AN ABSTRACT OF THE THESIS OF

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Title: RAPID CALIBRATION OF COASTAL STREAMS TO DETECT EFFECTS OF ROADBUILDING

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This study used data from the Alsea Watershed Study located approximately ten miles from the Pacific Ocean in the Oregon Coast Range. The purpose was to evaluate the effects of roadbuilding on storm flows in two experimental streams. One 138 acre watershed, Deer Creek II, was subjected to 3.5 percent treatment (roadbuilding); the other, Deer Creek III, has an area of 100 acres and received 6.7 percent treatment.

A rapid calibration method based upon individual storm hydrographs was selected to evaluate the effect of roadbuilding. This method of calibration was chosen because: 1) only 2.5 years were available prior to treatment; 2) there were temporary losses of record; and 3) a relatively sensitive method of detecting change was needed. The parameters examined in this method are time-to-peak, height-of-rise, and peak discharge of the storm hydrograph.

Every storm hydrograph was examined in the 2.5 year pre-treatment period and in the one year post-treatment period. The three parameters were obtained from all acceptable storm hydrographs. Regression was used to develop a relationship between the three parameters on Deer Creek II and III and the three corresponding parameters on Flynn Creek (control). Analyses of covariance were used to determine the significance of changes in slope and elevation of the regression lines.

Significant changes were detected in time-to-peak and height-of rise on Deer Creek II, while significant changes were detected in height-of-rise and peak discharge on Deer Creek III. The changes observed were related to roadbuilding and storm size.

Rapid Calibration of Coastal Streams to Detect Effects of Roadbuilding

by

Dennis James Gilleran

A THESIS

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INTRODUCTION

Hydrologists and land managers should understand the relationships between changes in soil or vegetative cover and the resultant changes in streamflow. This understanding is essential in Oregon where forested lands yield a large portion of the surface water and where logging is a major industry. Since the logger covers approximately 600,000 acres of forest land in Oregon each year, research which assists in the evaluation of the impact of that activity on the water resource is indeed important. The purpose of this thesis is to evaluate the effects of roadbuilding on storm flows in two small streams located approximately ten miles from the Pacific Ocean in the Coast Range of western Oregon.

In 1958, a 15-year research project, the Alsea Watershed Study, was launched with the cooperation of a number of state and federal agencies. This study has the general goals of evaluating the effect of logging practices on the hydrology, water quality, and ecology of small coastal streams. Standard logging practices include the construction of roads; therefore, the impact of roadbuilding is important and should be evaluated both separately and in conjunction with logging. The Alsea Watershed Study was designed to

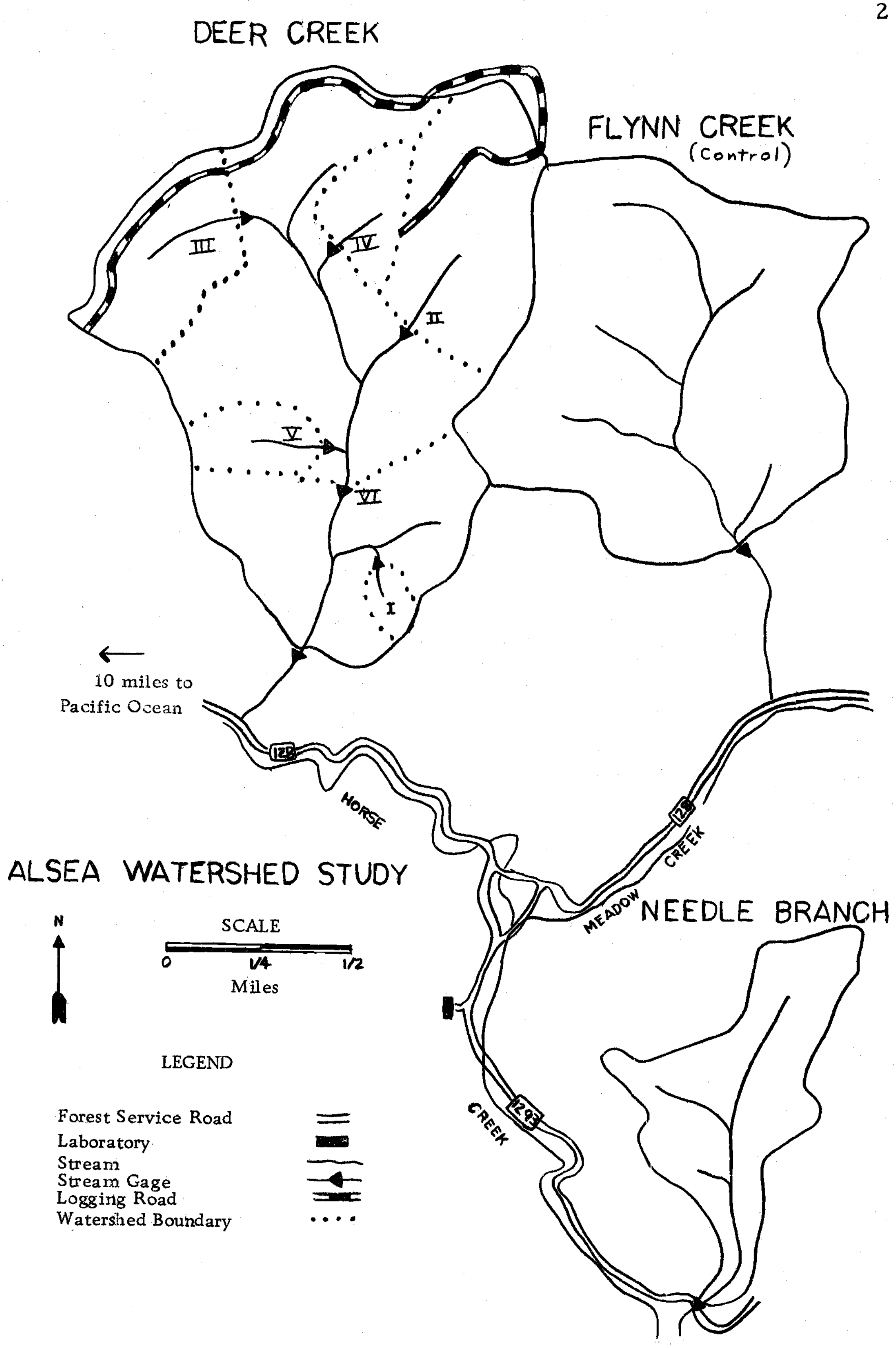


Figure 1. Planimetric map of the watersheds in the Alsea Watershed study.

allow for such detailed evaluation since roadbuilding was completed a full year ahead of all logging operations thereby providing the necessary data for this thesis. The three watersheds considered in this thesis--Deer Creek II, Deer Creek III, and Flynn Creek--are shown in Figure 1, as are the other six watershed units which make up the Alsea Watershed Study.

Oregon State University's School of Forestry installed stream gaging stations on Deer Creek I through VI in the fall of 1962. The purpose of these gaging sites was to provide flow data to assist in evaluating the impact of each individual logging and roadbuilding unit on water quality and quantity. Roadbuilding was completed on Deer Creek II and III in the summer of 1965 and logging was completed on these areas in the summer of 1966. Therefore, the pre-roadbuilding period of record was 2.5 years long, and the post-roadbuilding period of record was one year long.

Statement of the Problem

Conventional methods of determining land-use effects usually involve some type of yearly flow comparisons requiring a calibration period of at least five years (Wilm, 1943). If regression techniques are used, it can be easily demonstrated that the standard error of estimate of a regression line is inversely proportional to the square root of the number of observations. As the number of observations gets larger, the standard error of estimate gets smaller (Snedecor, 1946; Li, 1964). When each observation represents a whole year's record, as it would if the researcher were using total yearly discharge, a long period of record is clearly necessary. If double-mass analysis is used, a number of points are essential to establish a trend before treatment. When total annual discharge values are used as individual points, this method also involves a long period of calibration. However, if storm hydrograph parameters are used as individual points, double-mass analysis might then be used to detect a change in flow characteristics using only a short period of record.

The minimum calibration period of five years which is usually pre-requisite for the use of total annual discharge values was not available in this study. Therefore, a method of detecting changes in the flow characteristics in a stream using a relatively short calibration period was needed.

Other factors adding to the problem included the need for a high degree of sensitivity in the calibration method since the treatments (roadbuilding) covered only a very small percentage of the watersheds under study. In addition, the situation was further complicated by the need for a calibration method which would not be affected by the occasional loss of short periods of record. These losses were the result of temporary mechanical failure or technician error.

Objectives

The purpose of this thesis is to:

1) determine whether roadbuilding has changed the height-of-rise, time-to-peak, and peak discharge of the storm hydrographs of two small streams;
2) to explain any changes in the above storm hydrograph parameters in terms of roadbuilding; and
3) to indicate the efficacy of the statistical method of watershed calibration applied here.

DESCRIPTION OF STUDY AREA

Climate

The Alsea basin is located in the Coast Range in western Oregon, ten miles from the Pacific Ocean. The climate of the area is dominated by the proximity of the ocean which has a modifying effect on temperatures and is the source of moisture for precipitation. Precipitation is seasonal in character with the summer months accounting for less than five percent of the total yearly rainfall. The total rainfall for the year is approximately 95 inches. The geographic distribution of rainfall is greatly affected by topography since the moisture-laden air comes predominantly from the west and deposits heavier rains on the ocean-facing slopes. The average growing season is about 200 days.

Topography

The study area has a dendritic drainage pattern with all three major streams, Deer Creek, Flynn Creek, and Needle Branch, draining south. Most major slopes face either east or west. The topography could be described as being very steep with some slopes as steep as 75 percent. The mean slopes of the areas under study are between 20 and 40 percent. The watersheds have mean elevations between 742 and 1000 feet (U.S. Soil Conservation Service, 1964).

Soils and Geology

The soil is derived from level to sloping beds of sandstone and siltstone belonging to the Tyee formation of estuarine and marine sedimentary rock. There are two dominant soil types in the study area: Slickrock and Bohannon. The Slickrock series consists of moderately deep and well drained Brown Latosol soils that have developed from sandstone colluvium. The Bohannon series consists of well drained, fairly shallow Brown Latosol soils developed from medium textured sandstone residuum (U.S. Soil Conservation Service, 1964).

Vegetation

Vegetation on the study areas consists of various combinations of two dominant species: Douglas-fir (120 years old) and red alder (uneven-aged). On Deer Creek, 31 percent of the area is covered with pure alder. The remainder is covered with mixed stands of Douglas-fir and alder. Flynn Creek is similarly forested; 39 percent of the area supports stands of pure alder with the remainder supporting mixtures of that species and Douglas-fir (U.S. Soil Conservation Service, 1964).

LITERATURE REVIEW

The literature pertinent to this problem can roughly be divided into three subject areas: 1) the effect of roadbuilding and vegetation removal on streamflow, 2) the methods of detecting changes in the characteristics of storm runoff in a stream, and 3) the use of linear regression.

Effects of Vegetation Removal

Roadbuilding involves the removal of vegetation from an area wide enough to accommodate the road surface plus the cut and fill slopes. The fact that removal of forest vegetation increases streamflow is well documented (Hewlett and Hibbert, 1961; Kovner, 1956; Schneider and Ayer, 1961; Hibbert, 1967). Hoover (1944) found a considerable increase in streamflow after the removal of vegetation from entire watersheds in North Carolina. He claimed that the increase in streamflow amounted to 17 areal inches of water per year. Other researchers have reported similar results. Penman (1963) states that Katsumi measured an increase of approximately 4.7 inches of runoff after the selective cutting of 45 percent of the stock in a mixed forest in northern Japan. Increases in the total flow such as those documented by Hoover (1944) and Penman (1963) could change the average storm hydrograph to produce a shorter time-to-peak, a larger height-of-rise and a larger peak discharge.

Only a small portion of the watersheds in this experiment were cleared for roadbuilding, but the effect on streamflow should be similar in nature if not in magnitude. Increases in streamflow due to cutting fall into three categories. First, cessation of transpiration and interception losses contributes to the increase. Second, a removal of organic matter which usually acts to retard overland flow and encourage infiltration is another contributing factor. Third, a compaction of the surface soil in the roadbed by traffic and raindrop impact acts to reduce infiltration and thereby increase overland flow (Chow, 1964).

The result of cessation of transpiration and interception, loss of organic matter and the reduction of infiltration would seem quite obvious. All other conditions being held constant, the storm hydrograph should have a shorter lag time, a higher storm peak, and possibly a recession limb with a steeper slope for a storm of unit intensity and duration. Such assumptions should not be made though, before the actual results are evaluated. Rallison (1963) and Hewlett and Hibbert (1961) maintain that no treatment can be evaluated without reference to the land on which it is practiced. The evaluator must have a knowledge of how and to what degree these factors can be changed by man before it can be said that a particular factor brought about a particular change.

Methods of Detecting Change

The second subject area of importance to this problem concerns the methods of detecting changes in the characteristics of storm runoff in a stream. A watershed is used in hydrologic research as a model, because the assumption is made that it reacts in the same way as similar areas under similar influences. In order to detect a change in these reactions there must be a point of reference. Therefore, a watershed should be calibrated before a treatment. This implies use of a standard which is usually called a control watershed. Most watershed management research involves use of the control watershed technique. The calibration methods establish a relationship between the area to be treated and the control area. It is assumed of course that factors such as soil, vegetation, topography, and climate are similar because these things determine the relationship between rainfall and runoff on an area. If any of these factors differed greatly from one area to another, the change detected after treatment might not be representative of that treatment alone. Hence, it is important that the two areas under study have similar soils, vegetation, topography, and climate.

Some of the more commonly applied methods for detecting change are described by Hoover (1944) and Rich, Reynolds, and West (1961). These authors used annual discharge values from control and treatment watersheds to establish a regression line for the pre-treatment period. The standard error of estimate of such a relationship is a function of the number of observations (Snedecor, 1946; Li, 1964). Therefore, using annual discharge as a parameter, the minimum calibration period is at least five years (Wilm, 1943).

Double-mass analysis of yearly discharge as discussed by Anderson (1955) is also limited by the need for at least four or five years of pre-treatment record. Dougle-mass analysis is a graphical method of detecting change whereby a line denoting the relationship between two populations is constructed. The successive accumulations on a yearly basis of all observations from one population are plotted against the same values from the other population. This process is continued through the treatment period. Any change in the slope of the resultant line is indicative of a disproportionate change in one of the populations (Chow, 1964). It is clear that, when this method is employed using total annual discharge values, a relatively long pre-treatment record is required in order to reliably establish the slope of the line.

Reigner (1964) described calibration of a watershed using a combination of climatic and streamflow data. He used six years of precipitation, air temperature, and humidity records to predict streamflow. Regression analysis was used to develop the relationship. It should be noted that in this instance a control was not used.

However, others have used similar parameters and methods in conjunction with a control area (Penman, 1963).

None of the above methods, when used as they were in the cited articles, are feasible under the circumstances of this study. It is clear that all require at least five years of record, some of the parameters used require complicated analysis, and all three methods would be adversely affected by occasional loss of record.

A method of calibration which circumvents these problems was first described by Bethlahmy (1963). He illustrated how two or more watersheds could be related by comparing their reactions to the same storm. The parameters of comparison were rise-in-stage and time-to-peak of the storm hydrograph. Rise-in-stage is the total change in stage from the initial point of rise to the peak. Time-to-peak is the elapsed time from the initial point of rise to the peak. In addition to being easy to determine and use, these two parameters have been empirically related to watershed characteristics and found to be indicative of conditions on the watershed (Edson, 1951; Taylor, 1952). Peak discharge is used as an additional parameter of comparison in this study to give a quantitative measure of the change for various storm sizes. Simple linear regression and analysis of covariance are used to relate the parameters and detect any change in them respectively.

Behtlahmy's method circumvents the need for a long calibration period by using the parameters from each storm hydrograph as separate points for the regression. This allows the development of a very precise relationship in a period as short as one year. A one-year calibration period is possible in most climates, and especially in climates like western Oregon, where a relatively large number of storms produce runoff during a year. A one-year calibration is possible, but Bethlahmy states that an additional year could be used to further reduce the chance of error.

In addition to the shorter period required for calibration and the lower standard error of a large number of observations, this method is not affected by occasional loss of records. Usually, instrument malfunction or technician error cause the loss of a small number of storms. This loss would be significant using one of the methods considered earlier, but the loss of only a few points when the total is close to 100 is clearly not important in this method.

Limitations of the method are similar to those applying to most methods involving the control technique. The control and treatment watersheds must have similar vegetation, soils, and topography. Next, both areas must be subject to the same storms. This causes a very slight problem because, over the period of a year there are bound to be a few localized storms which do not affect control and treated watersheds alike. This drawback can be corrected by choosing only those storms which are corresponding in time and present on both hydrographs. Another possibility is that non-uniform storms affecting one area relatively more than the others would tend to introduce variance into the relationship. The total effect of such storms is minor, however, because the number of observations is large and such storms occur infrequently.

Another condition that must be met is that the correlation coefficient of the regression line between control and treatment watersheds before treatment must be high. The correlation coefficient (r), can vary from minus one to plus one. An 'r' value of plus one indicates perfect positive correlation, a value of zero indicates no correlation, and a value of minus one indicates perfect negative correlation. An 'r' value of .90 is generally considered to be high. This condition is a confirmation of the earlier requirement that the watersheds have similar characteristics. A high correlation coefficient before treatment indicates that the watersheds are similar in the characteristics affecting the variables used in the regression line, and that they are subject to the same rainfall events. A low correlation coefficient can be detected after just a few months of gaging and other, more similar watersheds can be chosen without appreciable loss of time (Bethlahmy, 1963).

Linear Regression

The third subject of importance to this problem is linear regression, since it is the statistical method applied to the analysis of storm parameters in this study. Regression considers the frequency distribution of one variable when another is held fixed at each of several levels. A linear regression is produced if the locus of the means of the arrays of the dependent population is a straight line (Li, 1964). The variable which is held fixed is called the independent variable. In this case, observations of the control watershed were considered to be the independent variables. Goodell (1951) and Rich et al.,(1961) have also considered the control watershed data as the independent variables in their use of regression, even though the data from the treatment watersheds was in no way dependent on the control data. These observations are related but they are not dependent on the control data. When regression is used in this way, it is just a method of correlation. Correlation considers the joint variation of two measurements, neither of which is restricted by the experimenter or observer (Li, 1964).

After regressions for the pre-treatment and post-treatment periods have been developed, they must be examined to determine if any change has occurred. There are only two types of change which can occur: change in slope and change in elevation. The most widely used method of examining the regression lines for such change is covariance analysis. Schneider and Ayer (1961) used covariance analysis of regression lines developed from precipitation and runoff data. This analysis showed that there had been a change in streamflow due to reforestation. Their analysis stopped after detecting a change in the slope of the regression lines. However, covariance analysis could also have been used to detect any change in the elevation of the regression lines. The test for homogeneity of adjusted means evaluates differences in elevation at a point on the regression lines which corresponds to the mean of the independent population. This point is chosen for the test because the mean of the population is usually in the range where most of the observations fall. Since a linear regression is only valid within the range of the data, this is an appropriate substitution for the usual covariance test of intercepts.

Finally, linear regression is widely known and utilized because it is a versatile tool for expressing the relationship between two sets of data in terms of an equation. Covariance analysis is almost as widely known, because with it the significance of any differences in the regression lines can be determined with accuracy and comparative ease.

METHOD

Design

The three watersheds considered in this thesis are Flynn Creek (control), Deer Creek II and Deer Creek III (Figure 1). The Deer Creek watersheds were chosen because: 1) they received differing amounts of roadbuilding, 2) they were equipped with the same type of flumes and level recorders to aid in the comparison, and 3) the correlation coefficients of the pre-treatment regressions were relatively high.

The road on Deer Creek II is about 2900 feet long, has an area of 4.75 acres, and covers 3.44 percent of the 138 acres in that watershed. The road on Deer Creek III is approximately 4,000 feet long, has an area of 6.70 acres, and covers 6.70 percent of the 100 acres in Deer Creek III. Flynn Creek with an area of 540 acres, remained undisturbed throughout the study.

The flumes installed on the three watersheds used in this experiment are discussed below in the Instrumentation section. No corrections in the stage hydrograph parameters were necessary to account for differences in flume construction because the flumes on Deer Creek II and III are of the same type.

The correlation coefficients of the pre-treatment regressions are given in the Results section. The correlation coefficient is an index which describes the closeness of fit of the data to the regression line. The correlation coefficient is important because it indicates to the researcher how well the events on one stream are related to events on the other stream.

The flumes and level recorders were installed on Deer Creek II and III in the fall of 1962 approximately 2.5 years prior to roadbuilding in these watersheds and 3.5 years prior to logging. The one-year period between roadbuilding and logging was used to gather storm hydrograph data to assist in achieving the goal of separate evaluation of roadbuilding.

Instrumentation

The subwatersheds of Deer Creek (II and III) were equipped with Belfort FW-1 water level recorders mounted on small stilling wells connected to venturi-trapezoidal flumes. The FW-1 level recorder is a small portable instrument designed particularly for use in well and ground water studies. A counter-balanced float is attached to a perforated steel tape which positions a floatwheel in reponse to changes in water level. The floatwheel shaft is geared to and drives a heart-shaped cam, which in turn moves a pen over a slowly revolving cylindrical chart driven by a clock mechanism. The resultant stage hydrograph gives a record of stage versus time which can be converted into discharge by applying the rating formula for the particular flume.

Each stilling well was constructed by welding two 25-gallon drums together and sinking this cylinder into the bank adjacent to the flume to a depth which would include the full range of water level fluctuation anticipated in the flume. This well was connected to the flume by a series of intake pipes at different levels to maintain a stage corresponding to that in the flume. A small shelter housed the recorder (see Figure 2).

The flumes used on Deer Creek are venturi trapezoidal flumes. These flumes have a trapezoidal cross-section and consist of an approach section, a converging section, a venturi section, and a diverging section (see Figure 2 and Appendix Figure 10). According to Robinson and Chamberlain (1960), the venturi section reduces the flow to critical depth which can be measured accurately and without numerous calculations. They also mentioned three important attributes of the venturi trapezoidal flume. First, material deposited in the throat does not change the stage-discharge relationship significantly. Second, a large range of flows can be measured through the structure with a comparatively small change in head. Third, the flume will operate under greater submergence than rectangular flumes without corrections being necessary to determine the discharge.

The installation on Flynn Creek (control) is operated by the

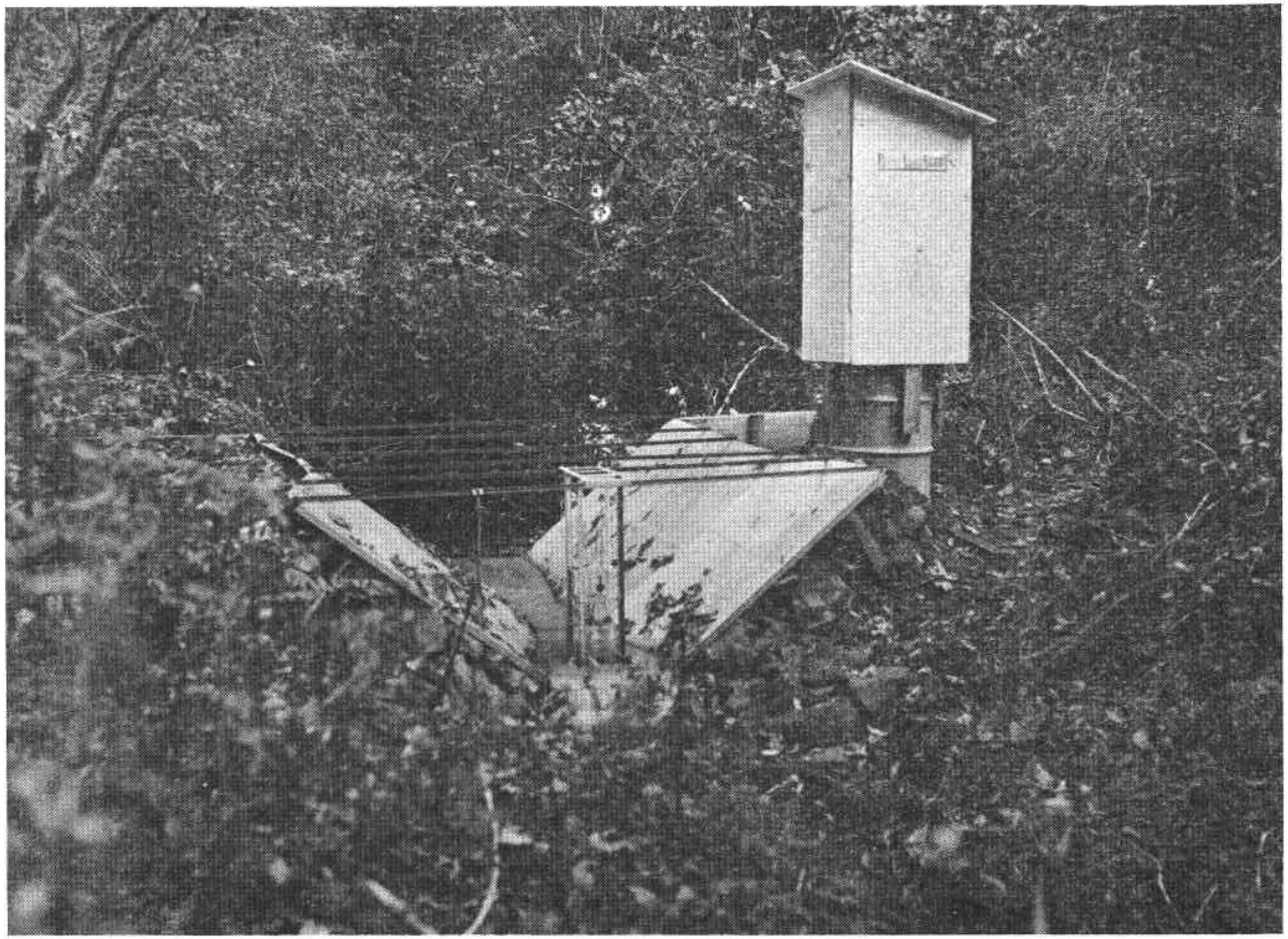


Figure 2. The gaging installation on Deer Creek II showing the flume, stilling well, and instrument shelter.

U.S. Geological Survey. A Leopold and Stevens Type A-35 recorder is mounted in a shelter above a stilling well. The A-35 recorder operates similarly to the FW-1 level recorder except that the A-35 can operate for much longer periods of time without need for maintenance. The stilling well and shelter are larger than those on the subwatersheds of Deer Creek, but the basic design and operation are the same (see Figure 3). Flow is regulated by a broad-crested, concrete, 120 degree V-notch weir. The weir is equipped with a shaper V-notch section at the center which aids in the measurement of low flows.

Selection of Hydrograph Parameters

The criteria for selecting storms used in this analysis were generally those presented by Bethlahmy (1963). The three criteria used here are: 1) storms must be apparent on hydrographs from both watersheds, 2) the storms must be corresponding in time, and 3) the points of initial rise and peak must be clearly defined on the stage hydrographs.

All storms selected were apparent on hydrographs from both watersheds because, first of all, two observations are necessary to make a comparison. Secondly, a storm which appeared on only one hydrograph indicated that this was a highly localized event and therefore was not included.

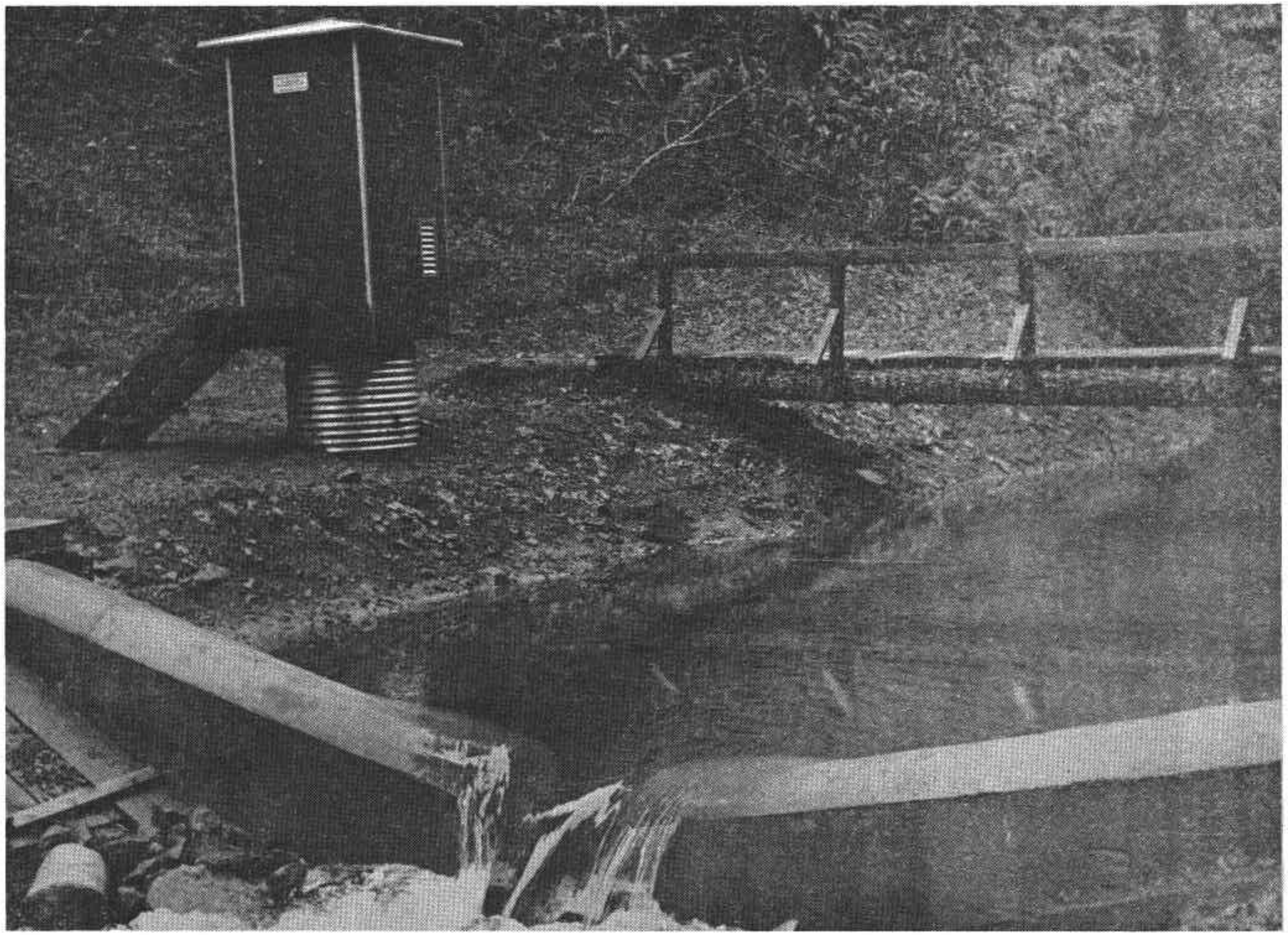


Figure 3. The U.S. Geological Survey gaging installation on Deer Creek which is similar in design to the installation on Flynn Creek. The broad-crested concrete weir, stilling well and instrument shelter are shown.

All storms selected were temporally related because variance can be introduced into the relationship if areally or temporally non-uniform storms are included. Since the factors which affect streamflow were held constant within each period of record, it was reasonable to assume that the only source of any difference in the times of appearance of storm hydrographs was irregularity in the meteorological events. If for instance, a storm appeared later on one stage hydrograph than on another, it was always possible to discover major differences in the shape of the hydrographs, thus indicating that the meteorological event was also non-uniform in either areal distribution or total rainfall. Such irregular storm events would reduce the reliability of the relationship between hydrograph parameters by increasing the variance. Therefore, the relatively few storm hydrographs resulting from irregular rainfall events were excluded from this analysis.

Selection of storms in accordance with the third criterion required that hydrographs exhibit clearly defined points of initial rise and clearly defined peaks. On small watersheds such as those used in this experiment, the changes in height-of-rise and time-to-peak were not very large because of the small treatments being considered. Due to debris or wave action in the flumes a very few of the storm hydrographs examined had a blurred or obscured trace.

These storm hydrographs might have injected error into the relationships between parameters. Consequently, such hydrographs were also excluded from this analysis.

After examination of all storm hydrographs, a total of 61 pre-treatment and 24 post-treatment storms were accepted (see Appendix Table II). When dealing with a complex hydrograph only the first peak was used because subsequent peaks were subject to irregularity due to the greater elapsed time and the difficulty of separating one complete event from another. Since the stage hydrograph used here is a plot of stage versus time, it was possible to read the storm parameters directly off of the charts.

Data Analysis

After selection of storm events, an orderly and convenient method of tabulation of the parameters was adopted. This was necessary to insure that the correct pairs of observations were correlated and that these correlations were kept in order. A separate tabulation was made for the pre-treatment and post-treatment data. An example of the tabulation method used here is in the Appendix, Table II.

The storm data was tabulated, converted into computer cards, and processed using the Control Data 3300 computer located on the Oregon State University Campus. The regressions were calculated pairing time-to-peak, height-of-rise,and peak discharge from Flynn Creek with the same parameters for the same storms on Deer Creek II and III. Since there were two treatment watersheds and three parameters of interest in each, there were six regressions in the pre-treatment period and six regressions in the post-treatment period.

The correlation coefficients of the pre-treatment regressions were then examined. As Bethlahmy (1963) mentioned, the correlation coefficient of each of the six regression lines must be relatively high. A low correlation coefficient would indicate either that the watersheds were not subject to the same climatic events or that the watersheds differed in some fundamental respect. If the correlation coefficients had been low, other more highly correlated watersheds would have been chosen.

A further analysis of the regression lines developed from the pre- and post-treatment periods of record was completed here. To determine if there was a significant change in the slopes of the regression lines due to treatment, an analysis of covariance test for homogeneity of regression coefficients was performed. A second test for homogeneity of adjusted means also was completed. The test of regression coefficients determines if there has been a change in the slope of the regression lines and the test of adjusted means checks for any change in elevation of the regression lines. A change in either slope or elevation would indicate that roadbuilding has influenced the storm hydrograph. Examples of the formulas used in each of the above tests can be found in the Appendix. The tests were performed as described by Li (1964).

RESULTS

The correlation coefficients for the pre-treatment regressions were considered prior to application of the statistical tests. The importance of the correlation coefficients has been mentioned earlier in this work and will not be reiterated here. The coefficients are presented in Table I.

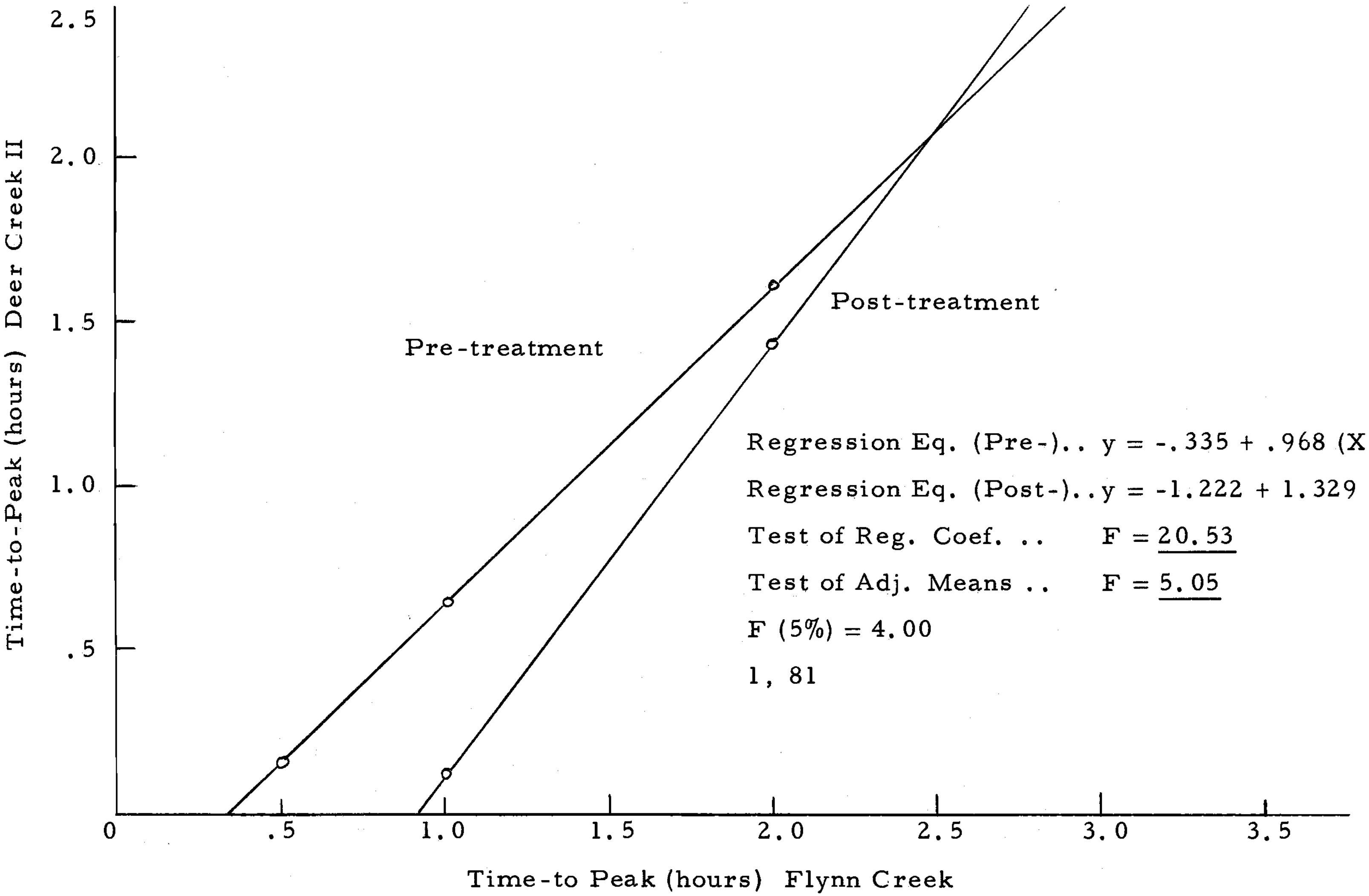
Table I. Correlation coefficients (r) for the pre-treatment regressions.

Parameter	Deer Creek II vs Flynn Creek	Deer Creek III vs Flynn Creek
Time-to-Peak	.988	.986
Height-of-Rise	.900	.910
Peak Discharge	.853	.861

The results of the tests involving the three storm parameters are given in the paragraphs to follow. Each parameter is considered individually.

Time-to-Peak

The regressions developed using the time-to-peak parameter are presented in Figures 4 and 5. The time-to-peak parameter is analogous to the lag time of a storm hydrograph, and it varies with watershed condition, storm intensity, and storm duration. The



Regression Eq. (Pre-).. y = -.335 + .968 (X)

Regression Eq. (Post-)..y = -1.222 + 1.329 (X)

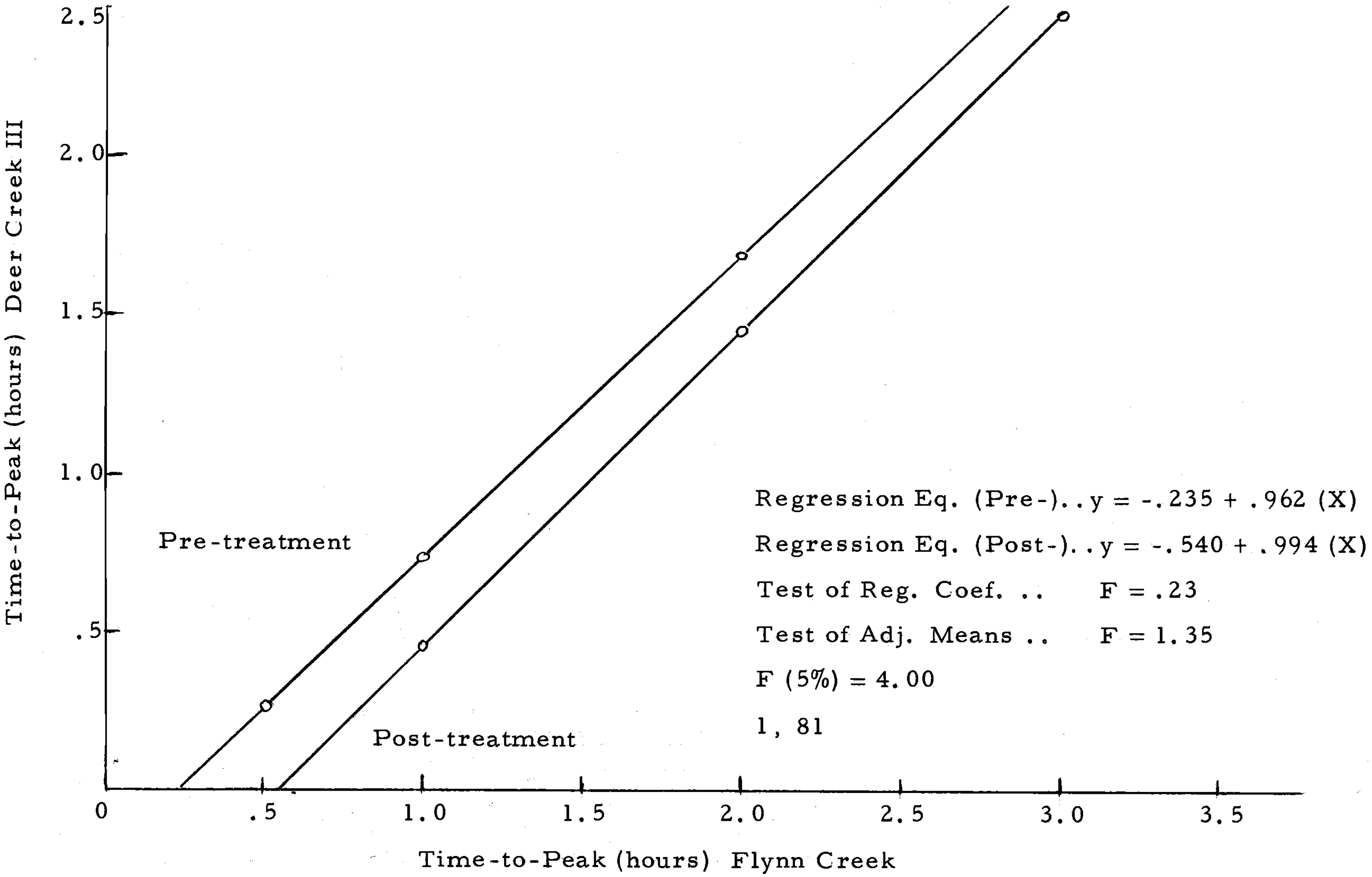
Test of Reg. Coef. .. F = 20.53

Test of Adj. Means .. F = 5.05

F (5%) = 4.00

1, 81

Figure 4. Comparison of pre- and post-treatment regressions of time-to-peak on Deer Creek II and Flynn Creek.



Regression Eq. (Pre-).. $y = -.235 + .962 (X)$

Regression Eq. (Post-).. $y = -.540 + .994 (X)$

Test of Reg. Coef. .. F = .23

Test of Adj. Means .. F = 1.35

F (5%) = 4.00

1, 81

Figure 5. Comparison of pre- and post-treatment regressions of time-to-peak on Deer Creek III and Flynn Creek.

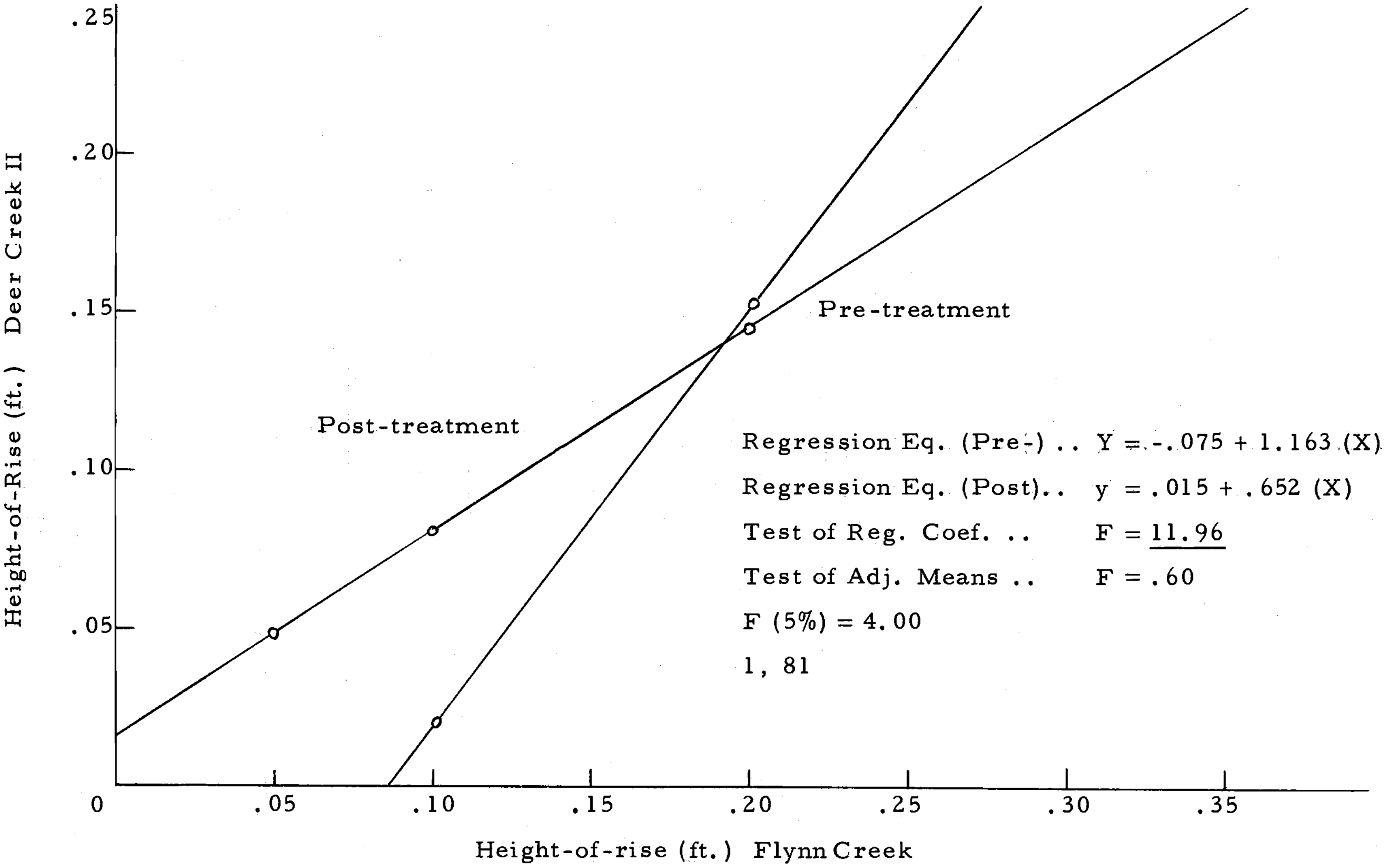
first two regression lines were developed from data on Deer Creek II and Flynn Creek (Figure 4). These lines indicate that significant changes (at the five percent level) occurred in both the regression coefficient and the adjusted mean of the post-treatment regression line. Apparently, the time it takes Deer Creek II to reach peak flow has been reduced for the smaller storms. However, the time-to-peak has been relatively increased for all those storms exceeding 2.5 hours. Approximately 75 percent of the observations on Deer Creek II are equal to or less than three hours, indicating that the lower part of the curve is well substantiated by actual observations and therefore is most important.

The relationship between Deer Creek III and Flynn Creek for the pre- and post-treatment periods is shown in Figure 5. It shows that there is a tendency for the post-treatment line to be below the pre-treatment line indicating that the time-to-peak values have been reduced due to treatment. However, the statistical tests show no significant change in regression coefficients or in adjusted means.

In evaluating the results of the test for homogeneity of adjusted means it should be noted that the general mean of all Flynn Creek observations is 3.80 hours. This is the point at which the regression lines in Figures 4 and 5 were compared. Any significant differences detected refer only to the position of the lines at that point. Where appropriate, values can be read directly from the graphs to illustrate the magnitudes of changes. Since a regression line indicates the mean of each array, points directly on the regression lines should accurately indicate the mean differences between lines. However, it should be noted that in the ranges where the differences in slope or elevation are not statistically significant, these differences could have resulted from chance and therefore are not reliable.

Height-of-Rise

The regressions developed using the height-of-rise parameter are presented in Figures 6 and 7. Height-of-rise is defined by Bethlahmy (1963) as the change in stage from the initial point of rise to the peak. The first of the two figures deals with data taken from Deer Creek II (Figure 6). The accompanying values indicate that there was a significant change in the regression coefficient but no significant change in the adjusted mean. Since 88 percent of all observations on Deer Creek II from the pre- and post-treatment periods were less than .15 feet, it is quite clear that the most important part of the graph is also below that value. The position of the two regression lines in the range from zero to .15 feet indicates that treatment did indeed cause the stream level to rise higher in response to rainfall events. The test of adjusted means was performed using .15 feet as the general mean of all Flynn Creek observations.



Regression Eq. (Pre-) .. $Y = -.075 + 1.163 (X)$

Regression Eq. (Post).. $y = .015 + .652 (X)$

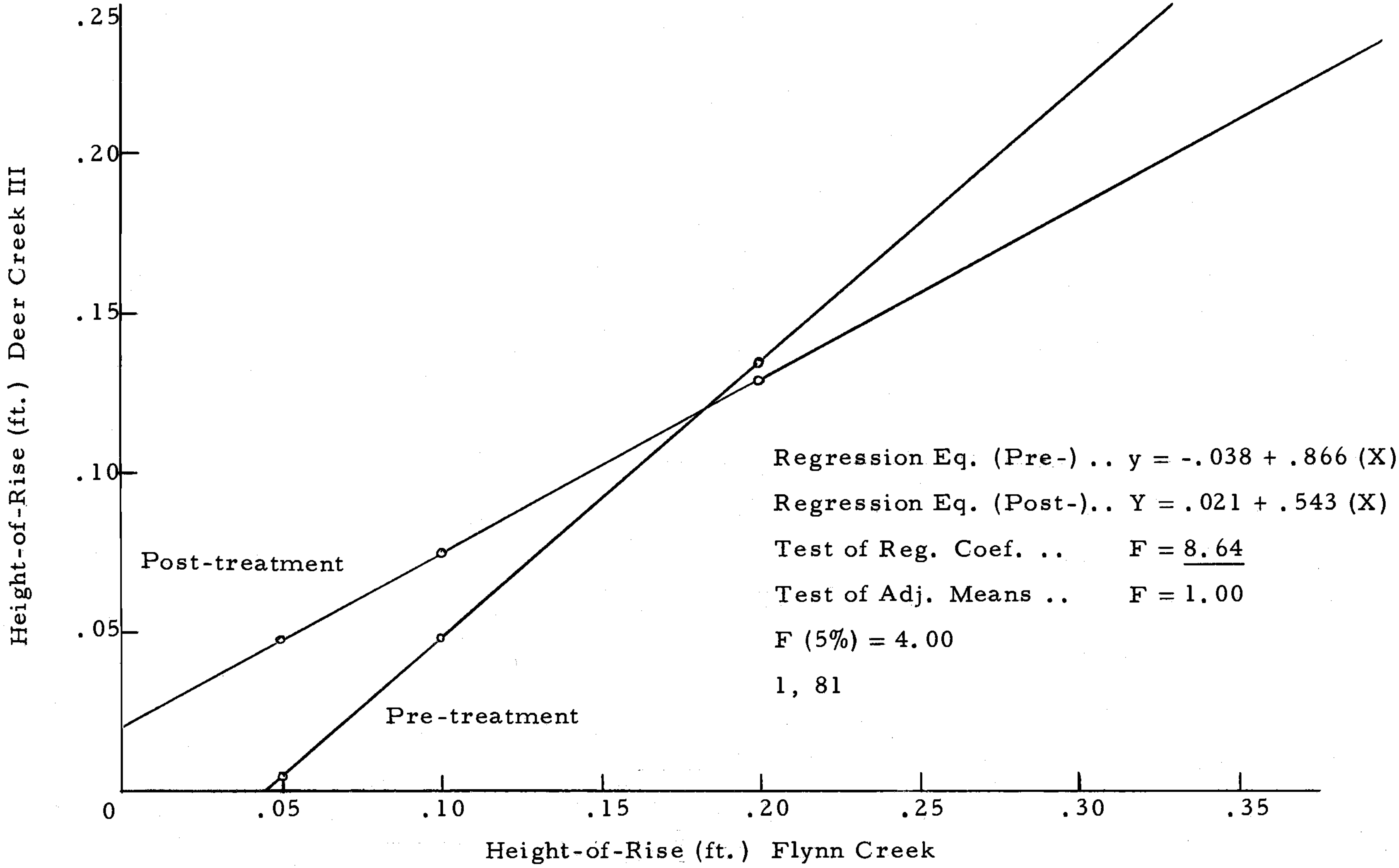
Test of Reg. Coef. .. $F = \underline{11.96}$

Test of Adj. Means .. $F = .60$

$F (5\%) = 4.00$

1, 81

Figure 6. Comparison of pre- and post-treatment regressions of height-of-rise on Deer Creek II and Flynn Creek.



Regression Eq. (Pre-) .. $y = -.038 + .866\,(X)$

Regression Eq. (Post-).. $Y = .021 + .543\,(X)$

Test of Reg. Coef. .. $F = \underline{8.64}$

Test of Adj. Means .. $F = 1.00$

$F\ (5\%) = 4.00$

1, 81

Figure 7. Comparison of pre- and post-treatment regressions of height-of-rise on Deer Creek III and Flynn Creek.

The results of the comparison using height-of-rise on Deer Creek III also show a difference after treatment (Figure 7). Again there is a significant change in the regression coefficients, but no significant change in adjusted means. Since the same Flynn Creek values were used here, the test for adjusted means was again performed using .15 feet as the general mean of all Flynn Creek observations. Again 88 percent of the Deer Creek III observations were less than .15 feet, so the lower section of the graph is well substantiated. It is apparent that the results here are very similar to those obtained in the comparison involving Deer Creek II.

Peak Discharge

The last two pairs of regressions were computed to see if some meaningful quantitative information about changes in peak storm flow could be collected using this method. These comparisons use peak discharge as the parameter of interest. Peak discharge is simply the largest discharge in cubic feet per second achieved during a storm. On small watersheds such as those used here, the magnitude of peak discharge is very closely related to watershed condition for all but the largest storms (Chow, 1964).

The regressions comparing peak discharge on Deer Creek II with the same parameter on Flynn Creek are plotted in the same manner as were the preceeding comparisons (Figure 8). The

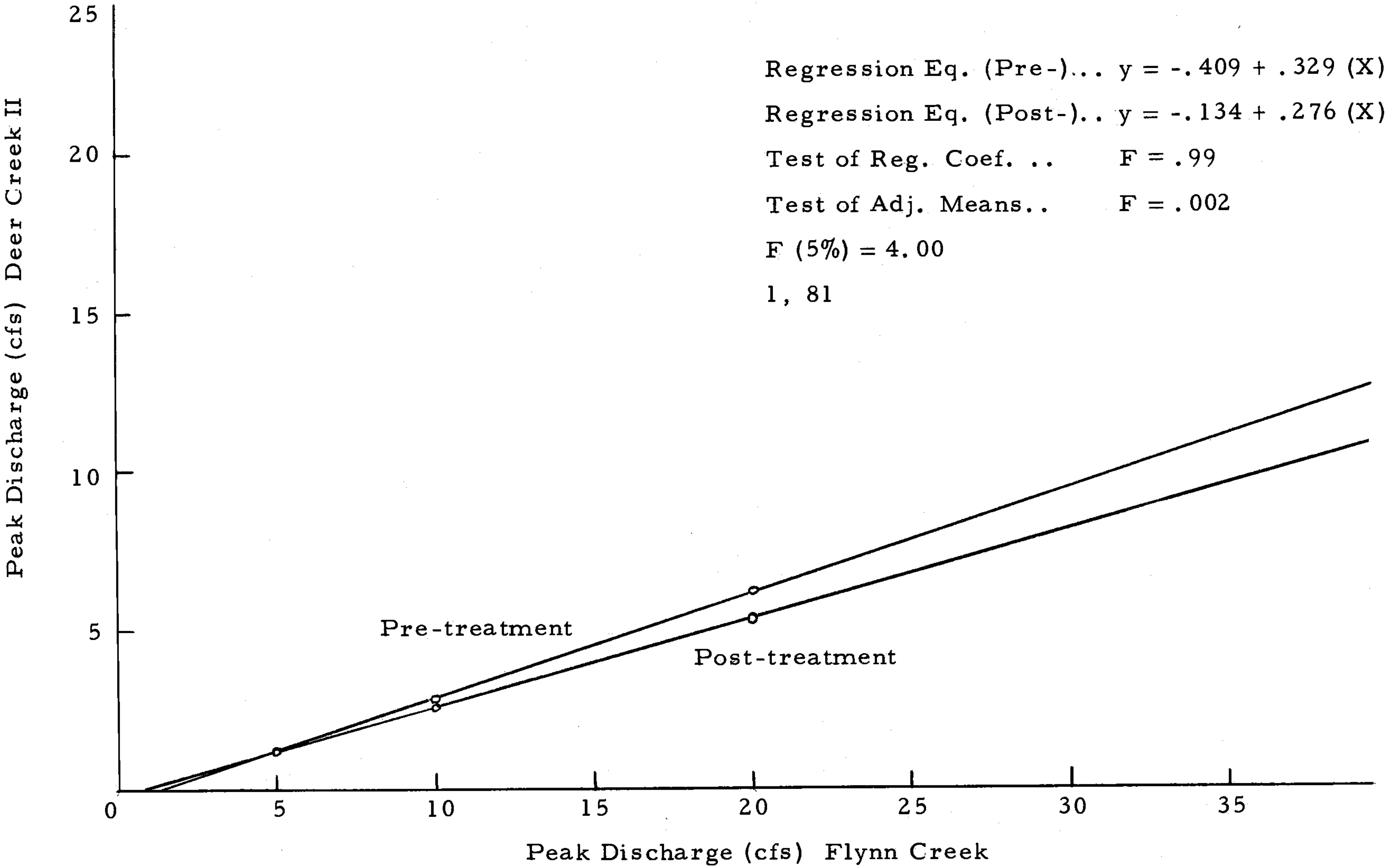


Figure 8. Comparison of pre- and post-treatment regressions of peak discharge on Deer Creek II and Flynn Creek.

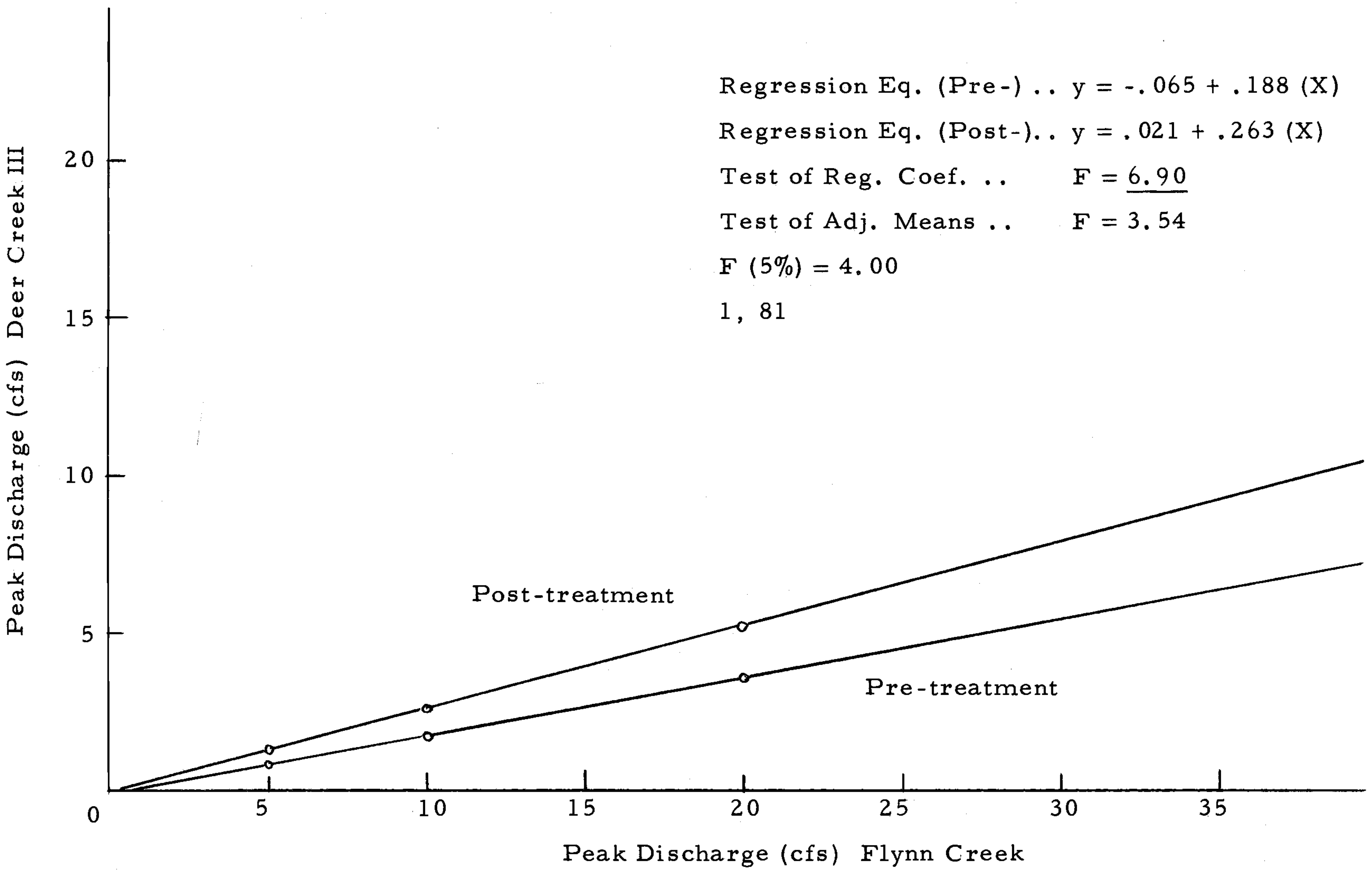


Figure 9. Comparison of pre- and post-treatment regressions of peak discharge on Deer Creek III and Flynn Creek.

accompanying statistical results indicate that there are no significant changes in either slope or elevation. Since treatment amounted to approximately three and one half percent of the area of Deer Creek II, it is not unreasonable to expect only a very small change in peak discharge, if any at all. The general mean of the Flynn Creek observations is equal to five cubic feet per second. The two lines have a common point at this value, so it is clear that the two periods showed very similar peak discharges.

The results of the comparison using peak discharge from Deer Creek III and Flynn Creek are plotted in Figure 9. Contrary to the previous results, the change in regression coefficients is significant and the test for homogeneity of adjusted means shows a change which is very close to the five percent level of significance. Both of the changes are in the positive direction indicating that the peak discharge of Deer Creek III is noticeably increased relative to Flynn Creek discharge as a result of treatment.

DISCUSSION AND CONCLUSIONS

Change in Parameters

The first objective of this thesis is to determine if roadbuilding has changed the characteristics of flow in the subwatersheds of Deer Creek. The regressions indicate that streamflow has been altered. Although only 3.5 percent of the area of Deer Creek II has been cleared, the time-to-peak and height-of-rise comparisons show statistically significant changes in the regression coefficients. The fact that most of the observations fall in the lower ranges where the regression lines show considerable differences lends strength to the hypothesis that changes in flow characteristics have occurred.

Deer Creek III showed changes in different characteristics than did Deer Creek II. Assuming other conditions to be equal, those changes must be the result of differences in the percentage of treated area. Deer Creek III contained approximately twice the percentage of treated area as did Deer Creek II. The main differences appeared in the comparisons involving time-to-peak and peak discharge. Deer Creek III showed a tendency towards a constant change (not statistically significant) in time-to-peak versus a changing relationship on Deer Creek II. Also, an increasing change in peak discharge is apparent as opposed to virtually no change on Deer Creek II. It must be concluded that roadbuilding has changed the time it takes water to flow off of these areas, the magnitude of storm response as measured by stream rise, and, with at least a seven percent treatment, the volume of peak storm discharge.

Discussion of Change

The second objective of this thesis is to interpret the observed changes in streamflow in terms of the factors which have been altered by treatment. The reduced post-treatment time-to-peak values observed on Deer Creek II, and the tendency towards reduction on Deer Creek III can be attributed to two factors: The removal of vegetation and accumulated organic matter, and the concentration and acceleration of water by the road surface.

The presence of vegetation and organic matter is known to retard the passage of water (Hoover, 1944). The removal of vegetation and organic matter facilitates the movement of water to the stream channels by overland flow and increased interflow. The road surface also acts to speed water movement since the reduced infiltration capacity of this surface causes overland flow. The ditch system concentrates this flow at several low points in the road. The culverts located at these low points direct this relatively large volume towards the stream channel over a comparatively small area which quickly becomes saturated. Subsequent road drainage is thus afforded speedier travel to the stream.

The increase in the height-of-rise values on both watersheds in the lower ranges is indicative of another change caused by vegetation removal for roadbuilding. The interception and detention storage afforded by the vegetation is more effective in substantially reducing the response to the smaller storms. When this influence is removed, the response in the range of the smaller storms should show the most significant change. This is verified by the regression lines from both watersheds. All storms beyond a certain size must not be noticeably affected by this relatively small change in storage capacity. This fact is also verified by the figures which show the regression lines crossing at a value of .18 feet. Storms which produce the larger rises must not be affected by the loss of interception and detention storage on such a small fraction of the total area (Penman, 1963).

Another change which must be explained is the increase in peak discharge exhibited on Deer Creek III after treatment. As mentioned earlier, the removal of vegetation eliminates the water loss to transpiration and interception caused by that vegetation. This is a factor contributing to the increase in peak discharge, but it probably is not the most important one. On these watersheds the most likely source of the increase is the removal of the ground cover and surface soil which accompanies roadbuilding. The ground cover softens raindrop impact and provides organic matter to the surface soil. This organic matter helps to develop soil structure, thus aiding the passage of water into and through the surface soil. Also, with vegetation removal, raindrop impact on mineral soil reduces infiltration and increases surface runoff.

Value of the Method

The final objective of this work is to indicate the value and efficiency of the calibration method used here. One important indication of the value of this method is that changes were detected even though the records used covered only a relatively short period, and were interrupted by many temporary stoppages. These two factors alone would have eliminated most methods of calibration. Another important consideration is the size of treatment. Even with treatment on only three and one half percent of the area, Deer Creek II showed a significant change in time-to-peak and height-of-rise. An important change was detected in peak discharge on Deer Creek III, which was subjected to a little less than seven percent treatment. Detection of changes in flow resulting from such small treatments is another sign of the efficiency and value of this method. Finally, the ease of computation and simplicity of analysis as exemplified by pages 47 through 49 in the Appendix and the graphs presented in the Results section complete the case in favor of this method.

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APPENDIX

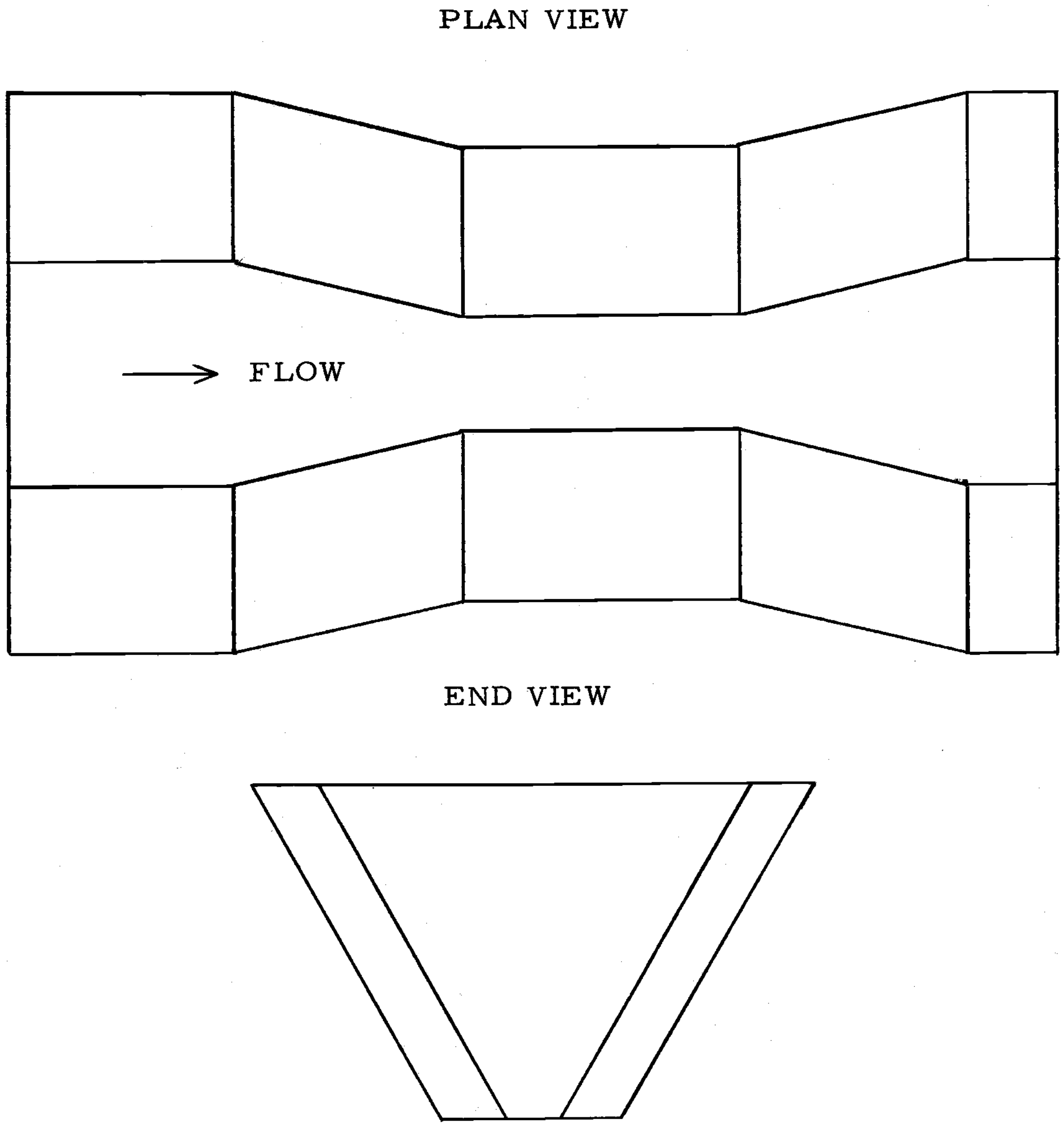

Figure 10. Plan and end views of venturi trapezoidal flume of the type used on Deer Creek II and III.

Table II. Storm parameters from which regressions were developed (Pre-treatment).

DEER CREEK II			DEER CREEK III			FLYNN CREEK			
Time to Peak(hrs)	Height of Rise(ft)	Peak Stage(ft)	Time to Peak(hrs)	Height of Rise(ft)	Peak Stage(ft)	Time to Peak(hrs)	Height of Rise(ft)	Peak Stage (ft)	
.50	.04	.62	.50	.08	.54	.75	.07	3.27	1
.75	.03	.31	.75	.03	.20	1.00	.07	2.68	2
.75	.02	.29	.75	.03	.19	1.00	.03	2.60	3
.75	.02	.59	.75	.02	.47	1.00	.03	3.23	4
1.00	.04	.18	1.00	.04	.15	4.00	.07	3.03	5
1.00	.02	.40	1.00	.03	.33	1.50	.04	2.70	6
1.00	.02	.27	1.00	.03	.25	1.50	.05	2.55	7
1.00	.06	.41	1.00	.06	.38	1.00	.13	2.83	8
1.00	.05	.52	1.00	.07	.47	1.50	.07	2.93	9
1.00	.01	.29	1.25	.02	.26	1.00	.03	2.63	10
1.00	.02	.05	3.00	.01	.06	4.00	.10	2.19	11
1.00	.06	.56	1.00	.09	.49	1.25	.13	3.06	12
1.00	.05	.56	1.00	.03	.49	1.25	.11	3.06	13
1.00	.02	.27	.50	.02	.16	1.00	.06	2.55	14
1.00	.02	.33	1.00	.03	.31	2.00	.10	2.85	15
1.00	.01	.40	1.00	.02	.33	1.50	.03	2.75	16
1.00	.02	.55	1.25	.04	.41	1.00	.04	3.15	17
1.00	.05	.60	1.00	.09	.52	1.50	.15	3.13	18
1.00	.02	.31	1.50	.03	.19	1.00	.07	2.68	19
1.00	.01	.42	1.00	.02	.40	1.00	.03	3.00	20
1.00	.02	.34	1.00	.02	.29	1.00	.05	2.83	21
1.00	.02	.15	1.00	.01	.15	1.00	.05	2.55	22
1.00	.03	.13	.50	.02	.15	2.00	.10	2.10	23
1.00	.04	.38	1.50	.06	.46	1.75	.17	2.77	24
1.25	.02	.29	1.50	.05	.27	1.50	.06	2.86	25
1.75	.06	.44	1.75	.07	.38	2.00	.14	2.85	26
2.00	.03	.32	2.00	.03	.31	2.00	.06	2.70	27
2.00	.05	.40	3.00	.07	.37	3.50	.10	2.80	28
2.00	.06	.45	2.00	.07	.41	2.00	.12	2.90	29
2.00	.08	.63	1.50	.06	.56	3.00	.15	3.02	30
2.00	.06	.09	2.00	.01	.06	2.50	.17	2.23	31
2.00	.09	.35	2.00	.10	.25	2.00	.21	2.71	32
2.00	.03	.35	2.00	.02	.31	1.50	.05	2.84	33
2.00	.05	.14	2.00	.01	.16	3.00	.22	2.17	34
2.00	.05	.30	2.00	.06	.30	2.50	.15	2.61	35
2.50	.06	.33	2.50	.08	.29	2.75	.15	2.67	36
2.50	.03	.40	2.50	.05	.35	2.50	.06	2.77	37
2.50	.07	.52	2.00	.10	.54	3.00	.15	3.10	38
2.50	.01	.19	2.50	.02	.18	3.00	.05	2.57	39
2.50	.06	.16	2.50	.05	.17	3.50	.15	2.58	40
2.50	.04	.10	2.00	.02	.13	3.50	.08	2.41	41
3.00	.05	.45	3.00	.05	.45	5.00	.08	2.60	42
3.00	.20	.45	3.00	.25	.50	3.00	.47	3.03	43
3.00	.03	.19	2.50	.04	.19	3.00	.13	2.60	44
3.25	.09	.39	3.25	.11	.34	3.50	.21	2.85	45
3.50	.02	.52	3.50	.04	.44	4.00	.05	2.97	46

Table II. Continued.

DEER CREEK II			DEER CREEK III			FLYNN CREEK			
Time to Peak(hrs)	Height of Rise(ft)	Peak Stage(ft)	Time to Peak(hrs)	Height of Rise(ft)	Peak Stage(ft)	Time to Peak(hrs)	Height of Rise(ft)	Peak Stage(ft)	
3.50	.09	.52	3.50	.08	.52	3.50	.19	3.01	47
4.00	.05	.35	4.00	.07	.30	3.00	.12	2.70	48
4.00	.07	.39	4.00	.09	.35	5.00	.18	2.78	49
4.00	.09	.12	6.00	.03	.07	4.00	.20	2.25	50
4.00	.12	.65	4.00	.17	.55	4.50	.25	3.20	51
5.00	.08	.44	5.00	.09	.45	5.00	.26	2.90	52
5.00	.05	.08	5.00	.01	.07	5.00	.13	2.24	53
6.00	.10	.28	7.00	.10	.26	6.50	.21	2.56	54
7.00	.18	.60	7.00	.20	.50	6.00	.22	2.82	55
12.00	.15	1.17	12.00	.09	.89	12.00	.15	3.51	56
14.00	.99	1.44	13.00	.66	1.10	14.00	.73	3.78	57
17.00	.39	.92	16.00	.33	.81	18.00	.43	3.33	58
18.00	.32	.94	18.00	.25	.77	19.00	.17	3.17	59
19.00	.65	1.50	19.00	.49	1.20	19.00	.59	3.83	60
19.00	.80	1.43	19.00	.64	1.10	20.00	.54	3.73	61

Table II. Continued. (Post-treatment).

DEER CREEK II			DEER CREEK III			FLYNN CREEK			
Time to Peak(hrs)	Height of Rise(ft)	Peak Stage(ft)	Time to Peak(hrs)	Height of Rise (ft)	Peak Stage(ft)	Time to Peak(hrs)	Height of Rise(ft)	Peak Stage (ft)	
.75	.02	.39	.75	.02	.35	1.50	.07	2.76	1
1.00	.07	.50	1.00	.05	.48	1.75	.13	2.77	2
1.00	.01	.38	1.00	.05	.32	1.00	.05	2.75	3
1.00	.02	.37	.50	.02	.39	1.00	.06	2.80	4
1.00	.03	.71	1.00	.06	.61	2.00	.13	2.97	5
1.50	.06	.21	1.50	.03	.21	3.00	.25	2.35	6
1.50	.03	.39	1.00	.05	.38	1.50	.05	2.76	7
1.50	.05	.58	1.00	.07	.63	1.00	.05	3.17	8
1.50	.09	.46	1.50	.07	.43	2.00	.17	2.77	9
1.50	.02	.49	1.50	.04	.48	1.50	.06	2.89	10
2.00	.01	.61	2.00	.04	.53	3.00	.05	3.10	11
2.00	.04	.57	2.00	.14	.59	3.00	.15	3.10	12
2.00	.03	.59	1.00	.10	.69	2.00	.05	3.20	13
3.00	.04	.50	3.00	.10	.59	3.25	.06	3.15	14
3.00	.06	.46	3.00	.13	.48	3.25	.15	2.87	15
3.25	.16	.77	3.50	.18	.80	3.50	.20	3.39	16
3.50	.06	.71	4.00	.12	.67	4.00	.10	3.19	17
3.50	.06	.39	3.50	.14	.46	4.00	.17	2.87	18
4.00	.08	.43	4.00	.08	.42	4.00	.25	2.82	19
5.00	.15	.36	4.50	.12	.78	7.00	.57	3.24	20
5.00	.03	.32	5.00	.10	.37	6.50	.08	2.70	21
6.00	.03	.50	4.50	.06	.50	5.50	.12	2.97	22
11.50	.42	.86	8.00	.43	.78	7.00	.57	3.24	23
14.00	.33	1.21	10.00	.20	1.19	10.00	.16	3.76	24

Table III. ANALYSIS OF COVARIANCE FORMULAS*

Test of Homogeneity of Regression Coefficients

$$F = \frac{\left(\dfrac{\dfrac{SP_1^2}{SSx_1} + \dfrac{SP_2^2}{SSx_2} - \dfrac{(SP_1 + SP_2)^2}{SSx_1 + SSx_2}}{k - 1} \right)}{\left(\dfrac{SSy_1 + SSy_2 - \dfrac{SP_1^2}{SSx_1} - \dfrac{SP_2^2}{SSx_2}}{\Sigma n - 2k} \right)}$$

Test of Homogeneity of Adjusted Means

$$F = \frac{\left(\dfrac{\Sigma W(\bar{y}_x)^2 - \dfrac{(\Sigma W\bar{y}_x)^2}{\Sigma W}}{k - 1} \right)}{\left(\dfrac{SSy_1 + SSy_2 - \dfrac{SP_1^2}{SSx_1} - \dfrac{SP_2^2}{SSx_2}}{\Sigma n - 2k} \right)}$$

Definition of Terms:

SSx_1	Residual sum of squares of the 'x' population; pre-treatment
SSy_1	Residual sum of squares of the 'y' population; pre-treatment
SSx_2	Residual sum of squares of the 'x' population; post-treatment
SSy_2	Residual sum of squares of the 'y' population; post-treatment

Table III cont.

SP	Residual sum of the products of the two populations
Σ	Sum of the ...
n	Number of observations
k	Number of populations - equals 2
$\bar{x}$	Mean of the 'x' population; Flynn Creek
$\bar{\bar{x}}$	General mean of both 'x' populations; pre- and post-treatment
$\bar{y}$	Mean of the 'y' population
W	Weighting factor $= \dfrac{n\,(SSx)}{SSx + n\,(\bar{x} - \bar{\bar{x}})}$

*After Li, 1964.