THESIS

CALIBRATION OF LITTLE BEAVER CREEK WATERSHED

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION

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ABSTRACT OF THESIS

CALIBRATION OF LITTLE BEAVER CREEK WATERSHED

Proposed logging operations on Little Beaver Creek provide an opportunity to add to the knowledge of timber-cutting effects on streamflow. This study was concerned with calibrating Little Beaver Creek in order that parameters of water yield, high and low flow, and streamflow timing could be evaluated after treatment as if treatment had not occurred. Precision of prediction relationships was assessed in terms of changes in the parameters which would be statistically detectable when six years of after-treatment data are available.

A change equivalent to 20 percent of the mean value of parameters in the period 1961 to 1966, was considered to be the smallest acceptable effect of treatment.

Double-mass curves of water yield from the study area against either precipitation data or concurrent water yield data from a nearby watershed showed some consistency, but precise linear relationships could not be defined.

Monthly, seasonal, and annual water yield volumes from Little Beaver Creek were correlated by simple, least squares regression with each of the following: concurrent precipitation data; water yield data from two adjacent watersheds; and snow water equivalent records from a snow course within the watershed. The only equation meeting the precision criteria had a combination of snow water equivalent measurements as the control variable. Other equations were generally less

precise, though some which involved monthly yields had high correlation coefficients.

Similar analyses for peak flows, half-flow intervals, low flow intervals, and discharge levels corresponding to ten percentages of time on the annual flow-duration curve, were made using corresponding data from the adjacent watersheds as control variables. The arbitrary level of detectable change could not be met with consistency for any of these parameters.

It was concluded that available precipitation records do not provide an accurate index of water available for runoff on Little Beaver Creek, and that the watersheds selected as controls have streamflow characteristics distinct from those of Little Beaver Creek.

An average recession curve for Little Beaver Creek was constructed and a mathematical model fitted by least squares regression. Parameters of the model indicate that there may be three sources of storage contributing to streamflow.

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Chapter I

INTRODUCTION

In recent years, increasing demand for water from the alpine and subalpine zones of the Colorado Rocky Mountains has created a need for information on factors affecting water production in the area. Although there have been several investigations into the effects of vegetation manipulation on streamflow in the United States, complex interrelationships among the many variables involved have precluded development of specific recommendations for management.

In Colorado, current studies in this field are largely confined to individual processes within the hydrologic cycle. These, together with a program of watershed studies in which the integrated effects of the processes are assessed, are likely to lead more rapidly to applicable results than if either type of investigation is carried out alone. Proposed logging operations on Little Beaver Creek provide an unprecedented opportunity for research of this nature. Since the area is part of the Little South Fork of the Cache la Poudre River, its proximity to Fort Collins, and the administrative situation involving Colorado State University and the U. S. Forest Service remove many of the obstacles commonly encountered in watershed research.

This study is part of the "whole watershed" approach to the problem. Its object is to calibrate the Little Beaver Creek watershed with respect to annual, seasonal, and monthly water yields, high and low flows, and streamflow timing and distribution. The method of Kovner and Evans (1954) will be used to determine changes in these parameters detectable with the derived prediction equations.

Discussing watershed calibration methods, Reinhart (1965) defined calibration as "...the determination of the normal relationship between a characteristic under study and other parameters." The establishment of this relationship is necessary because streamflow is affected by a wide range of uncontrolled variables. Hence, when, for example, vegetation is removed from a watershed, a change in annual water yield could be due to either the treatment or a change in annual precipitation. This problem is encountered in many biological experiments and is frequently overcome by maintaining an untreated, or control, population. Differences between the treated and control populations may then be assessed in terms of the treatment. This procedure requires that both populations be exactly alike in all respects except treatment, a situation seldom found in watershed studies. Wide variation of soils, geology, and topography of individual watersheds renders each unique. For this reason it is necessary to obtain an estimate of the study parameter as if treatment had not occurred. Predicted and observed values, after treatment, can then be compared and differences may be attributed to the treatment.

In previous studies several methods have been used to obtain the predicted value. All involve an observation period, before treatment, in which a relationship between the variable to be investigated and some control variable is established. This period, assumed to be "normal," is the calibration period.

Selection of the control variable is determined by two criteria: it must be relatively well correlated with the characteristic to be studied in order that the prediction relationship will be sufficiently precise to detect relatively small changes; and it must be unaffected by the treatment. Where water yield is being investigated, measures of precipitation generally meet the latter requirement satisfactorily. However, relationships between other streamflow characteristics and climatic variables are frequently too complex for precise evaluation. Thus the paired watershed technique has received considerable attention. With this method a control watershed similar to that to be treated is selected and relationships between corresponding flow characteristics on each are developed.

A further peculiarity of watershed experiments involving vegetation manipulation is that they are irreversible, at least in the short term. When treatment is applied, the watershed must be considered calibrated and the question naturally arises: how long should watersheds be calibrated? Lack of an estimate of the length of the calibration period has the consequences described by Wilm (1949):

> If too short a period is allowed, the experiment may lack satisfactory precision; it may not be possible to demonstrate the real nature of even fairly large effects of treatment. On the other hand, if the period is longer than necessary, the final answers are postponed and the total cost of the investigation becomes undesirably large.

It is hoped that this study will provide answers to this question for Little Beaver Creek, to enable the most efficient utilization of available data.

Chapter II

REVIEW OF LITERATURE

Methods of Detecting Streamflow Changes

Double-Mass Analysis

The technique of double-mass analysis is a simple, direct method for testing the consistency of hydrologic data. A discussion of the method and its limitations has been presented by Searcy and Hardison (1960). Its most frequent use has been to check the consistency of precipitation records with time, but analyses of streamflow records have also been made.

With precipitation records, accumulated totals from the station to be tested are plotted against concurrent accumulated totals either from a station known to be consistent, or from several similar stations. It is assumed that such a relationship will be linear, so a change will appear as a break in the curve. If any other relationship exists, then the curve will have continuous breaks and it may be necessary to use a transformation to induce linearity. The slope of the curve represents the constant of proportionality between the two records and so, when inconsistencies occur, the whole record can be adjusted to one period. Searcy and Hardison emphasized, however, that a rational basis for the inconsistency must be established before adjustments are made. If this cannot be done, statistical analyses can be made to determine the probability of the break occurring by chance.

As comparable watersheds with concurrent records of streamflow are seldom found, it was suggested that predicted values be plotted against observed values. In this case, adjustments to records should be made by evaluating the changes in the prediction relationship rather than by using the slopes of the double-mass curve.

The method has the disadvantage that long periods of record are necessary to evaluate changes accurately, and it is not possible to include an estimate of error. Furthermore, while a break in the curve indicates a change in relationship, the cause of the change remains open to conjecture.

By using prediction equations and plotting accumulations of calculated and observed values, Anderson (1955) studied the effects of burning on peak flows and annual flows. Pre-fire peak flows, when adjusted to post-fire conditions, gave a series suitable for frequency analysis.

The technique was also used in a study of the effects of improving cover conditions on the hydrology of the Pine Tree Branch watershed in Tennessee (Tennessee Valley Authority, 1955). Graphs of accumulated runoff, and precipitation, against time, were drawn and showed that the rate of accumulation of runoff decreased after treatment began.

Paired Watersheds

Varying influences of topography, soil, geology, and climate on runoff make evaluation of causes of changes in runoff difficult. For this reason, the paired watershed technique has received considerable attention. This method involves the observation of runoff from two similar watersheds for a period, treatment of one, and observation of runoff for a further period. Changes in the runoff relationship between the two watersheds are then evaluated in terms of the treatment.

The first such experiment in the United States was begun at Wagon Wheel Gap, Colorado, in 1909 (Bates and Henry, 1928). Streamflow from two adjacent watersheds, with similar forest cover, was compared for nine to ten years before one watershed was denuded. Observations were continued for a further seven years to determine differences in the behavior of the streams after denudation. Analyses consisted largely of comparing percents of precipitation appearing as streamflow in the two periods. These, plus detailed inspections of the snowmelt hydrographs, showed an increase in annual streamflow of approximately 15 percent was manifested in an earlier and faster rise of the hydrograph, a higher instantaneous peak, and a slightly lower rate of recession. An increase in late summer flows was attributed to greater storage in the soil due to a net decrease in evapotranspiration losses.

A similar study was made in southern California where an accidental fire denuded one watershed, while a nearby watershed was left intact (Hoyt and Troxell, 1934). A relation between the flows of the two watersheds was developed from data available for the period before the fire. This relation was the ratio of the flow of the unburned watershed to the flow of the watershed later burned. In the period after the fire, the flows of the unburned, or control watershed were used to predict what the flows would have been from the burned, or treated, watershed had the fire not occurred. Differences between the predicted and observed flows were then considered to indicate the effect of treatment. These analyses were made using annual, winter, and summer flows.

Reviewing these two studies, Wicht (1944) states:

> Such experiments do not preclude the possibility that the results were invalidated by a change in climate or some other, possibly unsuspected, hydrographic factor, coincident with the application of treatment. The success of the experiments depends on the assumption that the relation between the streamflow of the two watersheds would have remained constant had no treatment been applied.

In the same paper Wicht outlines a method of removing this source of error from an experiment designed to determine the effects of reforestation on streamflow at Jonkershoek, South Africa. One of six small watersheds has been designated the control. The remaining five will receive the same treatment, but there will be a period of eight years between treatment of successive watersheds giving replication in time. Each treatment, protection followed by afforestation, will be carried out in one year and eventually a range of forest age classes will be carried by the six watersheds taken together. Any climatic change is unlikely to occur coincident with treatment of all watersheds. Wicht further recognized that comparisons should be made of distributions of the variables under study, rather than of individual values.

In discussing this same facet of analysis, Wicht and Shuman (1957), concluded that although effects of treatment can be determined by comparing regressions of discharge on climate, and other variables, before and after treatment, the most objective analysis can be made by comparing regressions of discharge variables from a treated watershed on similar variables observed simultaneously on a control watershed.

The same concept was described by Wilm (1944). He suggested that by using least squares linear regression, a relation could be developed between the flows of the control and treated watersheds for the before- and after-treatment periods. A change in the relationship due to treatment could be determined by testing for a difference between the slopes of the two regression lines. If this is no greater than expected by chance, the flows from the treated watershed corresponding to the total period mean flow of the control watershed could be tested to determine whether they are significantly different. With rational justification, a multiple-linear, polynomial, or logarithmic relationship could be used.

Wilm (1949) lists the assumptions inherent in this method as follows: within the duration of the experiment the variation of the measured parameter is random and normally distributed; the residual deviations about the calculated regression line are random and normally distributed; and because there are errors in measurements of both dependent and independent variables they must be relatively highly correlated.

Within these assumptions Wilm developed a method for determining the length of watershed experiments using the following equation:

$$k = s^2_{y.x} \; F/d^2[2 + F/(k-1)]$$

where k is the length, in years, of the calibration period, (which equals the length of the observation period after treatment); $s_{y.x}$ is the standard error estimated from the sample; F is the estimated variance ratio; and d is the smallest worthwhile difference due to treatment. As there is no explicit solution for k, the equation is solved by successive approximations.

A graphical solution of the equation for the general case where calibration and treatment periods are not of equal length was presented by Kovner and Evans (1954). This permits rapid solution for any one of the variables if the others are known or values assigned. Thus, with a predetermined number of observations, the smallest difference detectable at any level of probability, can be found, or conversely, the number of observations necessary to determine a known difference at a certain probability level.

The calibration of five small forested watersheds at Fernow Experimental Forest, West Virginia, was reported by Reinhart (1958). The above graphical method was extended to cover a longer period of calibration as it was felt that effects of forest cutting would be short-lived due to regrowth. Analyses of annual, monthly, peak, and low flows were made using five years of record. Prediction equations for each watershed were developed from each of the others and the watershed giving the best correlations was selected as the control. Results indicated that from two to four years of observation after treatment would be sufficient to detect a ten percent change in flow, significant at the five percent probability level. A regression developed using all sixty monthly observations as independent variables gave an accurate prediction equation with a short period after treatment necessary to determine effects. It was considered that "serial" correlation effects made this last analysis questionable.

The use of this method for determination of treatment effects requires relatively long observation periods and therefore costs are high. A rapid calibration method using the characteristic reactions of watersheds to storms was proposed by Bethlamy (1963). Paired watersheds are used and it is necessary that the same storms influence the hydrographs of both. The method has the following advantages: each storm reaction is an observation and there will generally be several storms, with a wide range of intensity and magnitude represented in a year; analysis is not hampered by incomplete hydrographs due to instrument breakdowns; and poor selection of watersheds is revealed in a short time. Two parameters are taken direct from the hydrograph: the magnitude of the rise in stage, and the time from beginning of rise to the peak. Separate regressions using each of these, are computed and compared as with the method of Wilm (1944). The large number of storms that occur over a short period produce reliable prediction equations relatively quickly but this method can show only that a treatment has had an effect and "...additional analyses must be conducted on such diverse elements of streamflow as peak flow, low flow, or seasonal flow to establish exact changes in volume of flow" (Bethlamy, 1963).

Three methods of extending short period streamflow records by correlation with longer records were used by Martin (1960). These were a linear regression with a logarithmic transformation of discharges, a multiple regression which included the difference in precipitation as an independent variable, and a more complex regression using discharges from all calendar months and the difference in precipitation. To negate "serial" correlation effects in the last method, part of a Fourier series was substituted for the regression constant and coefficient.

The addition of the precipitation variable reduced the standard error for most monthly predictions, and in about half of these the regression coefficient was significant at the five percent level. An approximate test of the last method could not show it to give more reliable results than the separate monthly regressions.

In all the above cases streamflow data were obtained from continuously recording equipment. It was suggested by Reinhart (1964) that a considerable saving in cost could be realized by making streamflow measurements at regular intervals, such as daily or weekly. Data from a forest cutting experiment at the Fernow Experimental Forest, West Virginia, were analyzed assuming six frequencies of flow measurement ranging from continuous to once a month. Regressions were computed and treatment effects determined. The accuracy of prediction decreased rapidly with decreasing frequency of flow measurement but it was concluded that weekly observations gave acceptable accuracy where treatment effects were large.

The control watershed approach to detecting changes in streamflow has been widely used in watershed studies, (Dils, 1957; Goodell, 1958; Rich, Reynolds, and West, 1961). Its advantage is that it has an established procedure with a background of experience and success. There are, however, several disadvantages: a chance catastrophe, such as a fire, can completely change the character of the control; additional costs are involved in operating the control; it is difficult to find two similar watersheds close together; and there is the possibility that an undetected change could occur on the control after the calibration period (Reigner, 1964).

Climatic Calibration

Detection of changes in the water balance of a watershed after treatment would obviate the necessity for a separate control watershed but this method has proved impractical due to limitations in evaluating parameters on a whole watershed basis. A climatic calibration study, described by Reigner (1964), involved the use of streamflow and climatic data obtained during a calibration period, to develop prediction equations for annual and monthly runoff. The procedure amounts to a solution of the water balance by multiple regression. Some parameters of the balance, however, would be affected by treatment and so they, in turn, were predicted from unaffected climatic variables. The final prediction equations were relatively accurate but "...there is no way of knowing if the high correlations are valid, if they are the results of chance, or if they stem from overmanipulation of the data" (Reigner, 1964).

In watershed investigations which involve changes in vegetative cover, it can be important to keep the length of the observation period short, from the cost point of view, and also to allow a smaller chance of climatic changes confounding treatment effects. Regrowth of vegetation can have similar nullifying effects on results. However, the multiple regression analysis creates a situation of decreased degrees of freedom and wider confidence limits with each additional independent variable. The multiple regression technique is therefore limited to long periods of record where extraneous variation due to climate or vegetation is either negligible or can be included in the analysis. Moreover, the basic assumptions of absence of errors in the independent variables and normal distribution of the residuals, are seldom completely valid in hydrologic data. Therefore, although multiple regression will result in a line of best fit, and best estimating equation, it is not safe to place too much reliance on estimated values, particularly at levels far removed from the mean (Sharp et al, 1960).

Brakensiek (1959) made a less complex climatic calibration using data from small agricultural watersheds at Coshocton, Ohio. He showed that if the beginning of the water year is selected to occur during the most stable period of soil moisture content, change in soil moisture storage will be least between years and correlation between runoff and precipitation will be highest. At Coshocton, this period occurred towards the end of recharge in March.

Multiple-Watersheds

Striffler (1965) suggested a "multiple-watershed method" for evaluating the effects of forest disturbances on water and sediment yield from small mountain watersheds. The method was developed in an area where strip-mining has caused intense disturbances to varying proportions of a large number of diverse watersheds. Therefore, comparable watersheds in disturbed and undisturbed condition were not available. A large number of watersheds were selected so as to represent the range of all factors considered to affect the study parameters. These parameters, such as sediment yield, were then related by step-wise, multiple regression to the independent variables represented by all the watersheds. This method allows flexibility in selection of experimental areas, and results are applicable over broad regions.

Streamflow Timing

Schneider and Ayer (1961) used multiple regression techniques to detect a time trend in streamflow from a reforested watershed in central New York. Two sets of analyses were made, the first using climatic data and the second using runoff data from a control watershed. In both cases, time-since-treatment was included as an independent variable. Frequency analysis of flow data was rejected on the grounds that comparisons could only be visual, and that the time sequence of runoff could be as important as frequency and duration of flows arrayed by magnitude. For this reason, Satterlund and Eschner (1965), in analyzing data from the same study, used Court's (1962) half-flow dates and intervals, as measures of the time distribution of runoff. Wide variations in snowmelt timing and the occurrence of high flood peaks from rain necessitated the redefinition of the half-flow interval as the shortest period in which half the annual runoff occurred. The half-flow date was then the mid-point in flow of this interval. Quarter-flow intervals, similarly calculated, were also used to define the period of most concentrated runoff.

Multiple regression equations, with time as a significant independent variable, showed that snowmelt runoff had become more concentrated after reforestation. Total flow had decreased and so the ratio of the annual runoff from the treated and control watersheds was added to the regression. This did not explain any of the half-flow interval reduction.

In a similar study in the Adirondack Mountains of New York, Eschner and Satterlund (1966) correlated a slow improvement in forest cover with annual, seasonal, and monthly flows. A logarithmic transformation of time-since-treatment as one of the independent variables made a significant contribution to some regressions. Of the monthly regressions, only in April was time (transformed to the second power) significant. The increase in half-flow interval, and the decrease in total runoff, both time dependent, were indicative of an evening out of high flows with improving forest cover.

Troendle (1966) used both the shortest half- and quarter-flow intervals to determine the effects of four forest cutting treatments on streamflow timing at Fernow Experimental Forest. He concluded that the intervals may be lengthened or shortened depending on the intensity of cut. Further analyses, using the longest intervals for one percent and five percent of the annual runoff to occur, showed that harvesting had caused an increase in the general level of low flows. Although the half- and quarter-flow dates were not changed by treatment, the beginning dates of the one and five percent intervals were retarded. The degree of change was related to the volume of timber removed.

Flow-Duration

Searcy (1959) described the flow-duration curve as follows:

> The flow-duration curve is a cumulative frequency curve that shows percent of time specified discharges were equalled or exceeded during a given period. It combines in one curve the flow characteristics of a stream throughout the range of discharges without regard to the sequence of occurrence.

The usual method of constructing the flow-duration curve is to place all daily discharges in classes by magnitude, accumulate the time in each class starting with the highest, and calculate the percent of time flow is below the upper limit of each class. The flow-duration curve thus shows the integrated effect of the factors which affect runoff. A steep slope throughout the curve indicates a highly variable stream with flow largely from direct runoff, while a curve with a flat slope toward the lower end indicates considerable groundwater storage. Streams which derive a large part of their flow from snowmelt generally have flat slopes at the upper end of their flow-duration curve.

Searcy emphasizes that any flow-duration curve represents only the period of record from which it is derived. It should therefore be possible to use the curve to indicate changes in watershed conditions. Inspection of two curves drawn with data from before- and after-treatment periods may reveal changes but personal judgement and bias can invalidate conclusions.

A variability index, developed by Lane and Lei (1950), permits a numerical comparison of flow-duration curves. The index is the standard deviation of the natural logarithms of flows corresponding to the five percent level of time, and every ten percent thereafter to the ninety-five percent level.

The U. S. Geological Survey uses direct comparisons of the flows at the fifty and ninety percent of time levels in comparing the effects of geology on streamflow (Searcy, 1959). At the Coweeta Hydrologic Laboratory, North Carolina, the ratio of the flow for sixteen percent of the time to that at eighty-four percent of the time was used in preference to the standard deviation due to the inherent skewness of hydrologic data (Lieberman and Hoover, 1951). Flows at these levels and at the fifty percent level were compared before and after treatment. This type of analysis enables an estimate to be made of treatment effects on all levels of flow and conclusions can be drawn as to the physical processes involved.

Kunkle (1962), comparing the baseflow characteristics of streams, suggested the use of a baseflow-duration curve. This necessitates the separation of surface runoff from baseflow but "...although the separation may not be precise, the value of the technique as a comparative tool is not lost as long as a consistent method of separation is followed." If there is considerable bank storage at high flows, it will be reflected by a steep slope and a sharp break towards the upper end of the curve.

Analyses made by Reinhart (1966) at the Fernow Experimental Forest, West Virginia, involved prediction of the flow-duration curve from the calibration period conditions. Using the control watershed concept and each year's flow-duration curve, regressions were developed for several levels of flow, to predict the number of days per year each would be equalled or exceeded. A flow-duration curve predicted from the control watershed records, after treatment, can then be compared with the curve derived from observed values on the treated watershed. The probability of the length of each time interval occurring by chance can be calculated with this method.

Baseflow Recession Analysis

The baseflow-recession curve, or depletion curve, of a drainage basin represents the withdrawal of water from storage and can be described by a characteristic depletion equation:

$$q_t = q_0 K^t$$

in which q_t is the flow t time units after the flow q_o, and K is the recession constant and is less than unity (Linsley, Kohler, and Paulhus, 1958). If the time is one unit, then this equation simplifies to:

$$q_1 = q_o K$$

where q_1 is the flow one time unit after q_o. A graph of this relation will be a straight line with slope K. As the rate of outflow of water from storage depends on the characteristics of the drainage basin, it follows that the recession constant will be a basin characteristic. A change in the vegetative cover of the watershed could therefore result in a change in storage conditions and a change in the recession constant.

Vegetative Manipulation Effects on Streamflow

Considerable research effort has been made in this field. Results reported by Dils (1957), Brakensiek and Amerman (1960), Love and Goodell (1960), and many others, have provided some insight into the effects of vegetation on streamflow. In many cases it has been shown that forest cutting will increase water yield. The wide variation in the amounts of increase, however, suggests that specific recommendations for management must be developed in an area of comparable soil, vegetation, climate, and topography.

Of all the areas where this type of research has been conducted, the U. S. Forest Service Fraser Experimental Forest, Colorado, is probably most comparable to Little Beaver Creek. About three-fourths of the annual precipitation at Fraser falls as snow and is released as snowmelt in the late spring or early summer. Forests are composed of lodgepole pine (*Pinus contorta* Dougl.), Engelmann spruce (*Picea* engelmannii Parry), and subalpine fir (Abies lasciocarpa (Hook) Nutt). Alpine tundra vegetation or rock covers the high ridges and summits (Martinelli, 1964).

Earliest studies here were aimed at determining the effects of vegetative types on water equivalent of the snowpack. Love and Goodell (1960), reviewing some of these studies, reported that snowpack was least under dense pine forests, fourteen percent greater in open spaces within the forest, and thirty percent greater in stands of deciduous aspen.

The influence of natural forest openings, and intensity of forest cutting on snowpack was studied by Wilm and Dunford (1948). The water equivalent of the snowpack was least under dense pine forest and there was a linear increase in water content from the edge of the forest toward the center of the openings. In the intensity of cutting study the increase in water equivalent was generally proportional to the volume of timber removed. Snow disappeared from cut and uncut areas at about the same time indicating a faster melt rate in the cut areas due to less shading effects. Melt rates in group selection cut areas of spruce and fir forest were slightly lower than in the areas where thinning had been by individual tree selection (Love and Goodell, 1960). The increases in snow accumulation after cutting were attributed to decreased interception losses.

These studies showed that forest cutting would increase the water available for streamflow and the next step was to treat a whole watershed and measure the changes in water yield (Goodell, 1958). The 714-acre Fool Creek watershed with a cover of mature to over-mature forest was selected for treatment, calibrated, and one-half of the merchantable timber removed in alternate strips. In the first five years after treatment, there was an average increase in annual yield of 23.5 percent, mostly from an enlarged spring runoff. The snowmelt hydrograph began earlier and had a higher peak after treatment (Martinelli, 1964).

An outbreak of the Engelmann spruce beetle (*Dendroctonus engelmannii* Hopk.) on the White River Plateau, Western Colorado, in the early 1940s, killed approximately sixty percent of the trees on the White River Basin. A regression analysis comparing streamflow from this basin with an undamaged basin, showed an increase in water yield of approximately 25 percent from the damaged area (Love, 1955).

If the increases in streamflow in both these studies are attributed to the "treated" areas alone, they are about twice as great as the plot studies indicated. It therefore appears that both interception and transpiration losses were reduced by forest removal (Martinelli, 1964).

In the Fool Creek study, repeated snow surveys indicate that the total amount of snow on the watershed is the same as during the calibration period but its distribution has been changed. Hoover and Leaf (1966) report that observations during and after storms, show that although snow accumulates on foliage, it is soon removed by wind action and redeposited in adjacent openings. The streamflow increases are therefore attributed to increased rates of melt and more efficient delivery of water to stream courses and groundwater storage.

Previous Studies on Little Beaver Creek

As a subwatershed of the Little South Fork of the Cache la Poudre watershed, Little Beaver Creek is situated close to Fort Collins and so is convenient for studies conducted from Colorado State University. Within the last decade several studies have been conducted on and near the area and a brief review of the more pertinent follows.

In a study of the effects of glaciation on water yield, Hansen (1962) compared the physiographic and streamflow characteristics of Upper Little Beaver Creek (unglaciated) and nearby Fall Creek (glaciated). The short period of streamflow records precluded any specific conclusions, but observations and analyses showed that late-lying snowpacks in the glaciated watershed produced more evenly distributed runoff. Fall Creek had a higher total water yield but this was considered to be a result of higher precipitation rather than of glaciation. Suspended sediment contents of the two streams during summer runoff were similar.

Keller (1963) selected the Upper Little Beaver watershed for an investigation of the interrelationships of the ecology and hydrology of a mountain watershed. Eight stations on a transect across the watershed were used to locate plots on which measurements of soil, vegetation and topography were made. It was concluded that evapotranspiration on slopes of south-easterly aspect, and in stream bottoms, considerably diminished water yields. A water balance for the summer months showed that soil moisture depletion did not begin until August, and that potential evapotranspiration only slightly exceeded actual evapotranspiration. This is indicative of a humid climate and was attributed to summer snowmelt rather than high precipitation. Soils were considered to be permeable with a low moisture retention capacity. Detention storage was high, especially in the stream bottoms, and it was concluded that subsurface flow was the main form of water movement to channels.

Several studies have encompassed the whole Little South Fork watershed. According to Ollman (1965), there are definite cloud breeding areas in the watershed. Analyses of topography and cover characteristics of these areas showed that some cloud formation is likely to occur in the extreme headwaters of Little Beaver Creek. Although correlations were not high, it appears that some of these storms move in the direction of the general drainage pattern.

A multiple-use plan for the watershed was developed by Ritchey (1964). The Little Beaver subwatershed was considered to be largely suited for timber production, water production, and recreation. Conflicts among these uses were recognized and suggestions were made for maintaining recreation and water quality standards during proposed logging operations.

Chapter III

THE STUDY AREA

General

Forest cutting is to be carried out in the Little Beaver Creek watershed which is contained within the Little South Fork of the Cache la Poudre River. Situated on the northeast side of the Mummy Range, approximately 25 miles west of Fort Collins, the area is within the Roosevelt National Forest close to the northern boundary of Rocky Mountain National Park (Figure 1).

There are three watersheds suitable as controls: Fish Creek watershed immediately adjacent to Little Beaver Creek; the area above the Upper Little Beaver stream gage; and Fall Creek watershed five miles to the south. While the first of these is physically the most similar to Little Beaver Creek, its two years of streamflow records are not sufficient for derivation of precise prediction equations. Therefore, only the last two watersheds were tried as controls.

Topography and Geology

Little Beaver Creek watershed covers 11.4 square miles and is approximately three times larger than Fall Creek and thirteen times larger than Upper Little Beaver Creek. The area-elevation curves of the three watersheds (Figure 2) show further important differences. Upper Little Beaver Creek has the smallest elevation range with its

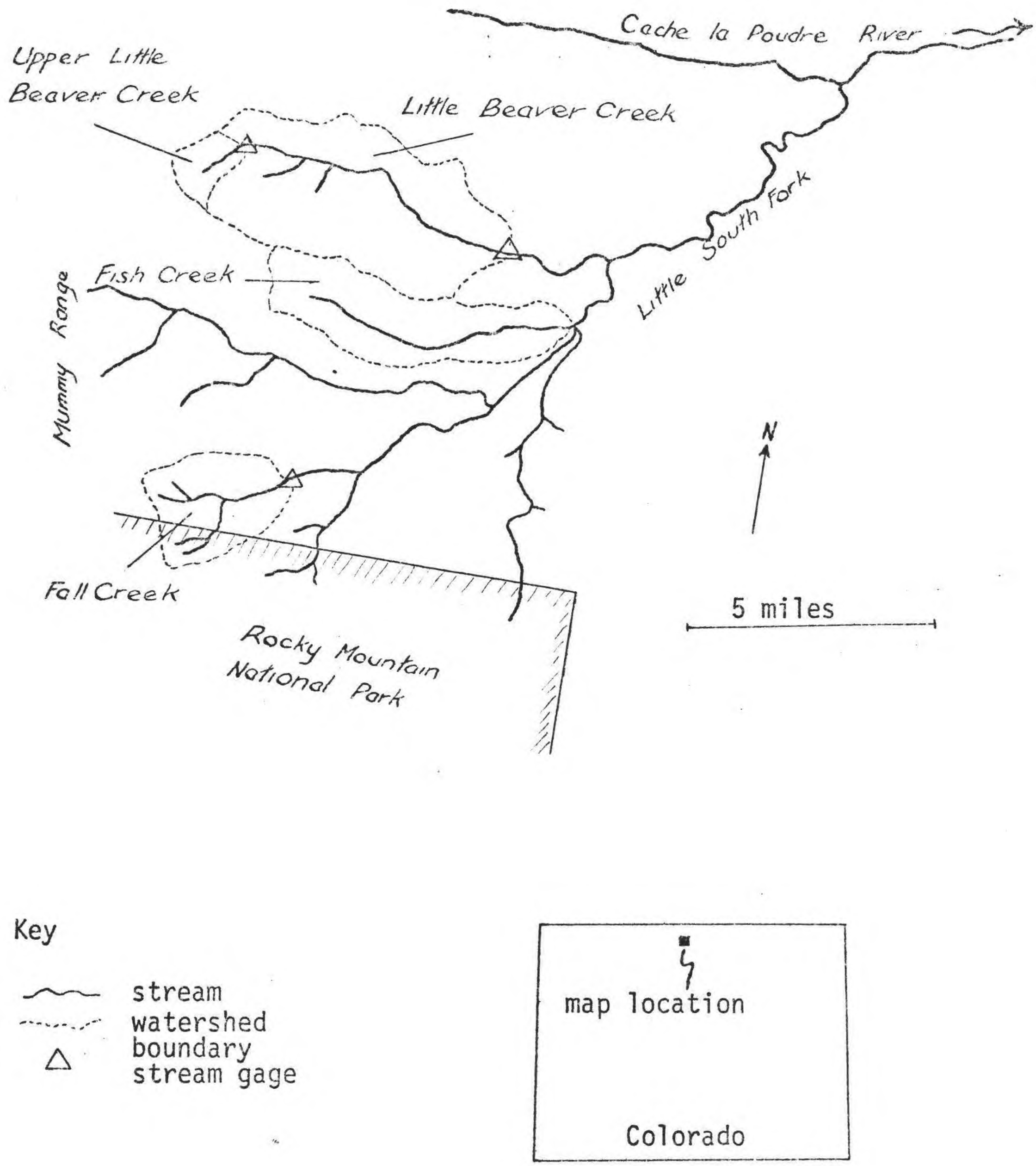

Figure 1. Location of the watersheds.

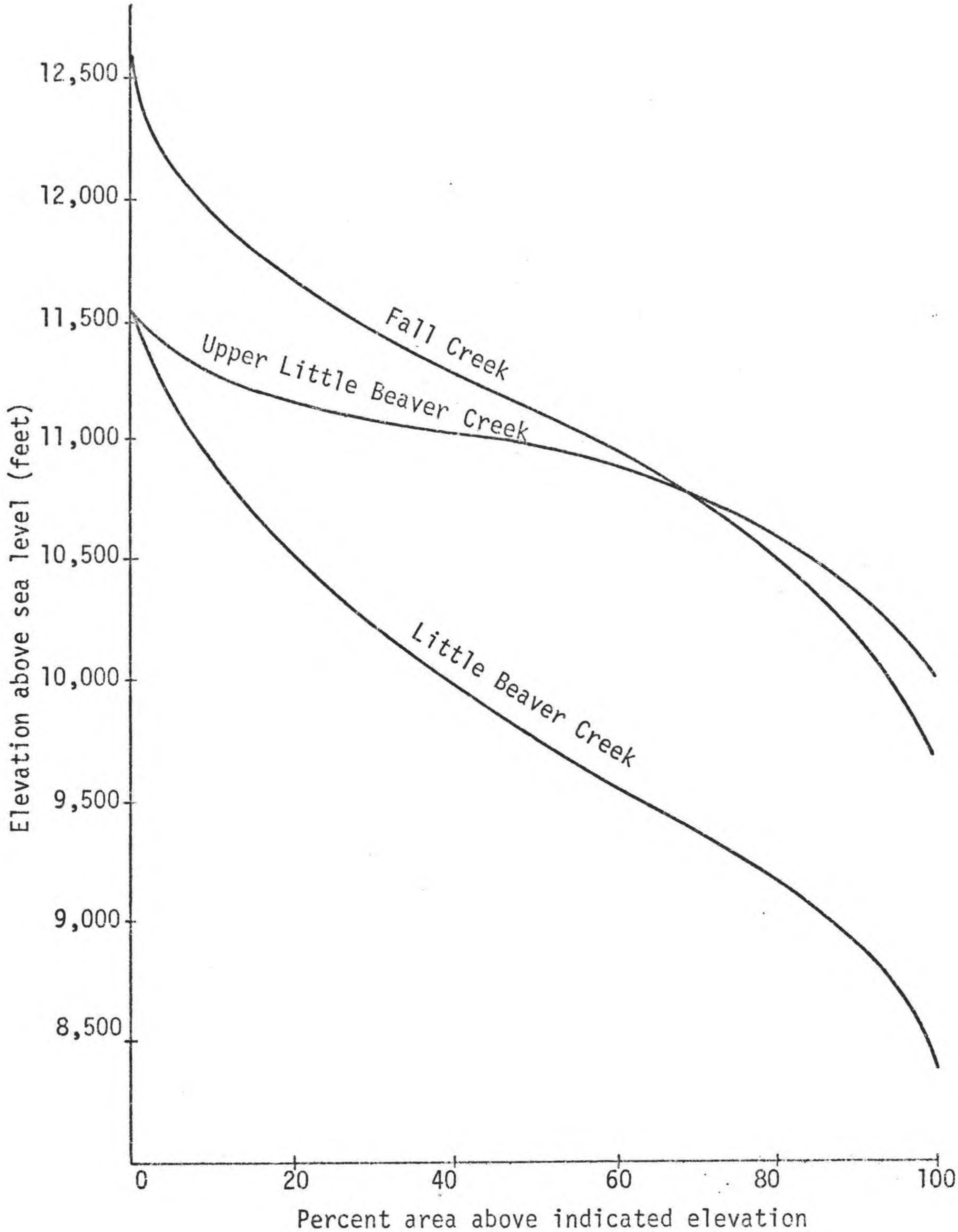

Figure 2. Area-elevation curves - Upper Little Beaver Creek, Little Beaver Creek and Fall Creek.

lowest point at 10,000 feet above sea level. Fall Creek and Little Beaver Creek have similar elevation ranges, but the former is approximately one thousand feet higher at all proportions of area. Salient topographic characteristics of the watersheds are summarized in Table 1.

Further contrasts were revealed in Hansen's (1962) analysis of the relief characteristics of Fall Creek and Upper Little Beaver Creek. Glaciation of the former has left cirques with steep headwalls, while Upper Little Beaver Creek has a broad V-shaped cross-section. Thus Upper Little Beaver Creek has an average land slope of 21 percent and an average stream channel slope of 18 percent. The corresponding parameters on Fall Creek are 39 percent and 9 percent, respectively. Aspects also differ, with Fall Creek having northeast and east facing slopes, and Little Beaver Creek having more slopes of south and southeast aspects.

The contact zone between Silver Plume granite and the older gneisses and schists of the Idaho Springs Formation occurs in Little Beaver Creek. Silver Plume granite is the main component of Fall Creek (Lovering and Goddard, 1960). These rocks, all of Pre-Cambrian age, weather slowly to produce coarse textured soils. Morainic deposits cover small but significant areas of Fall Creek and Hansen (1962), considered that some would be more than one hundred feet deep.

Soils and Vegetation

In an analysis of the Little South Fork watershed, Johnson (1963) classified soils and vegetation on the basis of three climate zones. The alpine zone lies above timberline at approximately 11,200 feet.

TABLE 1. TOPOGRAPHIC FEATURES OF LITTLE BEAVER CREEK, UPPER LITTLE BEAVER CREEK, AND FALL CREEK.

Watershed	Area miles^2	Maximum Elevation feet a.s.l.	Minimum Elevation feet a.s.l.	Median Elevation feet a.s.l.
Little Beaver	11.40	11,470	8,350	9,740
Upper Little Beaver	0.89	11,470	10,000	10,950
Fall Creek	3.64	12,700	9,765	11,130

Slopes are moderately rolling and soils are mostly shallow with imperfect drainage. Rock outcrops are common, especially on exposed ridges. Less than 10 percent of Little Beaver Creek, and approximately 40 percent of Fall Creek lie within this zone.

The subalpine zone extends from 9,000 feet to timberline and is almost entirely covered with spruce, fir, and lodgepole pine forests. The zonal soil of the area is a weakly-developed podzol but topography has caused wide variations in depth and drainage characteristics. Textures range from uniform sandy loam, to coarse gravelly sand on shallow sites.

The montane zone includes all areas below 9,000 feet, though scattered outcrops of the vegetation types may occur as high as 9,300 feet. Ponderosa pine and Douglas Fir are the dominant species with some areas of lodgepole pine. The coarse textured soils are shallow and generally well drained, though local peculiarities of topography have given rise to small areas of bog soils. Along stream bottoms and at lower altitudes, small areas of grassland are common. These are mostly associated with chernozem soils developed from deep alluvial deposits and are especially evident in Little Beaver Creek.

Keller (1963) made particle size analyses of several soil samples from a transect across the Upper Little Beaver watershed. His figures show the average water holding capacity to be approximately 17 percent by weight and he concluded that infiltration capacities and detention storage are high owing to the small amount of clay fraction. Furthermore, the most effective part of watershed detention storage was thought to be along stream bottoms in alluvial subsoils.

Climate

Weather of the Colorado Front Range is dominated by air mass movements from the north, west, and southeast. Cold fronts from the north commonly produce precipitation at low and mid-altitudes. Clear weather following their passage in summer produces convectional activity and thunderstorms. These last are responsible for most of the summer precipitation which is of high intensity but generally of short duration and limited areal extent. The coincidence of a cold front with the influx of warm moist air from the southeast causes widespread precipitation up to the continental divide. Greatest amounts from this source occur in the subalpine zone (Marr, 1961). Above 8,000 feet elevation, these weather patterns give rise to a climate of short, cool summers and long, cold winters with many snowfalls.

Johnson (1963) estimated the mean annual precipitation in the Little South Fork watershed as between 18 and 20 inches. On the basis of the water year from October 1st to September 30th, the Pingree Park rain gage measured an average of 21.45 inches per year from 1961 to 1966. From 1963 to 1966 the Quigley Mountain rain gage has received an annual average of 16.39 inches. At both stations approximately 40 percent of the annual precipitation occurs as snow between November 1st and April 30th. Mean annual and monthly precipitation data from the Pingree Park and Quigley Mountain gages are shown in Table 2.

Extrapolating limited data from a gage at 10,320 feet, Keller (1963) estimated precipitation to be 30.87 inches at this point for the 1961 calendar year. Further extrapolation of precipitation data is difficult owing to the wide range of topographic effects. However,

TABLE 2. MEAN ANNUAL AND MONTHLY PRECIPITATION AT QUIGLEY MOUNTAIN AND PINGREE PARK.

Period	Quigley Mountain Precipitation inches a/	Pingree Park Precipitation inches b/
October	0.44	0.79
November	0.40	0.84
December	0.79	1.36
January	0.84	1.33
February	0.71	1.35
March	1.26	1.47
April	2.24	2.52
May	1.31	2.29
June	2.44	2.63
July	1.84	2.62
August	2.07	2.30
September	1.88	2.15
Water year	16.39	21.48

a/1963-1966 average.

b/1961-1966 average.

Hansen (1962) considered that the orographic effect of the cirque headwalls in Fall Creek results in higher precipitation than in Little Beaver Creek.

Tabulations of Pingree Park wind velocity data by Johnson (1963) show that highest velocities occur during winter months. Higher velocities in the alpine zone cause considerable redisposition of snow into natural depressions and the subalpine forest.

Hydrology

Winter precipitation is mostly stored as snowpack. Rising temperatures in May and June produce a typical snowmelt cycle of runoff at all three stream gages. Annual runoff is thus concentrated in the snowmelt period with a peak occuring in early June. The steep recession following the peak is frequently interrupted by thunderstorm runoff during July and August. From October through May flow is low and steady.

Highest mean daily flow associated with snowmelt varies widely from year to year, being dependent on both the volume of water stored in the snowpack and the temperature regime during melt. During early snowmelt Fall Creek and Little Beaver Creek hydrographs are similar, showing approximately parallel responses to temperature changes. Peak flows are often coincident on the two watersheds, and on Fall Creek high flows may be maintained for up to three weeks before recession begins. On Little Beaver Creek the steeper recession begins soon after the peak.

High concentration of annual runoff is illustrated by Fig. 3 showing the percentage of the mean annual runoff occurring in each month on Little Beaver Creek and Fall Creek. The average length of the shortest interval for half the annual yield to pass the lower Little Beaver gaging station is 46 days.

Between 1961 and 1966 annual water yield from Little Beaver Creek ranged from 5 to 12 area inches. Similar variations occurred on Fall Creek with a range from 16 to 31 area inches.

Instrumentation

Climatic Stations

As streamflow records are available for the 1961 through 1966 years, climatic stations having continuous records over the same period are desirable. Colorado State University maintains climatic stations within the Little South Fork watershed at Pingree Park and Quigley Mountain. While the latter station is closer to the study area, its records begin in June 1962 and so the Pingree Park station with continuous records from 1960 was preferred. Automatic recording instruments measure temperature, humidity, and precipitation at both stations.

Since snowfalls on the Little South Fork watershed are generally the result of widespread storms, the Pingree Park precipitation records are considered to be a reliable index of winter precipitation on Little Beaver Creek. Thunderstorms are too localized to permit good correlations of summer rainfall records from this gage with runoff from Little Beaver Creek.

Sheep Saddle snow course was established by the Colorado State University Cooperative Watershed Management Unit in 1961. It is located in timber, close to the ridge above the Upper Little Beaver

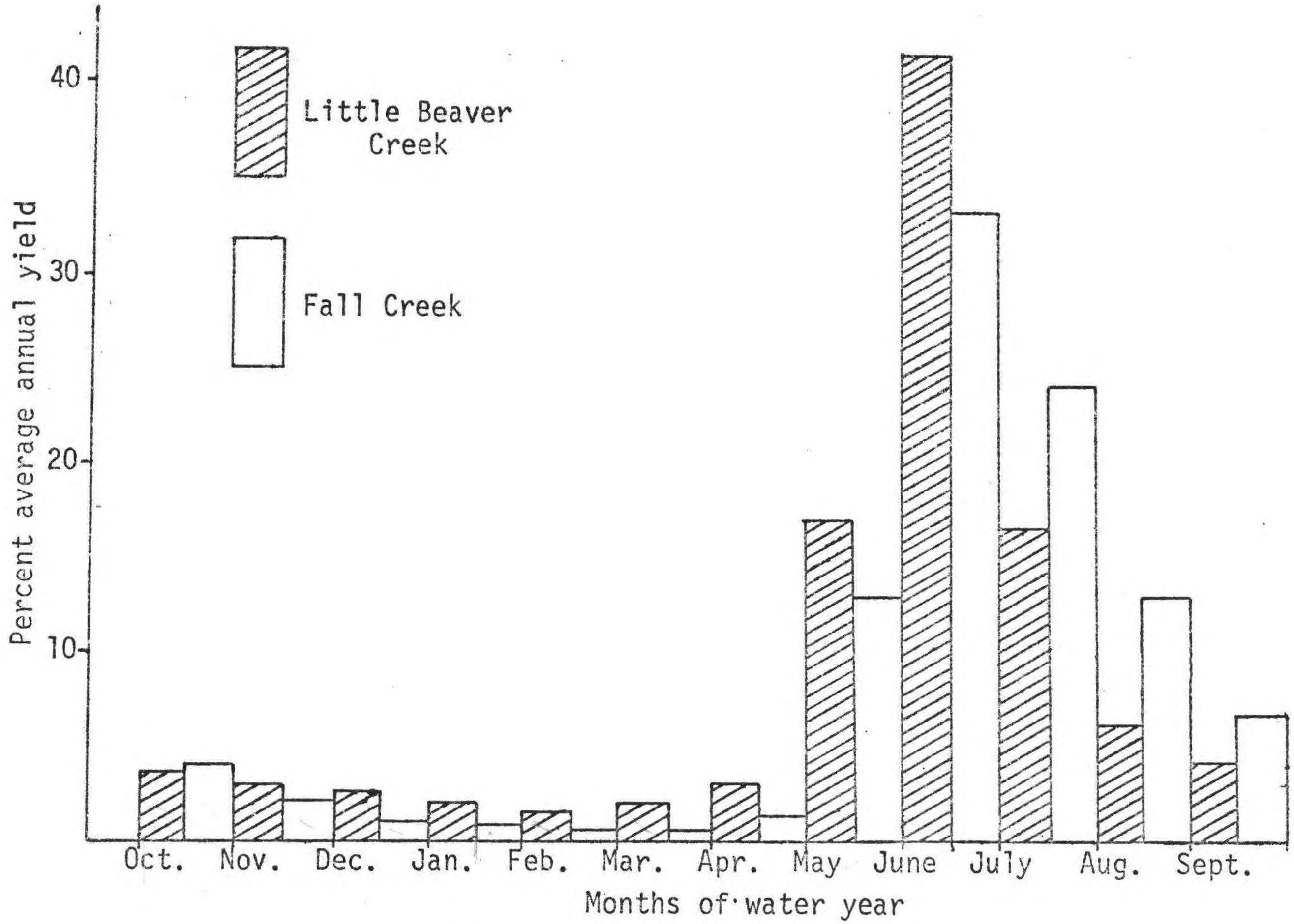

Figure 3. Average monthly water yields - Little Beaver Creek and Fall Creek.

stream gage. Snow measurements made on or near the beginning of each winter month are representative of snow accumulation in the subalpine zone.

Stream Gaging Stations

The three stream gages, from which data for this study were taken, are maintained and operated by the U. S. Geological Survey. All employ gas purged, servomanometer systems which give continuous records of stage, and their control sections are covered and heated in winter to prevent icing. Their accuracy is rated as good with 95 percent of the mean daily discharge records considered to be within 10 percent of the true values.

Both gages on Little Beaver Creek employ artificial controls: a Parshall flume for high flows and a V-notch weir for low flows at the upper gage; and a broad-crested weir sixteen feet wide at the lower gage. A stable reach on morainic material provides a natural control for the Fall Creek gage.

Chapter IV

METHODS OF ANALYSIS

General

The methods used in this study, with two exceptions, involve the derivation of prediction equations for the various streamflow parameters on Little Beaver Creek. In some cases several control variables were investigated to determine the most precise prediction. Tables 3 and 4 at the end of this chapter summarize the prediction relationships used.

Data Reduction

Most of the necessary data for this study were available in reduced form. All variables involving streamflow were derived from annual compilations of Colorado surface water records (U. S. Geological Survey, 1962; 1963; 1964; 1965; 1966; 1967). Monthly and annual summaries of requisite precipitation data were obtained from the files of the Department of Outdoor Recreation and Watershed Resources at Colorado State University. Field sheets from the same source were used to compile monthly averages of water equivalent at Sheep Saddle snow course. Basic data are shown in Tables A to E of the Appendix.

Water Yield

Mass curves and prediction equations derived by least squares linear regression were the two methods used to determine whether Little Beaver Creek is calibrated with regard to water yield.

Annual volumes of water yield, in area inches, from Little Beaver Creek were accumulated from 1961, and plotted against time. Concurrent precipitation data from Pingree Park were similarly plotted and both curves inspected for linearity. A double mass curve of these two variables was then made to determine if a consistent relationship existed between precipitation and runoff.

A second double mass curve with annual accumulations of runoff from Little Beaver Creek plotted against concurrent data from Fall Creek was similarly used.

Prediction equations for water yield were derived using two types of control variable: streamflow data from similar watersheds, and indices of water available for streamflow on Little Beaver Creek. In all cases some form of the Lower Little Beaver stream gage data provided the dependent variable.

The catchment of the Upper Little Beaver stream gage is outside the proposed timber cutting area and is therefore suitable for a control. The Lower Little Beaver stream gage also measures water from this area and so, in this case, the dependent variables are the differences in flow volumes measured at the two gages. Fall Creek water yields were regressed on the corresponding volumes of water actually measured at the Lower Little Beaver stream gage.

Prediction equations were derived for monthly, seasonal, and annual water yield for each case of the control variable. The only season used is the snowmelt period from May 1st to July 31st.

Two measures of precipitation, as indices of water available for runoff, were used as control variables. Monthly and annual data from the Pingree Park precipitation gage were correlated with concurrent runoff data while precipitation in the months November through April was used to predict both seasonal and annual yields.

Measurements of water equivalent in the snowpack are made at Sheep Saddle snow course on or near the beginning of February, March, April, and May each year. Four prediction equations (for snowmelt and annual water yield) were derived with each month's measurements as the control variable. To improve correlations, the average of all four measurements was then used as the control. Further averages, deleting February and March measurements successively, were also tried.

In all analyses the regression coefficient was tested to determine whether it was different from zero at the 5 percent significance level. The residual variances, from snowmelt and annual yield regressions with significant coefficients, were used to solve the "calibration equation." This relationship was adapted by Kovner and Evans (1954) to the form:

$$s^2_{y.x}/d^2 = n_1 n_2/F(n_1 + n_2)\,[1 + F/(n_1 + n_2 - 2)]^{-1}$$

where $s^2_{y.x}$ is the residual variance about the regression line; d is the smallest acceptable difference in the dependent variable due to treatment; n_1 and n_2 are the lengths of the before- and after-treatment periods in years; and F is the variance ratio with one and $(n_1 + n_2 - 2)$ degrees of freedom at any desired significance level.

With a significance level of 5 percent, the only unknowns are n_1, n_2, and the smallest detectable difference (d). It can be expected that regrowth after forest cutting on Little Beaver Creek will eventually nullify any water yield responses. Thus n_2, the observation period after treatment, was set at six years. The calibration equation was then solved for d with several values of n_1, the length of the calibration period. Values of d obtained in this way are the smallest changes in water yield that would be detectable at the 5 percent significance level.

High Flow

Inspections of annual hydrographs of Fall Creek and Little Beaver Creek reveal that peak flows are the result of snowmelt or rainfall. Most of the latter are associated with thunderstorms in summer and early fall months. The localized effects of these storms precludes any correlations between watersheds, or between measured rainfall and runoff.

Accordingly, the only analysis of peak flows was made on those associated with snowmelt. Annual peak mean daily discharges in cubic feet per second per square mile (csm), from the Fall Creek and Lower Little Beaver stream gages were correlated, with the former as controls. Upper Little Beaver data were also used as control variables to predict peak flows at the lower gage. Separations of data to obtain discharges due to the area between the gages were not made as time-of-travel from the upper to the lower gage was not known.

Low Flow

The longest continuous period for a proportion of the annual flow volume to pass the stream gage was used as a measure of the low flow conditions of a watershed for that year. Five percent of annual yield was chosen because on Fall Creek and Little Beaver Creek, the period for it to pass the stream gage is generally contained within one water year. The lengths of the period each year were calculated from mean daily flow records for the two watersheds and a regression analysis made with Fall Creek as the control.

A second measure of low flow is the total number of days that mean discharge is below a given level in each water year. Selection of the discharge level requires some judgment, however, if the number of days is to be indicative of low flow conditions for the year.

A table was constructed of the number of days in each water year that discharge was below levels from 0.10csm to 1.35csm in increments of 0.05csm. This showed there was little variation between years when the flow level used exceeded 0.25csm. Therefore, prediction equations for Little Beaver Creek were derived using Fall Creek data as controls, for the number of days corresponding to 0.10, 0.15, 0.20, and 0.25csm. The calibration equation was solved for the regression with the highest correlation coefficient.

Timing of Runoff

The annual runoff pattern on Little Beaver Creek is dominated by snowmelt. Management practices to modify water yield are aimed primarily at this section of the hydrograph, and therefore its timing is important. The date of occurrence of the peak flow on Little Beaver Creek was selected as a measure of timing of runoff and correlated with the date of the peak on Fall Creek. April 1st was used as the base date, as flow is normally at, or near its annual minimum at this time and the peak flow invariably occurs later.

Court (1962) considered that his half flow date was a better measure of timing than the peak flow date because it is dependent on the flow regime throughout the year. This parameter was calculated for each year using April 1st as the base date and prediction equations for Little Beaver Creek derived.

Concentration of flow in time is a further measure of its timing. The half flow interval defined by Court, is dependent on flow conditions up to the time of quarter flow as well as the snowmelt period. The shortest half flow interval, however, by definition always includes the most sustained period of high flow. The lengths of both intervals were calculated and correlations made between Fall Creek and Little Beaver Creek with the former as the independent variables.

Flow-Duration

To construct flow-duration curves, mean daily flows were grouped by increments of 2 cubic feet per second (cfs). The number of days in each interval was determined and a curve drawn to show the percent of time the upper limit of each interval was equalled or exceeded. Flow-duration curves for both watersheds for the period October 1961 to September 1966 were constructed and compared.

Six annual flow-duration curves for Little Beaver Creek and Fall Creek were drawn and discharges corresponding to percents of time from 5 percent to 95 percent at 10 percent intervals were read off each. Prediction equations for the discharge at each percent of time were derived with Fall Creek as the control.

Recession Analysis

A composite groundwater depletion curve for Little Beaver Creek was constructed by the method described by Johnson and Dils (1956).

Sections of the hydrograph when flow was derived from groundwater were fitted together to give a curve applicable over a wide range of flows.

In logarithmic form, the relationship assumed to describe the groundwater recession is:

$$\log q_t = \log q_o + t \log K$$

Thus a graph of $\log q_t$ against time is a straight line, and so a least squares line was fitted through the points of the recession curve plotted in this manner. The slope of this line is the logarithm of the recession constant (K).

Integration of the recession curve over time gives the volume of groundwater storage. By successively evaluating this integral over increasing time intervals on the derived recession curve, the volume of storage was found at several values of time. On the derived curve discharge is time dependent and so a graph of discharge versus volume of groundwater storage was constructed for Little Beaver Creek.

TABLE 3. SUMMARY OF PREDICTION RELATIONSHIPS DERIVED FOR WATER YIELD ON LITTLE BEAVER CREEK.

Predicted Variable	Control Variables Investigated
Annual Yield	Annual Yield Data:
	Upper Little Beaver Creek
	Fall Creek
	Precipitation Data:
	Pingree Park Annual
	Pingree Park November - April
	Sheep Saddle Snow Course Data:
	February - May Average
	March - May Average
	April - May Average
Snowmelt Yield	Snowmelt Yield Data:
	Upper Little Beaver Creek
	Fall Creek
	Precipitation Data:
	Pingree Park November - April
	Sheep Saddle Snow Course Data:
	February
	March
	April
	May
	February - May Average
	March - May Average
	April - May Average
Monthly Yields	Monthly Yield Data:
	Upper Little Beaver Creek
	Fall Creek
	Precipitation Data:
	Pingree Park all months

TABLE 4. SUMMARY OF PREDICTION RELATIONSHIPS DERIVED FOR STREAMFLOW PARAMETERS ON LITTLE BEAVER CREEK.

Flow Characteristic	Predicted Variable	Control Variables Investigated
High Flow	Snowmelt Peak	Snowmelt peak on: Upper Little Beaver Creek; Fall Creek
Low Flow	Longest interval for 5 percent of the annual yield to pass the gage	Corresponding interval on Fall Creek
	Number of days with discharge below 0.10, 0.15, 0.20 and 0.25csm	Corresponding data on Fall Creek
Timing of Runoff	Date of Peak	Fall Creek peak date
	Half Flow Date	Fall Creek half flow date
	Court's Half Flow Interval	Fall Creek half flow interval
	Shortest half flow Interval	Fall Creek shortest half flow interval
Flow Duration	Discharge corresponding to ten percents of time	Corresponding data on Fall Creek

Chapter V

RESULTS AND DISCUSSION

Water Yield

Mass curves of both annual precipitation and annual water yield against time are shown in Figure 4. Although precipitation accumulates the faster, similar changes in slope on both curves are generally concurrent. This is substantiated by Figure 5, in which the two variables are plotted against each other. The double mass curve, while not completely linear, does show a fairly consistent relationship. An exception is evident in the 1962 water year. Precipitation is less than in 1961, but water yields in the two years are similar. Monthly precipitation records show that most of the decrease in the 1962 annual precipitation occurred in the months April to September. Winter precipitation in the two years differed by only 0.52 inches. Thus the larger water input in 1961 occurred during the growing season and contributed little to streamflow.

The double mass curve of annual yields from Little Beaver Creek against those from Fall Creek shows a comparatively stable relationship (Figure 6). The short period of record, however, precludes the derivation of a precise estimate of the constant of proportionality between the two variables.

Statistics from regression analyses with Upper Little Beaver Creek and Fall Creek providing the independent variable are shown in

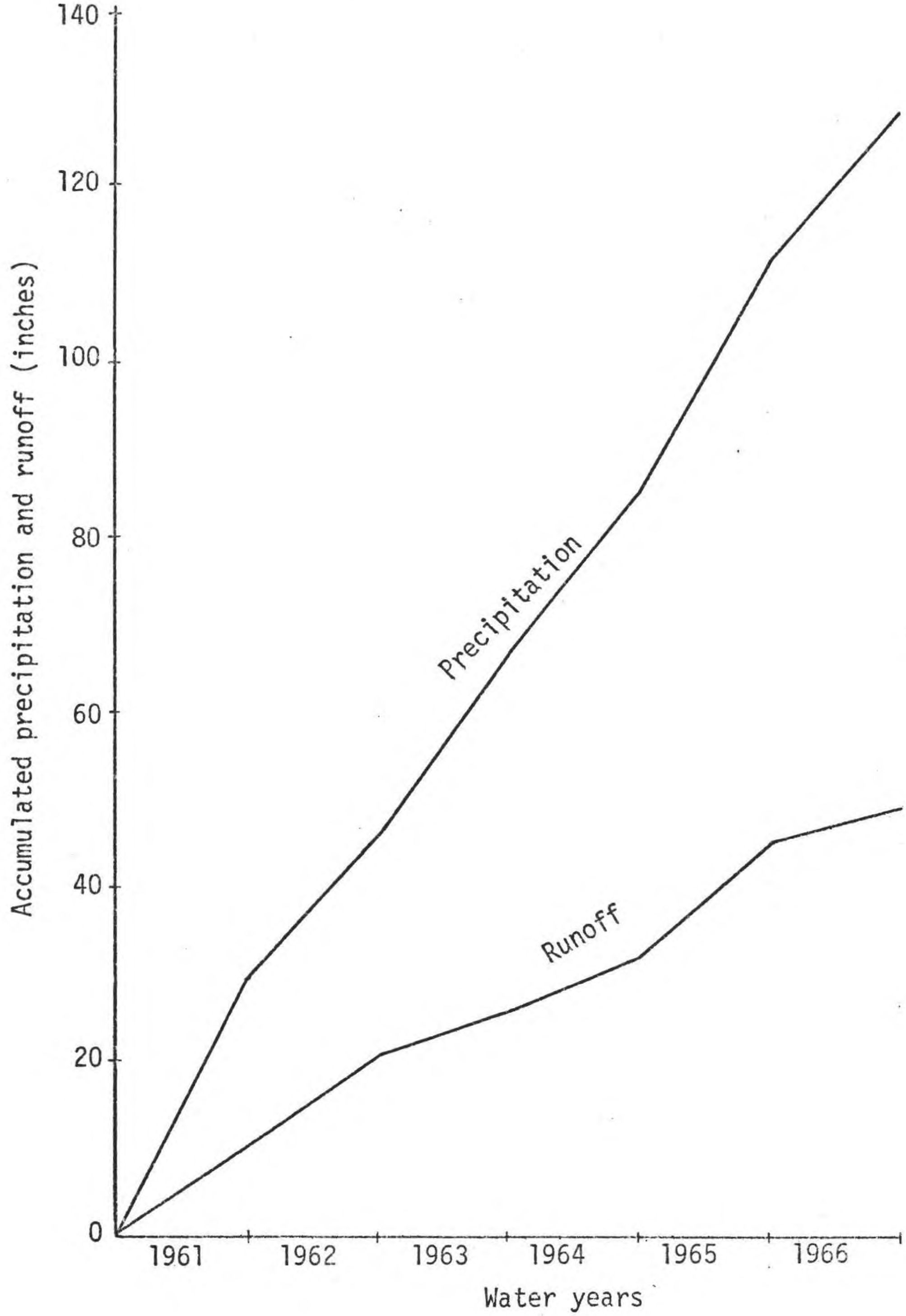

Figure 4. Mass curves of Little Beaver Creek annual runoff and Pingree Park precipitation 1961 - 1966.

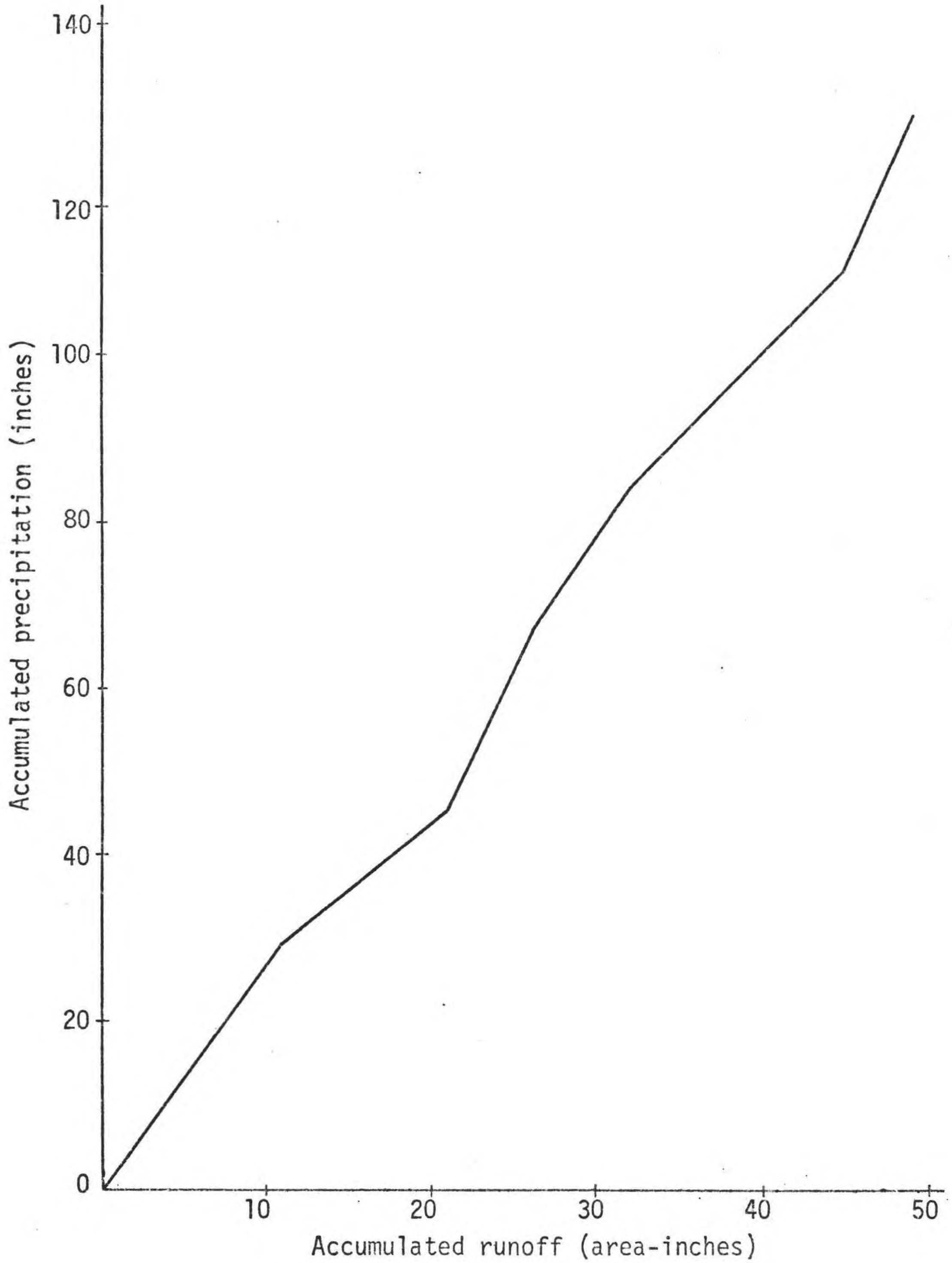

Figure 5. Double-mass curve of Little Beaver Creek annual runoff versus Pingree Park precipitation 1961 - 1966.

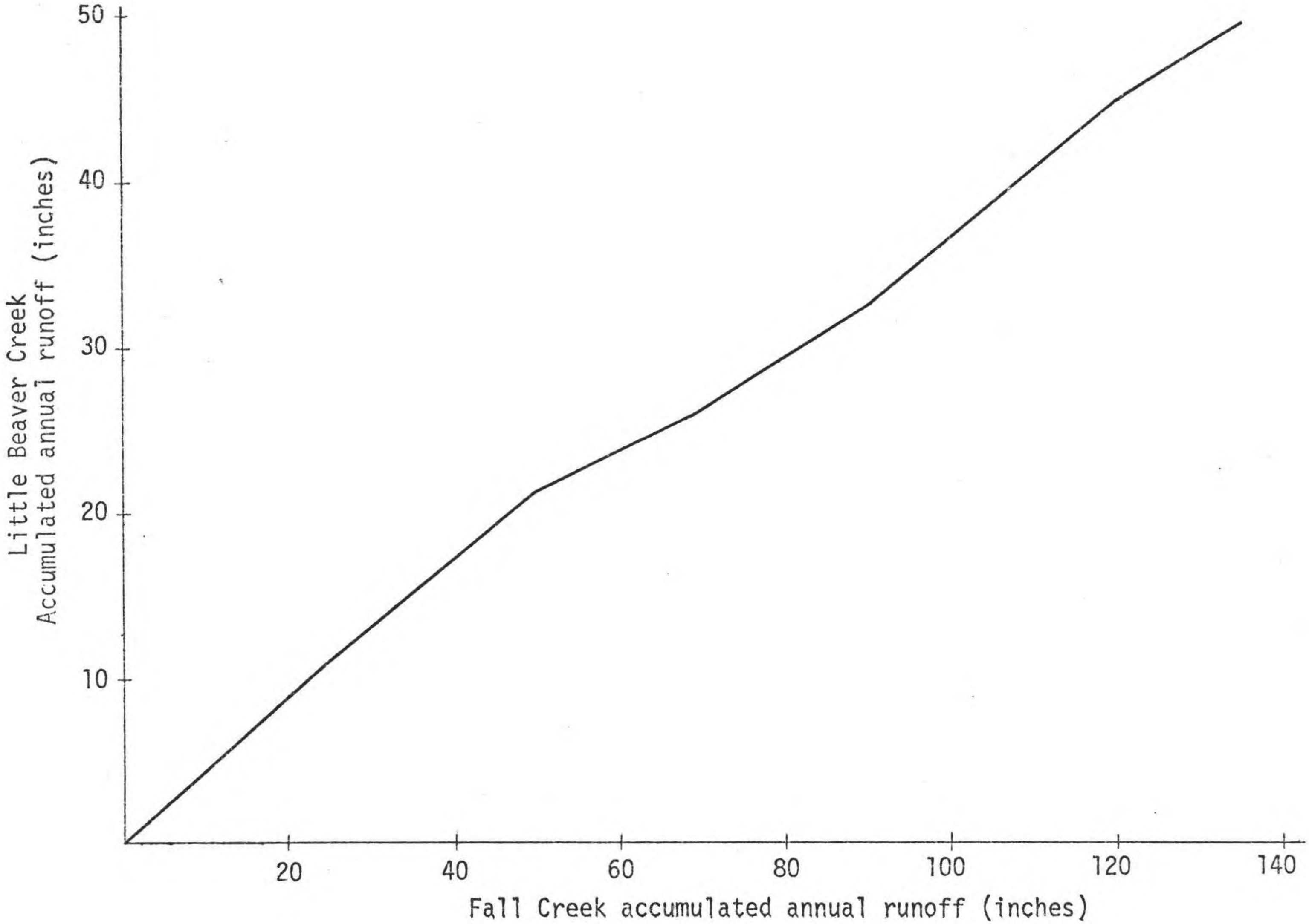

Figure 6. Double-mass curve of annual runoff - Little Beaver Creek versus Fall Creek.

Tables 5 and 6 respectively. In the analyses of the twelve monthly water yields, the latter control gives a larger number of regression coefficients significantly different from zero. As Upper Little Beaver Creek is higher than the area between the two gages on Little Beaver Creek, snowmelt is not synchronized. Thus water yields in May and August in particular, are poorly correlated. The elevation range of Fall Creek is similar to that of Little Beaver Creek and so snowmelt is more likely to begin concurrently.

In both cases of the control, prediction equations for snowmelt and annual water yield have significant regression coefficients and approximately 85 percent of the variation in the data is accounted for by the linear relationships. Standard errors of estimate for all four equations are between 0.51 and 0.75 inches.

When values for the independent variable were taken from Pingree Park precipitation records, none of the regression coefficients was significantly different from zero (Table 7). Negative coefficients in the case of some months are the result of storage of winter precipitation and the limited areal extent of summer thunderstorms.

Results of regression analyses with Sheep Saddle snow course data as controls are shown in Table 8. Where measurements made in individual months were used as controls only 64 percent of the data variation is explained and no regression coefficients are significant. The three averages of snow course data all gave significant regression coefficients when correlated with either snowmelt yield or annual yield. Higher correlation coefficients for the equations predicting annual yield were unexpected as snow course data were considered to be indices

TABLE 5. REGRESSION RESULTS - ANNUAL, SEASONAL, AND MONTHLY WATER YIELD - THE AREA BETWEEN THE UPPER AND LOWER LITTLE BEAVER GAGES VERSUS UPPER LITTLE BEAVER CREEK FOR 1961-1966.

Period of Water Yield	Regression Coefficient b	Intercept a	Correlation Coefficient r	Residual Variance	Variance Ratio a/ "F"
October	0.43	0.06	0.99	0.0002	346.2*
November	0.28	0.10	0.92	0.0012	21.9*
December	0.24	0.13	0.69	0.0023	3.7
January	0.27	0.11	0.74	0.0010	4.9
February	0.26	0.09	0.63	0.0007	2.7
March	0.53	0.09	0.75	0.0008	5.3
April	1.55	0.12	0.57	0.0149	1.9
May	-0.19	1.81	-0.36	0.2546	0.6
June	0.87	-0.30	0.96	0.4519	50.7*
July	0.33	-0.06	0.94	0.0696	28.8*
August	0.42	0.04	0.81	0.0081	7.6
September	0.68	-0.08	0.92	0.0017	22.9*
Snowmelt Season	0.82	-4.18	0.93	1.5749	25.9*
Water Year	0.88	-6.06	0.89	3.3566	15.6*

a/Tests whether the regression coefficient differs from zero.
*Indicates a significant difference at the 5 percent level.

TABLE 6. REGRESSION RESULTS - ANNUAL, SEASONAL, AND MONTHLY WATER YIELD - LITTLE BEAVER CREEK VERSUS FALL CREEK FOR 1961-1966.

Period of Water Yield	Regression Coefficient b	Intercept a	Correlation Coefficient r	Residual Variance	Variance Ratio a/ "F"
October	0.23	0.07	0.91	0.0027	20.5*
November	0.43	0.03	0.97	0.0006	67.5*
December	0.43	0.09	0.87	0.0012	12.9*
January	0.40	0.08	0.70	0.0013	3.9
February	0.58	0.05	0.79	0.0005	6.6
March	1.23	-0.02	0.95	0.0002	36.5*
April	0.56	0.07	0.98	0.0007	109.2*
May	-0.17	1.88	-0.19	0.2842	0.2
June	0.70	-1.86	0.93	0.8474	24.7*
July	0.33	-0.49	0.93	0.0982	25.0*
August	0.22	-0.15	0.87	0.0059	12.9*
September	0.16	0.07	0.88	0.0027	13.8*
Snowmelt Season	0.53	-2.36	0.83	3.3289	8.7*
Water Year	0.60	-5.23	0.93	1.7749	26.5*

a/Tests whether the regression coefficient differs from zero.
*Indicates a significant difference at the 5 percent level.

TABLE 7. REGRESSION RESULTS - ANNUAL, MONTHLY, AND SEASONAL WATER YIELD - LITTLE BEAVER CREEK VERSUS PINGREE PARK PRECIPITATION FOR 1961-1966.

Period of Water Yield	Regression Coefficient b	Intercept a	Correlation Coefficient r	Residual Variance	Variance Ratio a/ "F"
October	-0.01	0.30	-0.09	0.0164	0.0
November	0.06	0.18	0.19	0.0096	0.2
December	-0.05	0.26	-0.46	0.0041	1.1
January	-0.01	0.17	-0.22	0.0025	0.2
February	0.04	0.07	0.53	0.0009	1.6
March	-0.04	0.20	-0.76	0.0008	5.6
April	-0.02	0.29	-0.18	0.0182	0.1
May	0.08	1.20	0.37	0.2542	0.6
June	0.58	2.02	0.28	5.6131	0.3
July	-0.19	1.78	-0.15	0.6966	0.1
August	0.00	0.49	-0.01	0.0252	0.0
September	0.05	0.20	0.67	0.0065	3.3
Snowmelt b/	1.05	-3.17	0.78	4.9456	6.1
Water Year b/	1.04	-0.87	0.74	6.1186	4.8
Water Year c/	0.38	1.70	0.61	8.4549	2.4

a/Tests whether the regression coefficient differs from zero. *Indicates a significant difference at the 5 percent level.

b/Versus November - April precipitation.

c/Versus annual precipitation.

TABLE 8. REGRESSION RESULTS - ANNUAL AND SEASONAL WATER YIELD - LITTLE BEAVER CREEK VERSUS SHEEP SADDLE SNOW COURSE DATA FOR 1961-1966.

Snow Course Measurement a/	Regression Coefficient b	Intercept a	Correlation Coefficient r	Residual Variance	Variance Ratio b/ "F"
February	0.78	1.44	0.62	6.473	2.5
March	0.86	-1.46	0.79	3.879	6.9
April	0.82	-2.14	0.81	3.662	7.5
May	0.45	1.81	0.80	3.811	7.1
Feb-May Average	0.85	-1.15	0.85	2.847	10.8*
Mar-May Average	0.78	-1.24	0.88	2.465	13.1*
Apr-May Average	0.65	-0.26	0.85	2.493	12.4*
Feb-May Avge c/	1.00	-0.04	0.89	2.317	18.4*
Mar-May Avge c/	0.96	-0.67	0.95	0.990	49.6*
Apr-May Avge c/	0.72	1.43	0.84	3.203	11.9*

a/Water equivalent at or near beginning of indicated month.

b/Tests whether regression coefficient differs from zero.
*Indicates a significant difference at the 5 percent level.

c/Dependent variable is annual water yield.

of water available for runoff during snowmelt. However, there is considerable rainfall in June and July when soils are at or near saturation. This water therefore contributes to streamflow, but is not included in snow course measurements. In the full length of the water year, this effect is masked and a greater percentage of the variation in water yield is explained by linear regression.

Of all equations to predict annual water yield, the most precise uses the average of March, April and May snow course measurements as the control. The regression used to derive this equation has a correlation coefficient of 0.95 and a standard error of estimate of approximately 0.41 area inches of water yield.

Solutions of the calibration equation obtained using statistics from the significant regressions involving snowmelt yield and annual yield are shown in Figures 7 and 8 respectively. A significance level of 5 percent and an assumed value of 6 years for the observation period after treatment were used. In the family of curves for each case of water yield, each curve represents a particular control variable. The shapes of the curves are such that decreasing the detectable change in water yield requires a disproportionately large increase in the length of the calibration period.

Hence, while a 50 percent change in snowmelt yield could be detected with 6 years of calibration data, more than 20 years of data would be necessary to detect a 20 percent change regardless of the control variable selected. For annual water yield the situation is more favorable. With the average of March, April, and May snow course data as the control, a 20 percent change in yield could be detected with

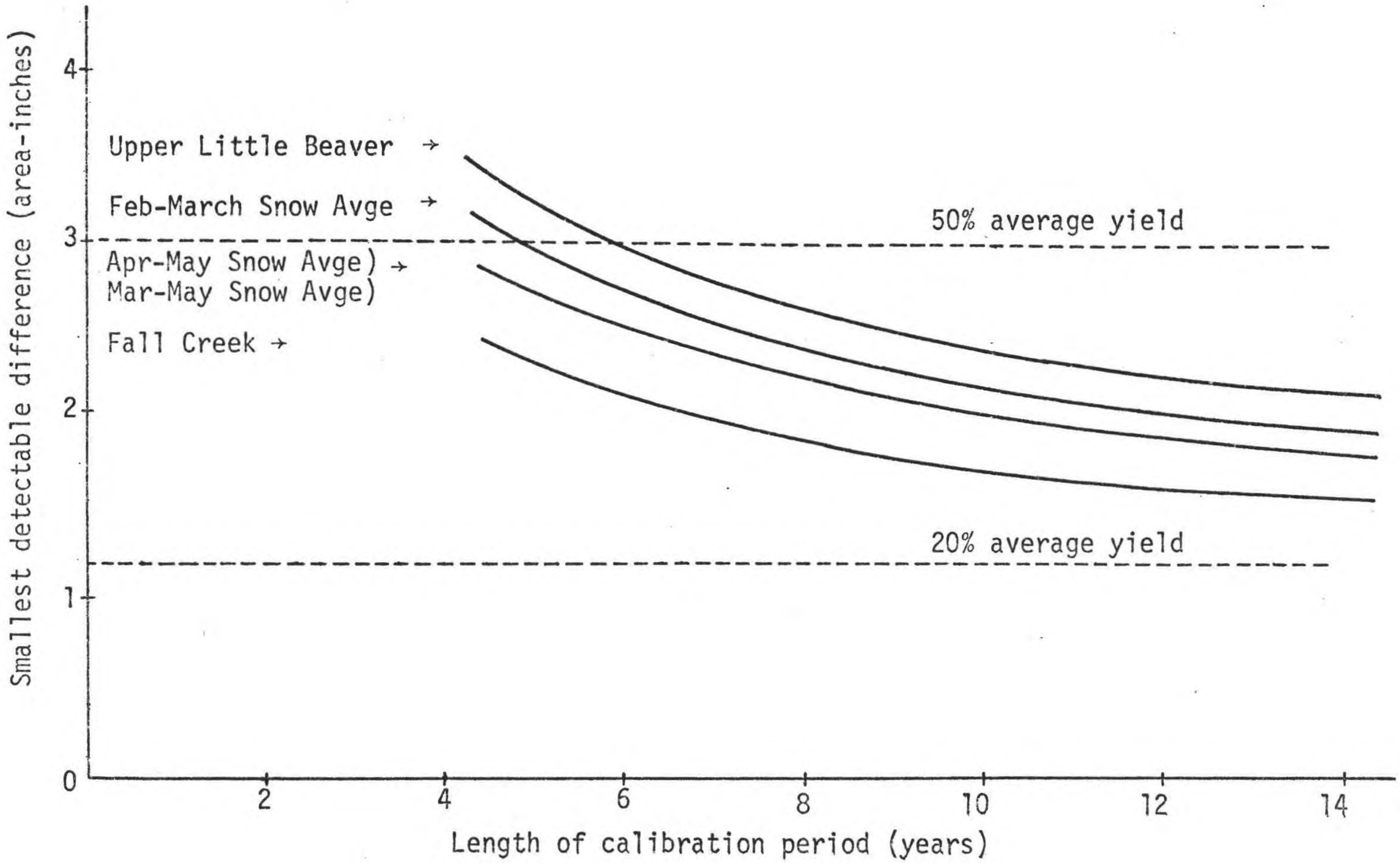

Figure 7. Variation of the smallest detectable difference in snowmelt yield with length of the calibration period.

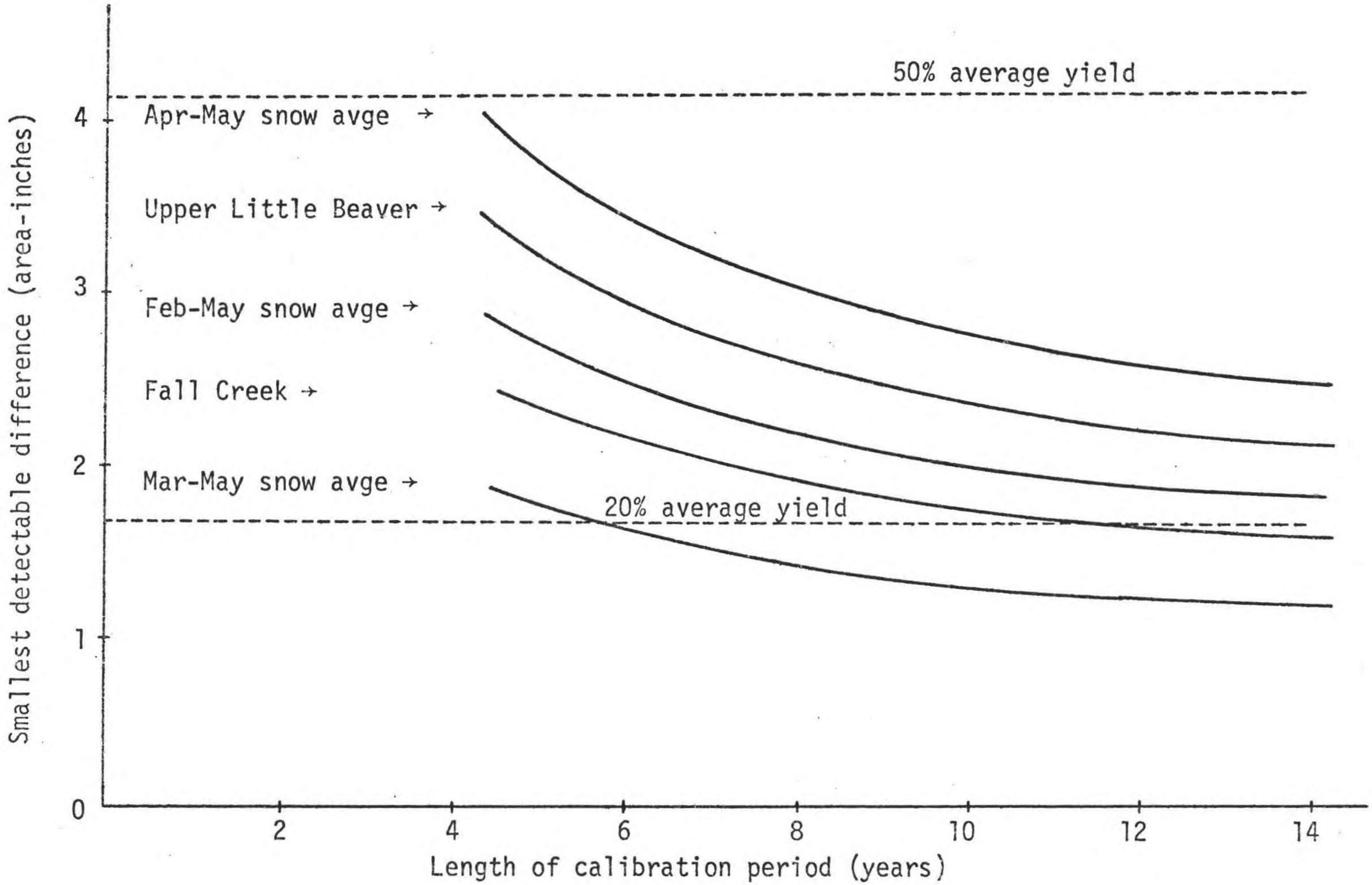

Figure 8. Variation of the smallest detectable difference in annual yield with length of the calibration period.

the 6 years of before-treatment records already available. Eleven years of record are required to detect the same change if Fall Creek is the control.

Changing the significance level from 5 to 10 percent doubles the probability of erroneous conclusions, but also decreases the smallest detectable difference by the ratio of the square roots of the respective F values. This ratio is approximately 25 percent for all control variables with a given length of the calibration period.

High Flow

Results from the two regression analyses made on peak flows are shown in Table 9.

TABLE 9. REGRESSION RESULTS - PEAK FLOWS - LITTLE BEAVER CREEK VERSUS FALL CREEK, AND UPPER LITTLE BEAVER CREEK FOR 1961-1966.

Control Variable	Regression Coefficient b	Intercept a	Correlation Coefficient r	Residual Variance	Variance Ratio a/ "F"
Upper Little Beaver	0.85	-3.32	0.94	2.6	31.8*
Fall Creek	0.64	-1.52	0.94	2.6	32.5*

a/Tests whether the regression coefficient differs from zero.
*Indicates a significant difference at the 5 percent level.

The regression coefficients are significantly different from zero with both control variables. Approximately 88 percent of the variation in peak flows is accounted for by each regression but residual variances are high. More than 20 years of calibration data would be required to detect a 20 percent change in the peak mean daily flow on Little Beaver Creek with either Fall Creek or Upper Little Beaver Creek as the control. Available data would permit detection of a 50 percent change in the peak significant at the 5 percent level.

Poor calibration despite high correlation coefficients is due to differences in the factors causing the peaks on the control and treatment watersheds. The controls have high water yields per unit area largely as a result of snow accumulation and melt. During snowmelt, discharge is maintained at a high level for a considerable period on both and the peaks are determined mainly by the volume of runoff in this period.

Little Beaver Creek has a lower unit area yield and the snowmelt hydrograph is more sharply peaked. The magnitude of the peak is determined only in part by the volume of runoff. Temperature fluctuations during melt have considerable effect, and a sustained period of high temperatures in early June will cause a rapid rise in discharge to a high peak. Thus, while peaks on control and treatment watersheds are correlated, there remains a large variation of the data about the regression line.

Low Flow

Correlation of the numbers of days in the longest continuous period for 5 percent of the annual flow volume to pass the stream gage on Fall Creek and Little Beaver Creek did not give a satisfactory prediction equation. The second measure of low flow, the number of days with flow below certain levels in each year, gave two regressions with significant coefficients as shown in Table 10.

TABLE 10. REGRESSION RESULTS - NUMBER OF DAYS PER YEAR BELOW CERTAIN LEVELS OF FLOW - LITTLE BEAVER CREEK VERSUS FALL CREEK FOR 1961-1966.

Level of Flow csm	Regression Coefficient b	Intercept a	Correlation Coefficient r	Residual Variance	Variance Ratio a/ "F"
0.10	0.40	14.00	0.71	307.8	4.1
0.15	1.38	0.33	0.96	360.1	41.4*
0.20	1.53	-29.20	0.87	935.6	12.6*
0.25	0.86	62.41	0.49	2484.3	1.2

a/Tests whether the regression coefficient differs from zero.
*Indicates a significant difference at the 5 percent level.

The prediction equation corresponding to a flow level of 0.15 csm has the highest correlation coefficient and statistics from it were used in the calibration equation. Presently available data would permit a 32 percent change in this number of days to be detected at the 5 percent level six years after treatment.

The relatively high degree of correlation was unexpected, as the two watersheds appear to have distinct recession characteristics. On Little Beaver Creek, the recession begins steeply but flattens progressively as the discharge level decreases. Flows are seldom less than one cubic foot per second. Fall Creek on the other hand, has a slower recession which often extends into October and November; low, steady flow is not evident until January in some years.

Timing of Runoff

The regression coefficient was not significantly different from zero when annual peak flow dates from Fall Creek and Little Beaver Creek were correlated. Although peaks tend to occur concurrently on the rising limb of the snowmelt hydrograph on both streams, the highest peaks may not occur together. High flows are maintained for some time on Fall Creek and the highest mean daily discharge can occur anywhere within this period depending on the temperature regime. On Little Beaver Creek the snowmelt hydrograph is narrower and while the magnitude of the peak may be temperature dependent, its timing is not.

Lengths of both the shortest and Court's half-flow intervals were also used as measures of streamflow timing and the results of the four regression analyses are shown in Table 11.

With Upper Little Beaver Creek as the control, significant regressions were derived for both the shortest half flow interval and Court's half flow interval. A 25 percent change in the length of either interval could be detected with present calibration data. High correlations are to be expected, however, as water from Upper Little Beaver Creek is measured at both gages and no separations were made before the intervals were calculated. The prediction equations may therefore be of limited use.

The shortest half-flow interval gave the only significant regression coefficient when Fall Creek was the control. The length of the shortest interval for half of the annual flow volume to pass the stream gage is a function of the distribution of snowmelt runoff while the length of Court's half flow interval is a function of streamflow distribution throughout the year. As discharge from October until the

TABLE 11. REGRESSION RESULTS - HALF-FLOW INTERVALS - LITTLE BEAVER CREEK VERSUS FALL CREEK AND UPPER LITTLE BEAVER CREEK FOR 1961-1966.

Measure of Timing	Regression Coefficient b	Intercept a	Correlation Coefficient r	Residual Variance	Variance Ratio a/ "F"
Upper Little Beaver Creek as Control					
Shortest half flow interval	2.04	-18.4	0.96	33.07	41.7*
Court's half flow interval	3.43	-64.0	0.96	94.32	47.5*
Fall Creek as Control					
Shortest half flow interval	1.55	-30.6	0.93	49.74	26.4*
Court's half flow interval	2.47	-78.9	0.78	467.81	6.4

[a]Tests whether regression coefficient differs from zero.
*Indicates a significant difference at the 5 percent level.

the beginning of snowmelt is relatively low and steady on Little Beaver Creek, the intervals are similar. The slower recession, after snowmelt, on Fall Creek frequently continues after September with the volume of water contributed to the succeeding water year depending on the volume of snowmelt runoff. Therefore, in any water year, Court's half-flow interval on Fall Creek is dependent in part on the water yield during the snowmelt season the previous year.

Flow-Duration

The flow-duration curves for the period 1961 to 1966 for Fall Creek and Little Beaver Creek illustrate differences in the hydrology of the two watersheds (Figure 9). Both curves have steep slopes in the high discharge range and flat slopes in the low discharge range, reflecting the high proportion of annual runoff that appears in a short time. At any percent of time the discharge on Fall Creek exceeds that on Little Beaver Creek although the curves converge at both extremes of time. Divergence is greatest at about the 10 percent of time level, so that the Fall Creek curve is the steeper at low flows. These differences are attributed to more sustained snowmelt runoff and lower rate of recession on Fall Creek.

Prediction equations for discharges corresponding to 10 percentages of time on the annual flow-duration curve were derived by linear regression with Fall Creek data as the controls. Results are shown in Table 12. All but three of the analyses have significant regression coefficients. At extremes of time, however, the data points were closely grouped and the prediction equations are unreliable. Hence, of the seven significant regressions, only those for discharges

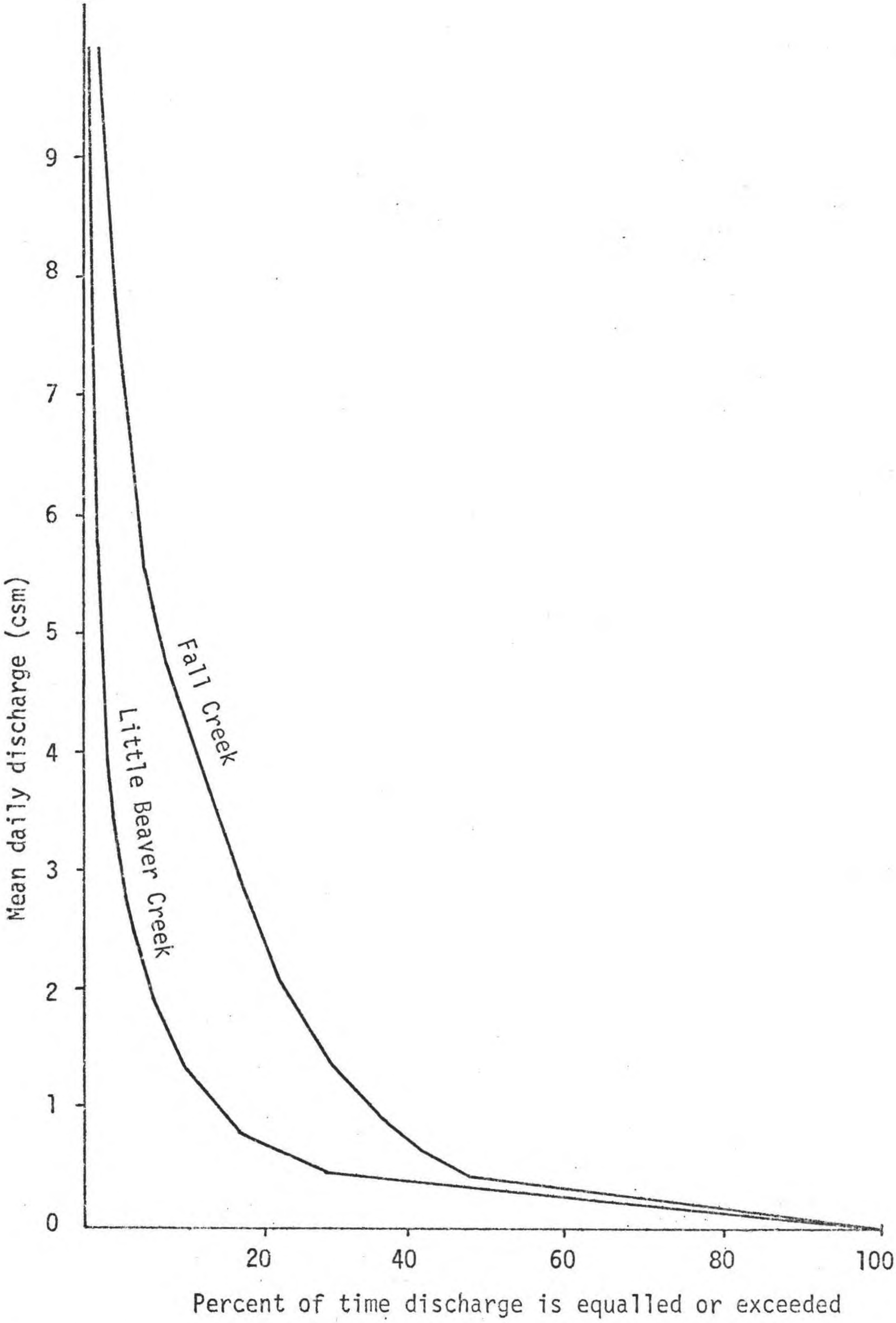

Figure 9. Flow-duration curves - Little Beaver Creek and Fall Creek 1961 - 1966.

TABLE 12. REGRESSION RESULTS - DISCHARGES EQUALLED OR EXCEEDED AT PERCENTS OF TIME ON THE ANNUAL FLOW DURATION CURVE - LITTLE BEAVER CREEK VERSUS FALL CREEK FOR 1961-1966.

Percent of Time	Regression Coefficient b	Intercept a	Correlation Coefficient r	Residual Variance	Variance Ratio a/ "F"
5	0.52	-0.80	0.86	0.8200	11.2*
15	0.39	-0.06	0.85	0.1023	10.8*
25	0.09	0.35	0.51	0.0182	1.4
35	0.07	0.27	0.72	0.0020	4.4
45	0.14	0.18	0.89	0.0004	15.6*
55	0.36	0.03	0.91	0.0009	19.4*
65	0.58	-0.04	0.84	0.0014	9.7*
75	0.86	-0.09	0.85	0.0014	10.0*
85	1.53	-0.16	0.83	0.0016	9.1*
95	2.38	-0.08	0.71	0.0012	4.2

a/Tests whether the regression coefficient differs from zero.
*Indicates a significant difference at the 5 percent level.

exceeded 45 percent and 55 percent of the time will permit detection of a 20 percent change with six years of calibration data.

Recession Analysis

A least squares line through sixty points of the constructed recession curve on semi-logarithmic graph paper, accounted for 97 percent of the data variation. Higher correlation coefficients were obtained when separate lines were fitted to the points on each side of an apparent break in slope. With a significance level of 1 percent, covariance analysis led to the rejection of the hypothesis that the slopes of the two lines were the same. The two slopes give rise to two relationships which describe the groundwater depletion curve over distinct ranges of discharge:

$$Q_t = 50.6(0.93)^t \;;\quad 50\text{cfs} > Q > 4\text{cfs}$$

$$Q_t = 13.4(0.97)^t \;;\quad 4\text{cfs} > Q > 2\text{cfs}$$

Graphical expressions of these relationships are shown in Figure 10. The recession constants expressed in this manner are 0.93 and 0.97 respectively and represent the proportional relationship between discharges on consecutive days when flow is derived from groundwater. On the mean daily hydrographs of Little Beaver Creek discharges below 2cfs were not sufficiently uniform to be included in the composite curve. The derived curve tends to zero flow with increasing time and since mean daily discharges on Little Beaver Creek are seldom less than 1cfs, it is apparent that a third, higher recession constant applies below the presently defined range. Furthermore, the recession equation for the higher flow range covers discharges exceeding many of the annual peaks

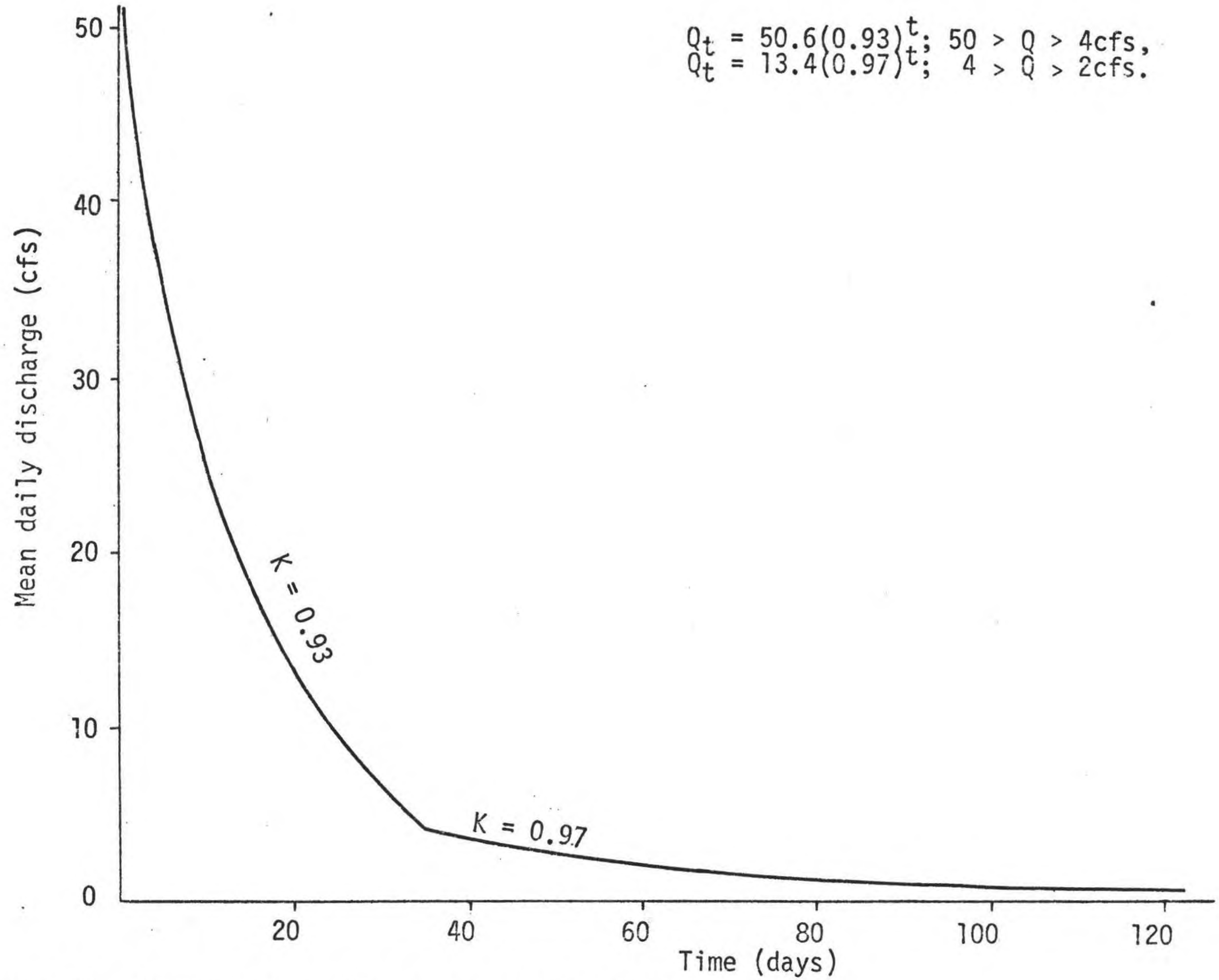

Figure 10. Derived recession curve - Little Beaver Creek.

during snowmelt. This is due to the extremely high mean daily peak in 1965 of 153cfs.

The coarse, porous nature of the soils in Little Beaver Creek suggests that there is very little surface runoff. Therefore, soon after the snowmelt peak, streamflow is derived from some form of storage and can be expected to decrease exponentially with time. As there are two evaluated parameters and a possible third, in the relationship describing the streamflow recession, it appears that there are three contributing sources of storage. These can be expected to follow a trend of decreasing rate of contribution to streamflow such as snow storage, soil storage, and aquifer storage.

The storage curve (Figure 11) was derived by successive integration of the expressions for the recession curve over time. To permit estimation of the volume of water in storage at any level of flow, the time axis was replaced by the corresponding discharge values from the recession curve. Since the recession constant at low levels of discharge was not evaluated, the storage curve underestimates the volume of water in storage through its range. This error is small except when discharge approaches 2cfs.

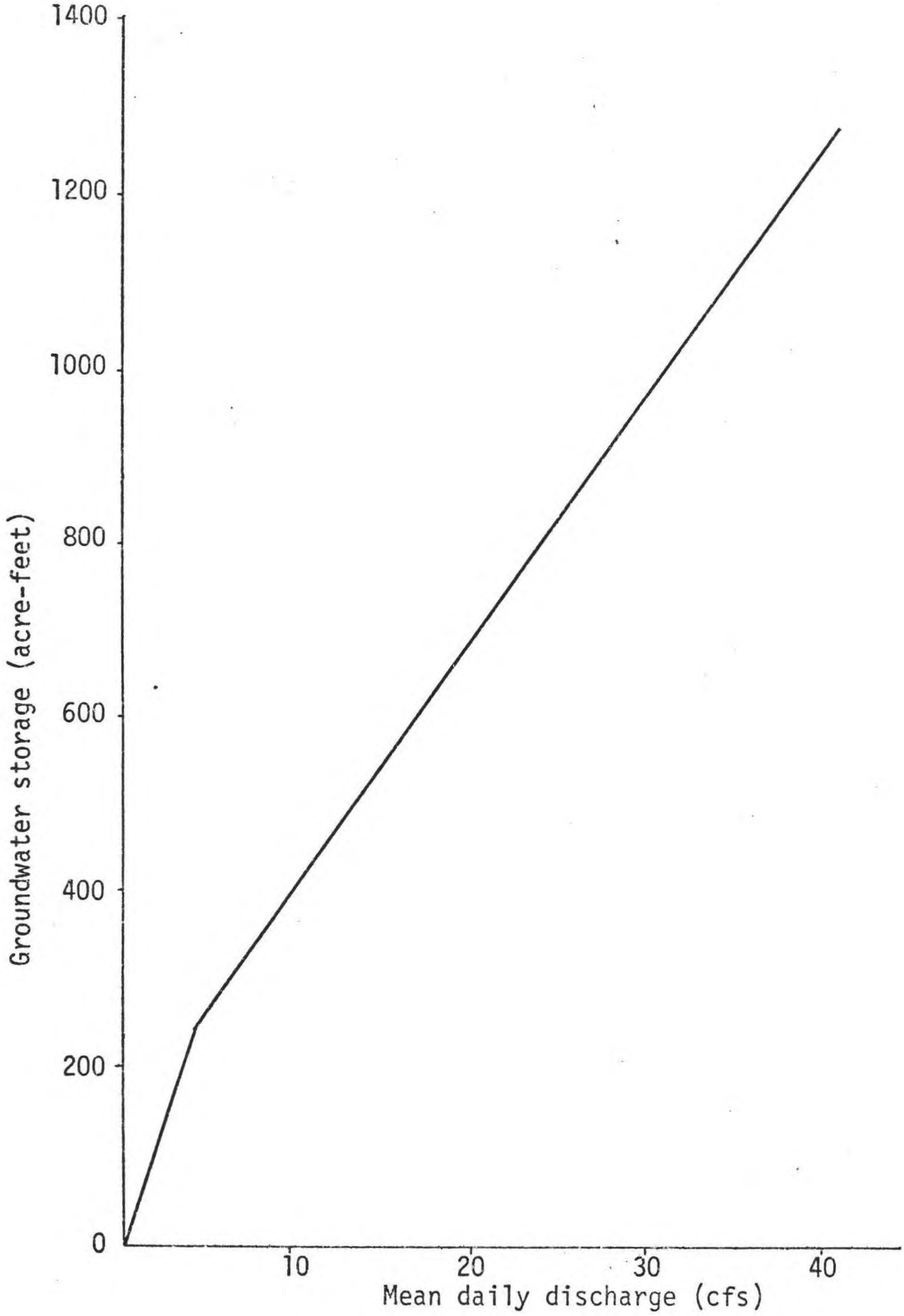

Figure 11. Groundwater storage curve - Little Beaver Creek.

Chapter VI

SUMMARY AND CONCLUSIONS

This study was primarily concerned with deriving prediction equations for streamflow characteristics of Little Beaver Creek watershed. It was intended that these relationships would provide data for comparison with records obtained when proposed logging operations in the area are completed.

Little Beaver Creek is part of the Little South Fork of the Cache la Poudre watershed, twenty-five miles west of Fort Collins, Colorado. The study watershed covers 11.4 square miles and ranges in altitude from 11,470 feet to 8,350 feet at the stream gage. The coarse textured soils on moderate to gentle slopes vary widely in depth and forest vegetation predominates below timberline at 11,200 feet above sea level.

Control variables in the prediction relationships for water yield were drawn from Fall Creek, Upper Little Beaver Creek, the Pingree Park precipitation gage, and Sheep Saddle snow course records. Equations to predict the magnitude of the snowmelt peak, and the lengths of half flow intervals were derived using Fall Creek and Upper Little Beaver Creek data. The other streamflow characteristics, measures of low flow and ten points on the annual flow-duration curve, were predicted using Fall Creek data alone.

The average of March, April and May snow course measurements gave the most precise equation for predicting annual water yield with a change of 1.6 area inches being detectable with six years of after-treatment data. A change of this magnitude is equivalent to 20 percent of the average annual water yield on Little Beaver Creek from 1961 to 1966. For water yield in the period May 1st to July 31st, designated the snowmelt season, the best equation resulted when Fall Creek data were the controls. However, a change equivalent to 35 percent of the average snowmelt yield from 1961 to 1966 would have to occur to be detected at the 5 percent significance level. Equations for monthly water yields were variable in precision with all types of control variable and in the light of low correlations with annual and seasonal water yields, their analyses were not pursued further than the derivation of parameters and estimates of error. None of the analyses with Pingree Park precipitation data as the control variables yielded a regression coefficient significantly different from zero. It is therefore concluded that as the precipitation gage is a considerable distance from Little Beaver Creek watershed, it does not provide an accurate index of water available for runoff.

Correlations of peak flows showed that Fall Creek and Upper Little Beaver Creek would be equally satisfactory as controls. Available calibration data would permit detection of a 50 percent change in the peak mean daily discharge on Little Beaver Creek.

As a measure of streamflow timing the date of occurrence of the peak flow on Little Beaver Creek could not be predicted with precision using similar data from either Fall Creek or Upper Little Beaver Creek. The latter control watershed gave a relatively high correlation coefficient when either Court's or the shortest half-flow interval was used as a measure of timing. A 25 percent change in the length of either interval could be detected with present calibration data. However, these equations may be of limited use as water from Upper Little Beaver Creek is measured at both gages and, therefore contributes to both the dependent and independent variables in the regression analysis. Even if the equations are statistically valid, a very large treatment effect would be necessary to cause a 25 percent change in the half-flow intervals at the lower gage when water from untreated Upper Little Beaver Creek is also included in the computation of the interval lengths.

The analyses with Fall Creek as the control gave a significant regression coefficient only in the case of the shortest half-flow interval. This is attributed to differences in the recession characteristics of the two watersheds and consequent effects on the length of Court's half-flow interval on Fall Creek.

The measure of low flow giving the most precise prediction equation was the number of days per water year that mean daily discharge was less than 0.15 csm. A change of approximately 30 percent in this parameter could be detected with present calibration data. The length of the longest continuous interval in which five percent of the annual flow volume passes the stream gage was selected as a second measure of low flow conditions on Little Beaver Creek. Correlation with the corresponding intervals on Fall Creek were made, but the regression coefficient could not be shown to differ significantly from zero.

Correlations made to predict discharges for ten percents of time on the annual flow-duration curve of Little Beaver Creek show some apparent anomalies. Although seven analyses show significant regression coefficients, only two are sufficiently precise to permit detection of a twenty percent change in the dependent variable with available calibration data. This appears to be the result of the constancy of the recession characteristics of the two watersheds and the consequent similarity of each year's flow-duration curve at high percents of time. Thus, while there is good correlation, the errors of estimate of the regressions are high.

In addition to the derivation of prediction equations, mass curve and recession analyses were made. Two double mass curves were drawn with precipitation, and Fall Creek water yields against water yields from Little Beaver Creek. The curves show some degree of linearity and may be useful for illustrative purposes when records from the after-treatment period are available. Evaluations of changes in water yield by this method can only be broad estimates, however, as the control relationship is not well defined with only six years of records available.

Recession analysis showed there are two recession constants on Little Beaver Creek and revealed the possibility of a third applying at very low flows. Soon after the snowmelt peak, when soils are still near saturation, the recession is steep and mean daily discharge is 93 percent of the previous day's discharge. Between discharge of 4cfs and 2cfs, a recession constant of 0.97 applies. When flows are less than 2cfs, the recession curve becomes quite flat but the recession constant in this range could not be evaluated from mean daily flow records.

From the above results it can be concluded that none of the sources of control variables is completely satisfactory alone. The only equation with the requisite precision is that which predicts annual water yield from the average of the March, April and May Sheep Saddle snow course measurements. Fall Creek, which was used as a control for all streamflow characteristics investigated, is only moderately well correlated with Little Beaver Creek. Standard errors of estimate from the regressions are too large to permit detection of small changes after treatment. This lack of satisfactory correlation is attributed to topographic dissimilarities: namely slope, shape, size, and aspect differences between the two watersheds.

Little Beaver Creek, therefore, cannot be considered calibrated and analyses show that an increase in the length of the calibration period will have only a small effect on the precision of the prediction equations.

Further possibilities for calibration do, however, remain: the more rigorous statistical analyses used by Markovic (1966) could be performed on data used in this study; after two or three years of data collection, Fish Creek watershed could be tried as a control; and a network of precipitation gages within Little Beaver Creek could be established and maintained to provide a possible control in five or six years' time.

The first of these choices would require the smallest investment of time and finance, and should therefore be investigated before the others. The second is preferable to the third, since a shorter period is required to assess the effectiveness of Fish Creek as a control watershed. Furthermore, Fish Creek is adjacent to, and physically more similar to Little Beaver Creek than any of the watersheds yet tried, and so could be expected to give a better control than Fall Creek. Nevertheless, the last possibility is not without merit. A control based upon the water input to the watershed provides a link in the cause and effect relationships leading to runoff. If studies on Little Beaver Creek are to yield significant results, the present investigation must be continued beyond the whole watershed approach, to the individual processes of the hydrologic cycle. When this point is reached, more complete precipitation data than is currently available will be essential.

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APPENDIX

TABLE A. ANNUAL AND MONTHLY WATER YIELDS - UPPER LITTLE BEAVER CREEK 1961-1966.

Period	Water Yield in Area Inches 1961	1962	1963	1964	1965	1966
October	0.253	0.864	0.337	0.463	0.337	0.737
November	0.173	0.779	0.232	0.337	0.232	0.653
December	0.137	0.485	0.158	0.232	0.166	0.527
January	0.099	0.316	0.099	0.156	0.110	0.358
February	0.059	0.179	0.070	0.107	0.082	0.253
March	0.042	0.150	0.065	0.082	0.078	0.190
April	0.029	0.147	0.063	0.072	0.088	0.152
May	0.442	1.854	2.570	1.706	0.337	2.086
June	9.607	7.942	4.487	6.236	10.217	4.614
July	3.602	4.993	1.517	3.034	6.383	1.643
August	1.243	0.885	0.864	0.927	1.369	0.653
September	0.737	0.463	0.590	0.485	0.674	0.400
Water Year	16.432	19.066	11.060	13.841	20.077	12.240

TABLE B. ANNUAL AND MONTHLY WATER YIELDS - LITTLE BEAVER CREEK 1961-1966.

	Water Yield in Area Inches					
Period	1961	1962	1963	1964	1965	1966
October	0.189	0.454	0.202	0.268	0.206	0.408
November	0.173	0.380	0.173	0.224	0.137	0.276
December	0.145	0.322	0.171	0.171	0.166	0.214
January	0.125	0.242	0.128	0.133	0.138	0.178
February	0.110	0.179	0.099	0.100	0.105	0.143
March	0.114	0.201	0.135	0.104	0.105	0.171
April	0.183	0.494	0.192	0.183	0.220	0.197
May	1.777	2.139	0.954	1.300	1.268	0.885
June	5.527	3.224	1.512	2.319	6.728	1.408
July	1.566	1.527	0.561	0.921	2.550	0.609
August	0.571	0.408	0.538	0.357	0.709	0.350
September	0.423	0.250	0.372	0.207	0.413	0.232
Water Year	10.906	9.821	5.034	6.284	12.749	5.067

TABLE C. ANNUAL AND MONTHLY WATER YIELDS - THE AREA BETWEEN THE UPPER AND LOWER LITTLE BEAVER STREAM GAGES 1961-1966.

Period	Water Yield in Area Inches					
	1961	1962	1963	1964	1965	1966
October	0.187	0.426	0.194	0.255	0.197	0.386
November	0.175	0.351	0.170	0.217	0.130	0.248
December	0.148	0.313	0.175	0.168	0.169	0.190
January	0.129	0.239	0.133	0.133	0.143	0.165
February	0.116	0.182	0.103	0.101	0.109	0.136
March	0.121	0.208	0.143	0.107	0.109	0.172
April	0.198	0.531	0.206	0.195	0.235	0.204
May	1.918	2.195	0.829	1.284	1.367	1.519
June	5.259	2.867	1.279	2.017	6.529	1.154
July	1.414	1.251	0.487	0.753	2.258	0.529
August	0.522	0.373	0.518	0.313	0.663	0.330
September	0.402	0.235	0.359	0.187	0.397	0.221
Water Year	10.594	9.171	4.591	3.917	12.309	4.526

TABLE D. ANNUAL AND MONTHLY WATER YIELDS - FALL CREEK 1961-1966.

Period	Water Yield in Area Inches					
	1961	1962	1963	1964	1965	1966
October	0.788	1.772	0.520	0.742	0.639	1.149
November	0.361	0.804	0.247	0.453	0.309	0.556
December	0.237	0.458	0.149	0.129	0.165	0.345
January	0.242	0.299	0.082	0.118	0.165	0.185
February	0.139	0.211	0.108	0.093	0.118	0.103
March	0.124	0.180	0.118	0.093	0.108	0.144
April	0.175	0.726	0.180	0.180	0.247	0.299
May	2.493	2.915	3.647	3.158	2.199	2.560
June	8.911	6.799	6.748	5.924	12.620	4.260
July	4.687	6.130	3.559	5.306	9.220	3.482
August	3.503	2.673	3.029	2.694	3.461	2.019
September	2.411	1.030	1.499	1.144	1.793	1.138
Water Year	24.055	24.004	19.883	20.037	31.060	16.226

TABLE E. ANNUAL AND MONTHLY PRECIPITATION - PINGREE PARK RAIN GAGE 1961-1966.

	Precipitation in Inches					
Period	1961	1962	1963	1964	1965	1966
October	2.12	0.93	0.47	0.43	0.11	0.65
November	1.07	0.93	0.57	0.41	0.92	1.13
December	1.96	1.02	0.90	1.07	2.30	0.90
January	0.37	1.14	2.20	1.04	2.75	0.49
February	1.22	1.95	1.69	1.27	0.81	1.15
March	1.79	1.03	1.44	1.51	2.51	0.54
April	2.18	2.00	1.05	3.86	3.95	2.08
May	6.42	1.09	0.42	1.47	2.97	1.37
June	2.18	2.02	3.84	1.16	3.62	1.93
July	3.79	2.20	2.63	2.47	2.08	2.53
August	1.90	0.49	4.19	2.57	1.82	2.82
September	4.38	1.02	1.50	1.38	2.45	2.06
Water Year	29.38	15.82	20.90	18.64	26.29	17.65

TABLE F. WATER EQUIVALENTS - SHEEP SADDLE SNOW COURSE 1961-1966.

Period	Water Equivalent in Inches					
	1961	1962	1963	1964	1965	1966
February	4.4	8.3	5.0	4.0	9.1	3.9
March	8.5	9.6	7.7	6.2	13.4	6.3
April	11.1	13.5	8.4	8.4	11.9	5.7
May	11.3	10.8	7.1	11.1	14.9	0.0 [a]

[a] Assumed value, no record available.

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