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RELATIONSHIP OF DISCHARGE REDUCTIONS TO AVAILABLE TROUT HABITAT FOR RECOMMENDING SUITABLE STREAMFLOWS

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ABSTRACT

The approach taken in this study to determine suitable streamflows to maintain trout habitat has focused on defining the changes observed for physical stream characteristics as streamflow was reduced. To relate these changes to reductions in available trout habitat, criteria were developed defining the cover preferences of trout, while for food production and spawning areas, criteria from the literature were applied.

Trout cover has been defined as instream rubble - boulder areas and overhanging bank cover in association with a water depth of at least 0.50 feet (0.15 meters). Using these cover preferences, a rating system has been developed allowing comparisons of available trout cover to be made for the same stream section at various discharge levels and for different stream reaches at approximately the same level of flow, based upon the average daily flows (ADF) for the sections. Also, verification of the rating system as an indicator of the standing crop of trout present has been initiated in an effort to quantify the biological significance of instream dewatering in regard to trout populations.

The primary study area, Douglas Creek below Pelton Creek had an average daily flow of 78.7 cfs (2.23 cu m/sec) and was intensively investigated in 1973 at 100%, 71%, 51%, 38%, 27%, and 11% ADF. Available trout habitat was found to decrease at the greatest rate for the discharge reduction interval from 27% to 11% ADF. These findings verify the results found by Wesche (1973) on two stream sections having smaller average daily flows. As a minimum flow to maintain trout habitat, a discharge in the 25% ADF range will avoid the flow range for which the rate of habitat decrease is greatest.

Key Words: Minimum flow/ trout habitat/ trout cover/ average daily flow

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INTRODUCTION

In the semi-arid West, water is becoming an increasingly valuable commodity. Annually, about 15.8 million acre-feet (1.943×10^{10} cu m) of surface water are produced by precipitation in Wyoming and another 1.5 million acre-feet (1.845×10^{9} cu m) per year flow into the state from neighboring states. While current consumptive use in Wyoming is about 2.6 million acre-feet (3.198×10^{9} cu m) per year, it is estimated that only an additional 3.8 million acre-feet (4.674×10^{9} cu m) per year are available for consumptive use in the state due to present physical and legal limitations (Wyoming State Engineer's Office, 1973). As demands for this water by industry, agriculture and municipalities increase, it is evident that additional water development projects, such as dams and diversions, will be necessary. When such projects are proposed, it is important to establish the amount of water required in the stream channel below the development to maintain the fishery resource present.

Basic to fish production are the quantity, quality and stability of the stream environment. It is the stream discharge, as influenced by the channel configuration, which must meet the hydraulic requirements necessary to provide the food-producing, spawning, incubation and cover (shelter) areas needed to support a trout population. Bell (1971) stated that an important element in the production of food in streams is the quantity of flow, as it is related to the width, depth and slope.

Allen (1952) found that instream areas having a depth of at least 0.50 feet (0.1524 m) and a water velocity of 1.0 foot per second (fps), 0.3048 m/sec, or greater, produce the greatest abundance of trout food organisms while Kennedy (1967) observed this in sections having velocities ranging from 1.0 to 1.7 fps (0.3048 to 0.5182 m/sec). Hooper (1973) states that present methods of evaluation consider stream segments having a rubble or cobble substrate with velocities of 1.0 to 3.0 fps (0.3048 to 0.9144 m/sec) as food-producing areas. In a study of bottom fauna distribution in a small Wyoming mountain stream, Kimble (1974) observed the highest mean numbers and mean biomass in areas having a rubble substrate, water velocities of 0.50 fps (0.1524 m/sec) or greater, and depths of less than one foot (0.3048 m).

In regard to hydraulic criteria for trout spawning areas, Hooper (1973) states that for resident trout, the California Department of Fish and Game consider those stream areas having water velocities of 0.5 to 3.0 fps (0.1524 to 0.9144 m/sec), depths of over 0.5 feet (0.1524 m) and a substrate consisting of gravel from pea size to three inches (7.6 cm) in diameter suitable for spawning. By examining trout egg survival under different flow regimes on a relatively low-gradient reach of the Fryingpan River in western Colorado, Hoppe and Finnell (1970) found that suitable trout spawning habitat should have a minimum water velocity of 1.5 fps (0.4572 m/sec).

Numerous studies in the past have indicated a relationship between trout populations and cover. Gunderson (1966) showed that a stream section with higher percentages of deeper water and more cover had a brown trout population over six inches (152 mm) long that was 27 and 44 percent greater by numbers and weight respectively, than a section of the same stream having less cover and shallower water. Shuck (1945) reported that the volume and depth of water were significant factors in determining the population density of larger brown trout in a section of stream, while Boussu (1954) showed that the removal of undercut banks and brush in a stream section caused a decrease in trout numbers and weight. Lewis (1969) determined that 66 percent of the variation in trout numbers between pools was accounted for by cover and current velocity. Wesche (1974), in a study of cover preferences of brown trout in small Wyoming streams, defined trout cover as instream rubble-boulder areas having a substrate diameter of at least three inches (7.6 cm), associated with a water depth of at least 0.50 feet (0.1524 m), and undercut banks which had a width of at least 0.3 feet (0.0914 m) in association with water at least 0.50 feet (0.1524 m) deep. Also, trout six inches (152 mm) or larger were shown to exhibit a stronger preference for undercut banks than did smaller fish. Using the data generated, a system for rating available trout cover was devised.

In recent years, several methodologies have been developed for determining the steam discharge necessary to maintain an adequate habitat for salmonid species below water development projects. Collings (1972) found that a flow which occurred 50 percent of the time on the average during the lowest flow month of the year was the limiting discharge for salmon that rear in streams year round. The Instream Needs Subgroup of the Northern Great Plains Resource Program (1974) developed a method for determining minimum flow requirements to assure maintenance of existing trout habitat based on the discharges which are exceeded 50 percent of the time for given periods of the year. Hooper (1973) stated that a two-day flow equivalent to the 17th percentile on the flow duration curve (Q_{17}), just prior to spawning, flushed accumulated fines from spawning gravels without scouring the channel. Also, a flow equal to Q_{40} on the duration curve will provide velocities of at least 1.5 fps (0.4572 in/sec) over spawning beds and a Q_{27} discharge during incubation will allow high rates of egg survival and hatching success. By comparing the durations of various flow levels, based on the average daily flow (ADF), to standing crop estimates of trout for eleven Wyoming stream reaches, Burton (1974) concluded that good trout populations can be maintained with flow levels of 30 to 20 percent ADF during the July to September period, and that flows of less than 20 percent during this period may be considered as a limiting factor for trout populations. These findings tend to agree with those of Tennant (1972), who, through many years of observing streamflows and the associated fishery values, developed the "Montana Method" of minimum streamflow determination, based on percentages of the mean annual flow of record. Tennant stated that a 10 percent of mean annual flow is at best a short term survival flow, while any discharge over 30 percent of the mean can be described as a satisfactory fishery flow. Using the "Montana Method" as a basis, Wesche (1973) investigated two stream reaches, on Douglas Creek and Hog Park Creek, at five discharge levels ranging from 200 percent down to 12.5 percent ADF, and found that for all hydraulic parameters studied and also for available trout cover, the greatest reduction rate occurred as flow dropped from 25 percent to 12.5 percent ADF. From these findings, it was concluded that a discharge in the 25 percent ADF range should be considered a suitable minimum streamflow to maintain a stable trout habitat throughout the year.

Thus, the objectives of this study involved with determining suitable streamflows to maintain trout habitat below water development projects were to:

1) Field investigate the findings of Wesche (1973) to determine if similar reduction patterns exist for physical and hydraulic parameters as streamflow decreases for stream sections having greater average daily discharges and for other flow reduction intervals.

2) Assemble the hydraulic data gathered at each flow level investigated to allow the application of trout habitat criteria available from the literature for food-producing and spawning areas, thus determining their reduction pattern as flow is decreased.

3) Continue to define the physical and hydraulic components of trout cover and the cover preferences of various size classes and species of trout.

4) Modify the Wesche trout cover rating system, as indicated by the data generated, and begin to determine the reliability of the system as an indicator of the standing crops of trout which can be supported in various stream reaches.

DESCRIPTION OF STUDY AREAS

One stream section was selected for detailed study and ten others were investigated for the trout cover analysis portion of this report. The primary study area was located on Douglas Creek, below the mouth of Pelton Creek, while the secondary areas consisted of six other reaches of the Douglas, two sections of Deer Creek, and one area on Hog Park Creek and the Laramie River.

Primary Area

Douglas Creek No. 7 (below Pelton Creek)

The Douglas Creek drainage lies in Albany and Carbon counties in southeastern Wyoming (Figure 1). The headwaters rise on the southeast slopes of the Medicine Bow Mountains at an elevation of 10,400 feet (3170 m) above mean sea level (msl) and flow 29 miles (46.7 km) southwest to enter the North Platte River, at approximately 7,500 feet (2,286 m) msl. At the higher elevations, Douglas Creek flows through coniferous forests which gradually give way to sagebrush and grassland hills at lower elevations.

The upper Douglas Creek drainage, from the headwaters 21 miles (33.8 km) down to the primary study area (8,200 feet, 2,499 m, msl), encompasses an area of 120 square miles (311 sq. km). The slopes and uplands support a rather dense conifer and aspen forest dominated by lodgepole pine (*Pinus contorta*). Floodplain vegetation is primarily willow (*Salix* sp.), sedges (*Carex* sp.) and various grass species.

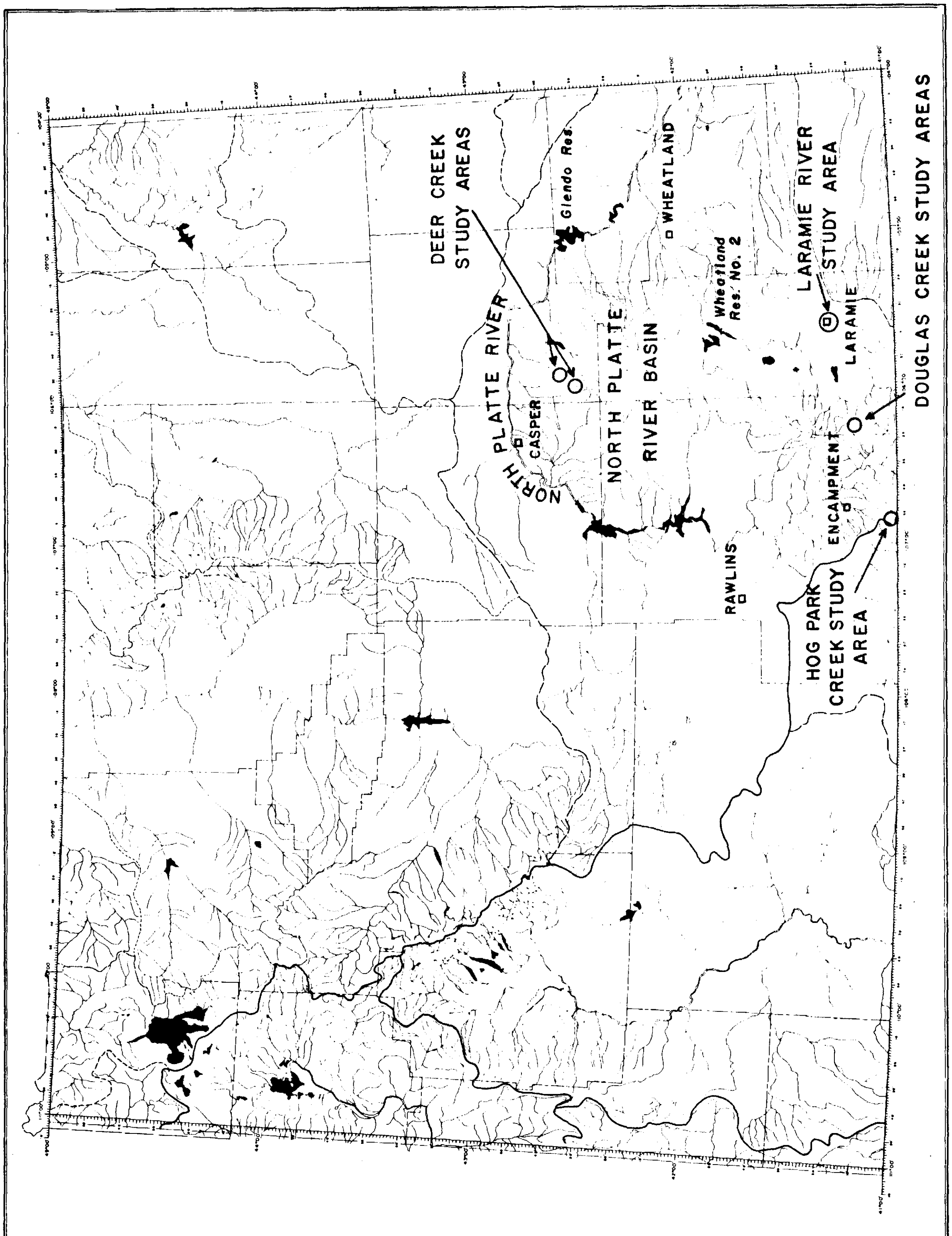

Figure 1. Wyoming map showing locations of the primary and secondary study streams.

Land uses in the area consist of gold and copper mining, livestock grazing in the summer months, and timber harvesting. Numerous graded roads and truck trails traverse the area. Rob Roy Reservoir represents the major water development in the drainage basin. Constructed in 1965-66 by the City of Cheyenne, Wyoming as a water supply source, the 8,900 acre-foot (1.0947×10^7 cu m) capacity reservoir and dam control the flow of Douglas Creek to a high degree in the upper portion of the basin. Extensive recreational use, consisting of fishing, big game hunting for deer and elk, boating and camping, is made of the drainage area.

The primary Douglas Creek study area was an 830 foot (253 m) stream section located 0.9 miles (1.45 km) below the mouth of Pelton Creek and 8.0 miles (12.9 km) upstream from the confluence of the Douglas and the North Platte River in Section 19, Township 13 North, Range 79 West. Figure 2 illustrates the location of the primary area (DC #7) in relation to the six secondary areas in the Douglas Creek drainage basin.

The primary area was a relatively wide (38 to 92 feet, 11.6 to 28.0 m) steep gradient (38.9 ft./mile, 7.4 m/km) reach having a substrate of coarse gravel, rubble and boulders. Figure 3 shows the middle portion of the section at two flow levels. Discharge records from United States Geological Survey (USGS) Gage Station Number 0662100 (1946 to 1972, discontinued), located at the upstream edge of the study area, show a maximum discharge of 1,630 cubic feet per second (cfs), 46.1 cu m/sec, on June 7, 1957, and a minimum of 2.3 cfs (0.065 cu m/sec) during portions of August and September, 1967. The average daily flow over the period of record is 78.7 cfs (2.23 cu m/sec), a flow

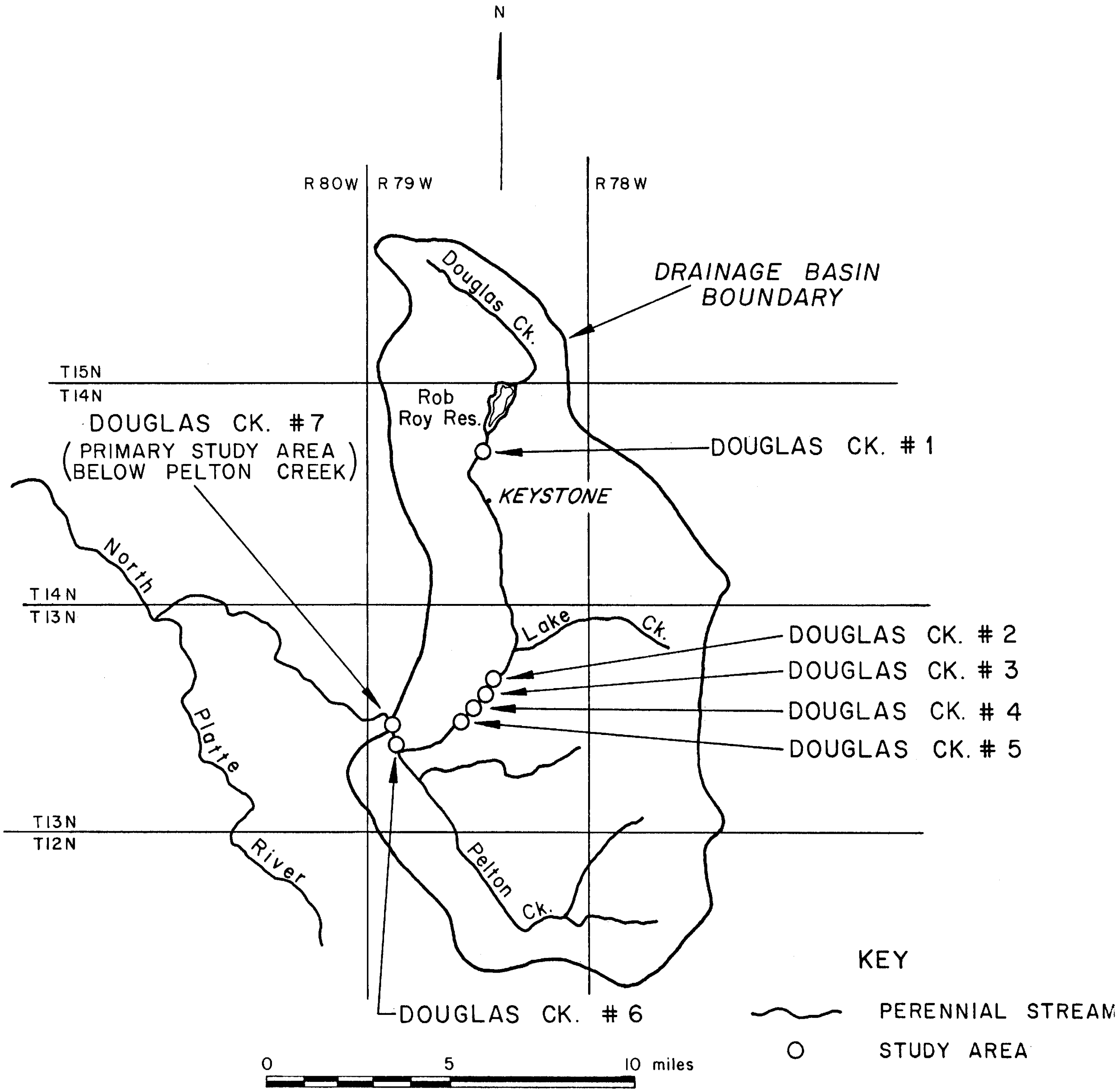

Figure 2. Location of the Douglas Creek primary and secondary sites.

Figure 3. General view of Douglas Creek No. 7 at 79 cfs (top) and 9 cfs (bottom).

which is equaled or exceeded 17.5 percent of the time. Mean monthly discharges and the annual flow duration curve are presented in Figures 4 and 5 respectively. The flow pattern through the area, partially controlled by Rob Roy Reservoir located 12 miles (19.3 km) upstream, follows a natural regime characterized by high spring runoff averaging approximately 400 cfs (11.3 cu m/sec) in May and June decreasing gradually to late fall and winter low flows of 5 to 15 cfs (0.14 to 0.42 cu m/sec).

Water temperatures during the summer of 1973 ranged from 8°C to 20°C. Chemical parameters throughout the period ranged as follows: dissolved oxygen, 6-8 mg/l; carbon dioxide, 1-2 mg/l; total alkalinity, 45-70 mg/l; and pH, 7.5-8.0.

From data obtained by electrofishing in the primary area, brown trout (*Salmo trutta*) comprised 90 percent of the total trout sample, rainbow trout (*Salmo gairdneri*) 7 percent, and brook trout (*Salvelinus fontinalis*) 3 percent. Small populations of longnose suckers (*Catostomus catostomus*), white suckers (*Catostomus commersoni*) and longnose dace (*Rhinichthys cataractae*) were also present.

Secondary Areas

The locations of the ten secondary study areas investigated in this study are shown in Figures 1 and 2, pages 7 and 9. Descriptions of these areas are provided in Table I. Fisheries data for the non-salmonid species collected at the eleven primary and secondary study areas are presented in Table A-III, page 71.

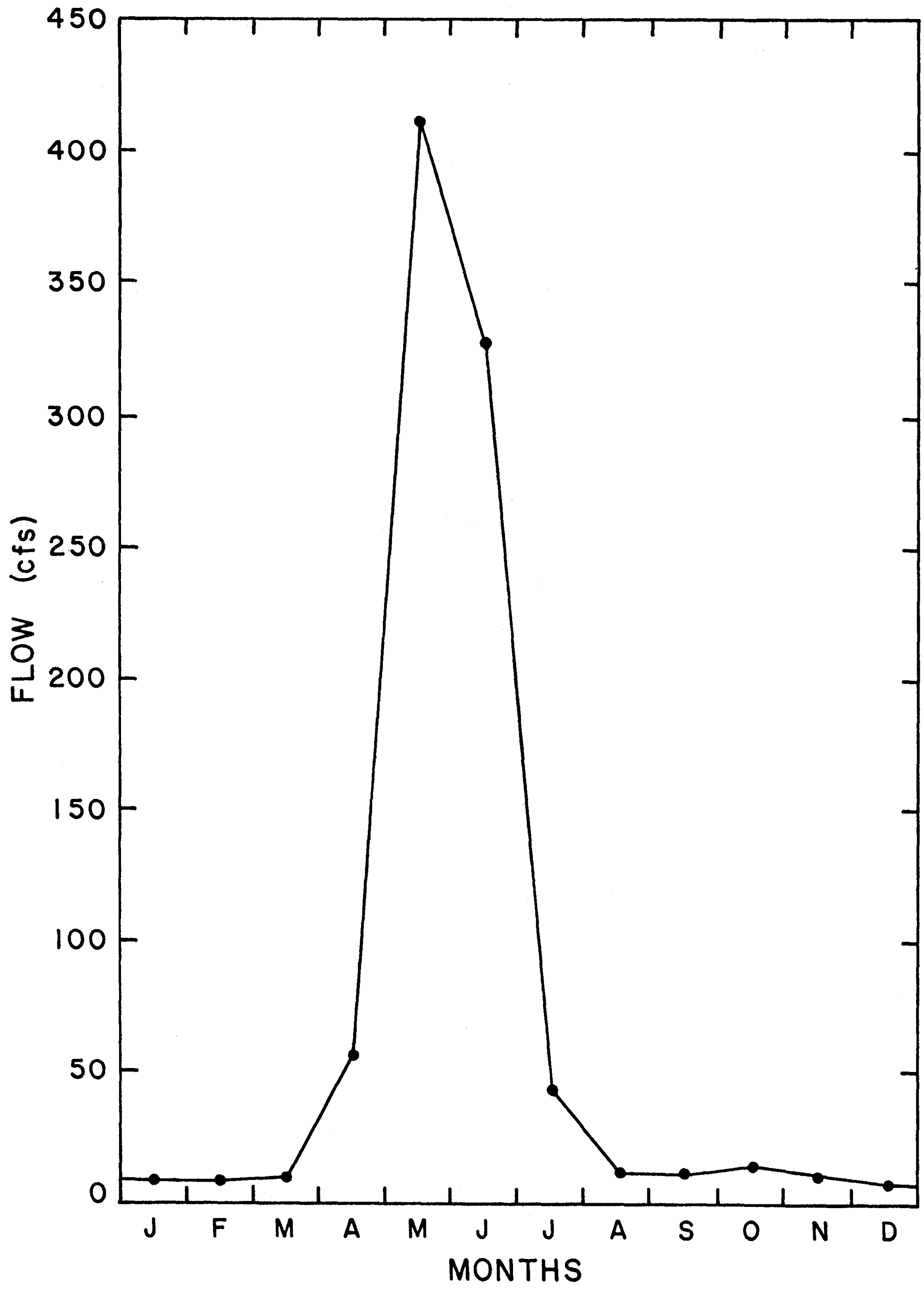

Figure 4. Mean monthly discharges for Douglas Creek No. 7 (below Pelton Creek).

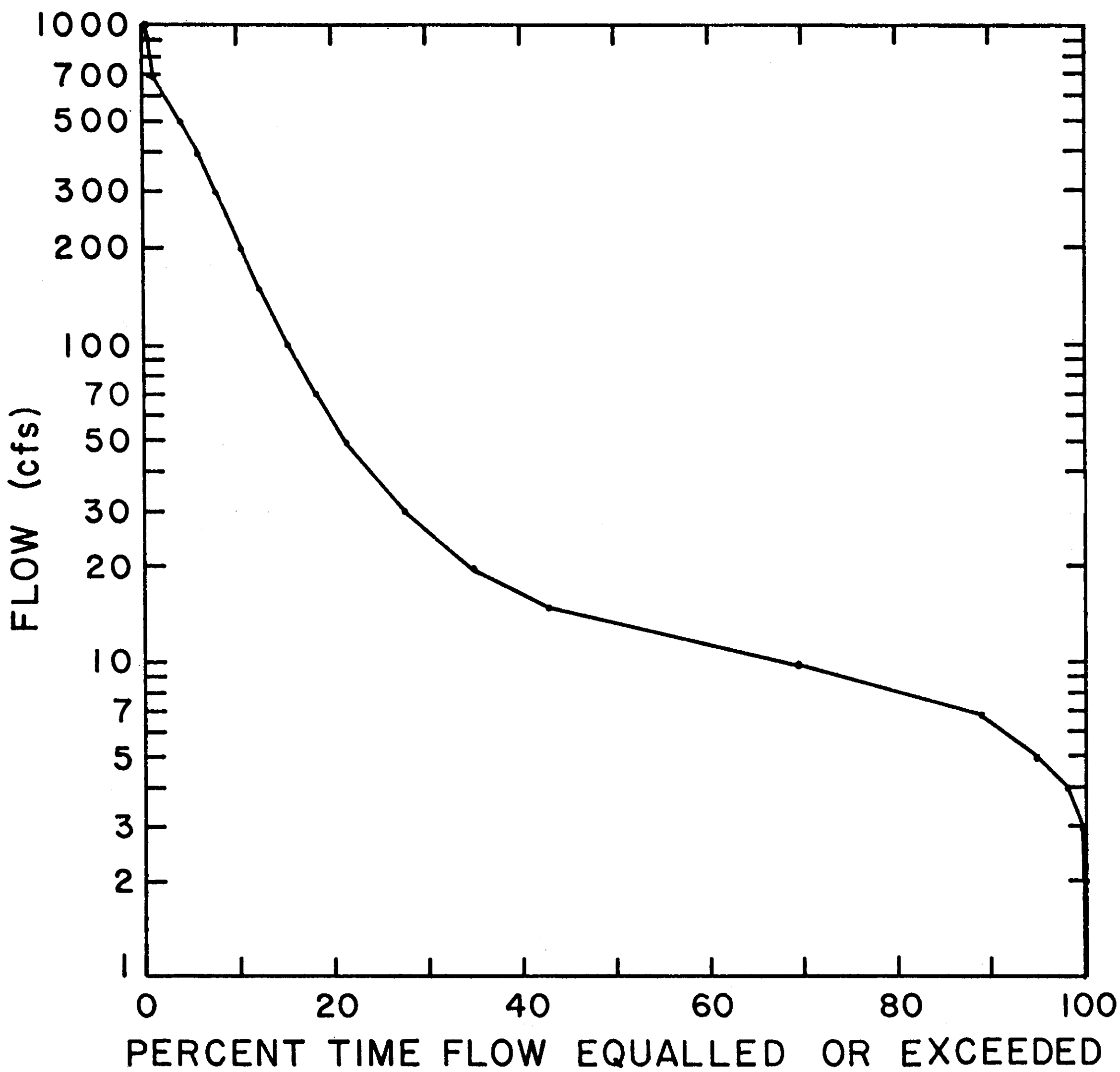

Figure 5. Flow duration curve for Douglas Creek No. 7 (below Pelton Creek).

TABLE I Continued

Study Area	Location	Elevation	Average Daily Flow-	Date Sampled-	Flow Sampled-	Channel Length-	Channel Width-	Surface Area Sampled-	Substrate	Fish Species Sampled-	Comments
		Above MSL-feet (meters)	cfs (Cum/sec)		cfs (Cum/sec)	feet (meters)	feet (meters)	sq. ft. (sq. m)			
Douglas Creek #6	S19,T13N, R79W 0.7 miles below mouth of Pelton Creek	8220 (2505)	78.7 (2.23)	Aug. 17, 1973	9 (0.25)	480 (146)	18-42 (5-13)	13,600 (1263)	Coarse Gravel, rubble, boulders	Brown Tr. (97%) Rainbow Tr. (2%) Brown Tr. (1%)	Banks willow covered with conifers on adjacent slopes
Hog Park Creek	S9,T12N, R 84W 1.4 miles below Hog Park Reservoir	8310 (2533)	27 (0.76)	Aug. 29, 1973	3.5 (0.10)	620 (189(	8-31 (2-9)	12,622 (1173)	Same as Above	Brown Tr. (61%) Brook Tr. (32%) Rainbow Tr. (7%)	See: Wesche, 1973 for additional data
Laramie River	S32, T16N,R73W Within city limits of Laramie,Wyo.	7200 (2195)	105 (2.79)	Sept. 10, 1974	12 (0.34)	750 (229)	25-50 (8-15)	26,632 (2474)	Sand and fine gravel	Brown Tr. (68%) Rainbow Tr. (32%) White & Longnose Suckers Creek Chubs Common Shiners Iowa Darters	Major tributary of North Platte River-Non-salmonid fishes abundant-Dense willow growth on banks
Deer Creek #1	S12,T31N, R77W 19 miles upstream from town of Glenrock,Wyo.	6500 (1981)	44 (125)	Oct. 2, 1973	10 (0.28)	600 (183)	34-68 (10-21)	27,000 (2508)	Gravel, rubble and boulders	Brown Tr. (67%) Rainbow Tr. (33%) White Suckers Creek Chubs Longnose Dace	Located in steep canyon- Floodplain predominantly sagebrush, pine, juniper and aspen-
Deer Creek #2	S7, T32N, R76W 11 miles above Town of Glenrock,Wyo. at Field's Campground	5300 (1615)	Unknown	Oct. 3, 1973	18 (0.51)	650 (198)	30-43 (9-13)	24,500 (2276)	Same as Above	Brown Tr. (67%) Rainbow Tr. (33%) Longnose & White Suckers Creek Chubs Longnose Dace	Damage observed from Spring, 1973 flood-Floodplain primarily cottonwood trees-

METHODS AND MATERIALS

Primary Area

The primary study area utilized in this investigation, Douglas Creek below Pelton Creek (Douglas Creek # 7) was selected on the basis of: 1) its larger discharges than the study sections used by Wesche, 1973; 2) its representation of the lower Douglas; 3) the presence of various water types, in regard to water depth and velocity; 4) the availability of USGS discharge records; and, 5) its ease of access. A second primary area, the Laramie River at Howell (seven miles below the City of Laramie, Wyoming) was also selected and monitored by the methods to be described. Five discharge levels, ranging from 129 percent down to 35 percent ADF, were investigated at this site. However, flows did not drop below the 20 percent ADF level for a long enough period of time during 1973 or 1974 to allow completion of the sampling under low flow conditions. It is anticipated that in the late summer or fall of 1975, this work can be completed. At that time, the results from the Laramie River primary study area will be published as a supplement to this report.

Streamflow data for the Douglas Creek study area were obtained from USGS records (1946-1972). The Water Resources Research Institute computer system was then used to develop flow duration curves and discharge summaries. The streamflow levels which were investigated during the summer and fall of 1973 are shown in Table II.

TABLE II. DISCHARGE LEVELS INVESTIGATED AT DOUGLAS CREEK BELOW PELTON CREEK STUDY AREA

Discharge-cfs (cu m/sec)	Percent Average Daily Flow	Percent Time Flow Equaled or Exceeded
79 (2.24)	100	17.5
56 (1.58)	71	20.7
40 (1.13)	51	23.8
30 (0.85)	38	28.0
21 (0.59)	27	34.5
9 (0.25)	11	75.0

Baselines were surveyed parallel to both banks of the primary study area, with stakes placed at five foot intervals. Mapping of the effective (total) surface area at each flow level was accomplished by measuring the length (to the nearest 0.5 feet (0.1524 m) of the perpendicular line from each baseline stake to the effective edge of the stream. The effective edge was considered to be the closest point perpendicular to the baseline having a water depth of 0.1 feet (0.0305 m) or greater. Maps were then drawn and the total surface area planimetered.

To monitor changes in water depth, velocity, top width, wetted perimeter, hydraulic radius and cross-sectional area, permanent cross-channel transects were established through the study area. Each transect was selected as being representative of a certain stream area having similar hydraulic characteristics. Fifteen such transects were selected in the 830 foot (253 m) primary area. Velocity and depth were measured at two foot intervals along each transect at each flow level. Depth was measured to the nearest 0.05 feet (0.0152 m). Velocity, measured with a Price current meter, was taken at 0.6 of the depth if less than 1.0 foot (0.3048 m) deep, and at 0.2 and 0.8 of the depth if greater than 1.0 foot (0.3048 m). To determine the mean velocity and the cross-sectional area of each transect, the standard stream discharge method (Corbett, 1962) was followed. Transect profiles were plotted to determine the wetted perimeter and the hydraulic radius. For each flow level, the mean value for a parameter was obtained by averaging all transects. Using the parameter value measured at the average daily flow as 100 percent, percentages remaining at each flow level were determined and plotted. Ratios between the percent decrease in a hydraulic parameter and the percent decrease in flow were then computed to determine the flow reduction interval for which the rate of parameter decrease was greatest.

The total surface area of each study section at each flow level was broken down into a sixteen class system, comprised of the following depth (feet) and velocity (feet per second) intervals: <0.50, 0.50-0.99, 1.0-1.49, $\geq$1.50. The percentage of each transect in each class was computed and multiplied by the surface area represented by each transect (for example see Table IV, page 32).

The average discharge velocity through the study area was determined by time-of-travel techniques. Red fluorescent dye was injected into the stream above the upstream end of the area. Water samples were taken every fifteen seconds at each end of the study area. Samples were measured with a fluorometer to determine dye concentrations. The time lapse between peak concentrations at the upstream and downstream ends was the time-of-travel through the study section. Dividing the length of the thalweg line by the time-of-travel gave the average water velocity through the channel.

Dissolved oxygen, pH, carbon dioxide and alkalinity were measured periodically throughout the summer and fall using a Hach Water Chemistry Kit. A Science Associate's three-pen recording thermograph was installed to monitor water and air temperatures throughout the study period.

Trout Cover Analysis

Since 1972, data have been gathered at the Douglas Creek #7 (primary area), Douglas Creek #6, Douglas Creek #1 and Hog Park Creek study areas to define the cover preferences of trout. Sampling was conducted by means of electrofishing at discharge levels ranging from 100 percent down to 11 percent ADF. For each trout captured, the following information was recorded: 1) water depth, to the nearest 0.05 feet (0.0152 m); 2) water velocity at the point location used for cover (i.e., below a boulder, underneath an undercut bank) as determined by a Stevens Midget Current Meter; 3) the type of cover being utilized (instream rubble-boulder areas, overhead bank cover); 4) for rubble-boulder areas being used, the substrate diameter was measured and for overhead bank cover, the width of the overhang was measured; and 5) the length (nearest 1.0 millimeter), weight (nearest 1.0 gram) and species. For trout sampled at the Douglas Creek #6 and #7 sites, the mean water velocity at the cover location was also measured.

At Douglas Creek #7 for each of the six flow levels investigated, the lengths, widths and associated water depths of all overhead bank cover were measured and the substrate types and associated water depths were mapped by the transect method previously described. This allowed trout cover ratings to be made for each discharge level studied using the methods developed by Wesche (1973). At a flow of 21 cfs (0.59 cu m/sec), a Peterson Mark and Recapture population estimate was made to determine the standing crop of trout present.

Investigations at the ten secondary study sites were conducted to determine the reliability of the Wesche cover rating system as an indicator of the standing crop of trout present. At each site, a DeLury population estimate (DeLury, 1947 and 1951) was conducted to determine the standing crop and a cover rating was made, at the discharge levels shown on Table I, page 14.

Condition factors for all trout sampled were calculated using the following equation:

$$K_{TL} = \frac{Wt \times 10^5}{L^3}$$

where,

K_{TL} = condition factor based on total fish length

Wt = weight of fish in grams

L = total fish length in millimeters.

RESULTS

Hydraulic Parameters

Mean transect values for each parameter at each flow level and time-of-travel velocities for the Douglas Creek below Pelton Creek study area (Douglas Creek #7), expressed as a percentage of the value obtained at 100 percent of the average daily flow (ADF), are summarized in Table III. Figure 6 illustrates changes observed at Transects 8 and 10 between 79 cfs (2.24 cu m/sec) and 9 cfs (0.25 cu m/sec).

Consistent with the findings of Kraft (1968) and Wesche (1973), the parameter most severely reduced by flow reductions at the primary area was velocity. The time-of-travel velocity, the mean for the entire stream reach, decreased from 1.91 fps (0.58 m/sec) at 100 percent ADF to 0.51 fps (0.16 m/sec) at 11 percent ADF, a 73.5 percent reduction. The changes between all flow levels investigated are shown in Table III.

Mean transect cross-sectional area realized the second greatest reduction over the dewatering range of 100 percent to 11 percent ADF. Douglas Creek No. 7 evidenced a decrease of 71.5 percent. Mean transect depth and hydraulic radius decreased together, the former being reduced 50.7 percent from the 100 percent ADF level, while the latter decreased 50.4 percent (Table III). Least affected by dewatering were mean transect top width and wetted perimeter, which were reduced to 59.3 percent and 59.1 percent, respectively, of their values at 100 percent ADF (Table III).

TABLE III.

PHYSICAL PARAMETERS OF DOUGLAS CREEK BELOW PELTON CREEK
STUDY AREA EXPRESSED AS PERCENTAGE OF 100% ADF VALUE

(Value in parentheses is ratio of % parameter decrease to % flow decrease)

	Mean Transect Parameters										
Flow (%ADF)	Top Width	Depth	Cross Section Area	Velocity	Wetted Perimeter	Hydraulic Radius	Time-of-Travel Velocity	Total Surface Area	Surface Area Velocity $\geq$1.0fps (0.30m/sec)	Surface Area Depth $\geq$0.50 ft (0.15m)	Mean Trout Cover Rating
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	(.089)	(.536)	(.615)	(.340)	(.103)	(.519)	(.901)	(.165)	(1.048)	(.533)	(.282)
71%	97.4%	84.4%	82.1%	90.1%	97.0%	84.9%	73.5%	95.2%	69.5%	84.5%	91.8%
	(.261)	(.488)	(.675)	(.842)	(.241)	(.488)	(.300)	(.345)	(.813)	(.778)	(.458)
51%	92.1%	74.5%	68.4%	73.0%	92.1%	75.0%	67.4%	88.2%	53.0%	68.7%	82.5%
	(.413)	(.423)	(.825)	(.619)	(.437)	(.452)	(.825)	(.849)	(.683)	(.754)	(.683)
38%	86.9%	69.2%	58.0%	65.2%	86.6%	69.3%	57.0%	77.5%	44.4%	59.2%	73.9%
	(.842)	(.658)	(.991)	(.342)	(.833)	(.649)	(.956)	(.579)	(.982)	(.789)	(.439)
27%	77.3%	61.7%	46.7%	61.3%	77.1%	61.9%	46.1%	70.9%	33.2%	50.2%	68.9%
	(1.184)	(.816)	(1.197)	(.921)	(1.184)	(.809)	(1.289)	(.895)	(1.243)	(1.375)	(1.322)
11%	59.3%	49.3%	28.5%	47.3%	59.1%	49.6%	26.5%	57.3%	14.3%	29.3%	48.8%

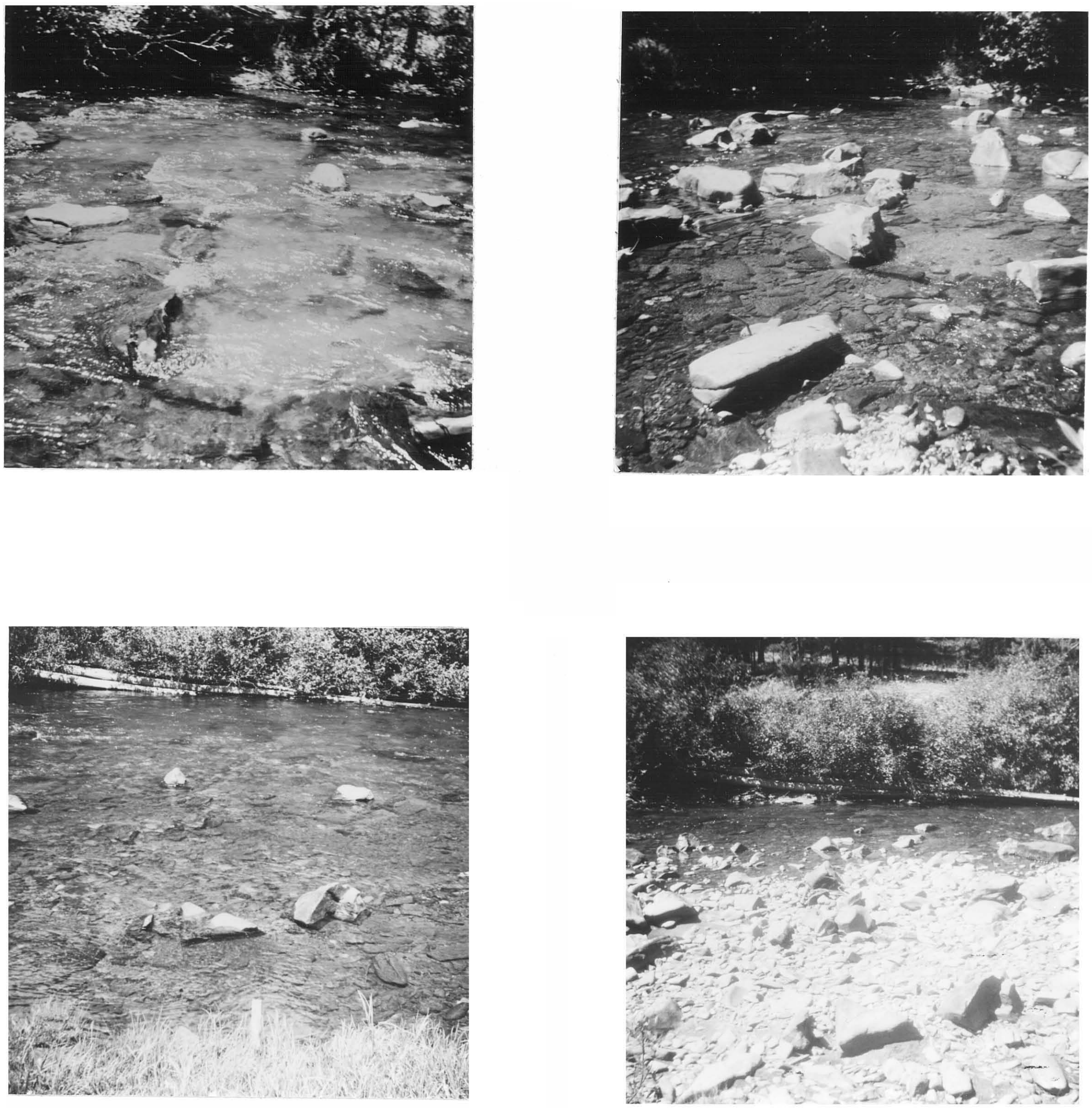

Figure 6. Changes observed at Transects No. 8 (top) and No. 10 (bottom) between 79 cfs (left) and 9 cfs.(right)at Douglas Creek No. 7.

As found by Wesche (1973), the hydraulic parameters were not reduced at a constant rate between discharge levels. However, for all parameters at the Douglas Creek No. 7 area, the greatest decrease for a percentage-point flow reduction occurred for the interval between 27 percent and 11 percent ADF, as shown on Table III, page 23.

Surface Area Composition

Surface area maps for the Douglas Creek No. 7 study area at the six flow levels investigated are presented in Figures 7 to 12. Table IV contains the surface area composition, by depth-velocity class, at each discharge.

As the flow dropped from 79 cfs to 21 cfs (2.24 to 0.59 cu m/sec), a 29.1 percent reduction, 12,135 square feet (1,127 sq. m), was observed in the total effective surface area. The reduction from 21 to 9 cfs (0.59 to 0.25 cu m/sec) resulted in an additional decrease of nearly 6,000 ft^2 (557 sq. m) leaving only 57.3 percent of the channel wetted. Table III, page 23, shows that effective surface area was reduced at the greatest rate in the interval from 21 to 9 cfs (0.59 to 0.25 cu m/sec).

Similar reduction patterns were observed for the deeper and higher velocity portions of the total surface area (Table III, page 23) 79 cfs (2.24 cu m/sec), approximately 33,000 sq. ft. (3,066 sq. m) of wetted surface area had a water depth of at least 0.50 feet (0.15 m). This was reduced to 16,571 sq. ft. (1,539 sq. m) at 21 cfs (0.59 cu m/sec), a 50 percent reduction. As flow decreased from 21 to 9 cfs (0.59 to 0.25 cu m/sec), an additional 6,882 sq. ft. (639 sq. ft.) of deeper water were lost, with only 29.3 percent of the 100 percent ADF value remaining. Fast water areas (velocity $\geq$ 1.0 fps, 0.3048 m/sec) were

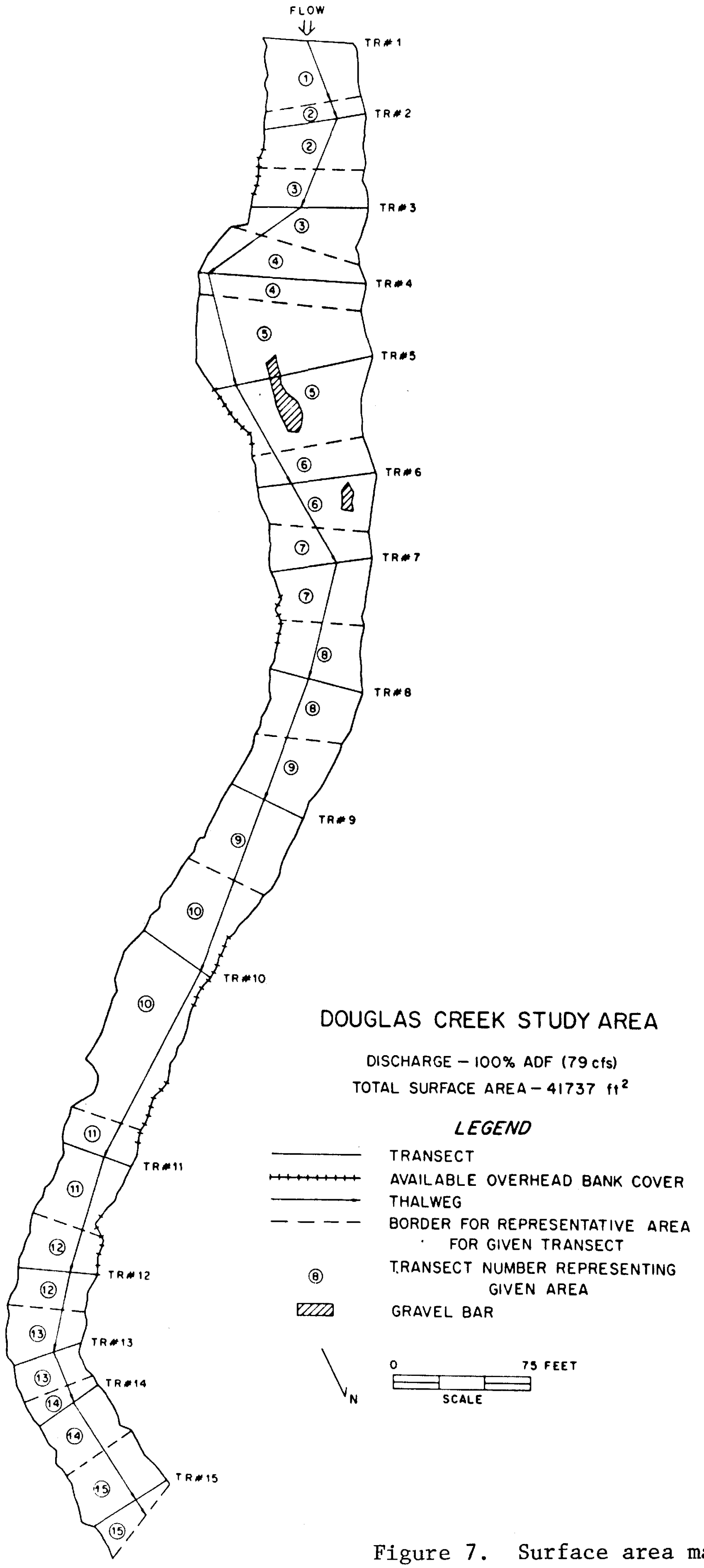

Figure 7. Surface area map of the Douglas Creek No. 7 study area at 100% of the average daily flow.

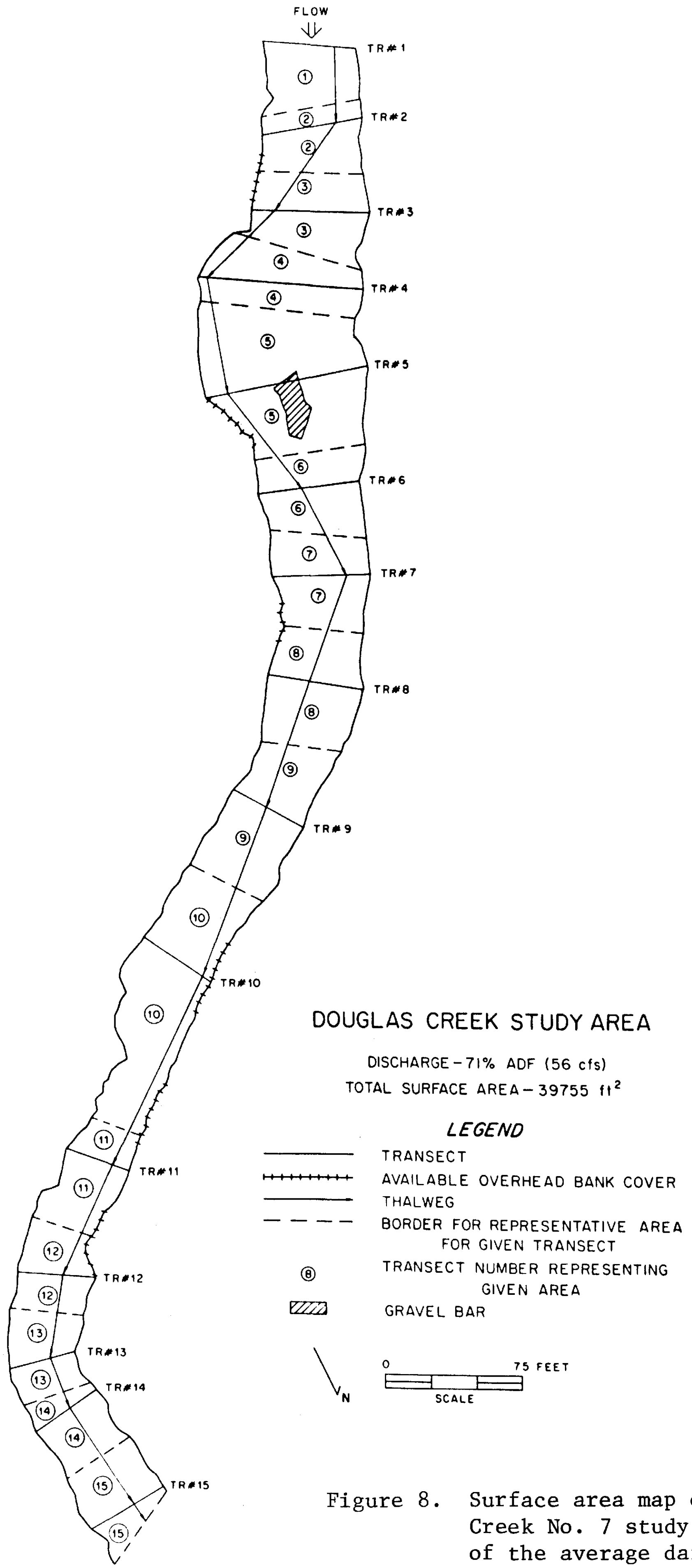

Figure 8. Surface area map of the Douglas Creek No. 7 study area at 71% of the average daily flow.

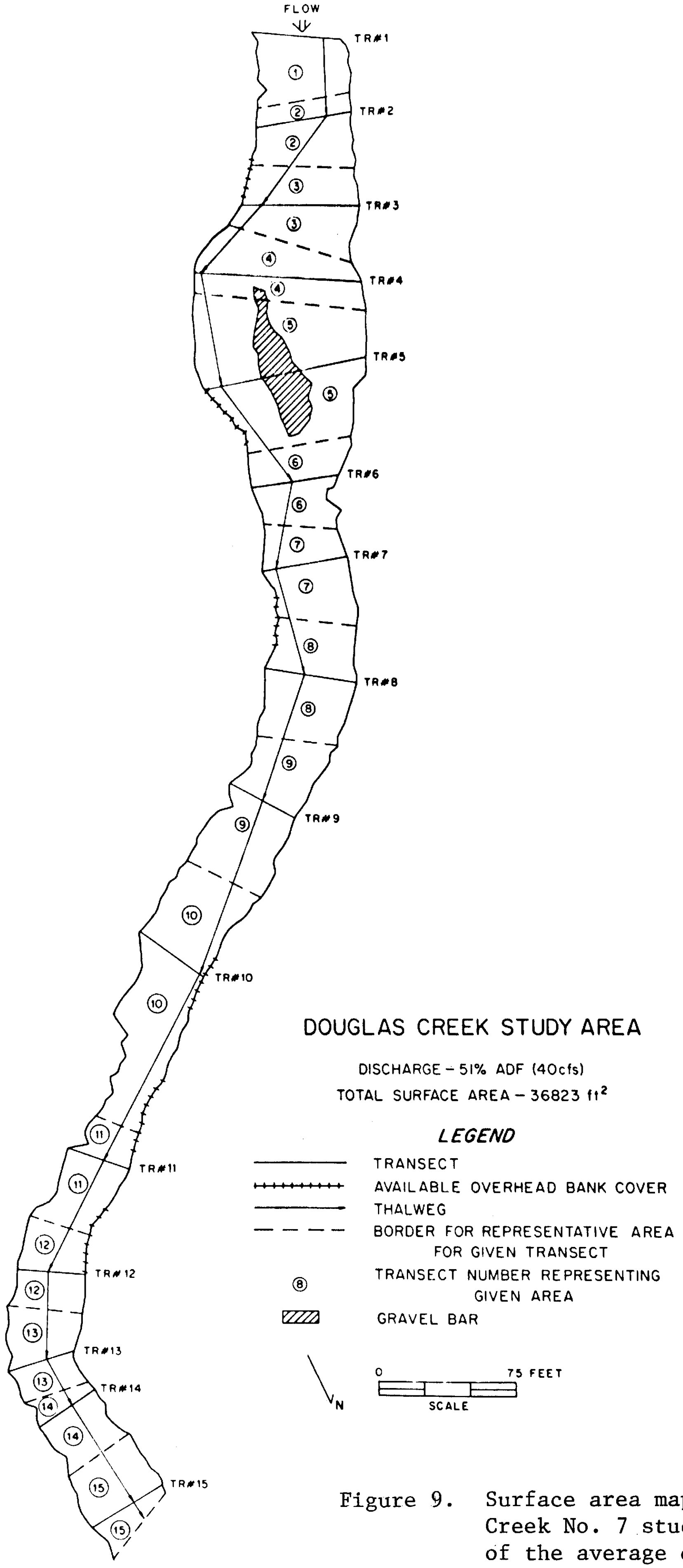

Figure 9. Surface area map of the Douglas Creek No. 7 study area at 51% of the average daily flow.

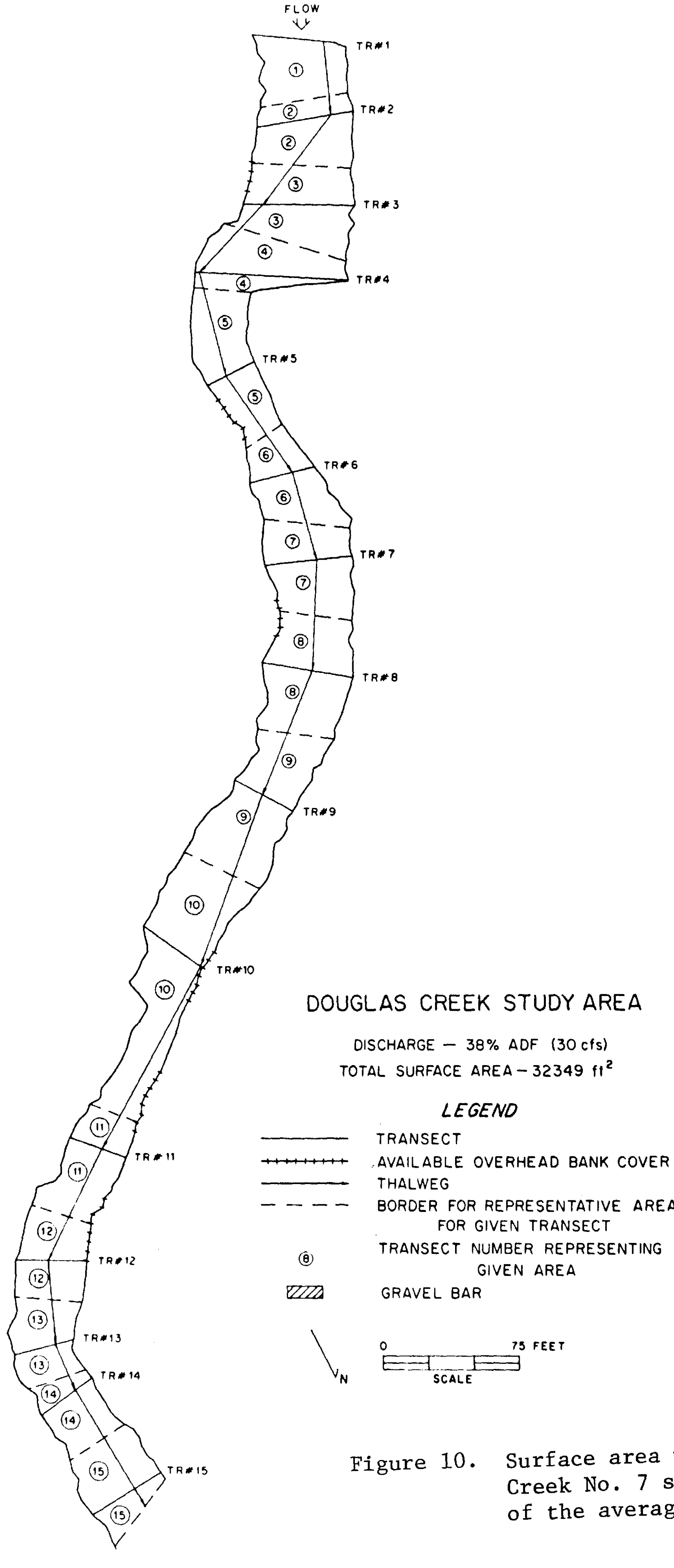

Figure 10. Surface area map of the Douglas Creek No. 7 study area at 38% of the average daily flow.

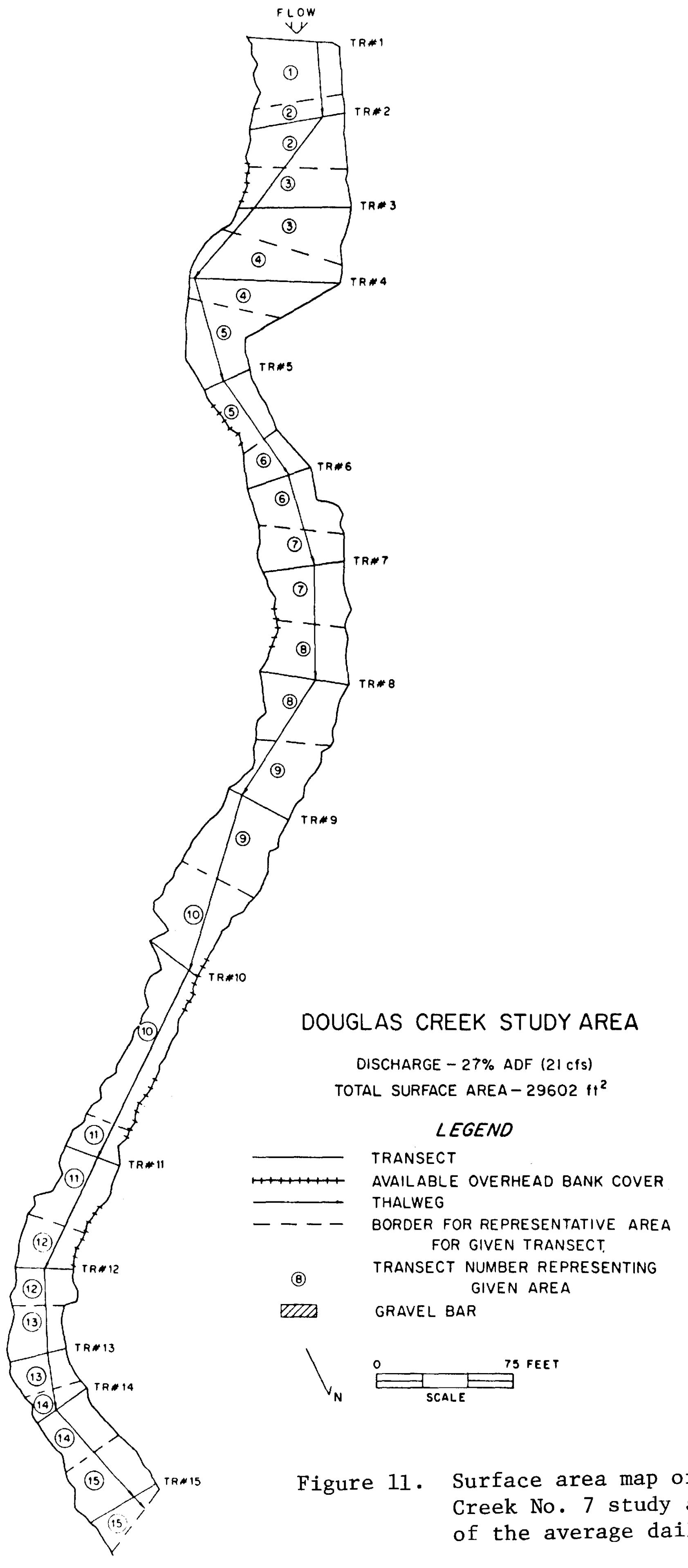

Figure 11. Surface area map of the Douglas Creek No. 7 study area at 27% of the average daily flow.

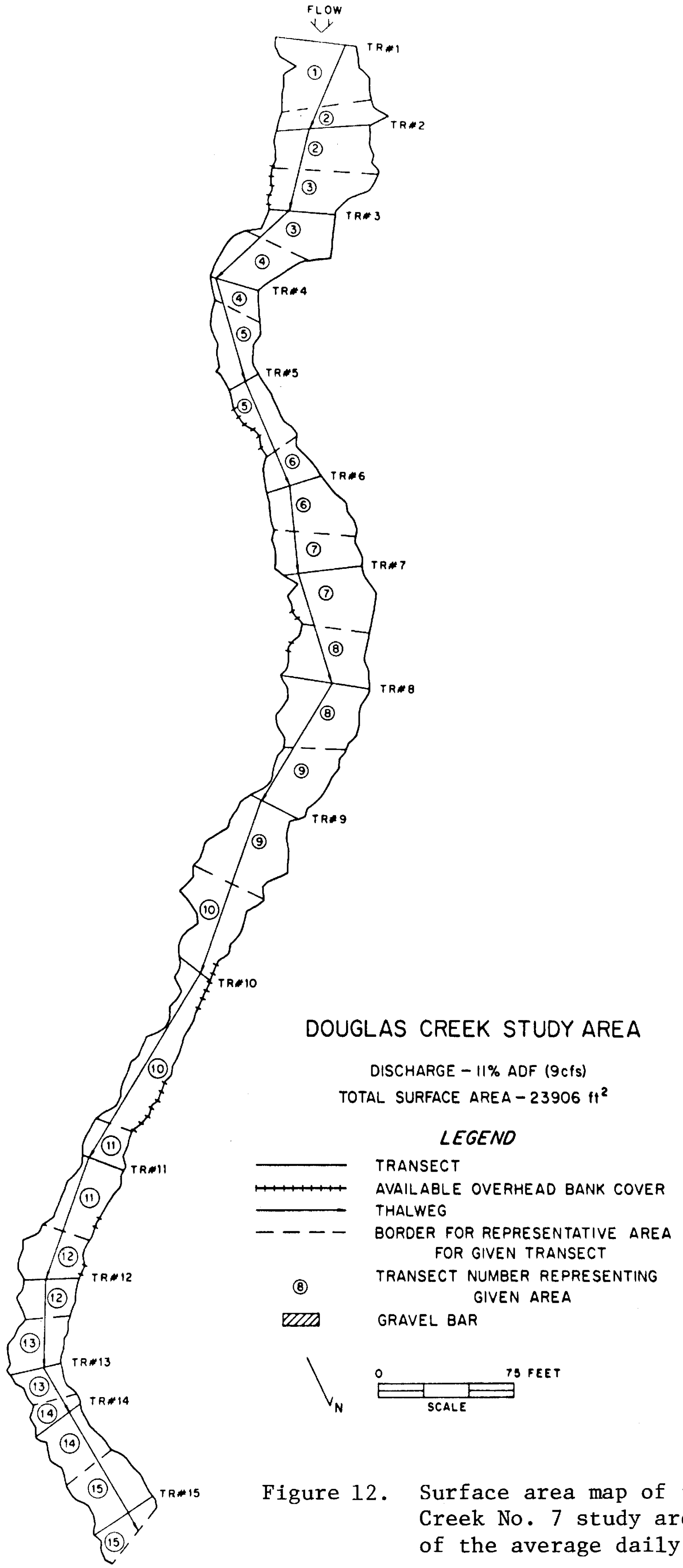

Figure 12. Surface area map of the Douglas Creek No. 7 study area at 11% of the average daily flow.

TABLE IV. SURFACE AREA COMPOSITION OF THE DOUGLAS CREEK BELOW PELTON CREEK STUDY AREA AT 100, 71, 51, 38, 27, AND 11% ADF.

Surface Area Composition (Sq. Ft.) at 100% ADF

Velocity (fps)	Depth (ft) <0.50	.50-.99	1.0-1.49	≥1.50	Total (%Total)
<0.50	2538	2679	338	374	5929 (14.2)
.50-.99	2116	3185	929	793	7023 (16.8)
1.0-1.49	2849	2651	2657	786	8943 (21.4)
≥1.50	1197	8311	7567	2767	19842 (47.6)
Total (% Total)	8700 (20.9)	16826 (40.3)	11491 (27.5)	4720 (11.3)	41737 (100.0)

1.0 foot = 0.3048 meters
1.0 square foot = 0.0929 square meters
1.0 foot per second = 0.3048 meters per second

Surface Area Composition (Sq. Ft.) at 71% ADF

Velocity (fps)	Depth (ft) <0.50	.50-.99	1.0-1.49	≥1.50	Total (%Total)
<0.50	4456	2930	1036	269	8691 (21.9)
.50-.99	5085	3817	1659	494	11055 (27.8)
1.0-1.49	1236	3372	2889	362	7859 (19.8)
≥1.50	1067	6689	3197	1197	12150 (30.5)
Total (%Total)	11844 (29.8)	16808 (42.3)	8781 (22.1)	2322 (5.8)	39755 (100.0)

1.0 foot = 0.3048 meters
1.0 square foot = 0.0929 square meters
1.0 foot per second = 0.3048 meters per second

TABLE IV (Continued)

Surface Area Composition (Sq. Ft.) at 51% ADF

Velocity (fps)	Depth (ft) <0.50	.50-.99	1.0-1.49	≥1.50	Total (%Total)
<0.50	7342	3136	728	67	11273 (30.6)
.50-.99	3789	3884	2167	466	10306 (28.0)
1.0-1.49	1960	2984	2568	75	7587 (20.6)
≥1.50	1048	4824	1480	305	7657 (20.8)
Total (%Total)	14139 (38.4)	14828 (40.3)	6943 (18.8)	913 (2.5)	36823 (100.0)

1.0 foot = 0.3048 meters
1.0 square foot = 0.0929 square meters
1.0 foot per second = 0.3048 meters per second

Surface Area Composition (Sq. Ft.) at 38% ADF

Velocity (fps)	Depth (ft) <0.50	.50-.99	1.0-1.49	≥1.50	Total (%Total)
<0.50	7596	3934	790	157	12477 (38.6)
.50-.99	2483	2986	1275	356	7100 (21.9)
1.0-1.49	1550	3840	2285	72	7747 (23.9)
≥1.50	1176	3804	44	0	5024 (15.6)
Total (%Total)	12805 (39.6)	14564 (45.0)	4394 (13.6)	585 (1.8)	32348 (100.0)

1.0 foot = 0.3048 meters
1.0 square foot = 0.0929 square meters
1.0 foot per second = 0.3048 meters per second

TABLE IV (Continued)

Surface Area Composition (Sq. Ft.) at 27% ADF

Velocity (fps)	Depth (ft) <0.50	.50-.99	1.0-1.49	≥1.50	Total (%Total)
<0.50	6924	3617	1109	90	11740 (39.6)
.50-.99	2343	4433	1355	180	8311 (28.1)
1.0-1.49	1884	2847	1213	0	5944 (20.1)
≥1.50	1880	1727	0	0	3607 (12.2)
Total (%Total)	13031 (44.0)	12624 (42.7)	3677 (12.4)	270 (0.9)	29602 (100.0)

1.0 foot = 0.3048 meters
1.0 square foot = 0.0929 square meters
1.0 foot per second = 0.3048 meters per second

Surface Area Composition (Sq. Ft.) at 11% ADF

Velocity (fps)	Depth (ft) <0.50	.50-.99	1.0-1.49	≥1.50	Total (%Total)
<0.50	7405	4548	885	80	12918 (54.0)
.50-.99	3835	2865	84	80	6864 (28.7)
1.0-1.49	2292	650	278	0	3220 (13.5)
≥1.50	685	219	0	0	904 (3.8)
Total (%Total)	14217 (59.5)	8282 (34.6)	1247 (5.2)	160 (0.7)	23906 (100.0)

1.0 foot = 0.3048 meters
1.0 square foot = 0.0929 square meters
1.0 foot per second = 0.3048 meters per second

reduced even more. At 9 cfs, 4,124 sq. ft. (383 sq. m) remained, only 14.3 percent of the 28,783 sq. ft. (2,674 sq. m) which were present at the 100 percent ADF discharge (Table III, page 23).

Trout Cover Analysis

Since the summer of 1972, the cover preferences of 1,160 trout have been analyzed at the Douglas Creek No. 1, 6 and 7 and Hog Park Creek study areas at discharges ranging from the 100 percent ADF level down to 11 percent ADF. Of the total sample, 884 (76.2 percent) were brown trout, 235 (20.3 percent) brook trout, and 41 (3.5 percent) rainbow trout. Subcatchables (less than 6.0 inches, 152 mm in length) comprised 64.8 percent of the total, while 35.2 percent were of catchable size. Table V summarizes the cover data obtained for the sample of 1,160 in regard to cover type, water depth and point water velocity, while this information is illustrated in Figures 13, 14 and 15. Mean water velocity data are also presented in Table V for a sample of 479 trout. As shown, between species, the data are quite similar for a given size class. However, between size classes, differences do appear, primarily in the cover type utilized.

Two primary types of trout cover were available in the study areas, overhead bank cover and instream rubble-boulder areas. The principal type of overhead cover in the study areas was undercut banks with lesser amounts of overhanging vegetation (logs, willows, brush jams, etc.) being present. As these two types were often found in association with each other, they were combined in the overhead bank cover category. Figure 16 illustrates the overhead bank cover types found at the study areas, while Figure 6, page 24, shows instream rubble-boulder areas. For subcatchables, 51.6 percent of all trout sampled were found in

TABLE V

SUMMARY OF TROUT COVER DATA

UCB = Undercut bank
OHV = Overhanging vegetation

Species	Cover Type: Rubble-Boulder	Cover Type: UCB & OHV	Water Depth (Ft): <.50	Water Depth (Ft): .5-.99	Water Depth (Ft): 1.0-1.49	Water Depth (Ft): ≥1.50	Point Velocity (FPS): <0.50	Point Velocity (FPS): ≥0.50	Mean Velocity (FPS): <0.50	Mean Velocity (FPS): 0.50-0.99	Mean Velocity (FPS): 1.0-1.49	Mean Velocity (FPS): ≥1.50
Brown												
<6.0" (<152 mm)	298	269	52	235	173	107	560	7	152	61	39	15
≥6.0" (≥152 mm)	78	239	22	87	98	110	314	3	89	52	24	11
Brook												
<6.0" (<152 mm)	76	82	13	50	56	39	151	7	4	0	0	0
≥6.0" (≥152 mm)	30	47	5	19	28	25	73	4	4	1	0	0
Rainbow												
<6.0" (<152 mm)	14	13	5	6	3	13	24	3	5	9	4	3
≥6.0" (≥152 mm)	3	11	0	5	4	5	14	0	3	2	0	1
Totals												
<6.0" (<152 mm)	388	364	70	291	232	159	735	17	161	70	43	18
(%Total For Size Class)	(51.6%)	(48.4%)	(9.3%)	(38.7%)	(30.9%)	(21.1%)	(97.7%)	(2.3%)	(53.7%)	(26.1%)	(14.0%)	(6.2%)
≥6.0" (≥152 mm)	111	297	27	111	130	140	401	7	96	55	24	12
(%Total For Size Class)	(27.2%)	(72.8%)	(6.6%)	(27.2%)	(31.9%)	(34.3%)	(98.3%)	(1.7%)	(51.4%)	(29.4%)	(12.8%)	(6.4%)

1.0 inch = 25.4 millimeters
1.0 foot = 0.3048 meters
1.0 foot per second = 0.3048 meters per second

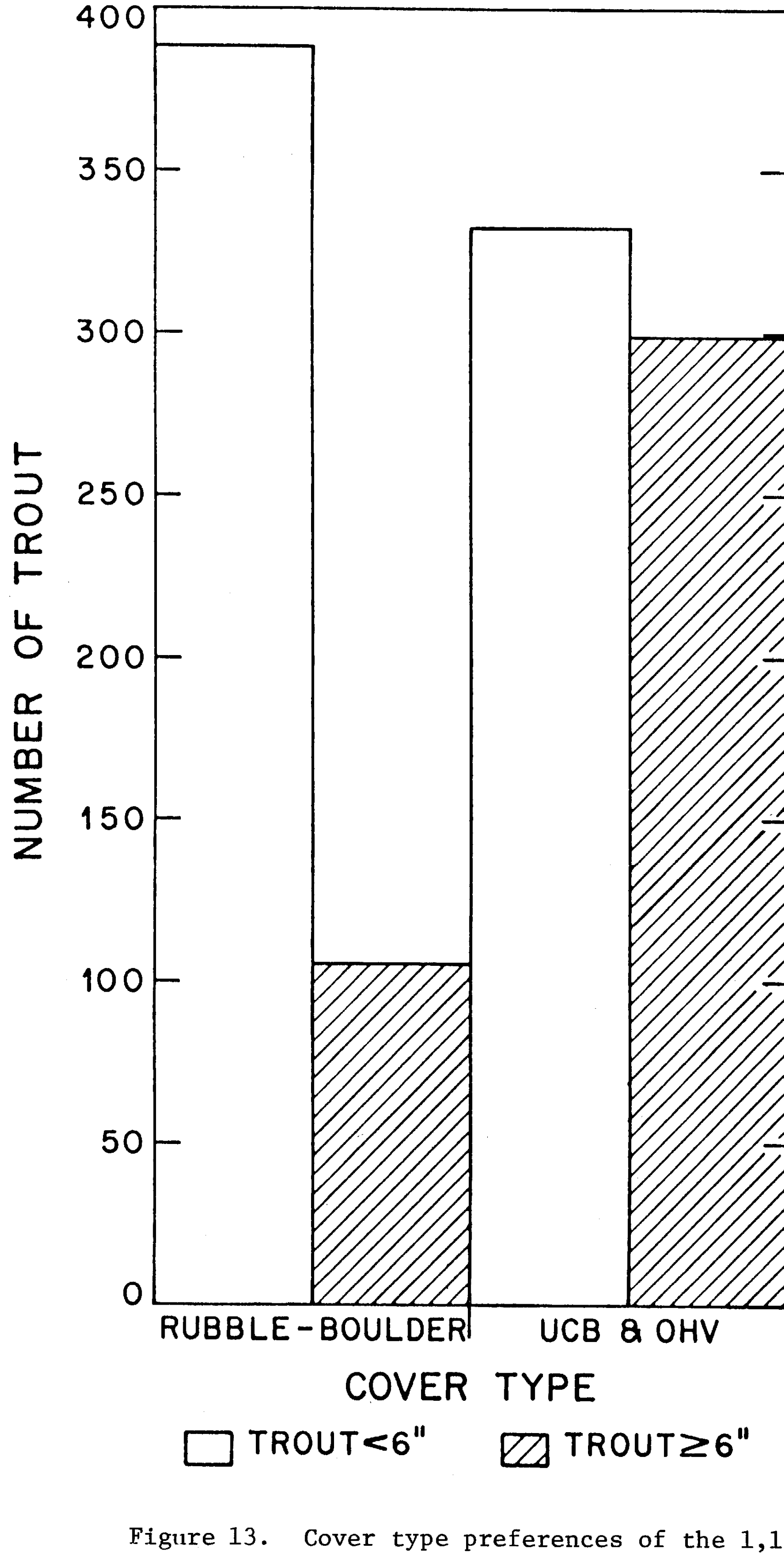

Figure 13. Cover type preferences of the 1,160 trout sampled at the Douglas Creek No. 1, 6, 7 and Hog Park Creek study areas by size class.

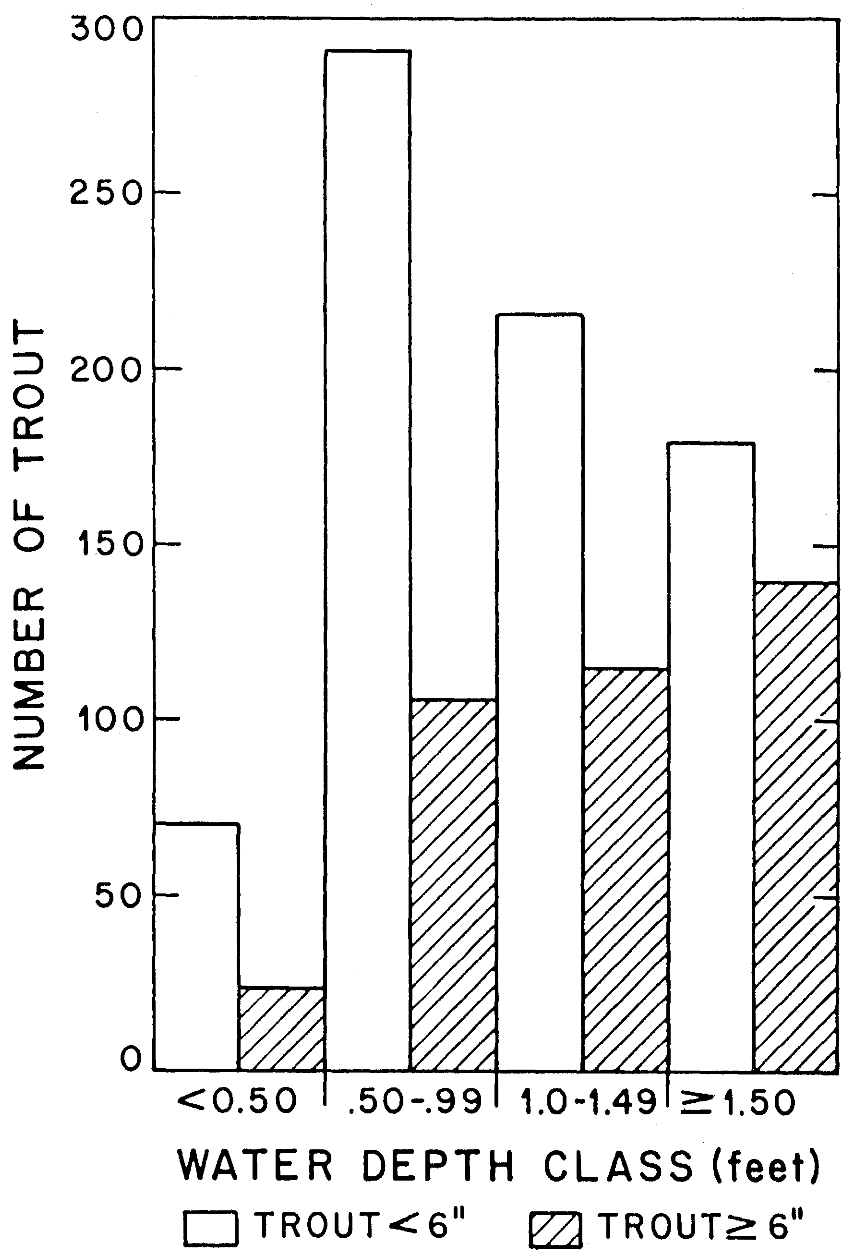

Figure 14. Water depth-frequency distribution of the 1,160 trout sampled at the Douglas Creek No. 1, 6, 7 and Hog Park Creek study areas by size class.

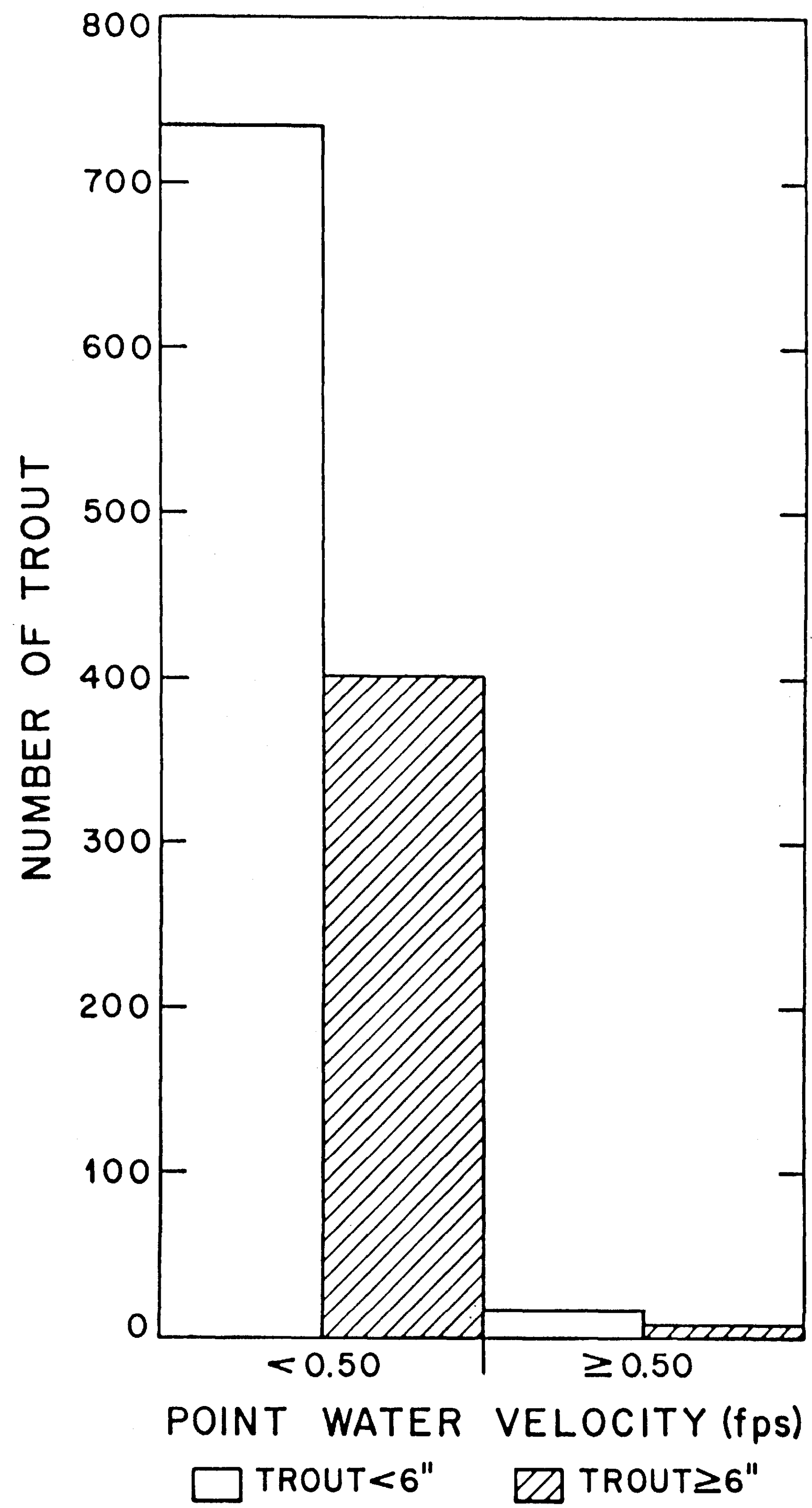

Figure 15. Point water velocity-frequency distribution for the 1,160 trout sampled at the Douglas Creek No. 1, 6, 7 and Hog Park Creek study areas by size class.

Figure 16. Types of overhead bank cover.
Top Left: Undercut banks at Douglas Creek No. 6.
Top Right: Log at Douglas Creek No. 7
Bottom Left: Brush jam at Douglas Creek No. 7
Bottom Right: Combination of overhanging willows and undercut banks at Douglas Creek No. 7.

rubble-boulder areas, while 48.4 percent were taken from overhead bank cover. For catchables, 72.8 percent utilized overhead cover and the remaining 27.2 percent were found in rubble-boulder areas (Figure 13, page 37). No fish were sampled in areas having a substrate size of less than 3.0 inches (7.6 cm) in diameter or in overhead bank cover of less than 0.30 feet (0.0914 m) in width, although such areas were present at the study sites.

Of the 1,160 trout sampled, 91.6 percent were found at locations having water depths of at least 0.50 feet (0.1524 m) (Figure 14, page 38). For the remaining 8.4 percent, most were sampled at low flows (12.5 percent and 11 percent ADF), when from 51 to 65 percent of the surface area of the study sites was composed of water less than 0.50 feet (0.15 m) in depth.

Ninety-eight percent of all trout cover being utilized was found in association with point water velocities of less than 0.50 feet per second (0.1524 m/sec) (Figure 15, page 39). Such low velocities were a direct function of the ability of the cover to minimize the force of the current, thus forming a resting area for the fish.

Mean water velocity data, taken at Douglas Creek No. 6 and 7 at flows ranging from 51 percent down to 11 percent ADF, show that approximately 80 percent of all trout sampled were taken at locations where velocities were less than 1.0 fps (0.3048 m/sec). As shown on Table V, page 32, virtually no differences were found between catchables and subcatchables. At the flow levels sampled, from 59 to 80 percent of the surface areas were composed of water having mean velocities less than 1.0 fps (0.3048 m/sec). Additional sampling at higher flow levels when greater amounts of fast water areas are present will be necessary to determine if preferences are being exhibited by trout for the slow water areas or if the results found are only a function of the surface area composition at the flow levels sampled.

Trout Cover Rating System

Using the data presented above, the following basic equation has been devised allowing for the comparative cover rating of the same stream section at different flow levels and different stream sections at the same level of flow:

$$\frac{L\ obc}{T}\ (PF\ obc) + \frac{A}{SA}\ (PF\ a) = CR$$

where,

L obc = length (ft. or m) of overhead bank cover in the stream section having a water depth of at least 0.5 feet (0.1524 m) and a width of at least 0.3 feet (0.0914 m).

T = length (ft. or m) of thalweg line through the stream section.

A = surface area (sq. ft. or sq. m) of the stream section having a water depth of at least 0.5 feet (0.1524 m) and a substrate size of 3" (7.6 cm) in diameter or greater.

SA = total surface area (sq. ft. or sq. m) of the stream section at the average daily flow.

PF obc = preference factor of trout for overhead bank cover.

PF a = preference factor of trout for instream rubble-boulder areas.

CR = cover rating of stream section for trout.

In the application of the system, if measurements cannot be made at the average daily flow, the following guidelines would apply in regard to the total surface area (SA): 1) for comparisons of two separate stream sections, measurements should be taken when both sections are at relatively the same flow level (i.e., the same percent of the average daily flow); 2) for comparisons of the same stream section at different flow levels, the surface area value used should be that value at the highest flow for which a cover rating is being made.

The preference factor for trout grater than or equal to 6.0 inches (catchables) for overhead bank cover is 0.75 (i.e., approximately 75 percent were found utilizing overhead bank cover). For smaller trout (subcatchables), the factor is 0.50. For instream rubble-boulder areas, the preference factor for catchables is 0.25, while for subcatchables, 0.50. The term "preference factor" has been applied because at each flow level, as far as could be determined, unutilized sections of overhead bank cover and rubble-boulder areas were available. Gibson and Keenleyside (1966) and McCrimmon and Kwain (1966) have stated that the value of cover is probably related to security and the photonegative response of trout causing them to seek cover. All sampling was done at mid-day, when, due to this photonegative response, the fish would most likely have been in the stream areas normally used for cover.

The difference among preference factors between the two size groups would appear to indicate a stronger preference for rubble-boulder areas by the subcatchables. Competition for favorable stream locations and territoriality, as were shown to exist in salmonid populations by Kalleburg (1958) and Newman (1956), are certainly possible explanations. However, unused cover, of both types, was available at each flow level, as far as could be determine.

Application of Cover Rating System

The following example, comparing available trout cover for catchables at Douglas Creek No. 7 at 100 percent and 11 percent ADF, illustrates the use of the system:

$$\frac{\text{L obc}}{\text{T}} \text{(PF obc)} + \frac{\text{A}}{\text{SA}} \text{(PF a)} = \text{CR}$$

At 100 percent ADF:

$$\frac{181'}{827'} (0.75) + \frac{17{,}315 \text{ ft}^2}{41{,}736 \text{ ft}^2} (0.25) = 0.2679$$

At 11 percent ADF:

$$\frac{126'}{827'} (0.75) + \frac{5{,}273 \text{ ft}^2}{41{,}736 \text{ ft}^2} (0.25) = 0.1459$$

The cover ratings obtained show that for catchables, available trout cover was reduced by nearly 50 percent in the flow reduction from 100 percent down to 11 percent ADF, with the greatest reduction being the dewatering of instream rubble-boulder areas, as shown in Figure 6, page 24.

One application of the system is to compare the amount of available trout cover present in a stream section at various discharge levels to aid in determining a suitable minimum streamflow to be maintained in reaches where flow is regulated by upstream water development projects. Wesche (1973) found that the greatest decrease rate for available trout cover at the Douglas Creek No. 1 and Hog Park Creek study areas occurred as flow was reduced from 25 percent ADF to 12.5 percent ADF. At the Douglas Creek No. 7 area, similar results were observed. The mean cover rating (determined by averaging the ratings for catchables and subcatchables) was reduced from 0.2924 at 100 percent ADF to 0.2014 at 27 percent ADF, a 31.1 percent reduction. As flow dropped to 9 cfs, 0.25 cu m/sec, (11 percent ADF), the mean cover rating decreased to 0.1426, an additional 20.1 percent reduction. Figure 17 compares the reductions in available cover which occurred at the three study areas as the discharge was reduced.

To begin to determine if a relationship did exist between the cover rating number and the standing crop of trout present in a stream reach, cover ratings and population estimates were made at the eleven primary and secondary study areas. The average daily flows in these areas ranged from 27 cfs (0.76 cu m/sec) at Hog Park Creek to 105 cfs (2.97 cu m/sec) at the Laramie River site and elevations varied from 5,300 feet (1,615 m) MSL at Deer Creek No. 2 to 9,300 feet (2,835 m) MSL at Douglas Creek No. 1. Wetted channel widths ranged from 8 feet (2.4 m) at Hog Park up to 71 feet (21.6 m) at Douglas Creek No. 7, while the length of the study areas varied from 250 feet (76.2 m) at Douglas Creek No. 5 to 830 feet (253.0 m) at Douglas Creek No. 7. Also, the relative amounts of the two primary cover types varied. At Douglas Creek No. 5, only 8.5 feet (2.6 m) of available bank cover were present, while at the Laramie River site, no instream rubble-boulder areas were present. Water chemistry parameters at all sites fell within the tolerance ranges of trout species, although a phenol "slick" was observed on the Laramie. Brown trout were the predominant salmonid species at each study area.

Table VI contains the length, weight, condition factor (K_{TL}), standing crop and mean cover rating data for each study area, while Figure 28 compares the trout standing crop estimates (pounds per

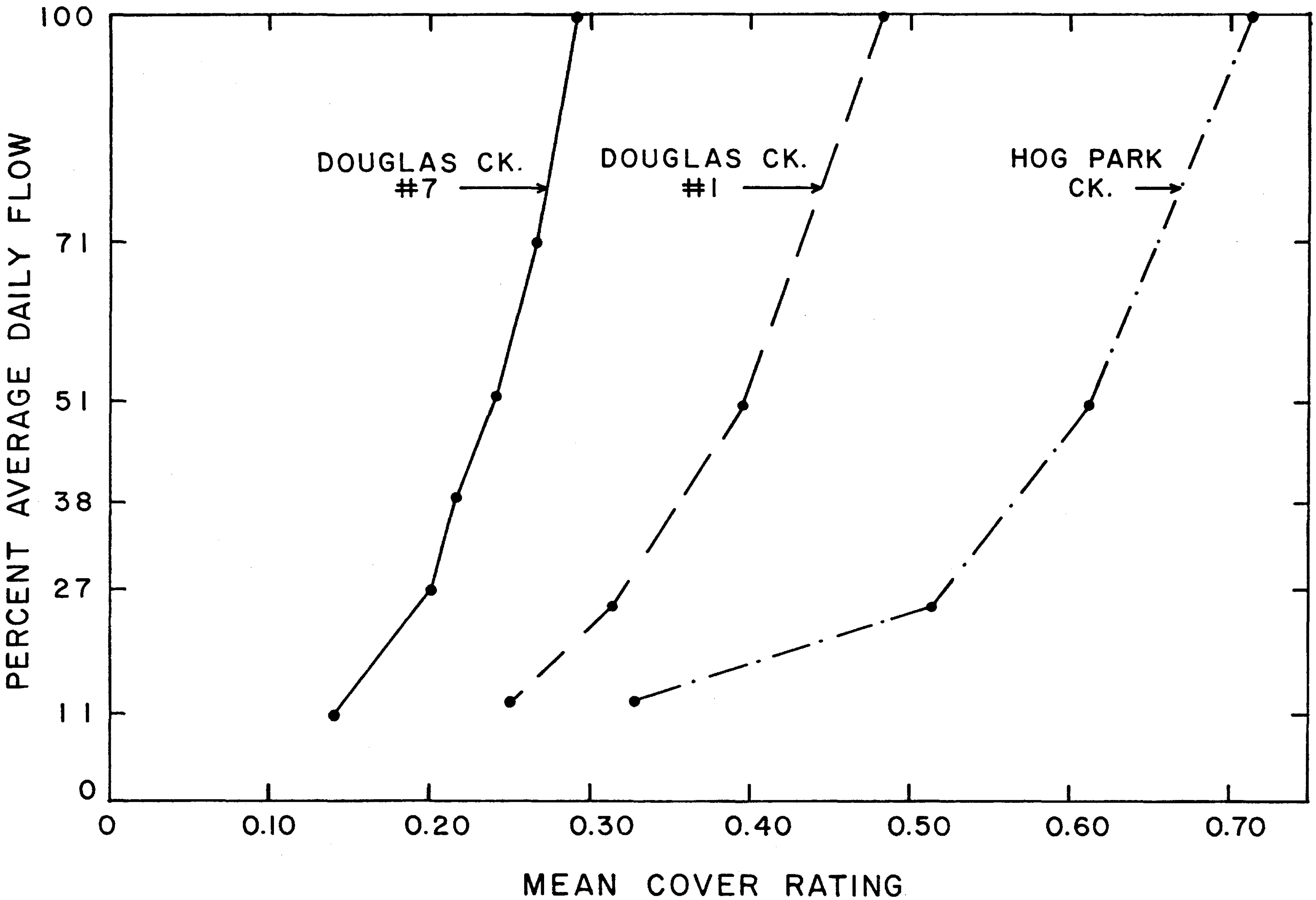

Figure 17. Changes observed in the mean trout cover rating as flow was reduced at the Douglas Creek No. 1, 7 and Hog Park Creek study areas.

TABLE VI

LENGTH, WEIGHT, CONDITION AND STANDING CROP DATA FOR TROUT POPULATIONS SAMPLED

Location	Species	Number	$\bar{L}$ inches (mm)	$\overline{Wt}$ lbs. (g)	$\overline{K_{TL}}$	Total Pounds Trout Per Surface Acre (95% Confidence Limits)	Mean Cover Rating	Estimated Total Pounds Trout Per Surface Acre (log Y=0.0204 + 5.338X)
Douglas Ck. #1	Brown Trout	85	6.14 (156)	0.122 (55)	0.939	51.6	0.2869	35.6
	Brook Trout	7	6.37 (162)	0.104 (47)	0.993	(39.2, 86.6)		
	Rainbow Trout	2	3.96 (100)	0.024 (11)	1.087			
Douglas Ck. #2	Brown Trout	48	5.48 (139)	0.088 (40)	1.063	26.4	0.2667	27.8
	Brook Trout	6	6.13 (156)	0.096 (44)	1.036	(24.1, 29.6)		
Douglas Ck. #3	Brown Trout	62	5.63 (143)	0.117 (53)	1.074	20.7	0.2511	22.9
	Brook Trout	8	5.55 (141)	0.078 (35)	1.042	(14.5, 45.8)		
	Rainbow Trout	1	2.80 (71)	0.007 (3)	0.834			
Douglas Ck. #4	Brown Trout	53	4.93 (125)	0.062 (28)	1.147	17.7	0.2129	14.4
	Brook Trout	23	4.71 (120)	0.053 (24)	1.172	(16.1, 19.7)		
Douglas Ck. #5	Brown Trout	18	5.40 (137)	0.098 (44)	1.034	8.0	0.1604	7.5
	Brook Trout	1	4.10 (104)	0.026 (12)	1.062	(7.6, 8.9)		
Douglas Ck. #6	Brown Trout	137	8.71 (221)	0.360 (163)	0.971	189.0	0.4200	183.1
	Brook Trout	1	5.30 (135)	0.053 (24)	0.986	(147.4, 289.2)		
	Rainbow Trout	3	9.53 (242)	0.302 (137)	0.950			
Douglas Ck. #7	Brown Trout	97	6.12 (155)	0.095 (43)	0.979	29.5	0.2371	19.3
	Brook Trout	3	6.50 (165)	0.098 (44)	0.990	(24.5, 34.5)		
	Rainbow Trout	8	4.54 (115)	0.048 (22)	1.151			

TABLE VI (Continued)

Location	Species	Number	$\overline{L}$ inches (mm)	$\overline{Wt}$ lbs (g)	$\overline{K}_{TL}$	Total Pounds Trout Per Surface Acre (95% Confidence Limits)	Mean Cover Rating	Estimated Total Pounds Trout Per Surface Acre (log Y=0.0204 + 5.338X)
Hog Park Ck.	Brown Trout	120	6.20 (157)	0.117 (52)	1.065	81.1	0.3407	69.1
	Brook Trout	57	5.68 (144)	0.079 (36)	1.069	(64.1, 118.8)		
	Rainbow Trout	12	6.42 (163)	0.121 (55)	1.119			
Laramie River	Brown Trout	15	9.21 (234)	0.713 (324)	1.103	30.7	0.2851	34.9
	Rainbow Trout	7	9.29 (236)	0.364 (165)	1.074	(18.7, 42.4)		
Deer Ck. #1	Brown Trout	14	7.30 (185)	0.278 (126)	1.052	7.1	0.1987	12.1
	Rainbow Trout	1	11.00 (279)	0.515 (234)	1.072	(6.1, 8.5)		
Deer Ck. #2	Brown Trout	10	11.90 (302)	0.756 (343)	0.898	37.3	0.3294	60.1
	Rainbow Trout	5	8.60 (218)	0.293 (133)	1.092	(28.9, 46.0)		

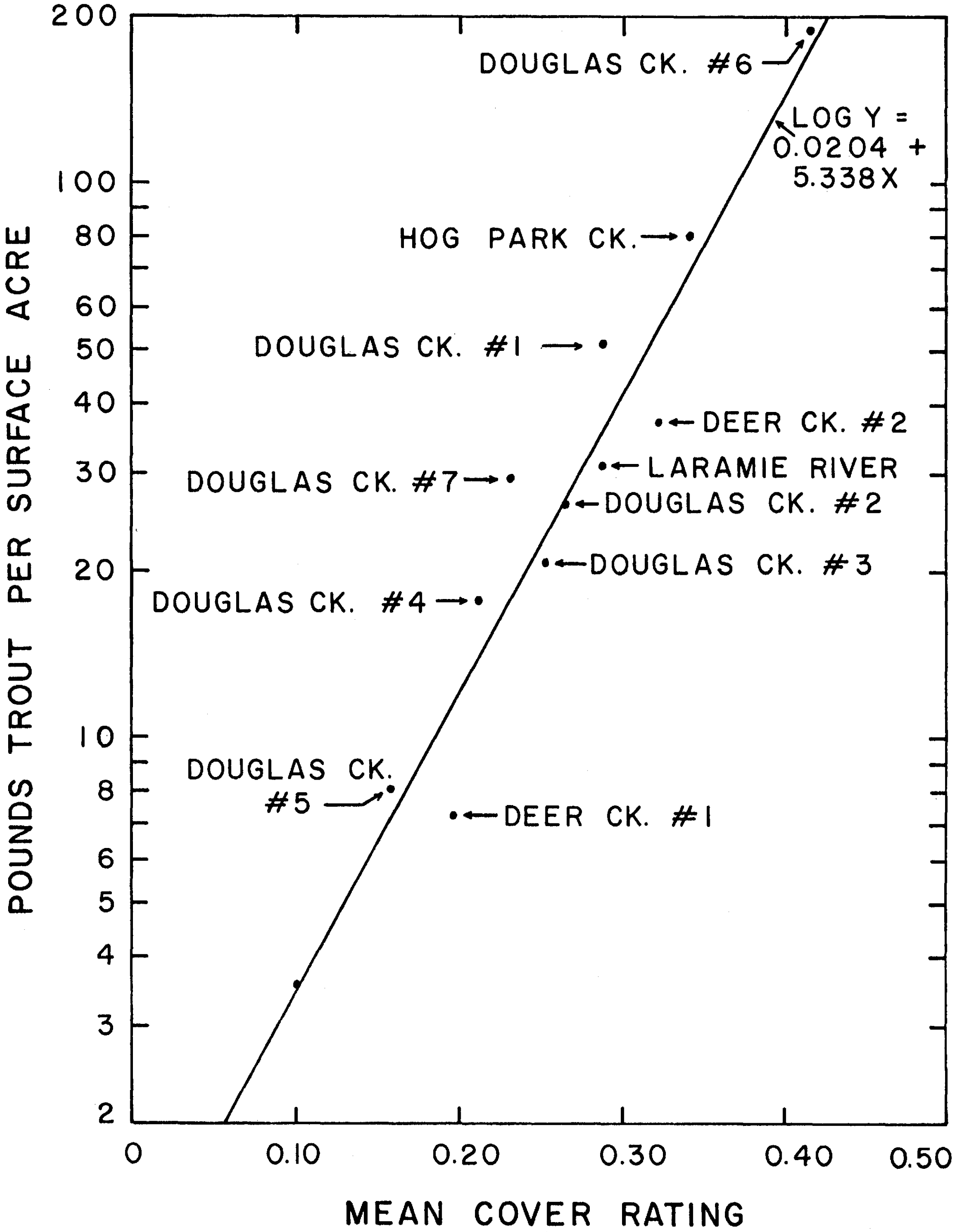

Figure 18. Relationship between mean trout cover ratings and the standing crop estimates of trout at the eleven primary and secondary study areas.

surface acre) to the mean cover ratings. When these points were plotted on an arithmetic scale, the resulting function appeared exponential in nature. To straighten the line, a semi-logarithmic transformation was used. The regression equation was:

$$\log Y = 0.0204 + 5.338 X,$$

where,

X = mean cover rating

and, Y = standing crop of trout (pounds per acre).

Testing of the significance of the regression coefficient led to the conclusion that a linear relationship does exist between the two variables at all levels of significance tested. From Figure 18, page 49, it appears that the mean cover rating values do serve as a relatively good indicator of the standing crops of trout present in various stream sections. Of course, discrepancies do occur between the measured standing crops and the estimated values, determined from the linear regression equation (Table VI). As shown, such differences range from 0.5 pounds per acre at Douglas Creek No. 5 up to 22.8 pounds at Deer Creek No. 2. Such a wide discrepancy at this latter study area can partially be explained by the severe floods during the spring of 1973 which caused extensive damage to the Deer Creek channel and may have caused some trout mortality. Also, the availability of trout cover is only one factor limiting trout populations. The rating system does not take into consideration such factors as water chemistry, water temperature, the availability of spawning and food producing areas, the flow regime through the sections and angler-caused mortality.

Length-frequency distributions for the trout populations sampled are provided in Table A-I, page 69. The data obtained to develop the DeLury population estimates for the ten secondary study sites are contained in Table A-II, page 70.

DISCUSSION

The approach taken by this study has been to relate the reductions of physical and hydraulic stream characteristics to discharge reductions. Parameters investigated at six flow levels included water depth, velocity, cross-sectional area, wetted perimeter, hydraulic radius, top width, and surface area and its composition by water depth-velocity classes. At the Douglas Creek No. 7 study site, all parameters were found to decrease at the greatest rate for discharge reduction interval from 27 percent to 11 percent ADF. This concurs with the findings of Wesche (1973), who found similar reduction patterns at Douglas Creek No. 1 and Hog Park Creek as flow was reduced from 25 percent to 12.5 percent ADF. However, to consider the potential biological significance of these findings in relation to stream dewatering, such as that shown in Figure 19, and to use them as a basis for making streamflow recommendations, it is necessary to apply available trout habitat criteria to the data.

The trout cover rating system previously described has been designed to become an easily applied habitat evaluation tool for both the fisheries manager and the researcher. In this study, the system was used to determine the loss of available trout cover as discharge was reduced. For the Douglas Creek No. 7, Douglas Creek No. 1 and Hog Park Creek study areas, it has been shown that the greatest rate of loss for available trout cover occurred as flow was reduced below approximately 25 percent of the average daily discharge (Figure 17, page 46). The

Figure 19. Loss of habitat by dewatering on the Laramie River

relationship found between mean cover ratings and the standing crops of trout at eleven stream sections, as shown on Figure 18, page 49, begins to define the significance of such flow reductions, in a quantitative biological sense, to the populations of trout which can be supported. As previously stated, there are numerous factors which can limit the carrying capacity of stream habitats. From this work, it is evident that the amount of available trout cover in a stream reach is a significant limiting factor. Other possible applications of the rating system would be:

1) Evaluating the effectiveness of stream improvement projects.
2) Determining the amount of stream improvement needed to return altered habitats (i.e., channelized sections) to their former condition.
3) Aiding in the determination of the carrying capacity of stream reaches to establish feasible stocking rates.
4) Conducting general trout habitat surveys.

A second habitat requirement for salmonids is the availability of "rearing" or "nursery" areas for the growth and development of juvenile fish. Thompson (1972) states that the period of the year when fish are not migrating, spawning or when fry and eggs are not in the gravels, is loosely defined as the rearing period and recommends as one guideline for a suitable rearing flow that most stream cover be available as shelter. The cover preferences of juvenile trout have been defined in the Results section of this report and these preferences have been incorporated into the rating system. Thus, it would appear that the cover ratings made for juvenile trout at the various flow levels investigated could serve as a basis for recommending suitable rearing flows.

Figure 20 compares the cover available for subcatchables at various flow levels at the Douglas Creek No. 1, No. 7 and Hog Park Creek study areas. As shown, the greatest loss was incurred when discharges dropped below approximately 25 percent ADF.

Other important habitat requirements for trout are the presence of food-producing and spawning areas. In recent years, study of the hydraulic criteria necessary for bottom fauna production has intensified. The results of several of these investigations have been presented in the Introduction of this report. Using the criteria stated by Hooper (1973), which define trout food-producing areas as those stream sections having water velocities from 1.0 to 3.0 fps (0.3048 to 0.9144 m/sec) over a gravel or rubble substrate, and applying them to the hydraulic data obtained at Douglas Creek No. 1, No. 7 and Hog Park Creek, the greatest reduction rate for available food-producing areas occurred as flow decreased below approximately 25 percent ADF, as shown on Figure 21.

A major source of food for fish in streams is provided by invertebrate drift and the supply of drift has been shown to be greater in areas of faster current velocities (Muller, 1953; and Nilsson, 1957). Also, Chapman (1966) has found that fish require less space to obtain needed food, territory size is reduced, and population densities can be greater in swifter areas of the stream. Thus, the mean velocity through a stream section would appear to be a significant factor in the regulation of trout populations. The greatest rate of decrease in the time-of-travel velocity through the Douglas Creek No. 7 study area has been shown to occur in the flow reduction interval between 27 percent and

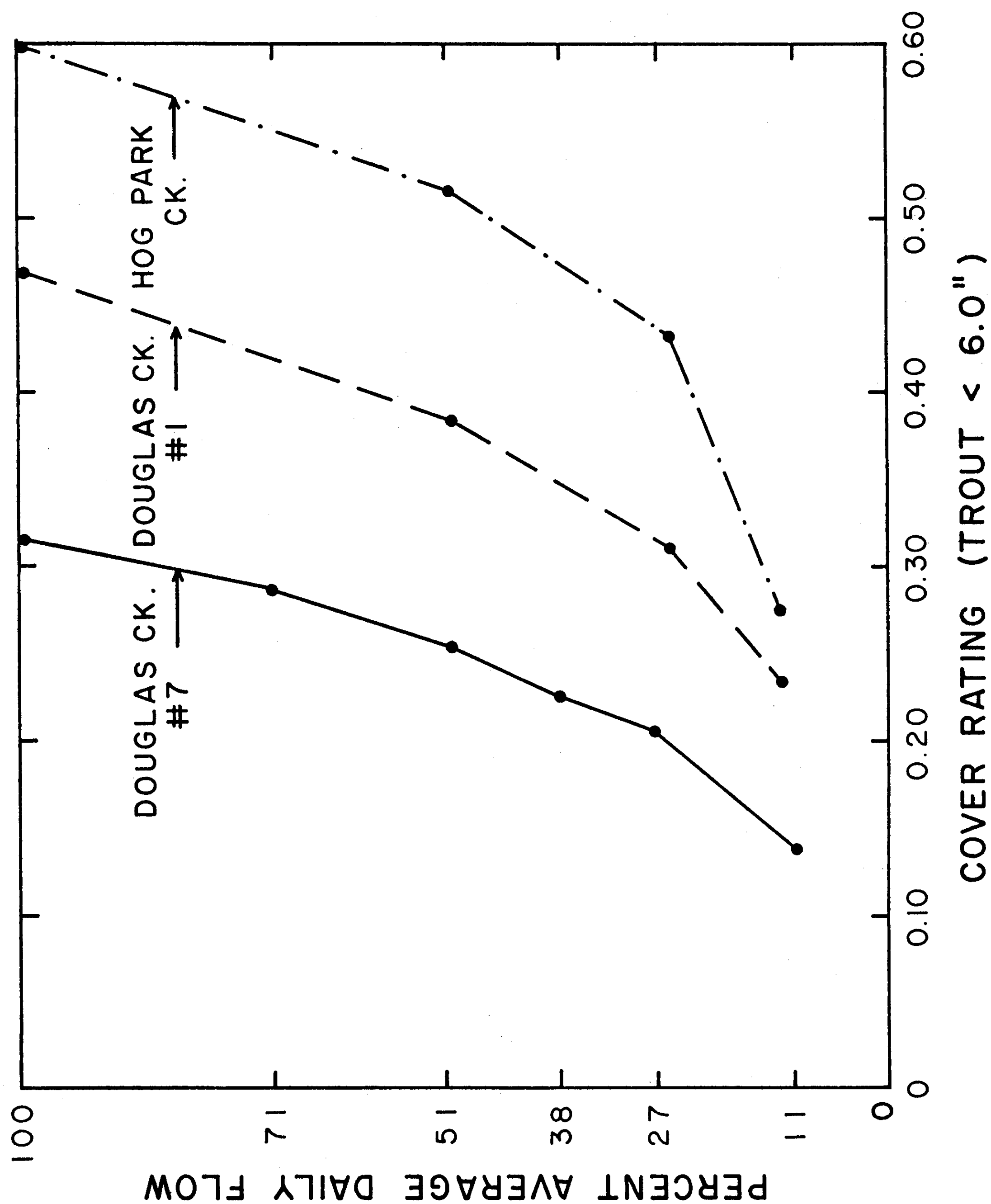

Figure 20. Changes observed in available cover for sub-catchable trout as flow was reduced at Douglas Creek No. 1, No. 7 and Hog Park Creek.

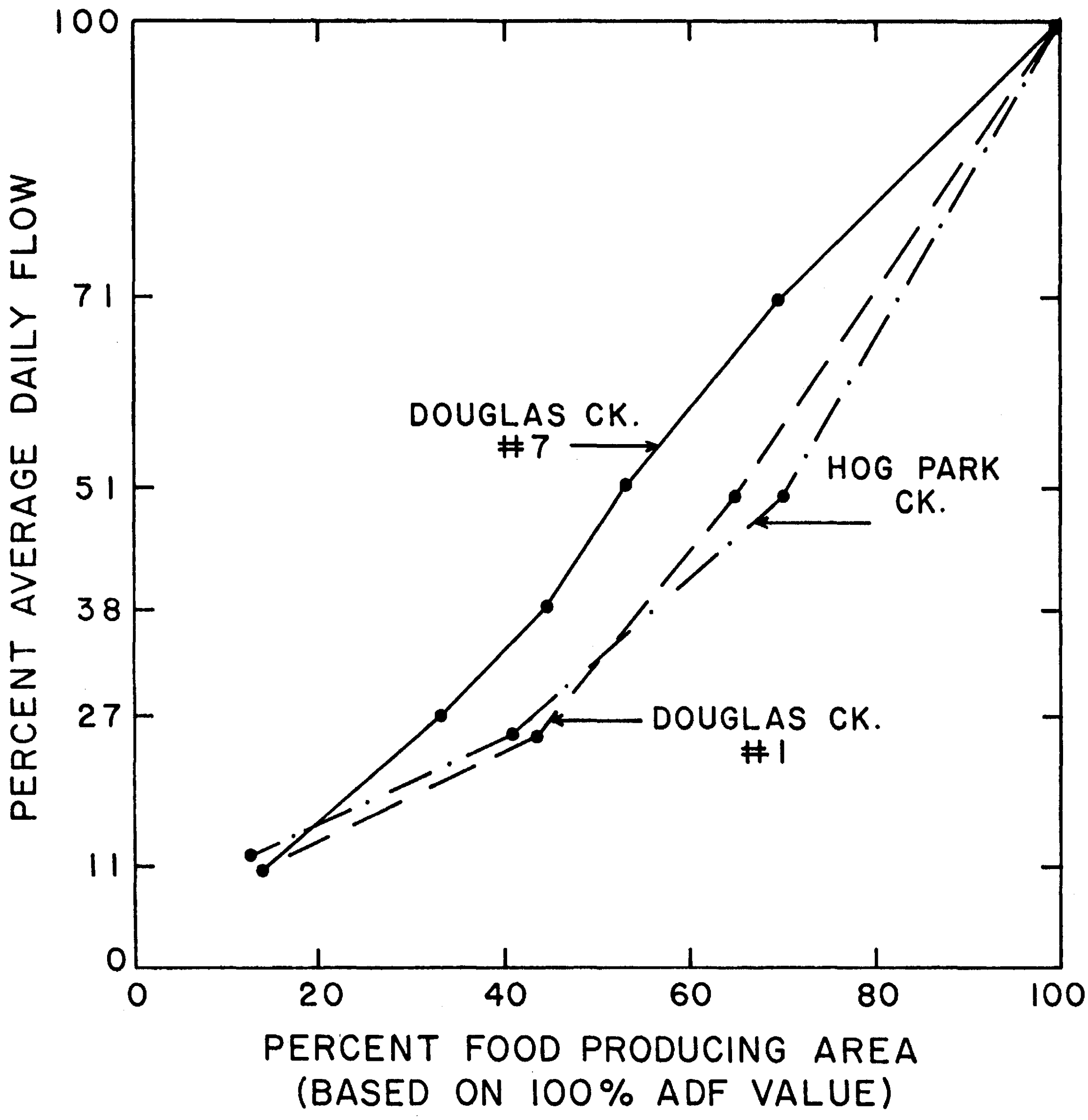

Figure 21. Changes observed in potential food-producing areas as flow was reduced at Doulgas Creek No. 1, No. 7 and Hog Park Creek.

11 percent ADF. This agrees with the findings of Wesche (1973) at the Douglas Creek No. 1 and Hog Park Creek areas.

The California Department of Fish and Game has defined spawning areas for resident trout as those stream locations where water velocities range from 0.50 to 3.0 fps (0.1524 to 0.9144 m/sec), depths are over 0.50 feet (0.1524 m) and at least a two square-foot (0.186 sq. m) section of pea size to three inch (7.6 cm) diameter gravel is present (Hooper, 1973). Applying these criteria to the Douglas Creek No. 7 area, 14,000 sq. ft. (1,301 sq. m) were present at 100 percent ADF. At 27 percent ADF, 5,427 sq. ft. (504 sq. m) still remained, 39 percent of the 100 percent ADF value. As flow decreased to 11 percent ADF, an additional 3,258 sq. ft. (303 sq. m) of potential spawning area were lost, leaving only 2,169 sq. ft. (202 sq. m), 15.9 percent of the 100 percent ADF value. For Douglas Creek No. 1 and Hog Park Creek, the spawning areas available at 100 percent ADF were 9,727 sq. ft. (904 sq. m) and 9,311 sq. ft. (865 sq. m), respectively. These were reduced to 1,202 sq. ft. (112 sq. m) and 912 sq. ft. (85 sq. m) by the time the 12.5 percent ADF flow was reached, 12.4 percent and 9.8 percent, respectively, of the 100 percent ADF values. Again, the greatest reduction rates for potential spawning area at each study section occurred as the flow was reduced below approximately 25 percent ADF (Figure 22). In regard to spawning criteria, it is interesting to note that Johnson, Giguere and Pister, 1966, while studying the hydraulic preferences of brown trout in selecting spawning locations, observed that the spawners seemed to prefer areas which were shaded by willows. This may indicate the existence of a relationship between the amount of available overhead bank cover present in a stream section and the amount of suitable spawning area in that section.

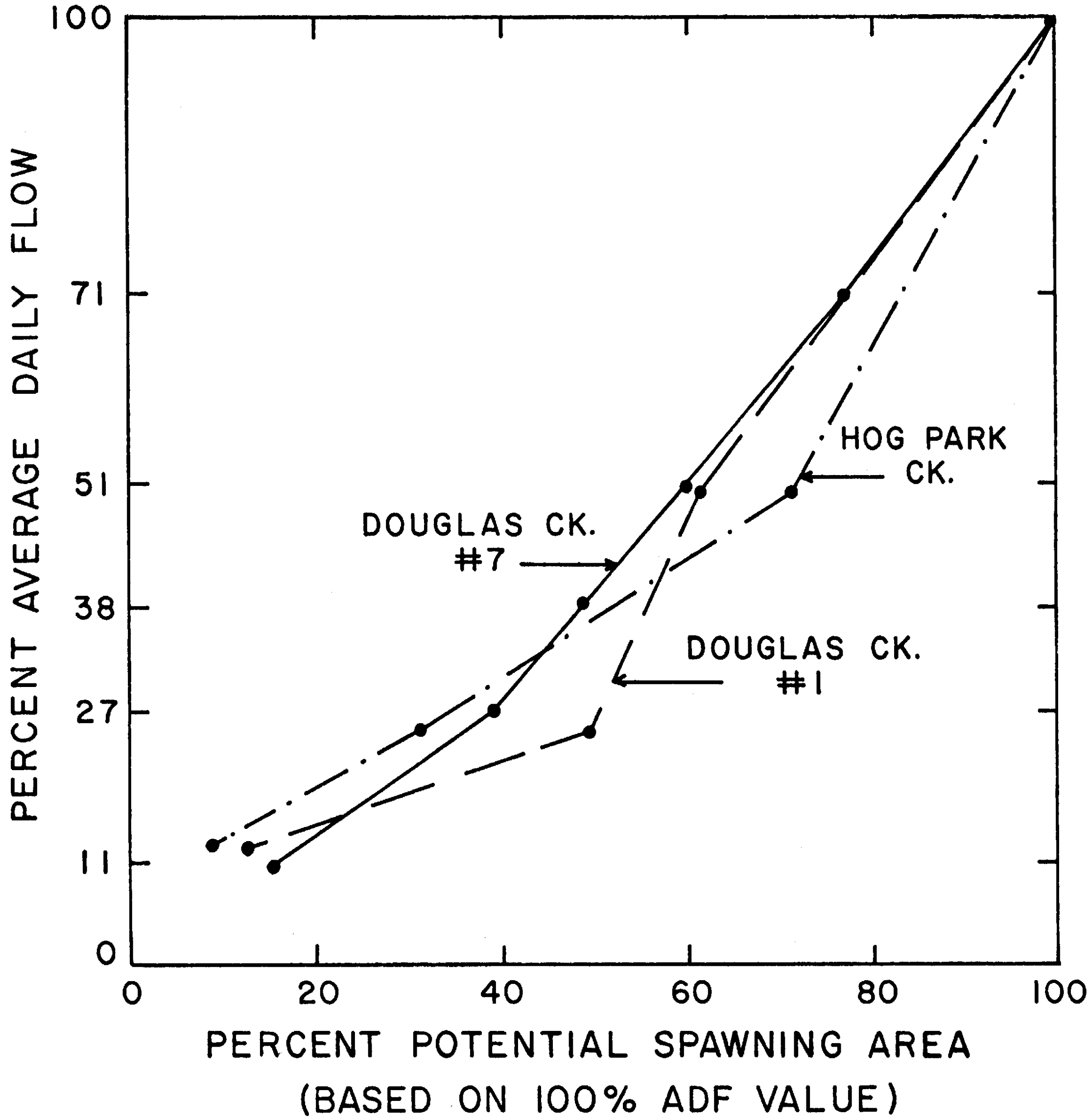

Figure 22. Changes observed in potential spawning areas for trout as flow was reduced at Douglas Creek No. 1, No. 7 and Hog Park Creek.

The preceding comparisons have been made to emphasize the relationships which exist between the parametric decreases noted between the flow levels investigated and the potential biologic significance of such discharge reductions. A trout population is limited by the amount of food-producing, spawning and cover areas provided it by the flow regime through the existing channel configuration. If subjected to extreme dewatering for extended time periods, a population optimally can only expand to the limits allowed by the existing habitat. The trout cover system which has been developed and the relationships which have been found between the cover ratings and the standing crops of trout are an initial attempt to aide the fisheries biologist in beginning to quantify what the limits are for a trout population at given levels of flow in various stream habitats.

The results of this study have shown that as streamflow is reduced below approximately 25 percent ADF, the greatest rates of decrease for available trout cover, food-producing areas and spawning areas are incurred. In determining streamflow recommendations for maintaining trout habitat, numerous factors must be considered. Certain of these would be the degree to which a dam or diversion will affect the natural flow regime of a stream section, the occurrence of lower or higher than normal water years, the type of fishery present, the quality of the fishery, the stability of the habitat and the hydraulic characteristics of the channel. In short, detailed streamflow recommendations should be site specific, adapted to the needs of each situation which arises. A recommendation for flows in the 25 percent ADF range can be used as a general starting point in such determinations and then be adjusted to meet specific critical needs of a trout population during certain periods of the year. Perhaps for a brown trout fishery in a certain stream, 30 percent of the average daily flow is necessary during the spawning and incubation period to provide suitable water velocities and depths over spawning gravels, while for the remainder of the year, a 20 percent ADF flow will maintain adequate cover in the channel. To determine this, on-site investigation would be necessary.

The Northern Great Plains Resource Program (1974) felt that a flow which was equaled or exceeded 50 percent of the time on a monthly or seasonal basis was necessary to maintain existing trout habitat. Applying this criterion to the late summer and early fall flow duration curves for the more productive trout streams investigated, Burton (1974) found that such flows were generally in the 20 percent to 30 percent ADF range. This tends to agree with the observations of Tennant (1972) that a flow level of 30 percent of the mean annual flow is a satisfactory fishery flow. The findings of Wesche (1973) and of this study have shown that available trout habitat decreases at the greatest rate as flow is reduced below approximately 25 percent ADF. Thus, while such a flow cannot be considered as optimum, a discharge in the 25 percent ADF range can be generally considered as a suitable minimum streamflow to maintain a stable trout habitat and as a basis for developing more detailed, site specific, streamflow recommendations.

Of course, in many Wyoming streams, the naturally occurring low flows during portions of the year, particularly the winter period, are less than the recommended 25 percent ADF. At such time, a 25 percent ADF discharge would be considered as an enhancement flow. Little study has been done toward defining what the instream habitat requirements of trout are during the winter season. Trout require food year-round, but probably lesser amounts are needed during the winter months than during the spring, summer and fall seasons. However, the environment which produces such food (the food-producing areas) is needed year-round to provide habitat for the insects which are trout food, as these insects must grow for at lease one year before they reach their adult stages and reproduce. The preference of trout for cover or shelter during the winter months is not well understood. It appears possible that ice cover on streams may add significantly to the overhead cover available; however, there is no evidence at the present time to indicate this. Spawning areas are only needed during the spawning period. However, for fall-spawning brown and brook trout in streams at high elevations, the incubation period may extend well into the late winter months due to slow egg development at very low water temperatures. Thus, to avoid dewatering of redds (locations of trout egg deposition), a stable habitat is necessary.

CONCLUSIONS AND RECOMMENDATIONS

1) The greatest rate of decrease for hydraulic parameters, surface area, and available trout habitat has been found to occur as streamflow was reduced below approximately 25 percent ADF, verifying the findings of Wesche, 1973. As a general "rule-of-thumb", a discharge in the 25 percent ADF range may be considered as a suitable minimum streamflow to maintain a stable trout habitat and as a basis for developing more detailed, site specific, streamflow recommendations.

2) From the analysis of the cover utilized by 1,160 trout (primarily brown trout), it has been found that a preference is exhibited for water having a depth of at least 0.50 feet in association with overhead bank cover or instream rubble-boulder areas. Larger trout ($\geq$ 6.0") tend to have a stronger preference for overhead bank cover than do smaller individuals, although competition and territoriality may explain this difference.

3) The trout cover rating system which has been developed is an easily applied habitat evaluation tool to determine the loss of available trout cover as flow is reduced. Also, work has been initiated to define the relationship between the mean cover rating for a stream section and the standing crop of trout present. For the eleven stream sections investigated, a linear relationship was found to exist between available cover and standing crop. Continued work in this area is needed to allow the fisheries biologist to better quantify the

biological significance of dewatering in regard to the trout carrying capacity of various stream reaches.

4) Additional research should be undertaken to determine the significance of the availability of overhead bank cover in relation to the instream areas selected by brown trout for spawning and to define the instream areas used for cover during the winter season. Also, study should be continued into the hydraulic requirements necessary for instream trout food production and spawning success.

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APPENDIX

TABLE A-I

LENGTH-FREQUENCY DISTRIBUTIONS FOR TROUT SAMPLED
AT THE ELEVEN PRIMARY AND SECONDARY STUDY AREAS

Number of Trout

Size Class-inches (millimeters)	Douglas Creek #1			Douglas Creek #2			Douglas Creek #3			Douglas Creek #4			Douglas Creek #5			Douglas Creek #6			Douglas Creek #7			Hog Park Creek			Laramie River			Deer Creek #1			Deer Creek #2		
	Br	BK	R	Br	Bk	R	Br	Bk	R	Br	Bk	R	Br	Bk	R	Br	Bk	R	Br	Bk	R	Br	Bk	R	Br	Bk	R	Br	Bk	R	Br	Bk	R
3.0-3.9 (76-99)	18	0	1	11	0	0	17	1	0	15	6	0	6	0	0	1	0	0	1	0	4	15	1	0	6	0	0	5	0	0	0	0	0
4.0-4.9 (102-124)	17	0	1	8	1	0	6	2	0	8	10	0	3	1	0	26	0	0	19	0	1	36	12	3	0	0	0	1	0	0	0	0	0
5.0-5.9 (127-150)	10	3	0	7	1	0	11	1	0	13	4	0	3	0	0	22	1	0	37	1	1	21	26	3	1	0	0	0	0	0	0	0	1
6.0-6.9 (152-175)	14	2	0	7	2	0	4	3	0	10	2	0	1	0	0	12	0	0	9	1	0	12	12	2	0	0	1	0	0	0	0	0	0
7.0-7.9 (178-201)	10	1	0	4	2	0	7	1	0	2	0	0	0	0	0	13	0	0	14	1	1	13	5	2	0	0	0	1	0	0	0	0	0
8.0-8.9 (203-266)	6	1	0	5	0	0	2	0	0	2	1	0	2	0	0	4	0	1	4	0	0	8	0	1	1	0	3	5	0	0	3	0	2
9.0-9.9 (229-251)	2	0	0	2	0	0	7	0	0	0	0	0	0	0	0	6	0	1	2	0	0	9	9	0	0	0	2	0	0	0	3	0	1
10.0-10.9 (254-277)	3	0	0	1	0	0	0	0	0	0	0	0	1	0	0	12	0	1	4	0	0	4	0	1	0	0	0	0	0	0	0	0	0
11.0-11.9 (279-302)	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	6	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0	0
12.0-12.9 (305-328)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1
13.0-13.9 (330-353)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	1	0	0	0	0	0	2	0	1	0	0	0	0	0	0
14.0-14.9 (356-378)	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0
15.0-15.9 (381-404)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.0-16.9 (406-429)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
17.0-17.9 (432-455)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
18.0-18.9 (457-480)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0

TABLE A-II

DELURY POPULATION ESTIMATE DATA FOR

TEN SECONDARY STUDY AREAS

Study Area	Effort No.	Catch/Effort(ct) (Number of trout)	Cumulative Catch (Kt) (Number of trout)
Douglas Creek No. 1	1	53	0
	2	30	53
	3	11	83
Douglas Creek No. 2	1	35	0
	2	13	35
	3	6	48
Douglas Creek No. 3	1	31	0
	2	22	31
	3	18	53
Douglas Creek No. 4	1	54	0
	2	18	54
	3	4	72
Douglas Creek No. 5	1	15	0
	2	3	15
	3	1	18
Doulgas Creek No. 6	1	78	0
	2	38	78
	3	25	116
Hog Park Creek	1	103	0
	2	60	103
	3	26	163
Laramie River	1	11	0
	2	8	11
	3	3	19
Deer Creek No. 1	1	12	0
	2	3	12
	3	0	15
Deer Creek No. 2	1	6	0
	2	5	6
	3	4	11

TABLE A-III

FISHERIES DATA COLLECTED
FOR NON-SALMONID SPECIES
AT THE PRIMARY AND SECONDARY STUDY AREAS

STUDY AREA	SPECIES	NUMBER	$\overline{L}$ (mm)	$\overline{Wt}$ (g)
Douglas Creek No. 1	Longnose suckers (*Catostomus catostomus*)	"few"	-	-
Douglas Creek No. 2	Longnose dace (*Rhinichthys cataractae*)	1	124	20
Douglas Creek No. 3	Longnose suckers	6	207	154
	White suckers (*Catostomus commersoni*)	1	325	382
	Longnose dace	1	127	20
Douglas Creek No. 4	Longnose dace	1	48	1
Douglas Creek No. 5	None collected			
Douglas Creek No. 6	None collected			
Douglas Creek No. 7	Longnose suckers	"few"	-	-
	White suckers	"few"	-	-
	Longnose dace	"few"	-	-
Hog Park Creek	None collected			
Laramie River	Longnose suckers	"abundant"	-	-
	White suckers	"abundant"	-	-
	Creek chubs (*Semotilus atromaculatus*)	"abundant"	-	-
	Common shiners (*Notropis cornutus*)	"abundant"	-	-
	Iowa darters (*Etheostoma exile*)	"rare"	-	-
Deer Creek No. 1	White suckers	11	211	-
	Creek chubs	2	97	-
	Longnose dace	1	79	-
Deer Creek No. 2	Longnose suckers	21	155	-
	White suckers	17	190	-
	Creek chubs	4	117	-
	Longnose dace	2	94	-