EVALUATION OF SELECTED INSTREAM FLOW METHODS IN MONTANA

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INTRODUCTION

The Montana Department of Fish, Wildlife and Parks (MDFWP) 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 altered by irrigation withdrawals. Annual variations of the standing crops of adult trout within each reach were found to be related to annual flow variations. From these relationships, instream flow recommendations were derived.

The use of long-term standing crop and flow data is not a practical means of deriving future flow recommendations due to the excessive time, cost and manpower required to collect data. Because of these limitations, flow recommendations for other waterways in Montana will primarily be derived from instream flow methods that incorporate limited biological data. However, 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 flow recommendations derived from the standing crop and flow data for the five river reaches provide a biologically derived standard for comparing and evaluating the recommendations of the various instream flow methods.

In this study four instream flow methods were applied to each of the five river reaches and their recommendations compared to those derived from the long-term standing crop and flow data. The four methods chosen were: (1) a single transect method utilizing the wetted perimeter-discharge relationship for a riffle cross-section, (2) a multiple transect method utilizing the wetted perimeter-discharge relationship for a composite of cross-sections, (3) the incremental method developed by the Cooperative Instream Flow Service Group (IFG) of the U. S. Fish and Wildlife Service and (4) a non-field or fixed percentage method which utilizes historical discharge records.

The policy of the MDFWP when deriving flow recommendations for Montana's wild trout rivers is to address the needs of only the adult trout, the stage that provides the recreational fishery. The reason for ignoring the other trout life stages is based on the premise that the number of new recruits entering a resident adult trout population is primarily dictated by the adults and not by the number of eggs, fry or juveniles which produce the recruits.

Simply stated, the need for new recruits decreases as the adult population approaches the stream's carrying capacity. If this premise is correct, then there is little justification for providing flows that attempt to maximize the potential spawning, incubation, fry or juvenile habitat since high levels of recruitment are not needed when adult populations are at or near the carrying capacity. Adult habitat is the overriding consideration.

On heavily fished streams in which overharvesting maintains the adult population far below the stream's carrying capacity, the highest possible level of recruitment may be desirable. In these situations, flows that maximize spawning, incubation, fry and juvenile habitat could be justified. However, it is our belief that the best option is to initiate restrictive angling regulations that limit the removal of adults rather than recommending a flow management plan that attempts to maximize the production of recruits. Again, adult habitat becomes the overriding consideration when formulating flow recommendations.

The recommendations derived from the trout standing crop and flow data and the selected instream flow methods are intended to satisfy the flow needs of only the adult trout stage. The selected instream flow methods are designed to meet this objective. Methodologies designed to address the flow needs of other life stages are not evaluated in this paper.

METHODS

The standing crop estimates, which provide the data base for evaluating the instream flow methods, were obtained using the mark-recapture method. Trout were captured with a boat-mounted electro-fishing unit. Estimates of standing crops by age-groups 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).

Single Transect Method

The single transect method involves the use of the wetted perimeter-discharge relationship for a single riffle cross-section to derive flow recommendations. 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 throughout the entire 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 flow recommendation is selected at this inflection point. An example of a wetted perimeter-discharge curve for a riffle cross-section is shown in Figure 1.

Wetted perimeter was chosen because it was judged to be the single parameter most likely related to the amount of habitat available for adult trout in the boulder and cobble strewn rivers of the study area. It was reasoned that a wetted perimeter-habitat relationship could exist since wetted perimeter is a "bottom" measurement and adult trout are primarily oriented to the river bottom. It was assumed that once the rate of loss of wetted perimeter begins to accelerate (at the inflection point on the wetted perimeter-discharge curve), the loss of adult habitat is also accelerating. Trout habitat and wetted perimeter relationships have not been documented in the literature at present. This approach assumes such relationships exist.

A riffle cross-section was chosen because riffles are the area of a stream most affected by flow reductions. It was assumed that if a given flow provided adequate adult habitat in riffles, more than adequate habitat would also be provided in pools and runs, areas normally occupied by adult trout. Riffle cross-sections would presumably provide more than a minimal adult recommendation.

The wetted perimeter-discharge curve for each riffle cross-section was derived using a wetted perimeter predictive (WETP) computer program developed by the MDFWP (Nelson, 1980). The WETP program uses two to ten sets of stage measurements taken at different known discharges at each cross-section to establish a least-squares fit of log-stage versus log-discharge. This rating curve coupled with the cross-sectional profile is all that is needed to predict the wetted perimeter for each flow of interest. In this study, the WETP program was calibrated to field data collected at three to four different flows for each riffle cross-section.

Multiple Transect Method

The multiple transect method involves the use of the wetted perimeter-discharge relationship for a composite of four to seven cross-sections to derive flow recommendations. 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 flow recommendation selected at the inflection point on the plot of average wetted perimeter versus discharge. The wetted perimeter-discharge curves were derived using the WETP computer program. The program was calibrated to field data collected at three to four different flows for each cross-section. An example of a wetted perimeter-discharge curve for a composite of cross-sections is shown in Figure 2.

As with the single transect method, wetted perimeter was chosen because it was assumed to provide an index of the amount of adult trout habitat. It was reasoned that, if proven reliable, multiple transect recommendations would be more acceptable to the water courts since the recommendations are based on several cross-sections encompassing various habitat types.

Figure 1. Wetted perimeter-discharge relationship for a single riffle cross-section in reach #3 of the Madison River.

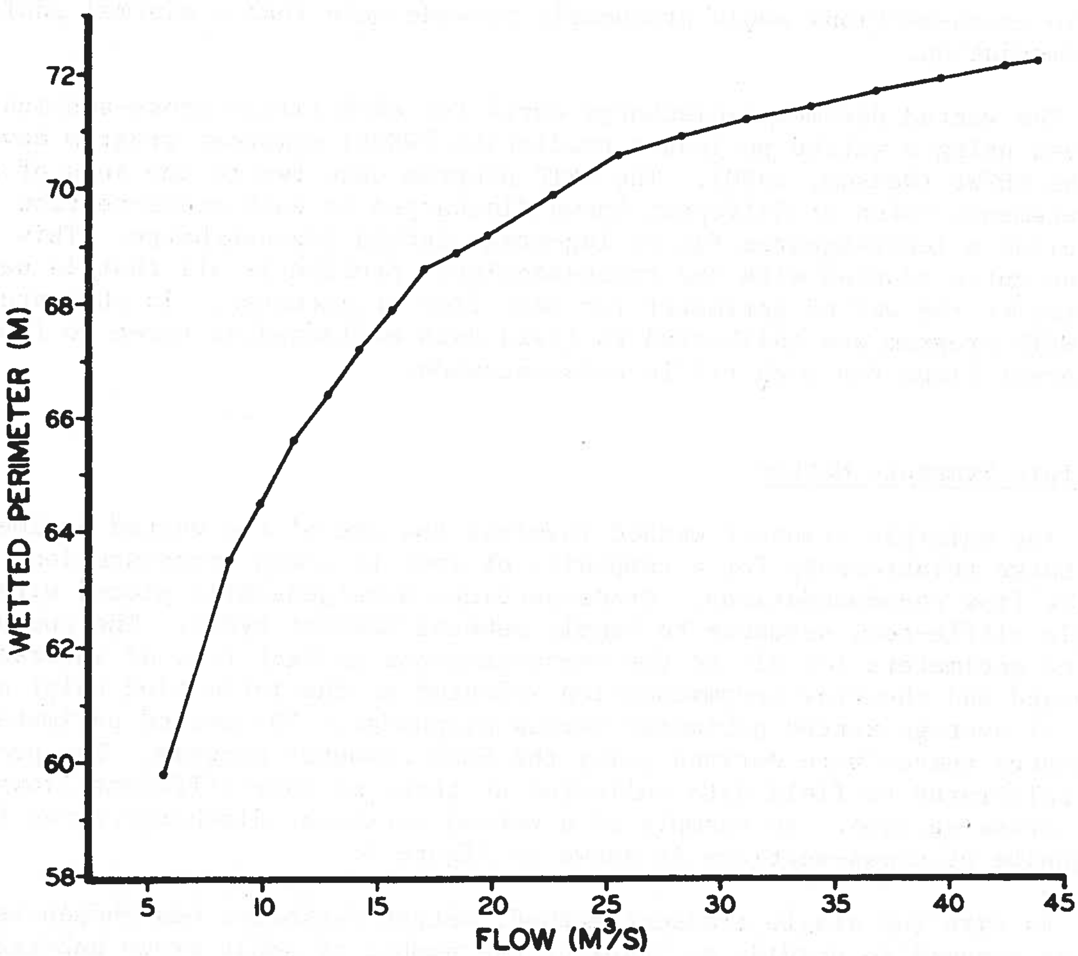
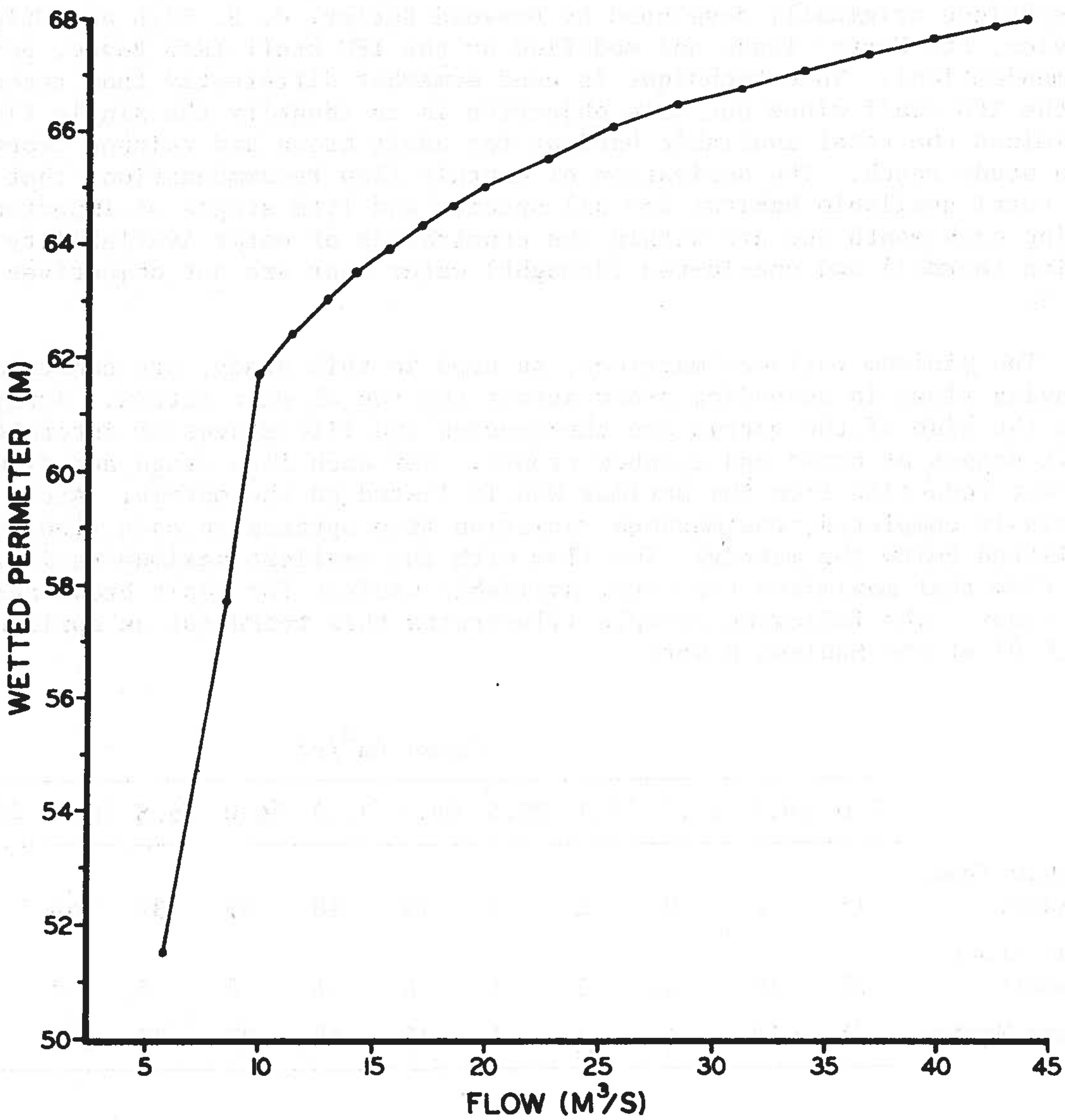


Figure 2. Wetted perimeter-discharge relationship for a composite of five cross-sections in reach #3 of the Madison River.



IFG Incremental Method

The IFG incremental method enables the biologist to quantify the potential impact of changes in stream flow on the habitat of a selected fish species and life stage. The physical variables of depth, velocity and temperature as associated with substrate are assumed to be the most important fish habitat variables when quantifying habitat changes under differing flow conditions. The habitat index calculated from these variables is termed the "weighted usable area" (WUA). The IFG model calculates a WUA value for each flow and life stage of interest. This method is described in Bovee and Cochnauer (1977), Bovee (1978) and Main (1978 and 1978a).

Flow recommendations were derived from the calculated WUA-discharge relationships for the life stages of interest using minimum variance matrices, a technique originally developed by Denwood Butler, U. S. Fish and Wildlife Service, Ft. Worth, Texas and modified by the IFG staff (Ken Bovee, personal communication). This technique is used somewhat differently than recommended by the IFG staff since our sole objective is to identify the single flow that maximizes the total available habitat for adult brown and rainbow trout within each study reach. The derivation of monthly flow recommendations that maximize the total available habitat for all species and life stages of importance during each month and are within the constraints of water availability for a median (normal) and one-in-ten (drought) water year are not objectives of this paper.

The minimum variance matrices, as used in this study, are constructed by arraying flows in ascending order across the top of each matrix. Arrayed down the side of the matrix are the species and life stages of interest (the adult stages of brown and rainbow trout). For each life stage and flow, the percent reduction from the optimum WUA is listed on the matrix. After the matrix is completed, the maximum variation from optimum in each flow column is listed below the matrix. The flow with the smallest maximum variation is the flow that maximizes the total available habitat for adult brown and rainbow trout. The following example illustrates this technique as applied to reach #1 of the Madison River:

	Flows (m^3/s)											
	17.0	19.8	22.7	24.1	25.5	28.3	31.2	34.0	36.8	39.7	42.5	45.3
Rainbow Trout Adult	15	2	0	2	4	12	18	27	37	46	54	60
Brown Trout Adult	21	10	4	3	1	0	1	3	5	7	10	13
Column Maxima	21	10	4	<u>3</u>	4	12	18	27	37	46	54	60

According to this matrix, the flow that maximizes the total available habitat for adult brown and rainbow trout in reach #1 of the Madison River is 24.1 m^3/s. Similar matrices were constructed for the remaining study reaches.

Non-Field Method

For this method, the monthly flow recommendations derived from the trout-flow data for the five study reaches are expressed as percentages of the mean and median annual flows of record as derived from USGS gage records. The purpose of this analysis is to determine if any general rules of thumb emerge for the study reaches. Rules of thumb would provide a basis for evaluating the applicability of instream flow methods, such as the Tennant method (Tennant, 1975), which base their recommendations on a fixed percentage of a historical flow of record.

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 240 km to Three Forks, Montana where is joins the Jefferson and Gallatin Rivers to form the Missouri River. The river drains about 6,475 sq km. There are two man-made impoundments on the river: Hebgen Reservoir, located 2.4 km downstream from the park boundary; and Ennis Reservoir, located 101 km downstream from Hebgen Reservoir.

Flows in the lower 175 km of 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 to early July. Stored water is released to downstream reservoirs from October through December.

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.

Reach #1 encloses a 64 km section of the Madison River between the river's mouth and Ennis Reservoir. The channel in the lower 42 km of reach #1 generally exceeds 91 m in width and is braided, forming many islands and side channels. Boulder, cobble and gravel comprise the bottom substrate. Weed beds are also common. Depths rarely exceed 1.2 m. Well-defined riffle-pool areas are absent. The immediate floodplain is vegetated with willow, alder and numerous cottonwoods. Gradient averages 3.0 m/km.

The upper 22 km of reach #1 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 4.0 m/km. The dominant sport fish in reach #1 in descending order of abundance are mountain whitefish, rainbow trout and brown trout.

The mean flow for a 39-year period of record at the USGS gage near the upstream boundary of reach #1 was 49.9 m^3/s. Flows ranged from 6.0 to 270.6 m^3/s.

Cross-sectional measurements in reach #1 were made in a 123 m subreach. The lowermost of five cross-sections was placed in a relatively deep constriction and the uppermost in a wide, shallow area containing weed beds.

Reach #3 encloses a 47 km section of the upper Madison River between river km 116 and 163. This reach consists of turbulent riffle-run areas interspersed with large boulders. The channel averages 68.0 m in width. Depths rarely exceed 1.2 m. Boulder, cobble and gravel comprise the bottom substrate. The gradient averages 5.1 m/km. The floodplain is vegetated with grasses mixed with willow, alder and an occasional cottonwood and conifer. The dominant sport fish in descending order of abundance are mountain whitefish, rainbow trout and brown trout.

Two USGS gages closely bound reach #3. The mean flow for a 13-year period of record at the USGS gage near the downstream boundary was 40.6 m^3/s. Flows ranged from 7.8 to 250.2 m^3/s. The mean flow for a 67-year period of record at the gage near the upstream boundary was 28.3 m^3/s. Flows ranged from 0.1 to 289.0 m^3/s.

Cross-sectional measurements in reach #3 were made in a 99 m subreach. The lowermost of five cross-sections was placed in a wide riffle area and the uppermost in a narrower run.

Beaverhead River

The Beaverhead River originates at the outlet of Clark Canyon Reservoir, an irrigation storage facility constructed in 1964, and flows 129 km before joining the Big Hole River to form the Jefferson River. The river drains about 12,950 sq km.

Reach #2 encloses a 26 km section of river between river km 103 and Clark Canyon Dam (river km 129). The average channel width is about 25 m. Gradient averages 2.5 m/km. 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. The dominant sport fish in descending order of abundance are mountain whitefish, brown trout and rainbow trout.

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 at the downstream boundary of reach #2. 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 flow for a 70-year period of record at the USGS gage located near the downstream boundary of reach #2 was 12.0 m^3/s. Flows ranged from 2.0 to 77.1 m^3/s. 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 180 m subreach. Seven cross-sections were placed in a riffle-pool sequence containing an island.

Gallatin River

The free flowing Gallatin River originates at Gallatin Lake in Yellowstone National Park and flows north for approximately 185 km to Three Forks, Montana where it joins the Madison and Jefferson Rivers to form the Missouri River. The river drains about 4,662 sq km, all above an elevation of 1,219 m. Most of the drainage basin above 1,524 m is covered with coniferous forest and located within Yellowstone National Park and the Gallatin National Forest. The drainage basin below 1,524 m consists primarily of the Gallatin Valley, one of the richest agricultural regions in Montana.

Reach #2 of the Gallatin River encloses a 55 km section located within the Gallatin Valley between the confluence of the East Gallatin River (river km 19) and the mouth of the Gallatin Canyon (river km 74). As the river leaves the canyon, flow is confined to a single channel. Mean channel width at this point is about 46 m and gradient averages 4.0 m/km. As the river progresses through the Gallatin Valley, the flow becomes braided into three to four channels with the main channel shifting from year to year. Mean channel width in the lower valley is about 197 m. The dominant sport fish in descending order of abundance are mountain whitefish, brown trout, rainbow trout and brook trout.

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. Cover in the lower valley is composed primarily of cottonwood log jams and debris piles. The large instream boulders of the upper valley are absent in the lower valley.

Reach #2 is markedly affected 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 depends on the annual flow with more severe dewatering occurring in low water years. In some years portions of the river are totally dewatered in late July and

August.

The mean flow for a 49-year period of record at the USGS gage near the upstream boundary of reach #2 was 23.1 m^3/s. Flows ranged from 3.3 to 274.6 m^3/s. 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.

Cross-sectional measurements in reach #2 were made in a 191 m subreach. Seven cross-sections were placed in a riffle-pool sequence.

Big Hole River

The free-flowing Big Hole River originates in the Bitterroot Mountains of southwest Montana and flows 251 km before joining the Beaverhead River to form the Jefferson River. The river drains about 6,413 sq km. 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 temperatures considered undesirably high for the growth and propagation of salmonids have been recorded in past years when severe dewatering has occurred.

Reach #1 encloses an 82 km section between the river's mouth and Divide, Montana. 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 38 m and gradient averages 2.7 m/km. The bottom substrate consists primarily of cobble and gravel interspersed with boulders. The dominant sport fish in descending order of abundance are mountain whitefish, brown trout and rainbow trout.

The mean flow for a 54-year period of record at the USGS gage located about mid-reach was 32.8 m^3/s. Extremes for the period of record since the failure of the Wise River Dam in 1927 have been a minimum of 1.4 m^3/s and a maximum of 405.2 m^3/s. 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.

Cross-sectional measurements in reach #1 of the Big Hole River were made in a 303 m subreach. Six cross-sections were placed in a riffle-pool sequence.

INSTREAM FLOW RECOMMENDATIONS

Standing Crop and Flow Data

The long-term standing crop and flow data generated a range of recommendations for each of the five reaches (Table 1). Flows less than the lower limit are judged undesirable since they lead to substantial reductions of 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 upper limit supported the highest adult standing crops during the period estimates were made. Flows between the lower and upper limits support intermediate standing crops or those standing crops that normally occur within each reach. The lower limits are selected as the flow recommendations. The reader is referred to Nelson (1980a and 1980b) for a discussion of the trout standing crop and flow data used to derive these recommendations and to Appendix A for a list of papers pertaining to these standing crop estimates.

Table 1. Range of flow recommendations (m^3/s) derived from the trout standing crop and flow data for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers. Recommendations apply to adult brown and rainbow trout.

Reach	Range of Flow Recommendations (m^3/s)
Madison #1	25.5 - 34.0
Madison #3	18.4 - 32.6
Beaverhead #2	4.3 a/ - 8.5 b/
Gallatin #2	7.1 - 14.8
Big Hole #1	11.3 - c/

a/ - Lower limit derived for age III rainbow trout.
b/ - Upper limit derived for age IV and older (trophy-size) brown and rainbow trout.
c/ - Upper limit presently undefined.

These recommendations are assumed to apply to all of the low flow or non-runoff months even though they may have been derived from data pertaining to 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 flow period generally includes the months of August through April. During the high flow or snow runoff period, which generally occurs during May, June and July, the MDFWP bases its recommendations on the high flows judged necessary to maintain the channel morphology and to flush bottom sediments. This methodology, which is referred to as the dominant discharge/channel morphology concept, is described and the flow recommendations for each of the five reaches during the high flow period are given in Montana Department of Fish and Game (1979). High flow recommendations will not be discussed in this paper.

The final monthly recommendations for the low flow period along with the median monthly flows of record are listed for each reach in Table 2. When the recommendation exceeded the median monthly flow, the median monthly flow became the final recommendation. Therefore, the monthly recommendations listed in Table 2 are within the constraints of water availability for a median

Table 2. Final monthly flow recommendations (m^3/s) for the low flow period for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers. Recommendations were derived from the long-term trout standing crop and flow data and apply to a median or normal water year.

	Madison #1		Madison #3		Beaverhead #2		Gallatin #2		Big Hole #1	
	Median	Rec.	Median[a]	Rec.	Median	Rec.	Median	Rec.	Median	Rec.
January	41.9	25.5	25.1	18.4	8.2	4.3	8.1	7.1	9.7	9.7
February	39.7	25.5	23.3	18.4	8.2	4.3	8.0	7.1	9.3	9.3
March	37.1	25.5	22.5	18.4	9.4	4.3	8.0	7.1	11.3	11.3
April 1-15	39.0	25.5	}24.8	18.4	10.3	4.3	9.9	7.1	23.2	11.3
April 16-30	37.1	25.5		18.4	10.2	4.3	13.7	7.1		
May 1-15	38.5	25.5	--	18.4	9.6	4.3	27.4	7.1		
May 16-31										
June 1-15										
June 16-30										
July 1-15										
July 16-31	43.9	25.5	--	18.4	10.3	4.3	25.2	7.1	25.6	11.3
August	44.8	25.5	32.9	18.4	9.0	4.3	15.6	7.1	12.6	11.3
September	47.3	25.5	38.1	18.4	8.6	4.3	13.2	7.1	8.6	8.6
October	62.6	25.5	41.8	18.4	9.2	4.3	11.9	7.1	12.7	11.3
November	60.1	25.5	39.3	18.4	11.0	4.3	10.0	7.1	13.5	11.3
December	43.6	25.5	29.6	18.4	9.4	4.3	8.5	7.1	9.9	9.9

a/ Median flows are unavailable and mean flows are substituted where available.

or normal water year.

Field Methods

The inflection point flows for the single and multiple transect methods and the flows that maximize the total available habitat for adult brown and rainbow trout, as derived from the IFG method, are compared to the range of flow recommendations derived from the trout-flow data in Table 3. These recommendations are intended to satisfy the flow needs of adult trout and are only applicable to the low flow or non-runoff period. The recommendations of the three field methods will not be listed by month nor adjusted to fall within the constraints of water availability for a median water year as in Table 2.

Table 3. Flow recommendations (m^3/s) of the single transect, multiple transect, and IFG incremental methods compared to those derived from the trout standing crop and flow data for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers.

	Flow Recommendations (m^3/s)			
Reach	Trout-Flow Data	Single Transect	Multiple Transect	IFG Incremental
Madison #1	25.5 - 34.0	26.9	26.9	24.1
Madison #3	18.4 - 32.6	17.0	12.8	17.0
Beaverhead #2	4.3 - 8.5	6.4	5.0	>9.7
Gallatin #2	7.1 - 14.8	8.5	9.2	6.4
Big Hole #1	11.3 - [a]	9.2	-	14.2

[a] Upper limit presently undefined.

Single Transect Method. The inflection point flows for three of the reaches (Madison #1, Madison #3 and Gallatin #2) are approximately equal to the lower limits of the flow ranges generated by the trout-flow data. For the Beaverhead #2 reach, the inflection point flow occurs midway between the lower and upper limits and in the remaining reach (Big Hole #1) the inflection point flow is somewhat less (2.1 m^3/s) than the lower limit. In general, the single transect recommendations compare favorably to those derived from the trout-flow data.

Multiple Transect Method. Only three of the multiple transect recommendations (Madison #1, Beaverhead #2 and Gallatin #2 reaches) are judged acceptable based on the comparison with those of the trout-flow data. The recommendation for the Madison #3 reach is unacceptable since it is 5.7 m^3/s less than the lower limit of the flow range derived from the trout-flow data. For the Big Hole #1 reach, a recommendation is unavailable since two inflection points (at 7.8 and 17.0 m^3/s) are present on the wetted perimeter-discharge curve.

IFG Incremental Method. The IFG recommendations are expected to exceed the upper limits of the flow ranges derived from the trout-flow data since they are intended to maximize the total available habitat for adult brown and rainbow trout and, thereby, sustain near optimal adult standing crops. Three of the IFG recommendations (Madison #1, Madison #3 and Gallatin #2 reaches) are in fact less than the lower limits of these flow ranges. These results led to an examination of the IFG model and its applicability to river environments. Ways for improving the IFG model for use on Montana's trout rivers were suggested by this examination. They are briefly discussed as follows:

The mean velocities in the water column, one of the variables used by the IFG model for computing the WUA, have little relation to the bottom velocities commonly chosen by the adult trout inhabiting the relatively high gradient, cobble and boulder strewn rivers of the study area. When the IFG model is adjusted to use bottom velocities rather than mean velocities for computing the WUA, the WUA-discharge curves for the study reaches are markedly altered. Figure 3 illustrates the magnitude of the changes that can occur to the WUA-discharge curves for adult brown and rainbow trout when bottom velocities are substituted for mean velocities. The use of the bottom velocities is a more realistic approach since adult trout are generally considered bottom oriented.

WUA-discharge curves were derived using bottom velocities for three of the study reaches. When these "new" curves are incorporated into the minimum variance matrices previously discussed, the flows that maximize the total available habitat for adult brown and rainbow trout in the Madison #1, Gallatin #2 and Big Hole #1 reaches are now 31.2, 8.5 and 25.5 m^3/s, respectively. These flows are 7.1, 2.1 and 11.3 m^3/s, respectively, greater than those previously derived using mean velocities. It is evident that the use of the mean velocities by the present IFG model as one of the variables for computing the WUA is unacceptable for Montana's trout rivers.

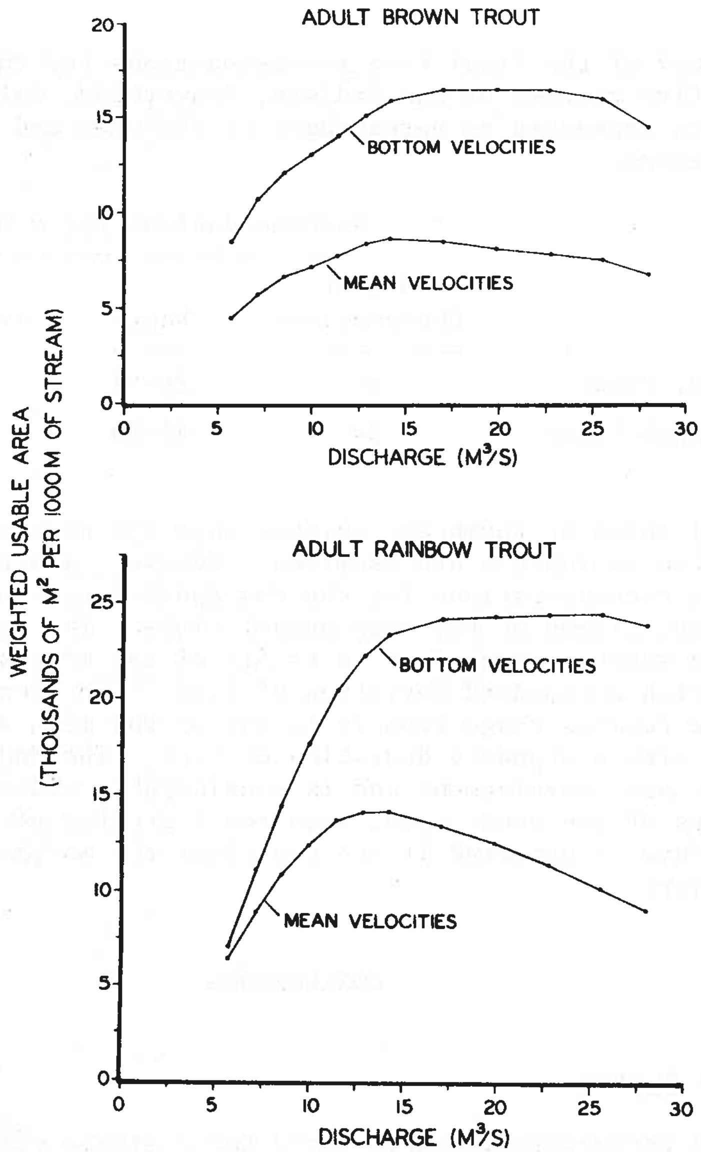
Based on the comparison of these "new" IFG recommendations for the Madison #1, Gallatin #2 and Big Hole #1 reaches with those of the trout-flow data, it was concluded that other modifications in addition to the incorporation of bottom velocities into the model are needed in order to improve the reliability of the IFG recommendations.

Cover, a variable influenced by flow and shown in many cases to be highly correlated with trout standing crops, is one factor that has the potential for altering the WUA-discharge curves and, thereby, improve the IFG recommendations. The IFG staff is presently incorporating cover into their model.

Probability-of-use curves developed for river trout populations are another modification that may be needed. The probability-of-use curves developed by the IFG staff and used in this study were primarily derived from data collected on streams and creeks. These curves may not be applicable to the larger waterways.

Data that would determine the magnitude of the changes these two modifications (addition of cover and probability-of-use curves for river trout populations) would have on the computed WUA and the resulting recommendations

Figure 3. Weighted usable area-discharge relationships derived from the IFG incremental method for adult brown and rainbow trout in reach #1 of the Big Hole River using both the mean and bottom velocities in the water column.



were not collected in this study. It is only assumed that these two modifications would greatly improve the IFG model for use on Montana's trout rivers.

Non-Field Method

The final monthly flow recommendations listed in Table 2 for the five study reaches are expressed as percentages of the mean and median annual flows of record. These percentages are summarized in Table 4.

Table 4. Summary of the final flow recommendations for the low flow months for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers expressed as percentages of the mean and median annual flows of record.

	Recommendations for a Median Water Year		
	No. of Observations	Range	Ave. (Standard Deviation)
% of Mean Annual Flows	54	26-51	39.2 (8.2)
% of Median Annual Flows	54	45-83	57.7 (11.0)

No general rules of thumb are evident when the percentages and standard deviations listed in Table 4 are examined. However, general rules are suggested when the recommendations for the two Madison reaches are removed and expressed as percentages of the mean annual flows. The recommendations for the two Madison reaches range from 46 to 51% of the mean annual flows and average 48.5% with a standard deviation of 2.6%. The recommendations for the remaining three reaches range from 26 to 35% of the mean annual flows and average 32.8% with a standard deviation of 2.6%. The Madison River, which generally lacks pool development and is considerably wider and shallower than the other rivers of the study area, requires a greater percentage of the mean annual flow. This is expected if one considers the morphological differences between the rivers.

CONCLUSIONS

Single Transect Method

The wetted perimeter-discharge curve for a single riffle cross-section provided acceptable flow recommendations for adult trout in the five study reaches. Single, well defined inflection points were generally present on the curves and were easily interpreted. In addition to providing reliable recommendations, the single transect method is 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 is the need for large field crews and elaborate boat operations. Field data can generally be collected by a crew of two since most riffles are wadable.

The acceptance of the single transect method as a valid means of deriving flow recommendations for adult trout implies that the wetted perimeter-discharge curves for riffle cross-sections bear some similarity to the relationship between trout standing crops and flow. Below the inflection point flow on the wetted perimeter-discharge curve, the capacity of each of the study rivers to sustain adult trout greatly diminishes. Why the wetted perimeter-discharge curves for riffle cross-sections relate to the carrying capacity is presently unclear.

One possible explanation is that the adult trout populations are food limited and the wetted perimeter-discharge curves for riffles, which are generally considered the primary invertebrate producing areas of a river, provide an index to a river's capacity to produce trout food organisms. Below the inflection point flow, the area available for food production greatly diminishes. The acceptance of this premise as the sole explanation for the apparent effectiveness of the single transect method is unlikely since living space rather than food supply is generally believed a more influential limiting factor on Montana's trout rivers. At present, the original premise that the wetted perimeter provides an index of the amount of adult trout habitat and recommendations derived from riffle cross-sections provide for more than the minimal habitat needs of the adults appears to be the most acceptable explanation.

Multiple Transect Method

The wetted perimeter-discharge curves for a composite of cross-sections provided acceptable flow recommendations for adult trout in only three of the reaches. Inflection points on the wetted perimeter-discharge curves were generally not as well defined as those for the single transect method and in one reach more than one were present.

It is probably best to use multiple transect data to support the recommendations derived from a more reliable field method such as the single transect method previously discussed. In situations where supportive recommendations are desired the additional time, expense and manpower required to collect multiple transect data may be justified.

IFG Incremental Method

The WUA values generated by the IFG incremental method for the rivers of the study area do not provide an accurate index of the actual amount of habitat that is available for adult brown and rainbow trout at the selected flows of interest. As a result, the IFG flow recommendations for the five study reaches are unreliable. Suggested ways for improving the accuracy of the WUA values and the resulting recommendations for adult trout include modifying the existing IFG model to use bottom velocities rather than the mean velocities for computing the WUA, developing probability-of-use curves from data collected for river trout populations and incorporating cover into the IFG model.

Non-Field Method

Data presented in this study suggest that flow recommendations based on a fixed percentage of the mean annual flow of record may be valid for Montana's trout rivers. The percentage selected as a flow recommendation for adult trout appears to depend on the channel morphology with the wider, shallower rivers such as the Madison requiring a higher percentage of the mean annual flow. The more typical rivers of the study area (Beaverhead, Gallatin and Big Hole Rivers) require instream flows equal to about 33% of the mean during the low flow or non-runoff months.

Recommendations of the Tennant method are based on a fixed percentage of the mean annual flow of record. However, Tennant applies his recommended percentages uniformly to all waterways without regard to differences in channel morphology. Based on the study results, channel morphology should be a major consideration when using a fixed percentage method to formulate flow recommendations.

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Vincent, E. R. 1971. River electrofishing and fish population estimates. Prog. Fish Cult., 33(3):163-169.

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APPENDIX A

Following is a list of the papers pertaining to the standing crop estimates used in deriving flow recommendations for this study.

<u>Madison River</u>

Vincent, E. R. 1971. Southwestern Montana fisheries study, evaluation of river fish populations. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-19, Job No. III-a. Montana Dept.

of Fish, Wildlife and Parks, Helena. 19 pp.

Vincent, E. R. 1973. Southwestern Montana fisheries study, evaluation of river fish populations. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-20, Job No. III-a. Montana Dept. of Fish, Wildlife and Parks, Helena. 17 pp.

Vincent, E. R. 1973. Southwestern fisheries inventory, inventory and survey of the waters of the project area. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-24, Job No. I-a. Montana Dept. of Fish, Wildlife and Parks, Helena. 19 pp.

Vincent, E. R. 1977. Southwest Montana fisheries investigation, Madison River trout harvest study. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-25, Job No. II-b. Montana Dept. of Fish, Wildlife and Parks, Helena. 7 pp.

Vincent, E. R. 1979. Southwestern Montana fisheries investigations, Madison River temperature study. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-26, Job No. II-a. Montana Dept. of Fish, Wildlife and Parks, Helena. 9 pp.

Vincent, E. R. 1979. Southwest Montana fisheries investigations, Madison River - West Gallatin River trout harvest study. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-27, Job No. 1l-b. Montana Dept. of Fish, Wildlife and Parks, Helena. 16 pp.

<u>Beaverhead River</u>

Elser, A. 1969. Southwest Montana fishery study, inventory of the waters of the project area. Job Completion Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-17, Job No. I. Montana Dept. of Fish, Wildlife and Parks, Helena. 16 pp.

Miller, H. W. 1972. 1971 summary of Clark Canyon - Beaverhead River project. Montana Dept. of Fish, Wildlife and Parks, Helena. 8 pp.

Montana Department of Fish and Game. 1975. Progress Rept., Beaverhead River and Clark Canyon Reservoir fishery study. Montana Dept. of Fish, Wildlife and Parks, Helena. 62 pp.

Nelson, F. A. 1977. Beaverhead River and Clark Canyon Reservoir fishery study. Montana Dept. of Fish, Wildlife and Parks, Helena. 118 pp.

Peterson, N. 1971. 1970 summary of Clark Canyon - Beaverhead River project. Montana Dept. of Fish, Wildlife and Parks, Helena. 19 pp.

Vincent, E. R. 1975. Southwestern fishery inventories, investigations of the influence of large reservoirs on stream fisheries. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-23, Job No. I-d. Montana Dept. of Fish, Wildlife and Parks, Helena. 6 pp.

Wells, J. D. 1978. Southwest Montana fisheries study, investigations of the influence of Clark Canyon Reservoir on the stream fishery of the Beaverhead River. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-26, Job No. I-d. Montana Dept. of Fish, Wildlife and Parks, Helena. 8 pp.

Wipperman, A. 1967. Southwest Montana fishery study, inventory of the waters of the project area. Job Completion Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-15, Job No. I. Montana Dept. of Fish, Wildlife and Parks, Helena. 14 pp.

Wipperman, A. and A. Elser. 1968. Southwest Montana fishery study, inventory of the waters of the project area. Job Completion Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-16, Job No. I. Montana Dept. of Fish, Wildlife and Parks, Helena. 14 pp.

<u>Gallatin River</u>

Vincent, E. R. and F. A. Nelson. 1978. Southwest Montana fisheries investigation, inventory and survey of the waters of the project area. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-26, Job No. I-a. Montana Dept. of Fish, Wildlife and Parks, Helena. 24 pp.

Wells, J. D. 1977. The relationship between flow regimes and trout populations in the West Gallatin River, Montana. A report to Blue Ribbons of the Big Sky Country Areawide Planning Organization, Bozeman. 21 pp.

<u>Big Hole River</u>

Elser, A. A. and R. G. Marcoux. 1971. Inventory of the waters of the project area. Job Progress Rept., Federal Aid in Fish and Wildlife Restoration Acts, Project No. F-9-R-18, Job No. I-a. Montana Dept. of Fish, Wildlife and Parks, Helena. 19 pp.

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