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The Elk River Basin drains 93 sq mi of steep forested terrain on the west side of the Klamath Mountains in Southwest Oregon. This river and its tributaries support a diverse and abundant population of anadromous fish; a hatchery located at river mile 13 (km 21) supplements these native populations. Clear weather in combination with dry summers and low streamflow produce warm water temperatures. Historical data indicate that summer stream temperatures as high as 76°F (24.4°C) have occurred in the mainstem of the Elk River.

This study was undertaken to evaluate summer stream temperatures and to what extent they were affected by natural factors and land use. In selected tributaries and along the mainstem of the Elk River, measurements were made on canopy cover, stream surface width, and thalweg depth during the summers of 1984 and 1985. Recording thermographs and maximum/minimum thermometers were used to determine the overall temperature pattern of the basin.

In general, maximum stream temperatures appear to be declining since 1970, following a period of increased landslide activity in the basin. The trend of decreasing maximum temperatures was not associated with changes in summer streamflow or summer precipitation patterns, suggesting that a recovery of streamside vegetation and/or change in channel morphology is proceeding within the basin.

Tributaries with relatively large width / depth ratios (exceeding 14 or more), generally exhibited large diurnal fluctuations in temperature indicating solar heating was occurring. For drainages of similar size, large diurnal temperature fluctuations were associated with large surface area to volume ratios. Tributaries found to be especially low in maximum temperatures generally flow subsurface as a result of channel aggradation. In the 1984 and 1985 field seasons, maximum stream temperatures in the tributaries never exceeded the maximum temperature of 69°F (20.6°C) found in the mainstem. The upper reaches of the mainstem, which is wide and aggraded, was the portion of the basin found to have the highest maximum stream temperatures.

Five pools were sampled to determine vertical profiles of temperature and dissolved oxygen. Temperatures and dissolved oxygen concentrations did not vary with depth.

SUMMER STREAM TEMPERATURES AND CHANNEL CHARACTERISTICS OF A SOUTHWESTERN OREGON COASTAL STREAM

by

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INTRODUCTION

Problem Statement

With the increasing demands on forest lands for timber production, fish habitat, and water quality (among other values), additional information is needed by land managers to evaluate potential impacts upon watersheds and stream systems. Several studies have established that removal of riparian vegetation, which provides shade to a stream, causes a significant increase in maximum water temperature (Levno and Rothacher, 1967; Brown, 1969; Meehan, 1970; Brown, et al., 1971). Excessively high water temperatures are often a concern due to potential effects on the biological communities of the stream.

Fishery resources are an important component of the Pacific Northwest's economy, hence, managers need to maintain high quality habitats. Salmonids are cold water fish known to prefer a narrow temperature range and having definite temperature requirements for rearing (Reiser and Bjornn, 1979). Brett (1952), found that young salmonids avoid temperatures above 59°F (15°C). Cold water fish have been noted to cease growth at temperatures above 68.5°F (20.3° C), and temperatures of 75.2 to 77°F (24 to 25°C) sustained for more than a few days are lethal (Brett, 1952; Everest and Harr, 1982).

Located in the Siskiyou National Forest, the Elk River drains

93 sq mi on the west side of the Klamath Mountains in the Coast Range. The Elk River and tributaries support an abundant and diverse population of fish including fall chinook salmon, coho salmon, winter steelhead trout, and sea-run cutthroat. To supplement these native populations, the Elk River fish hatchery was constructed at river mile 13 (km 20.9) and has maintained a rearing habitat for chinook salmon and steelhead trout since it began operation in 1969. A constant source of water is required for circulation through the holding ponds of the hatchery; direct diversion of water from the Elk River satisfies this demand.

Hot, dry summers combined with low stream flows result in maximum daily stream temperatures averaging 70°F (21°C), with annual peaks as high as 76°F (24.4°C). Concern for high water temperatures of the Elk River originated in the 1970's when temperatures exceeding 70°F (21°C) were noted to adversely affect the vitality of the hatchery fish populations (hatchery personnel, personal comm.). Everest and Harr (1982), note that the summer represents a critical time when the effects of increased stream temperature are most virulent for juvenile fish.

Logging operations in the Elk River basin began in the early 1950's. More recently, Siskiyou National Forest managers have become increasingly concerned as to the relations among landslides (i.e., aggradation and scour of the channel), water temperature, and fish habitat.

Study Objectives

The objectives of this study were to (1) describe the over all temperature pattern of the Elk River and tributaries during midsummer, and explain the factors influencing this pattern, (2) to identify portions of the basin with elevated temperatures and factors contributing to these increases, (3) to determine if pools provide a "thermal refuge" in streams with increased temperatures, and (4) to determine if "pulses" of heated water can be identified travelling downstream in the mainstem of the Elk River. That is, water may be heated along an exposed reach at the time of maximum incoming solar radiation. This water may then travel as a parcel or "pulse" of warm water, arriving downstream at a time late in the evening or night when heating from solar radiation is not possible. Therefore, it is possible that relatively high night-time temperatures may appear at a critical downstream site even after the primary source of heat, the sun, is absent.

LITERATURE REVIEW

Streamside Vegetation

Small forested streams shaded by vegetation generally show little daily (diurnal) or seasonal temperature fluctuations. However, when exposed to direct radiation, large fluctuations can occur (Brown, et al., 1971; Swift and Messer, 1971). A forest canopy tends to limit the nighttime radiational cooling, while also limiting daytime heating, thus minimizing the daily difference between maximum and minimum temperature. When the canopy is removed, the temperature range may be increased due to the effects of both nighttime cooling and daytime heating (Swift and Messer, 1971).

Brown and Krygier (1970), indicate that direct solar radiation striking the stream surface is the principle factor which governs temperature change. Large temperature increases have been observed where the stream is completely exposed to the sun. In one study, Brown and Krygier (1970), estimated that the maximum rate of net incoming solar radiation added to an exposed stream was more than 10 times that in a shaded reach.

In the Oregon Coast Range, investigation of 3 small watersheds by Brown and Krygier (1970), revealed average monthly maximum temperatures to have increased by 14°F (8°C) and annual maximums increased from 57°F to 85°F (14 to 29°C) the year following clearcut logging. Temperatures as high as 83°F (28.3°C) were recorded just downstream of a clearcut on the Steamboat drainage (Brown, et al., 1971). Similarly, Ringler and Hall (1975) found that mean temperature and diurnal fluctuations of water temperature increased as the forest canopy was removed. This increase was found to be proportional to the extent of logging (i.e., removal of streamside vegetation). As streamside vegetation is reestablished, any increases in water temperatures will decrease (Brown and Krygier, 1970).

Where vegetation is left along a stream, studies indicate little or no change in maximum stream temperature will result following logging of adjacent slopes. Several authors found that where patch cutting is employed, or buffer strips are left, no change in maximum stream temperature occurs (Levno and Rothacher, 1967; Brown and Krygier, 1970; Brazier and Brown, 1973). Only minor changes in stream temperature ($< 1^{\circ}F$) were produced in studies at Coweeta and Fernow Experimental Forests in the southern Appalachians, where the riparian forest was selectively thinned instead of clearcut (Swift and Messer, 1971).

It has been suggested that clearcutting in alternate blocks along a stream allows for the cooler, shaded environment to reduce the high water temperatures incurred while flowing through unshaded reaches. However, Brown, et al. (1971), measured no decrease in water temperature after the heated water flowed through a 600 ft (183 m) shaded reach on Cedar Creek of the Steamboat drainage. They concluded that large temperature reductions measured on other creeks within the same drainage were generally due to cold ground water entering the reach.

In another study, Brown (1967), measured a $8^{\circ}F$ ($4.5^{\circ}C$) temperature drop after water had flowed through 700 ft (213 m) of undisturbed canopy. This was attributed to cooler tributary waters mixing with the mainstem to produce lower temperatures, in conjunction with minimal heating of the mainstem due to shading by the canopy.

Complete exposure of the stream also results where floods or debris torrents scour the stream. Brown (1967), found that stream temperature increased by as much as 16°F (9°C) after flowing 1300 ft (396 m) through a completely exposed section of a clearcut. The exposed reach was a result of a large mud slide that had scoured the stream to bedrock, removing all channel debris and much of the alluvium. Significant increases in maximum stream temperatures were observed after a stream in the Cascades had been scoured by the 1964 flood, removing streamside vegetation (Levno and Rothacher, 1967).

Channel Morphology

Morphological changes of a stream can result from a wide variety of factors, although increased sedimentation may be one of the most important. Road construction, logging, and slash burning have been noted in several studies to significantly increase sediment yields (Beschta, 1978; Lyons and Beschta, 1983). These increases may bring about changes in channel width, water depth, and water velocity, which alter the solar radiation loading per unit mass of water in a stream. Aggradation occurs at a pool or riffle if rates of inflowing bed material are greater than the removal capacity of the stream (Jackson and Beschta, 1982).

Although Leopold, et al. (1964) have indicated that the outward characteristics of a river channel are not usually diagnostic of whether a channel is in the process of aggradation or degradation, Lisle (1981; 1982) has more recently found that channel widening is a consistent index of increased bedload transport. For example, Lisle observed changes in gaging sections after the 1964 flood from pool forms before aggradation, to more riffle-like forms with wider, flat cross-sections. Schumm, (1960), also noted that aggrading channels have higher width/depth ratios than degrading channels. Lyons and Beschta (1983), observed channel widening of the Middle Fork of the Willamette River as a result of the 1964 flood. Although some widening would have occurred naturally, accelerated sediment input from land use activities may have magnified the channel response. Stream widening from aggradation on the Kowai River in New Zealand also occurred during a major storm event in 1951 (Beschta, 1983a,b); channel width increased the most where aggradation was common. Again, land use appeared to have accelerated hillslope erosion during the 1951 storm. A formula developed by Schumm (1971), indicates that an increase in sediment load will influence channel width and related characteristics:

$$Qs = \frac{b, \lambda, s}{d, p}$$

where Qs = sediment discharge
b = width of channel
λ = channel wavelength
s = channel gradient
d = depth of stream
p = sinuosity of stream

Brown (1969) presented a simplified equation that predicts the increase in maximum daytime temperatures following the removal of forest vegetation:

$$\Delta T = \frac{\Sigma H \cdot A \cdot k}{Q}$$

where ΔT = change in temperature
ΣH = net rate of heat per unit surface area added to the stream
A = total stream surface area over which heat is added
Q = stream discharge
k = coefficient which converts heat loading per unit mass of water to change in temperature expressed in $^{\circ}F$ or $^{\circ}C$

In order that Brown's (1969), temperature prediction model may be used accurately, two other variables must be included. In his improved model, Brown (1972), noted that streambed composition can influence heat transfer, and where bedrock is the principal substrate, 15 - 20% of the net incoming radiation may be absorbed by the bedrock. Unless this loss is accounted for, an overestimate of the temperature increase results. Also, the flow of water within large pools is found to be rather confined. Therefore, only a limited portion of the water in a pool is active in the transfer of heated water downstream. Because of this, using average stream widths causes an overestimate of stream temperature. When these two variables are taken into account, the equation apparently can predict within 2 to 3°F (1 to 1.7°C) the maximum temperature change expected when a reach is fully exposed to solar radiation.

Manipulation of Brown's (1969) temperature prediction equation illustrates that changes in stream temperature are inversely related to channel depth and velocity. Since stream surface area (A) = length (L) times width (W) of an exposed reach, and discharge (Q) = depth (D) times width (W) times velocity (V), Brown's equation becomes:

$$\Delta T = \frac{\Sigma H \cdot L \cdot W \cdot k}{D \cdot W \cdot V} = \frac{\Sigma H \cdot L \cdot k}{D \cdot V}$$

That is, deep and narrow channels will realize a relatively smaller change in stream temperature when exposed to solar radiation than shallow and wide channels. Thus changes in channel morphology can influence water temperatures.

Studies generally agree that a change in stream temperature is inversely proportional to stream discharge, and that smaller streams will respond more rapidly to heat influx due to the smaller volume of water to be heated (Brown and Krygier, 1970; Brown, et al, 1971; Swift and Messer, 1971). Swift and Messer (1971), point out that although direct warming of mainstem streams requires a large net radiation input, warming of several small tributaries requires less radiation and may raise the temperatures in the mainstem. However, direct heating of mainstream water may still occur. Brown, et al, (1971), found that most of the increases in temperature in Steamboat Creek occurred in the wide, unshaded main stream, and was not due to entering of warm tributary waters.

Where inflow of water from tributaries to the mainstream occurs, the predicted temperature of the mainstream is adjusted with a mixing ratio, employing the temperature and discharge of both streams (Brown 1970):

$$\text{adjusted temperature} = \frac{(Qt)(Tt) + (Qm)(Tm)}{(Qt) + (Qm)}$$

where Qt and Qm = discharge of the tributary and mainstem, respectively

Tt and Tm = temperature of the tributary and mainstem, respectively

Biological Effects of Temperature Change

Lee and Samuel (1976), noted that water temperature affects all aquatic organisms, in particular, those microorganisms at the base of the food chain. At the Fernow Experimental Forest in West Virginia, they found that forest cutting increased mean and maximum summer stream temperatures and also modified temperature fluctuations. Sampling of benthic organisms revealed that the highest total numbers and total biomass of invertebrate fauna were found in streams draining the uncut watershed in comparison to one watershed with a buffer strip and one with herbaceous cover. The total number of emerging insects were also greatest in the uncut watershed.

As water temperature increases, the solubility of oxygen declines and a reduction in available oxygen necessary for metabolic processes will result (Hynes, 1970; Reiser and Bjornn, 1979). Furthermore, adverse effects on fish have been noted where oxygen levels fall below saturation levels. Sustainable swimming speeds of young coho and chinook salmon may decline, and fish may go into respiratory distress (Hynes, 1970).

Direct thermal effects can also be detrimental to fish populations. The timing and extent of temperature is known to influence breeding (Hynes, 1970), growth rate, ability to capture and utilize food, and ability to withstand disease outbreaks (Reiser and Bjornn, 1979). As waters become warmed, populations of fish pathogens can proliferate, bringing about a rise in mortality rate. Fish (1948), observed that the temperature of the Columbia River at Bonneville reached an all time high of 74.5°F

(23.6°C) in 1941. A bacteria lethal to blueback salmon fluorished, and the 1941 run was almost obliterated.

Species such as trout cannot sustain temperatures of 76°F (24.5°C) for extended periods (Hynes, 1970). Although trout can exist temporarily in warmer waters, the physiological stress may reduce their reistance to predation and disease or inhibit their feeding and reproduction. Thus, for trout, water should remain below 70°F (21.1°C) (Swift and Messer, 1971).

According to Brett (1956), evaporation in air-breathing vertebrates is the chief physical aid for heat loss. This is not the case for fish, where adaptations are subject to variations in environmental temperature. Because of this, the fundamental thermal requirement of fishes is an external environmental temperature most suitable to their internal tissues.

Temperature apparently sets lethal limits to life by (1) conditioning through acclimation to meet levels of temperature that otherwise would be lethal, (2) governing the development rate, (3) setting the limits of metabolic rate, and (4) acting as a directive factor causing congregation of fish within given thermal ranges, or conversely, causing movement to different environmental conditions. The upper and lower temperature limits are defined as the extremes of the tolerable thermal environment, and the lethal temperature as the temperature where 50% of the population could survive. Although the rate of increase in the ability to withstand higher temperatures is quite rapid, often requiring less than 24 hours at temperatures above 68°F (20°C) (Doudoroff, 1942; Brett, 1944), Brett (1956) indicates that temperature may act in the capacity of a lethal factor, and that fish performance is best in the region of the preferred temperature.

DESCRIPTION OF STUDY AREA

Location

The Elk River is a Pacific coastal stream draining the west side of the Klamath Mountains; the geologically older portion of the Coast Range Mountains. It empties into the Pacific approximately 3.5 mi (5.6 km) north of the city of Port Orford in Curry County, Southwest Oregon. All but the lower 11.8 mi (19 km) of the Elk River and it's drainage basin are within the boundaries of the Siskiyou National Forest and are managed by the Powers Ranger District (Figure 1).

Climate and Precipitation

Due to the proximity of the Elk River basin to the Pacific Ocean, the climate is wet and mild. However, high winds associated with winter storms can sometimes reach 90 mi/hr (40 m/s). Air temperatures average about 45°F (7°C) in winter and 65°F (18 °C) in summer. Annual precipitation averages 80 in (203 cm) along the coast and increases to 130 in (330 cm) at the summit of the Elk River drainage, with half of the annual precipitation normally arriving in the winter months of November, December and January. July receives the lowest monthly precipitation (0.7% of the average annual), or around 0.56 in to 0.91 in (1.4 to 2.3 cm) for the month (Froehlich, et al, 1982).

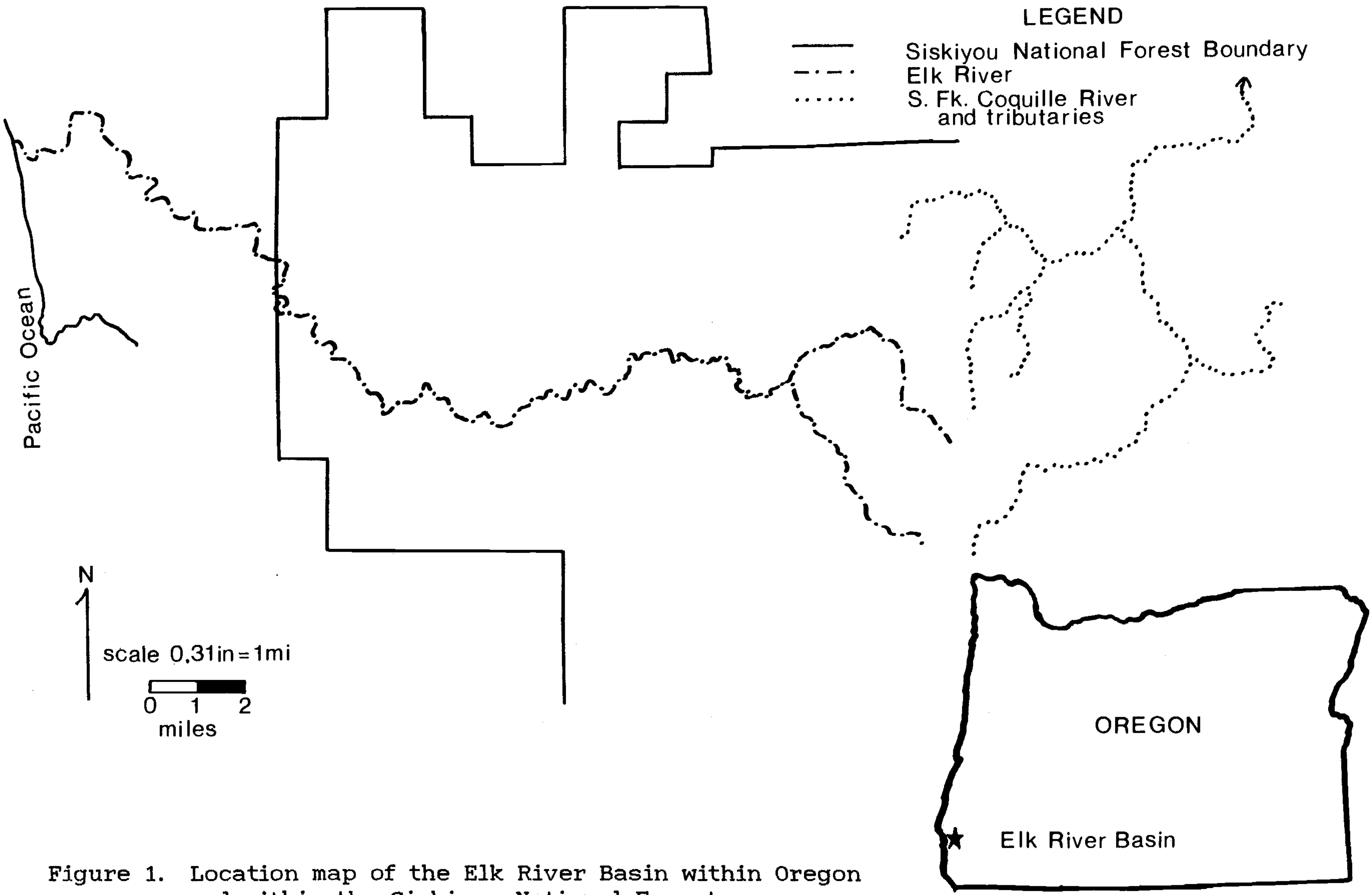

Figure 1. Location map of the Elk River Basin within Oregon and within the Siskiyou National Forest.

Topography and Geology

The topography of the Elk River Basin is characterized by deeply dissected, steep and rugged terrain with knife-like ridges. The elevation rises from near sea level at it's mouth to over 4000 ft (1200 m) in the eastern portion of it's headwaters.

The Klamath Mountains are the oldest rocks in western Oregon, and possibly the oldest in the state. They are made up of mostly pre-Tertiary formations that have undergone folding, faulting and intrusion by igneous bodies and serpentinized masses of ultramafic rocks.

During the late Jurassic, sediments were rapidly deposited into a subsiding trough to form what is now the Galice formation of dark gray to black, fine grained siltstone with slaty cleavage and sandstone beds. The Nevadan Orogeny, a major tectonic building period for the west, folded, faulted and slightly metamorphosed the existing sediments. The Galice was also intruded by diorite. Blocks of peridotite and other ultramafic rocks associated with the oceanic crust were moved into place, with some being altered to serpentinite during this period. Some of the serpentinite now present came from the alteration of ultrabasic intrusive bodies, instead of the movement of blocks. Deep trench deposition of sandstone and siltstone with blocks of sandstone, pillow lavas, breccias, chert and blueschist randomly distributed in the mixture, made up the melange of the Otter Point Formation. Lying unconformably on the Otter Point, is the conglomerate grading into sandstone of the Humbug Mt. Formation. Finally, the latest Jurassic Rocky Point Formation of alternating beds of sandstone and siltstone with a pebble conglomerate was laid down (Baldwin, 1976).

Soils

The soils of the Klamath Mountains are complex; a direct result of the wide variety in geology and topography. The upland soils are mostly Haplohumults (reddish-brown lateritic soils), derived from both sedimentary and igneous rocks. The A horizon is a silt-loam or silty clay loam; the B a silty clay. There are many valley bottom soils, and of the well drained soils, those derived from alluvium are the most important. These are Dystrandepts and Haplumbrepts of thick loam, silt loam, and silty clay loam. Those reddish soils derived from peridotite and serpentinite generally have a high pH, a magnesium-calcium imbalance, and a high percentage of heavy metals. Therefore, these Hapludalfs (gray-brown podzolic soils) or Xerochrepts (Regosols) are characteristically unproductive (Franklin and Dyrness, 1973).

Vegetation

According to the species zonation of Franklin and Dyrness (1973), the vegetation of the Elk River Basin falls within the *Tsuga heterophylla* (Western hemlock) zone, the most extensive and most important zone for timber production in western Oregon. The climax species are *Tsuga heterophylla-Thuja plicata* (Western hemlock-Western redcedar), and subclimax is *Pseudotsuga menziesii* (Douglas-fir). Hardwoods are uncommon except on recently disturbed sites or in specialized areas such as riparian zones.

Communities are arranged along a moisture gradient within the forest. On the dry end of the scale (south facing slopes, well drained soils), the association found is *Pseudotsuga menziesii/ Holodiscus discolor/Gautheria shallon* (Douglas-fir/oceanspray/ salal). Somewhat moister sites contain *Tsuga heterophylla-Pseudotsuga/Rhododendron macrophyllum/Berberis nervosa* (overstory of western hemlock and Douglas-fir with an understory of pacific rhododendron and Oregongrape). The regional climax is the *Tsuga heterophylla/Polystichum munitum* association (western hemlock/ swoardfern). These climax stands generally include large quantities of *Oxalis oregana* (Oregon oxalis) and other shrubs such as *Acer circinatum*, *Vaccinium parvifolium*, and *V. ovatum* (vine maple, red huckleberry and evergreen huckleberry). On the wet end of the scale, one finds *Tsuga heterophylla/ Polystichum-Oxalis* (western hemlock/swoardfern-oxalis). Very wet stream sides and terraces are occupied by *Thuja plicata* (western red cedar).

Although *Chamaecyparis lawsoniana* (Port-Orford cedar) grows in several vegetational zones, it attains optimal development in the southern part of the *Tsuga heterophylla* zone of the Siskiyou area. It is able to grow on a wide variety of sites in south-western Oregon, even on soils derived from serpentinite.

HISTORICAL DATA

USGS Flow Data

To determine to what extent summer low flows correlate with maximum stream temperatures, records of flow and temperature from the South Fk. of the Coquille River near Powers were analysed. Due to sporadic measurements of discharge from 1962 to the present for the Elk River, discharge values for the South Fk. Coquille were assumed to index general trends, from year to year, of high and low flow on the Elk River. Where relatively low discharge values were available for coinciding dates on the Elk River and the South Fk. Coquille River at Powers, the correlation between these flow values was found to be high ($r = 0.96$; $n = 16$; significance < 0.01).

The South Fk. of the Coquille River is a northerly flowing river, its headwaters draining the east side of the Elk River Basin's most easterly boundary, with a drainage area of 93.2 sq mi (242 sq km) for the "near Powers" gaging station and 169 sq mi (438 sq km) for the "at Powers" gaging station. Both facilities are maintained by the USGS (USGS, Water Resources Data for Oregon for discharge values; USGS Water Quality Records for temperature).

Elk River Historical Temperature Data

Temperature records, consisting of continuous recording charts and/or maximum and minimum data, are available for the Elk River during the summer months from 1970 - 1979 at a site just below the fish hatchery. Data also exists from July through

October, 1965, which preceeds hatchery construction. Analysis of these records, together with data collected in 1984 and 1985 were used to evaluate temperature trends in the Elk River over the past 20 years. Water temperature data for the mainstem and some tributary mouths during the summer months of 1974 and 1976 were also evaluated to determine the extent that tributary waters are affecting the overall temperature patterns of the mainstem. Similiar evaluations for the 1984 and 1985 temperature data would confirm if the influence of tributaries on mainstem temperatures has changed, if any, since 1974.

Landslide Inventory Data

Coordination with the 1984 Elk River Basin landslide inventory (McHugh, 1986) was planned so that the effects of sediment yields on stream temperature could be investigated. Inventory data utilized from that study include: (1) volume of sediment associated with slope failures and the estimated amount of soil debris that was actually introduced into major tributaries, and in the case of Butler Creek, location and approximate sizes of ravel sites, (2) identification of management activities at each of the inventoried sites, (3) identification of slides from aerial photos from 1943 - 1979, and (4) from the same photos, delineation of aggraded portions of the stream and the source of sediment where possible. The landslide data, together with stream width/depth data measured in this study, was used to evaluate relationships between sediment yield, stream width, and elevated stream temperatures.

Management and Landslide History

Prior to 1952, road building and harvest activity was minimal on Forest Service land within the Elk River Basin, reaching peak activity between 1956 and 1964 (McHugh, 1986). Figure 2 depicts landslide volumes categorized by management history from 1943 through 1979 for the Elk and Sixes River Basins (McHugh, 1986). This figure indicates that the majority of the debris is associated with roads. Calculations by McHugh (1986) found that the failure rate of road-related landslides for the years 1956 through 1968 was 110 times greater in comparison with the failure rate for unmanaged areas. The 1964 flood appears influential in triggering numerous mass failures in the Elk River Basin. Table 1 (after McHugh, 1986) brackets more tightly the timing of failures. Although McHugh (1986) indicated there was little evidence of channel changes on the 1969 aerial photos (which would contain the effects of the flood in 1964) for both managed and unmanaged areas, there was a dramatic increase in the number of landslides. For example, in unmanaged areas the slide frequency for 1965 - 1969 was 4.4 slides/year, the next largest frequency for any period covering 1943 - 1979 was 2.4 slides/year. The large storm event was undoubtedly instrumental in the initiation of the landslides.

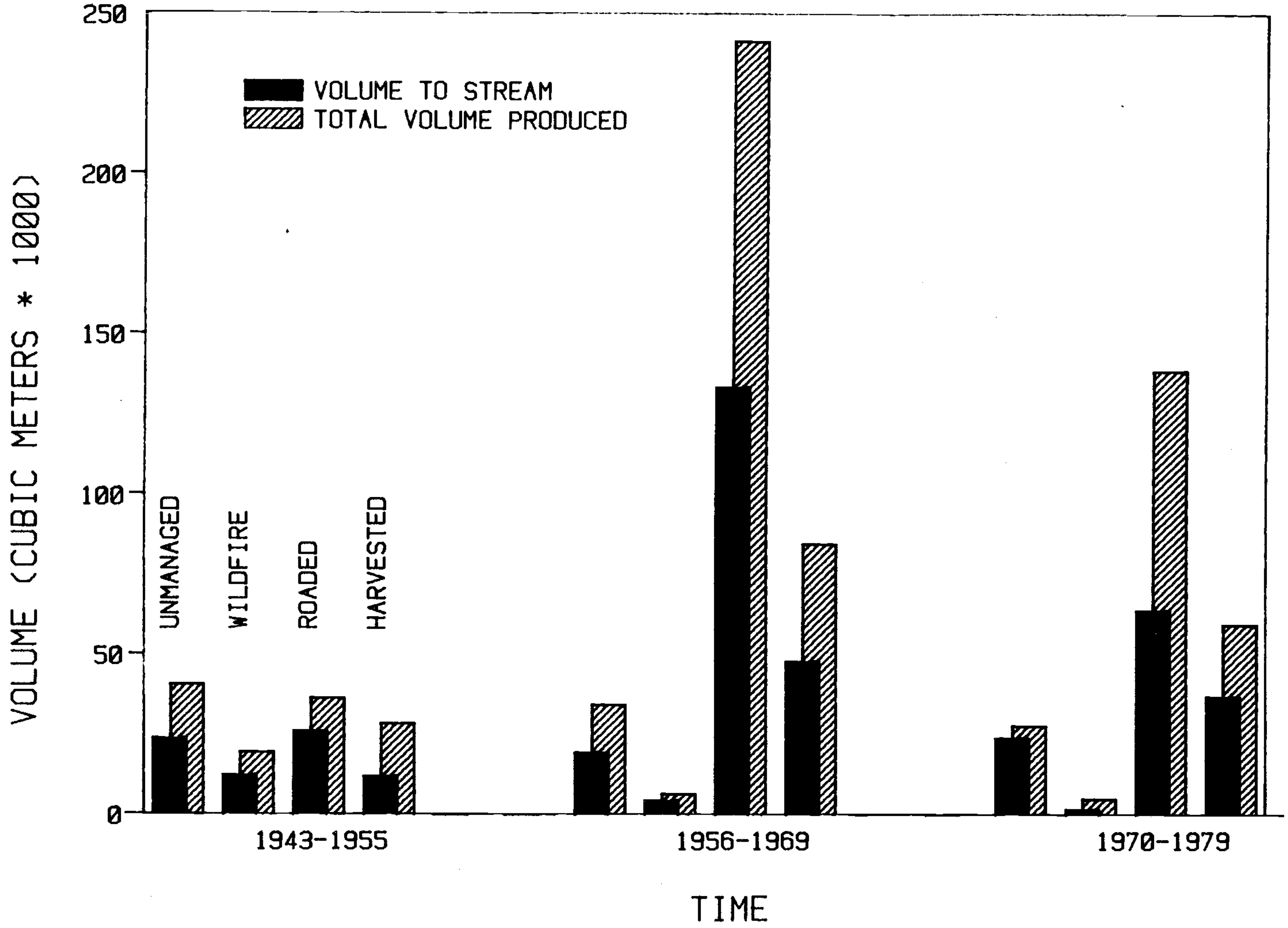

Figure 2. Landslide volume categorized by management history for the Elk and Sixes River Basins, 1943-1979 (after McHugh, 1986).

Table 1. Landslide failure frequency categorized by management history, and basin area in each management type for the Elk and Sixes River Basins, 1943-1979 (after McHugh, 1986).

YEARS	1943-52	1953-56	1957-64	1965-69	1970-73	1974-79
			UNMANAGED			
Unmanaged area (sq. mi)	127.4	126.9	118.7	113.2	109.8	107.7
Number of failures	22	8	6	22	6	11
Number of slides per year	2.4	2.0	0.75	4.4	1.5	1.5
			HARVESTED			
Area harvested (sq. mi)	0.3	1.2	6.1	4.3	2.8	1.4
Number of failures	4	0	12	21	11	22
Number of slides per year	0.44	0	1.5	4.2	2.75	3.1
			ROADED			
Area in roads (sq. mi)	0.2	0.7	2.0	1.1	0.7	0.6
Number of failures	4	6	38	48	30	24
Number of slides per year	0.44	1.5	4.75	9.6	7.5	3.4

METHODOLOGY

Temperature Instruments

In order to determine stream temperature patterns of the Elk River system, continuously recording Ryan thermographs and standard U-type (maximum-minimum) thermometers were employed. Two separate models of thermographs were used. Twelve thermographs consisted of the Ryan model J canister type with an external probe. A hi-expansion liquid operates a bellows mechanism, which in turn, controls the upward or downward movement of the tracking pen. Temperature accuracy was within 1°F (0.55°C). Another 12 thermographs were the Ryan internal thermistor type, accurate to within 2°F (1.1°C).

The thermographs and pocket thermometers were calibrated by stepping them through a temperature range from 41°F (5°C) to 80.6 °F (27°C) at 5.4°F (3°C) intervals in a temperature controlled water bath. A regression equation was then fit for each instrument using the thermograph data and the actual waterbath temperatures. Temperatures measured in the field were then corrected by using the regression equation associated with each instrument. Max-min thermometers were always checked in the field against calibrated field pocket thermometers and their values were adjusted accordingly.

Canopy Cover

An index of canopy cover was measured to quantify the relative abundance of shading in selected stream reaches. Canopy densities were measured at 100-ft (30.5 m) intervals with a handheld Lemon Canopy Densiometer, consisting of a half-sphere mirror with a grid overlay. Measurements were taken by standing in the center of the stream, facing south, and counting the number of grid squares reflecting trees or hillslopes, and expressing this value as a percent. Width of wetted surface, described below, was also determined at each 100-ft interval.

Channel Morphometry

Width of wetted surface and thalweg depth were measured at uniform intervals in various tributaries. Width of wetted surface was measured across the channel from the water's edge, taking care not to include protruding rocks, boulders or organic debris. Exclusion of the protruding objects from the width measure permits estimates of the surface area available for heating from direct incoming solar radiation. The deepest portion of the stream, (i.e. the thalweg), was also measured at each cross-section. For every tributary in which morphometry was measured, canopy density was also measured.

Selection of Control Tributary

To help determine what effect management activities might have upon summertime stream temperatures, a control stream was selected that was roadless and contained no harvest units. None of the tributaries on the south side of the basin met these criteria. On the north side of the Elk River, relatively undisturbed tributaries occurred from Anvil Cr. upstream to Butler Cr.

Geology of the stream valley was an important factor in the choice for the control, as lithology and rock structure are influential in stream morphometry and the geometry of the drainage basin (Morisawa, 1968). Those creeks distinguished as having high peak temperatures, Bald Mt., Butler and Panther Creeks, were ones to be compared with the control. Diorite constitutes most of Bald Mt. Cr., Butler Cr. is in the Humbug Mt. Formation of sandstones and a conglomerate, and Panther Cr. is composed of the Humbug Mt. Conglomerate at it's mouth, then changes to the meta-sediments of the Galice Formation. (For a complete geologic description of the Elk River Basin, see McHugh, 1986).

The geology of Anvil Cr. begins with serpentine and Colbrook Schist at it's mouth, changing to the Humbug Mt. Formation. Anvil Cr. was not chosen as the control due to a ridge top road constructed in it's headwaters, and the geology. Slate Cr. was not selected as the control because of it's small drainage area (0.59 sq mi; 1.5 sq km). Sunshine Cr. and Red Cedar Cr. both are composed of the Galice meta-sediments and the Humbug Mt. Formation towards the headwaters. Since Red Cedar Cr. was the larger of the two sub-basins (2.9 sq mi; 7.5 sq km), it was chosen to serve as the control for Butler and Panther Creeks. A recording thermograph and max-min thermometer was placed at it's mouth as a permanant station for the duration of the field season.

Dissolved Oxygen

Several large pools in both the mainstem and tributaries were monitored for changes in temperature and dissolved oxygen, with depth, using the YSI Model 54 Dissolved Oxygen meter. The meter is a membrane-covered polarographic oxygen detector. The system works by diffusion of oxygen through a permeable membrane into a film of electrolyte solution of potassium chloride KCl. An oxidation/reduction reaction occurs, and the flow of electrons produced from the reaction creates an electric current which is measured. The current produced is diffusion controlled and, therefore, is proportional to the concentration of oxygen. The reduction equation is as follows:

$$2H_2O + 4Ag + O_2 + 4KCl \rightleftharpoons 4AgCl + 4KOH$$

Accuracy of the YSI dissolved oxygen meter was determined by comparing several water samples in the lab. (The theory and procedures of this method, are presented by Jenkins, et al, 1980). Tap water was first measured with the meter, then DO content was determined by chemical analysis using the Winkler Method. The YSI meter was found to be, on the average, within approximately 0.1 mg/l (or 0.1 ppm) of the samples measured by the Winkler Method.

To ensure a constant flow of water around the probe necessary for accurate readings of DO, a submersible stirrer was attached to the probe. Although the instrument was also capable of reading temperature, comparisons against a laboratory thermometer indicated response time of the meter was extremely slow, oftentimes taking as long as 15 to 20 minutes to reach equilibrium. Therefore, max-min thermometers were placed at various depths in the pools measured, and minimum temperatures recorded from each.

A small two-man raft allowed placement of the instruments in the deepest regions of a pool. While maneuvering into place, efforts were made not to disrupt any thermal stratification of the waters that might exist. These measurements were made at times of maximum stream temperature, usually between the hours of 1 pm - 4:30 pm.

1984 Field Season

The emphasis for the 1984 field season was to establish permanent monitoring stations along the mainstem of the Elk River and to determine if tributaries contributed warmed waters to the mainstem, causing a rise in mainstem water temperatures. Six recording thermographs, coupled with max-min thermometers, were installed at intervals of approximately 3 mi (4.8 km) along the mainstem, for a total distance of 16.75 mi (26.8 km). These remained in place from July 7 to Sept. 13, 1984. One thermograph was placed just upstream from Anvil Creek and another 1/2 mi (800 m) below the junction of the North and South Forks. Two more permanent thermographs/max-mins were placed in each the North Fork Elk River and South Fork at the confluence. Figure 3 illustrates the monitoring scheme for the 1984 field season. Those marked with a "P" became a permenant temperature station for the season.

Thermographs were also installed at the mouths of tributaries where access was difficult. Max-min thermometers were placed at tributary mouths where access was relatively easy and they could be checked and reset at least once every two days. When checking the max-min thermometers, the current pocket thermometer temperature and time was noted, along with the maximum, minimum, and current temperature from the max-min thermometer. Every 7 to 10

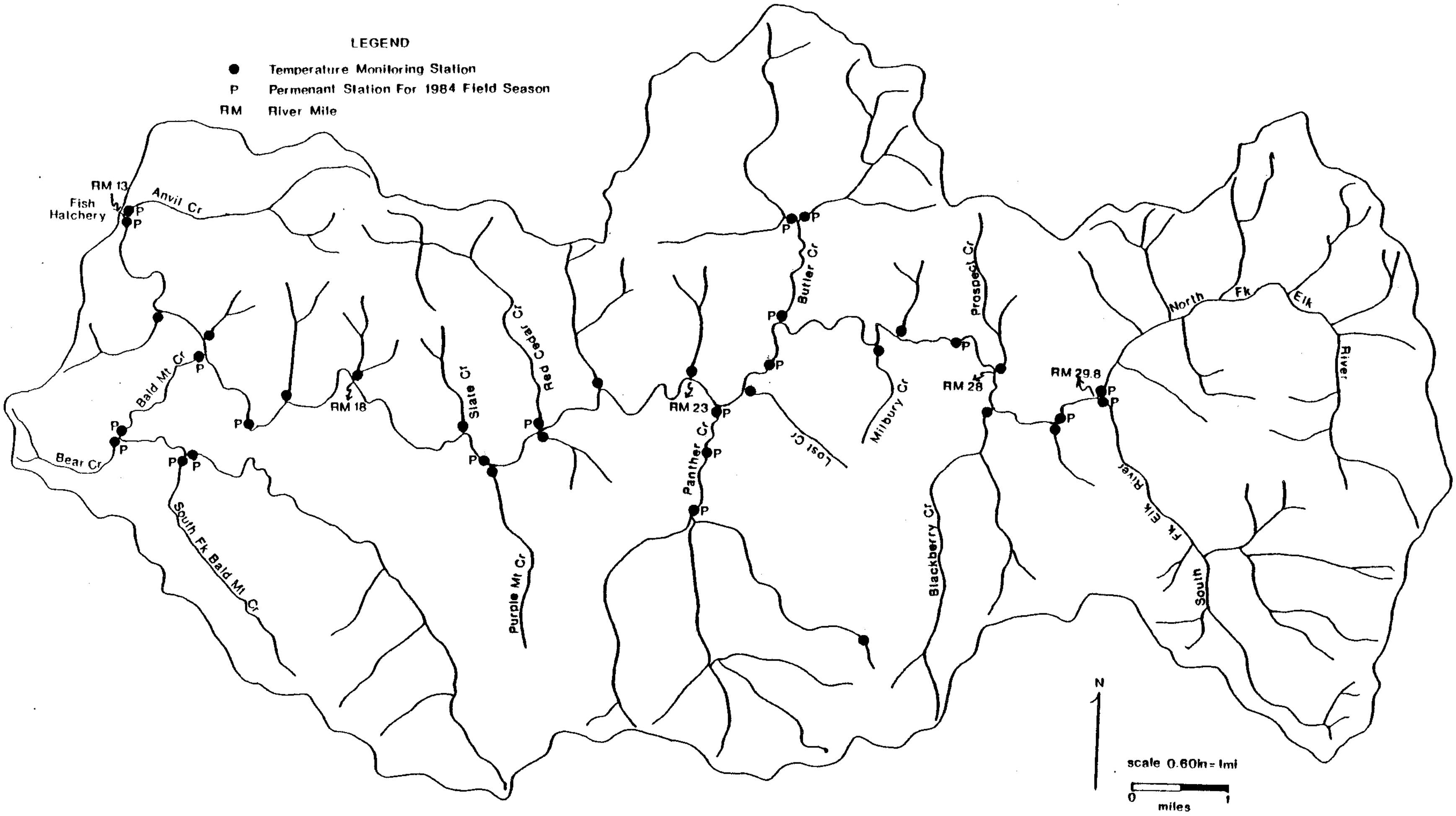

Figure 3. Elk River Basin location map of 1984 temperature stations.

days, recording thermographs were checked, the current time marked on the chart, and the current temperature noted with a pocket thermometer.

The number of available thermographs (24 in total) did not allow for simultaneous measurements of all tributaries throughout the basin. After the permanent mainstem thermograph/max-mins were installed, tributaries not already having a thermograph at their mouth were monitored with max-mins. If measurements revealed elevated temperatures relative to the mainstream or other tributaries, a thermograph was placed along with the max-min. Where temperatures at the tributary mouths were found to be relatively low (< 60°F [15.5°C]) and there was little diurnal fluctuation (< 1 to 2°F [0.55 to 1.1°C]), thermographs were removed and placed in other previously unmonitored tributaries.

Tributaries identified as having warm temperatures were monitored more extensively by placing thermographs further upstream in the tributary. In 1984, these included Butler Cr., Bald Mt. Cr. and Panther Cr., with peak temperatures of 68°F (20°C), 68°F (20 °C) and 67°F (19.4°C), respectively, where they enter the Elk River. An additional thermograph and max-min thermometer were placed in both the East Fork and the West Fork of Butler Cr. Bald Mt. Cr. received another set of temperature instruments in the South Fork, one set in the North Fork of Bald Mt. Cr. at the confluence with the South Fork, and a set just below the confluence with Bear Cr., where Bald Mt. Cr. changes orientation from a west-northwest flowing stream to northeast. Bear Creek's influence on Bald Mt. Cr. temperatures was also established with placement of a thermograph at it's confluence with Bald Mt. Cr. Panther Creek's monitoring scheme was broadened with the installation of a recording thermograph in the West Fork and one below the Middle Fork and East Fork junction. A fourth thermograph station was established in Panther Cr. approximately 0.53 mi (0.85 km) upstream from the confluence with the Elk River, where a geologic change occurring 0.25 mi (0.40 km) from the mouth allows for a widening and shallowing of the stream continuously up to the forks. This station is, hereafter, referred to as "Mid-Reach Panther".

An additional temporary station was established in a first-order stream in the headwaters of Panther Cr. This was to monitor the stream temperature of a tributary bordering a harvest unit to be cut that coming fall. Monitoring summer stream temperatures the year following harvest would help verify the success of the forest's streamside management units.

Although determination of the basin temperature pattern was the greatest concern for 1984, channel morphology, canopy and DO in pools were also measured that year. Thalweg depth and stream surface width were measured in Panther Cr. beginning at the forks and working downstream, covering a total distance of 1.4 mi (2.25 km) to the mouth. Uniform intervals of 5 ft (1.5 m), 10 ft (3 m), or 20 ft (6 m), were used to establish locations for width and depth measurements. Interval lengths were chosen so that good resolution was obtained with minimal number of measurements. Streams with relatively low discharge were measured at 5 ft (1.5 m) intervals and those with relatively high discharge were measured at 20 ft (6 m) intervals.

Width and depths were also measured in the East and West Forks Butler Cr. upstream from the forks for distances of 0.17 mi (274 m) and 0.22 mi (354 m), respectively. Canopy densities were measured at 100 ft (30.5 m) intervals in these three creeks over the same reaches that morphological measures were taken, as well as in the South Fork of the Elk River, and the mainstem below the forks for distances of 0.36 mi (579 m) and 0.61 mi (982 m), respectively, from the forks. Stream surface width measurements accompanied each canopy reading. The location of channel measurements and the placement of temperature instruments in 1985 is shown in Figure 4.

1985 Field Season

The 1985 field season began June 25, 1985 with the deployment of the mainstem Elk River recording thermographs and max-min thermometers in the same locations as the 1984 instruments. This field season's objectives were continued scrutiny of temperatures in the mainstem and tributaries identified as having relatively high maximum temperatures, continued monitoring of the control tributary, Red Cedar Cr., and completion of channel and canopy measurements.

Instruments were maintained, as during the 1984 field season, in the tributaries of Butler Cr., Red Cedar Cr., Blackberry Cr., and Bald Mt. Cr. The station in Bear Cr., a tributary to Bald Mt. Cr., was not reestablished due to it's low maximum temperatures. Although Blackberry Cr. and Purple Mt. Cr. stream temperatures

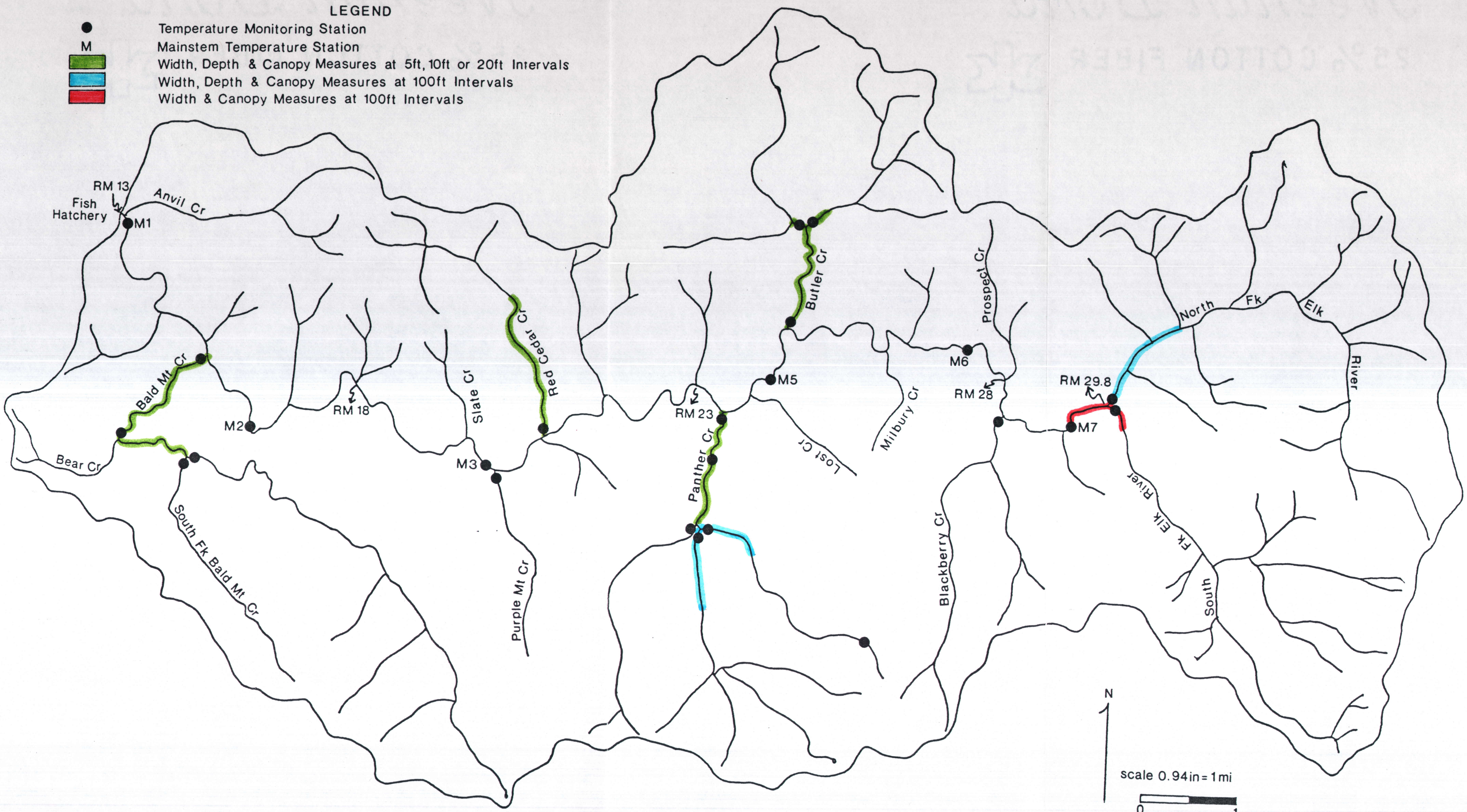

Figure 3. Elk River Basin location map of 1985 temperature stations and channel morphology measurements.

were quite cool (peak for 9/9/84 was 60°F [15.5°C] and 62°F [16.6 °C], respectively), observation of cooler tributary waters in the managed south side of the basin was desirable for comparison with the warmer tributaries. All temperature instruments remained at these designated stations for the duration of the 1985 field season with the exception of the Blackberry and Purple Mt. instruments. The device in Blackberry replaced a mal-functioning instrument in Butler Cr. mouth on 7/23/85 and, due to a shortage of instruments, the one in Purple Mt. Cr. was removed 7/24/85 for use in tracking the temperature of the newly logged, first-order tributary in Panther Creek's headwater.

A major goal for the 1985 field season was to gain morphometry data on as many tributaries as time allowed, with priority on the warmer tributaries and the control stream. Widths and depths were measured in Bald Mt. Cr at 20 ft (6 m) intervals, and in Butler Cr. and Red Cedar Cr. at 10 ft (3 m) intervals over distances of 2.5 mi (4 km), 1.4 mi (2.3 km), and 1.5mi (2.4 km), respectively.

As the end of the field season drew near, the sampling distance was increased to 100-ft (30.5-m) intervals. Width, depth and canopy measures were obtained for the North Fork Elk, East Fork Panther Cr. and Middle Fork Panther Cr. over distances of 1.02 mi (1.6 km), 0.63 mi (1.0 km), and 0.76 mi (1.2 km), respectively, upstream from their mouths.

Elk River Discharge and Velocity

Within an eight day period, between the dates of 7/26/85 and

8/2/85, summer low flows were measured with a Gurley meter at a variety of sites throughout the Elk River Basin. For flow measurement methods, see Hewlett, 1982, pg. 99. (Appendix Table A2 has discharge rates for the Elk River and selected tributaries).

Because average velocity for a given cross-section may not represent the average velocity for an entire reach, an equation of proportionality was set up to calculate the average velocity for the reach based on channel morphometry and the average velocity at a gaged section (i.e., the section where discharge was measured). Assuming that the discharge for the reach (Qr) is proportional to the discharge measured at the gage (Qg), and, since

$$Q = W \cdot D \cdot V, \text{ then:}$$

$$Wr \cdot Dr \cdot Vr = Wg \cdot Dg \cdot Vg$$

where Wr = average width for reach
Dr = average thalweg depth for reach
Vr = average velocity for reach
Wg = width at gage
Dg = thalweg depth at gage
Vg = average velocity at gage

And,

$$Vr/Vg = (Wg \cdot Dg) / (Wr \cdot Dr)$$

Inserting the width and depth values of each tributary for which values were available, Vr/Vg values were calculated for each, and a mean value of 0.81 was the result. Thus, 0.81 times Vg = Vr indicates that the velocity for the reach is 81% of the velocity at the gage, or, the velocity at the gage overestimates the velocity for the reach by approximately 20%. Average velocities for a reach were subsequently taken as 0.81 of the average velocity measured at a gage site. Appendix Table A3 is a table listing average velocities at the gage site, width and thalweg depth measures for the gage site and stream reach, and the cross-sectional area proportions (Wg•Dg / Wr•Dr) of gage to reach.

Table 2 lists basin area, discharge rates, maximum diurnal temperature fluctuations and averages of physical channel characteristics for selected tributaries of the Elk River.

Channel Gradient

Stream gradient measures were taken with a clinometer where discharge was evaluated, and also in tributaries measured for morphometry where breaks in slope greater than 2 to 3% occurred.

Statistical Analysis

Regression analysis and correlation among variables were considered to be "highly significant" at a probability level < 0.01, "significant" at a probability level of < 0.10, and "not significant" at a probability level of > 0.10.

Table 2. Basin area, streamflow, physical channel characteristics and maximum diurnal temperature fluctuations for selected Elk River tributaries in (A) English units and (B), in metric units.

A Tributary Temperature Station	Rank (by basin area)	Basin area (mi^2)	Discharge (cfs)	Average width (isolated) (ft)	Distance of isolated reach (ft)	Average width (total) (ft)	Distance of total reach (ft)	Average depth (isolated) (ft)	Average depth (total) (ft)	Average width/depth ratio (isolated)	Average width/depth ratio (total)	Average percent covered (isolated)	Maximum diurnal temperature fluctuation (°F)
East Fk Butler	1	2.2	1.5	--	--	8.5	895	--	0.83	--	10.2	45	2.5
East Fk Panther	2	2.3	2.1	--	--	12.7	3,300	--	0.95	--	13.3	74	2.0
Red Cedar	3	2.9	1.4	14.9(1)	5,200	13.8	7,920	0.98(1)	1.1	14.6(1)	13.0	74	5.0
Middle Fk Panther	4	3.7	3.5	--	--	18.3	4,000	--	1.0	--	18.6	62	7.5
West Fk Butler	5	4.1	0.9	--	--	9.0	1,170	--	1.3	--	7.1	84	1.5
Butler Mouth	6	7.0	2.7	17.0	7,550	15.3	9,615	1.7	1.6	10.0	9.7	56	6.0
South Fk Elk R.	7	7.9	5.5	--	--	15.4	1,900	--	--	--	--	64	4.5
Mid-Reach Panther	8	8.8	8.1	23.8	4,581	17.8	11,881	1.3	1.1	18.5	16.2	50	8.5
Panther Mouth	9	9.3	11.3	17.9	2,796	18.5	14,677	1.5	1.2	11.7	15.8	66	7.7
Bald Mt. at Bear Cr.	10	9.6	11.0	--	--	30.3	4,820	--	2.2	--	14.1	70	5.2
North Fk Elk R.	11	9.8	7.9	--	--	23.3	5,400	--	1.4	--	16.4	42	7.7
Bald Mt. Mouth	12	10.8	13.6	30.1	8,220	30.0	.13,040	2.2	2.2	14.0	14.0	60	7.4
Mainstem: Forks to M$_7$	13	18.2	13.4	23.5	3,200	21.8	10,500	--	--	--	--	60	5.0

B		(km^2)	(m^3/s)	(m)	(m)	(m)	(m)	(m)	(m)				(°C)
East Fk Butler	1	5.7	0.04	--	--	2.6	273	--	0.25	--	10.2	45	1.4
East Fk Panther	2	6.0	0.06	--	--	3.9	1,006	--	0.29	--	13.3	74	1.1
Red Cedar	3	7.5	0.04	4.5(1)	1,585	4.2	2,414	0.30(1)	0.32	14.6(1)	13.0	74	2.8
Middle Fk Panther	4	9.6	0.10	--	--	18.6	1,219	--	0.30	--	18.6	62	4.2
West Fk Butler	5	10.6	0.03	--	--	2.7	357	--	0.39	--	7.1	84	0.8
Butler Mouth	6	18.1	0.07	5.2	2,301	4.6	2,931	0.52	0.48	10.0	9.7	56	3.3
South Fk Elk R.	7	20.5	0.16	--	--	4.7	579	--	--	--	--	64	2.5
Mid-Reach Panther	8	22.8	0.23	7.3	1,396	5.4	3,621	0.40	0.33	18.5	16.2	50	4.7
Panther Mouth	9	24.1	0.32	5.4	852	5.6	4,473	0.46	0.36	11.7	15.8	66	4.3
Bald Mt. at Bear Cr.	10	24.9	0.31	--	--	9.2	1,469	--	0.66	--	14.1	70	2.9
North Fk Elk R.	11	25.4	0.22	--	--	7.1	1,646	--	0.44	--	16.4	42	4.3
Bald Mt. Mouth	12	28.0	0.3B	9.2	2,505	9.1	3,975	0.66	0.66	14.0	14.0	60	4.1
Mainstem: Forks to M$_7$	13	47.1	0.38	7.2	975	6.6	3,200	--	--	--	--	60	2.B

(1) average for length of stream only within the Galice Formation.

RESULTS AND DISCUSSION

Historical Temperatures - Temporal Patterns

Summer streamflow was found to be an important factor influencing water temperature. For example, July's average maximum water temperatures for the South Fk. Coquille River near Powers, available only from 1957 - 1970, were found to be inverseley correlated with average monthly flows for July at the same station ($r = - 0.82$; $n = 12$ significance < 0.01). Hence, when flows decrease, temperatures tend to rise. Although August's average maximum water temperatures were not as highly correlated with discharge as in July, the correlation remained significant ($r = - 0.57$; $n = 12$; significance < 0.05).

The relationship between summer flow and stream temperature for 1962 is illustrated in Figure 5. Notice that as flows continually decrease through July, the Coquille River becomes warmer. With the occurrence of rainfall and consequential increase in streamflow, stream temperatures drop almost as dramatically as the discharge rises. Moving into August, the water level begins to drop again, and temperatures once again soar. However, even when flows are equal to, or less than those recorded in July, the water temperature in August never reaches the maximum attained in July. These lower August temperatures can be explained by the decreasing solar angle (angle between the sun and the horizon at solar noon). This angle is at a maximum on June 22 and continues to decrease after that date. As the days become shorter, the shading by trees and topography increases, resulting in a decrease

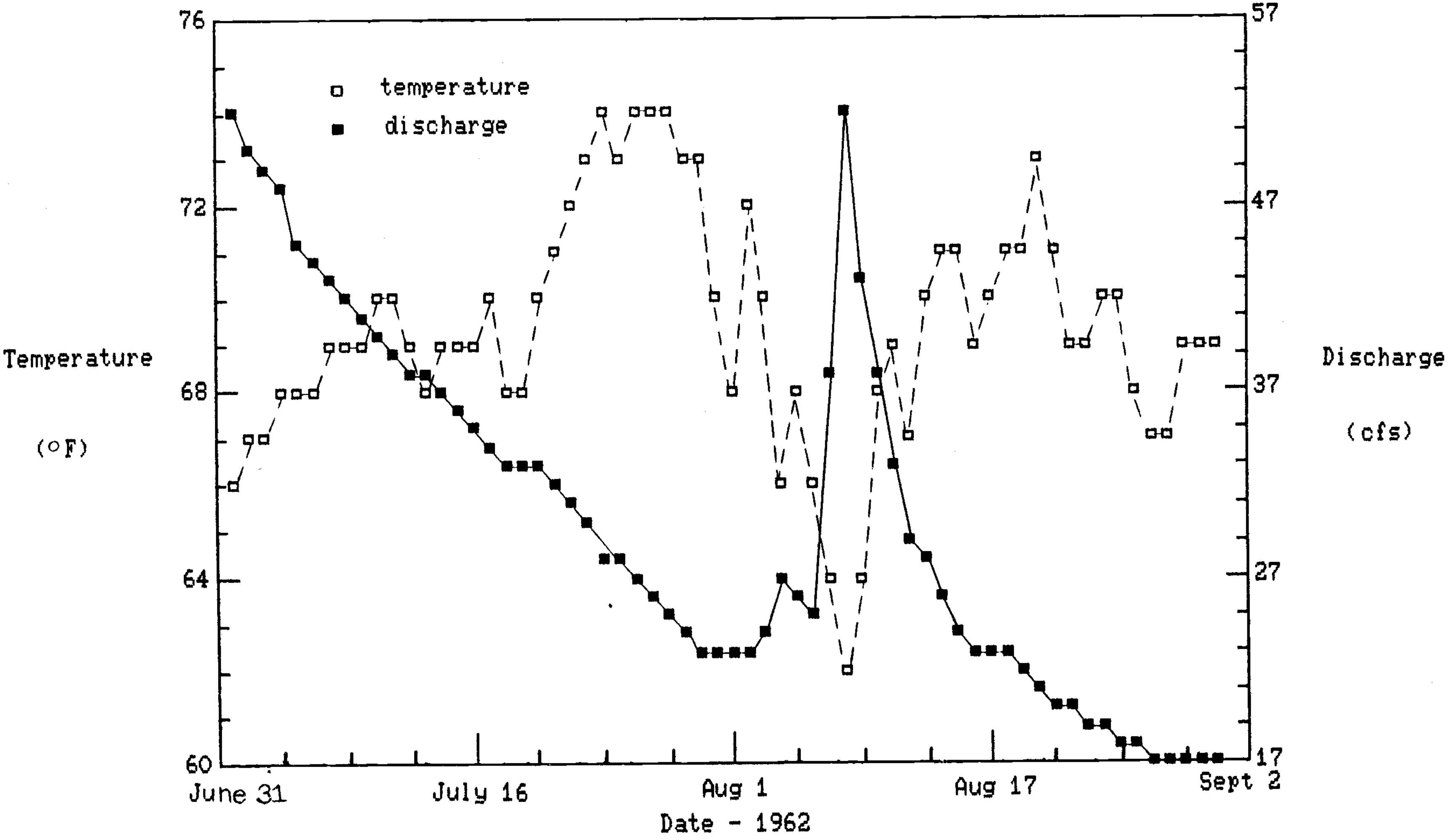

Figure 5. Daily maximum temperatures and daily discharge on the South Fk. of the Coquille River near Powers for July and August, 1962.

in net incoming solar radiation reaching the stream surface.

The amount of net incoming solar radiation striking the stream surface has been found to be the direct cause of increased stream temperature in numerous studies. Several factors including summer lowflow, summer precipitation and yearly peak discharge are variables which can affect summer temperature patterns occurring through time. As described previously, floods or debris torrents triggered by large storm events, can be responsible for exposing streams to solar radiation by scouring channels to bedrock, and by removing debris and streamside vegetation. This can result in increased stream temperatures, and for this reason, annual peak discharge was included in the analysis.

To determine the effectiveness of summer discharge, summer precipitation, and annual peak flow for indirectly influencing stream temperature, two regression models were fit: one for the available July data and a second for August. Average maximum daily stream temperature, by month, was considered the dependent variable; the remaining factors as independent variables. July's model indicated that average flow for the month, the number of days with measurable precipitation, and the amount of precipitation significantly influenced average monthly water temperature ($R^2 = 0.86$; each variable entered at a significance level of < 0.05). The model for August resulted in the annual peak flow being the only significant variable, explaining 49% of the variation in temperature (each variable entered at a significance level of < 0.05). When peak flow is left out of the model, average flow for the month of August is the only significant variable ($R^2 = 0.32$; significance < 0.05). These results indicate that several factors influence maximum stream temperatures. Which factors, and the extent to which they influence stream temperatures, varies with month.

Figure 6 illustrates the average maximum stream temperatures of the five warmest days in July and August for the South Fk. of the Coquille River near Powers, 1957-1970. Although variability is high from year to year, the apparent effects of the flood in December of 1964 was to increase maximum summer stream temperatures during the following years. Figure 7 shows the annual peak flows from 1917 - 1985 for the South Fork of the Coquille River at Powers. By any standards, the December 1964 flood (Water Year 1965), was of major proportions. Figure 8 illustrates reccurrence intervals for the South Fk. of the Coquille River and is based on 67 years of instantaneous peak flow data from the "at Powers" station (the figure does not include the 48,900 cfs (1,369 cumecs) flow for the 1965 water year).

Non-continuous temperature data gathered over the period 1965 through 1985 on the mainstem of the Elk River was also analyzed with respect to the factors identified above: monthly flow, number of days with measurable precipitation, monthly precipitation amounts and annual peak flow. July's maximum water temperature at the Elk River Hatchery and the average monthly flow for the Coquille River at Powers is shown for the period 1965 - 1985 in Figure 9.

In general, there appears to be a decline in temperature from 1965 to 1970 (Figure 9) followed by an increase in temperature

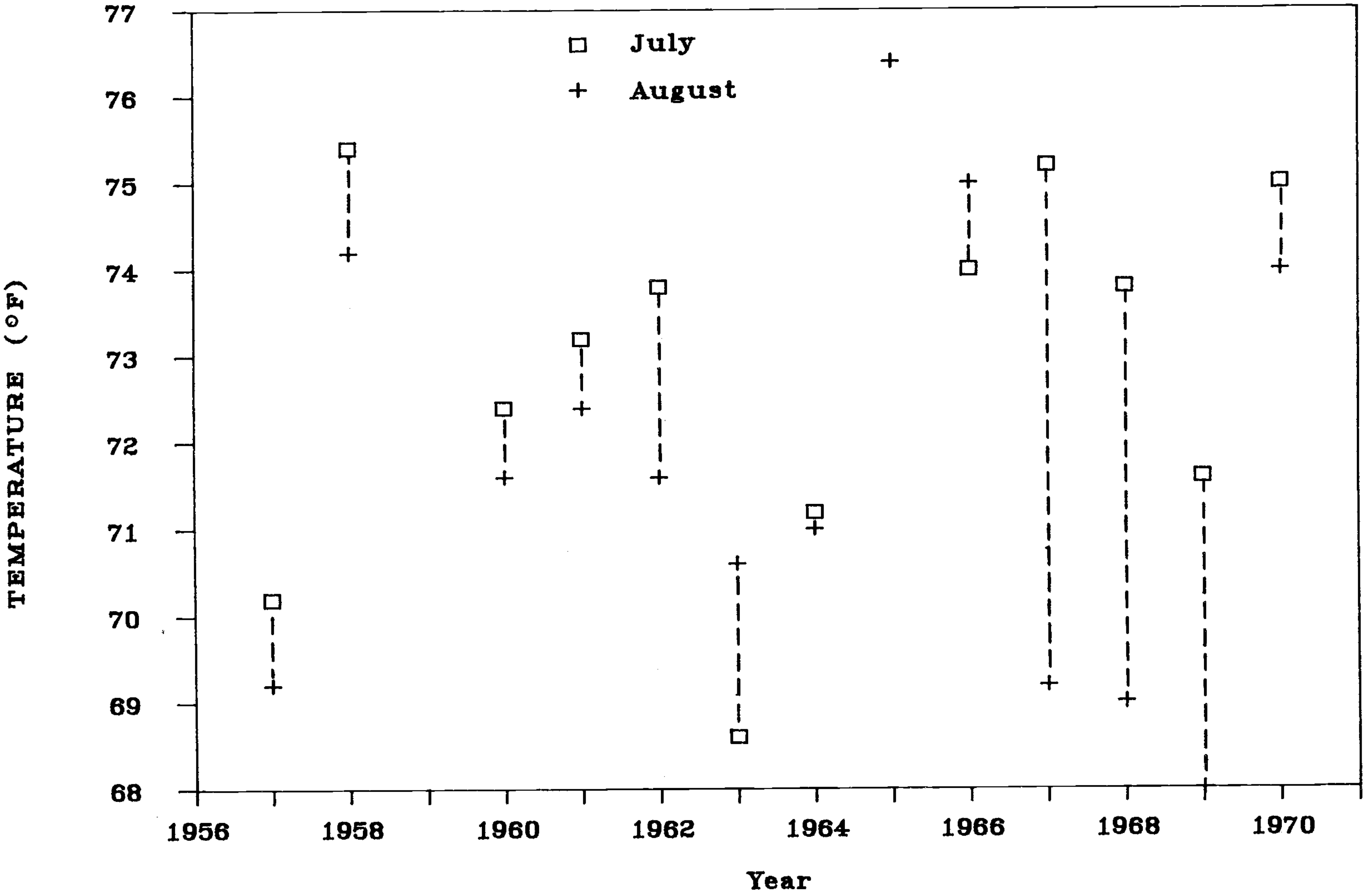

Figure 6. Average maximum temperatures of the five warmest days for July and August, South Fk. of the Coquille River near Powers, 1957-1970.

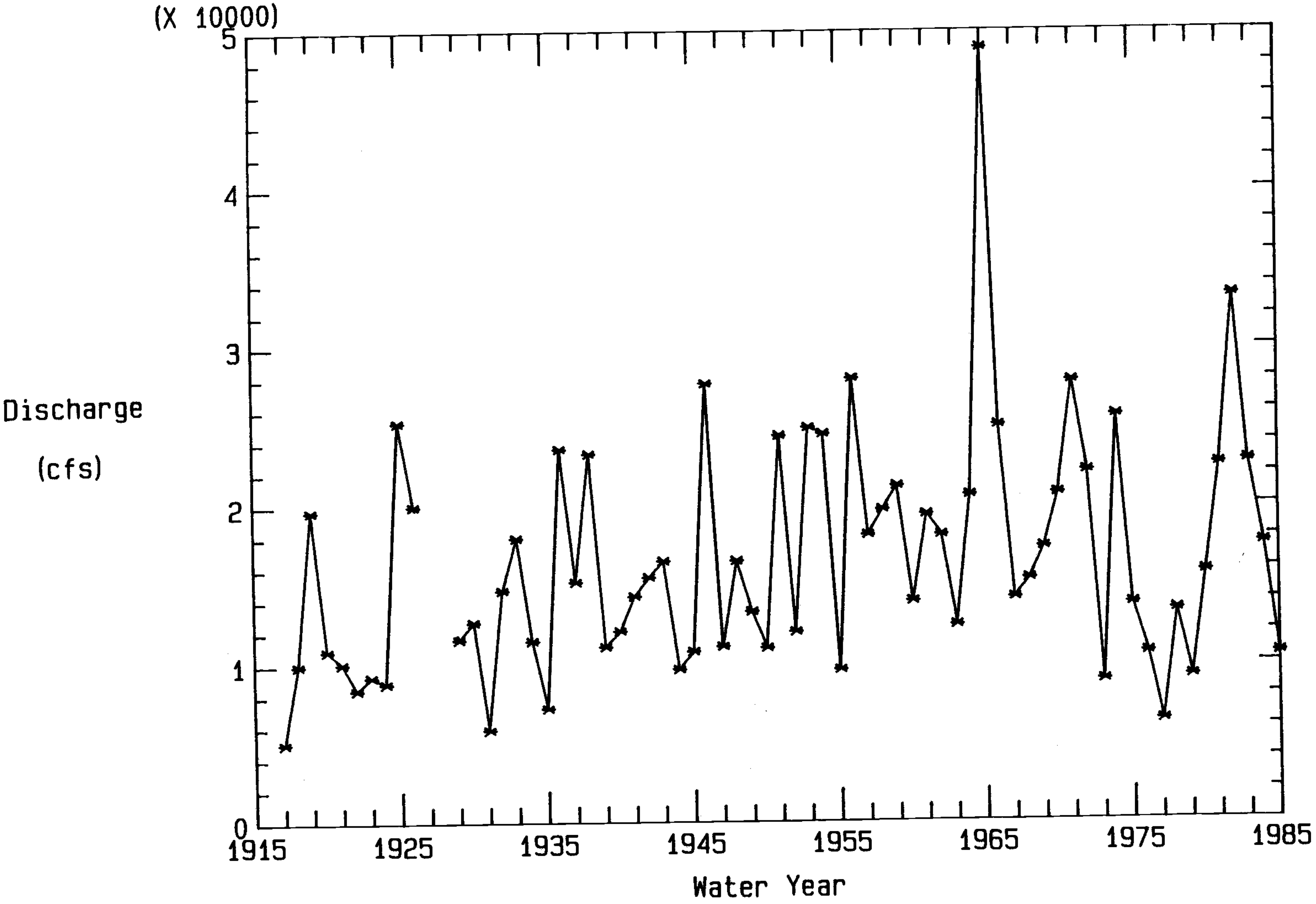

Figure 7. Annual instantaneous peak flows for the South Fk. of the Coquille River at Powers, 1917-1985. Note: data for 1927 and 1928 does not exist.

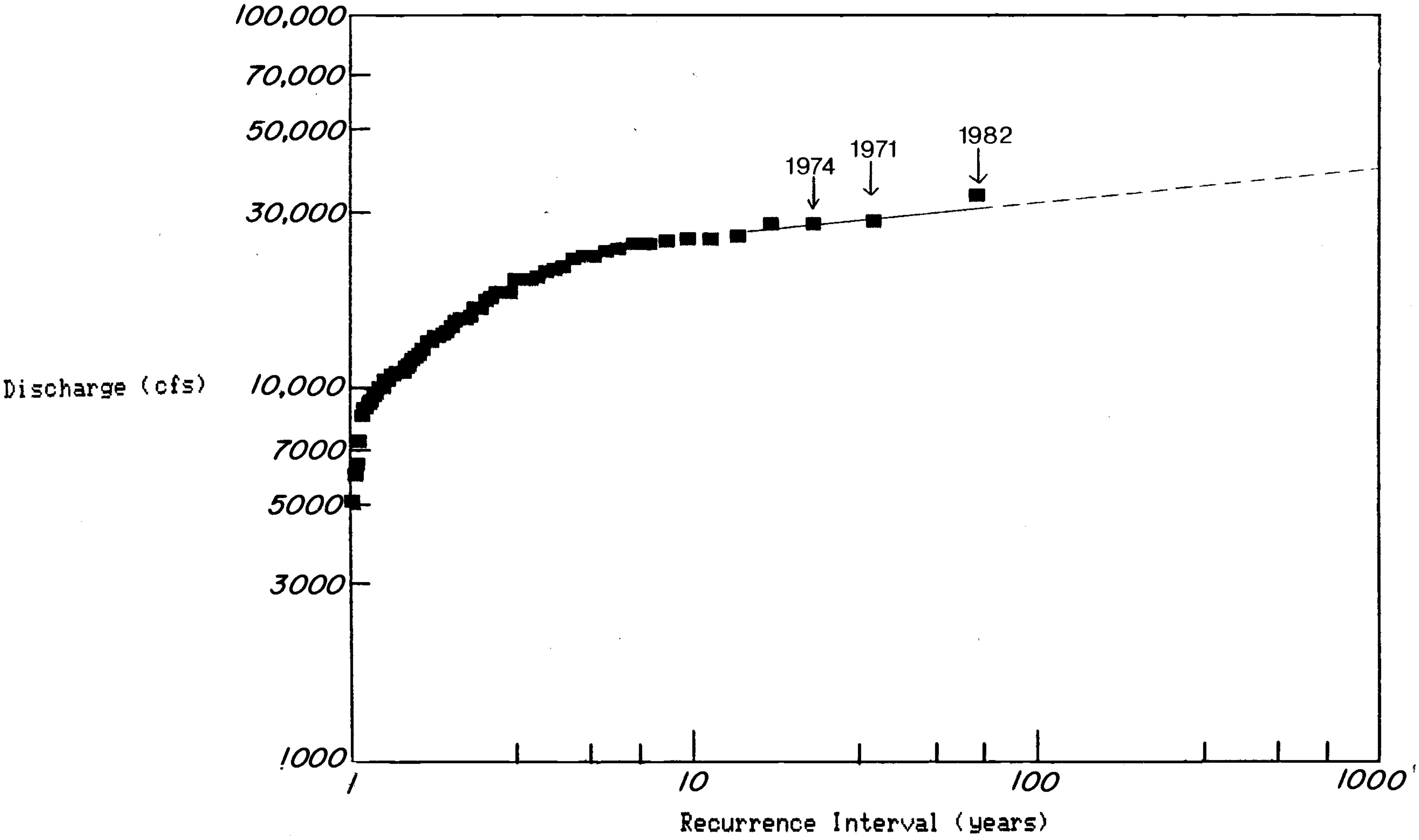

Figure 8. Reccurrence intervals of instantaneous peak flows for the South Fk. of the Coquille River at Powers, 1917-1985. Note: 1964 flood at 48,900 cfs not included.

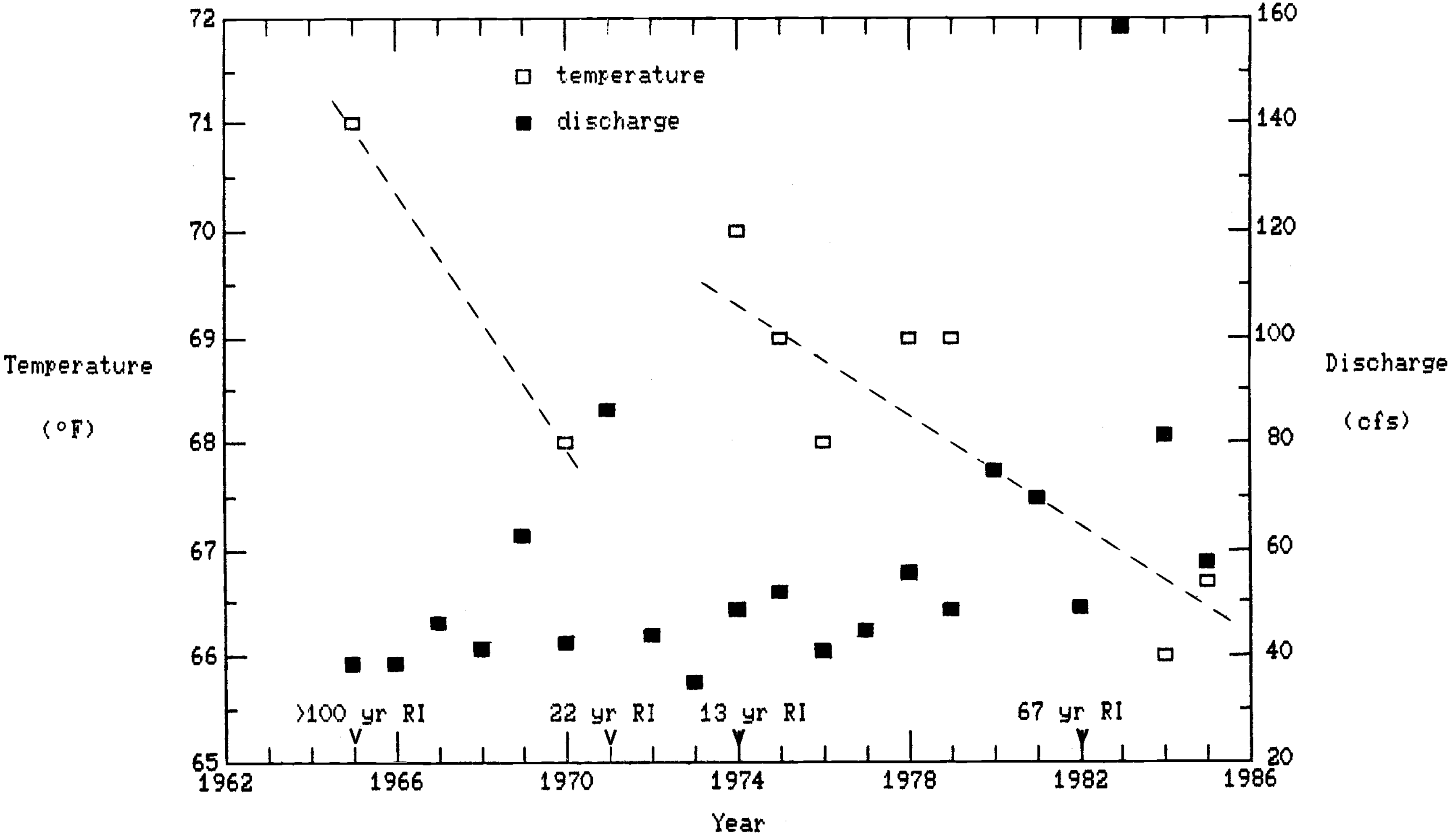

Figure 9. Maximum July stream temperatures at the Elk River Hatchery and average July streamflow for the South Fk. of the Coquille River at Powers, 1965-1985. Note: Recurrence Intervals (RI) of major peak flows are also indicated.

sometime between 1971 and 1974, and then a gradual decline through 1985. The general temperature pattern is apparently independent of summer flow and precipitation.

August temperatures in the Elk River have also been recorded at the hatchery and are shown with average monthly flows for the Coquille River at Powers in Figure 10. Generally, temperatures again appear to decrease from 1965 to 1970, increase sometime between 1971 and 1974, then gradually decrease over the period 1974 through 1985. Although summer streamflow and precipitation partially influence relative water temperatures from year to year, they seem to have little effect on the trend of declining temperatures observed from 1974 through 1985. For example, no precipitation, coupled with low flows in 1974 resulted in temperature of 72 °F (22.2°C). Temperatures remained high in 1975, although there was relatively high precipitation (6 days with a total of 0.93 in [2.36 cm]) and an increase in flows. Further increases in stream flow, and a large amount of moisture and cloud cover (13 days with a total of 2.62 in [6.65 cm]) in 1976 helped produce a dramatic drop in temperature to 67°F (19.4°C). However, in comparing temperatures for two widely separated years with comparable stream flow, there are substantial differences in temperature. For 1975 and 1985, both years have average flows of approximately 31 cfs (0.87 cumecs), and although more precipitation fell in 1975, it's maximum temperature was 6°F (3.3°C) greater than in 1985. Similarly, closer scrutiny of values for 1978 and 1985 reveal that, although flows were high and there was greater precipitation in 1978, temperatures were lower in 1985. These observations

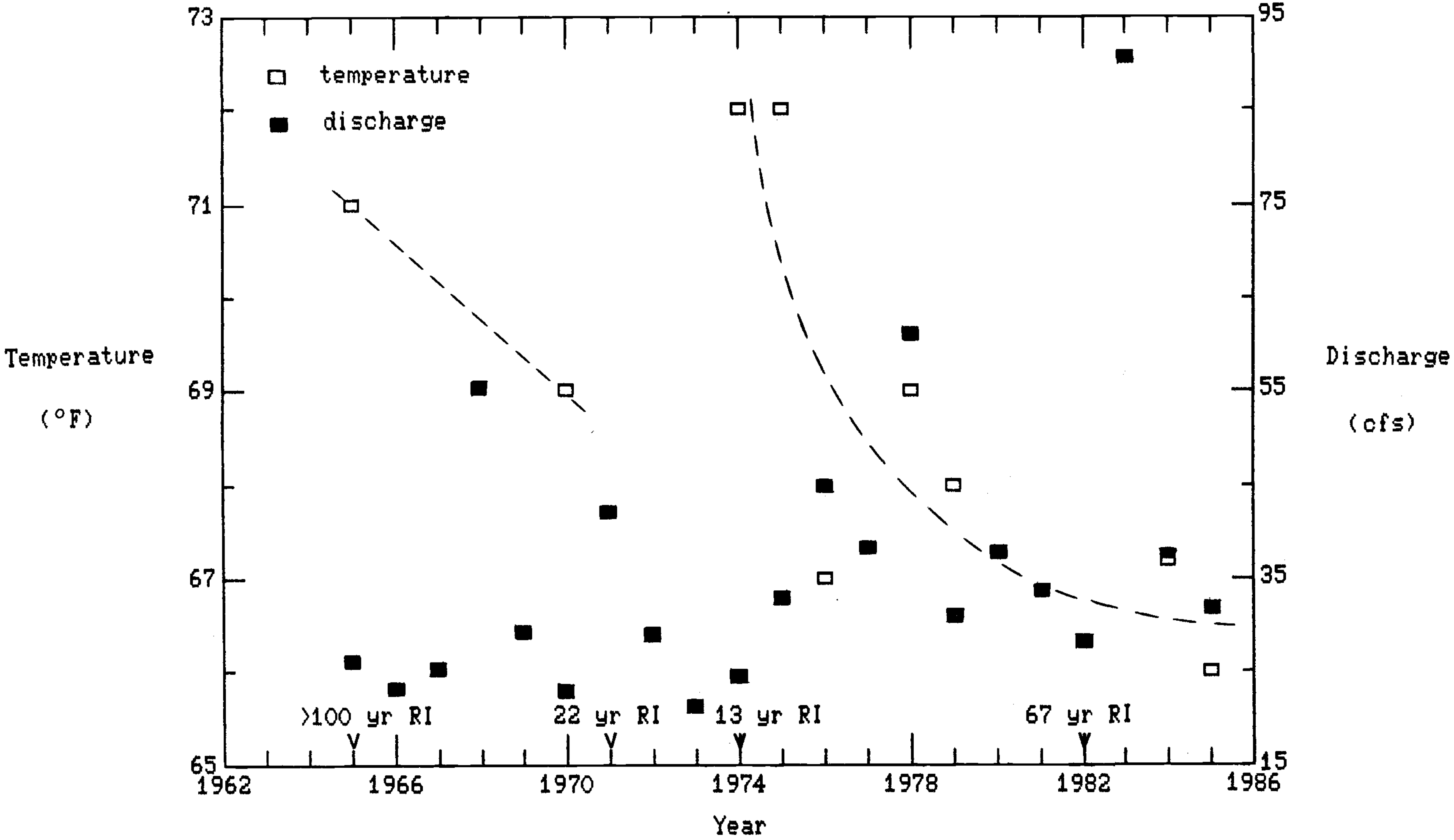

Figure 10. Maximum August stream temperature at the Elk River Hatchery and average August streamflow for the South Fk. of the Coquille River at Powers, 1965-1985. Note: Reccurrence Intervals (RI) of major peak flows are indicated.

indicate that trends of decreasing temperature are relatively independent of summer discharge.

Available temperature values for July at a location 11.5 mi (18.5 km) upstream from the hatchery on the Elk River (i.e. at a wide, gravel laden reach at the mouth of Butler Creek known as Butler Bar) are graphically portrayed in Figure 11. Again, monthly flow values from the Coquille River at Powers are displayed in the figure. Over the period of record (i.e., 1970 - 1985), there has been a relatively pronounced decline in temperatures.

A possible explanation for the relatively high stream temperatures in the early-to mid-1970's is the large volume of landslide debris generated between 1956 and 1968 as indicated in Figure 2. The general decline in temperature from the early 1970's to the present can possibly be attributed to a change in channel morphology from relatively wide and shallow stream reaches, to ones that are deeper and narrower. Streamside vegetation may also be a factor as it establishes itself along affected channels, hence providing shade to the stream.

For all three data sets above: July and August at the Elk River Hatchery and July at Butler Bar, a regression was run between maximum temperature and average monthly flow. All three showed a slight trend of decreasing maximum stream temperature with increasing streamflow, and only the data for July at Butler Bar was significant (significance < 0.10).

The residuals (the amount which the regression equation has not been able to explain the maximum water temperatures) were then

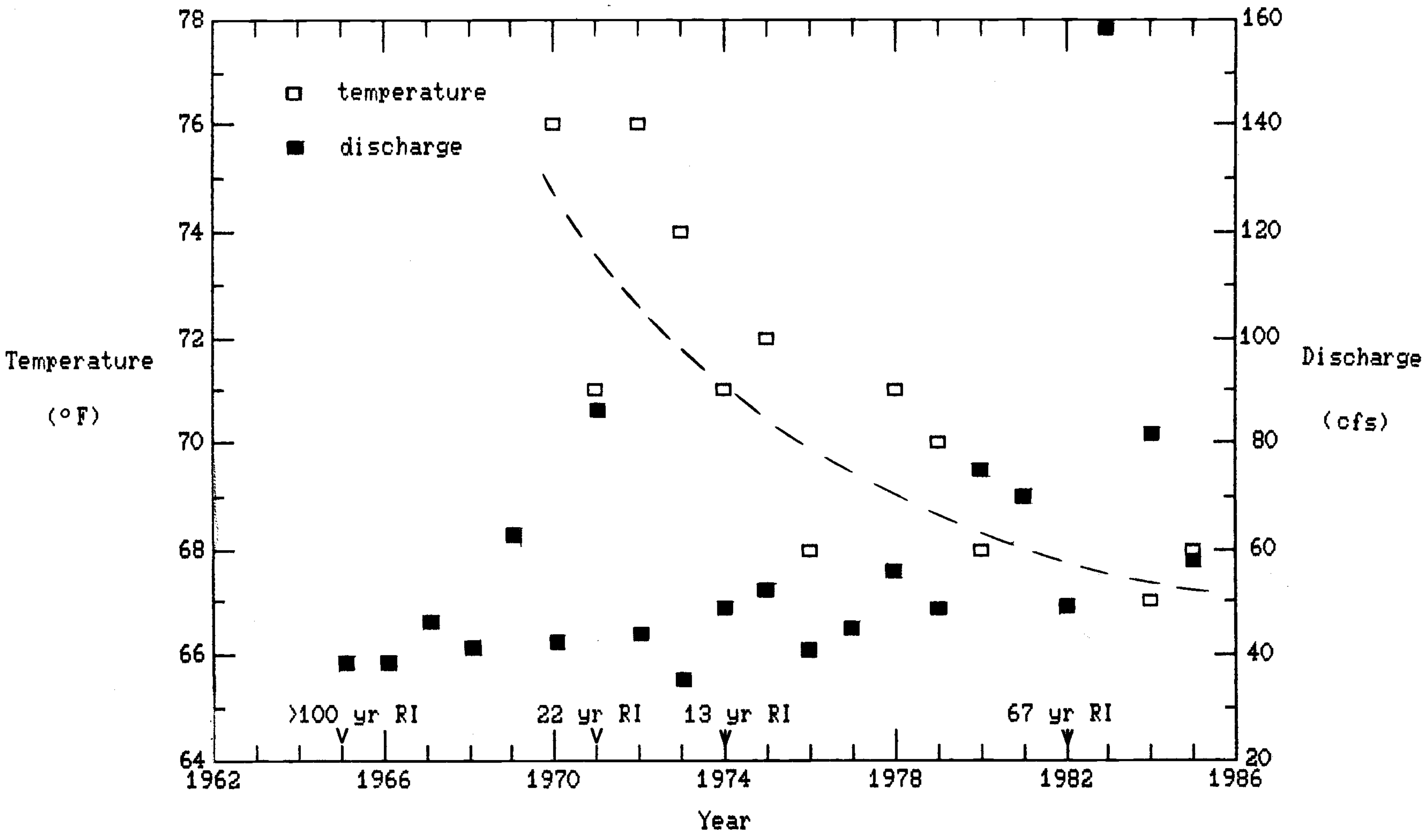

Figure 11. Maximum July stream temperature of the Elk River at Butler Bar and average July streamflow for the South Fk. of the Coquille River at Powers, 1966-1985. Note: Reccurrence Intervals (RI) of major peak flows are also indicated.

plotted vs time and inspected for trends. All three graphs revealed a general downward pattern suggesting that over time, temperatures have been falling for reasons other than changes in discharge levels. Figure 12 is the residual plot for the Butler Bar location. Closer examination of the residuals in Figure 12 reveals that a relatively large positive value for a residual point usually follows by one year, a relatively large annual peak flow. The reason for this apparent one-year delay in response is not known.

Another study by Beschta and Taylor (in press), analyzing temperatures and flow for the Salmon Cr. drainage in Oregon, also found that rises in stream temperature followed large peak flow events and the authors suggest this may have been a result of channel changes from mass soil erosion. Likewise, the absence of major flow events since 1971 and a drop in harvest activity since 1972, were perceived to be among several factors contributing to a general decrease in stream temperature since 1980 on Salmon Cr.

Historical Temperatures - Spatial Patterns

Temperature data gathered prior to this study illustrate several spatial patterns which were explored in more detail in 1984 and 1985. Figures 13 and 14 reveal maximum temperatures at various mainstem and tributary mouth locations for July and August of 1974 and 1976, respectively. Peaks of 73°F (22.8°C) and 71°F (21.7°C) occur around mile 22 (km 35.4) in the mainstem in August, 1974 and July, 1976, respectively. The tributary maximum temperatures are generally below the peaks in the main channel. Some

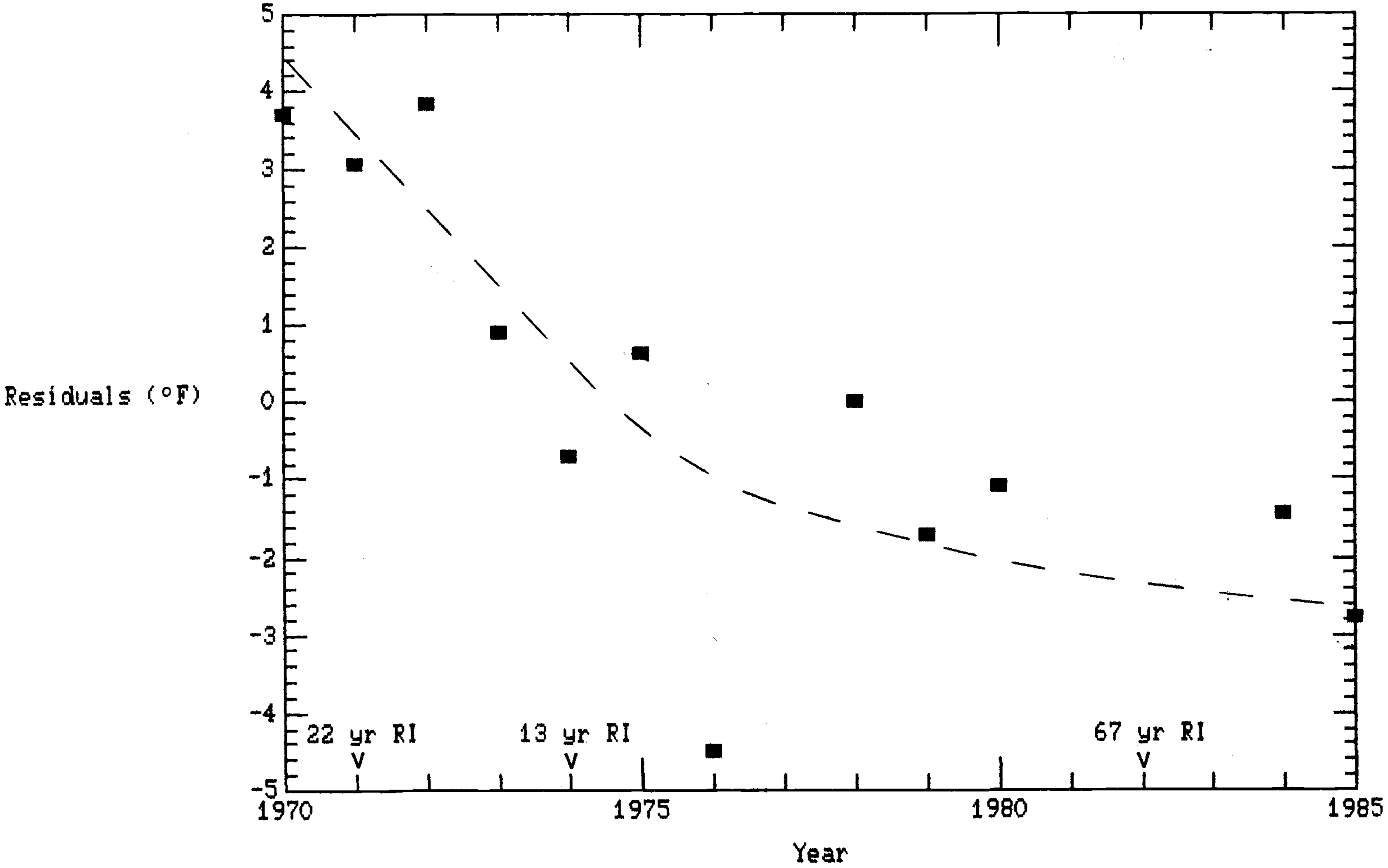

Figure 12. Residuals through time (1970-1985) from the regression of July maximum water temperatures at Butler Bar vs. average July streamflow of the South Fk. Coquille River at Powers.

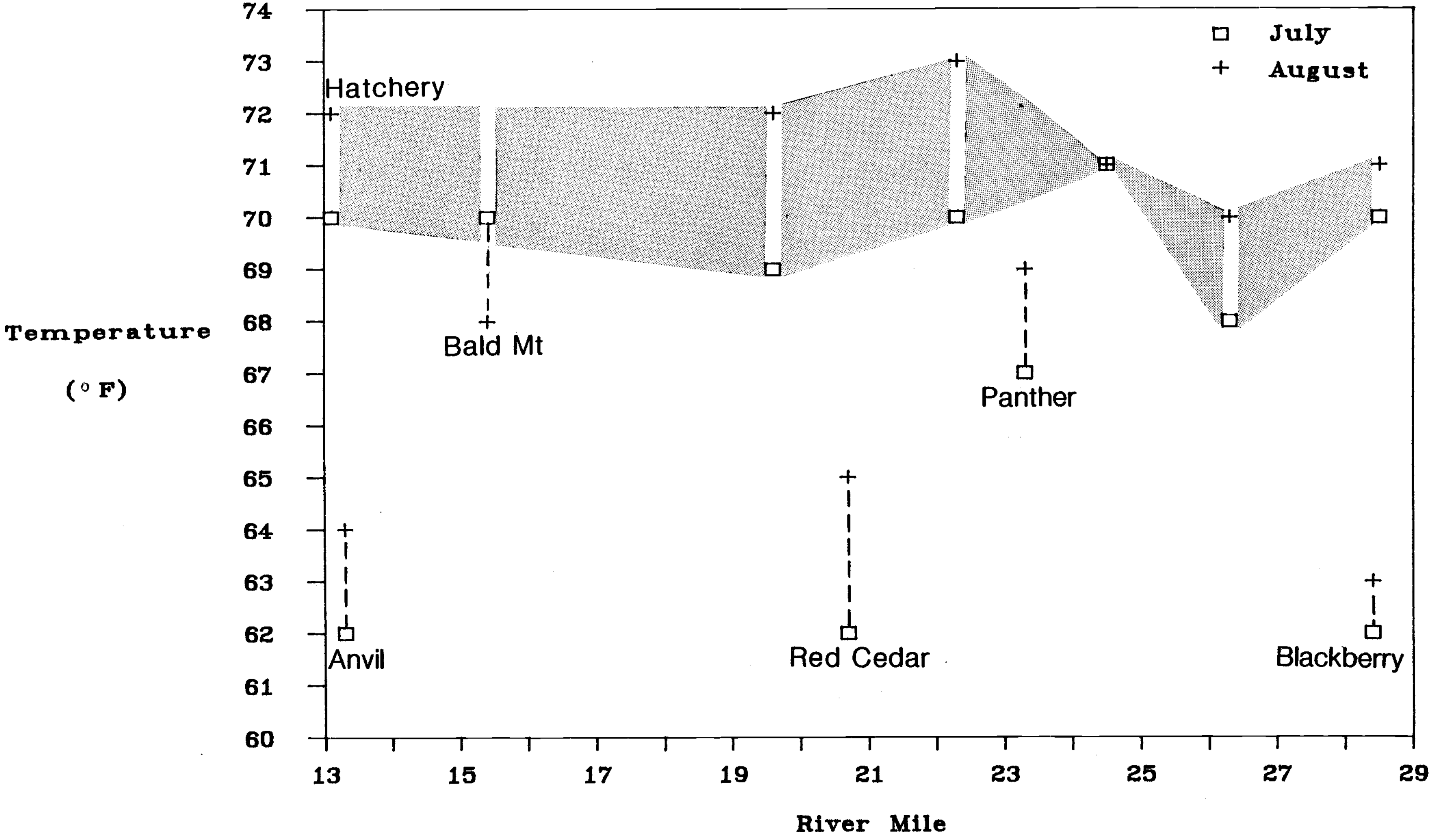

Figure 13. Maximum July and August stream temperatures for the Elk River and selected tributaries, 1974.

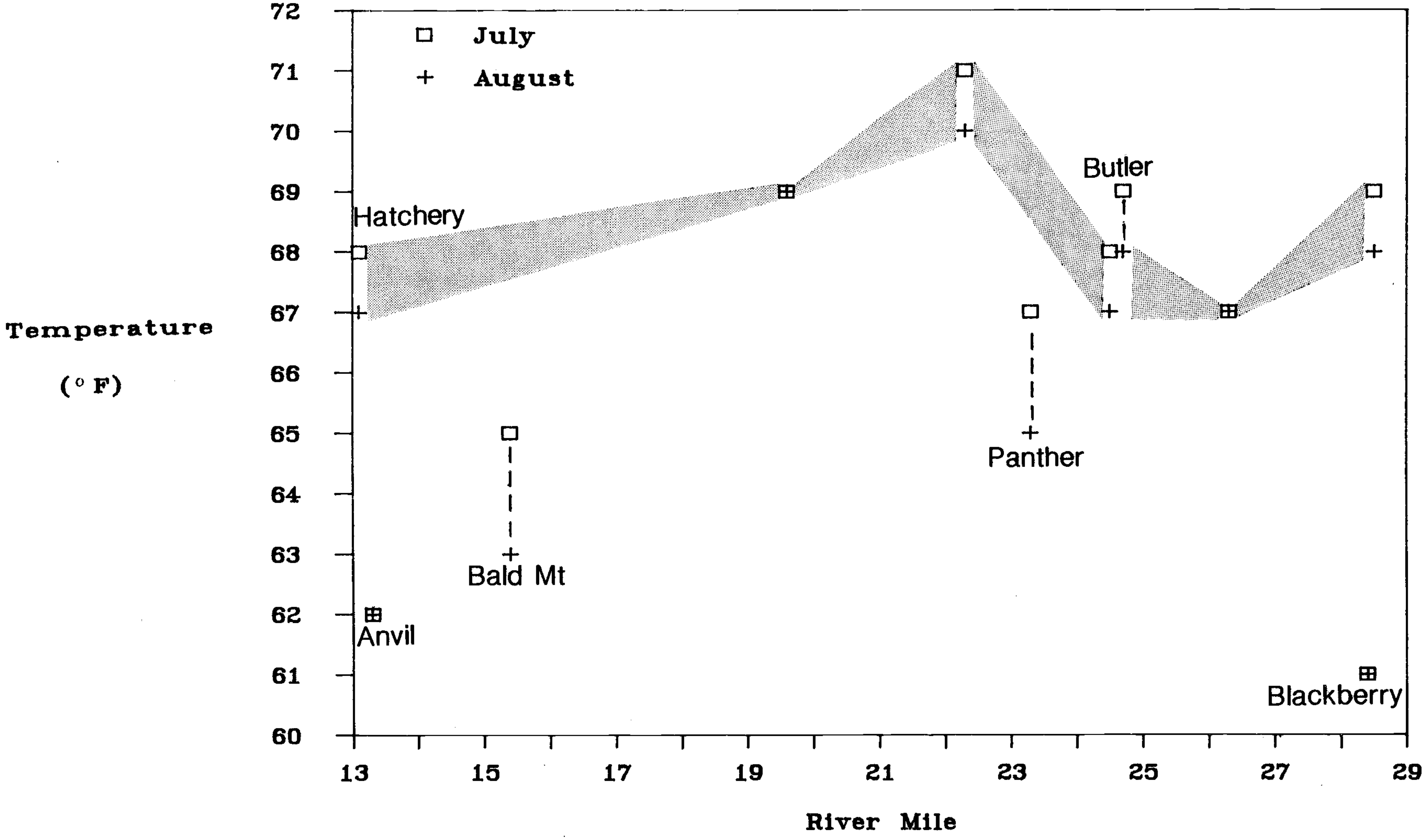

Figure 14. Maximum July and August stream temperatures for the Elk River and selected tributaries, 1976.

tributaries are even capable of significantly reducing mainstream maximum temperatures directly below their confluence, as illustrated with Blackberry Cr., Anvil Cr. and Red Cedar Cr.

Temperature data gathered over a 1 1/2 to 2 hour period (4 to 5:30 pm) on August 4, 1970 and (4 to 6 pm) on August 10, 1978 are illustrated in Figures 15 and 16. Discharge on the South Fork of the Coquille River at Powers was 28 cfs (0.78 cumecs) and 27 cfs (0.76 cumecs) for August 4, 1970 and August 10, 1978, respectively. In both years, the three warmest feeder streams are Butler Cr., Panther Cr. and Bald Mt. Cr., with temperatures for Panther Cr. and Butler Cr. well above the mainstream temperatures for the 1978 profile, and below for the 1970 profile. Both figures also suggest the warmest area in the system to be approximately 4 to 5 miles (6.4 to 8 km) below the hatchery location (1970 max = 72°F [22°C]; 1978 max = 74°F [23°C]). Because this data was collected over a 1 1/2 to 2 hour period, it does not represent the warmest daily temperatures experienced at various locations along the river and, thus, cannot be directly compared to the data collected in this study.

1984-1985 Temperatures - Spatial Patterns

The general heating pattern of the Elk River Basin upstream of the Hatchery became more apparent following analysis of the temperature data collected in the summers of 1984 and 1985. Figure 17 depicts the maximum temperatures reached in the mainstem and at selected tributary mouths on August 9, 1984 and July 27, 1985, the warmest day of each year. Temperatures at the hatchery

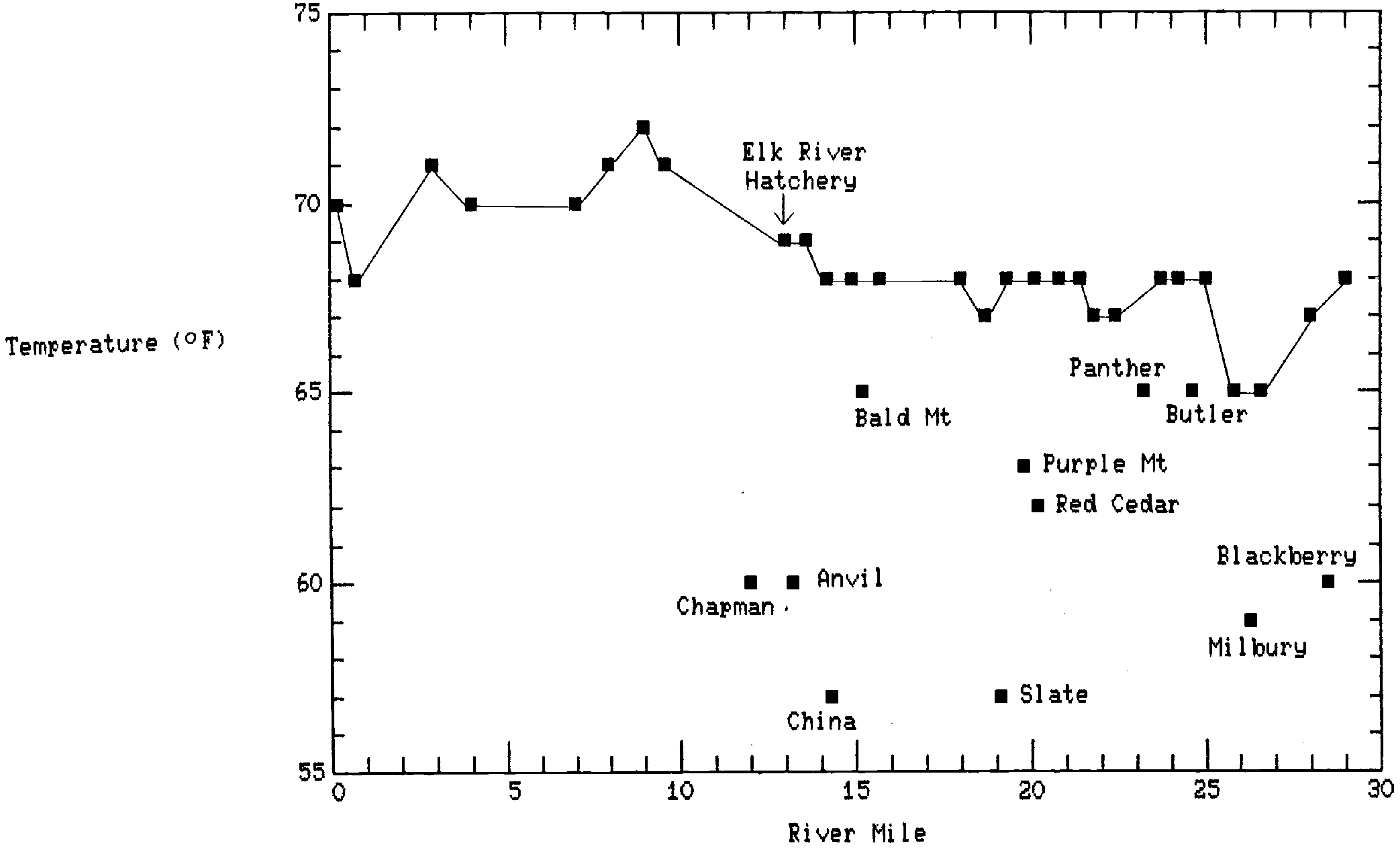

Figure 15. Stream temperatures of the Elk River and selected tributaries during 1600-1730 hours, August 4, 1970.

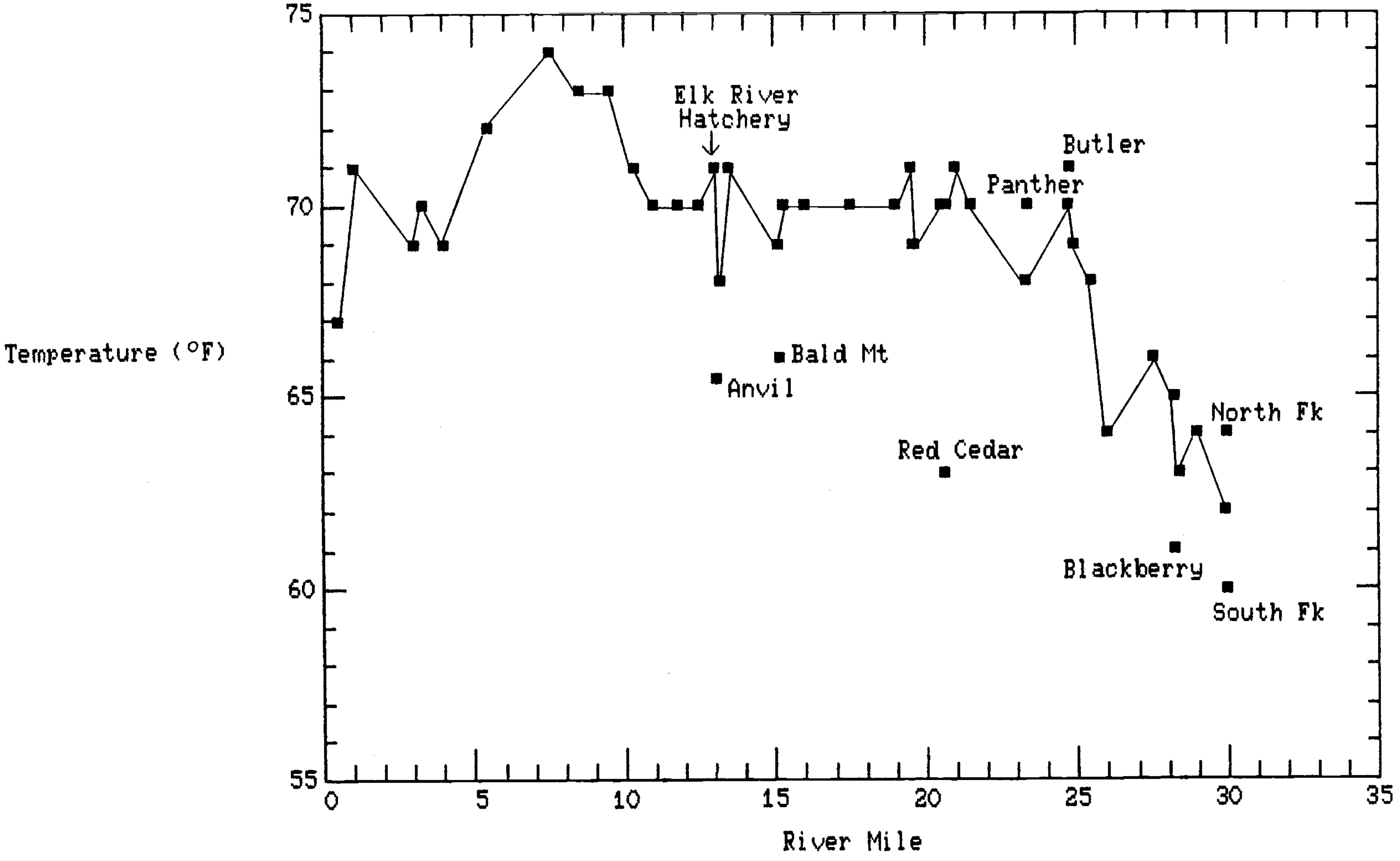

Figure 16. Stream temperatures of the Elk River and selected tributaries during 1600-1800 hours, August 10, 1978.

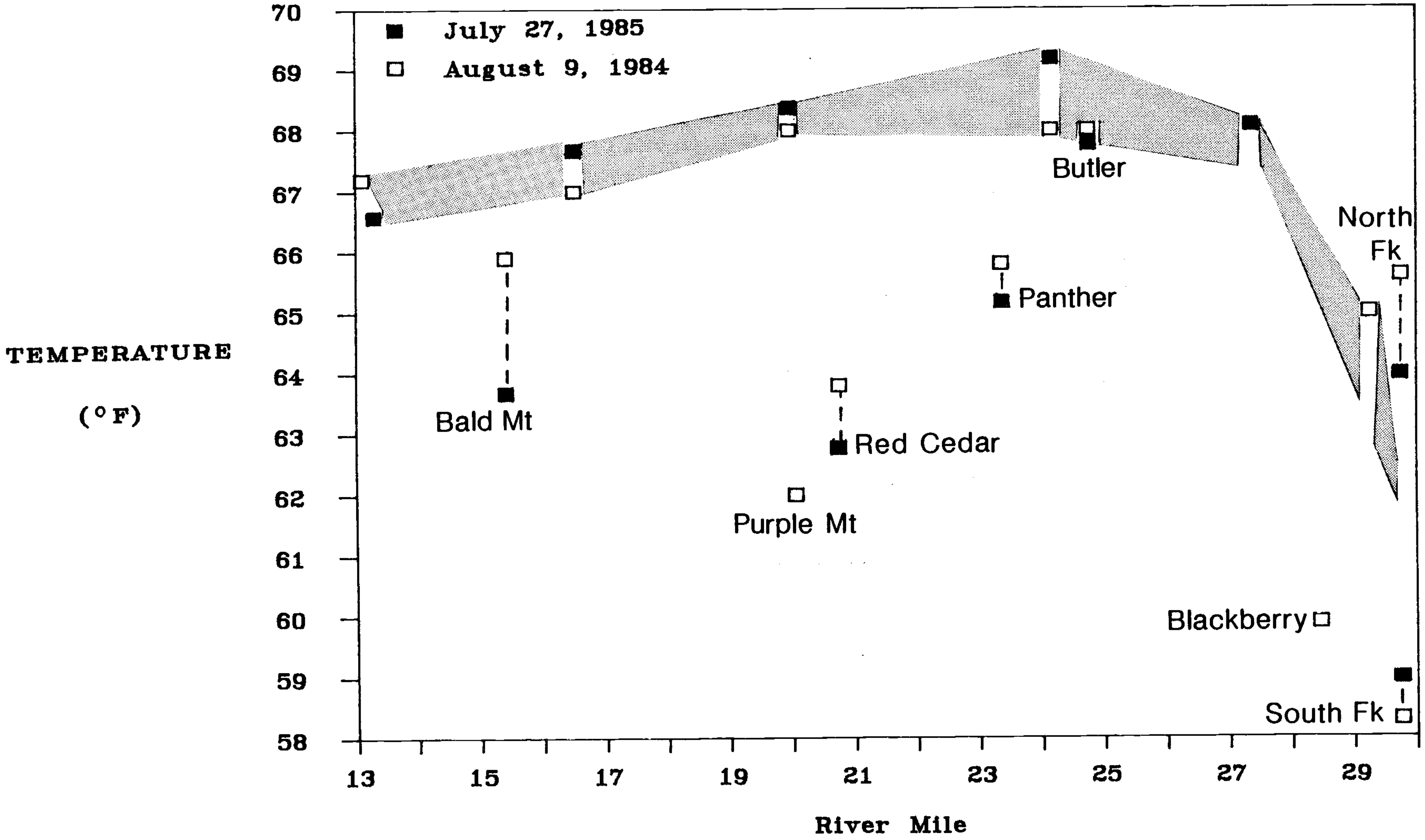

Figure 17. Maximum stream temperatures of the Elk River and selected tributaries for August 9, 1984 and July 27, 1985.

in 1984 reached 67.2°F (19.5°C), with maximum temperatures of 68°F (20°C) and higher in the mainstem from approximately mile 19 to 25 (km 30.6 to 40.2). The three warmest tributaries in the system, Butler Cr., Panther Cr., and Bald Mt. Cr., had maximum temperatures of 66 to 68°F (19 to 20°C). The North Fk. of the Elk River was also found to be one of the warmest tributaries, it's maximum attaining 65.8°F (18.8°C), the same as Panther Cr. and Bald Mt. Cr. The South Fk. of the Elk River remained relatively cool (maximum temperature of 58.5°F [14.7°C]), due to a long expanse of subsurface flow. Purple Mt. Cr. also had low maximum temperatures (62°F [16.6°C]); it's waters run subsurface for almost the entire stream length.

The use of the mixing equation (Brown, 1970) results in calculated temperature for 1984 and 1985 of 63°F (17.2°C) and 62°F (16.7°C), respectively, from the combined waters of the North and South Forks. Since no other source of warmed waters exists downstream of this confluence, pronounced warming (approximately 2°F [1.1°C]) occurs along the first 1/2 mi (0.80 km) stretch of the mainstem. Maximum temperatures continue to rise downstream until Butler Bar (Station M5; mile 24.7; km 39.7), despite the addition of cool tributary waters such as Blackberry Cr. and other, smaller creeks not shown. Maximum temperatures begin to decrease downstream of Butler Bar. A similiar situation occurred for the warmest day in 1985.

Figure 18 illustrates the maximum and minimum temperatures for Elk River and selected tributaries for July 27, 1985, the warmest day of the year. From this diagram, it is apparent that

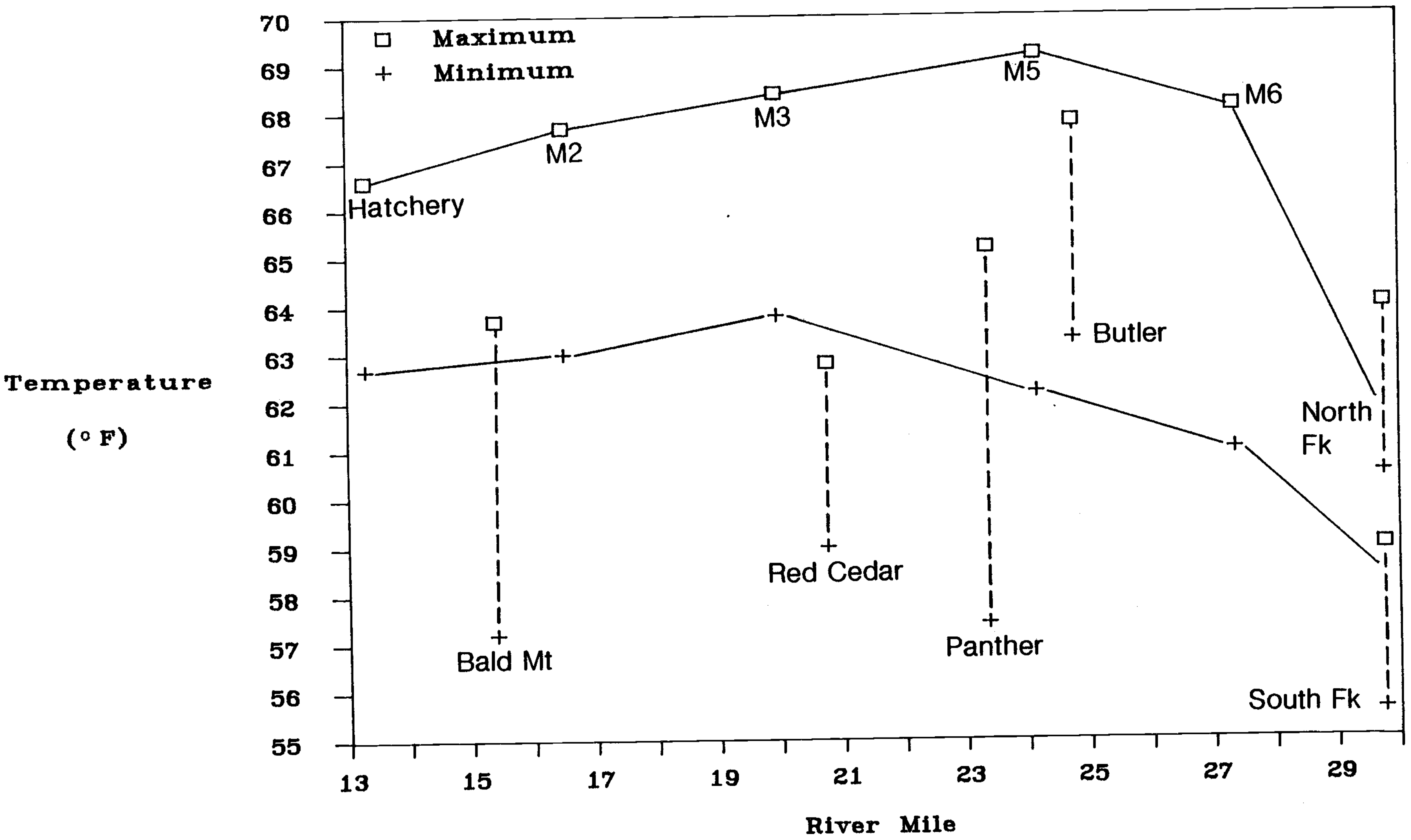

Figure 18. Maximum and minimum stream temperatures of the Elk River and selected tributaries for July 27, 1985.

the majority of heating is taking place between station M5 (mile 24.15; km 38.9) and the North and South Forks of the Elk River (mile 29.7; km 47.9), as indicated by the increase in maximum temperatures and the large diurnal fluctuation (difference between maximum and minimum temperatures). Because of travel times, water heated in this section of the mainstem may be partially responsible for the maximum daily temperature experienced at the downstream hatchery.

Figure 19 illustrates the time of peak temperature occurrence for the Elk River and selected tributaries for July 27, 1985. Knowing the time of peak temperatures at the various mainstem temperature stations, in conjunction with average velocities for the Elk River, one can estimate locations of the centroids of water parcels at various times during the day and night. For example, the maximum temperature at the junction of the North and South Forks of the Elk River occurs at approximately 4:00pm. The following day, the centroid of a water parcel from the Forks is now located at mile 22 (km 35.7) at 6:30am, the time of the minimum temperature (Figure 18). It is water from this location on the river that will later that same day contribute to the maximum temperature at the hatchery at mile 13 at 8:00pm. The same routing process can be done for stations M5 (mile 24; km 38.8), where a water parcel at the time of peak temperature for this station has its centroid located at station M3 (mile 20; km 32) at 6:30am the next day, when the minimum temperature occurs. Calculations indicate that at 5:00pm in the afternoon, the centroid of this water parcel will be in the vicinity of mile 8 (km

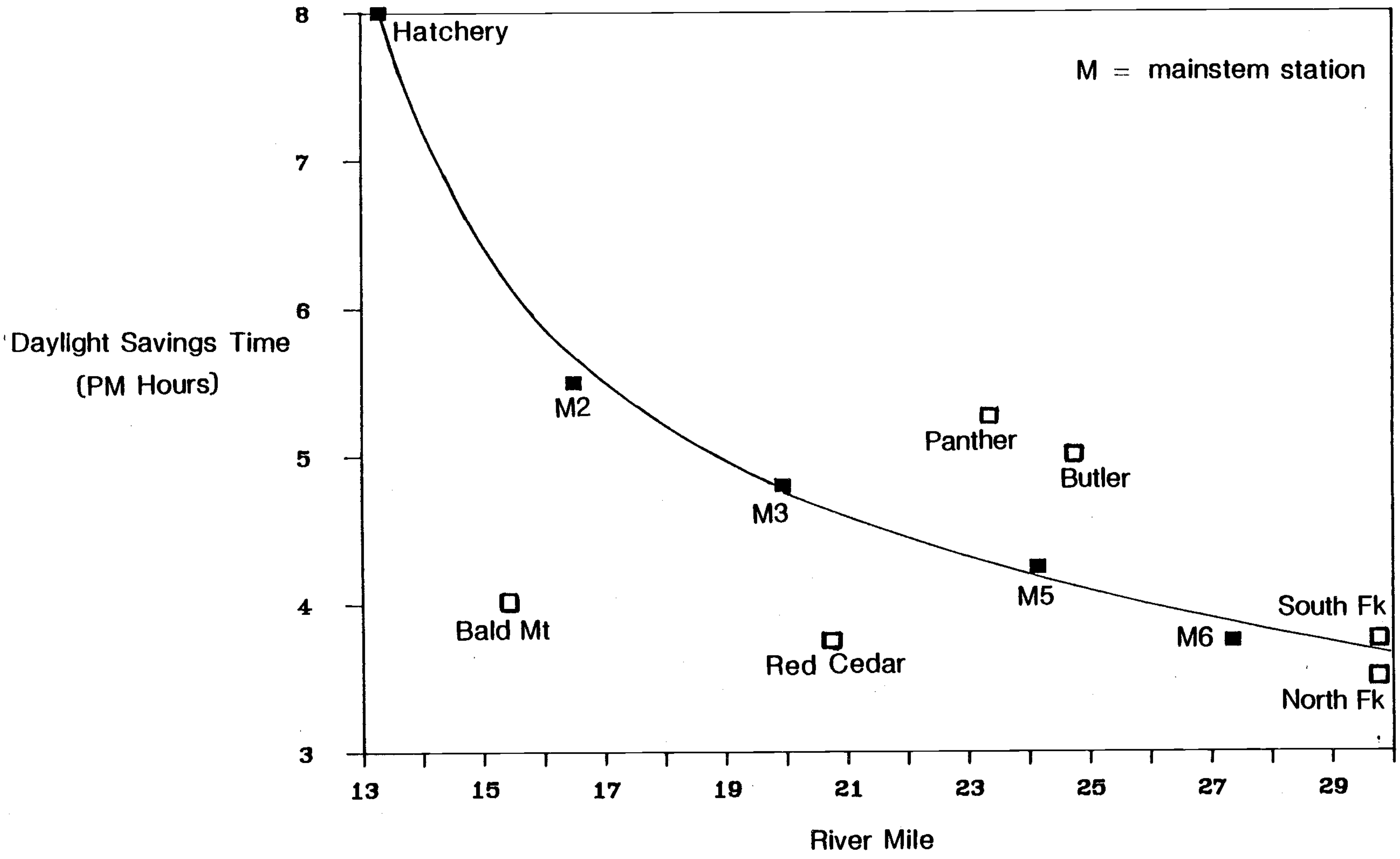

Figure 19. Timing of peak temperature occurrence of the Elk River and selected tributaries for July 27, 1985.

13), 5 mi (8 km) downstream of the hatchery, where the warmest area of the system is located (Figures 15 and 16).

Based on travel time considerations, it appears that heating between M5 (mile 24; km 38.9) and the North and South Forks of the Elk River (mile 29.7; km 47.9) is at least partially responsible for the maximum temperatures downstream (near the hatchery). High downstream maximum temperatures are particularly due to high minimum temperatures (between approximately mile 13 - 23) occurring downstream from the heating zone the following morning. Beginning with the high minimum values in the morning hours, continual heating during the afternoon results in high peak temperatures.

The addition of tributary waters also affects the mainstem temperatures by either cooling it, as does Red Cedar Cr., or by contributing to the increase in temperature as Bald Mt. Cr. appears to do. Although the maximum temperature of Bald Mt. Cr. does not approach that of the mainstem, the peak in temperature occurs earlier in the tributary (approximately 3-4 hours) in comparison to the time of peak temperature in the mainstem. Thus, these tributary waters can contribute to an increase in the rising limb of the daily thermograph. Figure 18 also illustrates that drainages facing the north, such as Bald Mt. Cr., Panther Cr., and the South Fork Elk River, have relatively low minimum temperatures. The South Fork of the Elk River, however, also shows a relatively small diurnal temperature fluctuation of about 4°F (2.2 °C), which is likely due to subsurface flow along the South Fork channel, allowing little input of solar radiation during the day and resulting in a relatively depressed maximum temperature. The diurnal fluctuations of the mainstem temperatures are seen to be quite large upstream (7 F at M6, mile 27; km 22.5), but continually decrease downstream to 4°F at the hatchery (mile 13; km 21).

Channel Morphology, Sediment, and Stream Temperature

Diurnal temperature fluctuations of the Elk River tributaries were found to be positively correlated with drainage area (Figure 20, $r = 0.68$; significance < 0.01), as previously seen in the Carnation Cr. temperature study (Holtby and Newcombe, 1982). An increase in wetted surface width is also found to be coincident with increasing drainage area (Figure 21, $r = 0.82$; significance < 0.01), and with wider streams the amount of shade available to the stream diminishes (Figure 22) allowing for greater exposure to incoming short wave radiation. In both Figures 22 and 23, the East Fk. Butler value (i.e. tributary # 1) is excluded from the regression due to the occurrence of subsurface flow which provides greater cover than measured with the canopy densiometer.

Where stream reaches are low in gradient ($< 3\%$), and the accumulation of sediment forms shallow, gravelly reaches, the diurnal temperature fluctuation may increase due to increased surface area, large travel time (low gradient), and a high amount of exposure (little canopy cover) (Figure 23). For example, the reach upstream of the Mid-Reach station in Panther Cr. has an average width of 24 ft (7 m), and is characterized by a shallow, gravel/cobble channel forming numerous mid-and side-channel bars, with a wide, terraced flood plain, and an average gradient of approximately 1%. Below the Mid-Reach station, the more competent

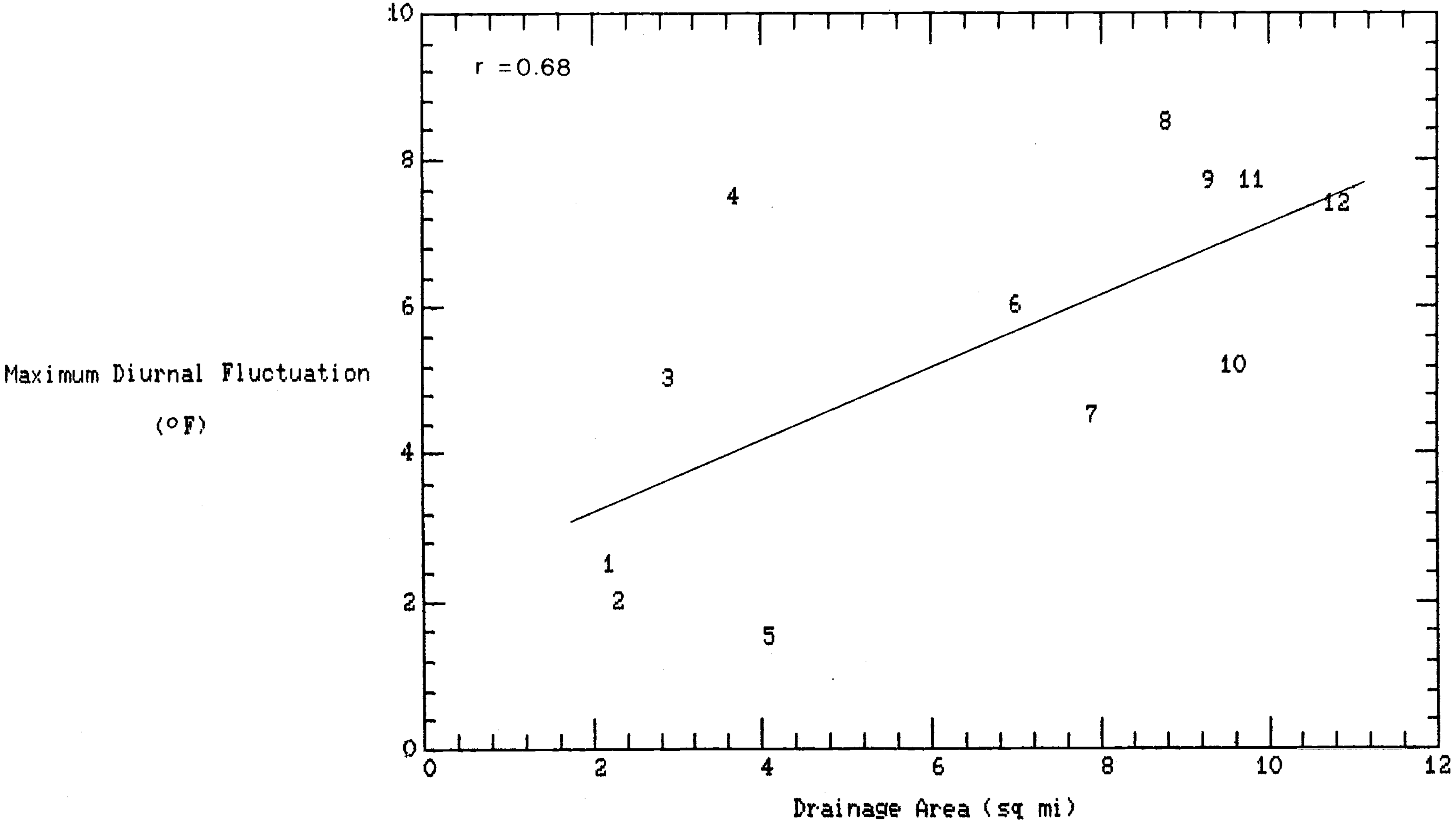

Figure 20. Maximum diurnal temperature fluctuations vs. drainage area for selected Elk River tributaries. Note: numbers correspond to tributaries in Table 2.

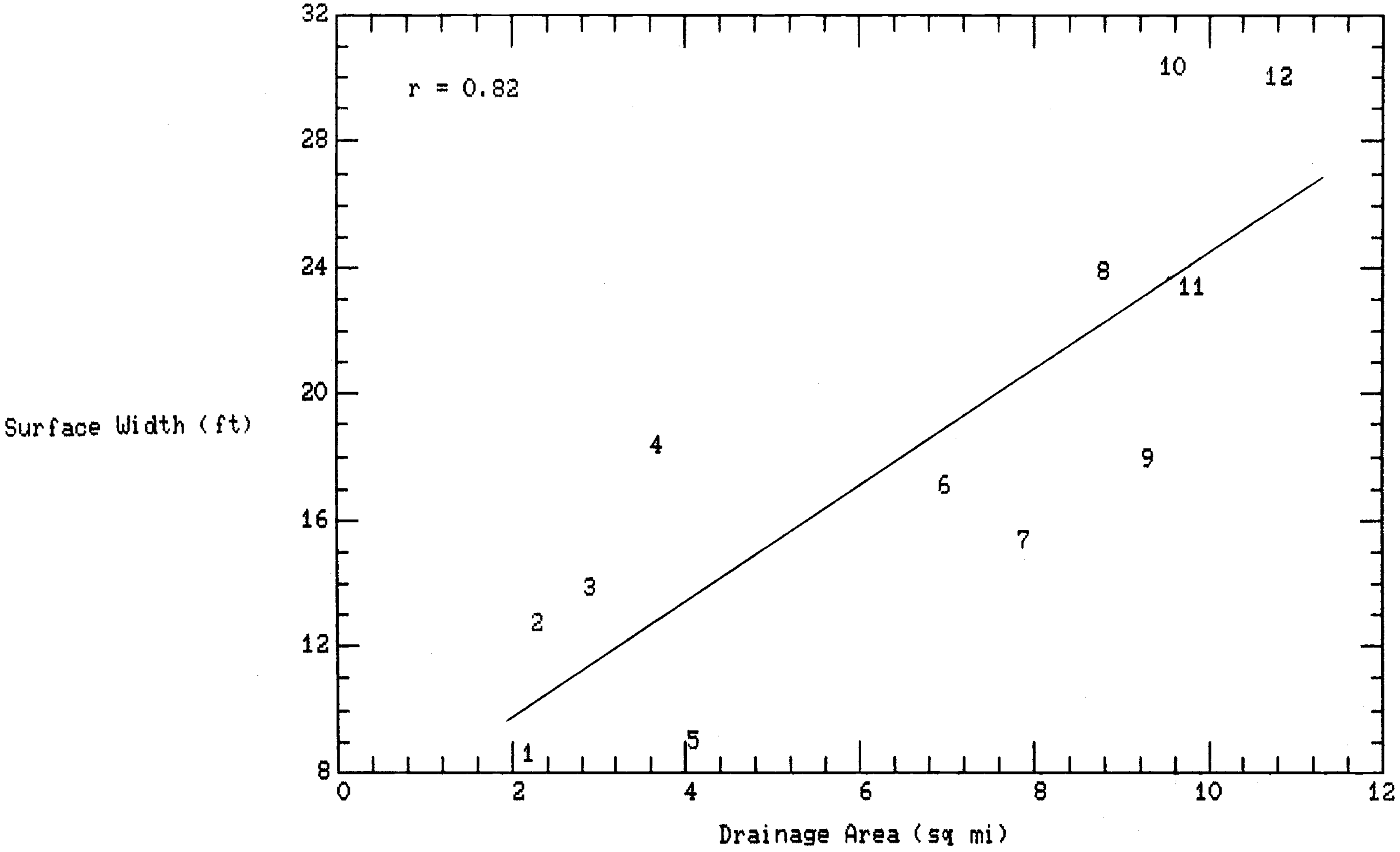

Figure 21. Average wetted surface width vs. drainage area for selected Elk River tributaries. Note: numbers correspond to tributaries in Table 2.

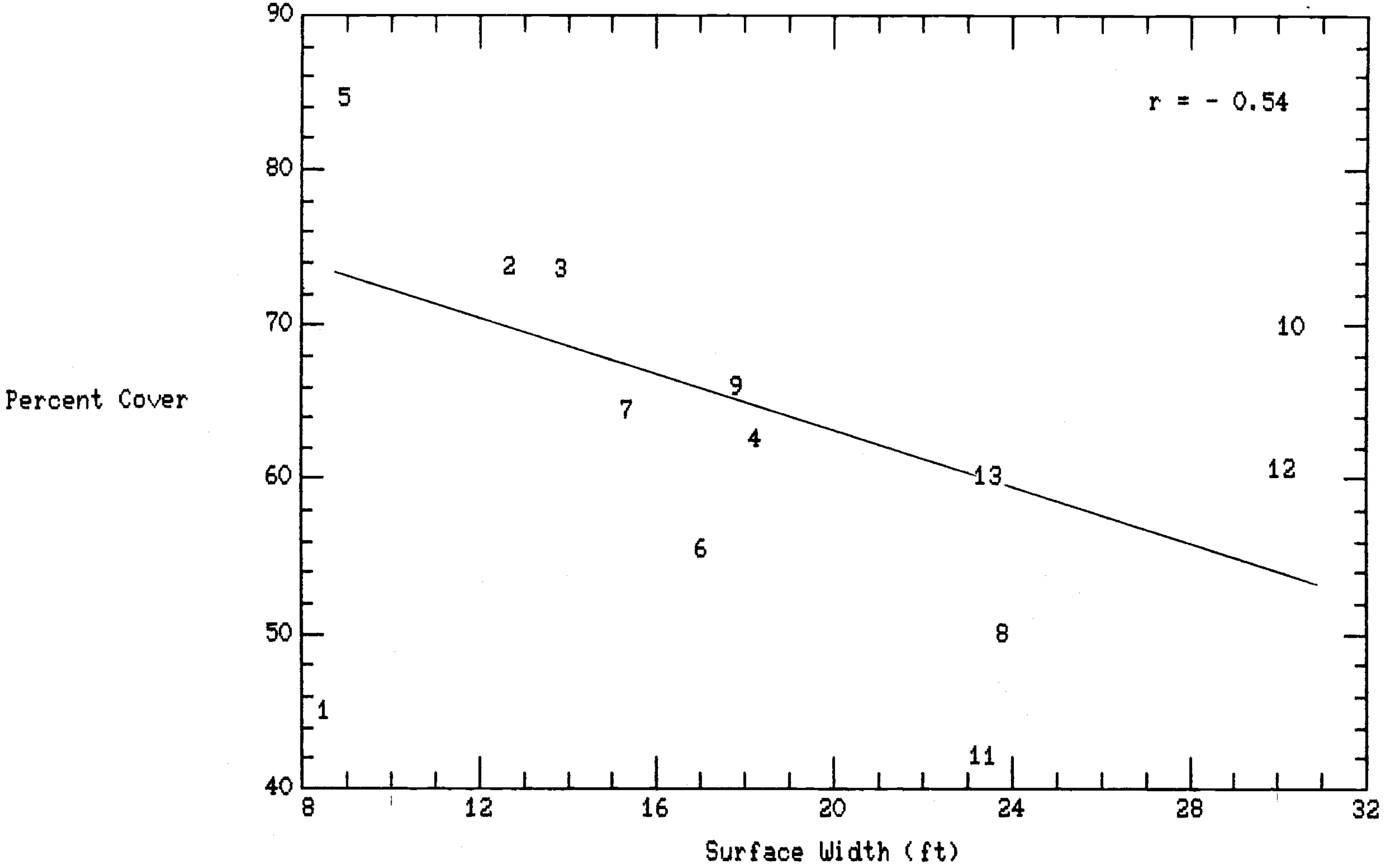

Figure 22. Average percent cover vs. average stream surface width for selected Elk River tributaries. Note: numbers correspond to tributaries in Table 2. Tributary 1 was excluded from analysis due to subsurface flow.

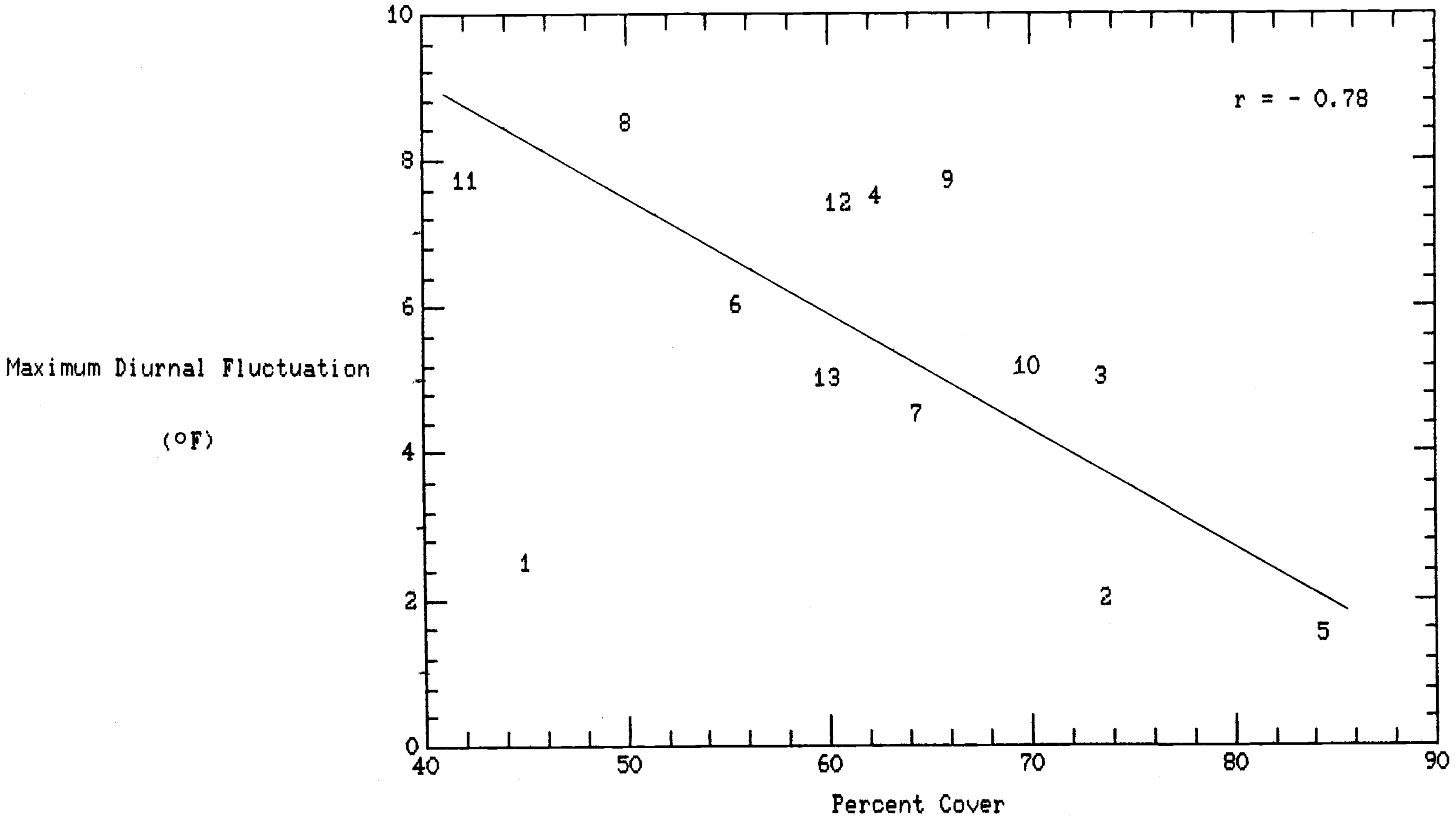

Figure 23. Maximum diurnal temperature fluctuation vs. average percent stream cover for selected Elk River tributaries. Note: numbers correspond to tributaries in Table 2. Tributary 1 excluded from analysis due to subsurface flow.

rock type, resistant to erosion, is characterized by a narrow, sediment "poor" bedrock channel with a higher gradient (approximately 4%) and an average width of 18 ft (5 m) (Figure 24). Similarly, active channel widths of three rivers in New Mexico increased from an average of 10 ft (3 m) to between 20 ft (6 m) and 30 ft (9 m) when the rock type changed from a more competent granite intrusion to unconsolidated sediments of the Santa Fe formation (Miller, 1958).

The width-to-depth ratio in the section above the Mid-Reach station was 18.5 and percent exposure to solar radiation was 50%. Below the Mid-Reach station, the width-to-depth ratio was 11.7, indicating a relatively narrow, deep channel compared to above the station, with 34% of the stream exposed to incident solar radiation. Figure 25 portrays the diurnal water temperature pattern over a two-day period at three stations along Panther Cr. for August 16 & 17, 1984. Although the peaks in temperature were at approximtely the same times in the afternoon for each of the three stations, most of the increase in temperature occurred between the Forks and the Mid-Reach station (i.e., the wide, low gradient, sediment "rich" section).

Figures 26 and 27 illustrate the differences in morphometry of Panther Cr. between the forks and the confluence with the Elk River. The most common width is 18 ft (5.5 m) for the Forks to Mid Reach section, with 21% of the channel with widths greater than or equal to 30 ft (9 m). In comparison, the peak in frequency of widths for the Mid-Reach to Mouth section is 14 ft (4.3 m), with only 3% of the channel widths greater than or equal to 30

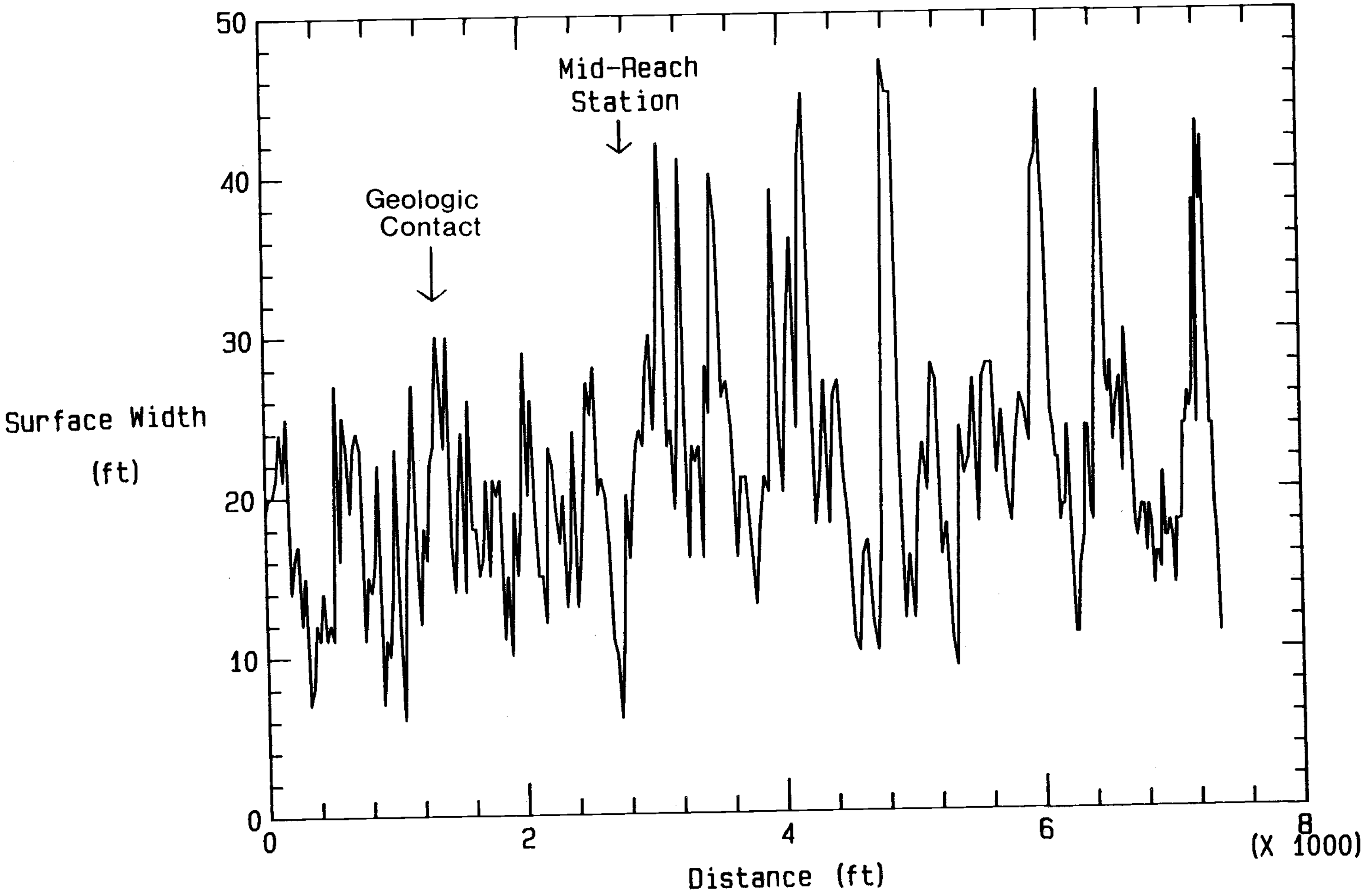

Figure 24. Surface width of the Panther Cr. tributary from the confluence with the Elk River to the forks.

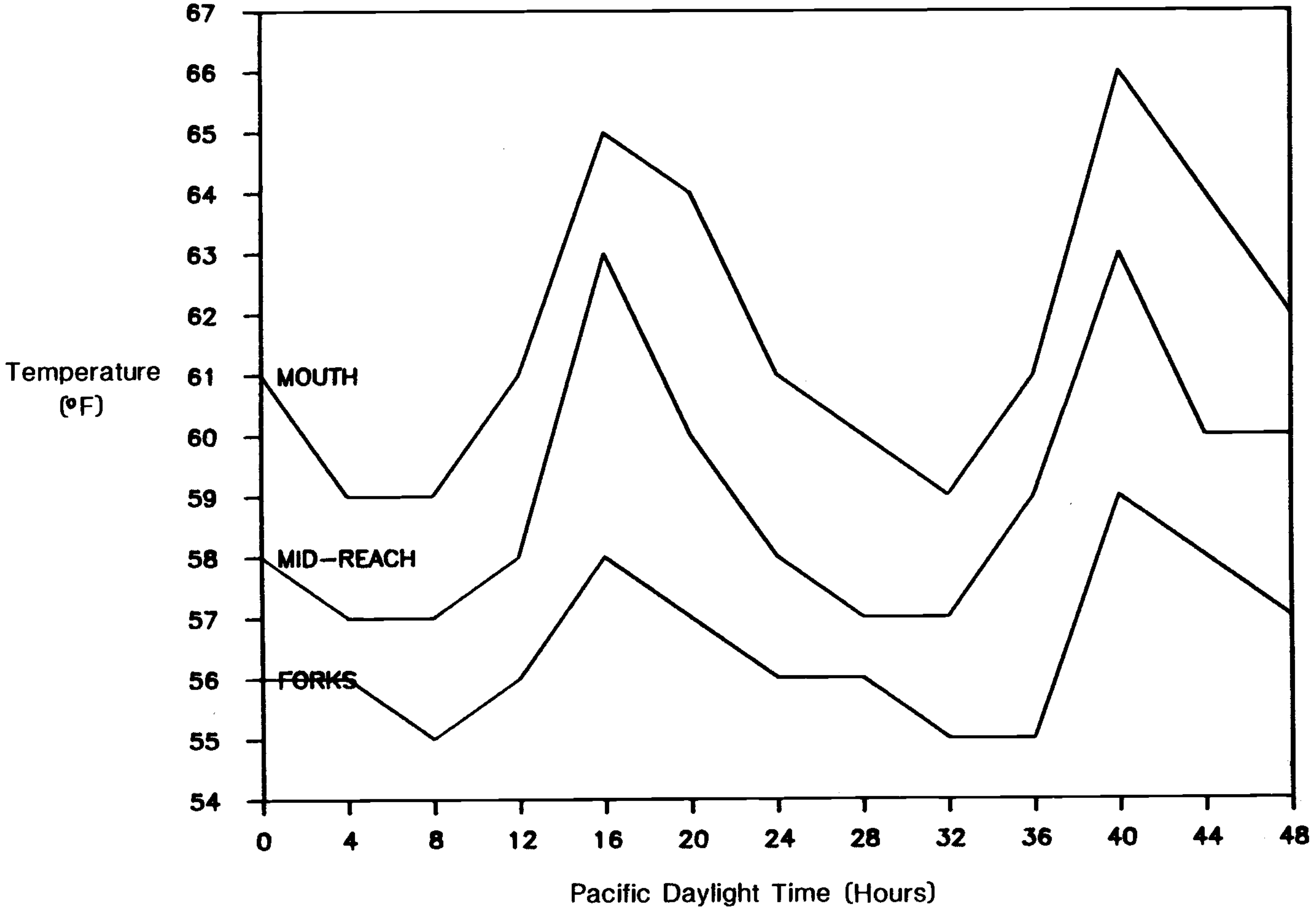

Figure 25. 48-hour temperature profile for three stations in the Panther Cr. tributary, August 16 and 17, 1984.

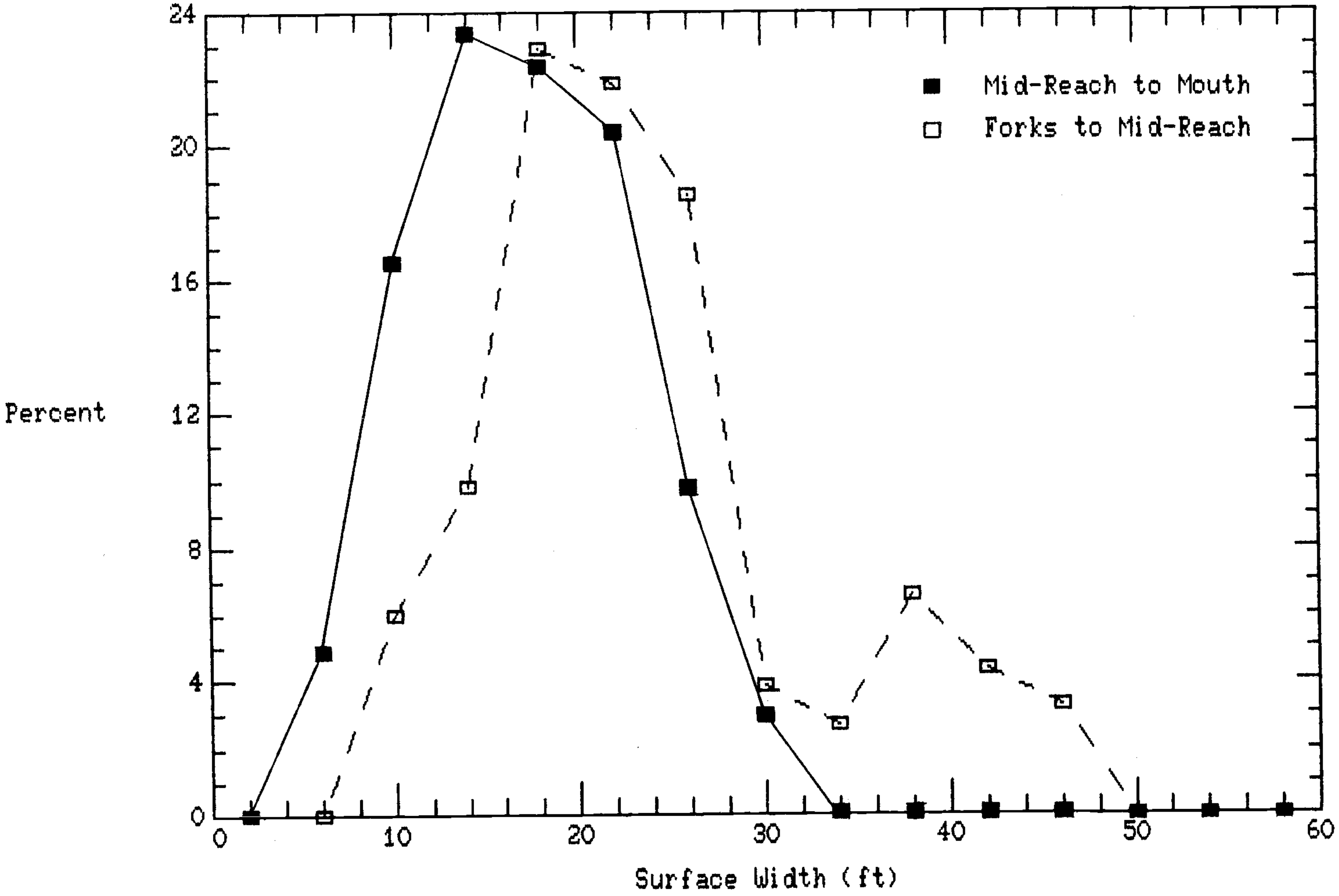

Figure 26. Relative frequency of wetted surface widths from the Forks to Mid-Reach station and the Mid-Reach to Mouth station of the Panther Cr. tributary.

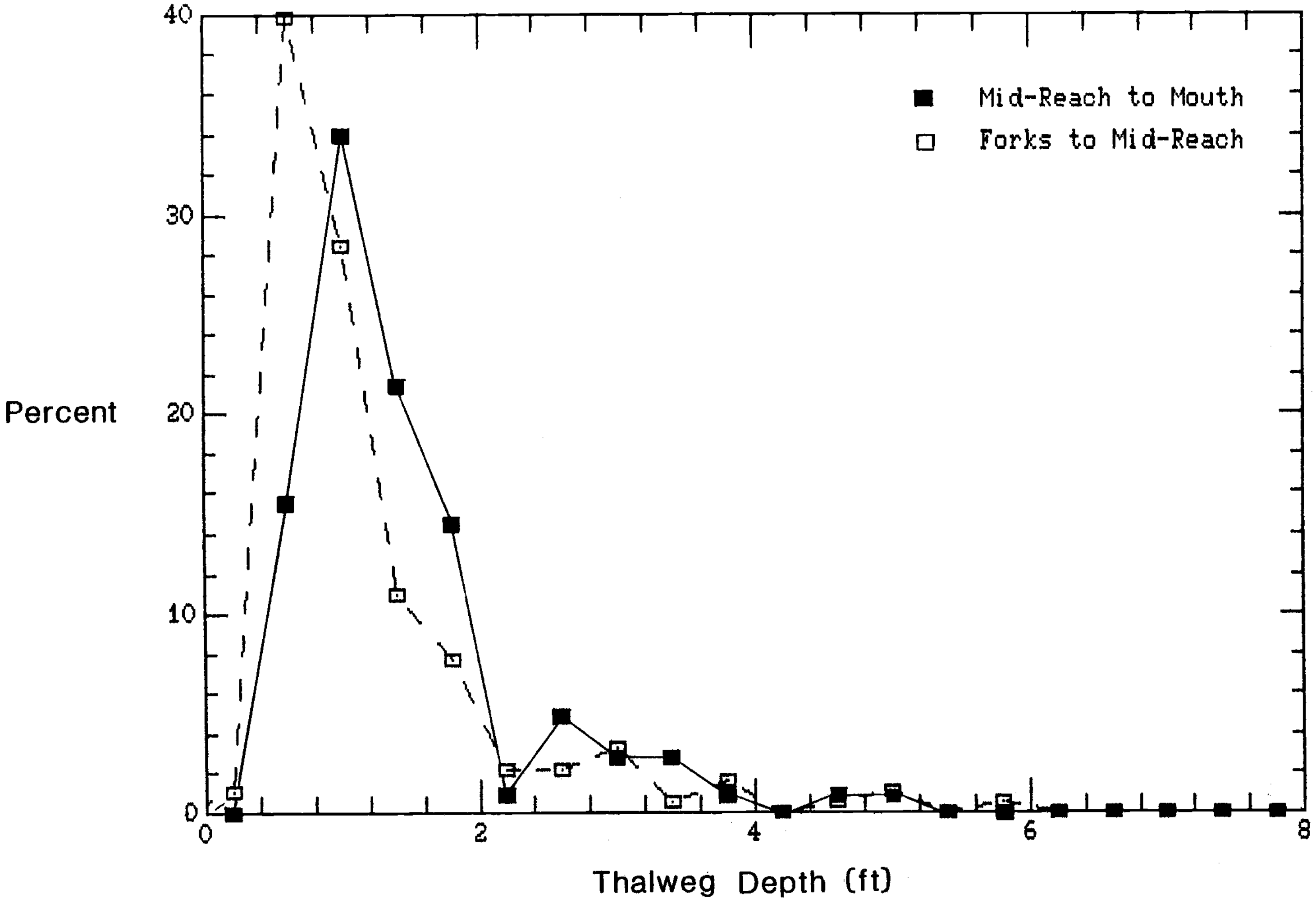

Figure 27. Relative frequency of thalweg depths from the Forks to Mid-Reach station and the Mid-Reach to Mouth station of the Panther Cr. tributary.

ft (9 m). The relative frequencies in depth for the Forks to Mid-Reach stream section shows 40% of the channel associated with a depth of 0.6 ft (0.18 m) and only 32% with depths larger than 1 ft (0.3 m). The Mid-Reach to Mouth span shows 34% of the channel associated with a depth of 1 ft (0.3 m) and 51% with thalweg depths greater than 1 ft (0.3 m). Because of the change in geology and the constriction caused by the contact between the more easily eroded Galice Fm and the indurated Humbug Mt. Conglomerate, aggradation in the reach above the contact (Forks to Mid-Reach), has historically been high as determined by analysis of aerial photos from as early as 1943. However, the photos also indicate that an increase in sedimentation and further widening of the channel has taken place over the last several years and has occurred concurrent with harvest activities in the Panther Cr. basin (McHugh, 1986).

Although wide streams are a significant factor contributing to higher water temperatures (a correlation coefficient between stream width and diurnal temperature fluctuation of 0.67 in this study), other factors are also important. For example, the surface area to volume ratio for all tributary streams (Figure 28) appears to show a negative correlation with diurnal temperature fluctuations. Closer inspection, however, reveals that lines drawn connecting points representing tributaries of relatively equal area, results in a positive correlation.

Since the surface area (L•W) to volume (L•W•D) ratio is basically the inverse of depth (1 / D), and assuming that the basin area can be substituted for discharge in a general sense,

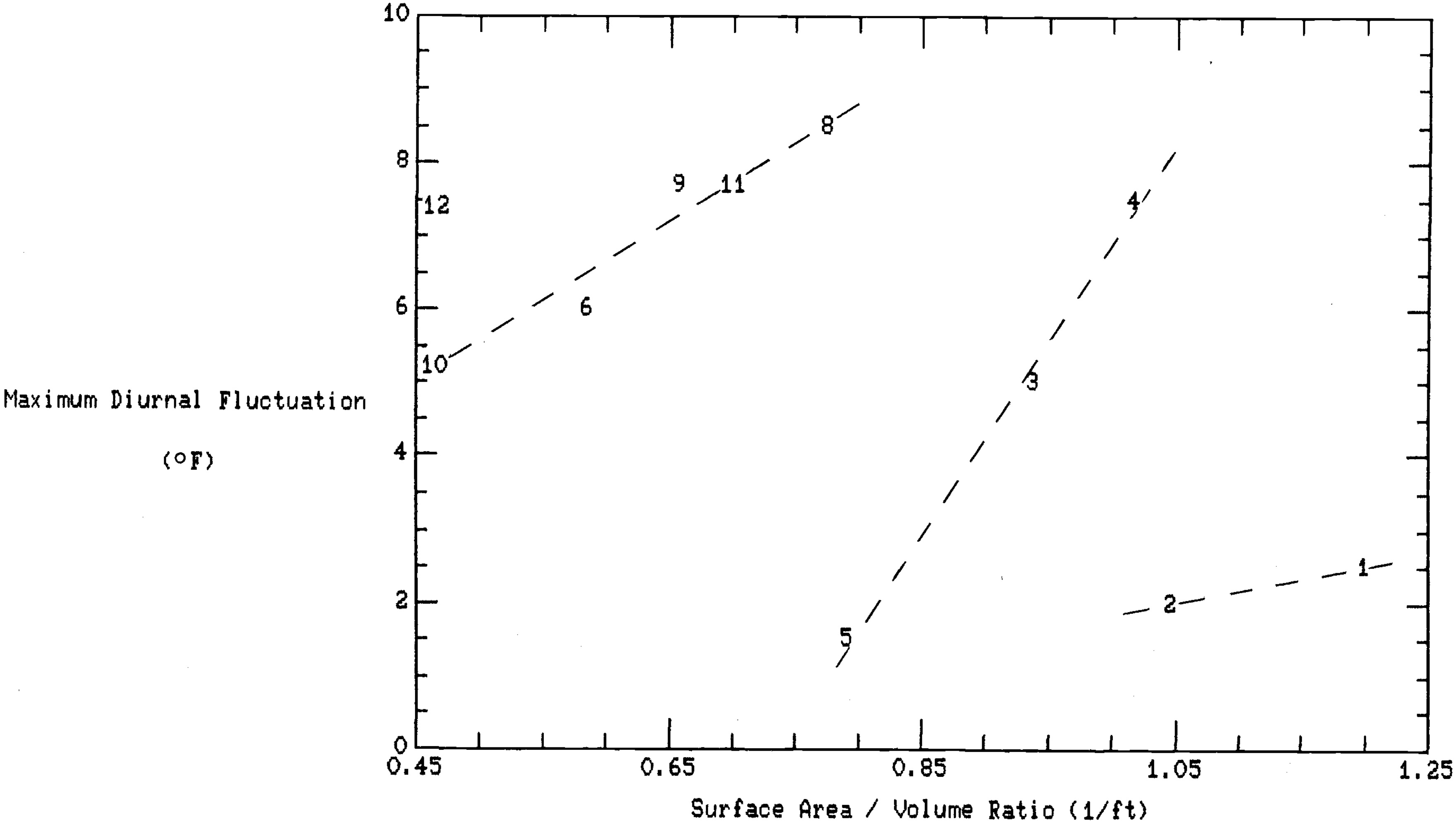

Figure 28. Maximum diurnal temperature fluctuation vs. surface area to volume ratio for selected Elk River tributaries. Note: numbers correspond to tributaries in Table 2. Lines connect tributaries of relatively equal drainage areas.

(correlation between basin area and discharge = 0.88; significance < 0.01; from table 2), Figure 28 indicates that for streams with similar discharge, a decrease in depth leads to an increase in diurnal fluctuation. Hack (1957), noted that enlargement of drainage area is accompanied by proportional increases in discharge. Concomitant with wide channels, streams with larger drainage areas also are deeper (Figure 29), and thus have smaller surface area to volume ratios (Figure 30) than smaller stream systems. Use of this ratio for explanations regarding diurnal temperature fluctuations should, therefore, be limited to streams of equal discharge.

Perhaps a more suitable variable for comparing tributaries is the width-to-depth ratio, which is not significantly correlated with basin area (r = 0.30; significance < 0.40; from table 2). Hack (1957), found that the rate change of width as drainage area increases is greater than the rate change of depth. However, the relationship was demonstrated for areas ranging from 1 to 1,000 sq mi (2.6 to 2,560 sq km), with extensive scatter about each regression line for width and depth. Tributaries in the Elk River Basin range from 1 to 20 sq mi (2.6 to 51 sq km) in area.

According to Leopold, Wolman and Miller (1964), width = $f\ \{Q^{0.5}\}$ and depth = $f\ \{Q^{0.4}\}$ in a downstream direction. Substitution of drainage area, A, for discharge, Q, in the above equations results in width-to-depth ratio as some function of drainage area to the 0.1 power ($W / D = f\ \{ A^{0.1} \}$); a relationship that is weakly dependent on "A". Data from the Elk River also supports a similar conclusion. Using the logarithms of the width-to-depth

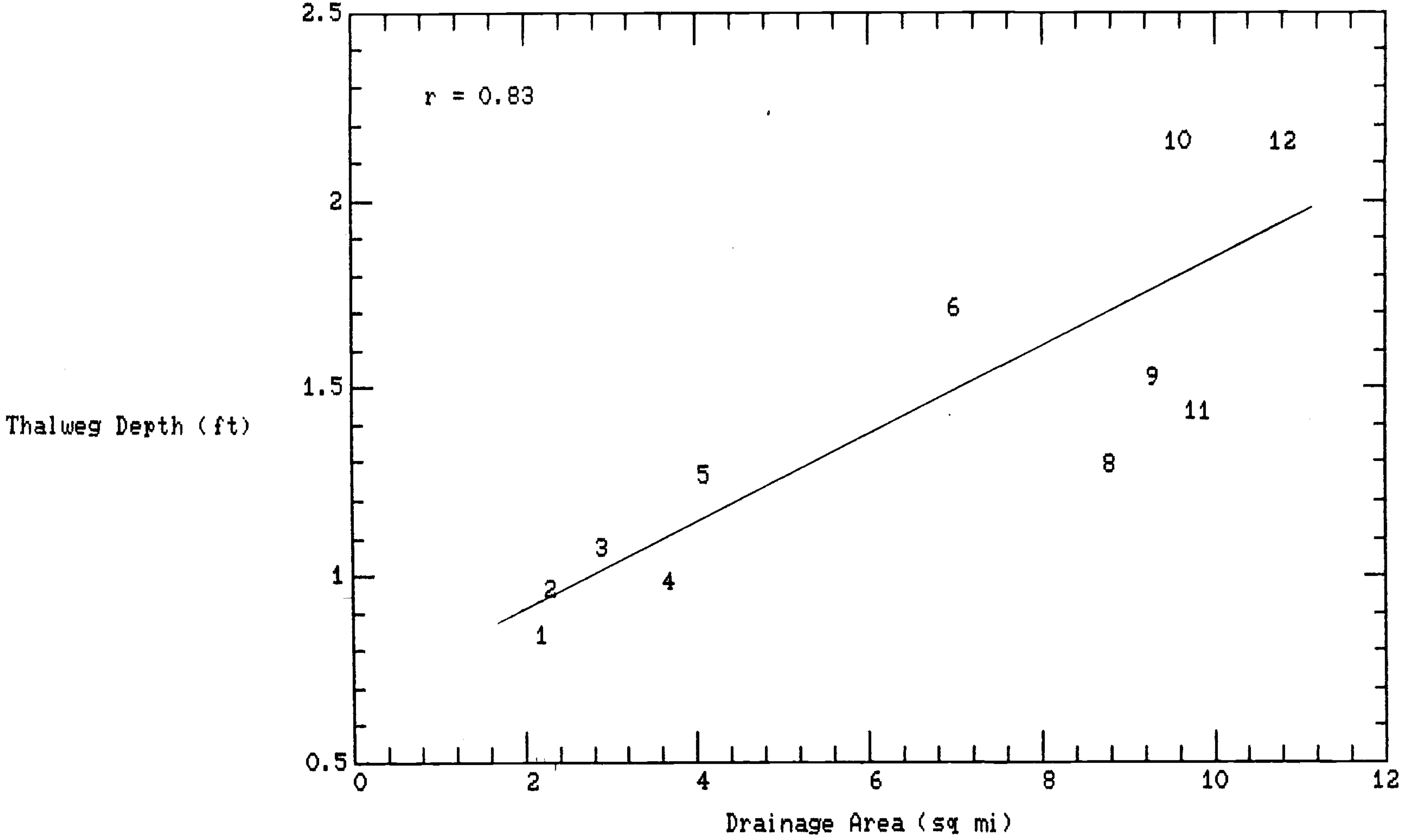

Figure 29. Average thalweg depth vs. drainage area for selected Elk River tributaries. Note: numbers correspond to tributaries in Table 2.

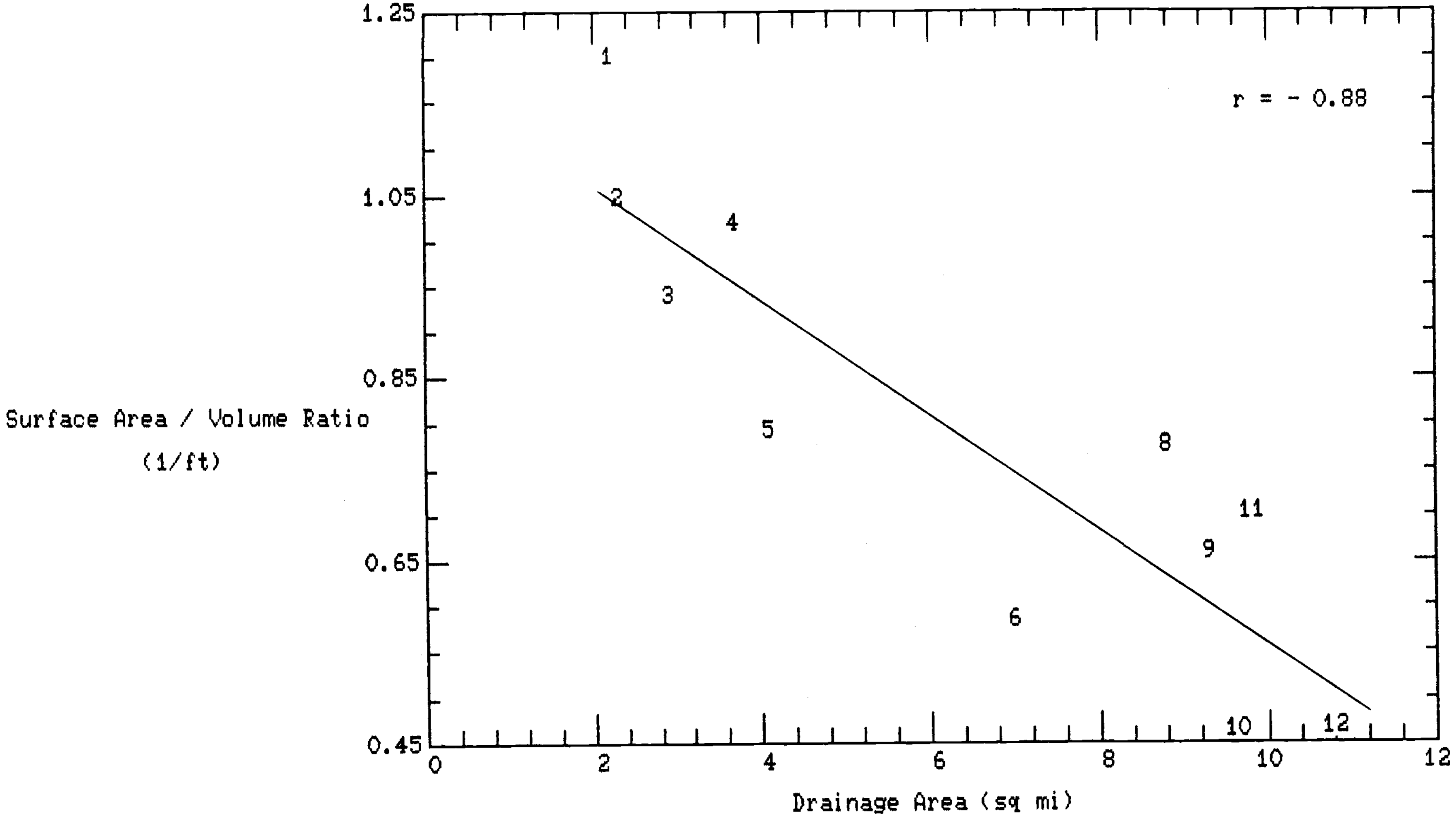

Figure 30. Surface area to volume ratio vs. drainage area of selected Elk River tributaries. Note: numbers correspond to tributaries in Table 2.

ratio and the logarithms of basin area, a regression slope of 0.13 was calculated, which is the same as w/d = f {$A^{0.13}$}. This means that in comparing width/depth with an area of 1 sq mi (2.6 sq km) to one of 20 sq mi (51 sq km), an increase in the ratio of 0.5 is directly related to basin area. Miller (1958), also related widths and depths to drainage area for four rivers in north central New Mexico, and developed power functions for the drainage areas to calculate width and depths. Using those equations, the average width/depth was found to be a function of drainage area to the 0.13 power. The basin areas included in Miller's study were from 0.4 sq mi (1 sq km) to over 100 sq mi (256 sq km).

A significant correlation ($r = 0.76$; significance < 0.01) was found between the diurnal temperature fluctuation and width/depth ratios (Figure 31) indicating (as expected) that wide, shallow streams heat more easily. To evaluate if management activities have changed width-to-depth ratios, a t-test was performed on the average width-to-depth ratios for managed vs unmanaged streams. Although the average width/depth was 10 for unmanaged streams ($n = 2$) and 14 for managed ($n = 9$), the hypothesis that the population means were equal was not rejected at the 10% significance level.

Attempts to more closely evaluate relationships between width-to-depth ratios and diurnal fluctuations in temperature met with minimal success, as comparisons were limited to monitored drainages with similiar geology and for which a monitored control or, unmanaged, system was available. Figure 32 is a frequency diagram of width-to-depth ratios for three tributaries in the Galice formation. Although both the Middle Fork Panther Cr. and

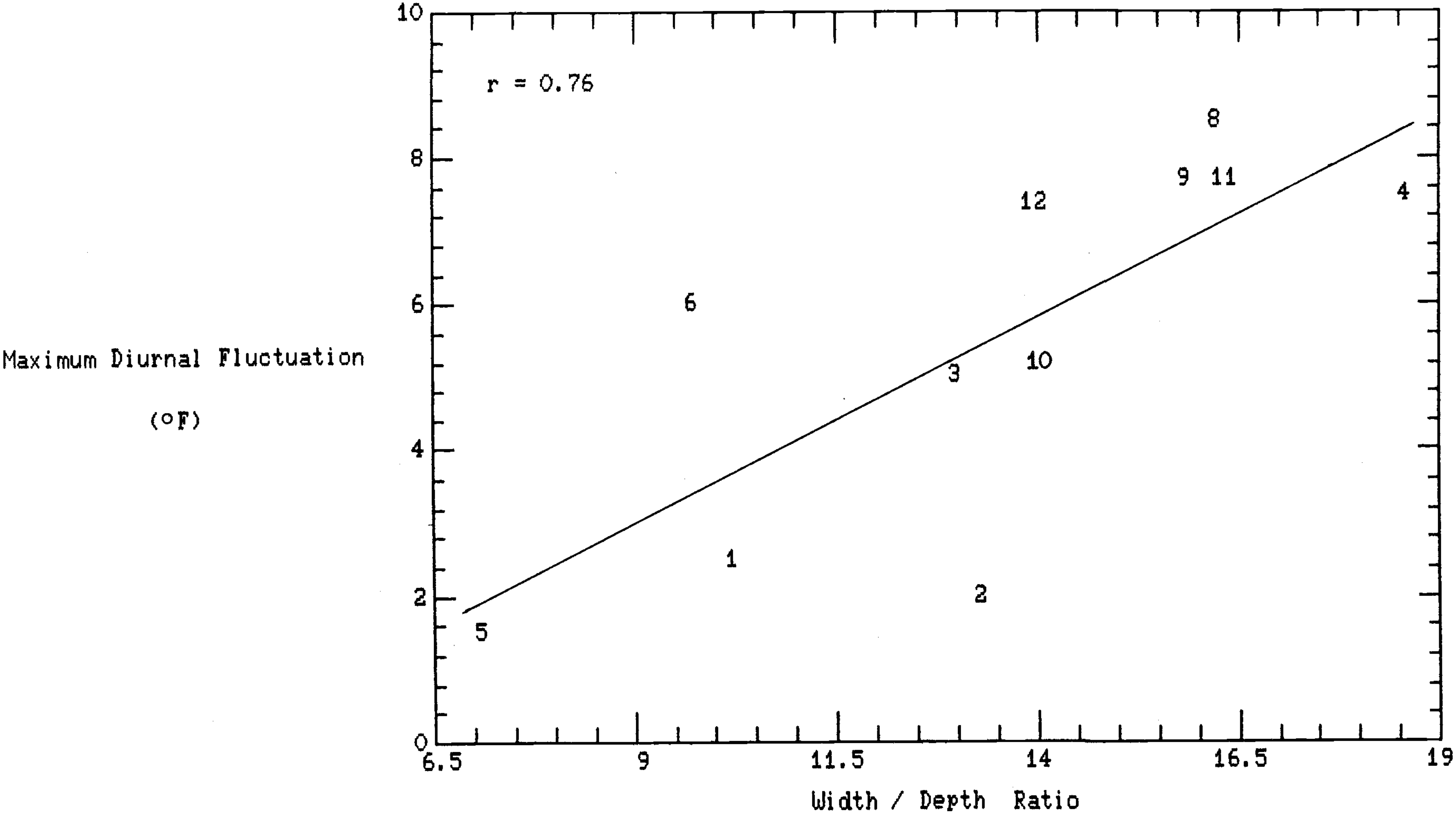

Figure 31. Maximum diurnal temperature fluctuation vs. width to depth ratio for selected Elk River tributaries. Note: numbers correspond to tributaries in Table 2.

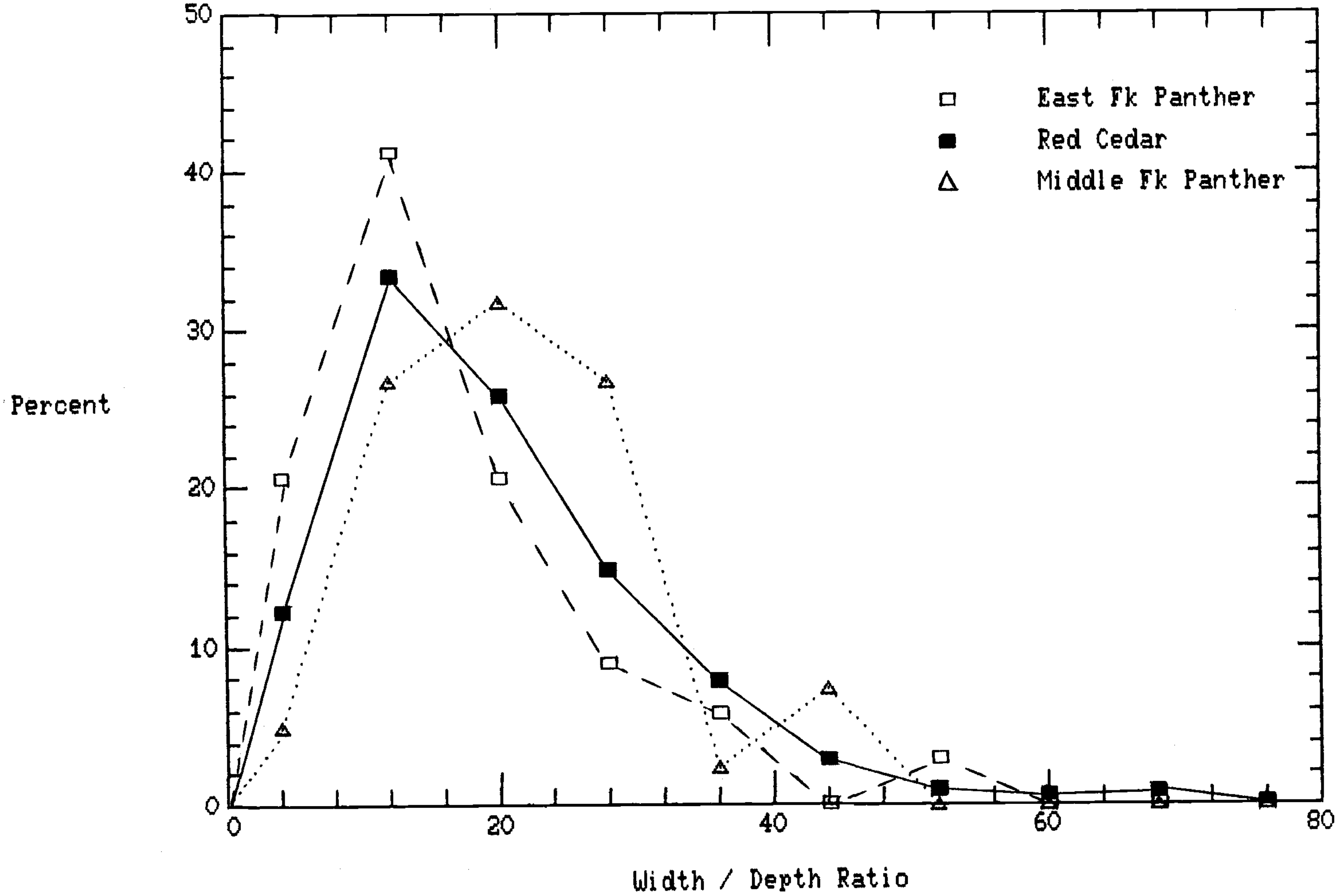

Figure 32. Relative frequency of stream surface width to thalweg depth ratios for the East Fk. Panther Cr., Red Cedar Cr. and Middle Fk. Panther Cr.

Red Cedar Cr. disect the Humbug Mt. Conglomerate further upstream in their headwaters, width and depth values are used only for the reaches in Galice. The relative frequency of width/depth ratios for the unmanaged stream, Red Cedar Cr., peaks at 12, the East Fork Panther Cr. also peaks at 12, and the Middle Fork Panther Cr. peaks at 20. The maximum diurnal fluctuations for the three tributaries were 5°F (2.8°C), 2°F (1.1°C), and 7.5°F (4.2°C), respectively. Comparison of average widths and depths (table 2), reveals that depths are nearly equal for all three tributaries, however, the average width for the Middle Fork is 22% greater than for Red Cedar Cr., and 44% greater than the average width of the East Fork. This suggests that the large width-to-depth ratio for the Middle Fork Panther Cr. is likely due to larger width values than would be expected for a basin of similar area.

To further evaluate some of the variations in width/depth ratios outlined above, the amounts and types of slope failures in each basin were determined. For the Middle Fk. of Panther Cr., calculations indicate that from 1943 (the first aerial photo flight) to 1979, 0.1% of the Middle Fork basin area has experienced mass failures, with 83% of the failure area associated with land use activity such as road construction, harvesting, and/or burning, and 17% due to natural causes and/or wildfire. In contrast, the East Fork has had 0.38% of it's area fail; 64% management related and 36% due to natural causes. (All failure areas and management classifications above, and those to follow, are from individual failures identified by McHugh, (1986). The percentages of each sub-basin with slope failures were then calculated).

Based on the above information, the basin with the greatest area in mass failures was originally expected to have wider channels with warmer stream temperatures, which is opposite to what was observed. A possible explanation lies in the type of failure that occurs within each basin. Upslope and to the east of the East Fork stream, there is a fault block of serpentinite and peridodite (McHugh, 1986), and due to it's natural instability, huge blocks slide off and come to rest in the stream bottom. These blocks provide constriction points for build-up of large woody debris and storage sites behind these dams for sediment entering the system from slope failures. Thus, the gravel, cobble and sand sized sediments are stored at various locations along the reach, and a sequence of "steps" in the longitudinal profile allow for the substantial subsurface flow behind the constrictions and jams.

In contrast, the Middle Fork has little in the way of obstructions to slow the movement of sediments. The linear, high gradient (approximately 50 %) reach is conducive to rapid downstream movement of sediment. The presence of buried logs, "blown out" log jams and large organic debris lying lengthwise along the channel banks all are evidence of a high energy environment for the transport of sediment and water. Thus, instead of having the sediment slowly metered out over time, from one "sink" to the next, as in the East Fork, much of this material in the Middle Fork is deposited where a break in slope occurs, at approximately 3/4 mi (1.2 km) above the forks, to below the forks at the Mid-

Reach constriction in the mainstem Panther Cr.

Red Cedar Cr., part of a designated wilderness area, has had 0.09% of it's area fail in over the past 35 years, all due to natural causes. Like the Middle Fork of Panther Cr., portions of Red Cedar Cr. has aggraded, exhibiting buried logs, shallow riffle reaches, and extensive side-and mid-channel bars. Unlike the Middle Fork, however, the presence of large logs and accumulations of large woody debris in the channel indicate flows have not been able to move debris out of this tributary.

The Butler Cr. tributaries provide another comparison of channel morphometry and temperatures in managed versus natural systems. Figures 33A and 33B illustrate depth and width frequencies for the East and West Forks. Road building and logging began in the early 1960's in the East Fork sub-basin. Surface ravel has since contributed large volumes of sediment to the stream (McHugh, 1986), resulting in subsurface flow of water during the summer low flow periods for most of it's length. The West Fork basin is part of a designated wilderness area. Thalweg depths of the East Fork are all less than 3.0 ft (0.91 m) and only 20% of the channel is equal to or wider than 11 ft (3.4 m). In contrast, the West Fork has 8% of its stream length in pools between 3.0 ft (0.91 m) and 6 ft (1.8 m) deep, and 32% in widths greater than or equal to 11 ft (3.4 m). These larger values for the unmanaged West Fork may be influenced by basin area, which is about double that of the East Fork. Examination of the width/depth frequencies, however, (Figure 34) discloses that the most frequent width/depth ratio is 6 for the West Fork and 10 for the East Fork. Similarly, 45% of

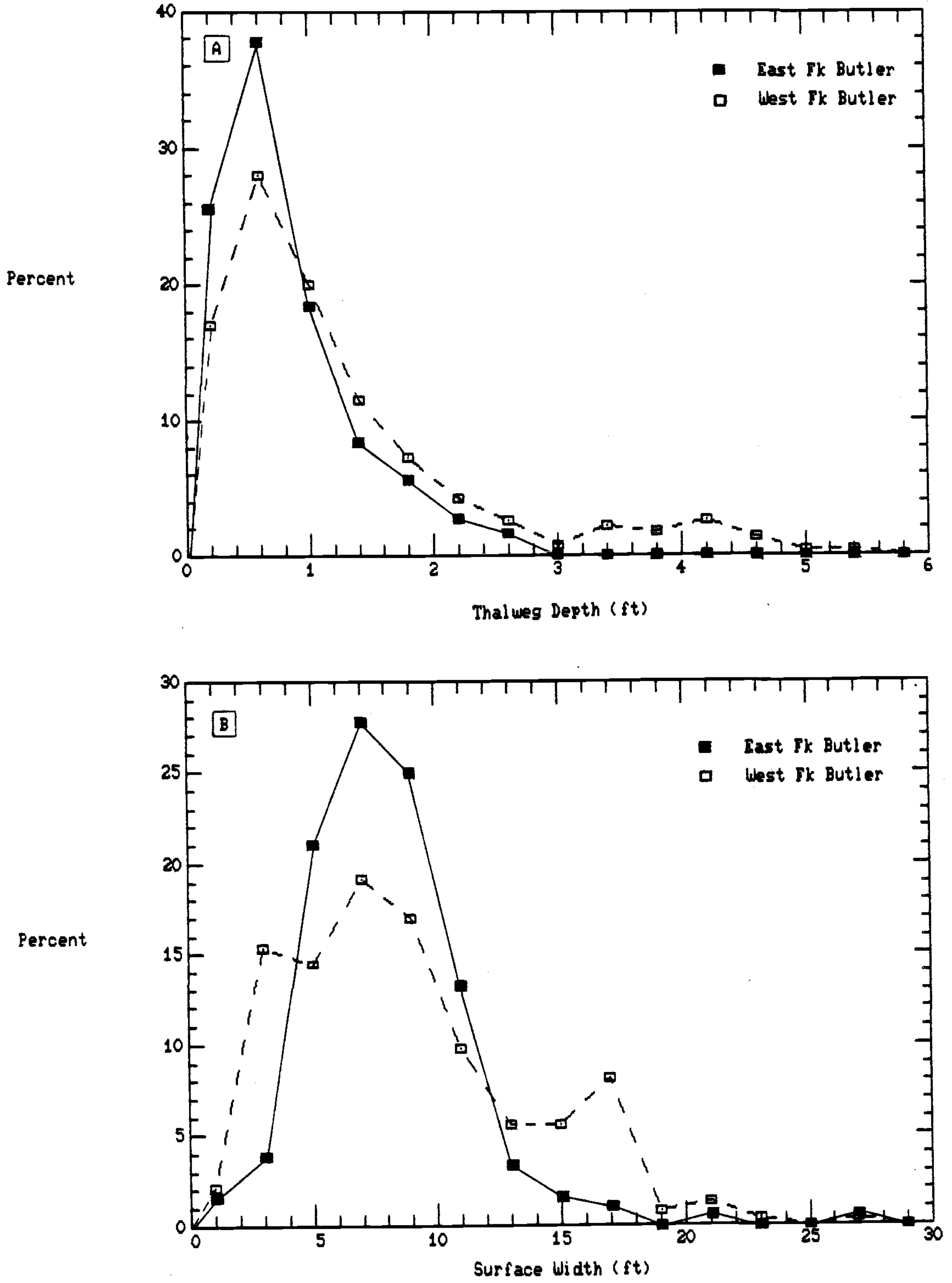

Figure 33. (A) Relative frequency of thalweg depths and (B), relative frequency of stream surface widths for the East Fk. Butler Cr. and West Fk. Butler Cr. tributaries.

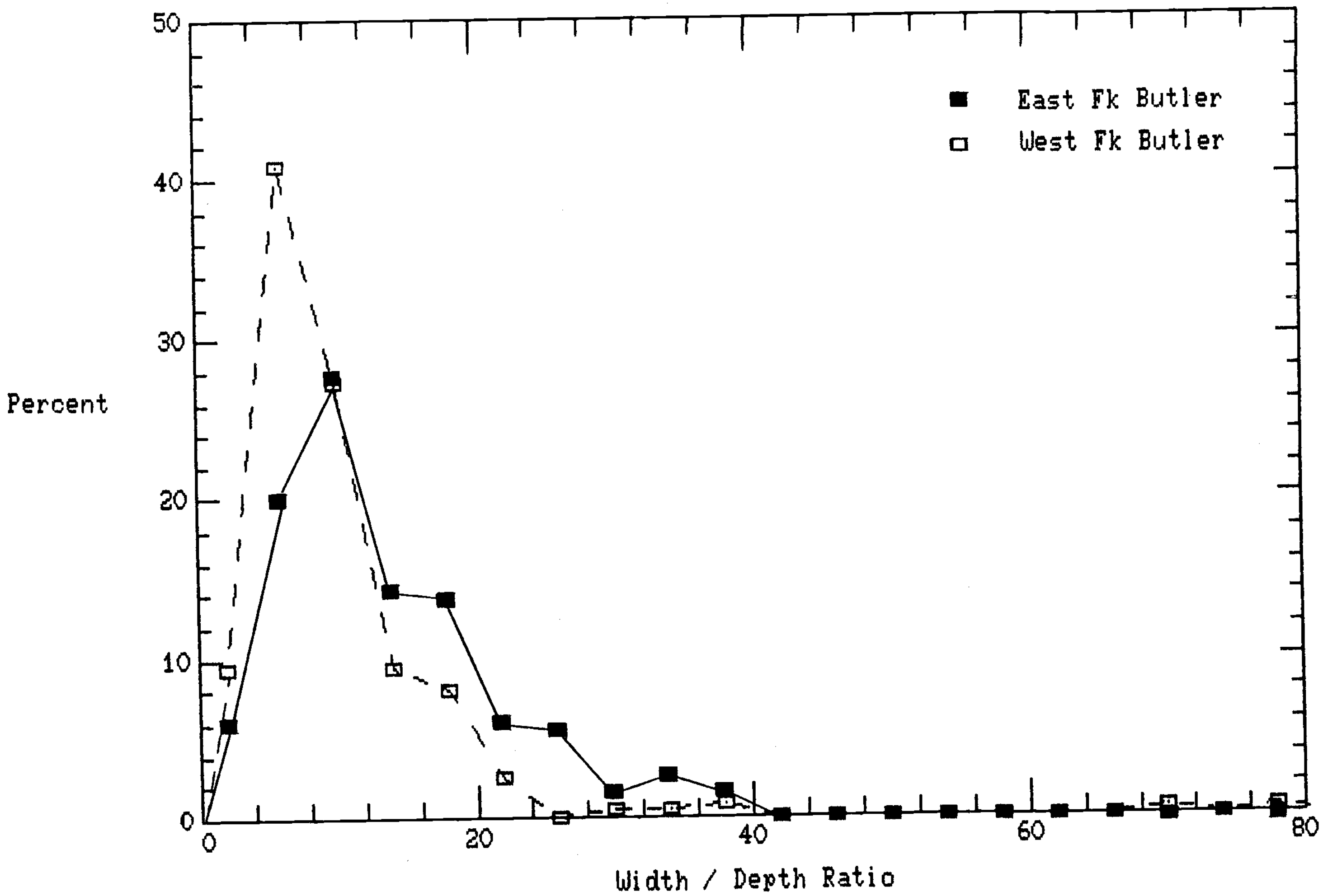

Figure 34. Relative frequency of stream surface width to thalweg depth ratio for the East Fk. Butler Cr. and West Fk. Butler Cr. tributaries.

the East Fork has width/depths greater than or equal to 14, whereas the West Fork has only 20% with width/depths larger than 14, even though it is generally a wider stream. The maximum diurnal temperature fluctuation observed in each tributary was 2.5°F (1.4 °C) and 1.5°F (0.83°C) for the West Fork and East Fork, respectively, with subsurface flow responsible for the low fluctuation in the East Fork.

From the width/depth ratio data and the channel conditions observed in the field, it was apparent that where dispersed storage sites for sediment do not exist along the length of a stream, the input of sediment from slope failures tends to widen and/or shallow the stream channel, resulting in a high value for the width-to-depth ratio. Indirectly, this causes an increase in the temperature fluctuation of the stream water. However, most of the anadromous fish appear to congregate in these low gradient (< 2%), high sediment reaches, where spawning gravels are abundant and low, terraced floodplains provide backwater channels for overwintering (G. Reeves, personal communication). McHugh (1986) points out that these high sediment, low gradient (<2%) reaches are geologically controlled and have been persistent for hundreds of years.

Where relatively large amounts of sediment occurs, such as the East Fork of Butler Cr., Purple Mt. Cr., and the South Fork Elk River, water flowing subsurface remains sheltered from the direct solar radiation and, therefore, remains cool. Although the change in diurnal fluctuation in response to increases in sediment load would be unique to each tributary, the general pattern is perhaps represented in Figure 35. As the proportion of basin area that has failed increases, the response appears to be first an increase in diurnal temperature fluctuation, followed by a decline in temperature variation as flow becomes subsurface.

Dissolved Oxygen and Temperature Stratification in Pools

Five pools were sampled in the Elk River Basin to determine vertical profiles of temperature and dissolved oxygen (DO) content. Mainstem pools were located downstream of Butler Cr, and directly downstream of the confluence with Sunshine Cr. The pool below Butler Cr. was sampled twice due to the DO probe malfunctioning. On Sept 2, 1984, the water temperature measured 62.6°F (17°C) at all depths to it's final depth of 9 ft (2.7 m). On Sept 4, 1984, the pool's temperature was 62°F (16.7°C) for all depths and measured 9.3 to 9.6 mg/l DO with no increase or decrease in DO in a consistent manner with depth. Max-min thermometers placed at 3 depths (below the surface, half-way down at approximately 4 ft [1.2 m], and on the bottom) all read a consistent 62°F (16.7°C) for a minimum temperature.

At the confluence with Sunshine Cr. on Sept. 8, 1984, the 8 ft (2.4 m) pool measured 62°F (16.7°C) at all depths according to the DO instrument. Max-min thermometers placed below the surface, at 4 ft (1.2 m) depth, and on the bottom all read minimum temperatures of 62°F (16.7°C). At approximately 1/4 mi (402 m) upstream in Butler Cr. a 7 ft (2 m) deep pool measured 62°F (16.7°C) at all depths on Sept. 2, 1984. A 5 ft (1.5 m) deep pool approximately 1/4 m (402 m) upstream in Panther Cr measured 63.5°F (17.5°C) for

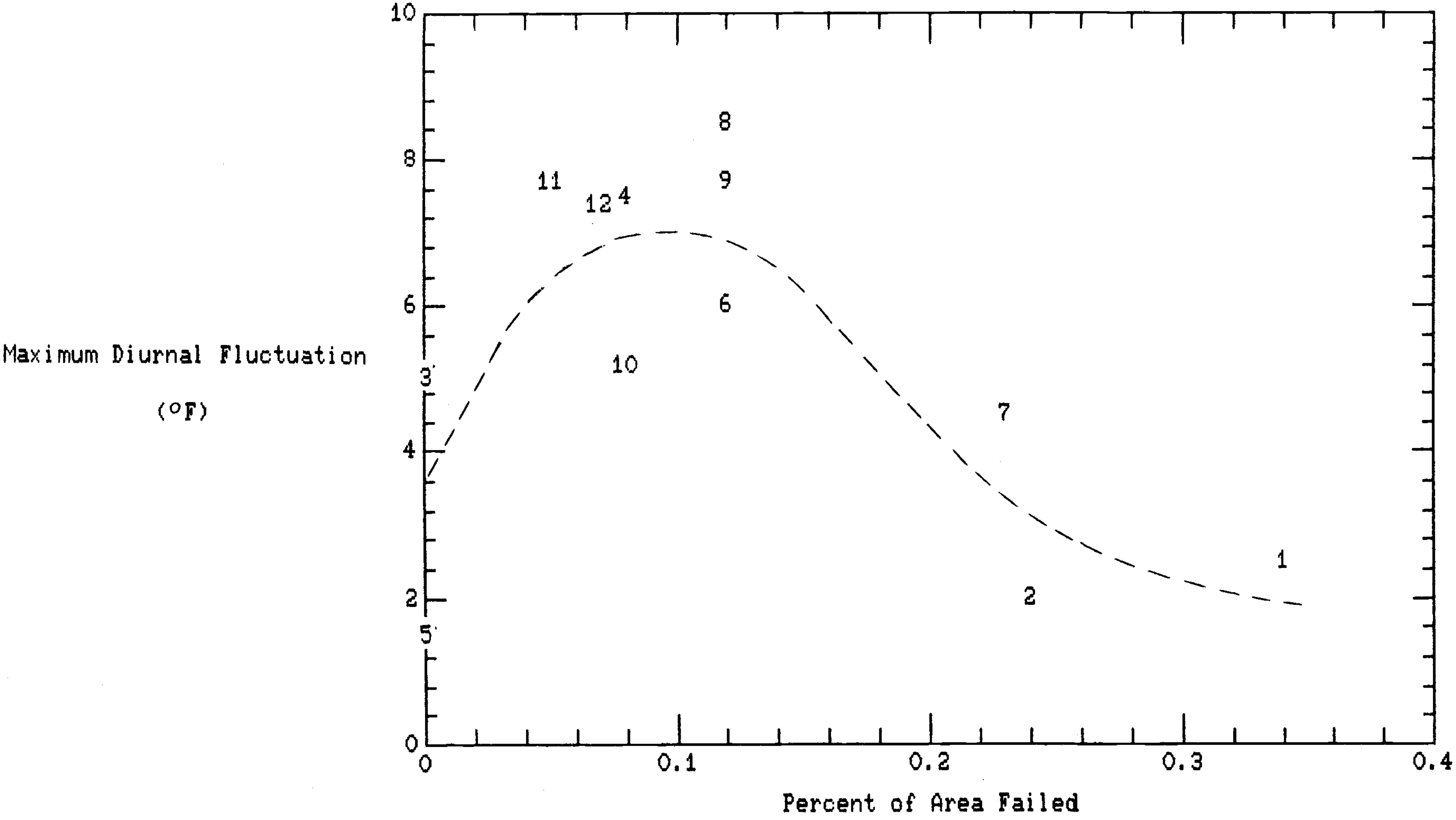

Figure 35. Maximum diurnal temperature fluctuation vs. percent drainage area in landslides due to management for selected Elk River tributaries. Note: numbers correspond to tributaries in Table 2.

all depths on Sept. 3, 1984.

In Bald Mt. Cr. just above the junction with South Fork Bald Mt. Cr., and where blocks of serpentinite and peridotite have slid into the creek forming a constriction, plunge pools approximately 6 ft (1.8 m) deep occur. The constriction, and the severely aggraded stream segment upstream of it, has served as a low gradient depositional site for large wood in the form of several large log jams, with the creation of plunge pools directly below the constriction. Temperatures in the Bald Mt. Cr. pools were 62.6°F (17°C) at various depths as measured on August 9, 1985, signifying complete mixing likely due to turbulence inherent in the motion of plunging water.

Evaluation of Streamside Management Unit

Prior to timber harvesting in the fall of 1984, the maximum summer stream temperature in the headwaters of the East Fork of Panther Cr. was found to be 54°F (12.2°C). Following logging, the maximum summer stream temperature in 1985 was 52°F (11.1°C). Discharge at the time of monitoring was < 1 cfs for both years. Low temperatures following harvest are attributed to channel cover from several sources. These sources are (1) the steep, V-notched channel naturally providing large woody debris and sediment (causing subsurface flow), and (2) the streamside vegetation which was left intact, including shrubs and selected conifers.

SUMMARY AND CONCLUSIONS

Maximum summertime stream temperatures in the mainstem Elk River exhibit a decline from 1965 - 1970 following the large runoff during the 1964 - 65 winter. Also, following two annual peak flows with return intervals of 18 years and 10 years in 1971 and 1974, summer temperatures initially increased and then declined over time. As there is no temperature data for the Elk River previous to the 1964 flood, it's effect on temperature can only be implied from other data, such as the information on the South Fork Coquille River. The south Fork Coquille River exhibited a dramatic increase in stream temperature the summer following the December 1964 flood (Figure 6), which had a >100 year return interval on this river.

The relatively high rates of mass failures associated with harvest units and roads, make it difficult to assess the direct impacts arising from the 1964 peak flow. McHugh's (1986) data indicate that the failure rate from the 1964 flood was greater due to land management than it otherwise would have been if left in a forested condition.

In general, since 1970, average maximum stream temperatures in the Elk River appear to be decreasing independent of changing summer stream flow or summer precipitation patterns. For example, given comparable flows from widely separated years, (1970 vs 1976 for example) maximum stream temperatures are lower for the more recent year. This general reduction in temperature and the increases in temperature following peak flows of relatively large magnitude, suggest that a recovery of streamside vegetation and/or change in channel morphology is proceeding within the basin.

The tributaries of the Elk River are important in bufferring the summertime maximum temperatures in the Elk River, and only those tributaries with very cool waters (and relatively large discharge) are capable of substantially reducing the mainstream temperature. Those tributaries found to be especially low in maximum temperature generally flowed subsurface as a result of channel aggradation. Portions of the streams which exhibit a rise in water temperature generally are wide and shallow, demonstrating large width-to-depth ratios, and have relatively little shade from streamside vegetation. For drainages of similiar size, large diurnal fluctuations are concomitant with large surface area to volume ratios. Furthermore, where width/depth ratios exceed 14 or more, large diurnal swings in temperature are common. Although the low gradient (< 3%) of the wide, shallow reaches are usually geologically controlled, extensive aggradation may occur if the sediment deposition rate is greater than the sediment removal rate of the stream. Upstream of these low gradient reaches, constriction forming controls such as bedrock outcrops, tight channel bends, or stable log jams, may create local sites of sediment storage. These storage sites allow for sediment to be slowly metered out over time to the low gradient reaches farther downstream.

The majority of heating of the Elk River appears to be occurring in the upper reaches of the mainstem, between the North and South Forks of the Elk River and the Butler Cr. area. Between the forks and Butler Cr., the river is a wide, aggraded reach with mid-and side-channel bars and low terraces. A reach, approximately 1 mi (1.6 km) long, is oriented north-south and has little cover. This results in high maximum stream temperatures. As one moves downstream of the Butler Cr. vicinity, the channel becomes relatively deep and narrow, and a change towards high, canyon-like walls above the stream channel, causes topographic shading. The result is less daytime heating along this length of stream which extends from Red Cedar Cr. to the vicinity of Bald Mt. Cr. Thus, maximum temperatures are greatest further upstream, and relatively low downstream.

Historical data indicate relatively high temperatures occur approximately 4 to 5 mi (6.4 to 8 km) downstream from the hatchery. These high temperatures are presumably due to the wide channel, the relative lack of shading vegetation, and the high minimum temperatures upstream which later in the afternoon result in the high temperatures.

Of the five pools measured for vertical changes in temperature and dissolved oxygen in the Elk River Basin, neither temperature or DO were found to vary with depth.

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APPENDIX

Table A1. Unit Conversion Factors

°F = 1.8°C + 32

1 mi = 5,280 ft = 1.609 km

1 mi^2 = 2.59 km^2

1 ft = 0.305 meters

1 in = 2.54 cm

1 mg/l = 1 ppm

1 cfs (cubic foot per second) =
0.028 cumecs (cubic meters per second)

Table A2. Discharge Rates for Elk River Temperature Stations and Selected Tributaries from 7/26/85 to 8/2/85. (R.M. River Mile)

Location	Discharge (cfs)	Discharge (CUMECS)
N. Fork Elk (R.M. 29.7)	7.88	0.22
S. Fork Elk	5.48	0.15
M_6 (R.M. 27.35) - Below Prospect	20.86	0.58
M_5 (R.M. 24.15) - Below Butler	23.92	0.67
M_3 (R.M. 19.95) - Below Purple Mt., Red Cedar Cr.	44.3	1.24
M_2 (R.M. 16.5) - Above Bald Mt.	56.6	1.58
M_1 (R.M. 13.3) - Above Hatchery	68.6	1.92
Bald Mt. (South Fork)	4	0.11
Bald Mt. (North Fork)	7	0.20
Bald Mt. (mouth)	13.6	0.38
Red Cedar	1.39	0.04
Butler (East Fork)	1.47	0.04
Butler (West Fork)	0.93	0.002
Butler (mouth)	2.65	0.07
Blackberry	3.61	0.10
Panther (mouth)	11.34	0.32
Panther (West Fork)	2.81	0.08
Panther (Middle Fork)	3.46	0.10
Panther (East Fork)	2.14	0.06

Table A3. Average velocity calculations for the Elk River and tributaries.

Tributary	Average velocity at gage (Vg)(ft/s)	Cross-sectional area at gage (Wg•Dg)	Cross-sectional area of reach (Wr•Dr)	Ratio of cross-sectional area of gage to reach $\frac{Wg \cdot Dg}{Wr \cdot Dr}$
North Fork Elk R.	0.40	36.9	33.3	1.11
Butler	0.66	5.94	29.1	0.20
East Fork Butler	0.26	12.87	7.10	1.81
West Fork Butler	0.45	3.5	11.34	0.31
Panther	1.17	21.75	29.73	0.73
Middle Fork Panther	0.34	14.03	17.94	0.78
East Fork Panther	0.28	13.13	12.14	1.08
Bald Mt.	0.68	39.78	64.64	0.62
Red Cedar	0.25	9.41	14.76	0.64

				$\bar{X} = 0.81$

$$\frac{\text{average Vr}}{\text{average Vg}} = \frac{Wg \cdot Dg}{Wr \cdot Dr} = 0.81$$

$$Vr = 0.81\ Vg$$

AVERAGE MAINSTEM VELOCITY

Mainstem Location	Vg
M_1 (R.M. 13.3)	0.75
M_2 (R.M. 16.5)	2.13
M_3 (R.M. 19.95)	1.33
M_5 (R.M. 24.15)	1.07
M_6 (R.M. 27.35)	0.76

	$\bar{X} = 1.21$

$Vr = 0.81\ (1.21) = 0.98$ ft/s

Table A4. Average monthly streamflow and average maximum temperatures for July and August (1957 - 1970) and the water years instantaneous peak flow (1957-1985) for the South Fork of the Coquille River. July and August precipitation amount and number of precipitation days at Powers, 1957-1985.

Water Year	Average Discharge (cfs)		Avg Maximum Temperature (^{o}F)		Precipitation Amount (in)		Number of precipitation days		Peak Flow near Powers (cfs)
	July	August	July	August	July	August	July	August	
1957	39.7	22.5	69.7	67.0	0.29	0.19	2	1	11,700
1958	37.1	16.8	72.0	72.0	1.50	0.02	2	1	13,500
1959	26.2	11.9	--	--	0	0	0	0	13,800
1960	42.3	19.0	70.0	68.0	0	0.31	0	3	3,150
1961	35.5	18.5	70.0	70.0	0.05	0.18	1	2	14,300
1962	35.7	24.8	70.0	69.0	0	0.28	0	6	13,600
1963	53.1	29.5	65.0	67.0	0.37	0.02	5	1	7,900
1964	46.5	25.0	67.0	68.0	0.54	0.58	9	5	14,900
1965	27.6	18.1	--	72.0	0.27	0.43	2	4	29,600
1966	26.6	15.5	70.0	71.0	1.30	0.44	8	1	16,200
1967	33.1	18.1	70.0	68.0	0	0	0	0	10,300
1968	31.7	41.8	71.6	66.2	0.03	2.43	1	12	10,200
1969	40.1	17.4	68.0	66.2	0.06	0	2	0	11,300
1970	28.3	16.0	72.5	--	0	0.06	0	1	13,000
1971					0	0.74	0	3	
1972					0	0.67	0	3	
1973					0.01	0.17	1	3	
1974					0.50	0	3	0	
1975					0.37	0.93	4	6	
1976					0.21	2.62	3	13	
1977					0	2.20	0	6	
1978					0.75	2.40	3	9	
1979					0.33	1.16	1	5	
1980					0.53	0.05	3	2	
1981					0.10	0.05	1	1	
1982					0.12	0.11	3	2	
1983					--	--	--	--	
1984					0.19	0.07	2	1	
1985					0.08	0.07	1	2	