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Hydrologic Effects of Contour Trenching on Some Aspects of Streamflow from a Pair of Watersheds in Utah

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HYDROLOGIC EFFECTS OF CONTOUR TRENCHING ON SOME ASPECTS OF STREAMFLOW FROM A PAIR OF WATERSHEDS IN UTAH

by

Robert Dean Doty

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The encouragement and understanding of my wife was also significant in the completion of this thesis. And to my children, perhaps some day they will read this and understand why I was not always able to play ball or read a story during that long winter of 1970.

I am also grateful to the members of my graduate committee, Dr. George Coltharp, Dr. Joel Fletcher, and Mr. Eugene Farmer for their helpful suggestions and encouragement.

Robert Dean Doty

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ABSTRACT

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by

Robert Dean Doty, Master of Science

Utah State University, 1970

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Streamflow from two drainages of the Davis County Experimental Watershed, Utah, was evaluated with respect to changes in distribution and volume following trenching of one of the drainages in 1964. Fifteen percent of the Halfway Creek drainage was trenched according to established U. S. Forest Service methods. Twelve years of records before trenching and four years of records after trenching were analyzed.

Analysis of the annual streamflow, the low streamflow period, and the spring streamflow period indicated no significant change in either volume or distribution of streamflow as a result of trenching. This conclusion was further substantiated by supplemental data of precipitation, soil moisture, snowpack water equivalent, and vegetation.

(78 pages)

INTRODUCTION

The deteriorated condition of numerous high mountain watersheds in the Intermountain West, at the turn of the century, resulted in severe flooding of valuable lowlands which caused the loss of life and considerable property damage. Overgrazing and burning are considered the primary factors in the deterioration and the resulting floods (Cannon, 1931). This theory is substantiated in many of the articles written about the floods since 1923 (Alter, 1930; Craddock, 1946; Forsling, 1931). Bailey (1934) points out that the geologic evidence left by the recession of Lake Bonneville some 20,000 years ago indicates that floods of such magnitude did not occur before recent times.

In an effort to correct this deteriorated condition, an extensive watershed rehabilitation program was undertaken in the early 1930's (Copeland, 1960). Contour trenching, among the numerous practices applied, was so successful that it has become widely accepted as a rehabilitation method (Bailey, et al., 1947). By 1961, approximately 30,000 acres had been treated by this method in the Intermountain Region.

Through the years contour trenches have developed from small handmade furrows or trenches one to two feet deep, to three and four-foot deep trenches made with heavy equipment.

THE PROBLEM

Contour trenching, from its inception, met with great success in preventing or reducing floods and little or no research has been undertaken to evaluate it. As time went by and the trenches became larger and demands for water greater, people began to question the practice of contour trenching due to its possible effect on water yields. The era of severe flooding has apparently passed and the benefits of trenching were forgotten.

Little or no analytical data has been collected over the years to assess the effects of contour trenching on streamflow. It has been suggested that annual streamflow is reduced by trenching. This is quite possible from the evidence given by water conservation practices such as contour terracing and water spreading techniques used on agricultural land (Branson, et al., 1966; Mickelson, 1968; Zingg and Hauser, 1959). Yet, total annual streamflow does not reflect usable annual streamflow, which may be increased by better distribution of the streamflow through the year. This leads us to the question of what effect the trenches have on spring streamflow, both from the standpoint of peak streamflow and total volume of streamflow over the spring streamflow period. The trenches provide a catchment within the snow zone which may retard and retain the moisture accumulated in the snowpack over the winter. With adequate infiltration rates most of the water resulting from snowmelt should reach the stream at a later date. The extent of this release and its timing is a most important question to answer if any possible change in useable annual streamflow is to be assessed. Base streamflow, or the low streamflow season, is expected to be the time most likely to benefit from such an altered streamflow pattern.

Although trenches were designed for and are used to regulate peak streamflows from high intensity summer rain storms, their direct effect on the total streamflow is probably not great, because streamflow from summer storms represents less than one percent of the total annual streamflow. It is the sharp peaks from such storms which cause flooding if not controlled.

In order to fully evaluate any changes in streamflow it is necessary to consider what possible sources of change are present. For instance, snow distribution in the trenched area is influenced by the nature of the trenches which may result in more snow available for runoff. On the other hand, water trapped in the trenches may be retained as soil moisture and not contribute directly to streamflow. The net effect of any changes should be reflected in the growth of vegetation and the consequent consumptive use (Quackenbush, 1967).

The problem might be summarized by saying that in order to properly assess whether or not contour trenching has an effect on streamflow, data are required which involves streamflow from an area both before and after it is trenched. Such streamflow data must be used to evaluate changes with regard to timing, as well as, to total streamflow.

OBJECTIVES AND SCOPE

Hydrologic effects of contour trenching were evaluated in this study on the basis of streamflow and precipitation records in terms of:

(1) The total volume of annual streamflow received from a pair of watersheds, measured over a 16 year period.

(2) The characteristics of spring streamflow relative to total volume of spring streamflow, peak volume of spring streamflow, and spring recession streamflow.

(3) The characteristics of the low streamflow period (July through February) with respect to total volume of streamflow.

To help evaluate and pinpoint sources of possible changes in the above factors, measurements of soil moisture, vegetation, and snow distribution were made on the trenched area and on an adjacent untrenched area.

It was not intended, within the scope of this study, to evaluate the trenches with respect to infiltration capacity, revegetation, or construction techniques. Information from this study may eventually be used in cost-benefit ratio analysis to determine the feasibility of future trenching operations.

PAST AND CURRENT WORK

Considerable information on contour trenching has been published concerning its apparent beneficial effect of reducing or preventing the recurrence of mudrock flows from deteriorated watersheds. Bailey and Croft (1937), in a comprehensive paper on the early work that was done, developed criteria for assessing the need for rehabilitation and the application of trenching. A later publication by Bailey and Copeland (1961) goes more into an analysis of the relationships between vegetation and soil erosion, as well as, an analysis of rehabilitation of damaged watersheds by engineering structures. In the progress report of research (USDA, 1940), contour trenching is discussed as a method of retaining water during high intensity storms and then yielding it slowly to the stream. For a detailed explanation of trenching criteria and trench construction, as applied by the U. S. Forest Service, the reader is referred to the following reference: Forest Service Category 2 Handbook 2533, Land Treatment Measures Handbook (1959). Also a more recent description of the U. S. Forest Service's criteria for trench design and application is given by Noble (1963).

Although much has been published on the technique of contour trenching, virtually no research has been done to determine what effects trenching has on streamflow. Bailey and Copeland (1960) compared streamflow records from a pair of watersheds on the Davis County Experimental Watershed. One of the watersheds was trenched in 1935 with small handmade trenches, while the other watershed served as a control. This study showed a gradual decrease of 2.70 inches in average annual streamflow from the trenched watershed over a 22-year period. Most of the decrease came during the high flow months of March, April, and May. This represents a 23 percent decrease in annual flow, apparently due to revegetation, as a result of the stabilizing effect of the trenches, and to restricted grazing. This study is significant in relating revegetation to streamflow and regulation of peak flows, but no records were available to compare total flow and peak flows on the trenched watershed before and after trenching. Nor, was there any data taken to assess changes in soil moisture, sediment production, or snow movement on the trenched area.

The Watershed Rehabilitation Project at Logan, Utah, under the direction of Paul E. Packer, initiated a study in 1964 to evaluate large trenches made with heavy equipment on the Davis County Experimental Watershed. That study goes into a thorough evaluation of infiltration and sedimentation in the trenches, and the vegetation development in and between the trenches. The scope of that study does not include an evaluation of soil moisture, snowpack, or streamflow although peak streamflows were reduced.

Considerable literature is available on agricultural type structures including terracing, contour furrows, and cropping practices which in effect are directed at slowing overland flow. This work may give some insight as to the possible effect of trenching on water yields, but it must be kept in mind that agricultural lands are generally less sloping with deeper soils than those commonly found on high mountain watersheds where contour trenching is done. Zingg and Hauser (1959) reported on work they did near Amarillo, Texas, where little surface runoff is expected normally. They theorized that by concentrating what runoff there was available, crop yields would be increased. They utilized a system of terraces consisting of benches with ridges on the outside. The area above the bench was normally sloped and served as a contributing area. Thus the crop and water were concentrated on a portion of the land area. Results were based on increased yields from the area or that portion of the area where the crop was grown. No actual runoff measurements were made, but estimates of probable runoff retained for plant growth were made by extrapolating a precipitation-runoff relationship for a broad area in the Mid-south. As much as two inches of surface runoff may have been retained under these conditions.

Mickelson (1968) used a similar method near Akron, Colorado. Soils there are a highly productive silt loam grading into a clay loam. Runoff from the contributing area above the terraces was measured, along with precipitation and soil moisture at the time of seeding and harvest. This area averages 16.7 inches of precipitation annually with only 1.2 inches of runoff; most of the runoff occuring during the summer. An increase in soil moisture of about four inches was measured from the concentration of this runoff in the bench area. Again results were measured in terms of the crop yield obtained.

Comparisons of the effects of contour furrowing, pitting, and ripping on rangelands from Montana to New Mexico were made by Branson, et al. (1966). Increases in soil moisture were recorded along with increases in forage production. The primary factor here was to increase infiltration by physically ripping up the land and delaying runoff. Again the area studied was one of low annual streamflow, the majority of which occured during summer rainstorms. In contrast, contour trenching, as studied here, is generally done at high elevations where considerable precipitation is received, much of which is yielded as streamflow during spring streamflow from snowmelt.

The effect that trenches might have on snowpack accumulation is suggested by Lull and Orr (1950) in work done with fence barriers. Density of the snow, as well as total water content after April 1 was increased by using 11-foot barrier fences. Peak flows were reduced while total runoff through the spring-early-summer period was increased. The results failed to indicate whether more water was held on the watershed or if this was just a redistribution of snow within the same watershed. Staple and Lehane (1955), in evaluating shelterbelts, found a reduction in wind velocity beyond the trees up to 20 times the tree height, which contributed to the accumulation of snow behind such barriers.

In reviewing our present knowledge of watershed hydrology, it becomes apparent that several causal relationships may exist between contour trenching and water yield. However, a more thorough understanding of trenching is necessary to adequately determine what, if any, changes in water yield or water quality can be attributed to contour trenching of watersheds.

DESCRIPTION OF THE AREA

The contour trenched area is located in the Halfway Creek drainage which is a sub-drainage of the Farmington Canyon watershed north-east of Farmington, Utah (figure 1). Farmington Canyon is an approximately ten square mile watershed which has been intensively studied by the U. S. Forest Service as a typical Wasatch Front watershed. Within this area are several sub-drainages which have varying lengths of streamflow records. A network of precipitation gages and snow courses, used in this study, also exist on the area. The description of the area which follows, highlights those aspects considered important to contour trenching. A more detailed survey of the area is given in a thesis by Glasser (1969). Although the following description of the area may apply to most of the Farmington Canyon watershed, it is primarily a comparison of the Halfway Creek and Miller Creek drainages.

Topography

The Wasatch range constitutes an abrupt transition from the Great Basin valley floor (elevation 4200 feet) to the top of the Wasatch Mountain range (Bountiful Peak elevation 9200 feet). Within the 464 acre Halfway Creek drainage elevations range from 6200 feet to 9000 feet. A similar situation exists for the Miller Creek drainage where elevations range from 6500 feet to 8500 feet. The resulting stream gradients for the two drainages are shown in figure 2. Both drainages

Figure 1. Topographic map of the Farmington Canyon watershed showing the locations of long term instrumentation.

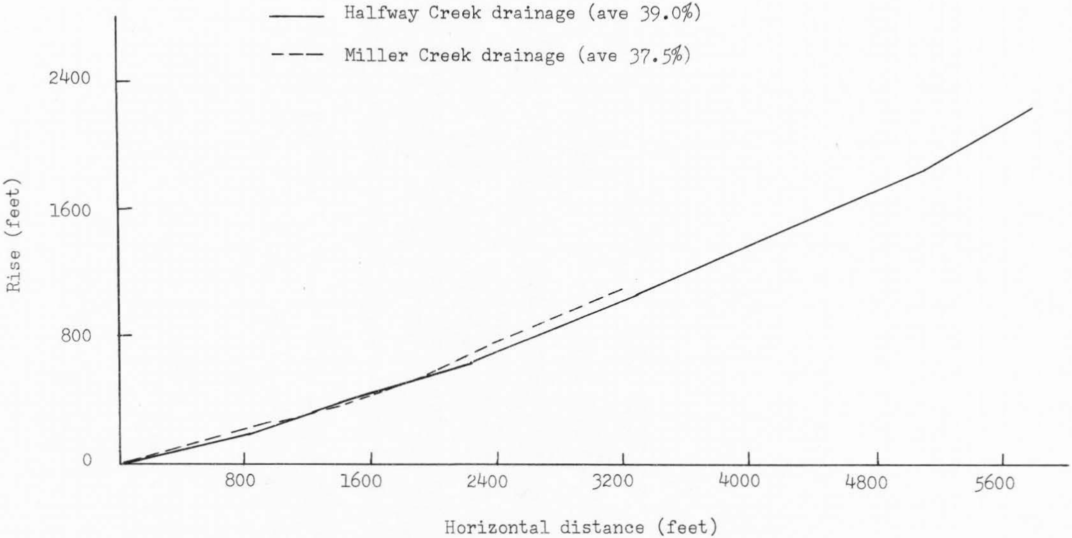

Figure 2. Stream gradient curves of the Halfway Creek and Miller Creek drainages.

show similar gradients of approximately 38 percent. The main difference is in the length of reach. The Halfway Creek main channel is slightly over one mile long, while the Miller Creek main channel is approximately two-thirds of a mile long. Measurements of stream gradient are based on detailed topographic maps made during a vegetation survey that was done in 1937.

A comparison of the Halfway Creek and Miller Creek drainages is given by the dimensionless area-elevation curve (Aronovici, 1966) in figure 3. Regardless of size, had the two drainages been similar in configuration the two curves would have coincided along their entire length. The departure of the curves reflects the fact that the Miller Creek drainage has a higher percentage of its area at the higher elevations. This greater proportion of headwater area is shown in the topographic map.

Aspects of the two watersheds are extremely different, with Halfway Creek facing southwest and Miller Creek facing north. This contributes to a difference in precipitation patterns and vegetation growth on the two watersheds. However, as extremely different as the two watersheds may appear, their hydrographs react quite similarly as will be shown later in the analysis.

The detailed maps that follow illustrate the complexity of the two drainages (figures 4 and 5). The major rock outcrops and the ridgelines are shown on the Halfway Creek drainage map. The Miller Creek drainage map does not show rock outcrops but they occur in a similar manner to those in the Halfway Creek drainage. The Halfway Creek drainage shows a find network of contributing streams, many

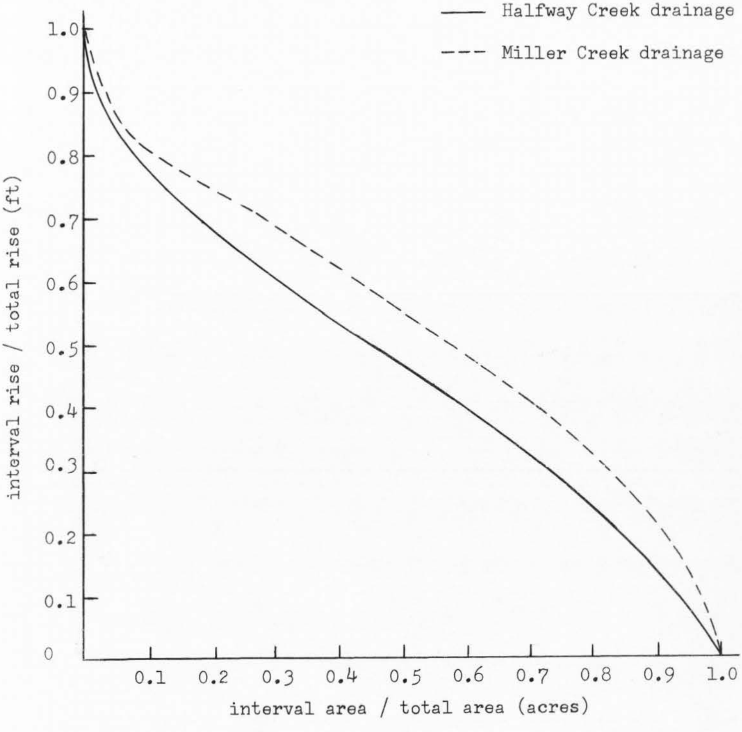

Figure 3. Dimensionless area-elevation curves for the Halfway Creek and Miller Creek drainages.

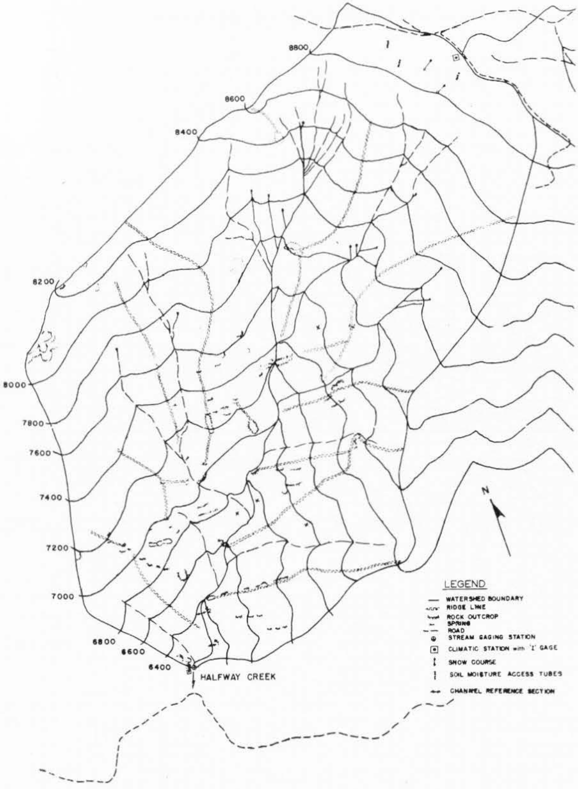

Figure 4. Detailed topographic map of the Halfway Creek drainage.

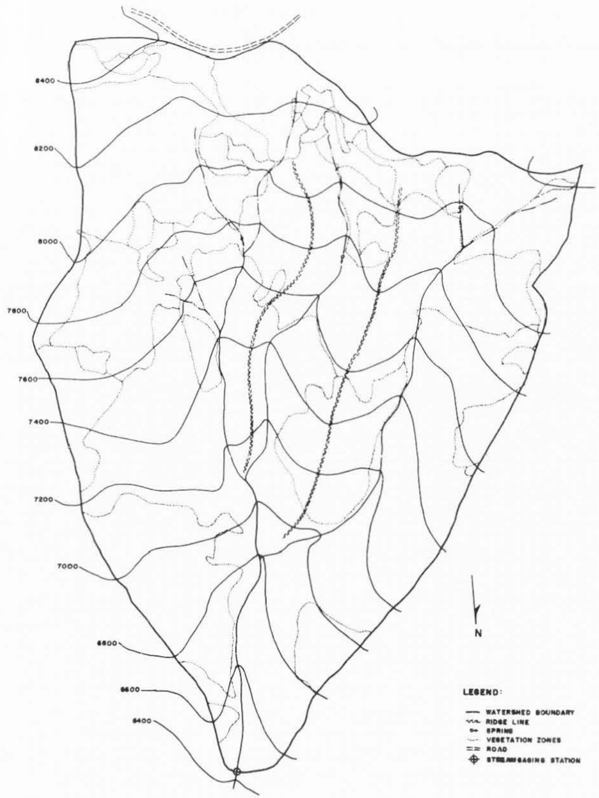

Figure 5. Detailed topographic map of the Miller Creek drainage.

of which are headed by perennial springs, therefore suggesting a broad contact zone. This zone occurs just below the lower extent of the trenching. Many of the intermittent stream channels that extend up into the trenched area are deeply incised "V"-shaped channels. Major channels in the Halfway Creek drainage are "V"-shaped, 10 to 20 feet deep and as wide as 40 to 60 feet. Such channels extend well up into the drainage with bedrock forming the bottom of the channels. Stream channels in Miller Creek do not reflect to any extent this degree of cutting. The lower reaches are well vegetated and less than 10 feet deep and 20 feet wide.

Geology

Local geologic structures have influenced the shaping of the area, but the diastrophic process which created the Wasatch range account for most of the area's present appearance (Thornbury, 1954). This is especially true due to the young (geologically) nature of the area (Bell, 1952). The running water erosion and frost action process which account for most of the aggradation of the area have not had a long time to make their work a predominant part of the landscape. Glacial periods have not greatly influenced the Halfway Creek drainage in a noticeable way. However, the area immediately to the west of the Halfway Creek drainage is evidently a cirque formation. Both the Miller Creek and Halfway Creek drainages were at least influenced by the increased cold and precipitation of the ice age.

Some important geologic features, which may also influence the results of this study, become apparent when the following geologic map (figure 6) is compared with the topography of the area (figure 7).

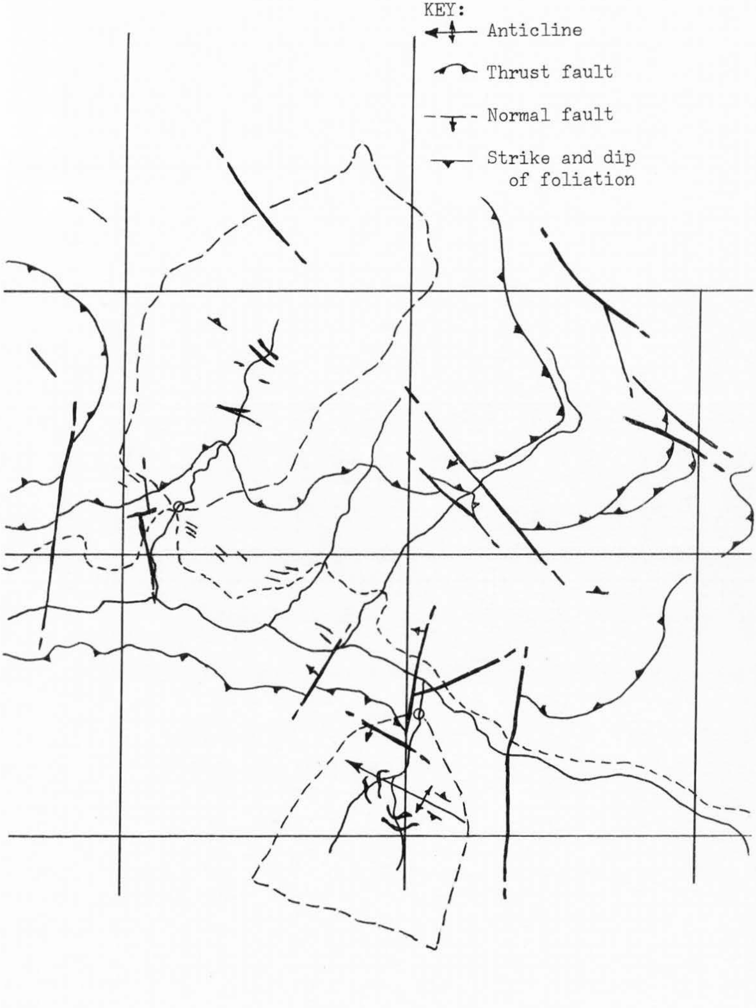

Figure 6. An enlarged portion of a geologic map, by Bell (1952), of the Halfway Creek drainage and nearby drainages showing associated geologic formations.

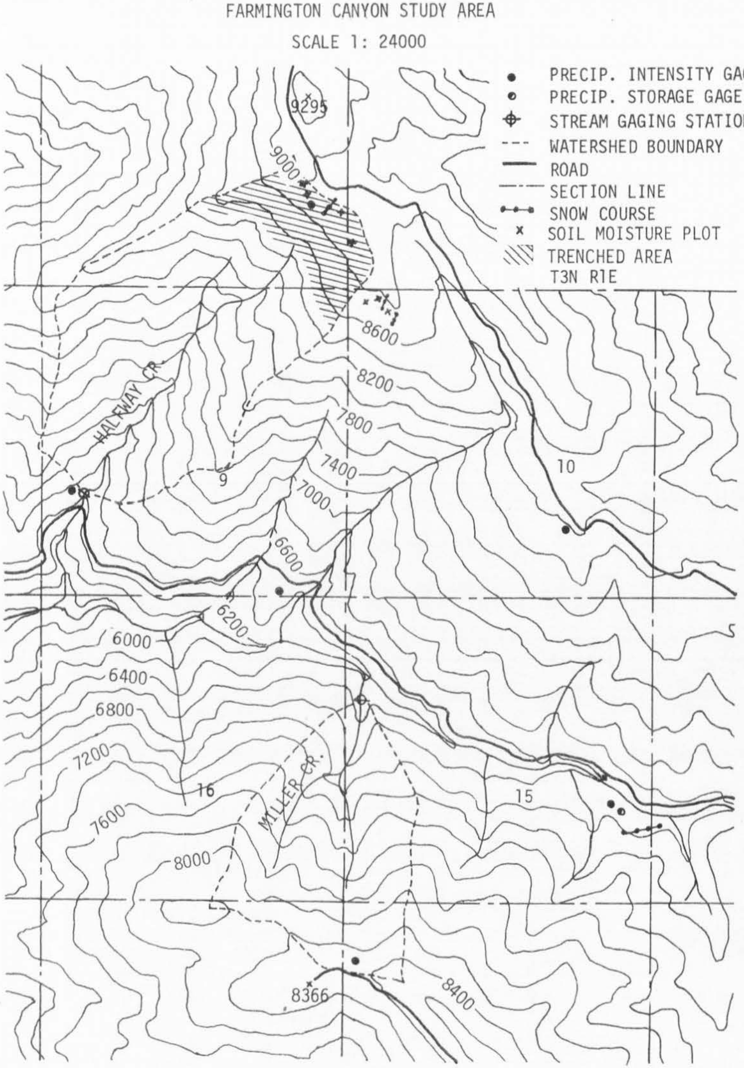

Figure 7. Topographic map of a portion of the Farmington Canyon watershed showing locations of instrumentation on the Halfway Creek drainage.

Comparison of the fault lines with stream locations, and the strike and dip information with contour lines, helps explain the occurrence of the contact zone in the Halfway Creek drainage. The prevailing winds move considerable snow out of the Halfway Creek drainage, which may return as seepage along the fault zone. Springs thus occur in the Halfway Creek drainage which are fed by the large accumulation of snow in the cirque basin immediately west of the Halfway Creek drainage. The headwater areas of the Halfway Creek and Corduroy Creek drainages are formed from the upper block of a thrust fault separating the two from the Whipple Creek drainage which is an unusual "L"-shaped drainage.

Rocks of the Halfway Creek and Miller Creek drainages are primarily from the Farmington Canyon Complex formation, which is made up of a group of metamorphic rocks. Basically the area consists of a megmatite rock mass which is essentially a bonded hornblende-biotite gneiss. Intruded into this are pegmatite dikes of a harder rock which has deformed much of the gneiss. This is quite often evidenced by the folded bands in the hornblende. The hornblende material is a soft metamorphic rock which weathers more rapidly than the intruded masses, and in the higher elevations it reduces to an unconsolidated mass in the frost zone. In many places the pegmatic rocks project above the surrounding terrain of weaker rocks.

Another predominate rock group present in the Halfway Creek drainage is the greenschist facies bisecting the drainage and forming major waterfalls at their intersection with the stream channel. The high content of quartz in this rock group makes it another hard crystalline rock.

There is also a group of rocks in the area which is remnants of a more recent Pliocene Weber Valley surface which is a pediment slope sitting on top of the fault block which makes up the Halfway Creek and Corduroy Creek headwaters area. In places this pediment surface has soils up to 100 feet thick.

Generally the soils are coarse textured, immature, rocky, and shallow. Seismic work conducted in the trenched area showed an average depth of surface material of seven feet. It appears from trench cuts and a dug pit that much of this seven feet of material is little more than parent material disintegrated in place by frost action.

Vegetation

An intensive vegetation survey was conducted on the area in 1939. The Miller Creek drainage was resurveyed in 1954 (Winters, 1954). The maps and description presented here are adapted from those surveys.

The Halfway Creek drainage may be broken down into five major vegetative zones as shown in figure 8. In this drainage the Aspen (Populus tremuloides) zone occupies the wetter sites along stable stream courses just below and to some extent up into the contact zone where numerous springs occur. Adjacent to the aspen, on slightly drier sites, are the Ceanothus (Ceanothus veutinus) and Mixed Brouse (Amelanchier utahensis, Prunus virginiana, Symphoricarpos sp., Alnus tenuifolia) zones. Both zones form dense thickets of brush with little understory. The ceanothus zone is separated from the mixed brouse zone because it so completely dominates the area where it occurs and forms a much shorter type of cover. Along the upper ridges

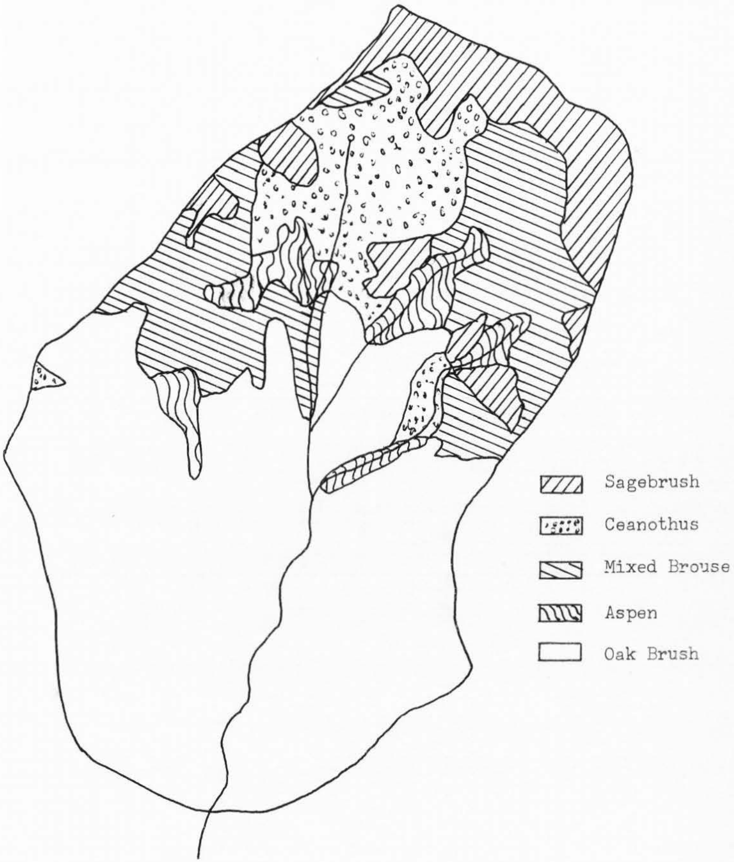

Figure 8. The Halfway Creek drainage map showing the five major vegetation zones.

and drier mid-slopes two forms of sagebrush (Artemisia tridentata, and Artemisia scopulorum) predominate with a variety of grasses and forbs occupying the zone as well. This zone represents the poorest sites and areas of least vegetation. As a result, it is this zone which is trenched in this particular case. Finally, the Oak Brush (Quercus gambelii) zone occupies over 50 percent of the drainage. The oak, as mapped here, ranges from sparcely vegetated dry slopes where much Mountain Mahogany (Cercocarpus ledifolias) is found, to a dense oak brush cover intermixed with Maple (Acer glabbrum) with little understory on the wetter sites.

The Miller Creek drainage is more forested and generally much better vegetated than the Halfway Creek drainage (figure 9). Here the ceanothus zone is replaced by Subalpine Fir (Abies lasiocarpa) which occupies much of the upper middle part of the drainage. Interspersed with the fir are clones of quaking aspen. Because of the exposure and wetter sites aspen is also found well down into the bottom of the drainage in the mixed browse zone. The oak brush zone is completely absent. Some oak does occur on the drier ridges and opposite the Miller Creek drainage on the south exposures. Along the top of the Miller Creek drainage the sagebrush zone occurs in a similar manner to that on the Halfway Creek drainage. This is just an extension of the same zone on the opposite side of the ridge and is primarily on the windswept portion of the watershed. The grass-forb zone occurs on those areas where snowbanks persist late into the summer, greening for only a short period during the growing season.

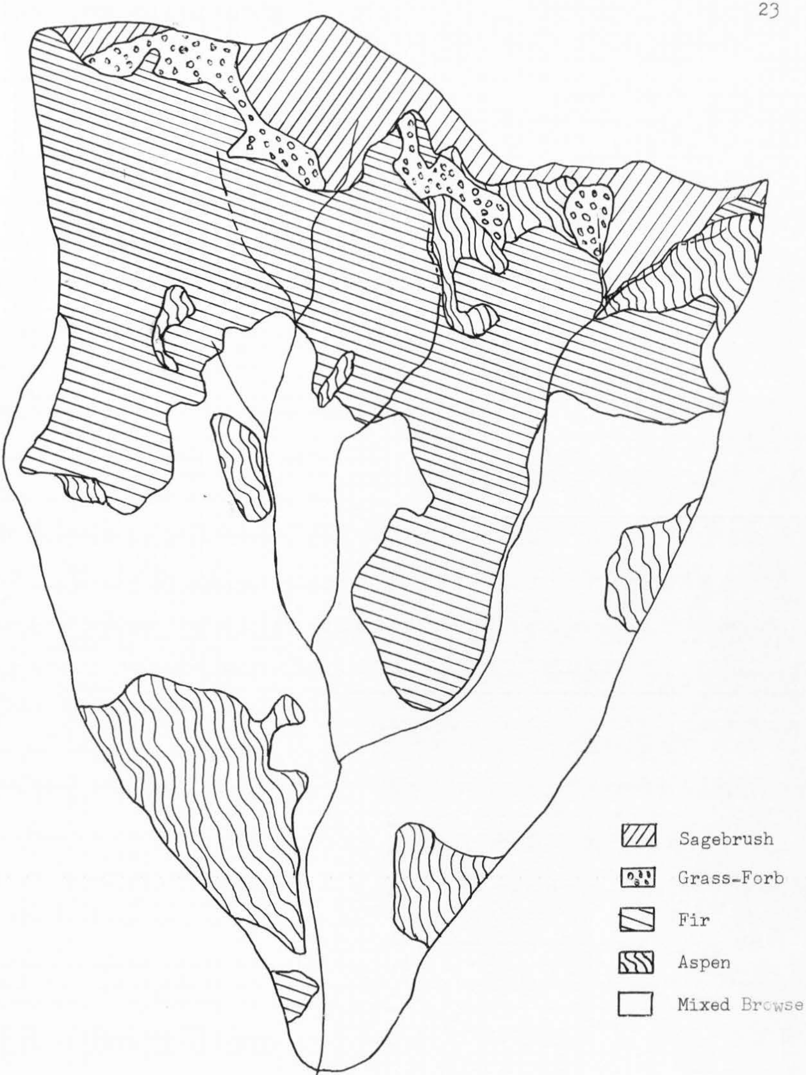

Figure 9. The Miller Creek drainage map showing the five major vegetation zones.

History of the Area

Settlement of the valley immediately adjacent to Farmington Canyon began around 1847. From that time on changes began to occur in the mountains. Timber was cut for construction materials (fenceposts, mine props, fuel, etc.). The land was grazed by livestock of all description including goats, and fires were often started to clear the land. As a result, a rapid decline in the vegetation occurred until by the turn of the century badly denuded areas were prevalent with large areas of bare ground exposed to high intensity summer rain storms. Consequently, severe mud-rock floods occurred throughout the area, with numerous major floods occurring between 1923-1930, which caused considerable property damage and loss of life (Berwick, 1962). Among other efforts to correct this situation, contour trenching was done between 1933 and 1939 on many of the badly denuded headwater areas, which included the Halfway Creek drainage. At the same time livestock grazing was excluded from the area and is still not permitted to this day. Although livestock is excluded, a substantial number of deer are found in the area.

Approximately ten acres of the Halfway Creek drainage was burned as late as 1938, but since that time no drastic changes have occurred on the drainage. As a result of a high intensity rainstorm in 1947 a mud-rock flood issued from the Halfway Creek drainage. This storm produced 0.79 inches of precipitation and the highest streamflow ever observed from the drainage. The gaging structure was unable to measure the peak streamflow, but it was estimated from measurements of the cross-section to be as high as 5000 csm. What part of this was water is highly speculative. Much of the stream channel cutting which has occurred in Halfway Creek over the past 100 years occurred during the 1947 flood.

Evidence of mineral prospecting is found throughout the area. Most of the diggings are small and have not significantly changed the area. Only one prospector went so far as to install mining equipment as a commercial venture. Most of the mines were in the wheelbarrow and pick stage when abandoned.

METHOD OF INVESTIGATION

A study of this type would be impossible without many years of precipitation and streamflow records. Consequently, the location of the study was, to some extent, dictated by the availability of such records. Locating a pair of drainages with streamflow records of sufficient length in an area where precipitation records were available and where trenching was feasible further restricts potential study areas available. With these criteria in mind, the Halfway Creek drainage in Farmington Canyon, Davis County Experimental Watershed was chosen for trenching.

Trench Construction

Contour trenches were constructed on the Halfway Creek drainage during the summer of 1964 (figure 10). All work was done according to standard trenching methods employed by the U. S. Forest Service as outlined in Forest Service Handbook 2569.11 (USFS, 1959). The trenches were designed to hold 50 percent of a 2 inch storm lasting one hour, plus allowing an additional 1.5 feet freeboard. Because of variations in slope gradient, the slope distance between trenches ranges from 40 to 120 feet. The vertical height from trench bottom to fill crest of each trench was maintained at 4.5 feet with grade slopes as shown in figure 11. This gave approximately 10 cubic feet of capacity per linear foot of trench.

The trenches were layed out using a hand level attached to a staff so that each trench is maintained on zero grade. Builders

Figure 10. Aerial photograph of the Halfway Creek drainage and nearby drainages.

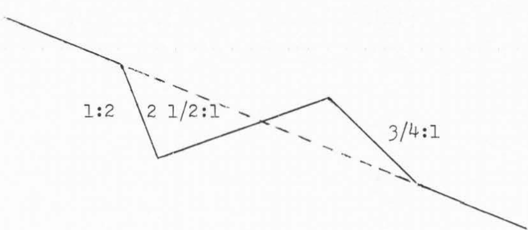

Figure 11. Typical contour trench cross-section showing cut and fill grade slopes.

lath stakes were used to locate the trenches for the tractor operator. Following the stakes, thus layed out, the tractor operator cut out a trench by tilting the tractor blade into the mountain side. Where slopes approached 70 percent, the operator first cut a level road bed from which to work while making the trench. Following the initial cutting of the trench another smaller tractor, with the aid of the survey crew, finished the trench to proper grade and dimensions. Then as this tractor was backed out of a trench, the operator pushed up cross dikes at 30 foot intervals completing the trench. As the trenches were completed they were seeded with a mixture of yellow clover (Melilotus officinalis), smooth brome (Bromus inermis), mountain brome (Bromus corinatus), intermediate wheatgrass (Agropyron intermedium), and tall oat grass (Atrhenotherum elatus). This seeding was done using hand operated broadcast seeders.

Instrumentation

The map presented on page 18 gives the location of nearly all of the instrumentation described here.

Streamgaging. Criteria were developed for the construction of the flumes on numerous watersheds in Farmington Canyon after an exhaustive study, in 1936, of various types of flumes and weirs. The developers were trying to meet requirements of reasonably accurate measurements under a wide range of streamflows and where streamflows were often debris-laden. As a result of this investigation, the modified Venturii Trapizodal flumes were developed and installed on the Halfway Creek and Miller Creek drainages along with other drainages in Farmington Canyon. This type flume is essentially a converging venturii section, with three foot vertical walls and radius side intakes, which is built into the bottom of a broad-crested trapezoidal weir section. The entire section is connected to a common stilling well and gage house (figure 12). The venturii section was calibrated in the field, as well as, in the laboratory, while the broadcrested weir was calibrated by model tests in the laboratory only. No flows large enough to reach the broadcrested weir section have ever been recorded in order to field test this section. The 1947 flood was too brief and debris-laden to be measured.

Figure 12. Photograph of stream gaging station on the Halfway Creek drainage.

Both the Halfway Creek and Miller Creek gages were equipped with "L-type"

Stevens recorders when they were built in 1936. The Miller Creek gage was equipped with a Stevens A-35 strip chart recorder in 1948 and the Halfway Creek gage was similarly equipped in 1953. Both gaging structures have been maintained since construction except for a brief period following the 1947 flood which temporarily disabled the Halfway Creek gage.

Precipitation. A network of weighing-type recording raingages has been maintained in the Farmington Canyon area since 1942. These gages are operated only during the summer months. A comprehensive report on these records has been published by Farmer and Fletcher (1969). In addition to the intensity gage records, two precipitation storage gages are maintained on the Farmington Canyon watershed. The Rice Climatic Station gage is in its thirtieth year and the Farmington Guard Station gage in its eighteenth year. These two gages are measured monthly throughout the year. Both are on 15-foot towers with Alter type wind shields. In conjunction with the Rice Climatic Station gage, summer precipitation intensity records, temperature records, and snow measurements are taken. Snow measurements are also made in conjunction with the Farmington Guard Station gage. Fifteen years of records are available from the snow courses.

Additional measurements. In addition to the streamflow and precipitation records which form the basis of this thesis, several other forms of data have been collected in the Farmington Canyon area which contribute to the conclusions reached here.

Soil moisture measurements were made on the trenched area and an adjacent untrenched area using a neutron probe method. In 1965, access tubes were placed in the soil to a depth of seven feet allowing six feet of measurement with the probe. The tubes were arranged in four plots of four tubes each. Figure 13 illustrates the location of the four holes in one plot on the trenched area. The four plots were arranged so that one plot was on each of three soil conditions in the trenched area and one plot was located in an untrenched area. Measurements were made at the beginning of the growing season and at the end of the growing season.

Vegetation measurements were taken as point samples along permanently located transects. Two 100-foot transects were located in the trenched area and two 100-foot transects were located in an adjacent untrenched area. At each measurement point an aerial strike and a ground strike was recorded. Measurements were recorded as shrub, grass, forb, litter, bare ground, or rock.

In addition to the snow courses run in cooperation with the Soil Conservation Service, four snow courses were established in conjunction with the contour trenches in the Halfway Creek drainage. Two of the courses were located in the trenched area so that each course crossed one trench. The other two courses were located in an adjacent untrenched area. Measurements were taken monthly throughout the winter of each year.

<u>Data Reduction</u>

The large quantity of data utilized in this study required some form of computer reduction to make it manageable. The streamflow records up to 1964 were reduced under a cooperative study which

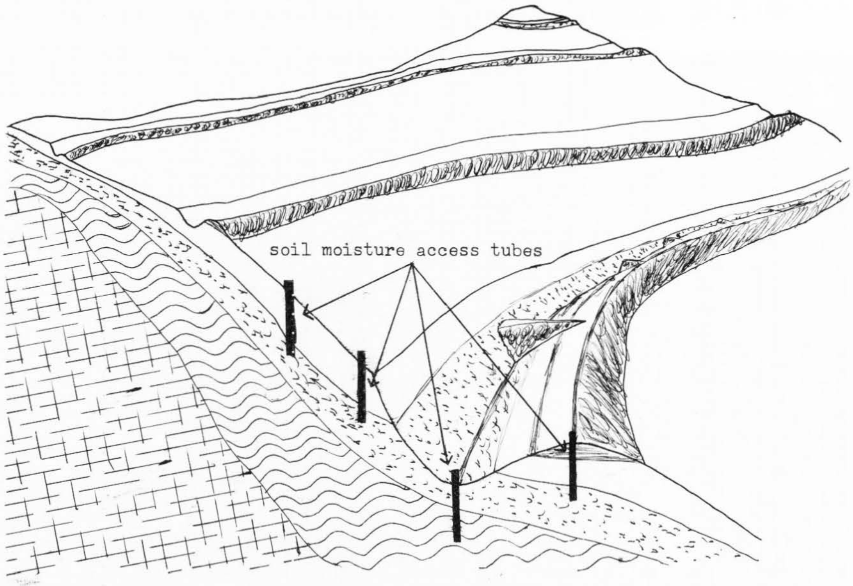

Figure 13. A sketch of the Halfway Creek trenched area with a cross-section showing the location of soil moisture access tubes and mantle layers.

resulted in a thesis (Glasser, 1969) and a paper by Hart (1969). Essentially the method consists of hand picking points along the hydrograph trace where the lines change slope. Points so picked are then punched on computer cards as digital entries. The program developed by Hart is then used to analyze these cards which results in volume of flow for increments of time between points. These values are then summed as daily flow, and monthly flows in cubic feet per second per square mile (csm), millimeters (mm), and area inches (in). An example of this reduction is shown by the computer print-out in the Appendix (table 6). An additional program was developed by Jack Homar[1] which tabulates the daily flow into a columnar display of streamflow by day and month, then summed by month and year (Appendix, table 7). Precipitation records used in this study were primarily the monthly storage gage records from Rice Climatic Station, which were hand tabulated from monthly readings (Appendix, table 8).

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[1]Mr. Homer is a computer programmer employed by the U. S. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah.

RESULTS

The relationship of streamflow from the Halfway Creek drainage, the Miller Creek drainage, and precipitation at the Rice Climatic Station was determined for the twelve years of records immediately prior to trenching. The degree of correlation between these three factors for different streamflow and precipitation periods became the primary basis for evaluating effects due to contour trenching. A longer period of record was available; however, this analysis was restricted to twelve years because of accuracy and completeness of those records. Also, events earlier in the history of the watershed may have influenced earlier records sufficiently to affect the results here.

The general nature of the relationship, before trenching, between the Halfway Creek streamflow, the Miller Creek streamflow, and the Rice Climatic Station precipitation is shown in figure 14. The precipitation pattern shown here does not necessarily represent the actual precipitation received by the Miller Creek or Halfway Creek drainages, but serves as an index to the precipitation received. The Rice Climatic Station tends to overestimate precipitation on the Halfway Creek drainage and underestimate precipitation on the Miller Creek drainage. This happens because of the aspect of the two drainages and the location of the precipitation gage. The extent of this under or over estimate is accentuated in wet years and decreases in dry years primarily because wet years generally are the result of

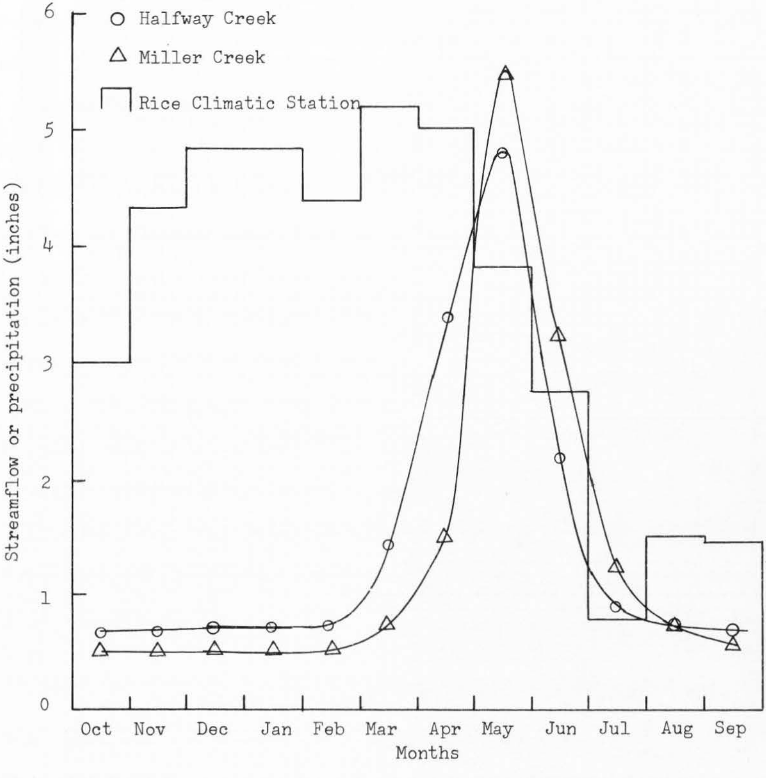

Figure 14. The 12-year average monthly streamflow from the Halfway Creek and Miller Creek drainages and the monthly precipitation at the Rice Climatic Station (1952-1964).

more snow. The movement of snow by wind from the Halfway Creek drainage into adjoining drainages is a significant factor in the actual distribution of precipitation available for streamflow.

Streamflow from the Halfway Creek and Miller Creek drainages shows an extremely close corrélation (r^2 = .878) considering the different exposures represented. Based on monthly streamflow patterns, the primary difference appears as a shift in the spring streamflow. The Miller Creek streamflow is somewhat delayed relative to the Halfway Creek streamflow as a result of delayed snowmelt on this north exposure. The Halfway Creek drainage, with its southwest exposure, shows a rapid release of water from the snowpack in the spring. This is accompanied by considerably more fluxuation in timing of the streamflow apparently due to a greater influence of temperature.

The following table summarizes the relationship between seasonal streamflow from the Halfway Creek and Miller Creek drainages prior to trenching (table 1):

Table 1. A summary of the average streamflow from the Halfway Creek and Miller Creek drainages before trenching.

Streamflow Period	Months	Halfway Creek		Miller Creek	
		Streamflow			
		(inches)	(percent)	(inches)	(percent)
July through February (Low streamflow)	8	6.25	33.3	5.51	33.3
March through June (Spring streamflow)	4	12.59	66.7	11.12	66.7
Wateryear (October-September)	12	18.86	100.0	16.63	100.0

With this background in mind an examination of the various streamflow periods and their reaction to trenching can be made.

Annual Streamflow

The October through September streamflow, as a measure of the effect of contour trenching, is perhaps too gross, but it does give a starting point from which to take a more detailed look. Lack of significance here does not preclude the possibility of finding significance in conditions relative to timing within the annual cycle.

A high degree of correlation ($r^2 = .878$) existed between the annual streamflow from the Halfway Creek and Miller Creek drainages prior to trenching. The straight line graphed in figure 15 is fitted to the 12 years of records prior to trenching by the equation $\hat{Y} = 2.144 + 1.004X$. Years where the streamflow is below average come closer to conforming to this line than years of high streamflow. Apparently, years of low streamflow are closely aligned by the more constant factors of consumptive use and watershed characteristics, while years of high streamflow are influenced more by variable factors of precipitation storm patterns and snowpack distribution prior to runoff (Gartska et al., 1958). The dotted lines on the graph indicate the mean values for the twelve years prior to trenching, while the six-sided symbol shows the mean value for the four years after trenching. The location of these points reflects the lack of significant change found, at the 95% level, in mean values of annual streamflow. A slight reduction in streamflow from Halfway Creek relative to Miller Creek is shown by the triangular symbols which represent the four years since trenching. The location of these points also suggests

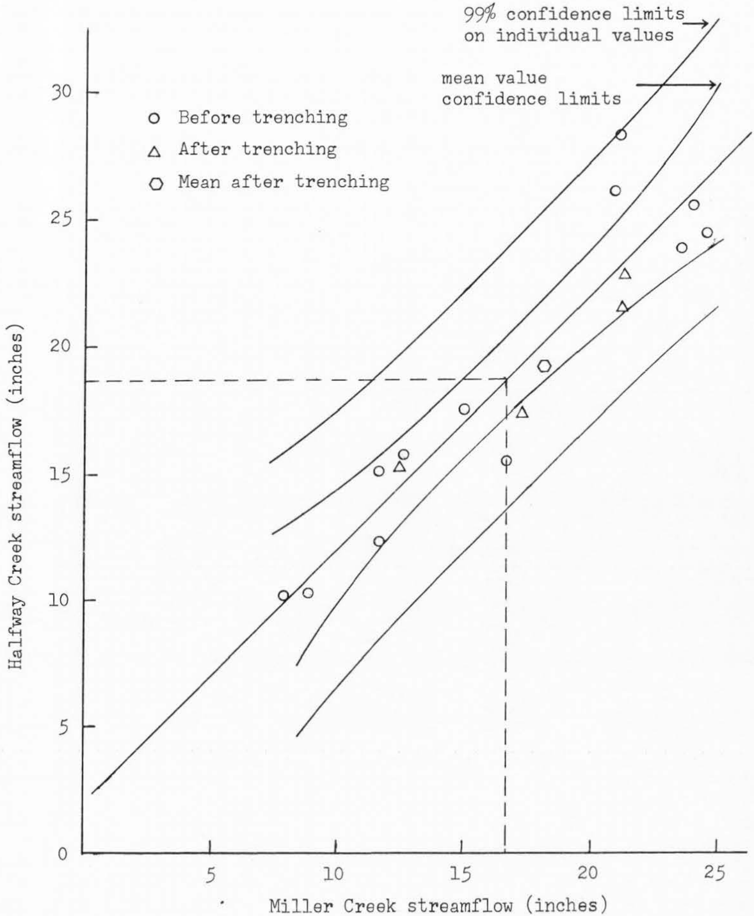

Figure 15. The regression line comparing annual streamflow from Halfway Creek drainage with that from Miller Creek drainage, 1952-1968, in inches.

a possible flattening of the slope of the line. Several years of records are needed to substantiate such a conclusion. Confidence limits for individual values, as well as, mean values at the 99% level, when plotted as in figure 15 illustrate the lack of significant changes since trenching. Actually, all but one of the years since trenching fall within the limits set for mean values.

Some of the scatter reflected in the simple linear regression between the Halfway Creek and Miller Creek drainages is explained by the multiple regression analysis which includes Rice Climatic Station precipitation data. With precipitation included the regression coefficient increases to an r^2 of .932. Figure 16 illustrates this relationship, which is defined by the equation:

$$\hat{Y} = 0.506\ X_i + 0.481\ X_{ii} - 8.876$$

Where:

$\hat{Y}$ = Halfway Creek annaul streamflow
X_i = Miller Creek annual streamflow
X_{ii} = Rice Climatic Station annual precipitation.

Again, following trenching no significant change in annual streamflow is shown.

Based on the above annual streamflow data a trend line is plotted in figure 17. This is a plot of the departure of observed values from expected values. The plot suggests a dome shaped curve with low values at the beginning of the 12-year period and low values after trenching. Perhaps more than anything, this suggests a lack of consistency in the data, or that a longer time period is needed to evaluate annual streamflow fluxuations due to a cyclic trend of which only a portion is presented in this data.

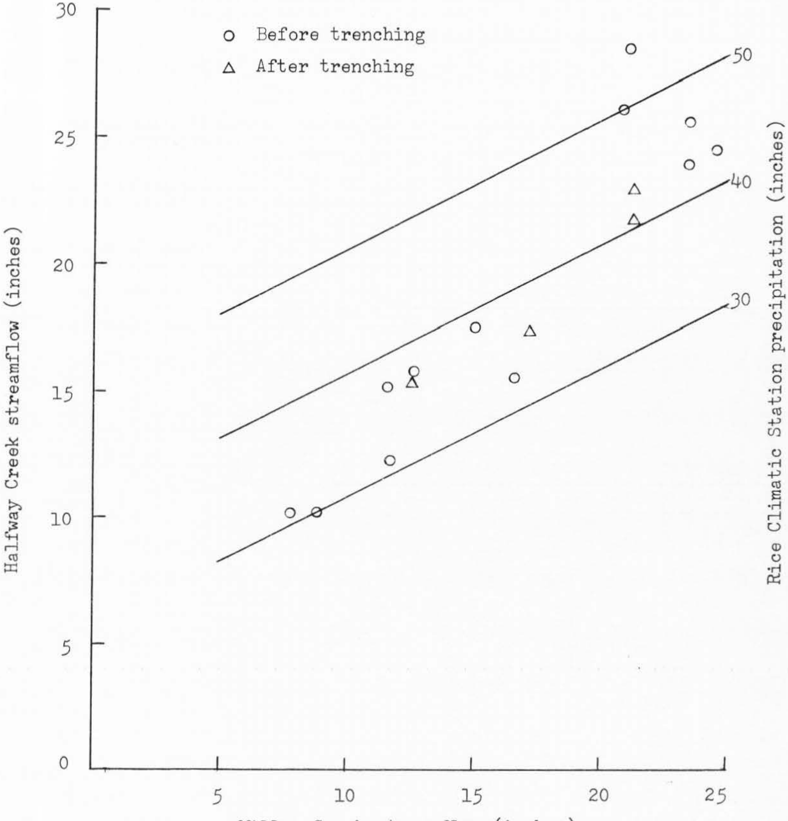

Figure 16. The regression lines comparing annual streamflow from the Halfway Creek and Miller Creek drainages and annual precipitation at Rice Climatic Station, 1952-1968, in inches.

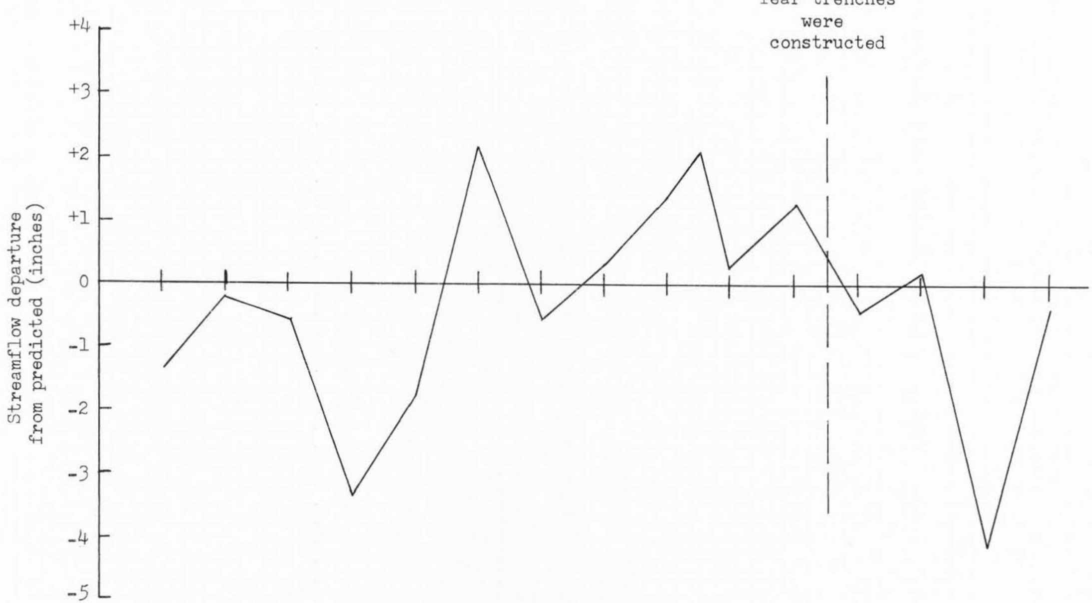

Figure 17. The departure of Halfway Creek annual streamflow from the predicted streamflow based on the relationship between the Halfway Creek and Miller Creek drainages, 1952-1968, in inches.

A double mass curve (Searcy and Hardison, 1960) was plotted for both the Halfway Creek and Miller Creek drainages to check the consistency of the records (figure 18). Data from six larger watersheds (Appendix, table 9) along the Wasatch range were plotted first against Halfway Creek streamflow and then Miller Creek streamflow. A break in the line on the Halfway Creek curve occurred at about the 1957-1958 wateryear. This break was not significant at the 2.5% level, but was significant at the 5% level of significance. Since the break occurs in the middle of the study period with no plausible reason for a change, no adjustment was made in the data.

Low Streamflow Period

The low streamflow period, as defined for this analysis, includes the streamflow for the successive months of July through February. Streamflow during this period is almost exclusively base-flow, or water resulting from deep seepage and interflow. Little water is contributed directly to streamflow from precipitation occurring during the period. During the summer months the storms which occur are generally light, with less than two percent of their precipitation resulting in direct runoff to the stream (Croft and Marston, 1950). Fall and winter precipitation, prior to the beginning of spring snowmelt, goes into recharge of the soil mantle and build up of the snow pack which results in the spring runoff during the March through June period. Consequently, the low streamflow period is very much a result of drainage characteristics while the influence of concurrent precipitation is much less (Hall, 1968).

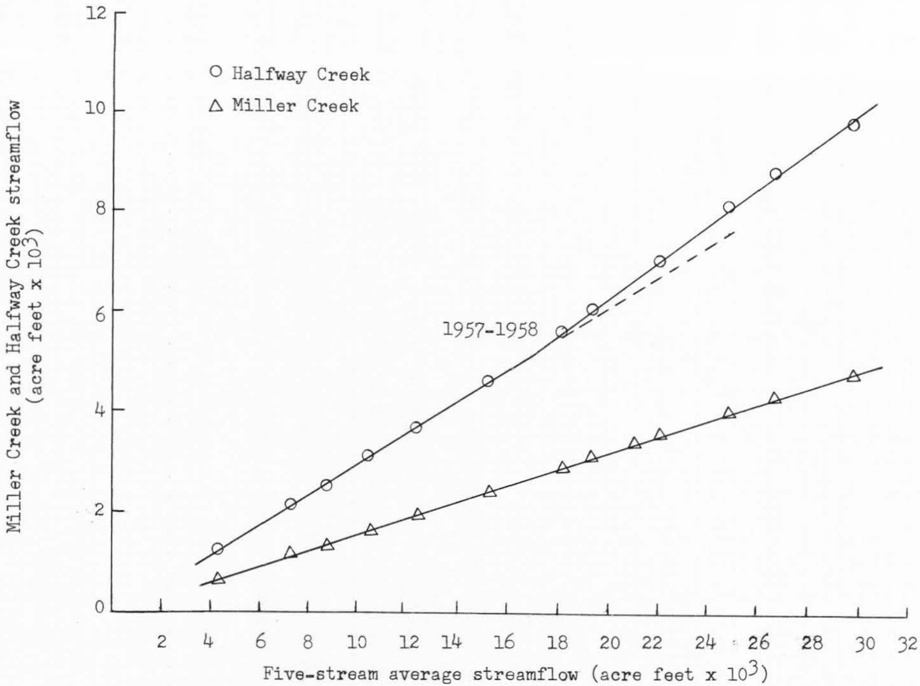

Figure 18. Double mass curves of annual streamflow: Halfway and Miller Creeks vs. five other streams (1952-1964).

From soil moisture data collected at various places on the Davis County Experimental Watershed (Johnston, Tew, and Doty, 1969) and from the fact that considerable streamflow always occurs during the spring flow period, it is apparent that the soil mantle is recharged to approximately the same level each year prior to the beginning of the July through February streamflow period. At times, fluxuations in streamflow are experienced at the beginning of the period, as a result of variable temperatures. This is particularly true of the Miller Creek drainage, but for the most part this is a rather stable streamflow period.

The low flow period relationship between Halfway Creek and Miller Creek was determined for the pre-treatment period (figure 19). This resulted in an r^2 of .46. The inability of Miller Creek to explain variations in Halfway Creek in this correlation is apparently due to a greater fluxuation of streamflow between the watersheds than between years. Applying this correlation to streamflow after trenching indicated no significant change in streamflow as a result of trenching. A slight decrease in streamflow after trenching has occurred as shown in table 2.

Table 2. Annual streamflow during July through February from Halfway and Miller Creeks following trenching.

Year	Halfway Creek (inches) (y)	Miller Creek (inches) (x)	Halfway predicted diff. (inches) ($\hat{y}$)	($y-\hat{y}$)	Percent of predicted (%)
1965-66	6.39	6.29	6.59	-.20	97
1966-67	5.31	4.43	5.78	-.47	92
1967-68	6.35	6.86	6.83	-.48	93

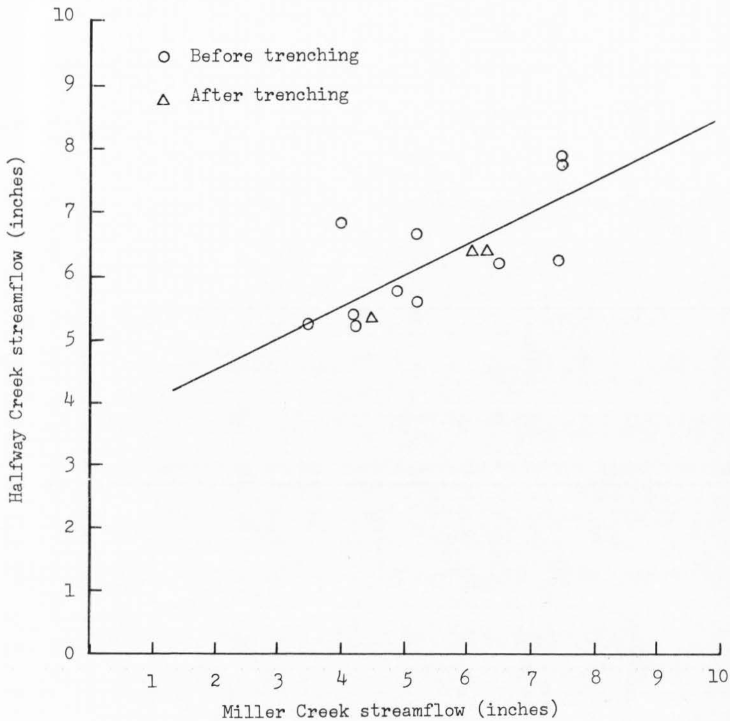

Figure 19. The relationship between seasonal low streamflow from the Halfway Creek drainage with that from the Miller Creek drainage, 1952-1968, in inches.

As was mentioned earlier, precipitation during the low streamflow period has little influence on the streamflow during that same period. Correlations were made between Halfway Creek streamflow and Rice Climatic Station precipitation values as well as between Miller Creek streamflow and Rice Climatic Station precipitation which verify this lack of relationship. Further, precipitation patterns during the summers, since trenching, have resulted in years of little precipitation and years of extreme precipitation with little apparent influence on streamflow yielded.

Spring Streamflow Period

Spring streamflow, or the March through June streamflow period, is extremely variable and represents the net effect of a highly complex system of variables (Croft, 1944). Total streamflow during this period has ranged from a low of 4.779 inches to a high of 19.609 inches. The latter occurred in 1964 just before trenching. The extremely variable streamflow from the Halfway Creek drainage is matched by that from the Miller Creek drainage. When streamflow from the two was compared, 88 percent of the variation of Halfway Creek was explained by Miller Creek streamflow (figure 20). This is highly significant when you consider the difference in aspect between the two watersheds. After trenching, no significant change in this correlation resulted. All but one of the four years tested since trenching fell below the line. All are well within the confidence limits of the analysis.

Some additional factors which contribute to the total streamflow were analyzed, but in most cases very little relationship seemed to exist. The April 1 or May 1 snowpack water equivalent at the Rice

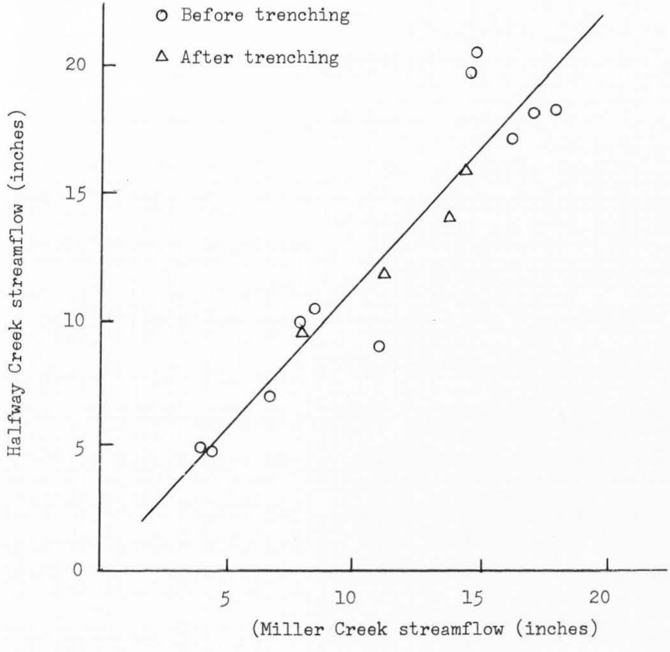

Figure 20. The relationship between the snowmelt period streamflow from the Halfway Creek drainage with that from the Miller Creek drainage, 1952-1968, in inches.

Climatic station contributed some to the analysis. While comparison of Halfway Creek streamflow with Miller Creek streamflow produced an r^2 of .88, the addition of May 1 snowpack data resulted in an r^2 of .91. A weak relationship exists between Halfway Creek spring streamflow and snowpack water equivalent or precipitation at Rice Climatic Station. However, when precipitation between March 1 and June 30 was combined with March 1 snowpack water equivalent values, a significant relationship resulted in an r^2 of .88 (figure 21).

Although, for this period no significant change in streamflow resulted following trenching, it is possible that redistribution of the streamflow within the period has resulted. The peak streamflow during the period reflects the most change. Based on daily streamflow measurements the highest single day of streamflow from the Halfway Creek drainage was compared with the highest single day of streamflow from the Miller Creek drainage for each year. The two days of each year thus compared do not necessarily coincide but the two do reflect the peak of the snowmelt generated streamflow for each year. On rare occasions the single highest day of streamflow did result from rain on snow, but such days were not used in this analysis. The twelve years of records prior to trenching resulted in a correlation in which 86 percent of the variation of the Halfway Creek streamflow was explained by the Miller Creek streamflow (figure 22). Following trenching, all peaks were lower than the regression line prediction with one year outside the confidence limits.

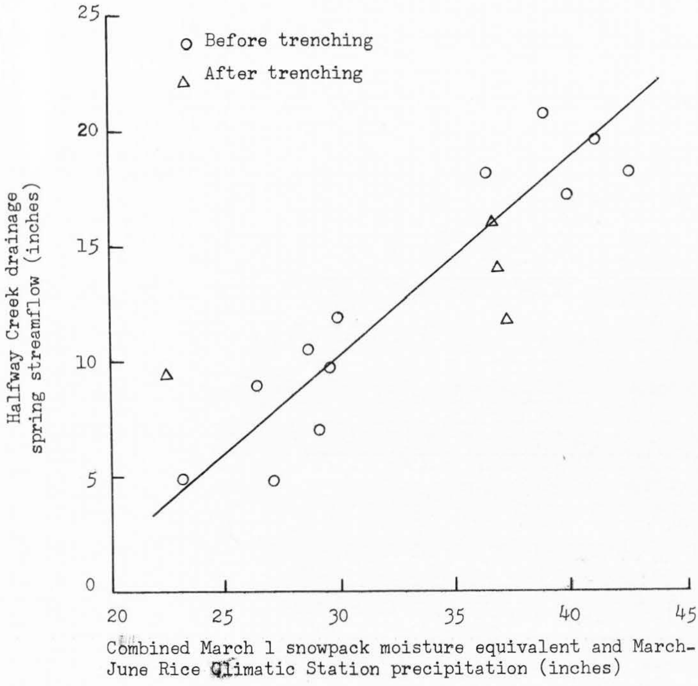

Figure 21. Comparison of spring peak streamflow from Halfway Creek with the combined March 1 snowpack moisture equivalent and March-June Rice Climatic Station precipitation, 1952-1964, in inches.

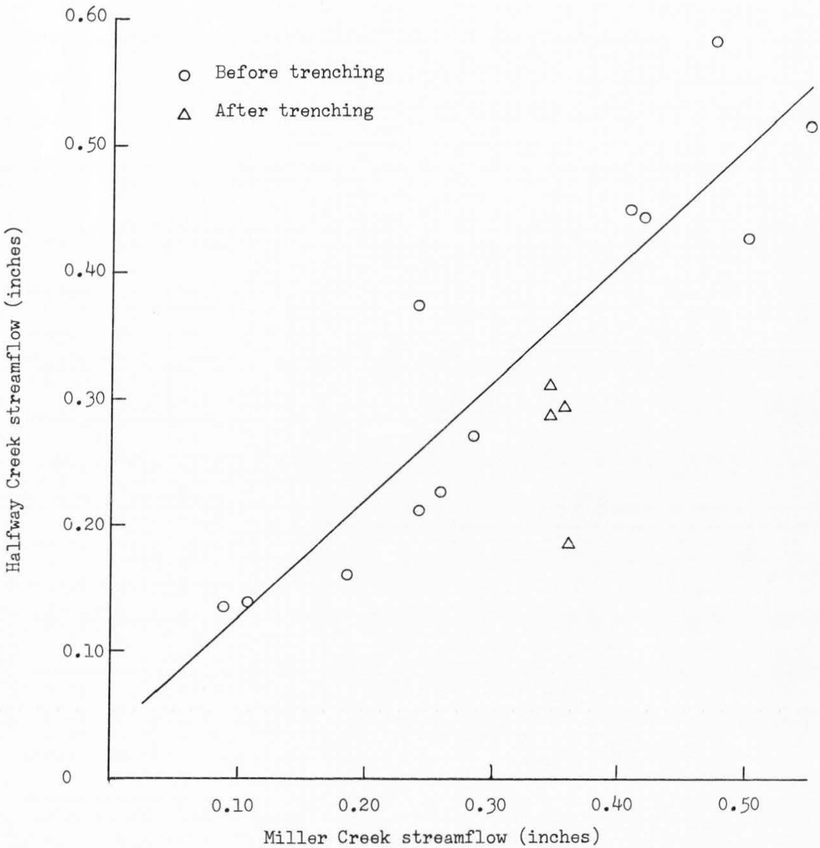

Figure 22. The relationship between the spring peak streamflow from the Halfway Creek drainage with that from the Miller Creek drainage, 1952-1968, in inches.

Since the peak streamflow from the Halfway Creek drainage generally occurs after the first of April a comparison between the April 1 snowpack water equivalent and the peak streamflow from Halfway Creek was made (figure 23). The line shown in figure 23 is plotted about the mean by graphic methods (Searcy, 1960). This relationship shows the same reduction in peak streamflow following trenching as was found earlier.

Some less obvious changes in the peak streamflow since trenching include less fluxuation in the height of the peak and a shift in the peak to a later date. In connection with this it is interesting to note that the peak on the Miller Creek drainage can generally be expected within a week of May 21, each year. While on the Halfway Creek drainage the peak may occur any time between March 24 and May 27. The average date of the peak flow from the Halfway Creek drainage is April 24 or nearly a month ahead of Miller Creek.

A close look at the precipitation immediately prior to peak flow reveals that 67 percent of the peaks were not directly generated by rain, but resulted from temperature conditions (table 3). Four out of the twelve years before trenching had greater than .10 inches of precipitation within five days before the peak. Two of the four years since trenching have received precipitation five days before the peak. Based on this data and procedures followed by Haupt (1968) and the U. S. Army Corp of Engineers (1960), potential snowmelt runoff due to temperature and precipitation was calculated and then compared with the actual streamflow produced (table 4). Prior to trenching, potential snowmelt

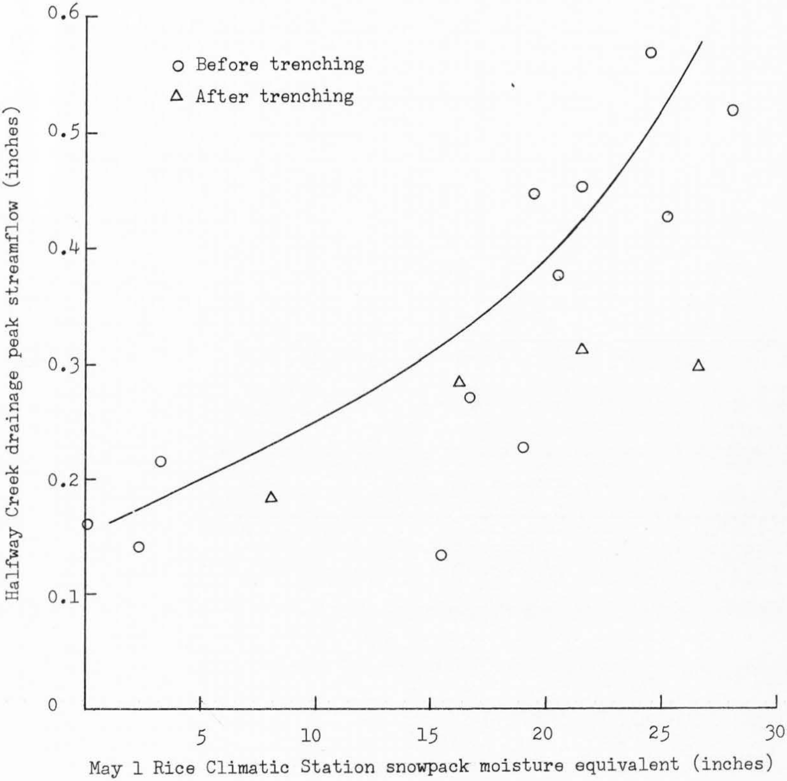

Figure 23. The annual peak daily streamflow from the Halfway Creek drainage plotted against the May 1 Rice Climatic Station snowpack moisture equivalent, 1952-1968, in inches.

Table 3. Precipitation and temperature conditions prior to peak streamflow on the Halfway Creek drainage.

Date	Precipitation during 6-day leading to peak streamflow (inches)						Total ppt (in.)	Mean Temp. (°F)	Accum max daily temp. (°F)
Before trenching									
4/23/53	.06	0	0	0	0	0	.06	43.8	327
4/06/54	0	0	0	0	0	.80	.80	39.5	297
5/09/55	0	0	0	0	.05	0	.05	46.5	347
3/25/56	0	0	0	0	0	0	0	42.1	318
5/27/57	0	.28	.45	.07	0	0	.75	43.1	316
5/06/58	0	0	0	0	0	0	0	47.8	367
4/06/59	0	0	0	0	0	0	0	47.1	338
3/24/60	0	0	0	0	0	0	0	41.3	323
4/04/61	0	0	0	0	0	0	0	38.2	291
4/26/62	1.01	0	0	0	.44	1.60	3.05	43.1	325
4/28/63	0	0	0	0	.75	1.75	2.50	34.6	286
5/17/64	0	0	0	0	0	0	0	50.5	391
After trenching									
5/13/65	.82	.58	0	0	0	0	1.40	41.0	306
3/30/66	0	0	0	0	0	0	0	43.5	340
5/10/67	.09	.30	0	0	0	1.01	1.40	42.2	321
5/05/68	0	0	0	0	0	0	0	47.4	368

Table 4. Calculations of potential snowmelt due to temperature and rainfall over a six day period.

Year	Temperature melt T_{max}	M*	Precipitation melt $T_a - 32$	.00695 pr	Mp**	M + Mp	Actual flow
Before trenching							
1953	327	3.000	2.5	.00042	.001	3.001	.426
1954	297	1.800	1.5	.00560	.008	1.808	.139
1955	345	3.800	12.0	.00034	.004	3.804	.227
1956	318	2.640	0	0	0	2.640	.214
1957	316	2.560	27.0	.0052	.044	2.604	.445
1958	367	4.600	0	0	0	4.600	.515
1959	338	3.440	0	0	0	3.440	.161
1960	323	2.840	0	0	0	2.840	.271
1961	290	1.560	0	0	0	1.560	.136
1962	325	2.920	23.5	.0111	.124	3.044	.460
1963	286	1.360	2.5	.0174	.044	1.404	.373
1964	391	5.560	0	0	0	5.560	.583
After trenching							
1965	306	2.160	27.5	.0097	.133	2.293	.288
1966	340	3.520	0	0	0	3.520	.186
1967	321	2.760	13.5	.0097	.096	2.856	.310
1968	368	4.640	0	0	0	4.640	.295

* M = 0.04 (T_{max} - 42), where T_{max} is 6-day maximum temp. total.
**Mp = 0.00695 pr (T_a - 32), where pr = 6-day total precipitation and T_a = sum of average temperature on days of precipitation.

runoff calculated by this method, on the average, exceeded actual measured peak streamflow by about nine times. After trenching it exceeded streamflow by 12 times. The significance of this is reduced by the inability of potential snowmelt to predict actual peak streamflow (r^2 = .36).

The peak flow cannot be influenced without subsequently showing some change in the recession streamflow. As was mentioned earlier, recession streamflow is characteristic of a particular watershed and more or less independent of current precipitation. Consequently, a change in the recession flow should be a good indicator of any alteration of watershed characteristics. Halfway Creek streamflow develops a rapid recession following the peak for approximately 60 days. By the end of 60 days the curve has flattened appreciably with a slight downward gradient until sometime in August or September.

A superficial or first approximation of the recession curve was developed by breaking the 60 day period following the peak into three smaller units on which slope coefficients were determined. Periods selected were (1) peak to 10 days later, (2) 10 to 40 days later, and (3) 40 to 60 days later. These periods were selected after looking at several years of records which showed that the curve has a tendency to break at these points. After averaging the slope coefficients for the 12 years of records prior to trenching a plot of the slope was made (figure 24). A similar procedure was followed for data after contour trenching. Although a smooth curve resulted from the 12 year average, data after trenching indicated a hump in the flow 40 days after the peak. A further evaluation of this was made by plotting daily flows for the 60 day period after the peak. The average of the 12 years prior to

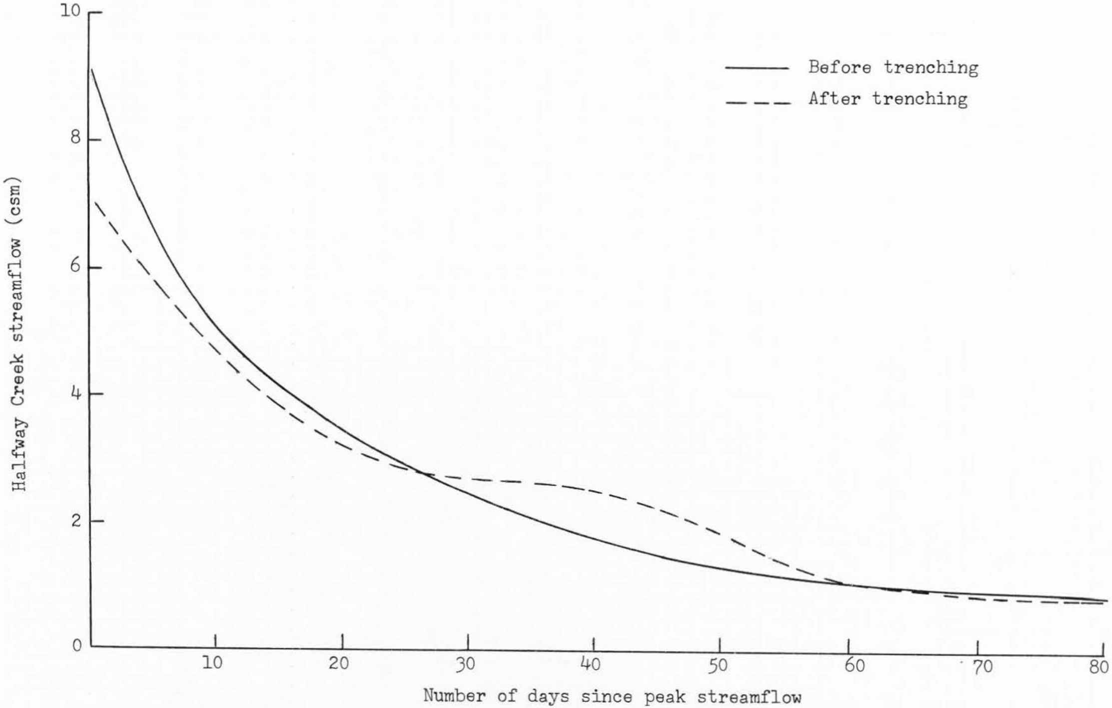

Figure 24. Approximated streamflow recession curves for the Halfway Creek drainage before and after trenching, 1952-1968, in csm.

trenching was plotted along with the four year average after trenching. (figure 25). Actually these smooth curves are approximations of the actual data which produced scatter about this line. The hump observed earlier in data after trenching (figure 24) did not appear here. However, daily values did fluxuate greatly about the fortieth day following the peak. No attempt was made to remove the influence of precipitation during the recession period which accounts for much of the fluxuation in the daily values. A greatly reduced peak and a flattened recession curve following trenching is evident. Also a general reduction in the flow is shown, although this does not represent a significant decrease as shown earlier.

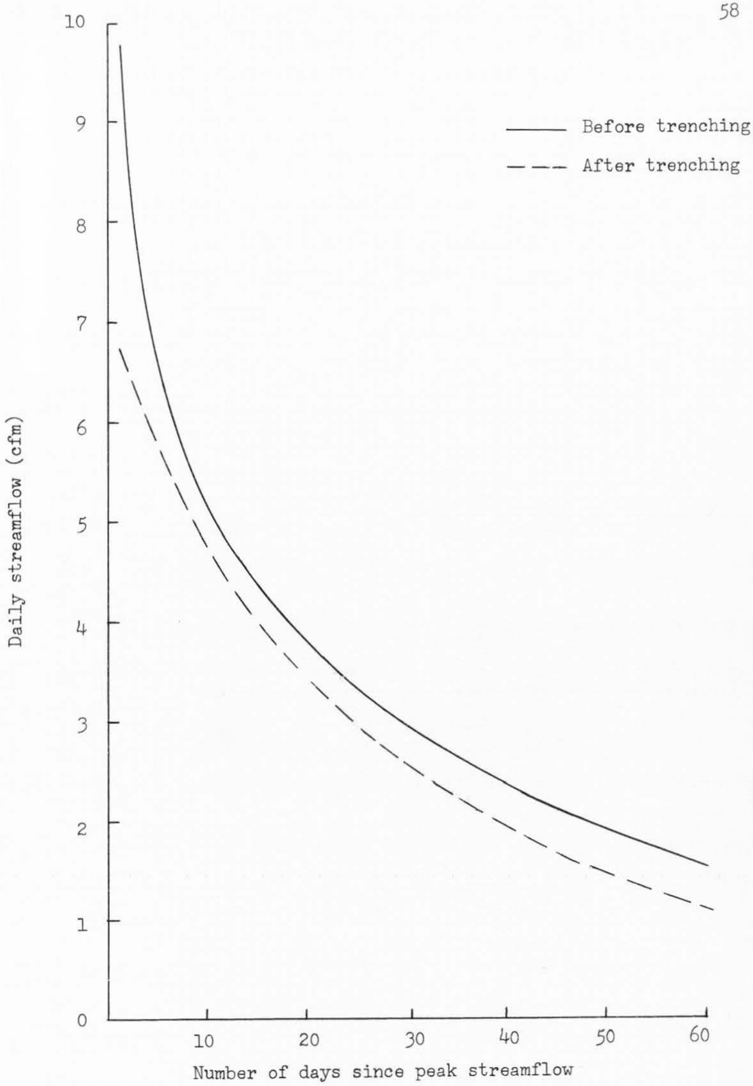

Figure 25. The recession streamflow from the Halfway Creek drainage based on daily flow periods before and after trenching.

SUMMARY AND CONCLUSIONS

Streamflow from two drainages of the Davis County Experimental Watershed was compared on the basis of annual streamflow, a low streamflow period, and spring streamflow period, both before and after contour trenching. In addition, various measurements of precipitation, snowpack moisture equivalents, soil moisture, vegetation, and drainage characteristics were included to better analyze distribution and volume of the streamflow.

The streamflow and precipitation data indicate no statistically significant change in streamflow patterns as a result of contour trenching. This conclusion is based on four years of records after trenching and 12 years of records before trenching. A slight decrease in streamflow since trenching is perhaps due to chance variation in the data or a slight increase in consumptive use due to a delay in the streamflow pattern from the trenched area. The possibility that any change is due to trenching is further reduced by supplemental data which shows no appreciable change in the distribution of moisture available as potential streamflow. Snow distribution remains approximately the same except for some on-site redistribution (Doty, 1970). The consumptive use of soil moisture by vegetation has not shown appreciable change although a trend similar to that reported by Bailey and Copeland (1960) may be developing.

The streamflow characteristics, before and after trenching, of the two drainages analyzed in this thesis are summarized in table 5.

Table 5. Summary of Halfway Creek and Miller Creek streamflow comparisons.

a. Average Streamflow Before Trenching

Streamflow period	Months	Halfway Creek Streamflow (inches)	(%)	Miller Creek Streamflow (inches)	(%)
July thru February	8	6.25	33.3	5.51	33.3
March thru June	4	12.59	66.7	11.12	66.7
Wateryear	12	18.84	100.0	16.63	100.0

b. Annual Streamflow Since Trenching

Year	Streamflow from Halfway Cr. (inches)	Streamflow from Miller Cr. (inches)	Predicted* Streamflow Halfway Cr. (inches)	Difference Actual-pred. (inches)	Percent of Predicted (%)
1964-65	21.58	21.35	22.04	-0.46	98
1965-66	15.29	12.45	15.06	+0.23	102
1966-67	17.30	17.27	21.47	-4.17	81
1967-68	22.91	21.31	23.23	-0.32	99

*Predicted based on regression: $\hat{Y} = -8.876 + 0.506\, X_i + 0.487\, X_{ii}$
Where: $\hat{Y}$ = Halfway Creek streamflow, X_i = Miller Creek streamflow, and X_{ii} = Rice Climatic Station precipitation.

c. Snowmelt Streamflow Since Trenching

Year	Streamflow from Halfway Cr. (inches)	Streamflow from Miller Cr. (inches)	Predicted* Streamflow Halfway Cr. (inches)	Difference Actual-pred. (inches)	Percent of Predicted (%)
1965	14.05	13.78	15.52	-1.47	90
1966	9.42	7.88	9.02	+0.40	104
1967	11.77	11.24	12.72	-0.95	92
1968	15.80	14.44	16.25	-0.45	97

*Predicted based on regression: $\hat{Y} = 0.325 + 1.103\, X$
Where: $\hat{Y}$ = Halfway Creek streamflow, X = Miller Creek streamflow.

Table 5. Continued

d. Low Streamflow Period Since Trenching

Year	Streamflow from Halfway Cr. (inches)	Streamflow from Miller Cr. (inches)	Predicted* Streamflow Halfway Cr. (inches)	Difference Actual-pred. (inches)	Percent of Predicted (%)
1965-66	6.39	6.29	6.59	-0.20	97
1966-67	5.31	4.43	5.78	-0.47	92
1967-68	6.35	6.86	6.83	-0.48	93

*Predicted based on regression: $\hat{Y} = 3.87 + 0.432\ X$
Where: $\hat{Y}$ = Halfway Creek streamflow, X = Miller Creek streamflow.

After examining streamflow regimen and such watershed characteristics as soil type and vegetation, it is concluded that contour trenching has not significantly affected streamflow patterns of the Halfway Creek drainage.

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APPENDIX

Table 6. Computer print out of streamflow volumes by time segments.

WS	MO	DA	YR	TIME	GAUGE FT.	DISCHARGE C.F.S.	INTERVAL RUNOFF, INCHES	ACCUMULATED UNOFF, INCHES (DAILY)	MEAN DAILY C.S.M.	DAILY RUNOFF MILLIMETERS	ACCUM. INCHES (MONTHLY)	ACCUM. MILLIMETERS (MONTHLY)
1	12	28	53	2400	.104	.23500	.011116	.022231				
							DAILY SUMMARY	.022231	.5978	.565	.555	14.087
1	12	29	53	1200	.104	.23500	.011116	.011116				
1	12	29	53	2400	.104	.23500	.011116	.022231				
							DAILY SUMMARY	.022231	.5978	.565	.577	14.651
1	12	30	53	1200	.104	.23500	.011116	.011116				
1	12	30	53	2400	.104	.23500	.011116	.022231				
							DAILY SUMMARY	.022231	.5978	.565	.599	15.216
1	12	31	53	1200	.104	.23500	.011116	.011116				
1	12	31	53	2400	.104	.23500	.011116	.022231				
							DAILY SUMMARY	.022231	.5978	.565	.621	15.781
							MONTHLY SUMMARY				.621	15.781

Table 7. Computer print-out of streamflow summaries showing daily values, monthly values, and yearly total.

DAILY STREAMFLOW SUMMARY
HALFWAY CREEK, 1966

CSM

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ERR
1	.6480	.6340	.7140	4.3820	2.2850	1.1390	.6840	.6340	.6260	.5940	.5940	.5830	
2	.6480	.6340	.7050	4.5420	2.2460	1.1520	.6670	.6250	.6410	.6010	.5950	.5860	
3	.6480	.6340	.6950	4.0110	2.2400	1.1040	.6630	.6270	.6380	.6050	.5990	.5840	
4	.6480	.6340	.6830	3.4770	2.2230	1.1440	.6560	.6230	.6340	.6020	.5950	.5790	
5	.6480	.6340	.6640	3.1040	2.1470	1.1260	.6460	.6220	.6310	.5990	.5990	.5770	
6	.6480	.6340	.6700	2.8280	2.0430	1.0300	.6370	.6150	.6280	.6010	.5880	.5720	
7	.6480	.6340	.7530	2.5130	1.9130	1.0910	.6350	.6090	.6290	.6020	.6010	.5720	
8	.6480	.6340	.8280	2.9450	1.8100	1.0880	.6270	.6050	.6180	.6030	.6020	.5720	
9	.6480	.6340	1.1700	3.0250	2.0450	1.0390	.6190	.5990	.6050	.6040	.5940	.5720	
10	.6480	.6340	1.9970	3.1040	3.8970	1.0210	.6310	.6020	.5930	.5960	.5930	.5670	
11	.6480	.6340	2.0430	3.0260	4.4690	.9730	.6330	.6020	.5950	.5920	.5950	.5650	
12	.6480	.6340	2.5220	2.6450	3.9470	.9420	.6250	.6050	.5870	.6310	.5990	.5600	
13	.6480	.6340	2.9760	2.2630	3.5350	.9320	.6140	.6040	.5900	.6690	.5970	.5580	
14	.6480	.6340	4.0650	2.3000	3.2870	.9120	.6080	.6030	.6050	.6120	.5860	.5580	
15	.6480	.6340	4.1110	2.3460	3.0250	.8730	.6080	.5990	.6130	.6010	.5860	.5530	
16	.6370	.6440	3.9910	2.2160	2.8010	.8950	.6110	.5990	.6100	.6050	.5860	.5560	
17	.6340	.6480	2.9130	2.5080	2.5870	.8860	.6090	.6000	.6080	.6020	.5820	.5600	
18	.6340	.6480	2.2350	2.5660	2.3690	.8640	.6050	.6010	.6000	.5930	.5790	.5600	
19	.6340	.6480	1.9310	2.3910	2.2150	.8270	.6000	.6030	.6100	.5860	.5790	.5610	
20	.6340	.6480	1.7610	2.3180	2.1030	.7900	.6020	.6030	.6050	.5860	.5790	.5580	
21	.6340	.6440	1.9280	2.3220	1.9950	.7890	.6030	.6090	.6040	.5870	.5790	.5580	
22	.6340	.6500	1.7960	2.2970	1.9390	.8210	.6050	.6150	.6060	.5930	.5790	.5560	
23	.6340	.6840	1.6500	2.2860	1.8300	.7960	.6020	.6060	.6060	.5930	.5790	.5510	
24	.6340	.7030	1.6390	2.2990	1.7290	.7790	.6050	.6080	.6070	.5930	.0000	.5490	
25	.6340	.6890	2.5050	2.3350	1.6530	.7630	.5890	.6020	.6040	.5930	.5650	.5440	
26	.6340	.6890	3.6760	2.4130	1.5830	.7320	.5900	.6030	.6020	.5930	.5770	.5440	
27	.6340	.6890	4.2660	2.4150	1.5490	.7030	.5820	.6060	.6060	.5960	.5770	.5440	
28	.6340	.6980	4.2210	2.3950	1.4800	.6810	.6090	.6000	.6100	.5950	.5780	.5390	
29	.6340	.0000	5.0050	2.3470	1.4060	.6710	.6220	.6030	.6040	.5930	.5780	.5300	
30	.6340	.0000	5.0120	2.3220	1.3230	.6560	.6270	.6030	.5980	.5820	.5790	.5300	
31	.6340	.0000	4.9190	.0000	1.4970	.0000	.6380	.6130	.0000	.5950	.0000	.5300	
SUM	19.8670	18.1920	74.0440	81.9410	71.1710	27.2190	19.2520	18.8480	18.3130	18.5970	17.0190	17.3280	

YEARLY TOTAL=401.7905

Table 8. Monthly and annual precipitation at the Rice Climatic Station for the period 1952-1968, in inches.

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annaul Total
1952-53	0.00	3.31	4.98	10.55	2.01	5.74	9.05	5.27	3.21	0.89	0.82	0.11	45.94
1953-54	2.14	2.61	4.40	2.52	2.14	6.96	2.61	2.03	3.13	0.84	1.31	1.53	32.21
1954-55	1.94	4.77	3.39	6.99	5.22	1.24	5.88	2.22	2.89	0.84	0.65	2.50	38.53
1955-56	2.28	4.35	8.08	8.30	3.76	0.60	3.32	4.46	0.37	1.28	0.43	0.37	37.60
1956-57	3.94	1.27	4.32	5.06	3.43	5.86	6.98	9.20	4.12	0.56	1.21	0.87	46.92
1957-58	2.83	4.35	6.20	3.92	8.39	6.01	5.54	0.90	0.09	0.31	0.80	0.65	39.99
1958-59	0.21	2.28	3.56	5.96	5.32	3.42	4.20	3.67	2.12	0.36	2.92	4.71	38.64
1959-60	1.33	0.44	1.95	4.62	8.07	6.46	2.80	1.92	0.87	0.07	1.24	1.37	31.13
1960-61	1.93	6.49	1.85	0.32	4.81	6.20	2.01	1.17	0.53	0.72	2.23	4.32	32.58
1961-62	5.45	5.39	4.92	3.17	7.38	6.90	4.22	4.34	0.98	2.09	0.09	0.77	45.70
1962-63	1.48	1.82	0.63	4.79	2.61	6.64	11.77	1.24	3.96	0.03	0.87	2.61	38.45
1963-64	2.59	3.01	2.39	6.52	1.36	7.19	8.41	6.44	5.42	0.02	0.40	0.14	43.89
1964-65	2.35	7.02	8.25	7.15	2.75	1.28	4.00	4.10	3.64	2.93	2.38	3.47	49.32
1965-66	0.61	5.80	5.47	2.30	4.35	2.55	2.31	3.70	0.19	0.44	0.09	1.63	29.44
1966-67	2.08	4.42	4.12	5.75	3.30	2.84	10.12	3.84	5.55	0.54	0.12	1.70	44.38
1967-68	2.46	0.65	8.83	1.28	8.35	6.66	5.94	3.73	2.75	0.69	0.09	1.35	42.78

Table 9. Streamflow data from the Holmes Creek, Ricks Creek, Parrish Creek, Centerville Creek, Stone Creek, and Mill Creek drainages used in the double mass plotting, in acres feet.

Year	Holmes	Ricks	Parrish	Centerville	Stone	Mill
1951-52	3940	2650	1940	3310	4280	10190
1952-53	3160	2160	1590	2550	3340	6400
1953-54	1490	817	486	983	1000	1930
1954-55	1960	1120	771	1330	1560	3490
1955-56	2180	1390	892	1520	1870	3380
1956-57	3360	2040	1580	2220	3150	5360
1957-58	3440	1880	1380	2220	3130	5270
1958-59	1690	958	580	1050	1270	2210
1959-60	2320	1300	751	1230	1380	3160
1960-61	1360	591	389	785	818	1760
1961-62	3420	2080	1370	1910	2740	5630
1962-63	2380	1330	827	1300	1630	3050
1963-64	3310	2360	1460	2370	2880	6260

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