THE EFFECTS OF SELECTIVE LOGGING ON LOW FLOWS AND WATER YIELD IN A COASTAL STREAM IN NORTHERN CALIFORNIA

by

Elizabeth T. Keppeler

A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

December, 1986

THE EFFECTS OF SELECTIVE LOGGING

ON LOW FLOWS AND WATER YIELD

IN A COASTAL STREAM IN NORTHERN CALIFORNIA

by

Elizabeth T. Keppeler

Approved by the Master's Thesis Committee

Carlton S. Yee	2/16/87 Date
Robert R. Ziemer	2/13/87 Date
Steven A. Carlson	2/16/87 Date
Director, Natural Resources Graduate Program	2/16/87 Date
87/WM-71/01/16 Natural Resources Graduate Program Number	Date

Approved by the Dean of Graduate Studies

Alba M. Gillespie	May 1987 Date

ABSTRACT

Using a low flow season defined as a function of antecedent precipitation, streamflow data for a 21 year period was analyzed to determine the effects of selective tractor harvesting of second-growth Douglas-fir and redwood forest on the volume, timing, and duration of low flows. and annual water yield. Significant increases in streamflow were detected for both the annual period and the low flow season. Maximum increases were realized the year following the completion. of logging. Greater relative increases were witnessed for the summer low flow period, however these increases were short-lived in comparison to the overall increase in annual water yield. Logging factors were found to be the most influential variables in describing flow differences between the control and treated watersheds. Summer flow increases were well correlated with the percent of the watershed area logged when this variable was defined to represent revegetation effects as a function of time since logging. In contrast, the enhancement of annual yield (predominately winter flows) was well correlated to the percent of the watershed area converted to roads, landings, and skid trails (15%). The flow response to logging was found to be highly variable. Some of this variablility was correlated to antecedent precipitation conditions, although much was unexplained. It was concluded that the potential augmentation of water yields resulting from harvest in north coastal California watersheds would be of minimal value as a management option for meeting specific water demand levels.

ACKNOWLEDGEMENTS

The U.S. Forest Service Pacific Southwest Forest and Range Experimental Station provided both financial and technical support for this study. I am grateful to have had the opportunity to be involved with the ongoing research at the Redwood Sciences Laboratory while being allowed the flexibility to work according to my own priorities.

RSL personnel provided essential assistence to this project. Diane Rainsford, Heather Kellum, and Pat Deenihan were especially helpful in assisting with computer programming and operation problems.

I received guidance for my statistical analyses from Robert Thomas, statistician employed by RSL, and Dr. Gerry Allen, Department of Forestry, Humboldt State University. Their special insights were very helpful.

I wish to express sincere thanks to my committee members, Dr. Carl Yee and Dr. Steve Carlson, for sharing their professional expertise in the fields of hydrology and natural resources, and for their careful reviews of this thesis; and special thanks to Dr. Robert Ziemer for his insights and guidance throughout this study, and his demonstration of confidence in my abilities.

The encouragement of my parents and family has been a very important motivation to me throughout my education. To Sean, Joshua, and Amanda, thank-you for being there to put all the minor frustrations into perspective.

TABLE OF CONTENTS

TABLE OP CONTENTS (CONTINUED) Page

TABLE OF CONTENTS (CONTINUED) Page

TABLE OF CONTENTS (CONTINUED) Page

TABLE OF CONTENTS (CONTINUED) page

LIST OF TABLES

LIST OF TABLES (CONTINUED) Page

' LIST OF FIGURES

INTRODUCTION

In rain-dominated portions of the Pacific Northwest, research suggests that water yield may be enhanced by the removal of forest vegetation from small upland watersheds. Yet questions and misconceptions linger regarding the effects of logging operations on streamflow under the variety of climatic, physiographic, and vegetative conditions of this region. Timber harvesting impacts have not been fully evaluated for the coastal region of northern California.

Previous studies at Caspar Creek near Fort Bragg, California have been directed at investigating the impacts of selective harvest of second-growth forest on streamflow processes of California's northern coast. Since 1962, various research efforts have focused on impacts on streamflow, sedimentation, aquatic habitat, and fish populations within the experimental catchment. This evaluation of logging and related factors affecting summer low flow quantity and timing at Caspar Creek will supplement our growing understanding of how streamflow processes are altered by natural and management-induced conditions.

Objectives

The objectives of this analysis are:

1. To determine if the streamflow volumes and timing during the low flow season have been affected by road building and partial-cutting at the Caspar Creek watershed;
2. To quantify the extent of any detectable changes in summer streamflow processes;

3. To determine the duration of any detected changes in summer streamflow processes; and,
4. To investigate the relative significance of various climatic and management factors in describing changes in summer streamflow characteristics.

Streamflow Processes: Factors Affecting Baseflow Recession Characteristics

It may be simply stated that precipitation is the source of all streamflow. However, not all precipitation on a watershed will be routed to the channel to appear as streamflow. Actual streamflow is a complex response to the diverse geological, climatological, morphological, and biological factors acting within a given drainage basin. This response is subject to great variation both in quantity and temporal and spatial distribution.

Hydrologists generally separate the stream hydrograph into two basic additive components: stormflow and baseflow. Runoff which arrives at the stream channel soon after a precipitation event is termed stormflow or direct flow (or alternately, quickflow (Hewlett and Hibbert, 1967)). It may consist of Horton overland flow, subsurface stormflow (interflow), return flow, and direct precipitation onto saturated areas (Dunne and Leopold, 1978). In contrast, water which percolates (recharging soil moisture and groundwater levels) travels at much lower velocities and along more lengthy paths and is slowly released into the channel to sustain streamflow during rainless periods. This latter component has been termed baseflow, dry-weather flow (Dunne and Leopold, 1978), delayed flow (Hewlett and Hibbert, 1967), groundwater flow, low flow, percolation flow, under-run, seepage flow, and sustained flow (Hall, 1968).

Modern interest in baseflow processes has been both quantitative and descriptive. Boussinesq (1877) developed the basic differential equation governing flow through an aquifer. In simple form, flow was defined as an exponential function of initial flow: Q_t-Q_0 exp(-at); where Q_t is flow rate at time t, Q_0 is initial flow, and a is a fitted constant. Subsequent analysts have proposed numerous linear and nonlinear modifications and alternatives, but problems arising from difficulties in interpreting the stream hydrograph and assumptions used in the mathematical development remain. While these mathematically derived equations adequately model the hydrologic system from which they were empirically determined, they do not reliably predict streamflow when applied in other situations. (Hall, 1968)

An alternative approach used in understanding the nature of streamflow processes has been to examine the on-site conditions to qualitatively describe the streamflow response. Observed natural conditions and management-induced alterations (urbanization, timber harvest, etc.) play interactive roles in the generation of streamflow.

Precipitation occurring within a watershed varies in form (rain, snow, fog, etc.), spatial distribution, and intensity. The characteristics of a particular precipitation event influence the proportion of water volume which will be intercepted and re-evaporated by vegetation, infiltrate into the soil, travel as surface or subsurface flow towards the channel, or be stored temporarily on the surface.

The geology and soils of the drainage basin also influence stream processes as they affect infiltration and percolation rates, water-holding capacity, depth and extent of the capillary fringe, and hydraulic conductivity. These characteristics are known to vary considerably within a watershed and are also influenced by antecedent moisture conditions.

The hydrologic response of a catchment is also influenced by basin morphology. The area, basin shape, steepness of slopes, roughness, hydraulic length, and existence of storage depressions are important morphological factors.

Vegetative factors are critical as they affect the proportion of precipitation evaporated and transpired versus that which is available for soil moisture storage and recharge of the groundwater levels which contribute to dry-weather flow. Krygier (1963) has estimated that 60 percent of annual precipitation in the Pacific Coastal Douglas-fir-hemlock-redwood forest translates into streamflow. Dunne and Leopold (1978) state that the difference between rainfall and runoff is largely explained by evapotranspiration. The proportionate contribution of precipitation to streamflow will vary greatly according to the manner in which interception and evapotranspiration are influenced by vegetation type, stage, rooting depth, and health.

Actual evapotranspiration rates are the result of the interaction of soil, atmospheric, and vegetative conditions (Ziemer, 1979). The water supply to a plant is governed by the energy necessary for roots to extract water (water potential). For a given soil, this potential is related to water content (Letey,1985). When soil water is limiting, water use by vegetation is reduced from the potential rate of transpiration which would be possible in existing atmospheric conditions if soil moisture was at field capacity (Russe11,1973). Furthermore, under conditions of high evaporative demand, transpiration rates may be limited by stomatal control and fluid transport rates within plant tissue (Ziemer, pers. comm.).

Solar radiation is held to be the dominant energy source which drives the evapotranspiration mechanism. Latitude, season, time of day, and cloudiness are factors which affect net incoming solar radiation and hence evapotranspiration (Dunne and Leopold, 1978). For example, winter evapotranspiration losses from a coniferous forest are less than 20 percent of those during other seasons (Kittredge, 1948).

Advection of sensible heat is another source of energy which influences water loss rates from vegetation. This source may be especially important in the evaporation of intercepted water within a forest, particularly in the winter when windspeeds tend to be higher while net incoming radiation is lower (Rutter,1975; Ziemer,1979). Nixon and Lawless (1968) report that in coastal regions on clear days advection of cool ocean air acts as an energy sink such that a greater proportion of net incoming radiation is converted into sensible heat making less radiation available for evapotranspiration. And, in winter, advected energy from the relatively warm ocean can provide an important net energy source.

Vapor pressure deficit, temperature, and wind velocity determine the ability of the atmosphere to transport water away from leaf surfaces, but this is subject to stomatal regulation. Environmental conditions and plant physiology determine the nature of this regulatory function (Ziemer, 1979). Forest transpiration losses have been shown to depend strongly on leaf area (darvis,1985). The size, density, species, phase, and stage of the vegetation also affect transpiration losses (Letey,1985) although these controls act in conjunction with climatic factors (Rather and Yoshioka,1968).

From the above discussion it can be concluded that basin outflow is a function of precipitation occurring within the watershed, changes in storage (including seepage into or out of the basin), and evapotranspiration losses. The role of these processes upon streamflow is determined by the dynamic interaction of climate, vegetation, soils. geology, and morphology within the particular watershed. During periods of dry weather, streamflow is predominantly represented by the baseflow component of the hydrograph, but even under these conditions a steady decline function is not applicable. The streamflow recession in a specific basin is characterized by the variability in storage conditions and evapotranspiration losses brought on by the interaction of basin factors.

Previous Studies

Paired watershed studies have been used worldwide to evaluate changes in streamflow resulting from land management practices. This conceptually simple approach, wherein measurements of a treated watershed are related by statistical interpretation to an adjacent undisturbed (control) watershed, is considered to be more precise and provides for greater statistical control than deterministic models based on calibration of a single watershed (Ponce et a1,1982; Nik et al, 1983).

Research on upland watersheds indicates water yield can be augmented by vegetation removal (Ponce and Meiman, 1983). However, it has been cautioned that the responses to treatment may be highly variable depending on the processes and conditions existing in the particular watershed studied (Hewlett and Hibbert, 1967).

Effects of Timber Harvest on Streamflow Processes

Logging operations alter the conditions and processes involved in the generation of streamflow. Most notably, evapotranspiration is affected by the removal of forest vegetation. Also, soil characteristics are inevitably modified by the construction of roads, skid trails, and landings which accompanies timber harvesting (Stone,1977). Localized soil disturbances associated with this construction include reduced infiltration capacity, decreases in bulk density, and a conversion of macropores to micropores. In addition, soil drainage patterns may be altered. Although the impacts of road construction and tractor-logging on soil surfaces have been documented by substantial research, the effects of these activities on the generation of streamflow are not fully understood (Sendak, 1985).

The Pacific Northwest. In reviewing the results of catchment studies at 11 locations in the Pacific Northwest, Harr (1979) reports annual water yields have increased up to 62 cm following timber harvest, while summer low-flows have as much as quadrupled, indicating reduced evapotranspiration and greater soil moisture levels on the logged basins. These increases diminished as revegetation proceeded, with annual flows returning to pre-treatment levels after four to five years.

Factors Affecting the Magnitude and Duration of Harvest Effects on Streamflow Processes

Researchers have related post-logging deviations in expected water yield to severa factors including time since logging, harvest practices, mean annual precipitation, precipitation form and amount, site conditions, insolation and aspect. and season.

Time since Logging. A time-duration model for predicting streamflow increase for a regrowing (eastern) forest was presented by Douglass and Swank (1972):

$$Q_i = a + b(\log T_i)$$

where Q_i is the increase in flow year i, a is the first-year increase, T_i is the ith year after treatment, and b is a negative coefficient. It is reasonable to expect a similar relationship to hold in other regions. As a gross index of revegetation and renewed interception and evapotranspiration losses, time since logging has been identified as the most important variable in explaining water yield increases in the Pacific Northwest region (Harr,1979).

Harvest Practices. Increases in streamflow have been shown to be proportional to the amount of cover removed (Hibbert, 1966). Partial cutting instead of cleareutting reduces the magnitude of streamflow augmentation (Rothacher,1971). However, because transpiration varies according to environmental conditions, partial cutting may actually enhance water use by the trees and understory vegetation which remain (Kittredge, 1948). Greenwood et al. (1985) conclude that reduced evapotranspiration from overstory vegetation following clearing may be strongly countered by increased evapotranspiration from the understory due to increased availability of energy and soil water.

Site Conditions. Research in Japan suggests the importance of site conditions as a factor affecting streamflow response to the removal of vegetation. Streamflow increases in watersheds with good soil and topographic conditions were smaller and diminished faster than in those in watersheds with conditions which were less favorable to tree growth, owing to the prompt recovery of the forest (Nakano, 1967). In reviewing the results from studies in the Pacific Northwest, Harr (1983) states that water yield increases in this region are short-lived due to favorable conditions which support rapid regrowth of forest and other vegetation. At the H.J. Andrews experimental forest east of Eugene, Oregon, similar annual water yield increases followed the clear-cutting of a 130-yr-old Douglas fir forest and a 450-yr-old Douglas fir forest suggesting that harvest of second-growth forest triggers an analagous response in terns of water yield as the removal of old-growth forest (Harr et al, 1982).

Precipitation. Annual precipitation has also been shown to be significant in predicting the magnitude of water yield increases which follow timber harvest operations in forested watersheds. Proportionately greater increases are realized in wetter years, while this effect is generally less in drier years (Harr,1979; Ponce and Meiman,1983). Bosch and Hewlett (1982) suggest that streamflow response depends also on the mean annual precipitation of the area. The effects are generally greatest in areas of high rainfall, but they are short-lived due to rapid regrowth of vegetation. According to Bosch and Hewlett, actual precipitation is influential only in low-rainfall areas. In high-rainfall areas, water yield changes as a result of treatment are independent of actual precipitation. This view contradicts those of Harr (1979) and Ponce and Meiman (1983).

Insolation and Aspect. Using data from several eastern watershed studies, Douglass and Swank (1975) found support for their hypothesis that increases in streamflow following logging are inversely proportional to potential annual insolation. A model was developed for predicting first-year increase in flow as a function of basal area cut and an index of insolation:

$$Q = a(BAC/I)^b$$

where Q is the first-year increase in streamflow (expressed as a depth), BAC is the percent basal area cut, I is potential annual insolation (langleys), and a and b are fitted constants. Insolation may vary considerably according to aspect during the winter season. Swift (1972) concluded that considerably more incoming radiation is incident on slopes which face south in comparison to north during the winter season, although little difference could be found during the growing season.

Season. Season, as an indicator of potential evapotranspiration, is an important variable affecting the streamflow response to logging. Seasonal analyses of yield increases on experimental forests in Western Oregon have been made by Rothacher (1970), Harr et al. (1979), and Ingwersen (1985). These studies have indicated that most of the increase in annual water yield in response to logging occurs in the October through March rainy season. The explanation for this is that logging reduces transpiration during the growing season, as well as, interception losses. Thus, the soil on logged watersheds is wetter at the onset of the rainy season requiring less rainfall to recharge soil moisture levels and allowing more precipitation to become available for streamflow. Ziemer's (19$1) analysis of peak flows on the Caspar Creek watershed supports this theory. Douglass and Swank (1975) presented the same explanation in their study of Eastern forest watershed responses to deforestation. Relative to pre-logging summer flow patterns, logging related streamflow increases were negligible until June, increased as the growing season advanced, and reached a maximum in September. An important climatic difference between the Eastern U.S. and the Pacific Northwest is that precipitation is relatively uniform throughout the year in the East, hence the growing season is wet relative to the dry summer season of the West.

In the Pacific Northwest, the greatest relative increases in streamflow have been observed during the summer season (although in absolute terms, larger increases have occurred during the rainy. season). but these increases are short-lived lasting only two to three years (Harr,1979). The number of low-flow days (where streamflow has fallen below some preset threshold value) was used to evaluate flow changes in the Alsea Watershed Study in Oregon's Coast Range. It was determined that there were fewer low-flow days following logging of the experimental watershed (Harr and grygier,1972).

_Fog Precipitation Processes. An important contradiction to this pattern of increased flows following logging has been observed in the Fox Creek Watershed Study within Portland's Bull Run Municipal Watershed. A small decrease in annual water yield was noted. Also, following timber harvest the number of low-flow days increased suggesting summer flows were actually reduced as a result of logging (Harr, 1980). It was hypothesized that this anomaly was the result of reduced fog drip interception with clearing of the forest. Measurements indicated as much as 44 percent more net precipitation beneath the forest canopy than in a clearing in the late spring and summer. During two fall seasons differences of 18 and 22 percent were observed (Harr,1982). Within the forest, fog drip accounted for roughly one-third of all precipitation for the May through September period. Harr concludes that in addition to offsetting canopy interception and evaporation losses, fog drip at this site may have provided 498 mm additional water to the forest floor.

Subsequent analysis of recent streamflow data from the Fox Creek Experimental Watershed indicates a recovery has occurred from the harvest impacts on summer water yield due to loss of fog drip (Ingwersen,1985). After about five post-logging years, the expected increase in water yield due to reduced evapotranspiration can be observed. This is attributed to renewed fog drip from prolific revegetation.

Ingwersen speculates that the proximity of clearcuts in the direction from which the prevailing fog-laden winds arise accounts for the importance of fog drip as a source of precipitation in this watershed. Where these winds are blocked by mature forest, the role of fog drip is not as influential.

According to Ingwersen's analysis, the decrease in annual water yield in the logged areas is associated with June and July flows only. He hypothesizes that during early summer, most forest sites do not yet have a soil moisture deficit, thus fog drip is readily translated into effective yield as atreamflow. Later in the summer, fog drip contributes to relieving soil moisture deficits and is not observable in streamflow yields. Therefore, the removal of the vegetation responsible for the interception and delivery of fog drip to the soil would result in measurably decreased streamflow only in the early summer months of June and July.

These results suggest that by the elimination of fog drip through the removal of forest vegetation, anticipated enhancement of summer flows may not be realized in areas where fog occurrence is a frequent source of significant moisture. The occurrence of fog and its role in influencing moisture conditions in coastal California and Oregon has been well documented, lending support to the hypothesis that significant amounts of moisture can be delivered in areas of high advection fog frequency (Isaac,1946; Byers,1953; Oberlander,1956; Azevedo and Morgan,1974; Goodman,1985).

Implications

In the late 1950's and early 1960's national interest in augmenting water yields through vegetative management prompted substantial research in various climatic zones. The precept that harvest of forest vegetation can increase water yield has been validated by numerous studies worldwide, but the responses of these experimental watersheds have been highly variable (Evans and Patric, 1984). Today it is held that the opportunity to augment water yield on a major basin-wide scale is not as promising as has been demonstrated within small experimentally controlled watersheds (Ponce and Meiman, 1983). However, the implications of forest management on streamflow conditions in small watersheds remain an important issue from the perspective of in-basin water users and fish and wildlife habitat requirements.

Caspar Creek

Previous studies have examined some of the effects of partial cutting on streamflow processes at the Caspar Creek Experimental Watershed.

In evaluating the short-term effects of the road building on the watershed Krammes and Burns (1973) noted suspended sediment loads and sediment deposition behind the South Fork weir increased, and that water temperatures were raised slightly. Tilley and Rice (1977) found an increase in suspended sediment to be the most apparent effect of logging. Analysis of the sediment/stream power relationship by Rice et al. (1979) related the increase in suspended sediment to the availability of additional sediment for transport.

Ziemer (1981) assessed the effects of road construction and logging on peak streamflow response and found that peak flows in response to the first fall storms of the rainy season increased about 300 percent after logging. Analysis of peak flows resulting from storms occurring later in the rainy season detected no statistically significant difference from pre-treatment peaks. It was suggested that this effect resulted from potentially substantial differences in soil moisture which developed between the logged and unlogged watersheds during the growing season. The logged watershed was hypothesized to be wetter due to reduced evapotranspiration losses. Thus, for the first fall storms, precipitation more readily translated into streamflow in comparison to the uncut watershed where more precipitation went to relieving the soil moisture deficit. Later in the rainy season after both watersheds had been recharged, the basins again began to respond similarly to the infiltration of additional precipitation.

Wright (1985) evaluated changes in storm hydrographs at the Caspar Creek site and determined that partial cutting did result in increased peaks and volumes for small storms. A 40 percent increase in in the stormflow volume for small storms (less than 121 kiloliters) was detected. Large storm peak flows were not significantly altered. Road-building did not affect the storm volumes according to Wright's study.

By analyzing changes in basin lag time, Sendek (1985) concluded that storm-runoff was routed more quickly to the stream channel after treatment than in the undisturbed state, but there was no detectable change in hydrograph shape.

While these studies suggest that the runoff characteristics of the South Fork watershed have been altered by timber harvest activities, the influences of this treatment on low flow season streamflow characteristics and the seasonal distribution of water yield in the Caspar Creek basin had, prior to this study, not been investigated.

STUDY SITE

The Jackson Demonstration State Forest, located in the coastal region of Mendocino County of northern California, serves as the site for this paired watershed study. Caspar Creek lies within the State Forest approximately 10 km south of the city of Fort Bragg (Figure 1). The legal description for the watershed area is sections 1,2,3,11,14, 15,16,2 , T 17 N, R 17 W and sections 35,36, T 18 N, R 17 W, Mt. Diablo Meridian.

The Caspar Creek watershed encompasses an area notably larger than those which have been used in similar studies in the Pacific Northwest (Harr,1979). The drainage area of the North Fork of the creek is 508 ha, while the area of the South Fork is 424 ha.

The dominant aspect of the study site is south-southwest. The elevation ranges from 37 to 320 m. The topography varies from steep slopes ear the stream channel to broad rounded ridgetops at the higher elevations. For the most part, however, slopes are moderate, ranging from 30 to 70 percent. Some 35 percent of the Caspar Creek study area has slopes which are less than 30 percent. Approximately seven percent of the North Fork watershed occurs on steep slopes in excess of 70 percent. In contrast, only one percent of the South Fork watershed occurs on slopes of such steepness.

The geology and soils of the experimental watershed appear to be representative of this part of Mendocino County. Soils are derived from sedimentary rocks (sandstone and shale) of the Cretaceous Age. These clay-loam and loam soils are moderately to very deep (mostly

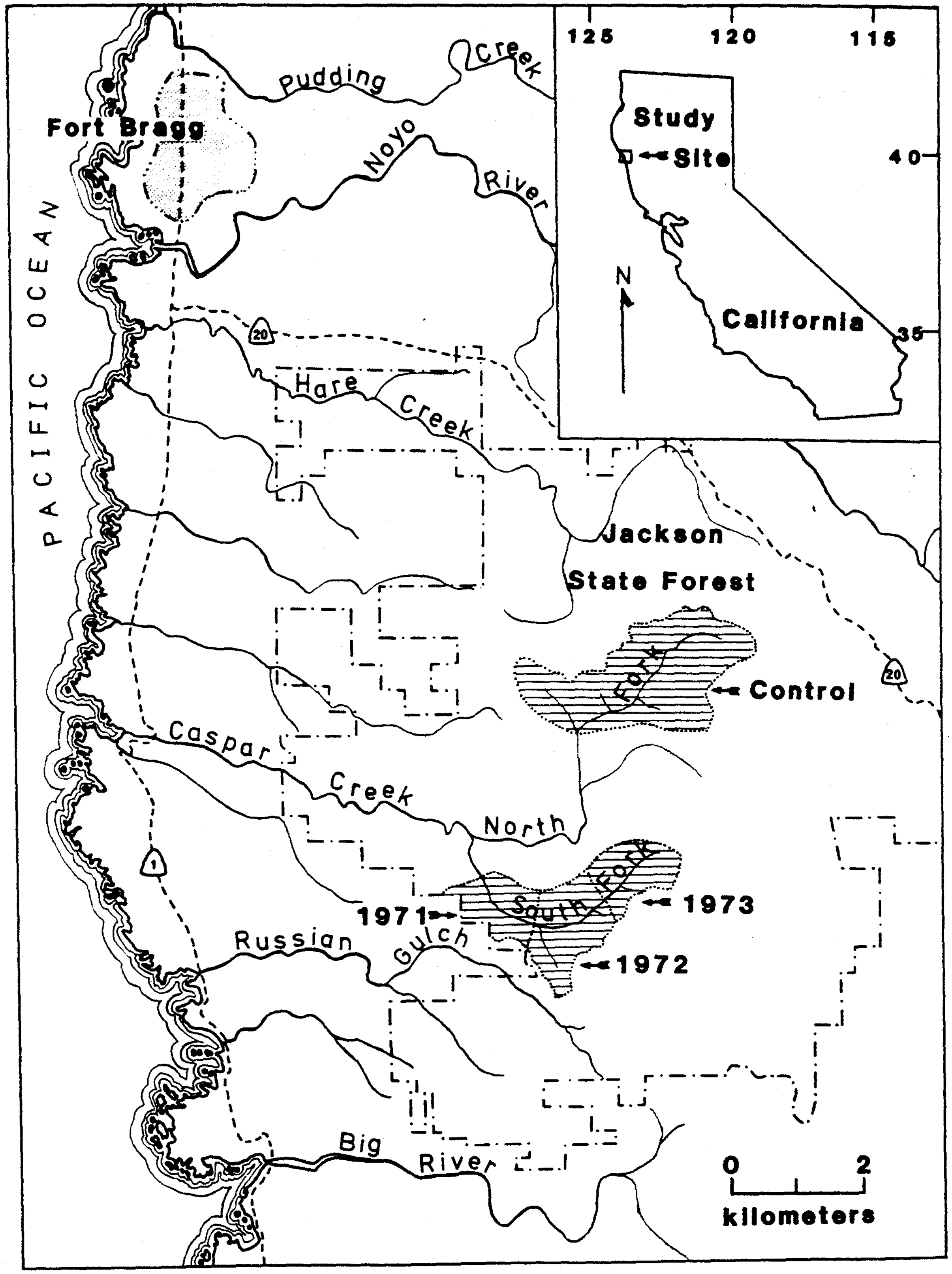


Figure 1. Caspar Creek Experimental Watersheds: North Fork (Control) and South Fork (logging years, areas indicated).

greater than 20 cm). The soils are considered well-drained having moderate permeability and moderate rates of infiltration. (California Department of Forestry, 1985)

Previously, the Caspar Creek soils had been classified as mainly Hugo and Mendocino soil series with less than 10 percent of the South Fork watershed classified as Caspar and Noyo soils (Krammes and Burns,1973). These classifications have been revised in the 1985 soil and vegetation mapping done by California Department of Forestry.

Current classifications indicate that the Irmulco and Tramway soil series dominate the majority of the study area, occurring mostly on the mid-slopes of the basin. The deeply shattered parent material of this soil consists of hard sandstone and coarse-grained shale which is moderately weathered. The fractured nature of this substratum allows for rapid water drainage and a moderately high waterholding capacity.

The Vandamme soil series accounts for approximately 40 percent of the North Fork watershed and 20 percent of the South Fork watershed. This series is found along the ridges and upper-slopes of the area. It is a deep (40 to 60 cm) soil with a fairly high waterholding capacity. The infiltration rate of the Yandamme soil is very slow and the rate of water transmission through the subsoil is also moderately slow in comparison to the Irmulco and Tramway soils.

In the bottoms of the North Fork watershed and the bottoms and lower-slopes of the South Fork watershed the Dehaven and Hotel soil series occur. Although still considered within the loam/clay-loam textural classes, these soils are high in gravel or sand content.

Along the ridge in a small portion of the South Fork basin the Caspar soil series is found. It is a very deep soil (greater than 60 cm) with moderate to moderately rapid subsurface drainage. Pleistocene age marine terrace deposits of sand and gravel have given rise to this soil series. The Quinliven and Ferncreek soils are associated with the Caspar. These soils differ from the Caspar in having moderately slow rates of infiltration and permeability, although water transmission in the substratum is rapid.

The climate of the study site is typical of northern California. The fall and winter seasons are characterized by a westerly flow of moist air which typically results in low-intensity rainfall and prolonged cloudy periods. In the winter, the southerly position of the north Pacific subtropical anticyclone allows frequent storms to enter the region, but in the spring this weather system migrates northward and rainfall is much less frequent. Summers are relatively dry and cool.

Temperatures are mild with muted annual extremes and fairly narrow diurnal fluctuations due to the moderating effect of the Pacific Ocean.

Mean annual precipitation at Caspar Creek is approximately 1190 mm ranging from 838 to 1753 mm during the 1962 to 198 study period. Ninety percent of this total annual precipitation occurs between the months of October and April. The frequent occurrence of summer coastal fog makes a small but unspecified contribution to the total precipitation in the form of fogdrip. Snowfall is rare event at these elevations in this region.

While the Caspar Creek study site has been included in the region known as the rain-dominated Pacific Northwest, its climate is not entirely typical of the overall region which encompasses Northern California, Oregon. Washington, and British Columbia. This experimental watershed lies at the southern border of the region and only about 5 km from the Pacific Ocean. Because of the lower latitude, proximity to the ocean, and lower elevations of the Caspar Creek site; the temperature regime here is warmer and less variable, and precipitation is less than the norm for the overall region. These differences should be remembered in comparing these results to those of other catchment studies in the rain-dominated Pacific Northwest.

Forest vegetation in this coastal region is the product of favorable climatic and soil conditions. The area supports fairly dense stands (averaging 700 m^3/ha) of second-growth Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), coast redwood (Sequoia sempervirens (D.Don) Endl.), western hemlock (Tsuga heterophylla (Raf.) Sarg.), and grand fir (Abies grandis (Dougl. ex D.Don) Lindl.). Some minor hardwoods including tanoak (Lithocarpus densiflorus (Hook. and Arn.) Rohn), and red alder (Alnus rubra Bong.); as well as some Bishop pine (Pinus muricata D.Don) had been established. In addition. a scattering of old-growth redwoods remains in the vicinity of the Caspar Creek watershed.

The understory vegetation includes brush species such as evergreen huckleberry (Vaccinum ovatum Pursh). Pacific rhododendron (Rhododendron macrophyllum D.Don), and sword fern (Polystichum munitum (Kaulf.) Presl.).

Historically, the most significant land management activity on both the North and South Fork watersheds occurred in the late 1800's when most of the original old-growth forest was removed by cleareut operations. Within each watershed. timber was hauled to the main channel by rail then transported in the channel, as facilitated by the construction of a splash-dam at a distance about three-quarters up the length of the stream. Following the removal of timber, both watersheds were burned. During World War II some minor pole and pile cutting was done, but since the original logging of nearly a century ago man-induced disturbances within the Caspar Creek drainage have been inconsequential. Other surrounding areas in the Jackson State Forest have been logged.

Treatment of the Caspar Creek Watershed

In 1962 when research activities began in the Caspar Creek Paired Watersheds, the age of the timber stands on the North and South Fork sites had reached 65 and 85 years, respectively. Due to this age difference the timber on the South Fork drainage area was deemed to be more marketable. It was thus decided that this catchment would be harvested and the North Fork basin be maintained undisturbed by timber harvesting activities so as to serve as the control site.

Methods of timber harvesting and road construction were designed to be consistent with the commercially acceptable standards of local contractors. Specific attention to protection of the watershed was limited to what was considered practical according to contemporary standards. Many of these practices would be in violation of present regulations.

Between the months of May and September of 1967 a road system was constructed providing access for the harvesting operations which were to follow. Right-of-way clearing required the removal of 18900 m^3 of timber from 19 ha of the watershed. The length of the main haul logging roads and spurs totalled 6.8 km. The majority of this construction (6 km) occurred within 60 m of the stream channel. Approximately 110 m of the South Fork streambed experienced direct disturbance from the operation of tractors in the stream in constructing bridges and landing sites. Upon completion of this road construction. areas of exposed soil and fill were fertilized and seeded with ryegrass. The completed road system occupied approximately 22 ha (5 percent) of the South Fork watershed.

The actual harvest of South Fork timber began in March 1971. Beginning with the lower portion and moving sequentially upstream three annual timber sales were held. (figure 1) Each sale used ridge to ridge boundaries and was carried out pursuant to existing State Forest policies.

The selective harvesting technique employed was directed so as to remove only single or small clusters of harvestable trees while reserving the healthy fast-growing stands of the more desireable species. In this way, the growth of the redwood and Douglas-fir was to be promoted by providing openings to encourage the regeneration of these species. Tractor yarding was used for skidding the downed trees to the landings.

The area of the first sale was 101 ha from which 59 percent of the stand volume was harvested. The following summer. 1972. 69 percent of the stand volume was harvested from a 128-ha area. During the third and final stage, summer 1973. selective cutting of the remaining 176 ha of the uppermost portion of the watershed resulted in the removal of 65 percent of the stand volume. Upon completion of the entire logging operation, 67 percent of the South Fork timber volume had been removed. This equates to the removal of nearly 200,000 m^3 of timber from right-of-way clearing through the three stages of harvesting activity. (Table 1)

During the actual harvesting operations an additional 43 ha (10 percent) of the South Fork drainage had been converted to relatively impervious surfaces-- 35 ha of skid trails and 8 ha of landings. The road construction carried out prior to the three-year logging operation accounted for another 5 percent of the watershed area. Overall then, 15 percent of the South Fork drainage basin had been rendered relatively impervious by the end of 1973.

Following the removal of the harvestable timber, no specific slash treatment was performed. Regeneration occurred through re-sprouting from redwood stumps and seedling growth of other forest species. No specific management activities were subsequently carried out which interfered with revegetation by tree and understory species.

Table 1. Treatment Summary of the South Fork Watershed.a

	Right-of-Way 1967	Stage 1 1971	Stage 2 1972	Stage 3 1973	Total Watershed
Area Harvested, ha	19	101	128	176	424
Average Stand Volume, m^3/ha	993	815	731	598	708
Volume Harvested. m^3/ha	993	483	502	386	471
m^3	18867	4878364256		67936	199842
%	100	59	69	65	67
Roads, ha	19.0	2.0	0.5	0.7	22.2
Skid trails, ha	0.0	8.8	11.2	15.4	35.4
Landings, ha	0.0	3.5	1.3	3.6	8.4
Percent Area Compacted	4.5	3.3	3.1	4.7	15.6

[a] Adapted from Rice et al (1979), Ziemer (1981), and Wright (1985).

METHODS

Data collection at the Caspar Creek Paired Watershed site was initiated in 1961 with the installation of a series of rain gauges within the two watersheds. The following year, a 120-degree ‘V’ notch weir with a Stephens A-35 recording stream gauge was set up at the point of outflow of each of the watersheds. This arrangement has provided a continuous record of precipitation and stream stage height from the fall of 1962 through the present. This particular study of low flows encompasses an analysis of data from the fall of 1962 through the end of 1983.

The precipitation record used in this study consists primarily of the measurements from a recording gauge located in a clearing near the South Fork weir. These data are complimented by a minimal amount of high quality estimates based on precipitation measured at the North Fork and at the city of Fort Bragg (10 km to the north).

Necessary streamflow gauging station maintenance activities were performed during some summer periods. This timing was chosen because the original primary emphasis of the Caspar Creek project was to examine winter streamflow processes including peak flows and sediment loads. The streamflow record was not complete due to these activities as well as equipment malfunctions and vandalism.

Preparation of the Streamflow Record

Data reconstructions were performed to correct for gaps in the existing summer flow record. For rainless periods, this was done by graphing stage height values preceding and following the gap on semi-log paper and connecting the segments with a straight line. This is a commonly used simple method of linearizing the recession curve (Hall, 1968). By plotting actual dry period stage measurements from Caspar Creek it was determined that this technique did appropriately linearize the baseflow curve and approximate real summer streamflow declines. The mean flows for 366 daily records were derived in this manner. This represents only about 2.5 percent of the total daily streamflow records.

For a single gap in the North Fork streamflow record (1971) it was necessary to account for measured precipitation in performing the reconstruction. The graphical method just described was used, but the effect of precipitation was estimated by examining other North Fork streamflow responses to similarly-sized rain events. With 132 days of data thus reconstructed, this was by far the longest gap in the streamflow record for which any reconstruction was attempted.

All precipitation and streamflow data was coded as an indication of quality. Four classifications were used: actual observed data; high-quality (short-length estimate, no precipitation); fair-quality (either due to the length of the estimate or attempt to account for significant precipitation influences); and, poor-quality (due to length of estimate, complicated precipitation influences, or no concurrent data with which to make comparison). This coding made it possible to cheek for systematic bias or other indications of inaccuracies in the information generated using data which included reconstructions.

A single significant gap remained in the atreamflow record for both forks between November 1976 and August 1977. It was decided that the quality of any reconstruction attempt for this lengthy period would be unacceptable. Therefore it was necessary to omit the 1977 season from analysis where actual stage measurements were lacking.

Using existing Redwood Sciences Lab programs and original programs, the raw stream stage data was converted to mean daily discharges for analysis.

Defining the Low Flow Season

In determining the low flow season for each year in the study period, the aim was to limit the distinction of the low flow season to that part of each year when the flow response from Caspar Creek was predominated by baseflow rather than stormflow or quickflow processes. Thus, it was expected that the source of summer flow would be groundwater and soil moisture storage. Lacking actual records of this storage component, an indirect measure of ground and soil water levels was needed.

Soil moisture and runoff levels may be indexed by a function of daily precipitation, the antecedent precipitation index (API). The API indicates the effects of previous rainfall in wetting the soil countered by the effects of basin drainage and evapotranspiration in reducing soil moisture at a logarithmically decreasing rate over time (Dunne and Leopo1d,1978). Using existing precipitation data and the exponential law of decay, residual precipitation effects can be calculated (Ziemer,1984). The antecedent precipitation index is defined as:

$$API_i = K * API_{i-1} + P_i' \ (i \geq 1)$$

where APIs is the index value expressed as a depth (cm), P_i is the precipitation (cm) occurring on the ith day of the calculation, and K is the recession factor ($K \leq 1$). The initial value. API_0. may be estimated as the amount of available moisture in the soil profile on the first day of the calculation. This concept was originated to predict runoff from storm rainfall in calculating flood hazards. In such an application, a recession factor varying between 0.85 and 0.95 is commonly used depending on basin charactersistics and climate (Linsley and Kohler,1951). To predict winter stormflow at Caspar Creek scientists have reasoned a recession factor of 0.90 to be appropriate.

For this analysis of low flows, it was reasoned that defining the starting and ending dates of the low flow season in terms of a moisture index of this type would be more meaningful than using arbitrary preset dates. The great variability in the arrival and cessation of the rainy season each year precludes the use of a constant starting and ending date for the low flow season throughout the study period.

It was hypothesized that a recession factor in the range of 0.95 to 0.99 would result in a reasonable API value to relate to the residual effect of previous precipitation on summer streamflow processes in the Caspar Creek drainage. This value is somewhat higher than is commonly used for stormflow applications, but this is deemed reasonable because it is the more gradually declining baseflow processes which are the primary focus of this investigation. Lower recession factors would frequently result in an API of zero, but at no time during the 22-year study period did streamflow in either fork cease.

A computer program was then devised in which a hypothetical starting and ending date for the low flow season each year could be calculated according to a set of user defined criteria. The following options were included:

I. Vary the recession factor used in computing the daily API.

II. Vary the start-of-season criteria such that the starting day occurs:

   A. at a peak in the daily API which

      1. is greater than or equal to a specified percent of the maximum one day API, or

      2. has not been exceeded in a specified number of preceding days or

      3. is preceded by an uninterrupted rise in the daily API equaling or exceeding a specified percent of the maximum one day API;

   B. when the daily API falls below a specified threshold and is not exceeded for the remainder of the season.

III. Vary the end-of-season criteria such that the final day of the season occurs:

   A. when the API is at minimum for the year, or

   B. when the API exceeds the specified threshold which signalled the start of the season.

In using each of the various options for the start and end of the summer flow season, different portions of the annual streamflow hydrograph may be included for analysis. According to a definition which starts the season at a peak in the API, option A. the season would begin with the last mayor rainfall of the winter rainy period. Thus, the transition from stormflow processes to summer baseflow would be included. The theory behind start-of-season option B would be to start the season when antecedent moisture conditions suggest that the influence of stormflow processes has resided and baseflow processes are governing streamflow. A definition wherein the end of the low flow season occurs when this API threshold has again been exceeded would continue the low flow season until moisture levels have been sufficiently recharged to reintroduce the possibility of a significant stormflow component to the stream response. When the definition requires that the season be ended on the date of minimum API this return to pre-summer flow levels is excluded.

A variety of definitions of the low flow season were generated for consideration. The choice of the 'best' definition for the proposed analysis was based on the regression analysis of the cumulative seasonal North Fork (control) streamflow volume on the cumulative seasonal antecedent precipitation index, visual comparison of the API recession and season starting/ending dates to plotted North Fork mean daily flows, and intuitive reasoning.

The regression analyses were done using a revision of an existing Redwood Sciences Lab computer program, R2MAP (Horne,1982), which automatically varied the characteristics of the independent variable, seasonal API. The seasonal API was obtained by summing the daily API values (in excess of a threshold daily value) for the period defined as a low flow season. Within each run the recession factor was varied according to user specifications. The threshold, a percentage of the maximum one day API for the study period, was also varied. For each run, a table of the coefficients of determination, r^2, between the streamflow volume and the seasonal APIs) was produced. Using this procedure the combinations of low flow season definition. API recession factor, and API threshold value most useful in explaining the variation in seasonal flow volume were identified for further evaluation.

The regressions which resulted in high r^2 values were then graphically superimposed on a plot of the actual data points. These were analyzed visually to check the appropriateness of the linear model, goodness of fit, presence of outliers, and distribution of values along the full range of the independent variable. Also, the F-statistic for a general linear test (Neter et al.,1983) was calculated using an alpha equal to 0.05 for the set of plausible regressions.

To further screen the remaining season and API definitions. North Fork streamflow, (mean daily flows) was plotted against time for the extent of the study period. A similar plot of daily API values was generated for the recession factors still in consideration. The shape of the API recession curve was then compared to that of North Fork streamflow to identify which API recession factor, K, best approximated the seasonal decline in streamflow. On these plots the potential starting and ending dates for the low flow season were indicated to check against the corresponding North Fork flow levels.

Using statistical analysis and scientific reasoning, a satisfactory definition of the low flow season based on antecedent precipitation was determined. The selected definition employed a recession coefficient of 0.97 and start/end-of-season criteria B. From this definition the beginning and ending dates for each year in the study period were also determined such that the current 'API year' began on the day which followed .the final day of the preceding low flow season and continued through the last day of the current low flow season.

Data Analysis: Determining the Effects of Timber Harvest on seasonal Streamflow Parameters

Development of Potential Streamflow Variables

After finalizing the definition of the low flow period, 15 streamflow variables were developed and their values calculated for the North and South Forks (Table 2). These variables were chosen to provide insight into particular aspects of the streamflow process, and so that any changes observed following logging could be more clearly identified. A file was created for each of these streamflow variables containing a North Fork value, a South Fork value, and a quality code (p 27) for each year in the study period.

Simple Regression of South Fork Streamflow on North Fork Streamflow

An important advantage of the paired basin approach to hydrologic investigations is that it accomodates the use of regression techniques to evaluate possible cause-and-effect relationships and temporal trends while minimizing unexplained variance (Ponce et

Table 2. Streamflow Variables Developed for Use in this Analysis.

Name	Definition
SUMVOL	The total flow volume for the low flow period.
SUMVLEN	The average daily flow volume for the low flow period. The total flow volume for the low flow period divided by the length (in days) of the low flow period.
TOTVOL	The total flow volume for the low flow season and the preceding rainy season. The total flow volume for the API year.
TOTYLEN	The average daily flow volume for the API year. The total flow volume for the low flow season and the preceding rainy period divided by the length (in days) of the API year.
PARTVOL	The ratio of total summer flow volume to total annual flow volume. ie SUM/VOL/TOTVOL.
END	The mean daily flow rate on the final day of the low flow period.
START	The mean daily flow rate on the first day of the low flow; season.
MINAPI	The mean daily flow rate on the date of the minimum one day API for the summer season.
MINFLO	The minimum mean daily flow rate for the low flow season.
CHANGE	The change in flow rate from the first to the final day of the low flow season, ie START-END.

Table 2. Streamflow Variables Developed for Use in this Analysis (continued).

Name	Definition
DECFLO	The decline in rate of streamflow from the first day of the summer flow period to the date of minimum flow, ie START-MINFLO.
DECTIME	The length of the decline period (in days) from the first day of the low flow period to the day of minimum flow.
DECFPT	The mean daily decline in flow rate from the first day of the low flow season to the day of minimum flow. The decline in flow divided by the length (in days) of the decline period ie DECFLO/DECTIME.
LOFLOZ	The number of days during the low flow season when the mean daily flow rate is less than 5.66 l/sec (0.2 cfs).[a]
LOFLEN	The number of days during the low flow season when the mean daily flow rate is less than 5.66 l/sec (0.2 cfs) divided by the length of the low flow period

[a] This is a somewhat arbitrary value based on the lowest flow class used in preliminary flow duration analysis at Caspar Creek. No particular flow threshold could be defined as 'stressful' to indigenous fish populations since the morphology of the stream seems to provide pools for refuge from even the lowest summer flows (Lynn Decker, personal communication).

al.1982). The choice of paired watersheds is based on the degree of natural correlation between the two which arises from similarities in climate, soils, vegetation, elevation, and aspect. When this assumption of similarity is met, the need to quantify watershed characterstics and conditions is reduced. Hydrologic measurements (paired in time) are made in both basins to establish a pre-treatment regression relationship. While data collection continues, one watershed is treated and the other maintained as a control. The post-treatment data are then used to develop a new regression. Comparison of the pre- and post-treatment regressions then provides statistical information on the effects of the treatment.

According to this paired watershed experimental design. South Fork streamflow measurements before, during, and after logging were paired with North Fork measurements. These data pairings were then divided into two classes for analysis: calibration and post-logging. At this stage it was decided to include the road construction years in the pre-logging (calibration) class. Previous Caspar Creek studies have found that road construction activities were not of sufficient magnitude to significantly alter the hydrologic response of the basin to a statistically detectable extent. In view of the limited size of the data set this grouping was expected to improve the strength of this statistical analysis. The calibration (pre-logging) period consisted of the years 1963 thru 1970. The years 1971 thru 1983 were included in the post-harvest period. Simple linear regression was then used to determine a calibration and a post-treatment relationship between the South Fork and the North Fork (South Fork. Y, regressed on North Fork. X).

For each of the 15 streamflow variables, two simple linear regression models were developed for the calibration period and the post-treatment period, respectively. This was done using the PLOT programming package (Hankin,1982) available at the Redwood Sciences Lab. The resulting regression equations were plotted graphically as were the actual data pairings (Appendixes A-N). The coefficient of simple determination was calculated for each regression for examination. The general linear test was used to test the significance of each regression. In cases where significant regression relationships were not indicated, transformations were attempted to achieve linearity and homogeneity of variance. Where this was not successful the variable was removed from further analysis.

Informal visual analyses of the North Fork versus South Fork plots were made to get a general idea of trends between the calibration and post-treatment responses.

Using the MINITAB statistical computer package (Ryan et al,1982), prediction limits (Neter et al,1983, pp 76-82) were calculated to determine if the post-harvest responses were within the range predicted by the calibration relationships. This was done both to test the magnitude of the impacts of the logging operations on streamflow and to determine the duration of statistically significant changes in the summer flow response at Caspar Creek. Again, this test was performed at the 0.05 significance level.

Data Analysis: Determination of Significant Factors Influencing the Low Flow Response

Multiple regression analysis was used to develop a descriptive model showing which management and climatic variables might be most influential in affecting the extent and duration of changes in summer flow processes at Caspar Creek. To study the relative change in response between the two Caspar Creek watersheds the ratio of difference was chosen for the dependent variable. Ratio of difference variables were developed for the relevant streamflow parameters to be examined (Table 3).

Development of Potential Descriptive (Independent) Variables

An extensive set of potential independent variables was compiled drawing from actual logging operation and precipitation data, as well as published information on normal monthly climatic conditions for the Caspar Creek vicinity. These variables were organized into four categories: logging, precipitation, antecedent precipitation, and general climatic norms.

Preliminary analysis suggested that the effects of logging on streamflow were at a maximum immediately following harvest thereafter declining as forest regeneration occurred. For this reason, logging variables were defined as an exponential function of time since logging. This relationship was suggested by visual analysis of residuals of post-treatment data points resulting from the calibration equations developed by simple linear regression of the South Fork variables on the North Fork. Due to substantial variability in the post-logging response, the appropriate exponential coefficient was not

Table 3. Dependent Variables Used in Multiple Regression Analysis.

Name	Definition (SF-NF)/NF [a]
SUMVOLSN	Ratio of difference between seasonal flow volume on the South and North forks.
TOTVOLSN	Ratio of difference between annual flow volume on the South and North forks.
PARTVOLSN	Ratio of difference between proportionate seasonal flow volume on the South and North forks.
STARTSN	Ratio of difference between the start-of-season rate of flow on the South and North forks.
MINSN	Ratio of difference between the minimum mean daily flow rate on the South and North forks.
ENDSN	Ratio of difference between the end-of-season rate of flow on the South and North forks.
LOFLOZSN	Ratio of difference between the number of 'low flow days' for the season on the South and North forks.

[a] SF - value of streamflow variable (Table 2) on the South Fork.
NF - value of streamflow variable (Table 2) on the North Fork.

readily perceived. For this reason four distinct logging variables were developed for further testing according to the following general model:

$$LOGVAR=ROAD_0+STGA_0e^{-\lambda t}\ At+STGB_0e^{-\lambda t}\ +STGC_0e^{-\lambda t}$$

where, $ROAD_0$ is the percent area or timber volume impacted by right-of-way clearing, $STGA_0$ is the percent area or timber volume impacted by stage one harvest, $STGB_0$ is the percent area or timber volume impacted by stage two harvest, $STGC_0$ is the percent area or timber volume impacted by stage three harvest, $-\lambda$ a is the recovery factor used to model a hypothesized forest recovery rate, and t is the time in years since impact for each particular stage. The percent impact tern was set equal to zero for the years preceding treatment and the actual year of treatment. The previous analysis suggests impacts of treatment on water yield did not become significant until the year following treatment. For the year immediately following treatment, time since impact, t, was set equal to zero so that the full impact could be modeled. For each subsequent year t was incremented by one. This model was used to derive the logging variables listed in Table 4a.

The exponential coefficient, $-\lambda$, was set according to the hypothetical recovery period deemed reasonable for the impact being modelled. Because recovery from soil compaction brought about by construction of roads, landings, and skid trails would be slow relative to the length of the study period the recovery factor, $-\lambda$, was set to zero for the variable representing the percent area compacted. %AC.

For a second logging variable, the time required for the forest to return to pre-harvest stand conditions was hypothesized to be 85

Table 4a. Logging Variables Developed for Use in the Multiple Regression Analysis as Independent Variables

Name	Definition
%AC	Percent of watershed area compacted, includes road, skid trail, and landing areas.
%ADF	Cumulative percent of area logged employing a recession constant, $-\lambda$, equal to -0.13 to model recovery in terms of vegetation water use. Half-life of recovery estimated at 5.5 years.
%ADF2	Cumulative percent of area logged employing a recession constant, $-\lambda$, equal to -0.20 to model recovery in terms of vegetation water use. Half-life of recovery estimated at 3.5 years.
C%TVR	Cumulative percent of timber volume removed from total South Fork watershed area employing a recession constant, $-\lambda$, equal to -0.08 which assumes complete (99.9x) regrowth of forest will require 85 years. Half-life of recovery estimated at approximately 9 years.

years since this was the average stand age at removal. Assuming that after 85 years the timber volume at the Caspar Creek site will approximate pre-harvest conditions, harvest impacts on streamflow will be negligible (for the sake of calculation. 0.001 of the original impact). This scenario was used to compute the value of $-\lambda$ Prom the following exponential function:

$$0.001 = e^{-\lambda t} \quad (t=85),$$

and solving for $-\lambda$

$$-\lambda = (\ln 0.001)/85 = -0.08.$$

Using the 85-year regrowth interval, $-\lambda$ was set at -0.08 for variable, C%TVR, which modelled the percent of the original timber volume removed.

For the variable C%TVR recovery is defined in terms of timber volume full regeneration. An alternative approach is to define forest recovery in terms of renewed water demand and evapotranspiration by the regenerating vegetation. Rapid regrowth of forest species and enhanced evapotranspiration demand from remaining forest and understory vegetation may result in a much shorter recovery period than hypothesized for the variable C%TVR. A second alternative to the timber volume regeneration definition of recovery is to define recovery in terms of canopy closure. Canopy closure and the consequential renewal of rainfall interception by the forest occurs prior to the full regeneration of the pre-harvest timber volume. These two alternatives appear to provide a more reasonable definition of forest recovery from the standpoint that it is the hydrologic implications of logging which are the primary focus of this investigation. With these alternative recovery scenarios 1n mind, two variables were developed to model area harvested, %ADF and %ADF2.

Visual analysis of the residuals of the post-treatment data points plotted according to the pre-treatment regressions of South Fork on North Fork suggested that the half-life of logging impacts was approximately five to six years (Appendixes A-N). Using this observation an appropriate value for $-\lambda$ was calculated to be used in defining the variable %ADF:

$$0.5 = e^{-\lambda t} \quad (t=5.5),$$

and solving for $-\lambda$

$$-\lambda = (\ln 0.5)/5.5 = -0.13.$$

Similarly, visual analysis of the above-mentioned residual plots provided some indications that treatment effects became negligible eleven years after logging was initiated. Or, after eleven years a significant deviation from the predicted response could not be readily discerned from the inherent variability of the response. In modelling a fourth logging variable, %ADF2, the assumption was made that the magnitude of logging impacts would be ten percent of the original:

$$0.1 = e^{-\lambda t} \quad (t=11),$$

and solving for $-\lambda$

$$-\lambda = (\ln 0.1)/11 = -0.2.$$

These latter two recovery scenarios as modelled in the variables %ADF and %ADF2 seem most probable in terms of results cited by previous studies in the Pacific Northwest region (Harr,1979), and research on time required to achieve canopy closure following harvest

(Chubatyi,1983). Preliminary analysis of the Caspar Creek response supports this as well.

The precipitation variables developed are simply different manifestations of actual data recorded at the study site. These are listed and defined in Table 4b.

The antecedent precipitation variables were developed to model moisture conditions in the Caspar Creek Basin. They are based on the actual rainfall record and the antecedent precipitation recession factor (0.97) and threshold (5 cm) arrived at in determining the low flow season. For a listing and description of these variables see Table 4c.

Lacking actual measurements of solar radiation, temperature, and cloud cover, general climate conditions were estimated by using published data on average conditions for the vicinity of the study site and the low flow periods previously defined as a function of the antecedent precipitation index. The variation in this group of variables arises from differences in timing and length of the low flow season. The published data used in developing these variables included tables of daily sunrise, sunset, and twilight at 39 degrees North latitude (U.S. Naval Observatory, 1946); average monthly extraterrestrial radiation at 39 degrees North latitude; and average monthly percent possible sunshine at Eureka, California (California Department of Water Resources, 1978). While this data cannot account for the inherent variation in actual climatic conditions during the study period, it was hypothesized that it might prove useful in partially explaining the inconsistent response of seasonal streamflow

Table 4b. Precipitation Variables Developed for Use in the Multiple Regression Analysis as Independent Variables

Name	Definition
PPTYR	Total measured precipitation for the API year, cm. [a]
MPPTYR	Total measured precipitation for the API year divided by the length of the API year, cm/day.
PPTSEAS	Total measured precipitation for the low flow season, cm.
MPPTSEAS	Total measured precipitation for the low flow season divided by the length of the low flow season, cm/day.
TRD	Total rainy days. Total number of days with recorded precipitation during the API year.
%TRD	Percent of days with recorded precipitation during the API year. Number of days with recorded precipitation during the API year divided by the length of the API year in days.
SRD	Summer rainy days. Number of rainy days with recorded precipitation during the low flow season.
%SRD	Percent of days during the summer season with measured precipitation. Number of days with recorded precipitation during the low flow season divided by the length of the low flow season in days.
PROPRD	Proportionate number of rainy days occurring in the summer. Number of days with recorded precipitation during the low flow period divided by the total number of days with recorded precipitation during the entire API year.
PREPPT	Total measured precipitation for the preceding API year, cm.

[a] The API year is defined as commencing on the day which follows the last day of the preceding low flow period and continuing through the final day of the current low flow period. Thus, it includes the 'winter' or 'rainy' season when the daily antecedent precipitation index exceeds the start-of-season threshold as well as the low flow season.

Table 4c. Antecedent Precipitation Variables Developed for Use in the Multiple Regression Analysis as Independent Variables

Name	Definition
LENYR	Length of the API year, days.
LENSEAS	Length of the low flow season, days.
PROPLEN	Proportionate length of the low flow season. Length of the low flow period divided by the length of the API year.
APIYR	Cumulative daily antecedent preciptation index for the API year. cm.
MAPIYR	Mean daily antecedent precipitation index for the API year. Cumulative daily API divided by the length of the API year, cm/day.
APISEAS	Cumulative daily antecedent precipitation index for the low flow season, cm.
MAPISEAS	Mean daily antecedent preciptation index for the low flow season. Cumulative daily API divided by the length of the low flow period, cm/day.
MINAPI	Minimum one day antecedent precipitation index for the low flow season (and API year), cm.
MAXAPI	Maximum one day antecedent precipitation index for the API year. cm.
PREAPI	Cumulative daily antecedent precipitation index for the preceding API year, cm.

processes to logging activities. The general climatic variablesscreened in this analysis are listed and defined in Table 4d.

Multiple Regression Analysis

At this point, 28 potential independent variables had been developed for consideration in building the multiple regression models with which to describe the differences in streamflow response between the North and South forks of Caspar Creek. It was suspected that multicollinearity existed among the independent variables. The correlation matrix was constructed showing correlation coefficients for all pairs of dependent and independent variables. Where the pairwise correlation coefficient between two potential independent variables was greater than 0.900, it was necessary to eliminate one of the pair from the independent variable set. This decision was a judgemental one based on the simple correlation between each variable in the pair and the dependent variables, the simple correlations between each variable in the pair and the other potential independent variables, and the experimenter's expectations of the value of each variable in performing this regression analysis. It was reasoned that elimination of a variable which was so highly correlated with another would not seriously affect the amount of information contained in the set of independent variables to be screened in this analysis. By this evaluation the number of potential independent variables was reduced to fifteen.

An all-possible-subsets regression selection procedure was used to examine possible regression models and identify 'good' models. The primary goal of this analysis was to develop a model which provides a

Table 4d. General Climate Variables Developed for Use in the Multiple Regression Analysis as Independent Variables

Name	Definition
HRLIT	Estimated total possible daylight for the low flow season based on times of sunrise and sunset at 39 degrees North latitude, hours. [a]
HDLITHR	Mean possible daylight per day for the low flow season. Estimated total possible daylight for the season divided by the length of the low flow season, hours/day.
LYSEAS	Estimated normal incoming solar radiation for the low flow season. Based on average monthly extraterrestrial radiation at 39 degrees North latitude multiplied by average monthly percent possible sunshine for Eureka, California; langleys (cal/cm^2).[b]
MLYDAY	Estimated normal mean daily incoming radiation for the low flow season. Total estimated normal incoming radiation for the low flow season divided by the length of the low flow season, langleys/day.

[a] (source: U.S. Naval Observatory. 1946)

[b] (source: California Department of Water Resources. 1978)

simple but realistic representation of the important factors influencing the differences in seasonal streamflow responses between the North and South Forks of Caspar Creek. For this reason no single statistical criteria was solely relied upon in choosing the 'best' model.

The WINNOW all-possible-subsets regression selection program (Sharpnaek,1980) was used as a starting point in screening possible models. This program ranks the possible regressions for each number of independent variables included according to the value of Mallow's Cp. Mallow's Cp is a test criterion concerned with the total mean squared error of the fitted values for each of the various subset regression models measured by the sum of the squared biases and the variance of the dependent variable (Daniel and Wood. 1971). To limit the amount of output, only the five highest ranked regressions for each number of included independent variables were printed. In addition to the Cp values, the output from this program includes several other statistics which aid in evaluation these regression models.

MINITAB was used to further evaluate the possible regressions. Comprehensive statistical information was generated for potential models including the adjusted coefficient of multiple determination, R_a^2; analysis of variance results; and residuals. A judgement on the aptness of each model was based on the evaluation of these results using the overall F test for the existence of a regression relation, the partial F test for the marginal reduction in variance associated with each additional variable, and graphical analysis of residuals. The correlation matrix derived earlier was also used to check for interdependencies among included independent variables. In addition.

the signs of the regression coefficients were considered in relation to to the simple correlation coefficient of that variable to the dependent streamflow variable and in relation to the expected directional influence of that variable. By this both objective and subjective process the preferred descriptive regression model was chosen for each of the streamflow ratio variables examined.

RESULTS

The Low Flow Season

The low flow season was defined using a recession factor of 0.97 as beginning when the daily API fell below 10 cm and continuing until the index exceeded 10 cm. On the average, the seasons thus defined began in early May and ended around the middle of November. Table 5 lists the dates of the low flow season and API year for the extent of the study period.

This low flow season definition was evaluated by regressing cumulative North Fork seasonal flow volume on cumulative seasonal API. The independent variable in this regression, cumulative seasonal API, was obtained by summing that portion of the daily API values which exceeded ten percent of the maximum one day API (approximately 5 cm). The general linear test F-statistic indicated that this regression was highly significant ($p < 0.001$, $n = 20$). The coefficient of determination, r^2, for this regression indicates 66.3 percent of the variation in the North Fork summer flow volume was explained by cumulative seasonal API. The values of the seasonal API were well distributed across the range of this variable.

Residual analysis suggested the presence of a single outlier, the 1971 observation, lying 2.5 standard deviations above its predicted value. Upon review of the streamflow record for this data point, the deviation was attributed to inadequate missing data reconstruction. The 1971 low flow record for the North Fork contained the only data

Table 5. Dates of the Low Flow Season and API Year.

Hydrologic Year	API Year Begins Mo Da Yr	Low Flow Season Begins Mo Da Yr	Low Flow Season Ends Mo Da Yr	API Yr Length (days)	Season Length (days)
1963	11 12 62	5 27 63	10 22 63	345	149
1964	10 23 63	4 5 64	11 9 64	384	219
1965	11 10 64	4 29 65	11 13 65	369	199
1966	11 14 65	4 23 66	11 13 66	365	205
1967	11 14 66	5 29 67	12 2 67	384	188
1968	12 3 67	4 17 68	11 24 68	358	222
1969	11 25 68	4 26 69	12 12 69	383	231
1970	12 13 69	4 7 70	11 5 70	328	213
1971	11 6 70	5 9 71	12 7 71	397	213
1972	12 8 71	4 25 72	11 4 72	333	194
1973	11 5 72	4 28 73	10 7 73	337	163
1974	10 8 73	5 2 74	12 3 74	422	216
1975	12 4 74	5 17 75	10 26 75	327	163
1976	10 27 75	4 23 76	11 10 76	381	202
1977	11 11 76	3 15 77	11 21 77	376	252
1978	11 22 77	5 27 78	1 10 79	415	229
1979	1 11 79	5 20 79	10 24 79	287	158
1980	10 25 79	5 13 80	12 2 80	405	204
1981	12 3 80	4 15 81	10 27 81	329	196
1982	10 28 81	5 11 82	10 29 82	367	172
1983	10 30 82	5 26 83	11 9 83	376	168

estimation which attempted to account for substantial summer precipitation (approximately 5 cm from May 21 thru September 30). This questionable data point was omitted from the regression because of the uniqueness of the reconstructed observation.

The starting dates of the low flow season were found to correspond well with an approximate North Fork flow rate of 1 cfs (28 liters/sec), while the end-of-season flow rates were more variable depending on the characteristics of late season precipitation events (Figure 2).

Although other low flow season definitions resulted in higher r^2 values this was attributed to the wide spacing of the independent variable (seasonal API). As explained by Neter et al. (1983, p 99), the value taken by r^2 is affected by the spacing of the independent variables since this spacing tends to influence the spread of the dependent observations about the mean. such that the total variation (SSTO) is greater when the range of the dependent variable is wide. However, the variation not explained by the regression (SSE) is not systematically affected by the spacing of the independent variables. From the formula for r^2

$$r^2 = (SSTO-SSE)/SSTO$$

it can be seen that when the SSTO is inflated by the spacing of the independent variables relative to the unaffected SSE, the statistic, r^2, tends to be higher.

For some low flow season definitions with high coefficients of determination other constraints were not met. For example, the values of the seasonal API were nonuniformly distributed such that a few points exerted undue influence on the slope of the regression line;

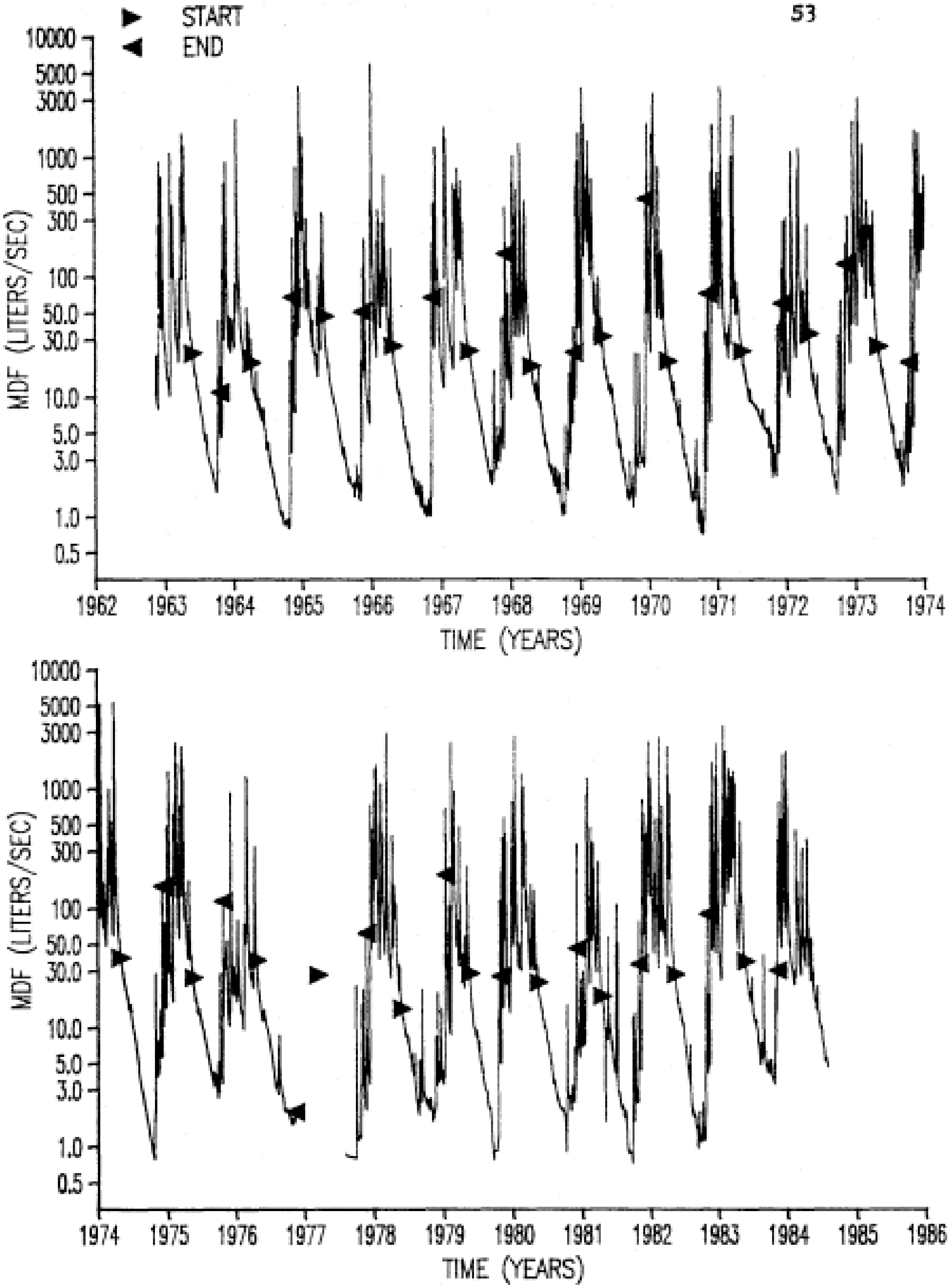


Figure 2. Starting/Ending Dates of the Low Flow Season and
Corresponding North Fork Flow Rates: 1963-1973 (top)
1974-1986 (bottom)

or, the season starting/ending dates did not correspond well with low flow levels on the North Fork.

Effects of Logging on Streamflow Parameters

The calibration period simple linear regressions of the 15 South Fork streamflow variables on those of the North Fork yielded significant relationships ($p < 0.025$) in all but one case. The regression of the flow rate on the day of minimum API, MINAPI, was not statistically significant. The coefficients of determination for the remaining 14 regressions ranged from 0.696 to 0.994 (eleven of these values were greater than 0.830).

For the post-logging period the relationships between the North Fork and South Fork streamflow variables was shown to be more variable. Twelve of these regressions were found to be significant ($p < 0.05$) according to the general linear test. The calculated values of the F-statistic used in this test were generally closer to the test value. No significant relationship could be detected between the North and South forks for three variables: MINFLO, LOFLOZ, and LOFLEN. The r^2 values for the 12 significant relationships ranged from 0.376 to 0.970, however only four of these exceeded 0.800. (Table 6a)

Visual analysis of the calibration and post-harvest regression lines suggests that atreamflow during both the low flow period and the API year may have been enhanced following logging of the South Fork drainage (Appendixes A-N). For eleven of the streamflow variables (SUMVOL, SUMVLEN, TOTVOL, TOTVLEN, START, END, MINFLO, DECFLO, DECFPT, and MINAPI), the post-logging regression line plotted above the

Table 6a. Comparison of Selected Statistics for Calibration and Post-treatment Regressions: South Fork Regressed on North Fork.

Variable	Calibration r^2	Calibration F (0.95,1,6)	Calibration Significance Level	Post-treatment r^2	Post-treatment F (0.95,1,10)	Post-treatment Significance Level
TOTVOL	0.980	286.80	0.001	0.970	322.80	0.001
TOTVLEN	0.978	273.00	0.001	0.970	321.90	0.001
SUMVOL	0.915	64.50	0.001	0.459	8.48	0.025
SUMVLEN	0.880	44.13	0.001	0.376	6.02	0.050
PARTVOL	0.838	31.03	0.005	0.676	20.87	0.005
LOFLOZ	0.913	62.97	0.001	0.245	3.24	*
LOFLEN	0.793	23.03	0.005	0.214	2.72	*
START	0.894	50.46	0.001	0.782	35.92	0.001
MINFLO	0.911	61.72	0.001	0.295	4.18	*
END	0.994	1032.00	0.001	0.827	47.84	0.001
DECFLO	0.925	73.93	0.001	0.816	44.48	0.001
DECFPT	0.780	21.23	0.005	0.578	13.72	0.005
DECTIME	0.696	13.73	0.025	0.418	7.17	0.025
CHANGE	0.993	852.10	0.001	0.787	36.89	0.001
MINAPI	0.481	0.30	*	0.454	8.30	0.025

* = Regression not significant ($p > 0.05$)

pre-logging equation suggesting that after logging South Fork valueswere higher relative to the North Fork. For the variables LOFLOZ and LOFLEN the post-logging regression lines fell below the calibration regressionline indicating that there were fewer low flow days on the South Fork following removal of timber from the watershed. A comparison of the regression coefficients is found in Table 6b.

While these observations seem to support the hypothesis that Caspar Creek streamflow was enhanced after timber harvest, further analysis was necessary to evaluate the statistical significance of these results. By using the calibration relationships and constructing prediction intervals, the significance, magnitude, and duration of logging impacts on South Fork streamflow parameters were studied. The construction of prediction limits (intervals) accounts for two possible sources of variation in the level of each new observation of the dependent variable: variation in the possible location of distribution of the dependent variable. and variation within the probability distribution of each dependent observation. Any additional variation is interpreted as resulting from an external source, such as a change in the nature of the regression relationship.

In using prediction limits to make inferences concerning new observations based on a predetermined regression relationship, certainty about the possible value of the dependent variable is influenced by the value of the independent variable in relation to its mean. A small change in the slope of the regression function will have only a small impact on the predicted value of the dependent variable when the value of the independent variable is at or near its mean.

Table 6b. Comparison of Calibration and Post-treatment Regression Coefficients: South Fork Regressed on North Fork.

Variable	Calibration b_0	Calibration b_1	Calibration s	Post-treatment b_0	Post-treatment b_1	Post-treatment s
TOTVOL	120.70	0.847	109.5	423.2	0.848	275.4
TOTVLEN	0.505	0.823	0.298	1.290	0.833	0.670
SUMVOL	-39.43	1.509	13.39	11.20	1.248	46.74
SUMVLEN	-172.4	1.467	69.33	211.9	1.026	228.0
PARTVOL	0.008	1.123	0.0006	0.016	0.945	0.0187
LOFLOZ	-43.204	1.216	9.234	10.341	0.570	32.18
LOFLEN	-0.508	1.688	0.0480	0.005	0.662	0.1627
START	8.11	0.534	1.927	4.082	0.830	3.463
MINFLO	-0.574	2.098	0.2774	1.860	0.852	1.161
END	-8.02	1.610	19.14	-39.98	3.093	89.42
DECFLO	6.96	0.527	17.30	0.145	0.759	29.93
DECFPT	39.09	0.592	17.30	44.82	0.692	29.93
DECTIME	8.484	0.909	19.89	26.995	0.795	20.70
CHANGE	-0.043	1.613	0.7361	-0.690	2.910	3.361
MINAPI	1.869	0.567	1.070	2.738	0.494	1.043

s = standard deviation of regression line

Consequently, the prediction interval is narrowest at this point. With increasing distance from the mean, confidence about the true location of the dependent variable at a given value of the independent variable is reduced due to the fact that even a small variation in the slope of the regression line can result in a relatively large change in the predicted value of the dependent variable. For this reason the prediction interval widens. Outside the range of the predetermined regression relationship, the prediction interval becomes quite expansive making it more difficult to detect a significant deviation from the predicted relationship.

South Fork observations which fell outside of the prediction interval ($p < 0.05$) were judged to be significantly different than the expected value determined by the calibration equation. Table 7 contains a summary of the relationship of the South Fork post-logging observations to the calibration prediction intervals. While a lack of consistently significant alterations of the streamflow response is apparent, there is some evidence of enhanced streamflow beginning in 1972. The most dramatic change, in terms of the number of streamflow variables exceeding the prediction limits, occurred in 1974. Flow enhancement is most strongly indicated by the variables TOTVLEN, START, and MINFLO.

Annual Flow Volume

During five post-treatment years: 1973, 1975, 1978, 1979, and 1982 the observed South Fork mean daily flow volume for the API year (TOTVLEN) exceeded the upper prediction limit, although in all years

Table 7. Summary of Relationships of South Fork Post-treatment Observations to Calibration Prediction Intervals.

Variable:

YR	TOTVOL	TOTVLEN	SUMVOL	SUMVLEN	PARTVOL	LOFLOZ	LOFLEN
71	-	-	m	m	m	m	m
72	-	-	A	ao	Ao	B	Bo
73	A	A	a	ao	ao	b	bo
74	ao	a	Ao	Ao	ao	B	Bo
75	A	A	A	ao	a	b	bo
76	ao	a	a	a	bo	B	b
77	m	m	m	m	m	m	m
78	A	A	A	A	a	Bo	Bo
79	a	A	-o	b	b	a	a
80	a	a	a	a	b	b	bo
81	ao	a	B	Bo	Bo	a	a
82	Ao	A	a	a	bo	b	b
83	-o	a	b	b	bo	ao	ao

Key:

A = Above Prediction Interval
a = Above Predicted Value but within interval
B = Below Prediction Interval
b = Below Predicted Value, but within interval
- = Approximates Predicted Value
m = Data Missing or Questionable Quality (code > 2)
o = Outside Range of Calibration Regression

Table 7. Summary of Relationships of South Fork Post-treatment Observations to Calibration Prediction Intervals (continued).

Variable:

YR	START	MINFLO	END	DECFLO	DECFPT	DECTIME	CHANGE
71	-	bo	b.	b	b	-	-
72	a	A	-	a	a	_	b
73	A	A	a	m	m	m	b
74	A	A	A	A	a	-	B
75	A	m	A	m	m	m	B
76	A	A	ao	A	a	-	bo
77	m	m	A	m	m	m	m
78	ao	a	A	a	ao	-	B
79	b	m	a	m	m	m	b
80	a	m	a	m	m	m	b
81	-	a	a	a	-	-	b
82	A	m	m	m	m	m	m
83	A	m	a	m	m	m	b

Key:

A - Above Prediction Interval
a = Above Predicted Value, but within interval
B = Below Prediction Interval
b = Below Predicted Value, but within interval
- = Approximates Predicted Value
m = Data Missing or Questionable Quality (code > 2)
o = Outside Range of Calibration Regression

subsequent to 1972, the observed value was greater than predicted. The increase during the post-treatment years ranged from 8 to 34 percent (only 2 percent in 1983) and averaged 16 percent. The greatest increase occurred in 1978 when daily flow volume averaged almost two acre feet more than predicted by the pre-logging equation.

Similarly, the total annual flow volume (TOTVOL) measured at the South Fork weir demonstrated an increase during the period from 1973 to 1982 ranging from an additional 7 to 34 percent of the expected flow. In absolute terms this increase in volume amounted to 187 to 804 additional acre feet each year (an average of 325 acre feet per year).

Summer Flow Volume

The volume of streamflow recorded at the South Fork weir during the low flow (summer) season, SUMVOL, exceeded the prediction limits during the 1972, 1974, 1975, and 1978 seasons. For the period 1972 through 1978, the observed summer flow volume was greater than the predicted value, but not all of these increases were shown to be statistically significant. Increases in summer flow volume in the range of 14 to 55 percent were observed. The greatest percent increase occurred in 1978, although in absolute terms the largest increase, 73 acre feet, occurred in 1974. On the average, the increase was 29 percent which equates to an additional 40 acre feet per low flow season.

During the 1981 season, a statistically significant decrease, 27 percent, in summer flow was detected. A 19 percent decrease was observed in 1983, but this was not found to be significant.

The response indicated by the average daily flow volume during the low flow period (SUNVLEN) followed the same pattern as the total summer flow volume variable, but a significant increase was detected only for the 1974 and 1978 seasons.

To investigate change in the seasonal distribution of streamflow volume on the South Fork following logging, the variable PARTVOL (SUMVOL/TOTVOL) was analyzed. Only during 1972 did the proportionate summer flow volume relative to annual flow volume exceed the prediction interval. In contrast, in 1981 the proportionate summer volume was less than lower prediction limit. For the years 1972 through 1975 and 1978, the observed value of this variable exceeded the predicted value. While for the years 1976 and 1979 through 1983, the observed value fell below the predicted value. From these results conclusions drawn based on changes on proportionate seasonal flow volumes must be considered speculative.

Number of Low Flow Days

Analysis suggests there were fewer low flow days (days with mean daily flow rates of less than 5.66 l/sec or 2 cfs) following logging. The number of low flow days, LOFLOZ, was significantly less than predicted for the years 1972, 1974, 1976, and 1978. For these four years there were between 26 and 70 fewer low flow days on the South Fork than were predicted by the calibration regression. During 1973, 1975, 1980, and 1982, the observed value for this variable was less than predicted, but this difference was not shown to be significant ($p > 0.05$). Between 1972 and 1978, the number of low flow days averaged 43 fewer than predicted. This equates to a 40 percent decrease in the number of low flow days on the South Fork for this period.

Results from the analysis of the number of low flow days per the length of the low flow season, LOFLEN, were similar to those of LOFLOZ except that a significant decrease was not detected for 1976.

Start of Season Mean Daily Flow Rate

The rate of flow at the onset of the low flow season was increased significantly on the South Fork relative to the North Fork for the years 1973 through 1976, 1982, and 1983. At the onset of the 1978 and 1980 seasons the flow rate was greater than predicted but a significant difference could not be detected. The maximum increase occurred in 1974 when this flow rate was 46 percent (13.4 l/sec) higher than predicted. From 1973 to 1983 the observed rate of flow averaged 25 percent above the predicted rate. These results suggest that at the start of the low flow season, flow rates on the South Fork were enhanced following logging for the duration of this study period.

Minimum Mean Daily Flow Rate

The minimum one day mean daily flow rate, MINFLO, was significantly increased on the South Fork following treatment for the years 1972 through 1976 (omitting 1975 when the flow estimate was of questionable quality). Subsequently, no significant difference between the two streams in the minimum rate of flow could be detected. However, in 1978 and 1981 the predicted minimum South Fork flow rate was exceeded and for all other years (1977,1979,1980,1982, and 1983) this data was missing or of questionable quality.

This flow rate was more than 300 percent greater than predicted in 1974. In absolute terms this increase was modest, equating to an additional 3.54 l/sec (.125 cfs). For the other years the increase averaged 43 percent above the predicted rate equating to less than 1.5 l/sec.

End of Season Mean Daily Flow Rate

Analysis of the mean daily flow rate for the final day of the low flow season, END, yielded some indications of an increase on the South Fork relative to the North Fork after harvest. According to the defintion of the low flow season, the final day of the season occurs when the daily API again exceeds the low flow season API threshold. Thus it is the occurrence of substantial precipitation which triggers the end of the low flow season.

Beginning in 1973 and continuing through the end of the study period. the observed end-of-season flow rate was greater than the predicted value, but only for the years 1974, 1975, 1977, and 1978 was this increase significant ($p < 0.05$). The increase averaged 87 percent and ranged from 6 percent (1979) to 178 percent (1976). In absolute terms, the maximum increase was manifest in 1974 when the observed flow rate was 382 l/sec (13.5 cfs) greater than predicted by the pre-logging calibration regression. During other years this increase varied from 2.2 l/sec (0.08 cfs) in 1979 to 250 l/sec (8.8 cfs) in 1978, and averaged 63.4 l/sec (2.2 cfs). It is worthwhile to note that a 145 percent increase was detected for the 1977 end-of-season flow rate since this is the only streamflow variable for which actual flow data was available for hydrologic year 1977.

Decline in flow from Onset of season to Day of Minimum Flow

The decline in streamflow, DECFLO, was determined by subtracting the minimum one day flow rate from the start-of-season rate of flow (START-MINFLO). Results indicate that the observed decline was significantly greater than predicted for the years 1974 through 1976. Increases in subsequent years were not shown to be statistically significant. The greatest difference detected occurred in 1974 when the decline was 39 percent more than predicted.

Noting that the start-of-season flow rates far exceeded the minimum flow rates (by more than seven hundred percent), these results may be viewed as an indication that the magnitude of start-of-season flow rate increases were much greater than the minimum flow rate increases. This lends support to the theory that the rate of flow at the onset of the low flow season was enhanced temporarily following logging, as opposed to the idea that flow rates were declining to lower levels following treatment.

Results from the analysis of the mean decline in flow per day for the length of the decline period, DECFPT, approximate those obtained from the analysis of the variable DECFLO although the increases were not significant ($p > 0.05$).

No significant difference was detected in the length of the decline period, DECTIME, following treatment of the South Fork watershed, nor was there evidence of any pattern in the relationship of the observed decline period to that which was predicted by the pre-logging regression.

Change in Flow Rate from the Onset to the End of the Low Flow Season

The difference between the start and end of season flow rates (START-END) was measured by the variable CHANGE. Interpretation of the results from the prediction interval analysis of this variable was not straightforward. All values for the variable CHANGE were negative. This was due to the fact that the ending day flow rates included the streamflow response to substantial precipitation, and thus these flow rates exceeded the starting flow rates in all cases. Observations which fell below the lower prediction limits then indicate a significantly larger (more negative) difference between flow rates at the start and end of the low flow period following treatment of the South Fork watershed.

Analysis indicated a significant difference for the years 1974, 1975, and 1978. In addition, the observed value of this variable for all post-treatment years (excepting 1971 and 1977) was less than the value predicted by the pre-logging regression although a significnant difference could not be detected for these other years.

The interpretation of these results is similar to that of the variable DECFLO. The increase in the end of season flow rate was greater than the increase in the start of season flow rate due to the fact that ending flow rates were several times greater than the flow rates at the start of the low flow season. Thus, these results are a restatement of the indication that end of season flow rates were higher than predicted after treatment of the South Fork basin.

Significant Factors Associated with Variations in the Streamflow Response

Multiple linear regression analysis was used to further examine the apparent inconsistencies in the alteration of the streamflow pattern following timber harvest and to identify factors which were significant in determining differences between the South Fork and North Fork streamflow response. This was accomplished by regressing each of the ratio of difference streamflow variables (Table 3) on the pre-determined set of potential management and climatic variables.

In each case the first variable to enter the multiple regression model was found to be one of those representing logging effects. That is, the variables representing logging effects were most useful in explaining the proportionate difference between North and South Fork streamflow parameters. The number of independent variables which made a significant contribution to the descriptive capabilities of the models ranged from one to four. Variables which were significant ($p < 0.05$) were included in the models except for two cases when a variable was not significant ($0.05 < p < 0.10$) but warranted inclusion to satisfy other regression constraints. These exceptions are noted.

Annual Flow Volume

Of the models evaluated for explaining the ratio of difference between South Fork and North Fork annual flow volumes (TOTVOLSN), two 3-variable models were determined to be most informative while satisfying the various regression criteria (Table 8a). The first included the variables which represented the cumulative percent of the

Table 8a. Multiple Regression Models: Annual Flow Volume Differences.

Dependent Variable: TOTVOLSN (n=19)

	Model 1	Model 2
First Variable	%AC	%AC
Std. Regr. Coefficient	0.8211	0.8037
Second Variable	APIYR	APIYR
Std. Regr. Coefficient	-0.6295	-0.7435
Third Variable	PREAPI	MLYDAY
Std. Regr. Coefficient	-0.4155	-0.3791
R^2	0.766	0.742
R^2_{adj}	0.719	0.693
Overall F Statistic	16.323	15.311
Significance Level	0.001	0.001
Standard Deviation	0.05529	0.05675
Correlation of Residuals to Expected Normal Values	0.995	0.990
Unusual Observations (Std. Residual, Year)	2.11 1978. -2.02 1980	2.25 1978

South Fork watershed area compacted by roads, skid trails. and landings (%AC); the cumulative annual antecedent precipitation index (APIYR); and the cumulative antecedent precipitation index for the preceding year (PREAPI). This model accounted for 76.6 percent of the variation between the treated and control watershed streams. This model suggests that compaction impacts acted to increase South Fork annual flow volume relative to the North Fork, while high antecedent moisture conditions for the preceding and current years had a diminishing effect on this difference. Although compaction effects are well correlated with the relative flow volume differences, direct causation cannot be implied.

The second model which described a significant amount of the variation in TOTVOLSN contained the variables %AC, APIYR, and also a variable representing the expected average incoming solar radiation for the low flow season. MLYDAY. This model explained 74.2 percent of the variation in annual flow volume between the two streams. As before, compaction effects exerted a positive influence on the ratio of difference variable suggesting an enhancement of streamflow attributed to logging operations in the South Fork watershed, while antecedent moisture effects exerted a negative influence such that the difference between the streams was reduced in wetter years. The variable MLYDAY also affected TOTVOLSN in a negative direction. This interpretation is more difficult. The value of MLYDAY is highest when the lowflow season is short and centered around the month of June because incoming solar radiation peaks in mid-June. When averaging expected incoming solar radiation over a longer low flow season, the computed value for this variable is less. With this in mind. the variable MLYDAY can then be interpreted as the composite expected effect of the timing and length of the low flow season and an index of the consequential opportunity for evapotranspiration over the extent of the growing season. It follows then that a high MLYDAY value might be inversely related to potential evapotranspiration over the length of the low flow season.

Summer Flow Volume

From the multiple regression analysis of the ratio of difference between South Fork and North Fork low flow season flow volumes (SUMVOLSN), three models were found to be informative while meeting regression analysis constraints (Table 8b). For each of these three models the variable representing the cumulative percent of the South Fork watershed area cut (using a half-life of 3.5 years in terms of water demand recovery), %ADF2, was found to be most significant. The role of the variable in these models indicates that the difference between the summer flow volumes of the two creeks was increased in proportion to the percent of the South Fork watershed logged.

The best 3-variable model in terms of the coefficient of multiple determination also included the variables representing total precipitation for the low flow season, PPTSEAS, and PREAPI. PPTSEAS exerted a positive influence on the value of SUMVOLSN, while PREAPI exerted a negative influence on this difference. This model explained 69.2 percent of the variance in the dependent variable SUMVOLSN.

A second 3-variable model contained the variables MLYDAY and %AC in addition to %ADF2. As in the TOTVOLSN regression, MLYDAY acted to decrease the difference between the South Fork and the North Fork. Although positively correlated with SUMVOLSN, %AC exerted a negative influence on the SUMVOLSN when entered into the model after %ADF2. It

Table 8b. Multiple Regression Models: Summer Flow Volume Differences.

Dependent Variable: SUMVOLSN (n=19)

	Model 1	Model 2	Model 3
First Variable	%ADF2	%ADF2	%ADF2
Std. Regr. Coefficient	0.6253	0.8861	1.0040
Second Variable	PPTSEAS	PPTSEAS	MLYDAY
Std. Regr. Coefficient	0.4143	0.3502	-0.4209
Third Variable	MLYDAY	PREAPI	%AC
Std. Regr. Coefficient	-0.3823	-0.3341	-0.3969
Fourth Variable	%SRD		
Std. Regr. Coefficient	-0.4508 *		
R^2	0.717	0.692	0.686
R^2_{adj}	0.641	0.630	0.627
Overall F Statistic	9.499	11.230	11.646
Significance Level	0.001	0.001	0.001
Standard Deviation	0.1509	0.1568	0.1539
Correlation of Residuals to Expected Normal Values	0.992	0.979	0.968
Unusual Observations (Std. Residual. Year)	-2.05 1981	-2.23 1981	

* This variable is significant (0.05 < p < 0.10).

should be noted that the pairwise correlation between %ADF2 and %AC was quite high (0.774). The presence of intercorrelation between independent variables makes interpretation of these regression coefficients difficult such that the meaning of any one coefficient cannot be evaluated in isolation from the other(s). This model explained 68.6 percent.

In addition to linearity and constant variance, normality is an important distributional criterion in determining the aptness of a linear regression model (Weisberg,1980). The two 3-variable models had not fully satisfied this criterion. The addition of a fourth variable to either of the two models just described was not significant. An alternate 4-variable model was considered which normalized the distribution of the error terms. This 4-variable model explained 71.7 percent of the variation in SUMVOLSN. Included in this model were the variables %ADF2, PPTSEAS, MLYDAY, and %SRD. The latter variable, which represents the percent of days during the low flow period with measured precipitation, may be perceived as a general index of cloud cover. It was significant ($0.05 < p < 0.10$). As in the models previously described, %ADF2 and PPTSEAS exerted a positive influence on the difference between the South Fork and North Fork summer flow volumes. The influence of MLYDAY was again negative. The role of the the last variable to enter the model, %SRD, was also negative.

The ratio of summer flow volume to annual flow volume provides another perspective on the seasonal distribution of streamflow in the Caspar Creek watershed. PARTVOLSN served as the variable for analyzing distributional differences between the logged and control watersheds. Two significant multiple regression models were developed which give

Table 8c. Multiple Regression Models: Proportionate Summer Flow Volume Differences.

Dependent Variable: PARTVOLSN (n=19)

	Model 1	Model 2
First Variable	%ADF2	%ADF2
Std. Regr. Coefficient	0.9994	1.128
Second Variable	%AC	%AC
Std. Regr. Coefficient	-0.8218	-0.6859
Third Variable	APIYR	PPTSEAS
Std. Regr. Coefficient	0.5267	0.4218
R^2	0.608	0.565
R^2_{adj}	0.535	0.483
Overall F Statistic	8.275	6.920
Significance Level	0.005	0.005
Standard Deviation	0.1688	0.1779
Correlation of Residuals to Expected Normal Values	0.987	0.984
Unusual Observations (Std. Residual. Year)	2.27 1972	-2.47 1981

insight into this relationship (Table 8c). Both of the chosen models contain three significant variables which include %ADF2 and %AC. As in previous regressions, the influence of xADF2 was to enhance the difference between the streams. When entered after %ADF2, %AC acted to diminish this difference. Recognizing that the variable TOTVOL is in the denominator of the ratio variable PARTVOL, it is reasonable that a variable having a positive influence on the TOTVOLSN regression would have the opposite effect in this case.

The third variable to enter the multiple regression model was APIYR. This variable exerted a positive influence on the predicted value of PARTVOLSN which is the opposite effect the variable had in the TOTVOL regressions. This regression explained 60.8 percent of the variation in PARTVOLSN.

In the second chosen regression model, the third variable to enter was PPTSEAS. As in the SUMVOLSN regressions the role of this variable was to increase the ratio of difference between the South Fork proportionate summer flow volume and that of the North Fork. This regression accounted for slightly less of the variation in PARTVOLSN (56.5 percent) but resulted in a slightly more normalized distribution of the residuals.

Number of Low Flow Days

In order to describe the variation in the number of low flow days on the South Fork relative to the North Fork, two appropriate regression models were determined for the variable LOFLOZSN. The first of these contained %ADF2 as the single independent variable. The second model includes two other independent variables in addition to

Table 8d. Multiple Regression Models: Number of Low Flow Days Differences.

Dependent Variable: LOFLOZSN (n=20)

	Model 1	Model 2
First Variable	%ADF2	%ADF2
Std. Regr. Coefficient	-0.6873	-0.5623
Second Variable		%SRD *
Std. Regr. Coefficient		0.5908
Third Variable		PPTSEAS *
Std. Regr. Coefficient		-0.4596
R^2	0.476	0.625
R^2_{adj}	0.447	0.554
Overall F Statistic	16.33	8.878
Significance Level	0.005	0.005
Standard Deviation	0.2007	0.1801
Correlation of Residuals to Expected Normal Values	0.965	0.964
Unusual Observations (Std. Residual, Year)	2.34 1971 -2.58 1972	-2.63 1972

* These two variables were only significant when entered as a pair.

%ADF2. Details from the statistical analysis of these models are provided in table 8d.

The simple linear regression model which accounted for the greatest amount of variation in LOFLOZSN contained the variable %ADF2. This regression model explained 47.6 percent of the variation in the dependent variable. The effect of %ADF2 on the value of LOFLOZSN was negative, such that the difference in the number of low flow days between the South Fork and the North Fork was more negative as the selectively harvested percent of the South Fork watershed area increased. Once this variable had been entered, no other single variable was found to be significant when subsequently introduced.

When both %SRD and PPTSEAS were added to this model the pair was determined to be significant. The third variable added to the model was significant ($0.05 < p < 0.10$) regardless of the order in which these two were entered. Both %SRD and PPTSEAS are positively correlated with LOFLOZSN and with each other. Within the model %SRD influenced the value of the dependent variable in the positive direction. The interpretation here is that during summer periods containing relatively more rainy days (and, presumably more frequent cloud cover) the response of the two streams in terms of number of low flow days would be more similar (i.e. less negative). For seasons where the proportionate number of rainy days is lower, fewer low flow days would be expected on the South Fork relative to the North Fork. PPTSEAS, acting in interaction with %SRD, countered this tendency. Fewer low flow days would be expected on the South Fork relative to the North Fork during those seasons with high total precipitation. This model accounted for 62.5 percent of the variation in LOFLOZSN.

Start of Season Mean Daily Flow Rate

The regression analysis of the ratio of difference between the South Fork and North Fork mean daily flow rate at the onset of the low flow season (STARTSN) resulted in models with poor descriptive ability in comparison to those models developed for other streamflow parameters in this phase of the study. Only models with two or fewer independent variables were found to be significant according to the partial F test. These models were able to explain less than half of the variation in STARTSN (Table 8e).

The simple linear model containing %ADF2 explained 32.5 percent of the variation in STARTSN. Here again, the role of this variable indicated an enhancement of the South Fork flow relative to the North Fork related to the percent of the South Fork watershed partially cut in logging operations. The distribution of residuals resulting from this model did not satisfy the assumption of normality.

The addition of a second independent variable did not reduce the error to a significant extent ($p > 0.05$). However, the reduction in the residual mean square associated with the addition of the variable PREAPI was shown to be significant ($p < 0.10$) and succesfully normalized the distribution of the residuals. This model explained 46.3 percent of the variation in STARTSN.

Possibly the addition of variables representing the timing and magnitude of storm events prior to the start of the low flow season would significantly increase the explained variance associated with this multiple regression analysis.

Table 8e. Multiple Regression Models: Start of the Season Flow Rate Difference.

Dependent Variable: STARTSN (n-20)

	Model 1	Model 2
First Variable	%ADF2	%ADF2
Std. Regr. Coefficient	0.5686	0.6514
Second Variable		PREAPI *
Std. Regr. Coefficient		-0.3898
Third Variable		
Std. Regr. Coefficient		
R^2	0.325	0.463
R^2_{adj}	0•288	0.396
Overall F Statistic	8.679	6.909
Significance Level	0.010	0.010
Standard Deviation	0.1193	0.1127
Correlation of Residuals to Expected Normal Values	0.932	0.984
Unusual Observations (Std. Residual, Year)	2.93 1978	2.37 1978

This variable was significant ($0.05 < p < 0.10$).

Minimum Mean Daily Flow Rate

The relative difference in minimum mean daily flow rate between the South Fork and the North Fork of Caspar Creek was regressed on four significant predictor variables. Three such 4-variable models were quite similar in terms of their coefficients of multiple determination and other statistical criteria (Table 8f).

The 'best' model include the variables %ADF2, APISEAS (representing the cumulative antecedent precipitation index for the low flow season), PREAPI, and MINAPI (which represents the minimum one day API for the low flow season). As in previous regression models, the variable %ADF2 exerted a positive influence on the ratio of difference between the two streams. The role of the variable APISEAS suggests an enhancement of the South Fork minimum flow level relative to the North Fork during seasons with higher antecedent precipitation conditions. The effect of PREAPI was aqain negative, indicating that following wetter years the minimum flow level on the South Fork relative to the North Fork would be reduced. MINAPI also exerted a negative influence on the value of MINSN which implies a greater minimum flow level in the South Fork relative to the North Fork during drier periods. This model explained 79.9 percent of the variation in MINSN.

Two other 4-variable models were effective in explaining more than 75 percent of the variation in the ratio of difference between South Fork and North Fork minimum flow levels, but the distribution of the residuals was not as satisfactory in these cases.

Table.8f. Multiple Regression Models: Minimum Flow Rate Differences.

Dependent Variable: MINSN (n=19)

	Model 1	Model 2	Model 3
First Variable	%ADF2	%ADF2	%ADF2
Std. Regr. Coefficient	0.5276	0.4469	0.4370
Second Variable	APISEAS	APISEAS	APISEAS
Std. Regr. Coefficient	0.6497	0.7920	0.5177
Third Variable	PREAPI	PREAPI	MINAPI
Std. Regr. Coefficient	-0.3127	-0.4474	-0.3548
Fourth Variable	MINAPI	PPTSEAS	LENYR
Std. Regr. Coefficient	-0.3102	-0.4083	0.2833
R^2	0.799	0.793	0.774
R^2_{adj}	0.741	0.734	0.714
Overall F Statistic	13.880	13.446	12.866
Significance Level	0.001	0.001	0.001
Standard Deviation	0.5534	0.5605	0.5662
Correlation of Residuals to Expected Normal Values	0.992	0.989	0.972
Unusual Observations (Std. Residual, Year)		2.07 1974	-2.04 1975

End of Season Mean Daily Flow Rate

The most successful multiple regression analysis (in terms of the ability of the models developed to describe the variation in the ratio of difference streamflow variable) was the regression analysis performed on the end of the season flow rate variable. ENDSN. More than 83 percent of this variation was explained by each of three such models (Table 8g).

The best of these models (based on the coefficient of multiple determination and the distribution of the residuals) included the variables %ADF2, PREAPI, PPTSEAS, and %SRD. As before, the most significant variable was the percent of the South Fork watershed area selectively harvested. %ADF2, which was shown to relate to an increase in the South Fork end of season flow rate relative to the North Fork. The variable PREAPI, entering second, again acted to reduce this difference as indicates by the sign of the regression coefficient. When entered third, the variable PPTSEAS exerted a positive influence on the the value of ENDSN. The final variable to be included in this regression model, %SRD, acted to reduce the difference between the South Fork and the North Fork end of season flow rates. This model explained 87.9 percent of the variation in ENDSN.

Summary of Results

Although different variables were found to be significant in the various regression models derived in this analysis, the results provide indications of the factors which were important to the relative difference between the South Fork and the North Fork streamflow parameters during the period from 1963 to 1983. The variables which

Table 8g. Multiple Regression Models: End of Season Flow Rate Differences.

Dependent Variable: ENDSN

	Model 1	Model 2	Model 3
First Variable	%ADF2	%ADF2	%ADF2
Std. Regr. Coefficient	0.8101	0.8029	0.8966
Second Variable	PREAPI	PREAPI	PREAPI
Std: Regr. Coefficient	-0.3112	-0.4463	-0.3688
Third Variable	PPTSEAS	APISEAS	PPTSEAS
Std: Regr. Coefficient	0.0533	0.2153	0.2062
Fourth Variable	%SRD		
Std: Regr. Coefficient	-0.3415		
R^2	0.879	0.847	0.832
R^2_{adj}	0.845	0.817	0.799
Overall F Statistic	25.430	27.729	24.780
Significance Level	0.001	0.001	0.001
Standard Deviation	0.3429	0.3723	0.3903
Correlation of Residuals to Expected Normal Values	0.994	0.991	0.979
Unusual Observations (Std. Residual, Year)			

represented logging effects were most influential in describing these differences in every ease. Most frequently. %ADF2 was used to model logging effects by representing the area selectively harvested and subsequent recovery due to regrowth. The percent of the South Fork watershed area compacted by roads skid trails, and landings (%AC) was significant in those regressions which considered differences in annual flow volume. The role of these variables indicated that an enhancement of the South Fork flow was associated with logging operations.

The antecedent precipitation variables were also influential in predicting relative differences between the two streams. High antecedent moisture conditions preceding and during the hydrologic year were associated with a reduction in the relative difference between the South Fork and the North Fork. A high value for the minimum daily API had the same effect in some regressions but the role of this variable was less dramatic. In contrast, a high value for the cumulative seasonal API was related to an enhancement of the South Fork flow level relative to the North Fork.

It should be noted that the value of the cumulative API variables are dependent on the length of the season or year as well as the timing and magnitude of the precipitation events during that period. The seasonal API may be especially dependent on the length of the low flow season because variation in the range of summed daily API's is limited by the preset start-of-season and end-of-season level (10 cm) and the threshold value (5 cm) subtracted from each daily value.

Precipitation during the low flow season was found to relate to streamflow differences in a positive direction. When seasonal precipitation was high, the South Fork flow level was enhanced relative to the North Fork. In contrast, %SRD, which may be viewed as an index of cloud cover, exerted a negative influence on this difference. During a season with frequent rainy days, the two streams in the Caspar Creek drainage responded more similarly.

The expected average incoming solar radiation per day during the low flow season. MLYDAY, was shown to exert a negative influence on streamflow differences between the South Fork and the North Fork. This variable may be interpreted as an index of the effects of the seasonal timing and duration of the low flow period, and hence, serve as an indication of potential evapotranspiration during a 'typical' growing season. This variable would have a lower value during a lengthy growing season which extended in either direction beyond the mid-June period of peak incoming solar radiation.

This study leads to the conclusion that streamflow on the South Fork of Caspar Creek was enhanced in response to the selective harvest of 67 percent of the timber volume. The increase in annul flow volume averaged 16 percent (325 acre feet) during the post-treatment years of the study period. This increase was best related to the percent of the watershed area compacted by roads, skid trails, and landings. The flow volume during the low flow season was also shown to have increased in response to the partial-cutting of this second-growth forest. In 1974, the year following the completion of logging operations an additional 73 acre feet of streamflow was measured during the low flow season. Summer flow enhancements were shown to be related to the percent of the watershed area partially-cut, decreasing with time since logging. After five post-treatment years a statistically significant increase in summer flow volume was not detected. It was determined that South Fork mean daily flow rates were enhanced at the start and end of the low flow season, as well as on the day of minimum flow. Proportionately, the greatest increases were evident at the end of the low flow season, although in absolute terms the increases at the start and end of the low flow season were similar.

DISCUSSION

Partial cutting of second-growth forest accompanied by tractor yarding at the Caspar Creek site resulted in enhanced streamflow beginning in 1972, the first summer following the beginning of harvesting. As in previous studies, most of this increase (approximately 90 percent) was realized during the rainy season while greater relative increases were witnessed during the summer low flow period. In addition, the enhancement associated with the low flow season was short-lived in comparison to the overall annual increase. Summer flow increases were not significant ($p > 0.05$) beyond 1978--five years after the end of cutting. However, an increase in annual flow volume was detected for 1982 (nine years after the completion of logging operations on the South Fork watershed). Similarly, the increase in start-of-season mean daily flow rate was shown to be more persistent than that detected for the end-of-season or minimum flow rate.

Logging factors were shown to be the most influential variables in describing flow parameter differences between the control and treated watersheds. Antecedent precipitation conditions were also found to be important in describing this difference.

Roads, Landings, and Skid Trails

By the completion of timber harvest operations in 1973. fifteen percent of the South Fork watershed was occupied by either roads (five percent), landings (two percent), or skid trails (eight percent).

These impacts, necessary for the yarding and transport of cut timber, can result in soil compaction and alteration of surface and subsurface topography (Stone,1977). The impacts of these changes on streamflow processes are less certain.

The high rates of infiltration which are typical of forest soils in the coastal Pacific Northwest generally preclude the occurrence of overland flow except for areas of bare rock or extremely shallow soil and intermittent channels (Harr,1979). This condition seems to be characteristic of the Caspar Creek site. Finding no consistent increase in winter store peak flows, Ziemer (1981) reasoned that precipitation continued to infiltrate and supply subsurface flow and that the construction of the timber transportation network at Caspar Creek did not result in compaction and reduced infiltration for the over-all watershed. However, a ten percent increase in mean peak discharge in the South Fork relative to the North Fork was noted in this study.

Subsequently. Sendek (1985) and Wright (1985) reported evidence indicating that the streamflow response to precipitation at Caspar Creek became quicker and more efficient after logging. It was hypothesized that the surface compaction, and interception and channelization of subsurface flows by road cuts and ditches played a significant role in this change. Skid trails converging in the direction of the stream in conjunction with the proximity of roads and landings to the stream may have resulted in direct runoff from this network. The channeling of surface flow towards the stream has been noted by direct observation along roadside ditches on the South Fork.

The increase in annual flow volume associated with the winter season noted in this analysis lends further support to the hypothesis of Sendek and Wright. Here, it was demonstrated that this increase, which averaged 15 percent above the predicted volume, was related to the percent of the watershed area converted to roads. landings, and skid trails. The variable used to represent these alterations in the regression analysis did not model recovery from these impacts as a function of time since logging (Table 4a). That is, they were considered permanent for the duration of the study period. Those variables chosen to represent removal of forest vegetation were modelled to decrease as a function of time since logging. If the increase in rainy season flow volume had been closely associated with a decrease in evapotranspiration as a result of the reduction in forest vegetation, one of the alternate logging factors which represented forest influences would have correlated more highly with this change. Also. it would be expected that the effect of logging on annual flow volume would have diminished in a manner similar to that of summer flow volume. This did not occur. A probable conclusion is that the increase in annual flow volume associated with the winter season was in part the result of the concentration and more efficient routing of precipitation to the stream channel accompanied by a minimal reduction in soil moisture storage.

Alteration of Forest Vegetation

Timber harvest operations selectively removed 67 percent of the South Fork timber volume between 1971 and 1973. In theory, the removal of forest vegetation reduces evapotranspiration and canopy interception losses thereby modifying soil moisture storage. It follows that during the growing season substantial soil moisture differences can develop between a logged and unlogged watershed. Although lower evapotranspiration rates characterize the winter period, it is possible for an,interstorn difference in soil moisture to exist between a logged an unlogged watershed during the winter. Such dissimilarity may be evidenced by differences in baseflow recession. The enhancement of flows on Caspar Creek can be explained in light of these principles.

Proportionately larger increases in mean daily flow rate relative to prelogging predicted rates progressed from the first day of the low flow season, to the day of minimum flow, to the final day of the low flow season. This suggests that soil moisture differences were developing between the two Caspar Creek watersheds as the growing season progressed.

Canopy interception is determined by total leaf area and the size and intensity of precipitation. Although during a major winter storm the amount of intercepted precipitation is probably inconsequential, a considerable amount can be intercepted by a dense coniferous forest during a light rain or fog (Dunne and Leopold,1978). The North Fork watershed supports such a forest. It is reasonable that during low intensity precipitation events interception on the North Fork was substantial in comparison to the South Fork after logging. This scenario seems probable particularly during periods of smaller storms which are separated by rainless intervals as occur in the late fall aid early spring along California's northcoast. Differences in interception between the two experimental watersheds may have contributed to the enhancement of water yields detected in the logged area.

Seasonal precipitation. PPTSEAS, related to an enhancement of summer flows on the South Fork relative to the North Fork. This suggests that a greater proportion of summer precipitation was delivered to the soil surface and made available to supplement baseflow on the logged watershed. On the control watershed more of this precipitation may have been evaporated directly from leaf surfaces. That portion which did reach the surface and infiltrate, most likely contributed to satisfying larger soil moisture deficits and plant transpiration needs on the forested watershed.

Regrowth

After 1978, increases in South Fork flow were detected only for the variables host strongly influenced by winter streamflow processes and meteorological conditions: TOTVOL, TOTVLEN, and START. For the variables which were reflective of summer conditions: SUMVOL, SUMYLEN, MINFLO, END, AND LOFLOZ; a significant increase was not detected. In 1981, a significant decrease was detected for summer flow.

The removal of timber by selective harvest operations was designed to improve the growth potential of the younger trees. By creating openings in the canopy and reducing competition for sunlight and water, the growth and water use of the remaining vegetation may have been accelerated as has been documented in other forest environments (Bogatyrev and Yasil'eva,1985; Jarvis,1985; Greenwood et a1,1985). This mechanism would explain the rapid diminishment of summer flow enhancements. and the possibility of decreased summer flows after growth has been stimulated in the remaining vegetation.

The hypothesized growth acceleration and renewed water demand by regenerating forest vegetation provides insight into the pattern observed in the variable PARTVOL following logging. The ratio of summer flow volume to annual flow volume was increased for the years 1972 through 1978 (excepting 1976), but decreased thereafter relative to the pre-logging relationship with the North Fork. This suggests that the seasonal distribution of South Fork streamflow was altered after logging. During the earlier post-logging years, the increase in summer flows resulting from a reduction in evapotranspiration and interception losses was substantial in comparison to the enhancement of winter flows due to compaction, altered drainage patterns. and reduced interception and evapotranspiration losses. By 1979. however, the renewed plant water demand occasioned by the stimulated regrowth of vegetation had offset the previous evapotranspiration savings. Assuming canopy closure proceeded more slowly than plant water demand recovery on the South Fork, differences in interception losses would be more persistent than evapotranspiration differences, while more limited to the rainy (winter) season. Enhancement of winter flows continued with the net effect that proportionately less water was flowing during the summer season. The fact that other summer flow variables, in addition to PARTVOL, showed signs of decline after 1978 suggests that summer flows were reduced in addition to this redistributional effect. This possibility requires further investigation.

Antecedent Moisture Influences

In this study, antecedent moisture conditions were represented by antecedent precipitation indices. Multiple regression analysis indicated that antecedent moisture conditions influenced the magnitude of flow differences between the two Caspar Creek watersheds. During years with high cumulative API values or preceded by years with high values, the logging effects on streamflow were of reduced magnitude. A logical explanation for this is that during wetter years soil moisture deficits are small for much of the year, and thus both basins exhibit similar recession characteristics. In contrast, during drier years extensive differences in soil moisture may develop between the basins due to reduced evapotranspiration on the logged watershed. The extent of these differences may be evidenced by summer flow recession characteristics on the two watersheds.

It is interesting that the cumulative API for the preceding year was identified as a significant variable in several regressions. This suggests that the carry-over effect of past antecedent moisture regimes may be quite substantial. The adequacy of soil moisture during critical growth periods can influence subsequent transpiration and growth rates depending on nutrient conditions and other growth requirements, but the extent of this effect is unclear (Russe11.1973). It is possible that the carry-over effect of the antecedent moisture conditions of the preceding year is an indirect reflection of variations in vegetation growth and over-all efficiency of water use, rather than a direct indication of persistent soil moisture differences.

The influence of cumulative low flow season API appears to be distinct from that of the annual API for the current or preceding year. During low flow seasons when summer precipitation was sufficient to maintain a high cumulative seasonal API (and, presumably, high soil moisture levels), increases in minimum and end-of-season flow rates were greater. By definition. ,the low flow season began and ended when the daily API (recessed by a factor of 0.97) fell below and rose above the 10 cm threshold level, respectively. Variations in the cumulative seasonal API, then, were purely a function of the timing and amount of summer precipitation. The interpretation here follows that of the role of the variable PPTSEAS. Differences in interception and evapotranspiration resulted in a larger proportion of summer precipitation contributing to streamflow on the logged watershed in comparison to the forested watershed. Had the selected recession factor been greater, the interpretation would hate been that summer precipitation would have been more influential in maintaining soil moisture levels. Inversely, a lower recession constant would have implied reduced (shorter duration) influence of precipitation on soil moisture levels.

Additional Climatic Factors

Detailed climatic data were not collected at the Caspar Creek study site, and thus, were unavailable for modelling streamflow differences between the logged and unlogged watersheds. Measurements of actual insolation, cloud cover, vapor pressure, wind, and temperature may have improved the predictive ability of the models developed, however the expense and difficulties associated with such measurements precluded this option. Instead, variables were developed to serve as rough indices of these factors.

The percent of rainy days variables (%SRD. %WRD, and %TRD) were screened as gross indicators of cloud cover. The variable %SRD made a significant contribution to variance reduction in modelling summer flow volume and end-of-season flow rate differences between the South and North Fork watersheds. The role of this variable suggests that cloud cover reduced evaporative demand and consequently a minor reduction in flow difference between the two streams was observed.

Variables representing expected normal insolation at the surface were also included in the model development procedure. The variable representing the seasonal mean expected normal incoming solar radiation was determined to be of some usefulness in explaining additional variation in summer and annual flow volute between the two streams. Increases in streanflow following logging were shown to be inversely proportional to this indicator of incoming radiation. This result is in accordance with the earlier findings of Douglass and Swank (1975).

Management Implications

Forest land management involves the protection and utilization of a variety of natural resources. The inter-relationships which exist between these various resources complicates the task of management. Maximizing the production of a single resource often results in detrimental and unacceptable impacts on others. The multiple-use concept of land management necessitates that positive practices for water resource improvements be tempered by the demands for other uses including timber production and habitat protection.

Water--Yield

This research indicates that the potential exists for increasing water yield from a second-growth forest by selective harvest operations. On the average, a 15 percent increase in annual water yield would be expected for the decade after logging. However, several important characteristics of this expected increase lessen its utility to water managers. First, the timing of the augmented yield is displaced from the time of peak demand. At Caspar Creek, 90 percent of the flow enhancement was realized during the rainy high-flow season. Water demand is usually greatest during low flow periods in the summer. Second, that portion of the annual flow enhancement which did occur during the low flow season diminished rapidly in the years following logging. Beyond five years after the completion of logging, no significant flow increases were detected and a possible decline in summer flows relative to pre-logging levels was noted. Persistent summer flow augmentation would not be expected without continuing vegetation management in the logged watershed. Third, the sizeable variation in flow enhancements detected in the post-logging years at Caspar Creek suggests that water yield increases could not be depended upon by planners and managers to meet specific water demand levels. This lack of certainty would reduce the utility of flow enhancement benefits. Fourth, the quality of the water is of paramount importance in defining its utility. The potential side-effect of increased sediment yields accompanying streamflow enhancements realized in logged watersheds would strongly counter the possible benefits.

Timber

A major emphasis of forest management is timber production. It appears probable that forest management decisions involving rotation age, harvest scheduling and practices will continue to be based primarily on the economics of timber production. Forest practices which encourage the rapid regeneration of particular tree species are not likely to result in prolonged water yield enhancement benefits. In contrast, forest operations designed to maximize water yield augmentations by inhibiting regrowth pose problems in terms of slope stability and sedimentation impacts, and timber economics.

Aquatic Habitat

Detrimental impacts on fisheries would not be expected to result directly from flow enhancements of the magnitude detected at Caspar Creek when this effect is considered in isolation. However, the potential side effects resulting from altered streamflow regimes warrant further examination.

Flow increases can change the energy regimen of the channel system, which may adversely affect the aquatic ecosystem by altering sediment transport characteristics (Harr,1983). At Caspar Creek, no significant increases in the magnitude or duration of the large channel forming flows were detected (Ziemer,1981; Wright,1985). It was reasoned that increases in the smaller flows would not appreciably increase sediment transport.

A major implication of water yield increases concerns impacts on erosion processes. Higher soil water contents in logged areas result from reduced evapotranspiration. Soil creep and earthflow processes which are most active during periods of maximum soil water content may be accelerated or prolonged by logging-induced enhancement of soil moisture levels (Harr,1979). The effects of such landslides can be significant in downstream as well as in upland areas where the movement occurs. Rice et al (1979) state that the delivery of sediment to the stream has been the principal effect of logging and roadbuilding at Caspar Creek. The major erosion mechanisms acting on the South Fork watershed following treatment were landslides and large gullies. Substantial increases in suspended sediment and average turbidity levels were detected. Further research is being initiated at Caspar Creek to evaluate the effects of logging-related erosion and sediment transport on fisheries.

There is some indication that there may be a decrease in summer flows beyond five years after logging resulting from accelerated transpiration and growth in the vegetation which was not removed during logging operations. If true, this may potentially impact the aquatic ecosystem. Reduced summer flows may change the temperature characteristics of the stream and affect the adequacy of pool-riffle sequence of the stream, and fish productivity. It is unclear if such alterations occurred at Caspar Creek and if they are of significance to the existing aquatic ecosystem.

Conclusions

The selective harvest operation of an 85-year-old second-growth Douglas-fir and redwood forest at the Caspar Creek watershed resulted in the alteration of the amount and seasonal distribution of streamflow. Streamflow was augmented both for the annual period and the low flow season. Increases were greatest in the year which followed the completion of logging activities. 1974, and diminished irregularly subsequently. Increases in summer flow volume were detected between 1972 and 1978, although not all of these increases were considered significant. Enhancement of the annual flow volume was shown to be more persistent than summer flow increases.

Summer flow increases were best related to removal of the forest vegetation. In contrast, annual flow increases (90 percent of which occurred during the winter rainy season) were more closely related to the percent of the watershed area occupied by roads, landings, and skid trails.

Variability in the magnitude of the flow enhancements was found to correspond with antecedent moisture conditions. Unexplained variation was attributed to varying climatic and vegetative conditions which were not measured.

Viewed from the perspective of water supply management, the prospects for water yield enhancements resulting from the selective harvest of second-growth forest along the north coast are not promising for two important reasons. First, the inability to reliably predict the timing and extent of streamflow increases resulting from logging would make this supply undependable. Second, while the quantity of available water may be enhanced, the quality of the supply would be impacted by suspended sediment and turbidity increases. It appears that water yield enhancements resulting from this type of lowing along the northern coast of California will be of minimal importance relative to other forest management and production goals.

REFERENCES CITED

Azevedo, J., and D.L. Morgan. 1974. Fog precipitation in coastal California forests. Ecology 55:1135-1141.

Bogatyrev, Y.G., and I.N. Vasil'eva. 1985. Water regime of soil and spruce regeneration on filled areas and beneath the canopy. Lesovedenie 2:16-25.

Bosch, J.M., and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55:3-23.

Boussinesq, J.R. 1877. Essai sur la theories des eaux courantes. Memoires presenter par divers savants a 1'aeademic des sciences de l'institut national de France 23(1).

Byers, H.R. 1953. Coast redwoods and fog drip. Ecology 34(1):192-193.

California Department of Forestry. 1985. Soil-vegetation survey: Jackson State Forest. Mendocino County. The Resources Agency. Sacramento. California (in cooperation with University of California and USDA Soil Conservation Service). 16 pp., map.

California Department of Water Resources. 1978. California sunshine-solar radiation data. Bulletin 187, The Resources Agency, State of California, Sacramento. California, 109 pp.

Chubatyi, O.Y. 1983. Change in the water balance of forest catehments under the influences of principal felling. Lesnoe Khozyaistvo, 2:18-20, (Zakarpat, USSR).

Daniel, C., and F.S. Wood. 1971. Fitting equations to data. John Wiley and Sons, New York. 273 pp.

Douglass, J.E., and f.T. Swank. 1975. Effects of management practices on water quality and quantity: Coweeta hydrologic laboratory. North Carolina. USDA Forest Service General Technical Report, SE-13. Southeastern Forest and Range Exp. Station, Franklin, North Carolina. 13 pp.

Douglass, J.E., and W.T. Swank. 1972. Streamflow modification through management of eastern forests. USDA Forest Service Research Paper, SE-94, Southeastern Forest and Range Exp. Station. 15 pp.

Dunne, T., and L.B. Leopold. 1978. Water in environmental planning. W.H. Freeman and Company. San Francisco, California. 818 pp.

Evans, J.O., and J.H. Patric. 1984. Harvest tress, reap water. Journal of Soil and Water Conservation 38(5):390-392.

Goodman, J. 1985. The Collection of fog drip. Water Resources Research 21(3):392-394.

Greenwood, E.A.. L. Klein, J.D. Beresford. G.D. Watson, and K.D. Wright. 1985. Evaporation form the understory in the Jarrah Forest, Southwestern Australia. Journal of Hydrology. 80(3/4):337-349.

Hall, F.R. 1968. Base-flow recessions-- a review. Water Resources Research 4(5):973-983.

Hankin, S. 1982. PLOT. Computer program package avaiable at Redwood Sciences Lab. 1700 Bayview, Arcata, California. 95521.

Harr, R.D., and J.T. Krygier. 1972. Clearcut logging and low flows in Oregon coastal watersheds. Forest Resource Lab. Research Note 54, Oregon State University, Corvallis, Oregon. 3 pp.

Harr, R.D., R.L. Fredricksen, and J. Rothacer. 1979. Changes in streamflow following timber harvest in southwestern Oregon. USDA Forest Service Research Paper PNW-249, Pacific Northwest Forest and Range Exp. Station. Portland. Oregon. 22 pp.

Harr, R.D. 1979. Effects of streamflow in the rain-dominated portion of the Pacific Northwest. USDA Forest Service Research Paper. Pacific Northwest Forest and Range Exp. Station. Oregon. 45 pp.

Harr, R.D. 1980. Streaflow after patch logging in small drainages within the Bull Run municipal watershed, Oregon. USDA Forest Service Research Paper PN4J-268, Pacific Noerhwest Forest and Range exp. Station. Portland. Oregon. 16 pp.

Harr, R.D. 1982. Fog drip in the Bull Run municipal watershed, Oregon. Water Resources Bulletin 18(5):785-?88.

Harr, R.D., A. Levno, and R. Mersereau. 1982. Streamflow changes after logging 130-year old douglas fir in two small watersheds. Water Resources Research 18(3):637-644.

Harr, R.D. 1983. Potential for augmenting water yield through forest practices in Western Washington and Western Oregon. Water Resources Bulletin 19(3):383-392.

Hewlett, J.D., and A.R. Hibbert. 1967. Factors affecting the response of small watersheds to preciptation in humid areas. Pages 275-290 in W.E. Sopper and H.W. Lull (eds). Proceedings of the inter national symposium on forest hydrology. Pergamon Press. New York. 556 pp.

Hibbert, A.R. 1966. Forest treatment effects on water yield. in International Symposium For. Hydrol. Proe. 1965, National Science Foundation. pp 527-543.

Borne. B. 1982. R2MAP. Computer program available at Redwood Sciences Lab. 1700 Bayview. Arcata, California, 95521.

Ingwersen. J.B. 1985. Fog drip, water yield, and timber harvesting in the Bull Run municipal watershed. Oregon. Water Resources Research 21(3):469-473.

Isaac, L.A. 1946. Fog drip and rain interception in coastal forests. USDA Forest Service Research Note, Pacific Northwest Forest and Range Exp. Station, PNW-34. pp 15-16.

Jarvis, P.G. 1985. Increasing forest productivity and value of temperate coniferous forest by manipulating site water balance. in R.Ballard et al (eds). Symposim: Forest potentials. Productivity and values. Weyerhaeuser Co., Tacoma. Washington. pp 39-74.

Kittredge, J. 1948. Forest Influences. Dover Publications. Inc., New York. 418 pp.

Krammes, J.S., and D.M. Burns. 1973. Road construction on Caspar Creek watersheds ...a 10-year progress report. USDA Forest Service Research Paper PSW-93, Pacific Southwest Forest and Range Exp. Station. Berkeley, California. 10 pp.

Krygier. J.T. 1963. Vegetational influences on water yield. in Symposium of forest watershed management, Oregon State University, Corvallis, Oregon, pp 59-75.

Letey, J. 1985. Relationship between soil physical properties and crop production. in B.A. Stewart (ed). Advances in Soil Science, Spinger-Verlag, New York, 1:277-294.

Linsley, R.K., and M.R. Kohler. 1951. Predicting runoff from storm rainfall. U.S. Weather Research Paper 34.

Mather, J.R., and G.A. Yoshioka. 1968. The role of climate in the distribution of vegetation. Annals of Am. Geog. 58(1):29-41.

Nakano, H. 1967. Effects of changes of forest conditions on water yield, peak flows, and direct runoff of small watersheds in Japan. in W.E. Sopper and H.W. Lull (eds), Proceedings of the inter national symposium on forest hydrology. Pergamon Press. New York, pp 551-564.

Neter. J.. W. Wasserman, and M.H. Kutner. 1983. Applied Linear Reg- ression models. Richard D. Irwin, Inc., Homewood, Illinois. 547 pp.

Nik, A.R.H.. R. Lee, and J.D. Helvey. 1983. Climatological watershed calibration. Water Resources Bulletin 19(1):47-50.

Nixon, P.R., and G.P. Lawless. 1968. Advective influences on the reduction of evapotranspiration in a coastal environment. Water Resources Research 4(1):36-44.

Oberlander. G.T. 1956. Summer fog precipitation on the San Francisco peninsula. Ecology 37(4):851-852.

Ponce, S.L.. D.W. Schindler, and R.C. Averett. 1982. The use of the paired-basin technique in flow-related wildland water-quality studies. USDA Forest Service Watershed Systems Development Group Report. WSDG-TP-00004. Fort Collins, Colorado. 21 pp.

Ponce, S.L., and J.R. Tleiman. 1983. Water yield augmentation through forest and range management-- issues for the future. Water Resources Bulletin 19(3):415-419.

Rice. R.M.. F.B. Tilley, and P.A. Datzman. 1979. A watershed's response to logging and roads: South Fork of Caspar Creek, California. 1967-1976. USDA Forest Service Research Paper PSW-146. Pacific Southwest Forest and Range Exp. Station. Berkeley, Calif. 12 pp.

Rothacher. J. 1970. Increases in water yield following clear-cut logging in the Pacific Northwest. Water Resources Research 6(2): 653-658.

Rothacher. J. 1971. Regimes of streamflow and their modification by logging. in J.T. Krygier and J.D. Hall (eds). Proceedings of a symposium on forest land uses and stream environments. Oregon State University. Corvallis, Oregon. Pp 40-54.

Russell. E.W. 1973. Soil conditions and plant growth. Longman Group Limited. London, pp 460-X69.

Rutter, A.J. 1975. The hydrological cycle in vegetation. Vegetation and Atmosphere 1:111-154.

Ryan. T.A.. B.L. Joiner. B.F. Ryan. 1985. MINITAB. Statistical computer package. Minitab release 5.1, Minitab Inc.

Sendek, K.H. 1985. Effects of timber harvest on the lag time of Caspar Creek watershed. Master's Thesis. Humboldt State University. Arcata, California. 46 pp.

Sharpnack. D. 1980. WINNOW. Computer program available at Redwood Sciences Lab, 1700 Bayview. Arcata, California, 95521.

Stone. E. 1977. The impact of timber harvest on soils and water. reprinted from the Report of the President's advisory on timber and the environment (1973). USDA Forest Service, Washington. D.C. pp 427-467.

Swift. L.W. Jr. 1972. Effect of forest cover and mountain physiography on the radiant energy balance. D.F. thesis. Duke University. Durhan. North Carolina, 53 pp.

Tilley, F.B., and R.M. Rice. 1977. Caspar Creek watershed study-- a current status report. State Forest Notes No. 66, State of Calif., Department of Forestry, Sacramento, California. 15 pp.

United States Naval Observatory. 1946. Tables of sunrise, sunset, and twilight. Supplement to the American Ephemeris, Washington, D.C., 259 pp.

Weisberg, S. 1980. Applied Linear Regression. John Wiley and Sons, New York, 378 pp.

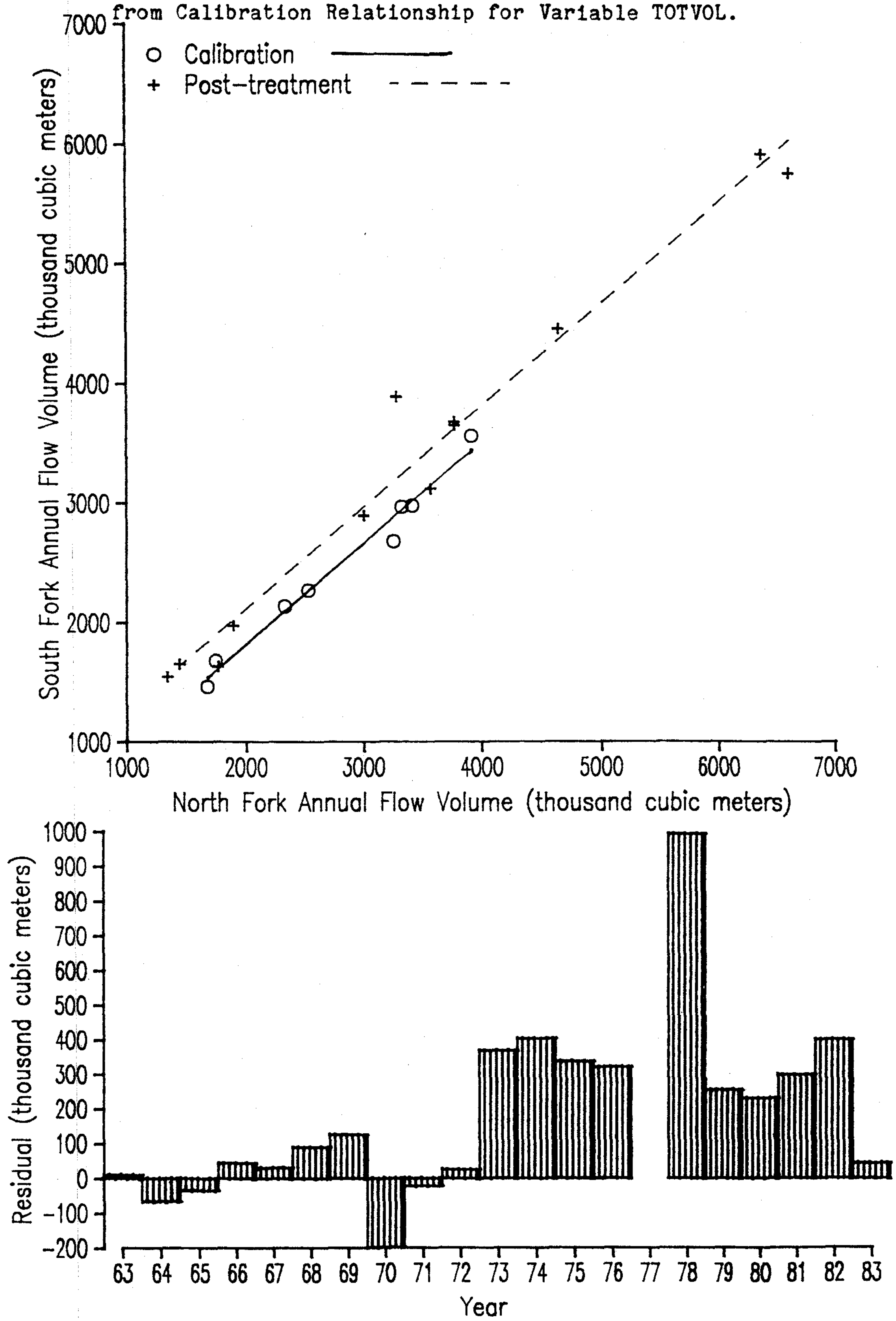
Wright, K.A. 1985. Changes in storm hydrographs after roadbuilding and selective logging on a coastal watershed in Northern California. Master's Thesis, Humboldt State University, Arcata, California. 54 pp.

Ziemer, R.R. 1979. Evaporation and transpiration. Reviews of Geophysics and space physics 17(6):1175-11$6.

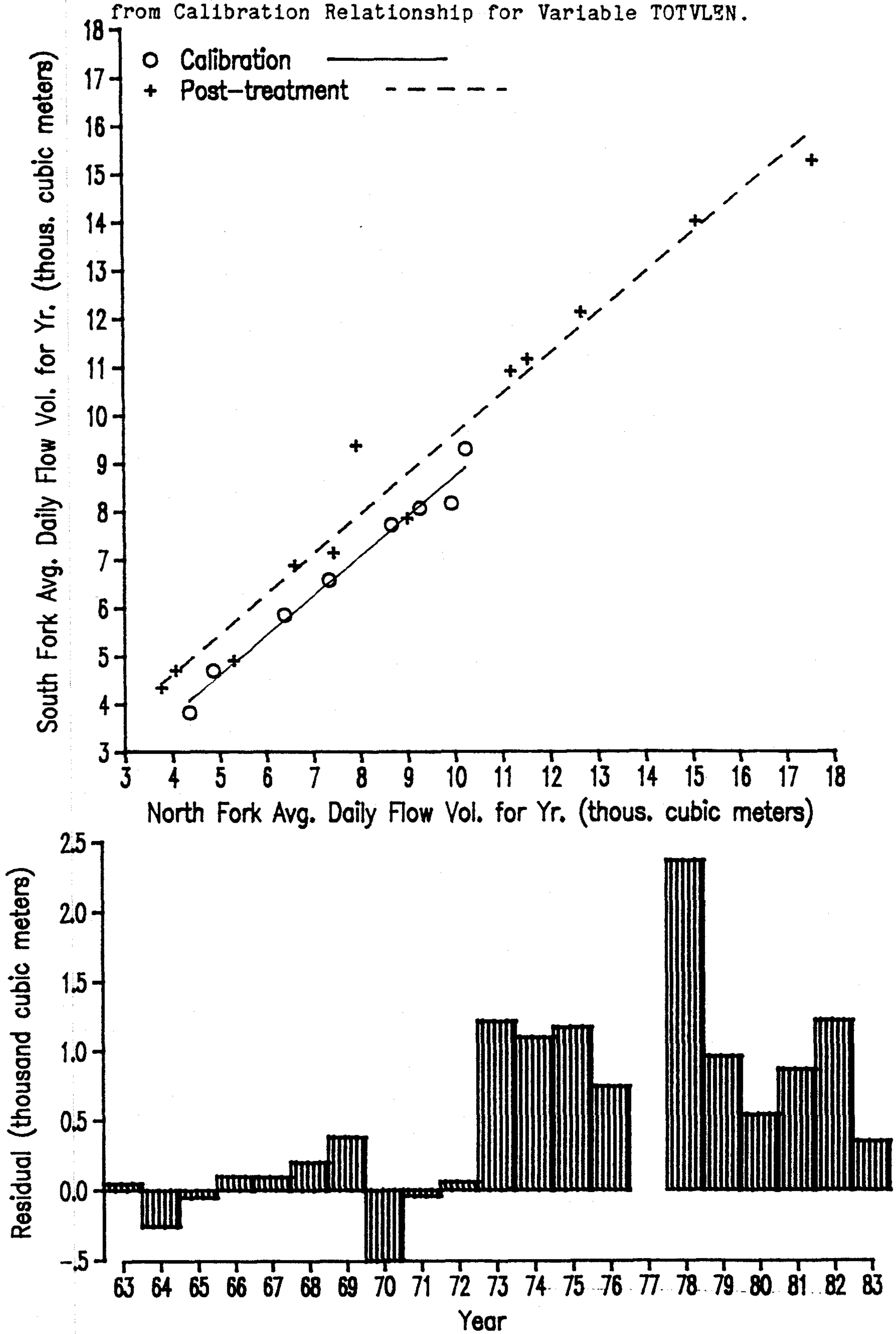
Ziemer, R.R. 1981. Storm flow response to roadbuilding and partial cutting in small streams of Northern California. Water Resources Research. 17(4):907-917.

Ziemer, R.R. 1984. Response of progressive hillslope deformation to precipitation. in Symposium on effects of forest land use on erosion and slope stability, 7-11 May 1984, Honolulu, Hawaii. pp 91-98.

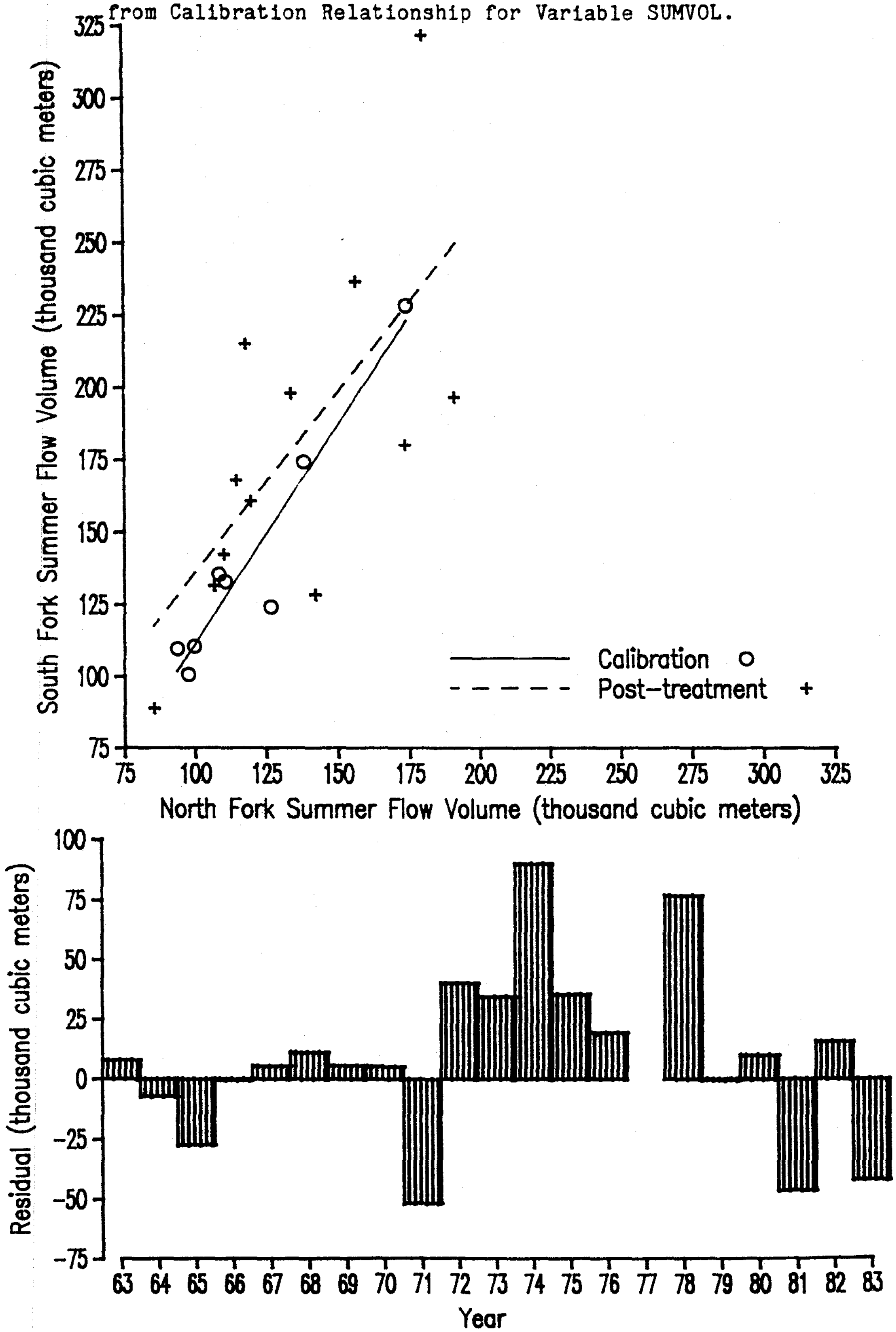
Appendix A. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable TOTVOL.



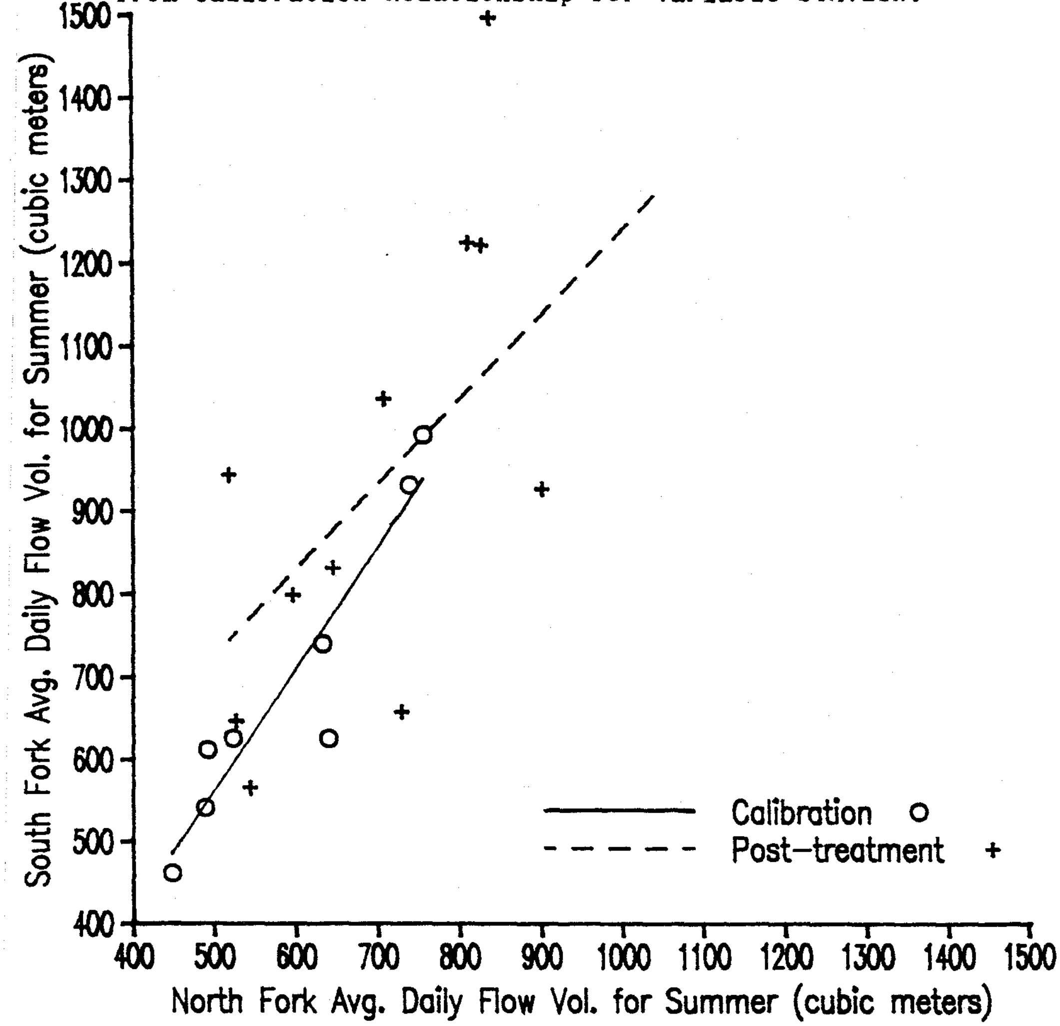
Appendix B. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable TOTVLEN.

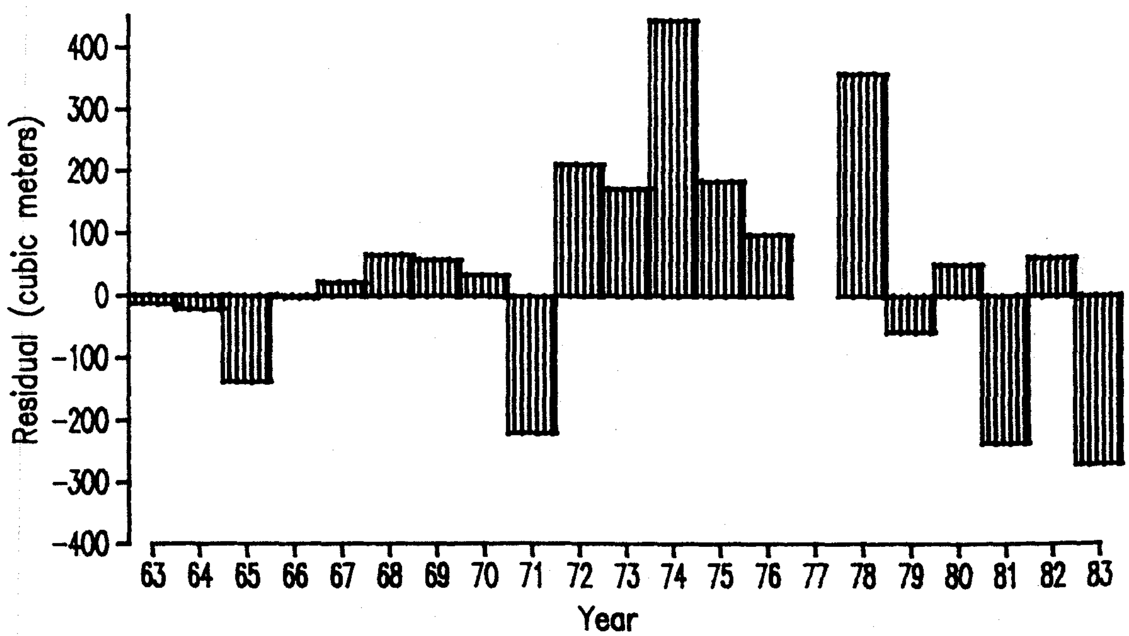


Appendix C. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable SUMVOL.

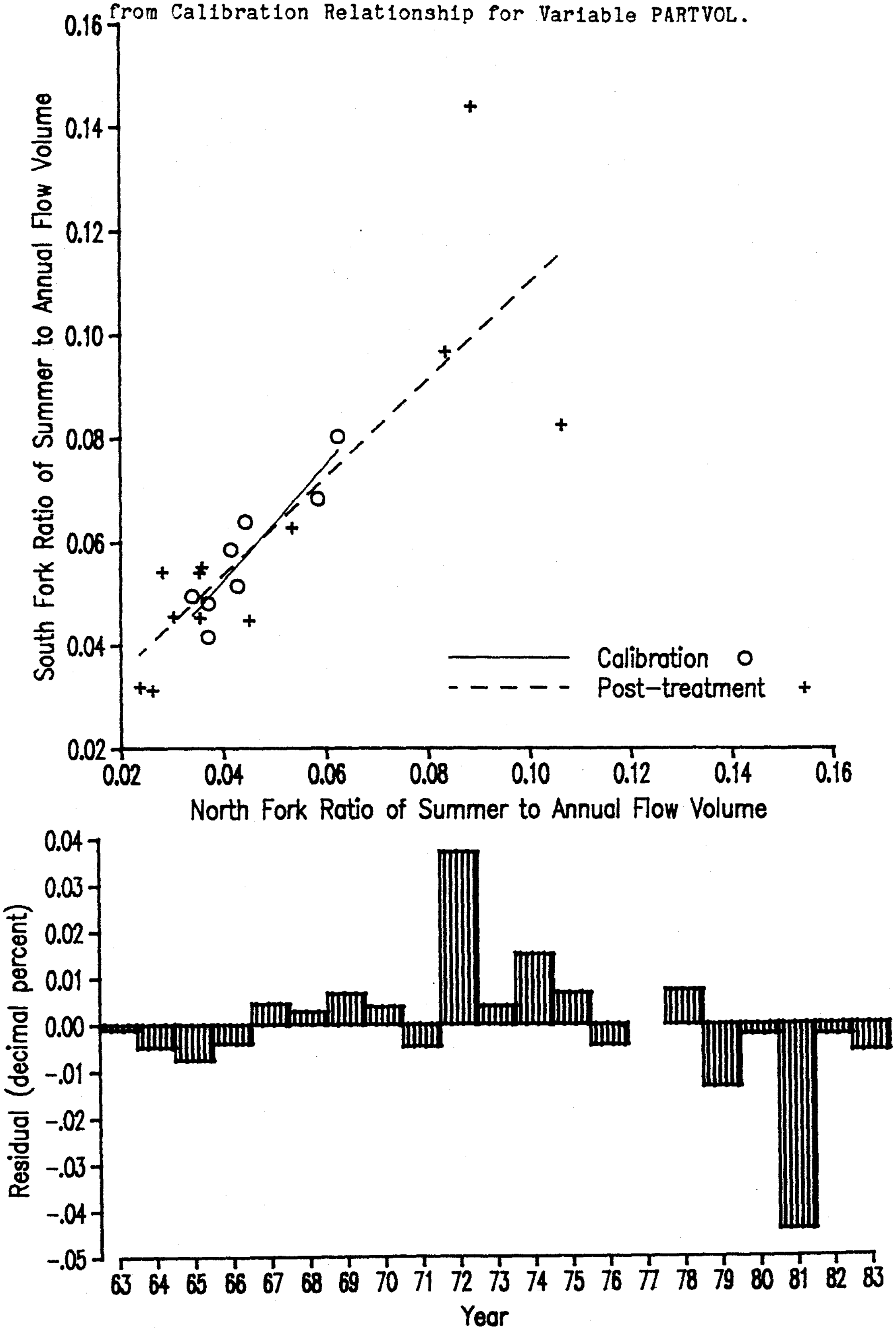


Appendix D. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable SUMVLEN.

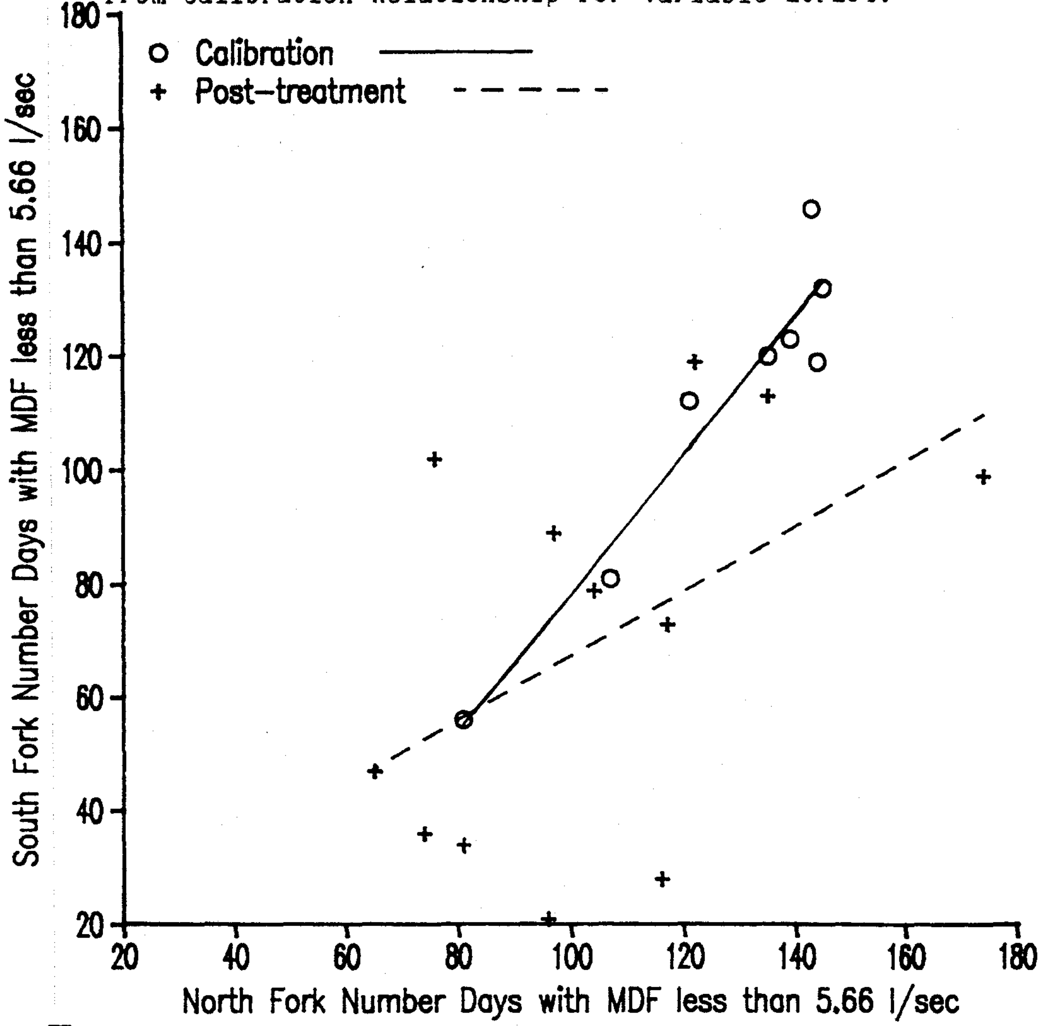


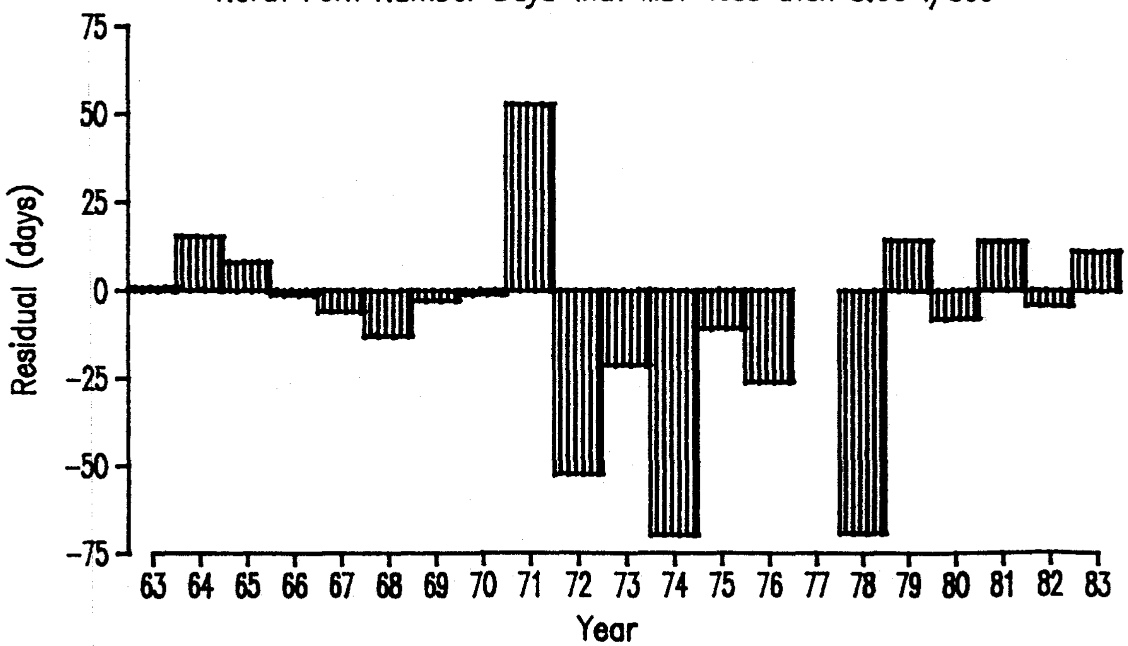


Appendix E. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable PARTVOL.

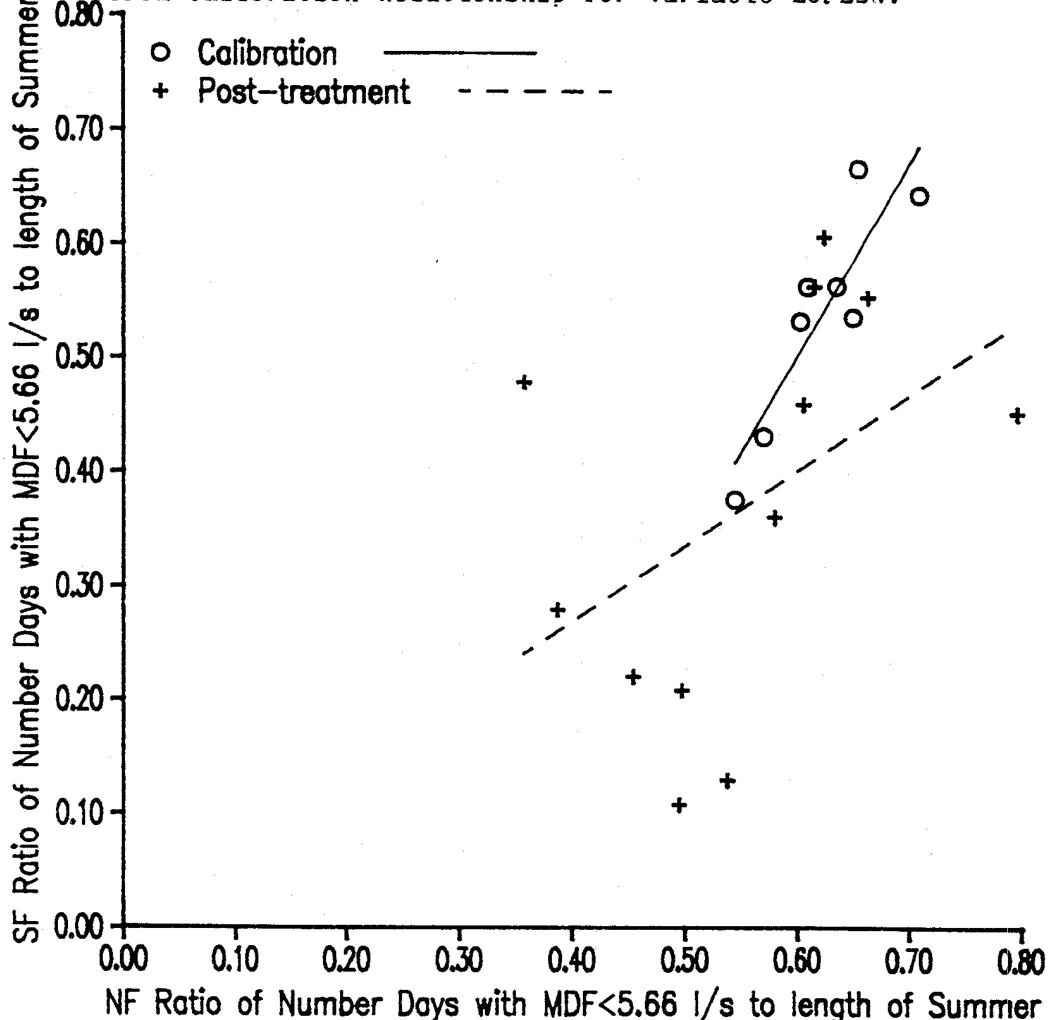


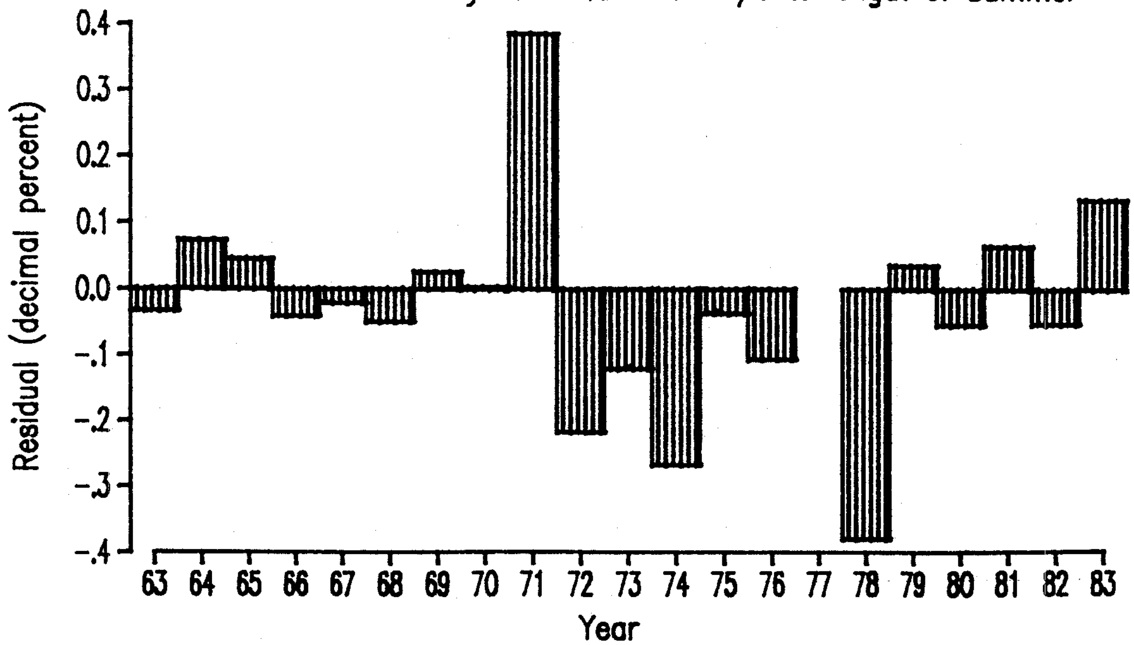
Appendix F. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable LOFLOZ.



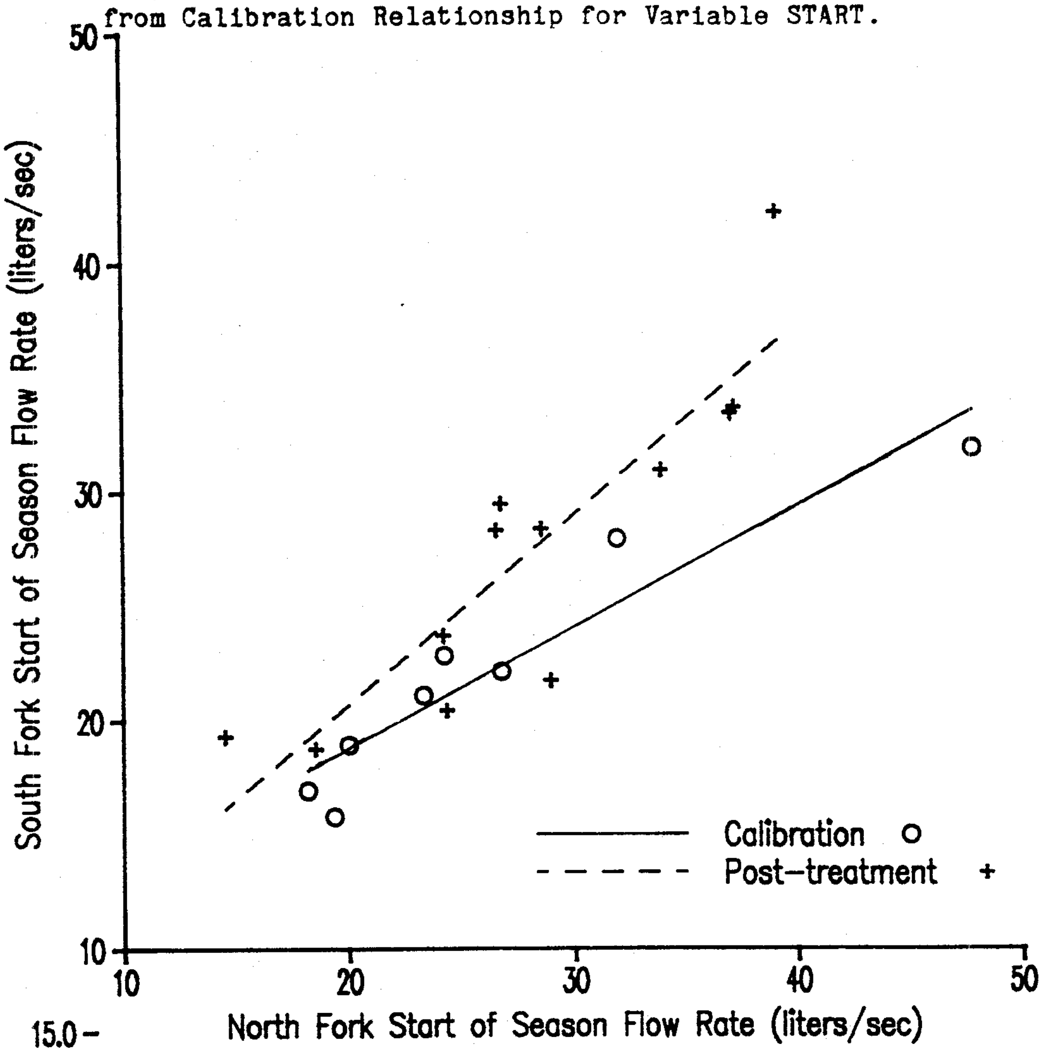


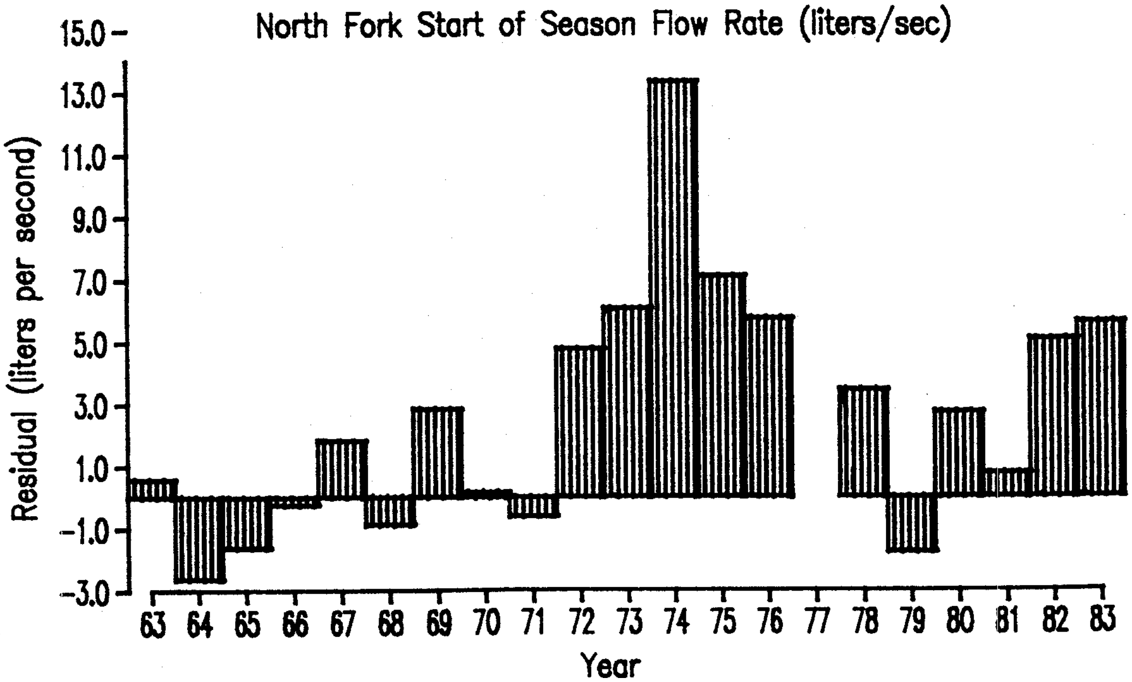
Appendix G. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable LOFLEN.



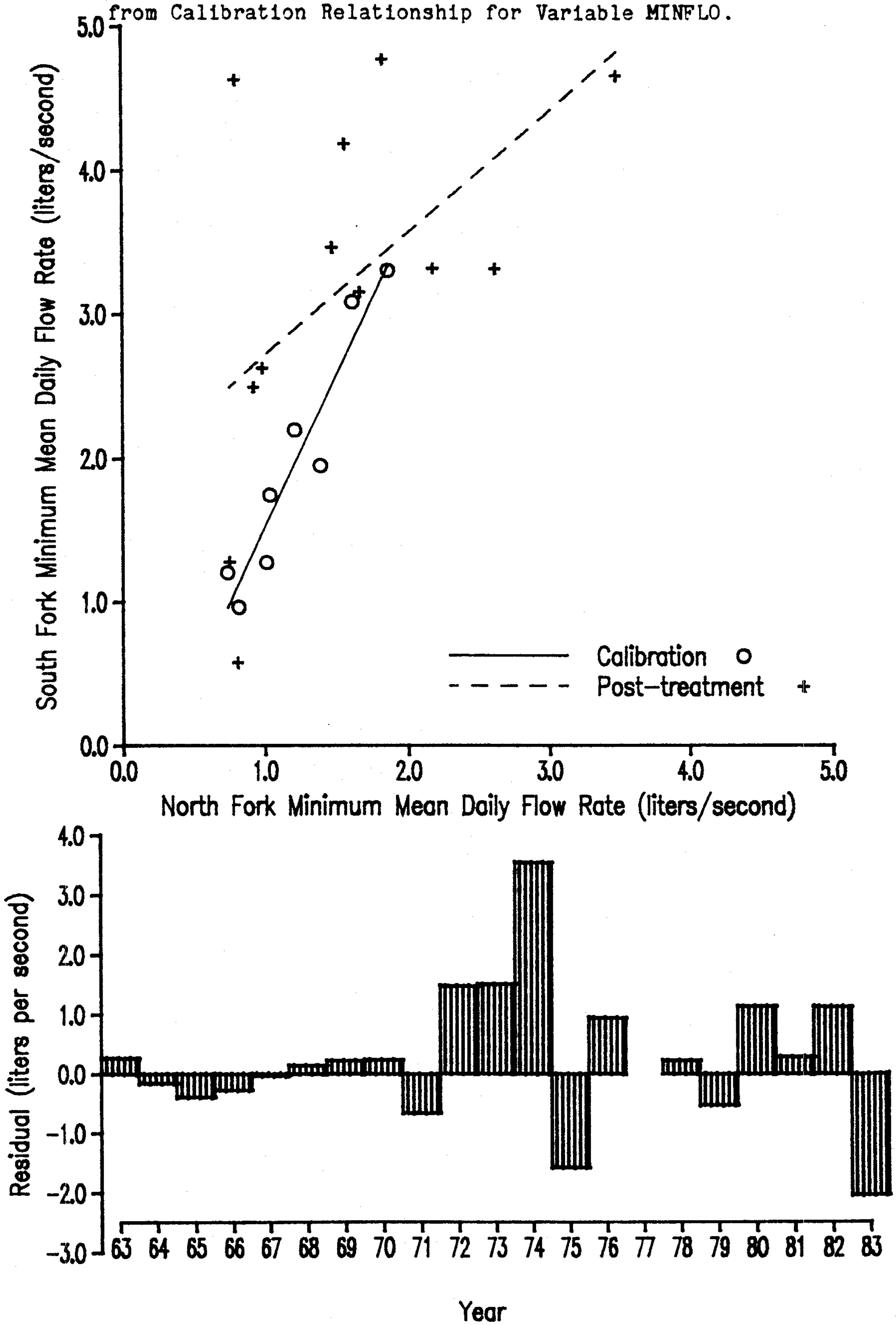


Appendix H. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable START.

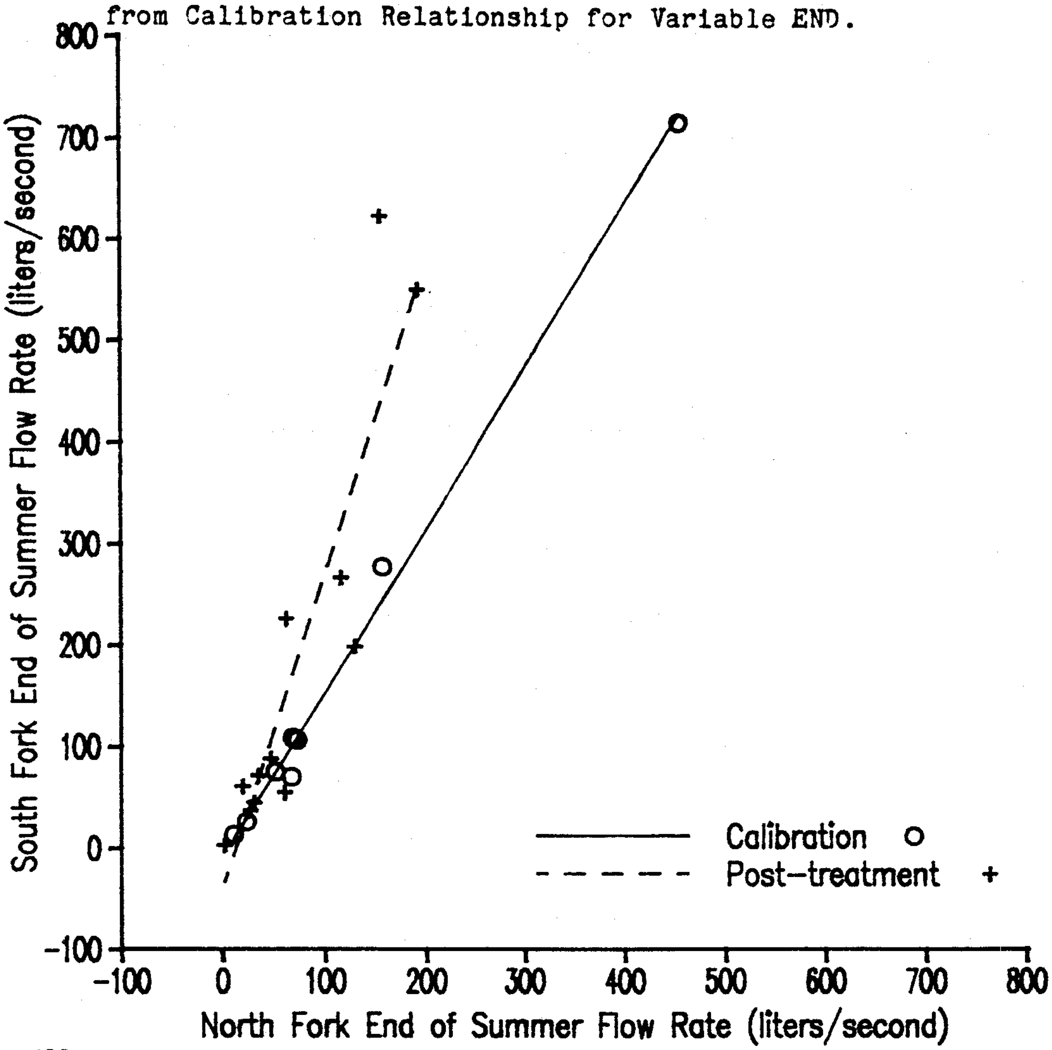


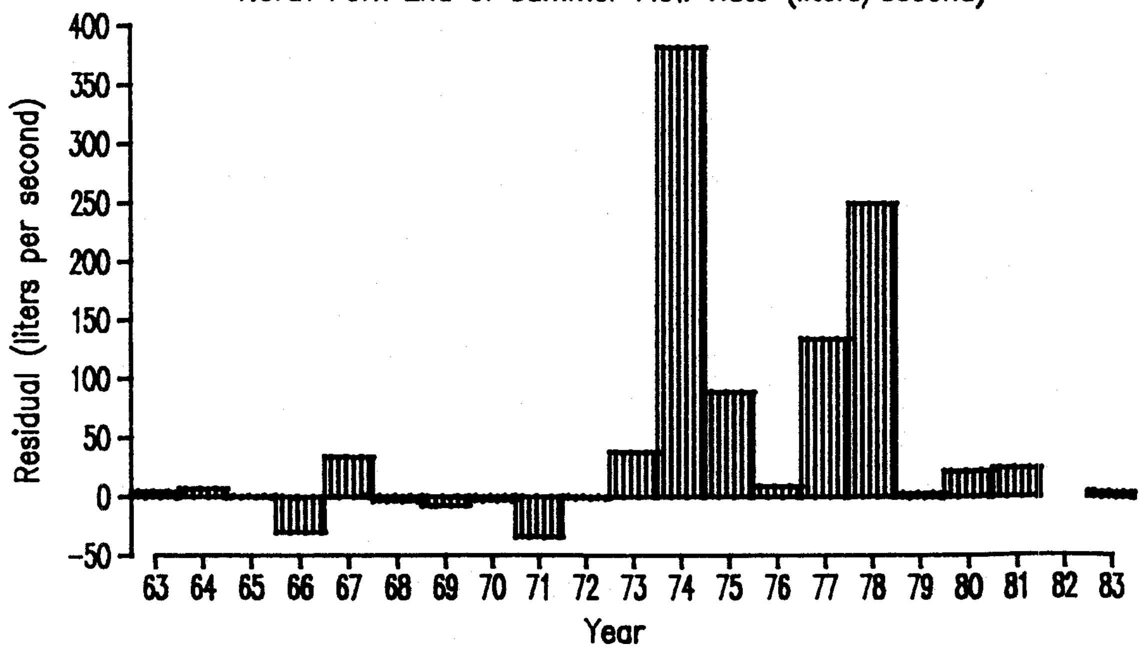


Appendix I. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable MINFLO.

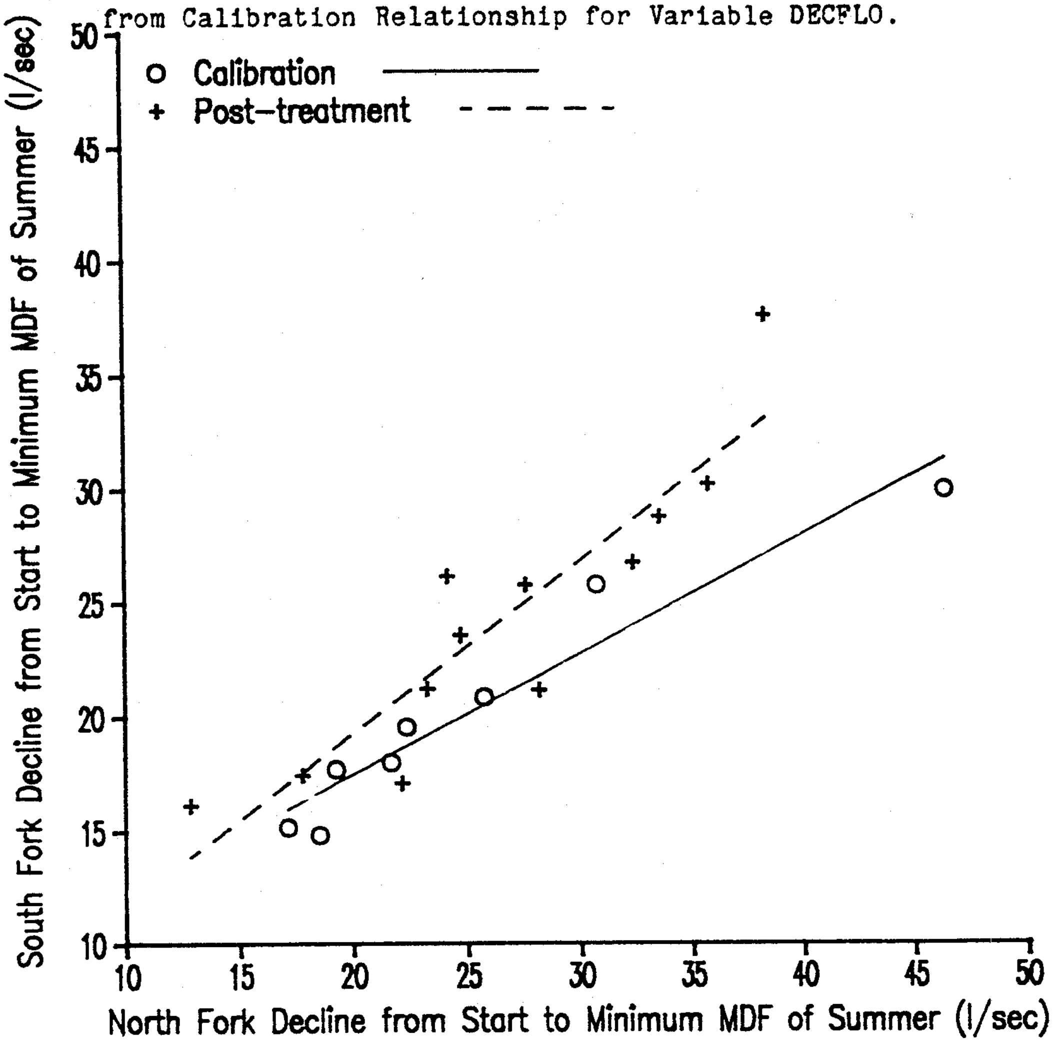


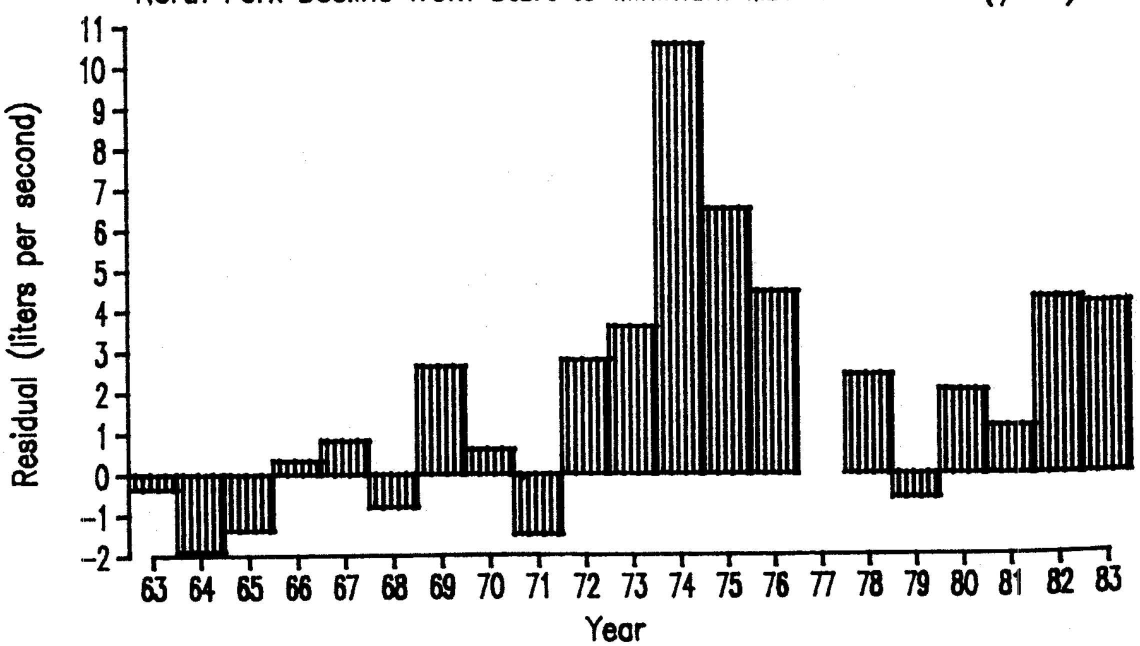
Appendix J. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable END.



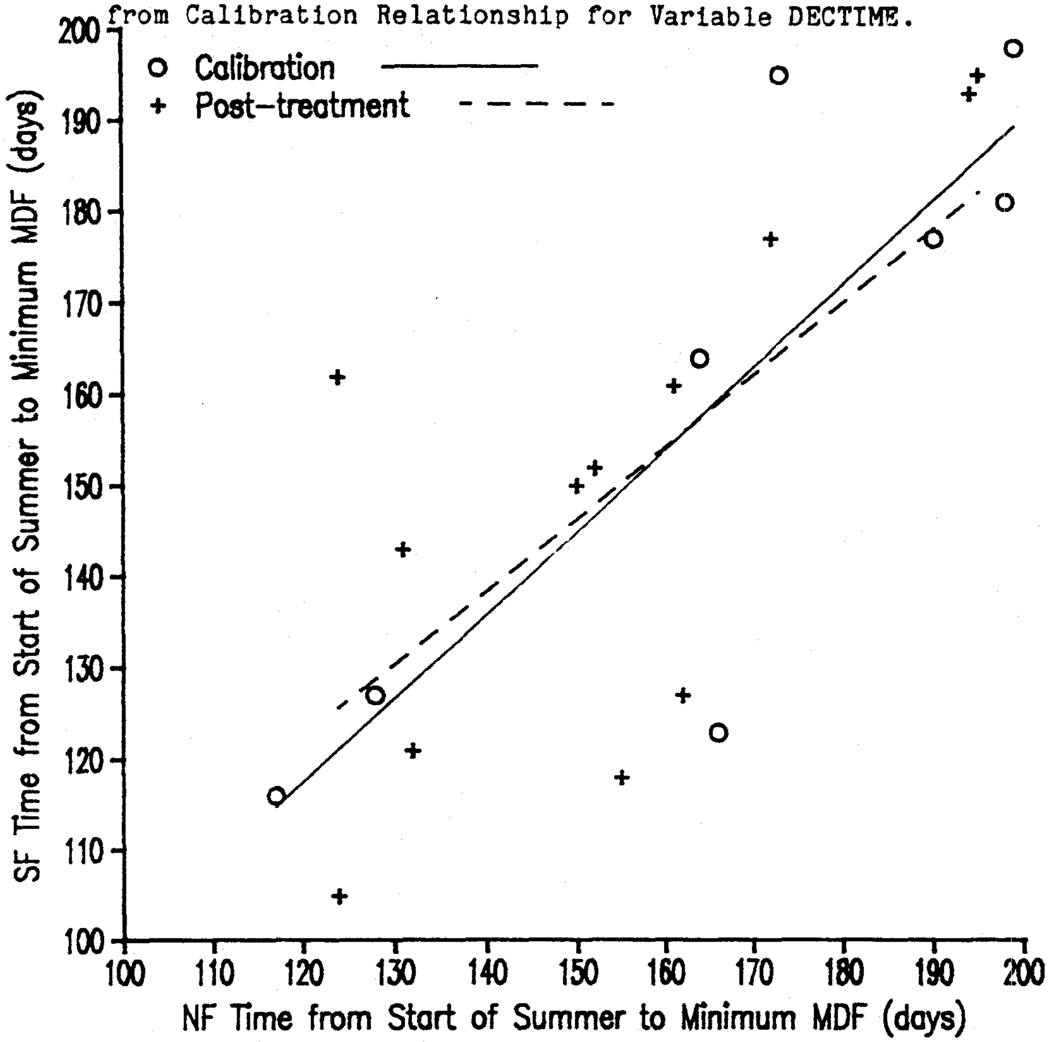


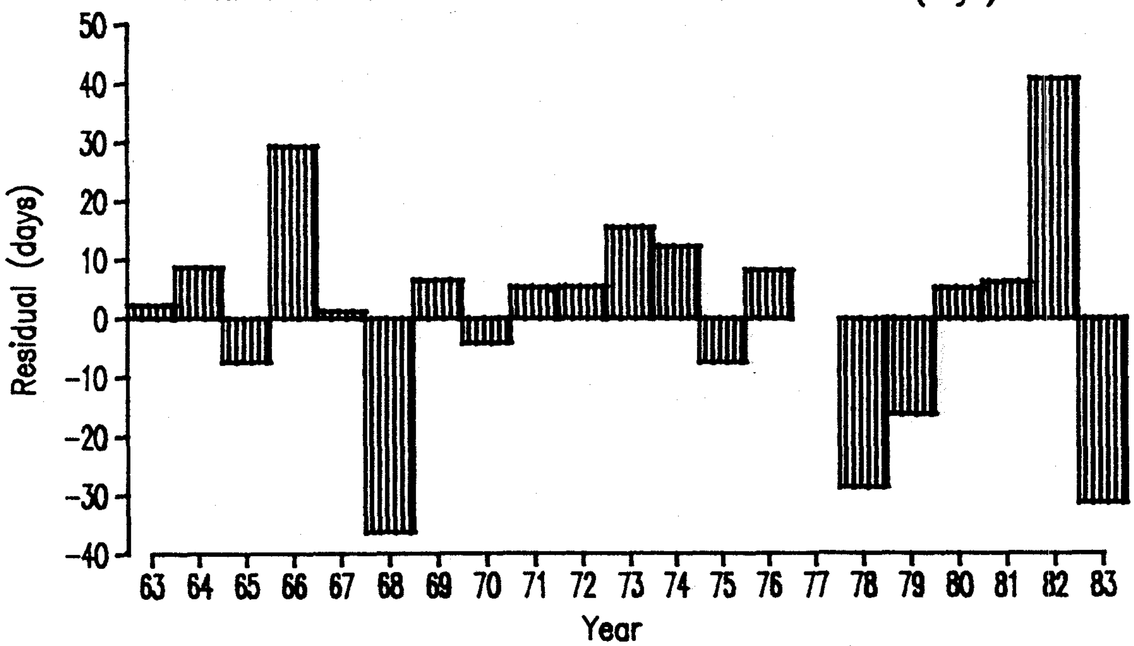
Appendix K. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable DECFLO.



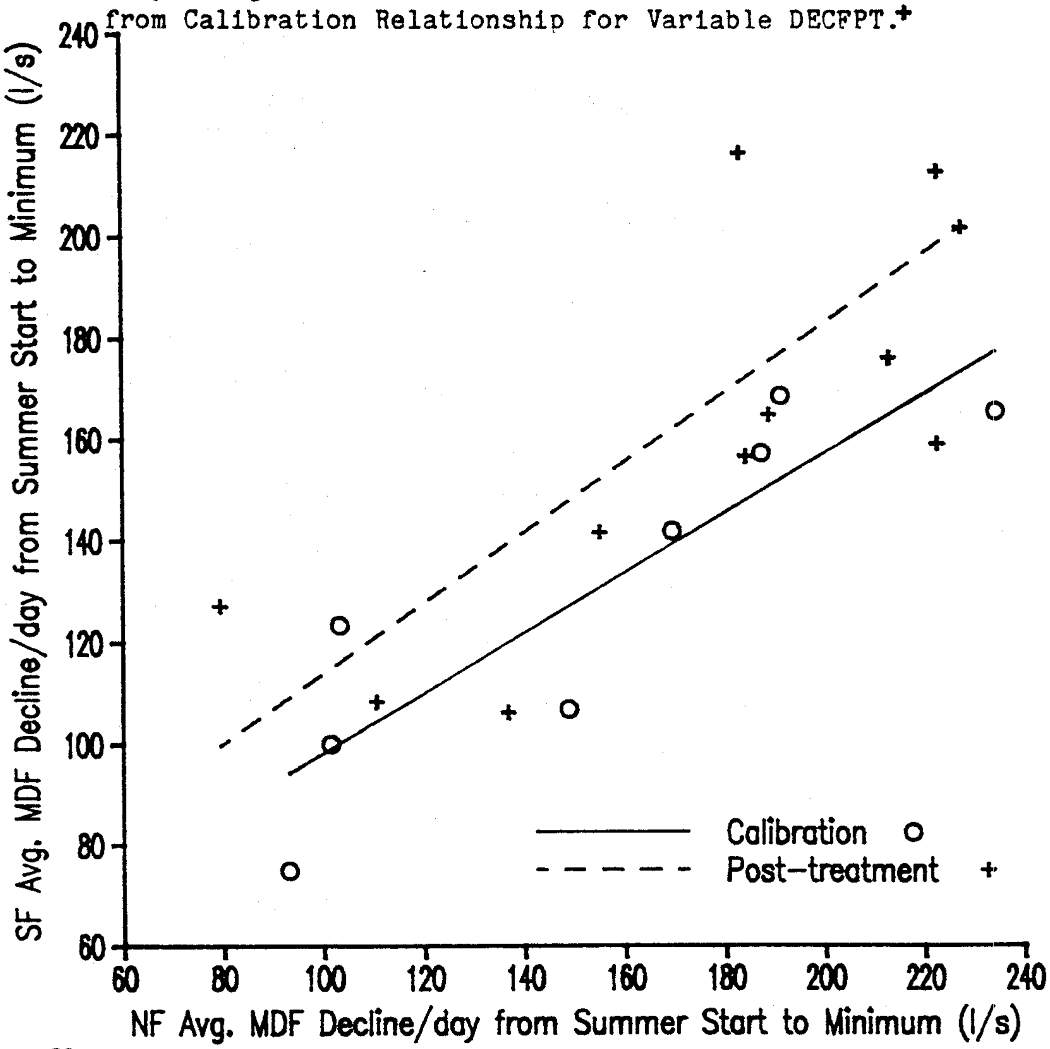


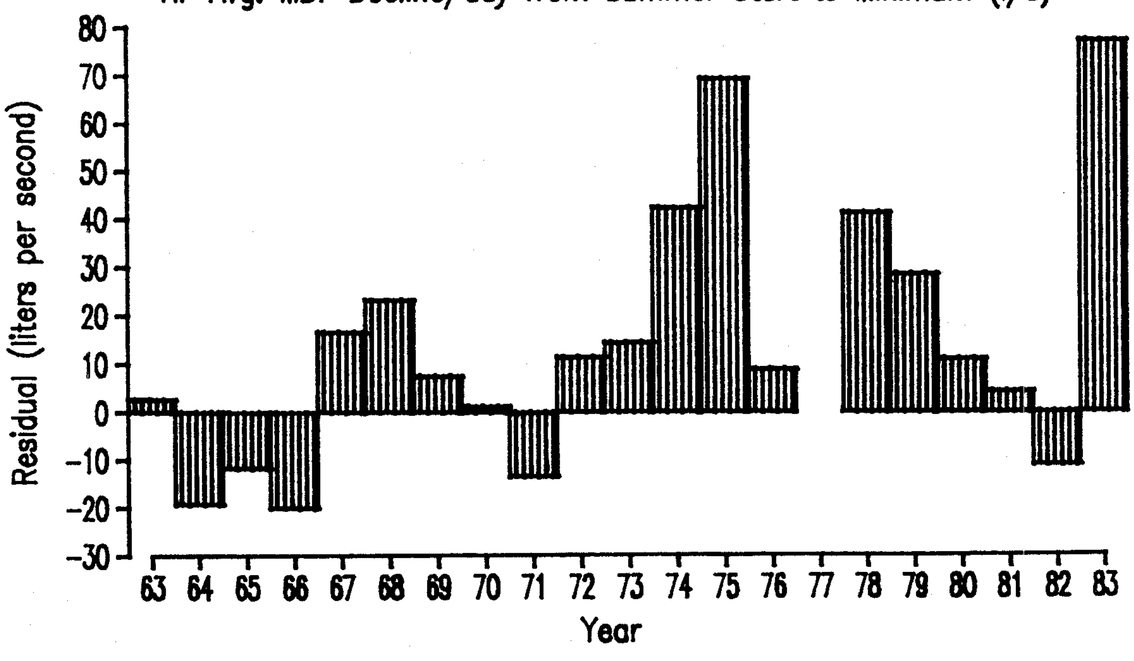
Appendix L. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable DECTIME.



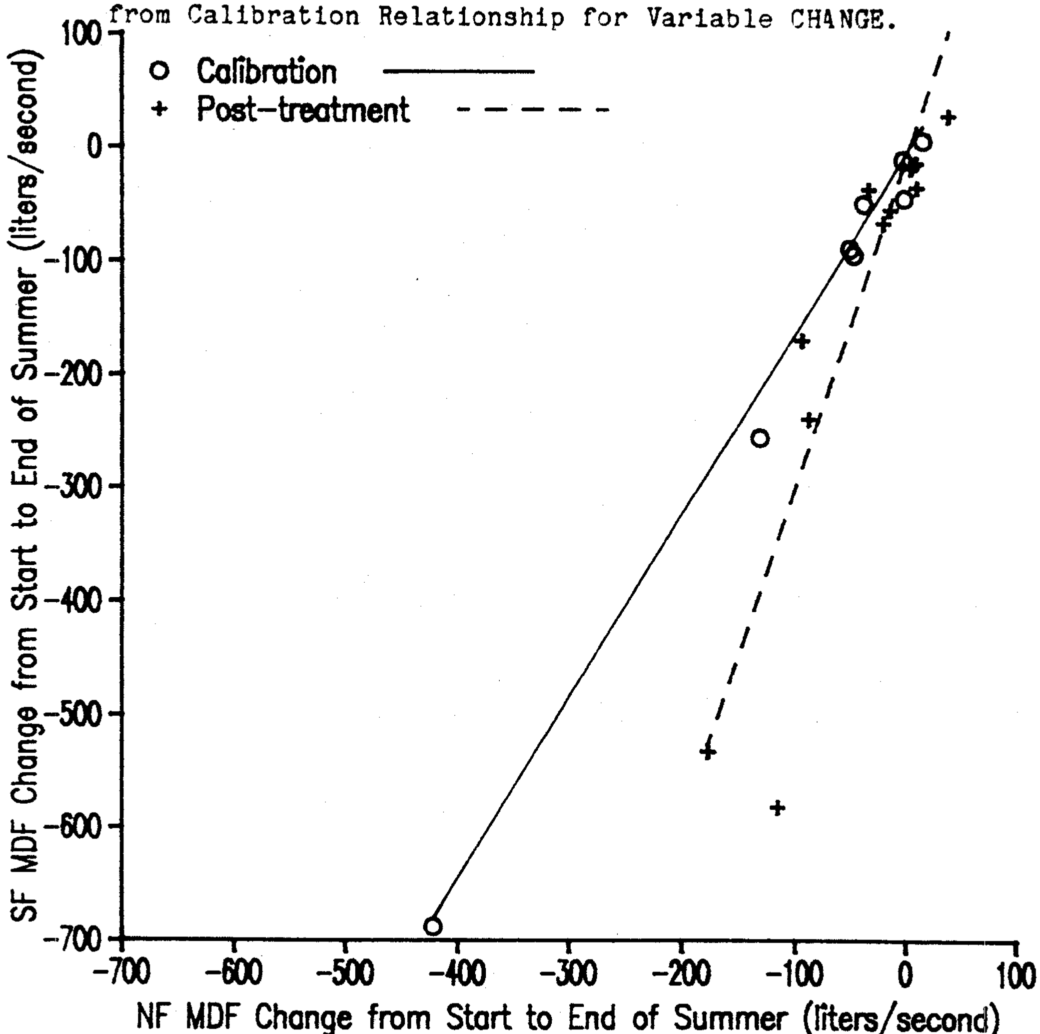


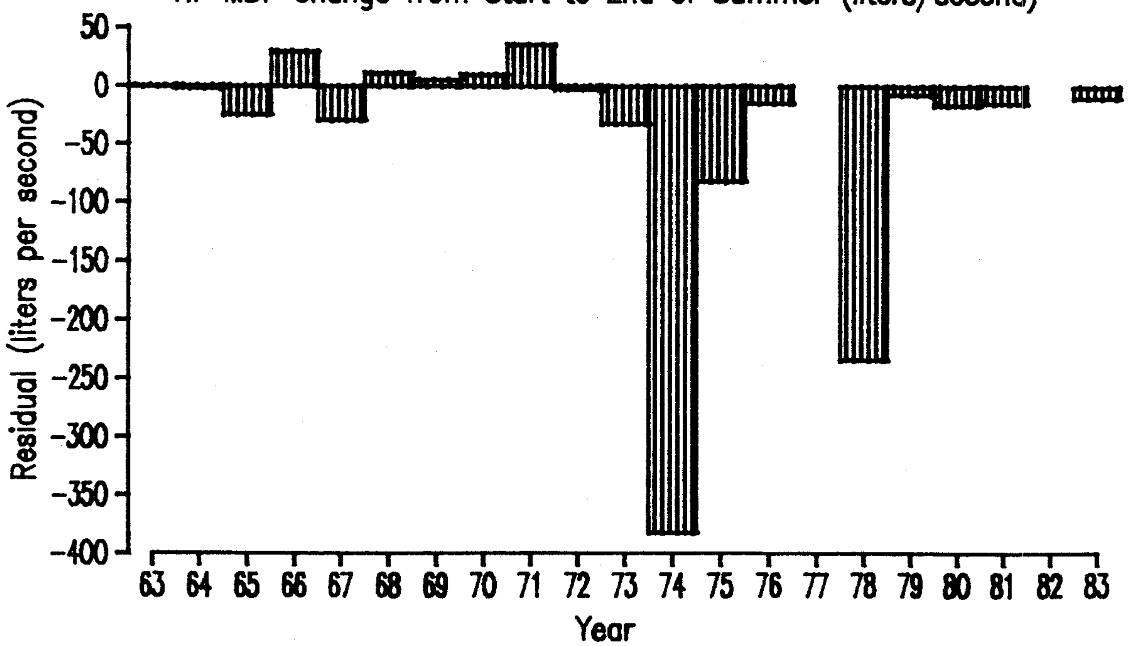
Appendix M. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable DECFPT.+





Appendix N. Simple Regression Results and Deviations of Observations from Calibration Relationship for Variable CHANGE.





Appendix 0. Caspar Creek Low Flow Study Data Set.

Caspar Creek Streamflow Variable: SUMVOL

YR = Current API year

N = North Fork Value (1000 cubic meters)

S = South Fork Value (1000 cubic meters)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	93.562	1.00	109.669	1.00
64	97.620	1.00	100.666	1.01
65	126.554	1.20	124.100	1.06
66	99.679	1.05	110.582	1.05
67	138.148	1.00	174.297	1.03
68	108.535	1.00	135.446	1.11
69	173.816	1.06	228.416	1.09
70	110.767	1.02	132.906	1.04
71	190.861	2.97	196.732	1.08
72	156.278	1.11	236.655	1.02
73	114.640	1.03	168.032	1.08
74	179.748	2.55	321.867	1.00
75	133.855	2.53	198.125	3.41
76	119.820	1.38	160.804	1.11
77	*	3.49	*	3.36
78	118.007	1.09	215.392	1.18
79	85.286	1.06	88.974	1.00
80	106.808	1.06	131.648	1.08
81	142.082	1.00	128.577	1.00
82	110.200	3.18	142.390	1.08
83	173.360	1.04	180.106	1.36

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: SUMYLEN

YR = Current API year

N = North Fork Value (cubic meters)

S = South Fork Value (cubic meters)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	0.512568	1.00	0.60081	1.00
64	0.363073	1.00	0.37440	1.01
65	0.518232	1.20	0.50818	1.06
66	0.396177	1.05	0.43951	1.05
67	0.598984	1.00	0.75572	1.03
68	0.398190	1.00	0.49692	1.11
69	0.612739	1.06	0.80522	1.09
70	0.423632	1.02	0.50830	1.04
71	0.729953	2.97	0.75241	1.08
72	0.656529	1.11	0.99420	1.02
73	0.573765	1.03	0.84099	1.08
74	0.677860	2.55	1.21381	1.00
75	0.669938	2.53	0.99160	3.41
76	0.483333	1.38	0.64866	1.11
77	*	3.49	*	3.36
78	0.419649	1.09	0.76596	1.18
79	0.440446	1.06	0.45949	1.00
80	0.426601	1.06	0.52581	1.08
81	0.590769	1.00	0.53462	1.00
82	0.522515	3.18	0.67515	1.08
83	0.841677	1.04	0.87443	1.36

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: TOTVOL

YR = Current API year

N = North Fork Value (1000 cubic meters)

S = South Fork Value (1000 cubic meters)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	2527.85	1.01	2271.29	1.00
64	1669.57	1.00	1468.82	1.02
65	3413.73	1.11	2976.76	1.04
66	2329.69	1.03	2138.60	1.03
67	3323.32	1.00	2966.43	1.03
68	1738.53	1.01	1683.26	1.08
69	3915.15	1.03	3562.73	1.07
70	3254.11	1.02	2678.58	1.12
71	3567.95	2.10	3120.46	1.05
72	1762.51	1.06	1638.84	1.01
73	3767.87	1.06	3681.45	1.15
74	6362.36	1.88	5913.93	1.09
75	3770.98	1.77	3652.29	2.20
76	1435.31	1.42	1657.63	1.09
77	*	4.00	*	4.00
78	3282.07	1.14	3892.98	1.12
79	1892.18	1.05	1978.13	1.15
80	3003.87	1.03	2896.03	1.07
81	1336.83	1.02	1551.31	1.07
82	4642.43	2.03	4453.89	1.11
83	6601.50	1.25	5756.09	1.29

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: TOTVLEN

YR = Current API year

N = North Fork Value (1000 cubic meters)

S = South Fork Value (1000 cubic meters)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	7.3271	1.01	6.5834	1.00
64	4.3478	1.00	3.8251	1.02
65	9.2513	1.11	8.0671	1.04
66	6.3827	1.03	5.8592	1.03
67	8.6545	1.00	7.7251	1.03
68	4.8562	1.01	4.7019	1.08
69	10.2223	1.03	9.3022	1.07
70	9.9211	1.02	8.1664	1.12
71	8.9873	2.10	7.8601	1.05
72	5.2928	1.06	4.9214	1.01
73	11.1806	1.06	10.9242	1.15
74	15.0767	1.88	14.0140	1.09
75	11.5320	1.77	11.1691	2.20
76	3.7672	1.42	4.3507	1.09
77	*	4.00	*	4.00
78	7.9086	1.14	9.3807	1.12
79	6.5930	1.05	6.8924	1.15
80	7.4170	1.03	7.1507	1.07
81	4.0633	1.02	4.7152	1.07
82	12.6497	2.03	12.1359	1.11
83	17.5572	1.25	15.3088	1.29

Appendix 0. Caspar Creek Low Plow Study Data Set (continued).

Caspar Creek Streamflow Variable: PARTVOL

YR = Current API year

N = North Fork Value (SUMVOL/TOTVOL)

S = South Fork Value (SUMVOL/TOTVOL)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	0.037125	1.01	0.048285	1.00
64	0.058470	1.00	0.068535	1.02
65	0.037072	1.20	0.041689	1.06
66	0.042787	1.05	0.051708	1.05
67	0.041569	1.00	0.058757	1.03
68	0.062429	1.01	0.080467	1.11
69	0.044396	1.06	0.064113	1.09
70	0.034039	1.02	0.049618	1.12
71	0.053493	2.97	0.063046	1.08
72	0.088668	1.11	0.144404	1.02
73	0.030426	1.06	0.045643	1.15
74	0.028252	2.55	0.054425	1.09
75	0.035496	2.53	0.054247	3.41
76	0.083480	1.42	0.097008	1.11
77	*	3.49	*	3.36
78	0.035955	1.14	0.055328	1.18
79	0.045073	1.06	0.044979	1.15
80	0.035557	1.06	0.045458	1.08
81	0.106283	1.02	0.082883	1.07
82	0.023738	3.18	0.031970	1.11
83	0.026261	1.25	0.031290	1.36

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: START

YR = Current API year

N = North Fork Value (liters per second)

S = South Fork Value (liters per second)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	23.3004	1	21.1202	1
64	19.3675	1	15.8139	1
65	47.7306	1	31.9592	1
66	26.7747	1	22.1480	1
67	24.2235	1	22.8729	1
68	18.1924	1	16.9409	1
69	31.9252	1	28.0035	1
70	20.0215	1	18.9399	1
71	24.3311	1	20.4633	1
72	33.9016	1	30.9936	1
73	26.5538	1	28.3716	1
74	39.0379	1	42.3054	1
75	26.7605	1	29.5156	1
76	37.1889	1	33.7232	1
77	*	4	*	4
78	14.5398	1	19.3278	1
79	28.9606	1	21.7856	1
80	24.1867	1	23.7676	1
81	18.5463	1	18.7785	1
82	28.5642	1	28.4509	1
83	37.0020	1	33.4825	1

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: MINFLO

YR = Current API year

N = North Fork Value (liters per second)

S = South Fork Value (liters per second)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	1.61679	1	3.08634	1
64	0.81264	1	0.96554	1
65	1.39310	1	1.95374	1
66	1.01368	1	1.27417	1
67	1.86313	1	3.30436	1
68	1.03916	1	1.74704	2
69	1.21471	1	2.20008	1
70	0.73336	1	1.20339	1
71	2.17459	2	3.32135	1
72	1.56582	1	4.19062	1
73	1.82915	1	4.77391	3
74	0.79565	2	4.63233	1
75	2.61064	1	3.31852	4
76	1.47804	1	3.46859	1
77	*	4	*	4
78	1.66775	1	3.15429	1
79	0.80415	3	0.58046	3
80	0.92307	1	2.50021	3
81	0.74752	1	1.27984	1
82	0.98819	4	2.63046	1
83	3.47142	1	4.66348	3

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: MINAPI

YR = Current API year

N = North Fork Value (liters per second)

S = South Fork Value (liters per second)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	1.68191	1	3.19393	1
64	0.86361	1	1.22321	1
65	1.52618	1	2.16893	1
66	1.58281	1	2.42659	1
67	2.01320	1	3.95277	1
68	1.79234	1	1.74704	2
69	1.44407	1	2.98440	2
70	0.96554	1	4.06887	2
71	6.48413	4	4.85319	1
72	3.14863	1	5.95465	1
73	3.75174	1	4.77391	1
74	1.99054	1	4.63233	1
75	4.32087	1	4.00657	4
76	1.68191	1	3.64697	1
77	1.24869	1	2.06416	1
78	1.95374	1	4.24442	1
79	0.93156	1	2.23689	1
80	1.37045	1	3.58468	1
81	0.74752	1	1.27984	1
82	1.80083	4	4.34069	1
83	5.41100	1	5.88952	1

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: END

YR = Current API year

N = North Fork Value (liters per second)

S = South Fork Value (liters per second)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQ	S	SQC
63	11.071	1	13.815	1
64	68.655	1	109.081	1
65	51.955	1	75.527	1
66	67.557	1	70.487	1
67	156.489	1	277.767	1
68	23.572	1	26.446	1
69	453.855	1	715.175	1
70	73.109	1	106.759	1
71	60.770	1	55.764	1
72	129.221	1	199.236	1
73	19.588	1	61.492	1
74	154.682	1	623.176	1
75	116.092	1	267.387	1
76	1.985	1	3.789	1
77	62.508	2	226.809	1
78	191.797	1	550.789	1
79	27.157	1	37.897	1
80	46.983	1	88.960	1
81	34.836	1	72.016	1
82	*	4	*	4
83	30.846	1	45.380	1

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: DECFLO

YR = Current API year

N = North Fork Value (liters per second)

S = South Fork Value (liters per second)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	21.6836	1	18.0338	1
64	18.5548	1	14.8484	1
65	46.3375	1	30.0054	1
66	25.7610	1	20.8738	1
67	22.3604	1	19.5685	1
68	17.1532	1	15.1938	2
69	30.7105	1	25.8035	1
70	19.2882	1	17.7365	1
71	22.1565	2	17.1419	1
72	32.3357	1	26.8030	1
73	24.7247	1	23.5977	3
74	38.2422	2	37.6731	1
75	24.1499	1	26.1970	4
76	35.7109	1	30.2546	1
77	*	4	*	4
78	12.8720	1	16.1735	1
79	28.1564	3	21.2051	3
80	23.2636	1	21.2674	3
81	17.7988	1	17.4987	1
82	27.5760	4	25.8204	1
83	33.5306	1	28.8190	3

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: DECFPT

YR = Current API year

N = North Fork Value (0.001 liters/second/day)

S = South Fork Value (0.001 liters/second/day)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	169.403	1	141.999	1
64	93.240	1	74.992	1
65	234.028	1	165.776	1
66	148.907	1	107.045	1
67	191.114	1	168.694	1
68	103.333	1	123.527	2
69	187.259	1	157.338	1
70	101.517	1	100.206	1
71	136.769	2	106.471	1
72	212.735	1	176.335	1
73	188.738	1	165.019	3
74	222.339	2	212.842	1
75	182.954	1	216.504	4
76	184.077	1	156.759	1
77	*	4	*	4
78	79.457	1	127.351	1
79	227.068	3	201.953	3
80	155.091	1	141.783	3
81	110.552	1	108.687	1
82	222.387	4	159.385	1
83	216.327	1	244.229	3

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: DECTIME

YR = Current API year

N = North Fork Value (days)

S = South Fork Value (days)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	128	1	127	1
64	199	1	198	1
65	198	1	181	1
66	173	1	195	1
67	117	1	116	1
68	166	1	123	2
69	164	1	164	1
70	190	1	177	1
71	162	2	161	1
72	152	1	152	1
73	131	1	143	3
74	772	2	177	1
75	132	1	121	4
76	194	1	193	1
77	*	4	*	4
78	162	1	127	1
79	124	3	105	3
80	150	1	150	3
81	161	1	161	1
82	124	4	162	1
83	155	1	118	3

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: CHANGE

YR = Current API year

N   = North Fork Value (liters per second)

S   = South Fork Value (liters per second)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	12.229	1	7.305	1
64	-49.288	1	-93.267	1
65	-4.225	1	-43.568	1
66	-40.782	1	-48.339	1
67	-132.265	1	-254.894	1
68	-5.380	1	-9.505	2
69	-421.930	1	-687.171	1
70	-53.088	2	-87.819	1
71	-36.439	2	-35.300	1
72	-95.320	1	-168.242	1
73	6.965	1	-33.120	1
74	-115.644	1	-580.871	1
75	-89.331	1	-237.872	1
76	35.204	1	29.935	1
77	*	4	t	4
78	-177.258	1	-531.461	2
79	1.804	1	-16.111	1
80	-22.796	1	-65.192	1
81	-16.290	1	-53.238	1
82	*	4	*	4
83	6.156	1	-11.898	1

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: LOFLOZ

YR = Current API year

N = North Fork Value (days)

S = South Fork Value (days)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	81	1	56	1
64	143	1	146	1
65	121	1	112	1
66	145	1	132	1
67	107	1	81	1
68	144	1	119	1
69	139	1	123	1
70	135	1	120	1
71	76	3	102	1
72	96	1	21	1
73	81	1	34	1
74	116	3	28	1
75	74	3	36	3
76	117	1	73	1
77	*	4	*	4
78	174	1	99	1
79	97	1	89	1
80	135	1	113	1
81	122	1	119	1
82	104	3	79	1
83	65	1	47	1

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek Streamflow Variable: LOFLEN

YR = Current API year

N = North Fork Value (percent of days, dec.fraetion)

S = South Fork Value (percent of days, dec.fraction)

NQC = Quality Code for this North Fork Value

SQC = Quality Code for this South Fork Value

YR	N	NQC	S	SQC
63	0.54362	1	0.37584	1
64	0.65297	1	0.66667	1
65	0.60804	1	0.56281	1
66	0.70732	1	0.64390	1
67	0.56915	1	0.43085	1
68	0.64865	1	0.53604	1
69	0.60173	1	0.53247	1
70	0.63380	1	0.56338	1
71	0.35681	3	0.47887	1
72	0.49485	1	0.10825	1
73	0.49693	1	0.20859	1
74	0.53704	3	0.12963	1
75	0.45399	3	0.22086	3
76	0.57921	1	0.36139	1
77	*	4	*	4
78	0.79452	1	0.45205	1
79	0.61392	1	0.56329	1
80	0.66176	1	0.55392	1
81	0.62245	1	0.60714	1
82	0.60465	3	0.45930	1
83	0.38690	1	0.27976	1

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

CASPAR CREEK: SOUTH FORK TREATMENT SUMMARY

YRLEN is .length of API year (in days).

SLEN is LENGTH of LOW FLOW period.

AH = Area harvested in given year, hectares

%AH = Percent of total area harvested in given year

TVR = Harvest Volume (timber volume removed). 1000s cubic meters per hectare in given yr.

%TVR = % timber volume in this STAGE AREA removed per given yr.

RD = Roads, hectares in given yr.

ST = Skid Trails, hectares in given yr.

LA = Landings, hectares in given yr.

%AC = Cumulative area compacted (roads, skid trails, and landings) % of total.

%ADF = Cumulative area harvested, -lambda = -.13, % of total.

%ADF2 = " " " -lambda = -.20, " " "

C%TVR = Cumulative % of total watershed timber volume removed, lambda= -.08,

(ASSUMES 99.9% regrowth occurs in 85 yrs.)

YR	YRLEN	SLEN	AH	%AH	TVR	%TVR	RD	ST	LA	%AC	%ADF	%ADF2	C%TVR
63	345	149	0	0.00	0.00	0	0.0	0.0	0.0	0.0	0.00	0.00	0.00
64	384	219	0	0.00	0.00	0	0.0	0.0	0.0	0.0	0.00	0.00	0.00
65	369	199	0	0.00	0.00	0	0.0	0.0	0.0	0.0	0.00	0.00	0.00
66	365	205	0	0.00	0.00	0	0.0	0.0	0.0	0.0	0.00	0.00	0.00
67	384	188	19	4.48	18.87	100	19.0	0.0	0.0	0.0	0.00	0.00	0.00
68	358	222	0	0.00	0.00	0	0.0	0.0	0.0	4.5	4.50	4.50	6.29
69	383	231	0	0.00	0.00	0	0.0	0.0	0.0	4.5	4.50	4.50	6.29
70	328	213	0	0.00	0.00	0	0.0	0.0	0.0	4.5	4.50	4.50	6.29
71	397	213	101	23.82	48.78	59	2.0	8.8	3.5	4.5	4.50	4.50	6.29
72	333	194	128	30.19	64.26	69	0.5	11.2	1.3	7.8	28.30	28.30	22.55
73	337	163	176	41.51	67.94	65	0.7	15.4	3.6	10.9	55.60	54.19	42.72
74	422	216	0	0.00	0.00	0	0.0	0.0	0.0	15.6	90.87	86.68	62.57
75	327	163	0	0.00	0.00	0	0.0	0.0	0.0	15.6	80.34	71.78	58.45
76	381	202	0	0.00	0.00	0	0.0	0.0	0.0	15.6	66.95	59.61	54.25
77	376	252	0	0.00	0.00	0	0.0	0.0	0.0	15.6	62.97	49.61	50.56
78	415	229	0	0.00	0.00	0	0.0	0.0	0.0	15.6	55.84	41.43	47.16
79	287	158	0	0.00	0.00	0	0.0	0.0	0.0	15.6	49.58	34.74	44.01
80	405	204	0	0.00	0.00	0	0.0	0.0	0.0	15.6	44.09	29.26	41.12
81	329	196	0	0.00	0.00	0	0.0	0.0	0.0	15.6	39.26	24.76	38.43
82	367	172	0	0.00	0.00	0	0.0	0.0	0.0	15.6	35.02	21.09	35.97
83	376	168	0	0.00	0.00	0	0.0	0.0	0.0	15.6	31.30	18.09	33.67

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

CASPAR CREEK: PRECIPITATION VARIABLES

YR = Current API year.

PPTYR = Cumulative daily precipitation for the API year in cm.

MPPTYR = PPTYR / (length of API year), ie MEAN ppt/day for current year.

PPTSEAS = Cumulative daily precipitation for the LOW FLOW SEASON in cm

MPPTSEAS = PPTSEAS/(length of lowflow season), ie mean daily ppt for season.

SRD = Number of days with recorded ppt in low flow season.

TRD = " " " " " the API year.

PROPRD = SRD/TRD

%SRD = SRD/(length of low flow season).

%TRD = TRD/(length of API year).

YR	PPTYR	MPPTYR	PPTSEAS	MPPTSEAS	TRD	SRD	PROPRD	%SRD	%TRD
63	101.549	0.294345	13.1318	0.088133	99	12	0.121212	0.080537	0.286957
64	99.568	0.259292	25.5778	0.116794	77	21	0.272727	0.095890	0.200521
65	113.335	0.307140	12.8778	0.064713	94	13	0.138298	0.065327	0.254743
66	96.749	0.265065	14.3256	0.069881	75	9	0.120000	0.043902	0.205479
67	141.605	0.368763	28.0924	0.149428	98	23	0.234694	0.122340	0.255208
6E	66.843	0.242577	23.1902	0.104460	79	31	0.392405	0.139640	0.220670
69	154.381	0.403084	31.2420	0.135247	111	28	0.252252	0.121212	0.289817
70	99.568	0.303561	17.8562	0.083832	56	13	0.232143	0.061033	0.170732
71	135.661	0.341716	27.8892	0.130935	123	49	0.398374	0.230047	0.309824
72	84.150	0.252703	23.8760	0.123072	78	18	0.230769	0.092784	0.234234
73	126.619	0.375724	13.7668	0.084459	100	4	0.040000	0.024540	0.296736
74	185.496	0.439564	20.8788	0.096661	105	14	0.133333	0.064815	0.248815
75	113.386	0.346745	13.9192	0.085394	69	8	0.115942	0.049080	0.211009
76	63.094	0.165600	1.0160	0.005030	52	3	0.057692	0.014851	0.136483
77	45.212	0.120245	20.6756	0.082046	40	17	0.425000	0.067460	0.106383
78	155.169	0.373900	28.0162	0.122342	101	21	0.207921	0.091703	0.243374
79	73.863	0.257363	13.2842	0.084077	66	11	0.166667	0.069620	0.229965
80	125.806	0.310633	15.3416	0.075204	90	17	0.188889	0.083333	0.222222
81	79.045	0.240258	20.6248	0.105229	63	17	0.269841	0.086735	0.191489
82	147.803	0.402732	14.5796	0.084765	101	12	0.118812	0.069767	0.275204
83	208.280	0.553936	23.9014	0.142270	122	19	0.155738	0.113095	0.324468

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

Caspar Creek: ANTECEDENT PPT VARIABLES

YR = Current APIYR

LENYR = Length of current API year (days)

LENSEAS = Length of current Low Flow Season (days)

PROPLEN = LENSEAS/LENYR

APIYR = Cumulative API for current API year (cm)

MAPIYR = APIYR/LENYR (mean daily API, cm)

APISEAS = Cumulative API for Low Flow Season (cm)

MAPISEAS = APISEAS/LENSEAS (mean daily API, cm)

MINAPI = Minimum daily API for current year (cm)

MAXAPI = Maximum daily API for Current Year (cm)

YR	LENYR	LENSEAS	PROPLEN	APIYR	MAPIYR	APISEAS	MAPISEAS	MINAPI	MAXAPI
63	345	149	0.431884	2088.32	6.0531	122.279	0.82067	0.28	25.82
64	384	219	0.570313	1807.60	4.7073	132.981	0.60722	0.06	25.64
65	369	199	0.539295	2866.36	7.7679	110.086	0.55320	0.11	40.28
66	365	205	0.561644	2126.88	5.8271	69.733	0.34016	0.22	35.53
67	384	188	0.489583	3104.63	8.0850	176.916	0.94104	0.39	28.53
68	358	222	0.620112	1875.76	5.2396	158.677	0.71476	0.52	21.18
69	383	231	0.603133	3501.32	9.1418	215.476	0.93280	0.20	36.21
70	328	213	0.649390	2584.82	7.8805	107.954	0.50682	0.04	47.79
71	397	213	0.536524	2957.91	7.4506	172.196	0.80843	0.78	34.84
72	333	194	0.582583	1676.21	5.0337	196.047	1.01055	0.45	19.39
73	337	163	0.483680	2993.19	8.8819	88.161	0.54086	0.16	35.34
74	422	216	0.511848	4528.22	10.7304	332.025	1.53715	0.05	28.55
75	327	163	0.498471	2756.06	8.4283	80.682	0.49498	0.14	33.84
76	381	202	0.530184	1285.40	3.3737	78.424	0.38824	0.03	16.01
77	376	252	0.670213	238.96	0.6355	140.459	0.55738	0.02	8.96
78	415	229	0.551807	3501.85	8.4382	86.395	0.37727	0.53	42.79
79	287	158	0.550523	1764.35	6.1476	69.222	0.43811	0.22	28.46
80	405	204	0.503704	2918.33	7.2058	62.671	0.30721	0.11	28.60
81	329	196	0.595745	1682.67	5.1145	140.762	0.71818	0.20	27.71
82	367	172	0.468665	3618.64	9.8601	123.764	0.71956	0.28	33.88
83	376	168	0.446809	5299.45	14.0943	236.407	1.40718	1.29	38.91

Appendix 0. Caspar Creek Low Flow Study Data Set (continued).

CASPAR CREEK: GENERAL CLIMATE CONDITIONS
SEASONAL VALUES ESTIMATED FROM AVERAGE CONDITIONS AT
39 DEGREES NORTH LATITUDE and/or THE NORTH COAST

HRLIT = Total hours of daylight for the low flow season.

MDLITMN = Mean minutes of daylight/day for the low flow season.

MDLITHR = " hours " " " " " " " "

LYSEAS = Total estimated langleys (cal/cm^2) for the low flow season.

MLYDAY = Mean " " per day for the low flow season.

Source: U.S. Naval Observatory and California Dept. of Water Resources.

(I4,F8.2,F6.1,F8.4,1X,I6,F8.3)

YR	HRLIT	MDLITMN	MDLITHR	LYSEAS	MLYDAY
63	2003.43	806.8	13.4467	64928	435.758
64	2911.82	797.8	13.2967	94497	431.493
65	2633.05	793.9	13.2317	84269	423.462
66	2715.08	794.7	13.2450	86999	424.385
67	2391.97	763.4	12.7233	72096	383.489
68	2905.10	785.2	13.0867	91632	412.757
69	2956.55	767.9	12.7983	90207	390.507
70	2844.88	801.4	13.3567	92895	436.127
71	2728.27	768.5	12.8083	83116	390.216
72	2595.58	802.8	13.3800	84532	435.732
73	2247.62	827.3	13.7883	75899	465.638
74	2788.05	774.5	12.9083	86191	399.032
75	2191.82	806.8	13.4467	71468	438.454
76	2684.58	797.4	13.2900	86480	428.119
77	3292.48	783.9	13.0650	104071	412.980
78	2806.30	?35.3	12.2550	78654	343.467
79	2127.00	807.7	13.4617	69369	439.044
80	2623.58	771.6	12.8600	80368	393.961
81	2645.40	809.8	13.4967	87294	445.377
82	2309.63	805.7	13.4283	75392	438.326
83	2208.25	788.7	13.1450	69742	415.131