IS-60

BEFORE THE MONTANA BOARD OF NATURAL
RESOURCES AND CONSERVATION

IN THE MATTER OF WATER RESERVATION APPLICATION NOS. LO77646-40S, LO77647-40Q, LO77749-40S, LO78651-40J, LO84482-40S, LO84483-40J, LO84484-39G, LO84485-39FJ, LO84486-40J, LO84487-41P, LO84488-40Q, LO84489-40J, LO84490-40J, LO84492-40R, LO84492-40P, LO84493-40J, LO84494-40G, LO84495-40O, LO84496-39E, LO84497-40Q, LO84498-39G, LO84499-40S, LO84500-40S, LO84501-40S LO84502-40R, LO84503-39G, IN THE LITTLE AND LOWER MISSOURI RIVER BASINS)

**DEPARTMENT OF FISH, WILDLIFE, AND PARKS'
PREFILED DIRECT TESTIMONY**

* *

Prefiled direct testimony submitted in support of the Department of Fish, Wildlife and Parks' application for instream flow reservations in the Little and Lower Missouri River Basins

* *

June 30, 1994

CURTIS E. LARSEN
Department of Fish,
Wildlife and Parks
1420 East Sixth Avenue
P.O. Box 200701
Helena, MT 59620-0701
Ph: (406) 444-4047

Attorney for Department of Fish, Wildlife and Parks

BEFORE THE MONTANA BOARD OF NATURAL
RESOURCES AND CONSERVATION

IN THE MATTER OF WATER
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LO84490-40J, LO84492-40R,
LO84492-40P, LO84493-40J,
LO84494-40G, LO84495-40O,
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DEPARTMENT OF FISH, WILDLIFE, AND PARKS' PREFILED DIRECT TESTIMONY

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* *

June 30, 1994

CERTIFICATE OF SERVICE

I hereby certify that on the 30th day of June, 1994, a true and accurate copy of the Department of Fish, Wildlife and Parks' Prefiled Direct Testimony was duly served upon all parties listed below by depositing the same, postage prepaid, in the United States Mail.

Joe Paine
Director of Pubic Works
City of Circle
P.O. Box 140
Circle, MT 59215

John Elias, Mayor
City of Chinook
P.O. Box 1177
Chinook, MT 59523

Elston Loken
Water Superintendent
City of Ekalaka
P.O. Box 338
Ekalaka, MT 59324

Francis Gallagher
Gallagher & Archambeault
P.O. Box 512
Glasgow, MT 59230

Richard Mohar
Director of Public Works
City of Harlem
P.O. Box 485
Harlem, MT 59526

Tim Miller
Water Superintendent
City of Havre
P.O. Box 231
Havre, MT 59501

John Demarais
Water Superintendent
City of Malta
Drawer L
Malta, MT 59538

William Bond
City of Wibaux
P.O. Box 219
Wibaux, MT 59353

Hill County Water District
312 Third Street
Havre, MT 59501

John Bloomquist
Max Hansen & Associates
P.O. Box 1301
Dillon, MT 59725

Ted J. Doney
Candace Torgerson
DONEY, CROWLEY & SHONTZ
Power Block Bldg, Ste. 300
P.O. Box 1185
Helena, MT 59624

Ted J. Doney
Candace Torgerson
DONEY, CROWLEY & SHONTZ
Power Block Bldg, Ste. 300
P.O. Box 1185
Helena, MT 59624

Fort Belknap Indian Community
% Ann Amundson
Thomas Fredreicks
1881 9th St., Ste. 216
Boulder, CO 80302

Frenchman's Water User's Ass'n
P.O. Box 488
Saco, MT 59261

Frenchman's Irrigation Co.
P.O. Box 347
Saco, MT 59261

Robert Hurly
P.O. Box 1170
Glasgow, MT 59230

Marion Hellstern
Hinsdale, MT 59241

Richland County Board of
County Commissioners
% Mike Weber
County Courthouse
201 West Main
Sidney, MT 59270

Eliot Strommen
Vandalia Ranch
Vandalia, MT 59273

U.S. Bureau of Reclamation
Office of the Solicitor
P.O. Box 31394
Billings, MT 59107-1394

U.S. Dept. Of Interior
Office of the Solicitor
Bureau of Indian Affairs
% John Chaffin
316 N. 26th Street
Billings, MT 59101-1362

U.S. Fish and Wildlife Service
Attn: David Schmidt
P.O. Box 25486
Denver Federal Center
Denver, CO 80225

Curtis Larsen

LIST OF WITNESSES FOR THE DEPARTMENT OF FISH, WILDLIFE, AND PARKS PREFILED DIRECT TESTIMONY

1. Larry G. Peterman
2. Liter Spence
3. Fredrick A. Nelson
4. Charles Parrett
5. Scott Gillilan
6. Carolyn Sime
7. Phillip A. Stewart
8. Robert G. White
9. Kent Gilge
10. William M. Gardner
11. Ken Frazer

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

<u>Exhibit No.</u>

1. F. Nelson (1989), Guidelines for Using the Wetted Perimeter (WETP) Computer Program of the Montana Department of Fish, Wildlife and Parks.
2. 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).
3. Photographs illustrating fish habitat found in the prairie streams where instream flows are requested.
4. C. Parrett and D.R. Johnson (1994). Estimates of Monthly Stream Flow Characteristics and Dominant Discharge Hydrographs for Selected Sites in the Lower and Little Missouri River Basins. U.S. Geological Survey Water Resources Investigation Report 94-4098.

PRE-FILED DIRECT TESTIMONY
OF LARRY G. PETERMAN
ON BEHALF OF THE MONTANA DEPARTMENT OF
FISH, WILDLIFE AND PARKS

Q. Please state your name and business address?

A. Larry G. Peterman
1420 E. Sixth Avenue
Helena, Montana 59620

Q. What is your present employment?

A. Administrator, Fisheries Division, Montana Department of Fish, Wildlife and Parks.

Q. Please state your educational background?

A. I received a Bachelor of Science degree in Biology from Wisconsin State University at Stevens Point, Wisconsin in 1969. In 1972, I received a Master of Science degree in Fish and Wildlife Management from Montana State University in Bozeman, Montana.

Q. Please state your employment experience?

A. I began working for the department in March of 1972, as a fisheries biologist conducting a fisheries planning and inventory study on the Upper Yellowstone River. I then supervised fisheries field investigations on the lower Yellowstone River that included instream flow work as part of the studies. In 1978 I took the position of water resource supervisor which dealt with instream flow issues, hydropower development and reservoir operations. I then became the Bureau Chief of the Research and Special Projects Bureau which included instream flow activities. I was also the department's liaison with the Northwest Power Planning Council and coordinated fish and wildlife negotiation efforts related to hydropower development, operation and mitigation. I currently administer the Fisheries Division which consists of four bureaus (Habitat, Management, Special Projects, Hatchery) seven regional fish managers and staff and nine hatcheries.

Q. What is the purpose of your testimony?

A. The purpose of my testimony is to place the application for a reservation of instream flow in the Missouri River basin in the perspective of the Department's overall mission to manage and protect fish and wildlife and their habitats and to discuss the Department's river conservation and restoration programs. I will also address the Department's policies for the management and protection of instream flows, particularly those that may be acquired through the water reservation process.

Q. What are the Department' duties and responsibilities for the fisheries, and the aquatic and riparian habitats of the state?

A. The Department is the executive branch agency mandated by law to provide for the protection, preservation and propagation of all fish and wildlife and their habitat within the state. The Department has the responsibility and duty to represent the people of Montana in applying for instream flow reservations for fish, wildlife and their habitat in the Missouri River Basin below Fort Peck Dam and in the Little Missouri River Basin.

Q. Can you summarize the background of the Department's stream conservation and restoration program?

A. Yes. The framework of a stream conservation and restoration program was developed in the early 1960s and focused on three essential components required to maintain or restore stream conditions which would benefit fisheries. Those three components were:

- The retention of a natural stream channel that included proper meanders, stream-side vegetation and other physical features that were conducive to fish and fish food production.

- The quality of the water flowing in these channels had to be such that it was not detrimental to fish and fish food production.

- The quantity of water, or stream flow, in the channel had to be sufficient to insure adequate to optimum fish and fish food production.

Q. Please review how this program has developed through the years?

A. The first of the three components to be addressed was the protection of the physical nature of stream channels.

The 1963 state legislature passed the Montana Stream Protection Act, the first law designed to protect the physical features of streams. This Act gives the Department authority to regulate state and local government activities involving stream channels. We also have agreements with numerous Federal agencies to comply with this act. The Natural Streambed and Land Preservation Act was passed in 1975. This Act extended the responsibility for protecting the physical features of streams to include private persons. This law is commonly called the "310" law, and is administered by the Conservation Districts with participation by the Department. A person must obtain a "310" permit before physical activity in streams is allowed.

In 1969, the legislature passed a number of amendments to the state law that protects <u>water quality</u>. The federal Clean Water Act passed in 1972 gave states the authority to administer portions of the federal program and, among other things, directed attention to point source waste discharges. This Act was amended in 1977 and in the 1980s and is up for reauthorization in 1994. Other congressional and legislative actions, including Section 319 of the Clean Water Act which addresses non-point pollution sources, the state Streamside Management Act, which protects streams against poor forest practices, and the federal Superfund law, which addresses the cleaning up of toxic waste sites, are designed to make water quality better for fish and other aquatic life. The primary responsibility for enforcing the water quality laws resides in the Montana Department of Health and Environmental Sciences (MDHES). Our Department, with its fisheries biologists stationed throughout the state, cooperates with the MDHES and employs one person who is a coordinator between the two agencies.

The goal of ensuring that our streams have an adequate <u>quantity of water</u> has been the most difficult component of our stream conservation and restoration program to achieve. Efforts to provide a legal mechanism to protect instream flows began in 1969, when Representative James Murphy of Kalispell introduced legislation that allowed the Department to file on the unappropriated water in portions of 12 of our highest quality trout streams, many of which are known as "Blue Ribbon" trout streams. These instream filings became known as "Murphy Rights." Parts of the Missouri, Gallatin, Madison and Smith rivers and Big Spring Creek were included in that legislation.

Four years later the 1973 Water Use Act was passed. Among other changes to state water law, this act authorized state agencies and political subdivisions and federal agencies to apply to the Board of Natural Resources and Conservation for reservations of water for a variety of purposes, including instream flow for fish, wildlife and recreation.

Q. How has the Department followed through with the instream water allocation portion of this stream conservation and restoration program?

A. To date, the primary achievements have been in filing for water in the Murphy Right streams authorized by the 1969 legislation and filing claims in the adjudication process and in instream flow reservations for the Yellowstone River and most of its tributary streams and for streams in the Missouri River basin above Fort Peck Dam. The Yellowstone River basin instream flow reservation was granted by the Board in 1978 and in the Missouri basin above Fort Peck Dam in 1992. The current application for reservations of flow in the lower Missouri River basin and Little Missouri River basin is the continuation of the program to protect and enhance Montana's fish, wildlife and recreational resources.

Q. What other programs are available to aid in the restoration of rivers and streams and to enhance instream flows?

A. A pilot water leasing program was established by the 1989 legislature to explore the feasibility of leasing existing consumptive water rights to restore and enhance instream flows. This water leasing study program needs to be distinguished from the current water reservation process. The water reservation process allocates water in the lower Missouri River basin and is an opportunity to maintain the status quo in selected streams throughout the basin which have fisheries values. The water leasing program allows the Department to lease existing water rights and temporarily convert them to instream flow rights in specific problem areas where the cost of leasing water is justified. To date two water leases have been implemented, and several others are pending.

The River Restoration Act, passed by the 1989 legislature, provides for the establishment of a fund to be used to restore damaged streams. The Department typically cooperates with private landowners in this effort. The Water Quality Bureau of DHES administers a program (the 319 program) to address sediment and other pollution from disperse non-point sources. The Montana Association of Conservation Districts (MACD) is actively promoting the protection and enhancement of stream-side vegetative areas through appropriate riparian management practices. We cooperate with them in that effort.

Q. Will any instream flows granted to the Department compete for water with water rights established prior to July 1, 1985 in the lower Missouri basin or July 1, 1989 in the Little Missouri basin?

A. Any instream flows granted to the Department in this process will not and cannot compete for available water with established water rights with priority dates prior to July 1, 1985, the priority date set by statute for Lower Missouri River basin reservations or July 1, 1989, established for reservations in the Little Missouri River basin. This is a clear and direct result of the prior appropriation doctrine that establishes the priority of use of available water. This reservation process allocates only that water available after use by consumptive senior users. Those senior rights with priority dates before the instream flow reservations are entitled to use their water right first and cannot be restricted by the junior instream flow reservations. The Department clearly understands and respects this significant aspect of state water law.

Instream flow reservations will restrict new junior users, when stream flow is physically not there to meet the instream flow reservations. Then, junior users, but only junior users, can be restricted until the flows return to the minimum instream flows of the reservations.

Q. What value, if any, do minimum instream flows provide for established, senior water right users?

A. I believe that minimum instream flows provide a practical benefit to senior water right users. Consumptive users, such as irrigators or municipalities, must first be able to divert their water from the stream or river. If there is a base flow provided by minimum instream flows, the water can be more easily diverted through headgates or their diversions. On the other hand, if the stream or river is almost entirely diverted for some consumptive uses, then some consumptive users may have a much more difficult time withdrawing water.

Another benefit of instream flows is maintaining water quality. Most beneficial water users require a minimum level of water quality. Lowered stream flows may affect water quality which, in turn, affects established water users.

The water that would satisfy minimum instream flow reservations applied for by the Department can also serve other purposes, such as meeting the needs of downstream consumptive users by, in effect, helping transport their water downstream.

Q. If minimum instream flows are beneficial to other water users in the ways you have just testified, why were minimum flows not adopted long ago?

A. I believe that the answer is in the history of development in the West and the accompanying uses of our water. Water was first put to use for mining and agriculture about 130 years ago. The laws regarding water use were established to protect one consumptive user's right from another's. Water was seen only in terms of such developments as mining, irrigation, municipal uses and power production. Water for fisheries, wildlife and water quality was either taken for granted or its value was not considered in the historic development of water use laws.

Today, the value our society places on instream flows has increased and is no longer taken for granted. Instream flows are recognized both for their inherent values and for their growing economic importance. If we were starting all over, it might be logical to allocate minimum instream flows along with allocations for consumptive uses. However, historically a different course was followed. Consumptive rights were allocated first and now we are trying to fit minimum instream flows into what remains of the available water. This makes accomplishing the goal of providing adequate stream flows for fish, wildlife and recreation more difficult. However, we are committed to working within the present process to assist the Board in making the best, most reasonable, and workable decisions to protect instream flow values.

The development of water for irrigation, mining and many other consumptive uses has already been largely completed. Water has been allocated and water rights perfected for most of the irrigation and mining that is practicably feasible without further adverse effects to fisheries. I view the reservation process as an opportunity to balance all competing, legitimate uses of water to the extent that this can be accomplished with the limited water still available in many streams.

Q. Why is the Department requesting instream flows in the lower and Little Missouri River basins?

A. The lower Missouri River and its tributaries are important fishing and recreational areas. Recreational use of the Missouri basin's water is important to the human experience, providing both enjoyment and relief from day-to-day pressures. Montana law recognizes this resource as worthy of protection and charges the Department to manage fish and wildlife. As an agency charged with management of the state's fish and wildlife resources, DFWP has a two-fold responsibility: (1) to protect and enhance the abundant and diverse fish, wildlife and recreational resources, and (2) to provide optimum opportunities for diverse outdoor recreation that are commensurate with resource preservation. Fish and wildlife populations and their habitats are inseparable. Therefore, preservation of fish and wildlife populations is necessarily dependent upon preservation of their habitats. Conservation of native fish species by sustaining this habitat reduces the potential for these species to become listed as threatened or endangered.

Q. Why did the Department file for an instream flow reservation below Fort Peck Dam when the flows are controlled by the dam?

A. The water reservation process is designed to allocate available water to existing and future beneficial uses. The fish and wildlife are beneficial uses of water which need to be considered in any water allocation process, just as future irrigation and municipal needs are considered. The Missouri River below Fort Peck Dam has substantial fishery and aquatic resources and a recognition of their flow requirements should be a consideration in the allocation of water below Fort Peck Dam. Once the flows are released from Fort Peck Dam they are available for beneficial uses.

Q. Since Fort Peck Dam controls the flows in the Missouri River below the dam, what effect would an instream flow reservation have on the operation of Fort Peck Dam?

A. Fort Peck Dam was built in the 1930s and its operations date back to that point. From a practical standpoint, the imposition of an instream flow reservation in 1994 may have little impact on the operation of Fort Peck Dam. It would, however, identify certain instream flow requirements for fisheries and aquatic resources below the dam which then should be considered by the Corps when they develop their annual reservoir operation plan. These instream flow requirements would become part of the balancing process the Corps goes through when they look at the available water supply in any given year; the reservoir water levels, the projected power requirements and instream flow needs. These instream flow levels would be targets to consider when looking at the various uses of the reservoir and the available water supply.

This is much the same process that we are involved in with the operation of several major reservoirs in the state. These reservoirs include Tiber, Yellowtail and Canyon Ferry. The instream flow requirements below the dams, the reservoir levels behind the dams and the available water supply are all considered when annual operating plans are developed. The principal value of an instream flow reservation below Fort Peck Dam would be to identify target flow levels to be considered when the annual operating plan is developed. The other aspect of an instream flow reservation is to provide some level of legal protection for instream flows once they are released below Fort Peck. The instream flow reservations below Fort Peck are balanced with future identified irrigation and municipal needs through this reservation process.

Q. What are the potential consequences of the Department not being granted instream reservations in the lower Missouri basin?

The natural flow of streams in the basin have been increasingly depleted over the past 130 years. If fisheries, and, consequently, fishing and other stream-based recreation opportunities are to be maintained in the future, there must be some recognition of the value of instream flows and a means found to maintain those flows. If a means is not provided, we can expect stream flows to continue to be depleted, increasing the annual occurrence of critically low flows. Should that occur, we would find ourselves more often facing the consequences of more frequent reductions in stream flows, particularly due to drought conditions. Increasingly, fish populations would not be able to recover, as has been the case in other chronically dewatered streams today.

I, Larry G. Peterman, being first duly sworn, states that the foregoing testimony is true.

DATED this 28 day of June, 1994.

Larry G. Peterman
Larry G. Peterman

Subscribed and sworn to before me this 28th day of June, 1994.

(NOTARY SEAL)

Debra K. McRae
Notary Public for the State of Montana
Residing at Helena
My Commission Expires May 14, 1998

PRE-FILED DIRECT TESTIMONY OF
LITER E. SPENCE
ON BEHALF OF THE
MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS (MDFWP)

Q. Please state your name and business address.

A. Liter E. Spence, MDFWP, 1420 E. 6th Avenue, Helena, MT 59620.

Q. By whom are you employed, and in what capacity?

A. I am employed by the Montana Department of Fish, Wildlife and Parks. My position is Water Resources Supervisor in the Fisheries Division. My primary responsibility is to implement the Department's instream flow program, which includes obtaining and protecting instream flow reservations and other instream flow water rights.

Q. What is your education and employment experience that is pertinent to this testimony?

A. I have a Bachelor of Science Degree in Zoology and Chemistry from the University of Idaho and a Master of Science Degree in Wildlife Conservation and Management from the University of Wyoming. After graduating from the University of Wyoming, I worked for two years for the U.S. Fish and Wildlife Service's Missouri River Basin studies office in Billings, Montana. Following that, I became employed by the then Montana Fish and Game Department as a fisheries field biologist in Missoula, Montana. I have worked approximately 21 years for the Montana Department of Fish, Wildlife and Parks. During that period, I have served two different times as Water Resources Supervisor for a total of about 11 years.

I have had additional education and training through several special schools, workshops and symposia concerning streams, stream processes and instream flows for aquatic life. I have authored numerous fisheries reports and popular articles concerned with my professional field. These are stated more explicitly in the attached biography which is incorporated herein.

I am a member of the American Fisheries Society and the Montana Chapter of the American Fisheries Society. I was certified as a Fisheries Scientist by the American Fisheries Society in 1970.

Between 1978 and 1986 I had a break in employment with the Department while I was in private business.

I have had previous experience with the water reservation process in Montana while serving as Water Resources Supervisor in the mid-1970s and again beginning in the mid-1980s up to the present. I was primarily responsible for coordinating the assembly of the Department's instream flow reservation application in the Yellowstone River Basin submitted in November 1976, the reservation application for the Upper Clark Fork basin submitted in 1986 and the upper Missouri basin application submitted in 1989. Instream reservations were granted in the Yellowstone Basin by the Board of Natural Resources and Conservation (Board), in 1978 and in the upper Missouri basin in 1992. No decision has been made in the upper Clark Fork basin due to a temporary basin closure and moratorium on new permits and water reservations.

Q. What are your responsibilities in your present position?

A. I am responsible for most of the activities which involve obtaining and maintaining the quantity of water in streams. Such activities include monitoring and protecting instream flows obtained prior to 1973 (Murphy Rights), obtaining and protecting instream flow reservations and monitoring new water use permits which could affect those instream water rights. I am also responsible for the water leasing program which allows DFWP to lease existing diversionary water rights to enhance instream flows.

Q. What is the purpose of your testimony in this proceeding?

A. My testimony relates to the content of the application for reservations of water in the Missouri River Basin below Fort Peck Dam submitted by the Department in June, 1991. My testimony will relate to the various portions of the application and the persons responsible for completing those portions. I will also provide testimony concerning the impacts of our reservation requests on other existing and future water use activities, the non-economic benefits of the requested reservations to other parties, the environmental, public health, welfare and safety aspects of the reservations, alternatives to the reservations, and the management plan.

Q. Has any information become available since the Department's application was submitted that will be the subject of testimony in this proceeding?

A. Yes, some of the provisional dominant discharge values provided by the USGS shown in Appendix A of the application have been revised. The provisional and revised (final) values are shown in Appendix A of my testimony. Also, the USGS provisional water availability data for the Frenchman River and Missouri River reaches #7 and #8, provided in Appendix B of our application, were revised. The provisional and final values are shown in Appendix B of my testimony. Charles

Parrett will testify about the reasons for these revisions.

These changes resulted in different total flow requests for 9 of the 14 streams where channel maintenance flows were requested. Total volume of the flows requested increased in four and decreased in five of the nine streams. The flow requests for Missouri River reaches #7 and #8 were not affected by the revisions. The flows originally requested for the 21 stream reaches on 18 streams, the changes to those requests, and location maps are shown in Appendix C of my testimony.

These changes also resulted in corrections to the flow request table for each of the following streams in our application:

STREAM	APPLICATION PAGE NO.
Battle Creek	71
Beaver Creek #2 (Phillips County)	80
Frenchman River	84
Rock Creek	88
Redwater River #1	94
Redwater River #2	97
Poplar River	117
West Fork Poplar River	120
Box Elder Creek (Little Missouri)	132

The corrected tables for these streams are shown in Appendix D of my testimony.

A correction was also made to the requested time period for the dominant discharges to occur for the four streams in the Poplar River basin: East Fork Poplar, Middle Fork Poplar, West Fork Poplar and main Poplar rivers. Recently examined USGS data show the time period the dominant discharge would most frequently occur in these streams is March 1 - April 30. These corrections are also shown in Appendix D of my testimony.

Q. What was your role in the preparation of the Department's application?

A. My primary role was coordinating the preparation of the application. I was responsible for ensuring that the contents of the application met the requirements of the ARM rules for water reservations and that sufficient information was provided in the application to justify the instream flow requests for each of the streams.

Q. Were other persons responsible for preparing portions of the application?

A. Yes. Several other DFWP personnel prepared information on the specific stream reaches and other parts of the application. Charles Parrett, U.S. Geological Survey hydrologist, provided the Department with provisional water availability information on each of the streams in the application as required under the ARM rules for Determination of the Amount of the Reservations. This information is contained in Appendix B of the application. Mr. Parrett also provided the provisional dominant discharge hydrograph values contained in Appendix A of the application.

Q. Who else is testifying in support of the application?

A. Larry Peterman is testifying about the background of DFWP programs and policies related to instream flow protection in Montana. Fred Nelson is testifying as to the methods used in deriving instream flow requests. Carolyn Sime is testifying as to her role in preparing the application and to those parts to which she contributed information. Scott Gillilan is testifying about the channel maintenance flows requested. Charles Parrett is testifying about the USGS water availability and dominant discharge values he provided.

In addition, the following individuals will provide testimony on the individual streams in the application:

Bill Gardner - Missouri River reaches #7 and #8, except for the flows recommended in reach #7 for April 1 - May 10 and July 1 - September 30, about which Ken Frazer will testify.

Ken Frazer - Missouri River reach # 7. Flows recommended for April 1 - May 10 and July 1 - September 30 only.

Kent Gilge - Beaver Creek (Hill County), Little Box Elder Creek, Clear Creek, Battle Creek, Peoples Creek, Beaver Creek (Phillips County) reach #1, Beaver Creek (Phillips County) reach #2, Frenchman River, Rock Creek.

Phil Stewart - Redwater River, reaches #1 and #2, East Fork Poplar River, Middle Fork Poplar River, West Fork Poplar River, Poplar River, Box Elder Creek and Little Missouri River.

Robert White - Beaver Creek and Little Beaver Creek in the Little Missouri basin.

Vicinity maps locating each of the streams where flow requests have been made will be provided in the testimony of each of the above individuals.

Q. Will the requested instream flow reservations improve the fisheries in the lower Missouri River Basin and its tributary streams?

A. No. The reservations themselves cannot make any new water available for instream flows. The reservations will only maintain the status quo of flow conditions and, therefore, the fisheries in these streams. However, they will also establish a target flow level that could be reached more frequently should additional water become available in the future.

Q. Will instream flow reservations affect persons who wish to change their existing water rights?

A. Granting the reservations could allow the Department to become involved in any proceedings for a change in an existing right, such as changing a point of diversion, a place of use or the purpose of use. Priority date is not a factor in changes in appropriation rights. If a person believes that a proposed change in another person's existing right will adversely affect his or her own water rights, he or she may object to the change. If the reservations are granted, the Department would have the same right as other water right holders to object to a change if the changed use will adversely affect an instream flow reservation.

Q. The Department has had instream reservations in the Yellowstone Basin since 1978 and on Murphy Right streams since 1970 and 1971. Has the Department objected to water right changes in those streams since that time?

A. Yes. However, the Department's history of objecting to changes in water rights with respect to these streams shows it objects infrequently to such changes.

Q. Will the granting of instream reservations in the Missouri basin alter the standing of the Department in the current water court adjudication proceedings?

A. The Department has been an active participant in the adjudication process since its beginning. We already have standing to object to temporary preliminary decrees and preliminary decrees because we have our own existing diversionary water rights as well as some pre-1973 instream flow rights in many basins. We do not believe the granting of water reservations will alter what we are already doing in that process.

Based on MDFWP and water court records of the 85 basins involved in the statewide adjudication process, the Department has some kind of pre-1973 water right claim in 49 of those individual basins. There are 14 individual basins in the

Missouri Basin below Fort Peck Dam, and six individual basins in the Little Missouri basin. The Department has pre-1973 water right claims in 6 of the basins below Fort Peck Dam and one in the Little Missouri basin. Further, seven of the eight basins below Fort Peck Dam in which the Department does not have pre-1973 water right claims flow into basins where we have such claims. Thus, the Department already has standing in every basin below Fort Peck Dam except one (Milk River below Whitewater Creek, Basin 40O) within the boundaries of this reservation request.

Q. Would granting reservations provide the Department with any additional standing to participate in the issuance of new water use permits?

A. The Department of Natural Resources and Conservation now allows us standing to object to new permit applications where we have no water rights. However, objections made on the basis of impacts to stream flows and the fishery resources where we do not have some type of instream water right, such as our pre-1973 instream rights (Murphy Rights) or water reservations, are difficult to sustain on the basis that the permitting criteria are not met because there is no instream flow right to measure the impacts of the new appropriations against. Granting instream reservations in the lower Missouri River Basin would allow the Department to fully participate in the water use permitting process where there may be adverse impacts to the fisheries protected by the reservations.

Q. What is the "reach concept" discussed in the Management Plan section of the application?

A. The reach concept is simply a term used to indicate how the Department would monitor and protect instream flows that may be granted. Except for some of the larger, longer rivers and streams, most instream flow recommendations were derived at a site near the stream's mouth, with the designated reach extending from the mouth to the headwaters. A designated "reach" merely serves to identify a stretch of stream where junior water users would be subject to the instream reservation which was derived at, and will be monitored at, a site near the lower end of the stream reach. The reach, as we define it, does not represent a stream segment that has the same flow regime or instream flow requirement throughout its length. It simply identifies the upper and lower boundaries of a stream within which junior water users would be contacted by DFWP if we wished to make a "call" for the water when the flow at the downstream monitoring site drops below the instream flow reservation. We presently do not make a call on junior users located outside of the designated stream reach.

Q. Does the reach concept apply to all of the instream flows requested?

A. The concept applies to both the flows requested for the January 1 - December 31 period and the dominant discharge flows. However, administration of the two kinds of flows will likely differ. Administration of low flows would be as described in the previous answer; junior users would be "called" when the streamflow drops below the instream reservation. Dominant discharge flow administration is less definable and will be more challenging. A dominant discharge flow occurs about every two years, <u>on the average</u>. It is a rather frequent flow event, but does not necessarily occur every two years, and may not occur in any given year. So, in any given year, we will not know for sure whether the dominant discharge will occur.

Q. How, then, would you propose to administer the dominant discharge flows, if granted?

A. It may be difficult, and perhaps unnecessary, to administer the dominant discharge under natural flow conditions. Its administration is most likely to be needed if new water storage projects are built that could intercept, and reduce, these high flows. The following is a suggested means of administration, should it be necessary:

1. Use annual streamflow forecasting by the SCS, USGS or others to predict whether the dominant discharge is expected to occur that year and notify junior users that high flow water use may be restricted or unavailable to them; monitor flows continuously during the high flow period at appropriate gauging sites to determine need for compliance by junior users;

2. recommend or require, as appropriate, that an authorization for a new storage project be subject to the instream reservations and be operated so that releases of the dominant discharge flow regime (hydrograph) are made during years when it occurs;

3. recommend new water use permits be conditioned to the instream reservations so that the junior permittee can only use water that is available over and above the dominant discharge hydrograph;

4. use existing or develop new annual forecasting models to develop relationships between snow pack and runoff events so that the capability to predict the dominant discharge hydrograph can be refined. This would enable us to work more effectively with junior water users in determining their possible high water use in a given year.

domestic livestock use.

Q. What are the effects of not granting the DFWP reservations?

A. Without the reservations, 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 sightseeing. The human environment would be similarly impacted through loss of scenic values, and the basin's cultural, historical and social environments could be diminished. Increases in the warmwater angling industry will directly benefit communities in the lower and Little Missouri basins. But, if instream flows are not protected now and the water is used for other purposes, then the future potential of this industry may not be realized.

Without instream flow protection, other benefits to municipalities, agriculture and industry would also be diminished. New consumptive uses of water would continue to reduce downstream water availability. The recharge of streamside aquifers, the assimilative capacity of streams and the viability of riparian ecosystems in sub-irrigated croplands could be diminished. Industrial and municipal waste treatment costs could increase. The potential for contamination of public drinking water supplies by hazardous chemicals could become more likely. Water disputes between consumptive users could 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 lower and Little Missouri basins.

Q. What alternative actions could be taken if the DFWP reservations are not granted?

A. Actions that could be taken to maintain or enhance instream flows in Montana range from doing nothing to the intensification of water conservation and management practices, buying or transferring water rights, leasing water rights, constructing water storage facilities, revising the process for evaluating water right permit applications, closing basins and application of the Public Trust Doctrine.

Improved 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 diverting only the amount of water actually needed for crop production. The latter involves installation and better management of water diversion and delivery systems, accurate measurement of water delivered to users, better information and education about water needs for specific crops, better irrigation scheduling and increased use of water commissioners. If such an infrastructure could be provided to improve agricultural water use efficiency, instream flows could theoretically increase. However, this is not necessarily a viable alternative to reserving instream flows. In many instances, any water salvaged through efficiency, and thus left instream, could simply be diverted by other water users. Or, a water right holder salvaging water might use it for expanding his or her operation or sell or lease it to someone else to use.

Buying or transferring water rights for instream flow purposes is an open question at this time. Even though DFWP could acquire a water right through the transfer of existing rights and utilize those rights for instream uses, it is questionable whether this would be allowed under current state law due to the requirements for a diversion.

DFWP can lease water rights for instream flow purposes under Section 85-2-436, MCA, which allows the temporary leasing of an existing water right for instream flow enhancement purposes from willing individuals. However, the water right remains with the owner and the lease does not establish a water right for an instream use. The administration and logistics of the leasing program are complex and it may take many years to acquire a sufficient number of water leases to show an improvement in instream flows statewide. By contrast, the reservation process provides an opportunity to protect instream values on a broader scale when future consumptive uses are considered. Only two water leases have so far been implemented since authorization in 1989, although several are pending. Water leasing will probably be most effective in small tributary streams to larger rivers where fish spawning potential can be improved by enhancing the flows in these tributary streams, thus improving main river fish populations.

Constructing new water storage projects is currently not a state priority under the State Water Plan and the number of such projects that could be constructed to improve stream flows on a regional or statewide basis is certainly limited. Environmental effects of new reservoirs are also a factor in the analysis of their benefits. Water storage may be feasible in some cases, but cannot be considered a substitute for acquisition of instream flows through the reservation process.

Revising the process for evaluating water right permit applications would help protect instream flows if the public interest and reasonable use criteria, which now apply only to larger water permit applications, could be expanded to include smaller applications as well. However, at the present time these criteria are applied only to applications for 5.5 cfs and 4,000 acre/feet per year. Most permit applications are for much less than that. However, it is difficult to determine the impacts of individual water use permit applications on stream flows and fisheries without an instream water right to measure the effects against. Also, the water permitting process does not address how much instream water to reserve for the future. That is a function of the water reservation process.

Basins can be closed through petition of water users in the basin or through the legislature. Basins closed by petition occur because water users are having difficulty receiving their water under their existing water rights and new water users would only aggravate the situation. Thus, the closure is implemented only after most water is no longer available for instream uses. There is no opportunity in Montana water law for the general public to initiate action to close basins because of instream flow concerns. Following the reservation process in the Upper Missouri basin, the legislature closed four of the basins where reservations were granted to new water use permits, with certain exceptions. Basin closures are a positive factor in limiting the number of new water uses that would remove water from streams in the state. By limiting certain new uses, the closures accomplish some of the same purposes that would be accomplished by water reservations, that is, limiting new consumptive water uses. But, they do not provide instream flow protection against changes in existing water uses.

The use of the public trust doctrine for protecting instream flows in Montana is largely untested and, as an absolute protection strategy, it should probably be considered only as an alternative of last resort. But, because it does lie there in the background, it may serve as an impetus to resolving instream flow issues through other means like water reservations, water leasing and cooperative efforts among consumptive and non-consumptive water interests.

With the possible exception of the intensification of water conservation and management practices and the positive aspect of closing basins to certain new uses, the above alternatives would be less effective in solving instream flow issues because they are either more costly, would be less immediate, lack legislative authority or would be more limited in applicability than would granting the DFWP reservations.

Q. Does the Department's application fairly represent the instream flow needs of streams in the lower and Little Missouri River Basin?

A. Yes. The application requests instream flow reservations on 18 streams (21 stream reaches). The flows requested for each of the stream reaches are specific to that stream reach and essential to maintaining the existing aquatic environment of that reach. A wide range of flows have been requested, varying from less than one cubic foot per second (cfs) in some prairie streams to several thousand cfs in the Missouri River mainstem below Fort Peck Dam.

Flow quantities requested in this application reflect the size and character of the existing stream channel as well as the needs of the existing fish and wildlife found there. The quantity of water needed to sustain existing aquatic life in a stream reach must be independently determined. This has been done in the preparation of this application.

I, Liter Spence, being first duly sworn, states that the foregoing testimony is true.

DATED this 29th day of June, 1994.

Lita E. Spence

Liter E. Spence

Subscribed and sworn to before me this 29th day of June, 1994.

Debra K. McRae

Notary Public for the State of Montana
Residing at Helena, Montana
My commission expires May 14, 1998

BIOGRAPHY

Liter E. Spence
June 15, 1994

Current position: Water Resources Supervisor, Montana Department of Fish, Wildlife and Parks, Helena, MT 59620

Education:

1954-1956 Boise Jr. College, Boise, Idaho. Received AA degree in General Science with emphasis in biology, chemistry and mathematics.

1959-1961 University of Idaho, Moscow, Idaho. Received BS degree in Zoology with minor in chemistry.

1961-1963 University of Wyoming, Laramie, Wyoming. Received MS in Wildlife Conservation and Management. Course work emphasized fisheries management.

Experience:

Summer 1962 - Fishery Aid, Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, Juneau, Alaska. Tagged sockeye salmon migrating from the Pacific Ocean to determine where they spawn in streams of Aleutian Peninsula and recovered tagged fish on their spawning grounds.

1963-1965 - Fishery Biologist, U.S. Fish and Wildlife Service, Missouri River Basin Studies, Billings, Montana. Investigated the effects of proposed federal water development projects on fisheries in Montana and Wyoming.

1965-1970 - Project Fishery Biologist, Montana Department of Fish and Game, Missoula, Montana. Conducted fisheries inventories and creel censuses on streams and lakes in western Montana fisheries region.

1970-1974 - Planning Ecologist, Montana Department of Fish and Game, Ovando, Montana. Conducted baseline inventory study of water quality, fisheries and wildlife in upper Blackfoot River in connection with a proposed industrial copper mining venture by the Anaconda Company.

1974-1978 - Water Resources Supervisor, Montana Department of Fish and Game, Helena, Montana. Coordinated efforts by Fish and Game Department to implement provisions of the Montana Water Use Act which provides for flow reservations for fish, wildlife and recreation. Responsible for assembly of Fish and Game Department application for water reservations in the Yellowstone River Basin submitted to the Board of Natural Resources in 1976.

1978-1985 - In private retail business in California and Nevada.

1986-present - Water Resources Supervisor, Montana Department Fish, Wildlife and Parks, Helena. Responsible for Department's instream flow program statewide, including preparation of Department's application for instream flow reservations in the Missouri River Basin above and below Fort Peck Dam, and in the Little Missouri River Basin.

Additional Education and Training:

(1) July 12-23, 1970. Training school in water quality studies conducted by Environmental Protection Agency, Pacific Northwest Water Laboratory, Corvallis, Oregon.

(2) October 11-12, 1972. River mechanics seminar, Montana State University, Bozeman. Sponsored by Department of Fish and Game with participants from Corps of Engineers, Vicksburg, Mississippi and Civil Engineering Department at Colorado State University, Fort Collins.

(3) October 9-December 11, 1973. Hydrology course taught by Dr. Richard Bruskern, Civil Engineer, Montana State University, Bozeman through the Montana State University continuing education program.

(4) September 5-6, 1974. Instream flow needs problem analysis workshop, Sun Valley, Idaho. Sponsored by Washington Water Research Center, Washington State University, Pullman, WN.

(5) September 27, 1974. Stream gaging techniques field workshop, Yellowstone National Park, Mammoth, Wyoming. Conducted by Ron Shields, U.S. Geological Survey, Helena, Montana for Department of Fish and Game biologists to demonstrate proper techniques for streamflow measurement.

(6) January 22, 1975. Water Surface Profile Program (WSP) workshop, Billings, Montana. Conducted by U.S. Bureau of Reclamation hydraulic engineers for fishery biologists from Montana and Wyoming to explain how WSP can be used for instream flow determinations.

(7) September 17-19, 1975. Instream flow needs workshop, Utah State University, Logan, Utah. Conducted by Utah State University and Office of Biological Services, U.S. Fish and Wildlife Service, Washington, D.C. Workshop resulted in a state-of-the-art document describing methodologies currently used to recommend instream flows for fish, wildlife and recreation. The document is entitled Stalnaker, C.B. and J.L. Arnette. 1976. Methodologies for determination of stream resource flow requirements: an assessment.

USFWS, OBS, West. Water Allocation. 199 p.

(8) May 3-6, 1976. Instream flow needs symposium and specialty conference, Boise, Idaho. Sponsored by Western Division American Fisheries Society and Power Division American Society of Civil Engineers. A series of papers discussing solutions to technical, legal and social problems caused by increasing competition for limited streamflow. Proceedings of the conference published by American Fisheries Society. I presented a paper and moderated a panel.

(9) June 29, 1976. Stillwater River near Absarokee. One day field workshop with Fish and Game and Bureau of Reclamation personnel for field instruction and demonstration of Water Surface Profile (WSP) program technique. Instruction by Mr. Richard DeVore, Hydraulic Engineer, U.S. Bureau of Reclamation, Billings.

(10) March 31 - April 1, 1988. Instream flow protection in the western United States - a practical symposium. Sponsored by University of Colorado, School of Law, Boulder, Colorado. Presented a paper on Department of Fish, Wildlife and Parks instream flow protection procedures.

(11) October 20-21, 1989. Western Regional Instream Flow Conference, Jackson Hole, Wyoming. Sponsored by Trout Unlimited.

(12) April 21-22, 1994. Montana Rivers: Conflict of Confluence? An educational symposium on streamflow issues held at Montana State University, Bozeman, Montana. Sponsored by University of Montana Law School; Montana Watercourse and the Montana Water Center at Montana State University and the legislative Water Policy Committee. I presented two papers.

<u>Professional Organizations:</u>

Member, American Fisheries Society and Montana Chapter, American Fisheries Society. Certified as a Fisheries Scientist by the American Fisheries Society in 1970.

<u>Articles and Publications:</u>

Spence, L.E. 1965-1970. Western Montana fishery study. Inventory of waters of the project area. Fed. Aid in Fish Restor. Proj. F-12-R, Mont. A series of annual progress reports. Mont. Fish and Game Dept., Helena. Mimeo.

Spence, L.E. 1971. Rock Creek creel census. Final report, summer census. Fed. Aid in Fish Restor. Proj. F-27-R, Job 1, Mont. Mont. Fish and Game Dept., Helena. 28 p. + appendix. Mimeo.

Spence, L.E. 1968. Georgetown Lake winter creel census. Fed. Aid in Fish Restor. Proj. F-12-R-13, Job 2. Mont. Mont. Fish and

Game Dept., Helena. 18 p. Mimeo.

Spence, L.E. 1968. Georgetown Lake winter creel census. Fed. Aid in Fish Restor. Proj. F-12-R-14 Job 2, Mont. Mont. Fish and Game Dept., Helena. 6 p. Mimeo.

Spence, L.E. 1970. Georgetown Lake winter creel census. Fed. Aid in Fish Restor. Proj. F-12-R-16 Job I-b, Mont. Mont. Fish and Game Dept., Helena. 12 p. + appendix. Mimeo.

Spence, L. 1970. Evaluation of random boulders for stream improvement in Rock Creek. Work conducted under Fed. Aid in Fish Restor. Proj. F-12-R, Mont. Mont. Fish and Game Dept., Helena. 9 p. Mimeo.

Spence, L.E. 1971. Georgetown Lake summer creel census. Fed. Aid in Fish Restor. Proj. F-12-R-17, Job I-b, Mont. Mont. Fish and Game Dept., Helena. 11 p. + appendix. Mimeo.

Spence, L.E. 1975. Upper Blackfoot River study. A preliminary inventory of aquatic and wildlife resources. Mont. Dept. of Fish and Game, Helena and the Anaconda Company, Butte, MT 87 p. + appendix.

Spence, Liter. 1970. Diversion tactics. Montana Outdoors Vol. V No. 2. Mont. Fish and Game Dept., Helena. February 1970.

Spence, Liter. 1970. Montana's most-fished lake. Montana Outdoors Vol. V No. 7. Mont. Fish and Game Dept., Helena. July 1970.

Spence, Liter. 1975. The Blackfoot is beautiful. In The Montana Fishing Guide by Dick Konizeski. Mountain Press Pub. Co., Missoula, MT p. 41.

Spence, L.E. 1974. An inexpensive surface water dissolved oxygen sampler. Prog. Fish Cult. 36(1): p. 26.

Spence, Liter. 1975. "The new water law." Montana Outdoors column in The Independent Record, Helena, MT. Mont. Dept. Fish, and Game, Helena 59601.

Spence, Liter. 1976. "What has the 1973 Montana Water Use Act done for aquatic resources?" Paper presented at Montana Chapter, Amer. Fish. Soc. meeting, Missoula, MT January 22, 1976. Mont. Dept. Fish & Game, Helena 59601.

Spence, L.E. 1976. WSP - Will it do the job in Montana? In Proceedings of Instream Flow Needs Symposium & Specialty Conference, presented by Western Division American Fisheries Society & Power Division, Amer. Soc. Civil Engineers, Boise, Idaho

May 3-6, 1975. Pub. by Amer. Fish. Soc., 5410 Grosvenor Lane, Bethesda, MD 20014. September 1976.

Spence, Liter. "Yellowstone reservation explained." Montana Outdoors column in the Independent Record, Helena, MT. Mont. Dept. Fish & Game, Helena 59601.

Spence, Liter. 1977. "Montana's new water law - is it working?" Montana Outdoors, Jan.-Feb. 1977. pg. 23. Mont. Dept. Fish & Game, Helena, MT 59601.

Spence, Liter. 1987. Clark Fork R_x - Prescription for Renewal? Montana Outdoors, Vol. 18(6) Nov./Dec. Mont. Dept. Fish, Wildlife and Parks, Helena, MT 59620. pg. 2.

Spence, Liter. 1990. Instream Flow on the Mighty Mo. Montana Outdoors. Vol 21(4), July/Aug. Mont. Dept. Fish, Wildlife and Parks, Helena, MT 59620. pg. 2.

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APPENDIX A

Estimated provisional and final dominant discharge hydrographs

Site No.	Stream Name	Day	Mean Daily Discharge Provisional	Final
5	Battle Creek at mouth, near Chinook, MT	1	45	40
		2	95	90
		3	470	210
		4	930	470
		5	1970	1520
		6	1330	710
		7	650	260
		8	180	130
		9	130	100
		10	90	85
		11	75	70
		12	65	60
		13	60	55
		14	50	45
7	Frenchman River at mouth, near Saco, MT	1	10	No Change
		2	30	
		3	50	
		4	70	
		5	150	
		6	290	
		7	450	
		8	740	
		9	1320	
		10	1010	
		11	760	
		12	580	
		13	470	
		14	360	
		15	280	
		16	200	
		17	160	
		18	120	
		19	90	
		20	70	
		21	60	
9	Beaver Creek at mouth, near Saco, MT	1	10	10
		2	10	190
		3	40	880
		4	160	2210
		5	400	1750
		6	1160	1180
		7	920	640
		8	440	500
		9	320	390
		10	240	300
		11	200	210
		12	160	180
		13	120	150
		14	85	120
		15	75	100
		16	55	80
		17	45	60
		18	30	40
		19	25	20
		20	20	10
		21	15	10

10	Rock Creek at mouth, near Hinsdale, MT	1	15	No Change
		2	25	
		3	80	
		4	780	
		5	1900	2180
		6	2560	2960
		7	1750	1970
		8	1260	1320
		9	760	
		10	480	
		11	310	
		12	200	
		13	140	No Change
		14	100	
		15	80	
		16	55	
		17	45	
		18	35	
		19	25	
		20	20	
		21	20	
11	Redwater River above confluence of East Fork Redwater, near Vida, MT	1	5	0
		2	90	20
		3	890	60
		4	1440	180
		5	1730	370
		6	870	780
		7	170	540
		8	60	340
		9	50	230
		10	40	120
		11	40	100
		12	30	80
		13	30	60
		14	30	40
12	Redwater River near Vida, MT	1	5	5
		2	100	70
		3	1040	110
		4	1680	300
		5	2010	490
		6	1010	900
		7	200	700
		8	70	480
		9	60	290
		10	50	180
		11	40	150
		12	40	130
		13	40	110
		14	30	90

13	Poplar River above confluence of East Poplar River, near Scobey, MT (This stream is called Middle Fork Poplar River in the reservation application, p.109)	1	40	No Change
		2	150	
		3	670	
		4	1000	
		5	670	
		6	320	
		7	160	
		8	110	
		9	80	
		10	60	
		11	50	
		12	30	
		13	20	
		14	20	
14	East Poplar River at mouth, near Scobey, MT	1	2	No Change
		2	6	
		3	10	↓
		4	60	
		5	280	
		6	540	
		7	330	
		8	200	
		9	80	
		10	60	
		11	20	
		12	9	
		13	7	
		14	5	6
15	Poplar River at Fort Peck Reservation boundary, near Scobey, MT	1	50	50
		2	190	200
		3	810	880
		4	1210	1930
		5	810	1530
		6	390	1000
		7	190	820
		8	130	600
		9	100	400
		10	70	300
		11	40	220
		12	30	170
		13	20	120
		14	20	70
16	West Fork Poplar River at Fort Peck Reservation boundary, near Four Buttes, MT	1	50	5
		2	180	90
		3	800	450
		4	1190	850
		5	800	570
		6	380	480
		7	190	350
		8	120	200
		9	100	170
		10	70	140
		11	40	110
		12	30	80
		13	30	60
		14	20	40

18	Little Missouri River at Camp Crook, S. Dak.	1	10	No Change
		2	15	
		3	20	
		4	75	
		5	290	
		6	1450	
		7	2540	
		8	2320	
		9	1670	
		10	1150	
		11	940	
		12	760	
		13	600	
		14	430	
		15	280	
		16	240	
		17	200	
		18	280	
		19	240	
		20	200	
		21	150	
19	Boxelder Creek near Webster, MT	1	6	No Change
		2	25	↓
		3	55	
		4	170	
		5	340	
		6	850	
		7	1820	1910
		8	1480	↑
		9	1220	
		10	860	
		11	640	
		12	380	No Change
		13	160	↓
		14	120	
		15	55	
		16	35	
		17	15	
		18	10	
		19	5	
		20	4	
		21	3	

20	Little Beaver Creek near Marmarth, N. Dak.	1	2	No Change
		2	3	
		3	7	
		4	9	
		5	620	
		6	2050	
		7	3310	
		8	1080	
		9	250	
		10	160	
		11	110	
		12	75	
		13	55	
		14	41	
		15	35	
		16	30	
		17	25	
		18	20	
		19	20	
		20	15	
		21	15	
21	Beaver Creek near Trotters, N. Dak.	1	10	No Change
		2	15	
		3	35	
		4	130	
		5	390	
		6	790	
		7	1050	
		8	660	
		9	330	
		10	130	
		11	65	
		12	53	
		13	40	
		14	35	

APPENDIX B

Estimated monthly and annual streamflow characterictics

Provisional

Site Name	Month	Q.90	Q.80	Q.50	Q.20	QM
Frenchman River at mouth, near Saco, MT.	October	0	0	3	12	9
	November	.6	2	5	10	6
	December	0	.1	2	6	3
	January	0	0	.3	3	2
	February	0	0	.7	6	15
	March	3	11	69	181	137
	April	21	47	217	686	418
	May	9	15	54	177	126
	June	0	1	19	85	53
	July	0	0	11	34	37
	August	0	0	4	11	8
	September	0	0	2	7	5
	Annual	--	--	--	--	68

Final

[Q.XX, monthly mean streamflow exceeded XX percent of the years, in cubic feet per second; QM, mean streamflow for specified month, or mean annual streamflow when Annual is specified, in cubic feet per second]

Site no.	Stream name	Month	Q.90	Q.80	Q.50	Q.20	QM
7	Frenchman River at mouth, near Saco, Mont.	October	0	0	3	13	10
		November	.7	2	5	11	7
		December	0	.1	2	7	3
		January	0	0	.3	3	2
		February	0	0	.8	7	17
		March	3	13	76	199	151
		April	23	52	239	755	460
		May	10	17	59	195	139
		June	0	1	21	94	58
		July	0	0	13	37	41
		August	0	0	4	13	9
		September	0	0	2	8	6
		Annual	--	--	--	--	75

PROVISIONAL

PROVISIONA

Site Name	Month	Q.90	Q.80	Q.50	Q.20	QM
Missouri River below Fort Peck, MT.	October	3500	5310	10300	15300	11500
	November	3690	4870	9010	13100	8830
	December	1550	5450	9320	11300	8320
	January	1450	4670	9860	12600	8710
	February	1180	2820	8240	13800	8660
	March	1470	3480	7620	11100	7420
	April	1770	3830	7240	10300	7300
	May	1860	3890	6960	11900	7900
	June	1290	3690	7900	12600	8160
	July	3530	5620	10100	13200	10200
	August	5710	7570	12100	18100	12700
	September	4290	6360	11400	18300	12200
	Annual	--	--	--	--	9330
Missouri River nr Culbertson, MT	October	4150	5670	10400	16500	11800
	November	3640	4990	9020	12900	9140
	December	1670	5570	8740	11500	8230
	January	1450	5060	9030	12700	8620
	February	1410	3180	9220	14200	9170
	March	3560	5290	10400	14700	10200
	April	4570	7430	10600	16900	11500
	May	2360	4880	8470	14700	9560
	June	2820	5310	8620	13800	9560
	July	5090	6420	9920	13400	10900
	August	6350	7590	11600	17100	12700
	September	4700	7100	11600	18200	12500
	Annual	--	--	--	--	9440

FINAL

Site no.	Stream name	Month	Q.90	Q.80	Q.50	Q.20	QM
1	Missouri River below Fort Peck Dam, Mont.	October	5,200	6,060	11,500	19,100	12,600
		November	4,590	5,800	9,210	13,200	9,460
		December	5,150	6,880	10,100	11,300	9,040
		January	4,470	6,640	10,900	13,000	9,620
		February	2,130	5,500	10,900	14,100	9,600
		March	1,250	4,130	7,740	11,200	7,620
		April	2,120	4,430	7,520	10,500	7,440
		May	2,800	5,500	7,380	12,000	8,310
		June	2,500	4,170	7,900	12,700	8,420
		July	3,640	5,770	10,000	13,200	10,300
		August	5,980	7,720	12,100	18,900	13,000
		September	5,900	7,020	11,900	18,800	13,000
		Annual	--	--	--	--	9,870

Site no.	Stream name	Month	Q.90	Q.80	Q.50	Q.20	QM
17	Missouri River near Culbertson, Mont.	October	5,520	6,430	11,500	18,900	12,800
		November	4,610	6,320	9,290	13,100	9,800
		December	5,380	6,960	9,620	11,600	8,950
		January	4,620	6,160	11,000	12,700	9,490
		February	2,390	6,020	11,200	14,400	10,200
		March	4,150	5,420	10,700	14,400	10,400
		April	4,950	7,470	10,900	16,900	11,900
		May	3,270	6,050	9,260	14,800	10,000
		June	4,480	5,440	8,620	13,800	9,780
		July	5,160	6,430	9,940	13,500	11,000
		August	6,470	7,670	12,200	19,200	13,000
		September	6,620	7,420	12,100	19,100	13,200
		Annual	--	--	--	--	10,900

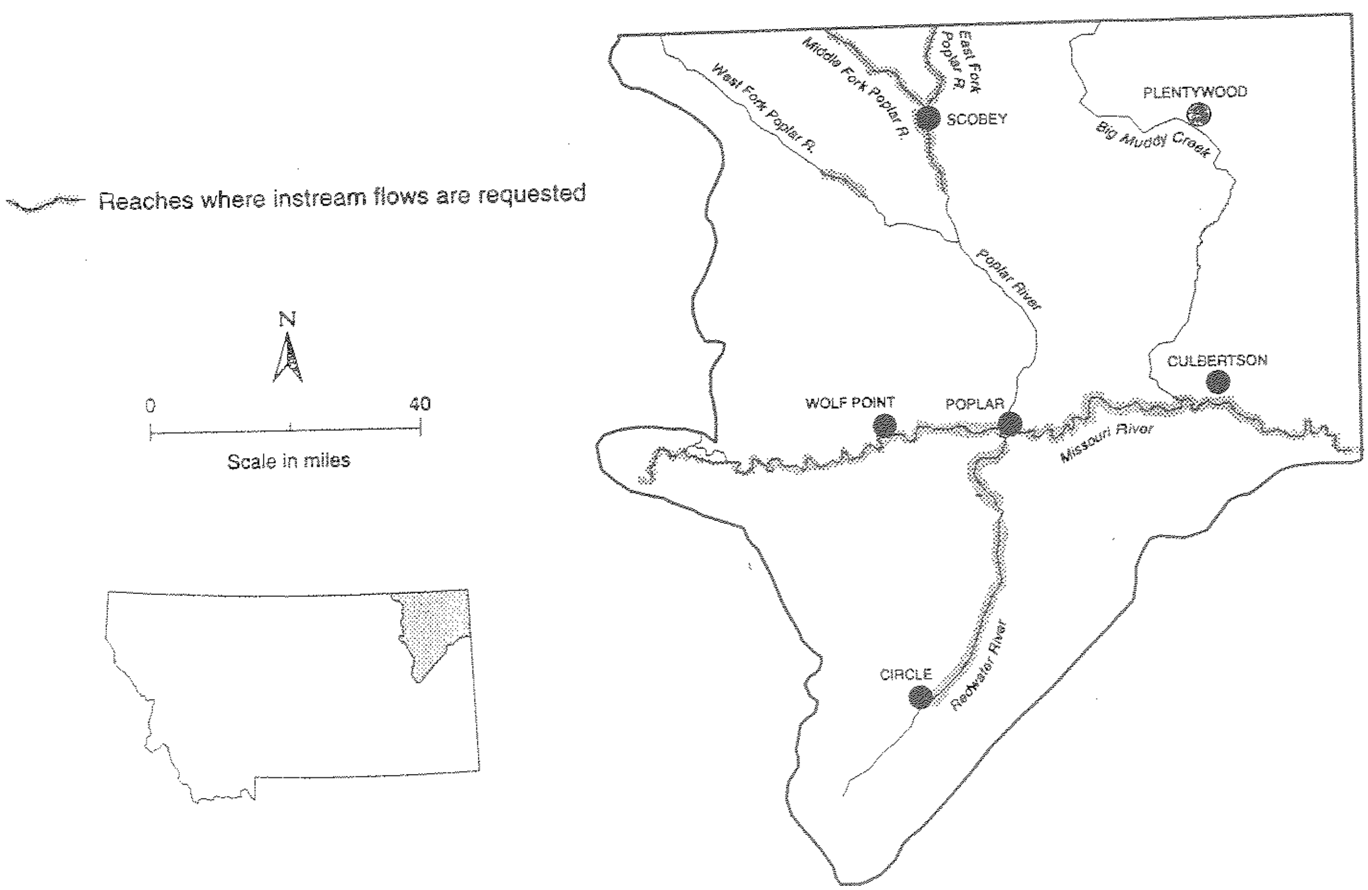
Table 3-2. Montana Department of Fish, Wildlife and Parks Instream Flow Requests

Stream	Reach	Dates Requested	—Amount Requested— (cfs)	(af)	(af/yr)
Milk River Subbasin					
Battle Creek	International boundary to mouth	Jan., Feb., Mar., Dec.,	2.0	480	~~15,078~~ 10,524
		Apr. through Nov.	5.0	2,420	
		Channel Maintenance Flows	~~1,970*~~ 1,520	~~12,178~~ 7,624	
Beaver Creek (Hill County)	Reservation boundary to Beaver Creek Reservoir	Year-round	7.0	5,068	5,068
Beaver Creek #1 (Phillips Co.)	Headwaters to reservation boundary	Year-round	0.2	145	145
Beaver Creek #2 (Phillips County)	Highway 191 to mouth	Jan., Feb., Mar., Dec.	7.0	1,679	~~15,950~~ 23,342
		Apr. through Nov.	11.0	5,324	
		Channel Maintenance Flows	~~1,160*~~ 2210	~~8,947~~ 16,339	
Clear Creek	Headwaters to Clear Creek Road	Year-round	5.0	3,620	3,620
Frenchman River	International boundary to mouth	Jan., Feb., Mar., Dec.	2.0	480	~~26,314~~ 25,798
		Apr. through Nov.	~~5.0~~ 6.0	~~2,420~~ 2904	
		Channel Maintenance Flows	2,050*	22,414	
Little Box Elder Creek	Headwaters to Clear Creek Road	Year-round	1.0	724	724
Peoples Creek	Headwaters to Barney Olson Road	Year-round	1.0	724	724
Rock Creek	International boundary to mouth	Jan., Feb., Mar., Dec.	2.0	480	~~27,600~~ 25,457
		Apr. through Nov.	8.0	3,872	
		Channel Maintenance Flows	should be 2960 → ~~2,180*~~ 2,560	~~23,248~~ 21,105	
Missouri River #7	Fort Peck Dam to Milk River	April 1-May 10	7,800	618,843	5,620,361
		May 11-June 30	11,000	1,112,727	
		July 1-Sept. 30	7,800	1,423,338	
		Oct. 1-Feb. 28	7,000	2,096,528	
		March 1-March 31	6,000	368,925	
Missouri River #8	Milk River to state line	May 11-June 30	11,500	1,163,305	5,522,972
		July 1-May 10	7,000	4,359,667	
East Fork Poplar River	International boundary to Middle Fork	Jan., Feb., Mar., Dec.	3.0	719	6,870 no change
		April	15	893	
		May	10	615	
		June through Nov.	4	1,452	
		Channel Maintenance Flows	540*	3,191	
Middle Fork Poplar River	International boundary to East Fork	Jan., Feb., Mar., Dec.	1.0	239	10,685 no change
		April	30.0	1,785	
		May	20.0	1,230	
		June through Nov.	2.0	726	
		Channel Maintenance Flows	1,000*	6,705	
Poplar River	Junction of Middle and East Forks to reservation boundary	Jan., Feb., Mar., Dec.	8.0	1,920	~~21,207~~ 29,593
		April	70.0	4,165	
		May	50.0	3,074	
		June through Nov.	11.0	3,993	
		Channel Maintenance Flows	~~1,210*~~ 1930	~~8,055~~ 16,441	
West Fork Poplar River	County bridge south of Peerless to reservation boundary	Jan., Feb., Mar., Dec.	3.0	719	~~13,121~~ 12,315
		April	30.0	1,785	
		May	20.0	1,230	
		June through Nov.	4.0	1,452	
		Channel Maintenance Flows	~~1,100*~~ 850	~~7,935~~ 7,129	

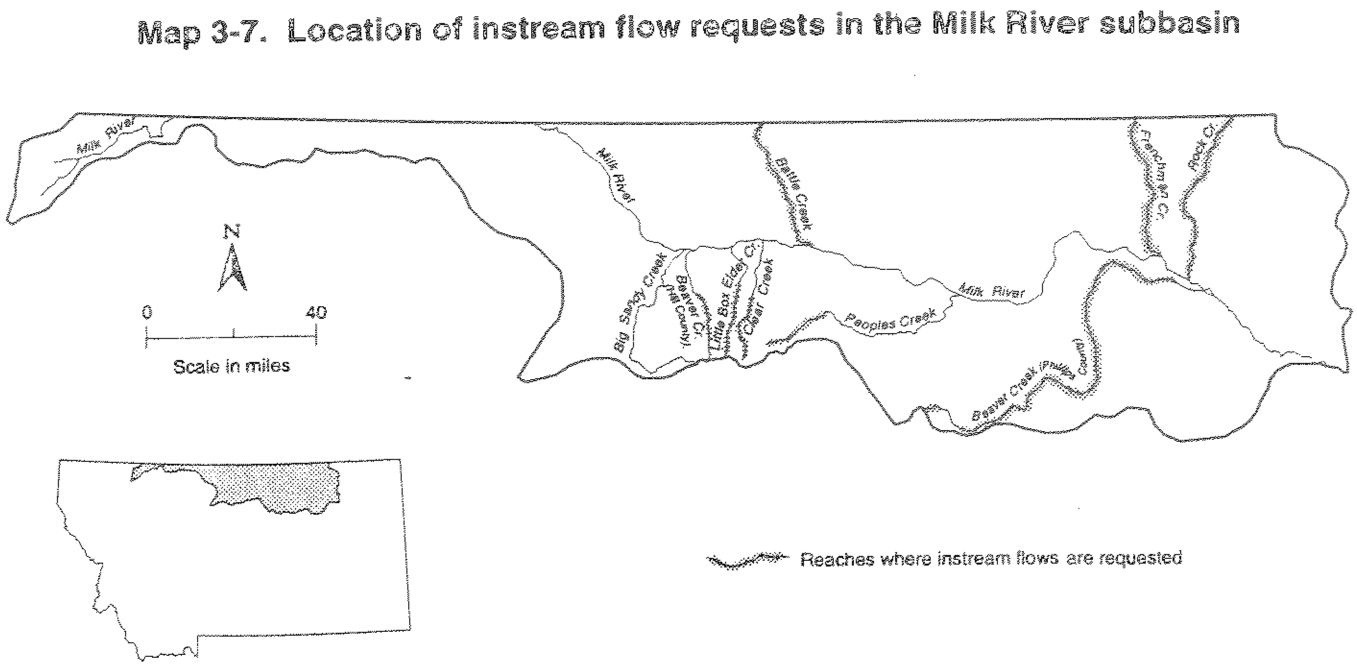
Stream	Reach	Dates Requested	Amount Requested (cfs)	Amount Requested (af)	Amount Requested (af/yr)
Lower Missouri River Subbasin					
Redwater River #1	Circle to East Redwater Creek	Jan., Feb., Mar., Dec.	2.0	480	~~12,792~~ 7726
		Apr. through Nov.	3.0	1,452	
		Channel Maintenance Flows	~~1,730*~~ 780	10,860 5,791	
Redwater River #2	East Redwater Creek to mouth	Jan., Feb., Mar., Dec.	2.0	480	~~15,060~~ 10,359
		Apr. through Nov.	4.0	1,936	
		Channel Maintenance Flows	~~2,010*~~ 900	~~12,644~~ 7,643	
Little Missouri River Subbasin					
Beaver Creek (Wibaux County)	Lamesteer Creek to state line	Jan., Feb., Mar., Dec.	1.0	239	7,984 no change
		Apr. through Nov.	0.7	340	
		Channel Maintenance Flows	1,050*	7,405	
Boxelder Creek	One mile west of Belltower to state line	Jan., Feb., Mar., Dec.	4.0	960	~~20,682~~ 20,718
		Apr. through Nov.	7.0	3,388	
		Channel Maintenance Flows	~~1,020*~~ 1,910	~~16,334~~ 16,370	
Little Beaver Creek	Russell Creek to state line	Year-round	3.0	2,171	17,895 no change
		Channel Maintenance Flows	2,050*	15,724	
Little Missouri River	Montana-Wyoming border to Montana-South Dakota border	Jan., Feb., Mar., Dec.	5.0	1,199	32,562 no change
		Apr. through Nov.	8.0	3,872	
		Channel Maintenance Flows	2,540*	27,491	

*Channel maintenance flow request are for varying amounts over a 13- to 21-day period; only the peak daily request is included here.
af - acre-feet af/yr - acre-feet per year cfs - cubic feet per second
Source: Department of Fish, Wildlife and Parks 1991

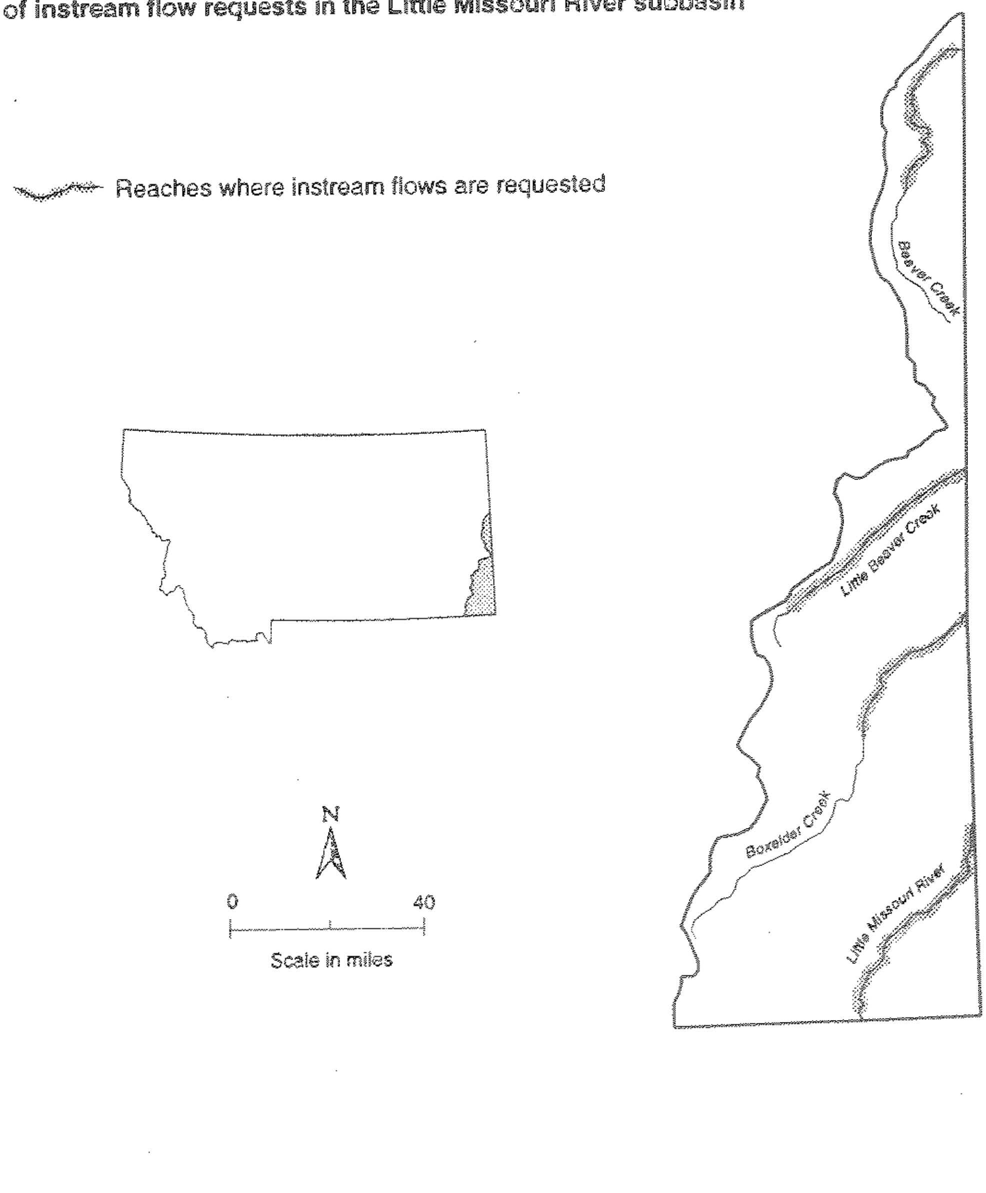
Map 3-5. Location of instream flow requests in the Lower Missouri River subbasin



Map 3-7. Location of instream flow requests in the Milk River subbasin



Map 3-8. Location of instream flow requests in the Little Missouri River subbasin



APPENDIX D

Corrected tables of DFWP flow requests for nine stream reaches.[1]

[1]Resulting from USGS revisions of water availability data and dominant discharge hydrographs.

Battle Creek

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	2.0	123[a]
February	2.0	111[a]
March	2.0	123[a]
		~~12,178~~[b] 7,624
April	5.0	298[a]
May	5.0	307[a]
June	5.0	298[a]
July	5.0	307[a]
August	5.0	307[a]
September	5.0	298[a]
October	5.0	307[a]
November	5.0	298[a]
December	2.0	123[a]
Total:		~~15,078~~ 10,524

[a] Flows derived using the Base Flow Approach.

[b] Additional water during a 14-day period to start no earlier than March 1 nor later than April 30, according to the following pattern:

Day	CFS	AF
1	~~45~~ 40	~~89~~ 79
2	~~95~~ 90	~~188~~ 178
3	~~470~~ 210	~~932~~ 416
4	~~930~~ 470	~~1,845~~ 932
5	~~1,970~~ 1520	~~3,907~~ 3015
6	~~1,330~~ 710	~~2,638~~ 1408
7	~~650~~ 260	~~1,289~~ 516
8	~~180~~ 130	~~357~~ 258
9	~~130~~ 100	~~258~~ 198
10	~~90~~ 85	~~179~~ 168
11	~~75~~ 70	~~149~~ 139
12	~~65~~ 60	~~129~~ 119
13	~~60~~ 55	~~119~~ 109
14	~~50~~ 45	~~99~~ 89
		~~12,178~~ 7,624

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	7.0	430[a]
February	7.0	389[a]
March	7.0	430[a]
		~~8,947~~[b] 16,339
April	11.0	655[a]
May	11.0	676[a]
June	11.0	655[a]
July	11.0	676[a]
August	11.0	676[a]
September	11.0	655[a]
October	11.0	676[a]
November	11.0	655[a]
December	7.0	430[a]
Total:		~~15,950~~ 23,342

[a] Flows derived using the Base Flow Approach.

[b] Additional water during a ~~19~~ 18-day period to start no earlier than March 1 nor later than April 30, according to the following pattern:

Day	CFS	AF
1	~~40~~ 190	~~79~~ 377
2	~~160~~ 880	~~317~~ 174
3	~~400~~ 2210	~~793~~ 4383
4	~~1,160~~ 1750	~~2,301~~ 3471
5	~~920~~ 1180	~~1,825~~ 2340
6	~~440~~ 640	~~873~~ 1269
7	~~320~~ 500	~~635~~ 992
8	~~240~~ 390	~~476~~ 774
9	~~200~~ 300	~~397~~ 595
10	~~160~~ 210	~~317~~ 416
11	~~120~~ 180	~~238~~ 357
12	~~85~~ 150	~~169~~ 298
13	~~75~~ 120	~~149~~ 238
14	~~55~~ 100	~~109~~ 198
15	~~45~~ 80	~~89~~ 159
16	~~30~~ 60	~~60~~ 119
17	~~25~~ 40	~~50~~ 79
18	~~20~~ 20	~~40~~ 40
~~19~~	~~15~~	~~30~~
		~~8,947~~ 16,339

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	2.0	123[a]
February	2.0	111[a]
March	2.0	123[a]
		22,414[b]
April	~~5.0~~ 6.0	~~298~~[a] 357
May	~~5.0~~ 6.0	~~307~~[a] 369
June	~~5.0~~ 6.0	~~298~~[a] 357
July	~~5.0~~ 6.0	~~307~~[a] 369
August	~~5.0~~ 6.0	~~307~~[a] 369
September	~~5.0~~ 6.0	~~298~~[a] 357
October	~~5.0~~ 6.0	~~307~~[a] 369
November	~~5.0~~ 6.0	~~298~~[a] 357
December	2.0	123[a]
Total:		~~25,314~~ 25,798

[a] Flows derived using the Base Flow Approach.

[b] Additional water during a 21-day period to start no earlier than March 1 nor later than April 30, according to the following pattern:

Day	CFS	AF
1	30	60
2	45	89
3	70	139
4	110	218
5	240	476
6	450	893
7	690	1,369
8	1,150	2,281
9	2,050	4,066
10	1,570	3,114
11	1,180	2,340
12	900	1,785
13	730	1,448
14	560	1,111
15	430	853
16	310	615
17	240	476
18	190	377
19	150	298
20	110	218
21	95	188
		22,414

Rock Creek

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	2.0	123[a]
February	2.0	111[a]
March	2.0	123[a]
		~~23,248~~[b] 21,105
April	8.0	476[a]
May	8.0	492[a]
June	8.0	476[a]
July	8.0	492[a]
August	8.0	492[a]
September	8.0	476[a]
October	8.0	492[a]
November	8.0	476[a]
December	2.0	123[a]
Total:		~~27,600~~ 25,457

[a] Flows derived using the Base Flow Approach.

[b] Additional water during a 21-day period to start no earlier than March 1 nor later than April 30, according to the following pattern:

Day	CFS	AF
1	15	30
2	25	50
3	80	159
4	780	1,547
5	~~2,180~~ 1900	~~4,324~~ 3768
6	~~2,960~~ 2560	~~5,871~~ 5078
7	~~1,970~~ 1750	~~3,907~~ 3471
8	~~1,320~~ 1260	~~2,618~~ 2499
9	760	1,507
10	480	952
11	310	615
12	200	397
13	140	278
14	100	198
15	80	159
16	55	109
17	45	89
18	35	69
19	25	50
20	20	40
21	20	40
		~~23,248~~ 21,105

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	2.0	123[a]
February	2.0	111[a]
March	2.0	95[a]
		~~10,860~~[b] 5,791
April	3.0	179[a]
May	3.0	184[a]
June	3.0	179[a]
July	3.0	184[a]
August	3.0	184[a]
September	3.0	179[a]
October	3.0	184[a]
November	3.0	179[a]
December	2.0	123[a]
Total:		~~12,764~~ 7,726

[a] Flows derived using the Base Flow Approach.

[b] Additional water during a ~~14~~ 13-day period to start no earlier than February 1 nor later than April 30, according to the following pattern:

Day	CFS	AF
1	~~5~~ 20	~~10~~ 40
2	~~90~~ 60	~~179~~ 119
3	~~890~~ 180	~~1,765~~ 357
4	~~1,440~~ 370	~~2,856~~ 734
5	~~1,730~~ 780	~~3,431~~ 1547
6	~~870~~ 540	~~1,726~~ 1071
7	~~170~~ 340	~~337~~ 674
8	~~60~~ 230	~~119~~ 456
9	~~50~~ 120	~~99~~ 238
10	~~40~~ 100	~~79~~ 198
11	~~40~~ 80	~~79~~ 159
12	~~30~~ 60	~~60~~ 119
13	~~30~~ 40	~~60~~ 79
~~14~~	~~30~~	~~60~~
		~~10,860~~ 5,791

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	2.0	123[a]
February	2.0	111[a]
March	2.0	95[a]
		~~12,644~~[b] 7,943
April	4.0	238[a]
May	4.0	246[a]
June	4.0	238[a]
July	4.0	246[a]
August	4.0	246[a]
September	4.0	238[a]
October	4.0	246[a]
November	4.0	238[a]
December	2.0	123[a]
Total:		~~15,032~~ 10,359

[a] Flows derived using the Base Flow Approach.

[b] Additional water during a 14-day period to start no earlier than February 1 nor later than April 30, according to the following pattern:

Day	CFS	AF
1	5	10
2	~~100~~ 70	~~198~~ 139
3	~~1,040~~ 110	~~2,063~~ 218
4	~~1,680~~ 300	~~3,332~~ 595
5	~~2,010~~ 490	~~3,987~~ 972
6	~~1,010~~ 900	~~2,003~~ 1785
7	~~200~~ 700	~~397~~ 1388
8	~~70~~ 480	~~139~~ 952
9	~~60~~ 290	~~119~~ 575
10	~~50~~ 180	~~99~~ 357
11	~~40~~ 150	~~79~~ 298
12	~~40~~ 130	~~79~~ 258
13	~~40~~ 110	~~79~~ 218
14	~~30~~ 90	~~60~~ 178
		~~12,644~~ 7,943

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	8.0	492[a]
February	8.0	444[a]
March	8.0	492[a]
April	70.0	4,165[b]
		~~8,055~~[c] 16,441
May	50.0	3,074[b]
June	11.0	655[a]
July	11.0	676[a]
August	11.0	676[a]
September	11.0	655[a]
October	11.0	676[a]
November	11.0	655[a]
December	8.0	492[a]
Total:		~~21,207~~ 29,593

[a] Flows derived using the Base Flow Approach.

[b] Flows derived to meet spawning and incubation needs.

[c] Additional water during a March 14-day period to start no earlier than ~~April~~ 1 nor later than April 30 ~~May 31~~, according to the following pattern:

Day	CFS	AF
1	50	99
2	~~190~~ 200	~~377~~ 397
3	~~810~~ 880	~~1,607~~ 1745
4	~~1,210~~ 1930	~~2,400~~ 3828
5	~~810~~ 1530	~~1,607~~ 3035
6	~~390~~ 1000	~~774~~ 1983
7	~~190~~ 820	~~377~~ 1626
8	~~130~~ 600	~~258~~ 1190
9	~~100~~ 400	~~198~~ 793
10	~~70~~ 300	~~139~~ 595
11	~~40~~ 220	~~79~~ 436
12	~~30~~ 170	~~60~~ 337
13	~~20~~ 120	~~40~~ 238
14	~~20~~ 70	~~40~~ 139
		~~8,055~~ 16441

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	3.0	184[a]
February	3.0	167[a]
March	3.0	184[a]
April	30.0	1,785[b]
		~~7,935~~[c] 7,129
May	20.0	1,230[b]
June	4.0	238[a]
July	4.0	246[a]
August	4.0	246[a]
September	4.0	238[a]
October	4.0	246[a]
November	4.0	238[a]
December	3.0	184[a]
Total:		~~13,121~~ 12,315

[a] Flows derived using the Base Flow Approach.

[b] Flows derived to meet spawning and incubation needs.

[c] Additional water during a ~~14~~ 13-day period to start no earlier than ~~April~~ March 1 nor later than ~~May 31~~ April 30, according to the following pattern:

Day	CFS	AF
1	~~50~~ 90	~~99~~ 178
2	~~180~~ 450	~~357~~ 892
3	~~800~~ 850	~~1,587~~ 1686
4	~~1,190~~ 570	~~2,360~~ 1130
5	~~800~~ 480	~~1,587~~ 952
6	~~380~~ 350	~~754~~ 694
7	~~190~~ 200	~~377~~ 397
8	~~120~~ 170	~~238~~ 337
9	~~100~~ 140	~~198~~ 298
10	~~70~~ 110	~~139~~ 218
11	~~40~~ 80	~~79~~ 159
12	~~30~~ 60	~~60~~ 119
13	~~30~~ 40	~~60~~ 79
~~14~~	~~20~~	~~40~~
		~~7,935~~ 7,129

FLOW REQUEST:

Based on the information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	3.0	184[a]
February	3.0	167[a]
March	3.0	184[a]
		3,191[b]
April	15.0	893[c]
May	10.0	615[c]
June	4.0	238[a]
July	4.0	246[a]
August	4.0	246[a]
September	4.0	238[a]
October	4.0	246[a]
November	4.0	238[a]
December	3.0	184[a]
Total:		6,870

[a] Flows derived using the Base Flow Approach.

[b] Additional water required during a 13-day period to start no earlier than ~~February~~ March 1 nor later than April 30, according to the following pattern:

Day	CFS	AF
1	6	12
2	10	20
3	60	119
4	280	555
5	540	1,071
6	330	655
7	200	397
8	80	159
9	60	119
10	20	40
11	9	18
12	7	14
13	6	12
		3,191

[c] Flows derived to meet spawning and incubation needs.

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF
January	1.0	61[a]
February	1.0	56[a]
March	1.0	61[a]
April	30.0	1,785[b]
		6,705[c]
May	20.0	1,230[b]
June	2.0	119[a]
July	2.0	123[a]
August	2.0	123[a]
September	2.0	119[a]
October	2.0	123[a]
November	2.0	119[a]
December	1.0	61[a]
Total:		10,685

[a] Flows derived using the Base Flow Approach.

[b] Flows derived to meet spawning and incubation needs.

[c] Additional water during a 14-day period to start no earlier than ~~April~~ March 1 nor later than ~~May 31~~ April 30, according to the following pattern:

Day	CFS	AF
1	40	79
2	150	298
3	670	1,329
4	1,000	1,983
5	670	1,329
6	320	635
7	160	317
8	110	218
9	80	159
10	60	119
11	50	99
12	30	60
13	20	40
14	20	40
		6,705

Box Elder Creek

FLOW REQUEST:

Based on information discussed in the above INSTREAM FLOW METHODS section, the following flows are requested:

Time Period	Instream Flow CFS	Instream Flow AF	
January	4.0	246[a]	
February	4.0	222[a]	
March	4.0	246[a]	
		~~16,334~~[b]	16,370
April	7.0	417[a]	
May	7.0	430[a]	
June	7.0	417[a]	
July	7.0	430[a]	
August	7.0	430[a]	
September	7.0	417[a]	
October	7.0	430[a]	
November	7.0	417[a]	
December	4.0	246[a]	
Total:		~~20,682~~	20,718

[a] Flows derived using the Base Flow Approach.

[b] Additional water during a 17-day period to start no earlier than March 1 nor later than April 30, according to the following pattern:

Day	CFS	AF	
1	25	50	
2	55	109	
3	170	337	
4	340	674	
5	850	1,686	
6	~~1,820~~ 1910	~~3,610~~	3788
7	1,480	2,936	
8	1,220	2,420	
9	860	1,706	
10	640	1,269	
11	380	754	
12	160	317	
13	120	238	
14	55	109	
15	35	69	
16	15	30	
17	10	20	
		~~16,334~~	
		16,370	

**PREFILED DIRECT TESTIMONY OF
FREDERICK A. NELSON
ON BEHALF OF THE MONTANA DEPARTMENT OF FISH,
WILDLIFE AND PARKS (MDFWP)**

Q. Please state your name and business address.

A. Fred Nelson, MDFWP, 1400 South 19th Ave., Bozeman, MT 59715

Q. What is your present employment?

A. I am a fisheries biologist employed by the Montana Department of Fish, Wildlife and Parks.

Q. Please state your educational background and experience.

A. I am a 1968 graduate of Cornell University, Ithaca, NY, with a B.S. degree in Fishery Science. I received a M.S. degree in Fish and Wildlife Management at Montana State University in 1976. I've been employed by the MDFWP since 1976.

Q. Briefly describe your instream flow-related training.

A. My instream flow-related training began in 1978 when I attended a week-long instream flow methods workshop, conducted by the U.S. Fish and Wildlife Service, in California. Since then, I've attended a number of other workshops and training sessions. These are listed in my vita, which is included with this prefiled testimony.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony is to: (1) briefly describe my role in the instream flow-related work that culminated with the MDFWP's reservation application, and (2) provide information on the instream flow methods that were employed by MDFWP in its application.

MY ROLE IN MDFWP'S INSTREAM FLOW RESERVATION PROGRAM

Q. Briefly describe your role in the reservation process.

A. Since 1976, when I began work with MDFWP, my duties have focused on instream flow and other water-related issues. In regard to this reservation application, my main contributions are summarized as follows:

1) Based on my research and information provided by other professionals, the MDFWP adopted the Wetted Perimeter Inflection Point Method (WPIPM) as the primary instream

Washington in the early 1970s, was, under my auspices, slightly modified from its original form for use in Montana.

2) I oversaw the development of MDFWP's wetted perimeter (WETP) predictive computer program, an integral part of the WPIPM. This program and later updates incorporated state-of-the-art simulation procedures that were developed by the Cooperative Instream Flow Service Group of the U.S. Fish and Wildlife Service, Fort Collins, Colorado.

3) In 1980, I researched and wrote the MDFWP's guidelines for applying the WPIPM and using the WETP program. I wrote guideline updates in 1984 and 1989. The 1989 revision is presented in Exhibit 1.

4) I wrote, along with Steve Leathe, Regional Fisheries Manager, MDFWP, Great Falls, the publication titled "A Literature Evaluation of Montana's Wetted Perimeter Inflection Point Method For Deriving Instream Flow Recommendations." This publication provides an up-to-date synopsis of the history of the WPIPM, examines its theoretical and experimental basis, identifies its strengths and weaknesses as compared to other available methods, and provides justification for its use in Montana (see Exhibit 2).

5) I conducted, often in conjunction with the USGS, Helena, workshops to train MDFWP personnel in the use of the WPIPM. Training included: theory, surveying and other field techniques, selection of study sites, data coding, and flow-measuring procedures.

6) I assisted, when called upon, other MDFWP biologists who were conducting instream flow studies in the lower Missouri Basin. I primarily assisted with data coding and aided with problem solving.

7) I led the team of workers that established study sites and collected WETP field data on four cold-water trout streams in the Bear Paw Mountains where the WPIPM was employed. I served as MDFWP's liaison with the USGS personnel who calculated bankfull discharges and base flows for the warm-water prairie streams in MDFWP's application. Using these data, I compiled instream flow requests for each prairie stream.

INSTREAM FLOW METHODS

Q. What is the purpose of instream flows?

A. The purpose of instream flows is to provide an adequate amount of water in a stream to maintain the fisheries and aquatic resource at a desired level.

Q. How are instream flows determined?

A. The required instream flows are determined using instream flow methods. There are many different instream flow methods described in the literature.

Q. What instream flow methods were used by MDFWP in its application?

A. The MDFWP employed the following instream flow methods:
1. Wetted Perimeter Infection Point Method (WPIPM)
2. Fixed Percentage Method
3. Base Flow Approach
4. Dominant Discharge/Channel Morphology Concept (DDCMC)
5. Biological - Flow Relationships

1. <u>Wetted Perimeter Inflection Point Method (WPIPM)</u>

Q. Where was the WPIPM applied?

A. The WPIPM was applied to the cold-water reaches of Beaver Cr. (Hill County), Box Elder Cr., Clear Cr. and Peoples Cr., four trout streams in the Bear Paw Mountains. WPIPM was also applied to the Missouri River Reaches #7 and #8 to derive instream flow recommendations for selected time periods.

Q. Are other states and provinces using the WPIPM?

A. The WPIPM is widely accepted, particularly in the West. Most states and provinces having protective instream flow legislation employ a variety of instream flow methods, depending on the needs of a particular situation. Agencies in Colorado, Washington, Minnesota, Wyoming, Idaho and British Columbia presently use variations of the WPIPM in their instream flow programs.

Q. What is wetted perimeter and what is an inflection point?

A. Wetted perimeter is the distance (in feet) along the bottom and sides of a channel cross-section that is in contact with water when the stream is viewed in cross-section (see Appendix A of this testimony). 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. Appendix B depicts the relationship between wetted perimeter and flow, showing an inflection point.

The wetted perimeter-flow relationship thus provides a measure of the amount of stream bottom that is covered by water at various flows.

Q. To what area of a stream is the WPIPM applied?

A. The relationship between wetted perimeter and flow is derived for stream 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.

Q. Why does the WPIPM focus on riffles?

A. Aquatic insects, such as caddis flies, stone flies and mayflies, and other aquatic invertebrates are the primary food of Montana's stream-dwelling gamefish. It is widely accepted that the production of these aquatic food items is greatest in riffles of streams. Thus, riffles are the primary fish food-producing area in streams.

Q. How is food production related to streamflows?

A. Aquatic invertebrates, the major food items in Montana's streams, inhabit the small spaces within the bottom substrate. Flowing water supplies the oxygen that is needed to sustain these gill-breathing life forms. Without a cover of water, the bottom substrate becomes uninhabitable. The amount of riffle habitat covered with water will increase with flow, causing the food-producing potential to also increase. Streamflow controls the amount of riffle area that is wetted and, thus, controls the amount of habitat that is available for producing food.

Q. What is the connection between the wetted perimeter-flow relationship for riffles and food production?

A. The relationship between wetted perimeter and flow for stream riffles generally, but not always, shows two inflection points where the rate of increase of wetted perimeter changes. In the example (Appendix C), these inflection points occur at approximate flows of 8 and 12 cfs. Below the lower inflection point (8 cfs), 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 (12 cfs), 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.

The area available for food production is believed near optimal at the upper inflection point because almost all of the available riffle, or food-producing, area is covered with water. 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).

Q. How is the recommended flow selected from the wetted perimeter-flow relationship?

A. The WPIPM 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, while flows exceeding the upper inflection point are considered to maximize the food-producing area.

The final flow recommendation is selected from this range of flows by the biologist who collected and analyzed all relevant field data for the stream of interest. The biologist's 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", 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. Upper inflection point flows were selected as the instream flow recommendations for the streams in this application where the WPIPM was applied.

Additional information on the WPIPM can be found on pages 14-21 of MDFWP's application and in the following publications, which are included as Exhibits 1 and 2.

Leathe, S.A. and F.A. Nelson. 1986. A literature evaluation of Montana's wetted perimeter inflection point method for deriving instream flow recommendations. Montana Department of Fish, Wildlife and Parks, Helena, Montana. Revised February 1989. 70 pp.

Nelson, F.A. 1980. 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 and March 1989. 56 pp.

Q. Has the WPIPM been validated in recent scientific studies?

A. A Ph.D thesis study by Samuel Lohr, which was completed at Montana State University in 1993 and titled "Wetted Stream Channel, Fish-Food Organisms and Trout Relative to the Wetted Perimeter Inflection Point Instream Flow Method", examined the following biological assumptions of WPIPM:

1. abundance of aquatic invertebrates is proportional to riffle area,
2. wetted perimeter can be used as an index of invertebrate abundance, and
3. at flows below the wetted perimeter-discharge inflection point, stream fish population may become food limited.

To evaluate these assumptions, field and laboratory tests were conducted to investigate the relationships among (1) stream discharge, riffle wetted perimeter, and aquatic invertebrate abundance; (2) cutthroat trout density and growth relative to increased prey abundance; and (3) prey abundance, habitat volume, and cutthroat residency in artificial stream channels.

Q. Briefly, what did Lohr conclude?

A. He concluded that the "Biological assumptions of the wetted perimeter instream flow method were generally supported by the findings of this study. Differences in abundance of invertebrates were observed between artificially dewatered riffles and riffles exposed to the natural flow regime. Additionally, differences in food abundance were shown to affect growth rates of cutthroat trout in field enclosures, as well as density of small trout in artificial stream channels." He also concluded that "Reductions in stream discharge affected abundance of fish-food organisms primarily through declines in riffle area and invertebrate drift rate, with the greatest reduction occurring when stream discharge was below the wetted perimeter inflection point."

2. **Fixed Percentage Method**

Q. Where was the Fixed Percentage Method applied?

A. This method was applied to the cold-water segment of Beaver Creek (Reach #1) in Phillips County, a trout stream in the Little Rocky Mountains.

Q. Why wasn't the WPIPM used?

A. Due to time constraints and the remoteness of the area, the WPIPM was not applied to this stream reach.

Q. Describe the Fixed Percentage Method.

A. For this method, the high inflection point flows that were derived from the Wetted Perimeter Inflection Point Method for the four trout streams in the Bear Paw Mountains were expressed as a percentage of the average annual flow for each stream. These percentages were 37, 56, 19 and 19 for Beaver, Clear, Little Box Elder, and Peoples creeks, respectively. These percentages were then averaged to derive a basin mean percentage (33%), which was then applied to Beaver Creek Reach #1. Thirty-three percent of 0.6 cfs, the average annual flow for Reach #1 of Beaver Creek, is 0.2 cfs, which is the recommended instream flow. (See page 21 of MDFWP's application for further information.)

3. **Base Flow Approach**

Q. Where was the Base Flow Approach applied?

A. This method was applied to the warm-water prairie streams in this application to derive instream flow recommendations for the low flow period that precedes and follows spring runoff. These streams are:

Battle Creek
Beaver Creek (Phillips County) Reach #2
Beaver Creek (Wibaux County)
E.F. Poplar River
Frenchman River
Little Beaver Creek
Little Box Elder Creek
Little Missouri River
M.F. Poplar River

Poplar River
Redwater River Reaches #1 and 2
Rock Creek
W.F. Poplar River

Q. Why wasn't the WPIPM used?

A. The warm-water streams of the lower Missouri and Little Missouri River basins look nothing like the cold-water trout streams of the mountain headwaters where the WPIPM is the method of choice. These warm-water prairie streams generally meander widely, are low-gradient, and consist of long, deep, low-velocity pools separated by short, widely-spaced riffles. During the low flows of late summer, fall and winter, flow over the few riffles can virtually cease for long periods. Despite critically low flows, the pools hold a sufficient reservoir of water to sustain more than 20 fish species that have adapted to and survive in this extreme prairie environment. These naturally occurring low flows help to maintain sufficient water depth in pools to provide a refuge for fish. These low flows also provide an exchange of water that freshens the pools, thus preventing dissolved oxygen concentrations and other water quality criteria from reaching levels that are lethal to fish. Reducing these critically low flows would further stress the fish community by degrading the already borderline habitat. The continued survival of the fish community could be in jeopardy if additional flow reductions were to occur. To protect fish habitat in these prairie waters, maintenance of the existing stream flows is recommended during the low flow period.

Q. How were recommendations derived?

A. Flow requests using this "base flow" approach were derived from the mean monthly flows, calculated by the USGS, for the prairie streams in this application. The mean monthly flows for each reach were grouped into two periods: (1) the winter period from December through March and (2) the non-winter period from April through November. The lowest mean monthly flow for each period was then identified and subsequently became the flow request throughout that period. (See pages 22 and 23 of DFWP's application for further explanation.)

4. **Dominant Discharge/Channel Morphology Concept (DDCMC)**

Q. Where was the DDCMC applied?

A. This method was applied to the same warm-water streams previously listed under the Base Flow Approach to derive instream flow recommendations for the high flow period of spring runoff.

Q. What is the primary purpose of the instream flow recommendations generated by the DDCMC?

A. The purpose of the channel maintenance flows generated by the DDCMC is: (1) to maintain the width, depth, slope and general configuration of the stream channel and (2) to flush the sediments that annually accumulate within the pools where adult and juvenile warm-water fishes reside and within the rubble/gravel areas where important warm-water gamefish, including sauger, walleye and smallmouth bass, reproduce.

Q. What period of the year are channel maintenance flows recommended?

A. Channel maintenance flows are recommended for the high flow period of late winter and early spring when melting snow and seasonal rains cause the flows of prairie streams to rise, commonly reaching their highest levels for the year.

Q. Why are channel maintenance flows important for fish populations in prairie streams?

A. Over time, fish populations have adapted to the physical constraints of channel configuration and flow. Basic to the fishes' survival is the perpetuation of the existing habitat that has historically sustained them. In the case of the warm-water prairie streams in this application, the existing channel (long, deep pools separated by widely-spaced riffles) is crucial to the survival of gamefish from late summer through winter when flows in these prairie waters nearly cease for long periods. Pools provide the only refuge for fish during the critical low flows of summer-winter. Maintaining the existing channel shape is essential to the continued survival of the diverse fish communities of these prairie waters. Channel maintenance flows are intended to accomplish this task. Some examples of these prairie stream habitats are shown in the photographs in Exhibit 3.

Q. How would prairie streams change if channel maintenance flows were eliminated?

A. Once channel maintenance flows are eliminated or greatly reduced in magnitude, the channel will adjust to this new condition. The lower water velocities that accompany the reduced high flows will decrease the stream's capacity to scour the channel and transport sediments. With this change, the channel is likely to narrow as sediments accumulate on bars and channel edges. Sediments will also accumulate in the pools, causing pool depths to decrease. As pools fill with sediments, their value as summer-winter refuges for warm-water fishes greatly diminishes. Rubble/gravel areas where important gamefish species reproduce will likely clog with sediments, lowering the stream's reproductive potential.

Q. What are potential threats to preserving channel maintenance flows in prairie streams?

A. There are two potential threats: (1) large reservoir projects that store the high flows of spring runoff and (2) extensive waterspreading projects that effectively tap the runoff flows.

Q. Are there standard methods or approaches to determine the magnitude of the required channel maintenance flows for a particular waterway?

A. No standard method or approach has been developed for this purpose. A common element of many of the more than 15 channel maintenance methods that are described in the literature is the recommendation of the bankfull flow or dominant discharge to maintain the channel shape and to flush sediments.

Q. What is the underlying principle of the DDCMC?

A. The dominant discharge, often considered the dominant force in maintaining channel shape and form, has been found to be approximately the same as the bankfull discharge for many natural channels. Bankfull discharge is the flow at which water begins to top the stream banks and overflow onto the active floodplain. For many channels, the bankfull discharge has been found to be approximately equal to the 1.5 - 2.0 year frequency peak flow. A stream's annual peak flow is likely to exceed the 2.0 year frequency event in 50 out of 100 years; likewise, in 50 out of 100 years, the annual peak flow is likely to be less than the 2.0 year frequency event. The bankfull flow, as estimated by the USGS using the 2.0 year frequency peak flow, is the basis of MDFWP's instream flow recommendations to maintain channel shape and to flush accumulated sediments.

Q. When was the DDCMC developed?

A. The DDCMC was developed by the MDFWP in the late 1970's. The underlying principles of the DDCMC are based on well-founded channel maintenance theory that was extracted from the scientific literature.

Q. Describe the DDCMC in more detail.

A. High flow requests in this application include one day of flow at the bankfull discharge. Until studies further clarify the necessary duration of the bankfull discharge, a duration period of 24 hours was requested. Other channel maintenance methods that incorporate a dominant/bankfull discharge recommend duration periods of 2-3 days.

MDFWP's high flow requests are "stair-stepped" up to the bankfull discharge, then "stair-stepped" down to the base flow. All of the "stair-steps" encompass a 13-21 day period, depending on the normal duration of the stream's annual high flows. These daily "stair-steps" are intended to mimic the shape of the stream's natural hydrograph during high flows and to reflect normal water availability. High flow requests are also timed to correspond to the period that these flows typically occur in the natural system.

"Stair-steps" are recommended because a rapid increase and/or decrease in flows can result in accelerated bank erosion. Also, once sediments are mobilized in the water column, sufficient flow and time are needed to transport sediments out of the system to prevent pools from refilling. The "stair-steps" that comprise the receding limb of the hydrograph are intended to serve this purpose. (See pages 23-25 of MDFWP's application for additional information on the DDCMC.)

5. **Biological - Flow Relationships**

Q. Where were biological - flow relationships used to derive instream flow recommendations?

A. This approach was used to derive instream flow recommendations for selected periods and selected streams where sufficient data were available to base recommendations on the observed responses of fish populations to instream flow variations or on the observed relationships between changing flows and critical elements of the fishes' habitat. Streams in this group were the Missouri River Reaches #7 and #8, E.F. Poplar River, M.F. Poplar River, Poplar River and W.F. Poplar River.

Q. What were these relationships?

A. The testimony of Phil Stewart, Bill Gardner and Ken Frazer, biologists who derived the biological - flow relationships used in MDFWP's application, will describe these relationships.

Q. Do the instream flow recommendations in MDFWP's application exceed the available streamflows?

A. There can be time periods, especially during spring runoff and in late summer, when the recommendations exceed the available flows in some years. On streams where the appropriations of consumptive water users have caused the existing flows to be far less than the natural condition, recommendations can often exceed the existing water availability during the summer irrigation season when major depletions occur.

Q. If the requested instream flows are granted, would MDFWP expect them to be maintained throughout the specified time periods?

A. The concept of the flow recommendations being available at all times is incompatible with the wide seasonal and annual flow variations that characterize Montana's streams. Because streamflow is variable and subject to depletion by consumptive users, the recommendations of MDFWP can periodically exceed the available supply. Only when the instream flow recommendations equal the historic low flows of record would they never exceed the available streamflows.

The fact that the requested instream flows periodically exceed the available water supply should not be viewed as inappropriate. In many respects, the requests are comparable to a late, or junior, consumptive water right on a stream having many senior appropriators. Because of the late priority date, this junior right holder may not receive the full amount of his right. When water in excess of the needs of the senior users is available, the junior right holder can use this excess up to the amount of his right. The fact that a right is held for a specified flow rate, water volume and period of use does not guarantee that the full amount will always be available during the period of need. The unavailability of a full water supply does not prevent the junior user from exercising his right nor does it invalidate his legal claim to this excess water. The same reasoning applies to an instream flow reservation, which, like a junior consumptive water right, has a granted flow rate, volume and period of use and a late priority date, one far later than the senior-most consumptive rights on the stream. In the case of the Lower Missouri Basin instream reservations, the instream priority date will be 1985 or 1989, many years after the first consumptive water uses were established in this basin. On many streams, the needs of the senior consumptive water users will significantly limit the supply of water that will be available to satisfy the instream reservations. The instream reservations, once granted, simply allow any excess flows up to the amount of the granted instream flows to be reserved for the needs of fish.

Q. How should the instream flow recommendations of MDFWP be viewed in relation to the rights of senior water users?

A. The instream flow recommendations provide the "trigger" flows at which <u>junior</u> water users must cease their withdrawals. The users who are senior to the instream flow reservations can continue to withdraw water without being subject to the "trigger" flows. Consequently, senior users can continue to withdraw water after streamflows fall below the "trigger" levels designated by the instream flow reservations.

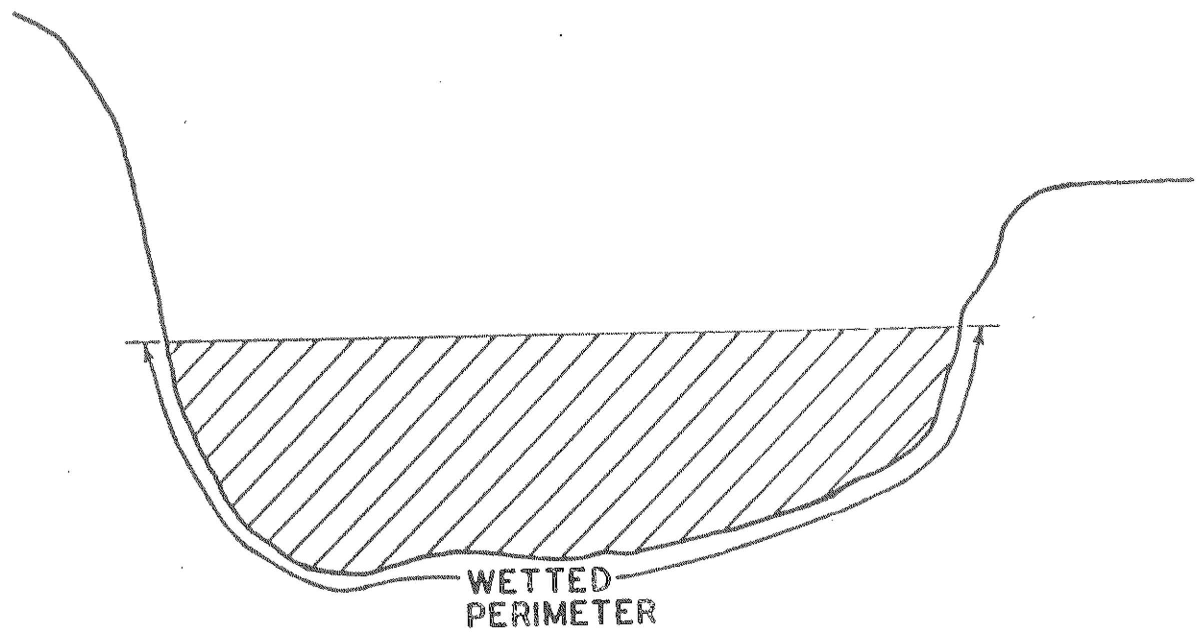
Frederick A. Nelson, being duly sworn, states that the foregoing testimony is true.

Dated this 22 day of June, 1994.

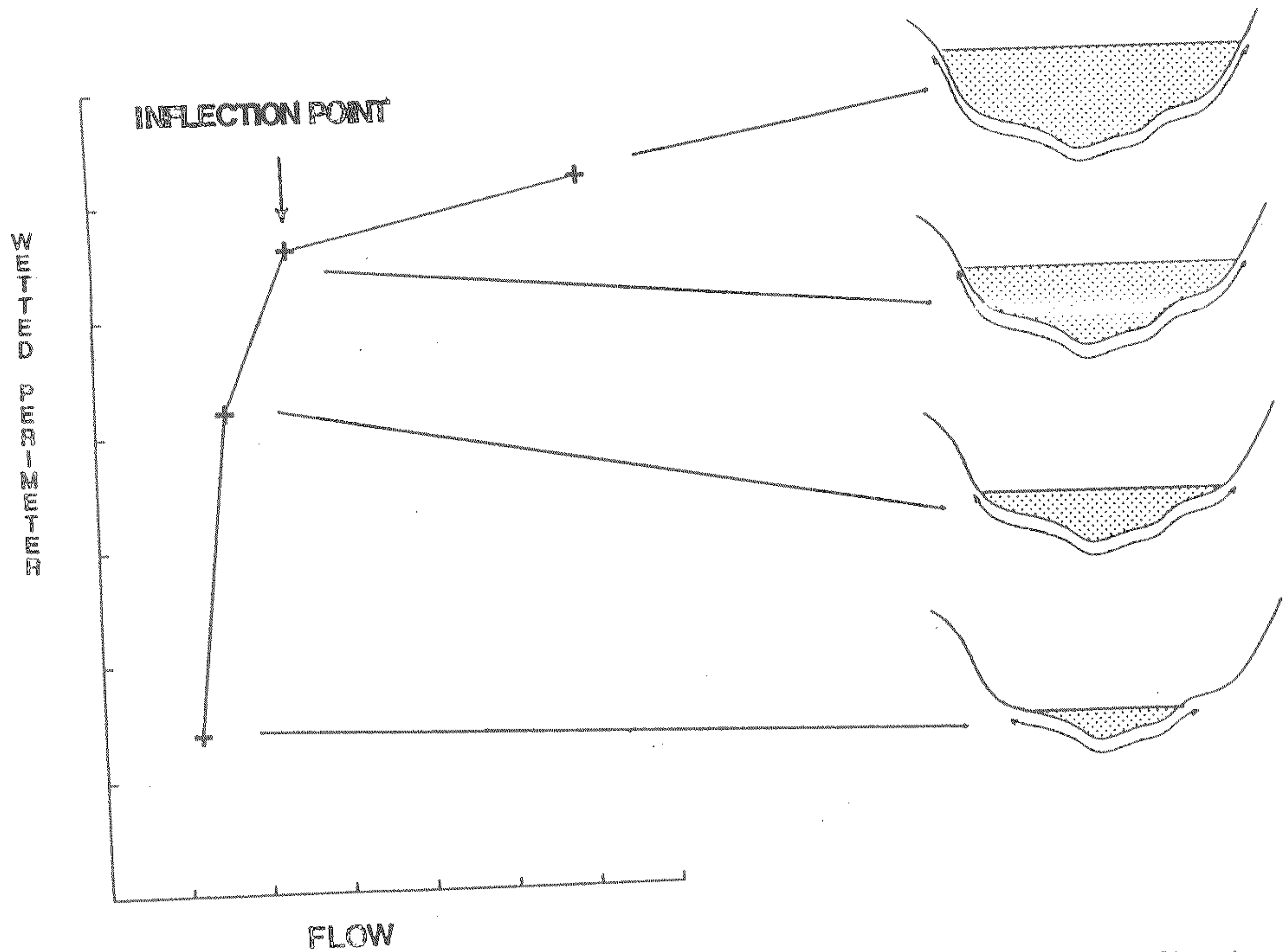
Frederick A. Nelson

Subscribed and sworn to before me this 22 day of June, 1994.

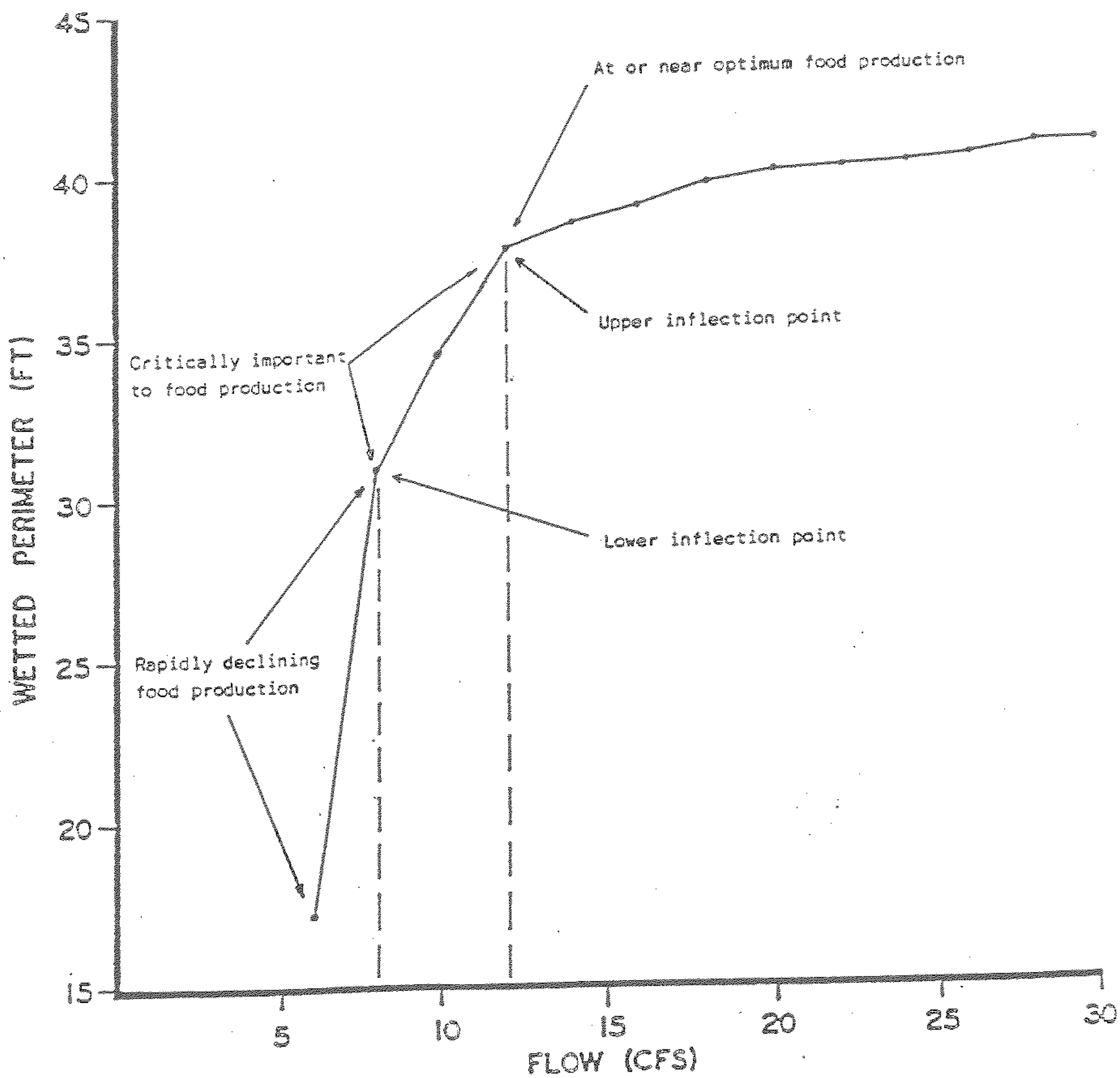
Notary Public for the State Of Montana
Residing at Helena, Montana
My Commission expires 11/19/95



The wetted perimeter in a channel cross-section.



Relationship between wetted perimeter and flow, showing an inflection or break point.



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

VITA -- Frederick A. Nelson

Current Position — Fishery Biologist, Montana Department of Fish, Wildlife and Parks, Bozeman, MT 59715

Place and Date of Birth — Pittsburgh, Pennsylvania; November 10, 1944

Education

1962-68 Cornell University, Ithaca, New York
Received BS degree in Fishery Science

1973-76 Montana State University, Bozeman, Montana
Received MS degree in Fish and Wildlife Management, with emphasis in fisheries

Thesis -- The Effects of Metals on Trout Populations in the Upper Boulder River, Montana

Experience

Summer 1966 -- Fishery Biologist Aide, New York State Department of Environmental Conservation, Stamford, New York. Surveyed lake fish populations and estimated fish numbers in various waterways of the Catskill Mountain region of New York.

Summer 1967 -- Fishery Biologist Aide, New York State Department of Environmental Conservation, Oakdale, New York. Surveyed the fish populations in the lakes and ponds of Long Island, New York.

Spring and Summer 1974 -- Fisheries Field Worker, Montana Department of Fish, Wildlife and Parks, Livingston, Montana. Participated in a comprehensive fisheries inventory of the waterways of the Shields and upper Yellowstone River drainages of southwest Montana.

1976 - Present -- Fishery Biologist, Montana Department of Fish, Wildlife and Parks, Bozeman, Montana. My responsibilities primarily involve instream flow and other water-related issues, including the preparation and filing of instream flow claims under Montana's water reservation and water right processes.

Special Schools and Workshops

1. March 1978. Attended a week-long training school in the use of the Instream Flow Incremental Method (IFIM) for deriving instream flow recommendations, conducted by the U.S. Fish and Wildlife Service in Santa Cruz and Sacramento, California.

2. June 7-11, 1982. Attended a short course in stream mechanics given through the Continuing Education Program of the Montana State University Civil Engineering and Engineering Mechanics Department, Bozeman, Montana.

3. November 29-December 1, 1983. Attended the Instream Flow Technology Section of the 1983 Hydropower Conference, Portland, Oregon.

4. June 25, 1985. Attended a workshop on streamflow measurements and the maintenance of current meters, conducted by Ron Shields of the U.S. Geological Survey, Helena, Montana.

5. February 24-26, 1987. Attended an instream flow methods workshop taught by E. Woody Trihey and sponsored by OEA Research, Helena, Montana.

6. September 12-13, 1989. Attended an instream flow methods workshop, sponsored by the U.S. Fish and Wildlife Service, Green Bay, Wisconsin, and gave a presentation on the Wetted Perimeter Inflection Point Method.

Professional Organizations

Member, American Fisheries Society and Montana Chapter, American Fisheries Society

Publications

Leathe, S.A. and F.A. Nelson. 1986. A literature evaluation of Montana's wetted perimeter inflection point method for deriving instream flow recommendations. Montana Department of Fish, Wildlife and Parks, Helena, Montana. Revised February 1989. 70 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. 1980. Evaluation of four instream flow methods applied to four trout rivers in southwest Montana. Montana Department of Fish, Wildlife and Parks, Bozeman, Montana. 105 pp.

Nelson, F.A. 1980. Supplement to evaluation of four instream flow methods applied to four trout rivers in southwest Montana. Montana Department of Fish, Wildlife and Parks, Bozeman, Montana. 55 pp.

Nelson, F.A. 1980. 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. 1980. 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 and March 1989. 56 pp.

Nelson, F.A. 1984. 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.A. 1986. Effect of flow fluctuations on brown trout in the Beaverhead River, Montana. North American Journal of Fisheries Management 6:551-559.

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.

PREFILED DIRECT TESTIMONY
OF CHARLES PARRETT
ON BEHALF OF THE MONTANA DEPARTMENT OF FISH,
WILDLIFE AND PARKS

Q. Please state your name and address

A. My name is Charles Parrett and my home address is 1265 Landmark Drive, Helena, Montana.

Q. What is your present employment, and how long have you been employed in this position?

A. I am employed by the U.S. Geological Survey in Helena as a Supervisory Hydrologist. I worked for the Survey as a Hydrologist from 1977 to 1988 and have been a Supervisory Hydrologist from 1988 to the present.

Q. Please state your educational background and experience.

A. I graduated with honors from Montana Tech in 1967 with a B.S. degree in Engineering Science. After working as a Hydraulic Designer for 2 years with the Montana Department of Highways, I returned to Montana State University in 1969. I obtained an M.S. degree in Civil Engineering in 1970 and took additional course work toward a doctorate until 1971. I began employment with the Montana Water Resources Board (later the Department of Natural Resources and Conservation) as a Hydraulic Engineer in charge of the Floodway Management Program. I left the Department in 1977, and after a three-month stint as a Hydrologist/Engineer with the Morrison-Maierle engineering firm, began work with the U.S. Geological Survey as a Hydrologist in October 1977.

While employed with the Survey, I have been the project chief on numerous surface-water hydrological investigations, including various flood studies, studies that developed methods for estimating streamflow characteristics at ungaged sites, state-wide water-use project, and various streamflow modeling studies. I have been the sole or principal author of 21 formal U.S. Geological Survey technical reports, including one Professional Paper and three Water-Supply Papers. In addition, I have been a co-author on 12 other U.S. Geological Survey reports.

My current title is Chief, Hydraulics and Hydrology Unit. In this position I supervise 2 hydrologic technicians, 1 hydraulic engineer, and 2 hydrologists.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony is to provide MDFWP and the record of this proceeding with estimates of monthly streamflow characteristics and dominant-discharge hydrograph data at selected sites in the lower Missouri River and Little Missouri River Basins, Montana, and to provide for the record the written report describing the estimates and the methodologies used to derive them. These estimates and report were requested by MDFWP and were completed under a cooperative agreement with the Survey.

Q. What was the written report that you prepared?

A. The written report, U.S. Geological Survey Water-Resources Investigations Report 94-4098, is entitled "Estimates of Monthly Streamflow Characteristics and Dominant Discharge Hydrographs for Selected Sites in the Lower Missouri and Little Missouri River Basins in Montana," and describes the methodology and presents estimates for 21 sites on 18 streams where MDFWP has requested water reservations.

Q. Is a true and correct copy of the report contained in the Department of Fish, Wildlife, and Parks' exhibits filed with its prefiled direct testimony?

A. Yes. A true and correct copy of the report is contained in the Department's exhibits as Exhibit 4.

Q. Please describe your role in the preparation of the above-described estimates.

A. I served as project chief on a cooperative project with the Montana Department of Fish, Wildlife, and Parks to provide estimates of long-term (1937-86) monthly streamflow characteristics and dominant-discharge hydrograph data at selected sites in the Missouri River and Little Missouri River basins. Based on previous work, several methods for estimating streamflow at ungaged sites were used at most of the selected sites. I was responsible for determining which methods would be used at the sites. I also directed the work of hydrologic technicians who compiled data, measured drainage areas, and helped develop computer programs for estimating discharge.

Q. Are the methods used to determine monthly streamflow characteristics and dominant-discharge hydrographs generally accepted in the scientific community?

A. Yes. The methods used to estimate streamflow characteristics have been previously described in several U.S. Geological Survey reports, including one completed in cooperation with the Department of Fish, Wildlife, and Parks entitled Estimates of Monthly Streamflow Characteristics at Selected Sites in the Upper Missouri River Basin, Montana, Base Period Water Years 1937-86. The methods for estimating monthly streamflow characteristics include the concurrent-measurement method and the use of a drainage-area-ratio adjustment. Both methods are based on the transfer of streamflow characteristics determined from streamflow record at a gaged site to an ungaged site and have been widely used to estimate monthly streamflow characteristics throughout Montana.

The methods used to estimate dominant discharge have also been described in previous U.S. Geological Survey publications and are widely used for the estimation of dominant discharge (2-year flood discharge) throughout Montana. These methods are based on the use of the log-Pearson Type 3 probability distribution to determine magnitude and frequency of annual peak discharge at gaged sites. For ungaged sites, magnitude and frequency information is transferred from a gaged site on the same stream using a drainage-area-ratio adjustment.

Q. Please describe the monthly streamflow characteristics that were estimated.

A. Streamflow characteristics that were estimated were the monthly-mean discharges that are exceeded 90, 80, 50, and 20 percent of the years of extended record (1937- 86) and the mean-monthly discharge for each month. These estimates are shown on pages 19 through 24 of the technical report.

Q. Please describe the dominant-discharge hydrographs that were estimated.

A. The dominant-discharge hydrographs were hydrographs of daily mean discharge having maximum discharges equal to the estimated 2-year peak discharge. The 2-year peak discharge is an annual peak discharge that is exceeded, on average, once every 2 years. The duration of each dominant-discharge hydrograph was either 14 or 21 days, depending upon whether the duration of a typical or representative hydrograph determined from recorded hydrographs was closer to 14 or 21 days. The dominant-discharge hydrographs are shown on pages 25 through 29 of the technical report.

Q. Are the estimated monthly streamflow characteristics in the technical report in agreement with the provisional data contained in the MDFWP's water reservation application, Appendix B?

A. The estimated monthly streamflow characteristics in the technical report are different from those in the application for the Missouri River below Fort Peck Dam, the Frenchman River at the mouth, and the Missouri River near Culbertson. The revised data in the technical report are considered to be more accurate than the provisional, unreviewed data originally furnished to the MDFWP.

Q. Why were the monthly streamflow characteristics for the two Missouri River sites and the Frenchman River revised?

A. Provisional data originally furnished to the Montana Department of Fish, Wildlife, and Parks did not receive the detailed technical scrutiny and review that are required for U. S. Geological Survey publication standards. As a result of the additional technical review required for publication, it was determined that the period of record for calculation of streamflow characteristics for the two Missouri River sites needed to be changed. The 1937-86 base period initially used includes the 1937-42 period during which Fort Peck Lake was being filled. The period of record used for calculation of streamflow characteristics thus was changed to exclude the years 1937-1942. In addition, the additional technical review determined that the drainage-area-ratio adjustment for the Frenchman River was initially incorrect.

Q. Are the estimated dominant-discharge data in agreement with provisional data contained in the MDFWP's water reservation application, Appendix A?

A. Not in all cases. Daily mean discharges for dominant-discharge hydrographs in the report were revised for eight of the 14 sites as follows:

Site Number	Stream name
5	Battle Creek at mouth near Chinook
9	Beaver Creek at mouth near Saco
10	Rock Creek at mouth near Hinsdale
11	Redwater River above confluence of East Fork Redwater River near Vida
12	Redwater River near Vida
15	Poplar River at Fort Peck Reservation boundary near Scobey
16	West Fork Poplar River at Fort Peck Reservation boundary near Four Buttes
19	Boxelder Creek near Webster

Q. Why were the daily mean discharges for dominant-discharge hydrographs revised for the eight sites?

A. Provisional data originally furnished to the Montana Department of Fish, Wildlife, and Parks did not receive the detailed technical scrutiny and review that are required for U. S. Geological Survey publication standards. As a result of the additional technical review required for publication, it was determined that dominant discharge was incorrectly calculated at eight sites. At six sites the correction for dominant discharge was so large that daily mean discharges for all days throughout the duration of the hydrograph also had to be corrected. At Beaver Creek at mouth near Saco, only the dominant discharge required correction, and at Rock Creek at mouth near Hinsdale only 4 daily mean discharge values required correction.

I, Charles Parrett, being first duly sworn, states that the foregoing testimony is true.

Dated: 6/28/94

Charles Parrett
Charles Parrett

Subscribed and sworn to before me this 28th day of June, 1994.

Debra K. McRae
Notary Public for the State of Montana
Residing at Helena, Montana
My commission expires: May 14, 1998

PREFILED TESTIMONY OF SCOTT GILLILAN,
ON BEHALF OF THE MONTANA DEPARTMENT OF FISH, WILDLIFE, AND PARKS

Q: Please state your name and business address.

A. Scott Gillilan, 25 N. Willson Ave., Suite 5, Bozeman, MT 59715

Q: What is your present employment?

A: I am a hydrologist employed by Inter-Fluve, Inc.

Q: Please state your educational background and experience.

A. I hold a BS in Biology from Lewis and Clark College (1984), Portland, Oregon and an MS in Hydrology from Oregon State University, College of Forestry, Forest Engineering Department (1990), Corvallis, Oregon. I have been employed with Inter-Fluve since 1990. Prior work experience includes fisheries research, wildlife biology and watershed evaluation for the US Forest Service, human genetics and radiobiology research.

Q: What type of work does Inter-Fluve perform?

A. We are a consulting company that specializes in aquatic restoration, including stream and river construction, restoration, stabilization, fisheries and hydrology investigations and bioengineering. Specific and recent projects include technical oversight of multi-million dollar river restoration projects for the Central Utah Water Conservation District and Cal-Tahoe Conservancy District. We frequently work with federal and state agencies, corporations, municipalities, and individuals throughout the country. We provide field inventory services, site-specific research , construction designs and supervision.

Q: What role do you perform with the company?

A: I am involved with all aspects of project management, research, design, and construction. My specialty is applied hydrology and fluvial geomorphology. With Inter-Fluve, I have worked on over 50 projects relating to stream and river evaluation, physical habitat modification, bank stabilization, and restoration. My role typically is to perform the field investigations and office hydrologic analysis, characterization of the geomorphic processes at work in the system and design remedies for improvement. For example, I authored a 100 page document for the

US Environmental Protection Agency detailing reclamation of placer mined drainages in Montana. In that document, all aspects of basin hydrology, fluvial geomorphology, channel design, revegetation, and associated costs were presented in a format useful for agency resource professionals and others. I am currently working on the Montana Stream Management Guide, an informational resource detailing how streams work and are best managed, for a group composed of the Montana Department of Natural Resources, EPA, Water Quality Bureau, and Montana Department of Fish, Wildlife, and Parks.

Q: How frequently does your work deal specifically with fluvial geomorphology?

A: My services are typically required when a fluvial system is experiencing a problem. Therefore, an evaluation of channel shape and bedload transport, related to a drainage's hydrology, is necessary in every case. These evaluations are both quantitative, as in the case of channel measurement, survey, aerial photo interpretation and substrate classification, and qualitative, which involves interpretation of observed channel features, such as bar forms and sediment load. This gathered information is then cross-referenced with the existing body of literature and final interpretations made.

Q: What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony is to describe fluvial (in-channel) processes in context with the requested instream flow reservations. Specifically, my role is to relate the concepts of the dominant discharge to the maintenance of channel geometry and, therefore, the maintenance of fish habitat.

Q: What professional experience do you have in this area?

A: An evaluation of dominant discharge is necessary for any channel design work, whether it is the construction of a new channel or modification of a current one. Therefore, I am regularly involved in these assessments.

Q: What is a dominant discharge?

A: There are a variety of overlapping definitions. The most common one is the flow that performs the most work on a channel, with work defined in terms of sediment transport. The dominant discharge is the flow that moves the most sediment and ultimately defines channel shape.

Q. What is channel geometry?

A. Channel geometry is the description of the shape of a stream or river in plan (as it appears looking down from above; described hereafter as "planform") and cross-sectional views. Factors in channel geometry include channel width and depth, wetted perimeter, hydraulic radius, meander shape, and sinuosity. Width, depth, wetted perimeter and hydraulic radius describe the channel in cross-section. The wetted perimeter is the length of the channel boundary in contact with the water. Hydraulic radius is the cross-sectional area of the channel divided by the wetted perimeter. The resultant value is used in hydraulic analysis of the channel and qualitatively describes shape. The shape of a meander loop, whether a broad or narrow wave, is a planform characteristic. Sinuosity is also a plan characteristic which measures actual stream length against a straight, down valley distance.

Q: How do geomorphologists describe stream channels?

A: Geomorphology is the study of process, or change in landscapes. Streams are active agents of change, serving as conduits for water and sediment delivered by the watershed. Except for channels through bedrock, the channel boundary, or perimeter, is deformable. In other words, a channel's load of water and sediment actively shapes the channel by deforming the bed and banks. Flowing water provides the energy to do this shaping by simultaneously eroding some channel boundaries and building others. This is known as erosion and aggradation (deposition), and can be characterized by channel width and depth. Because of ongoing erosion and deposition, channels migrate, or meander, within their floodplain. Channel migration is a change in planform, and is a normal process. Stream channels are not static landscape features.

Q: Is there any relationship between the dominant discharge and the frequency and magnitude of a stream's high flows?

A: There is a large and accepted body of research which suggests that the peak flow that occurs in alluvial channels, on average, once every 1.5- to 2-years corresponds well with the discharge that does the most channel work averaged over time. This discharge also corresponds approximately with the bankfull flow of an equilibrium channel. An equilibrium channel is one with a stable geometry resulting from a balance between its supply of water and sediment.

Q: Are there any discrepancies between researchers concerning the frequency-magnitude of the dominant discharge?

A: Since this theory was established in 1960, there has been a great deal of study to determine its validity. Currently, the theory is accepted as valid, though some research has indicated that the frequency of the dominant discharge varies from stream to stream and region to region. While most studies in alluvial channels consider the 1.5-2-year peak discharge dominant, some researchers have found that less frequent and greater magnitude flows have the greater immediate impact on channel shape. These discrepancies are easily explained. Every channel is unique in terms of its watershed geology (sediment source) and the amount and timing of the water which it carries. For example, one would expect that a sandbed channel in a typhoon climate would behave differently than a gravel bed channel in a temperate climate because of the differences in erodibility and frequency of catastrophic floods. The range in dominant discharge frequency reflects these environmental differences.

Q: Do you subscribe to the dominant discharge theory?

A: Absolutely. Not only is this theory well supported in the research community, my own professional observation of stream channels indicates that flows on the order of the 2-year peak discharge have the most effect on channel form. When Inter-Fluve builds channels, we utilize the estimated 2-year peak discharge for design, recognizing that the resultant geometry is inherently the most stable.

Q: Are there other flow frequencies that could affect the channel's shape?

A: Yes. The shape of a channel is a balance between all past discharges and the most recent ones performing work on the channel. For example, a catastrophic flood may greatly widen a river channel while successive and more frequent high flows act to narrow it. Further, two 1-year frequency peak flows occurring for sustained duration in a single year may perform more work on the channel than the single, short duration 2-year peak flow.

Q: How applicable is the dominant discharge theory described here to the requested Lower Missouri Basin channel maintenance flows?

A: The high discharges identified by Charles Parrett (USGS) are the discharges having a 2-year return interval and are therefore within accepted dominant discharge theory. The method in which the flows would be stair-stepped up to the peak, and then down, also emulates a natural hydrograph.

Q: Why is stair-stepping, and therefore the hydrograph shape, important for channel maintenance flows?

A: A hydrograph has several parts, including baseflow, the rising limb at the start of runoff, the peak discharge for the year, and a falling limb (Appendix A). It is not just the peak discharge which is responsible for sediment movement and therefore, channel form. Channel sediments are mobilized and deposited at different points in the hydrograph. For example, the finest sediments may become mobile before the peak discharge, with only the larger ones being mobilized near the peak. As the hydrograph recedes, larger sediments are deposited first, followed by the finer ones. This is the concept of sediment sorting, and is critical to the establishment of clean riffles and the maintenance of channel bar forms. Stair-stepping of flows is therefore necessary to maintain natural channel shaping processes and efficient sediment transport.

Q: How important is the timing of these flows?

A: Because vegetation colonizes newly deposited sediment, an important component in building new stream banks, maintenance flows should occur during the start of the growing season. Additionally, the resident fishery has evolved to exploit varying discharges through the seasons. In the Lower Missouri Basin, this corresponds to the natural runoff period.

Q: Is the one day duration of the 2-year peak flow requested by DFWP appropriate?

A: A one day duration is conservative. There is research which indicates durations of up to three days comprise the dominant discharge.

Q: How is the concept of the dominant discharge, or channel maintenance flow, related to fish habitat?

A: Viewed from the perspective of channel shape and the forces responsible for it, a fish's physical environment is the product of erosional and depositional processes within a channel. For example, a riffle and pool sequence, when viewed in cross-section, indicates areas of deposition and erosion, respectively (Appendix B). Many riffles and all bars are depositional areas in channels. Pools are areas of sediment transport and erosion. Fish utilize these features for specific needs in their life-cycle. A channel in natural condition will maintain, through the dominant discharge, these diverse channel features through time. Most natural channels have a great deal of physical habitat diversity.

Q: What is a channel in natural condition?

A: A channel in natural condition is one largely unaffected by human activities, including diversion of water, physical channel changes, and those which impact the surrounding watershed.

Q: What are the hydrologic effects of diverting flows from channels during the runoff period?

A: Diversion of flows reduces the magnitude of flows in the channel. Depending on when the diversion takes place, all phases of the hydrograph can be affected. In other words, the increasing flows before the peak (rising limb of the hydrograph), the peak, and the receding flows (falling limb of the hydrograph) can be reduced, or "clipped" (Appendix A). In terms of frequency, a channel experiencing a great deal of diversion, or impoundment, may experience a marked reduction in the frequency of occurrence of the natural 1.5- to 2-year peak discharge.

Q: How do reductions in the magnitude and frequency of natural discharges affect channel form?

A. There is no simple answer to this question, though it can be conclusively stated that changes take place. Channel form is a consequence of both discharge and sediment supply. If one were to assume that the supply of sediment to a channel remained unchanged, but the magnitude of the annual high flows was reduced, channel narrowing and filling of pools would be expected (Appendix B). Vegetation can encroach onto the sediment bars, accelerating channel narrowing. In addition, depending on the size of the sediment in the channel, one would also anticipate a steady accumulation of fine sediments in coarser riffle gravel. This combination of events leads to an aggrading channel, as deposition exceeds the erosional forces.

Q: Besides filling of riffles and pools with fine sediments, what other changes in channel form, associated with flow reductions, affect fish habitat?

A: Natural channels tend to meander. They frequently form new channels while abandoning others. This is particularly true in riverine environments with broad floodplains. These channels are referred to as multiple thread channels. While some threads may contain the majority of the river's flow, others may only flow at high discharges. When the high flows recede, the secondary channels often become backwater sloughs and isolated ponds. These areas provide significant habitat for fish. When high flows are reduced through upstream diversion or storage, sediment accumulates in the main and secondary channels. This results in many of these valuable side channels being either filled or cut-off from the main channel.

Q: Are there other possible effects on channel form, other than channel narrowing, from the reduction of high flows?

A: Yes. To complicate the picture, human use in watersheds often increases the rate and amount of sediment introduced to the channel. If sediment loads are increased above normal levels, a channel may begin to widen in an attempt to convey the excess sediment downstream. It does this by eroding its banks. When this occurs, the sediment problem is exacerbated through the introduction of more sediment from the banks. Such channels lose their physical diversity through filling of pools, loss of depth, failing of undercut banks, loss of riparian vegetation, etc., impairing their fish habitat.

Q: What are other common symptoms of stream channels unable to transport their sediment load because of reduced annual flows?

A: Among other possibilities, the channel may become braided. A braided channel is one with multiple unstable channels between the banks. Because pools and riffles are transient features in braided channels, they do not provide consistent long-term habitat.

Q: What are the effects of in-channel impoundments on the shape of a channel?

A: Besides the alteration of the natural hydrograph, which typically means a reduction in the magnitude of the annual flood, in-channel impoundments also change the way sediment is transported in the channel. For example, an impoundment traps most sediment delivered to it from upstream. Water released from an impoundment is, therefore, clear. This has two effects. First, clear water has more erosive energy than does sediment laden water. Therefore, erosion of the channel below impoundments is common. Secondly, when a channel is cut-off from its normal sediment supply, it no longer has material to build more bars, banks, and floodplains, as does a channel in natural condition. The result is that a channel experiences more erosion. These and other affects are well researched and documented in the literature.

Q: What are the benefits of maintaining a dominant discharge?

A: The resident fishery has evolved to exploit the habitat found in natural channels. The dominant discharge maintains this habitat.

Q: How are these benefits related to the health of the fisheries in the warm water streams in this application?

A: The resident fish populations rely on, and are adapted to exploit, both clean gravels in riffle areas and residual pools in late summer through winter. Reducing the magnitude of the 2-year peak flow will tend to fill both the pools and the space between the gravels in the riffles with fine sediment, thereby reducing or eliminating suitable habitat for fish.

Q: Would flows with magnitudes less than the 1.5- to 2-year flow still serve to flush fine sediments from riffles and pools?

A: It is impossible, without extensive study of every system, to determine the exact magnitude and frequency of flows necessary to transport and sort sediment associated with both riffle and pool formation and maintenance. However, it is generally true that reducing flows from those which naturally occur, leads to problems with deposition of fine sediments in riffles and pools.

Q: Are their other benefits, besides those to the fishery, to flows which flush fine sediments downstream?

A: Yes. When streams are unable to move their sediment load, it is common for headgates and diversion ditches to become silted in, requiring annual maintenance to keep them functional. Also, if a channel widens in response to an excess sediment load, it is often necessary to relocate headgates. I have personally been involved with remedies for both of these scenarios and have observed countless others.

Q: Do high flows provide other benefits in addition to the maintenance of channel form?

A: Yes. The shape of a channel also affects the manner in which a channel recharges the local water table. A channel in balance with its water and sediment supply is shaped such that at bankfull flows, water moves from the channel into the adjacent floodplain watertable. These areas are referred to as soil saturation zones. After high flows recede, water stored in the saturation zone discharges back into the channel, enhancing base flow levels. When a channel has either incised (down cut) from excessive erosion, or severely widened, it loses full contact with the floodplain watertable and, consequently, is inefficient in recharging it.

Q: What effect do the requested channel maintenance flows have on riparian vegetation.

A: Vegetation is a major component in the maintenance of channel form, because riparian vegetation makes stream banks resistant to erosion. Plants on streambanks need a moist to saturated environment to thrive. In semi-arid climates such as the Lower Missouri River area, the majority of this streambank moisture is delivered during runoff. The 2-year peak discharge maintenance flow, therefore, is critical to viability of the riparian communities. Further, it is well documented that the establishment of new cottonwoods on channel margins is dependent on annual to semi-annual high flows. Cottonwoods are an important component of channel stability and fish habitat where they occur.

Scott Gillilan, being first duly sworn, states that the foregoing testimony is true.

DATED this 24th day of June, 1994.

Scott Gillilan

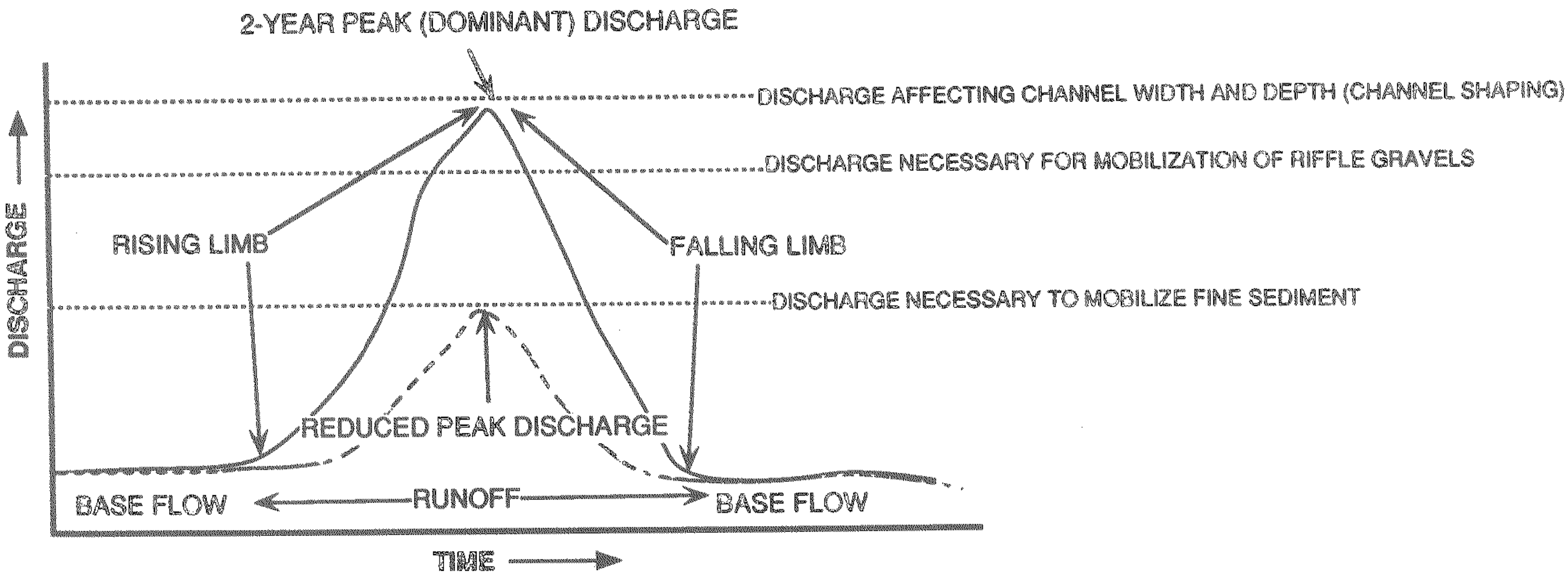
Scott Gillilan

Subscribed and sworn to before me this 24th day of June, 1994.

Notary Public for the State of Montana

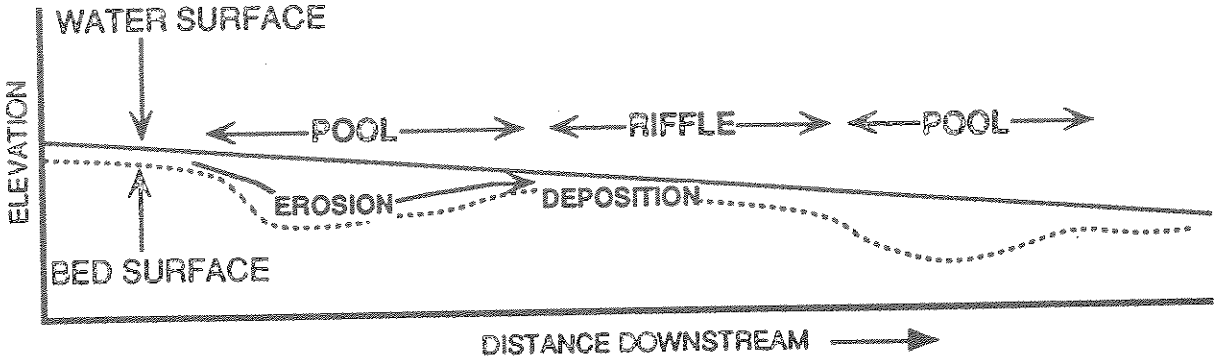
My commission expires: 1-1-96

APPENDIX A
CONCEPTUAL HYDROGRAPH WITH NORMAL AND REDUCED DISCHARGES AND RELATIVE AFFECT ON CHANNEL SHAPING AND SEDIMENT MOBILIZATION

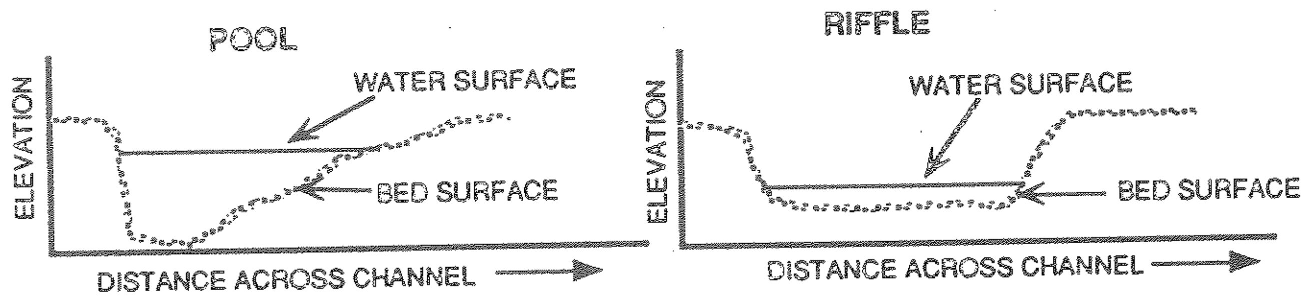


APPENDIX B
POOL AND RIFFLE CHANNEL GEOMETRY WITH REFERENCE TO AFFECTS OF REDUCED FLOWS

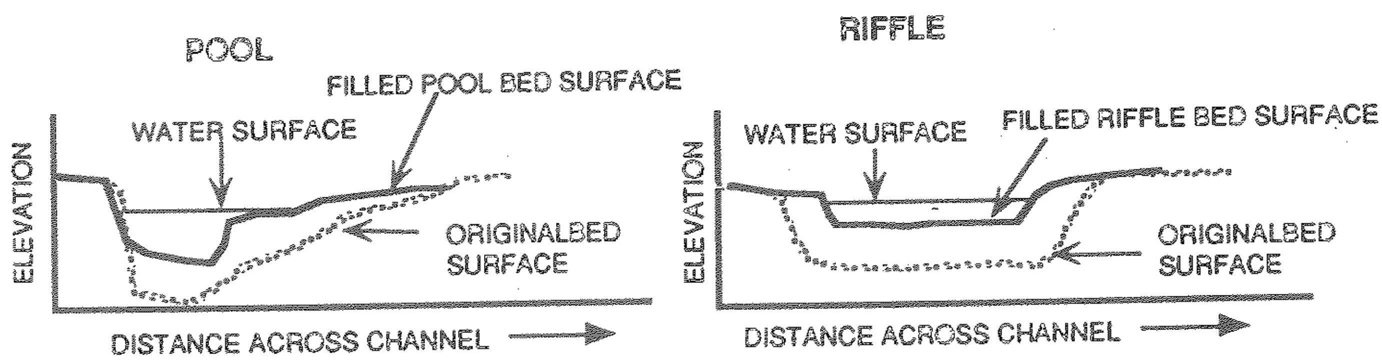
LONGITUDINAL PROFILE



NATURAL POOL AND RIFFLE CROSS-SECTION



POOL AND RIFFLE CROSS-SECTION AFTER DEPOSITION FROM REDUCTION OF PEAK FLOWS



NOTE CHANNEL NARROWING AND BED AGGRADATION (DEPOSITION) IN REDUCED PEAK FLOW SCENARIO

PRE-FILED DIRECT TESTIMONY
OF CAROLYN A. SIME
ON BEHALF OF THE
MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS

Q. Please state your name and business address.

A. Carolyn A. Sime, Montana Department of Fish, Wildlife and Parks, 490 N. Meridian Road, Kalispell, MT 59901

Q. By whom are you employed, and in what capacity?

A. I am employed by the Montana Department of Fish, Wildlife and Parks (DFWP). My position is Fish and Wildlife Biologist in the Wildlife Division.

Q. What is your education and employment experience that is pertinent to this testimony?

A. I received a Bachelor of Science degree in Biology (Fish and Wildlife Management Option) from Montana State University in March, 1988 and a Master of Science degree in Fish and Wildlife Management from Montana State University in March, 1991. Undergraduate studies emphasized general science, and graduate studies emphasized wildlife-related courses although a strong academic background in fisheries was also obtained.

My employment history includes seasonal jobs with the National Park Service as a naturalist-interpreter and the U.S. Fish and Wildlife Service as a biological technician. I was hired for a six month period in January 1991 by the DFWP Fisheries Division to help prepare the application for water reservations in the lower and Little Missouri river basins. Upon the completion of the application, I continued to work for the Department as a seasonal employee in various capacities for both the Fisheries and Wildlife divisions. While working for the Fisheries Division, I assisted with fish population studies and habitat surveys in the Bitterroot River drainage during the latter half of 1991 and conducted spawning surveys of arctic grayling in the Madison River/Ennis Reservoir system and assisted with other fish population surveys during spring 1992. While working for the Wildlife Division, I administered hunter check stations, conducted hunter harvest surveys, conducted wildlife surveys, analyzed several long-term data sets and wrote reports, and authored a management plan and environmental analysis on noxious weeds. I have also worked seasonally for the U.S. Forest Service as a range technician and a wildlife technician.

Q. What are your responsibilities in your present position?

A. My primary responsibility, as Project Biologist of the Northwest Montana White-tailed Deer Research Project, is to investigate white-tailed deer population/habitat relationships, to evaluate hunter harvest effects on populations, and to develop and evaluate methodologies for monitoring population size and trend. Secondarily, my responsibilities relate to assisting with the day-to-day operations of the Kalispell Regional Headquarters Wildlife Office.

Q. What is the purpose of your testimony in this proceeding?

A. My testimony relates to the preparation and content and of the application for reservations of water in the lower and Little Missouri River basins submitted by the Department in June 1991.

Q. What was your role in the preparation of the Department's application?

A. My role principally related to the assembly of application materials from a variety of sources (or individuals) into a cohesive document, the preparation of tables and figures, and to the drafting of specific sections of the application. My activities were directly supervised by Liter Spence (DFWP Fisheries Division, Water Resources Supervisor) and Fred Nelson (DFWP Fisheries Division, Fish and Wildlife Biologist).

I was responsible for writing various sections of the application, as assigned by my supervisors. For other sections, I was only responsible for obtaining the correct numerical statistics which applied to the lower and Little Missouri river basins and incorporating these into the passages which were taken from Volume 1 of the DFWP application for reservations of water in the Missouri River basin above Fort Peck. The sections, or subsections thereof, with which I was actively involved are as follows:

-- sections 7,8,9 of the "Analysis of Need" section on pages 11-13

-- description of the Lower Missouri River basin on pages 33-36

-- description of the Milk River sub-basin on pages 55-57

-- description of the Little Missouri basin on pages 123-124

-- the discussion of the direct benefits of reservations to fisheries and fishing opportunities on pages 143-147 and the first two full paragraphs on page 152

-- the discussion of the direct benefits of reservations to recreation (pages 154-156) and to riparian areas (last paragraph on page 156)

-- the discussion of the direct benefits of reservations to economic conditions in section 4 on pages 156-158

-- the discussion of economic benefits of the reservations to business, industry, and municipalities on pages 161-168

-- the discussion of indirect costs of the reservation to municipalities, industry, and agriculture on pages 173-183

Q. What methods did you use to gather the information contained in the application and what were your sources?

A. Application materials were typically obtained from two sources. One source was DFWP fish and wildlife biologists who drafted various sections of the application based on their knowledge of a particular area and the associated fish and/or wildlife resources. These biologists were responsible for the accuracy and content of the stream reach narratives contained in the application.

The second source of supporting information germane to the lower and Little Missouri river basins was obtained by verbal or written consultation with knowledgeable individuals both inside and outside DFWP and by securing written reports when available. Sources included, but were not limited to: Montana Department of State Lands, Montana Department of Natural Resources and Conservation, Montana Department of Commerce, Montana Natural Heritage Program, Montana Department of Health and Environmental Sciences, Montana Travel and Promotion Office, Western Area Power Administration, and the Montana Crop and Livestock Reporting Service.

Q. Why is the reservation needed for fishes of "special concern" and for wildlife?

A. Fishes of special concern are those native Montana species identified by the Montana Chapter of the American Fisheries Society as occupying habitats which are limited in availability and/or species which have limited distributions or population numbers. Eight of the 18 fish species meeting these criteria are found in the lower and Little Missouri river basins. They are: pallid sturgeon, paddlefish, sicklefin chub, sturgeon chub, shortnose gar, pearl dace, blue sucker, and the northern redbelly dace x finscale dace hybrid. The pallid sturgeon is listed as endangered under the federal Endangered Species Act and the paddlefish, blue sucker, sturgeon chub, and the sicklefin-chub are candidate species (C2) for inclusion on this list. (Montana Natural Heritage Program 1991). Instream flow reservations would help maintain the habitat requirements of this group of fishes.

Some wildlife species also depend on flowing waters to meet their life history requirements. Although the precise flow requirements are not quantified, the dependency of these species on unimpaired riverine habitats is generally accepted (Flath 1991). The bald eagle and the least tern, both listed as endangered under the Endangered Species Act, and the piping plover, listed as threatened, are all known to occur along the lower Missouri River. In addition, snapping and softshelled turtles, species of special concern according to the Montana Natural Heritage Program, also reside in the lower Missouri basin. The Natural Heritage Program classifies the American white pelican as endangered and imperiled in Montana because of its rarity. This species also occurs along the lower Missouri River.

Q. What are some of the economic benefits of instream flows?

A. The entire Missouri River basin's nationally acclaimed sport fisheries provide a significant boost to Montana's economy. In 1985, the annual net value of Montana's lake and stream fisheries totaled $215 million (Duffield 1988). Warmwater angling in the lower and Little Missouri River basins contributed $1.7 million annually to the state's economy in 1989 (Brooks 1991). These angling-related revenues depend on the maintenance of adequate river flows to protect the fishery resources.

Q. What are some of the direct benefits of instream flow reservations to fisheries?

A. Direct benefits of the reservations are those benefits which accrue directly to DFWP and the public which the agency represents. To the extent that DFWP is charged with the stewardship of the fish, wildlife, parks, and recreational resources of Montana, the direct benefits really accrue to the citizens of, and visitors to, Montana.

According to DFWP studies, 18 families and 80 species of fish are known to occur in Montana. Of these, 43 inhabit the waters of the lower Missouri River between Fort Peck Dam and the North Dakota border (Gardner and Stewart 1987). Furthermore, 30 species inhabit the waters of the Little Missouri River basin (Elser et al. 1979). Although they support fewer species than the Missouri basin above Fort Peck, the lower and Little Missouri river basins make a significant contribution to the biological diversity of the aquatic resources of Montana and the region. Each of these warm, turbid prairie streams supports 20-30 different fish species. By comparison, most cold, clear trout streams support less than 10 species.

As described above, eight of the fish species inhabiting the lower and Little Missouri basins are classified as species of special concern. Among them, the paddlefish, pallid sturgeon, shovelnose sturgeon, and the shortnose gar, are relics from an earlier geologic time. Paddlefish are found in only two river basins in the world: the Yangtze in China and the Mississippi/Missouri. Paddlefish populations in most of their historic range have been reduced or depleted by overharvest, pollution, habitat alteration and blockage of migration routes. However, Montana populations are some of the best in the entire Mississippi/Missouri river system. Paddlefish are Montana's largest game fish, although harvest is strictly regulated. Angling opportunities are closely tied to spawning which, in turn, is closely tied to high run-off events. The run-off contributed by the Milk River to the Missouri River is significant in triggering spawning runs, and during good run-off years, paddlefish will even ascend the Milk River to spawn on flooded gravel bars. Studies of tagged paddlers indicate that these fish make extensive movements within the Missouri River system, particularly between the dredge cuts below Fort Peck Dam, Intake Dam on the Yellowstone River, and Lake Sacacawea (the reservoir impounded by Garrison Dam in North Dakota).

Pallid sturgeon are also known to move long distances within the lower Missouri River, although less is known of their life history requirements. Because of its rarity, the pallid sturgeon has been included on the federal endangered species list. Pallids are rarely sighted or harvested by anglers. However, shovelnose sturgeon are more numerous and prized by knowledgeable anglers. The shortnose gar, another primitive fish, is very rare, with historical records indicating only a handful of gar taken from the dredge cuts in the last 20 years. Collectively, these prehistoric species are holdovers from the warm, turbid prairie streams of 150 - 200 million years ago and require adequate instream flows for survival in today's world. These species benefit directly from instream flows.

Forage and game fish populations also directly benefit from instream flows. Game fish species in the lower and Little Missouri basins include northern pike, sauger, walleye, channel catfish, and burbot. Stream-dwelling trout (rainbow, brown, and brook) also occur in cold, headwater streams originating in the Bear Paws and the Little Rocky mountains and in the Missouri River immediately below Fort Peck Dam. Forage fish species include various species of suckers, bass, and minnows. All of these species require adequate flows to meet their life history requirements, particularly during spawning and low-flow periods. In particular, the run-off from tributaries triggers spawning movements. In addition, the reproduction of both forage and game fish that takes place in smaller tributaries makes a significant contribution to the fish populations of the mainstem Milk and the lower and Little Missouri rivers. Thus, tributaries contribute to the maintenance of stream flows and water quality in these streams and rivers, and they may also support warmwater fish at some time during the year.

Fish inhabiting prairie streams would also benefit from reserved stream flows which will help maintain enough water in the deep pools typically occupied by fish during the low-flow periods of late summer, fall and winter. Reserved instream flows would also benefit the cold, headwaters of Milk River tributaries where trout populations have been limited by dewatering and drought.

Q. What are some of the direct benefits of instream flow reservations to fishing opportunities?

A. Warmwater species account for the majority of angling opportunities in the lower and Little Missouri river basins. Licensed anglers logged about 78,700 angler-days on Montana's warmwater streams in 1985; 36% (28,667 angler-days) was in the lower and Little Missouri river basins (McFarland 1989). These totals underestimate angler-use because only <u>licensed</u> anglers were sampled in the mail surveys used to generate pressure estimates. Furthermore, these data can mask the significance of local waterways to the small, rural communities of eastern Montana where angling opportunities can be limited by the scarcity of fish-holding waters.

Opportunities to catch stream-dwelling trout in the cold, headwater tributaries of the Milk River are also highly valued by local anglers. Trophy-sized rainbow trout in the Fort Peck Dam tailrace not only attract local attention, but also the attention of anglers from all over the state. The high species diversity, the presence of primitive fish, and the significance of other fishery values has led DFWP to rate the entire lower Missouri River as a Class I fishery (Montana Rivers Information System 1991). This rating is reserved for those fisheries DFWP considers to have the highest resource values. Significant portions of the Redwater and Poplar rivers are rated as Class II because of high species diversity, important local angling interest, and because they provide valuable spawning habitat for mainstem Missouri fishes. The Little Missouri River is rated as Class II because of high species diversity and the importance of angling opportunities to the local communities. Ratings are only available for two tributaries of the Little Missouri. Beaver Creek is rated as Class I because of high species diversity and its contribution to local angling opportunities. Little Beaver Creek is rated as Class III, although this rating likely underestimates the values of this tributary because only fisheries values were encompassed in the rating while other values such as recreation were not. Nonetheless, Little Beaver Creek supports as many fish species as the mainstem Little Missouri River.

Warmwater fishing is an opportunity valued by both residents and non-residents. The net economic value of warmwater stream fishing has been estimated at about $65 per day (Brooks 1991). Based on the 1985 estimates of fishing pressure, the value of warmwater fishing in the lower Missouri River basin is $1,756,235 per year (Brooks 1991). In the Little Missouri River basin, the net economic value is $107,120 per year (Brooks 1991). However, trends in the number of warmwater angler-days are increasing (McFarland 1991). Preliminary fishing pressure estimates for 1990 indicate that while angler-use on all state waters remained relatively stable from 1985 to 1990, pressure on warmwater fisheries increased by an estimated 11%. The increase was more pronounced for warmwater streams where overall angler-use increased by an estimated 29%.

Q. What are some of the direct benefits of instream flows to recreation?

A. Reserved instream flows will directly benefit non-angling forms of recreation. Floating is an activity enjoyed by over 30% of Montanans (Frost and McCool 1986). Adequate instream flows are important not only for the convenience of floaters but for their safety as well. Floaters can avoid hazards such as large boulders, partially-submerged logs, gravel bars, rip/rap, or diversion structures if sufficient flows enable maneuvering around them. Since the Missouri figured so prominently in Montana history, present-day floaters can glimpse into the past while floating the isolated waters of the lower Missouri River. Other recreational pursuits along waterways include camping, picnicking, photography, and wildlife viewing.

Q. What are some of the indirect benefits of instream flows to businesses, municipalities, and industries?

A. Indirect benefits are those benefits of the reservation that accrue to water users or entities other than DFWP. Businesses in the lower and Little Missouri river basins should indirectly benefit from DFWP reservations. The instream flows requested in DFWP's application are necessary to protect recreational and aesthetic benefits provided by the rivers and streams in these basins. Protection of these amenities contributes significantly to the economic well-being of Montana because tourism, one of the fastest growing segments of the state's economy, is directly tied to these amenities. Tourists spent an estimated $19 million while traveling in the lower Missouri River basin during 1988, generating 700 jobs (Yuan et al. 1989). In addition, 336,000 people traveled to Montana for business reasons or for a combination of business and pleasure (Moisey et al. 1990). While in Montana, 31% of these business travelers participated in fishing and fishing-related recreation. This business travel has an annual economic significance to Montana of at least $146,900,000 (Moisey et al. 1990).

The lodging tax collection is evidence of increasing numbers of visitors coming to Montana, whether for business or pleasure. Collections show increasing trends across the counties of the lower and Little Missouri river basins (Thomas 1991). The DFWP instream flow reservation will help ensure the integrity of river corridors and the quality of the environment which have had much to do with the past successes of travel promotion. The reservation may also help ensure the projected expansion of warmwater angling. More travelers may be attracted to eastern Montana where the majority of warmwater angling occurs. By patronizing local lodging and business establishments, anglers contribute to local economies. Thus the recreational and aesthetic attributes of rivers not only enrich the quality of life of Montana residents, they also generate a source of steady revenue that helps diversify the other staples of Montana's economy: agriculture, mining, and the wood products industry.

DFWP reservations would indirectly benefit industries and municipalities by helping to stabilize wastewater treatment costs. The Montana Department of Health and Environmental Sciences issues waste discharge permits based on the current 7 day - 10 year low stream flow (7Q10). As streams decrease in flow, the 7Q10 also decreases and places a higher treatment standard on waste treatment facilities when they receive a permit. A higher standard of treatment may require costly upgrading of the facilities to meet the standard. Preserving instream flows is a more cost effective way of meeting discharge permit limits than is upgrading treatment facilities or securing alternative disposal locations (Shewman 1994).

Municipalities will benefit from stabilized waste water treatment costs in the same manner as industries. By using instream flows to meet discharge permit levels, municipalities avoid the logistical and financial hardships potentially imposed by the suspension and alternative disposal of waste or by the renovation of facilities to treat the waste. Furthermore, DFWP reservations would help maintain stream discharge levels necessary to dilute the toxic effects of hazardous materials and microbial organisms entering surface waters. Unless adequate dilution is achieved, concentrations of such substances in public drinking water supplies may reach levels harmful to human health. DFWP reservations will also help protect instream flows from incremental depletions by future water users, thus assuring future water quality and water delivery for municipal uses.

Q. What are some of the indirect costs of the reservations to municipalities, industry, and agriculture?

A. Indirect costs of reserved water are those costs that accrue to other users or entities. The following is a summary of some indirect costs. A more detailed discussion can be found in the DFWP reservation application. Granting DFWP reservations in the lower or Little Missouri river basins would not necessarily limit new uses of water by municipalities, industry, or agriculture when other surface or groundwater sources would adequately meet the needs. Granting of the reservations may limit future availability of surface waters for new uses such as: hardrock mining, sand, gravel, or coal extraction, oil and natural gas development, energy production facilities, irrigated agriculture, and municipal water supplies. A discussion of future availability for these new uses follows.

While mining and the processing of mined products are important industries in the upper and middle Missouri River basins, there is only one active hardrock mine operation in the lower and Little Missouri river basins. The Zortman-Landusky mine in Phillips County utilizes groundwater for ore processing. DFWP reservations are not expected to affect future activities of this operation because ore processing would continue to use groundwater at the existing facility (Webster 1991). There is limited hardrock mining potential in the lower and Little Missouri river basins in general. Sand and gravel extraction operations are more common in these basins. Actual extraction procedures do not require water (Burke 1991). Secondary processing (e.g. rinsing) does require water and companies typically secure water from existing water right holders. Potential sources include stock ponds, municipal fire hydrants, irrigation ditches and water storage facilities (Burke 1991). Thus, DFWP reservations should not significantly affect future mining activities.

Oil and natural gas drilling operations require water, but little use of surface waters from major rivers or perennial tributaries occurs (Halvorson 1991). Water used during drilling is usually derived from farm or ranch ponds and wells or, in some cases, purchased from existing water right holders. Therefore, DFWP reservations should have little impact on future development of oil and natural gas in the lower and Little Missouri river basins.

Although several proposals to develop energy facilities in the lower and Little Missouri river basins were brought to the attention of the Montana Department of Natural Resources and Conservation during the last decade, none have been acted on in recent years (McLane 1991). Until such projects come forth in more detail, an analysis of the effects of the FWP reservations on water availability cannot be made.

Instream water reservations would not affect existing agricultural uses in the lower and Little Missouri river basins, nor would they necessarily preclude development of additional irrigation through the use of groundwater. A DFWP reservation could limit future expansion of irrigation if new surface water sources are needed or new storage projects are proposed on streams where a DFWP reservation is granted.

Future water demands for municipalities are difficult to predict because of problems associated with population growth projections. Several municipalities have requested water reservations in the lower or Little Missouri river basins. Based on the Board's Order granting requests for municipal reservations in the upper Missouri basin, these municipal applications are likely to be granted, for the most part, as requested and given the highest priority. Municipalities seeking ground water sources to meet their increased demands will not be affected by a DFWP reservation. Municipalities which seek surface waters to meet future demands may be affected by a DFWP reservation depending on the location of the water source. However, with a few exceptions, the majority of water used for human consumption throughout the lower and Little Missouri river basins is taken from groundwater because of the marginal water quality of surface waters.

Q. Do you believe the overall benefits of DFWP's reservations outweigh the costs?

A. Yes. Whereas DFWP reservations may limit some new uses of <u>surface</u> waters in the future, the reservations do not and cannot have any adverse affects on water use by existing water right holders. The direct and indirect benefits of the DFWP reservation cover a broad spectrum of the public interest while the potential costs of the reservations are narrow, and would not cause any irretrievable losses. Irretrievable losses may occur if DFWP reservations are <u>not</u> granted.

Benefits to the citizens of Montana include preservation of the aesthetic, cultural, historical, and social values associated with river corridors like the lower and Little Missouri rivers. Furthermore, maintenance of instream flows benefits recreationists directly, whether they are anglers, floaters, campers, picnickers, photographers, wildlife watchers, or swimmers. These forms of recreation contribute to the quality of life for residents of, and visitors to, Montana. Montana's economic climate will benefit because of the economic activity generated by business travellers, tourists, and anglers. Lastly, maintenance of instream flows preserves the heritage of the natural resources of Montana. Montana's fishery and wildlife assets are recognized both nationally and internationally and valued for their existence and their diversity. As Montanans, we have a trust responsibility to preserve the integrity of these resources for this and future generations.

I, Carolyn A. Sime, being first duly sworn, states that the foregoing testimony is true.

DATED this 28 day of June, 1994.

Carolyn A. Sime

Carolyn A. Sime

Subscribed and sworn to before me this 28 day of June, 1994.

(NOTARY SEAL)

Sandy Newman

Notary Public for the State of Montana
Residing at Flathead Co.
My Commission Expires April 7, 1998

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BIOGRAPHY

Education

Master of Science in Fish and Wildlife Management. March, 1991. Montana State University, Bozeman.

Bachelor of Science in Biology, Fish and Wildlife Management Option. March, 1988. Montana State University, Bozeman.

Professional Experience

Wildlife Biologist, April 1994 to present
Montana Department of Fish, Wildlife and Parks, Kalispell
Conducting ongoing research on the population dynamics and habitat use of white-tailed deer in northwest Montana coniferous ecosystems.

Check Station Attendant, October 1993 to February 1994
Montana Department of Fish, Wildlife and Parks, Bozeman
Assisted in the operation of the Gallatin Check Station during the general rifle season and the A-7 Flying D hunt, including collection of biological data from harvested big game; assisted in the operation of the Gardiner Check Station.

Project Coordinator, July to October 1993
Montana Department of Fish, Wildlife and Parks, Bozeman
Authored the Management Plan and Environmental Assessment pertaining to noxious weed management on all properties administered by DFWP in southwest Montana.

Biological Technician, May to July 1993
U.S. Forest Service, Lewis and Clark National Forest
Conducted fish, wildlife, and plant surveys on the Rocky Mountain Ranger District.

Fish and Wildlife Biologist, December 1992 to May 1993
Montana Department of Fish, Wildlife and Parks, Bozeman
Assisted the Livingston Biologist with regular management duties while he was working on a special assignment. Responsible for supervising the Gardiner late season elk hunt, analyzing harvest data, and writing the report; conducting spring wildlife surveys; analyzing harvest data from previous Gardiner late season elk hunts, and writing appropriate reports.

Check Station Attendant, October to December 1992
Montana Department of Fish, Wildlife and Parks, Bozeman
Assisted in the operation of the Gallatin Check Station during the general rifle season and the A-7 Flying D hunt, including hunter management and collection of biological data.

Range Technician, June to September 1992
U.S. Forest Service, Lewis and Clark National Forest and Montana Department of Fish, Wildlife and Parks

Conducted range survey and inventory on two national forest cattle allotments, one of which is important bighorn sheep winter range; project was jointly funded. Also assisted with vegetation monitoring of the DFWP Sun River Wildlife Management Area.

Fisheries Fieldworker II, March to June 1992
Montana Department of Fish, Wildlife and Parks, Bozeman

Conducted survey of the Arctic grayling population in the Ennis Lake/Madison River system; emphasis was qualitative and quantitative description of spring spawning activity. Also assisted with data analysis, database management, and field work associated with other fish population surveys.

Check Station Attendant, January to February 1992
Montana Department of Fish, Wildlife and Parks, Bozeman

Assisted in the operation of the Gardiner Check Station during the late elk hunt, including hunter management and collection of biological data.

Fisheries Fieldworker I, June to December 1991
Montana Department of Fish, Wildlife and Parks, Hamilton

Assisted with fish population and habitat surveys on the Bitterroot National Forest; also assisted with fish population surveys of the Bitterroot River.

Missouri River Reservation Biologist, January to June 1991
Montana Department of Fish, Wildlife and Parks, Helena

Conducted research for and was a principal compiler of the DFWP instream flow reservation application for the lower Missouri and Little Missouri rivers; also initiated the literature review and information search for the wildlife portion of the Natural Resource Damage Assessment for the Clark Fork River Basin.

Research Assistant, March 1988 to June 1990 and September to December 1990; Department of Biology, MSU, Bozeman

As a graduate student, investigated movements and habitat use by sage grouse; also assisted other fish and wildlife graduate students.

Research Associate/Volunteer, June to September 1990
U.S. Fish and Wildlife Service, Lostwood Wildlife Refuge; Kenmare, North Dakota

With a grant from the North Dakota Chapter of The Wildlife Society, initiated a long term research project on aspen reduction; also assisted with general refuge field work.

Biological Technician, September to December 1987 & September to December 1988. Department of Biology, MSU, Bozeman

Compiled and summarized data from golden and bald eagle trapping operations; also reviewed and transcribed field notes and summarized behavioral data of nesting bald eagle pairs.

Ranger Naturalist-Interpreter, June to September 1987 National Park Service, Olympic National Park; Port Angeles, Washington

Gave presentations to park visitors, conducted guided walks, wrote and narrated interpretive messages aired on local radio station.

Professional Affiliations

Member, The Wildlife Society, 1988 to present

Member, Montana Chapter, The Wildlife Society, 1988 to present

Secretary-Treasurer, Montana Chapter, The Wildlife Society, March 1994 to present

Northwest Section Representative of the Student Affairs Committee, The Wildlife Society, 1990

Participant, Riparian Resource Management Workshop, May 1989

Participant, Continuing Education Seminar on "Negotiations" sponsored by the Montana Chapter of the American Fisheries Society, February 1991

Participant, Elk Vulnerability Symposium, April 1991

Participant, Western States and Provinces Elk Workshop, May 1993

Publications

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Sime, C. A. 1992. Habitat fragmentation after the fact: female sage grouse use of a crested wheatgrass planting. Abstract in Proceedings of the 1992 Annual Meeting of the Montana Chapter of The Wildlife Society.

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PRE-FILED TESTIMONY OF
PHILLIP A. STEWART
On behalf of the
MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS

Q. Please state your name and business address.

A. Phillip A. Stewart, Montana Department of Fish, Wildlife and Parks, Box 1630, Miles City, MT 59301.

Q. Who is your employer and what is your position?

A. I am the Region 7 Fisheries Manager for the Montana Department of Fish, Wildlife and Parks based in Miles City.

Q. Please describe your educational and employment history.

A. I received a B.S. degree from the University of Arizona at Tucson in 1965 with a major in Fisheries Management. In 1967 I received a M.S. in Fisheries Management from the same school. I was awarded a Ph.D. in Fisheries Science by Colorado State University in 1970. Research work for the M.S. degree involved productivity relations in four reservoirs. Ph.D. research was concerned with physical features of a trout stream influencing trout density.

Following the awarding of the Ph.D. degree I was employed as a water quality biologist by the Ontario, Canada, Department of Lands and Forests from 1970 to 1971. I've been employed by the Montana Department of Fish, Wildlife and Parks from 1971 to the present time. I worked as a fisheries biologist from 1971 to 1976 at Columbus, Montana. Work during that time focused on potential effects of hardrock mining and quantification of instream flows for fish and other aquatic life in streams draining the Beartooth Mountains in south central Montana.

From 1976 to 1983 I worked as a fisheries biologist at Wolf Point, Montana. Work there consisted of defining instream flows to protect aquatic life on the Poplar and Redwater River drainages, determining the effect on fish populations of a Canadian dam on the East Fork Poplar River, and defining fisheries resources on the Missouri River from Fort Peck Dam to North Dakota.

I've been the Regional Fisheries Manager in Miles City since spring 1983.

Q. What is the purpose of your testimony?

A. My testimony will describe the fishery resources and support MDFW&P's instream flow water reservation requests for two river reaches in the Redwater River drainage and four river reaches in the Poplar River drainage. I will also describe the role I played in the fisheries studies in the Little Missouri River and three tributary streams: Beaver Creek, Little Beaver Creek and Boxelder Creek, two of which will be the subject of Robert G. White's testimony and two will be presented in my testimony. Vicinity maps of these streams are contained in Appendix A. of this testimony.

Q. Do you have any experience in dealing with instream flow issues in relation to fisheries resources.

A. Yes, a considerable amount. I spent five years as a fisheries biologist defining fish populations and related biological populations in streams tributary to the Yellowstone River in south-central Montana. An important part of that work was formulating recommended instream flows to protect fish populations and related aquatic life in those streams. During the years 1977 through 1982 I did field work and data analysis to develop the instream flows for streams in the Poplar River drainage and for the Redwater River requested in this application.

Q. What was your involvement in the preparation of the Lower Missouri River water reservation application?

A. I supervised and participated in the collection of field data used to formulate requested flows for the Poplar and Redwater rivers. I did much of the analysis and interpretation of the fisheries field data and stream flow data. I also gave assistance to two graduate students doing field work on streams in the Little Missouri River drainage. I supplied them with an electrofishing boat for fish sampling and fish tagging gear and instructed them in the use of the equipment. I spent a day in the field with them and was able to verify their proficiency with gear and field techniques. These students were supervised by Dr. Robert White of the Cooperative Fishery Research Unit at Montana State University.

Q. Much of the fish population work in the Poplar River drainage and Redwater River was done in the late 1970s and early 1980s. Do you think it is relevant today?

A. Yes. No major changes in fish habitat have been identified since the time of the studies. Statewide fishing use surveys in 1989 and 1991 indicate continued use of these streams by anglers. Recently local anglers objected to a bridge replacement project on the West Fork Poplar River because of its potential effect on the northern pike.

Q. Please summarize in tabular form for each stream reach included in your testimony: stream name and reach; amount of the streamflow request; methods used; and fisheries values.

A. I have summarized this information in Appendix B. It is attached to and is a part of this testimony.

Q. Please summarize the work you did on Reach #1 of the Redwater River that relates to the reservation requests.

A. Using electrofishing and seining gear I surveyed fish populations. I also noted habitat features. I found that northern pike were present at low densities, being somewhat more abundant in downstream areas of the reach. Approximately 15-20 additional fish species are present. The river channel consisted of relatively deep pools often several hundred feet long connected by short riffles.

Q. What methods were used to determine the amount of flow requested for Reach #1 of the Redwater River?

A. The Dominant Discharge/Channel Morphology Concept and the Base Flow Approach, along with an understanding of the fish populations present and their needs, were used to derive flow requests. The Dominant Discharge/Channel Morphology Concept and the Base Flow Approach are discussed in the testimony of Fred Nelson.

Q. Please describe the fisheries values the Department is trying to protect on Reach #1 of the Redwater River.

A. Although habitat conditions are generally marginal, this river reach contains a low density of northern pike. These fish often reach a weight of several pounds and are the basis for recreation by mostly local anglers. Northern pike spawn in this river reach as evidenced by the presence of young-of-the-year fish. The forage base for this predator species consists of a relatively large number of species of fish from several families. Despite very low stream flows for much of the year, pools are relatively deep, often with maximum depths at low flow of four or five feet. These pools provide security for fish and sufficient depth of water to prevent the river from freezing to the bottom in winter and causing fish death.

Q. Why is an instream reservation needed in Reach #1 of the Redwater River?

A. The requested flow is necessary to maintain the existing northern pike population and the forage fish species that support it. The requested flows will allow northern pike spawning to continue through flooding of terrestrial vegetation. These flows will also maintain recreational fishing for local anglers. The Department's mail survey of anglers indicated 1,882 angler days of use on the Redwater River from March 1989 through February 1990. An unknown fraction of this fishing pressure was on Section #1. Maintaining the low base flows requested will help prevent dissolved oxygen levels from falling to levels lethal to fish. The dominant discharge would scour pools and maintain sufficient pool depths to prevent water from freezing to the river bottom and would also allow northern pike movement into this upstream section from downstream areas.

Q. What flow is being requested for Reach #1 of the Redwater River?

A. The Department is requesting 2.0 cfs from December 1 through March 31, 3.0 cfs from April 1 through November 30 and 14 days of additional water stepping up to and down from a peak flow of 780 cfs (dominant discharge). These fourteen days of flow are to occur within the period February 1 through April 30.

Q. Is there sufficient water in Reach #1 of the Redwater River to meet the MDFW&P flow request?

A. USGS gauging records indicate that the requested flows may not be fully available in all months of every year. However, the requested flows are necessary to prevent future dewatering of the river, especially at times when the requested flows are present. This is especially true for the dominant discharge flows.

Q. Please summarize the work you did on Reach #2 of the Redwater River that relates to the reservation requests.

A. With electrofishing gear I surveyed fish populations to determine species present and relative abundance. I also noted habitat features. I found adult and young-of-the-year walleye and northern pike throughout the length of the section. Several other fish species are present. Sauger, channel catfish and burbot were present only in the very lowest part of the section near the Missouri River.

Q. What methods were used to determine the amount of flow requested for Reach #2 of the Redwater River?

A. The Dominant Discharge/Channel Morphology Concept and the Base Flow Approach, along with an understanding of the fish populations present and their needs, were used to derive flow requests.

Q. Please describe the fisheries values the Department is trying to protect on Reach #2 of the Redwater River?

A. Although habitat conditions are not highly favorable for sustaining high fish densities, some northern pike and walleye reach a size of several pounds. A relatively large number of forage species are also present. Sauger, channel catfish and burbot are present in the lower end of the section. Both northern pike and walleye are self-sustaining, finding suitable spawning habitat in this section. The section also rears significant numbers of young-of-the-year walleye and northern pike. Despite very low streamflows for much of the year, pools are relatively deep, often with maximum depths at low flow of 4 to 5 feet. These pools provide good security for adult walleye and northern pike and sufficient depth to prevent the river from freezing to the bottom in winter and causing fish death.

Q. Why is an instream reservation needed on Reach #2 of the Redwater River?

A. The requested flow is necessary to maintain the existing northern pike and walleye populations and the forage fish species that support them. The requested flows will allow northern pike and walleye spawning and rearing to continue. These flows will also maintain recreational fishing for local anglers. The Department's mail survey of anglers indicated 1,882 angler days of use on the Redwater River from March 1989 through February 1990. An unknown fraction of the fishing pressure was on Reach #2. Maintaining the low base flows requested will prevent dissolved oxygen levels from falling to levels lethal to fish. The dominant discharge will scour pools and maintain the sufficient depth for fish security as well as maintaining sufficient pool depth to prevent winter freezing all the way to the river bottom. The dominant discharge will also allow northern pike movement from this section to the upstream Reach #1.

Q. What flow is being requested for Reach #2 of the Redwater River?

A. The Department is requesting 2.0 cfs from December 1 through March 31, 4.0 cfs from April 1 through November 30, and 14 days of additional water stepping up to and down from a peak flow of 900 cfs (dominant discharge). These 14 days of flow are to occur within the period February 1 through April 30.

Q. Is there sufficient water in Reach #2 of the Redwater River to meet the MDFW&P flow request?

A. USGS gauging records indicate that the requested flows may not be fully available in all months of every year. However, the requested flows are necessary to prevent future dewatering of the river, especially at times when the requested flows are present. This is especially true for the dominant discharge flows.

Q. Please summarize the work you did on the East Fork Poplar River that relates to the reservation requests.

A. Using electrofishing gear, I sampled fish populations and made age specific population estimates for walleye and northern pike on two river sections. Fish were aged from scales and population estimates were made. I also made detailed habitat measurements. I measured channel width and depth at 100 foot intervals in sections where fish population estimates were made. Invertebrate samples were collected and identified. I sampled walleye eggs and drifting larval fish to determine reproductive success. Walleye spawners were sampled to determine spawning locations. Walleye and northern pike were tagged to determine movements. Dissolved oxygen was measured under the ice in winter. Data was used to determine relationships between northern pike and walleye reproductive success, adult survival and stream flow.

Q. What methods were used to determine the amount of flow requested for the East Fork Poplar River?

A. The methods of determining flow requests were based on detailed biological data from several years of fish population sampling and estimating fish numbers by year class. Year class strengths of age 0+ walleye and northern pike were compared to April-May flows using linear regression to determine minimum flows required for strong year class production.

The Dominant Discharge/Channel Morphology Concept was used to determine flows required to maintain pool depth. For low flow months, the Base Flow approach was used.

Q. Please describe the fisheries values the Department is trying to protect on the East Fork Poplar River.

A. Although fish population densities fluctuate greatly from year to year, the number of age 1+ and older walleye were as high as 170 per mile and northern pike age 1+ and older were as high as 229 per mile. The populations are produced by natural spawning. Approximately 15 additional fish species are present, most of which are important as forage for walleye and northern pike.

Even at streamflows of only one or two cfs, pools are quite deep, often with maximum depths of approximately five feet. These pools are used by walleye and northern pike in all seasons, providing security during spring, summer and fall and preventing freezing of the river to the bottom in most winters. Maintenance of pool depth is essential for long term survival of existing fish populations.

Q. Why is an instream reservation needed on the East Fork Poplar River?

A. The requested flows are necessary to maintain the existing northern pike and walleye populations and the forage fish species that support them. Population estimates of age 0+ walleye and regression analysis indicated the requested April-May streamflows are the minimums required to produce strong year classes of young walleye. The dominant discharge would scour pools and maintain pool depth required for walleye and northern pike winter survival. This elevated flow will also allow movement of walleye and northern pike from downstream areas to replenish walleye and northern pike following periodic winter kill. The low base flows will maintain water in pools and help prevent low dissolved oxygen and resultant fish die-offs.

Q. What flow is being requested for the East Fork Poplar River?

A. The Department is requesting 3.0 cfs from December 1 through March 31, 15 cfs in April, 10 cfs in May and 4.0 cfs from June 1 through November 30, and 13 days of additional water stepping up to and down from a peak flow of 540 cfs (dominant discharge). These 13 days of flow are to occur within the period February 1 to April 30.

Q. Is there sufficient water in the East Fork Poplar River to meet the MDFW&P flow request?

A. USGS gauging records indicate the requested flows are not fully present in every month of every year. However, the requested flows are necessary to prevent future dewatering of the river at times when the requested flows are present. This is especially true for the dominant discharge flows.

Q. Please summarize the work you did on the Middle Fork Poplar River that relates to the reservation requests.

A. Work consisted of fish population estimates over a five year period, fish aging, habitat measurements, measuring walleye spawning success and determining relationship of walleye spawning success to stream flows. This work was the same as was done on the East Fork Poplar River.

Q. What methods were used to determine the amount of flow requested for the Middle Fork Poplar River?

A. Methods used were the same as those used for the East Fork Poplar River. These consisted of relationships between walleye spawning success and streamflow, the Dominant

Discharge/Channel Morphology Concept and the Base Flow Approach.

Q. Please describe the fisheries values the Department is trying to protect on the Middle Fork Poplar River.

A. Fisheries values are very similar to those of the East Fork Poplar River. They consist of walleye and northern pike populations and associated forage fish species. Adult walleye numbered as high as 90 per mile and adult northern pike up to 199 per mile. Deep pools are especially important to game fish survival.

Q. Why is an instream reservation needed on the Middle Fork Poplar River?

A. The requested flow is necessary to maintain the existing northern pike and walleye populations and the forage fish species that support them. See the response to the same question for the East Fork Poplar River for details.

Q. What flows are being requested for the Middle Fork Poplar River?

A. The Department is requesting 1.0 cfs from December 1 through March 31, 30 cfs for April, 20 cfs for May and 2.0 cfs for June 1 through November 30. The request also includes additional water over a 14 day period stepping up to and down from a peak flow of 1,000 cfs (dominant discharge). These 14 days of flow are to occur within the period April 1 to May 31.

Q. Is there sufficient water in the Middle Fork Poplar River to meet the MDFW&P flow request?

A. USGS gauging records indicate the requested flows are not fully present in every month of every year. However, the requested flows are necessary to prevent future dewatering of the river when the requested flows are present. This is especially true for the dominant discharge flows.

Q. Please summarize the work you did on the mainstem Poplar River that relates to the reservation requests.

A. Work was similar to that done on the East Fork Poplar and Middle Fork Poplar rivers. Population estimates were made for young-of-the-year and adult walleye and northern pike. I made detailed habitat measurements, especially of channel depth at low flow, tagged walleye and northern pike to determine movements and located walleye spawning areas. Data was used to determine the relationship between walleye spawning success and April-May streamflow.

Q. What methods were used to determine the amount of flow requested for the Poplar River?

A. Methods used were similar to those used on the East Fork and Middle Fork of the Poplar River. These were the relationship between walleye spawning success and streamflow, the Dominant Discharge/Channel Morphology Concept and the Base Flow Approach.

Q. Please describe the fisheries values the Department is trying to protect on the Poplar River.

A. Fisheries values are similar to those of the East Fork and Middle Fork Poplar River. These values consist of northern pike and walleye populations and associated forage species and long deep pools. Walleye and northern pike reach a somewhat larger size in the Poplar River and young-of-the-year production is more dependable. Long, deep pools are necessary to maintain these populations.

Q. Why is an instream reservation needed on the Poplar River?

A. The requested flow is necessary to maintain the existing northern pike and walleye populations, forage fish species and pool depth. See the response to the same question for the East Fork Poplar River for detail.

Q. What flows are being requested for the Poplar River?

A. The Department is requesting 8.0 cfs from December 1 through March 31, 70 cfs in April, 50 cfs in May, 11.0 cfs from June 1 through November 30 and additional water over a 14 day period stepping up to and down from 1,930 cfs (dominant discharge). These 14 days of flow are to occur within the period April 1 to May 31.

Q. Is there sufficient water in the Poplar River to meet the MDFW&P flow request?

A. USGS gauging records indicate the requested flows are not fully present in every month of every year. These flows are, however, necessary to prevent future dewatering of the river when the requested flows are present.

Q. Please summarize the work you did on the West Fork Poplar River that relates to the reservation request.

A. Fish populations were sampled with electrofishing gear and seining to determine species present and to estimate the number per mile of walleye adults and young-of-the-year. I made habitat measurements, including detailed records of pool depth at low flow. Walleye eggs and larvae were sampled to determine spawning success and locations.

Q. What methods were used to determine the amount of flow requested for the West Fork Poplar River?

A. Walleye population data was not sufficient to specifically define the spring flows required to produce year classes of age 0+ walleye. The West Fork Poplar River is very similar to the Middle Fork Poplar River, so similar instream flows were requested for the walleye spawning-incubation period. Flow requests for other months were based on the Dominant Discharge/Channel Morphology Concept and the Base Flow Approach.

Q. Please describe the fisheries values the Department is trying to protect on the West Fork Poplar River.

A. Fisheries values are similar to those of the other forks of the Poplar River. Walleye are the most abundant of the game fish, but northern pike, sauger and smallmouth bass are also present. Approximately 15 additional fish species are present, many of which are forage for the game fish. Population estimates indicated similar numbers of walleye per mile as in the East and Middle forks of the Poplar River. Young-of-the-year walleye, northern pike and smallmouth bass were collected, indicating these species reproduce successfully in the West Fork.

Q. Why is an instream reservation needed on the West Fork Poplar River?

A. The requested flow is necessary to maintain the existing northern pike, walleye, sauger, smallmouth bass and forage fish populations. April-May flows will produce a year class of young fish in most years. The Dominant Discharge will maintain pool depth critical to overwinter survival of fish. Base flows in the remainder of the year will maintain water exchange to freshen pools where fish live and cover riffles for insect production.

Q. What flows are being requested for the West Fork Poplar River?

A. The Department is requesting 3.0 cfs from December 1 through March 30, 30 cfs in April, 20 cfs in May, and 4.0 cfs from June 1 through November 30. Additional water is requested over a 14 day period, stepping up to and down from 850 cfs. These 14 days of flow are to occur within the period April 1 through May 31.

Q. Is there sufficient water in the West Fork Poplar River to meet the MDFW&P flow request?

A. Limited USGS records suggest the requested flows are not fully present in every month of every year. However, the requested flows are necessary to prevent further dewatering of the river when the requested flows are present.

Q. Please summarize the work done on the Little Missouri River that relates to the reservation requests.

A. Using various sampling gear, fish populations were first sampled in the late 1970s to determine species composition. More intensive work was done in 1990 by two MSU graduate students to determine the status of fish populations using electrofishing and seining. Sauger spawners were collected. Channel catfish also spawned in this stream as evidenced by collection of young-of-the-year in late summer. Some work to document habitat and fish usage of various habitat types was also done.

Q. What methods were used to determine the amount of flow requested for the Little Missouri River?

A. Along with knowledge of the basic needs of the fish populations present, the Dominant Discharge/Channel Morphology Concept and the Base Flow Approach were used to derive flow requests.

Q. Please describe the fisheries values the Department is trying to protect on the Little Missouri River.

A. This stream has fishable populations of sauger and channel catfish and contains a relatively large number of other fish species, many of which are likely important forage species. The deep pools, which exist even at low flows, are an important habitat feature used by many of the fish species year-round and are the only refuge for fish in winter, when shallow riffles and runs freeze almost to the river bottom.

Q. Why is an instream reservation needed on the Little Missouri River?

A. The requested flows are necessary to maintain the existing sauger and channel catfish populations and the related forage fish species. The requested base flows will keep pool, run and riffle habitat available to all fish species. The dominant discharge will scour pools and maintain pool depth that is critical for winter survival and required by adult channel catfish in all seasons.

Q. What flow is being requested for the Little Missouri River?

A. The Department is requesting 5.0 cfs from December 1 through March 31, 8.0 cfs from April 1 through November 30 and 21 days

of additional water, stepping up to and down from a peak flow of 2,540 cfs (dominant discharge). These 21 days of flow are to occur within the period March 1 to April 30.

Q. Is there sufficient water in the Little Missouri River to meet the MDFW&P request?

A. USGS gauging records indicate the requested flows are not fully present in every month of every year, but are available much of the time. The requested flows are necessary to prevent future dewatering of the river when the requested flows are present. This is especially true for the dominant discharge flows.

Q. Please summarize the work done on Box Elder Creek that relates to the reservation request.

A. With various sampling gear, fish populations were first sampled in the late 1970's to determine species composition. More intensive work was done in 1990 by two MSU fisheries graduate students with electrofishing gear, seines and baited trap nets. Sauger spawners were collected, indicating sauger spawning in the stream. Adult and young-of-the-year channel catfish were collected. It was concluded that this species also spawns successfully in Box Elder Creek. Only two adult northern pike were collected, and no young-of-the-year. Some work to document habitat and fish usage of various habitat types was also done.

Q. What methods were used to determine the amount of flow requested for Box Elder Creek?

A. Along with knowledge of the basic needs of the fish populations present, the Dominant Discharge/Channel Morphology Concept and the Base Flow Approach were used to derive flow requests.

Q. Please describe the fisheries values the Department is trying to protect on Box Elder Creek.

A. Box Elder Creek has migratory populations of sauger. Channel catfish and sauger reproduce in this stream. A fishery of local importance exists for both species. A large number of non-game fish species are also present. Deep pools, which exist at even near zero flows are an important habitat feature utilized especially by channel catfish.

Q. Why is an instream reservation needed on Box Elder Creek.

A. The requested flows are necessary to maintain the existing sauger and channel catfish populations and related forage fish species. The ability of these two species to migrate into Box

Elder Creek from the Little Missouri River will be preserved by the requested flows. The dominant discharge will scour pools and maintain pool depth that is important for channel catfish, sauger and other fish species.

Q. What flow is being requested for Box Elder Creek?

A. The Department is requesting 4.0 cfs from December 1 through March 31, 7.0 cfs from April 1 through November 30 and 17 days of additional water, stepping up to and down from a peak flow of 1,910 cfs (dominant discharge). These 17 days of flow are to occur within the period March 1 to April 30.

Q. Is there sufficient water in Box Elder Creek to meet the MDFW&P request?

A. USGS gauging records indicate the requested flows are not fully present in every month of every year, but are available much of the time. The requested flows are necessary to prevent future dewatering of the river when the requested flows are present. This is especially true for the dominant discharge flows.

Phillip A. Stewart, being first duly sworn, states that the foregoing testimony is true.

DATED this 25th day of June 1994.

Phillip A. Stewart

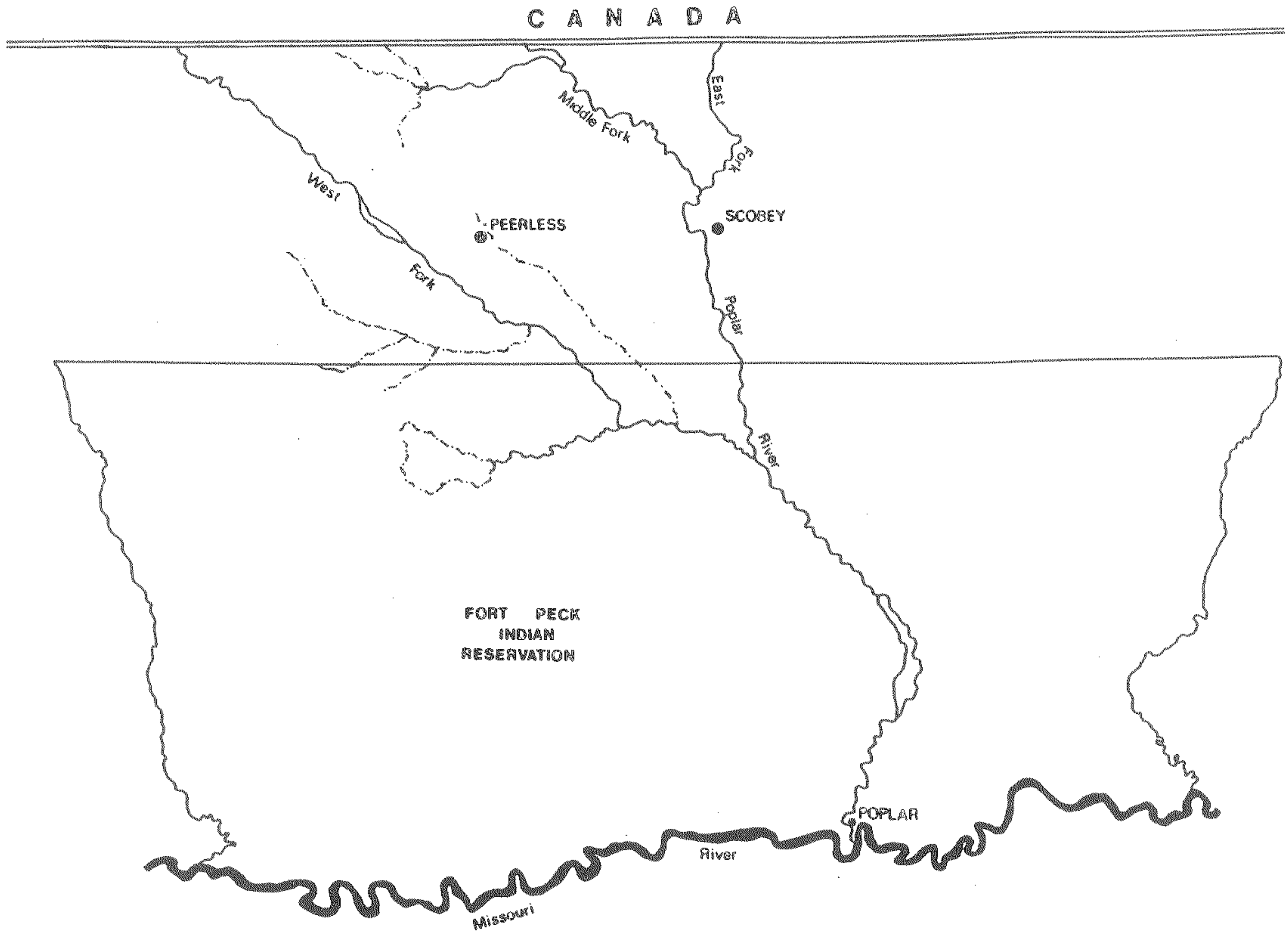
Phillip A. Stewart

Subscribed and sworn to me this 27th day of June 1994.

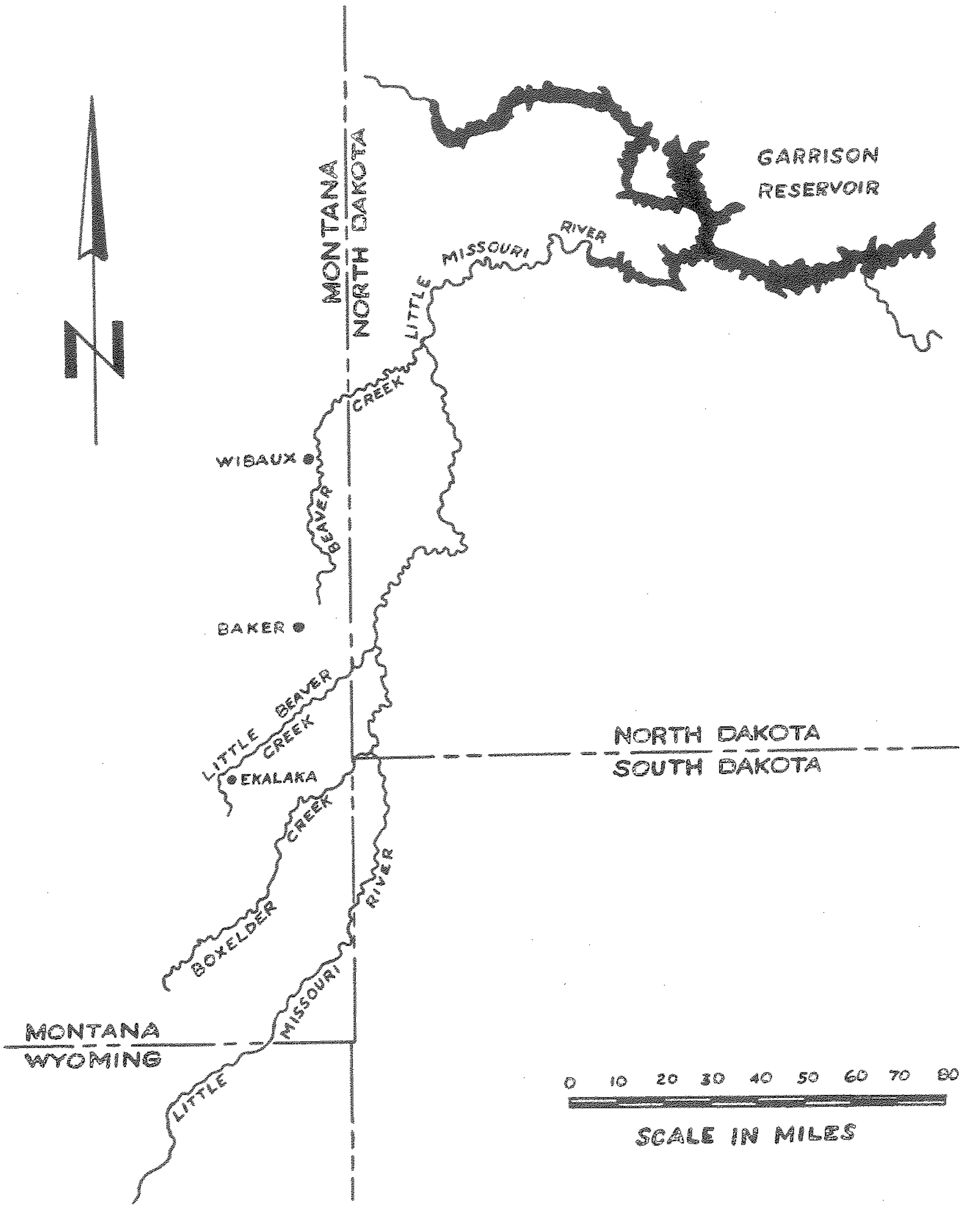
Faye Buffalo

Notary Public for the State of Montana
Residing at Miles City, Montana
My commission expires: August 1994

Appendix A. Map locating the Redwater River sub-basin.



Appendix A. Map locating the Poplar River sub-basin.



APPENDIX A Map of the Little Missouri River basin.

APPENDIX B

Summary of stream resource values, instream flow requests and methods used.

Stream Name	Reach	Flow Request	Methods Used	Northern pike fishery and forage fish species
Redwater River	#1 - Town of Circle to East Redwater Creek	2.0 cfs 12/1-3/31; 3.0 4/1-11/31 plus dominant discharge of 780 cfs	Base Flow and Dominant Discharge	Northern pike and walleye fishery and forage fish species
Redwater River	#2 - East Redwater Creek to mouth	2.0 cfs 12/1-3/31; 4.0 cfs 4/1-11/31; plus dominant discharge of 900 cfs	Base Flow and Dominant Discharge	Walleye and northern pike fishery and forage fish species
East Fork Poplar River	Canadian border to Middle Fork Confluence	3.0 cfs 12/1-3/31; 15 cfs in April; 10 cfs in May; 4.0 cfs 6/1-11/31 plus dominant discharge of 540 cfs	Fish spawning and survival requirements; Base Flow; Dominant Discharge	Walleye and northern pike fishery and forage fish species
Middle Fork Poplar River	Canadian border to confluence with East Fork Poplar River	1.0 cfs 12/1-3/31; 30 cfs in April; 20 cfs in May; 2.0 cfs 6/1-11/31 plus dominant discharge of 1,000 cfs	Fish spawning and survival requirements; Base Flow; Dominant Discharge	Walleye and northern pike and smallmouth bass fishery; forage species

Poplar River	Junction of Middle and East Forks to Ft. Peck Indian Reservation boundary	8.0 cfs 12/1-3/31; 70 cfs in April; 50 cfs in May; 11.0 cfs 6/1-11/31 plus dominant discharge of 1,930 cfs	Fish spawning and survival requirements; Base Flow; Dominant Discharge	Channel catfish and sauger fishery; forage fish species
West Fork Poplar River	County Bridge 6 mi. south of Peerless to Ft. Peck Indian Reservation boundary	3.0 cfs 12/1-3/31; 30 cfs in April; 20 cfs in May; 4.0 cfs 6/1-11/30 plus dominant discharge of 850 cfs	Fish spawning and survival requirements; Base Flow; Dominant Discharge	Channel catfish and sauger fishing; forage fish species
Little Missouri River	Montana-Wyoming border to Montana-South Dakota border	5.0 cfs 12/1-3/31; 8.0 cfs 4/1-11-31; plus dominant discharge of 2,540 cfs	Base Flow and Dominant Discharge; Fish Migration and spawning	
Box Elder Creek	One mile west of Belltower to the Montana-South Dakota border	4.0 cfs 12/1-3/31; 7.0 cfs 4/1-11/31; plus dominant discharge of 1910 cfs	Base Flow; Dominant Discharge; Fish migration and spawning	

BIOGRAPHY

PHILLIP A. STEWART

June 1994

Montana Dept. of Fish, Wildlife and Parks
P.O. Box 1630
Miles City, MT 59301

Birthdate: February 1, 1944
Office Phone: 232-4365
Home Phone: 232-7207

EDUCATION

Grade school and high school - Tucson, Arizona public school system - high school graduation 1961.

B.S. - Fisheries Management, with distinction, 1965, University of Arizona at Tucson.

M.S. - Fisheries Management, 1967, University of Arizona at Tucson. Thesis entitled "Factors Influencing Trout Production in Four Eastern Arizona Reservoirs." Supported by Research Assistantship from the Arizona Cooperative Fishery Research Unit. Thesis study concerned relationships between nutrient supply to reservoirs, phytoplankton productivity, zooplankton standing crops and fish production.

Ph.D. - Fisheries Science, 1970, Colorado State University at Fort Collins. Thesis entitled "Physical Factors Influencing Trout Density in a Small Stream." Thesis study identified physical variables correlated with trout density in stream sections and physical aspects of fright cover used by brook and rainbow trout.

PROFESSIONAL MEMBERSHIPS

Member of the American Fisheries Society and Montana Chapter of the American Fisheries Society.

PROFESSIONAL EXPERIENCE

June 1983 to present. Regional Fisheries Manager for Montana Department of Fish, Wildlife and Parks based at Miles City. Supervise fisheries management program in southeastern Montana (Region 7). Program elements include survey, inventory and monitoring of fish populations and angler use in area waters; development and evaluation of fish planting program; administration of two state stream protection laws; development and evaluation of fishing regulations; supervision of special studies and research projects; acquiring and development of fishing access sites; preparation of management plans for area waters or fish species; preparation of environmental assessments for management actions;

preparation or supervision of preparation of project reports; Region 7 covers 12 southeastern counties and contains approximately 120 publicly managed fishing reservoirs and three important warm water fishing rivers. These waters supply approximately 100,000 days of angling annually. Supervise a staff of approximately 3-4 FTE.

December 1976 to June 1983. Fisheries Biologist III with Montana Department of Fish, Wildlife and Parks based at Wolf Point. Through 1978 work consisted mostly of basic fisheries investigations in the Poplar River drainage. Some similar work was also done on Big Muddy Creek and the Redwater River, all Missouri River tributaries. I determined species present, made population estimates for game fish species, made quantitative measurements of fish habitat, collected invertebrate samples, located walleye spawning sites, sampled walleye eggs and drifting larvae to determine spawning success. Data was used to determine instream flow needs of fish populations. I did data reduction and synthesis and authored project reports.

From 1979 to 1983 I did fish population investigations on the Missouri River from Fort Peck Dam to the North Dakota border. Some work also continued in the Poplar River drainage during this period. Purpose of the work on the Missouri River was to gain a basic understanding of the nature of fish population and their needs. I sampled fish populations with electrofishing gear, seines and traps, determined spawning success by locating fish eggs and sampling drifting larvae, sampled benthic invertebrates, and tagged fish to determine movements and location of residence. The data was synthesized and reports were written.

September 1971 to December 1976. Fisheries Biologist III with Montana Department of Fish and Game, based at Columbus. I investigated the status of fish populations in streams of the Rosebud, Stillwater and Boulder River drainages expected to be affected by hardrock mining in the Beartooth-Absaroka Mountain Range. I made fish population estimates, measured standing crops of benthic invertebrates, investigated historical streamflows, measured water quality and developed recommended instream flows for many of the streams in the three drainages. I did considerable work reducing data and wrote progress reports.

ORAL PRESENTATIONS

Great Plains Fishery Workers Association. "Physical factors influencing trout density in a small stream." Presented at annual meeting, February 1969, Billings, MT.

Montana Chapter of the American Fisheries Society. "Management of small reservoirs in southeastern Montana." Presented at annual meeting, February 1988, Kalispell, MT.

American Fisheries Society. "The paddlefish fishery at Intake, Montana." Presented at annual meeting, September 1992, Rapid City, SD.

Also, numerous presentations to clubs, public meetings and environmental groups concerning findings of research and development of management programs.

PUBLICATIONS

Gardner, W.M. and P.A. Stewart 1987. The fishery of the Lower Missouri River, Montana. Federal Aid to Fish and Wildlife Restoration Project FW-2-R, Job I-b. Montana Department of Fish, Wildlife and Parks. 224 pp.

Also authored articles for Montana Outdoors and numerous project reports.

PRE-FILED DIRECT TESTIMONY
OF ROBERT G. WHITE
ON BEHALF OF THE MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS

Q. Please state your name and business address.

A. Robert G. White, Montana Cooperative Fishery Research Unit, Biology Department, Montana State University, Bozeman, MT 59717-0346.

Q. Who is your employer and what is your position?

A. I am a fisheries research biologist employed by the U. S. National Biological Survey as Leader of the Montana Cooperative Fishery Research Unit located on the campus of Montana State University. I am an Adjunct Professor of Fish and Wildlife Management and a member of the Graduate Faculty of the College of Letters and Science.

Q. What is your educational background and experience.

A. I hold B.S. and M.S. Degrees in science education from Northeast Missouri State University and a Ph.D. in Wildlife Resources (Fisheries) from Utah State University (1974). I was Assistant Leader of the Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow from 1974-1980. I have been in my present position since 1980. I am certified as a Fisheries Scientist by the American Fisheries Society.

Q. What is the purpose of your testimony?

A. My testimony is to support the Department's instream flow reservation requests and describe the fishery resources in Beaver Creek and Little Beaver Creek, tributaries of the Little Missouri River in southeast Montana.

Q. What experience do you have related to instream flow?

A. As a research biologist, I have been involved in a number of studies dealing with flow needs of aquatic organisms (see attached list of publications). My first contract at the University of Idaho was to develop a methodology for use in establishing "stream resource maintenance flow" recommendations for large rivers. Stream resource maintenance flows were defined as "a range of flows within which fish, wildlife, other aquatic organisms, and related recreational activities (fishing and hunting) are maintained or protected". The approach addressed environmental requirements of fish species for passage, spawning and rearing. It was based on the concept of predicting loss of habitat at reduced discharge and relating the predicted loss to physical and biological requirements of key fish species. The Montana Department of Fish and Game and the U. S. Forest Service were concurrently working on a similar predictive approach. The rearing flow approach was patterned after recommendations of USGS and the Washington Department of Fisheries and was based upon the assumption that rearing is proportional to food production, which is, in, turn assumed proportional to wetted perimeter.

Since 1975, I have directed a number of studies on habitat requirements of fish and how these are influenced by flow. Two Montana studies have been directly related to a methodology for recommending instream flows. One study experimentally examined response of rainbow trout to reductions in discharge and related this to predictions of the wetted perimeter methodology. A recently completed study examined the validity of the food limitation assumption of the methodology.

Q. Why is there a need for minimum instream flows?

A. Stream flow has an overriding influence on fish populations. In general, the more water available, the more fish that can be produced. Changes that occur as a result of altering the quantity of natural water flow are complex but usually result in a reduction in the fish carrying capacity of the stream for fish. Each species of fish has specific flow-related habitat requirements. As flows decrease below natural levels, quantity of suitable rearing habitat and food production habitat is decreased.

Q. Has any new data been collected since the application was filed?

A. Yes. The following two M.S. theses have been completed by graduate students at the Cooperative Fishery Research Unit.

Barfoot, C. A. 1993. Longitudinal distribution of fishes and habitat in Little Beaver Creek, Montana. M. S. Thesis, Montana State University, Bozeman. 66 pp.

Guzevich, J. W. 1993. The relationships of physical habitat to the distribution of northern pike and walleye in two Montana prairie streams. M. S. Thesis, Montana State University, Bozeman. 94 pp.

Q. What was your involvement in the research conducted on Beaver Creek and Little Beaver Creek?

A. I supervised and helped design the research of Mr. Craig Barfoot and Mr. John Guzevich, M.S. Candidates in Fish and Wildlife Management, MSU. The study was funded by the Department of Fish, Wildife and Parks to collect physical and biological information for the reservation process. Graduate students spent two field seasons (1990-1992) evaluating the fish communities and habitat of these streams. I initially spent several days with them in the field to discuss sampling design and fish collection techniques. During the remainder of the study I accompanied them to the field on approximately 6 days. About once a week I had phone contact with the students to discuss progress and work out problems. I also supervised the writing of their theses.

Q. Where were the study areas located on Beaver Creek and Little Beaver Creek?

A. Study streams and sample sites are shown in Figures 1, 2, and 3 in Appendix A of my testimony. Figures 1 and 2 are for Beaver Creek and Figure 3 is for Little Beaver Creek.

Q. Please summarize the game fish distribution in Beaver Creek and Little Beaver Creek.

A. Small reproducing populations of northern pike were found in both streams, while walleye were confined to Beaver Creek. Northern pike up to nearly 9 pounds were found in the middle portion of each stream. Much larger pike have reportedly been caught by anglers. Pike distribution coincided with the presence of large, deep permanent pools which were most numerous in the middle sections. Important characteristics of pools associated with northern pike presence included submerged aquatic plants, relatively clear water and large pool volume. In Beaver Creek, walleye up to about 11 pounds were associated with large, wide pools with moderate turbidity and no instream cover.

Q. Is the associated fish community important to northern pike and walleye?

A. Yes. Each of these species depends on other fish as food during much of their life cycle. Twenty-three other fish species were collected in Beaver Creek and Little Beaver Creek. A detailed examination of longitudinal distribution of all fish species in Little Beaver Creek (22) showed that the number of species generally increased going downstream. The most abundant and species-rich group was the minnow family (Cyprinidae) which are usually small in size and are important forage for walleye and northern pike. Several habitat variables were significantly correlated with the relative abundance of fish species in segments of Little

Beaver Creek. Fishes characteristic of the mid-stream and upstream segments were correlated with habitat features associated with pools. Species most abundant in the downstream segment were characteristic of less stable habitats (wide, shallow channel with larger substrate).

Q. Why are instream flows needed on Beaver Creek and Little Beaver Creek?

A. Beaver Creek and Little Beaver Creek are characterized by long deep pools and short riffles. Both streams are often intermittent during much of the year, resulting in a relatively harsh environment. Survival in the face of high summer temperatures, natural low flows and extreme winter conditions depends on adequate water storage in pools during summer and winter. Spring flushing discharges are important in maintaining present stream morphology. These flows scour pools, maintaining sufficient depth to avoid excessively high or low temperatures and provide habitat suitable for large northern pike and walleye and the associated fish community.

Q. Is the nongame fish community important in its own right?

A. Yes. Although the community is characteristic of prairie streams, some species such as the creek chub and sand shinner have somewhat limited distributions in Montana. Although we sampled no sturgeon chub, these rare fish have also been reported to occur here. It is important that these and other nongame species be maintained.

Q. How would you describe the importance of the fishery in Beaver Creek and Little Beaver Creek?

A. The fishery appears to be important locally but no angler use data were collected. Although pressure is light and game fish densities low, anglers incidentally encountered while we were sampling the streams indicated a genuine interest and enthusiasm for the recreational opportunity provided by northern pike and walleye.

I, Robert G. White, being first duly sworn, states that the foregoing testimony is true.

DATED this 27 day of June 1994.

Robert G. White

Robert G. White

Subscribed and sworn to before me this 27 day of June, 1994.

(NOTARY SEAL)

Peggy A. Smith
Notary Public for the State of Montana
Residing at Bozeman
My Commission Expires April 13, 1996

APPENDIX A

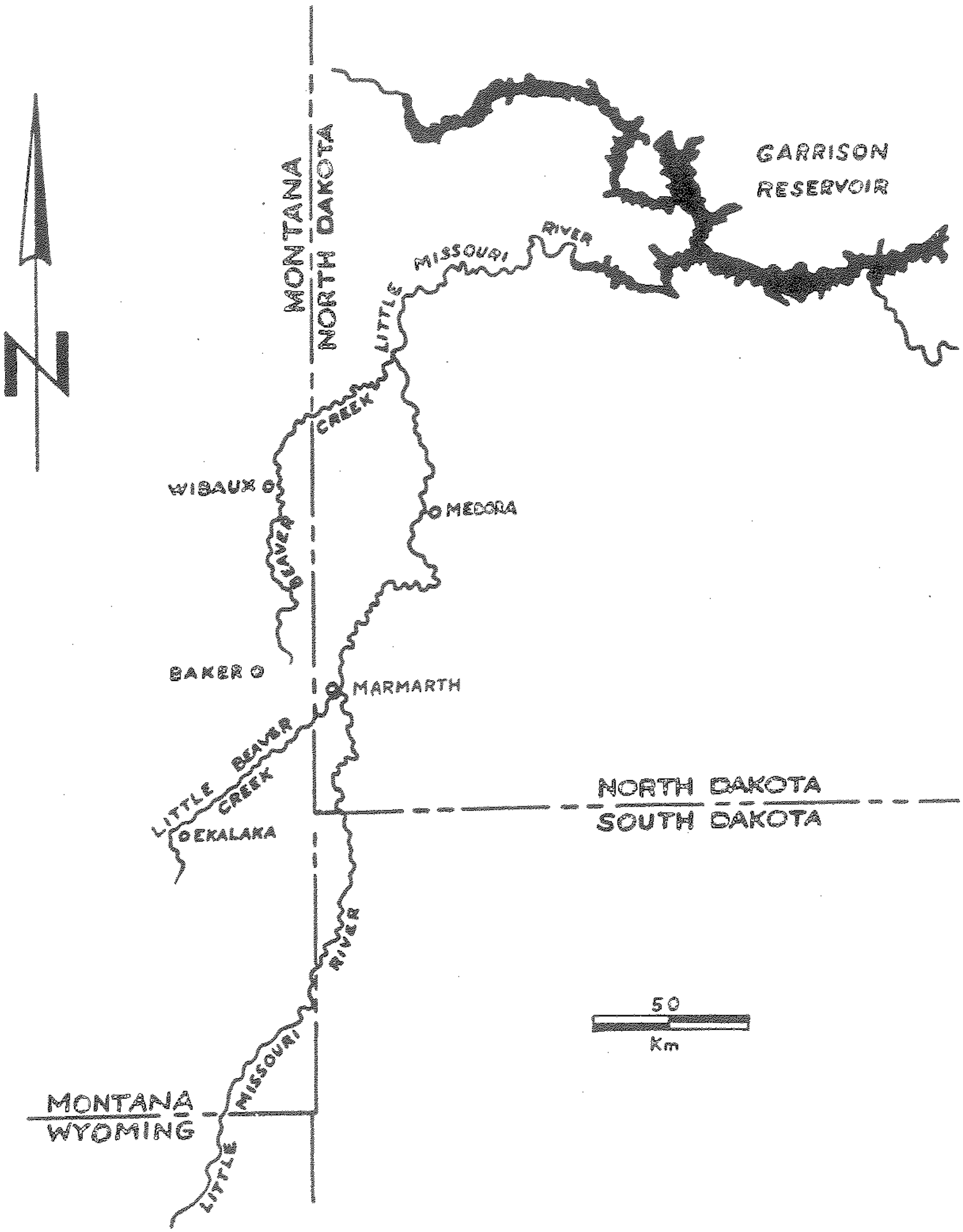


Figure 1. Location of Beaver Creek and Little Beaver Creek study areas within the Little Missouri River drainage.

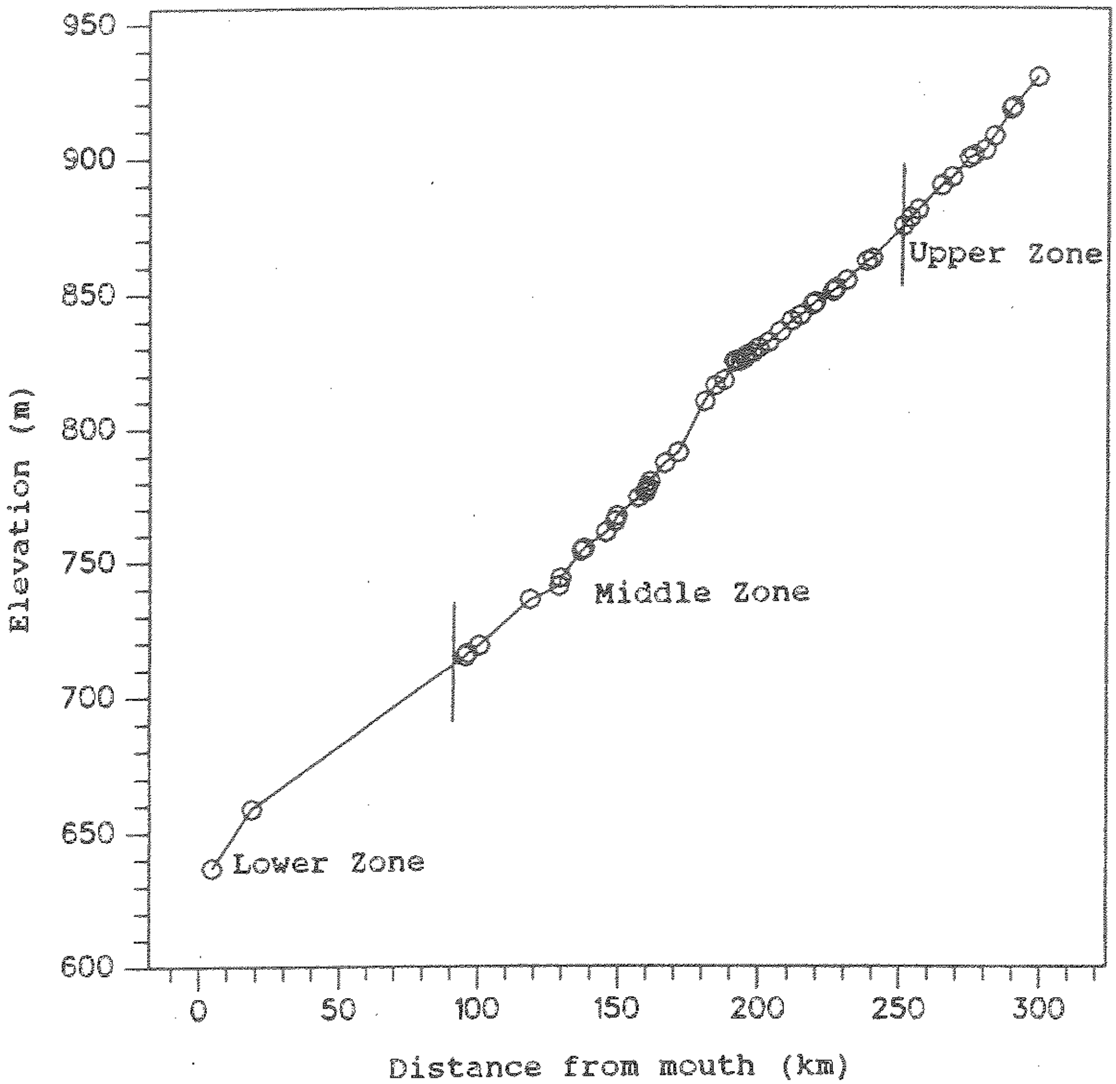


Figure 2. Location of sampling sites and delineation of the Upper, Middle and Lower Zones for Beaver Creek.

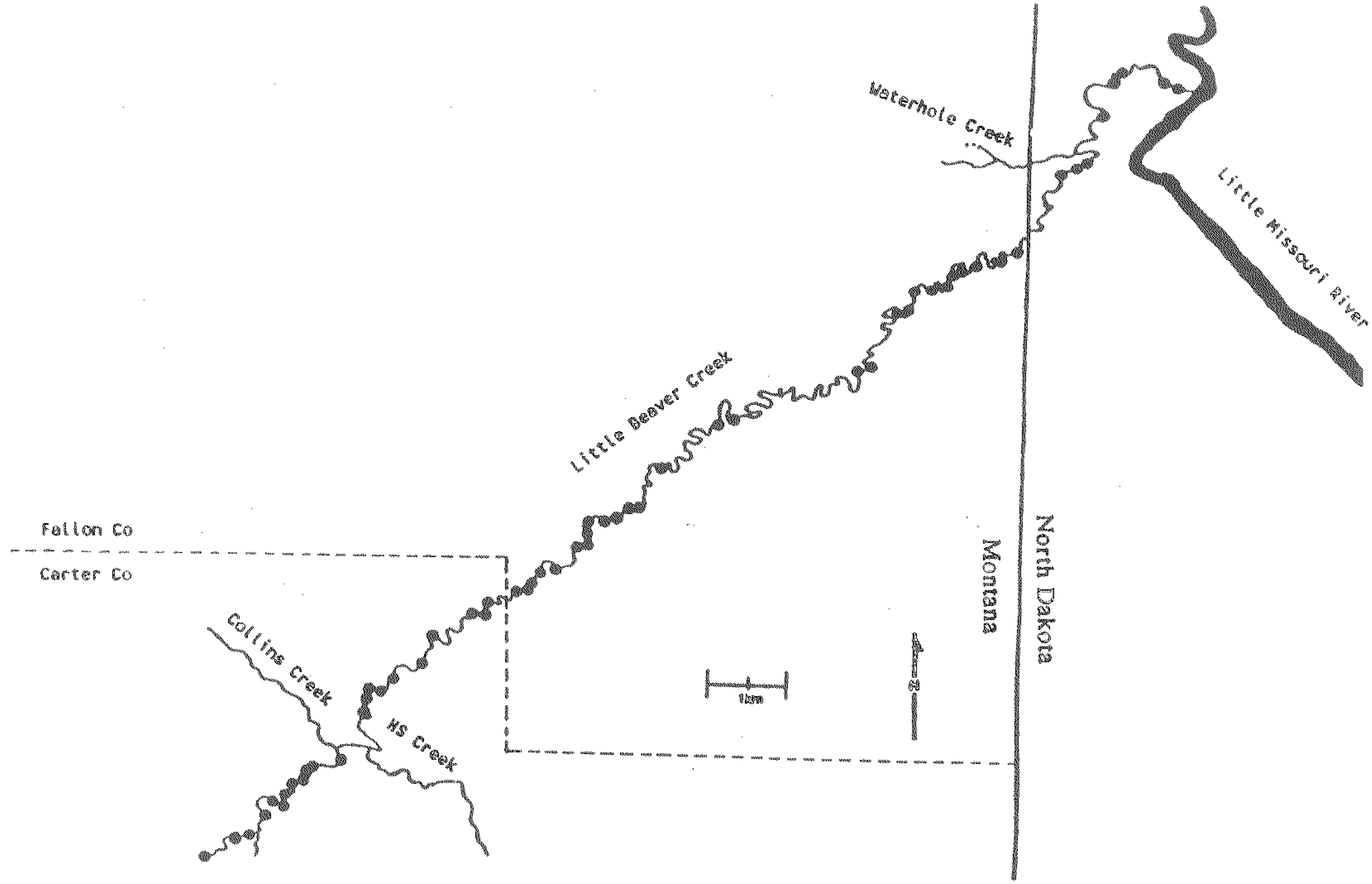


Figure 3. Little Beaver Creek study area in southeastern Montana. Circles indicate sample sites.

CURRICULUM VITAE

Name: *Robert G. White*

Title: *Leader, Montana Cooperative Fishery Research Unit*
Adjunct Professor, Fish and Wildlife Management,
Montana State University

Date and Place of Birth:

July 21, 1940, Gilman City, Missouri

Education:

B.S. *Northeast Missouri Univ. Kirksville, Mo., 1962*
M.S. " " " " ", *1963*
Stephens College, Columbia, Mo., 1967
Ph.D. *Utah State Univ. Logan, Utah, 1974*

Major Research Interest:

Aquatic Ecology - Altered aquatic systems - Fishery Management

Scientific and Professional Organizations:

American Fisheries Society
Montana Chapter American Fisheries Society
Fisheries Educators Section AFS
Fisheries Management Section AFS
Bioengineering Section AFS
Asian Fisheries Society
Society of Sigma Xi
Phi Delta Kappa

Honors, Awards and Professional Society Involvement:

1962-63	Teaching Assistantship, Northeast Missouri University
1968	Outstanding Teacher Award, Braymer C-4 School
1968-71	NDEA pre-doctoral fellowship
1971	Citation of the American Fisheries Society for the best technical exhibit by a student member at the 101st meeting
1972	Sigma Xi research grant
1975	President elect and Program chairman, Idaho Chapter AFS
1976-77	President, Idaho Chapter AFS
1976	Student Affairs Committee, AFS
1977	Membership, Student Affairs and Best Student Paper, National AFS
1979	Western Division AFS - elected representative on National AFS nominating committee
1979	Promoted to Associate Professor Fishery Resources, Univ. of Idaho
1979	Editor Idaho Chapter AFS Newsletter
1980-85	Western Division AFS Streamflow Committee
1980-81	President-Elect and Program Chairman Western Division
1981-85	Program Committee National AFS
1981-84	Time and Place Committee National AFS
1981-82	President Western Division AFS
1981-82	Parent Society Executive Committee
1982-85	Chairman Steering Committee for small Hydro-power and Fisheries Symposium Bio-Engineering Section - Western Division AFS
1982-84	Chairman Nominating and Self Evaluation Committees, Western Division
1983-84	Nominating Committee Chairman, Montana Chapter AFS
1984-85	Program Chairman, National AFS meeting
1985	Elected Second Vice President, National AFS
1985-86	Co-chairman, National AFS Membership Committee
1985	Who's Who in Frontiers of Science and Technology
1985	Who's Who in the West
1986	Elected First Vice President National AFS
1986	Chairman Membership Committee, National AFS
1986	Promoted to Professor Fish and Wildlife Mgmt. (Adjunct)
1987	President-elect American Fisheries Society
1988	President American Fisheries Society
1989	Outstanding Contribution to the Fisheries Profession, Montana Chapter, American Fisheries Society
1992	Special Achievement Award, U. S. Fish & Wildlife Service

Professional Experience:

1962-63	*Teaching Assistant, Northeast Missouri University, assisted in teaching zoology, comparative anatomy and botany*
1963-68	*High school science teacher; taught biology, chemistry and general science*
1968	*Assistant Director Bear Lake Biological Lab. Utah State University*
1968-71	*NDEA research fellow in fisheries; assisted teaching fishery techniques and ichthyology*
1971-73	*Senior research biologist, Bear Lake Biological Laboratory, Utah State University*
1974-80	*Assistant Leader, Idaho Cooperative Fishery Research Unit; Assistant Professor, Fishery Resources*
1980	*Leader, Montana Cooperative Fishery Research Unit, Adjunct Professor, Fish and Wildlife Management*

Publications:

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Olson, F. W., R. G. White, and R. H. Hamre. 1985. Technical Editors, Symposium on Small Hydropower and Fisheries. American Fisheries Society. 497 p. (Conceived symposium).

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White, R. G. and Tim Cochnauer. 1975. Stream resource maintenance flow studies. Coop. Study Report: Idaho Dept. Fish and Game, and Idaho Cooperative Fishery Resource Unit. Published by IFG. 136 p.

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PREFILED DIRECT TESTIMONY
OF KENT GILGE
ON BEHALF OF MONTANA DEPARTMENT OF FISH,
WILDLIFE, AND PARKS (DFWP)

Q. Please state your name and business address.

A. My name is Kent Gilge. I work out of a DFWP field office at 87 Third St., Chinook, Montana 59523.

Q. What is your employment history with the Department of Fish, Wildlife and Parks?

A. I am currently a regional biologist in DFWP Administrative Region 6. At this time, I have responsibilities for management of all public fishing waters within the western half of DFWP administrative Region 6, with headquarters in Glasgow. I have worked in this capacity since 1979. During this time period, I conducted a considerable amount of larval fish sampling throughout the Milk River Drainage and its tributaries. I also developed a comprehensive species distribution list for the Milk River and tributaries. Survey and inventory of adult fish populations in the middle reach of the Milk River are ongoing. Prior to 1979, I assisted with fisheries projects on the Poplar River and several blue ribbon trout streams in southwestern Montana. My employment history, education, and other vita are attached.

Q. What is the purpose of your testimony?

A. The purpose of my testimony is to provide supporting documentation for the Department of Fish, Wildlife and Parks' water reservation requests for nine tributary streams in the Milk River basin as they relate to existing fish populations. I was not responsible for determining the amount of water in the requests. The amounts requested will be discussed in Fred Nelson's testimony.

Q. Specifically, which streams will you discuss?

A. Beaver Creek (Hill Co.)
Little Box Elder Creek
Clear Creek
Battle Creek
Peoples Creek
Beaver Creek (Reach #1) Phillips Co.
Beaver Creek (Reach #2) Phillips Co.
Frenchman River
Rock Creek

A map showing the general location of each of the above streams is attached as Appendix A to this testimony. The specifics of the requests and supporting documentation can be found in the Department's application on pages 53-88.

Q. Is it possible to generally characterize the streams listed ?

A. Yes. The stream reaches listed easily fall into two types; one type being cold water mountain trout streams and the other prairie streams inhabited by cool/warmwater fishes.

Q. Is one type more important, from a fisheries standpoint, than the other?

A. No. They are just very different. The great diversity of fishes found within this relatively small geographical area is one of northcentral Montana's greatest attributes.

Q. Why are instream flow reservations needed for the headwater trout creeks, namely Beaver Creek (Hill County), Little Box Elder Creek, Clear Creek, Peoples Creek, and Beaver Creek (Reach #1) Phillips County?

A. Fishing opportunities for wild trout in northcentral Montana are relatively limited. These creeks provide almost all of the available wild trout fishing in northcentral Montana. All of these creeks, with the exception of Beaver Creek (Reach #1) in Phillips County, are found in the Bears Paw Mountains near Havre. They are characterized by clear water over rocky substrate. They are higher gradient streams than their prairie counterparts and contain less diversity of species. The rocky riffles provide aquatic insect production for food. The pools and undercut banks provide safe refuge. Public access is good to all of these streams. Beaver Creek (Reach #1) in Phillips County provides 100% of the available non-reservation wild trout fishing in the Little Rocky Mountains. Access to this small, remote fishery is also good.

The Department's flow reservation requests will help protect these important fisheries by providing the necessary habitat requirements for food production, cover, spawning and subsequent overwintering of brook trout eggs, the principal trout species found in all these waters. Due to the relatively low elevation of the mountains and subsequent lack of summer snowmelt, water temperatures and flows often reach critical levels. These flow requests will help insure that these wild trout stocks will be maintained at their current levels.

Q. What fisheries values could benefit from the department's instream flow reservations on the prairie streams listed, namely Battle Creek, Beaver Creek (Reach #2), Frenchman River, and Rock Creek?

A. All of these Milk River tributaries provide refuge for a great diversity of species. These streams are characterized by their low gradient, highly productive water with long pools broken occasionally by gravel riffles. The mouths of these streams provide a type of habitat not found in the adjoining Milk River. Flows at the mouths of these streams are generally less turbid than the Milk, allowing aquatic plant growth to occur. The aquatic plants often provide the only areas for many miles where aquatic invertebrates can flourish and provide food for forage fish and juvenile sport fish. These weedy areas also provide food, cover and spawning substrate for many species.

The abundance of minnows and suckers found in all of these creeks causes them to be sought out by individual bait fishermen and commercial bait suppliers. The majority of recreational fishing in the Milk River occurs at, or immediately above, the confluence of these streams with the Milk River. These tributaries also supply forage fishes to the Milk River, which produces few forage fish of its own due to its sand/silt substrate and erratic flow fluctuations.

Larval fish sampling on Battle Creek, Beaver Creek (Reach #2), and the Frenchman River has proven the importance of these tributaries as spawning locations for walleye and sauger. Though as yet undocumented, Rock Creek has great spawning potential for walleye and sauger due to the amount of gravel throughout its lower reaches. Suitable mid-summer flows currently allow for maintenance of fish populations by mitigating the harsh temperature/oxygen conditions typically encountered in these prairie streams.

The requested flows would also assist in maintaining the channel morphology that provides deep pools and clean riffles that are essential for fish survival and reproduction during low flow periods. Sufficient flows in the spring allow migratory sport fishes, such as sauger and walleye, access to the excellent spawning substrate available in the lower reaches of these streams.

I, Kent Gilge, being first duly sworn, states that the foregoing testimony is true.

DATED this 27 day of June, 1994.

Kent Gilge

Subscribed and sworn to before me this 27 day of June, 1994.

(NOTARY SEAL)

Notary Public for the State of Montana
Residing at [illegible]
My Commission Expires [illegible] 1998

BIOGRAPHY -- KENT W. GILGE

PERSONAL: Born January 8, 1953, Oak Park, Illinois

HIGHER EDUCATION: B.S. Degree in Fish and Wildlife Management
Montana State University, Bozeman, Montana

WORK EXPERIENCE:

August 1979 to present - Fisheries Biologist III, MT Department of Fish, Wildlife, and Parks, Chinook, MT. My present duties include management of all public fishing waters in the western half of administrative Region 6. This includes gathering data in the Ft. Peck Res./ Missouri River Paddlefish population, trout streams in waters of the Bears Paw and Little Rocky mountains, and numerous creeks containing cool and warm water species. My work also involves monitoring and management of two large walleye/northern pike fisheries (Fresno and Nelson Reservoirs) and several intermediate size walleye fisheries. Numerous small reservoirs containing perch, trout, bass, crappie, tiger musky, catfish, and northern pike are monitored and managed. I received certification as a Fisheries Scientist from the American Fisheries Society in 1983.

April 1977 to August 1979 - Fisheries Biologist I, DFWP, Wolf Point, MT. Assisted the project biologist in gathering baseline data on the Poplar River fisheries. Acquired expertise in larval fish identification.

June 1975 to April 1977 - Fisheries field worker, DFWP, Bozeman. Assisted project biologist with trout population monitoring on the Madison, Gallatin and Beaverhead rivers. Conducted numerous tributary surveys and surveyed high mountain lakes in the Madison Range.

PUBLICATIONS:

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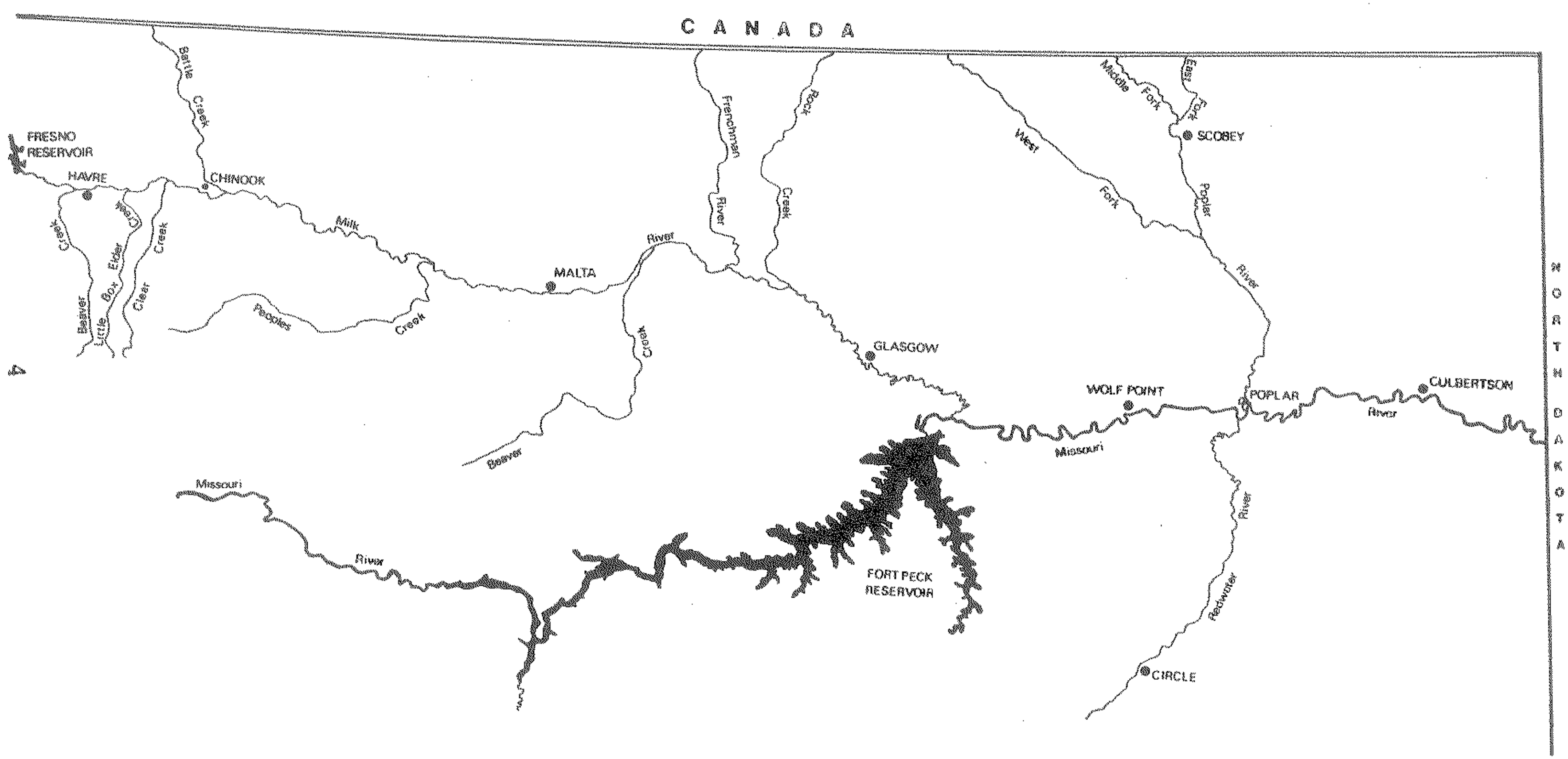
APPENDIX A



Map of the Missouri River basin below Fort Peck Dam.

PREFILED DIRECT TESTIMONY
OF WILLIAM M. GARDNER
ON BEHALF OF THE MONTANA DEPARTMENT OF FISH,
WILDLIFE AND PARKS (MDFWP)

Q. Please state your name and business address.

A. William M. Gardner, Montana Department of Fish, Wildlife and Parks, P.O. Box 1088, Fort Benton, MT 59442.

Q. What is your present employment?

A. I am a fisheries biologist employed by the Montana Department of Fish, Wildlife and Parks (MDFWP).

Q. Please state your education and employment experience.

A. I received a B.S. degree in 1974 and a M.S. degree in 1977 both in Fish and Wildlife Management at Montana State University. I have been employed with the MDFWP from 1979 to the present. During my 15 years of employment with the MDFWP, I have worked on seven different projects. From 1979 to 1981, Mr. Rod Berg and I conducted an instream flow study on the wild and scenic portion of the Missouri River. The following year I assisted Mr. Berg with an instream flow study on the Missouri River between Holter Dam and Cascade, Montana. From 1982 to 1983, I conducted a one-year instream flow study related to the Marias River fishery near Tiber Dam. The next three years I spent completing a fisheries planning/inventory study that determined the instream flow requirements for the fisheries in the lower Missouri River downstream of Fort Peck Dam. From 1986 to 1989, I surveyed 19 tributaries of the middle Missouri River basin and evaluated the fisheries values and instream flow requirements for these tributaries. Presently I am conducting studies to determine the population status of the pallid sturgeon in the Missouri River and investigating the reproductive success of paddlefish in the lower Yellowstone River. Details of my work experience are included in the attached biography.

Q. What is your experience in studying instream flow requirements for fisheries?

A. During 12 years of employment with the MDFWP, I have been investigating instream flow requirements for various fisheries throughout Montana either as a primary or secondary study objective. I received technical training for collecting wetted perimeter data to be used in the Wetted Perimeter Inflection Point Method from Messrs. Fred Nelson and Rod Berg, MDFWP. I received training in stream flow measuring techniques from Mr. Ron Shields, U.S. Geological Survey.

Also, I attended a three day instream flow methods workshop sponsored by OEA Research, a Helena consulting firm.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony is to support the MDFWP's instream flow request for the Missouri River reaches #7 and #8 that I was responsible for in the Department's application. Additionally, I will provide information concerning the population status of the federally listed pallid sturgeon and four other candidate species for listing under the Endangered Species Act: sicklefin chub, sturgeon chub, paddlefish and blue sucker, all of which are found in the lower Missouri River downstream of Fort Peck Dam.

Q. What was your part in the preparation of the MDFWP's lower Missouri River Basin water reservation application?

A. I was involved with the collection and analyses of fisheries and wetted perimeter information in reaches #7 and #8 of the lower Missouri River. I assisted with preparing the flow requests for Reach #8 and for that portion of Reach #7 representing the time periods May 11 through June 30 and October 1 through March 31. Flow requests for the time periods April 1 through May 10 and July 1 through September 30 were the responsibility of Ken Frazer.

Q. What methods were used to derive the instream flow requests for reaches #7 and #8 of the Missouri River ?

A. The Wetted Perimeter Inflection Point Method was used for determining riffle habitat maintenance. Stage height/discharge modelling was used for determining sauger spawning and egg incubation habitat requirements. Details of these methods are found on pages 40-42 and 49-50 of the application.

Q. Please describe the resource values to be protected for reaches #7 and #8.

A. Nationwide, the Missouri River has been substantially altered. Hesse (1987) reports that 67% of its length is either impounded or channelized. A total of 27% of the Missouri River length is impounded in Montana. Reaches #7 and #8 of the lower Missouri River represent 34% of the remaining 537 miles of free-flowing Missouri River in Montana and 32% of the entire remaining unchannelized, free-flowing Missouri River. This portion of remaining free-flowing river is significant because of the unique large-river native fish community it supports. Because of this, the lower Missouri River in Montana is important for its fishery value and for the variety of other recreational opportunities and aesthetic values it provides.

Reaches #7 and #8 support a very good resident and migratory warmwater fishery. Resident species include sauger, walleye, channel catfish, northern pike, burbot and shovelnose sturgeon. Important migratory species include paddlefish and blue sucker. The pallid sturgeon, an endangered species, is found in these two reaches along with two minnow species, sicklefin chub and sturgeon chub, which are presently classified as category II species by the U.S. Fish and Wildlife Service (USFWS), under the federal Endangered Species Act.

Q. Please describe the instream flows requested in reach #7.

A. The flow requests are from Fort Peck Dam to the confluence with the Milk River. A flow of 11,000 cfs is requested for the period May 11 - June 30 to provide the required flow conditions for downstream sauger spawning and incubation in reach #8. During this period, reach #7 normally contributes 96% of the flow to reach #8. The difference between these two reaches is the result of the normal contribution of spring flows from the Milk River. A flow of 7,000 cfs is requested for the period October 1 - February 28 to provide the required flow for downstream riffle maintenance in reach #8. A flow of 6,000 cfs is requested for the month of March to provide the required flow for downstream riffle maintenance in reach #8. The differences in flow quantities between March and the other fall and winter months is due to the increases of Milk River flows normally experienced in March.

Ken Frazer will give testimony concerning flow requests in Reach #7 for the remaining portion of the year.

Q. Please describe the instream flows requested in Reach #8.

A. The flow requests are from the confluence with the Milk River to the Montana/North Dakota border. A flow of 11,500 cfs is requested for the period May 11 - June 30 to maintain adequate conditions for sauger spawning and incubation. We determined that Missouri River sauger require a two-foot minimum water depth over their spawning areas to successfully reproduce. River stage height vs. flow modelling allowed us to predict the flow that would maintain this two-foot spawning criterion. This flow was determined to be 11,500 cfs. For the remaining portion of the year, July 1 - May 10, a flow of 7,000 cfs is requested to maintain main channel riffle habitat.

Q. Please discuss in more detail the endangered species and candidate species under the Endangered Species Act that reside in the Missouri River downstream of Fort Peck Dam?

A. These species include the pallid sturgeon and four other category II species, one of which, the sicklefin chub, is being evaluated for federal listing. By definition, a category II species is one which information now in the possession of the USFWS indicates that proposing to list as endangered or threatened is possibly appropriate, but for which conclusive data on biological vulnerability and threat are not currently available to support proposed rules.

The pallid sturgeon is found in the Missouri River in both reaches #7 and #8. During the period 1989-1993 a total of 8 different pallid sturgeon were observed. The USFWS's pallid sturgeon recovery plan has designated this portion of the Missouri as one of the six recovery-priority management areas, nation-wide, because of the potential this portion of the Missouri exhibits for providing critical pallid sturgeon habitat. I believe that the flows requested for these two reaches will be beneficial for the pallid. The requested flows roughly replicate the natural spring hydrograph, although at a much lesser magnitude. Present and historic flow records indicate that flow increases during the spring were one-and-one-half to two times the magnitude of the flows being requested. Pallid sturgeon evolved with, and depended upon, the high spring flows to fulfill their habitat requirements. Therefore, I feel the MDFWP flow requests will help provide the high flow requirements of this species.

The other four fish that are listed as category II species by the USFWS, and found in the lower Missouri River (sicklefin chub, sturgeon chub, blue sucker and paddlefish) also evolved with substantial increases in flow during the spring. Therefore, I believe the MDFWP flow requests will be beneficial for these four species too.

REFERENCE

Hesse, L. W. 1987. Taming the wild Missouri: what has it cost? Fisheries 12(2): 2-9.

I, William M. Gardner, being duly sworn, states that the foregoing testimony is true.

DATED this 27 day of June, 1994.

William M. Gardner

Subscribed and sworn before me this 27th day of June, 1994.

(NOTARY SEAL)

Notary Public for the State of Montana
Residing at Lewistown
My commission expires 12-1-94

BIOGRAPHY
WILLIAM M. GARDNER
June 1994

PERSONAL:

Born August 9, 1952, Ashland, Wisconsin

EDUCATION:

B.S. Fish and Wildlife Mgmt., Montana State University, 1974.
M.S. Fish and Wildlife Mgmt., Montana State University, 1977.

EXPERIENCE:

1989 to present. MDFWP. Fort Benton. Fishery Biologist. Conducting a study to determine the population status of the pallid sturgeon in the Missouri River. Monitor movements of pallids using radio telemetry techniques and sample for pallids using trammel nets to determine distribution and abundance and habitat use. I am also conducting a paddlefish reproduction study in the Yellowstone River. Paddlefish spawning areas and timing of spawning is being studied by sampling the fry with plankton nets.

1986 to 1989. MDFWP. Fort Benton. Fishery Biologist. Assisted with determining the instream flow requirements for important fisheries in the Missouri River basin. Collected fisheries information on 19 streams in the basin and determined the instream flow requirements using the wetted perimeter and base flow methodologies.

1983 to 1986. MDFWP. Fort Peck. Fishery Biologist. Completed the lower Missouri River fisheries study begun earlier. Monitored paddlefish spawning movements, completed fisheries sampling for determining distribution and abundance of the species found in the study area, conducted an inventory study of aquatic insect communities, determined instream flow requirements for maintaining riffles, side channels and sauger spawning habitat, and completed final study report.

1982 to 1983. MDFWP. Chester. Fishery Biologist. Conducted the Marias River instream flow study. Responsibilities included study design and implementation of a research project that assessed the instream flow requirements for the existing fisheries. Conducted mountain whitefish population estimates, investigated the life histories of the resident trout populations, determined the distribution and abundance of resident fish species, conducted an aquatic insect study and evaluated the fisheries instream flow requirements using the wetted perimeter inflection point methodology and completed the final study report.

1981 to 1982. MDFWP. Cascade. Fishery Biologist. Assisted with field data collection for the upper Missouri River fisheries study. Conducted trout population estimates, investigated young-of-year trout habitat use, monitored trout spawning in tributary streams, and completed an inventory study of the aquatic insect communities in the study area.

1979 to 1981. MDFWP. Fort Benton. Fishery Biologist. Conducted the Wild and Scenic Missouri River instream flow study. Responsibilities included design and implementation of a fisheries research project assessing instream flow requirements for the existing fisheries. The importance of side channel areas was investigated, paddlefish spawning migration was monitored using radio telemetry techniques, the ecology of several fish species found in the study area was studied, and the final study report was completed.

REPORTS:

Gardner, W. M. and R. K. Berg. 1982. An analysis of instream flow requirements for selected fishes in the wild and scenic portion of the Missouri River. Mont. Dept. of Fish Wildlife and Parks. Helena. 111p.

Gardner, W. M. and R. K. Berg. 1983. Instream flow requirements for the Marias River fishery downstream of Tiber Dam. Mont. Dept. of Fish Wildlife and Parks. Helena. 82p.

Gardner, W. M. and P. A. Stewart. 1987. The fishery of the lower Missouri River, Montana. Fed. Aid to Fish and Wildlf. Rest. Proj. FW-2-R. Job Ia. Mont. Dept. of Fish Wildlife and Parks. Helena. 224p.

Gardner, W. M. 1986-87. Middle Missouri River Basin - instream flow studies. Fed. Aid to Fish and Wildlf. Rest. Proj. FW-2-R 15 and 16. Job Ib. Mont. Dept of Fish Wildlife and Parks. Helena.

Gardner, W. M. 1988-89. Middle Missouri River Basin - instream flow studies. Fed. Aid to Fish and Wildlf.

Rest. Proj. F-38-R. Job II. Mont. Dept of Fish Wildlife and Parks. Helena.

Gardner, W. M. 1990-93. Missouri River pallid sturgeon inventory. Fed. Aid to Fish and Wildlf. Rest. Proj. F-46-R. Study III, Job D. Mont. Dept of Fish Wildlife and Parks. Helena.

Gardner, W. M. 1990-93. Yellowstone River paddlefish spawning study. Fed. Aid to Fish and Wildlf. Rest. Proj. F-46-R. Study III, Job E. Mont. Dept of Fish Wildlife and Parks. Helena.

PAPERS PRESENTED

American Fisheries Society, 123rd Annual Meeting. (Portland, Oregon, August, 1993.) Population status and habitat use of pallid sturgeon in the upper Missouri River system of Montana and North Dakota.

Great Plains Fishery Workers Assoc. (Lewistown, MT, February, 1988) Status of the paddlefish in the Missouri River, Montana.

Montana Chapter American Fisheries Society, (Bozeman, MT, March, 1987) Status of the paddlefish and pallid sturgeon in Montana.

Great Plains Fishery Workers Assoc. (Ft. Collins, CO, February, 1987) Instream flow evaluations for the sauger fishery in the lower Missouri River, Montana.

Great Plains Fishery Workers Assoc. (Rapid City, SD, February, 1985) The occurrence of large shovelnose sturgeon in the middle Missouri River, Montana.

PRE-FILED DIRECT TESTIMONY
OF KEN FRAZER
ON BEHALF OF THE MONTANA DEPARTMENT OF FISH
WILDLIFE AND PARKS

Q. Please state your name and business address?

A. Ken Frazer, Montana Department of Fish, Wildlife and Parks, 2300 Lake Elmo Rd., Billings, MT 59105

Q. What is your present employment?

A. I am a regional fisheries biologist with Montana Department of Fish, Wildlife and Parks (FWP) in Billings, MT.

Q. Please state your educational background and experience.

A. I was educated in Montana public school through high school. I received a B.A. in biology from Carroll College in 1974 and an M.S. in aquatic biology from Murray State University in Kentucky in 1981.

I started working with Montana FWP as a seasonal fisheries worker in the spring of 1974. I worked seasonally for three years assisting with field sampling on various projects throughout the Kalispell region. The majority of my work involved sampling on Flathead Lake.

I attended graduate school between 1977 and 1979 doing my thesis and working as a research assistant on a project to study trace metal contamination in fish.

I started full time with Montana FWP in June of 1980 and have been with them since. I worked on various projects in the Kalispell region between 1980 and 1983 with major emphasis on studying kokanee salmon in the Flathead Lake and River system and inventorying fisheries resources in the Bob Marshall/Great Bear Wilderness area. I helped set up and collect field data for wetted perimeter instream flow analyses on all three forks and the main Flathead River, and was responsible for combining all instream flow requests for the Flathead River into a final report.

Between July 1983 and July 1987, I worked on a project funded by the Corps of Engineers at Fort Peck. The first part of this project was to evaluate the potential impacts to the fishery of building a re-regulating dam downstream of Fort Peck Dam. The second part of the project was to design, implement and evaluate a habitat improvement project to try and improve the rainbow fishery downstream from Fort Peck Dam. I used wetted perimeter analysis to evaluate flow needs in a side channel complex below the dam for maintaining and improving the rainbow fishery.

In July 1987 I moved to Helena as the Missouri River Instream Flow Coordinator. I coordinated work between all parties involved with the reservation process on the Missouri River from Canyon Ferry Reservoir downstream to Fort Peck Dam. I set up wetted perimeter transects, collected flow, water surface elevation and fisheries data on numerous streams in the Upper Missouri River Basin. I also assisted other biologists when they needed help with wetted perimeter studies or fisheries sampling on other streams. I reviewed and organized all write-ups for Volume 3 of the FWP reservation application for the upper Missouri basin, and assisted with some sections of the department's application for the lower Missouri basin.

Since April 1989, I have been a regional fisheries biologist in the Billings region. My major responsibilities are the Bighorn River, Bighorn Lake, the Musselshell River and the smaller ponds and reservoirs in the region.

Q. What is the purpose of your testimony in this proceedings?

A. The purpose of my testimony is to describe my involvement with the reservation requests for Reach #7 of the Missouri River, and to provide information that supports these reservation requests and the Department's position on the requests.

Q. What portion of the Department's application for instream flow reservations in the lower Missouri River Basin is supported by your testimony, and what are the flow levels being requested?

A. The request for flows of 7,800 cfs from April 1 through May 10 and from July 1 through September 30 in Reach #7 of the Missouri River are based on my work.

Q. Were you involved with any other work pertaining to the Department's application for instream flow reservations in the lower Missouri River Basin?

A. I assisted Bill Gardner, DFWP fisheries biologist, in collecting data needed for the wetted perimeter inflection point analyses in Reaches #7 and #8 of the Missouri River, but was not involved in final analysis of these data.

Q. Please describe the fisheries and other resource values the Department is trying to protect with its request for 7,800 cfs in Reach #7 of the Missouri River from April 1 - May 10 and July 1 - September 30.

A. The tailwater area below Fort Peck Dam supports a self-sustaining rainbow trout fishery that provides a unique resource in Northeast Montana. Adult rainbow in this population average nearly four pounds and occasionally exceed seven pounds. Rainbow in this population are highly dependent on one side channel complex below the dam for spawning and rearing habitat. Flows are being requested to protect important habitat in this side channel complex for rainbow; however, the requested flows will also benefit many other fish species in this reach.

Q. Please discuss the life history stages of the rainbow population being protected by these flow requests, and how the indicated dates relate to these different life stages.

A. Rainbow spawning below Fort Peck Dam occurs from mid-March into June with spawning activities peaking in early to mid-May. The April 1 starting date for these flow requests was selected to insure good flows in the side channel during a majority of the spawning period. Emergence of young trout (fry) from spawning gravels begins in early June and continues into mid-July. It is important to maintain good flows during this period since even temporary dewatering of spawning areas during this critical period can result in major losses of developing eggs or emerging fry.

Flows are being requested from fry emergence through the end of September to maintain side channel flows for rainbow trout rearing. Young-of-year (YOY) rainbow reside in the side channel throughout the summer and fall if flows allow. Availability of quality rearing habitat is a major factor affecting the success of natural recruitment to this rainbow population. The side channel complex provides the best rearing habitat available below the dam. It is important to maintain as much of this habitat as possible until YOY rainbow are large enough to contend with the normal fluctuating flow conditions that occur within the side channel due to operation of Ft. Peck Dam.

Q. Please describe your involvement in the collection of flow and/or fisheries data that resulted in the flow requests listed above.

A. The flow requests were developed as part of a fisheries study conducted below Fort Peck Dam between July 1983 and July 1987. The major emphasis of this study was to identify and evaluate the impacts fluctuating water levels due to peaking power generation at the dam were having on the downstream fisheries. The major focus of this study was on the trophy rainbow fishery in the tailwater.

As the biologist on this study, I conducted field studies to evaluate the needs and impacts of flow fluctuations on all life stages of the rainbow population. Based on observed impacts, I designed and implemented habitat improvement projects in the side channel area to improve rainbow spawning and rearing success, and evaluated the effectiveness of these projects. I also worked closely with the Corps of Engineers to obtain operational changes at the dam to reduce impacts on the rainbow population.

Q. Describe the procedures and methods used to establish the flow request for maintaining essential side channel habitat for rainbow trout in Reach #7 of the Missouri River.

A. The Wetted Perimeter Inflection Point Method was used to establish flow requirements for the side channel. Actual flows were then measured in the side channel at a number of different releases from Fort Peck Dam. Flow and discharge data were entered into a computer and a Statgraphics software program was used to develop a regression line relating side channel flow to dam discharge (Figure 4, Appendix A). This flow-discharge curve was used to determine what discharge was required from Fort Peck Dam to maintain the side channel flow identified by the wetted perimeter inflection point analysis.

Q. Please discuss the differences in the minimum discharge levels requested in your 1985 and 1987 reports to maintain the same flow of 250 cfs in the side channel, and explain why the discharge request in the 1987 report is more reliable.

A. The same process was used to calculate both discharge requests. The difference is a result of the regression curve used to determine what discharge was needed to maintain a flow of 250 cfs in the side channel. The curve used in the 1987 report is more accurate for two reasons. This curve was developed using almost twice as many side channel flow measurements as the 1985 curve and these measurements were made over a wider range of dam discharges. A second major factor was the way the regression curve was developed. In 1987 the expanded data set was entered into a computer and a computer program was used to calculate a curved regression line for the data. A computer was not available in 1985 for developing the regression curve. A hand calculator was used to calculate a linear regression line. Using this line as a base and my knowledge of how flows in the side channel should respond to changes in discharge, I drew a curved line to fit the available data. This hand drawn line was then used to develop the minimum discharge request for the 1985 report.

Ken Frazer being first duly sworn, states that the foregoing testimony is true.

DATED this 22 day of June 1994.

Ken Frazer

Ken Frazer

Subscribed and sworn to before me this 22 day of June 1994.

Dianne J. Cantrell

Notary Public for the State of Montana
Residing at Yellowstone City, Montana
My commission expires: Aug. 1, 1996

BIOGRAPHY - KEN FRAZER

PERSONAL:

Born February 28 1952, Billings, MT

EDUCATION:

B.A. Biology, Carroll College, 1974
M.S. Aquatic Biology, Murray State University, 1981

EXPERIENCE:

4/1989 - Present: Montana Department of Fish, Wildlife and Parks (FWP). Regional Fisheries Biologist. Responsibilities include management of the fisheries on the Bighorn River, Bighorn Lake, the Musselshell River, the lower Yellowstone River, and many of the smaller lakes and small warmwater ponds in the region; directing walleye egg taking on Bighorn Lake; working with local conservation districts and conducting 310 and SPA inspections on regional waters.

7/87 - 4/89: Montana FWP. Missouri River Instream Flow Coordinator. Responsibilities included coordinating the work efforts of all parties involved in the Department's application for instream flow reservations on the Missouri River between Canyon Ferry Reservoir and Fort Peck Dam; setting up wetted perimeter transects and collecting flow, water surface elevation, stream profile and fisheries data on numerous streams in the Helena area and the upper Musselshell River Drainage; collecting wetted perimeter data or fisheries data on other streams in cooperation with other biologists or worked as part of their crew when they needed extra help.

I also completed reservation requests for all streams on which I did the major work, and helped write up some stream reaches where older data were used. I reviewed and edited all stream write-ups prepared for Volume 3 of the application and assembled the final draft of this volume. I prepared all drainage maps used in the application, and assisted with some sections of Volumes 1 and 2.

5/85 - 7/87: Montana FWP. Regional Fisheries Biologist. Designed fisheries study for Fort Peck tailwater area based on problems determined during previous contract work. Prepared proposal and budget and obtained funding from Corps of Engineers (COE). Directed fisheries study working on improvement of both trout and warm water fisheries through improved water level management and habitat enhancement. Managed budget for study, worked with COE to obtain improved discharges from Fort Peck Dam, designed, implemented and evaluated habitat improvement projects, and wrote monthly and annual reports.

7/83 - 4/85: Montana FWP. Regional Fisheries Biologist. Supervised study to evaluate the fishery in the Missouri River and dredge cuts below Fort Peck Dam and to identify potential impacts of a proposed reregulation dam on this fishery. Duties included: supervising temporary employees, developing research goals, directing and assisting in field sampling, analyzing data and writing monthly and final reports. Worked closely with the COE in evaluating several proposed plans for increasing power production at Fort Peck Dam, identified game and forage fish present, located important habitat areas, determined seasonal movement patterns and identified the effects fluctuating water levels and habitat loss resulting from various rereg proposals would have on fish and plankton in the area. Major game species studied included: walleye, sauger, northern pike, paddlefish and rainbow trout. Also assisted in collection of channel profile data for a number of instream flow transects on the Missouri River below Fort Peck Dam that were used for wetted perimeter analysis.

9/81 - 7/83: Montana FWP. Fisheries Fieldman. Assisted on study investigating factors effecting kokanee spawning along the shoreline of Flathead Lake. Duties included: designing and building sampling equipment, locating kokanee spawning areas using boats and SCUBA, marking and mapping spawning areas,monitoring egg survival and fry emergence from natural and experimental redds and evaluating groundwater and gravel movement, groundwater D.O. and lake levels in relation to embryo survival. Assisted in data analysis and graphics preparation for annual reports. Was also responsible for collection, analysis and write-up of data for a zooplankton monitoring report as part of this study.

4/81 - 9/81: Montana FWP. Fisheries Fieldman. Organized and updated all instream flow recommendations for the Flathead drainage and combined in a final report. Coordinated and ran a creel census and recreational use study on Flathead Lake and the upper Flathead drainage. Duties included: directing and supervising field crews, developing random sampling schedule and coordinating work schedules for shoreline, boat, and aerial counting and interviewing crews, training crew members, maintaining car counters, assisting with counts and interviews and processing collected data.

6/80 - 4/81: Montana FWP. Fisheries Fieldman. Worked as a crew leader on study to evaluate and inventory fisheries resources in the Middle Fork drainage of the Flathead River. Most work was in the Bob Marshall and Great Bear Wilderness areas requiring approximately 60 days of backpacking and wilderness camping. Duties included: measuring and recording habitat features on numerous stream reaches in the drainage, snorkeling sections of each reach to identify fish species present and to look at size and age structure, walking streams in the fall to count bull trout redds, and setting up and collecting necessary data on several transects along the river for use in establishing minimum instream flows using the Wetted Perimeter Inflection Point Method. Laboratory work included reading scales and otoliths, analyzing stomach samples, organizing habitat and snorkel data for entrance into a computer, analyzing data and working on figures for an annual report.

6/79 - 6/80: Montana FWP. Fisheries Fieldman. Worked on study to evaluate the effects of Hungry Horse Dam on the fish and invertebrate fauna of the Flathead River. Duties included: designing and building necessary sampling equipment, monthly sampling of fish and invertebrates from various sites along the river, picking and identifying benthic samples and monitoring seasonal fish population trends in the river. Other work included: identifying kokanee spawning areas in the river, studying kokanee spawning success and incubation mortality and trying to relate these findings to the flow records from Hungry Horse Dam, monitoring cutthroat migration in the river using tagging and biotelemetry, helping set up and collect field data on numerous transects in the Flathead drainage for establishing minimum flows using the Wetted Perimeter Inflection Point Method. Analyzed data and worked on tables and figures for annual progress report.

9/77 - 6/79: Murray State University. Graduate Research Assistant. Worked on project to study the origin, distribution and bioaccumulation of selenium in two large reservoir systems. Duties included: collection of fish, water and sediment samples on a monthly basis, preparing samples for analysis and assisting in laboratory analysis using atomic absorption spectroscopy. Also analyzed data and wrote reports for the project.

5/76 - 12/76, 6/75 - 12/75, 5/74 - 9/74: Montana FWP. Fisheries Laborer. Primary commitment was to the Flathead Lake Fisheries Study on a 35-foot research boat. Duties included: preparing and launching wooden boat each spring, maintaining boat and all related equipment in good order, and assisting in all experimentation and research done on the boat. Used specialized nets and other sampling equipment to study the fish populations of Flathead Lake and to gather limnological data at standard stations around the lake. Worked with newly developed hydro-acoustic echo sounding and recording system, helped develop a midwater trawl to use in conjunction with this electronic gear, worked as member of a kokanee egg-taking crew, and assisted with other fisheries projects throughout the region.

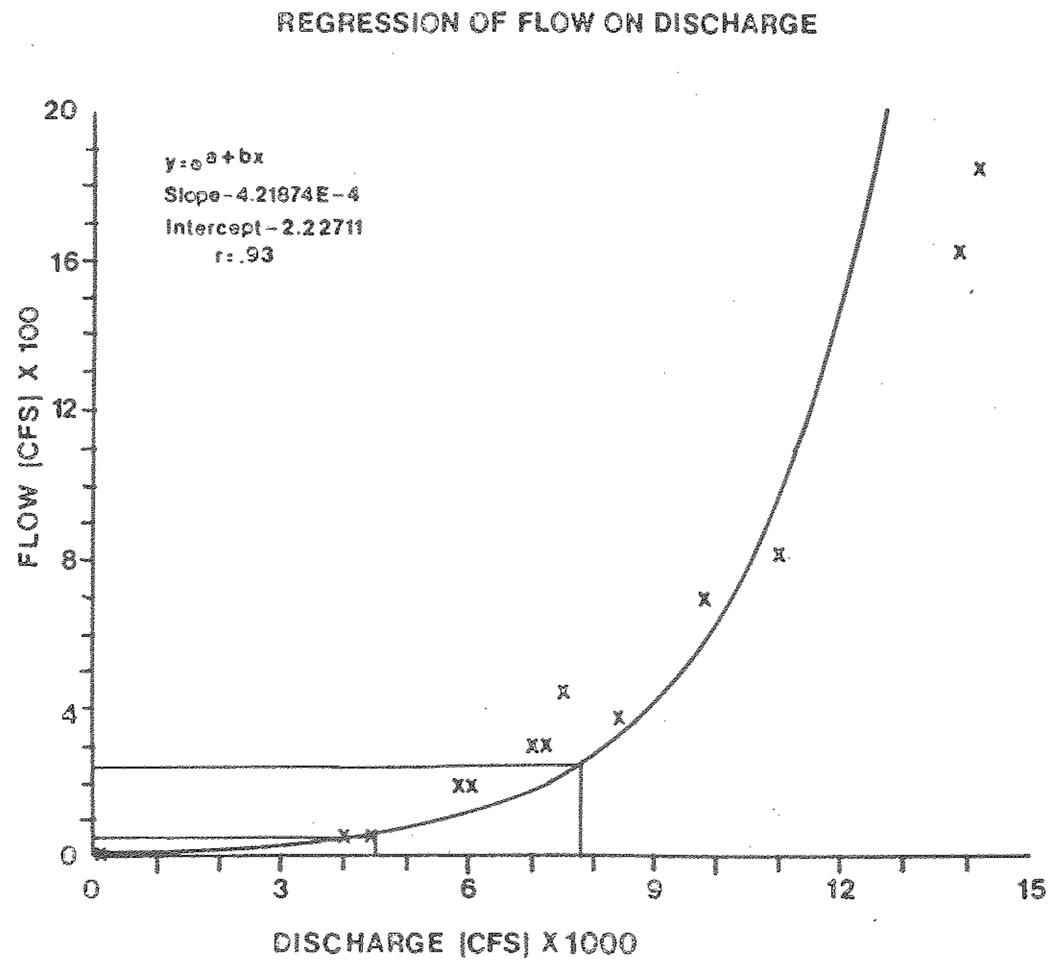


Figure 4. Regression curve of flow in the east side channel to discharge from Fort Peck Dam.

EXHIBIT 1

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

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

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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.

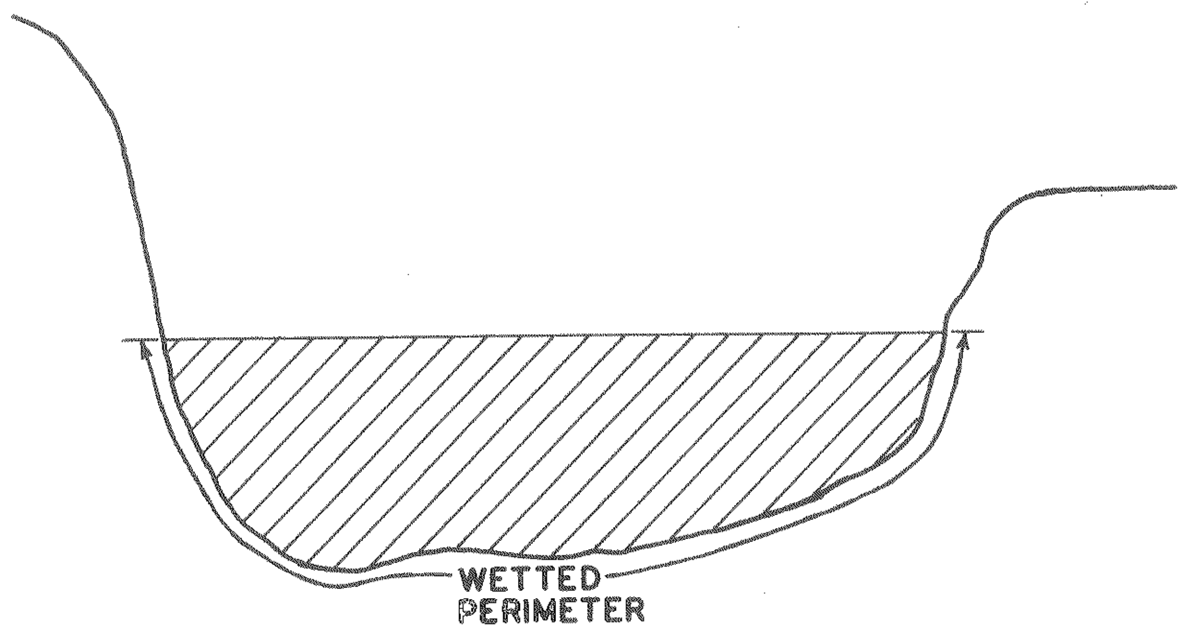

Figure 1. The wetted perimeter in a channel cross-section.

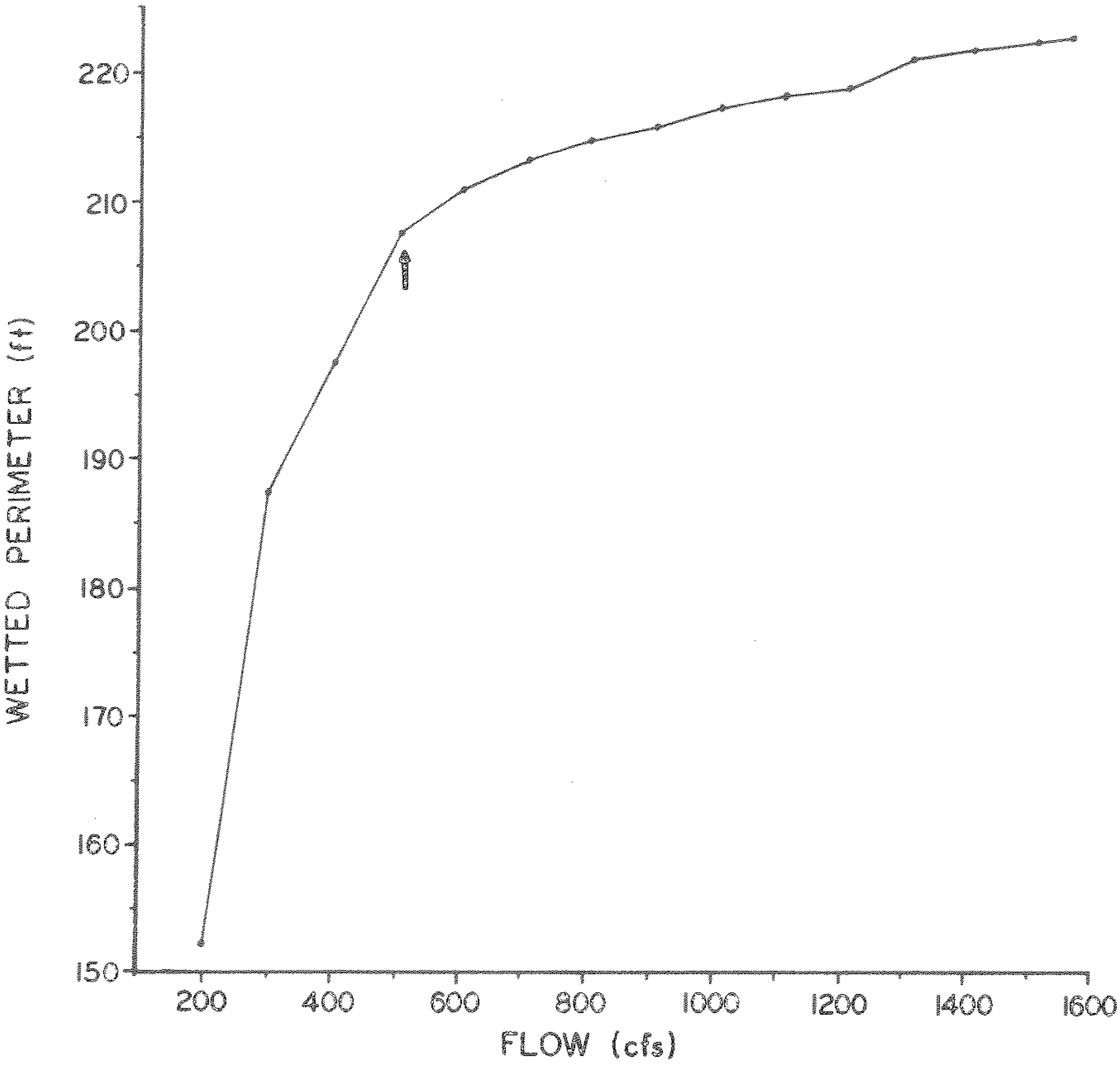

Figure 2. An example of a relationship between wetted perimeter and flow for a riffle cross-section.

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.

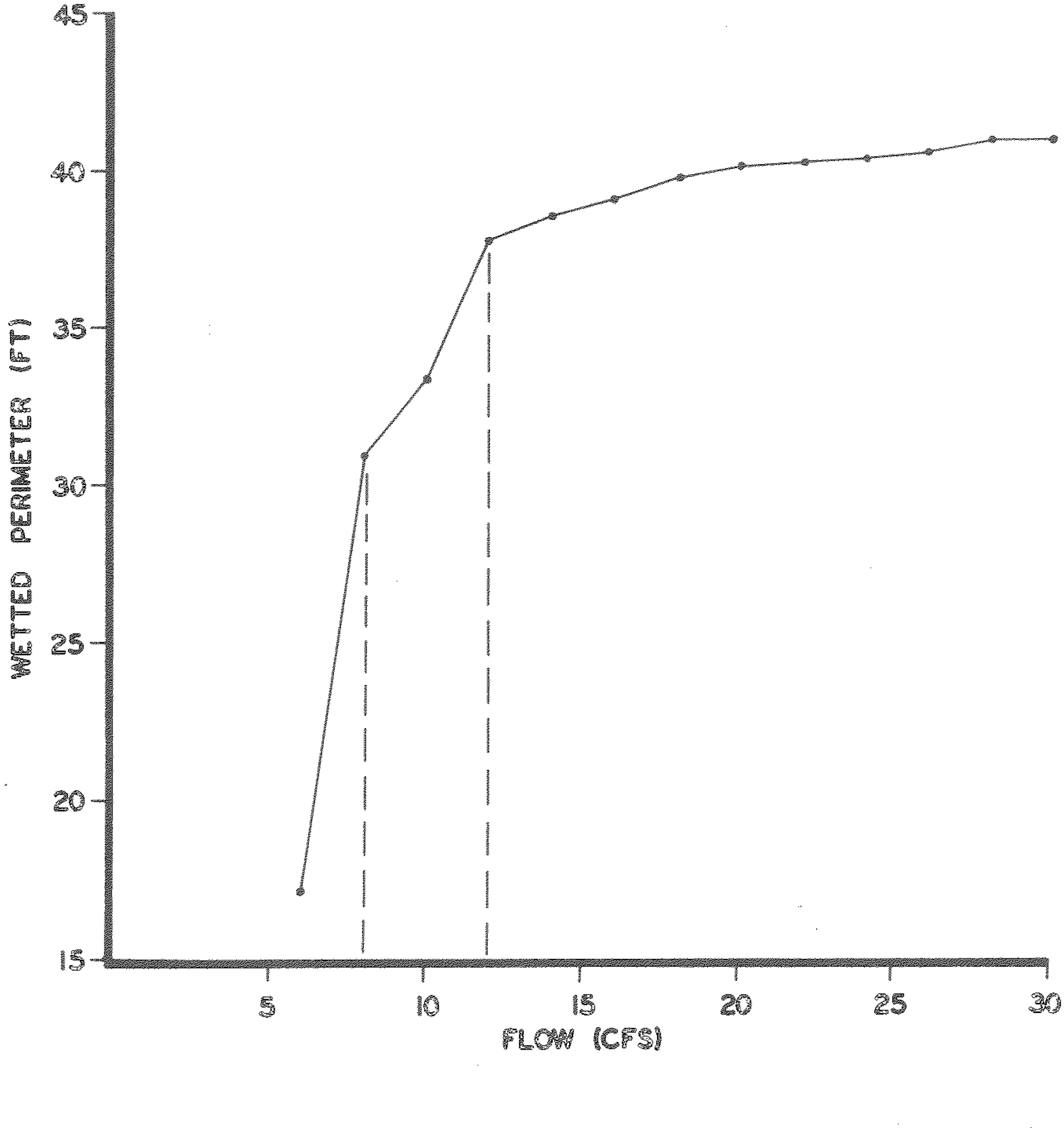

Figure 3. An example of a relationship between wetted perimeter and flow for a riffle cross-section.

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.

<u>Establishing Bench Marks</u>

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.

Measuring Stream Discharges

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.

Measuring Cross-Sectional Profiles

The channel profile has to be determined for each cross-section. Unlike the measurement of water surface elevations, this has to be done only once. 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 <u>are not</u> 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 ≥ 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 $\geq$ 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.

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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

Station No. 11-4775

Discharge measurements of Eel River at Scotia, Calif. during the year ending Sept. 30, 19 68

No.	Date	Made by	Width (feet)	Area (sq ft)	Mean velocity (fps)	Gage height (feet)	Discharge (cfs)	Rating shift adj.	Percent diff.	Method	No. secs.	Gage height change	Time (hrs)	Meas. rated	Water temp.	Outside gage	Remarks
495	1965 Aug 31	Hammond McGuire	153	W 199	0.78	8.92	155			0.6	34	-.01	1.2	G	73	8.78	
496	Oct. 5	La Rue	155	W 148	0.82	8.79	121			.6	28	0	.5	G	41	8.87	Zero flow = 8.5 ± 0.05
497	Nov 2	La Rue do	154	W 158	0.85	8.88	135			.6	29	0	.5	G	60	8.89	Zero flow = 8.5 ± 0.05
498	30	Crumrine	454	2,030	2.47	12.52	5,010			.6, .2/.8	33	-.01	1.1	G	46	12.95	
499	1966 Jan. 3	La Rue Hammond	553	6,790	7.19	21.03	48,800			.2/.8	29	+0.50	1.75	G/F	46	21.59	Jan. 5 peak 45.84
500	25	Crumrine	512	2350	1.73	12.74	4,050			.6, .2/.8	25	-.02	1.3	P	45	12.80	
501	25	do	506	2270	1.71	12.13	3,880			.6, .2/.8	28	0	2	F	—	[illegible]	
502	31	La Rue	543	3960	4.18	16.08	16,500			.6, .2/.8	32	-.07	1.25	G	—	16.13	
503	Feb. 21	do	533	3000	2.70	13.85	8,100			.2/.8	36	-.03	1.4	G	48	13.86	
504	Mar. 31	do	2-Channels		—	13.94	7,420			.2/.8	37	.00	1.6	G	57	13.59	
505	Apr. 28	do	454	1890	1.90	12.13	3,600			.6, .2/.8	36	-.01	1.3	G	58	12.18	
506	June 1	Palmer	434	1200	0.83	10.62	1,000			.6, .2/.8	40	0	1.7	G	62	10.64	
507	July 6	do	196	193	1.56	9.82	302			.6	39	0	.9	G	70	9.83	
508	Aug. 8	do	184	W 126	1.11	9.40	140			.6	38	0	.75	F/P	67	—	Zero flow = 9.35 ± 0.05
509	Sept. 12	Hammond	77	W 74.1	1.48	9.26	110			.6	31	0	.8	F	66	9.32	Zero flow = 9.35 ± 0.05
510	Oct. 4	Palmer	184	116	1.01	9.30	117			.6	34	0	.7	F	64	9.31	

Computed by W-Wedding

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

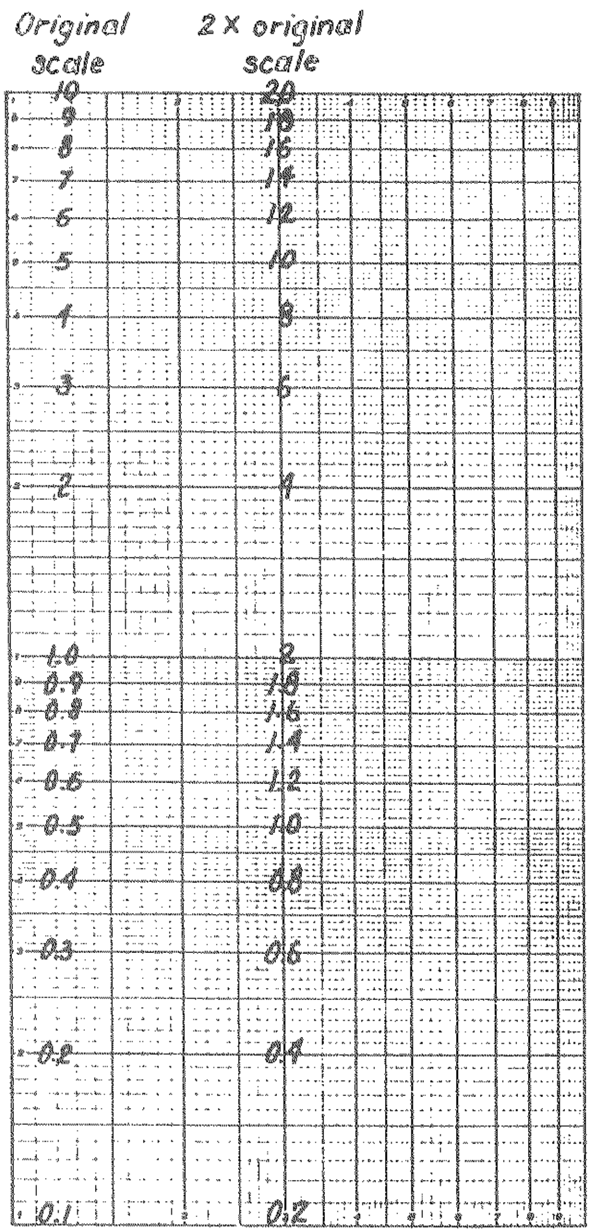

FIGURE 140.—Example showing how the logarithmic scale of graph paper may be transposed.

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.

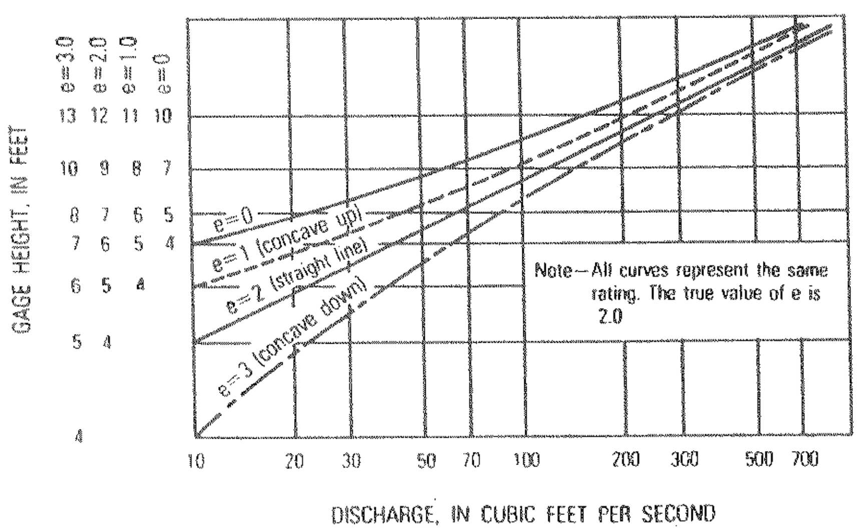

FIGURE 141.—Rating-curve shapes resulting from the use of differing values of effective zero flow.

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

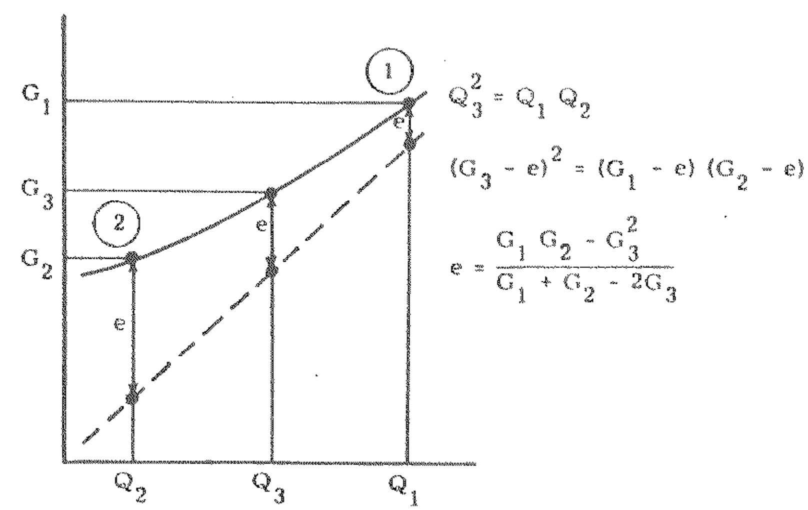

FIGURE 142.—Schematic representation of the linearization of a curve on logarithmic graph paper.

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 ertain advantages, particularly in the study of the pattern of shifts he lower part of the rating. A change in the low-flow rating at any 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.

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

PUNCHING INSTRUCTIONS

PAGE 1 OF 4

FORTRAN STATEMENT

```
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 71
     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

Cross-section identification

Do not enter profile data past space 70.

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.

**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

FORTRAN STATEMENT

	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	Water surface elevations							
CAL2	2		9357		113	Each is the average for the WE and WER							
CAL3	2		9323		38	Without decimal points, reads as 93.90, 93.57 and 93.23 ft							
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

*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 3 of 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								
CAL2	3		9626		113								
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												
	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

} Calibration flows
Without decimal points, reads as 33.4, 11.3 and 3.8 cfs

(XSEC 5 card:) ⟵ For non-riffle cross-sections enter zf here

* 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 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
POOL 1 2 3 4 5
POOL 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 ≥ .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	Y
.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	S
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

XSEC		1	2	3	4	5						AVG
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

XSEC		1	2	3	4	5						AVG
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

XSEC		1	2	3	4	5						AVG
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											
XSEC		1	2	3	4	5						AVG
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											
XSEC		1	2	3	4	5						AVG
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	53.12	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		9.32	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	8.94	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	33.43	87.40	88.51	81.89	.00	.00	.00	.00	.00	85.60
PMAX		86.79	33.43	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

XSEC		1	2	3	4	5						AVG
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

XSEC		1	2	3	4	5						AVG
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

												AVG
XSEC		1	2	3	4	5						
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

												AVG
XSEC		1	2	3	4	5						
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

												AVG
XSEC		1	2	3	4	5						
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	63.94	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	.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											AVG
XSEC		1	2	3	4	5						
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											AVG
XSEC		1	2	3	4	5						
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

												AVG
XSEC		1	2	3	4	5						
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

												AVG
XSEC		1	2	3	4	5						
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

EXHIBIT 2

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).

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)

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

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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.

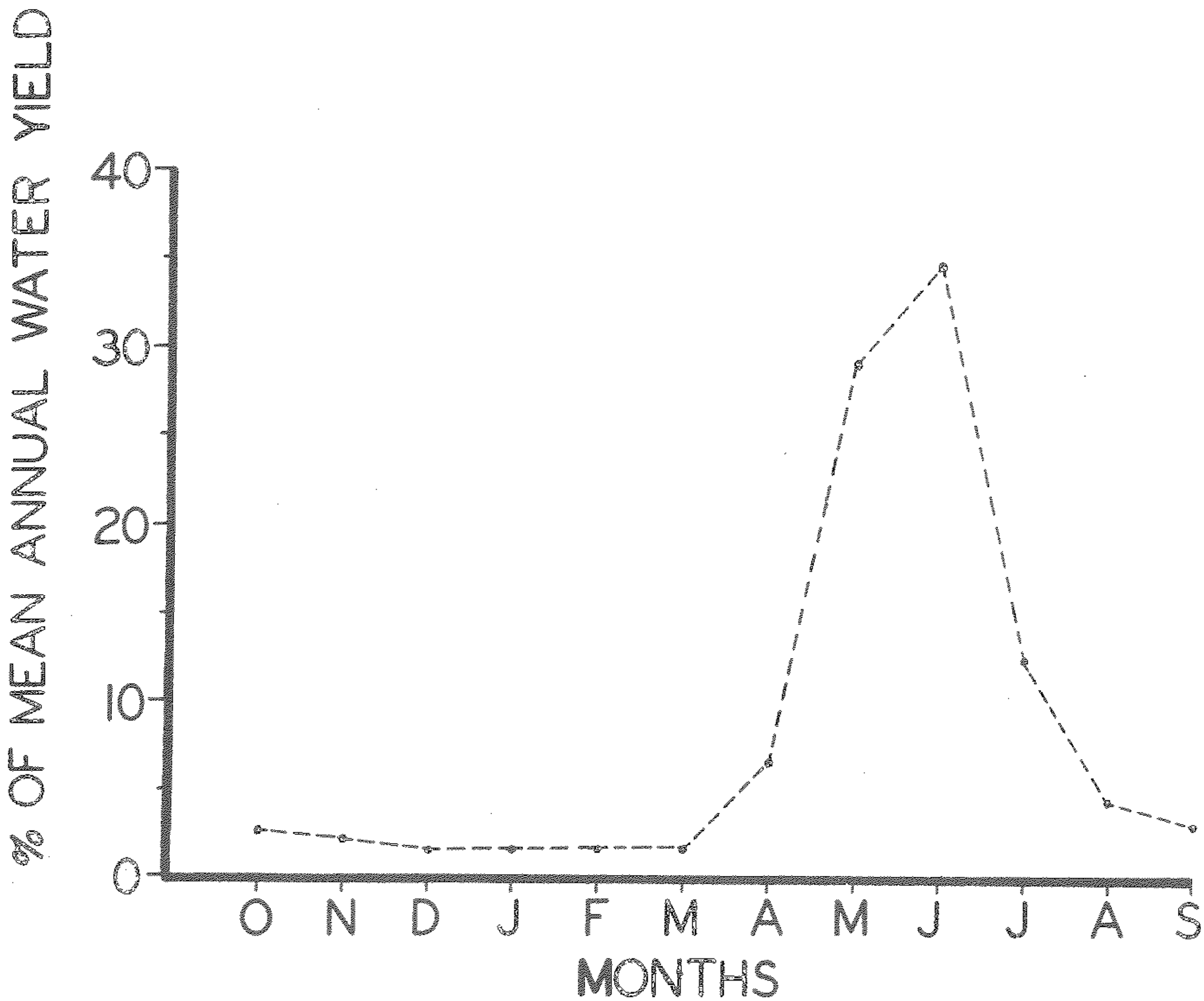

Figure 1. Monthly water availability for mountain trout streams in Montana. The monthly values are the averages for five unregulated streams east of the Continental Divide.

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

coefficients representing the habitat preferences of various life stages of target fish species. Finally, measures of habitat suitability and availability (as wetted surface area, a_i) are used in computation of Weighted Usable Area (WUA), an index of habitat condition. This index is computed for each life stage [e.g., spawning (S), fry (F), juvenile (J), and adult (A)] and can be plotted against discharge" (Figure 2).

A major difference between IFIM and the "habitat retention" methods is that it builds a two-dimensional surface area model of a stream section while the other methods usually examine habitat characteristics in terms of usable width at discrete cross-sectional transects. IFIM divides the study section into a matrix of rectangular cells (Figure 3) and uses either a single-flow (WSP-type model incorporating Manning's equation) or a multiple-flow stage-discharge hydraulic modeling approach to describe flow-related changes in depth and velocity within each cell. Once the hydraulic model for each cell is constructed, habitat suitability curves are consulted to determine habitat suitability for a given life stage of a given species for each flow of interest.

Example habitat suitability curves for velocity, depth, and substrate are shown in the upper right on Figure 2. Suitability factors range between 0.0 (most unsuitable) and 1.0 (most suitable). A composite habitat suitability factor is determined for each cell in the study section at each flow of interest by multiplication of factors for depth, velocity, substrate and/or cover. This composite suitability factor also ranges between 0.0 and 1.0 and it is multiplied by the surface area of the cell to determine the "usable" area in the cell at a particular flow. These values are tabulated for all

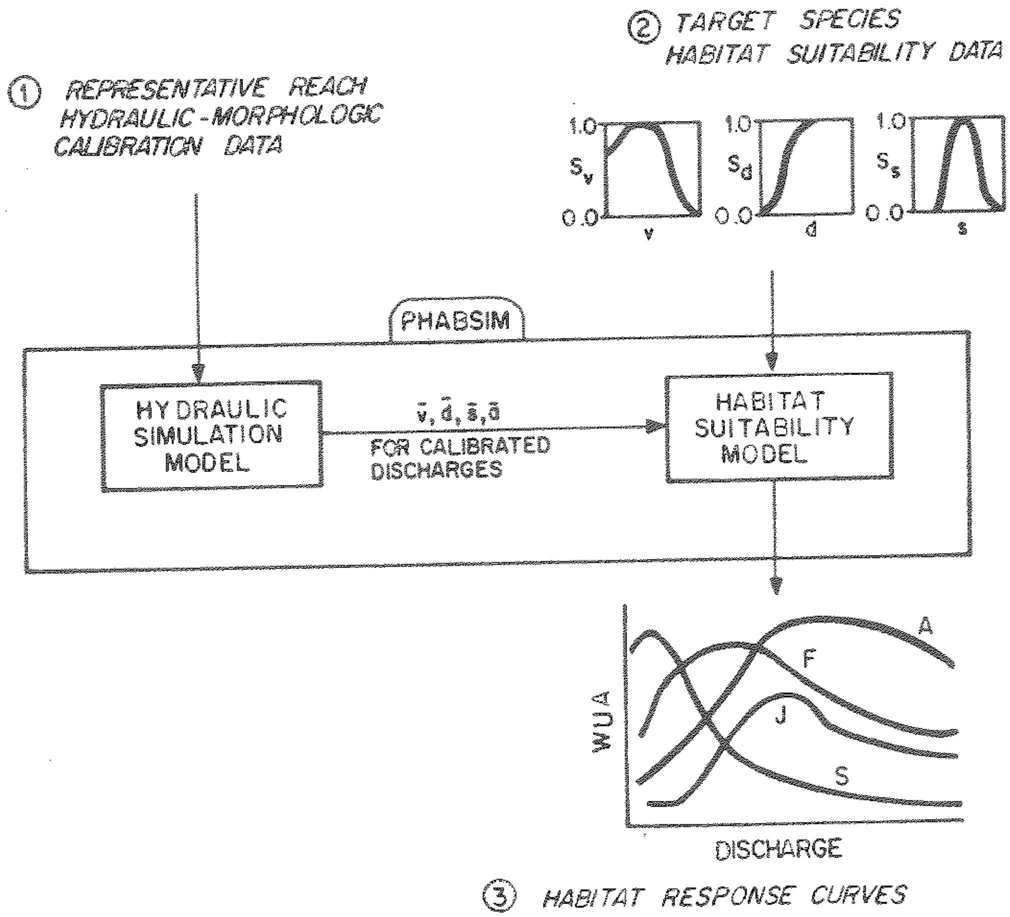

Figure 2. Organization and information processing in the Instream Flow Incremental Method (IFIM) for instream flow assessment (from Loar and Sale 1981).

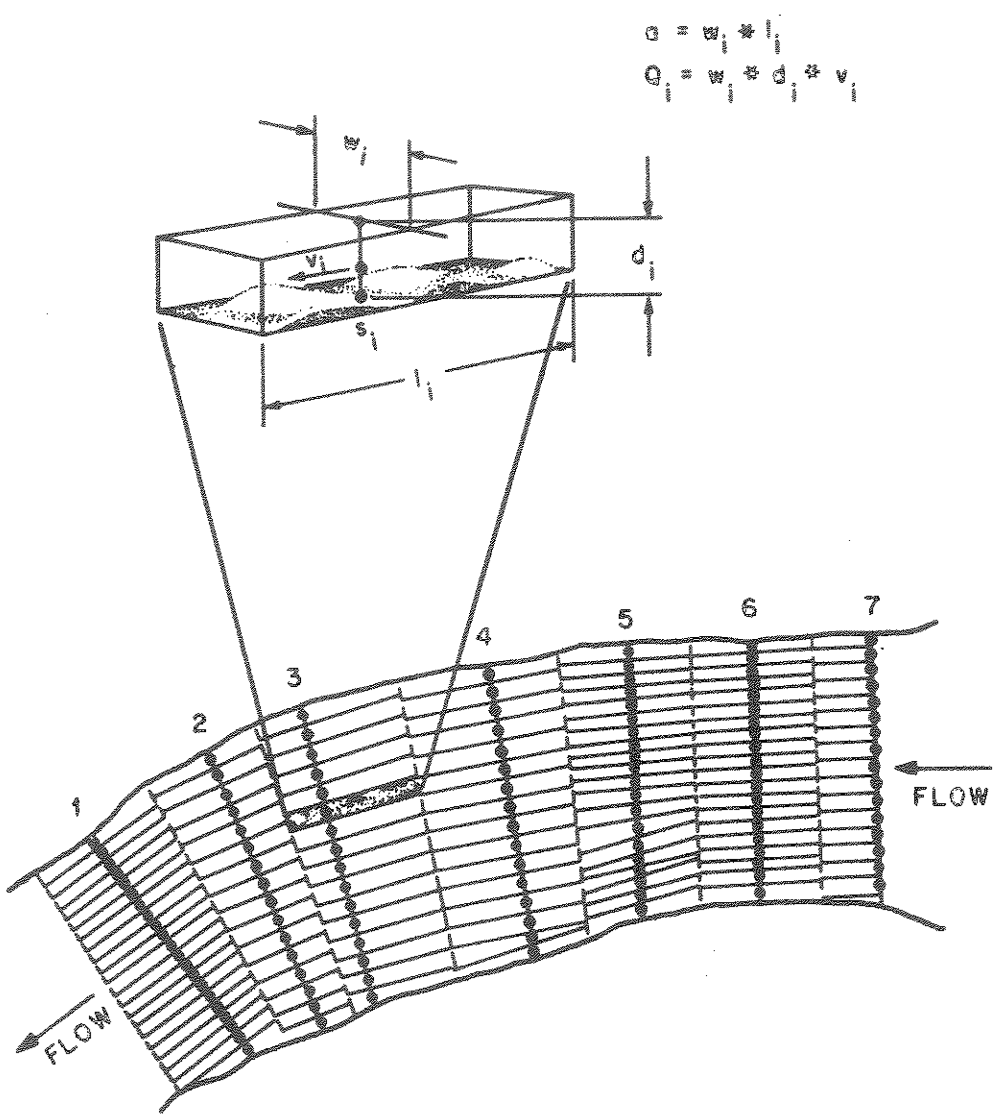

Figure 3. Subdivision of a stream reach into transects and mapping cells for computational purposes with the Instream Flow Incremental Method (IFIM) (from Loar and Sale 1981).

cells in the study section to determine total weighted usable area (WUA) at a given flow for a life stage of a species (i.e., WUA for rainbow trout fry in stream section "x" at 13 cfs). Using habitat suitability curves and depth and velocity predictions from the hydraulic model, graphs of WUA versus discharge for various life stages of a fish species can be generated (i.e., lower right in Figure 2).

Advantages and Limitations of IFM's

There are a number of IFM's that can be employed to determine the instream flow needs for fishery resources. Wesche and Rechard (1980) listed 11 common techniques, many of which are still in use. There is no consensus on which method is the most appropriate for all situations. Such a consensus may not be possible because of regional differences in instream flow program structures and goals, hydrology, channel morphology, fish community structure and habitat use, available funding, and continuing advances in the "state-of-the-art" of instream flow analysis.

Because there is no "best" method to determine instream flows to meet fishery needs under all conditions, the following discussion will examine the assumptions, strengths, and limitations of the main IFM's. The interested reader is encouraged to consult the excellent review by Loar and Sale (1981) since much of the following is derived from that source. Since the main objective of this report is to evaluate Montana's wetted perimeter inflection point method, particular attention will be paid to this technique.

We will discuss the advantages and limitations of the various IFM's with regard to the following main subject areas: hydraulics and channel morphology, decision-making capabilities, and data and manpower requirements. Many of the IFM evaluation studies conducted to date will be discussed with particular attention paid to assumptions and experimental design. Finally, the results of studies that evaluate the effectiveness of Montana's wetted perimeter method are summarized, and criteria for selecting a particular IFM are discussed.

Hydraulics and Channel Morphology

The ability of various IFM's to account for differences in channel morphology between watersheds or even individual stream reaches is an important consideration. The "non-field" IFM's have the least ability to compensate for such differences because they do not rely on site-specific relationships between habitat and discharge. For example, the Tennant Method (probably the most widely used non-field IFM) assumes that a certain percentage of mean annual flow will provide adequate channel width and depth to maintain aquatic resources at some desired level. However, watershed geomorphology investigations have identified a number of variables besides flow frequency (such as watershed area, geology, slope, age, and stream order) that play important roles in determining stream channel and flow characteristics. These variables have been shown to vary significantly between watersheds but none of the common "non-field" IFM's address this problem (Loar and Sale 1981). Hence these methods are best suited for regional application where assumptions regarding the relationship between channel geometry, stream flow and habitat are met.

The "incremental" and "habitat retention" IFM's utilize site-specific habitat measurements that account for differences in channel morphology between watersheds or stream reaches by developing habitat-discharge relationships for each stream reach. To develop these relationships, some form of hydraulic model (either empirical or mathematical) is used. Each type of hydraulic model is based on certain assumptions and has certain advantages and limitations.

Empirical relationships between habitat and discharge are derived by direct measurement over a range of stream flows. This is a simple and straightforward approach but it involves extensive time and manpower investments and offers limited ability to predict habitat characteristics outside the range of observed flows. Trihey and Baldridge (1985) recommend an empirical approach for high gradient streams with complex hydraulic features, but their method requires three or more field visits to develop acceptable habitat-discharge relationships. The need for a large number of site visits is common with empirical approaches because habitat-discharge relationships are seldom linear, thus necessitating numerous "points" (data sets) on graphs to adequately describe these relationships. Extrapolation between and beyond observed test flows can be a questionable practice if empirical field data are inadequate to properly describe the shape of habitat-discharge curves.

Mathematical models are used by many of the field-oriented IFM's to (1) reduce the amount of field effort required and (2) provide more ability to extrapolate beyond observed flows. Three general types of hydraulic models are typically used. The simplest and most direct hydraulic models are those based on stage-discharge relationships generated by regression techniques. These relationships are commonly derived from field measurements made at three different flows, although accuracy can be improved by additional measurements. In certain instances, measurements can be made at two flow levels but significant "two-point" errors can result (Bovee and Milhous 1978).

Several "habitat retention" IFM's such as the R2-Cross, or Colorado, Method utilize a second type of hydraulic model based on Manning's equation. This model develops a simulated stage-discharge relationship for a given 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 préference 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 <u>consistency</u> 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 <u>adequacy</u>

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.

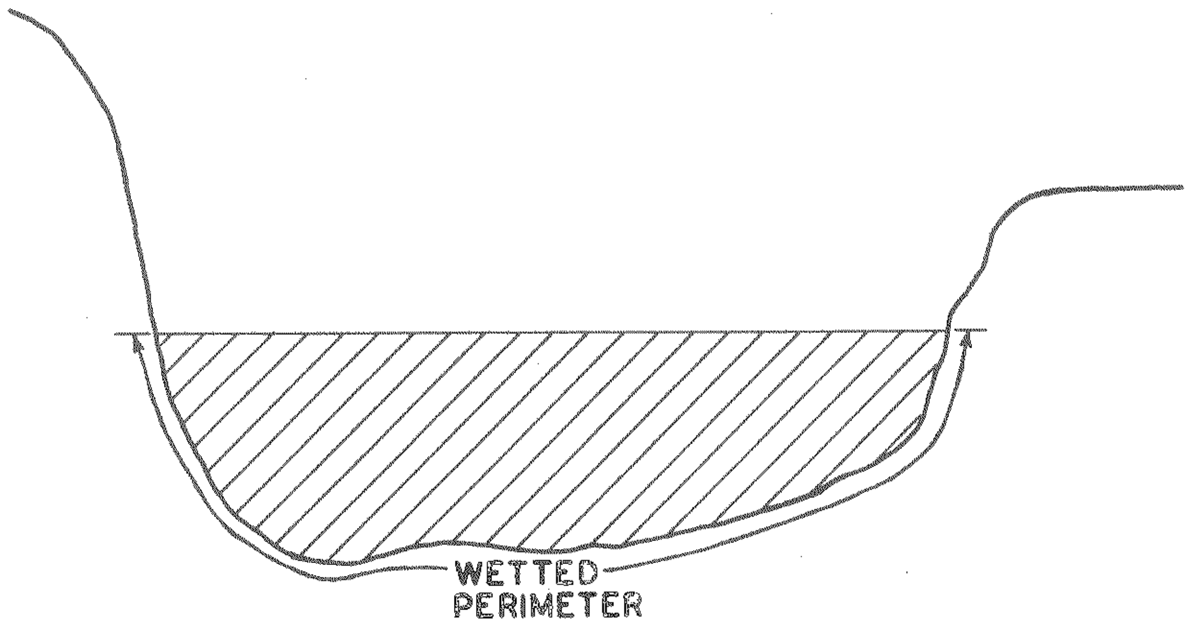

Figure 4. The wetted perimeter in a channel cross-section.

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

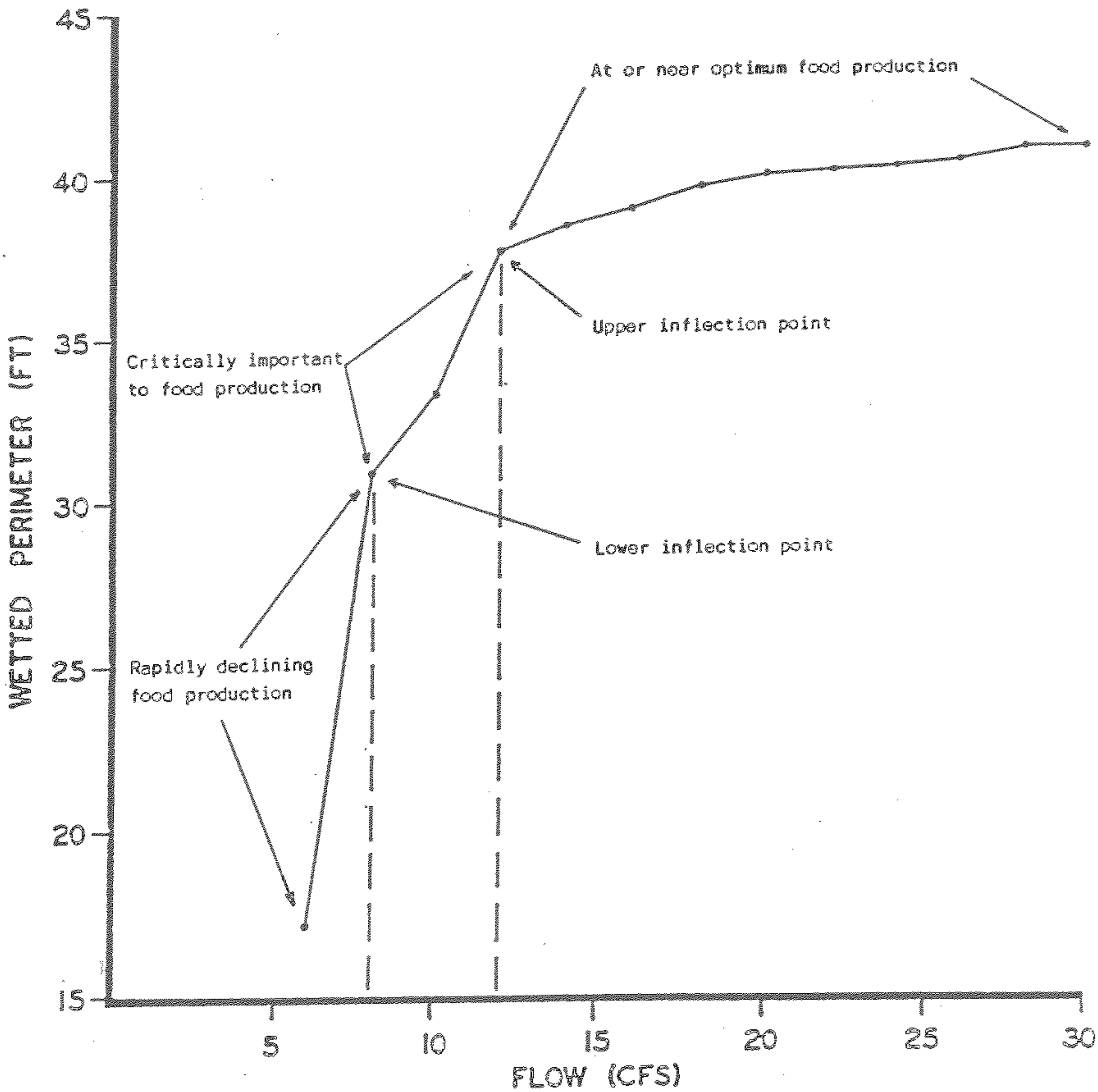

Figure 5. An example of a relationship between wetted perimeter and flow for a stream riffle cross-section showing upper and lower inflection points.

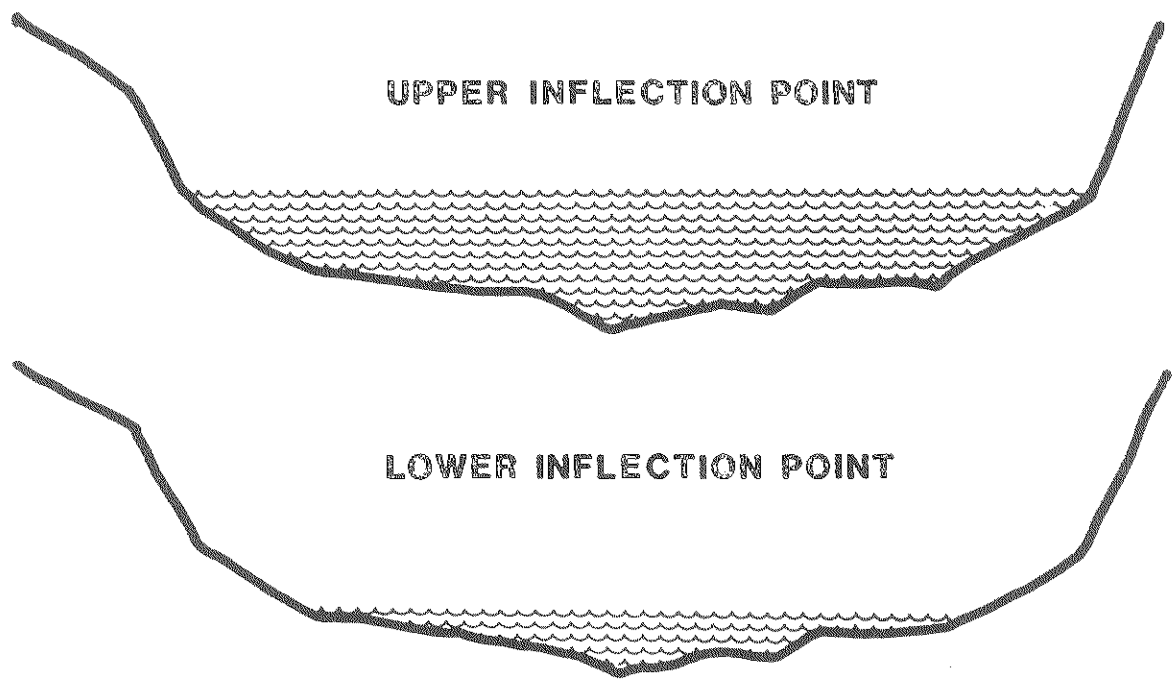

Figure 6. A diagrammatic representation of the flow at the upper and lower inflection points in a stream cross-section.

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 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

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.

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.

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EXHIBIT 3

Photographs illustrating fish habitat found in the prairie streams where instream flows are requested.

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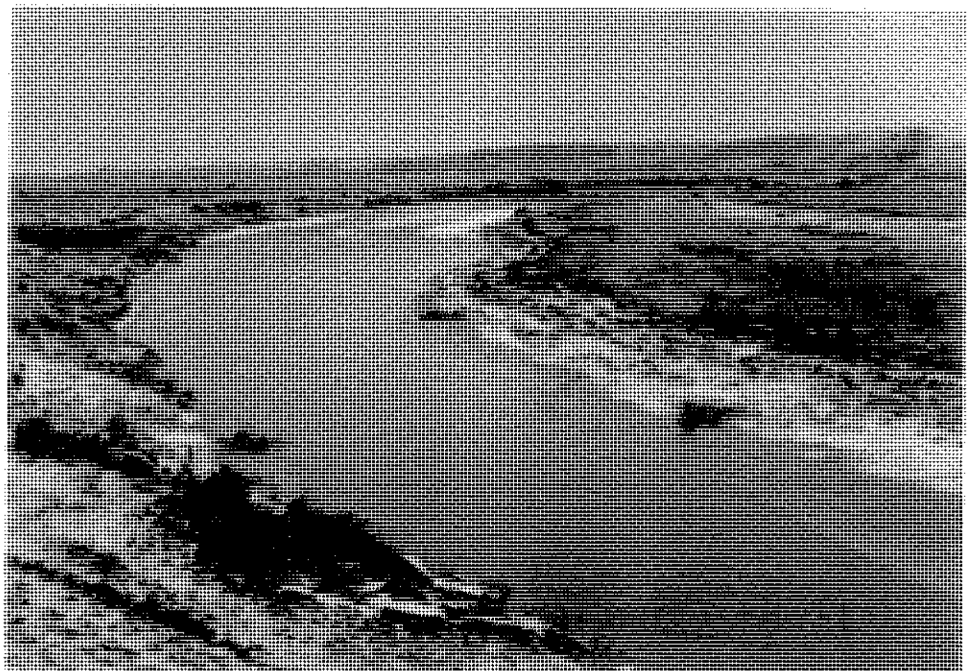
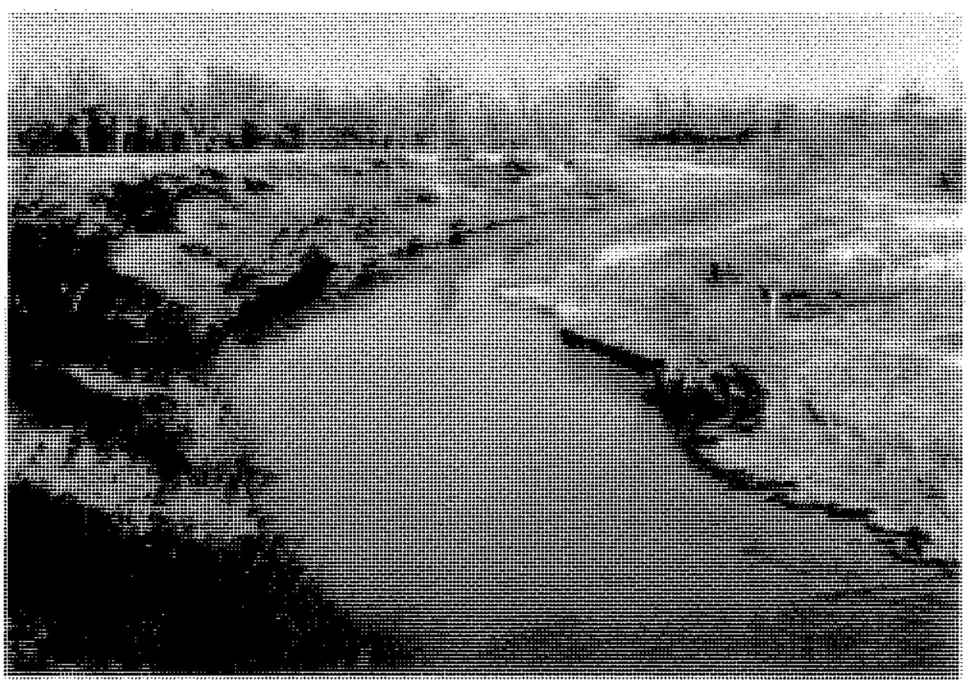
Photographs illustrating fish habitat found in the prairie streams where instream flows are requested.



Poplar River at Highway 248 crossing near Scobey, MT
Photo by Liter Spence. November 19, 1992.

East Fork Poplar River at Highway 13 crossing north of Scobey, MT.
Photo by Liter Spence. November 19, 1992.

Little Missouri River on Camp Crook Road between Alzada and Capitol, MT.
(Note riffle between pools.)
Photo by Liter Spence. November 16, 1992.



Little Missouri River at Capitol, MT.
Photo by Liter Spence. November 16, 1992.

Beaver Creek (Little Missouri River) at Highway 7 crossing near Wibaux, MT.
Photo by Liter Spence. November 17, 1992.

Box Elder Creek at Highway 323 crossing south of Ekalaka, MT.
Photo by Liter Spence. November 16, 1992.

EXHIBIT 4

C. Parrett and D.R. Johnson (1994). Estimates of Monthly Stream Flow Characteristics and Dominant Discharge Hydrographs for Selected Sites in the Lower and Little Missouri River Basins. U.S. Geological Survey Water Resources Investigations Report 94-4098.

ESTIMATES OF MONTHLY STREAMFLOW CHARACTERISTICS AND DOMINANT-DISCHARGE HYDROGRAPHS FOR SELECTED SITES IN THE LOWER MISSOURI AND LITTLE MISSOURI RIVER BASINS IN MONTANA

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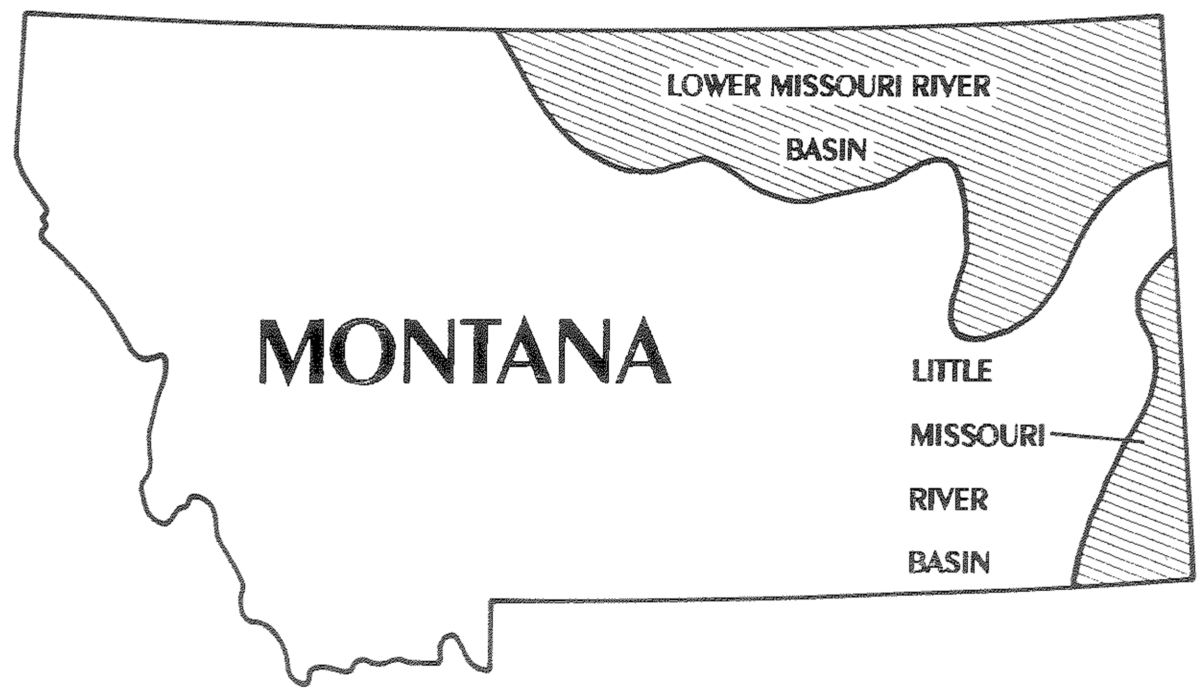

Prepared in cooperation with the

MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS

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Helena, Montana
June 1994

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
428 Federal Building
301 South Park Avenue
Drawer 10076
Helena, MT 59626-0076

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CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer

Estimates of Monthly Streamflow Characteristics and Dominant-Discharge Hydrographs for Selected Sites in the Lower Missouri and Little Missouri River Basins in Montana

By Charles Parrett and Dave R. Johnson

Abstract

Various streamflow characteristics were estimated for water-reservation purposes for 17 sites in the lower Missouri River Basin and four sites in the Little Missouri River Basin in Montana. The characteristics were mean monthly and annual streamflow and monthly mean streamflow that is exceeded 90, 80, 50, and 20 percent of the time. In addition, dominant-discharge hydrographs were estimated for 10 of the 17 sites in the lower Missouri River Basin and for all four sites in the Little Missouri River Basin. Dominant discharge, generally defined as the bankfull discharge, was considered to be equal to the peak discharge having a recurrence interval of two years.

Monthly streamflow characteristics generally were based on a common 1937-86 base period. A mixed-station record-extension program was used to estimate missing flow data during the base period for streamflow-gaging stations.

Two methods were used to estimate characteristics at ungaged sites. One method was based on correlating miscellaneous discharge measurements at the estimating site with concurrent daily mean discharges at a nearby gaged site. The second method was based on using a drainage-area ratio to transfer streamflow characteristics at a gaged site to the estimating site.

Dominant discharges for gaged sites were obtained from a previous flood-frequency report or by fitting a log-Pearson Type 3 probability distribution to recorded peak-flow data. A drainage-area-ratio adjustment was used to transfer dominant discharges from gaged sites to ungaged sites. Dominant-discharge hydrographs were determined from visual examination of recorded hydrographs having maximum daily discharges that were relatively close to the estimated dominant discharges.

INTRODUCTION

The surface-water supply for most tributary streams in the lower Missouri and Little Missouri River Basins in Montana is seasonally variable and generally unable to satisfy demands of all users. To allocate the remaining finite supply among the competing users, the State of Montana developed an administrative process enabling governmental agencies to reserve surface water for existing and future beneficial uses. Among the uses for which water may be reserved are fish, wildlife, and recreation. To establish an instream-flow reservation for these uses, the Montana Department of Fish, Wildlife and Parks (DFWP) needs to determine various streamflow characteristics. The U.S. Geological Survey (USGS) previously determined monthly streamflow characteristics for several hundred sites in the upper Missouri River Basin (Parrett and others, 1989) for water-reservation purposes. The USGS, in cooperation with DFWP, conducted the study reported here to determine streamflow characteristics at 17 sites in the lower Missouri River Basin and 4 sites in the Little Missouri River Basin for which water reservations are requested.

PURPOSE AND SCOPE

The purpose of this report is to present the estimated streamflow characteristics and data for the dominant-discharge hydrographs and to describe the methods used to make the estimates for 21 selected sites in the lower Missouri and Little Missouri River Basins in Montana. The estimates include (1) mean monthly and annual streamflow; (2) various points on the monthly mean streamflow-duration curve (monthly mean streamflow that is exceeded 90, 80, 50, and 20 percent of the time) for all 21 selected sites; and (3) dominant-discharge hydrographs for 14 of the 21 sites where DFWP considered the maintenance of existing stream-channel morphology to be important for water-reservation purposes. To ensure that estimates of monthly and annual streamflow were consistent with estimates previously made for the upper Missouri

River Basin (Parrett and others, 1989), the common base period used in the previous study (water years 1937-86) was also used in this study. The dominant-discharge hydrograph at each of the 14 sites was based on a hydrograph duration of 14 or 21 days and a maximum daily discharge equal to the dominant (bankfull) discharge. The dominant discharge was assumed to be equal to the peak discharge having a recurrence interval of 2 years.

Monthly streamflow characteristics were estimated for 17 sites in the lower Missouri River Basin between Fort Peck Lake and the Montana-North Dakota border and 4 sites in the Little Missouri River Basin in Montana (fig. 1). Of the 21 selected sites, 7 are located at streamflow-gaging stations having continuous-record streamflow data, 2 have miscellaneous discharge-measurement data, and 12 have no flow data, although a streamflow-gaging station is located on the same stream upstream or downstream from each of the 12 sites. Three of the estimation sites (18, 20, and 21) are located at the Montana border. Streamflow-gaging stations are located just downstream from all three sites, and the gaged streamflows are considered to be equivalent to those at the border. Streamflow data from nearby streamflow-gaging stations were used to estimate monthly streamflow characteristics at the 2 sites having only miscellaneous measurements and the 12 sites having no streamflow data. Of the 14 sites selected for the determination of dominant-discharge hydrographs, 10 are in the lower Missouri River Basin and 4 are in the Little Missouri River Basin. None of the 10 sites in the lower Missouri River Basin have gaged data, but a streamflow-gaging station is located on the same stream upstream or downstream from each of the 10 ungaged sites. Although all four sites in the Little Missouri River Basin have gaged data, data from one gaged site (site 21) were not used to determine a dominant-discharge hydrograph because streamflow during the short period of record was considered to be unrepresentative of long-term hydrologic conditions. Recorded streamflow data from a streamflow-gaging station on the same stream were used to estimate dominant-discharge hydrographs at each of the 10 ungaged sites and the site having a short period of record. The locations of the estimation sites and the nearby streamflow-gaging stations used for estimation purposes are shown on figure 1. The sites, types of streamflow data available, and whether dominant-discharge hydrographs were estimated are shown in table 1. The estimated monthly streamflow characteristics at the sites are presented in table 7 at the back of the report, and daily mean discharges from the estimated dominant-discharge hydrographs are presented in table 8 at the back of the report.

ESTIMATES OF MONTHLY STREAMFLOW CHARACTERISTICS

The 7 streamflow-gaging stations for which monthly streamflow characteristics were estimated and the 11 nearby gaging stations used for estimation have variable record lengths as shown in table 2. To ensure that estimated monthly streamflow characteristics were representative of the same general hydrologic conditions, a common base period of record (1937-86) was developed for 16 of the 18 stations using a streamflow record-extension program (Alley and Burns, 1983) that was previously used for the study in the upper Missouri River Basin. Monthly streamflow characteristics at the 2 mainstem Missouri River sites (sites 1 and 17) were based on the period since Fort Peck Lake was substantially filled and became operational (1943). After streamflow records were extended to the common base period, two general methods, the concurrent-measurement method and the drainage-area-ratio-adjustment method, were used to estimate monthly streamflow characteristics at ungaged sites. Both methods are based on the use of monthly streamflow characteristics at gaged sites to estimate those characteristics at ungaged sites.

Development of the common base period, 1937-86 water years

As described by Alley and Burns (1983), the streamflow record-extension program is a mixed-station program that selects the best base station from all the available streamflow-gaging stations in a region to estimate each month of missing streamflow record at a site. The criterion for selection is to use the base station that results in the smallest standard error of prediction for that station for that month. Only stations with streamflow record for a particular month were used to estimate missing values at other sites for that month; previously estimated monthly flows were not used to estimate any missing flows. To make full use of recorded flow data before 1937 and after 1986, the record-extension program was used to estimate missing monthly flows at all 18 stations for the period 1906-90. All estimated and recorded flows for the periods 1906-36 and 1987-90 were eliminated and monthly streamflow characteristics at all gaged sites except the two mainstem Missouri River sites were determined based on only the 1937-86 period. For the 2 mainstem Missouri River sites, all estimated and recorded flows for

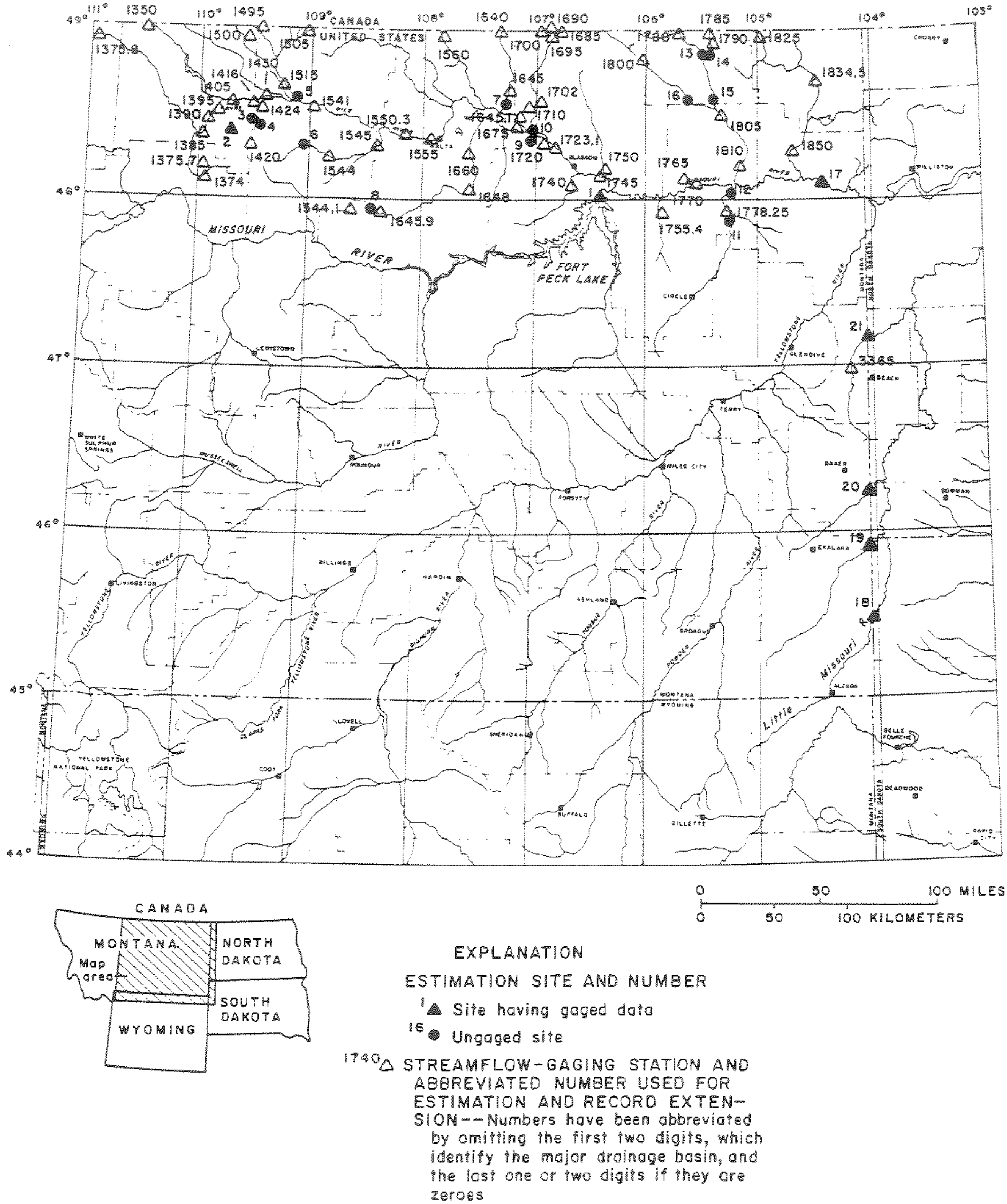


Figure 1. Location of streamflow estimation sites and streamflow-gaging stations.

Table 1. Streamflow estimation sites and available data

Site no.	Stream name	Drainage area, square miles	Type of streamflow data available: Gaged record	Miscellaneous measurement	None	Dominant-discharge hydrograph estimated
1	Missouri River below Fort Peck Dam, Mont.	57,556	X	--	--	--
2	Beaver Creek above Lower Lake, near Havre, Mont.	87.4	X	--	--	--
3	Little Boxelder Creek at Clear Creek Road, near Havre, Mont.	53.2	--	--	X	--
4	Clear Creek at Clear Creek Road crossing, near Lohman, Mont.	91.3	--	--	X	--
5	Battle Creek at mouth, near Chinook, Mont.	1,710	--	--	X	X
6	Peoples Creek at Barney Olsen Road, near Dodson, Mont.	90.6	--	--	X	--
7	Frenchman River at mouth, near Saco, Mont.	2,565	--	--	X	X
8	Beaver Creek at Fort Belknap Indian Reservation, near Zortman, Mont.	5.5	--	--	X	--
9	Beaver Creek at mouth, near Saco, Mont.	1,798	--	--	X	X
10	Rock Creek at mouth, near Hinsdale, Mont.	1,376	--	--	X	X
11	Redwater River above confluence of East Fork Redwater River, near Vida, Mont.	1,706	--	--	X	X
12	Redwater River near Vida, Mont.	2,113	--	--	X	X
13	Poplar River above confluence of East Poplar River, near Scobey, Mont.	572	--	--	X	X
14	East Poplar River at mouth, near Scobey, Mont.	755	--	--	X	X
15	Poplar River at Fort Peck Reservation boundary, near Scobey, Mont.	1,745	--	X	--	X
16	West Fork Poplar River at Fort Peck Reservation boundary, near Four Buttes, Mont.	732	--	X	--	X
17	Missouri River near Culbertson, Mont.	91,557	X	--	--	--
18	Little Missouri River at Montana-South Dakota border[1]	1,970	X	--	--	X
19	Boxelder Creek near Webster, Mont.	1,092	X	--	--	X
20	Little Beaver Creek at Montana-North Dakota border[2]	615	X	--	--	X
21	Beaver Creek at Montana-North Dakota border[3]	616	X	--	--	X

[1]Name of streamflow-gaging station is Little Missouri River at Camp Crook, S. Dak.
[2]Name of streamflow-gaging station is Little Beaver Creek near Marmarth, N. Dak.
[3]Name of streamflow-gaging station is Beaver Creek near Trotters, N. Dak.

the periods 1906-42 and 1987-90 were eliminated, and the monthly streamflow characteristics were determined based on the 1943-86 period. Base stations used for this study and their periods of record from 1906 to 1986 are shown in table 3. At one gaged site, East Poplar River at International Boundary (06178500), recorded flows prior to the completion of a reservoir in Canada in 1976 were not used in the analysis. All monthly flows for this site during the period 1937-76 were considered to be missing and were estimated using the streamflow record-extension program. Because the period 1977-86 generally was drier than normal in the lower Missouri River Basin in Montana, use of the streamflow record-extension program in this instance to estimate missing flows under regulated conditions was considered to provide a more reasonable and consistent flow record than the use of recorded, regulated flows for 1977-86 only. Table 4 shows the number of monthly flows estimated for each of the 18 stations (including the 2 mainstem Missouri River sites) using the streamflow record-extension program and the average standard error of prediction.

The average standard error of prediction shown in table 4 is the average across all months. The average standard error of prediction ranged from 18.6 percent to 176.5 percent. The number of monthly flows estimated by the streamflow-record extension program at each of the 18 sites ranged from 0 to 600. For the streamflow-gaging station, Little Box Elder Creek at mouth, near Havre (06141600), all 600 monthly flows in the base period were estimated. The only recorded flows at this station were 48 values outside the base period. At 5 other stations, more than 500 monthly flows out of the 600 in the 1937-86 base period were

Table 2. Monthly streamflow estimation sites and associated streamflow-gaging data

Site no.	Stream name	Streamflow-gaging station data: At estimation site: Number	At estimation site: Period of record	At nearby site used for estimation: Number	At nearby site used for estimation: Period of record
1	Missouri River below Fort Peck Dam, Mont.	06132000	1943-90[1]	--	--
2	Beaver Creek above Lower Lake, near Havre, Mont.	06140299[2]	1966-90	--	--
3	Little Boxelder Creek at Clear Creek Road, near Havre, Mont.	--	--	06141600	1987-90[3]
4	Clear Creek at Clear Creek Road crossing, near Lohman, Mont.	--	--	06142400	1984-90[3]
5	Battle Creek at mouth, near Chinook, Mont.	--	--	06151500	1906-21; 1944; 1984-90[3]
6	Peoples Creek at Barney Olsen Road, near Dodson, Mont.	--	--	06154400	1967-90
7	Frenchman River at mouth, near Saco, Mont.	--	--	06164000	1917-90[3]
8	Beaver Creek at Fort Belknap Indian Reservation, near Zortman, Mont.	--	--	06164590	1983-90
9	Beaver Creek at mouth, near Saco, Mont.	--	--	06166000	1920-21; 1981-90[3]
10	Rock Creek at mouth, near Hinsdale, Mont.	--	--	06169500	1916-17; 1956-77; 1978-90[3]
11	Redwater River above confluence of East Fork Redwater River, near Vida, Mont.	--	--	06177825	1976-85
12	Redwater River near Vida, Mont.	--	--	06177825	1976-85
13	Poplar River above confluence of East Poplar River, near Scobey, Mont.	--	--	06178000	1931-90[3]
14	East Poplar River at mouth, near Scobey, Mont.	--	--	06178500	1931-90[3,4]
15	Poplar River at Fort Peck Reservation boundary, near Scobey, Mont.	--	([5])	06178000	1931-90[3]
16	West Fork Poplar River at Fort Peck Reservation boundary, near Four Buttes, Mont.	--	([6])	06178000	1931-90[3]
17	Missouri River near Culbertson, Mont.	06185500	1943-52; 1958-90[1]	--	--
18	Little Missouri River at Montana-South Dakota border[7]	06334500	1906-07; 1956-90	--	--
19	Boxelder Creek near Webster, Mont.	06334630	1961-73	--	--
20	Little Beaver Creek at Montana-North Dakota border[8]	06335000	1938-79	--	--
21	Beaver Creek at Montana-North Dakota border[9]	06336600	1977-90	--	--

[1]Period of record since completion of Fort Peck Dam. Earlier record not used to calculate monthly flow characteristics.
[2] Streamflow-gaging station operated by U.S. Soil Conservation Service. Number assigned for compatibility with USGS numbers.
[3] Seasonal data only available for some periods.
[4] Recorded data before 1977 not used because of completion of Canadian reservoir, 1976. Flows for 1937-76 were estimated using streamflow record-extension program.
[5]Sixty-seven measurements of discharge are available at a site several miles downstream.
[6]Nine measurements of discharge are available.
[7]Name of streamflow-gaging station is Little Missouri River at Camp Crook, S. Dak.
[8]Name of streamflow-gaging station is Little Beaver Creek near Marmarth, N. Dak.
[9]Name of streamflow-gaging station is Beaver Creek near Trotters, N. Dak.

Table 3. Streamflow-gaging stations used in the streamflow-record extension program

Streamflow-gaging station no.	Streamflow-gaging station name	Period of record from 1906-86
06135000	Milk River at eastern crossing of International Boundary	1909-86
06137400	Big Sandy Creek at reservation boundary, near Rocky Boy, Mont.	1982-86
06137570	Boxelder Creek near Rocky Boy, Mont.	1976-86
06137580	Sage Creek near Whitlash, Mont.	1977-82;1985-86
06138500	Big Sandy Creek near Box Elder, Mont.	1927-39
06139000	Big Sandy Creek near Laredo, Mont.	1918-20
06139500	Big Sandy Creek near Havre, Mont.	1946-54;1984-86
06140299	Beaver Creek above Lower Lake, near Havre, Mont.	1966-86
06140500	Milk River at Havre, Mont.	1906-23;1954-86
06141600	Little Boxelder Creek at mouth, near Havre, Mont.	--
06142000	Clear Creek near Bearpaw, Mont.	1918-22
06142400	Clear Creek near Chinook, Mont.	1984-86
06143000	Milk River at Lohman, Mont.	1918-21;1923-26;1934-51
06149500	Battle Creek at International Boundary	1917-86
06150000	Woodpile Coulee near International Boundary	1927-77
06150500	East Fork Battle Creek near International Boundary	1927-71;1973-77
06154100	Milk River near Harlem, Mont.	1960-69;1983-86
06154410	Little Peoples Creek near Hays, Mont.	1972-86
06154500	Peoples Creek near Dodson, Mont.	1918-22;1951-73;1982-86
06155030	Milk River near Dodson, Mont.	1983-86
06155500	Milk River at Malta, Mont.	1906-22
06156000	Whitewater Creek near International Boundary	1927-80
06164000	Frenchman River at International Boundary	1917-86
06164510	Milk River at Juneberg Bridge, near Saco, Mont.	1978-86
06164800	Beaver Creek above Dix Creek, near Malta, Mont.	1967-69;1976-82
06167500	Beaver Creek near Hinsdale, Mont.	1918-21
06168500	Rock Creek at International Boundary	1914-16;1927-62
06169000	Horse Creek at International Boundary	1914-17;1927-62
06170000	McEachern Creek at International Boundary	1924-77
06170200	Willow Creek near Hinsdale, Mont.	1965-73
06171000	Rock Creek near Hinsdale, Mont.	1906-07;1912-20
06172000	Milk River near Vandalia, Mont.	1915-25;1928-39;1970-73;1983-86
06172310	Milk River at Tampico, Mont.	1974-77;1987-86
06174000	Willow Creek near Glasgow, Mont.	1954-86
06174500	Milk River at Nashua, Mont.	1940-86
06175000	Porcupine Creek at Nashua, Mont.	1908-25;1982-86
06175540	Prairie Elk Creek near Oswego, Mont.	1976-85
06176500	Wolf Creek near Wolf Point, Mont.	1908-14;1950-53;1982-86
06177000	Missouri River near Wolf Point, Mont.	1929-86
06177500	Redwater River at Circle, Mont.	1929-72;1975-84;1986
06179000	East Fork Poplar River near Scobey, Mont.	1935-40;1975-80
06180000	West Fork Poplar River near Richland, Mont.	1935-49
06180500	Poplar River near Bredette, Mont.	1934-47
06181000	Poplar River near Poplar, Mont.	1908-25;1947-69;1975-79;1982-86
06182500	Big Muddy Creek at Daleview, Mont.	1947-72
06183450	Big Muddy Creek near Antelope, Mont.	1979-86
06185000	Big Muddy Creek near Culbertson, Mont.	1908-22
06334000	Little Missouri River near Alzada, Mont.	1911-25;1928-32;1935-69
06334500	Little Missouri River at Camp Crook, S. Dak.	1957-86
06334630	Boxelder Creek near Webster, Mont.	1961-73
06335000	Little Beaver Creek near Marmarth, N. Dak.	1938-79
06336500	Beaver Creek at Wibaux, Mont.	1938-69;1979-83
06336600	Beaver Creek near Trotters, N. Dak.	1921;1938-69;1979-83

Table 4. Results from the streamflow-record extension program

Streamflow-gaging station no.	Streamflow-gaging station name	Average standard error of prediction	No. of monthly flows estimated for 1937-86, except as noted
06132000	Missouri River below Fort Peck Dam, Mont.	--	[1]0
06140299	Beaver Creek above Lower Lake, near Havre, Mont.	27.8	400
06141600	Little Boxelder Creek at mouth, near Havre, Mont.	77.2	600
06142400	Clear Creek near Chinook, Mont.	95.5	583
06151500	Battle Creek near Chinook, Mont.	78.3	588
06154400	Peoples Creek near Hays, Mont.	75.1	362
06164000	Frenchman River at International Boundary	176.5	349
06164590	Beaver Creek near Zortman, Mont.	26.6	559
06166000	Beaver Creek below Guston Coulee, near Saco, Mont.	144.3	561
06169500	Rock Creek below Horse Creek, near International Boundary	38.3	328
06177825	Redwater River near Vida, Mont.	92.0	480
06178000	Poplar River at International Boundary	86.5	192
06178500	East Poplar River at International Boundary	54.7	148
06185500	Missouri River near Culbertson, Mont.	18.6	[1]75
06334500	Little Missouri River at Camp Crook, S. Dak.	100.0	240
06334630	Boxelder Creek near Webster, Mont.	90.9	444
06335000	Little Beaver Creek near Marmarth, N. Dak.	135.9	84
06336600	Beaver Creek near Trotters, N. Dak.	71.8	507

[1]Number of estimates for 1943-86.

estimated using the streamflow-record extension program.

To determine the effect that a large average standard error of prediction coupled with a short record length might have on monthly streamflow characteristics based on a long extended record, the streamflow-record extension program was tested at one station. As shown in table 4, Little Beaver Creek near Marmarth, N. Dak. (06335000) had a large standard error of prediction (135.9 percent) but a relatively long record length (only 84 out of 600 monthly flows estimated during the 1937-86 base period). The period of record at station 06335000 used for the test was 1939-79. Monthly mean flows exceeded 90, 50, and 20 percent of the time (Q.90, Q.50, and Q.20, respectively) were calculated based on the 1943-79 period (excluding the 48 months of recorded flows prior to 1943). Then, assuming that the only recorded flows available for use in the streamflow-record extension program were the 48 monthly values for the 1939-42 period, all flows for station 06335000 during the 1943-79 period were estimated using the streamflow-record extension program. Q.90, Q.50, and Q.20 were then calculated based on the estimated flows for the 1943-79 period and compared to those calculated from the actual 1943-79 record. This test was considered to represent a situation similar to that for station 06141600 wherein a relatively small number of recorded flows (48) were available only for a period outside the selected base period. In one sense, the test represents a "worst case" situation because the standard error of prediction for station 06335000 (135.9 percent) is substantially larger than that for station 06141600 (77.2 percent).

The results of the test are displayed in figure 2. Figure 2A shows the comparison between a low-flow characteristic (Q.90) calculated from the actual 1943-79 record and that calculated from the extended record. For most months, the differences between Q.90 from the actual record and Q.90 from the extended record are within 1.0 cubic foot per second or less. The single exception is for the high-runoff month of June where the difference is about 4.0 cubic feet per second. For a medium-flow characteristic (Q.50), figure 2B shows that the only two months having a significant difference between Q.50 from the actual record and Q.50 from the extended record are the high-runoff months of March and June. The largest difference occurs in June and is about 30 cubic feet per second. Figure 2C shows the comparison for a high-flow characteristic (Q.20). Again, the only months having a significant difference between Q.20 from the actual record and Q.20 from the extended record are the high-runoff months of March and June. The largest difference in Q.20 is about 120 cubic feet per second in March. Overall, figure 2 indicates that, for the test station, monthly flow characteristics based on a period (1943-79) containing only estimated flows generally are very close to characteristics based entirely on recorded flows for the same

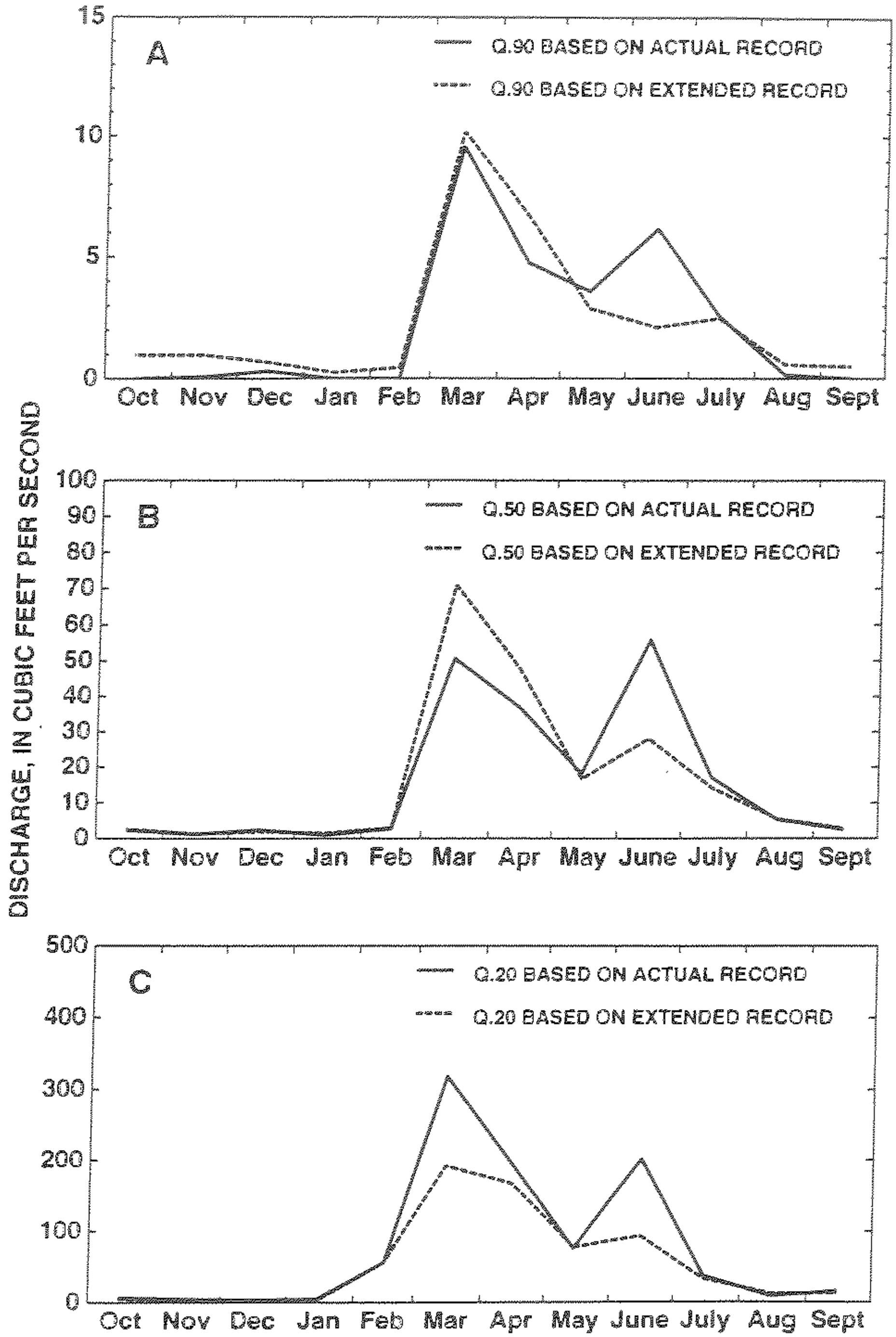


Figure 2. Monthly mean discharge exceeded 90, 50, and 20 percent of the time (Q.90, Q.50, and Q.20) for Little Beaver Creek near Marmarth, N. Dak. (06335000) as determined from actual 1943-79 record and 1943-79 extended record.

period. Flow characteristics calculated from a completely extended record are significantly different from those calculated from actual record only for months of generally high runoff, presumably because flow characteristics for those months are sensitive to a few, large recorded flows that were not duplicated by the streamflow-record extension program.

Concurrent-measurement method

One method for estimating streamflow characteristics at an ungaged site requires a series of discharge measurements at the site. The measured discharges are correlated with concurrent discharges at some nearby, hydrologically similar, gaged site, and the relation between the discharges at the two sites is used to transfer the desired long-term streamflow characteristic at the gaged site to the ungaged site. This estimation method, referred to in this report as the concurrent-measurement method, was used to estimate monthly streamflow characteristics for the 1937-86 base period at two sites (sites 15 and 16). Although Poplar River at Fort Peck Reservation boundary, near Scobey, Mont. (site 15) has no continuous-record of streamflow, 67 miscellaneous measurements of discharge were made from 1977 to 1981 at a site several miles downstream. The measured discharges were considered to be equivalent to discharges at the boundary and were used as a basis for the estimation of monthly streamflow characteristics at the boundary. Similarly, nine miscellaneous measurements of discharge made from 1975 to 1976 at West Fork Poplar River at Fort Peck Reservation boundary, near Four Buttes, Mont., (site 16) were used to estimate monthly streamflow characteristics at that ungaged site. The measured discharges at each site were presumed to be equivalent to daily mean discharges and were paired with concurrent daily mean discharges at the streamflow-gaging station Poplar River at International Boundary (station 06178000). The MOVE.1 curve-fitting technique described by Parrett and others (1989, p. 10-13) was used to develop a relation between discharge at each ungaged site and discharge at the gaged site. The relations, expressed in the form of linear equations, are as follows:

$$\log y_{15} = 0.899 + 0.743 \log x \qquad (1)$$

$$\log y_{16} = 0.520 + 0.673 \log x \qquad (2)$$

where

$\log y_{15}$ is the base 10 logarithm of discharge at site 15 in cubic feet per second,

$\log x$ is the base 10 logarithm of discharge at station 06178000 in cubic feet second, and

$\log y_{16}$ is the base 10 logarithm of discharge at site 16 in cubic feet per second.

The correlation coefficient between discharges at the correlating station (station 06178000) and sites 15 and 16 were 0.89 and 0.93, respectively. The standard errors of estimate (standard deviations of the residuals) for equations 1 and 2 were 0.368 log units and 0.188 log units, respectively. The MOVE.1 equations and the scatter about the lines described by the equations are illustrated by the graphs in figure 3. The relations for concurrent daily mean discharges were presumed to be applicable also for monthly streamflow characteristics, and equations 1 and 2 were used to calculate monthly streamflow characteristics at sites 15 and 16 from monthly streamflow characteristics at station 06178000.

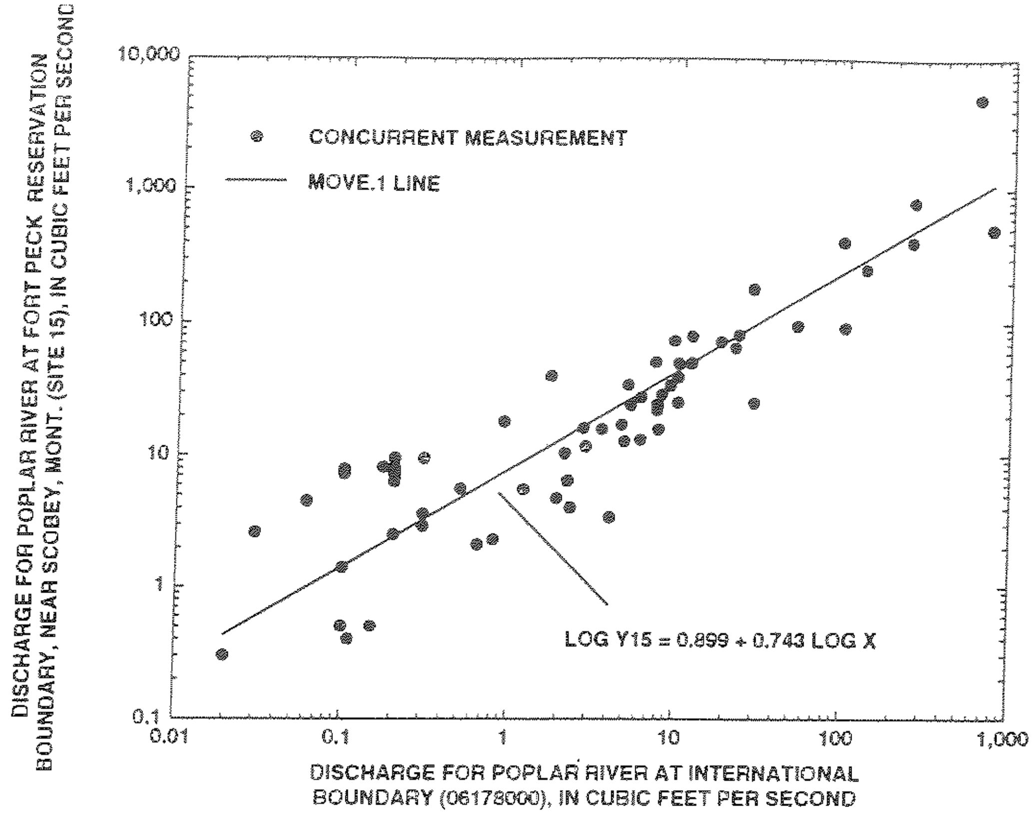
Drainage-area-ratio-adjustment method

A second method for estimating streamflow characteristics at an ungaged site requires continuous-record streamflow data from a gaged site on the same stream as the ungaged site. Long-term streamflow characteristics at the gaged site are transferred to the ungaged site by multiplying the values of the characteristics at the gaged site by the ratio of the drainage area at the ungaged site to the drainage area at the gaged site. For example, if the drainage areas at the ungaged and gaged sites are 150 and 100 square miles, respectively, each desired long-term streamflow characteristic for the ungaged site would be calculated by multiplying the value of that characteristic at the gaged site by (150/100), or 1.5.

This method for estimating streamflow characteristics at ungaged sites, termed the drainage-area-ratio-adjustment method in this report, was used to estimate monthly streamflow characteristics for 12 sites. The sites and data used for the drainage-area-ratio adjustments are shown in table 5. For the Frenchman River at mouth, near Saco (site 7), the drainage-area-ratio adjustment was applied to recorded flows at the upstream gaging station, Frenchman River at International Boundary (06164000), after subtraction of flows in the Frenchman Canal near Saco (06164500).

ESTIMATES OF REPRESENTATIVE DOMINANT-DISCHARGE HYDROGRAPHS

Dominant discharges for 14 selected sites were estimated based on recorded data at the site or at a streamflow-gaging station located on the same stream. Representative hydrographs having a maximum daily discharge equal to the dominant discharge were estimated from visual examination of selected recorded



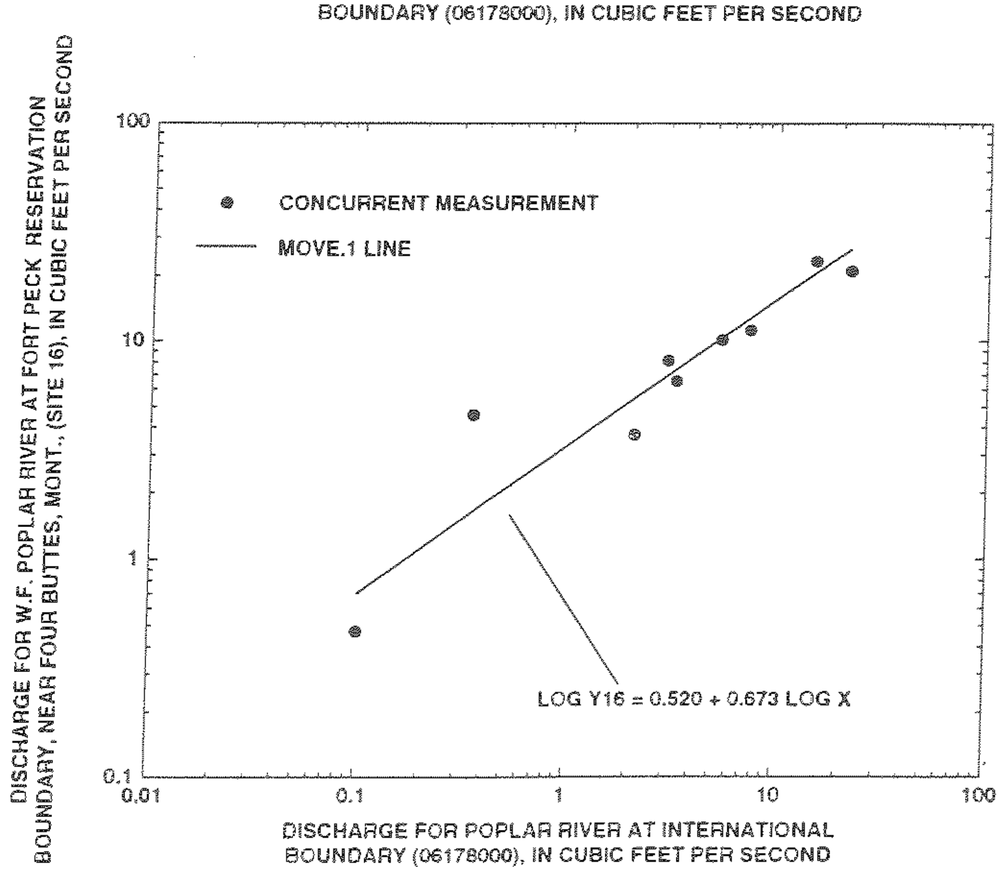


Figure 3. Relation between measured discharge at ungaged sites and concurrent discharge at gaged site, defined by the MOVE.1 curve-fitting technique.

Table 5. Estimation sites where drainage-area-ratio-adjustment method was used to estimate monthly streamflow characteristics

[mi^2, square miles]

Site no.	Stream name	Drainage area (mi^2)	Streamflow-gaging station used for estimation		Drainage-area ratio
			No.	Drainage area, (mi^2)	
3	Little Boxelder Creek at Clear Creek Road, near Havre, Mont.	53.2	06141600	95.9	0.56
4	Clear Creek at Clear Creek Road crossing, near Lohman, Mont.	91.3	06142400	135	.68
5	Battle Creek at mouth, near Chinook, Mont.	1,710	06151500	1,623	1.05
6	Peoples Creek at Barney Olsen Road, near Dodson, Mont.	90.6	06154400	220	.41
7	Frenchman River at mouth, near Saco, Mont.	2,565	06164000	2,299	[1]1.12
8	Beaver Creek at Fort Belknap Indian Reservation, near Zortman, Mont.	5.5	06164590	10.1	.54
9	Beaver Creek at mouth, near Saco, Mont.	1,798	06166000	1,200	1.50
10	Rock Creek at mouth, near Hinsdale, Mont.	1,376	06169500	328	4.20
11	Redwater River above confluence of East Fork Redwater River, near Vida, Mont.	1,706	06177825	1,974	.86
12	Redwater River near Vida, Mont.	2,113	06177825	1,974	1.07
13	Poplar River above confluence of East Poplar River, near Scobey, Mont.	572	06178000	365	1.57
14	East Poplar River at mouth, near Scobey, Mont.	755	06178500	541	1.40

[1]Flows at Frenchman Canal near Saco (06164500) were subtracted from station 06164000 before applying drainage-area-ratio adjustment factor.

hydrographs at the site or at a gaged site on the same stream.

Dominant discharge

The dominant discharge generally has been defined as the bankfull discharge (Montana Department of Fish, Wildlife and Parks, 1981; Reiser and others, 1985). The bankfull discharge, an index discharge generally considered to be important for channel formation, has been found to have a recurrence interval of 1 to 2 years for most alluvial streams (Leopold and others, 1964). Although the recurrence interval for the bankfull discharge has considerable site-to-site variability, the peak discharge having a recurrence interval of 2 years was used as the dominant discharge for all sites in this study. In this report, the term dominant discharge is used in place of the peak discharge having a recurrence interval of 2 years.

For each streamflow-gaging station used to estimate dominant discharge (table 6), the dominant discharge was based on recorded annual peak-flow data. For most stations, dominant discharges were obtained from a flood-frequency report by Omang (1992). For those stations not included in the flood-frequency report, dominant discharges were determined by fitting a log-Pearson Type 3 probability distribution to recorded annual peak discharges using procedures of the Interagency Advisory Committee on Water Data (1982) as described by Omang (1992, p. 4-8).

For each ungaged estimation site and for one gaged site (site 21) where recorded peak-discharge data were considered to be generally unrepresentative of long-term hydrologic conditions, dominant discharge was estimated by applying a drainage-area-ratio adjustment described by Omang (1992, p. 12-13) to the dominant discharge at a gaged site on the same stream. The drainage-area-ratio adjustment developed by Omang (1992) is similar to the drainage-area-ratio-adjustment method used to estimate monthly streamflow characteristics, except that the drainage-area-ratio for dominant discharge is taken to some power less than 1.0. For sites in the lower Missouri River Basin, the exponent on the drainage-area ratio is 0.69, and for sites in the Little Missouri River Basin, the exponent is 0.55 (Omang, 1992, table 2). For example, if the dominant discharge for a gaged site in the lower Missouri River Basin having a drainage area of 300 square miles was 400 cubic feet per second, and if the ungaged site on the same stream had a drainage area of 500 square miles, the estimated dominant discharge for the ungaged site would be $400 \times (500/300)^{0.69}$, or 569 cubic feet per second.

Although Omang (1992) suggested that the use of a regional equation for estimation of dominant discharge might be better than the use of the drainage-area-ratio adjustment for drainage-area ratios less than

Table 6. Dominant-discharge hydrograph estimation sites and associated streamflow-gaging station data

Site no.	Stream name	Station used to estimate dominant discharge	Period of peak-flow record	Drainage-area ratio
5	Battle Creek at mouth, near Chinook, Mont.	06151500	1906-21; 1952; 1986-90	1.05
7	Frenchman River at mouth, near Saco, Mont.	06164000	1917-90	1.11
9	Beaver Creek at mouth, near Saco, Mont.	06164800	1967-69; 1974-82; 1986	1.94
10	Rock Creek at mouth, near Hinsdale, Mont.	06169500	1917-90	4.20
11	Redwater River above confluence of East Fork Redwater River, near Vida, Mont.	06177825	1976-85	.86
12	Redwater River near Vida, Mont.	06177825	1976-85	1.07
13	Poplar River above confluence of East Poplar River, near Scobey, Mont.	06178000	1931-90	1.58
14	East Poplar River at mouth, near Scobey, Mont.	06178500	1931-90	1.40
15	Poplar River at Fort Peck Reservation boundary, near Scobey, Mont.	06181000	1909; 1915; 1921; 1923; 1946; 1948-1963; 1965-1969; 1975-1979; 1982-1989	.54
16	West Fork Poplar River at Fort Peck Reservation boundary, near Four Buttes, Mont.	06180000	1935-49; 1990	1.71
18	Little Missouri River at Montana-South Dakota border[1]	06334500	1904-06; 1957-90	--
19	Boxelder Creek near Webster, Mont.	06334630	1960-75	--
20	Little Beaver Creek at Montana-North Dakota border[2]	06335000	1938-79	--
21	Beaver Creek at Montana-North Dakota border[3]	06336500	1872; 1921; 1929; 1938-1969; 1979-1983	1.75

[1]Name of streamflow-gaging station is Little Missouri River at Camp Crook, S. Dak.
[2]Name of streamflow-gaging station is Little Beaver Creek near Marmarth, N. Dak.
[3]Name of streamflow-gaging station is Beaver Creek near Trotters, N. Dak.

0.5 or greater than 1.5, the adjustment was used in this study for drainage-area ratios as large as 4.20 (table 6). Because the regional equation for the estimation of dominant discharge developed by Omang (1992) had a relatively large standard error (equivalent to having only 3 years of gaged record), the authors believe that the drainage-area-ratio adjustments provided more reliable estimates of dominant discharge than did a regional equation.

Development of Representative Hydrograph

After the dominant discharge was estimated for each site, a representative runoff hydrograph of daily mean discharge was developed (fig. 4). Although dominant discharge estimated in this study is for an instantaneous peak, the dominant discharge was also used for the maximum daily discharge for each representative hydrograph to be consistent with previous work for DFWP (Montana Department of Fish, Wildlife and Parks, 1979; 1981). In addition, each representative hydrograph developed in this study had a duration of either 14 or 21 days to be consistent with representative hydrographs previously developed for DFWP (Montana Department of Fish, Wildlife and Parks, 1979). Limiting representative hydrograph durations to just two values is intended to simplify administration of the water reservations.

To estimate reasonable runoff hydrographs having these characteristics, flow records for each gaged site used to determine the dominant discharge were examined, and annual hydrographs having maximum daily discharges relatively close to the dominant discharge at the estimation site were selected for further analysis. For the 14 selected sites, runoff hydrographs

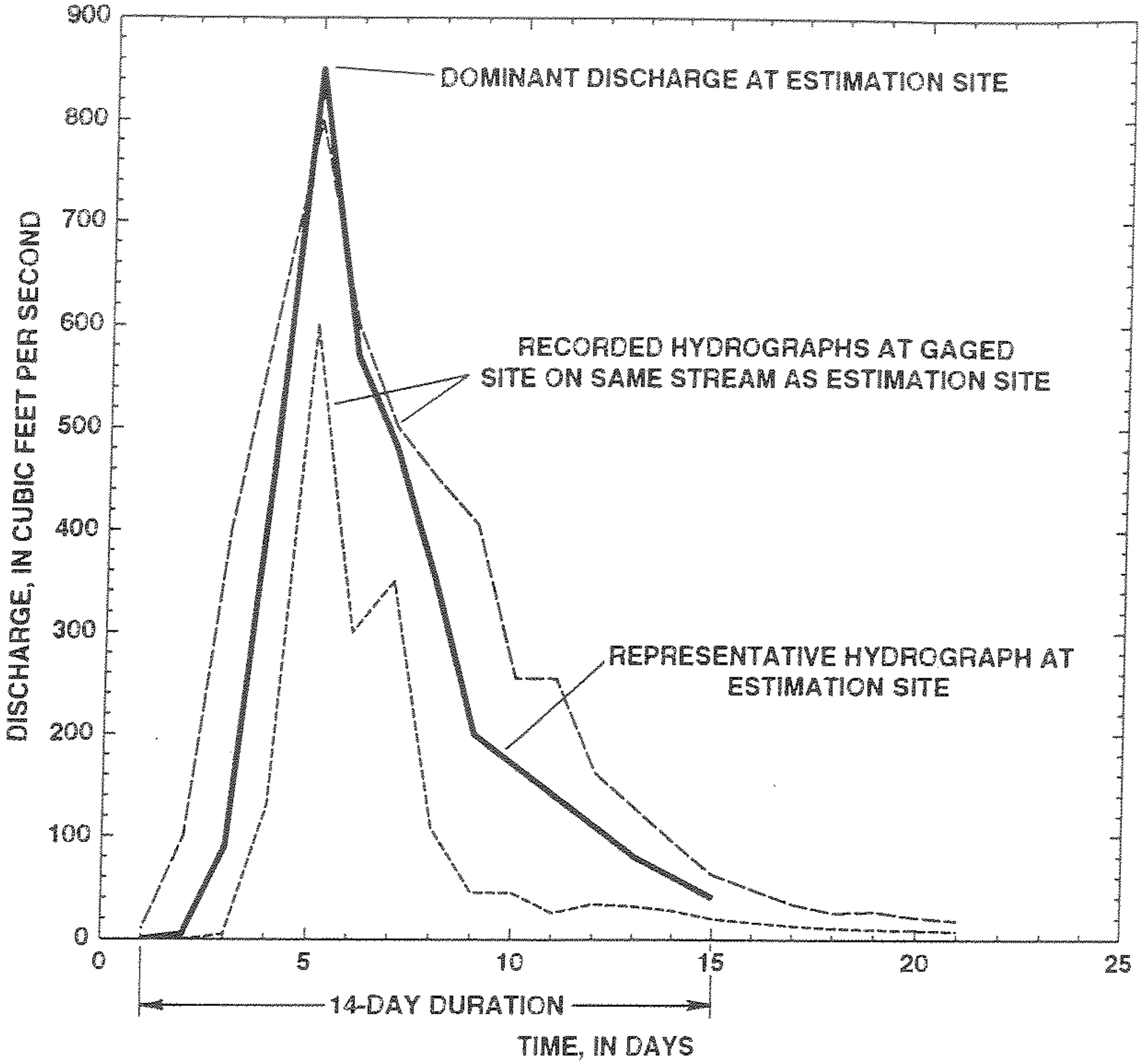


Figure 4. Development of a representative hydrograph using recorded hydrographs.

resulting from summer thunderstorms generally have durations that are shorter than 14 days. These runoff hydrographs were excluded from the analysis regardless of the maximum daily discharge value. Although the use of either 14- or 21-day durations for typical runoff hydrographs may seem overly restrictive, most recorded annual snowmelt runoff hydrographs that were analyzed had durations reasonably close to either 14 or 21 days.

Selected hydrographs were plotted together with their maximum daily discharges in alignment on a common day so that hydrograph durations and shapes could be more easily compared (fig. 4). The dominant discharge for the estimation site was also plotted on the same day as the maximum daily discharges for the recorded hydrographs. Visual examination was used to estimate values of daily discharge on either side of the dominant discharge such that the slopes of the rising and recession limbs of the representative hydrograph were in close agreement with the average slopes of the recorded hydrographs. In some instances, one or more recorded hydrographs may have had shapes that were significantly different from other recorded hydrographs. In these instances, the atypical recorded hydrographs either were not used to develop representative hydrographs or were given less weight in developing representative hydrographs.

On many recorded hydrographs, generally smooth hydrograph recession curves were interrupted by storm runoff. The resultant sudden increases in flow on the recession curves were ignored in the determination of representative discharge values. The representative values of daily discharge generally were visually determined average values of several recorded hydrographs. In some instances, however, the representative values of discharge were determined largely from one recorded hydrograph that was considered to be most representative of normal, long-term runoff conditions. The choice of a 14- or 21-day duration for the representative hydrograph was somewhat arbitrary, but was largely based on the following criteria: (1) the discharge values for the first and last day had to be close to base flow, and (2) the slope of the recession limb of the hydrograph had to be fairly constant so that successive values of discharge near the end of the duration were not repeated. In some instances, the first criterion was not fully met because the best value for a representative hydrograph duration was probably greater than 21 days. In some instances, the second criterion was not fully met because the best value for a representative hydrograph duration was probably less than 14 days.

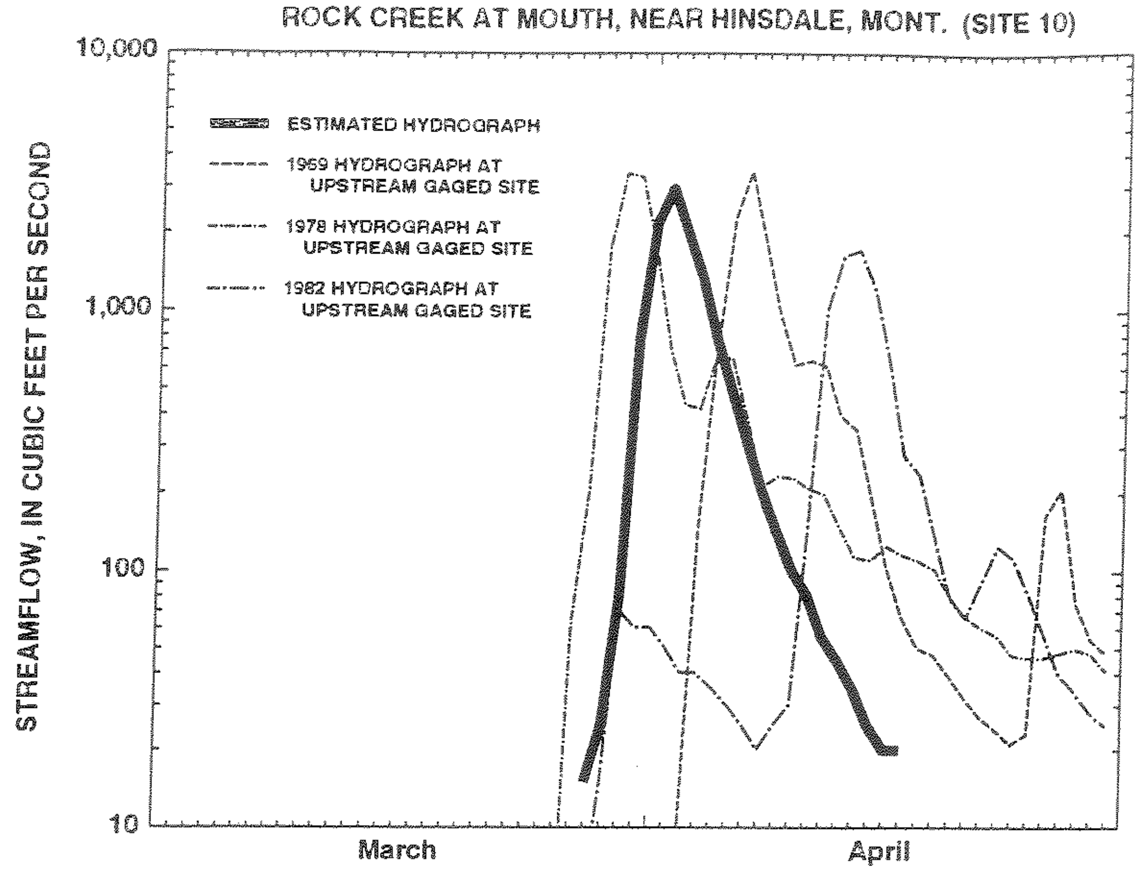
The estimated dominant discharge, hydrograph duration (either 14 or 21 days), and values of discharge on the rising and recession limbs of the hydrograph were used to plot a dominant-discharge hydrograph for each site. From the plot, daily discharges were determined for each day of the selected duration period. Dominant-discharge hydrographs for two sites are compared to the selected recorded hydrographs from which they were developed in figure 5. Recorded hydrographs in figure 5 are shown on the actual days of occurrence. The dates on the dominant discharge hydrographs in figure 5 are arbitrary and were selected so that all hydrographs could be easily compared. Because estimated discharges were rounded, the dominant-discharge hydrographs shown in figure 5 are not completely smooth throughout the rising and recession limbs. As indicated in figure 5, the dominant-discharge hydrographs are similar in shape to the recorded hydrographs and are considered to be reasonably representative of general runoff conditions at the gaged sites where the data were recorded. In one instance, Rock Creek at mouth, near Hinsdale (site 10), the selected recorded hydrographs used to develop the dominant-discharge hydrograph were for a gaged site having a drainage area less than one-fourth that of the estimation site. Although the dominant discharge was estimated based on a drainage-area-ratio adjustment, no such adjustments are available for hydrograph characteristics such as duration and slopes of the rising and recession limbs. Natural hydrographs at ungaged estimation sites thus may have different durations and shapes from those of the estimated dominant-discharge hydrographs, particularly if the difference in drainage area between the gaged and ungaged sites is large.

RELIABILITY OF ESTIMATES

Although the reliability of the estimates of monthly flow characteristics and dominant-discharge hydrographs cannot be directly measured, some inferences can be made based on findings of the previous study for the upper Missouri River Basin (Parrett and others, 1989) and the results of the test of the streamflow-record extension method described earlier. As described by Parrett and others (1989), estimates of monthly flow characteristics at gaged sites generally are the most accurate and, if the record spans the base period, the only error is measurement error. Measurement error is generally small and, for purposes of this report, will be ignored. On that basis, the estimated flows for the Missouri River below Fort Peck Dam (site 1) are considered to be virtually error free because the recorded flow record for the 1943-86 period is complete. For the other gaged sites, the error of estimation is due solely to the error of the record-extension method. The error of the record-extension method depends on the length of record and the average standard error of prediction. The shorter the length of actual record and the larger the average standard error of prediction, the greater the error.

The test of the streamflow-record extension method that was described earlier in this report found that the error of record extension was significant only during months of generally high runoff. Although the test was not rigorous, it did represent a probable "worst-case" situation wherein the standard error of prediction for the streamflow-record extension method was relatively large and all flows during the selected base period were estimated. The test results suggest that record-extension errors probably are not significant for most monthly streamflow characteristics for most months at streamflow-gaging stations used in the study. Parrett and others (1989) found that record-extension errors in the upper Missouri River Basin generally were less, even for record lengths as short as 5 years, than the errors resulting from estimation based on regional regression equations or the concurrent-measurement method at ungaged sites.

For the two ungaged sites where the concurrent-measurement method was used, the error of estimation depends upon the number of concurrent measurements and the degree of correlation between the estimation site and the nearby gaged site. Because of the greater number of measurements spanning a greater range in flow, the estimated monthly flow characteristics for Poplar River at Fort Peck Reservation boundary, near Scobey (site 15) are considered to be more reliable than the estimated monthly flow characteristics for West Fork Poplar River at Fort Peck Reservation boundary,



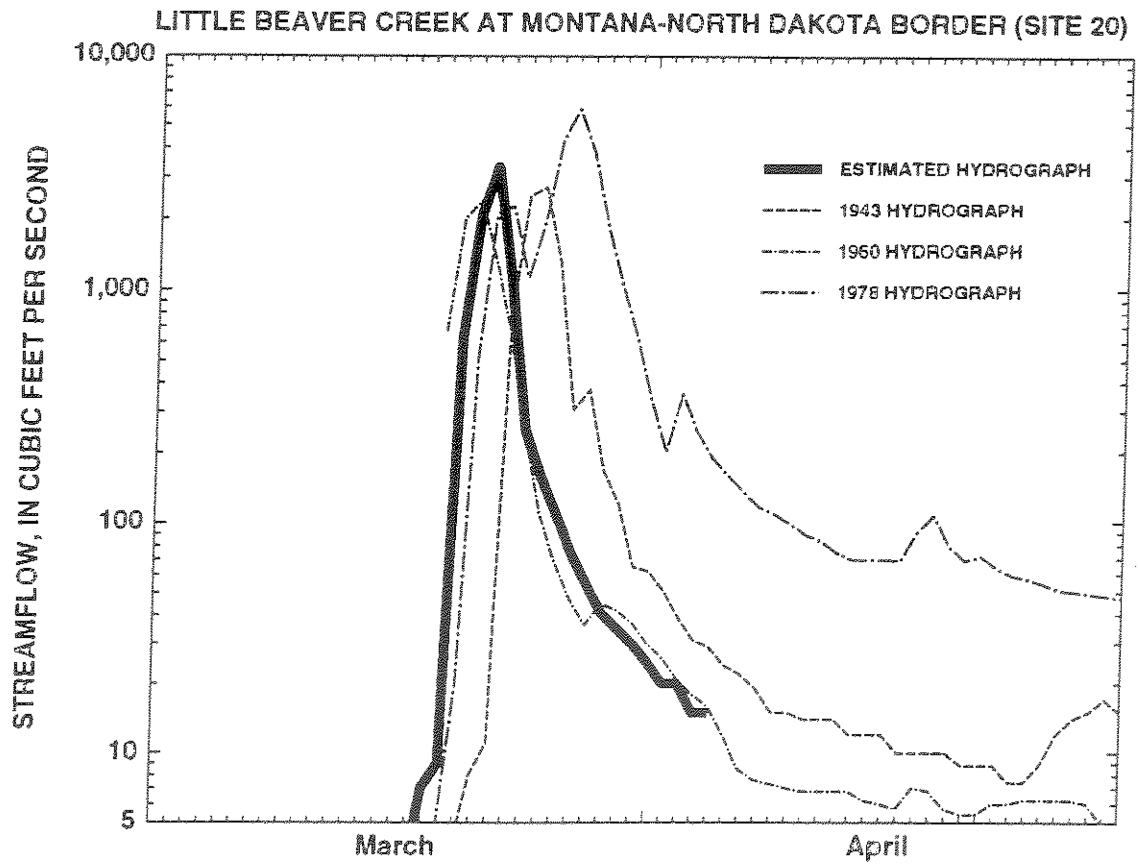


Figure 5. Dominant-discharge hydrographs and selected recorded hydrographs at selected streams in Montana.

near Four Buttes (site 16). Based on the value of the correlation coefficient, the degree of correlation between the estimation site and the gaged site was considered to be relatively good.

The reliability of the estimated monthly flow characteristics for sites where the drainage-area-ratio-adjustment factor was used is primarily dependentupon the difference in hydrologic characteristics between the gaged and ungaged sites. To the degree that the difference in hydrologic characteristics is related to drainage area difference, the reliability depends upon the drainage-area ratio. For sites where the drainage-area ratio is close to 1.0, the reliability of flow estimates is considered to be almost as good as for gaged sites. For sites where the ratio is less than about 0.5 or greater than about 1.5, the reliability is considered to be significantly less than for gaged sites.

The reliability of the estimated dominant-discharge hydrographs is difficult to determine because there is no single runoff hydrograph to which each dominant-discharge hydrograph can be compared. Statements about the reliability of dominant-discharge hydrograph estimates thus are more general than for estimates of monthly flow characteristics. In general, the estimated dominant-discharge hydrographs for gaged sites are considered to be more reliable than those for ungaged sites. As noted previously, however, the dominant-discharge hydrograph for site 21 (Beaver Creek near Trotters, N. Dak.), was based on a different streamflow-gaging station than the one near the site. In this instance, considering the site to be ungaged and using the drainage-area-ratio adjustment provided a more reliable dominant-discharge hydrograph than did the gaged record.

For ungaged sites in general, the closer the drainage-area ratio is to 1.0, the more reliable is the estimated dominant discharge. On that basis, the estimated dominant discharges for Battle Creek at mouth, near Chinook (site 5) and Redwater River near Vida (site 12) are considered to be the most reliable, and the estimated dominant-discharge for Rock Creek at mouth, near Hinsdale (site 10) is considered to be the least reliable. The reliability of the dominant-discharge hydrographs is also related to the number of recorded hydrographs used for visual comparison and the degree of similarity among them. On that basis, the dominant-discharge hydrograph for Redwater River near Vida, although having one of the more reliable dominant discharge estimates, is one of the least reliable hydrographs overall because the recorded hydrographs used for visual comparison had widely varying shapes. On the other hand, the dominant-discharge hydrograph for West Fork Poplar River at Fort Peck Reservation boundary, near Four Buttes (site 16) is considered to be one of the most reliable because the recorded hydrographs on which it is based had fairly consistent hydrograph shapes.

SUMMARY

To establish an instream-flow reservation in the lower Missouri River and Little Missouri River Basins for fish, wildlife, and recreation purposes, DFWP requires information about various streamflow characteristics. USGS, in cooperation with DFWP, conducted a study to determine streamflow characteristics at 17 sites in the lower Missouri River Basin and 4 sites in the Little Missouri River Basin in Montana. Mean monthly and annual streamflow and monthly mean streamflow exceeded 90, 80, 50, and 20 percent of the time was estimated for all 21 sites. Streamflow-gaging stations were located at 7 of the selected sites, and the streamflow record was used as a basis for determining the monthly streamflow characteristics. For each of the 14 ungaged sites, streamflow records from nearby gaging stations were used as a basis for estimating streamflow characteristics.

For all sites but two on the Missouri River mainstem, the streamflow estimates were based on a common 1937-86 base period. For the two Missouri River sites, streamflow characteristics were estimated based on the period of record since Fort Peck Lake was substantially filled and became operational (1943-86). A streamflow record-extension program was used to estimate missing values of monthly flow during the 1937-86 base period at streamflow-gaging stations used to estimate flow characteristics at the selected sites.

For two ungaged sites in the Poplar River Basin, miscellaneous measurements of discharge were correlated with concurrent daily mean discharges at the streamflow-gaging station Poplar River at International Boundary (station 06178000) using the MOVE.1 curve-fitting technique. The resultant log-linear equations relating discharge at the ungaged sites to discharge at the Poplar River at International Boundary were used to estimate monthly streamflow characteristics at the ungaged sites.

For each of the other 12 ungaged sites, monthly streamflow characteristics at a streamflow-gaging station located on the same stream were used to estimate monthly streamflow characteristics at the ungaged site using a drainage-area-ratio-adjustment method. The ratio of the drainage area at the ungaged site to the drainage area at the gaged site was multiplied by the value of each monthly streamflow characteristic at the gaged site to estimate the value of the characteristic at the ungaged site. An adaptation of the drainage-area-ratio-adjustment method was used to estimate monthly streamflow characteristics for Frenchman River at mouth, near Saco. For this site, the drainage-area-ratio adjustment was applied to streamflow characteristics developed from flow records at Frenchman River at International Boundary (station 06164000) minus flow records for Frenchman Canal near Saco (station 06164500).

Dominant-discharge hydrographs were estimated for 10 ungaged sites in the lower Missouri River Basin and 4 gaged sites in the Little Missouri River Basin. The dominant discharge was considered to be equivalent to the peak discharge having a recurrence interval of 2 years and, for 3 of the 4 gaged sites, was determined from recorded data at the streamflow-gaging stations. For each of the 10 ungaged sites and 1 gaged site, the dominant discharge was determined by multiplying the dominant discharge at a gaged site on the same stream by a drainage-area-ratio adjustment. Dominant discharges at all gaged sites were obtained from a USGS flood-frequency report or by fitting a log-Pearson Type 3 probability distribution to the recorded data.

For each of the 14 selected sites, the dominant discharge was used as the maximum daily discharge for the dominant-discharge hydrograph. Visual examination of selected recorded hydrographs from each gaged site used to determine dominant discharge was used to determine the duration and daily mean discharges on the rising and recession limbs of the dominant-discharge hydrograph.

Based on results of a previous study for the upper Missouri River Basin, the estimates of monthly streamflow characteristics are considered to be most reliable for gaged sites. Ignoring measurement error, estimates for one Missouri River site (site 1) are virtually error free because the estimates are based on gaged records with no months of missing flow data. The reliability of the monthly streamflow estimates for two sites (sites 15 and 16) using the concurrent-measurement method is considered to be almost as good as that for gaged sites. Likewise, the estimates of monthly streamflow based on the drainage-area-ratio-adjustment method for sites where the drainage-area ratios are close to 1.0 are considered to be almost as reliable as those for gaged sites.

The reliability of the estimated dominant-discharge hydrographs is difficult to assess. In general, the estimates made at gaged sites are better than those made for ungaged sites except for Beaver Creek at Montana-North Dakota border (site 21). At ungaged sites, the closer the drainage-area ratio is to 1.0 the more reliable is the estimate for dominant discharge. The reliability of representative hydrographs developed from recorded hydrographs generally is related to the degree of similarity of the recorded hydrographs and the distance from the estimation site to the gaged site.

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SUPPLEMENTAL DATA

Table 7. Estimated monthly and annual streamflow characteristics

[Q.XX, monthly mean streamflow exceeded XX percent of the time, in cubic feet per second; QM, mean streamflow for specified month, or mean annual streamflow when Annual is specified, in cubic feet per second]

Site no.	Stream name	Month	Q.90	Q.80	Q.50	Q.20	QM
1	Missouri River below Fort Peck Dam, Mont.	October	5,200	6,060	11,500	19,100	12,600
		November	4,590	5,800	9,210	13,200	9,460
		December	5,150	6,880	10,100	11,300	9,040
		January	4,470	6,640	10,900	13,000	9,620
		February	2,130	5,500	10,900	14,100	9,600
		March	1,250	4,130	7,740	11,200	7,620
		April	2,120	4,430	7,520	10,500	7,440
		May	2,800	5,500	7,380	12,000	8,310
		June	2,500	4,170	7,900	12,700	8,420
		July	3,640	5,770	10,000	13,200	10,300
		August	5,980	7,720	12,100	18,900	13,000
		September	5,900	7,020	11,900	18,800	13,000
		Annual	--	--	--	--	9,870
2	Beaver Creek above Lower Lake, near Havre, Mont.	October	3	4	7	12	9
		November	4	4	7	12	9
		December	2	2	6	11	7
		January	4	5	7	8	7
		February	7	7	8	13	10
		March	7	8	18	33	20
		April	12	14	23	39	27
		May	17	18	23	126	54
		June	14	19	38	74	49
		July	3	4	11	31	18
		August	2	3	5	13	8
		September	2	2	4	10	7
		Annual	--	--	--	--	19
3	Little Boxelder Creek at Clear Creek Road, near Havre, Mont.	October	0	0	.2	3	1
		November	0	0	.3	3	1
		December	0	0	.3	2	1
		January	0	0	.2	1	2
		February	0	0	.7	6	4
		March	.4	3	6	18	11
		April	.6	1	5	17	11
		May	.1	1	3	18	15
		June	.1	.4	3	15	11
		July	0	0	1	7	5
		August	0	0	.2	2	1
		September	0	0	.2	1	1
		Annual	--	--	--	--	5
4	Clear Creek at Clear Creek Road crossing, near Lohman, Mont.	October	0	0	.2	2	1
		November	0	.1	.5	3	2
		December	0	.1	.6	3	2
		January	0	0	.5	1	2
		February	0	.1	.9	6	6
		March	.5	.8	9	34	23
		April	.7	1	6	23	16
		May	.2	2	6	32	29
		June	.1	.5	6	27	20
		July	0	.1	2	10	5
		August	0	0	.1	2	1
		September	0	0	0	.7	1
		Annual	--	--	--	--	9

Table 7. Estimated monthly and annual streamflow characteristics (Continued)

Site no.	Stream name	Month	Q.90	Q.80	Q.50	Q.20	QM
5	Battle Creek at mouth, near Chinook, Mont.	October	0	0	.5	16	7
		November	0	0	.3	10	5
		December	0	0	.3	7	4
		January	0	0	.1	2	2
		February	0	0	1	14	12
		March	0	.1	15	93	54
		April	0	4	31	85	146
		May	0	.5	34	116	75
		June	0	.1	21	47	40
		July	0	.1	12	26	14
		August	0	.1	.5	8	6
		September	0	0	.3	7	24
		Annual	--	--	--	--	32
6	Peoples Creek at Barney Olsen Road, near Dodson, Mont.	October	0	0	.5	2	1
		November	0	0	.5	2	1
		December	0	0	.4	2	.9
		January	0	0	.4	1	1
		February	0	0	1	6	4
		March	.5	2	7	18	13
		April	3	4	7	18	11
		May	.6	1	4	17	12
		June	.4	1	6	20	12
		July	0	0	2	8	4
		August	0	0	.2	2	1
		September	0	0	0	.9	1
		Annual	--	--	--	--	5
7	Frenchman River at mouth, near Saco, Mont.	October	0	0	3	13	10
		November	.7	2	5	11	7
		December	0	.1	2	7	3
		January	0	0	.3	3	2
		February	0	0	.8	7	17
		March	3	13	76	199	151
		April	23	52	239	755	460
		May	10	17	59	195	139
		June	0	1	21	94	58
		July	0	0	13	37	41
		August	0	0	4	13	9
		September	0	0	2	8	6
		Annual	--	--	--	--	75
8	Beaver Creek at Fort Belknap Indian Reservation, near Zortman, Mont.	October	.2	.3	.4	.5	.4
		November	.2	.3	.5	1	.3
		December	.1	.2	.3	.5	.3
		January	0	0	.2	.3	.2
		February	0	.1	.2	.3	.2
		March	.2	.3	.5	.5	.5
		April	.2	.3	.5	1	.5
		May	.2	.2	.5	2	1
		June	.1	.2	1	3	2
		July	.1	.3	.5	1	1
		August	.1	.1	.5	1	.5
		September	.2	.2	.4	.5	.5
		Annual	--	--	--	--	.6

Table 7. Estimated monthly and annual streamflow characteristics (Continued)

Site no.	Stream name	Month	Q.90	Q.80	Q.50	Q.20	QM
9	Beaver Creek at mouth, near Saco, Mont.	October	0	.2	5	38	27
		November	2	2	5	18	11
		December	2	2	5	13	8
		January	1	2	3	8	7
		February	2	2	9	58	47
		March	6	21	80	339	204
		April	2	5	25	225	198
		May	3	18	91	643	329
		June	4	7	35	207	133
		July	2	3	27	129	85
		August	1	2	14	29	18
		September	.2	.2	2	21	48
		Annual	--	--	--	--	93
10	Rock Creek at mouth, near Hinsdale, Mont.	October	1	2	7	13	8
		November	3	4	7	10	8
		December	2	2	3	5	3
		January	0	0	.8	3	2
		February	0	0	2	11	16
		March	1	18	151	738	354
		April	39	59	239	1130	508
		May	16	20	46	164	84
		June	9	14	34	115	70
		July	2	5	13	59	36
		August	0	0	.4	6	15
		September	0	0	.4	6	15
		Annual	--	--	--	--	93
11	Redwater River above confluence of East Fork Redwater River, near Vida, Mont.	October	.7	1	3	6	4
		November	2	2	3	4	4
		December	.6	1	3	4	3
		January	0	0	.6	2	2
		February	.6	1	3	67	52
		March	7	14	77	221	213
		April	5	9	24	62	109
		May	4	5	11	34	21
		June	2	4	13	101	70
		July	.6	2	6	52	35
		August	.6	.7	2	6	4
		September	1	1	1	4	3
		Annual	--	--	--	--	43
12	Redwater River near Vida, Mont.	October	.9	1	3	7	4
		November	2	2	4	5	4
		December	.7	2	3	4	3
		January	0	0	.9	2	2
		February	.7	2	4	83	64
		March	10	17	95	274	263
		April	6	12	30	77	135
		May	5	6	14	43	27
		June	2	5	16	125	87
		July	.7	2	7	64	43
		August	.7	.9	2	7	5
		September	1	1	2	4	4
		Annual	--	--	--	--	53

Table 7. Estimated monthly and annual streamflow characteristics (Continued)

Site no.	Stream name	Month	Q.90	Q.80	Q.50	Q.20	QM
13	Poplar River above confluence of East Poplar River, near Scobey, Mont.	October	.3	1	4	6	4
		November	1	2	4	6	4
		December	0	.7	2	4	2
		January	0	0	.4	2	1
		February	0	0	.6	4	4
		March	.4	13	62	207	115
		April	14	18	60	353	168
		May	8	11	20	47	32
		June	3	5	13	31	26
		July	.5	1	4	10	12
		August	.2	.2	.5	3	3
		September	.2	.2	.7	3	2
		Annual	--	--	--	--	31
14	East Poplar River at mouth, near Scobey, Mont.	October	2	3	4	4	4
		November	2	3	4	4	4
		December	2	3	4	4	3
		January	2	2	4	4	3
		February	2	3	4	5	4
		March	4	4	5	74	33
		April	4	4	9	163	68
		May	5	9	15	37	20
		June	4	4	5	26	18
		July	3	3	4	6	5
		August	3	3	4	5	5
		September	3	3	4	4	4
		Annual	--	--	--	--	14
15	Poplar River at Fort Peck Reservation boundary, near Scobey, Mont.	October	2	7	16	21	17
		November	5	8	16	22	17
		December	0	0	9	15	11
		January	0	0	2	9	8
		February	0	0	4	15	16
		March	3	39	122	298	192
		April	41	50	119	443	255
		May	27	34	52	99	74
		June	13	20	39	73	64
		July	3	6	16	31	35
		August	1	1	3	14	12
		September	1	1	4	13	11
		Annual	--	--	--	--	59
16	West Fork Poplar River at Fort Peck Reservation boundary, near Four Buttes, Mont.	October	1	3	6	8	7
		November	2	3	6	8	7
		December	0	2	4	6	4
		January	0	0	1	4	3
		February	0	0	2	6	6
		March	1	14	40	89	60
		April	15	17	39	127	77
		May	10	12	18	33	25
		June	5	8	14	25	22
		July	1	3	6	12	13
		August	.7	.7	1	6	5
		September	.7	.7	2	5	4
		Annual	--	--	--	--	19

Table 7. Estimated monthly and annual streamflow characteristics (Continued)

Site no.	Stream name	Month	Q.90	Q.80	Q.50	Q.20	QM
17	Missouri River near Culbertson, Mont.	October	5,520	6,430	11,500	18,900	12,800
		November	4,610	6,320	9,290	13,100	9,800
		December	5,380	6,960	9,620	11,600	8,950
		January	4,620	6,160	11,000	12,700	9,490
		February	2,390	6,020	11,200	14,400	10,200
		March	4,150	5,420	10,700	14,400	10,400
		April	4,950	7,470	10,900	16,900	11,900
		May	3,270	6,050	9,260	14,800	10,000
		June	4,480	5,440	8,620	13,800	9,780
		July	5,160	6,430	9,940	13,500	11,000
		August	6,470	7,670	12,200	19,200	13,000
		September	6,620	7,420	12,100	19,100	13,200
		Annual	--	--	--	--	10,900
18	Little Missouri River at Montana-South Dakota border[1]	October	2	3	4	18	55
		November	3	3	5	8	8
		December	2	3	5	7	5
		January	1	1	3	6	6
		February	1	2	6	39	68
		March	15	38	192	613	359
		April	8	26	72	532	282
		May	9	17	71	639	319
		June	9	22	230	790	418
		July	5	14	46	119	86
		August	1	4	16	71	38
		September	2	2	5	53	40
		Annual	--	--	--	--	140
19	Boxelder Creek near Webster, Mont.	October	2	2	5	12	32
		November	3	4	6	8	7
		December	2	2	4	6	5
		January	2	2	3	6	4
		February	.9	1	5	48	44
		March	15	21	95	398	211
		April	11	17	58	285	257
		May	7	15	48	255	149
		June	13	25	123	263	174
		July	3	6	32	72	50
		August	1	2	10	37	22
		September	.9	2	5	27	21
		Annual	--	--	--	--	81
20	Little Beaver Creek at Montana-North Dakota border[2]	October	0	.4	2	6	10
		November	.3	1	3	4	3
		December	0	.5	2	3	3
		January	0	0	1	4	4
		February	0	.3	3	46	27
		March	9	14	52	266	149
		April	5	9	28	133	113
		May	5	6	16	49	42
		June	5	15	53	138	83
		July	2	4	15	37	29
		August	.2	1	4	9	10
		September	0	.3	3	14	13
		Annual	--	--	--	--	41

Table 7. Estimated monthly and annual streamflow characteristics (Continued)

Site no.	Stream name	Month	Q.90	Q.80	Q.50	Q.20	QM
21	Beaver Creek at Montana-North Dakota border[3]	October	0	0	.3	2	1
		November	0	0	.4	2	3
		December	0	.2	1	2	1
		January	0	0	.6	2	2
		February	.1	.7	5	63	39
		March	8	14	71	429	181
		April	4	7	23	140	111
		May	.8	1	8	24	14
		June	.9	3	10	55	35
		July	.1	.6	5	25	39
		August		0	0	.3	3
		September	0	0	.3	2	.7
		Annual	--	--	--	--	36

[1]Name of streamflow-gaging station is Little Missouri River at Camp Crook, S. Dak.
[2]Name of streamflow-gaging station is Little Beaver Creek near Marmarth, N. Dak.
[3]Name of streamflow-gaging station is Beaver Creek near Trotters, N. Dak.

Table 8. Daily mean discharges from the estimated dominant-discharge hydrographs

Site no.	Stream name	Day	Daily mean discharge, in cubic feet per second
5	Battle Creek at mouth, near Chinook, Mont.	1	40
		2	90
		3	210
		4	470
		5	1,520
		6	710
		7	260
		8	130
		9	100
		10	85
		11	70
		12	60
		13	55
		14	45
7	Frenchman River at mouth, near Saco, Mont.	1	10
		2	30
		3	50
		4	70
		5	150
		6	290
		7	450
		8	740
		9	1,320
		10	1,010
		11	760
		12	580
		13	470
		14	360
		15	280
		16	200
		17	160
		18	120
		19	90
		20	70
		21	60
9	Beaver Creek at mouth, near Saco, Mont.	1	10
		2	190
		3	880
		4	2,210
		5	1,750
		6	1,180
		7	640
		8	500
		9	390
		10	300
		11	210
		12	180
		13	150
		14	120
		15	100
		16	80
		17	60
		18	40
		19	20
		20	10
		21	10

Table 8. Daily mean discharges from the estimated dominant-discharge hydrographs (Continued)

Site no.	Stream name	Day	Daily mean discharge, in cubic feet per second
10	Rock Creek at mouth, near Hinsdale, Mont.	1	15
		2	25
		3	80
		4	780
		5	1,900
		6	2,560
		7	1,750
		8	1,260
		9	760
		10	480
		11	310
		12	200
		13	140
		14	100
		15	80
		16	55
		17	45
		18	35
		19	25
		20	20
		21	20
11	Redwater River above confluence of East Fork Redwater River, near Vida, Mont.	1	0
		2	20
		3	60
		4	180
		5	370
		6	780
		7	540
		8	340
		9	230
		10	120
		11	100
		12	80
		13	60
		14	40
12	Redwater River near Vida, Mont.	1	5
		2	70
		3	110
		4	300
		5	490
		6	900
		7	700
		8	480
		9	290
		10	180
		11	150
		12	130
		13	110
		14	90

Table 8. Daily mean discharges from the estimated dominant-discharge hydrographs (Continued)

Site no.	Stream name	Day	Daily mean discharge, in cubic feet per second
13	Poplar River above confluence of East Poplar River, near Scobey, Mont.	1	40
		2	150
		3	670
		4	1,000
		5	670
		6	320
		7	160
		8	110
		9	80
		10	60
		11	50
		12	30
		13	20
		14	20
14	East Poplar River at mouth, near Scobey, Mont.	1	2
		2	6
		3	10
		4	60
		5	280
		6	540
		7	330
		8	200
		9	80
		10	60
		11	20
		12	9
		13	7
		14	5
15	Poplar River at Fort Peck Reservation boundary, near Scobey, Mont.	1	50
		2	200
		3	880
		4	1,930
		5	1,530
		6	1,000
		7	820
		8	600
		9	400
		10	300
		11	220
		12	170
		13	120
		14	70
16	West Fork Poplar River at Fort Peck Reservation boundary, near Four Buttes, Mont.	1	5
		2	90
		3	450
		4	850
		5	570
		6	480
		7	350
		8	200
		9	170
		10	140
		11	110
		12	80
		13	60
		14	40

Table 8. Daily mean discharges from the estimated dominant-discharge hydrographs (Continued)

Site no.	Stream name	Day	Daily mean discharge, in cubic feet per second
18	Little Missouri River at Montana-South Dakota border[1]	1	10
		2	15
		3	20
		4	75
		5	290
		6	1,450
		7	2,540
		8	2,320
		9	1,670
		10	1,150
		11	940
		12	760
		13	600
		14	430
		15	280
		16	240
		17	200
		18	280
		19	240
		20	200
		21	150
19	Boxelder Creek near Webster, Mont.	1	6
		2	25
		3	55
		4	170
		5	340
		6	850
		7	1,910
		8	1,480
		9	1,220
		10	860
		11	640
		12	380
		13	160
		14	120
		15	55
		16	35
		17	15
		18	10
		19	5
		20	4
		21	3

Table 8. Daily mean discharges from the estimated dominant-discharge hydrographs (Continued)

Site no.	Stream name	Day	Daily mean discharge, in cubic feet per second
20	Little Beaver Creek at Montana-North Dakota border[2]	1	2
		2	3
		3	7
		4	9
		5	620
		6	2,050
		7	3,310
		8	1,080
		9	250
		10	160
		11	110
		12	75
		13	55
		14	41
		15	35
		16	30
		17	25
		18	20
		19	20
		20	15
		21	15
21	Beaver Creek at Montana-North Dakota border[3]	1	10
		2	15
		3	35
		4	130
		5	390
		6	790
		7	1,050
		8	660
		9	330
		10	130
		11	65
		12	53
		13	40
		14	35

[1]Name of streamflow-gaging station is Little Missouri River at Camp Crook, S. Dak.
[2]Name of streamflow-gaging station is Little Beaver Creek near Marmarth, N. Dak.
[3]Name of streamflow-gaging station is Beaver Creek near Trotters, N. Dak.