WINTER STREAM CONDITIONS AND BROOK TROUT HABITAT USE ON THE SNOWY RANGE, WYOMING

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ABSTRACT

As demand for water increases in Wyoming, water diversion from high mountain areas is being considered more often. Instream flow assessment methods are based on summer and fall flows, but low base-flows extend into winter. LIttle is known of winter conditions in high mountain streams or the instream flow requirements during winter. The objectives of this study were: (1) to describe winter habitat conditions on streams at elevations above 8,000 feet, (2) to determine the effect of decreasing elevation on the amount of potential habitat excluded by ice, (3) to verify brook trout use of stream habitats at elevations above 8,000 feet, and (4) to determine brook trout winter habitat associations in such streams.

Above 9,000 feet, snow insulated the study streams and habitat exclusion by ice was minimal. As elevation decreased, snow depths increased and ice formation increased. Ice depths and the amount of ice-excluded habitat were greatest at the lowest study site (7,500 feet). Stream conditions were harshest and most variable at mid-elevation sites (8,300-8,800 feet) where the streams were partially ice and snow covered and subject to anchor ice formation.

Brook trout remained active in streams above 9,800 feet throughout the winter. Current velocity was the most important variable governing habitat

selection by adult brook trout with the fish showing preference for areas with a mid-stream velocity of less than 6 inches/second. Water depth and substrate did not appear to influence trout distribution under deep snow. Flowing water is needed during winter in high mountain streams for incubating trout eggs, enabling young-of-year trout survival and preserving stream invertebrate production.

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INTRODUCTION

Demands for water in the semi-arid West are growing as the population increases and as industry and agriculture expand. A solution to help meet this demand is water diversion and storage on streams in high mountain areas. Examples of this are the active programs or trans-basin water diversion employed by the cities of Denver, Colorado and Cheyenne, Wyoming (U.S. Forest Service 1981). Degradation of stream habitat and fisheries related to water development projects has been documented (Orsborn and Allman 1976). Alteration of historic flow regimes through water diversion or storage has led to development of methodologies for estimating suitable instream flow and for predicting the effects of various flow levels on existing stream habitat and fisheries.

Instream flow methodologies have developed rapidly during the past 15 years (Fausch and Parsons 1984). These methodologies, developed primarily for use of data obtained during summer and fall months , commonly focus on fish spawning and rearing requirements. However, in high mountain streams, fish populations may not be limited by summer or fall flow levels, but by the low base-flow periods extending into winter (Wesche and Rechard 1980, Binns 1982). Hooper (1973) stated, "minimum flows should be established for winter as well as other periods of the year, particularly where freezing may be a significant factor".

Complicating instream flow recommendations is the fact that the flow requirements of salmonids vary by species (Hartman 1965, Cunjak and Green 1983, Gibson 1966,1978, Jenkins 1969, Nyman 1970), age (Griffith 1972, Haraldstad and Jonsson 1983, Kennedy and Strange 1982, Raleigh 1982), size (Butler and Hawthorne 1968, Giger 1973), and season (Hartman 1965, Logan 1963, Cooper 1953, Chapman and Bjornn 1969), as well as the size of the river (Bovee 1978). While instream flow models have been developed to incorporate knowledge of species and age specific requirements, the winter requirements of salmonids generally have been ignored.

Winter conditions have been recognized as limiting to trout in northern latitude streams (White et al. 1976, Chapman 1966, Bjornn 1971, Giger 1973, Bustard and Narver 1975, Mason 1976, Kurtz 1980, White 1975). Overwinter mortality has been identified as a key factor determining salmonid production in streams (Wentworth and Labar 1984, Strange and Whitworth 1983, Hunt 1969,1971, Avery 1978, Hassinger et al. 1974). Poor overwinter survival of hatchery trout in streams has been well documented (Hubbs and Trautman 1935, Needham 1949, Needham and Slater 1944, Nielson et al. 1957, Brynildson and Christenson 1961, Mason et al. 1963, Reimers 1963, Bachman 1982). Despite recognition of the importance of winter as a crucial period for salmonids in streams, research on winter stream conditions encountered by trout or winter requirements of trout is limited.

Winter stream ecology in relation to trout activity and feeding has been investigated. In streams that were not completely ice and snow covered, Leonard (1942) observed that brook trout (*Salvelinus fontinalis*) fingerlings of Hunt Creek, Michigan, actively fed on midge and black fly larvae, as well as mayfly nymphs in winter. He noted a reduced digestive rate during winter and questioned whether trout derive benefit from winter feeding. Maciolek and Needham (1952) reported that immature benthic invertebrates were most abundant during winter and trout fed regularly and would surface feed whenever aerial insects were available. Reimers (1957) researched winter trout food and feeding, digestion rates, and the effects of starvation in winter. He reported that ice conditions cause an increase in invertebrate drift and that trout were active during winter but food uptake and digestion rates were low, and that healthy trout could withstand long periods of starvation in cold water. Winter food uptake by trout in Convict Creek, California was less than half that observed during summer, despite indications of a more abundant food fauna in winter (Reimers 1963). Kennedy (1967) also found that numbers of benthic invertebrates were highest during winter and that trout ate less than in summer. Abundant stream invertebrates during winter also were observed by Needham and Jones (1959) who reported trout actively feeding at water temperatures between 0 and 1 C. Benson (1955) stated that trout in the Pigeon River, Michigan, were not actively feeding during winter.

Past winter research also has addressed the effects of ice and snow cover on trout and invertebrates in streams. Needham and Slater (1944) and Needham et al. (1945) attributed overwinter trout mortality to winter conditions, especially collapsing snow banks. Maciolek and Needham (1952) reported brown (Salmo trutta) and rainbow trout (Salmo gairdneri) mortality caused by subsurface ice which blocked streamflow. Needham and Jones (1959) and Reimers (1957) concluded that rainbow trout mortality during winter was caused mainly by snow and ice conditions and not lack of food or prolonged low water temperatures.

Anchor ice cycles cause dislodgement and drift of benthic insects (Reimers 1957), although only small numbers of organisms are affected (Brown et al. 1953, Benson 1955). Prolonged surface ice cover reduces periphytic algae and consequently the grazing organisms important as fish food (Reimers 1957). Logan (1963) found no reduction in the benthic insects under surface ice, but proposed it may have been due to intermittent occurrance of ice. Benson (1955) suggested that trout sac fry mortality could occur if anchor ice formed during the emerging period.

Winter habitat selection and movement of salmonids also has been studied, but findings are contradictory. Lower water temperatures trigger downstream movement of salmonids from tributaries into larger streams, where fish overwinter (Chapman and Bjornn 1969, Hynes 1970). Bjornn (1971) postulated that fall downstream emigration from tributary streams by pre-smolt trout and salmon occurred because of a lack of suitable winter habitat. Bustard and Narver (1975) reported juvenile coho salmon (Oncorhynchus kisutch) movement from Carnation Creek into a tributary, 750 Creek, resulted in higher overwinter survival rates of tributary fish, presumably because of better winter habitat in these areas. Tschaplinski and Hartman (1983) reported similar coho movements from the main stream to seek the winter shelter of low velocity tributaries and valley sloughs during fall and winter. Stuart (1975) observed a mass movement of juvenile brown trout from the streams to lakes before the onset of winter and a comparable return movement in the spring. Others (Hunt 1965,1974, McFadden 1961) have summarized brook trout migrations as an upstream movement of adults to spawning areas during fall, downstream movement of adults to deeper water during winter, and a predominantly downstream movement of young trout from spawning areas. Downstream movement of young and adult brook trout decreased after habitat development work increased pool area and streambank hiding-cover (Hunt 1974). Bjornn (1971) noted a lack of brook trout fry migration and speculated that no fish would move if populations did not exceed the winter cover capacity of the streams.

Researchers have reported salmonid winter habitat associations. Hartman (1963) reported that the degree of association of juvenile brown trout with experimental bottom structures or other types of cover was much greater in winter than summer. Temperatures below 4-6 C induce 'hiding behavior' in salmonids, with fish closely associated with the substrate or other cover (Chapman and Bjornn 1969, Bustard and Narver 1975 a,b). White (1939) stated that wintering juvenile salmon were quiescent and found only beneath stones. Allen (1941) noted that young Atlantic salmon (*Salmo salar*) lay quiescent in sheltered places at temperatures below 7 C. Lewis (1967) reported that rainbow trout move to deeper water during winter. Logan (1963) found rainbow trout in riffle areas under surface ice during winter. Febinger (1980) observed brook trout in riffles, while Benson (1955) found them in quiet eddies and under banks during winter. Cooper (1953) reported that brook trout deserted pools occupied in the spring, summer, and fall months and moved to areas of heavy cover in winter.

Winter habitat utilization and movement by brown trout in Wyoming was measured by Wichers (1978) using radio telemetry. Her study was conducted on a 1.2 km section of the Laramie River near Jelm, Wyoming. The study site had an elevation of 2360 m and an average daily discharge of 1.90 m / second from November through February. She reported that after first ice formation and a period of re-orientation associated with the change in habitat, brown trout showed little movement. Velocity was the most important parameter determining the microhabitat occupied by brown trout and less than 0.15 m/second was preferred. Depth preferences were for areas with water greater than 0.15 m. In a follow-up study, Johnson (1981) used radioisotopes to track brown trout under ice cover on Wagonhound Creek. Elevation of this study site was 2260 m. She reported little movement during winter and preference for areas of slow velocity. In addition, Johnson described ice exclusion of available stream habitat and developed equations to predict its effect.

Future water development projects on high-mountain streams in Wyoming and the Rocky Mountain West become more likely as the demand for water increases. There is a need for research defining the winter requirements and habitat needs of trout if suitable stream flows are to be established to maintain existing fisheries (Hooper 1973, Wesche and Rechard 1980). Winter research in general is limited and none is known to have been conducted at elevations greater than 2440 m in montane or subalpine zones.

Thus, the objectives of this study were: (1) to describe winter habitat conditions on streams at elevations above 2440m, (2) to determine the effect of decreasing elevation on the amount of potential habitat excluded by ice, (3) to evaluate the predictive regression models of Johnson et al. (1982) in estimating the effect of ice cover on available trout habitat, (4) to verify brook trout use of stream habitats at elevations above 2440 m, and (5) to determine brook trout winter habitat associations in streams.

DESCRIPTION OF STUDY AREAS

Portions of two streams, Telephone Creek and Nash Fork Creek, were selected for investigation of winter stream habitat conditions and brook trout habitat use. These streams are located in Albany County, Wyoming, on the Snowy Range in the Medicine Bow National Forest. Two study reaches, an upstream and a downstream site, were located on each creek. Table 1 lists biological, hydrological and chemical characteristics for these reaches. The factors which were used in the selection of the study reaches were: (1) elevation greater than 2440 m above sea level, (2) existence of nearby Wyoming Water Research Center (WWRC) stream gaging stations, and (3) presence of an identifiable riffle-pool sequence. Figure 1 shows the WWRC research watersheds where the four study sites were located. Travel to and from the study areas during winter was by snowmobile.

The watershed of the study areas was public land managed by the United States Department of Agriculture Forest Service. Primary uses were: timber production, livestock grazing and various forms of recreation. Study site riparian areas were alpine meadows with vegetation dominated by willow (Salix spp.), grasses and sedges (Carix spp.). Upland vegetation consisted primarily of spruce-fir (Abies spp. and Picea spp.) mixed with lodgepole pine (*Pinus*

Table 1. Biological, Chemical and Hydrological Characteristics of the 1983-84 study sites, Snowy Range, Medicine Bow National Forest.

Stream and Location	Period of Study	Species Composition * and Biomass	Average Daily Flow Range(m^3/s) October-September, 1969-1984 **	Water Temperature Range,C January-March,1985	Water Chemistry			
					Dissolved Oxygen (mg/l)	pH	Total Alkalinity (mg/l)	Hardness (mg/l)
Upstream Telephone Creek	September 1983 - February 1985	100% Brook Trout - 318 kg/ha	0.011-0.78	1.0-0.5	7.3-9.2	7-8	24	60
Downstream Telephone Creek	September 1983 - February 1985	100% Brook Trout - 106 kg/ha	0.011-0.99	1.0-0.0		7-8	31	68
Upstream Nash Fork Creek	September 1983 - February 1985	100% Brook Trout - 189 kg/ha	0.017-1.14	0.5-0.0		8	34	77
Downstream Nash Fork Creek	September 1983 - February 1985	54% Brook 46% Brown Trout - 125 kg/ha	0.037-2.44	0.5-0.0		7-8	31	94

* From electrofishing data collected September 1983 and Summer 1984

** WWRC gaging station records

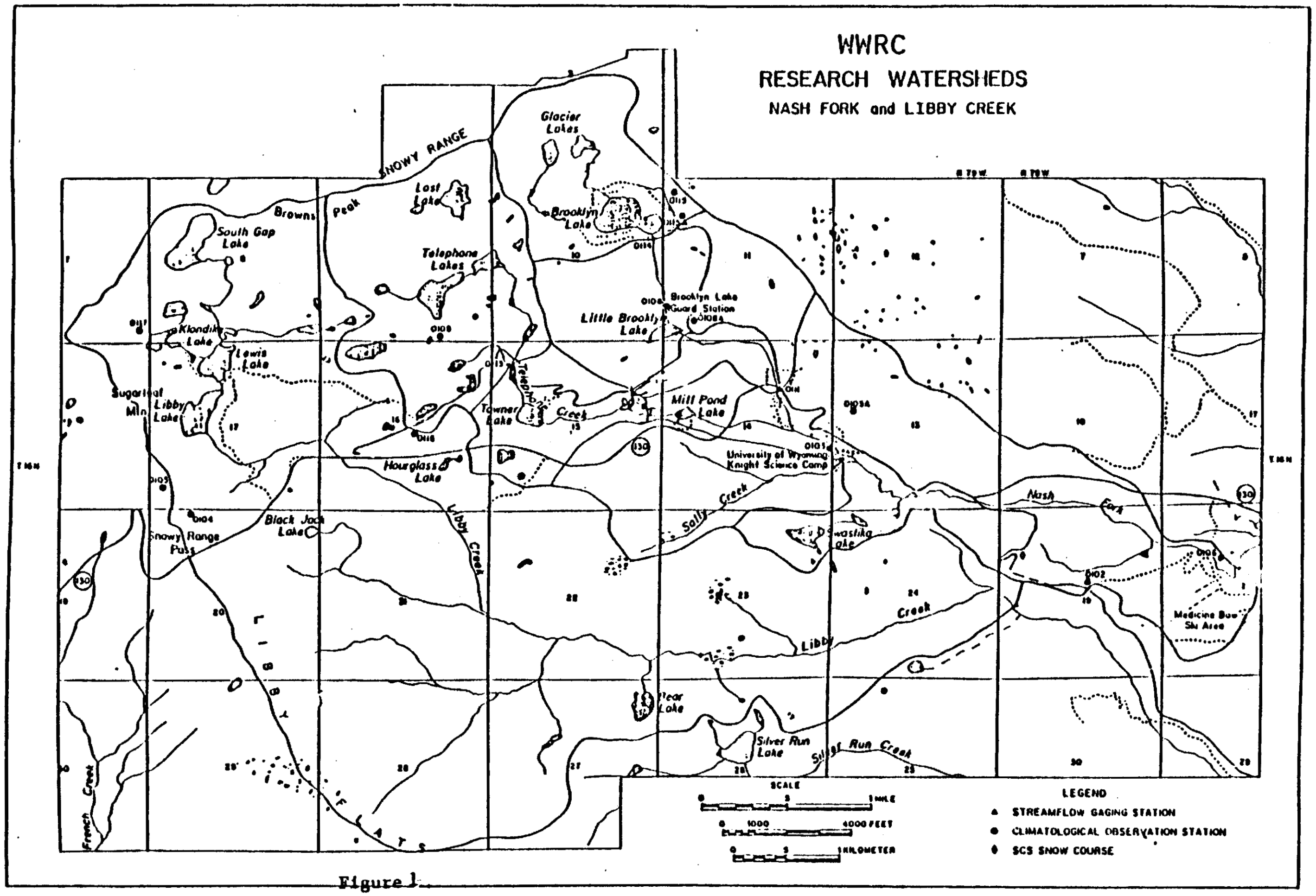
WWRC
RESEARCH WATERSHEDS
NASH FORK and LIBBY CREEK
SNOWY RANGE
Browns Peak
Glacier Lakes
Lost Lake
Brooklyn Lake
South Gap Lake
Telephone Lakes
Brooklyn Lake Guard Station
Little Brooklyn Lake
Klondike Lake
Lewis Lake
Sugarloaf Mtn
Libby Lake
Towner Lake
Telephone Creek
Mill Pond Lake
University of Wyoming Knight Science Camp
Hourglass Lake
Black Jack Lake
Snowy Range Pass
Libby Creek
Sally Creek
Nash Fork
Swastika Lake
Medicine Bow Ski Area
Libby Creek
Libby Flats
Bear Lake
Silver Run Lake
Silver Run Creek
French Creek
SCALE
1 MILE
1000
4000 FEET
1 KILOMETER
LEGEND
STREAMFLOW GAGING STATION
CLIMATOLOGICAL OBSERVATION STATION
SCS SNOW COURSE

Figure 1

contorta) at the lower elevations. Streams in the watershed have flow patterns typical for the Rocky Mountain Region with low flows from late fall until spring, when peak runoff occurs due to snowmelt (Wesche 1982).

Telephone Creek

Telephone Creek is a second order alpine stream with an elevation ranging from 3350 m at its headwaters, to 3040 m where it flows into Nash Fork. The Upstream Telephone Creek (TCU) study site was located above Towner Lake (elevation 3205 m), in the northwest quadrant of Section 15,T16N, R79W. The site was 140 m downstream from WWRC Gaging Station 0113, which has a Parshall Flume with recorder to monitor discharge. Telephone Creek at the study site is a second order stream meandering through a meadow area. Stream gradient through a 75 m reach encompassing the primary study area was 0.39 %. Total land area drained by Telephone Creek at this site is 3.9 square kilometers. Hydrologic records from Station 0113 for water years 1983 and 1984 showed a maximum mean daily discharge of 0.97 m^3/second on July 1, 1984 and a minimum mean daily discharge of 0.004 m^3/second on April 13, 1984. During winter 1983-84 (November 1983 through April 1984), average daily flows ranged from 0.004 to 0.056 m^3/second.

The Downstream Telephone Creek (TCD) sampling site was located below Middle Pond (elevation 3150 m) in the northeast quadrant of Section 15, T16N, R79W. The study site was 125 m upstream from the

WWRC Parshall Flume at Gaging Station 0112. Telephone Creek at this study site was a second order stream with a gradient of 0.70 % (75 m reach). Drainage area at this location was 5.2 square kilometers. Hydrologic records from station 0112 for water years 1983 and 1984 showed a maximum mean daily discharge of 3.08 m^3/second on July 3, 1983 and a minimum mean daily discharge of 0.005 m^3/second occurring at various times during February, March and April 1983 and April 1984. During winter 1983-84, average daily flows ranged from 0.005 to 0.338 m^3/second.

Nash Fork Creek

Nash Fork Creek is a third order stream with headwaters flowing out of East Glacier Lake at an elevation of 3290 m. The stream flows 11 km in a southeasterly direction until its confluence with the North Fork of the Little Laramie River. Elevation at its mouth is 2670 m. The Upstream Nash Fork (NFU) study site was located 300 m downstream from Little Brooklyn Lake in the northwest quadrant of Section 14, T16N, R79W, at an elevation of 3120 m. Nash Fork Creek at this study site is a first order stream and has a 5.4 kilometer drainage area monitored by WWRC Stream Gage 0111. The study site was located 600 m upstream from WWRC Station 0111. No perennial tributaries existed between the study area and gaging station. Gradient in the 70 m stream reach encompassing the study site was 1.23 %. Hydrologic records from Station 0111 for water years 1983 and 1984 showed a maximum mean daily discharge of 3.2 m^3/second on

July 3, 1983 and a minimum mean daily discharge of 0.003 m^3/second on several days during April 1983. During winter 1983-84, average daily flows ranged from 0.015 to 0.12 m^3/second.

The Downstream Nash Fork (NFD) study site was located 275 m downstream from the confluence of Sally Creek in the northwest quadrant of Section 13, T16N, R79W. Nash Fork Creek at this site is a third order stream and has an elevation of 2993 m. Stream gradient through a 70 m reach encompassing the study site was 1.35 %. Drainage area was 14.8 square kilometers. Discharge records for this study site were derived by combining the discharges recorded at Telephone Creek below Middle Pond (WWRC Station 0112), Nash Fork above Brooklyn Lodge (WWRC Station 0111) and Sally Creek (WWRC Station 0103). Transmission losses and gains between the gaging stations and the study site downstream were assumed to be negligible and not considered in the computations. Hydrologic records at WWRC Gaging Stations 0103, 0111, and 0112, for water years 1983 and 1984, indicated a maximum mean daily discharge of 7.13 m^3/second occurred on July 3, 1983 and a minimum mean daily discharge of 0.008 m^3/second occurred on April 11, 1983. During winter 1983-84 average daily flows ranged from 0.004 to 0.440 m^3/second.

Additional Sites

In fall 1984, nine study areas were established on the same stream system, to investigate changes in stream conditions with decreasing elevation. These additional study sites were located in

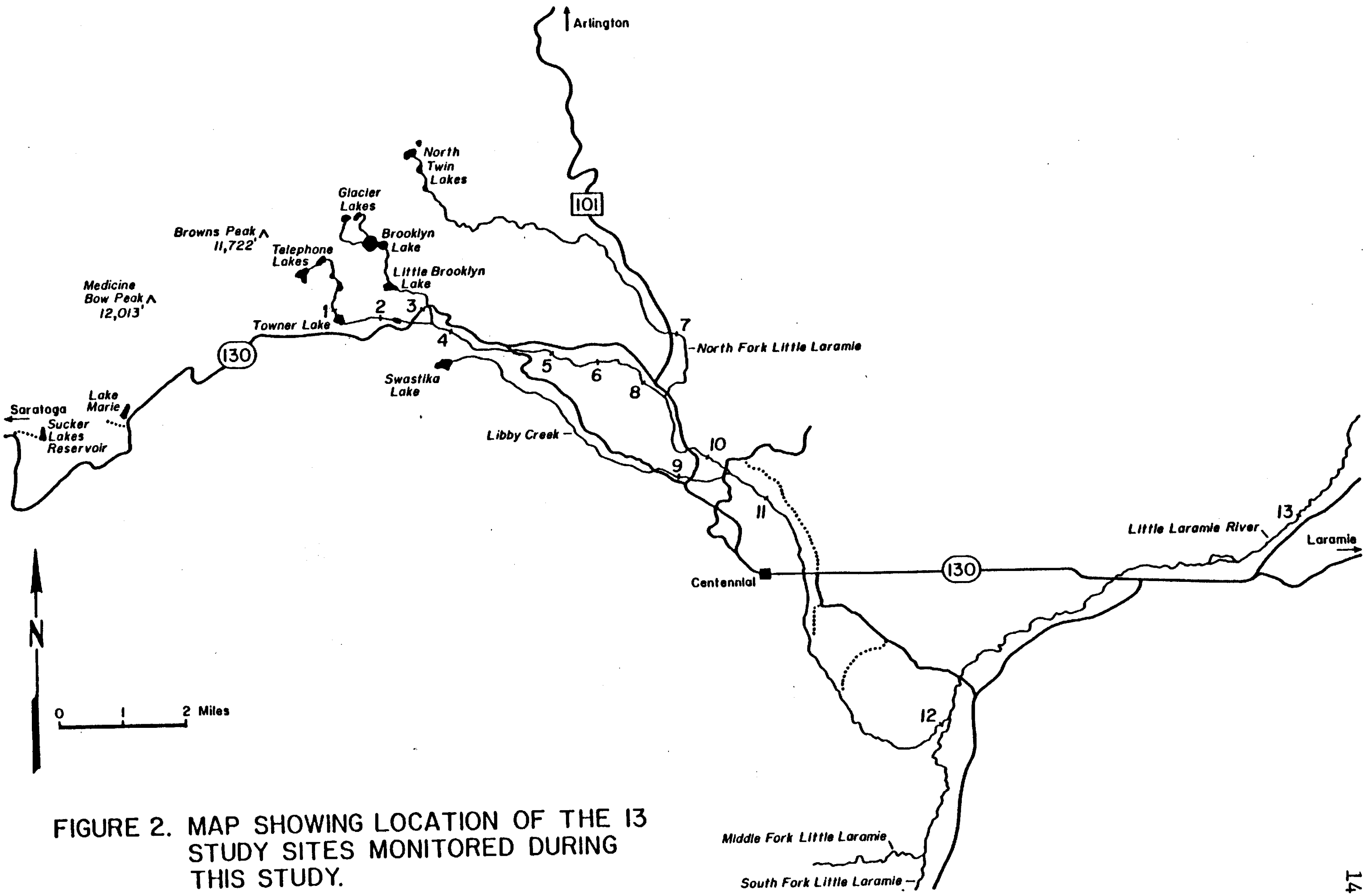

FIGURE 2. MAP SHOWING LOCATION OF THE 13 STUDY SITES MONITORED DURING THIS STUDY.

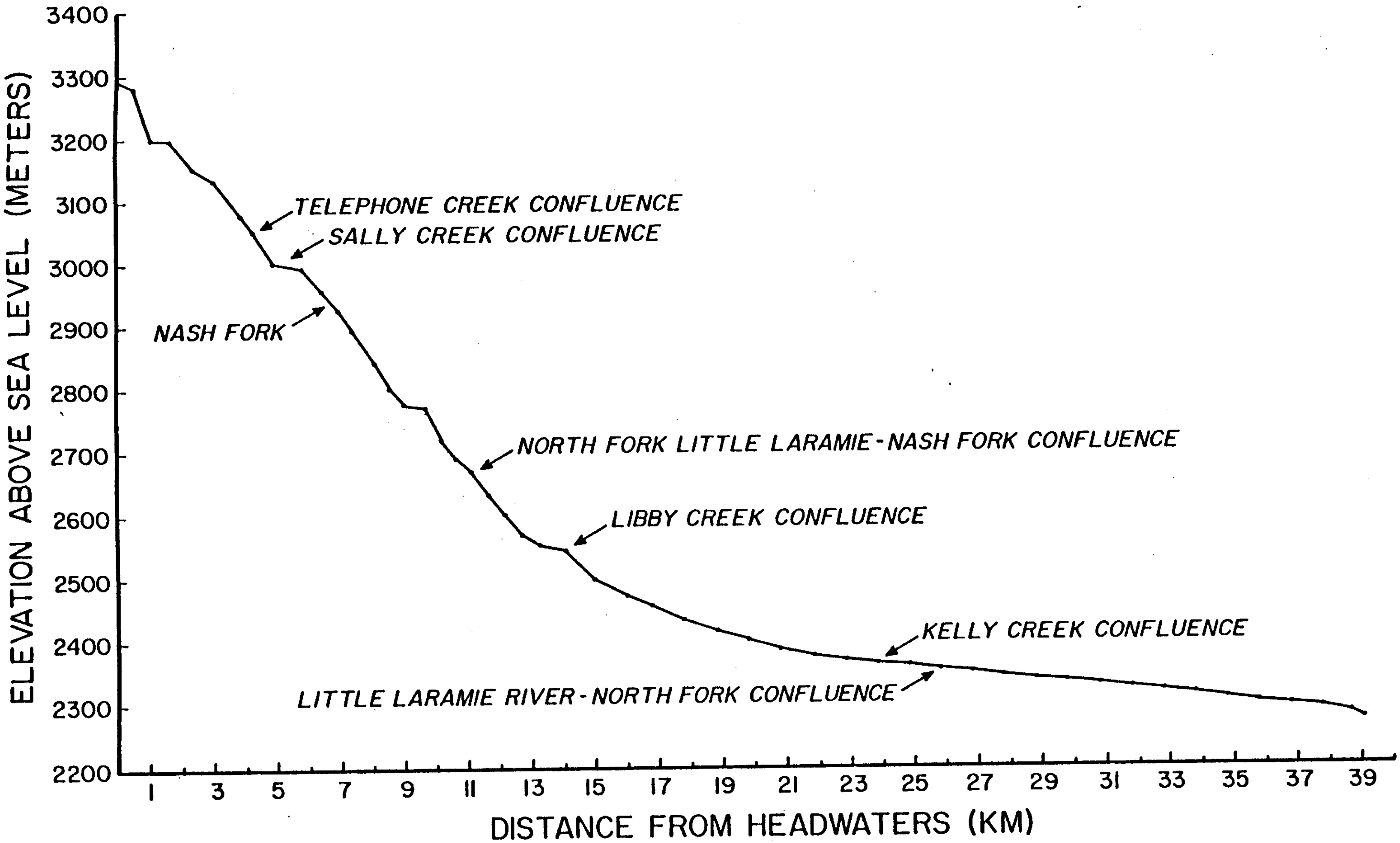

FIGURE 3. PROFILE OF UPPER LITTLE LARAMIE RIVER.

Albany County on Nash Fork Creek, the North Fork of the Little Laramie River, Libby Creek, and the Little Laramie River. Their locations, as well as that of the four original study sites are presented in Figure 2.

The criteria for selection of the additional study areas were: (1) location on the same stream system as previously established sites, (2) presence of an identifiable riffle-pool sequence, (3) representative of an elevation, down to 2250 m, and (4) a stream reach gradient similar to the original four study sites. Figure 3 presents the stream profile for the entire stream system studied.

The 13 study sites increased the altitudinal range or winter conditions being monitored, from 3205 m at the upstream Telephone Creek site, to 2280 m at the most downstream site on the Little Laramie River. Appendix A presents the legal location and descriptive information for each additional study site.

METHODS

Hydrologic Measurements

Winter 1983-84

To monitor instream habitat changes during winter, permanent transects were established in September 1983 at each of the four study sites on Telephone Creek and Nash Fork Creek. The transects were perpendicular to streamflow and crossed a riffle (TR 1), transition (area between riffle and pool, TR 2), and a pool (TR 3) at each site. Stakes (0.6 m long) were surveyed level in the bank at the ends of each transect to enable precision of depth measurements and to allow plotting of stream profiles. Steel reinforcing rod (18 mm diameter) was driven into the bank behind the survey stakes and 3.5 m-long wooden poles attached so transects could be located in deep snow. Distances between pairs of stakes at each study site were recorded to enable location of snow covered stakes in the event that only two stakes could be found. As a further precaution, compass bearings from two nearby prominent landmarks to each reinforcing rod were recorded. The landmarks were flagged with red surveyors tape and a detailed description was recorded in field notebooks.

Stream characteristics measured at each transect were: water depth, stream width, ice depth, snow depth, and distance between water and snow or water and ice (air gap). Water discharge information was obtained from nearby WWRC gaging stations. All transect measurements were taken by stretching a tape between the two stakes denoting a transect. Measurement intervals were determined by the stream width (Hamilton and Bergerson 1984), such that a minimum of ten measurements were obtained for each transect. Usually, transect monitoring during winter 1983-84 followed the procedure listed below: (1) snow between marking stakes was removed (trench 0.6 to 1.0 m wide), (2) snow (and ice if present) in the stream was removed so the transect was free of ice and snow from stake to stake, (3) measuring tape was attached to the top of the survey stakes with clamp, from left to right bank, (4) water depth, ice depth and air gap were measured (to nearest 1.5 cm, 3 cm, and 3 cm, respectively), (5) snow depth was recorded (to nearest 3 cm) using tape measure, at left bank, mid-stream, and right bank if snow cover was complete. If snow cover was not complete, snow depths were measured at the same intervals as ice depth, and (6) the snow trench was refilled. The transects were sampled periodically during winter 1983-84 in the fall (September-October) and again in the winter (December-April), resulting in each transect being sampled 7 or 8 times.

To obtain comparative stream reach velocities at each of the study areas during fall and winter, time of travel velocities were measured in April and September 1984 (Wesche et al. 1983).

Rhodamine B dye was injected at an upstream site far enough from the measuring station to allow complete mixing. Water samples were then taken every 15 seconds at each end of the study reach. A fluorometer was used to measure dye concentrations in the water samples. Time of travel through the study reach was the time lapse between peak concentrations at the upstream and downstream ends of the measured study reach. Average water velocity through the channel was calculated by dividing the thalweg (line of maximum water depth) length of the stream reach by the time interval. Length of stream reaches used to measure time of travel velocity ranged from 75 m to 135 m.

Stream gradient at the study sites was measured with a survey rod and transit-level. Study site transects were located at the approximate middle of the stream reaches used to measure gradient.

<u>Winter 1984-85</u>

Nine additional study sites were established in fall 1984 to examine the consequence of decreasing elevation on winter stream conditions. Transects were monitored and gradient was determined (Appendix A) using the same methods as in 1983-84. Length of the stream reaches for gradient measurement ranged between 30 and 40 m.

Except for site number 6 at the Medicine Bow Ski Area (Figure 3), stream gages could not be used to provide water discharge information. Water velocity measurements were obtained at four of the nine sites during November 1984 and eight of the nine study sites during January 1985. Velocity was measured at 0.6 of total depth for each interval across the transition transect, using a Pygmy or Marsh-McBirney current meter and the methods described by Buchanan and Somers (1969). Generally, about 20 velocity measurements were taken across the transects.

Total discharge was computed as the sum of all partial discharges across a transect (Bovee and Milhous 1978). Partial discharges were calculated as the width represented by each measurement interval, times the water depth for that interval, times the velocity. Velocity measurements taken at the 0.6 total depth under ice cover were adjusted to the change in velocity profile by multiplying by 0.92 (Buchanan and Somers 1969).

Telemetry

Verification brook trout use of the study sites during winter and evaluation of brook trout winter habitat associations were accomplished by radio telemetry. Radio telemetry is a valid tool for assessing habitats used by stream fishes (Wichers 1978, Larimore and Garrels 1985). The radio telemetry equipment used in this study was constructed by Custom Telemetry, Athens, Georgia. A 49 MegaHertz (MHz) receiver and a bidirectional loop antenna were used to receive the transmitter signals. Transmitter pulse rate was approximately 30 per minute. Maximum length and width of the transmitters were 2.5 cm and 1.5 cm, respectively. The transmitters were neutrally buoyant in water, with air weights ranging from 4.8 to 6.2 grams. Transmitter detection accuracy ranged from plus or minus 0.6-1.2 m. Radio frequencies, pulse rates and detection accuracy were checked for each transmitter prior to implantation.

Winter 1983-84

Brook trout were collected at the four study sites on Telephone Creek and Nash Fork Creek, using a Coffelt BP-2 backpack electrofishing unit. The two largest brook trout collected at each study site were selected for implantation. Fish were anesthetized with tricaine (MS 222) and surgically implanted with radio transmitters at the streamside.

Surgery followed the general methods of Hart and Summerfelt (1975). Individually anesthetized brook trout were inverted in a V-shaped trough and a 15 to 20-mm incision was made in the abdomen, immediately anterior to the pelvic girdle. After inserting the transmitter into the trout's body cavity, the incision was closed with 4-5 stitches, using a cutting needle and non-absorbable 00 silk suture. Water containing anesthetic was kept flowing over the gills throughout the operation. Immediately following surgery, fish were placed in fresh stream water and allowed to recover. During this time, the radio receiver was used to check transmitter operation and frequency. Five to 15 minutes after fish had regained equilibrium they were returned to their capture point.

The radio-tagged fish were located twice a week. Radio transmitters were identified by different frequencies at 0.025 MHz intervals within the 49 MHz band.

During the fall prior to snow cover, fish were tracked using a hand-held loop antenna by walking along the stream bank. Radio locations of fish were determined by triangulation. During the winter months, snow covered the stream and all tracking was done to a point directly above a fish location. Attenuation of transmitter signal strength occurred as one moved away from the fish and the point of maximum signal strength was used to define a fish location. All locations were referenced to two described landmarks by compass bearing or measurements of distance.

Winter 1983-84 locations of fish were plotted in the stream and marked with red-flagged wire during summer 1984. When two or more locations occurred within 5 m of each other, the thalweg distance between the furthest upstream and furthest downstream location was halved and a transect established at that point. Additional transects were run upstream and downstream from this central transect at intervals of one half the width of the stream until all fish locations were encompassed. This series of transects defined a home area. Individual locations were described by a transect across the stream at that point.

Available habitat was measured by transects spaced at 5 m intervals and encompassing the furthest upstream and furthest downstream location of fish within each study area. Along each transect, water depth and predominent substrate class, stream width, and an index of velocity were measured. The velocity index was the measured 0.6 total depth velocity at the maximum water depth across a transect. Depth measurement intervals across a transect were determined by the width of the stream, such that a minimum of 10 measurements were taken. Substrate particle size was determined visually at each measurement interval as belonging to one of the following classes (modified from Platts et al. 1983):

Sediment Classification	Particle diameter size
boulder	305 mm or more
rubble	76.1 mm to 304.0 mm
gravel	4.8 mm to 76.0 mm
sand and silt	4.71 mm and less

Winter 1984-85

To assess the importance of low-gradient areas to overwintering brook trout, in October 1984, eight fish were surgically implanted with radio transmitters in reaches 50-310 m upstream from a beaver pond on Nash Fork Creek (elevation 2990 m).

Surgery followed the same procedure used in 1983. Radio-tagged fish were located twice a week through December 1984 and then once a week until the end of February 1985. Locations were determined and recorded in a manner similar to winter 1983-84.

To ascertain habitat types used during winter 1984-85, telemetry locations were plotted on a detailed map constructed during summer

1984. The map encompassed two natural boundaries, the beaver dam at the downstream end and a falls at the upstream end of the study site. A 392-m baseline was surveyed along the stream and transects were run bank to bank at 3.05 m intervals to describe the habitat in this section. Stream width, water depth, substrate class and the velocity index were measured at each transect. Using distance measurements from the baseline, an outline of the stream channel was drawn to scale (3.05 m = 2.54 cm).

Telemetric locations were referenced to points along the baseline by compass bearing and distance, and subsequently plotted on the map. The transect closest to a radio location, and all information collected across that transect, were considered representative of that location. If a fish location fell halfway between two transects, both transects were used. Transects at fish locations (or selected habitat) were weighted by the number of times fish were found at each transect. For example, if a fish was found at transect 1 five times and transect 2 once, transect 1 would be entered five times and transect 2 once, to reflect the corresponding number of times a fish was found there. Available habitat was taken as the sum of all transects for the mapped area.

Data Analysis

Transect Data

The Wyoming Water Research Center WRDS computer system was used to develop flow duration curves and historical stream discharge and air temperature summaries. Stream profiles were plotted to scale by computer using a Fortran program written by Thomas M. Price of the University of Wyoming. Wetted perimeter along the 1983-84 stream profiles was determined with a map wheel.

All hydrologic variables at each transect monitored in winter 1983-84 were averaged and plotted relative to time, to discern overwinter trends. Stream characteristics monitored during the sample period or winter 1984-85 at all 13 study sites were averaged and regressed on elevation using the SPSS (Statistical Package for the Social Sciences) program (Nie et al. 1975) on the University of Wyoming CYBER computer. Significance level for all statistical tests was set at $p < 0.05$. Water depth, width, width to depth ratio, cross-sectional area of water, cross-sectional area of ice, and width with water depth greater than 15.2 cm, were computed and regression analysis was used to examine their relationship with decreasing elevation. Those segments of the transect with a depth greater than 15.2 cm were calculated by a computer program which drew a straight line between the measurement intervals and summed all distances across the transect where the water depth was greater than 15.2 cm. Log transformations of mean snow depth and mean ice thickness were analyzed for appropriateness and regressed with elevation using BMDP (Dixon et al. 1979).

The regression models developed by Johnson et al. (1982) to predict the amount of habitat excluded by ice was used to predict excluded habitat values on nine of the 13 study sites for which data were available during winter 1984-85. Percent habitat excluded was calculated as the cross-sectional area of ice divided by the potential cross-sectional area of water if ice cover had not been present (this area was based on water depths welled up in each hole through which measurements were taken). The values predicted by the equations were compared to observed excluded habitat for the nine sites. Johnson et al. (1982) three predictive equations were :

<u>Riffle</u>: % excluded = 138 + .326 (Day) - .0263 (S) - 200 (D) - 11.7 (V)

<u>Run</u>: %excluded = 104.0 - .655 (Day) + .0359 (S) - 82.6 (D) - 66.4 (V)

<u>Pool</u>: %excluded = 8.53 - 1.31 (Day) + .0974 (S) + 50.4 (D) - .934 (V)

where Day is the number of days from the winter solstice (December 22) that sampling occurred, S is the degree days of frost (computed as $S=\Sigma(32-T)$), D is the mean water depth across the transect (in feet) and V is the mean velocity across the transect (in feet per second). Degree days of frost were computed using average daily temperature in degrees Fahrenheit as T.

Telemetry Data

Frequency distributions of depth, velocity and substrate measurements from available and selected habitat were compared using the G-Test for Independence (Sokal and Rolf 1981) on BMDP Program, BMDP4F. Depths were aggregated into nine classes by 15.2 cm intervals. There were 11 classes of current velocity, aggregated by intervals or 15.2 cm/second, and four classes of substrate (corresponding to the four substrate types). An example computation of the G-test statistic is presented in Appendix B. When analysis indicated significant ($p < 0.05$) differences among habitat available and habitat selected, Strauss' Electivity Index was used to clarify at which interval strongest selection occurred (Strauss 1979). Index values range between +1 and -1. Positive electivity values indicate preference and negative values indicate avoidance, with random association being indicated by zero.

When differences in available and selected habitat during winter 1984-85 were noted, discriminant function analysis was performed to examine which variables were the most important contributors determining that difference (Klecka 1980). In the discriminant analysis, the mean depth, mean width, mean velocity, and substrate class at each transect representing a fish location was compared to the mean values or transects representing the available habitat (number or transects=134), using the SPSS program. Values for transects representing fish locations (selected habitat) were then randomly sampled to approximate the sample size in the available habitat. This was done to satisfy the mathematical requirements of the discriminant analysis technique, to obtain reliable results.

RESULTS

Historical Discharge Data

At the Upstream Telephone Creek site, winter discharges on sampling dates in 1983-84 ranged between 0.010 and 0.056 m^3/second. Values less than 0.028 m^3/second were exceeded on the winter (October to April) flow duration curve for this site, 63 % of the time. A discharge or 0.056 m /second was equalled or exceeded 23 % of the time. At the downstream Telephone Creek site, winter values on sampling dates in 1983-84 ranged between 0.005 and 0.076 m^3/second. Values less than 0.028 m^3/second were exceeded on the winter flow duration flow curve for this site, 46 % of the time. A discharge of 0.076 m /second was equalled or exceeded 34 % of the time. At the upstream Nash Fork site, winter values on sampling dates in 1983-84 ranged between 0.006 and 0.112 m^3/second. Values less than 0.028 m^3 /second were exceeded 27 % of the time on the winter flow duration curve for this site. Discharges of 0.112 were equalled or exceeded on the duration curve 44 % of the time during winter. February discharges for these sites during water years 1983 and 1984 were generally within the range established by the entire period of record, with the average daily flow (ADF) in 1984 being somewhat higher than that in 1983 (Table 2).

Stream Conditions

Winter 1983-84

Water temperature was monitored periodically from December 1984 until March 1985 and remained constant, ranging from 0 to 1 C at the four study sites. Values for hydrologic parameters monitored at the four study sites are presented in Appendix C. From September 23, 1983 through May 10, 1984, cross-sectional area, wetted perimeter, water depth, and top width generally decreased. This decrease paralleled a decrease in discharge recorded at the stream gaging stations. Exceptions to the decreasing trend for these variables were noted in October and December and reflected concurrent increases in discharge, probably caused by warm weather and snowmelt.

Values for the cross-sectional area, wetted perimeter, width and depth recorded at the Upstream Nash Fork site also follow discharge, but a discrepancy occurred on December 24, 1983. An increase in cross-sectional area for the transition (TR 2) and pool (TR 3) transects was not reflected in an increase in discharge at this site. This discrepancy could be due to measuring depth at this site without completely clearing the transects and stream of collapsed snow, which caused water to back up and resulted in sampling inaccuracy, or from a similar situation occurring naturally downstream.

Table 2. February discharge in cubic meters per second (and cubic feet per second) during water years 1983 and 1984 and the period of record for study sites on stream reaches associated with gages, Snowy Range, Medicine Bow National Forest.

Sites	1983	1984	Average Daily Flow for the Historical Record		
	Average Daily Flow		Mean	Mean Minimum	Mean Maximum
Upstream Telephone Creek	0.02 (.59)	0.01 (.45)	0.01 (.50)	0.01 (.40)	0.02 (.70)
Downstream Telephone Creek	0.01 (.30)	0.02 (.55)	0.02 (.60)	0.01 (.50)	0.03 (.90)
Upstream Nash Fork Creek	0.01 (.42)	0.03 (1.0)	0.03 (1.2)	0.02 (.60)	0.04 (1.4)
Site 6	0.08 (2.9)	0.11 (4.1)	0.05 (1.7)	0.05 (1.5)	0.06 (2.1)
Site 9	0.03 (.89)	0.03 (1.1)	0.06 (2.1)	0.05 (1.9)	0.07 (2.5)
Site 13			0.58 (20.5)	0.55 (19.5)	0.63 (22.1)

Average water depths through winter 1983-84 for the four study sites are presented in Figures 4, 5, 6, 7. These figures depict the overall decreasing trend in water depth. Percent decrease in water depth over the sampling period for the riffle transect was 30 % at TCU, 20 % at TCD, and 15 % at NFD. As noted above, NFU experienced an increase in mean water depth, equal to 29 % at the riffle transect.

Physical exclusion of stream habitat by ice formation was minimal but did increase as elevation decreased. Maximum and mean ice depths and percent of the transect that was ice covered during winter 1983-84 are presented for the four study sites in Appendix D. Ice formation was not found at the TCU site and occurred only to a small extent on the TCD and NFU study sites. The maximum ice depths recorded for both these study sites was 9.1 and 16.2 cm, respectively. These values represent ice thickness found along the stream banks at the pool transect of each site. Ice cover on the TCD and NFU sites gradually diminished through the winter, persisting only at the edges of the stream and often seperated from the water surface by an air gap. More extensive ice was found at the NFD site. A maximum ice depth of 24.4 cm recorded along the pool transect on December 5, 1983, diminished to 12.2 cm on April 10, 1984. Ice formation was greatest at the riffle and pool transects, with mean ice depths ranging from 2.4 to 8.5 cm and 4.9 to 15.8 cm, respectively (Figure 8). Data from this study site suggested that ice thickness and coverage generally decreased through winter, but

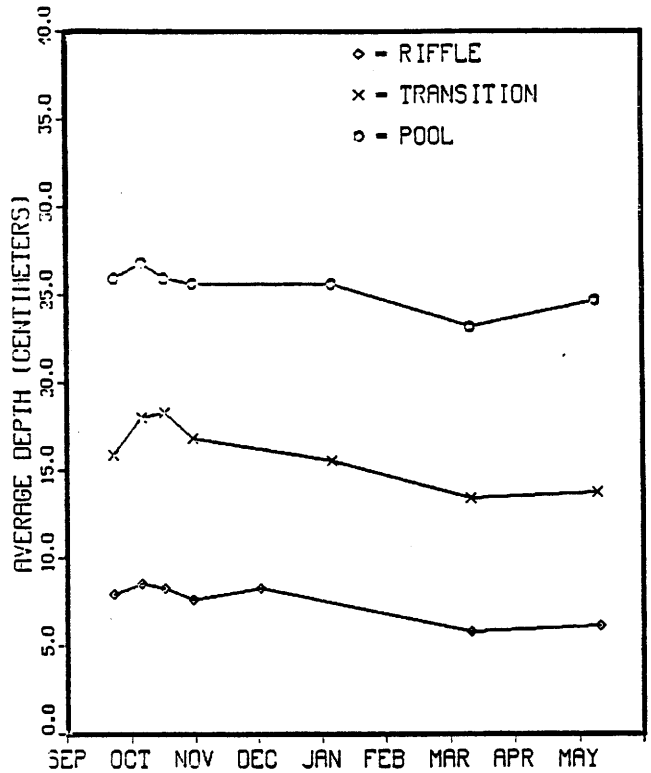

Figure 4. Average water depth for the Upstream Telephone Creek site, during winter 1983-84.

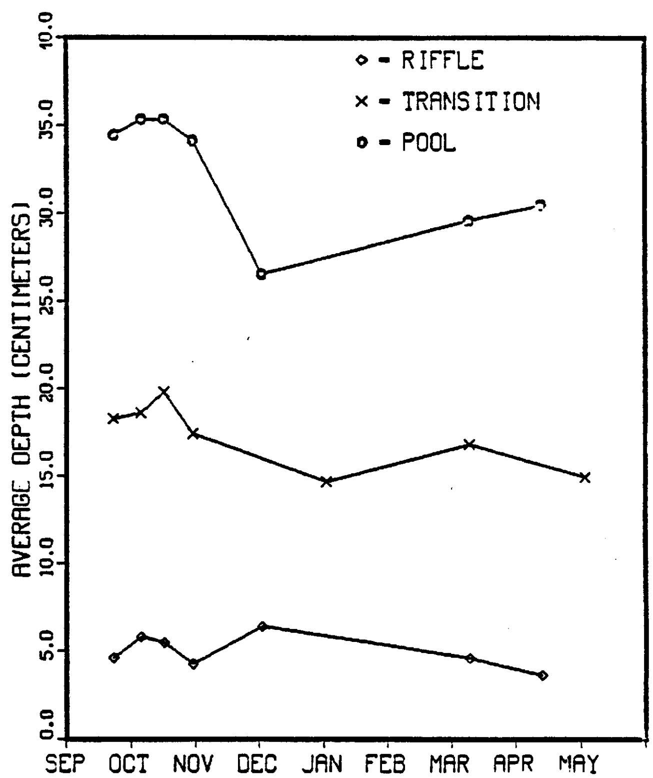

Figure 5. **Average water depth for the Downstream Telephone Creek site, during winter 1983-84.**

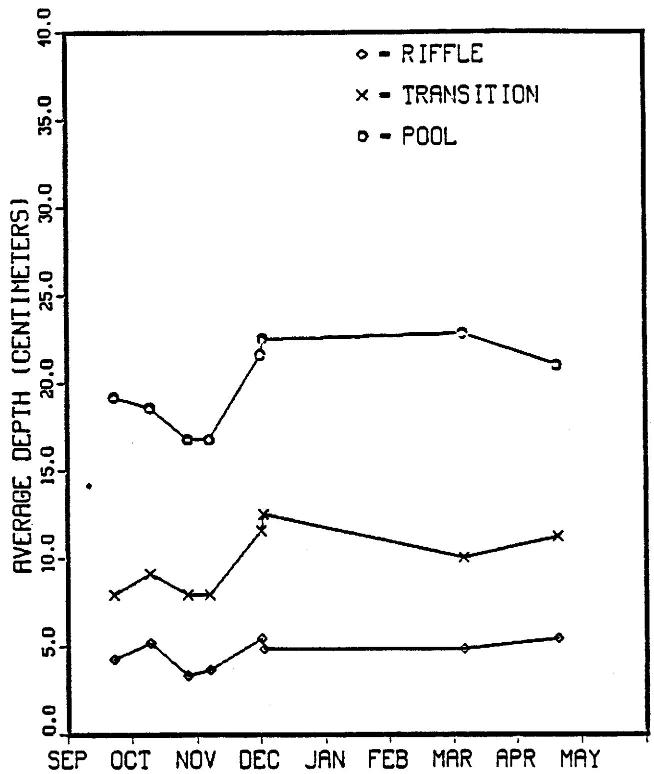

Figure 6. Average water depth for the Upstream Nash Fork Creek site, during winter 1983-84.

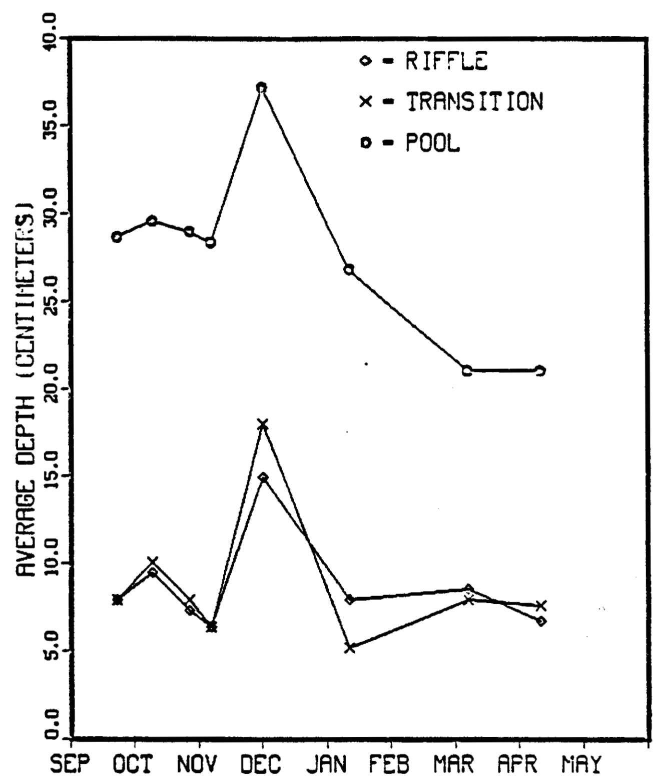

Figure 7. Average water depth for the Downstream Nash Fork Creek site, during winter 1983-84.

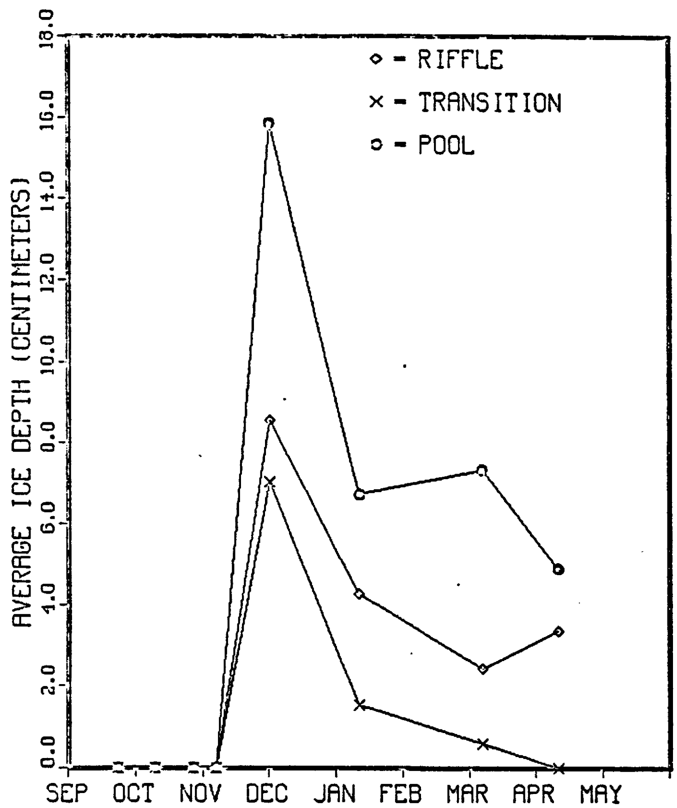

Figure 8. Plot of the average ice depth at the Downstream Nash Fork Creek site, during winter 1983-84.

was highly variable (Appendix D). Observations of NFD while radio tracking fish supported this conclusion.

Snow accumulation across the streams was first recorded on December 5, 1983, and increased through the winter (Figures 9, 10 11, 12). Maximum snow depths at the four study sites were : TCU - 3.81 m, TCD - 4.33 m, NFU - 2.32 m, and NFD - 1.28 m . One hundred percent of the stream width of the three highest study sites (TCU,TCD,NFU) was covered by snow following initial accumulation. At NFD, percentage of the transects covered by snow ranged from 6 to 100 %, with corresponding maximum snow depths of 0.4 to 1.1 m.

Time or travel velocities were measured for each or the four study sites during fall and winter to obtain representative stream reach velocities. Time of travel velocities were much less in winter than in fall (Table 3).

Winter 1984-85

Winter stream conditions changed as elevation decreased. Linear regression of the log of mean snow depth on elevation showed that a statistically significant relation existed between these variables (Figure 13). Adjusted R-square values for the riffle, transition, and pool transects were : 0.72, 0.54, and 0.58, respectively. A significant negative relationship was found to exist between the log of mean ice depth and elevation (Figure 14). Adjusted R-square values for regression equations developed for the riffle, transition,

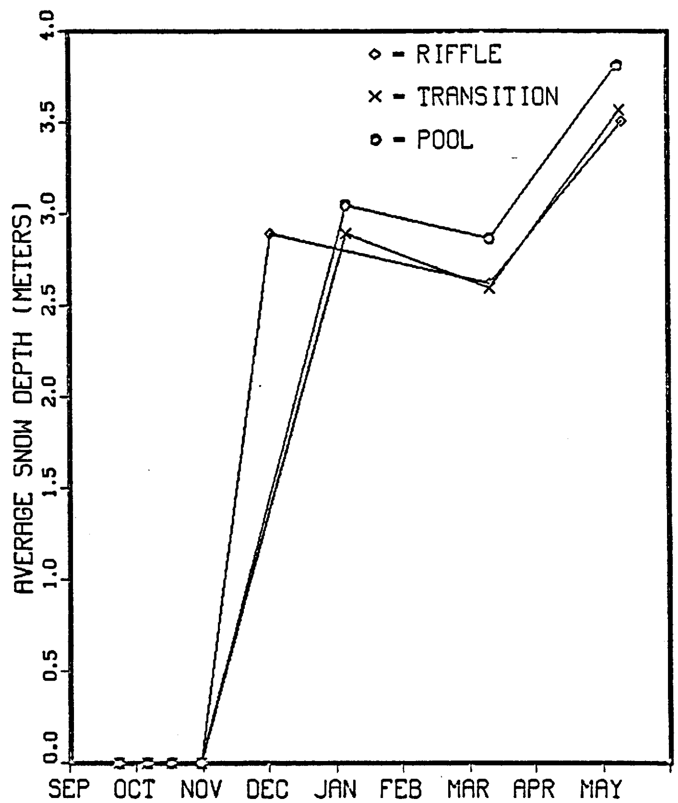

Figure 9. Plot of the average snow depth for the Upstream Telephone Creek site, during winter 1983-84.

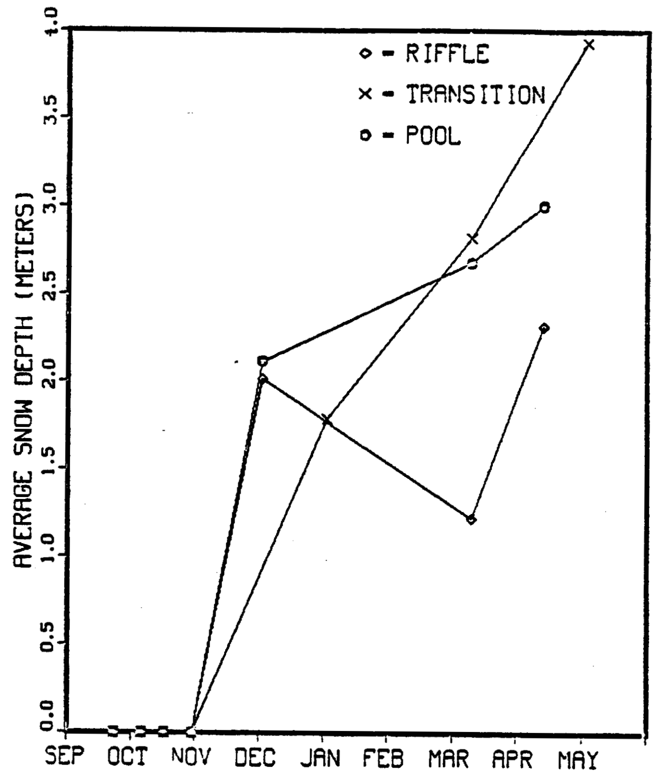

Figure 10. Plot of the average snow depth for the Downstream Telephone Creek site, during winter 1983-84.

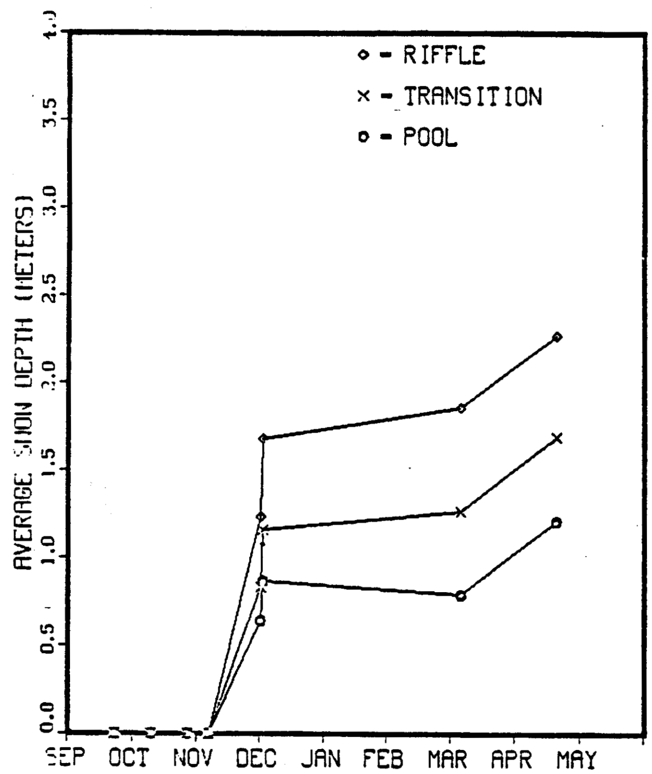

Figure 11. **Plot of the average snow depth for the Upstream Nash Fork Creek site, during winter 1983-84.**

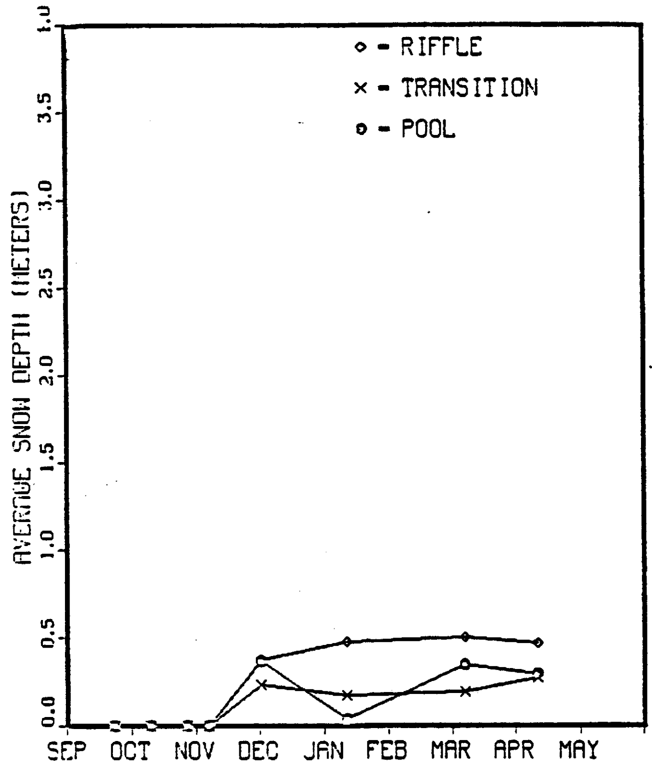

Figure 12. Plot of the average snow depth for the Downstream Nash Fork Creek site, during winter 1983-84.

Table 3. Comparison of time of travel velocities sampled in September and April 1984, at the Telephone Creek and Nash Fork Creek study sites.

Sample Site	Fall Velocity (m/s)	Fall Q* (m^3/s)	Winter Velocity (m/s)	Winter Q* (m^3/s)	Magnitude of Variation (m/s)	(Q)
Upstream Telephone Creek	0.28	0.05	0.07	0.01	3.8	5.1
Downstream Telephone Creek	0.17	0.07	0.06	0.01	2.8	5.0
Upstream Nash Fork Creek	0.17	0.10	0.09	0.02	1.9	4.1
Downstrean Nash Fork Creek	0.33	0.18	0.12	0.03	2.7	5.2

*Q signifies discharge, and is equal to cross-sectional area times velocity

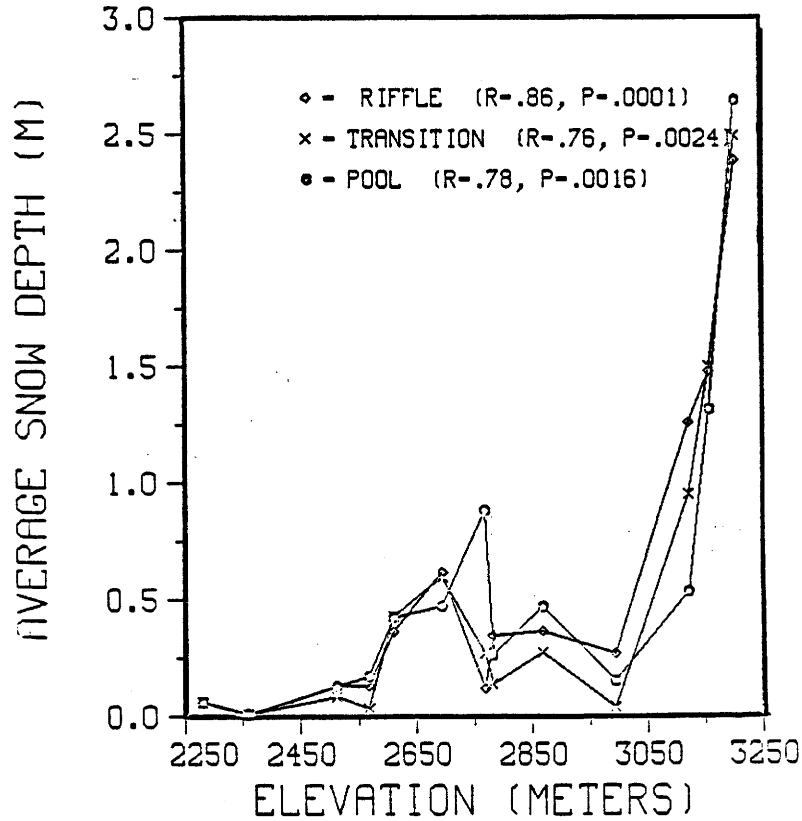

Figure 13. Plot of mean snow depth with elevation for the 13 study sites sampled in January 1985. Correlation coefficients and associated probabilties for the riffle, transition, and pool transects are from a regression of the log of mean snow depth on elevation.

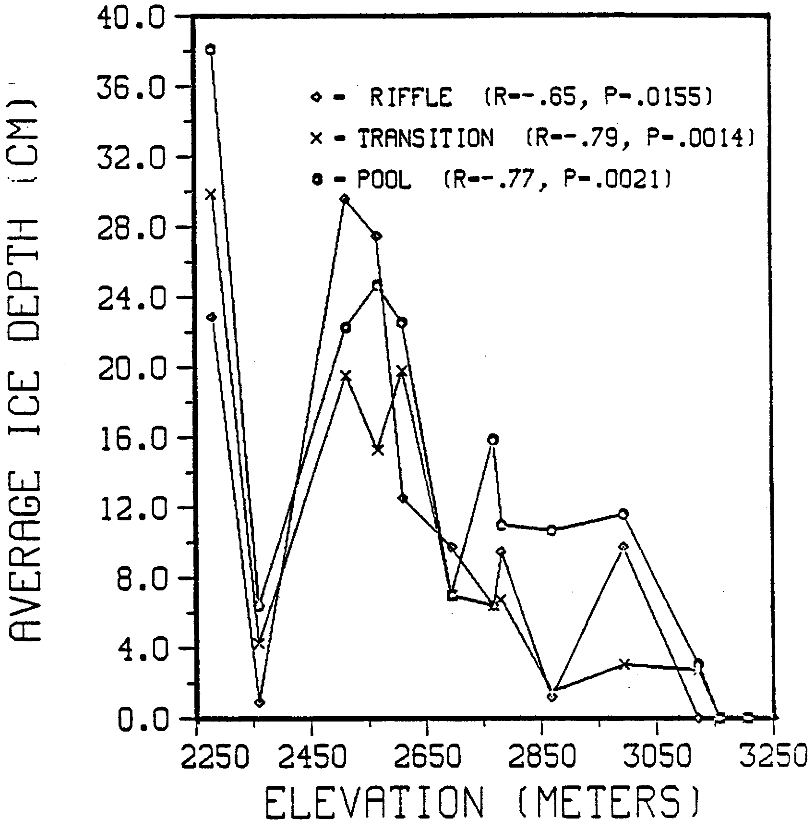

Figure 14. Plot of mean ice depth with elevation for the 13 study sites sampled in January 1985. Correlation coefficients and associated probabilties for the riffle, transition, and pool transects are from a regression of the log of mean ice depth on elevation.

and pool transects were : 0.37, 0.57, and 0.56, respectively.

Regression of mean ice depth on mean snow depth resulted in an adjusted R-square value and associated two-tailed probability of $R^2 =$ 0.23, p= .054 for the riffle transect, $R^2 =$ 0.16, p=.099 for the transition transect, and $R^2 =$ 0.24, p=.051 for the pool transect.

Regressions of cross-sectional area, average water depth, stream width, and total width greater than 15.2 cm deep on elevation also produced significant relationships (Appendix E). Because of the natural increase in stream size with decreasing elevation, these relationships were all negative. It should be noted that although there was a significant negative relationship between average water depth and elevation for the riffle and transition transects, this was not true for the pool transects. This indicated that pool depths did not increase in winter as stream size increased and elevation decreased. Appendix E also presents plots of the width/depth ratio and air gap versus elevation. Individual regression analysis of these two variables with elevation did not produce significant relationships, with the exception of the pool transect in the width/depth ratio regression. The relationship of an increasing width/depth ratio with elevation, for the pool transect, indicates a widening cnannel.

Ice formation increased with decreasing elevation. Appendix F presents the cross-sectional area of ice, the cross-sectional area of water and the relative percent of both ice and water to the total cross-section. With the exception of Site 12 at the mouth of the North Fork of the Little Lararmie, all sites below 2800 m had at least two or the three transects with ice making up 40 % or more of the total cross-section. Riffle transects at these sites generally had the highest percentage of ice, ranging from 52 to 67 %. Cross-sectional areas of ice were generally greatest in the pool and riffle areas at all sites below 2995 m , with values ranging from 0.31 to 3.49 square meters and 0.06 to 2.47 square meters, respectively. Anchor and frazil ice were observed in the stream sections at Sites 8, 9, and 10, but amounts and extent coverage were not quantified.

Data collected during winter 1984-85 were used to test the model developed by Johnson et al. (1982), for predicting the percent of ice-excluded habitat. Computed values used by the model and predicted and observed % of ice-excluded habitat are presented in Appendix G . While this model produced accurate predictions for ice excluded habitat on Wagonhound Creek where it was developed, it was not applicable to my study streams. Only one of the nine sites had any observed ice-excluded habitat according to the model guidelines, and predicted ice-excluded habitat values varied from -79 to 201 %, suggesting inappropriate representation of conditions on these streams. Because the amount of ice-excluded habitat was based on the water depths welled up in each hole through which measurements were taken, if water levels have dropped, observed amount of ice-excluded habitat would be calculated as zero, regardless of the cross-sectional area of ice formed.

Winter Beaver Pond Conditions

The beaver pond at the downstream end of the mapped telemetry area on Nash Fork Creek (elevation 2990 m) was monitored at three transects for ice, water depth, and velocity on January 15, 1985. The results or this work are presented in Table 4. Extensive ice cover was observed, with ice depths ranging from 40 to 56 cm. Cross-sectional area of ice was greater than that of water at each transect, making up 66 to 72 % of the total cross-section. Average water depth was nearly half the depth of the ice, ranging from 16 to 30 cm. Mean velocity in the beaver ranged from 1.68 to 2.52 cm/second. Based on Johnson's (1981) definition, previously discussed in the Methods section, observed ice-excluded habitat ranged from 75 to 77 %.

Winter Telemetry

Telemetry observations were made during a 152-day period during winter 1983-84 and a 130-day period in 1984-85. Before snow and ice cover transmitter ranges were 30-50 m. With snow and ice cover, transmitter ranges were slightly less. In 1983, mean total lengths of the 3 female and 5 male transmitter-equipped brook trout were 198 and 205 mm, respectively. Total lengths ranged from 182 to 227 mm. Transmitter weight ranged from 3.7 to 7.1 % body weight for the eight fish. Mean total lengths or the 2 female and 6 male brook trout radio-tagged in 1984 were 215 and 226 mm, respectively, range 209 to

Table 4. Values of physical parameters measured at three transects across the Nash Fork Creek beaver pond (elevation 2993 m) on January 15, 1985.

Transect	Width (m)	Cross-sectional Area of Water (m^2)	% of total cross section	$\bar{D}$ (cm)	Cross-sectional Area of Ice (m^2)	% of total cross section	$\bar{D}$ (cm)	$\bar{V}$ (cm/s)	% of ice excluded habitat
A	7.6	2.24	34	29.3	4.26	66	56.1	1.96	76
B	4.0	1.07	34	15.9	2.12	66	40.2	2.52	75
C	7.2	1.14	28	27.1	2.88	72	53.6	1.68	77

$\bar{D}$ = mean water depth across a transect

$\bar{V}$ = mean water velocity across a transect, measured at 0.6 total depth and adjusted to the condition of complete ice cover by multiplying by 0.92

268 mm.

Brook-Trout Winter Movement

Brook trout were active during both winters when tracking occurred. The majority of movement during winter was downstream (Appendix H). Average movement between home areas or single locations was 86 m. Five of the seven fish tracked during 1983-84 moved downstream, one exhibited net upstream movement, and one fish remained in the same area all winter. Movement was variable, ranging from 0 to 206 m. All radio-tagged brook trout remained in low-gradient sections of the stream.

During 1984-85, trout exhibited downstream movement. Net movement between locations or home areas ranged from 33 to 342 m. Mean distance moved was 163 m. The most sedentary fish (Fish 10 and 11) occupied pools alongside the main current in the higher gradient areas. Net movement of these two fish ranged between 33 and 36 m. Four of the six fish that moved to the beaver pond were located there on October 24, the day after implant surgery. All six fish occupying the beaver pond were located in its boundaries within two weeks following surgery. The six fish that moved into the beaver pond remained mobile during the winter, moving from one end of the pond to the other (Appendix I). Distances moved for these fish ranged between 54 and 342 m.

Habitat Selection

Winter 1983-84

Seven of the eight transmitters implanted into brook trout operated for 152 days and provided useful data. Radio-tagged brook trout remained in the low-gradient meadow areas where they were captured for the entire tracking period. The G-test for independence between the distribution of habitat selected by individual fish and the distribution of habitat available to them, indicated significant differences ($p < 0.001$) existed for the velocity index, substrate and depth variables (Table 5). These differences between habitat used and habitat available remained when all 7 fish and all available habitats were combined and compared.

The velocity index frequency distibution for areas selected by all fish during winter 1983-84 was compared with the velocity index distribution of the available habitat in Figure 15. The comparison indicated that highest use occurred in areas with a velocity index of less than or equal to 15.2 cm /second. These areas made up 21 % of the available habitat but brook trout were observed in these areas 42 % of the time. Strauss' electivity index for the selected water velocity index supports this observation (Appendix J). When all fish were combined, positive selection occurred only for areas with a velocity index of 0-15 cm /second. The electivity index for this velocity class was 0.21. Other velocity classes had electivity index values ranging from 0.02 to -0.12. Four of the seven fish showed

Table 5. G-test for independence between available and selected habitats during winter 1983-84. (* denotes significant difference, p 0.001)

DEPTH

	Fish Number							
	1	2	3	4	6	7	8	All Fish
G^2-test statistic	32.3*	142.7*	24.3*	65.8*	57.4*	44.4*	26.8*	1035.7*

SUBSTRATE

	Fish Number							
	1	2	3	4	6	7	8	All Fish
G^2-test statistic	60.2*	91.4*	20.9*	141.5*	44.2*	72.8*	43.2*	49.8*

VELOCITY INDEX

	Fish Number							
	1	2	3	4	6	7	8	All Fish
G^2-test statistic	378.8*	579.6*	360.7*	622.4*	183.4*	270.3*	319.3*	532.5*

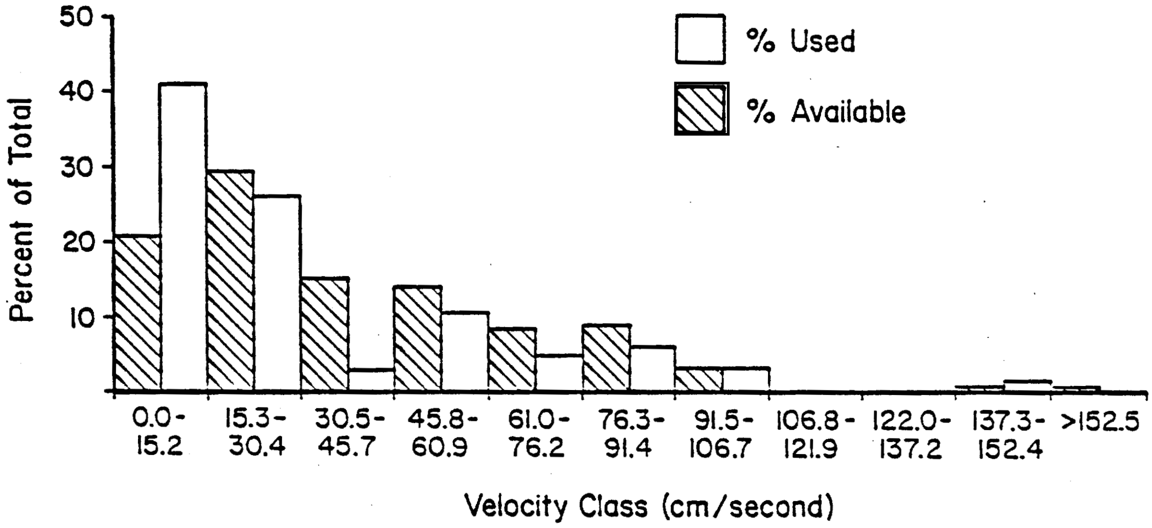

Figure 15. Comparison of velocity index intervals selected with velocities available for all fish monitored during winter 1983-84.

selection parallel to the seven fish combined, with strongest selection occurring for areas with a velocity less than or equal to 15.2 cm /second and negative selection or random association with all other velocity classes. Fish 2, 3, and 4 were apparently associated with faster water, with highest use for Fish 2 occurring at areas with a velocity index between 76.2 and 91.4 cm/second. Fish 3 and 4 occurred most often in areas with velocity indices of 106.7 to 121.9 and 15.2 to 30.4, respectively.

Frequency distributions of the depth class selected by all fish versus that in the combined available habitat are presented in Figure 16. Appendix J lists Strauss' electivity index for the depth interval selected by individual fish and all fish combined. Figure 16 indicated a lack of strong selection for any depth class. Highest brook trout use occurred in areas with a depth from 15.2 to 30.5 cm, where they were found 31 % of the time. Electivity values ranged from 0.02 to -0.07 for all fish combined.

Frequency distributions of the substrate class in areas all fish used versus that in the combined available habitat are presented in Figure 17. Similar to depth use, strong association with a particular substrate class did not occur. Areas of highest use had a substrate particle size or less than or equal to 4.7 mm, being occupied 46 % of the time while making up 36 % of the available habitat. Review of the electivity index for selected substrate by all fish combined (Appendix J), indicated that selection for a

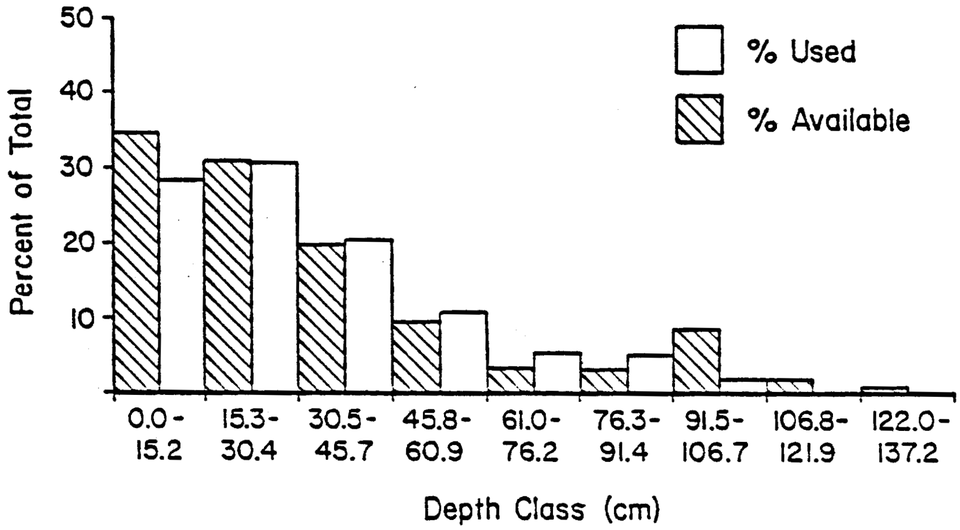

Figure 16. Comparison of depth intervals selected with depths available for all fish monitored during winter 1983-84.

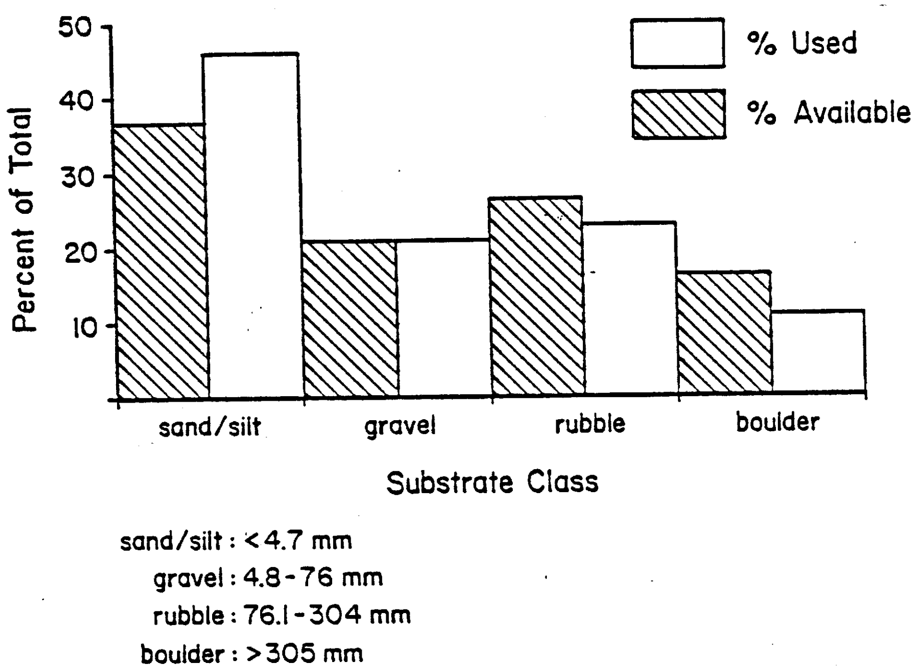

Figure 17. Comparison of substrate class selected with that available for all fish monitored during winter 1983-84.

particular substrate class was weak. Index values ranged from a high or 0.09 to -0.05. Individually, the strongest selection occurred by Fish 2 for areas with a rubble substrate (4.8 to 76 mm diameter), with an index value of 0.30. Substrate size selection by the other fisn was highly variable.

Winter 1984-85

Habitat selection during winter 1984-85 was consistent with that found in 1983-84. The G-test for independence between available habitat distributions and selected habitat distributions for each fish and all fish combined showed significant differences existed for the velocity index, substrate, and depth variables in all cases (Table 6).

Comparison of the velocity index recorded at selected habitat with that in the available habitat for all eight fish showed strong selection for areas with a velocity index less than or equal to 15.2 cm /second (Figure 18). Areas with a velocity index equal to or less than 15.2 cm /second made up 33 % of the available habitat but were used by the radio-tagged fish 86 % of the time. Six of the eight fish showed strong selection for areas with this velocity index interval (Appendix K). These six fish moved from areas with stream reach gradients between 1.6 and 6.3 % to the beaver pond within two weeks of implantation and remained there for the entire tracking period. The two fish that stayed in the higher gradient sections of the study area were associated with higher velocities.

Table 6. G-test for independence between available and selected habitats during winter 1984-85. (* denotes significant difference, p 0.001)

DEPTH

	Fish Number								
	9	10	11	12	13	14	15	16	All Fish
G^2-test statistic	607.3*	269.7*	147.0*	923.1*	815.4*	844.8*	939.0*	549.4*	1035.7*

SUBSTRATE

	Fish Number								
	9	10	11	12	13	14	15	16	All Fish
G^2-test statistic	1031.8*	107.6*	192.0*	1664.0*	1547.2*	1653.3*	1210.1*	1101.2*	1825.3*

VELOCITY INDEX

	Fish Number								
	9	10	11	12	13	14	15	16	All Fish
G^2-test statistic	997.0*	689.5*	688.9*	1671.4*	1599.7*	1716.9*	1727.3*	990.2*	2055.3*

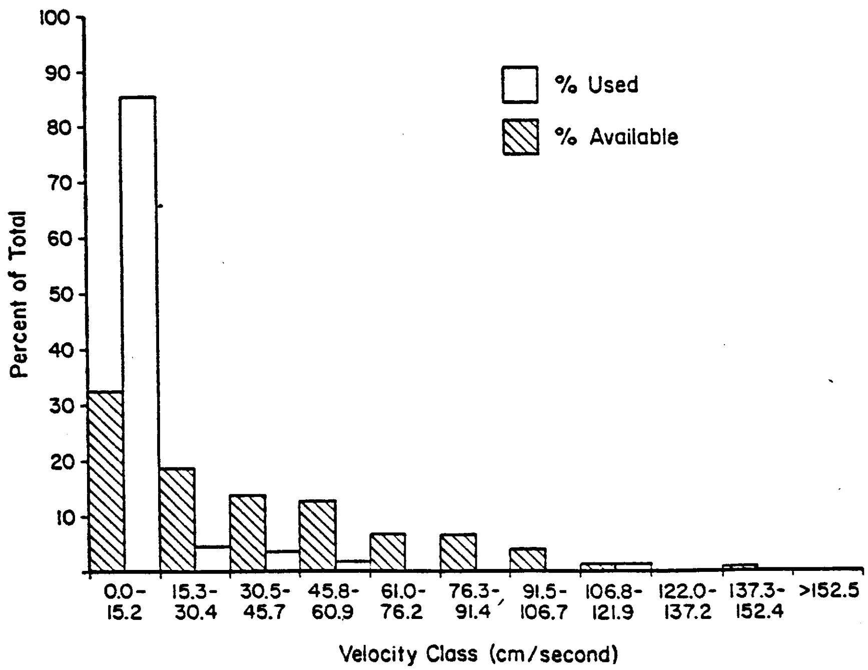

Figure 18. Comparison of velocity index intervals selected with velocities available for all fish monitored during winter 1984-85.

Comparison of depth frequency distributions of habitat used by all fish with habitat available is presented in Figure 19. The most highly used depth interval was 30.5 - 45.7 cm, being occupied 23 % of the time. Strongest selection occurred for the 60.9 to 76.2 cm interval, which had an index value of 0.12 (Appendix K).

During winter 1984-85, fish were also most often associated with sand/silt substrate (Figure 20). Brook trout were present in areas with a substrate class of 1 (4.7 mm diameter or less) 83 % of the time, and this class made up 27 % of the available habitat. The six fish which moved to and remained in the beaver pond were strongly associated with substrate class 1 (Appendix K). The two fish (Fish 10 and 11) which remained in the higher gradient sections of the stream were most often associated with substrate classes 3 and 4 (rubble and boulder).

Discriminant analysis of the difference between available and selected habitat using width, substrate, velocity, and depth resulted in a significant discriminant function with an associated canonical correlation of 0.58. Discrimination between the two groups was significant, with $p < 0.0001$. Variable loadings, group means and classification results for this analysis are presented in Appendix L. Results of the G-Test and Electivity Index suggested that the width and substrate variables may not be important forces in winter habitat selection. When width and substrate were dropped from the analysis, strong discrimination between the groups remained ($p<0.0001$) and the

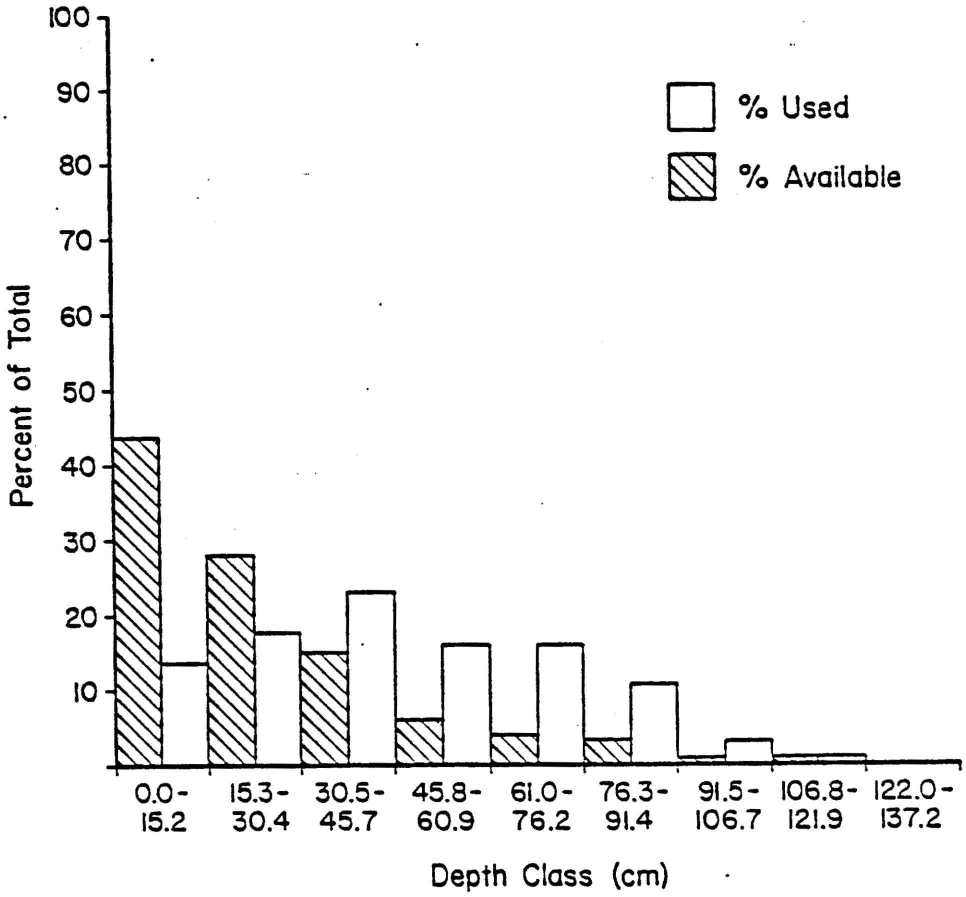

Figure 19. Comparison of depth intervals selected with depths available for all fish monitored during winter 1984-85.

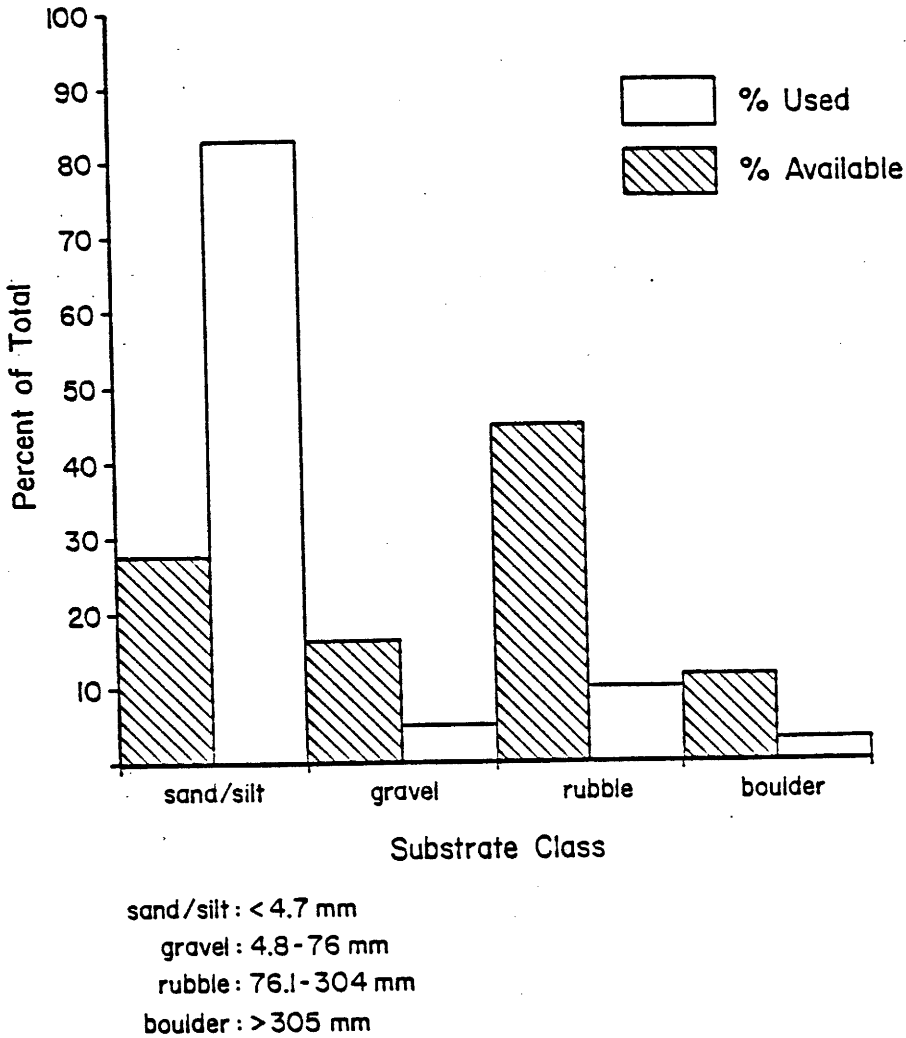

Figure 20. Comparison of substrate class selected with that available for all fish monitored during winter 1984-85.

relationship between the groups and the first discriminant function did not change drastically (canonical correlation =0.49). Also, the percent of cases correctly classified dropped less than 6 % (Appendix L). This suggests that depth and velocity are important variables determining brook trout winter habitat.

DISCUSSION

Stream Conditions

Winter 1983-84

Ice formed at the study sites prior to the accumulation of snow, but after snow cover, ice formation ceased. Ice typically forms on small streams by a process known as shore ice formation, whereby ice is nucleated at the stream banks and proceeds from the shore outward. Shore ice formation provides the means for covering up areas of rapid flow (Michel 1971). Ice thickens by crystallization on the underside, as heat is transferred upward through the ice (Maciolek and Needham 1952). Although minimal ice cover was found at three of the four study sites above 2990 m, it was often separated from the water surface by an air gap, and its thickness diminished through winter. The most extensive ice formation occurred at the NFD site, but was highly variable in thickness and coverage (Table D, Figure 8). Because of this variability, it is doubtful if ice formation at this site resulted in significant exclusion of stream habitat.

Anchor ice was not found at any of the study sites above 2990 m. Anchor ice forms on rocks on the stream bed by radiative heat transfer (Burgi et al. 1974). Since the snow cover on the study streams above 2990 m was generally complete, it prevented the loss of stream bed heat by radiation and anchor ice did not form.

Further evidence of the protective nature of snow cover at the study sites exceeding 2990 m elevation was provided by the time of travel velocitites in fall and winter. Although time of travel velocities were much less in winter than in fall, when differences in discharge were accounted for, it was apparent that velocity differences were a function of reduced flows and not an increase in channel roughness caused by ice and snow. This suggested that at the study sites above 2990 m in elevation, ice formation was insignificant and conditions similar to open channel flow occurred, despite complete snow cover.

While snow cover was found to prevent the formation of surface and anchor ice in these streams, snow can actively assist the growth of white ice in alpine lakes by promoting slushing (Adams 1981). The extensive ice exclusion reported for the beaver pond on Nash Fork Creek (elevation 2990 m) probably resulted from a combination of factors. Extensive pre-snow ice formation, wind action keeping snow depths to a minimum, and white ice growth formed by snow-caused slushing all probably contributed to ice formation at this beaver pond.

Winter 1984-85

Stream conditions changed as elevation decreased. The log value of mean snow depth and mean ice depth were both significantly related to elevation (Figures 13 and 14). The negative relation of ice with elevation and the positive relation of snow with elevation suggested that depth or snow cover may be a controlling factor for ice depth in these streams. To examine this relation, regression analysis of mean ice depth on mean snow depth was performed. The marginal significance of the resulting relationship suggested that there are other factors influencing ice formation, such as air temperature, which snow depth does not address, and yet this simplistic relation between snow and ice depths is an important one.

Cross-sectional areas of ice were largest at the study site with the lowest elevation (2280 m) and decreased as elevation and snow cover increased. The amount of ice-excluded habitat at the lowest site was higher (64-84%) than the maximum reported by Johnson (1981) or 65-71 % at a slightly lower elevation (2261 m) on Wagonhound Creek, Wyoming. In Johnson's (1981) study, initial amounts of ice-excluded habitats were greatest in the riffle and pool transects. January measurements in my study indicated that below 2995 m, ice thickness and cross-sectional areas of ice also were greatest at the riffles and pools. Deviation from this general trend occurred at Site 12. The relatively low amounts of ice formation (11 to 14 % of the total cross-section) encountered at Site 12 was probably due to the south aspect of the exposed left bank at this site.

Anchor and frazil ice were observed at the sites between 2550 and 2700 m in elevation, but not at elevations above and below, where snow or ice cover generally was complete. Because the stream was exposed to the air and subject to frazil and anchor ice formation at these mid-elevation sites, stream conditions may be harsher than at elevations above and below this. Maciolek and Needham (1952) stated that anchor ice had a more pronounced effect on streamlife than surface ice. Reimers (1957) concluded that bottom dwelling organisms are harmed less by partial snow and ice cover than by repeated exposure to the radical changes in flow that accompany subsurface ice action. Reiser and Wesche (1979) reported inter-gravel freezing as a cause of brown trout egg mortality. Trout mortality caused by anchor ice was documented by Tack (1938).

Another important aspect of underwater ice to consider is that greater quantities of ice are produced in an open water area as frazil than that produced, under identical atmospheric conditions, by the static growth of surface ice cover (Michel 1971). Frazil flocs and slush can fill the low velocity areas underneath downstream ice cover, back up water, and effectively dewater downstream areas (Maciolek and Needham 1952, Needham and Jones 1959, Michel 1971).

Pool depths did not increase in winter as stream size increased and elevation decreased. Regression analysis of average water depth on elevation produced a significant negative relationship for all except the pool transects. This was probably a function of the geology of these streams limiting maximum stream depths. A corollary explanation could be that this resulted from the snow cover at high elevations insulating the streams such that pool depths were unaffected by winter, and ice formation at lower elevation pools effectively decreasing water depths.

Methods for predicting river and lake ice formation are not new (Billello 1963, Burgi et al 1974). However, the model presented by Johnson et al. (1982) is unique in that it uses atmospheric and hydrologic parameters to predict the amount of ice-excluded habitat in a stream. Testing of the model with data collected at the study streams in January 1985 indicated that the model was not applicable to these sites. Failure to account for the effects of snow depth, wind, and pre-ice water temperature on ice formation and inordinate emphasis on the depth variable could help explain the models poor performance. It also is possible that the temperature records and date of initial ice formation I used were not accurate enough, but the magnitude of variation between actual and predicted ice-excluded habitat seemed to preclude these as sole causes of the model's failure.

Results from the winter stream transect monitoring suggested that at elevations greater than 2990 m, recommendations for winter instream flows can be based on historical discharge information. Problems associated with water withdrawal would probably not be compounded by winter conditions at these elevations. However, the effect of winter water withdrawal on lower elevation sites on the same stream system may be more severe, because of habitat exclusion and alteration by surface and underwater forms of ice. Although ice cover was generally complete and cross-sectional areas of ice extensive below 2550 m, I believe that the most harsh and variable conditions occur at elevations between 2550 and 2700 m, where streams are exposed to the open air and formation of underwater and surface ice occurs. Ultimately, the effects of water development must be considered for an entire atream system, including areas downstream from the directly affected reach.

Habitat Selection

Winter 1983-84

Brook trout habitat selection was for areas of slow velocity (< 15 cm/second). Wicner's (1978) study on winter microhabitat selection by brown trout reported a similar preference for areas of slow velocity (< 15 cm/second). Bustard and Narver (1975a) reported that at 7 C or less, most coho salmon and steelhead trout in a small west coast Vancouver Island stream were associated with water velocities < 15 cm/second. Tschaplinski and Hartman (1983) reported that juvenile coho salmon winter microhabitats were characterized by water velocities less than or equal to 30 cm/second.

Although their combined selectivity was for areas with velocity indices less than 15 cm/second, three of the seven radio-tagged trout were associated with faster water of various speeds. This variability points out possible shortcomings in using an entire transect to represent a fish location. While focal point velocities would probably be more accurate and more consistent from fish to fish, winter sampling in snow covered streams with transmitter detection accuracies between 0.6 to 1.2 m presented logistical constraints to accurately measuring them.

The results from the 1983-84 telemetry season indicated that overwintering brook trout are selecting for areas with slow velocity and these areas are most often, but not exclusively associated with depths greater than 15 cm and with sand-silt substrate. Distinct selection by fish in 1983-84 for depth was not apparent. This lack of sensitivity to depth could be a function of the security of complete snow cover found at the study sites and the relatively slow velocities throughout the meadow areas where these fish remained. Bustard and Narver (1975a) reported that age 1+ coho salmon and steelhead trout were found at a range of depths mainly greater than 45 cm during the winter months. Similar to depth use by brook trout on these study streams, strong association with a particular substrate class did not occur. Substrate size selection by brook trout was highly variable, with areas of highest use having a sand-silt substrate class.

During winter 1983-84, complete overhead cover was provided by snow or ice at all of the study areas. Although not tested by this study, I believe that cover was an important factor determining suitability of brook trout winter habitat. Cover is an important aspect in winter habitat selection, providing shelter and reducing stream velocities (Tschaplinski and Hartman 1983). Stronger association with the bottom during winter affords fish protection against predation and displacement in the stream (Hartman 1963). Hunt (1971) showed that by adding overhanging bank cover and increasing pool area, overwinter survival of brook trout was nearly doubled. By increasing the number of hiding places in a small stream, Saunders and Smith (1962) nearly doubled the population of brook trout. They also showed reduction of trout populations as a result of destruction of hiding places by heavy siltation. Bjornn et al. (1977) and Stowell et al. (1983) have reported that sediment deposition in pools reduces the winter carrying capacity by filling in the interstitial spaces fish use for cover.

I believe that brook trout association with sand-silt substrate was actually a function of selection for low water velocities and overhead cover. Brook trout affinity for overhead cover during winter has been reported by Cooper (1953) and Gibson (1978). Gibson (1978) reported that although rubble substrate is generally regarded as preferred habitat for Atlantic salmon parr, this is a reflection of this substrate type being associated with riffle areas and a turbulent water surface. Rubble per se did not appear to be attractive to parr in these conditions (Gibson and Power 1975).

Gibson (1978) concluded by saying that rubble provides pockets of reduced water velocity, suitable as holding areas and reference points for parr in fast water conditions, and that it is the turbulent water surface that is an attractant to Atlantic salmon parr.

Winter 1984-85

Habitat selection during 1984-85 was consistent with that found in 1983-84. Areas with a velocity index less than 15 cm/s were selected. Six of the eight radio-tagged brook trout moved to and remained in the beaver pond within two weeks of implantation surgery.

Fish apparently selected for water depth greater than 30 cm. The discriminant analysis supported inclusion of depth as an important variable determining selected fish habitat. However, this was probably a function of most fish remaining in the beaver pond and measuring beaver pond habitat in the summer. Winter conditions in the beaver pond were such that the largest percentage of the total cross-section was ice (Table 4). Water depths in the beaver pond in January averaged 16 to 29 cm, indicating that there was little depth over 30 cm. This provided further evidence that brook trout were selecting primarily for low velocities and overhead cover.

The dominant substrate class in the beaver pond was sand-silt and was the substrate most often associated with brook trout. It seems reasonable to conclude that apparent selection for substrate was an effect of fish choosing for areas of slow velocity.

Velocities selected by brook trout in winter were encompassed by those presented as probability of use criteria for brook trout (Bovee 1976). However, results of this study suggest that the probability curve for velocity used for brook trout in winter should be refined somewhat to reflect the preference for areas with velocities less than 15 cm/s.

Implicit in all biotelemtry studies is the assumption that presence of the transmitter does not seriously affect the animal (Stasko and Pincock 1977). Obviously, brook trout occupation of the beaver pond at the downstream end of the study area in 1984-85 was a major component of the difference between available and selected habitat determined by this study. Since four of the six fish that eventually remained in the beaver pond during winter were located there the day after being implanted with transmitters, it could be argued that their initial residence in the beaver pond was the result of stress-induced movement caused by the implant surgery. Body load of our neutrally buoyant transmitters was high (4-7%), but this range was based on air weights. McCleave and Stred (1975) implanted transmitters with up to 6 % body load in Atlantic salmon smolts and noted no decrement in swimmming speed. Stasko and Pincock (1977) stated that the weight ratio (of transmitters to body weight) was probably more critical for pelagic fish than for bottom dwelling fish and invertebrates.

In my study, subsequent movement distances within the beaver pond area suggested that the radio-tagged fish were actively selecting habitat and not impeded by their transmitters. Consistency with winter 1983-84 results also should dispel doubt as to whether post-surgery stress was an overriding factor in initial habitat selection during 1984-85.

Research Recommendations

This study was largely descriptive and by no means exhaustive of the research needs on winter trout habitat requirements and stream conditions. Research identifying the major factors affecting ice formation in small streams is needed, with emphasis on development of models which predict the amount of ice formation. Such models should be tested with independent data and refined to be applicable regionally. In southeastern Wyoming appropriate study site elevations would probably be on streams up to 2450 m, where ice cover generally is complete.

The effects of frazil and anchor ice on trout stream ecology should be quantified. This will demand development of precise and accurate methods for measuring amounts, sources and effects of underwater ice forms. Previous research in this area has been largely descriptive.

Development of an accurate method for quantifying overwinter trout mortality will allow assessment of critical stream sections and habitat requirements of trout in these areas. Additional telemetry work at mid-elevations may indicate how fish in these reaches cope with anchor and frazil ice formation. Continued studies may show seasonal movements, downstream in the winter and upstream in the spring, and may have implications on recommending suitable flows on an annual basis.

Summary

Above 2990 m, snow cover insulated the stream and habitat exclusion by ice was minimal. Discharge rates decreased through winter but otherwise were unaffected by winter conditions. As elevation decreased below 2990 m, snow depths decreased and ice formation increased. Ice depths and the amount of ice-excluded habitat was greatest at the lowest site (2280 m), but it was speculated that stream conditions are harshest and most variable at the mid-elevation sites (2550-2700 m) where the streams are partially ice and snow covered and subject to frazil and anchor ice formation. Johnson's (1981) model for predicting the amount of ice-excluded stream habitat was not applicable on these streams. Possible reasons for this include failure to account for snow depths, wind action and possible inaccuracies in temperature records and in estimating freeze-up date.

Fish remained active during winter, with movement distances ranging from 0 to 342 m. Direction of fish movement was generally downstream. Brook trout habitat selection was consistent during the two winters. Fish remained in the streams above 2990 m in elevation, selecting for areas of slow velocity. Discriminant analysis indicated that velocity and depth were important variables determining the difference between selected and available habitats. However, since an important component of the selected habitat was a beaver pond and because of ice formation average water depths were less than depths indicated as being selected for, it was felt that depth was not being used as a selection factor by brook trout. Strongest substrate association was with sand and silt, which was common in areas of slow velocity in these streams.

Results from the winter stream transect monitoring suggested that at elevations greater than 2990 m, recommendations for winter instream flows can be based on historical discharge information. Problems associated with water withdrawal would probably not be compounded by winter conditions at these elevations. However, the effect of winter water withdrawal on lower elevation sites on the same stream system may be more severe, because of habitat exclusion and alteration by surface and underwater forms of ice. I propose that winter instream flow recommendations for streams with brook trout should aim at preserving slow-water areas with fish access into and out of these areas.

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APPENDICES

APPENDIX A

Location and descriptive information for additional study sites monitored during winter 1984-85.

Site	Elevation (m)	Location	Brief Description	Land Ownership	Stream Gradient	Stream order at study site location
5	2868	NW1/4,NW1/4, Section 19, R78W, T16N	Nash Fork Creek approx. 1.5 km below Green Rocks picnic ground	Federal	1.5%	3
6	2780	SE1/4,NW1/4, Section 20, R78W, T16N	Nash Fork Creek at Medicine Bow Ski Area	Federal	0.7%	3
7	2767	SE1/4,SW1/4, Section 16, R78W, T16N	North Fork Little Laramie at Sand Creek Road	Federal	0.7%	3
8	2694	NW1/4,SW1/4, Section 21, R78W, T16N	Lower Nash Fork Below Hanging Lake	Federal	4.3%	3
9	2609	SW1/4,SE1/4, Section 28, R78W, T16N	Libby Creek at Libby Creek Campground Area	Federal	1.6%	3
10	2566	NE1/4,SE1/4, Section 28, R78W, T16N	North Fork Little Laramie at Corner Mountain	Federal	3.7%	4
11	2511	SE1/4,NE1/4, Section 34, R78W, T16N	North Fork Little Laramie Below Confluence of Libby	Private	2.4%	4
12	2359	NE1/4,SW1/4, Section 18, R77W, T15N	North Fork Little Laramie at Confluence of Little Laramie	Private	0.2%	4
13	2280	SW1/4,SW1/4, Section 36, R77W, T16N	Little Laramie at Public Fishing Area	State	0.3%	5

APPENDIX B

Example computation of the G^2-test statistic, for the substrate selected by Fish Number 1 versus that in the available habitat; and corresponding output from program BMDP4F.

HAB	SUBSTR				
	FS1	FS2	FS3	FS4	TOTAL
AVAL	102	94	67	22	285
SEL	1049	301	356	226	1932
TOTAL	1151	395	423	248	2217

MINIMUM ESTIMATED EXPECTED VALUE IS 31.88

STATISTIC	VALUE	D.F.	PROB.	STATISTIC	VALUE	D.F.	PROB.
PEARSON CHISQUARE	65.479	3	.0000	LIKELIHOOD-RATIO CHISQ.	60.165	3	.0000
PHI	.172						
CONTINGENCY COEF. C	.169			CRAMER'S V	.172		

Aval = available habitat frequency distribution
Sel = selected habitat frequency distribution
FS0-FS4 = substrate classes, defined in the Methods section

Formula used : $G^2 = 2 \quad f \ln(f/F)$
where : f is the 'observed' frequency
F is the 'expected' frequency

$$G^2 = 2 \left[1049 \ln(1049/102) + 301 \ln(301/94) + 356 \ln(356/67) + 226 \ln(226/22) \right]$$

$$G^2 = 60.2$$

APPENDIX C

Physical parameters for the Upstream Telephone Creek study site, recorded from fall 1983 through winter 1984.

Date (Mo./Day)	Transect Number	Cross-Sectional Area (m^2)	Wetted Perimeter (m)	Mean Depth (cm)	Average Velocity (m/s)	Top Width (m)	Total Width (m) >15 cm deep	Average Daily Flow (m^3/s)
9/23	1	0.13	1.65	8.28	0.23	1.57	0	0.03
10/6		0.14	1.80	8.91	0.21	1.57	0	0.03
10/17		0.13	1.80	8.39	0.31	1.55	0	0.04
10/31		0.12	1.77	7.74	0.33	1.55	0	0.04
12/17		0.12	1.68	8.22	0.42	1.46	0	0.05
3/10		0.08	1.65	5.71	0.25	1.40	0	0.02
5/10		0.09	1.65	6.43	0.11	1.40	0	0.01
9/23	2	0.23	1.71	16.91	0.13	1.36	0.79	0.03
10/6		0.26	1.92	17.81	0.12	1.46	0.83	0.03
10/17		0.26	1.86	17.81	0.15	1.46	0.89	0.04
10/31		0.24	1.80	16.78	0.17	1.43	0.83	0.04
1/6		0.23	1.80	15.75	0.09	1.46	0.93	0.02
3/10		0.20	1.77	13.70	0.10	1.46	0.87	0.02
5/9		0.20	1.77	13.70	0.05	1.46	0.75	0.01
9/23	3	0.55	2.56	26.57	0.05	2.07	1.82	0.03
10/6		0.59	2.56	27.83	0.05	2.12	1.89	0.03
10/17		0.57	2.56	26.57	0.07	2.13	1.78	0.04
10/31		0.56	2.56	26.29	0.07	2.13	1.89	0.04
1/6		0.52	2.38	26.26	0.04	1.98	1.89	0.02
3/10		0.47	2.35	23.74	0.04	1.98	1.85	0.02
5/8		0.51	2.38	25.76	0.02	1.98	1.86	0.01

APPENDIX C (continued)

Physical parameters for the Downstream Telephone Creek study site, recorded from fall 1983 through winter 1984.

Date (Mo./Day)	Transect Number	Cross-Sectional Area (m^2)	Wetted Perimeter (m)	Mean Depth (cm)	Average Velocity (m/s)	Top Width (m)	Total Width (m) > 15 cm deep	Average Daily Flow (m^3/s)
9/23	1	0.22	4.75	4.66	0.23	4.72	0	0.05
10/6		0.28	4.82	5.82	0.21	4.81	0	0.06
10/17		0.28	4.82	5.85	0.21	4.79	0	0.06
10/31		0.22	4.82	4.59	0.18	4.79	0	0.04
12/29		0.30	4.66	6.65	0.13	4.51	0	0.04
3/9		0.20	4.63	4.49	0.15	4.45	0	0.03
4/12		0.17	4.63	3.82	0.06	4.45	0	0.01
9/23	2	0.93	5.06	19.06	0.05	4.88	3.45	0.05
10/6		0.93	5.06	19.18	0.06	4.85	3.47	0.06
10/17		0.99	4.94	20.28	0.06	4.88	3.80	0.06
10/31		0.87	4.75	18.67	0.05	4.66	3.44	0.04
1/3		0.75	4.69	16.41	0.04	4.57	2.83	0.03
3/9		0.76	4.57	17.92	0.03	4.24	2.99	0.02
5/2		0.77	4.72	16.96	0.01	4.54	3.22	0.01
9/23	3	1.29	4.27	35.83	0.04	3.60	3.11	0.05
10/6		1.31	4.33	36.39	0.05	3.60	3.14	0.06
10/17		1.32	4.21	36.67	0.05	3.60	3.24	0.06
10/31		1.28	4.21	35.56	0.03	3.60	3.12	0.04
12/30		1.04	4.08	28.89	0.04	3.60	3.10	0.04
3/9		1.14	3.99	31.67	0.03	3.60	3.08	0.03
4/12		1.18	4.02	32.78	0.01	3.60	3.17	0.01

APPENDIX C (continued)

Physical parameters for the Upstream Nash Fork Creek study site, recorded from fall 1983 through winter 1984.

Date (Mo./Day)	Transect Number	Cross-Sectional Area (m^2)	Wetted Perimeter (m)	Mean Depth (cm)	Average Velocity (m/s)	Top Width (m)	Total Width (m) >15 cm deep	Average Daily Flow (m^3/s)
9/23	1	0.20	4.63	4.59	0.30	4.36	0	0.06
10/10		0.22	4.60	5.07	0.36	4.34	0	0.08
10/28		0.15	4.48	3.46	0.40	4.33	0	0.06
11/7		0.16	4.57	3.70	0.31	4.33	0	0.05
12/5		0.27	4.45	6.28	0.41	4.30	0	0.11
12/29		0.23	4.51	5.35	0.30	4.30	0	0.07
3/5		0.20	4.33	4.72	0.10	4.24	0	0.02
4/19		0.23	4.39	5.42	0.04	4.24	0	0.01
9/23	2	0.33	4.18	8.53	0.18	3.87	1.01	0.06
10/10		0.39	4.15	10.00	0.21	3.90	1.10	0.08
10/28		0.34	4.08	8.79	0.18	3.87	0.80	0.06
11/7		0.32	4.00	8.33	0.16	3.84	0.65	0.05
12/5		0.43	4.15	11.38	0.26	3.78	0.87	0.11
12/30		0.50	4.08	13.23	0.14	3.78	1.76	0.07
3/5		0.40	3.96	10.50	0.05	3.81	0.70	0.02
4/19		0.44	4.08	11.55	0.02	3.81	0.97	0.01
9/23	3	0.70	2.59	30.57	0.09	2.29	1.77	0.06
10/10		0.45	2.56	19.91	0.18	2.26	1.69	0.08
10/28		0.41	2.47	18.72	0.15	2.19	1.63	0.06
11/7		0.41	2.38	18.72	0.12	2.19	1.62	0.05
12/5		0.46	2.41	22.22	0.24	2.07	1.62	0.11
12/30		0.50	2.62	22.12	0.14	2.26	1.85	0.07
3/5		0.51	2.60	22.87	0.04	2.23	1.94	0.02
4/19		0.46	2.41	21.90	0.02	2.10	1.69	0.01

APPENDIX C (continued)

Physical parameters for the Downstream Nash Fork Creek study site, recorded from fall 1983 through winter 1984.

Date (Mo./Day)	Transect Number	Cross-Sectional Area (m^2)	Wetted Perimeter (m)	Mean Depth (cm)	Average Velocity (m/s)	Top Width (m)	Total Width (m) >15 cm deep	Average Daily Flow (m^3/s)
9/23	1	0.39	4.94	8.14	0.31	4.79	0	0.12
10/10		0.50	5.12	9.94	0.32	5.03	0.23	0.16
10/28		0.37	5.00	7.63	0.32	4.85	0	0.12
11/7		0.32	4.75	6.82	0.38	4.69	0	0.12
12/5		0.96	5.67	17.20	0.21	5.58	4.22	0.20
1/12		0.43	4.88	8.92	0.19	4.82	0	0.08
3/6		0.42	4.57	9.25	0.07	4.54	0	0.03
4/10		0.31	4.33	7.47	0.10	4.15	0	0.03
9/23	2	0.33	4.08	8.59	0.36	3.84	0	0.12
10/10		0.43	4.30	10.86	0.37	3.96	1.00	0.16
10/28		0.33	3.96	8.40	0.36	3.93	0.15	0.12
11/7		0.25	3.87	6.67	0.48	3.75	0	0.12
12/5		0.90	4.69	19.96	0.22	4.51	3.10	0.20
1/12		0.23	3.90	5.94	0.35	3.87	0	0.08
3/6		0.24	2.93	8.28	0.13	2.90	0	0.03
4/10		0.21	2.77	7.84	0.14	2.68	0	0.03
9/23	3	1.49	5.15	30.28	0.08	4.92	3.61	0.12
10/10		1.58	5.24	31.35	0.10	5.04	3.86	0.16
10/28		1.50	5.24	30.55	0.08	4.91	3.65	0.12
11/7		1.42	5.03	29.89	0.08	4.75	3.49	0.12
12/5		2.02	5.39	40.64	0.10	4.97	4.39	0.20
1/12		1.46	4.85	30.74	0.05	4.75	3.48	0.08
3/6		1.16	4.42	26.79	0.03	4.33	3.26	0.03
4/10		1.05	4.33	25.74	0.03	4.08	3.08	0.03

APPENDIX D

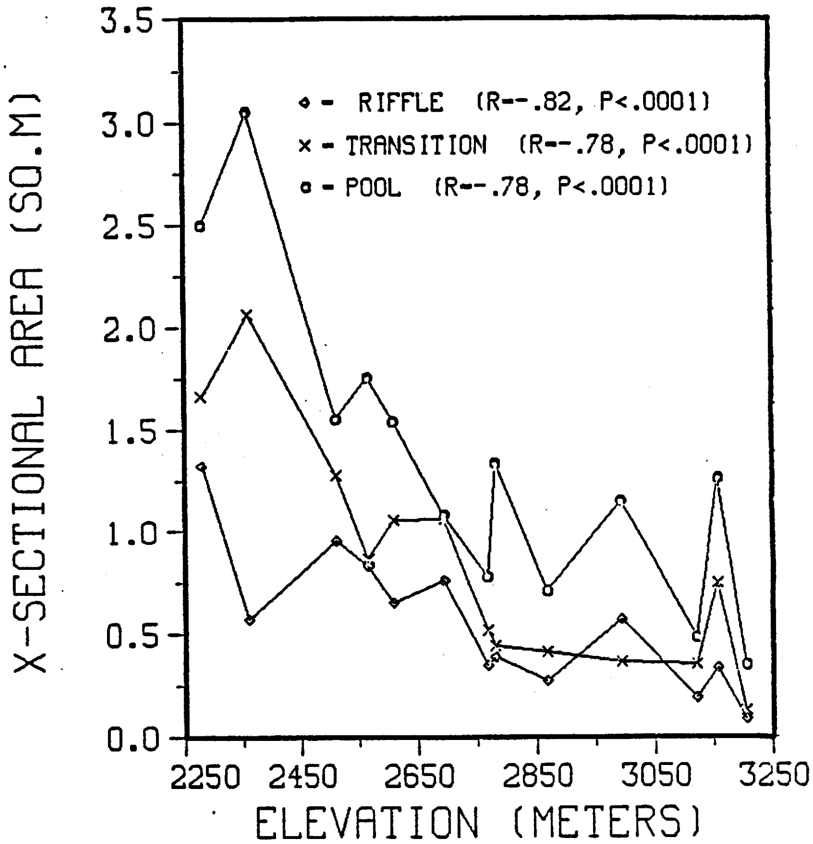
Summary of ice formation data for the riffle (Tr. 1), transition (Tr. 2), and pool (Tr. 3) transects, at the four study sites, during winter 1983-84, Snowy Range, Medicine Bow National Forest.

		Study Site					
		Upstream Telephone Creek			Downstream Telephone Creek		
Sampling Occasion (Date Range-Mo./Day)	Transect Number	Maximum ice depth (cm)	Mean ice depth (cm)	% transect covered	Maximum ice depth (cm)	Mean ice depth (cm)	% transect covered
1 (9/23)	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	0	0	0	0
2 (10/6-10/10)	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	0	0	0	0
3 (10/17-10/28)	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	0	9.1	3.0	89
4 (10/31-11/7)	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	0	0.6	0	3
5 (12/5-1/3)	1	0	0	0	0	0	0
	2	0	0	0	6.1	0.9	27
	3	0	0	0	0	0	0
6 (12/29-3/10)	1	0	0	0	4.6	0.3	5
	2	0	0	0	0	0	0
	3	0	0	0	4.6	0.3	8
7 (3/6-5/10)	1	0	0	0	4.6	0.3	5
	2	0	0	0	4.6	0.3	7
	3	0	0	0	4.6	0.3	8
8 (4/10-4/19)	1						
	2						
	3						

APPENDIX D (continued)
Summary of ice formation data for the riffle (Tr. 1), transition (Tr. 2), and pool (Tr. 3) transects, at the four study sites, during winter 1983-84, Snowy Range, Medicine Bow National Forest.

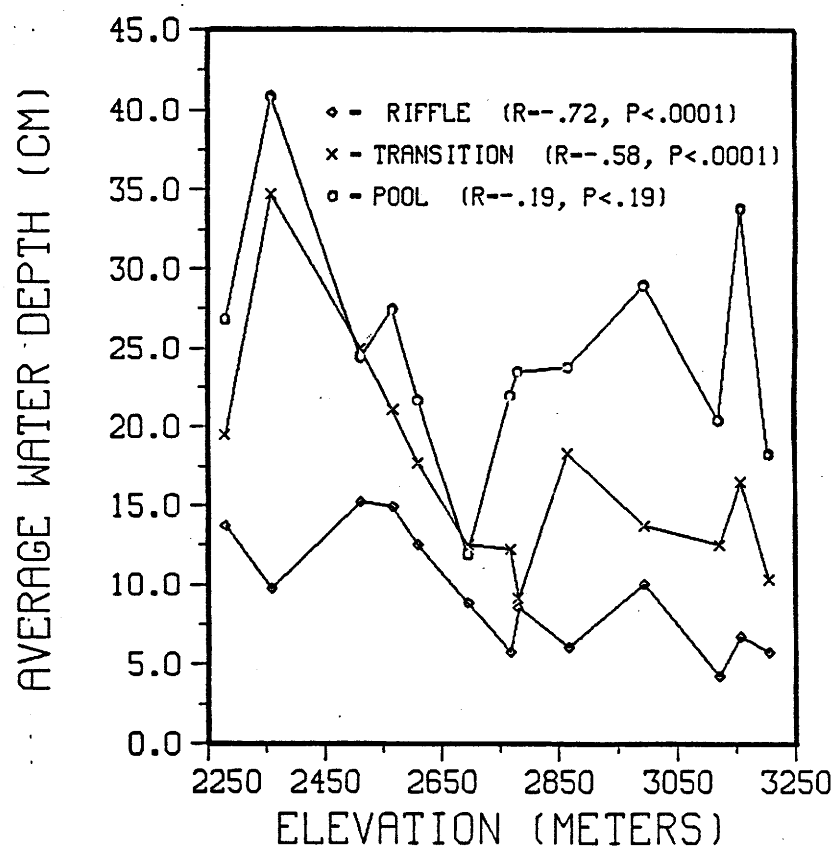
		Study Site					
		Upstream Nash Fork Creek			Downstream Nash Fork Creek		
Sampling Occasion (Date Range Mo./Day)	Transect Number	Maximum ice depth (cm)	Mean ice depth (cm)	% transect covered	Maximum ice depth (cm)	Mean ice depth (cm)	% transect covered
1	1	0	0	0	0	0	0
(9/23)	2	0	0	0	0	0	0
	3	0	0	0	0	0	0
2	1	0	0	0	0	0	0
(10/6-	2	0	0	0	0	0	0
10/10)	3	0	0	0	0	0	0
3	1	0	0	0	0	0	0
(10/17-	2	0	0	0	0	0	0
10/28)	3	0	0	0	0	0	0
4	1	0	0	0	0	0	0
(10/31-	2	0	0	0	0	0	0
11/7)	3	0	0	0	0	0	0
5	1	0	0	0	18.3	8.5	64
(12/5-	2	15.2	2.7	19	17.7	7.0	44
1/3)	3	16.2	3.7	53	24.4	15.8	94
6	1	0	0	0	12.2	4.3	46
(12/29-	2	0	0	0	4.6	1.5	28
3/10)	3	3.0	0.3	16	13.7	6.7	78
7	1	0	0	0	11.6	2.4	47
(3/6-	2	0	0	0	5.5	0.6	12
5/10)	3	4.6	0.3	15	15.2	7.3	92
8	1	0	0	0	12.2	3.4	25
(4/10-	2	0	0	0	0	0	0
4/19)	3	0	0	0	12.2	4.9	31

APPENDIX E



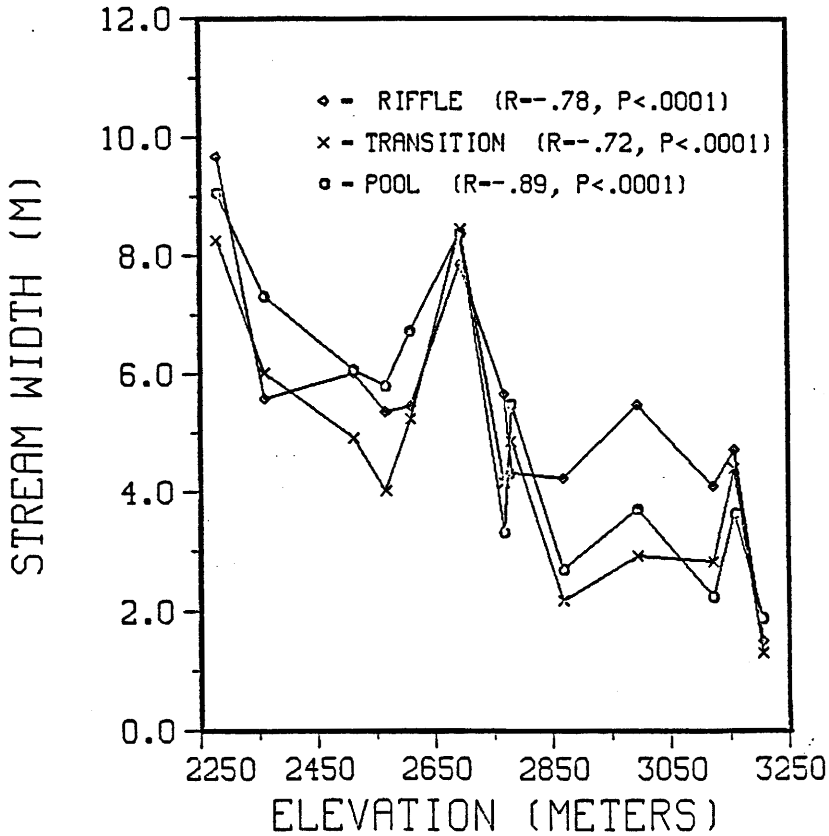
Plot of cross-sectional area with elevation for the 13 study sites sampled in January 1985. Correlation coefficients and associated probabilities for the riffle, transition, and pool transects are from a regression of cross-sectional area on elevation.

APPENDIX E (continued)



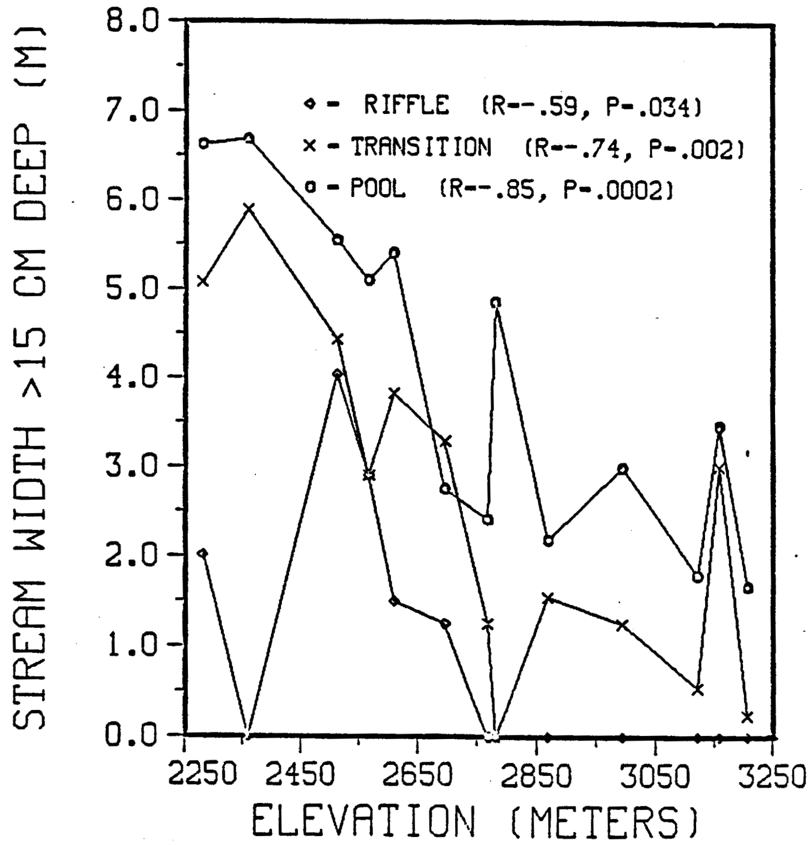
Plot of mean water depth with elevation for the 13 study sites sampled in January 1985. Correlation coefficients and associated probabilities are from a regression of mean water depth on elevation.

APPENDIX E (continued)



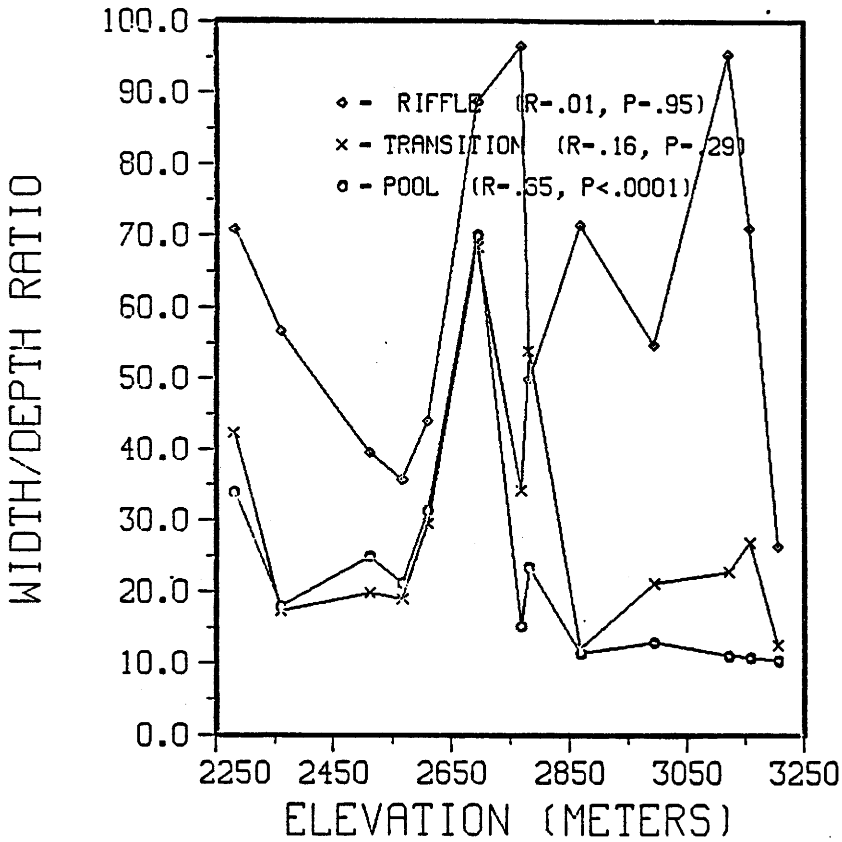
Plot of stream width with elevation for the 13 study sites sampled in January 1985. Correlation coefficients and associated probabilities are from a regression of stream width on elevation.

APPENDIX E (continued)



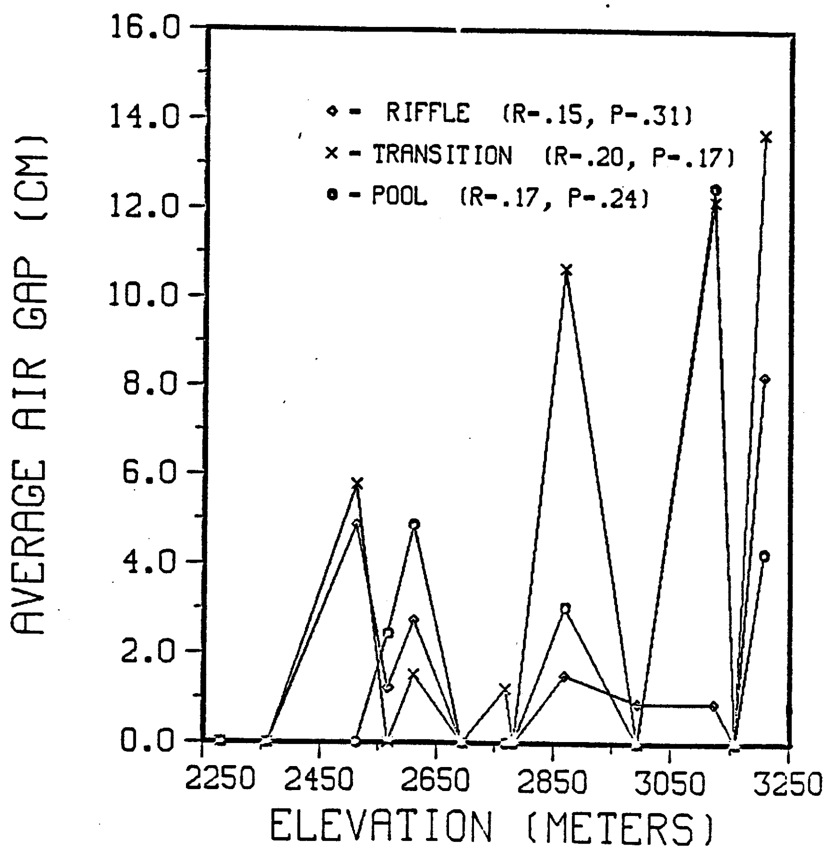
Plot of total stream width with a water depth greater than 15 centimeters deep on elevation for the 13 study sites sampled in January 1985. Correlation coefficients and associated probabilities are from a regression of the variable on elevation.

APPENDIX E (continued)



Plot of the width/depth ratio with elevation for the 13 study sites sampled in January 1985. Correlation coefficients and associated probabilities are from a regression of the width/depth ratio on elevation.

APPENDIX E (continued)



Plot of mean air gap with elevation for the 13 study sites sampled in January 1985. Correlation coefficients and associated probabilities are from a regression of mean air gap on elevation.

APPENDIX F

Cross-sectional area (square meters) of water and ice and relative percentages of water and ice tn the total cross-section, for the 13 study sites monitored during January 1985.

Site	Elevation (m)	Transect* Number	Cross-sectional area of water	% of total cross-section	Cross-sectional area of ice	% of total cross-section
Upstream	3206	1	0.09	100	0	0
Telephone		2	0.13	100	0	0
Creek		3	0.35	100	0	0
Downstream	3158	1	0.34	100	0	0
Telephone		2	0.75	100	0	0
Creek		3	1.26	100	0	0
Upstream	3121	1	0.19	100	0	0
Nash Fork		2	0.35	83	0.07	17
Creek		3	0.48	87	0.07	13
Downstream	2993	1	0.57	53	0.50	47
Nash Fork		2	0.37	73	0.14	27
Creek		3	1.15	72	0.44	28
Site 5	2868	1	0.27	82	0.06	18
		2	0.42	98	0.01	2
		3	0.71	70	0.31	30
Site 6	2780	1	0.39	46	0.46	54
		2	0.44	57	0.33	43
		3	1.34	68	0.62	32
Site 7	2767	1	0.35	46	0.41	54
		2	0.52	57	0.40	43
		3	0.78	58	0.57	42

APPENDIX F (continued)

Cross-sectional area (square meters) of water and ice and relative percentages of water and ice to the total cross-section for the 13 study sites monitored during January 1985.

Site	Elevation (m)	Transect* Number	Cross-sectional area of water	% of total cross-section	Cross-sectional area of ice	% of total cross-section
Site 8	2694	1	0.77	48	0.82	52
		2	1.06	60	0.70	40
		3	1.08	64	0.62	36
Site 9	2609	1	0.65	43	0.86	57
		2	1.06	50	1.08	50
		3	1.54	49	1.60	51
Site 10	2566	1	0.83	33	1.72	67
		2	0.87	55	0.72	45
		3	1.75	52	1.61	48
Site 11	2511	1	0.96	33	1.97	67
		2	1.28	56	1.02	44
		3	1.55	51	1.46	49
Site 12	2359	1	0.57	89	0.07	11
		2	2.06	86	0.33	14
		3	3.05	87	0.47	13
Site 13	2280	1	1.32	35	2.40	65
		2	1.66	40	2.47	60
		3	2.50	42	3.49	58

*Transect 1 - riffle ; Transect 2 - transition ; Transect 3 - pool

APPENDIX G

Summary of values used by WWRC Model equations, generated predicted % ice-excluded habitat, and observed % ice-excluded habitat for nine study sites monitored in January 1985.

Site	Transect* Number	S	$\bar{D}$ (ft.)	$\bar{V}$ (fps)	Days from winter solstice	Predicted % habitat excluded	Observed % habitat excluded
Upstream	1	1745.75	0.25	1.07	16	35.0	0
Telephone	2		0.56	0.52		75.8	0
Creek	3		0.87	0.22		201.1	0
Downstream	1	1580.50	0.15	0.69	17	64.3	0
Telephone	2		0.59	0.17		89.6	0
Creek	3		1.17	0.12		199.0	0
Upstream	1	1027.23	0.12	1.05	18	80.5	0
Nash Fork	2		0.28	0.51		72.1	0
Creek	3		0.61	0.41		115.4	0
Downstream	1	1372.78	0.22	1.27	17	48.2	0
Nash Fork	2		0.22	1.64		15.4	0
Creek	3		0.98	0.29		169.0	0
Site 6	1	840.00	0.41	0.65	18	31.4	0
	2		0.50	0.62		40.1	0
	3		0.97	0.31		115.5	0
Site 7	1	856.00	0.46	1.02	19	17.7	0
	2		0.40	0.80		36.5	0
	3		0.82	0.43		107.9	0
Site 11	1	816.00	0.50	1.37	24	8.1	0
	2		0.85	0.96		-16.2	0
	3		0.73	0.87		92.7	0
Site 12	1	895.94	0.37	2.33	24	21.6	0
	2		1.12	0.86		-32.8	0
	3		1.25	0.66		117.2	0
Site 13	1	706.04	0.56	1.61	19	-4.8	84
	2		1.34	1.29		-79.4	64
	3		1.34	0.90		119.1	64

* Transect 1 - riffle ; Transect 2 - transition ; Transect 3 - pool

APPENDIX H

Summary of brook trout movements from October 20, 1983 to March 21, 1984, as determined by telemetry.

Fish Number	Location	Distance (m) Moved between Home Areas, from release point or previous Home Area	Direction Moved, Upstream (+) or Downstream (-)	Number of Locations at a Home Area	Length (m, thalweg) of Home Area	Net Distance (m) Moved and Direction (upstream + or downstream -)
1	Telephone Creek	24	-	3	1	
		20	-	1		
		15	-	1		
		5	-	1		
		51	-	1		
		49	-	13	10	
		41	-	8	18 BP*	206(-)
2	Telephone Creek	0		5	3	
		61	-	25	5	
		15	-	2	2	76(-)
3	Telephone Creek	12	-	21	2	
		18	-	4	4	
		47	-	2	2	
		71	-	10	4	148(-)
4	Telephone Creek	218	+	1		
		218	-	33	6	0
6	Nash Fork Creek	26	+	14	4	
		6	-	18	5	20(+)
7	Nash Fork Creek	15	+	1		
		15	-	2	4	
		17	-	1		
		43	-	1		
		18	-	29	17 BP*	93(-)
8	Nash Fork Creek	62	-	13	12 BP*	
		62	+	1		
		26	-	12	24 BP*	
		32	-	4	1	58(-)

BP* : Home Area within beaver pond

APPENDIX I

Summary of brook trout movements in Nash Fork Creek from October 23, 1984 to March 1, 1985, as determined by telemetry.

Fish Number	Distance (m) Moved Between Home Areas, from release point or previous Home Area	Direction Moved, Upstream (+) or Downstream (-)	Number of Locations at a Home Area	Length (m, thalweg) of Home Area	Net Distance (m) Moved and Direction (upstream + or downstream -)
9	348	-	1 BP*		
	10	-	8 BP*	6	
	15	+	1 BP*		342(-)
10	12	-	6		
	15	-	1		
	6	-	18	6	33(-)
11	4	-	4	3	
	17	-	1		
	15	-	15	3	36(-)
12	110	-	1		
	69	-	1		
	184	-	5 BP*	9	
	12	+	3 BP*	6	
	3	-	1 BP*		
	12	-	11 BP*	9	
	40	+	1 BP*		326(-)
13	107	-	1		
	32	-	1 BP*		
	21	-	1 BP*		
	6	+	15 BP*	6	
	6	+	1 BP*		
	5	-	1 BP*		
	9	+	1 BP*		143(-)

BP* : Home Area within beaver pond

APPENDIX I (continued)
Summary of brook trout movements in Nash Fork Creek from October 23, 1984 to March 1, 1985, as determined by telemetry.

Fish Number	Distance (m) Moved Between Home Areas, from release point or previous Home Area	Direction Moved, Upstream (+) or Downstream (-)	Number of Locations at a Home Area	Length (m,thalweg) of Home Area	Net Distance (m) Moved and Direction (upstream + or downstream -)
14	162	-	3 BP*	9	
	6	+	5 BP*	6	
	3	-	2 BP*	3	
	7	+	2 BP*	3	
	17	-	2 BP*	3	
	12	+	7 BP*	3	
	20	+	1 BP*		136(-)
15	151	-	2 BP*	3	
	3	+	2 BP*	3	
	25	+	4 BP*	3	
	1	+	2 BP*	3	
	2	-	1 BP*		
	28	-	2 BP*	3	
	3	-	5 BP*	3	
	37	+	1 BP*		
	6	-	1 BP*		
	31	-	5 BP*	2	54(-)
16	0		1		
	146	-	4 BP*	6	
	3	-	2 BP*	3	
	18	+	3 BP*	3	
	6	-	2 BP*	6	137(-)

BP* : Home Area within beaver pond

APPENDIX J

Strauss' Electivity Index for water velocity index selected during winter 1983-84, for each fish and for all fish combined.

Velocity Class (cm/second)

Fish Number	0.0-15.2	15.2-30.4	30.5-45.7	45.8-60.9	61.0-76.2	76.3-91.4	91.5-106.7	106.8-121.9	122.0-137.2	137.3-152.4	152.5 +
1	0.34	0.03	-0.18	0.05	-0.10	-0.07	-0.02				
2	0.05	-0.26	-0.18	-0.12	0.11	0.24	0.11				
3	-0.06	-0.14	-0.01	-0.06	-0.10	0.05	0.07	0.25			
4	0.15	0.18	-0.14	0.09	-0.10	-0.18					
6	0.26	0.04	-0.06	-0.10		-0.05	-0.06				-0.04
7	0.26	0.01	-0.12	-0.01	-0.07		-0.05			-0.03	
8	0.36	-0.06	-0.12	-0.03	-0.08		-0.05			-0.03	
All	0.21	-0.02	-0.12	-0.03	-0.03	-0.02	0.00	0.02		-0.01	-0.01

APPENDIX J (continued)

Strauss' Electivity Index for water depths selected during winter 1983-84, for each fish and for all fish combined.

Depth Class (cm)

Fish Number	0.0-15.2	15.2-30.4	30.5-45.7	45.8-60.9	61.0-76.2	76.3-91.4	91.5-106.7	106.8-121.9	122.0-137.2
1	0.02	-0.14	0.07	0.05	-0.00	-0.00			
2	0.08	0.13	-0.08	-0.12	-0.01	-0.00			
3	-0.07	0.14	-0.04	-0.02	-0.00				
4	-0.05	-0.14	0.03	0.15	0.01				
6	-0.27	0.18	0.08	0.01					
7	-0.05	0.01	-0.04	-0.06	0.04	0.07	0.03	-0.01	-0.00
8	-0.06	-0.01	-0.04	-0.03	0.04	0.06	0.02	0.01	-0.00
All	-0.07	0.00	0.01	0.02	0.02	0.01	0.01	0.00	-0.00

APPENDIX J (continued)

Strauss' Electivity Index for substrate class selected during winter 1983-84, for each fish and for all fish combined.

Substrate Class

Fish Number	sand/silt	gravel	rubble	boulder
1	0.19	-0.17	-0.05	0.04
2	-0.14	0.30	-0.12	-0.05
3	-0.10	0.01	0.12	-0.03
4	0.01	0.18	-0.06	-0.20
6	-0.08	-0.14	0.14	0.08
7	0.22	-0.11	-0.10	-0.01
8	-0.16	-0.05	0.00	-0.01
All	0.09	-0.00	-0.04	-0.05

sand/silt : 4.7 mm and less
gravel : 4.8 mm to 76 mm
rubble : 76.1 mm to 304 mm
boulder : 305 mm and more

APPENDIX K

Strauss' Electivity Index for water velocity index selected during winter 1984-85, for each fish and for all fish combined.

Velocity Class (cm/second)

Fish Number	0.0-15.2	15.3-30.4	30.5-45.7	45.8-60.9	61.0-76.2	76.3-91.4	91.5-106.7	106.8-121.9	122.0-137.2	137.3-152.4	152.5 +
9	0.67										
10	-0.33	0.26	0.35	-0.11	-0.03						
11	-0.33	0.15	0.01	0.13	-0.07	-0.05	-0.04	0.22			
12	0.64	-0.18	-0.13	-0.12			-0.03				
13	0.67					-0.06					
14	0.67										
15	0.67										
16	0.65		-0.13								
All	0.53	-0.14	-0.10	-0.11	-0.07	-0.07	-0.04	-0.02			

APPENDIX K (continued)

Strauss' Electivity Index for water depths selected during winter 1984-85, for each fish and for all fish combined.

Depth Class (cm)

Fish Number	0.0-15.2	15.3-30.4	30.5-45.7	45.8-60.9	61.0-76.2	76.3-91.4	91.5-106.7	106.8-121.9	122.0-137.2
9	-0.36	-0.17	0.08	0.10	0.25	0.09	0.01	0.01	
10	0.11	0.18	0.15	-0.06	-0.04	-0.03	-0.01	-0.01	
11	0.16	0.01	-0.03						
12	-0.35	-0.15	0.09	0.12	0.19	0.08	0.02	0.01	
13	-0.37	-0.13	0.13	0.11	0.15	0.12	-0.00	0.00	
14	-0.38	-0.11	0.11	0.14	0.10	0.10	0.03	0.02	
15	-0.36	-0.17	0.11	0.12	0.15	0.10	0.03	0.03	
16	-0.38	-0.10	0.13	0.12	0.09	0.12	0.03	0.01	
All	-0.30	-0.11	0.08	0.10	0.12	0.08	0.02	0.01	

APPENDIX K (continued)

Strauss' Electivity Index for substrate class selected during winter 1984-85, for each fish and for all fish combined.

Substrate Class

Fish Number	sand/silt	gravel	rubble	boulder
9	0.71	-0.15	-0.44	-0.12
10	-0.19	0.03	0.22	0.00
11	-0.23	0.08	0.01	0.14
12	0.67	-0.14	-0.42	-0.12
13	0.70	-0.15	-0.44	-0.12
14	0.70	-0.14	-0.44	-0.12
15	0.60	-0.09	-0.40	-0.12
16	0.70	-0.15	-0.43	-0.12
All	0.56	-0.11	-0.36	-0.09

sand/silt : 4.7 mm and less
gravel : 4.8 mm to 76 mm
rubble : 76.1 mm to 304 mm
boulder : 305 mm and more

APPENDIX L

Results from discriminant analysis (SPSS) using width, depth, velocity, and substrate as variables. Group 1 (available habitat), n=134; Group 2 (selected habitat), n=138.

Pooled within-groups correlations between the canonical discriminant functions and discriminating variables. Variables are ordered by the function with the largest correlations and the magnitude of that correlation.

	Function 1
Width	0.98399
Depth	0.83712
Substrate	-0.79112
Velocity	-0.68187

Canonical discriminant functions evaluated at group means (group centroids)

Group	Function 1
1	-0.71181
2	0.69118

Classification Results :

Actual Group	No. of Cases	Predicted Group Membership 1	Predicted Group Membership 2
Group 1	134	117 87.3%	17 12.7%
Group 2	138	42 30.4%	96 69.6%
Ungrouped Cases	1136	1013 89.2%	123 10.8%

Percent of grouped cases correctly classified 78.31

APPENDIX L (continued)

Results from discriminant analysis (SPSS) using depth and velocity as variables. Group 1 (available habitat), n=134; Group 2 (selected habitat), n=136.

Pooled within-groups correlations between the canonical discriminant functions and discriminating variables. Variables are ordered by the function with the largest correlations and the magnitude of that correlation.

	Function 1
Depth	0.97998
Velocity	-0.76392

Canonical discriminant functions evaluated at group means (group centroids)

Group	Function 1
1	-0.56174
2	0.55348

Classification Results :

Actual Group	No. of Cases	Predicted Group Membership 1	Predicted Group Membership 2
Group 1	134	103 76.9%	31 23.1%
Group 2	136	43 31.6%	93 68.4%
Ungrouped Cases	1136	628 55.3%	508 44.7%

Percent of grouped cases correctly classified 72.59