Two 1970's methods for prescribing instream flow regimens

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Abstract. At the beginning of the decade of the 1970's it was clear that unless an instream flow regimens was quantified the need for an instream flow. Three 1970's methods are reviewed: 1) a method based on the characteristics of the streamflows is the Montana Method, 2) a method based on the hydraulic attributes of the channel is the Water Surface Profile Method, and a method that uses hydraulic attributes contained in papers on the Montana Method. Strong points of the Montana Method are the relation between the magnitude of the instream flow and the quality of the habitat, and the variation of the instream flow between seasons. The WSP Method did link biological needs to river hydraulics which is a strong point. These links have proven to be very fruitful in instream flow studies. The Montana Method hydraulic criteria are useful but there is a stream size effect that was not accounted for in the application of the criteria.

1. Introduction

During the 1960,s there was an increasing interest in the quality of rivers. At first this was mostly about the quality of the water in the river. Overtime this interest included knowledge that a river without water was not really a river. In the Northwestern states, in California, and in British Columbia this also included a desire to maintain a viable salmon fishery, and in all the western states a desire to maintain a good trout fishery in mountain rivers. In both cases the interest was both aesthetic and economic. The salmon fishery was very important economically and aesthetically. In all the west a trout fishery was an important economic driver and important aesthetically. Also, a dry river was not part of the natural landscape except in the desert regions.

In this paper two mid-1970's techniques for determining an instream flow regimens for rivers will be reviewed. The review will be based on papers as these techniques existed in early to and as presented at a symposium on instream flows held in Boise, Idaho in 1976 (Orsborn and Allman, 1976). Two methods reviewed are the 1) Montana Method, and 2) the Water Surface Profile Method as used in Montana and Idaho... The major paper on the Montana Method also included hydraulic criteria. These hydraulic criteria are also reviewed. In the Boise proceedings there are a number of good papers on techniques used along the Pacific Coast which are not reviewed in this paper.

At the beginning of the decade of the 1970's it was clear that unless an instream flow regimens was quantified the need for an instream flow would be ignored. In all the western states there were attempts to quantify an instream flow need. Some of these methods were based on the hydraulic attributes of the channel and some on characteristics of the streamflows. A method based on the characteristics of the streamflows is the Montana Method. A method based on the hydraulic attributes of the channel is the Water Surface Profile Method.

2. Montana Method

The 'Montana Method' (Tennant 1975, 1976a, and 1976b) for quantifying an instream flow regimens in a river was an early attempt to do more than say 'we need water in a river.' or using a more recent term 'water is the master variable'. In the western states there is significant competition for water, the Montana Method was an attempt to quantify the streamflows needed to meet instream values. There were also attempts within the federal water establishment to determine instream flow needs below federal reservoirs. The Montana Method also met the needs of the federal water establishment in the Montana an d Wyoming region quantify the instream flows needed below the reservoirs. The method was also used by Montana Fish and Game Department (Eiser, 1972). The 'Montana Method' is some times called the 'Tennant Method' because it is based on the skill and experience of Don Tennant.

The 1972 version of the Montana Method used three percentages of the annual flow as alternative levels of instream flow requirements. In response to a question on how the percentages were determine Tennant made the following comment:

> *Well, I arrived at them just, from a lot of experience looking at different flows and what I felt were good flows. I always like to look at a 10% because I think that's a danger to most any stream I've seen. When you get 10% or below you're in serious trouble. It's a short-term survival habitat situation usually, at best, and I color it red because I see red when I observe a flow less than that and a third always looks like a pretty good flow and two-thirds always looked real good, but instead of using 33.333 and 66-2/3, I rounded it off at 30% and 60%. (from Eiser, Allen A, 1972.* Tennant comments on pages 9-11)

Between 1972 and 1975 Tennant continued his studies by studying 10 streams in the US (mostly in Montana and Wyoming) and refined the % of mean flow required to maintain those streams in states of well-being varying from degraded to outstanding. There are three papers in which Tennant presented the revised criteria (Tennant 1975, 1976a, and 1976b). The 1976 Tennant recommendations for an instream flow regimen are presented in Table 1. The description of flows can be considered as a level of habitat quality.

The Montana method is applied to two streams in this section. These two streams are the Clarks Fork Yellowstone River in Montana and North Crestone Creek in Colorado. Information on both streams is presented in Table 2. Both streams are primarily snow-melt runoff streams. The use of the data for river and for a creek is to show how the method works for wide rang of streamflows

Both of the streams are unregulated. The data used for the Clarks Fork Yellowstone River a re form the U.S. Geological Survey web-page. The North Crestone Creek data are from the Colorado Division of Water Resources web-page. The North Crestone Creek data for 1938-1947 does not include winter streamflows; therefore, the annual streamflows are based on measurements for water years 1948 - 2015.

Table 1. Instream flow regimens for fish, wildlife, recreation and related environmental resources based on the Montana Method. (Tennant, 1976)

Narrative Description of Flows	Recommended Base Flow Regimens	
	October - March.	April - Sept -
Flushing or Maximum	200%. of the average flow	
Optimum Range	60%.-100%. of the average flow	
Outstanding	40%.	60.00%
Excellent	30%.	50%.
Good	20%.	40%.
Fair or Degrading	10%.	30.00%
Poor or Minimum	10%.	10.00%
Severe Degradation	10%. of average flow to zero flow	

Table 2. Selected information on the streamflows in the Clarks Fork Yellowstone River in Montana and the North Crestone Creek in Colorado.

Stream	Watershed area, sq mi	Annual discharge, cfs	1 in 1.5 year peak discharge, cfs	Years
Clarks Fork Yellowstone	1152	938	6870	1922-2015
North Crestone Creek	10.7	11.6	71.5	1936-2015

2.1. Clarks Fork Yellowstone River

The average discharges for each day are shown on Figure 1. The annual average discharge is 938 cfs for the 94 years starting with water year 1922 and ending with water year 2015. The Montana Method is very simple to apply. The results are in Table 3. The streamflows needed for excellent habitat conditions are compared to the average streamflow for each day in Figure 1.

In the 1970's instream flow investigations had an objective of protecting low flows in the streams with little concern for the need for higher flows. The exception to this generalization is efforts to protect spawning flows along the west coast and passage streamflows in some rivers. A strong point of the Montana Method was that different quantities of water allocated to meet instream flow needs result in different levels of habitat quality. A second point was that the magnitude of streamflow needed for a give level of habitat quality varied with season. The method clearly moved from the concept common at the time that a single minimum streamflow met all instream flow needs.

Table 3. Instream flow requirements for various levels of habitat quality as determined for Clark's Fort Yellowstone River near Belfry, Montana determined using the Montana Method.

Narrative Description of Flows	Recommended Base Flow Regimens, cfs	
	October - March.	April - Sept -
Flushing or Maximum	1876	
Optimum Range	938	
Outstanding	375	563
Excellent	281	469
Good	188	375
Fair or Degrading	94	281
Poor or Minimum	94	94
Severe Degradation	94	

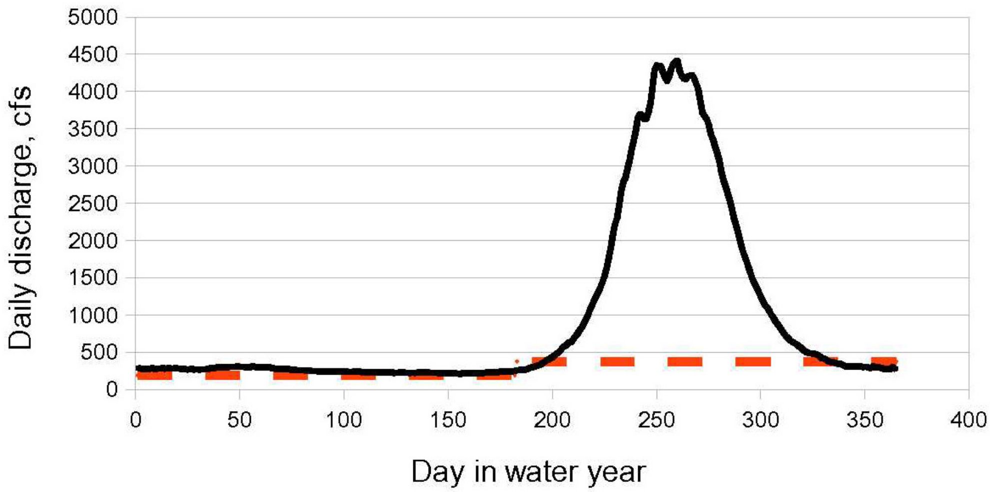

Figure 1. Average daily discharges for the Clarks Fork Yellowstone River near Belfry, Montana. The dashed line is the Montana Method criteria for excellent habitat.

2.2 North Crestone Creek.

The regimen of instream flows determined for North Crestone Creek using the Montana Method are given in Table 4 and the streamflows needed for excellent habitat shown on Figure 2.

Table 4. Instream flow regimen for various levels of habitat quality as determined for North Crestone Creek, near Crestone, Colorado determined using the Montana Method.

Narrative Description of Flows	Recommended Base Flow Regimens, cfs	
	October - March.	April - Sept -
Flushing or Maximum	23.2	
Optimum Range	11.6	
Outstanding	4.6	7.0
Excellent	3.5	5.8
Good	2.3	4.6
Fair or Degrading	1.2	3.5
Poor or Minimum	1.2	1.2
Severe Degradation	1.2	

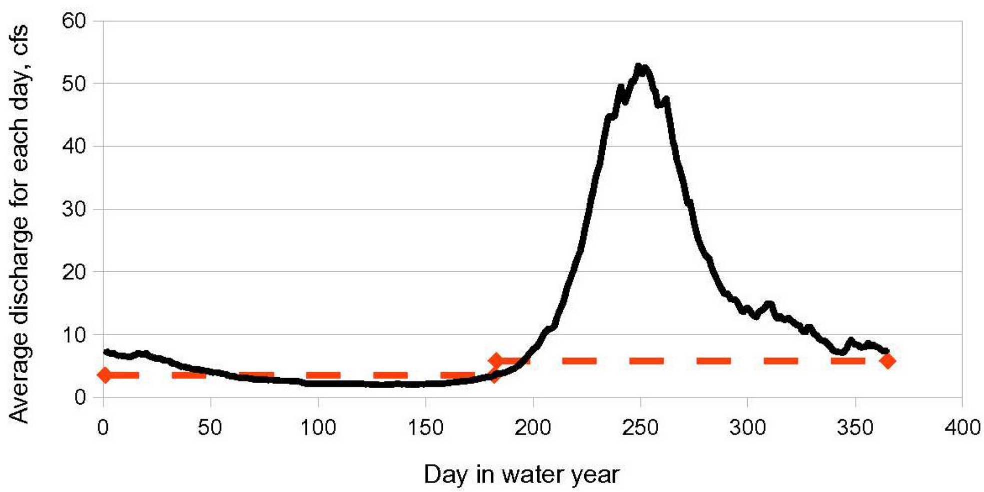

Figure 2. Average daily discharges for the North Crestone Creek near Crestone, Colorado. The dashed line is the Montana Method criteria for excellent habitat.

3. Water Surface Profile Method

In 1976 there were a number of methods either being used or proposed for use that used the relation between hydraulic attributes at a cross section or along a reach of the stream. Three of the approaches were the single cross section approach used by the U.S. Forest Service, the water surface profile approach being used by Montana Fish and Game, and an approach used in Idaho for large rivers which also used the water surface profile. These three approaches had similarities and differences. Most of this section will discuss the water surface profile method as used in Montana and Idaho as presented at an Instream Flow Symposium and Specialty Conference held in Boise, Idaho May 3-6, 1976 (Orsborn and Allman, 1976).

In 1976 Montana did have a process for instream water reservations. The process required that instream water reservations be approved by a Board of Natural Resources composed of politically appointed citizens of the state. The board could not approve an instream reservation unless it was shown 1) there was a purpose of the reservation, 2) a need for the reservation, 3) the quantity of streamflow necessary for the purpose of the reservation, and 4) that the reservation was in the public interest, (Spence, 1976). In 1976 Montana Fish and Game was seeking a methodology which could be used with existing field personnel, budget and manpower limitations. The WSP (Water Surface Profile) program seemed to fit those needs (Spence, 1976).

Dooley, 1976, suggested the physical parameter s needed to demonstrate the quantity of streamflow necessary for the purpose of the instream flow reservation included: 1) flow velocities, 2) water depths, 3) stream widths, and 4) cross sectional areas. Dooley also considered that the data needed could be collected through actual field measurements at many flows or could be determined using one good set of field measurements and the U.S. Bureau of Reclamation's WSP Program to predict the hydraulic parameters for various streamflows.

Montana's use of the WSP closely paralleled developments in Idaho were a modification of a "usable width" approach was used to determine the discharge requirements for passage, spawning and rearing . In Montana it was assumed that if the streamflow was adequate for passage, the spawning requirements were also met. The methodology is founded upon the concept of predicting loss of habitat at reduced discharges and relating the predicted loss to physical and biological requirements of key species. Aquatic insect production was also evaluated with WSP. By utilizing predicted depths and velocities, insect losses with decreasing flows could be evaluated (Elser, 1976).

Workman, 1976, used the Water Surface Profile program to determine instream flow needs in Sixteenmile Creek. Conveyance area, wetted perimeter and water velocity were parameters chosen from the WSP results to analysis changes in trout habitat with changes in streamflows. The analysis of conveyance area and wetted perimeter changes with discharge showed an accelerated rate of loss in these two parameters when flows were reduced below 50 cfs and the analysis identified a critical point at 25 cfs. Water velocity were considered to be adequate to supply the needs of trout and food producing organisms if flows could be maintained at levels which would provide needed space and wetted perimeter. The assumption was that velocities ranging from 1.0 to 3.0 ft/sec generally provide for the needs of trout and food producing organisms. Workman also identified a need to determine the streamflows required during May and June to maintain a clear intergravel environment (not determined in the paper).

Cochnauer, 1976, presented a methodology for use in determining instream flow techniques for large rivers. The methodology predicted loss of habitat at reduced discharges and relate this loss to physical and biological requirements of key fish species. The basis of the methodology was the USBR WSP program. The output from WSP was used with known biological criteria of the species in the Snake River to determine streamflow requirements for fish passage, fish rearing, and waterfowl nesting. Species criteria were needed for spawning, rearing, and passage of white sturgeon (*Acipenser transmontanus*), spawning and rearing for smallmouth bass (*Micropterus dolomieui*), and channel catfish (*Ictalurus punctatus*), and rearing for rainbow trout. Rearing flows were determined from wetted perimeter versus discharge relation. The logic given by

Cochnauer is:

> *'Starting at zero discharge, wetted perimeter increases rapidly for small increases in discharge up to the point where the river channel nears its maximum width. Beyond the inflection point, the wetted perimeter increases slowly while discharges increases rapidly. The discharge at the inflection point provides the optimum quantity of water for rearing (food production) and is considered the minimum rearing flow.'*

The discharges required for spawning were not determined because knowledge of specific requirements for those species found in the study section of the Snake River was not available. Maximum discharges during the waterfowl nesting by determining elevations of nesting sites and using these to select the maximum discharge that did not flood the sites during the waterfowl nesting period. (Cochnauer,1976).

White, 1976, presented a set of criteria for use in the application the Snake River methodology based upon ecological requirements of the key fish species. There criteria for passage, spawning and rearing.

<u>Passage:</u> Flows suitable for passage of sturgeon also accommodate any passage requirements of smallmouth bass and channel catfish. The evaluation of passage was done using hydraulic attributes at shallow riffles or sandbars because these are the locations where passage is likely impeded by reduced streamflows. From these projections, a minimum passage flow is recommended for those months in which sturgeon are active (mid-February to mid-November). The passage criteria recommended by White is that a minimum continuous depth of 1.5 meters be maintained over 25 percent of the width of the cross section.

<u>Spawning:</u> Based on a review of the literature the recommended minimum depth criteria for spawning is 1.5 meters. The velocity criteria is a range of velocities from 0.6-1.1 meters/second.

<u>Rearing:</u> The rearing streamflows are based on the approach used by the Washington Department of Fisheries method for recommending rearing flows for Pacific Salmon species based on the assumption that rearing is proportional to food production, which is in turn assumed proportional to wetted perimeter. The logic of using the criteria was given above.

A paper by Isaacson, 1976, was almost completely on the collection of data with a simple statement about criteria. That statement is: “The minimum depth required for fish survival is 0.5 foot at some point in the cross section profile.”

A cross section of the Virgin River, Utah is used to illustrate the use of the criteria described in this section. The cross section is from the Juniper Bluff reach of the river. The data used was collected by the US Bureau of Land Management. Figure 3 is the wetted perimeter versus discharge relation for the cross section. The triangle shows the location on the relation that meets the criteria described by Cochnauer.

The instream flow requirements based on the various criteria described in this section are presented in Table 5. The range in the table is normal. The analyst has the task of selecting the most appropriated instream flow need.

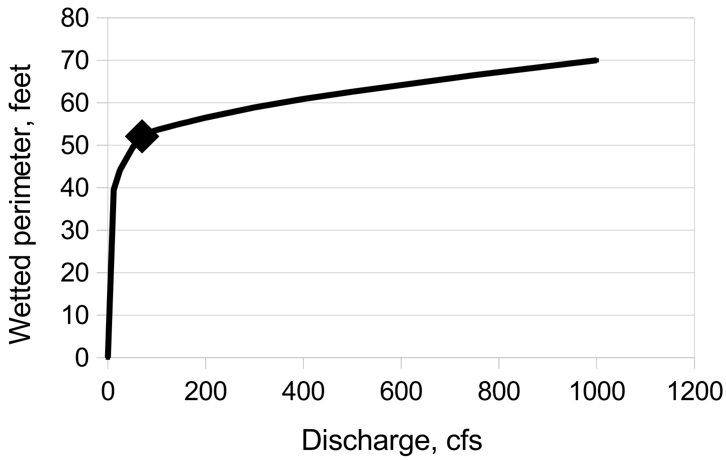

Figure 3. Wetted perimeter as related to discharge in the Juniper Bluff reach of the Virgin River, Utah.

Table 5. Instream flow requirements for one cross section of the Juniper Bluff reach of the Virgin River in Utah.

Attribute	criteria	Discharge, cfs
Velocity, fps	1.0	20.7
Maximum depth, feet	0.6	10.9
Average depth, feet	0.4	14.1
Cross section area, sq ft		100
Wetted perimeter, feet		70

4. Tennant hydraulic criteria

In his 1975 paper Tennant added a diagram that shows velocity, depth and width that represent observation from field tests of the Montana method. The diagram is Figure 4.

The velocity, depth and % width for the various % of annual discharge for the three levels of habitat quality from the Montana method indicated by the relations in Figure 4 are presented in Table 6. The hydraulic criteria in Table 6 will be used to calculate istream flow regimens in Clarks Fork Yellowstone River and in North Crestone Creek. These regimens are then compared to the results from the Montana Method.

The hydraulic geometry relations are used to calculate the instream flow regimens based on the criteria in Table 6. Discharge measurement summaries are available for each gaging station. The measurement data for Clarks Fork Yellowstone River is from the USGS web-page; the North Crestone Creek data from the Colorado Department of Water Resource web-page.

The width criteria requires that the width of the stream at the annual mean discharge be known. The width of the Clarks Fork Yellowstone River at the annual mean discharge of 938 cfs is 58.3 feet. The width of North Crestone Creek at the mean annual discharge of 11.6 cfs is 9.88 feet.

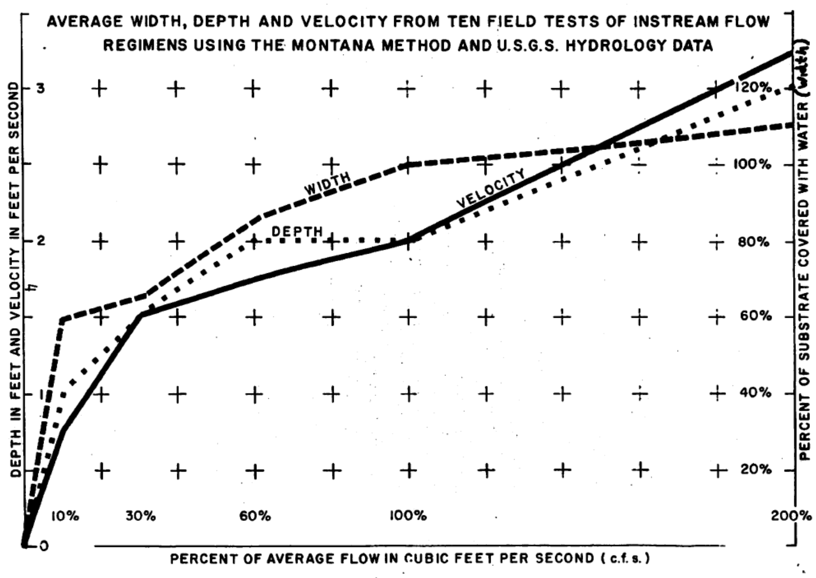

Figure 4. Tennant width, velocity and depth relations from studies mostly in Montana and Wyoming (from Tennant, 1976).

Table 6. Velocity, depth and width requirements for three levels habitat condition based on the Montana Method criteria and the hydraulic standards from Tennant, 1975.

Habitat Condition	Low flow period			High flow period		
	Velocity, fps	Depth, ft	Width requirement*	Velocity, fps	Depth, ft	Width requirement*
Short-term survival	0.75	1.00	60	0.75	1.00	60
Good	1.12	1.25	62	1.57	1.62	70
Excellent to outstanding	1.50	1.50	65	1.64	1.75	80

*Width requirement is the percent of the width at mean annual discharge

The required regimens based on the velocity, depth, and width criteria is given in Table 7 for Clarks Fork Yellowstone River and in Table 8 for North Crestone Creek.

Table 7. Instream flow requirements for the Clarks Fork River and for three levels of habitat.

Habitat Condition	Low flow period				High flow period			
	Tennant	Velocity	Depth	Width	Tennant	Velocity	Depth	Width
Short-term survival	94	67	121	11	94	67	121	11
Good	188	171	197	15	375	376	348	42
Excellent to outstanding	281	338	294	22	469	417	413	135

Table 8. Instream flow requirements for the North Crestone Creek and for three levels of habitat.

Habitat Condition	Low flow period				High flow period			
	Tennant	Velocity	Depth	Width	Tenna nt	Velocity	Depth	Width
Short-term survival	1.16	1.72	22	2.56	1.16	1.72	22	2.56
Good	2.32	5.83	43	2.82	4.64	16.24	97	4.04
Excellent to outstanding	3.48	14.14	76	3.24	5.8	18.54	123	5.99

Using the maximum discharge of the three discharges calculated using the velocity, depth and width criteria as the 'hydraulic' discharge and comparing that to the Montana method discharge it is reasonable to conclude the hydraulic criteria is similar to the Montana Method for the Clarks Fork but defiantly not for North Crestone Creek. A reasonable conclusion is that there is a river size parameter missing in the hydraulic criteria.

5. Discussion

Strong points of the Montana Method are the relation between the magnitude of the instream flow and the quality of the habitat, and the variation of the instream flow between seasons. This was at a time when most instream flow needs were the same for all seasons and there was no indication what the specified streamflow produced in terms of the quality of the habitat.

Streamflows in Montana and Wyoming are low in October – March when precipitation is being stored as snow and high in April – September during spring runoff. Tennant recognized the streamflow regimen might be different from the Montana-Wyoming regimens in other regions with the following statement:

> *These phenomena may be seasonally.. reversed for anadromous fishes using the coastal streams of Alaska, the Canadian Provinces, and our west coast states and flow regimens should be adjusted accordingly. (Tennant, 1975)*

The phenomena are the biological processes in the stream. These comments suggest that October – March is the low streamflow season and April- Sept is the high flow when the Montana Method is applied to streams other than the snow-melt streams of Montana and Wyoming. Orth and Maughan, 1981, modified the method for use in Oklahoma streams. Their recommendation is that the '*Montana method should be modified so that the lower of two recommended base flows apply to the period from July through December, rather than that from October through March*'.

The Montana Method is still used as is demonstrated by a 2014 paper by Patsialis et al. Patsialis et al modified the Montana method for use in Greece. One of the modifications was to use the average discharge for the wet season to calculate an instream regimen for the wet season and average during dry season to calculate the regimen for the dry season instead of the average for the whole year.

The WSP Method did link biological needs to river hydraulics which is a strong point.

These links have proven to be very fruitful in instream flow studies.

The Tennant hydraulic criteria are useful but there is a stream size effect that was not accounted for in the application of the criteria.

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