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STREAM CHANNEL MODIFICATION TO ENHANCE TROUT HABITAT UNDER LOW FLOW CONDITIONS

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ABSTRACT

The traditional impetus for stream improvement for fisheries has centered around restoring channels which have been physically abused by the activities of man (road construction, mining, livestock grazing, etc.) in the presence of an ample water supply. In an increasing number of situations in the Rocky Mountain region, the fishery problems associated with low natural flows are compounded by diversion for municipal, agricultural, or other uses.

Based on water depths and velocities required for various phases of the trout life cycle, channel modification to constrict and consolidate low flows and thereby increase trout habitat in Douglas Creek was carried out in the summer of 1974.

Artificial overhangs and low profile gabion structures were found to be effective, easy to install, strong enough to withstand high discharge, and fairly inexpensive.

Effects of the modification on the fishery cannot be quantified without several more years of evaluation, however trout were found using the artificial overhangs and in the vicinity of all other structures.

Key Words: Channel Modification/Trout Habitat/Stream Improvement/ Gabion/Flow Consolidation/Low Profile Structure/Trout Cover/Instream Flows/Stream Resource Maintenance Flows

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

CHAPTER I

INTRODUCTION

The natural pattern of streamflow in much of the Rocky Mountain region is characterized by high runoff discharges during the spring and early summer months, followed by a gradual recession of flows throughout summer and early fall. By late fall a baseflow, which remains fairly constant through the winter, is reached. In an increasing number of situations, this natural flow regime is markedly disrupted as a result of water storage facilities and diversions for agricultural, industrial, and municipal use. In those cases where the alteration causes severe dewatering for extended periods of time, conditions may be created within the stream which are detrimental, or even disastrous, to biological systems, particularly fisheries. In an effort to prevent this, extensive research has been done in recent years to identify the instream requirements of fish. These flow requirements can be divided into three categories: 1) spawning needs; 2) food and feeding needs; and 3) shelter needs.

Thompson (1972) suggests that flows required by salmonids are based on water depth and velocity expressed in terms of four biological activities: passage, spawning, incubation, and rearing. He explains methods to determine the flow needed for each of these activities and gives the following as guidelines: trout passage, minimum depth of 0.4 feet and maximum velocity of 4.0 feet per second (fps); trout spawning, water velocity of 1.0 to 3.0 fps and water depth of 0.4 to 0.6 feet; rearing, riffle-pool ratio near 50:50, with riffle velocities 1.0 to 1.5 fps and pool velocities of 0.3 to 0.8 fps, and approximately 60 percent of the riffle area covered by flow of adequate depth. Hoppe and Finnell (1970) suggest that a minimum water velocity of 1.5 fps is necessary for suitable trout spawning habitat. Kennedy (1967) found that water velocities ranging from 1.0 to 1.2 fps and depths from 3 to 6 inches produced the greatest abundance of trout food organisms, an observation which was substantiated by Ruggles (1966). Kennedy (1967) also observed that the majority of organisms preferred substrate composed of rocks 2.6 to 7.0 inches in diameter. Cover needs have been studied by Wesche (1973), Kraft (1968), Wipperman (1969), and Boussu (1954). Wesche noted that brown trout in smaller streams prefer undercut banks having a water depth of at least 0.5 feet and a width of at least 0.3 feet. Kraft observed that while flow reductions of 25 to 75 percent caused notable decreases in velocity, cover losses exceeded 36 percent in only one of six test areas. Wipperman concluded that in Blacktail Creek, Montana, cover may have played a major role in maintaining brook trout populations during high levels of dewatering. He found that 90 percent volume reductions below low normal summer flow for 72 days failed to significantly influence cover. The importance of cover losses was demonstrated by Boussu. His work showed that brush and undercut bank removal decreased numbers and pounds of legal-sized trout, while the addition of brush cover increased total pounds of trout in four experimental sections by 258.1 percent. A preference factor of brown trout for overhanging cover as opposed to instream rubble-boulder areas and a system for measuring cover were developed by Wesche (1973). Using this system, Wesche (1974) began to quantitatively define the relationship between available cover and the standing crops of trout present in smaller streams.

Methodologies for recommending minimum flows for fisheries have been developed with these ecological needs as a basis. Collings (1972) developed the "wetted-perimeter" method, which is based on the fact that, in typical channels, the wetted perimeter increases rapidly with increasing discharge to a point where the majority of the streambed is covered. Past this "breaking point" increases in flow bring about only small increments in wetted perimeter. These "breaking points," in association with certain velocities and water quality considerations, are assumed to be optimal for fish rearing. Tennant (1972) developed the Montana Method, which is based on percentages of the mean annual flow of record and varies on a half-year basis to coincide with various phases of the fish life cycle. The method developed by Wesche (1973) utilizes the combined effects of hydraulic parameters, surface-water types, and available trout cover in relation to the average daily flow (ADF) over the period of record. Other studies dealing with recommendation of suitable minimum flows for stream fisheries have been carried out by the United States Forest Service (Chrostowski, 1972), the Oregon Fish Commission (Pearson et al., 1970), the State of California (Delisle and Eliason, 1961), and the Northern Great Plains Resource Program (1974).

There are currently numerous situations, however, in which the flow regimes below dams were determined before minimum fishery flow criteria were developed, and some situations where the regimes were determined ignoring minimum flow criteria. In many of these instances, priorities and demands on the available water prevent application of minimum flow criteria, and the fishery is forced to adapt to vastly fluctuating regimes, ranging from flooding to virtually dry conditions in a single season. Examples of this phenomenon can be seen on Douglas Creek immediately below Rob Roy dam and the Cheyenne diversion (Water Resources Data for Wyoming, 1972) and the Big Laramie River below Wheatland Reservoir Number 2 in Wyoming (Pugh, 1970). It seems desirable that, for situations where low flows cannot be augmented to the recommended 25 to 30 percent of the average daily flow (Wesche, 1973, and Tennant, 1972), methods and techniques could be developed which make the best possible fishery use of the limited water in the channel. This means consolidating low flows to maximize depth, velocity, and cover with the available water.

The concept of "stream improvement" is not new. In 1932, Hubbs, Greeley and Tarzwell published one of the first comprehensive reports on stream improvement for enhancing fisheries in Michigan. A number of other other projects were carried out in the 1930's by the federal government through the Civilian Conservation Corps (Ehlers, 1956), but, for these early projects, emphasis was placed on theory and methods rather than increased trout production. Shetter, Clark, and Hazzard (1946) published what is generally agreed to be the first comprehensive before-and-after evaluation of stream improvement carried out over a long period of time. Their results indicated an increase in both numbers and pounds of brook trout over a five-year period after improvement. Other subsequent studies have shown much the same thing--that stream improvement, done properly, increases the size and numbers of fish in the improved section (Warner and Porter, 1960; Saunders and Smith, 1962; and Hunt, 1969).

In 1973, the Office of Water Resources Research of the Department of the Interior in Washington, D.C., granted the University of Wyoming Water Resources Research Institute funds for the current project to investigate the possibilities for enhancement of fisheries in severely dewatered channels by flow consolidation using low-profile structures. Assuming that the basic problem (lack of water) cannot be corrected, the objectives of this research were:

1) To maximize available trout habitat in streams having extended periods of low flow insufficient to sustain a fishable trout population. This was done by designing and field testing various types of low-profile stream modification devices in regard to their ability to withstand high flows and create habitat diversity, as well as their effectiveness in the consolidation of low flows and aesthetic appeal.

2) To determine the cover preferences of brook and brown trout when exposed to natural cover in a dewatered condition, as opposed to artificial cover introduced at the same flow level.

3) To carefully monitor costs of such a project, and attempt to develop and apply techniques which minimize the cost of stream improvement.

CHAPTER II

DESCRIPTION OF STUDY AREA

The area studied was a section of Douglas Creek 1.75 miles downstream from its confluence with Lake Creek. The Douglas Creek drainage lies in Albany and Carbon counties in the Snowy Range of the Medicine Bow Mountains in southeastern Wyoming (Figure 1). It rises at an elevation of 10,400 feet above mean sea level (msl) and flows south toward the Wyoming-Colorado border, then northwest and empties into the North Platte River at an elevation of approximately 7,500 feet msl, 29 miles from its headwaters. In the upper reaches, the creek flows through typical Rocky Mountain terrain being forested on either side, breaking occasionally into grassy meadows. This gradually gives way at lower elevations to sagebrush and grassland hills. Figure 2 shows a map of the drainage basin.

The total area drained by Douglas Creek above the study site is 72.4 square miles. Vegetation present throughout the drainage basin is primarily lodgepole pine (*Pinus contorta*) forest with various grasses and sagebrush (*Artemesia* sp.) on the open slopes. The flood plain is vegetated primarily with various willows (*Salix* sp.), sedges (*Carex* sp.), and grasses. The general geology of the area has rocks classified in two categories; those of Precambrian and those of Cenozoic age (Currey, 1965).

Since the land, controlled almost entirely by the U.S. Forest Service, is public domain, uses consist of livestock grazing in the

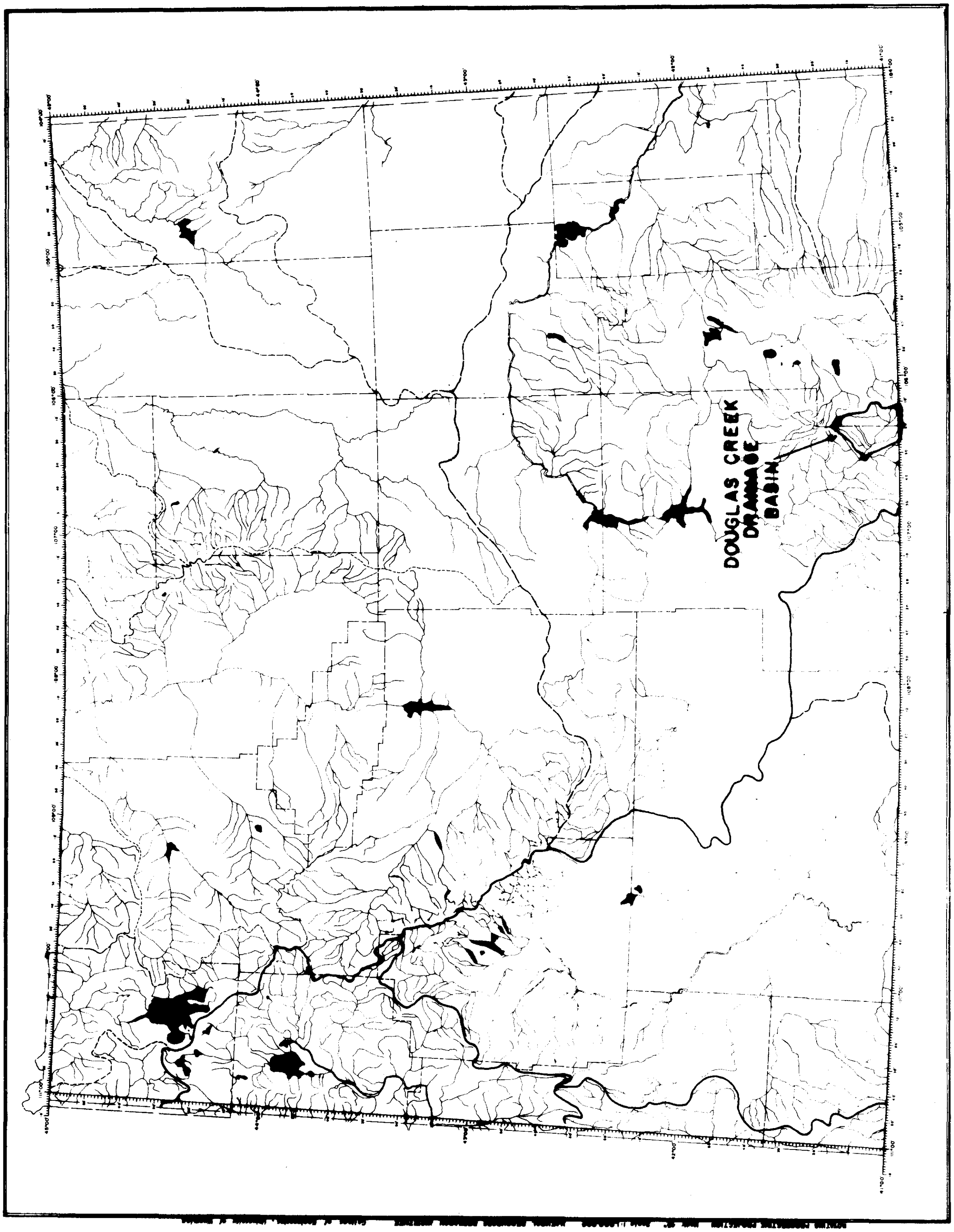


Figure 1. Wyoming Map Showing Location of Douglas Creek Drainage Basin

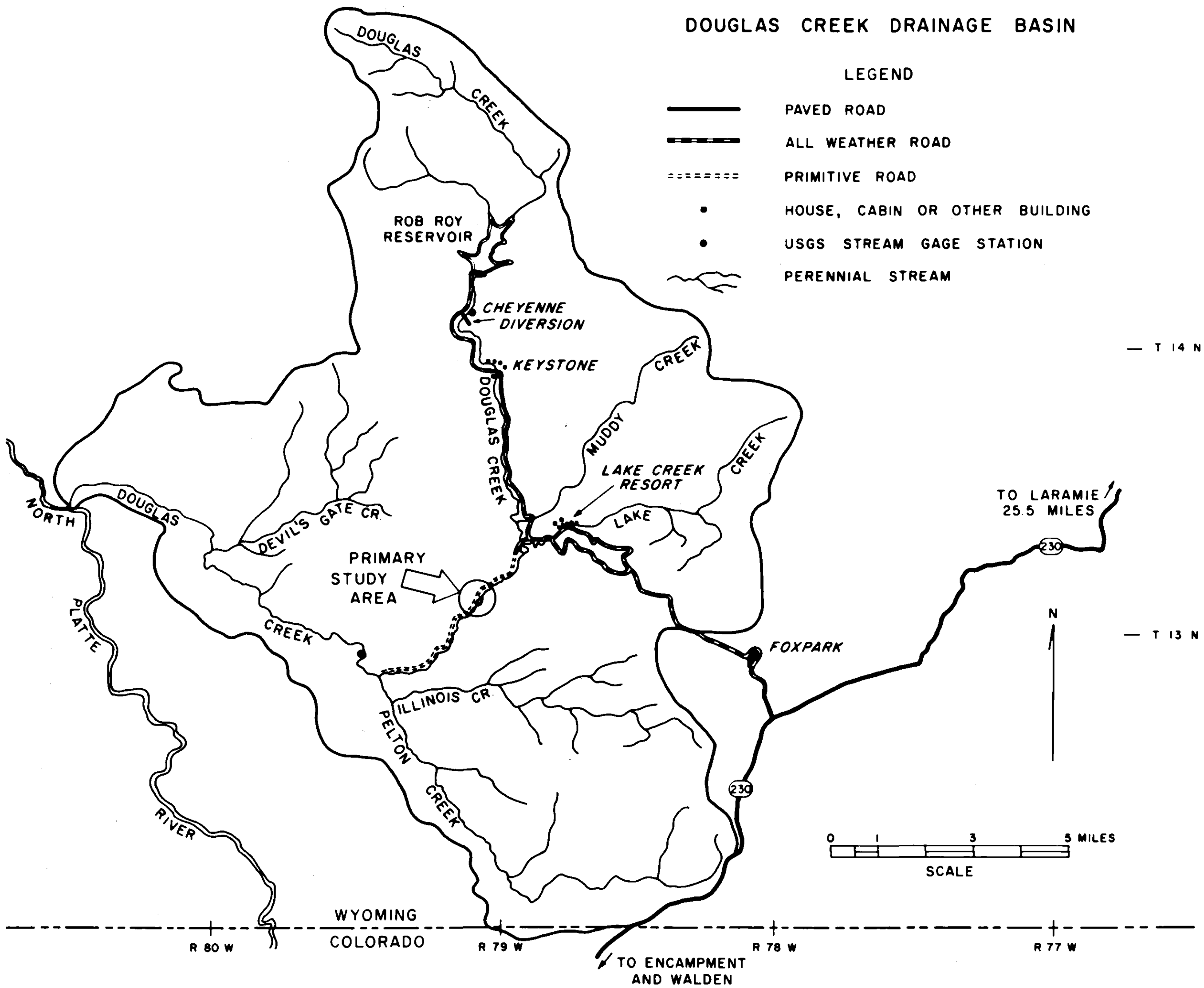


Figure 2. Douglas Creek Drainage Basin Showing Location of the Study Area.

summer months, timber harvesting, some limited mining activity for copper and gold, and public recreation in the forms of fishing, camping, hiking, backpacking, and big game hunting for deer and elk. Major developments in the area include: 1) Fox Park, a small lumber mill settlement located approximately 7 miles overland from the site; 2) Lake Creek resort, a group of summer cabins 2.75 miles upstream from the study site; 3) Rob Roy reservoir (the basin's only impoundment) and the Cheyenne diversion complex located 8.5 and 7.35 miles upstream, respectively; and 4) the old mining town of Keystone which now consists only of summer cabins, 6.4 miles upstream on the banks of Douglas Creek. The last two of these developments deserve special mention.

In the early 1960's, the city of Cheyenne, Wyoming, recognized the need for more municipal water than was present in the surface and groundwater formations in its immediate area. The city government secured rights to Douglas Creek water, agreeing to replace the amount diverted with water from the unused portion of Wyoming's Colorado River allotment (J. T. Banner and Associates, Inc., 1961). A system of pipelines was then built to divert the needed amounts of water to storage facilities. Rob Roy reservoir and the Cheyenne diversion were built to meet these needs and, at present, the two structures together almost completely control the discharge in Douglas Creek throughout the year.

The town of Keystone grew out of the discovery, in the late 1800's, of gold in the basin. As the placer operation was carried out through the years, the gravel in the streambed of Douglas Creek proper was dredged and sifted for gold ore, then deposited in large piles on the stream banks, leaving a disrupted substrate in the channel. In the years since the operation ceased in 1938, the banks have partially revegetated and the streambed has stabilized, although huge unsightly piles of gravel still line the stream.

The primary study site on Douglas Creek (DCLC) is a 907 foot section located 1.75 miles downstream from the mouth of the Lake Creek (T13N, R79W, Section 15). The WRRI gage installation at the site has only been operating since 1973, so most discharge records for the creek were obtained from the USGS gages below Rob Roy dam and below the Pelton Creek confluence. Records from the gage below Rob Roy 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 discharge over a period of 9 years was 32.9 cfs. For the Pelton Creek gage, the maximum recorded discharge was 1,630 cfs on June 7, 1975, while the minimum was 2.3 cfs in August and September of 1967. The average discharge over a period of 25 years is 78.7 cfs. Mean monthly discharges and flow duration curves for the two gages are compared in Figures 3 and 4.

The site was chosen for this particular study because: 1) dewatered conditions are present for an extended period of time each year, due partly to the low natural flow patterns and partly to the diversion of water to Cheyenne; 2) it is located on public land, thereby permitting the public to benefit from the improved fishery conditions; and 3) it is near enough to Laramie that year-round access is available.

The actual study site consists of a main channel (MC) which carries most of the discharge (width, 50 to 60 feet), and a side

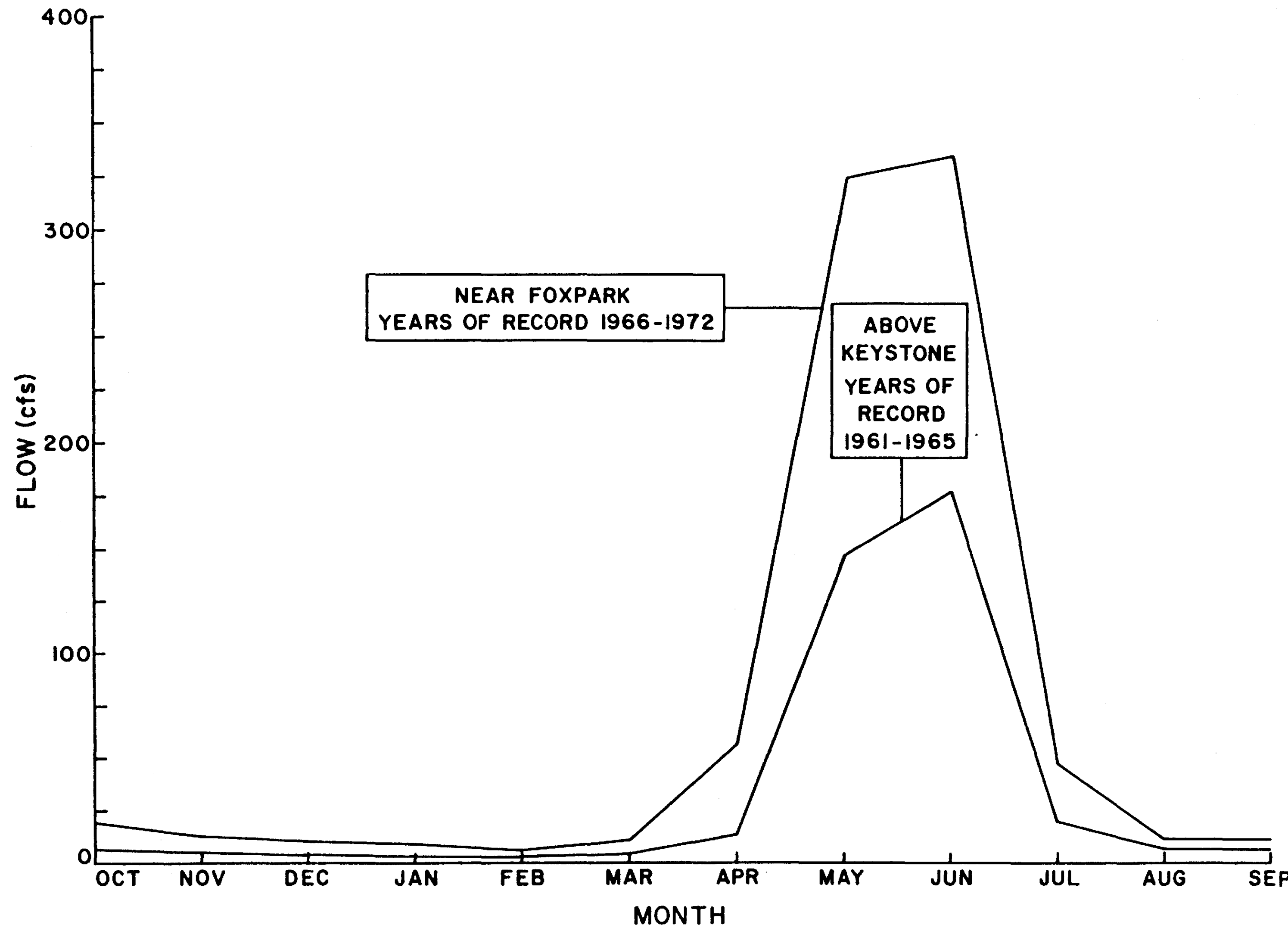


Figure 3. Mean Monthly Discharges for Douglas Creek Near Foxpark and Above Keystone

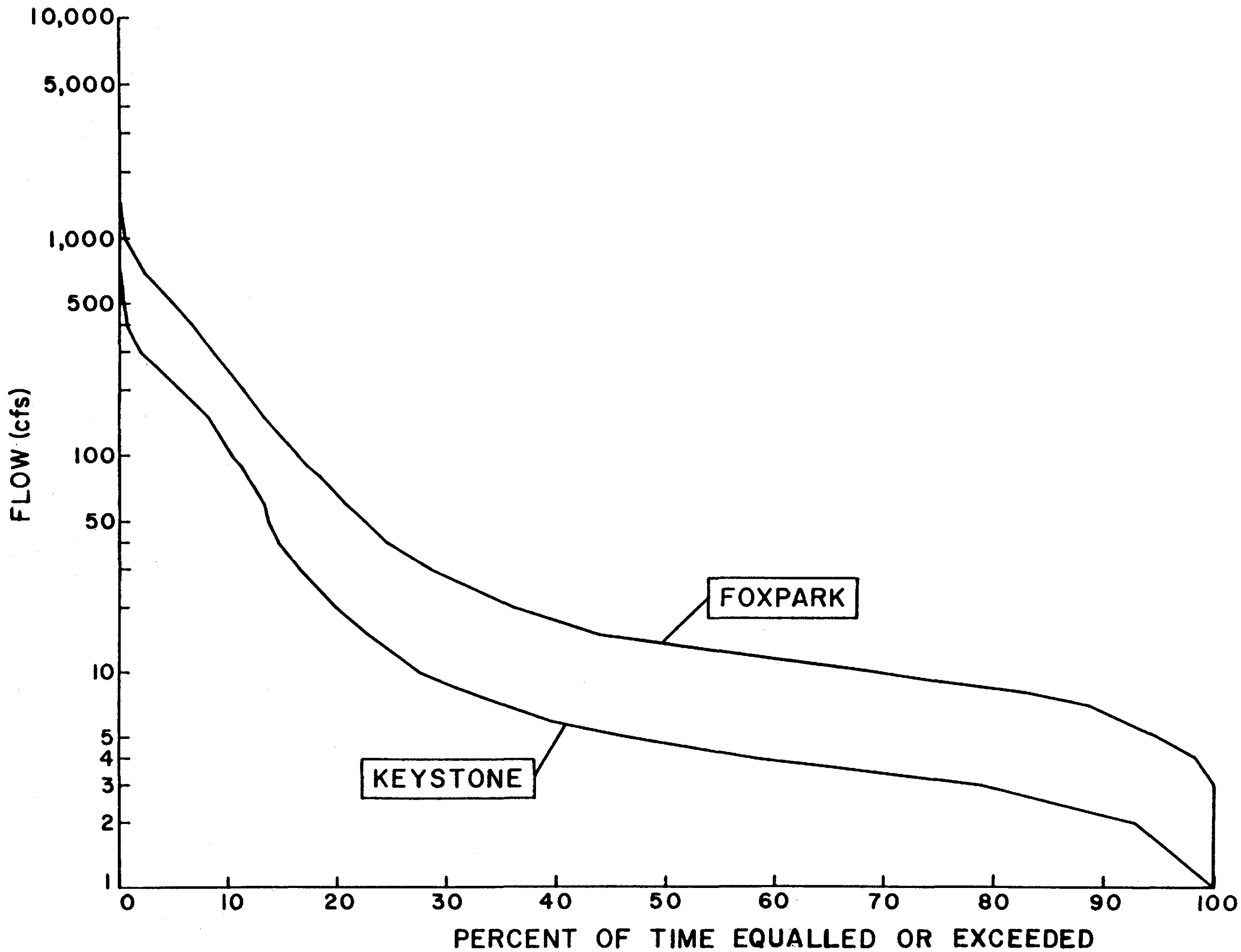


Figure 4. Flow Duration Curves for Douglas Creek Above Keystone and Near Foxpark

channel (SC) which carries a lesser amount of flow year-round (width, 15 to 20 feet). Figure 5 shows a general map of the site.

Water temperatures for the creek throughout the period of study ranged from 32°F in winter, when the creek completely freezes over, to 79°F recorded in August, 1975. Chemical parameters measured throughout the study ranged as follows: DO, 6.4 to 12.4 mg/l; CO_2, 1.5 to 3.0 mg/l; total alkalinity, 11 to 52 mg/l; pH, 6.5 to 8.5 (colorimetric); specific conductance, 28 to 42 μmhos.

Fish species present as obtained from electrofishing data were brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), rainbow trout (*Salmo gairdneri*), longnose sucker (*Catostomus catostomus*), and longnose dace (*Rhinicthys cataractae*).

Various species of aquatic invertebrates have been identified from the section. Representatives of the orders Diptera and Trichoptera were most abundant, with Coleoptera, Ephemeroptera, and Plecoptera also present in moderate numbers.

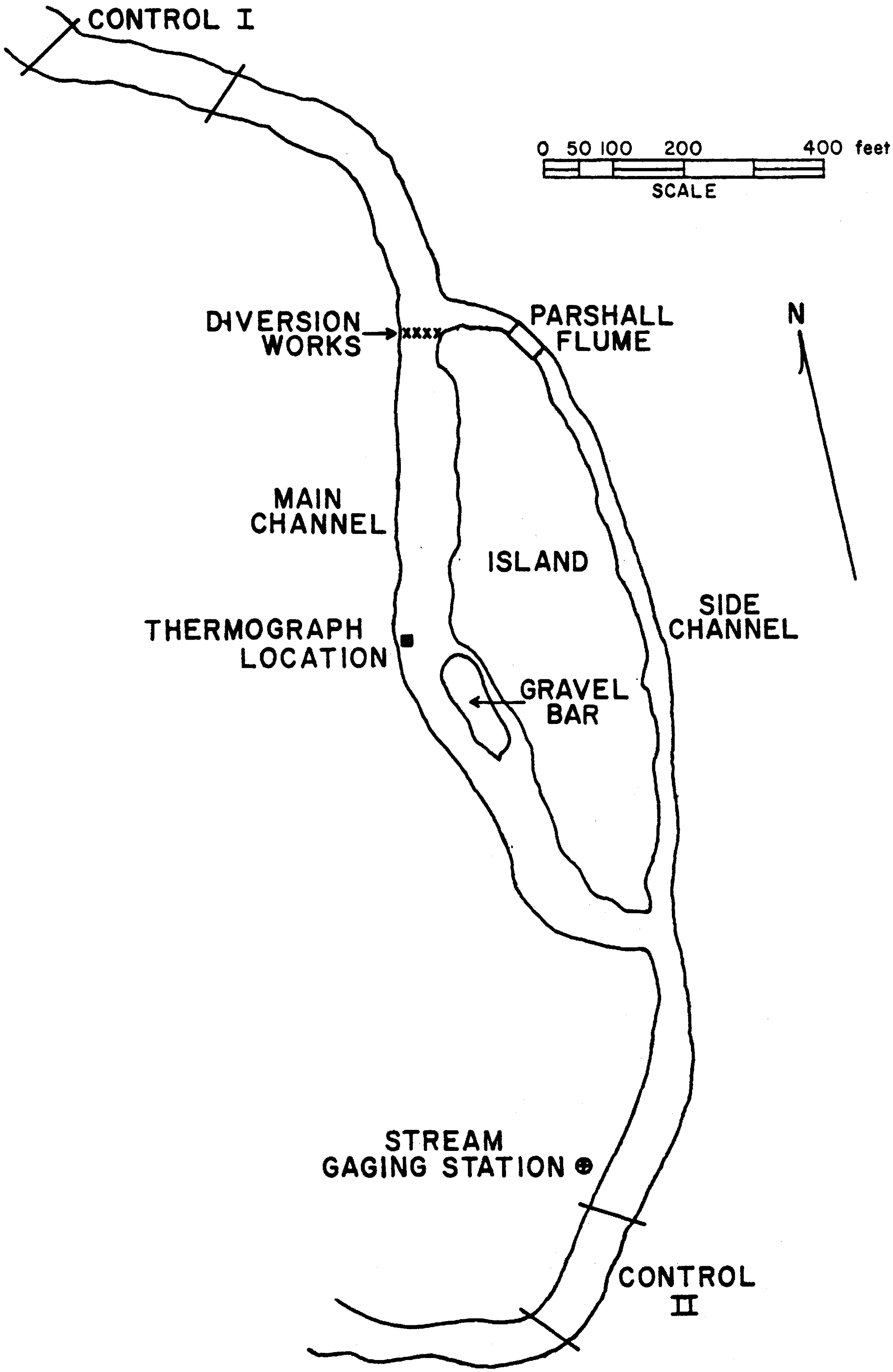


Figure 5. General Map of the Douglas Creek Study Site

CHAPTER III

METHODS AND MATERIALS

Before initiating any type of channel modification program, it is necessary to inventory the existing conditions, determine where and why they are inadequate, and provide for in-depth study of the long-range effects of any and all parts of the proposed change on the entire system. For these reasons, the physical, hydrologic, chemical, and biological factors of the study area were evaluated and studied for 10 months prior to installation of any devices. The methods used were as follows:

Physical, Hydrologic and Chemical

A complete physical map of the area was constructed by surveying baselines along the stream banks with stakes placed every five feet (Figure 6). These baselines were used as references throughout the study, and for mapping the total surface area at different flow levels by measuring the length of the perpendicular line from each baseline stake to the edges of the stream. The changes in channel configuration and stream surface area due to installation of the structures were partly determined by comparison of these baseline maps before and after modification. Water surface slope of the sections was determined using surveying techniques.

In order to determine changes in water depth, velocity, hydraulic radius, cross-sectional area, and wetted perimeter due to structure

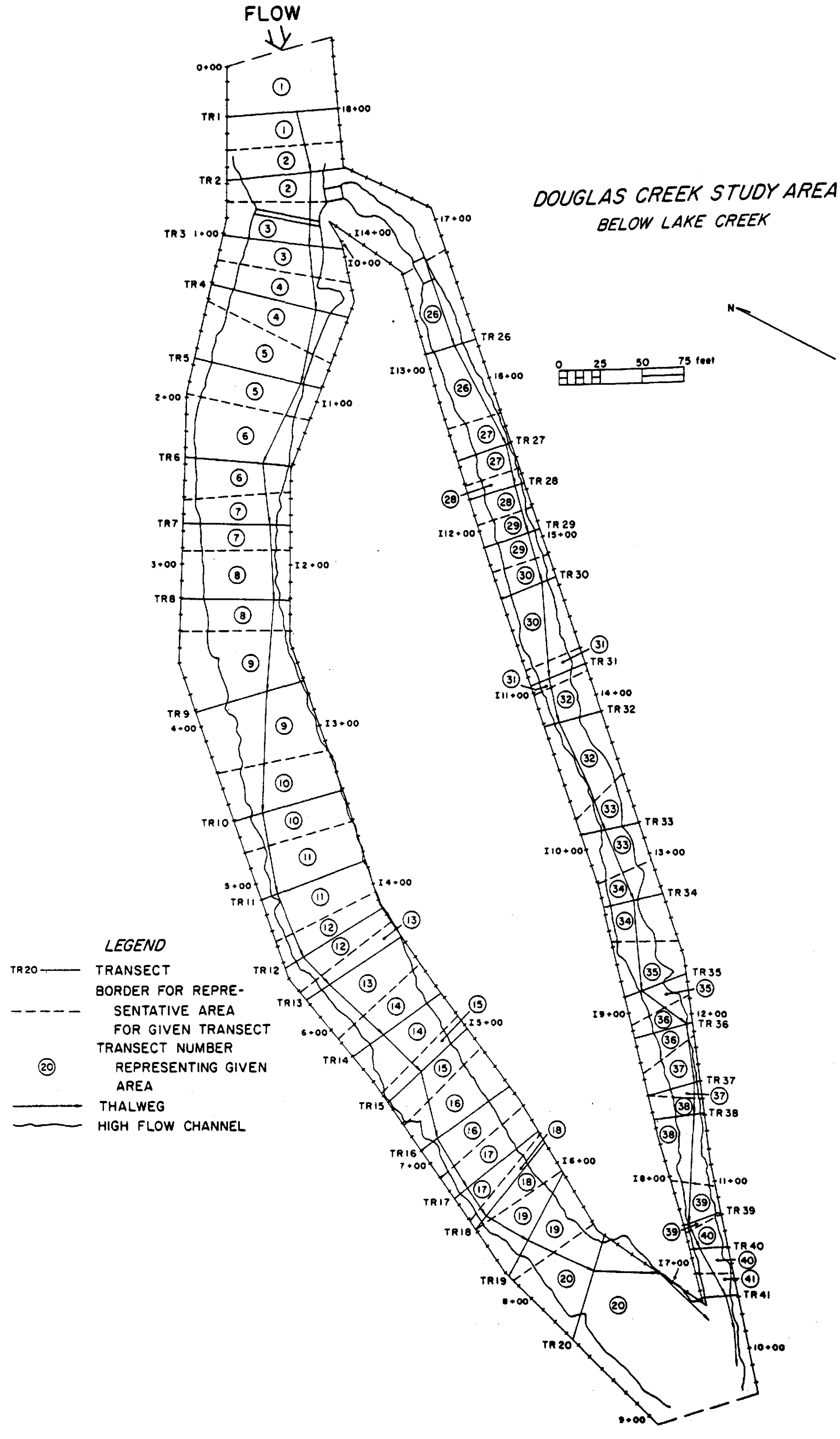


Figure 6. Detailed Physical Map of the Douglas Creek Study Area

installation, permanent cross-channel transects were established to represent a certain stream area having similar hydraulic characteristics. In the primary study area each parameter was measured at each transect every time a notable change in discharge occurred throughout the study period except when high flows prohibited instream work. For the primary study area on Douglas Creek, 21 transects were set up on the main channel and 18 on the side channel.

Velocity and depth were measured at two-foot intervals along transects with a Price current meter and top setting wading rod. Velocities were determined using the two-point and the six-tenths depth methods as described by the USBR (1967). Mean transect velocity was found using Q/A (discharge in cfs divided by cross-sectional area in square feet), and mean depth was found using A/TW (cross-sectional area in square feet divided by top width in feet). Transect cross-sectional profiles were plotted for the primary area to determine wetted perimeter and to give a picture of the changes in bottom configuration due to structure installation.

A stream gaging station was installed in October, 1974, downstream from the study area, consisting of a staff gage and Servo-manometer with Stevens A-35 recorder. A rating curve was determined by correlating gage height readings with discharge obtained using standard USGS stream gaging procedure (USGS, 1943). To obtain discharges in the side channel, a four-foot Parshall flume was installed, and discharge in the main channel could then be obtained by subtracting the side channel discharge from the total flow recorded at the gage station.

In order to manipulate flows in the channels, a wooden headgate was built and installed at the upstream end of the side channel and a diversion was built across the main channel. This was done to permit simulation of low flows in each channel, as obtained from project records, by diverting to one channel while working in the other.

Time-of-travel velocities through the study areas were determined using fluorescent dye techniques as described by Wesche (1973).

Using the cover measurement criteria developed by Wesche (1973), length of each section of overhead cover was measured to the nearest 0.5 feet, while width of overhangs and depth of water at the outer edge of the overhangs were measured to the nearest 0.05 feet. Substrate was mapped and classified at two-foot intervals along transects. These data were used to compare available cover at low flow to available cover at various higher flows.

Chemical parameters measured throughout the study were dissolved oxygen, carbon dioxide, total alkalinity, pH, hardness, turbidity, and specific conductance. In 1973 and 1974, these were taken with Ecolab test kits, while in 1975 D.O. and specific conductance were taken with Yellow Springs Instrument Co. meters, pH with a Sargent-Welche meter, and turbidity with a HACH turbidometer. Water and air temperatures were recorded throughout the study with a Belfort two-pen thermograph.

Biological

Since the primary emphasis of the study dealt with the creation of the greatest possible fish-holding area with a minimum amount of water available, trout size and numbers were carefully monitored throughout the entire study. Population estimates were made on the basis of semi-annual sampling in all sections.

In order to observe any physical, chemical, or biological changes which may have occurred in the immediate Douglas Creek area due to an outside influence (i.e., other than the investigator's modification work), two 300-ft. control sections were established, one above (Control I) and one below (Control II) the primary study site. These were sampled and fish populations assessed in exactly the same manner as the main and side channels and on approximately the same dates. Physical and hydraulic data were gathered as on the primary sections. No modifications or instream alteration was imposed on the controls.

Estimates of trout populations were obtained using the Removal Method discussed by DeLury (1947). This was done by blocking both ends of the study section with seines to prevent fish movement into or out of the area, and electrofishing. Two battery-powered backpack electrofishing units were used starting at the lower end and working side by side upstream to the head of the section. Fish captured were removed from the section and held until three complete runs had been made. Then, using a BASIC linear regression computer program, cumulative catch was statistically regressed against catch per effort to obtain the population estimate. These assessments were carried out on the main and side channels in October, 1973, and on all four sections (MC, SC, CI, CII) in July and September, 1974, and July and September, 1975.

Fish captured were weighed to the nearest gram and measured to the nearest millimeter, and a scale sample was taken from several representatives of different size groups for age-growth analysis. A surveyor's flag was placed at each location where a trout was collected so that depth, velocity, cover type, and cover size could be measured.

Trout captured in the Douglas Creek area were marked with a different fin clip for each section as shown:

Section	Clip
Control I	Upper caudal corner
Main Channel	Adipose
Side Channel	Lower caudal corner
Control II	Adipose and lower caudal corner

This was done in order to better understand any movement or displacement which may have occurred as a result of high runoff flows or dewatered conditions. The marks were also used in determining whether or not migration into the modified sections from up- or downstream had occurred.

CHAPTER IV

MODIFICATION OF THE PHYSICAL CHANNEL

As spring runoff flows recede and water diversions deplete the streamflow at the study area, available trout cover decreases rapidly as the effective edge of the stream draws away from the banks, leaving dewatered undercuts. These undercuts were measured and their locations marked, and became the basis for improvement device installation. Construction was geared toward raising the low flow water surface level back up to a level which made the dewatered overhead cover again usable as trout cover through channel construction, flow consolidation, and check damming.

The works of Brooks (1974) and Lu (1975) describe the similitude theory method of laboratory stream modeling on the Douglas Creek primary study area. In both studies, physical and hydraulic data gathered at the study area were used to construct a laboratory model in which various types, sizes, configurations, and angles of channel modification structures were tested and verified for erosional effects on the channel and ability to consolidate low flows. The results of their lab work served as a starting point for the actual field modification.

Because of their flexibility of size, shape, and application, wire mesh gabions were used for the modification structures. Since a main objective of the study was to emphasize aesthetics, structures were designed to be submerged at all but the lowest flows. This not only ensured a natural-looking situation, but also saved installation time and expense by recognizing that there was little need in Douglas Creek for any modification of the channel at higher than minimum flows. For this reason, the structures needed to be no higher than the minimum water depth required to maintain the fishery at low flow. Using these criteria as a basis, barriers, deflectors, and spur dams were designed to be 0.5 feet high, while the height of check dams was designed to be equal to the elevation at the upstream end of the undercuts which would benefit from the depths created by the dam. The appendix contains information concerning selection of locations, design, construction, and installation techniques.

Structures were formed of various combinations and sizes of gabion cells. Original gabion baskets as received from the factory measured 6.5 ft. x 12 ft. x 0.5 ft., each containing five separate cells. Structures were built by cutting the factory basket to make three separate smaller gabions 6.5 ft. x 2.5 ft. x 0.5 ft. (in the cutting process, two cells are wasted), then lacing baskets together to form the desired configuration and filling with rock from the dredge piles lining the banks. Rock used varied in size, but attempts were made to pick the majority of rocks only slightly larger than the mesh size (3.0 inches in diameter), in order to assure the least amount of spaces between rocks and, therefore, a tighter seal.

Deflectors and spur dams were constructed of one layer of six-inch cells, with V-mesh fencing wire laced to the top of the vertical faces and sloped to the stream bed to eliminate excessive erosion caused by high velocities against the vertical surface. Check dams were built using two layers of baskets installed at an angle to the streambed. A rubber mat was used inside the baskets to more completely seal the dam at low flows and facilitate the movement of high flows over the dam, decreasing the force on the upstream face.

Barriers were formed by lacing a series of 0.5 feet high cells end to end and placing them in the stream parallel to the current. The upstream end was tied into the bank and the baskets and the area behind the baskets were filled with gravel. This made the entire streambed behind the barrier 0.5 feet higher than it had previously been and forced the low flow into the constriction created between the barrier and the bank. Again, any vertical structure faces which were approximately perpendicular to the current were sloped using V-mesh wire to inhibit excessive scour.

Artificial boulders, described in detail by Wesche and Cooper (1974), were designed for moderately high gradient situations where the high point velocities normally prevent permanent trout inhabitation. Their function is to create pockets of low velocity in mid-stream which can be used as resting, hiding, or spawning areas.

Artificial overhangs were used in conjunction with each type of structure as well as along bank areas which naturally lacked overhead cover. Since stream flows in the region fluctuate so greatly, the fixed type of artificial bank cover, described by White and Brynildson (1967) and used in many stream improvement projects, is only functional at flows higher than those with which the present study was concerned. Also, the expense, time, and need for heavy equipment connected with the traditional artificial bank cover made it undesirable for use in low-flow situations. In order for the overhangs to be functional at all flows, the concept of floating artificial bank cover was developed. The present project experimented at length with various materials and sizes of floating artificial overhangs and found them to be functional, easy to install, and economical. The types used in Douglas Creek were made of corrugated strongbarn sheet-metal. Mechanics and installation techniques are described in the Appendix.

The diversion at the upper end of the section for regulation of flows in the channels was installed in July, 1974. Flow from the side channel was diverted to the main channel and modification of the side channel began at a regulated flow of 0.5 cfs. It was felt that this flow most closely approximated the average annual low flow in the channel, and created dewatered conditions which were precarious to the trout population.

Using depths, velocities, and cover measurements obtained during low flow periods for locating areas which could be restored, a modification plan for the side channel was mapped. Temporary structures were built of 2 in. x 8 in. x 6 ft. rough lumber planks hinged together at one end so the angle could be varied, and draped with polyethelene plastic to completely seal out the flow. Various types, sizes, and configurations of structures were tested, with the final pattern being shown in Figure 7.

Criteria and measurements used for installation were as follows: (refer to Figure 7).

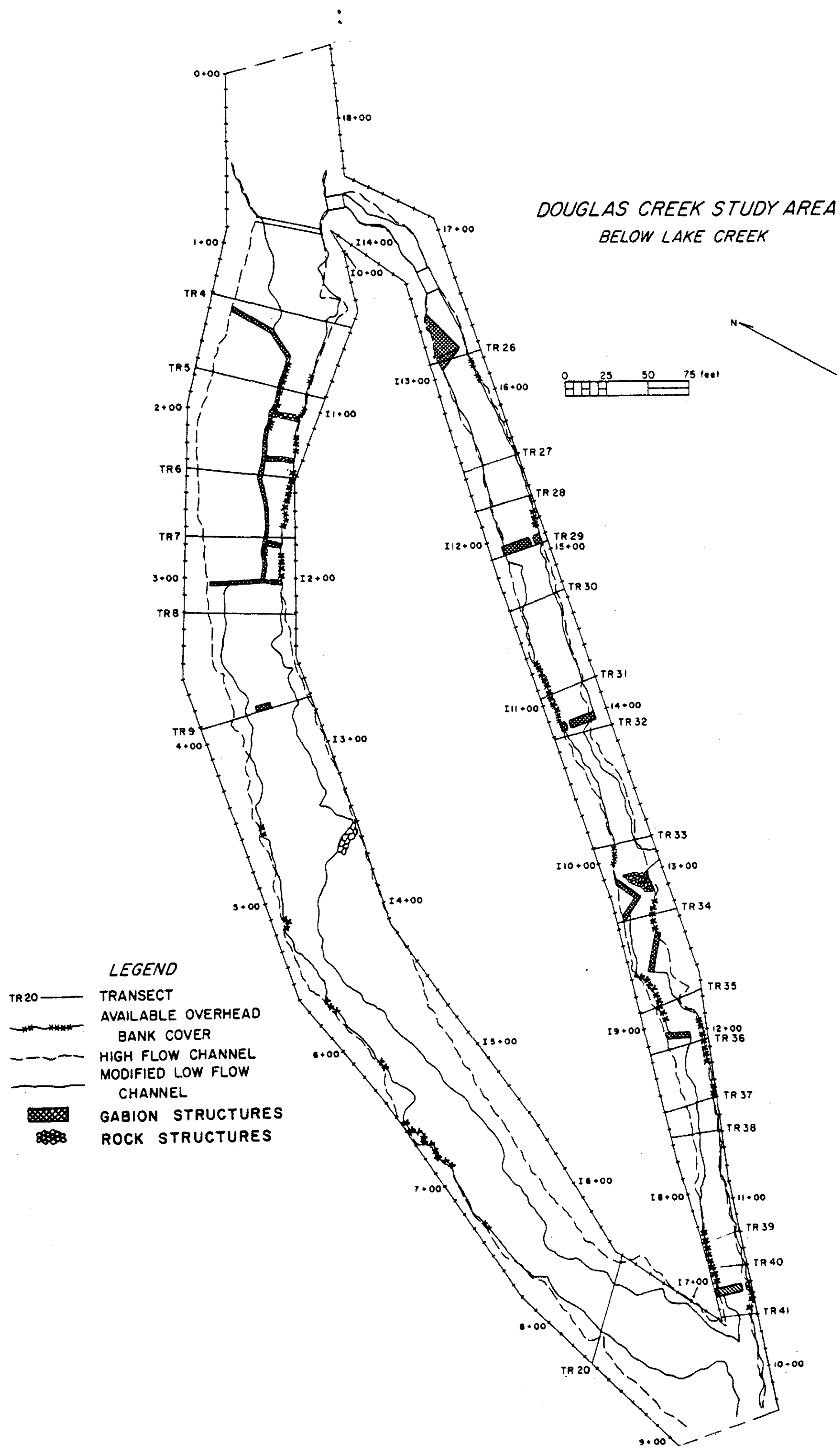


Figure 7. Douglas Creek Study Area at Low Modified Flow
MC-5 cfs, SC-0.5 cfs

Structure #1

Point deflector to utilize overhang at stake 16+25 to 16+05 by flow consolidation and deflection to east bank.

Structure #2

Check dam at 15+05 perpendicular to the present banks, to raise the water level up to utilize overhang at 15+10 to 15+20. The elevation of the bottom of the spillway is the same as the elevation of the underside of the upstream end of the overhang.

Structure #3

Check dam at 13+95 perpendicular to existing banks to utilize overhangs at I10+90 to I11+25.

Structure #4

Constriction of the flow using two point deflectors in series to create two small pools with a riffle between where one long slow pool had previously been. The construction also has a damming effect immediately upstream to inundate undercut banks at I10+00 to I10+20. The angle of the constricted chute was aligned so that the flow is directed to the undercut bank at 12+65 to 12+80, in order to deepen the water at the bank and increase the velocity through the downstream pool.

Structure #5

Constriction of the flow with a barrier-deflector from the downstream end of the undercut bank at 12+65 partway across the channel at a 30° angle. This structure ensures sufficient depths in the upstream pool and deflects the consolidated low flow to the undercut bank at I8+95 to I9+30.

Structure #6

Spur dam at I8+90 to deflect flow to the cutbanks at 11+85 to 12+05, while raising the water level immediately upstream to utilize undercut banks and overhanging vegetation at I9+00 to I9+28.

Structure #7

Check dam at I7+45 to I7+40. This structure was built perpendicular to the existing banks and raised the water level in the pool upstream to utilize the overhangs at I7+43 to I7+60.

Other modification of the side channel consisted of the installation of artificial overhangs in locations where structures made water depths and velocities sufficient to create potential trout holding areas.

Following completion of the side channel construction, most of the flow in the stream was diverted to the side channel, leaving a regulated flow of 4.6 cfs in the main channel. All construction in the main channel was directed at consolidating wide sections of flat water, increasing depths, and creating cover. Emphasis was placed on the barrier shown in Figure 7.

The main channel barrier was the largest structure installed, extending from reference stake 1+35 downstream 175 feet to stake 3+05. Before modification, the stream in this section at low flow (4.6 cfs) was wide (27 feet average), shallow (0.3 feet deep average), and completely lacked trout cover. The structure narrowed the channel and forced the total flow to the dewatered undercuts at I0+90, I1+00, I1+10, I1+55, I1+70, I1+85, and I2+00, making them again usable as cover. Artificial overhangs were also installed in conjunction with the main channel barrier.

The only other modification device used in the main channel was placement of an artificial boulder at transect #9.

CHAPTER V

RESULTS

The most efficient way to evaluate the effects of research in which physical characteristics of a stream are altered is found in the comparison of certain parameters, features, and measurements before the alternation, with the same parameters, features, and measurements after the alteration. The results of the current research are presented in this manner.

Physical, Hydrologic and Chemical

Of the nine different flows investigated in each channel throughout the period of study, three flows in each channel were identified to represent the primary emphasis of the research: 1) a high natural flow (Figure 8); 2) a low natural flow (Figure 9); and 3) a low modified flow (Figure 7). The high natural (HN) flow was chosen to be a flow which completely filled the channels and inundated, without flooding, all bank and instream cover and was, in general, sufficient to support a good, well-structured population of trout (HN was 75 cfs for the main channel, and 7 cfs for the side channel). A low natural (LN) flow was considered to be the lowest flow which, as a result of dewatering, was present in the channels for an extended period of time during the period of study as obtained from project records. Low natural flow was generally typified by extreme withdrawal of instream water from the stream banks, greatly decreased depths and velocities throughout the sections, and a generally marginal situation for a

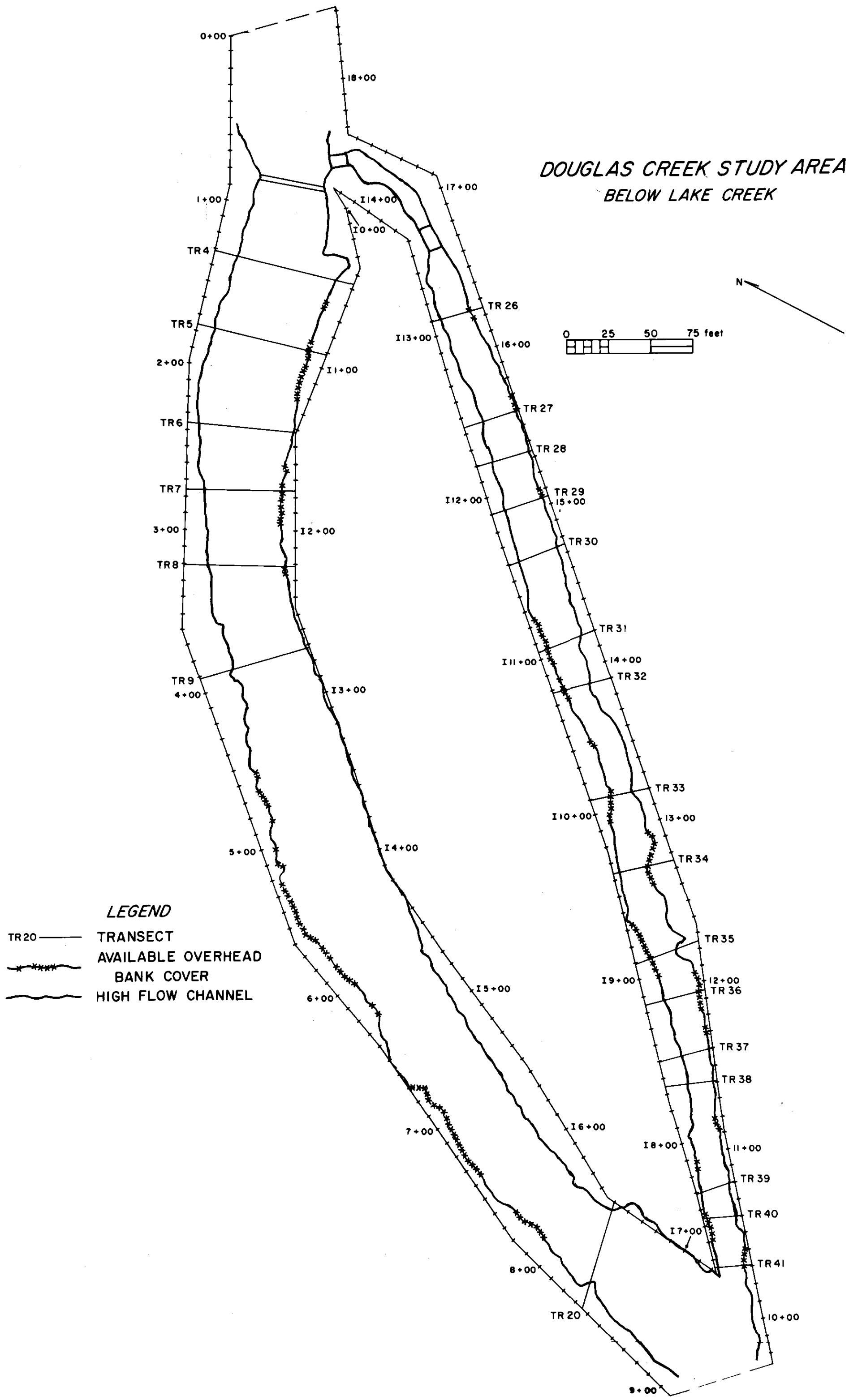


Figure 8. Douglas Creek Study Area at High Natural Flow
MC-75 cfs, SC-7 cfs

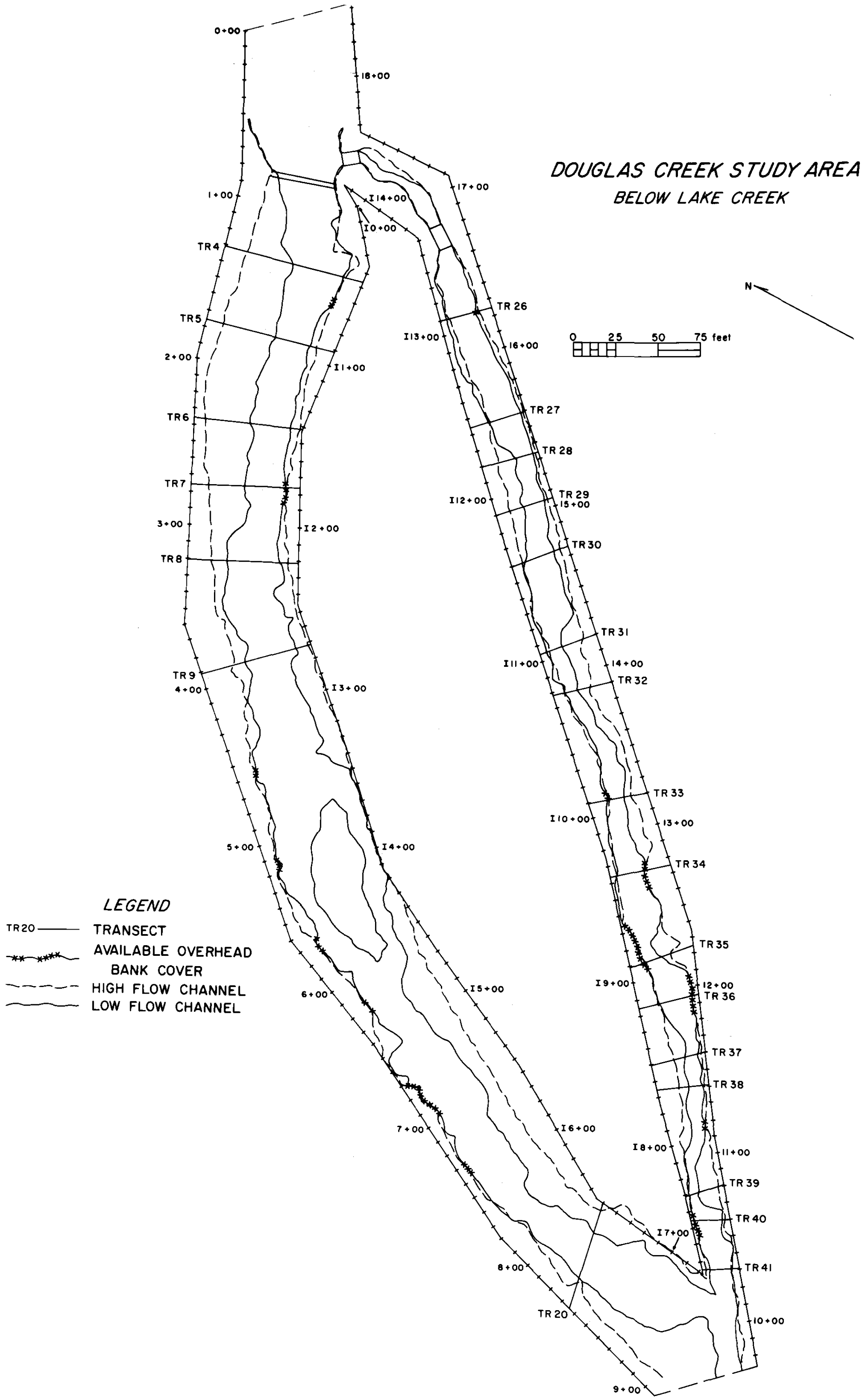


Figure 9. Douglas Creek Study Area at Low Natural Flow
MC-5 cfs, SC-0.5 cfs

fishable trout population (main channel LN was 5 cfs, side channel LN was 0.5 cfs). The low modified (LM) flow was equal to the low natural flow, but was measured after completion of the modification.

The changes in physical features of the primary study area as discharges decreased from high natural flow to low natural flow are illustrated in Figures 8 and 9, while Tables I and II show the hydraulic comparisons. The water surface area of the main channel was found to decrease by only 36 percent as discharge decreased 93 percent, indicating that critical changes in depth occur as flow is decreased. Similarly, decreasing the side channel discharge by 93 percent caused a corresponding decrease in surface area of only 34 percent. The problem becomes obvious. Stream top widths do not decrease proportionally with discharge, and the results of dewatering are low discharges with wide, flat areas of shallow water. Reducing the top width can correct this situation. Figure 7 shows the low modified flow. The total surface area in the modified section of the main channel was reduced from 5640 square feet to 1140 square feet by creation of the low flow channel, and the suggested average depths of 0.5 feet (Wesche, 1973) were maintained at a 93 percent discharge decrease. Total surface area in the unmodified section of the main channel did not change as a result of the modification.

The side channel total surface area actually increased from low natural flow to low modified flow as a result of the three check dams, but the wide, flat, shallow areas which were present at low natural flow were consolidated. Mean depth throughout the side channel was increased by the modification.

TABLE I. Hydraulic Parameter Comparisons of Low Natural (LN) and Low Modified (LM) Flows With High Natural (HN) Douglas Creek Main Channel

HN - 75 cfs
LN - 5 cfs
LM - 5 cfs

Transect	Top Width (ft.)			Wetted Perimeter (ft.)			Mean Depth (ft.)			Hydraulic Radius (ft.)			Mean Velocity (fps)			X-Sectional Area ft.^{2})		
	HN	LN	LM	HN	LN	LM	HN	LN	LM	HN	LN	LM	HN	LN	LM	HN	LN	LM
4	56	26	30	60.30	26.20	30.17	.85	.35	.32	.79	.34	.32	1.58	.55	.52	47.60	9.00	9.60
5	50	23	13	54.50	24.20	13.70	.90	.34	.72	.82	.32	.68	1.67	.64	.53	44.90	7.85	9.36
6	52	26	18	54.10	26.40	18.27	.70	.34	.33	.67	.34	.33	2.06	.56	.84	36.40	8.95	5.94
7	44	24	8	46.50	23.50	8.68	.71	.23	.48	.67	.24	.44	2.39	.89	1.30	31.35	5.60	3.84
8	40	31	32	45.30	33.10	32.14	1.06	.27	.29	.93	.26	.29	1.77	.56	.54	42.35	8.95	9.28
9	40	24	23	43.30	27.80	23.20	.90	.37	.39	.83	.32	.39	2.08	.56	.54	35.95	8.95	8.97
10	52	52	52	56.40	49.00	52.73	.79	.22	.23	.72	.23	.23	1.84	.43	.42	40.85	11.45	11.96
11	57	57	57	59.00	54.40	57.94	.64	.12	.15	.62	.27	.15	2.05	.76	.58	36.55	6.60	8.55
12	56	22	20	54.60	20.30	20.60	.50	.27	.25	.52	.18	.24	3.24	1.33	1.00	23.15	3.75	5.00
13	54	16	14	57.40	16.60	15.13	.56	.43	.40	.52	.42	.37	2.50	.72	.89	30.00	6.95	5.60
14	38	20	20	41.30	22.60	20.28	.86	.51	.49	.80	.45	.48	2.28	.49	.51	32.85	10.10	9.80
15	45	33	32	47.30	33.30	32.48	.69	.28	.30	.66	.28	.30	2.42	.54	.52	31.05	9.25	9.60
16	36	28	28	37.80	29.30	29.42	.82	.41	.40	.78	.39	.38	2.54	.43	.45	29.55	11.55	11.20
17	37	29	26	37.60	29.70	26.78	.86	.34	.32	.85	.33	.31	2.35	.51	.60	31.85	9.90	8.32
18	40	31	31	40.70	31.30	31.34	.69	.23	.23	.68	.23	.23	2.72	.70	.70	27.55	7.15	7.13
19	45	21	20	46.30	21.70	20.35	.74	.55	.52	.72	.54	.51	2.25	.43	.48	33.40	11.60	10.40

1 foot = .3048 meters
1 ft^2 = .0929 meters^2
1 fps = .3048 meters per second

TABLE II. Hydraulic Parameter Comparisons of Low Natural (LN) and Low Modified (LM) Flows With a High Natural (HN) Flow Douglas Creek, Side Channel

HN - 7 cfs
LN - .5 cfs
LM - .5 cfs

	Top Width (ft.)			Wetted Perimeter (ft.)			Mean Depth (ft.)			Hydraulic Radius (ft.)			Mean Velocity (fps)			X-Sectional Area (ft.^{2})		
Transect	HN	LN	LM	HN	LN	LM	HN	LN	LM	HN	LN	LM	HN	LN	LM	HN	LN	LM
26	18	18	16	20.49	19.02	17.32	.47	.36	.38	.46	.23	.35	.82	.08	.08	8.50	6.48	6.08
27	20	19	18	21.53	19.31	18.45	.36	.11	.20	.33	.10	.20	.97	.25	.14	7.20	2.00	3.60
28	31	13	12	21.12	13.01	12.22	.33	.15	.21	.32	.15	.21	1.02	.25	.20	6.85	2.00	2.52
29	22	11	1	22.34	11.26	1.00	.33	.23	.45	.33	.22	.45	.96	.20	1.11	7.30	2.50	.45
30	23	18	14	23.30	18.02	14.41	.36	.13	.15	.35	.13	.15	.85	.21	.23	8.25	2.40	2.10
31	16	7	22	15.31	7.52	23.08	.41	.34	.69	.43	.32	.65	1.06	.21	.03	6.60	2.40	15.10
32	12	6	1	14.14	6.31	1.00	.43	.22	.45	.37	.21	.45	1.35	.38	1.11	5.20	1.30	.45
33	12	10	10	13.20	10.84	10.74	.95	.72	1.36	.87	.66	1.27	.61	.07	.04	11.45	7.15	13.60
34	16	13	12	17.12	14.11	12.88	.75	.62	1.53	.70	.57	1.43	.58	.06	.03	12.05	8.10	18.40
35	23	10	9	24.60	11.13	10.42	.47	.41	.48	.44	.42	.42	.65	.12	.12	10.80	4.10	4.33
36	20	20	4	21.64	21.21	4.95	.59	.35	.92	.54	.33	.74	.60	.07	.14	11.70	7.08	3.68
37	14	8	6	15.15	8.65	6.72	.49	.48	.47	.45	.44	.42	1.02	.13	.18	6.85	3.80	2.83
38	14	8	20	14.37	8.18	21.88	.44	.24	.46	.43	.24	.42	1.13	.26	.05	6.20	1.95	9.20
39	16	6	20	18.38	6.12	21.67	.40	.13	1.19	.35	.13	1.10	1.09	.63	.02	6.40	0.80	23.80
40	17	16	20	17.70	16.39	21.24	.58	.29	1.58	.55	.28	1.48	.71	.11	.02	9.80	4.60	31.50
41	14	5	4	16.19	5.32	4.29	.77	.15	.27	.68	.14	.14	.65	.66	.83	10.80	0.75	.60

1 foot = .3048 meters
1 ft^2 = .0929 meters^2
1 fps = .3048 meters per second

Tables III and IV show the percent reductions in hydraulic parameters that occur as a result of dewatering. The parameters most affected by the drop from high natural to low natural flow were mean velocity and mean cross-sectional area in both the side and main channels. Even after modification in the main channel, these two parameters remained the greatest affected. However, in the side channel, the mean velocity decreased less from high natural to low modified flow than from high natural to low natural flow, while the mean low modified cross-sectional area was greater than the mean high natural cross-sectional area. Figures 10 and 11 illustrate the changes in cross-sectional area and channel shape from low natural to low modified flow.

The parameter which showed the greatest response to the modification in both channels was mean depth. Side channel depths after modification at low flow exceeded depths at natural high flow in ten of the eighteen transects and the overall effect of modification in the side channel was to increase the mean depth by 0.3 feet.

The modified section of the main channel (transects 4 through 8) also showed substantial increases in mean depth, although the overall mean remained below the recommended 0.5 feet.

Due to the flatness of the channel cross sections, wetted perimeter in both channels changed in response to top width. Similarly, changes in hydraulic radius corresponded to changes in mean depth.

Time-of-travel velocities for the main and side channels at high natural, low natural and low modified flows are shown in Table V.

TABLE III. Percent Reduction in Hydraulic Parameter Values From High Natural (HN) to Low Natural (LN) and Low Modified (LM) Flows Douglas Creek Main Channel

HN = 100% = 75 cfs

	Top Width		Wetted Perimeter		Mean Depth		Hydraulic Radius		Mean Velocity		X-Sectional Area	
Transect	LN	LM	LN	LM	LN	LM	LN	LM	LN	LM	LN	LM
4	53	46	57	50	59	62	57	59	72	74	81	80
5	54	74	56	75	62	20	61	17	69	75	83	79
6	50	65	51	66	51	53	49	51	78	67	75	84
7	45	82	49	81	68	32	64	34	70	56	82	88
8	23	20	27	29	75	73	72	69	75	75	80	78
9	40	43	36	46	59	57	61	53	78	78	75	75
10	0	0	7	13	72	71	68	68	81	82	72	71
11	0	0	8	2	81	77	56	76	70	77	82	77
12	61	64	63	62	46	50	65	54	67	75	87	82
13	74	70	71	74	23	29	19	29	77	72	77	81
14	47	47	45	51	41	43	44	40	82	82	69	70
15	27	28	30	31	59	57	58	55	82	83	70	69
16	22	22	22	22	50	51	50	51	86	86	61	62
17	22	30	21	30	60	63	61	64	83	79	69	74
18	23	23	23	23	67	67	66	66	79	79	74	74
19	53	56	53	56	26	30	25	29	85	83	65	69
MEANS												
TR 4-7	50.5	66.8	53.3	68.0	60.0	41.8	57.8	40.3	72.3	68.0	80.3	82.8
TR 8-19	33.5	34.8	34.5	47.3	53.1	54.1	52.1	53.2	79.3	79.3	72.8	73.1
TR 4-19	37.1	41.8	38.7	44.4	56.2	52.2	54.7	50.9	77.1	76.4	75.1	75.8

TABLE IV. Percent Reduction in Hydraulic Parameter Values From High Natural (HN) to Low Natural (LN) and Low Modified (LM) Flows Douglas Creek Side Channel

HN = 100% = 7 cfs
+ indicates % increase

Transect	Top Width		Wetted Perimeter		Mean Depth		Hydraulic Radius		Mean Velocity		X-Sectional Area	
	LN	LM	LN	LM	LN	LM	LN	LM	LN	LM	LN	LM
26	0	12	8	15	23	19	30	24	90	90	24	28
27	9	10	10	14	69	44	70	39	74	86	72	50
28	38	43	38	42	55	36	53	34	75	80	71	63
29	50	95	50	95	30	+36	33	+36	79	+16	66	94
30	22	39	23	38	64	58	63	57	73	73	71	75
31	56	+27	51	+41	17	+67	26	+51	80	97	64	+128
32	50	92	55	93	49	+4	43	+22	72	+18	75	91
33	16	16	18	19	24	+43	25	+46	88	93	38	+18
34	19	25	18	25	17	+104	19	+104	90	95	33	+53
35	57	61	54	58	16	+2	5	5	82	82	52	60
36	0	80	1	77	34	+56	39	+37	88	77	39	69
37	43	57	43	56	2	4	2	4	87	82	45	59
38	43	+42	43	+52	45	+5	45	2	77	96	69	+48
39	63	+25	67	+18	68	+197	63	+214	42	98	87	+272
40	5	+18	10	+20	50	+172	49	+169	85	97	53	+221
41	64	71	67	74	81	81	79	79	+2	+22	93	94
MEAN	33.4	30.6	34.8	29.7	40.3	+28.0	40.3	+27.0	73.8	68.1	50.6	+7.3

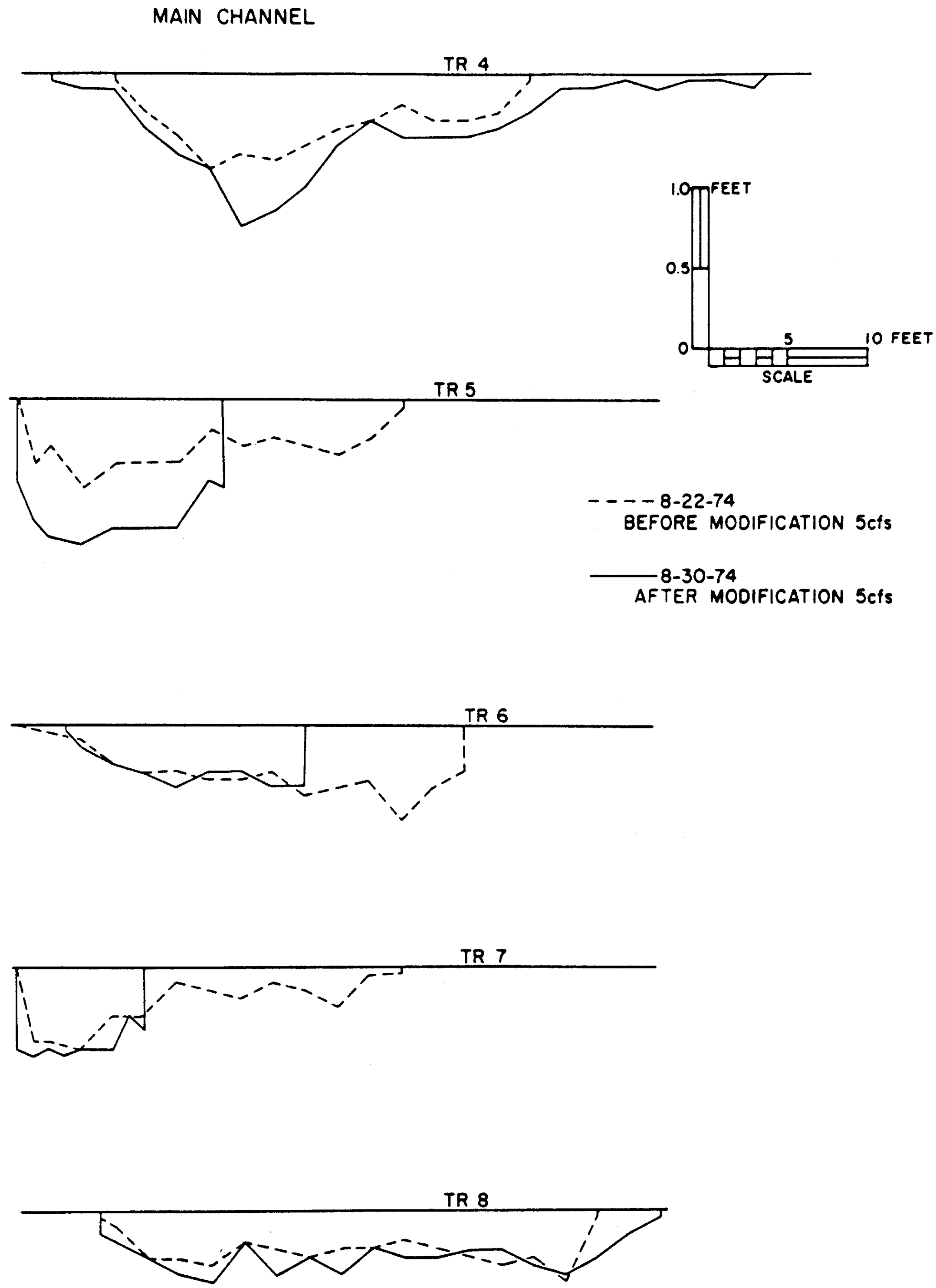


Figure 10. Changes in Cross-Sectional Area and Channel Shape Due to Modification, MC-5 cfs.

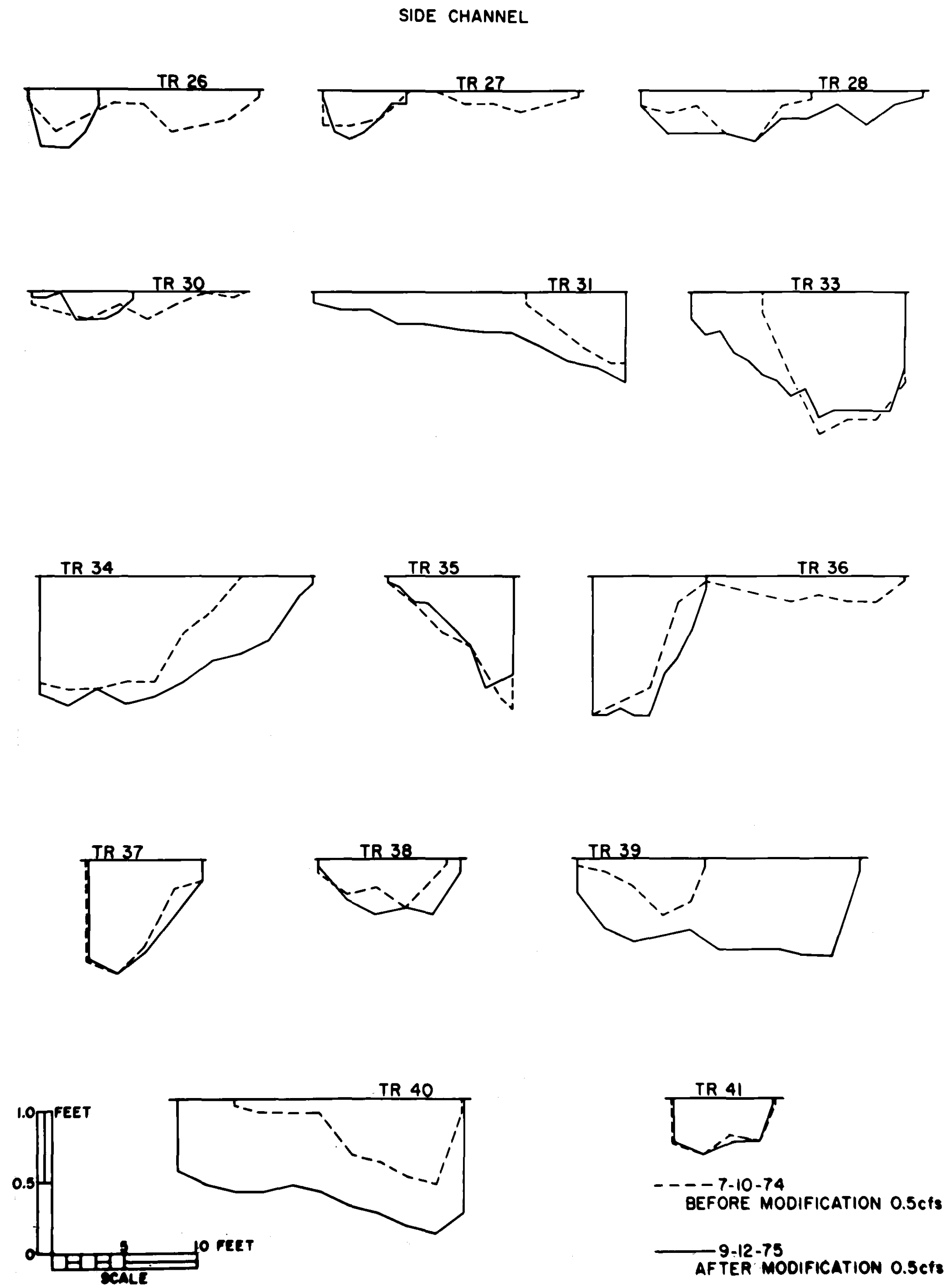


Figure 11. Changes in Cross-Sectional Area and Channel Shape Due to Modification, SC-0.5 cfs.

TABLE V

Time of Travel Velocities through Main and Side Channels at HN, LN, and LM flows

Section	Date	Flow (cfs)	Length of Section (ft.)	Time of Travel (min.-sec.)	Velocity (fps)
MC	6/27/74	75 (HN)	710	5- 0	2.36
	8/22/74	5 (LN)	710	23-25	0.51
	9/3/74	5 (LM)	710	20- 0	0.59
SC	6/25/74	7 (HN)	660	10-30	1.00
	7/10/74	0.5 (LN)	660	56-15	0.19
	9/3/74	0.5 (LM)	660	67-30	0.16

Changes in cover as flows drop and dewatering occurs are shown in Figures 8 and 9. Using the cover rating system for brown trout devised by Wesche (1973), the values obtained for the flows studied are shown in Table VI.

TABLE VI

Cover Data for Primary Section at representative flows

Section	Length of Section	Flow	Bank Cover (ft^2)	Length of Undercut Banks (ft)	Total Cover Area (ft^2)	Mean Cover Rating
MC	650	HN (75 cfs)	151.7	208	9597	0.24
		LN (5 cfs)	88.4	80	1796	0.09
		LM (5 cfs)	167.6	150	2051	0.14
SC	659	HN (7 cfs)	101.9	147	2260	0.21
		LN (0.5 cfs)	46.2	72	748	0.09
		LM (0.5 cfs)	87.0	114	2256	0.18
CI	260	25 cfs	13.8	46	3483	0.27
	252	25 cfs	2.6	8.5	3593	0.16

Although the cover rating values apply only to brown trout, the values for bank cover and total cover area are useful in the comparison of pre- and post-modification cover conditions for other trout species

TABLE VII
Water Chemistry, Douglas Creek Primary Area

	Date	Air Temp, °F	Water Temp, °F	D.O., mg/l	Alkalinity mg/l	Total Hardness mg/l	pH	CO_2 mg/l	Specific Conductance µmhos
Pre-Modification	6/20/74	72	62	7.8	11.0	18.0	7.6	3.0	
	7/1/74	-	60	6.7	30.0	28.0	6.5	2.5	
	7/15/74	-	-	6.4	40.0	28.0	6.5	3.0	
	8/5/74	73	64	7.3	42.0	25.0	6.5	2.5	
Post-Modification	9/19/74	70	51	7.9	38.0	31.0	8.5	1.5	
	11/7/74	39	48	8.4	52.0	40.0	8.0	2.5	
	1/17/75	-	-	11.6	-	-	-	-	
	3/13/75	-	-	10.6	-	-	-	-	
	4/4/75	-	-	10.6	-	-	-	-	
	5/12/75	46	31	10.4	-	-	-	-	
	5/21/75	43	38	10.2	-	-	7.7	-	28
	5/28/75	41	37	9.9	-	-	7.7	-	25
	7/23/75	70	59	7.7	-	-	7.0	-	42
	7/24/75	74	65	7.6	-	-	7.5	-	33
	9/12/75	62	54	8.9	41.0	-	7.5	-	36
	9/16/75	71	56	9.1	39.0	-	7.5	-	32

as well. The total number of square feet of usable bank cover in each channel was nearly doubled at low flow by modification, and in-stream rubble-boulder cover (substrate 3 in. average, and depth 0.5 ft.) was increased 17 percent and 67 percent in the main and side channels, respectively. It is important to remember that modification was carried out in essentially all of the side channel, while only 20 percent of the entire length of the main channel was modified, causing the main channel to appear less affected in comparison when, actually, the modified sections were affected approximately the same.

Data for water chemistry measurements throughout the study are presented in Table VII. All chemical parameters at the Douglas Creek primary area fell easily within the tolerance suggested by Bell (1973), and Mills (1971). Maximum water temperatures recorded by the thermograph at transect 10 was 79°F on two consecutive afternoons in August, 1975, at a discharge of approximately 15 cfs. Maximum turbidity was measured as 2.7 JTU on May 28, 1975.

Biological

Table VIII presents the results of the population sampling for the five sample periods, while Table IX shows standing crop estimates for the same dates. In general, standing crops were higher in the fall than in the spring in all sections except the side channel, which fluctuated seemingly at random. It should be noted that the Fall, 1973 data for the main channel are based on the entire main channel (transects 1 through 23) as it was originally mapped, while all subsequent sampling covered transects 4 through 19 only. Transects 1

TABLE VIII. Population Data for the Trout Collected During Five Consecutive Sample Periods, Douglas Creek

		Main Channel					Side Channel					Control I				Control II			
		Pre-Mod.		Post-Mod.			Pre-Mod.		Post-Mod.										
		Fall 73	Spring 74	Fall 74	Spring 75	Fall 75	Fall 73	Spring 74	Fall 74	Spring 75	Fall 75	Spring 74	Fall 74	Spring 75	Fall 75	Spring 74	Fall 74	Spring 75	Fall 75
No. Collected	BT	225	62	206	143	287	154	53	34	165	41	48	175	98	148	18	207	65	155
	Brk	6	8	23	15	34	68	23	35	37	15	6	35	12	30	1	13	2	1
	RBT	5	1	9	1	7	4	—	—	2	—	—	3	—	1	—	4	—	1
	Total	236	71	238	159	328	226	76	69	204	56	54	213	110	179	19	224	67	157
Average Length (mm)	BT	186.07	143.00	172.92	131.36	149.17	131.26	125.22	154.64	110.07	132.05	145.57	125.68	112.09	129.03	137.17	144.66	118.71	141.76
	Brk	97.28	139.70	144.53	148.53	161.97	119.17	119.63	139.41	125.00	144.00	155.79	135.78	157.08	149.33	104.14	120.36	118.50	175.00
	RBT	130.56	71.12	110.91	133.00	143.71	83.82	—	—	69.10	—	—	129.54	—	122.00	—	125.09	—	144.00
Average Weight (grams)	BT	97.03	53.21	71.57	39.39	43.67	26.75	28.32	31.18	16.81	29.76	42.55	27.99	20.33	27.04	44.33	36.58	25.42	33.83
	Brk	—	35.50	29.79	41.14	44.68	20.40	23.87	30.12	24.60	32.67	43.50	31.68	44.67	34.03	12.00	17.46	18.50	61.00
	RBT	—	3.00	15.44	24.00	40.00	—	—	—	—	—	—	25.00	—	24.00	—	25.25	—	32.00
Average $K_{(TL)}$ Factor	BT	1.07	1.14	1.38	1.14	1.32	1.29	1.14	1.11	1.08	1.29	1.37	1.21	1.12	1.26	1.30	1.21	1.07	1.19
	Brk	—	1.30	0.99	1.13	1.03	1.21	1.08	1.11	1.26	1.09	1.15	1.26	1.00	1.02	1.06	1.10	1.07	1.14
	RBT	—	0.84	1.13	1.02	1.34	—	—	—	—	—	—	1.15	—	1.32	—	1.29	—	1.07

BT - Brown Trout
Brk - Brook Trout
RBT - Rainbow Trout

TABLE IX. Standing Crop Estimates for Trout Collected During Five Consecutive Sample Periods, Douglas Creek

		MC					SC					C I				C II			
		Fall 1973	Spring 1974	Fall 1974	Spring 1975	Fall 1975	Fall 1973	Spring 1974	Fall 1974	Spring 1975	Fall 1975	Spring 1974	Fall 1974	Spring 1975	Fall 1975	Spring 1974	Fall 1974	Spring 1975	Fall 1975
Acres		0.72	0.50	0.50	0.62	0.50	0.23	0.18	0.18	0.22	0.18	0.19	0.16	0.19	0.16	0.22	0.25	0.22	0.25
Population Estimate, Trout/acre	BT	374.5	161.1	446.3	244.6	654.9	766.8	809.4	206.6	781.4	222.8	260.4	1372.7	625.2	1049.5	81.1	895.6	319.8	654.6
	Brk	8.2	11.9	46.4	24.4	71.2	357.7	149.0	206.6	181.4	97.7	41.7	248.4	72.9	217.4	4.5	56.2	9.0	4.0
	RBT	7.0	1.6	18.1	1.6	14.1	17.2	—	—	9.3	—	—	18.6	—	6.2	—	18.0	—	4.5
Total		389.7	174.6	510.8	270.6	740.2	1141.7	458.4	413.2	972.1	320.5	302.1	1639.7	698.1	1273.1	85.6	969.8	328.8	663.1
Weight Estimate, lb/acre	BT	67.0	11.7	65.6	20.0	55.8	39.1	18.2	16.7	28.4	14.6	23.4	67.0	22.9	54.7	7.1	75.1	14.6	51.9
	Brk	—	1.0	3.0	2.2	6.8	13.2	6.7	12.6	9.3	5.9	3.0	15.2	6.2	13.9	0.1	2.2	0.3	0.6
	RBT	—	0.1	0.6	0.1	1.2	—	—	—	—	—	—	1.1	—	0.3	—	1.0	—	0.3
Total		67.0	12.8	69.2	22.3	63.8	52.3	24.9	29.3	37.7	20.5	26.4	83.3	29.1	68.9	7.2	78.3	14.9	52.8

1 acre = .405 hectare

1 lb/acre = 1.12 kg/hectare

through 3 and 20 through 23 were excluded because two unusually deep, slow pools, which were considered highly unrepresentative of Douglas Creek in the immediate area, were present within these transects. It was felt that the hydraulic and biological data would be biased as a result of the inclusion of the pools.

It should also be noted that the side channel represented an essentially closed and separate population of trout (Reiser, 1974), distinct from the population in the main channel and controls. Consequently, it appeared that natural factors affecting population sizes in the main channel and controls might not have a similar effect on side channel fish.

Age-growth analysis of the Douglas Creek fish indicates extremely slow growth of individuals in both channels (Reiser, 1974). Tables X and XI give empirical growth histories of brown trout for the main and side channels as of July, 1974, and September, 1975, as determined from scale analysis.

Zero plus age (young-of-the-year) fish were not weighed and measured in the field because of the large numbers collected, the difficulty in accurate weighing of trout in that weight range, and the lack of ability of fish in this size group to withstand a large amount of handling. For these reasons, the numbers of zero age fish were counted and marked down as young-of-the-year, and then released.

The data in Tables X and XI show similar growth in the two channels for the first three years of life, but, probably due to habitat restrictions, older age fish grow much slower in the side

TABLE X. Growth History of Brown Trout, Main Channel

	July 10, 1974				September 26, 1974			
	Empirical Data		Back-Calculated Data		Empirical Data		Back-Calculated Data	
Age	No.	Mean Length (mm)	No.	Mean Length (mm)	No.	Mean Length (mm)	No.	Mean Length (mm)
0+	0	--	0	--	0	--	0	--
I+	13	99.06	42	82.08	13	127.78	45	91.11
II+	15	148.83	29	139.64	25	170.58	32	138.70
III+	7	199.55	14	193.54	7	215.90	7	179.75
IV+	6	232.40	7	240.22	0	--	0	--
V+	0	--	1	319.50	0	--	0	--
VI+	1	388.60	1	343.60	0	--	0	--

TABLE XI. Growth History of Brown Trout, Side Channel

	July 10, 1974				September 26, 1974			
	Empirical Data		Back-Calculated Data		Empirical Data		Back-Calculated Data	
Age	No.	Mean Length (mm)	No.	Mean Length (mm)	No.	Mean Length (mm)	No.	Mean Length (mm)
0+	0	--	0	--	0	--	0	--
I+	10	99.32	39	73.09	8	120.66	28	88.60
II+	23	150.08	29	126.44	17	166.14	20	134.16
III+	4	180.97	6	160.50	3	192.20	3	181.73
IV+	2	209.55	2	174.55	0	--	0	--

channel than in the main channel.

Brook trout numbers were considered to be too few for a complete age-growth analysis at this time.

The overall salmonid population in the controls and main channel of Douglas Creek was consistently made up of approximately 85 to 90 percent brown trout, 9 to 15 percent brook trout and 2 percent rainbow trout, while the side channel averaged between 50 and 80 percent brown trout, 20 to 50 percent brook trout, and an occasional rainbow trout. Figures 12 through 15 show species composition at each sampling period and site by percent of catchable (≥6.0 inches, 152.4 mm) and subcatchable (<6.0 inches) trout. A general decrease in the percent of catchable brown trout is shown to occur in the main channel and Control I during the study period, while in the side channel and Control II, the composition of catchable as well as subcatchable populations fluctuated only slightly through the study. In the main channel, brook trout numbers seemed to be increasing during the study period, but were decreasing slightly in the side channel and Control II. Rainbow trout were present in numbers too few and sporadic to make any inferences; however, it was noted that of the total of 38 rainbows collected in the three years, all but two were collected in the fall.

The unexpected fluctuations in number collected, average length and weight, and estimates of trout per acre and pounds per acre through the period of study showed few conclusive results concerning effects of modification on the fish stocks. However, a few consistencies can be noted. The data in Table VIII indicate that the

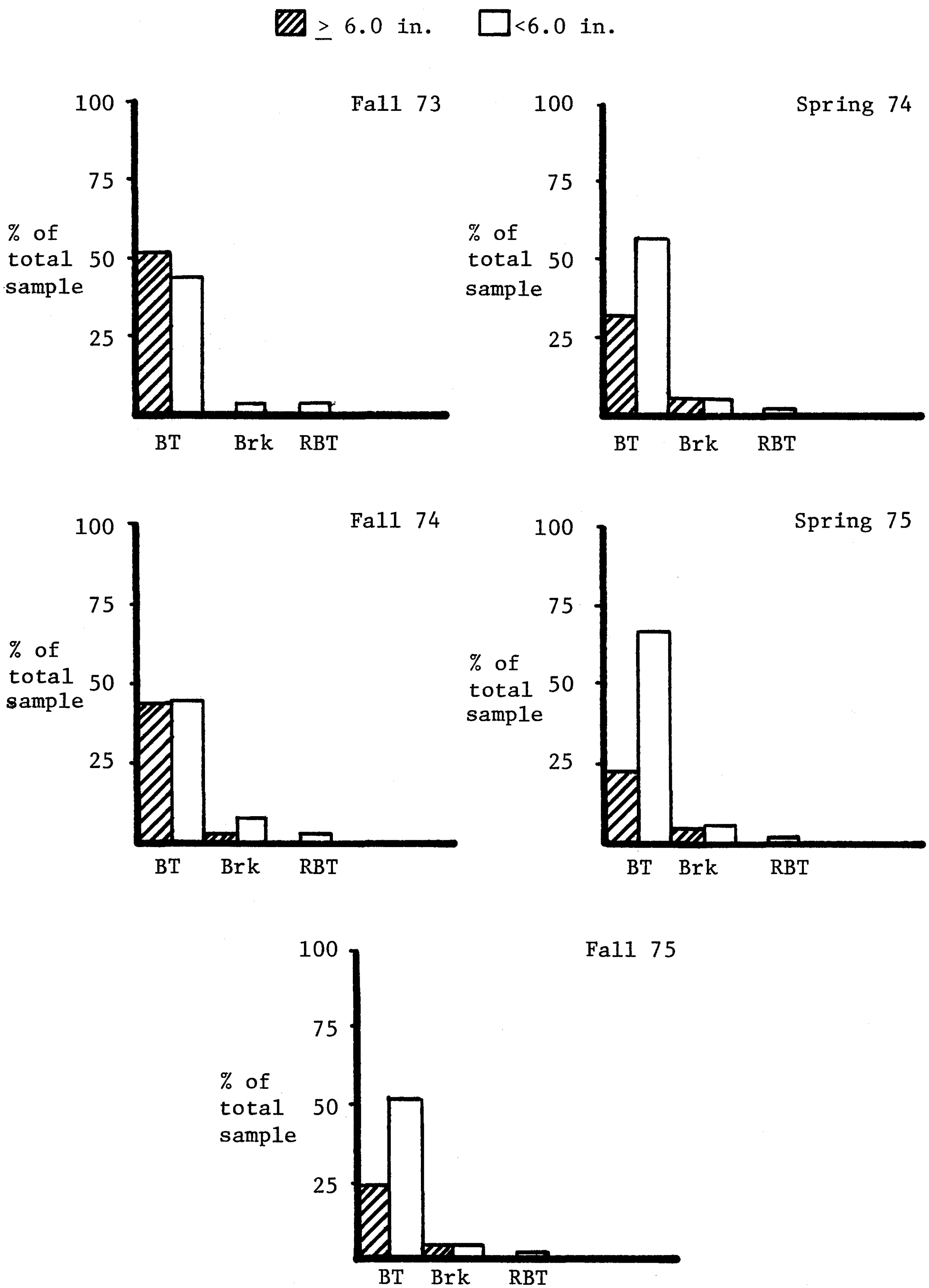


Figure 12. Species Composition by Per Cent of Catchable and Subcatchable Trout for Five Consecutive Sample Periods, Douglas Creek Main Channel.

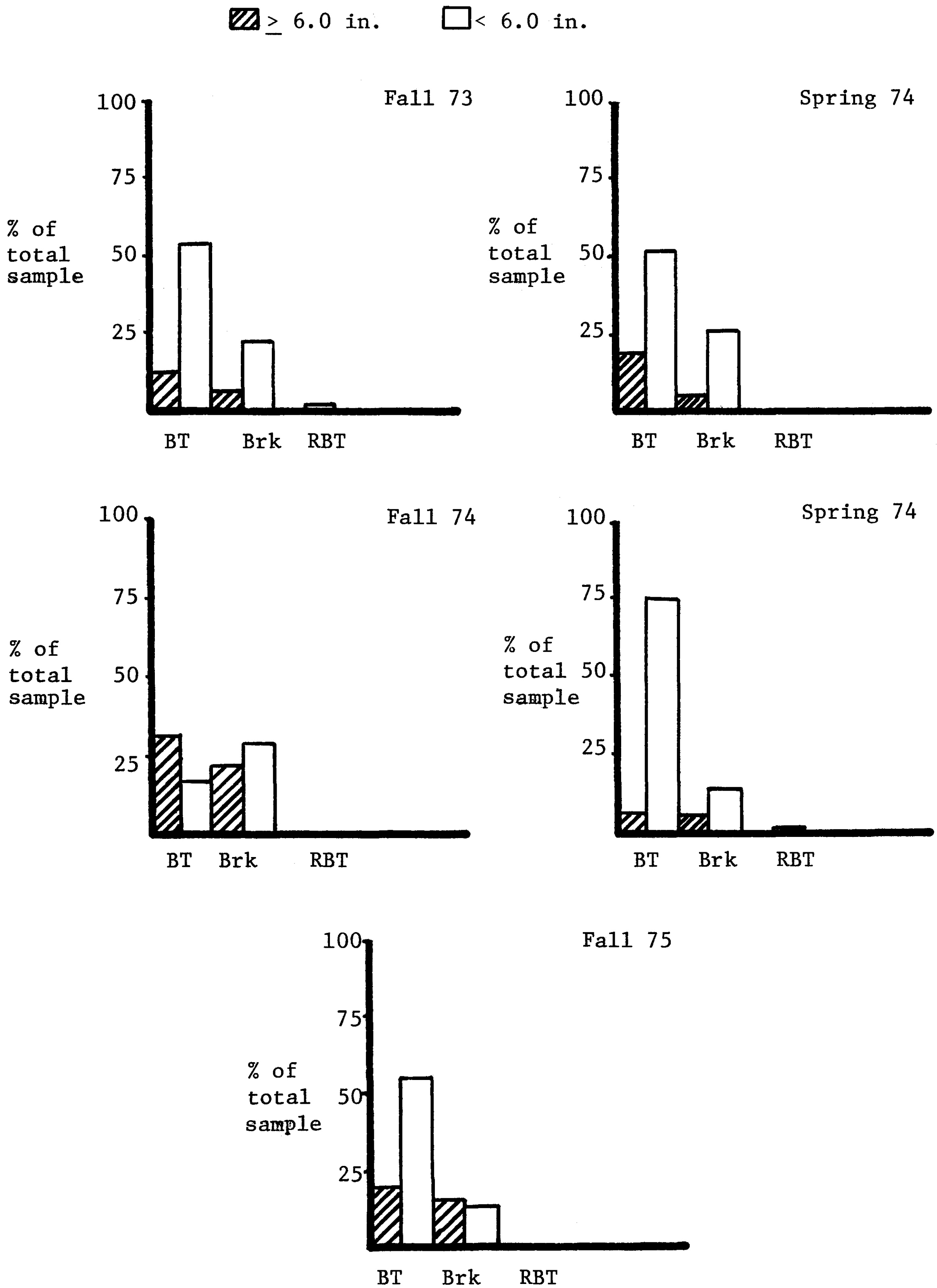


Figure 13. Species Composition by Per Cent of Catchable and Subcatchable Trout for Five Consecutive Sample Periods, Douglas Creek Side Channel.

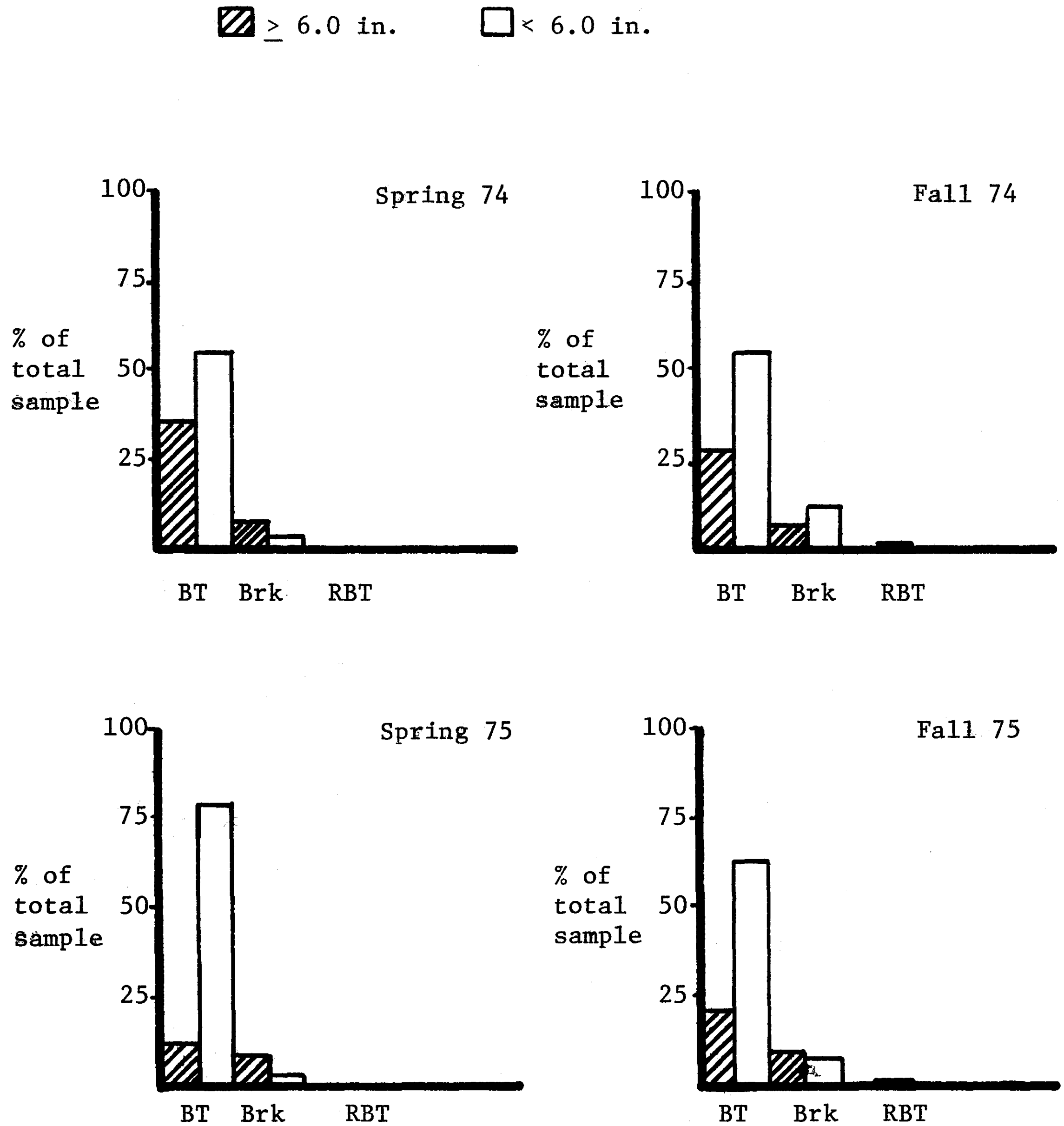


Figure 14. Species Composition by Per Cent of Catchable and Subcatchable Trout for Four Consecutive Sample Periods, Douglas Creek Control I.

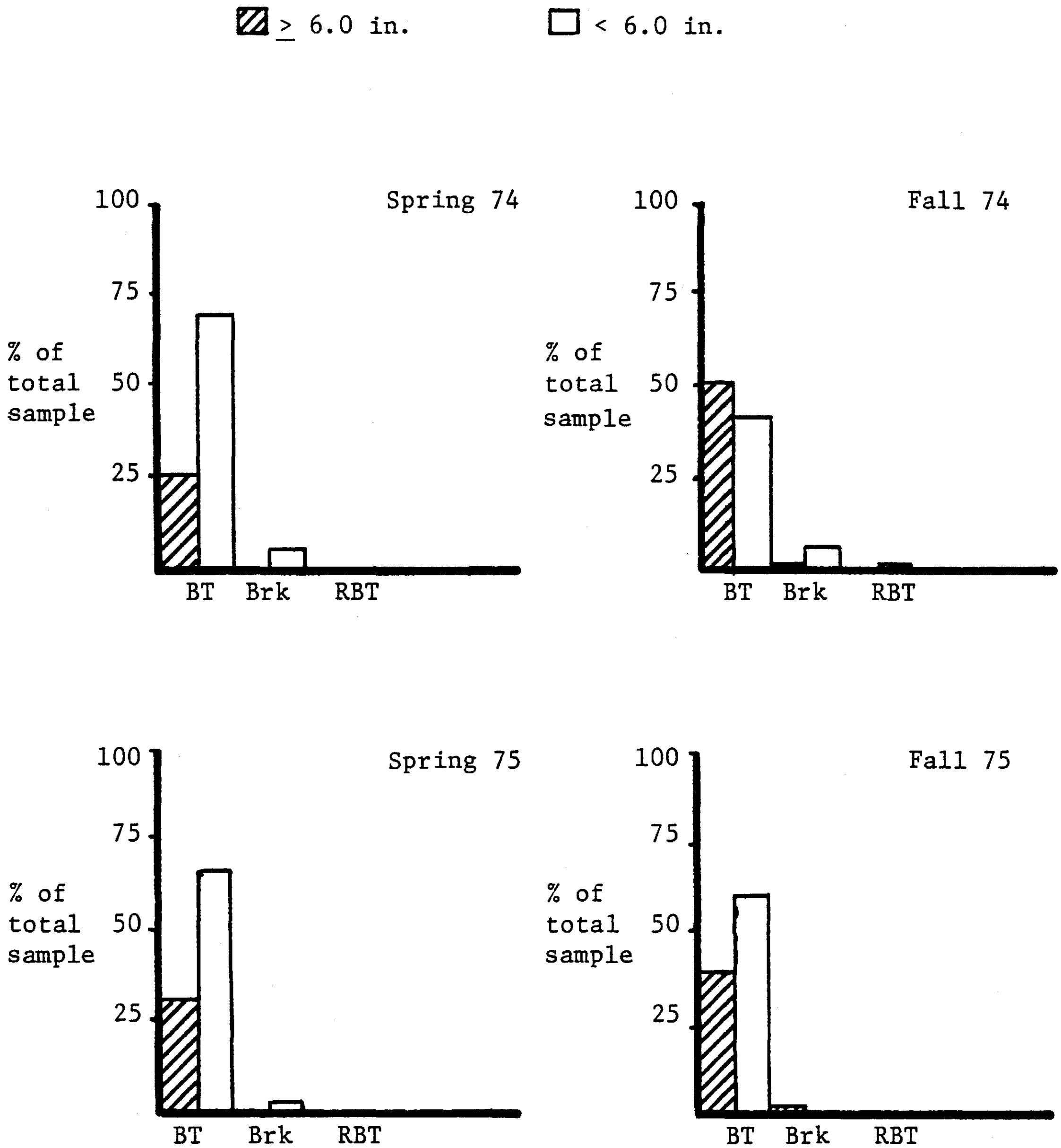


Figure 15. Species Composition by Per Cent of Catchable and Subcatchable Trout for Four Consecutive Sample Periods, Douglas Creek Control II.

population numbers fluctuate seasonally, thus it seems the best way to analyze the data is by grouping and comparing fall estimates to other fall estimates, and spring estimates to other spring estimates, for without sampling every week or every other week, there is no way to correlate the low spring populations to the high fall populations.

The two control areas, which were established to be indicators of natural changes (unrelated to the project) occurring through the study period, showed 57 and 74 percent increases in population numbers from spring, 1974 to spring, 1975. Similarly, the main and side channels showed respectively, 36 and 47 percent numbers increases during the same period. Fall, 1975 estimates for Control I and the side channel, however, were 23 percent less than fall, 1974 estimates, and the estimate for Control II was 32 percent less. However, the numbers estimate for the main channel was 31 percent greater in the fall of 1975 than in the fall of 1974. This trend is contrary to the natural pattern shown by the controls and indicates that more trout stayed in the main channel section, possibly as a result of the modifications. Total poundage estimates followed a similar pattern, except that the modified main and side channel estimates decreased from fall, 1974 to fall, 1975, but by a smaller amount than did the controls.

Average lengths and weights for brown trout were greater than for brook and rainbow trout through the fall, 1974, sampling in all sections except Control I, but during the two 1975 sampling periods, average lengths and weights of brook trout exceeded those for brown trout. This was not brought about by the fact that brown trout average size decreased in 1975, but rather that the average size of brook trout increased. Table XII compares length-frequency distributions in each section at the beginning of the study (pre-modification) with those at the end (post-modification).

Mean condition, or plumpness of trout (K_{TL}) also appeared to fluctuate through the period of study (Table VIII). Generally, as would be expected with fall spawning species because of gonadal development, average condition of individuals was higher in the fall than spring. The condition fluctuations in the side and main channels in 1974 could have been affected by the instream work which occurred between the spring and fall sample dates. The condition factor of brown trout in both controls was higher in the spring of 1974 than in the following fall possibly indicating a stream-wide trend, while the following season showed condition of individuals to again be lower in the spring than in the fall. The only conclusive fact that can be noted from the condition data is that no drastic or steady declines, or increases, have occurred with modification or through the period of study.

The results of the marked fish data are shown in Table XIII. Starting in the spring of 1974, all trout captured by electrofishing except young-of-the-year, were fin-clipped before they were released.

All sections showed a number of trout remaining in the section from season to season. The main channel showed the greatest capacity to retain marked fish, the least amount of migration out to other sections, and the greatest capacity to attract trout from other sections. The greatest amount of migration to other sections was from the side channel.

TABLE XII. Comparison of Length-Frequencies of all Species At the Beginning of the Study and End of the Study in all Sections

	MC									SC								
	BT			Brk			RBT			BT			Brk			RBT		
Length mm	Fall 73*	Spring 74	Fall 75	Fall 73*	Spring 74	Fall 75	Fall 73*	Spring 74	Fall 75	Fall 73	Spring 74	Fall 75	Fall 73	Spring 74	Fall 75	Fall 73	Spring 74	Fall 75
< 76	5	6	72	0	0	8	0	1	0	11	3	18	7	6	13	2	0	0
77-100	6	17	3	4	1	0	0	0	1	10	9	7	20	10	1	0	0	0
101-125	33	6	119	1	2	6	4	0	2	41	6	17	12	4	3	2	0	0
126-150	59	11	45	1	1	11	0	0	1	62	9	1	13	2	2	0	0	0
151-175	26	4	61	0	2	11	0	0	2	12	8	3	8	0	7	0	0	0
176-200	26	7	22	0	1	4	0	0	1	9	2	5	7	1	0	0	0	0
201-225	15	2	22	0	0	2	1	0	0	6	2	1	1	0	0	0	0	0
226-250	14	7	2	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0
251-275	9	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
276-300	6	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
301-325	4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
326-350	9	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
351-375	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
376-400	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
401-425	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
426-450	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
451-475	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Fall, 1973 MC data include trout from transects 1 through 23. Spring 74 and Fall 75 data is from transects 4 through 20.

TABLE XII (CONTINUED)

	C I						C II					
	BT		Brk		RBT		BT		Brk		RBT	
Length mm	Spring 74	Fall 75	Spring 74	Fall 75	Spring 74	Fall 75	Spring 74	Fall 75	Spring 74	Fall 75	Spring 74	Fall 75
<76	3	4	0	0	0	0	1	0	0	0	0	0
77-100	11	56	0	1	0	0	6	32	0	1	0	0
101-125	8	12	1	1	0	0	3	4	1	0	0	0
126-150	7	17	1	3	0	0	3	10	0	1	0	0
151-175	7	3	2	5	0	0	1	11	0	0	0	0
176-200	4	4	2	2	0	0	0	6	0	0	0	0
201-225	5	1	0	1	0	0	2	0	0	0	0	0
226-250	2	1	0	0	0	0	0	0	0	0	0	0
251-275	1	0	0	0	0	0	1	0	0	0	0	0
276-300	0	0	0	0	0	0	1	0	0	0	0	0

TABLE XIII. Mark-Recapture Data for the Trout Collected During Four Consecutive Sample Periods, Douglas Creek

	Main Channel				Side Channel				C I				C II			
	Spring 1974	Fall 1974	Spring 1975	Fall 1975	Spring 1974	Fall 1974	Spring 1975	Fall 1975	Spring 1974	Fall 1974	Spring 1975	Fall 1975	Spring 1974	Fall 1974	Spring 1975	Fall 1975
No. marked	71	238	159	328	76	69	204	56	54	213	110	179	19	224	67	157
No. recaptured same section as marked	--	15	16	86	--	23	17	16	--	13	15	54	--	6	21	46
No. recaptured other sections originally marked in this section	--	1	0	5	--	5	2	16	--	2	11	7	--	1	1	2
No. marked other sections recaptured in this section	--	5	7	14	--	-	4	3	--	3	0	15	--	2	3	9
Total number marked in this section still present in all sections	--	16	16	91	--	28	19	32	--	15	26	61	--	7	22	48

Twenty percent of the trout marked in the main channel in the first three sample periods were still present throughout the study area in the fall of 1975. Ten percent of all trout marked in the side channel were still present in fall, 1975, while approximately 15 percent of those marked in both control areas still remained within the study area.

CHAPTER VI

RESULTS OF PHYSICAL MODIFICATION

The overall effects of the construction work on the trout populations in the study sections cannot be known until much additional post-modification data are collected, but immediate effects should be noted. Similarly, specific hydraulic measurements at points around and in the areas of the structures before the modification should be compared to those at the same points after modification. Therefore, a structure-by-structure description of these conditions was recorded (refer to Figures 16-24).

Side Channel

Structure #1 (Figure 16).

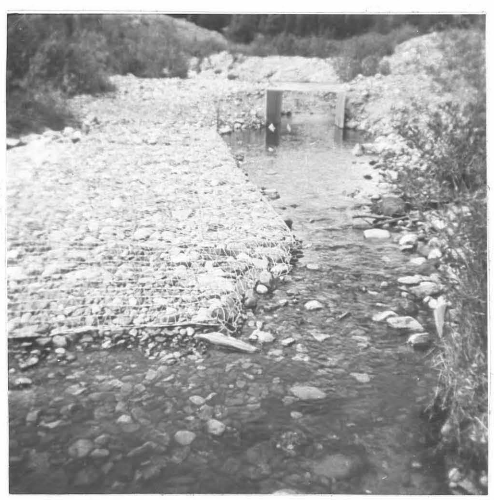
Data points were chosen after the location of the structure was mapped to represent areas upstream, downstream, and adjacent to the structure which were likely or desired to change hydraulically.

The structure increased the mean depth, decreased the top width and increased the point velocity at each point except point 6, where the depth remained the same.

Prior to structure installation, electrofishing produced no trout at the undercut bank at stakes 16+05 to 16+25, while the fall 1974 electrofishing produced two trout; spring 1975, four trout; and fall 1975, three trout.

Structure #1 location at 25 cfs

Structure #1 location at 0.5 cfs



Structure #1 at 0.5 cfs post modification

Figure 16. Structure #1

Structure #2 (Figure 17).

Premodification data points for this structure were taken as transect cross-sections were routinely run (that is, depths and velocities were measured every two feet across the channel), at a location five feet upstream from the check dam location.

The structure created a pool at low natural flow 24 feet wide and approximately 45 feet long, with a depth at the outer edge of the undercut at 15+10 of over one foot.

One trout was captured before modification in spring 1975 at this location, while after modification three trout were captured in the fall 1974, nine in the spring 1975, and six in the fall 1975.

Structure #3 (Figure 18).

Like structure #2, the data points for this check dam were compared by the transect method. A pool 24 feet wide and approximately 40 feet long was formed by the structure with a mean depth immediately upstream from the dam of 0.7 feet and a depth at the right bank undercut (stakes I10+90 to I11+25) of 1.25 feet. A total of 30 linear feet of natural undercut bank was inundated.

Electrofishing before modification (spring 1974) produced three trout from the area affected by the structure. After structure installation, in fall 1974, fifteen trout were captured from the undercut bank; in spring 1975, fifteen trout; and in fall 1975, nine trout were captured.

Location for Structure #2, 0.5 cfs

Completed Structure #2, 0.5 cfs

Structure #2, 100 cfs

Figure 17. Structure #2

Location for Structure #3,
looking upstream, 0.5 cfs

Location for Structure #3,
left to right, 0.5 cfs

Completed Structure #3,
looking upstream, 0.5 cfs

Completed Structure #3,
left to right, 0.5 cfs

Figure 18. Structure #3

Structure #4 (Figure 19).

Preconstruction data points for the two-point deflectors on opposite banks were located in the area where the constriction would be created between the downstream wing of the upper deflector and the upstream wing of the lower deflector. Since it was also intended that the constriction would increase upstream depths to inundate undercuts at I10+00 to I10+20, transect data were also gathered at transect 33 for pre- and post-modification comparison.

The deflectors increased the upstream depth at the undercut banks, increased the velocity through the section, and increased the depth at the undercut bank below the constriction. The structure divided the long, slow pool into two smaller pools with greater depths at undercut banks, and a higher time-of-travel velocity.

Prior to installation, fourteen trout were electrofished from the structure area, while fall 1974 sampling yielded eighteen trout from the same section; spring 1975 showed fourteen trout using the section; and in the fall 1975, twelve trout were captured there.

Structure #5 (Figure 20).

Again, the transect method was used for the data comparison points. The intended function of the structure was to reduce the surface area of the wide, flat pool, increase the depth and velocity by constriction with a barrier-type deflector, and move the consolidated flow to the undercut banks at I9+35 to I8+95.

This structure, in conjunction with structure #4, increased the depth at the undercut banks at stakes 12+80 to 12+60, and increased

Location of Structure #4,
0.5 cfs, looking upstream

Completed Structure #4,
0.5 cfs, looking upstream

Completed Structure #4,
0.5 cfs, left to right

Completed Structure #4,
100 cfs

Figure 19. Structure #4

Location of Structure #5,
0.5 cfs, looking downstream

Completed Structure #5,
0.5 cfs, looking downstream

Completed Structure #5
100 cfs, left to right

Figure 20. Structure #5

the time-of-travel velocity from transect 33 to transect 35. It also increased the depth at the undercut bank at I9+35 to 0.55 feet.

Trout collected before modification in this section numbered thirteen. After modification, the fall 1974 electrofishing produced seven trout, while spring 1975 yielded thirteen trout, and fall 1975, eleven trout.

Structure #6 (Figure 21).

Comparative data for this structure were collected along transects 35 and 36. The intent of this spur dam was to deepen, in conjunction with structure #5, the water along the undercut banks and overhanging vegetation from I8+95 to I9+30, while diverting the flow to the undercuts at 12+00 to 11+85.

The structure increased the depths at undercuts both upstream and downstream, and reduced the amount of slow, shallow water downstream from transect 36 by directing the total flow to the left bank.

Premodification electrofishing yielded nineteen trout in the area affected by the spur dam, while in the fall immediately after modification, only ten trout were captured in the same area. Spring and fall 1975 electrofishing produced fourteen and twelve trout respectively from the same cover.

Structure #7 (Figure 22).

Transect data for transects 40 and 41 served as comparison points for the check dam at stake 10+45. The function of this structure was to raise the water level immediately upstream to over 0.5 feet to utilize the 20 feet of natural undercut on the right bank.

Location of Structure #6,
9 cfs, looking downstream

Completed Structure #6,
0.5 cfs, looking downstream

Completed Structure #6,
0.5 cfs, left to right

Completed Structure #6,
100 cfs, left to right

Figure 21. Structure #6

Completed Structure #7,
0.5 cfs, looking upstream

Completed Structure #7,
0.5 cfs, left to right

Completed Structure #7,
100 cfs, left to right

Figure 22. Structure #7

The total effect was to create a pool 20 feet wide and 35 feet long, and increase the mean depth at transect 40 and near the undercuts.

Before installation of the structure, electrofishing yielded five trout. In the fall of 1974, ten trout were captured in the pool; in the spring of 1975, eight trout; and in fall 1975, six trout.

The artificial overhangs were installed after all other structures were completed. Areas which met depth criteria and lacked natural bank cover were chosen for artificial overhang location. On September 27, 1974, ten days after the artificial overhangs were installed on the side channel, a total of 34 trout were electrofished from under the overhangs. Maximum number of trout using one 1 foot x 5 foot overhang was 9, with the mean number found utilizing these structures being 5.6. In the spring 1975, ten trout were captured from artificial overhangs and in the fall 1975, the artificial overhangs yielded six trout.

The general effect of the side channel modification was an overall increase in mean depth, a decrease in time-of-travel velocity, and an increase in surface area. These changes are all noted in Tables I through IV. Total amount of usable cover was also greatly increased (Table VI).

Trout were found to be using the structures and areas affected by the structures in all sampling subsequent to the modification. Sizes of fish collected at each location should have been noted before any modification for comparative purposes, but, regrettably, this was overlooked.

Sizes and locations of trout were noted in the spring 1975 sampling, but are of little value for the purposes here, without any data for comparison.

After two seasons of low flow and one season of runoff, the side channel structures appear to function well. Fluorescent dye injected at 75 cfs indicated that the low profile of the structures does not restrict high flows to the low flow channel; rather, when depths exceed 0.5 feet, the excess merely runs over the top of the barrier, spur dam and deflectors, and the structures have no visible effect. Check dams were visible even at 100 cfs (Figure 17), but since they were perpendicular to the flow with the spillway being the lowest elevation, the high flow did not appear to cause pressure on the banks. An exception was noted with structure number 3, where the low left bank allowed high flow water to run around the end of the check dam, scouring out a three by ten foot hole approximately one foot deep. This was filled with boulders in the summer of 1975, and the low bank at the left end of the check dam was built up with large rock and a log.

Other scour was noted immediately downstream from the check dams as the formation of a plunge pool occurred, but the v-mesh down ramp prevented any undercutting of the structures and no undesirable effects were noted. The only other scour noted after recession of high flows was off the point of structure number one, where high velocities coming through the Parshall flume had displaced fine gravels and deposited them in a point bar extending about ten feet below the downstream end of the deflector. This deposition filled in under the artificial overhang at stake 16+25 making it unusable. This overhang was removed in the summer 1975.

Some deposition of silt occurred in the ponds created by the check dams, and it is felt that this condition may become a problem in the future.

In the fall of 1975, after all post-modification evaluations were complete, it was found that a colony of beaver had moved into the side channel and become active during the early fall. All three check dams had been built up with rock and willows between 0.5 and 1.0 feet higher than the gabions, and the spillways plugged. In addition, the barrier-deflector at stake 12+55 had been extended to create another dam completely across the channel. What effect this will have on the hydraulics and fishery in the channel remains to be seen.

Since installation, and particularly during spring runoff, the gabion structures have collected leaves, willows, sticks, grass, and other debris which partially camouflage the wire mesh and help make them aesthetically unobjectionable. It is expected that this debris will continue to accumulate as time goes by, and the artificial appearance of the structures will become less and less visible.

Main Channel

After much consideration of transect data, it was decided that the major section of the main channel which suffered most as a result of dewatering was the wide, flat, shallow reach from stake 1+40 downstream to stake 3+00. It was found that a barrier to constrict the channel in this section would consolidate the flow, increase the depths to utilize undercuts in the whole section, increase low flow velocities, and greatly decrease the surface area at low flow. Figure 23 shows the barrier.

Depth velocity data from transects 4 through 8 were used as pre- and post-modification change indicators for the main channel barrier. In addition, a series of seventeen data points were picked in the channel near the left bank extending from transect 4 downstream to below transect 8. The barrier, by constricting the channel, caused an increase in depths across transect 4 as well as in the modified reach. At transects 5, 6, and 7, depths and velocities were increased and top width and surface area were decreased. The data point depths were increased sufficiently to inundate the natural bank cover throughout the length of the section.

Electrofishing produced fourteen trout from the 170 foot section in the spring 1974 before installation of the barrier. In the fall of 1974, 63 trout were captured here, while the spring 1975 electrofishing yielded 39 trout. A total of 94 trout were caught from the section in the fall 1975.

Eleven 5 ft. x 1 ft. corrugated sheet metal artifical overhangs were installed on the main channel; one at stake 7+35, and ten in the area of the barrier. The overhang at 7+35 and three others were installed as explained in the Appendix, while the remaining seven were attached to the barrier using gabion lacing wire. Figure 24 shows an artificial overhang.

Barrier area,
9 cfs

Barrier during construction,
5 cfs

Completed barrier,
5 cfs

Barrier area, May 1975,
25 cfs

Figure 23. Main Channel Barrier

In the fall 1974 sampling, fifteen trout were found using the main channel overhangs, while spring 1975 showed twenty-one trout, and fall 1975 showed forty-two trout.

Post-runoff evaluation of the main channel barrier and overhangs showed no signs of adverse scour or substrate movement. The fill area behind the gabions showed no movement, and, in general, the structure functions well.

An experimental artificial boulder was installed at transect 9 in the fall of 1974. This type structure had been developed and installed in the Black's Fork river (Wesche and Cooper, 1974) during the early fall of 1974, and it was decided to include one as a test structure in Douglas Creek. The structure was placed directly in the thalweg at 18 cfs, to test the strength of the design, and, unlike the seven artificial boulders installed in the Black's Fork River, the rubber mat described in the Appendix was not included, in order to see if it was necessary. No electrofishing was done prior to installation, as the main interest was in the strength of the structure, and trout would not normally be expected to be present in that particular area because of low depths and lack of cover.

In the spring 1975 following recession of runoff flows, the structure was found to have washed out and been swept over 400 feet downstream to transect 20 by flows greater than 400 cfs. It was felt that the lack of the rubber mat and the failure to reinforce the upstream edge with boulders allowed the pressure of high flows to scour around the edges and behind the structure, causing it to tip backward and roll downstream.

The total cost of structure construction materials for the Douglas Creek modification, at 1974 prices, was approximately $1500. This estimate does not include costs of labor, tractor rental, or other expenses incurred in travel to and from the section, preliminary surveying time and labor, or materials expended in unsuccessful structures which had to be removed. These expenses are expected to vary grossly in different situations, so no attempt to itemize them is offered here. In many situations, the availability of gravel for fill may constitute a major expenditure which was not encountered in the current research.

In general, the total cost of the structures does not seem to be excessive. The fact that any one of the structures could be installed by one man with a shovel and pliers makes the cost seem even more reasonable. Life expectancy of the gabion structures varies with water chemistry, but for the Douglas Creek structures, corrosion tests one year after installation give estimates of between 2 and 10 years. The gabions used were 14 gage uncoated galvanized wire, but black plastic coated baskets of the same size are also available for a slightly higher cost.

A large beaver dam was also noted in the late fall of 1975 on the main channel in the vicinity of transect 18. The dam has no effect on the modified area, but increases the total surface area of the main channel and decreases the time-of-travel velocity. All post-modification evaluation was complete before the dam was built.

Completed artificial
boulder, R to L, 60 cfs

Installed artificial overhang with
willows attached, 0.5 cfs

Installed artificial overhang with
willows attached, 0.5 cfs

Figure 24. Other Structures used in Douglas Creek

CHAPTER VII

DISCUSSION

The approach to habitat maximization at low flows as investigated under the current research is a new concept. The literature is plentiful concerning stream improvement as a means of restoring stream channels which have been physically abused by the activities of man (roadway construction, mining, livestock grazing, etc.). Similarly, many references can be found which recognize the efforts of interest groups in their desires to contribute to the field of fisheries through small habitat expansion programs. But, the problem of loss of habitat due to extended periods of low natural flows or low flows created by man is a very real situation which has been studied only in relation to augmentation or prevention, but not enhancement.

The results of the current research offer a useful tool for the expansion of the amount of habitat available to trout in mountain streams which are subject annually to flows marginal, or even critical, to the fishery. In accordance with Liebig's law of the minimum (Odum, 1959), a trout population is limited by its dynamics at the lowest flow which occurs in that stream for an extended period of time. For example, if a stream runs 50 cfs year round, its trout population is a function of the depths, velocities, and cover which occur at 50 cfs. But, if the same stream flows 50 cfs for ten months, and 2 cfs for the other two months, the fishery can only expand to the depth, velocity and cover limits which occur at 2 cfs. This means that, in order to best utilize the habitat present for the ten months at 50 cfs, the maximum possible use must be made of the conditions present at 2 cfs.

The depth, velocity, and cover requirements of trout for spawning, growing, feeding, resting and hiding have been identified by Wesche (1973), Hoppe and Finnell (1970), Thompson (1972), Kennedy (1967), and others. The creation of these conditions throughout an entire low flow section by modification of the channel was found to be possible by the current research. It was found that with a flow which was estimated to be 10 percent of the average daily flows in a medium-sized mountain stream, depths and velocities suggested as essential for trout growth and reproduction can be attained by flow manipulation.

Low profile structures, which are designed to affect low flows, were found to be inexpensive, easy to install and fully functional for the vastly fluctuating flow regimes which are found in the Rocky Mountain area. Where spring runoff flows may be 1,000 times greater than fall low flows in the same channel, it seems hydraulically dangerous to construct modification devices which deflect or restrict any flow much greater than the minimum. The low structures used were found to have very little constricting or consolidating effect on the high flows encountered at Douglas Creek, and were relatively unnoticeable, except the check dams, at flows greater than minimum.

It is felt that changes in total population size, average size of trout captured, and an indication of a less fluctuating seasonal stock will emerge as partial indicators of the success of the research. Reasons for the vast seasonal fluctuation in population numbers have never been certain, but the most likely explanation is a substantial up or downstream migration during the late fall and through the winter when flows are lowest and space competition is highest. Sampling in the early fall always showed from two to five times as many trout present in the sections as there were the preceding or following spring. The presence of a jaw-tagged twelve-inch brown trout (tagged in the fall 1974 by the Wyoming Game and Fish Department in the North Platte River where Douglas Creek runs in) under one of the main channel artificial overhangs in the spring 1975 sampling indicates an upstream movement from the North Platte of roughly 16 miles. Though the information from one fish is in no way conclusive, it suggests that the Douglas Creek trout population is highly migratory and only a small scattering of permanent residents (as indicated by mark returns) inhabit the areas defined by the low flows. It is felt that the increase in the amount of inhabitable water in the main and side channels may contribute to the expansion of the trout population in either numbers or size, or both. If conclusive results can be shown to that effect over a period of years, it seems reasonable to assume that a project of this nature could benefit a growing number of streams or rivers in similar low flow conditions.

The greater depths, velocities, and cover created by the structures, and the finding that trout are regularly using these artificial niches, add substantially to the trout production potential of the reach. As trout of all sizes have been found to migrate into the modified sections, a logical assumption is that they are vacating other niches in doing so. The availability of this extra space increases the carrying capacity of the section. The fact that there appears to be no preference, on the part of the trout in the study, for natural cover as opposed to artificial cover, as long as depth and velocity criteria are met, indicates a vast potential for expanding the amount of overhead cover in dewatered streams. Also, the design of the overhang, which permits it to float and fluctuate with the flows, makes it superior to the fixed type of bank cover described by White and Brynildson (1967).

The cost involved in improving a section of stream has often been the target of anti-stream improvement fisheries workers. While it is recognized that the dollar value of the number of pounds of catchable trout which enters the creels of Douglas Creek anglers will probably never approach the cost of the modification, the application of the research to other situations where a fishery has been lost or damaged, or was never present, due to dewatering, could be of substantial value. Further, it is probable that young trout remain in various sections of Douglas Creek until they outgrow their niche, and then are forced to migrate to areas of greater depth, velocity, and cover (probably the North Platte River) as flows become depleted. Since the required depths and velocities in cover areas are maintained as a result of channel modification, it is not unreasonable to expect that conditions may induce more trout of catchable size to remain in the sections through the low flow period, with the total effect being a substantial increase in the average size of trout available to the creel. The data show the presence of an occasional brown trout in the 16- to 18-inch class, suggesting that, in those few areas where physical, hydraulic, and biologic conditions are naturally maintained at low flows, brown trout can continue to grow to large catchable size. It is, therefore, possible that the value of the Douglas Creek fishery can increase, and the cost of modification be partially offset, by the section's becoming known for its ability to yield a limit of medium and large catchable trout. This is desirable because: 1) few streams in the Snowy Range offer the angler much more than a limit of pan-sized catchable trout; and 2) most streams in the immediate area capable of yielding a number of 16- to 18-inch trout are on private land, and, therefore, relatively inaccessible to the general angling public. The emergence of Douglas Creek as an easily accessible stream with a well-structured population of large-sized catchable trout could be of substantial value to local anglers.

The immediate hydraulic results of the research indicate that desirable depths, velocities, cross-sectional areas, and cover can be created using low profile gabion structures. The biological results, however, are slower to evolve. Immediate post-modification observations showed trout to be present in the areas of all structures, and that artificial cover was being used to a substantial degree. However the final results of the present research on the fishery (i.e., changes in average size, species composition, or numbers) cannot be included here for obvious reasons. Long term post-modification evaluation is, therefore, a necessity.

In this era of increasing demands on precious streamflows, much research is being carried on to identify instream flow needs for trout, and subsequently recommend flow regimes to prevent marginal fishery conditions. However, it is important to realize that there may be situations where these instream flow criteria cannot be met, and an alternative plan should be available and implementable. The current project begins to fulfill this need.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

1) Low profile structures for dewatered channel enhancement are extremely efficient for consolidating, constricting, and deflecting the flow to areas of dewatered cover, making these areas again usable by trout. The lowness of the structures was found to affect only minimally the higher flows encountered in the channel, but optimized the mean depths and velocities at low flows.

2) The use of gabions for low profile structures in Douglas Creek gave desirable results. Gabions are easy to work with and can be formed to any desired configuration. They are relatively inexpensive and were found to be solid enough to withstand flows of runoff magnitude. The addition of a down ramp to any vertical faces which approached perpendicular to the flow was functional in restricting and preventing scour, and is recommended. Due to the necessity in low flow work of keeping the water consolidated, it is required that some impermeable material be placed inside structures, such as check dams, whose desired function depends on using the maximum amount of water available. The spaces left between the rocks used for fill permit a certain amount of leakage. For deflectors, barriers, and spur dams, the impermeable material is not always necessary.

3) Floating artificial overhangs were found to be just as

attractive to brook and brown trout as natural overhangs, as long as depth-velocity criteria were met. After barrier and artificial overhang installation on the main channel of Douglas Creek, the number of trout collected there tripled.

4) The aesthetics of gabion structures are encouraging. They blend well with the surrounding substrate, and collect debris at high flows, helping them to appear even more natural. The artificial overhangs are relatively unnoticeable from over ten feet away. The reaction of anglers to the structures is not known at this time, but should be determined in the future.

5) It is recommended that in further stream modification work, the plastic-coated gabions be used. Galvanized coating has been found to oxidize readily in situations where the gabion is alternately in contact with air and water. Life expectancy of the plastic-coated wire is in excess of fifteen years, and aesthetics are comparable to, or exceed, those of the galvanized gabions.

6) The trout populations in the Douglas Creek study area were found to fluctuate by as much as $\pm$ 50% annually. Reasons for this were not positively identified. However, it is hoped that the expansion of available cover which occurred as a result of this research will influence more trout to remain in the area.

7) A common shortcoming of stream improvement projects is the failure to follow up with an intense evaluation program and securing of needed data relating to post-modification conditions and populations. It is necessary, and recommended, that post-modification

evaluation of the effects on the fishery be continued for at least five years. This will allow the following of one year class of trout through a life cycle and begin to indicate trends, if any, which may result from the modification. It is further recommended that monitoring of the two controls be continued in order to detect streamwide changes which may occur unrelated to the modification.

8) While the research provides answers to the problems studied, a number of questions were generated which could not be answered within the time frame and scope of the present project. Among these were: 1) To what extent can a trout stream be dewatered, and still be enhanced by modification?; 2) How is the upper limit of low flow modification on a given stream reach (i.e., the point where trout biomass ceases to increase, even with continued habitat expansion) identified, and how can it be obtained? Further study of these concepts could contribute much to the ideas investigated in the present project.

9) In the present study, temporary structures were used to precisely determine the hydraulic effects of a proposed structure before permanent installation was begun. In a situation where time does not allow this approach, as is often the case in management, an alternative approach for laying out a modification plan could be used. Using Manning's equation the hydraulic effects of various modification configurations could be predicted using premodification low flow transect data gathered from the areas needing improvement.

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APPENDIX

APPENDIX

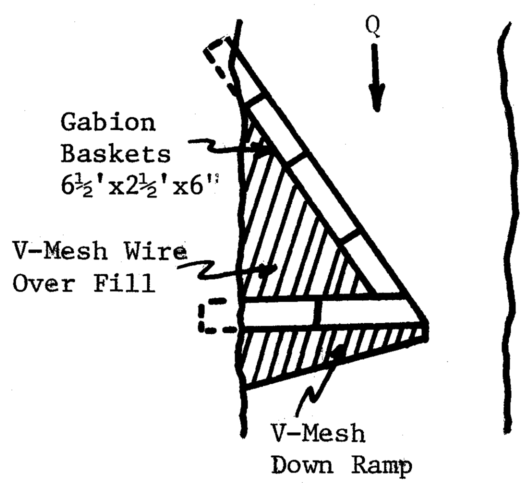
DESIGN AND INSTALLATION OF STRUCTURES

I. Deflectors

The large deflector at the upper end of the side channel (structure #1) was built to constrict the flow coming through the Parshall flume and direct the current to the undercut bank at stage 16+25. Since it was the first structure built, the desire to be sure it would not wash out led to a degree of overdesign, although it does function as planned. The first step in building the deflector was to locate reference points in the current and along the banks. These were marked with surveyor's flags and depths and velocities were measured at each point. On the basis of these measurements, it was found desirable to constrict the low flow channel to approximately two feet wide at 16+30. This would increase the depth at the undercut to 0.5 feet.

The temporary structure was then installed and draped with sheet plastic in order to test the design. Measurements were again taken at the reference points and changes in water depth and velocity noted. The length, width, and angle of the temporary structure were varied until the desired effect was attained. At this point, surveyor's flags were placed along the edges of the temporary structure to mark its position and the structure was removed.

Using shovels, the streambed where the deflector would lie was then leveled. Six 6.5 ft. x 2.5 ft. x 0.5 ft. gabion cells were cut and placed end to end along the flagged outline and laced to each other, as shown in the following sketch:

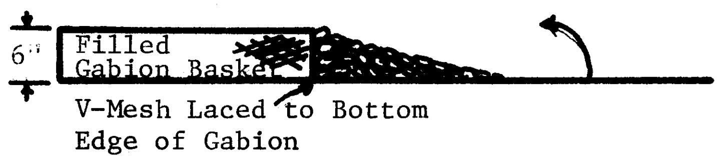


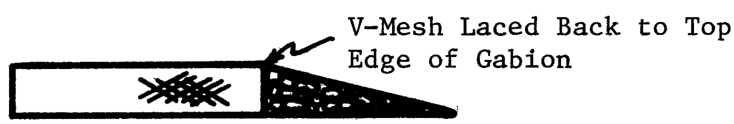
Where the ends of the structure abutted the bank of the high flow channel, a trench was dug back into the bank so as to imbed the structure at least one foot, to avoid the possibility of erosion.

When the baskets were all laced together and lying level in the desired position, they were filled with 3- to 4-inch cobble rock from the dredge piles on the banks of the creek. It took three men with a washtub and shovels approximately four hours to fill the baskets. The cells were filled level full, packed, then filled again until they were moderately rounded on top. Lids were then laced on tightly. It was found that lacing lids to one edge of the basket before filling, decreased the amount of lacing time, as forcing the lacing wire down through the tightly packed rocks after the basket was full was somewhat tedious.

After the baskets were filled and closed, the area enclosed by the deflector was filled with the same size rock until it was level with the filled gabions. V-mesh fencing wire was then laced over the top of the filled area, being secured on two sides to the gabion cells and staked into the bank on the third side with 3/8" reinforcing steel rod.

The final important step was to lace a section of V-mesh wire to the downstream edge of the gabion basket, lay it out flat, fill gravel in a sloping manner on half of it, as shown in the following sketch, and then fold the remaining half back over the fill and lace it to the top edge of the gabion structure, creating a downramp to resist scour.



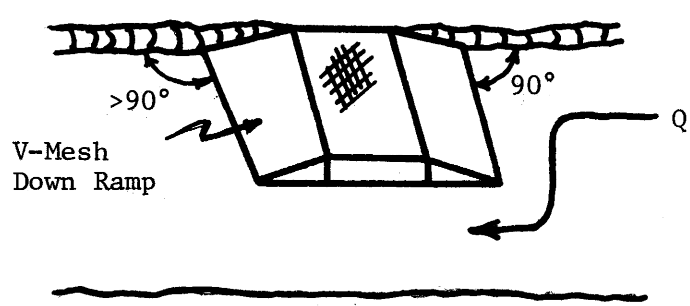


These downramps were added to every structure where a vertical gabion face approached perpendicular to the current in order to prevent any abrupt resistance to the flow which might eventually result in undesirable scour around the structure edges. When the vertical faces of the structures were parallel to the current, this V-mesh downramp was considered unnecessary.

The other point deflector at I9+95 was constructed using the same techniques, except that the area within the triangle formed by the baskets was filled with large (6- to 12-inch) rock and not covered with V-mesh wires. It was felt this would save time in construction and function just as well.

II. Spur Dams

The single spur dam at I8+90 was designed to deflect the low flow current to the undercut banks at 11+85 to 12+00, and raise the upstream water level enough to utilize the dewatered banks at I9+00 to I9+18. Lu (1975) found that the upstream depths created by a spur dam were greatest when the angle between the bank and the dam was 90^{o}. The spur dam built on the side channel consisted of one gabion basket 2.5 ft. x 6.5 ft. x 0.5 ft. placed at a 90^{o} angle to the right bank with V-mesh downramps on both the upstream and the downstream vertical faces. Procedure for installation was the same as for deflectors; 1) picking of data points, 2) measurement of data points, 3) trial design with portable structure, 4) flagging the best design, 5) removal of temporary structure, 6) leveling of streambed, 7) installation of structure, 8) tying in to the bank, and 9) addition of downramps. The following sketch illustrates a completed spur dam.

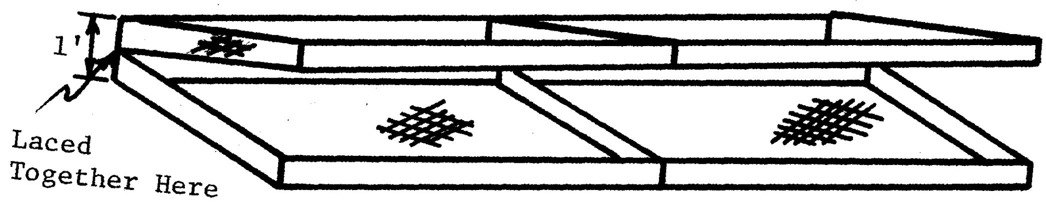


III. Check Dams

Gabion check dams were built in three locations on the side channel, at reference stakes 15+05, 13+90, and 10+45. Their purpose in every case was to impound enough water to raise the upstream surface level to inundate good undercut banks and overhanging vegetation which were unusable by trout at low flow. The locations were chosen from data obtained at higher flows where trout were found using the cover. Using a transit, the height of the check dam spillway was determined to be equal to the elevation of the underside of the upstream end of the bank cover. Check dams were used when a substantial amount of bank cover would benefit from the increased depths created by the dam.

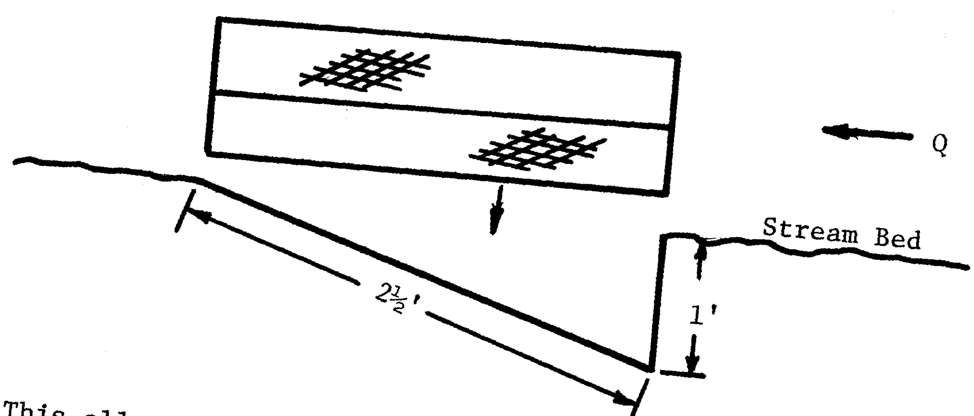
The first step in installation of the gabion check dams after locations were chosen was, again, the picking of data points where the structure would affect hydraulic parameters. Depth and point velocity measurements were taken at each point before any modification was attempted. Then, the proposed structure was set up using the temporary materials in order to observe the effects the dam would have on the channel and banks. Having decided the structure was desirable and functional, construction of the permanent check dam began.

First the streambed where the structure would lie was leveled. While this was being done by two crew members, others were preconstructing the gabion structure on the bank. This consisted of first cutting eight 6.5 ft. x 2.5 ft. x 0.5 ft. cells from the factory gabions. Four of these were laced end to end making the base of the dam 26 feet long and 2.5 feet wide. The other four baskets were also laced end to end and one of the lower edges was laced to the corresponding upper edge of the first row of baskets as shown in the sketch.

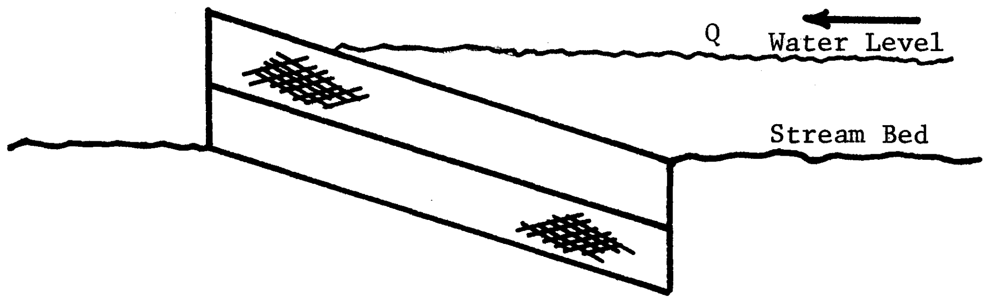


This made a structure one foot high, 2.5 feet wide, and 26 feet long.

The streambed where the upstream edge of the dam would be was then dug down one foot (the height of the structure) and sloped as shown.



This allowed the two rows of baskets to be laid into the excavation in a sloping manner, thus creating the ramp and dam (see sketch). The upper row of baskets was then folded back so that the lower row could be filled with rock from the dredge piles. When this was complete, the top



row of baskets was once again folded over the bottom row and laced down so that it became the lid for the bottom row. The top row was then filled level full with 4- to 6-inch diameter rock. At this point, a layer of rubber mat was draped over the rock in the top row of baskets and tucked in around the edges of the gravel.
This was done to completely seal the structure so no leakage could occur through the spaces between the fill rocks, and to facilitate the movement of high flows over the dam and resist scour. Another layer of rock was then placed over the mat to conceal it, and the lid was laced on to complete the structure. Again, wherever the ends of the structures abutted the stream banks, they were dug back into the banks to prevent erosion around the ends, covered with bank material, and then reinforced with boulders.

Next, using the basic continuity equation Q = VA, the desired cross-sectional area of the spillway could be determined by knowing the minimum desired velocity through the spillway, and the discharge. For example, the regulated discharge being modified in the side channel was 0.5 cfs. If a minimum velocity of 1 fps through the spillway was desired, the area of the spillway needed to be $\frac{Q}{V}$, or 0.5 ft.^{2} The spillways in each of the three side channel check dams were built to be 0.2 feet deep and between 0.8 and 1.0 feet wide. Location of spillways in the structure was determined by location of the thalweg through the structure area, while height of the spillway was determined by the height of the bank cover upstream from the dam. It was found that the spillway should be located as near the thalweg line as possible, but not right against the bank. This maintained the natural pattern of flow through the pool and still avoided scour at the channel banks, while maximizing the depths at the bank cover immediately upstream. Construction of spillways was accomplished by first choosing the location based on the above criteria. The depths desired in the upstream pool, as well as the desired length of the pool, were then noted. When the width and depth of the spillway were thus decided, the upper basket of the dam was cut open at the desired place, and fill rocks were removed or hand placed until the correct spillway was formed. The rubber mat within the upper baskets was formed to fit the spillway, and the gabion was then molded to fit the depression and laced shut.

The final step in check dam construction was the addition of the V-mesh downramp on the downstream edge to prevent undercutting of the check dam at high flow by not allowing an abrupt plunge to occur (see Figure 25), except in the area of the spillway. The plunge pool formed below the spillways, then created a standing wave sufficient to aid trout in passage over the check dam even at low flow.

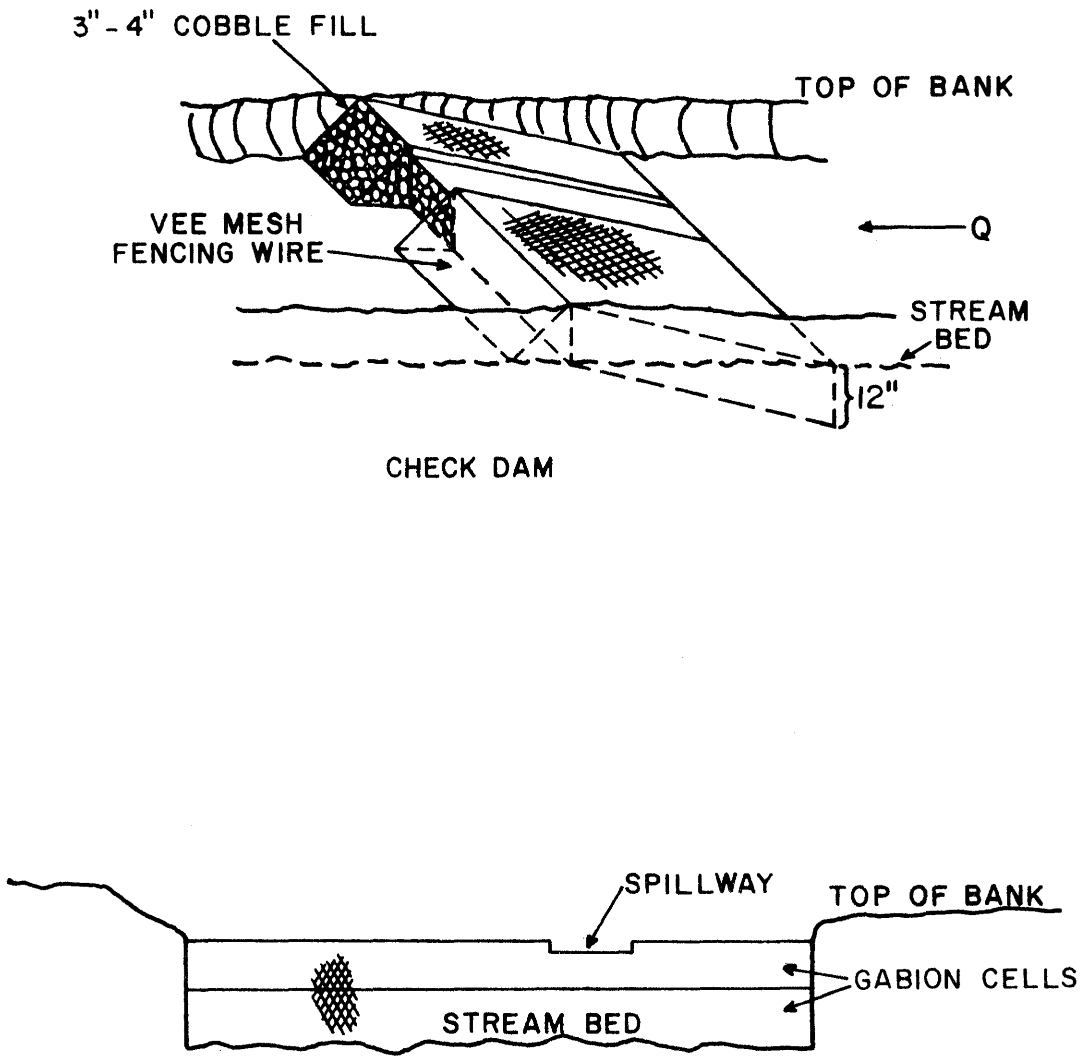


Figure 25. Completed Check Dam

IV. Barriers

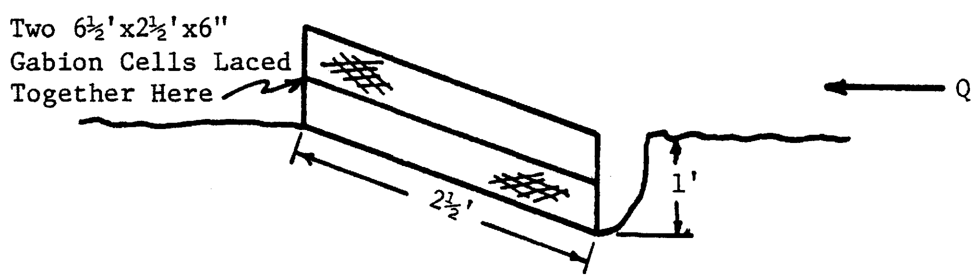
Barriers were built using the same techniques as for all previously described structures, except that the one layer of the 6.5 ft. by 2.5 ft. by 0.5 ft. baskets laced end to end was installed parallel to the current in order to narrow the channel. Figure 23 shows various stages in barrier construction. The large main channel barrier was installed to constrict the channel and deepen the water at the bank cover from stake I0+85 to I2+25. The upstream end was imbedded in the bank and angled out into the middle of the channel, then turned parallel to the current and continued downstream for 140 feet. The lower end was also tied back into the bank. The area enclosed by the barrier was filled with the same size rock as was used inside the gabions and, thus, raised the level of the streambed on the right side of the channel by 0.5 feet, and created the low flow channel between the barrier and the left bank. The width of the low flow channel was determined mostly by experimenting with various temporary barriers until a configuration was reached which created sufficient depths against the previously dewatered banks to again make them usable. Length of the constricted area was determined solely on the basis of the length of the section of dewatered bank cover.

Another barrier-type deflector was constructed on the side channel at stakes 12+65 to 12+45. Its purpose was to constrict the channel and increase the velocity in the reach, while deflecting the consolidated flow to the undercuts at I9+25 to I9+30. The structure was built like the main channel barrier, except the lower end was not tied back into the bank because it was felt that side channel velocities were never high enough to make the added expense and time worthwhile.

V. Artificial Boulders

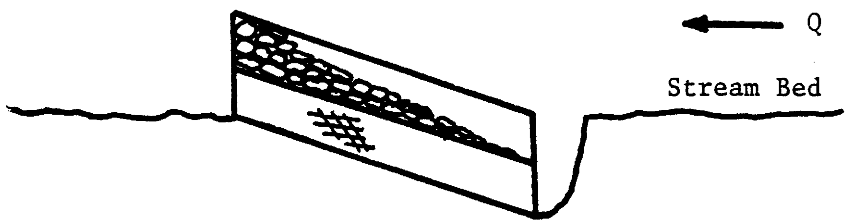
Artificial boulder structures are used in situations where neither bank cover nor natural boulders are present and poor access or lack of heavy equipment (tractors, etc.) make it impossible to install natural boulders from another source.

Artificial boulders are described in detail by Wesche and Cooper (1974). The basic materials used were two 6.5 ft. x 2.5 ft. x 0.5 ft. gabion cells laced together in the same manner as the two rows of cells in check dam construction. A 6.5 ft. x 2.5 ft. x 0.5 ft. excavation was dug into the streambed in the desired location and the two cells were placed in the excavation as shown in the sketch.

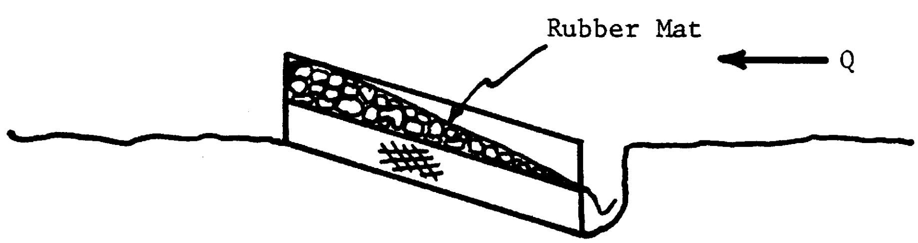


The bottom basket was filled with 3 to 4-inch cobble rock and the top basket was folded down and became the lid for the bottom basket. At this point, the lower front edge of the top basket was cut open approximately five feet along the laced seam connecting the cells.

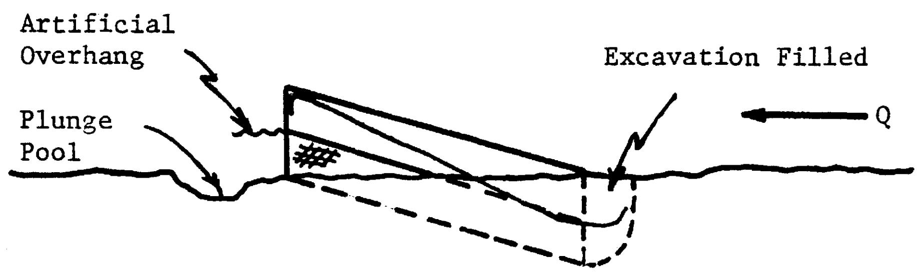
The top cell was partially filled in a sloping manner as shown.



A 5 ft. x 5 ft. piece of rubber mat was then placed over the rocks in the top cell and pushed through the cut at the lower front of the basket so that it extended on into the excavation below the level of the streambed and could be buried. The basket was then



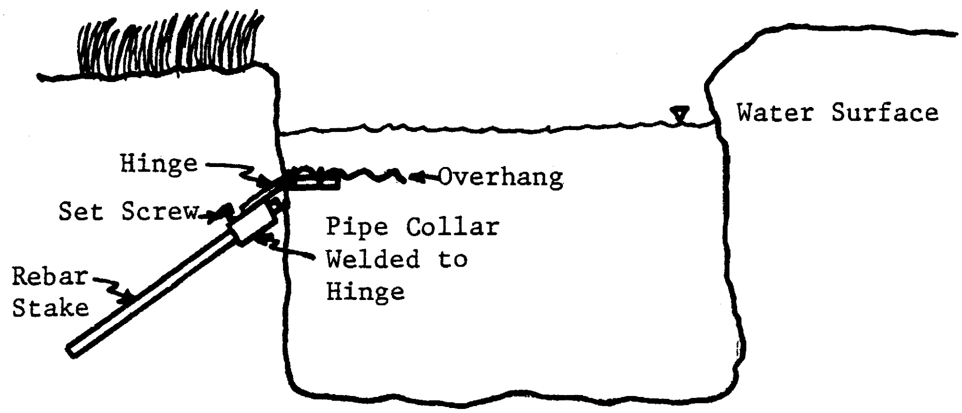
filled to the top in order to cover the mat, and the lid was folded over and laced down. Boulders were placed around the edges of the structure to restrict scour as a last step. The completed structure is shown in the following sketch.



VI. Artificial Overhangs

The WRRI overhead bank cover has proved to be a relatively simple device to construct and install. The floating overhangs can be made of a variety of materials such as wood, sheet plexiglass, or corrugated sheet metal and are usually fitted to the particular bank situation where they are being used. Construction and installation of a typical corrugated sheet metal artificial overhang is as follows.

A section of bank which lacks cover but has sufficient water depth, either naturally or as a result of barriers, deflectors, etc., is located. The section is measured and a piece of corregated sheet metal is cut to fit the section. A strap hinge welded to a 6-inch collar of one-inch diameter pipe is then bolted to each end of the overhang. Three 3/8" set screws are machined into each collar so that they can be slipped over a 3/4" diameter reinforcing steel bar stake and tightened securely. The overhang is then folded back on the hinges and the stakes are driven into the existing bank. When done correctly, the overhang should then be snug against the bank and barely submerged to hide it from obvious sight, as shown in the following sketch.



It was found that if the overhang was painted a flat black or mottled black and brown color before installation, it was much less visible when submerged. The same equipment can be used to install an overhang made of log or other material. If the overhang is made of wood, it should be from wood which is native to the stream drainage as it will float on the surface and be visible to anyone walking the stream. The floating effect is desirable to make the cover usable at all surface levels created by fluctuating discharge. A rock or boulder can be placed under the overhang to provide additional still water if necessary. The overhangs are described at length by Wesche (1974).

GLOSSARY

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.

Back-Calculated Growth History

In fisheries biology, a method of determining the size of a fish at some time or age in its past, by statistically back-calculating from the present length and weight measurements of numerous individuals in the population.

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.

Empirical Growth History

A direct method of determining the size of a trout at a certain age by aging a number of individuals of different sizes, then grouping those of the same age and using their mean length or weight as the representative size at that age.

Fishable trout population

A comparative term used to describe a trout population which contains sufficient numbers of catchable ($\geq$6.0 in.) trout to contribute to an angling effort, as opposed to a population containing few or no catchable trout.

Flow Duration Curve

A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Gabion

A rectangular wire mesh basket which is placed in a streambed, filled with rocks and wired shut.

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.

$K_{(TL)}$

Condition or plumpness factor of a trout calculated from the total length and weight of the trout in metric units.

$$K_{(TL)} = \frac{Wt(g) \times 10^5}{L^3(mm)}$$

Mean Depth

The average depth of water in a stream channel along a transect. It equals the cross-sectional area divided by the top width.

Mean Monthly Discharge

The total of all the daily discharges in a month divided by the number of days in the month.

Mean Water Velocity

The average velocity of water in a stream channel. It is equal to the discharge in cubic feet per second divided by the cross-sectional area in square feet. For a specific location, it is the velocity measured at 0.6 of the depth from the surface.

Parshall flume

A specially shaped open channel flow section which may be installed in a canal, stream, lateral, or ditch to measure the rate of flow of water.

Standing Crop

The total weight or number of organisms present at any one time within a specified area, e.g. pounds per acre, number per mile.

Stream Improvement

Manipulation of the physical, chemical or vegetational qualities of a body of water with the objective of improving living conditions for one or several kinds of animals.

Thalweg

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.