BEFORE THE MONTANA BOARD OF NATURAL

RESOURCES AND CONSERVATION

* *

IN THE MATTER OF WATER)
RESERVATION APPLICATION NOS.)
69903-41O 71895-41I 72578-41L)
70115-41F 71966-41S 71579-41T)
70117-41H 71997-41J 72580-41A)
70118-41H 71998-41S 72581-41I)
70119-41H 72153-41P 72582-41I)
70270-41B 72154-41K 72583-41P)
71537-41P 72155-41A 72584-41S)
71688-41L 72256-41P 72585-41M)
71889-41Q 72307-41Q 72586-41P)
71890-41K 72574-41O 72587-41G)
71891-41P 72575-41K 72588-40C)
71892-41G 72576-40E 73198-41I)
71893-41K 72577-41P 73199-41S)
71894-41I IN THE UPPER)
MISSOURI RIVER BASIN)

* * * * * * * * * * * * * *

DEPARTMENT OF FISH, WILDLIFE AND PARKS' EXHIBITS FOR PREFILED DIRECT TESTIMONY

* * * * * * * * * * * * * *

Exhibits for prefiled direct testimony submitted in support of the Department of Fish, Wildlife and Parks' application for instream flow reservations in the upper Missouri River Basin

* * * * * * * * * * * * * *

November 1, 1991

Volume 1

BEFORE THE MONTANA BOARD OF NATURAL

RESOURCES AND CONSERVATION

*

IN THE MATTER OF WATER	)
RESERVATION APPLICATION NOS.	)
69903-41O 71895-41I 72578-41L	)
70115-41F 71966-41S 71579-41T	)
70117-41H 71997-41J 72580-41A	)
70118-41H 71998-41S 72581-41I	)
70119-41H 72153-41P 72582-41I	)
70270-41B 72154-41K 72583-41P	)
71537-41P 72155-41A 72584-41S	)
71688-41L 72256-41P 72585-41M	)
71889-41Q 72307-41Q 72586-41P	)
71890-41K 72574-41O 72587-41G	)
71891-41P 72575-41K 72588-40C	)
71892-41G 72576-40E 73198-41I	)
71893-41K 72577-41P 73199-41S	)
71894-41I IN THE UPPER	)
MISSOURI RIVER BASIN	)

* * * * * * * * * * * * * *

DEPARTMENT OF FISH, WILDLIFE AND PARKS' EXHIBITS FOR PREFILED DIRECT TESTIMONY

* * * * * * * * * * * * * *

Exhibits for prefiled direct testimony submitted in support of the Department of Fish, Wildlife and Parks' application for instream flow reservations in the upper Missouri River Basin

* * * * * * * * * * * * * *

November 1, 1991

LIST OF EXHIBITS

Exhibit No.

Volume 1

1. S. Leathe and F. Nelson, A Literature Evaluation of Montana's Wetted Perimeter Inflection Point Method for Deriving Instream Flow Recommendations (MDFWP 1986, rev. 1989).

2. F. Nelson, Guidelines for Using the Wetted Perimeter (WETP) Computer Program of the Montana Department of Fish, Wildlife and Parks (1989).

3. Photographs of Big Hole River near Twin Bridges, Montana; Graph of Wetted Perimeter/Flow Relationship for Big Hole River.

4. C. Parrett, D. Johnson and J. Hull, Estimates of Monthly Streamflow Characteristics at Selected Sites in the Upper Missouri River Basin, Montana, Base Period Water Year's 1937-86 (USGS 1989).

5. J. Elliot, The Direct and Indirect Benefits and Costs of Granting a Water Reservation for In-stream Flows in the Missouri River Basin (1989).

6. K. Knudson, The Montana Department of Fish, Wildlife and Parks' Missouri River Water Reservation Request is in the Public Interest (April 1989).

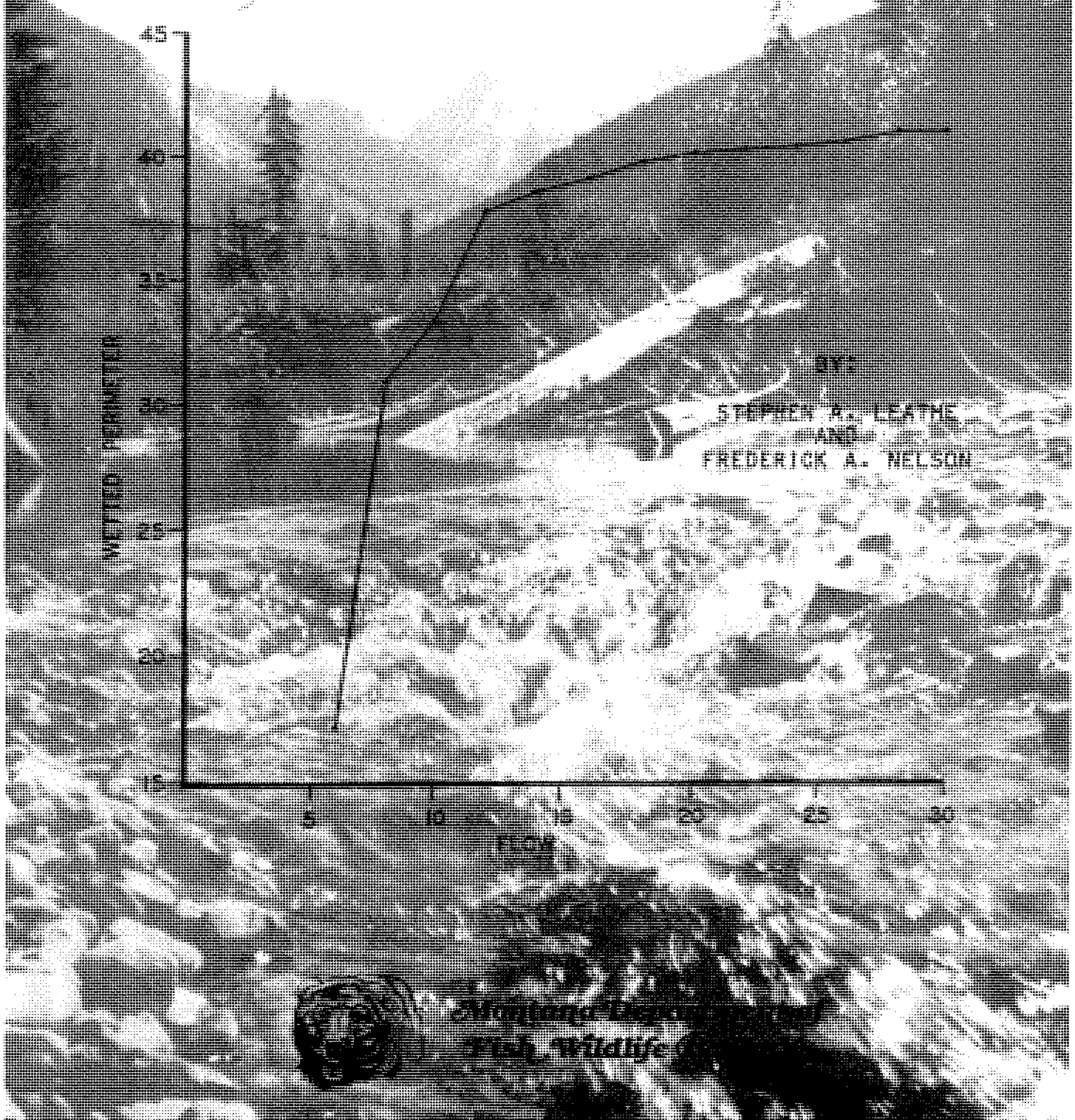
Volume 2

7. J. Duffield, J. Loomis and R. Brooks, The Net Economic Value of Fishing in Montana. Prepared for Montana Department of Fish, Wildlife and Parks, Helena, (1987).

8. J. Duffield, S. Allen and J. Holliman, Contingent Valuation of Montana Trout Fishing By River and Angler Subgroup (1988).

9. J. Duffield, et al, Instream Flows in the Missouri River Basin: A Recreation Survey and Economic Study (DNRC 1990).

A LITERATURE EVALUATION OF MONTANA'S WETTED PERIMETER INFLECTION POINT METHOD FOR DERIVING INSTREAM FLOW RECOMMENDATIONS



BY:

STEPHEN A. LEATHE

AND

FREDERICK A. NELSON

Montana Department of Fish, Wildlife & Parks

A Literature Evaluation of Montana's Wetted Perimeter Inflection Point Method for Deriving Instream Flow Recommendations

By:

Stephen A. Leathe
and
Frederick A. Nelson

Montana Department of Fish, Wildlife and Parks
1420 East Sixth Avenue
Helena, Montana 59620

December, 1986
(Revised February, 1989)

TABLE OF CONTENTS

	Page
INTRODUCTION	1
HISTORY	2
RELATIONSHIPS BETWEEN STREAMFLOW AND FISH POPULATIONS	6
SURVEY AND ANALYSIS OF INSTREAM FLOW METHODS	17
Survey of Available Techniques	17
Non-Field Methods	17
Habitat Retention Methods	18
Incremental Methods	20
Advantages and Limitations of IFM's	25
Hydraulics and Channel Morphology	26
Decision-Making Capabilities	29
Data and Manpower Requirements	32
IFM Evaluation Studies	35
Carrying Capacity and Limiting Factors	36
Experimental Design	37
Evaluations of Montana's Wetted Perimeter Method	41
Criteria for Selecting an IFM	43
MONTANA'S INSTREAM FLOW METHOD	46
Wetted Perimeter Inflection Point Method	48
Brief Description of the Wetted Perimeter (WETP) Computer Program and Data Needs	56
MONTANA'S WETTED PERIMETER METHOD - FINAL CONSIDERATIONS	58
LITERATURE CITED	62

INTRODUCTION

Since the inception of the Montana Department of Fish, Wildlife and Parks' (MDFWP's) instream flow program in the mid-1970's, the wetted perimeter inflection point method has been the primary means for deriving instream flow recommendations for the preservation of aquatic resources during the low-water period in Montana's streams and rivers. Because the field of instream flow method (IFM) development has continually expanded over the past decade or so, the Department felt a need to review its method in light of recent advances in the "state-of-the-art." The purpose of this document is to (1) provide an up-to-date synopsis of the history of the wetted perimeter inflection point method, (2) examine its theoretical and experimental basis, and (3) identify its strengths and weaknesses as compared to other available procedures. We will also discuss the applicability of the wetted perimeter inflection point method to a variety of streams, both large and small, guidelines for its use, and provide a justification for the use of the method in Montana.

HISTORY

The development of methods to determine the amounts of water to remain instream for the protection of fish and wildlife resources and related recreational opportunities has been a relatively recent phenomenon (Loar and Sale 1981). The primary reason for this has been a reluctance of various state governments to recognize instream uses as "beneficial" uses of water. Because of limited water availability and resultant user conflicts, it was in the arid western states where instream flow methods (IFM's) were first devised. These developments followed the establishment of institutional frameworks (instream flow programs), which have proliferated in the western states since 1973 (Lamb and Meshorer 1983). However, the degree of protection afforded to fish and wildlife by instream flow programs differs markedly among states due to differing levels of statutory protection, water availability, and user conflicts. Consequently, a variety of IFM's have been devised by state fisheries agencies to meet the needs of their particular instream flow programs (Trihey and Stalnaker 1985). Another factor contributing to the diversification of IFM's was that the characteristics of aquatic resources (such as warmwater vs. coldwater habitat, anadromous vs. resident species) vary both within and between states.

Many of the first studies concerning instream flow needs were conducted during the 1950's and 1960's below federally funded hydroelectric and irrigation dams on large rivers in the West (Trihey and Stalnaker 1985). Because these projects had their most visible impacts on naturally occurring low summer streamflows, biologists were most concerned with setting minimum flow "standards" for the summer-fall periods. The first applications of IFM's to streams and rivers on a statewide basis began in Oregon during the late 1960's. The early development of IFM's in Oregon was not just coincidence because in 1955 Oregon became the first western state to provide for the administrative establishment of flow standards. Their program was quite successful and has been a prototype for other western states, including Montana (Lamb and Meshorer 1983).

A series of workshops were held in the Northwest during the early 1970's to review and discuss available IFM technology. Three of the more significant events in the development of IFM's did not occur until 1976. The first event was a publication by Stalnaker and Arnette (1976) that comprised the first compilation and critical evaluation of existing IFM's. Second, a conference sponsored by the Western Division of the American Fisheries Society was held in Boise, Idaho. This landmark event brought together IFM practitioners, developers and administrators to discuss the legal, social and biological aspects of the instream flow issue, and resulted in the publication of a two-volume document (Orsborn and Allman 1976). The third significant event was the formation of the Instream Flow Group (IFG) by the U.S. Fish and Wildlife Service at Fort Collins, Colorado. The purpose of this group was to advance the "state-of-the-art" and become the center of activity related to instream flow assessments. In the late 1970's the IFG developed the Instream Flow Incremental Method (IFIM), which has been in a continual state of refinement ever since.

The timetable for the development of Montana's IFM closely paralleled those for the other western states. In the early 1960's a series of unsuccessful legislative attempts were made to obtain "beneficial use" status for fish and wildlife and to develop a procedure to obtain instream flows for these resources (Peterman 1979). The first provisions for the instream flow needs for fish and wildlife were made in 1969 when the Montana legislature authorized the Fish and Game Commission to file for rights to the unappropriated waters in portions of 12 streams. Because the "state-of-the-art" of IFM development was in its infancy, most of these original filings were based on the professional judgment of local fisheries biologists. In 1980 and 1981 they were quantified using the wetted perimeter method.

The passage of the Montana Water Use Act in 1973 and the Yellowstone Moratorium in 1974 provided the main stimuli for the development of methods to quantify the instream flow needs of fish and wildlife in Montana. The Water Use Act was a revolutionary legislative act that specifically defined fish and wildlife as beneficial users of water and established a process for reserving unappropriated water for these purposes. The Yellowstone Moratorium was enacted in response to a "rush" of applications for Yellowstone River water by industrial and water-marketing concerns and placed a moratorium on all large diversion or storage applications in the Yellowstone Basin. The Yellowstone Moratorium provided a period of three years to quantify all future beneficial uses (including fish and wildlife) in the basin and allocate water to meet those needs (Peterman 1979).

In 1973 and 1974, in response to this mandate, the MDFWP began in earnest to develop an IFM that was appropriate for the rivers and streams of Montana and could be cost and time-effectively applied on a basinwide scale (Spence 1976). After a review of available IFM's, the MDFWP decided to enter into a cooperative program with the U.S. Bureau of Reclamation and in 1974 began using the Bureau's WSP (water surface profile) model to generate hydraulic and channel configuration information on which instream flow recommendations were based (Spence 1975; Dooley 1976). Data from the WSP model were used to define

(1) passage flows for migratory fish, (2) nest protection flows for Canada geese, and for the first time in Montana, (3) to define minimum flows for fish during the low flow periods based on the relationship between wetted perimeter and discharge in riffles (Elser 1976). Preliminary field testing of the WSP model was conducted during the mid-1970's by MDFWP personnel (Elser 1976; Workman 1976). These evaluations were geared towards the technical aspects of the WSP hydraulic model as well as the appropriateness of using wetted perimeter-discharge relationships to derive instream flow recommendations for the low flow period.

Following the completion of fieldwork associated with the Yellowstone water reservation in 1977, the MDFWP shifted emphasis to the Upper Clark Fork and Upper Missouri River Basins. An action plan was devised to guide Department efforts at securing instream flows (Nelson and Peterman 1979). The wetted perimeter method using the WSP hydraulic model continued to be the primary means of deriving minimum flow recommendations for the low flow period until the results of an evaluation study were published by MDFWP (Nelson 1980a, 1980b and 1980c). This study, funded by the U.S. Fish and Wildlife Service under the auspices of the IFG, evaluated four IFM's applied to five river reaches in southwest Montana. Besides providing a basis for using the wetted perimeter inflection point method, the study led to the development of an improved and simplified method to generate wetted perimeter- discharge relationships for streams and rivers (Nelson 1984a). The resultant WETP computer program replaced the WSP model and since 1980 has provided the wetted perimeter-discharge data upon which the Department's flow recommendations are based.

RELATIONSHIPS BETWEEN STREAMFLOWS AND FISH POPULATIONS

Many physical and biological factors interact to regulate fish abundance in streams. Hall and Knight (1981) list five major factors: streamflow, habitat quality, food abundance, predation, and movement and migration. In a natural stream environment, it is difficult to measure the effect of one factor independently of the others. The exact role each factor plays in regulating a given stream population is often masked by the interaction of the others. This complexity hampers the ability of fishery scientists to predict the response of a fish population in a given stream to environmental variations, such as man-caused changes in streamflow. Accurate predictions require the development of a model that quantitatively describes the relationship between fish abundance and all regulating variables. The "state-of-the-art" has not yet advanced to this level, nor is it evident that such models, if ever developed, would be applicable to a broad range of streams.

Because there are wide gaps in our knowledge of how fish respond to environmental changes, fishery scientists must rely on broad, general assumptions when discussing the means by which stream fish populations are regulated. These assumptions may not fully describe the means of regulation for a given stream of interest or apply to all streams in a particular region, and many have not been tested in definitive scientific studies. Despite these limitations, the assumptions, in general, are logical and defensible, but not immune to criticism. These assumptions are an essential part of all instream flow methods. This section will briefly discuss some of the assumptions regarding the regulation of fish abundance in Montana's streams, and provide a basis of support from the scientific literature.

The standing crops (number and total weight) of fish that a particular stream supports can vary over time. For Montana's streams, standing crops are typically lowest following the rigors of winter and highest in fall after the summer growing season. The magnitude of these annual lows and highs can vary substantially from year-to-year.

A factor often considered a major, if not the overriding, cause of this variability within a particular stream is the year-to-year variation in streamflows. Simply stated, more water translates into more space for fish and the population increases to fill this void. Conversely, lower flows provide less space and lead to a reduction in fish standing crops. It is the logic of this relationship that has led many to believe that the period of lowest streamflows is the single factor having the greatest impact on a stream's carrying capacity. Carrying capacity here is defined as the standing crops of fish that can be maintained indefinitely by the aquatic environment.

Substantial support for this belief is provided in the literature. Positive correlations between the magnitude of a stream's annual low flows and the variation in fish standing crops over time have been documented in numerous studies (Neave 1949 and 1958, McKernan et al. 1950, Wickett 1951, Henry 1953, Neave and Wickett 1953, Pearson et al. 1970, Burns 1971 and White et al. 1976). In Montana, such relationships have been suggested for the Gallatin, Big Hole, Madison, Bighorn and Yellowstone rivers (Nelson 1984b, Fredenberg 1985, Vincent 1987, and Clancy 1988).

Flows can increase to a level where they no longer benefit fish populations. High flows, especially those associated with floods, have been shown to adversely impact fish, with eggs and young generally affected more severely than adults (Allen 1951, Elwood and Waters 1969, Seegrist and Gard 1972 and Anderson and Nehring 1985). However, the magnitude of the impact on the population can vary by species, the time of year high flows occur and the physical stream characteristics.

Not all space in a stream is equally suited for fish. Fish tend to concentrate and spend much of their time in specific habitats, which consist, among other things, of a preferred range of bottom substrates, current velocities and water depths, and contain cover. Components of the preferred fish habitat - not all of which are readily identifiable - can vary with the species, life stage and size of fish and by stream and season.

Cover, or shelter, has long been recognized as one of the basic and essential components of fish habitat. Cover serves as a means for avoiding predators and provides areas of moderate current speed used as resting and holding areas by fish. Cover is provided by such things as undercut banks, overhanging and submerged bank vegetation, woody debris, aquatic vegetation, instream boulders and cobbles, and surface turbulence. Water depth by itself is a form of cover.

Fish habitat can be improved through artificial manipulation, thus increasing a stream's carrying capacity. One of the most cited examples occurred at Lawrence Creek, Wisconsin, where the brook trout biomass (total weight) increased almost threefold following extensive habitat improvements that increased bank cover by 416% and pool area by 289% (Hunt 1971 and 1976). Fish habitat can also be degraded by man's activities. The destruction of bank vegetation is a prime example that leads to habitat losses and, in turn, reduces the carrying capacity. For example, a study evaluating the effects of habitat manipulation on trout abundance in a small Montana stream reported that the removal of a portion of the overhanging brush cover reduced the trout biomass in a test section by 41% (Boussu 1954). It is thus well established that fish do respond, sometimes dramatically, to habitat alterations.

The amount of available fish habitat in a particular stream is strongly influenced by streamflow. This is an obvious relationship because many habitat components, such as water velocity, depth, and available bank cover, are directly affected by the magnitude of the flow (Randolph 1984 and Wesche 1973). It is through its influence on fish habitat that streamflow is believed to primarily regulate fish abundance. Greater flows expand the available habitat, allowing the fish population to increase. Conversely, following flow reductions, fish populations decrease in response to shrinking habitat. Numerous studies have documented positive relationships between fish standing crops and various indices of habitat quantity (Gunderson 1966, Lewis 1969, Stewart 1970, Wesche 1974 and 1980, Nickelson and Hafele 1978 and Loar et al. 1985b).

While streamflow primarily regulates fish standing crops through its effect on physical habitat, other factors that can contribute to the variation in fish abundance over time are also influenced by flow. One such factor is food supply. The abundance, production and composition of food items can be altered by variations in flow (Cushman 1985).

Aquatic insects, such as caddisflies, stoneflies and mayflies, and other aquatic invertebrates are the primary food of Montana's stream-dwelling game fish (Brown 1971). It is widely accepted that the production of these aquatic food organisms is greatest in riffles of streams (Hynes 1970). Needham (1934) and Briggs (1948) reported that 80 percent of the invertebrate production in their study streams occurred in riffles. A riffle is a section of stream in which the water flow is rapid and shallower than the sections above and below. Streams usually consist of a succession of pools and riffles.

Aquatic invertebrates normally become available as a food source when drifting in the current, although salmonids and other fish also rely heavily at times on bottom foraging. The majority of the studies reported in the literature support the general conclusion that a strong positive correlation exists between the abundance of aquatic drift and water velocities (or stream discharge) (Chapman 1966, Waters 1969, and Everest and Chapman 1972). Increasing velocities, which are necessary to free invertebrates from the bottom substrate, should increase the quantity of drift up to the point where flows near flood levels (Waters 1969).

While increased water velocity is the generally accepted mechanism for creating drift, sufficient riffle habitat must be available to produce this food source. To sustain maximum invertebrate production, the riffle habitat should be wetted year-round because the majority of aquatic insects live from one to three years on the stream bottom before emerging as air breathing, winged forms and completing their life cycles. These organisms cannot be expected to readily recolonize those areas that are alternately wetted, dried and rewetted each year. Up to 47 days may be required to fully recolonize a dewatered substrate (Gerisch and Brusven 1981). Thus, both the total amount of wetted riffle area and the velocities through these riffles appear to be important factors determining the quantity of drift.

The assumption that food supply can be an important factor controlling fish abundance is supported by a number of studies. Mason and Chapman (1965), Peterson (1966), Elliott (1973) and Gibson and Galbraith (1975) reported that stream sections having the higher incoming drift supported greater fish standing crops. Murphy et al. (1981) found that trout biomass at six stream sites in Oregon's Cascade Mountains was highly correlated with the biomass (in riffle samples) of the collector-gatherer group of invertebrates (r=0.99,

$P<0.01$) and moderately correlated with the total invertebrate biomass ($r=0.83$, $P<0.05$).

Fish abundance can reflect the quantity of the food supply and, in those streams where food is limiting, populations will benefit if food production was optimized. One means for accomplishing this goal is to maintain a flow level that wets the maximum amount of a stream's riffle area. The underlying assumption is that fish standing crops will respond to increases in wetted riffle area via the impact on food production. Support for this logic is provided by Pearson et al. (1970), who found that pools having larger upstream riffles averaged higher production of coho salmon per unit of pool area than did pools with smaller riffles. On the negative side, Cada et al. (1983) were unable to show a consistent relationship between invertebrate densities and riffle wetted perimeter (an index of wetted riffle area) at various flows for four southern Appalachian trout streams. However, they concluded that their analysis was only preliminary and, in a subsequent correspondence with the MDFWP, Cada stated that he hoped to restudy the relationship in greater detail and suspected that there was some value in examining wetted perimeter when considering flow effects on aquatic invertebrates.

Streamflow will control the amount of riffle area that is covered by water and, as a result, may influence food production. This potential relationship between streamflows and food production is of particular significance during the warmer months when higher water temperatures initiate fish growth and young fish are hatched and enter the population. Due to this growth and recruitment, the population increases over summer in both numbers and biomass, typically reaching its highest level in fall. The fact that fish populations in Montana's streams tend to increase over summer suggests that the amount of preferred habitat needed for population expansion is in excess at this time. Vacant habitat would have to be available in order for this expansion to occur. This is consistent with the fact that streamflow in Montana's unregulated streams is normally highest in summer and lowest in winter (Figure 1). (Prairie streams, regulated streams and those heavily depleted for irrigation often violate this "rule of thumb"). Consequently, habitat availability is expected to be greatest during summer and lowest in winter. On these streams, food supply may be more influential in limiting the summer population expansion than is a lack of unfilled habitat. Experiments of Wilzbach (1985) suggested that, in summer, food abundance was the overriding factor determining the abundance and distribution of adult cutthroat trout in streams. (In 1987, the Cooperative Fisheries Research Unit at Montana State University began a study to assess the role of summer food supply in regulating trout abundance in Montana's streams. No study results are available at this time.)

In winter, Montana's streams normally exhibit high fish losses, which are attributed to the seasonally low flows coupled with the detrimental effects of sub-surface ice formation, ice scouring and other harsh physical conditions that typically characterize a Montana stream in winter. The severity of the winter environment on trout survival has been discussed by a number of authors (Maciolek and Needham 1952, Needham and Jones 1959, Butler 1979 and Kurtz 1980) and borne out by the high over-winter mortality rates that have been documented for a number of Montana streams (MDFWP 1984 and Schrader 1985). By winter's end, populations are typically reduced to the lowest level of the year in response to the adverse habitat conditions. The winter period and its associated low flows are believed to ultimately regulate the capacity of most Montana streams to sustain fish.

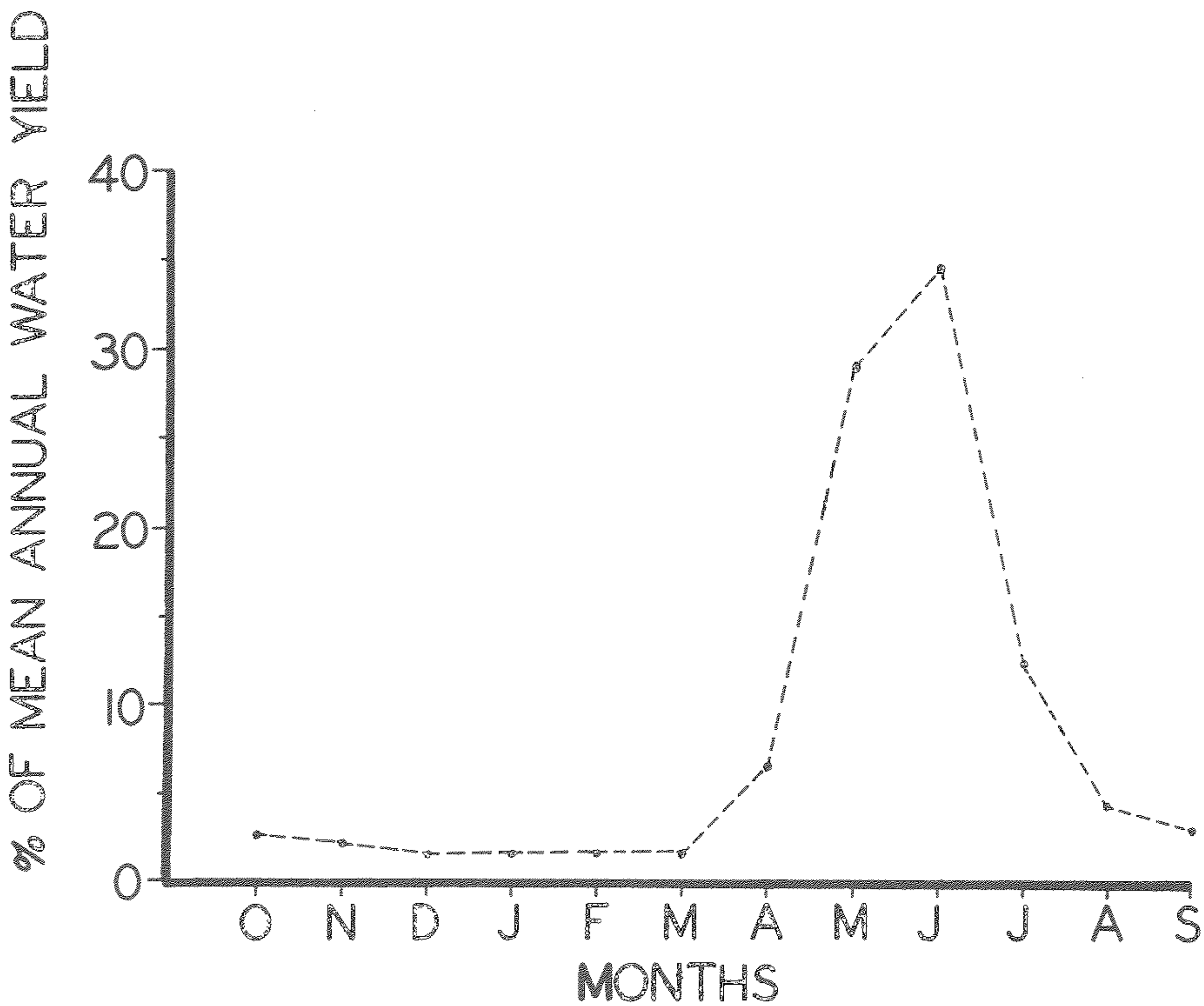


Figure 1. Monthly water availability for mountain trout streams in Montana. The monthly values are the averages for five unregulated streams east of the Continental Divide.

A better understanding of the connection between food supply and winter habitat in regulating fish abundance is provided by Mason (1976). He was able, through supplemental feeding, to increase the summer biomass of juvenile salmon in a small British Columbia stream by 6-7 fold when compared to natural levels. However, the over-winter loss of these fish was extremely high, resulting in a spring population that was numerically similar to the population under natural conditions (no supplemental feeding). This study demonstrated that food supply was the most important factor controlling population size in summer, but physical habitat in winter ultimately limited the population, preventing a high carry-over of fish from the previous summer's supplemental feeding.

The role of habitat in regulating fish abundance in Montana's streams is probably dominant in winter and of lesser importance in summer when food supply likely plays a key role. During the transition period between summer and winter when flow levels start to approach the winter lows (Figure 1), habitat should begin to play a more prominent role in controlling population size. As natural flows progressively decline, a theoretical point is reached when habitat reductions overtake food supply as the primary limiting factor. Justification for habitat becoming a key limiting factor prior to the winter low flow period being reached is based on the fact that the habitat needs of individual fish are generally considered greatest during the warmer months when fish grow, reproduce, and actively defend territories. In winter, escaping from the rigors of the harsh physical environment appears to be the primary life function. For protection, wintering fish tend to seek out the deeper pools, enter the bottom substrate or congregate amid heavy accumulations of brush and debris (Chapman and Bjornn 1968). Because wintering fish typically confine their activities to limited areas and are less active, their individual habitat requirements appear to be less than their non-winter requirements. Thus, a greater flow is needed in the warmer months than is required during winter to support the same fish abundance. Stated another way, a given flow should provide less fish habitat during the warmer months than in winter. (This generality applies only to those time periods when sub-surface ice is not the dominant determinant of channel structure. When icing is severe, physical habitat is grossly altered and is no longer comparable to the habitat in summer.)

The amount and availability of physical habitat may limit fish populations during the non-winter months in streams that are depleted for irrigation. The habitat reductions that result when irrigation water is removed, especially in late summer and fall when natural flow levels have dropped considerably, become more limiting to the population than the food supply and, if flow depletions are severe, replace winter habitat as the ultimate population control. Data collected for the Gallatin, Big Hole and Shields Rivers - Montana streams that are severely depleted for irrigation - suggest that the summer low flow has become the ultimate population regulator on portions of these streams (Nelson 1984b and Clancy 1985).

How streamflow regulates populations during the non-winter months - via food supply, habitat or a combination of both - is less relevant than the fact that regulation does occur. As a result, there are distinct benefits to maintaining non-winter flow levels that exceed the winter lows. One important benefit is that the higher flows of the non-winter period allow the population to achieve maximum growth and expansion over summer, providing anglers with a harvestable surplus of fish before the upcoming population adjustment in winter. Anglers have the opportunity to take a portion of the fish biomass that will normally be lost over winter, without materially impacting future fish abundance. Maintaining flows year-round at the low level of winter would not allow for this summer expansion and would, therefore, diminish or eliminate fishing opportunities. Another real possibility is that a year-round low (winter) flow would reduce the fall population to a level below the carrying capacity of the winter habitat, and thus lead to a major reduction in future fish abundance. This stems from the likelihood that habitat requirements of individual fish may be greater in the warmer months than in winter. Clearly, neither fish nor fishermen would benefit if flows were maintained year-round at their low winter levels.

While streamflow is often considered the most important variable regulating fish densities, its influence can be masked or overridden by other controls, such as man-caused pollution and the over-harvesting of fish by anglers. In these situations, fish standing crops are suppressed by factors unrelated to flow and held at a level far below the stream's carrying capacity. The influence of flow levels, therefore, becomes secondary except possibly under extremely low flows. If these other controls were reduced or eliminated, streamflow would again become the dominant population regulator.

When deriving flow recommendations for Montana's streams, fishery managers strive to provide a level of protection that will maximize fish populations. Given this goal, a prudent and defensible approach is to fully protect winter flows. Flow reductions during the winter low flow period would only serve to aggravate an already stressful situation for fish (MDFWP 1984), potentially leading to even greater over-winter losses. For the remainder of the year, a reasonable strategy is to provide a flow that maintains food production and fish habitat at a level that maximizes the growth of individual fish and the expansion of the population over the summer growing season.

SURVEY AND ANALYSIS OF INSTREAM FLOW METHODS

Survey of Available Techniques

Probably the best and most defensible method for determining streamflows necessary to maintain existing aquatic resources is to observe responses of fish populations to changing flow regimes in a specific water over a period of years. While this approach is desirable, it is impractical for use on a broad scale because of time and manpower requirements. The need to collect data over a wide range of annual flow conditions is an additional constraint since researchers seldom have control over this variable. Although such information exists for a few of Montana's "blue ribbon" trout streams (Nelson 1980a and 1980b), it is not a viable alternative to the commonly used IFM's.

Recent reviews by Wesche and Rechard (1980), Loar and Sale (1981), and Trihey and Stalnaker (1985) have shown that the commonly used and accepted instream flow methods can be classified into three categories. They will be referred to as:

1. Non-field
2. Habitat retention
3. Incremental

Non-Field Methods

The first category includes a variety of "non-field" methods that set minimum flows based on existing historical streamflow records. One of the most common of these is the Tennant Method, also known as the Montana Method. The name "Montana Method" is a misnomer because it is not the preferred method in the MDFWP's program to set instream flows. This method derives flow recommendations based on percentages of the mean annual flow for the stream in question. Other related methods are based on manipulations of water yield or flow duration information. All such methods are similar in that they are usually performed in the office using existing hydrologic information with few, if any, on-site visits required. These methods are also generally weak in establishing a biological basis for the recommended flows.

Habitat Retention Methods

The second group of IFM's includes a wide array of techniques that examine relationships between discharge and generalized fish habitat indices to derive flow recommendations intended to maintain the stream resource at a desired level. They are called "habitat retention" methods because they specify flow levels where certain desirable aquatic habitat characteristics (such as riffle wetted perimeter) are retained. These methods require one or more visits to the stream or river where habitat measurements are made along established cross-sectional transects. Some methods employ hydraulic simulation models (such as Manning's equation or stage-discharge relationships) while others rely on repetitive measurements made at several different flows.

Habitat retention methods commonly apply criteria to define flows necessary to provide suitable conditions for one or more of the following life functions:

1. unimpeded passage to spawning areas
2. adequate spawning habitat
3. adequate rearing habitat
4. adequate food producing habitat.

For example, the Oregon Method addresses fish passage requirements by examining water depths and current velocities over a range of flows at several transects. These transects are established across critical riffles where fish passage problems would first appear as discharge decreases. Criteria developed for various fish species from field observations and laboratory studies are then compared to cross-sectional information to identify flows where channel width, water depth, and current velocity conditions no longer allow adequate passage. Depth and velocity passage criteria for a variety of fish species were presented by Thompson (1972). Similarly, several habitat retention techniques use either species-specific or generic depth and velocity criteria and carefully placed cross-sectional transects to derive flow recommendations for known spawning areas (Wesche and Rechard 1980).

While not all of the habitat retention methods described by Wesche and Rechard (1980) consider passage and spawning requirements, they do share a common emphasis on defining flows required to provide adequate fish rearing habitat. However, as pointed out by Thompson (1972), the identification of appropriate rearing flows is far more difficult than determining passage and spawning flows. Fish habitat requirements for rearing purposes are complex because preferences for water depth, velocity, cover, and substrate usually vary not only between species but also between life stages (i.e., fry, juveniles, adults) of a single species. Further, the habitat requirements (primarily current velocity, substrate and depth) of the numerous species of aquatic macroinvertebrates that comprise the main food base for trout in most streams also vary significantly between species.

Because rearing habitat requirements of lotic fish species and food organisms are so complex and interrelated, the habitat retention IFM's typically evaluate the relationship between streamflow and some general index of physical habitat conditions in deriving flow recommendations. Many of these methods focus on riffles because of their importance as food producing areas and the belief that the maintenance of riffles will provide adequate amounts of habitat in other areas of the stream (Stalnaker and Arnette 1976). As shown in Table 1, four of the seven common "habitat retention" methods specifically consider riffle habitats and five methods give at least some consideration to the amounts of wetted perimeter retained in the stream.

Incremental Methods

The third group of IFM's can be referred to as "incremental." These techniques produce habitat-discharge relationships for specific life stages of various fish species. They are termed "incremental" methods because they attempt to predict the actual amount of suitable fish habitat present as flow changes incrementally. The "California Method" for rainbow trout and the "WRRI Method" for brown trout (both described by Wesche and Rechard 1980) are included in this group. However, the best known technique is the Instream Flow Incremental Method (IFIM). IFIM is the most sophisticated instream flow method and it continues to be refined by the IFG at Fort Collins, Colorado.

The IFIM has been described in detail elsewhere (Trihey and Wegner 1981, Bovee 1982, Milhous et al. 1984). Loar and Sale (1981) describe the method as follows:

> "A package of computer programs, collectively called PHABSIM (Physical HABitat SIMulation system), is used to implement this analysis of instream flow needs. The overall approach combines (1) multiple-transect field data from a representative and/or critical river reach, (2) hydraulic simulation models to predict physical habitat parameters such as mean velocity (v), depth (d), and substrate (s), and (3) species-specific suitability functions (S_v, S_d, S_s). Suitability functions are used to calculate weighting

Table 1. Summary of the common "habitat retention" methods used to determine rearing flow requirements (derived from Wesche and Rechard 1980).

Method	Species	Habitat Unit Considered	Rearing Criteria
Oregon	salmonids	riffles	- adequate depth - 60% wetted - velocity 1.0 to 1.5 ft/sec
		pools	- velocity 0.3-0.8 ft/sec - pool-riffle ratio near 50:50
Colorado (USFS Region 2)	salmonids	riffles	- 50% wetted - average velocity 1.0-1.5 ft/sec - depth 0.2-0.4' if width less 20' 0.5-0.6' if width more 20'
USFS Region 4	salmonids	all units (pools, riffles, runs, etc.)	- numerical rating system for pool quality, pool structure, stream-bed and bank environment
USFS Region 6	salmonids	"typical rearing habitat"	- depth 0.5-3.0 ft - velocity 0.2-1.6 ft/sec
		"food producing habitat"	- depth 0.1-3.0 ft - velocity 1.0-4.0 ft/sec
Washington	salmonids	riffle/pool sequence	- inflection point on wetted perimeter: discharge curves
Idaho	warmwater	riffles	- inflection point on wetted perimeter: discharge curves
Montana's WETP	salmonids	riffles	- inflection point on wetted perimeter: discharge curves

cross- section based on field measurements of cross-sectional area, hydraulic radius, energy slope, and channel roughness at a single discharge. This method is advantageous because it entails only one set of field measurements. However, it is not well suited to natural stream channels where flow conditions are not always uniform. Manning's equation was developed to describe flow conditions in manmade channels where energy slope and channel roughness (Manning's "n") remain relatively constant as flow changes. These coefficients often vary significantly in natural channels as discharge changes, thus reducing the accuracy of the predicted stage-discharge relationship (Bovee and Milhous 1978). Consequently, for most natural stream channels, stage-discharge relationships are best obtained using an empirical approach using three (or more) sets of field observations. The regression approach also allows extrapolation over a greater range of flows (Bovee and Milhous 1978).

"Step-backwater" models comprise the third main group of hydraulic models used in IFM's. The most well known of these models is the WSP (Water Surface Profile) model. This method produces three dimensional depth and velocity maps of a stream section using Manning's equation and the Bernoulli Energy Equation. It can be applied using only one set of field measurements, but its accuracy and range of extrapolation can be enhanced by one or more additional sets of field data (Bietz et al. 1985). Step-backwater models require more precise and detailed field survey data and also require accurate and mandatory placement of transects across all hydraulic control points in the study section. IFIM is the most flexible IFM in terms of hydraulic modeling because it allows the use of empirical, regression, or step-backwater procedures as well as combinations of the latter two.

Decision-Making Capabilities

All the various IFM's have advantages and disadvantages in terms of ease of interpretation for decision making, ability to "customize" flow recommendations, and defensibility of decision criteria and processes. Trihey and Stalnaker (1985) identified two types of IFM's that relate to decision-making capabilities. They are the "standard setting" methods and the "incremental" methods. What we've called "non-field" and "habitat retention" methods are standard setting methods. These methods identify minimum flow standards that may constrain development, whereas incremental methods (of which IFIM is the best known) quantify tradeoffs by examining fish habitat responses to flow alterations.

The standard setting methods are by far the easiest to interpret for making decisions since they are concerned with setting minimum flows, whether it be for spawning, passage, incubation, rearing, or food production. However, because these methods recommend minimum flows they can actually compromise some portion of the aquatic resource if these minimum flows are all that is maintained during the period of recommendation. Trihey and Stalnaker's (1985) analogy was that fish communities may be able to withstand near-drought conditions for one year in ten (or one month per year), however, standard setting methods may impose such conditions for 10 out of 10 years (or all months of the year). This could have serious biological consequences because fish and other aquatic organisms are often dependent on seasonal variations in streamflow.

Incremental methods, in particular IFIM, can compensate for this problem to some degree because they can develop seasonal flow recommendations for several life stages of many species if adequate hydrologic and habitat suitability data are available. In this regard it is a superior method to the "habitat retention" methods that consider flow-related changes in only one (such as riffle wetted perimeter) or a very few habitat components to indicate overall ecosystem response. The ability of IFIM to generate complex seasonal/species/life stage-specific flow recommendations can also be a limitation. At times, an almost overwhelming amount of information can be generated, creating problems with data synthesis and determination of recommended flows. Problems that must be addressed include determining which life stage is most limiting to a species, and which life stage of which species is most important during a given season. These difficult decisions often require "professional judgment" and are necessary because a flow that is beneficial to one life stage of a given species may be detrimental to other species or to other life stages of the same species.

The various procedures used by IFM's to derive the final flow recommendation(s) offer certain advantages and limitations. The simplest and most direct procedures are employed by the "non-field" methods that simply select percentages of annual flow or some other measure of flow frequency. While this approach lacks biological sensitivity and, at times, is unrealistic, the mechanics of deriving the flow recommendations are relatively unassailable.

The approaches used by various "habitat retention" IFM's to derive final flow recommendations are the source of some controversy. Two approaches are typically used. The first uses habitat criteria for such things as depth, velocity, width, and wetted perimeter as shown previously in Table 1. For example, the Oregon method specifies that minimum flows for salmonid rearing must provide adequate depth in riffles, cover approximately 60% of riffle area by flow, provide 1.0 to 1.5 feet/sec riffle water velocity, provide 0.3 to 0.8 feet/sec pool water velocity, and must produce a pool:riffle ratio of 50:50

(Thompson 1972). The second approach relies on the identification of inflection (or breaking) points on habitat-discharge curves to identify critical flows below which habitat losses increase rapidly.

Loar and Sale (1981) and Annear and Conder (1984) criticized the inflection point approach as being too subjective and having the potential to "create rather than alleviate controversy over water allocation needs." Loar and Sale (1981) recommend using habitat criteria because they "are much less ambiguous than inflection-point calculations and are preferable because the value judgments are clear and relatively more defensible." However, Bietz et al. (1985) presented an entirely opposite argument and rejected the use of habitat criteria because none of the parameters have been directly related to habitat quality. They further state: "The relationship between percent (emphasis added) wetted perimeter retained and aquatic habitat quality is even more tenuous. Unlike the wetted perimeter inflection point, there is no currently available rationale for claiming that a fixed percentage of wetted perimeter represents an acceptable or non-acceptable level of aquatic habitat retention."

As emphasized by Loar and Sale (1981), all IFM's involve some level of subjectivity, and professional judgment is essential to formulate final flow recommendations. Inflection point methods require judgment in selecting inflection point flows, while methods employing habitat criteria require judgment in defining the criteria to use. The selection of inflection points is often very simple and requires little professional judgment. However, in some cases the biologist must use judgment to select inflection point flows that will provide adequate habitat for the existing aquatic resource. To employ habitat criteria, the judgment has to be made by the biologist at the outset, but it should not be construed as being any less subjective than that employed in selecting inflection points.

Data and Manpower Requirements

Each IFM has specific requirements for streamflow gaging information, field transect data, and site-specific habitat suitability data for target species. In Montana, the requirements for flow gaging information are critical because most of the stream reaches involved in water allocation proceedings have no gaging records. The habitat retention IFM's are best suited for ungaged streams since they require little or no long-term flow information and also involve one to three or more visits to the site. Flow measurements and channel morphology observations made during these visits give the biologist some idea of the annual hydrologic regime and a "feel" for the flow-related changes in fish habitat quality and quantity.

Many of the non-field IFM's require long-term streamflow records. However, mean annual flow of many streams can be adequately estimated using watershed analysis techniques requiring little or no fieldwork. The Tennant method (a non-field method based on percentage of mean annual flow) can, therefore, be used in the absence of good streamflow records, provided mean annual flow can be accurately predicted from basin characteristics. Long-term hydrologic information is considered essential by the IFG to negotiate flow recommendations.

The non-field IFM's typically require little or no transect information gathered on-site. On the other hand, the habitat-retention and incremental methods often require extensive amounts of transect data at several flows. Field data requirements for habitat retention methods can be substantial if passage, spawning, and rearing flow requirements all need to be determined. This could require two or more sets of transects in different habitats that would each need to be visited three or more times and possibly at different seasons. Montana's wetted perimeter inflection point method is one of the simplest field methods because it requires only three sets of water surface elevation data and one set of channel profile measurements at each transect. In contrast, many other habitat retention methods, as well as IFIM, require depth, velocity, substrate and/or cover measurements at numerous points across each transect for each visit to the site.

Habitat suitability curves for species of interest are essential to the application of IFIM as discussed previously and illustrated in Figure 2. Originally, preferences for depth, velocity, substrate, and cover for a single life stage of a species were thought to be similar in all streams. Hence, suitability data gathered in one stream would be transferrable to others, thus saving additional time and effort. However, problems in applying IFIM in some areas have been traced to the fact that fish may not use habitat equivalently in different stream environments (Nelson 1980c, Annear and Conder 1983). Moyle and Baltz (1985) recommend developing habitat suitability curves on-site for each species of interest because variations in fish population densities and species composition within and between streams can lead to differences in habitat use via intra- and inter-specific competition. Also, well known diurnal and seasonal habitat preference shifts can seriously complicate the use of IFIM (Campbell and Neuner 1985). Perhaps the best solution to this problem is to identify which limiting factors operate during each season to regulate fish populations and then focus instream flow analysis and habitat criteria on these conditions (Campbell and Neuner 1985). If site-specific habitat preference data are indeed mandatory, the costs and time involved in IFIM applications become very high.

Manpower requirements vary significantly among various IFM's and have been discussed in detail by Wesche and Rechard (1980) and Loar and Sale (1981). The "non-field" methods typically require little or no fieldwork and can usually be completed with less than one man-day of office effort. Manpower requirements are highly variable between "habitat retention" methods and depend upon which method is used and what life functions (spawning, incubation, passage, rearing) are considered. According to Wesche and Rechard (1980), the Oregon Method requires 3-6 man-days of field effort and 1-3 man-days of office work to derive recommendations for each of three functions: spawning, passage, and rearing. The Washington Method requires much more effort (man-days): 10-20 field days and 15-30 office days for spawning; the same for rearing; and 5-10 field days and 1-3 office days for wetted perimeter. The Montana wetted perimeter inflection point method requires relatively little manpower - about 4-6 man-days in the field and ½-1 man-days in the office. None of the above manpower estimates include travel time.

As might be expected, IFIM has very high manpower and training time requirements. Loar and Sale (1981) estimated that IFIM would typically require up to ten times the manpower as the simpler habitat retention methods such as the Colorado (R2-Cross) Method and Montana's wetted perimeter inflection point method. In addition to manpower, the training costs for IFIM are very high compared to other methods. The USFWS conducts a mandatory series of 4-5 short courses to train IFIM users. These courses involve 150-170 hours of training and cost $1,500-$2,000 to complete, excluding salary, travel, and lodging expenses. In addition, access to IFIM computer software is extremely limited for non-federal personnel.

IFM Evaluation Studies

The question of how effective various IFM's are for determining instream flow needs for maintenance of fisheries and other aquatic resources is one of the most important issues facing fisheries biologists today, yet remains the most difficult to resolve. Although many studies have been published that "evaluate" one or more IFM's (e.g. Nehring 1979, Prewitt and Carlson 1979, Stalnaker 1979, Hilgert 1981, Orth and Maughan 1982, Annear and Conder 1983 and 1984, Bietz et al. 1985), most of them are deficient because they tended to focus on the mechanics of the models used, or the uniformity of the results, rather than on the biological adequacy of the instream flow recommendations.

The problem of relating the results of various IFM applications directly to fish populations was recognized by Wesche and Rechard (1980), who stated, "the fallacy of the 'state of the art' has been that no methodology, no matter how detailed, addresses the question of potential biological consequences." The following statement by Trihey and Stalnaker (1985) indicates that we continue to face this dilemma:

> "Despite the successes, fisheries biologists have not yet achieved the capability of forecasting the number of fishes produced in response to any particular water management scheme. This question is being brought up more and more in present-day water development and constitutes a third phase. Within the next decade or so a scramble is expected for research and method development aimed at predicting changes in numbers of fish resulting from flow and channel alterations. This will be similar to the 1970's when methods to quantify the response of fish habitat to streamflow were developed. Only after reaching this third phase can we begin to quantify the economic value of altering the instream resource. This will provide an equivalent basis for comparison of fishery resources with other instream/out-of-stream values."

Our present inability to thoroughly evaluate the adequacy of instream flow recommendations is related to two major difficulties. These are: (1)

lack of a thorough understanding of the carrying capacity of lotic systems and how various factors operate to limit carrying capacity, and (2) problems with experimental design. Both of these problems are complicated by the fact that aquatic ecosystems are comprised of complex assemblages of organisms that interact with one another as well as with their physical environment (Giger 1973). Further, these interactions may vary seasonally, between life stages of a species, and between stream environments.

Carrying Capacity and Limiting Factors

A persistent problem that hampers efforts to successfully evaluate and apply IFM's is the knowledge of what the carrying capacity of the stream is, whether or not fish populations are at carrying capacity, and what factor(s) act to regulate carrying capacity. Although the concept of carrying capacity may be simply defined (the standing crops of fish that can be maintained indefinitely by the aquatic environment) the controlling mechanisms are not easily quantified. Carrying capacity is determined by the action of one or more limiting factors.

Giger (1973) reviewed a number of publications and agreed with McFadden (1969) who concluded that it was impossible to identify any one factor that exclusively regulated populations of early trout and salmon life stages (fry and juveniles). Rather, a number of factors interact to regulate fish populations and "each factor can be understood properly only within the context of the network of relationships" (Giger 1973). It is likely that limiting factors vary between streams, or at least regionally, due to differences in species composition, hydrology, climate, and habitat.

There is general agreement among researchers that in most cases physical habitat during the late summer, fall, and winter months when streamflows are at annual lows is the primary factor limiting fish populations in western coldwater streams and rivers (Wesche and Rechard 1980, Giger 1973). Loar and Sale (1981) suggest that fish habitat may be a limiting factor only during very high or very low flow conditions. They further state that at intermediate flows when habitat availability is high, other factors such as food production may become more important as limiting factors. It is obvious that continued research is needed to develop consistent methods to identify limiting factors so that instream flow recommendations can be better tailored to suit differing seasons and stream environments (Campbell and Neuner 1985).

Experimental Design

Based on a review of available literature, three main approaches have been used to evaluate the adequacy of various IFM's for making appropriate instream flow recommendations. These are:

(1) Approaches that examine short-term relationships between streamflow or some habitat index (such as weighted usable area (WUA) derived using IFIM) and fish population size or standing crop.

(2) Approaches involving experimental manipulations of flow and fish populations or standing crops.

(3) Long-term studies of relationships between flow regimes and fish populations or standing crops.

Each of the above approaches has certain advantages and limitations. The first is probably the least suitable for evaluating IFM's. At least two studies (Stalnaker 1979, Annear and Conder 1983) have examined the relationships between WUA (a measure of habitat quantity) and trout populations in several streams at one point in time, typically during the low flow period when habitat is assumed to be limiting. While this approach does offer some insight into the ability of IFIM to quantify amounts and quality of fish habitat, it does little to address the question of the adequacy of IFIM's flow recommendations. The relevance of this approach in addressing the first question (relationship between WUA and fish population size) is questionable since one must assume that the fish populations were at carrying capacity during the one point in time when populations were estimated. This assumption is seldom tested, primarily due to a lack of rapid and accepted assessment techniques.

A similar approach was utilized by Orth and Maughan (1982) who examined relationships between WUA and biomass of several fish species in riffle areas of a warmwater stream during two consecutive summer low flow periods. Although significant positive correlations were observed, their work was strongly criticized by Mathur et al. (1985), primarily on the grounds of small sample size and assumptions concerning carrying capacity. Irrespective of these criticisms, the short-term nature of such studies and the lack of any *a priori* knowledge of what the minimum flow should be renders them ineffective in truly evaluating the adequacy of IFM recommendations.

The study by Kraft (1972) illustrates the pitfalls that can be encountered by short-term studies where carrying capacity is not taken into account. In this study (conducted in southwest Montana), responses of a wild brook trout population were related to manipulated flows in a natural stream channel. The results indicated that significant dewatering (up to 90%) during a three-month, summer, low flow period had little effect on trout populations or biomass.

Kraft's results are somewhat surprising in view of the abundant evidence (both experimental and intuitive) supporting the contention that the flow regime plays a major role in regulating fish populations. Shortcomings in

Kraft's study that may explain these anomalous findings are that no attempt was made to determine (1) whether the stream was at carrying capacity, (2) what factor(s) limited the population, and (3) what the long-term effects of such a flow regime might be. (Another possible, although unproven, explanation that would support his findings is that brook trout are more tolerant of low flows than are other trout species.) Kraft's study apparently contained the only evidence that Mathur et al. (1985) could provide to support their suggestion that "short term" reductions in flow may not affect fish population size.

The second IFM evaluation approach involves the manipulation of fish populations and flow regimes in experimental channels. Examples of such designs are studies by Easterbrooks (1981), White et al. (1981), and Randolph (1984). A unique and key ingredient of these studies is the attempt to insure that initial fish population levels are at carrying capacity. This is accomplished by oversaturating the habitat with introduced wild fish, then allowing the population to reach equilibrium (via emigration) prior to dewatering.

This is a conceptually appealing method to examine responses of fish populations (at carrying capacity) and habitat to streamflow reductions, but it also has shortcomings. Randolph (1984) suggested that equilibrium fish population size before and after such experiments may be affected by initial stocking density. While this phenomenon obviously creates some "accounting" problems, it may not significantly affect the overall study objective, which is to identify critical flows and habitat conditions below which the stream's ability to support a healthy aquatic resource rapidly diminishes. Other limitations to this study design are that (1) only one (or a few at most) stream channel is examined, (2) investigations are usually confined to one flow regime during one period of the year (i.e., late summer low flow), and

(3) it is not applicable to larger streams and rivers because of logistical difficulties.

The third approach to IFM evaluation involves the examination of fish-flow information collected over a period of years on one or more streams. This empirical approach overcomes many of the shortcomings inherent in short-term and/or experimental studies, but it too has limitations. First, this method involves a long-term commitment of time and manpower, probably for at least five to ten or more years. This is essential to insure a diversity of observations at a variety of flows. Long study periods are also required to enable the researcher to follow individual year classes of fishes through their life cycle (from fry to adult) which commonly requires three to five years. Because of the long-term nature of such studies, the researcher must remain aware of, and try to account for, changes in the watershed (logging, grazing, other development) and management policies (fish stocking changes, fishing regulations) that may also affect fish populations. Further, long-term studies can generate enormous amounts of complex hydrologic and fisheries information (if multiple species and life stages are considered), which can prove difficult to compile in a consistent, meaningful, and defensible manner. Consequently, this approach has been applied to only a few waters.

Due to their intensive data requirements, long-term, empirical IFM evaluation studies are relatively rare. They are advantageous because they provide flow recommendations based on direct observations of fish population response to a flow regime under "natural" conditions. The adequacy of IFM flow recommendations can then be critically evaluated, as Nelson (1980a, 1980b and 1980c) and Anderson and Nehring (1985) have done. Annear and Conder (1984) stressed the continued need for such studies:

"The question of adequacy of any instream flow method for fisheries will only be resolved by long-term biological documentation - a component of all comparisons of instream flow methods that is noticeably missing. Until this issue is resolved, studies such as this one will continue to only hint at acceptable procedures for identifying realistic fishery needs for instream flow."

Evaluations of Montana's Wetted Perimeter Method

The adequacy of Montana's wetted perimeter inflection point method has been tested using all three of the above study approaches with generally good results. Orth and Maughan (1982) compared the wetted perimeter, Tennant, and IFIM methods on a warmwater stream in Oklahoma. They found that all three methods produced similar, acceptable minimum flow recommendations for the low flow period.

Randolph (1984) evaluated the wetted perimeter method in a small stream in southwestern Montana during a two-month period in late summer/early fall. Wild rainbow trout densities in three stream sections were enhanced to simulate "carrying capacity" by the relocation of wild fish from upstream areas. He concluded that the wetted perimeter inflection point method produced an accurate minimum flow recommendation for a section characterized by riffle-pool habitat, but it underestimated fish flow needs in riffle-run sections. Fish population response to reduced flows (emigration) appeared to be more closely related to riffle depth (total or longest, continuous top width having depth of 15 cm or more) than to changes in wetted perimeter. Hence, depth criteria may be violated before the wetted perimeter inflection point is reached in the relatively shallow riffle-run habitats of small streams.

Nelson (1980a and 1980b) compared minimum flow recommendations derived using the wetted perimeter, Tennant, and IFIM methods to long-term information on trout standing crop and flow in five reaches of four "blue ribbon" rivers in southwest Montana. With one exception, the empirical trout/flow data sets included information for 4-13 years. He concluded that inflection points on wetted perimeter-discharge curves for one riffle in each river provided acceptable flow recommendations. Recommendations based on composites of several transects through various habitat units (pools, runs, and riffles combined) were not as reliable because inflection points were less easily recognized. The Tennant method was found to be of some use in making minimum flow recommendations, but percentage of flow required appeared to vary between rivers. Finally, IFIM flow recommendations were inordinately low due to the application of a small stream habitat model to a large river and the program's use of mid-depth velocity measurements, rather than the velocities near the stream bottom, to describe the water velocities used by fish. The IFG has since corrected these problems.

Loar et al. (1985a) observed population fluctuations of three age classes of rainbow trout in two Appalachian streams over a two-year period in relation to late summer low flows. They found that young-of-the-year rainbow trout preferred shallow riffle habitats, and flow-related population declines of these fish were related to reductions in riffle wetted perimeter.

Studies by Annear and Conder (1984) and Bietz et al. (1985) examined the consistency of the wetted perimeter recommendations for a number of streams by comparing them to recommendations derived from other methods or by converting them to percentages of the mean annual flow and comparing these to each other. These studies, while contributing to the advancement of the state-of-the-art, are not considered in this discussion because they do not address the adequacy of the wetted perimeter recommendations in maintaining the stream fisheries at acceptable levels.

Criteria for Selecting an IFM

A number of factors must be considered before selecting an appropriate IFM for a given situation. These include biological goals, geographic scope, administrative goals, time and manpower availability, biological and historical streamflow data availability, ability to monitor and enforce flow recommendations, and the type of decision-making process followed.

The geographic scope and the type of water allocation process involved are the primary considerations in selecting an appropriate IFM. Trihey and Stalnaker (1985) concluded that standard setting methods (such as the Tennant method and Montana's wetted perimeter inflection point method) are most appropriate for:

1. Protecting the instream flow resource.
2. State water plans.
3. State water allocation permits or reservations.
4. Identifying target flow for use during project feasibility studies.

They concluded that incremental methods (primarily IFIM) are most appropriate for:

1. Time series analysis to identify limiting flow conditions.
2. Fine tuning a resource maintenance objective (maximum utilization of available water).
3. Avoiding or minimizing flow-related impacts.
4. Comparing mitigation alternatives.

These recommendations carry substantial weight and are based on considerable experience; one of the authors (Dr. Stalnaker) has been the leader of the

IFG since its formation one decade ago.

The "standard setting" methods are most appropriate for basinwide water allocation because they can provide cost effective, simple, single, minimum flow values for a large number of streams with a minimal amount of time consuming negotiations. Simple, minimum flow recommendations facilitate water allocation processes and can be monitored and enforced with relative ease. Other advantages are that these methods require little or no long-term streamflow data and (at least in Montana) appear to provide reasonable minimum flow recommendations for streams and rivers alike.

The high time and manpower requirements and the nature of the decision-making process make IFIM an impractical tool for use in State water allocation programs. As pointed out by the developers of the method (Bovee 1982, Trihey and Stalnaker 1985), IFIM is not designed to set minimum flows. Rather, it is designed for negotiating flow regimes for specific project areas by quantifying flow-related habitat tradeoffs.

We contacted water resource administrators in fish and wildlife agencies in several western states and the provinces of Alberta and British Columbia in early 1986 to solicit their views regarding the use of the wetted perimeter inflection point method and to ascertain which IFM(s) they utilized. The results indicated that most states or provinces follow a hierarchical approach similar to that described by Loar and Sale (1981) or Trihey and Stalnaker (1985). That is, they employ a variety of IFM's (non-field, habitat retention, and incremental) in their programs depending upon the needs of a particular situation. The use of IFIM is usually restricted to significant water development projects or highly controversial allocation disputes.

Six of the eight agencies (Colorado, Washington, Minnesota, Wyoming, Idaho, and British Columbia) that responded indicated that they used some variation of the wetted perimeter method in some part of their instream flow program. California and Alberta do not use the wetted perimeter method. California currently has no basinwide allocation process analogous to Montana's water reservation system, so they are primarily concerned with new water development projects on which they place "conditions" (personal communication with Gary Smith, Fisheries Biologist, California Fish and Game). California requires project developers to fund and conduct IFIM studies, which the State then reviews. Alberta is currently developing a modification of the Tennant method to be used on a basinwide planning scale and uses IFIM on large water development projects.

MONTANA'S INSTREAM FLOW METHOD

An IFM that was compatible with the State's water reservation process was a major consideration when the MDFWP selected its primary method for making instream flow recommendations. Under the reservation process, the unappropriated waters in a basin are allocated among all competing uses, including municipal, agricultural and industrial as well as instream for the protection of fish and wildlife and water quality. When granted, the instream reservation becomes a part of the priority date system, with some future uses subject to, or junior to, the instream reservation. During some time periods, especially in water short years, junior consumptive users will have to comply with the terms of the reservation and cease withdrawing water when streamflows fall below the granted instream flows. Given this requirement, complex flow recommendations that vary by time period and by year are generally unsuitable because they confuse junior water users and exacerbate problems with compliance and policing. A single, year-round recommendation tends to minimize these problems, but such a recommendation may fail to fully satisfy the instream flow needs of all fish species and all of their life stages and functions. However, keeping the recommendations simple appears, in the long run, to be in the best interest of the resource because compliance and policing problems are minimized.

Under the reservation process, the Department has the responsibility for requesting instream flow protection for literally hundreds of streams. Due to the large number of streams, funding, manpower and time limitations also became an important consideration in the selection of an appropriate method. Of the three broad categories of methods previously described, two were quickly relegated to a secondary role in deriving recommendations under the reservation process.

Office or non-field methods (Category 1) were judged less desirable because of the Department's contention that the recommendations would be more credible if they reflected stream-specific habitat and discharge relationships rather than a flow quantity derived solely from the historic flow record. Furthermore, the lack of sufficient historic flow data for the vast majority of Montana's streams precluded the use of virtually all office methods. In addition, the consensus in the literature is that this category should be confined to deriving preliminary or reconnaissance grade recommendations (Stalnaker and Arnette 1976), thus limiting their suitability for Montana's reservation program.

Methods that apply species- and life stage-specific habitat criteria in evaluating the condition of the stream environment at various flows (Category 3) proved to be incompatible with the basic goal of the Department's instream flow program, which is to set flow recommendations at a level that will sustain existing fishery resources. Category 3 methods, of which the IFIM is the best known and most commonly applied example, were designed to be used in negotiating flows rather than setting minimum standards. This is a costly, complex and time consuming analysis that has limited application in Montana's water reservation process.

Those methods that examine various components of a stream's hydraulic characteristics at various flows for the purpose of developing generalized habitat-discharge relationships are included in Category 2. The flow recommendations would not, in most cases, be based on detailed evaluations of the habitat requirements of specific fish species or life stages. The simplified prediction techniques that this group uses in evaluating the condition of the stream environment reduce the field data requirements to the point where dollar costs, manpower needs and time expended are reasonable. The outcome of the analysis is a minimum flow standard that is intended to fully protect some aspect of the stream resource. These methods are most appropriate when instream protection is requested for a large number of streams, as occurs in state water allocation programs (Trihey and Stalnaker 1985).

The MDFWP was, therefore, limited to selecting a method from Category 2. The method chosen was the wetted perimeter inflection point method. A brief description of the method, its assumptions and data needs follow.

Wetted Perimeter Inflection Point Method

This method focuses on the previously discussed assumption that the food supply can be a major factor influencing a stream's carrying capacity during the non-winter months. The principal food of many of the juvenile and adult game fish inhabiting the streams of Montana is aquatic invertebrates, which are produced primarily in stream riffle areas. The method assumes that the game fish carrying capacity is related to food production, which in turn is related to the amount of wetted perimeter in riffles.

Wetted perimeter is the distance along the bottom and sides of a channel cross-section in contact with water (Figure 4). As the flow in a stream channel increases, the wetted perimeter also increases, but the rate of gain of wetted perimeter is not constant throughout the entire range of flows.

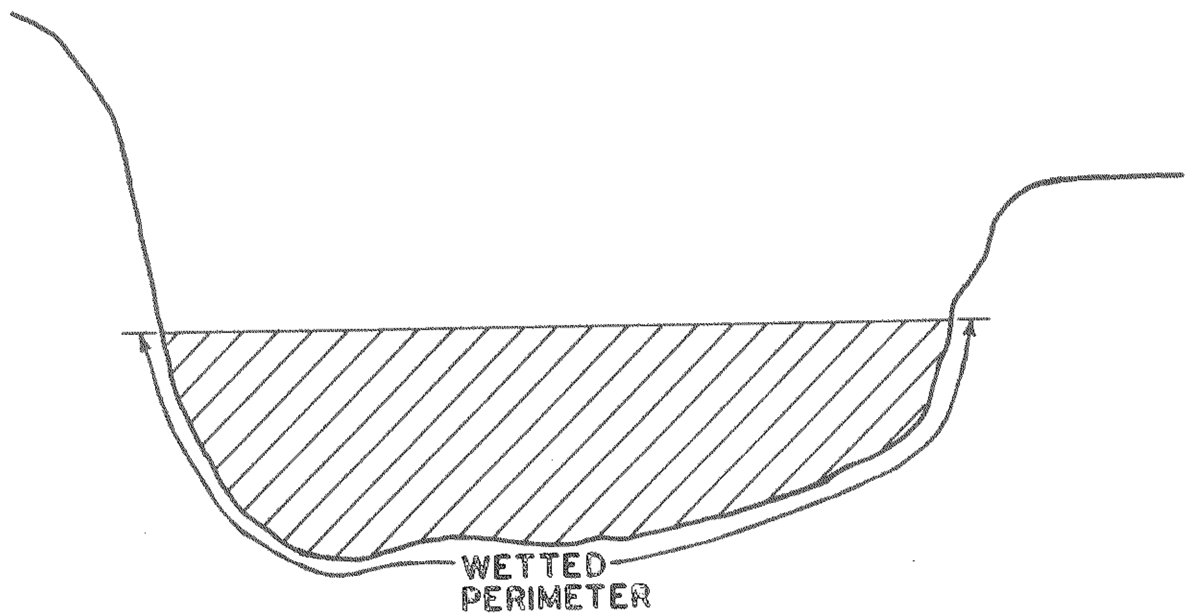


Figure 4. The wetted perimeter in a channel cross-section.

The plot of wetted perimeter versus flow for stream riffle cross-sections generally, but not always, shows two points, referred to as break or inflection points, where the rate of increase of wetted perimeter changes. In the example (Figure 5), these inflection points occur at approximate flows of 8 and 12 cfs. Below the lower inflection point, the flow is spreading out horizontally across the stream bottom, causing the wetted perimeter to increase rapidly for very small increases in flow. A point is eventually reached (at the lower inflection point) where the water starts to move up the sides of the active channel and the rate of increase of wetted perimeter begins to decline. At the upper inflection point, the stream is approaching its maximum width and begins to move up the banks as flow increases. Large increases in flow beyond the upper inflection point cause only small increases in wetted perimeter. Flow levels at these inflection points are depicted in Figure 6.

The area available for food production is considered near optimal at the upper inflection point because almost all of the available riffle area is wetted. At flows below the upper inflection point, the stream begins to pull away from the riffle bottom until, at the lower inflection point, the rate of loss of wetted bottom begins to rapidly accelerate. Once flows are reduced below the lower inflection point, the riffle bottom is being exposed at an even greater rate and the area available for food production greatly diminishes. The method is intended to establish a threshold below which a stream's food producing capacity begins to decline (upper inflection point) and a threshold at which the loss is judged unacceptable (lower inflection point).

While this inflection point concept focuses on food production, there are indications that wetted perimeter relates to other factors that influence a

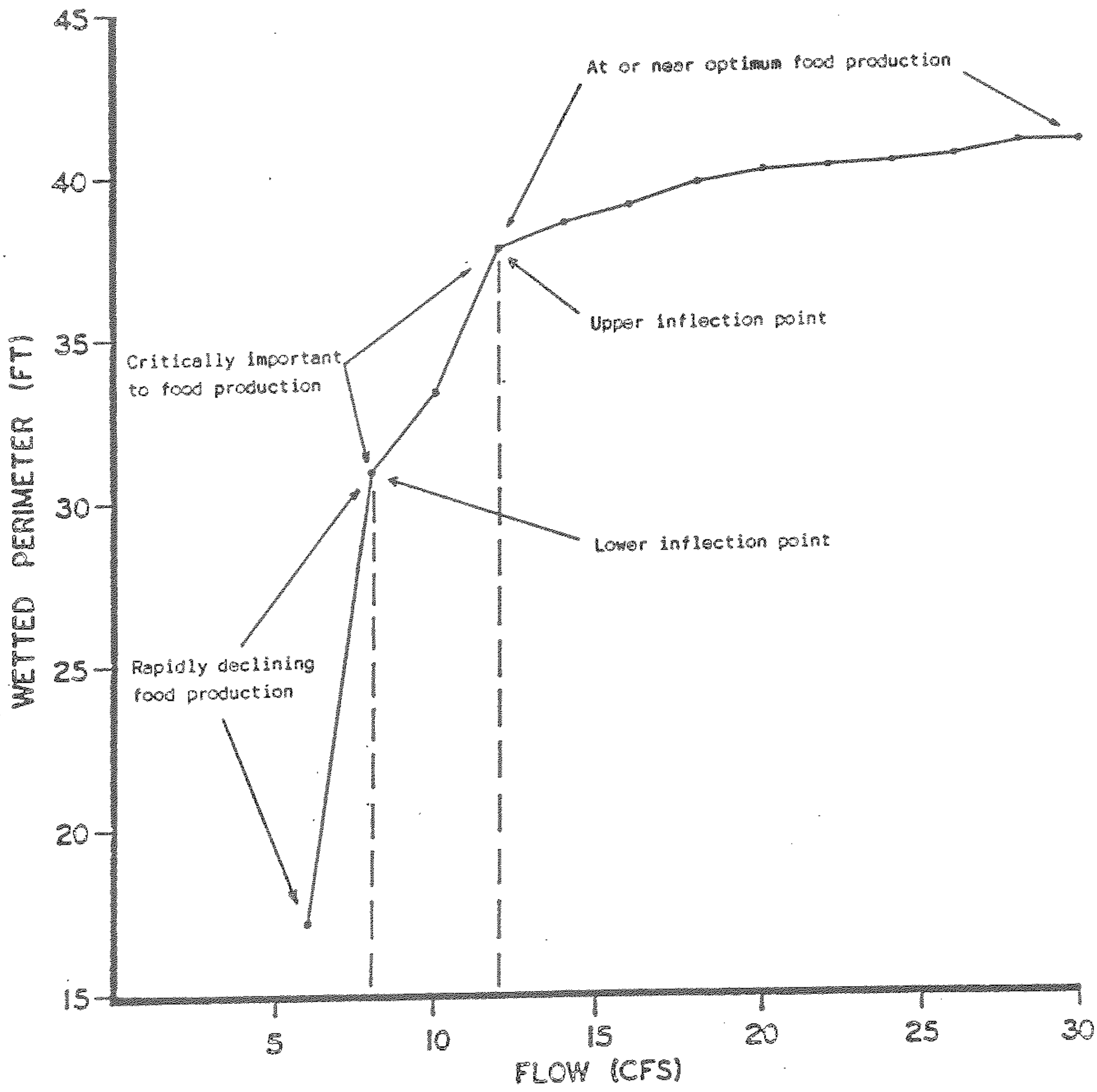


Figure 5. An example of a relationship between wetted perimeter and flow for a stream riffle cross-section showing upper and lower inflection points.

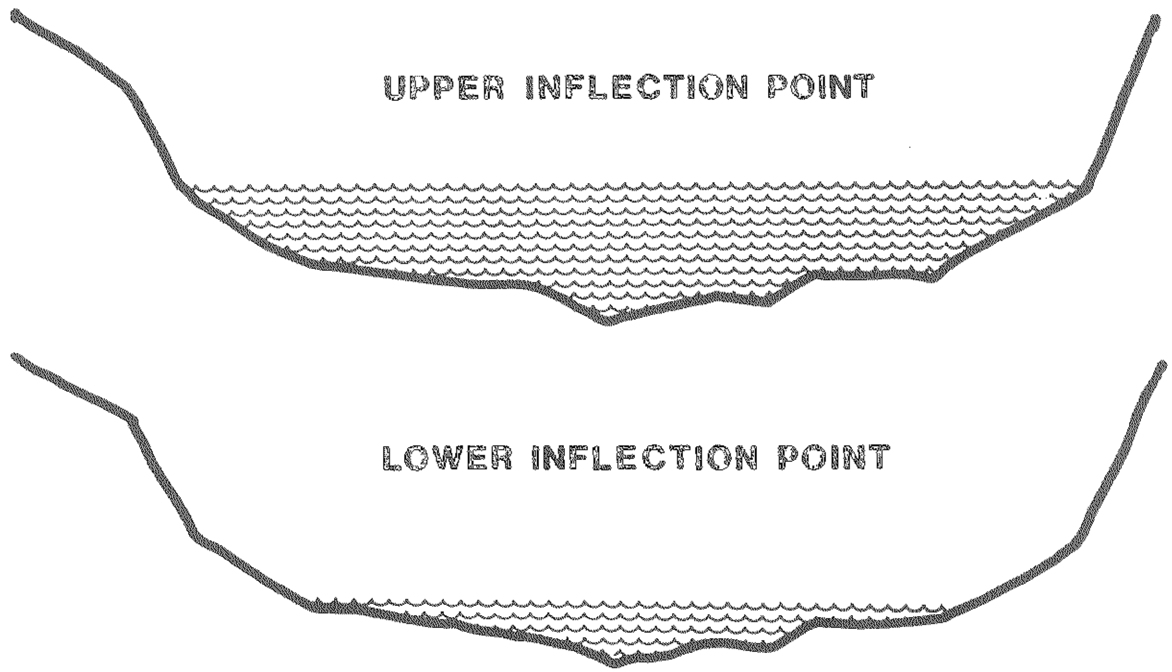


Figure 6. A diagrammatic representation of the flow at the upper and lower inflection points in a stream cross-section.

stream's carrying capacity. One such factor is cover (or shelter), a well recognized component of fish habitat.

In the headwater streams of Montana, overhanging and submerged bank vegetation and undercut banks are often important components of cover. In Wyoming, overhead bank vegetation was the cover parameter that explained the greatest amount of variation in trout population size in small, brown trout streams (Wesche et al. 1987). The wetted perimeter-flow relationship for a stream channel is, in some cases, similar to the relationship between bank cover and flow. Flows exceeding the upper inflection point are considered to provide near optimal bank cover. Below the upper inflection point, the water pulls away from the banks, decreasing the amount of bank cover associated with water. At flows below the lower inflection point, the water is sufficiently removed from the bank cover to severely reduce its value as fish shelter. Support for this relationship is provided by Randolph (1984), who found a high correlation between riffle wetted perimeter at various flows and the total area of overhanging bank vegetation ($r = 0.88-1.00$) and undercut banks ($r = 0.84-0.97$) for three study sections in a small Montana stream.

In addition to producing food, riffles also are used by many game fish species for spawning and the rearing of their young (Sando 1981 and Loar et al. 1985a). Thus, the protection of riffles insures that the habitat required for these critical life functions is also protected.

Another important consideration that supports the keying of recommendations to riffles is the fact that riffles are the area of a stream most affected by flow reductions (Bovee 1974, Nelson 1977 and Loar et al. 1985a). By providing a recommendation that wets a large portion of the available riffle area, we are, at the same time, helping to protect both runs and pools - areas where adult fish normally reside.

The wetted perimeter inflection point method provides a range of flows (between the lower and upper inflection points) from which a single instream flow recommendation is selected. Flows below the lower inflection point are judged undesirable based on their probable impacts on food production, bank cover, and spawning and rearing habitats. Flows exceeding the upper inflection point are considered to provide near optimal conditions for fish. The upper and lower inflection points are believed to bracket those flows needed to maintain the high and low levels of aquatic habitat potential. These flow levels are defined as follows:

1. High Level of Aquatic Habitat Potential - That flow regime which will consistently produce abundant, healthy and thriving aquatic populations. In the case of game fish species, these flows would produce abundant game fish populations capable of sustaining a good to excellent sport fishery for the size of stream involved. For rare, threatened or endangered species, flows to accomplish the high level of aquatic habitat maintenance would: 1) provide the high population levels needed to ensure the continued existence of that species, or 2) provide the flow levels above those which would adversely affect the species.
2. Low Level of Aquatic Habitat Potential - Flows to accomplish a low level of aquatic habitat maintenance would provide for only a low population of the species present. In the case of game fish species, a poor sport fishery could still be provided. For rare, threatened or endangered species, their populations would exist at low or marginal levels. In some cases, this flow level would not be sufficient to maintain certain species.

The final flow recommendation is generally selected from this range of flows by a consensus of the biologists who collected and analyzed all relevant field data for the stream of interest. The biologists' rating of the stream resource forms the basis for the flow selection process. Factors considered in the evaluation include: (1) the level of recreational use, (2) the existing level of environmental degradation, (3) water availability and (4) the magnitude and composition of existing fish populations. Fish population information, which is essential for all streams, is a major consideration. A marginal or poor fishery would likely justify a flow recommendation at or near the lower inflection point unless other considerations, such as the presence of species of "special concern" (arctic grayling and cutthroat trout, for example) warrant a higher flow. In general, streams with significant resident fish populations, those providing crucial spawning and/or rearing habitats for migratory populations, and those supporting significant populations of species of "special concern" should be considered for recommendations at or near the upper inflection point.

Other candidates for upper inflection point recommendations are streams that have the capacity to provide outstanding fisheries, but are prevented from reaching their potential due to stream dewatering. The flow at the upper inflection point would provide a goal to strive for should the means become available to improve streamflows through such mechanisms as water storage projects or the purchase of irrigation rights. Streams that are subjected to other forms of environmental degradation, such as mining pollution, and which have the potential to support significant fisheries if reclaimed, are additional candidates for upper inflection point recommendations.

The process of deriving the flow recommendation for the low flow period thus combines a field method (wetted perimeter inflection point method) with a thorough evaluation by field biologists of the existing stream resource.

Brief Description of the Wetted Perimeter (WETP) Computer Program and Data Needs

The wetted perimeter-flow relationship for a stream of interest is derived using a wetted perimeter predictive (WETP) computer program developed in 1980 for the MDFWP.

Two pieces of information - the cross-sectional profile and stage-discharge rating curve - are required for each riffle cross-section as input to the WETP program. These data are obtained in the field using standard surveying procedures.

The stage-discharge rating curve describes the relationship between the height of the water surface (the stage) in the riffle cross-section and the magnitude of the flow (discharge) through the cross-section. This rating curve, when coupled with the cross-sectional profile, is all that is needed to compute the riffle wetted perimeter at most flows of interest.

The WETP program requires at least two sets of stage measurements taken at different known flows to develop the stage-discharge rating curve. However, the use of three sets of stage-discharge data collected at a high, intermediate and low flow is recommended. The three measurements are made when runoff is receding (high flow), near the end of runoff (intermediate flow) and during late summer-early fall (low flow). The high flow should be considerably less than the bankfull flow, while the low flow should approximate the lowest flow that normally occurs during the summer-fall season. Although the WETP program will run using only two sets of stage-discharge data, this practice is not recommended because substantial "two-point" error can result. However, when only two data sets are obtainable, the higher discharge should be at least twice as high as the lower discharge.

The channel profile also has to be measured for each cross-section. Unlike the measurements of water surface elevation, this has to be done only once. It is best to measure profiles at the lowest calibration flow when wading is easiest.

The wetted perimeter method is applied solely to riffles. Cross-sections can be established in a single riffle or in a number of different riffles. Cross-sections should describe the typical riffle habitat within the stream segment being studied. For each riffle, the upper limit is three cross-sections placed at the riffle's head, middle and bottom. Fewer can be used if the riffle is fairly uniform. To be safe, you may want to model two or three separate riffles in each study area. At least three and preferably five riffle cross-sections should be used in the WETP analysis. The WETP program accepts up to 10 cross-sections. The computed wetted perimeters for all riffle cross-sections at each flow of interest are averaged and the recommendation derived from the wetted perimeter-flow relationship for the composite of all riffle cross-sections.

An in-depth description of the WETP computer program and data collection procedures is provided in a publication titled "Guidelines for Using the Wetted Perimeter (WETP) Computer Program of the Montana Department of Fish, Wildlife and Parks" (Nelson 1984a).

MONTANA'S WETTED PERIMETER METHOD - FINAL CONSIDERATIONS

The wetted perimeter method is intended to quantify the flow needs of fish during the non-winter period from approximately April through October, excluding the high flow, or snow runoff, months of May, June and July when about 75% of a stream's annual water yield passes through the system (Figure 1). Flow recommendations for the high flow period should be based on those flows deemed necessary for flushing the annual accumulation of bottom sediments and maintaining the existing channel morphology.

A stream's annual high flow characteristics are generally accepted as being the major force in the establishment and maintenance of channel form. It is the high spring flows that determine the shape of the channel rather than the average or low flows.

The major functions of the high 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 egg 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 surfaces. A significantly altered channel configuration would affect both the abundance and species composition of the present aquatic populations by altering the existing habitat types.

Montana's high flow method, termed the dominant discharge/channel morphology concept (Montana Dept. of Fish and Game 1979), requires at least 10 years of continuous USGS gage records to derive recommendations and, consequently, cannot be applied to most streams. Recommendations from the wetted perimeter inflection point method do not satisfy flushing or channel maintenance requirements. Because most water users, particularly irrigators, are unable to divert a significant portion of the runoff flows and, therefore, are incapable of materially impacting the high flow functions of bedload movement and sediment transport, high flow recommendations may be unnecessary in most cases. Therefore, extending the wetted perimeter recommendations through the high flow period - a common practice of the MDFWP - should not jeopardize the maintenance of adequate high flows for most streams. Furthermore, Montana law limits the granted instream flows for gaged streams to no more than 50% of the average annual flow, thus eliminating flushing and channel maintenance flows from consideration in a reservation application.

As discussed in an earlier section, the protection of natural flow levels during the critical winter months is justified if the goal is to maintain fish populations at their existing levels. As a guideline, the winter recommendation should not be less than the base flow, which is defined as the lowest mean monthly flow during the winter months. Because the vast majority of Montana's waters are ungaged, winter base flows are unquantified for most streams. Past work by the MDFWP has shown that the upper inflection point recommendations of the wetted perimeter method typically exceed base flows (Leathe et al. 1985). Winter flows would, therefore, be protected if upper inflection point recommendations were extended through the winter period. This is a common practice of the MDFWP when recommending flows. Lower inflection point recommendations are normally inadequate for protecting winter base flows.

Regardless of the method used to quantify instream flows, there will be some time periods, especially during drought years, when the recommendations exceed the available flows. Only when the recommendations equal the historic low flows would they never exceed the available water supply. However, such recommendations would devastate a stream fishery if maintained for any length of time and are analogous to asking a farmer to produce his crops using only the amount of water available during the worst drought year on record.

Leathe and Enk (1985) evaluated the amount of time the wetted perimeter recommendations for five gaged, mountain streams in Montana's Swan River drainage exceeded the available streamflows. Year-round, upper inflection point recommendations were found to exceed daily streamflows from 24 to 64% of the time, depending on which of the five streams was evaluated. On the average, recommendations exceeded the available daily flows 41% of the time and, conversely, were less than the daily flows 59% of the time. In other words, excess water would be available for other uses 59% of the time, on the average. Unpublished data for a number of the larger rivers in southwest Montana showed that the wetted perimeter recommendations generally fell within the 60th to 90th percentile range of flows, meaning that the available daily streamflows, even with existing depletions, will still exceed the recommendations from 60 to 90% of the time.

The wetted perimeter inflection point method has primarily been applied in Montana to coldwater trout streams east and west of the Continental Divide. Results of validation studies in Montana support the use of this method in deriving minimum flow recommendations for these waters (Nelson 1980a, 1980b and 1980c and Randolph 1984). The logic behind the method should apply to warmwater streams as well. However, no biological studies have been conducted in Montana to confirm the reliability of warmwater recommendations, although a warmwater evaluation in Oklahoma supported the use of wetted perimeter (Orth and Maughan 1982).

The wetted perimeter method is unsuitable in certain situations. The method is designed for use on stream reaches in which the flow is confined to a single channel, although the application to side channels off of main river channels is a commonly used approach for deriving recommendations for those rivers in which side channels are crucial to the well-being of certain species. When the flow is distributed among many channels, cross-sections through these braided reaches are very difficult to model hydraulically, making most computer models, including WETP, unworkable in this situation. Waters having little or no riffle development, such as cascading mountain streams that plunge from pool to pool and some low gradient, prairie streams, are another exception, as are spring creeks. The stable, year-round flows that characterize spring creeks prevent the collection of field data at a high, medium and low flow - information needed to calibrate the WETP computer program.

LITERATURE CITED

Allen, K.R. 1951. The Horokiwi stream: a study of a trout population. New Zealand Mar. Dept. Fish. Bull. No. 10. 231 pp.

Anderson, R.M. and R.B. Nehring. 1985. Impacts of stream discharge on trout rearing habitat and trout recruitment in the South Platte River, Colorado. Pp. 59-64 in F.W. Olson, R.G. White and R.H. Hamre (eds.), Proceedings of the Symposium on Small Hydropower and Fisheries. Am. Fish. Soc., Bethesda, Maryland. 497 pp.

Annear, T.C. and A.L. Conder. 1983. Evaluation of instream flow methods for use in Wyoming. Completion Report. Fish Division, Wyoming Game and Fish Department, Cheyenne, Wyoming. 248 pp.

Annear, T.C. and A.L. Conder. 1984. Relative bias of several fisheries instream flow methods. North American Journal of Fisheries Management 4:531-539.

Bietz, B.F., J.A. Martin, and J. Englert. 1985. Instream flow needs for fish in Alberta: A user's guide to assessment methods. Alberta Energy and Natural Resources, Fish and Wildlife Division, Edmonton, Alberta. 124 pp.

Boussu, M.F. 1954. Relationship between trout populations and cover on a small stream. J. Wildl. Mgmt. 18:229-239.

Bovee, K.D. 1974. The determination, assessment and design of "instream value" studies for the Northern Great Plains region. Univ. of Montana. Final Report. Contract No. 68-01-2413, Envir. Protection Agency. 204 pp.

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Information Paper 12. U.S. Fish and Wildlife Service, Instream Flow Group, Fort Collins, Colorado. FWS/OBS-82/26. 248 pp.

Bovee, K.D. and R.T. Milhous. 1978. Hydraulic simulation in instream flow studies: Theory and techniques. Instream Flow Information Paper No. 5. U.S. Fish and Wildlife Service. 130 pp.

Briggs, J.C. 1948. The quantitative effects of a dam upon the bottom fauna of a small California stream. Trans. Amer. Fish. Soc. 78:70-81.

Brown, C.J.D. 1971. Fishes of Montana. Big Sky Books, Montana State University, Bozeman, Montana. 207 pp.

Burns, J.W. 1971. The carrying capacity for juvenile salmonids in some northern California streams. Calif. Fish and Game 57(1):44-57.

Butler, R.L. 1979. Anchor ice, its formation and effects on aquatic life. Science in Agriculture, Vol. XXVI, Number 2, Winter, 1979.

Cada, G.F., M.J. Sale, R.M. Cushman, and J.M. Loar. 1983. Field test of a biological assumption of instream flow models. Pp. 1305-1313 in Proceedings of the 1983 International Conference on Hydropower, Volume III.

Campbell, R.F. and J.H. Neuner. 1985. Seasonal and diurnal shifts in habitat utilized by resident rainbow trout in western Washington Cascade Mountain streams. Pp. 39-48 in F.W. Olson, R.G. White, and R.H. Hamre (eds.). Proceedings of the Symposium on Small Hydropower and Fisheries. Am. Fish. Soc., Bethesda, Maryland. 497 pp.

Chapman, D.W. 1966. Food and space as regulators of salmonid populations in streams. Am. Natur. 100:345-357.

Chapman, D.W. and T.C. Bjornn. 1968. Distribution of salmonids in streams, with special reference to food and feeding. Pp. 153-176 in Symposium on Salmon and Trout in Streams, H.R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B.C.

Clancy, C.G. 1985. Inventory and survey of waters of the project area. Job Progress Report, Project No. F-9-R-33, Job I-c, Fed. Aid in Fish and Wildl. Rest. Acts. 44 pp.

Clancy, C.G. 1988. Effects of dewatering on spawning by Yellowstone cutthroat trout in tributaries to the Yellowstone River, Montana. Am. Fish. Soc. Symposium 4:37-41.

Cushman, R.M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. N. Amer. Jour. of Fish. Mgmt. 5:330-339.

Dooley, J.M. 1976. Application of U.S. Bureau of Reclamation Water Surface Profile program (WSP). Pp. 478-495 in J.F. Orsborn and C.H. Allman (eds.), Instream Flow Needs, Volume II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Easterbrooks, J.A. 1981. Response of rainbow and cutthroat to depth reductions in simulated stream channels. Master's thesis, University of Idaho, Moscow, Idaho.

Elliott, J.M. 1973. The food of brown and rainbow trout (Salmo trutta and S. gairdneri) in relation to the abundance of drifting invertebrates in a mountain stream. Oecologia 12:329-347.

Elser, A.A. 1976. Use and reliability of Water Surface Profile program data on a Montana prairie stream. Pp. 496-504 in J.F. Orsborn and C.H. Allman (eds.), Instream Flow Needs, Volume II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Elwood, J.W. and T.F. Waters. 1969. Effects of floods on food consumption and production rates of a stream brook trout population. Trans. Amer. Fish Soc. 98:253-262.

Everest, F.H. and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Bd. Canada 29:91-100.

Fredenberg, W. 1985. South central Montana - fisheries investigations, Bighorn Lake and Bighorn River post-impoundment study. Job Progress Report, Project No. F-20-R-29, Job IV-a, Fed. Aid in Fish and Wildl. Rest. Acts. Montana Dept. of Fish, Wildlife and Parks, Helena, Montana. 80 pp.

Gersich, F.M. and M.A. Brusven. 1981. Insect colonization rates in near-shore regions subjected to hydroelectric power peaking flows. Journal of Freshwater Ecology 1:231-236.

Gibson, R.J. and D. Galbraith. 1975. The relationships between invertebrate drift and salmonid populations in the Matamek River, Quebec, below a lake. Trans. Amer. Fish. Soc. 104:529-535.

Giger, R.D. 1973. Streamflow requirements of salmonids. Job Final Report, Project AFS-62-1, Research Division, Oregon Wildlife Commission, Portland, Oregon. 117 pp.

Gunderson, D.R. 1966. Stream morphology and fish populations in relation to floodplain use. Master's thesis, Montana State University, Bozeman, Montana. 21 pp.

Hall, J.D. and N.J. Knight. 1981. Natural variation in abundance of salmonid populations in streams and its implications for design of impact studies. A review. Prepared for Corvallis Environmental Research Lab, Corvallis, Oregon.

Henry, K.A. 1953. Analysis of factors affecting the production of chum salmon (Oncorhynchus Keta) in Tillamook Bay. Fish Comm. of Oregon Contr. 18. 37 pp.

Hilgert, P. 1981. Evaluation of instream flow methodologies and determination of water quantity needs for stream fisheries in the State of Nebraska. Nebraska Game and Parks Commission, Lincoln, Nebraska. 119 pp.

Hunt, R.L. 1971. Responses of a brook trout population to habitat development in Lawrence Creek. Wisconsin Dept. Nat. Resour. Tech. Bull. No. 48. 35 pp.

Hunt, R.L. 1976. A long-term evaluation of trout habitat development and its relation to improving management-related research. Trans. Amer. Fish. Soc. 105:361-364.

Hynes, H.B.N. 1970. The ecology of running waters. Univ. of Toronto Press, Toronto, Canada. 555 pp.

Kraft, M.E. 1972. Effects of controlled flow reduction on a trout stream. Journal of the Fisheries Research Board of Canada 28:1405-1411.

Kurtz, J. 1980. Fishery management investigations - a study of the upper Green River fishery, Sublette County, Wyoming (1975-1979). Completion Report. Wyoming Game and Fish Department, Cheyenne. 250 pp.

Lamb, B.L. and H. Meshorer. 1983. Comparing instream flow programs: A report on current status. Proceedings of the Conference on Advances in Irrigation and Drainage. American Society of Civil Engineers, Irrigation and Drainage Division, Jackson, Wyoming. July 1983.

Leathe, S.A., S. Bartelt, and L.M. Morris. 1985. Cumulative effects of micro-hydro development on the fisheries of the Swan River drainage, Montana, II: Technical information. Montana Dept. of Fish, Wildlife and Parks, Kalispell, Montana. 106 pp.

Leathe, S.A. and M.D. Enk. 1985. Cumulative effects of micro-hydro development on the fisheries of the Swan River drainage, Montana. I: Summary report. Montana Dept. of Fish, Wildlife and Parks, Kalispell, Montana. 114 pp.

Lewis, S.L. 1969. Physical factors influencing fish populations in pools of a trout stream. Trans. Amer. Fish. Soc. 98:14-19.

Loar, J.M., G.F. Cada, and M.J. Sale. 1985a. Age-specific responses of rainbow trout to naturally occurring low flows in two southern Appalachian streams. Abstract of paper presented to the 115th Annual Meeting of the American Fisheries Society, Sun Valley, Idaho, September 8-12, 1985.

Loar, J.M. and M.J. Sale. 1981. Analysis of environmental issues related to small-scale hydroelectric development. V. Instream flow needs for fishery resources. Environmental Sciences Division, Oak Ridge National Laboratory, Publication No. 1829. 123 pp.

Loar, J.M., M.J. Sale, G.F. Cada, D.K. Cox, R.M. Cushman, G.K. Eddlemon, J.L. Elmore, A.J. Gatz, P. Kanciruk, J.A. Solomon, and D.S. Vaughan. 1985b. Application of habitat evaluation models in southern Appalachian trout streams. ORNL/TM-9323. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 310 pp.

Maciolek, J.A. and P.R. Needham. 1952. Ecological effects of winter conditions on trout and trout foods in Convict Creek, California, 1951. Trans. Amer. Fish. Soc. 81:202-217.

Mason, J.C. 1976. Response of underyearling coho salmon to supplemental feeding in a natural stream. J. Wildl. Mgmt. 40:775-788.

Mason, J.C. and D.W. Chapman. 1965. Significance of early emergence, environmental rearing capacity and behavioral ecology of juvenile coho salmon in stream channels. J. Fish. Res. Bd. Canada 22:173-190.

Mathur, D., W.H. Bason, E.J. Purdy, Jr., and C.A. Silver. 1985. A critique of the Instream Flow Incremental Methodology. Canadian Journal of Fisheries and Aquatic Sciences 42:825-831.

McFadden, J.T. 1969. Dynamics and regulation of salmonid populations in streams. Pp. 313-329 in Symposium on Salmon and Trout in Streams. H.R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B. C.

McKernan, D.C., D.R. Johnson and J.I. Hodges. 1950. Some factors influencing the trends of salmon populations in Oregon. Trans. N. Amer. Wildl. Conf. 15:427-449.

Milhous, R.T., D.L. Wegner, and T. Waddle. 1984. Users guide to the Physical Habitat Simulation System (PHABSIM). Instream Flow Information Paper 11. United States Fish and Wildlife Service, Instream Flow Group, Fort Collins, Colorado. FWS/OBS-81/43, Revised January 1984. 300 pp.

Montana Department of Fish and Game. 1979. Instream flow evaluation for selected streams in the upper Missouri River basin. Montana Dept. of Fish and Game, Helena, Montana. 254 pp.

Montana Department of Fish, Wildlife and Parks. 1984. Handbook for the assessment of small hydroelectric developments: Appendix D. Montana Dept. of Fish, Wildlife and Parks, Helena, Montana.

Moyle, P.B. and D.M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: Developing criteria for instream flow determinations. Trans. Amer. Fish. Soc. 114:695-704.

Murphy, M.L., C.P. Hawkins and N.H. Anderson. 1981 Effects of canopy modification and accumulated sediment on stream communities. Trans. Amer. Fish. Soc. 110:469-478.

Neave, F. 1949. Game fish populations of the Cowichan River. Fish. Res. Bd. Can. Bull. 84. 32 pp.

Neave, F. 1958. Stream ecology and production of anadromous fish. Pp. 43-48 in Symposium on the Investigation of Fish-Power Problems. H.R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B.C.

Neave, F. and W. P. Wickett. 1953. Factors affecting the freshwater development of Pacific salmon in British Columbia. Proc. 7th Pacific Sci. Congr. 4:548-555.

Needham, P.R. 1934. Quantitative studies of stream bottom foods. Trans. Amer. Fish. Soc. 64:238-247.

Needham, P.R. and A.C. Jones. 1959. Flow, temperature, solar radiation, and ice in relation to activities of fishes in Sagehen Creek, California. Ecology 40(3):465-474.

Nehring, R. 1979. Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado. Colorado Division of Wildlife, Fort Collins, Colorado. 144 pp.

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

Nelson, F.A. 1980a. Evaluation of four instream flow methods applied to four trout river in southwest Montana. Montana Dept. of Fish, Wildlife and Parks, 8695 Huffine Lane, Bozeman, Montana. 105 pp.

Nelson, F.A. 1980b. Supplement to evaluation of four instream flow methods applied to four trout river in southwest Montana. Montana Dept. of Fish, Wildlife and Parks, 8695 Huffine Lane, Bozeman, Montana. 105 pp.

Nelson, F.A. 1980c. Evaluation of selected instream flow methods in Montana. Pp. 412-432 in Western Proceedings 60th Annual Conference of the Western Association of fish and Wildlife Agencies. Western Division, American Fisheries Society.

Nelson, F.A. 1984a. Guidelines for using the wetted perimeter (WETP) computer program of the Montana Department of Fish, Wildlife and Parks. Montana Department of Fish, Wildlife and Parks, Bozeman, Montana. Revised July, 1984. 60 pp.

Nelson, F.A. 1984b. Some trout-flow relationships in Montana. Pp. 122-126 in F. Richardson and R.H. Hamre (eds.), Proceedings of the Wild Trout III Symposium. Trout Unlimited, Vienna, Virginia.

Nelson, F. and L. Peterman. 1979. Determination of instream flows in Montana: An action plan. Montana Department of Fish, Wildlife and Parks, Helena, Montana. 64 pp.

Nickelson, T.E. and R.E. Hafele. 1978. Streamflow requirements of salmonids. Proj. AFS-62, Oregon Dept. of Fish and Wildlife, Portland, Oregon. 26 pp.

Orsborn, J.F. and C.H. Allman. 1976. Instream Flow Needs. Volumes I and II. American Fisheries Society, Bethesda, Maryland. 551 and 657 pp.

Orth, D.J. and O.E. Maughan. 1982. Evaluation of the Incremental Methodology for recommending instream flows for fishes. Trans. Amer. Fish. Soc. 111:413-445.

Pearson, L.S., K.R. Conover and R.E. Sams. 1970. Factors affecting the natural rearing of juvenile coho salmon during the summer low flow season. Unpublished manuscript, Fish Commission of Oregon, Portland, Oregon. 64 pp.

Peterman, L.G. 1979. The ecological implications of Yellowstone River flow reservations. Montana Department of Fish, Wildlife and Parks, Helena, Montana. 70 pp.

Peterson, G.R. 1966. The relationship of invertebrate drift abundance to the standing crop of benthic organisms in a small stream. Master's thesis, Univ. of British Columbia, Vancouver, B.C. 39 pp.

Prewitt, C. and C. Carlson. 1979. Evaluation of four instream flow methodologies used on the Yampa and White rivers, Colorado. Department of Fishery Biology, Colorado State University, Fort Collins, Colorado. 65 pp.

Randolph, C.L. 1984. Validity of the wetted-perimeter method for recommending instream flows for rainbow trout in a small stream. Master's thesis, Montana State University, Bozeman, Montana. 95 pp.

Sando, S.K. 1981. The spawning and rearing habitats of rainbow trout and brown trout in two rivers in Montana. Master's thesis, Montana State University, Bozeman, Montana. 67 pp.

Schrader, B. 1985. Fish populations and winter habitat in South Willow Creek, Montana prior to small hydroelectric development. Progress report, Montana Cooperative Fishery Research Unit, Montana State University, Bozeman, Montana. 23 pp.

Seegrist, D.W. and R. Gard. 1972. Effects of floods on trout in Sagehen Creek, California. Trans. Amer. Fish. Soc. 101:478-482.

Spence, L.E. 1975. Guidelines for using Water Surface Profile program to determine instream flow for aquatic life. Montana Department of Fish and Game, Helena, Montana. 32 pp.

Spence, L.E. 1976. WSP - Will it do the job in Montana? Pp. 475-477 in J.F. Orsborn and C.H. Allman (eds.), Instream Flow Needs, Volume II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Stalnaker, C.B. 1979. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. Pp. 321-337 in J. V. Ward and J. A. Stanford (eds.), The Ecology of Regulated Streams. Plenum Press, New York. 398 pp.

Stalnaker, C.B. and J.L. Arnette (editors). 1976. Methodologies for the determination of stream resource flow requirements: An assessment. U.S. Fish and Wildlife Service, Office of Biological Services. 199 pp.

Stewart, P.A. 1970. Physical factors influencing trout density in a small stream. Ph.D. thesis, Colorado State University, Fort Collins, Colorado. 78 pp.

Thompson, K.E. 1972. Determining stream flows for fish life. Pp. 31-50 in Proceedings of the Instream Flow Requirement Workshop. Pacific Northwest River Basins Commission, Portland, Oregon.

Trihey, E.W. and J.E. Baldridge. 1985. An empirical approach for evaluating microhabitat response to streamflow in steep-gradient, large bed-element streams. Pp. 215-222 in F.W. Olson, R.G. White and R.H. Hamre (eds.), Proceedings of the Symposium on Small Hydropower and Fisheries. Am. Fish. Soc., Bethesda, Maryland. 497 pp.

Trihey, E.W. and C.B. Stalnaker. 1985. Evolution and application of instream flow methodologies to small hydropower development: An overview of the issues. Pp. 176-183 in F.W. Olson, R.G. White and R.H. Hamre (eds.), Proceedings of the Symposium on Small Hydropower and Fisheries. Am. Fish. Soc., Bethesda, Maryland. 497 pp.

Trihey, E., and D.L. Wegner. 1981. Field data collection procedures for use with the physical habitat simulation system of the Instream Flow Group. U.S. Fish and Wildlife Service, Instream Flow Group, Fort Collins, Colorado. 151 pp.

Vincent, E.R. 1987. Effects of stocking catchable-size hatchery rainbow trout on two wild trout species in the Madison River and O'Dell Creek, Montana. N. Amer. Jour. of Fish. Mgmt. 7:91-105.

Waters, T.F. 1969. Invertebrate drift - ecology and significance to stream fishes. Pp. 121-134 in Symposium on Salmon and Trout in Streams. H.R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B.C.

Wesche, T.A. 1973. Parametric determination of minimum streamflow for trout. Water Resources Series No. 37, Water Resources Research Institute, University of Wyoming, Laramie, Wyoming.

Wesche, T.A. 1974. Relationships of discharge reductions to available trout habitat for recommending suitable streamflows. Water Resources Series No. 53, Water Resources Research Institute, University of Wyoming, Laramie, Wyoming.

Wesche, T.A. 1980. The WRRI Trout Cover Rating Method: Development and application. Water Resources Series Publication No. 78. Water Resources Research Institute, University of Wyoming, Laramie, Wyoming. 46 pp.

Wesche, T.A. and P.A. Rechard. 1980. A summary of instream flow methods for fisheries and related research needs. Water Resources Institute, University of Wyoming, Laramie, Wyoming. 122 pp.

Wesche, T.A., C.M. Goertler, and C.B. Frye. 1987. Contribution of riparian vegetation to trout cover in streams. N. Amer. Jour. of Fish. Mgmt. 7:151-153.

White, R.G., J.G. Milligan, A.E. Bingham, R.A. Ruediger, T.S. Vogel, and D.H. Bennett. 1981. Effects of reduced stream discharge on fish and aquatic macroinvertebrate populations. Idaho Water and Energy Resources Research Institute, University of Idaho, Moscow, Idaho.

White, R.J., E.A. Hansen and G.R. Alexander. 1976. Relationship of trout abundance to streamflow in midwestern streams. Pp. 597-615 in J.R. Orsborn and C.H. Allman (eds.), Proceedings of the Symposium and Specialty Conference on Instream Flow Needs: Volume II. Western Division of the American Fisheries Society, Bethesda, Maryland.

Wickett, W.P. 1951. The coho salmon population of Nile Creek. Fish. Res. Bd. Canada, Progress Reports 89:88-89.

Wilzbach, M.A. 1985. Relative roles of food abundance and cover in determining the habitat distribution of stream-dwelling cutthroat trout (Salmo clarki). Canadian Journal of Fisheries and Aquatic Sciences 42:1668-1672.

Workman, D.L. 1976. Use of the Water Surface Profile program in determining instream flow needs in Sixteenmile Creek, Montana. Pp. 505-514 in J.F. Orsborn and C.H. Allman (eds.), Instream Flow Needs, Volume II. American Fisheries Society, Bethesda, Maryland. 657 pp.

GUIDELINES FOR USING THE WETTED PERIMETER (WETP) COMPUTER PROGRAM OF THE MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS

By
Frederick A. Nelson
Montana Department of Fish, Wildlife and Parks
1400 South 19th Avenue
Bozeman, Montana 59715

Revised
March, 1989

TABLE OF CONTENTS

INTRODUCTION 1

DERIVING RECOMMENDATIONS USING WETTED PERIMETER 4

DESCRIPTION OF THE WETP PROGRAM 8
Stage Height at Zero Flow 8
Stage-Discharge Data 9
Other Hydraulic Predictions 9

FIELD DATA REQUIREMENTS 10

FIELD METHODS 11
Equipment 11
Selecting Study Areas and Placing Cross-Sections 11
Establishing Bench Marks 13
Surveying Techniques 14
Measuring Water Surface Elevations 14
Measuring Stream Discharges 15
Measuring Cross-Sectional Profiles 15

OFFICE METHODS 17
WETP Data Format 17
Selecting Flows of Interest 17
WETP Data Output 18
Detecting Errors 18
Plotting Wetted Perimeter-Flow Relationships 20

OTHER USES FOR THE WETP OUTPUT 22

FINAL CONSIDERATIONS 26

LITERATURE CITED 27

APPENDICES
A. Calculation of stage height at zero flow (zf) from Rantz (1982)
B. Example of WETP input format
C. Example of WETP data output

INTRODUCTION

The wetted perimeter and flow relationships for selected riffle cross-sections are a useful tool for deriving instream flow recommendations for the rivers and streams of Montana. Wetted perimeter is the distance along the bottom and sides of a channel cross-section in contact with water (Figure 1). As the flow in a stream channel increases, the wetted perimeter also increases, but the rate of gain of wetted perimeter is not constant throughout the entire range of flows. Starting at zero flow, wetted perimeter increases rapidly for small increases in flow up to the point where the stream channel nears its maximum width. Beyond this break or inflection point, the increase of wetted perimeter is less rapid as flow increases. An example of a wetted perimeter-flow relationship showing a well-defined inflection point is given in Figure 2. The instream flow recommendation is selected at or near this inflection point.

The MDFWP developed in 1980 a relatively simple wetted perimeter predictive (WETP) computer model for use in its instream flow program. This model eliminates the relatively complex data collecting and calibrating procedures associated with the hydraulic simulation computer models in current use while providing more accurate and reliable wetted perimeter predictions.

The WETP computer program was written by Dr. Dalton Burkhalter, aquatic consultant, 1429 South 5th Avenue, Bozeman, Montana 59715. The program is written in FORTRAN IV and is located at the computer center, Montana State University, Bozeman. Direct all correspondence concerning the program to Fred Nelson, Montana Department of Fish, Wildlife and Parks, 1400 South 19th Avenue, Bozeman, Montana 59715.

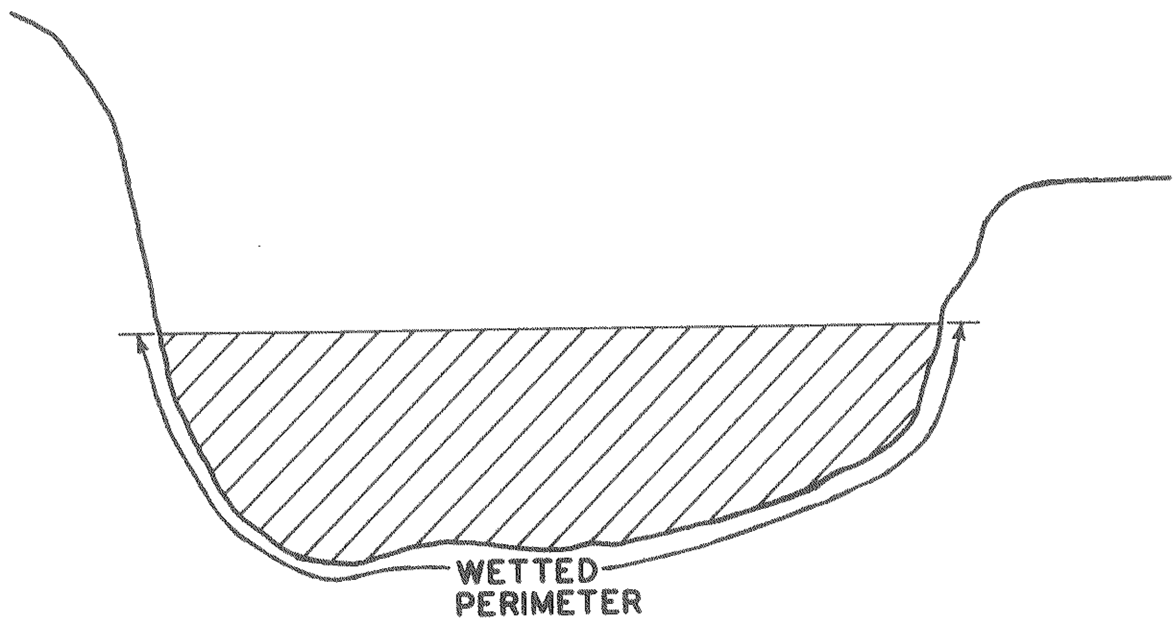


Figure 1. The wetted perimeter in a channel cross-section.

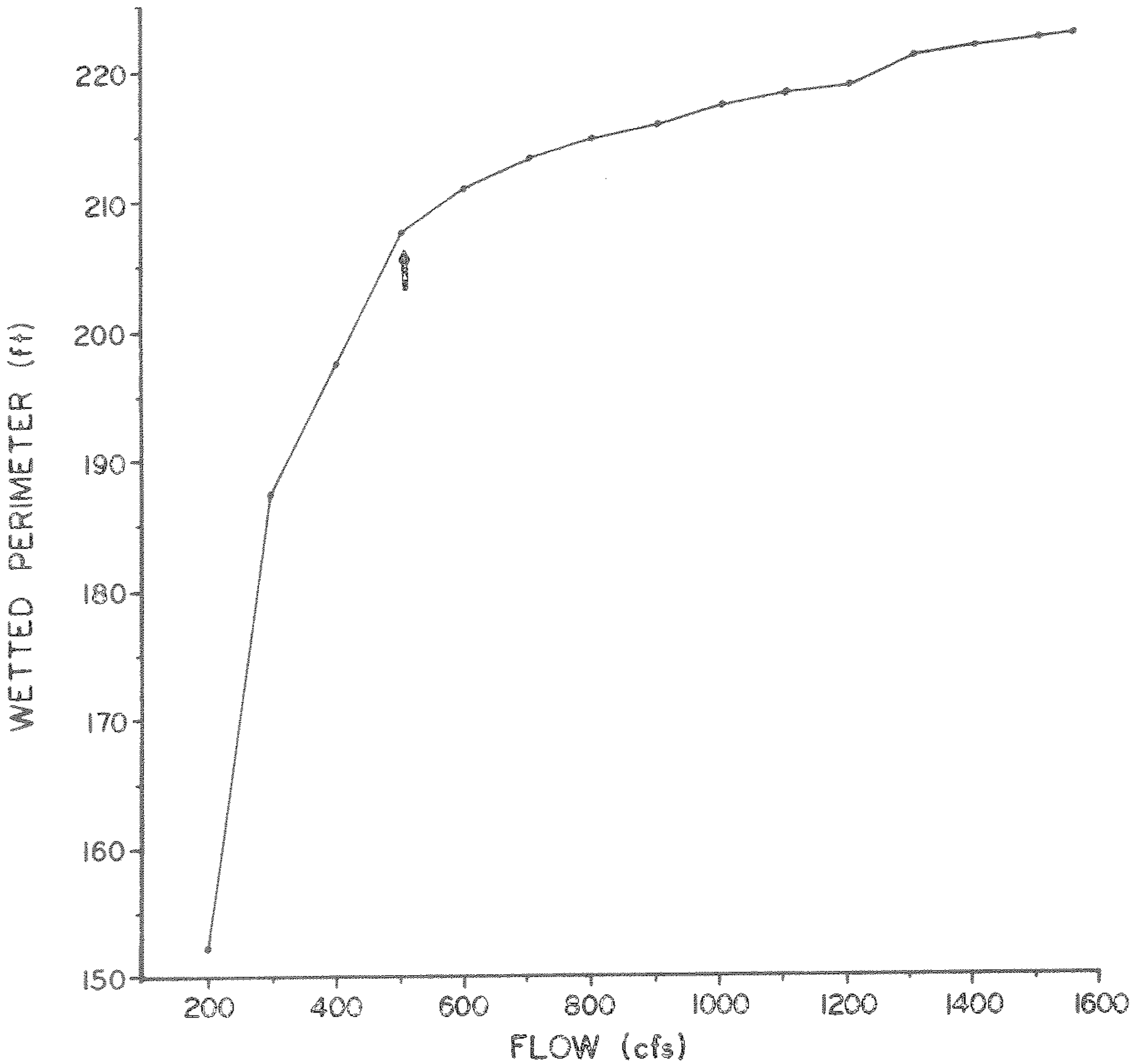


Figure 2. An example of a relationship between wetted perimeter and flow for a riffle cross-section.

DERIVING RECOMMENDATIONS USING WETTED PERIMETER

When formulating flow recommendations for a waterway, the annual flow cycle is generally divided into two separate periods. They consist of a relatively brief runoff or high flow period, when a large percentage of the annual water yield passes through the channel, and a non-runoff or low flow period, which is characterized by relatively stable base flows maintained primarily by groundwater outflows. For headwater rivers and streams, the high flow period generally includes the months of May, June and July, while the remaining months encompass the low flow period.

Method for the Low Flow Period

The wetted perimeter inflection point method is presently the primary method used by the MDFWP for deriving low flow recommendations for rivers and streams. This method is primarily based on the assumption that the food supply is a major factor influencing a stream's carrying capacity (the numbers and pounds of fish that can be maintained indefinitely by the aquatic habitat). The principal food of many of the juvenile and adult game fish inhabiting the streams of Montana is aquatic invertebrates, which are primarily produced in stream riffle areas. The method assumes that the game fish carrying capacity is related to food production, which in turn is related to the wetted perimeter in riffle areas. This method is a slightly modified version of the Washington Method (Collings, 1972 and 1974). The Idaho Method (White and Cochnauer, 1975 and White, 1976) is also based on a similar premise.

The plot of wetted perimeter versus flow for stream riffle cross-sections generally shows two inflection points, the uppermost being the more prominent. In the example (Figure 3), these inflection points occur at approximate flows of 8 and 12 cfs. Beyond the upper inflection point, large changes in flow cause only very small changes in wetted perimeter. The area available for food production is considered near optimal beyond this point. At flows below the upper inflection point, the stream begins to pull away from the riffle bottom until, at the lower inflection point, the rate of loss of wetted perimeter begins to rapidly accelerate. Once flows are reduced below the lower inflection point, the riffle bottom is being exposed at an even greater rate, causing the area available for food production to greatly diminish. The method is intended to establish a threshold below which a stream's food producing capacity begins to decline (upper inflection point) and a threshold at which the loss is judged unacceptable (lower inflection point).

The wetted perimeter-flow relationship may also provide an index of other limiting factors that influence a stream's carrying capacity. One such factor is cover. Cover, or shelter, has long been recognized as one of the basic and essential components of fish habitat. Cover serves as a means for avoiding predators and provides areas of moderate current speed used as resting and holding areas by fish. It is well documented that cover improvements typically increase the carrying capacity of streams, especially for larger-size fish. Cover can be significantly influenced by streamflow.

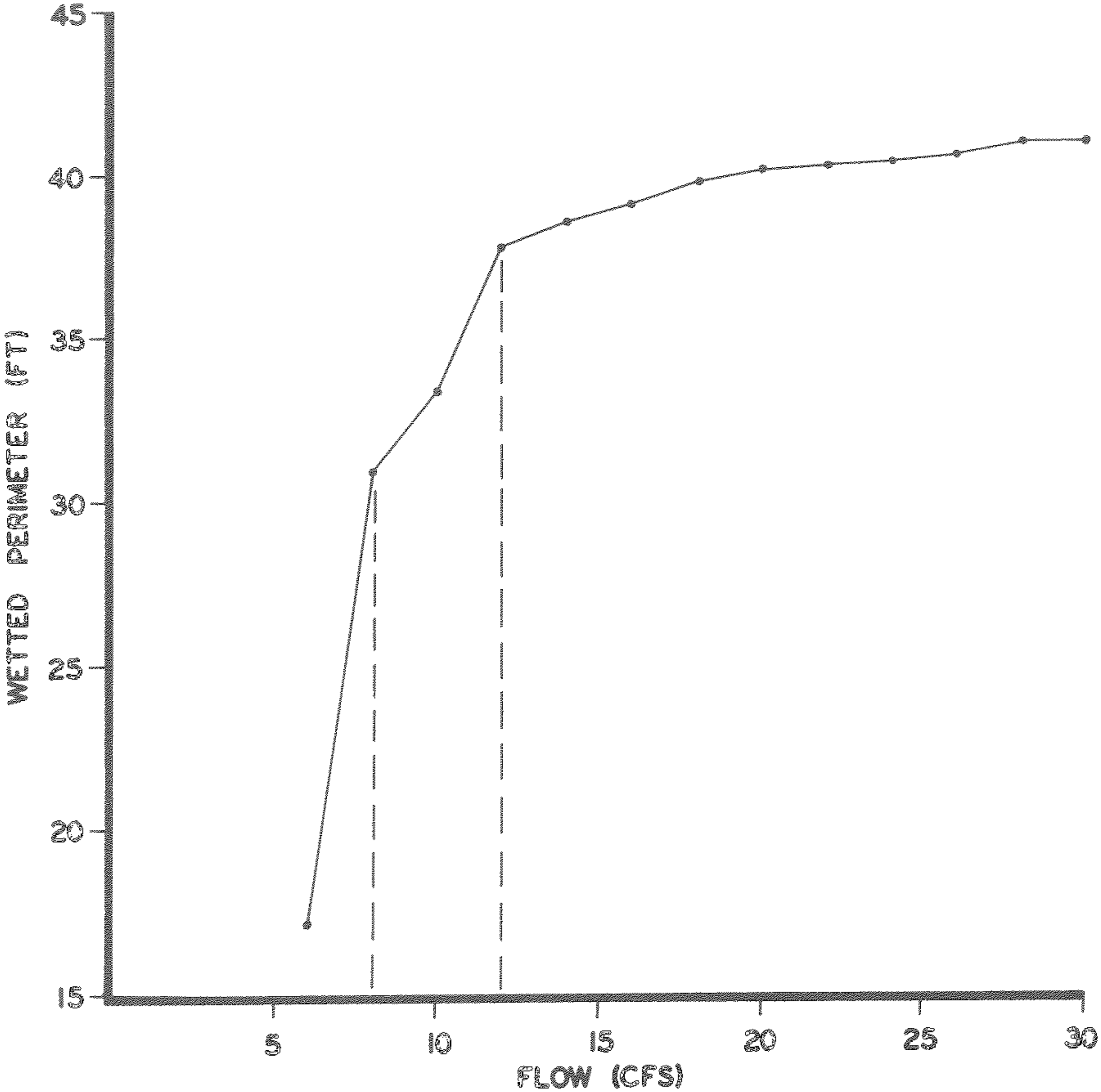


Figure 3. An example of a relationship between wetted perimeter and flow for a riffle cross-section.

In the headwater streams of Montana, overhanging and submerged bank vegetation and undercut banks are often important components of cover. The wetted perimeter-flow relationship for a stream channel may bear some similarity to the relationship between bank cover and flow. At the upper inflection point, the flow begins to pull away from the banks, decreasing the amount of bank cover associated with water. At flows below the lower inflection point, the water is sufficiently removed from the bank cover to severely reduce its value as fish shelter.

Riffles also are used by many game fish species for spawning and the rearing of their young. Thus, the protection of riffles insures that the habitat required for these critical life functions is also protected.

Another important consideration that supports the keying of recommendations to riffles is the fact that riffles are the area of a stream most affected by flow reductions. By providing a recommendation that wets a large portion of the available riffle area, we are, at the same time, helping to protect both runs and pools - areas where adult fish normally reside.

The wetted perimeter inflection point method provides a range of flows (between the lower and upper inflection points) from which a single instream flow recommendation can be selected. Flows below the lower inflection point are judged undesirable based on their probable impacts on food production, bank cover and spawning and rearing habitats, while flows exceeding the upper inflection point are considered to provide a near optimal habitat for fish. The lower and upper inflection points are believed to bracket those flows needed to maintain the low and high levels of aquatic habitat potential. These flow levels are defined as follows:

1. High Level of Aquatic Habitat Potential - That flow regime which will consistently produce abundant, healthy and thriving aquatic populations. In the case of game fish species, these flows would produce abundant game fish populations capable of sustaining a good to excellent sport fishery for the size of stream involved. For rare, threatened or endangered species, flows to accomplish the high level of aquatic habitat maintenance would: 1) provide the high population levels needed to ensure the continued existence of that species, or 2) provide the flow levels above those which would adversely affect the species.

2. Low Level of Aquatic Habitat Potential - Flows to accomplish a low level of aquatic habitat maintenance would provide for only a low population of the species present. In the case of game fish species, a poor sport fishery could still be provided. For rare, threatened or endangered species, their populations would exist at low or marginal levels. In some cases, this flow level would not be sufficient to maintain certain species.

The final flow recommendation is selected from this range of flows by a consensus of the fishery biologists who collected, summarized and analyzed all relevant field data for the streams of interest. The biologist's rating of the stream resource forms the basis of the flow selection process. Factors considered in the evaluation include the level of recreational use, the existing level of environmental degradation, water availability and the magnitude and composition of existing fish populations. The fish population information, which is essential for all streams, is a major consideration. A marginal or poor fishery would likely justify a flow recommendation at or near the lower inflection point unless other considerations, such as the presence of species of special concern (arctic grayling and cutthroat trout, for example), warrant a higher flow. In general, only streams with exceptional resident fish populations or those providing crucial spawning and/or rearing habitats for migratory populations would be considered for a recommendation at or near the upper inflection point. The process of deriving the flow recommendation for the low flow period thus combines a field method (wetted perimeter inflection point method) with a thorough evaluation by a field biologist of the existing stream resource.

A publication of the MDFWP (Leathe and Nelson, 1989) provides an up-to-date synopsis of the history of the wetted perimeter inflection point method, examines its theoretical and experimental basis, identifies its strengths and weaknesses as compared to other available methods, and provides a justification for its use in Montana. Refer to this publication to further explain the method.

DESCRIPTION OF THE WETP PROGRAM

The WETP program uses 2 to 10 sets of stage (water surface elevation) measurements taken at different known discharges (flows) to establish a rating curve. This curve has the equation, $Q = p(S - zf)^n$ where:

Q = discharge
S = stage height
zf = stage height at zero flow
p = a constant
n = a constant exponent.

The relationship of measured points, if perfect, would plot as a straight line on log-log paper with n equal to the slope of the line and p equal to the discharge when $(S - zf) = 1$. The actual line is determined by least squares regression using the measured points. Once the stage-discharge rating curve for each cross-section is determined, the stage at a flow of interest can be predicted. This rating curve, when coupled with the cross-sectional profile, is all that is needed to predict the wetted perimeter at most flows of interest.

Stage Height at Zero Flow

The stage height at zero flow (zf) may be taken as the lowest elevation in the cross-sectional profile for riffles but is more difficult to determine for non-riffles, particularly pools, in which case the procedures of Rantz (1982) should be consulted. The applicable portions of that paper are included in Appendix A.

The zf value for a non-riffle cross-section can also be measured in the field. It is the elevation of the thalweg (as referenced to the bench mark elevation) at the downstream control, which is typically the head of a riffle. The control is a channel feature that causes water to back up in an upstream direction.

The value of zf is controlled by use of an option record (OPTS) in the input data. If the option is set to one, zf is either set to a value supplied by the user or, in the absence of a supplied value, zf is automatically set to the lowest elevation in the cross-sectional profile. If the user does not want zf to equal the lowest elevation in the cross-sectional profile, the values for zf are entered on the XSEC records. The option record must be the first entry in the data file and is illustrated in Appendices B and C.

The option of setting zf to zero by setting the option record to zero is also available. All results for an earlier version of the WETP program were obtained with zf automatically set to zero. Option zero is included solely for the purpose of comparing results. Because the program now incorporates zf into the calculations, the accuracy of the hydraulic predictions for those flows of interest that are less than the lowest measured calibration flow should improve over calculations previously made with zf = 0.

Stage-Discharge Data

The program should be run using three sets of stage-discharge data collected at a high, intermediate and low flow. Additional data sets are desirable, but not mandatory. The three measurements are made when runoff is receding (high flow), near the end of runoff (intermediate flow) and during late summer-early fall (low flow). The high flow should be considerably less than the bankfull flow, while the low flow should approximate the lowest flow that normally occurs during the summer-fall field season. Sufficient spread between the highest and lowest calibration flows is needed for the program to compute a linear, sloping rating curve.

The WETP program will run using two sets of stage-discharge data. This practice is not recommended due to the potential for "two point" error. At times, however, only two points are obtainable and must be used in the derivation. Bovee and Milhous (1978) concluded that two points can be used effectively if done with care. To minimize "two point" error, they recommend that the calculations incorporate the stage at zero flow (zf) and that the higher calibration flow be at least twice as high as the lower one. They further concluded that the limit of reliability could be approached with only two data points, provided strict limitations were placed on the range of extrapolation. While the findings of the above authors remove some of the uncertainty associated with the use of two-point rating curves, abiding by their recommendations does not guarantee that "two-point" error will be eliminated in all cases.

Other Hydraulic Predictions

In addition to wetted perimeter (WETP), the program also predicts other hydraulic characteristics that may be useful in deriving flow recommendations. These are the mean depth (DBAR) in ft, mean velocity (VBAR) in ft/sec, top width (WDTH) in ft, cross-sectional area (AREA) in ft^2, stage (STGE) in ft, and maximum depth (DMAX) in ft.

A useful program option, termed the width-at-given-depth (WAGD) option, will calculate for up to 10 given depths the width (in ft) and percentage of the top width having depths greater than or equal to the given values. The width and percentage of the longest, continuous segment having the required depths is also listed for each flow of interest. This option is illustrated in Appendices B and C.

FIELD DATA REQUIREMENTS

The required inputs to the WETP program for each cross-section are:

1. Three sets of stage-discharge data measured at a high, intermediate and low flow. The stage height at zero flow (zf) is mandatory only when non-riffles are modeled.

2. The cross-sectional profile, which consists of channel elevations (vertical distances) and the horizontal distance of each elevation measurement from the headstake (zero point).

The following are needed to document field work:

1. Slides or photographs of the study area and cross-sections at the time field data are collected.

2. Field notebooks containing all surveying data, notes and calculations recorded in a neat, consistent manner.

FIELD METHODS

Equipment

1. A self-leveling or automatic level such as a Wild NAK1.

2. 25-ft, telescoping, fiberglass level rod.

3. 50-500 ft canyon line or other measuring tape. Tape should be calibrated to 0.1 ft.

4. Rebar cut in 30-inch pieces (stakes). Two stakes are needed per cross-section.

5. Two clamps (modified vise grips with flat jaws).

6. Engineers field notebook.

7. Pencils.

8. Current meter and rod, stopwatch and beeper box. Gurley or Price AA current meters are preferred.

9. Small sledge hammer.

10. Camera.

11. Fluorescent spray paint and flagging.

12. Forms for recording stream discharges and cross-sectional profiles.

13. A rod fitted with a porcelain, enameled, iron gage (Part No. 15405, Leupold and Stevens, Inc., P. O. Box 688, Beaverton, Oregon 97075) for measuring water depths. A current meter rod can be substituted.

14. Machete and tree pruner for trimming vegetation.

Selecting Study Areas and Placing Cross-Sections

Follow these guidelines when selecting study areas and placing cross-sections.

1. It is best to locate study areas and stake cross-sections during low water prior to the onset of runoff. A good time is the fall when flows are low, most waters are easily waded, and riffles are readily discernible. It will be difficult to select these sites during the high water period when data collection begins.

2. The selected study area is normally located near the stream's mouth. The study area is not intended to represent the channel form and flow regime that occur throughout the designated stream reach, which, in

the case of the smaller streams, typically encompasses the entire stream length between the headwaters and mouth. With this approach, the reach boundaries serve merely to identify those junior water users who will be subject to the instream right or reservation, which is monitored at or near the stream's mouth. Should the flow at this site fall below the granted instream flow, then all junior users within the designated reach must cease withdrawing water until the flow recovers. All upstream users are, thus, keying to a flow that is measured on the lower stream. Having similar flow regimes and channel configurations at the upper and lower reach boundaries are not required with this approach.

Designating only one reach is generally unacceptable for the larger waterways. Here, a limited number of reaches must be established using reasonable and defensible boundaries, such as major tributary inflows and dams. For example, the Madison River has four designated reaches: 1) Yellowstone Park boundary - Hebgen Reservoir, 2) Hebgen Dam - junction of the West Fork, 3) junction of the West Fork - Ennis Reservoir, and 4) Ennis Dam - mouth. Each reach may well encompass areas having a similar flow regime and channel configuration, although this is not a reach requirement. Again, the reach merely identifies those junior users who are subject to the granted instream right or reservation.

3. Place the cross-sections in riffles if the wetted perimeter inflection point method is used to derive recommendations. Cross-sections can be placed in a single riffle or a number of different riffles. Cross-sections should describe the typical riffle habitats within the stream segment being studied. Other critical habitat types can also be used, depending on your chosen method.

   For a particular riffle, the upper limit is three cross-sections placed at the riffle's head, middle and tail. Fewer can be used if the riffle is fairly uniform. To be safe, you may want to model two or three separate riffles in each study area. We recommend using at least three and preferably five riffle cross-sections when deriving the wetted perimeter-flow relationship for each study area. The WETP program accepts up to 10 cross-sections per study area.

   Theoretically, one strategically placed cross-section could effectively model the "typical" riffle habitat within a study area. More cross-sections (up to 5) are recommended under the assumption that this will result in a more accurate end product. The ability of the biologist to exercise good judgment is the crucial element when placing cross-sections to model a stream's riffle habitat.

4. The WETP model assumes that the water surface elevations at the water's edge on the left bank (WEL) and right bank (WER) of a cross-section are always equal at a requested flow. This is a valid assumption because the water surface elevations at WEL and WER generally remain within 0.1 ft of each other as the flow changes, provided the water surface elevations at WEL and WER were matched when the cross-section was established. Avoid placing cross-sections in areas where this assumption is likely to be violated, such as

sharp bends in rivers and multiple channels containing islands. If cross-sections through these areas are unavoidable, you should proceed with caution.

5. Place the headstake marking each cross-section well up on the bank. Drive the headstake almost flush with the ground and mark well. In addition to marking the cross-section and providing a fixed reference point for establishing elevations, the headstake is also your zero reference point for measuring horizontal distances across the cross-section. Headstakes for all the cross-sections within a study area should be located on the same bank.

   Another stake is driven on the bank opposite the headstake. Place this stake so that the water surface elevations at the WEL and WER of the established cross-section are equal or similar (within 0.05 ft). This will require the use of a level and level rod. This stake is used to mark the cross-section on the bank opposite the headstake and also to attach the measuring tape when the channel profile is measured, so should not be driven to ground level. Cross-sections, when established, should be roughly perpendicular to the banks. Eliminate all diagonal cross-sections.

6. Number the cross-sections consecutively from downstream to upstream (the downstream-most cross-section is #1).

7. Measure the distances between cross-sections. This is an optional measurement that might be useful in locating cross-sections during return trips.

8. Remember, the WETP model is invalidated if channel changes occur in the study area during data collection. For this reason, all field measurements should be completed during the period beginning when runoff is receding and ending with the onset of runoff the following year. The stream channel is expected to be stable during this period.

9. Over winter, headstakes can frost heave, changing their elevations. This is an important reason for completing all field measurements during the summer-fall period. However, this does not prevent you from placing your headstakes and establishing your cross-sections in fall and starting your measurements the following summer when runoff is receding.

Establishing Bench Marks

Establish a bench mark at or near your study area. The bench mark is a point that will not be disturbed or moved. A nail driven into the base of a tree, a fixed spot on a bridge abutment and a survey stake driven into the ground are examples of bench marks. Designating one of the cross-sectional headstakes within a study area as the bench mark is an acceptable practice, provided all field measurements are completed before the onset of winter. Bench marks should be well marked in the field and their locations described in your field notebook so they can be easily located during return trips. All channel and water surface elevations are established relative to the bench mark, which is assigned an elevation of 100.00 or 10.00 ft. Use 10.00 ft whenever possible.

For streams having "heavy" vegetative cover, the use of a single bench mark may not be practical. In this case, the individual headstakes can serve as bench marks. For example, the headstake for cross-section #1 could serve as the bench mark for cross-sections #1 and 2, while the headstake for cross-section #3 could serve as the bench mark for cross-sections #3, 4 and 5. Each headstake could also serve as the bench mark for that individual cross-section. While this is not the best surveying technique, certain stream reaches may require its use. Be sure to carefully record in your notebook which headstakes are used as bench marks to avoid confusion and errors on return trips.

Remember, channel and water surface elevations for all cross-sections within a study area do not have to be tied to a single bench mark for the WETP program to run properly. However, the use of a single bench mark demonstrates good field technique.

Surveying Techniques

The reader is referred to Spence (1975) and Bovee and Milhous (1978) for a discussion of the surveying techniques used to measure cross-sectional profiles and water surface elevations. Both papers should be read by those unfamiliar with the mechanics of surveying. All investigators must receive field training before attempting any measurements.

It is important to be consistent and to use good technique when collecting and recording data. Record all data in your notebook and complete all calculations while in the field, so that any surveying errors can be detected and corrected. Remember, your field notebooks may be examined in court or hearing proceedings. Good quality equipment such as an automatic level is also an asset.

Measuring Water Surface Elevations (Stages)

Water surface elevations should be measured for each cross-section at three different flows. If cross-sections are established prior to runoff (this practice is recommended), you must return to the study area at least three more times; when runoff is receding (high flow), near the end of runoff (intermediate flow) and during late summer or early fall (low flow).

It is unnecessary to collect surface elevation measurements for all of the cross-sections within a study area at the same flows. For example, if another cross-section is added to the study area at a later date, the calibration flows for this new cross-section do not have to match those for the other cross-sections. It is also unnecessary to have the same number of calibration flows for all of the cross-sections within a study area.

Water surface elevations are measured at the water's edge directly opposite the stake marking the cross-section on each bank. Visually line up the points (WEL and WER) in the cross-section where surface elevations will be measured. The stretching of a tape across the cross-section is unnecessary because the horizontal distances from the headstake to the WEL and WER are not needed. Measure water surface elevations to the nearest 0.01 ft. The mechanics of this measurement are discussed in Bovee and Milhous (1978). Once water surface elevations are calculated, repeat the measurements to check for surveying errors. If all cross-sections are tied to a single bench mark, water surface elevations should increase as the cross-sections progress upstream.

As previously discussed, the WETP model assumes that the water surface elevations at WEL and WER are always equal at a selected flow of interest. In a stream channel, the surface elevations at the WEL and WER of a cross-section should remain fairly equal as the flow varies, provided the elevations at WEL and WER were matched when the cross-section was established. Consequently, it is necessary to measure the water surface elevations at both WEL and WER during all return trips to verify this assumption. These two measurements should always be within approximately 0.1 ft of one another. For the larger waterways, a greater difference is allowable. Average these two measurements to obtain the water surface elevation that is entered on the coding sheets.

<u>Measuring Stream Discharges</u>

The flow through the study area must be measured each time water surface elevations are determined. On the larger waterways, it is best to locate study areas near USGS gage stations to eliminate a discharge measurement.

Use standard USGS methods when measuring discharges. Publications of Bovee and Milhous (1978), Buchanan and Somers (1969), and Smoot and Novak (1968) describe these methods and provide information on the maintenance of current meters. Read these publications before attempting any discharge measurements. Field training by USGS personnel is also mandatory.

<u>Measuring Cross-Sectional Profiles</u>

The channel profile has to be determined for each cross-section. Unlike the measurement of water surface elevations, this has to be done only <u>once</u>. It is best to measure profiles at the lowest calibration flow when wading is easiest. For the unwadable, larger waterways that require the use of a boat, profiles are best measured at the intermediate calibration flow.

For wadable streams, a measuring tape is stretched across the cross-section with the zero point set on top of the headstake. Setting the headstake at zero, while not mandatory, is a good practice that provides consistency in your field technique. Never attach the tape directly to the headstake. The tape is attached with a vise grip to a stake that is driven behind the headstake. A vise grip can be attached directly to the stake on the opposite bank to stretch and hold the tape in place.

Elevations are now measured between the headstake and water's edge using your level and level rod. Elevations are measured at major breaks in the contour. The horizontal distance of each elevation measurement from the headstake (zero point) is also recorded. Elevations are also measured between the water's edge at the opposite bank and the opposite stake and the horizontal distance from the headstake recorded for each measurement. Elevations of the exposed portions of instream rocks and boulders are also measured in this manner. Measure elevations to the nearest 0.01 ft and horizontal distances to the nearest 0.1 ft.

Be sure to collect profile measurements for points well above the water's edge. It is a good practice, although not mandatory, to begin at the headstake (distance of 0.0 ft) and end at the stake on the opposite bank. Remember, the highest elevations on both banks of the cross-sectional profile must be substantially higher than the stage at the highest calibration flow if predictions are to be made for flows of interest that exceed the highest calibration flow.

For small streams having a smooth bottom and little depth, the entire profile can be surveyed using your level and level rod. For larger streams, a different approach involving the measurement of water depths is used to determine the profile of the segment of the cross-section that contains water. Water depth is measured using a current meter rod or a rod fitted with a porcelain, enameled, iron gage. Do not use your level rod. (Prolonged use of your level rod in water ruins the foot markings on the rod.) Measure depths at all major breaks in the bottom contour. Generally, 30 or more depth measurements are needed for streams and creeks. Measure depths to the nearest 0.05 ft (current meter rod) or 0.01 ft (rod fitted with gage). For each depth measurement, record the horizontal distance from the headstake (zero point). The bottom elevation at each distance from the headstake is determined by subtracting the water depth from the water surface elevation (average for WEL and WER). For example, if the average water surface elevation is 9.26 ft and at 10.2 ft from the headstake the water depth is 0.40 ft, then the bottom elevation at this distance is 8.86 ft (9.26 ft minus 0.40 ft). Elevations for all points covered by water are calculated in this manner.

For the unwadable, larger waterways, cross-sectional profiles are measured using a boat, depth recorder and range finder. Graham and Penkal (1978) describe this technique.

The WETP program will handle vertical banks. When recording these data, the horizontal distance from the headstake to both the top and bottom of the vertical will be the same, but the elevations will be different.

The program <u>will not</u> handle undercut banks. These data have to be adjusted before being entered on the coding sheets. The best method is to treat undercuts as vertical banks. To accomplish this, the horizontal distance from the headstake to the top of the undercut is substituted for the horizontal distance to the bottom of the undercut, creating a vertical bank.

The program will handle islands, bars and multiple channels, provided the water surface elevations at all the water's edges in the cross-section remain relatively equal as the total stream flow changes. Because this is unlikely, these areas should be avoided when establishing cross-sections.

OFFICE METHODS

WETP Data Format

An example describing the WETP format is given in Appendix B. Much of the format is self-explanatory. Carefully examine this example and the explanatory notations before entering your data on the coding sheets.

The five cross-sections in the example were located in riffles. The stage height at zero flow (zf) was therefore set to the lowest elevation in the cross-sectional profile for each.

All elevations in the example were keyed to a single bench mark, which was assigned an elevation of 100.00 ft for illustration only. A bench mark elevation of 10.00 ft would be more appropriate and should be used whenever possible.

Enter the WETP data on the coding sheets in the following manner:

1. Flows of interest (up to 100 flows are accepted by the program)

   Integers in cfs or with decimal points (not to exceed six characters, including decimal point if used)

2. Cross-sectional profile (up to 150 sets of measurements are accepted)

   Distances from headstake - nearest 0.1 ft
   Channel elevations - nearest 0.01 ft

3. Stage-discharge data (2 to 10 sets of measurements are accepted)

   Stages (water surface elevations) - nearest 0.01 ft
   Discharges (flows) - nearest 0.1 cfs

4. Stage height at zero flow (zf) (one for each non-riffle cross-section)

   zf - nearest 0.01 ft

If the cross-sectional profile, stage-discharge and zf data are entered as described above, decimal points are not needed. However, decimal points can be used if desired.

Selecting Flows of Interest

You will be extrapolating data for flows of interest that are less than the lowest measured calibration flow for a particular cross-section. The extrapolation of data beyond the highest calibration flow is a less desirable option because our main interest is to derive minimum flow recommendations. Remember, the stage-discharge rating curve generally flattens out at extremely high (above bankfull) and extremely low flows.

At these flows, the predicted stages from the measured rating curve are questionable and could lead to inaccurate hydraulic predictions.

Bovee and Milhous (1978) recommend the following limits when selecting flows of interest:

1. Two point stage-discharge rating curve

   Hydraulic predictions should not be made for flows that are less than 0.77 times the minimum measured flow, nor for flows higher than 1.3 times the maximum measured flow.

2. Three point (or greater) stage-discharge rating curve

   Hydraulic predictions should not be made for flows that are less than 0.4 times the minimum measured flow, nor for flows higher than 2.5 times the maximum measured flow.

These are only guidelines, not hard and fast rules. Common sense, rather than the strict adherence to a suggested guideline, should govern the extent of your extrapolations.

<u>WETP Data Output</u>

The output for the input example in Appendix B is given in Appendix C. Carefully examine this output.

<u>Detecting Errors</u>

Practicing good technique when surveying cross-sections and measuring flows will eliminate errors (except data entry and coding errors) in your WETP input and lead to reliable hydraulic predictions at the requested flows of interest. Despite precautions, errors can go undetected. However, most will become evident when you examine your printouts and do the following:

1. Check for data entry errors

   Carefully proof the profile and stage-discharge data on the printouts to detect errors made by the data entry people. Few printouts are without these errors. Format and recording errors on the coding sheets are other major causes for errors in the profile and stage-discharge data.

2. Check for error messages

   The vast majority of error messages that occasionally appear on the printouts are the result of format errors on the coding sheets. In general, these are easily corrected before the printout is sent to the cooperator.

   An error message will appear when predictions are requested for flows of interest having stages that are higher than the highest elevations in the cross-sectional profile. Additional profile measurements collected higher up on the banks will correct this problem if deemed necessary.

3. Examine the cross-sectional profiles

Look for sudden elevation decreases in the cross-sectional profiles. For example, elevations that suddenly drop from 7.42 ft to 5.35 ft then jump to 7.36 ft are suspect. Sudden elevation increases are also suspect. These, however, could reflect large rocks within the cross-sectional profile.

4. Examine the r^2 values

If the r^2 value for a stage-discharge rating curve is less than approximately 0.90, the cross-section should be eliminated from the analysis. Low r^2 values may be due to errors, so recheck the stage and discharge measurements before eliminating these cross-sections. A faulty discharge calculation may be the culprit. For those cross-sections having only two sets of stage-discharge measurements (remember, this practice is not recommended), r^2 values are automatically 1.000 and, consequently, of no use in assessing the reliability of the hydraulic predictions.

Near perfect r^2 values (>0.96) are the norm. If your values are not consistently 0.96 or higher, your surveying and discharge measuring skills need improving.

5. Examine the stages

At each calibration flow, the measured stage (water surface elevation) should <u>increase</u> as the cross-sections progress upstream, provided all cross-sections are keyed to the same bench mark. If a decrease occurs (i.e., water is flowing uphill), errors are present. For example, the stages for cross-sections 1, 2, 3, 4 and 5 at the calibration flow of 23.8 cfs are 4.87, 5.23, 5.36, 6.53 and 5.96 ft, respectively. All stages for cross-sections 4 and 5 need rechecking to determine which cross-section is incorrect. If errors cannot be found, eliminate the offending cross-sections. Allowing such errors to go undetected in the field is indicative of shoddy technique.

For each cross-section, calculate the increase of the measured stage between the low and intermediate calibration flows and the intermediate and high calibration flows. Increases should be similar for all riffle cross-sections. For example, if the stage between the low and intermediate calibration flows for riffle cross-sections 1, 2, 3, 4 and 5 increases by 0.31, 0.22, 0.20, 0.24 and 0.94 ft, respectively, stage measurements for cross-section 5 should be rechecked. If an error is not found, eliminate cross-section 5 from the analysis.

6. Compare the stages to the cross-sectional profile

   For each cross-section, compare the measured stages at the calibration flows to the elevations in the cross-sectional profile to see if the stages and profile elevations are "in line." For example, the stages for a riffle cross-section in a small stream are around 4 ft and the lower elevations in the profile are about 1 ft. The magnitude of this difference (3 ft) indicates errors.

7. Examine the zf values

   The zf value, taken as the lowest elevation in the cross-sectional profile for riffles, should generally increase as the riffle cross-sections progress upstream, provided all cross-sections are keyed to the same bench mark. If an upstream riffle cross-section has a zf value that is significantly less than that of its downstream neighbor, the accuracy of the profile is suspect. A recording or data entry error is often responsible. For example, a profile elevation of 4.94 ft is entered as .94 ft, causing the zf value to be excessively low.

8. Compare measurements to predictions

   Include the flow at which you measured cross-sectional profiles as one of your requested flows of interest. At this flow, your field measurements will include the top width (WDTH), maximum depth (DMAX) and stage (STGE) for each cross-section. On the printout, compare these measured values to the predictions. If the measured and predicted values are dissimilar, errors are present.

9. Compare predictions for all cross-sections

   Compare the hydraulic predictions for all riffle cross-sections at one of the lower flows of interest to see if the predictions are similar. For example, at a flow of 5.0 cfs the predicted wetted perimeters for riffle cross-sections 1, 2, 3, 4 and 5 are 4.23, 19.74, 18.62, 16.72 and 23.49 ft, respectively. The value for cross-section 1 is out of line with the others and, consequently, is suspect.

<u>Plotting Wetted Perimeter-Flow Relationships</u>

The computed wetted perimeters for all riffle cross-sections at each flow of interest are averaged and the flow recommendation is selected from the plot of average wetted perimeter versus flow. Average wetted perimeters are listed in the far right column on the printouts.

As a general guideline when plotting wetted perimeter-flow relationships for mountain streams, the flows on the x axis should extend a little beyond the stream's average annual flow. Because the inflection points typically fall well below the average annual flow, extending the plot far beyond this point is unnecessary. The limit of the lower flow is a judgment decision based on how comfortable you are with your data extrapolations.

You may have to change the scale on your plots a number of times to better define the inflection points. Do not be concerned if a lower inflection point is not discernible on your final plot. If it is not evident, simply state so in the narrative. The uppermost point, which is far more useful when deriving most recommendations, is typically well-defined for riffles and easily located on the plots. A department computer program that calculates changes in slope on the wetted perimeter-flow curves is available to aid in selecting inflection points if needed.

If the upper inflection point flow on the composite plot is, in your judgment, too high relative to water availability, you should plot the individual wetted perimeter-flow relationships comprising the composite to see if any single relationship is overly influencing the composite. This could be the cause of a "high" recommendation. You may choose to remove the offending cross-section from the composite.

As a general guideline, upper inflection point flows for mountain streams equal, on average, about 40% of the average annual flow. The percentage can vary considerably for individual streams, commonly ranging between 25 and 75%.

OTHER USES FOR THE WETP OUTPUT

The wetted perimeter inflection point method, as previously described, is the primary method the MDFWP is presently using to derive instream flow recommendations for the waterways of Montana. The WETP program and output can also be used in other ways for deriving recommendations. Some of these uses are discussed in the following examples.

Passage of Migratory Trout

Many streams provide important spawning and rearing habitats for migratory salmonids. Sufficient stream flows are needed not only to maintain spawning and rearing habitats, but also to pass adults through shallow riffle areas and other natural barriers while moving to their upstream spawning sites.

Trout passage criteria relating to stream depth have been developed in Oregon and Colorado (Table 1). These criteria, when used in conjunction with the WETP output for critical riffles, can be used to derive minimum passage flows. For example, passage criteria developed by the Colorado Division of Wildlife for streams 20 ft and wider indicate that the minimum average depth needed to pass trout through riffles is 0.5-0.6 ft. The output for the Tobacco River (Table 2) shows that the average depth for all five riffle cross-sections exceeds 0.5 ft, the approximate minimum average depth required for passage, at a flow of 120 cfs. A flow of at least 120 cfs is therefore recommended during the spawning period to facilitate the passage of adult trout to upstream spawning areas.

Table 1. Trout passage criteria (from Wesche and Rechard, 1980).

Species	Source	Minimum Depth (ft)	Average Depth (ft)	Where Developed
Large Trout ≥20 inches	Thompson 1972	0.6	--	Oregon
Other Trout <20 inches	Thompson 1972	0.4	--	Oregon
Trout (on streams 20 ft or greater)	Colo. Div. of Wild. 1976	--	0.5-0.6 across riffles	Colorado
Trout (on streams 10-20 ft wide)	Colo. Div. of Wild. 1976	--	0.2-0.4 across riffles	Colorado

Table 2. Average depths for five riffle cross-sections in the Tobacco River, Montana, at selected flows of interest. Average depths were derived using the WETP computer program.

	Average Depth (ft)				
Flow (cfs)	Riffle cs #1	Riffle cs #2	Riffle cs #3	Riffle cs #4	Riffle cs #5
100	.44	.65	.79	.68	.47
110	.49	.69	.85	.72	.52
120	.54	.73	.91	.75	.57

The minimum depth criteria developed in Oregon could also be used in conjunction with the WAGD option of the WETP program to derive passage recommendations. For this evaluation, criteria are developed requiring at least a certain percentage of the top width of a cross-section to have water depths greater than or equal to the minimum needed for fish passage. In Oregon, at least 25% of the top width and a continuous portion equaling at least 10% of the top width are used (Thompson, 1972). The flow that satisfies these criteria for all cross-sections is recommended.

Goose Nesting Requirement

The maintenance of adequate flows around islands selected by Canada geese for nesting is necessary to insure that the nests are protected from mammalian predators. Under low flows, predators have easy access to the islands and can significantly reduce goose production. The security of the islands is a primary factor in their selection as nest sites by geese. This security is provided by adequate side channel flows, which are a function of depth, width, and velocity. Because wetted perimeter is a function of both width and depth, its relationship to discharge may be the best indicator of the minimum flows that are needed to maintain secure nesting islands.

The wetted perimeter inflection point method is applied to the shallowest area of the side channel bordering each nesting island. A wetted perimeter-side channel discharge curve is generated for each cross-section and the inflection point determined. A curve correlating the side channel flow to the total river flow is also derived during the field season. From these curves, the total river discharge that would provide the inflection point flow in each side channel is determined. The final recommendation is derived by averaging the recommendations for each island or choosing the river flow that would maintain at least the inflection point flow around all the islands being sampled in the study area. The latter method is preferred.

Minimum depth and width criteria could also be developed and used in conjunction with the WAGD option of the WETP program to formulate flow recommendations for nesting.

Maintenance of Spawning and Rearing Habitats in Side Channels

Side channels provide important and sometimes critical spawning and rearing habitats for many cold- and warm-water fish species. The maintenance of these habitats depends on adequate side channel flows.

The wetted perimeter inflection point method, when applied to the riffle areas of critical side channels, will provide a measure of the side channel flow that is needed to maintain the spawning and rearing habitats at acceptable levels. When this side channel recommendation is used in conjunction with a curve correlating the side channel flow to the total river flow, the total river flow that would maintain adequate side channel flow can be determined.

This method is applied to a series of side channels and the final recommendation derived by averaging the recommendations for each or choosing the river flow that would maintain at least the inflection point flow in all the sampled side channels. The latter method is again preferred.

Recreational Floating Requirement

Minimum stream depth and width criteria have been developed for various types of boating craft by the Cooperative Instream Flow Service Group of the U.S. Fish and Wildlife Service (Hyra, 1978). These are listed in Table 3.

Table 3. Required stream width and depth for various recreation craft.

Recreation Craft	Required Depth (ft)	Required Width (ft)
Canoe-kayak	0.5	4
Drift boat, row boat-raft	1.0	6
Tube	1.0	4
Power boat	3.0	6
Sail boat	3.0	25

These criteria are minimal and would not provide a satisfactory experience if the entire river was at this level. However, if the required depths and widths are maintained in riffles and other shallow areas, then these minimum conditions will only be encountered a short time during the float and the remainder of the trip will be over water of greater depths.

Cross-sections are placed in the shallowest area along the waterway. The WAGD option of the WETP program is used to determine the flow that will satisfy the minimum criteria for the craft of interest. For example, if deriving a recommendation for power boats, the flow providing depths $\geq$ 3.0 ft for at least a 6.0 ft, continuous length of top width is recommended. When a series of cross-sections are used, the results for each cross-section are analyzed separately and the flow satisfying the criteria for all cross-sections is recommended.

This analysis can be expanded using additional criteria. For example, in addition to the above criteria for power boats, it can also be required that a certain percentage of the top width, such as 25%, has depths ≥ 3.0 ft. Remember, you will have to justify all criteria used in your analysis.

FINAL CONSIDERATIONS

Be sure to compare your instream flow recommendations to water availability. For gaged streams, many summary flow statistics, such as the mean and median monthly flows of record, are available for comparison. For ungaged streams, instantaneous flow measurements collected by various state and federal agencies and simulated data are useful. The primary purpose is to determine if the recommendation is reasonable when compared to water availability. It is also desirable, for future planning, to define the period in which water in excess of the recommendation is available for consumptive uses and to quantify this excess.

It is common for the low flow recommendations for many of the headwater rivers and streams to equal or exceed the normal water availability for the months of November through March. This is the winter period when the natural flows are lowest for the year. These naturally occurring low flows, when coupled with the adverse effects of surface and anchor ice formation and the resulting scouring of the channel at ice-out, can impact the fishery. Consequently, water depletions during the winter have the potential to be extremely harmful to the already stressed fish populations. For headwater rivers and streams, it is generally accepted that little or no water should be removed during the critical winter period if fish populations are to be maintained at existing levels.

The recommendations derived from the wetted perimeter inflection point method only apply to the low flow or non-runoff months. For the high flow or runoff period, flow recommendations should be based on those flows judged necessary for flushing bottom sediments and maintaining the existing channel morphology. This method, termed the dominant discharge/channel morphology concept (Montana Department of Fish and Game, 1979), requires at least ten years of continuous USGS gage records for deriving high flow recommendations, so cannot be applied to most streams.

LITERATURE CITED

Bovee, K. D. and R. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and techniques. Instream Flow Information Paper: No. 5. Cooperative Instream Flow Service Group, Fort Collins, CO. 131 pp.

Buchanan, T. J. and W. P. Somers. 1969. Discharge measurements at gaging stations. Techniques of Water Resources Investigations of the United States Geological Survey, Book 3, Chapter A8.

Collings, Mike. 1972. A methodology for determining instream flow recommendations for fish. In Proceedings of Instream Flow Methodology Workshop. Washington Dept. of Ecology, Olympia, WA. pp. 72-86.

________________. 1974. Generalization of spawning and rearing discharges for several Pacific salmon species in western Washington. USGS, Open File Report. 39 pp.

Colorado Division of Wildlife. 1976. Required instream flows Crystal River and Avalanche Creek. Open File Letter. Colorado Division of Wildlife, Denver, CO. 33 pp.

Graham, P. J. and R. F. Penkal. 1978. Aquatic environmental analysis in the lower Yellowstone River. Montana Department of Fish, Wildlife and Parks, Helena. 254 pp.

Hyra, R. 1978. Methods of assessing instream flows for recreation. Instream Flow Information Paper: No. 6. Cooperative Instream Flow Service Group, Fort Collins, CO. 49 pp.

Leathe, S and F. Nelson. 1989. A literature evaluation of Montana's wetted perimeter inflection point method for deriving instream flow recommendations. Montana Department of Fish, Wildlife and Parks, Helena. 70 pp.

Montana Department of Fish and Game, 1979. Instream flow evaluation for selected streams in the upper Missouri River basin. Montana Department of Fish, Wildlife and Parks, 1420 East Sixth Avenue, Helena, MT 59620. 254 pp.

Rantz, S. E. (and others). 1982. Measurement and computation of streamflow: Volume 2. Computation of discharge. Geological Survey Water-Supply Paper 2175. U.S. Government Printing Office, Washington, D.C.

Smoot, G. F. and C. E. Novak. 1968. Calibration and maintenance of vertical-axis type current meters. Techniques of Water Resources Investigations of the United States Geological Survey, Book 8, Chapter B2.

Spence, L. E. 1975. Guidelines for using Water Surface Profile program to determine instream flow needs for aquatic life. Montana Dept. of Fish, Wildlife and Parks, Helena. Prelim. Draft. 22 pp.

Thompson, K. E. 1972. Determining streamflows for fish life. In Proc. Instream Flow Requirement Workshop, Pacific NW River Basins Comm., Portland, OR. pp. 31-50.

Wesche, T. A. and P. A. Rechard. 1980. A summary of instream flow methods for fisheries and related research needs. Eisenhower Consortium Bulletin 9. Water Res. Research Inst., Univ. of Wyoming, Laramie. 122 pp.

White, Robert G. 1976. A methodology for recommending stream resource maintenance flows for large rivers. In Proceedings of the Symp. and Spec. Conf. on Instream Flow Needs, ed. J. F. Orsborn and C. H. Allman. Vol. II, pp. 367-386. Amer. Fish. Soc., Bethesda, MD.

White, Robert and Tim Cochnauer. 1975. Stream resource maintenance flow studies. Idaho Dept. of Fish and Game and Idaho Coop. Fishery Research Unit Report. 136 pp.

APPENDIX A

Calculation of stage height at zero flow (zf) from Rantz (1982)

period. On the other hand, if, as is usually the case, discharge measurements are lacking to define the upper end of the rating, the defined lower part of the rating curve must be extrapolated to the highest stage experienced. Such extrapolations are always subject to error, but the error may be reduced if the analyst has a knowledge of the principles that govern the shape of rating curves. Much of the material in this chapter is directed toward a discussion of those principles, so that when the hydrographer is faced with the problem of extending the high-water end of a rating curve he can decide whether the extrapolation should be a straight line, or whether it should be concave upward or concave downward.

The problem of extrapolation can be circumvented, of course, if the unmeasured peak discharge is determined by use of the indirect methods discussed in chapter 9. In the absence of such peak-discharge determinations, some of the uncertainty in extrapolating the rating may be reduced by the use of one or more of several methods of estimating the discharge corresponding to high values of stage. Four such methods are discussed in the section titled "High-flow Extrapolation."

In the discussions that follow it was generally impractical to use both English and metric units, except where basic equations are given. Consequently English units are used throughout, unless otherwise noted.

STAGE-DISCHARGE CONTROLS

The subject of stage-discharge controls was discussed in detail in chapter 3, but a brief summary at this point is appropriate.

The relation of stage to discharge is usually controlled by a section or reach of channel downstream from the gage that is known as the station control. A section control may be natural or manmade; it may be a ledge of rock across the channel, a boulder-covered riffle, an overflow dam, or any other physical feature capable of maintaining a fairly stable relation between stage and discharge. Section controls are often effective only at low discharges and are completely submerged by channel control at medium and high discharges. Channel control consists of all the physical features of the channel that determine the stage of the river at a given point for a given rate of flow. These features include the size, slope, roughness, alinement, constrictions and expansions, and shape of the channel. The reach of channel that acts as the control may lengthen as the discharge increases, introducing new features that affect the stage-discharge relation.

Knowledge of the channel features that control the stage-discharge relation is important. The development of stage-discharge curves where more than one control is effective, and where the number of

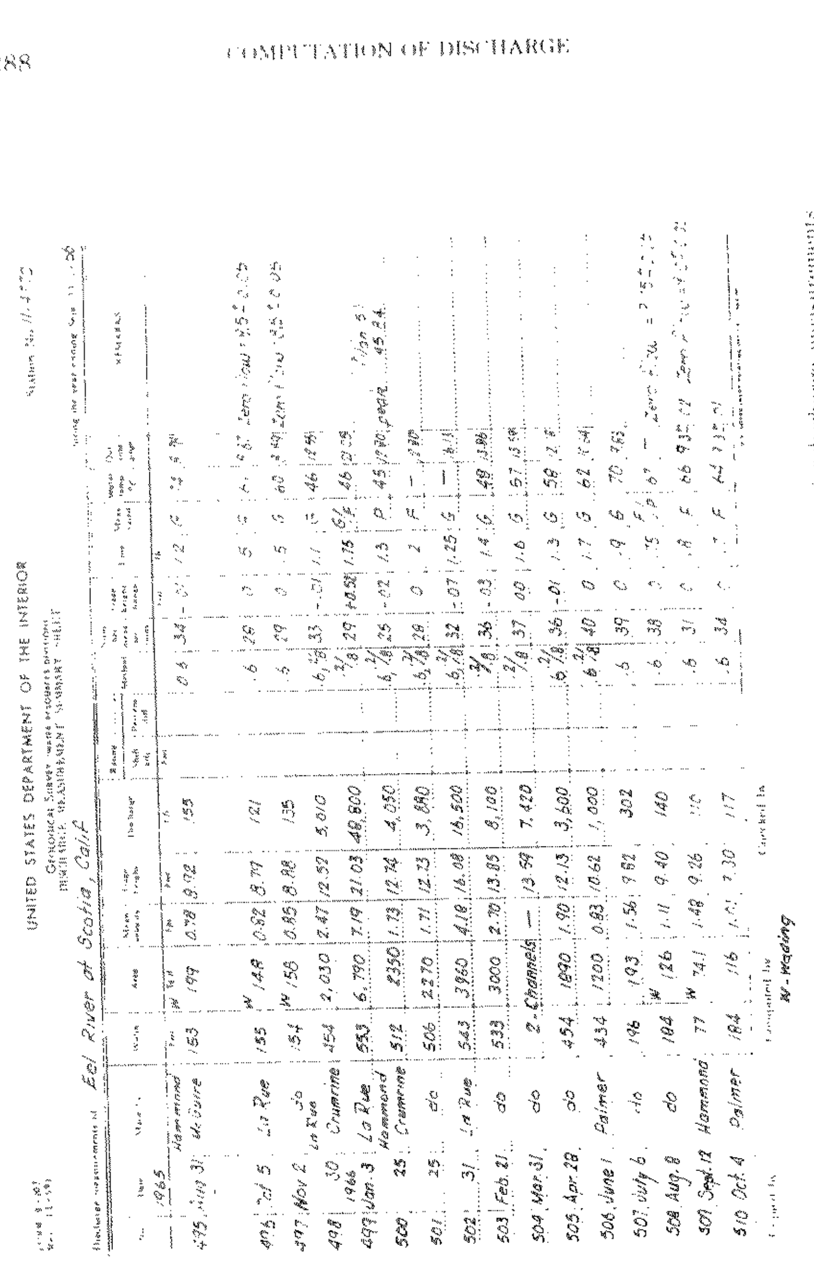
measurements is limited, usually requires judgment in interpolating between measurements and in extrapolating beyond the highest measurements. That is particularly true where the controls are not permanent and the various discharge measurements are representative of changes in the positioning of segments of the stage-discharge curve.

GRAPHICAL PLOTTING OF RATING CURVES

Stage-discharge relations are usually developed from a graphical analysis of the discharge measurements plotted on either rectangular-coordinate or logarithmic plotting paper. In a preliminary step the discharge measurements available for analysis are tabulated and summarized on a form such as that shown in figure 139. Discharge is then plotted as the abscissa, corresponding gage height is plotted as the ordinate, and a curve or line is fitted by eye to the plotted points. The plotted points carry the identifying measurement numbers given in figure 139; the discharge measurements are numbered consecutively in chronological order so that time trends can be identified.

At recording-gage stations that use stilling wells, systematic and significantly large differences between inside (recorded) gage heights and outside gage heights often occur during periods of high stage, usually as a result of intake drawdown (see section in chapter 4 titled, "Stilling Wells"). For stations where such differences occur, both inside and outside gage heights for high-water discharge measurements are recorded on the form shown in figure 139, and in plotting the measurements for rating analysis, the outside gage readings are used first. The stage-discharge relation is drawn through the outside gage readings of the high-water discharge measurements and is extended to the stage of the outside high-water marks that are observed for each flood event. The stage-discharge relation is next transposed to correspond with the inside gage heights obtained from the stage-recorder at the times of discharge measurement and at flood peaks. It is this transposed stage-discharge relation that is used with recorded stages to compute the discharge.

The rationale behind the above procedure is as follows. The outside gage readings are used for developing the rating because the hydraulic principles on which the rating is based require the use of the true stage of the stream. The transposition of the rating to inside (recorded) stages is then made because the recorded stages will be used with the rating to determine discharge. The recorded stages are used for discharge determination because if differences exist between inside and outside gage readings, those differences will be known only for those times when the two gages are read concurrently. If the



UNITED STATES DEPARTMENT OF THE INTERIOR
Geological Survey Water Resources Division
Discharge Measurement Summary Sheet

Discharge measurements of Eel River at Scotia, Calif

No.	Date	Made by	Width	Area	Mean velocity	Gage height	Discharge
495	1965 Aug. 31	Hammond McGuire	153	W 199	0.78	9.92	155
496	Oct. 5	La Rue	155	W 148	0.82	8.77	121
497	Nov. 2	La Rue do	154	W 158	0.85	8.88	135
498	30	Crumrine	454	2,030	2.47	12.57	5,010
499	1966 Jan. 3	La Rue Hammond	553	6,790	7.19	21.03	48,800
500	25	Crumrine	512	2350	1.73	12.74	4,050
501	25	do	506	2270	1.71	12.13	3,880
502	31	La Rue	543	3960	4.18	16.08	16,500
503	Feb. 21	do	533	3000	2.70	13.85	8,100
504	Mar. 31	do	2-Channels		—	13.59	7,420
505	Apr. 28	do	454	1890	1.90	12.13	3,600
506	June 1	Palmer	434	1200	0.83	10.62	1,000
507	July 6	do	196	193	1.56	9.62	302
508	Aug. 8	do	184	W 126	1.11	9.40	140
509	Sept. 12	Hammond	77	W 74.1	1.48	9.26	110
510	Oct. 4	Palmer	184	116	1.01	7.30	117

W-Wading

FIGURE 139.—Example of form used for tabulating and summarizing current-meter discharge measurements.

outside gage heights were used with the rating to determine discharge, variable corrections, either known or assumed, would have to be applied to recorded gage heights to convert them to outside stages. We have digressed here to discuss differences between inside and outside gage heights, because in the discussions that follow no distinction between the two gages will be made.

The use of logarithmic plotting paper is usually preferred for graphical analysis of the rating because in the usual situation of compound controls, changes in the slope of the logarithmically plotted rating identify the range in stage for which the individual controls are effective. Furthermore, the portion of the rating curve that is applicable to any particular control may be linearized for rational extrapolation or interpolation. A discussion of the characteristics of logarithmic plotting follows.

The measured distance between any two ordinates or abscissas on logarithmic graph paper, whose values are printed or indicated on the sheet by the manufacturer of the paper, represents the difference between the logarithms of those values. Consequently, the measured distance is related to the ratio of the two values. Therefore, the distance between pairs of numbers such as 1 and 2, 2 and 4, 3 and 6, 5 and 10, are all equal because the ratios of the various pairs are identical. Thus the logarithmic scale of either the ordinates or the abscissas is maintained if all printed numbers on the scale are multiplied or divided by a constant. This property of the paper has practical value. For example, assume that the logarithmic plotting paper available has two cycles (fig. 140), and that ordinates ranging from 0.3 to 15.0 are to be plotted. If the printed scale of ordinates is used and the bottom line is called 0.1, the top line of the paper becomes 10.0, and values between 10.0 and 15.0 cannot be accommodated. However, the logarithmic scale will not be distorted if all values are multiplied by a constant. For this particular problem, 2 is the constant used in figure 140, and now the desired range of 0.3 to 15.0 can be accommodated. Examination of figure 140 shows that the change in scale has not changed the distance between any given pair of ordinates; the position of the ordinate scale has merely been transposed.

We turn now to a theoretical discussion of rating curves plotted on logarithmic graph paper. A rating curve, or a segment of a rating curve, that plots as a straight line of logarithmic paper has the equation,

$$Q = p(G - e)^N, \qquad (53)$$

where

Q is discharge;

$(G - e)$ is head or depth of water on the control—this value is indicated by the ordinate scale printed by the manufacturer or

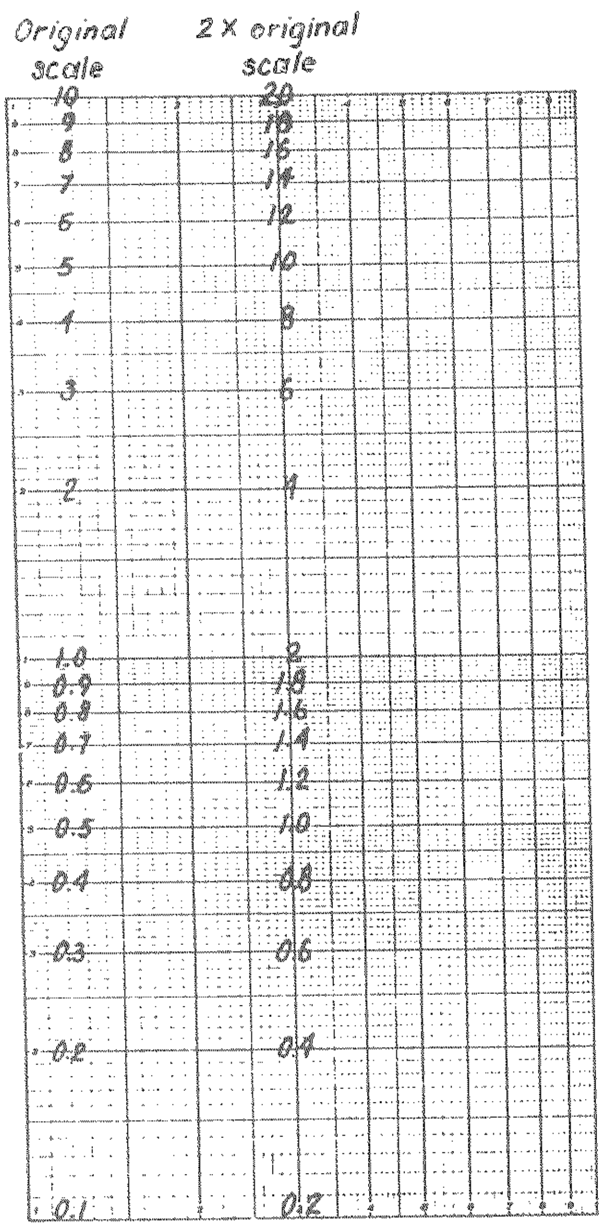


FIGURE 140.—Example showing how the logarithmic scale of graph paper may be transposed.

A-3

by the ordinate scale that has been transposed, as explained in the preceding paragraph;

G is gage height of the water surface;

e is gage height of zero flow for a section control of regular shape, or the gage height of effective zero flow for a channel control or a section control of irregular shape;

p is a constant that is numerically equal to the discharge when the head $(G - e)$ equals 1.0 ft or 1.0 m, depending on whether English or metric units are used; and

N is slope of the rating curve. (Slope in equation 53 is the ratio of the horizontal distance to the vertical distance. This unconventional way of measuring slope is necessary because the dependent variable Q is always plotted as the abscissa.)

We assume now that a segment of an established logarithmic rating is linear, and we examine the effect on the rating of changes to the control. If the width of the control increases, p increases and the new rating will be parallel to and to the right of the original rating. If the width of the control decreases, the opposite effect occurs; p decreases and the new rating will be parallel to and to the left of the original rating. If the control scours, e decreases and the depth $(G - e)$ for a given gage height increases; the new rating moves to the right and will no longer be a straight line but will be a curve that is concave downward. If the control becomes built up by deposition, e increases and the depth $(G - e)$ for a given gage height decreases; the new rating moves to the left and is no longer linear but is a curve that is concave upward.

When discharge measurements are originally plotted on logarithmic paper, no consideration is given to values of e. The gage height of each measurement is plotted using the ordinate scale provided by the manufacturer or, if necessary, an ordinate scale that has been transposed as illustrated in figure 140. We refer now to figure 141. The inside scale $(e = 0)$ is the scale printed by the paper manufacturer. Assume that the discharge measurements have been plotted to that scale and that they define the curvilinear relation between gage height (G) and discharge (Q) that is shown in the topmost curve. For the purpose of extrapolating the relation, a value of e is sought, which when applied to G, will result in a linear relation between $(G - e)$ and Q. If we are dealing with a section control of regular shape, the value of e will be known; it will be the gage height of the lowest point of the control (point of zero flow). If we are dealing with a channel control or section control of irregular shape, the value of e is the gage height of *effective* zero flow. The gage height of effective zero flow is not the gage height of some identifiable feature on the irregular section control or in the channel but is actually a mathematical constant that is considered as a gage height to preserve the concept of a logarithmically linear head-discharge relation. Effective zero flow is usually determined by a method of successive approximations.

In successive trials, the ordinate scale in figure 141 is varied for e values of 1, 2 and 3 ft, each of which results in a different curve, but each new curve still represents the same rating as the top curve. For example, a discharge of 30 ft³/s corresponds to a gage height (G) of 5.5 ft on all four curves. The true value of e is 2 ft, and thus the rating plots as a straight line if the ordinate scale numbers are increased by that value. In other words, while even on the new scale a discharge of 30 ft³/s corresponds to a gage height (G) of 5.5 ft, the head or depth on the control for a discharge of 30 ft³/s is $(G-e)$, or 3.5 ft; the linear rating marked $e = 2$ crosses the ordinate for 30 ft³/s at 5.5 ft on the new scale and at 3.5 ft on the manufacturer's, or inside, scale. If values of e smaller than the true value of 2 ft are used, the rating curve will be concave upward, if values of e greater than 2 ft are used, the curve will be concave downward. The value of e to be used for a rating curve, or for a segment of a rating curve, can thus be determined by adding or subtracting trial values of e to the numbered scales on the logarithmic plotting paper until a value is found that results in a straight-line plot of the rating. It is important to note that if the logarithmic ordinate scale must be transposed by multiplication or division to accommodate the range of stage to be plotted, that transposition must be made before the ordinate scale is manipulated for values of e.

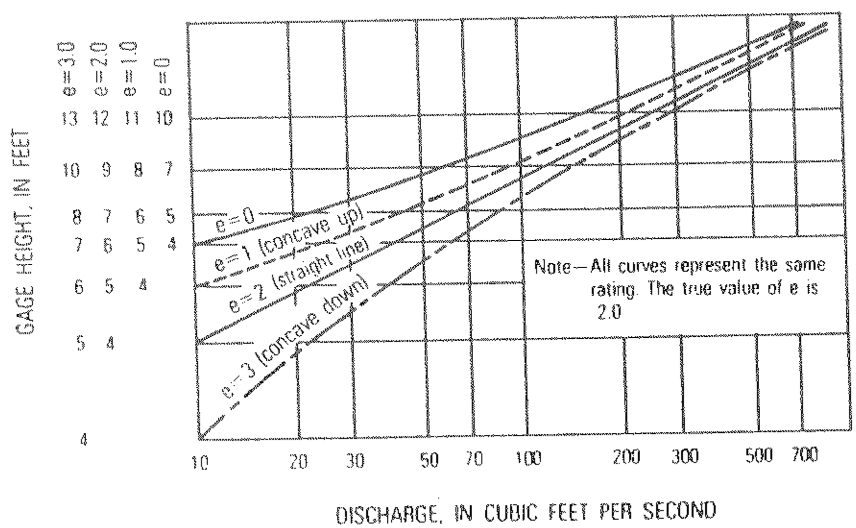


FIGURE 141.—Rating-curve shapes resulting from the use of differing values of effective zero flow.

A more direct solution for e, as described by Johnson (1952) is illustrated in figure 142. A plot of G versus Q has resulted in the solid-line curve which is to be linearized by subtracting a value of e from each value of G. The part of the rating between points 1 and 2 is chosen, and values of G_1, G_2, Q_1 and Q_2 are picked from the coordinate scales. A value of Q_3 is next computed, such that

$$Q_3^2 = Q_1 Q_2.$$

From the solid-line curve, the value of G_3 that corresponds to Q_3 is picked. In accordance with the properties of a straight line on logarithmic plotting paper,

$$(G_3 - e)^2 = (G_1 - e)(G_2 - e). \qquad (54)$$

Expansion of terms in equation 54 leads to equation 55 which provides a direct solution for e.

$$e = \frac{G_1 G_2 - G_3^2}{G_1 + G_2 - 2G_3} \qquad (55)$$

A logarithmic rating curve is seldom a straight line or a gentle curve for the entire range in stage. Even where a single cross section of the channel is the control for all stages, a sharp break in the

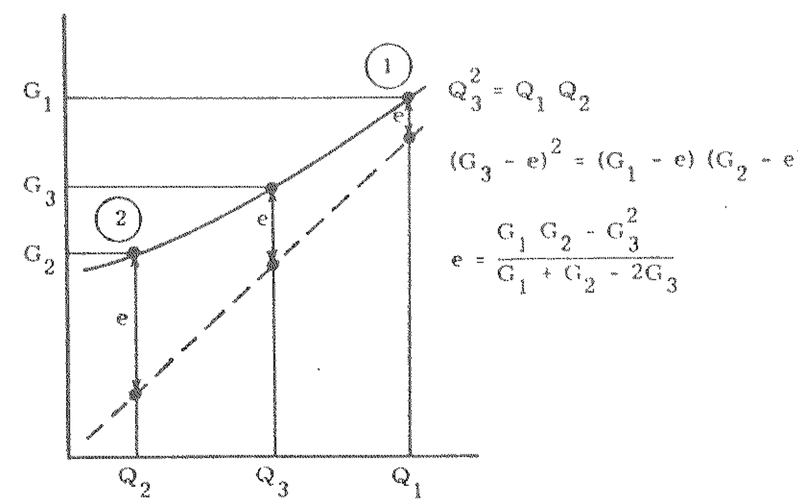


FIGURE 142.—Schematic representation of the linearization of a curve on logarithmic graph paper.

contour of the cross section, such as an overflow plain, will cause a break in the slope of the rating curve. Commonly, however, a break in slope is due to the low-water control being drowned out by a downstream section control becoming effective or by channel control becoming effective.

The use of rectangular-coordinate paper for rating analysis has ...rtain advantages, particularly in the study of the pattern of shifts ...he lower part of the rating. A change in the low-flow rating at ...ny sites results from a change in the elevation of effective zero flow (e), which means a constant shift in gage height. A shift of that kind is more easily visualized on rectangular-coordinate paper because on that paper the shift curve is parallel to the original rating curve, the two curves being separated by a vertical distance equal to the change in the value of e. On logarithmic paper the two curves will be separated by a variable distance which decreases as stage increases. A further advantage of rectangular-coordinate paper is the fact that the point of zero flow can be plotted directly on rectangular-coordinate paper, thereby facilitating extrapolation of the low-water end of the rating curve. That cannot be done on logarithmic paper because zero values cannot be shown on that type of paper.

As a general rule logarithmic plotting should be used initially in developing the general shape of the rating. The final curve may be displayed on either type of graph paper and used as a base curve for the analysis of shifts. A combination of the two types of graph paper is frequently used with the lower part of the rating plotted on an inset of rectangular-coordinate paper or on a separate sheet of rectangular-coordinate paper.

A-5

SECTION CONTROLS

ARTIFICIAL CONTROLS

At this point we digress from the subject of logarithmic rating curves to discuss the ratings for artificial section controls. A knowledge of the rating characteristics of controls of standard shape is necessary for an understanding of the rating characteristics of natural controls, almost all of which have irregular shapes. On pages that follow we first discuss thin-plate weirs, then broad-crested weirs, and finally flumes.

Thin-plate weirs are generally used in small clear-flowing streams, particularly where high accuracy is desired and adequate maintenance can be provided, as in small research watersheds. Flumes are preferred for use in small streams and canals that carry sediment and debris, and in other situations where the head loss (backwater) associated with a thin-plate weir is unacceptable. Most types of flume may also be used under conditions of submergence, as opposed to free-flow

conditions, thereby permitting them to operate with even smaller head loss but with some loss of accuracy of the stage-discharge relation. The broad-crested weirs are commonly used in the larger streams.

TRANSFERABILITY OF LABORATORY RATINGS

Standard shapes or dimensions are commonly used in building artificial controls, and many of these standard structures have been rated in laboratory model studies (World Meteorological Organization, 1971). The transfer of a laboratory discharge rating to a structure in the field requires the existence, and maintenance, of similitude between laboratory model and prototype, not only with regard to the structure, but also with regard to the approach channel. For example, scour and (or) fill in the approach channel will change the head-discharge relation, as will algal growth on the control structure. Both the structure and the approach channel must be kept free from accumulations of debris, sediment, and vegetal growth. Flow conditions downstream from the structure are significant only to the extent that they control the tailwater elevation, which may influence the operation of structures designed for free-flow conditions.

Because of the likelihood of the existence or development of conditions that differ from those specified in a laboratory model study, the policy of the Geological Survey is to calibrate the prototype control in the field by discharge measurements for the entire range of stage that is experienced. (See section in chapter 3 titled, "Artificial Controls.") In-place calibration is sometimes dispensed with where the artificial control is a standard thin-plate weir having negligible velocity of approach.

THIN-PLATE WEIRS

The surface of the weir over which the water flows is the crest of the weir. A thin-plate weir has its crest beveled to a chisel edge and is always installed with the beveled face on the downstream side. The crest of a thin-plate weir is highly susceptible to damage from floating debris, and therefore such weirs are used as control structures almost solely in canals whose flow is free of floating debris. Thin-plate weirs are not satisfactory for use in canals carrying sediment-laden water because they trap sediment and thereby cause the gage pool to fill with sediment, sometimes to a level above the weir crest. The banks of the canal must also be high enough to accommodate the increase in stage (backwater) caused by the installation of the weir, the weir plate being an impedance to flow in the canal. The commonly used shapes for thin-plate weirs are rectangular, trapezoidal, and triangular or V-notch.

APPENDIX B

Example of WETP input format

IBM ← Title and location of study area

FORTRAN Coding Form

GX28-7327-6 U/M 050**
Printed in U.S.A.

Program: Bear Creek-Big Hole Drainage - SW, SE, Sec. 34, T2N, R12W

Programmer: Fred Nelson   Date: 6-27-84

Page 1 of 4

FORTRAN STATEMENT

Stage Height At Zero Flow (zf) Option

I. Riffles

Set OPTS to one.

zf will equal lowest elevation on cross-sectional profile.

II. Non-Riffles

Set OPTS to one and enter zf on the XSEC records.

III. Want zf to equal zero.

Set OPTS to zero.

Use only for comparing results.

```
OPTS 1
QARD  1.5
QARD  2
QARD  2.5
QARD  3
QARD  3.5
QARD  4
QARD  5
QARD  6
QARD  7
QARD  8
QARD  9
QARD 10
QARD 15
QARD 20
QARD 25
QARD 30
QARD 40
QARD 50
QARD 60
XSEC 1
     1   0 9657   9 9642  15 9600  16 9424  21 9411  30 9389
     1  41 9386  51 9383  60 9363  61 9297  63 9283  64 9273
     1  68 9253  73 9243  78 9233  83 9233  88 9223  93 9233
```

Flows of interest. Up to 100 flows allowed. Enter as integers or with decimal points.

Profile Data

Distance from headstake

Channel elevation

Reads as 1.5 ft

Reads as 96.00 ft

Do not enter profile data past space 70.

Cross-section identification

*A standard card form, IBM electro 888157, is available for punching statements from this form.

**Number of forms per pad may vary slightly

IBM

FORTRAN Coding Form

GX28-7327-6 U/M 050
Printed in U.S.A.

Program: Bear Creek

Page 2 of 4

	1	98	9238	103	9243	108	9243	113	9243	118	9248	123	9263
	1	128	9268	133	9273	135	9283	140	9314	150	9330	159	9350
	1	162	9407	170	9485	182	9502	194	9536				
CAL1	1		9359		334 ← Calibration data for CS#1 - high flow								
CAL2	1		9321		113 ← " " - intermediate flow								
CAL3	1		9283		38 ← " " - low flow								
XSEC	2												
	2	0	9726	4	9719	10	9676	19	9632	20	9463	25	9404
	2	35	9383	43	9396	44	9357	52	9356	54	9342	63	9342
	2	75	9332	77	9323	80	9318	85	9313	90	9313	91	9293
	2	96	9293	101	9293	107	9288	113	9298	117	9293	120	9273
	2	125	9273	130	9273	135	9273	137	9293	138	9323	139	9393
	2	140	9435	147	9464	155	9483	158	9515	168	9531	179	9536
	2	190	9552										
CAL1	2		9390		334								
CAL2	2		9357		113								
CAL3	2		9323		38								
XSEC	3												
	3	0	9799	10	9782	20	9755	29	9724	36	9706	46	9674
	3	51	9662	52	9602	63	9600	74	9607	81	9618	90	9630
	3	99	9636	109	9636	118	9619	127	9601	130	9590	133	9585
	3	138	9575	141	9565	147	9555	150	9550	155	9540	160	9535
	3	165	9530	170	9515	175	9525	180	9520	185	9515	190	9540
	3	195	9545	198	9550	199	9590	200	9697	201	9717	210	9709

(Annotation for the CAL1–CAL3 values 9390, 9357, 9323 of cross-section 2:) Water surface elevations. Each is the average for the WEL and WER. Without decimal points, reads as 93.90, 93.57 and 93.23 ft

Number of forms per pad may vary slightly

GX28-7327-6 U. M 050
Printed in U.S.A

IBM FORTRAN Coding Form

Bear Creek 3 4

	3	195	9545	198	9550	199	9590	200	9697	201	9717	210	9709
	3	220	9707	224	9741	231	9746	240	9748	250	9751		
CAL1	3		9663		334	} Calibration flows							
CAL2	3		9626		113	Without decimal points, reads as 33.4, 11.3 and 3.8 cfs							
CAL3	3		9590		38								
XSEC	4												
	4	0	9863	10	9848	14	9824	24	9813	34	9809	43	9800
	4	50	9785	60	9766	70	9761	80	9746	90	9734	96	9700
	4	101	9687	108	9673	109	9661	110	9661	116	9661	121	9656
	4	130	9656	140	9656	145	9656	147	9651	153	9646	158	9646
	4	160	9636	165	9626	170	9626	175	9616	185	9626	195	9626
	4	200	9631	205	9636	210	9636	215	9636	220	9641	223	9646
	4	228	9646	234	9651	238	9656	242	9661	244	9666	250	9667
	4	255	9687	261	9717	265	9742	272	9748	278	9763	287	9754
	4	295	9740	310	9743	342	9745	346	9793	353	9829	361	9829
CAL1	4		9714		334								
CAL2	4		9685		113								
CAL3	4		9661		38								
XSEC	5		( ) ←	For non-riffle cross-sections enter zf here									
	5	0	9830	10	9806	14	9793	16	9769	18	9675	19	9640
	5	22	9625	30	9615	40	9615	50	9625	58	9615	60	9625
	5	65	9620	70	9630	80	9635	90	9635	98	9645	102	9655
	5	105	9675	106	9688	110	9706	119	9690	122	9680	129	9687
	5	135	9705	141	9736	149	9747	152	9775	161	9782	170	9788

IBM

FORTRAN Coding Form

GX28-7327-6 U/M 050**
Printed in U.S.A.

Program: Bear Creek

Page 4 of 4

FORTRAN STATEMENT

```
      5  180 9777  190 9765  200 9754  215 9748  231 9746  242 9753
      5  244 9809  248 9831  254 9842  265 9842
CAL1  5      9725      334
CAL2  5      9697      113
CAL3  5      9675       38
D .4 1.0
PØØL 1 2 3 4 5
PØØL 3 4 5
```

Optional Entry

In this example, results are also averaged for CS# 3, 4 and 5. Use as many POOL entries as needed.

Mandatory Entry

Prints results for each cross-section as well as the averages for all cross-sections.

Width-At-Given-Depth (WAGD) Option

Up to 10 depths allowed. Separate depths of interest with single space. In this example, asking for length of top width having depths $\geq$ .4 ft and 1.0 ft.

APPENDIX C

Example of WETP data output

```
Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W
PROGRAM WETP

          *** MONTANA DEPT. OF FISH, WILDLIFE AND PARKS ***

                Program WETP Rev. 1-84 (16 June 1984)

Program WETP calculates the following parameters for a stream
cross-section. Up to 10 stream cross-sections may be pooled
together to obtain an average of pooled cross-sections. Cross-
sections may be defined by up to 150 points.

  WETP - wetted perimeter
  DBAR - average depth
  VBAR - average velocity throughout cross-sectional area
  WDTH - top width of cross-section
  AREA - cross-sectional area
  STGE - water surface elevation
  DMAX - maximum depth
  WTOT - width at a depth > or = to a given value
  WMAX - max. cont. width at a depth > or = to a given value
  PTOT - ratio of WTOT/WDTH expressed as a percent
  PMAX - ratio of WMAX/WDTH expressed as a percent
```

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

CROSS-SECTION DATA

1		2		3		4		5						
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X
.0	96.57	.0	97.26	.0	97.99	.0	98.63	.0	98.30					
.9	96.42	.4	97.19	1.0	97.82	1.0	98.48	1.0	98.06					
1.5	96.00	1.0	96.76	2.0	97.55	1.4	98.24	1.4	97.93					
1.6	94.24	1.9	96.32	2.9	97.24	2.4	98.13	1.6	97.69					
2.1	94.11	2.0	94.63	3.6	97.06	3.4	98.09	1.8	96.75					
3.0	93.89	2.5	94.04	4.6	96.74	4.3	98.00	1.9	96.40					
4.1	93.86	3.5	93.83	5.1	96.62	5.0	97.85	2.2	96.25					
5.1	93.83	4.3	93.96	5.2	96.02	6.0	97.66	3.0	96.15					
6.0	93.63	4.4	93.57	6.3	96.00	7.0	97.61	4.0	96.15					
6.1	92.97	5.2	93.56	7.4	96.07	8.0	97.46	5.0	96.25					
6.3	92.83	5.4	93.42	8.1	96.18	9.0	97.34	5.8	96.15					
6.4	92.73	6.3	93.42	9.0	96.30	9.6	97.00	6.0	96.25					
6.8	92.53	7.5	93.32	9.9	96.36	10.1	96.87	6.5	96.20					
7.3	92.43	7.7	93.23	10.9	96.36	10.8	96.73	7.0	96.30					
7.8	92.33	8.0	93.18	11.8	96.19	10.9	96.66	8.0	96.35					
8.3	92.33	8.5	93.13	12.7	96.01	11.0	96.61	9.0	96.35					
8.8	92.23	9.0	93.13	13.0	95.90	11.6	96.61	9.8	96.45					
9.3	92.33	9.1	92.93	13.3	95.85	12.1	96.56	10.2	96.55					
9.8	92.38	9.6	92.93	13.8	95.75	13.0	96.56	10.5	96.75					
10.3	92.43	10.1	92.93	14.1	95.65	14.0	96.56	10.6	96.88					
10.8	92.43	10.7	92.88	14.7	95.55	14.5	96.56	11.0	97.06					
11.3	92.43	11.3	92.98	15.0	95.50	14.7	96.51	11.9	96.90					
11.8	92.48	11.7	92.93	15.5	95.40	15.3	96.46	12.2	96.80					
12.3	92.63	12.0	92.73	16.0	95.35	15.8	96.46	12.9	96.87					
12.8	92.68	12.5	92.73	16.5	95.30	16.0	96.36	13.5	97.05					
13.3	92.73	13.0	92.73	17.0	95.15	16.5	96.26	14.1	97.36					
13.5	92.83	13.5	92.73	17.5	95.25	17.0	96.26	14.9	97.47					
14.0	93.14	13.7	92.93	18.0	95.20	17.5	96.16	15.2	97.75					
15.0	93.30	13.8	93.23	18.5	95.15	18.5	96.26	16.1	97.82					
15.9	93.50	13.9	93.93	19.0	95.40	19.5	96.26	17.0	97.88					
16.2	94.07	14.0	94.35	19.5	95.45	20.0	96.31	18.0	97.77					
17.0	94.85	14.7	94.64	19.8	95.50	20.5	96.36	19.0	97.65					
18.2	95.02	15.5	94.83	19.9	95.90	21.0	96.36	20.0	97.54					
19.4	95.36	15.8	95.15	20.0	96.97	21.5	96.36	21.5	97.48					
.0	.00	16.8	95.31	20.1	97.17	22.0	96.41	23.1	97.46					
.0	.00	17.9	95.36	21.0	97.09	22.3	96.46	24.2	97.53					
.0	.00	19.0	95.52	22.0	97.07	22.8	96.46	24.4	98.09					
.0	.00	.0	.00	22.4	97.41	23.4	96.51	24.8	98.31					
.0	.00	.0	.00	23.1	97.46	23.8	96.56	25.4	98.42					
.0	.00	.0	.00	24.0	97.48	24.2	96.61	26.5	98.42					
.0	.00	.0	.00	25.0	97.51	24.4	96.66	.0	.00					
.0	.00	.0	.00	.0	.00	25.0	96.67	.0	.00					
.0	.00	.0	.00	.0	.00	25.5	96.87	.0	.00					
.0	.00	.0	.00	.0	.00	26.1	97.17	.0	.00					
.0	.00	.0	.00	.0	.00	26.5	97.42	.0	.00					

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

.0	.00	.0	.00	.0	.00	27.2	97.48	.0	.00
.0	.00	.0	.00	.0	.00	27.8	97.63	.0	.00
.0	.00	.0	.00	.0	.00	28.7	97.54	.0	.00
.0	.00	.0	.00	.0	.00	29.5	97.40	.0	.00
.0	.00	.0	.00	.0	.00	31.0	97.43	.0	.00
.0	.00	.0	.00	.0	.00	34.2	97.45	.0	.00
.0	.00	.0	.00	.0	.00	34.6	97.93	.0	.00
.0	.00	.0	.00	.0	.00	35.3	98.29	.0	.00
.0	.00	.0	.00	.0	.00	36.1	98.29	.0	.00

CALIBRATION DATA

1		2		3		4		5						
Q	S	Q	S	Q	S	Q	S	Q	S	Q	S	Q	S	Q
33.4	93.59	33.4	93.90	33.4	96.63	33.4	97.14	33.4	97.25					
11.3	93.21	11.3	93.57	11.3	96.26	11.3	96.85	11.3	96.97					
3.8	92.83	3.8	93.23	3.8	95.90	3.8	96.61	3.8	96.75					

REGRESSION CURVE CONSTANTS

CONSTANTS AND R-SQUARED VALUES ARE GIVEN FOR THE
REGRESSION LOG (S - ZF) = A + B * LOG Q

1		2		3		4		5							
A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
-.429	.377	-.514	.391	-.299	.313	-.549	.358	-.382	.279						

R2	R2	R2	R2	R2	R2	R2	R2
.987	.984	.992	.997	1.000			

ZF	ZF	ZF	ZF	ZF	ZF	ZF	ZF
92.23	92.73	95.15	96.16	96.15			

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W
COMPUTED VALUES

FLOW= 1.5 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		6.21	5.10	6.28	8.20	8.75	.00	.00	.00	.00	.00	6.91
DBAR		.24	.23	.36	.16	.34	.00	.00	.00	.00	.00	.26
VBAR		1.01	1.37	.71	1.19	.52	.00	.00	.00	.00	.00	.96
WDTH		6.11	4.73	5.97	8.14	8.46	.00	.00	.00	.00	.00	6.68
AREA		1.49	1.09	2.12	1.26	2.87	.00	.00	.00	.00	.00	1.77
STGE		92.66	93.09	95.72	96.49	96.61	.00	.00	.00	.00	.00	94.91
DMAX		.43	.36	.57	.33	.46	.00	.00	.00	.00	.00	.43
WTOT	.40	.34	.00	2.55	.00	3.01	.00	.00	.00	.00	.00	1.18
WMAX		.34	.00	2.55	.00	2.16	.00	.00	.00	.00	.00	1.01
PTOT		5.60	.00	42.66	.00	35.64	.00	.00	.00	.00	.00	16.78
PMAX		5.60	.00	42.66	.00	25.51	.00	.00	.00	.00	.00	14.75
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 2.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		6.82	5.70	6.55	8.91	8.86	.00	.00	.00	.00	.00	7.37
DBAR		.27	.25	.40	.18	.38	.00	.00	.00	.00	.00	.29
VBAR		1.11	1.54	.82	1.28	.63	.00	.00	.00	.00	.00	1.07
WDTH		6.71	5.28	6.19	8.84	8.53	.00	.00	.00	.00	.00	7.11
AREA		1.81	1.30	2.45	1.57	3.20	.00	.00	.00	.00	.00	2.06
STGE		92.71	93.13	95.77	96.52	96.65	.00	.00	.00	.00	.00	94.96
DMAX		.48	.40	.62	.36	.50	.00	.00	.00	.00	.00	.47
WTOT	.40	.84	1.50	3.19	.00	4.57	.00	.00	.00	.00	.00	2.02
WMAX		.84	1.50	3.19	.00	4.57	.00	.00	.00	.00	.00	2.02
PTOT		12.51	28.47	51.53	.00	53.61	.00	.00	.00	.00	.00	29.23
PMAX		12.51	28.47	51.53	.00	53.61	.00	.00	.00	.00	.00	29.23
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 2.5 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		7.12	6.11	6.83	9.28	8.95	.00	.00	.00	.00	.00	7.66
DBAR		.30	.26	.43	.20	.40	.00	.00	.00	.00	.00	.32
VBAR		1.19	1.67	.91	1.36	.72	.00	.00	.00	.00	.00	1.17
WDTH		6.98	5.66	6.43	9.21	8.58	.00	.00	.00	.00	.00	7.37

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

AREA		2.10	1.50	2.73	1.84	3.47	.00	.00	.00	.00	.00	2.33
STGE		92.76	93.17	95.82	96.55	96.69	.00	.00	.00	.00	.00	95.00
DMAX		.53	.44	.67	.39	.54	.00	.00	.00	.00	.00	.51
WTOT	.40	1.90	1.59	3.79	.00	4.80	.00	.00	.00	.00	.00	2.42
WMAX		1.90	1.59	3.79	.00	4.80	.00	.00	.00	.00	.00	2.42
PTOT		27.16	28.19	58.96	.00	55.89	.00	.00	.00	.00	.00	34.04
PMAX		27.16	28.19	58.96	.00	55.89	.00	.00	.00	.00	.00	34.04
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 3.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		7.25	6.39	7.08	12.11	9.03	.00	.00	.00	.00	.00	8.37
DBAR		.33	.29	.45	.18	.43	.00	.00	.00	.00	.00	.34
VBAR		1.27	1.78	1.00	1.41	.81	.00	.00	.00	.00	.00	1.25
WDTH		7.09	5.91	6.64	12.04	8.63	.00	.00	.00	.00	.00	8.06
AREA		2.36	1.69	2.99	2.13	3.71	.00	.00	.00	.00	.00	2.58
STGE		92.79	93.20	95.86	96.58	96.71	.00	.00	.00	.00	.00	95.03
DMAX		.56	.47	.71	.42	.56	.00	.00	.00	.00	.00	.54
WTOT	.40	2.46	1.68	4.34	.28	5.19	.00	.00	.00	.00	.00	2.79
WMAX		2.46	1.68	4.34	.28	5.19	.00	.00	.00	.00	.00	2.79
PTOT		34.64	28.34	65.41	2.32	60.14	.00	.00	.00	.00	.00	38.17
PMAX		34.64	28.34	65.41	2.32	60.14	.00	.00	.00	.00	.00	38.17
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 3.5 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		7.38	6.60	7.33	12.54	9.10	.00	.00	.00	.00	.00	8.59
DBAR		.36	.31	.47	.19	.45	.00	.00	.00	.00	.00	.36
VBAR		1.35	1.88	1.09	1.45	.89	.00	.00	.00	.00	.00	1.33
WDTH		7.19	6.10	6.86	12.46	8.68	.00	.00	.00	.00	.00	8.26
AREA		2.60	1.86	3.23	2.42	3.93	.00	.00	.00	.00	.00	2.81
STGE		92.83	93.23	95.89	96.60	96.74	.00	.00	.00	.00	.00	95.06
DMAX		.60	.50	.74	.44	.59	.00	.00	.00	.00	.00	.57
WTOT	.40	2.96	1.75	4.73	.64	5.74	.00	.00	.00	.00	.00	3.16
WMAX		2.96	1.75	4.73	.64	5.74	.00	.00	.00	.00	.00	3.16
PTOT		41.18	28.68	68.94	5.10	66.10	.00	.00	.00	.00	.00	42.00
PMAX		41.18	28.68	68.94	5.10	66.10	.00	.00	.00	.00	.00	42.00

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 4.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		7.49	6.69	7.47	13.37	9.16	.00	.00	.00	.00	.00	8.84
DBAR		.39	.33	.49	.20	.47	.00	.00	.00	.00	.00	.38
VBAR		1.42	1.98	1.16	1.48	.97	.00	.00	.00	.00	.00	1.40
WDTH		7.29	6.16	6.97	13.28	8.71	.00	.00	.00	.00	.00	8.48
AREA		2.82	2.02	3.44	2.70	4.12	.00	.00	.00	.00	.00	3.02
STGE		92.86	93.26	95.93	96.62	96.76	.00	.00	.00	.00	.00	95.08
DMAX		.63	.53	.78	.46	.61	.00	.00	.00	.00	.00	.60
WTOT	.40	4.42	1.82	4.96	.96	7.10	.00	.00	.00	.00	.00	3.85
WMAX		4.42	1.82	4.96	.96	7.10	.00	.00	.00	.00	.00	3.85
PTOT		60.72	29.46	71.12	7.23	81.55	.00	.00	.00	.00	.00	50.02
PMAX		60.72	29.46	71.12	7.23	81.55	.00	.00	.00	.00	.00	50.02
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 5.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		7.69	6.86	7.69	13.76	9.25	.00	.00	.00	.00	.00	9.05
DBAR		.43	.37	.54	.24	.51	.00	.00	.00	.00	.00	.42
VBAR		1.55	2.15	1.30	1.55	1.12	.00	.00	.00	.00	.00	1.53
WDTH		7.45	6.28	7.13	13.66	8.75	.00	.00	.00	.00	.00	8.65
AREA		3.23	2.32	3.84	3.22	4.46	.00	.00	.00	.00	.00	3.42
STGE		92.91	93.30	95.98	96.66	96.80	.00	.00	.00	.00	.00	95.13
DMAX		.68	.57	.83	.50	.65	.00	.00	.00	.00	.00	.65
WTOT	.40	5.03	2.37	5.31	3.04	7.50	.00	.00	.00	.00	.00	4.65
WMAX		5.03	1.94	5.31	3.04	7.50	.00	.00	.00	.00	.00	4.56
PTOT		67.45	37.74	74.45	22.25	85.68	.00	.00	.00	.00	.00	57.51
PMAX		67.45	30.84	74.45	22.25	85.68	.00	.00	.00	.00	.00	56.13
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 6.0 CFS

AVG

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

XSEC		1	2	3	4	5					
WETP		7.87	7.26	9.51	14.33	9.77	.00	.00	.00	.00	.00	9.75
DBAR		.47	.39	.47	.26	.52	.00	.00	.00	.00	.00	.42
VBAR		1.67	2.31	1.42	1.62	1.26	.00	.00	.00	.00	.00	1.66
WDTH		7.60	6.63	8.89	14.22	9.22	.00	.00	.00	.00	.00	9.31
AREA		3.60	2.60	4.22	3.70	4.77	.00	.00	.00	.00	.00	3.78
STGE		92.96	93.35	96.03	96.70	96.83	.00	.00	.00	.00	.00	95.17
DMAX		.73	.62	.88	.54	.68	.00	.00	.00	.00	.00	.69
WTOT	.40	5.34	4.14	5.61	3.55	7.78	.00	.00	.00	.00	.00	5.28
WMAX		5.34	2.14	5.61	3.55	7.78	.00	.00	.00	.00	.00	4.88
PTOT		70.21	62.47	63.16	24.96	84.38	.00	.00	.00	.00	.00	61.04
PMAX		70.21	32.22	63.16	24.96	84.38	.00	.00	.00	.00	.00	54.99
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 7.0 CFS

											AVG
XSEC		1	2	3	4	5					
WETP		8.00	7.76	10.47	14.47	10.23	.00	.00	.00	.00	.00	10.19
DBAR		.51	.40	.47	.29	.52	.00	.00	.00	.00	.00	.44
VBAR		1.78	2.45	1.51	1.69	1.39	.00	.00	.00	.00	.00	1.76
WDTH		7.69	7.10	9.76	14.34	9.64	.00	.00	.00	.00	.00	9.71
AREA		3.93	2.86	4.63	4.13	5.05	.00	.00	.00	.00	.00	4.12
STGE		93.01	93.38	96.07	96.73	96.86	.00	.00	.00	.00	.00	95.21
DMAX		.78	.65	.92	.57	.71	.00	.00	.00	.00	.00	.73
WTOT	.40	5.57	4.65	5.81	4.01	7.97	.00	.00	.00	.00	.00	5.60
WMAX		5.57	4.65	5.81	4.01	7.97	.00	.00	.00	.00	.00	5.60
PTOT		72.44	65.43	59.54	27.93	82.73	.00	.00	.00	.00	.00	61.62
PMAX		72.44	65.43	59.54	27.93	82.73	.00	.00	.00	.00	.00	61.62
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 8.0 CFS

											AVG
XSEC		1	2	3	4	5					
WETP		8.12	8.22	11.00	14.67	10.53	.00	.00	.00	.00	.00	10.51
DBAR		.55	.41	.49	.31	.54	.00	.00	.00	.00	.00	.46
VBAR		1.89	2.57	1.59	1.76	1.50	.00	.00	.00	.00	.00	1.86
WDTH		7.76	7.53	10.22	14.54	9.89	.00	.00	.00	.00	.00	9.99
AREA		4.24	3.12	5.02	4.54	5.32	.00	.00	.00	.00	.00	4.45
STGE		93.05	93.42	96.11	96.75	96.89	.00	.00	.00	.00	.00	95.24
DMAX		.82	.69	.96	.59	.74	.00	.00	.00	.00	.00	.76

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

WTOT	.40	5.89	4.67	5.94	4.42	8.09	.00	.00	.00	.00	.00	5.80
WMAX		5.89	4.67	5.94	4.42	8.09	.00	.00	.00	.00	.00	5.80
PTOT		75.88	62.11	58.12	30.42	81.75	.00	.00	.00	.00	.00	61.66
PMAX		75.88	62.11	58.12	30.42	81.75	.00	.00	.00	.00	.00	61.66
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
FLOW=	9.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		8.22	9.21	11.49	14.87	10.82	.00	.00	.00	.00	.00	10.92
DBAR		.58	.40	.51	.33	.55	.00	.00	.00	.00	.00	.47
VBAR		1.99	2.65	1.67	1.83	1.62	.00	.00	.00	.00	.00	1.95
WDTH		7.82	8.48	10.64	14.73	10.15	.00	.00	.00	.00	.00	10.36
AREA		4.53	3.39	5.40	4.91	5.56	.00	.00	.00	.00	.00	4.76
STGE		93.08	93.45	96.15	96.78	96.92	.00	.00	.00	.00	.00	95.28
DMAX		.85	.72	1.00	.62	.77	.00	.00	.00	.00	.00	.79
WTOT	.40	6.33	4.70	6.06	5.74	8.19	.00	.00	.00	.00	.00	6.21
WMAX		6.33	4.70	6.06	5.74	8.19	.00	.00	.00	.00	.00	6.21
PTOT		80.92	55.46	56.93	39.01	80.73	.00	.00	.00	.00	.00	62.61
PMAX		80.92	55.46	56.93	39.01	80.73	.00	.00	.00	.00	.00	62.61
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
FLOW=	10.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		8.32	9.29	11.95	15.06	11.11	.00	.00	.00	.00	.00	11.15
DBAR		.61	.43	.52	.35	.56	.00	.00	.00	.00	.00	.49
VBAR		2.08	2.74	1.74	1.90	1.72	.00	.00	.00	.00	.00	2.04
WDTH		7.89	8.53	11.03	14.91	10.41	.00	.00	.00	.00	.00	10.55
AREA		4.80	3.65	5.76	5.26	5.80	.00	.00	.00	.00	.00	5.05
STGE		93.12	93.48	96.18	96.80	96.94	.00	.00	.00	.00	.00	95.30
DMAX		.89	.75	1.03	.64	.79	.00	.00	.00	.00	.00	.82
WTOT	.40	6.75	4.73	6.23	6.03	8.29	.00	.00	.00	.00	.00	6.41
WMAX		6.75	4.73	6.23	6.03	8.29	.00	.00	.00	.00	.00	6.41
PTOT		85.54	55.45	56.49	40.46	79.65	.00	.00	.00	.00	.00	63.52
PMAX		85.54	55.45	56.49	40.46	79.65	.00	.00	.00	.00	.00	63.52
WTOT	1.00	.00	.00	.66	.00	.00	.00	.00	.00	.00	.00	.13
WMAX		.00	.00	.39	.00	.00	.00	.00	.00	.00	.00	.08

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

PTOT		.00	.00	5.99	.00	.00	.00	.00	.00	.00	.00	1.20
PMAX		.00	.00	3.53	.00	.00	.00	.00	.00	.00	.00	.71
FLOW=	15.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		9.30	10.40	14.20	15.79	12.30	.00	.00	.00	.00	.00	12.40
DBAR		.69	.51	.57	.44	.59	.00	.00	.00	.00	.00	.56
VBAR		2.50	3.12	2.02	2.21	2.20	.00	.00	.00	.00	.00	2.41
WDTH		8.72	9.47	13.02	15.60	11.48	.00	.00	.00	.00	.00	11.66
AREA		6.01	4.80	7.43	6.80	6.83	.00	.00	.00	.00	.00	6.37
STGE		93.26	93.61	96.32	96.90	97.03	.00	.00	.00	.00	.00	95.43
DMAX		1.03	.88	1.17	.74	.88	.00	.00	.00	.00	.00	.94
WTOT	.40	7.30	5.99	6.96	8.58	8.49	.00	.00	.00	.00	.00	7.46
WMAX		7.30	5.99	6.96	8.58	8.49	.00	.00	.00	.00	.00	7.46
PTOT		83.77	63.26	53.47	54.98	73.92	.00	.00	.00	.00	.00	65.88
PMAX		83.77	63.26	53.47	54.98	73.92	.00	.00	.00	.00	.00	65.88
WTOT	1.00	.33	.00	2.57	.00	.00	.00	.00	.00	.00	.00	.58
WMAX		.33	.00	2.57	.00	.00	.00	.00	.00	.00	.00	.58
PTOT		3.84	.00	19.70	.00	.00	.00	.00	.00	.00	.00	4.71
PMAX		3.84	.00	19.70	.00	.00	.00	.00	.00	.00	.00	4.71
FLOW=	20.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		10.02	10.62	16.20	16.29	12.78	.00	.00	.00	.00	.00	13.18
DBAR		.76	.61	.61	.50	.65	.00	.00	.00	.00	.00	.63
VBAR		2.83	3.45	2.22	2.47	2.60	.00	.00	.00	.00	.00	2.71
WDTH		9.33	9.51	14.82	16.08	11.88	.00	.00	.00	.00	.00	12.32
AREA		7.08	5.80	9.01	8.08	7.70	.00	.00	.00	.00	.00	7.53
STGE		93.38	93.72	96.43	96.99	97.11	.00	.00	.00	.00	.00	95.52
DMAX		1.15	.99	1.28	.83	.96	.00	.00	.00	.00	.00	1.04
WTOT	.40	7.65	6.31	8.96	12.16	8.62	.00	.00	.00	.00	.00	8.74
WMAX		7.65	6.31	7.32	12.16	8.62	.00	.00	.00	.00	.00	8.41
PTOT		81.96	66.33	60.31	75.66	72.55	.00	.00	.00	.00	.00	71.36
PMAX		81.96	66.33	49.43	75.66	72.55	.00	.00	.00	.00	.00	69.19
WTOT	1.00	2.28	.00	3.99	.00	.00	.00	.00	.00	.00	.00	1.25
WMAX		2.28	.00	3.99	.00	.00	.00	.00	.00	.00	.00	1.25
PTOT		24.39	.00	26.90	.00	.00	.00	.00	.00	.00	.00	10.26
PMAX		24.39	.00	26.90	.00	.00	.00	.00	.00	.00	.00	10.26
FLOW=	25.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		10.59	10.80	16.39	16.61	12.98	.00	.00	.00	.00	.00	13.47
DBAR		.82	.70	.70	.56	.70	.00	.00	.00	.00	.00	.70

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

VBAR		3.11	3.76	2.41	2.72	2.96	.00	.00	.00	.00	.00	2.99
WDTH		9.80	9.54	14.84	16.37	12.02	.00	.00	.00	.00	.00	12.51
AREA		8.04	6.66	10.39	9.20	8.43	.00	.00	.00	.00	.00	8.54
STGE		93.48	93.81	96.53	97.05	97.17	.00	.00	.00	.00	.00	95.61
DMAX		1.25	1.08	1.38	.89	1.02	.00	.00	.00	.00	.00	1.12
WTOT	.40	7.82	7.37	10.37	13.47	8.72	.00	.00	.00	.00	.00	9.55
WMAX		7.82	7.37	7.80	13.47	8.72	.00	.00	.00	.00	.00	9.04
PTOT		79.85	77.28	69.83	82.29	72.54	.00	.00	.00	.00	.00	76.36
PMAX		79.85	77.28	52.53	82.29	72.54	.00	.00	.00	.00	.00	72.90
WTOT	1.00	4.77	1.69	4.96	.00	1.49	.00	.00	.00	.00	.00	2.58
WMAX		4.77	1.69	4.96	.00	1.32	.00	.00	.00	.00	.00	2.55
PTOT		48.70	17.75	33.40	.00	12.40	.00	.00	.00	.00	.00	22.45
PMAX		48.70	17.75	33.40	.00	10.94	.00	.00	.00	.00	.00	22.16

FLOW= 30.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		10.84	11.60	16.55	16.87	13.15	.00	.00	.00	.00	.00	13.80
DBAR		.90	.73	.78	.61	.75	.00	.00	.00	.00	.00	.75
VBAR		3.36	4.03	2.59	2.94	3.31	.00	.00	.00	.00	.00	3.25
WDTH		9.93	10.20	14.86	16.59	12.13	.00	.00	.00	.00	.00	12.74
AREA		8.92	7.44	11.58	10.19	9.07	.00	.00	.00	.00	.00	9.44
STGE		93.57	93.89	96.61	97.11	97.22	.00	.00	.00	.00	.00	95.68
DMAX		1.34	1.16	1.46	.95	1.07	.00	.00	.00	.00	.00	1.20
WTOT	.40	8.13	8.53	11.34	14.29	9.04	.00	.00	.00	.00	.00	10.27
WMAX		8.13	8.53	8.21	14.29	8.77	.00	.00	.00	.00	.00	9.59
PTOT		81.87	83.66	76.28	86.13	74.50	.00	.00	.00	.00	.00	80.49
PMAX		81.87	83.66	55.25	86.13	72.29	.00	.00	.00	.00	.00	75.84
WTOT	1.00	5.39	2.02	5.46	.00	3.28	.00	.00	.00	.00	.00	3.23
WMAX		5.39	1.89	5.46	.00	2.27	.00	.00	.00	.00	.00	3.00
PTOT		54.27	19.82	36.74	.00	27.08	.00	.00	.00	.00	.00	27.58
PMAX		54.27	18.56	36.74	.00	18.72	.00	.00	.00	.00	.00	25.66

FLOW= 40.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		11.51	12.94	17.23	17.29	13.44	.00	.00	.00	.00	.00	14.48
DBAR		1.00	.79	.89	.70	.83	.00	.00	.00	.00	.00	.84
VBAR		3.82	4.48	2.93	3.35	3.93	.00	.00	.00	.00	.00	3.70
WDTH		10.45	11.35	15.39	16.96	12.32	.00	.00	.00	.00	.00	13.29
AREA		10.47	8.94	13.65	11.93	10.17	.00	.00	.00	.00	.00	11.03
STGE		93.73	94.02	96.74	97.22	97.31	.00	.00	.00	.00	.00	95.80
DMAX		1.50	1.29	1.59	1.06	1.16	.00	.00	.00	.00	.00	1.32
WTOT	.40	9.07	9.47	13.45	15.01	10.09	.00	.00	.00	.00	.00	11.42
WMAX		9.07	9.47	8.95	15.01	8.90	.00	.00	.00	.00	.00	10.28

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

PTOT		86.79	83.43	87.40	88.51	81.89	.00	.00	.00	.00	.00	85.60
PMAX		86.79	83.43	58.17	88.51	72.23	.00	.00	.00	.00	.00	77.83
WTOT	1.00	6.84	4.68	6.04	.88	5.12	.00	.00	.00	.00	.00	4.71
WMAX		6.84	4.68	6.04	.88	5.12	.00	.00	.00	.00	.00	4.71
PTOT		65.49	41.22	39.25	5.17	41.55	.00	.00	.00	.00	.00	38.54
PMAX		65.49	41.22	39.25	5.17	41.55	.00	.00	.00	.00	.00	38.54
FLOW=	50.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		13.02	13.27	17.72	17.64	13.80	.00	.00	.00	.00	.00	15.09
DBAR		1.00	.89	.98	.78	.88	.00	.00	.00	.00	.00	.91
VBAR		4.20	4.86	3.24	3.72	4.51	.00	.00	.00	.00	.00	4.11
WDTH		11.86	11.54	15.76	17.26	12.61	.00	.00	.00	.00	.00	13.81
AREA		11.90	10.29	15.45	13.44	11.09	.00	.00	.00	.00	.00	12.43
STGE		93.86	94.14	96.86	97.31	97.38	.00	.00	.00	.00	.00	95.91
DMAX		1.63	1.41	1.71	1.15	1.23	.00	.00	.00	.00	.00	1.43
WTOT	.40	9.68	9.52	14.83	15.61	10.94	.00	.00	.00	.00	.00	12.11
WMAX		9.68	9.52	14.83	15.61	9.08	.00	.00	.00	.00	.00	11.74
PTOT		81.58	82.49	94.08	90.46	86.73	.00	.00	.00	.00	.00	87.07
PMAX		81.58	82.49	94.08	90.46	72.01	.00	.00	.00	.00	.00	84.12
WTOT	1.00	7.28	5.40	6.64	3.70	7.34	.00	.00	.00	.00	.00	6.07
WMAX		7.28	5.40	6.64	3.70	7.34	.00	.00	.00	.00	.00	6.07
PTOT		61.37	46.82	42.12	21.42	58.23	.00	.00	.00	.00	.00	45.99
PMAX		61.37	46.82	42.12	21.42	58.23	.00	.00	.00	.00	.00	45.99
FLOW=	60.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		14.72	13.51	18.15	18.22	14.34	.00	.00	.00	.00	.00	15.79
DBAR		.99	.99	1.06	.83	.91	.00	.00	.00	.00	.00	.96
VBAR		4.48	5.22	3.52	4.06	5.03	.00	.00	.00	.00	.00	4.46
WDTH		13.48	11.65	16.08	17.81	13.10	.00	.00	.00	.00	.00	14.42
AREA		13.41	11.50	17.04	14.79	11.92	.00	.00	.00	.00	.00	13.73
STGE		93.97	94.25	96.96	97.38	97.45	.00	.00	.00	.00	.00	96.00
DMAX		1.74	1.52	1.81	1.22	1.30	.00	.00	.00	.00	.00	1.52
WTOT	.40	9.93	9.75	14.85	16.07	11.67	.00	.00	.00	.00	.00	12.45
WMAX		9.93	9.56	14.85	16.07	9.24	.00	.00	.00	.00	.00	11.93
PTOT		73.64	83.69	92.35	90.22	89.14	.00	.00	.00	.00	.00	85.81
PMAX		73.64	82.04	92.35	90.22	70.55	.00	.00	.00	.00	.00	81.76
WTOT	1.00	7.63	6.14	7.06	5.79	7.90	.00	.00	.00	.00	.00	6.91
WMAX		7.63	6.14	7.06	5.79	7.90	.00	.00	.00	.00	.00	6.91
PTOT		56.58	52.71	43.93	32.49	60.37	.00	.00	.00	.00	.00	49.22
PMAX		56.58	52.71	43.93	32.49	60.37	.00	.00	.00	.00	.00	49.22

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W
COMPUTED VALUES

FLOW= 1.5 CFS

XSEC		1	2	3	4	5						AVG
WETP		.00	.00	6.28	8.20	8.75	.00	.00	.00	.00	.00	7.74
DBAR		.00	.00	.36	.16	.34	.00	.00	.00	.00	.00	.28
VBAR		.00	.00	.71	1.19	.52	.00	.00	.00	.00	.00	.81
WDTH		.00	.00	5.97	8.14	8.46	.00	.00	.00	.00	.00	7.52
AREA		.00	.00	2.12	1.26	2.87	.00	.00	.00	.00	.00	2.08
STGE		.00	.00	95.72	96.49	96.61	.00	.00	.00	.00	.00	96.27
DMAX		.00	.00	.57	.33	.46	.00	.00	.00	.00	.00	.45
WTOT	.40	.00	.00	2.55	.00	3.01	.00	.00	.00	.00	.00	1.85
WMAX		.00	.00	2.55	.00	2.16	.00	.00	.00	.00	.00	1.57
PTOT		.00	.00	42.66	.00	35.64	.00	.00	.00	.00	.00	26.10
PMAX		.00	.00	42.66	.00	25.51	.00	.00	.00	.00	.00	22.72
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 2.0 CFS

XSEC		1	2	3	4	5						AVG
WETP		.00	.00	6.55	8.91	8.86	.00	.00	.00	.00	.00	8.11
DBAR		.00	.00	.40	.18	.38	.00	.00	.00	.00	.00	.32
VBAR		.00	.00	.82	1.28	.63	.00	.00	.00	.00	.00	.91
WDTH		.00	.00	6.19	8.84	8.53	.00	.00	.00	.00	.00	7.85
AREA		.00	.00	2.45	1.57	3.20	.00	.00	.00	.00	.00	2.40
STGE		.00	.00	95.77	96.52	96.65	.00	.00	.00	.00	.00	96.32
DMAX		.00	.00	.62	.36	.50	.00	.00	.00	.00	.00	.50
WTOT	.40	.00	.00	3.19	.00	4.57	.00	.00	.00	.00	.00	2.59
WMAX		.00	.00	3.19	.00	4.57	.00	.00	.00	.00	.00	2.59
PTOT		.00	.00	51.53	.00	53.61	.00	.00	.00	.00	.00	35.05
PMAX		.00	.00	51.53	.00	53.61	.00	.00	.00	.00	.00	35.05
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 2.5 CFS

XSEC		1	2	3	4	5						AVG
WETP		.00	.00	6.83	9.28	8.95	.00	.00	.00	.00	.00	8.35
DBAR		.00	.00	.43	.20	.40	.00	.00	.00	.00	.00	.34
VBAR		.00	.00	.91	1.36	.72	.00	.00	.00	.00	.00	1.00
WDTH		.00	.00	6.43	9.21	8.58	.00	.00	.00	.00	.00	8.07

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

AREA		.00	.00	2.73	1.84	3.47	.00	.00	.00	.00	.00	2.68
STGE		.00	.00	95.82	96.55	96.69	.00	.00	.00	.00	.00	96.35
DMAX		.00	.00	.67	.39	.54	.00	.00	.00	.00	.00	.53
WTOT	.40	.00	.00	3.79	.00	4.80	.00	.00	.00	.00	.00	2.86
WMAX		.00	.00	3.79	.00	4.80	.00	.00	.00	.00	.00	2.86
PTOT		.00	.00	58.96	.00	55.89	.00	.00	.00	.00	.00	38.28
PMAX		.00	.00	58.96	.00	55.89	.00	.00	.00	.00	.00	38.28
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
FLOW=	3.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		.00	.00	7.08	12.11	9.03	.00	.00	.00	.00	.00	9.41
DBAR		.00	.00	.45	.18	.43	.00	.00	.00	.00	.00	.35
VBAR		.00	.00	1.00	1.41	.81	.00	.00	.00	.00	.00	1.07
WDTH		.00	.00	6.64	12.04	8.63	.00	.00	.00	.00	.00	9.10
AREA		.00	.00	2.99	2.13	3.71	.00	.00	.00	.00	.00	2.94
STGE		.00	.00	95.86	96.58	96.71	.00	.00	.00	.00	.00	96.38
DMAX		.00	.00	.71	.42	.56	.00	.00	.00	.00	.00	.56
WTOT	.40	.00	.00	4.34	.28	5.19	.00	.00	.00	.00	.00	3.27
WMAX		.00	.00	4.34	.28	5.19	.00	.00	.00	.00	.00	3.27
PTOT		.00	.00	65.41	2.32	60.14	.00	.00	.00	.00	.00	42.62
PMAX		.00	.00	65.41	2.32	60.14	.00	.00	.00	.00	.00	42.62
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
FLOW=	3.5 CFS											AVG
XSEC		1	2	3	4	5						
WETP		.00	.00	7.33	12.54	9.10	.00	.00	.00	.00	.00	9.66
DBAR		.00	.00	.47	.19	.45	.00	.00	.00	.00	.00	.37
VBAR		.00	.00	1.09	1.45	.89	.00	.00	.00	.00	.00	1.14
WDTH		.00	.00	6.86	12.46	8.68	.00	.00	.00	.00	.00	9.33
AREA		.00	.00	3.23	2.42	3.93	.00	.00	.00	.00	.00	3.19
STGE		.00	.00	95.89	96.60	96.74	.00	.00	.00	.00	.00	96.41
DMAX		.00	.00	.74	.44	.59	.00	.00	.00	.00	.00	.59
WTOT	.40	.00	.00	4.73	.64	5.74	.00	.00	.00	.00	.00	3.70
WMAX		.00	.00	4.73	.64	5.74	.00	.00	.00	.00	.00	3.70
PTOT		.00	.00	68.94	5.10	66.10	.00	.00	.00	.00	.00	46.71
PMAX		.00	.00	68.94	5.10	66.10	.00	.00	.00	.00	.00	46.71

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 4.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		.00	.00	7.47	13.37	9.16	.00	.00	.00	.00	.00	10.00
DBAR		.00	.00	.49	.20	.47	.00	.00	.00	.00	.00	.39
VBAR		.00	.00	1.16	1.48	.97	.00	.00	.00	.00	.00	1.20
WDTH		.00	.00	6.97	13.28	8.71	.00	.00	.00	.00	.00	9.66
AREA		.00	.00	3.44	2.70	4.12	.00	.00	.00	.00	.00	3.42
STGE		.00	.00	95.93	96.62	96.76	.00	.00	.00	.00	.00	96.44
DMAX		.00	.00	.78	.46	.61	.00	.00	.00	.00	.00	.62
WTOT	.40	.00	.00	4.96	.96	7.10	.00	.00	.00	.00	.00	4.34
WMAX		.00	.00	4.96	.96	7.10	.00	.00	.00	.00	.00	4.34
PTOT		.00	.00	71.12	7.23	81.55	.00	.00	.00	.00	.00	53.30
PMAX		.00	.00	71.12	7.23	81.55	.00	.00	.00	.00	.00	53.30
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 5.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		.00	.00	7.69	13.76	9.25	.00	.00	.00	.00	.00	10.23
DBAR		.00	.00	.54	.24	.51	.00	.00	.00	.00	.00	.43
VBAR		.00	.00	1.30	1.55	1.12	.00	.00	.00	.00	.00	1.32
WDTH		.00	.00	7.13	13.66	8.75	.00	.00	.00	.00	.00	9.85
AREA		.00	.00	3.84	3.22	4.46	.00	.00	.00	.00	.00	3.84
STGE		.00	.00	95.98	96.66	96.80	.00	.00	.00	.00	.00	96.48
DMAX		.00	.00	.83	.50	.65	.00	.00	.00	.00	.00	.66
WTOT	.40	.00	.00	5.31	3.04	7.50	.00	.00	.00	.00	.00	5.28
WMAX		.00	.00	5.31	3.04	7.50	.00	.00	.00	.00	.00	5.28
PTOT		.00	.00	74.45	22.25	85.68	.00	.00	.00	.00	.00	60.79
PMAX		.00	.00	74.45	22.25	85.68	.00	.00	.00	.00	.00	60.79
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 6.0 CFS

AVG

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

XSEC		1	2	3	4	5					
WETP		.00	.00	9.51	14.33	9.77	.00	.00	.00	.00	11.20
DBAR		.00	.00	.47	.26	.52	.00	.00	.00	.00	.00	.42
VBAR		.00	.00	1.42	1.62	1.26	.00	.00	.00	.00	.00	1.43
WDTH		.00	.00	8.89	14.22	9.22	.00	.00	.00	.00	.00	10.77
AREA		.00	.00	4.22	3.70	4.77	.00	.00	.00	.00	.00	4.23
STGE		.00	.00	96.03	96.70	96.83	.00	.00	.00	.00	.00	96.52
DMAX		.00	.00	.88	.54	.68	.00	.00	.00	.00	.00	.70
WTOT	.40	.00	.00	5.61	3.55	7.78	.00	.00	.00	.00	.00	5.65
WMAX		.00	.00	5.61	3.55	7.78	.00	.00	.00	.00	.00	5.65
PTOT		.00	.00	63.16	24.96	84.38	.00	.00	.00	.00	.00	57.50
PMAX		.00	.00	63.16	24.96	84.38	.00	.00	.00	.00	.00	57.50
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 7.0 CFS

											AVG
XSEC		1	2	3	4	5					
WETP		.00	.00	10.47	14.47	10.23	.00	.00	.00	.00	.00	11.72
DBAR		.00	.00	.47	.29	.52	.00	.00	.00	.00	.00	.43
VBAR		.00	.00	1.51	1.69	1.39	.00	.00	.00	.00	.00	1.53
WDTH		.00	.00	9.76	14.34	9.64	.00	.00	.00	.00	.00	11.25
AREA		.00	.00	4.63	4.13	5.05	.00	.00	.00	.00	.00	4.60
STGE		.00	.00	96.07	96.73	96.86	.00	.00	.00	.00	.00	96.55
DMAX		.00	.00	.92	.57	.71	.00	.00	.00	.00	.00	.73
WTOT	.40	.00	.00	5.81	4.01	7.97	.00	.00	.00	.00	.00	5.93
WMAX		.00	.00	5.81	4.01	7.97	.00	.00	.00	.00	.00	5.93
PTOT		.00	.00	59.54	27.93	82.73	.00	.00	.00	.00	.00	56.73
PMAX		.00	.00	59.54	27.93	82.73	.00	.00	.00	.00	.00	56.73
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 8.0 CFS

											AVG
XSEC		1	2	3	4	5					
WETP		.00	.00	11.00	14.67	10.53	.00	.00	.00	.00	.00	12.07
DBAR		.00	.00	.49	.31	.54	.00	.00	.00	.00	.00	.45
VBAR		.00	.00	1.59	1.76	1.50	.00	.00	.00	.00	.00	1.62
WDTH		.00	.00	10.22	14.54	9.89	.00	.00	.00	.00	.00	11.55
AREA		.00	.00	5.02	4.54	5.32	.00	.00	.00	.00	.00	4.96
STGE		.00	.00	96.11	96.75	96.89	.00	.00	.00	.00	.00	96.59
DMAX		.00	.00	.96	.59	.74	.00	.00	.00	.00	.00	.77

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

WTOT	.40	.00	.00	5.94	4.42	8.09	.00	.00	.00	.00	.00	6.15
WMAX		.00	.00	5.94	4.42	8.09	.00	.00	.00	.00	.00	6.15
PTOT		.00	.00	58.12	30.42	81.75	.00	.00	.00	.00	.00	56.77
PMAX		.00	.00	58.12	30.42	81.75	.00	.00	.00	.00	.00	56.77
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 9.0 CFS

XSEC	1	2	3	4	5						AVG
WETP	.00	.00	11.49	14.87	10.82	.00	.00	.00	.00	.00	12.39
DBAR	.00	.00	.51	.33	.55	.00	.00	.00	.00	.00	.46
VBAR	.00	.00	1.67	1.83	1.62	.00	.00	.00	.00	.00	1.71
WDTH	.00	.00	10.64	14.73	10.15	.00	.00	.00	.00	.00	11.84
AREA	.00	.00	5.40	4.91	5.56	.00	.00	.00	.00	.00	5.29
STGE	.00	.00	96.15	96.78	96.92	.00	.00	.00	.00	.00	96.61
DMAX	.00	.00	1.00	.62	.77	.00	.00	.00	.00	.00	.79

WTOT	.40	.00	.00	6.06	5.74	8.19	.00	.00	.00	.00	.00	6.67
WMAX		.00	.00	6.06	5.74	8.19	.00	.00	.00	.00	.00	6.67
PTOT		.00	.00	56.93	39.01	80.73	.00	.00	.00	.00	.00	58.89
PMAX		.00	.00	56.93	39.01	80.73	.00	.00	.00	.00	.00	58.89
WTOT	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PTOT		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PMAX		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

FLOW= 10.0 CFS

XSEC	1	2	3	4	5						AVG
WETP	.00	.00	11.95	15.06	11.11	.00	.00	.00	.00	.00	12.70
DBAR	.00	.00	.52	.35	.56	.00	.00	.00	.00	.00	.48
VBAR	.00	.00	1.74	1.90	1.72	.00	.00	.00	.00	.00	1.79
WDTH	.00	.00	11.03	14.91	10.41	.00	.00	.00	.00	.00	12.12
AREA	.00	.00	5.76	5.26	5.80	.00	.00	.00	.00	.00	5.61
STGE	.00	.00	96.18	96.80	96.94	.00	.00	.00	.00	.00	96.64
DMAX	.00	.00	1.03	.64	.79	.00	.00	.00	.00	.00	.82

WTOT	.40	.00	.00	6.23	6.03	8.29	.00	.00	.00	.00	.00	6.85
WMAX		.00	.00	6.23	6.03	8.29	.00	.00	.00	.00	.00	6.85
PTOT		.00	.00	56.49	40.46	79.65	.00	.00	.00	.00	.00	58.87
PMAX		.00	.00	56.49	40.46	79.65	.00	.00	.00	.00	.00	58.87
WTOT	1.00	.00	.00	.66	.00	.00	.00	.00	.00	.00	.00	.22
WMAX		.00	.00	.39	.00	.00	.00	.00	.00	.00	.00	.13

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

PTOT		.00	.00	5.99	.00	.00	.00	.00	.00	.00	.00	2.00
PMAX		.00	.00	3.53	.00	.00	.00	.00	.00	.00	.00	1.18
FLOW=	15.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		.00	.00	14.20	15.79	12.30	.00	.00	.00	.00	.00	14.10
DBAR		.00	.00	.57	.44	.59	.00	.00	.00	.00	.00	.53
VBAR		.00	.00	2.02	2.21	2.20	.00	.00	.00	.00	.00	2.14
WDTH		.00	.00	13.02	15.60	11.48	.00	.00	.00	.00	.00	13.37
AREA		.00	.00	7.43	6.80	6.83	.00	.00	.00	.00	.00	7.02
STGE		.00	.00	96.32	96.90	97.03	.00	.00	.00	.00	.00	96.75
DMAX		.00	.00	1.17	.74	.88	.00	.00	.00	.00	.00	.93
WTOT	.40	.00	.00	6.96	8.58	8.49	.00	.00	.00	.00	.00	8.01
WMAX		.00	.00	6.96	8.58	8.49	.00	.00	.00	.00	.00	8.01
PTOT		.00	.00	53.47	54.98	73.92	.00	.00	.00	.00	.00	60.79
PMAX		.00	.00	53.47	54.98	73.92	.00	.00	.00	.00	.00	60.79
WTOT	1.00	.00	.00	2.57	.00	.00	.00	.00	.00	.00	.00	.86
WMAX		.00	.00	2.57	.00	.00	.00	.00	.00	.00	.00	.86
PTOT		.00	.00	19.70	.00	.00	.00	.00	.00	.00	.00	6.57
PMAX		.00	.00	19.70	.00	.00	.00	.00	.00	.00	.00	6.57
FLOW=	20.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		.00	.00	16.20	16.29	12.78	.00	.00	.00	.00	.00	15.09
DBAR		.00	.00	.61	.50	.65	.00	.00	.00	.00	.00	.59
VBAR		.00	.00	2.22	2.47	2.60	.00	.00	.00	.00	.00	2.43
WDTH		.00	.00	14.82	16.08	11.88	.00	.00	.00	.00	.00	14.26
AREA		.00	.00	9.01	8.08	7.70	.00	.00	.00	.00	.00	8.26
STGE		.00	.00	96.43	96.99	97.11	.00	.00	.00	.00	.00	96.84
DMAX		.00	.00	1.28	.83	.96	.00	.00	.00	.00	.00	1.02
WTOT	.40	.00	.00	8.94	12.16	8.62	.00	.00	.00	.00	.00	9.91
WMAX		.00	.00	7.32	12.16	8.62	.00	.00	.00	.00	.00	9.37
PTOT		.00	.00	60.31	75.66	72.55	.00	.00	.00	.00	.00	69.51
PMAX		.00	.00	49.43	75.66	72.55	.00	.00	.00	.00	.00	65.88
WTOT	1.00	.00	.00	3.99	.00	.00	.00	.00	.00	.00	.00	1.33
WMAX		.00	.00	3.99	.00	.00	.00	.00	.00	.00	.00	1.33
PTOT		.00	.00	26.90	.00	.00	.00	.00	.00	.00	.00	8.97
PMAX		.00	.00	26.90	.00	.00	.00	.00	.00	.00	.00	8.97
FLOW=	25.0 CFS											AVG
XSEC		1	2	3	4	5						
WETP		.00	.00	16.39	16.61	12.98	.00	.00	.00	.00	.00	15.33
DBAR		.00	.00	.70	.56	.70	.00	.00	.00	.00	.00	.65

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

VBAR		.00	.00	2.41	2.72	2.96	.00	.00	.00	.00	.00	2.70
WDTH		.00	.00	14.84	16.37	12.02	.00	.00	.00	.00	.00	14.41
AREA		.00	.00	10.39	9.20	8.43	.00	.00	.00	.00	.00	9.34
STGE		.00	.00	96.53	97.05	97.17	.00	.00	.00	.00	.00	96.92
DMAX		.00	.00	1.38	.89	1.02	.00	.00	.00	.00	.00	1.10
WTOT	.40	.00	.00	10.37	13.47	8.72	.00	.00	.00	.00	.00	10.85
WMAX		.00	.00	7.80	13.47	8.72	.00	.00	.00	.00	.00	9.99
PTOT		.00	.00	69.83	82.29	72.54	.00	.00	.00	.00	.00	74.89
PMAX		.00	.00	52.53	82.29	72.54	.00	.00	.00	.00	.00	69.12
WTOT	1.00	.00	.00	4.96	.00	1.49	.00	.00	.00	.00	.00	2.15
WMAX		.00	.00	4.96	.00	1.32	.00	.00	.00	.00	.00	2.09
PTOT		.00	.00	33.40	.00	12.40	.00	.00	.00	.00	.00	15.27
PMAX		.00	.00	33.40	.00	10.94	.00	.00	.00	.00	.00	14.78

FLOW= 30.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		.00	.00	16.55	16.87	13.15	.00	.00	.00	.00	.00	15.52
DBAR		.00	.00	.78	.61	.75	.00	.00	.00	.00	.00	.71
VBAR		.00	.00	2.59	2.94	3.31	.00	.00	.00	.00	.00	2.95
WDTH		.00	.00	14.86	16.59	12.13	.00	.00	.00	.00	.00	14.53
AREA		.00	.00	11.58	10.19	9.07	.00	.00	.00	.00	.00	10.28
STGE		.00	.00	96.61	97.11	97.22	.00	.00	.00	.00	.00	96.98
DMAX		.00	.00	1.46	.95	1.07	.00	.00	.00	.00	.00	1.16
WTOT	.40	.00	.00	11.34	14.29	9.04	.00	.00	.00	.00	.00	11.55
WMAX		.00	.00	8.21	14.29	8.77	.00	.00	.00	.00	.00	10.42
PTOT		.00	.00	76.28	86.13	74.50	.00	.00	.00	.00	.00	78.97
PMAX		.00	.00	55.25	86.13	72.29	.00	.00	.00	.00	.00	71.22
WTOT	1.00	.00	.00	5.46	.00	3.28	.00	.00	.00	.00	.00	2.92
WMAX		.00	.00	5.46	.00	2.27	.00	.00	.00	.00	.00	2.58
PTOT		.00	.00	36.74	.00	27.08	.00	.00	.00	.00	.00	21.27
PMAX		.00	.00	36.74	.00	18.72	.00	.00	.00	.00	.00	18.49

FLOW= 40.0 CFS

												AVG
XSEC		1	2	3	4	5						
WETP		.00	.00	17.23	17.29	13.44	.00	.00	.00	.00	.00	15.98
DBAR		.00	.00	.89	.70	.83	.00	.00	.00	.00	.00	.81
VBAR		.00	.00	2.93	3.35	3.93	.00	.00	.00	.00	.00	3.41
WDTH		.00	.00	15.39	16.96	12.32	.00	.00	.00	.00	.00	14.89
AREA		.00	.00	13.65	11.93	10.17	.00	.00	.00	.00	.00	11.92
STGE		.00	.00	96.74	97.22	97.31	.00	.00	.00	.00	.00	97.09
DMAX		.00	.00	1.59	1.06	1.16	.00	.00	.00	.00	.00	1.27
WTOT	.40	.00	.00	13.45	15.01	10.09	.00	.00	.00	.00	.00	12.85
WMAX		.00	.00	8.95	15.01	8.90	.00	.00	.00	.00	.00	10.96

Bear Creek - Big Hole Drainage - SW, SE, SEC 34, T2N, R12W

PTOT		.00	.00	87.40	88.51	81.89	.00	.00	.00	.00	.00	85.93
PMAX		.00	.00	58.17	88.51	72.23	.00	.00	.00	.00	.00	72.97
WTOT	1.00	.00	.00	6.04	.88	5.12	.00	.00	.00	.00	.00	4.01
WMAX		.00	.00	6.04	.88	5.12	.00	.00	.00	.00	.00	4.01
PTOT		.00	.00	39.25	5.17	41.55	.00	.00	.00	.00	.00	28.66
PMAX		.00	.00	39.25	5.17	41.55	.00	.00	.00	.00	.00	28.66

FLOW= 50.0 CFS

XSEC		1	2	3	4	5						AVG
WETP		.00	.00	17.72	17.64	13.80	.00	.00	.00	.00	.00	16.39
DBAR		.00	.00	.98	.78	.88	.00	.00	.00	.00	.00	.88
VBAR		.00	.00	3.24	3.72	4.51	.00	.00	.00	.00	.00	3.82
WDTH		.00	.00	15.76	17.26	12.61	.00	.00	.00	.00	.00	15.21
AREA		.00	.00	15.45	13.44	11.09	.00	.00	.00	.00	.00	13.33
STGE		.00	.00	96.86	97.31	97.38	.00	.00	.00	.00	.00	97.18
DMAX		.00	.00	1.71	1.15	1.23	.00	.00	.00	.00	.00	1.36
WTOT	.40	.00	.00	14.83	15.61	10.94	.00	.00	.00	.00	.00	13.79
WMAX		.00	.00	14.83	15.61	9.08	.00	.00	.00	.00	.00	13.17
PTOT		.00	.00	94.08	90.46	86.73	.00	.00	.00	.00	.00	90.42
PMAX		.00	.00	94.08	90.46	72.01	.00	.00	.00	.00	.00	85.52
WTOT	1.00	.00	.00	6.64	3.70	7.34	.00	.00	.00	.00	.00	5.89
WMAX		.00	.00	6.64	3.70	7.34	.00	.00	.00	.00	.00	5.89
PTOT		.00	.00	42.12	21.42	58.23	.00	.00	.00	.00	.00	40.59
PMAX		.00	.00	42.12	21.42	58.23	.00	.00	.00	.00	.00	40.59

FLOW= 60.0 CFS

XSEC		1	2	3	4	5						AVG
WETP		.00	.00	18.15	18.22	14.34	.00	.00	.00	.00	.00	16.90
DBAR		.00	.00	1.06	.83	.91	.00	.00	.00	.00	.00	.93
VBAR		.00	.00	3.52	4.06	5.03	.00	.00	.00	.00	.00	4.20
WDTH		.00	.00	16.08	17.81	13.10	.00	.00	.00	.00	.00	15.66
AREA		.00	.00	17.04	14.79	11.92	.00	.00	.00	.00	.00	14.58
STGE		.00	.00	96.96	97.38	97.45	.00	.00	.00	.00	.00	97.26
DMAX		.00	.00	1.81	1.22	1.30	.00	.00	.00	.00	.00	1.44
WTOT	.40	.00	.00	14.85	16.07	11.67	.00	.00	.00	.00	.00	14.20
WMAX		.00	.00	14.85	16.07	9.24	.00	.00	.00	.00	.00	13.39
PTOT		.00	.00	92.35	90.22	89.14	.00	.00	.00	.00	.00	90.57
PMAX		.00	.00	92.35	90.22	70.55	.00	.00	.00	.00	.00	84.37
WTOT	1.00	.00	.00	7.06	5.79	7.90	.00	.00	.00	.00	.00	6.92
WMAX		.00	.00	7.06	5.79	7.90	.00	.00	.00	.00	.00	6.92
PTOT		.00	.00	43.93	32.49	60.37	.00	.00	.00	.00	.00	45.60
PMAX		.00	.00	43.93	32.49	60.37	.00	.00	.00	.00	.00	45.60

THE DIRECT AND INDIRECT BENEFITS AND COSTS OF GRANTING A WATER RESERVATION FOR IN-STREAM FLOWS IN THE MISSOURI RIVER BASIN

Joe C. Elliott, Ph.D.
Ecological Consultant

THE DIRECT AND INDIRECT BENEFITS AND COSTS OF GRANTING A WATER RESERVATION FOR IN-STREAM FLOWS IN THE MISSOURI RIVER BASIN

January 1989

Submitted to:
Montana Department of Fish, Wildlife and Parks
1420 East Sixth Avenue
Helena, Montana 59620

Submitted by:
Joe C. Elliott
Ecological Consultant
835 Eighth Avenue
Helena, Montana 59601

TABLE OF CONTENTS

Section		Page
I	INTRODUCTION	1
II	DIRECT BENEFITS OF THE RESERVATION	2
	A. Tourism and Recreation	2
III	DIRECT COSTS OF THE RESERVATION	10
	A. Stream Gaging	10
IV	INDIRECT BENEFITS OF THE RESERVATION	11
	A. Hydropower	11
	B. Pollution Control	13
	C. Public Health	18
V	INDIRECT COSTS OF THE RESERVATION	20
	A. Mining	20
	B. Agriculture	33
	C. Municipal Water Supplies	38

LITERATURE CITED

LIST OF TABLES

Table		Page
1	RECREATIONAL VALUE BY SITE FOR STREAMS IN THE UPPER MISSOURI RIVER BASIN	4
2	RECREATIONAL VALUE BY SITE FOR STREAMS IN THE LOWER MISSOURI RIVER BASIN	5
3	NUMBER OF FLOATERS USING THE SMITH RIVER	7
4	KILOWATT HOUR (KWH) GENERATION PER ACRE-FOOT (AF) OF WATER	12
5	MONTANA PERMIT DISCHARGE ELIMINATION SYSTEMS - MUNICIPAL, INDUSTRIAL, AND PLACER MINE PERMITS	14
6	OPERATING MINES PERMITTED BY THE DEPARTMENT OF STATE LANDS IN THE MISSOURI RIVER BASIN	21
7	WATER REQUIREMENTS, WATER SOURCES, AND PRODUCTION OF PERMITTED PRECIOUS METAL MINES IN MONTANA	23
8	WATER REQUIREMENTS AND PRODUCTION FOR PERMITTED PRECIOUS METAL MINES OBTAINING WATER FROM SURFACE SOURCES IN MONTANA	25
9	WATER REQUIREMENTS AND PRODUCTION FOR PERMITTED PRECIOUS METAL MINES OBTAINING WATER FROM GROUND WATER SOURCES IN MONTANA	26
10	WAGES AND SALARIES FROM METAL MINING IN THE UPPER AND LOWER MISSOURI RIVER BASIN	28
11	HISTORIC EXTRACTION OF GOLD AND SILVER IN THE MISSOURI RIVER BASIN	29
12	PROVEN GOLD AND SILVER RESERVES IN THE MISSOURI RIVER BASIN	32
13	LIVESTOCK AND CROPS CASH RECEIPTS IN THE UPPER MISSOURI RIVER BASIN	34
14	LIVESTOCK AND CROPS CASH RECEIPTS IN THE LOWER MISSOURI RIVER BASIN	35

Table		Page

15 IRRIGATED AND NON-IRRIGATED LAND IN UPPER MISSOURI RIVER BASIN 36

16 IRRIGATED AND NON-IRRIGATED LAND IN LOWER MISSOURI RIVER BASIN 37

I. INTRODUCTION

The Montana Department of Fish, Wildlife and Parks (MDFWP) is preparing an application for reservation of water in the Missouri River Basin.[1] As part of the application, MDFWP must discuss direct and indirect benefits and costs of the reservation on future economic activities and environment in the Basin.

This report presents information on the current status of major economic activities in the Missouri River Basin including recreation, agriculture, industries, and municipalities. The indirect benefits and costs of granting MDFWP the reservation of water also are discussed.

---

[1] The Missouri River Basin in this report includes all waters of the Missouri River and its tributaries upstream from the Fort Peck Dam. Canyon Ferry Dam is the dividing point between what are referred to in this report as the "upper" and "lower" basins.

II. DIRECT BENEFITS OF THE RESERVATION

A. Tourism and Recreation

Tourism, one of the fastest growing industries in Montana, is directly affected by the quality of the natural environment, particularly rivers and streams. In 1986, nearly 2.8 million non-residents visited Montana, generating over $475,000,000 in income for the state (Montana Department of Commerce 1988).

According to a survey of tourism in Montana conducted by Montana State University (Brock et al. 1984), 95.4 percent of non-residents surveyed perceived Montana as good or excellent in terms of the state's outdoor recreation amenities. Similarly, 91.3 percent of surveyed non-resident anglers reported Montana to have good or excellent angling opportunities.

Data from the Sport Fishing Institute also indicate that Montana is highly valued for its fishery resource. In 1987, for example, Montana ranked fourth in the nation for the number of non-resident fishing licenses sold. Although Montana ranks 44th nationally in population, it attracts a disproportionately large number of non-resident anglers because of its unique and productive cold-water fisheries resource.

A study conducted by the University of Montana (Frost and McCool 1986) documented that the Missouri River Basin is extensively used for water-based recreation by state, national, and foreign residents. Fifty-six percent of Montanans fish and over 30 percent float in rafts, canoes, and kayaks. Frost and McCool (1986) reported that about 35 percent of river floaters considered rivers in the Missouri River drainage to be their favorite Montana streams to float. The favorite Montana stream cited by floaters was the Yellowstone (19.7 percent) followed by the Missouri (11.2 percent) and the Madison (8.8 percent).

The economic values that accrue from fishing on Montana's rivers and streams are considerable. Stream fishing alone in 1985 was valued at over $122,000,000 annually (Duffield et al. 1987). Residents of Montana typically traveled an average of 119 miles per fishing trip, whereas non-residents traveled an average of 1,521 miles per fishing trip. Expenditures by Montanans for stream fishing were $36 per person per trip, whereas non-residents spent $536 per person per trip.

Duffield et al. (1987) calculated that the total recreational value of streams of the Missouri River drainage upstream from Canyon Ferry Dam is $50,962,000 per year, or 42 percent of the total value of all streams within the state (Table 1). The mainstem Madison River is the most valuable fishing water in the state with an estimated economic value of $17,509,000 per year, followed by the Gallatin River with an annual value of $9,722,000 (Table 1). The Madison River also has the heaviest fishing pressure of any water in the state with 108,712 angler days per year.

The net economic value of fishing in the Missouri River drainage between Canyon Ferry Reservoir and Fort Peck Dam is estimated to be $11,478,000 (Table 2). Approximately 9 percent of the total fishing value of all streams in the state is derived from streams in the lower Missouri River Basin. Together the streams in both the upper and lower Missouri River Basin provide about 51 percent of the statewide fishing-related values.

TABLE 1

RECREATIONAL VALUE BY SITE FOR STREAMS IN THE UPPER MISSOURI RIVER BASIN

Stream	Value Per Day	Annual Angler Days	Annual Site Value
Gallatin Tributaries (combined)	$171.54	14,045	$ 2,409,000
Upper Missouri	$ 87.72	25,419	$ 2,230,000
Jefferson	$ 79.21	29,129	$ 2,307,000
Beaverhead	$ 95.75	24,239	$ 2,321,000
Big Hole	$108.55	47,910	$ 5,201,000
East Gallatin	$142.80	6,191	$ 884,000
Gallatin	$152.22	63,871	$ 9,722,000
Madison	$161.06	108,712	$17,509,000
Madison Tributaries (combined)	$254.04	11,224	$ 2,851,000
Beaverhead Tributaries (combined)	$139.47	25,878	$ 3,609,000
Big Hole Tributaries (combined)	$103.07	18,621	$ 1,919,000
Total		375,239	$50,962,000
Average	$136.00		$ 4,633,000

State Total $122,315,000

Percent of State Total 42%

Source: Duffield *et al*. 1987.

TABLE 2

RECREATIONAL VALUE BY SITE FOR STREAMS IN THE LOWER MISSOURI RIVER BASIN

Stream	Value Per Day	Annual Angler Days	Annual Site Value
Missouri River (between Marias River and Fort Peck Dam)	$ 77.84	22,340	$ 1,739,000
Missouri River (Canyon Ferry to Marias River)	$ 61.36	67,557	$ 4,145,000
Marias River	$ 58.77	5,925	$ 348,000
Musselshell River	$ 55.96	11,218	$ 628,000
Missouri River (Holter to Cascade)	$ 50.33	72,788	$ 3,663,000
Smith River	$ 70.96	11,824	$ 839,000
Smith River Tributaries (combined)	$ 16.29	7,143	$ 116,000
Total		198,795	$11,478,000
Average	$ 55.93	28,399	$ 1,640,000

State Total $122,315,000

Percent of State Total 9.4%

Source: Duffield *et al.* 1987.

In addition to fishing, there are other water-based recreational values of streams in the Missouri River Basin. Floating, camping, swimming, and hunting are also popular recreational activities directly associated with the Missouri River and its tributaries. There is very little economic data available that allows for economic analysis of the values of the Missouri River and its tributaries for recreation other than fishing. The values reported for Duffield et al. (1987) for streams in Montana would be significantly higher if recreational values in addition to fishing were considered.

The Bureau of Land Management (U.S. Department of the Interior 1988) reported that 66,585 visitors spent 75,582 visitor days annually along the Wild and Scenic reach of the Missouri River, between Fort Benton and Fred Robinson Bridge. Based on recreational surveys conducted in 1987, these visitors floated, camped, hunted, and fished along this 149-mile portion of the river. Assuming that the recreational value for all outdoor recreation would be similar to the value of fishing reported by Duffield et al. (1987) (i.e., $77.84 per day, Table 2), the recreational value of the Wild and Scenic portion of the Missouri River, based on Bureau of Land Management data, would be $5,883,303 per year.

Recreational use of the Smith River by floaters and fishermen has been monitored by MDFWP since 1984. This popular floating and fishing river receives the most recreational use during late May, June, and early July, when the water levels are the highest. During the rest of July and the months of August and September, recreational use declines sharply due to low water levels brought about by irrigation diversions and naturally low flows during dry years (Table 3). During 1987, approximately 1,240

TABLE 3

NUMBER OF FLOATERS USING THE SMITH RIVER

Month/Week	1987	1986	1984	Total
May				
Week 1	52	79	35	166
Week 2	63	15	35	113
Week 3	118	55	93	266
Week 4	260	264	45	569
June				
Week 1	119	167	50	336
Week 2	183	233	147	563
Week 3	140	240	349	729
Week 4	58	380	413	851
July				
Week 1	10	114	502	626
Week 2	55	142	119	316
Week 3	57	114	32	203
Week 4	57	47	33	137
August				
Week 1	28	42	34	104
Week 2	7	31	18	56
Week 3	10	14	24	48
Week 4	23	34	3	60
Total	1,240	1,971	1,932	5,143

Source: Montana Department of Fish, Wildlife and Parks, Helena, Montana.

floaters spent a total of about 5,133 days on the river (Montana Department of Fish, Wildlife and Parks 1987). According to Duffield et al. (1987), the total annual value of the Smith River for fishing is $837,000. Because all Smith River floaters do not fish, the total value for both floating and fishing would be higher. Data collected by MDFWP show that about 25 percent of those floaters do not fish. Assuming that recreational value of floating is comparable to the value for fishing (i.e., $70.96 per day based on Duffield et al. (1987)), the total value for floating and fishing would be approximately $1,160,000 per year.

The recreational, economic, and aesthetic values of the rivers and streams in the Missouri River Basin clearly reflect premier Montana resources. An instream flow reservation would preserve these unique and significant natural resource values for the present and future benefits of the public and economic well-being of the state.

MDFWP, in recognition that fishing is an important recreational activity in Montana, has developed long-range, comprehensive plans (SCORP) to ensure that future management is consistent with future public demands on the fishing resource in the state (Montana Department of Fish, Wildlife and Parks 1986). In 1984, anglers throughout the state spent a total of 1,365,000 days fishing in rivers and streams. By 1990, fishing is expected to increase by about 11 percent to 1,531,400 angler days statewide (Montana Department of Fish, Wildlife and Parks 1986).

Fishing pressure in 1984 in MDFWP Regions 3 and 4 (approximately three-fourths of the Missouri River Basin) was 714,800 angler days, about 54 percent of all stream fishing in the state. By 1990, the demand for fishing is projected to increase by more than 12 percent in Regions 3 and

4 to over 804,500 angler days. Adequate instream flows to maintain the fishing resource are essential to meet the projected future demand for fishing and other water-based forms of recreation.

III. DIRECT COSTS OF THE RESERVATION

A. Stream Gaging

Some stream reaches of the Missouri River Basin do not have gages at appropriate locations to adequately monitor streamflows. Once reservations are granted, monitoring of streamflow on the stream reaches may be necessary for protection of the granted flows. Costs of installing gages would range from $600 to $17,500 per gage, depending on the level of technology required for adequate monitoring (Karp 1987). Annual operating costs would range from $800 to $5,500, depending on the complexity of the monitoring program (Karp 1987).

IV. INDIRECT BENEFITS OF THE RESERVATION

A. Hydropower

Maintaining instream flows through a water reservation would provide monetary benefits through electrical generation. Water that is available in the Missouri River system passes through seven major hydropower generating facilities in Montana, North Dakota, and South Dakota. Table 4 presents the average generating capacity of each facility and the cumulative electrical generation per acre-foot of water as it passes from one facility to the next one down the Missouri River system.

There are varying concepts of how water in streams and reservoirs are most appropriately valued. Doth the Western Area Power Administration (WAPA) and the U.S. Corps of Army Engineers (Corps) have provided estimates of the value of an acre-foot of water in the Missouri River Basin for hydropower. The value of an acre-foot of water passing through the seven hydropower facilities would depend on the sale price of electricity. According to WAPA, the price of electricity ranges from 7.5 mils per kilowatt hour (KWH) for "firm" power to 14 mils per KWH for "surplus" power (Dick Schirk, pers. comm., 1987). Based on the cumulative generation of electricity through the Missouri River mainstem dams (Table 4), the value of an acre-foot of water would range from $5.83 to $10.88.

John Velehradsky (pers. comm., 1988), Chief of the Planning Division of the Corps in Omaha, Nebraska, estimated that an acre-foot of water flowing through the six[2] mainstem dams from Fort Peck Reservoir

---

[2] This estimate did not include Canyon Ferry Dam.

TABLE 4

KILOWATT HOUR (KWH) GENERATION PER ACRE-FOOT (AF) OF WATER (Median Water or Most Probable Runoff)

Power Plant	Average Generation (KWH/AF)	Cumulative (KWH/AF)
Gavins Point	35	777
Fort Randall	95	742
Big Bend	56	647
Oahe	154	591
Garrison	148	437
Fort Peck	164	289
Canyon Ferry	125	125

Source: Western Area Power Administration, January 20, 1984.

downstream would produce $4.90 worth of electrical power. This figure was based on a value of 7.23 mils per KWH of electricity.

Velehradsky also stated that the perceived benefits of hydropower are much greater than $4.90 worth of electricity produced per acre-foot of water. If new power sources must be brought on line, the cost could be 60 mils per KWH or higher, or equivalent to about $41.00 per acre-foot.

Instream flow reservations would help maintain the electrical generating capacity of the hydropower plants on the Missouri River. Hydropower plants currently provide some of the most economical electrical power in the western states.

B. Pollution Control

Maintaining instream flows in the upper Missouri River Basin would provide sufficient water volumes to dilute wastewater discharges from municipalities and industrial sources as well as return flows from irrigation systems. Currently, there are 43 municipalities, 46 industries, and 20 placer mining operations in the Missouri River Basin with discharge permits issued by the Montana Department of Health and Environmental Sciences (DHES) (Table 5).

DHES issues permits to municipalities and industries to discharge wastewater into streams where there are sufficient streamflows to dilute wastes. Each discharge permit has criteria attached specifying that receiving waters would be protected as long as streamflow does not fall below the 7-day, 10-year low flow[3] limit for a given stream. If the flow of receiving water falls below the 7-day, 10-year limit, waste discharges

[3]The 7-day, 10-year low flow is the lowest flow that would occur at a probability of once every 10 years for a 7-day consecutive period.

TADLE 5

MONTANA PERMIT DISCHARGE ELIMINATION SYSTEMS - MUNICIPAL, INDUSTRIAL, AND PLACER MINE PERMITS

Permittee	County	Receiving Water	Permit Expiration Date
A. MUNICIPAL PERMITS			
Dillon	Beaverhead	Beaverhead River	01-31-89
Townsend	Broadwater	Missouri River	05-31-93
Belt	Cascade	Belt Creek	01-31-89
Great Falls WTP	Cascade	Missouri River	05-31-92
Great Falls	Cascade	Missouri River	09-30-92
Village Water & Sewer	Cascade	Sun River	03-31-93
Vaughn	Cascade	Sun River	12-31-89
Big Sandy	Chouteau	Big Sandy Creek	10-31-88
Geraldine	Chouteau	Flathead Creek	05-31-93
Chouteau/Highwood	Chouteau	Highwood Creek	01-31-89
Fort Benton WTP	Chouteau	Missouri River	05-31-89
Fort Benton WTP	Chouteau	Missouri River	08-31-91
Denton	Fergus	Wolf Creek	01-31-89
Lewistown	Fergus	Big Spring Creek	01-31-89
Willow Creek Sewer	Gallatin	Unnamed Drain Ditch	07-31-90
Bozeman	Gallatin	East Gallatin River	05-31-93
Three Forks	Gallatin	Madison River	10-31-89
Manhattan	Gallatin	Gallatin River	09-30-92
Cut Bank	Glacier	Cut Bank Creek	05-31-93
Browning	Glacier	Depot Creek/Willow Creek	05-31-86
Whitehall	Jefferson	Jefferson River	12-31-89
Hillbrook Nursing Home	Jefferson	Prickly Pear Creek	03-31-89
Boulder	Jefferson	Boulder River	03-31-89
Hobson	Judith Basin	Unnamed Drainage	09-30-88
Stanford	Judith Basin	Skull Creek	05-31-91
Helena	Lewis & Clark	Prickly Pear Creek	05-31-91
US BOR Canyon Ferry	Lewis & Clark	Missouri River	08-31-89
US BOR CF Govt Camp	Lewis & Clark	Missouri River	08-31-89
Helena WTP	Lewis & Clark	Prickly Pear Creek	09-30-91
East Helena	Lewis & Clark	Prickly Pear Creek	05-31-91
Sheridan	Madison	Mill Creek	03-31-89
Ennis	Madison	Madison River	09-30-88
White Sulphur Springs	Meagher	Lone Willow Creek	05-31-93
Valier	Pondera	Unnamed Dry Creek Bed	11-30-89
Conrad	Pondera	Marias River	07-31-89
Brady Water Users	Pondera	South Pondera Coulee	05-31-93

Table 5 (continued)

Permittee	County	Receiving Water	Permit Expiration Date
MUNICIPAL PERMITS (continued)			
Choteau	Teton	Teton River	01-31-89
Fairfield	Teton	Freezeout Lake	05-31-93
Dutton	Teton	Hunt Coulee	05-31-93
Toole/Sweetgrass	Toole	Unnamed Dry l. Bed	05-31-93
Sunburst	Toole	Unnamed Dry l. Bed	01-31-90
Shelby	Toole	Marias River	05-31-93
Fort Peck	Valley	Missouri River	05-31-93
B. INDUSTRIAL PERMITS			
Anaconda Minerals	Cascade	Missouri River	02-28-89
Janetski, Lee B.	Cascade	Missouri River	06-30-90
Antonioli, Mrs. P.	Cascade	Squaw Creek	12-31-89
MPC-Rainbow	Cascade	Missouri River	06-30-89
MPC-Black Eagle	Cascade	Missouri River	06-30-89
MT Refining Co.	Cascade	Missouri River	07-01-88
MPC-Ryan	Cascade	Missouri River	06-30-89
Genco Industries	Cascade	Belt Creek	07-31-92
Blue Range Mining	Fergus	Big Spring Creek	10-31-89
Blue Range Eng.	Fergus	East Fork Fords Creek	09-30-91
SourDough Cr. Prop.	Gallatin	Various	08-31-91
Ideal Basic Ind.	Gallatin	Missouri River	02-28-91
Beren Corp.	Glacier	Unnamed Slough	06-01-91
Flying J, Inc.	Glacier	Spring Coulee	05-31-93
Corbin Water Users	Jefferson	Corbin Creek	05-31-91
Boulder Hot Springs	Jefferson	Little Boulder River	05-31-92
MT Tunnels Mining	Jefferson	Trib. to Spring Creek	10-31-91
Pangea Mining	Jefferson	Basin Creek	05-31-93
Pangea Mining	Jefferson	Monitor Creek	05-31-93
Ash Grove Cement	Jefferson	Prickly Pear Creek	12-31-89
Gulf Titanium	Lewis & Clark	Jennies Fork	09-30-91
Black Hawk Mining	Lewis & Clark	Banner Creek	09-30-90
Clark, Dexter	Lewis & Clark	Spring Creek	12-31-92
MT Gold & Sapphire	Lewis & Clark	Missouri River	06-30-88
MPC-Holter	Lewis & Clark	Missouri River	06-30-89
MPC-Hauser	Lewis & Clark	Missouri River	06-30-89
Century Silver	Lewis & Clark	Ten Mile Creek	08-31-92
Liquid Air Corp.	Lewis & Clark	Prickly Pear Creek	12-31-89
Uncle Sam Mines	Madison	Middle Fork Mill Creek	04-30-92
U.S. Grant Gold	Madison	Alder Creek	01-31-92
Rocky Mtn. Minerals	Madison	Rochester Creek	05-31-89
Red Pine/Shermont	Madison	Indian Creek	02-28-90
MT Talc	Madison	Johnny Gulch Creek	09-30-92
Cyprus Ind. Min.	Madison	Middle Fork Stone Creek	07-31-89

Table 5 (continued)

Permittee	County	Receiving Water	Permit Expiration Date
INDUSTRIAL PERMITS (continued)			
MPC-Madison	Madison	Madison River	06-30-89
Denimil Resources	Madison	Pony Creek	12-31-89
Cyprus Ind. Min.	Madison	Sweetwater Creek	05-31-93
Zortman-Landusky	Phillips	King Creek	10-31-91
Zortman-Landusky	Phillips	Various	10-31-91
Malta Ready Mix	Phillips	Milk River-Dodson Canal	05-31-93
Western Reserves	Toole	Unnamed Closed Basin	07-31-89
Texaco, Inc.	Toole	Stockponds	10-31-88
Silver Fox Oil	Toole	Ephemeral Drainage	04-01-89
A & G Oil & Gas	Toole	Stockponds	04-30-88
East. Amer. Energy	Toole	Unnamed Coulee	12-31-87
Devon Water, Inc.	Toole	Tiber Reservoir	11-30-88
C. PLACER MINES & SUCTION DREDGES			
Golden Star	Beaverhead	Big Moosehorn Creek	09-90
Golden Star	Beaverhead	Ruby Creek	09-90
Golden Star	Beaverhead	Little Moosehorn Creek	09-90
Miragliotta, Vito	Beaverhead	Jeff Davis Creek	08-88
Searle Bros.	Beaverhead	Jeff Davis Creek	03-93
Towner, Bob	Beaverhead	Grasshopper Creek	07-89
Wright, Alan	Broadwater	Indian Creek	03-92
Klies, Forrest	Jefferson	Jack Creek	10-90
Klies, Forrest	Jefferson	Basin Creek	10-90
Jefferson Creek	Lewis & Clark	Jefferson Creek	06-86
Holzworth, Dick	Lewis & Clark	Skelly Creek	03-88
Modern Expl., etc.	Lewis & Clark	Prickly Pear Creek	12-92
Morris, Bud	Lewis & Clark	Hauser Lake	05-93
MT Gold & Sapphire	Lewis & Clark	Missouri River	06-88
Fredriksen, etc.	Lewis & Clark	Missouri River	12-92
Sypult, Cleatus	Lewis & Clark	Madison Gulch	10-90
Placer Recovery	Lewis & Clark	Jefferson Creek	02-93
Brown's Gulch	Madison	Brown's Gulch Creek	09-86
Parker, Rodney	Madison	Barton Gulch	06-90
Lince, Carol G.	Madison	California Creek	08-92

Source: Montana Department of Health and Environmental Sciences, Helena, Montana, 1988.

would not necessarily be curtailed but the biological integrity of the streams would no longer be protected (Loren Bahls, pers. comm., 1988).

Instream flow reservations would help prevent streams receiving wastewater discharges from dropping below the 7-day, 10-year low flow limit established to prevent water quality degradation and damage to aquatic ecosystems. If flows should be depleted below minimum levels to provide adequate dilution of wastewater discharge, prevention of damage to aquatic ecosystems would only be avoided by suspending the discharge of wastewater to streams with flows lower than the 7-day, 10-year low flow limit. Preventing industries and municipalities from discharging during periods when the low flow criteria are not met would pose serious operational and economic consequences. Either treatment facilities would need to be upgraded to reduce the quantity of various chemical compounds and organic materials in wastewater, or effluents would have to be disposed of on land or through some other means. Such measures would be extremely expensive methods of preventing damage to streams. Preventing damage to aquatic ecosystems through maintenance of instream flows would be more cost effective than upgrading sewage treatment facilities or land disposal of wastewater.

In addition to providing dilution for effluents discharged by municipalities and industries, streamflows in the Missouri River and its tributaries dilute return flows from irrigated farm land. Return flows from irrigation systems and other non-point sources from farming, ranching, and forest practices contribute soluble inorganic salts as well as pesticides and other organic materials, including bacteria, to surface waters. Water reservations would help provide adequate dilution of chemicals and bacteria entering surface waters due to these activities. Adequate dilution is important for human health and for maintaining suitable water quality for other uses such as recreation.

C. Public Health

Natural levels of toxic elements present in the Missouri River drainage also require adequate dilution to reduce human health hazards. High concentrations of the toxic metal arsenic originate from geothermal sources in Yellowstone Park and enter the Missouri River drainage via the Madison River (U.S. Geological Survey 1987). Tributaries to the Madison dilute arsenic concentrations, lowering concentrations downstream. The Environmental Protection Agency (EPA) measured arsenic concentrations of 200 to 300 micrograms per liter (ug/l) in the upper Madison River and concentrations of 20 to 40 ug/l in the Missouri River upstream from Canyon Ferry Reservoir (at Toston). Human health concerns exist because the allowable limit for arsenic in drinking water is 50 ug/l (U.S. Environmental Protection Agency 1986).

Data collected by the U.S. Geological Survey (USGS) in 1985 (U.S. Geological Survey 1987), show that arsenic levels exceed drinking water standards in the Madison River below Hebgen Lake (i.e., 78 to 180 ug/l), below Ennis Lake (49 to 100 ug/l), and at Three Forks (45 to 87 ug/l). Arsenic levels in the Missouri River at Toston ranged from 22 to 40 ug/l and below Canyon Ferry Reservoir from 22 to 34 ug/l.

Between March 1986 and September 1988, 16 samples were collected by USGS from the Madison River at the Yellowstone Park boundary near West Yellowstone. The mean concentration of arsenic was 252 ug/l (max. = 360; min. = 140) (U.S. Geological Survey 1989). The Jefferson and Gallatin rivers which do not have high arsenic concentrations are normally major diluters of the arsenic concentrations in the Madison River. A water sample collected by USGS on August 17, 1988 (a drought year) at Toston contained 100 ug/l dissolved arsenic (twice the EPA drinking water standard). The previous maximum concentration recorded from 58 samples collected at that site since 1972 was 52 ug/l. The mean concentration of all 58 samples was 24 ug/l (U.S. Geological Survey 1989).

Extremely low flows prevailed in the Jefferson and Gallatin rivers in 1988. On August 17, 1988, the flow in the Jefferson River was only 52 cubic feet per second (8 percent of the long-term daily mean flow) and the Gallatin River was at only 60 percent of its long-term mean daily flow (U.S. Geological Survey 1989). This lack of streamflow for dilution caused the increased concentration of arsenic at Toston on August 17, 1988, illustrating the importance of instream flow for water quality.

V. INDIRECT COSTS OF THE RESERVATION

A. Mining

Industry in the Missouri River Basin historically has been and continues to be dominated by mining and processing of mined products. Currently, there are approximately 36 active mining operations in the basin that have been issued permits by the Montana Department of State Lands (DSL) for the mining of talc (5 permits), gold (16 permits), limestone (5 permits), gypsum (2 permits), silica/quartz (6 permits), iron (1 permit), and chlorite (1 permit) (Table 6).

The existing gold mines are primarily placer mines which are non-consumptive water users, and mines which extract gold through cyanide leaching of ore. Quartz and limestone are quarried for the production of cement, the processing of which consumes no water except for domestic purposes (i.e., drinking water and wastewater treatment). Talc and gypsum chlorite mines consume little or no water in mining and processing.

Additional gold mines have permits pending in the Upper Missouri River Basin. The AGAU/Montoro Joint Venture in the Rattlesnake Creek drainage near Argenta proposes to process ore through cyanide heap leaching. The Yellowband Mine, also near Argenta, would process gold and silver ore through a flotation mill.

New gold and silver mines probably would be the major future industrial consumers of water in the Missouri River Basin. To estimate the amount of water that might be needed by future mines, water use by existing mines in Montana has been determined (Table 7). Water use for 13 mines obtaining water from both surface and ground water sources was 6,882.6 gallons per minute (gpm) for processing 208,400 tons of ore.

TABLE 6

OPERATING MINES PERMITTED BY THE DEPARTMENT OF STATE LANDS IN THE MISSOURI RIVER BASIN

Company	County	Stream Drainage	Product	Process
Mt. Heagan Development Inc.	Jefferson	Boulder River	Gold	Cyanide Heap Leach
Searle Bros. Construction, Inc.	Beaverhead	Horse Prairie Creek	Gold	Placer
S and G Mining	Jefferson	Boulder River	Gold	Placer
Browns Gulch Mining	Madison	Alder Gulch	Gold	Placer
RLTCO	Beaverhead	Grasshopper Creek	Gold	Placer
Golden Sunlight Mine	Jefferson	Jefferson River	Gold	Cyanide Vat Leaching
Golden Star Mine	Beaverhead	Big Hole River	Gold	Placer
Continental Lime Inc.	Jefferson	Indian Creek	Limestone	Quarry
Hemphill Bros. Inc.	Jefferson	Boulder River	Quartz	Quarry
Stauffer Chemical Co.	Beaverhead	Big Hole River	Quartz	Quarry
Ideal Basic Industries	Gallatin	Missouri River	Limestone	Quarry
Cyprus Industrial	Madison	Madison River	Talc	Mine
Cyprus Industrial	Madison	Madison River	Talc	Mine
Cyprus Industrial	Beaverhead	Beaverhead River	Talc	Mine
Pfizer Inc.	Beaverhead	Beaverhead River	Talc	Mine
Willow Creek Talc	Madison	Ruby River	Talc	Mine
Cyprus Industrial	Jefferson	Jefferson River	Chlorite	Mine
Spotted Horse	Fergus	Spotted Horse Gulch	Gold	Cyanide Leach
Pauper's Dream	Lewis & Clark	Ten Mile Creek	Gold	Cyanide Leach

Table 6 (continued)

Company	County	Stream Drainage	Product	Process
Pegasus	Phillips	Ephemeral Drainage	Gold	Cyanide Leach
Montana Tunnels	Jefferson	Spring Creek	Gold	Cyanide Leach
Mortenson Construction	Cascade	Missouri River	Gravel	Quarry
Intergem	Meagher	Missouri River	Iron	Open Pit
Walter Savoy	Cascade	Sun River	Rip-rap	Quarry
Chouteau County	Chouteau	Teton River	Rock Rip-rap	Quarry
Ash Grove Cement	Jefferson	Prickly Pear Creek	Limestone	Quarry
U.S. Gypsum	Jefferson	Prickly Pear Creek	Gypsum	Quarry
Maronick Construction	Judith Basin	Judith River	Gypsum	Quarry
Maronick Construction	Jefferson	Prickly Pear Creek	Limestone	Quarry
Special Lady	Lewis & Clark	Ten Mile Creek	Gold	Placer
St. Joseph	Lewis & Clark	Ten Mile Creek	Gold	Placer
Gulf-Titanium	Lewis & Clark	Little Prickly Pear Creek	Gold	Cyanide Leach
AMAX	Judith Basin	Judith River	Gold/Silver	Cyanide Leach
Kendall Venture	Fergus	Judith River	Gold	Cyanide Leach
Pacific Silica	Jefferson	Prickly Pear Creek	Silica	Quarry
Indian Creek	Jefferson	Indian Creek	Limestone	Quarry

Source: Montana Department of State Lands, Helena, Montana. Permit Application Files (November, 1988).

TABLE 7

WATER REQUIREMENTS, WATER SOURCES, AND PRODUCTION OF PERMITTED PRECIOUS METAL MINES IN MONTANA[1]

Mine	County	Production (tons/day)	Water Consumption (gpm)	Water Source
Spotted Horse	Fergus	50	1.6	Discharge from existing adit
Pauper's Dream	Lewis & Clark	1,500	28	Wells
ASARCO-Troy	Lincoln	60,000	1,700	Wells
Pegasus	Phillips	80,000	1,700	Wells
Jardine	Park	1,050	300	Bear Creek and Pine Creek
Beal Mountain	Silver Bow	5,500	200	Beefstraight Creek
Chartam	Broadwater	3,000	300	Wells
CoCa	Flathead	5,000	660	Wells
Black Pine	Granite	1,000	5	South Fork Lower Willow Creek
Montana Tunnels	Jefferson	15,000	918	600 to 900 gpm from Spring Creek, Prickley Pear Creek, and Clancy Creek, 90 gpm from adits
Golden Sunlight	Jefferson	35,000	700	Jefferson Slough
Mt. Heagan	Jefferson	300	20	Slaughterhouse Gulch Creek
Stillwater	Stillwater	1,000	350	Mine workings & wells
Total		208,400	6,882.6	
Average		16,031	529.4	

1 gpm to process 30.3 tons/day

Source: Montana Department of State Lands, Helena, Montana. Permit Application Files (November, 1988).

[1]All of these mines are not in the Missouri River Basin.

Average water use was 529.4 gpm and average ore production was 16,031 tons per day (an average of 1 gpm is required to process 30 tons per day of ore).

Water use and production for mines obtaining water from surface sources (Table 8) was compared with water use and ore production for mines obtaining water from ground water sources (Table 9). Mines obtaining water from surface sources processed a total of 57,850 tons of ore per day and used 2,197,440 gallons of water per day (1 gpm to process 38 tons/day). Mines obtaining water from ground water sources processed 150,550 tons of ore per day and used 6,825,600 gallons of water per day (1 gpm to process 31.8 tons/day). Approximately 72 percent of the ore mined was processed utilizing ground water.

The impact that water reservations would have on future mining development in the Missouri River Basin would be related to the number of new mines opened and the water sources used to process ore. Estimating the numbers of mines that would open is speculative given the volatile nature of precious metals prices. Typically, gold and silver mining follow "boom and bust" cycles. Although mining in Montana may currently be expanding, it is not possible to predict whether this trend will continue.

According to McCulloch _et al_. (1988), gross production in 1988 from metal mines in Montana was up 45 percent from the previous year. The number of new or renewal exploration permits issued by the Montana Department of State Lands also has increased from 56 in 1982 to 111 in 1987 and 192 in 1988 (McCulloch _et al_. 1988). Although it is speculative to predict future precious metal mining activities in the Missouri River

TABLE 8

WATER REQUIREMENTS AND PRODUCTION FOR PERMITTED PRECIOUS METAL MINES OBTAINING WATER FROM SURFACE SOURCES IN MONTANA

Mine	County	Production (tons/day)	Water Consumption (gpm)	Water Source
Jardine	Park	1,050	300	Bear Creek and Pine Creek
Beal Mountain	Silver Bow	5,500	200	Beefstraight Creek
Black Pine	Granite	1,000	5	South Fork Lower Willow Creek
Golden Sunlight	Jefferson	35,000	700	Jefferson Slough
Mt. Heagan	Jefferson	300	20	Slaughterhouse Gulch Creek
Montana Tunnels	Jefferson	15,000	300	Spring Creek
Total		57,850	1,525	
Average		9,642	254	

1 gpm to process 38 tons/day

Source: Montana Department of State Lands, Helena, Montana, Permit Application File (November, 1988)

TABLE 9

WATER REQUIREMENTS AND PRODUCTION FOR PERMITTED PRECIOUS METAL MINES OBTAINING WATER FROM GROUND WATER SOURCES IN MONTANA

Mine	County	Production (tons/day)	Water Consumption (gpm)	Water Source
Pauper's Dream	Lewis & Clark	1,500	28	Wells
Spotted Horse	Fergus	50	1.6	Discharge from existing adit
ASARCO-Troy	Lincoln	60,000	1,700	Wells
Pegasus	Phillips	80,000	1,700	Wells
Chartam	Broadwater	3,000	300	Wells
CoCa	Flathead	5,000	660	Wells
Stillwater	Stillwater	1,000	350	Mine workings & wells
Total		150,550	4,739.6	
Average		21,507	677	
		1 gpm to process 31.8 tons/day		

Source: Montana Department of State Lands, Helena, Montana. Permit Application Files (November, 1988).

Basin, a 7-year trend was tabulated of wages and salaries paid to miners in the Missouri River Basin from 1981-87 (Table 10). As shown in Table 10, mining in the Missouri River Basin provided 41.2 percent of salaries and wages paid throughout the state for metal mining in 1987. Wages and salaries increased in the upper Missouri River Basin from $2,392,000 in 1981 to $11,937,000 in 1987. In the lower Missouri River Basin, wages and salaries increased from $4,359,000 in 1981 to $7,876,000 in 1987.

Fairly reliable estimates of the remaining precious metals resources in the Missouri River Basin can be derived by examining past mining activities in the basin because future mining is predicted to occur where mining has historically taken place (Terry Webster and Rai Hahn, pers. comm., 1988). New mining and ore processing technologies have made it economically feasible to extract metals from ore bodies that were previously not mined. According to Hahn (1988), minimum reserves of gold and silver in Montana are 8,012,000 and 617,165,000 ounces, respectively. Historic production of gold and silver in Montana was 20,396,000 and 950,253,000 ounces, respectively. The ratio of present estimated metal reserves compared to past production is 1:2.5 for gold and 1:1.5 for silver. If the estimated reserves of gold were correct, there are approximately .40 ounces of gold reserves for every ounce that already has been mined. Similarly, there are approximately .67 ounces of silver reserves for each ounce that has been mined.

To obtain an estimate of gold and silver reserves in the Missouri River Basin, historic gold and silver production was tabulated for mining districts in the basin (Table 11). Approximately 57 percent of all gold and 16 percent of all silver mined in the state came from mining districts

TABLE 10

WAGES AND SALARIES FROM METAL MINING IN THE
UPPER AND LOWER MISSOURI RIVER BASIN
(Thousands of Dollars)

		Lower Missouri River Basin		Upper Missouri River Basin	
Year	State Total	Wages/Salaries	Percent of State Total	Wages/Salaries	Percent of State Total
1987	$48,078	$7,876	16.4%	$11,937[1]	24.8%
1986	$33,944	$4,928	14.5%	$ 5,760	17.0%
1985	$26,812	$3,392	12.6%	$ 5,091[2]	19.0%
1984	$32,988	$6,737	20.4%	$ 4,864[3]	14.7%
1983	$44,683	$4,311	9.6%	$ 6,044	13.5%
1982	$52,448	$3,406[4]	6.5%	$ 2,307	4.4%
1981	$57,756	$4,359[5]	7.5%	$ 2,392	4.1%
Average	$42,387	$5,001	11.8%	$ 5,485	12.9%

Source: Montana Department of Labor and Industry, Montana Employment, Wages, and Contributions, Annual Average 1981-1987.

[1] Excludes Broadwater County for purposes of confidentiality.

[2] Excludes Beaverhead County for purposes of confidentiality.

[3] Excludes Gallatin County for purposes of confidentiality.

[4] Excludes Meagher County for purposes of confidentiality.

[5] Excludes Cascade County for purposes of confidentiality.

TABLE 11

HISTORIC EXTRACTION OF GOLD AND SILVER IN THE MISSOURI RIVER BASIN[1]

Mining District	County	Production (ounces) Gold	Silver
Argenta	Beaverhead	64,400	562,000
Bannack	Beaverhead	387,000	141,000
Bluewing	Beaverhead	500	470,000
Bryant	Beaverhead	17,400	13,924,000
Elkhorn	Beaverhead	2,000	387,000
Polaris	Beaverhead	300	120,000
Vipond	Beaverhead	1,100	1,025,000
Confederate Gulch	Broadwater	650,000	7,570
Park	Broadwater	120,000	394,000
Radersburg	Broadwater	325,000	311,000
Winston	Broadwater	118,000	2,058,000
Neihart	Cascade	67,000	29,070,000
North Moccasin	Fergus	450,000	50,000
Warm Springs	Fergus	335,000	317,000
Alhambra/Basin	Jefferson	15,400	118,000
Boulder	Jefferson	480,000	14,770,000
Clancy	Jefferson	140,000	2,500,000
Elkhorn	Jefferson	100,000	12,600,000
Whitehall	Jefferson	563,000	277,000
Wickes	Jefferson	372,000	47,700,000
Barker	Judith Basin	3,500	2,738,000
Gould/Stemple	Lewis & Clark	345,000	500,000
Heddleston	Lewis & Clark	--	1,409,000
Lincoln	Lewis & Clark	682,000	120,000
Marysville	Lewis & Clark	1,390,000	8,880,000
York	Lewis & Clark	335,000	--
Rimini/Scratchgravel	Lewis & Clark	100,000	100,000
Norris	Madison	265,000	102,000
Pony	Madison	346,000	227,000
Renova	Maiison	162,000	113,000
Sheridan	Madison	40,000	105,000
Silver Star	Madison	225,000	152,000
Tidal Wave	Madison	33,400	133,000
Virginia City	Madison	2,617,000	1,456,000

Table 11 (continued)

Mining District	County	Production (ounces) Gold	Silver
Washington	Madison	16,600	42,000
Castle Mountain	Meagher	--	4,270,000
Little Rockies	Phillips	960,000	2,440,000
Total		11,728,600	149,688,570
State Total		20,396,000	950,253,000
Percent of State Total		57.5%	15.7%

Source: Hahn, 1988. Gold and Silver Districts in Montana.

[1]Only mines which have produced more than 10,000 ounces of gold or more than 100,000 ounces of silver are listed.

in the Missouri River Basin. Assuming that the ratio of reserves to mined production were 1:2.5 for gold and 1:1.5 for silver, there would be approximately 4,691,440 ounces of gold reserves and 100,224,342 ounces of silver reserves remaining in historic mining districts in the Missouri River Basin. Approximately 28 percent of the original reserves of gold and 40 percent of the original reserves of silver remain to be mined in the Missouri River Basin, provided new technologies allow for cost-effective extraction of these metals.

Estimating future metals production in the Missouri River Basin based on past statewide production may underestimate the future metals reserves in the basin. Data for "proven"[4] gold and silver reserves in the Missouri River Basin as of January 1989 (Rai Hahn, pers. comm. 1989) are shown in Table 12. Assuming that both the statewide metals reserves and the Missouri River Basin proven reserves are correct, proven gold reserves in the basin would be 91 percent of the total state reserves. Similarly, the proven silver reserves in the basin would be 34 percent of the total state reserves.

Reservations of instream flows in the Missouri River drainage would have no impact on existing mining or new mines utilizing ground water, but they may affect future mining and ore processing if the new mines would rely entirely upon surface water for consumptive purposes. Development of new mines requiring surface water could be adversely affected, particularly during periods of low stream flow, unless water storage facilities were utilized.

---

[4]Proven reserves are silver and gold deposits that have been measured utilizing exploration methods. It is assumed that metals from these ore bodies could be economically extracted at 1988 metals prices.

TABLE 12

PROVEN GOLD AND SILVER RESERVES
IN THE MISSOURI RIVER BASIN

District	Gold Reserve	Silver Reserve
Winston	360,000	--
North Moccasin	60,000	--
Warm Springs	24,000	175,000
Elkhorn	500,000	--
Whitehall	2,500,000	2,500,000
Wickes	2,520,000	23,660,000
Lincoln	103,000	120,000
Marysville	50,000	--
Rimini	270,000	--
Jardine	330,000	--
New World	100,000	--
Little Rockies	500,000	7,750,000
Total	7,317,000	34,205,000

Source: Montana Department of State Lands, Helena, Montana, 1989.

B. Agriculture

Revenues from agriculture in the Missouri River Basin are nearly equally provided by livestock and crop production. Average cash receipts from crops for the 7-year period (1980-86) contributed approximately 43 percent of the total state crop revenues (see average values in Tables 13 and 14). Similarly, livestock production in the Missouri River Basin provided about 43 percent of total state livestock revenues (see average values in Tables 13 and 14).

Irrigated land in the Missouri River Basin comprises about 50 percent of all irrigated land in the state (Tables 15 and 16). Non-irrigated land in the basin makes up about 43 percent of all dryland agriculture on a statewide basis (Tables 15 and 16). The upper Missouri River Basin has about 24 percent of the irrigated land in the state (Table 15), whereas the lower Missouri River Basin has approximately 25 percent of the irrigated land in the state. The lower basin differs from the upper basin primarily in the amount of dryland farming. The lower basin has about 40 percent of the dryland agriculture in the state as compared with only 2.4 percent of the total state dryland farming in the upper basin.

Instream water reservations would not affect existing agricultural use in the basin, but they may limit future expansion of irrigated agriculture in some areas. The Montana Department of Natural Resources and Conservation (DNRC) is currently conducting studies of potentially irrigable lands in the Missouri River Basin. As part of the DNRC's analysis of water reservation applications in the basin, they will conduct

TABLE 13

LIVESTOCK AND CROPS CASH RECEIPTS
IN THE UPPER MISSOURI RIVER BASIN[1]
(Thousands of Dollars)

Year	Livestock Receipts	State Total	Percent of State Total	Crop Receipts	State Total	Percent of State Total
1986	$119,700	$838,353	14.3%	$37,385	$493,015	7.6%
1985	$124,522	$902,859	13.8%	$42,639	$422,444	10.1%
1984	$114,022	$844,683	13.5%	$34,684	$653,780	5.3%
1983	$ 98,651	$731,537	13.5%	$44,893	$846,939	5.3%
1982	$ 88,667	$724,805	12.2%	$60,714	$980,328	6.2%
1981	$ 86,218	$705,528	12.2%	$53,007	$854,196	6.2%
1980	$ 98,470	$828,880	11.9%	$41,102	$660,450	6.2%
Average	$104,321	$796,663	13.1%	$44,918	$701,593	6.4%

Source: Montana Crop and Livestock Reporting Service.

[1]Includes Beaverhead, Broadwater, Gallatin, Jefferson, and Madison counties.

TABLE 14

LIVESTOCK AND CROPS CASH RECEIPTS
IN THE LOWER MISSOURI RIVER BASIN[1]
(Thousands of Dollars)

Year	Livestock Receipts	State Total	Percent of State Total	Crop Receipts	State Total	Percent of State Total
1986	$241,741	$838,353	28.8%	$184,082	$493,015	37.3%
1985	$272,147	$902,859	30.1%	$136,036	$422,444	32.2%
1984	$248,880	$844,683	29.5%	$252,933	$653,780	38.7%
1983	$215,725	$731,537	29.5%	$328,134	$846,939	38.7%
1982	$228,313	$724,805	31.5%	$355,893	$980,328	36.3%
1981	$222,745	$705,528	31.6%	$311,016	$854,196	36.4%
1980	$261,051	$828,880	31.5%	$240,195	$660,450	36.4%
Average	$241,515	$796,663	30.3%	$258,327	$701,593	36.8%

Source: Montana Crop and Livestock Reporting Service.

[1] Includes Cascade, Chouteau, Fergus, Glacier, Judith Basin, Lewis and Clark, Meagher, Phillips, Pondera, Teton, Toole, Petroleum, Wheatland, Golden Valley, Musselshell, and Garfield counties.

TABLE 15

IRRIGATED AND NON-IRRIGATED LAND IN UPPER MISSOURI RIVER BASIN[1]

Year	Upper Missouri River Basin Irrigated	State Total	Percent of State Total	Upper Missouri River Basin Non-irrigated	State Total	Percent of State Total
1987	360,770	1,618,500	22.3%	201,400	7,623,000	2.6%
1986	344,470	1,601,000	21.5%	175,000	7,814,200	2.2%
1985	428,830	1,635,200	26.2%	171,500	5,977,500	2.8%
1984	481,300	1,805,600	26.7%	164,400	7,377,400	2.2%
1983	395,700	1,538,900	25.7%	220,700	7,151,400	3.1%
1982	417,850	1,729,900	24.1%	155,400	7,926,200	2.0%
1981	426,350	1,733,300	24.6%	144,000	7,932,600	1.8%
Average	407,896	1,666,057	24.5%	176,057	7,400,329	2.4%

Source: Montana Crop and Livestock Reporting Service.

[1]Includes Beaverhead, Broadwater, Gallatin, Jefferson, and Madison counties.

TABLE 16

IRRIGATED AND NON-IRRIGATED LAND
IN LOWER MISSOURI RIVER BASIN[1]

Year	Lower Missouri River Basin Irrigated	State Total	Percent of State Total	Lower Missouri River Basin Non-irrigated	State Total	Percent of State Total
1987	410,150	1,618,500	25.3%	3,121,000	7,623,000	40.9%
1986	429,280	1,601,000	26.8%	3,207,900	7,814,200	41.1%
1985	382,500	1,635,200	23.4%	2,367,800	5,977,500	39.6%
1984	462,700	1,805,600	25.6%	3,141,500	7,377,400	42.6%
1983	405,400	1,538,900	26.3%	2,959,100	7,151,400	41.4%
1982	460,400	1,729,900	26.6%	3,105,100	7,926,200	39.2%
1981	426,800	1,733,300	24.6%	3,097,100	7,982,600	38.8%
Average	425,319	1,666,057	25.5%	2,999,929	7,407,471	40.5%

Source: Montana Crop and Livestock Reporting Service.

[1]Includes Cascade, Chouteau, Fergus, Glacier, Judith Basin, Lewis and Clark, Meagher, Phillips, Pondera, Teton, Toole, Petroleum, Wheatland, Golden Valley, Musselshell, and Garfield counties.

detailed economic and environmental studies concerning the costs and benefits of granting or not granting competing water reservations.

C. Municipal Water Supplies

Five municipalities in the upper Missouri River basin expect to need more water to supply commercial, residential, and industrial needs by the year 2025 (HKM Associates 1987). Three of the communities (Dillon, Three Forks, and Belgrade) plan to obtain the needed water from wells, whereas West Yellowstone and Bozeman will supplement their water supply from surface waters.

West Yellowstone plans to pump 2,550 acre-feet per year from Whiskey Springs at a rate of 1,582 gpm by the year 2025. Bozeman predicts that it will need an additional 4,030 acre-feet per year to supplement ground water sources and water available from Hyalite Reservoir. Bozeman plans to construct a dam on Bozeman Creek to provide the water required by the year 2025.

Granting of instream flow reservations would probably not conflict with the needs of Bozeman for additional water because the proposed dam on Bozeman Creek would probably fill during the high flow period in the spring when requested instream flows are normally exceeded. Instream flow reservations could affect West Yellowstone's proposed project because no water storage is anticipated. However, such an effect would depend on the priority date of the instream reservations. Instream reservations would not conflict with those communities obtaining additional water from wells.

LITERATURE CITED

LITERATURE CITED

Bahls, L., Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena, Montana. Conversation (1988) with Joe C. Elliott, Ecological Consultant, Helena, Montana.

Brock, J., J. Larson, W. Muhs, M. Reilly, and J. Rogers. 1984. Montana tourism and marketing research project. Unpublished report prepared for the Montana Department of Commerce, Helena, Montana.

Duffield, J., J. Loomis, and R. Brooks. 1987. The net economic value of fishing in Montana. Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Frost, J. and S. McCool. 1986. The Montana outdoor recreation needs survey. Prepared for the Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Hahn, R. Gold and silver districts of Montana. 1988. Geological Society of America, Abstracts with Programs, Vol. 20, p. 276.

Hahn, R., Hard-Rock Mining Bureau, Montana Department of State Lands, Helena, Montana. Conversations (1988 and 1989) with Joe C. Elliott, Ecological Consultant, Helena, Montana.

HKM Associates. 1987. Application for reservation of water for Three Forks, Belgrade, Dillon, Bozeman, and West Yellowstone. Submitted to the Montana Department of Natural Resources and Conservation, Helena, Montana.

Karp, R. 1987. Gaging station costs. Unpublished report submitted to the Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Knapton, R., U.S. Geological Survey. Telephone conversation (January 10, 1989) with Liter Spence, Montana Department of Fish, Wildlife and Parks, Helena, Montana.

McCulloch, R., B. Berg, and M. Sholes. 1988. Mining and mineral developments in Montana - 1988. Montana Bureau of Mines and Geology, Butte, Montana.

Montana Department of Commerce, Helena, Montana. 1988. The economic impacts of travel/tourism in 1986. Unpublished report.

Montana Department of Fish, Wildlife and Parks, Helena, Montana. 1986. Design for tomorrow. 1985-1990. A strategic plan for management of Montana's fish, wildlife, and parks resources.

Montana Department of Fish, Wildlife and Parks, Helena, Montana. 1987. Smith River annual report for 1987 - The year of the boat camp declaration map. Unpublished report.

Schirk, R., Western Area Power Administration, Billings, Montana. Conversation (1987) with Joe C. Elliott, Ecological Consultant, Helena, Montana.

U.S. Department of the Interior, Bureau of Land Management, Lewistown, Montana. 1988. FY 87 Recreation use statistics, incident summary, and volunteer reports. Unpublished report.

U.S. Environmental Protection Agency. 1986. National primary drinking water regulations. 40 C.F.R. Part 141, July 1, 1986 edition.

U.S. Geological Survey. 1987. Arsenic data for streams in the Upper Missouri River Basin, Montana and Wyoming. Open-file report 87-124. Prepared for the Montana Department of Health and Environmental Sciences, Helena, Montana.

Velehradsky, J., Chief, Planning Division, U.S. Army Corps of Engineers, Omaha, Nebraska. Letter of November 10, 1987, to Liter Spence, Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Webster, T., Hard-Rock Mining Bureau, Montana Department of State Lands, Helena, Montana. Conversation (1988) with Joe C. Elliott, Ecological Consultant, Helena, Montana.

U.S. Geological Survey. 1989. Phone communication between Roger Knapton, USGS, Helena, MT. and Liter Spence, Mont. Dept. Fish, Wildlife and Parks, Helena, MT. January 10, 1989.

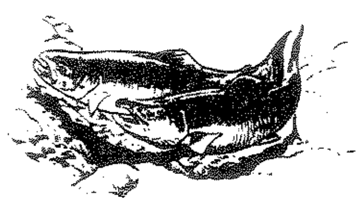
THE MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS' MISSOURI RIVER WATER RESERVATION REQUEST IS IN THE PUBLIC INTEREST

Suggested Format and Arguments To Address
ARM 36.16.105 C(1)(a),(b) and (c)

Prepared By

Ken Knudson
Ecological Resource Consulting
540 Breckenridge
Helena, Montana 59601

April 10, 1989



THE MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS' MISSOURI RIVER WATER RESERVATION REQUEST IS IN THE PUBLIC INTEREST

Suggested Format and Arguments To Address
ARM 36.16.105 C(1)(a),(b) and (c)

Prepared By

Ken Knudson
Ecological Resource Consulting
540 Breckenridge
Helena, Montana 59601

April 10, 1989

PREFACE

The following information was taken primarily from two earlier reports prepared for the Department of Fish, Wildlife and Parks - "Information For the Public Interest Portion of the Missouri River Water Application" (Ken Knudson; July 31, 1988) and "The Direct and Indirect Benefits and Costs of Granting a Water Reservation for In-Stream Flows in the Missouri River Basin" (Joe Elliot; January, 1989).

With suggestions from Mr. Elliot and Liter Spence of the Department, Mr. Knudson combined and edited the above reports into the format that follows. He also prepared most of the narrative for the Direct and Indirect Benefits sections, as well as the discussion covering the effects of not granting the reservation.

Mr. Elliot prepared some of recreational use data found in the Direct Benefits section. He also researched and wrote most of the material addressing indirect economic costs, as well as some of the material for indirect economic benefits of the reservation.

Liter Spence provided invaluable guidance and editing throughout the preparation of this document. Fred Nelson, Dick Vincent and Steve Leathe of the Department provided editorial suggestions for the Direct Benefits section.

Both authors have listed all written information sources, as well as all persons verbally contacted for additional or clarifying information, in the Literature Cited section.

TABLE OF CONTENTS

Preface i
List of Tables iv
List of Figures vi

I. Direct Benefits and Costs of the Reservation 1

A. Direct Benefits 1

1. Fisheries and Fishing Opportunities 1

2. Floating 14

3. Other Benefits 17

B. Direct Costs 18

II. Indirect Benefits and Costs of the Reservation 19

A. Effects of the Reservation on Future Economic Activity 19

1. An Overview of Indirect Economic Benefits . . 19

2. Economic Benefits to Other Users or Parties . 26
a. Municipalities 26
b. Industry 31
c. Agriculture 39

B. Effects of the Reservation on the Environment, Public Health, Welfare and Safety 40

1. An Overview of Indirect Non-Economic Benefits 40

2. Non-Economic Benefits to Other Uses or Parties 43
a. Municipalities 43
b. Industry 46
c. Agriculture 46

C. Economic Opportunity Costs of the Reservation . . 49

1. An Overview of Indirect Economic Costs . . . 49

2. Economic Costs to Other Uses or Parties . . . 50
a. Municipalities 50
b. Industry 52
c. Agriculture 66

III. Effects of Not Granting the Reservation 73

A. Loss of Irretrievable Resources 73

B. Alternative Actions That Could Be Taken if the Reservation is Not Granted 75

1. No Action 75

2. Intensification of Water Conservation and Management Practices 75

3. Buying or Leasing Water Rights 76

4. Constructing Offstream Water Storage Facilities 78

5. Revising the Process for Conditioning Water Rights Permits 80

6. Closing Basins 81

7. Application of the Public Trust Doctrine . . 83

IV. Literature Cited 85

LIST OF TABLES

Table		Page
1	ANGLER USE OF STREAMS IN THE UPPER MISSOURI RIVER BASIN DURING 1985	5
2	ANGLER USE OF STREAMS IN THE UPPER MISSOURI RIVER BASIN DURING 1985	10
3	NUMBER OF FLOATERS USING THE SMITH RIVER	15
4	NET RECREATIONAL FISHING VALUES OF STREAMS IN THE UPPER MISSOURI BASIN DURING 1985	23
5	NET RECREATIONAL FISHING VALUES OF STREAMS IN THE LOWER MISSOURI BASIN DURING 1985	25
6	KILOWATT HOUR (KWH) GENERATION PER ACRE-FOOT (AF) OF WATER	32
7	MONTANA PERMIT DISCHARGE ELIMINATION SYSTEMS - MUNICIPAL, INDUSTRIAL, AND PLACER MINE PERMITS	36
8	OPERATING MINES PERMITTED BY THE DEPARTMENT OF STATE LANDS IN THE MISSOURI RIVER BASIN	53
9	WATER REQUIREMENTS, WATER SOURCES, AND PRODUCTION OF PERMITTED PRECIOUS METAL MINES IN MONTANA	56
10	WATER REQUIREMENTS AND PRODUCTION FOR PERMITTED PRECIOUS METAL MINES OBTAINING WATER FROM SURFACE SOURCES IN MONTANA	57
11	WATER REQUIREMENTS AND PRODUCTION FOR PERMITTED PRECIOUS METAL MINES OBTAINING WATER FROM GROUND WATER SOURCES IN MONTANA	59
12	WAGES AND SALARIES FROM METAL MINING IN THE UPPER AND LOWER MISSOURI RIVER BASIN	60
13	HISTORIC EXTRACTION OF GOLD AND SILVER IN THE MISSOURI RIVER BASIN	62
14	PROVEN GOLD AND SILVER RESERVES IN THE MISSOURI RIVER BASIN	65
15	LIVESTOCK AND CROPS CASH RECEIPTS IN THE UPPER MISSOURI RIVER BASIN	67

Table Page

16 LIVESTOCK AND CROPS CASH RECEIPTS IN THE LOWER MISSOURI RIVER BASIN 68

17 IRRIGATED AND NON-IRRIGATED LAND IN UPPER MISSOURI RIVER BASIN 69

18 IRRIGATED AND NON-IRRIGATED LAND IN LOWER MISSOURI RIVER BASIN 70

LIST OF FIGURES

Figure Page

1 FISHING USE OF MONTANA RIVER BASINS, 1985 4

2 NET RECREATIONAL FISHING VALUES OF MONTANA RIVER BASINS, 1985 22

I. Direct Benefits and Costs of the Reservation

The following is pursuant to ARM 36.16.105 c(1)(a) of the Water Reservation Rules, e.g. "In making a showing that the reservation is in the public interest, the application shall contain . . . an analysis of the direct benefits and costs associated with applying reserved water to the proposed beneficial use." Direct benefits and costs are defined at ARM 36.16.102 (6) and (7) as "benefits and costs to the reservant derived from applying reserved water to the use for which it is granted." The following, therefore, describes the public benefits and costs of the reservation as they apply to the stream-based recreational resources managed by the Department of Fish, Wildlife and Parks on the portions of the Missouri River included in this reservation request.

A. Direct Benefits

1. Fisheries and Fishing Opportunities

Interest and utilization of public fishing resources in Montana continue to increase, despite the state's stable (or at times declining) population over the past two decades. In 1966, 159,466 resident fishing licenses were sold. By 1976 these sales had increased to 170,000. In 1986, despite reports of recent wide-spread emigration from the state, 183,291 resident fishing licenses were sold (Herman 1988).

Data from the Sport Fishing Institute indicate that Montana is also highly valued for its fishery resource by people from outside the state. In 1987, Montana ranked fourth in the nation for the number of non-resident fishing licenses sold. Despite being relatively isolated from major population centers, Montana attracts a disproportionately large number of nonresident anglers because of its unique and productive fisheries resource. The opinions of these visitors reflect the quality of fishing in Montana; 91.3 percent of surveyed non-resident anglers reported

Montana to have good or excellent angling opportunities (Brock et al. 1984).

The national significance of Montana trout streams was also brought clearly into focus in the spring, 1989, issue of Trout - The Magazine for Trout and Salmon Anglers. The feature article of this issue, a special publication commemorating the thirtieth anniversary of the magazine, was "America's 100 Best Trout Streams" (Alexander, et al. 1989). Of these nationally-acclaimed fishing streams, 12 are in Montana, which is the highest total of any state in the nation. Alaska ranks second to Montana with 11 listed streams, followed by Idaho (9), New York (6), and Wyoming (6). It is significant to note that 6 of America's best 100 trout streams, i.e. the Beaverhead, Big Hole, Gallatin, Madison, Missouri, and Smith rivers, are in the portion of the Missouri Basin covered by this reservation request.

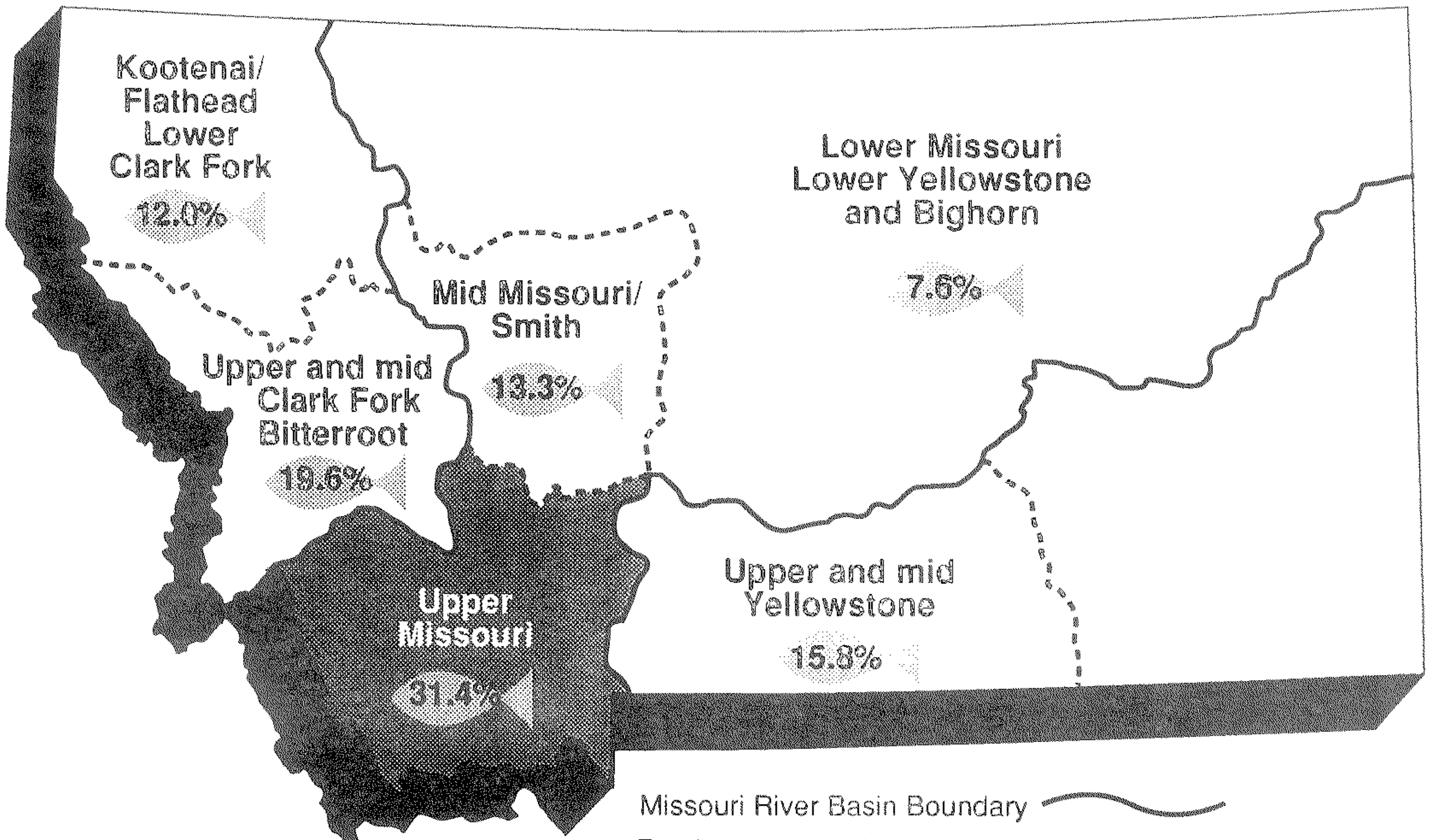
Even though fishing represents only one of many stream-related recreational activities, it can serve as a valuable indicator of overall recreational use. Based upon questionnaires sent to fishing license holders, the DFWP annually estimates the fishing pressure (angler use) of streams in Montana. During May through October, 1985, the Department increased the intensity of this angler survey by doubling the number of questionnaires normally mailed (McFarland 1988). The results of this research emphasized the exemplary stream-based, public recreational benefits of the upper Missouri River.

The rivers and streams of the Missouri above Canyon Ferry Reservoir accounted for 375,239 of the total 1,193,000 days spent stream fishing in Montana during 1985. Despite being less than 10% of the geographic area of Montana, the upper Missouri supported 31.4% of the state's stream fishing. As is illustrated in Figure 1, no other geographic area of similar or even larger size supported nearly as high a percentage of total stream fishing in Montana. Angler use of streams in the upper Missouri Basin during 1985 is tabulated in Table 1.

The fact that hundreds of thousands of people annually fish the upper Missouri Basin is testimony to the exceptional wild (naturally-reproducing) trout fishery that is found there. Very high angler success rates for wild brown and rainbow trout have made the Madison one of the most popular rivers in North America. Some reaches of the Madison contain over 3,500 catchable trout per mile. The salmonfly hatches of the Madison, Big Hole and Gallatin rivers are legendary, attracting a following of anglers who annually chase "the hatch" from river to river. Due to its relatively undeveloped watershed, the Big Hole is one of the largest trout streams outside of designated national wilderness areas that remains essentially non-turbid during runoff. This river is also home to the last major population of river-dwelling arctic grayling in the lower forty-eight states. The Gallatin River is another nationally-acclaimed trout stream, offering a wide variety of fishing experiences--from swift-gradient, mountain canyons to slow-moving, broad valley sections.

Figure 1. Fishing Use of Montana River Basins, 1985

Values are the percentage of total, state-wide fishing days occuring in each river basin, and were computed from information collected during the 1985 DFWP fisheries survey (McFarland, 1988).



For the purpose of this map, the mid Missouri is the mainstem from Canyon Ferry Reservoir to the mouth of the Marias River.

TABLE 1

ANGLER USE OF STREAMS
IN THE UPPER MISSOURI RIVER BASIN DURING 1985

Stream	Annual Angler Days
Beaverhead River	24,239
Big Hole River	47,910
East Gallatin River	6,191
Gallatin River	63,871
Madison River	108,712
Jefferson River and Tributaries	29,129
Upper Missouri River and Tributaries above Canyon Ferry Dam	25,419
Madison River Tributaries	11,224
Gallatin and East Gallatin River Tributaries	14,045
Beaverhead River Tributaries (includes Ruby and Red Rock rivers and tributaries)	25,878
Big Hole River Tributaries	18,621
Total	375,239

State Total 1,193,000 days

Percent of State Total 31.4%

Source: McFarland 1988.

The Madison, Big Hole and Gallatin rivers, while certainly exceptional fishing streams on a national scale, are really not that unusual in the trout-rich upper Missouri Basin. Along with these three rivers, the Missouri mainstem from Toston Dam to Canyon Ferry Reservoir and the Beaverhead River are also rated by the Department of Fish, Wildlife and Parks as Class One, "blue ribbon" trout streams. This distinction has been given to only a select number of streams in Montana that are considered to have "the highest valued fishery resource" in the state. The Ruby, East Gallatin, Jefferson, and Red Rock rivers are also very important trout streams, as are many tributaries of the basin's major rivers. The latter not only serve as vital spawning streams for the larger rivers, but also often contain an abundance of resident trout. These smaller trout streams provide heavily-utilized backcountry stream fishing opportunities. For example, the Big Hole River tributaries which received 18,624 days of angler use in 1985, support significant fisheries for rainbow, brook and cutthroat trout as well as arctic grayling.

Below the confluence of the Madison, Jefferson and Gallatin rivers, the mainstem of the Missouri and numerous tributaries continue to provide additional high-quality trout fishing opportunities. The river above Canyon Ferry Reservoir not only contains resident populations of rainbow and brown trout, it also supports heavily-fished spawning migrations of trout from the reservoir; these migrants are the primary reason for the "blue ribbon" rating of the River between Toston Dam and Canyon Ferry.

The six mile stretch of free-flowing river between Hauser Dam and Holter Reservoir is also a significant fishery for migrant trout and Kokanee salmon.

Fish migrations from other reservoirs and lakes provide many important stream fishing opportunities throughout the basin. In fact, all tributaries to reservoirs or lakes that contain a trout fishery will support spawning runs, but only if adequate habitat, water quality and instream flows exist in these feeder streams.

These spawning runs also help sustain the trout populations of reservoirs and lakes. Although many of these water bodies are routinely stocked with hatchery fish, successful runs of wild trout augment, and in some cases exceed, the contribution of planted fish. For example, in Hebgen and Harrison reservoirs, maintenance of trout populations is highly dependent upon natural reproduction. As well, reservoir-dwelling brook and brown trout rely on streams and/or spring areas for their reproductive needs, since hatchery plants of these species have essentially been discontinued in Montana during recent years.

The benefits of adequate instream flows therefore extend beyond flowing waters to include reservoirs and lakes. These waterbodies support a significant amount of recreational fishing. In 1985, reservoirs and lakes in the Missouri Basin above Holter Dam supported 322,661 angler days; in the basin below Holter Dam to Fort Peck Reservoir, these waterbodies supported 160,704 angler days (McFarland 1988). Combining these figures demonstrates that the portion of the Missouri Basin covered by the reservation request supported 483,365 days of reservoir and lakes fishing, which was 44.7 percent of the statewide total (Op.Cit.).

During 1985, the Missouri River from Holter Dam to Cascade sustained over six percent of all stream fishing in Montana (72,788 angler days). Since this high amount of usage occurred along only 35 miles of river, this reach of the Missouri received more recreational fishing per mile than any other stream in Montana. The Madison, for example, also received heavy use (108,712 angler days, the highest total use of any stream), but it was dispersed along more than 80 miles of river. Rainbow trout comprise the bulk of the fishery in the Holter Dam to Cascade reach, although trophy-sized brown trout, some as large as 15-20 pounds, are also occasionally taken by anglers.

From Cascade to its confluence with the Sun River near Great Falls, the Missouri continues to support a respectable trout fishery. Some trout are even found as far downstream as the confluence with the Marias River below Fort Benton.

The Smith River, which enters the Missouri just above Great Falls, is also an important trout stream. Although relatively small and inaccessible, it sustained 11,824 fishing days in 1985.

There are also other streams in the Missouri Basin that contain significant, locally-important trout populations. The upper Judith and Musselshell rivers, Big Spring Creek near Lewistown, and the twenty-mile reach of the Marias below Tiber Dam, provide quality trout fishing for residents of Lewistown, Harlowton, Chester and other nearby communities. In fact, for its size, Big Spring Creek is an exceptional rainbow and brown trout fishery, with population estimates approaching 3,000 catchable trout per mile (Leathe and Hill 1987). Without adequate instream flow protection for these and other tributaries of the lower Missouri, many residents of north-central Montana would have to travel several hours to obtain suitable alternatives for stream fishing.

From Morony Dam below Great Falls to Fort Peck Reservoir, the Missouri River and its tributaries support a warm water fishery of national, if not international, significance. Although it presently receives a relatively small amount of angler use (see Table 2 for angler use data of all streams in the lower Missouri), this 207-mile, free-flowing reach does contain an exceptionally diverse, unique and presently under-utilized fishery.

Of the 18 families and 80 species of fish reported to be found in Montana (Brown 1971), 14 families and 53 species are found in this reach and/or its tributaries. Of Montana's 52 native fish species, 35 can be found in the lower Missouri Basin (Berg 1981).

The paddlefish population of the lower Missouri/Fort Peck Reservoir system is of particular importance. Paddlefish are Montana's largest gamefish, with female specimens often reaching five to six feet in length and weighing 75 to 125 pounds. Once abundant during the Triassic Period 150 million years ago, these

TABLE 2

ANGLER USE OF STREAMS IN
THE LOWER MISSOURI RIVER BASIN DURING 1985

Stream	Annual Angler Days
Missouri River and Tributaries (between Marias River and Fort Peck Dam)	22,340
Missouri River (Canyon Ferry to Marias River; excluding Holter to Cascade)	67,557
Missouri River (Holter to Cascade)	72,788
Marias River	5,925
Musselshell River	11,218
Smith River	11,824
Smith River Tributaries	7,143
Total	198,795

State Total 1,193,000 days

Percent of State Total 16.7%

Source: McFarland 1988.

very primitive fish are presently found in only two river basins--the Yangtze in China and the Mississippi/Missouri system (Hubbs and Lagler 1967; Romer 1962). Even in these basins, the distribution and abundance of paddlefish have been dramatically reduced during the past 100 years (Pflieger 1975; Yasetskiy 1971). Although "spoonbill cats" once supported a significant commercial fishery, particularly along the Mississippi, stream channelization, dams, over-harvesting, and alteration of stream flows have reduced the range of paddlefish in the United States to only six isolated, self-sustaining populations.

Growth rates of paddlefish in the lower Missouri/Fort Peck system are superior to the other five remaining Mississippi/Missouri populations; the lower Missouri population is also older (in terms of average age of fish) and more secure than anywhere else in North America (Berg 1981). This security and biological success is largely due to the unaltered, free-flowing characteristics of this reach of river, which provides essential and irreplaceable spawning areas for paddlefish. Berg (1981) identified nine critical paddlefish spawning sites in the lower river from just below the confluence of the Marias River to just above Fort Peck Reservoir.

The relatively undeveloped characteristics of the lower Missouri also provide the most secure unaltered habitat remaining in the Mississippi/Missouri Basin for two other relics of the dinosaur era--the pallid and shovelnose sturgeons. Sitings of the pallid sturgeon have been rare over the past few decades

(Brown 1971; Holton 1981). Only one pallid sturgeon was captured in the lower Missouri during electrofishing studies conducted by the DFWP 1975-1980. Because of its presently rare occurrence, the U. S. Fish and Wildlife Service is considering listing the pallid sturgeon as an endangered species.

The shovelnose sturgeon population of the lower Missouri River is healthy and vigorous. Fish of this species residing in the Missouri above Fort Peck Reservoir are much larger than those found in the Missouri River in South Dakota, the Mississippi River in Iowa or the Chippewa River in Wisconsin. In these midwestern rivers, shovelnose sturgeon rarely exceeded 5 to 7 pounds, whereas several collected in the river system above Fort Peck have weighed over 10 pounds. In fact, the <u>average</u> weight and length of shovelnose from this Montana river reach, equalled or exceeded the <u>maximum</u> size of those from the South Dakota, Iowa and Wisconsin rivers (Berg 1981).

Significant sport populations of sauger and channel catfish are also found in the lower Missouri above Fort Peck. Growth of channel catfish in this river reach is equivalent or superior to growth in other northern waters; it also compares favorably with growth of this species in lakes and rivers of southern states (Op.Cit.). Channel catfish, sauger and shovelnose sturgeon all utilize the free flowing lower Missouri, as well as the lower Marias and Judith rivers for spawning. The lower Missouri also supports spawning runs of goldeye, bigmouth buffalo and smallmouth buffalo, which contribute to the commercial fishery in Fort Peck Reservoir.

Data for the lower Missouri river indicate relatively light harvest rates for all fish species. For example, only 0.5 percent of shovelnose sturgeon that were tagged by biologists were returned by anglers, compared to a 2.3 percent return in the Red Cedar/Chippewa River system in Wisconsin (Berg 1981). Priegel (1973), in studies on the Menominee River in Wisconsin, felt that sturgeon populations can sustain harvest rates of up to 5.0 percent without harm.

Cumulative paddlefish harvest rates in the lower Missouri are also low compared to other waters. Only 7.0 percent of the fish tagged during 1972-1977 were returned by anglers. This compares to a 13.8 percent return rate during 1964-1975 on the lower Yellowstone in Montana (Elser 1976), and a 24.5 percent rate of return during three years of tagging studies on the Osage River, Missouri (Purkett 1963). (This latter population no longer exists; paddlefish spawning sites on the free-flowing Osage River were eliminated by the reservoir behind Truman Dam in 1978.)

The above data, along with tag-return information for channel catfish and sauger, indicate that the lower Missouri is an under-utilized recreational fishing resource. Opportunities for steady growth in the recreational use of the lower Missouri is, therefore, very good. Protection of adequate instream flows will allow this potential to materialize.

2. **Floating**

Rivers and streams in Montana provide exceptional recreational benefits to a broad spectrum of the public. Fifty-six percent of all Montanans fish and over thirty percent float in rafts, canoes or kayaks (Frost and McCool 1986).

A study conducted by the University of Montana (Op.Cit.) documented that the Missouri River Basin is extensively used for water-based recreation by Montanans and out-of-state visitors. These researchers reported that about 35 percent of river floaters considered rivers in the Missouri River drainage to be their favorite Montana streams to float. The Montana stream most cited by floaters was the Yellowstone River (19.7 percent) followed by the mainstem of the Missouri (11.2 percent) and the Madison River (3.8 percent).

The Smith River is also very popular with floaters. Although agricultural water diversions usually restrict floating opportunities after mid-July, an average of 1,714 people floated the Smith during 1984-1986 (Table 3). Floating the Smith usually takes several days. Because of these multi-day floats, the Smith actually supported about 7,000 floating days per year from 1984-1986.

The Smith is the only river in the Missouri Basin above Fort Benton where floating use has been extensively evaluated. But, this is not to say that the Missouri and its tributaries are not extensively used, and popular, for floating. Nearly half of the

TABLE 3

NUMBER OF FLOATERS USING THE SMITH RIVER

Month/Week	1987	1986	1984	Total
May				
Week 1	52	79	35	166
Week 2	63	15	35	113
Week 3	118	55	93	266
Week 4	260	264	45	569
June				
Week 1	119	167	50	336
Week 2	183	233	147	563
Week 3	140	240	349	729
Week 4	58	380	413	851
July				
Week 1	10	114	502	626
Week 2	55	142	119	316
Week 3	57	114	32	203
Week 4	57	47	33	137
August				
Week 1	28	42	34	104
Week 2	7	31	18	56
Week 3	10	14	24	48
Week 4	23	34	3	60
Total	1,240	1,971	1,932	5,143

Source: Montana Department of Fish, Wildlife and Parks (1988).

pages of a popular Montana floating guide (Fisher 1979) are devoted to float trips in the Missouri Basin. From the spectacular canyons of the Dearborn, Smith and Gallatin rivers to the meandering solitude of the Marias, Red Rock and lower Missouri rivers, the basin abounds with floating opportunities.

The lower Missouri River from Fort Benton to Fort Peck Reservoir not only supports a unique, diverse and productive fish community, it is also the largest unaltered, free-flowing and relatively uninhabited segment of the nation's longest river. For 149 miles the river winds through spectacular breaks, cliffs and badlands within a gorge several hundred feet below the Great Plains. There are no channel pilings, flood walls, rock and concrete flow deflectors, dams, reservoirs or large irrigation structures that typify the "Mighty Mo" as it sluggishly travels from Fort Peck to its confuence with the Mississippi River. Only from Fort Benton to Fort Peck does the Missouri remain as it existed for prairie-dwelling Native Americans, Lewis and Clark, and the steamboats that vanguarded the first major immigration of white people into Montana during the last century. The number of modern-day adventurers that retrace this historic river route is significant. The Bureau of Land Mangement (U. S. Department of the Interior 1988) reported that 66,585 visitors enjoyed 75,582 visitor days annually along the Missouri between Fort Benton and the Fred Robinson Bridge, which is located just above Fort Peck Reservoir.

Congress, in recognition of the extraordinary biological, recreational, scenic and historical values found along this 149 miles of river, officially designated this reach as a National Wild and Scenic River in 1976. Although this designation does allow minor diversion and pumping of water for agricultural purposes, no dams are allowed and specific protection measures must be taken before any large-scale human-development can occur.

3. Other Benefits

The stream discharge rates requested in this application will not only benefit the fishing and floating recreational resources of the Missouri Basin, but they will also be vital for maintaining the health and vigor of stream-side (riparian) vegetation. The often shallow-rooted, water-loving plants found in riparian areas depend upon adequate instream flows to recharge shallow, stream-side aquifers.

Riparian areas contain highly diverse plant, songbird and small mammal populations. They are also the most productive wildlife areas in North America and are utilized extensively by big game, furbearers and waterfowl. The biological abundance and diversity found within riparian areas also adds to the number and kinds of people who recreate along streams; i.e. photographers, bird-watchers, science students, hunters, berry-pickers, naturalists, etc.

* * * * *

From its blue ribbon headwaters to its wild and scenic lower reaches, the Missouri and its tributaries are enormous recreational and aesthetic assets for the people of Montana and the nation. As will be discussed in the Indirect Benefits section of this application, the free-flowing Missouri River system also provides a substantial economic base for the people of Montana. In order to protect and provide the opportunity to enhance these direct public benefits, it is essential that the instream flows requested in this application be granted.

B. Direct Costs of the Reservation

Some stream reaches of the Missouri River Basin do not have gages at appropriate locations to adequately monitor streamflows. Once reservations are granted, monitoring of streamflow on the stream reaches may be necessary for protection of the granted flows. Costs of installing gages would range from $600 to $17,500 per gage, depending on the level of technology required for adequate monitoring (Karp 1987). Annual operating costs would range from $800 to $5,500, depending on the complexity of the monitoring program (Karp 1987).

The only other direct costs are those for DFWP operations to implement whatever program is required to protect the granted reservations. Specific information and costs cannot be given at this time.

II. Indirect Benefits and Costs of the Reservation

Indirect benefits and costs, as defined in ARM 36.16.102 (12) and (13), mean the benefits and costs of applying reserved water to beneficial use that accrue to other uses or to parties other than the reservant. For the purpose of this application "indirect," therefore, refers to "uses or parties other than" the DFWP; and the DFWP reservation will be the means "of applying reserved water to beneficial use."

ARM 36.16.105 C(1)(b) requires that all applications for reserved water include a discussion of the benefits and costs (to other uses or parties) associated with (the reservation) that considers effects on (i) future economic activity, (ii) the environment, (iii) public health and safety, and (iv) the economic opportunity costs that the requested flow may have to parties other than the reservant.

The economic considerations of these requirements, subsections (i) and (iv) are discussed below in **A. Effects of the Reservation on Future Economic Activity,** and in **C. Economic Opportunity Costs of the Reservation.** The indirect economic **benefits** of the reservation are covered in A., while indirect economic **costs,** including foregone opportunity costs, are addressed in C. Non-economic considerations, as per sections (ii) and (iii) above, are presented in **B. Effects of the Reservation on the Environment, Public Health, Welfare and Safety.**

When establishing and prioritizing water reservation requests, a major criterion utilized by the Board of Natural Resources and Conservation is an evaluation of the effects that a reservation may have upon "other uses or parties." The following discussion, therefore, presents the overall indirect benefits and costs of the MDFWP reservation as well as its specific effects upon municipal, agricultural and industrial users.

A. Effects of the Reservation on Future Economic Activity

1. An Overview of Indirect Economic Benefits

The instream flows requested in this application are necessary to protect the direct recreational and aesthetic benefits provided by the rivers and streams of the Missouri Basin. Protection of these amenities also significantly contributes to the economic well-being of Montana.

Tourism, one of the fastest growing segments of Montana's economy, is directly related to the amenities of the state's natural environment, particularly those provided by rivers and streams. In 1986, nearly 2.8 million non-residents visited Montana, generating over $475,000,000 in income for the state (Montana Department of Commerce 1988).

Most major highways in Montana closely parallel rivers and streams. It is along these waterways that visitors gather many of their lasting impressions of the state. According to a survey of tourism in Montana conducted by Montana State University (Brock et al. 1984), 95.4 percent of non-residents surveyed perceived Montana as good or excellent in terms of the state's outdoor recreation amenities. Maintaining the instream flows requested in this application will help protect the outstanding scenic and recreational values of the Missouri's free flowing waters. This will help ensure that tourists will continue to speak highly of the state's recreational amenities.

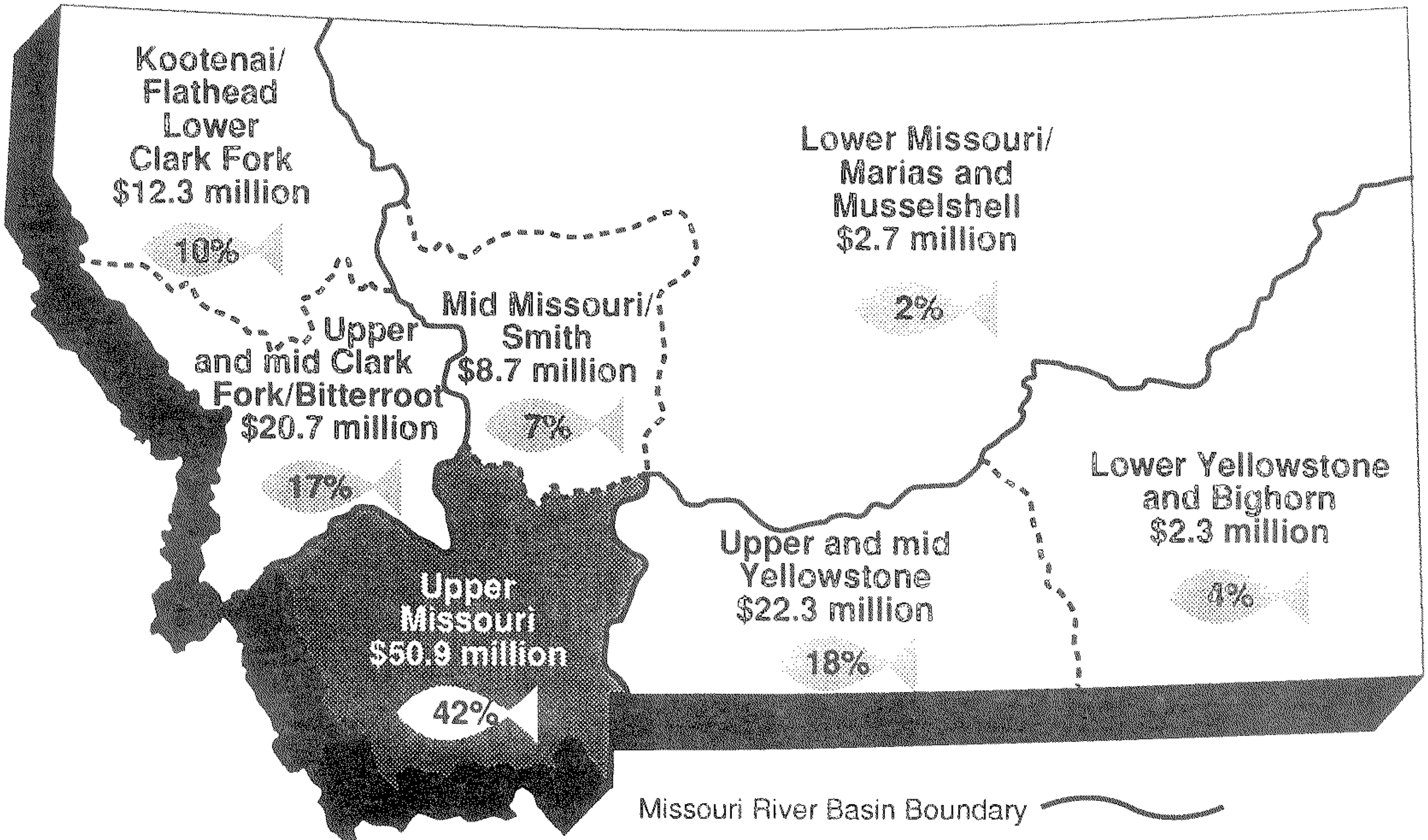
Since word of mouth is often the best advertisement for any commodity, satisfied tourists will in turn lead to continued growth for businesses supported by non-residents. Recent labor statistics for Montana revealed that growth in tourism-related, service-sector jobs is already significant. During the first half of the 1980s when the wood products, metal mining, energy development and agricultural industries were floundering, the service sector of Montana's economy steadily generated 18,000 new jobs (Powers 1987).

The recreational and aesthetic attributes of rivers and streams that attract tourists are also responsible for attracting new, economically-independent residents to Montana. As pollution, crowded conditions, crime rates and loss of natural areas continue to increase in major cities, an increasing number of retired people and/or persons endowed with sufficient interest, dividend or rent incomes, are choosing to move to areas with uncrowded, high-quality recreational opportunities and aesthetically-pleasing natural settings. Many of these people, especially those seeking unmatched fishing, floating and scenic values, are moving to the Missouri Basin in Montana. The contribution to Montana's economy made by these independent, "non-labor" income sources is already substantial; it presently accounts for over one-third of Montana's economic base. In recent years, non-labor income has added nearly 4 billion dollars per year to the state's economy, compared to Montana's total labor income of about 7 billion dollars per year (Op. Cit.).

Of the many recreational benefits provided by the rivers and streams of the Missouri Basin, fishing is unquestionably a highly-valued commodity. A recent economic study (Duffield et al. 1987) determined the total aggregate value of stream fishing in Montana to be $122,000,000 per year. Remarkably, $50,962,000 per year, 42% of the state-wide total, was attributable to streams and rivers in the basin above Canyon Ferry Reservoir (Figure 2). A breakdown of net recreational fishing values for streams in the upper Missouri Basin are presented in Table 4.

Figure 2. Net Recreational Fishing Values of Montana River Basins, 1985

Basin values were computed from information presented in Duffield et al. (1987). Numbers in fish outlines are percentages of state-wide stream fishing values found within the basins.



For the purpose of this map, the mid Missouri is the mainstem from Canyon Ferry Reservoir to the mouth of the Marias River.

TABLE 4

NET RECREATIONAL FISHING VALUES OF STREAMS IN THE UPPER MISSOURI RIVER BASIN DURING 1985

Stream	Value Per Day	Annual Angler Days	Annual Site Value
Beaverhead River	$ 95.75	24,239	$ 2,321,000
Big Hole River	$108.55	47,910	$ 5,201,000
East Gallatin River	$142.80	6,191	$ 884,000
Gallatin River	$152.22	63,871	$ 9,722,000
Madison River	$161.06	108,712	$17,509,000
Jefferson River and Tributaries	$ 79.21	29,129	$ 2,307,000
Upper Missouri River and Tributaries above Canyon Ferry Dam	$ 87.72	25,419	$ 2,230,000
Madison River Tributaries	$254.04	11,224	$ 2,851,000
Gallatin and East River Gallatin Tributaries	$171.54	14,045	$ 2,409,000
Beaverhead Tributaries (Includes Ruby and Red Rock Rivers and Tributaries)	$139.47	25,878	$ 3,609,000
Big Hole River Tributaries	$103.07	18,621	$ 1,919,000
Total		375,239	$50,962,000

State Total $122,315,000

Percent of State Total 42%

Source: Duffield *et al*. 1987.

Of the 45 streams and/or stream reaches evaluated by Duffield et al., the upper Missouri Basin was found to contain three of the most highly valued rivers in the state. The Madison was the most valuable river in Montana ($17,509,000 per year). The Gallatin was the third most valuable stream in the state ($9,722,000 per year), while the Big Hole was fourth ($5,201,000 per year). Only the upper Yellowstone ($10,905,000 per year) was more highly valued than the Gallatin or Big Hole.

The net economic value of fishing in the Missouri River drainage between Canyon Ferry Reservoir and Fort Peck Dam was estimated to be $11,478,000 (Table 5). Approximately nine percent of the total fishing value of all streams in the state was derived from streams in the lower Missouri River Basin. Together, the streams in both the upper and lower Missouri River Basin accounted for about 51 percent of the statewide fishing-related values.

The site values listed in Tables 4 and 5 were computed by multiplying the value of a fishing day on a given stream times the fishing pressure (as determined by the 1985 DFWP angler use survey). A Travel Cost Model was used to calculate the value per day for each stream. See Duffield et al. (1987) for a detailed discussion of this model.

Duffield et al. caution that their study did not quantify the total economic value of streams in Montana. Rather, it only addressed the economic benefits derived by present angler use.

TABLE 5

NET RECREATIONAL FISHING VALUES OF STREAMS IN THE LOWER MISSOURI RIVER BASIN DURING 1985

Stream	Value Per Day	Annual Angler Days	Annual Site Value
Missouri River (between Marias River and Fort Peck Dam)	$ 77.84	22,340	$ 1,739,000
Missouri River (Canyon Ferry to Marias River excluding Holter to Cascade)	$ 61.36	67,557	$ 4,145,000
Missouri River (Holter to Cascade)	$ 50.33	72,788	$ 3,663,000
Marias River	$ 58.77	5,925	$ 348,000
Musselshell River	$ 55.96	11,218	$ 628,000
Smith River	$ 70.96	11,824	$ 839,000
Smith River Tributaries	$ 16.29	7,143	$ 116,000
Total		198,795	$11,478,000
State Total	$122,315,000		
Percent of State Total	9.4%		

Source: Duffield *et al.* 1987.

These researchers further state that, based on the study's reported costs, the net present value (market value) of just fishing-related recreation for Montana streams is roughly 3.1 billion dollars.

In addition to fishing, streams provide many other recreational benefits. Floating, camping, picnicking, swimming, bird-watching, sight-seeing and hunting are also popular recreational activities conducted along the Missouri River and its tributaries. However, there is very little data available that allows for economic analysis of the values of stream recreation other than fishing. The economic value of the Missouri and other streams in Montana would, therefore, would be significantly higher than $122,000,000 per year if all river-based recreational activities were evaluated.

2. Economic Benefits to Other Uses or Parties

a. Municipalities

Municipalities will benefit from the DFWP reservation because of increased assurances about the future availability of drinking water. Maintenance of instream flow levels will, in turn, sustain water levels at city intake structures and infiltration galleries. If incremental stream flow depletions were to continue as they have occurred in the past, relocation of these supply structures and/or development of alternative water supplies could be necessary. Either of these alternatives would be costly for municipalities.

The effects of the DFWP reservation upon the availability of surface drinking water supplies are important considerations to be weighed during water reservation deliberations. However, the economic benefits of the reservation to stream-side communities also extend beyond the issue of municipal water supply sources. The recreational values of the free-flowing Missouri River system provide the basis for many thriving businesses in Ennis, West Yellowstone, Bozeman, Great Falls, Helena, Fort Benton, Three Forks and many other smaller river-side towns. The economic growth and stability of these communities, particularly the smaller ones, is highly dependent upon businesses supported by fishing, floating and other forms of river-based recreation.

Outfitting businesses, of course, most clearly benefit from the maintenance of adequate instream flows. The percentage of state-wide fishing-outfitting businesses that are located in the Upper Missouri Basin closely approximates the angler-use data displayed earlier in Figure 1. About 31% (83 out of 270) of the licensed fishing outfitters and guides who requested to be listed in the Department of Commerce's 1988 Montana Travel Planner were headquartered in cities and towns of the Upper Missouri Basin.

In 1986, a total of 205 registered Montana fishing outfitters provided 10,213 clients with 20,128 fishing days (Montana Department of Fish, Wildlife and Parks 1987). In that year, 187 outfitters also listed the major rivers that they worked. A total of 104 outfitters (56%) listed rivers and streams in the Missouri Basin.

Along with outfitting, municipalities in the Missouri Basin also depend upon the economic success of many other service sector businesses, ranging from motels, campgrounds and restaurants, to sporting goods stores, automobile service stations and gift shops. These businesses are highly dependent upon a steady supply of non-resident vistors. The DFWP reservation will help maintain the high quality recreational and scenic opportunities sought by tourists, thereby securing this aspect of economic prosperity for the Missouri Basin.

The DFWP reservation will unquestionably protect opportunities for the perpetuation and enhancement of recreational and service sector businesses; but, the amenities it helps maintain will also help attract new kinds of businesses offering employment opportunities beyond the scope traditionally credited to recreation. Specialty food and mail order companies, computer and data processing businesses, and consulting firms are examples of "distance-independent businesses," since they typically do not consider distance from markets a liability and, therefore, are often successful in "remote" areas like Montana.

In his keynote address to the Governor's "Montana - An Economy in Transition" conference in May 1986, Dr. David Birch, a nationally-renowned small business researcher, suggested as two of three major recommendations for improving Montana's economy that: (1) better recognition be given to attracting these kinds of businesses; and (2) that the state do a better job of promoting tourism (Birch 1986). Calling Montana "one of the most spectacularly beautiful places in the world," he concluded that the state should invest more effort towards promoting its natural attributes. This added promotion would not only enhance Montana's tourism businesses, the major source of economic growth in the state since 1980, but it would also most certainly help attract more distance-independent companies to Montana.

Areas of the state that are blessed with an abundance of spectacular trout rivers like the Upper Missouri River Basin, have the highest potential for attracting both tourists and distance-independent companies. In fact, significant new growth in the latter is already evident in the upper basin. During the past three years, several small to mid-sized companies have moved to Bozeman. Much of the credit for attracting these businesses can be given to the Gallatin Development Corporation (GDC), a local business advocacy group that has definitely followed the advice of Dr. Birch about promoting an area's natural beauty. According to the executive director of the GDC, recreational opportunities and local trout streams are major selling points for attracting new businesses to the Bozeman area. The GDC promotional video "Pioneering for the Future," mentions fly fishing several times. As well, <u>all</u> of the newly-arrived distance-independent companies have at some time commented on the recreational opportunities available in the area (Smith, 1988). Some examples of these new businesses include:

Gibson Guitar Company, which moved part of its Nashville, Tennessee operations to Bozeman during the summer of 1988, and expects to employ 60 people by late 1989.

CCG Inc., a specialized consulting firm helping market research ideas and concepts that are developed at Montana State University.

Life-Link, a sporting goods manufacturer that had expected to hire about 35 people during its first year in Bozeman, but greatly exceeded these expectations. The company started operations in March, 1988. By February, 1989, Life-Link had employed 75 full-time and 12 part-time employees. All but eight were from the Bozeman area. The company predicts that its annual sales this year will be near $9,000,000 and that it will employ 150 people within the next two years (Bozeman Chronicle 1989).

Patagonia, a world-famous outdoor clothing manufacturer, recently moved the mail order portion of its company to the Gallatin Valley. Initially employing about 30 people, this figure is expected to increase to 100 during the next five years. A spokeswoman for Patagonia stated that Bozeman was chosen by the company "primarily because of the recreational opportunities not available in Ventura" (the former California site of the mail order business). She continues, "Ventura is a great town, but there is not a lot of great rivers. You can't fly fish here either. Bozeman has all those things and you can get to [them] relatively easily." (Bozeman Chronicle, 1987)

The DFWP flow reservation will help protect the aesthetic qualities and recreational opportunities that will continue to attract the above economic benefits to municipalities. These benefits, along with the amenities provided by rivers and streams to residents of stream-side cities and towns, are important to the quality of life and the economic future of municipalities in the Missouri Basin.

b. Industry

Hydropower is a major beneficiary of the DFWP reservation. Nine hydroelectric facilities in the Montana portion of the Missouri Basin, including four near Great Falls, along with Holter, Hauser, Ennis, Canyon Ferry and Fort Peck dams, annually produce about 3.7 million megawatt hours of electricity (DNRC 1986). Nearly half of this electrical energy is produced at the two latter facilities.

Maintaining instream flows through a water reservation would provide monetary benefits through electrical generation at existing, publically-owned facilities. Water that is available in the Missouri River system not only passes through the Bureau of Reclamation's Canyon Ferry Dam and the Corps of Engineers' dam at Fort Peck, it also powers five other major hydropower generating facilities owned by the federal government in North Dakota and South Dakota. Table 6 presents the average generating capacity of each facility and the cumulative electrical generation per acre-foot of water as it passes from one facility to the next.

TABLE 6

KILOWATT HOUR (KWH) GENERATION PER ACRE-FOOT (AF) OF WATER (Median Water or Most Probable Runoff)

Power Plant	Average Generation (KWH/AF)	Cumulative (KWH/AF)
Gavins Point	35	777
Fort Randall	95	742
Big Bend	56	647
Oahe	154	591
Garrison	148	437
Fort Peck	164	289
Canyon Ferry	125	125

Source: Western Area Power Administration, January 20, 1984.

There are varying concepts of how water in streams and reservoirs are most appropriately valued. Both the Western Area Power Administration (WAPA) and the U. S. Army Corps of Engineers (Corps) have provided estimates of the value of an acre-foot of water in the Missouri River Basin for hydropower. The value of an acre-foot of water passing through the seven hydropower facilities would depend on the sale price of electricity. According to WAPA, the price of electricity ranges from 7.5 mils per kilowatt hour (KWH) for "firm" power to 14 mils per KWH for "surplus" power (Schirk 1987). Based on the cumulative generation of electricity through the Missouri River mainstem dams (Table 6), the value of an acre-foot of water would range from $5.83 to $10.88.

The indirect economic benefit of the DFWP reservation to the nine hydroelectric facilities in the Montana portion of the basin is also very significant. When the price of electricity, as quoted by the WAPA (OP.Cit.), is applied to the electrical production rates at these Montana facilities, the value of wholesale power produced ranges from $27,800,000 to $51,800,000 per year (i.e., 3.7 million megawatts per year x 7.5 to 14 mils per kilowatt hour). These estimated values are conservative. Roughly one half of the hydroelectric power production in the Missouri Basin in Montana is from private facilities, which typically receive a much higher sale price for their electricity (Dodds 1989).

Velehradsky (1987) provided a slightly lower estimate for the value of electrical production at the Corps of Engineers'

Missouri River facilities ($4.90/acre-foot). However, he also stated that the perceived benefits of hydropower are much greater than any current production estimates. If new power sources must be brought on line, the cost could be 60 mils per KWH or higher, or equivalent to about $41.00 per acre-foot.

The instream flows requested in this application and those required for existing hydropower facilities are mutually supportive, as long as water release schedules from these dams are closely tied to the needs of fish and water-based recreation. The reservation would help maintain the electrical generating capacity of the hydropower plants on the Missouri River, which currently provide some of the most economical electrical power in the western states.

The DFWP reservation will also help stabilize industrial waste treatment costs. Maintaining instream flows in the Missouri River Basin would help provide sufficient water volumes to dilute and assimilate wastewater discharges from existing facilities. The Montana Department of Health and Environmental Sciences (DHES) only issues discharge permits to waste treatment facilities where there are sufficient streamflows to dilute the wastes. Each discharge permit has criteria attached specifying that receiving waters would be protected as long as streamflow does not fall below the 7-day, 10-year low flow limit for a given stream. (The 7-day, 10-year low flow is the lowest flow that would occur at a probability of once every 10 years for a 7-day consecutive period.) If the flow of receiving water falls below the 7-day, 10-year limit, waste discharges would not necessarily be curtailed, but the biological integrity of the streams would no longer be protected (Bahls 1989).

Instream flow reservations would help prevent streams receiving wastewater discharges from dropping below the 7-day, 10-year low flow limit established to prevent water quality degradation and damage to aquatic ecosystems. If flows should be depleted below minimum levels to provide adequate dilution and assimilation of wastewater discharges, prevention of damage to aquatic ecosystems would only be avoided by suspending the discharge of wastewater to streams. Preventing permitted facilities from discharging during these periods could pose serious operational and economic consequences. Either treatment facilities would need to be upgraded to reduce the quantity of various chemical compounds and organic materials in wastewater, or effluents would have to be disposed of on land or through some other means. Such measures would be extremely expensive. Preventing damage to aquatic ecosystems through maintenance of instream flows would be more cost effective than upgrading waste treatment facilities or land disposal of wastewater.

Municipalities are also recipients of the above indirect economic benefit of the reservation, since there are nearly as many permitted municipal sewage treatment plant dischargers in the Missouri Basin (43) as there are industrial dischargers (46). All Montana Pollution Discharge Elimination System (MPDES) - permitted facilities in the Missouri Basin that receive benefits associated with stabilized instream flows/waste treatment costs are listed in Table 7.

TABLE 7

MONTANA PERMIT DISCHARGE ELIMINATION SYSTEMS -
MUNICIPAL, INDUSTRIAL, AND PLACER MINE PERMITS

Permittee	County	Receiving Water	Permit Expiration Date
A. MUNICIPAL PERMITS			
Dillon	Beaverhead	Beaverhead River	01-31-89
Townsend	Broadwater	Missouri River	05-31-93
Belt	Cascade	Belt Creek	01-31-89
Great Falls WTP	Cascade	Missouri River	05-31-92
Great Falls	Cascade	Missouri River	09-30-92
Village Water & Sewer	Cascade	Sun River	03-31-93
Vaughn	Cascade	Sun River	12-31-89
Big Sandy	Chouteau	Big Sandy Creek	10-31-88
Geraldine	Chouteau	Flathead Creek	05-31-93
Chouteau/Highwood	Chouteau	Highwood Creek	01-31-89
Fort Benton WTP	Chouteau	Missouri River	05-31-89
Fort Benton WTP	Chouteau	Missouri River	08-31-91
Denton	Fergus	Wolf Creek	01-31-89
Lewistown	Fergus	Big Spring Creek	01-31-89
Willow Creek Sewer	Gallatin	Unnamed Drain Ditch	07-31-90
Bozeman	Gallatin	East Gallatin River	05-31-93
Three Forks	Gallatin	Madison River	10-31-89
Manhattan	Gallatin	Gallatin River	09-30-92
Cut Bank	Glacier	Cut Bank Creek	05-31-93
Browning	Glacier	Depot Creek/Willow Creek	05-31-86
Whitehall	Jefferson	Jefferson River	12-31-89
Hillbrook Nursing Home	Jefferson	Prickly Pear Creek	03-31-89
Boulder	Jefferson	Boulder River	03-31-89
Hobson	Judith Basin	Unnamed Drainage	09-30-88
Stanford	Judith Basin	Skull Creek	05-31-91
Helena	Lewis & Clark	Prickly Pear Creek	05-31-91
US BOR Canyon Ferry	Lewis & Clark	Missouri River	08-31-89
US BOR CF Govt Camp	Lewis & Clark	Missouri River	08-31-89
Helena WTP	Lewis & Clark	Prickly Pear Creek	09-30-91
East Helena	Lewis & Clark	Prickly Pear Creek	05-31-91
Sheridan	Madison	Mill Creek	03-31-89
Ennis	Madison	Madison River	09-30-88
White Sulphur Springs	Meagher	Lone Willow Creek	05-31-93
Valier	Pondera	Unnamed Dry Creek Bed	11-30-89
Conrad	Pondera	Marias River	07-31-89
Brady Water Users	Pondera	South Pondera Coulee	05-31-93

Table 7 (continued)

Permittee	County	Receiving Water	Permit Expiration Date
MUNICIPAL PERMITS (continued)			
Choteau	Teton	Teton River	01-31-89
Fairfield	Teton	Freezeout Lake	05-31-93
Dutton	Teton	Hunt Coulee	05-31-93
Toole/Sweetgrass	Toole	Unnamed Dry l. Bed	05-31-93
Sunburst	Toole	Unnamed Dry l. Bed	01-31-90
Shelby	Toole	Marias River	05-31-93
Fort Peck	Valley	Missouri River	05-31-93
B. INDUSTRIAL PERMITS			
Anaconda Minerals	Cascade	Missouri River	02-28-89
Janetski, Lee B.	Cascade	Missouri River	06-30-90
Antonioli, Mrs. P.	Cascade	Squaw Creek	12-31-89
MPC-Rainbow	Cascade	Missouri River	06-30-89
MPC-Black Eagle	Cascade	Missouri River	06-30-89
MT Refining Co.	Cascade	Missouri River	07-01-88
MPC-Ryan	Cascade	Missouri River	06-30-89
Genco Industries	Cascade	Belt Creek	07-31-92
Blue Range Mining	Fergus	Big Spring Creek	10-31-89
Blue Range Eng.	Fergus	East Fork Fords Creek	09-30-91
SourDough Cr. Prop.	Gallatin	Various	08-31-91
Ideal Basic Ind.	Gallatin	Missouri River	02-28-91
Beren Corp.	Glacier	Unnamed Slough	06-01-91
Flying J, Inc.	Glacier	Spring Coulee	05-31-93
Corbin Water Users	Jefferson	Corbin Creek	05-31-91
Boulder Hot Springs	Jefferson	Little Boulder River	05-31-92
MT Tunnels Mining	Jefferson	Trib. to Spring Creek	10-31-91
Pangea Mining	Jefferson	Basin Creek	05-31-93
Pangea Mining	Jefferson	Monitor Creek	05-31-93
Ash Grove Cement	Jefferson	Prickly Pear Creek	12-31-89
Gulf Titanium	Lewis & Clark	Jennies Fork	09-30-91
Black Hawk Mining	Lewis & Clark	Banner Creek	09-30-90
Clark, Dexter	Lewis & Clark	Spring Creek	12-31-92
MT Gold & Sapphire	Lewis & Clark	Missouri River	06-30-88
MPC-Holter	Lewis & Clark	Missouri River	06-30-89
MPC-Hauser	Lewis & Clark	Missouri River	06-30-89
Century Silver	Lewis & Clark	Ten Mile Creek	08-31-92
Liquid Air Corp.	Lewis & Clark	Prickly Pear Creek	12-31-89
Uncle Sam Mines	Madison	Middle Fork Mill Creek	04-30-92
U.S. Grant Gold	Madison	Alder Creek	01-31-92
Rocky Mtn. Minerals	Madison	Rochester Creek	05-31-89
Red Pine/Shermont	Madison	Indian Creek	02-28-90
MT Talc	Madison	Johnny Gulch Creek	09-30-92
Cyprus Ind. Min.	Madison	Middle Fork Stone Creek	07-31-89

Table 7 (continued)

Permittee	County	Receiving Water	Permit Expiration Date
INDUSTRIAL PERMITS (continued)			
MPC-Madison	Madison	Madison River	06-30-89
Denimil Resources	Madison	Pony Creek	12-31-89
Cyprus Ind. Min.	Madison	Sweetwater Creek	05-31-93
Zortman-Landusky	Phillips	King Creek	10-31-91
Zortman-Landusky	Phillips	Various	10-31-91
Malta Ready Mix	Phillips	Milk River-Dodson Canal	05-31-93
Western Reserves	Toole	Unnamed Closed Basin	07-31-89
Texaco, Inc.	Toole	Stockponds	10-31-88
Silver Fox Oil	Toole	Ephemeral Drainage	04-01-89
A & G Oil & Gas	Toole	Stockponds	04-30-88
East. Amer. Energy	Toole	Unnamed Coulee	12-31-87
Devon Water, Inc.	Toole	Tiber Reservoir	11-30-88
C. PLACER MINES & SUCTION DREDGES			
Golden Star	Beaverhead	Big Moosehorn Creek	09-90
Golden Star	Beaverhead	Ruby Creek	09-90
Golden Star	Beaverhead	Little Moosehorn Creek	09-90
Miragliotta, Vito	Beaverhead	Jeff Davis Creek	08-88
Searle Bros.	Beaverhead	Jeff Davis Creek	03-93
Towner, Bob	Beaverhead	Grasshopper Creek	07-89
Wright, Alan	Broadwater	Indian Creek	03-92
Klies, Forrest	Jefferson	Jack Creek	10-90
Klies, Forrest	Jefferson	Basin Creek	10-90
Jefferson Creek	Lewis & Clark	Jefferson Creek	06-86
Holzworth, Dick	Lewis & Clark	Skelly Creek	03-88
Modern Expl., etc.	Lewis & Clark	Prickly Pear Creek	12-92
Morris, Bud	Lewis & Clark	Hauser Lake	05-93
MT Gold & Sapphire	Lewis & Clark	Missouri River	06-88
Fredriksen, etc.	Lewis & Clark	Missouri River	12-92
Sypult, Cleatus	Lewis & Clark	Madison Gulch	10-90
Placer Recovery	Lewis & Clark	Jefferson Creek	02-93
Brown's Gulch	Madison	Brown's Gulch Creek	09-86
Parker, Rodney	Madison	Barton Gulch	06-90
Lince, Carol G.	Madison	California Creek	08-92

Source: Montana Department of Health and Environmental Sciences, Helena, Montana, 1988.

Lastly, and very importantly, the diversity and abundance of water-based recreational opportunities that are supported by the DFWP reservation provide the base for a highly diverse, environmentally-sensitive industry in the Missouri Basin. The amenities protected by the reservation support water-based recreational businesses and also attract tourists, "distance-independent" businesses and people with independent incomes. All of these businesses and income sources collectively comprise an amenity-based, growth-oriented industry that is essential to the continued growth and prosperity of the basin.

c. **Agriculture**

Existing agricultural water right holders will benefit from the DFWP reservation because of increased legal and physical assurances about future delivery and supply of water for their crops and livestock. Although the long-term stability that will be provided to these landowners has not been quantified economically, it is no doubt substantial as far as its influence on property values, crop production rates and reductions in potential legal costs arising from disputes between junior and senior water users. However, since no firm monetary data exist for these economic benefits, they have been incorporated into the discussion about non-economic benefits of the reservation (II.2.c).

B. **Effects of the Reservation on the Environment, Public Health, Welfare and Safety**

1. **An Overview of Indirect, Non-Economic Benefits**

The scenic and recreational values of rivers are largely a function of their water quantity (instream flows), water quality and riparian areas. As has been previously discussed, the DFWP reservation preserves these attributes, which are vital components of the Missouri Basin's **natural environment**. In fact, all direct benefits of the reservation are also indirect benefits to the environment, since the DFWP is a public agency charged with the protection and enhancement of other significant components of the natural environment, i.e Montana's fish, wildlife and parks.

However, protection of the natural environment through adequate instream flows does far more than just preserve hydrologic conditions and biological abundance. It also benefits the **human environment**, as well as the public's health, welfare and safety.

The combination of exercise and relaxation that is part of fishing, floating and other water-based recreation unquestionably benefits physical health, while providing welcome relief from the mental stresses of everyday life. These recreational activities also require varying degrees of skill, and so become avenues for gaining a sense of personal accomplishment. To improve these skills requires better understanding of the functions of river systems; this, in turn, increases individual consciousness and self-confidence.

The sociological benefits of river recreation are also important. River outings provide opportunities for families and friends to socialize or meet new people in a relaxed and aesthetically-pleasing setting. Sharing these pleasant experiences benefits and expands interpersonal relationships.

Many people float rivers only to fish, but others enjoy the cultural and historical aspects associated with free-flowing streams throughout the Missouri Basin. Retracing the journeys of early explorers like Lewis and Clark, Mullan, Colter, Bozeman and others, certainly requires adequate instream flows for present day river navigators. Yet, just as importantly, these streamflows also preserve the natural setting or viewing backdrop of river bottoms, which has other important cultural and historic implications.

For example, the scene at the Big Hole Battlefield National Monument would be greatly diminished without adequate instream flows--for it was within the lush riparian vegetation and braiding stream channels of Trail Creek that Chief Joseph and his band of Nez Perce confronted the U. S. Army. Further reductions in instream flows and/or riparian vegetation within the battlefield area would change the physical setting, and thus the historical and cultural experience of visitors. In a similar sense, it would be difficult to conjure up images of John Colter using the Gallatin River as a hiding place from fleet-footed warriors if the river near Headwaters State Park were to become further dewatered. And, the Missouri's Wild and Scenic stretch would not offer visitors the same historic feel if it no longer had streamflows similar to those that existed during the steamboat era.

In stories and songs--from Native American lore to the writings of today's authors and poets--rivers are never described merely as physical conduits where water runs downhill. Rather, it is the beauty or strength of rivers and/or the influence of rivers upon individuals or societies that resonates through human memory.

The rivers and streams of the Missouri Basin, therefore, not only provide ongoing recreational and health benefits, they are also vital and important linkages to our past. These free-flowing waters and the riparian vegetation that they nourish are as much a part of the historical, social and cultural environment of the basin as are any human-fabricated structures or devices. The DFWP instream flow reservation will, in essence, protect irreplaceable components of the Missouri Basin's human environment.

Adequate instream flows are also important to the safety of floaters. Hazards, such as large boulders, logs, gravel bars, rip rap, and diversion structures, can be avoided by floaters if stream flows are high enough to allow manuevering.

In the sections that follow, other indirect non-economic benefits of the reservation to other uses or parties will be described. It is important to note that there are no indirect, non-economic <u>costs</u> of the reservation to the environment, public health, welfare or safety.

2. Non-Economic Benefits to Other Users or Parties

a. Municipalities

The instream flows requested in the DFWP reservation will continue to enhance the human environment for municipal residents in the Missouri Basin. Adequate stream flows will help enhance the visual attributes of river bottom lands by keeping riparian plant communities healthy and viable and by providing habitat for wildlife and birds that residents enjoy observing. The attractiveness of a stream is also closely tied to its water level; discharge levels below those requested in this application would lead to increases in exposed (dewatered) channel reaches as well as decreases in total living space available for trout and other aquatic life. The reservation will help preserve both the volume and surface area of streams, thereby perpetuating sport fishing and, where presently conducted, river floating opportunities. These amenities are substantial and irreplaceable social, aesthetic and recreational benefits of the reservation for citizens of municipalities that border free-flowing streams. The opportunity to fish, float or swim in the streams, observe wildlife and birds, or to just enjoy the serenity of sparkling waters beneath the shade of cottonwoods in a city park, all contribute immeasurably to the quality of life in these communities.

A major public health benefit of the DFWP Reservation is its role in protecting municipal water supplies. Many municipalities in the Missouri Basin utilize surface water or shallow, stream-side aquifers as their drinking water sources. The reservation will help maintain stream discharge levels necessary to dilute the toxic effects of hazardous materials and microbial organisms that enter these streams. Some herbicides and pesticides that are used by farmers, ranchers, weed districts, and urban gardeners/lawn-growers are quite persistent (slow to decompose). Leaks, spills or improper application, storage and disposal of these chemicals result in contaminated surface and ground waters. Unless adequate dilution is available, concentrations of these substances in public water supplies can reach levels harmful to human health.

The benefit of maintaining adequate instream flows to dilute toxic substances is illustrated in the Missouri Basin by problems associated with the toxic element arsenic. High concentrations of this metal originate from geothermal sources in Yellowstone Park and enter the Missouri River drainage via the Madison River (U. S. Geological Survey 1987). Tributaries to the Madison dilute arsenic concentrations, lowering concentrations downstream. The Environmental Protection Agency (EPA) measured arsenic concentrations of 200 to 300 micrograms per liter (ug/l) in the upper Madison River and concentrations of 20 to 40 ug/l in the Missouri River upstream from Canyon Ferry Reservoir (at Toston). Human health concerns exist because the allowable limit for arsenic in drinking water is 50 ug/l (U. S. Environmental Protection Agency 1986).

Data collected by the U. S. Geological Survey (USGS) in 1985 (U. S. Geological Survey 1987), show that arsenic levels exceed drinking water standards in the Madison River below Hebgen Lake (i.e., 78 to 180 ug/l), below Ennis Lake (49 to 100 ug/l), and at Three Forks (45 to 87 ug/l). Arsenic levels in the Missouri River at Toston ranged from 22 to 40 ug/l and below Canyon Ferry Reservoir from 22 to 34 ug/l.

Between March, 1986, and September, 1988, 16 samples were collected by the USGS from the Madison River at the Yellowstone Park boundary near West Yellowstone. The mean concentration of arsenic was 252 ug/l (max. = 360; min. = 140) (Knapton 1989). The Jefferson and Gallatin rivers which do not have high arsenic concentrations are normally major diluters of the arsenic concentrations in the Madison River. A water sample collected by USGS on August 17, 1988 (a drought year) at Toston contained 100 ug/l dissolved arsenic (twice the EPA drinking water standard). The previous maximum concentration recorded from 58 samples collected at that site since 1972 was 52 ug/l. The mean concentration of all 58 samples was 24 ug/l (Op.Cit.).

Extremely low flows prevailed in the Jefferson and Gallatin rivers in 1988. On August 17, 1988, the flow in the Jefferson River was only 52 cubic feet per second (8 percent of the long-term daily mean flow) and the Gallatin River was at only 60 percent of its long-term mean daily flow (Op.Cit.). This lack of streamflow for dilution caused the increased concentration of arsenic at Toston on August 17, 1988, illustrating the importance of adequate instream flows to protect the quality of public water supplies.

b. Industry

The two largest hydroelectric facilities on the Missouri River in Montana, Canyon Ferry and Fort Peck, are operated by the federal government. Maintaining instream flows will benefit public welfare by assuring reliable water delivery for power generation at these federal facilities.

Many headwater trout streams in the Missouri Basin are presently impaired by discharges of acid and toxic metals from abandoned mining operations, i.e the upper Wise River, Boulder River, Prickly Pear Creek (near Helena), Belt Creek (near Great Falls), Grasshopper Creek (near Bannack), and others. Reduction in instream flows would, in turn, reduce the capacity of these streams to dilute the discharges, causing toxicity problems to spread farther downstream. This would result in degradation of more miles of viable trout streams.

c. Agriculture

Regardless of the amount of water apportioned for instream flow reservations, existing water rights in the basin will at all times be honored. In fact, if the DFWP's reservation is granted, existing water users will be provided with additional assurances of future surface and groundwater availability. Reserved instream flows will help maintain water levels at existing headgates and will provide a legal buffer to counter any future water development plans by new water users. During low flow years, maintenance of existing stream flows will also help ease conflicts between junior and senior water users in the basin.

Instream flows often recharge shallow, alluvial groundwater tables that adjoin rivers and streams. Maintenance of these vital groundwater systems provides additional benefits to agriculture:

The riparian vegetation that is supported by shallow groundwater, i.e. willows, cottonwood, birch and aspen, all have extensive root systems that stabilize stream banks and channels. The soil stability provided by healthy, well-managed riparian areas not only prevents erosion, but also reduces the potential for damage to crops and farm buildings caused by flooding.

In many valleys of the upper basin, moist meadows and other riparian-like areas are often used to grow alfalfa and hay crops, or as highly productive pasture lands. Many of these sites are "sub-irrigated" by shallow water tables that are recharged by surface water supplies. The DFWP reservations would help maintain these moist growing sites by protecting flows against new water uses. New diversions could reduce essential recharge which, in turn, could reduce the forage productivity of these existing agricultural lands. A reduction in recharge would most certainly occur if the new offstream use were to be located on benchlands not directly connected to shallow, stream-side aquifers.

Finally, stream-side aquifers are often utilized as domestic, livestock or irrigation water supplies. The reservation would help sustain existing water table levels, and thereby, the availability and/or quantity of these shallow groundwater supplies.

C. Economic Opportunity Costs of the Reservation

1. An Overview of Indirect Economic Costs

Agriculture is by far the largest offstream consumptive water user in Montana, accounting for approximately 97.6% (15.41 million acre-feet) of the water diverted. In the Missouri Basin in Montana, agriculture accounts for an even larger share of the water diverted by consumptive users, approximately 99% (7.99 million acre-feet). Of this diverted water, only about 22% (1.76 million acre-feet) is actually consumed (DNRC 1986). Loss of water to the atmosphere from reservoir surfaces likely results in a nearly equal amount of water consumption in the basin. Estimates for reservoir evaporation losses specific to the Missouri Basin were not presented in the 1986 DNRC report; however, during 1980 on a state-wide basis, evaporation from reservoirs was estimated to account for 53.8% of all water consumption in Montana, compared to 44.6% by agricultural users.

In the Missouri Basin in Montana, use of surface water by municipalities and industry is relatively minor, about 1% of total water consumption. During 1980, 0.071 million acre-feet of water was diverted for municipal use, but only 0.025 million acre-feet was consumed. Water withdrawals for industry-owned water supplies were even less, amounting to only 0.003 million acre-feet in 1980 (Op.Cit.). Even when the more highly populated and industrialized lower Missouri River states are included in these figures, non-agricultural uses are still relatively insignificant, amounting to less than 4% of the water consumed in the entire ten-state basin (O'Keefe, et al. 1986).

Agricultural uses of water are primarily for irrigation and to a lesser extent for stock watering. Industrial uses include mining (placer and ore processing), manufacturing (process and cooling water) and hydropower. Municipal use is primarily for public water supplies.

2. Economic Costs to Other Uses or Parties

a. Municipalities

Future water demands for municipalities are difficult to predict, not only because of problems associated with growth projections for cities and towns, but also because of uncertainties about the cost-effectiveness of surface water supplies in the future. Recent outbreaks of Giardiasis in Bozeman and other smaller communities in the Basin have prompted the need for additional treatment of surface drinking water supplies. Giardia cysts are not destroyed by conventional water treatment methods. Filters, which are large, costly and difficult to operate and maintain, are presently the most commonly-prescribed treatment for removing the minute cysts.

Giardiasis is spread by mammalian feces. During the past decade its incidence has increased dramatically in surface waters of the Northern Rockies. Because of the Giardiasis outbreak and other water quality considerations, the 1986 Amendments to the Federal Safe Drinking Water Act require that all surface drinking water supplies be subjected to additional filtration requirements by the early 1990s. Treatment costs for surface drinking water sources will, therefore, inevitably increase, which will decrease the economic attractiveness of these sources as future drinking water supplies.

Presently, five municipalities in the upper Missouri River basin are planning to need more water to supply commercial, residential, and industrial needs by the year 2025 (HKM Associates 1987). Three of the communities (Dillon, Three Forks, and Belgrade) plan to obtain the needed water from wells, whereas West Yellowstone and Bozeman will supplement their water supply from surface waters.

West Yellowstone plans to pump 2,550 acre-feet per year from Whiskey Springs at a rate of 1,582 gpm by the year 2025. Bozeman predicts that it will need an additional 4,030 acre-feet per year to supplement ground water sources and water available from Hyalite Reservoir. Bozeman plans to construct a dam on Bozeman Creek to provide the water required by the year 2025.

Granting of instream flow reservations would probably not conflict with the needs of Bozeman for additional water because the proposed dam on Bozeman Creek would probably fill during the high flow period in the spring when requested instream flows are normally exceeded. Instream flow reservations could affect West Yellowstone's proposed project because no water storage is anticipated. However, such an effect would depend on the priority date of the instream reservations. Instream reservations would not conflict with those communities obtaining additional water from wells.

b. Industry

Within the ten-state Missouri Basin, the largest industrial use of water is for thermoelectric power generation; in 1978, 0.443 million acre-feet of water was diverted for the cooling water needs of coal-fired plants (O'Keefe et al. 1986). However, there are no thermoelectric plants in the portion of the Missouri Basin covered by this reservation request. Even if there were, the water needs for this industry would be relatively minor. For example, water withdrawals for the seven coal-fired electric plants in the Yellowstone Basin amounted to 0.094 million acre-feet in 1980, but only about 10% of this water was actually consumed (DNRC 1986). As well, if any coal-fired plants were to be built near Fort Peck Reservoir, water would be available for lease pursuant to authority granted by the 1987 Legislature (HB 608).

Mining and processing of mined products is an important industry in the Missouri River Basin in Montana. Currently, there are approximately 36 active mining operations in the basin that have been issued permits by the Montana Department of State Lands (DSL) for the mining of talc (5 permits), gold (16 permits), limestone (5 permits), gypsum (2 permits), silica/quartz (6 permits), iron (1 permit), and chlorite (1 permit) (Table 8).

TABLE 8

OPERATING MINES PERMITTED BY THE DEPARTMENT OF STATE LANDS IN THE MISSOURI RIVER BASIN

Company	County	Stream Drainage	Product	Process
Mt. Heagan Development Inc.	Jefferson	Boulder River	Gold	Cyanide Heap Leach
Searle Bros. Construction, Inc.	Beaverhead	Horse Prairie Cr	Gold	Placer
S and G Mining	Jefferson	Boulder River	Gold	Placer
Browns Gulch Mining	Madison	Alder Gulch	Gold	Placer
RLTCO	Beaverhead	Grasshopper Creek	Gold	Placer
Golden Sunlight Mine	Jefferson	Jefferson River	Gold	Cyanide Vat Leaching
Golden Star Mine	Beaverhead	Big Hole River	Gold	Placer
Continental Lime Inc.	Jefferson	Indian Creek	Limestone	Quarry
Hemphill Bros. Inc.	Jefferson	Boulder River	Quartz	Quarry
Stauffer Chemical Co.	Beaverhead	Big Hole River	Quartz	Quarry
Ideal Basic Industries	Gallatin	Missouri River	Limestone	Quarry
Cyprus Industrial	Madison	Madison River	Talc	Mine
Cyprus Industrial	Madison	Madison River	Talc	Mine
Cyprus Industrial	Beaverhead	Beaverhead River	Talc	Mine
Pfizer Inc.	Beaverhead	Beaverhead River	Talc	Mine
Willow Creek Talc	Madison	Ruby River	Talc	Mine
Cyprus Industrial	Jefferson	Jefferson River	Chlorite	Mine
Spotted Horse	Fergus	Spotted Horse Gulch	Gold	Cyanide Leach
Pauper's Dream	Lewis & Clark	Ten Mile Creek	Gold	Cyanide Leach

Table 8 (continued)

Company	County	Stream Drainage	Product	Process
Pegasus	Phillips	Ephemeral Drainage	Gold	Cyanide Leach
Montana Tunnels	Jefferson	Spring Creek	Gold	Cyanide Leach
Mortenson Const.	Cascade	Missouri River	Gravel	Quarry
Intergem	Meagher	Missouri River	Iron	Open Pit
Walter Savoy	Cascade	Sun River	Rip-rap	Quarry
Chouteau County	Chouteau	Teton River	Rock rip-rap	Quarry
Ash Grove Cement	Jefferson	Prickly Pear Creek	Limestone	Quarry
U.S. Gypsum	Jefferson	Prickly Pear Creek	Gypsum	Quarry
Maronick Const.	Judith Basin	Judith River	Gypsum	Quarry
Maronick Const.	Jefferson	Prickly Pear Creek	Limestone	Quarry
Special Lady	Lewis & Clark	Ten Mile Creek	Gold	Placer
St. Joseph	Lewis & Clark	Ten Mile Creek	Gold	Placer
Gulf-Titanium	Lewis & Clark	Little Prickly Pear Creek	Gold	Cyanide Leach
AMAX	Judith Basin	Judith River	Gold/ Silver	Cyanide Leach
Kendall Venture	Fergus	Judith River	Gold	Cyanide Leach
Pacific Silica	Jefferson	Prickly Pear Creek	Silica	Quarry
Indian Creek	Jefferson	Indian Creek	Limestone	Quarry

Source: Montana Department of State Lands, Helena, Montana. Permit Application Files (November, 1988).

The existing gold mines are primarily placer mines which are non-consumptive water users, and mines which extract gold through cyanide leaching of ore. Quartz and limestone are quarried for the production of cement, the processing of which consumes no water except for domestic purposes (i.e., drinking water and wastewater treatment). Talc and gypsum chlorite mines consume little or no water in mining and processing.

Additional gold mines have permits pending in the Upper Missouri River Basin. The AGAU/Montoro Joint Venture in the Rattlesnake Creek drainage near Argenta proposes to process ore through cyanide heap leaching. The Yellowband Mine, also near Argenta, would process gold and silver ore through a flotation mill.

New gold and silver mines probably would be the largest future industrial consumers of water in the Missouri River Basin in Montana. To estimate the amount of water that might be needed by future mines, water use by existing mines in Montana has been determined (Table 9). Water use for 13 mines obtaining water from both surface and ground water sources was 6,882.6 gallons per minute (gpm) for processing 208,400 tons of ore. Average water use was 529.4 gpm and average ore production was 16,031 tons per day (an average of 1 gpm is required to process 30 tons per day of ore).

Water use and production for mines obtaining water from surface sources (Table 10) was compared with water use and ore production for mines obtaining water from ground water sources

TABLE 9

WATER REQUIREMENTS, WATER SOURCES, AND PRODUCTION OF PERMITTED PRECIOUS METAL MINES IN MONTANA

Mine	County	Production (tons/day)	Water Consumption (gpm)	Water Source
Spotted Horse	Fergus	50	1.6	Discharge from existing adit
Pauper's Dream	Lewis & Clark	1,500	28	Wells
ASARCO-Troy	Lincoln	60,000	1,700	Wells
Pegasus	Phillips	80,000	1,700	Wells
Jardine	Park	1,050	300	Bear Creek and Pine Creek
Beal Mountain	Silver Bow	5,500	200	Beef-straight Creek
Chartam	Broadwater	3,000	300	Wells
CoCa	Flathead	5,000	660	Wells
Black Pine	Granite	1,000	5	South Fork Lower Willow Creek
Montana Tunnels	Jefferson	15,000	918	600 to 900 gpm from Spring Creek, Prickley Pear Creek, and Clancy Creek, 90 gpm from adits
Golden Sunlight	Jefferson	35,000	700	Jefferson Slough
Mt. Heagan	Jefferson	300	20	Slaughterhouse Gulch Creek
Stillwater	Stillwater	1,000	350	Mine workings & wells
Total		208,400	6,882.6	
Average		16,031	529.4	

1 gpm to process 30.3 tons/day

Source: Montana Department of State Lands, Helena, Montana. Permit Application Files (November, 1988).

Note: All of these mines are not in the Missouri River Basin.

TABLE 10

WATER REQUIREMENTS AND PRODUCTION FOR PERMITTED PRECIOUS METAL MINES OBTAINING WATER FROM SURFACE SOURCES IN MONTANA

Mine	County	Water Production (tons/day)	Water Consumption (gpm)	Water Source
Jardine	Park	1,050	300	Bear Creek and Pine Creek
Beal Mountain	Silver Bow	5,500	200	Beefstraight Creek
Black Pine Willow	Granite	1,000	5	South Fork Lower Creek
Golden Sunlight	Jefferson	35,000	700	Jefferson Slough
Mt. Heagan	Jefferson	300	20	Slaughterhouse Gulch Creek
Montana Tunnels	Jefferson	15,000	300	Spring Creek
Total		57,850	1,525	
Average		9,642	254	
		1 gpm to process 38 tons/day		

Source: Montana Department of State Lands, Helena, Montana, Permit Application File (November, 1988)

(Table 11). Mines obtaining water from surface sources processed a total of 57,850 tons of ore per day and used 2,197,440 gallons of water per day (1 gpm to process 38 tons/day). Mines obtaining water from ground water sources processed 150,550 tons of ore per day and used 6,825,600 gallons of water per day (1 gpm to process 31.8 tons/day). Approximately 72 percent of the ore mined was processed utilizing ground water.

The impact that water reservations would have on future mining development in the Missouri River Basin would be related to the number of new mines opened and the water sources used to process ore. Estimating the numbers of mines that would open is speculative given the volatile nature of precious metals prices. Typically, gold and silver mining follow "boom and bust" cycles. Although mining in Montana may currently be expanding, it is not possible to predict whether this trend will continue.

According to McCulloch et al. (1988), gross production in 1988 from metal mines in Montana was up 45 percent from the previous year. The number of new or renewal exploration permits issued by the Montana Department of State Lands also has increased from 56 in 1982 to 111 in 1987 and 192 in 1988 (McCulloch et al. 1988). Although it is speculative to predict future precious metal mining activities in the Missouri River Basin, a 7-year trend of wages and salaries paid to miners in the Missouri River Basin was tabulated for 1981-87 (Table 12). As shown in Table 12, mining in the Missouri River Basin provided 41.2 percent of salaries and wages paid throughout the state for

TABLE 11

WATER REQUIREMENTS AND PRODUCTION FOR PERMITTED PRECIOUS METAL MINES OBTAINING WATER FROM GROUND WATER SOURCES IN MONTANA

Mine	County	Production (tons/day)	Water Consumption (gpm)	Water Source
Pauper's Dream	Lewis & Clark	1,500	28	Wells
Spotted Horse	Fergus	50	1.6	Discharge from existing adit
ASARCO-Troy	Lincoln	60,000	1,700	Wells
Pegasus	Phillips	80,000	1,700	Wells
Chartam	Broadwater	3,000	300	Wells
CoCa	Flathead	5,000	660	Wells
Stillwater	Stillwater	1,000	350	Mine workings & wells
Total		150,550	4,739.6	
Average		21,507	677	
1 gpm to process 31.8 tons/day				

Source: Montana Department of State Lands, Helena, Montana. Permit Application Files (November, 1988).

TABLE 12

WAGES AND SALARIES FROM METAL MINING IN THE
UPPER AND LOWER MISSOURI RIVER BASIN
(Thousands of Dollars)

Year	State Total	Lower Missouri River Basin Wages/Salaries	Lower Missouri River Basin Percent of State Total	Upper Missouri River Basin Wages/Salaries	Upper Missouri River Basin Percent of State Total
1987	$48,078	$7,876	16.4%	$11,937[1]	24.8%
1986	$33,944	$4,928	14.5%	$ 5,760	17.0%
1985	$26,812	$3,392	12.6%	$ 5,091[2]	19.0%
1984	$32,988	$6,737	20.4%	$ 4,864[3]	14.7%
1983	$44,683	$4,311	9.6%	$ 6,044	13.5%
1982	$52,448	$3,406[4]	6.5%	$ 2,307	4.4%
1981	$57,756	$4,359[5]	7.5%	$ 2,392	4.1%
Average	$42,387	$5,001	11.8%	$ 5,485	12.9%

Source: Montana Department of Labor and Industry, Montana Employment, Wages, and Contributions, Annual Average 1981-1987.

[1] Excludes Broadwater County for purposes of confidentiality.

[2] Excludes Beaverhead County for purposes of confidentiality.

[3] Excludes Gallatin County for purposes of confidentiality.

[4] Excludes Meagher County for purposes of confidentiality.

[5] Excludes Cascade County for purposes of confidentiality.

metal mining in 1987. Wages and salaries increased in the upper Missouri River Basin from $2,392,000 in 1981 to $11,937,000 in 1987. In the lower Missouri River Basin, wages and salaries increased from $4,359,000 in 1981 to $7,876,000 in 1987.

Fairly reliable estimates of the remaining precious metals resources in the Missouri River Basin can be derived by examining past mining activities in the basin because future mining is predicted to occur where mining has historically taken place (Webster and Hahn 1988). New mining and ore processing technologies have made it economically feasible to extract metals from ore bodies that were previously not mined. According to Hahn (1988), minimum reserves of gold and silver in Montana are 8,012,000 and 617,165,000 ounces, respectively. Historic production of gold and silver in Montana was 20,396,000 and 950,253,000 ounces, respectively. The ratio of present estimated metal reserves to past production is 1:2.5 for gold and 1:1.5 for silver. If the estimated reserves of gold were correct, there are approximately .40 ounces of gold reserves for every ounce that already has been mined. Similarly, there are approximately .67 ounces of silver reserves for each ounce that has been mined.

To obtain an estimate of gold and silver reserves in the Missouri River Basin, historic gold and silver production was tabulated for mining districts in the basin (Table 13). Approximately 57 percent of all gold and 16 percent of all silver mined in the state came from mining districts in the Missouri River Basin. Assuming that the ratio of reserves to mined

TABLE 13

HISTORIC EXTRACTION OF GOLD AND SILVER IN THE MISSOURI RIVER BASIN[1]

Mining District	County	Production (ounces) Gold	Silver
Argenta	Beaverhead	64,400	562,000
Bannack	Beaverhead	387,000	141,000
Bluewing	Beaverhead	500	470,000
Bryant	Beaverhead	17,400	13,924,000
Elkhorn	Beaverhead	2,000	387,000
Polaris	Beaverhead	300	120,000
Vipond	Beaverhead	1,100	1,025,000
Confederate Gulch	Broadwater	650,000	7,570
Park	Broadwater	120,000	394,000
Radersburg	Broadwater	325,000	311,000
Winston	Broadwater	118,000	2,058,000
Neihart	Cascade	67,000	29,070,000
North Moccasin	Fergus	450,000	50,000
Warm Springs	Fergus	335,00	317,000
Alhambra/Basin	Jefferson	15,400	118,000
Boulder	Jefferson	480,000	14,770,000
Clancy	Jefferson	140,000	2,500,000
Elkhorn	Jefferson	100,000	12,600,000
Whitehall	Jefferson	563,000	277,000
Wickes	Jefferson	372,000	47,700,000
Barker	Judith Basin	3,500	2,738,000
Gould/Stemple	Lewis & Clark	345,000	500,000
Heddleston	Lewis & Clark	—	1,409,000
Lincoln	Lewis & Clark	682,000	120,000
Marysville	Lewis & Clark	1,390,000	8,880,000
York	Lewis & Clark	335,000	—
Rimini/Scratchgravel	Lewis & Clark	100,000	100,000
Norris	Madison	265,000	102,000
Pony	Madison	346,000	227,000
Renova	Madison	162,000	113,000
Sheridan	Madison	40,000	105,000
Silver Star	Madison	225,000	152,000
Tidal Wave	Madison	33,400	133,000
Virginia City	Madison	2,617,000	1,456,000

Table 13 (continued)

Mining District	County	Production (ounces) Gold	Silver
Washington	Madison	16,600	42,000
Castle Mountain	Meagher	—	4,270,000
Little Rockies	Phillips	960,000	2,440,000
Total		11,728,600	149,688,570
State Total		20,396,000	950,253,000
Percent of State Total		57.5%	15.7%

Source: Hahn, 1988. Gold and Silver Districts in Montana.

Note: Only mines which have produced more than 10,000 ounces of gold or more than 100,000 ounces of silver are listed.

production were 1:2.5 for gold and 1:1.5 for silver, there would be approximately 4,691,440 ounces of gold reserves and 100,224,342 ounces of silver reserves remaining in historic mining districts in the Missouri River Basin. Approximately 28 percent of the original reserves of gold and 40 percent of the original reserves of silver remain to be mined in the Missouri River Basin, provided new technologies allow for cost-effective extraction of these metals.

Basing future metals production in the Missouri River Basin on past statewide production (as just discussed) may underestimate the future metals reserves in the basin. Data for "proven" gold and silver reserves in the Missouri River Basin as of January 1989 (Hahn 1989) are shown in Table 14. (Proven reserves are silver and gold deposits that have been measured by actual exploration methods; it is assumed that metals from these ore bodies could be economically extracted at 1988 metals prices.) Assuming that both the statewide metals reserves and the Missouri River Basin proven reserves are correct, proven gold reserves in the basin would be 91 percent of the total state reserves. Similarly, the proven silver reserves in the basin would be 34 percent of the total state reserves.

Reservations of instream flows in the Missouri River drainage would have no impact on existing mining or new mines utilizing ground water, but they could affect future mining and ore processing if the new mines would rely entirely upon surface water for consumptive purposes. Development of new mines

TABLE 14

PROVEN GOLD AND SILVER RESERVES
IN THE MISSOURI RIVER BASIN

District	Gold Reserve	Silver Reserve
Winston	360,000	--
North Moccasin	60,000	--
Warm Springs	24,000	175,000
Elkhorn	500,000	--
Whitehall	2,500,000	2,500,000
Wickes	2,520,000	23,660,000
Lincoln	103,000	120,000
Marysville	50,000	--
Rimini	270,000	--
Jardine	330,000	--
New World	100,000	--
Little Rockies	500,000	7,750,000
Total	7,317,000	34,205,000

Source: Montana Department of State Lands, Helena, Montana, 1989.

requiring surface water could be adversely affected, particularly during periods of low stream flow, unless water storage facilities were utilized or alternative groundwater supplies were available. At the same time, the water quantities needed are small, based on traditional water use.

c. Agriculture

Revenues from agriculture in the Missouri River Basin are nearly equally provided by livestock and crop production. Average cash receipts from crops for the 7-year period (1980-86) contributed approximately 43 percent of the total state crop revenues (see average values in Tables 15 and 16). Similarly, livestock production in the Missouri River Basin provided about 43 percent of total state livestock revenues (see average values in Tables 15 and 16).

Irrigated land in the Missouri River Basin comprises about 50 percent of all irrigated land in the state (Tables 17 and 18). Non-irrigated land in the basin makes up about 43 percent of all dryland agriculture on a statewide basis (Tables 17 and 18). The upper Missouri River Basin has about 24 percent of the irrigated land in the state (Table 17), whereas the lower basin has approximately 25 percent of the State's irrigated land. The lower basin differs from the upper basin primarily in the amount of dryland farming. The lower basin has about 40 percent of the dryland agriculture in the state as compared with only 2.4 percent of the total state dryland farming in the upper basin.

TABLE 15

LIVESTOCK AND CROPS CASH RECEIPTS
IN THE UPPER MISSOURI RIVER BASIN[1]
(Thousands of Dollars)

Year	Livestock Receipts	State Total	of State Total	Crop Receipts	Percent State Total	Percent of State Total
1986	$119,700	$838,353	14.3%	$37,385	$493,015	7.6%
1985	$124,522	$902,859	13.8%	$42,639	$422,444	10.1%
1984	$114,022	$844,683	13.5%	$34,684	$653,780	5.3%
1983	$ 98,651	$731,537	13.5%	$44,893	$846,939	5.3%
1982	$ 88,667	$724,805	12.2%	$60,714	$980,328	6.2%
1981	$ 86,218	$705,528	12.2%	$53,007	$854,196	6.2%
1980	$ 98,470	$828,880	11.9%	$41,102	$660,450	6.2%
Average	$104,321	$796,663	13.1%	$44,918	$701,593	6.4%

Source: Montana Crop and Livestock Reporting Service.

---

1 Includes Beaverhead, Broadwater, Gallatin, Jefferson, and Madison counties.

TABLE 16

LIVESTOCK AND CROPS CASH RECEIPTS IN THE LOWER MISSOURI RIVER BASIN[1]
(Thousands of Dollars)

Year	Livestock Receipts	State Total	Percent of State Total	Crop Receipts	State Total	Percent of State Total
1986	$241,741	$838,353	28.8%	$184,082	$493,015	37.3%
1985	$272,147	$902,859	30.1%	$136,036	$422,444	32.2%
1984	$248,880	$844,683	29.5%	$252,933	$653,780	38.7%
1983	$215,725	$731,537	29.5%	$328,134	$846,939	38.7%
1982	$228,313	$724,805	31.5%	$355,893	$980,328	36.3%
1981	$222,745	$705,528	31.6%	$311,016	$854,196	36.4%
1980	$261,051	$828,880	31.5%	$240,195	$660,450	36.4%
Average	$241,515	$796,663	30.3%	$258,327	$701,593	36.8%

Source: Montana Crop and Livestock Reporting Service.

1 Includes Cascade, Chouteau, Fergus, Glacier, Judith Basin, Lewis and Clark, Meagher, Phillips, Pondera, Teton, Toole, Petroleum, Wheatland, Golden Valley, Musselshell, and Garfield counties.

TABLE 17

IRRIGATED AND NON-IRRIGATED LAND IN UPPER MISSOURI RIVER BASIN[1]

Year	Upper Missouri River Basin Irrigated	State Total	Percent of State Total	Upper Missouri River Basin Non-irrigated	State Total	Percent of State Total
1987	360,770	1,618,500	22.3%	201,400	7,623,000	2.6%
1986	344,470	1,601,000	21.5%	175,000	7,814,200	2.2%
1985	428,830	1,635,200	26.2%	171,500	5,977,500	2.8%
1984	481,300	1,805,600	26.7%	164,400	7,377,400	2.2%
1983	395,700	1,538,900	25.7%	220,700	7,151,400	3.1%
1982	417,850	1,729,900	24.1%	155,400	7,926,200	2.0%
1981	426,350	1,733,300	24.6%	144,000	7,932,600	1.8%
Average	407,896	1,666,057	24.5%	176,057	7,400,329	2.4%

Source: Montana Crop and Livestock Reporting Service.

Note: Includes Beaverhead, Broadwater, Gallatin, Jefferson, and Madison counties.

TABLE 18

IRRIGATED AND NON-IRRIGATED LAND IN LOWER MISSOURI RIVER BASIN[1]

Year	Lower Missouri River Basin Irrigated	State Total	Percent of State Total	Lower Missouri River Basin Non-irrigated	State Total	Percent of State Total
1987	410,150	1,618,500	25.3%	3,121,000	7,623,000	40.9%
1986	429,280	1,601,000	26.8%	3,207,900	7,814,200	41.1%
1985	382,500	1,635,200	23.4%	2,367,800	5,977,500	39.6%
1984	462,700	1,805,600	25.6%	3,141,500	7,377,400	42.6%
1983	405,400	1,538,900	26.3%	2,959,100	7,151,400	41.4%
1982	460,400	1,729,900	26.6%	3,105,100	7,926,200	39.2%
1981	426,800	1,733,300	24.6%	3,097,100	7,982,600	38.8%
Average	425,319	1,666,057	25.5%	2,999,929	7,407,471	40.5%

Source: Montana Crop and Livestock Reporting Service.

1 Includes Cascade, Chouteau, Fergus, Glacier, Judith Basin, Lewis and Clark, Meagher, Phillips, Pondera, Teton, Toole, Petroleum, Wheatland, Golden Valley, Musselshell, and Garfield counties.

Instream water reservations would not affect existing agricultural use in the basin, nor would they preclude the use of groundwater or water stored in offstream reservoirs for the development of additional irrigation. Reservations could limit future expansion of irrigated agriculture if new surface water sources are needed. However, even the maximum potential cost of the DFWP Reservation to new irrigated crop acreage in the upper Missouri Basin would be relatively small. Sanders (1989) provided a higher estimate for the number of existing irrigated acres in the upper basin (622,250 acres) than is displayed in Table 18 (407,896 acres). As of March 24, 1989, the Jefferson Valley, Broadwater and Gallatin Conservation Districts had submitted reservation requests for the irrigation of 23,925 additional acres by surface water upstream from Canyon Ferry Reservoir (Op.Cit.). If no other reservation applications for agricultural surface water diversions are submitted by other upper basin Conservation Districts, the maximum opportunity for growth in irrigated agriculture in the upper basin would essentially be limited to a 3.6% to 5.9% increase over existing acres. The maximum potential cost that the DFWP reservation could have upon agriculture above Canyon Ferry would, therefore, be to inhibit this relatively small increase in total irrigated crop acreage.

In the lower Missouri Basin, irrigated acreage estimates by Sanders (425,319 acres) were also higher than those in Table 18 (334,250). As of March 24, 1989, information was not available regarding reservation requests by Conservation Districts in the lower basin. The Montana Department of Natural Resources and Conservation (DNRC) is currently compiling these figures, while refining estimates of existing and potentially irrigable lands throughout the basin.

III. Effects of Not Granting the Reservation

A. Loss of Irretrievable Resources and Economic Opportunity

Not granting the DFWP reservation would cause irreplaceable losses to the wide-spread benefits associated with the protection of adequate instream flows in the Missouri Basin. Incremental stream flow depletions would continue to reduce critical components of the natural environment, including fish, wildlife riparian areas and water quality. This, in turn, would reduce the recreational activities supported by these resources, including fishing, floating, hunting and sight-seeing. The human environment would be similarly impacted through loss of scenic values and diminution of the basin's cultural, historical and social environment.

Long-term economic costs would be significant if instream flow depletions were to continue in the Missouri Basin. The brunt of these losses would be borne by stream flow-dependent recreational businesses and the cities and towns that receive the benefits of these sustainable enterprizes. However, since the recreational and scenic attributes that attract people to the basin would also diminish, these municipalities would also sustain other economic opportunity losses, i.e being less attractive to distance-independent companies, tourists and new potential residents with independent incomes. Service sector jobs would also be impacted. Not granting the DFWP flow reservation would, in essence, preclude a unique opportunity to support and protect collectively, the public interest, the environment and business interests. Denial of the reservation would be particularly incongruous at a time when the newly established "bed-tax" is just beginning to fund multi-million dollar, nation-wide advertising campaigns for recreational and service sector businesses, and local economic development organizations like the Gallatin Development Corporation are just beginning to attract new kinds of businesses to the Missouri Basin.

Without instream protection, other significant benefits to municipalities, agriculture and industry would also be diminished. New consumptive uses of water would continue to reduce downstream water availability and hydropower production. The recharge of stream-side aquifers, the assimilative capacity of streams and the viability of riparian ecosystems and sub-irrigated croplands would be diminished. Industrial and municipal waste treatment costs could increase. The potential for contamination of public drinking water by hazardous chemicals would become more likely, as would additional impacts to streams receiving abandoned mining discharges. Water disputes between consumptive users would worsen as water availability at headgates declines. The effects of not granting the reservation would, therefore, be cumulative, and in many cases irretrievable, to a broad spectrum of resources and water users in the Missouri Basin.

B. **Alternative Actions That Could Be Taken If the Reservation is Not Granted**

1. **No Action**

A no action alternative regarding water reservations in the Missouri Basin would result in the same costs to recreation, fish and wildlife, economics, aesthetic qualities and other public amenities that were just described in the Effects of Not Granting the Reservation. Other alternative actions that could reasonably be taken to protect these amenities and economic assets are described below. With the possible exception of 2, these alternatives either are more costly, would be less immediate, lack legislative mandates and/or would be more limited in applicability, than would implementing the DFWP reservation as requested in this application.

2. **Intensification of Water Conservation and Management Practices**

Examples of water conservation practices include better maintenance and lining of ditches, converting irrigation projects from flood to sprinkler systems, limiting the use of sprinklers during windy periods and of course, only diverting the amount of water actually needed for proper crop production. The latter involves installation and/or better management of water diversion and delivery systems, including improved operation and use of headgates and flumes to accurately measure water delivered to users; better information and education about water needs for specific crops throughout the basin's widely varying soil, climatic and topographic conditions; better irrigation scheduling; and increased utilization of water commissioners.

Proper water conservation and management practices not only enhance water efficiency, they also reduce soil erosion by preventing overland (sheet) runoff from croplands and minimizing volumes of silt-laden irrigation return flows. As such, application of the above measures should be encouraged regardless of any other legal directions elected during this reservation process.

Although unquestionably worthwhile and necessary, good water conservation and management practices do not represent a viable alternative to reserving instream flows. In many instances, any water conserved, and thus left instream, may simply be diverted by other offstream users. Even if the state were to offer to pay for the infrastructure necessary to improve efficiency in agricultural water use, which in turn would reduce offstream diversion rates and theoretically increase instream flow levels, there is presently no legal method for a public agency to claim or protect water acquired in this manner. This same legal obstacle is also a deterrent to the buying or leasing of water rights.

3. Buying or Leasing of Water Rights

A state agency's ability to protect instream water rights that have been converted from offstream rights through leases, gifts, purchases or improved conservation measures has been severely hampered by a recent court decision involving a water right claim for Bean Lake. The lower court ruled that the pre-1973 claim by the DFWP for instream use was invalid because the agency never diverted or impounded the water, never demonstrated an intent to claim the water right or gave notice to other water users of that intent. The State Supreme Court recently upheld the lower court's ruling. Unless the legislature removes the diversion requirement for claiming instream water rights, the leasing or buying of water is not a valid alternative to the reservation of instream flows.

This is particularly unfortunate for streams where present water users would be willing to lease their offstream rights as part of a water conservation program. For example, water users would receive annual lease payments and farm their lands as usual except during low water years. Then, in accordance with lease agreements, normally-diverted water would be left instream. The annual lease payments would provide compensation to landowners for irrigated crop damage suffered during the low flow years. Actual crop loss could also be reduced if the landowners planted non-irrigated crops on the leased land following years when snowpack is low enough to curtail normal irrigation practices.

Even if, or when, legal obstacles for protecting transferred water rights are removed, the buying or leasing of water would still not be a viable, basin-wide approach for enhancing instream flows. The administration and logistics of such an extensive program would be exceedingly complex, and the cost to the public would be high. This alternative might, however, be best applied in drainages that are severely dewatered, where present offstream users are willing to sell or lease their rights and where water adjudication proceedings have been completed. The later condition is very important, since it would be difficult to accurately transfer water rights without precise knowledge of water use and availability in a given drainage.

4. Constructing Offstream Water Storage Facilities

The construction of offstream reservoirs that would store runoff waters and release them during summer is an often overrated alternative for enhancing instream flows. Construction, operation and maintenance costs are usually prohibitive, unless cooperatively undertaken with offstream users. Even then, there is considerable uncertainty about agreed-upon releases ever reaching critical downstream reaches.

The problems associated with protecting transferred water rights, as was just discussed for buying, leasing or conserving water, also apply to water that is "owned" because of participation (cost-sharing) in the development of multipurpose storage facilities. The water release arrangement for Painted Rocks Reservoir exemplifies these problems.

Located in the headwaters of the Bitterroot River, this state-owned facility was originally constructed for irrigation use. Since part of this offstream use has never materialized, the DFWP has routinely purchased water to be delivered to chronically dewatered reaches of the river. However, until a water commissioner was appointed by the court in the late 1980s, most of this purchased water was diverted for offstream use before reaching the Bell Crossing area near Hamilton.

The usefulness of reservoir storage may also be limited by the hydrogeology of a drainage. The case of the proposed irrigation/recreation reservoir on the Little Boulder River illustrates this point. During the environmental analysis of this proposal, it was found that the thick, unconsolidated gravels of the Boulder Valley cause the river to be a "losing stream," i.e. in most reaches it looses more surface water than it normally receives as recharge during summer, low-flow conditions. Much of the water released from this proposed reservoir would have, therefore, recharged the valley's groundwater instead of augmenting instream flows. Similar hydrogeologic conditions undoubtedly occur in other drainages of the Missouri Basin. In these drainages, counting on reservoirs to supplement surface streamflows during summer would not be a wise investment.

Reservoirs often create other environmental costs, including:

1) detrimental effects to cold water fisheries resulting from increased temperatures of stored waters;

2) detrimental effects to stability and diversity of stream channels and riparian areas because of reduced frequencies and intervals of flushing flow discharges; and

3) increased depletion of surface water because of increased evaporation rates; these depletions also cause

concentrations of dissolved solids (salinity) and other contaminants like nutrients and pesticides to increase within reservoirs.

5. Revising the Process for Conditioning Water Rights Permits

For water use applications or transfer of water rights exceeding 4,000 acre-feet per year and 5.5 cfs, MCA 85-2-311 (2)(c) requires that certain "public interest" and "reasonable use" criteria be met before approval to divert the water is granted. Criteria to be evaluated include demands on future water supply; needs to preserve instream flows; benefits to the applicant and the state; effects on water quality, including the potential for creating saline seep; the feasibility of using other (low-quality) water; and consideration of other adverse environmental impacts.

Although the above "conditioning" of water use permits would certainly be helpful for protecting instream flows from large offstream diversions, it does not represent a widely applicable alternative to the water reservation process. Applications for water use that are large enough to trigger utilization of the above criteria are very uncommon. In fact, 80% of all water use permits issued by the DNRC since July 1973 have been for quantities less than 1.0 cfs.

To be an effective component of an instream protection strategy, the conditioning of water use permits must, therefore, be revised to include the review of much smaller requests.

Instead of an arbitrary volume figure, conditions triggering the use of public interest/reasonable use criteria should instead be guided by the effects of an application upon a given stream's available flow and upon the cumulative basin-wide impacts of all future water appropriations. Unfortunately, there are few streams in the basin that have enough stream gauging data to document existing available flows. Nor have enough streams in the basin been adjudicated, which makes documentation of existing use extremely difficult.

Finally, even if conditioning of permits were to be revised to incorporate some smaller "triggering criteria," this alternative should only be considered as a supplement to the protection of instream flows through water reservations. Unless conditioning criteria were to be applied to <u>every</u> water use application in the Missouri Basin (an unlikely situation in the foreseeable future), many "small" water use permits, those still not surpassing the revised criteria, could continue to be granted without adequate consideration of immediate and cumulative effects upon fish and wildlife uses.

6. Closing Basins

Montana water law at MCA 85-2-319 states that the DNRC "may by rule reject permit applications or modify or condition permits issued in a highly appropriated basin or sub-basin," but "only upon a petition signed by at least 25% or 10, whichever is less" of present water users in the basin or sub-basin. The petition must allege that throughout or during certain times of the year there are no unappropriated waters in the basin; the rights of present users will be adversely affected; or further uses will interfere unreasonably with other already permitted uses, or uses for which water has been reserved. Upon receiving a petition, the DNRC must either deny it, or if needed, conduct a water availability study and initiate rule-making proceedings.

A petition to close the Musselshell River Basin has been submitted to the DNRC by the Deadman's Basin Water Users Association. A water availability study is being conducted, and a predictive model is being developed, to better examine the concerns raised in the petition and to determine if rule-making proceedings will be necessary.

On March 30, 1983, the DNRC closed the Milk River mainstem to any further applications "for direct diversion without storage of waters . . . for irrigation or any other consumptive use." The department acted to close the river (except for some reaches during runoff periods), pursuant to MCA 85-2-321, a legislatively-mandated water availability study and rule making procedure directed specifically at the Milk River Basin.

Both the Musselshell and Milk River proceedings occurred because of concerns raised by existing offstream water users in already "highly appropriated" basins. These is no opportunity in Montana water law for the general public or state agencies to initiate action to close basins because of instream flow concerns (thereby preventing the over-appropriated conditions occurring in the above basins). By the time closures are being considered, there may not be water available for instream flow needs. As such, this procedure is not a viable alternative to the timely implementation of instream flow reservations.

7. Application of the Public Trust Doctrine

The Montana Supreme Court applied the public trust doctrine in two 1984 decisions involving the public's right to use water courses for fishing and floating. The court held that "under the public trust doctrine and the Montana Constitution, any surface waters that are capable of recreational use may be so used by the public without regard to streambed ownership or navigability for non-recreational purposes." In an attempt to provide management policies that address and implement these court decisions, the 1985 Montana Legislature passed the "Stream Access" bill. The provision in the Montana Constitution specifying that all waters of the state "are the property of the state for the use of its people," was an important factor guiding the court decisions and the subsequent legislation. In 1987 the court further overruled an appeal by landowners that the above actions represented an unconstitutional taking of private property without just compensation. In this latter decision, however, the court did appear to limit the application of the public trust doctrine to recreational water use in Montana.

The limits to, and effectiveness of, the public trust doctrine for protecting instream flows in Montana remains largely untested. As an absolute protection strategy, it should probably be considered only as an alternative of last resort. Hopefully, the spirit and intent of the doctrine will guide and direct the final decision for an adequate amount of instream flow protection for fish, wildlife and recreation in the Missouri River Basin.

LITERATURE CITED

Alexander, G. R. and 49 other coauthors. 1989. America's 100 Best Trout Streams. Trout Magazine, Vol. 30, No. 2.

Bahls, L. 1988. Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena, Montana. Conversation with Joe C. Elliott, January 13, 1988.

Berg, R. K. 1981. Fish Populations of the Wild and Scenic Missouri River, Montana. Montana Department of Fish, Wildlife and Parks. Ecological Services Division. Helena, Montana.

Birch, D. E. 1986. Keynote Address to Montana-An Economy in Transition Conference. Butte, Montana. July 22, 1986.

Bozeman Chronicle. 1987. Outdoor Clothes Company Moving Mail Order Here. Bozeman, Montana. September 24, 1987.

Bozeman Chronicle. 1989. Creating New Jobs. Bozeman, Montana. February 5, 1989.

Brock, J., J. Larson, W. Muhs, M. Reilly, and J. Rogers. 1984. Montana tourism and marketing research project. Unpublished report prepared for the Montana Department of Commerce, Helena, Montana.

Brown, C. J. D. 1971. Fishes of Montana. Big Sky Books. Montana State University. Bozeman, Montana.

DNRC. 1983. Final Order Closing the Milk River Basin to Water Use Permit Applications. Montana Department of Natural Resources and Conservation, Water Resources Division. Helena, Montana.

DNRC. 1986. Montana Water Use in 1980. Montana Department of Natural Resources and Conservation, Water Resources Division. Helena, Montana.

Dodds, D. 1989. Montana Department of Natural Resources and Conservation, Helena, Montana. Conversation with Ken Knudson, March 23, 1989.

Duffield, J. E., J. Loomis and R. Brooks. 1987. Net Economic Value of Fishing in Montana. Prepared for the Montana Department of Fish, Wildlife and Parks.

Elser, A. A. 1976. Southeast Montana Fisheries Investigations. Fed. Aid for Fish and Wildlife Restoration. Montana Department of Fish, Wildlife and Parks. Proj. No. F-30-R-12.

Fisher, H. 1979. The Floater's Guide to Montana. Falcon Press Publishing Co. Helena, Montana.

Frost, J. and S. McCool. 1986. The Montana outdoor recreation needs survey. Prepared for the Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Hahn, R. Gold and silver districts of Montana. 1988. Geological Society of America, Abstracts with Programs, Vol. 20, p. 276.

Hahn, R. 1988 and 1989. Hard-Rock Mining Bureau, Montana Department of State Lands, Helena, Montana. Conversations with Joe C. Elliott, November 25 and 27, 1988; January 13 and 17, 1989.

Herman, J. 1988. Montana Department of Fish, Wildlife and Parks. Helena, Montana. Conversation with Ken Knudson, March 10, 1988.

Holton, G. D. 1981. Identification of Montana's Most Common Game and Sport Fishes. Montana Outdoors. May/June 1981.

Hubbs, C. L. and K. F. Lagler. 1967. Fishes of the Great Lakes Region. University of Michigan Press. Ann Arbor, Michigan.

Karp, R. 1987. Gaging station costs. Unpublished report submitted to the Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Knapton, R. 1989. U. S. Geological Survey, Helena, Montana. Conversation with Liter Spence, Montana Department of Fish, Wildlife and Parks, January 10, 1989.

Leathe, S. and B. Hill. 1987. Northcentral Montana Fisheries Study. Montana Department of Fish, Wildlife and Parks, Great Falls, Montana. Proj. No. F-S-R-36.

McFarland, B. 1988. Montana Department of Fish, Wildlife and Parks. Bozeman, Montana. Conversation with Ken Knudson, May 5, 1988.

McCulloch, R., B. Berg and M. Sholes. 1988. Mining and mineral developments in Montana - 1988. Montana Bureau of Mines and Geology, Butte, Montana.

Montana Department of Commerce, Helena, Montana. 1988. The economic impacts of travel/tourism in 1986. Unpublished report.

Montana Department of Fish, Wildlife and Parks, Helena, Montana. 1987. Outfitter Report 1986. Montana Department of Fish Wildlife and Parks open file report. Information given to James Boyer (DNRC) by Bill Maloit (DFWP).

Montana Department of Fish, Wildlife and Parks, Helena, Montana. 1988. Smith River annual report for 1987 - The year of the boat camp declaration map. Unpublished report.

O'Keefe, M., N. E. Slocum, D. R. Snow, J. E. Thorson and P. Vandenberg. 1986. Boundaries Carved in Water. Northern Lights Institute. Missoula, Montana.

Pflieger, W. L. 1975. The Fishes of Missouri. Missouri Department of Conservation. Jefferson City, Missouri.

Powers, T. 1987. A Mysterious Part of Our Economic Base. In: Currents, A publication of the Clark Fork Coalition. Missoula, Montana.

Priegel, G. R. 1973. Lake Sturgeon Management on the Menominee River. Wisconsin Department of Natural Resources. Tech. Bull. No. 67.

Purkett, C. A. 1963. The Paddlefish Fishery of the Osage River and Lake of the Ozarks, Missouri. Trans. Am. Fish. Soc. 92(3):239-244.

Romer, A. S. 1962. The Vertebrate Body. W. B. Saunders Co. Philadelphia, Pennsylvania.

Sanders, J. 1989. Montana Department of Natural Resources and Conservation, Helena, Montana. Conversation with Liter Spence, March 24, 1989.

Schirk, R. 1987. Western Area Power Administration, Billings, Montana. Conversation with Joe C. Elliott, October 26, 1987.

Smith, B.H. 1988. Executive Director of the Gallatin Development Corporation, Bozeman, Montana. Conversation with Ken Knudson, August 1, 1988.

U. S. Department of the Interior, Bureau of Land Management, Lewistown, Montana. 1988. FY 87 Recreation use statistics, incident summary, and volunteer reports. Unpublished report.

U. S. Environmental Protection Agency. 1986. National primary drinking water regulations. 40 C.F.R. Part 141, July 1, 1986 edition.

U. S. Geological Survey. 1987. Arsenic data for streams in the Upper Missouri River Basin, Montana and Wyoming. Open-file report 87-124. Prepared for the Montana Department of Health and Environmental Sciences, Helena, Montana.

Velehradsky, J. 1987. U. S. Army Corps of Engineers, Omaha, Nebraska. Letter of November 10, 1987, to Liter Spence, Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Webster, T. 1988. Hard-Rock Mining Bureau, Montana Department of State Lands, Helena, Montana. Conversation with Joe C. Elliott, October 19, 1987.