.

Sauger abundance in 1977 appeared to follow a similar trend in the three downstream sections; however, only 3 days separated the peak in section 2 and 1 (fig. 9). Section 2 may have peaked later since this section was not sampled on the same day that section 1 reached peak abundance (April 18).

During 1977 sauger abundance peaked 35 days before walleye reached maximum abundance in section 1 (figs. 10 and 11). Sauger were abundant throughout April 1976, while walleye abundance peaked on April 12, 1976. Walleye reached maximum abundance 11 days earlier in 1976 than 1977 (fig. 11). In general, both walleye and sauger were more numerous in 1976 than 1977 in section 1. During April 1977 the mean discharge was 220 m^3/s compared to a mean discharge of 328 m^3/s during April 1976, at the U.S. Geological survey gage at Sidney, Montana [5].

Percent composition of sauger to walleye in section 1 was similar in both 1976 and 1977 with sauger comprising 75 and 70 percent of the combined catch, respectively. This was the only section shocked during both years. Trends in abundance through the spring were similar both years. Relatively few walleye and sauger were present during early April and larger numbers during mid- and late April. Most of the fish collected were ripe or nearly ripe, similar to 1976 collections (Haddix and Estes [2]).

Some movement was noted between sections below the Intake diversion. Only 8 of 232 walleye and 10 of 548 sauger tagged below the Intake diversion during the spring of 1977 were recaptured. All 8 walleye and all but 2 sauger were recaptured in the same section where they were originally tagged. One of the 2 sauger which exhibited movement left section 2 and was recaptured 8 km

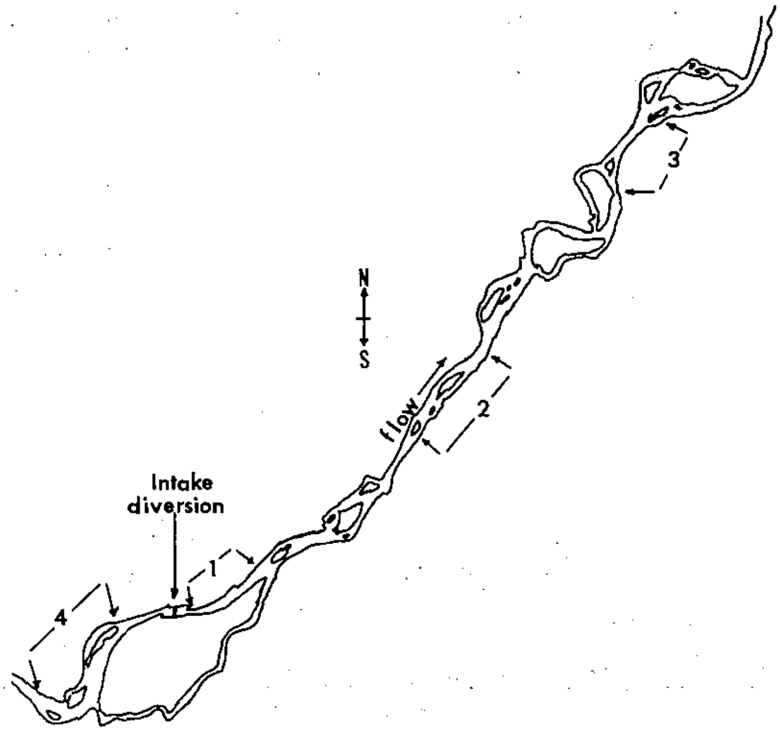


Figure 6.-Electrofishing sections 1, 2, and 3 downstream from Intake diversion and section 4 upstream from the diversion, sampled during 1977.

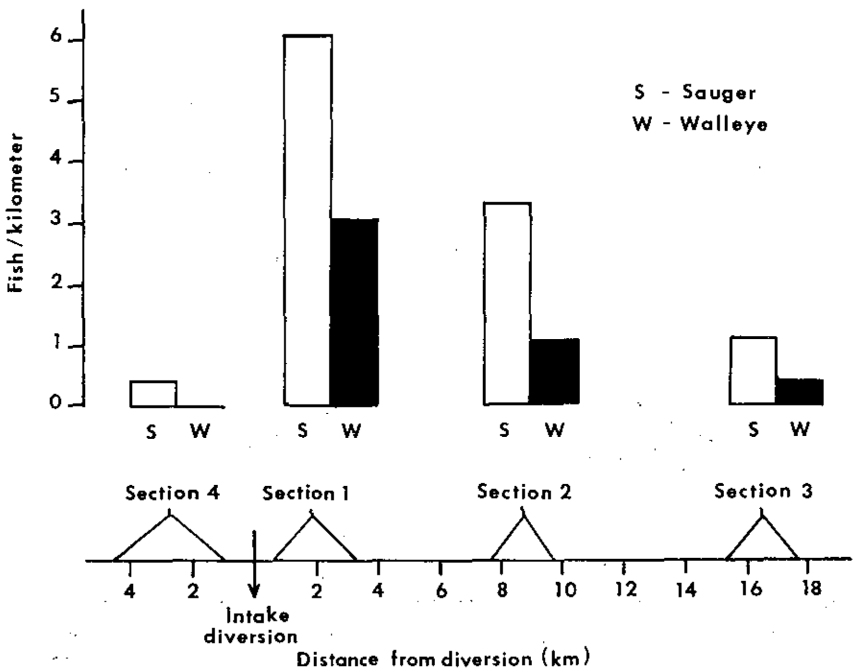


Figure 7.-Average sauger and walleye abundance in four electrofishing sections near Intake diversion in the Yellowstone River, sampled during spring 1977.

upstream in section one 29 days later. The other sauger moved downstream 14 km from section 1 and was recaptured 3 days later, in section 3. The low number of recaptures probably reflects a large population size or a large turnover of fish in the spawning area or both.

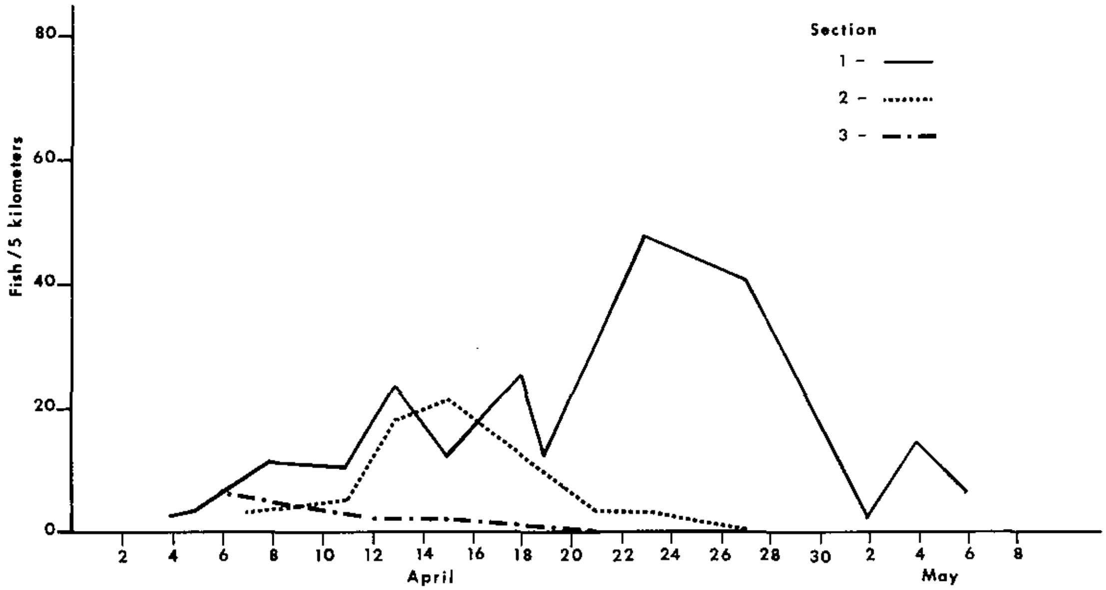


Figure 8.-Number of walleye collected per 5 km of stream reach in sections 1, 2, and 3 downstream from Intake diversion in the Yellowstone River during spring 1977.

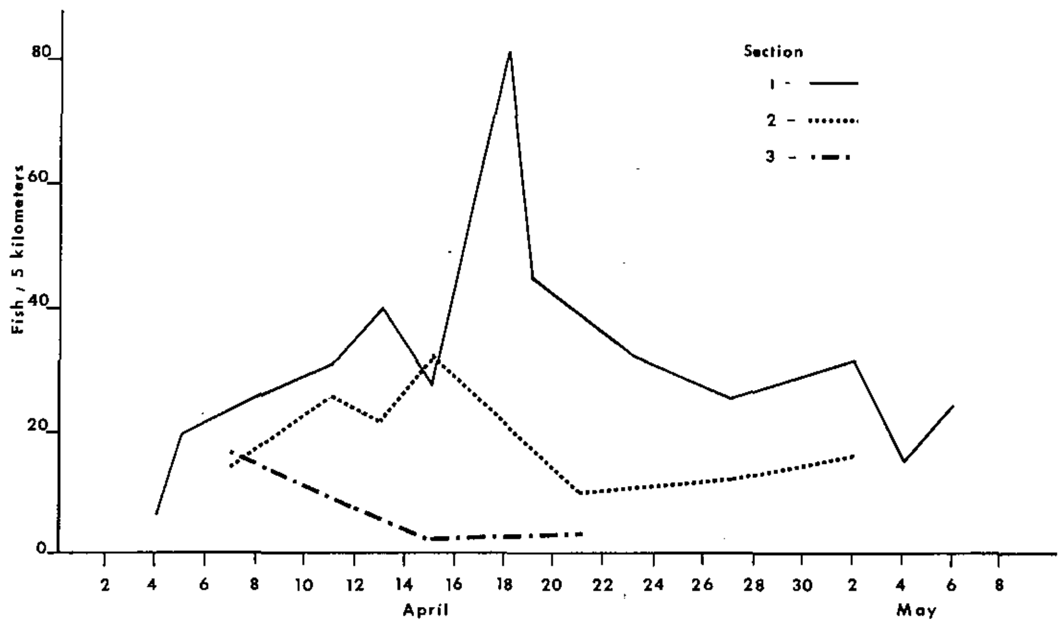


Figure 9.-Number of sauger collected per 5 km of stream reach in sections 1, 2, and 3 downstream from Intake diversion in the Yellowstone River during spring 1977.

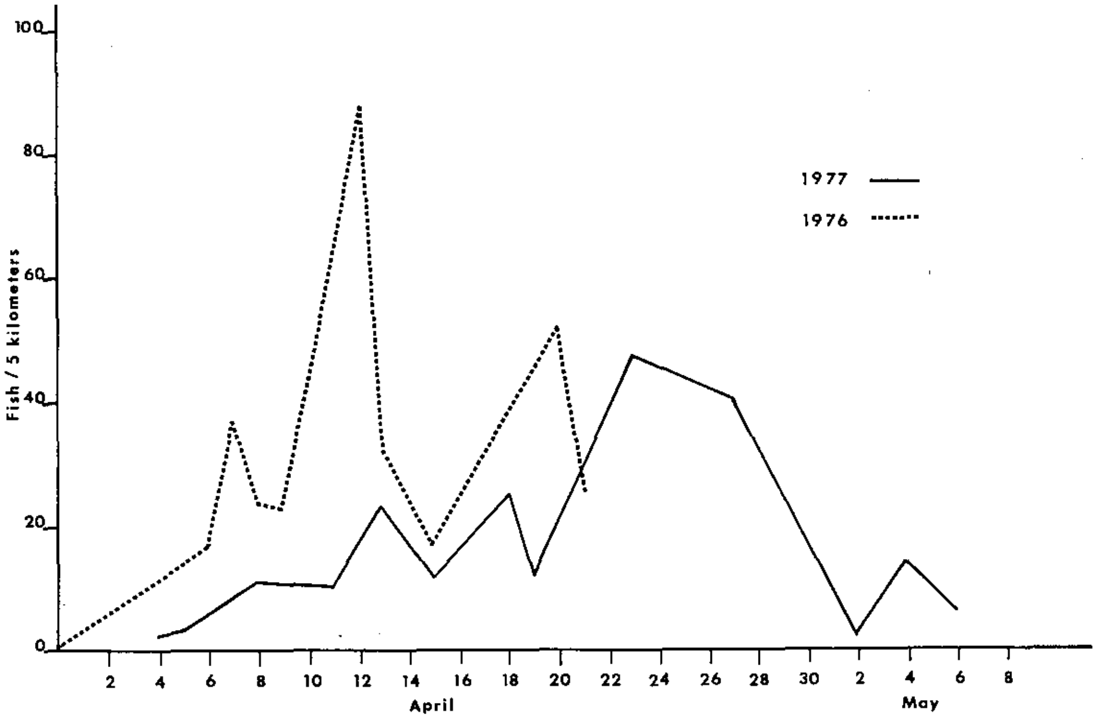


Figure 10.-Number of walleye collected per 5 km of stream reach in section 1 downstream from Intake diversion in the Yellowstone River during spring 1976 and 1977.

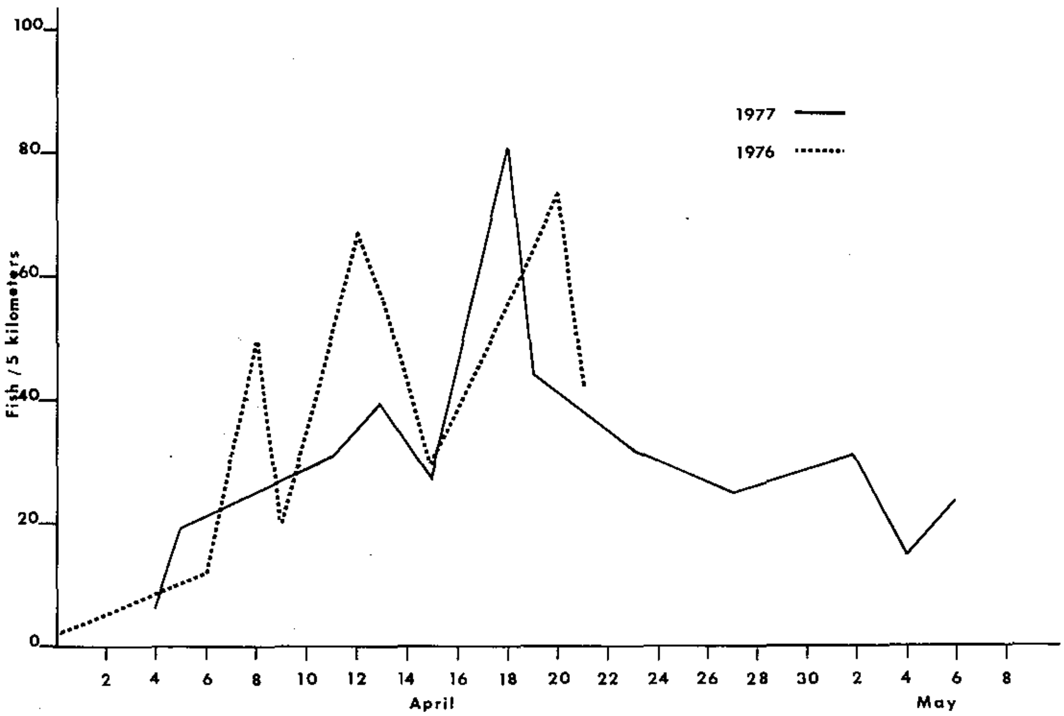


Figure 11.-Number of sauger collected per 5 km of stream reach in section 1 downstream from Intake diversion in the Yellowstone River during spring 1976 and 1977.

Fish and Game personnel tagged a total of 2573 sauger and 697 walleye between September 1973 and October 1977 in the lower Yellowstone River. This includes 800 sauger and 17 walleye tagged in summer-autumn collections during 1977. Fifty-one walleye were recaptured through October 1977 including 35 returns from anglers and 16 recaptures by Fish and Game personnel. Sauger returns totaled 195; 149 by anglers and 46 by Fish and Game personnel. Walleye returns divided by tagging location were 49 from the Yellowstone River and 2 from the Tongue River. Sauger returns by tagging location were: 128 from the Yellowstone River, 56 from the Tongue River, and 11 from the Powder River. A minimum harvest estimate, based on fisherman tag returns, was 5 percent for both walleye and sauger.

Movements of walleye and sauger out of the Intake area during and following spring was extensive. Using fisherman tag returns, 25 of 34 (74 percent) walleye tagged downstream from Intake from 1975 to 1977 and recaptured the same year were caught downstream in the Missouri River and Garrison Reservoir (fig. 12). Average distance moved downstream from the tagging site was 190 km with a range of 71 to 360 km. The majority of fish were captured in the upper one-third of the reservoir.

Although walleye concentrated below Intake diversion, fish movement did occur upstream over the structure (fig. 12). Movement over the diversion occurred in 1976 and 1977, and may have occurred in 1975. Six of 36 (17 percent) walleye tagged at Intake and recaptured the same year (including 2 recaptured by Fish and Game personnel) moved upstream an average of 171 km (fig. 12). None were recaptured upstream from Miles City (river km 298). Six of seven walleye were recaptured during the following year, but during the same season were either captured at or downstream from the tagging location (fig. A-1). The same trend was evident for walleye captured during the following year but in a different season (fig. A-2).

Sauger tagged downstream from Intake diversion also exhibited extensive movement but the majority moved upstream. Of 30 sauger recaptured during the year they were tagged, 17 (57 percent) moved upstream, 10 (33 percent) moved downstream, and 3 (10 percent) were recaptured near the tagging location during a different season (fig. 13). Sauger recaptured downstream from Intake moved an average of 172 km with a range of 13 to 417 km. Two sauger were recaptured 58 and 304 km upstream in the Missouri River from the confluence of the Missouri and Yellowstone Rivers. Average distance moved by sauger upstream over Intake diversion was 203 km with a range of 129 to 269 km. No fish tagged below Intake diversion were recaptured upstream from Forsyth diversion, 269 km upstream.

Sauger recaptured during the year following tagging exhibited similar movement patterns to fish recaptured during the same year (fig. A-3). Only two sauger were recaptured during the same season they were tagged, and both were within 14 km of the tagging location. Seven were recaptured during seasons other than the one they were tagged; three were caught near Intake, three moved upstream to Miles City and Forsyth diversion, and one was recaptured in the Missouri River.

Walleye were seldom collected upstream from Intake diversion at any time and were scarce below Intake except during the spring. In electrofishing collections made downstream from Intake diversion, walleye constituted 20, 35, and 30 percent of the combined walleye and sauger catch during the spring of 1975, 1976, and 1977, respectively. During July 1977, walleye composed only 2 percent of the combined catch. Near Miles City, walleye comprised 3 percent of the combined walleye and sauger catch during the spring of 1975. Near Forsyth diversion walleye comprised 4 and 3 percent of the combined catch during the spring of 1974 and 1975, respectively (Haddix and Estes [2]).

Sauger, although abundant in the lower Yellowstone River, seldom moved over Forsyth diversion as determined by tag returns. Seventeen (74 percent) of the sauger tagged below Forsyth diversion and recaptured during the same year were captured within 5 km of the area they were tagged (fig. A-4). Three (13 percent) were recaptured upstream from the diversion an average of 101 km and 3 (13 percent) were recaptured downstream an average of 79 km. No sauger tagged below the Forsyth diversion and recaptured the following year was recaptured upstream from the Forsyth diversion (fig. A-5).

Although some sauger can negotiate the diversion, most appear to be restricted in their range of upstream movement by the Forsyth diversion. Of 195 tag returns, only 9 sauger were recaptured upstream from the Forsyth diversion from 1973 through 1977 (fig. A-6). Four were tagged at Forsyth, two near Miles City, and three were tagged in

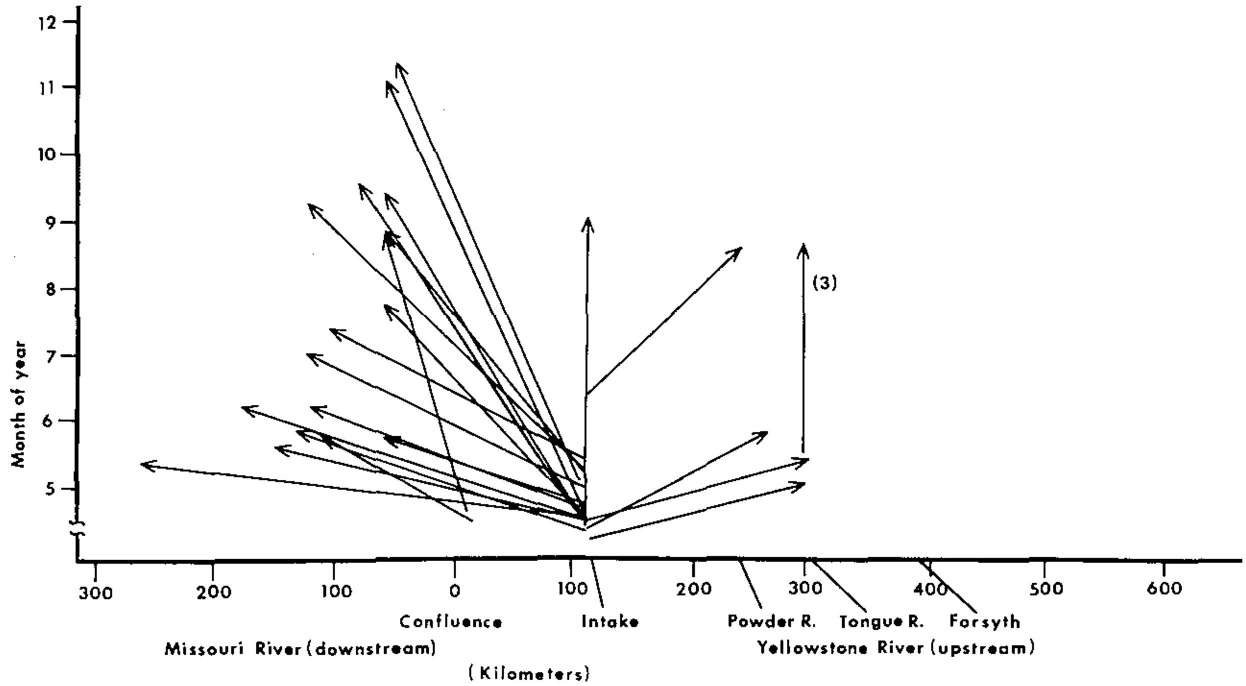


Figure 12.-Movement of walleye tagged in the lower Yellowstone River, 1974-77, and recaptured in the Yellowstone or Missouri Rivers within the same calendar year.

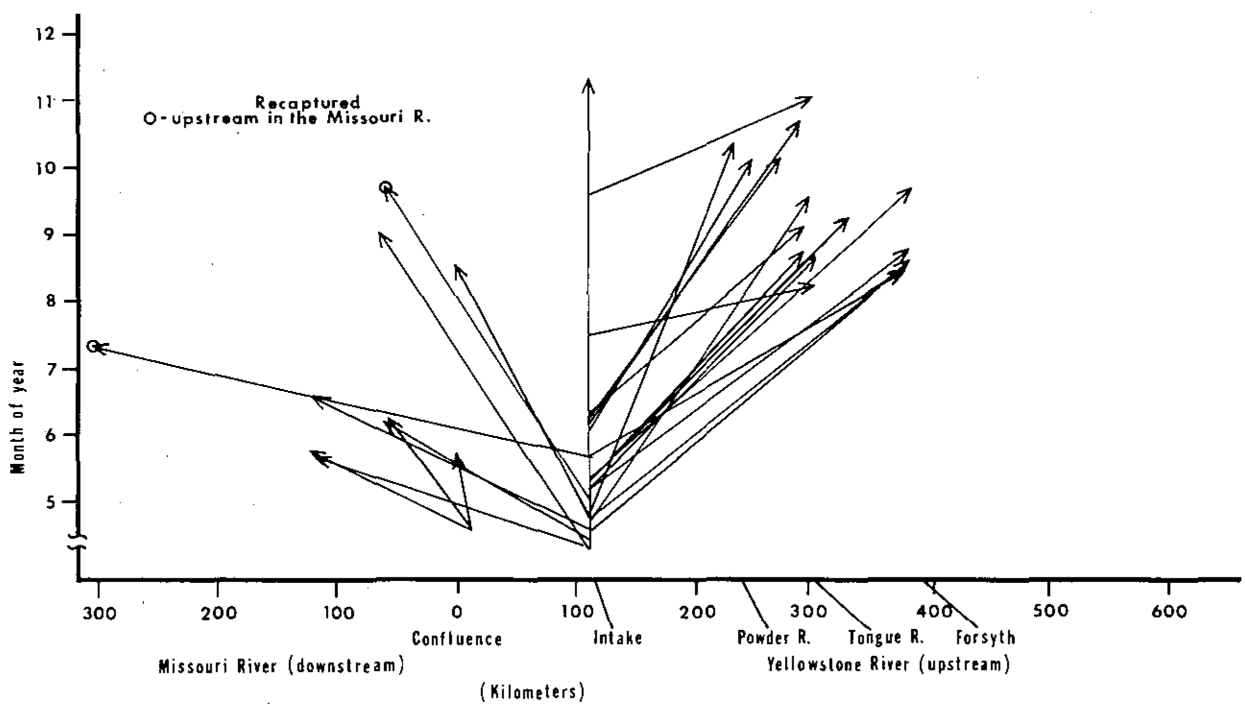


Figure 13.-Movement of sauger tagged in the Yellowstone River downstream from Intake diversion, 1975-77, and recaptured in the Yellowstone or Missouri Rivers during the same calendar year.

the lower Tongue River. Average distance moved upstream from the diversion was 58 km and ranged from 5 to 126 km.

Sauger concentrated in other areas in the lower Yellowstone River drainage during the spring. Relatively large numbers of sauger were collected in the lower Tongue and Powder Rivers and in the Yellowstone River near Miles City (Haddix and Estes [2], Elser et al. [12], Rehwinkel and Gorges [13]). All fish tagged in the Powder River and recaptured in the Yellowstone River moved upstream (figs. A-7 and A-8). It appears that some fish captured on supposed spawning grounds may be recaptured in several of these areas during the same or following springs. Two sauger, tagged in the lower Powder River, were recaptured in the Tongue River during the same spring and early summer. One of the sauger was recaptured only 19 days after it was tagged after moving 92 km upstream. In addition, two sauger tagged in the lower Powder River in spring were recaptured below Forsyth diversion the following spring.

Those sauger, tagged in the lower Tongue River and recaptured in the Yellowstone River during the same year, generally remained near the mouth (73 percent) or migrated upstream (23 percent) (fig. A-9). Nine (82 percent) of the sauger captured in the Yellowstone River the following spring were caught just below or upstream from Forsyth diversion (fig. A-10). Those sauger caught the following year but during seasons other than spring exhibited similar upstream movement patterns; i.e., seven (64 percent) were caught near Forsyth diversion (fig. A-11).

Sauger tagged in the Yellowstone River near Miles City and recaptured during the same year were divided in their movement patterns; fish were captured at the following locations: five (29 percent) in the Yellowstone River within 5 km of Miles City, five (29 percent) upstream from the mouth of the Tongue River, three (18 percent) downstream from the mouth of the Tongue River, and four (24 percent) in the lower Tongue River (fig. A-12). Those sauger tagged in the Yellowstone River near Miles City and recaptured the following year were also divided: eight (42 percent) showed no movement and nine (49 percent) were recaptured upstream near or above Forsyth diversion (figs. A-13 and A-14).

DISCUSSION

Large concentrations of sauger and walleye in spawning condition were evident below Intake diversion during the spring of 1977. Returns of sauger tagged downstream from Intake diversion indicated that a large number of sauger moved over the diversion during or following the spring spawning season. Walleye could negotiate the Intake diversion; however, most of them concentrated downstream from the structure during the spawning season. Walleye were rarely collected upstream from Intake and generally moved downstream to Garrison Reservoir after spawning. Intake diversion could be more important as a motivational barrier than a physical barrier to upstream spawning migrants who, after reaching the diversion, probably searched for the nearest suitable spawning areas downstream from the diversion.

Adequate spawning habitat for these fish exists downstream from the diversion in the form of extensive cobble and gravel bars. Physical habitat is quite different between the areas just upstream and downstream from Intake. Section 1, downstream from the diversion, was a wide run with a predominantly cobble-pebble substrate which had higher than average velocities for the lower Yellowstone. Section 4, upstream from the diversion, was typified by slower than average velocities and comparatively smaller substrate (see Physical Habitat Above and Below Intake Diversion). Densities of both walleye and sauger during the spawning season decreased the farther a shocking section was downstream from Intake diversion. The highest concentrations of eggs were found in the section immediately downstream from the diversion (see Life History and Habitat Requirements for Major Sport Fish).

Forsyth diversion appears to be more of a physical barrier than Intake because of the 0.5-m vertical drop (at summer flows). A good sauger fishery exists immediately downstream from Forsyth diversion and many tagged sauger were returned from this area. However, few tagged sauger and no walleye were recaptured upstream from Forsyth diversion.

The upstream spawning migration of walleye probably does not begin until spring because of harsh conditions in the lower Yellowstone River during the winter. Ice generally breaks up and moves out during March. This breakup often begins in upstream areas, in part, because the river flows in a northeasterly direction. Ice jams which frequently occur in the lower Yellowstone River may interrupt these migrations. Priegel [14] noted that male walleye did not enter the spawning marsh until after ice broke up on the Fox River.

Intake and other lower river spawning grounds are areas where walleye and probably sauger return each spring. Several studies have found evidence of homing behavior in walleye (Forney [7], Crowe [15], Olson and Scidmore [16]). Forney further suggested that three distinct walleye populations existed within Lake Oneida and that differences in their distribution were evident. The distribution of walleye tag returns from Garrison Reservoir may indicate the existence of a subpopulation in the reservoir. A large majority of walleye tagged in the lower Yellowstone River were recaptured in the upper end of Garrison Reservoir. The upper area of the reservoir is characterized by more turbid, flowing water than the lower reservoir. This was not the habitat type most preferred by walleye in other Missouri River reservoirs. Walleye preferred intermediate depths and turbidities in four Missouri River reservoirs as determined by percent of catch (Nelson and Walburg [17]). A turbid river habitat was not preferred by walleye as indicated by their scarcity in the Missouri River prior to impoundment. The existence of a walleye fishery in the upper end of Garrison Reservoir may be dependent on the success of walleye spawning below Intake diversion.

Sauger movements were more complex than walleye. A small portion of the Intake spawning population returned to Garrison Reservoir. Nelson [10] reported that sauger migrated upstream from Lewis and Clark Lake on the Missouri River in fall and winter, concentrated in the tailwater below Fort Randall Dam, and returned to the reservoir after spawning in the spring. In contrast to these movements, the majority of sauger from the Intake population were recaptured an average distance of 203 km upstream from Intake. The apparent void of fish in the sample section upstream from Intake diversion in spring indicates that sauger did not concentrate in any numbers upstream from the diversion and further indicates that after spawning, those fish which moved upstream over the diversion continued upstream a relatively long distance. The majority of sauger which were captured in the Powder and Tongue Rivers during spring and recaptured in the Yellowstone River had moved upstream from or were located near the mouth of the tributary in which they were tagged.

Further analysis of movement patterns of the sauger population will require additional data on summer distribution of sauger tagged at Intake and other known spawning grounds. Several movement patterns may exist for the lower Yellowstone River sauger population(s). A portion of the sauger population resides downstream from Intake in the Yellowstone River and/or Garrison Reservoir. During the spring they may move upstream to spawn below Intake and return downstream or continue upstream to rear. In addition, some sauger from the upper and middle areas of the lower Yellowstone may migrate downstream to spawn below Intake and return upstream to rear in late spring. These sauger are probably a separate segment of the Yellowstone population since no sauger tagged at Intake in the spring were recaptured at purported upstream spawning grounds (Peterman and Haddix [1], Rehwinkel and Gorges [13], Elser et al. [12]) in following springs. Also, no sauger tagged at these upstream spawning grounds (Powder River, Tongue River, and Yellowstone River at Forsyth) were ever recaptured below Intake diversion.

The upstream movement of sauger in the Yellowstone River would act to maintain population stability in upstream areas, offsetting the downstream drift of fry following emergence. Walleye and sauger fry are poor swimmers and are carried downstream in river currents (Houde [18], Nelson [10]). A large majority of the young fish may end up many miles downstream from where they were spawned. If a barrier in the stream, such as a diversion dam, prevents upstream migration, a reduction or elimination of the population upstream from the diversion would occur. Intake diversion does not appear to be greatly affecting sauger movement while Forsyth diversion does. Perhaps this structure has adversely affected the sauger population upstream as indicated by lower densities of sauger in the upstream areas (see Life History and Habitat Requirements of Major Sport Fish).

Besides affecting those fish which now migrate in the Yellowstone River, other migrating species may have been present prior to construction of the diversion. Species which require passage to an upstream area for survival such as to spawn or for rearing during a certain life stage may have been eliminated, reduced in abundance, or restricted in range following construction of the diversion. This appears to be the case for shovelnose sturgeon (*Scaphirhynchus platorynchus*) which at present are not found above Forsyth diversion, but were reportedly collected along shallow gravel shoals upstream from the diversion prior to its construction. A diversion may be a barrier to some bottom dwelling fish, such as catfish, ling, shovelnose, and pallid sturgeon all or most of the year, while a more pelagic species may pass over the diversion during high water or when ice jams below the diversion raise the water level.

LIFE HISTORY AND HABITAT REQUIREMENTS OF MAJOR SPORT FISH

INTRODUCTION

The objective of this section was to gather data on life history and habitat requirements of selected fish species. The two fish species chosen for this study were walleye and sauger. Relative abundance and growth of sauger were determined for fish collected in the lower Yellowstone River during the late summer and autumn of 1977. These types of data collected over a number of years, provide a basis for analysis of sauger abundance, growth, and condition during natural flow regimes. Flow regimes which have been altered for a number of years because of increased water withdrawal may alter survival, growth, and condition of fish if the withdrawal affects their preferred habitat or food source. Sauger were selected for this phase of study because they were abundant throughout the lower Yellowstone River. Age and growth data were also used to try and define subpopulations of sauger within the river system.

Water fluctuations and changes in water temperature on the spawning grounds have been shown to have detrimental effects to fish eggs and embryo survival and may have a measured effect on the variability of year-class strength (Walburg [19], Nelson [10], Johnson [20], Koenst and Smith [21]). Walleye and sauger reproduction in the lower Yellowstone River is of particular importance not only to the river fishery but also to the Garrison Reservoir fishery. Nelson and Walburg [17] found that variation in mean flows of Lake Oahe tributaries accounted for 70 percent of the variation in year-class strength of walleye. Large concentrations of both walleye and sauger below Intake diversion during the spawning season provided an opportunity to measure spawning habitat for both species in a river environment. Spawning time and physical conditions under which spawning occurs were determined for walleye and sauger below Intake during 1977.

METHODS

Abundance and Age-growth

Forty electrofishing runs were made along 553 km of the lower Yellowstone River to determine late summer-fall abundance and distribution of sauger and walleye. Sampling occurred between August 2 and October 6, 1977 and encompassed the section of river between Huntley, Montana and the North Dakota border. Fish were handled and data collected as described in Effects of Diversion on Upstream Fish Migration. Collection sites were approximately 8 km in length and consisted of one run along each shore. Sampling sections were lumped into three major areas for data analysis: (1) lower, downstream from Intake diversion; (2) middle, Powder River to Intake diversion; and (3) upper, Huntley diversion to Powder River.

Age-growth data were analyzed for sauger collected during both spring (below Intake) and summer-fall; data for the latter were divided into the three river areas. Scales were removed from all fish sampled. Scales were collected from an area below the first dorsal fin and above the lateral line. Cellulose acetate impressions of all scales were examined at 66X magnification.

To obtain back calculated lengths at annulus, a curvilinear equation (method 4 in Tesch [22]) was used to describe the total length:anterior scale radius relationship:

$$\text{Log } L = K + n \log S$$

where

L = total length (mm)
S = total scale radius (mm)
K = intercept on the ordinate (log units)
n = slope of the relationship

This equation expressed the relationship as well as or better than a linear equation (method 2 in Tesch [22]) (table A-1).

Length-mass relationships were determined using the following equation (formula 9.3 in Ricker [23]):

$$\text{Log } W = \log a + b \log L$$

where

W = mass (g)
L = total length (mm)
a = intercept of the ordinate
b = slope of the relationship

Condition factor ($\bar{k}$) was determined for sauger 150 mm and longer by 10-mm-length intervals using the following formula (Carlander [24]):

$$\bar{k} = \frac{W\,10^5}{L^3}$$

where

W = mass (g)
L = total length (mm)

The condition factors were weighted and lumped into 50-mm-length intervals to reduce length related bias.

Spawning Criteria

Walleye and sauger eggs were collected at night on a large gravel bar 0.8 km downstream from Intake diversion to determine the preferred depth, mean velocity, and substrate for spawning in the lower Yellowstone River. Sampling was at 0.15-m water depth intervals from 0.3 to 0.9 m along four transect lines beginning on the gradually sloping north shore (fig. 14) using a net described by Priegel [25]) (figs. 15 and 16). The net was a 510-mm square basket 127 mm deep, and angled at the base. It was covered by fine wire mesh (1.5 mm) and attached to a fiberglass pole. Water velocities were measured at each site prior to egg sampling. One person held the net down while another kicked and swept his feet along the bottom moving toward the net from a distance of approximately 4.6 m upstream.

The number of transects sampled each night varied because of insufficient time to complete all four transects. Twenty-five drift net sets were made from 20 seconds (approximate time required for a kick sample) to 5 minutes on the transect lines during the first two nights of sampling to determine if eggs were drifting into the kick samples. Only one egg was collected in drift samples, indicating that little drift was occurring in the net.

Additional samples were taken on eight transect lines from 4 to 25 km downstream from Intake diversion. Four large gravel bars were sampled at depths of 0.3, 0.6, and 0.9 m on April 24 and 26.

Egg diameters were measured to determine species. The literature suggests that walleye and sauger eggs can be distinguished by size (Scott and Crossman [26], Priegel [14, 25]). Diameters of 157 eggs on the Intake bar averaged 2.0, 2.3, and 2.0 mm and ranged from 1.9 to 2.3, 2.0 and 2.4, and 2.0 to 2.4 mm on April 18, 21, and 24, respectively. Differences in size of walleye and sauger could not be determined, however, as known walleye and sauger eggs (obtained from the body cavity) both averaged 2 mm. Eggs from other species that have comparable egg diameters spawn in early and midspring in this area of the lower Yellowstone River. Only four eggs with diameters outside the range of 1.8 to 2.4 mm were collected (2.7 to 3.0 mm).

RESULTS

Abundance and Age-growth

A total of 931 sauger and walleye were collected during late summer and early autumn electrofishing runs on the Yellowstone River. Sauger comprised over 98 percent of the total catch. Walleye consisted of 5, 1, and 2 percent of the catch in the lower, middle, and upper areas, respectively. Relative abundance of sauger decreased by 55 percent from the lower to upper area. The mean number of sauger collected per 8-km section of river was 33.6, 23.2, and 15.1 in the lower, middle, and upper areas, respectively (table 1).

Mean total length of sauger in the sample increased in upstream river areas; 316, 339, and 366 mm in the lower, middle, and upper areas, respectively (table 1). There were significant differences in mean length of sauger between the upper and middle areas ($P < 0.005$) and middle and lower areas ($P < 0.0005$).

Annulus formation probably occurred during May in 1977, with some fish forming annuli in April and June. Mean length and mass at annulus, growth (in increments of length) (table 2), and length-mass

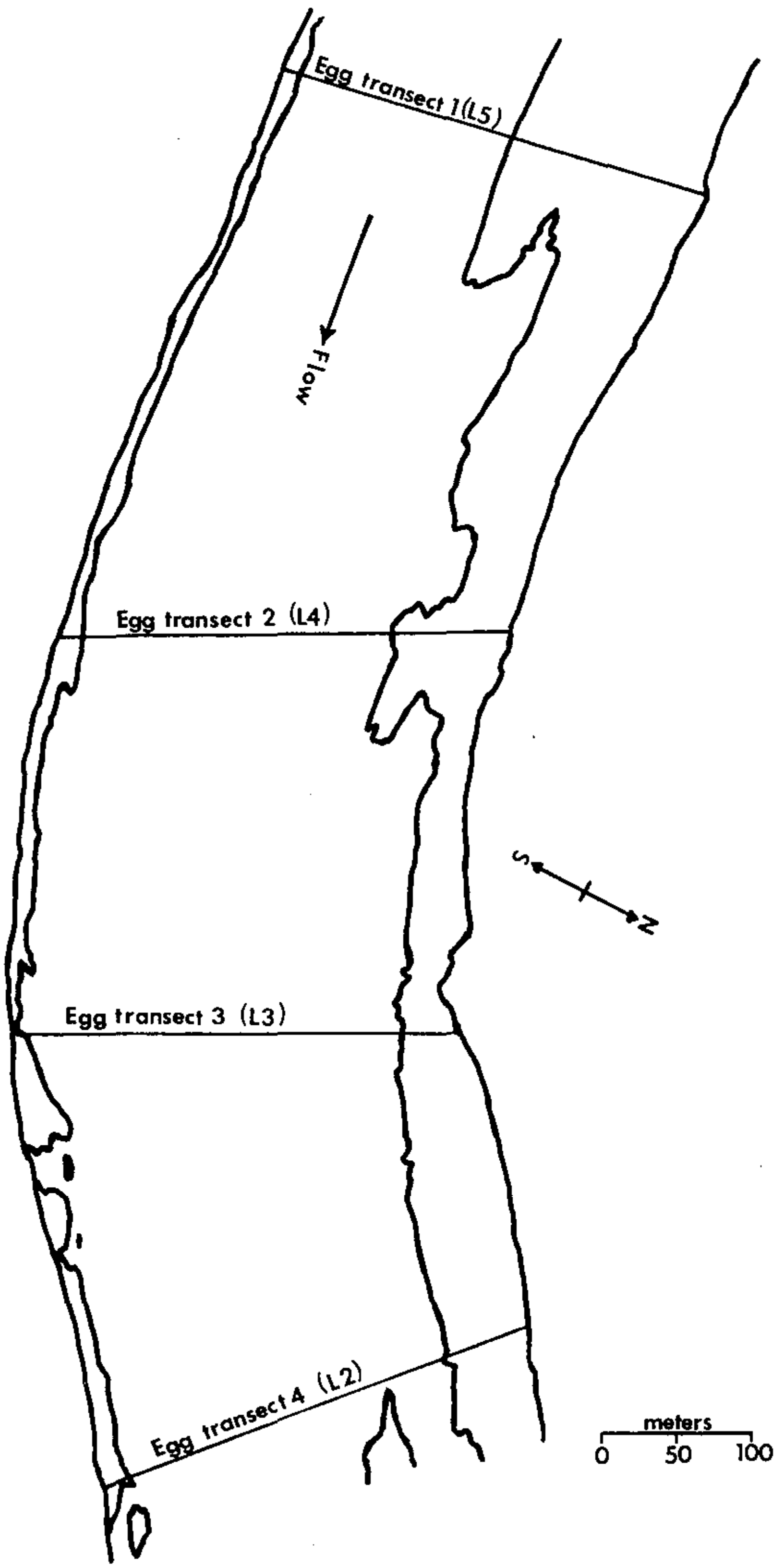


Figure 14.-Map of egg transect sites located 0.8 km downstream from Intake diversion. The corresponding water surface profile cross sections are in parentheses.

relationships (table A-1) were similar for sauger collected in all three river areas during summer-autumn. Grand mean total lengths at annuli did not differ between river areas by more than 15 mm for sauger through age 5 (table 2). Sauger in the middle area were longer at similar ages than those in the upper and lower areas; the largest differences occurred at age 1, approximately 14 mm, and decreased as age increased. Grand mean increments of length were very similar among all three areas with a maximum difference of only 9 mm between areas for age groups 2 through 5 (table 2). The

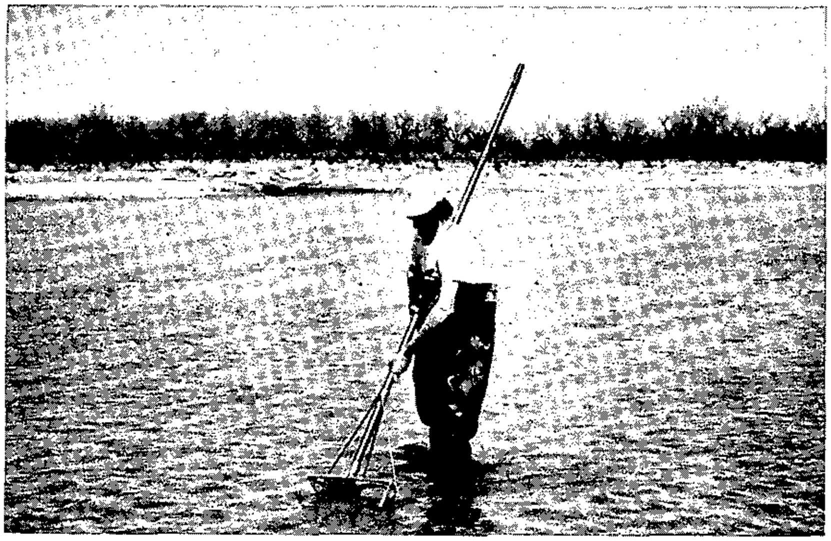


Figure 15.-Net used to collect eggs on the Intake gravel bar at night to develop walleye and sauger spawning criteria. Photo P1279-D-79148

Figure 16.-Eggs were counted and placed, along with debris, into plastic containers; egg diameters were measured the following day. Photo P1279-D-79152

Table 1.-*Average number of sauger per collection, their average length, and the percent of age 4 and older sauger in collections made in three sections of the lower Yellowstone River during late summer and early autumn, 1977*

Section	Number of collections	Number of sauger per collection	Average length (mm)	Percent of age 4 and older sauger
Lower	7	33.6	316	13
Middle	13	23.2	339	23
Upper	18.5	15.1	366	32

Table 2.-*Average calculated total length, increment of length, and calculated mass for sauger collected in three areas of the lower Yellowstone River during the late summer and early autumn, 1977*

Year class	Number of fish (%)	Lower area Length (mm) at annulus formation					
		1	2	3	4	5	6
1971	5 (2)	179	274	350	419	470	511
1972	18 (6)	168	253	322	377	417	
1973	16 (5)	178	267	322	365		
1974	95 (32)	151	232	293			
1975	99 (34)	150	243				
1976	62 (21)	160					
	295						
Grand mean calculated length		155	241	302	378	428	511
Grand mean increment of length		155	87	62	52	42	41
Grand mean calculated mass		29	109	214	417	613	1034

Year class	Number of fish (%)	Middle area Length (mm) at annulus formation						
		1	2	3	4	5	6	7
1970	1 (0)	225	275	315	391	439	490	520
1971	8 (3)	202	283	361	409	443	471	
1972	18 (6)	185	263	321	367	407		
1973	40 (14)	181	260	313	352			
1974	107 (37)	163	245	304				
1975	62 (22)	161	256					
1976	50 (17)	167						
	286							
Grand mean calculated length		168	252	310	364	419	473	520
Grand mean increment of length		168	83	58	43	38	30	30
Grand mean calculated mass		39	131	243	391	597	857	1139

Table 2.-*Average calculated total length, increment of length, and calculated mass for sauger collected in three areas of the lower Yellowstone River during the late summer and early autumn, 1977—Continued*

Year class	Number of fish (%)	Upper area Length (mm) at annulus formation 1	2	3	4	5	6	7
1970	4 (1)	173	270	329	402	454	499	537
1971	7 (2)	151	234	294	367	406	443	
1972	25 (9)	163	259	328	385	426		
1973	57 (20)	156	240	302	348			
1974	114 (40)	153	238	302				
1975	38 (13)	140	248					
1976	39 (14)	155						
	284							
Grand mean calculated length		153	243	305	362	425	463	537
Grand mean increment of length		153	90	64	52	42	40	38
Grand mean calculated mass		28	114	232	391	639	838	1302

largest increment of length for the combined areas was 157 mm at age 1 and increments decreased progressively through age 7 (table 3).

Differences in back calculated masses at annuli between river areas followed the same trends observed in back calculated lengths (table 2). Age 1 fish in the middle areas were larger than age 1 fish in either the upper or lower areas, but the difference decreased with age, and by age 5, the mass of sauger in both upper and lower areas exceeded the mass of sauger in the middle area. Although the

Table 3.-*Average calculated total length, increment of length, and calculated mass for sauger collected in the lower Yellowstone River during late summer and early autumn and those collected during the spring downstream from Intake in 1977*

Year class	Number of fish (%)	Combined areas Length (mm) at annulus formation 1	2	3	4	5	6	7
1970	5 (1)	182	270	325	399	450	497	534
1971	20 (2)	174	260	333	395	436	470	
1972	61 (7)	169	257	323	376	418		
1973	113 (13)	165	249	307	352			
1974	316 (37)	154	237	299				
1975	199 (23)	150	245					
1976	151 (17)	160						
	865							
Grand mean calculated length		157	244	305	365	424	476	534
Grand mean increment of length		157	87	62	50	42	37	36
Grand mean calculated mass		30	114	227	392	619	878	1250

Table 3.-*Average calculated total length, increment of length, and calculated mass for sauger collected in the lower Yellowstone River during late summer and early autumn and those collected during the spring downstream from Intake in 1977—Continued*

Year class	Number of fish (%)	Intake (spring) Length (mm) at annulus formation 1	2	3	4	5	6	7	8
1969	1 (0)	192	267	310	358	412	451	489	526
1970	2 (0)	164	264	317	398	450	484	507	
1971	16 (3)	197	286	370	428	466	493		
1972	35 (6)	168	262	332	367	435			
1973	104 (19)	167	255	310	344				
1974	334 (61)	165	251	298					
1975	58 (11)	162	247						
1976	2 (0)	162							
	552								
Grand mean calculated length		166	253	305	359	444	490	501	526
Grand mean increment of length		166	87	51	38	58	29	37	37
Grand mean calculated mass		30	113.3	208	350	673	935	1004	1172

length-mass relationship increased from the lower to the upper area, differences were slight (table A-1) so a single curve was used to represent all areas (fig. 17).

Sampling during late summer-fall revealed a larger percent of older sauger in the upstream sections. The percent of age 4 and older sauger in the catch increased 2-1/2-fold (13 to 32 percent) from the lower area to the upper area (table 1). Likewise, 1- and 2-year-old fish comprised a larger share of the population in the downstream areas; 55, 39, and 27 percent of the sample in the lower, middle, and upper areas, respectively (table 2).

Sauger collected in the spring in the lower area were similar in total length at annulus to the combined summer-autumn catch (table 3). Grand mean calculated masses were also similar and closely followed trends in back calculated length. Length-mass relationships were similar for both groups (table A-1).

Three-year-old fish were the largest age class (37 percent) of sauger collected in all three areas of the lower Yellowstone during the summer-fall (table 3). Three-year-old fish were also the largest year class below Intake in the spring (61 percent). This probably resulted from a strong age 3 year class and because age 3 sauger were more susceptible to the sampling gear than younger, smaller sauger.

Grand mean condition factors were not significantly different among river areas. Condition factors, calculated for 50-mm-length intervals, indicated a relatively isometric growth pattern for sauger collected during summer and autumn. Sauger in the lower river had the smallest condition factors, and fish in the upper area had slightly better condition factors than fish in the middle area (table 4). Sauger collected in the lower area during the spring had the smallest condition factors, but they were significantly different from the condition of the combined summer-autumn fish (table 5). The spring spawning population also exhibited relatively isometric growth.

Spawning Criteria

Spawning of walleye and sauger was documented downstream from the Intake diversion in the spring of 1976 (Haddix and Estes [2]) and 1977. In five sampling efforts, 233 eggs were collected during the spring of 1977 (fig. 18). Peak sauger abundance occurred several days prior to the initiation of egg sampling in 1977 and walleye abundance reached a maximum during the egg sampling period (figs. 10 and 11). Largest number of eggs (98) was collected

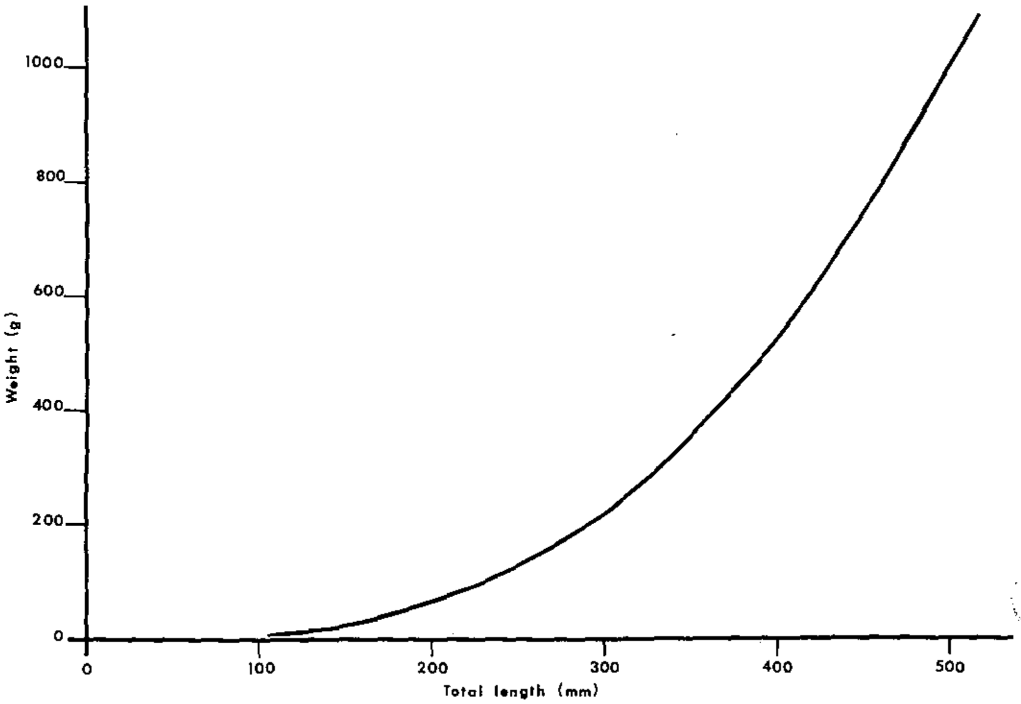


Figure 17.-Total length versus mass relationship for sauger collected in the lower Yellowstone River during 1977.

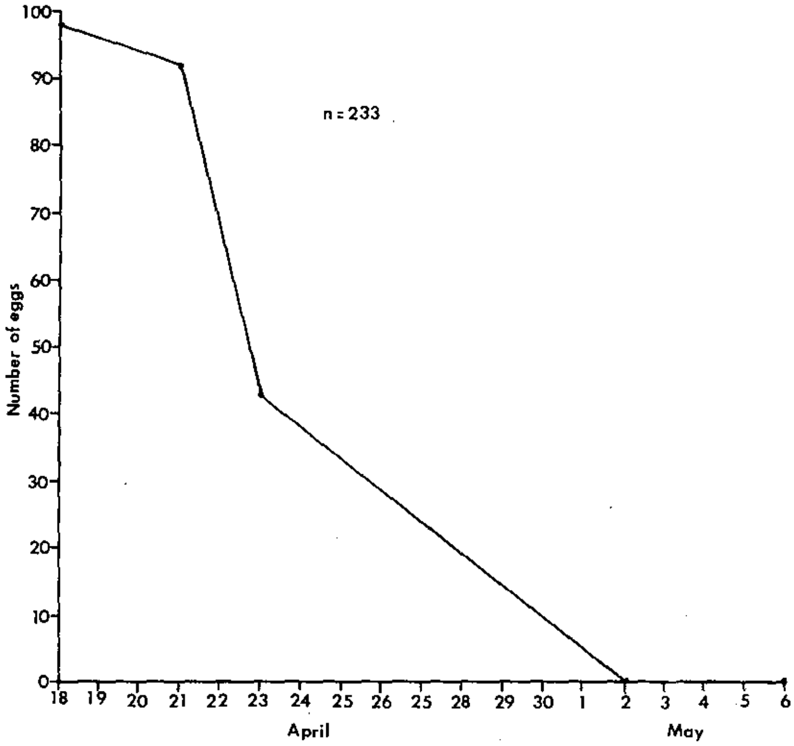


Figure 18.-Total number of eggs collected on the Intake gravel bar during spring 1977.

Table 4.-*Mean condition factors ($\bar{k}$), by 50-mm-length intervals, of sauger collected in three sections of the lower Yellowstone River during late summer and early autumn, 1977*

Length interval (mm)	Lower		Middle		Upper	
	n*	$\bar{k}$**	n	$\bar{k}$	n	$\bar{k}$
150-199	2	0.722	1	0.734	0	
200-249	59	.794	14	.831	17	0.911
250-299	62	.766	64	.813	42	.774
300-349	110	.762	100	.821	86	.802
350-399	36	.772	67	.786	83	.854
400-449	10	.795	16	.827	29	.812
450-499	10	.769	15	.829	16	.880
Grand mean condition factor	296	0.775	283	0.813	280	0.826

* n = number of fish
**$\bar{k}$ = mean condition factor

Table 5.-*Mean condition factors ($\bar{k}$), by 50-mm-length intervals, of sauger collected in the lower section during the spring and in the combined lower, middle, and upper sections of the Yellowstone River during late summer and early autumn, 1977*

Length interval (mm)	Lower (spring)		Combined (summer-fall)	
	n*	$\bar{k}$**	n	$\bar{k}$
150-199	3	0.573	4	0.726
200-249	17	.703	90	.822
250-299	202	.726	168	.786
300-349	171	.723	296	.794
350-399	54	.737	186	.813
400-449	19	.814	55	.813
450-499	6	.804	41	.834
500-549	6	.858	16	.851
Grand mean condition factor	479	0.731	859	0.804

* n = number of fish
**$\bar{k}$ = mean condition factor

on the first sampling date, and egg numbers decreased continually to zero by May 2.

Initial combined walleye and sauger spawning criteria were determined for depth, mean velocity (measured at 0.6 the depth), and substrate on the Intake gravel bar. Eggs would be expected to occur in a range of depths from 0.46 to 1.04 m at a 90-percent probability level. Most eggs (71 percent) were collected in 0.76 m of water or deeper (fig. 19). This sharp break in the curve suggests a preferred spawning depth of over 0.6 m.

Nearly all the eggs were collected along transects 2 and 3 (99 percent) in water 0.75 m or deeper (table A-2). Only on transect 4, the downstream-most transect, was a large proportion of eggs collected (67 percent) in water 0.60 m or shallower. Mean water velocities on transect 4 at 0.45 and 0.60 m usually exceeded mean water velocities at 0.75 m for both transects 2 and 3. Implications are that a combination of depth and velocity is important for spawning to occur.

At the 90-percent probability level, eggs can be expected to occur in a range of velocities from 0.72 to 0.96 m (fig. 20). The range of velocities sampled was 0.36 to 1.11 m/s. Eggs were not found at sites with a mean water velocity of 0.66 m/s or slower on the Intake gravel bar.

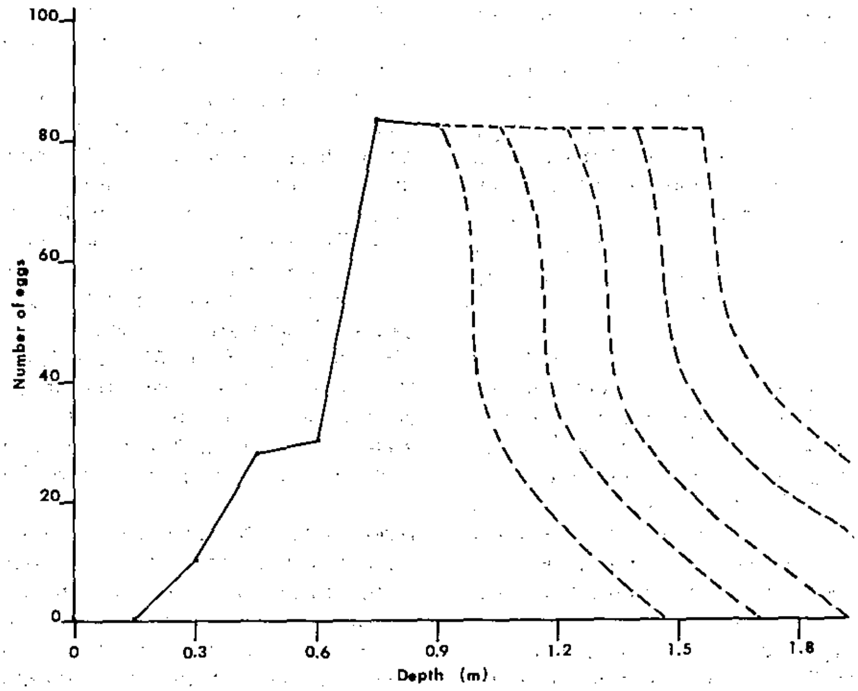


Figure 19.-Total number of eggs collected at each depth interval along transect lines on the Intake gravel bar during spring 1977. Solid line represents measured egg abundance and the dashed lines are hypothetical representations of egg abundance at water depths over 0.9 m using the complement of the measured curve.

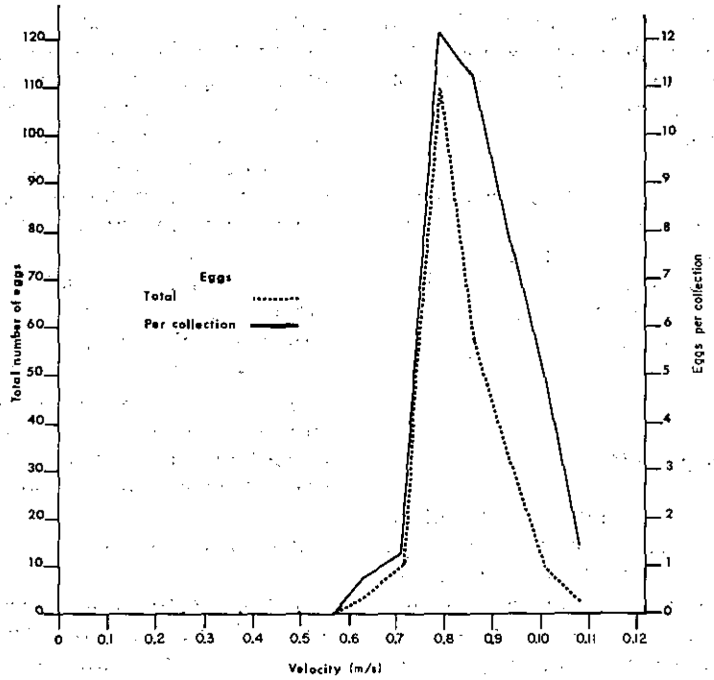


Figure 20.-Total number of eggs collected at each 0.075 m/s water velocity interval and the number of eggs per collection at each 0.075-m/s interval on the Intake gravel bar during spring 1977.

The majority of eggs (89 percent) was collected over mixed pebble-cobble or pebble substrate, with the remaining 11 percent over primarily cobble substrate. No eggs were collected in substrate covered by or containing sand and silt. Nearly all eggs (97 percent) were found over loose substrate as opposed to compacted or semicompacted substrate (that which could not be dislodged by kicking). Sample sites included 53 percent loose cobble-pebble, 31 percent compacted cobble-pebble, and 10 percent substrate dominated by sand.

The WSP program was used to predict hydraulic parameters at the four Intake egg sections (see Development of a Method for Obtaining Cross-section Data for the Water Surface Profile Program and its Application to Analyze Habitat on the Lower Yellowstone River). These hydraulic parameters were used to predict the amount of top width (almost identical to wetted perimeter) present at various flows which met spawning criteria at each cross section (fig. 21). These criteria included: a mean water velocity between 0.70 and 0.96 m/s, a depth not less than 0.46 m, and a cobble or pebble substrate. Any length of top width not meeting all the criteria was excluded.

Combined top width measurements meeting spawning criteria for all four transects declined sharply at a discharge of less than 140 m/s (fig. 22). Optimum flows appeared to be between 170 and 310 m^3/s. A reduction in flow below 140 m^3/s would result in dewatering of eggs, increased silt deposition, and/or a reduction of the number of fish which actually spawn.

To determine whether eggs could be collected at other sites along the river, eight additional transects downstream from the Intake bar were sampled. Only one egg was collected (table A-3). It was found in 0.9 m of water on the large gravel bar downstream from the Intake bar.

DISCUSSION

Abundance and Age-growth

Results from summer-autumn electrofishing collections showed differences in abundance, age composition, and average length of sauger between the lower, middle, and upper sections of the lower Yellowstone. Sauger in the upper section were less abundant, but had a larger average length and age than those in the lower section, while sauger in the middle section were intermediate in all three respects. However, there was little or no difference in absolute growth of sauger among the three sections. Tag returns indicated that sauger tended to move up the Yellowstone during spring and/or early summer from spawning grounds below Intake diversion and suspected spawning grounds in the lower Powder and Tongue Rivers (see Effects of Diversion on Upstream Fish Migration). These data suggest the existence of a general upstream migration of mature sauger after spawning. Berg [27] found that the average length of sauger increased in upstream sections of the 296-km reach of the Missouri River between Fort Peck Reservoir and Morony Dam. He found that sauger averaged 316 mm (531 fish) in the upper area and 289 mm (209 fish) in the lower area of this free-flowing reach of the Missouri River.

Average length and mass at annulus, average increments of length, and coefficients of condition were similar for sauger in all three areas and also similar to the spring spawning population downstream from Intake. Growth of Yellowstone River sauger compared favorably to reported growth data on sauger in other waters in the Missouri River drainage (table 6). Yellowstone sauger were comparable in length to sauger in Missouri River Reservoirs through age 3, but were somewhat smaller at ages 4 and older.

Subpopulations of sauger could exist in the lower Yellowstone River as a result of the large distances between spawning areas. Growth rates of sauger were similar between river areas and between seasons in the lower area. Differences in growth rates of subpopulations would be masked because of the mixing of sauger from different spawning areas during the summer and autumn.

Further studies should include: (1) continued monitoring of summer-autumn distribution and movement of sauger and other sport fish in the lower Yellowstone, (2) assessment of factors which might influence sauger distribution, growth, and survival (including prey abundance, turbidity, temperature, rearing preference, etc.), and (3) continue to collect data for age-growth analysis.

Spawning Criteria

In the lower Yellowstone River walleye and sauger spawn during a period of relatively stable flows between ice-out in March and high spring flows beginning in May. Below Intake the majority of walleye and sauger spawned in water deeper than

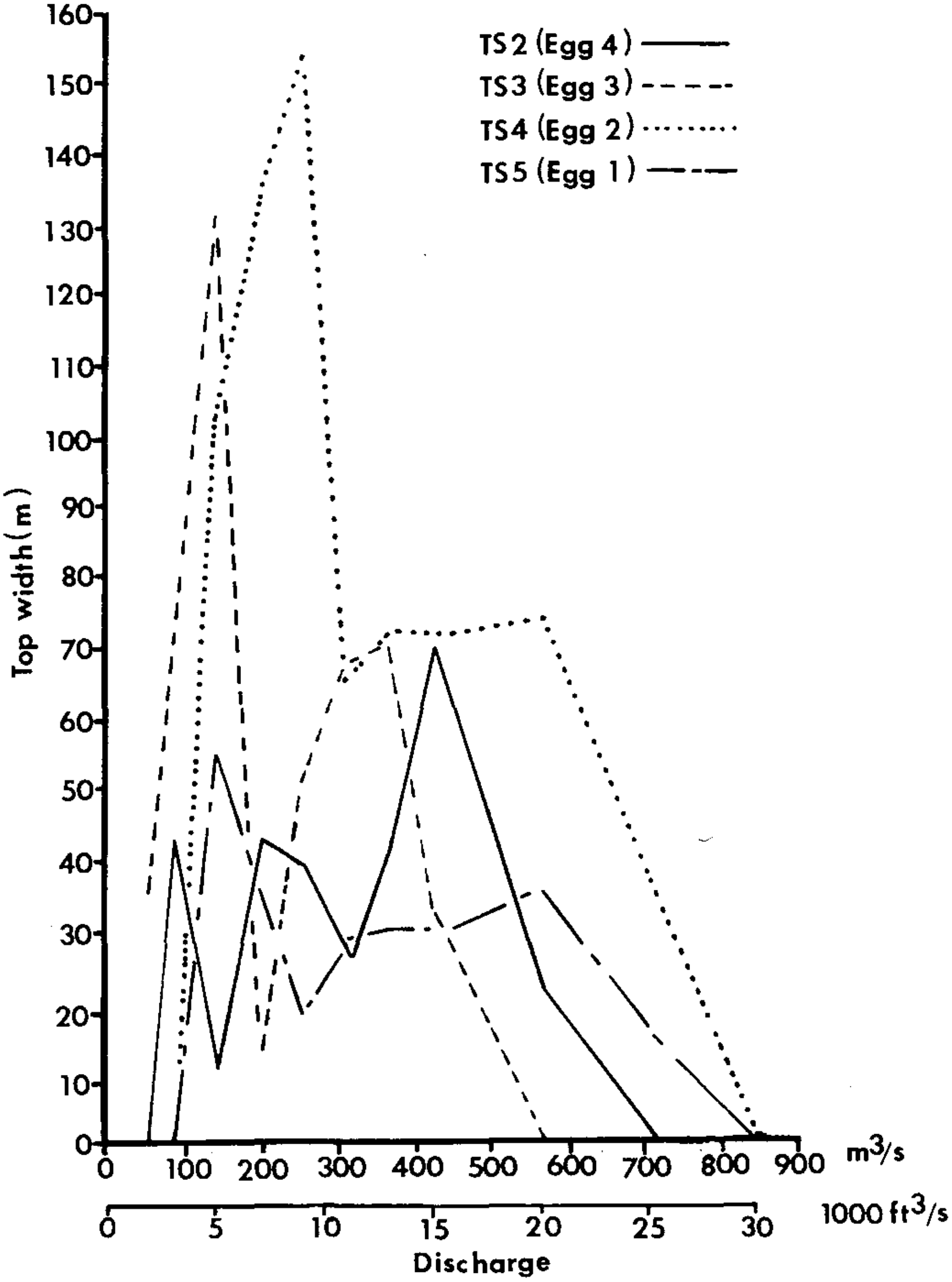


Figure 21.-Amount of top width of lower Intake TS (transects) 2, 3, 4, and 5 (meeting initial, combined walleye and sauger spawning criteria of: a mean velocity between 0.70 and 0.96 m/s, a depth of not less than 0.46 m, and a cobble or pebble substrate) at various discharges.

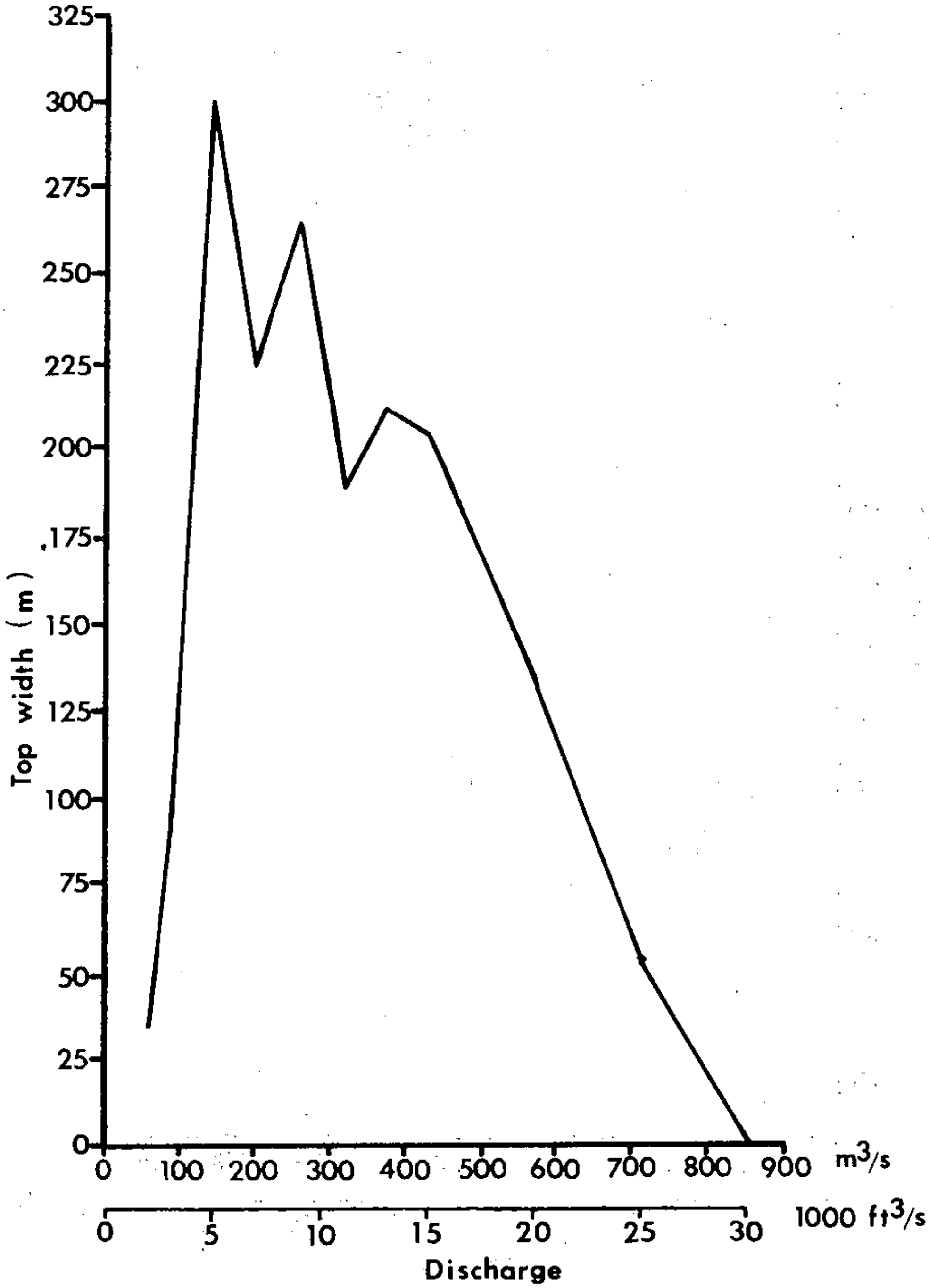


Figure 22.-Combined amount of top width of lower Intake transects 2, 3, 4, and 5 (meeting initial, combined walleye and sauger spawning criteria of: a mean velocity between 0.70 and 0.96 m/s, a depth of not less than 0.46 m, and a cobble or pebble substrate) at various discharges.

Table 6.-*Grand mean total length of sauger from several different waters*

Locality (source)	Number of fish	Grand mean total length at annuli (mm) 1	2	3	4	5	6	7
Yellowstone River[1] (present study)	859	157	244	305	365	424	476	534
Garrison Reservoir, N. Dak. (Carufel [28])	318	125	221	310	386	461	587	
Upper Mississippi River Backwaters (Christenson & Smith [29])	42	124	229	302	345			
Lewis and Clark Lake, S. Dak. (Nelson [10])	1,112	188	324	404	466	514	560	
Marias River, Mont., 1961 (Peters [30])	58	112	203	282	335	384	465	
Fort Peck, Mont., 1948 (Peters [30])	503	130	224	297	363	429	493	
Fort Peck, Mont., 1949 (Peters [30])	504	122	244	325	389	447	490	

[1] Includes combined summer-fall fish collections.

0.6 m which currently would ensure the survival of most of the eggs during years of normal flow fluctuations. Several authors reported that water fluctuations on spawning grounds were significant in determining year-class strength of sauger and walleye (Walburg [19], Nelson and Walburg [17], Priegel [14]).

Depth criteria for walleye and sauger spawning were indicative only of minimum spawning depth since sampling in water deeper than 0.9 m proved inadequate. The upper range of preferred spawning depth can be hypothesized using the complement curve of measured preferred depth and extending several hypothetical curves for preferred maximum depths (fig. 19). Velocity criteria limited maximum spawning depth at 2 m.

No eggs were collected at sites having a water velocity of 0.7 m/s or smaller. Egg abundance peaked and fell within the range of measured velocities, which suggests that measurements were made at the range of velocities at which the majority of fish spawned (fig. 20). The relative swift velocities for spawning criteria (0.70 to 0.96 m/s) would prevent silt from covering the dispersed ova. In addition, these velocities were generally associated with a relatively loose cobble-pebble substrate.

On the Intake gravel bar, walleye and sauger selected pebble-cobble substrate on which to spawn and also seemed to prefer loose as opposed to semicompacted or compacted substrate. Johnson (20) determined that substrate on spawning grounds was a significant factor in walleye egg survival. He observed the best survival on gravel-rubble substrate and further determined that egg survival increased by more than 10 times on a sand bottom when gravel and rubble had been added. Survival of eggs was poorest on muck bottoms.

When spawning criteria for depth, water velocity, and substrate were combined, the midrange of optimum spawning flows (determined from WSP data) was 240 m^3/s (fig. 22). This was very similar to the historical (1939-74) median flow for the Yellowstone River during April, 260 m^3/s (from flow duration hydrograph compiled by U.S. Geological Survey [5]). There was a very sharp decline in suitable spawning width at discharges less than 140 m^3/s and larger than 368 m^3/s.

Sampling should continue at spawning sites on the Yellowstone River to increase the sample size and increase the range of habitats sampled. Samples should also be taken downstream from Forsyth diversion where a large number of sauger congregated, but relatively few walleye. Sampling should be continued at Intake and an attempt should be made to determine the degree of overlap between walleye and sauger spawning. Presence of hybrids in the population suggests that overlap may occur to some degree every year.

Further studies should include estimates of year-class strength to determine what factors are important to survival and when they operate. Several authors determined that factors influencing year-class strength primarily affect early life stages, including: (1) spawning and egg survival, (2) survival during the first summer, and (3) survival over the first winter (Johnson [20], Priegel [14], Nelson and Walburg [17]).

DEVELOPMENT OF A METHOD FOR OBTAINING CROSS-SECTION DATA FOR THE WATER SURFACE PROFILE PROGRAM AND ITS APPLICATION TO ANALYZE HABITAT ON THE LOWER YELLOWSTONE RIVER

INTRODUCTION

Basic to determination of aquatic habitat criteria for a particular species of fish in a lotic environment is the knowledge of various physical and hydraulic characteristics of the river through its range of flows. Habitat data can be collected which relate biological activities of the fish (spawning, incubating, rearing, migrating, etc.) to physical characteristics existing in the river. Known habitat requirements of the species can then be correlated to these physical parameters and impacts predicted for altered streamflows (Bovee and Cochnauer [31], Prewitt and Carlson [32]). One objective of this portion of the study was to develop a method to collect physical and hydraulic information on a deep, turbid, fast-flowing river such as the lower Yellowstone.

Important physical criteria in a lotic environment include: depth, velocity, substrate size, channel width, and conveyance area. Since these physical parameters vary with discharge, they should be determined for the range of observed flows. The most accurate method of determining these parameters over a wide range of flows is by actual measurement; however, (1) this is extremely costly and time consuming, and (2) several years may pass before flows desirable for measurement may occur. For these reasons, methods have been developed for predicting various hydraulic parameters as a function of discharge (Stalnaker and Arnette [33]). The method used for this study was the WSP (Water Surface Profile) program developed by the Bureau of Reclamation (Dooley [34]). The program used data collected at only one discharge to predict changes in water surface elevation, velocity, wetted perimeter, and conveyance area of a stream profile cross section at other specified discharges. Dooley [34] listed field data and descriptions needed for the WSP program. These include:

- A map showing stream sections being studied and cross-section locations.
- Cross-section survey data.
- Distances between cross sections, including inside and outside distances at stream meanders.
- Measured flow in cubic feet per second.
- Corresponding water surface elevations at all cross sections at the measured flow.
- Photographs of the stream reach being studied and photographs at each cross section.
- Descriptions of the streambed material at each cross section (sand, gravel, cobble, boulder, muck, debris).
- Description of bank and overbank material and vegetation (trees, brush, grass, logs).
- Identification of points where streambed material, vegetation, and streambank change within the cross sections.
- A list of flows to be used for predicting various physical parameters within the study section.

Problems encountered when obtaining cross-sectional data for a large, turbid river too deep to wade were: (1) elevations of the streambed were difficult to obtain by standard surveying techniques, (2) breaks in streambed contour could not be observed, (3) streambed substrate particle size could not be observed, and (4) stream controls were often difficult to find. Other drawbacks in collecting data on a large versus small river were increased time, manpower, and expense. In addition, accuracy was more difficult to obtain on a large than small river. Obtaining discharges in a large river can also be a problem; however, U.S. Geological Survey gage stations were located near study sections on the Yellowstone. A method was developed to solve some of these data collection problems.

The second major objective was to determine the effects of Intake diversion, a low-head dam, on the physical aquatic habitat. This was accomplished by using the WSP program on sections of river above and below the diversion structure. Intake is an important area of the lower Yellowstone River because seasonally large concentrations of walleye, sauger, paddlefish, and other fish species occur there. Quantitatively assessing the previously mentioned hydraulic parameters upstream and downstream from Intake diversion would provide insight into the effects of diversion structures on physical channel features and provide additional information on life history requirements of certain fish species.

METHODS

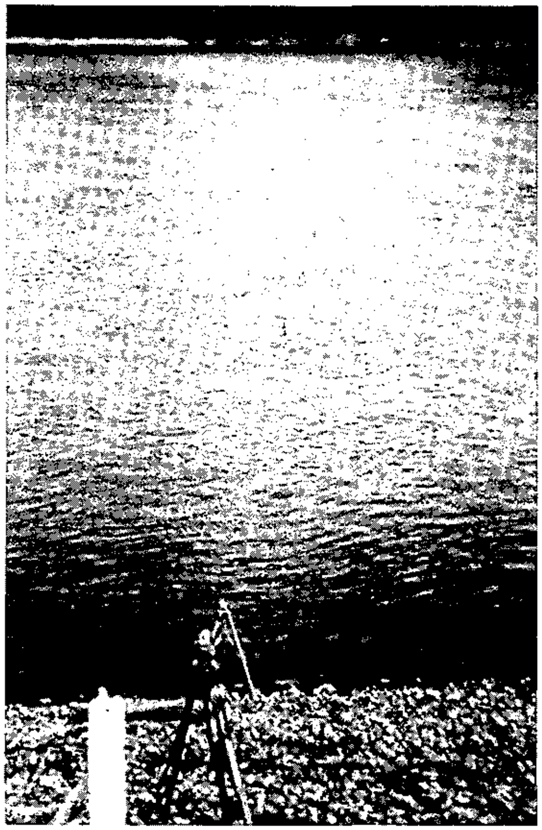
Two methods of collecting large river cross-sectional survey data for use in the WSP program were tested. Initial procedures for surveying the channel and streambank above water level and to a depth of 0.9 m (wadable depth) were common to both methods (fig. 23) and closely followed that described by Spence [35]. Equal water surface elevations were located on both shores to ensure that the transect was perpendicular to the general direction of flow. Permanent bench marks were placed above the high water marked on the transect line on both banks of the river. Flow measurements were obtained from the nearest U.S. Geological survey gage station to determine discharge.

Differences in the two methods were in the technique of collecting cross-sectional data in water depths greater than 0.9 m. In the first method, an observer remained on shore while two people in a johnboat measured water depths using a sounding rod. The driver moved the boat across the channel in a leapfrog pattern by drifting downstream from the transect line and moving back upstream to a new point on the line. Location and distance along the transect line were determined by use of a level set upon shore and a stadia rod mounted in the boat (Cochnauer [36]). Communication between shore and boat was aided by walkie-talkies. Because depth and turbidity prevented observation of the channel bottom except in shallow water, substrate was determined by the feel of the channel with the rod. Although three people were required in this method, Cochnauer [36] sounded the Snake River, Idaho with only one person in the boat by using more elaborate sounding equipment.

A second method was developed and tested which needed only two people. The onshore observer used a rangefinder (Lietz, model SD-5F) instead of a level to determine distances and keep the boat on the transect line (fig. 24). Rangefinder accuracy was ± 1, ± 2, ± 5 percent at distances from 0 to 90, 90 to 250, and $+150$ m, respectively. A portable, constant-recording Fathometer (Raytheon, model DE-719B) powered by a 12-V diesel truck battery, was mounted in the boat with the transducer suspended in a water-filled container (fig. 25). Feedback was reduced by placing only enough water in the container to cover the transducer. The depth-sounder printout was calibrated in increments of 0.3 m and could be interpolated to 0.03 m. Depth-sounder printouts could not be read for depths of 0.6 m or shallower (fig. 26). A large diesel truck battery was used to ensure adequate current supply for a full day's use. The installation of a voltmeter would permit use of a smaller battery or extend the use of the larger battery by indicating reductions in voltage. Depth-sounder accuracy decreased when voltage dropped below 11.5 V.

To provide targets for the boat operator when crossing the channel and minimize contact of the boat propeller with rocks in the shallow water alongshore, two large floats were placed off each bank in 0.9 m of water (fig. 23). Also, use of floats reduced the distance to be read with the rangefinder and thus increased accuracy.

To measure profiles, the operator maneuvered the boat upstream to the float on the far side of the channel. The observer, watching through the rangefinder, would signal the operator with a walkie-talkie and keep him on the transect line as he moved across the channel to the near shore. The observer called out predetermined distances as the boat passed them. The operator used an automatic marker on the depth sounder to mark the location of these distances on the depth profile.



(a) level (foreground) Photo P1279-D-79153

(b) stadia rod (far back) Photo P1279-D-79212

Figure 23.-Distances across the channel were measured with a level (a) and a stadia rod (b). A 7.3-m collapsible stadia rod was used because of the high banks in many sections of the Yellowstone River. Standard surveying techniques were used to obtain elevations between bench marks (steel posts) and a wadable depth (white floats).

Profile distances between the predetermined measurements could then be interpolated from the printout. Maneuverability of the boat along the transect line was good during low and intermediate flows. Substrate was determined by appearance of the stream bottom on the Fathometer printout (fig. 26).

After initial trial runs, the second method was superior to the first for the following reasons: (1) less time was needed to run a profile, (2) one less person was required, (3) the depth-sounder printout provided more information than sounding and (4) it was more cost efficient. While both methods provided similar profiles when uniform bottoms were surveyed, the depth sounder provided more accurate data for irregular and/or deep bottom profiles (fig. 26). It was possible to miss dips, rises, and/or the thalweg in an irregular profile unless numerous soundings were made (fig. 26). In some sections, water depths were over 5.2 m deep, making sounding difficult, particularly with the accompanying high flow velocities. Changes in bottom substrate, as well as the relative roughness across a transect, were vividly depicted in the depth-sounder printouts (fig. 26). Numerous soundings in a river this deep and turbid would be needed to obtain comparable data. Predominate substrate was obtained from the printouts by classifying degree of irregularity; bedrock and boulder were the most irregular and pebble-sand substrates were the most uniform (fig. 26).

Equipment common to both methods included a 4.3-m johnboat and a 7.5-hp outboard motor, a 7.3-m collapsible stadia rod (fig. 23), a level or transit, a 100-m tape, bench markers (steel fence posts) and two walkie-talkies. In addition, three people and a sounding rod were needed for the first

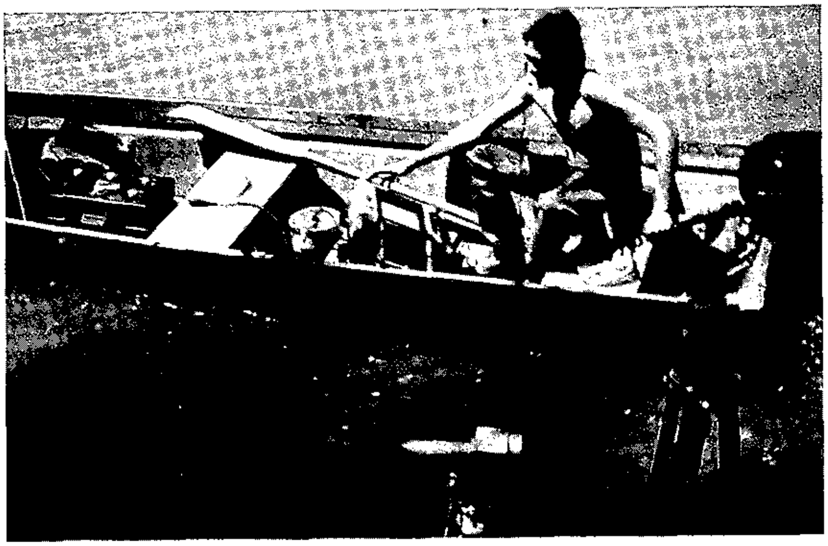


Figure 24.-The rangefinder (center foreground) was used to measure the distance to the boat as it crossed the channel when taking depth profiles. Photo P1279-D-79154

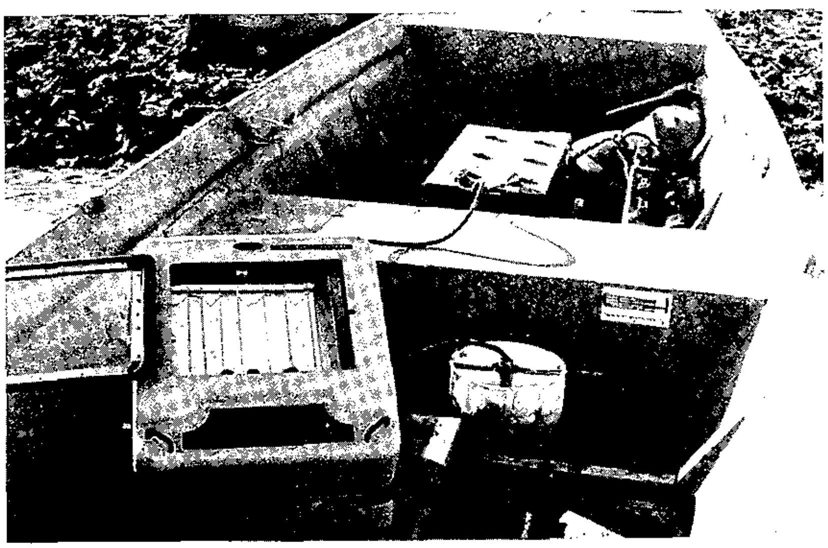


Figure 25.-This portable, constant-recording Fathometer had a variable depth scale and a fix marker. The transducer was submerged inside the cylinder and could transmit through the hull. A large 12-V diesel truck battery was used for the power source. Photo P1279-D-79209

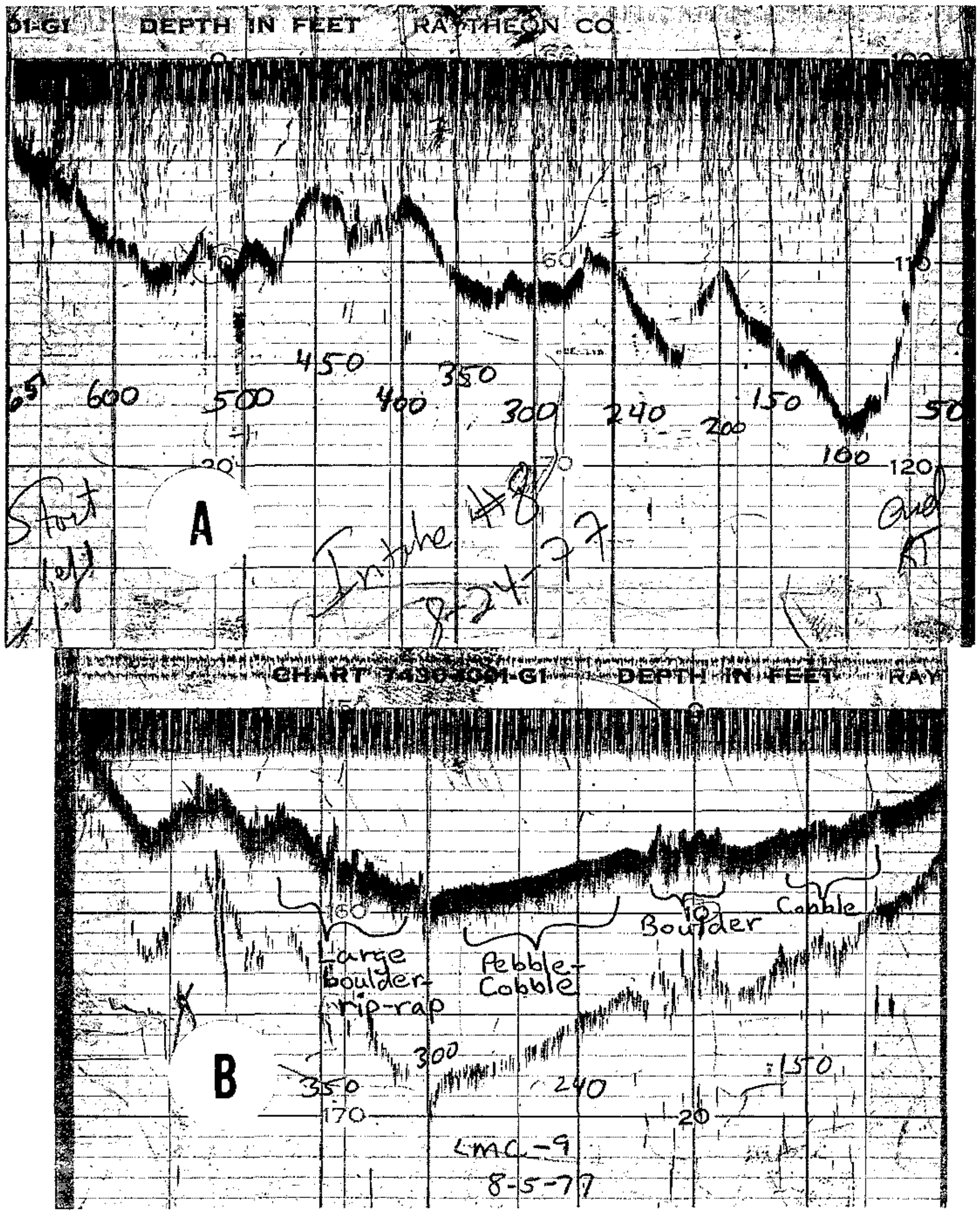


Figure 26.-Original printouts of bottom profiles taken with a constant-recording Fathometer. Each horizontal line represents 0.3 m in depth and vertical lines were automatically marked at predetermined distances from the water's edge by the boat driver. Profile A is lower Intake transect 8 and B is lower Miles City transect 9.

method; whereas two people, a rangefinder, a portable constant-recording Fathometer with transducer, and two floats were needed for the second method.

Initial costs were higher for the second method because of the additional equipment; however, by the end of the first field season, the second method was comparable in cost due to less time and manpower required to run a transect.

The WSP data were analyzed in a computer by Bureau of Reclamation personnel at Billings, Montana.

RESULTS AND DISCUSSION

Physical Habitat Above and Below Intake Diversion

The Intake diversion backs water upstream creating a pool-like environment, while downstream a long run is formed through a wide channel with predominantly gravel substrate. Water surface profiles were measured at two study sections, one upstream and one downstream from Intake diversion, in an attempt to quantify these obvious differences in physical channel features created by Intake diversion.

Eight transects were surveyed downstream from Intake diversion, six upstream and one across the diversion. Location of each transect in relation to the diversion is shown in figure 27. A typical upstream and downstream cross section is shown in figure 28.

Some physical parameters of each transect, during a discharge of 368.1 m^3/s, are listed in table 7. Because upper transect 2 (U2) and lower transect 8 (L8) were nearest the dam and displayed some of the most pronounced effects of the diversion, these cross sections were analyzed separately and compared to transects upstream and downstream from the diversion, respectively. Also, lower transects 2, 4, and 6 (L246) were compared with upper transects 3, 4, and 5 (U345) to determine some general differences in the physical aquatic environment above and below the diversion dam. These six transects were chosen because: (1) they were far enough up or downstream to avoid the extremes in river environment created directly above

Table 7.-*Some physical characteristics of 15 transects of the Yellowstone River at Intake at a discharge of 368.1 m^3/s*

Transect	Distance from dam (m)	Top width (m)	Wetted perimeter (m)	Mean depth (m)	Conveyance area (m^2)	Mean velocity (m/s)
L1	2584	493	493	0.70	312	1.32
L2	1612	314	315	0.94	374	1.51
L3	1354	302	302	1.06	313	1.23
L4	1046	305	307	1.23	378	1.04
L5	737	239	239	1.36	327	1.25
L6	400	388	388	0.93	375	1.02
L7	83	226	229	2.24	512	0.74
L8	56	226	230	3.51	799	0.49
U1	0(dam)	219	222	1.37	302	1.22
U2	64	232	234	2.34	590	0.68
U3	475	227	230	2.54	589	0.66
U4	1020	226	228	2.13	474	0.79
U5	1689	322	324	1.32	409	0.92
U6	2321	199	200	1.86	378	1.01
U7	3137	271	272	1.64	431	0.89

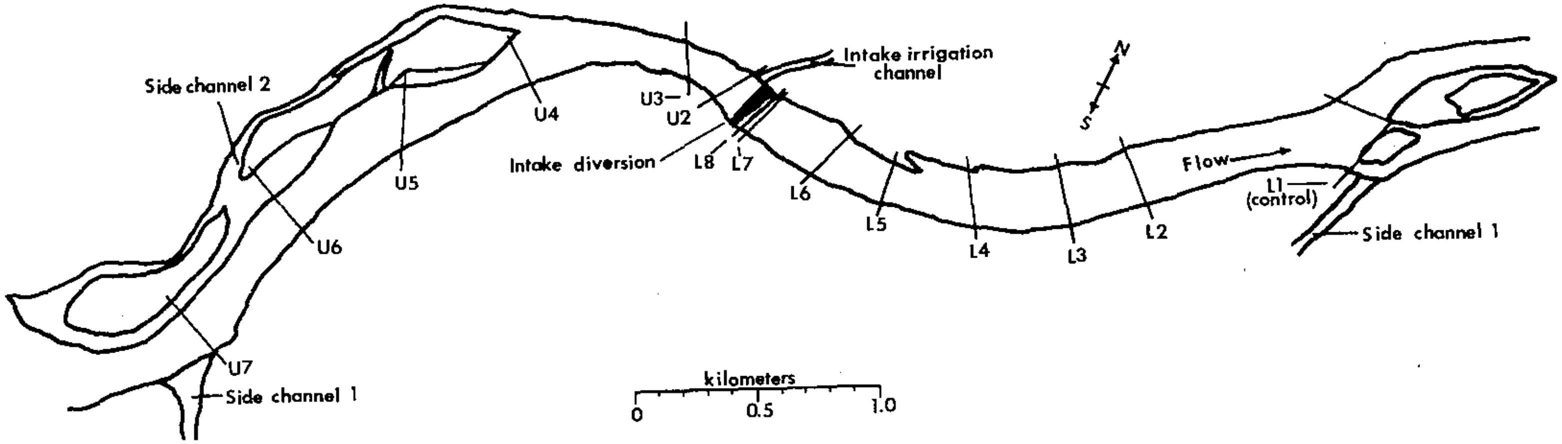


Figure 27.-Location of water surface profile transects upstream and downstream from Intake diversion, Yellowstone River.

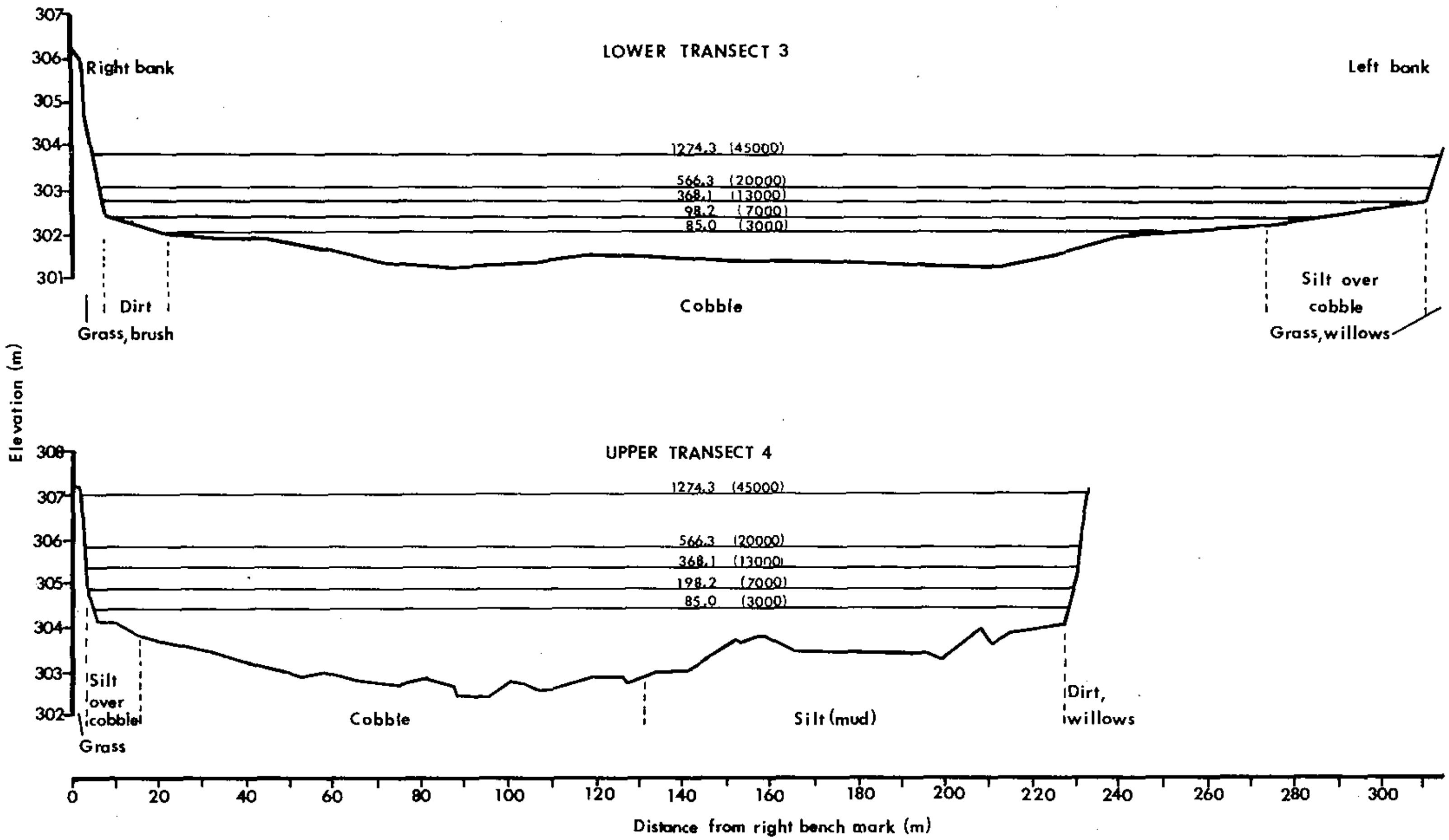


Figure 28.-Typical stream cross sections and predicted water surface elevations, downstream and upstream from Intake diversion, at various discharges in m^3/s.

or below the dam, and (2) they were similar distances above or below the diversion (fig. 27). Thalweg depths, mean depths, top widths, and mean velocities were compared at a discharge of 368.1 m^3/s, the mean annual flow of the Yellowstone River at Sidney (U.S. Geological Survey [5]). Bank-full flow was estimated to be 1472.5 m^3/s using the 1-½-year frequency floodflow (Leopold et al. [37]).

At discharges greater than 566.3 m^3/s, the accuracy of predicted water surface elevations was reduced because water began flowing in two side channels that were not surveyed (fig. 27). However, even at high flows the loss in accuracy was considered to be small, because the combined flow down both channels did not exceed 10 percent of the total flow. Side channel 1 (fig. 27) flowed around both the upper and lower sections and did not directly influence accuracy. Side channel 2 (fig. 27) directly affected accuracy of upper transects 4 through 6, but the decrease in predictive accuracy at high flows was considered to be minimal. During high spring flows, the discharge measured at Sidney was probably slightly greater than in the Intake study section because of withdrawal at the Intake diversion and flow circumventing the study area through side channel 1.

Thalweg and predicted water surface elevations are shown in figure 29. Above the diversion a deep pool was created with a maximum thalweg depth of 6.4 m during a discharge of 368.1 m^3/s at a distance of 475 m above the diversion (U3).

Except for the scour pool directly below the dam, the downstream transects had consistently smaller mean depths than transects located similar distances upstream from the diversion (fig. 30). Grand mean depths were 2.0 and 1.0 m for U345 and L246, respectively.

Top widths upstream from the diversion were generally slightly wider than that of the diversion (219 m) while most of those downstream were much wider (table 7). Mean top widths of U345 and L246 were 258 and 336 m, respectively (fig. 31). The diversion constricted the channel immediately up and downstream even during a discharge of 1274 m^3/s.

Wetted perimeter of the upper transects increased in steps as discharge increased (fig. 32). Inflections occurred at 198.2, 368.1, 424.8, 566.3, and 707.9 m^3/s. Wetted perimeter of U4 increased only slightly with increased flows due to its narrow channel and high banks. Instead, only depth and velocity increased. This was similar to the transect across the dam and lower transects 7 and 8 which crossed a pool below the diversion. Wetted perimeter for the lower transects had only one major inflection point which occurred at discharges from 254.9 to 424.8 m^3/s (fig. 33).

At flows greater than 56.6 m^3/s, mean wetted perimeter was as much as 29 percent larger for L246 than U345 (fig. 34). Discharges of 368.1 m^3/s and 566.3 m^3/s were needed to wet 95 percent of the maximum perimeter (bank-full flow) of L246 and U345, respectively. Because of the pool-like nature above the diversion, a low flow of 56.6 m^3/s wetted a greater percent of the maximum perimeter for U345, 64 percent, than for L246, 50 percent.

Mean conveyance area for U345 was larger than for L246 at all discharges, again depicting the pool-like nature of the Yellowstone River above the Intake diversion (fig. 35). At small discharges this difference was more pronounced; mean conveyance area of L246 was 51 and 76 percent of U345 during discharges of 850 and 1132.7 m^3/s, respectively.

The mean velocity of all the transects upstream from the diversion appeared to be influenced by the effect of the diversion backing water upstream. Downstream from the diversion, mean velocities were larger than upstream, except those for transects across the scour pool. Mean velocities ranged from 0.66 to 1.01 m/s and 0.49 to 1.51 m/s upstream and downstream, respectively (fig. 36). With increased discharge the grand mean velocity for the downstream transects (L246) increased faster than for the upstream transects (U345). The grand mean velocity increased faster at small discharges than large (fig. 37). Water surface gradients, 64 to 1689 m upstream from the diversion and 56 to 1612 m downstream from the diversion, were 0.23 and 0.80 m/km, respectively (368.1 m^3/s).

Below the diversion the substrate in the scour pool was composed of riprap and boulders while downstream cobbles and pebbles were dominant (87 percent). Above the diversion the dominant substrate increased in size with distance upstream from the diversion. Pebbles and silt were the dominant particle size near the dam (67 and 33 percent, respectively), while cobbles were dominant upstream (89 percent).

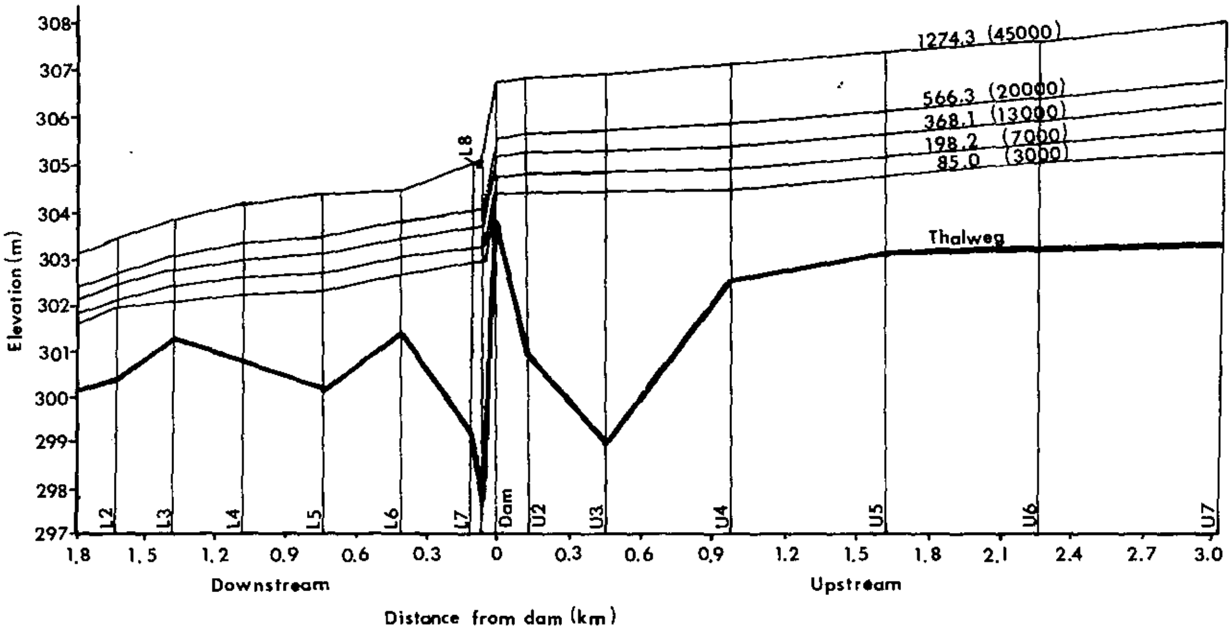


Figure 29.-Thalweg and predicted water surface elevations at various discharges in m³/s for transects upstream (U) and downstream (L) from Intake diversion dam, Yellowstone River.

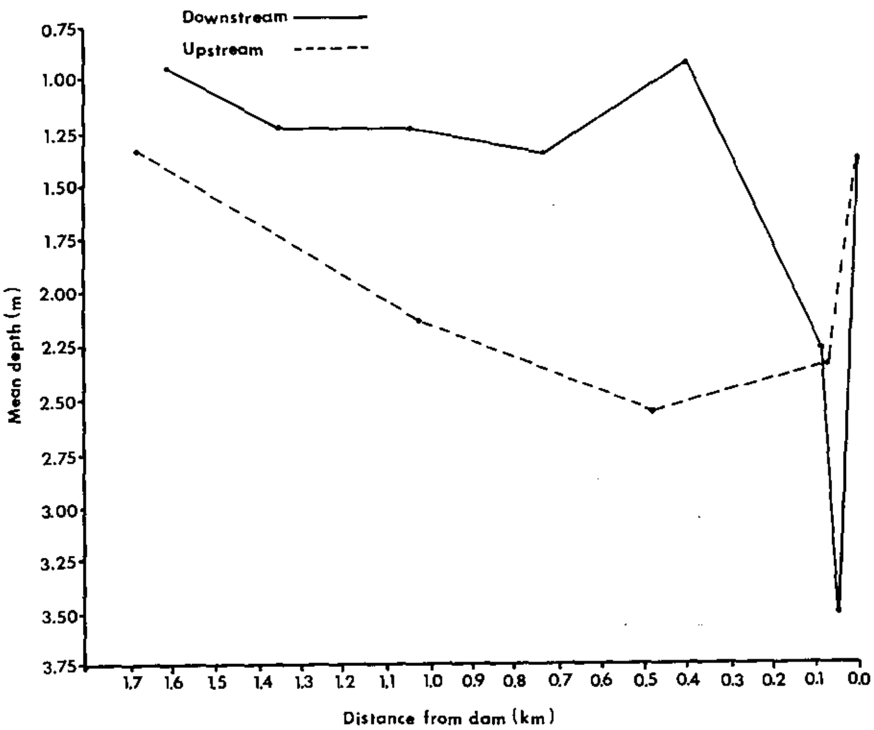


Figure 30.-Mean depth of transects upstream and downstream from Intake diversion on the Yellowstone River for the mean annual discharge of 368.1 m³/s.

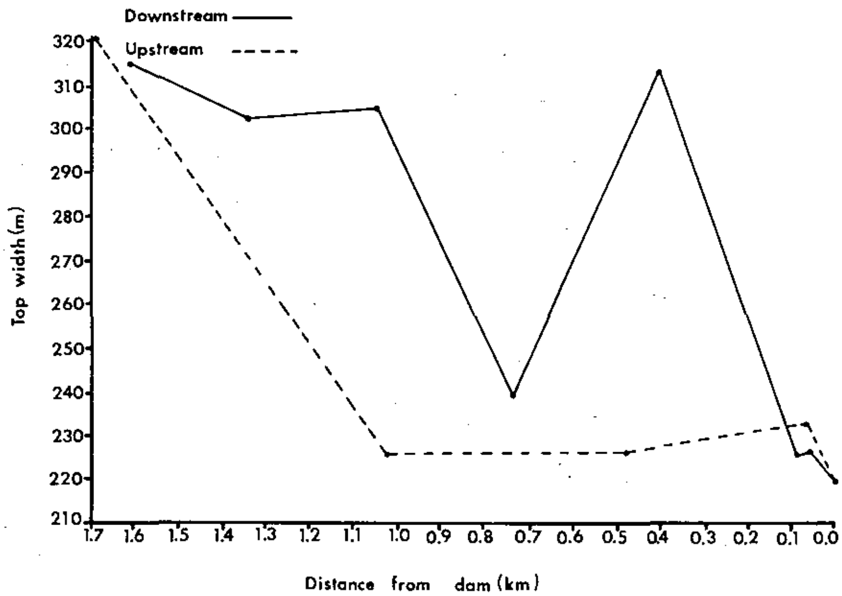


Figure 31.-Top width of transects on the Yellowstone River upstream and downstream from Intake diversion for the mean annual discharge of 368.1 m^3/s.

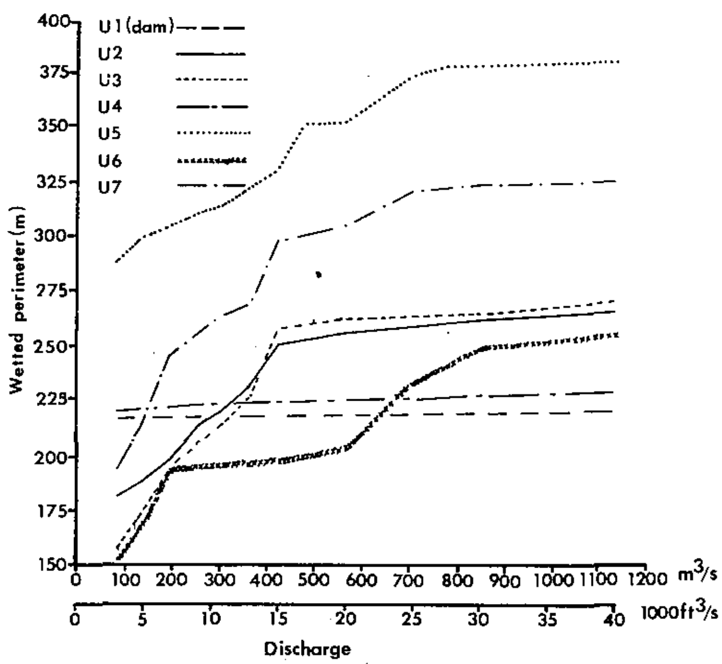


Figure 32.-Wetted perimeter versus discharge for seven transects (U1 through U7) on the Yellowstone River above Intake diversion.

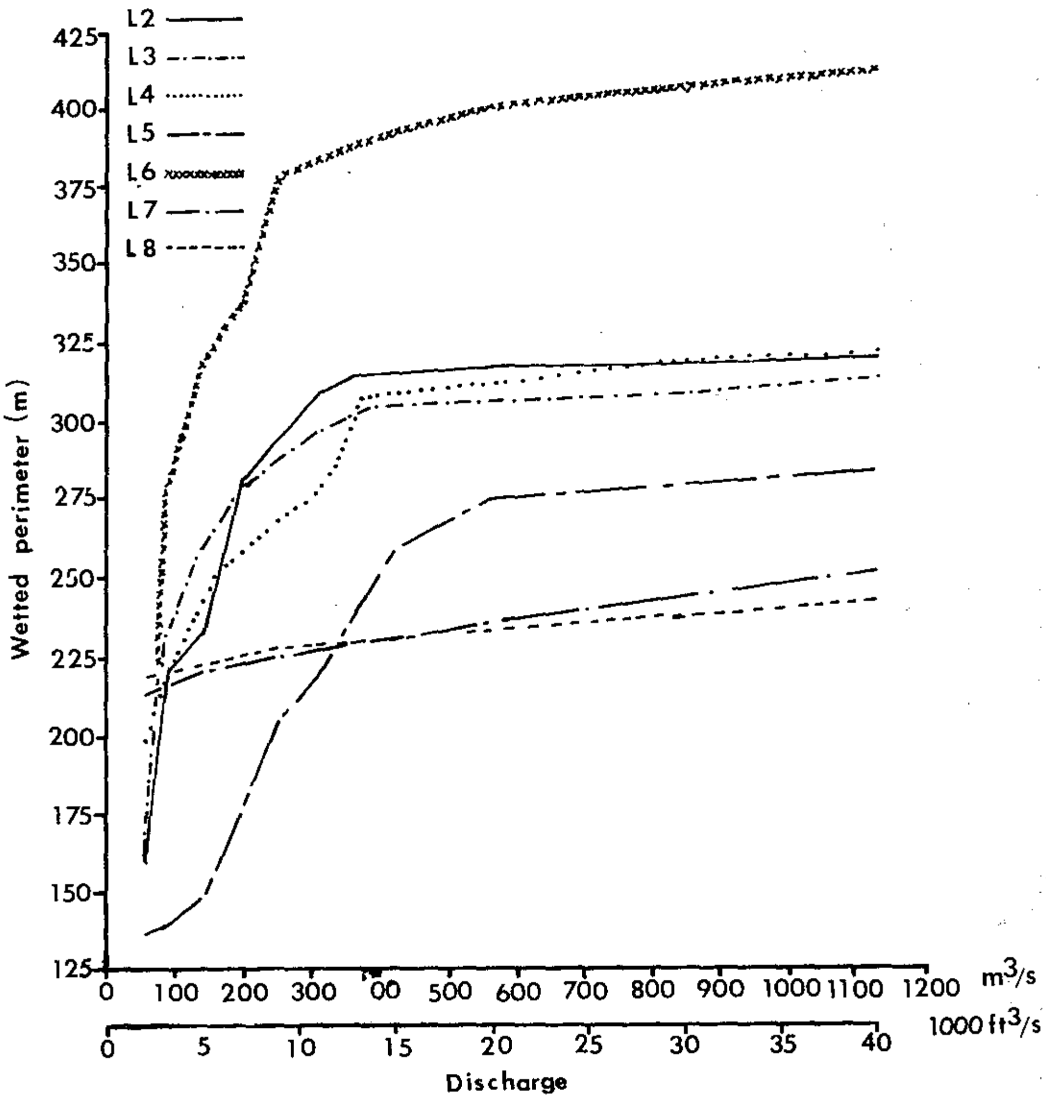


Figure 33.-Wetted perimeter versus discharge for seven transects (L2 through L8) on the Yellowstone River downstream from Intake diversion.

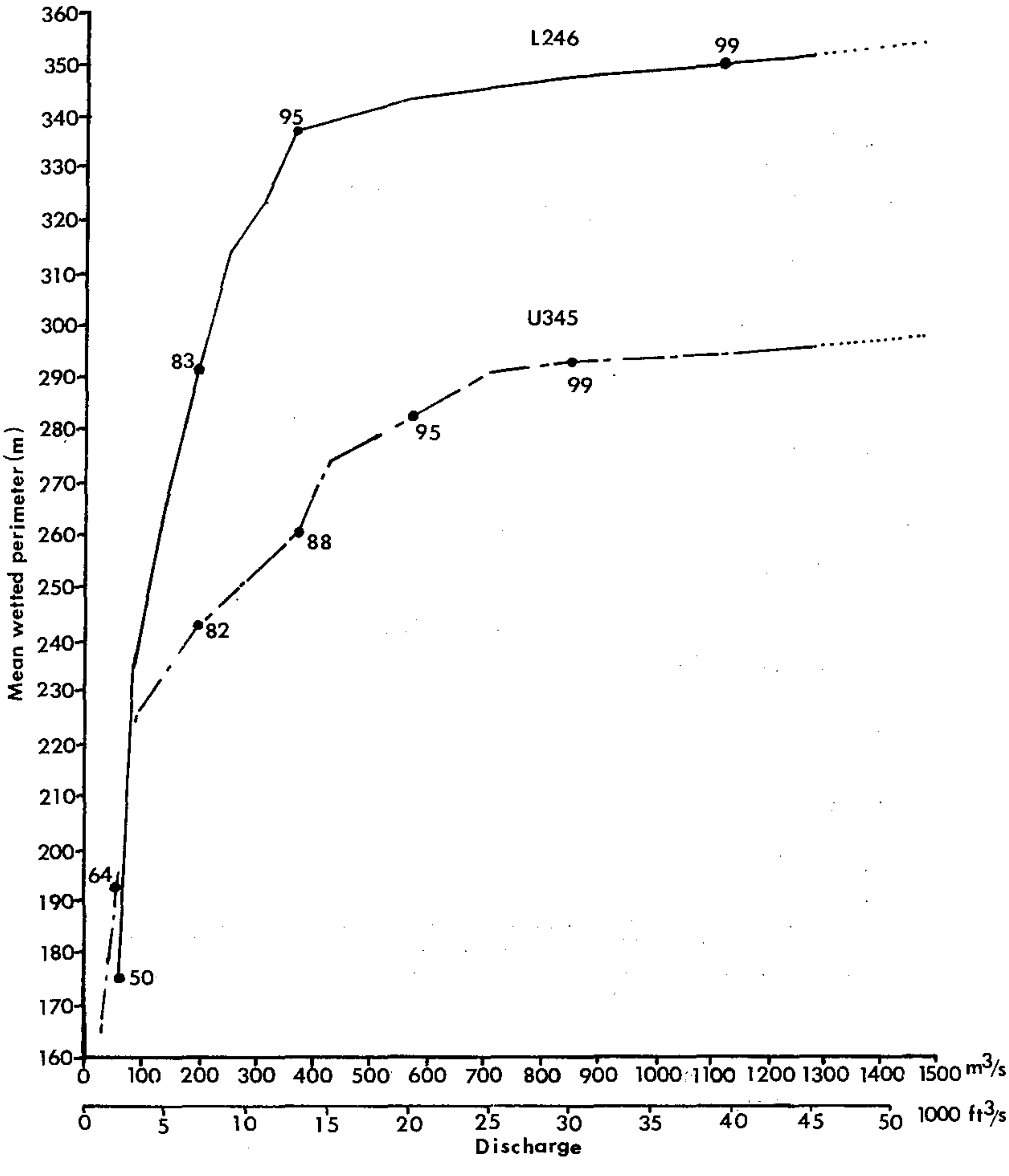


Figure 34.-Mean wetted perimeter versus discharge of three transects upstream (U345) and downstream (L246) from Intake diversion on the Yellowstone River. Percentages of projected maximum wetted perimeter during bank-full flow are given.

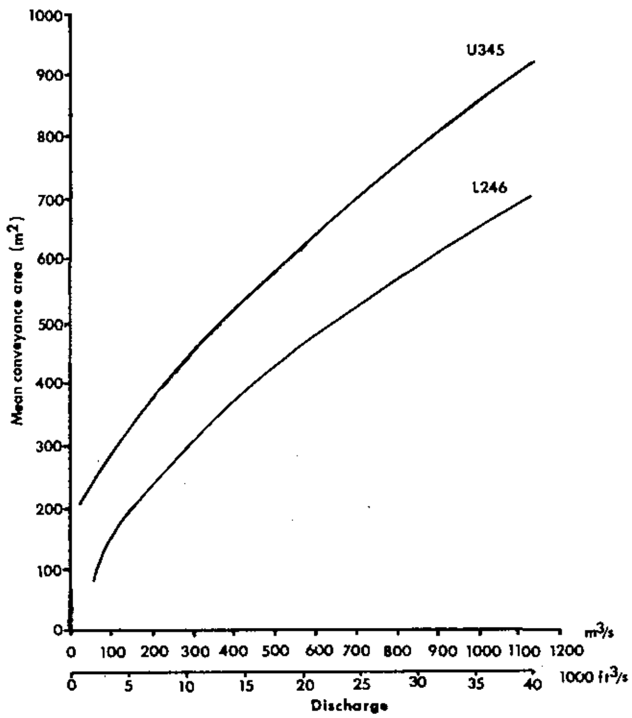


Figure 35.-Mean conveyance area of upper transects 3, 4, and 5 (U345) above Intake diversion and lower transects 2, 4, and 6 (L246) below Intake diversion, Yellowstone River.

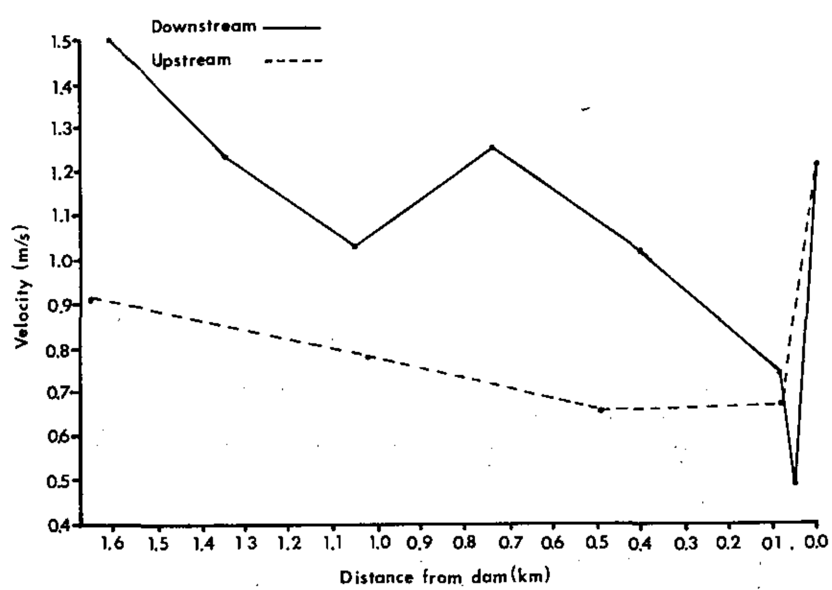


Figure 36.-Mean velocity of transects upstream and downstream from Intake diversion, Yellowstone River, at the mean annual discharge of 368.1 m³/s.

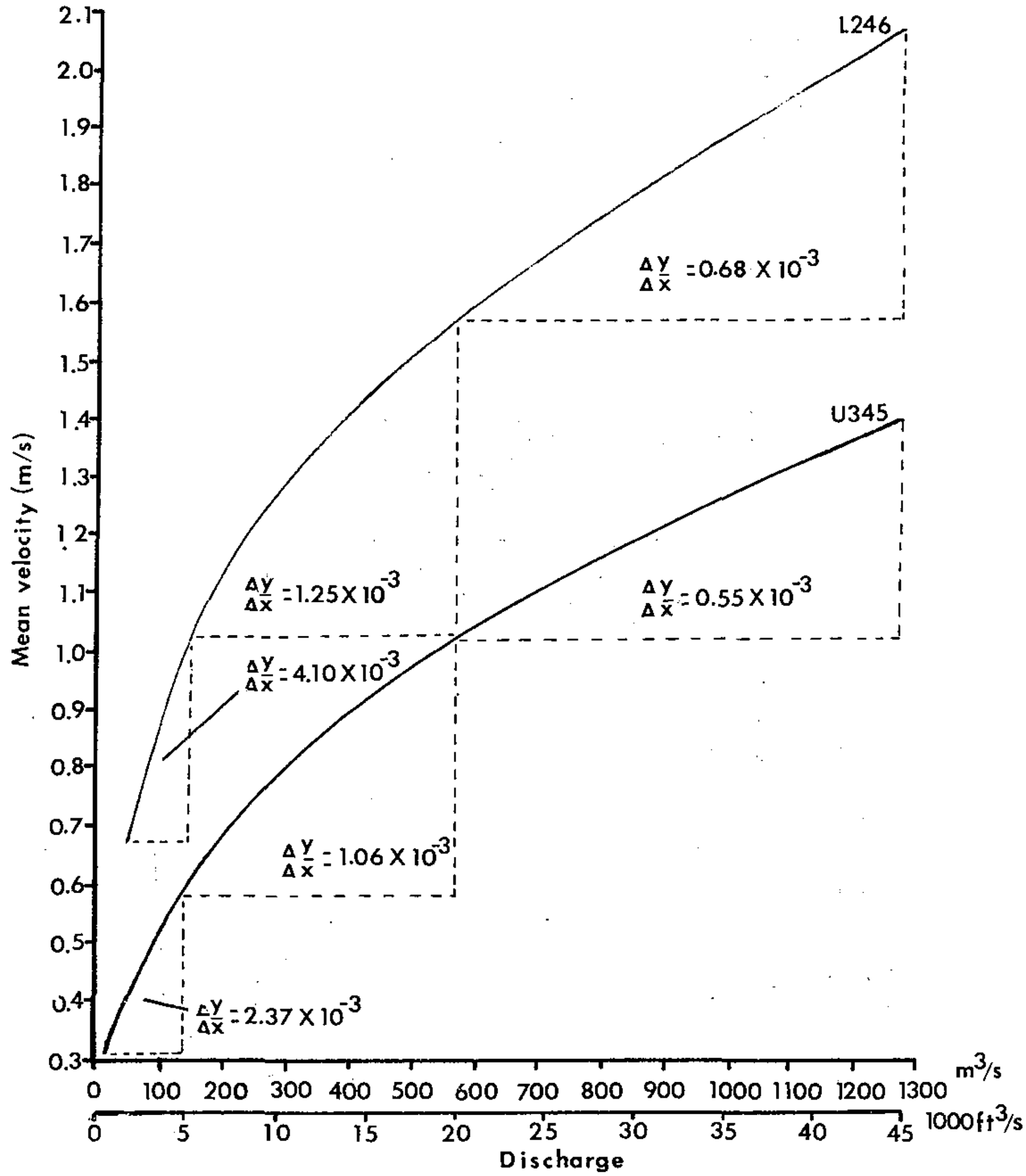


Figure 37.-Grand mean velocity versus discharge of three cross sections upstream (U345) and downstream (L246) from Intake diversion, Yellowstone River.

Limitations of the WSP on the Lower Yellowstone River

Single Channel.—Eleven transects were surveyed on a straight section of the Yellowstone River, downstream from State Highway 22 bridge near Miles City, to determine the accuracy of predicted water surface elevations for a relatively simple channel configuration (transects 8 through 18, fig. 38). The transects encompassed 2.62 km of river. Water surface elevations were measured at the eight upstream transects during various flows to check the predictive accuracy of the WSP program.

The predicted water surface elevations were closer to the observed elevations at low flows (those nearer the discharge during surveying) than at high flows. At a discharge of 137.3 m³/s, the predicted water surface elevations averaged 0.13 m (range: 0.09 to 0.18 m) higher than the observed elevations, while predicted elevations averaged 0.46 m (range: 0.33 to 0.64 m) higher than observed elevations at a discharge of 583.3 m³/s. Average maximum depths for these transects were 1.9 m (range: 1.4 to 2.5 m) and 3.0 m (range: 2.6 to 3.6 m) at discharges of 137.3 m³/s and 583.3 m³/s, respectively. Milhouse and Bovee [38] found that the WSP program was generally accurate at a range of flows from 0.4 to 2.5 times that at the time of surveying. The range of flows at which the WSP program can accurately predict hydraulic parameters can also be increased by obtaining numerous water surface elevations.

Accuracy for this series of transects may have been affected by the fact that water surface elevations were not all surveyed at the same discharge. This happened because the transects could not all be surveyed on the same day and discharge fluctuated during this period, 123.3 to 162.3 m³/s. All the transects should have been surveyed first and then water surface elevations obtained for each transect on the same day. To run the WSP program, the

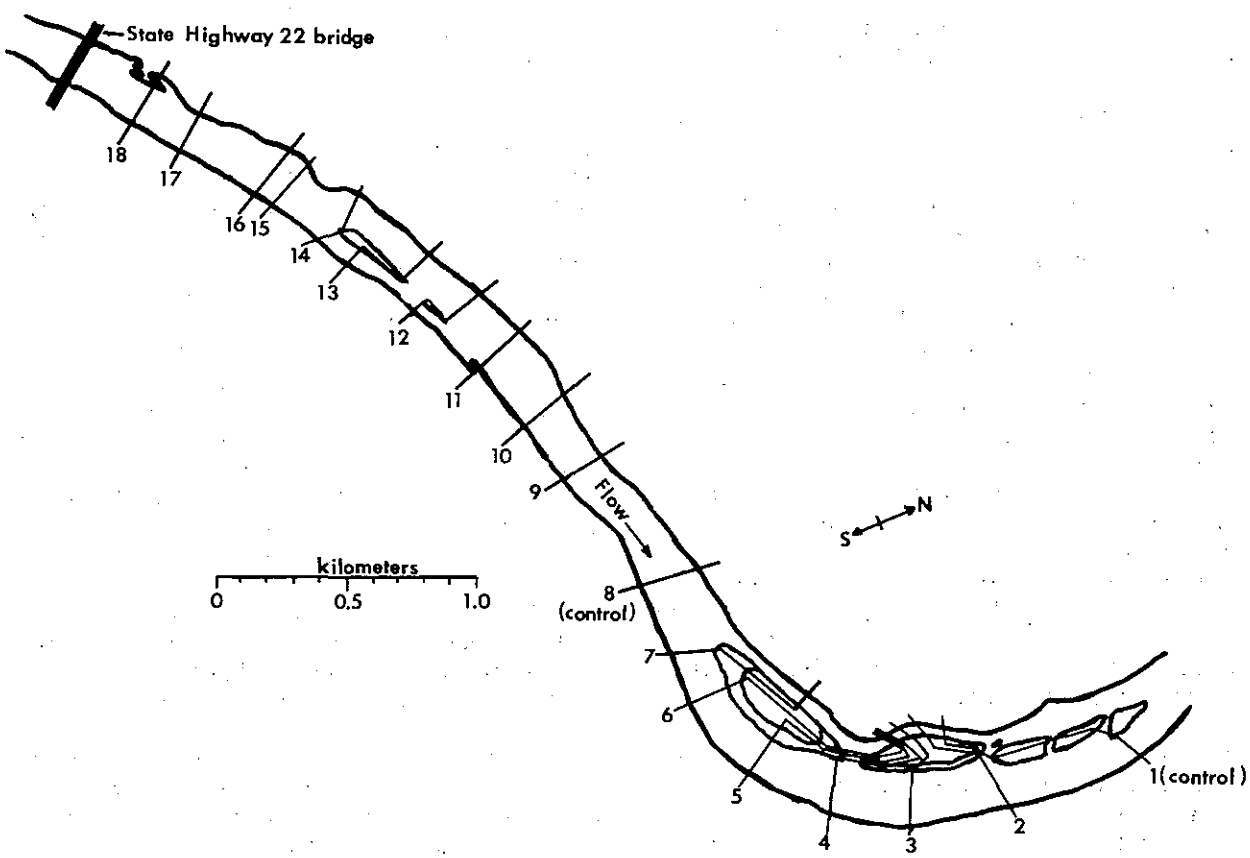


Figure 38.-Location of water surface profiles at the Miles City section, Yellowstone River.

downstream-most control, transect 8, was eliminated from the study reach which also may have influenced accuracy.

To reassess this study section, the data were reanalyzed through the WSP program, but only transects 11 through 18 were included in the study reach. A series of water elevations were obtained at flows of 583.3, 441.7, 214.9, 166.2, and 137.3 m^3/s for all eight transects. The WSP program used these data at the downstream-most transect (11) to increase the accuracy of the computed slope. The observed water surface elevations at the upstream transects (12 through 18) were compared to these new predicted elevations and were an average of 0.11 m higher than the observed values at all the discharges. Differences in predicted and observed water surface elevation did not increase with increased discharge which occurred when only one set of water surface elevations were known. Maximum difference in observed and predicted water surface elevation at a discharge of 583.3 m^3/s was 0.18 m, identical to the maximum error at a discharge of 137.3 m^3/s. The error, in predicted increase of water surface elevation with increase in discharge (from 137.3 to 583.3 m^3/s), ranged from 2 to 10 percent. Elser [39] found the WSP accurately predicted water surface elevations (within 0.03 m) on the Tongue River for flows smaller than at the time of surveying.

The Yellowstone River should be surveyed in the late summer/fall or possibly late March/April because: (1) low water allows stream controls to be found, (2) discharges are usually not fluctuating greatly during this time, (3) less of the channel is underwater which makes surveying easier, and (4) water velocities are not excessive. Accuracy of predicted hydraulic parameters for a wide range of flows can be increased by obtaining several water surface elevations over the range of flows. Because accuracy of the WSP predictions decreased for discharges with greater deviation from that at the time of survey, a minimum of two water surface elevation series should be obtained, one during the time of surveying and one during high flow. A third measurement between these extremes would also be useful, as accuracy increased by obtaining water surface elevations at several flows.

The WSP program uses the computed slope and observed water surface elevation(s) at the downstream-most cross section to predict water surface elevations at transects upstream. Predicted and observed water surface elevations are then compared at the upstream transects. Because accuracy of the computed slope (and thus, other predicted hydraulic parameters) increases with increased number of known water surface elevations, it is desirable to know the degree of accuracy gained in relation to the number of known water surface elevations. Further study should reveal this relationship. This can be accomplished by running the program several times using a combination of known water surface elevations at various flows. Suggested combinations include: (1) low flow only, (2) low flow and high flow, (3) low flow, high flow, and one intermediate flow, and (4) low flow, high flow, and a minimum of two intermediate flows.

Multiple channel.—Seven transects were surveyed along a simple braided section of the Yellowstone River near Miles City, 3.27 km downstream from State Highway 22 bridge (transect 1 through 7, fig. 38). The study section covered a reach of 2.26 km. The upstream end of this section was divided into two channels. Downstream, the major portion of the flow in the left side channel (channel 2, fig. 39) returned to the main channel (channel 1) through a small chute between two islands (channel 3). Channel 4 contained the remaining flow. Transects on the side channels were often spaced short distances apart at stream controls but were located greater distances apart on the main channel. This occurred because transects were initially chosen on the main channel with matching water surface elevations subsequently found on the side channels. The largest change in water surface elevation occurred at these short control areas on the side channels, while changes in water surface elevation along the main channel were not so obvious. For this reason, cross sections could have been more properly spaced if transects were initially chosen on the side channel(s) and expanded to the main channel. Controls on the side channel closely matched controls on the main channel. Surveying occurred during a time when flow down the side channels was small (5.3 m^3/s).

The WSP program did not accurately or consistently predict hydraulic conditions existing in this braided section of river. Problems encountered were: (1) Too much water was allocated to the side channels, (2) The program predicted some unrealistically large side channel velocities (a function of No. 1); and (3) Different flows were predicted at successive transects on the same channel for the same discharge.

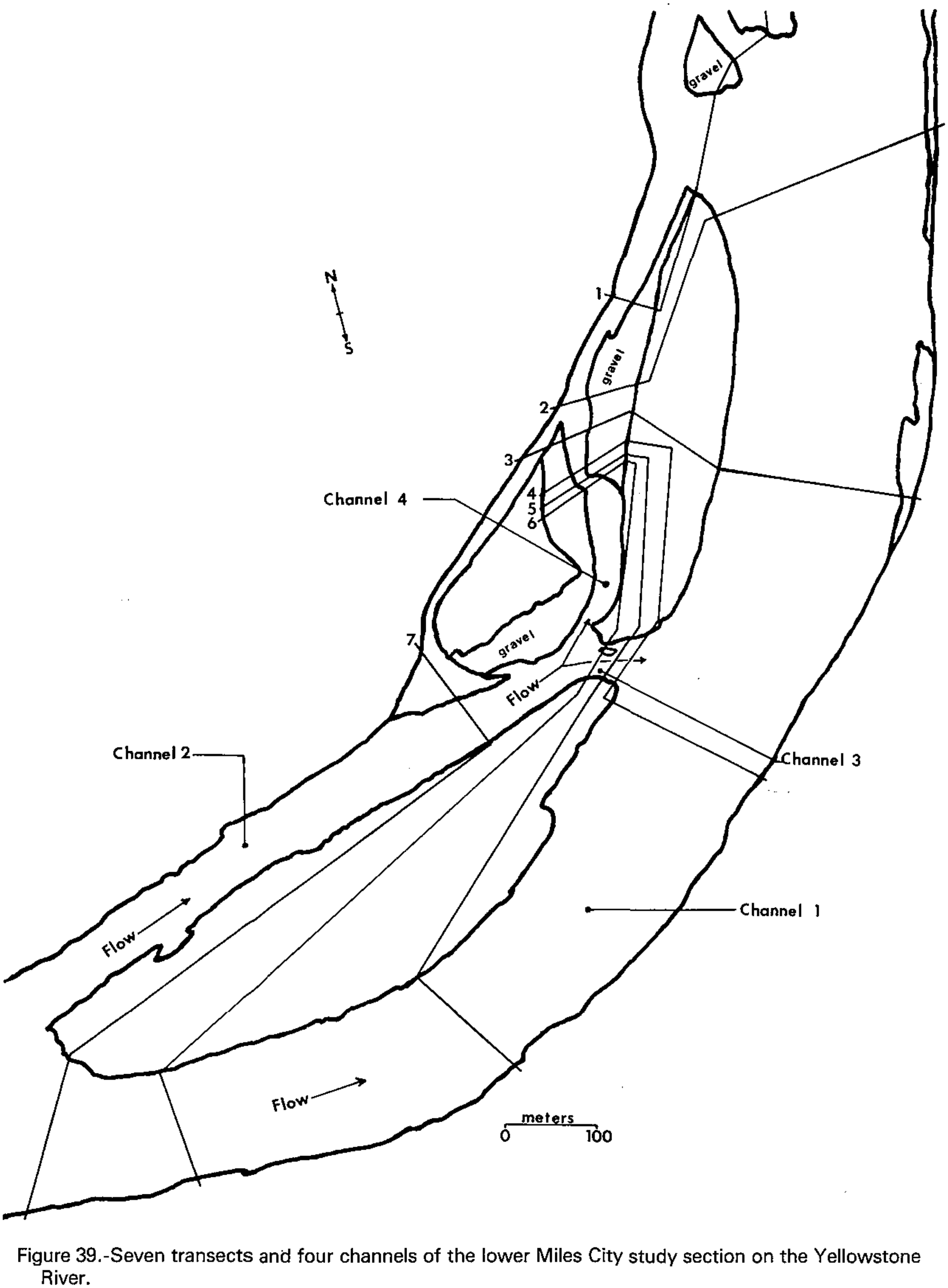


Figure 39.-Seven transects and four channels of the lower Miles City study section on the Yellowstone River.

Some of the predicted discharges down the side channels were excessive when compared to measured flows (table 8). At a total river discharge of 126.6 m³/s, a flow of 21.3 m³/s was predicted for side channel 3 (transect 5) while 0.6 m³/s was the actual discharge; these flows represented 16.8 and 3.7 percent of the total river discharge, respectively. Transect 6 also predicted larger than actual discharges.

The flow predicted at each transect varied greatly even though they were estimated for the same channel (table 8). The predicted flow for side channel 3 during a total river discharge of 249.9 m³/s varied from 19.2 to 118.9 m³/s; 8 to 47 percent of the total river discharge. Predicted flows down channel 4 ranged from 0.9 to 63.5 m³/s; 0.3 to 25 percent of the total discharge.

Predicted velocities at side channel cross-sectional segments were often excessive; again, indicative that the program was allocating too much water to the side channels. When 4.7 m³/s of water was flowing in channel 3, the maximum and mean velocity observed was 1.23 and 0.74 m/s, respectively. The corresponding mean velocity predicted in channel 3 at nearby transects ranged from 1.13 to 4.94 m/s. In channel 4, during a discharge of 0.6 m³/s, predicted mean velocities ranged from 0.00 to 6.62 m/s. At total discharges of 254.9 and 1274.3 m³/s, maximum predicted cross-sectional velocities in channel 4 (at transect 3) were 2.40 and 10.27 m/s, respectively (table 9).

The side channel discharges predicted by the WSP program were more realistic for transects 1, 2 and 7, which had only two channels in the cross

Table 8.-*Observed and predicted discharges (m³/s) for a braided section of the Yellowstone River near Miles City*

	Total river discharge	Channel 1		Channel 2		Channel 3		Channel 4		Total side channel discharge	
Observed	126.6	121.3	(95.8)*	5.3	(4.2)	4.7	(3.7)	0.6	(0.5)	5.3	(4.2)
Predicted	126.6										
	Transect 7	124.1	(98.0)	2.5	(2.0)	-				2.5	(2.0)
	6	108.5	(85.7)	-		14.3	(11.3)	3.8	(3.0)	18.1	(14.3)
	5	105.1	(83.0)	-		21.3	(16.8)	0.1	(0.0)	21.4	(16.9)
	4	123.6	(97.6)	-		2.7	(2.1)	.3	(.2)	3.0	(2.4)
	3	126.0	(99.5)	-		-		.6	(.5)	-	
	2	83.3	(65.8)	-		-		.0	(.0)	-	
	1	126.3	(99.8)	-		-		.3	(.2)	-	
Predicted	254.9										
	Transect 7	240.8	(94.5)	14.0	(5.5)	-				14.0	(5.5)
	6	130.4	(51.1)	-		60.9	(123.9)	63.5	(24.9)	123.5	(48.5)
	5	133.9	(52.5)	-		118.9	(46.7)	2.1	(0.8)	121.0	(47.5)
	4	221.3	(86.8)	-		19.2	(7.5)	14.3	(5.6)	33.5	(13.1)
	3	223.9	(87.9)	-		-		30.6	(12.1)	-	
	2	251.5	(98.7)	-		-		3.4	(1.3)	-	
	1	254.0	(99.7)	-		-		0.9	(0.3)	-	

* Parentheses indicate percentages of total river discharge.

Table 9.-*Observed and mean predicted velocities (m^3/s) in side channels of the Yellowstone River, lower Miles City study section*

	Channel		
	2	3	4
Total river discharge = 126.6 m^3/s			
Range of observed velocities	0.32 - 0.56	0.48 - 1.24	-
Range of predicted velocities			
Transect 7	0.25	-	-
Transect 6	-	1.51	2.02
5	-	0.97	0.09
4	-	0.34	0.12 - 0.25
3	-	-	.91
2	-	-	-
1	-	-	.20
Total river discharge = 254.9 m^3/s			
Range of predicted velocities			
Transect 7	0.46	-	-
6	-	2.15	0.82 - 2.55
5	-	1.65	.13 - 0.30
4	-	0.68	.50 - 0.53
3	-	-	.62 - 2.40
2	-	-	.29 - 0.44
1	-	-	0.63
Total river discharge = 1274.3 m^3/s			
Range of predicted velocities			
Transect 7	0.50 - 0.69	-	-
6	-	1.17	1.29 - 2.25
5	-	1.68	0.20 - 1.38
4	-	0.87	0.99 - 2.00
3	-	-	2.16 -10.27
2	-	-	1.10 - 1.79
1	-	-	1.23

sections (table 8). At a total river discharge of 254.9 m^3/s transect 3, which had two channels in the cross section, predicted a considerably larger side channel discharge (when compared to the other three transects) and erroneously high mean velocities (table 9).

Apparently, the WSP program could not determine from which upstream channel each side channel derived its water. Channels 3 and 4 derived all their water from channel 2; however, the program did not account for this because too much water was allocated channels 3 and 4 (transects 3 through 6, table 8). The WSP program appears to simply proportion discharge to each channel of a cross section without regard to what has happened to the water upstream. Perhaps this explains the more accurate predictions for cross sections across two versus three channels (transects 1, 2, 7). Transect 3, which bisected only two channels, did not fall into this pattern, because too large a flow was allocated to channel 4 (table 8). This error may have been the result of the data portraying an erroneously wide side channel. During surveying, flow in channel 4 was confined to the thalweg. The transect line, derived by finding identical water surface elevations on each side of the channel, was not the shortest point between the two banks, but extended up the channel at an angle. When predicting larger flows, the program probably misinterpreted the channel as being wider than it actually was, thus allocating too large a flow to this side channel. Transects 3, 4, 5, and 6 on channel 4 may have been influenced by this type of error, since these transect lines extended up the channel at an angle. Transects 1 and 2 for channel 4 and transects across channels 2 and 3 were generally perpendicular to both banks.

The WSP program was not designed to handle multiple channels, so its application on this type of channel should be used with caution. The program should be used only for a single, or at most, a simple divided channel, because predictions of hydraulic parameters appeared more accurate when not more than two channels were bisected by the transects. If water surface profiles are necessary for a split channel, each channel should be treated as a separate stream with WSP data gathered accordingly. It is then necessary to know the discharge in each channel of the braided stream during the time when water surface elevations are measured. To obtain accurate predictions in side channels, transects should be measured when side channel discharge is large enough to wet most of the channel.

To avoid time-consuming calculations, it is recommended that mean depth, an important habitat criterion, be included in the WSP printout for each segment of a cross section at the various discharges. The capability of dividing the cross section into more than nine segments should also be incorporated into the program to increase accuracy of locating specified physical criteria (such as velocity) within the channel of a large river.

In summary, WSP program predictions can be accurate and reliable if a few common errors are avoided. First, water surface elevations for all transects should be obtained during the same discharge. Surveying should occur during periods of stable flow (late summer or fall) in the lower Yellowstone River. If transects cannot all be surveyed on the same day, a set of water surface elevations should be obtained after profiles have been surveyed. Second, accuracy of WSP predictions over a wide range of flows can be increased by obtaining water surface elevations over the range of flows. Differences between observed water surface elevations and predicted water elevations at 4.25 times the flow ranged from 12 to 47 percent in the single channel section. When several more water surface elevations taken over a range of flows were included in the analysis, the differences between observed and predicted was from 2 to 10 percent. Three measurements, one at a high, low, and intermediate flow, are desirable. Predicting hydraulic parameters for discharges outside the range 0.4 to 2.5 times the discharge at the time of surveying may result in a significant loss of accuracy unless these extra water surface elevations are taken. And third, the WSP program should be used only for a single channel. If WSP information is desired for a split or braided channel, each channel should be treated as a separate stream and WSP data gathered accordingly.

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APPENDIXES

APPENDIX A

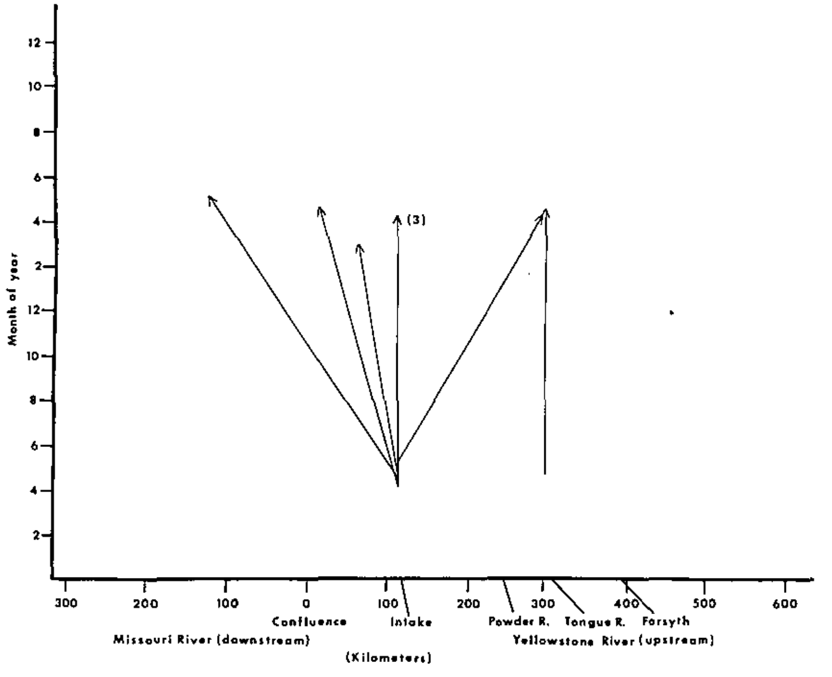

Figure A-1.-Movement of walleye tagged in the lower Yellowstone River, 1974-76, and recaptured in the Yellowstone or Missouri Rivers during the same season of the following calendar year.

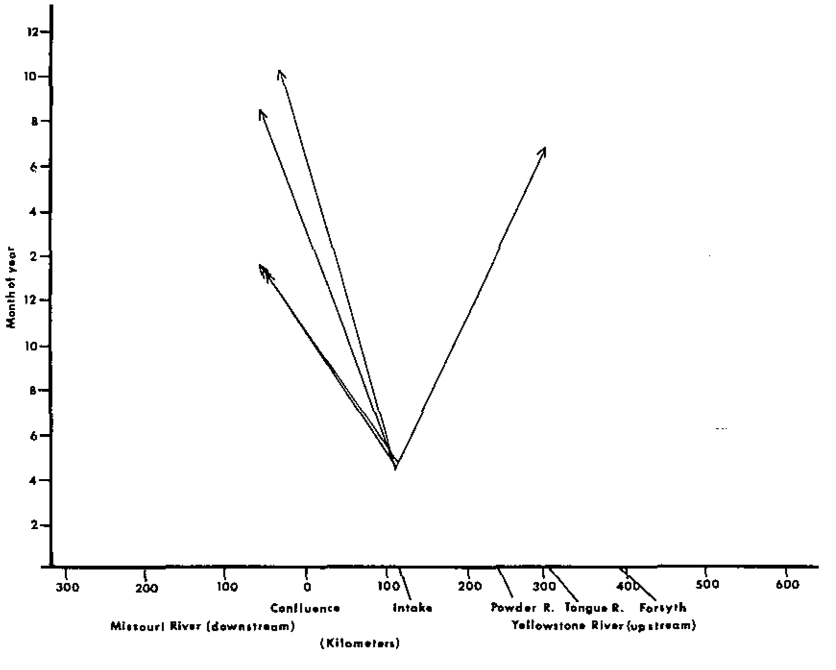

Figure A-2.-Movement of walleye tagged in the lower Yellowstone River, 1974-76, and recaptured in the Yellowstone or Missouri Rivers the following calendar year in a different season.

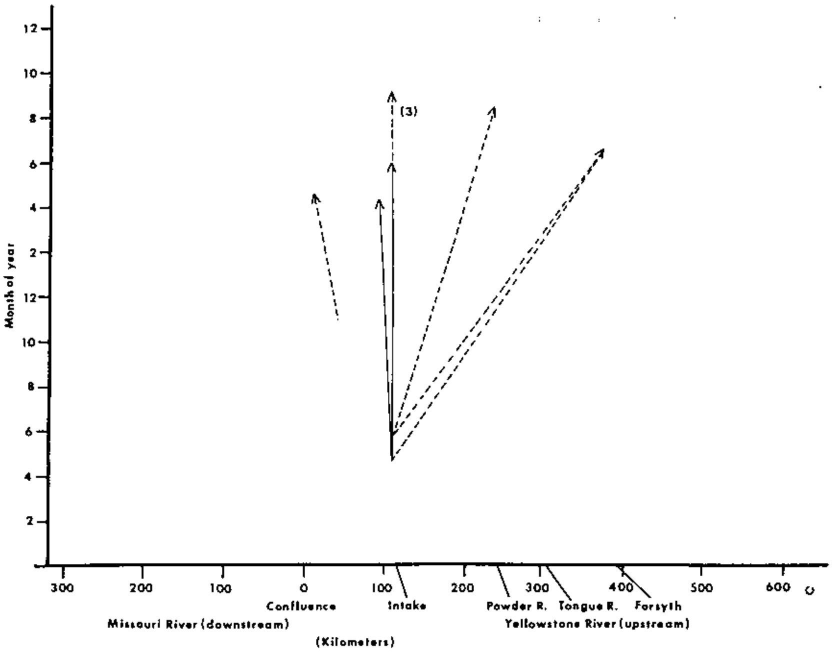

Figure A-3.-Movement of sauger tagged in the Yellowstone River downstream from Intake diversion, 1975-76, and recaptured in the Yellowstone or Missouri Rivers the following calendar year during the same season (——) and different seasons (----).

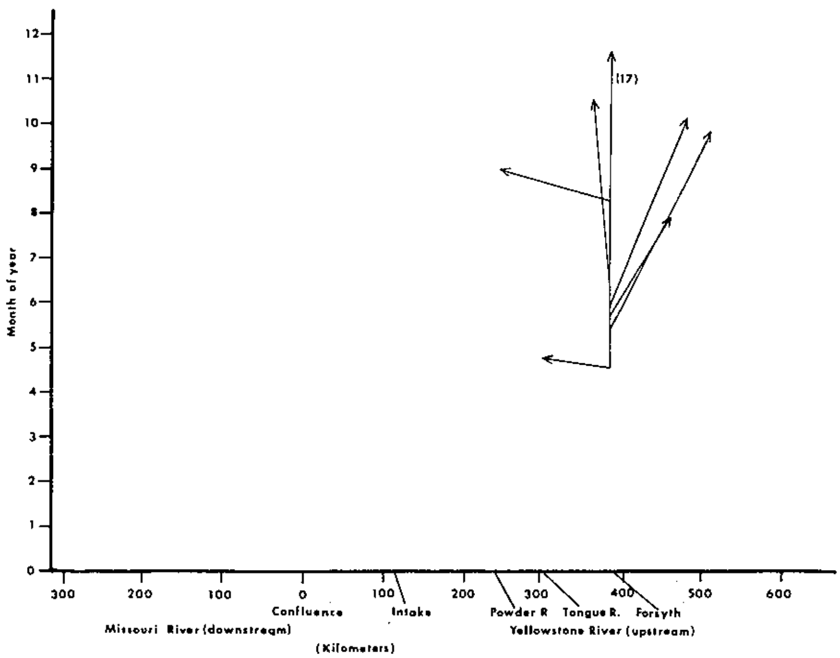

Figure A-4.-Movement of sauger tagged in the Yellowstone River downstream from Forsyth diversion, 1974-77, and recaptured in the Yellowstone River during the same calendar year.

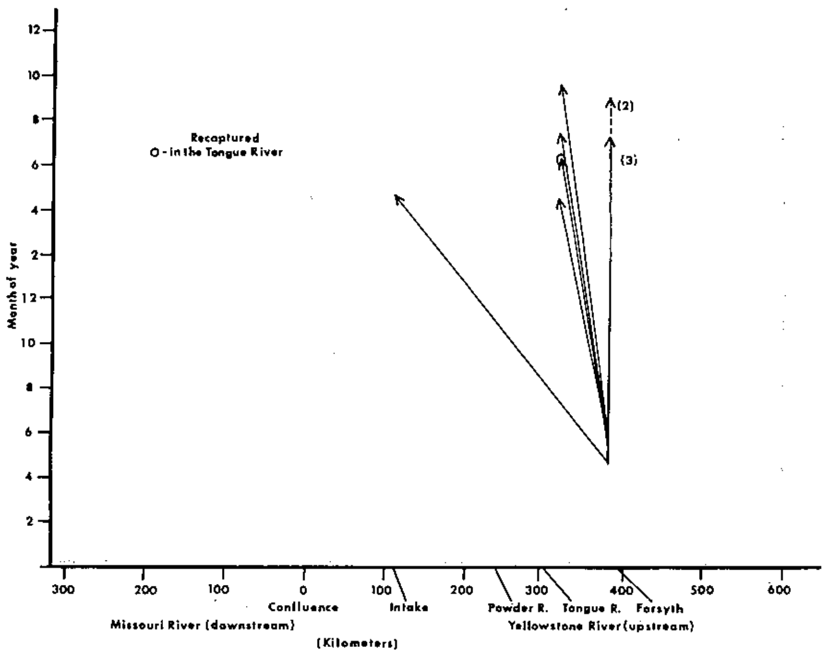

Figure A-5.-Movement of sauger tagged in the Yellowstone River downstream from Forsyth diversion, 1974-76, and recaptured in the Yellowstone or Tongue Rivers during the same (——) and different (----) seasons of the following calendar year.

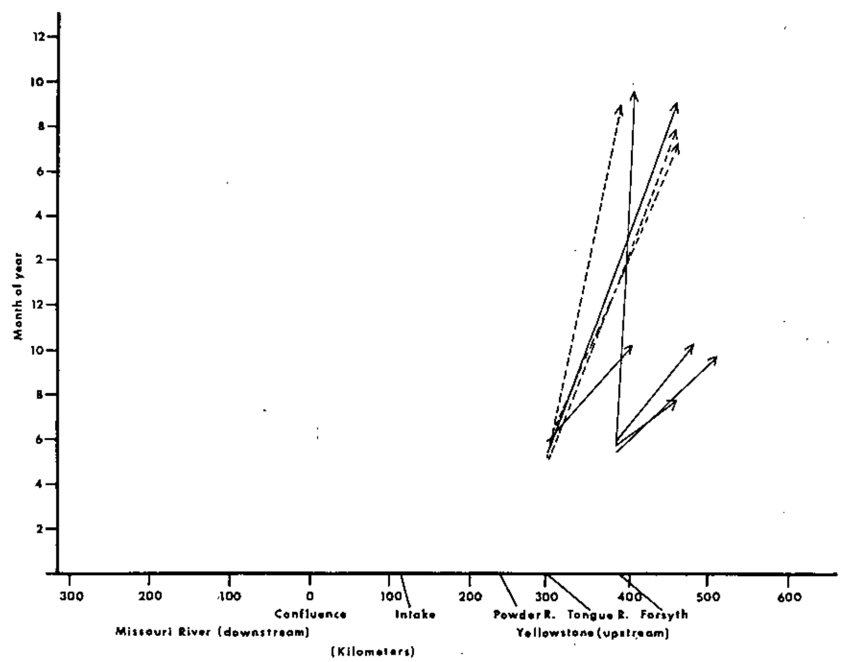

Figure A-6.-Fish tagged in the Yellowstone River (——) and Tongue River (----), 1974-77, and recaptured upstream from Forsyth diversion during the same or a consecutive calendar year.

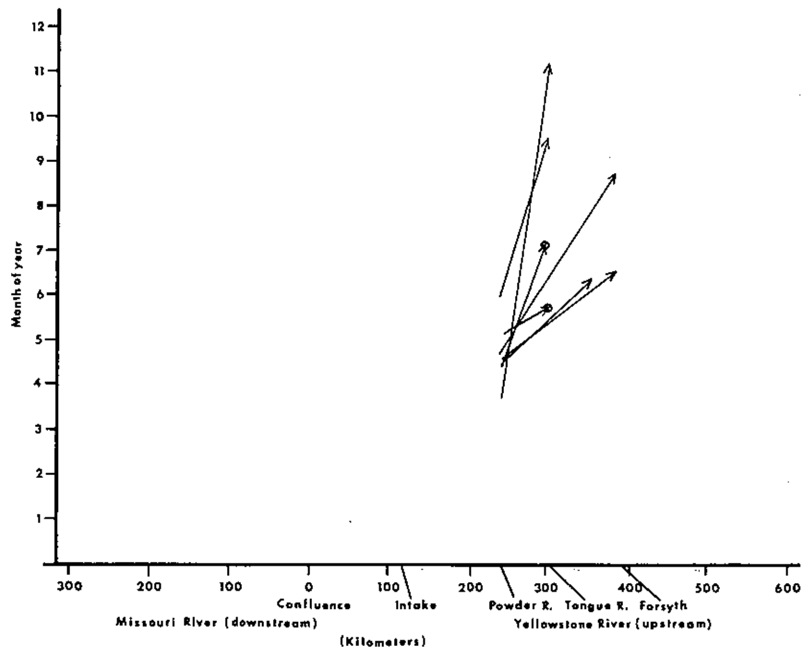

Figure A-7.-Movement of sauger tagged in the Powder River in 1976 and 1977 and recaptured in the Yellowstone and Tongue Rivers during the same calendar year.

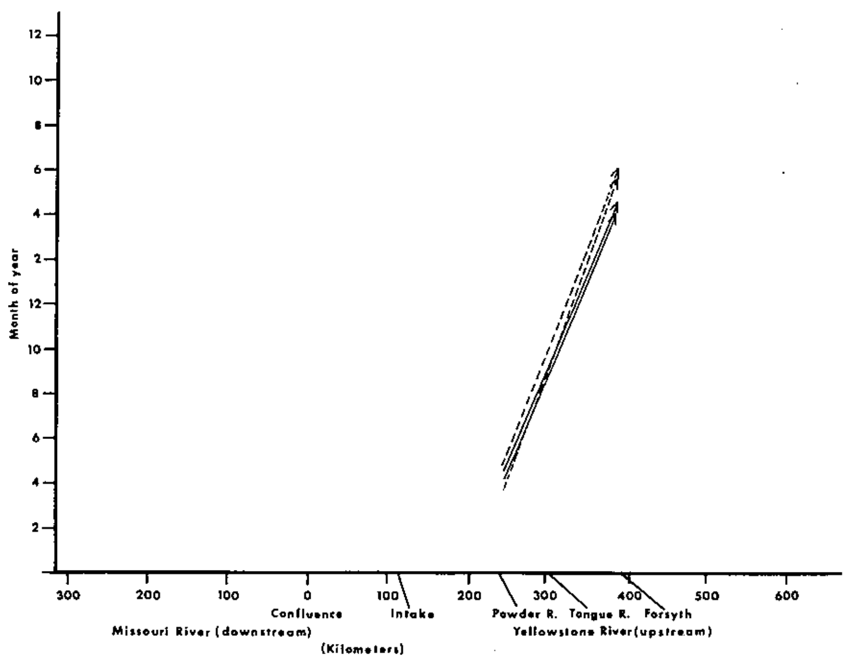

Figure A-8.-Movement of sauger tagged in the Powder River in 1976 and recaptured in the Yellowstone River during the same (——) and different (——) seasons in 1977.

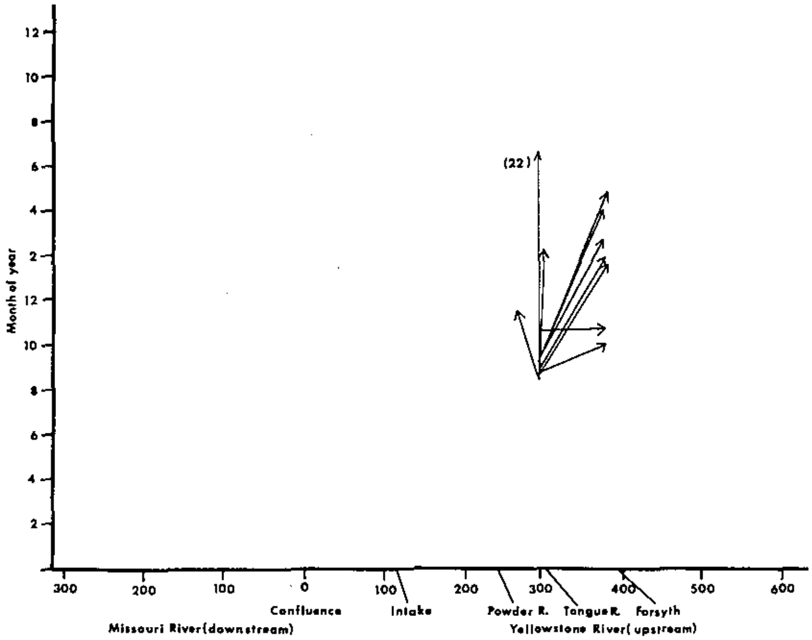

Figure A-9.-Movement of sauger tagged in the lower Tongue River, 1975-77, and recaptured in the Yellowstone River during the same calendar year.

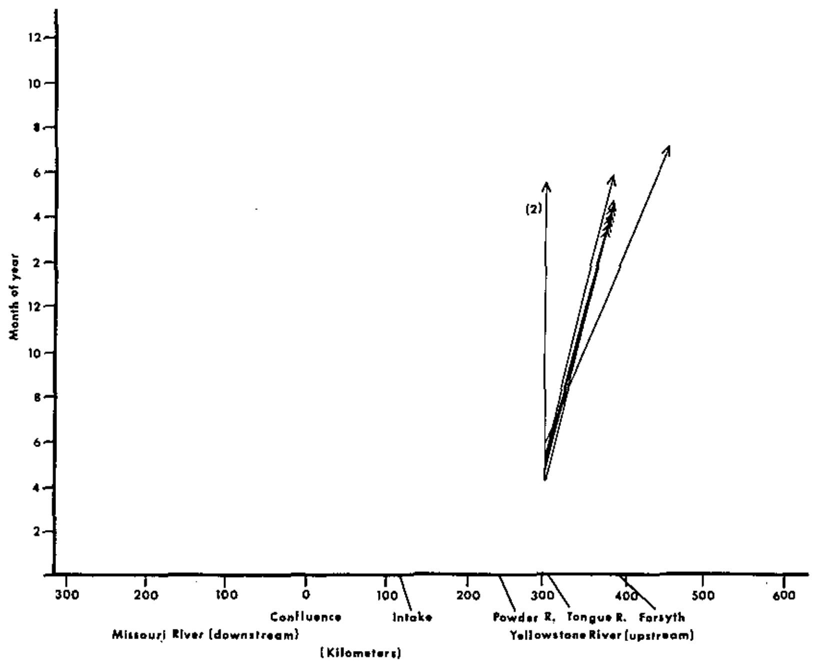

Figure A-10.-Movement of sauger tagged in the lower Tongue River in 1975 and 1976 and recaptured in the Yellowstone River during the same season of the following calendar year.

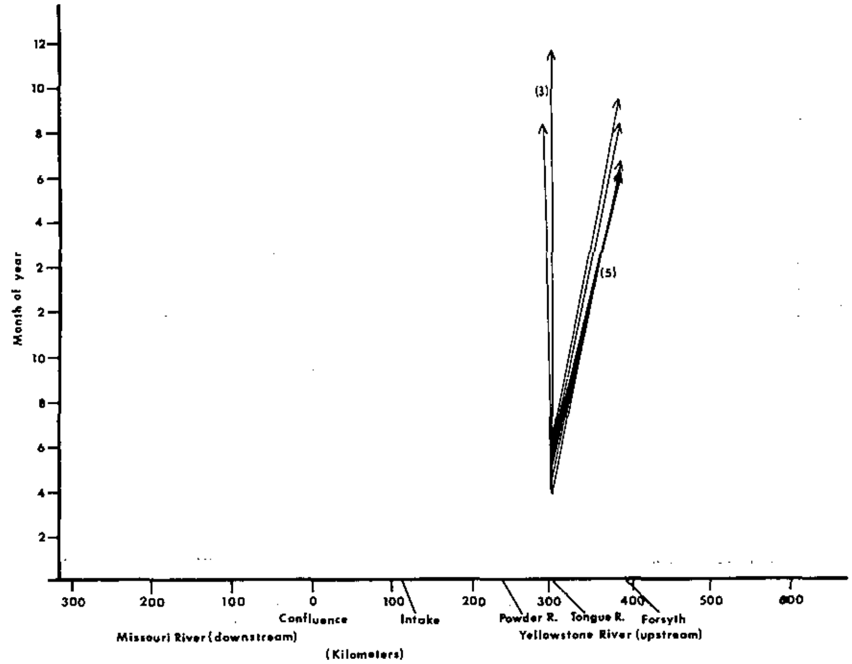

Figure A-11.-Movement of sauger tagged in the lower Tongue River in 1975 and 1976 and recaptured in the Yellowstone River during different seasons of the following calendar year.

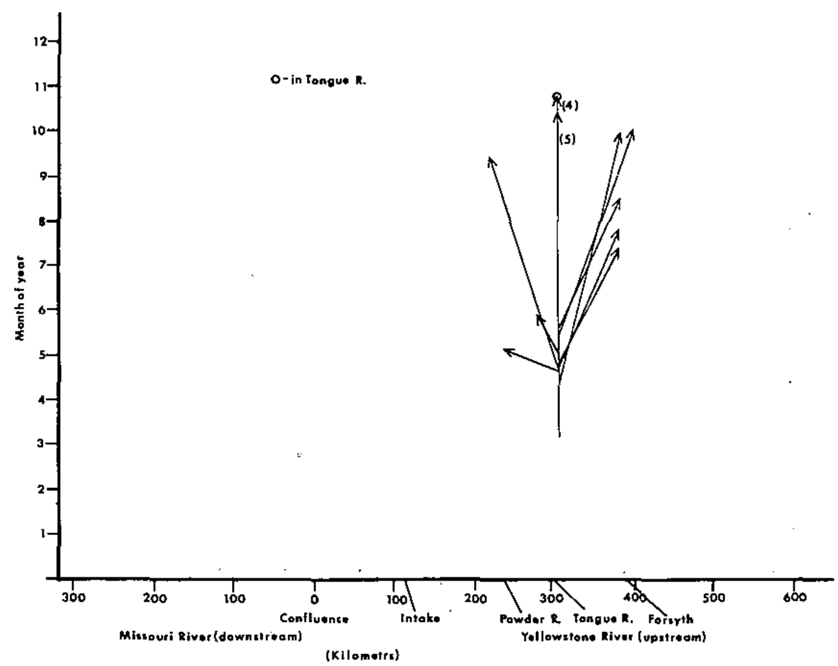

Figure A-12.-Movement of sauger tagged in the Yellowstone River near Miles City, 1974-77, and recaptured in the Yellowstone or Tongue Rivers during the same calendar year.

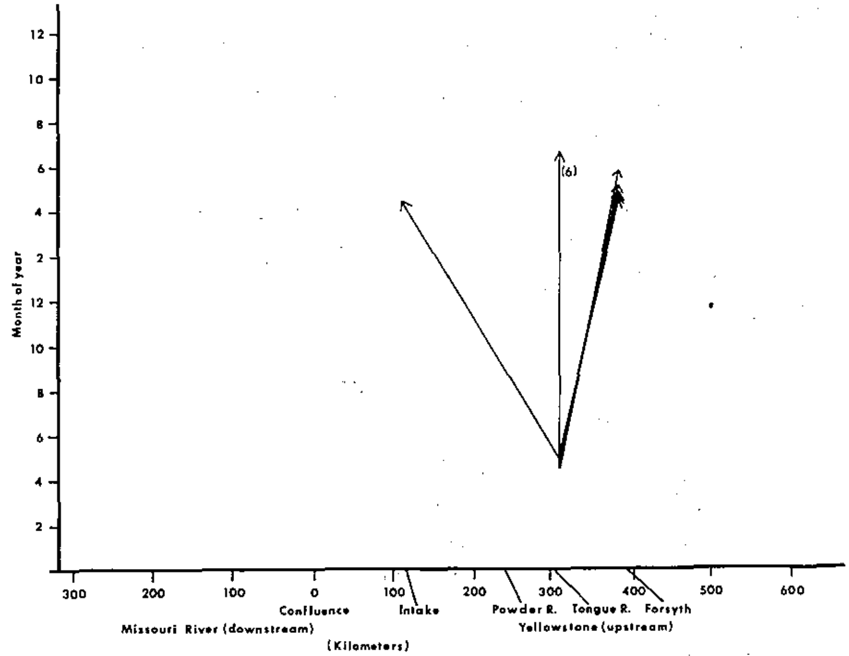

Figure A-13.-Movement of sauger tagged in the Yellowstone River near Miles City, 1974-76, and recaptured in the Yellowstone River during the same season of the following calendar year.

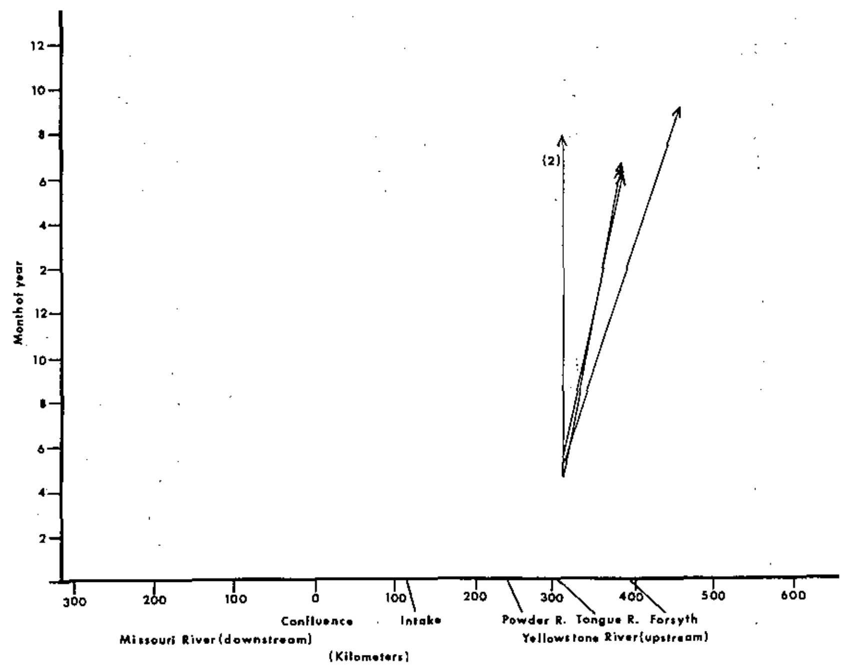

Figure A-14.-Movement of sauger tagged in the Yellowstone River near Miles City, 1974-76, and recaptured in the Yellowstone River during different seasons of the following calendar year.

Table A-1.-*Total length versus anterior scale radius and mass versus total length regressions for sauger collected in three areas of the Yellowstone River in the spring (S) and late summer to early autumn (A)*

	Total length versus anterior scale radius					
	Linear		Curvelinear			
Area	Regression	r	Regression	r	n
Lower (S)	$L = 43.6 + 0.690\ S$	0.83	$L = 5.69 \times S^{0.82}$	0.83	479
Lower (A)	$L = 16.1 + .776\ S$	.88	$L = 4.07 \times S^{.89}$	.89	296
Middle (A)	$L = 73.5 + .629\ S$	.79	$L = 7.22 \times S^{.77}$	.81	283
Upper (A)	$L = 40.3 + .667\ S$	.82	$L = 4.48 \times S^{.87}$	.84	280
Combined (A)	$L = 40.5 + .701\ S$	.84	$L = 4.79 \times S^{.86}$	.86	859

	Mass versus total length		
Area	Regression	r	n
Lower (S)	$\log W = -5.634 + 3.199 \log L$	0.97	479
Lower (A)	$\log W = -5.154 + 3.016 \log L$	.98	296
Middle (A)	$\log W = -5.112 + 3.008 \log L$	.98	283
Upper (A)	$\log W = -5.249 + 3.064 \log L$	.97	280
Combined (A)	$\log W = -5.247 + 3.059 \log L$	.98	859

L = Total length (mm)
S = Anterior median scale radius (mm) × 66
W = Mass (g)

Table A-2.-*Number of combined sauger and walleye eggs, depth, velocity, substrate and date sampled at four transect locations on a gravel bar downstream from Intake diversion in the lower Yellowstone River, sampled on April 18, 21, and 24, and May 2 and 6, 1977*

Transect (Date)	Depth (meters)	Velocity (m/s)	Number of eggs	Substrate
1	0.30	0.36	0	Sand-cobble
(4/18)	.46	.47	0	Sand-cobble
	.61	.54	0	Compacted cobble
	.76	.56	0	Compacted cobble
	.91	.62	0	Gravel, cobble
2	0.30	0.43	0	Sand-pebble
(4/18)	.46	.47	0	Sand-pebble
	.61	.54	0	Compacted pebble
	.76	.69	0	Pebble
	.91	.80	21	Pebble-cobble
3	0.30	0.47	0	Pebble-cobble
(4/18)	.46	.36	0	Compacted cobble
	.61	.69	0	Compacted cobble
	.76	.80	21	Pebble-cobble
	.91	.82	10	Pebble-cobble
4	0.30	0.73	0	Cobble-pebble
(4/18)	.30	.67	3	Cobble-pebble
	.46	.84	15	Cobble
	.61	.91	8	Pebble-cobble
	.76	.94	17	Pebble-cobble
	.91	1.06	3	Pebble-cobble

Table A-2.-*Number of combined sauger and walleye eggs, depth, velocity, substrate and date sampled at four transect locations on a gravel bar downstream from Intake diversion in the lower Yellowstone River, sampled on April 18, 21, and 24, and May 2 and 6, 1977—Continued*

Transect (Date)	Depth (meters)	Velocity (m/s)	Number of eggs	Substrate
1	0.30	0.36	0	Sand-cobble
(4/21)	.46	.49	0	Sand-cobble
	.61	.50	0	Compacted cobble
	.76	.57	0	Compacted cobble
	.91	.61	0	Pebble-cobble
2	0.30	0.38	0	Sand-pebble
(4/21)	.46	.48	0	Sand-pebble
	.61	.54	0	Compacted pebble
	.76	.79	25	Pebble
	.91	.87	20	Pebble-cobble
3	0.30	0.45	0	Pebble-cobble
(4/21)	.46	.54	0	Compacted cobble
	.61	.67	0	Compacted cobble
	.76	.76	3	Pebble-cobble
	.91	.84	14	Pebble-cobble
4	0.30	0.78	0	Cobble-pebble
(4/21)	.30	.71	3	Cobble-pebble
	.46	.81	10	Cobble
	.61	.92	7	Pebble-cobble
	.76	.98	5	Pebble-cobble
	.91	1.00	5	Pebble-cobble
2	0.30	0.41	0	Sand-cobble
(4/24)	.46	.44	0	Sand-cobble
	.61	.66	1	Semicompacted cobble
	.76	.78	3	Cobble-pebble
	.91	.83	6	Cobble-pebble
3	0.30	0.41	0	Compacted cobble-pebble
(4/24)	.46	.59	0	Compacted cobble-pebble
	.61	.72	0	Compacted cobble-pebble
	.76	.78	3	Cobble-pebble
	.91	.89	3	Cobble-pebble
4	0.30	0.68	0	Pebble-cobble
(4/24)	.30	.68	4	Semicompacted pebble-cobble
	.46	.73	3	Semicompacted pebble-cobble
	.61	.81	14	Pebble-cobble
	.76	.91	6	Pebble-cobble
	.91	.95	0	Compacted cobble-pebble

Table A-2.-*Number of combined sauger and walleye eggs, depth, velocity, substrate and date sampled at four transect locations on a gravel bar downstream from Intake diversion in the lower Yellowstone River, sampled on April 18, 21, and 24, and May 2 and 6, 1977—Continued*

Transect (Date)	Depth (meters)	Velocity (m/s)	Number of eggs	Substrate
4	0.30	0.76	0	-
(5/2)	.30	.66	0	-
	.46	.84	0	-
	.61	.98	0	-
	.76	1.00	0	-
	.91	1.06	0	-
3	0.30	0.48	0	Pebble
(5/6)	.46	.58	0	Compacted cobble-pebble
	.61	.67	0	Compacted cobble
	.76	.76	0	Compacted cobble
	.91	.89	0	Compacted cobble
4	0.30	0.78	0	Pebble-silt
(5/6)	.30	.73	0	Compacted pebble
	.46	.67	0	Semicompacted cobble-pebble
	.61	.98	0	Cobble-pebble
	.76	1.04	0	Semicompacted cobble-pebble
	.91	1.11	0	Cobble-pebble

Table A-3.-*Number of combined sauger and walleye eggs, depth, velocity, and substrate at eight transects in the lower Yellowstone River, sampled on April 24 and 29, 1977*

Transect (river kilometer)	Depth (meters)	Velocity (m/s)	Number of eggs	Substrate
5	0.30	0.23	0	Compacted cobble
(109.9)	.61	.23	0	Compacted cobble
	.91	-	0	Compacted cobble
6	0.30	0.32	0	Semicompacted cobble
(109.6)	.61	.41	0	Compacted cobble
	.91	.47	1	Cobble
7	0.30	0.35	0	Cobble-pebble
(105.7)	.61	.43	0	Cobble-pebble
	.91	.49	0	Cobble
8	0.30	0.32	0	Cobble-pebble
(104.9)	.61	.48	0	Cobble-pebble
	.91	.56	0	Cobble

Table A-3.-*Number of combined sauger and walleye eggs, depth, velocity, and substrate at eight transects in the lower Yellowstone River, sampled on April 24 and 29, 1977—Continued*

Transect (river kilometer)	Depth (meters)	Velocity (m/s)	Number of eggs	Substrate
9	0.30	0.82	0	Pebble-cobble
(100.2)	.61	1.17	0	Pebble-cobble
	.91	1.19	0	Cobble
10	0.30	0.35	0	Semicompacted pebble
(99.4)	.61	.52	0	Pebble
	.91	.67	0	Pebble
11	0.30	0.46	0	Compacted pebble-cobble
(89.8)	.61	.57	0	Compacted pebble-cobble
	.91	.71	0	Compacted pebble-cobble
12	0.30	0.82	0	Pebble-cobble
(89.5)	.61	1.15	0	Pebble-cobble
	.91	-	0	Pebble-cobble

APPENDIX B

ELECTROFISHING LARGE RIVERS - THE YELLOWSTONE EXPERIENCE

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Presented at:

The Electrofishing Workshop
St. Paul, Minnesota
March 9 and 10, 1978

INTRODUCTION

There is presently in the fisheries literature a scarcity of published documents or available information concerning fish populations or the life history of fish inhabiting large, fast-flowing rivers. The relative dearth of biological data from large rivers can probably be attributed to: (1) The difficulty of capturing the wide variety of fish species commonly found in large rivers, (2) the problem of sampling a large enough portion of any one fish population to obtain reliable data, and (3) sampling all of the habitat types of a large river. It is generally possible, using a variety of techniques, to capture a few individuals of most species found in even the larger rivers. The major problem is sampling a large enough segment of a particular fish population to obtain reliable estimates of certain population parameters such as population numbers, biomass, year-class strength, relative abundance among species or even an index of a single species. In addition, reliability of certain types of data demands either random sampling of the population or random sampling of the different habitat types. While certain assumptions inherent in the reliability of data collected on small streams and rivers are routinely and easily met, these same assumptions can be major stumbling blocks on large rivers.

Since 1974, Montana has been forced into intensive biological sampling of the large and free-flowing Yellowstone River. The primary need for research on the lower Yellowstone River came not from the river's uniqueness, not from its species composition, nor its populations of "rare" fishes, but from the fact that it flows through the western coal reserves known as the Fort Union Coal Formation. The Fort Union Coal Formation is of critical importance to the nation's long-range energy plan as an intermediate energy source. The Yellowstone River is expected to supply much of the water for the energy conversion facilities. Direct, large-scale industrial water withdrawals, interbasin transfer of Yellowstone River water, and the impending construction of a 2100-MW coal-fired generating complex at Colstrip, Montana, prompted the initial research efforts in 1974. Biological data had to be obtained for adequate impact analysis and mitigation and development of an instream flow request to protect the aquatic resource.

Prior to 1973, with the exception of paddlefish harvest information, lower Yellowstone River fish populations were relatively unstudied. The first task in this endeavor was simply to develop new sampling equipment and techniques or adapt those already in existence to the particular conditions found on the lower Yellowstone. It became readily apparent, after initial attempts with various sampling methods, that electrofishing offered one of the best possibilities as a major sampling tool. Sampling with gill nets, seines, trammel nets, and trap nets was extremely difficult, and at times hazardous, due to the relatively high flow rate, numerous bottom obstructions, and frequent debris conditions. Consequently, a major effort was directed toward construction of an electrofishing boat that was both effective in sampling the major fish populations found in the lower Yellowstone River and which incorporated adequate safety features for crew safety during the electrofishing operations.

It is difficult to address the subject of sampling large rivers in a general sense due to the great physical and biological variability of rivers on a national or even regional scale. While the Yellowstone can certainly be considered a large river in terms of problems associated with electrofishing and fish sampling, it is not in the same category as the lower Missouri or Mississippi Rivers. The following is a discussion of some of the problems faced on the lower Yellowstone, the solutions or partial solutions to those problems, the effectiveness of the electrofishing equipment used, and some possible direction for future development.

Although the comments pertain principally to the lower Yellowstone and upper Missouri Rivers, some of the information presented may be of use to others faced with the often frustrating task of sampling large, fast-flowing rivers.

The Yellowstone River is free-flowing over its entire length, making it unique among the large rivers of the continental United States. The Yellowstone River originates in the northwest corner of Wyoming and flows northeasterly through Montana before joining the Missouri River near Cartwright, North Dakota. It has a total drainage area of approximately 1.82 X 10^7 ha (70 400 mi^2) and is 1090 km (678 mi) long, 885 km (550 mi) of which are in Montana.

The Yellowstone can be divided into three general zones related to fish distribution. From its headwaters in Wyoming to its mouth in North Dakota, the river changes from an alpine, salmonid fishery to a diverse, warm-water ecosystem. The river contains a 357-km (222-mi) cold-water zone (headwaters to Big Timber), a 257-km (160-mi) transition zone (Big Timber to Bighorn River), and a 476-km (296-mi) warm-water zone (Bighorn River to confluence with Missouri River). All the experimental design testing was conducted on the warm-water portion of the Yellowstone River. However, the basic design has also been used on the Missouri River as well as the smaller Tongue, Powder, Poplar, and Marias Rivers in Montana.

PROBLEMS OF LARGE RIVER ELECTROFISHING

Of the many variables influencing the effectiveness of large river electrofishing, the physical features of size, depth, water velocity, and turbidity probably encompass the major problems to be overcome. The range of conductivity commonly experienced in the Yellowstone River was not a major deterrent to sampling. However, in some drainages, conductivity (either high or low) can definitely be a limiting factor.

Size

Obviously, a major hindrance to sampling large rivers is physical size. As rivers increase in size (and usually in depth), more areas become available to fish both as habitat and for security. As rivers increase in size, the easily sampled areas decrease in proportion to the total water surface. For example, undercut banks (which are easily sampled) may be the major habitat component on smaller streams, but become relatively less important or completely absent in relation to the total surface area in large rivers.

In addition, as rivers increase in size, the effective area sampled by the electrofishing boat in relation to total surface area becomes smaller and more effort per river mile is needed. Multiple sampling runs are common on sections of large rivers as are left bank, right bank, and midstream sampling locations. As rivers increase in size, electrofishing efficiency (ability to capture a given percentage of the population) decreases, while population numbers and biomass per river mile generally increase.

The physical size of large rivers decreases the reliability of certain types of data by decreasing sampling efficiency and limiting the areas of river that can be readily sampled. Proper electrofishing boat design and component selection can, at least partially, overcome some of these problems.

Depth

Deep water conditions obviously limit the effectiveness of electrofishing boats. In large, fast-flowing rivers, deep pools and deep runs often harbor a large segment of the fish population that are untouched by most sampling methods. The inability to sample deep areas of rivers probably adds more bias to most types of data analysis than any other single factor.

Flow Velocity

Flow velocities greater than 1.5 m/s (5 ft/s) can adversely affect electrofishing effectiveness of large rivers as well as increase the hazards associated with river work. Flows are principally a function of river gradient and discharge and will increase with increasing flow or with an increase in gradient caused by channel alterations which result in an overall shortening of a given section of river.

Excessive flows adversely affect electrofishing efficiency by reducing the effective response area around the electrodes and the depth from which the fish can respond. In relatively high flows, unless a fish is well within the electrical field, the boat may float past the fish before it can be drawn close enough to be netted. Netting is also less effective at high flows.

Turbidity

While slightly turbid water conditions may actually increase sampling efficiency in some areas of large rivers (shallow water areas less than 0.9 m (3 ft) deep), excessive turbidities severely limit the effectiveness of electrofishing by limiting the depths into which netters can see and consequently net fish. Turbid water conditions will generally have a greater effect on sampling efficiencies in water 0.9 m (3 ft) or more in depth than in shallower areas.

Description of the River

A brief description of the lower Yellowstone River itself is necessary to obtain the proper perspective on the sampling problems encountered on this river in relation to those encountered on other rivers. The Yellowstone is a free-flowing river and has a flow regime and channel characteristics quite unlike that of most regulated river systems. It has a mean flow of approximately 368 m^3/s (13 000 ft^3/s) and discharges 1.08 X 10^{10} m^3 (8.8 M acre-ft) of water annually into the Missouri River. The flow regime is characterized by an annual spring flood which occurs during May, June, and July, with the highest flows commonly occurring in June. A low water period normally occurs from late August through February. In most years, there is an 8- to 10-fold increase from the normal range of flows 113 to 283 m^3/s (4000 to 10 000 ft^3/s) to the normal range of high flows 1133 to 2832 m^3/s (40 000 to 100 000 ft^3/s). Along with the change in flows is a concurrent change in those parameters directly related to flow, such as water depth, water velocity, water width, cross-sectional (conveyance) area, conductivity, and, to some degree, turbidity.

At low flows, riffle areas range from 0.3 to 1.2 m (1 to 4 ft) in depth, while pools vary from 2.4 to 4.6 m (8 to 15 ft) deep. During spring high flow conditions, pools may increase their depth by 1.5 to 2.7 m (5 to 9 ft), depending on channel configuration and flow levels. During summer low flow conditions, water widths vary from 213 to 305 m (700 to 1000 ft). Channel width varies from 274 to 366 m (900 to 1200 ft) except in braided sections where total channel width is significantly greater.

Water velocities are generally a function of gradient and discharge. The average river gradient for the lower Yellowstone is 0.000 53 (2.8 ft/mi). Gradients for individual sections within this area vary from 0.000 18 to 0.001 08 (1.0 to 5.7 ft/mi). Average water velocity for a cross section of the Yellowstone at Miles City (river mile 185.0) varies from 0.76 m/s (2.5 ft/s) at 142 m^3/s (5000 ft^3/s) to over 2.1 m/s (7.0 ft/s) at 1700 m^3/s (60 000 ft^3/s) (fig. B-1). Average velocity may reach 2.7 to 3.0 m/s (9 to 10 ft/s) during uncommonly high spring flows.

Conductivity varies seasonally in the lower Yellowstone. Lowest conductivity occurs during spring runoff and highest conductivity from December through April. Conductivity during spring runoff may vary from 240 to 500 μS (μmhos) while December through April conductivity may range from 600 to 1150 μS (USGS [5].

Turbidity also increases during spring runoff; however, heavy precipitation during the low period may also result in short-term increases in turbidity. During spring runoff conditions, suspended sediment concentrations of 500 to 3500 mg/L (p/m) limit visibility from 0 to 150 mm (0 to 6 in). Visibility increases to nearly 1.2 m (4 ft) during late summer and fall low flow conditions.

AN ELECTROFISHING BOAT FOR THE LOWER YELLOWSTONE RIVER

There are two basic types of electrofishing: a.c. (alternating current) and d.c. (direct current). An a-c system simply stuns and immobilizes the fish with little attraction of the fish to the electrodes (electrotetanus). A d-c or pulsed d-c system causes a fish to exhibit a forced swimming response toward the positive electrode (electrotaxis).

It became readily apparent after initial sampling efforts that a d-c or pulsed d-c system would be essential for successful electrofishing on the lower Yellowstone. The major problems to overcome are water depths, velocities, and occasionally high turbidities. The fish must be pulled up from the pools and held in the current long enough to be netted. During highly turbid conditions, fish often have to break the surface to be seen and netted.

The attractive force of d.c. far outweighs the disadvantages of the smaller electrical field. A good compromise between the attractive force and size of electrical field is obtained with pulsed d.c. (Novotony and Priegel [11]). After field testing a number of different boat and electrode designs, the electrofishing boat described below was, by far, the most successful combination (fig. B-2). The positive and negative electrode designs largely follow those described by Novotony and Priegel and appear to have fairly universal application. Specific boats selected for certain types of rivers may, however, exhibit less adaptability to varying conditions.

Power Source and Rectifying Unit

The electrical power source for the electrofishing system is a 4500-W, 230-V (60-Hz, 1-Φ) a-c generator. When electrofishing without lights, a 3500-W generator is adequate. A Coffelt Model VVP-10 rectifying unit is used to change the a-c to pulsed or continuous d-c output, or to regulate the a-c output. Output from the rectifying unit is selectable from 0 to 300 V and corresponding amperages from 0 to 25 are monitored. Pulse frequency is adjustable from 20 to 200 pulses per second and pulse width can be varied from 20 to 80 percent. Meters monitor d-c and a-c output voltage and amperage,

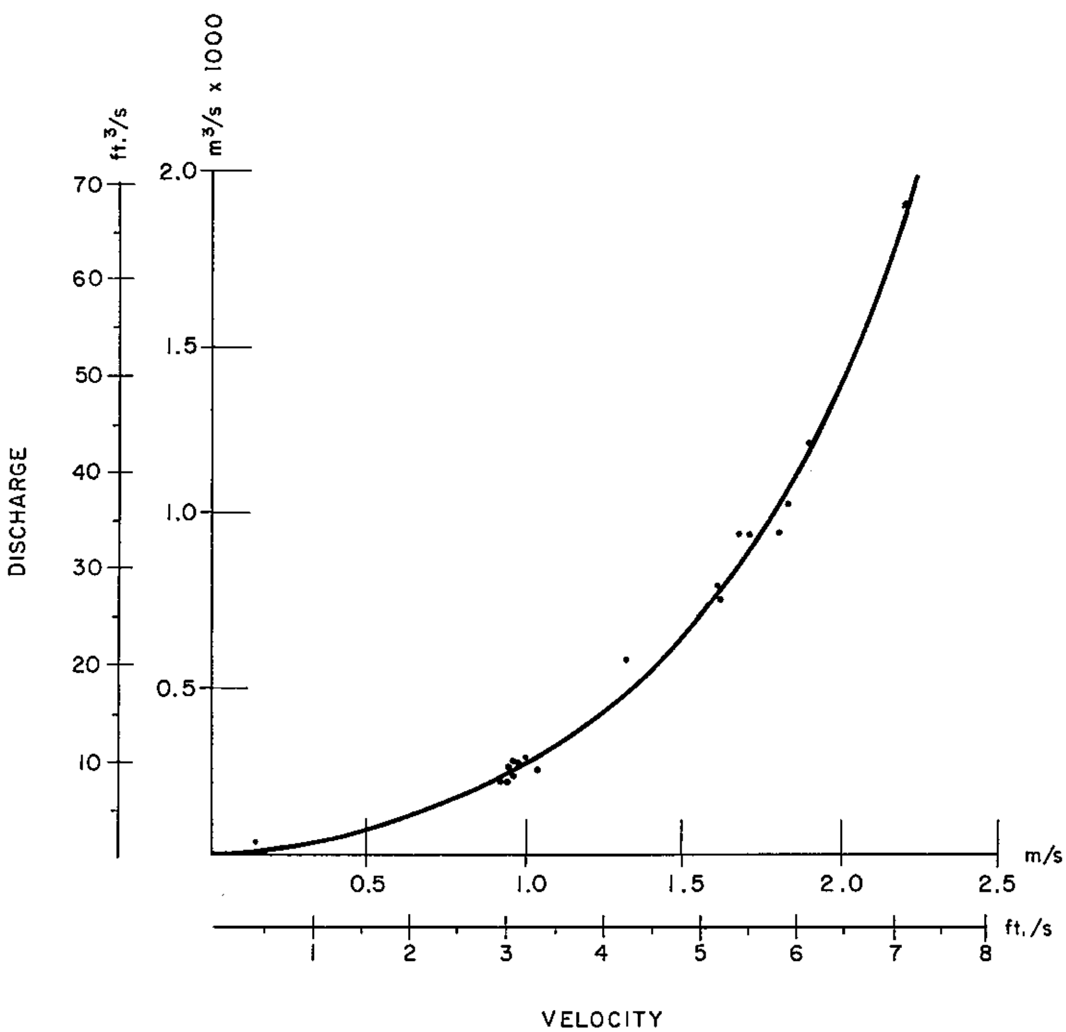

Figure B-1.-Curve illustrating the average water velocity for a cross section of the Yellowstone River at Miles City at a given flow.

percent of pulse width, and frequency (pulses per second). In addition, the voltmeter may be switched to monitor generator output.

Electrode Design

The electrode system of the boat consists of positive (anode) and negative (cathode) arrays and was designed primarily for operating in the d-c mode; however, this electrode system is also adequate for operation with a.c. Although construction details may differ, the design of the positive dropper electrode assemblies (fig. B-3) and the negative electrode arrays (fig. B-4) follow closely that developed and described in detail by Novotony and Priegel [11]. The spherical electrodes described below were designed principally for the Yellowstone River (fig. B-5). Principal design features of the anode and cathode arrays are briefly described below.

Anode array — The positive electrode system consists of two anodes suspended from fiberglass booms approximately 1.8 m (6 ft) in front of the bow of the boat (fig. B-3). The booms are spaced 2 m (7 ft) apart and are adjusted for height by means of pin-locked adjustments. Each anode consists of either (1) a spherical electrode, 380 mm (15 in) in diameter, constructed from 9.5-mm (3/8-in) diameter copper tubing, or (2) an array of 12 to 15 "dropper" electrodes clipped to a 0.9-m (3-ft) diameter aluminum support ring. The support

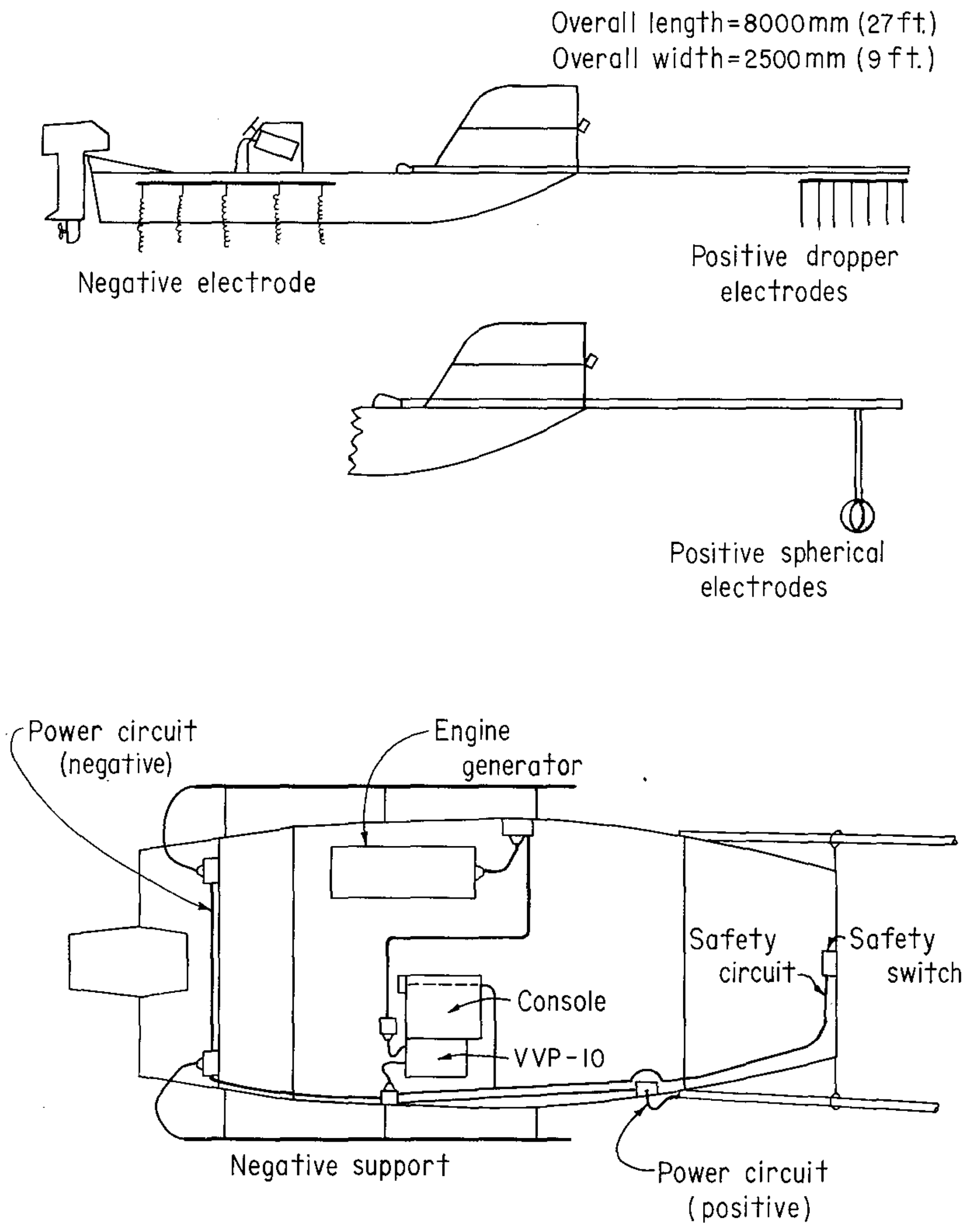

Figure B-2.-Major component location and electrode configuration.

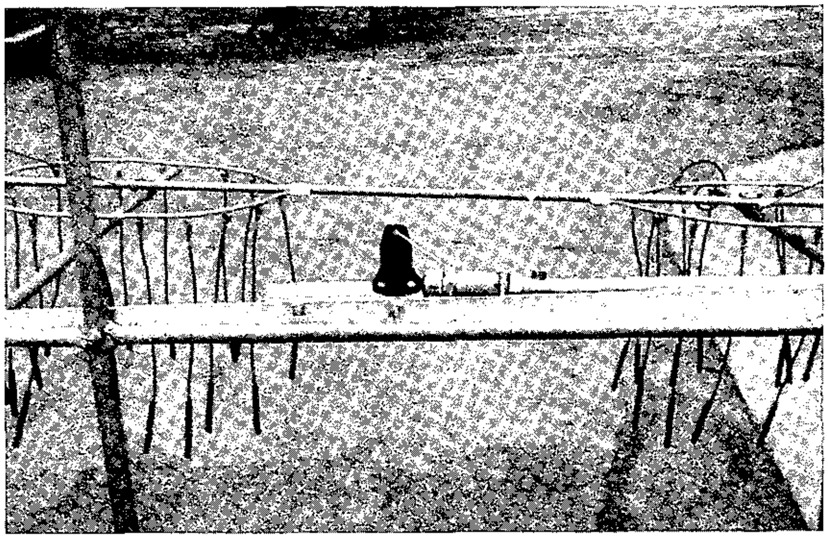

Figure B-3.-Positive dropper electrodes and safety switch for netter. Photo P1279-D-79206

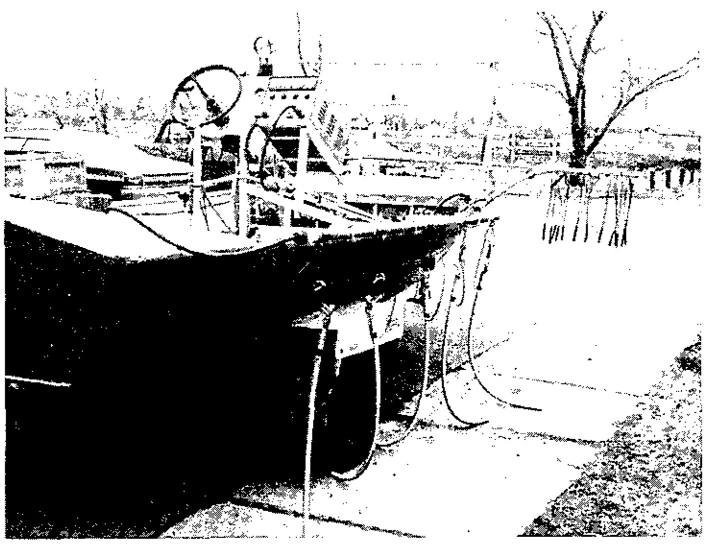

Figure B-4.-Negative electrode array. Photo P1279-D-79207 ring provides mechanical support and an electrical connection for the droppers which actually carry the current into the water. Individual "droppers" consist of 150-mm (6-in) lengths of 15.9-mm (5/8-in) diameter stainless steel tubing supported by a 457-mm (18-in) length of heavy gage insulated copper wire having a 20-A test clip for attachment to the support ring. By adjusting a movable sleeve of insulating material (15.8-mm (5/8-in) diameter automatic wiring loom), surface exposure of the "droppers" can be varied for waters of differing conductivity (Novotony and Priegel [11]).

The electrode arrangement of positive dropper electrodes suspended from an aluminum ring is superior to that of the spherical electrodes. The dropper arrangement offers greater flexibility over a range of conductivities, greater control of current output, and less chance of snagging on obstructions. Fish generally exhibit similar response to both designs except at the lower conductivity range (250 μ S) where small shovelnose sturgeon (less than 0.4 kg (1.0 lb)) and burbot respond better to the spherical design. The spherical design does offer the advantage of being inexpensive and easy to construct.

Cathode array — The negative electrode system consists of two cathode arrays, one mounted on each side of the boat (fig. B-4). Each array consists of one set of five 1.2-m (4-ft) lengths of 19-mm (3/4-in) diameter flexible conduit (Novotony and Priegel [11]) supported by a 2.4-m (8-ft) length of fiberglass boom. Each length of conduit is fastened to the support boom by a chain and rubber insulator. The top of each length of conduit is insulated with electrical tape or shrink tube.

Boat and Motor Selection

Since large rivers vary considerably in their physical characteristics, a single boat or boat design cannot be expected to work equally well in all situations. Large river electrofishing operations are dependent upon a certain amount of mobility, making the selection of the proper size and type of motor nearly as important as selecting the boat. Major factors to consider in boat/motor selection are water depth (or the lack of it), water velocity, substrate type, and access.

Depth becomes important only by its absence; that is, when riffles or other portions of the channel are shallow (less than 0.3 m (1 ft) deep) and the possibility of frequent grounding exists. Flow velocity primarily influences the size of motor required, although in rivers with high flow velocities boat design is of equal importance. Substrate type primarily influences the selection of hull thickness. Access to the river becomes a factor only when it is limited and may influence the size of boat and motor required.

Frequently, the choice of a boat and motor is determined by considering a combination of the above factors. Generally, rivers having high or moderate gradients near mountainous or headwater areas tend to have high flows, relatively abundant shallow water areas, and a gravel or cobble substrate. A boat/motor combination selected for this type of river would have characteristics different from one chosen for a deep, slow-moving river.

The above conditions as they exist on the lower Yellowstone are:

- **Depth** - Under low summer flows, riffles are from 0.3 to 1.2 m (1 to 4 ft) deep and the main channel contains many shallow areas and midstream gravel bars.

- **Velocity** - ranges from 0.8 to 1.2 m/s (2.5 to 4 ft/s) under low summer flow conditions, to 1.5 to 2.4 m/s (5 to 8 ft/s) during spring runoff (fig. B-1).

- The **substrate** is predominantly gravel and cobble with occasional bedrock areas.

- **Access** is poor with four boat ramps on 480 km (300 mi) of river; however, physical access to gravel bars or low bank areas is more frequent (every 24 to 40 km (15 to 25 mi)).

The boat chosen for this reach was a 5-km (17-ft) flat-bottomed aluminum boat powered by an 6.3 X 10^4-W (85-hp) outboard motor fitted with a jet propulsion lower unit. The hull thickness is 3.2-mm (0.125-in) (bottom) and 2.5-mm (0.10-in) (sides). It has a load capacity of 680 kg (1500 lbs); however, additional flotation had to be added to obtain this capacity.

The aluminum boat offered the advantage of simple, reliable grounding of all electrical components. The thick hull material eliminated the problem of punctures or abrasion; but, the weight of the boat was nearly double that of a comparable size boat with standard 1.5-mm (0.061-in) hull thickness. An outboard jet unit enabled the boat to be operated (when planing) over waters as shallow as 150 mm

(6 in) and offered no extensions below the hull to contact bottom obstructions. The 6.3×10^4-W (85-hp) outboard motor was necessary for mobility to overcome the scarcity of access sites, that is, to travel to sampling sites. However, a much smaller outboard would have been adequate for mobility during the electrofishing operation itself.

The Missouri River offers a different problem. Although the physical characteristics are quite similar, main channel depths are greater and flows fluctuated less as a result of upstream dams. The main problem with the Missouri River is access. Between Fort Benton, Montana and the Fred Robinson Bridge near Landusky (240 km (149 mi)), there are only four acceptable sites with as many as 80 km (50 mi) between two of the sites.

The relative inaccessibility of the river requires week-long sampling trips. The boat not only has to function as an electrofishing boat, but also has to carry the necessary food, fuel, camping gear, and sampling equipment for 7 to 10 days. The boat chosen for this project was a 6.7-m (22-ft) semi-vee aluminum boat powered by a 1.8×10^5-W (245-hp) inboard jet (fig. B-6). The boat is constructed of heavy gage aluminum (4.8-mm (0.187-in) bottom, 3.2-mm (0.125-in) hull) and has a load capacity of 1100 kg (2500 lbs). Primary considerations in selecting this boat were: (1) a large load capacity, (2) shallow water capability, (3) dependable, low maintenance motor, and (4) acceptable fuel economy.

After 4 years of experience with the outboard jet boats and 2 years with the inboard jet, some general comments can be made. It is not advisable to use an outboard jet propulsion lower unit unless shallow water conditions demand it. There is approximately a 30- to 35-percent power loss when compared to the standard propeller-driven lower unit. Reverse thrust is also very poor. The heavy electrofishing boat makes necessary a fairly large jet outboard. The dependability of the outboard jet combination decreases drastically after approximately 500 hours of use. In addition, fuel consumption is high; 0.42 to 1.28 km/L (1 to 3 mi/gal).

The inboard jet unit does not suffer the large power loss as does the outboard jet. In addition, fuel economy and dependability are much greater. The initial cost of the inboard jet is only slightly higher, but operating costs are significantly less. The inboard jet requires a semi-vee hull design and at least 1 foot deeper water to operate in than the outboard jet.

Operating Guidelines For Electrofishing Large Rivers

The primary considerations in electrofishing effectiveness, given the wide variation in experience and capability of electrofishing crews, are the design features of the electrical system, including the power source, the rectifying unit, and the electrodes. There are, however, several operating procedures which may increase sampling efficiency.

Boat speed can be a major factor in the success of large river electrofishing. In general, it is advantageous to operate the boat relatively fast in relation to the flow in shallow water areas. Slow boat speeds in shallow water may tend to scatter fish into deeper areas of the channel.

In most other cases with d-c and pulsed d-c electrofishing, slow boat speeds are desirable to allow sufficient time for the fish to respond. It is generally most effective, when sampling deep pool or run areas, to operate the boat at the same speed as the flow. There is little advantage to moving slower than the flow, since fish then tend to be carried downstream out of reach of the netters. Moving faster than the flow causes fish to come up under or behind the boat.

Intermittent use of the electrical current can increase sample sizes in certain areas. Drifting to the middle of a pool, the lower end of an island or midstream gravel bar, or the mouth of a tributary stream before turning on the current has, at times, proven effective.

During clear water conditions and in sections of river containing pools too deep to electrofish, sample sizes may be significantly increased by electrofishing shallow water areas at night. Frequently, large fish are also captured by night shocking. During turbid water conditions, however, the difference in sample size between day and night shocking is much less pronounced.

Sampling Effectiveness

The wide variation in flow conditions significantly influences sampling effectiveness on an annual basis in the lower Yellowstone. While it is difficult to quantify effectiveness of electrofishing on a large river, certain qualitative assessments can be made.

An important factor in electrofishing is water velocity. Generally, velocities between 0.6 and

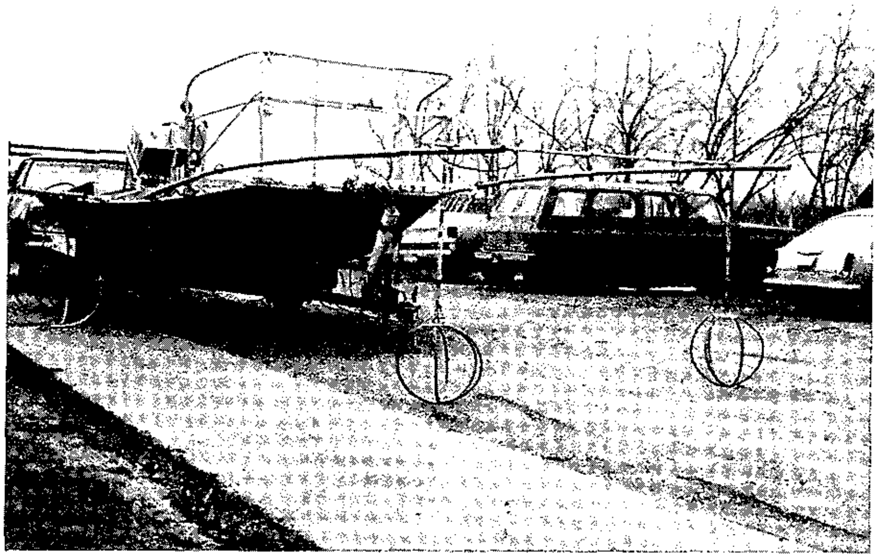

Figure B-5.-Positive spherical electrodes. Photo P1279-D-79205

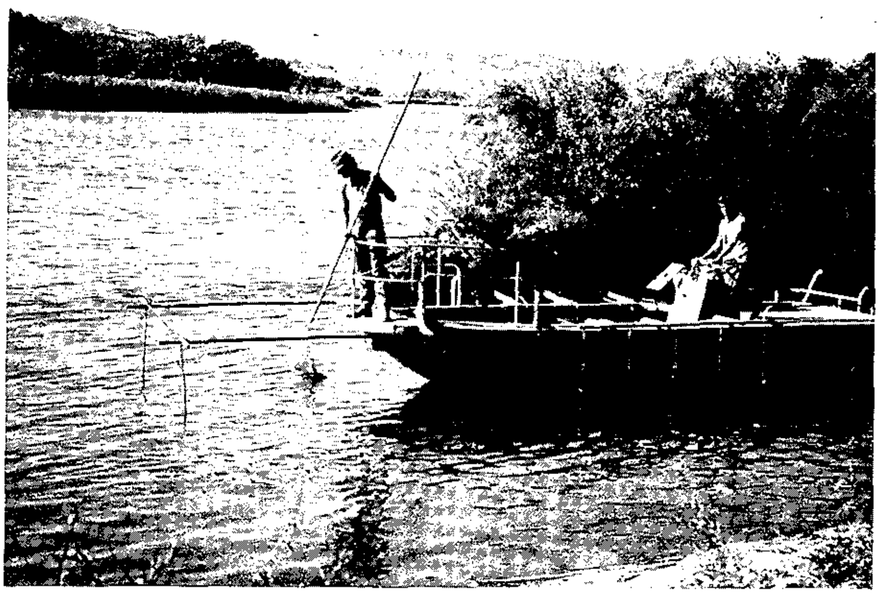

Figure B-6.-A 6.7-m (22-ft) inboard jet adapted for electrofishing on Missouri River. Photo P1279-D-79210

1.1 m/s (2.0 and 3.5 ft/s) present few problems, but between 1.1 and 1.5 m/s (3.5 and 5.0 ft/s), some problems with netting fish and fish response occur. At velocities greater than 1.5 m/s (5.0 ft/s) and with the associated higher flow levels (fig. B-1), sampling problems increase significantly.

Increasing turbidity generally tends to limit sampling to shallower portions of the channel. Fish are probably responding from deeper waters, but they are not visible to the netter. In shallow waters, fish tend to break the surface more frequently.

Conductivity commonly ranges between 250 and 1000 μS during the sampling season on the lower Yellowstone River. Conductivity at either end of the range does not appear to significantly affect electrofishing effectiveness or fish response, even though a lower electrical output occurs at the lower conductivity range.

The electrical system with variable output control and exposure control on the dropper electrodes is flexible enough to handle the range of conductivity experienced on the Yellowstone. Brief sampling efforts in some tributaries, however, encountered conductivities that were definitely limiting sampling effectiveness. Electrofishing is possible with a conductivity between 1300 and 1600 μS, but care must be taken so that the electrical system is not overloaded. At conductivities over 2000 μS, drastic alterations in electrode surface areas are necessary and operation is limited to the a-c mode.

Under ideal sampling conditions, fish can be captured with pulsed d.c. from depths of 2.4 to 3.7 m (8 to 12 ft). As an example, shovelnose sturgeon were readily captured in midchannel areas from those depths during October 1977. The shovelnose is principally a bottom-dwelling species and most of the sturgeon probably responded from or very near the bottom. Individual fish capture locations were marked and later measured with a depth recorder. Water clarity at the time allowed fish to be visible at depths of about 1.5 m (5 ft). Conductivity was approximately 800 μS and water temperatures varied between 7.2 and 10 °C (45 and 50 °F). Average flow velocities varied between 0.5 and 0.8 m/s (1.5 and 2.5 ft/s).

SAFETY GUIDELINES

The electrofishing boat for the lower Yellowstone was constructed with sampling effectiveness and crew safety as primary objectives. Many of the design and construction safety features incorporated into the electrofishing boat were the result of developmental efforts by Wisconsin (Novotony and Priegel [11]), consultation with a major electrofishing component manufacturer, and past experience. The discussion of safety guidelines is divided into electrical design and construction considerations, boat and mechanical components, general operational safety considerations, and common river hazards.

Electrical Design and Construction

Two major safety considerations in designing an electrofishing boat are: (1) design and construction of the electrical system to avoid the possibility of electrical shock within the boat through insulation or component failure, and (2) to provide a safety circuit that automatically shuts off the power circuits (and hence electrodes) if a crew member steps out of place or accidentally falls into the water.

A major electrical safety consideration involved in the construction of an electrofishing boat is the grounding of all components of the power system and all metal parts involved with the boat proper. An aluminum boat hull offers the advantage of simple, reliable grounding of all electrical equipment by the physical attachment of the equipment to the boat. Where there is questionable grounding contact, grounding straps should be used.

The case and frame of the generator should be grounded to the hull. A battery grounding strap provides a reliable and durable connection. When the case and frame of the generator are grounded, the internal ground found in most generators must be disconnected. In addition, the generator should have a quick, positive shutoff device that has an ON and OFF position, rather than a "kill" button which must be held down until the generator stops.

All permanent wiring within the boat associated with the power, safety, and lighting circuits should be enclosed in waterpropof conduit and junction boxes. To facilitate grounding, metal conduit, junction boxes, and conduit clamps should be used. To ensure a reasonably waterproof conduit system, the following materials and procedure were used: Outdoor weatherproof junction boxes are fastened to conduit using screw-type conduit connectors which can be readily waterproofed with a suitable sealing compound. Amphenol-type MS screw lock electrical plugs and chassis-mount receptacles are used for all connections associated with the power outlets, such as positive and negative electrode connections, rectifying unit connections, and power source (generator) connections. Amphenol screw-lock connectors offer a secure connection which cannot shake or vibrate loose as well as a connection which is easily waterproofed (fig. B-7).

The Amphenol chassis-mount outlet is mounted in the side or back of the junction box by drilling about a 28.6-mm (1-1/8-in) hole and securing it with four bolts, gasket, and sealant. Power circuit wires are then attached to the Amphenol chassis-mount outlet by soldering and the entire junction box is filled with a nonconductive silicon rubber. The silicon rubber further weatherproofs the system and eliminates vibration of the wires. A rigid, blank plate is used to cover the open side of the box. Screw caps are available for the exposed portion of the chassis-mount outlet when the power circuit is not in use.

Amphenol-type screw-lock electrical plugs and chassis-mount outlets are used for all connections in the power circuit except on the generator. The constant vibration and heat associated with the operation of a large generator can cause insulation failure of the mating plug and produce undesirable results. The standard plugs supplied with the generator are retained.

All wiring used in the boat is overrated for the particular current capacities anticipated to ensure a margin of safety. The types of wire used in the permanent wiring circuits placed in the conduit are: For the power circuit, 10- or 12-AWG, Type THHN or THWN stranded wire is used. This wire is gas and oil resistant and 600-V insulated. Similar, but smaller, wiring (14 gage) is used for the lighting circuit. The safety circuit is low voltage (12 V), so 16-or 18-gage stranded wire is used.

A 600-V insulated, 12-2 or 12-4 power cord (gas and oil resistant) is used for all exposed wiring associated with the power circuit. This wiring is used for plugging the generator, rectifying unit, and electrode arrays into the power circuit.

In many electrofishing boats, there are three electrical systems which perform separate functions: lighting, power, and safety. The three electrical systems should be run in separate conduit systems. This prevents the possibility of an insulation or electrical failure of one system affecting another and is of particular concern in the safety circuit.

The positive and negative electrode arrays are insulated from the boat. The positive electrode arrays are insulated by using nonconducting fiberglass booms. Dip nets use nonconducting material (wood or fiberglass) for handles. The negative electrodes are isolated from the boat by using a link of nonconducting rubber in the chain suspending the negative electrode, and a fiberglass boom for the entire array.

Both the boat operator and dip netter(s) should be provided with safety switches that shut off the power circuit when either person steps out of position. In addition, a low-voltage relay built into the safety circuit provides the operator with the only opportunity to energize the power circuit, even though all safety switches are closed.

Three basic types of safety switches were tested: the foot tredle, the safety mat, and an outboard ignition safety stop switch. While all performed satisfactorily, the outboard ignition safety stop switch (figs. B-3 and B-7) (Mercury), mounted on the bow railing and attached to the netter(s) waders by a nylon cord and clip, best met our needs. It provided a reliable, lightweight system with a minimum of restriction in movement.

Boat and mechanical components.—The boat chosen for electrofishing should have a load capacity adequate to carry all the necessary persons and gear without jeopardizing either boat handling or freeboard. Good maneuverability and handling characteristics increase in importance on rivers with high flow velocities. Motors should be of adequate horsepower to provide the necessary maneuverability. Flotation should be adequate to float the boat plus equipment.

An aluminum boat is desirable, since it greatly facilitates grounding of all electrical components within the boat. A bow railing partially encloses the work deck and provides a mounting location for lights.

An aluminum center console enables the boat operator to have a good view of the river immediately in front of the boat while providing a mounting location for the rectifying unit. The rectifying unit and

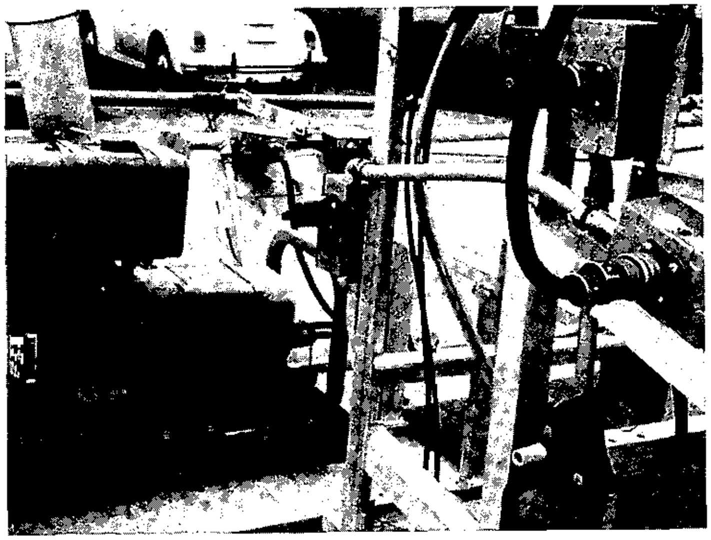

Photo P1279-D-79208

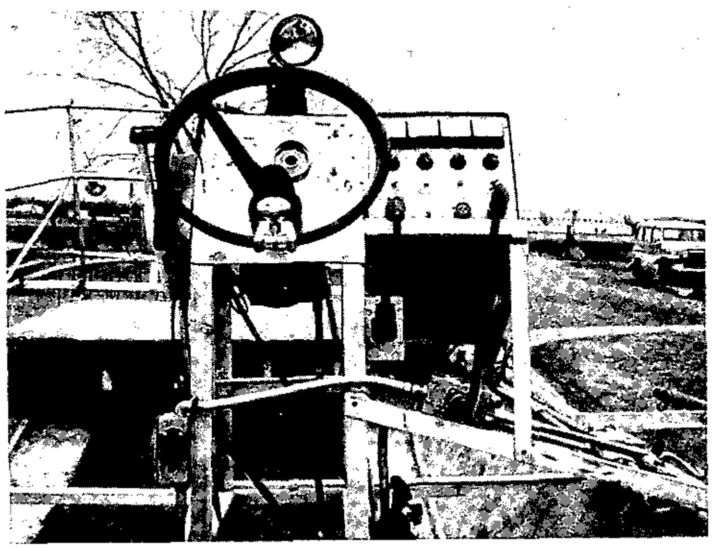

Photo P1279-D-79211

Figure B-7.-Amphenol screw-lock connectors, waterproof conduit system, and safety switch for boat operator.

generator should be close to and easily controlled by the operator. A fire extinguisher should be mounted in the boat.

Operational Safety Considerations

The single most important factor in operational safety and effectiveness in river electrofishing is the ability and experience of the crew. Regardless of the safety guidelines established, the capability of the crew in adhering to the guidelines and handling unforeseen circumstances is of overriding importance. With this in mind, the following safety precautions should be observed:

(1) Always wear hip boots or waders.

(2) Always wear rubber gloves.

(3) Always wear Coast Guard approved life jackets.

(4) Do not bypass safety circuit.

(5) One person, usually the operator, should be in charge of the operation. He should be skilled in river navigation and have a working knowledge of the electrical and mechanical components of the electrofishing boat.

(6) All crew members should be familiar with the operation of the boat and its electrical system. Electrical safety considerations (Novotony and Priegel [11]) are especially pertinent.

(7) All crew members should have at least rudimentary knowledge of first-aid procedures including cardiopulmonary resuscitation.

(8) All equipment, both electrical and mechanical, should be regularly inspected and maintained in good working condition.

(9) The fire extinguisher should be readily available and located away from fuel tanks and generator.

(10) Do not electrofish in the rain or when the major electrical components inside the boat are wet.

(11) Night shocking on large, fast-flowing rivers should only be done with the utmost caution.

Common River Hazards

Sampling large rivers by electrofishing presents certain hazards not normally encountered on lakes or reservoirs. On the lower Yellowstone River, these are most commonly some form of navigational obstruction, and their danger increases with increases in flow.

The most common and perhaps dangerous form of obstruction on the lower river is the snag, which generally consists of one or more dead trees having fallen into the water on an eroding bend or grounded in midstream. Snags are hazardous since, even at low or moderate flow, they can swamp or upset a boat and the current may carry the occupants beneath them. Snags are more common in wooded bottomlands or in braided sections of a river where eroding banks are common.

Bank stabilization projects can also present a hazard. These manmade projects are generally on badly eroding banks with relatively high flow. The most common material used is large rock riprap; however, car bodies and steel "jacks" have also been extensively used. Jacks are X-shaped devices made of 3.0-m (10-ft) long pieces of channel iron cabled to the banks. They are originally designed to entrap debris. Both car bodies and jacks will often be found in midstream and, in addition to being a navigation hazard, can cause electrical problems if they come in contact with the electrodes.

Old bridge crossings are areas that should be viewed with caution. Several bridge pillars are likely to be in midstream and flow is generally higher around these structures. The channel is usually constricted and abutments are commonly stabilized with large rock riprap.

The importance of a capable, experienced operator and adequately maintained equipment cannot be overemphasized. Most of the hazardous situations that occur on rivers are generally the result of poor judgment on the part of the operator, or equipment failure at the wrong time, or both.

FUTURE DEVELOPMENT

The development of electrofishing boats certainly is not a static field and the design and construction features are nearly as varied as there are agencies and departments involved in capturing fish with electricity. For the lower Yellowstone River, the boat design described in this paper is not considered an end point, but rather, a stepping stone toward a final goal. While we are reasonably well satisfied with the electrode design and power and conversion units, several aspects of the boat are less than satisfactory. The outboard jet unit has high initial and maintenance costs and only a relatively short life. Fuel consumption is high while dependability decreases after the first season. The boat itself is quite heavy.

New and lightweight electrical components offer useful opportunities for improved design and construction features. The ultimate goal for a boat on the lower Yellowstone River is to maintain the effectiveness and mobility of the present boat, but with a lighter, more dependable and more fuel-efficient design. In addition, the boat should have the capability to be controlled and maneuvered manually in the event of engine failure.

With fuel efficiency a major factor in future design considerations, efforts are underway to develop an electrofishing boat with minimum fuel consumption. A promising design is the McKenzie-style drift boat. A heavy duty aluminum drift boat is currently being outfitted with the boom-mounted electrofishing apparatus previously described. This unit will be tested during the 1980 field season. The drift boat design offers stability, shallow drift, and excellent maneuverability with either oars or a small outboard. However, upstream travel would be limited. A 4.3-m (14-ft) drift boat can be pulled by a small truck and offers the possibility of continued sampling on limited fuel supplies.

It is hoped that development of electrofishing boats and their adaptation to various water situations will continue through the exchange of ideas.

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