REPRODUCTIVE BIOLOGY OF BROWN AND RAINBOW TROUT BELOW HAUSER DAM, MISSOURI RIVER, WITH REFERENCE TO PROPOSED HYDROELECTRIC PEAKING

by

Ronald L. Spoon

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Fish and Wildlife Management

MONTANA STATE UNIVERSITY
Bozeman, Montana

June 1985

APPROVAL

of a thesis submitted by

Ronald L. Spoon

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Date	Chairperson, Graduate Committee

Approved for the Major Department

Date	Head, Major Department

Approved for the College of Graduate Studies

Date	Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature ______________________________

Date ______________________________

ACKNOWLEDGMENT

Successful completion of this study would not have been possible without the sacrifices and dedication of many people other than myself. As committee chairman and principle investigator, Dr. Robert White deserves special thanks for his skillful direction of this study. I can only repay him through my respect. Drs. Calvin Kaya and Ray White reviewed the manuscript and offered valuable comments. Field companions Dan Carty and George Liknes provided countless hours of assistance for which I am grateful. Fellow students Rob Hitchcock, Chris Randolph, and Tom Carlsen were always present when needed. I thank Chris Vitello and Frank Pickett, along with the Montana Power Company employees at Hauser Dam, for their help and tolerance during the many flow tests. For preparation of figures, I am obliged to Sharon Gaughan. Montana Department of Fish, Wildlife and Parks furnished generous amounts of manpower and equipment. I express my most sincere appreciation to my family for their encouragement, support, and patience. Acting as surrogate parents were Doug and Lisa Shoop, and Jodie Canfield provided friendship in its truest form. The Montana Power Company funded this project through the Montana Cooperative Fishery Research Unit.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

ABSTRACT

This study evaluated potential impacts of flow fluctuations on spawning success of brown and rainbow trout (Salmo trutta and S. gairdneri)in the Missouri River below Hauser Dam. Trout spawning habitat, and its relationship to discharge, was evaluated by using the physical habitat simulation method (PHABSIM) in conjunction with empirical observations. PHABSIM underestimated discharges required to provide maximum available spawning habitat because of biases in depth criteria, and inadequacy of model inputs (depth, velocity, and substrate) in describing preferred spawning habitat. In the Missouri River and Beaver Creek, physical and hydraulic characteristics of redds were measured to establish spawning criteria. Water velocity appeared to be the most important variable in spawning site selection, and as discharge varied, lateral adjustments in spawning site selection were dictated by water velocity. Dewatering of brown trout redds in the Missouri River occurs at about 60% of the spawning discharge. Spawning of either brown or rainbow trout occurs for at least 5 months of the year. Nocturnal spawning was predominant though fish were observed spawning at all times during a 24-hour period. Duration of brown trout redd construction (Missouri River) ranged from 1 to 5 days, with most redds being completed in 3 days. Quantity of adequate spawning habitat appears limited for brown trout, which show a high incidence of redd superimposition. Use of Beaver Creek for spawning by river migrants was extensive for rainbow trout but was negligible for brown trout.

INTRODUCTION AND OBJECTIVES

In recent years, Montana Power Company's (MPC) hydroelectric facilities have generated about 400 megawatts annually and met a little over half the total electrical demand for the State of Montana. At the start of this study, Hauser Dam was one of four existing hydroelectric generation sites scheduled for redevelopment. The goal of redevelopment was to "more ecomomically utilize the water available at the existing sites" (MPC 1984).

Hauser Dam is presently operated as a run-of-the-river plant with a generating capacity of 16.5 megawatts. Engineering studies performed for MPC indicate that an additional 25 megawatt powerhouse, combined with a peaking operation, would produce the highest cost-benefit ratio. The flow pattern associated with increasing the generating capacity below Hauser Dam could result in daily discharges ranging between 42.5 and 269.0 m^3/second (1,500 and 9,500 cfs).

The flowing portion of the Missouri River between Hauser Dam and the impounded water of Holter Reservoir is an extremely popular recreation area with fishing for brown and rainbow trout (Salmo trutta and S. gairdneri) being an important aspect. This reach has been designated as a Class 1, Blue Ribbon trout stream with national importance (Brown et al. 1959). Little information concerning the fish populations in this reach of river and its major tributary, Beaver Creek, was available prior to this investigation.

Spawning, incubation of eggs, and rearing of young-of-the-year trout are the life history features assumed to be most influenced by fluctuating flows in the Missouri River study area. Factors relating to brown and rainbow trout spawning and egg incubation were evaluated in this study.

Selection of spawning sites is not a random process, but rather, depends upon a specific set of physical and hydraulic conditions including particle size of streambed materials, water depth, water velocity, and escape cover for spawners. Each species has evolved to select the combination of these parameters which will result in maximum reproductive success within the environment in which it evolved. In the Missouri River study area, brown trout are entirely self-sustaining and depend on the short, flowing segment of river for spawning. The rainbow trout population, however, is supplemented by hatchery fish. The average stocking rate in Hauser and Holter Reservoirs during recent years has been 200,000 and 300,000 fingerlings, respectively (Berg and Lere 1983).

This stocking probably has a large influence on the resident river population.

The objective of this investigation was to determine the reproductive requirements of brown and rainbow trout and to predict the impact of altering the discharge pattern from Hauser Dam on trout reproduction. The approach taken in assessing impact was to:

1) Determine the importance of Beaver Creek as a spawning tributary.

2) Locate important spawning habitat and describe distribution and abundance of redds.

3) Measure physical and hydraulic characteristics of redds to determine spawning requirements.

4) Monitor timing of spawning runs.

5) Monitor movements of spawning trout

6) Observe general spawning habits that may aid in predicting spawner responses to changes in discharge pattern.

7) Use hydraulic and habitat modeling to examine a series of discharges in relation to spawning habitat.

Results addressing the objective of this study are presented in this thesis, but conclusions and specific flow recommendations can not be published at this time. Recommendations relating to proposed Hauser Dam expansion are available in White et al. (1984) which will be released at a later date.

Information presented in this thesis was collected during 301 field days between 20 October 1981 and 8 January 1984.

DESCRIPTION OF STUDY AREA

Hauser Dam is located on the Missouri River approximately 22.5 km northeast of Helena, Montana. The Missouri River study area included the 6.8 km flowing segment of river between Hauser Dam and Upper Holter Reservoir (Figure 1). The flowing segment becomes increasingly influenced by the impounded water of Holter Reservoir downstream from the island located 4.5 km below Hauser Dam.

The Missouri River flows through a high walled, rugged canyon from Hauser Dam to the mouth of Beaver Creek. The remainder of the study area lies in a narrow floodplain bordered by broad benches or bars. Access to the study area is primarily limited to boat and foot travel by the steep topography of the surroundings.

Hauser Dam is positioned between Holter Dam, which is 43.0 km downstream, and Canyon Ferry Dam which is located 24.9 km upstream (Table 1). These impoundments greatly influence the fishery within the study area. The limnology of Canyon Ferry Reservoir largely governs that of Hauser and Holter Reservoirs (F. Pickett pers. comm.). Holter Reservoir provides an extensive rearing area for fish produced in the flowing segment below Hauser Dam.

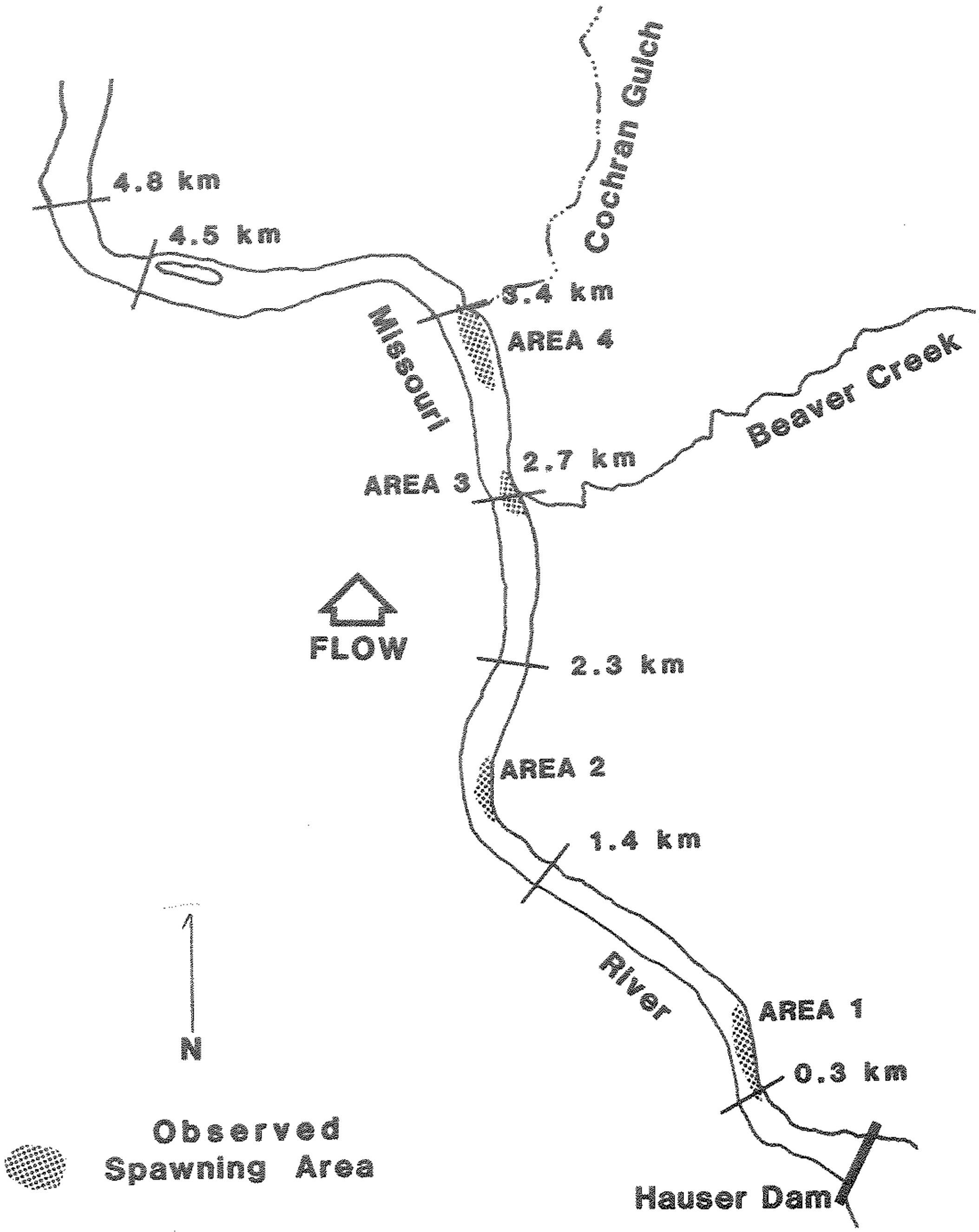

Figure 1. Missouri River study area showing spawning areas and distances below Hauser Dam.

Hauser Dam is a run-of-the-river plant which began operating in 1911. The dam is a concrete gravity structure with a spillway crest 135.6 m long, and an elevation of 1,103.7 m above sea level. The height of the dam above the riverbed is 39.6 m and the intake depth below water surface is 8.2 m at the midpoint. Capacity of water intake is 121.8 m^3/second (4,300 cfs).

Table 1. Date of installation, surface area, electrical capacity, and storage capacity of three impoundments in the upper Missouri River.

	Canyon Ferry	Hauser	Holter
Year Installed	1953	1911	1918
Electrical Capacity (megawatts)	50	16.5	49
Reservoir Storage (million cubic meters)	2530.0	67.8	101.2
Surface Area (ha)	14,238	1,497	1,943

The average annual monthly flow at Hauser Dam is 139.6 m^3/second (4,929 cfs) (MPC flow data for period 1929 to 1978). Flows are above average from April through July. Highest flows occur in June ($\overline{X}$ = 227.6 m^3/second; 8,036 cfs) while September is the month of lowest flow ($\overline{X}$ = 107.8 m^3/second; 3,805 cfs). The drainage area of the Missouri River at the dam is 43,708 km^2.

Beaver Creek, the only perennial tributary in the flowing segment, was also evaluated. This stream, which empties into the Missouri River 2.7 km below Hauser Dam, is approximately 27 km long, with an average gradient of 1.72% (Figure 2). From its source to the town of Nelson, the creek flows through a narrow, limestone canyon. Below this, Beaver Creek meanders through a broader flood plain. Numerous beaver dams are found throughout the length of the stream. Most of the land surrounding Beaver Creek is administered by the U. S. Forest Service (USFS); a USFS road parallels the creek upstream from the mouth for over 19 km.

Severe habitat degradation on Beaver Creek has resulted from alteration of the stream bed for construction of roads and a pipeline, as well as from dewatering and channelization. Prior to 1974, the lower 3.2 km of the stream was under private control and had been completely dewatered for several years during the irrigation season (Hill and Wipperman 1976). The Department of Fish, Wildlife and Parks surveyed the stream in 1973 and found that 24% of a 22.4 km length had been adversely impacted by human activities (Hill and Wipperman 1976).

The Missouri River and Beaver Creek study areas lie within a ponderosa pine - grassland vegetation type. Riparian zones are dominated by red dogwood (*Cornus stolonifera*) and Willow (*Sallix spp.*).

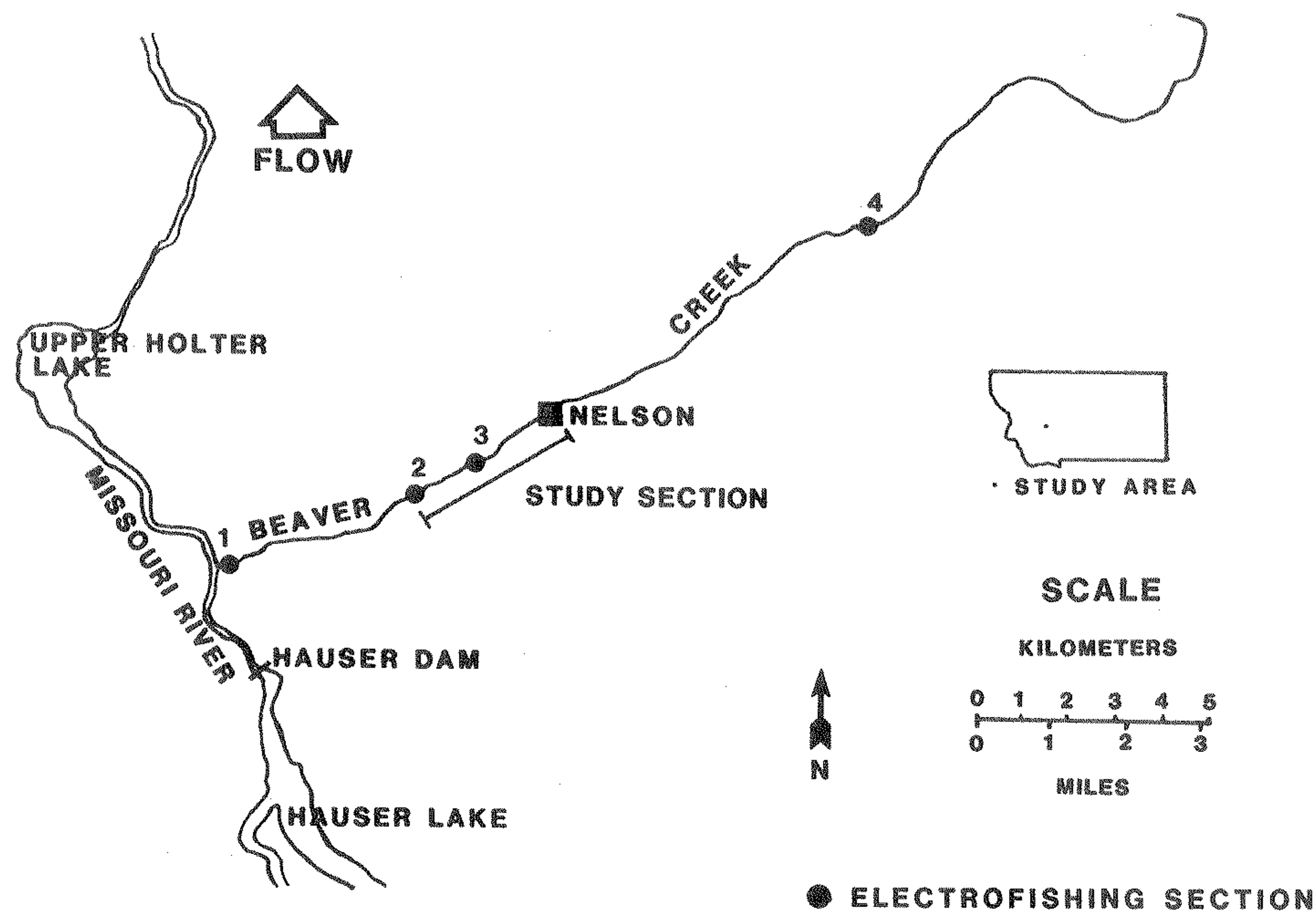

Figure 2. Beaver Creek study area showing locations of electrofishing sections and study section.

METHODS

Fish Sampling

Several aspects of the spawning life history were investigated by electrofishing the Missouri River and Beaver Creek. Four different electrofishing systems were used to meet a variety of sampling situations.

For electrofishing the Missouri River, a fixed-electrode system was suspended from a 4.8 m aluminum boat. The system was powered by a 1500-watt, 115-volt AC generator, and a Coffelt rectifying unit (Model VVP-2C) was used to adjust voltages and convert alternating current to pulsed direct current (60 pulses per second). Most river electrofishing was conducted at night to enhance capture efficiency. Four 120-volt flood lights were attached to the boat to provide lighting for the netter and boat operator.

Three types of mobile electrode systems were used to sample fish populations in Beaver Creek. During low and moderate discharges, battery backpack rectifying units were effective in capturing spawners. A more powerful system was used in Beaver Creek during periods of high discharge. For this system, a 5.2 m aluminum canoe carried the same power source and rectifying unit used in the fixed electrode system, but the positive electrode was hand-held and the negative electrode was suspended from the canoe.

Estimates of fish populations in Beaver Creek were made using a bank electrofishing unit. The components were the same as used in the canoe system, except the hand-held positive electrode was attached to a 152 m length of electrical cord. Beaver Creek electrofishing was primarily confined to sections which were chosen as being representative of the habitat available. Population estimate sections were 305 m long. Section 1 was the lower-most 305 m of Beaver Creek. Sections 2, 3, and 4 were located 4.8 km, 6.4 km, and 17.7 km upstream from the mouth, respectively (Figure 2). Population estimates were calculated using the Chapman modification of the Peterson formula.

During spawning periods, the Missouri River and Beaver Creek study sections were electrofished periodically to determine where spawning fish were concentrated and their stage of maturity. Spawners were classified as: 1) gravid - sex products well developed; small quantities of milt extruded from males when light pressure was applied to abdomen; eggs in females well developed but not released when pressure was applied, 2) ripe - milt and eggs readily released when light pressure was applied to the ventral cavity, and 3) spent - testes and ovaries empty; females in this condition had flaccid abdomens. Secondary sexual characteristics, such as kypes and the degree of scale embeddedness, were also used to differentiate between males and females when they were not ripe. Males tended to have more pronounced kypes and scales more deeply embedded.

Trout Movement

Trout longer than 200 mm total length were marked with individually identifiable Floy T-tags using a Mark II tagging gun. Five thousand fish were tagged from 12 March 1982, to 23 March 1983--4,000 in the Missouri River and 1,000 in Beaver Creek.

Tagged fish captured by anglers and electrofishing were used to monitor movement of brown and rainbow trout. Spawning movement was determined by using recapture data for fish showing sexual maturity when tagged or recaptured. General (non-spawning) movement was evaluated from fish that were not ripe, gravid, or spent when tagged or recaptured.

To determine movement patterns within the 4.5 km study section, the Missouri River study area was divided into four subsections coinciding with frequently used stopping places where fish were tagged and released. The four subsections ranged from 0.8 to 1.4 km in length. Reliable recapture locations were obtained from only 1,264

(81.0%) of the 1,560 recaptures because standard fish processing stops were not always used and fisherman catch locations (received by phone or mail) were often too general.

Movement of trout from the Missouri River to Beaver Creek or from Beaver Creek to the river was also measured. Angler returns from Holter Reservoir, two tributaries of Holter Reservoir, and the Missouri River below Holter Dam provided further movement information.

Redd Distribution and Abundance

Missouri River

The Missouri River between Hauser Dam and the slack water of Upper Holter Lake (approximately 5 km) was monitored regularly to record the progression of spawning activity for brown trout (fall 1981 and 1982) and rainbow trout (spring 1982 and 1983). Redd counts were made by walking the shoreline, by floating, and by observing spawning areas from the surrounding bluffs. Efficiency of counting redds was affected by wind, cloud cover, and turbidity.

The presence (or absence) of deep-water spawning was an important consideration in this investigation. We unsuccessfully attempted to locate and count redds by snorkeling in relatively deep water. On 14 December 1983, river discharge was decreased from 169.5 m^3/second (5,986 cfs) to 42.7 m^3/second (1,506 cfs) for 2 hours. During this time, a helicopter was used to search for and count brown trout redds in deep water areas, and a ground crew examined shallow and dewatered areas. Aerial photographs were taken covering 4.8 km of the Missouri River below Hauser Dam. From these, surface areas of redd aggregates within intensively used spawning areas were determined.

Beaver Creek

Approximately 3.2 km of Beaver Creek from Nelson to the second bridge below Nelson (electrofishing section 2) were selected for periodic redd counts (Figure 2). Redds were counted by wading upstream or walking the shoreline. Fish could occasionally be observed on redds, allowing for species confirmation, and size estimation. From 1981 to 1983, the number of redds was estimated in the lower 11.6 km of Beaver Creek near the end of the brown trout spawning period. Reliable counts of rainbow trout redds were not obtained in Beaver Creek during the spring of 1982 because of turbid water. Rainbow trout redds were counted during 1983.

Physical and Hydraulic Characteristics of Redds

Preferred habitat for spawning in the Missouri River and Beaver Creek was determined by measuring physical conditions at and around brown and rainbow trout redds. Each redd observed was marked with a painted rock so that it would not be counted or measured again. The length of each redd was measured from the upper edge of the pit to the lowermost portion of the tailspill (Figure 3). Three equidistantly spaced width measurements were also taken. From these, an estimate of the surface area of the redd was made using the following formula (Reiser 1981):

$$\text{Area} = (1/2L \times Wt) + (1/3L \times Wm) + (1/6L \times Wu)$$

L = length of redd
Wt = width across lower third
Wm = width across midpoint
Wu = width across upper third

Measurements of water depth and point velocity (taken approximately 20 mm above the substrate surface) were made at the upper edge, the pit, and the tailspill of each redd. Mean water velocity (at 0.6 of depth) was measured at the upper edge of the redd (Figure 3). Water depths (nearest 2.0 cm) were measured with a top setting rod and velocities were measured with a Marsh-McBirney (Model 201) electronic current meter. When applicable, I also measured the distance to cover, riffle, and shore, and noted cover type.

Spawning substrate was sampled by using a modified McNeil sampler with a 178-mm-diameter tube (McNeil 1964). The tube was embedded immediately in front of the redd to a depth of 190 mm and the enclosed substrate and suspended solids extracted and stored for later particle size analysis. Thirty-five substrate samples (consisting of bed-material) were collected from brown and rainbow trout

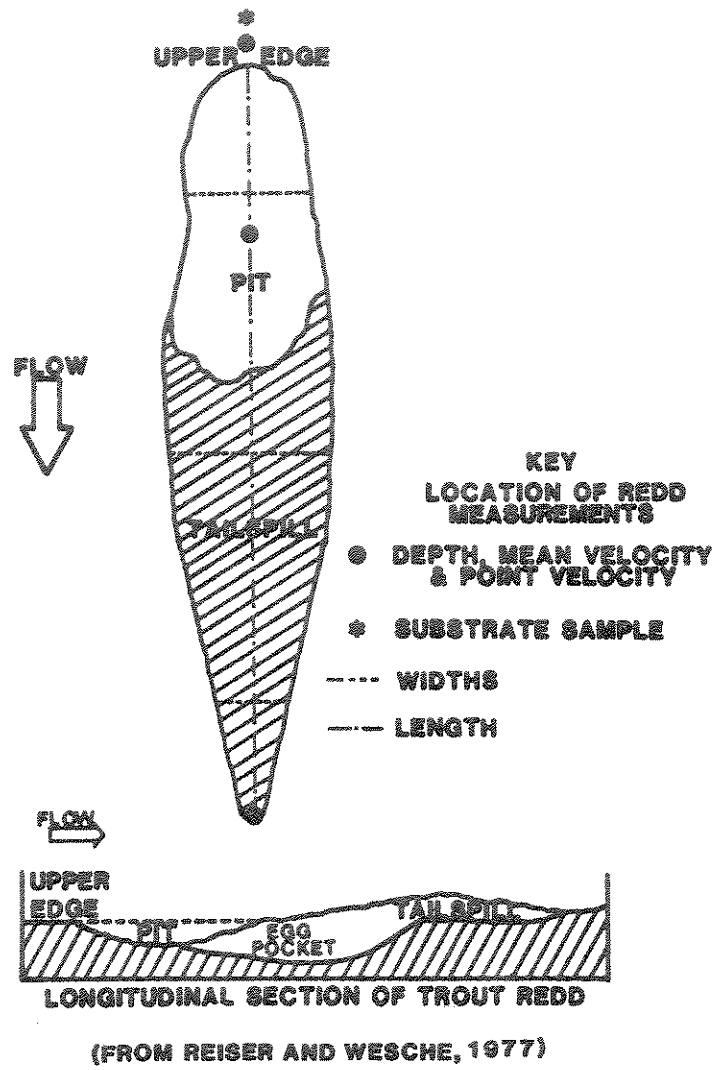

Figure 3. Location of redd measurements.

redds in Beaver Creek, and 50 samples were collected in the Missouri River. At major spawning sites, substrate in the river was observed and photographed during a flow reduction test. During 1983, visual estimates of substrate composition were made at brown trout redds in Beaver Creek.

Substrate samples were dried in a forced air oven for 4 hours at a temperature of 150 C. Sieving was done using a Tyler Ro-Tap sieve shaker and U.S. Standard Testing Sieves in nine sizes of square mesh ranging from 63.50 mm to 0.42 mm. The samples were halved to prevent clogging of sieves, and the shaker was operated for 1 minute per half sample for a total of 2 minutes per sample. The substrate material in each sieve was weighed to the nearest 4.54 gm (0.01 lb) and the percentage of the total sample weight was computed.

Measurements along cross-sectional transects were taken to quantify habitat available for brown trout spawning. Prior to the brown trout spawning period, 65 transects were randomly located along the 3.2 km study section of Beaver Creek. Readings of water depth and mean water column velocity were taken at 0.5-m intervals along cross sections, and substrate composition was visually estimated at 1.0 m intervals using the modified Wentworth scale (Table 2). Stream width and presence of overhead cover were also recorded at each transect.

Table 2. Classification of substrate based on a modified version of the Wentworth particle size scale.

Substrate Type	Particle Size (mm)
Fines	<2.0
Gravel	2.0 - 64.0
Cobble	64.0 - 250.0
Boulder	>250.0

To compare use and availability of spawning substrate, a method was developed to derive a single value representing the mean particle size of a visual observation. The method is explained in Appendix A.

Duration and Pattern of Redd Construction

From 18 October to 12 November 1982, brown trout spawning in the Missouri River was monitored daily to determine the amount of time required for redd construction, and to document daily spawning pattern of individual fish. By placing a painted rock in the pit of the redd, additional spawning at that redd could be detected. Selected redds were observed once or twice each day from the time redd building activity began until it ceased to determine times of the day when fish were on the redd. Some night observations were also made using a spotlight.

Predicted Hatching and Emergence Time

Surface water temperature data from the Missouri River were used to estimate development rates of brown and rainbow trout embryos. Temperature units were calculated from the mean daily temperature (average of maximum and minimum daily temperature), with one temperature unit equaling one degree Fahrenheit above freezing (0 C) for a period of 24 hours. The number of days and temperature units required for eggs to hatch were obtained from the literature (Leitritz and Lewis 1976; Carlander 1969). Hatching dates were calculated for the earliest and latest redds observed in the river to determine the range of hatching times.

Whitlock-Vibert boxes were used to observe egg development for rainbow trout. Eggs and sperm were taken from spawners collected during electrofishing. One hundred fertilized eggs were placed in each box and the boxes were buried 150 to 200 mm (the depth which eggs were observed in natural redds) in the gravel. Three boxes were placed in each of two spawning areas in the vicinity of rainbow trout redds. We had hoped to retrieve the boxes individually at various incubation times, but none could be reached until high spring flows in the river receded.

Physical Habitat Simulation

The U. S. Fish and Wildlife Service physical habitat simulation (PHABSIM) system was used to relate changes in discharge to changes in the quantity of usable spawning habitat. The basic premises of PHABSIM include: 1) each species exhibits preference within a range of habitat conditions it can tolerate, 2) these ranges can be defined for each species, and 3) the area of stream providing these conditions can be quantified as a function of discharge and channel structure (Bovee 1982). The primary output of the model is a measure of usable microhabitat called weighted usable area (WUA)..

The basic model components are: 1) a water surface profile (WSP) model which predicts changes in water surface elevation, depth, velocity, and wetted perimeter along transects, 2) a judgement of the boundaries of suitable spawning substrate within the transect areas (these boundaries were determined during a reduced flow test), and 3) observed spawning preferences for depth, velocity, and substrate presented as probability of use curves. Curves were generated from GOSTAT/GOPLT programs, which perform an exponential polynomial curve fit on frequency data.

Field data required for hydraulic simulation included cross-section survey data (to highwater marks), distances between cross-sections, corresponding water surface elevations at all cross sections at the known discharge. Also recorded were descriptions of substrate, bank and overbank material and vegetation as well as where these change within the cross sections.

During the 3-day period in which transect data were collected, MPC regulated the river at a constant flow of 146.6 m^3/second (5,178 cfs), as determined from the stage-discharge ralationship developed by MPC in 1982. Survey data were collected along four transects in each of three sections of the river; these sections corresponded to spawning areas 1,2 and 4.

Bank and wadable areas (depth $<$ 1.0 m) were surveyed using a level and hand-held stadia rod. Channel profiles in unwadable areas were surveyed from a boat equipped with a constant recording fathometer (Raytheon, model DE-719B). A range finder (Lietz, model SD-5F), operated by a person on shore, was used to determine distance along the transect and to keep the boat on course. To provide targets for the boat operator, two large floats were placed off each bank at the outer extent of the measurements taken by wading. For a more detailed description of field techniques, see Graham et al. (1979).

The PHABSIM model calculates a weighted suitability index which reflects the relative preference of the spawners for the combination of structural and hydraulic characteristics found in each stream segment (or set of four transects). This index is expressed as the percentage of the gross surface area in the stream segment which contains suitable combinations of habitat variables for each life stage of the species for each simulated discharge. For a detailed explanation of how the PHABSIM system functions, see Bovee (1982) and Milhous et al. (1981).

Predicted Dewatering of Utilized Spawning Habitat

In 1982, 77 brown trout redd depths were measured at spawning areas 1 and 2. The number of these redds dewatered at a specific discharge was determined by using predicted changes in water surface elevation. Three inputs were required to use this method: 1) discharge and water surface elevation of the river at the time of spawning; 2) distribution of redd depths at spawning areas 1 and 2; and 3) water surface elevations at numerous discharges from hydraulic modeling.

The number of redds dewatered at areas 1 and 2 was determined at 2.8 m^3/second (100 cfs) increments between 85.0 m^3/second (3,000 cfs) and 70.8 m^3/second (2,500 cfs). The number of redds dewatered at a given discharge was divided by the number of redd depth measurements (77) to determine the percentage dewatered. Spawning areas 3 and 4 were not included in this analysis because hydraulic modeling was not available at area 3, and the backwater of

Holter Reservoir made hydraulic modeling unreliable at area 4. Also, redds at area 4 are not dewatered within the range of flows outlined above.

Reduced-Flow Test - 1982

A reduced-flow test was conducted on 17 August 1982. The purpose of the test was to provide additional information for evaluating potential impacts on spawning habitat of periodic flow reductions from approximately 269.0 m^3/second (9,500 cfs) to 38.5 m^3/second (1,358 cfs). The 38.5 m^3/second (1,358 cfs) flow was based on the stage-discharge relationship developed in 1982 by MPC.

Three major spawning areas of brown and rainbow trout were examined during the 38.5 m^3/second (1,358 cfs) flow to evaluate substrate size in areas known to be used for spawning, to measure depths and velocities of potential spawning areas with suitable substrate, and to determine bottom profiles of spawning areas as far into the channel as possible. Thirteen permanent transects were established at known spawning sites: six transects at the first gravel bar along the right bank 0.2 km below the dam, six at the series of gravel bars along the right bank approximately 1.6 km downstream from the dam, and one at the mouth of Beaver Creek. Along each transect, substrates were sampled and photographed, profiles of spawning areas were made, and depths and mean column velocities were measured.

Reduced-Flow Test - 1983

On 4 August 1983, a reduced-flow test was conducted to evaluate the accuracy of hydraulic modeling predictions at three major brown and rainbow trout spawning areas (areas 1, 2, and 4). Water surface elevations were measured by surveying techniques at four discharges [81.1 m^3/second (2,863 cfs), 66.7 m^3/second (2,357 cfs), 55.4 m^3/second (1,956 cfs), and 143.0 m^3/second (5,048 cfs)]. Water depths and velocities were measured along modeling transects to compare observed with predicted values, and to determine suitability of these areas for spawning and/or incubation at the three lowest discharges.

Temperature and Discharge Monitoring

Water temperatures were recorded continuously with submersible Ryan 90-day thermographs (Model J) that were installed in October, 1981. The thermograph in the Missouri River was located 0.4 km below the dam, while the thermograph in Beaver Creek was placed near the U. S. Forest Service gauging station 2.4 km above the mouth.

Streamflow data in the Missouri River were gathered from a U. S. Geological Survey station 0.3 km below Hauser Dam. Beaver Creek flow data were recorded at the U. S. Forest Service gauging station.

RESULTS

Redd Distribution and Abundance

Brown Trout - Missouri River

During the 3 years brown trout spawning was monitored, spawning began between 11 and 22 October and was completed by mid to late December. Water temperature at initiation of spawning was between 9.4 and 11.1 C (Figure 4). Spawning activity peaked in early to mid November during 1981 and 1982 (Figure 5).

During each field season, most redds (87 to 100%) were observed in four general spawning areas: 1) the large gravel bar immediately below the dam, 2) the series of small gravel bars 1.6 km below the dam, 3) the delta at the mouth of Beaver Creek, and 4) the broad, homogeneous run above Cochran Gulch (Figure 1).

Fifty-five and 160 brown trout redds were observed in 1981 and 1982, respectively. These redd counts were known to be underestimates. Factors contribuing to the low redd counts were: 1) the high incidence of multiple redds and superimposed redds, 2) the presence of redds in relatively deep water that were not visible to the observer, and 3) the inability to distinguish between brown trout and kokanee salmon redds. In areas jointly used by brown

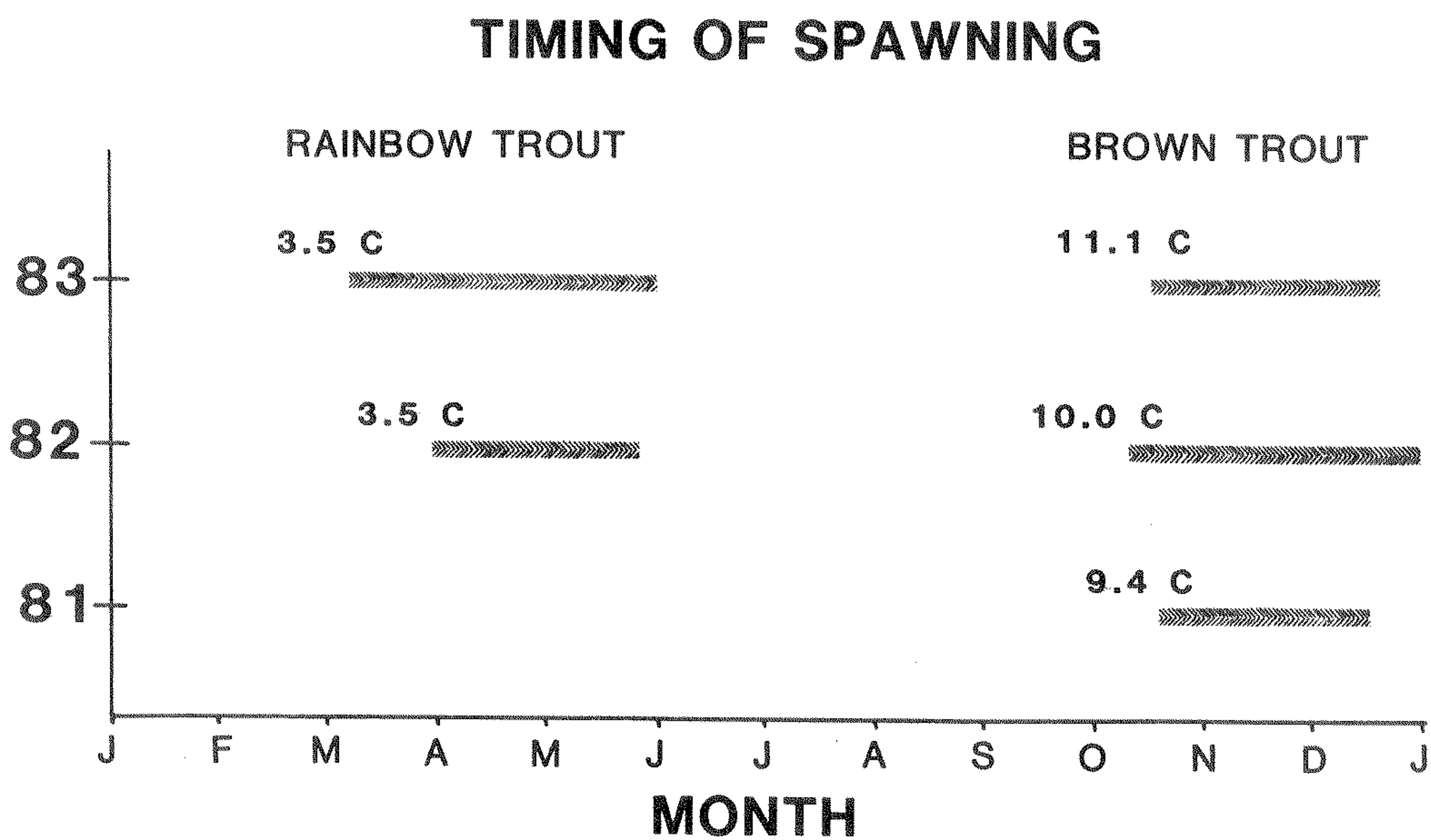

Figure 4. Timing of trout spawning, and water temperature at initiation of spawning in the Missouri River study area (1981-83).

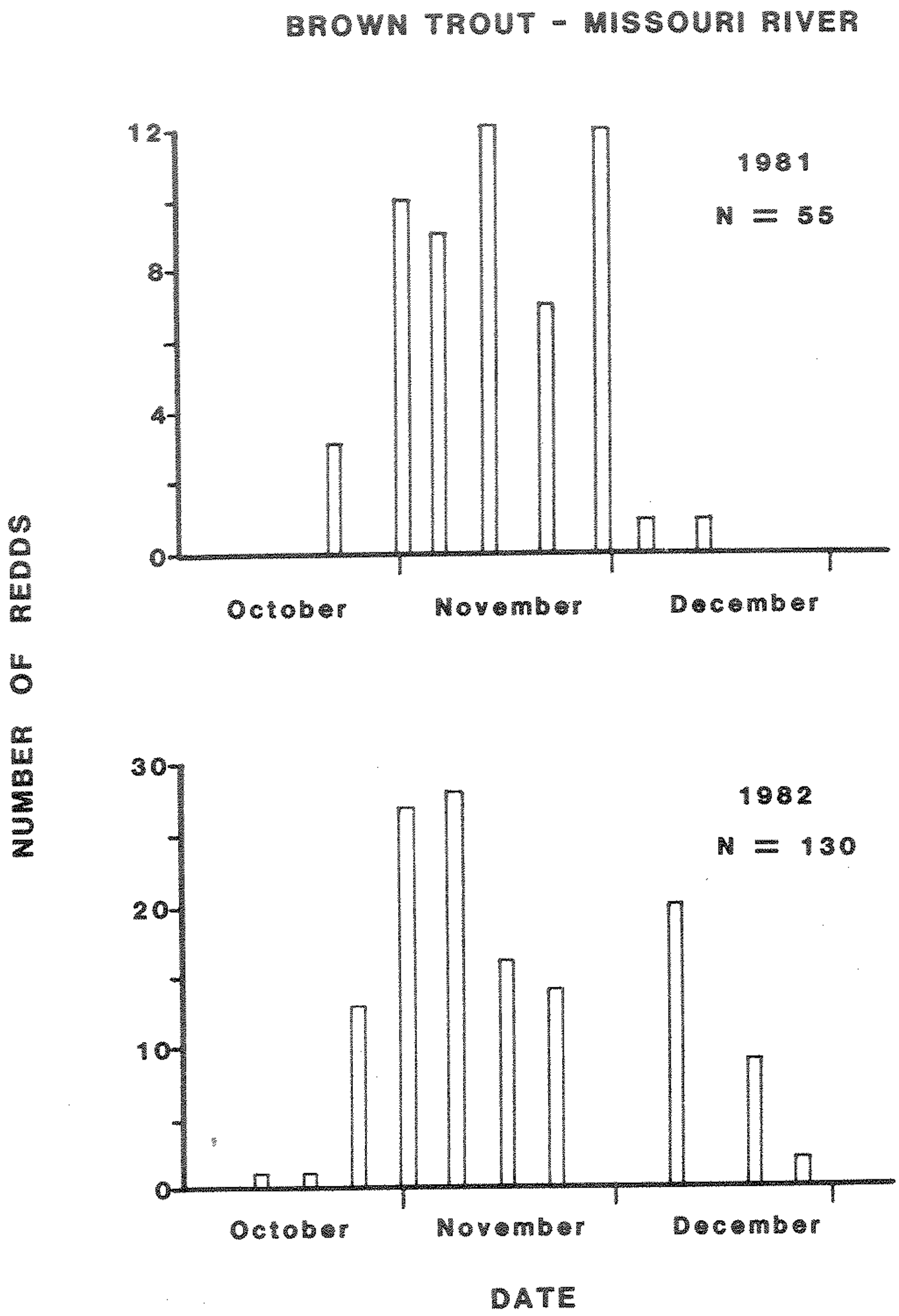

Figure 5. Temporal distribution of redd starts by brown trout in the Missouri River study area (1981-82).

trout and kokanee spawners, redds were omitted from the counts unless positive identification of the redd builder was made. Kokanee spawning progressively increased during each of the three fall spawning periods.

In 1982, considerably more redds were counted than in 1981. This was due to more frequent observations which allowed better enumeration of multiple and superimposed redds. During 1982, only an estimated 22% of the redds observed were single spawning sites (Table 3). All other redds were aggregates with additional construction in front of, adjacent to, or directly over the original spawning site (superimposed). The 55 redds counted in 1981 actually represent 55 redd aggregates; the number of individual spawning sites was probably much larger. The discovery of spawning area 4 also supplemented the 1982 redd count.

Table 3. Total number and percentage of single (not superimposed) brown trout redds constructed in the Missouri River, 1982.

Spawning Area	Total Number of Redds	Number of Single Redds	Percent Single Redds
1	26	6	23%
2	66	18	27%
3	34	4	12%
Other	4	1	25%
Total	130	29	22%

In 1983, an estimated 487 brown trout redds were observed on 14 December during a reduced flow test. This higher estimate was primarily a result of observing deep-water redds adjacent to known spawning areas, especially at area 3. The redd count was also increased by more accurately estimating the number of redds within large redd aggregates by using aerial photographs and planimetric methods. The estimated number of redds at area 4 was significantly increased by using this method. Also observed were 49 deep-water redds that were not associated with the four major spawning areas.

Kokanee spawning was extensive in areas 1 and 3 during 1983, but no kokanee were observed spawning in areas 2 and 4 during the 3 years of investigation. Electrofishing also failed to find spawning kokanee concentrated in areas 2 and 4. Deep-water redds observed in these areas during 1983 were designated as brown trout redds because brown trout spawners were predominantly electrofished there.

The delta at the mouth of Beaver Creek (area 3) was heavily used by brown trout in 1981 and 1982. In 1983, kokanee appeared to displace brown trout spawners from the shallow, observable portion of the delta. Because of heavy use by kokanee, redds in this area were all designated as kokanee redds although some brown trout spawning probably occurred. Deep-water redds in the vicinity of the delta (approximately 175 redds) were counted as brown trout redds, although kokanee spawning may have occurred there. During electrofishing, kokanee were primarily concentrated in the shallow portion of the delta, while brown trout were captured in the deeper waters above and below the delta.

By comparing ground and aerial counts of brown trout redds during the 14 December 1983 flow reduction, an estimate of the number of brown trout redds that were not visible to ground observers during higher flows was made at areas 1, 2, and 3 (Table 4). In area 1, six of the 20 observed brown trout redds (30%) were found in areas that would not normally be visible to the redd observer. In area 2, 19 of 64 redds (30%) were found in areas not visible at normal flows. In 1983, no ground count of brown trout redds was made in area 3 because of extensive kokanee spawning activity. In 1981 and 1982, however, 21 and 25 brown trout redds, respectively, were observed at this site. This would represent less than 20% of the total number of redds at this area if a similar amount of deep water spawning occurred during the 3 years.

In 1982, an estimated 30 redds were located at area 4. Redds in this area were aggregated, away from shore, and were at water depths of about 120 cm. Therefore, it was difficult to estimate the number of redds present. During 1983, this group of redds comprised an area of

295.7 m^2. Dividing this surface area measurement by the average size of individual brown trout redds gave an estimate of 170 redds--a much higher and probably more accurate estimate than could have been made from the ground.

Table 4. Comparison of redd counts from the ground and from a helicopter during the 14 December, 1983 flow reduction, Missouri River.

Spawning Area	Number of Redds		
	Ground Survey	Ground and Helicopter	Not Visible From Ground
1	14	20	6 (30%)
2	45	64	19 (30%)
3	21 to 25*	175	~150 (> 80%)
4	no count	170	--

*From 1981 and 1982 redd counts (no count in 1983).

The relative importance of spawning areas changed between years because of differences in discharge. In 1981, when discharge was 111.9 m^3/second (3,951 cfs) during peak spawning (November), the largest number of redds (44%) was observed in area 1. In 1982, when November discharge averaged 142.9 m^3/second (5,045 cfs), area 2 was the most used spawning site with 41% of the redds (Table 5). During 1983, the average discharge in November was 194.9 m^3/second (6,882 cfs). The number of redds at spawning area 2 was similar during 1982 and 1983 despite the increased flow in 1983 (Table 5). The

Table 5. Estimated number and percentage of brown and rainbow trout redds in major spawning areas below Hauser Dam, Missouri River.

	Brown trout					
	1981		1982		1983	
Area*	Number of redds	(%)	Number of redds	(%)	Number of redds	(%)
1	24	(44)	26	(16)	20	(4)
2	17	(31)	66	(41)	64	(13)
3	14	(25)	34	(21)	175	(36)
4	no count		30	(19)	164	(34)
Other	no count		4	(3)	64	(13)
Total	55		160		487	

	Rainbow trout			
	1982		1983	
1	34	(25)	78	(15)
2	61	(45)	198	(38)
3	26	(19)	37	(7)
4	9	(7)	125	(24)
Other	7	(5)	90	(17)
Total	137		528	

*See Figure 1.

spawning riffles at area 2 are partially dewatered at discharges less than about 127.4 m^3/second (4,500 cfs), thus the flow increase between 1981 and 1982 significantly increased available spawning habitat at area 2. The flow increase from 1982 to 1983 added little new spawning habitat at this site.

The higher redd count in 1983 was not a result of an increase in spawner abundance. During the 1982 spawning period, the Missouri River study area was electrofished 14 times from 2 October to 3 December. A total of 367 brown trout in spawning condition was captured: 110 males and 257 females (Table 6). The efficiency of capture (recaptured/marked) for brown trout of spawning size, 356 to 686 mm, was approximately 35% during the fall population estimate. This electrofishing efficiency gives an indication of the proportion of the total spawning population sampled.

During 1983, the number of sexually mature brown trout was estimated separately using mark/recapture techniques. A number of assumptions inherent in mark/recapture estimates are violated when trying to estimate the size of a transient population; however, the estimate gives a rough indication of the abundance of spawning fish. A total of 713 ($\pm$ 219) females, and 202 ($\pm$ 59) males were estimated during October 1983 electrofishing. The male/female sex ratio, determined

Table 6. Number, length, and sex ratio of sexually mature trout captured in the Missouri River below Hauser Dam and in Beaver Creek (1982-83).

Location	Date	Sex	Length (mm) Mean	Length (mm) Range	Number observed	M/F sex ratio
			Brown trout			
Missouri R.	1982	male	551	(338-757)	110	1:2.3
		female	508	(272-676)	257	
Missouri R.	1983	male	523	(277-704)	127	1:1.9
		female	498	(320-721)	249	
Beaver Cr.	1982	male	297	(216-399)	35	1.2:1
		female	287	(216-373)	30	
			Rainbow trout			
Missouri R.	1982	male	406	(234-630)	220	1.1:1
		female	437	(297-516)	193	
Missouri R.	1983	male	417	(246-549)	471	1.1:1
		female	437	(335-544)	429	
Beaver Cr.*	1982	male	366	(168-592)	214	2.5:1
		female	442	(246-587)	84	
Beaver Cr.**	1982	male	394	(249-592)	163	2.0:1
		female	442	(249-587)	82	
Beaver Cr.**	1983	male	403	(249-526)	318	1:1
		female	432	(254-503)	313	

*Residents and river migrants
**River migrants only

from all sexually mature brown trout captured during fall 1983, was 1:1.9 and was not consistent with the above estimate. The tendency for female spawners to spend less time at the spawning grounds than males may have reduced the number of recaptures and inflated the female estimate. By comparing spring and fall brown trout population estimates during 1982 and 1983, it appeared that approximately 1000 spawners entered the study area each year in the fall (Table 7).

Table 7. Estimates of brown trout population numbers during spring and fall of 1982 and 1983 in the 4.5 km Missouri River study area (80% confidence intervals in parentheses).

Year	Month	Population estimate	Difference
1982	May	249 (± 47)	1,138
	October	1,387 (± 181)	
1983	May	426 (± 33)	920
	October	1,346 (± 212)	

Each of the three methods used to estimate the size of the spawning population (capture efficiency of spawning sized fish, mark/recapture of sexually mature fish, and comparisons of spring and fall population estimates) indicate that brown trout spawners number about 1000 fish in the study area.

Brown Trout - Beaver Creek

Timing of brown trout spawning in Beaver Creek was similar to that observed in the Missouri River (Figures 5 and 6). Peak spawning in the 3.2 km study section for all years occurred during November. Mean daily temperature at onset of spawning was between 5.8 C and 8.0 C each year.

Brown trout of Missouri River or reservoir origin were rarely observed in Beaver Creek during the three spawning periods. Judgement of spawner origin was primarily based on size. In 1981, a beaver dam approximately 300 m upstream from the mouth was believed to be a barrier to migration. Missouri River brown trout were not concentrated in this section, and only nine redds were constructed. These redds were presumably made by river spawners that moved into the creek at night and returned to the river during the day.

Spawning by brown trout resident to Beaver Creek was extensive. In the lower 8.7 km of Beaver Creek, from the mouth to Nelson, 252, 205, and 209 redds were counted during 1981, 1982, and 1983, respectively. In the lower 11.6 km, 324 and 345 redds, respectively, were counted in 1981 and 1982.

Rainbow Trout - Missouri River

Spawning of rainbow trout in the Missouri River study section continued for over 2 months in 1982 and for 3 months in 1983, with peaks in spawning activity occurring

Brown Trout - Beaver Creek

Timing of brown trout spawning in Beaver Creek was similar to that observed in the Missouri River (Figures 5 and 6). Peak spawning in the 3.2 km study section for all years occurred during November. Mean daily temperature at onset of spawning was between 5.8 C and 8.0 C each year.

Brown trout of Missouri River or reservoir origin were rarely observed in Beaver Creek during the three spawning periods. Judgement of spawner origin was primarily based on size. In 1981, a beaver dam approximately 300 m upstream from the mouth was believed to be a barrier to migration. Missouri River brown trout were not concentrated in this section, and only nine redds were constructed. These redds were presumably made by river spawners that moved into the creek at night and returned to the river during the day.

Spawning by brown trout resident to Beaver Creek was extensive. In the lower 8.7 km of Beaver Creek, from the mouth to Nelson, 252, 205, and 209 redds were counted during 1981, 1982, and 1983, respectively. In the lower 11.6 km, 324 and 345 redds, respectively, were counted in 1981 and 1982.

Rainbow Trout - Missouri River

Spawning of rainbow trout in the Missouri River study section continued for over 2 months in 1982 and for 3 months in 1983, with peaks in spawning activity occurring

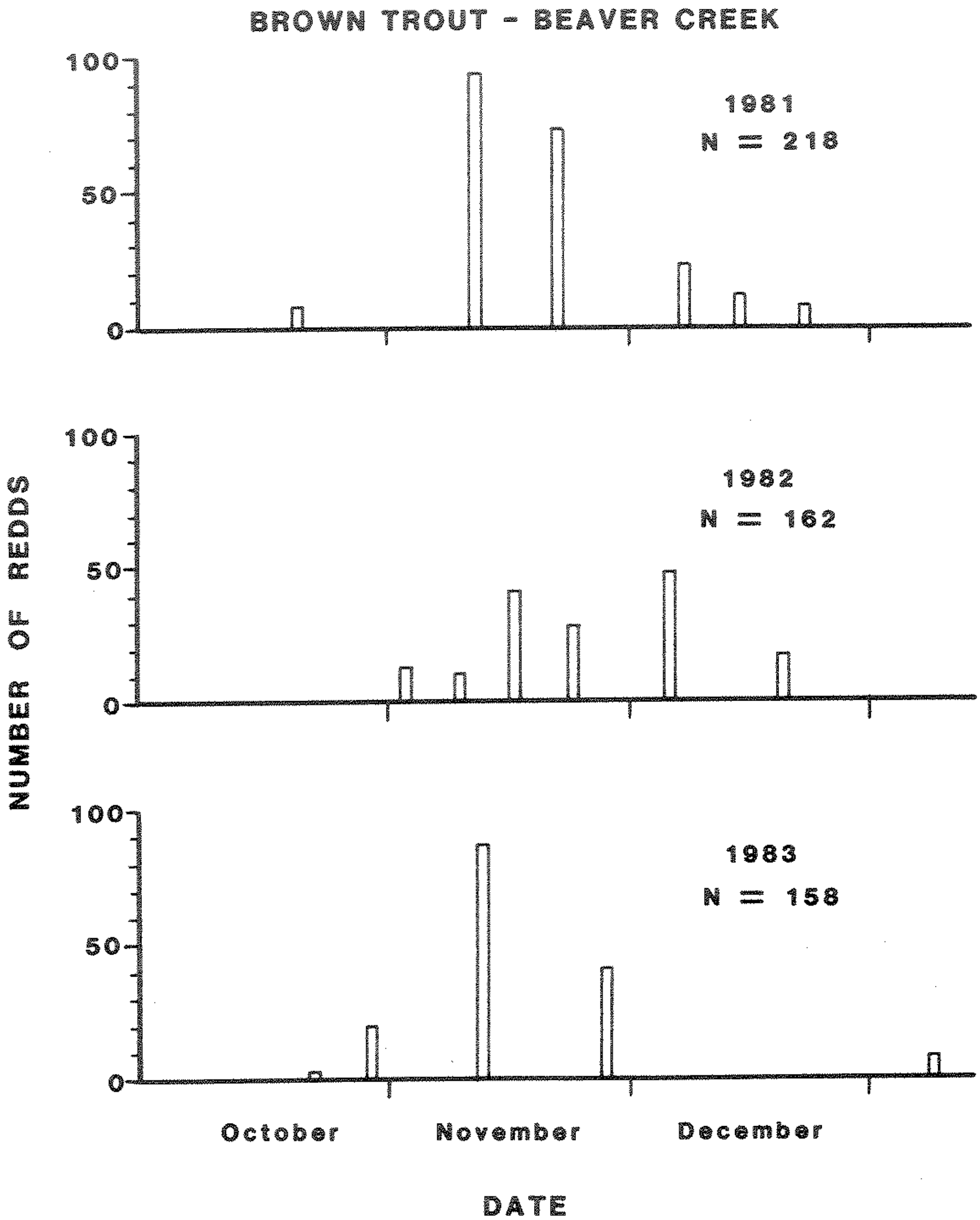

Figure 6. Temporal distribution of redd starts by brown trout in Beaver Creek (1981-83).

in late May (Figure 7). Water temperature at onset of spawning was 3.5 C both years (Figure 4). In 1982, redds were first observed on 27 March and by 23 May, 137 redds had been counted. Redd counts could no longer be made after 23 May because of water turbidity. The first redds in 1983 were found on 7 March, and 528 redds were counted by 7 June. Water clarity was excellent throughout the spawning period and partly accounted for the higher redd count in 1983.

A less conservative approach in estimating the number of redds within redd aggregates also contributed to a higher redd count in 1983. During spring 1982, exceptionally large redds were counted as one redd. Additional experience, and more frequent redd counts during the subsequent spawning season allowed for better recognition and enumeration of multiple redds.

In 1982, all but 4 of the 137 redds observed were located on the east (right) side of the river between Hauser Dam and Cochran Gulch in the same general areas used by brown trout. Only seven redds (5%) were found outside the four major spawning areas. Ninety redds (17% of total) were found outside the four major spawning areas in 1983. During both spawning years the largest number of redds (45% and 37.5%) was located at the series of riffles at area 2 (Table 5).

The Missouri River was electrofished 20 times from 26

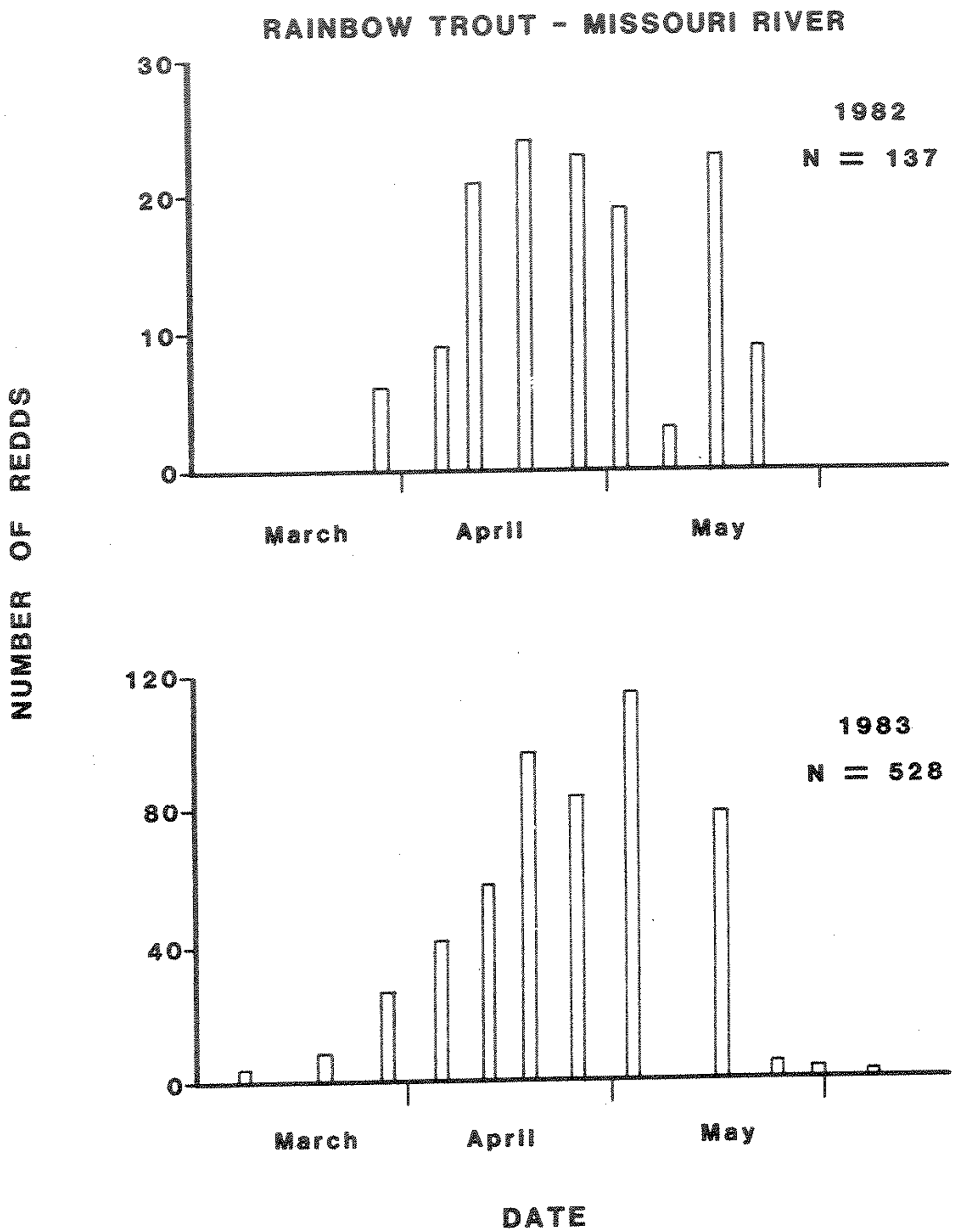

Figure 7. Temporal distribution of redd starts by rainbow trout in the Missouri River study area (1982-83).

March to 7 June during the 1982 rainbow trout spawning run. The percentage of females in spawning condition was determined at selected times during the spawning period to confirm that redd counts accurately identified the peak of spawning activity. On 26 and 27 March, 12% of the rainbow trout females electrofished were gravid or ripe. Forty-three percent of the rainbow trout females were gravid or ripe on 8 May, and 10% were in spawning condition during the period 2-7 June. During 1983 a similar pattern was observed during electrofishing. Twelve percent of the females were gravid or ripe on 23 and 24 March, 55% on 8 and 10 May, and by 28 and 29 May, only 6% of the females were in spawning condition.

During 1982 spring electofishing, 413 rainbow trout in spawning condition were captured: 220 males and 193 females (Table 6). The efficiency of capture for spawning sized rainbow trout (330 to 508 mm) was approximately 4% during the spring population estimate. In 1983, when electrofishing efficiency was 12%, 900 rainbow trout in spawning condition were captured: 471 were males and 429 were females. Early in the spawning season there was a much larger number of mature males than females, but by late April the sex ratio approached 1:1.

Rainbow Trout - Beaver Creek

Rainbow trout of river or reservoir origin used Beaver Creek extensively for spawning in 1982 and 1983.

In 1982, the first spawners were observed in Beaver Creek on 27 March, coinciding with the beginning of spawning in the Missouri River. Spawners began moving into Beaver Creek when the mean daily water temperature in the stream was 5.5 C. A beaver dam approximately 300 m above the mouth concentrated the migrants until 23 April when the dam was removed by the U. S. Forest Service. Approximately 20 redds (with considerable superimposition) were present in this short section of stream at the time of dam removal. During 1983, the first rainbow spawners appeared in Beaver Creek on 16 April, over a month after initiation of spawning in the river. The delay in entering Beaver Creek was probably related to low spring flows.

During the spring flows of April, May, and June, rainbow trout spawners ascended Beaver Creek without difficulty despite the presence of several beaver dams. River migrants were electrofished as far as 10.5 km up the stream in 1982 and 1983.

On 14 May, 1982, 88 redds were counted in the lower 10.5 km of Beaver Creek; this was in addition to the estimated 20 redds located near the mouth in April. These 108 redds represented a partial count, since turbid water conditions prevented regular redd counts. In 1982, 245 rainbow trout of river origin were captured during spring electrofishing. All but three of the migrants were

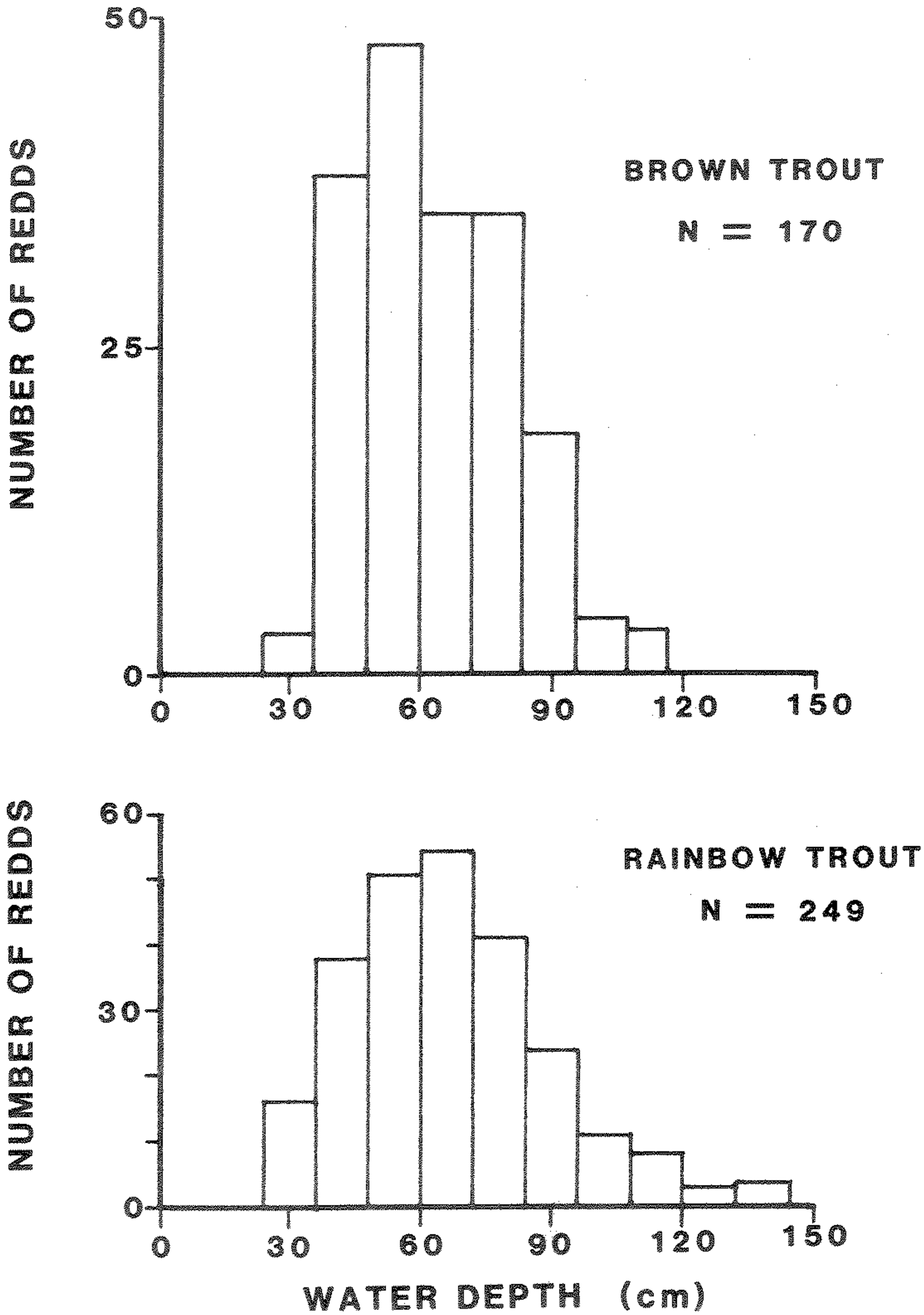

Figure 8. Distribution of spawning depths for brown and rainbow trout, Missouri River study area.

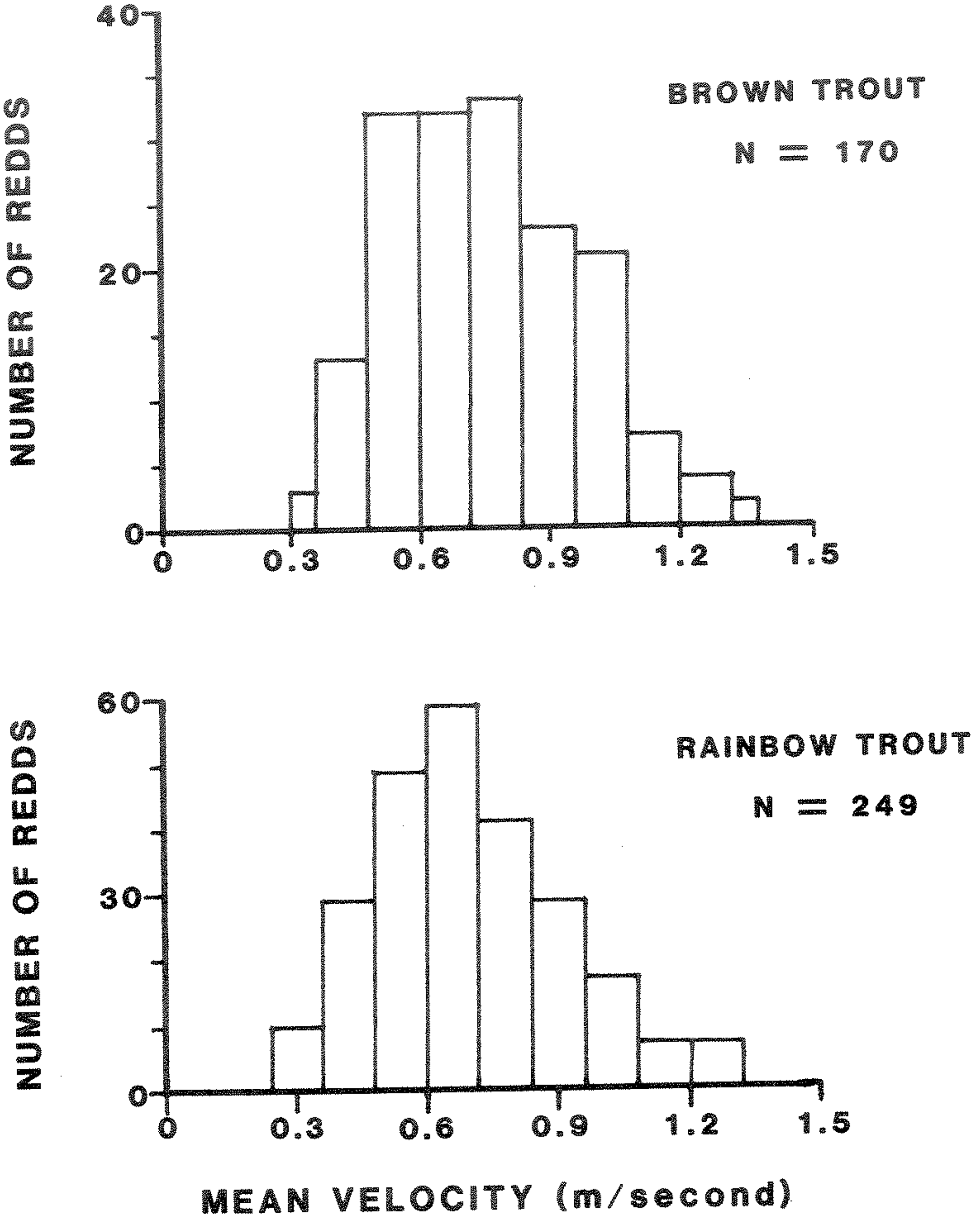

Figure 9. Distribution of mean velocities at brown and rainbow trout redds, Missouri River study area.

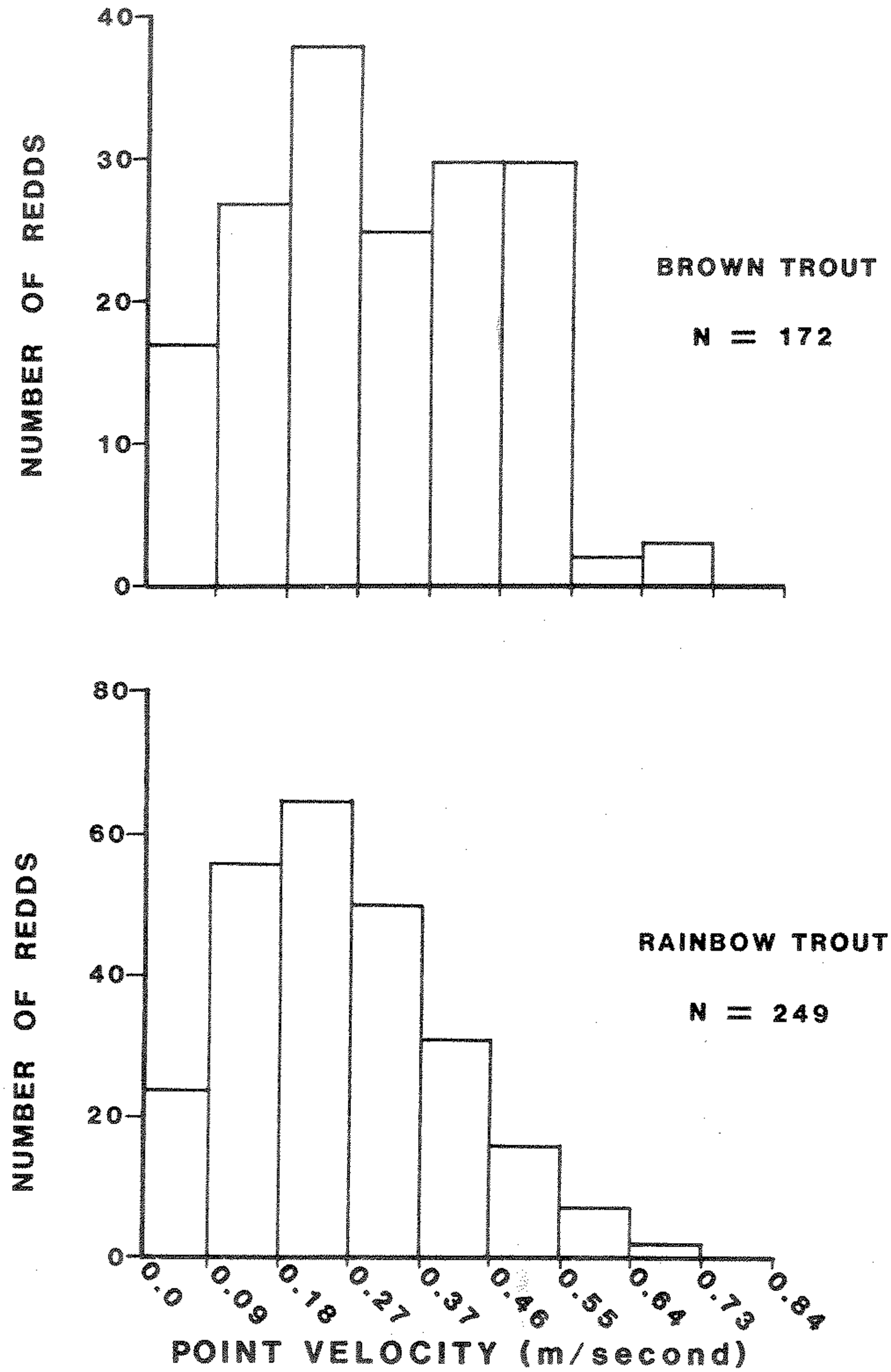

Figure 10. Distribution of point velocities (20 mm above substrate) at brown and rainbow trout redds, Missouri River study area.

Table 8. Mean, range, and standard deviation of redd depths and velocities selected by brown trout (N = 170) in the Missouri River study area.

	Mean ± SD	Range
Depth (cm)	64.0 ± 18.1	24.4 to 118.9
Mean Column Velocity (m/second)	0.76 ± 0.23	0.33 to 1.40
Point Velocity* (m/second)	0.29 ± 0.16	0.00 to 0.67

*Taken 20 mm above substrate level.

Flow during brown trout spawning periods was highest during 1983, lowest in 1981, and intermediate in 1982 (Figure 11). The 1982 fall discharge most closely approximated historical (post-Canyon Ferry Dam) flows. During 1981, discharge increased from 89.5 to 112.7 m^3/second (3,162 to 3,978 cfs) at the end of October and then increased to 132.2 m^3/second (4,668 cfs) at the end of November. Since peak spawning occurred during November, most redds were measured at a discharge of about 113.3 m^3/second (4,000 cfs). In 1982, the discharge remained relatively constant throughout the spawning period at approximately 141.6 m^3/second (5,000 cfs). The mean November discharge in 1983 was 194.9 m^3/second (6,883 cfs).

The 20 to 25% increase in discharge from 1981 to 1982 resulted in a 33.5% increase in depth selected for spawning, but only a 4.7% increase in mean velocity

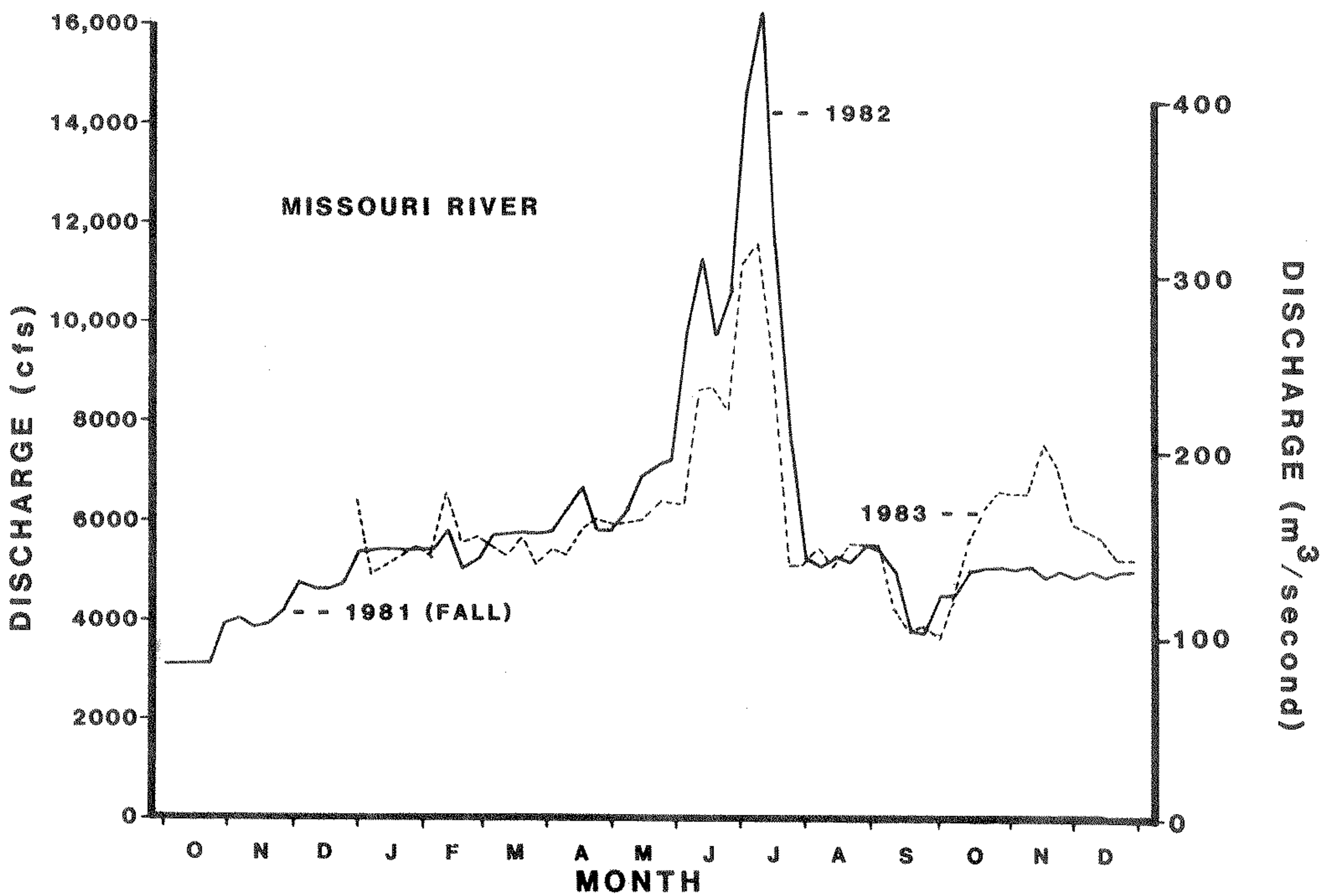

Figure 11. Mean weekly discharge of the Missouri River below Hauser Dam (October 1981 through December 1983).

selected (Table 9). Although only 17 redds were measured in 1983, a similar trend in water depth and velocity selection was noted. Mean river discharge at the time of redd measurements (13 to 30 October) was 168.3 m^3/second (5,944 cfs); an increase of 19% from 1982. Redd depth increased by 5.7% and mean velocity at redd sites decreased by 3.1% compared to 1982.

Selection of certain water velocities is further illustrated by examining characteristics of redd sites at four different times and discharges on transect "B", located across the large gravel bar just below the dam (Figure 12). As discharge increased, spawning activity moved toward shore. Although depths at spawning sites progressively increased, mean velocity remained virtually unchanged at this transect location until discharge increased to 184.1 m^3/second (6,500 cfs) at which time mean velocity decreased. The gradually descending contour of this spawning area allowed the spawners to make the described adjustments.

At the series of riffles about 1.6 km below the dam, the spawners were less able to make lateral adjustments to changes in discharge because of more limited spawning substrate. At one of the riffle areas, nine redds in 1981 were at an average depth of 54.9 cm and were at an average mean velocity of 0.52 m/second. In 1982, 18 redds were observed at an average depth 80.2 cm and average mean

Table 9. Hydraulic variables, redd area, and distance to shore of brown trout redds in the Missouri River below Hauser Dam (1981-83).

Area	Variable	1981		1982		1983	
		Mean	N	Mean	N	Mean	N
1	Depth (cm)	50.6	24	64.0	26	71.3	6
	Mean velocity (m/sec)	0.94	24	0.99	26	0.84	6
	Point velocity (m/sec)	0.37	24	0.37	26	0.26	6
	Redd area (m^2)	3.08	21	2.57	9	0.94	1
	Distance to shore (m)	7.80	24	8.24	26	4.52	3
2	Depth (cm)	53.7	17	72.9	51	71.3	7
	Mean velocity (m/sec)	0.53	17	0.68	51	0.68	7
	Point velocity (m/sec)	0.20	17	0.25	51	0.21	7
	Redd area (m^2)	1.96	16	1.54	22	0.68	2
	Distance to shore (m)	8.81	15	7.77	46	6.71	5
3	Depth (cm)	52.1	14	67.1	19	85.3	2
	Mean velocity (m/sec)	0.65	14	0.75	19	0.84	2
	Point velocity (m/sec)	0.25	14	0.36	19	0.18	2
	Redd area (m^2)	2.33	7	2.17	5	--	-
	Distance to shore (m)	6.00	14	6.00	14	8.20	2
Total*	Depth (cm)	51.8	55	69.2	98	73.1	17
	Mean velocity (m/sec)	0.74	55	0.77	98	0.75	17
	Point velocity (m/sec)	0.29	55	0.30	98	0.22	17
	Redd area (m^2)	2.55	44	1.89	36	0.74	5
	Distance to shore (m)	7.62	53	7.62	88	6.32	12

*Includes miscellaneous redds not in the three major areas.

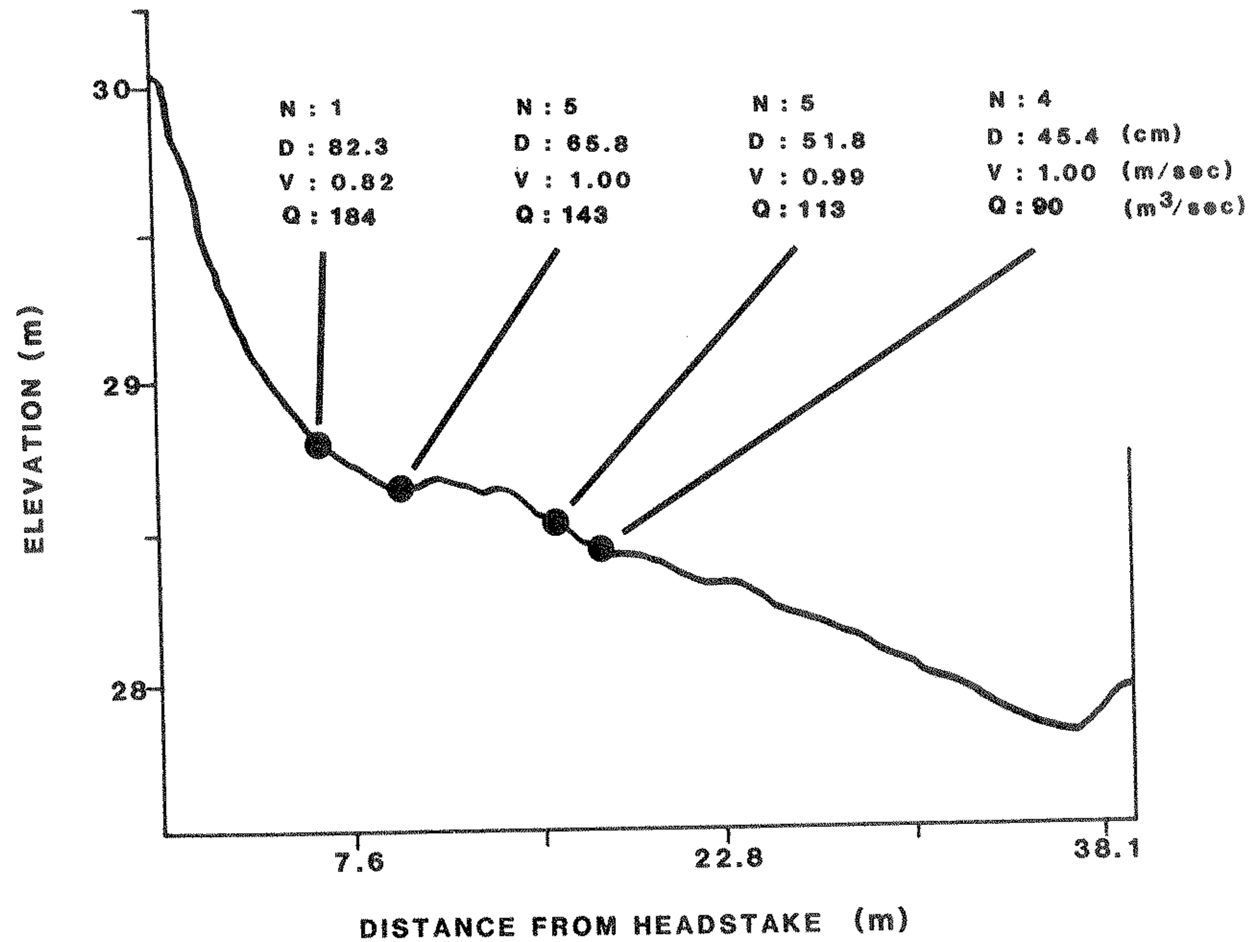

Figure 12. Relationship between spawning aggregations and hydraulic variables along a single, cross sectional transect at four discharges, Missouri River study area (1981-83) (N = Number of redds, D = Depth, V = Mean column velocity, Q = Discharge).

velocity was 0.70 m/second. The mean distances to shore in 1981 and 1982 were 9.66 m and 10.60 m, respectively. Spawning locations were nearly the same both years; differences in redd distance to shore primarily reflected the change in water's edge. The 46.1% increase in water depth and the 35.1% increase in mean velocity selected for spawning at this riffle were considerably higher than the overall depth and velocity increases from 1981 to 1982.

Not included in depth and velocity preferences for brown trout were the redds located in spawning area 4. During 1982 and 1983, considerable spawning was observed about 35 m from the east (right) shore. At a discharge of 141.6 m^3/second (5,000 cfs), the general area was 120 cm deep, with mean column velocities ranging from 0.91 to 1.13 m/second. Since this area was not wadable, these measurements were taken from a boat; individual redd measurements were not obtained. Therefore, the reported mean water depth of river redds is biased due to the absence of individual measurements on redds located in relatively deep water. Additional deep-water redds located during the 14 December flow reduction further bias the spawning depth criteria data.

The average area of a brown trout redd in the Missouri River (1982 and 1983 combined) was 1.74 m^2. Redd areas were considerably larger in 1981 than in 1982 and 1983 and are considered to be poor estimates because many of the sites counted as redds in 1981 were really aggregates of several redds. The mean estimated area of 1981 redds was 2.55 m^2; 47% larger than for the individual redds measured in 1982 and 1983 when a distinction between single and multiple redds was made.

Measurements were taken on seven multiple redds that were each constructed by two females. Multiple redds were 86% larger than redds believed to be constructed by a single female. The mean distance of redds to shore was identical in 1981 and 1982 ($\overline{X}$ = 7.6 m).

Brown Trout - Beaver Creek

Preferred depths and velocities at spawning sites were determined from measurements taken on 240 brown trout redds in Beaver Creek during 1981 and 1982. Redds were found at an average depth of 16.8 cm. The averages of mean column velocity and point velocity were 0.49 and 0.29 m/second, respectively (Table 10). Mean area of brown trout redds was 0.66 m^2.

Table 10. Mean, range, and standard deviation of redd depths and velocities selected by brown trout (N = 240) in Beaver Creek.

	Mean $\pm$ SD	Range
Depth (cm)	16.8 $\pm$ 6.98	4.60 to 61.0
Mean Column Velocity (m/second)	0.49 $\pm$ 0.14	0.06 to 1.04
Point Velocity (m/second)	0.29 $\pm$ 0.11	0.00 to 0.67

Spawning criteria data are less meaningful if a description of available habitat is lacking. In the 3.2 km study section of Beaver Creek, available brown trout spawning habitat was quantified (using random transects) and compared with habitat measurements at 200 redds. The variance of water depth, mean column velocity, and substrate size at redds was significantly less ($p < .001$) than the variance of these parameters at random sites.

Water velocity, substrate size, and water depth, in descending order of importance, were selected by brown trout spawners in Beaver Creek. Available habitat not used (outside of 95%-use curves) was greatest for velocity (42.2%), and least for water depth (30.9%) (Figure 13). Water velocity measurements also had the lowest coefficient of variation.

It is difficult to determine the importance of substrate size in the selection of spawning sites because substrate size is related to the hydraulic parameters. A method was developed (see Appendix B) to quantify surface particle size based on visual substrate observations in an attempt to more closely examine the relationship between hydraulic parameters and substrate size. Poor correlations, however, were observed between substrate size and velocity ($r = 0.36$) and substrate size and depth ($r = 0.27$) during October flow in Beaver Creek. This was not surprising since channel form is largely determined

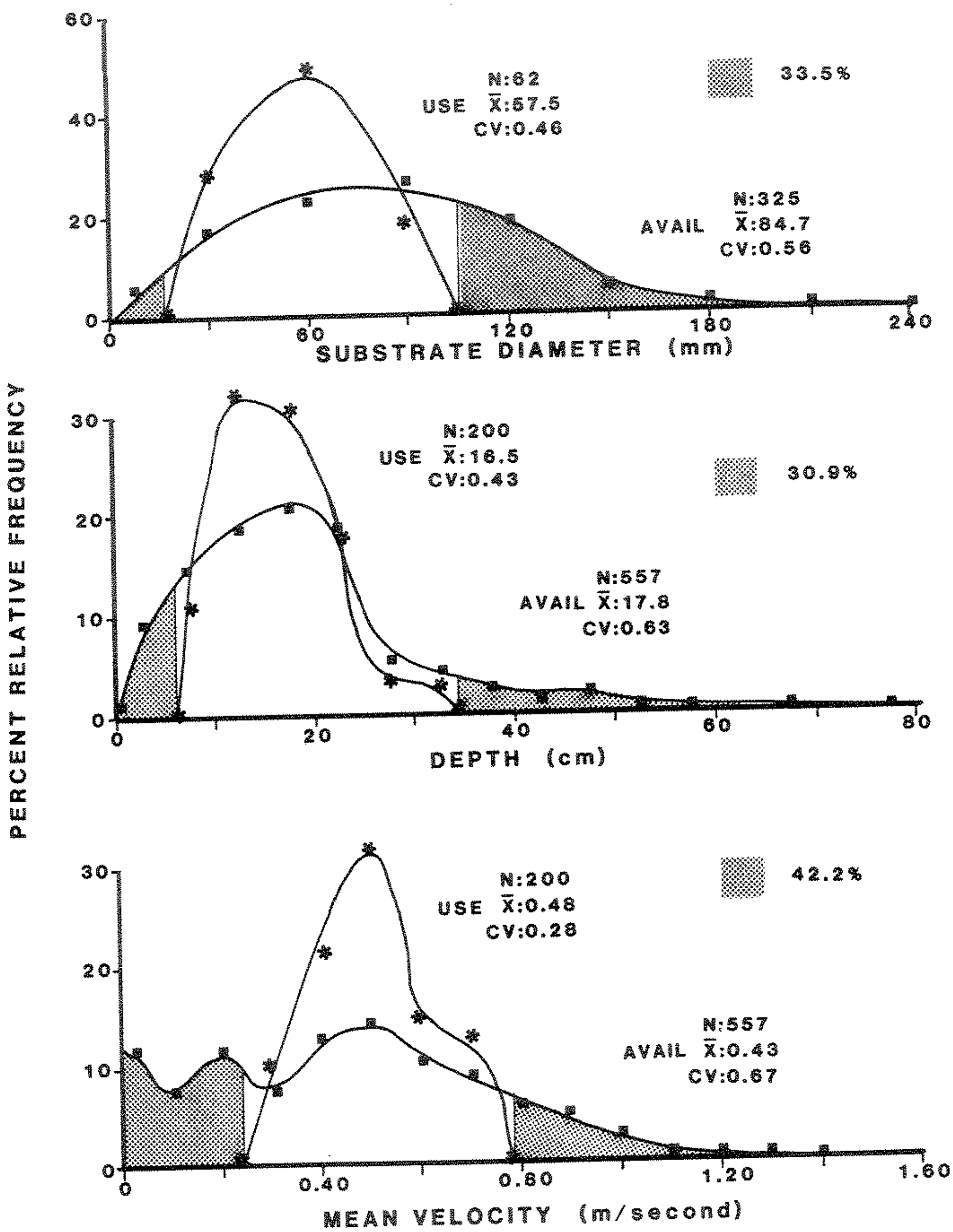

Figure 13. Comparisons of substrate, depth, and velocity between used and available brown trout spawning habitat in Beaver Creek.

from hydraulic conditions during high discharges.

Overhead cover, typically present as overhanging vegetation, was observed over 45.4% of the redds--a significantly ($p < .001$) higher frequency than observed at random locations (20%). In addition, redds were frequently located near shore. Mean distance of redds to shore was 0.85 m, and the mean width of the stream in the study section was 4.88 m. The tendency of near-shore spawning may be related to the increased availability of overhead cover.

Rainbow Trout - Missouri River

In 1982 and 1983, measurements were taken on 249 rainbow trout redds in the Missouri River to determine depth and velocity preferences of spawners. Rainbow trout spawned at an average depth of 66.8 cm, and the mean column velocity was 0.70 m/second. The average point velocity near substrate level was 0.26 m/second (Table 11).

Table 11. Mean, range, and standard deviation of redd depths and velocities selected by rainbow trout (N = 249) in the Missouri River study area.

	Mean ± SD	Range
Depth (cm)	66.8 ± 23.8	24.4 to 143.3
Mean Column Velocity (m/second)	0.70 ± 0.23	0.09 to 1.37
Point Velocity (m/second)	0.26 ± 0.14	0.00 to 0.70

During 1982, rainbow trout spawned at discharges ranging from 164.3 m^3/second (late March) to about 283.2 m^3/second at the end of May (5,800 to 10,000 cfs) (Figure 11). Despite higher discharge during rainbow trout spawning, depths and velocities associated with redds were similar to those observed for brown trout redds (Figures 8, 9, and 10). In 1983, the mean monthly discharge for March, April, and May ranged from 155.7 to 173.9 m^3/second (5,498 to 6,139 cfs); depths and velocities at redds were similar to those measured in 1982 (Table 12).

The average area of rainbow trout redds in the Missouri River (1982 and 1983 combined) was 1.35 m^2. The mean distance of redds to shore was 6.1 m and 6.8 m in 1982 and 1983, respectively.

Rainbow Trout - Beaver Creek

Measurements were taken of hydraulic characteristics of 169 rainbow trout redds constructed in Beaver Creek during 1982 and 1983. Redds were built at an average depth of 22.6 cm, where average mean velocity was 0.72 m/second and average point velocity was 0.42 m/second (Table 13).

Table 12. Hydraulic variables, redd area, and distance to shore of rainbow trout redds in the Missouri River below Hauser Dam (1982-83).

Area	Variable	1982 Mean	1982 N	1983 Mean	1983 N
1	Depth (cm)	58.8	32	50.6	17
	Mean velocity (m/sec)	0.85	32	0.72	17
	Point velocity (m/sec)	0.31	32	0.30	17
	Redd area (m^2)	1.52	20	--	--
	Distance to shore (m)	7.26	30	7.61	17
2	Depth (cm)	74.1	61	74.1	63
	Mean velocity (m/sec)	0.60	61	0.59	63
	Point velocity (m/sec)	0.20	61	0.20	63
	Redd area (m^2)	1.36	51	0.93	18
	Distance to shore (m)	5.35	59	6.51	63
3	Depth (cm)	64.3	26	56.1	9
	Mean velocity (m/sec)	0.96	26	0.87	9
	Point velocity (m/sec)	0.32	25	0.41	9
	Redd area (m^2)	1.51	20	1.43	2
	Distance to shore (m)	7.03	12	5.30	9
Total*	Depth (cm)	65.8	135	67.4	115
	Mean velocity (m/sec)	0.74	135	0.66	115
	Point velocity (m/sec)	0.26	134	0.25	115
	Redd area (m^2)	1.46	107	0.97	23
	Distance to shore (m)	6.13	116	6.80	116

*Includes miscellaneous redds not in the three major areas

Table 13. Mean, range, and standard deviation of redd depths and velocities selected by rainbow trout (N = 169) in Beaver Creek.

	Mean $\pm$ SD	Range
Depth (cm)	22.6 $\pm$ 6.46	10.7 to 41.1
Mean Column Velocity (m/second)	0.72 $\pm$ 0.19	0.20 to 1.19
Point Velocity (m/second)	0.42 $\pm$ 0.15	0.03 to 0.84

The higher velocities and increased depths of rainbow trout redds compared to brown trout redds in Beaver Creek probably reflect the larger size of rainbow spawners and the differences in discharge during the two spawning periods [0.31 to 0.42 m^3/second (11 to 15 cfs) during brown trout spawning in October and November, and 0.71 to 1.42 m^3/second (25 to 50 cfs) during rainbow trout spawning in April and May] (Figure 14).

Rainbow trout redds were associated with overhead cover at 34.2% of the sites, which was significantly higher ($p = .01$) than the frequency of occurrence of overhead cover at random sites. Rainbow redds, like brown trout redds, were often located near shore ($X = 1.34$ m) and were not randomly distributed thoughout the channel.

Average size of rainbow trout redds in Beaver Creek was somewhat larger (1.58 m^2) than redds in the Missouri River (1.35 m^2) despite similar sized spawning females (Table 6). The probable reason for the larger Beaver

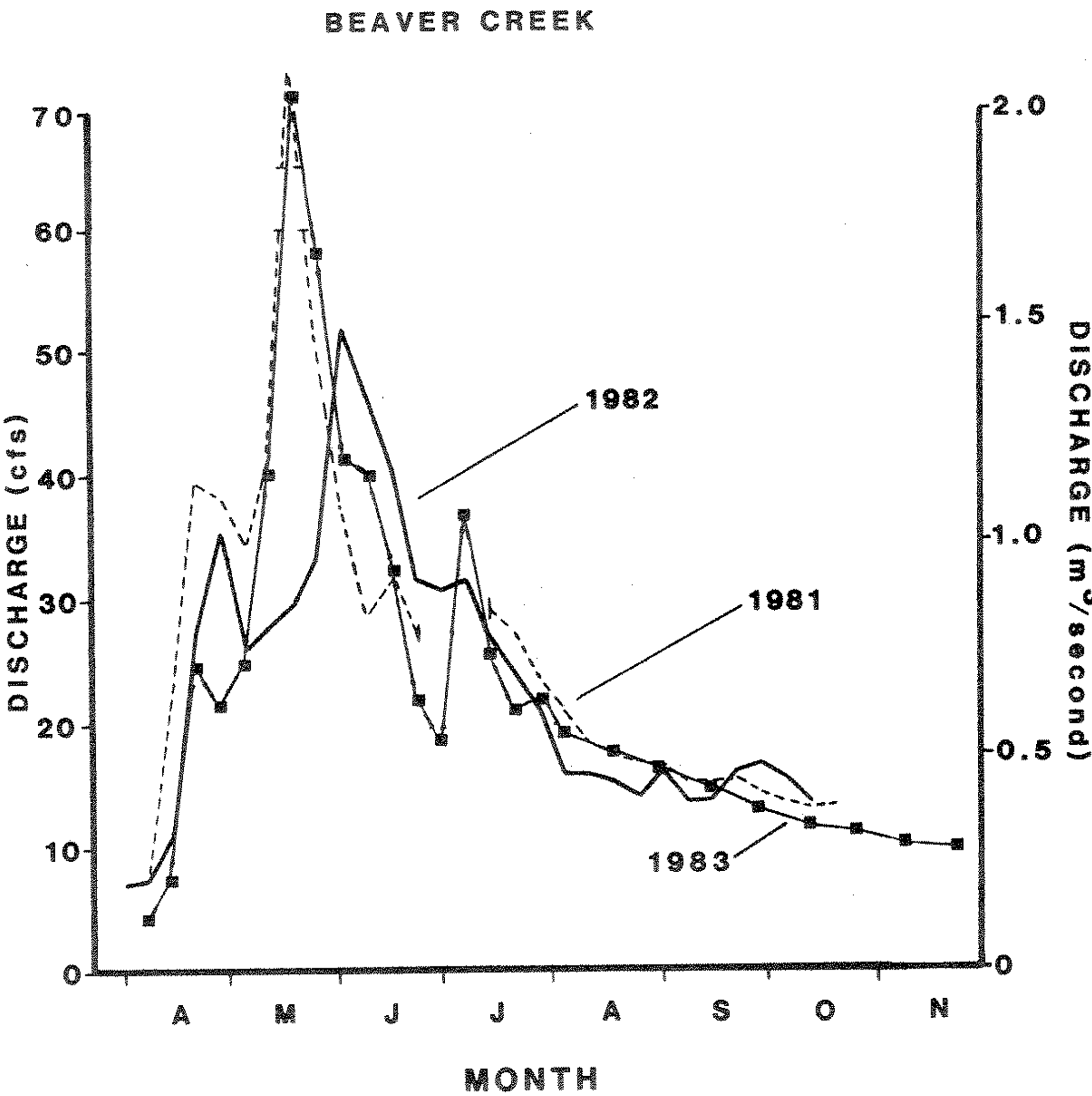

Figure 14. Mean weekly discharge of Beaver Creek (1981-83).

Creek redds was the higher point velocities at redd locations which resulted in longer redds.

Core Sampling of Spawning Substrate

Brown and rainbow trout in the Missouri River spawn in the same general areas but appear to have different substrate size preferences. At spawning area 1, for example, most brown trout redds were located at the upstream portion of the gravel bar, and the mean particle diameter at redds was 30.5 mm. Most rainbow trout redds were at the tail of the gravel bar where mean particle size at redds was 19.8 mm. Substrate samples from the other three major spawning areas for both species revealed the same trend; samples from brown trout redds contained a larger mean particle diameter than samples from rainbow redds, $\bar{X}$ = 27.4 mm and 19.1 mm, respectively (Figure 15). Mean particle sizes at brown and rainbow trout redds in Beaver Creek were 21.1 and 22.4 mm, respectively.

With the exception of brown trout redds in the Missouri River, the amount of fine materials at spawning sites in the Missouri River and Beaver Creek was relatively high (Table 14). Rainbow trout embryo survival, which can be predicted based on the amount of sediment smaller than 9.50 and 0.85 mm (Irving and Bjornn 1984), was estimated to be 19.66% and 27.19% in the Missouri River and Beaver Creek, respectively. No

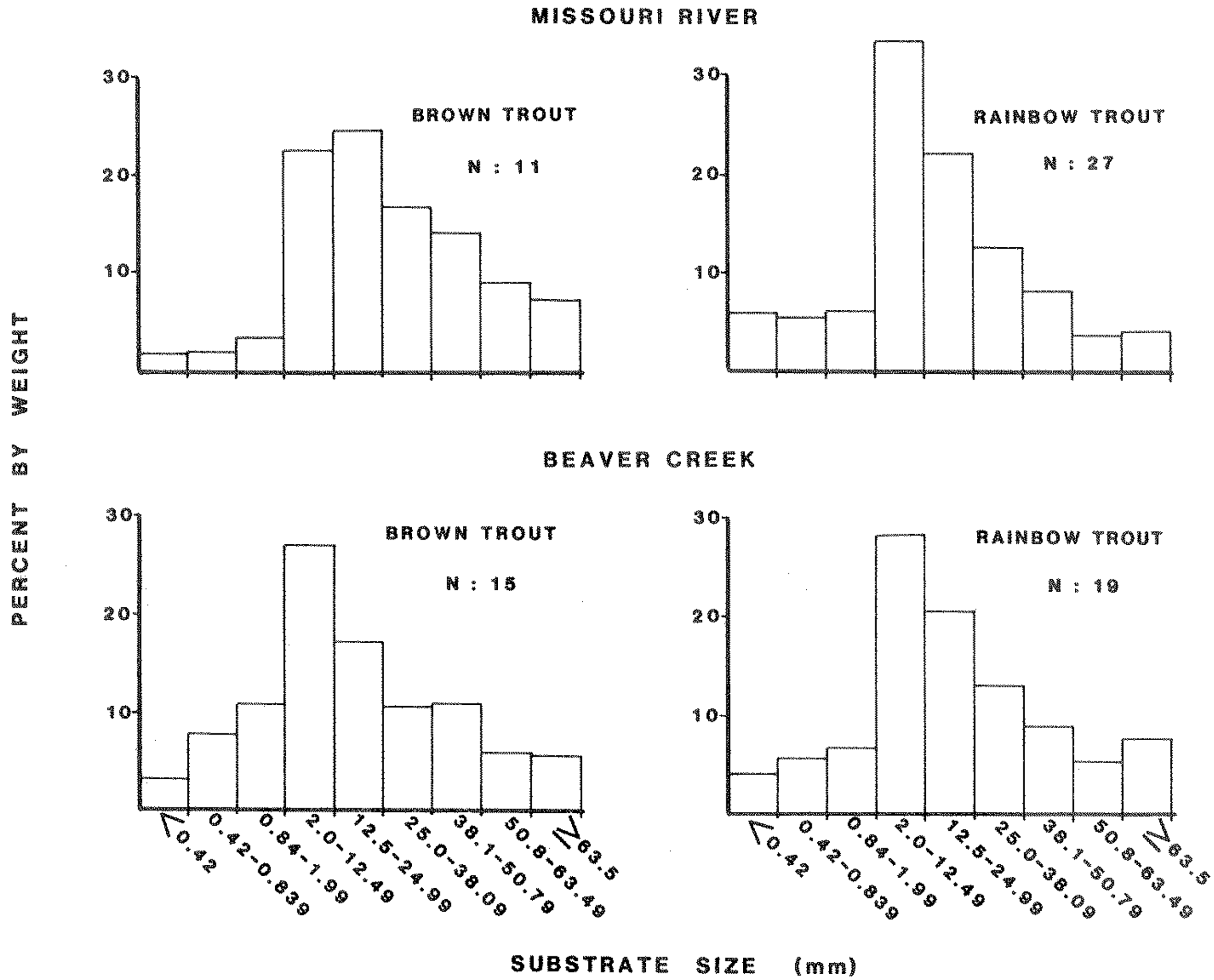

Figure 15. Particle size distribution at brown and rainbow trout redds in the Missouri River study area and Beaver Creek.

equation is available for brown trout embryo survival.

Table 14. Amounts of fine materials found at brown and rainbow trout redds in the Missouri River study area and Beaver Creek, and predicted effects on survival of rainbow trout embryos through emergence.

	N	Percent smaller than 9.50 mm	Percent smaller than 0.85 mm	Percent* Survival
Missouri River				
Brown Trout	11	21.97**	3.17**	--
Rainbow Trout	27	40.70	11.07	19.66
Beaver Creek				
Brown Trout	15	42.98	11.07	--
Rainbow Trout	19	37.48	9.79	27.19

*From equations of Irving and Bjornn (1984)
**Significantly fewer fines ($p < 0.002$)

Effects of Reduced Flow on Spawning and Egg Incubation Habitat

In 1982 and 1983, reduced-flow tests were conducted to examine spawning and egg incubation habitat at selected test flows. Validity of hydraulic modeling results was also determined during reduced flow tests. To estimate suitability of a series of minimum flows, water surface elevations and velocities predicted by hydraulic modeling were evaluated in areas of observed spawning. This information was used to determine the range of minimum flows required to maintain favorable conditions for embryos and alevins occupying the intergravel environment.

Observed Impacts of Reduced Flows

During the 1982 reduced-flow test, spawning areas 1, 2, and 3 (Figure 1) were considerably dewatered during the 38.5 m^3/second (1,358 cfs) test flow. Although spawning area 4 was not closely examined, relatively little substrate was dewatered due to the shape of the channel and probable influence of backwater of Holter Reservoir.

In the three spawning areas examined, all rainbow trout redd locations observed during spring 1982 were dewatered during the reduced flow. Brown trout spawning areas were also extensively dewatered. In spawning areas 1, 2, and 3, respectively, 63%, 100%, and 50% of the observed brown trout redd locations were dewatered at a flow of 38.5 m^3/second (1,358 cfs).

The suitability and amount of potential brown trout spawning habitat that remained covered with water at the reduced flow was also examined. Suitable spawning area was defined as having substrate within the size range utilized for spawning, having a depth greater than 24.4 cm, and mean velocity greater than 0.30 m/second. The velocity criterion used was conservative in that this was the minimum velocity associated with observed redds. The preferred velocity (based upon frequency of utilization) was 0.76 m/second. No velocity measured over potential spawning substrate at the test flow was in the "preferred range". Maximum mean velocities observed in spawning areas 1, 2, and 3 were 0.53, 0.35, and 0.14 m/second, respectively.

A conservative estimate of minimum incubation velocities was obtained by assuming that the minimum velocity selected for spawning was approximately the same as the minimum velocity required for successful egg incubation. Therefore, the criterion for estimating potential spawning habitat also describes suitable incubation habitat. Velocities exceeding 0.30 m/second were not observed where depth was less than 24.0 cm, so the depth criterion did not apply in determining the quantity of suitable spawning/incubation habitat at 38.5 m^3/second (1,358 cfs).

The quantity of spawning/incubation habitat at 38.5 m^3/second (1,358 cfs), as defined by the linear length of spawning substrate meeting depth and velocity criteria outlined above, was relatively small (Table 15). The proportion of suitable habitat ranged from 0 to 55% of the wetted length of each transect over suitable spawning substrate in spawning area 1. Virtually no suitable habitat remained in spawning areas 2 and 3 at the reduced flow.

Spawning and incubation habitat was evaluated during the 4 August 1983 flow reduction using the same criteria used during the 1982 flow test. At a discharge of 81.1 m^3/second (2,863 cfs), the proportion of suitable habitat ranged from 0 to 98% of the wetted length at spawning areas 1 and 2. At area 3, measurements were only taken in

Table 15. Amount of habitat with suitable depths and velocities for spawning and/or egg incubation in the Missouri River at two discharges.

Discharge	Area	Transect	Remaining spawning habitat: Meters wetted	Meters of suitable habitat*	(%)
38.5 m^3/sec (1,358 cfs)	1	A	10.0	0.0	(0)
		B	15.0	8.0	(53)
		C	13.0	4.0	(31)
		D	22.0	12.0	(55)
		E	20.5	11.0	(54)
		F	25.0	8.0	(32)
	2	G	0.0	0.0	(0)
		H	0.0	0.0	(0)
		I	0.0	0.0	(0)
		J	0.0	0.0	(0)
		K	0.0	0.0	(0)
		L	0.5	0.0	(0)
	3	M	1.6	0.0	(0)
81.1 m^3/sec (2,863 cfs)	1	B	25.5	25.0	(98)
		between C&D	31.2	21.0	(67)
		E	27.3	20.0	(73)
		F	30.5	26.0	(85)
	2	G	9.9	6.2	(63)
		I	9.5	6.0	(63)
		J	10.4	0.0	(0)
		between K&L	6.3	0.0	(0)
	3**				
	4	N	53.3	50.0	(94)
		O	53.3	52.1	(98)
		P	53.3	48.8	(91)

*Habitat with velocity $\geq$ 0.3 m/second and depth $\geq$ 24 cm.

**Single measurement in vicinity of deep-water redds with suitable velocity (0.82 m/second).

the vicinity of deep water spawning habitat where the mean velocity was 0.82 m/second. At spawning area 4, little dewatering occurred and adequate spawning and incubation velocities were present throughout most (91 to 98%) of the spawning area (Table 15).

As a part of the flow test, validity of Water Surface Profile (WSP) hydraulic predictions was evaluated at four discharges and three transect sets corresponding to spawning areas 1, 2, and 3 (Table 16). At transect sets 1 and 2, predicted water surface elevations compared favorably with observed values. The predicted changes in water surface elevation during a change in flow from 55.4 m^3/second (1,956 cfs) to approximately 141.6 m^3/second differed from observed elevations by 10.9% and 1.6% at transect sets 1 and 2, respectively. At transect set 3, however, the predicted change in water surface elevation was 95% higher than observed (Table 16). Apparently, slack water of Holter Lake influences this river segment, effectively damping changes in water levels as discharge from Hauser Dam varies. Similar discrepancies between predicted and observed water surface elevation at transect set 3 between 55.4 m^3/second (1,956 cfs) and 81.1 m^3/second were not evident.

The WSP model predicts water velocities at predetermined cells along a river cross section. Predicted mean segment velocities were compared with

Table 16. Comparison of observed and predicted changes in water surface elevation during controlled flows, Missouri River.

Transect set		Change in discharge m^3/second (cfs)	Change in surface elevation (cm)*
1	Observed	55.4 to 81.1 (1,956 to 2,863)	31.1
	Predicted	55.4 to 81.1 (1,956 to 2,863)	22.2
	Observed	55.4 to 143.0 (1,956 to 5,048)	74.7
	Predicted	55.4 to 145.7 (1,956 to 5,145)	67.4
2	Observed	55.4 to 81.1 (1,956 to 2,863)	30.8
	Predicted	55.4 to 81.1 (1,956 to 2,863)	27.7
	Observed	55.4 to 143.0 (1,956 to 5,048)	74.4
	Predicted	55.4 to 141.6 (1,956 to 5,000)	75.6
3	Observed	55.4 to 81.1 (1,956 to 2,863)	17.1
	Predicted	55.4 to 81.1 (1,956 to 2,863)	21.3
	Observed	55.4 to 143.0 (1,956 to 5,048)	33.8
	Predicted	55.4 to 145.7 (1,956 to 5,145)	66.1

*Average of four transects.

observed point velocities (0.6 depth if $\leq$ 61.0 cm; average of 0.2 and 0.8 depth if > 61.0 cm). Since segments encompassing the measured velocities ranged from 0.9 to 15.2 m in length, predicted mean segment velocity and observed point velocity would not be expected to exactly correspond. This comparison, however, provides a means of determining reasonableness of predictions. Velocity comparisons were made for the three lowest discharges of the flow test, and two additional discharges examined in 1982 [38.5 m^3/second (1,358 cfs) and 146.6 m^3/second (5,178 cfs)].

Predictions of velocity by the model appeared reliable (Table 17). In general, predicted velocities were higher than observed; 25 of the 38 comparisons (66%) resulted in larger predicted values. At the highest observed discharge [146.6 m^3/second (5,178 cfs)], predicted velocities averaged 20% less than observed velocities. At transect sets 1 and 2, the average difference in predicted vs. observed velocity was 0.12 m/second and 0.14 m/second, respectively. The minimum difference in velocity was 0.003 m/second, while the maximum difference was 0.31 m/second (Table 17). At transect set 3 (spawning area 4), predicted and observed velocities were not generally available at comparable discharges thus allowing only gross velocity comparisons. At 146.6 m^3/second (5,178 cfs), predicted and observed velocities differed by 0.02

Table 17. Comparison of observed and predicted mean water velocities in the Missouri River below Hauser Dam.

	Predicted			Observed			Observed minus predicted
	Discharge m^3/second (cfs)	velocity (m/second)	Segment length (m)	Discharge m^3/second (cfs)	velocity (m/second)	Number of measurements	
Transect set 1							
Transect #1	38.5 (1,358)	0.78	15.2	38.5 (1,358)	0.67	1	−0.11
	90.6 (3,200)	0.37	2.4	81.1 (2,863)	0.55	1	+0.18
		0.65	6.4		0.51	3	−0.14
		0.80	0.9		0.91	1	+0.12
	146.6 (5,178)	0.97	15.2	146.6 (5,178)	1.07	1	+0.09
Transect #2	90.6 (3,200)	0.16	2.7	81.1 (2,863)	0.00	1	−0.16
		0.33	7.6		0.14	4	−0.19
		0.41	1.2		0.32	1	−0.09
		0.62	15.2		0.51	4	−0.11
Transect #3	38.5 (1,358)	0.27	15.2	38.5 (1,358)	0.22	1	−0.05
	90.6 (3,200)	0.53	15.2	81.1 (2,863)	0.61	9	+0.08
Transect set 2							
Transect #5	38.5 (1,358)	0.16	10.4	38.5 (1,358)	0.00	1	−0.16
	56.6 (2,000)	0.12	1.2	55.4 (1,956)	0.02	1	−0.10
		0.17	3.0		0.06	1	−0.11
	79.3 (2800)	0.08	1.8	81.1 (2,863)	0.01	1	−0.07
		0.15	2.4		0.15	1	0.00
		0.19	2.4		0.36	2	+0.17
		0.27	3.0		0.44	2	+0.17
	146.6 (5,178)	0.38	2.4	146.6 (5,178)	0.61	1	+0.23
		0.41	2.4		0.56	1	+0.15

Table 17. (concluded)

	Predicted			Observed			Observed minus predicted
	Discharge m^3/second (cfs)	velocity (m/second)	Segment length (m)	Discharge m^3/second (cfs)	velocity (m/second)	Number of measurements	
Transect #6	38.5 (1,358)	0.16	10.4	38.5 (1,358)	0.00	1	-0.16
	56.6 (2,000)	0.01	1.8	55.4 (1,956)	0.00	2	-0.01
	79.3 (2,800)	0.12	1.8	81.1 (2,863)	0.00	1	-0.12
		0.19	3.7		0.06	1	-0.13
		0.15	4.6		0.18	3	+0.03
		0.13	5.8		0.27	3	+0.14
		0.15	5.2		0.14	2	-0.01
		0.17	6.1		0.27	3	-0.10
	146.6 (5,178)	0.45	3.7	146.6 (5,178)	0.52	1	+0.07
		0.42	4.6		0.53	1	+0.11
Transect #7	79.3 (2,800)	0.24	6.4	81.1 (2,863)	0.01	3	-0.23
Transect #8	38.5 (1,358)	0.30	7.6	38.5 (1,358)	0.06	1	-0.23
		0.40	7.6		0.22	1	-0.18
		0.26	7.6		0.24	1	-0.02
	56.6 (2,000)	0.16	4.6	55.4 (1,956)	0.00	2	-0.16
		0.31	2.4		0.00	2	-0.31
Transect set 3							
Transect #9	38.5 (1,358)	0.70	15.2	55.4 (1,956)	0.66	4	*
	90.6 (3,200)	0.91	15.2	66.7 (2,357)	0.76	4	*
	145.7 (5,145)	1.02	15.2	81.1 (2,863)	0.84	4	*
Transect #10	38.5 (1,358)	0.71	15.2	55.4 (1,956)	0.72	4	*
	90.6 (3,200)	0.86	15.2	66.7 (2,357)	0.78	4	*
	145.7 (5,145)	0.95	15.2	81.1 (2,863)	0.90	4	*
Transect #11	38.5 (1,358)	1.03	15.2	55.4 (1,956)	0.70	4	*
	90.6 (3,200)	0.98	15.2	66.7 (2,357)	0.72	4	*
	145.7 (5,145)	1.01	15.2	81.1 (2,863)	0.93	4	*
	146.6 (5,178)	0.97	15.2	146.6 (5,178)	0.99	1	+0.02

*Discharges not close enough for meaningful comparison.

m/second, although only one measurement was taken in a 15.2 m segment. At the three lower discharges the hydraulic model tended to overestimate mean velocities, but the discrepancy was not large (Table 17). Predicted velocities at 38.5 m^3/second (1,358 cfs) were either greater than or nearly equal to velocities observed at the same segment during the 55.4 m^3/second (1,956 cfs) flow.

Predicted Impact of Reduced Flows

The extent to which redds may be dewatered by reduced flows during the incubation period are related to the magnitude of flow during redd construction. Predicted dewatering analyses were based on redds constructed during spawning flows that most closely approximated historical (post-Canyon Ferry) spawning discharges, and mean spawning discharges were calculated for the period that redd depths were measured. During 1982, brown trout spawning occurred at a flow of 141.6 m^3/second (5,000 cfs), compared to a mean historical flow of 139.8 m^3/second (4,935 cfs) during November. Based on model predictions, brown trout redds constructed at spawning areas 1 and 2 would begin to be dewatered at a discharge between 85.0 and 99.1 m^3/second (3,000 and 3,500 cfs) (Table 18). Of the 77 brown trout redds observed in the two spawning areas, six (7.8%) would be dewatered at a discharge of 85.0 m^3/second (3,000 cfs). Between each 2.8 m^3/second (100 cfs) decrease in discharge from 85.0 to 70.8 m^3/second (3,000 to 2,500 cfs), an

Table 18. Predicted dewatering of brown and rainbow trout redds at a series of discharges in the Missouri River below Hauser Dam.

	Spawning area 1 N = 26		Spawning area 2 N = 51		Areas 1 and 2 combined N = 77	
Discharge m^3/second (cfs)	Number of redds dewatered	(%)	Number of redds dewatered	(%)	Number of redds dewatered	(%)
Brown trout (1982)						
99.1 (3,500)	0	(0.0)	0	(0.0)	0	(0.0)
85.0 (3,000)	0	(0.0)	6	(11.8)	6	(7.8)
82.1 (2,900)	2	(7.7)	6	(11.8)	8	(10.4)
79.3 (2,800)	5	(19.2)	8	(15.7)	13	(16.9)
76.5 (2,700)	5	(19.2)	10	(19.6)	15	(19.5)
73.6 (2,600)	5	(19.2)	18	(35.3)	23	(29.9)
70.8 (2,500)	7	(26.9)	19	(37.3)	26	(33.8)
Rainbow trout (1983)						
	N = 17		N = 56		N = 73	
127.4 (4,500)	0	(0.0)	0	(0.0)	0	(0.0)
113.3 (4,000)	0	(0.0)	1	(1.8)	1	(1.4)
99.1 (3,500)	5	(29.4)	3	(5.4)	8	(11.0)
85.0 (3,000)	11	(64.7)	14	(25.0)	25	(34.2)
82.1 (2,900)	11	(64.7)	15	(26.8)	26	(35.6)
79.3 (2,800)	12	(70.6)	17	(30.4)	29	(39.7)
76.5 (2,700)	13	(76.5)	19	(33.9)	32	(43.8)
73.6 (2,600)	14	(82.3)	25	(44.5)	39	(53.4)
70.8 (2,500)	15	(88.2)	29	(51.8)	44	(60.3)

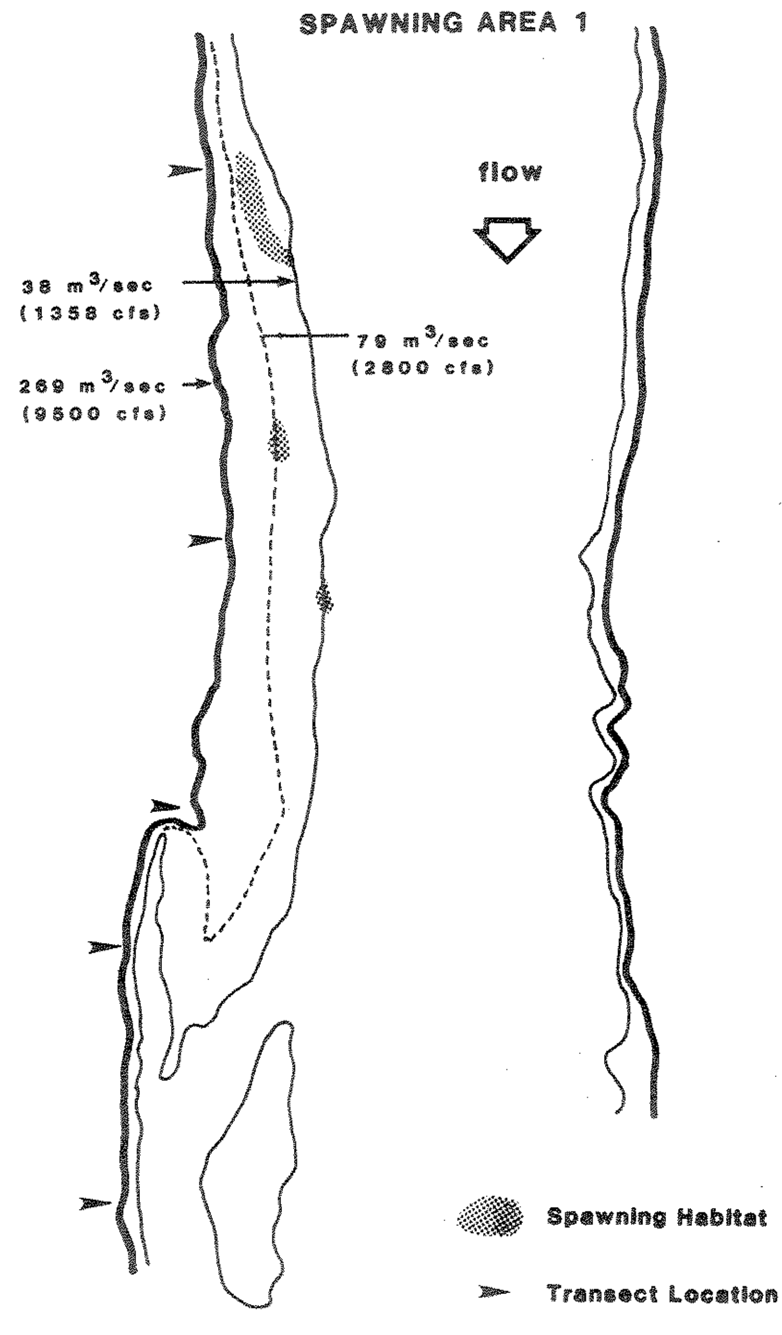

Figure 16. Amount of brown trout spawning habitat wetted at three discharges, Missouri River (area 1).

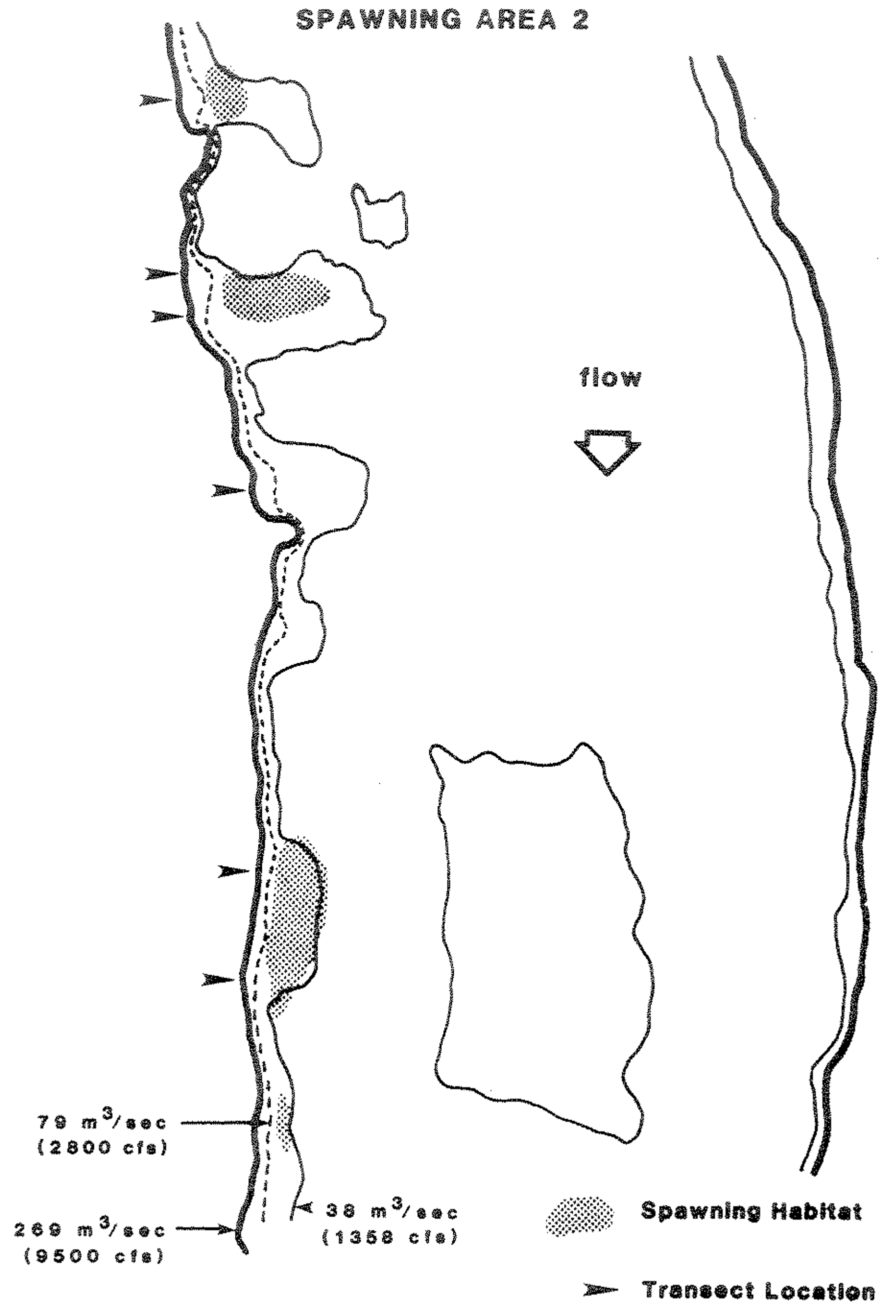

Figure 17. Amount of brown trout spawning habitat wetted at three discharges, Missouri River (area 2).

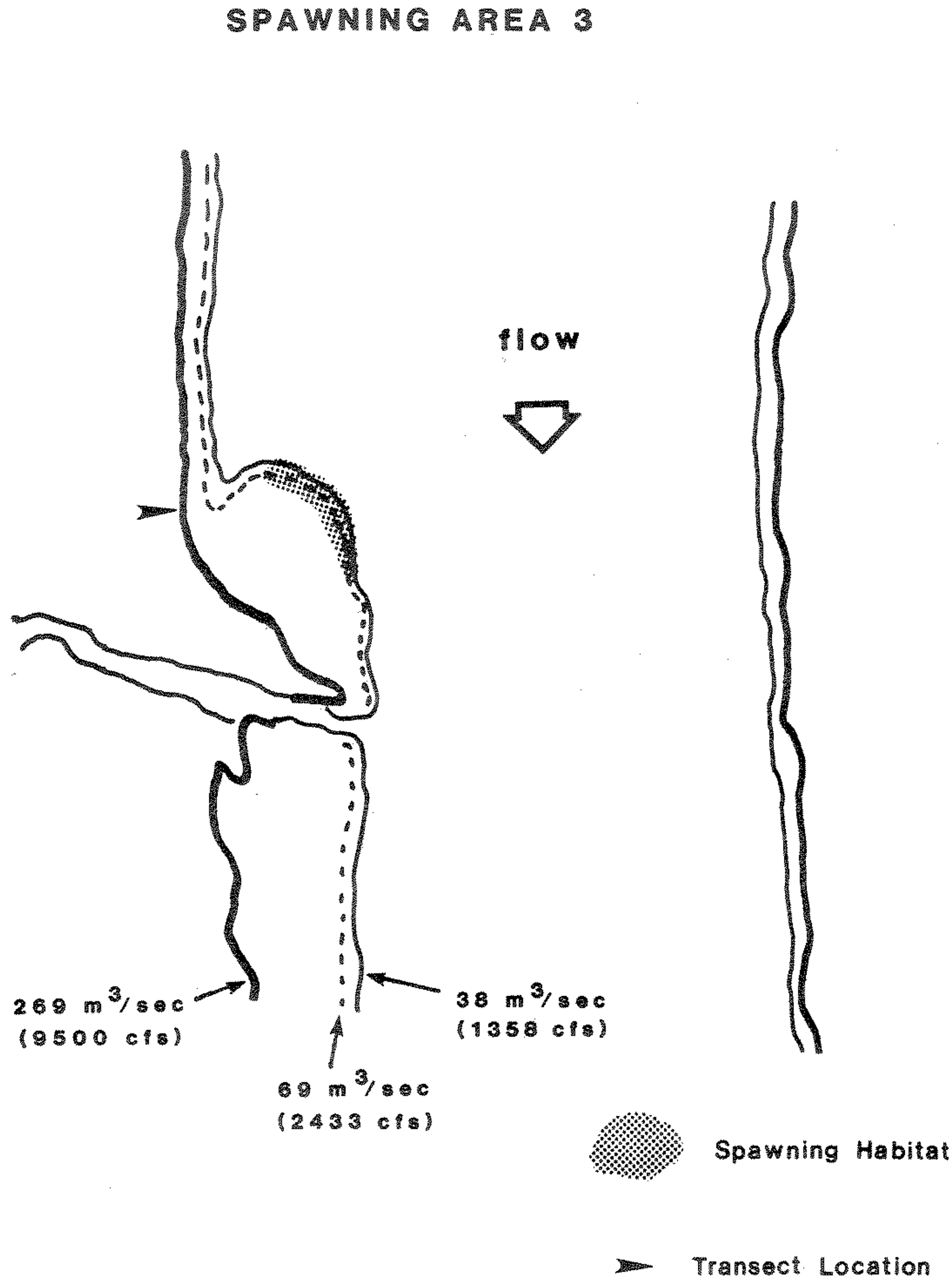

Figure 18. Amount of brown trout spawning habitat wetted at three discharges, Missouri River (area 3).

Time of Hatching and Emergence

Mortality resulting from redd dewatering varies with the stage of development. Since dewatering mortality is highest for individuals at the post-hatching stage, the period when alevins occupied the intergravel environment between hatching and emergence was estimated.

Brown Trout - Missouri River

Using temperature units, brown trout hatching time in 1981-82 was estimated to extend from 26 January to 23 April depending on when the redds were built (Table 19). The wide range in estimated hatching times is due to the rapidly declining temperature during brown trout spawning (October-December) (Figure 19). Eggs deposited early in the spawning period develop much faster than those deposited later because of higher water temperatures at that time. One redd examined on 30 April contained fry with large yolk sacs, indicating that they had recently hatched. After hatching, the amount of time fry were in the gravel is not precisely known. In 1982, we unsuccessfully attempted to trap emerging brown trout fry. Fry were first observed along the shoreline on 25 and 10 April in 1982 and 1983, respectively (White et al. 1984).

Rainbow Trout - Missouri River

Estimates of hatching dates of rainbow trout eggs in 1982 ranged from 20 May to 2 June for early spawners, and from 27 to 28 June for relatively late spawners (Table

Table 19. Estimated dates of hatching for brown and rainbow trout in the Missouri River below Hauser Dam.

Date of spawning	Temperature units (TU) or days	Predicted hatching date	Source of method
Brown trout (1981-82)			
27 October	800 TU	26 January	Leitritz and Lewis (1976)
	95 days	30 January	Carlander (1969)
	100 days	4 February	Leitritz and Lewis (1976)
22 December	120 days	21 April	Carlander (1969)
	600 TU	23 April	Leitritz and Lewis (1976)
	122 days	23 April	Leitritz and Lewis (1976)
Rainbow trout (1982)			
30 March	67 days	4 June	Leitritz and Lewis (1976)
	634 TU	31 May	Leitritz and Lewis (1976)
	65 days	2 June	Carlander (1969)
1 June	27 days	27 June	Carlander (1969)
	555 TU	28 June	Leitritz and Lewis (1976)
	28 days	28 June	Leitritz and Lewis (1976)

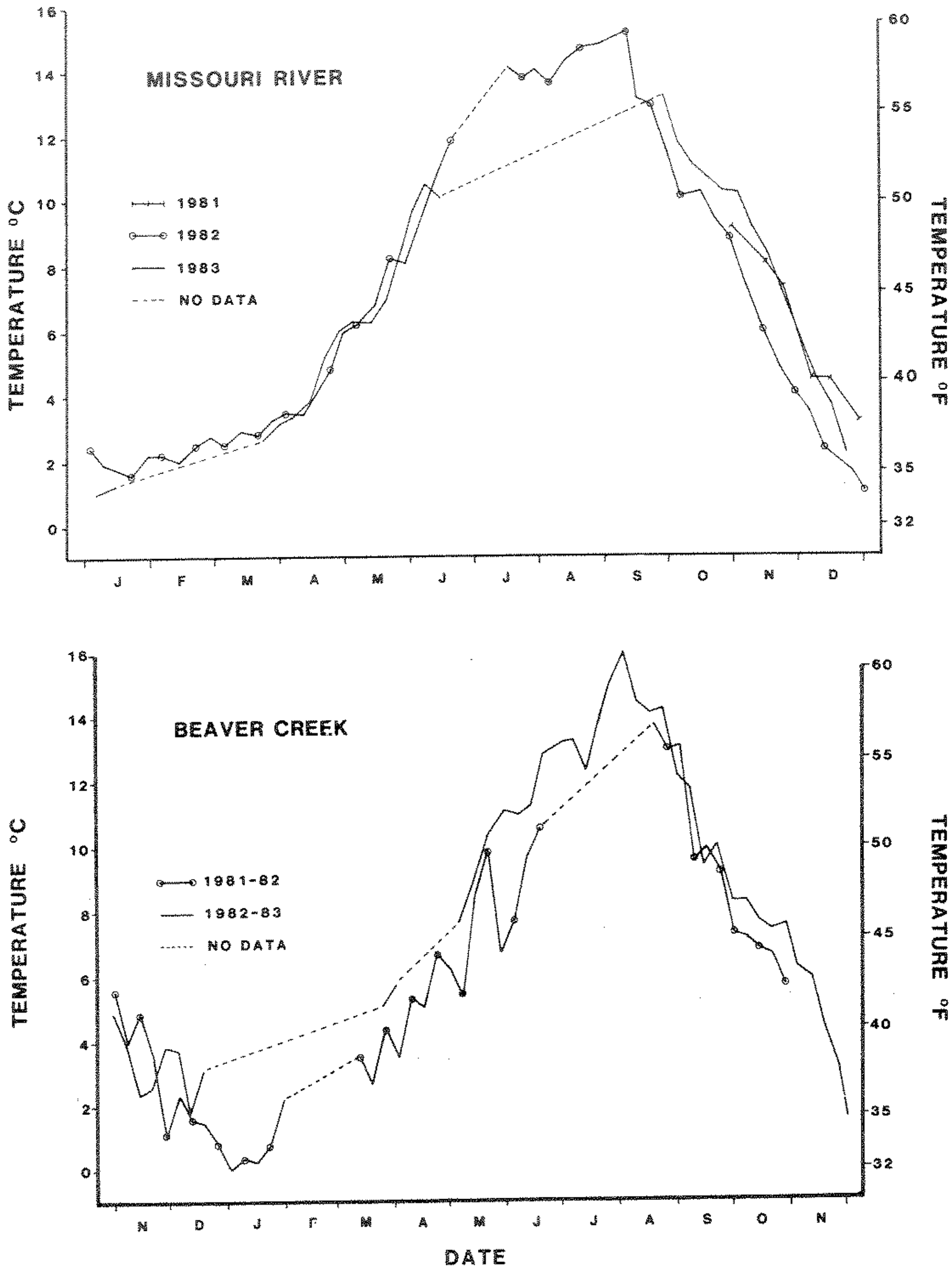

Figure 19. Mean weekly temperature of the Missouri River study area and Beaver Creek (1981-83).

19). Eggs in Whitlock-Vibert boxes, planted in the river on 8 May, were not retrieved until 22 July because of high flows. Fry observed in the boxes at that time had absorbed their yolk sacs, and therefore, must have hatched considerably earlier, as would be expected from the estimated hatching dates. Dates of first fry sightings were on 22 and 13 June in 1982 and 1983, respectively (White et al. 1984).

Duration and Pattern of Redd Construction

The duration of spawning activity associated with 32 brown trout redds in the Missouri River was recorded in 1982. Time required for redd construction and spawning ranged from approximately 1 to 5 days, with most redds being completed within 3 days (less than 72 hours) (Figure 20). Five of the seven redds which were completed within 24 hours were of a relatively normal, large size and were believed to be successful spawning sites. The other two redds were small and were believed to be abandoned or false redds.

Most spawning occurred at night early and late in the spawning period. Fish were rarely observed on redds during the day the first 2 or 3 weeks of spawning, or after the peak of spawning (about 15 November). During peak spawning, the first 2 weeks of November, brown trout were commonly observed on spawning sites at all times of the

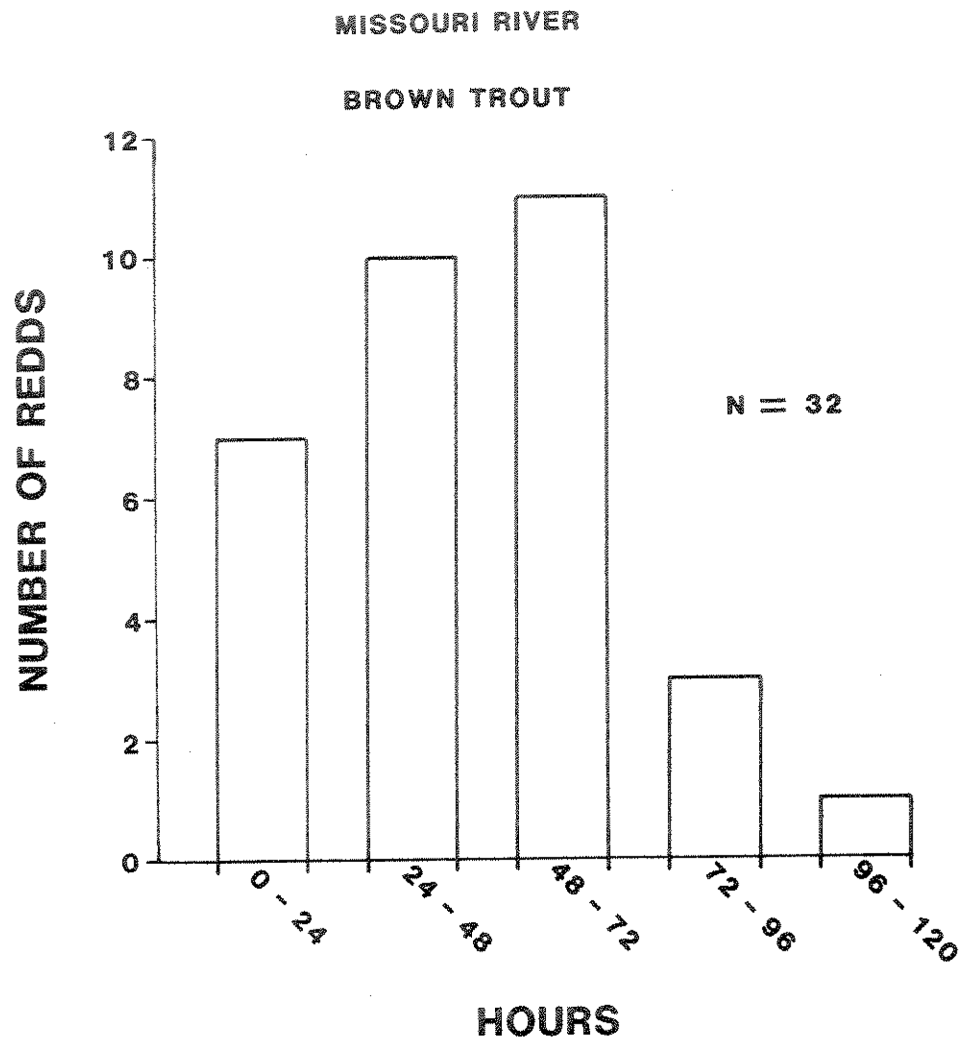

Figure 20. Duration of brown trout redd construction and spawning in the Missouri River study area.

day. At this time they also spawned at night as judged from overnight progress in redd construction and spot observations using a light. At the mouth of Beaver Creek (area 3), spawning fish were rarely observed on redds during daylight, which was probably due to heavy fishing pressure at this site.

Although rainbow trout spawning was not monitored as intensively, a similar pattern of spawning activity was observed. Daytime spawning was more frequently observed at some locations than others.

Physical Habitat Simulation

Physical and hydraulic conditions in spawning areas 1, 2, and 4 were predicted for as many as 36 discharges ranging from 36.8 to 269.0 m^3/second (1,300 to 9,500 cfs). The percentage of usable habitat for spawning was predicted for each simulated flow on the basis of distribution of predicted depths and velocities, substrate associations, and known habitat preferences of brown and rainbow trout.

Depth, velocity, and substrate data collected at brown trout redds in 1981 and 1982 and at rainbow trout redds in 1982 were used to develop probability of use curves (Figures 21 and 22). These data were collected from all measureable redds at all observed spawning sites.

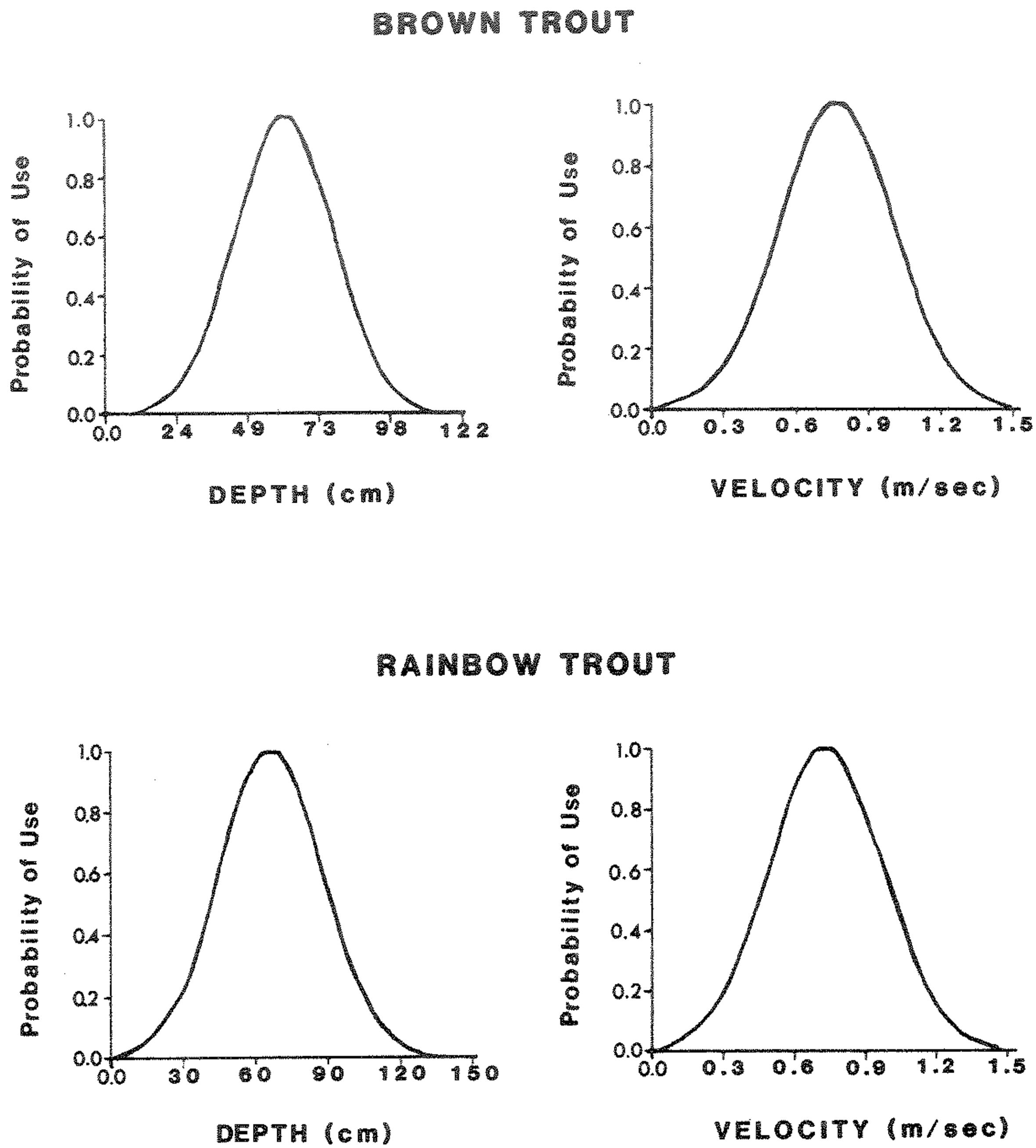

Figure 21. Depth and mean velocity probability of use curves for brown and rainbow trout spawning in in the Missouri River below Hauser Dam.

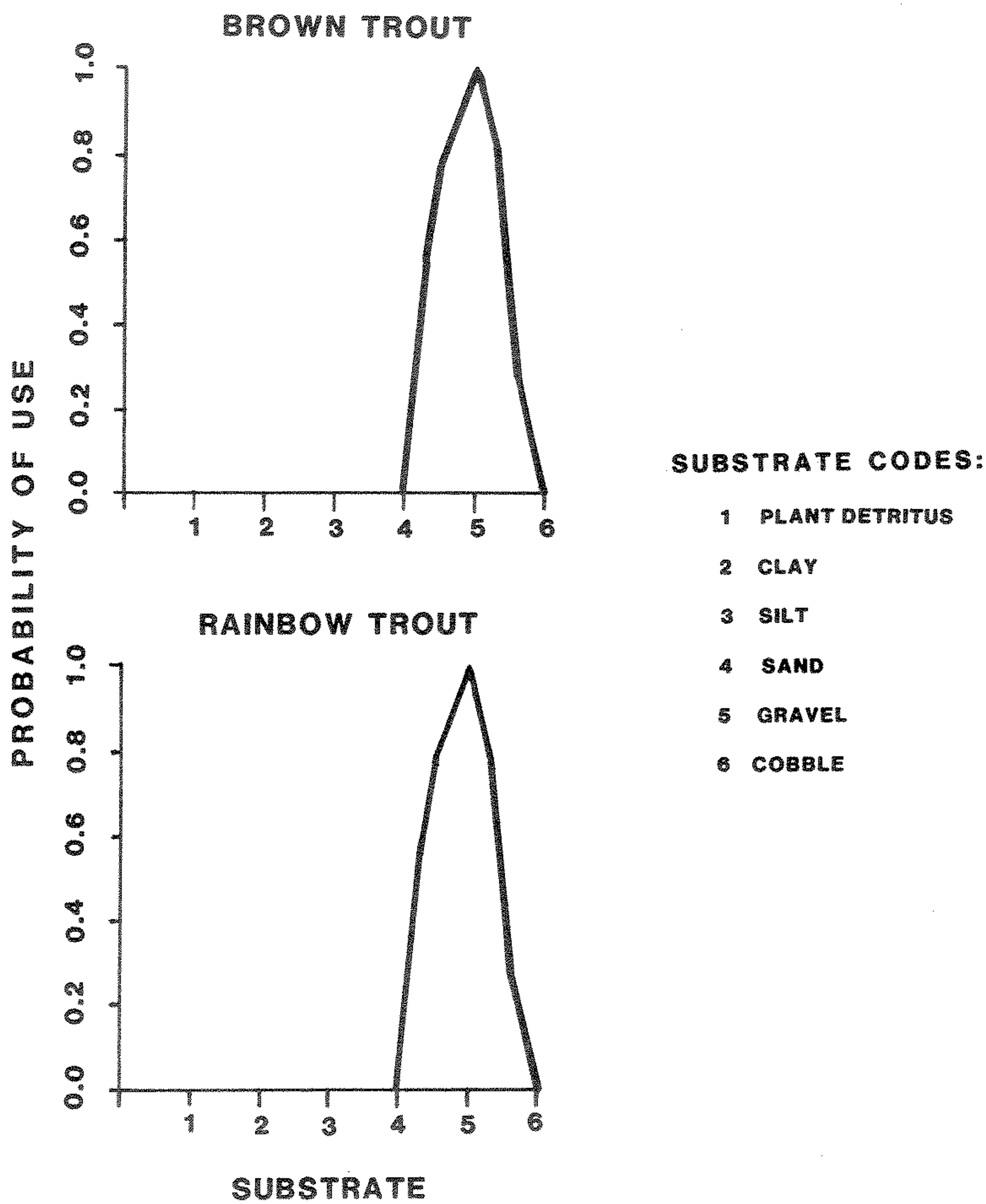

Figure 22. Probability of use curves for brown and rainbow trout spawning substrate (from Bovee, 1978).

The curves were then entered into the PHABSIM model to predict usable spawning habitat at each simulated flow.

At spawning area 1 (Figure 1), maximum predicted usable spawning habitat for brown trout (10.98% of the total segment area) was at a discharge of 99.1 m^3/second (3,500 cfs) (Figure 23). The available spawning area decreased abruptly at discharges greater than 99.1 m^3/second (3,500 cfs) and discharges less than 56.6 m^3/second (2,000 cfs). The secondary peak in the curve at 62.3 m^3/second (2,200 cfs) was probably a result of increased availability of spawning habitat at the lower portion of the gravel bar during lower discharges.

Maximum rainbow trout spawning habitat (15.01% of total segment area) was also predicted at a discharge of 99.1 m^3/second (3,500 cfs) (Figure 24). At discharges less than about 85.0 m^3/second (3,000 cfs) and greater than about 113.3 m^3/second (4,000 cfs), the amount of estimated spawning habitat declined sharply.

At transect set 2, located at the series of riffles about 1.6 km below Hauser Dam (spawning area 2; Figure 1), maximum brown trout spawning area was predicted to occur at 146.6 m^3/second (5,178 cfs) (Figure 23). At this discharge only 3.48% of the total segment area was usable for spawning. As flow decreases, a second peak in habitat suitability occurred at 59.5 to 62.3 m^3/second (2,100 to 2,200 cfs). No brown trout redds were observed in the

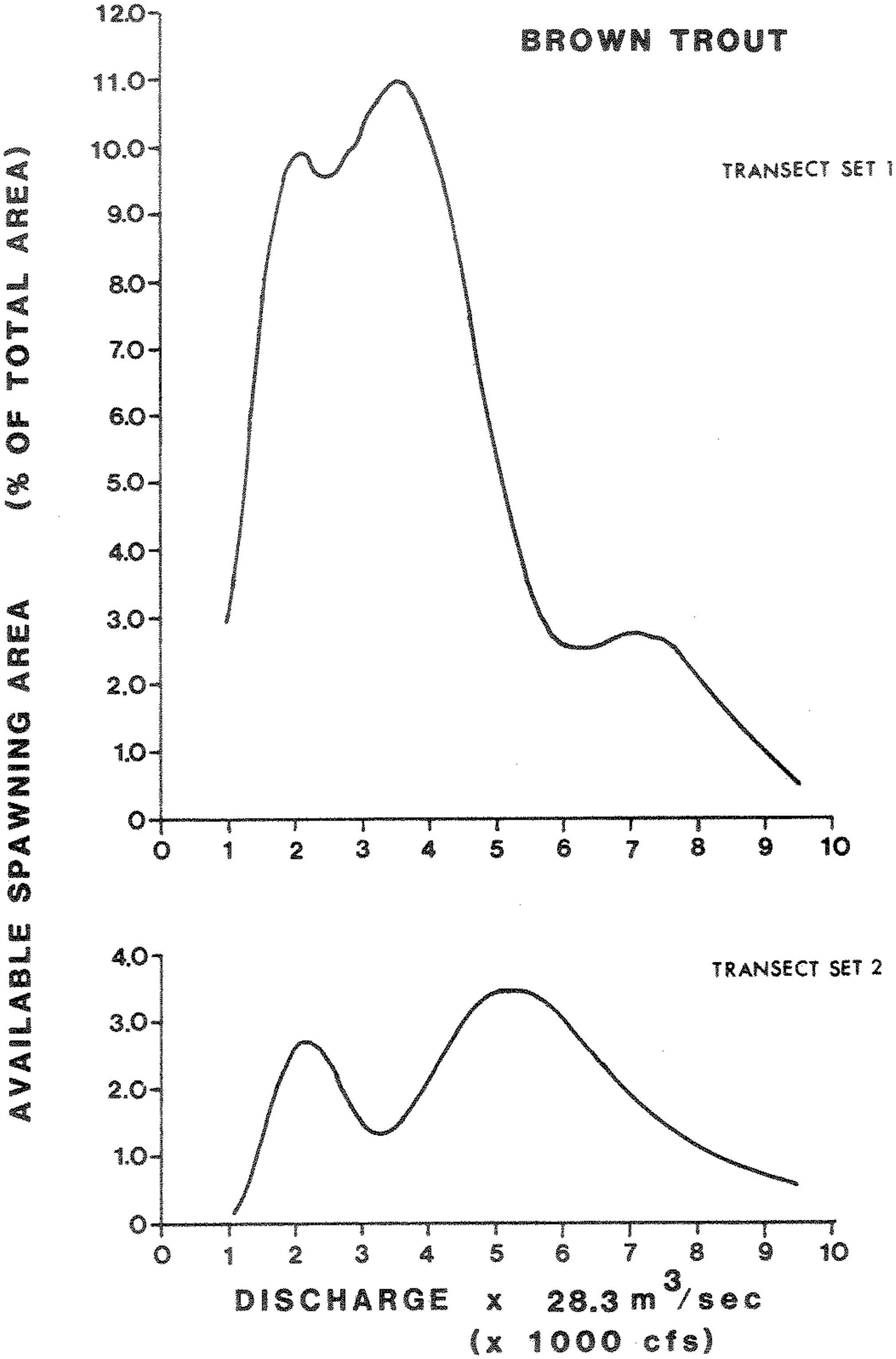

Figure 23. Predicted flow related changes in available spawning habitat for brown trout in the Missouri River study area.

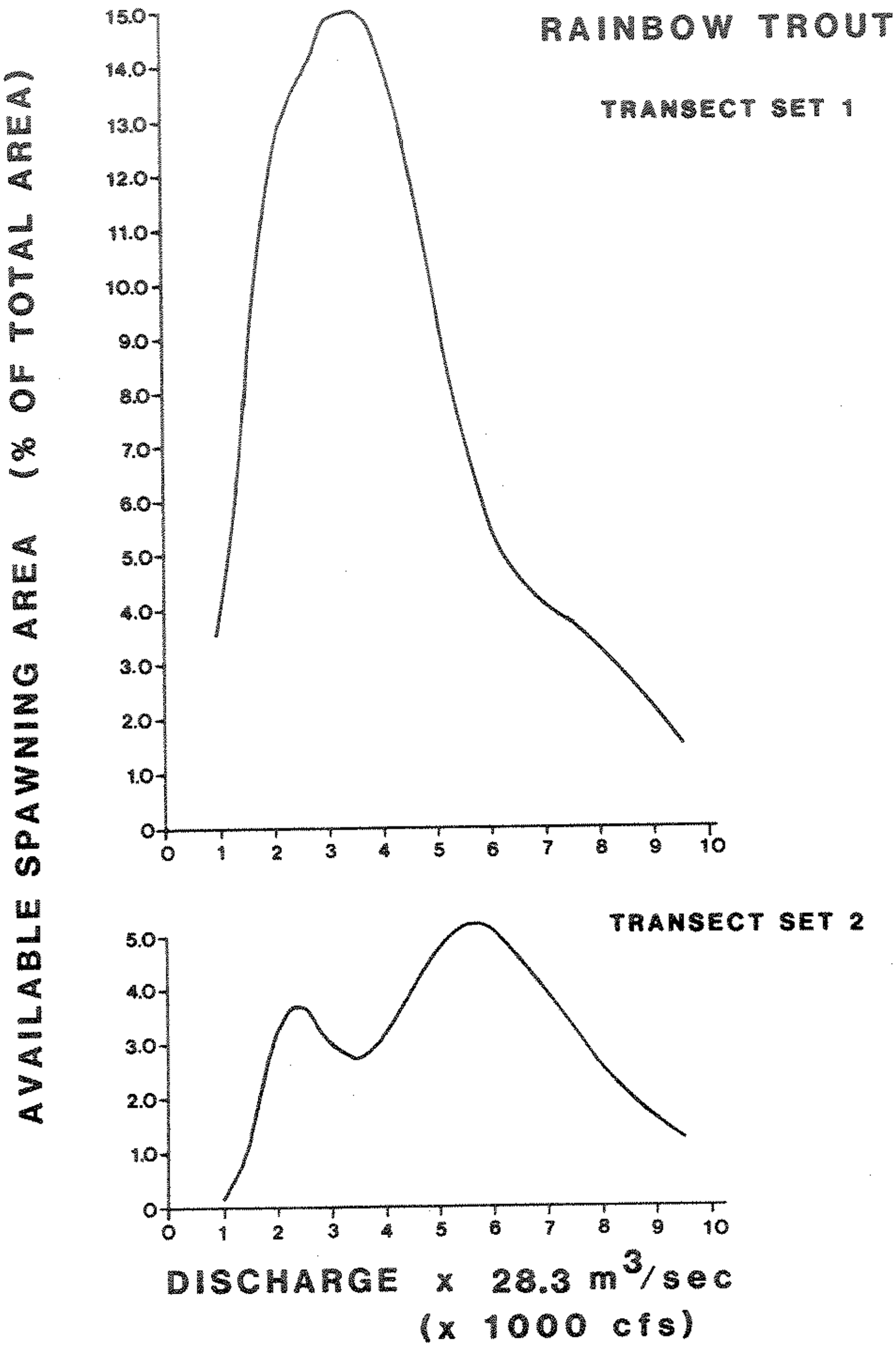

Figure 24. Predicted flow related changes in available spawning habitat for rainbow trout in the Missouri River study area.

area represented by the second peak during the course of the study.

Area of available rainbow trout spawning at transect set 2 was maximum (5.15% of total segment area) at 155.8 m^3/second (5,500 cfs) (Figure 24). The secondary peak on the usable area curve was at 68.0 m^3/second (2,400 cfs).

Peaks of available spawning habitat occurred at higher discharges for rainbow trout, compared to brown trout, because of the differences in spawning depth criteria. Rainbow redds, on average, were located at greater depths (Figure 21).

Transect set 3 was located at spawning area 4, just upstream from Cochran Gulch (Figure 1). At this area the hydraulic model predicted reasonably well at higher discharges, but at lower flows the model overestimated velocities and underestimated decreases in water surface elevation (Tables 16 and 17). These observations suggest that this area is influenced by the backwater of Holter Reservoir; therefore, modeling data at transect set 3 were not used in the evaluation.

Fecundity

Only three brown trout were sampled for egg counts. Three females, 538, 395, and 592 mm total length, contained 2,708, 1,687, and 3,845 eggs, respectively. Seventeen rainbow trout, captured in the Missouri River, ranging from 344 to 501 mm ($\bar{X}$ = 410 mm) contained an average of 1,804 eggs (range = 847 to 2,919 eggs). Eight rainbow trout females, captured in Beaver Creek, ranged from 368 to 457 mm ($\bar{X}$ = 421 mm) contained an average of 2,368 eggs (range = 1,811 to 3,558 eggs).

Age Distribution of Spawners

First spawning for male and female brown trout in the Missouri River occurred at age 2+. Predominant age classes comprising male and female spawning populations were age 2+ (37%) and age 3+ (42%), respectively (Table 20). Missouri River rainbow trout males and females first spawn at age 1+ and 2+, respectively. Age 3+ was the predominant spawning cohort for both males and females (Table 20).

Table 20. Age compostion of brown and rainbow trout spawners in the Missouri River study area.

		Males		Females	
	Age	N	(%)	N	(%)
Brown trout					
	2+	10	37.0	24	31.6
	3+	8	29.6	32	42.1
	4+	7	25.9	18	23.6
	5+	1	3.7	2	2.6
	6+	1	3.7	0	0.0
		27		76	
Rainbow trout					
	1+	1	2.4	0	0.0
	2+	10	24.4	4	15.4
	3+	28	68.3	21	80.8
	4+	2	4.3	1	3.8
		41		26	

Trout Movement and Harvest

Five thousand fish were tagged in the study area from March 1982 to March 1983. These included 3,478 rainbow trout and 1,435 brown trout. The remaining tags were placed in brook, cutthroat, and rainbow/cutthroat hybrid trout as well as walleye. Recapture of tagged fish by fishermen or by electrofishing provided information on movement. Brown and rainbow trout movement trends were classified as non-spawning (or general movement), pre-spawning movement, and post-spawning movement. Non-spawning movement was determined from fish not gravid or ripe when tagged, or recaptured. Pre-spawning movement was based on fish that were not ripe or gravid when first captured, but were in spawning condition when recaptured. Post-spawning movement was determined from fish captured in spawning condition, but were not ripe or gravid when later recaptured. Tagged fish recovered by anglers were assumed to be non-ripe or non-gravid when caught outside of the spawning season, but were not assumed to be ripe or gravid when caught during the spawning season.

Harvest

Anglers reported catching 11.7% of the rainbow trout tagged in the Missouri River study area and 4.0% of the rainbows tagged in Beaver Creek. The brown trout harvest rate in the river was higher than for rainbows with a reported harvest of 14.5%; only 3.0% of the brown trout tagged in Beaver Creek were reported caught. Brown trout harvest rate was highest during October and November (the spawning period) of 1982. Harvest of spawners which had returned to Holter Lake primarily occurred during the spring and early summer. Rainbow trout harvest in the Missouri River was highest during April of 1983. Fish returning to Holter Lake were most often caught during mid-summer.

Brown trout males appeared to be more vulnerable to harvest during the spawning period than were females. Thirty males and 41 females, previously tagged and sexed, were reported harvested; 60% of the males were harvested during the spawning period, compared to 39% of the females. This sex-specific harvest may, in part, account for the nearly 2 to 1 female/male sex ratio observed during the spawning period.

Brown Trout Movement

During 1982 and 1983, 489 recapture locations were obtained from 1,435 brown trout tagged in the Missouri River and Beaver Creek. Spawning movement trends were determined from 104 recapture locations, and 385 tag returns were related to non-spawning movement.

For non-spawning brown trout (general movement), an average of 69.6% of the recaptures (range between sections = 80.9% to 16.7%) were recovered in the initial tagging subsection (Table 21). Eight brown trout, which were not

Table 21. Non-spawning movement of brown and rainbow trout in the Missouri River study section and surrounding areas (1982-84).

Tagging* location	Number of recaptures from tagging location								Total number of recaptures
	Section 1	Section 2	Section 3	Section 4	Section 5	Beaver Creek	Holter Lake	Below Holter Dam	
Brown trout									
Section 1	55 (80.9%)	9 (13.2%)	2 (2.9%)	--	--	--	2 (2.9%)	--	68
Section 2	12 (30.0%)	22 (55.0%)	2 (5.0%)	--	4 (10.0%)	--	--	--	40
Section 3	1 (3.7%)	4 (14.8%)	9 (33.3%)	6 (22.2%)	5 (18.5%)	--	2 (7.4%)	--	27
Section 4	2 (11.1%)	2 (11.1%)	7 (38.9%)	3 (16.7%)	3 (16.7%)	--	1 (5.6%)	--	18
Section 5	--	6 (7.4%)	4 (4.9%)	9 (11.1%)	59 (72.8%)	--	3 (3.7%)	--	81
Beaver Cr.	--	--	--	--	--	151 (100%)	--	--	151
									385
Rainbow Trout									
Section 1	125 (60.0%)	56 (26.8%)	9 (4.3%)	2 (1.0%)	8 (3.8%)	--	8 (3.8%)	1 (0.5%)	209
Section 2	38 (29.2%)	58 (44.6%)	12 (9.2%)	6 (4.6%)	4 (3.1%)	--	12 (9.2%)	--	130
Section 3	5 (10.0%)	8 (16.0%)	16 (32.0%)	3 (6.0%)	11 (22.0%)	--	7 (14.0%)	--	50
Section 4	2 (5.3%)	2 (5.3%)	8 (21.0%)	5 (13.2%)	13 (34.2%)	--	8 (21.0%)	--	38
Section 5	2 (1.7%)	7 (6.0%)	11 (9.5%)	10 (8.6%)	78 (67.2%)	--	7 (6.0%)	1 (0.9%)	116
Beaver Creek	--	--	--	--	--	14 (100%)	--	--	14
									557

*Kilometers below Hauser Dam
Section 1 = 0.0 to 1.4
Section 2 = 1.4 to 2.3
Section 3 = 2.3 to 2.7
Section 4 = 2.7 to 3.4
Section 5 = 3.4 to 4.5

in spawning condition when tagged, were recovered by anglers in Holter Lake. Four of these trout were tagged during early October when secondary sexual characteristics would be less prominent and may have been overlooked. These movements were possibly spawning related. No resident brown trout from Beaver Creek were recovered in the Missouri River (Table 21).

Brown trout pre-spawning movements revealed no discernable trends (Figure 25). Compared to non-spawning fish, however, spawning brown trout were less frequently recaptured in the subsection from which they were tagged. For spawning brown trout, an average of 53.1% of the recaptures occurred at the initial tagging location.

Post-spawning relocations were most often downstream from the tagging location (Figure 26). Fifty percent of the recaptures were from anglers at Holter Lake, and most tagged fish were creeled prior to 1 July of the following year. One tagged brown trout was recovered by an angler below Holter Dam.

Twenty-one brown trout (19 females and 2 males) were observed in spawning condition during consecutive years. Ten (47.6%) repeat spawners were recaptured within the same subsection in each of the 2 years (Figure 27). One female was observed in spawning condition 3 consecutive years.

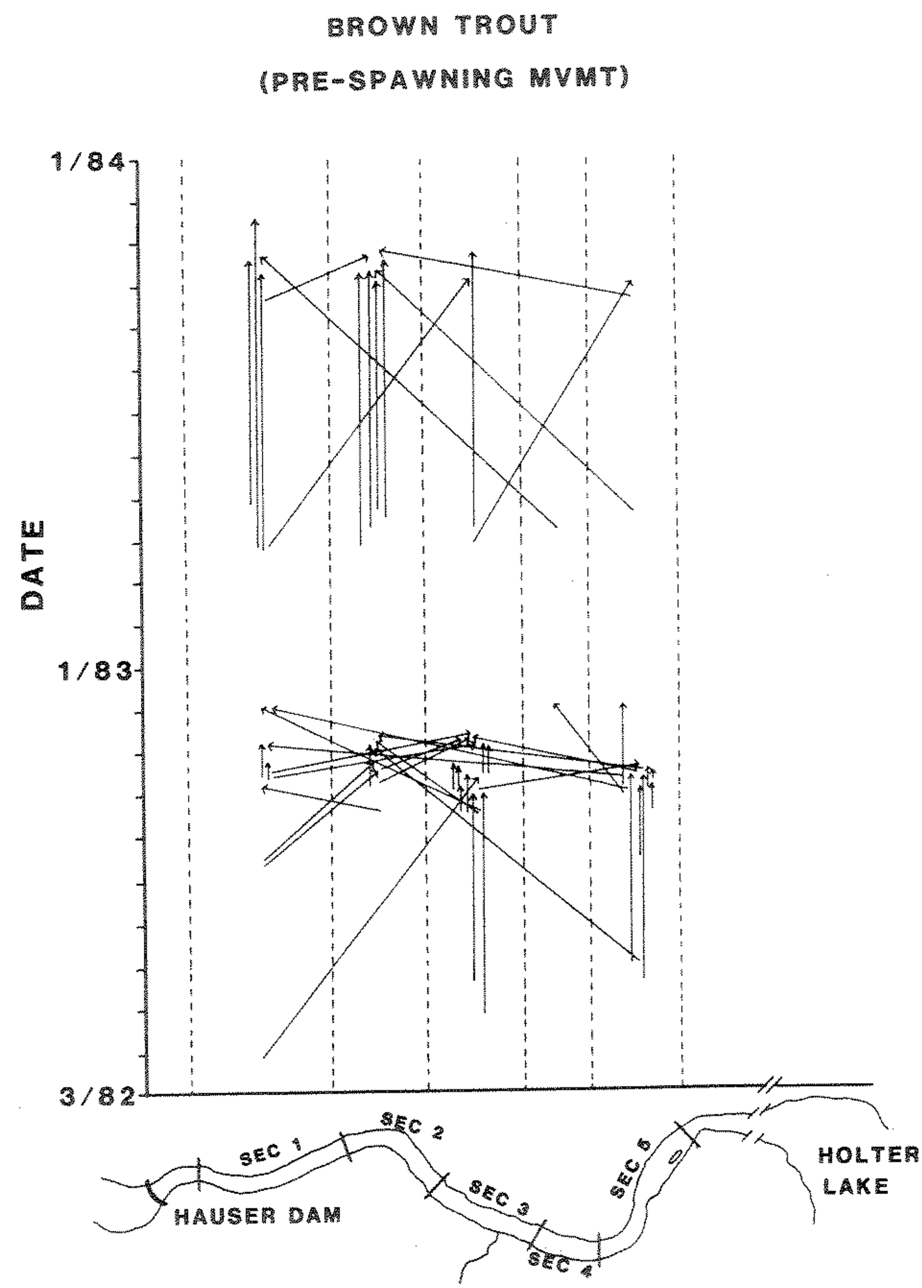

Figure 25. Movement of brown trout in the Missouri River study area prior to spawning (1982-83) (Each arrow represents the movement of one fish, and broken lines correspond with section boundaries).

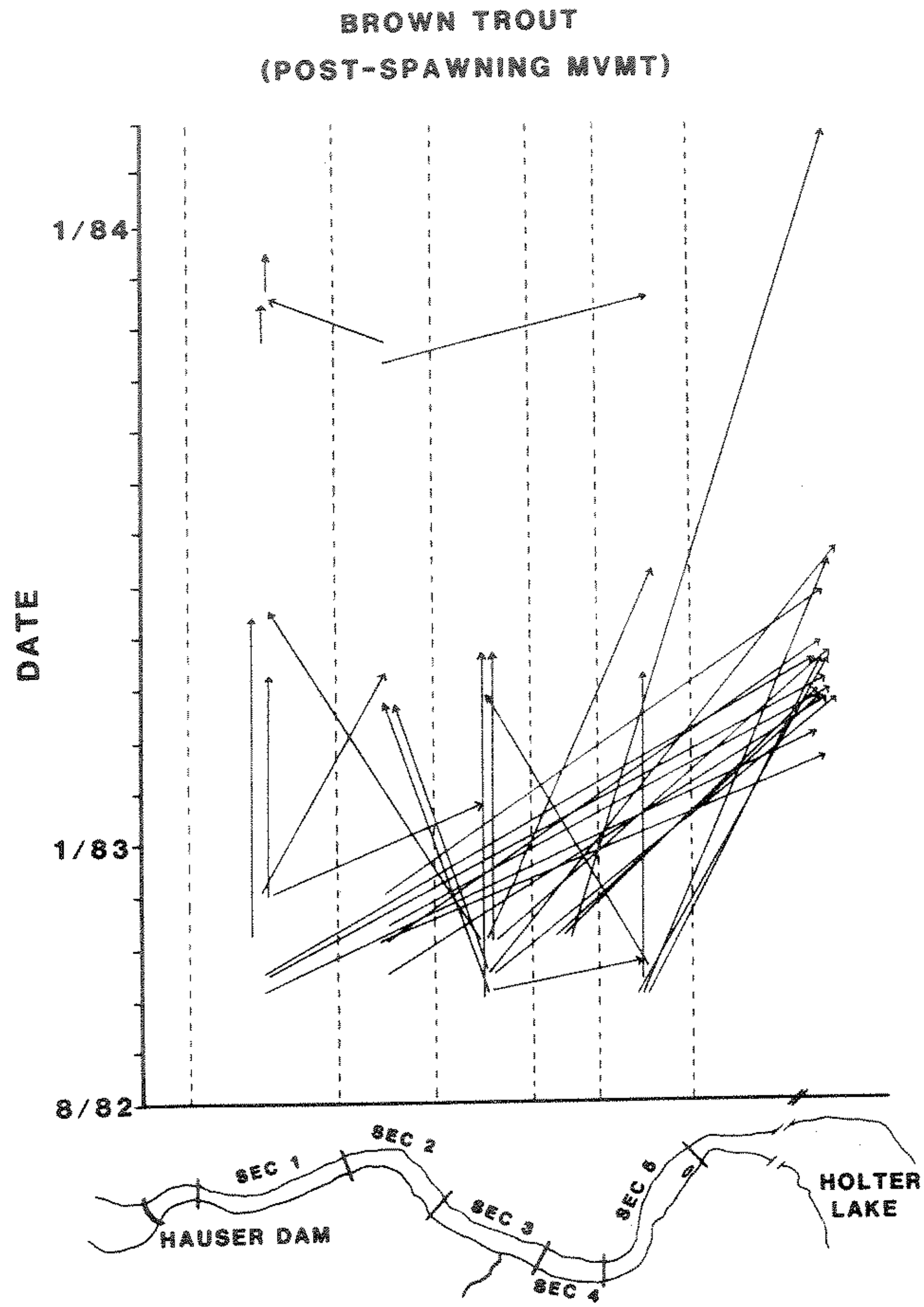

Figure 26. Movement of brown trout in the Missouri River study area after spawning (1982-83).

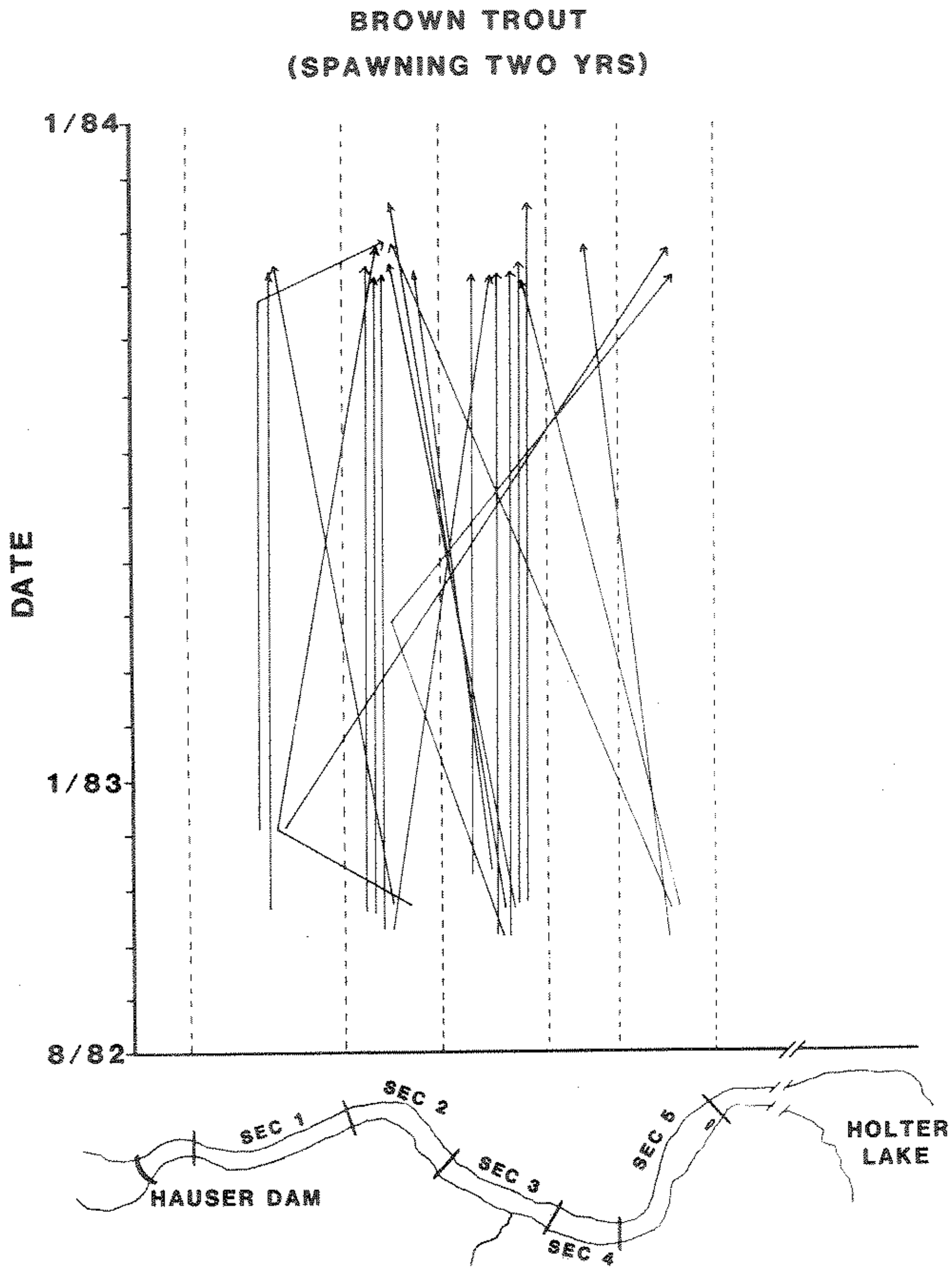

Figure 27. Locations of brown trout in spawning condition two consecutive years in the Missouri River study area (1982-83).

Rainbow Trout Movement

During 1982 and 1983, 2,830 rainbow trout were tagged in the Missouri River, and 648 were tagged in Beaver Creek. Non-spawning movement was based on 556 recapture locations, and spawning movement was determined from 218 recapture locations.

In the Missouri River, an average of 56.6% of the non-spawning recaptures (range between sections = 67.8 to 13.2%) were from the initial tagging subsection (Table 21). During pre-spawning movement, rainbow trout were less frequently recaptured within the initial tagging subsection; only 25% of the recaptures were from the initial capture location (Figure 28). No non-spawning rainbow trout tagged in Beaver Creek were recovered in the Missouri River.

A relatively large number of non-spawning rainbow trout were recovered by anglers in Holter Lake. Of the 42 angler returns from Holter Lake, 32 were from non-spawning rainbows tagged in the spring. It is likely that some of the non-spawners tagged in the spring were associated with the spawning migration but were not in spawning condition at the time of capture. There also appeared to be a fall migration of rainbow trout from Holter Lake to our study section, and a similar proportion of fall and spring migrating fish were harvested in Holter Lake during the

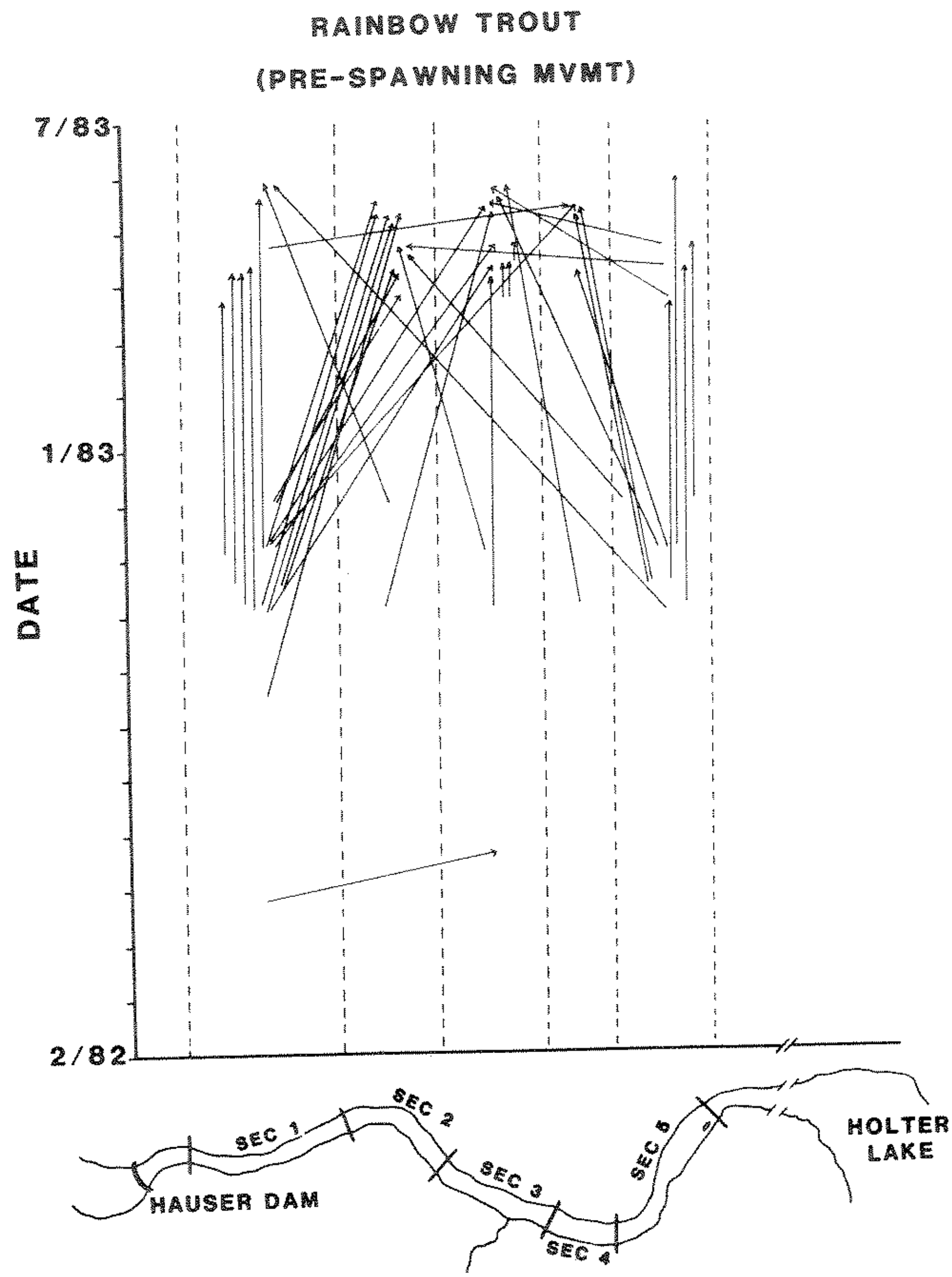

Figure 28. Movement of rainbow trout in the Missouri River study area prior to spawning (1982-83).

spring and early summer. Two non-spawning rainbows were recovered by anglers below Holter Dam.

Rainbow trout post-spawning movement was similar to the brown trout post-spawning movement pattern (Figure 29). Sixty-seven percent of the relocations were downstream from the initial tagging location, and 52% of the relocations were from anglers downstream from the lower boundary of the 4.5 km study section. Of the 22 angler returns below the study section, 13 were creeled in Holter Lake, 7 were caught below Holter Dam, and 2 were recovered in tributaries of Holter Reservoir; one each in Willow Creek (18.6 river km below Hauser Dam) and in Cottonwood Creek (27.4 river km below Hauser Dam).

Fifty rainbow trout spawning movements from the Missouri River to Beaver Creek were observed in 1982 and 1983. In 1982, 90% of the spawners recovered in Beaver Creek were tagged at or below the mouth of Beaver Creek (sections 3, 4, and 5) earlier during the spring (Figure 30). In 1983, most (74%) relocations in Beaver Creek were from fish tagged during the fall of 1982 since few tags were distributed during 1983. Of the rainbow trout spawners marked in 1982 and recovered in Beaver Creek in 1983, 45%, 26%, and 29% were tagged above, at, or below the mouth of Beaver Creek, respectively.

After spawning in Beaver Creek, most rainbow trout were recovered downstream from the mouth of Beaver Creek

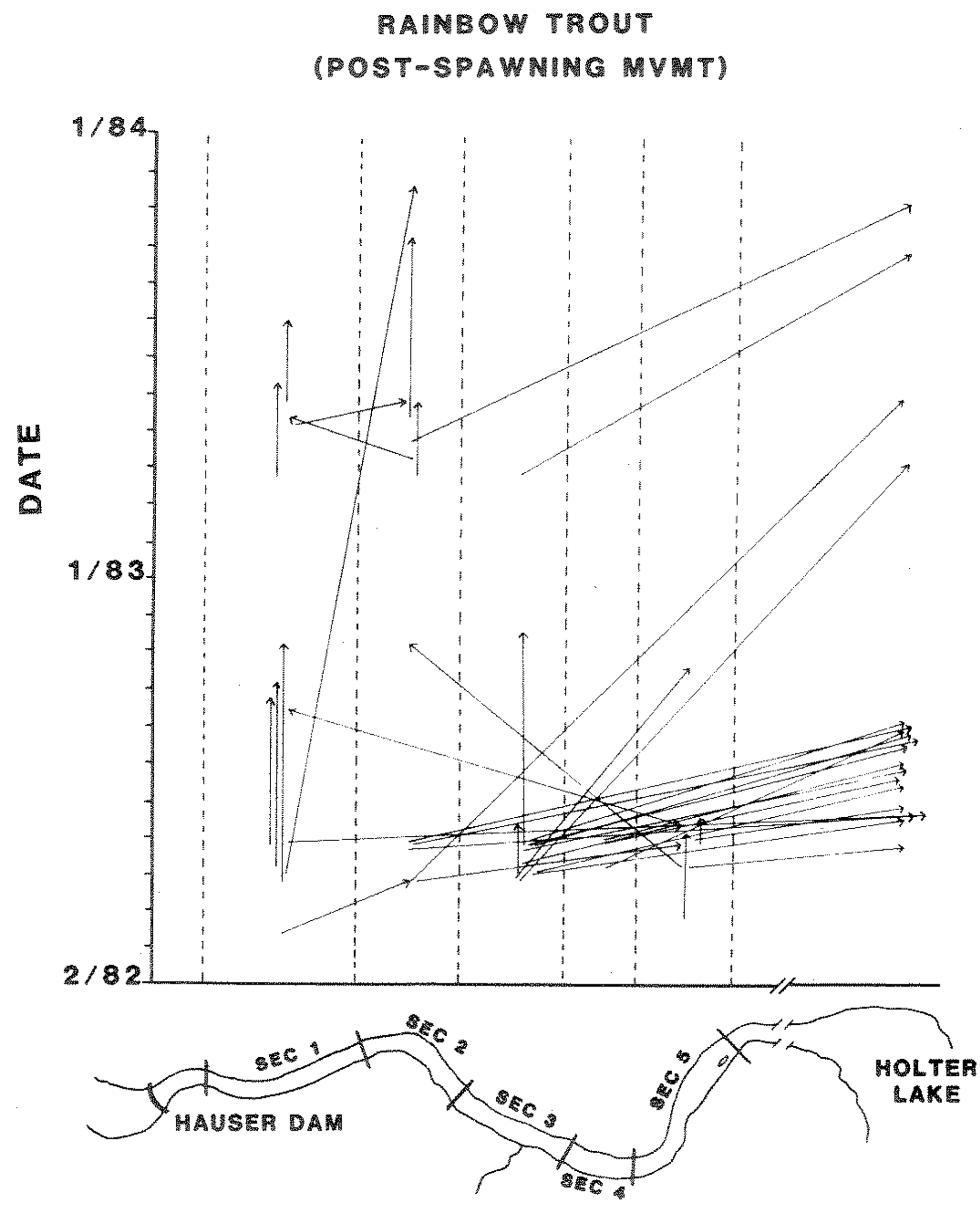

Figure 29. Movement of rainbow trout in the Missouri River study area after spawning (1982-84).

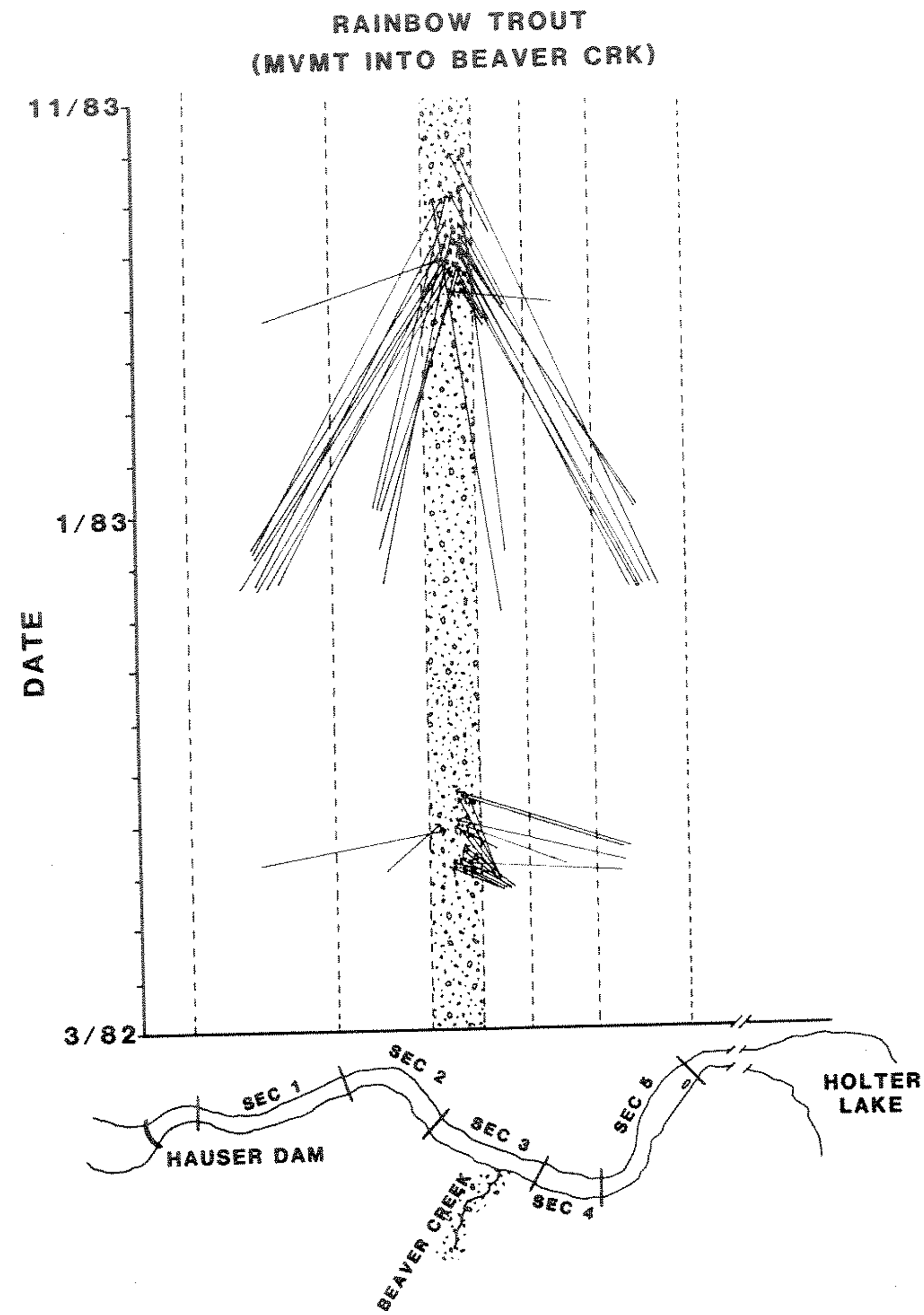

Figure 30. Rainbow trout spawning movement from the Missouri River to Beaver Creek (1982-83).

(Figure 31). Twenty-four recapture locations (35%) were from sections 4 and 5, 22 (32%) were from Holter Lake, and two (2.9%) were from below Holter Dam.

Twenty rainbow trout (11 males and 9 females) were observed in spawning condition during 2 consecutive years. When recapture locations at section 3 (at the mouth of Beaver Creek) were combined with Beaver Creek relocations, 15 (75%) were observed in the same spawning area each of the 2 years (Figure 32).

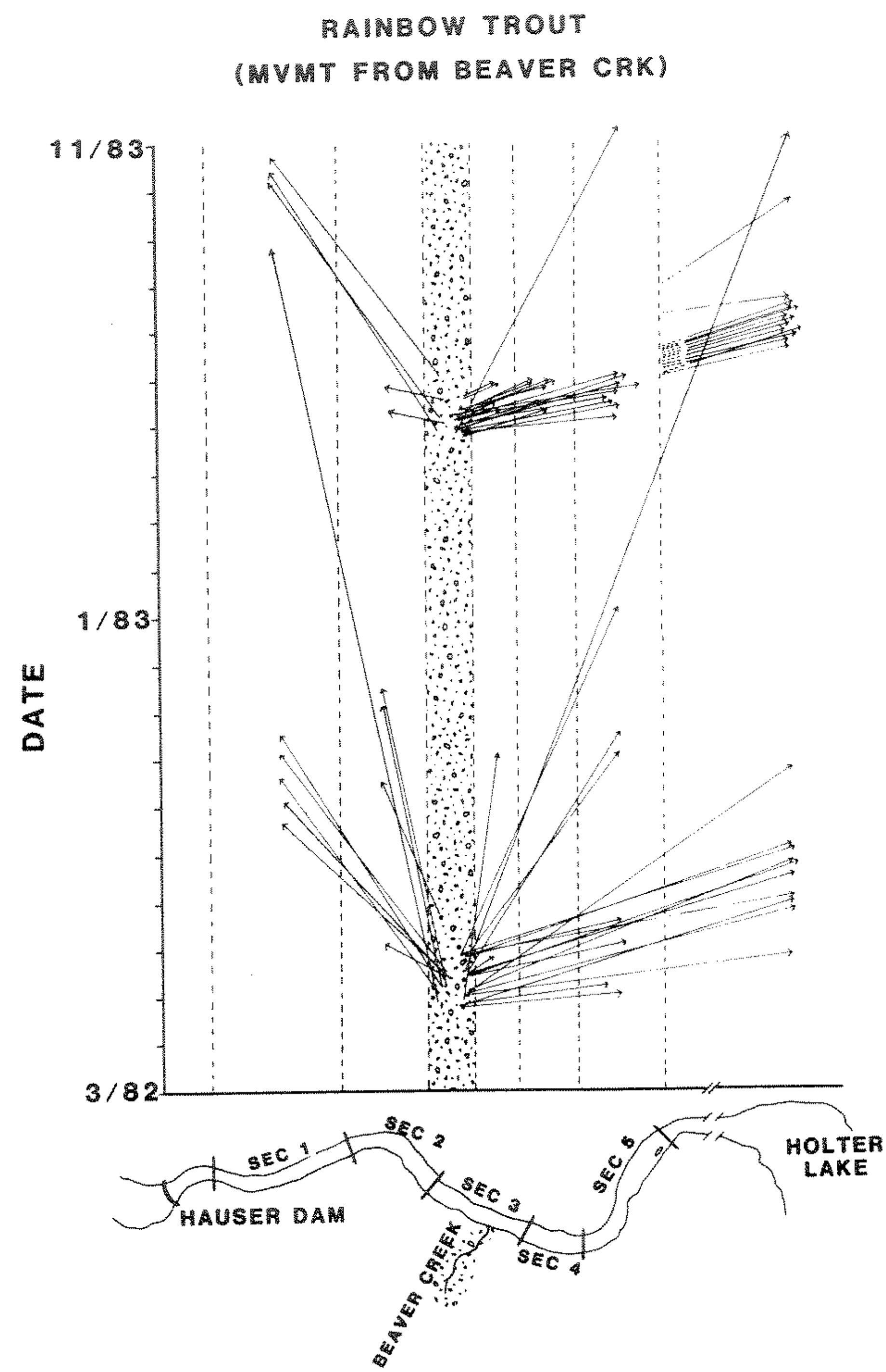

Figure 31. Rainbow trout movement from Beaver Creek to the Missouri River study area after spawning (1982-83).

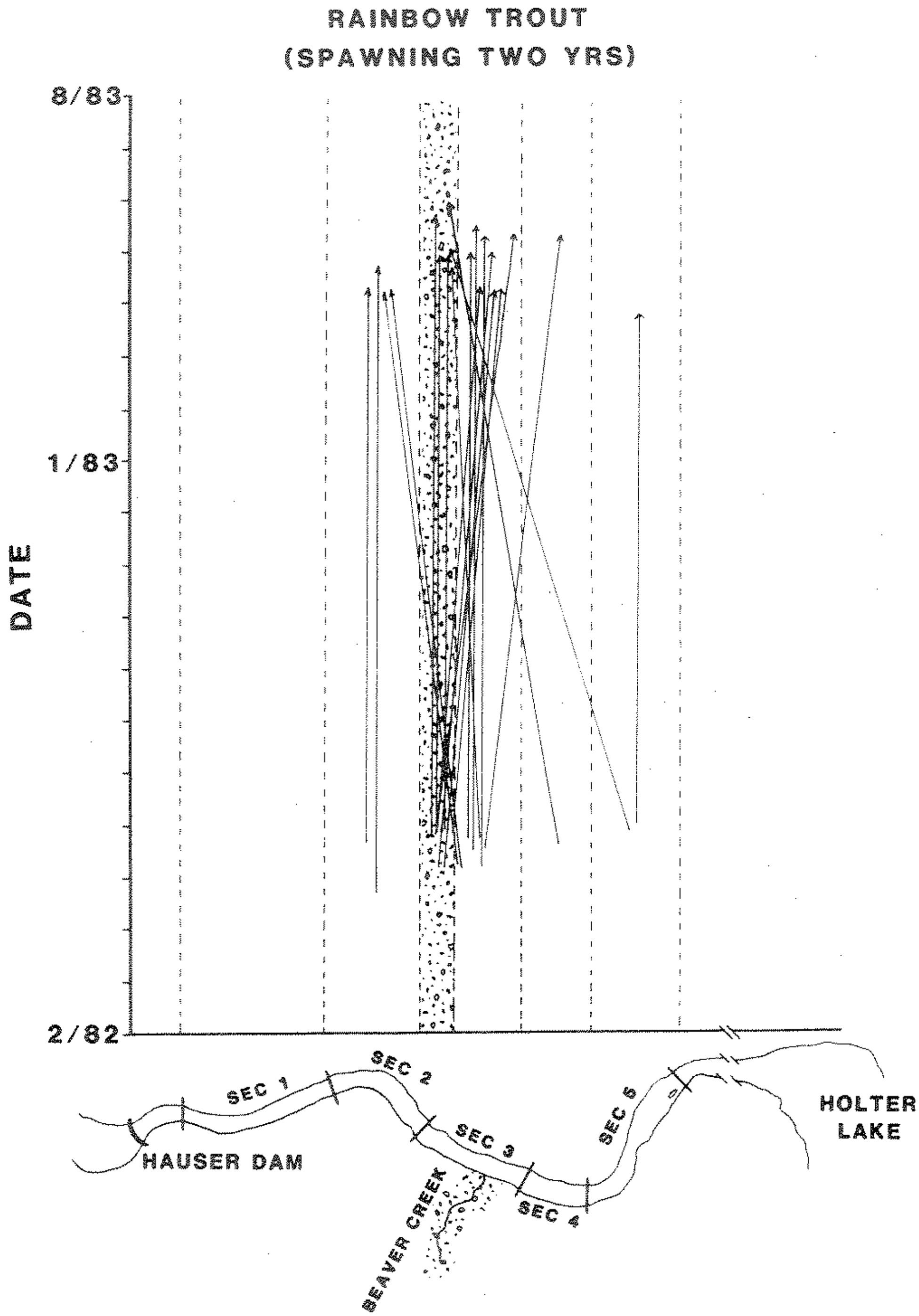

Figure 32. Locations of rainbow trout in spawning condition two consecutive years in the Missouri River study area and Beaver Creek (1982-83).

DISCUSSION

Spawning, incubation of eggs, and emergence of fry are the life stages of trout most likely to be influenced by fluctuating flows in the Missouri River study area. Diminished success of any of these processes could result in decreased abundance of trout.

In the Missouri River study area, the known quantity of adequate spawning habitat is small relative to the size of the spawning populations. Only four areas are known to be used extensively for spawning. Although daily fluctuations in discharge of the magnitude proposed have not occurred in the past, the present channel was formed by much higher discharges. Thus, flows in the range tested are not expected to remove spawning substrate.

The intensive aggregation and superimposition of redds is possible evidence of the scarcity of suitable spawning sites and suggests that the brown trout population in the study area may be limited by available spawning habitat. Stuart (1953) noted that superimposition is inevitable when available spawning area is limited and the spawning population is large. Redd superimposition results in mortality of eggs previously deposited. Redd aggregates, however, may be partly due to attraction of spawners to disturbed substrate; this has been observed with spawning chinook salmon (Chapman et al. 1982). Multiple redds were less frequently observed in Beaver Creek except when spawners were concentrated below beaver dams.

Flows which reduce the quantity of suitable spawning habitat would likely increase the frequency of superimposition. Although spawning is rarely limiting to stream fish populations (McFadden 1969), the downstream reservoir in the study area provides increased space and food to support larger numbers and biomass of trout than could be supported in the river. If the brown trout population is limited by spawning habitat, any reduction or enhancement of spawning success would directly affect the future adult populations. The rainbow trout population in the Missouri River study area is less likely to be limited by spawning habitat because of extensive tributary spawning and hatchery stocking.

Spawning habitat located in the zone of fluctuating flows would be influenced most by proposed peaking flows. The largest impact would occur at the two spawning areas above Beaver Creek where only 30% of the brown trout redds were located in relatively deep water that would be less influenced by flow fluctuations (Table 4). Most redds below Beaver Creek would not be adversely affected because of reduced flow fluctuations and greater spawning depths.

Trout spawning activity below Hauser Dam occurs for 4 to 5 months of the year, and water temperature at initiation of spawning was similar between years. Brown trout spawning began when water temperature dropped to 9.5 - 11.1 C in mid October, and extended through December with peak spawning occurring in early to mid November. Berg (1981) reported similar timing of brown trout spawning in the Missouri River below Holter Dam.

Rainbow trout spawned from late March to about mid June in 1982. Spawning began in early March in 1983, although water temperature at first spawning was the same each year (3.5 C). Temperature during trout spawning was similar to that reported in the literature (Tables 22 and 23). Migrations of rainbow trout into Beaver Creek were less influenced by water temperature, and appeared to be triggered by increases in streamflow.

Many studies have shown that salmonids spawn within a relatively narrow range of hydraulic conditions (Tables 22 and 23). Data collected to establish spawning criteria for depth, velocity, and substrate have been gathered since the early 1950's. Since most of these criteria were developed by quantifying physical characteristics of trout redds in streams smaller than the Missouri River, the ranges and means of depth and velocity were generally wider and had higher maximums in the Missouri River study area. Bovee's (1978) probability of use curves for

Table 22. Minimum depth, range of velocity, and water temperature associated with brown trout spawning. Modified from Reiser and Wesche (1977).

Parameter	Value	Source
Minumum depth (cm)	4.6	Present study (Beaver Creek)
	24.4	Present study (Missouri R.)
	29.0	Berg 1983 (Missouri R.)
	18.0	Sando 1981 (Beaverhead R.)
	17.0	Sando 1981 (Yellowstone R.)
	24.4	Thompson 1972
	24.4	Smith 1973
	15.2	Bovee 1975
Mean column velocity (m/sec)	0.06-1.04	Present study (Beaver Creek)
	0.33-1.40	Present study (Missouri R.)
	0.38-1.37	Berg 1983 (Missouri R.)
	0.35-0.95	Sando 1981 (Beaverhead R.)
	0.28-0.63	Sando 1981 (Yellowstone R.)
	0.21-0.64	Thompson 1972
	0.30-0.91	Hooper 1973
	0.20-0.68	Smith 1973
	0.30-0.76	California (in Hunter, 1973)
	0.43-0.82	Bovee 1975
Water temperature (C)	5-7	Present study (Beaver Creek)
	9-11	Present study (Missouri R.)
	6-7	Stuart 1953
	7	Hoppe and Finnel 1970
	10	Bell 1973
	7-9	Hooper 1973
	7-13	Hunter 1973
	6-13	Bovee 1975

Table 23. Minimum depth, range of velocity, and water temperature associated with rainbow trout spawning. Modified from Reiser and Wesche (1977).

Parameter	Value	Source
Depth (cm)	10.7	Present study (Beaver Creek)
	24.4	Present study (Missouri R.)
	4.4	Sando 1981 (Beaverhead R.)
	22.0	Sando 1981 (Yellowstone R.)
	12.2	MDFWP (Yellowstone R.)*
	12.2	Sanborn (Soap Creek)**
	18.3	Sanborn (Big Horn R.)**
	18.3	Smith 1973
	15.2	Thompson 1972
	12.2	Bovee 1975
Mean column velociy (m/sec)	0.20-1.19	Present study (Beaver Creek)
	0.09-1.37	Present study (Missouri R.)
	0.22-1.21	Sando 1981 (Beaverhead R.)
	0.41-0.65	Sando 1981 (Yellowstone R.)
	0.27-1.04	MDFWP (Yellowstone R.)*
	0.25-1.27	Sanborn (Soap Creek)**
	0.49-0.91	Sanborn (Big Horn R.)**
	0.30-0.91	Smith 1973
	0.43-0.82	Thompson 1972
	0.10-1.23	Bovee 1975
Water temperature (C)	3-6	Present study (Beaver Creek)
	3.5	Present study (Missouri R.)
	3.3	Sanborn (Big Horn R.)**
	2-20	Bell 1973
	11	Hooper 1973
	4-13	Hunter 1973
	2-8	Orcutt, Pulliam, and Arp 1968
	7-13	Bovee 1975

* Unpublished data from Berg and Workman.
** Thesis in preparation.

spawning, which are based on available literature, approximate hydraulic conditions at Beaver Creek redds more closely than Missouri River redds (Figure 21). Separate probability of use curves for various catagories of stream size may result in more accurate predictions of effects of flow modifications. To define comprehensive spawning criteria for salmonids, Reiser and Wesche (1977) emphasize additional collection of spawning requirements in larger rivers. Annear and Conder (1984), however, indicated that Bovee's (1978) spawning and incubation curves are "reasonably accurate" for most species.

There is need for standardizing methods of developing spawning criteria. Mean column velocity was used in this study because the hydraulic model used to predict effects of various flows predicts mean velocity. Others have used mean column velocity in developing spawning criteria (Reiser and Wesche 1977, Sando 1981, Bovee 1978). Recently Shirvell and Dungey (1983) measured focal point velocities (2 cm above the highest point of the redd) to investigate brown trout spawning microhabitat selection. Since focal point position is primarily a function of spawner size, Hunter (1973) measured velocity at 0.4 feet (12.2 cm) above the streambed for salmonids larger than 4 pounds (1.8 kg), and at 0.25 - 0.30 feet (8 - 9 cm) for smaller trout.

Mean column velocity is higher than the velocity encountered by the spawner at the substrate level, and this discrepency increases as stream size increases. Velocity criteria, therefore, are variable between different sized streams when mean column velocity is measured. Shirvell and Dungey (1983), using spawning focal point, observed consistent selection for velocity in various sizes of rivers. Similarly, point velocities of redds, measured at the substrate level, were comparable in the Missouri River and Beaver Creek. A drawback of measuring velocity at approximately the substrate level is the variation observed related to streambed roughness. As a result, the coefficient of variation is higher for point velocity at substrate level than for mean column velocity. Although not measured in this study, focal point velocity of the spawning female would likely be the most representative, least variable, and most comparable measurement of preferred velocity for spawning.

Presentation of spawning microhabitat data also needs standardization. Since quantification of unused habitat can be as informative as measurements of habitat used, suitability curves representing use of a parameter relative to its availability are being more commonly used. These suitability functions more accurately describe habitat selection, and consequently, may differ markedly from utilization functions (Baldridge and Amos 1981).

Velocity appeared to be more important than depth for spawning site selection in the Missouri River study area. This is evidenced by flow associated changes in spawning depth while spawning velocity remained similar (Figure 12). Water velocity chosen by spawners remained consistent even at the deepest of spawning areas. In general, water depth did not appear to be an important component in the selection of spawning sites with the exception of a minimum depth spawners would utilize. Substrate composition defined the boundaries within which spawners made adjustments according to water velocity. Others have noted the importance of water velocity and substrate for the selection of spawning sites (Reiser and Wesche 1977; Shirvell and Dungey 1983), while Rinne (1980) believed water velocity to be less important than depth and substrate.

Water velocity also appeared to be the habitat variable most selected for in Beaver Creek (Figure 13). An additional parameter influencing the selection of spawning sites in this small stream was overhead cover. The tendency for brown and rainbow trout redds to be located near shore may, in part, be related to the increased availability of overhead cover. Brown trout selection of spawning sites adjacent to undercut banks and overhanging vegetation was also observed by Reiser and Wesche (1977). In larger streams, such as the Missouri River, overhead cover is less important because of the security provided by spawning at greater depths. In addition, rainbow trout redds in Beaver Creek were less frequently associated with overhead cover compared to brown trout redds. Rainbow trout spawn in deeper water during higher, more turbid flow conditions which may reduce the need for structural cover.

Since distribution of depths and velocities over suitable spawning substrate is a function of flow, the amount of adequate spawning habitat varies with discharge. Flows too high or too low result in unfavorable conditions for spawning (Fraser 1972).

From hydraulic and PHABSIM habitat modeling, it was evident that the relationship between the predicted quantity of suitable spawning habitat and flow differs between spawning areas. Maximum predicted brown trout spawning habitat at area 1 was provided by a flow of 99.1 m^3/second (3,500 cfs), while the maximum at area 2 was at 146.6 m^3/second (5,178 cfs) (Figure 23). A comparison of the number of brown trout redds in the two areas seems to support the model's predictions. In 1981, when discharge during most of the spawning period was approximately 113.3 m^3/second (4,000 cfs), 44% of observed redds were at spawning area 1 and 16% were at area 2. During the higher discharge of 1982 (approximately 141.6 m^3/second; 5,000 cfs), 41% of observed redds were at spawning area 2 and 31% were at area 1 (Table 5). This difference in spawning use probably reflects changes in availability of preferred habitat in the two areas. The example above also demonstrates the ability of the PHABSIM system to predict relative changes in habitat availability as flow changes.

The model also predicted that high discharges will reduce spawning habitat as abruptly as low discharges. Although there will be a point above which high discharge will produce excessive velocities, consideration of adjustments by spawners to avoid high velocities is not within the capabilities of the model. In 1982, for example, as discharge increased to about 200 m^3/second (7,000 cfs), rainbow trout spawners at area 2 began to spawn in small areas behind boulders that were not previously used. Redd making also shifted to areas between the small riffles which had lower velocities and sometimes increased depths.

Predictions of weighted usable area (WUA) at increased flows were also misleading because of biases in spawning criteria. Although the number of measurements taken at redds was considered "good" (200 measurements are needed for "excellent" utilization curves) (Bovee and Cochnauer 1977), Missouri River depth criteria did not accurately represent depth preferences. A lack of individual redd depth readings at deep-water spawning areas was the primary reason for the biased data. Swift (in Estes 1985) also observed that spawning fish were not restricted by water depth alone. As a result of this bias, the model considered areas unsuitable for spawning at higher discharges despite the existence of suitable substrate and velocity.

Biased depth criteria can be modified based on field observations, as suggested by Estes (1985). This was not done because there were additional reasons for questioning the reliability of predictions based on this modeling.

For the model to provide realistic predictions, the user must accurately identify the available spawning habitat. Observed spawning activity, however, was concentrated in small areas and did not occur throughout most of the habitat that appeared available. For example, at spawning area 4, redds were typically concentrated within a small portion of the available spawning area despite relatively homogeneous water depths and velocities (Figures 33 and 34). Size of bottom materials at area 4 was also relatively uniform throughout the channel area.

Other factors such as intergravel permeability, subtle changes in bottom contour, or groundwater inflow may have attracted spawners to small areas within the larger areas that appeared suitable for spawning. Stuart (1953) also observed that small areas may be used for

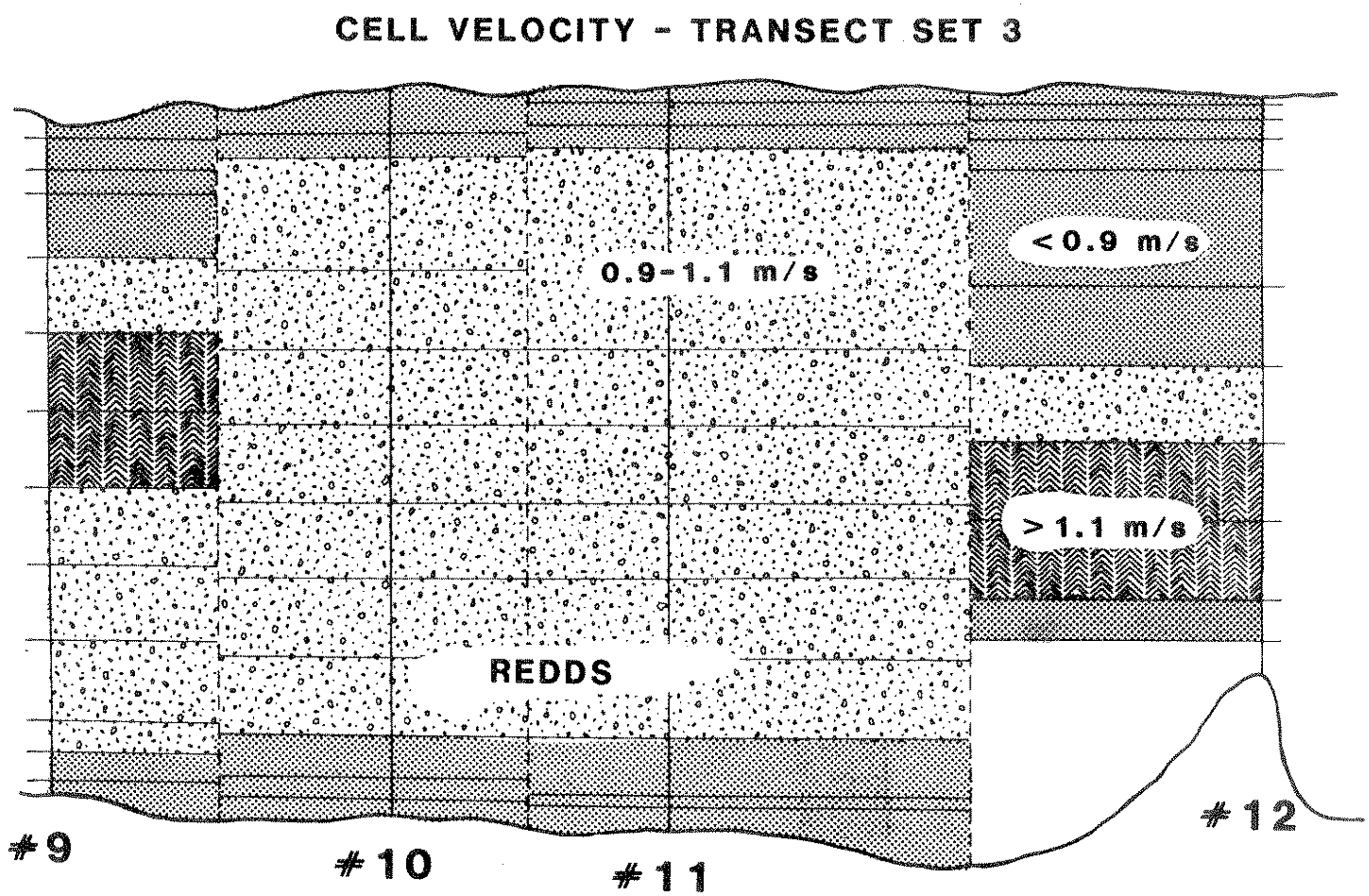

Figure 33. Locations of brown trout redds (1982) in relation to predicted mean column water velocity, Missouri River.

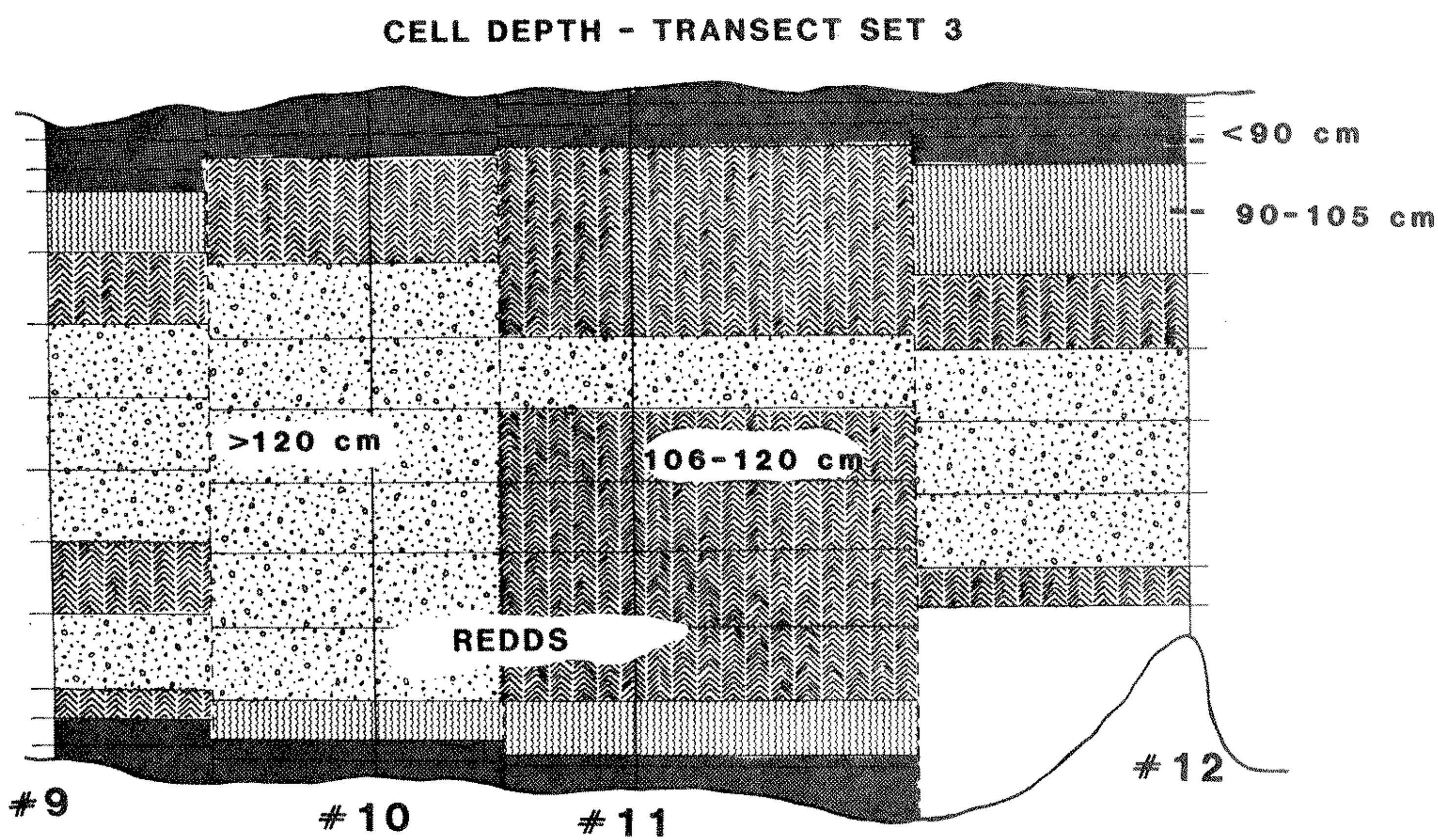

Figure 36. Locations of brown trout redds (1982) in relation to predicted water depth, Missouri River.

spawning despite extensive availability of suitable substrate, depths, and velocities. He concluded that areas with downwelling of surface water through the gravels were preferred for redd building. Estes (1985) believed upwelling to be an important variable for spawning chum salmon. Attraction of spawners to disturbed sites (previously constructed redds) may have also resulted in redd aggregates. Regardless of the cause, it was not possible to predict whether a site would be used for spawning based only on water depth, velocity, and substrate suitability (the inputs to the PHABSIM system). Spawners did not use several sites where these three components were within the preferred range for spawning.

In spawning areas 1 and 2, areas of maximum spawning use were located in the shallower, shoreward portion of a much larger area considered suitable for spawning. The deeper portion of the areas had little use, even during the lower 1981 flows. Thus, WUA predictions were biased in favor of lower flows. The overall maximum quantity of spawning habitat (areas 1 and 2 combined) was predicted to occur at about 59.5 m^3/second (2,100 cfs) for brown trout, and 85.0 m^3/second (3,000 cfs) for rainbow trout. On the basis of my observations during five spawning periods, and examination of numerous test flows, I believe that these predictions underestimate the flows which would produce maximum spawning habitat. Annear and Conder (1984) concluded that PHABSIM methods tend to provide relatively low minimum flow requirement estimates on larger streams (annual flow greater than 100 cfs), and high estimates for small streams. The difference in water depth selection for the two species accounts for the different flows at which the maximum WUA is predicted.

Because of the problems discussed above, habitat modeling results were not used to assess flow-related impact on spawning and egg incubation. An alternative approach that did not involve speculation about available spawning habitat was adopted. This was to observe actual spawning locations and assess how these areas would be impacted at specific flows by using predictive hydraulic modeling.

Reliable hydraulic modeling was only available for areas 1 and 2 because the backwater of Holter Reservoir influences the Missouri River below Beaver Creek. Thus, analyses of redd dewatering and suitability of incubation velocities was limited to these two areas. Since spawning areas 1 and 2 had a higher proportion of redds in relatively shallow water compared to areas 3 and 4, the minimum discharge ensuring successful spawning would be lower at areas 3 and 4. Although hydraulic modeling may not be reliable at area 4, empirical observations confirm that redd dewatering does not occur at the lowest flow observed at this site (55.4 m^3/second); 1,956 cfs).

Incubation velocities also remain adequate at this flow. Adequate minimium flows for the other three spawning areas will also be adequate at area 4. The prediction of impact of the various flow regimes on spawning success for the entire river segment is likely to be conservative since it is based on redd dewatering at the shallowest spawning areas.

Acceptable incubation flows will vary with the magnitude of the spawning flow because of lateral adjustments in spawning as flow changes. Despite the 20 to 25% difference in spawning flows during 1981 and 1982, initial redd dewatering occurred at 60% and 62% of the spawning discharge, respectively. This roughly coincides with Wesche and Rechard's (1980) method of recommending an incubation flow at two-thirds of the spawning flow.

Despite the large number of redds in spawning area 4, its contribution to recruitment may be low. Redds close enough to shore to allow collection of substrate samples contained considerably more fine materials than other redds below Hauser Dam. From the rainbow trout embryo survival equation developed by Irving and Bjornn (1984), less than 0.5% survival would be expected in this spawning area. Although most redds at area 4 were at least 30 m from shore, where fewer fine materials would be expected, the homogeneity of this area with respect to water depth, velocity, and substrate composition suggests that large amounts of fine materials may also exist in redds located away from shore.

The influence of fluctuating flows on spawning behavior was a concern that was not feasible to address in this study, and only limited research on this potential problem has been conducted. Nelson (1984) has recently analyzed long-term brown trout population data from the Beaverhead River, Montana. He compared average daily flows during the 1964 through 1978 brown trout spawning periods (1 October - 30 November) with abundance of age I+ juveniles produced. He found that spawning flows associated with five of the six poor yearling classes were characterized by daily fluctuations of 250 cfs or more (200 to 400% fluctuation). Fair and good year classes were produced during years devoid of extreme fluctuations. Factors related to dam completion probably influenced reproduction the year in which the dam was built. In analyses contrasting flows associated with fair and good year class strength, Nelson (1984) found poor correlations between the magnitude of stable spawning flows and the numbers of age I+ brown trout produced.

Similar relationships were not evident from Nelson's (1984) evaluation of flow conditions during the incubation period. Thus, it appears that fluctuating flows during the spawning period were the primary cause of poor yearling crops produced. Further, the level of flow encountered (low or high) appeared to have no large influence on year class strength as long as large flow fluctuations did not occur during the spawning period.

It is not known why fluctuating flows during spawning seasons produced poor yearling crops of brown trout in the Beaverhead River. The most reasonable explanation is that fluctuating flows influence spawning behavior. Unfortunately, no known research has evaluated this potential problem for brown trout.

Studies of the effects of fluctuating flows on chinook salmon spawning appear to be contradictory. Hamilton and Buell (1976) conducted a study to determine possible effects of daily flow fluctuations ranging between 1,000 cfs and 9,300 cfs on the Campbell River fishery. As a part of this study, spawning chinook were observed as flows were varied. They reported that flow increases of 50%, or decreases of 30%, had "a major disruptive impact" on spawning behavior. Spawning females appeared to be disoriented by the flow changes resulting in untimely release of eggs and failure to cover eggs once released. Once redds were abandoned, even if not completed, spawners rarely returned to them when flow was restored. This is in contrast to the findings of Chapman et al. (1982) and Stober et al. (1982) who reported that once redd construction is initiated, chinook usually return to complete the redd even though it is periodically dewatered by fluctuating flows.

Bauersfeld (1978) reported that in the Columbia River (Vernita Bar), 46% of the chinook redds constructed in the zone of fluctuation were false redds (redds not containing eggs), and not all redds containing eggs (above and below the minimum flow level) contained a full compliment. In a follow-up study, Chapman et al. (1982) found living embryos in 84% of the redds above the minimum flow level but did not determine if the redds contained the normal number of eggs. They found no evidence that flows reduced for up to 8 hours per day influenced the distribution of redds.

Bauersfeld (1978) observed "abnormal redds" in areas of water fluctuation. He attributed this to spawning under depth and velocity conditions other than preferred. Most redds lacked the prominent tailspill that was observed in previous years; the lack of a tailspill was speculated to result in redd scouring and/or increased predation by sculpin or stoneflies within the redd. Chapman et al. (1982), however, found no evidence that this was the case.

After examining carcasses of chinook salmon, Bauersfeld (1978) found no evidence that fluctuating flows significantly affected the ability of a female salmon to void her eggs. He pointed out, however, that it was unknown if the eggs were all deposited in the gravel.

The important question is whether disrupted spawning behavior translates into a significant decrease in spawning success. Unfortunately, none of the studies on chinook salmon evaluated resulting cohorts. To my knowledge, Nelson (1984) is the only investigator to relate flow fluctuations to resulting standing crops of fish.

Successful trout spawning is not an end in itself. Incubating eggs require an adequate flow of water through the gravel to supply oxygen and carry away metabolites (Wickett 1954). Adequate flow during the incubation period is not frequently a problem in unregulated streams. However, in regulated streams, fluctuating or low flows may reduce embryo survival because of dessication, freezing, sedimentation of redds, or reduced intragravel dissolved oxygen levels (Reiser and White 1981a, 1981b).

Reiser and White (1981a) reported that egg dewatering prior to hatching had little influence on embryo survival as long as desiccation or freezing did not occur. Desiccation, which is influenced by temperature and particle size distribution, would probably not be a problem in the study area. Freezing, however, could occur if brown trout eggs were dewatered during winter. Because of reduced sediment recruitment in the study area as a result of Hauser Dam, sediment deposition over redds would not likely occur as a result of proposed flow alterations. Low flow over redds may result in a "stagnant" egg environment which causes high embryo mortality (Reiser and White 1981b).

One problem which I did not evaluate, and to my knowledge has not been evaluated by others, is the impact of trampling redds on embryo survival. Because of the relatively small length of free flowing river in the study area, and the popularity of the area for fishing (particularly in the vicinity of spawning beds), flow regimes which expose redds would likely result in considerable trampling of spawning sites. The only information we have on effects of trampling relates to cattle. In association with the studies of Reiser and White (pers. comm.), cattle entered a one-half mile study section of Big Spring Creek, trampling on about 50% of the Whitlock-Vibert boxes being used in embryo survival studies. Although embryo survival in the study section was poor due to other causes, the boxes, burried about 1 foot, were crushed by the cattle and presumably most eggs in the boxes were also crushed. To prevent much of the possible human disturbance at redd sites, flows which expose redds should be avoided.

In contrast to developing embryos, sac fry, which remain in the gravel for several weeks after hatching, cannot tolerate dewatering. Becker et al. (1982) found nearly 100% mortality of pre-emergent chinook salmon fry exposed to 1 hour daily dewatering. Since brown trout eggs hatch from late January to mid April in the Missouri River study area, with emergence not complete until about mid May, any dewatering of redds during this time would result in high mortality of fry.

A factor not related to flow pattern, but presently influencing the brown trout population is angler harvest. Brown trout harvest rates increase during the spawning period, and males appear to be particularly vulerable to angling at this time. Sex-specific harvest may partly account for the nearly two to one female/male sex ratio observed below Hauser Dam during spawning. This skewed sex ratio does not occur below Canyon Ferry Dam where the female/male ratio is 1.4:1.0 (Berg and Lere 1983), or below Holter Dam where the ratio is 0.9:1.0 (Berg 1983). Spawning fish are either less concentrated or less accessible in these two areas, resulting in less vulnerability to harvest.

Summary

1) Rainbow trout of river or reservoir origin used Beaver Creek extensively for spawning, but there was no significant brown trout spawning run up Beaver Creek. Consequently, brown trout recruitment to the study area and Holter Reservoir largely depends on successful

reproduction in the flowing segment of river below Hauser Dam.

2) Brown and rainbow trout spawning was concentrated in four general areas of the Missouri River study area. Redd counts were lower than the estimated number of spawning females. The presence of deep-water redds adjacent to the major spawning areas, and underestimation of the number of redds in areas of concentrated redd building account for most of the discrepancy between the number of spawners and the number redds observed.

3) Based upon the measurement of physical and hydraulic characteristics of redds, the minimum depth and velocity selected by brown and rainbow trout spawners in the Missouri River study area was 24 cm and 0.3 m/second, respectively; preferred mean velocity was about 0.7 m/second. In Beaver Creek, rainbow trout selected greater water depths and higher velocities for spawning than did brown trout. Water velocity and substrate composition were more important than water depth for the selection of spawning sites.

4) In the Missouri River and Beaver Creek, brown trout spawned from mid-October through December with peak spawning in mid-November. Rainbow trout spawned from mid-March through late May, peaking in late April.

5) Approximately 1000 brown trout enter the 4.5 km study section during the fall spawning period. After spawning,

brown and rainbow trout were most often recaptured downstream for the tagging location or in Holter Reservoir. One brown trout and nine rainbow trout were recovered below Holter Dam after being tagged in the study area. Trout in spawning condition were less frequently recaptured near the original tagging location than were non-spawning trout.

6) Duration of brown trout redd construction ranged from approximately 1 to 5 days with most redds being completed within 3 days. Early and late in the spawning period, most spawning occurred at night. During peak spawning, both brown and rainbow trout spawned during both day and night.

7) Owing to uncertain reliability of habitat modeling (PHABSIM), hydraulic (WSP) modeling alone was used to assess flow related impacts on spawning habitat. Brown trout redds begin to be dewatered at about 60% of the spawning discharge. Redds constructed when flow was about 142 m^3/second (5,000 cfs) would remain nearly 100% wetted in spawning areas 1 and 2 at discharges greater than 85 m^3/second (3,000 cfs). Rainbow trout redds built at a discharge of 159 m^3/second (5,600 cfs) would remain wetted at flows greater than 127 m^3/second. At discharges less than 113 m^3/second (4,000 cfs), the percentage of spawning habitat wetted would decrease rapidly.

REFERENCES CITED

REFERENCES CITED

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

Baldrige, J.E., and D. Amos. 1981. A technique for determining fish habitat suitability criteria: a comparison between habitat utilization and availability. Pages 251-258 in N.B. Armantrout, editor. Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. American Fisheries Society, Portand, Oregon, USA

Bauersfeld, K. 1978. The effect of daily flow fluctuations on spawning fall chinook in the Columbia River. State of Washington Department of Fisheries, Technical Report No. 38.

Becker, C.D., D.H. Fickeisen, and J.C. Montgomery. 1982. Effects of dewatering on chinook salmon redds: tolerance of four developmental phases to daily dewaterings. Transactions of the American Fisheries Society 111: 624-637.

Berg, R.K. 1981. Middle Missouri River planning project job progress report. Federal Aid to Fish and Wildlife Restoration Project No. FW-3-R-9, Job 1-A. Montana Department of Fish, Wildlife and Parks, Ecological Services Division, Helena, Montana, USA.

Berg, R.K. 1983. Middle Missouri River planning project job progress report. Federal Aid to Fish and Wildlife Restoration Project No. FW-3-R-9, Job 1-A. Montana Department of Fish, Wildlife and Parks, Ecological Services Division, Helena, Montana, USA.

Berg, R.K., and M. Lere. 1983. Fish populations of Hauser and Holter Reservoirs, Montana with emphasis on tributary recruitment. USDI, Bureau of Reclamation Progress Report. Montana Department of Fish, Wildlife and Parks, Ecological Services Division, Helena, Montana, USA.

Bovee, K.D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria probability-of-use curves for instream flow assessments. Fisheries Instream Flow Information Paper 3. FWS/OBS-77/63. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Fort Collins, Colorado, USA.

Bovee, K.D. 1978. Probability of use criteria for the family Salmonidae. Instream Flow Information Paper 4. FWS/OBS-77/63. U.S. Fish and Wildlife Service, Office of Biological Services, Fort Collins, Colorado, USA.

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

Brown, C.J.D., J.M. Halterman, G.D. Holton, and A.N. Whitney. 1965. A classification of Montana streams. Stream Classification Committee, Billings, Montana, USA.

Carlander, K.D. 1969. Handbook of freshwater fishery biology, Volume I. Iowa State University Press, Ames, Iowa, USA.

Chapman, D.W., D.E. Weitkamp, T.L. Welsh, and T.H. Schadt. 1982. Effects of minimum flow regimes on fall chinook spawning at Vernita Bar 1978-1982. Final Report to Grant County Public Utility District.

Estes, C.C. 1985. Evaluation of methods for recommending instream flows to support spawning by salmon. Master's Thesis. Washington State University, Pullman, Washington, USA.

Everett, R.J., F. Allendorf, and R. Leary. 1985. Genetic comparison between Missouri River Salmo and Arlee strain rainbow trout. Genetics Laboratory Report 85/4. University of Montana, Missoula, Montana, USA.

Fraser, J.C. 1972. Regulated discharge and the stream environment. Pages 263-286 in R.T. Oglesby et al., editors. River ecology and man. Academic Press, New York, USA.

Graham, P.J., R.F. Penkal, and L. Peterman. 1979. Aquatic studies of the Yellowstone River. Report No. REC-ERC-79-8. Montana Department of Fish and Game, Helena, Montana, USA.

Hamilton, R., and J.W. Buell. 1976. Effects of modified hydrology on Campbell River salmonids. Fishery and Marine Services Technical Report PAC/T-76-20. Vancouver, British Columbia, Canada.

Hill, W.J., and A.H. Wipperman. 1976. Inventory and survey of waters in the western half of region four. Federal Aid to Fish and Wildlife Restoration Project No. F-5-R-25, Job 1-A. Montana Department of Fish, Wildlife and Parks, Helena, Montana, USA.

Hunter J.W. 1973. A discussion of game fish in the State of Washington as related to water requirements. Report by Fish Management Division of Washington Department of Game to Washington State Department of Ecology.

Irving, J.S., and T.C. Bjornn. 1984. Effects of substrate size composition on survival of kokanee salmon and cutthroat and rainbow trout embryos. Intermountain Forest and Range Experiment Station, Completion Report No. 12-11-204-11, USDA, U.S. Forest Service, Boise, Idaho, USA.

Leitritz, E., and R.C. Lewis. 1976. Trout and salmon culture. California Department of Fish and Game, Fish Bulletin No. 164.

Lund, R.E. 1983. MSUSTAT, an interactive statistical analysis package. 1983 microcomputer version-CP/M. The Statistical Center, Department of Mathematical Sciences Technical Report, Montana State University, Bozeman, Montana, USA.

McFadden, J.T. 1969. Dynamics and regulation of salmonid populations in streams. Pages 313-329 in Symposium on Salmon and Trout in Streams. T.G. Northcote, editor. H.R. McMillan Lectures in Fisheries, University of British Columbia, Victoria, Canada.

McNeil, W.J. 1964. Effects of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish and Wildlife Service. Fisheries Bulletin 65(2): 495-523.

Milhous, R.T., D.L. Wegner, and T. Waddle. 1981. User's guide to the Physical Habitat Simulation System. Instream Flow Information Paper 11. FWS/OBS-81/43. U.S. Fish and Wildlife Service, Office of Biological Services, Fort Collins, Colorado, USA.

Montana Power Company. 1984. Projection of electric loads and resources: 1984-2008. Load Forcasting and Resource Planning Section, Butte, Montana, USA.

Nelson, F.A. 1984. Effects of variable flows on standing crops of trout in the Beaverhead River, Montana. Manuscript submitted to North American Journal of Fisheries Management.

Reiser, D.W., and T.A. Wesche. 1977. Determination of physical and hydraulic preferences of brown and brook trout in the selection of spawning locations. Water Resources Research Institute, Water Resources Series 64, Laramie, Wyoming, USA,

Reiser, D.W. 1981. Effects of streamflow reduction, flow fluctuation, and flow cessation on salmonid egg incubation and fry quality. Doctoral dissertation. University of Idaho, Moscow, Idaho, USA.

Reiser, D.W., and R.G. White. 1981a. Effects of flow fluctuation and redd dewatering on salmonid embryo development and fry quality. Research Technical Completion Report, Idaho Water and Energy Resources Institute, Moscow, Idaho, USA.

Reiser, D.W., and R.G. White. 1981b. Influence of streamflow reductions on salmonid embryo development and fry quality. Research Technical Completion Report, Idaho Water and Energy Resources Institute, Moscow, Idaho, USA.

Rinne, J.N. 1980. Spawning habitat and behavior of gila trout, a rare salmonid of the Southwestern United States. Transactions of the American Fisheries Society 109: 83-91.

Sando, S.K. 1981. The spawning and rearing habits of rainbow trout and brown trout in two rivers in Montana. Master's Thesis. Montana State University, Bozeman, Montana, USA.

Shirvell, C.S., and R.G. Dungey. 1983. Microhabitats chosen by brown trout for feeding and spawning in rivers. Transactions of the American Fisheries Society 112: 355-367.

Stober, Q.J., S.C. Crumley, D.E. Fast, E.S. Killibrew, R. Woodin, G. Engman, and G. Tutmark. 1982. Effects of hydroelectric discharge fluctuation on salmon and steelhead in the Skagit River, Washington. Final Report, Fisheries Research Institute, University of Washington, to Seattle Department of Lighting. FRI-UW-8218.

Stuart, T.A. 1953. Spawning migration, reproduction and young stages of the loch trout (S. trutta). Freshwater and Salmon Fisheries Research Home Department, Report No. 5, Scotland.

Wesche, T.A., and P.A. Rechard. 1980. A summary of instream flow methods for fisheries and related research needs. Eisenhower Consortium Bulletin 9.

White, R.G., G.A. Liknes, R.L. Spoon, and D.G. Carty. 1984. Potential impacts of altering discharge from Hauser Dam, Missouri River, on fish populations. 1984 Completion Report. Montana Cooperative Fisheries Research Unit, Montana State University, Bozeman, Montana, USA.

Wickett, W.P. 1954, The oxygen supply to salmon eggs in spawning beds. Journal of Fisheries Research Board Canada 11(6): 933-953.

APPENDICES

APPENDIX A

METHOD FOR QUANTIFYING VISUAL SUBSTRATE OBSERVATIONS

METHOD FOR QUANTIFYING VISUAL SUBSTRATE OBSERVATIONS

A modified version of the Wentworth particle size scale (see Table 1) was used to visually classify spawning substrate in Beaver Creek. Substrate classes (fines, gravel, cobble, boulder) were assigned percentages at 25% increments according to the estimated surface area each class comprised at an observation.

A weighted mean approach was used to quantify substrate observations so that comparisons could be made between used and available spawning substrate. A single value representing the mean particle size of a visual observation was obtained by multiplying the midpoint of a particle size class by the percentage it comprised at an observation. These products are then summed to arrive at the overall mean diameter of substrate at the site. Midpoints of particle size classes are: Fines = 1.0 mm, Gravel = 33.0 mm, Cobble = 160.0 mm, Boulder (approximate) = 300 mm.

For example, the mean particle size for a visual observation of 50% fines and 50% gravel would be:

1.0 mm (fines midpoint) x 0.50 (% fines) = 0.50 mm
33.0 mm (gravel midpoint) x 0.50 (% gravel) = 16.50 mm

mean substrate diameter at site = 17.00 mm

A list of particle size diameters is presented in Table 24.

Table 24. Mean particle size diameter at each combination of substrate type in ascending order (F = Fines, G = Gravel, C = Cobble, B = Boulder).

Substrate Classification*	Mean Substrate Diameter (mm)
100F	1.00
75F, 25G	9.00
50F, 50G	17.00
100G	25.00
75F, 25C	33.00
50F, 25G, 25C	40.75
25F, 50G, 25C	56.75
75G, 25C	64.75
75F, 25B	75.75
50F, 50C	80.50
50F, 25G, 25B	83.75
25F, 25G, 50C	88.50
25F, 50G, 25B	91.75
50G, 50C	96.50
75G, 25B	99.75
50F, 25C, 25B	115.50
25F, 75C	120.25
25F, 25G, 25C, 25B	123.50
25G, 75C	128.25
50G, 25C, 25B	131.50
50F, 50B	150.50
25F, 50C, 25B	155.25
25F, 25G, 50B	158.50
100C	160.00
25G, 50C, 25B	163.25
50G, 50B	166.50
25F, 25C, 50B	190.25
75C, 25B	195.00
25G, 25C, 50B	198.25
25F, 75B	225.25
50C, 50B	230.00
25G, 75B	233.25
25C, 75B	265.00
100B	300.00

*Numbers are percentages.

APPENDIX B

GENETICS OF SPAWNING "RAINBOW TROUT"

GENETICS OF SPAWNING "RAINBOW TROUT"

Large numbers of Arlee strain rainbow trout are stocked in the reservoirs surrounding the Missouri River study area. It is not known whether or not these hatchery fish successfully reproduce in the wild. Spawning and young-of-the-year trout were collected for electrophoretic analysis with the objective of determining the presence or absence of the Arlee strain among the spawning population of rainbow trout.

In total, 33 fish were collected in the Missouri River and Beaver Creek. Twenty females in spawning condition were collected during the spring of 1983; ten were from the Missouri River, and ten were river or reservoir migrants spawning in Beaver Creek. The 13 fish sampled during the fall of 1982 included five age 0 fish known to be wild, five ripe males that were Beaver Creek residents, and three ripe fish (two males, one female) collected in the Missouri River. Muscle, eye, and liver tissues were dissected, frozen, and sent to Rebecca Everett (University of Montana Genetics Laboratory) for electrophoretic analysis. Findings presented below are summarized from Everett et al. (1985).

Table 25. Enzymes, loci, and tissues examined from rainbow trout (L = Liver, M = Muscle, E = Eye).

Enzyme	Loci	Tissue
Adenylate kinase	Ak	M
Alcohol dehydrogenase	Adh	L
Aspartate aminotransferase	Aat-1;2;3,4	L,L,M
Creatine kinase	Ck-1;3	M,L,E
Glucose phosphate isomerase	Gpi-1;2;3	M
Glyceraldehyde-3-phosphate dehydrogenase	Gap-3;4	M
Glycerol-3-phosphate dehydrogenase	G-3-P1;G-3-P-2	L
Glycyl leucine peptidase	Gl-1;Gl-2	E
Isocitrate dehydrogenase	Idh-1;2;3,4	M;M;L
Lactate dehydrogenase	Ldh-1;2;3;4;5	M;M;E;L;E
Leucyl-glycyl glycine	Lgg-1	E
Malate dehydrogenase	Mdh-1,2;3,4	L;M
Malic enzyme	Me-1,2;3;4	M;L
Phosphoglucomutase	Pgm-1-t;2	L;M
6-phosphogluconate	6Pg	E
Sorbitol dehydrogenase	Sdh	L
Superoxide dismutase	Sod-1	L
Xanthine dehydrogenase	Xdh	L