JS-21

EVALUATION OF FOUR INSTREAM FLOW METHODS APPLIED TO FOUR TROUT RIVERS IN SOUTHWEST MONTANA

By

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OBJECTIVES

The Montana Department of Fish, Wildlife and Parks began in 1966 to estimate standing crops (numbers and biomass) of trout in the rivers of the Missouri drainage of southwest Montana. Presently, long-term standing crop estimates are available for five reaches of the Madison, Beaverhead, Gallatin and Big Hole rivers, all nationally acclaimed wild trout fisheries. In these five reaches, the flows, which are gaged by the USGS, are either regulated by dams or affected by irrigation withdrawals. Annual variations of the standing crops of trout within each reach were found to be related to annual flow variations. From these relationships, instream flow recommendations were derived for the five reaches.

The use of long-term standing crop and flow data is not a practical means of deriving future instream flow recommendations due to the excessive time, cost and manpower requirements involved in collecting data. Because of these limitations, flow recommendations for other waterways in Montana will primarily be derived from instream flow methods that incorporate little if any biological data. The reliability of the recommendations generated by the methods in current use has not been adequately documented. Acceptance of these recommendations has generally been based on theoretical considerations and professional judgment rather than biological proofs. The instream flow recommendations derived from the standing crop and flow data for the five river reaches provide a biologically derived standard for comparing the recommendations generated by the instream flow methods.

In this study, four instream flow methods were applied to each of the five river reaches and their flow recommendations compared to those derived from the long-term standing crop and flow data. The four methods chosen for evaluation were (1) a single transect method utilizing the IFG-4 hydraulic simulation model, (2) a multiple transect method utilizing the Water Surface Profile (WSP) or "Pseudo" hydraulic simulation model, (3) a non-field method utilizing historical discharge records, and (4) the incremental method developed by the Cooperative Instream Flow Service Group (IFG) of the U.S. Fish and Wildlife Service. In addition to evaluating the reliability of the recommendations generated by each method, other objectives were to compare the final flow recommendations to the monthly hydrograph for each reach, determine the cost, time and manpower requirements associated with each method, and assess the predictive capabilities of the IFG-4 and WSP hydraulic simulation models.

MATERIALS AND METHODS

The standing crop estimates, which provided the data base for evaluating the four instream flow methods, were obtained using the mark-recapture method. Fish were captured with a boat-mounted electrofishing unit. Estimates of standing crops by age-groups and confidence intervals were calculated using computerized methods summarized by Vincent (1971 and 1974).

Cross-sectional data for the three field methods were collected simultaneously to conserve field time. Cross-sectional measurements were made using surveying and discharge measuring techniques described in Bovee and Milhous (1978). Major equipment used to collect this data included a Wild NAK1 automatic level, a 25-foot telescoping fiberglas level rod, 300 and 500-foot canyon lines and rod-held Gurley type AA current meters. For unwadable cross-sections, the current meter was suspended from a crane mounted on a 10-foot fiberglas boat. The crane was provided by the USGS, Helena, Montana. The USGS also provided much of the summarized flow data presented in this paper.

Single Transect Method

The single transect method involved the use of the wetted perimeter-discharge relationship for a single riffle cross-section to derive instream flow recommendations for each of the five river reaches. Wetted perimeter is the distance along the bottom and sides of a channel cross-section in contact with water. As the discharge in a stream channel decreases, the wetted perimeter also decreases, but the rate of loss of wetted perimeter is not constant over a given range of discharges. Starting at zero discharge, wetted perimeter increases rapidly for small increases in discharge up to the point where the stream channel nears its maximum width. Beyond this inflection point, the increase of wetted perimeter is less rapid as discharge increases. The instream flow recommendation is selected at this inflection point.

The capacity of a river to sustain fish populations is assumed to decrease proportionately with the decrease in physical habitat. Wetted perimeter, which is one of the physical parameters least affected by flow reductions, was arbitrarily chosen as an index of the physical condition of the river habitat. It is reasoned that once the rate of loss of wetted perimeter begins to accelerate other physical parameters such as mean depth, maximum depth, mean velocity and cross-sectional area have already shown substantial declines. Fish population and wetted perimeter relationships have not been documented in the literature at present. This approach assumes such relationships do exist.

Riffles are the area of a river most affected by flow reductions. It is reasoned that by maintaining adequate physical conditions in riffles, more than adequate conditions would also be maintained in pools and runs, areas normally occupied by adult salmonids.

The wetted perimeter curve for each riffle cross-section was derived using the IFG-4 hydraulic simulation computer program developed by the Cooperation Instream Flow Service Group (Main, 1978). The model was calibrated to field data collected at the following flows:

Subreach	Riffle Cross-section #	Calibration Flows (cfs)			
Madison (#1)	5	1,339,	1,760,	2,070	
Madison (#3)	1	918,	1,211,	1,555	
Beaverhead (#2)	1	255,	289,	343	
Gallatin (#2)	1	281,	477,	646	
Big Hole (#1)	1	444,	570,	587,	985

Since well defined riffles are scarce in reach #1 of the Madison River, cross-section #5, which transected a relatively shallow area containing weed beds, was substituted.

The IFG-4 program does not directly predict wetted perimeter. The wetted perimeter for a flow of interest is approximated by having the program sum all of the segment widths having an average depth of at least 0.1 foot. The error associated with this approximation is assumed to be negligible for the relatively large, wide waterways the model was applied.

Multiple Transect Method

The multiple transect method involved the use of the wetted perimeter-discharge relationship for a composite of four to seven channel cross-sections to derive instream flow recommendations for each of the five reaches. Cross-sections were generally placed within a single riffle-pool sequence to sample several habitat types. The computed wetted perimeters for all of the cross-sections at each flow of interest were averaged and the instream flow recommendation selected at the inflection point on the plot of average wetted perimeter versus discharge.

Again, it is assumed that the capacity of a river to sustain fish populations decreases proportionately with the decrease in the physical habitat. The average wetted perimeter is assumed to provide an index of the physical condition of the average habitat type within each river reach.

The wetted perimeter curves for four of the five reaches were derived using the "Pseudo" or Water Surface Profile (WSP) hydraulic simulation computer program developed by the Bureau of Reclamation. The WSP model was applied to the four river reaches according to procedures prescribed in Spence (1975). The model was not applied to reach #3 of the Madison River. The wetted perimeter curve for the composite of cross-sections in this reach was derived using the IFG-4 model which was calibrated to field data collected at flows of 918, 1,211 and 1,555 cfs. Field data for the WSP model were collected at the following single flows:

Subreach	Cross-section #	Calibration Flows (cfs)
Madison (#1)	1 through 5	1,339
Beaverhead (#2)	1 through 4	343
Gallatin (#2)	1 through 7	646
Big Hole (#1)	1 through 6	985

Mr. Rick DeVore of the Bureau of Reclamation, Billings, Montana, calibrated the WSP model to the field data and provided technical assistance.

Non-field Method

The non-field method selected for evaluation was the Tennant or Montana method developed by Donald L. Tennant of the U.S. Fish and Wildlife Service, Billings, Montana (Tennant, 1975). Flow recommendations are based on a percentage of the mean flow of record. The method is described as follows:

"Tennant or Montana Method" for prescribing Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources (from Tennant, 1975).

Narrative Description of Flows	Recommended Base Flow Regimens Oct-Mar	: Apr-Sept
Flushing or Max.	200% of the average flow	
Optimum Range	60%-100% of the average flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	10% of average flow to 0 flow	

IFG Incremental Method

The IFG incremental method was applied to the five river reaches according to the procedures prescribed in Bovee and Cochnauer (1977), Bovee (1978) and Main (1978 and 1978a). The habitat in each of the subreaches was described using from five to seven cross-sections. The model was calibrated to field data collected at the following flows:

Subreach	Cross-section #	Calibration Flows (cfs)
Madison (#1)	1 and 2,	1,339, 1,760, 1,874
	3, 4 and 5	1,339, 1,760, 2,070
Madison (#3)	1 through 5	918, 1,211, 1,555
Beaverhead (#2)	1 through 7	255, 289, 343
Gallatin (#2)	1 through 7	281, 477, 646
Big Hole (#1)	1 through 6	444, 570, 587, 985

The IFG-4 hydraulic simulation program and the probability-of-use curves developed by the IFG were employed in the application of this method.

STUDY AREA

Madison River

The Madison River originates in Yellowstone National Park at the junction of the Firehole and Gibbon rivers and flows in a northerly direction for 149 miles to Three Forks, Montana where it joins the Jefferson and Gallatin rivers to form the Missouri River (Figure 1). There are two man-made impoundments on the river; Hebgen Reservoir, located 1.5 miles downstream from the park boundary, and Ennis Reservoir, located 58 miles downstream from Hebgen Reservoir. From its source in the park, the Madison flows across a high conifer forested plateau (7,000 ft and higher in elevation) to Hebgen Reservoir. Upon leaving Hebgen Reservoir, the river flows about 1.5 miles through a narrow canyon to Quake Lake, a natural lake formed by an earth slide during a major earthquake on August 17, 1959. Below Quake Lake the river enters the upper Madison River valley where it flows about 51 miles before entering Ennis Reservoir. After leaving Ennis Reservoir, the Madison enters a narrow gorge (Bear Trap Canyon) where it flows about 14 miles before entering the lower Madison River valley for the final 26 miles to its junction with the Jefferson and Gallatin rivers.

The Madison River drains approximately 2,500 square miles. About 70% of the drainage is covered with coniferous forests. The riparian zone of the wide, open upper and lower Madison River valleys is vegetated with willow, alder, cottonwood, and an occasional conifer. Agricultural lands in the upper and lower valleys are primarily used for cattle grazing and hay production.

Flows in the Madison River are regulated by Hebgen Reservoir. Hebgen Reservoir, built in 1915 by the Montana Power Company, stores water for downstream hydro-electric generation. Water storage usually occurs during the snow runoff period of mid-May through early July. Stored water is released to downstream reservoirs during the fall (October-December). Fall releases usually range from 1,500 to 2,200 cfs at Hebgen Dam.

Ennis Reservoir, built in 1908 by the Montana Power Company, has a rather stable water level with little storage capacity of its own. Its primary function is to create a head for the hydro-electric facility immediately below Ennis Dam. Outflows from Ennis Reservoir are mainly regulated by Hebgen Dam.

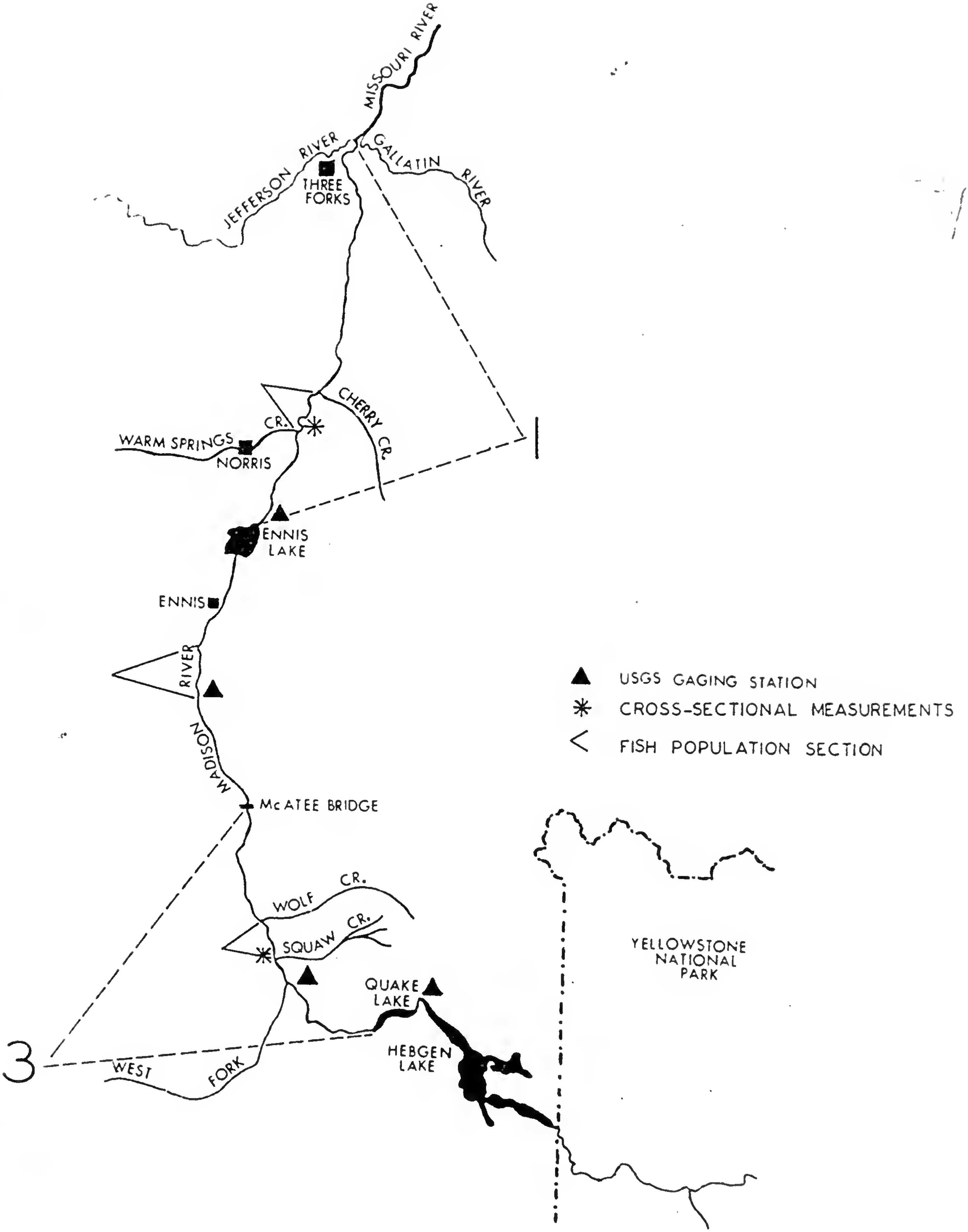

Figure 1. Map of the Madison River.

Long-term flow records are available for three USGS gaging sites on the Madison River below Hebgen Dam. The mean flow for a 39-year period of record at the gage below Ennis Dam (near McAllister) was 1,762 cfs. Flows ranged from 210 to 9,550 cfs. The mean flow for a 13-year period of record at the gage upstream of Ennis (near Cameron) was 1,432 cfs. Flows ranged from 275 to 8,830 cfs. The mean flow for a 67-year period of record at the gage below Hebgen Dam (near Grayling) was 999 cfs. Flows ranged from 5 to 10,200 cfs.

Water quality throughout the Madison River can generally be described as good. The water is moderately hard; the pH ranges from 8.3-8.5; and dissolved oxygen averages 10 mg/l. Other selected chemical properties are given in Table 1.

Table 1. Selected chemical properties of the Madison River near Three Forks, Montana in summer and fall, 1977 and spring, 1978 (data from Bahls et al., 1979).

	Summer	Fall	Spring	Mean
Specific Conductance (umhos @ 25 C)	321	-	-	-
Total Alkalinity (mg/l $CaCO_3$)	114	-	-	-
Phosphate (PO_4 as P in mg/l)	.009	.014	.033	.019
Total Phosphorous (P in mg/l)	.025	.020	.053	.033
Nitrate plus Nitrite (NO_3+NO_2 as N in mg/l)	$<$.01	.02	.04	-
Ammonia (NH_3 as N in mg/l)	$<$.01	$<$.01	.02	-
Kjeldahl Nitrogen (N in mg/l)	.33	.19	.21	.24

Reach #1 encompasses a 40-mile section between the river's mouth (river mile 0) and Ennis Reservoir (river mile 40). The upper 14 miles of reach #1 (river miles 26 to 40) lie within the narrow Bear Trap canyon. The river within the canyon is characterized by turbulent riffle-run areas interspersed with pools and large boulders. Gradient averages 21 ft per mile.

Near the mouth of Cherry Creek at river mile 26, the river enters the lower Madison valley. The channel becomes braided forming many islands and side channels. Boulder, cobble and gravel comprise the bottom substrate. Weed beds are also common. The channel generally exceeds 300 ft in width. Depths rarely exceed 4 ft. Well defined riffle-pool areas are absent. The immediate floodplain is vegetated with willow, alder and numerous cottonwoods. Gradient averages 16 ft per mile.

Brown trout, rainbow trout, mountain whitefish and an occasional arctic grayling, brook trout and cutthroat trout comprise the sport fish in reach #1. Other fish present include white sucker, longnose sucker, mountain sucker, mottled sculpin, longnose dace, Utah chub, carp and yellow perch.

Cross-sectional measurements in reach #1 were made in a 404-ft subreach located near the mouth of Warm Springs Creek at river mile 30. Five cross-sections were placed within the subreach. The lowermost cross-section was placed in a relatively deep constriction and the uppermost in a wide, shallow area containing well defined weed beds (Figures 2, 3 and 4).

Reach #3 encompasses a 29-mile section of the upper river between McAtee Bridge (river mile 72) and Quake Lake (river mile 101). The channel averages 223 ft in width. Depths rarely exceed 4 ft. This reach consists of turbulent riffle-run areas interspersed with large boulders. Boulder, cobble and gravel comprise the bottom substrate. The gradient averages 27 ft per mile. The floodplain is vegetated with grasses mixed with willow, alder and an occasional cottonwood and conifer.

Rainbow trout, brown trout, and mountain whitefish are the dominant sport fish in reach #3. Other fish present include cutthroat trout, arctic grayling, longnose sucker, white sucker, mountain sucker, mottled sculpin and longnose dace.

Cross-sectional measurements in reach #3 were made in a 323-ft subreach located near the mouth of Squaw Creek at river mile 88. Five cross-sections were placed in the subreach. The lowermost cross-section was placed in a wide riffle area and the uppermost in a narrower run (Figures 5 and 6).

Beaverhead River

The Beaverhead River (Figure 7) originates at the outlet of Clark Canyon Reservoir, an irrigation storage facility constructed in 1964, and flows 80 miles before joining the Big Hole River to form the Jefferson River. It drains an area of about 5,000 square miles. Gradient averages 12 ft/mile. Selected chemical and physical properties of the river are given in Table 2. A detailed description of the river and its fishery is given by Nelson (1977).

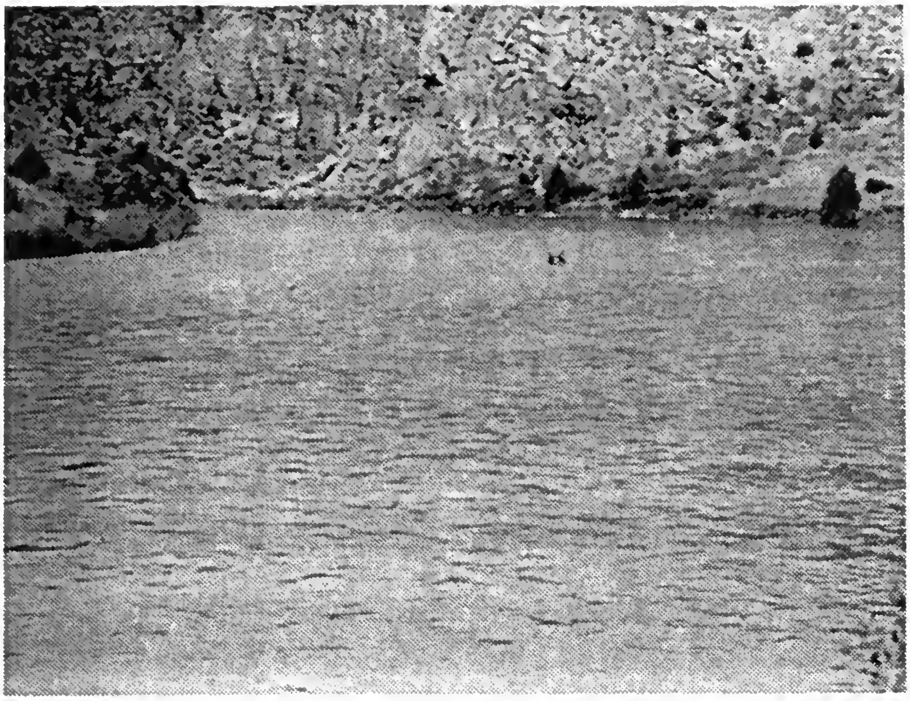

Figure 2. Subreach #1 of the Madison River looking downstream. Flow is 1,760 cfs.

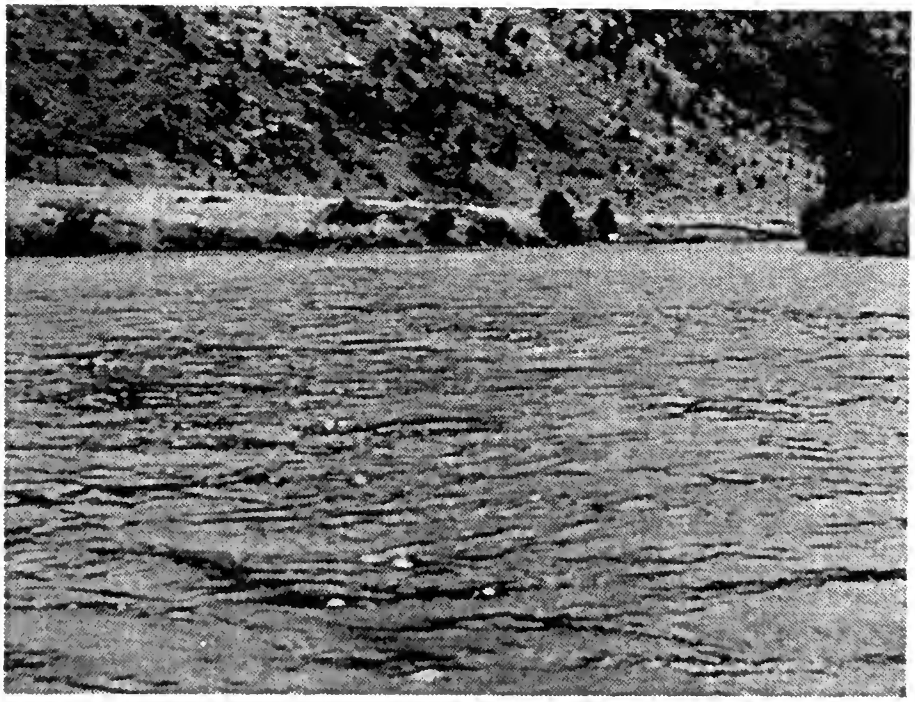

Figure 3. Subreach #1 of the Madison River looking upstream. Flow is 1,339 cfs.

Figure 4. Aerial photograph of subreach #1 of the Madison River showing the location of the five cross-sections.

Figure 5. Subreach #3 of the Madison River looking downstream. Flow is 1,211 cfs.

Figure 6. Aerial photograph of subreach #3 of the Madison River showing the location of the five cross-sections.

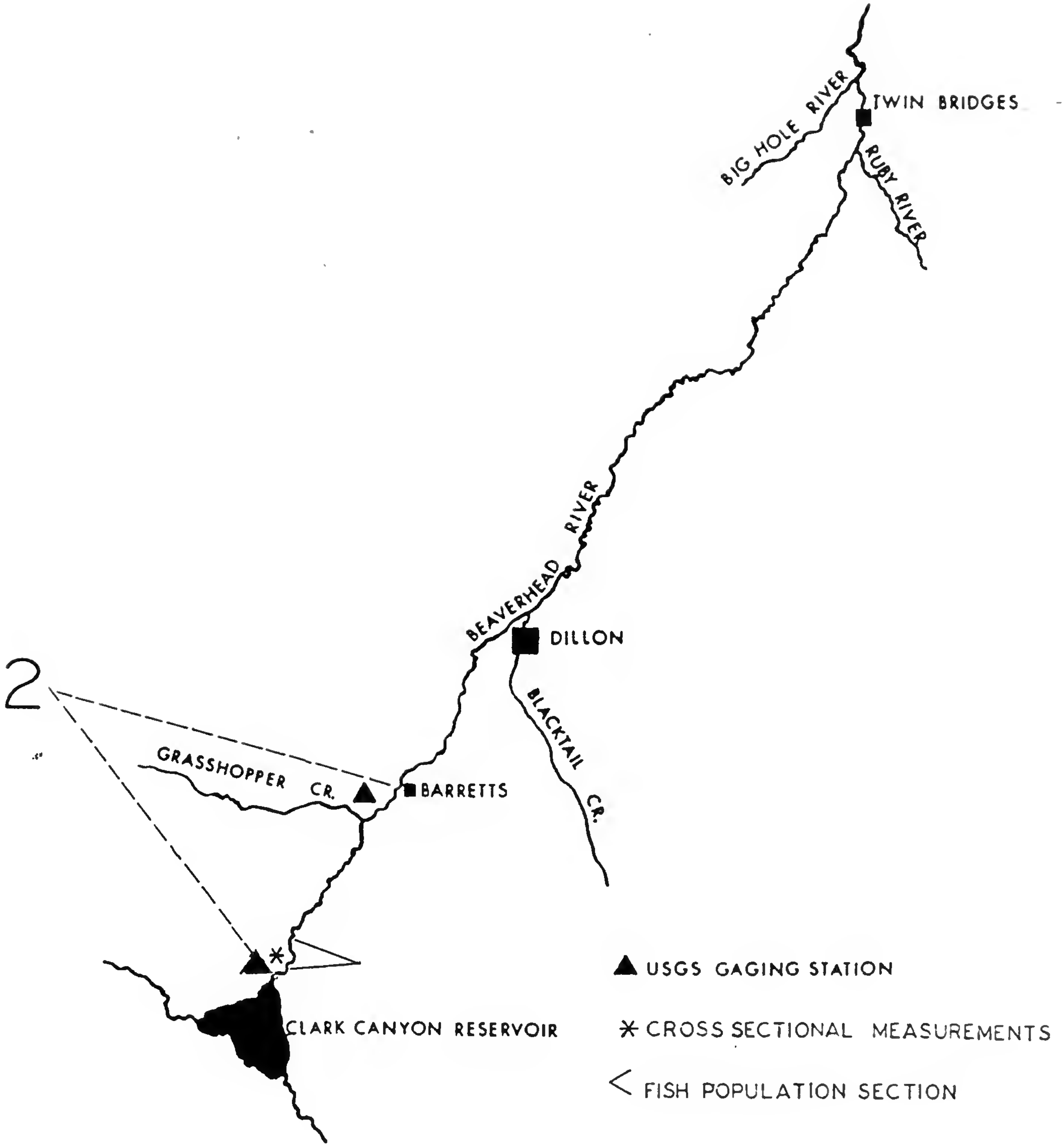

Figure 7. Map of the Beaverhead River.

Table 2. Mean chemical and physical properties of the Beaverhead River in the summer of 1972 at sites 0.25, 6.0, 15.0 and 27.0 miles below Clark Canyon Dam (data from Smith, 1973).

	Site (miles)			
	0.25	6	15	27
Turbidity (JTU)	4	4	7	5
Conductivity (umhos @ 25 C)	565	572	555	617
pH	8.1	8.2	8.2	8.1
Dissolved Oxygen (ppm)	9.6	9.7	9.3	10.0
Total Alkalinity (ppm $CaCO_3$)	198	199	190	218
Total Hardness (ppm $CaCO_3$)	220	230	216	252
Ammonia (ppm NH_3-N)	.14	.08	.05	.02
Nitrate (ppm NO_3^--N)	.057	.110	.089	.285
Nitrite (ppm NO_2^--N)	.015	.018	.015	.006
Orthophosphate (ppm PO_4^{-3})	.11	.10	.08	.05

Reach #2 encompasses a 16-mile section of river between the East Bench Diversion Dam at Barretts (river mile 64) and Clark Canyon Dam (river mile 80). The average channel width is about 83 ft. The streambed primarily consists of cobble and gravel. Submerged and overhanging willows and undercut banks provide much of the trout cover in this reach. Flow is confined to one or two channels consisting primarily of riffle-pool areas. Brown trout, rainbow trout, mountain whitefish, burbot, white sucker, longnose sucker, mottled sculpin, and longnose dace inhabit this reach.

The flows in reach #2 are completely regulated by Clark Canyon Dam. From October through March, Clark Canyon Reservoir stores water for the upcoming irrigation season. Releases into the river are minimal during this period. Irrigation releases occur from April through September. The diversion of irrigation water begins 16 miles below the dam. The major impact of the reservoir on the flow regime in reach #2 was to extend the high water period an additional four months from April through September. This extension occurs at the expense of October through March flows.

The mean discharge for a 70-year period of record at the USGS gage located 16 miles below Clark Canyon Dam (at Barretts) was 424 cfs. Discharges ranged from 69 to 2,720 cfs. The historic peak flows occurred in late May to mid-June. Since 1964, flows at this gage reflect regulation by Clark Canyon Dam.

Cross-sectional measurements in reach #2 were made in a 540-ft subreach located at river mile 78. Seven cross-sections were placed in a riffle-pool sequence containing an island (Figures 8, 9 and 10).

Gallatin River

The free-flowing Gallatin River (Figure 11) originates at Gallatin Lake in Yellowstone National Park at an elevation of 8,834 ft. It flows north for approximately 115 miles to Three Forks, Montana where it joins the Madison and Jefferson rivers to form the Missouri River. The Gallatin River drains an area of about 1,800 square miles, all above an elevation of 4,000 ft. Most of the drainage basin above 5,000 ft is covered with coniferous forest and located within Yellowstone National Park and the Gallatin National Forest. The drainage basin below 5,000 ft consists primarily of the Gallatin valley, one of the richest agricultural regions in Montana.

Reach #2 of the Gallatin River encompasses a 34-mile section located within the Gallatin valley between the mouth of the East Gallatin River (river mile 12) and the mouth of the Gallatin canyon (river mile 46) near Gallatin Gateway. As the river leaves the canyon, flow is confined to a single channel. Mean channel width at this point is approximately 151 ft. As the river progresses through the Gallatin valley, the flow becomes braided into 3-4 channels with the main channel shifting from year to year. Mean channel width in the lower valley is approximately 647 ft.

The streambed at the mouth of the canyon is approximately 20% boulder, 70% cobble and 10% gravel and sand. In the lower portion of reach #2, the streambed is approximately 50% cobble and 50% gravel, sand and silt.

Fish cover in the upper valley consists primarily of overhanging, rooted, bank vegetation and large instream boulders. Fish cover in the lower valley is composed primarily of cottonwood log jams and debris piles. Rooted vegetation is of lesser importance due to the unstable, erodable banks. The large instream boulders of the upper valley are absent in the lower valley.

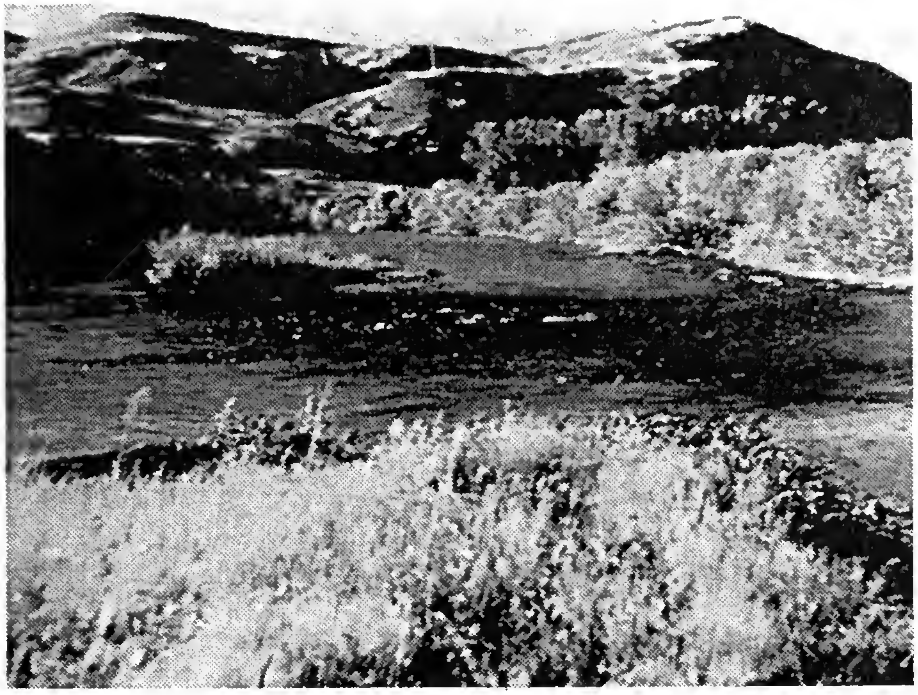

Figure 8. Subreach #2 of the Beaverhead River looking downstream. Flow is 343 cfs.

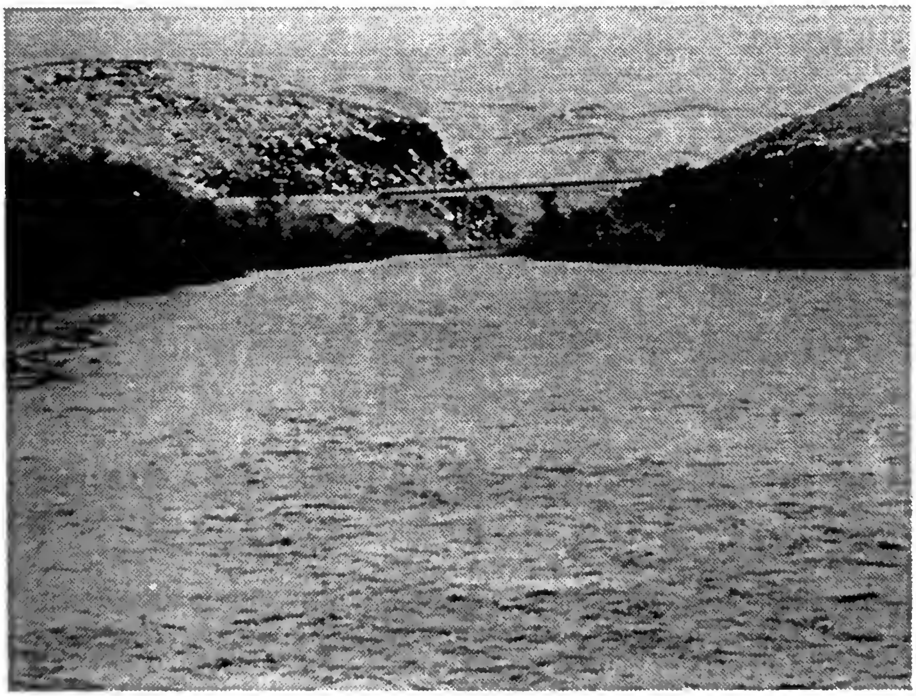

Figure 9. Subreach #2 of the Beaverhead River looking upstream. Flow is 289 cfs.

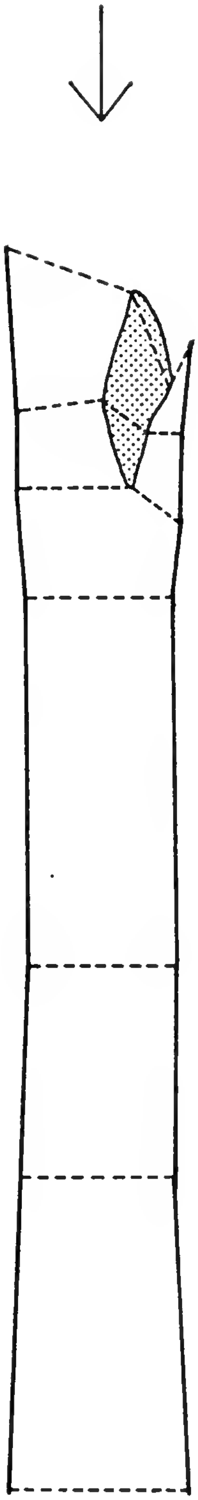

Figure 10. Subreach #2 of the Beaverhead River showing the location of the seven cross-sections.

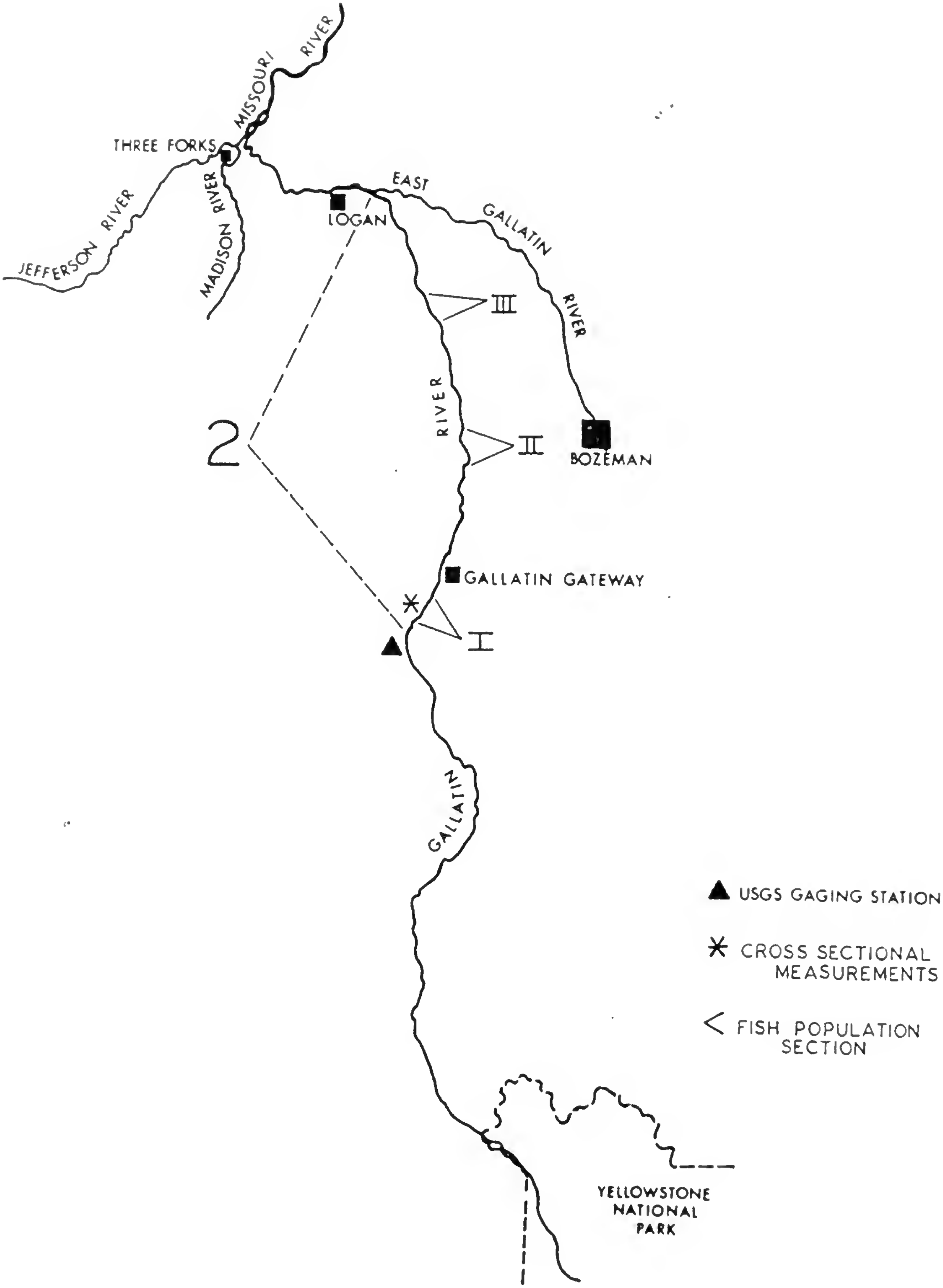

Figure 11. Map of the Gallatin River.

Reach #2 is markedly affected by man, most notably by irrigation diversions. As the river progresses through the valley, water is diverted for the irrigation of hay lands during the summer growing season. The degree of flow reduction (dewatering) depends on the annual discharge with more severe dewatering occurring in low water years. A dewatering survey in the summer of 1966 showed that 12 miles of reach #2 were dewatered over 90% for 3-8 weeks (Wipperman 1967). In some years portions of the river are totally dewatered in late July and August.

The mean discharge for a 49-year period of record at the USGS gage near the mouth of the Gallatin canyon (near Gallatin Gateway at river mile 48) was 817 cfs. Discharges ranged from 117 to 9,690 cfs. This gage, which is upstream of all irrigation diversions, reflects the natural flow regime of the river. The high water period normally occurs from late May to late July with peak flows occurring in early June.

Water quality in reach #2 can generally be described as good. Selected chemical properties of the river near Belgrade in 1977 and 1978 are given in Table 3.

Table 3. Selected chemical properties of the Gallatin River near Belgrade, Montana in summer and fall, 1977 and spring, 1978 (data from Bahls et al., 1979).

	Summer	Fall	Spring	Mean
Specific Conductance (umhos @ 25 C)	319	-	-	-
Total Alkalinity (mg/l $CaCO_3$)	124	-	-	-
Phosphate (PO_4 as P in mg/l)	.004	.005	.028	.012
Total Phosphorus (P in mg/l)	.010	.020	.037	.022
Nitrate plus Nitrite (NO_3+NO_2 as N in mg/l)	<.01	.09	.07	-
Ammonia (NH_3 as N in mg/l)	<.01	<.01	.02	-
Kjeldahl Nitrogen (N in mg/l)	.14	.08	.10	.11

The water in reach #2 is comparatively cold except in areas subject to extreme dewatering. The highest water temperature recorded in 1976 and 1977 near the canyon mouth was 66 F while temperatures as high as 78 F were recorded in dewatered sections of the lower river (Nelson, 1977a).

Brown trout, rainbow trout, brook trout and mountain whitefish are the dominant sport fish in reach #2. Other fish present include cutthroat trout, white sucker, longnose sucker, mountain sucker, mottled sculpin and longnose dace.

Cross-sectional measurements in reach #2 were made in a 624-ft subreach located near Gallatin Gateway at river mile 44. Seven cross-sections were placed in a riffle-pool sequence (Figures 12, 13 and 14).

Big Hole River

The free-flowing Big Hole River originates in the Bitterroot Mountains of southwest Montana and flows 156 miles before joining the Beaverhead River to form the Jefferson River (Figure 15). The river drains an area of approximately 2,476 square miles. Throughout its length, cattle ranches and irrigated hay lands occupy much of the river valley. During low water years, the dewatering of the river for the irrigation of hay crops can be severe.

Water quality throughout the river can generally be described as excellent. The river has a calcium-bicarbonate type water with low turbidity and low sulfate, sodium, chloride and metals concentrations. Selected chemical properties of the river near Twin Bridges in 1977 and 1978 are given in Table 4. Water temperatures considered undesirably high for the growth and propagation of salmonids have been recorded downstream of the USGS gage near Melrose in past years when severe dewatering has occurred.

Table 4. Selected chemical properties of the Big Hole River near Twin Bridges, Montana in summer and fall, 1977 and spring, 1978 (data from Bahls et al., 1979).

	Summer	Fall	Spring	Mean
Specific Conductance (umhos @ 25 C)	271	-	-	-
Total Alkalinity (mg/l $CaCO_3$)	116	-	-	-
Phosphate (PO_4 as P in mg/l)	.013	.012	.065	.030
Total Phosphorous (P in mg/l)	.025	.070	.135	.077
Nitrate plus Nitrite (NO_3+NO_2 as N in mg/l)	$<.01$	$<.01$	.03	-
Ammonia (NH_3 as N in mg/l)	$<.01$	$<.01$	.02	-
Kjeldahl Nitrogen (N in mg/l)	.32	.27	.60	.40

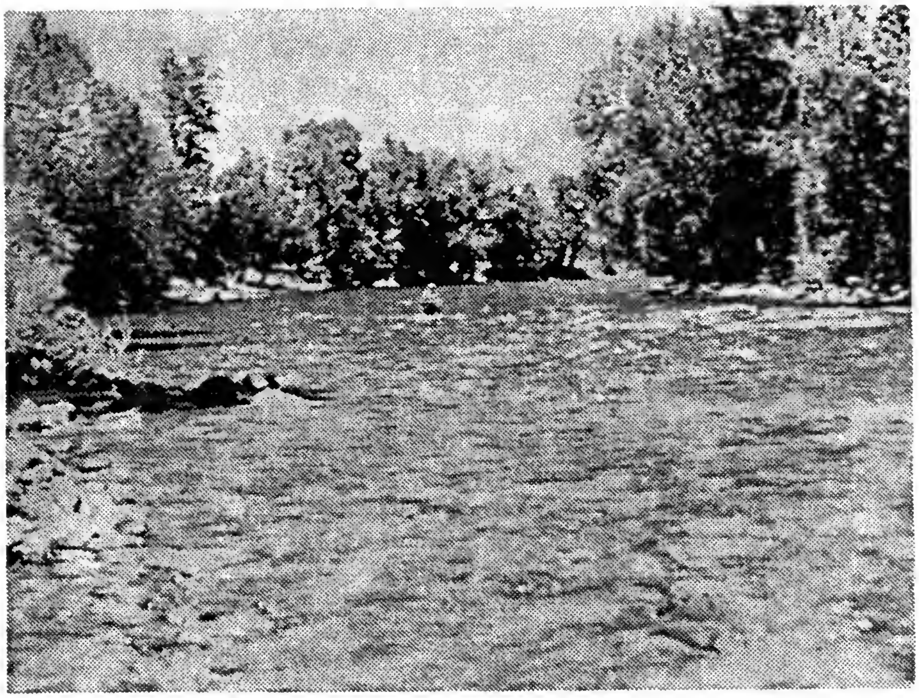

Figure 12. Subreach #2 of the Gallatin River looking downstream. Flow is 646 cfs.

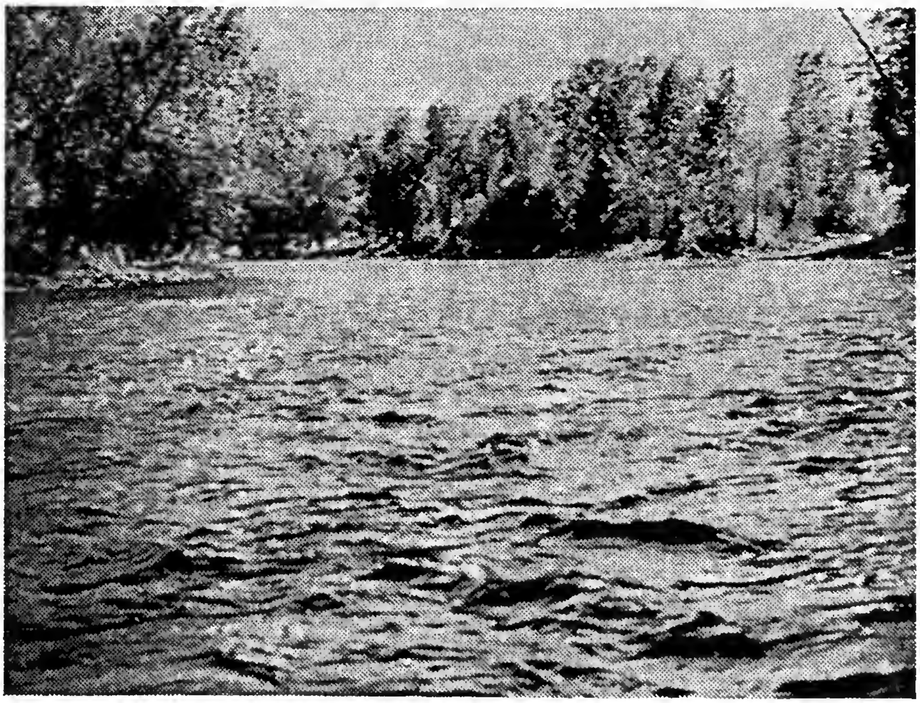

Figure 13. Subreach #2 of the Gallatin River looking upstream. Flow is 477 cfs.

Figure 14. Aerial photograph of subreach #2 of the Gallatin River showing the location of the seven cross-sections.

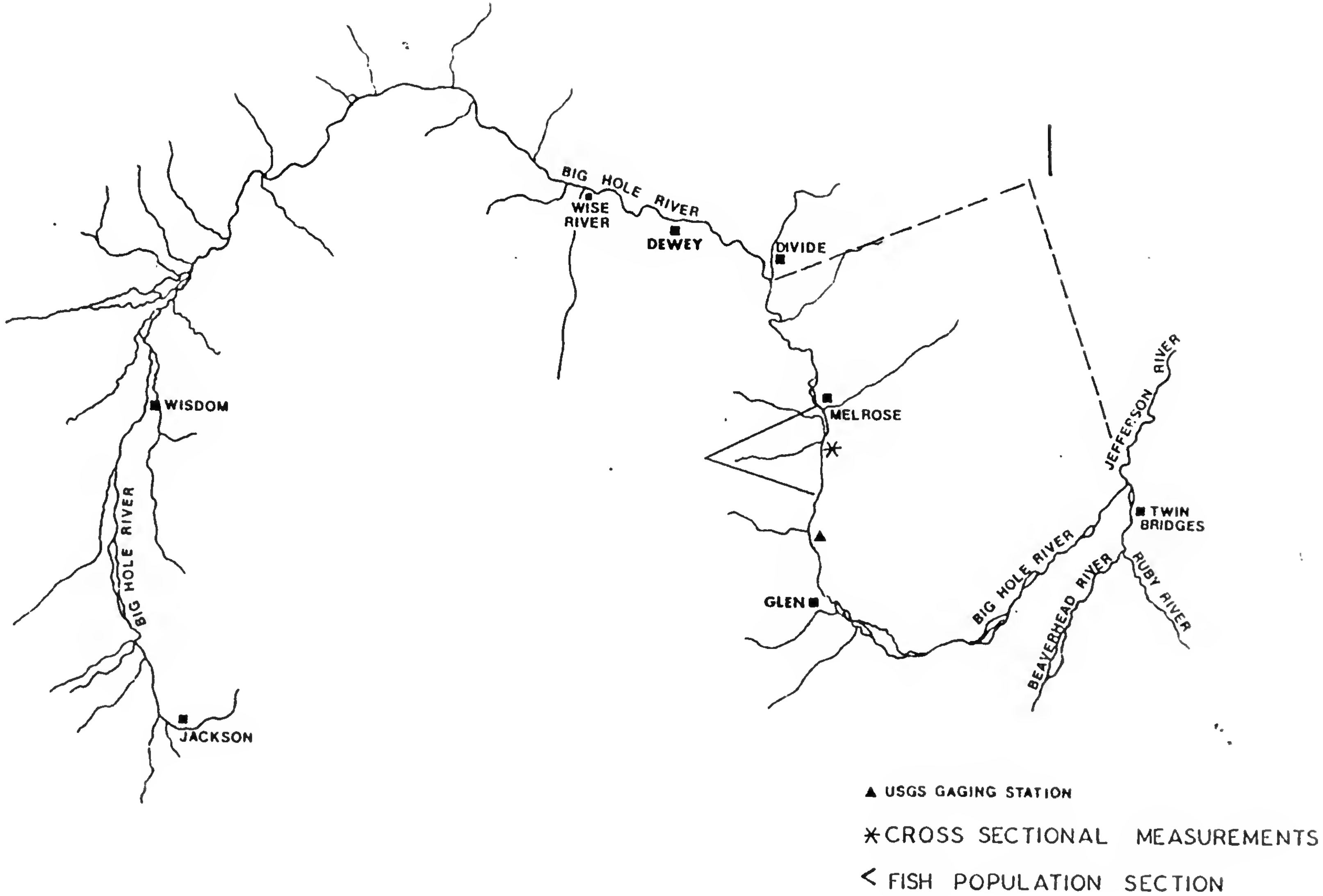

Figure 15. Map of the Big Hole River.

Reach #1 encompasses a 51-mile section between the river's mouth (river mile 0) and Divide, Montana (river mile 51). Much of this reach is typical of a river crossing an erodible floodplain. The river meanders through cottonwood-lined banks and in many places breaks up into more than one channel. The channel width generally exceeds 125 feet and gradient averages 14 ft/mile. The bottom substrate consists primarily of cobble and gravel interspersed with boulders.

The average discharge in reach #1 from 1924-1977, as measured at the USGS gage near Melrose (river mile 31), was 1,157 cfs. Extremes for the period of record since the failure of the Wise River Dam in 1927 have been a minimum of 49 cfs and a maximum of 14,300 cfs. The high water or snow runoff period normally extends from mid-April to mid-July, with peak flows occurring in early June. The lowest flows generally occur during the irrigation season in late August or September. Flows remain relatively low until the onset of runoff the following year.

Brown trout, rainbow trout and mountain whitefish are the dominant sport fish in reach #1. Other species present include brook trout, cutthroat trout, arctic grayling, longnose dace, mottled sculpin, white sucker, mountain sucker, longnose sucker, burbot, and carp.

Cross-sectional measurements in reach #1 of the Big Hole River were made in a 993-ft subreach located at river mile 36. Six cross-sections were placed in a riffle-pool sequence (Figures 16, 17 and 18).

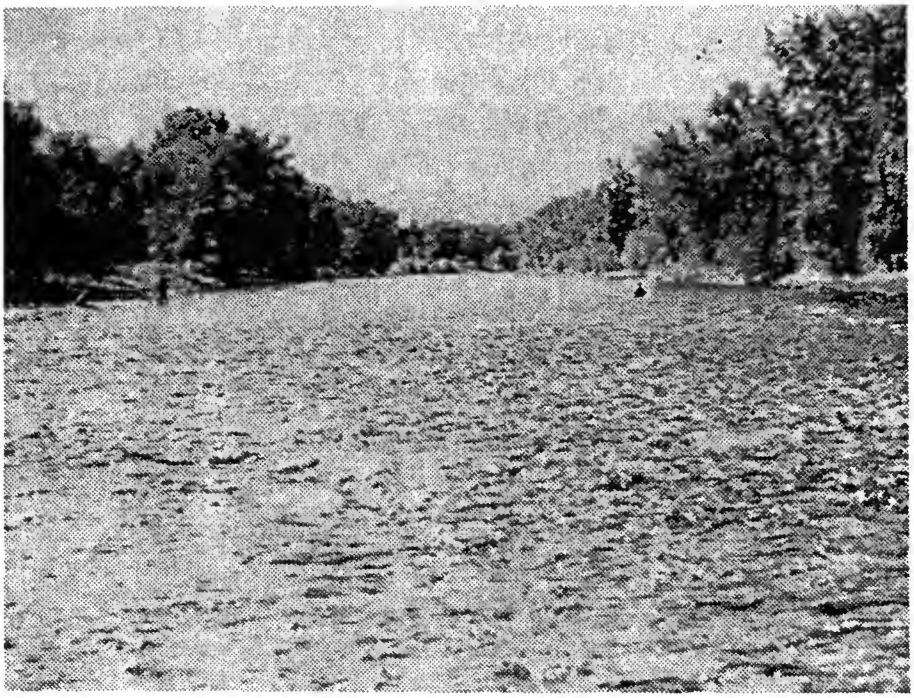

Figure 16. Subreach #1 of the Big Hole River looking downstream. Flow is 570 cfs.

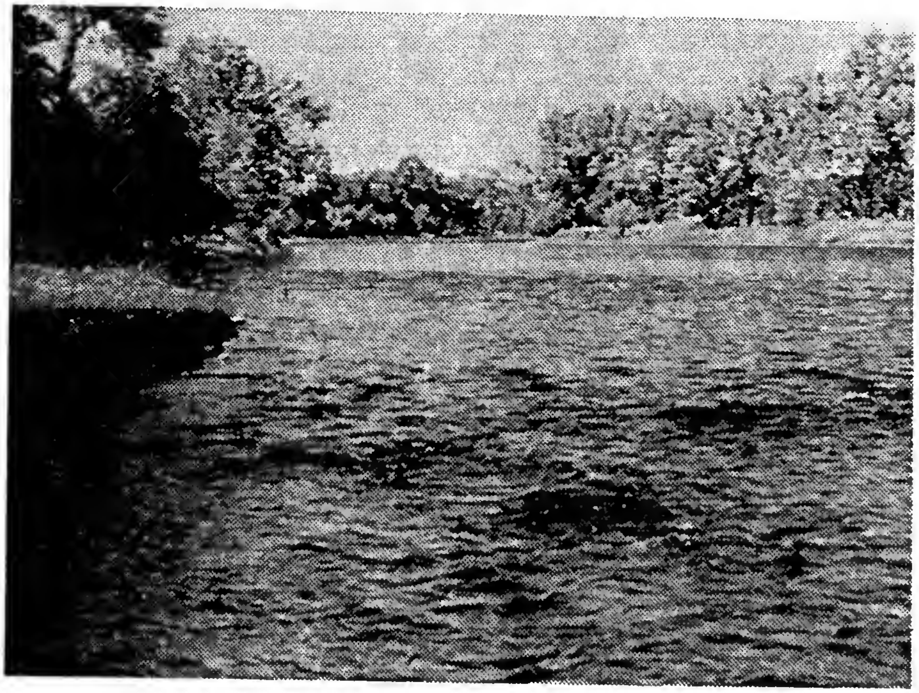

Figure 17. Subreach #1 of the Big Hole River looking upstream. Flow is 570 cfs.

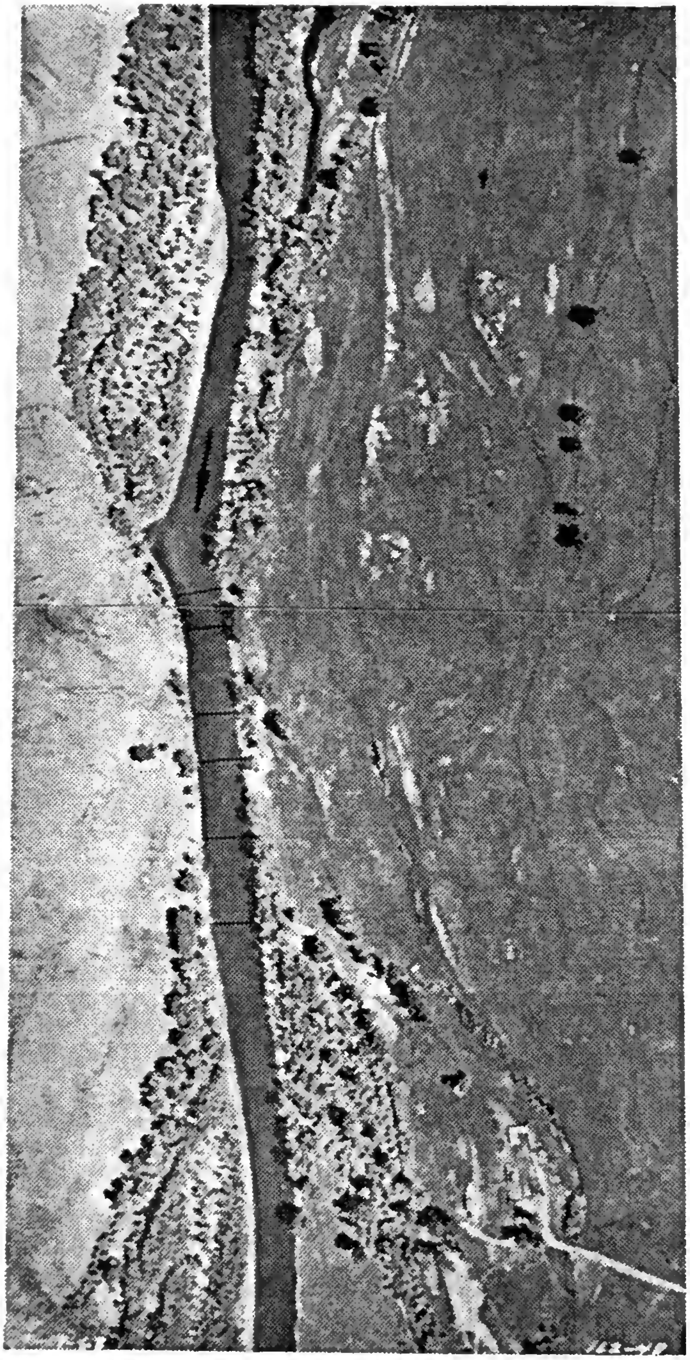

Figure 18. Aerial photograph of subreach #1 of the Big Hole River showing the location of the six cross-sections.

RESULTS

Standing Crop and Flow Relationships

The standing crop and flow data collected in past years for the Madison, Beaverhead, Gallatin and Big Hole Rivers are discussed by river reach in this section. The flow recommendations derived from this data are summarized and referenced to the monthly hydrograph for each reach in later sections. These recommendations will serve as the standard for evaluating the reliability of the flow recommendations generated by the four instream flow methods.

Relatively wide confidence intervals were obtained for the standing crop estimates to be presented in this section. The narrow confidence intervals advocated for research are impractical if not impossible to obtain for population estimates on the larger waterways such as those in this study. The standing crop comparisons in this paper are based entirely on differences in point estimates rather than statistical differences. The confidence intervals are presented solely for the benefit of the reader.

Madison River - Reach #1

Flows in the Madison River are primarily regulated by Hebgen Reservoir which stores water for downstream hydroelectric generation. Before 1968, the Montana Power Company began storing water in Hebgen Reservoir in late February to early March prior to the onset of spring runoff. This policy resulted in extremely low flows in the Madison River during late winter and early spring. In 1968, Montana Power agreed to start storing water when runoff begins in late April to early May. This change resulted in higher flows in the river from February to May.

The estimated standing crops of trout in a 4-mile section of reach #1 in spring 1967, prior to the flow increases, and in the spring of 1968, 1969, 1970, and 1971, after flows were increased, are given in Table 5. In 1971, three years after the policy change, the numbers and biomass of age II and older trout were 171 and 124%, respectively, of those in 1967.

It is assumed that the reduced winter flows prior to 1968 were the major factor limiting the trout populations in reach #1 and the population increases between 1967 and 1971 primarily reflect the higher flows following the change in storage policy. In recent years, fishing pressure and elevated summer water temperatures resulting from the thermal heating of Ennis Reservoir are known to affect trout populations in this reach. While these limiting factors were probably operating prior to 1971, flow is assumed to be the overriding factor.

Table 5. Estimated numbers and biomass (lbs) of trout in a 4-mile section of reach #1 of the Madison River in Spring 1967 through Spring 1971. 95% confidence interval in parenthesis.

	Spring				
Age-Group	1967	1968	1969	1970	1971
			BROWN TROUT-NUMBER		
II	3,037	5,217	2,943	5,713	3,077
III	981	2,397	3,090	2,441	3,675
IV & Older	689	727	911	793	765
	4,707(±2,206)	8,341(±2,728)	6,944(±1,940)	8,947(±2,021)	7,517(±1,312)
			RAINBOW TROUT-NUMBER		
II	1,804	1,092	2,068	2,749	3,197
III	268	285	509	495	786
IV & Older		100	104	57	113
	2,072(±1,768)	1,477(±1,014)	2,681(±1,738)	3,301(±1,648)	4,096(±863)
Total Number	6,779(±2,827)	9,818(±2,910)	9,625(±2,605)	12,248(±2,608)	11,613(±1,570)
			BROWN TROUT-POUNDS		
II	1,432	1,617	971	1,947	855
III	1,241	2,300	2,781	2,243	2,996
IV & Older	1,625	1,200	1,809	1,358	1,150
	4,298	5,117	5,561	5,548(±1,292)	5,001(±958)
			RAINBOW TROUT-POUNDS		
II	811	328	724	869	1,014
III	343	240	361	297	552
IV & Older		67	186	89	191
	1,154	635	1,271	1,255(±540)	1,757(±374)
Total Pounds	5,452	5,752	6,832	6,803(±1,400)	6,758(±1,028)

Rainbow trout responded more favorably to the flow increases than did brown trout. In 1971 numbers and biomass of age II and older rainbow trout were 198 and 152%, respectively, of those in 1967 while brown trout numbers and biomass were 160 and 116%, respectively, of those in 1967. Younger rainbow trout (age II and III) responded more favorably to the flow increases than age IV and older rainbow trout and age III brown trout responded more favorably than age II and age IV and older brown trout.

The distribution of the average daily flows for the approximate 12-month period preceding each estimate shows the magnitude of the flow increases following the 1967 estimate (Table 6). The lowest estimate of trout numbers and biomass (in 1967) followed the 12-month period containing the lowest flows. Between spring 1966 and spring 1967, 7% of the average daily flows were less than 900 cfs versus 0% for the other years and 18% were less than 1,100 cfs versus 0 - 3% for the other years. The highest estimate of trout numbers (in 1970) followed the 12-month period containing the highest flows. Between spring 1969 and spring 1970, 97% of the average daily flows exceeded 1,400 cfs and none were less than 1,240 cfs. The estimated trout biomass peaked in 1969 and remained stable through 1970 and 1971. During the 12-month period preceding each of these three biomass estimates, 94 to 100% of the average daily flows exceeded 1,200 cfs and none were less than 923 cfs.

The population and flow data for the 1966-71 period suggest that standing crops of trout were reduced by flows less than approximately 900-1,100 cfs. During this period, the highest trout standing crops were preceded by flows greater than approximately 1,200-1,400 cfs. The optimum flow in reach #1 for adult rainbow and brown trout probably exceeds 1,200 cfs.

Madison River - Reach #3

Standing crops of brown trout, the dominant trout species, and rainbow trout in a 5-mile section near reach #3 of the Madison River were estimated in fall 1967 through fall 1978. The study section begins 12 miles downstream of the lower boundary of reach #3 at river mile 60 (Figure 1). The section provides a measure of the flows needed to maintain trout populations in the upper river even though it is not located within reach #3.

Table 6. Distribution of the average daily flows during the approximate 12-month period preceding the trout population estimates in a 4-mile section of reach #1 of the Madison River in Spring 1967 through Spring 1971.

Spring to Spring	Average Daily Flows (cfs)													Age II & Older Trout	
	695 - 699	700 - 799	800 - 899	900 - 999	1000 - 1099	1100 - 1199	1200 - 1299	1300 - 1399	1400 - 1499	1500 - 1599	1600 - 1699	1700 - 1799	≥1800	Number	Biomass (lbs)
1966-67	1	16	10	8	36	37	37	63	42	26	17	9	90	6,779	5,452
1967-68	0	0	0	3	3	6	7	17	27	23	26	28	182	9,818	5,752
1968-69	0	0	0	2	9	10	19	18	26	55	37	31	171	9,625	6,832
1969-70	0	0	0	0	0	0	1	9	29	39	50	23	207	12,248	6,803
1970-71	0	0	0	1	2	6	8	16	15	93	13	15	192	11,613	6,758

The estimates of junvenile (age I+) brown trout appear to reflect the flow patterns during this period. Standing crops of wild rainbow trout and adult (age II+ and older) brown trout during portions of 1967-1978 were affected by the stocking of catchable, hatchery rainbow trout and intense fishing pressure. These groups were eliminated from the analyses since population fluctuations are not directly correlated to flow variations.

The USGS gage at the head of the study section was not operating during much of the 1967-1978 period. The approximate flows for the section were obtained by adjusting those for the USGS gage below Hebgen Reservoir.

The approximate distribution of the average daily flows during the 12-month period preceding each estimate of age I+ brown trout is given in Table 7. It is assumed that these standing crops primarily reflect the magnitude of the flows during the 12-month period preceding each estimate and not the flows during spawning, incubation, and the first summer of growth for that particular year class.

The lowest standing crop estimate (1,643 age I+ trout weighing 405 lbs in 1967) followed the lowest flows. Between October 1966 and September 1967, approximately 17% of the average daily flows were less than 650 cfs compared to 0 to 1.5% for the other years and approximately 19% of the average daily flows were less than 750 cfs compared to 0 to 3.5% for the other years.

The highest standing crop estimate (7,876 age I+ trout weighing 1,696 lbs in 1976) followed the highest flows. Between October 1975 and September 1976, approximately 95% of the average daily flows exceeded 1,150 cfs and none were less than approximately 1,088 cfs.

The estimated numbers of age I+ brown trout for years other than 1967 and 1976 were relatively stable, ranging from 3,012 to 4,410. The biomass estimates for these years were more variable, ranging from 583 to 1,044 lbs.

The data suggest that flows greater than approximately 1,150 cfs would sustain the highest standing crops of juvenile brown trout while flows less than approximately 650-750 cfs appear to severely reduce their numbers. The optimum flow for juvenile (age I+) brown trout probably exceeds 1,150 cfs.

A 6-mile section of reach #3 between the mouths of Wolf and Squaw creeks (Figure 1) has been closed to angling since February 1977. This section was established in conjunction

Table 7. Approximate distribution of the average daily flows during the 12-month period preceding the estimates of age I+ brown trout in a 5-mile section near reach #3 of the Madison River in fall 1967 through fall 1978.

	AVERAGE DAILY FLOWS (cfs)									Age I+ Brown Trout	
Fall to Fall	450 - 549	550 - 649	650 - 749	750 - 849	850 - 949	950 - 1049	1050 - 1149	1150 - 1249	≥1250	Number	Biomass (lbs)
1966-67	0	56	7	1	4	76	7	7	178	1,643	405
1967-68	0	0	0	0	2	19	63	76	175	4,410	1,044
1968-69	0	0	0	0	0	20	71	34	215	3,179	583
1969-70	0	0	0	0	0	31	115	49	150	3,876	775
1970-71	0	1	0	13	11	14	61	21	231	3,689	726
1971-72	0	0	0	0	0	0	28	34	296	3,012	727
1972-73	0	0	0	0	0	0	48	75	218	3,597	825
1973-74	0	0	0	0	0	26	76	43	195	4,013	851
1974-75	0	0	0	0	0	7	4	85	242	4,834	966
1975-76	0	0	0	0	0	0	17	74	255	7,876	1,696
1976-77	3	2	7	40	46	2	10	76	157	4,332	947
1977-78	0	0	0	0	13	51	42	15	221	3,596	767

with a study evaluating "catch and release" angling on the upper Madison River. Spring and fall estimates of trout standing crops by age-groups in a 4½-mile portion of the closed section have been made annually beginning in 1975. By fall of 1978, following 19 months of closure, the estimated biomass of trout in the 4½-mile study section increased by 104%. At this time the trout population was believed to be at or near the carrying capacity.

Flows in reach #3, as measured at the USGS gage above the mouth of the West Fork (Kirby Ranch), were generally maintained at 700-1,500 cfs throughout the summer of 1978. The minimum flow recorded was 516 cfs.

Flows during 1979, a below average water year, were considerably lower than those in 1978. Flows were generally maintained at 600-900 cfs throughout the summer of 1979. The minimum flow recorded was 487 cfs.

Between September 1978 and September 1979, the estimated biomass of adult trout (age II+ and older) in the 4½-mile study section increased by 12% from 7,163 lbs to about 8,029 lbs. By species, the biomass of adult rainbow trout increased by about 23% and that of brown trout decreased by about 4%. If the assumption that the population in 1978 was at carrying capacity is correct, then flows of about 600-900 cfs do not appear to adversely affect standing crops of adult trout in reach #3.

It is suspected that because of their above average size, the recommendations previously derived for age I+ brown trout are probably more applicable to adults than to the juvenile stage. During the study, age I+ brown trout averaged 8.0 inches and 0.22 lbs. Until more conclusive data becomes available, the recommendations derived for age I+ brown trout will also be applied to adult brown and rainbow trout with one minor adjustment. A minimum flow of about 650 cfs for adults is judged more compatible with the standing crop and flow data previously discussed for reach #3 than is the 650-750 cfs derived for age I+ brown trout.

Beaverhead River - Reach #2

The Beaverhead River provides the most complete set of standing crop and flow data presently available to the Montana Department of Fish, Wildlife and Parks. In the following discussion, the data collected through 1978 are summarized. A paper incorporating the 1979 data is presently being prepared for publication in 1980.

Standing crops of trout in a 6,455 ft section of reach #2 of the Beaverhead River were estimated in the fall and spring between October 1966 and October 1978. The section begins 1.8 miles below Clark Canyon Dam and 1.4 miles below a USGS gage (Figure 7). Fall estimates were made between September 20 and October 28. Spring estimates were made between March 1 and April 2. Age I+ (yearling) and age II trout were the youngest group estimated in the fall and spring, respectively. Fall estimates of age II+ and older brown trout and spring estimates of age II and older rainbow trout are generally inflated due to the upstream movement of spawners into the study section. These estimates were eliminated from the analysis since most do not reflect standing crops of resident trout. Fall estimates of age I+ brown trout are assumed to be valid estimates of residents.

During the study, spring estimates of numbers and biomass of age II and older brown trout ranged from 317 - 1,749 and 721 lbs - 2,623 lbs, respectively. Fall estimates of numbers and biomass of age I+ and older rainbow trout ranged from 112 - 1,338 and 224 lbs - 1,857 lbs, respectively.

Flows varied considerably during the study. Between 1966 and 1978 the mean flows during the irrigation season (approximately April 16 - October 14) ranged from 320 - 870 cfs and mean flows during the non-irrigation season (approximately October 15 - April 15) ranged from 97 to 467 cfs. Average daily flows ranged from 57 - 1,365 cfs.

Two variables, the year-class strength during the previous estimate and the magnitude of the flow releases between successive estimates, were found to explain much of the annual variation in the estimated numbers of the various age-groups of rainbow trout (Table 8). In combination, the number of average daily flows less than 100 cfs between successive fall estimates and the estimated numbers of age I+ rainbow trout the previous fall explain 96% of the annual variation in the fall estimates of numbers of age II+ rainbow trout, the number of average daily flows less than 150 cfs and the estimated numbers of age II+ rainbow trout the previous fall explain 90% of the annual variation in the fall estimates of numbers of age III+ rainbow trout, and the number of average daily flows less than 300 cfs and the estimated numbers of age III+ and older rainbow trout the previous fall explain 81% of the annual variation in the fall estimates of numbers of age IV+ and older rainbow trout.

Similar analyses were conducted for the biomass estimates (Table 8). In combination, the number of average daily flows less than 100 cfs and the estimated biomass of age I+ rainbow trout the previous fall explain 98% of the annual variation

Table 8. Partial and multiple correlation coefficients for the multiple linear relationships between standing crops of rainbow trout and average daily flows (ADF) in the Beaverhead River.

Dependent Variable	Partial Correlation Coefficients		Multiple Correlation(r)
	No. of Age I+ Rainbow Trout-Previous Fall	No. of ADF ≤ 100 cfs	
No. of Age II+ Rainbow Trout-Fall	.96[a]	-.93[a]	.98[a]
	No. of Age II+ Rainbow Trout-Previous Fall	No. of ADF ≤ 150 cfs	
No. of Age III+ Rainbow Trout-Fall	.95[a]	-.87[b]	.95[a]
	No. of Age III+ and Older Rainbow Trout-Previous Fall	No. of ADF ≤ 300 cfs	
No. of Age IV+ & Older Rainbow Trout - Fall	.89[a]	-.80[b]	.90[b]
	Biomass of Age I+ Rainbow Trout - Previous Fall	No. of ADF ≤ 100 cfs	
Biomass of Age II+ Rainbow Trout-Fall	.98[a]	-.96[a]	.99[a]
	Biomass of Age II+ Rainbow Trout - Previous Fall	No. of ADF ≤ 150 cfs	
Biomass of Age III+ Rainbow Trout-Fall	.88[a]	-.73[c]	.88[b]
	Biomass of Age III+ and Older Rainbow Trout-Previous Fall	No. of ADF ≤ 300 cfs	
Biomass of Age IV+ & Older Rainbow Trout - Fall	.74[c]	-.69[c]	.77[d]

a - Significant at the 99% confidence level.
b - Significant at the 95% confidence level.
c - Significant at the 90% confidence level.
d - Significant at the 85% confidence level.

in the fall estimates of biomass of age II+ rainbow trout, the number of average daily flows less than 150 cfs and the estimated biomass of age II+ rainbow trout the previous fall explain 77% of the annual variation in the fall estimates of biomass of age III+ rainbow trout, and the number of average daily flows less than 300 cfs and the estimated biomass of age III+ and older rainbow trout the previous fall explain 59% of the annual variation in the fall estimates of biomass of age IV+ and older rainbow trout.

Only the standing crops of older brown trout appear to be influenced by the magnitude of the flow releases during the study (Table 9). In combination, the number of average daily flows less than 300 cfs between successive spring estimates and the estimated numbers of age III and older brown trout the previous spring explain 71% of the annual variation in the spring estimates of numbers of age IV and older brown trout, and the number of average daily flows less than 300 cfs and the estimated biomass of age III and older brown trout the previous spring explain 55% of the annual variation in the spring estimates of biomass of age IV and older brown trout.

During the study, fall estimates of numbers of age I+ brown trout ranged from 39 to 908 and those of rainbow trout ranged from 10 to 997. Flows were examined to determine if this extreme variation in numbers could be attributed to flow variations.

The flow and population data suggest that average daily flows less than 250 cfs favored the survival of rainbow trout up to age I+. This relationship was not evident for brown trout.

Spawning flows produced the most consistent relationship with numbers of age I+ brown trout. The data suggest that the pattern and magnitude of the flow releases during the brown trout spawning period influenced reproductive success which in turn led to the extreme variation in numbers of age I+ brown trout. Flow fluctuations during spawning appear to have a greater impact on reproductive success than the magnitude of the spawning flows and decreasing flows appear more favorable than constant flows. In general, spawning flows devoid of violent fluctuations and gradually decreasing to a minimum of 150 cfs during the 47-day brown trout spawning period (September 15 - October 31) appear to maximize reproductive success.

Much of the fluctuation of the spawning flows that occurred during the study can be attributed to the Montana Department of Fish, Wildlife and Parks requesting lower flow releases to facilitate the completion of the fall population estimates. This practice was discontinued in 1974.

Table 9. Partial and multiple correlation coefficients for the multiple linear relationships between standing crops of brown trout and average daily flows (ADF) in the Beaverhead River.

	Partial Correlation Coefficients		
Dependent Variable	No. of Age III & Older Brown Trout - Previous Spring	No. of ADF ≤ 300 cfs	Multiple Correlation (r)
No. of Age IV & Older Brown Trout - Spring	.84[a]	-.60[d]	.84[a]
	Biomass of Age III & Older Brown Trout - Previous Spring	No. of ADF ≤300 cfs	
Biomass of Age IV & Older Brown Trout - Spring	.74[b]	-.56[d]	.74[c]

a - Significant at the 95% confidence level.
b - Significant at the 90% confidence level.
c - Significant at the 85% confidence level.
d - Significant at the 80% confidence level.

In conclusion, annual variations in the reproductive success of brown trout appear to be the major factor influencing the variations in total standing crops of brown trout during the study. Reproductive success was probably related to the magnitude and pattern of the flow releases during the fall spawning period. Flows had little direct influence on the total standing crop of brown trout even during the final years of the study when densities of brown trout were highest and flows were among the lowest. The one exception is age IV and older brown trout whose numbers and biomass appear to be partially limited by flows less than approximately 300 cfs.

The magnitude of the flow releases directly affected all age groups of rainbow trout. Results indicate that standing crops of age II+, III+, and IV+ and older rainbow trout were partially limited by flows less than approximately 100, 150, and 300 cfs, respectively, while numbers of rainbow trout up to age I+ appear to be limited by flows greater than approximately 250 cfs. During low flow years, the higher numbers and presumably higher survivial of age I+ rainbow trout partially compensated for the elevated losses of older rainbow trout, resulting in little change in the total standing crops. The high numbers of age I+ rainbow trout in turn greatly influenced year class strength in succeeding years. Yearling strengths in previous years and flows were the major factors regulating standing crops of age II+ and older rainbow trout during the study. In general, older trout were more affected by flow reductions than were younger trout, and rainbow trout were more affected than brown trout.

Age IV+ and older rainbow trout are highly desired for the sport fishery of the Beaverhead River due to their trophy size. During the study, this group averaged 4.97 lbs with specimens as large as 13.25 lbs captured. The results of the study suggest that continually managing the flows solely for trophy-size trout may eventually result in low densities of rainbow trout by providing unfavorable conditions for age I+ rainbow trout and, thereby, limit recruitment into the population. A minimum instream flow less than the optimum needed for a trophy fishery may be desirable in terms of providing higher densities of rainbow trout but not necessarily of trophy size.

Gallatin River - Reach #2

Three study sections were established within a 22-mile portion of reach #2 of the Gallatin River in 1976 to evaluate the impact of summer irrigation withdrawals (dewatering) on trout populations (Figure 11). Section I began near the canyon mouth at river mile 44 and extended 15,000 ft downstream. This section is upstream of the majority of irrigation diversions.

Section II began at river mile 33 and extended 10,000 ft downstream. Summer flow is reduced from Section I, but is maintained even during low water years. Section III began at river mile 24 and extended 8,000 ft downstream. Summer flow is much reduced compared to Section II and in some years ceases entirely. During the non-irrigation months of November through June, flows in the three sections are similar.

Gaging sites were established at the study sections in July, 1976. Flows were measured with a Gurley-type AA current meter and the stage-discharge relationship for each site determined. Flows were recorded weekly.

Standing crops of trout by species were estimated in Section I in September 1976 and September 1977; in Section II in September 1977; and in Section III in September 1976 (Table 10). Standing crops of rainbow trout could not be estimated in Sections II and III due to their low numbers. April estimates were also made but are not included in this paper. All estimates are presented and discussed in Vincent and Nelson (1978).

Summer flows in Section I in 1977 were reduced when compared to those in 1976. The minimum summer flow measured in 1977 (393 cfs) was 75% of the minimum measured in 1976 (523 cfs).

During the study, the population of brown trout was relatively stable in Section I. The estimated number and biomass of age II+ and older brown trout in September 1977, which followed a low water year (1977), were 98 and 105%, respectively, of those in September 1976, which followed three successive above average water years (1974, 1975, and 1976). Mean annual flows for the Gallatin River during the 1974, 1975 and 1976 water years, as measured at the USGS gage near Gallatin Gateway, were the three highest for a 44-year period of record, while the mean annual flow during the 1977 water year was one of the lowest with a rank of 33.

The population of rainbow trout, the dominant trout species in Section I, decreased during the study. The estimated number and biomass of age II+ and older rainbow trout in September 1977 were 66 and 73%, respectively, of those in September 1976. The estimated number and biomass of all age-groups of rainbow trout were reduced when compared to those in September 1976 with age-group II+ showing the greatest reduction in number (49%) and biomass (49%) and age III+ the least (5% for number and 6% for biomass).

Table 10. Estimated numbers and biomass (lbs) of trout by age-groups in Sections I, II and III of the Gallatin River in September 1976 and 1977. Approximate 80% confidence interval in parenthesis.

SECTION I - BROWN TROUT

	September 1976		September 1977	
Age-Groups	N/15,000 Ft	lbs/15,000 Ft	N/15,000 Ft	lbs/15,000 Ft
II+	389	188	530	295
III+	784	917	457	570
IV+ & Older	297	632	455	964
	1,470 (±347)	1,737 (±411)	1,442 (±379)	1,829 (±587)

SECTION I - RAINBOW TROUT

	N/15,000 Ft	lbs/15,000 Ft	N/15,000 Ft	lbs/15,000 Ft
II+	1,790	474	877	233
III+	759	441	724	415
IV+ & Older	599	624	461	483
	3,148 (±899)	1,539 (±351)	2,062 (±353)	1,131 (±203)

SECTION II - BROWN TROUT

			N/10,000 Ft	lbs/10,000 Ft
II+			826	516
III+	No Estimate		297	351
IV+ & Older			165	315
			1,288 (±233)	1,182 (±257)

SECTION III - BROWN TROUT

	N/8,000 Ft	lbs/ 8,000 Ft		
II+	336	164		
III+	242	241	No Estimate	
IV+ & Older	245	354		
	823 (±270)	759 (±299)		

Flows in Section II during the summer of 1977 were less than those in the summer of 1976. The minimum summer flow measured in 1977 (250 cfs) was 63% of the minimum flow measured in 1976 (396 cfs).

Fall estimates of brown trout, the dominant trout species in Section II, could not be compared since no estimate was made in September 1976. However, the summer (April - September) rate of population decrease, referred to as the mortality rate, is available for comparison to the rate for Section I. In 1977, a summer mortality of 65% for age III+ and older brown trout was measured in Section II, which had a minimum summer flow of 250 cfs, while Section I, which had a minimum summer flow of 393 cfs, showed a summer mortality of only 26% for age III+ and older brown trout. The summer mortality rate in Section II was elevated when compared to the rate for Section I, the least dewatered study section. This elevated summer mortality of older trout coincided with a 36% reduction in the minimum summer flow between Sections I and II. Mortality rates for younger trout are not available for comparison.

The lowest summer flow measured in Section III in 1976 was 198 cfs. Section III was totally dewatered for a 5-day period in July 1977. Prior to 1977, the total dewatering of Section III last occurred in 1973. The September 1976 estimate of brown trout, the dominant trout species in Section III, followed three successive above average water years and preceded total dewatering.

While differences in angling pressure and habitat may be contributing to the variation in standing crops of trout between study sections, data collected in this study suggest that summer flow is the major factor limiting trout populations. Simple linear regression analyses show that the minimum summer flows measured in Sections I, II, and III in 1976 and 1977 explain 99.6 and 95.0%, respectively, of the variation in the September estimates of numbers and biomass of age II+ and older trout (Figure 19). Both relationships are significant at the 95% confidence level.

Figure 19 shows that the study section having a minimum summer flow of 523 cfs supported about two times the number and biomass of adult trout that occurred in the study section having a minimum summer flow of 250 cfs. It appears that summer flows of approximately 523 cfs and greater would sustain the highest standing crops of trout, while summer flows of approximately 250 cfs are judged undesirable on the basis of the approximate 50% reduction of the trout standing crop.

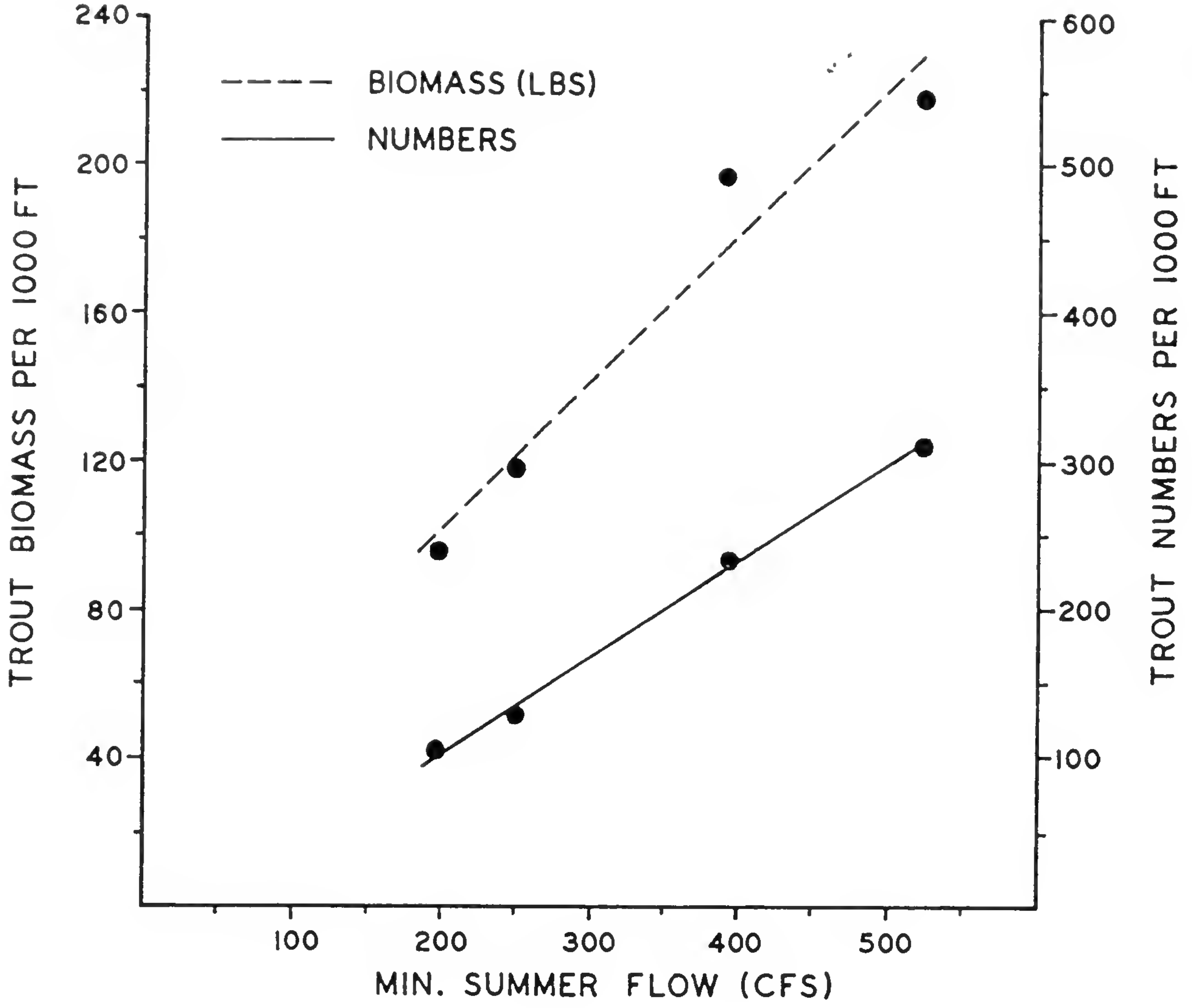

Figure 19. Relationship between the minimum summer flow (cfs) and the estimated numbers and biomass (lbs) of age II+ and older trout in Sections I, II and III of reach #2 of the Gallatin River in September 1976 and 1977.

Study results suggest that flow reductions affect rainbow trout more severely than brown trout. A 25% reduction in the minimum summer flow in Section I (from 523 cfs in 1976 to 393 cfs in 1977) coincided with a 27% reduction in the estimated biomass of adult rainbow trout, but had no adverse effect on brown trout. The rainbow trout population was also highest in the least dewatered study section (Section I), considerably reduced in Section II, and nearly absent in Section III, where dewatering is severe. A comparative measure of the abundance of rainbow trout is provided by the April 1977 electrofishing runs in which 627, 72, and 5 rainbow trout were captured in Sections I, II and III, respectively. Brown trout appear to be adversely affected by summer flows of 250 cfs as indicated by the elevated summer mortality in Section II. These results suggest that the optimum flow for adult rainbow trout exceeds 523 cfs while the optimum for brown trout is lower, lying between 250 and 393 cfs.

Standing crops of mountain whitefish were estimated in the upper 8,000 ft of Section I in September 1976 and 1977 (Table 11). The estimated number and biomass of age III+ and older whitefish in 1977 were 68 and 67%, respectively, of those in 1976. This 33% reduction in the biomass of whitefish coincided with a 25% reduction in the minimum summer flow (from 523 cfs in 1976 to 393 cfs in 1977).

Table 11. Estimated numbers and biomass (lbs) per 8,000 ft of mountain whitefish in Section I of the Gallatin River in September 1976 and 1977. Approxmate 80% confidence interval in parenthesis.

SECTION I - MOUNTAIN WHITEFISH

	September 1976		September 1977	
Age-Group	N/8,000 ft	lbs/8,000 ft	N/8,000 ft	lbs/8,000 ft
III+ & Older	3,993(±737)	3,796(±739)	2,714(±382)	2,559(±343)

Between April and September 1977, the estimated number and biomass of age III and older whitefish in Section II increased by 62 and 93%, respectively. These increases probably reflect the upstream movement of whitefish from the severely dewatered downstream reaches of the Gallatin River.

The April 1977 estimates provide a comparative measure of the abundance of the resident mountain whitefish in the study sections. Section I, the least dewatered study section, supported the highest population. The estimated number of age III and older whitefish per 1,000 ft in Sections I, II, and III in April 1977 was 467, 433, and 289, respectively. The estimated biomass of whitefish per 1,000 ft in Sections I, II, and III was 374, 335, and 255 lbs, respectively. These estimates followed three successive above average water years (1974, 1975 and 1976). The minimum summer flows measured in 1976 in Sections I, II and III were 523, 396 and 198 cfs, respectively.

The data suggest that summer flows of approximately 523 cfs and greater would sustain the highest standing crops of adult mountain whitefish. Flows of approximately 393 cfs are judged undesirable on the basis of the 33% reduction in the biomass of adult whitefish in Section I between 1976 and 1977. On the basis of the 32% reduction in the biomass of adult whitefish between Sections I and III in April 1977, flows of approximately 198 cfs are judged undesirable. A minimum instream flow of about 198 cfs is, therefore, suggested for adult whitefish. The optimum flow for adult whitefish probably exceeds 523 cfs.

Big Hole River - Reach #1

Standing crops of brown and rainbow trout in a 4.5-mile section of reach #1 of the Big Hole River were estimated in September 1969, 1970, 1977 and 1978 (Table 12). The 1969 and 1970 estimates are for rainbow trout greater than 7 inches and brown trout greater than 10 inches. The 1977 and 1978 estimates are for rainbow trout greater than 10 inches and age II+ and older brown trout. It is assumed that the September estimates of trout standing crops primarily reflect the magnitude of the dewatering that occurs in reach #1 during the summer irrigation season. This assumption is supported by Kozakiewicz (1979) who measured fishermen use and harvest during 1977 and 1978 on a 10-mile section of reach #1. He concluded that angler harvest did not appear to be an immediate threat to the well-being of the trout populations and the fishery resource would best be served by efforts to maintain and enhance the habitat, especially stream flows.

The distributions of the average daily flows during the summer (June-September) preceding each estimate are given in Table 13. These four summers include both below and above average water years in which the level of dewatering ranged from mild to severe. The minimum average daily flows measured in the summers of 1969, 1970, 1977 and 1978 were 208, 248, 173 and 408 cfs, respectively.

Table 12. Estimated numbers and biomass (lbs) of trout in a 4.5 mile section of reach #1 of the Big Hole River in September 1969, 1970, 1977 and 1978. Eighty percent (80%) confidence interval in parenthesis.

September			
1969	1970	1977	1978
BROWN TROUT-NUMBERS			
1,707(±409)[a]	1,613(±403)[a]	1,856(±425)[c]	2,465(±553)[c]
RAINBOW TROUT-NUMBERS			
788(±394)[b]	815(±238)[b]	344(±130)[a]	1,074(±486)[a]
BROWN TROUT-POUNDS			
2,629(±699)[a]	2,605(±535)[a]	2,714(±604)[c]	3,322(±649)[c]
RAINBOW TROUT-POUNDS			
654[b]	594(±159)[b]	401(±152)[a]	1,074(±478)[a]

a - Estimate for trout 10 inches and greater (approximately age II+ and older).

b - Estimate for trout 7 inches and greater.

c - Estimate for trout age II+ and older.

Table 13. Distribution of the average daily flows during the approximate 4-month summer period (June-September) preceding the trout population estimates in reach #1 of the Big Hole River in September of 1969, 1970, 1977 and 1978.

	Average Daily Flows (cfs)											
June-Sept.	173 - 199	200 - 249	250 - 299	300 - 349	350 - 399	400 - 449	450 - 499	500 - 549	550 - 599	600 - 699	700 - 799	800 - 899	Greater than 900
1969	0	20	9	5	2	6	0	4	0	2	2	1	60
1970	0	1	19	1	2	0	1	7	5	9	5	5	62
1977	9	15	7	4	5	5	3	5	6	7	8	6	28
1978	0	0	0	0	0	5	4	7	4	8	7	15	68

The four September estimates, while not directly comparable to one another due to the different groups of trout estimated in each year, do indicate that standing crops of trout were highest following the summer of 1978 when flows were highest. The estimated number of brown trout in 1978 was about 133 to 153% of those in previous years and the estimated biomass was about 122 to 128% of those in previous years. The estimated number of rainbow trout in 1978 was about 132 to 312% of those in previous years and biomass was about 164 to 268% of those in previous years. The rainbow trout population responded more favorably to the 1978 summer flow increases than did the brown trout population.

The study section was extended an additional 5.5 miles in 1977. Standing crop estimates by age-groups for the 10-mile extended section in September 1977 and 1978 are given in Table 14. In 1978 the estimated number and biomass of age II+ and older brown trout were 109 and 109%, respectively, of those in 1977, while the number and biomass of age II+ and older rainbow trout were 207 and 165%, respectively, of those in 1977. Total trout numbers and biomass in 1978 were 119 and 114%, respectively, of those in 1977. Again, adult rainbow trout responded more favorably to the 1978 summer flow increases than did adult brown trout.

All age-groups of brown trout increased in number between 1977 and 1978 with age IV+ and older showing the greatest increase (18%) and age III+ the least (5%). Numbers of age II+ rainbow trout increased by 173% and those of age III+ rainbow trout by 91%. Numbers of age IV+ and older rainbow trout remained about the same.

The flow and limited population data for the 1969 to 1978 period suggest that standing crops of rainbow and brown trout in the study sections were reduced by summer flows less than approximately 400 cfs. Until more definitive data become available, a minimum flow of 400 cfs is recommended.

Table 14. Estimated numbers and biomass (lbs) of trout by age-groups in a 10-mile section of reach #1 of the Big Hole River in September 1977 and 1978. Eighty percent (80%) confidence interval in parenthesis.

Age-Groups	September 1977	September 1978
	BROWN TROUT-NUMBERS	
II+	2,805	2,991
III+	1,974	2,075
IV+ & older	1,367	1,617
	6,146 (±983)	6,683 (±1,031)
	RAINBOW TROUT-NUMBERS	
II+	377	1,030
III+	137	262
IV+ & older	201	189
	715 (±315)	1,481 (±574)
Total Numbers	6,861 (±1,032)	8,164 (±1,180)
	BROWN TROUT-POUNDS	
II+	2,192	2,472
III+	2,698	2,674
IV+ & older	2,936	3,373
	7,826 (±1,207)	8,519 (±1,267)
	RAINBOW TROUT-POUNDS	
II+	257	656
III+	152	267
IV+ & older	345	318
	754 (±264)	1,241 (±413)
Total Pounds	8,580 (±1,236)	9,760 (±1,333)

Instream Flow Recommendations

Standing Crop and Flow Relationships

The standing crop and flow data generated a range of minimum instream flow recommendations for each of the five reaches. Flows less than the lower limit are judged undesirable since they appear to lead to substantial reductions of the standing crop of adult fish or the standing crop of a particular group of fish, such as trophy-size trout. This lower limit will be referred to as the absolute minimum instream flow recommendation. Flows equal to or greater than the upper limit supported the highest standing crops. This upper limit will be referred to as the most desirable minimum instream flow recommendation. The flows needed to sustain optimum standing crops will probably exceed the most desirable minimum. The flows between the absolute and most desirable minimums are assumed to sustain intermediate or normal population levels. These minimums are listed by reach in Table 15. The life stage and species of fish for which each minimum was derived are also given.

Table 15. Summary of the minimum instream flow recommendations derived from the fish population and flow data collected in five reaches of the Madison, Beaverhead, Gallatin and Big Hole rivers. The life stage and species of fish for which each recommendation applies are also listed.

		Instream Flow Recommendations (cfs)	
Reach	Life Stage and Species	Absolute Minimum	Most Desirable Minimum
Madison(#1)	adult brown trout	900-1,100	1,200-1,400
	adult rainbow trout	900-1,100	1,200-1,400
Madison(#3)	juv. brown trout	650- 750	1,150
	adult brown trout	650	1,150
	adult rainbow trout	650	1,150
Beaverhead(#2)	adult brown trout	-	300[a]
	juv. rainbow trout	-	≤250
	adult rainbow trout	150[b]	300[c]
Gallatin(#2)	adult brown trout	250	250-393[d]
	adult rainbow trout	393	523
	adult mtn. whitefish	198	523
Big Hole(#1)	adult brown trout	400	-
	adult rainbow trout	400	-

a - applies to age IV and older brown trout.
b - applies to age III+ rainbow trout.
c - applies to age IV+ and older (trophy-size) rainbow trout.
d - the optimum flow lies within this range.

The final flow recommendations for each reach (Table 16) were derived to meet the needs of adult trout. For the rivers of southwest Montana, the amount of water or living space required by adults is believed to be greater than the amount needed by any other life stage, including spawning and incubation. The minimum recommendations in Table 16 should, therefore, meet the needs of all life stages.

The instream flow recommendations are assumed to apply to all of the low water or non-runoff months even though recommendations may have been derived for only a portion of this period, such as the summer irrigation season. In the headwaters of the Missouri River drainage of southwest Montana, the low water period generally includes the months of August through April. During the high water or snow runoff period, which generally occurs during May, June and July, the Montana Department of Fish, Wildlife and Parks bases its flow recommendations on the high flows judged necessary to maintain the channel morphology and to flush bottom sediments. This methodology is discussed and the flow recommendations for each of the five reaches during the high water period are given in Montana Department of Fish and Game (1979).

Single Transect Method

The minimum instream flow recommendation was selected at the inflection point on the graph of wetted perimeter versus discharge for a single riffle cross-section within the Madison #3, Beaverhead, Gallatin and Big Hole reaches. For the Madison #1 reach, a cross-section through a shallow area containing weed beds was used since well defined riffles were absent. These curves are shown in Figures 20 through 24.

The recommendations generated by the single transect method compare favorably to those derived from the trout-flow data (Table 16). In three of the five reaches, the inflection

Table 16. Comparison of the minimum instream flow recommendations derived from the single transect method and the trout standing crop and flow data for five reaches of the Madison, Beaverhead, Gallatin and Big Hole rivers.

	INSTREAM FLOW RECOMMENDATIONS (cfs)		
	Single Transect Method	Trout Standing Crop-Flow Data	
Reach	Minimum Flow	Absolute Min. Flow	Most Desirable Min. Flow
Madison(#1)	1,100	900-1,100	1,200-1,400
Madison(#3)	600	650	1,150
Beaverhead(#2)	225	150	300
Gallatin(#2)	400	250	523
Big Hole(#1)	450	400	-

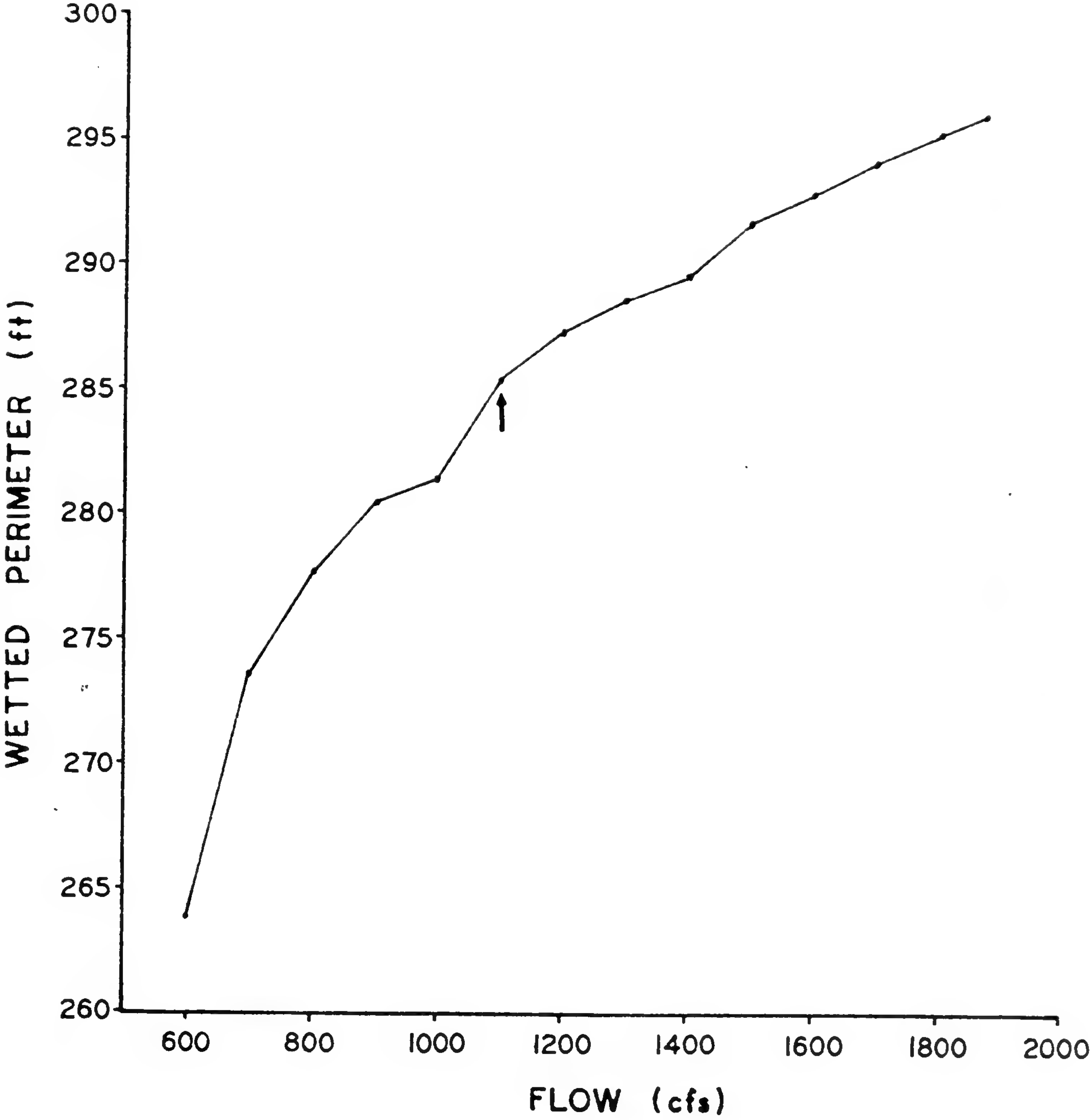

Figure 20. The relationship between wetted perimeter and flow for a single cross-section (CS #5) in reach #1 of the Madison River.

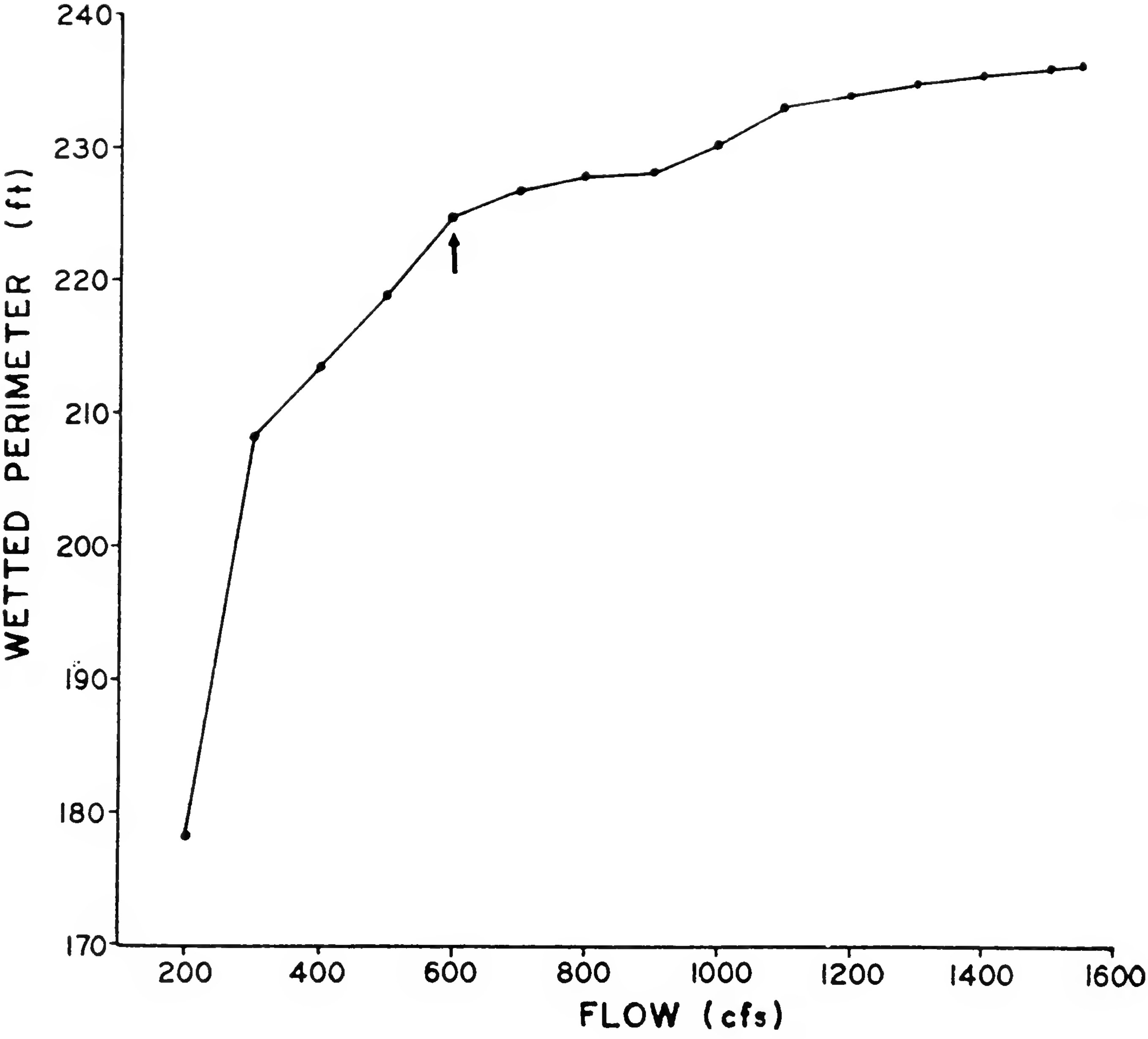

Figure 21. The relationship between wetted perimeter and flow for a single riffle cross-section (CS #1) in reach #3 of the Madison River.

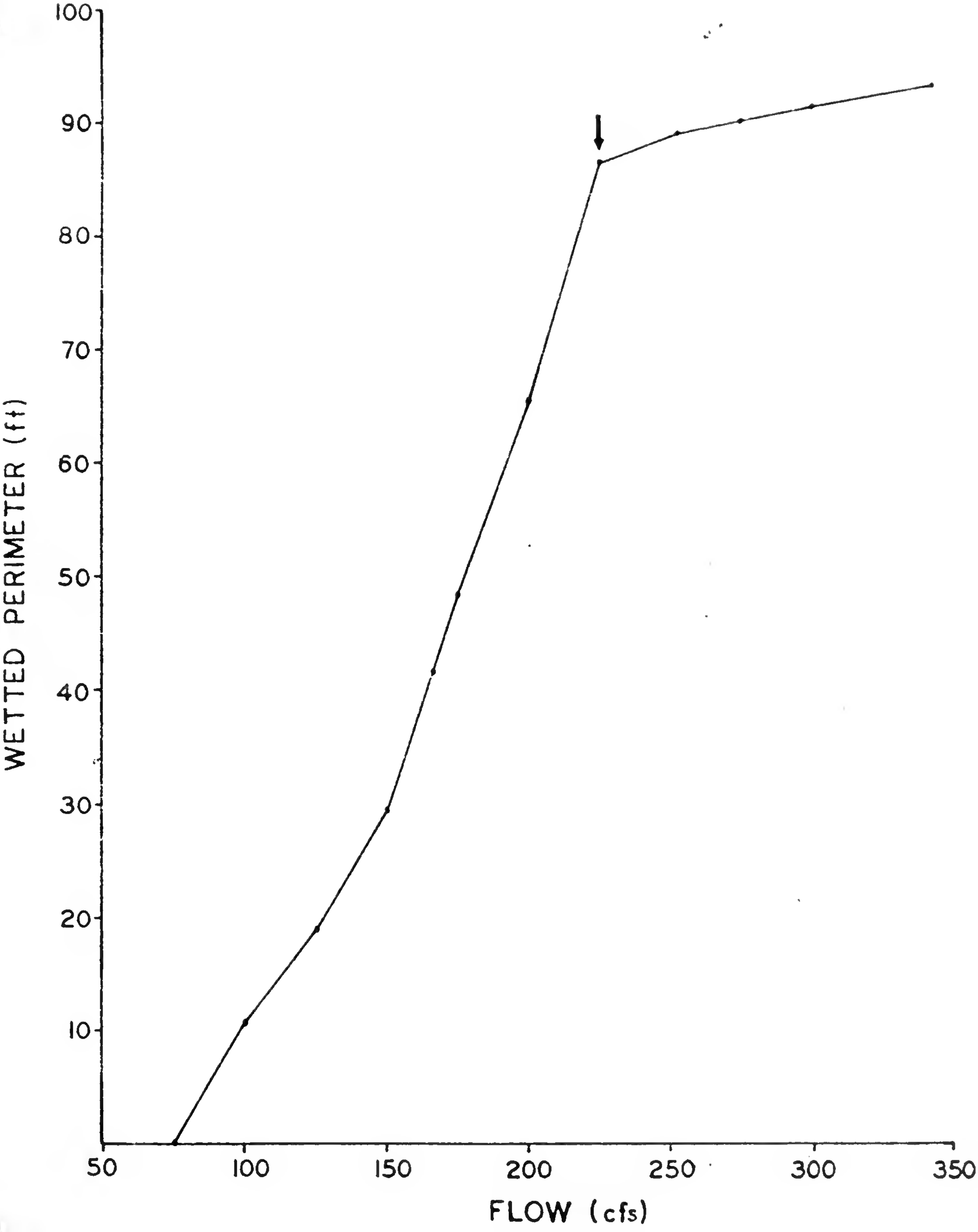

Figure 22. The relationship between wetted perimeter and flow for a single riffle cross-section (CS #1) in reach #2 of the Beaverhead River.

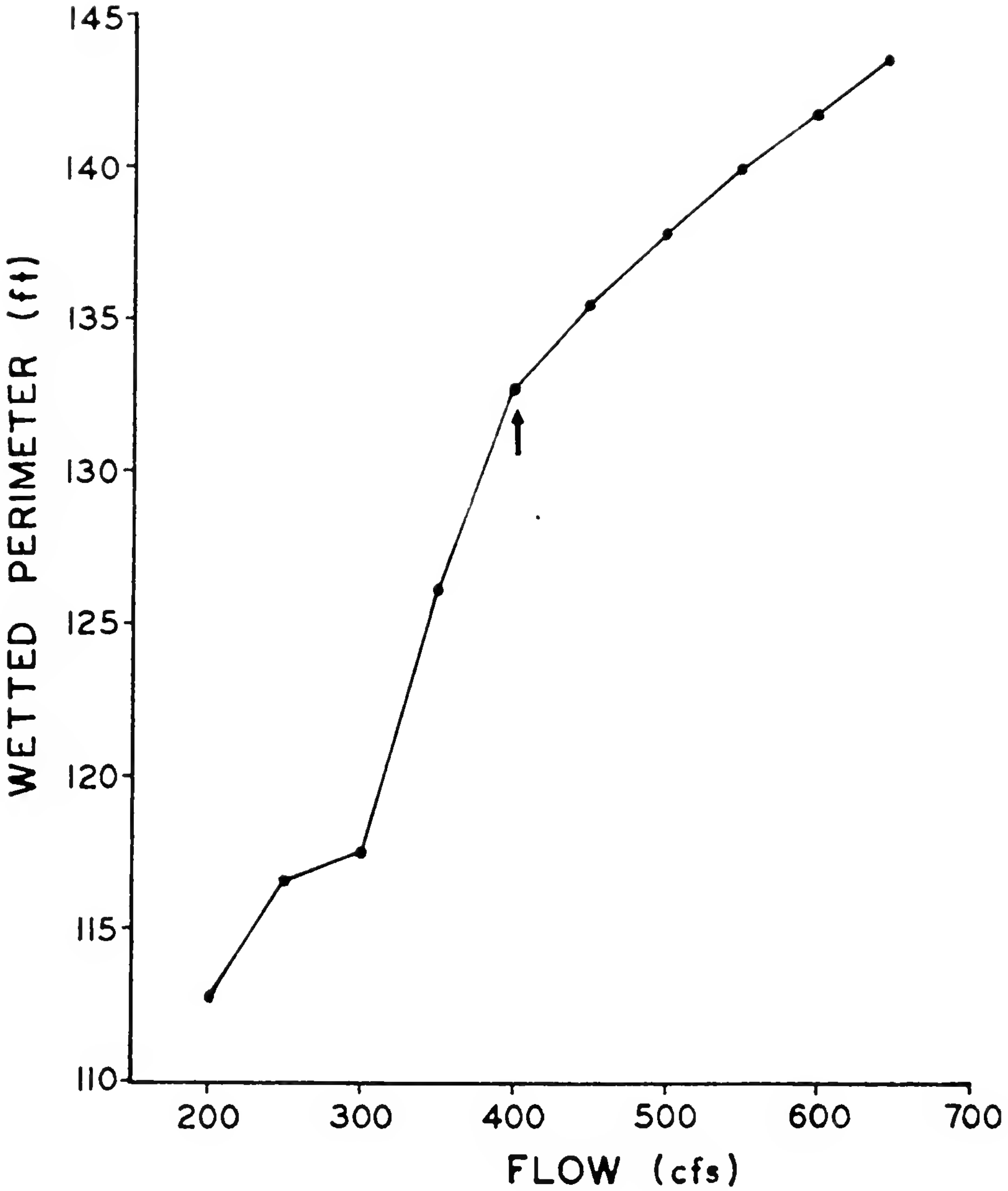

Figure 23. The relationship between wetted perimeter and flow for a single riffle cross-section (CS #1) in reach #2 of the Gallatin River.

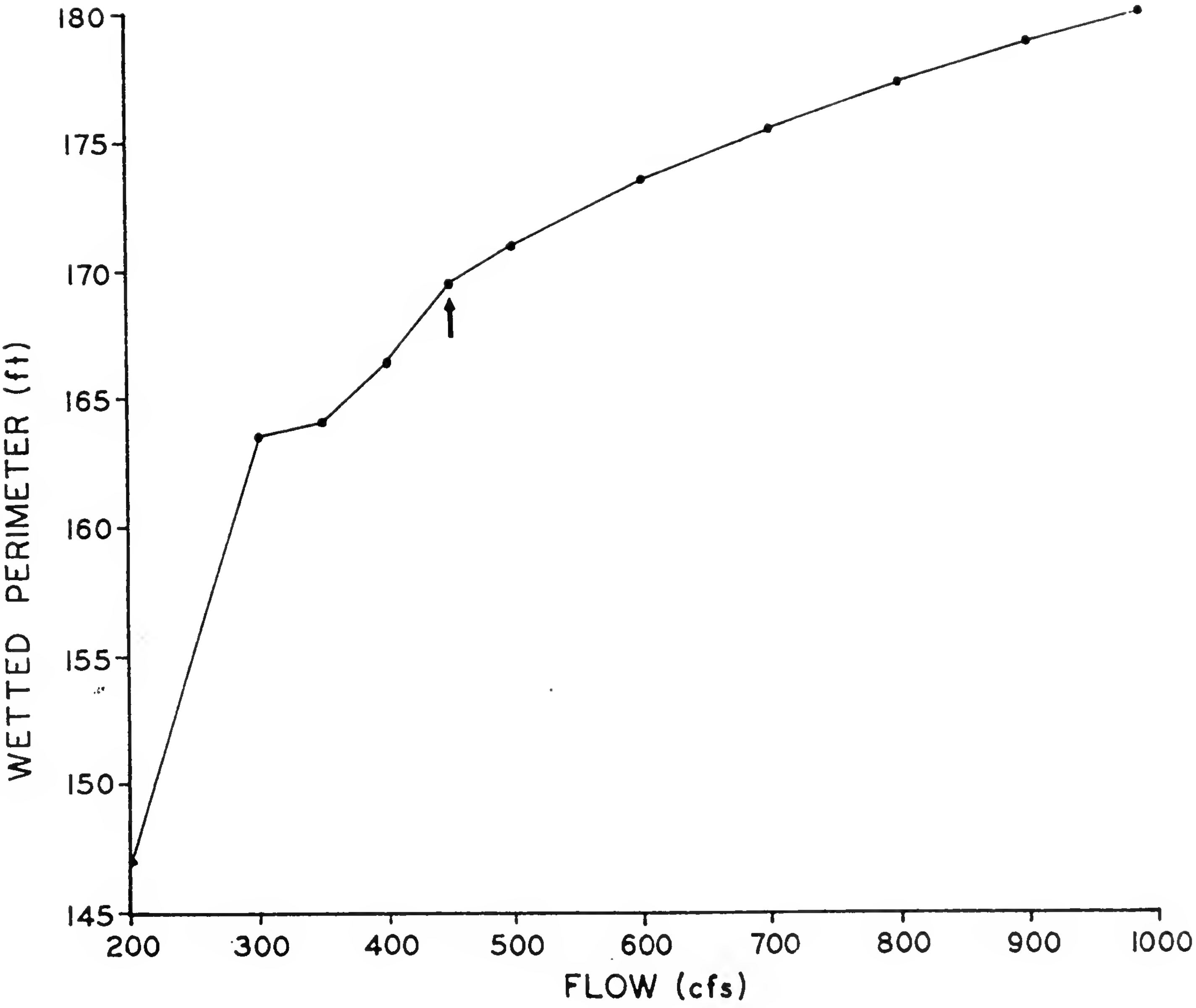

Figure 24. The relationship between wetted perimeter and flow for a single riffle cross-section (CS #1) in reach #1 of the Big Hole River.

points occurred at or near the absolute minimum flow recommendations while in the remaining two reaches (Beaverhead and Gallatin) the inflection points occurred midway between the absolute and most desirable minimums. It should be noted that the minimum flow of 400 cfs derived for the Gallatin reach compares favorably to the absolute minimum of 393 cfs derived from the trout-flow data for adult rainbow trout. This biological data suggested that a minimum of about 400 cfs is needed if the Gallatin reach were managed primarily for rainbow rather than brown trout. On this basis, the single transect recommendation for the Gallatin reach is judged acceptable as an absolute minimum recommendation.

Multiple Transect Method

The minimum instream flow recommendation was selected at the inflection point on the graph of wetted perimeter versus discharge for a composite of four to seven cross-sections within each reach. Cross-sections 5, 6 and 7 in the Beaverhead reach were eliminated from the analysis due to problems with the calibration of the WSP model and the placement of the transects. The curves are shown in Figures 25 through 29.

The flows at which the inflection points occurred are listed by reach and compared to the minimum recommendations derived from the trout standing crop and flow data in Table 17. Inflection points were generally not as well defined as those on the wetted perimeter curves used in the single transect method. On the curve for the Gallatin reach, a discernible inflection point was not present and no minimum recommendation could be derived. In the Madison #1 and Big Hole reaches, inflection points occurred at more than one flow.

Table 17. Comparison of the minimum instream flow recommendations derived from the multiple transect method and the trout standing crop and flow data for five reaches of the Madison, Beaverhead, Gallatin and Big Hole rivers.

	INSTREAM FLOW RECOMMENDATIONS (cfs)		
	Multiple Transect Method	Trout Standing Crop-Flow Data	
Reach	Minimum Flow	Absolute Min. Flow	Most Desirable Min. Flow
Madison(#1)	900 and 1,400	900-1,100	1,200-1,400
Madison(#3)	500	650	1,150
Beaverhead(#2)	100	150	300
Gallatin(#2)	-	250	523
Big Hole(#1)	400 and 700	400	-

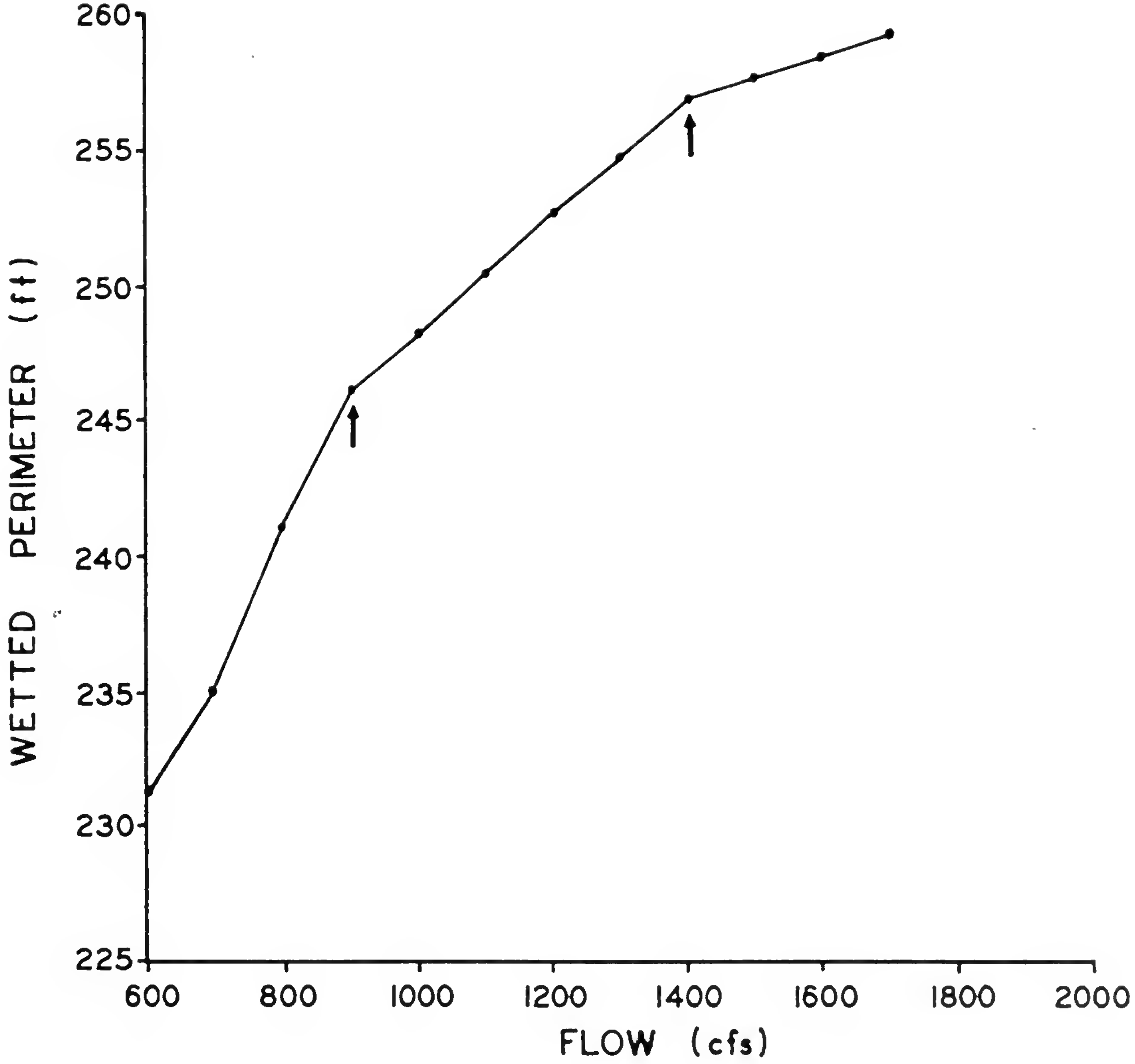

Figure 25. The relationship between wetted perimeter and flow for a composite of five cross-sections in reach #1 of the Madison River.

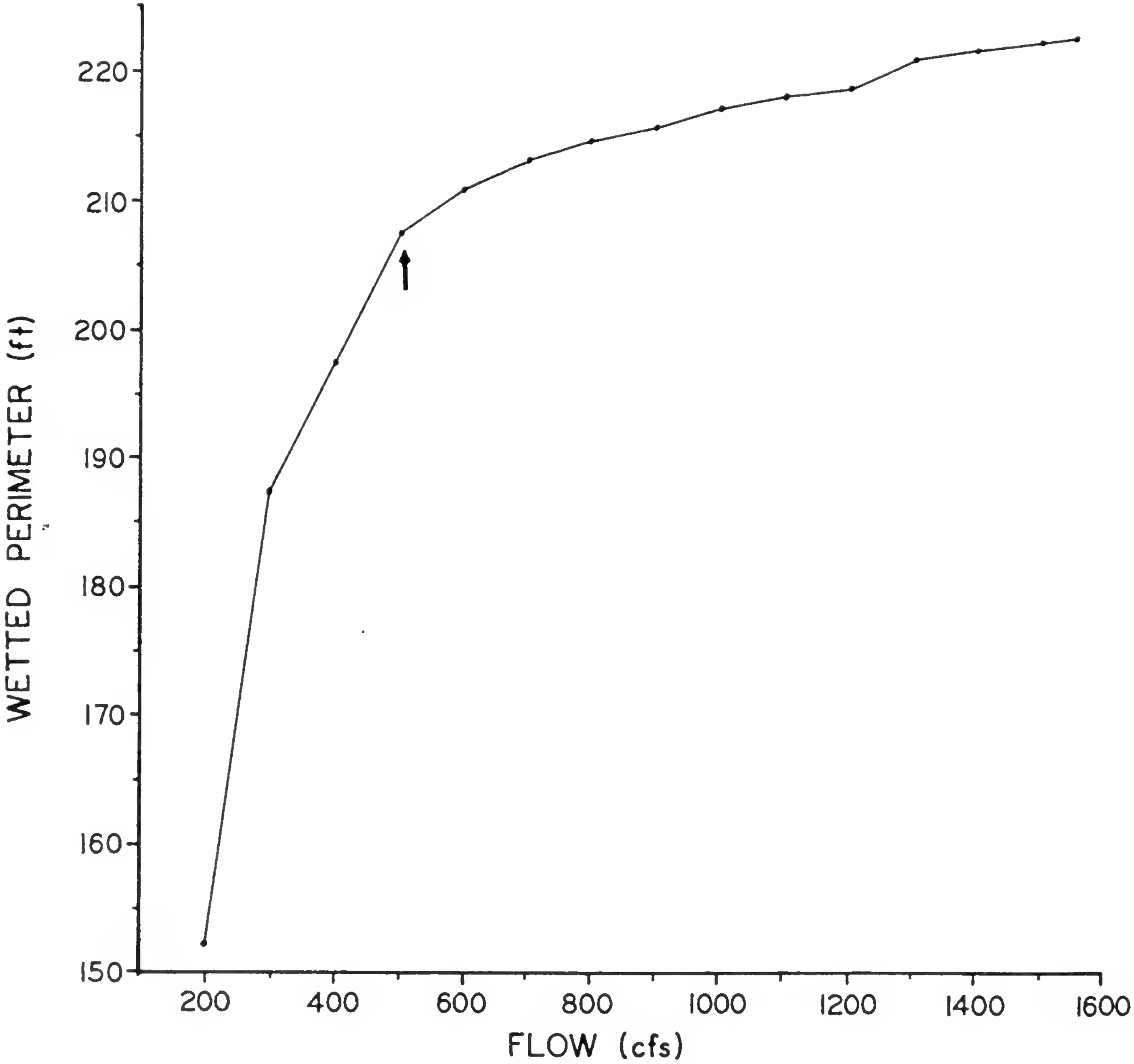

Figure 26. The relationship between wetted perimeter and flow for a composite of five cross-sections in reach #3 of the Madison River.

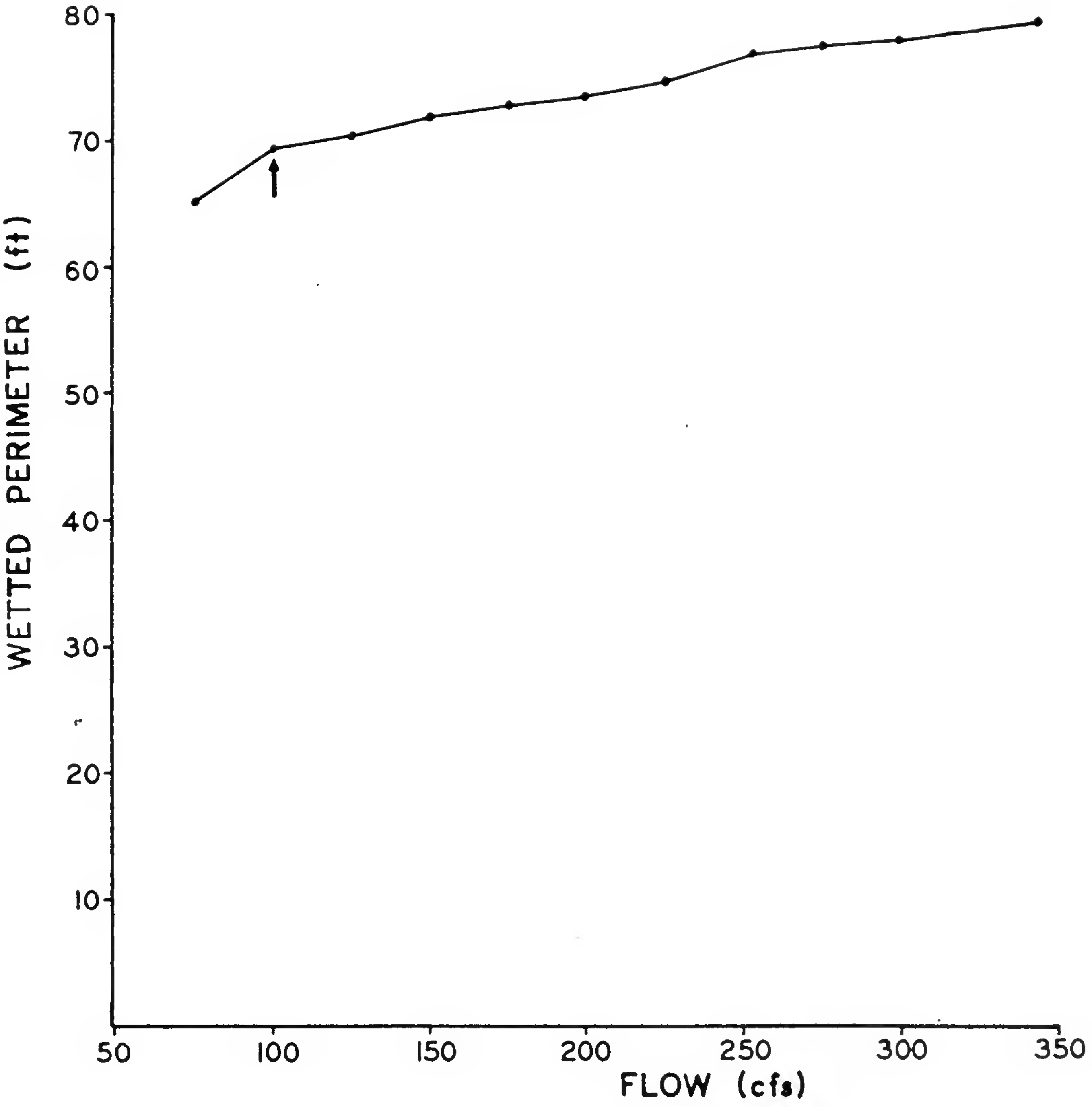

Figure 27. The relationship between wetted perimeter and flow for a composite of four cross-sections in reach #2 of the Beaverhead River.

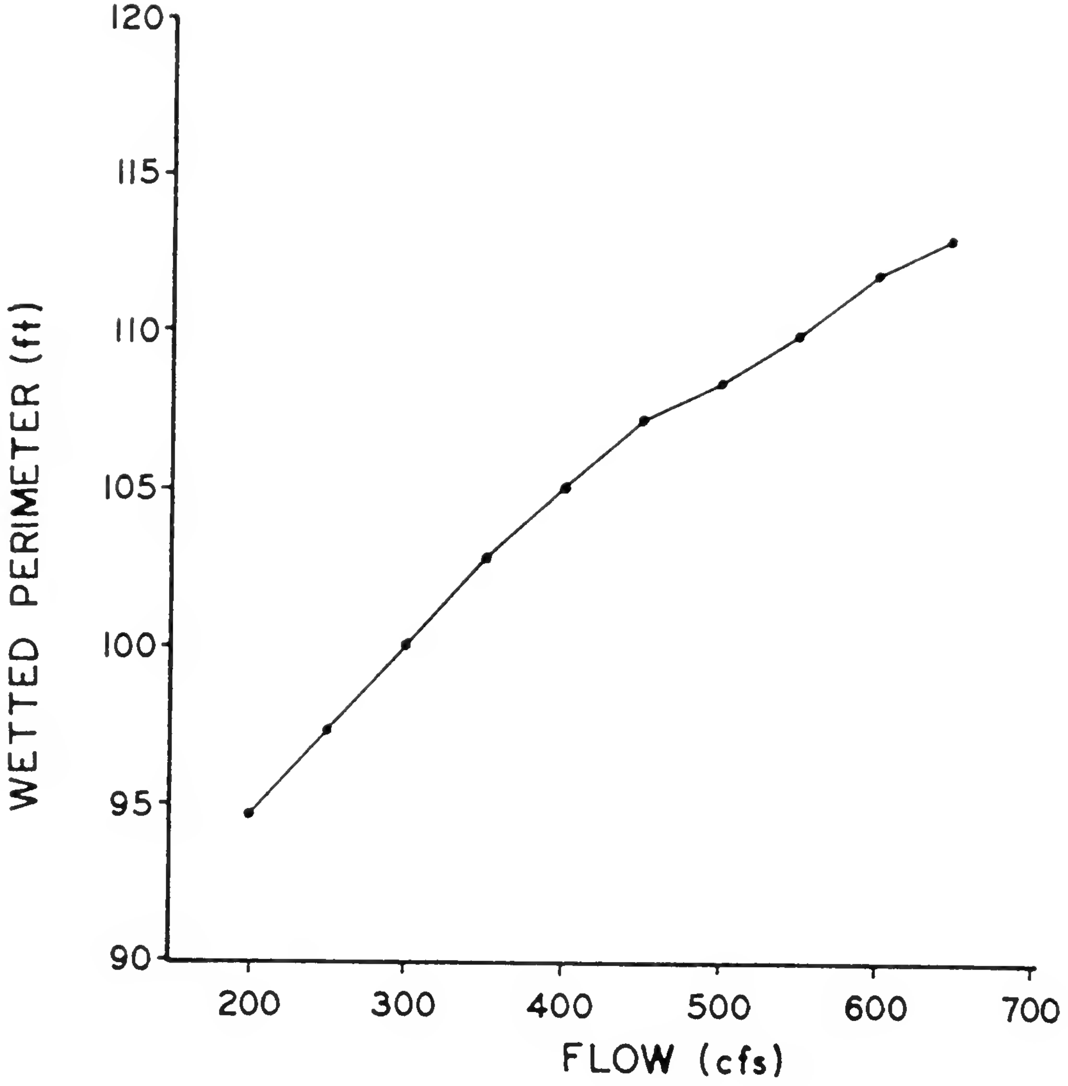

Figure 28. The relationship between wetted perimeter and flow for a composite of seven cross-sections in reach #2 of the Gallatin River.

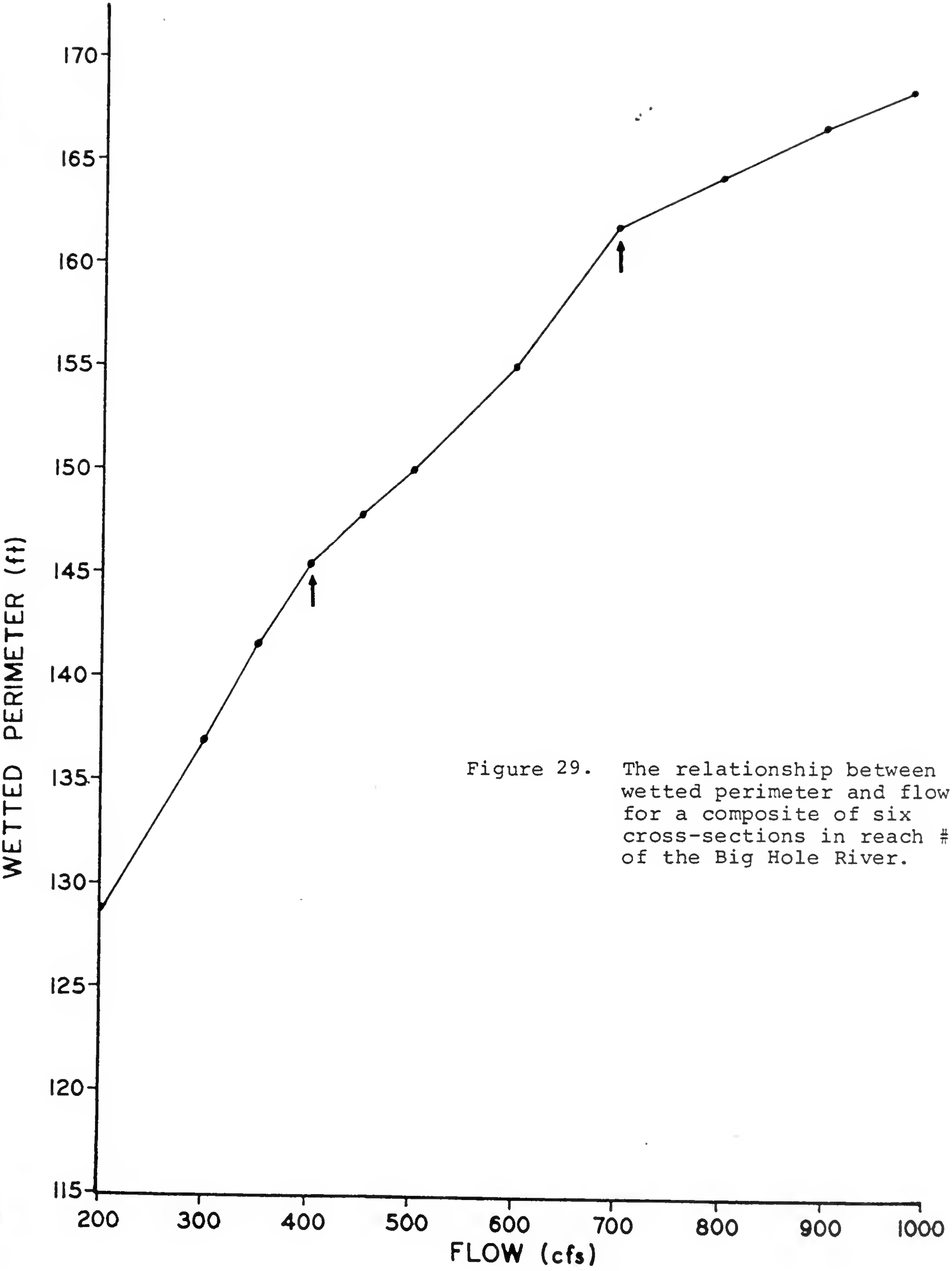

Figure 29. The relationship between wetted perimeter and flow for a composite of six cross-sections in reach #1 of the Big Hole River.

A minimum instream flow recommendation based on a single inflection point could be derived for only two (Madison #3 and Beaverhead) of the five reaches. The minimum for the Beaverhead reach (100 cfs) was slightly less than the absolute minimum recommendation of 150 cfs derived from the trout-flow data and the minimum for the Madison #3 reach (500 cfs) was less than the absolute minimum of 650 cfs.

Two inflection points occurred on each of the wetted perimeter curves for the Madison #1 and Big Hole reaches. The lowermost inflection point for each of these two reaches occurs at the flow approximately equal to the absolute minimum recommendation. The uppermost inflection point for the Madison #1 reach occurs at the flow approximately equal to the most desirable minimum recommendation.

The recommendations generated by the multiple transect method for the four reaches having discernible inflection points were judged acceptable although minimum recommendations for two of the reaches were somewhat less than the absolute minimums derived from the trout-flow data. In the two reaches having more than one inflection point, the lowermost occurred at the flow closely approximating the absolute minimum recommendation derived from the trout-flow data.

Non-field Method

The flow recommendations generated by the Tennant method are listed by river reach in Table 18. The Tennant method greatly underestimates the flows needed to sustain desirable trout populations in all five reaches. Tennant's minimum flow recommendations, which are equal to 10% of the mean flow of record, were no more than 32% of the absolute minimum recommendations derived from the trout-flow data for the five reaches. Tennant's minimums are in fact less than the minimum average daily flows of record for four of the five reaches (Table 19). The absolute minimums derived from the trout-flow data generally fall within the range of flows Tennant describes as excellent to optimum for the October-March period and fair to outstanding for the April-September period.

The percentage of the mean flow (10%) chosen by Tennant to derive a minimum flow recommendation is inadequate when compared to the percentages derived from the trout-flow data. The absolute minimum flow recommendations for the two reaches of the Madison River were at least 45 and 51% of the mean flows. The absolute minimums for the Beaverhead, Gallatin and Big Hole reaches were from 31 to 35% of the mean flows. The Madison River, which generally lacks pool development and is considerably wider and shallower than the other rivers of the study area, required a greater percentage of the available flow. This is expected if one considers the differences in channel morphology between the rivers.

Table 18. Instream flow recommendations derived by the Tennant Method for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers.

	Flow Recommendations (cfs)	
Description of Flows	Oct-Mar	Apr-Sept
	Madison (#1)	
Flushing or Max.	3,524	3,524
Optimum range	1,057-1,762	1,057-1,762
Outstanding	705	1,057
Excellent	529	881
Good	352	705
Fair or degrading	176	529
Poor or minimum	176	176
Severe Degradation	0-176	0-176
	Madison (#3)	
Flushing or Max.	2,864	2,864
Optimum range	859-1,432	859-1,432
Outstanding	573	859
Excellent	430	716
Good	286	573
Fair or degrading	143	430
Poor or minimum	143	143
Severe Degradation	0-143	0-143
	Beaverhead (#2)	
Flushing or Max.	882	882
Optimum range	265-441	265-441
Outstanding	176	265
Excellent	132	221
Good	88	176
Fair or degrading	44	132
Poor or minimum	44	44
Severe Degradation	0-44	0-44
	Gallatin (#2)	
Flushing or Max.	1,628	1,628
Optimum range	488-814	488-814
Outstanding	326	488
Excellent	244	407
Good	163	326
Fair or degrading	81	244
Poor or minimum	81	81
Severe Degradation	0-81	0-81

continued

Table 18. - continued

Description of Flows	Flow Recommendations (cfs) Oct-Mar	 Apr-Sept
	Big Hole (#1)	
Flushing or Max.	2,314	2,314
Optimum range	694-1,157	694-1,157
Outstanding	463	694
Excellent	347	579
Good	231	463
Fair or degrading	116	347
Poor or minimum	116	116
Severe Degradation	0-116	0-116

Table 19. Comparison of the minimum flows of record and the minimum flow recommendations derived by the Tennant Method for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers.

Reach	Years of Record	Minimum Flow of Record (cfs)	Tennant Method Min. Flow Recommendation (cfs)
Madison(#1)	39	210	176
Madison(#3)	13	275	143
Beaverhead(#2)	70	69	44
Gallatin(#2)	50	117	81
Big Hole(#1)	54	49	116

The most desirable minimum flow recommendations derived from the trout-flow data ranged from 64 to 80% of the mean flows and fell within the range of flows that Tennant describes as optimum (60-100% of the mean flow of record).

Evidence presented in this section suggests that an absolute minimum instream flow recommendation based on a fixed percentage of the mean flow of record may be valid for the trout rivers of southwest Montana. The percentages derived in this study fell within the approximate range of 31 to 51% which is considerably higher than the minimum of 10% recommended by Tennant. The percentage selected as an absolute minimum recommendation appears to depend on the channel morphology with the wider, shallower rivers such as the Madison requiring a higher percentage of the mean flow. The more typical rivers of the study area (Beaverhead, Gallatin and Big Hole rivers) required an absolute minimum instream flow equal to about 33% of the mean.

IFG Incremental Method

The optimum instream flows derived from the IFG incremental method are compared to those values derived from the standing crop and flow data in Table 20. The actual optimums for the five reaches could not be derived from these data. What is available for comparison are the most desirable minimum flow recommendations listed in Table 15. The actual optimums should either equal or exceed the most desirable minimums. The IFG predicted optimums that equal or exceed the most desirable minimums are judged acceptable as optimum flow recommendations.

Thirteen comparisons are available for the five reaches. In 6 of the 13 comparisons, the IFG predicted optimums exceeded the most desirable minimums derived from the standing crop and flow data. In the remaining seven comparisons, the IFG predicted optimums were less than the most desirable minimums and in six of these seven the IFG predicted optimums were even less than the absolute minimum flow recommendations listed in Table 15. The IFG optimum flow recommendations were acceptable in only 6 (46%) of the 13 comparisons.

The IFG optimum recommendations for brown and rainbow trout were acceptable in the Beaverhead and Big Hole reaches and unacceptable in the remaining three reaches, for an acceptability rate on a reach basis of only 40%.

Table 20. Comparison of the optimum instream flow recommendations derived by the IFG Incremental Method and the standing crop and flow data for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers.

Reach	Life Stage and Species	Optimum Instream Flows (cfs) IFG Method	Standing Crop-Flow Data
Madison (#1)	adult brown trout	1,000	≥1,200-1,400
	adult rainbow trout	800	≥1,200-1,400
Madison (#3)	juvenile brown trout	400	≥1,150
	adult brown trout	600	≥1,150
	adult rainbow trout	600	≥1,150
Beaverhead(#2)	adult brown trout	≥343	≥300
	juvenile rainbow trout	255	≤250
	adult rainbow trout	≥343	≥300
Gallatin(#2)	adult brown trout	≤200	250-393
	adult rainbow trout	250	≥523
	adult mountain whitefish	550	≥523
Big Hole(#1)	adult brown trout	500	≥400
	adult rainbow trout	500	≥400

The IFG method also generated optimum flow recommendations for other life stages of rainbow trout, brown trout and mountain whitefish (Table 21). Since flow recommendations based on biological data are not available for comparison, no attempt will be made to evaluate the reliability of these predicted optimums. It should be noted that the IFG optimum flow recommendations were generally highest for the adult life stage. An obvious exception occurred in the Gallatin reach in which the IFG optimum flows for spawning brown and rainbow trout greatly exceeded those for the other life stages including adults. In this case, the optimum flow recommendations for spawning trout are misleading. Examination of the weighted usable areas shows that spawning habitat for all flows of interest was extremely limited for this particular subreach.

The IFG optimum recommendations for adult mountain whitefish were considerably higher than those for adult brown and rainbow trout. When compared to the recommendations derived from the standing crop and flow data, the IFG predicted optimums for whitefish appear to be more realistic estimates of the actual flow needs of adult trout than were the IFG predicted optimums derived for trout.

Table 21. Optimum instream flows derived from the IFG Incremental Method for various life stages of brown trout, rainbow trout and mountain whitefish in five reaches of the Madison, Beaverhead, Gallatin and Big Hole rivers.

Reach	Species	Optimum Instream Flows (cfs)				
		Spawning	Incubation	Fry	Juvenile	Adult
Madison(#1)	brown trout	900	≤600	≤600	800	1,000
	rainbow trout	800	≤600	700	≤600	800
	mountain whitefish	800	-	1,100	700	1,300
Madison(#3)	brown trout	300	300	400	400	600
	rainbow trout	400	300	300	400	600
	mountain whitefish	400	-	900	500	900
Beaverhead(#2	brown trout	225	275	≥343	≥343	≥343
	rainbow trout	225	275	300	255	≥343
	mountain whitefish	≥343	-	≥343	≥343	≥343
Gallatin(#2)	brown trout	≥646	≤200	≤200	≤200	≤200
	rainbow trout	≥646	≤200	≤200	≤200	250
	mountain whitefish	300	-	≤200	≤200	550
Big Hole(#1)	brown trout	≤200	250	400	400	500
	rainbow trout	≤200	250	350	400	500
	mountain whitefish	400	-	700	450	900

Hydrographs

The final minimum flow recommendations derived from the trout standing crop and flow data for the five reaches are compared to monthly mean, median and 80% exceedence (percentile) flows in Figures 30 through 34. The percentile flows by month of the minimum recommendations are given in Table 22. A brief discussion of this data follows.

Madison River - Reach #1

Summary flow statistics for a 29-year period of record were derived from data collected at the USGS gage below Ennis Reservoir (near McAllister). Throughout this period flows at this gage reflect regulation by Ennis and Hebgen reservoirs.

The absolute minimum recommendation of 900-1,100 cfs is available in at least 9 of 10 years for the months of August through December, and at least 7 of 10 years for the months of January through April. Overall, the absolute minimum is readily obtainable during the low water months of August through April.

On a monthly basis, the most desirable minimum of 1,200-1,400 cfs is available in at least 4 of 10 years. The most desirable minimum is generally obtainable in average and above average water years.

The Montana Power Company, operator of Ennis and Hebgen reservoirs, presently has an informal agreement with the Montana Department of Fish, Wildlife and Parks to provide a minimum flow of 1,100 cfs at the USGS gage below Ennis Reservoir.

Madison River - Reach #3

Mean monthly flows for a 9-year period of record were derived from data collected at the USGS gage above Ennis Reservoir (near Cameron). Due to insufficient records, only the mean monthly flows are available for comparison. Flows at this gage reflect regulation by Hebgen Reservoir.

The absolute minimum recommendation of 650 cfs is less than the mean monthly flows for all months. The absolute minimum flow appears to be readily obtainable during the low water months of August through April.

The most desirable minimum of 1,150 cfs was greater than the mean monthly flows for five of the nine low water months, suggesting that the most desirable minimum is probably unobtainable in other than above average water years.

The Montana Power Company presently has an informal agreement with the Department of Fish, Wildlife and Parks to provide a minimum flow of 600 cfs at the USGS gage near the mouth of the West Fork (Kirby Ranch)

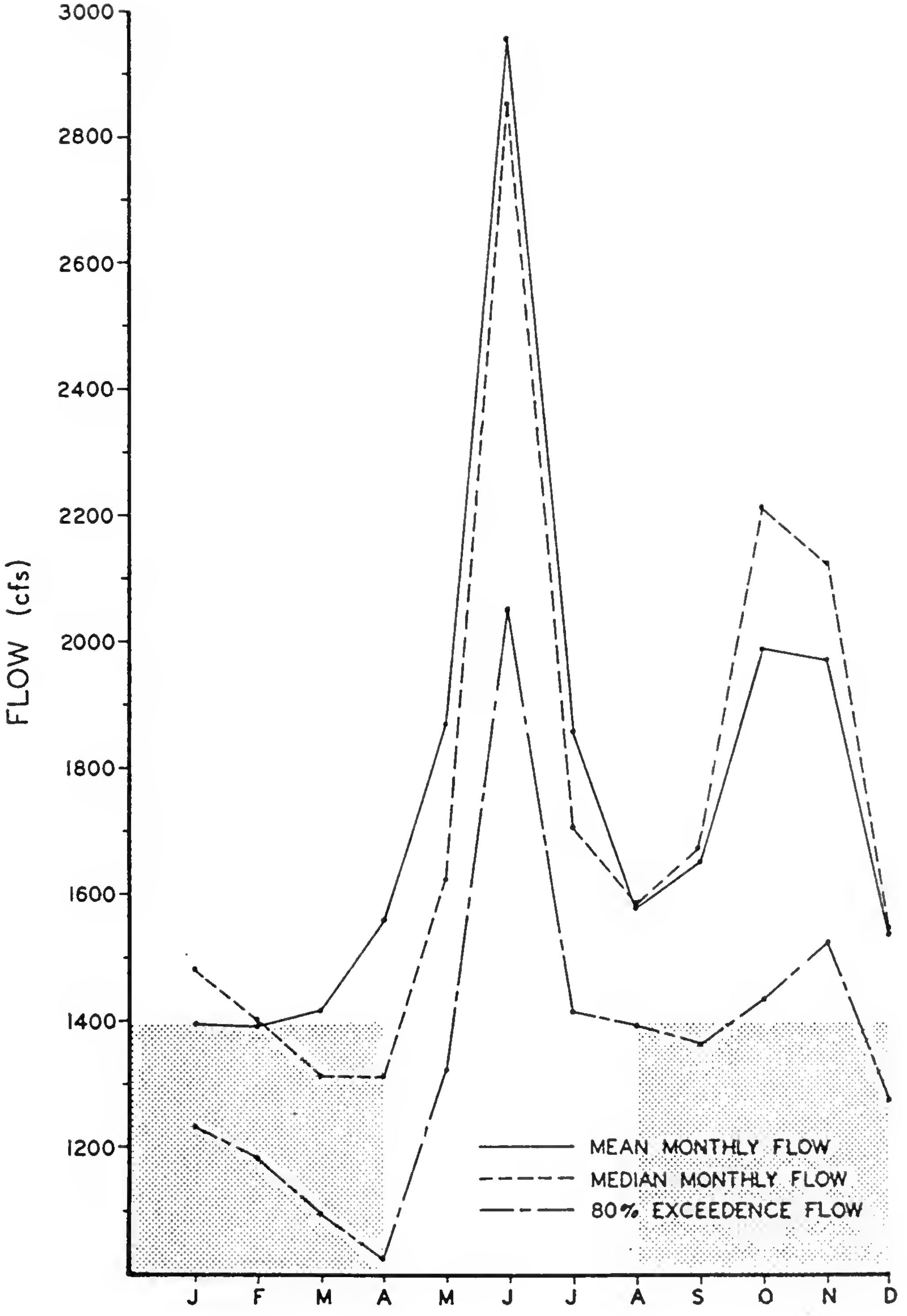

Figure 30. Comparison of the absolute minimum (900-1100 cfs) and most desirable minimum (1200-1400 cfs) flow recommendations for reach #1 of the Madison River to the monthly mean, median and 80% exceedence flows. Recommendations apply only to the low water months of August through April.

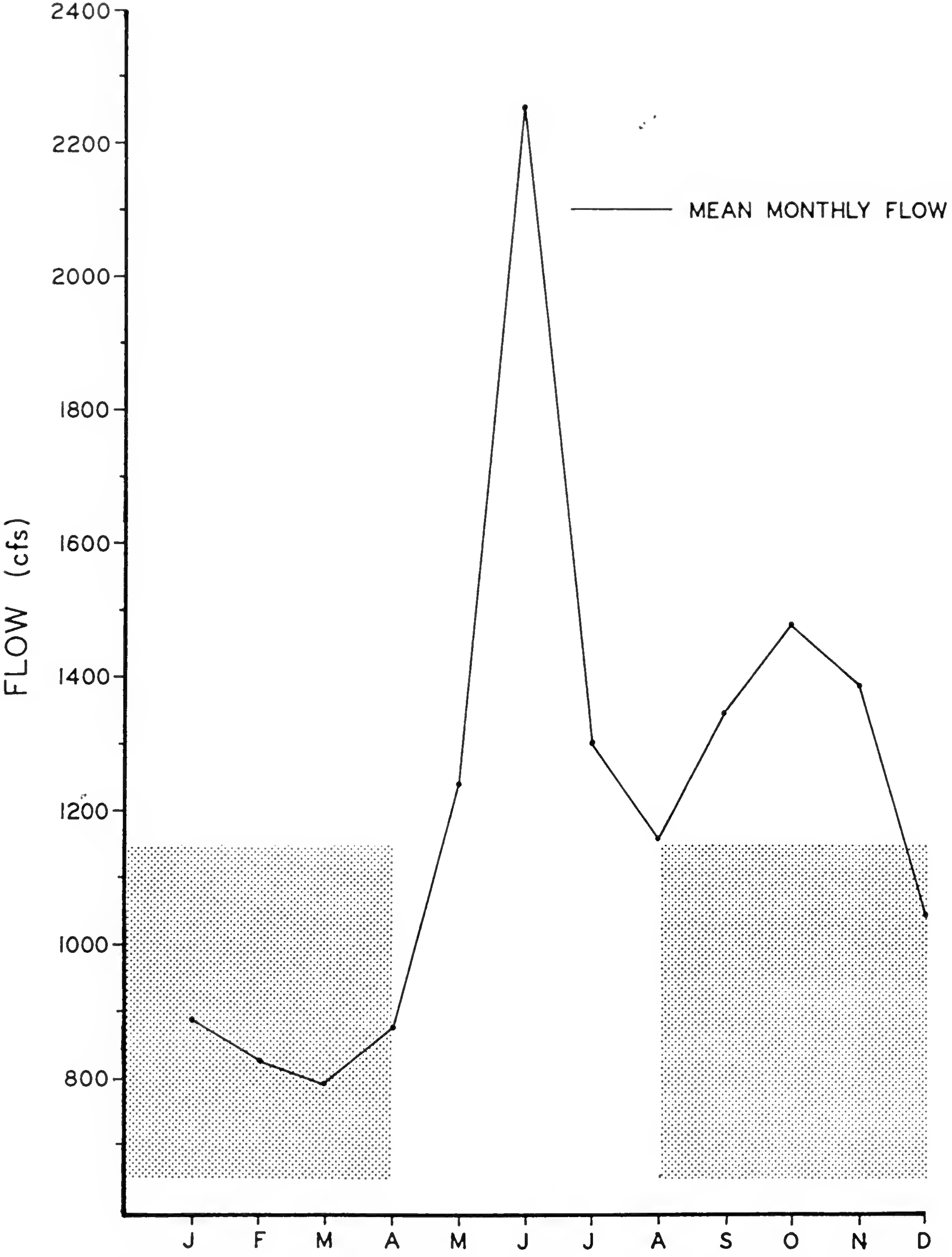

FIGURE 31. Comparison of the absolute minimum (650 cfs) and most desirable minimum (1,150 cfs) flow recommendations for reach #3 of the Madison River to the monthly mean flows. Recommendations apply only to the low water months of August through April.

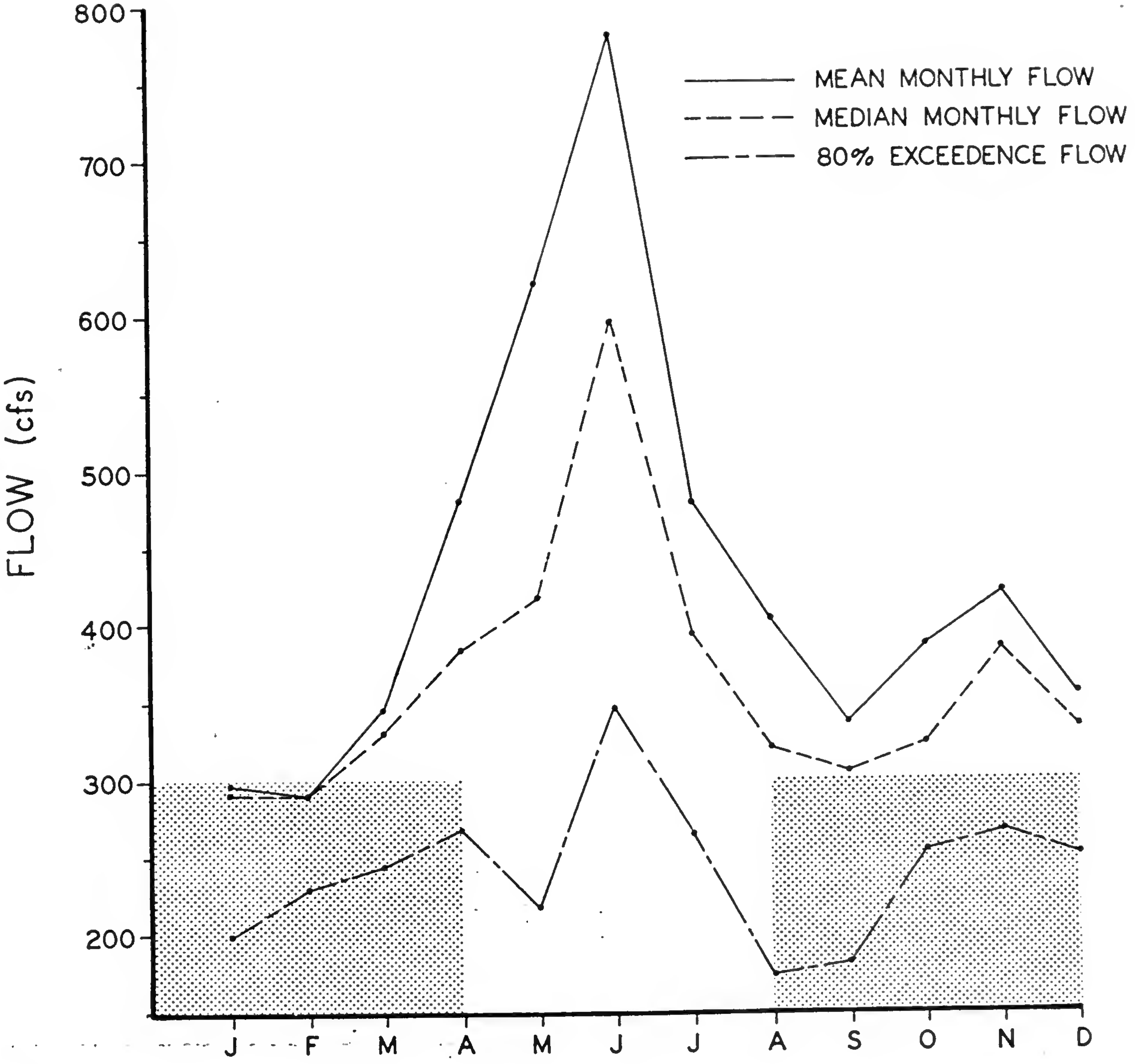

FIGURE 32. Comparison of the absolute minimum (150 cfs) and most desirable minimum (300 cfs) flow recommendations for reach #2 of the Beaverhead River to the monthly mean, median and 80% exceedence flows. Recommendations apply only to the low water months of August through April.

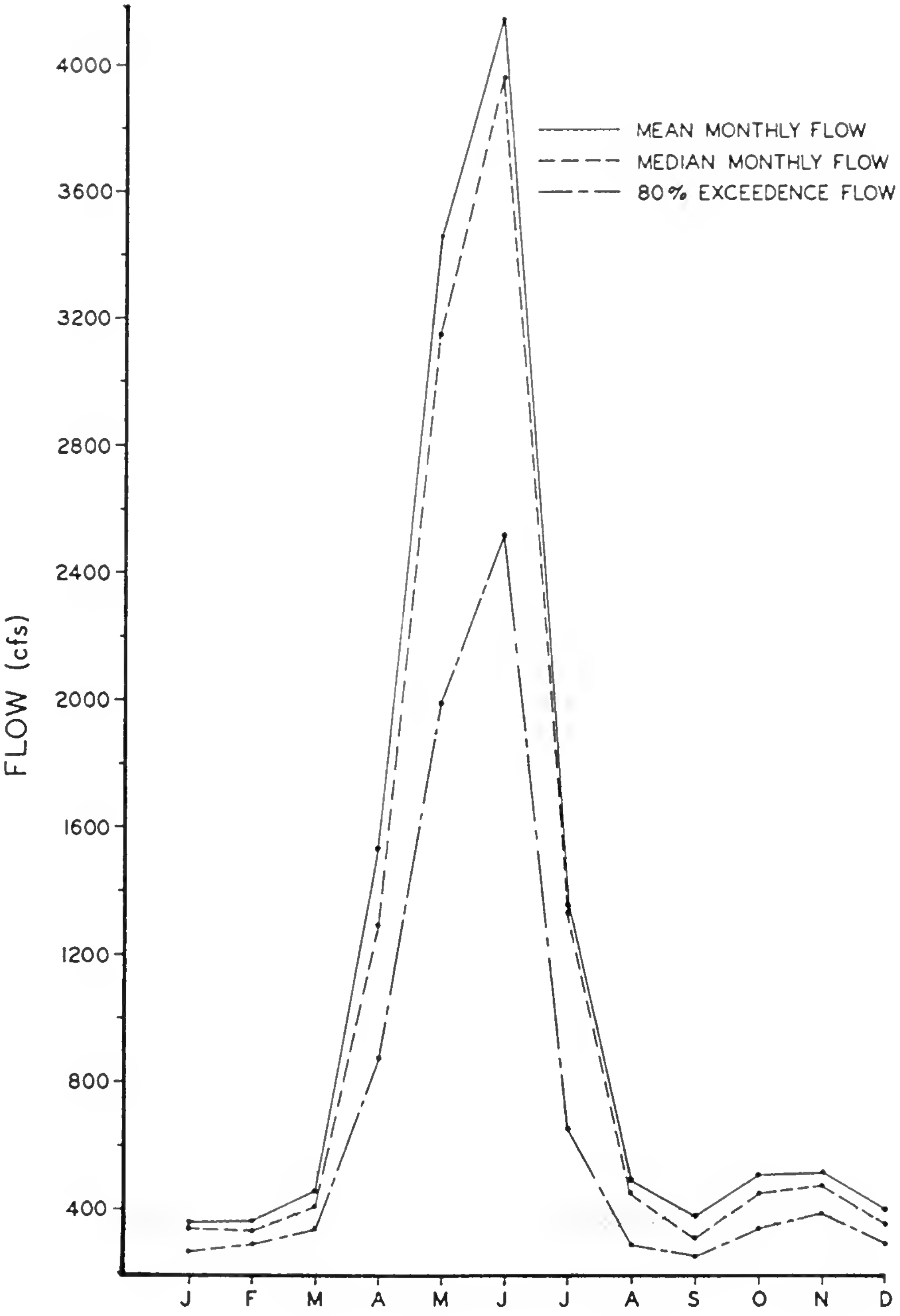

Figure 34. Comparison of the absolute minimum (400 cfs) flow recommendation for reach #1 of the Big Hole River to the monthly mean, median and 80% exceedence flows. Recommendations apply only to the low water months of July through March.

Table 22. Percentile flows by month of the minimum instream flow recommendations derived from the trout population-flow data for reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers. Recommendations apply only to the low water months.

Reach	Recommended Minimum Flows (cfs)	Percentile Flow by Month J	F	M	A	M	J	J	A	S	O	N	D
Madison (#1)	900-1,100a/	100-88	100-86	100-79	90-74	e/			100-92	100-96	100-97	100	100
	1,200-1,400b/	82-58	75-50	72-42	65-46				87-79	89-78	94-83	100-85	100-66
Madison (#3)	650 c/												
	1,150												
Beaverhead (#2)	150	95	100	100	96				86	85	90	100	97
	300	44	45	63	72				54	51	55	68	61
Gallatin (#2)	250	79	82	83	100				100	100	100	99	86
	523	0	0	0	28				61	34	23	6	0
Big Hole (#1)	400 d/	24	29	50				90	60	34	62	76	39

a - Absolute minimum instream flow recommendation.
b - Most desirable minimum instream flow recommendation.
c - Percentile flows unavailable due to insufficient flow records.
d - Most desirable minimum instream flow undetermined.
e - High water or snow runoff months are blank.

Beaverhead River - Reach #2

Summary flow statistics for a 49-year period of record were derived from data collected at the USGS gage at Barretts. Since 1964, flows at this gage reflect regulation by Clark Canyon Reservoir.

The absolute minimum recommendation of 150 cfs is available in at least 9 of 10 years for the months of October through April, and at least 8 of 10 years for the months of August and September. Overall, the absolute minimum is readily obtainable in most water years.

On a monthly basis, the most desirable minimum of 300 cfs is available in at least 4 of 10 years and appears generally obtainable in average and above average water years.

The East Bench Irrigation District, which has assumed operation of Clark Canyon Dam from the Bureau of Reclamation, presently has an informal agreement with the Montana Department of Fish, Wildlife and Parks to provide a minimum flow of about 225 cfs in reach #2. The Clark Canyon project only provides a guaranteed minimum instream flow of 25 cfs for fish and wildlife benefits.

Gallatin River - Reach #2

Summary flow statistics for a 39-year period of record were derived from data collected at the USGS gage at the head of reach #2 (near Gallatin Gateway). Flows at this gage reflect the natural flow regime since it is located upstream of all irrigation diversions. The flow depletions throughout much of reach #2 occur only during the irrigation period from about July 1 through October 15.

During the non-irrigation months when no depletions occur, the absolute minimum recommendation of 250 cfs is available in at least 8 of 10 years. If no depletions occurred during the irrigation season, the absolute minimum would be available in all water years. At the present level of irrigation depletions, an absolute minimum of 250 cfs is even unobtainable in above average water years in some sections of reach #2.

The most desirable minimum recommendation of 523 cfs is unavailable during most of the low water months, even under the natural flow conditions. During December through March the most desirable minimum is never available and available in less than 4 of 10 years during April, September, October and November.

The most desirable minimum was derived solely for the summer irrigation months and assumed to apply to all low water months. This assumption, which may not be valid for the Gallatin River, probably explains the unavailability of the most desirable minimum during the winter period.

Big Hole River - Reach #1

Summary flow statistics for a 49-year period of record were derived from data collected at the USGS gage near Melrose. Flows at this gage reflect the diversion of water that occurs during the July through October irrigation period.

During the winter months of December through March when few depletions occur, the absolute minimum recommendation of 400 cfs is available in 5 of 10 years and less. This absolute minimum was derived solely for the summer irrigation months and assumed to apply to all low water months. This assumption, which may not be valid for the Big Hole River, may partially explain the general unavailability of the absolute minimum recommendation during the winter period.

During the irrigation months, the availability of water for instream uses appears most limited during September when the absolute minimum recommendation is available in less than 4 of 10 years. Additional irrigation depletions above the present level should be curtailed if a desirable fishery is to be maintained in reach #1.

Manpower and Cost Evaluations

The man-hours expended and costs of applying the three field methods to the five river reaches are summarized in Tables 23 and 24. When computing man-hours and costs for each method, it was assumed no other methods were applied in order to provide a more realistic evaluation.

The IFG method required the greatest expenditure of time. The total man-hours expended on each of the reaches ranged from 71 to 120 for the IFG method versus 34 to 55 for the multiple transect method and 12 to 20 for the single transect method. Most of the total man-hours for all three field methods was expended on the collection of field data.

The IFG method was also the costliest of the field methods, requiring from $2,981 to $3,265 to apply to each of the reaches. Costs of the multiple transect method per reach ranged from $2,705 to $2,865 and costs of the single transect method ranged from $2,563 to $2,610. Much of the total cost of each method is attributable to the initial costs of equipment (automatic level, tripod, level rod, canyon lines, and minor field equipment) and training (workshop at Santa Cruz, California). This amounted to $2,465 or more than 75% of the total cost of each field method.

Table 23. Man-hours expended to derive instream flow recommendations for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers using the single transect, multiple transect, and IFG Incremental methods.

			Percent of Total Man-Hours			
Subreach	Instream Flow Method	Total Man-Hours[a]	Pre-Field Planning	Field Effort	Data Processing	Data Analysis
Madison(#1)	Single Transect	20	5	85	5	5
	Multiple Transect	34	3	84	7	6
	IFG Incremental	120	1	96	2	1
Madison(#3)	Single Transect	15	7	80	7	7
	Multiple Transect	-	-	-	-	-
	IFG Incremental	86	1	94	4	1
Beaverhead(#2)	Single Transect	12	8	75	8	8
	Multiple Transect	55	2	90	5	4
	IFG Incremental	109	1	95	3	1
Gallatin(#2)	Single Transect	12	8	75	8	8
	Multiple Transect	38	3	85	7	5
	IFG Incremental	71	1	93	4	1
Big Hole(#1)	Single Transect	12	8	75	8	8
	Multiple Transect	48	2	88	5	4
	IFG Incremental[b]	90	1	94	3	1

a - Excludes travel time and unproductive trips.
b - Total man-hours are for three calibration flows only.

Table 24. Costs of deriving instream flow recommendations for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers using the single transect, multiple transect and IFG Incremental methods.

			Percent of Total Cost		
Subreach	Instream Flow Method	Total Cost[a]	Initial	Time Costs	Computer Time
Madison(#1)	Single Transect	$2,610	94.4	5.4	0.2
	Multiple Transect	2,705	91.1	8.8	0.1
	IFG Incremental	3,265	75.5	24.3	0.2
Madison(#3)	Single Transect	2,577	95.7	4.2	0.2
	Multiple Transect	-	-	-	-
	IFG Incremental	3,061	80.5	19.3	0.2
Beaverhead(#2)	Single Transect	2,564	96.1	3.7	0.2
	Multiple Transect	2,867	86.0	14.0	0.1
	IFG Incremental	3,265	75.5	24.3	0.2
Gallatin(#2)	Single Transect	2,564	96.1	3.7	0.2
	Multiple Transect	2,736	90.1	9.8	0.1
	IFG Incremental	2,981	82.7	17.1	0.2
Big Hole(#1)	Single Transect	2,563	96.2	3.7	0.2
	Multiple Transect	2,825	87.3	12.7	0.1
	IFG Incremental	3,133	78.7	21.2	0.1

[a] - Includes training and equipment costs, salaries and benefits at 18%. Excludes costs of transportation, per diem and unproductive trips.

The number of individuals in the field crew was dependent on the availability of personnel and the wadability of the river reaches. For wadable cross-sections a minimum crew of two was needed, while at least three persons were needed for unwadable cross-sections. In both cases, as many as five persons were used. Crews of other instream flow projects provided the extra manpower when needed. Brief resumes for all field personnel participating in this project are given in Appendix Table 25. Fred Nelson, the project leader, and Jeff Bagdanov, fisheries field worker, participated in the collection of all field data.

Recommendations derived from the non-field method (Tennant method) required a time expenditure of less than one man-hour per reach at a cost of about $8.00 per reach.

Reliability of Hydraulic Simulation Models

IFG-4 Model

A test of the reliability of the rating curve approach used by the IFG-4 model for predicting hydraulic parameters can be made by examining the correlation coefficients (r) for each set of stage-discharge and velocity-discharge measurements. Excellent correlation was found for all 30 of the stage-discharge relationships generated for the 5 subreaches (Table 26). The r^2 values for these relationships range from

Table 26 . Correlation coefficients^2 (r^2) for the stage-discharge relationships generated by the IFG-4 hydraulic simulation model for five subreaches of the Madison, Beaverhead, Gallatin, and Big Hole Rivers.

	Correlation Coefficient^2 (r^2)				
CS#	Madison (#1)	Madison (#3)	Beaverhead (#2)	Gallatin (#2)	Big Hole (#1)
1	.99	1.00	1.00	.98	.96
2	1.00	.99	.96	.99	.98
3	1.00	1.00	1.00	.99	.98
4	1.00	1.00	.99	.99	.98
5	1.00	1.00	1.00	1.00	.98
6			1.00	.97	1.00
7			.99	.99	

.96 to 1.00 with a median of .99. The only problem encountered with the stage-discharge approach occurred in cross-sections 5, 6 and 7 of the Beaverhead subreach. These cross-sections transected an island and included a left and right channel. Between the highest and lowest calibration flows (343 and 255 cfs, respectively), the water surface elevations for these 3 cross-sections decreased by .38 to .56 ft in the right channel and only .22 to .24 ft in the left channel. The water surface elevations for the right channel, which contained over 90% of the flow, were used to calibrate the IFG-4 model. This was the only situation in which the stage-discharge rating curve approach proved inadequate.

The reliability of the velocity predictions as determined by the correlation coefficients(r) for the velocity-discharge relationships varied for each subreach (Table 27). The median r values by cross-section generally exceeded .90 for the Madison #1, Madison #3, and Gallatin subreaches. The one exception was cross-section #2 of the Madison #3 subreach in which the median r value was .85. Correlations were poorest for the Beaverhead subreach. In this subreach, median r values by cross-section ranged from .46 to .915. Some of the poor correlation can be attributed to the proximity of the calibration flows (255, 289, and 343 cfs). Morphological characteristics of the subreach also appear to be a contributing factor. Islands and gravel bars located at the head of the subreach had an unexpected influence on the flow distribution and slope of the water surface as the flows decreased. These influences also produced many inverse velocity-discharge relationships. Due to the problems encountered in the Beaverhead subreach, the reliability of the velocity predictions obtained by extrapolating beyond the highest and lowest calibration flows is questionable.

Based solely on an evaluation of correlation coefficients (r), the rating curve approach for predicting velocities is judged relatively poor for the Beaverhead subreach, fair for the Big Hole subreach, and excellent for the remaining three subreaches.

The velocities generated by the IFG-4 model for the calibration flows were also statistically compared by subreach to the measured velocities using t-tests for paired data. This analysis shows that the predicted velocities for all five subreaches are significantly different ($p \leq .05$) from the measured velocities. Even though statistical differences occurred, the magnitude of the bias of the predictions, as measured by the differences between means for the IFG-4 predicted versus the measured velocities (Table 28), does not appear large enough to have any practical significance in a real world situation. The differences between means were all relatively small, ranging from .051 to .161 ft/sec for the five subreaches.

Table 27. Correlation coefficients (r) for the velocity-discharge relationships generated by the IFG-4 hydraulic simulation model for five subreaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers.

CS#	No. of Regressions[a/]	Correlation Coefficient (r) Range	Correlation Coefficient (r) Median
		Madison (#1)	
1	20	.67-1.00	.95
2	23	.42-1.00	.97
3	25	.02-1.00	.94
4	26	.03-1.00	.93
5	25	.51-1.00	.97
		Madison (#3)	
1	30	.40-1.00	.97
2	28	.17-1.00	.85
3	28	.01-1.00	.95
4	28	.11-1.00	.94
5	26	.68-1.00	.965
		Beaverhead (#2)	
1	17	.00-1.00	.76
2	20	.01-1.00	.915
3	28	.00-1.00	.59
4	13	.01- .95	.46
5	24	.00-1.00	.83
6	24	.01-1.00	.84
7	27	.00-1.00	.77
		Gallatin (#2)	
1	16	.70-1.00	.965
2	18	.00-1.00	.935
3	27	.61-1.00	.99
4	20	.94-1.00	.995
5	17	.89-1.00	1.00
6	16	.59-1.00	.915
7	17	.12-1.00	.92
		Big Hole (#1)	
1	23	.31- .98	.71
2	18	.42- .99	.83
3	27	.74- .99	.89
4	16	.63- .99	.905
5	14	.51- .99	.84
6	14	.01-1.00	.68

[a/] Includes only those regressions having 3 or more data sets.

Table 28. Differences between the means for the IFG-4 predicted versus the measured velocities in five subreaches of the Madison, Beaverhead, Gallatin, and Big Hole Rivers. The standard error is in parenthesis.

	IFG-4 Predicted Vs. Measured Velocities	
Subreach	No. of Observations	Difference Between Means in ft/sec
Madison (#1)	364	.144(.009)
Madison (#3)	442	-.109(.009)
Beaverhead (#2)	531	.115(.019)
Gallatin (#2)	408	-.161(.011)
Big Hole (#1)	470	-.051(.010)

A better measure of the bias of the velocity predictions is the standard error for the differences between the predicted versus the measured means (Table 28). The subreach having the smallest standard error would have the most reliable velocity predictions. For the Madison #1, Madison #3, Big Hole, and Gallatin subreaches, the standard errors were similar, ranging from .009 to .011 ft/sec, and highest (.019 ft/sec) for the Beaverhead subreach. The standard errors indicate that the predicted velocities were the least reliable for the Beaverhead subreach while the reliability of the predictions for the remaining four subreaches was about equal.

The Beaverhead is the only subreach in which the reliability of the IFG-4 velocity predictions is questionable. The author believes that the bias, however, is not large enough to invalidate the predictions within the range of the calibration flows.

Comparison of IFG-4 and WSP Models

In this section the predictions of water surface elevation, velocity and depth generated by the two models are compared to the measured values. A comparison could not be made without first adjusting the IFG-4 and measured velocities and depths. The WSP model only predicts a mean depth and velocity by segment with a maximum of nine segments allowed per cross-section. The IFG-4 predicted and measured velocities and depths within each segment were averaged in order to obtain data comparable to the WSP output. The water surface elevations and segment velocities and depths generated by the two models were statistically compared to the measured values using t-tests for paired data (Table 29). Only four subreaches are compared since the WSP model was not applied to the Madison #3 subreach. Cross-section #7 of the Beaverhead subreach was also eliminated from the analysis since the WSP model could not be calibrated to the field data for this cross-section.

Table 29. Statistical comparison of the reliability of the predictions of the water surface elevations and the segment velocities and depths generated by the IFG-4 and WSP hydraulic simulation models for subreaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers. The number of observations is in parenthesis.

	IFG-4			WSP		
Subreach	WSE	Velocity	Depth	WSE	Velocity	Depth
Madison (#1)	0(15)	0(48)	X(48)	0(15)	0(48)	0(48)
Beaverhead(#2)	0(18)	X(70)	X(70)	0(18)	X(70)	X(70)
Gallatin(#2)	0(21)	X(68)	X(68)	X(21)	X(68)	X(68)
Big Hole(#1)	0(24)	X(72)	X(72)	X(24)	X(72)	X(72)

X = Predicted values are significantly different ($P \leq .05$) from the measured values.

O = Predicted values are not significantly different ($P > .05$) from the measured values.

In two of the four subreaches the WSP predicted water surface elevations were significantly different ($p \leq .05$) from the measured elevations. None of the IFG-4 predicted elevations were significantly different from the measured values. Neither model produced statistically superior velocity or depth predictions. The velocity predictions for both models were significantly different from the measured velocities in three of the four subreaches. The WSP predicted depths were significantly different from the measured depths in three subreaches while the IFG-4 predicted depths were significantly different from the measured depths in all four subreaches. On a statistical basis, the IFG-4 model was superior to the WSP model in the prediction of only water surface elevations.

The above statistical analysis does not provide a measure of the bias of the predictions nor does it indicate which model provides the better velocity and depth predictions. The differences between means for the IFG-4 predicted versus the measured data and the WSP predicted versus the measured data does provide some measure of the magnitude of the bias. An indication of the better model can be obtained by comparing these differences (Table 30). The model having the smaller difference is considered the better predictor.

Table 30. Differences between the means for the IFG-4 predicted versus the measured water surface elevations, mean segment velocities, and mean segment depths and the WSP predicted versus the measured water surface elevations, mean segment velocities and mean segment depths for subreaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers. The standard error is in parenthesis.

	Difference Between Means			
	Madison(#1)	Beaverhead(#2)	Gallatin(#2)	Big Hole(#1)
Water Surface Elev.(ft)				
IFG-4 vs. Measured	.007(.006)	.007(.009)	.007(.010)	-.003(.012)
WSP vs. Measured	.030(.021)	-.026(.033)	-.215(.027)	-.117(.025)
Velocity(ft/sec)				
IFG-4 vs. Measured	.046(.031)	.253(.062)	-.238(.033)	-.154(.023)
WSP vs. Measured	.100(.052)	.670(.082)	.222(.052)	.225(.036)
Depth(ft)				
IFG-4 vs. Measured	-.105(.016)	-.135(.026)	-.066(.021)	-.099(.015)
WSP vs. Measured	-.018(.020)	-.159(.032)	-.192(.021)	-.146(.015)

In all four subreaches, the differences between means for the IFG-4 versus the measured water surface elevations were considerably less than those for the WSP versus the measured elevations. The differences ranged from .003 to .007 ft for the IFG-4 model and .026 to .215 ft for the WSP model. The IFG-4 model is clearly the better predictor of water surface elevations.

In three of four subreaches, the differences for the IFG-4 model were less than those for the WSP model for both velocity and depth. Velocity differences ranged from .046 to .253 ft/sec for the IFG-4 model and .100 to .670 ft/sec for the WSP model. Depth differences ranged from .066 to .135 ft for the IFG-4 model and .018 to .192 ft for the WSP model.

A better measure of the bias of the predicted values is provided by the standard error for the differences between means (Table 30). Again, the model having the smaller standard error is considered the better predictor. In all four subreaches, the IFG-4 model produced smaller standard errors for both water surface elevation and velocity. In two of four subreaches, the standard errors for the differences between means for depth were smaller for the IFG-4 model and were equal for both models for the remaining two subreaches.

Based on the above evaluation of the differences between means and their standard errors, the IFG-4 model was undoubtedly the better hydraulic simulation model in this study.

The lower reliability of the WSP predictions of mean segment velocity and depth may in fact have little practical significance. A comparison of the differences between means in Table 30 suggests that, except for the velocity predictions for the Beaverhead subreach, the bias of the WSP predictions of velocity and depth are not of a magnitude to be of major concern. Results of the study suggest that in single channels where mean segment velocities and depths are desired, the WSP model should provide reasonably accurate predictions.

The application of any hydraulic simulation model to subreaches containing island complexes should proceed with caution. If islands or multiple channels are unavoidable, the IFG-4 model is preferred. In these situations, it may be unwise to extrapolate the IFG-4 data beyond the highest and lowest calibration flows.

Wetted Perimeter Predictions

The reliability of the predictions of wetted perimeter for the two models could not be determined since the actual values were not available for comparison. The IFG-4 model should be the better predictor of wetted perimeter based on the greater accuracy of the predictions of water surface elevation. However, the wetted perimeters generated by the IFG-4 model are only an approximation and may be subject to some error. This error was assumed to be negligible for the relatively large waterways the model was applied.

Wetted perimeter curves generated by the WSP and IFG-4 models for the composite of cross-sections in four of the five river reaches are compared in Figures 35 through 38. The inflection points on the curves for the two models generally occurred at approximately the same flows (Table 31). The obvious exception was the Beaverhead reach in which the inflection point occurred at 100 cfs for the WSP model and 225 cfs for the IFG-4 model. Neither model provided discernible inflection points for the Gallatin reach.

Table 31. Comparison of the flows at which inflection points occurred on the wetted perimeter-discharge relationships generated by the WSP and IFG-4 hydraulic simulation models for a composite of cross-sections in reaches of the Madison, Beaverhead, Gallatin and Big Hole rivers.

	Inflection Point Flows (cfs)	
Reach	WSP Model	IFG-4 Model
Madison(#1)	900, 1,400	900
Beaverhead(#2)	100	225
Gallatin(#2)	-	-
Big Hole(#1)	400, 700	450, 700

On a statistical basis, the wetted perimeter curves generated by the two models were significantly different ($P \leq .05$) from one another in the Madison #1, Beaverhead and Gallatin reaches. The most obvious discrepancy occurred in the Beaverhead reach (Figure 36). Some of this difference between models may be due to the extrapolation of the IFG-4 data beyond the lowest calibration flow. The IFG-4 wetted perimeter curve may be subject to some error due to the problems previously discussed. In a previous study, a wetted perimeter curve generated by the WSP model for a composite of 20 cross-sections in

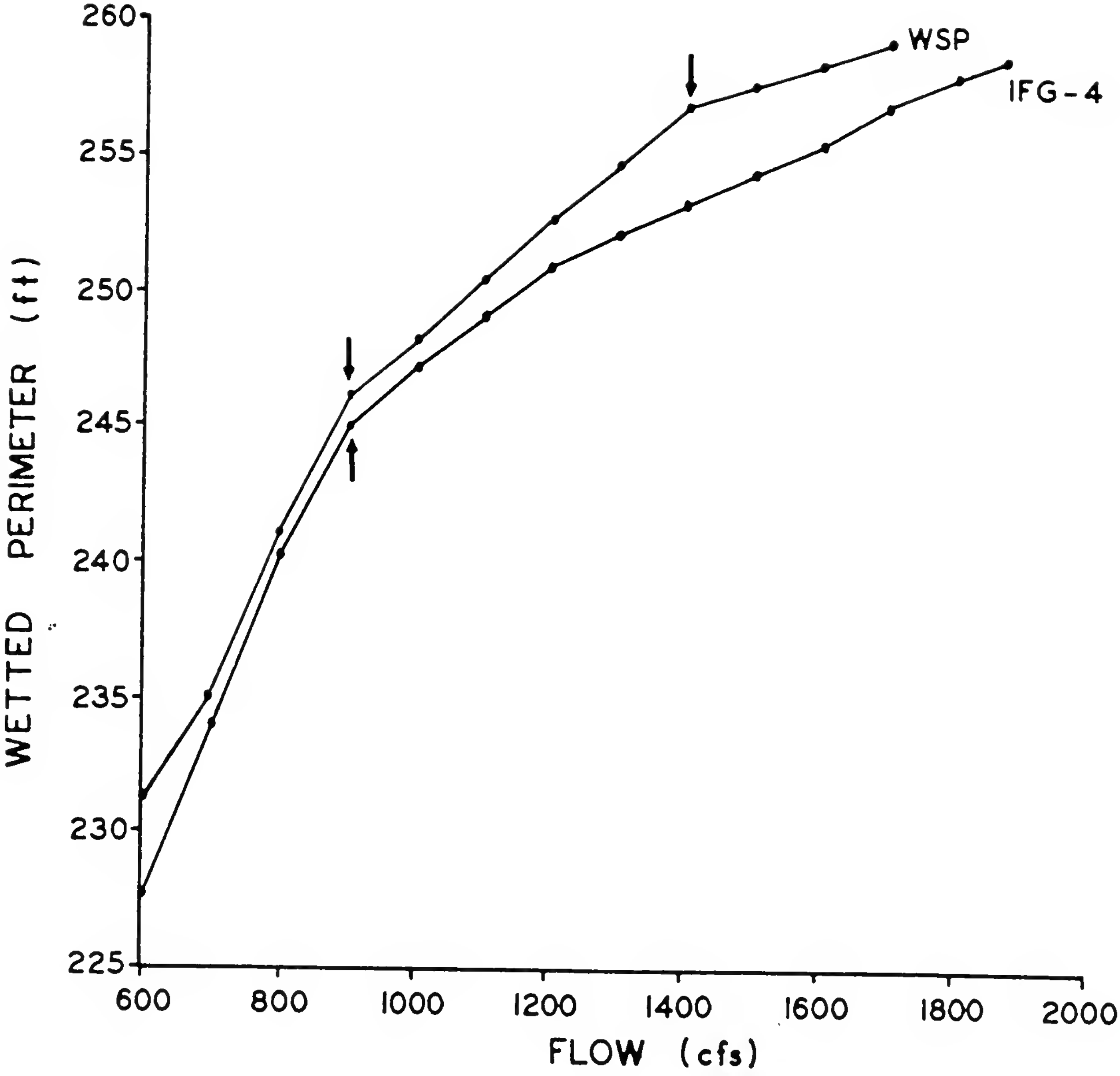

Figure 35. Comparison of the wetted perimeter and flow relationship derived by the IFG-4 and WSP hydraulic simulation models for a composite of five cross-sections in reach #1 of the Madison River.

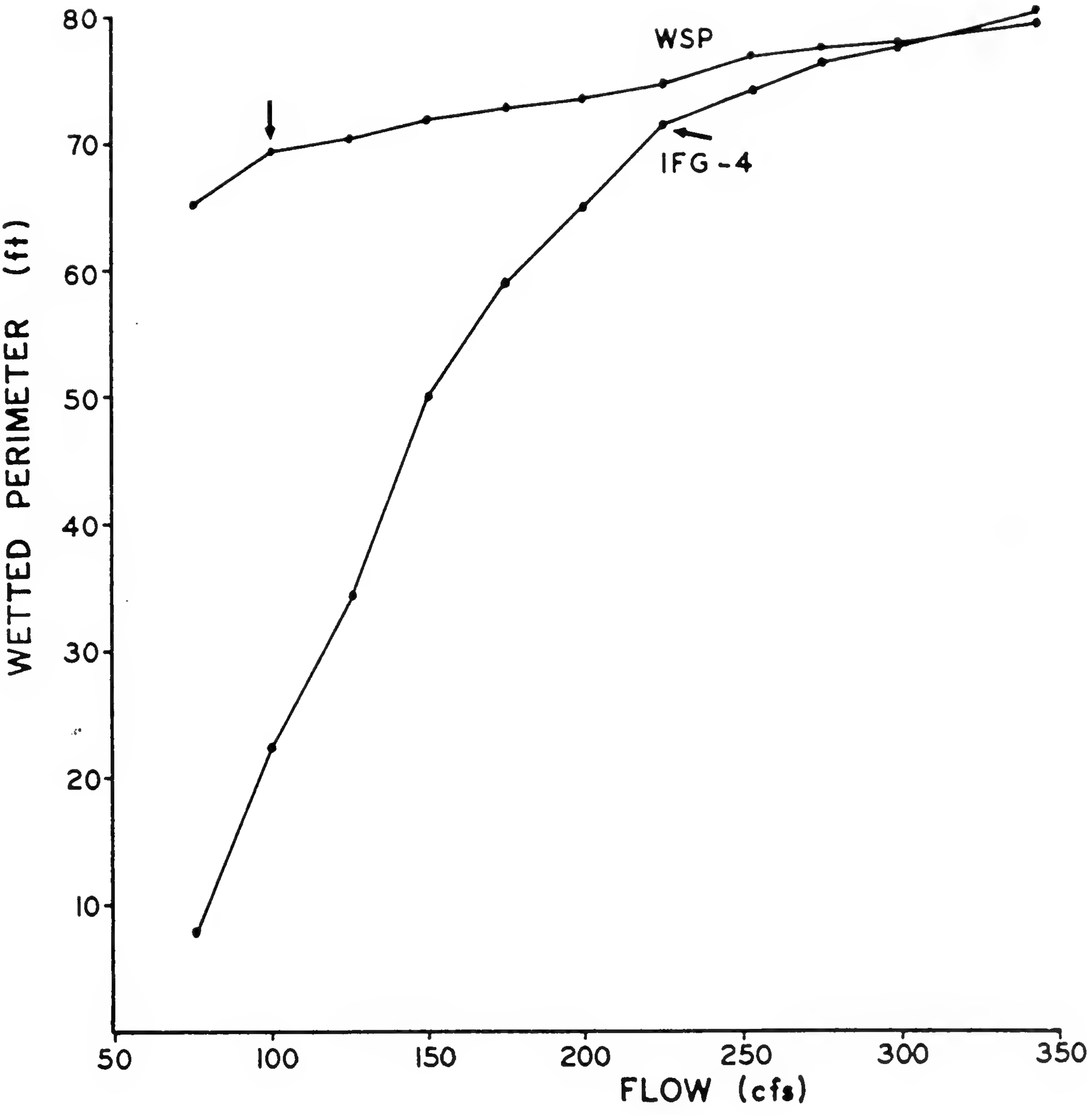

Figure 36. Comparison of the wetted perimeter and flow relationships derived by the IFG-4 and WSP hydraulic simulation models for a composite of four cross-sections in reach #2 of the Beaverhead River.

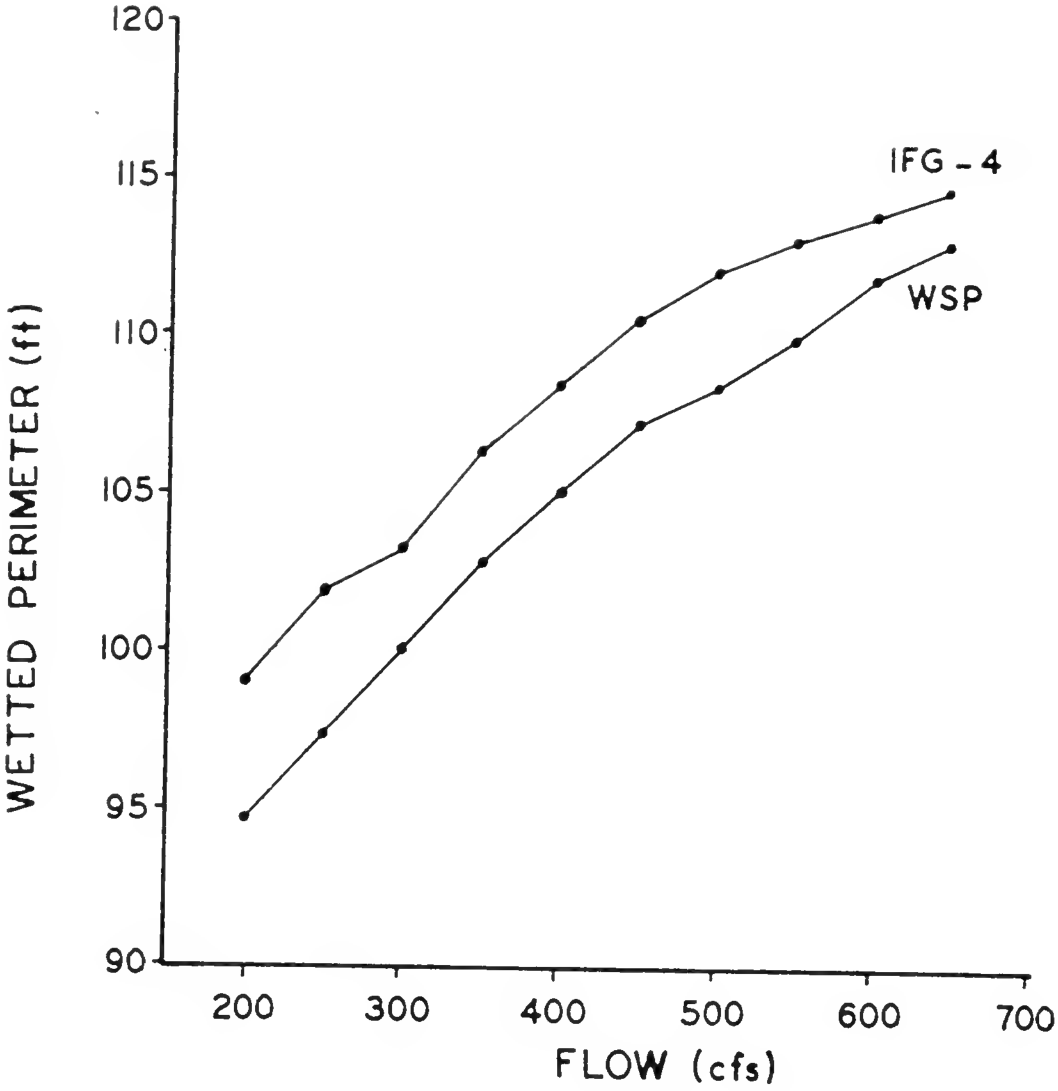

Figure 37. Comparison of the wetted perimeter and flow relationships derived by the IFG-4 and WSP hydraulic simulation models for a composite of seven cross-sections in reach #2 of the Gallatin River.

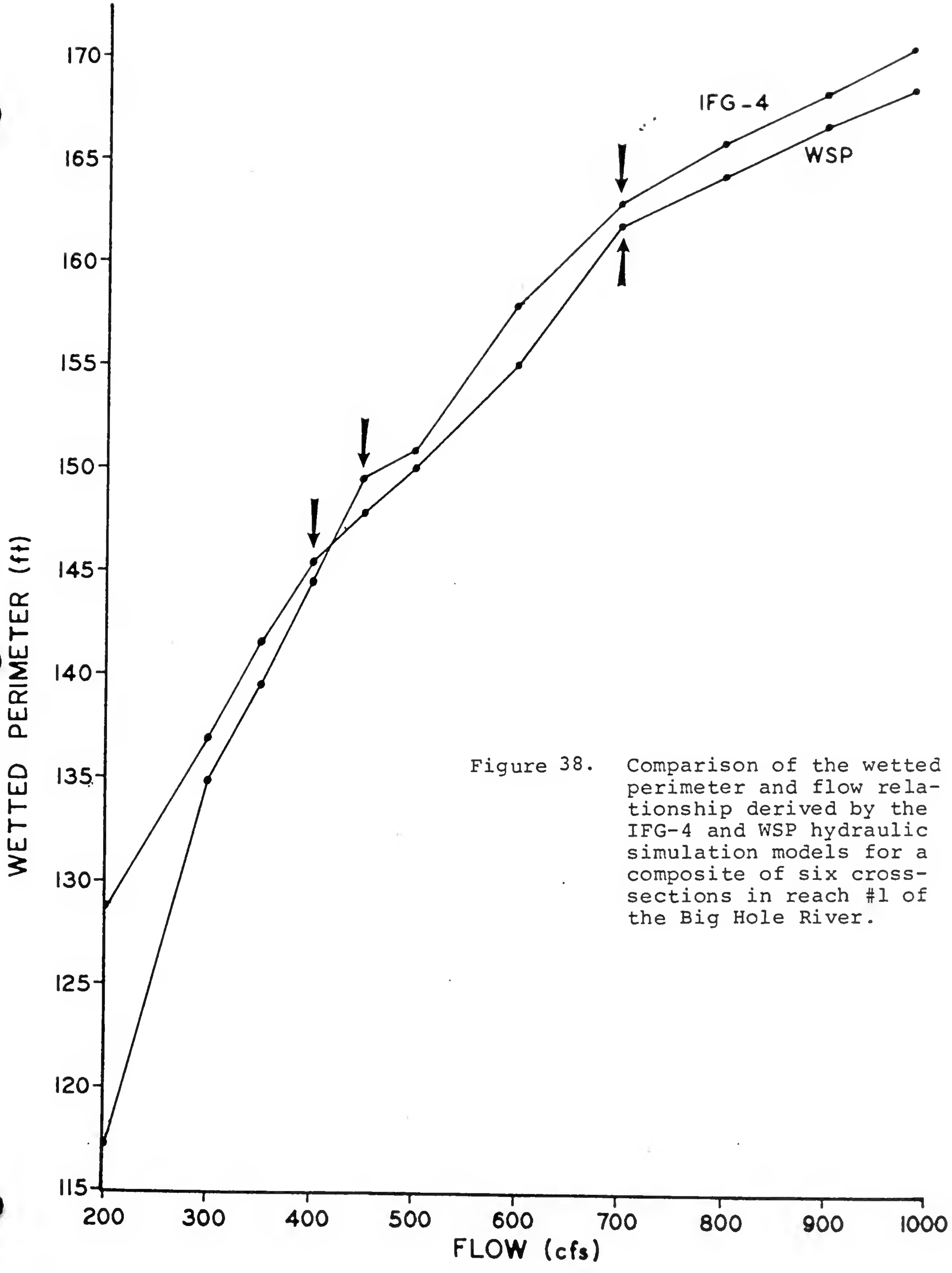

Figure 38. Comparison of the wetted perimeter and flow relationship derived by the IFG-4 and WSP hydraulic simulation models for a composite of six cross-sections in reach #1 of the Big Hole River.

the Beaverhead #2 reach showed an inflection point at about 200-225 cfs (Nelson, 1977). This 200-225 cfs inflection point, which compares favorably to the 225 cfs derived from the IFG-4 curve, would suggest that the present WSP curve is grossly inaccurate.

There is still some question as to which of the models generated the more accurate wetted perimeter curves. Based on the study results, the IFG-4 predictions are judged better than those of the WSP model. However, the best model would be one that uses a stage-discharge rating curve approach using three or more calibration flows to directly predict rather than approximate the wetted perimeter at a flow of interest. This wetted perimeter predictive model is presently being developed by the Montana Department of Fish, Wildlife and Parks for use in its instream flow program. This model will eliminate the uncertainties associated with the wetted perimeter predictions of the two models used in this study.

APPRAISAL OF METHODS

Single Transect Method

The wetted perimeter curve for a single riffle cross-section provided acceptable absolute minimum flow recommendations for all five river reaches. Single, well defined inflection points were generally present and easily interpreted. In addition to being a relatively consistent and reliable method, it was also the most time and cost efficient of the three field methods.

The single transect method has other advantages. The extra effort and uncertainties involved in the selection of representative subreaches and the placement of multiple cross-sections are eliminated as are the need for large field crews and elaborate boat operations. Data collection can generally be handled by a crew of two since most riffles are wadable.

The defense of the single transect method before the non-scientist as would occur in Montana's flow reservation process is probably enhanced by its simple, easily explained, yet scientific approach to flow recommendations. The results can be graphically depicted; single inflection points are generally well defined and recommendations easily derived. This greatly adds to the credibility of the recommendations. Pictures of the riffle cross-sections showing the area of exposed bottom substrate at various flows can also be used to great advantage. In general, the simplicity of the method greatly enhances its persuasive capabilities before the non-scientific community.

The consistency of the minimum flow recommendations derived from the single transect method suggests that the wetted perimeter curve for a given river bears some similarity to the relationship between trout standing crops and flows. Below the inflection point on the wetted perimeter curve, the capacity of the river to sustain adult trout greatly diminishes. Why the wetted perimeter would relate to the carrying capacity is unclear, particularly when standing crops reflect a myriad of factors not common to all rivers nor of the same magnitude.

The inflection point may bear some relationship to the area of bank cover. At the inflection point, the water begins to pull away from the banks, bank cover is lost and the carrying capacity declines. This premise probably has little application to the rivers of the study area since instream cobbles and boulders rather than undercut banks and submerged and overhanging bank vegetation are the primary cover types. The one exception is the Beaverhead River where bank cover is exceptional.

Another question is why does the wetted perimeter curve for riffles, areas generally uninhabited by adult trout, provide acceptable flow recommendations. If one assumes that trout populations are food limited, then the wetted perimeter curves for riffles, which are generally considered the primary invertebrate producing areas of a river, may provide an index to the river's capacity to produce trout food organisms. Below the inflection point, the area available for food production greatly diminishes. The acceptance of this premise is unlikely since living space rather than food supply is generally believed a more influential limiting factor on Montana's trout rivers.

The acceptance of the single transect method as a valid means for deriving minimum flow recommendations implies that the wetted perimeter curve for a riffle cross-section somehow relates or provides an index to the physical needs of adult trout. At present, the acceptance of this method will have to be based solely on its consistency as a predictor of minimum flows since a realistic explanation for its apparent effectiveness is lacking.

The question of the reliability of the wetted perimeter predictions derived from the IFG-4 model will not be totally resolved until the data are rerun using a model that directly predicts rather than approximates the wetted perimeter. The author believes that the IFG-4 predicted wetted perimeters, even though approximations, are still superior to those generated by the WSP model due to the greater accuracy of the predictions of water surface elevations.

Additional testing of the single transect method using a better wetted perimeter predictive model will be needed before the method is fully accepted for use in Montana's instream flow program. Existing cross-sectional data collected in other drainages of the state will be analyzed using a wetted perimeter program being developed for the Montana Department of Fish, Wildlife and Parks to determine if the recommendations derived by the single transect method are reasonable. Acceptance of these recommendations will be based solely on professional judgment since little long-term biological data is available for deriving comparable recommendations. An additional question to be answered is whether the site of the inflection point for a single riffle cross-section is similar for all riffles within a river reach. A comparison of the wetted perimeter curves for a series of riffle cross-sections is needed to resolve this question.

Multiple Transect Method

The wetted perimeter curves for a composite of cross-sections within each river reach generally did not provide single, well defined inflection points on which to derive minimum flow recommendations. When present, inflection points were not as readily discernible as those in the single transect method and in some cases more than one were present. While the multiple transect method did provide acceptable absolute minimum flow recommendations for the four reaches having discernible inflection points, it had no advantage over the single transect method. It was costlier, more time consuming, required greater effort to locate sampling sites, sometimes difficult to interpret, and occasionally unproductive.

The study results indicate that in most cases the multiple transect method can provide acceptable absolute minimum flow recommendations. It is probably best to use multiple transect data to support the recommendations derived from a more consistent field method such as the single transect method previously discussed. In critical instream flow situations where supportive recommendations are desired, the additional time, expense and manpower involved in collecting multiple transect data may be justified.

The reliability of the wetted perimeter curves derived for the multiple transect method was questioned due to the greater error associated with the predictions of water surface elevations by the WSP model. The accuracy of the predicted water surface elevations can be improved by supplying water surface elevations for a series of known flows rather than a single flow as was done in the study. These additional data were available but not used in calibrating the WSP model. In past years the Montana Department of Fish, Wildlife and Parks has generally collected only one set of water surface elevations due to time and manpower limitations. Since this has been a typical practice, an evaluation based on more than one set of calibration data was considered inappropriate. At present, the author believes it is best to avoid using the WSP model to generate wetted perimeter curves for the high gradient, boulder and cobble-strewn rivers until additional testing clarifies the model's reliability.

The acceptance of the multiple transect method as a valid means of deriving minimum flow recommendations implies that the wetted perimeter curve for a composite of cross-sections encompassing various habitat types somehow relates to the physical needs of adult trout. As previously discussed for the single transect method, a precise explanation for a wetted perimeter and standing crop relationship is presently lacking. Acceptance of this methodology will have to be based solely on the apparent reliability of its recommendations.

Non-field Method

The study results suggest that minimum flow recommendations based on a fixed percentage of the mean flow of record may be valid for the trout rivers of southwest Montana. The percentage required appears to depend on the channel morphology with the shallower, wider rivers requiring a greater percentage of the mean. The more typical rivers of the study area required an absolute minimum flow equal to about 33% of the mean. A minimum flow of 10% of the mean as recommended by the "Tennant or Montana" method was totally inadequate in this study.

The discrepancy between the minimum flow recommendations derived from the trout-flow data and the Tennant method is partially the result of conflicting definitions. Tennant's minimum is defined as the flow that sustains short-term survival habitat for most aquatic life forms. Flows less than the minimum result in the catastrophic degradation of the fishery resource. The impact on the fishery of the absolute minimum flow derived from the trout-flow data is less severe. This minimum is defined as the lowest flow that will sustain intermediate or normal standing crops of adult trout or a particular group of adults, such as trophy-size trout. For Montana's nationally acclaimed wild trout fisheries such as the Madison, Beaverhead, Gallatin and Big Hole Rivers, a minimum flow that sustains less than normal population levels is totally unacceptable. Considering these definitions, the absolute minimum derived from the trout-flow data is expected to exceed Tennant's minimum.

The flow regimen Tennant describes as fair or degrading is probably more compatible with the definition of the absolute minimum recommendations. To provide fair or degrading aquatic conditions, Tennant recommends a flow regimen of 10% of the mean flow during the October-March period and 30% during the April-September period. The 30% recommendation during the April-September period compares favorably to the absolute minimum recommendations for the more typical rivers of the study area while the 10% recommendation during the October-March period is totally unacceptable.

Presently, a fixed percentage method would only be used by the Montana Department of Fish, Wildlife and Parks to make preliminary flow recommendations in situations where time or cost limitations prohibit field studies. More extensive use of this method would depend on further testing of its reliability. If proven valid, it is likely a fixed percentage method would primarily be used to support the flow recommendations derived from field methods, such as the single and multiple transect methods previously discussed.

IFG Incremental Method

The acceptance of less than 50% of the optimum flow recommendations indicates that the IFG method in its present state of development is not a consistent method for deriving instream flows for the trout rivers of Montana. Possible means for improving the present model for use on Montana's trout rivers are briefly discussed as follows.

1. The present IFG model uses the mean velocity in the water column as one of the variables for computing the weighted usable area. The mean velocities probably have little relation to the velocities commonly chosen by the trout within the column, particularly in the high gradient, cobble and boulder-strewn rivers of Montana.

   The impact of this premise on the optimum flow recommendations generated by the IFG method was evaluated using velocity data collected in the subreaches. These data were used to modify the existing probability-of-use curves for velocity in order to adjust for the model's use of the mean velocities rather than the bottom velocities, generally believed the velocities to which the trout are oriented.

   Velocity data for depths ≥2.5 ft in three of the subreaches show that the mean velocities in the column are highly correlated with the velocities at 0.8 of the depth (Appendix Table 32). These relationships were used to adjust the velocity curves for adult trout. For example, the curve for adult rainbow trout on file with the IFG assigns a probability-of-use of .95 for a velocity of 1.05 ft/sec. From Appendix Table 32 a bottom velocity (0.8 of the depth) of 1.05 ft/sec in the Madison #1 subreach corresponds to a mean velocity of 1.90 ft/sec. A probability of .95 is now assigned to a velocity of 1.90 ft/sec, the mean velocity in the column. All data sets for the velocity curves for adult rainbow and brown trout in each of the three subreaches were adjusted in this manner. In order to make this adjustment it was assumed that the velocity relationships in Appendix Table 32 also apply to depths less than 2.5 ft.

   This single adjustment increased the flows at which the optimum weighted usable areas occurred by 10 to 80% (Table 33). However, the optimum flows were not sufficiently increased in the Madison #1 and Gallatin reaches to compare favorably to those derived from the trout-flow data (Table 20). While a velocity modification of the existing IFG model is apparently needed, it is not the only problem area.

Table 33. Comparison of the optimum instream flows derived from the IFG Incremental Method using both the mean and bottom (0.8 of the depth) velocities in the water column.

Reach	Life Stage and Species	IFG Methodology Optimum Instream Flow(cfs) Mean Velocity	Bottom Velocity
Madison(#1)	Adult brown trout	1,000	1,100
	Adult rainbow trout	800	1,100
Gallatin(#2)	Adult brown trout	< 200	≤200
	Adult rainbow trout	250	375
Big Hole(#1)	Adult brown trout	500	700
	Adult rainbow trout	500	900

2. The probability-of-use curves on file with the IFG and used in this study were primarily developed from data collected on smaller streams and creeks. These curves may not adequately describe the preferences of trout inhabiting the larger waterways. It is also possible that one set of curves cannot be applied to all rivers. Curves may have to be developed on a river or regional basis.

3. Cover, a variable influenced by flow and shown in many cases to be highly correlated with standing crops of trout, should be incorporated into the IFG method.

The Montana Department of Fish, Wildlife and Parks does not plan to utilize the present IFG method in its instream flow program for the rivers of the state. The method, however, may be valid for the smaller waterways. The field data needed to apply the IFG method to streams and creeks are being collected concurrently with the data needed for the wetted perimeter methods. The IFG method will be used if proven applicable to the smaller waterways.

SUMMARY

Four instream flow methods were applied to five reaches of the Madison, Beaverhead, Gallatin and Big Hole rivers of southwest Montana. The methods were:

(1) a single transect method in which the minimum flow recommendation is selected at the inflection point on the wetted perimeter-discharge curve for a single riffle cross-section,

(2) a multiple transect method in which the minimum flow is selected at the inflection point on the wetted perimeter-discharge curve for a composite of channel cross-sections,

(3) the Tennant method, and

(4) the incremental method developed by the Cooperative Instream Flow Service Group (IFG) of the U.S. Fish and Wildlife Service.

Recommendations derived from the four methods were compared to those derived from long-term trout standing crop and flow data. The trout-flow data generally provided two minimum flow recommendations for each reach. Flows less than the absolute minimum recommendation appear to lead to substantial reductions in the standing crops of adult trout or the standing crops of a particular group of adults, such as trophy-size trout. Flows greater than the most desirable minimum recommendation sustained the highest standing crops. The optimum flow should either equal or exceed the most desirable minimum.

The recommendations generated by the single transect method for all five reaches compare favorably to the absolute minimums derived from the trout-flow data. Single, well defined inflection points were generally present and easily interpreted. In addition to providing reliable and consistent recommendations, the single transect method was also the most time and cost efficient of the three field methods.

The multiple transect method provided acceptable absolute minimum recommendations for the four reaches having discernible inflection points. Inflection points, when present, were generally not as well defined as those on the wetted perimeter curves derived for the single transect method. In the two reaches having more than one inflection point, the lowermost occurred at the flow approximately equal to the absolute minimum recommendation. While the multiple transect method did provide acceptable absolute minimum recommendations for four of the reaches, it had no advantage over the single transect method. It was costlier, more time consuming, sometimes difficult to interpret, and occasionally unproductive.

Minimum flow recommendations based on a fixed percentage of the mean flow of record may be valid for the trout rivers of southwest Montana. The absolute minimum recommendations derived from the trout-flow data for the five reaches ranged from about 31-51% of the mean flow. The percentage required appears to depend on the channel morphology with the wider, shallower rivers such as the Madison requiring a greater percentage of the mean. The more typical rivers of the study area (Beaverhead, Gallatin and Big Hole) required an absolute minimum equal to about 33% of the mean. A minimum flow of 10% of the mean as recommended by the "Tennant or Montana" method was unacceptable in all five reaches. Since Tennant's minimum flow is defined as a short-term survival flow, the absolute minimums derived from the trout-flow data are expected to exceed Tennant's minimum recommendations.

The acceptance of less than 50% of the optimum flow recommendations indicates that the IFG incremental method in its present state of development is not a consistent method for deriving instream flow recommendations for the trout rivers of Montana. Possible means for improving the present IFG method for use on the relatively high gradient, boulder and cobble-strewn trout rivers of the study area include (1) modifying the existing IFG model to use bottom velocities rather than the mean velocities in the water column to compute the weighted usable area, (2) developing probability-of-use curves from data collected for river populations of trout, and (3) incorporating cover into the IFG model.

The predictive capabilities of the IFG-4 and the Water Surface Profile (WSP) hydraulic simulation models were also evaluated. The IFG-4 predictions of water surface elevations, velocity and depth were generally superior to those of the WSP model. The IFG-4 predictions of wetted perimeter, even though approximations, were judged superior to those of the WSP model based on the greater accuracy of the predictions of water surface elevation. Additional testing is needed to clarify the reliability of the wetted perimeter predictions of both models.

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APPENDIX

Table 25. Brief resumes for all field personnel participating in the project evaluating instream flow methodologies.

Jeffrey Bagdanov, Fisheries Field Worker

Jeff Bagdanov received a B.S. degree in Fish and Wildlife Management from Montana State University in 1975. He has been employed by the Montana Department of Fish, Wildlife & Parks as a Fisheries Field Worker for 3 years.

George Wayne Black, Fisheries Field Worker

Wayne Black received a B.S. degree in General Biology from Purdue University in 1976. He has been employed as a Fisheries Field Worker by the Montana Department of Fish, Wildlife & Parks since 1978.

Burrell Buffington, Fisheries Biologist

Burrell Buffington received an A.A.S. degree in Forestry from Paul Smiths College in 1965 and a B.S. degree in Aquatic Biology from the University of Montana in 1968. He was employed by the New York State Department of Environmental Conservation for 8 years, the last 3 as a senior aquatic biologist. In 1978 he was briefly employed by the Montana Department of Fish, Wildlife & Parks before returning to New York.

Thomas Greason, Fisheries Field Worker

Tom Greason received a B.A. degree in Business Administration from Ohio University in 1969 and a B.A. degree in Industrial Education and Technology from Glassboro State College in 1974. He has been employed by the Montana Department of Fish, Wildlife & Parks as a Fisheries Field Worker for 1½ years.

Richard Korowicki, Fisheries Field Worker

Dick Korowicki received a B.S. degree in Fisheries Management from Utah State University in 1973. He was employed by the Utah Division of Wildlife Resources for 3 years as a Fisheries Aid. In 1977 and 1978 he was employed by the Montana Department of Fish, Wildlife & Parks as a Fisheries Field Worker, and is presently a Hatchery Worker at the State hatchery in Anaconda, Montana.

Frederick Nelson, Project Leader

Fred Nelson received a B.S. degree in Fishery Science from Cornell University in 1968 and a M.S. degree in Fish and Wildlife Management from Montana State University in 1976. He has been employed as a Fisheries Biologist by the Montana Department of Fish, Wildlife & Parks since 1976. He has worked as a Fisheries Aid in New York and a Fisheries Field Worker in Montana.

Table 25. continued

Bruce Rehwinkel, Fisheries Biologist

Bruce Rehwinkel received a B.A. degree in General Biology from Wartburg College in 1969, a B.S. degree in Fish and Wildlife Management from Montana State University in 1972, and a M.S. degree in 1976. He has been employed by the Montana Department of Fish, Wildlife & Parks since 1976 and is presently a Fisheries Biologist in Whitehall, Montana.

Scott Sanford, Fisheries Field Worker

Scott Sanford is presently completing a B.S. degree in Fish and Wildlife Management at Montana State University. In 1977 and 1978 he was employed by the Montana Department of Fish, Wildlife & Parks as a Fisheries Field Worker.

Kevin Schaal, Fisheries Field Worker

Kevin Schaal received a B.S. degree in Fish and Wildlife Management from Montana State University in 1975. He has been employed by the Montana Department of Fish, Wildlife & Parks since 1975 and is presently a Warden Trainee in Bozeman, Montana.

Jerry Wells, Fisheries Biologist

Jerry Wells received a B.S. degree in Fish and Wildlife Management from Montana State University in 1974 and a M.S. degree in 1976. He has been employed by the Montana Department of Fish, Wildlife & Parks since 1976 and is presently a Fisheries Biologist in Dillon, Montana.

Table 32. Relationship between the mean velocity in the water column and the velocity at 0.8 of the depth for depths $\geq$ 2.5 ft in subreaches of the Madison, Gallatin and Big Hole Rivers.

Subreach	Observations	r	Equation
Madison(#1)	142	.90	$\bar{X}\ \text{Vel} = \frac{.8\ \text{Vel} + .8335}{.9902}$
Gallatin(#2)	106	.88	$\bar{X}\ \text{Vel} = \frac{.8\ \text{Vel} + .0520}{.7493}$
Big Hole(#1)	73	.92	$\bar{X}\ \text{Vel} = \frac{.8\ \text{Vel} + .5281}{.8859}$