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PARAMETRIC DETERMINATION

OF

MINIMUM STREAM FLOW FOR TROUT

by

Thomas A. Wesche June, 1973

Completion Report

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ABSTRACT

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The approach taken in the determination of a suitable minimum flow to be maintained in a stream channel for the preservation of trout populations has centered on three types of physical stream characteristics and the changes observed in them between various discharge levels, based on the average daily flow (ADF) over the period of record: 1) hydrologic parameters; 2) surface area and its composition, based on water depth and velocity; and, 3) available trout cover.

Portions of Douglas Creek and Hog Park Creek, relatively small streams (average daily flows approximately 30 cubic feet per second) located in the North Platte River drainage of southeastern Wyoming, were intensively investigated in the summer and fall of 1972 at 200%, 100%, 50%, 25%, and 12.5% ADF. Water depth, velocity, cross-sectional area, wetted perimeter, hydraulic radius, top width, total surface area, surface area having a velocity of at least 1.0 feet per second, surface area of depth 0.5 feet or greater, and available brown trout cover were found to decrease at the greatest rate for the discharge reduction interval from 25% to 12.5% ADF. As a minimum flow, 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/ hydrologic parameters/ trout cover/ average daily flow/ brown trout/

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INTRODUCTION

Basic to fish production are the quantity, quality, and stability of the stream environment. When a water development project, such as a dam or diversion, is proposed on a stream, it is important to establish the amount of water required in the stream channel below the development to maintain the fish populations present. The tools and techniques currently available for making a minimum flow determination are not well developed. The North Platte River below Glendo Reservoir, as shown in Figure 1, serves to illustrate the general effects of severe dewatering on a stream section.

The factors upon which trout production depend are water quality, adequate food supply, spawning areas, and shelter (Delisle and Eliason, 1961). The stream discharge, as influenced by the channel configuration, must meet the hydrologic requirements necessary to provide these factors. Kennedy (1967) has shown that the greatest abundance of trout food in a stream occurs in sections having water velocities ranging between 1.0 and 1.7 feet per second (fps). Bell (1972) 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. By examining trout egg survival under different flow regimes, Hoppe and Finnell (1970) found that suitable trout-spawning habitat should have a minimum water velocity of 1.5 fps. Gunderson (1966) showed that a stream section with higher percentages of deeper water and more

Flow approximately 1750 cfs

Flow approximately 30 cfs

Flow approximately 1750 cfs

Flow approximately 30 cfs

Figure 1. North Platte River below Glendo Reservoir above Casa (top photos) and at the mouth of Horseshoe Creek (bottom photos) before and after dewatering in the fall.

cover had a population of brown trout (over six inches 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. The removal of undercut banks and brush in a stream section caused a decrease in trout numbers and weight (Boussu, 1954). Shuck (1945) reported that volume and depth of water were significant factors in determining the population density of larger brown trout in a section of stream; while, in a study of trout selection of specific pools, Lewis (1969) determined that 66 percent of the variation in trout numbers between pools was accounted for by cover and current velocity.

The effects of reduced flows on the physical characteristics of rivers have been shown by Weber (1959), Curtis (1959), and Kraft (1972). The Wyoming Game and Fish Commission has investigated the general habitat changes occurring at different test flow levels on the North Platte River below Alcova Reservoir (Peterson and Leik, 1958) and Kortes Reservoir (1963), and on the Green River below Fontenelle Reservoir (1964). Tennant (1972), through many years of observing stream flows and the associated fishery values, developed the "Montana Method" of minimum streamflow determination which was 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. The next step in the utilization of the "Montana Method" is to set several flow recommendations and evaluate them in the field (Elser, 1972).

Using the "Montana Method" as a basis, the objectives for the parametric determination of minimum streamflow requirements for trout fisheries were:

1) To determine the relationship of various levels of streamflow, based on the average daily flow (ADF), to changes in such hydrologic factors of the stream channel as water velocity, depth, top width, wetted perimeter, and hydraulic radius, as measured at selected stream transects.

2) To determine the effects various flow levels have on changes in total stream surface area and its composition, based on water velocity and depth.

3) To evaluate the use, for cover, by brown trout of certain physical features of a stream channel (for example, undercut banks and instream rubble or boulder areas), and to attempt to devise a system for rating available cover which allows for changes in the cover as the discharge changes.

DESCRIPTION OF STUDY AREAS

Two stream sections were chosen for detailed study and two others were observed in a less intensive manner. The primary study areas were: 1) the Douglas Creek between Rob Roy Dam and the Cheyenne diversion dam; and 2) Hog Park Creek below Hog Park Dam. The secondary areas were: 1) a lower section on Douglas Creek; and 2) a section of the Laramie River below Wheatland Reservoir.

Primary Areas

Douglas Creek No. 1

The Douglas Creek drainage lies in Albany and Carbon counties in southeastern Wyoming (Figure 2). The headwaters rise on the southeast slopes of the Medicine Bow Mountains at an elevation of 10,400 feet above mean sea level (msl) and flow 29 miles southwest to enter the North Platte River, at approximately 7,500 feet 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 9.7 miles down to the primary study area (9,300 feet msl), encompasses an area of 21.7 square miles. 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. Land uses in the area consist of gold and copper mining, livestock grazing in the summer months, and

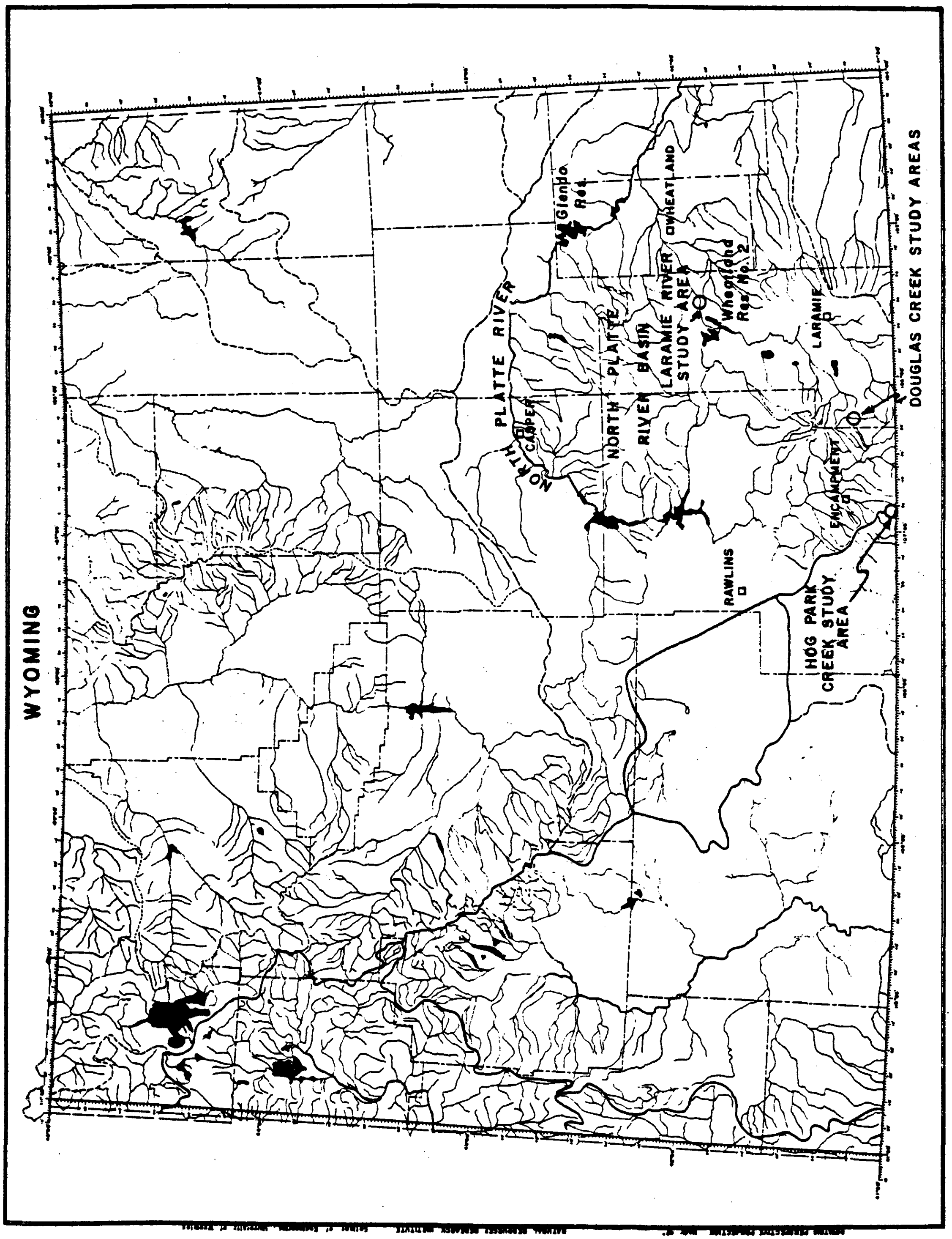


FIGURE 2. Wyoming Map showing study area locations.

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 capacity reservoir and dam control the flow of Douglas Creek to a high degree. Extensive recreational use, consisting of fishing, big game hunting for deer and elk, boating and camping, is made of the drainage area. Figure 3 illustrates the drainage basin, while Table I, summarizes its physical description.

The primary Douglas Creek study area (DC #1) is a 680 foot stream section located 0.55 miles below Rob Roy Reservoir and 2.4 miles north of the town of Keystone, Wyoming, in Section 9, Township 14 N, Range 79 W. Discharge records from a United States Geological Survey (U.S.G.S.) gage (1955-65), located 1.2 miles below the study area, and the Cheyenne, Wyoming Board of Public Utilities (C.B.P.U., 1966-71), show a maximum discharge of 865 cubic feet per second (cfs) on June 5, 1957, and a minimum discharge of 1.3 cfs from March 1-31, 1958. The average daily flow over the period of record is 31 cfs, a flow which is equalled or exceeded 16.6 percent of the time. Mean monthly discharges and the flow duration curve are shown on Figures 4 and 5 respectively. The flow pattern through the study area, controlled completely by Rob Roy dam, follows a rather natural regime with high flows of normally several hundred cfs in June decreasing gradually to winter low flows of approximately 3 cfs. Figure 6 gives an excellent overview of the study area itself, while Figure 7 shows the surrounding area.

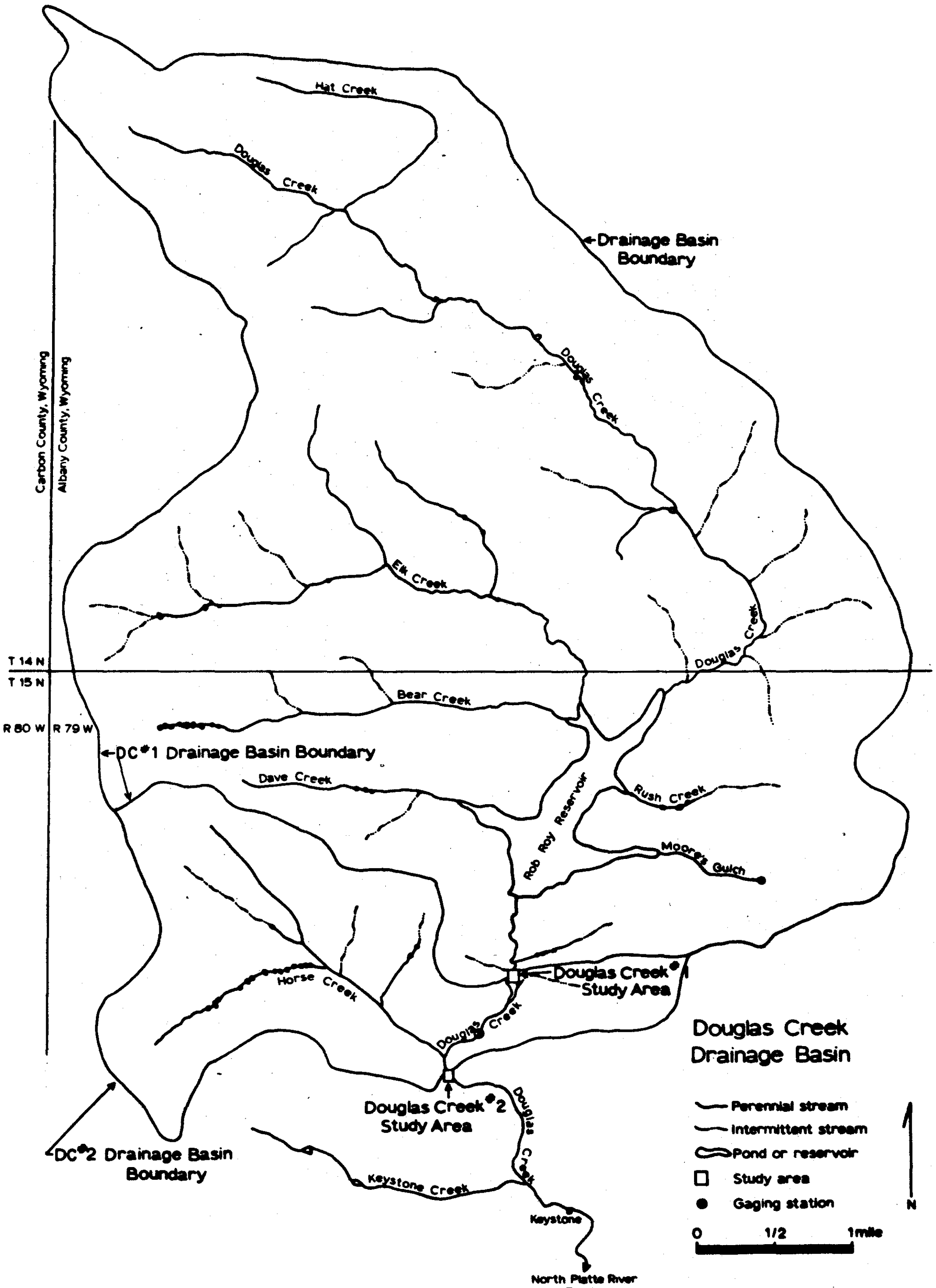


Figure 3 Map of the Douglas Creek Drainage Basin above the Douglas Creek No. 1 and No. 2 Study Areas.

TABLE I

DOUGLAS CREEK AND HOG PARK CREEK DRAINAGE BASIN FEATURES

	Douglas Creek #1 Study Area	Hog Park Creek Study Area
Drainage Area (square miles)	21.7	16.2
Main Stream Length (miles)	9.7	6.2
Total Length of Streams (miles)	36.9	37.2
Drainage Density	1.70	2.29
Stream Order	4	3
Mean Elevation (feet MSL)	9,728	8,945
Median Elevation (feet MSL)	9,638	8,867
Mean Stream Length (miles)	3.64	3.03
Stream Slope (ft/mile)	69.7	81.0
Aspect	S 26°5' E	E 7° S
Highest Elevation in Basin (feet MSL)	10,402	10,440
Highest Elevation on Study Stream (feet MSL)	10,402	9,774
Elevation at Study Area (feet MSL)	9,300	8,310
Distance from Dam to Study Area (miles)	0.55	1.36

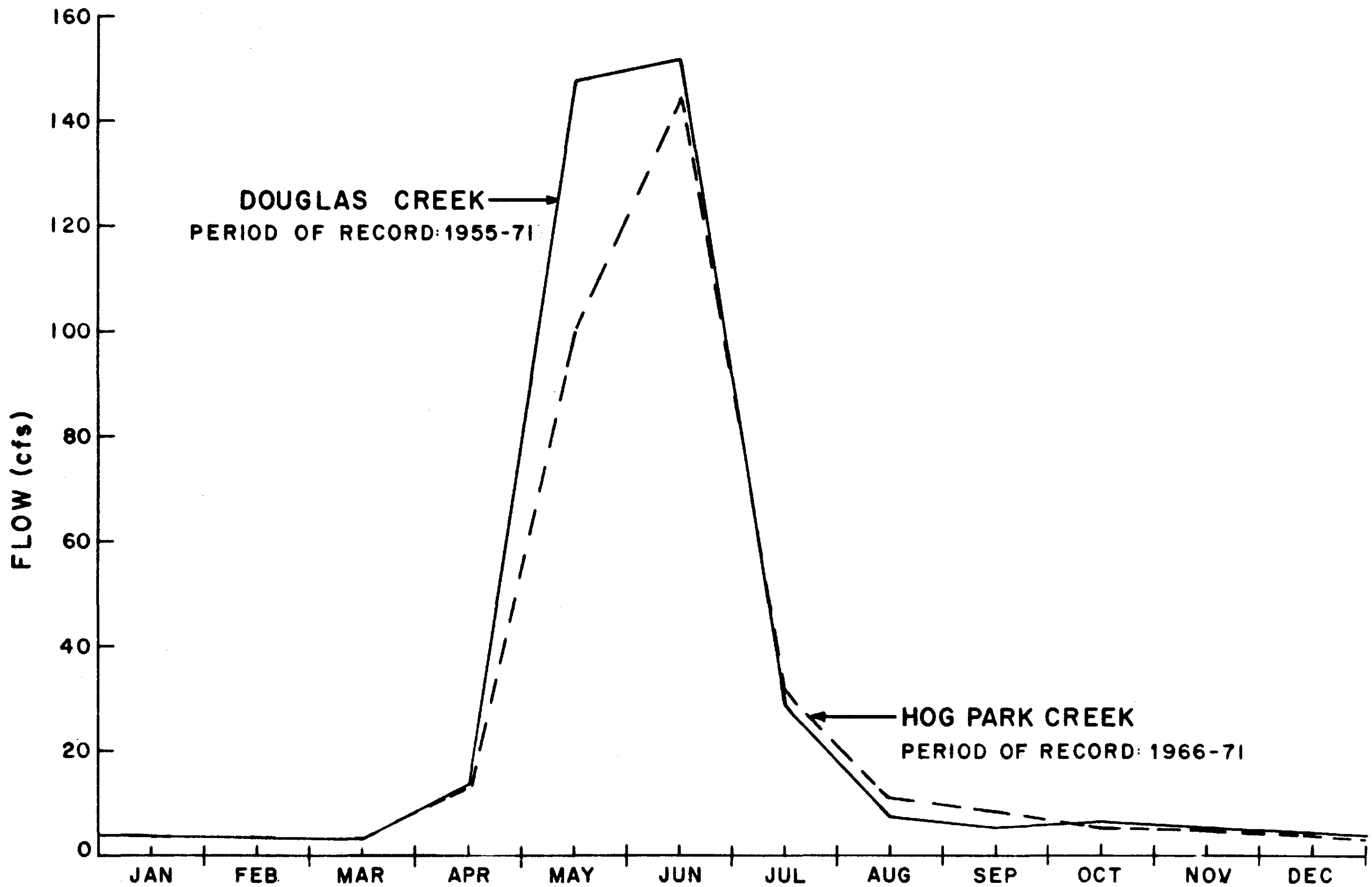


Figure 4 Mean Monthly Discharge for Douglas Creek and Hog Park Creek.

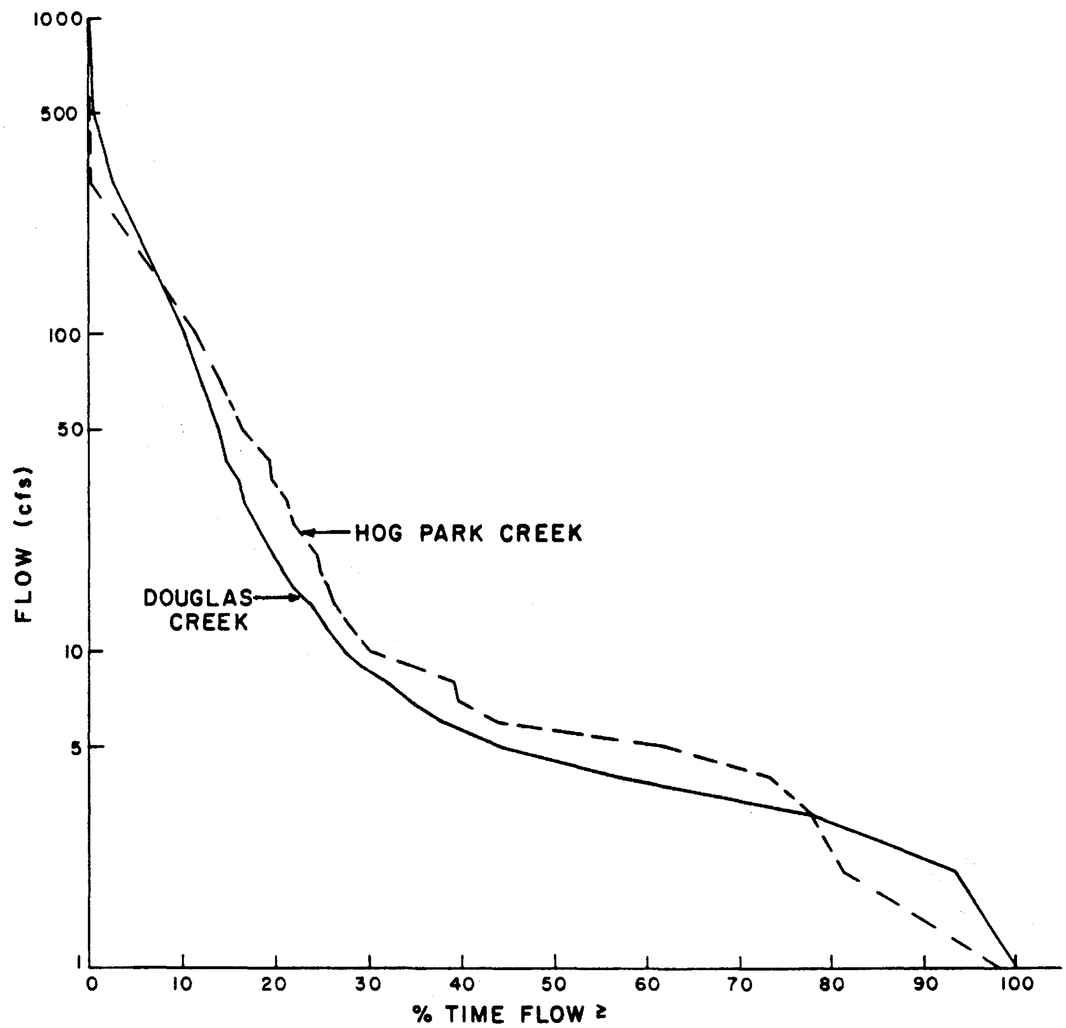


Figure 5 Flow Duration Curves for Douglas Creek and Hog Park Creek.

Figure 6. Aerial view of the Douglas Creek No. 1 Study Area. Flow is from the top to the bottom of the photo.

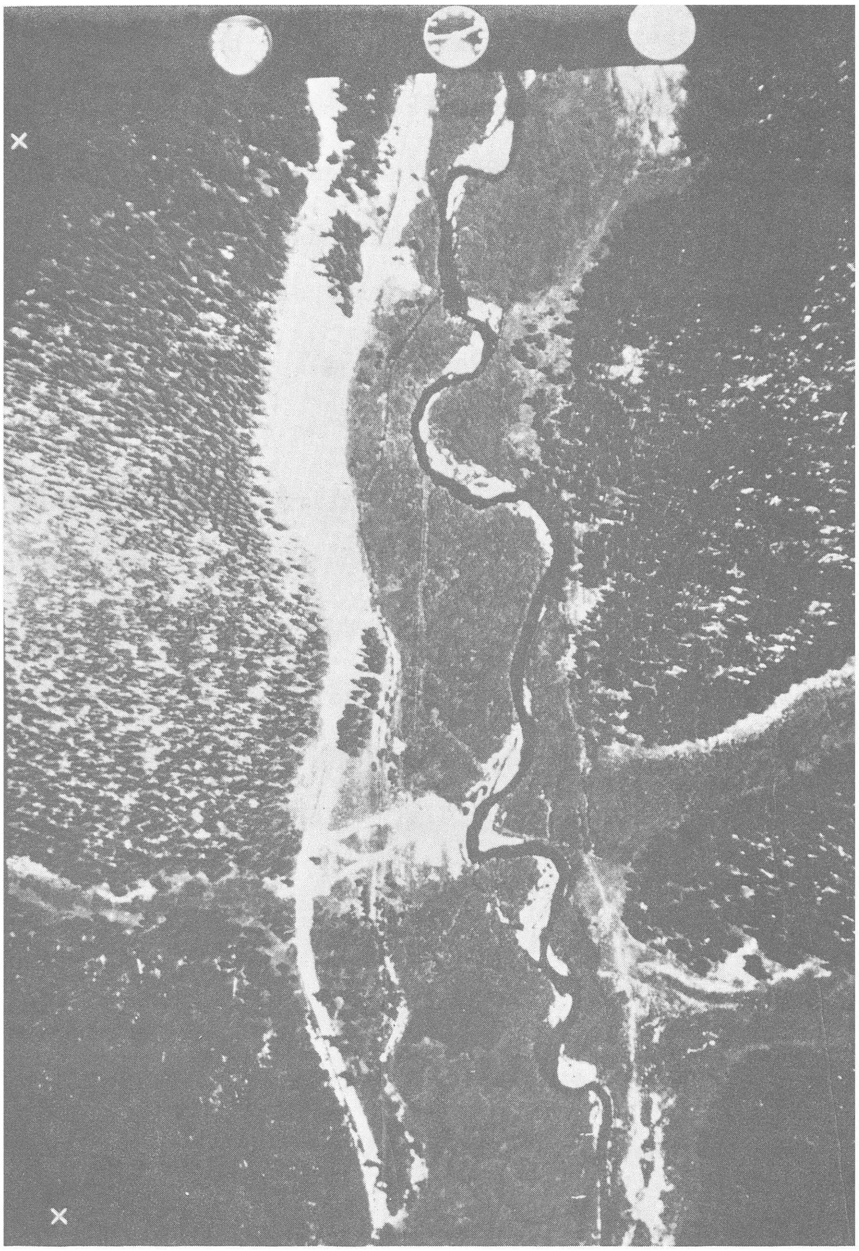


Figure 7. Aerial view of Douglas Creek and the adjacent land area above and below the Douglas Creek No. 1 Study Area. Flow is from the top to the bottom of the photo.

Water temperatures ranged from 8.0°C to 11.0°C for July through October, 1972. Chemical parameters throughout the period ranged as follows: dissolved oxygen, 10-11 ppm; carbon dioxide, 2-5 ppm; total alkalinity, 11-20 ppm; and pH, 7.0-7.4.

From data obtained by four electrofishing days in the study area, brown trout (*Salmo trutta*) comprised 76% of the total trout sample, brook trout (*Salvelinus fontinalis*) 22%, and rainbow trout (*Salmo gairdneri*) 2%. A small population of longnose suckers (*Catostomus catostomus*) was also present.

Hog Park Creek

The Hog Park Creek drainage lies entirely within Carbon county in southeastern Wyoming (Figure 2, page 6). The headwaters rise on the east slope of the Continental Divide at an elevation of 9,774 feet msl in the Sierra Madre mountain range of the Medicine Bow National Forest. Small tributaries in the drainage have their beginnings at elevations ranging from 8,600 to 10,000 feet msl. From the Continental Divide, Hog Park Creek flows 7.6 miles to the east, entering the Encampment River, a major tributary to the North Platte River. The upper portion of Hog Park Creek flows through coniferous and aspen forests, while the lower portion meanders through open park land, dominated by sagebrush (*Artemesia* sp.) and various grass species on the gradual slopes, with willow and sedges in the bottom land.

The Hog Park Creek drainage, from the headwaters 6.2 miles down to the study area (8,310 feet msl) entails an area of 16.2 square miles. Livestock grazing and timber harvesting constitute the major land uses. In the past, the area also supported limited copper and gold mining.

The major water development in the basin is Hog Park Reservoir. Constructed in 1965-66 by the City of Cheyenne, Wyoming, for storage of water brought to the east side of the Continental Divide by means of a tunnel diversion into Hog Park Creek, the 3,000 acre-foot capacity reservoir and dam regulate almost completely the flow of Hog Park Creek. With graded roads providing easy access from Encampment, Wyoming, 24 miles to the northeast, and from northern Colorado, extensive recreational use is made of the area. Major recreational uses include fishing, boating, camping and big game hunting for deer and elk. The drainage basin is shown on Figure 8, while Table I, page 9, summarizes its physical description.

The Hog Park Creek study area (HPC) is a 620 foot stream section located 1.36 miles below Hog Park Reservoir, 0.25 miles above the confluence with the South Fork of Hog Park Creek, and 1.5 miles north of the Wyoming-Colorado border, in Section 9, Township 12 N, Range 84 W. Discharge records from a C.B.P.U. gage station (1966-71), located 0.4 miles below the dam, show a maximum discharge of 310 cfs on May 29, 1967, and a minimum of 0.5 cfs from August 29 to September 5, 1966. The average daily flow over the period of record is 27 cfs, a discharge which is equalled or exceeded 21.7% of the time. Mean monthly discharges and the flow duration curve are shown on Figures 4, page 10, and 5, page 11, respectively.

The flow pattern through the study area follows a rather natural regime, with high flows of normally 150 to 200 cfs in late May and early June decreasing to late fall and winter flows of around 3 cfs. The stream flows in a well-defined channel. In one side channel a large

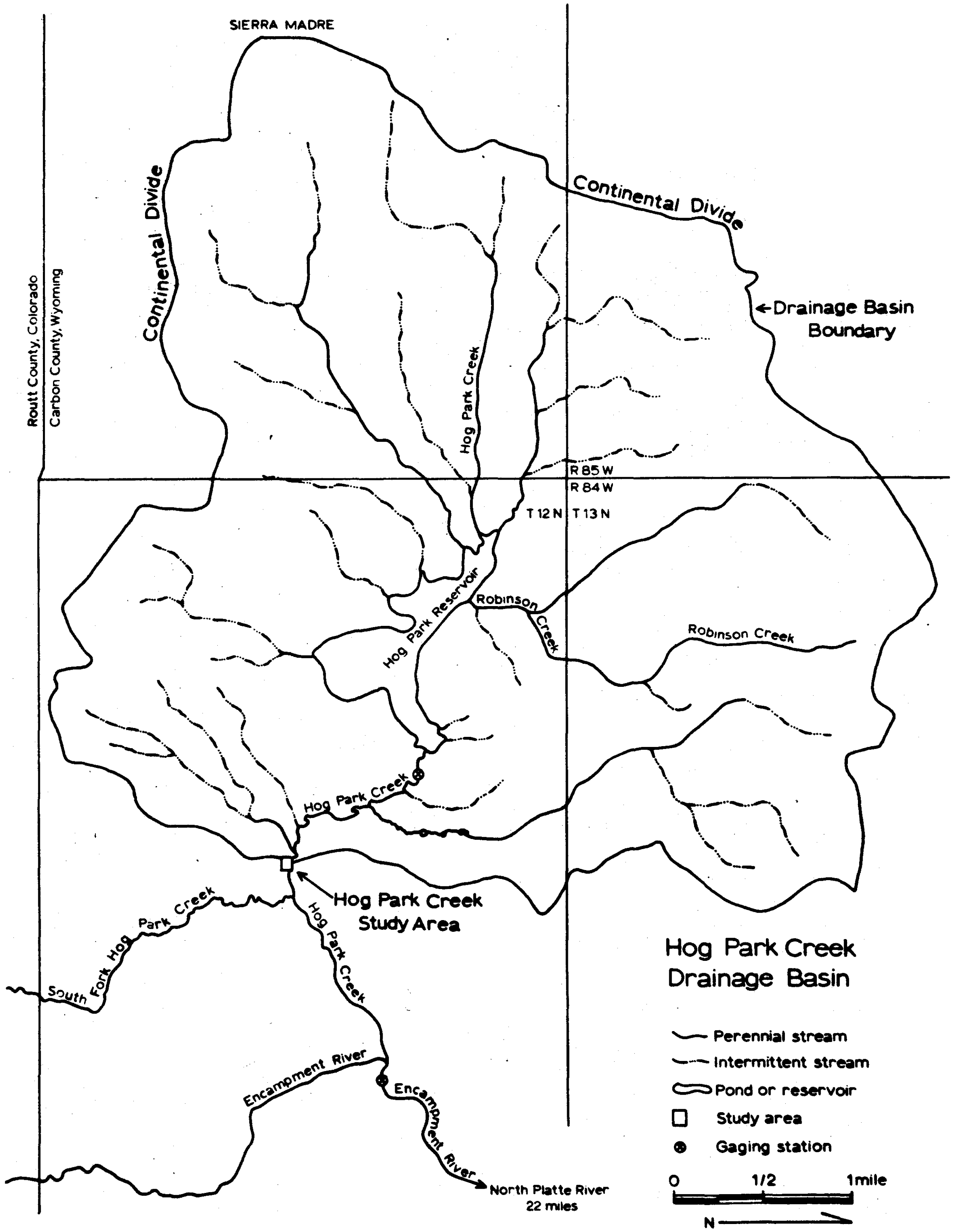


Figure 8 Map of the Hog Park Creek Drainage Basin above the Hog Park Creek Study Area.

beaver pond has been formed, accessible to the trout population throughout the summer, until the low flow level (3.4 cfs) is reached. Figure 9 gives an overview of the study area itself, while Figure 10 shows the adjacent area.

Water temperatures ranged from 14.0°C to 20.5°C for July through October, 1972. Chemical parameters throughout this period ranged as follows: dissolved oxygen, 7-9 ppm; carbon dioxide, 2-5 ppm; total alkalinity, 10-20 ppm; and pH, 6.9-7.4.

From data obtained by four electrofishing days in the study area, brown trout comprised 72% of the total trout sample, brook trout 22%, and rainbow trout 6%. Also present was a small population of longnose suckers.

Secondary Areas

Douglas Creek No. 2

A shorter section of Douglas Creek with different substrate and flow characteristics was chosen for less detailed observation. The 250 foot stream section is located at an elevation of 9,200 feet msl, 1.4 miles below Rob Roy Reservoir, 0.25 miles below the Cheyenne diversion, and 1.5 miles above Keystone, Wyoming, in Section 16, Township 14 N, Range 79 W. The drainage area for this location on Douglas Creek, as shown on Figure 3, page 8, is 25.5 square miles. Due to the dewatering effects of the diversion, flows do not follow a natural pattern and are normally less than at the DC #1 area, located 0.9 miles upstream, above the diversion. Flows greater than 2 to 3 cfs are rarely encountered after mid-August.

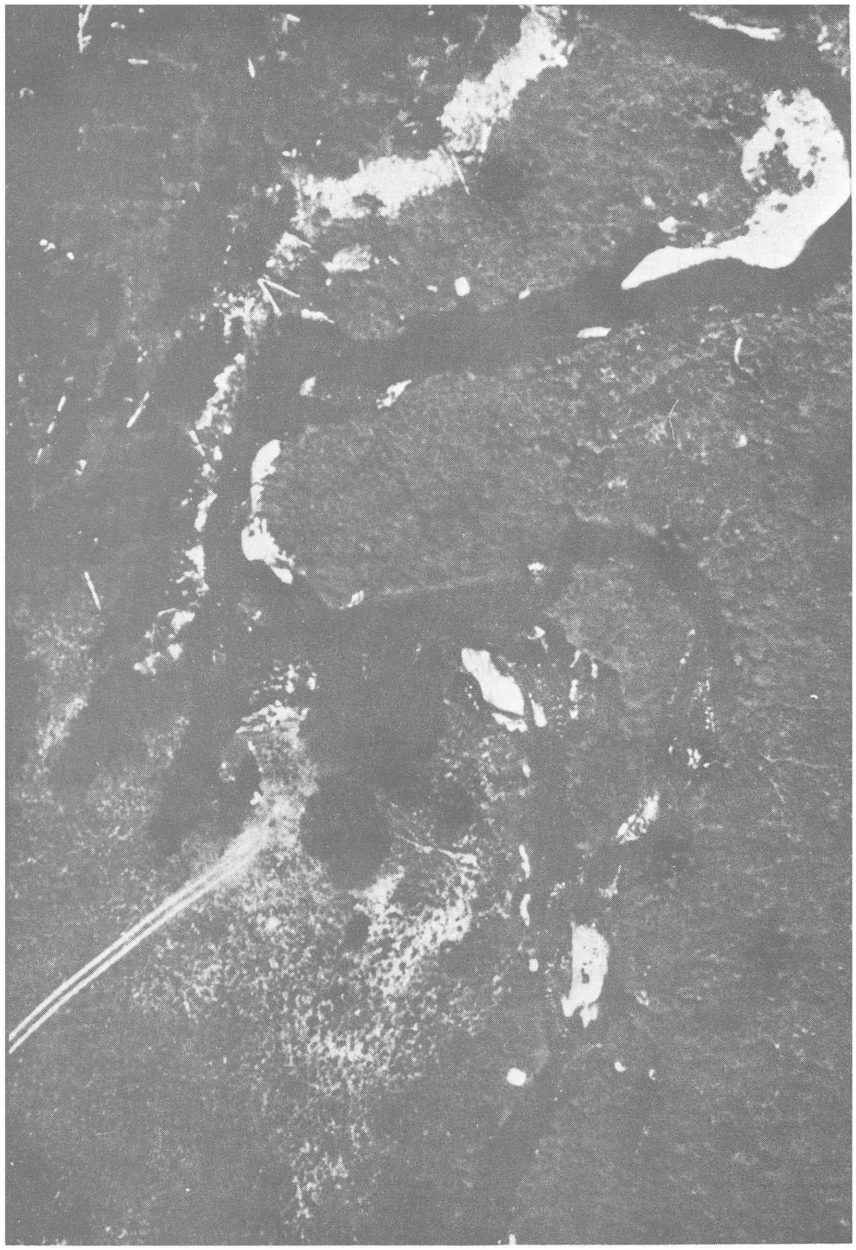


Figure 9. Aerial view of the Hog Park Creek Study Area. Flow is from the top to the bottom of the photo.

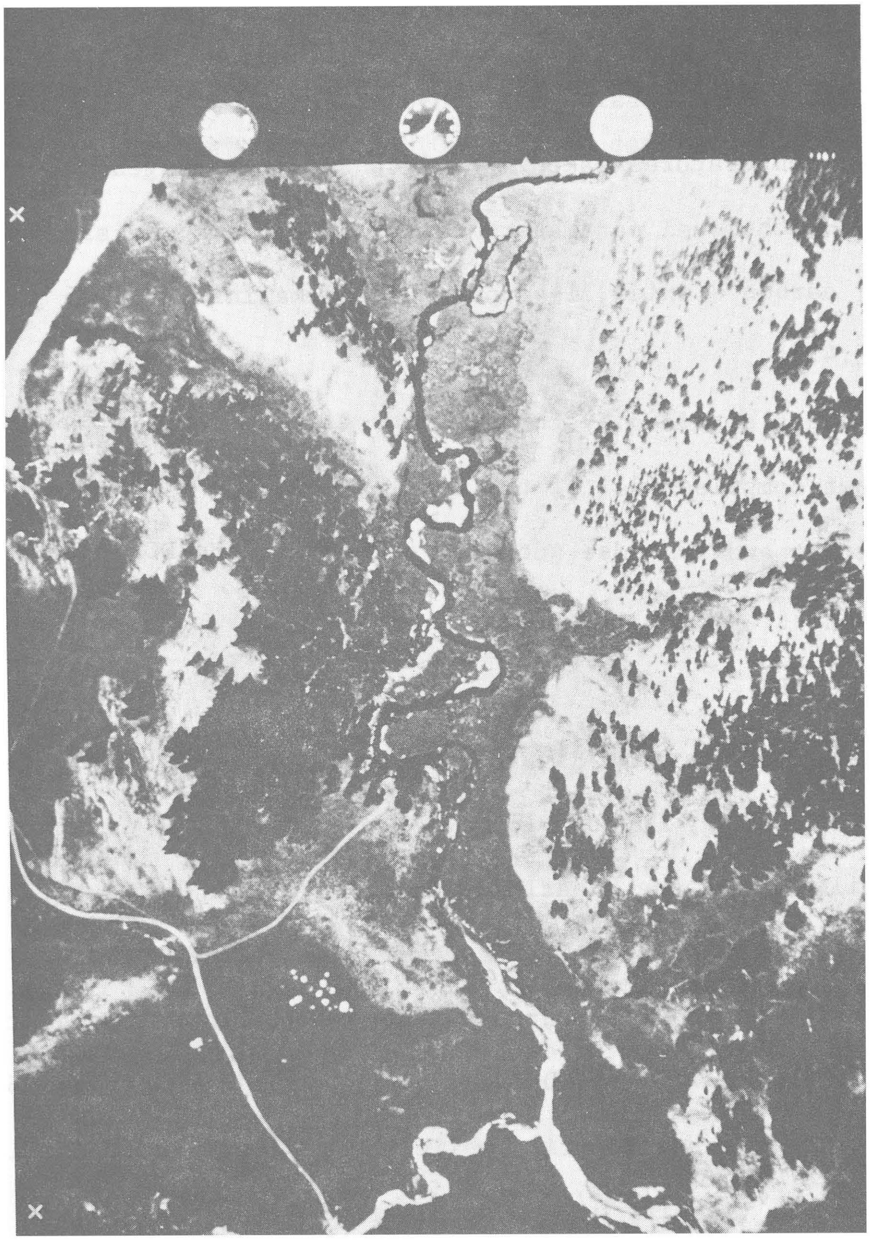


Figure 10. Aerial view of the Hog Park Creek and the adjacent land area above and below the Hog Park Creek Study Area. The confluence with the South Fork of Hog Park Creek is shown in the lower center portion of the photo. Flow is from the top to the bottom.

The upper one-quarter of the section is comprised of small backwater pools formed by numerous large boulders. Two large instream islands form a braided channel in the lower portion. Roads closely border the stream banks on both the east and west sides. Discharge records below the diversion are non-existent.

Water temperatures taken in July and August ranged between 11°C and 16.5°C. Chemical parameters ranged as follows: dissolved oxygen, 8–10 ppm; carbon dioxide, 1–4 ppm; total alkalinity, 15–25 ppm; and pH, 7.0–7.4.

From data obtained by three electrofishing days in the section, brown trout comprised 61% of the total sample and brook trout 39%. Rainbow trout and longnose suckers, present in the DC #1 area, were not found.

Laramie River

The 480 foot Laramie River study area (elevation 6,470 feet msl) is located in Albany County, 16 miles below Wheatland Reservoir No. 2, and 1.0 mile above the Wheatland Tunnel Diversion to Bluegrass Creek, in Section 35, Township 23 N, Range 72 W, (Figure 2, page 6). During the irrigation season (May through September), flows through the area normally range from 100 to 500 cfs. Discharges vary between 5 and 25 cfs from October through April, while the reservoir upstream is being filled. In the vicinity of the study area, livestock grazing and the haying of native grasses are the primary land uses. Sagebrush and grassland hills surround the stream section. During periods of high discharge, a heavy sediment load is carried, causing extreme turbidity.

September water temperatures ranged from 14.5 to 16.5°C. Chemical parameters ranged as follows: dissolved oxygen, 7-9 ppm; carbon dioxide, 0 ppm; total alkalinity, 190-195 ppm; and pH, 8.4-8.6.

Electrofishing was attempted at the area, but due to mechanical failure of the shocking units, species composition could not be determined. Many white suckers (Catostomus commersoni) were observed, however.

METHODS

Hydrologic

Primary Areas

The primary streams utilized in the investigation, Douglas Creek and Hog Park Creek, were selected because their relatively small discharges permitted instream work at the higher flow levels, and upstream dams allowed for flow regulation. Primary study areas were chosen on the basis of: 1) their representation of the total stream, 2) the presence of various water types, in regard to depth and velocity; and 3) their ease of access.

Streamflow data for Douglas Creek were obtained from U.S.G.S. records (1955-1965) and the C.B.P.U. records (1966-1971). C.B.P.U. records (1966-71) provided the discharge records for Hog Park Creek. The Water Resources Research Institute computer system was used to develop flow duration curves and stream discharge summaries. Records for Hog Park Creek were available only for the period since the reservoir was constructed; however, the flow-duration curve was compared to those for other streams in the immediate area and a close agreement was found. Drainage basin characteristics were determined from U.S.G.S. 7 1/2 minute quadrangle sheets following methods described by Linsley, Kohler, and Paulhus (1949).

The discharge levels investigated at the primary study areas are shown in Table II.

TABLE II

DISCHARGE LEVELS INVESTIGATED AT PRIMARY STUDY AREAS

Percent of Average Daily Flow		Discharge (CFS) Douglas Creek #1	Hog Park Creek
200	(2x ADF)	62.0	54.0
100	(1x ADF)	31.0	27.0
50	(1/2x ADF)	15.5	13.5
25	(1/4x ADF)	7.8	6.8
12.5	(1/8x ADF)	3.9	3.4

Work began in late June and early July, 1972, at the 200% ADF level on each stream section, and continued until the 12.5% level was reached in late September and October. Approximately one week was spent at each flow level at each study area. This pattern of flow reduction closely paralleled the natural regime.

Baselines were surveyed parallel to both banks of each 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) 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 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 stream transects were established across the study areas. Each transect was selected as being representative of a certain stream area having similar hydrologic characteristics. Sixteen such transects were selected in the 680 foot DC #1 area, while fifteen were used in the 620 foot Hog Park Creek 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. Velocity, measured with a Price current meter, was taken at 0.6 of the depth if less than 1.0 feet deep, and at 0.2 and 0.8 of the depth if greater than 1.0 feet. To determine the mean velocity and the cross-sectional area of each transect, the standard stream discharge method (Corbett, 1952), was followed. Transect profiles were plotted to determine the wetted perimeter and the hydraulic radius. For each flow level at each study area, the mean value for a parameter was obtained by averaging all transects. Using the parameter value measured at the average daily flow as 100%, percentages remaining at each flow level were determined and plotted. Ratios between the percent decrease in a hydrologic 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, ≥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 Figure 25, page 47).

The average discharge velocity through the study areas was determined by time-of-travel techniques. Red fluorescent dye was injected into the stream above the upstream end of the areas. Water samples were then taken every fifteen seconds at each end of the study areas. 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.

Six preliminary dissolved oxygen, pH, CO_2, and alkalinity measurements were taken at each flow level using a Hach Water Chemistry Kit.

Three samples were analysed from a fast-water area (velocity ≥ 1.0 fps) and three from a slow-water area (velocity <1.0 fps). Water temperatures were measured each day between 2:00 and 3:30 P.M.

Aerial infrared photographs were taken of the primary study areas by Dr. Morris Skinner of the Colorado State University Hydrology Research Center.

Secondary Areas

The secondary study areas, Douglas Creek #2 (DC #2) and the Laramie River area, were representative of stream sections which are dewatered for extensive time periods each year due to upstream diversion and reservoir storage. Lacking flow regulation, adequate time and discharge records, these areas were not monitored in the same detail as the primary areas.

Discharge levels investigated at the DC #2 area were 46, 18, 5 and 2.5 cfs. Baselines were surveyed, with stakes at five foot intervals for mapping purposes. Eight transects were selected and monitored. Dye dilution methods were employed to measure time-of-travel velocity at each flow level. Dissolved oxygen, CO_2, pH, alkalinity and water temperature were measured.

Two flow levels, 160 and 10 cfs., were observed at the Laramie River study area. Baselines were surveyed, with stakes at fifteen foot intervals, for surface mapping purposes. Four stream transects were chosen to monitor hydrologic changes. Water chemistry was measured using a Hach Kit.

The results obtained at the secondary study areas are presented in Appendix B.

Trout Cover Analysis

Trout populations were sampled at the DC #1 and HPC study areas at the 100%, 50%, 25%, and 12.5% ADF discharge levels to determine the stream areas used for cover. Sampling was done by electrofishing using Tiny Tiger Backpack shocking units. Due to equipment failure, only two-thirds of the HPC area was sampled at the 12.5% ADF level.

For each trout captured, the following information was recorded: 1) the water depth measured to the nearest 0.05 feet; 2) the water velocity at the point location used for cover (determined using a Stevens Midget Current Meter); and, 3) the type and location of cover. Two cover types were present, undercut banks and instream rubble-boulder areas. Depths were measured at the outer edge of all undercut banks. The widths of all undercut banks were measured to the nearest 0.05 feet. At each flow level, the location, depths, widths, and lengths of potential cover were recorded. Potential cover refers to all undercut banks and rubble-boulder areas in a section, regardless of whether or not any fish were captured at a given location.

Captured fish were anesthetized with MS-222 (Tricaine Methanesulfonate) and measured (total length) to the nearest 0.1 inch. All trout were fin-clipped during the first three sampling periods for mark-recapture population estimates and held in live cars until the sampling for that day was completed. Estimates were made using the Schnabel Method.

RESULTS

Hydrologic Parameters

The values obtained for the hydrologic parameters investigated at individual transects in the DC #1 and HPC study areas are summarized in Tables A-I and A-II, pages 78 and 82, Appendix A. Mean transect values for each parameter at each flow level and time-of-travel velocities, expressed as a percentage of the value obtained at 100% of the average daily flow (ADF), are summarized in Tables III and IV, and plotted on Figures 11 to 16. Time-of-travel velocities are presented because they are more representative of the velocity in the whole section than would be the average of transect values.

Consistent with the findings of Kraft (1968), the parameter most severely reduced by flow reductions at both study areas was velocity. At DC #1, velocity decreased from 1.81 fps at 100% ADF to 0.44 fps at low flow, a 75.7% reduction. For the HPC area, over the same dewatering range, the decrease was from 1.08 fps to 0.36 fps, a 66.6% reduction. Time-of-travel velocity changes are shown in Figure 16.

Mean transect cross-sectional area realized the second greatest reduction over the dewatering range of 100% to 12.5% ADF. DC #1 and HPC evidenced decreases of 55.9% and 47.5%, respectively (Figure 11). Mean transect depth and hydraulic radius decreased together, the former being reduced 39.0% at DC #1 from the 100% ADF level and 35.9% at HPC

TABLE III

PHYSICAL PARAMETERS OF DOUGLAS CREEK #1 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)	Cross Section Area	Top Width	Depth	Wetted Perimeter	Hydraulic Radius	Time-of-Travel Velocity	Total Surface Area	Surface Area Velocity ≥1.0 fps	Surface Area Depth ≥0.5'	Cover Brown Trout ≥6"	Cover Brown Trout <6"
200%	140.7%	114.0%	124.6%	110.5%	128.1%	135.4%	115.6%	126.0%	132.6%	-	-
	(0.407)	(0.140)	(0.246)	(0.105)	(0.281)	(0.354)	(0.156)	(0.260)	(0.326)	-	-
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	(0.535)	(0.135)	(0.434)	(0.189)	(0.376)	(0.718)	(0.156)	(0.694)	(0.502)	(0.320)	(0.376)
50%	73.3%	93.3%	78.3%	90.6%	81.2%	64.1%	92.2%	65.3%	74.9%	84.0%	81.2%
	(0.444)	(0.284)	(0.234)	(0.310)	(0.229)	(0.597)	(0.246)	(0.848)	(0.476)	(0.720)	(0.664)
25%	62.2%	86.2%	72.4%	82.8%	75.5%	49.2%	86.1%	44.1%	63.0%	66.0%	64.6%
	(1.446)	(1.200)	(0.914)	(1.104)	(0.993)	(1.989)	(1.650)	(2.152)	(1.696)	(0.800)	(1.168)
12.5%	44.1%	71.2%	61.0%	69.0%	63.1%	24.3%	65.4%	17.2%	41.8%	56.0%	50.0%

TABLE IV

PHYSICAL PARAMETERS OF HOG PARK 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)	Cross Section Area	Top Width	Depth	Wetted Perimeter	Hydraulic Radius	Time-of-Travel Velocity	Total Surface Area	Surface Area Velocity ≥1.0 fps	Surface Area Depth ≥0.5'	Cover Brown Trout ≥6"	Cover Brown Trout <6"
200%	134.9%	103.0%	131.2%	104.7%	129.0%	195.8%	111.9%	138.3%	125.7%	-	-
	(0.349)	(0.030)	(0.312)	(0.047)	(0.290)	(0.958)	(0.119)	(0.383)	(0.257)	-	-
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	(0.411)	(0.105)	(0.326)	(0.112)	(0.318)	(0.301)	(0.213)	(0.590)	(0.428)	(0.302)	(0.282)
50%	79.4%	94.7%	83.7%	94.4%	84.1%	84.9%	89.4%	70.5%	78.6%	84.9%	85.9%
	(0.650)	(0.278)	(0.462)	(0.351)	(0.419)	(0.831)	(0.410)	(1.196)	(0.600)	(0.516)	(0.560)
25%	63.2%	87.8%	72.2%	85.6%	73.6%	64.2%	79.1%	40.6%	63.6%	72.0%	71.9%
	(0.856)	(0.584)	(0.646)	(0.569)	(0.635)	(2.460)	(1.424)	(2.224)	(1.896)	(0.768)	(1.000)
12.5%*	52.5%	80.9%	64.1%	78.5%	65.7%	33.4%	61.3%	12.8%	39.9%	62.4%	59.4%
12.5%**							49.9%	12.8%	29.3%	46.2%	45.3%
							(2.335)	(2.224)	(2.744)	(2.064)	(2.128)

* = Including isolated beaver pond channel

** = Excluding isolated beaver pond channel

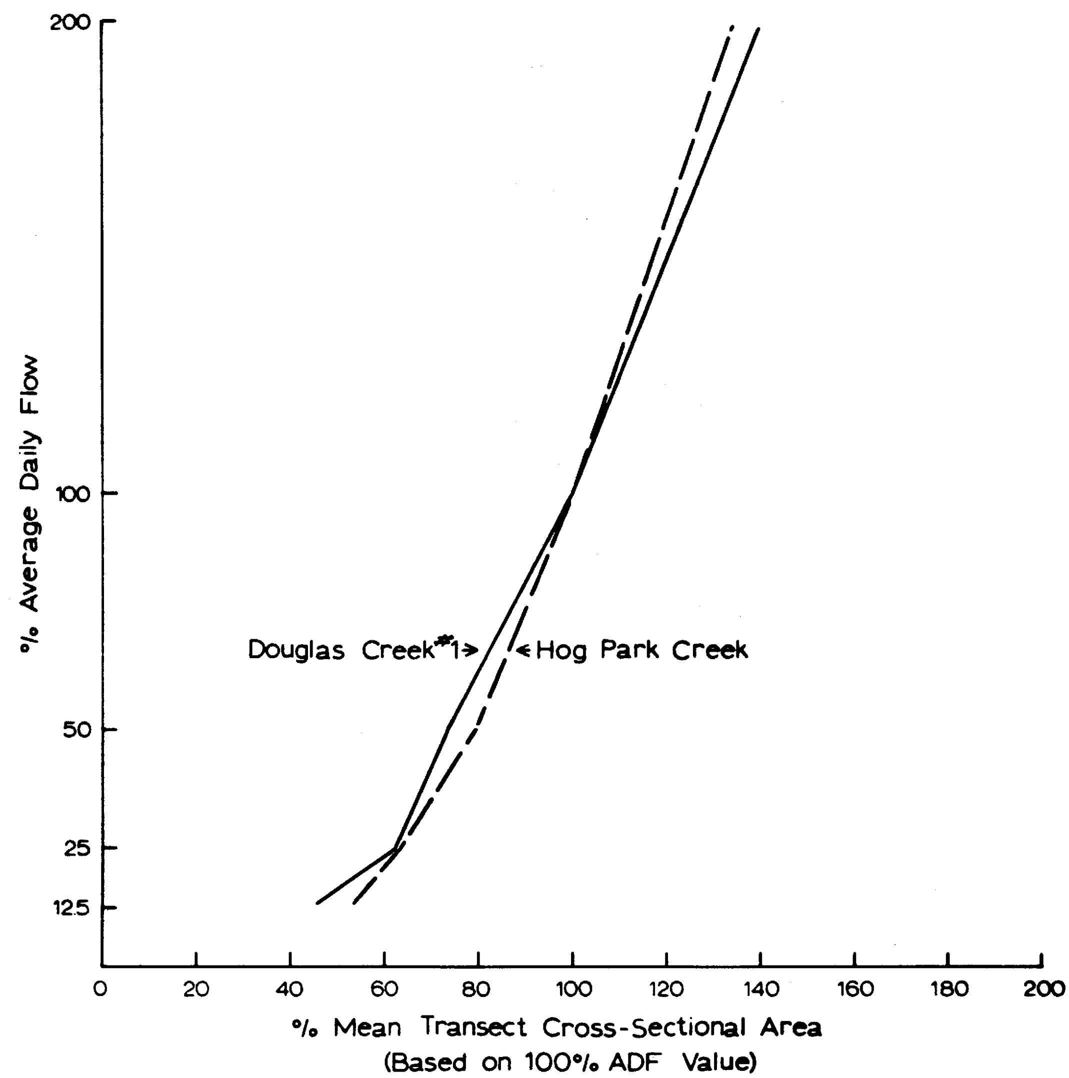


Figure 11. Changes observed in the mean transect cross-sectional area as flow was reduced at the Douglas Creek No. 1 and Hog Park Creek study areas, expressed as a percentage of the parameter value at 100% of the average daily flow.

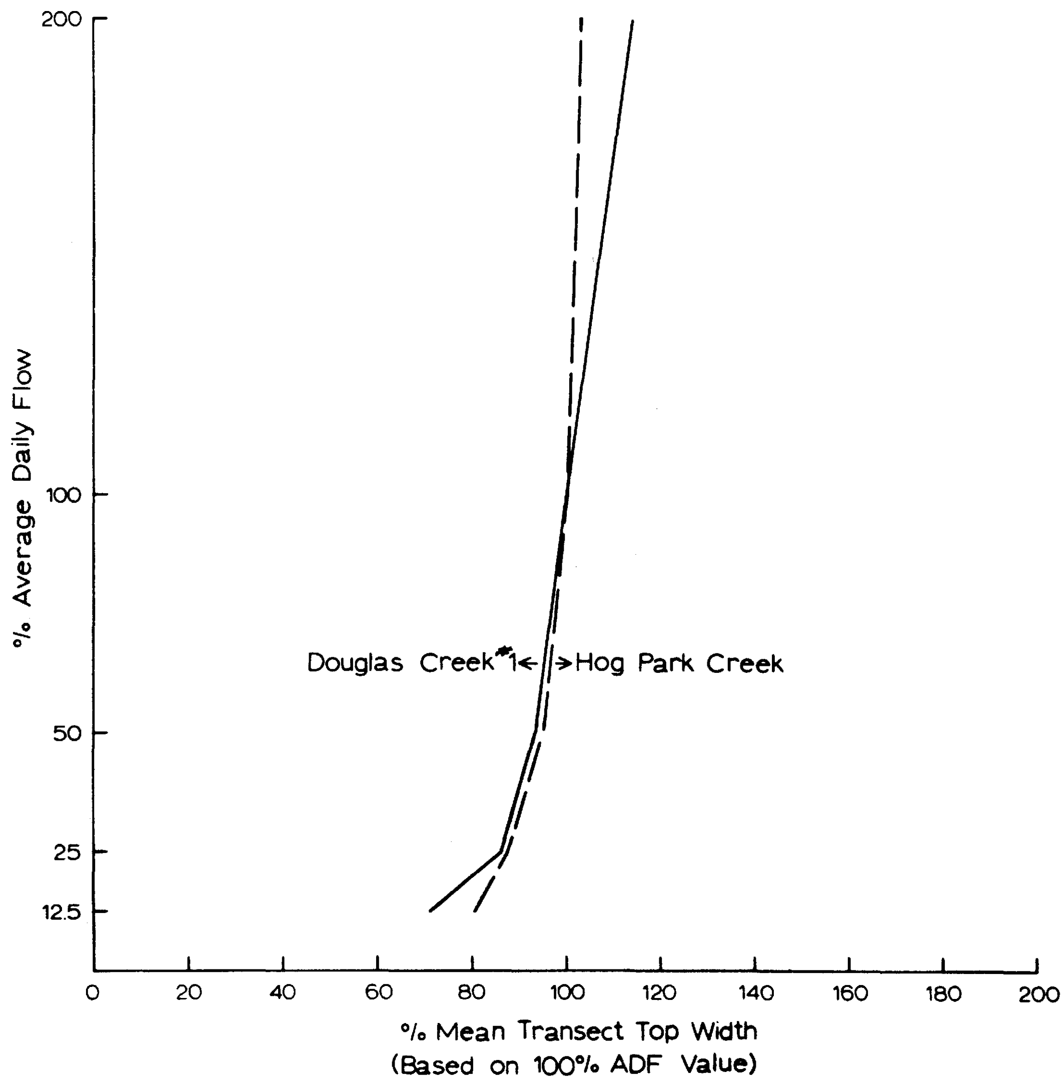


Figure 12. Changes observed in the mean transect top width as flow was reduced at the Douglas Creek No. 1 and Hog Park Creek study areas, expressed as a percentage of the parameter value at 100% of the average daily flow.

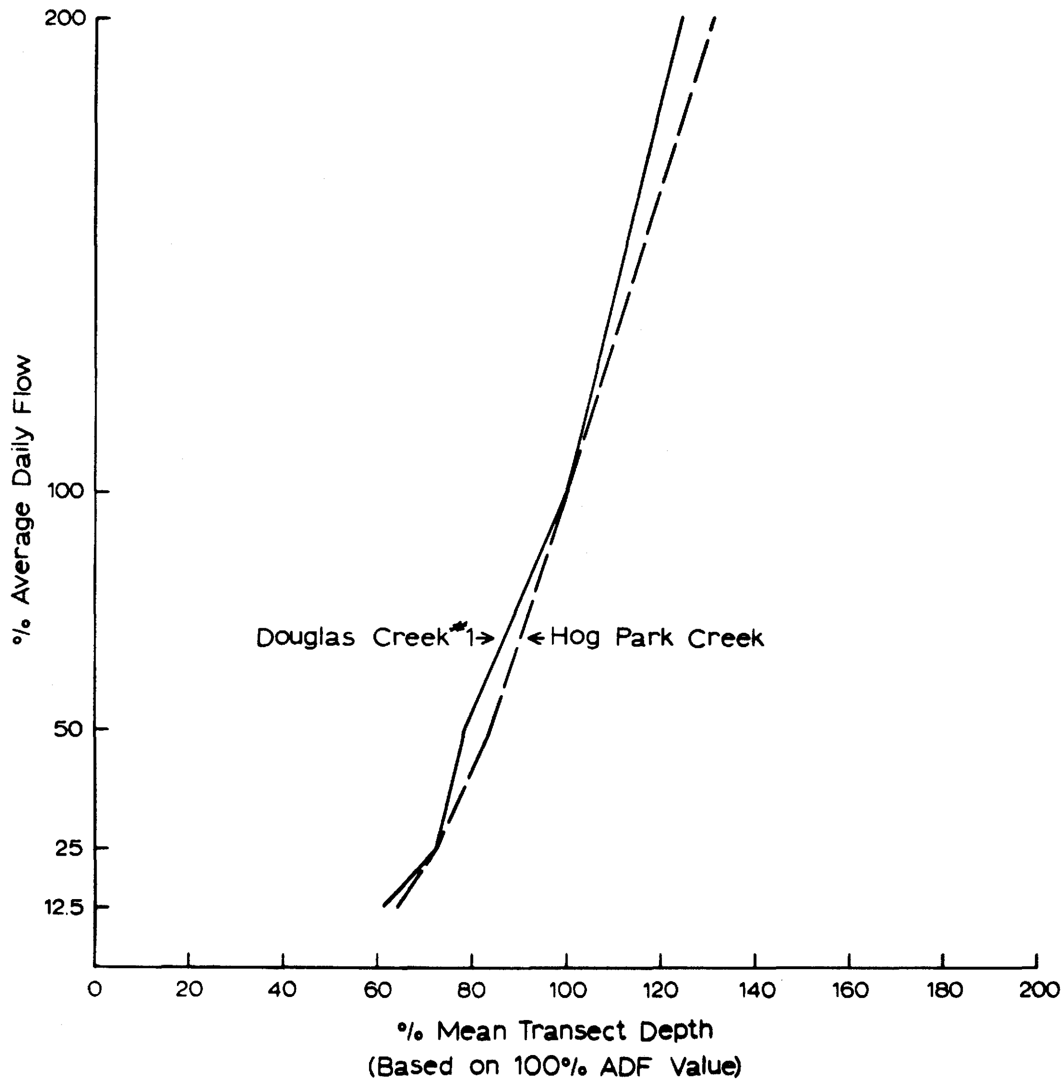


Figure 13. Changes observed in the mean transect depth as flow was reduced at the Douglas Creek No. 1 and Hog Park Creek study areas, expressed as a percentage of the parameter value at 100% of the average daily flow.

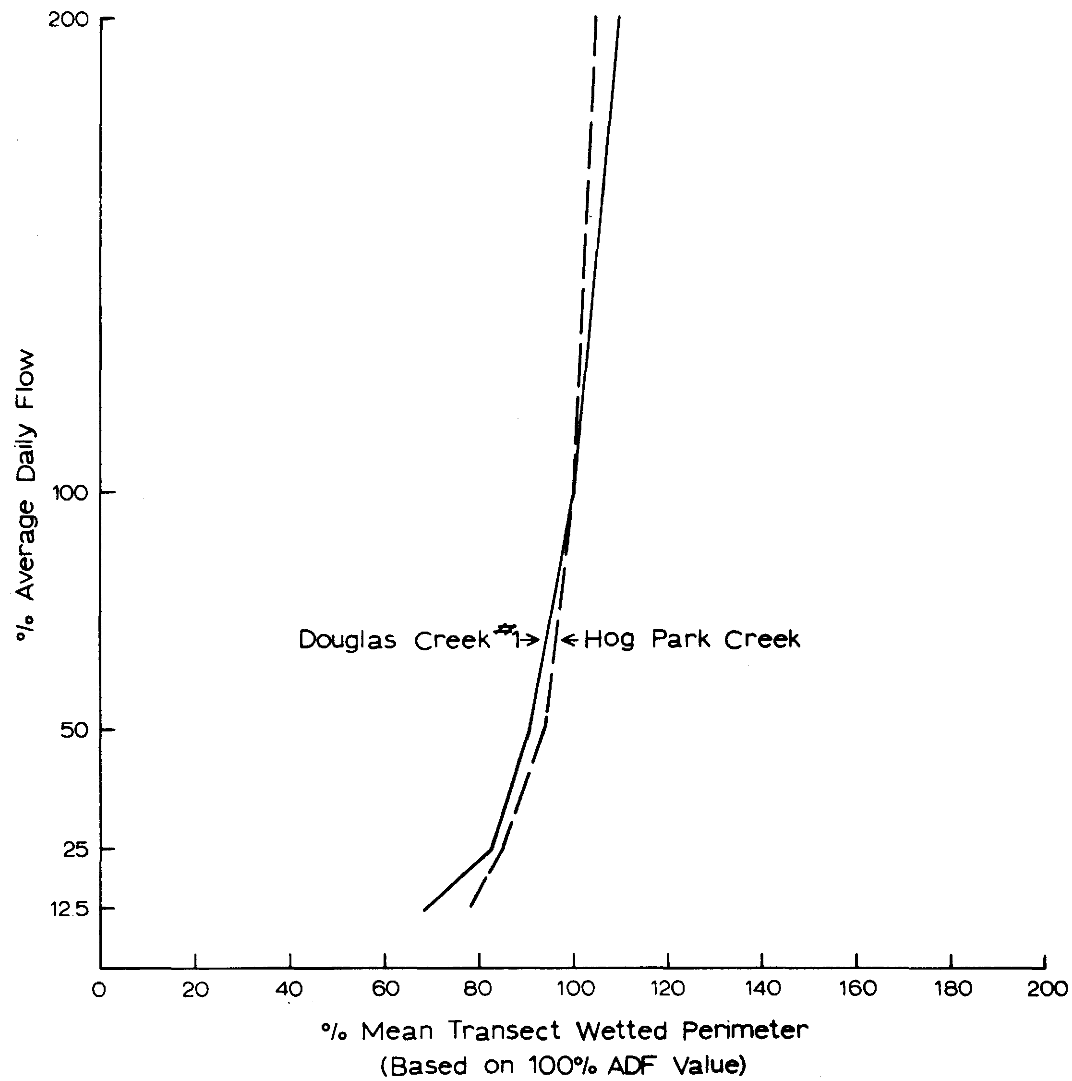


Figure 14. Changes observed in the mean transect wetted perimeter as flow was reduced at the Douglas Creek No. 1 and Hog Park Creek study areas, expressed as a percentage of the parameter value at 100% of the average daily flow.

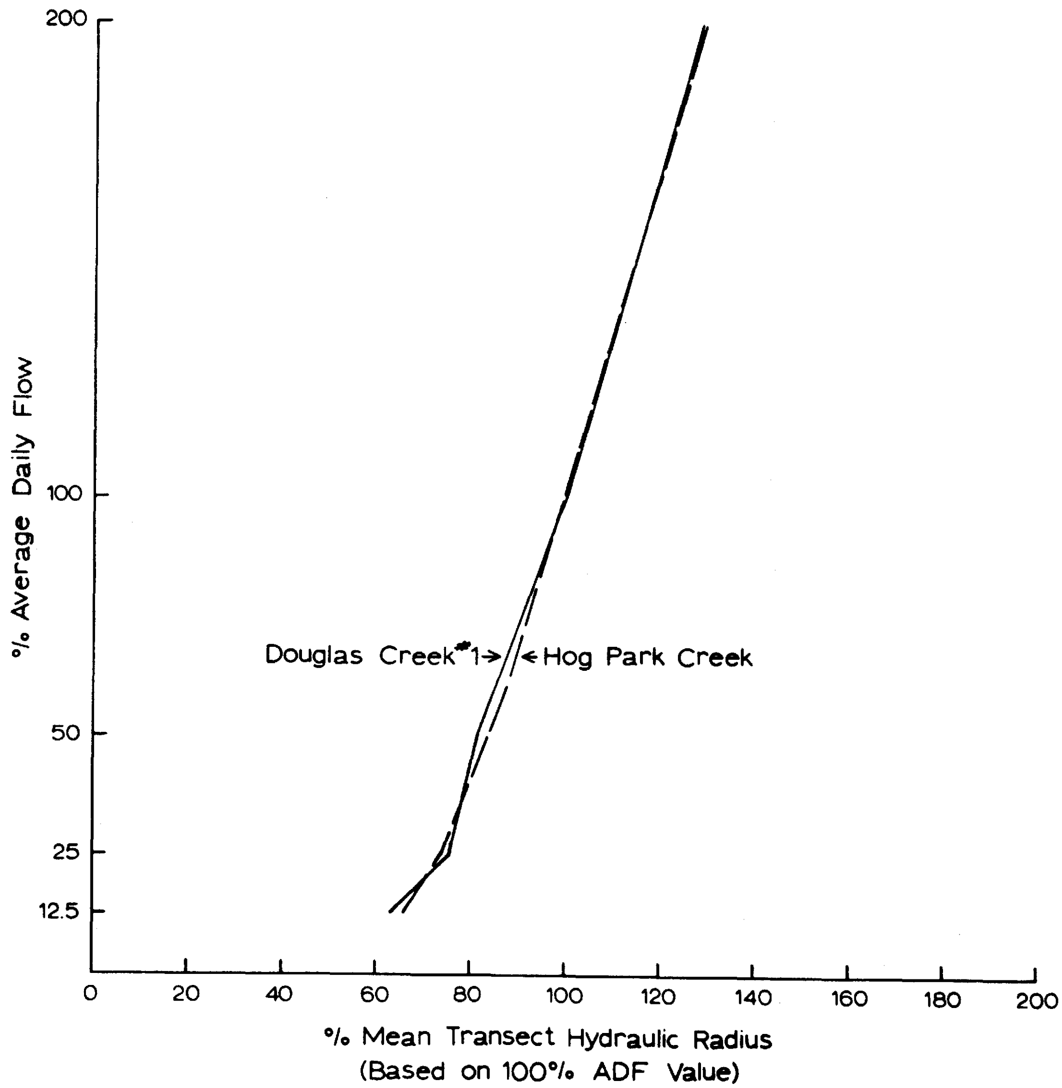


Figure 15. Changes observed in the mean transect hydraulic radius as flow was reduced at the Douglas Creek No. 1 and Hog Park Creek study areas, expressed as a percentage of the parameter value at 100% of the average daily flow.

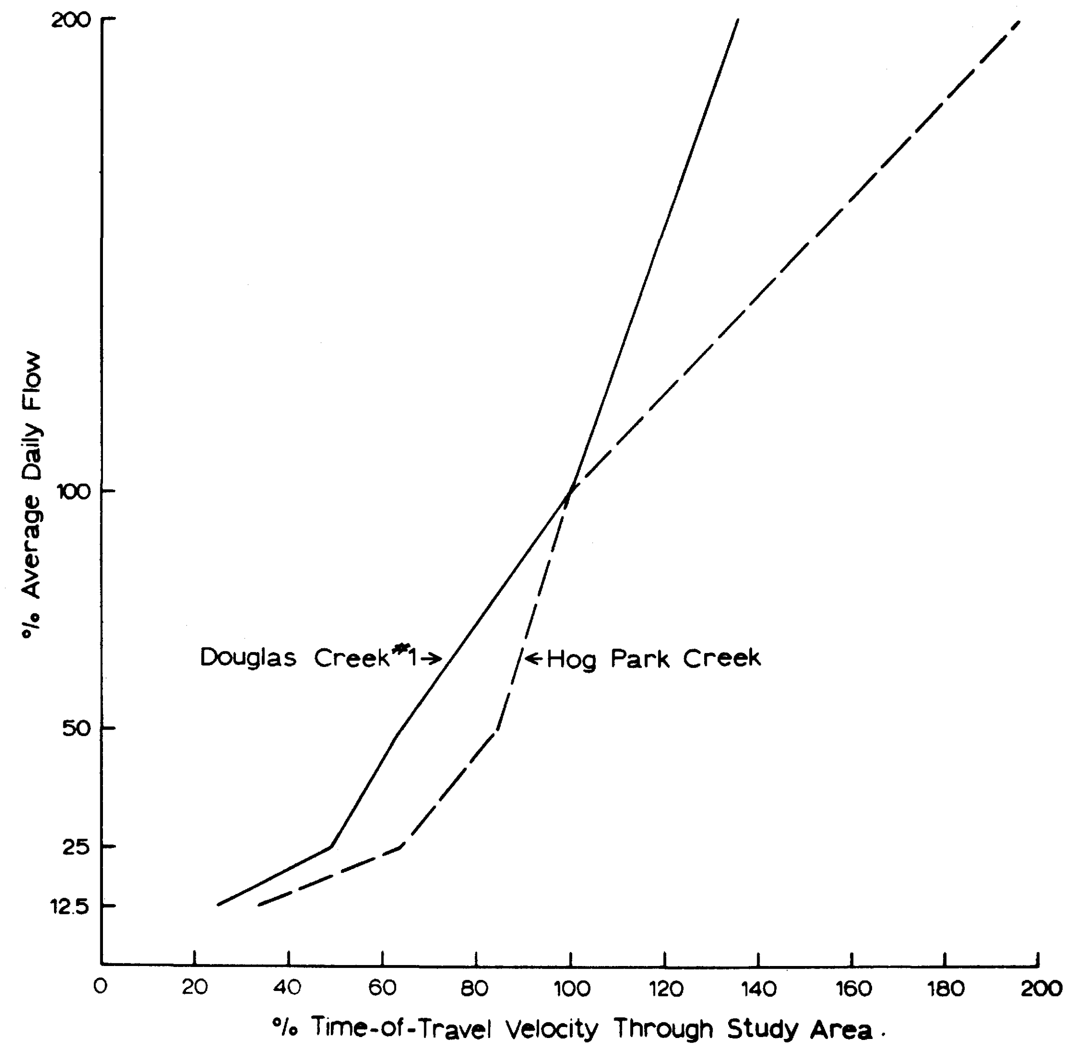


Figure 16. Changes observed in the time-of-travel velocity as flow was reduced at the Douglas Creek No. 1 and Hog Park Creek study areas, expressed as a percentage of the parameter value at 100% of the average daily flow.

(Figure 13, page 33) while the latter decreased 36.9% at DC #1 and 34.3% at HPC (Figure 15, page 35). Least affected by dewatering was mean transect top width, which was reduced only 19.1% at DC #1 and 28.8% at HPC (Figure 12, page 32).

Figures 17 and 18 illustrate the transect changes observed as the flow was reduced.

Hydrologic parameters were not reduced at a constant rate between discharge levels. The ratios between the percent change in a given parameter and the corresponding percent change in flow are given in Tables III and IV, pages 29 and 30. For all parameters at each study area, the greatest decrease for a percentage-point flow reduction occurred for the interval between 25% and 12.5% ADF.

Effective Surface Area and Water-Type Classification

Effective surface area reductions were similar for both primary study sections (Figure 19). As flow dropped from 200% to 25% ADF, a 29.5% reduction (4,874 sq. ft.) was observed at DC #1. An additional 3,407 sq. ft. were lost in the final reduction, leaving 65.4% of the surface area present, based on the 100% ADF value of 16,513 sq. ft. For HPC, a 32.8% reduction was realized as flow decreased from 200% to 25% ADF. At low flow, the beaver pond channel was inaccessible to trout from the main channel. If the isolation of the beaver pond is considered a loss of effective surface area at 12.5% ADF, only 10,280 sq. ft. remained, 49.9% of the 100% ADF surface area. Including the beaver pond channel as effective surface area, even though inaccessible, 12,622 sq. ft. remained at low flow, 61.3% of the 100% ADF total.

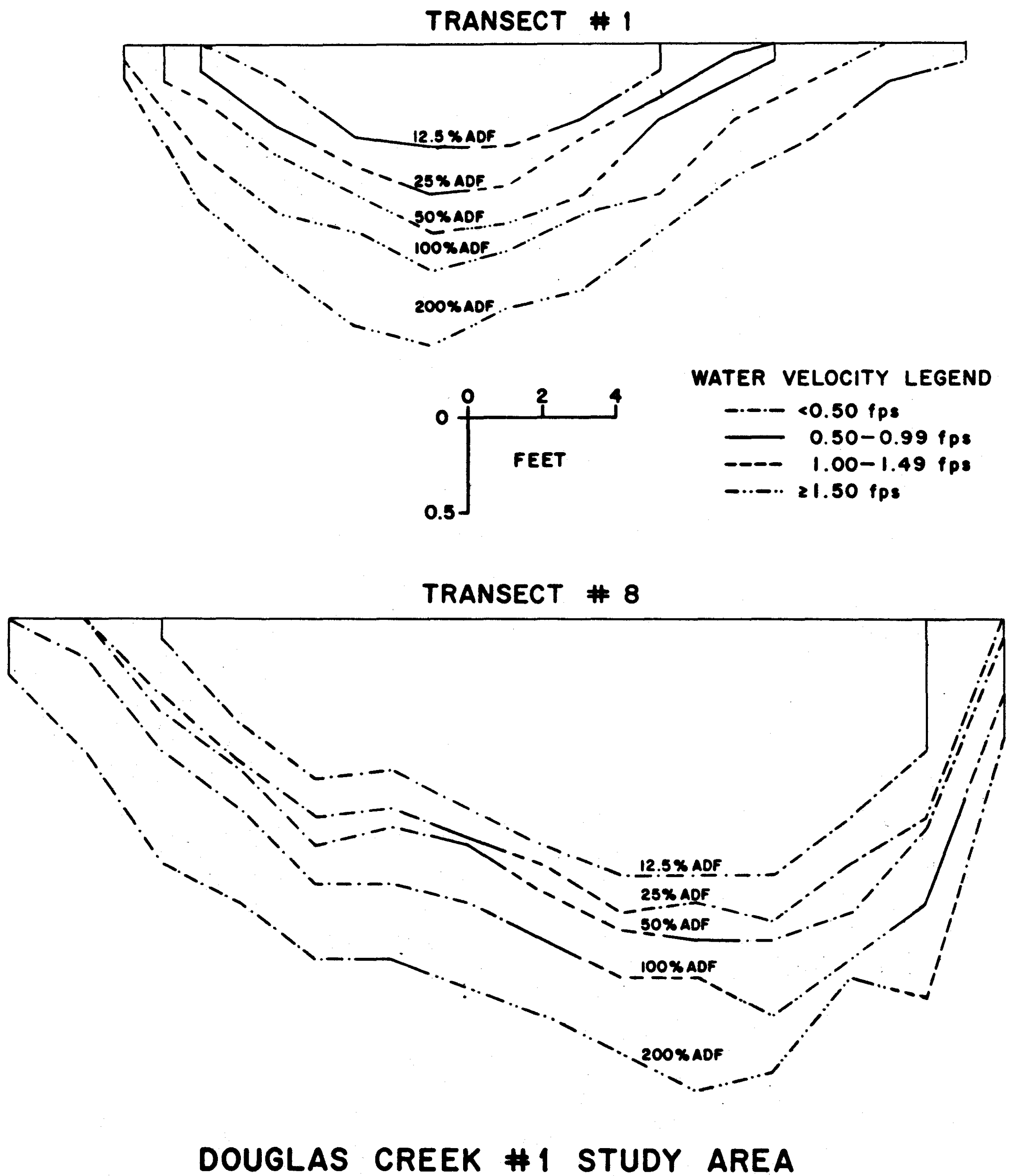
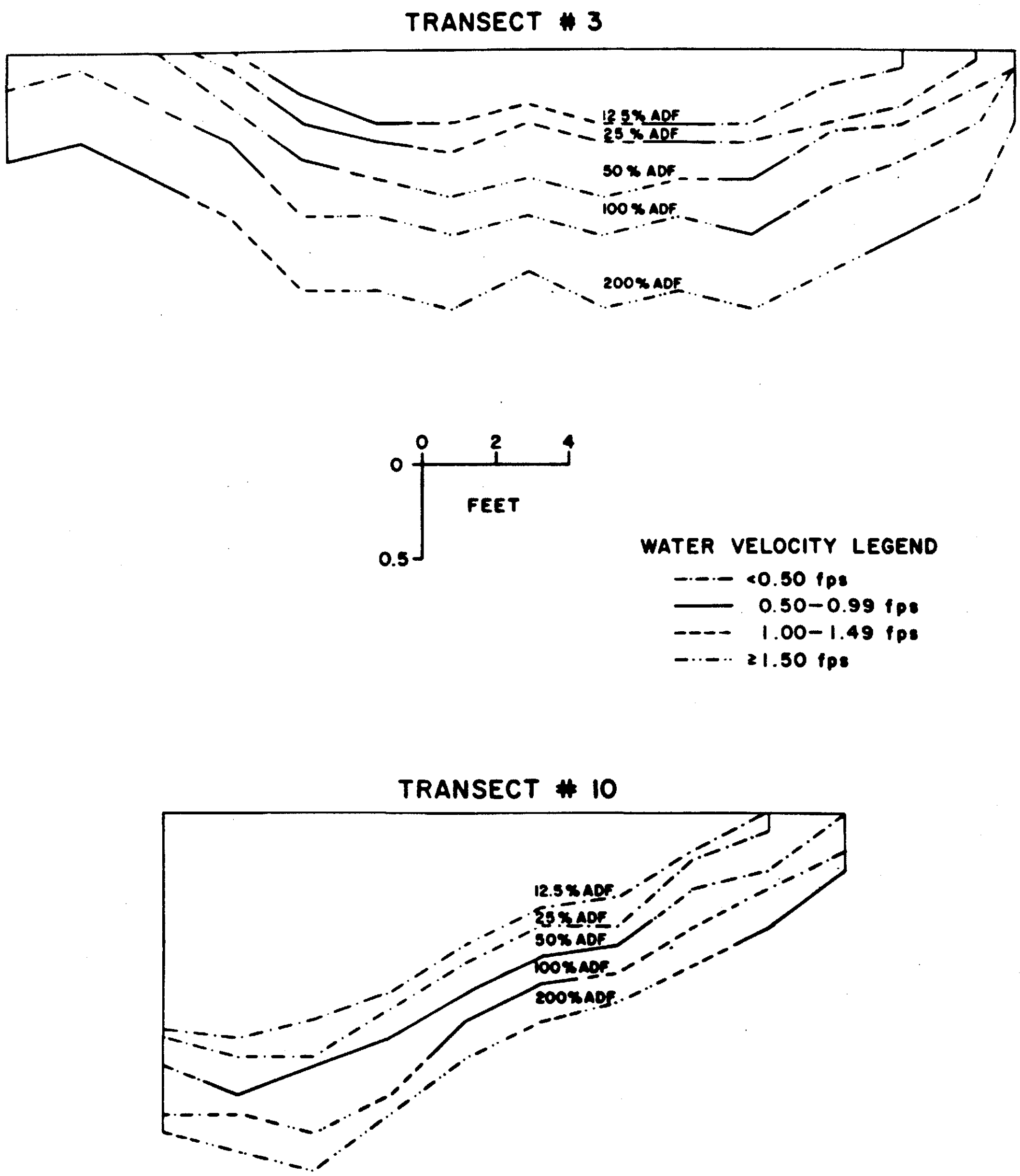


Figure 17. Douglas Creek No. 1 transect profiles illustrating physical changes which occurred as the flow was reduced from 200% to 12.5% of the average daily flow.



HOG PARK CREEK STUDY AREA

Figure 18. Hog Park Creek transect profiles illustrating physical changes which occurred as the flow was reduced from 200% to 12.5% of the average daily flow.

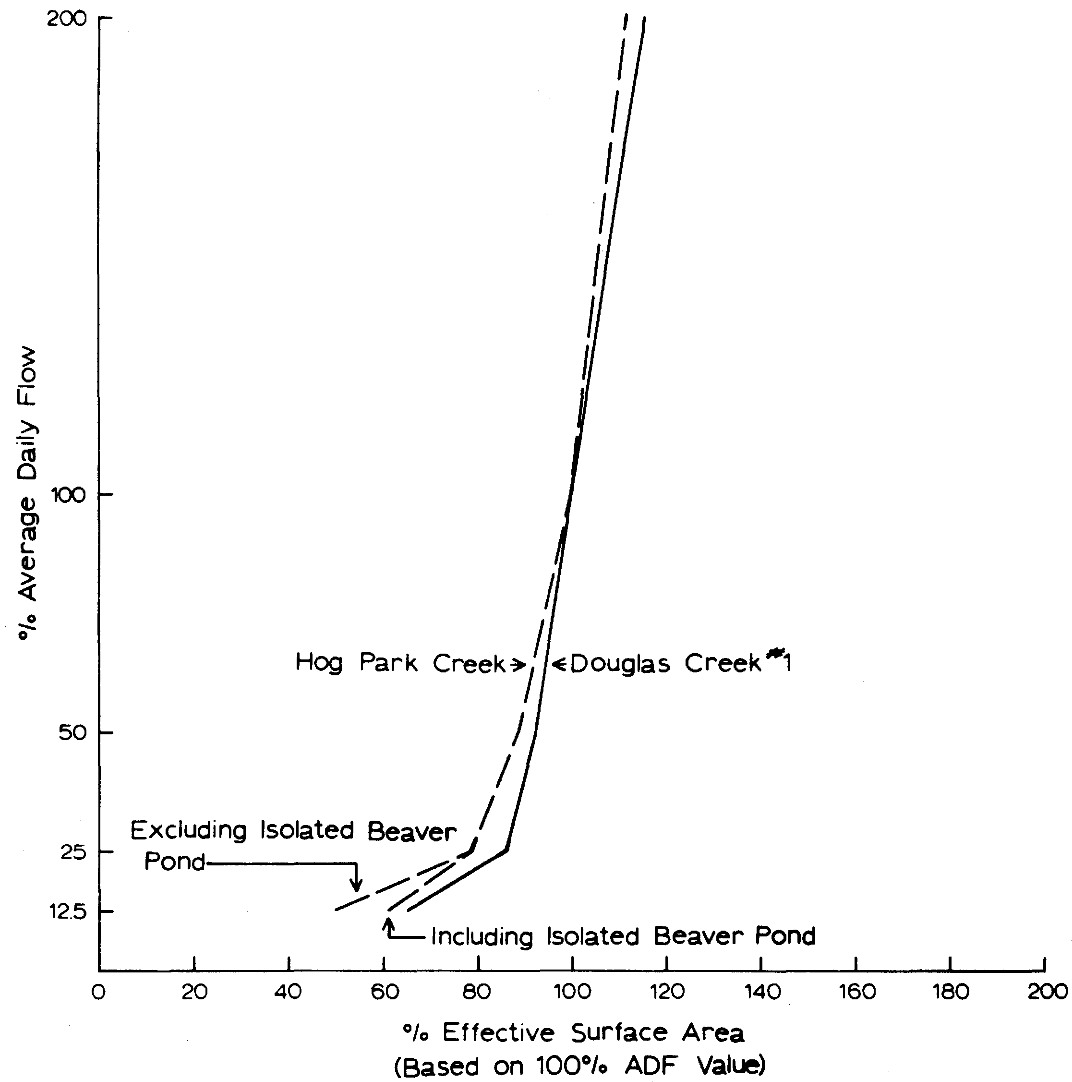


Figure 19. Changes observed in the effective (total) surface area as flow was reduced at the Douglas Creek No. 1 and Hog Park Creek study areas, expressed as a percentage of the value at 100% of the average daily flow.

Considering the ratios of the percent decrease of effective surface area and the percent flow decrease, the greatest reduction was observed for the interval 25% to 12.5% ADF, as shown in Tables III and IV, pages 29 and 30. For the DC #1 area, the rate of surface area reduction was from 8 to 10 times greater for the 25% to 12.5% ADF interval than for any other interval. The impact of discharge reductions on effective surface area are shown on Figures 20 and 21, comparing the 100%, 25%, and 12.5% ADF levels. Figures 22, 23, and 24, illustrate habitat changes and reductions.

The breakdown of the total effective surface area for each flow level into a sixteen category water-type system are shown on Figures 25 to 34. Considering all water depths having a velocity of 1.0 fps or greater for DC #1, at 200% ADF, 68.4% of the effective surface area (19,087 sq. ft.) fell into this category. At the 100% ADF level, 62.8% of the habitat met the 1.0 fps criteria. For the 50% and 25% ADF levels, the percentages were 44.5% and 32.2% respectively. Only 16.5% of the surface area present had maintained a water velocity of 1.0 fps or greater at low flow. For HPC, the percentage of the total surface area at each flow level of at least 1.0 fps, from 200% down to a low flow of 12.5% ADF, were the following: 52.2%, 42.3%, 33.3%, 21.7%, and 8.9%, respectively. The expression of these values as a percentage of that present at 100% ADF is illustrated in Figure 35. Again, the greatest reduction rate in such fast-water areas for a 1.0% flow reduction occurred for the interval 25% to 12.5% ADF, as shown on Tables III and IV, pages 29 and 30.

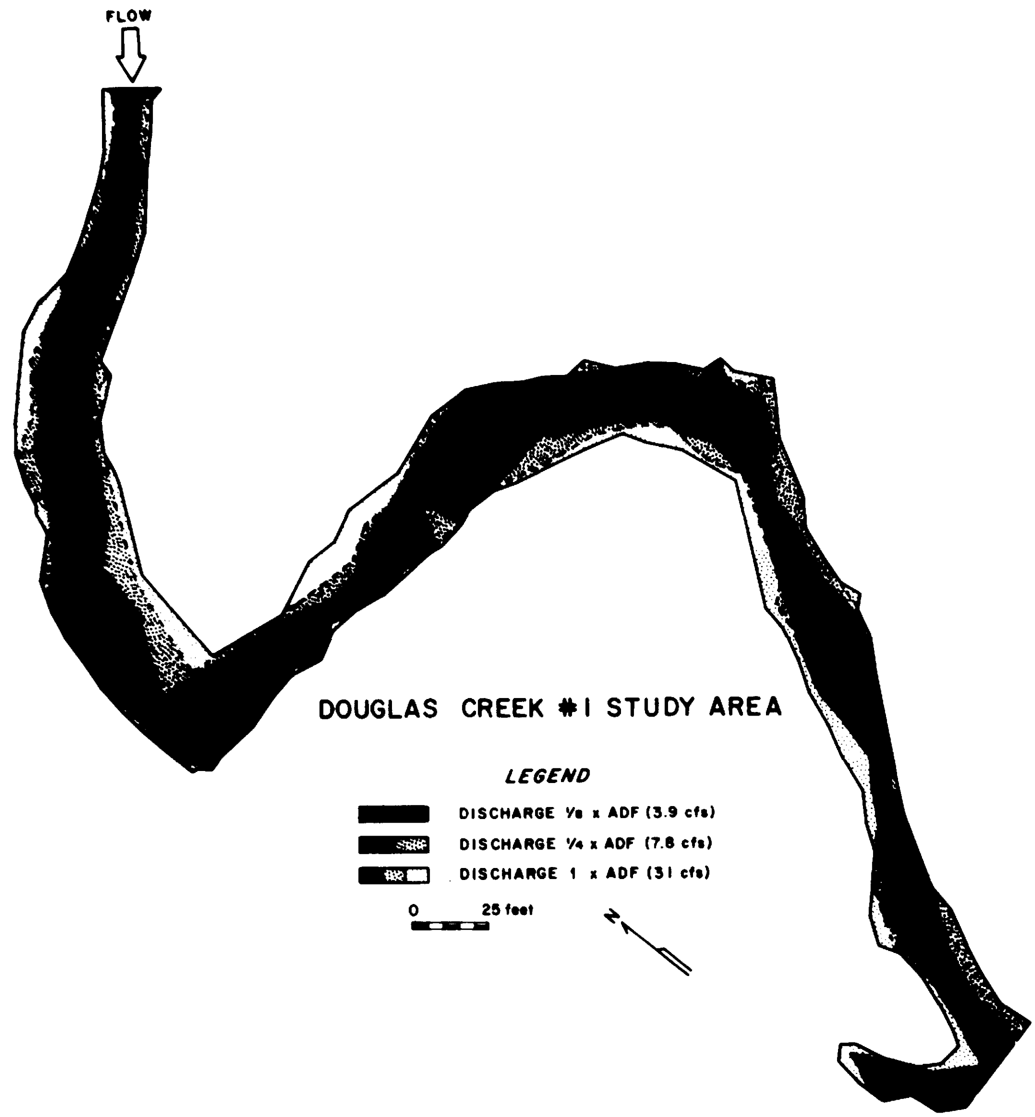


Figure 20. Map of the Douglas Creek No. 1 Study Area comparing the relative surface areas at 100%, 25% and 12.5% of the average daily flow.

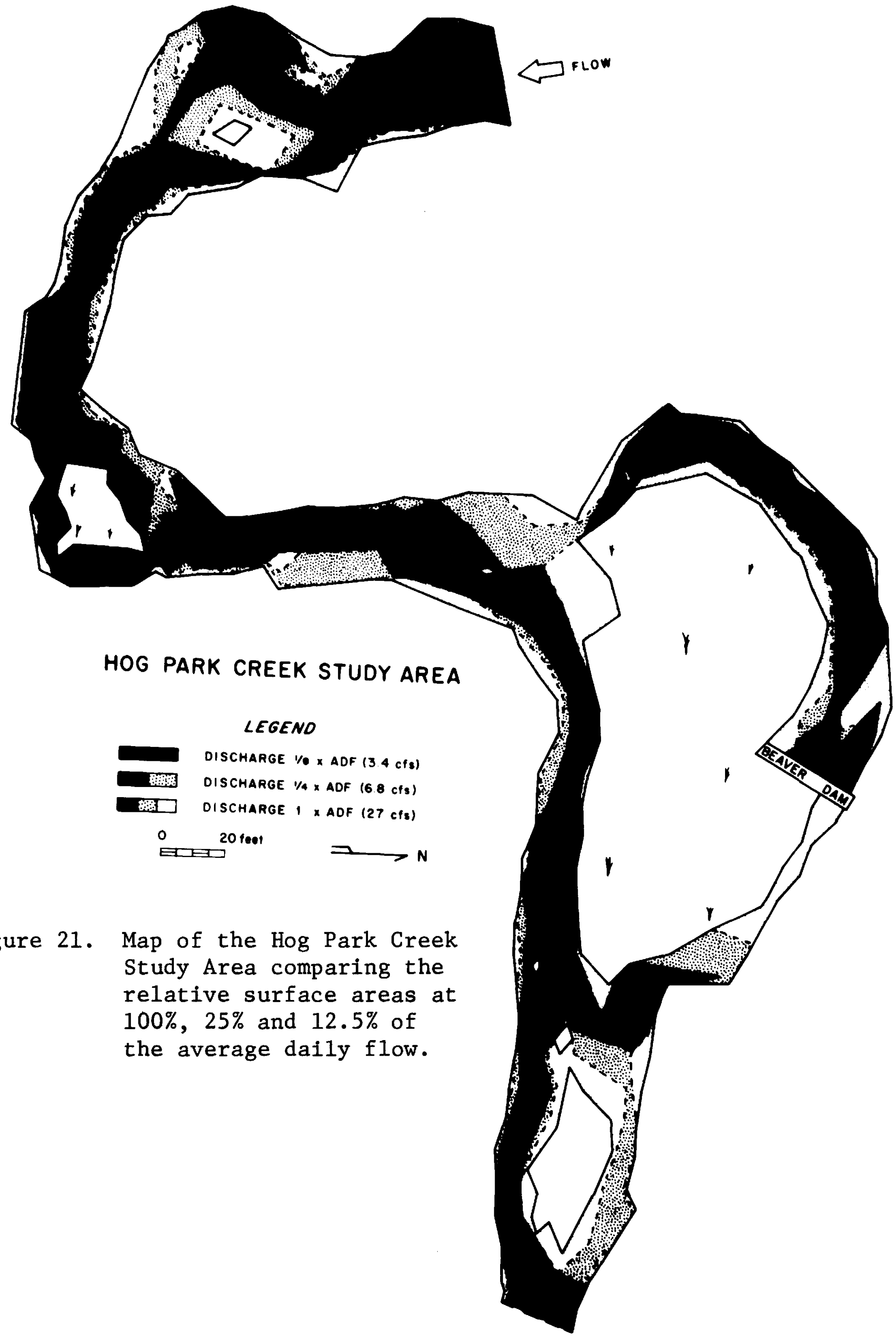
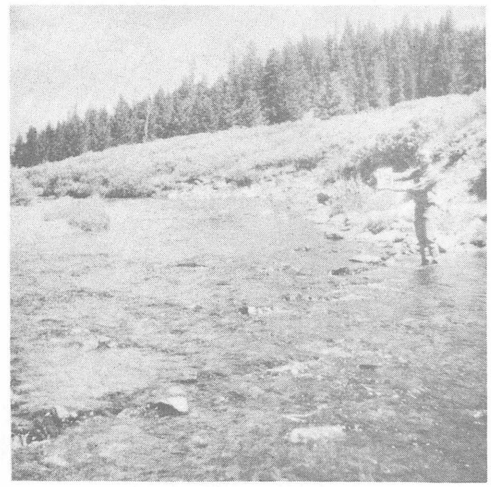


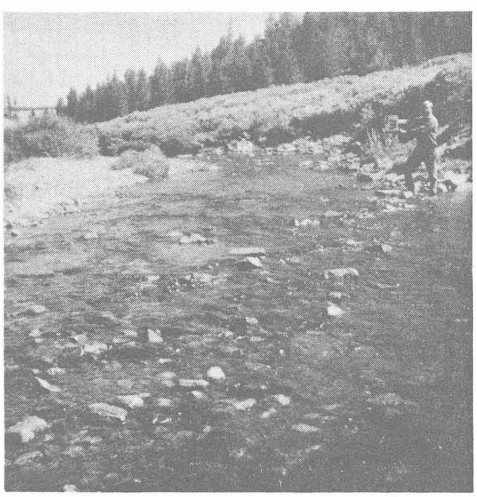
Figure 21. Map of the Hog Park Creek Study Area comparing the relative surface areas at 100%, 25% and 12.5% of the average daily flow.

100% ADF (31.0 cfs)

50% ADF (15.5 cfs)



25% ADF (7.8 cfs)



12.5% ADF (3.9 cfs)

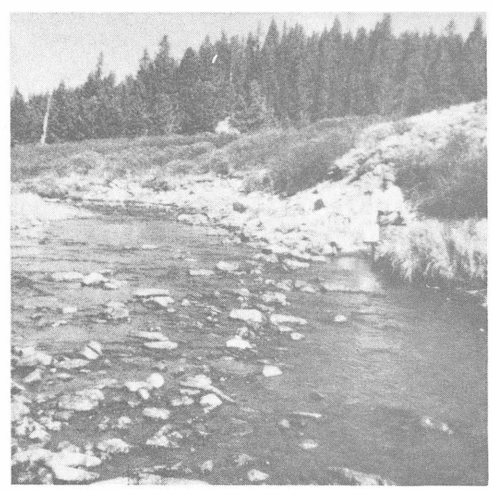
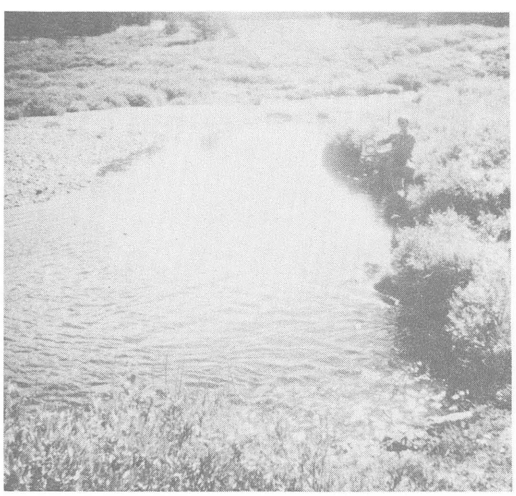


Figure 22. Transect No. 13 in the Douglas Creek No. 1 Study Area at 100%, 50%, 25% and 12.5% of the average daily flows, looking upstream.

100% ADF (31.0 cfs)

50% ADF (15.5 cfs)

25% ADF (7.8 cfs)



12.5% ADF (3.9 cfs)

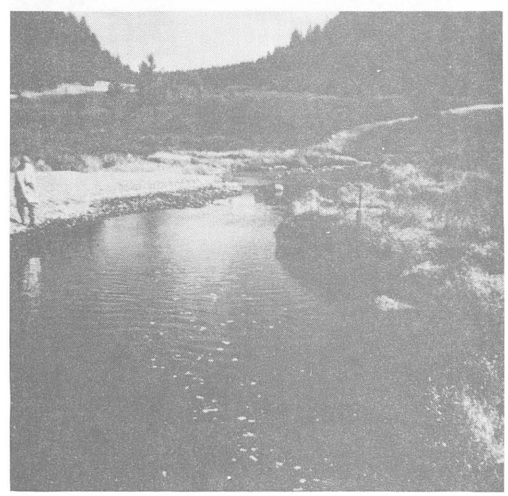
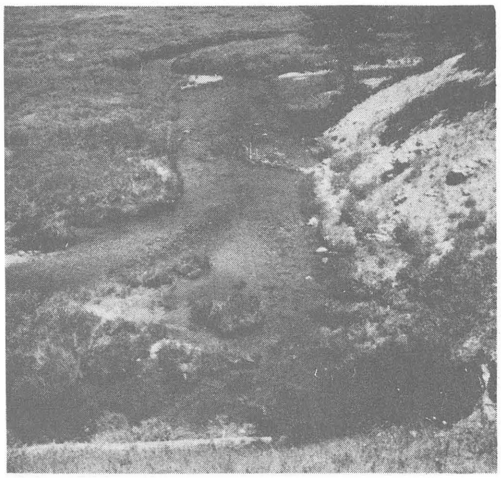


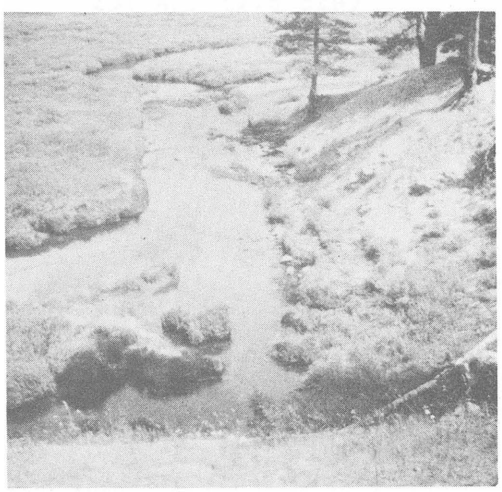
Figure 23. Transect No. 8 in the Douglas Creek No. 1 Study Area at 100%, 50%, 25% and 12.5% of the average daily flow, looking downstream.

100% ADF (27.0 cfs)



50% ADF (13.5 cfs)

25% ADF (6.8 cfs)



12.5% ADF (3.4 cfs)

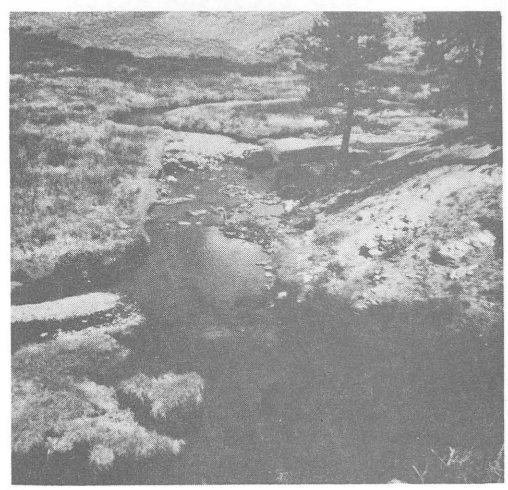


Figure 24. Middle section of the Hog Park Creek Study Area at 100%, 50%, 25%, 12.5% of the average daily flow, looking downstream. The entrance to the beaver pond channel (upper center of each photo) is gradually dewatered, until at low flow, the channel is isolated.

SURFACE AREA (ft^2) BY WATER DEPTH-VELOCITY CLASS

(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50-0.99	1.0-1.49	≥1.50	ROW TOTAL
<0.50	1529 (8.0%)	434 (2.2%)	267 (1.4%)	872 (4.6%)	3102 (16.2%)
0.50-0.99	1158 (6.0%)	939 (4.9%)	779 (4.2%)	3691 (19.3%)	6567 (34.4%)
1.0-1.49	530 (2.8%)	397 (2.1%)	554 (2.9%)	3443 (18.0%)	4924 (25.8%)
≥1.50	621 (3.3%)	420 (2.3%)	503 (2.5%)	2952 (15.5%)	4496 (23.6%)
COLUMN TOTAL	3838 (20.1%)	2190 (11.5%)	2103 (11.0%)	10958 (57.4%)	19089 → TOTAL SURFACE AREA (100%)

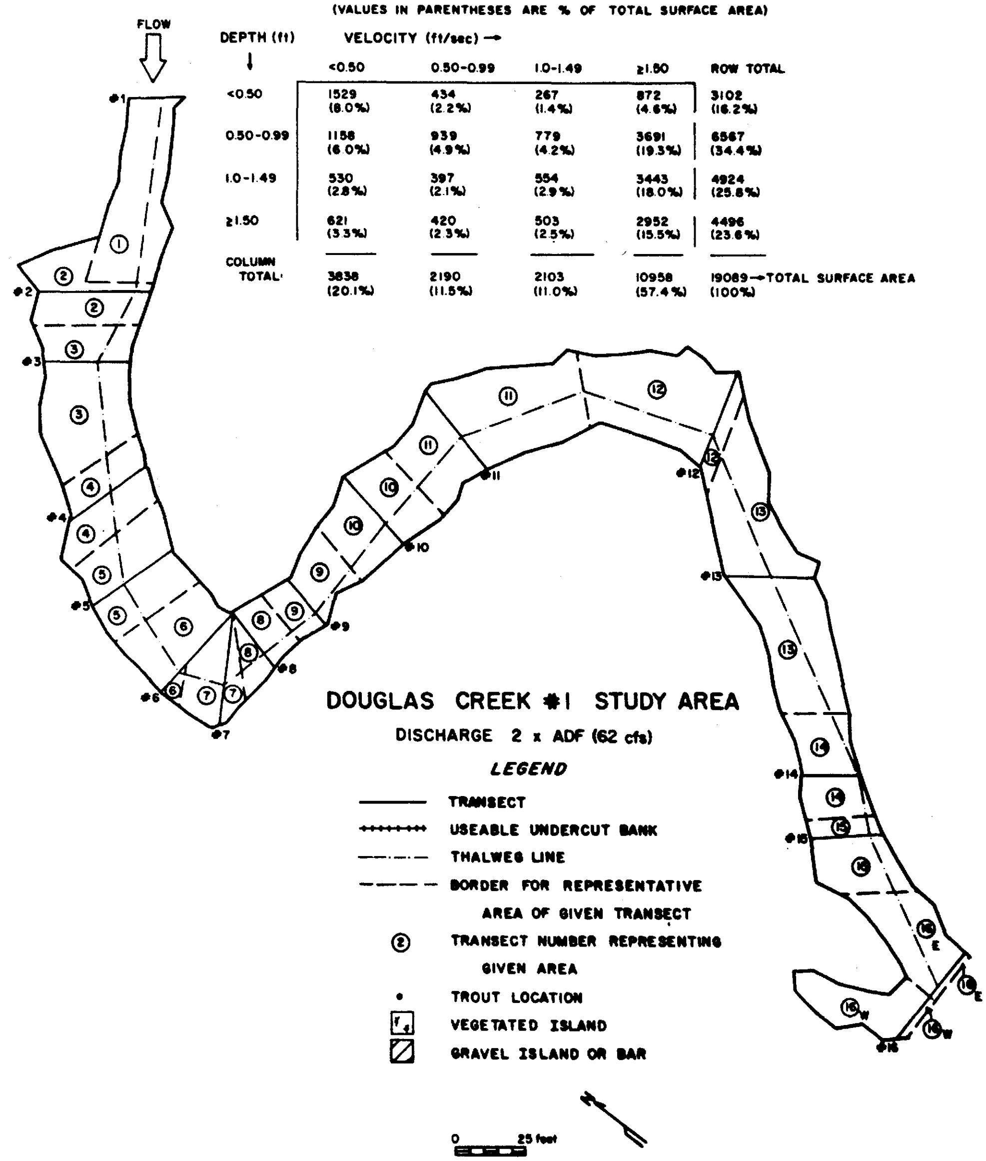


Figure 25. Surface area map and water depth-velocity classification of the Douglas Creek No. 1 study area at 2 x (200%) the average daily flow.

SURFACE AREA (ft^2) BY WATER DEPTH-VELOCITY CLASS

(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50-0.99	1.0-1.49	≥1.50	ROW TOTAL
<0.50	2013 (12.2%)	371 (2.2%)	803 (4.9%)	1267 (7.7%)	4454 (27.0%)
0.50-0.99	1064 (6.4%)	506 (3.1%)	1202 (7.3%)	3867 (23.4%)	6639 (40.2%)
1.0-1.49	565 (3.4%)	601 (3.6%)	650 (3.9%)	1384 (8.4%)	3200 (19.4%)
≥1.50	703 (4.3%)	324 (2.0%)	270 (1.6%)	923 (5.6%)	2220 (13.4%)
COLUMN TOTAL	4345 (26.3%)	1802 (10.9%)	2925 (17.7%)	7441 (45.1%)	16513 → TOTAL SURFACE AREA (100%)

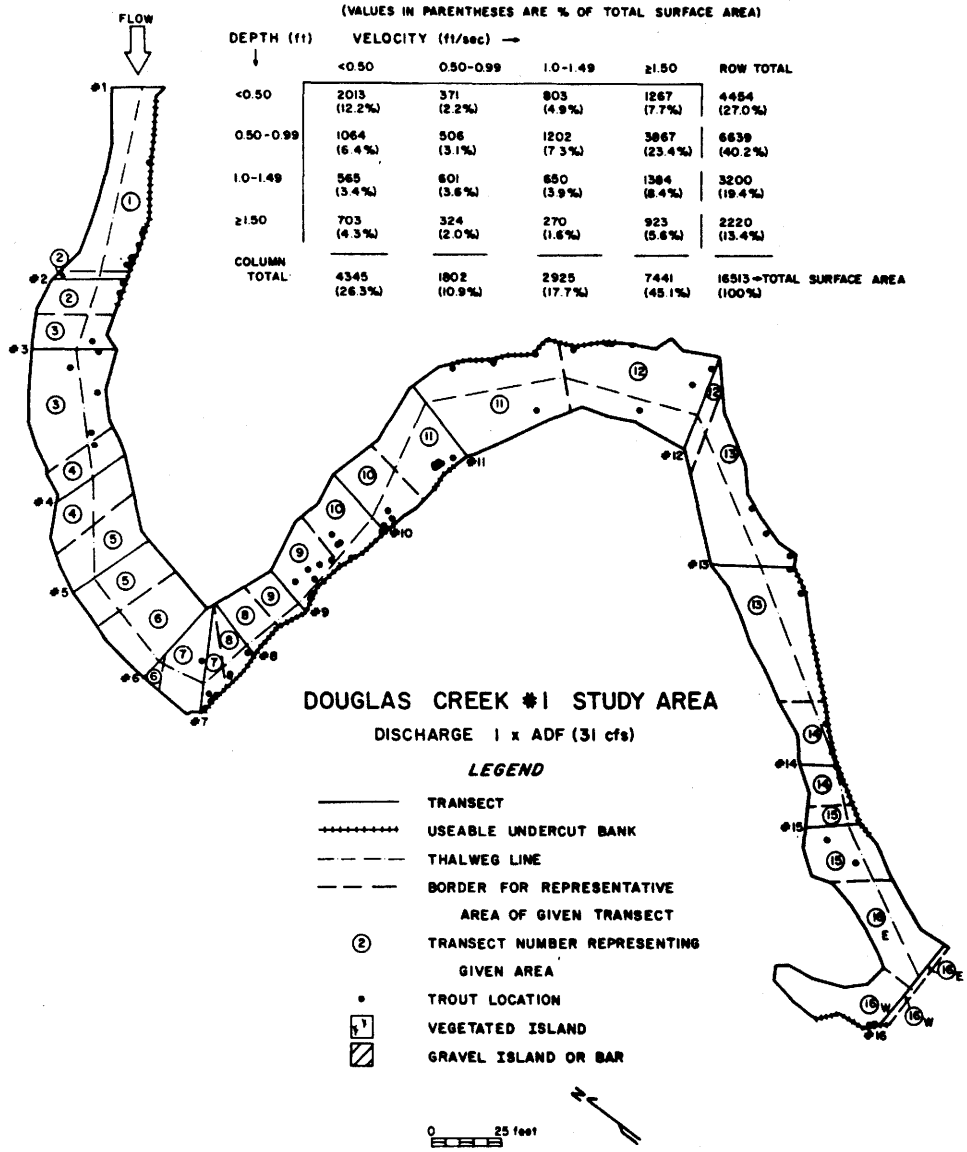


Figure 26. Surface area map and water depth-velocity classification of the Douglas Creek No. 1 study area at 1 x (100%) the average daily flow.

SURFACE AREA (ft^2) BY WATER DEPTH-VELOCITY CLASS

(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50-0.99	1.0-1.49	≥1.50	ROW TOTAL
<0.50	2109 (13.8%)	1292 (8.5%)	1743 (11.4%)	1056 (6.9%)	6200 (40.7%)
0.50-0.99	1361 (8.9%)	920 (6.0%)	1221 (8.0%)	1710 (11.2%)	5212 (34.2%)
1.0-1.49	1084 (7.1%)	724 (4.8%)	691 (4.5%)	221 (1.5%)	2720 (17.9%)
≥1.50	610 (4.0%)	355 (2.3%)	131 (0.9%)	0	1096 (7.2%)
COLUMN TOTALS	5164 (33.9%)	3291 (21.6%)	3786 (24.9%)	2987 (19.6%)	15228 → TOTAL SURFACE AREA (100%)

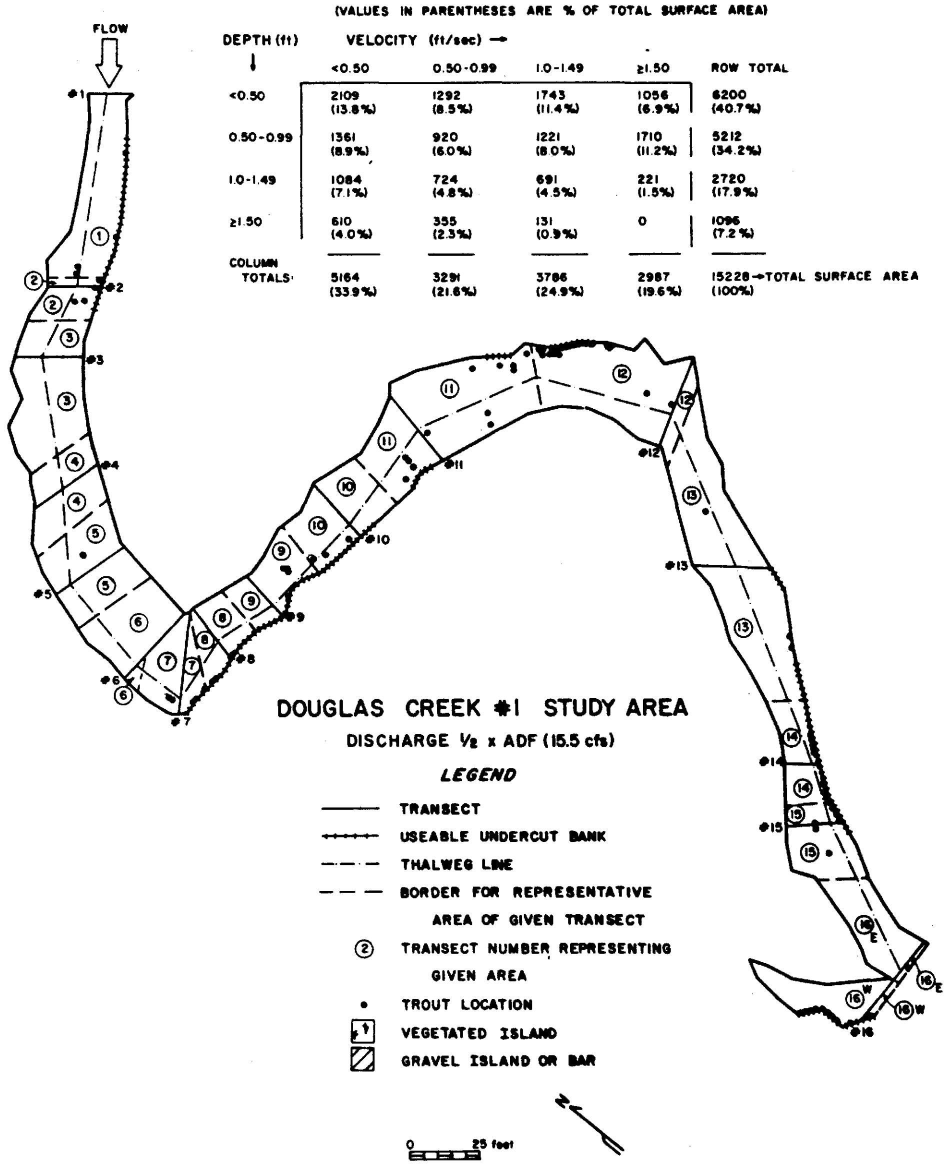
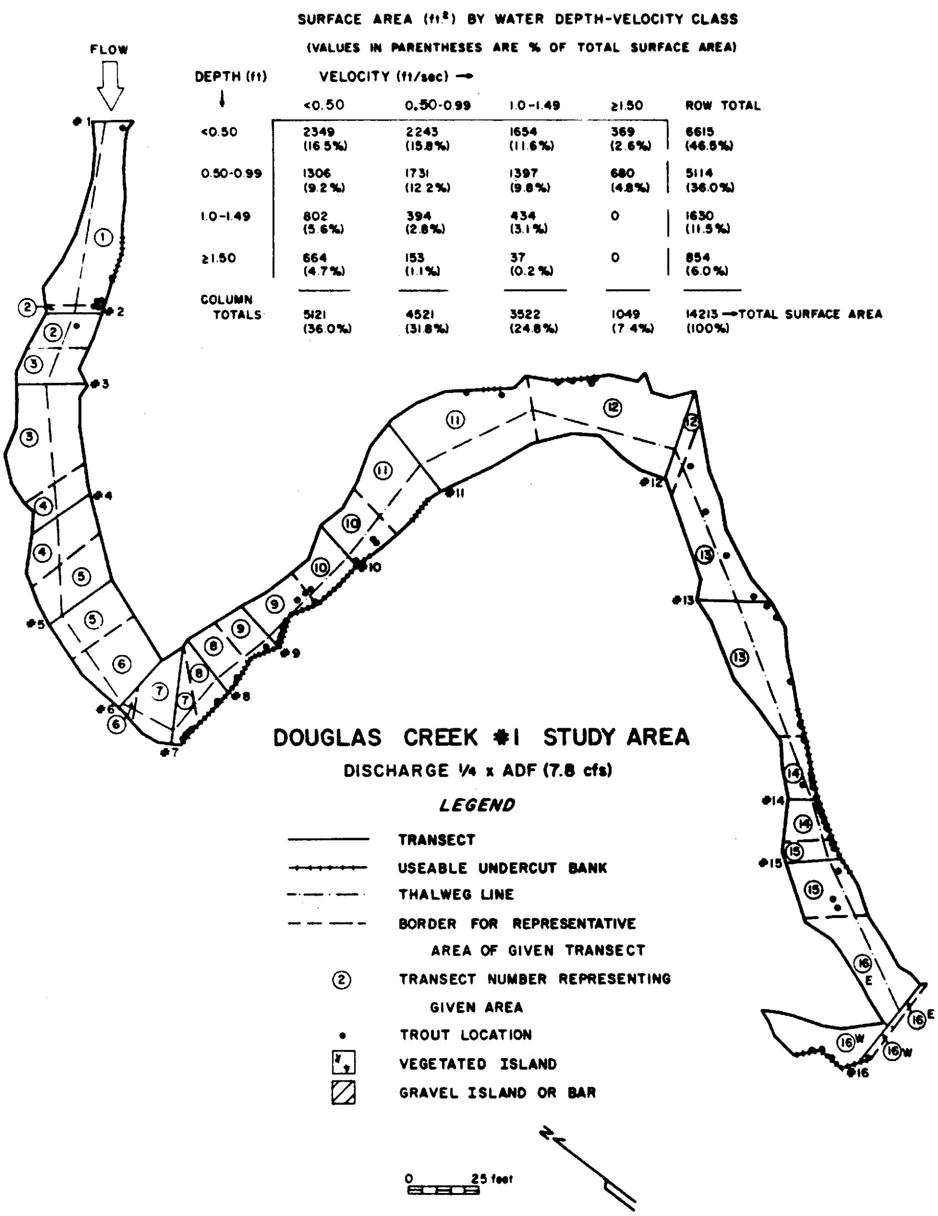


Figure 27. Surface area map and water-depth classification of the Douglas Creek No. 1 study area at 1/2 x (50%) the average daily flow.



SURFACE AREA (ft^2) BY WATER DEPTH-VELOCITY CLASS

(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50-0.99	1.0-1.49	≥1.50	ROW TOTAL
<0.50	2349 (16.5%)	2243 (15.8%)	1654 (11.6%)	369 (2.6%)	6615 (46.5%)
0.50-0.99	1306 (9.2%)	1731 (12.2%)	1397 (9.8%)	680 (4.8%)	5114 (36.0%)
1.0-1.49	802 (5.6%)	394 (2.8%)	434 (3.1%)	0	1630 (11.5%)
≥1.50	664 (4.7%)	153 (1.1%)	37 (0.2%)	0	854 (6.0%)
COLUMN TOTALS	5121 (36.0%)	4521 (31.8%)	3522 (24.8%)	1049 (7.4%)	14213 → TOTAL SURFACE AREA (100%)

Figure 28 Surface area map and water depth-velocity classification of the Douglas Creek No. 1 study area at 1/4 x (25%) the average daily flow.

SURFACE AREA (ft^2) BY WATER DEPTH-VELOCITY CLASS

(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50-0.99	1.0-1.49	≥1.50	ROW TOTAL
<0.50	2143 (19.8%)	1966 (18.2%)	1362 (12.6%)	298 (2.8%)	5769 (53.5%)
0.50-0.99	2404 (22.2%)	1081 (10.0%)	121 (1.1%)	0	3606 (33.3%)
1.0-1.49	1028 (9.5%)	0	0	0	1028 (9.5%)
≥1.50	403 (3.7%)	0	0	0	403 (3.7%)
COLUMN TOTAL:	5978 (55.3%)	3047 (28.2%)	1483 (13.7%)	298 (2.8%)	10806 → TOTAL SURFACE AREA (100%)

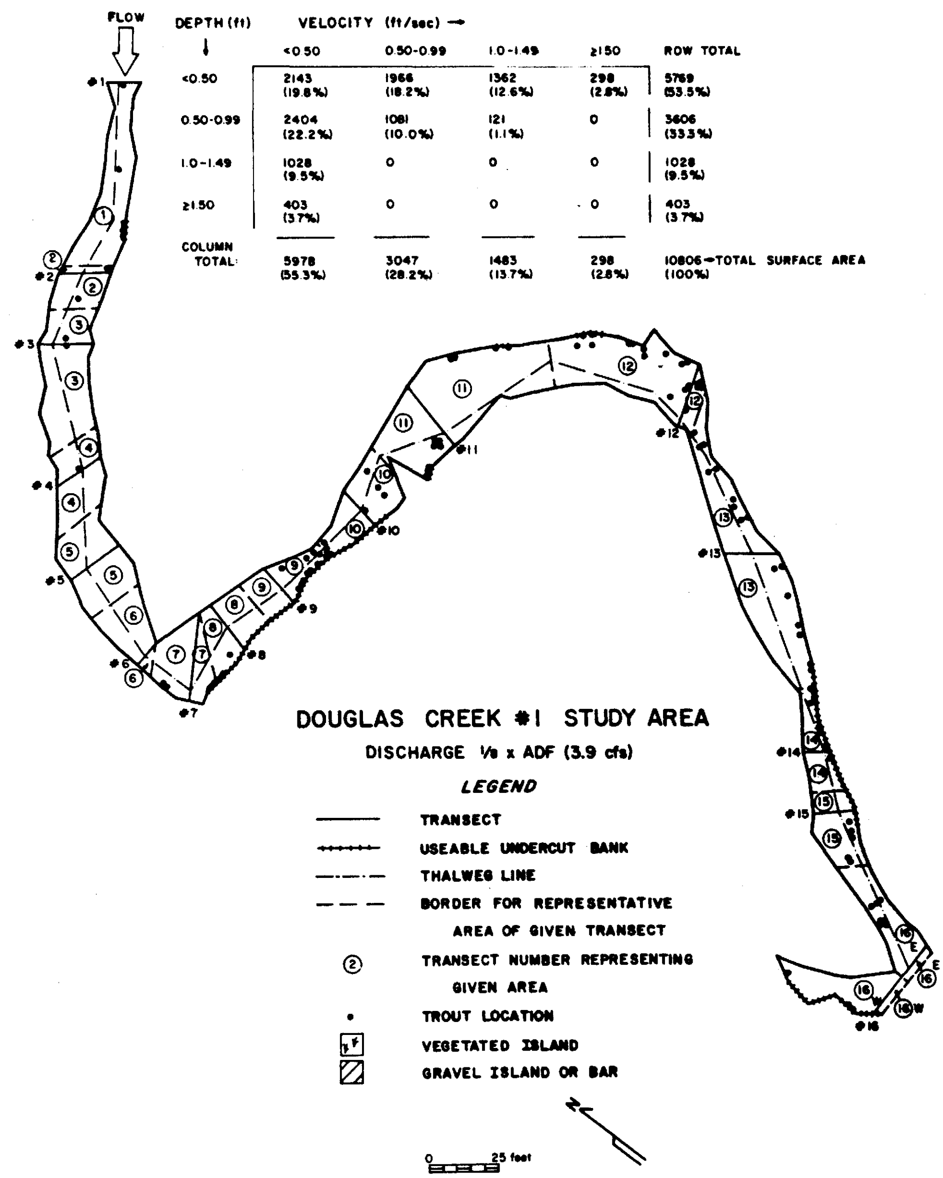
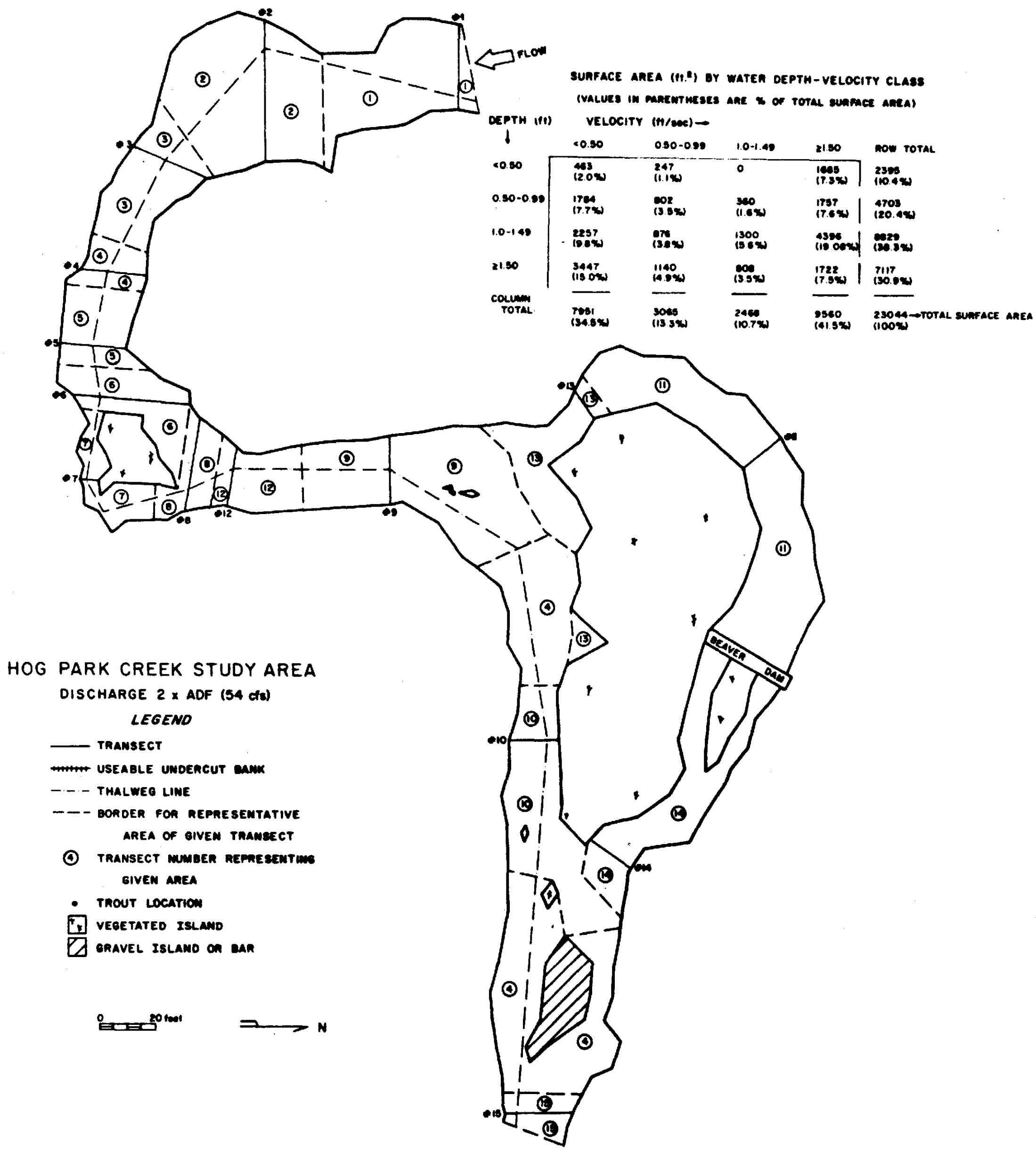


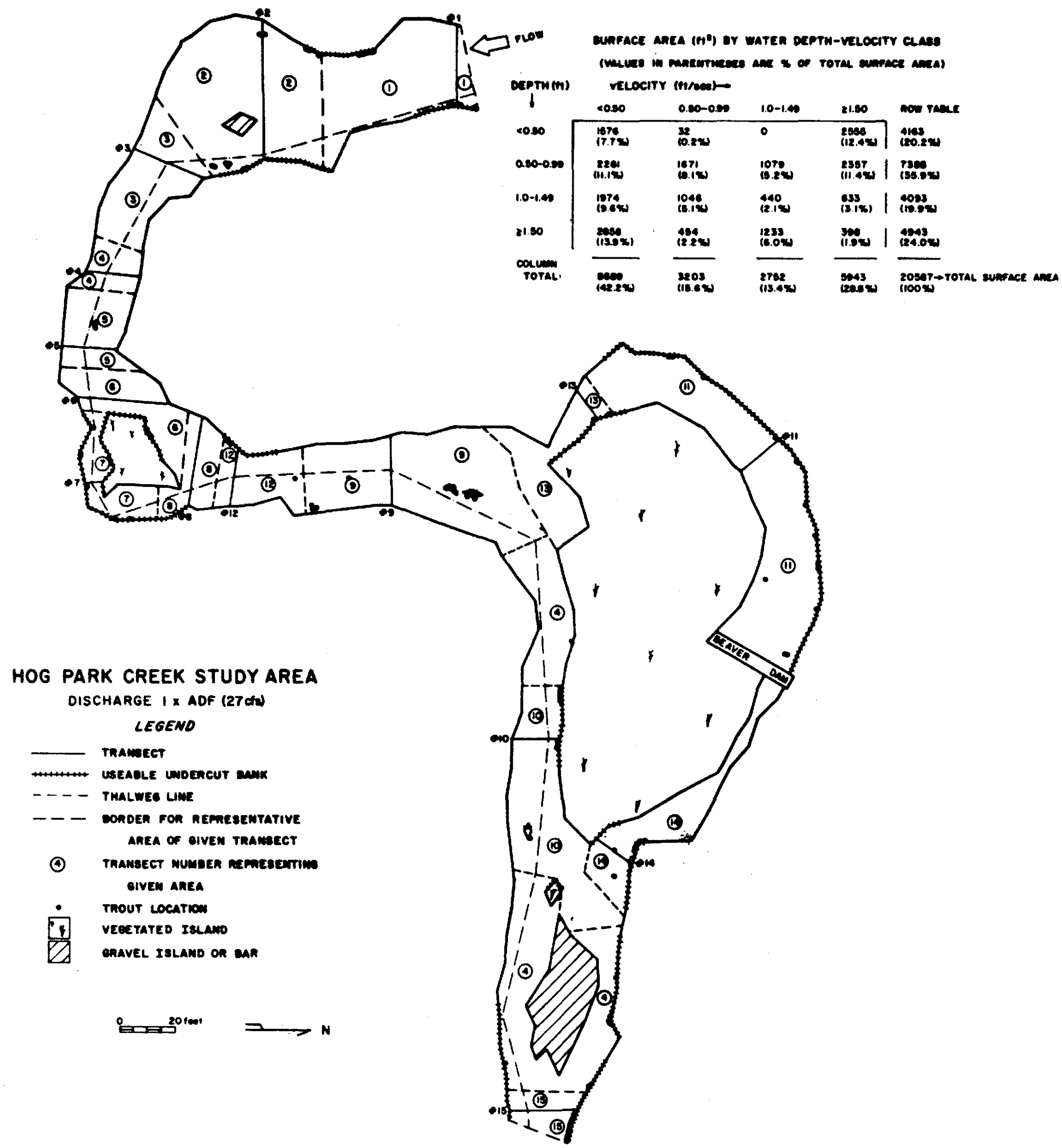
Figure 29. Surface area map and water depth-velocity classification of the Douglas Creek No. 1 study area at 1/8 (12.5%) the average daily flow.



SURFACE AREA (ft.²) BY WATER DEPTH-VELOCITY CLASS
(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50-0.99	1.0-1.49	≥1.50	ROW TOTAL
<0.50	463 (2.0%)	247 (1.1%)	0	1685 (7.3%)	2395 (10.4%)
0.50-0.99	1784 (7.7%)	802 (3.5%)	360 (1.6%)	1757 (7.6%)	4703 (20.4%)
1.0-1.49	2257 (9.8%)	876 (3.8%)	1300 (5.6%)	4396 (19.08%)	8829 (38.3%)
≥1.50	3447 (15.0%)	1140 (4.9%)	808 (3.5%)	1722 (7.5%)	7117 (30.9%)
COLUMN TOTAL	7951 (34.5%)	3065 (13.3%)	2468 (10.7%)	9560 (41.5%)	23044 → TOTAL SURFACE AREA (100%)

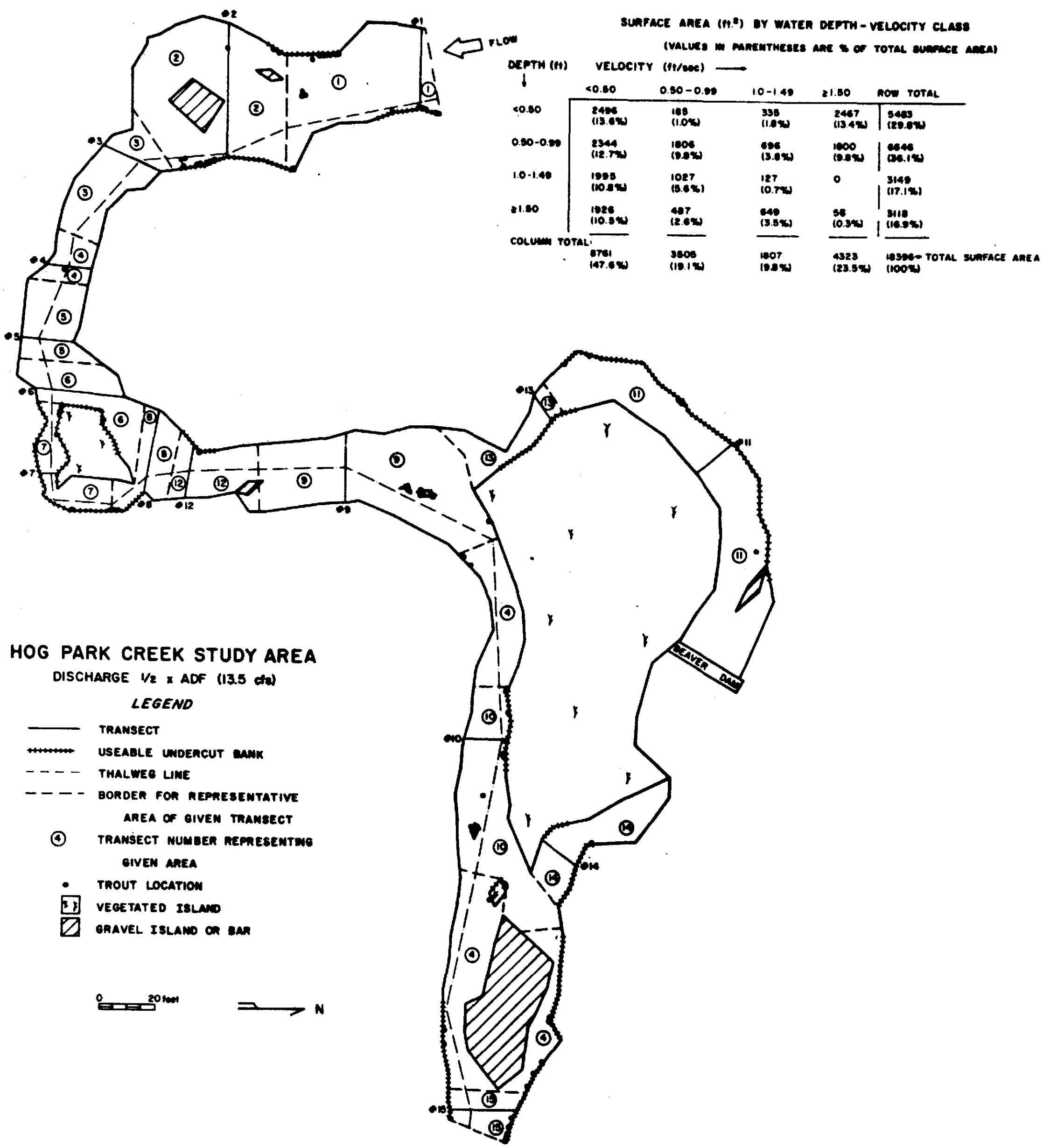
Figure 30. Surface area map and water depth-velocity classification of the Hog Park Creek study area at 2 x (200%) the average daily flow.



SURFACE AREA (ft^2) BY WATER DEPTH-VELOCITY CLASS
(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50–0.99	1.0–1.49	≥1.50	ROW TABLE
<0.50	1676 (7.7%)	32 (0.2%)	0	2555 (12.4%)	4163 (20.2%)
0.50–0.99	2281 (11.1%)	1671 (8.1%)	1079 (5.2%)	2357 (11.4%)	7388 (35.9%)
1.0–1.49	1974 (9.6%)	1046 (5.1%)	440 (2.1%)	633 (3.1%)	4093 (19.9%)
≥1.50	2858 (13.9%)	454 (2.2%)	1233 (6.0%)	398 (1.9%)	4943 (24.0%)
COLUMN TOTAL:	8689 (42.2%)	3203 (15.6%)	2752 (13.4%)	5943 (28.8%)	20587 → TOTAL SURFACE AREA (100%)

Figure 31. Surface area map and water depth-velocity classification of the Hog Park Creek study area at 1 x (100%) the average daily flow.

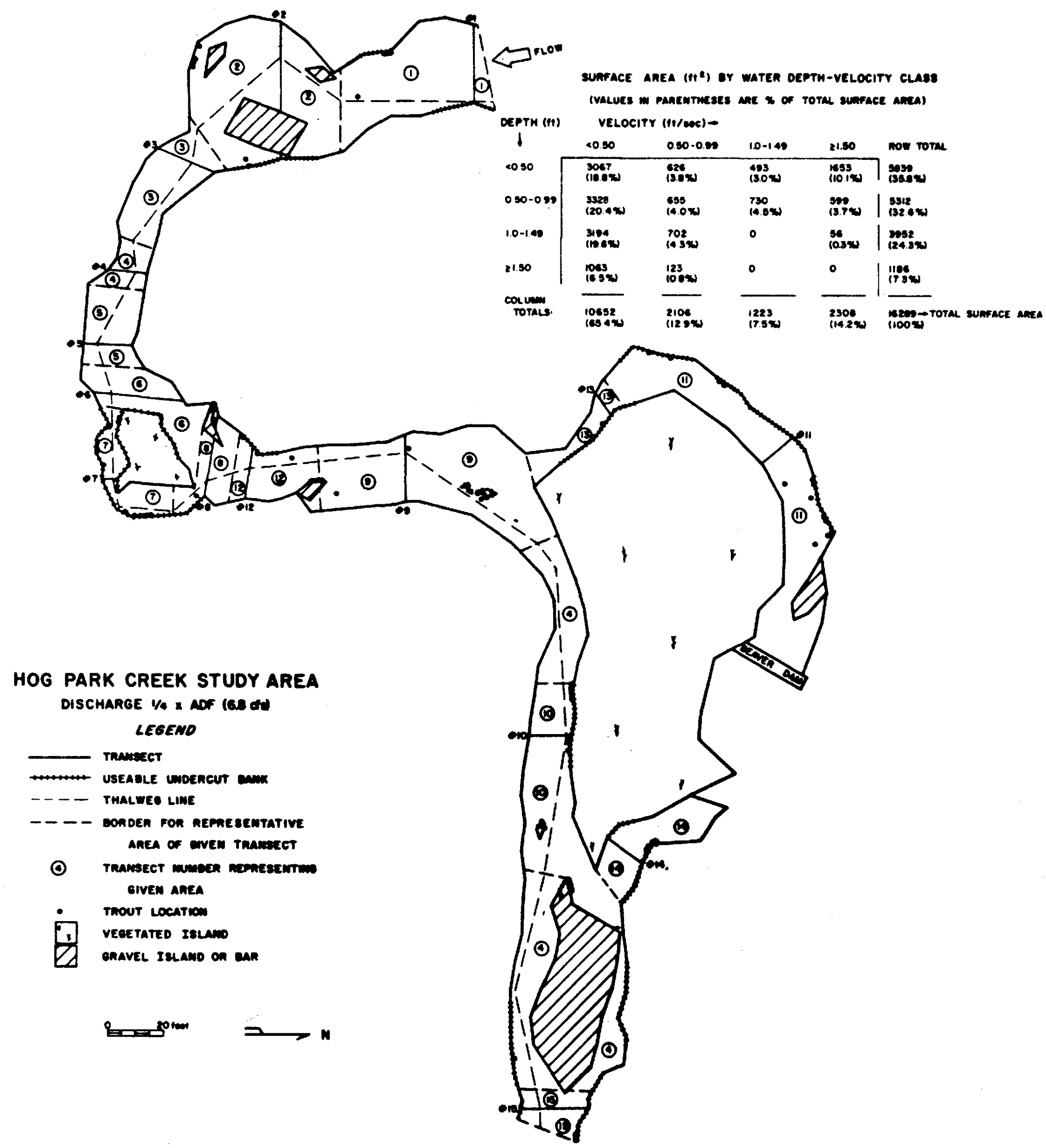


SURFACE AREA (ft.²) BY WATER DEPTH - VELOCITY CLASS

(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50 - 0.99	1.0 - 1.49	≥1.50	ROW TOTAL
<0.50	2496 (13.6%)	185 (1.0%)	335 (1.8%)	2467 (13.4%)	5483 (29.8%)
0.50-0.99	2344 (12.7%)	1806 (9.8%)	696 (3.8%)	1800 (9.8%)	6646 (36.1%)
1.0-1.49	1995 (10.8%)	1027 (5.6%)	127 (0.7%)	0	3149 (17.1%)
≥1.50	1926 (10.5%)	487 (2.6%)	649 (3.5%)	56 (0.3%)	3118 (16.9%)
COLUMN TOTAL	8761 (47.6%)	3506 (19.1%)	1807 (9.8%)	4323 (23.5%)	18396 ← TOTAL SURFACE AREA (100%)

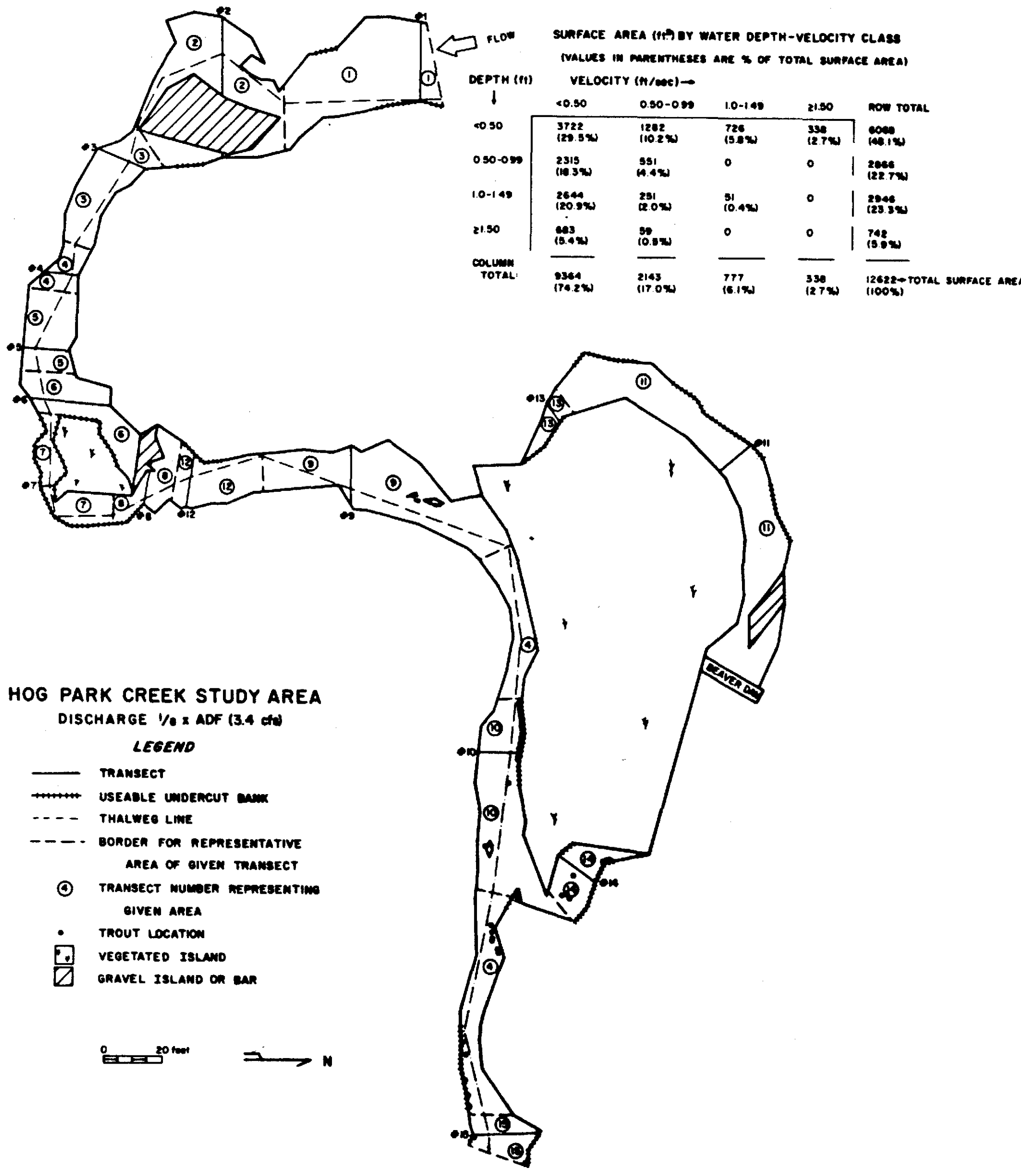
Figure 32. Surface area map and water depth-velocity classification of the Hog Park Creek study area at 1/2 x (50%) the average daily flow.



SURFACE AREA (ft²) BY WATER DEPTH-VELOCITY CLASS
(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50-0.99	1.0-1.49	≥1.50	ROW TOTAL
<0.50	3067 (18.8%)	626 (3.8%)	493 (3.0%)	1653 (10.1%)	5839 (35.8%)
0.50-0.99	3328 (20.4%)	655 (4.0%)	730 (4.5%)	599 (3.7%)	5312 (32.6%)
1.0-1.49	3194 (19.6%)	702 (4.3%)	0	56 (0.3%)	3952 (24.3%)
≥1.50	1063 (6.5%)	123 (0.8%)	0	0	1186 (7.3%)
COLUMN TOTALS:	10652 (65.4%)	2106 (12.9%)	1223 (7.5%)	2308 (14.2%)	16289 → TOTAL SURFACE AREA (100%)

Figure 33. Surface area map and water depth-velocity classification of the Hog Park Creek study area at 1/4 x (25%) the average daily flow.



SURFACE AREA (ft²) BY WATER DEPTH-VELOCITY CLASS
(VALUES IN PARENTHESES ARE % OF TOTAL SURFACE AREA)

DEPTH (ft) ↓ / VELOCITY (ft/sec) →	<0.50	0.50-0.99	1.0-1.49	≥1.50	ROW TOTAL
<0.50	3722 (29.5%)	1282 (10.2%)	726 (5.8%)	338 (2.7%)	6068 (48.1%)
0.50-0.99	2315 (18.3%)	551 (4.4%)	0	0	2866 (22.7%)
1.0-1.49	2644 (20.9%)	251 (2.0%)	51 (0.4%)	0	2946 (23.3%)
≥1.50	683 (5.4%)	59 (0.5%)	0	0	742 (5.9%)
COLUMN TOTAL:	9364 (74.2%)	2143 (17.0%)	777 (6.1%)	338 (2.7%)	12622 ← TOTAL SURFACE AREA (100%)

Figure 34. Surface area map and water depth-velocity classification of the Hog Park Creek study area at 1/8 (12.5%) the average daily flow.

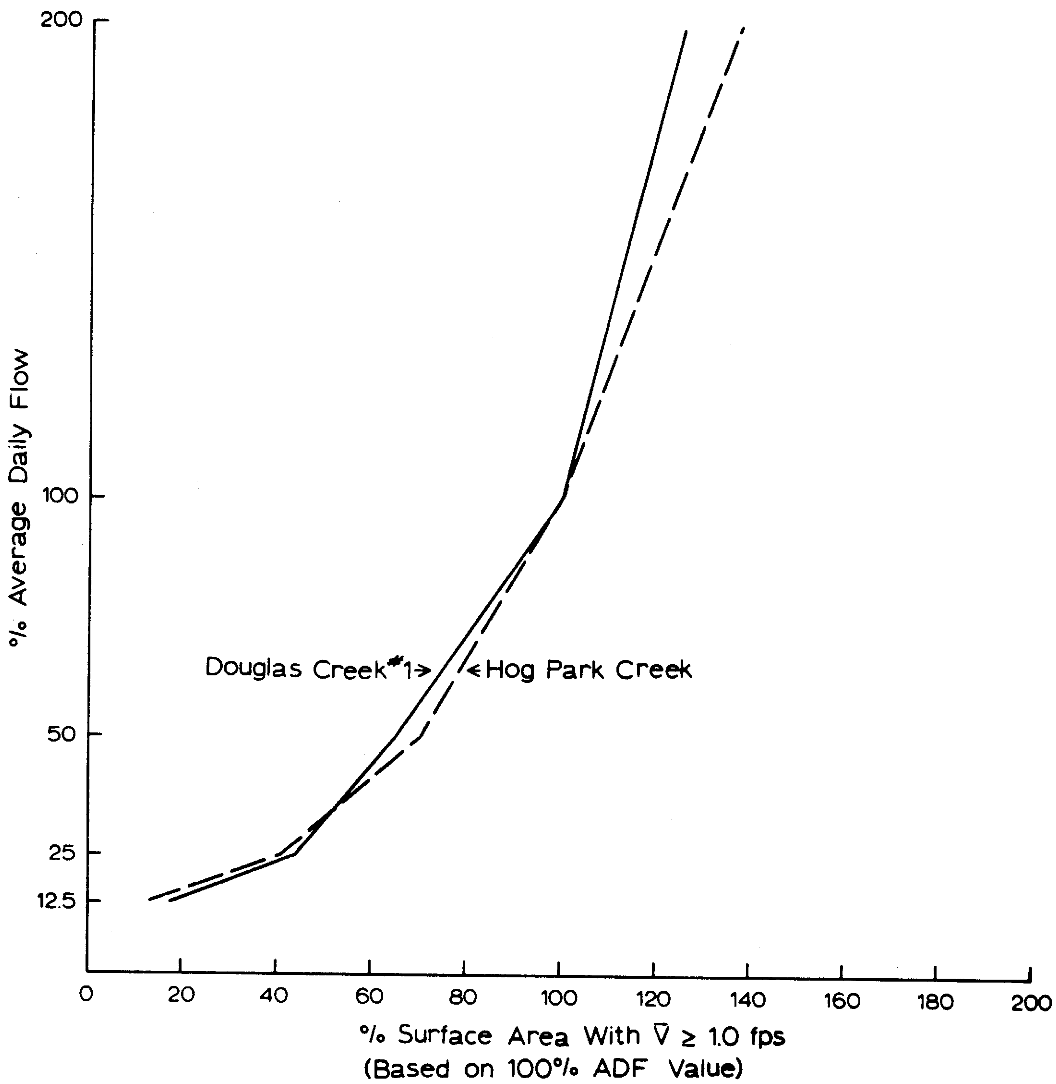


Figure 35. Changes observed in the surface area having a water velocity of at least 1.0 feet per second as flow was reduced at the Douglas Creek No. 1 and Hog Park Creek study areas, expressed as a percentage of the value at 100% of the average daily flow.

Grouping all water depth categories 0.5 feet or greater, regardless of velocity, 83.8% of the DC #1 area at 200% ADF met or exceeded this depth. For the flow levels ranging from 100% to 12.5% ADF, the percentages were 73.0%, 59.3%, 53.5%, and 46.6% respectively. At HPC, 89.6% of the surface area at 200% ADF was of depth 0.5 feet or greater, while at 100% ADF, 79.8% of the habitat met the depth requirement. For the remaining discharge levels, 50%, 25%, and 12.5% ADF, the percentages were 70.2%, 64.2%, and 51.9% respectively. The expression of these values as a percent of the area at least 0.5 feet in depth at 100% ADF is shown on Figure 36. As seen on Tables III and IV, pages 29 and 30, the greatest reduction rate for such areas again occurred for the flow reduction from 25% to 12.5% ADF.

Trout Cover Analysis

The cover utilized by 684 trout was analysed at the DC #1 and HPC study areas. The locations at which trout were captured are shown on Figures 26 to 29, pages 48 to 51, and Figures 31 to 34, pages 53 to 56. Of the total catch, 514 (75.1%) were brown trout, 145 (21.2%) brook trout, and 25 (3.7%) rainbow trout. The results presented and the cover rating system described will pertain only to brown trout, due to their population dominance in the study areas. Tables V and VI summarize the brown trout cover data obtained. Supplemental brook and rainbow trout information is provided in Table A-III, page 85 in Appendix A.

Two types of trout cover were available in the study areas, undercut banks and instream rubble-boulder areas. Overhanging vegetation was lacking. Of the 514 brown trout sampled, 94% were found in water

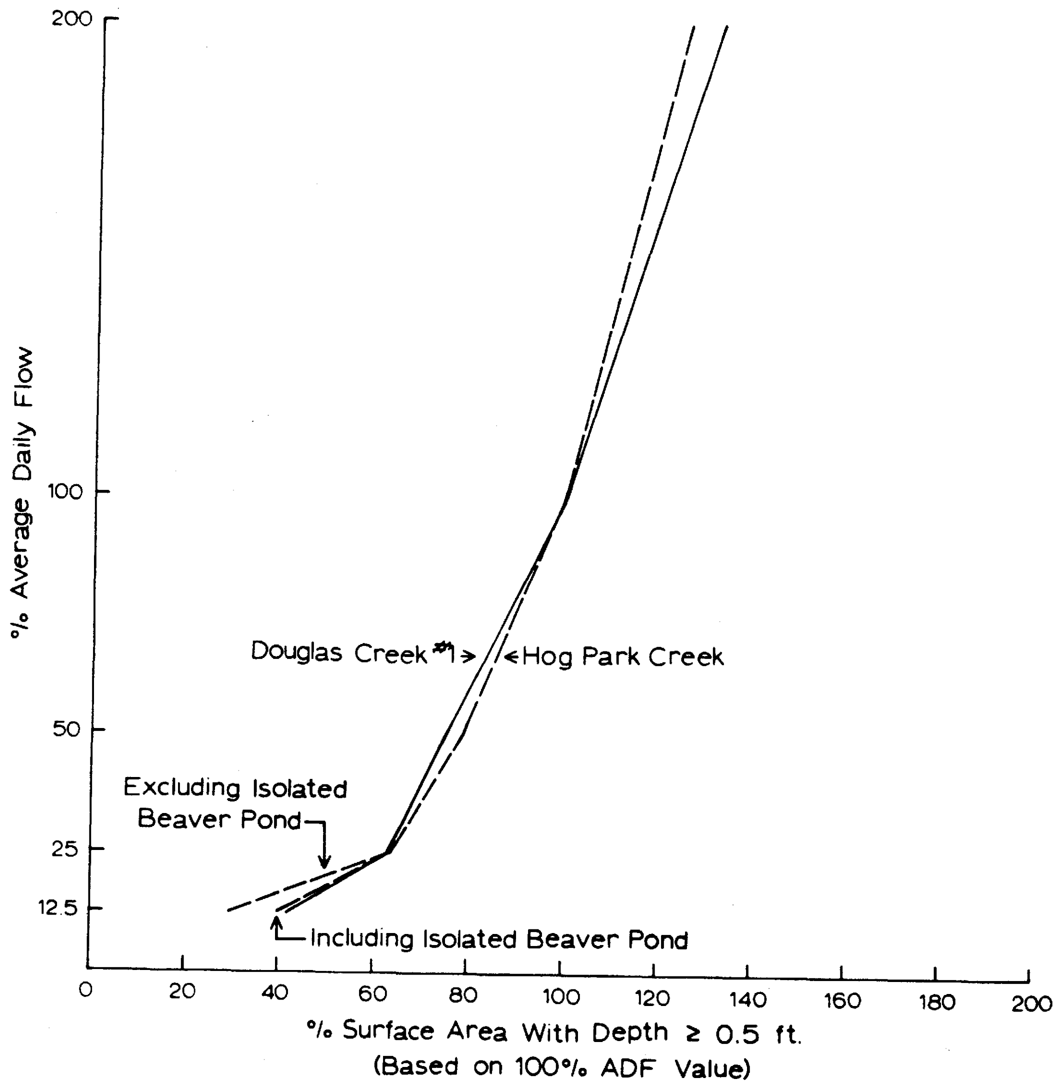


Figure 36. Changes observed in the surface area having a water depth of at least 0.5 feet as flow was reduced at the Douglas Creek No. 1 and Hog Park Creek study areas, expressed as a percentage of the value at 100% of the average daily flow.

TABLE V

BROWN TROUT ($\geq$6.0") COVER ANALYSIS FOR DOUGLAS CREEK #1 AND HOG PARK CREEK STUDY AREAS

Flow (%ADF)	Total No. Sampled	No. in Rubble-Boulder Areas	No. in Undercut Banks	Mean Depth (ft.)	Mean Velocity (fps)
100%	59	12	47	1.44	0.17
50%	41	0	41	1.51	0.12
25%	34	2	32	1.26	0.06
12.5%	43	11	32	1.05	0.05
Total	177	25	152		
% Total	100%	15%	85%		

TABLE VI

BROWN TROUT (<6.0") COVER ANALYSIS FOR DOUGLAS CREEK #1 AND HOG PARK CREEK STUDY AREAS

Flow (% ADF)	Total No. Sampled	No. in Rubble-Boulder Areas	No. in Undercut Banks	Mean Depth (ft.)	Mean Velocity (fps)
100%	81	31	50	1.28	0.15
50%	98	39	59	1.17	0.15
25%	59	24	35	1.07	0.06
12.5%	99	61	38	0.80	0.05
Total	337	155	182		
% Total	100%	45%	55%		

having a depth of 0.5 feet or greater (Figure 37). Of the remaining 6% (30 fish), 24 were sampled at the lowest flow level, when 51% of the combined study areas comprised water less than 0.5 feet deep. For all fish (334) found utilizing undercut banks for cover, the widths of the undercuts being used were 0.3 feet or greater. Several short sections of narrower undercut banks were present, but no trout were taken from them. The locations of available undercut banks having at least 0.5 feet of water at their outer edge and widths of 0.3 feet or greater are illustrated at each flow level on Figures 26 to 29, pages 48 to 51, and Figures 31 to 34, pages 53 to 56. Thirty-five percent of all brown trout captured were found utilizing instream rubble-boulder areas as cover. No fish were found in areas having a substrate size of less than 3" diameter. Point water velocities measured at the location of the cover being used ranged from 0.0 to 0.5 fps. Such low velocity readings appear to be a direct function of the ability of the cover to minimize the force of the current, thus forming a resting area for the fish.

Using these data, 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:

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

where;

L ucb = length (ft) of undercut banks in the stream section having a water depth of at least 0.5 feet and a width of at least 0.3 feet.

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

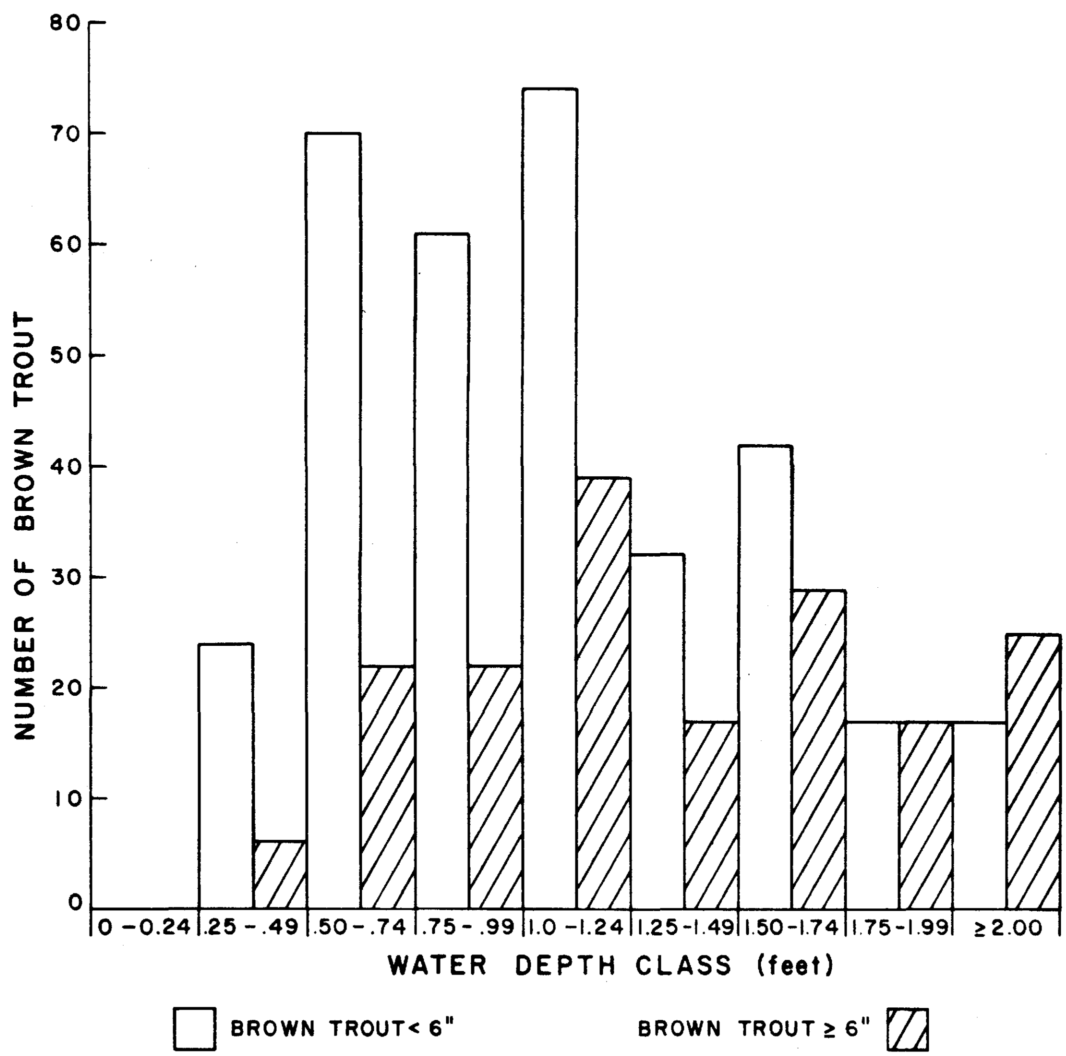


Figure 37. Water depth-frequency distribution for the 514 brown trout sampled at the Douglas Creek No. 1 and Hog Park Creek study areas.

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

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

PF ucb = preference factor of brown trout for undercut banks.

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

CR = cover rating of stream section for brown 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 of brown trout $\geq$6.0" (catchables) for undercut banks is 0.85 (i.e., 85% were found utilizing undercut banks for cover). For smaller browns (subcatchables), the factor is 0.55. For instream rubble-boulder areas, the preference factor for catchables is 0.15, while for subcatchables, 0.45. The term "preference factor" has been applied because at each flow level, as far as could be determined, unutilized sections of undercut banks 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 determined.

The following examples, comparing DC #1 and HPC for brown trout $\geq$6.0" at 100% ADF illustrates the use of the system:

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

For Douglas Creek:

$$\frac{350'}{680'} \quad (0.85) \quad + \frac{7{,}055 \text{ sq. ft.}}{16{,}510 \text{ sq. ft.}} \quad (0.15) \quad = 0.50$$

For Hog Park Creek:

$$\frac{650'}{620'} \quad (0.85) \quad + \frac{3{,}175 \text{ sq. ft.}}{20{,}590 \text{ sq. ft.}} \quad (0.15) \quad = 0.93$$

The cover rating values obtained show that for brown trout $\geq$6.0" at 100% ADF, HPC offers more available cover than does DC #1. Figure 38 compares available cover for the larger browns at both areas, while Figure 39 compares cover ratings for the subcatchables. Losses of undercut banks due to the dewatering observed as flow was reduced are illustrated by Figure 40. Figure 22, page 44, shows the loss of in-stream rubble-boulder areas with decreasing flow.

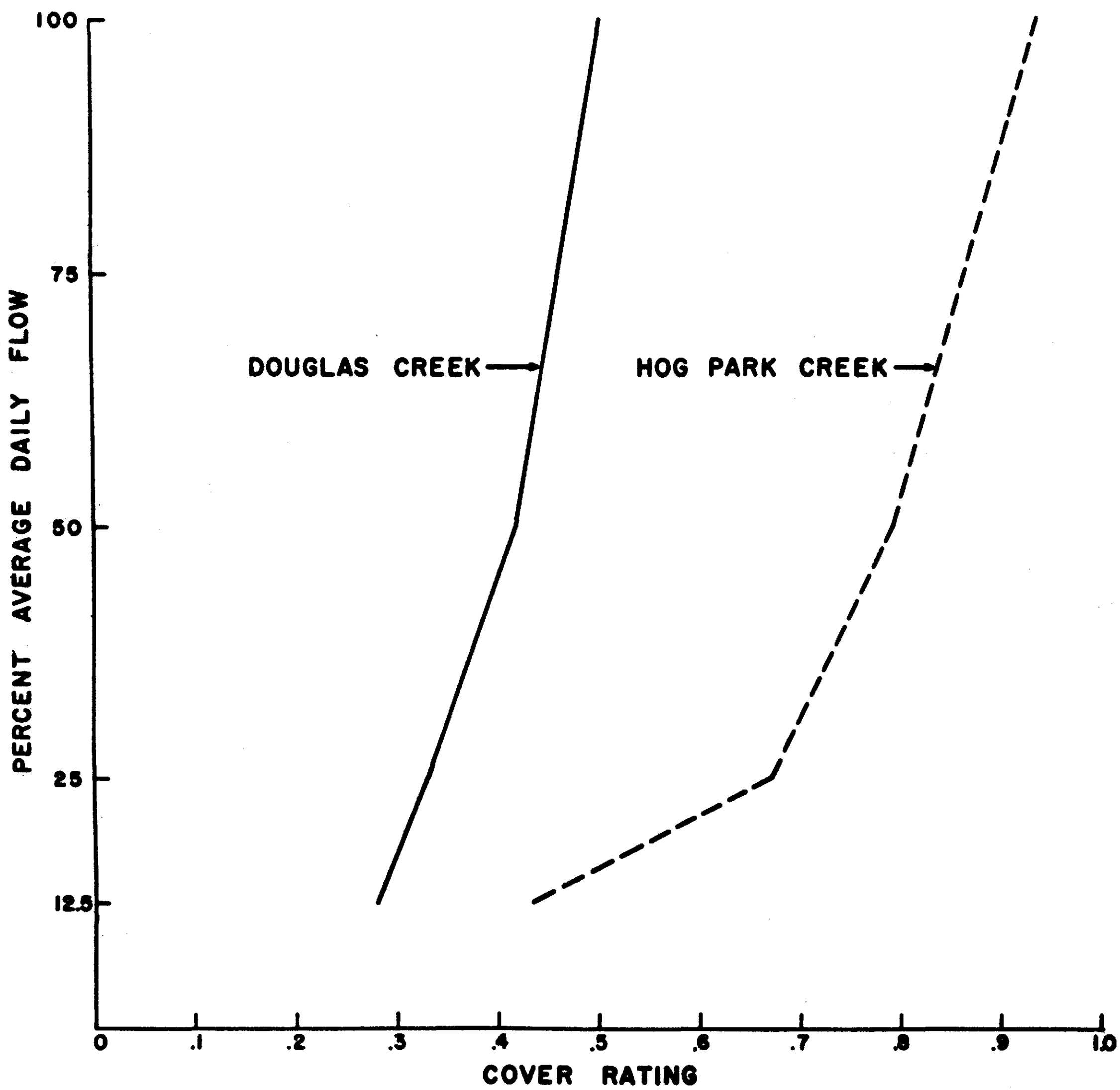


Figure 38. Changes observed in the cover rating of the Douglas Creek No. 1 and Hog Park Creek study areas for brown trout at least six inches in length as flow was reduced.

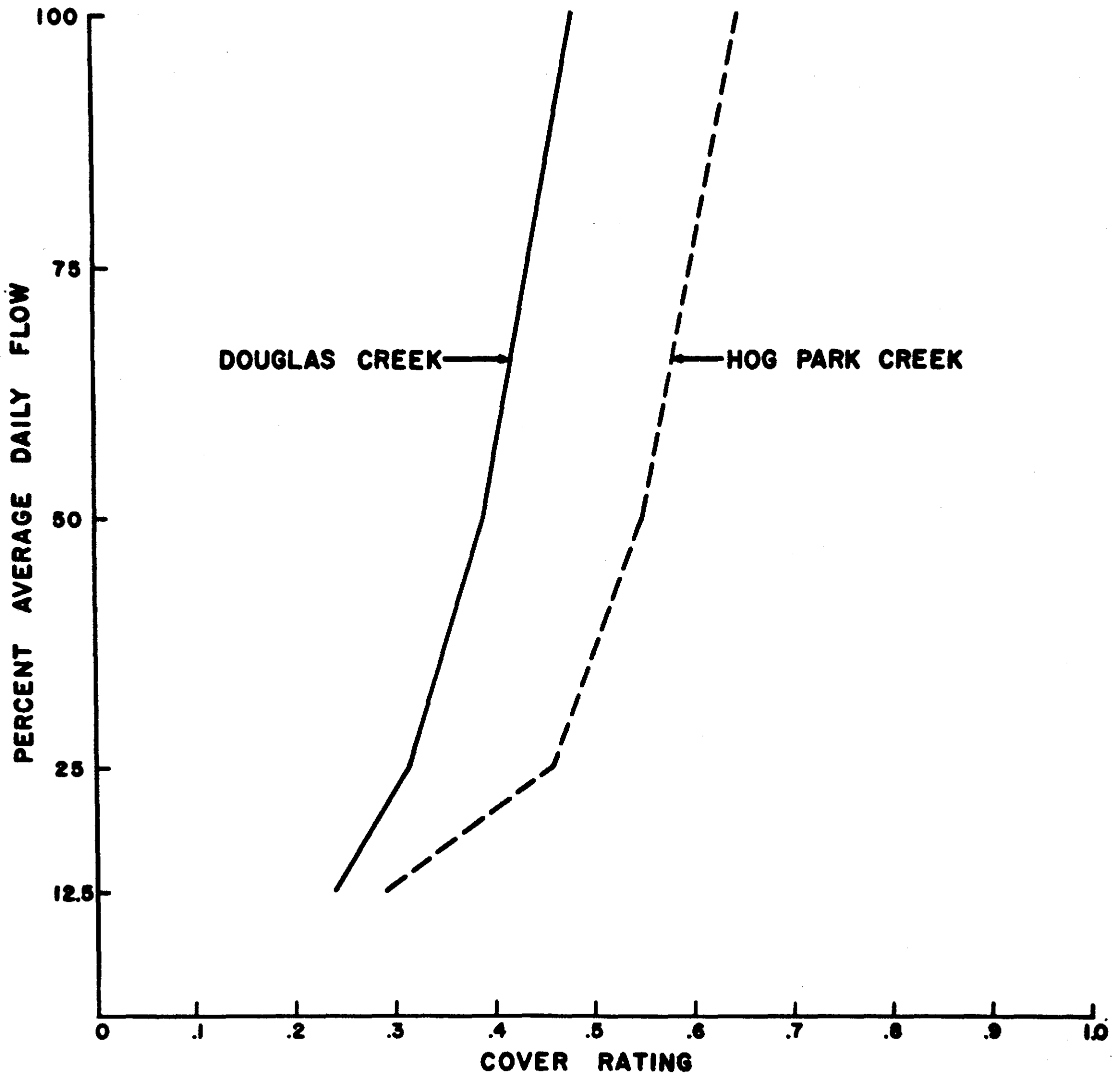
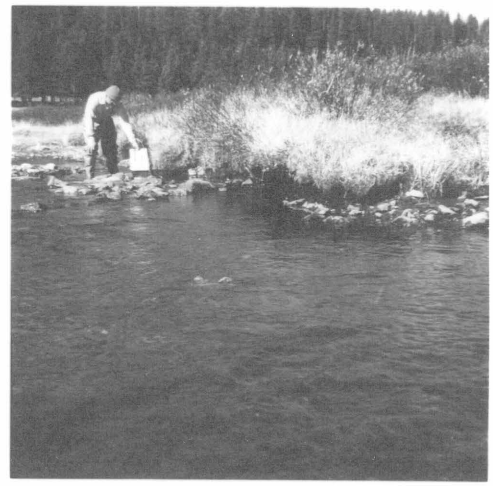


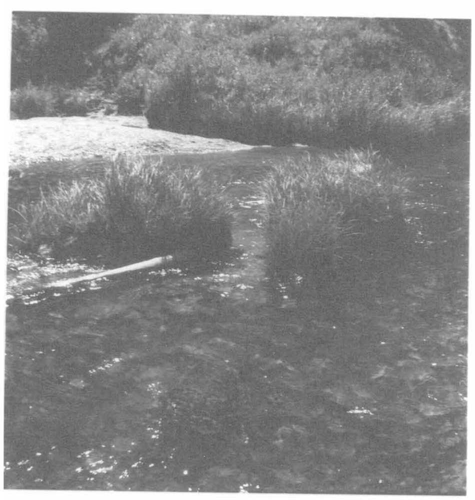
Figure 39. Changes observed in the cover rating of the Douglas Creek No. 1 and Hog Park Creek study areas for brown trout less than six inches in length as flow was reduced.

100% ADF (31.0 cfs)

12.5% ADF (3.9 cfs)



100% ADF (27.0 cfs)



12.5% ADF (3.4 cfs)

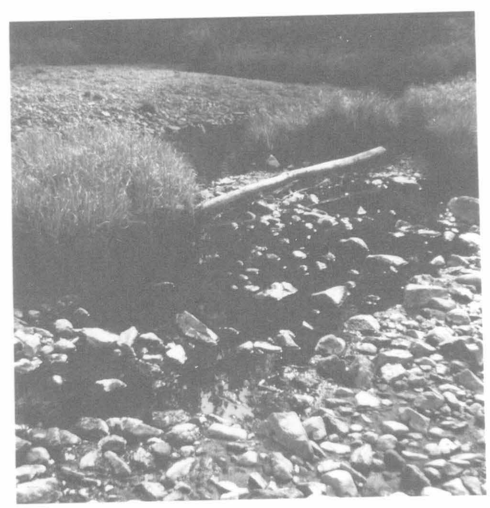


Figure 40. Loss of undercut banks at the Douglas Creek No. 1 (top photos) and Hog Park Creek (bottom photos) study areas due to dewatering as flow was reduced from 100% to 12.5% of the average daily flow.

HPC offered more available cover at each flow level than did DC #1. Mark-recapture population estimates indicated a population of 72 catchables (190 per surface acre at 100% ADF) and 261 subcatchables (691 per surface acre at 100% ADF) at the DC #1 area. Estimates for HPC revealed 116 catchables (246 per surface acre at 100% ADF) and 393 subcatchables (838 per surface acre at 100% ADF). One explanation for the larger HPC populations would be the greater availability of brown trout cover.

Relating the cover rating values obtained to percentages of the 100% ADF values, as shown in Tables III and IV, pages 29 and 30, indicates the same pattern of decrease observed in the hydrologic parameters and the surface area - water type classification. Available brown trout cover, for both study areas and size groups, is lost at the greatest rate as flow is reduced from 25% to 12.5% ADF.

DISCUSSION

The determination of a suitable minimum flow is a difficult problem. The approach taken has centered on the following three types of physical stream characteristics and the changes observed in them between various levels of flow, based on the average daily flow over the period of record:

1) Hydrologic parameters.
2) Surface area - water types.
3) Available trout cover.

In the determination of a minimum flow for trout, these factors must be considered together, not separately. Water depth, velocity, cross-sectional area, wetted perimeter, hydraulic radius, top width, total surface area, surface area having a velocity of 1.0 fps or greater, surface area of depth 0.5 feet or greater, and available brown trout cover have been shown to decrease at the greatest rate for the discharge reduction interval from 25% to 12.5% ADF.

The literature defining the actual instream hydrologic requirements for a trout population to maintain or improve itself is not plentiful. However, certain criteria have been suggested. Allen (1952) has found that instream areas having a depth of at least 0.50 feet and a water velocity of 1.0 fps or greater, produce the greatest abundance of trout food organisms. Applying these depth and velocity criteria to DC #1 and HPC, at the 100% ADF level, 8,295 sq. ft. of prime trout food producing area existed at DC #1 and 6,140 sq. ft. at HPC. Following a 75% flow reduction, 2,548 sq. ft. (31%) remained at DC #1, while 1,385 sq. ft. (23%) was still present at HPC. At low flow, 12.5% ADF, only 121 sq. ft. (1.5% of that present at 100% ADF) remained in DC #1. For the HPC area, 51 sq. ft. was still present, only 0.8% of that which was available for prime trout food producing area at the 100% ADF level.

Invertebrate drift is a major food source for fish in streams and the supply of drift is greater in areas of faster current velocities (Muller, 1953, and Nilsson, 1957). 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 primary study areas has been shown to occur in the flow reduction interval between 25% and 12.5% ADF. At DC #1, the velocity decreased from 0.89 fps at 25% ADF to only 0.44 fps at 12.5% ADF. For Hog Park Creek, the reduction was from 0.70 fps to 0.36 fps.

Hoppe and Finnell (1970) found by examining trout egg survival under different flow regimes that suitable spawning habitat should have a minimum water velocity of 1.5 fps as measured at the 0.6 depth. Applying this criterion, regardless of water depth and substrate size, 7,440 sq. ft. existed at DC #1 at the 100% ADF level, and 5,943 sq. ft. at HPC. At 25% ADF, 1,049 sq. ft. (18%) remained in DC #1 and 2,308 sq. ft. (39%) at HPC. At low flow, potential suitable spawning area was reduced to 298 sq. ft. in DC #1, 4% of that which had been present at 100% ADF, while 338 sq. ft., only 6%, remained at HPC.

The preceding comparisons are made to emphasize the relationship between the parametric decreases noted between the flow levels investigated and the potential biologic significance of such discharge reductions. Minimum flow is not optimum flow. Elser (1972) stated that the more water in the stream, up to flood stage, the better the fishery potential. A trout population is limited by the amount of available food-producing, spawning, and cover areas provided it by the discharge through the existing channel configuration. If subjected to extreme dewatering for extended time periods, a trout population optimally can only expand to the limits allowed by that existing stream habitat. The results of this study have shown that in the flow reduction from 25% to 12.5% ADF, the greatest rate of decrease for hydrologic parameters, surface area-water types, and available brown trout cover is incurred. An optimum flow for trout has not been defined. However, a discharge in the 25% ADF range will provide substantially more available trout habitat than a 12.5% flow, and, as a minimum flow, will avoid the flow range for which the rate of habitat decrease is greatest.

CONCLUSIONS AND RECOMMENDATIONS

1) The greatest rate of decrease for the hydrologic parameters, the surface area-water types, and the available brown trout cover investigated occurs in the flow reduction from 25% to 12.5% ADF. A minimum flow in the 25% ADF range will avoid the flow range of greatest habitat decrease rate. Investigations on streams having larger average daily flows should be conducted to determine if the same reduction patterns occur.

2) Brown trout exhibit a preference for water of depth 0.5 feet or greater and prefer undercut banks as cover to instream rubble-boulder areas. Larger brown trout ($\geq$6") tend to have a stronger preference for undercut banks than do smaller individuals, although competition and territoriality may explain this difference. The cover rating system should be regarded as a preliminary system, restricted to streams of the relative size of those investigated and having populations comprised predominantly of brown trout. Investigations should be continued, taking into consideration streams of various size, trout populations of differing species composition, and various combinations of cover types.

3) Additional research to investigate the hydrologic requirements of instream trout food production and spawning success should be undertaken to supplement information in the literature.

SELECTED REFERENCES

Allen, K. Radway, "A New Zealand Trout Stream - Some Facts and Figures," Fisheries Bulletin No. 10 A, New Zealand Marine Department, Wellington, New Zealand, 1952.

Bell, Milo C., "Water Demands for Enhancement of Fisheries (Food and Growth)," Report No. 3A, Study B, State of Washington, Water Research Center, Pullman, Washington, 1971, p. 27.

Boussu, Marvin F., "Relationships Between Trout Populations and Cover on a Small Stream," J. Wildl. Mgmt., Vol. 18, 1954, pp. 229-239.

Chapman, Donald W., "Food and Space as Regulators of Salmonid Populations in Streams," Amer. Natur., Vol. 100, 1966, pp. 345-357.

Corbett, D.M., "Stream-Gaging Procedure," Water Supply Paper No. 888, U. S. Geol. Survey, U. S. Printing Office, Washington, D.C., 1962, p. 245.

Curtis, B., "Changes in a River's Physical Characteristics Under Substantial Reductions in Flow Due to Hydroelectric Diversion," Journal, California Fish and Game, Vol. 45, 1959, pp. 181-188.

Delisle, G.E. and B.E. Eliason, "Effects on Fish and Wildlife Resources of Proposed Water Developments on Middle Fork Feather River," Water Proj. Rep., Calif. Dept. Fish and Game, No. 2, 1961, p. 55.

Elser, Allen A., "A Partial Evaluation and Application of the 'Montana Method' of Determining Stream Flow Requirements," Proceedings, Instream Flow Requirement Workshop, Pacific Northwest River Basin Commission, Vancouver, Washington, 1972, pp. 3-8, 12-15.

Gibson, R. John and Miles H.A. Keenleyside, "Responses to Light of Young Atlantic Salmon (Salmo salar) and Brook Trout (Salvelinus fontinalis)." J. Fish. Res. Bd. Can., Vol. 23, 1966, pp. 1007-1024.

Gunderson, Donald R., "Stream Morphology and Fish Populations in Relation to Floodplain Use," Unpubl. Thesis (M.S.), Montana State Univ., Bozeman, 1966, p. 21.

Hoppe, R. A. and L. M. Finnell, "Aquatic Studies on Fryingpan River, Colorado - 1969-70," Mimeo Report, Bureau of Sport Fisheries and Wildlife, Div. of River Basin Studies, 1970, p. 12.

Kalleburg, H., "Observations in a Stream Tank of Territoriality and Competition in Juvenile Salmon and Trout (Salmo salar and S. trutta)." Inst. Freshw. Res. Drottningholm, Vol. 39, 1958, pp. 55-98.

Kennedy, Harry D., "Seasonal Abundance of Aquatic Invertebrates and Their Utilization by Hatchery Reared Rainbow Trout," Technical Paper No. 12, U. S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Washington, D.C., 1967.

Kraft, Melvin E., "The Effects of Controlled Dewatering on a Trout Stream," M.S. Thesis, Montana State University, Bozeman, 1968, p. 31.

_________, "Effects of Controlled Flow Reduction on a Trout Stream," J. Fish. Res. Bd. Canada, Vol. 29, 1972, pp. 1405-1411.

Lewis, Stephen L., "Physical Factors Influencing Fish Populations in Pools of a Trout Stream," M.S. Thesis, Montana State University, Bozeman, 1967, p. 34.

Linsley, R. K., Jr., M. A. Kohler, and J. L. H. Paulhus, Applied Hydrology, (Chapter 10), McGraw-Hill Book Co., Inc., New York, 1949, p. 689.

McCrimmon, Hugh and Wen-Hwa Kwain, "Use of Overhead Cover by Rainbow Trout Exposed to a Series of Light Intensities," J. Fish. Res. Bd. Canada, Vol. 23, 1966, pp. 983-990.

Muller, Karl, "Investigations on the Organic Drift in North Swedish Streams," Inst. Freshw. Res. Drottningholm, Vol. 35, 1953, pp. 133-148.

Newman, Murray A., "Social Behavior and Interspecific Competition in Two Trout Species," Physiol. Zool., Vol. 29, 1956, pp. 64-81.

Nilsson, Nils-Arvid, "On the Feeding Habits of Trout in a Stream of Northern Sweden," Inst. Freshw. Res. Drottningholm, Vol. 38, 1957, pp. 154-166.

Peterson, L. W. and T. H. Leik, "A Fisheries Evaluation of North Platte River Water Flows Resulting from Releases at Alcova Reservoir," Wyoming Game and Fish Commission Report, Project 255-5-2, 1958, p. 31.

Shuck, Howard A., "Survival, Population Density, Growth and Movement of the Wild Brown Trout in Crystal Creek," Trans., Amer. Fish Soc., Vol. 73, 1945, pp. 209-230.

Tennant, Donald L., "A Method for Determining Instream Flow Requirements for Fish, Wildlife, and the Aquatic Environment," Proceedings, Instream Flow Requirement Workshop, Pacific Northwest River Basins Commission, Vancouver, Washington, 1972, pp. 3-11.

Weber, D.T., "Effects of Reduced Stream Flows on the Trout Fishery Below Granby Dam, Colorado," M.S. Thesis, Colorado State University, Multilith., 1959, p. 149.

Wyoming Game and Fish Commission, "An Evaluation of Data and Observations on Trial Flow-Releases in the North Platte River Between Kortes and Pathfinder Reservoirs," Substantiating Report, Wyoming Game and Fish Comm., Fish Div., 1963, p. 20.

__________, "An Evaluation of Data and Observations on Trial Flow-Releases in the Green River Below Fontenelle Dam," Admin. Report Wyoming Game and Fish Comm., Fish Div., 1964, p. 15.

APPENDIX A

SUPPLEMENTAL DATA FOR PRIMARY STUDY AREAS

TABLE A-I

PHYSICAL PARAMETERS OF DOUGLAS CREEK #1 STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft^2)	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#1	62	20.8	22.0	0.95	22.6	0.92	2.98
	31	14.3	19.0	0.75	20.3	0.70	2.17
	15.5	10.0	16.0	0.62	18.1	0.55	1.55
	7.8	7.2	14.0	0.51	15.2	0.47	1.08
	3.9	4.5	12.0	0.38	12.2	0.37	0.87
2	62	39.5	38.0	1.04	39.9	0.99	1.57
	31	24.5	24.5	1.02	27.2	0.90	1.27
	15.5	19.0	19.0	1.00	20.1	0.95	0.82
	7.8	17.0	17.0	0.94	19.0	0.89	0.46
	3.9	13.3	13.3	0.78	17.7	0.75	0.29
3	62	41.1	30.0	1.37	31.1	1.32	1.51
	31	31.1	30.0	1.04	30.7	1.01	1.00
	15.5	25.1	26.0	0.96	26.5	0.95	0.62
	7.8	22.8	25.0	0.91	24.5	0.93	0.34
	3.9	18.6	20.0	0.93	20.4	0.91	0.21
4	62	24.2	34.0	0.71	34.5	0.70	2.56
	31	16.3	30.0	0.54	30.4	0.54	1.90
	15.5	10.2	28.0	0.36	28.1	0.36	1.52
	7.8	9.4	24.0	0.39	24.3	0.39	0.83
	3.9	5.2	18.0	0.29	18.3	0.28	0.75
5	62	31.2	32.0	0.98	32.7	0.95	1.99
	31	23.8	32.0	0.74	32.4	0.73	1.30
	15.5	16.7	30.0	0.56	30.2	0.55	0.93
	7.8	14.4	28.0	0.52	28.2	0.51	0.54
	3.9	9.9	22.0	0.45	22.2	0.45	0.39

TABLE A-I (CONT'D)

PHYSICAL PARAMETERS OF DOUGLAS CREEK #1 STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft^2)	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#6	62	30.9	36.0	0.86	36.6	0.84	2.01
	31	18.0	32.0	0.56	34.3	0.52	1.72
	15.5	8.6	31.0	0.28	31.1	0.27	1.80
	7.8	5.8	22.0	0.26	24.2	0.24	1.34
	3.9	2.0	10.0	0.20	10.1	0.20	1.95
7	62	55.0	38.0	1.45	39.1	1.41	1.13
	31	38.6	36.0	1.07	38.8	1.00	0.80
	15.5	29.4	36.0	0.82	36.2	0.81	0.53
	7.8	24.1	34.0	0.71	34.7	0.70	0.32
	3.9	17.3	33.0	0.52	33.3	0.52	0.23
8	62	45.4	26.0	1.75	27.6	1.64	1.37
	31	34.4	24.0	1.43	26.9	1.28	0.90
	15.5	28.0	24.0	1.17	24.6	1.14	0.55
	7.8	25.3	24.0	1.05	24.4	1.04	0.31
	3.9	19.8	20.0	0.99	20.9	0.94	0.20
9	62	40.5	22.0	1.84	24.5	1.65	1.53
	31	34.0	20.0	1.70	24.1	1.41	0.91
	15.5	29.4	20.0	1.47	21.9	1.34	0.53
	7.8	26.2	20.0	1.31	21.6	1.21	0.27
	3.9	22.2	18.0	1.23	19.3	1.15	0.18
10	62	29.6	32.0	0.92	33.3	0.89	2.09
	31	22.0	28.0	0.78	29.1	0.76	1.41
	15.5	16.0	26.0	0.62	26.8	0.60	0.97
	7.8	13.4	19.0	0.71	18.8	0.72	0.58
	3.9	10.0	17.0	0.59	17.5	0.57	0.39

TABLE A-I (CONT'D)

PHYSICAL PARAMETERS OF DOUGLAS CREEK #1 STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft^2)	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#11	62	30.7	36.0	0.85	36.9	0.83	2.02
	31	21.3	30.0	0.71	32.3	0.66	1.46
	15.5	15.7	30.0	0.52	30.3	0.52	0.99
	7.8	13.6	30.0	0.45	30.2	0.45	0.57
	3.9	9.0	27.0	0.33	27.4	0.33	0.43
12	62	27.7	38.0	0.73	38.4	0.72	2.24
	31	20.0	36.0	0.56	38.2	0.52	1.41
	15.5	14.0	35.0	0.40	35.2	0.40	1.11
	7.8	12.0	34.0	0.35	34.2	0.35	0.65
	3.9	7.3	24.0	0.30	25.2	0.30	0.53
13	62	24.9	32.0	0.78	32.8	0.76	2.49
	31	16.0	30.0	0.53	30.6	0.52	1.94
	15.5	11.7	28.0	0.42	28.5	0.41	1.32
	7.8	9.3	27.0	0.34	27.3	0.34	0.84
	3.9	4.2	19.0	0.22	23.2	0.18	0.93
14	62	21.9	20.0	1.10	22.3	0.98	2.83
	31	14.9	14.0	1.06	16.0	0.93	2.08
	15.5	10.3	12.0	0.86	13.4	0.77	1.50
	7.8	8.6	10.0	0.86	11.4	0.76	0.91
	3.9	7.1	10.0	0.71	11.2	0.64	0.55
15	62	27.3	21.0	1.30	22.6	1.21	2.27
	31	21.2	20.0	1.06	21.3	0.99	1.46
	15.5	15.8	20.0	0.79	20.9	0.76	0.98
	7.8	12.8	19.0	0.67	19.8	0.64	0.61
	3.9	9.6	15.0	0.64	15.6	0.61	0.41

TABLE A-I (CONT'D)

PHYSICAL PARAMETERS OF DOUGLAS CREEK #1 STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft^2)	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#16	62	51.0	37.0	1.38	38.9	1.31	1.22
	31	43.1	35.0	1.23	38.4	1.12	0.72
	15.5	37.2	35.0	1.06	36.2	1.03	0.42
	7.8	32.9	34.0	0.97	35.1	0.94	0.24
	3.9	27.2	30.0	0.91	31.0	0.88	0.14

TABLE A-II

PHYSICAL PARAMETERS OF HOG PARK CREEK STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft^2)	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#1	54	34.9	30.0	1.16	32.2	1.08	1.55
	27	26.3	29.0	0.91	30.8	0.85	1.03
	13.5	22.8	29.0	0.78	30.7	0.74	0.59
	6.8	19.6	28.0	0.70	29.7	0.66	0.35
	3.4	15.8	27.0	0.58	28.4	0.56	0.22
2	54	45.5	50.0	0.91	52.6	0.86	1.19
	27	31.0	50.0	0.62	51.9	0.60	0.87
	13.5	22.8	49.0	0.46	50.3	0.45	0.59
	6.8	19.2	33.0	0.58	35.8	0.54	0.35
	3.4	16.2	31.0	0.52	30.7	0.53	0.21
3	54	29.2	27.0	1.08	28.2	1.04	1.85
	27	18.6	27.0	0.69	27.4	0.68	1.45
	13.5	12.6	23.0	0.55	23.2	0.54	1.07
	6.8	8.3	21.0	0.40	21.1	0.39	0.82
	3.4	5.6	18.0	0.31	18.1	0.31	0.61
4	54	17.4	22.0	0.79	22.8	0.76	3.10
	27	10.3	20.0	0.52	20.6	0.50	2.62
	13.5	6.2	16.0	0.39	16.3	0.38	2.18
	6.8	4.0	14.0	0.28	14.1	0.28	1.70
	3.4	2.7	12.0	0.22	12.2	0.22	1.26
5	54	41.9	22.0	1.90	23.2	1.80	1.29
	27	32.9	20.0	1.64	22.9	1.44	0.82
	13.5	28.8	19.0	1.51	20.8	1.38	0.47
	6.8	24.1	18.0	1.34	18.7	1.29	0.28
	3.4	22.2	16.0	1.39	17.8	1.25	0.15

TABLE A-II (CONT'D)

PHYSICAL PARAMETERS OF HOG PARK CREEK STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft^2)	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#6	54	61.6	40.0	1.54	41.2	1.49	0.88
	27	49.7	34.0	1.46	34.7	1.43	0.54
	13.5	41.5	32.0	1.30	32.6	1.27	0.32
	6.8	36.5	32.0	1.14	32.4	1.13	0.19
	3.4	31.1	28.0	1.11	28.5	1.09	0.11
7	54	11.8	6.0	1.97	9.6	1.22	1.48
	27	9.8	6.0	1.63	9.0	1.09	1.28
	13.5	8.5	6.0	1.42	8.5	1.00	1.01
	6.8	7.2	6.0	1.21	8.3	0.88	0.72
	3.4	6.4	6.0	1.07	8.0	0.81	0.45
8	54	32.6	33.0	0.99	36.6	0.89	1.65
	27	19.3	32.0	0.60	34.2	0.56	1.40
	13.5	11.8	30.0	0.39	33.4	0.35	1.15
	6.8	6.9	26.0	0.27	29.2	0.24	0.99
	3.4	3.4	19.0	0.18	21.2	0.14	1.00
9	54	27.7	25.0	1.11	26.3	1.05	1.95
	27	20.8	25.0	0.83	25.8	0.80	1.30
	13.5	16.0	25.0	0.64	25.3	0.63	0.84
	6.8	11.4	23.0	0.50	23.4	0.49	0.60
	3.4	8.5	22.0	0.39	22.2	0.37	0.40
10	54	22.2	18.0	1.23	20.1	1.10	2.43
	27	19.1	18.0	1.06	19.9	0.96	1.41
	13.5	15.5	17.0	0.91	19.4	0.80	0.87
	6.8	13.1	16.0	0.82	17.4	0.75	0.52
	3.4	11.4	16.0	0.71	17.2	0.66	0.30

TABLE A-II (CONT'D)

PHYSICAL PARAMETERS OF HOG PARK CREEK STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft^2)	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#11	54	25.8	18.0	1.43	19.4	1.33	0.0
	27	21.4	18.0	1.19	19.1	1.12	0.0
	13.5	16.8	16.0	1.05	18.6	0.90	0.0
	6.8	12.8	15.0	0.85	15.7	0.81	0.0
	3.4	10.0	14.0	0.72	13.6	0.74	0.0
12	54	40.4	20.0	2.02	23.2	1.74	1.34
	27	33.6	20.0	1.68	22.6	1.49	0.80
	13.5	28.9	20.0	1.44	22.1	1.31	0.47
	6.8	25.3	19.0	1.33	21.0	1.20	0.27
	3.4	22.2	19.0	1.17	20.6	1.08	0.15
13	54	17.2	12.0	1.43	14.7	1.17	0.0
	27	12.6	12.0	1.05	14.0	0.90	0.0
	13.5	10.8	11.0	0.98	12.7	0.85	0.0
	6.8	8.0	9.0	0.89	10.5	0.77	0.0
	3.4	7.2	8.0	0.91	9.5	0.76	0.0
14	54	27.6	17.0	1.62	19.2	1.44	0.0
	27	25.0	17.0	1.47	19.0	1.32	0.0
	13.5	22.8	17.0	1.34	18.8	1.21	0.0
	6.8	20.5	17.0	1.20	18.4	1.11	0.0
	3.4	17.0	16.0	1.06	17.4	0.98	0.0
15	54	29.9	23.0	1.30	26.2	1.14	1.81
	27	21.3	23.0	0.92	25.3	0.84	1.27
	13.5	18.2	23.0	0.79	25.0	0.73	0.74
	6.8	14.2	23.0	0.62	24.5	0.58	0.48
	3.4	13.9	23.0	0.61	24.5	0.57	0.24

TABLE A-III

BROOK AND RAINBOW TROUT COVER ANALYSIS FOR DOUGLAS CREEK #1 AND HOG PARK CREEK STUDY AREAS

Flow (% ADF)	Species	Total No. Sampled	No. in Rubble-Boulder Areas	No. in Under-Cut Banks	Mean Depth (ft)	Mean Velocity (fps)
100%	Brook	43	19	24	1.49	0.14
	Rainbow	5	2	3	1.44	0.22
50%	Brook	34	9	25	1.24	0.21
	Rainbow	8	1	7	1.47	0.04
25%	Brook	38	10	28	1.12	0.06
	Rainbow	5	0	5	1.65	0.00
12.5%	Brook	30	16	14	0.86	0.04
	Rainbow	7	1	6	1.51	0.07
Total	Brook	145	54	91		
	Rainbow	25	4	21		
% Total	Brook	100%	37%	63%		
	Rainbow	100%	16%	84%		

APPENDIX B

DATA FOR SECONDARY STUDY AREAS

TABLE B-I

PHYSICAL PARAMETERS OF DOUGLAS CREEK #2 STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft^2)	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#1	46	31.2	34.0	0.92	35.7	0.88	1.47
	18	18.4	34.0	0.54	35.0	0.53	0.98
	5	13.3	34.0	0.39	34.6	0.38	0.38
	2.5	12.0	34.0	0.35	33.4	0.36	0.21
2	46	16.1	22.0	0.73	22.7	0.71	1.71
	18	7.5	20.0	0.38	20.2	0.37	1.44
	5	3.4	12.0	0.28	12.0	0.28	0.88
	2.5	2.0	9.0	0.22	9.2	0.22	0.75
3	46	11.3	8.0	1.41	10.4	1.09	1.49
	18	5.8	8.0	0.72	9.1	0.63	0.75
	5	3.0	8.0	0.38	8.5	0.36	0.60
	2.5	2.4	8.0	0.31	8.4	0.29	0.37
4	46	18.0	15.0	1.20	15.8	1.14	0.85
	18	10.9	12.0	0.91	12.7	0.86	0.33
	5	7.8	11.0	0.64	11.6	0.67	0,10
	2.5	7.0	9.0	0.78	9.5	0.74	0.01
5	46	11.0	14.0	0.79	15.1	0.73	1.32
	18	6.4	13.0	0.49	13.4	0.48	0.38
	5	4.1	13.0	0.32	13.2	0.31	0.33
	2.5	3.4	13.0	0.26	12.2	0.28	0.29
6	46	21.2	20.0	1.06	22.0	0.96	1.20
	18	14.2	20.0	0.71	21.1	0.67	0.54
	5	10.8	18.0	0.60	19.1	0.57	0.22
	2.5	9.4	18.0	0.52	19.1	0.49	0.18

TABLE B-I (CONT'D)

PHYSICAL PARAMETERS OF DOUGLAS CREEK #2 STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft^2)	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#7	46	23.7	28.0	0.85	29.9	0.79	0.87
	18	15.4	26.0	0.59	27.2	0.56	0.50
	5	8.6	19.0	0.45	19.7	0.43	0.21
	2.5	6.6	15.0	0.44	15.7	0.42	0.08
8	46	6.1	10.0	0.61	11.1	0.55	1.71
	18	2.8	6.0	0.46	6.4	0.43	1.90
	5	1.2	5.0	0.24	5.2	0.22	0.95
	2.5	0.6	4.0	0.14	4.2	0.13	0.90

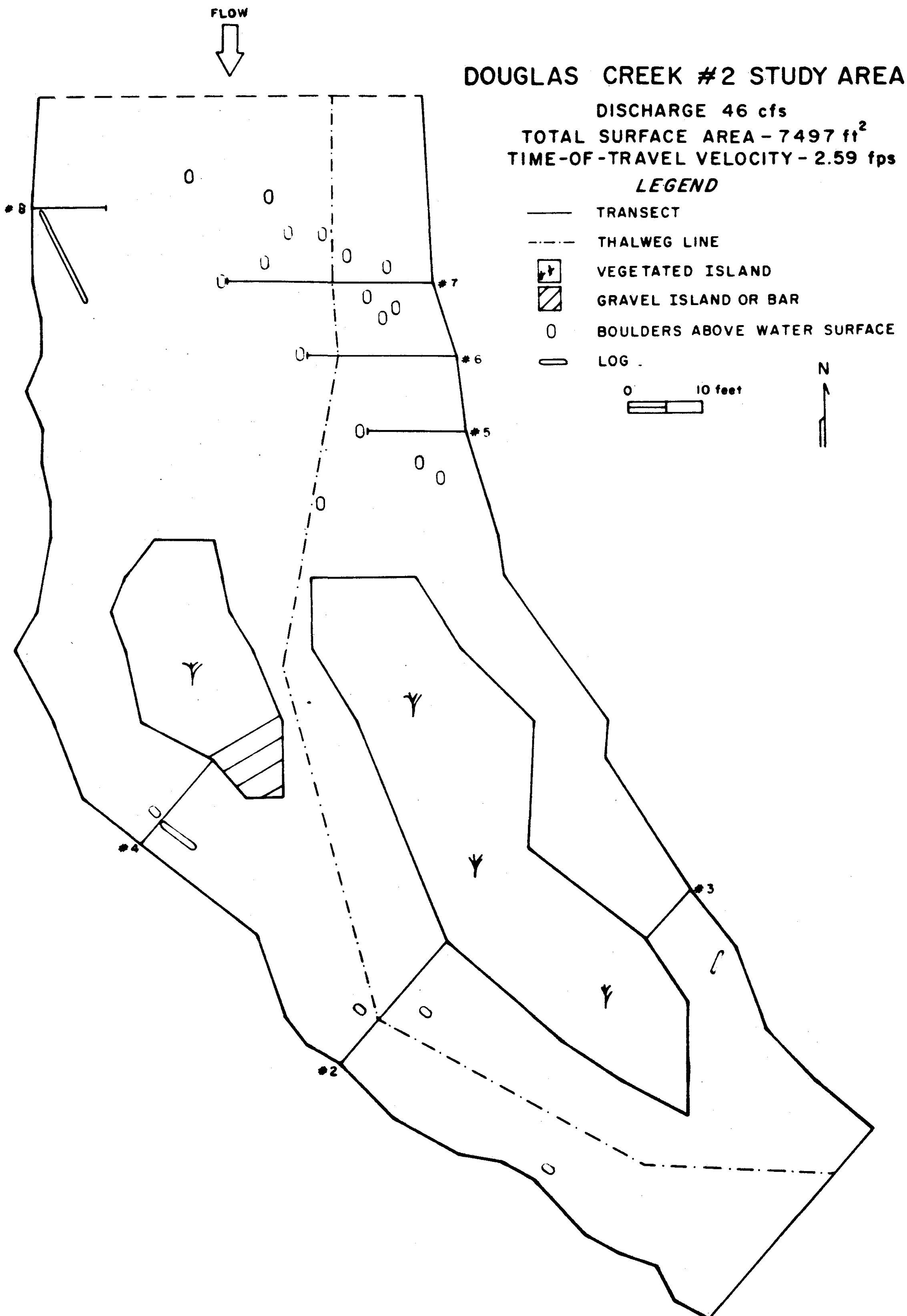


Figure B-1. Surface area map of the Douglas Creek No. 2 study area at 46.0 cfs.

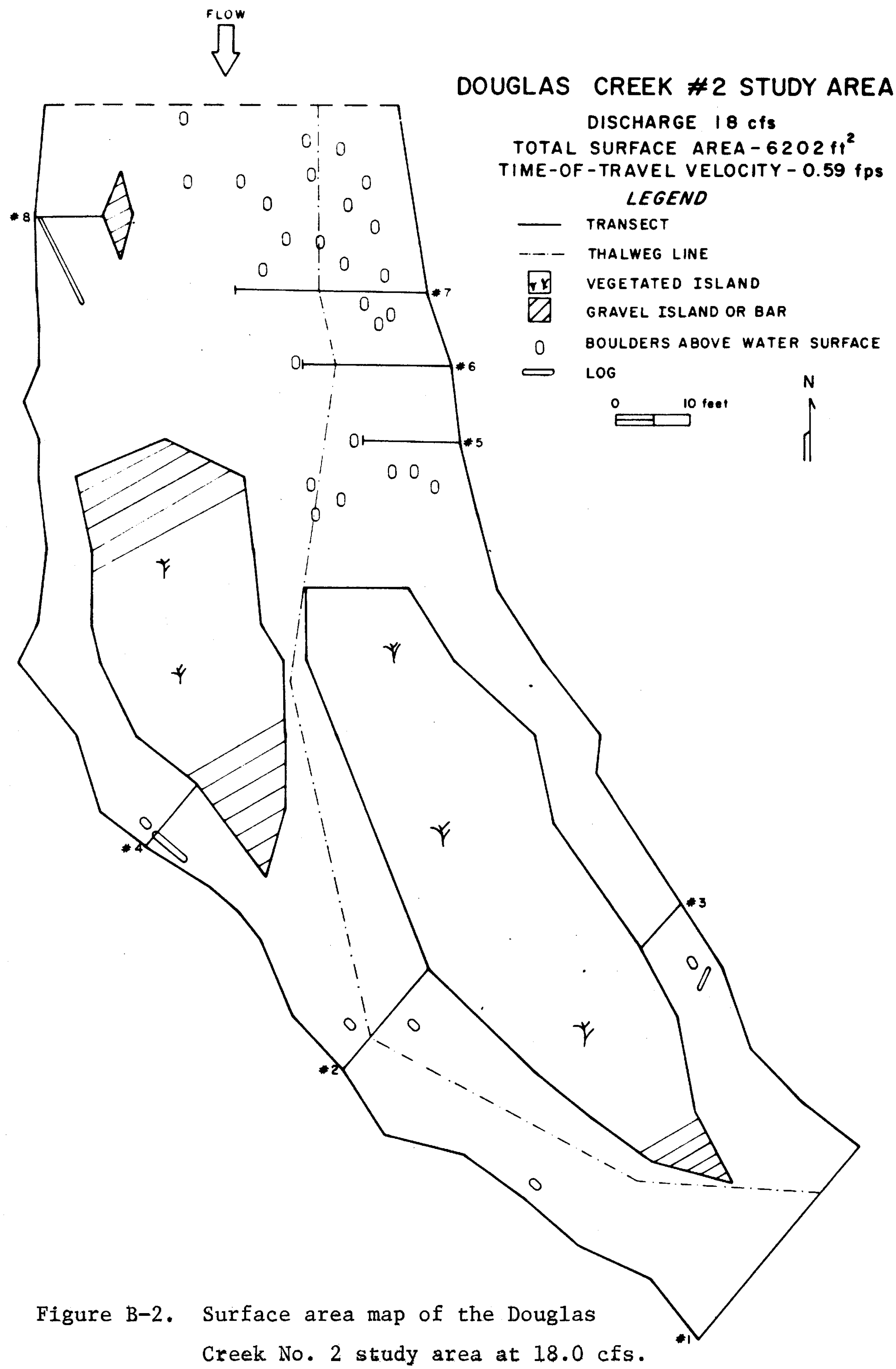


Figure B-2. Surface area map of the Douglas Creek No. 2 study area at 18.0 cfs.

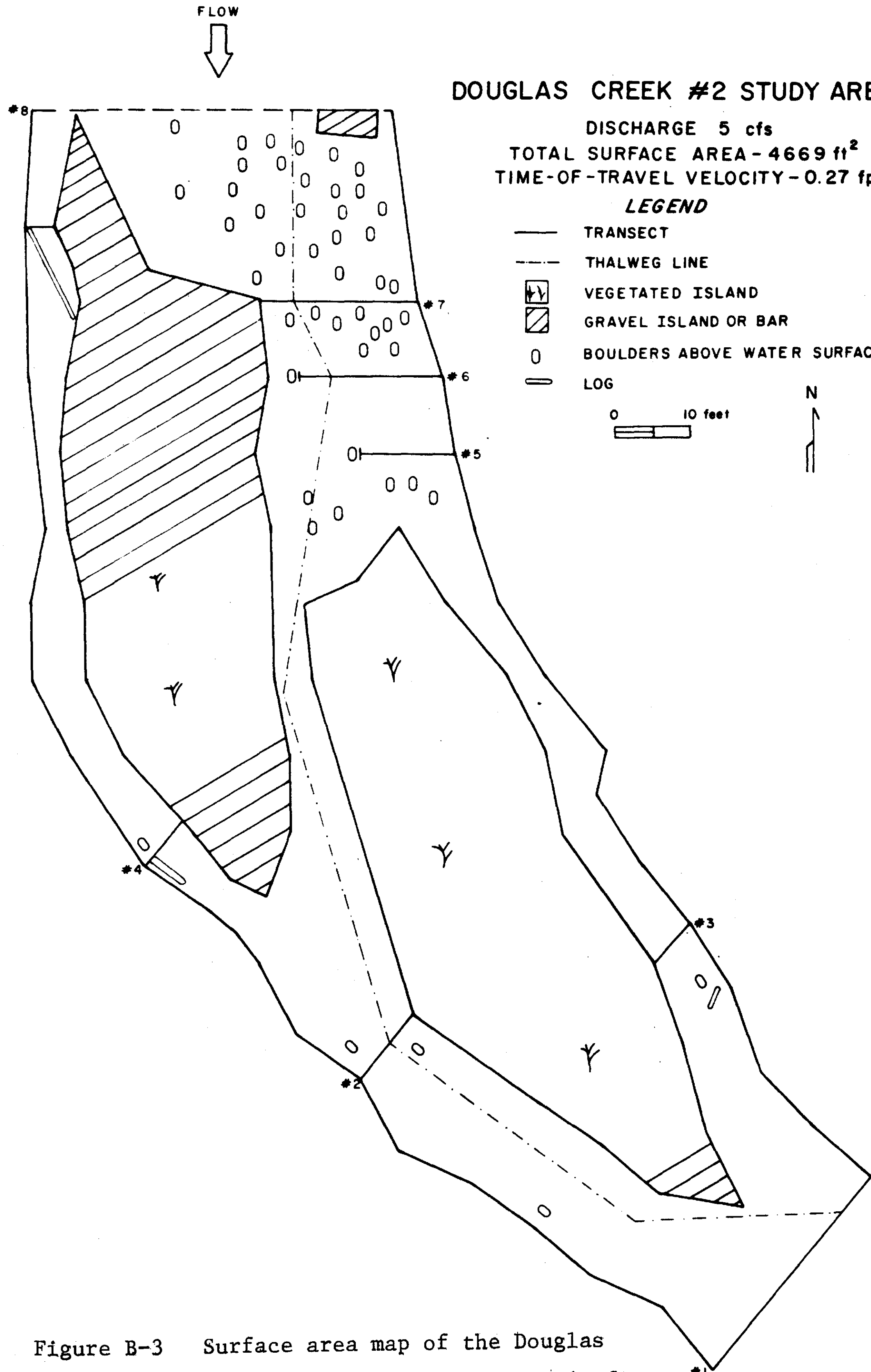


Figure B-3 Surface area map of the Douglas Creek No. 2 study area at 5.0 cfs.

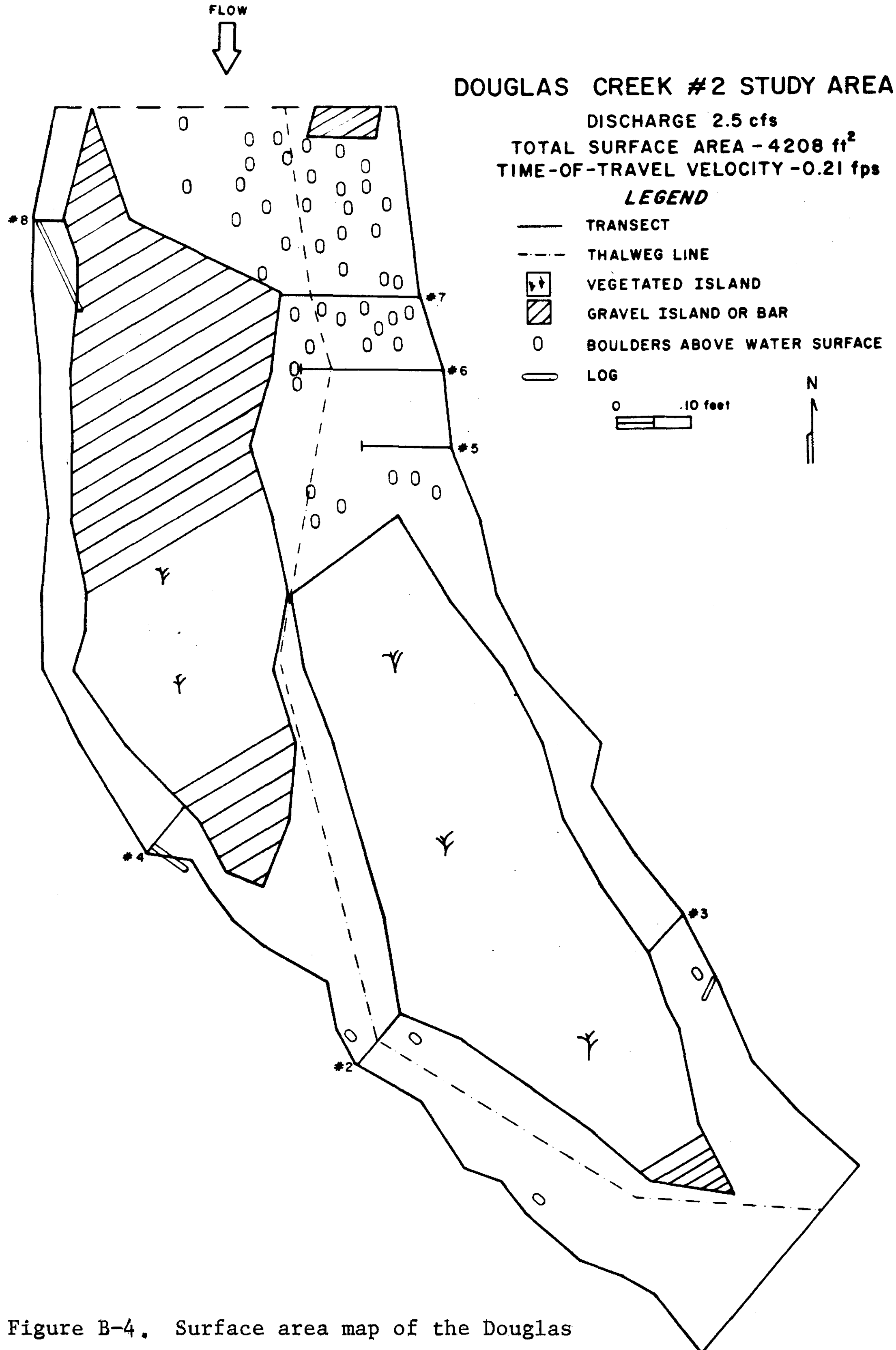
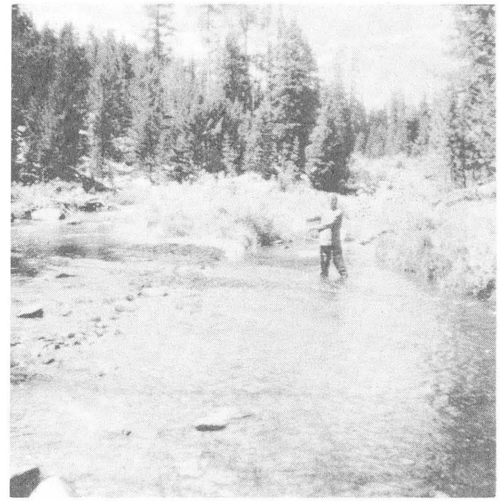


Figure B-4. Surface area map of the Douglas Creek No. 2 study area at 2.5 cfs.

46.0 cfs

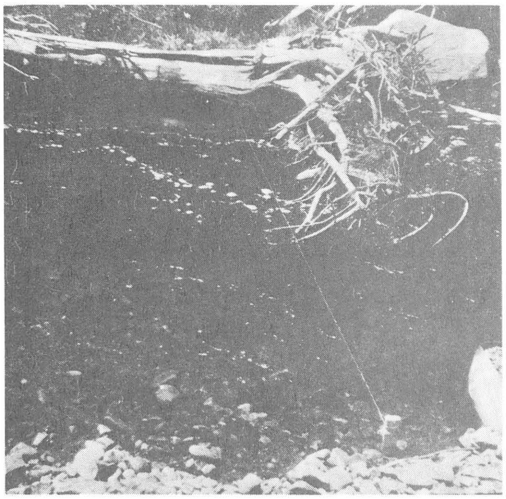
18.0 cfs



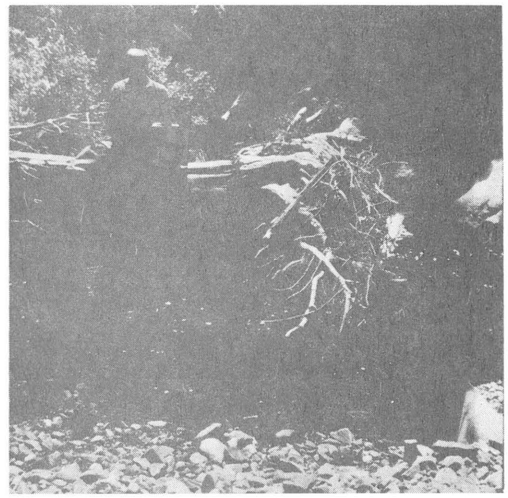
2.5 cfs

Figure B-5. Transect No. 1 in the Douglas Creek No. 2 Study Area at 46.0, 18.0 and 2.5 cfs, looking upstream.

46.0 cfs



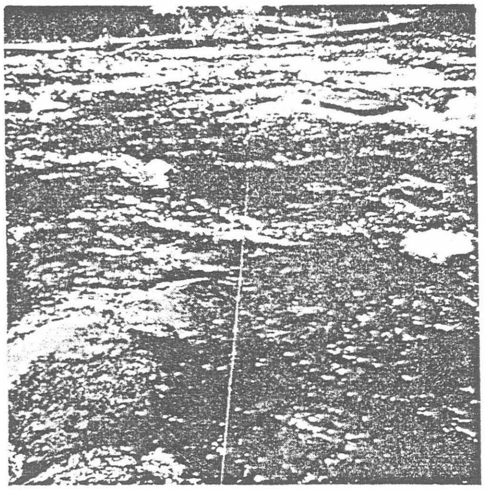
18.0 cfs



2.5 cfs

Figure B-6. Transect No. 4 in the Douglas Creek No. 2 Study Area at 46.0, 18.0 and 2.5 cfs.

46.0 cfs



18.0 cfs

2.5 cfs

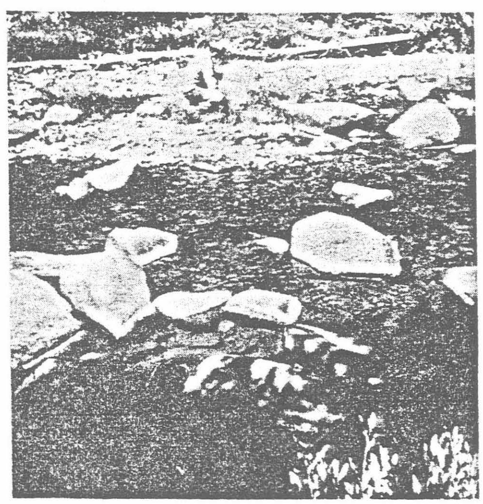


Figure B-7. Transect No. 7 in the Douglas Creek No. 2 Study Area at 46.0, 18.0 and 2.5 cfs.

TABLE B-II

PHYSICAL PARAMETERS OF LARAMIE RIVER STUDY AREA TRANSECTS

Transect Number	Flow (cfs)	Cross-Sectional Area (ft ^{2})	Top Width (ft)	Mean Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Mean Velocity (fps)
#1	160	102.0	82.0	1.24	82.9	1.23	1.57
	10	31.2	60.0	0.52	60.4	0.52	0.32
2	160	38.8	28.0	1.39	29.4	1.32	0.64
	10	10.0	14.0	0.72	14.4	0.70	0.00
3	160	16.8	32.0	0.53	32.5	0.52	1.47
	10	0.0	0.0	0.00	0.0	0.0	0.0
4	160	133.0	101.0	1.32	101.7	1.31	1.20
	10	66.2	85.0	0.78	85.1	0.78	0.15

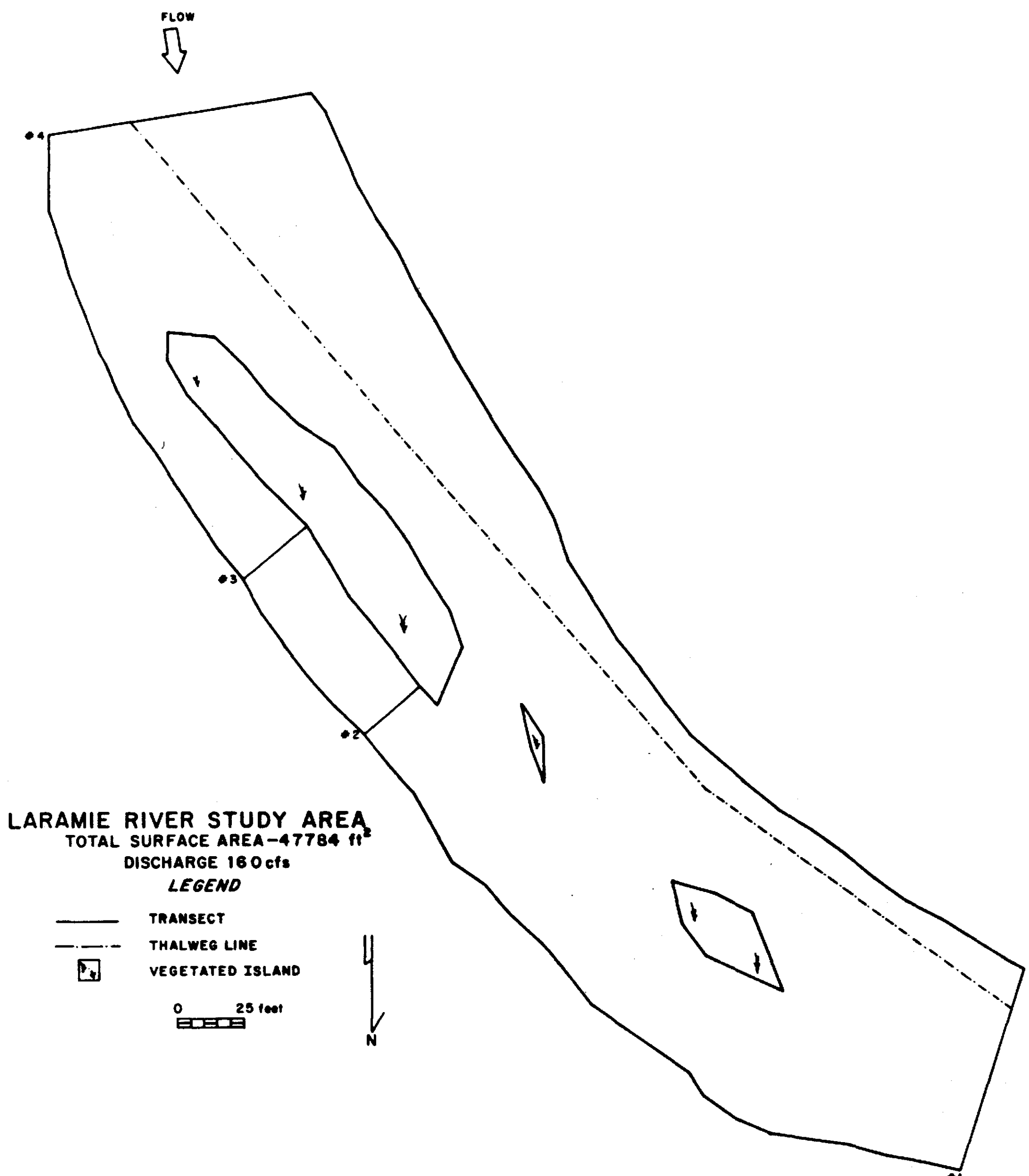


Figure B-8. Surface area map of the Laramie River study area at 160 cfs.

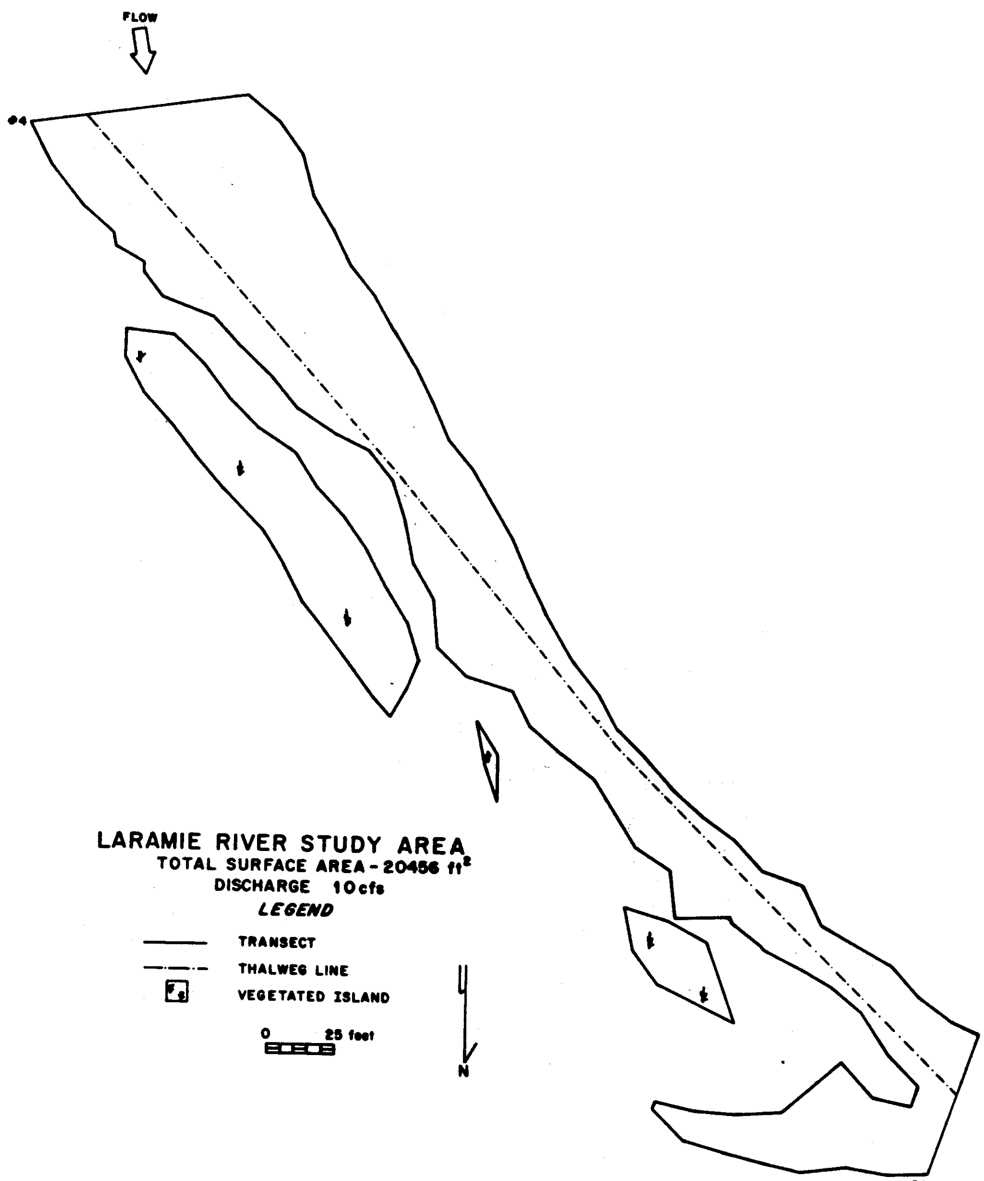


Figure B-9. Surface area map of the Laramie River study area at 10 cfs.

160 cfs 10 cfs

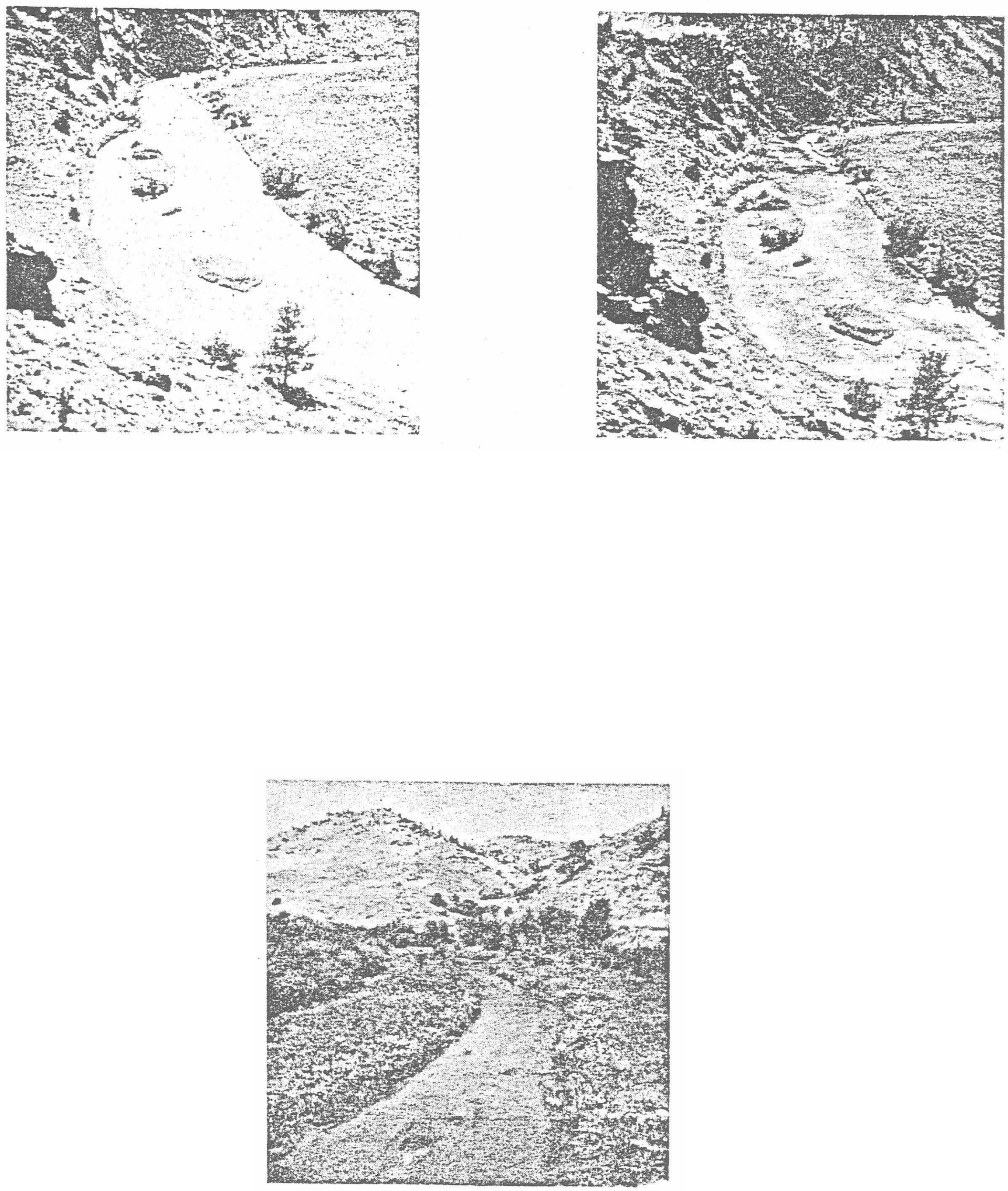


Figure B-10. Laramie River Study Area (top photos) above the Wheatland tunnel diversion before and after dewatering in the fall. The river channel below the diversion (bottom photo) has become heavily vegetated after many years of dewatering.

APPENDIX C

GLOSSARY OF TERMS

GLOSSARY OF TERMS

Aspect - The compass direction, looking downslope, toward which a sloping land area faces.

Average Daily Flow - The mean daily rate of discharge at a given stream location, usually expressed in cubic feet per second, computed for the period of record by dividing the total volume of runoff, in acre-feet, by two times the number of days in the period.

Cover - Areas of shelter in a stream providing fish protection from predators and a place in which to rest and conserve energy due to a reduction in the force of the current.

Cross-Sectional Area - The area of water on a transect line at right angles to the thalweg computed as the sum of the products of the depths and representative widths across a stream.

Cubic Feet Per Second (CFS) - A unit expressing rates of discharge. One cubic foot per second is equal to the discharge through a rectangular cross-section, one foot wide and one foot deep, flowing at an average velocity of one foot per second.

Drainage Area - The entire area drained by a river or system of connecting streams such that all streamflow originating in the area is discharged through a single outlet.

Drainage Density - The relative density of natural drainage channels in a given area, usually expressed in terms of miles of stream channel per square mile of drainage area. The value is obtained by dividing the total length of stream channels in the area in miles by the drainage area in square miles. Generally, a drainage density of one or more indicates "good" drainage.

Flow Duration Curve - A cumulative frequency curve that shows the percent of time during which specified rates of flow were equalled or exceeded during a given period.

Hydraulic Radius - The cross-sectional area of a stream of water divided by the length of that part of its periphery in contact with its conducting channel; the ratio of area to wetted perimeter.

Mean Depth - The average depth of water in a stream channel, which is equal to the cross-sectional area divided by the top width.

Mean Elevation of a Drainage Basin - The average elevation (feet MSL) of a drainage basin, computed by summing the products of the areas between contour lines and the average elevation between contours and dividing this sum by the total area of the drainage basin.

Mean Water Velocity - The average velocity of water in a stream channel, which is equal to the discharge in cubic feet per second divided by the cross-sectional area in square feet. For a specific point location, it is the velocity measured at 0.6 of the depth or the average of the velocities as measured at 0.2 and 0.8 of the depth.

Median Elevation of a Drainage Basin - The elevation (feet MSL) at which 50% of the drainage area is of a lower elevation and 50% is of a higher elevation.

Minimum Streamflow for Trout - That flow which, when discharged below a water development project, will at least maintain the existing or natural trout population which was present previous to development. It is hypothesized to be that flow which is greater than the flow range in which the rate of decrease of trout habitat is greatest.

Streamflow - The discharge which occurs in a natural channel.

Stream Order - A method of classifying streams as part of a drainage basin network. Tributaries which have no branches are designated as of the first order, streams which receive only first order tributaries are of the second order, larger branches which receive only first order and second order tributaries are designated third order, and so on, with the main stream being always of the highest order.

Stream Slope - The total fall in elevation between two points on a stream divided by the stream length between the two points.

Thalweg Line - The main thread of the current and flow along a channel.

Top Width - The width of the effective area of flow across a stream channel.

Wetted Perimeter - The length of the wetted contact between the stream of flowing water and its containing channel, measured in a plane at right angles to the direction of flow.