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

By

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IFG INCREMENTAL METHOD

Flow Recommendations of the IFG Method

Revised flow recommendations for the IFG Method were derived 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). The objective of these flow recommendations is to maximize the total habitat potential for a stream within the constraints of water availability.

The first step after the weighted usable area (WUA) - discharge relationships for the life stages of each target species are derived, is to develop a minimum variance matrix for each month. Across the top of the matrix, flows are arrayed in ascending order. The highest listed flow is the monthly median flow and the smallest flow is the lowest flow for which a WUA was derived. The 1-in-10 year monthly flow is also included in the array. Arrayed down the side of the matrix are all the species and life stages of importance during the month. 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 recommendation for the month is the one which gives the smallest maximum variation within the constraints of water availability. The following example illustrates this technique as applied to reach #1 of the Madison River.

Median and 1-in-10 monthly flows for reach #1 of the Madison River

Month	Median Flow (cfs)	1-in-10 Flow (cfs)
Jan.	1,480	1,070
Feb.	1,400	1,040
Mar.	1,310	993
Apr.	1,310	896
May	1,620	960
Jun.	2,850	1,580
Jul.	1,700	1,280
Aug.	1,580	1,120
Sep.	1,670	1,180
Oct.	2,210	1,340
Nov.	2,120	1,300
Dec.	1,540	1,260

Flow recommendations will now be derived for the month of May. During May the following life stages are important:

Rainbow Trout

1. Adult
2. Juvenile
3. Spawning
4. Incubation

Brown Trout
1. Adult
2. Juvenile
3. Fry

Mountain Whitefish
1. Adult
2. Juvenile
3. Fry

The matrix for May follows:

	Flows (cfs)											
	600	700	800	900	960	1000	1100	1200	1300	1400	1500	1620
Rainbow Trout												
Adult	15	2	0	4	9	12	18	27	37	46	54	62
Juvenile	0	3	1	5	7	8	14	22	30	38	44	51
Spawning	9	3	0	2	7	11	22	33	44	54	62	68
Incubation	0	5	12	19	23	25	32	38	43	48	52	57
Brown Trout												
Adult	21	10	4	1	0	0	1	3	5	7	10	14
Juvenile	5	1	0	1	2	4	9	16	23	29	35	42
Fry	0	0	5	11	15	17	24	30	37	42	47	52
Mt. Whitefish												
Adult	68	57	45	33	27	22	12	4	0	0	4	12
Juvenile	6	0	1	5	9	12	19	25	30	34	38	44
Fry	39	26	14	5	2	0	0	1	5	11	17	25
Column Maxima	68	57	45	33	27	<u>25</u>	32	38	44	54	62	68

According to this matrix, the flow that maximizes the total available habitat within the constraints of water availability for a median or normal water year is 1,000 cfs. The flow that maximizes the total available habitat within the constraints of water availability for a 1-in-10 or drought water year is 960 cfs, or the 1-in-10 monthly flow. Therefore, the May flow recommendation for a median water year is 1,000 cfs and 960 cfs is recommended for a 1-in-10 water year. This procedure is repeated for each month, changing the range of flows and the life stages for each month.

The recommendations, which maximize the total available habitat for all life stages of rainbow trout, brown trout and mountain whitefish within the constraints of water availability during a median and 1-in-10 water year, are listed for the five study reaches in Table 1. The WUA-discharge relationships and species' periodicity tables used to construct the matrices are given in Appendix Tables 2 through 11. In cases where the optimum WUA was unknown, the highest WUA within the range of requested flows was substituted for the optimum. The WUA-discharge relationships for mountain whitefish incubation were unavailable and not used in deriving the recommendations for the five reaches.

Table 1 . Monthly flow recommendations (cfs) derived from the IFG Incremental Method for median and 1-in-10 water years. Recommendations maximize the total habitat potential for all life stages of brown trout, rainbow trout and mountain whitefish.

	Madison #1		Madison #3		Beaverhead #2		Gallatin #2		Big Hole #1	
	Median	Rec.	Median[a/]	Rec.	Median	Rec.	Median	Rec.	Median	Rec.
Jan	1480	1000	886	600	290	290	287	287	344	344
Feb	1400	1000	823	600	290	290	282	282	328	328
Mar	1310	1000	794	600	330	330	281	281	400	400
Apr	1310	1000	875	600	384	343	416	375	1290	500
May	1620	1000	1239	600	416	343	1710	375	3150	500
Jun	2850	1000	2250	500	595	343	2980	300	3970	600
Jul	1700	1000	1300	500	393	343	1230	300	1330	600
Aug	1580	1000	1160	500	319	319	551	300	445	445
Sep	1670	1000	1346	500	304	304	466	300	305	305
Oct	2210	1000	1475	500	323	323	419	419	447	447
Nov	2120	1000	1386	500	388	343	353	353	475	475
Dec	1540	1000	1046	500	333	333	300	300	348	348
	1-in-10	Rec.	1-in-10[b/]	Rec.	1-in-10	Rec.	1-in-10	Rec.	1-in-10	Rec.
Jan	1070	1000			175	175	234	234	229	229
Feb	1040	1000			176	176	228	228	250	250
Mar	993	993			199	199	227	227	304	304
Apr	896	896			192	192	314	314	675	500
May	960	960			165	165	979	375	1860	500
Jun	1580	1000			249	249	1530	300	1200	600
Jul	1280	1000			194	194	658	300	398	398
Aug	1120	1000			136	136	424	300	179	179
Sep	1180	1000			120	120	340	300	190	190
Oct	1340	1000			150	150	302	302	262	262
Nov	1300	1000			188	188	270	270	314	314
Dec	1260	1000			178	178	240	240	254	254

a/ Median flows are unavailable and mean flows were substituted

b/ 1-in-10 year flows are unavailable.

The above approach is not the approach the author would choose in deriving recommendations with the IFG Method. I would first eliminate the mountain whitefish from the matrices, since it is difficult to justify their use as a target species for the wild trout rivers of Montana. The mountain whitefish is held in low esteem by the majority of anglers due to their poor sporting qualities. Relatively few anglers intentionally fish for whitefish or utilize them as a food fish. Anglers generally believe that whitefish compete with trout and the removal of whitefish would benefit trout populations. Consequently, anglers tend to categorize whitefish with suckers, carp and other "undesirables." As a means of reducing whitefish populations, pressure groups forced the passage of a bill during the 1979 Montana Legislature which authorized the Fish and Game Commission to establish commercial hook and line whitefish fishing on the wild trout rivers of the state. This potential commercial designation along with the present creel limit of 30 whitefish per day attests to the indifference of the general angling public towards this species. Considering the prejudices of the majority of anglers, the mountain whitefish is best ignored when deriving flow recommendations for Montana's wild trout rivers. The recommendations derived after mountain whitefish are eliminated from the minimum variance matrices are listed in Table 12.

I would also choose to address the flow needs of only the adult trout stage when deriving monthly recommendations for Montana's wild trout rivers. My recommendations derived from the minimum variance matrices would, therefore, maximize the habitat potential for only adult brown and rainbow trout, the stage that is providing the recreational fishery. The only objection I see to this approach is that it may jeopardize spawning, incubation, fry or juvenile habitat, thereby, limit recruitment into the adult trout population and prevent the adults from reaching the carrying capacity. In my opinion, this argument is invalid for the majority of wild trout rivers of Montana.

I am unaware of any studies indicating that the number of new recruits entering a resident adult population is primarily a function of the number of eggs, fry, or juveniles from which they evolved. It is my opinion that the level of recruitment is in fact dictated by the adult population. 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 they are not the overriding factor determining the level of recruitment.

Results of the wild trout studies being conducted on the Madison River by Dick Vincent of the Montana Department of Fish, Wildlife and Parks (MDFWP) support this premise (Dick Vincent, personal communication). His data is summarized as follows. Approximately three years after a 6-mile study section was closed to fishing, the adult trout biomass increased by 163% and presumably reached the carrying capacity of the river. Along with this population increase, numbers of juvenile trout dramatically declined. The estimated numbers of juvenile (age I+) rainbow and brown trout in 1979, following three summers of closure, were only 27 and 51%, respectively, of those in 1977, following one summer of closure. There is no evidence that this decline of younger trout

Table 12. Monthly flow recommendations (cfs) derived from the IFG Incremental Method for median and 1-in-10 water years. Recommendations maximize the total habitat potential for all life stages of brown and rainbow trout.

	Madison #1		Madison #3		Beaverhead #2		Gallatin #2		Big Hole #1	
	Median	Rec.	Median[a]	Rec.	Median	Rec.	Median	Rec.	Median	Rec.
Jan	1480	700	886	400	290	290	287	200	344	344
Feb	1400	700	823	400	290	290	282	200	328	328
Mar	1310	700	794	400	330	330	281	200	400	400
Apr	1310	700	875	400	384	343	416	375	1290	350
May	1620	700	1239	400	416	343	1710	375	3150	350
Jun	2850	700	2250	400	595	343	2980	200	3970	400
Jul	1700	800	1300	400	393	343	1230	200	1330	450
Aug	1580	800	1160	400	319	319	551	200	445	445
Sep	1670	800	1346	400	304	304	466	200	305	305
Oct	2210	800	1475	400	323	323	419	400	447	400
Nov	2120	700	1386	400	388	343	353	400	475	400
Dec	1540	700	1046	400	333	333	300	200	348	348
	1-in-10	Rec.	1-in-10[b]	Rec.[c]	1-in-10	Rec.	1-in-10	Rec.	1-in-10	Rec.
Jan	1070	700		400	175	175	234	200	229	229
Feb	1040	700		400	176	176	228	200	250	250
Mar	993	700		400	199	199	227	200	304	304
Apr	896	700		400	192	192	314	314	675	350
May	960	700		400	165	165	979	375	1860	350
Jun	1580	700		400	249	249	1530	200	1200	400
Jul	1280	800		400	194	194	658	200	398	398
Aug	1120	800		400	136	136	424	200	179	179
Sep	1180	800		400	120	120	340	200	190	190
Oct	1340	800		400	150	150	302	302	262	262
Nov	1300	700		400	188	188	270	270	314	314
Dec	1260	700		400	178	178	240	200	254	254

a/ Median flows are unavailable and mean flows were substituted.

b/ 1-in-10 year flows are unavailable.

c/ Recommendations are believed to be less than the 1-in-10 flows for all months was caused by flow related losses of spawning, incubation, fry or juvenile habitat. Simply, it appears that once the adult population had reached the carrying capacity, there was little "space" available for new recruits and adjustments unrelated to flow occurred between the spawning and juvenile stages to severely limit their availability.

This data supports my contention that adult populations at or near the carrying capacity require little annual recruitment to sustain this maximum population level. In these situations, 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. 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, the author believes that the best option for these situations 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.

Adult trout populations, which are comprised of many year classes, are also capable of partially compensating for insufficient recruitment through higher survival, better growth and earlier maturation of the remaining adults. The population basically shifts from one of many small fish to one of fewer larger fish. The end result can be little change in the total biomass with the population remaining at or near the carrying capacity. Poor recruitment does not necessarily degrade a recreational fishery.

In conclusion, the flow recommendations of the MDFWP for the resident trout rivers of the state address the needs of only adult trout. Consequently, the recommendations I would derive from the minimum variance matrices for the five study reaches would maximize the habitat potential for only the adult stages of brown and rainbow trout. These monthly recommendations are listed for median and 1-in-10 water years in Table 13.

Improving the IFG Model

The purpose of the velocity adjustments of the probability-of-use curves discussed on pages 96 and 97 of the final report was to show that the WUA-discharge relationships derived for the study reaches are markedly altered if the bottom velocities in the water column rather than the mean velocities are used as one of the variables for computing the WUA. The use of the bottom velocities is a more realistic approach since adult trout are generally considered bottom oriented. Figures 1 through 4 illustrate the magnitude of the changes that occur to the WUA-discharge relationships for adult brown and rainbow trout when bottom velocities are substituted for the mean velocities.

Table 13. Monthly flow recommendations (cfs) derived from the IFG Incremental Method for median and 1-in-10 water years. Recommendations maximize the total habitat potential for adult brown and rainbow trout.

	Madison #1		Madison #3		Beaverhead #2		Gallatin #2		Big Hole #1	
	Median	Rec.	Median a/	Rec.	Median	Rec.	Median	Rec.	Median	Rec.
Jan	1480	850	886	600	290	290	287	225	344	344
Feb	1400	850	823	600	290	290	282	225	328	328
Mar	1310	850	794	600	330	330	281	225	400	400
Apr	1310	850	875	600	384	343	416	225	1290	500
May	1620	850	1239	600	416	343	1710	225	3150	500
Jun	2850	850	2250	600	595	343	2980	225	3970	500
Jul	1700	850	1300	600	393	343	1230	225	1330	500
Aug	1580	850	1160	600	319	319	551	225	445	445
Sep	1670	850	1346	600	304	304	466	225	305	305
Oct	2210	850	1475	600	323	323	419	225	447	447
Nov	2120	850	1386	600	388	343	353	225	475	475
Dec	1540	850	1046	600	333	333	300	225	348	348
	1-in-10	Rec.	1-in-10 b/	Rec.(b)	1-in-10	Rec.	1-in-10	Rec.	1-in-10	Rec.
Jan	1070	850			175	175	234	225	229	229
Feb	1040	850			176	176	228	225	250	250
Mar	993	850			199	199	227	225	304	304
Apr	896	850			192	192	314	225	675	500
May	960	850			165	165	979	225	1860	500
Jun	1580	850			249	249	1530	225	1200	500
Jul	1280	850			194	194	658	225	398	398
Aug	1120	850			136	136	424	225	179	179
Sep	1180	850			120	120	340	225	190	190
Oct	1340	850			150	150	302	225	262	262
Nov	1300	850			188	188	270	225	314	314
Dec	1260	850			178	178	240	225	254	254

a/ Median flows are unavailable and mean flows were substituted.

b/ 1-in-10 flows are unavailable.

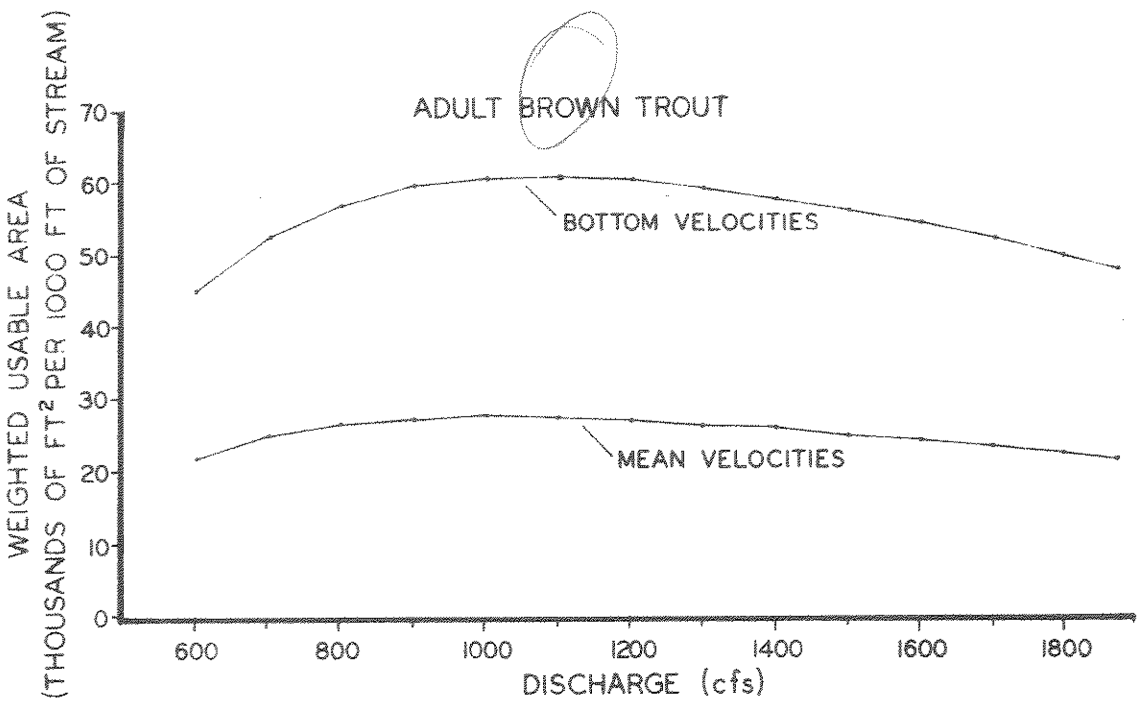

Figure 1. Comparison of the weighted usable area - discharge relationships derived for reach #1 of the Madison River using both the mean and bottom velocities in the water column.

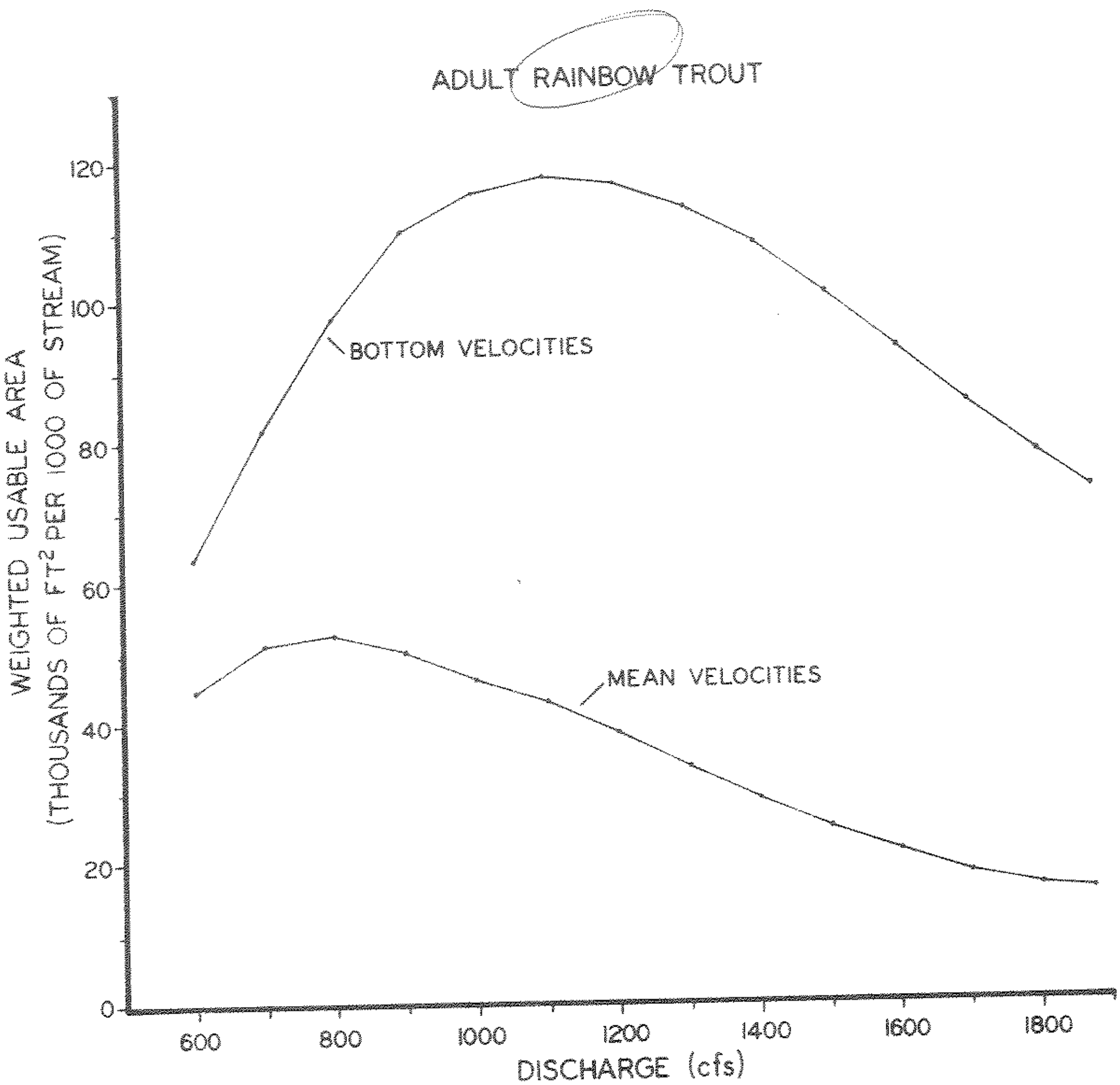

Figure 2. Comparison of the weighted usable area - discharge relationships derived for reach #1 of the Madison River using both the mean and bottom velocities in the water column.

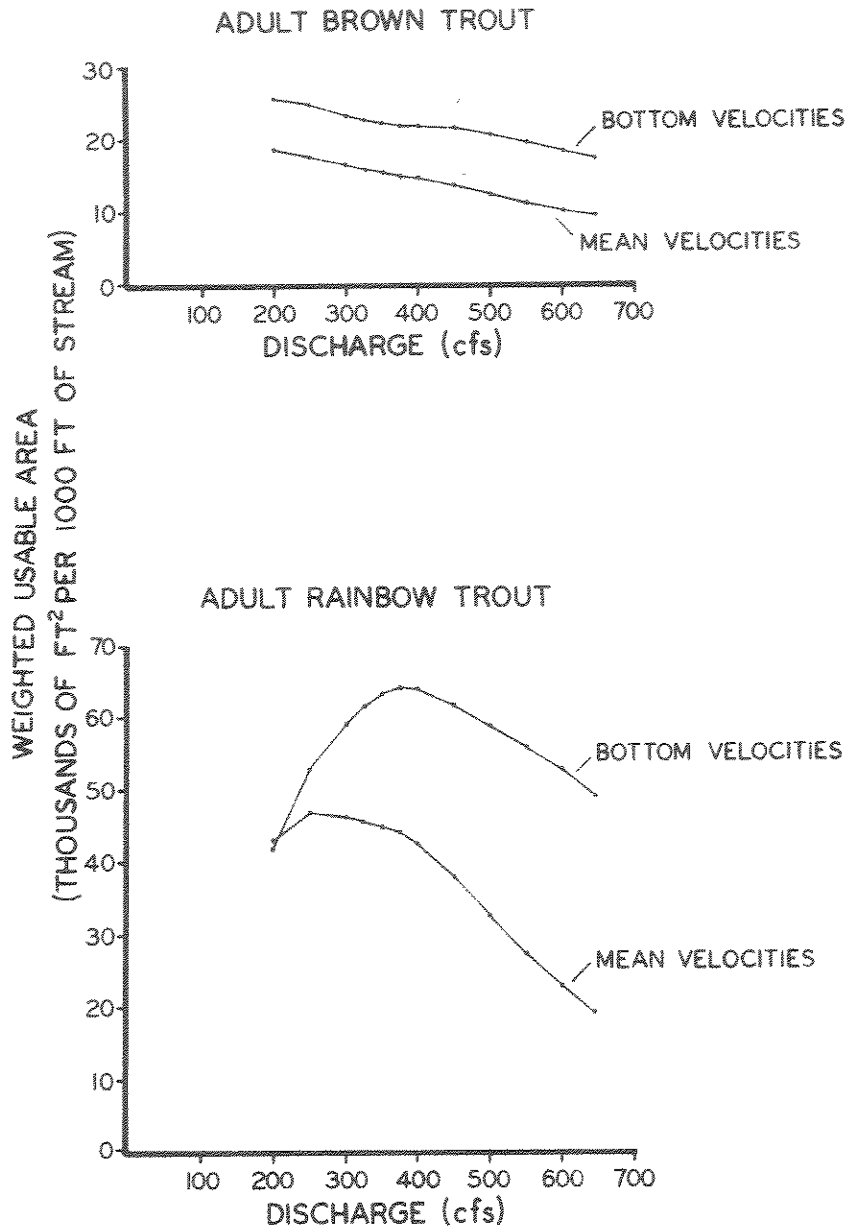

Figure 3. Comparison of the weighted usable area - discharge relationships derived for reach #2 of the Gallatin River using both the mean and bottom velocities in the water column

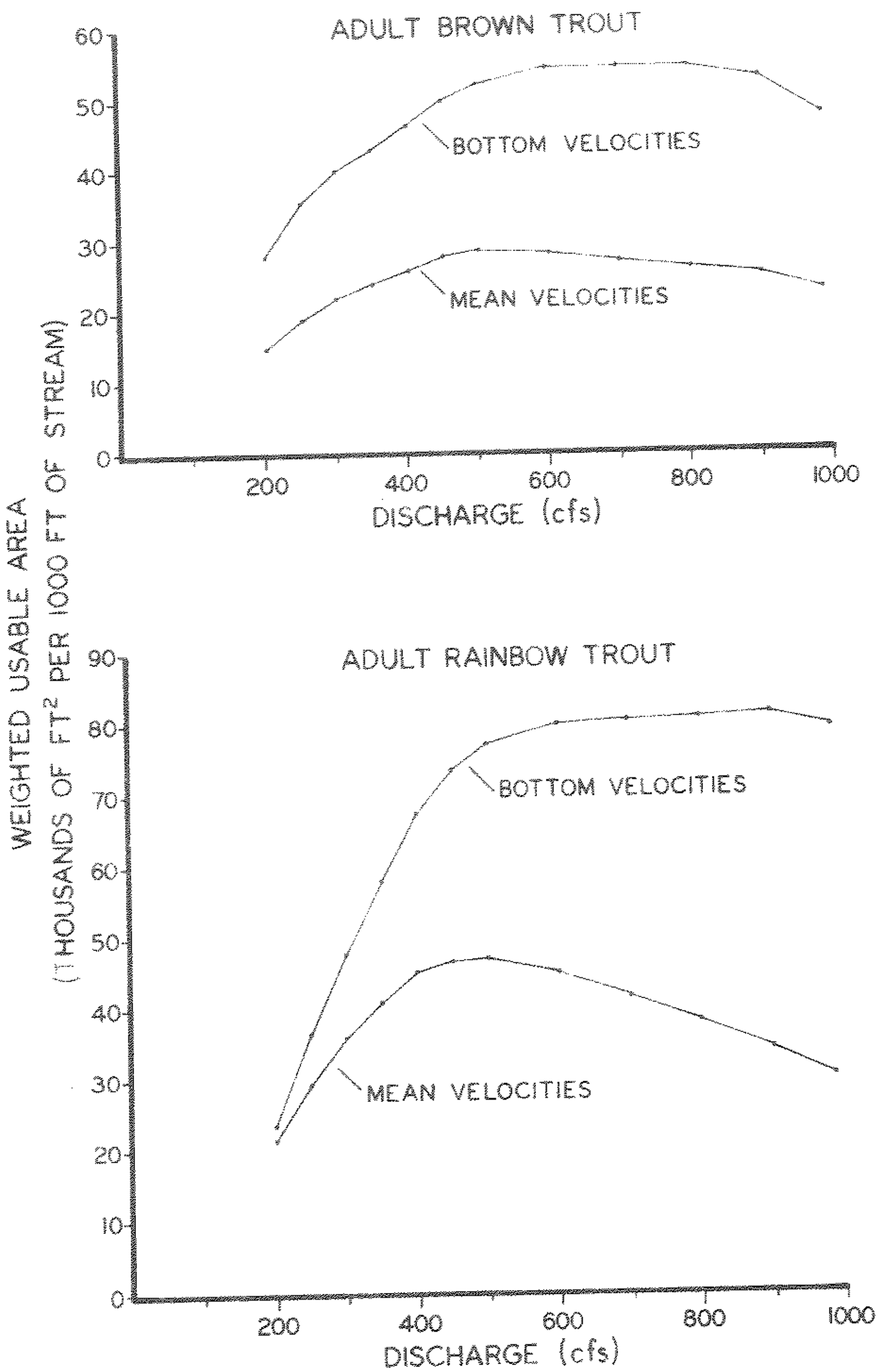

Figure 4. Comparison of the weighted usable area - discharge relationships derived for reach #1 of the Big Hole River using both the mean and bottom velocities in the water column.

When these "new" WUA-discharge 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 1,100, 300 and 900 cfs, respectively. These flows are 250, 75 and 400 cfs, 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 the rivers of Montana.

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, I reasoned that other modifications in addition to the incorporation of bottom velocities into the model were needed in order to improve the accuracy of the IFG recommendations. Cover, which the IFG staff is presently incorporating into the model, and probability-of-use curves developed from data collected for river fish populations are two factors that have the potential for altering the WUA-discharge curves, thereby, improving the accuracy of the recommendations. Data that would determine the magnitude of the changes these two modifications would have on the computed WUA and the resulting recommendations were not collected in this study.

The above discussion of mean versus bottom velocities, cover and probability-of-use curves leads me to conclude that the WUA-discharge relationships for the five study reaches do not accurately depict the actual relationships between trout habitat and flow. If this is the case, the IFG Method cannot provide valid flow recommendations for Montana's trout rivers without extensively modifying the existing model. As stated previously, these modifications include the use of bottom velocities and cover for computing the WUA. The development of probability-of-use curves from data collected for river trout populations may also be necessary.

Weighted Usable Area - Standing Crop Plots

The following discussion pertains to the asked for plots of calculated WUA versus standing crops (pounds of adult trout/mile of river) which accompanied the final report. A reevaluation of the plots resulted in the elimination of some data sets and a slight modification of the remaining sets. These new plots (Figure 5) are basically the same as those originally submitted and show the same general trends.

In my opinion, standing crop estimates for only three of the reaches represent the adult trout carrying capacity for the critical flow periods within these reaches. These are the Madison #1, Gallatin #2 and Big Hole #1 reaches. Only these data sets are included in the new plots. I eliminated the data sets for the Madison #3 reach because the standing crop estimates were made approximately five months after the critical flow period had ended. Estimates for the Beaverhead #2 reach do not reflect the stream's carrying capacity and were not included in the original nor the new plots.

The critical flow period for the Gallatin #2 and Big Hole #1 reaches is the summer irrigation season (July-September) when water depletions occur.

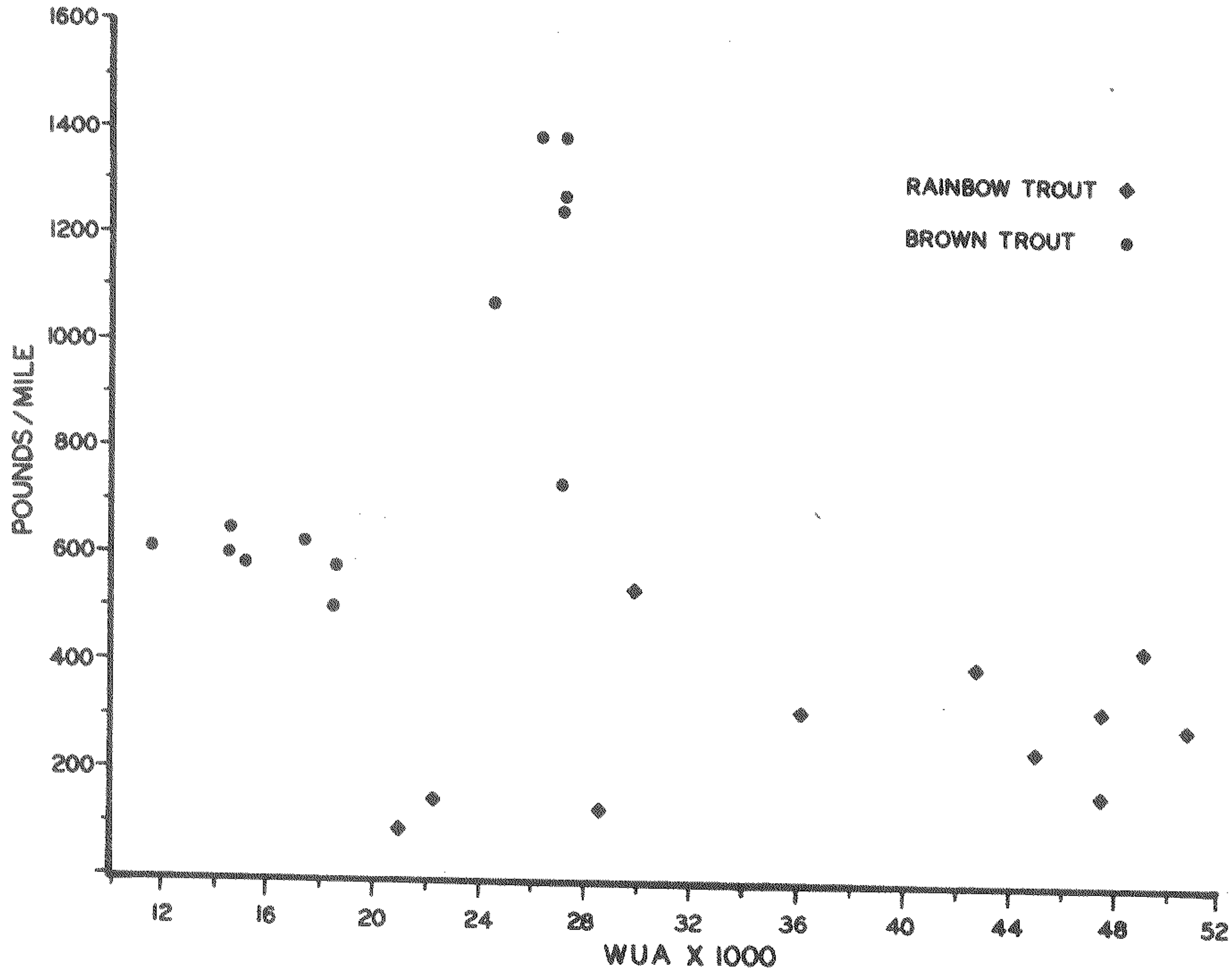

Figure 5. Estimated standing crops (pounds per mile) of adult brown and rainbow trout versus the weighted usable area per 1,000 ft. for three Montana rivers.

The standing crop estimates were made in the fall (September and October) immediately following this critical period. The critical flow period for the Madison #1 reach occurs during January-April when yearly flows are lowest. The standing crop estimates were made in March and April towards the end of this critical period.

The WUA was calculated for the lowest measured flow during the critical flow period immediately preceding each estimate. For the Madison #1 and Big Hole #1 reaches the lowest average daily flow during the critical flow period was determined from USGS gage records. For the Gallatin #2 reach, low flows measured by personnel of the MDFWP were used in computing the WUA.

The absence of well-defined relationships between the calculated WUA and the standing crops of adult brown and rainbow trout (Figure 5) is not unexpected when considering my original contention that the WUA-discharge relationships derived for the study reaches do not depict the actual relationships between adult trout habitat and flow. Before the WUA values can have any comparative significance or be used in deriving recommendations, they must provide an index to the amounts of actual habitat that is available for the various life stages. This has not been demonstrated for the trout rivers of the study area.

TROUT STANDING CROP AND FLOW RELATIONSHIPS

Recommendations for the Low Flow Months

Trout standing crop and flow relationships were used to derive the final monthly flow recommendations for the low flow (non-runoff) months in each of the five reaches. These recommendations are defined as the lowest flows that will maintain populations of adult brown and rainbow trout at the levels normally occurring within each reach. The reasons for ignoring the flow needs of mountain whitefish and the other trout life stages when deriving the final recommendations were previously discussed.

The recommendations for the Big Hole and Gallatin reaches were derived from data pertaining to the summer irrigation season (July, August and September) when water depletions occur. The population estimates given in the final report were made in the fall (September and October) immediately following this critical summer flow period. Data presented in the report indicated that annual variations of the fall population levels primarily reflected the magnitude of the flows during the critical summer period (July-September) preceding each estimate. The adult recommendations derived from these data were assumed to apply to the other low flow months as well.

Flows in the Madison and Beaverhead reaches are regulated by dams. In the Beaverhead reach flows are lowest during the non-irrigation season (October 15-April 15) when Clark Canyon Reservoir stores water and releases into the river are reduced. Population data presented in the report were collected in the spring (March and April), at the end of the non-irrigation season, and in the fall (September and October), at the end of the irrigation season (April 15-October 15). Annual population variations of the various age groups of adult rainbow trout and older brown trout were found to be partially related to the magnitude of the flow releases during the non-irrigation season, when the yearly flows are generally lowest. The adult recommendations derived for this period were assumed to apply to the other low flow months as well.

Flows in the two Madison reaches are presently lowest during January-April when Hebgen Reservoir is passing the flows that approximate the natural condition. Prior to 1968, the filling of the reservoir during this January-April period resulted in the severe dewatering of the river. Once this winter flow problem was corrected (in 1968) populations in the two reaches increased substantially. These population increases presumably reflect the higher January-April flows provided by the change in the storage plan for Hebgen Reservoir. The adult recommendations are based on data pertaining to this critical January-April flow period and were assumed to apply to the other low flow months as well.

Recommendations for the High Flow Months

During the high flow (snow runoff) period, the flow recommendations of the MDFWP are based on the high flows judged necessary to maintain the channel morphology and to flush bottom sediments. This methodology is termed the dominant discharge/channel morphology concept and is discussed as follows (from Montana Department of Fish and Game, 1979):

Several major components of the aquatic habitat in river systems are related to the physical features and form of the river channel itself. Over time, aquatic populations have adapted and thrived within the physical constraints of channel configuration and flow. Basic to the maintenance of the existing aquatic populations is the maintenance of the existing habitat that has historically sustained them.

It is generally accepted that the major force in the establishment and maintenance of a particular channel form in view of its bed and bank material is the annual flood characteristics of the river. It is the high spring flows that determine the shape of the channel rather than the average or low flows.

Most streams and rivers in the Missouri drainage in Montana which are not regulated are characterized by an annual spring high water period which normally occurs during May and June and result from snowmelt in the mountainous headwaters. Lowland prairie streams in the eastern part of the state, which lack mountain headwater areas, have a highwater period which occurs earlier and is the result of lowland snowmelt and runoff. Annual spring flow conditions on unregulated streams are heavily dependent upon snowpack and its rate of thawing. On regulated streams, the occurrence and magnitude of the high water period may vary depending upon reservoir operation and storage capacity.

The major functions of the high spring flows in the maintenance of channel form are bedload movement and sediment transport. It is the movement of the bed and bank material and subsequent deposition which forms the mid-channel bars and subsequently the islands. High flows are capable of covering already established bars with finer material which leads successively to vegetated islands. Increased discharge associated with spring runoff also results in a flushing action which removes deposited sediments and maintains suitable gravel conditions for aquatic insect production, fish spawning and incubation.

Reducing the high spring flows beyond the point where the major amount of bedload and sediment is transported would interrupt the ongoing channel processes and change the existing channel form and bottom substrates. A significantly altered channel configuration would affect both the abundance and species composition of the present aquatic populations by altering the existing habitat types.

Several workers (Leopold, Wolman and Miller 1964, U. S. Bureau of Reclamation 1973, and Emmett 1975) adhere to the concept that the form and configuration of river channels are shaped by and designed to accommodate a dominant discharge. The discharge which is most commonly referred to as a dominant discharge is the bankfull discharge (Leopold, Wolman and Miller 1974, Emmett 1975). Bankfull discharge is defined as that flow when water just begins to over flow onto the active floodplain.

Bankfull discharge tends to have a constant frequency of occurrence among rivers (Emmett 1975). The recurrence interval for bankfull discharge was determined by Emmett (1975) to be 1.5 years and is in close agreement with the frequency of bankfull discharge reported by other studies (Leopold, Wolman and Miller 1964, Emmett 1972).

The bankfull discharge for the rivers of the upper Missouri River drainage was estimated by using the 1½ year frequency peak flow. The 1½ year frequency peak flow was determined by interpolation between the 1.25 and 2 year frequency peak flows as supplied by USGS for the steams in question.

It is not presently known how long the bankfull flow must be maintained to accomplish the necessary channel formation processes. Until studies further clarify the necessary duration of the bankfull discharge, a duration period of 24 hours was chosen.

A gradual rising and receding of flows should be associated with the dominant discharge and the shape of the spring hydrograph should resemble that which occurs naturally. USGS flow records were used to determine the time when the high flow period and peak flow normally occurs on a given stream. The dominant discharge is requested for that period when it normally occurs. Flows are increased from a base flow level to the dominant discharge in 2-week intervals at the 70th percentile flow level, corresponding to the natural timing of the high flow period.

The high flow months are the least likely periods to be affected by water depletions since withdrawals make up a significantly smaller percentage of the flow during spring runoff than during the low flow months of late summer and winter. It is likely that the high flow months can withstand substantial withdrawals and not alter the basic functions of channel maintenance.

The major threat to channel maintenance functions during the high flow period are large water storage projects which have the capability of capturing a large portion of the high flows for later release. The loss of the dominant discharge flow through mainstem impoundment projects can result in a drastically altered channel form.

Final Monthly Flow Recommendations

The final recommendations were derived using the trout-flow relationships (low flow months) and the dominant discharge/channel morphology concept (high flow months). Again, the recommendations for the low flow months are intended to meet the needs of only the adult trout stage.

50%tile 10%tile

The final monthly recommendations are given for a median and 1-in-10 water year in Tables 14 through 18. These recommendations serve as the standard for evaluating the recommendations of the other methodologies.

SINGLE TRANSECT METHOD

In the past personnel of the MDFWP have used the wetted perimeter-discharge relationships for riffle cross-sections to derive flow recommendations for the rearing of warm-water fishes. This approach was based on the principle that the food of most sub-adult fishes in river systems is aquatic invertebrates and aquatic invertebrate production occurs primarily in riffle areas. Rearing is assumed proportional to food production which, in turn, is assumed proportional to the wetted perimeter in riffle areas.

Riffles are also the area of a stream which are most affected by flow reductions. Consequently, the maintenance of suitable riffle habitat for food production will also maintain suitable pool habitat for rearing.

For this study, I chose a somewhat different approach intended to address the flow needs of only adult trout. Wetted perimeter appeared in my judgment to be the single parameter most likely related to the amount of habitat available for adults 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 basically oriented to the river bottom. I 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.

As previously stated, riffles are the area of a stream most affected by flow reductions. I assumed that if a given flow is providing adequate habitat conditions in riffles, more than adequate conditions 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. In this study, cross-sections were placed in riffle areas that typified each study reach.

Table 14. Finalflow recommendations (cfs) for reach #1 of the Madison River for a median and 1-in-10 water year. Recommendations are derived from the trout-flow data (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	1480	900	1070	900
February	1400	900	1040	900
March	1310	900	993	900
April	1310	900	896	896
May 1-15	1358	900	865	865
May 16-31	1871	1514	963	963
June 1-15[a/]	2887	2135	1292	1292
June 16-30	2788	2008	1293	1293
July 1-15	1866	1623	1187	1187
July 16-31	1551	900	1138	900
August	1580	900	1120	900
September	1670	900	1180	900
October	2210	900	1340	900
November	2120	900	1300	900
December	1540	900	1260	900

a/ Includes a flow of 4130 cfs for 24 hours.

Table 15. Finalflow recommendations (cfs) for reach #3 of the Madison River for a median and 1-in-10 water year. Recommendations are derived from the trout-flow data (low flow months).

	Median a/	Rec.	1-in-10 b/	Rec. c/
January	886	650		
February	823	650		
March	794	650		
April	875	650		
May 1-15	-	650		
May 16-31				
June 1-15a/				
June 16-30				
July 1-15				
July 16-31	-	650		
August	1160	650		
September	1346	650		
October	1475	650		
November	1386	650		
December	1046	650		

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

b/ 1-in-10 flows are unavailable

c/ Recommendations undetermined due to unavailability of 1-in-10 monthly flows.

Table 16. Final flow recommendations (cfs) for reach #2 of the Beaverhead River for a median and 1-in-10 water year. Recommendations are derived from the trout-flow data (low flow months) and the dominant discharge/channel morphology concept (high flow months)

	Median	Rec.	1-in-10	Rec.
January	290	150	175	150
February	290	150	176	150
March	330	150	199	150
April	384	150	192	150
May 1-15	340	150	157	150
May 16-31	458	255	156	156
June 1-15 a/	620	387	206	206
June 16-30	504	345	197	197
July 1-15	417	304	181	181
July 16-31	363	150	170	150
August	319	150	136	136
September	304	150	120	120
October	323	150	150	150
November	388	150	188	150
December	333	150	178	150

a/ Includes a flow of 1035 cfs for 24 hours.

Table 17. Finalflow recommendations (cfs) for reach #2 of the Gallatin River for a median and 1-in-10 water year. Recommendations are derived from the trout-flow data (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	287	250	234	234
February	282	250	228	228
March	281	250	227	227
April	416	250	314	250
May 1-15	968	250	481	250
May 16-31	2128	1579	1076	1076
June 1-15 a/	3093	2379	1529	1529
June 16-30	2458	1962	1317	1317
July 1-15	1561	1116	769	769
July 16-31	891	250	540	250
August	551	250	424	250
September	466	250	340	250
October	419	250	302	250
November	353	250	270	250
December	300	250	240	240

a/ Includes a flow of 4220 cfs for 24 hours.

Table 18. Final flow recommendations (cfs) for reach #1 of the Big Hole River for a median and 1-in-10 water year. Recommendations are derived from the trout-flow data (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	344	344	229	229
February	328	328	250	250
March	400	400	304	304
April 1-15	818	400	383	383
April 16-30	1609	1098	750	750
May 1-15	2332	1734	1154	1154
May 16-31	3518	2626	1748	1748
June 1-15 a/	4431	3306	1484	1484
June 16-30	3120	1933	892	892
July 1-15	1579	1042	478	478
July 16-31	902	400	315	315
August	445	400	179	179
September	305	305	190	190
October	447	400	262	262
November	475	400	314	314
December	348	348	254	254

a/ Includes a flow of 5630 cfs for 24 hours.

The recommendations derived from the single transect method were applied to all of the low flow months. Again, the recommendations for the low flow months were intended to meet the flow needs of only the adult trout stage. Recommendations for the high flow months were derived using the dominant discharge/channel morphology concept previously discussed. Monthly recommendations are listed for a median and 1-in-10 water year in Tables 19 through 23.

MULTIPLE TRANSECT METHOD

Personnel of the MDFWP have applied the WSP (PSEUDO) computer model to a variety of streams in the state. However, little of the WSP output has been used in formulating flow recommendations. During the flow reservation process on the Yellowstone drainage, the wetted perimeter-discharge curves generated by the WSP program for riffle cross-sections were used to derive flow recommendations for the rearing of warm-water fishes. The other hydraulic parameters of the WSP output (segment velocity and depth, cross-sectional area and top width) have not been used in the past due to the difficulty in relating these parameters to the needs of fish. Consequently, Montana's experience with the WSP program in deriving flow recommendations is limited to one parameter (wetted perimeter), one river drainage and one purpose (rearing of warm-water fishes).

As with the single transect method, wetted perimeter was chosen in this study because it was assumed to provide an index to the amount of adult trout habitat. I 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.

Other than wetted perimeter, I cannot justify the use of the other parameters of the WSP output for deriving flow recommendations. The average segment velocities and depth are in my opinion unrelated to trout needs. Trout are presumably oriented to a specific range of point velocities and depths, not an average value. This is particularly evident on the relatively high gradient rivers of the study area where trout are generally oriented to the low velocities on the stream bottom, behind the boulders and cobbles. In this situation average segment velocities have little relation to the bottom velocities chosen by the fish. The only valid use I see for average segment velocities and depths for the rivers of the study area is in deriving passage recommendations for shallow riffle areas that act as barriers to migrating fish. Fish passage is not a major concern for Montana's resident trout rivers.

The recommendations derived from the multiple transect method were applied to all of the low flow months. Again, the recommendations for the low flow months were intended to meet the flow needs of only the adult trout. Recommendations for the high flow months were derived using the dominant discharge/channel morphology concept previously discussed. Monthly recommendations are listed for a median and 1-in-10 water year in Tables 24 through 27.

Table 19. Flow recommendations (cfs) for reach #1 of the Madison River for a median and 1-in-10 water year. Recommendations are derived from the single transect method (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	1480	1100	1070	1070
February	1400	1100	1040	1040
March	1310	1100	993	993
April	1310	1100	896	896
May 1-15	1358	1100	865	865
May 16-31	1871	1514	963	963
June 1-15 [a/]	2887	2135	1292	1292
June 16-30	2788	2007	1293	1293
July 1-15	1866	1623	1187	1187
July 16-31	1551	1100	1138	1100
August	1580	1100	1120	1100
September	1670	1100	1180	1100
October	2210	1100	1340	1100
November	2120	1100	1300	1100
December	1540	1100	1260	1100

a/ Includes a flow of 4130 cfs for 24 hours.

Table 20. Flow recommendations (cfs) for reach #3 of the Madison River for a median and 1-in-10 water year. Recommendations are derived from the single transect method (low flow months).

	Median[a/]	Rec.	1-in-10[b/]	Rec.[c/]
January	886	600		
February	823	600		
March	794	600		
April	875	600		
May 1-15	-	600		
May 16-31				
June 1-15				
June 16-30				
July 1-15				
July 16-31	-	600		
August	1160	600		
September	1346	600		
October	1475	600		
November	1386	600		
December	1046	600		

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

b/ 1-in-10 flows are unavailable

c/ Recommendations undetermined due to unavailability of 1-in-10 monthly flows.

Table 21. Flow recommendations (cfs) for reach #2 of the Beaverhead River for a median and 1-in-10 water year. Recommendations are derived from the single transect method (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	290	225	175	175
February	290	225	176	176
March	330	225	199	199
April	384	225	192	192
May 1-15	340	225	157	157
May 16-31	458	255	156	156
June 1-15[a/]	620	387	206	206
June 16-30	504	345	197	197
July 1-15	417	304	181	181
July 16-31	363	225	170	170
August	319	225	136	136
September	304	225	120	120
October	323	225	150	150
November	388	225	188	188
December	333	225	178	178

a/ Includes a flow of 1035 cfs for 24 hours.

Table 22. Flow recommendations (cfs) for reach #2 of the Gallatin River for a median and 1-in-10 water year. Recommendations are derived from the single transect method (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	287	287	234	234
February	282	282	228	228
March	281	281	227	227
April	416	400	314	314
May 1-15	968	400	481	400
May 16-31	2128	1579	1076	1076
June 1-15 a/	3093	2379	1529	1529
June 16-30	2458	1962	1317	1317
July 1-15	1561	1116	769	769
July 16-31	891	400	540	400
August	551	400	424	400
September	466	400	340	340
October	419	400	302	302
November	353	353	270	270
December	300	300	240	240

a/ Includes a flow of 4220 cfs for 24 hours.

Table 23. Flow recommendations (cfs) for reach #1 of the Big Hole River for a median and 1-in-10 water year. Recommendations are derived from the single transect method (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	344	344	229	229
February	328	328	250	250
March	400	400	304	304
April 1-15	818	450	383	383
April 16-30	1609	1098	750	750
May 1-15	2332	1734	1154	1154
May 16-31	3518	2626	1748	1748
June 1-15 a/	4431	3306	1484	1484
June 16-30	3120	1933	892	892
July 1-15	1579	1042	478	478
July 16-31	902	450	315	315
August	445	445	179	179
September	305	305	190	190
October	447	447	262	262
November	475	450	314	314
December	348	348	254	254

a/ Includes a flow of 5630 cfs for 24 hours.

Table 24. Flow recommendations (cfs) for reach #1 of the Madison River for a median and 1-in-10 water year. Recommendations are derived from the multiple transect method (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	1480	900	1070	900
February	1400	900	1040	900
March	1310	900	993	900
April	1310	900	896	896
May 1-15	1358	900	865	865
May 16-31	1871	1514	963	963
June 1-15a/	2887	2135	1292	1292
June 16-30	2788	2007	1293	1293
July 1-15	1866	1623	1187	1187
July 16-31	1551	900	1138	900
August	1580	900	1120	900
September	1670	900	1180	900
October	2210	900	1340	900
November	2120	900	1300	900
December	1540	900	1260	900

a/ Includes a flow of 4130 cfs for 24 hours.

Table 25. Flow recommendations (cfs) for reach #3 of the Madison River for a median and 1-in-10 water year. Recommendations are derived from the multiple transect method (low flow months).

	Median[a/]	Rec.	1-in-10[b/]	Rec.[c/]
January	886	500		
February	823	500		
March	794	500		
April	875	500		
May 1-15	-	500		
May 16-31				
June 1-15				
June 16-30				
July 1-15				
July 16-31	-	500		
August	1160	500		
September	1346	500		
October	1475	500		
November	1386	500		
December	1046	500		

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

b/ 1-in-10 flows are unavailable

c/ Recommendations undetermined due to unavailability of 1-in-10 monthly flows.

Table 26. Flow recommendations (cfs) for reach #2 of the Beaverhead River for a median and 1-in-10 water year. Recommendations are derived from the multiple transect method (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	290	100	175	100
February	290	100	176	100
March	330	100	199	100
April	384	100	192	100
May 1-15	340	100	157	100
May 16-31	458	255	156	156
June 1-15[a/]	620	387	206	206
June 16-30	504	345	197	197
July 1-15	417	304	181	181
July 16-31	363	100	170	100
August	319	100	136	100
September	304	100	120	100
October	323	100	150	100
November	388	100	188	100
December	333	100	178	100

a/ Includes a flow of 1035 cfs for 24 hours.

Table 27. Flow recommendations (cfs) for reach #1 of the Big Hole River for a median and 1-in-10 water year. Recommendations are derived from the multiple transect method (low flow months) and the dominant discharge/channel morphology concept (high flow months).

	Median	Rec.	1-in-10	Rec.
January	344	344	229	229
February	328	328	250	250
March	400	400	304	304
April 1-15	818	400	383	383
April 16-30	1609	1098	750	750
May 1-15	2332	1734	1154	1154
May 16-31	3518	2626	1748	1748
June 1-15[a/]	4431	3306	1484	1484
June 16-30	3120	1933	892	892
July 1-15	1579	1042	478	478
July 16-31	902	400	315	315
August	445	400	179	179
September	305	305	190	190
October	447	400	262	262
November	475	400	314	314
December	348	348	254	254

a/ Includes a flow of 5630 cfs for 24 hours.

NON-FIELD METHOD

The final flow recommendations derived from the trout-flow data and the dominant discharge/channel morphology concept are expressed as percentages of the mean and median annual flows of record in Appendix Tables 28 through 36. The median and mean annual flows used in this analysis along with the monthly medians and means for the study reaches are listed in Appendix Table 37. 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, in which recommendations are based on a fixed percentage of a historical flow of record. Only the recommendations for the low flow months are discussed since the high flow recommendations, as derived from the dominant discharge/channel morphology concept, are not conducive to this type of analysis. The percentages in Appendix Tables 28 through 36 are summarized for the five study reaches in Table 38.

Table 38. Summary of the final flow recommendations for the low flow months in the five study reaches expressed as percentages of the mean and median annual flows of record.

	Median Water Year Recommendations		
	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)
	1-in-10 Water Year Recommendations		
	No. of Observations	Range	Ave. (Standard Deviation)
% of Mean Annual Flows	43	15-51	34.8 (10.7)
% of Median Annual Flows	43	36-80	53.2 (8.4)

No general rules of thumb are evident when the percentages and standard deviations listed in Table 38 are examined. However, general rules are suggested when the recommendations for the two Madison reaches for a median water year are removed and expressed as percentages of the mean annual flow. The recommendations for the two Madison reaches ranged from 46 to 51% of the mean annual flows and averaged 48.5% with a standard deviation of 2.6%. The recommendations for the remaining three reaches ranged from 26 to 35% of the mean annual flows and averaged 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, required a greater percentage of the mean annual flow. This is expected if one considers the differences in channel morphology between the rivers.

missing

CONCLUSIONS

Single Transect Method

The wetted perimeter-discharge curve for a single riffle cross-section provided acceptable flow recommendations for the five river 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 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 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, 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 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 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 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 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) required 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, this approach is unacceptable.

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APPENDIX

Table 2. Discharge (cfs) vs. weighted usable area per 500 ft. of stream for reach #1 of the Madison River.

Rainbow Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
1874.	1942.	7371.	3854.	1464.	13777.
1800.	2227.	7905.	4196.	1631.	14785.
1700.	2607.	8786.	4765.	1893.	16299.
1600.	3055.	10340.	5723.	2200.	17949.
1500.	3569.	12122.	6346.	2458.	19679.
1400.	4318.	14206.	7006.	2773.	21504.
1300.	5280.	16528.	7899.	3128.	23558.
1200.	6307.	19107.	8797.	3443.	25815.
1100.	7299.	21378.	9713.	3939.	28260.
1000.	8349.	23074.	10415.	4479.	30926.
900.	9198.	25019.	10791.	4716.	33732.
800.	9382.	26137.	11173.	4941.	36593.
700.	9087.	25567.	10931.	5020.	39379.
600.	8522.	22341.	11323.	4479.	41393.

Brown Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
1874.	1624.	10556.	10550.	8566.	13777.
1800.	1831.	10942.	11205.	9100.	14785.
1700.	2166.	11490.	12187.	9955.	16299.
1600.	2608.	11873.	13424.	10886.	17949.
1500.	3056.	12321.	14708.	11842.	19679.
1400.	3646.	12705.	16101.	12952.	21504.
1300.	4295.	12994.	17550.	14245.	23558.
1200.	5109.	13293.	19179.	15669.	25815.
1100.	6028.	13529.	20734.	17207.	28260.
1000.	6924.	13654.	21935.	18657.	30926.
900.	7798.	13493.	22571.	19953.	33732.
800.	7696.	13063.	22744.	21321.	36593.
700.	7303.	12339.	22487.	22458.	39379.
600.	7499.	10764.	21635.	22524.	41393.

Mountain Whitefish

Q	Spawning	Adult	Juveniles	Fry
1874.	9707.	25339.	13429.	2810.
1800.	10383.	27944.	14257.	2981.
1700.	11549.	30931.	15352.	3219.
1600.	12953.	33863.	16566.	3482.
1500.	14555.	36576.	17840.	3757.
1400.	16741.	37899.	18998.	4047.
1300.	19132.	38021.	20399.	4319.
1200.	21885.	36508.	21802.	4493.
1100.	24568.	33594.	23458.	4551.
1000.	26633.	29691.	25568.	4532.
900.	27693.	25314.	27612.	4311.
800.	27773.	20789.	28690.	3930.
700.	26326.	16472.	28946.	3377.
600.	24321.	12107.	27072.	2769.

Table 3. Discharge (cfs) vs. weighted usable area per 500 ft. of stream for reach #3 of the Madison River.

Rainbow Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
1550.	3359.	3735.	4097.	1463.	5613.
1300.	4367.	4084.	5437.	1955.	7721.
1200.	4871.	4672.	5656.	2171.	8808.
1000.	5964.	7443.	6372.	2331.	11903.
900.	7042.	9961.	7258.	2403.	13951.
800.	8835.	13538.	8360.	2808.	16482.
700.	10921.	17197.	10567.	3449.	19617.
600.	13827.	19467.	13618.	4281.	23609.
500.	17887.	18116.	17869.	5595.	28796.
400.	21539.	15204.	21023.	7528.	34263.
300.	21525.	10676.	20668.	9039.	40685.
200.	13619.	4922.	11845.	7816.	33577.

Brown Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
1550.	2653.	9124.	7915.	10508.	5635.
1300.	3548.	9762.	10928.	12937.	7722.
1200.	4079.	10325.	12640.	13884.	8808.
1000.	5196.	11078.	15789.	16051.	11903.
900.	5911.	11589.	17842.	17386.	13951.
800.	7026.	12277.	19568.	19132.	16482.
700.	8728.	12964.	21335.	21404.	19617.
600.	10554.	13411.	22349.	23820.	23609.
500.	13644.	13251.	23695.	26265.	28796.
400.	17606.	11887.	24060.	27458.	34265.
300.	19405.	8837.	21194.	25116.	40842.
200.	13697.	3068.	14248.	17435.	35270.

Mountain Whitefish

Q	Spawning	Adult	Juveniles	Fry
1550.	5686.	5538.	9415.	1574.
1300.	7120.	10264.	12196.	2312.
1200.	7769.	12977.	13424.	2813.
1000.	11195.	17740.	16227.	3750.
900.	14197.	18278.	17916.	3796.
800.	18089.	16903.	19739.	3611.
700.	23321.	14289.	22081.	3270.
600.	27971.	11563.	24298.	2867.
500.	32089.	9128.	25904.	2361.
400.	32714.	6905.	25711.	1726.
300.	27059.	4450.	21680.	1024.
200.	12491.	1881.	10915.	363.

Table 4. Discharge (cfs) vs. weighted usable area per 500 ft. of stream for reach #2 of the Beaverhead River.

Rainbow Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
343.	5966.	5808.	5327.	2404.	12373.
300.	6782.	4408.	5328.	2539.	13384.
275.	6877.	3555.	5344.	2347.	13556.
250.	6905.	2693.	5488.	2426.	13507.
225.	7035.	1981.	5034.	2255.	13135.
200.	6629.	1478.	3014.	2008.	12186.
175.	3438.	1105.	1311.	958.	10727.
150.	1380.	695.	747.	379.	7681.
125.	479.	354.	327.	156.	3326.
100.	179.	119.	144.	89.	1637.
75.	21.	30.	15.	20.	630.

Brown Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
343.	4911.	5615.	8541.	10120.	12373.
300.	5380.	5124.	8229.	9754.	13384.
275.	5553.	4915.	7702.	9006.	13556.
250.	5807.	4146.	6815.	8178.	13507.
225.	6298.	2851.	5923.	7403.	13135.
200.	6265.	1810.	5270.	6287.	12186.
175.	3581.	1176.	3480.	3994.	10727.
150.	1768.	765.	1798.	2082.	7681.
125.	578.	485.	967.	1119.	3326.
100.	172.	128.	581.	715.	1637.
75.	43.	1.	121.	166.	630.

Mountain Whitefish

Q	Spawning	Adult	Juveniles	Fry
343.	9347.	5873.	8382.	1811.
300.	8346.	4311.	7276.	1458.
275.	7500.	3538.	6759.	1263.
250.	6593.	2783.	6160.	994.
225.	5213.	2173.	5086.	738.
200.	2925.	1611.	3206.	522.
175.	1663.	896.	1705.	299.
150.	909.	424.	978.	171.
125.	486.	200.	644.	75,
100.	180.	90.	286.	17.
75.	9.	6.	11.	0.

Table 5. Discharge (cfs) vs. weighted usable area per 500 ft. of stream for reach #2 of the Gallatin River.

Rainbow Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
646.	789.	9503.	2430.	1712.	4689.
600.	765.	11336.	2584.	1715.	4510.
550.	730.	13552.	2761.	1712.	4466.
500.	695.	16135.	3044.	1743.	4566.
450.	628.	18876.	3296.	1802.	4722.
400.	544.	21151.	3593.	1914.	4980.
375.	511.	21888.	3786.	1983.	5152.
350.	491.	22413.	4008.	2136.	5348.
325.	471.	22681.	4192.	2294.	5545.
300.	452.	22963.	4383.	2381.	5758.
250.	380.	23378.	4846.	2601.	6237.
200.	363.	21262.	5665.	2953.	6835.

Brown Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
646.	747.	4611.	9548.	8619.	4692.
600.	648.	5007.	9915.	9118.	4513.
550.	571.	5504.	10379.	9823.	4467.
500.	523.	6075.	11047.	10783.	4567.
450.	485.	6723.	12145.	12053.	4722.
400.	449.	7266.	13399.	13596.	4980.
375.	423.	7407.	14113.	14456.	5152.
350.	388.	7644.	14835.	15354.	5348.
325.	350.	7897.	15575.	16286.	5545.
300.	321.	8223.	16378.	17294.	5758.
250.	287.	8712.	17947.	19443.	6237.
200.	229.	9238.	18753.	21244.	6835.

Mountain Whitefish

Q	Spawning	Adult	Juveniles	Fry
646.	7032.	16754.	9292.	1722.
600.	7913.	17401.	10305.	1855.
550.	9001.	17590.	11380.	1973.
500.	10444.	17417.	12398.	2085.
450.	12382.	17020.	13556.	2211.
400.	14633.	16202.	15464.	2354.
375.	15776.	15734.	16668.	2414.
350.	16523.	15202.	18036.	2477.
325.	16830.	14617.	19421.	2519.
300.	16880.	13774.	20659.	2541.
250.	16260.	11747.	22618.	2633.
200.	14974.	9583.	23403.	2722.

Table 6. Discharge (cfs) vs. weighted usable area per 500 ft. of stream for reach #1 of the Big Hole River.

Rainbow Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
985.	2935.	14803.	6497.	2663.	19938.
900.	3318.	16708.	7961.	3452.	21948.
800.	3565.	18772.	9821.	4024.	24231.
700.	3573.	20550.	11174.	5174.	26341.
600.	3746.	22103.	12322.	6116.	28190.
500.	3884.	23252.	13503.	6651.	30336.
450.	4024.	23040.	13846.	6738.	31534.
400.	4192.	22408.	13980.	7082.	32807.
350.	4430.	20217.	13550.	7213.	34172.
300.	4779.	17705.	12903.	7061.	35470.
250.	5033.	14450.	12744.	6315.	35783.
200.	5530.	10514.	12470.	5897.	35625.

Brown Trout

Q	Spawning	Adult	Juveniles	Fry	Incubation
985.	2332.	11087.	15714.	13062.	19938.
900.	2589.	12306.	18108.	15774.	21948.
800.	2638.	12817.	20020.	19192.	24231.
700.	2709.	13333.	22160.	22744.	26341.
600.	2800.	13965.	24964.	25833.	28190.
500.	3033.	14112.	26584.	28083.	30336.
450.	3214.	13615.	27096.	28954.	31534.
400.	3455.	12650.	27387.	29574.	32807.
350.	3548.	11687.	27103.	29555.	34172.
300.	3607.	10800.	26602.	28936.	35470.
250.	3608.	9387.	24075.	26468.	35783.
200.	4161.	7261.	20613.	23098.	35625.

Mountain Whitefish

Q	Spawning	Adult	Juveniles	Fry
985.	20386.	26407.	17046.	3073.
900.	24282.	26654.	21664.	3300.
800.	25922.	25557.	25644.	3497.
700.	26978.	24179.	27303.	3556.
600.	29217.	21982.	28468.	3504.
500.	31490.	19111.	29419.	3339.
450.	32195.	16741.	29496.	3161.
400.	32786.	13911.	29280.	2926.
350.	32080.	10932.	28547.	2547.
300.	30741.	8214.	27116.	2082.
250.	28049.	5900.	25252.	1537.
200.	23835.	4132.	21795.	953.

Table 7. Species' periodicity table for reach #1 of the Madison River.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainbow Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry							X	X	X	X	X	X
Incubation					X	X						
Spawning				X	X							
Brown Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	
Mt. Whitefish												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	

Table 8. Species' periodicity table for reach #3 of the Madison River.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainbow Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry						X	X	X	X	X	X	X
Incubation				X	X							
Spawning			X	X								
Brown Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	
Mt. Whitefish												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	

Table 9. Species' periodicity table for reach #2 of the Beaverhead River.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainbow Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation			X	X								
Spawning		X	X									
Brown Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	
Mt. Whitefish												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	

Table 10. Species' periodicity table for reach #2 of the Gallatin River.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainbow Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry							X	X	X	X	X	X
Incubation					X	X						
Spawning				X	X							
Brown Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	
Mt. Whitefish												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	

Table 11. Species' periodicity table for reach #1 of the Big Hole River.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainbow Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry							X	X	X	X	X	X
Incubation					X	X						
Spawning				X	X							
Brown Trout												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	
Mt. Whitefish												
Adult	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
Fry					X	X	X	X	X	X	X	X
Incubation	X	X	X	X							X	X
Spawning										X	X	

Table 28. Final flow recommendations for reach #1 of the Madison River for a median water year expressed as percentages of the annual mean and median flows of record.

Madison #1 Reach

Median Water Year Flow Recommendations

	% of Annual Mean	% of Annual Median
Jan	51	57
Feb	51	57
Mar	51	57
Apr	51	57
May 1-15	51	57
May 16-31	86	96
Jun 1-15	121	135
Jun 16-30	114	127
Jul 1-15	92	103
Jul 16-31	51	57
Aug	51	57
Sep	51	57
Oct	51	57
Nov	51	57
Dec	51	57

Table 29. Final flow recommendations for reach #3 of the Madison River for a median water year expressed as percentages of the annual mean and median flows of record.

Madison #3 Reach

Median Water Year Flow Recommendations

	% of Annual Mean	% of Annual Median
Jan	46	53
Feb	46	53
Mar	46	53
Apr	46	53
May 1-15	46	53
May 16-31		
Jun 1-15		
Jun 16-30		
Jul 1-15		
Jul 16-30	46	53
Aug	46	53
Sep	46	53
Oct	46	53
Nov	46	53
Dec	46	53

Table 30. Final flow recommendations for reach #2 of the Beaverhead river for a median water year expressed as percentages of the annual mean and median flow of record.

Beaverhead #2 Reach

Median Water Year Flow Recommendations

	% of Annual Mean	% of Annual Median
Jan	35	45
Feb	35	45
Mar	35	45
Apr	35	45
May 1-15	35	45
May 16-30	60	76
Jun 1-15	91	116
Jun 16-30	81	103
Jul 1-15	72	91
Jul 16-31	35	45
Aug	35	45
Sep	35	45
Oct	35	45
Nov	35	45
Dec	35	45

Table 31. Final flow recommendations for reach #2 of the Gallatin river for a median water year expressed as percentages of the annual mean and median flows of record.

Gallatin #2 Reach

Median Water Year Flow Recommendations

	% of Annual Mean	% of Annual Median
Jan	31	58
Feb	31	58
Mar	31	58
Apr	31	58
May 1-15	31	58
May 16-31	194	367
Jun 1-15	292	553
Jun 16-30	241	456
Jul 1-15	137	260
Jul 16-31	31	58
Aug	31	58
Sep	31	58
Oct	31	58
Nov	31	58
Dec	31	58

Table 32. Final flow recommendations for reach #1 of the Big Hole river for a median water year expressed as percentages of the annual mean and median flows of record.

Big Hole #1 Reach

Median Water Year Flow Recommendations

	% of Annual Mean	% of Annual Median
Jan	30	72
Feb	28	68
Mar	35	83
Apr 1-15	35	83
Apr 16-30	95	229
May 1-15	150	361
May 16-31	227	547
Jun 1-15	286	689
Jun 16-30	167	403
Jul 1-15	90	217
Jul 16-31	35	83
Aug	35	83
Sep	26	64
Oct	35	83
Nov	35	83
Dec	30	73

Table 33. Final flow recommendations for reach #1 of the Madison river for a 1-in-10 water year expressed as percentages of the annual mean and median flows of record.

Madison #1 Reach

1-in-10 Water Year Flow Recommendations

	% of Annual Mean	% of Annual Median
Jan	51	57
Feb	51	57
Mar	51	57
Apr	51	57
May 1-15	49	55
May 16-31	55	61
Jun 1-15	73	82
Jun 16-30	73	82
Jul 1-15	67	75
Jul 16-31	51	57
Aug	51	57
Sep	51	57
Oct	51	57
Nov	51	57
Dec	51	57

Table 34. Final flow recommendations for reach #2 of the Beaverhead river for a 1-in-10 water year expressed as percentages of the annual mean and median flows of record.

Beaverhead #2 Reach

1-in-10 Water Year Flow Recommendations

	% of Annual Mean	% of Annual Median
Jan	35	45
Feb	35	45
Mar	35	45
Apr	35	45
May 1-15	35	45
May 16-31	37	47
Jun 1-15	49	61
Jun 16-30	46	59
Jul 1-15	43	54
Jul 16-31	35	45
Aug	32	41
Sep	28	36
Oct	35	45
Nov	35	45
Dec	35	45

Table 35. Final flow recommendations for reach #2 of the Gallatin river for a 1-in-10 water year expressed as percentages of the annual mean and median flows of record.

Gallatin #2 Reach

1-in-10 Water Year Flow Recommendations

	% of Annual Mean	% of Annual Median
Jan	29	54
Feb	28	53
Mar	28	53
Apr	31	58
May 1-15	31	58
May 16-31	132	250
Jun 1-15	188	356
Jun 16-30	162	306
Jul 1-15	94	179
Jul 16-31	31	58
Aug	31	58
Sep	31	58
Oct	31	58
Nov	31	58
Dec	29	56

Table 36. Final flow recommendations for reach #1 of the Big Hole river for a 1-in-10 water year expressed as percentages of the annual mean and median flows of record.

Big Hole #1 Reach

1-in-10 Water Year Flow Recommendations

	% of Annual Mean	% of Annual Median
Jan	20	48
Feb	22	52
Mar	26	63
Apr 1-15	33	80
Apr 16-30	65	156
May 1-15	100	240
May 16-31	151	364
Jun 1-15	128	309
Jun 16-30	77	186
Jul 1-15	41	100
Jul 16-31	27	66
Aug	15	37
Sep	16	40
Oct	23	55
Nov	27	65
Dec	22	53

Table 37. Monthly mean and median flows (cfs) for five reaches of the Madison, Beaverhead, Gallatin and Big Hole Rivers.

	Madison #1		Madison #3		Beaverhead #2		Gallatin #2		Big Hole #1	
	Mean	Median	Mean	Median[a/]	Mean	Median	Mean	Median	Mean	Median
Jan	1398	1480	886		296	290	307	287	349	344
Feb	1390	1400	823		290	290	307	282	363	328
Mar	1415	1310	794		345	330	309	281	445	400
Apr	1557	1310	875		479	384	480	416	1526	1290
May	1866	1620	1239		619	416	1731	1710	3449	3150
Jun	2952	2850	2250		780	595	2991	2980	4121	3970
Jul	1853	1700	1300		477	393	1323	1230	1347	1330
Aug	1576	1580	1160		401	319	611	551	482	445
Sep	1649	1670	1346		335	304	494	466	377	305
Oct	1987	2210	1475		385	323	461	419	507	447
Nov	1969	2120	1386		420	388	388	353	508	475
Dec	1535	1540	1046		353	333	326	300	398	348
Annual	1762	1580	1406	1230	424	335	814	430	1157	480

a/ Median monthly flows are unavailable.