To Cal.
With my regards.
George

A WATER BALANCE STUDY OF TWO SMALL WATERSHEDS

A Thesis

Presented in partial fulfillment of the requirements for the

Degree of Master of Science in Agricultural Engineering

in the

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by

George Lukens Bloomsburg

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BIOGRAPHICAL SKETCH OF THE AUTHOR

George Lukens Bloomsburg was born in Salmon, Idaho on March 28, 1931. In 1942 his parents moved to Worley, Idaho where he attended high school and received his diploma in 1948. That fall he entered the University of Idaho and enrolled in the College of Agriculture. The following year he stayed out of school and in 1950 enlisted in the United States Army.

After serving in the Infantry in Japan and Korea, he was discharged in 1953. He returned to the University of Idaho in February 1954 and enrolled in Agricultural Engineering, receiving his Bachelor of Science degree in Agricultural Engineering in 1957. In June 1957 he enrolled in the Graduate School of the University of Idaho and in August 1958 completed the work for a Master of Science degree in Agricultural Engineering of which this thesis is a part.

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BY

GEORGE LUKENS BLOOMSBURG

INTRODUCTION

There is a great need for better knowledge of the runoff characteristics and the disposition of rainfall on many small watersheds in the United States. This is particularly true in western United States where much of the terrain is very irregular and the runoff characteristics of seemingly similar watersheds may be very different due to dissimilarities in geological formations, in amounts, distribution, and intensities of rainfall and in types and amounts of vegetation.

The means by which the knowledge of these factors is obtained is termed a water balance study, which is essentially a study to determine the amount and the disposition of precipitation. On any particular watershed this disposition occurs as: interception by vegetation, evaporation from the soil surface, surface runoff, water used by vegetation (transpiration) and deep percolation. Interception, evaporation and transpiration are usually summed together under the term evapotranspiration or consumptive use, as the same factors affect all three in the same manner and they are very difficult to separate. As there is no accurate way to determine deep percolation these studies are usually carried out in areas where the geological formations are such that there is little or no deep percolation. In such a case the total precipitation is simply separated into a depth of surface runoff and a depth of evapotranspiration loss. This value for evapotranspiration loss may then be used for studies in areas of similar vegetation and climatic conditions to determine the water loss due to deep percolation.

During the past several decades many communities in the United States have experienced shortages of water. This has come about due to several factors. Some of these are: increased use of water for irrigation; a tremendous increase in population, particularly in the western states; soil erosion, which has several secondary effects on water supplies; and a lowering of the underground water table in many areas. An example of a region with the latter problem is the Moscow-Pullman area of northern Idaho and eastern Washington, where the present study was made. However, there are many other communities, particularly in the midwestern and southwestern states, which have the same problem (36).

In 1891 there were many flowing wells in the Moscow-Pullman area, including ten in Moscow (29). By 1897 the static water level at Moscow was 8 to 9 ft below the ground surface and by 1923 was down approximately 44 ft (16). At this time the Moscow City Council became concerned about the lowering water table and requested assistance from the Department of Mines and Geology at the University of Idaho to determine whether the water supply was in danger of being exhausted. In the resulting report (16), the conclusion was reached that the annual recharge to the underground aquifer was considerably more than the annual pumpage. However, the actual data used in this report were extremely meager.

Since 1937, the United States Geological Survey (8) has determined the yearly fall of the static water level in the Moscow and Pullman wells, as shown in Table 1. In 1957, the water level at Moscow was approximately 100 ft below the ground surface.

During the summer of 1955, the water supply in Moscow became very short and some curtailment of use was necessary, as the production of several of the city's wells dropped considerably. At this time the City Council became interested in the possibility of utilizing the surface runoff from nearby forested watersheds as many communities have done. However, as in many areas, there have been few hydrologic data collected and analyzed.

Table 1 Yearly Decline in Static Water Level in Moscow and Pullman Wells.

Moscow		Pullman	
Years	Decline (inches per year)	Years	Decline (inches per year)
1937-1940	21-22	1936-1945	5-9
1941-1949	11	1946-1951	21-22
1950-1952	30-35	1952-1955	10-13
1953-1955	50-55		

The lack of knowledge of the hydrologic characteristics of the watersheds led to the establishment of stream gaging stations on Gnat and Crumerine Creeks during January 1956. The purpose of these gages was to obtain some actual records of the amount of runoff, which might be expected under comparable climatic conditions. In addition, by carrying out a complete water balance study, much information on the evapotranspiration losses and ground water recharge under these conditions would be obtained. The information obtained here could then be utilized in similar studies in other areas.

During 1955 there was some concern that logging practices on the watersheds could be reducing the annual recharge to the groundwater supply, by changing the runoff characteristics. This led to a report by Mr. Paul

Packer of the Intermountain Forest and Range Experiment Station of the U. S. Forest Service (21). This report was based on slightly more factual data than Lauey's report (16) and made use of some experimental data on evapotranspiration losses from other areas. The conclusion was reached that the runoff characteristics of the watersheds had not changed and the annual recharge was more than the annual pumpage.

PURPOSE OF STUDY

This study was undertaken to devise methods of carrying out water balance studies on watersheds where there is a deficiency of data and where there is not sufficient time to collect records of all climatic factors through complete instrumentation.

An area near Moscow was selected for study because stream gaging stations had already been established in cooperation with the City of Moscow and these watersheds are representative of many small watersheds in the Northwest. In addition, there have been hydrologic data collected at variour times in the past but these data were never analyzed to determine the water balance of the region.

A reasonably accurate analysis of the water balance was attempted by making maximum use of all previously gathered data on precipitation, data collected during the period of study, and information on evapotranspiration from other areas.

The results desired from the application of the methods used herein were as follows:

1. The variation of precipitation which may be expected in an area of like climatic and topographic conditions.
2. The evapotranspiration loss due to vegetation of the types found on these watersheds.
3. The amount of surface runoff to be expected on watersheds under comparable climatic conditions.
4. The amount of groundwater recharge which may be expected in areas of similar geological conditions.

LITERATURE SURVEY

During the past twenty-five years there has been a great increase in hydrologic research.

The first hydrologic study undertaken in western United States was started in 1910 by Bates (1) at Wagon Wheel Gap, Colorado, where two similar forested watersheds were used to find the effect of forest cover on streamflow and erosion. Records of runoff and precipitation were kept for eight years with the watersheds in the original condition. The timber on one watershed was then clear cut and the limbs and other debris burned. Records of runoff were then kept for another seven years, at which time the study was discontinued. These watersheds were considered to have no deep percolation loss; therefore, the annual precipitation all went to streamflow or evapotranspiration losses.

During the entire study the runoff of the undisturbed watershed was 29 per cent of the annual precipitation. Before clear cutting the runoff of the other watershed was 29 per cent but after cutting was 35 per cent of the annual precipitation. The greater part (80 per cent) of this increase occurred during the flood period each spring. The amount of silt carried from the watershed after deforestation was approximately eight times as great as when in the natural condition, but was still small when compared to some agricultural watersheds.

Hoyt and Troxell (12) in 1934 analyzed the Wagon Wheel Gap study and a watershed in Southern California which had runoff records before being swept by a forest fire. These watersheds were under entirely different climatic and vegetative conditions.

After burning there was an increase of 29 per cent in annual streamflow from the California watershed. Using a different definition of flood period than Bates (1) had used, it was determined that 52 per cent of the increased runoff on the Colorado watersheds occurred during non-flood periods. The increase was determined to be due to less interception, which allows more water to reach the ground, and a reduction in transpiration due to less vegetation. The erosion in Colorado was termed negligible but in California was serious, particularly the first year after burning when vegetation had not, as yet, become re-established.

The conclusion reached was that in many instances, the value of the increased water supply throughout the year is great enough to offset the disadvantages of higher flood peaks and greater erosion caused by deforestation, particularly if the forest can be replaced by vegetation which will control erosion but use less water.

Probably the most extensive hydrologic study which has been undertaken is that on the San Dimas Experimental Forest of southern California (41). This project was started in 1933 and is still active. The entire study covers an area of 17,000 acres, in two major watersheds, each of which consists of several minor watersheds. The elevation varies from 1500 to 5200 ft above sea level.

All climatic elements, including temperature, evaporation, humidity, wind velocity and wind direction, have been recorded at seven stations throughout the complete range of elevation. Runoff and sediment from all separate watersheds are continuously measured. In addition, a number of plots for erosion and runoff studies have been set up with different vegetative types. Evapotranspiration studies have been carried out by means of lysimeters. These are soil-filled tanks in which different types of vegetation are grown. All water entering at the top and percolating out the bottom is measured and the difference is the amount of water going to evapotranspiration losses. This study was to determine how watersheds actually function rather than to find the effects of different vegetation on the runoff and erosion.

Another quite extensive watershed study was that in the Coweeta experimental Forest in North Carolina, started in 1942 (10) (13). Records of the runoff were kept for a long enough period of years to determine the runoff characteristics with natural vegetation. Different practices, such as clearing the land for farming, intensive grazing and various logging methods were then carried out on different watersheds, and the runoff was recorded. The maximum water supply with no erosion was obtained from an area which was clear out annually with all debris left on the ground to control erosion.

Rowe (26) discusses plot studies in central California and also the plot studies in the San Dimas Forest. These studies were to determine water losses and water yield under different types of natural vegetation, under annually burned conditions, and under completely bare conditions; and, in addition, to determine the water losses and water yield of a complete watershed. The plot studies were in three groups, each of several plots, on which the different vegetative practices were carried out.

The interception loss on these plots ranged from 5 per cent of the precipitation in chaparral to 12 per cent in ponderosa pine, while total annual losses ranged from 14 inches of water in chaparral to 19 inches in chamise.

The interception loss was reduced by surface burning but the infiltration rate at the soil was also reduced causing more surface runoff and more erosion. Burning did not significantly change the evapotranspiration rate. Interception and evapotranspiration losses were greatly reduced on the plots which were maintained completely bare throughout the study. Erosion and surface runoff, however, were greatly increased.

Stage (31) writes of the runoff characteristics of a small forested watershed in northern Idaho. This is the Benton Creek watershed in the Priest River Experimental Forest, on which work was started in 1938. The watershed consists of 950 acres, very heavily timbered, and varying in elevation from 2660 to 5510 ft above sea level.

The average annual precipitation over the basin was 39.34 inches for a 16 year period. The annual runoff for this period was 14.93 inches, leaving nearly 25 inches for evapotranspiration losses, as it was assumed there was no deep percolation. These data were then extended to the 44 year period for which precipitation records had been kept. For this period the average annual watershed precipitation was 36.21 inches. There were 11.21 inches of surface runoff and the remainder of 25 inches was evapotranspiration loss.

Plot studies were carried on in an aspen forest in Utah from 1936 to 1946. Croft and Manninger (6) wrote of these studies in 1953. Their purpose was to find the effect of altering aspen forest cover on evapotranspiration losses, surface runoff, erosion, and moisture storage in the soil. Removing the deep-rooted trees reduced the annual evapotranspiration loss by 4 inches while the removal of all vegetation reduced the loss 8 inches leaving a loss of 14 inches per year from bare ground.

Briggs and Shantz carried out extensive studies on the water requirements of plants in Colorado during 1911-1912 (4). These were primarily tank studies of agricultural crops. The water requirement was defined as the ratio of the water used during growth to the weight of dry matter produced. It was found that this water requirement was affected by many factors, such as fertility of the soil, type of plant and leaf area of the plant; by far, the most important was atmospheric conditions.

Briggs and Shantz in 1916 (3) wrote that there was a very close correlation between transpiration, evaporation, and temperature. Studies were made of the change in transpiration rate throughout the day, as the atmospheric conditions change, on plants with a wide range of water use rates. Stevens in 1919 (33) applied the data obtained by Briggs to various agricultural crops and yields in the Northwest with good results.

Lowry and Johnson in 1942 (19) discussed a number of tank studies and several watershed studies, including the Wagon Wheel Gap study (1). It was concluded that temperature gave the best correlation with transpiration and the relationship is linear for temperatures greater than 32 ° F. Small scale experiments such as with tanks and lysimeters were said to be of questionable value except as an indication of the relative effects of atmospheric conditions.

Kittredge (15) also questioned the value of tank experiments and studies of the transpiration rates of individual leaves and twigs. These values require the use of such large correction factors when applied to an entire watershed that a very small error is greatly magnified. He wrote that, in general, interception and transpiration increase and evaporation from the soil decreases as the density and height of vegetation increase. However, in many areas the transpiration of plants is limited by the available water in the soil. He stated that perhaps the best method of evaluating the evapotranspiration loss was a continuing account of all precipitation entering the watershed and all streamflow leaving, using regular soil moisture measurements to evaluate the water in storage.

Hursh, Hoover and Fletcher (13) used a monthly accounting procedure in the Coweeta Experimental Forest. Measured rainfall and runoff were tabulated for each month. The difference between rainfall and runoff was the amount of water remaining in storage which was either lost by evapotranspiration, remained in the soil, or remained for streamflow at some later time.

Rowe (26) used an accounting procedure and divided each watershed into segments having the same hydrologic characteristics.

Hendrickson (9), and Croft (5) used soil moisture measurements to evaluate the evapotranspiration losses and the water needed to replenish soil water storage.

Blaney and Criddle (2) developed an empirical equation relating temperature, length of growing season, monthly per cent of annual daytime hours and consumptive use of water. The data needed to apply this relationship are the temperature records, latitude, and the empirical consumptive use coefficient for the particular crop. The difficulty in using this equation is in the evaluation of the consumptive use coefficient which apparently has seldom been determined for vegetation other than agricultural crops. Also, Stallings (32) mentions that the derivation of the magnitude of these coefficients is somewhat questionable.

Thornthwaite and Mather (37) state that evapotranspiration depends on the following four factors:

1. The external supply of energy to the evaporating surface (solar energy).
2. The capacity of the air to remove vapor (humidity, wind speed).
3. Nature of the vegetation (root system, extent of ground coverage).
4. Nature of the soil (amount of available water, fertility).

The first two of these are considered to be the most important. The same authors in the Yearbook of Agriculture 1955 (38) qualify this by saying that land management, soil type, and soil structure have little effect when the soil moisture is at the optimum; also, the amount used by vegetation depends more on the amount of solar energy than on the kind of vegetation when the root zone is well supplied with water. This would, therefore, more likely apply to irrigated crops than natural vegetation which will usually have a moisture deficit during the summer. These factors are the basis for Thornthwaite's method (37) of determining the entire water balance of an area. An empirical equation is used which relates mean monthly temperature, latitude of the area, and monthly precipitation to the potential evapotranspiration or the amount of water which would be lost to evapotranspiration if there were an unlimited supply in the soil. The advantage of this method over the Blaney-Criddle method is that the only data required are readily available at weather stations.

This method was used by the Army Corps of Engineers at Glacier Park (40) to determine the evapotranspiration loss, and was used by Stage in the Priest River Experimental Forest (31) to determine the water balance of the area.

Taylor (34) showed that the consumptive use of riparian vegetation, which has a nearly unlimited water supply, may be as much as 54 inches annually while the consumptive use of vegetation away from streams was 19 inches annually.

Rich (25) states that consumptive use of water depends on amount and distribution of rainfall, topography, climate, storage capacity of the soil and the type of vegetation. This may be determined by dividing the year into four periods:

1. Soil moisture recharge.
2. Water surplus.

3. Soil moisture utilization.
4. Water deficit.

He determined on experimental watersheds in Arizona that evapotranspiration of forested watersheds varied from 77 to 90 per cent of the annual precipitation, shereas the evaporation from bare ground was 78 per cent.

Raber (23) in 1937 wrote that the most important reason for variation in the transpiration rate is due to environmental factors, which would include climatic factors and the soil type. He mentions three methods which have been used to evaluate the transpiration of individual plants or the water use per acre:

1. By obtaining the transpiration per unit leaf area and multiplying this by the leaf area per plant.
2. By obtaining the transpiration per unit mass of leaves and multiplying this by the mass of leaves per plant.
3. By obtaining the water consumption per pound of dry matter produced, and then multiplying by the dry matter produced per acre.

He also gives a table showing the transpiration per board foot of timber produced for western American conifers (Table 2).

Table 2 Water Used to Produce Timber by Western American Conifers.

Board Feet per Acre Year	Inches of Water Used*
50	1.77
100	3.54
200	7.08
500	17.07
1000	35.40

* in acre inches per acre

In addition, Douglas fir was said to transpire 7.67 inches annually and white pine 8.06 inches. He concluded by saying that a great deal more work should be done on water requirements for different areas and types of trees.

Horner and McCall (11) in erosion control and reclamation studies at Pullman, Washington found that deciduous trees removed moisture to a depth of 12 ft. Approximately 30 inches of water were absorbed by the soil the following winter.

Thiessen, in 1911, (35) developed a method to obtain the average precipitation over an area which has a network of precipitation gages. This method consists of constructing perpendicular bisectors to all the lines connecting adjacent gages on a map. The amount of rainfall recorded at each gage is considered to extend over the area defined by the polygon surrounding that gage. The average rainfall over the entire area is then the weighted average of all the gages.

Another method of obtaining the average precipitation over an area is the isohyetal method (17). This consists of constructing lines of equal precipitation or isohyets on a map. The area between two consecutive lines is assumed to be the area over which the average of the rainfall at the two lines falls. The average precipitation for the entire watershed is determined by multiplying the average precipitation for each area by the percentage which this area is of the total area. The total of these figures from each area is the average watershed precipitation.

A method used by the Corps of Engineers is the isopercentual method (40). This is similar to the isohyetal method, in that, lines of equal percentage of the mean annual precipitation are drawn on a map for the year under study. The final figure for the precipitation over the area is in terms of a percentage of the mean annual precipitation.

It is generally recognized that precipitation, in general, increases with increase in altitude (39) (40) (44). The Corps of Engineers found that on a particular watershed in Glacier Park, this increase was about 30 inches per year, from an elevation of 5000 ft to 7000 ft above sea level.

McDonald (20), and Paulhus and Kohler (22) used the normal ratio method to estimate missing precipitation records. This is given by the equation;

$$P_x = \frac{N_x}{N_1} P_1;$$

where P_x is the record to solve for, N_x is the mean of that station for a period of years, N_1 is the mean of another station for the same period of years and P_1 is the record of this station for the period in question.

Croft (5) mentions a number of factors which affect water supply forecasting for any particular year.

1. Water content of the soil mantle when the snow begins melting.
2. Amount of snow melt during the winter.
3. The speed with which the snow melts.

Spring rainfall produces more runoff than fall rainfall since the soil is more apt to be saturated in the spring: also, rapid snow melt produces more runoff than slow snow melt since the infiltration rate of the soil may be exceeded.

The Soil Conservation Service (42) uses a "rule of thumb" to evaluate the annual runoff from watersheds. This is,

$$\text{Runoff (inches)} = \frac{(\text{October to April precipitation})^2}{100}.$$

This has proven fairly accurate for many areas where the annual rainfall is greater than 12 inches.

Stafford and Troxell (30) discuss some of the differences in runoff characteristics from watersheds under the same climatic and vegetative conditions. They cite cases of five watersheds, all with 30 inches of precipitation, which produced 1.0, 1.25, 3.8, 8.7, and 10.6 inches of runoff, due to different degrees of fracturing of the underlying materials, which is not visible nor easily determined. It is for this reason that they emphasize that extreme caution must be used in transferring runoff-precipitation relationships from one watershed to another, and that fullest use should be made of all available data for the watershed under study.

having a mean temperature of 67.2° F. and the coldest month, January, having a mean temperature of 28.2° F. The average annual precipitation at Moscow is 21.70 inches of which 17.89 occurs during the October through May period.

Crumerine Creek drains an area of 1570 acres, of which 1380 acres, or 88 per cent, are forested. The vegetation varies considerably between the ridge tops and stream bottoms. Ridge-top and south-slope vegetation consists of ponderosa pine (Pines ponderosa), Douglas fir (Pseadotsuga taxifolia), ninebark (Physocarpus), Oregon grape (Berberis aquifolium) and other small brush types. The north slopes appear to have more moisture with the vegetation being white fir (Abies grandis), western Larch (Larix Occidentalis), Douglas Fir, white pine (Pins monticola), twin flower (lonicera), ocean spray (sericotheca discolor) and rose (Rosa). The land along the streams appears quite wet with spruce (Picea engelmanni), white pine, cedar (Thuja plicata) and lily (trillium ovatum) being the principal vegetation.

The remainder of the watershed, all at the lower elevations, consists of cropland. This land is farmed according to the common practices in the Palouse, that is, a rotation consisting of winter wheat, spring grain or peas, and summer fallow. The elevation of this watershed varies from 2800 ft at the gaging station to 4600 ft at the highest elevation.

Gnat Creek drains an area of 2725 acres of which 1460 acres, or 53.5 per cent, are forested and the remainder is in cropland and pasture. The forest vegetation is in general the same as on Crumerine Creek. This watershed borders on the west of the Crumerine Creek watershed and extends farther south. The elevation is also lower, varying from 2670 ft at the gaging station to 4100 ft. Figure 1 is a contour map of the watersheds and includes the City of Moscow.

The limits of the watersheds were obtained by tracing a map from aerial photographs on which the areas of woodland and cropland could be easily observed. The ridge lines which are the boundaries of the watersheds could also be seen. As the scale of the maps was known the areas were then determined by the use of a planimeter.

Precipitation

A water balance study must begin with accurate determination of the precipitation over the watershed, as this governs the amount of water available to be divided into the various components of the water balance.

Precipitation at several points for a short period of time can be easily and accurately determined by means of standard rain gages. However, large errors may be made when extending these records over a period of years for an entire watershed. This is particularly true in drier areas where the terrain is irregular, as rainfall varies more from year to year and from place to place in such an area (39). The ideal situation is to have records from an extensive network of gages for a long period of years.

In conducting this particular study, records of a network of precipitation gages between Moscow and Moscow Mountain were fortunately available for the six-year period from 1934 to 1940. One of these gages, No. 7, was re-established in September 1957 at the previous location (Figure 2). Two precipitation gages have been maintained at high elevations on the watersheds for the past two years in connection with studies of the effect of snow capping on precipitation gages. These are termed the West Twin and Moscow Mountain gages. The locations of all these gages are shown on the

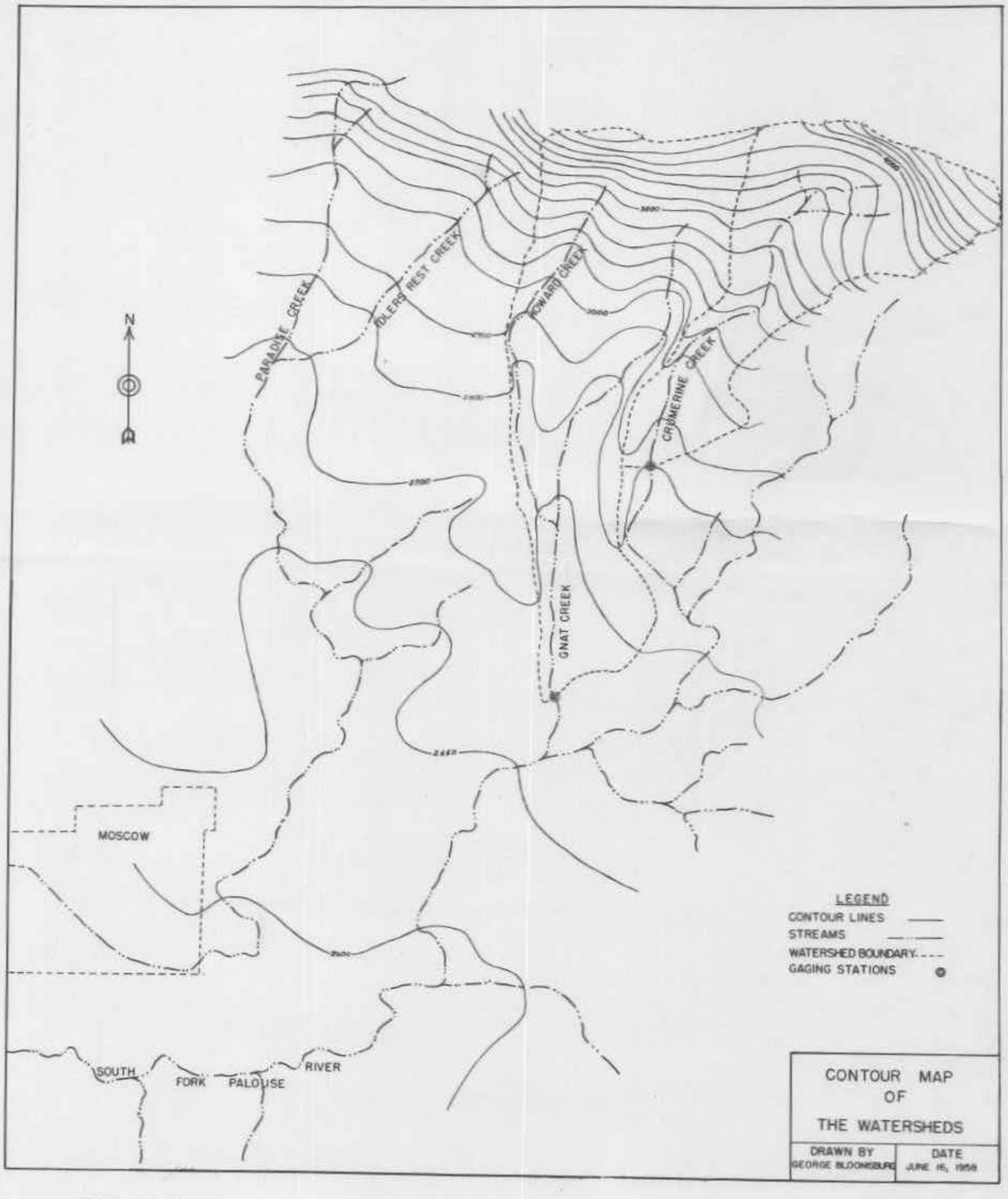

Figure 1 Contour Map of the Crumerine and Gnat Creek Watersheds

Figure 2 Recording Precipitation Gage Which Was
Installed September, 1957

isohyetal map (Figure 3) and the available records are given in Appendix B.

The precipitation gage at the University of Idaho has an uninterrupted record for 65 years. It was, therefore, desired to obtain a relationship between the precipitation at Moscow and the precipitation at each of the other gages, in order to extend their records.

It was first necessary to determine whether there was actually a relationship between the precipitation at the different gages. This was carried out by calculating the correlation coefficient between each gage and the gage at Moscow. When this was done it became apparent that there was a significant relationship between records at different gages. A regression equation was then calculated by the method of least squares relating the

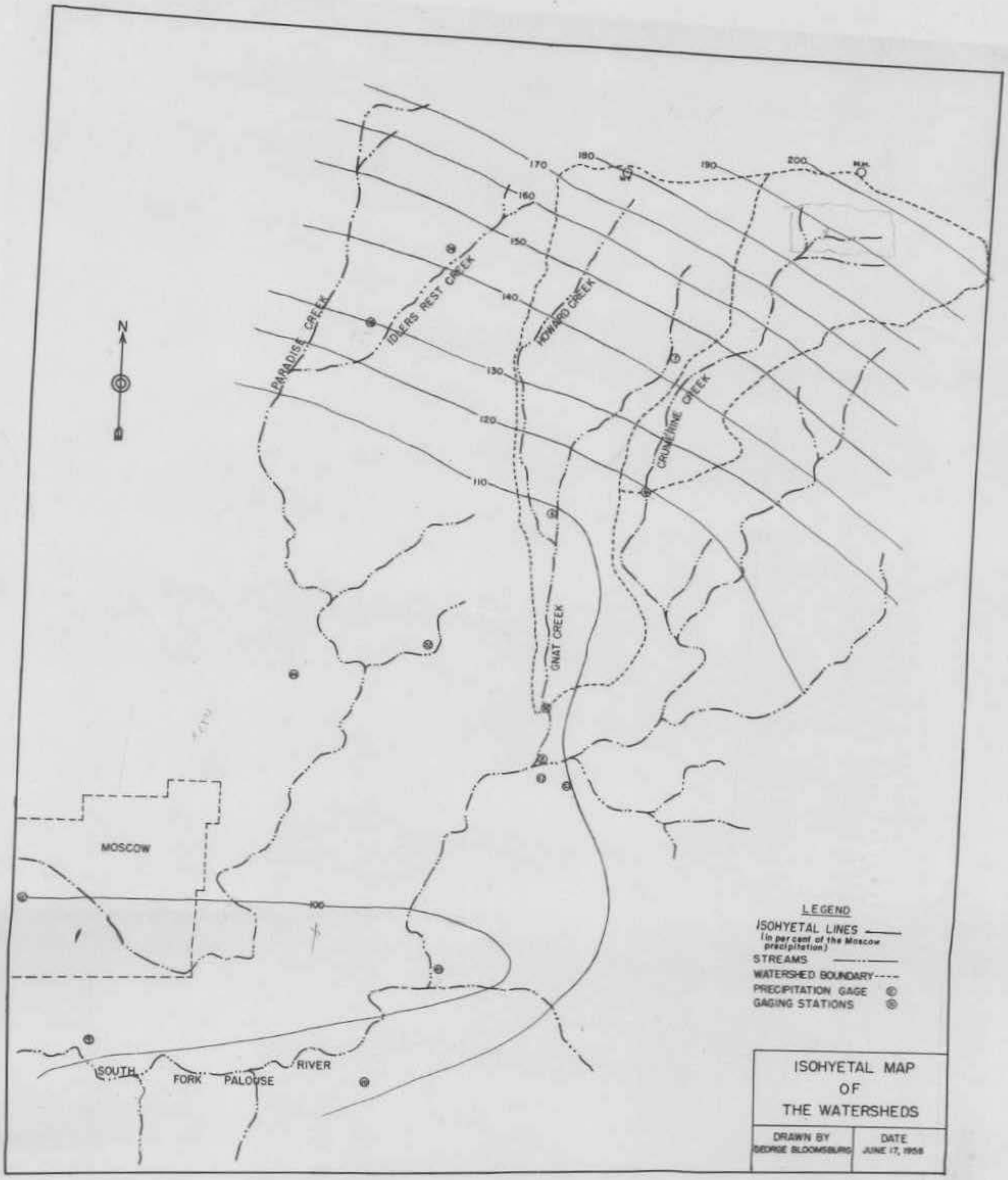

Figure 3 Isohyetal Map of the Crumerine and Gnat Creek Watersheds

precipitation record at each gage to the record at Moscow. This procedure was followed for all gages which had records for the years 1934 to 1940.

A slightly different procedure was followed for the West Twin and Moscow Mountain gages. The correlation coefficient was calculated the same way but when the regression equation was calculated, the Y intercept was greater than 1 inch. That is, when precipitation at Moscow was zero, precipitation at these gages was greater than 1 inch. After examining the precipitation record for each period it was noted that the April 1958 precipitation was so unusual that it changed the regression equation considerably. During this month the precipitation at Moscow was 4.60 inches or 300 per cent of normal, while that at higher elevations was only slightly more than normal. The regression equation was then calculated using all monthly totals except April. This line very nearly went through the origin. As it was not desirable to throw out one month's record, (particularly with so few months of records), it was then decided to include the April total but to assume that the regression line went through the origin and through the point $\bar{X}$, $\bar{Y}$, where $\bar{X}$ and $\bar{Y}$ are the average abscissa and ordinate respectively. Therefore the slope, m, is given by the equation;

$$m = \frac{\bar{Y}}{\bar{X}} .$$

In this way the large deviations from the regression have less weight because they are not squared, as in using the method of least squares. If there had been a large number of data, one month would not have had so great an effect and the method of least squares would have been used. As a check, the method was used on gage No. 7 for the period October, 1957 through June, 1958. The slope of the regression line was 1.41 whereas it was 1.06 for this period by the method of least squares. For the same gage for the period 1934 to 1940, the slope of the regression line by the method of least squares was 1.45. This indicates that for a short period, which includes April, 1958 the relationship between the Moscow precipitation and the precipitation at higher elevations on Moscow Mountain is more accurately determined by simply using the averages at the different gages than by the method of least squares. Table 4 lists all gages, the periods of record, and the slope of the regression lines when the records are compared with Moscow records.

The isohyetal method was used to obtain the average precipitation over the watersheds, rather than the Thiessen method. Linsey, Kohler and Paulhus (17) state that the isohyetal method is the most accurate because all available data may be used, and if there is an indication of orographic precipitation the isohyets may roughly follow the ground contour lines. In the area under study there is definitely orographic precipitation and the spacing of the various gages is not uniform enough to use the Thiessen method with any degree of accuracy.

To obtain the average precipitation over the watersheds, it was desired to have the average as a percentage of the precipitation at Moscow. For this reason the isohyets were drawn at 10 per cent intervals, that is, 110 per cent, 120 per cent, 130 per cent, etc.

When drawing the isohyetal map it was possible to space the isohyets at 10 per cent intervals between the position of the various gages on the map by interpolation. The isohyets were then drawn, in general, parallel to the ground contour lines. The area between the isohyets was then measured with a planimeter and the ratio of each area to the total area was expressed as a percentage. This percentage, multiplied by the average precipitation over the area, gave that area's contribution to the entire watershed. The total of these figures for each area then gave the average precipitation over the entire watershed in terms of a certain percentage of the Moscow yearly total. These data are shown in Table 5.

Evapotranspiration

Basically, four methods are presently used to calculate evapotranspiration losses on watersheds. The first two of these involve calculating the transpiration and interception loss separately. In the first method the transpiration rate of individual leaves or masses of leaves is arrived at experimentally. This value is then multiplied by the number of leaves or the weight of leaves on the watershed to get the transpiration for the entire watershed. The interception loss is usually determined by equations which have been determined experimentally relating the annual precipitation and interception.

The second method involves determining the water efficiency of the vegetation as the ratio of the weight of dry matter produced to the weight of water used. This figure of water efficiency is then multiplied by the weight of dry matter produced annually over the entire watershed. On forested watersheds this is often figured as the water used per board foot of timber produced annually. The interception loss is then calculated in the same way as before.

The third method is that of having an experimental watershed in which there are no deep percolation losses. In this case the combined transpiration and interception loss or evapotranspiration is simply the difference between the depth of precipitation and the depth of surface runoff. This value for evapotranspiration may then be used for other watersheds under similar vegetative and climatic conditions.

The fourth method is that developed by Thornthwaite (37), which consists of computing a water balance for each month by use of an empirical equation which relates temperature and potential evapotranspiration.

The first method has very doubtful accuracy in that a small error in the transpiration rate of a mass of leaves will be greatly magnified when applied to an entire watershed. In fact, there have been instances where this method was used and the transpiration loss was determined to be greater than the annual precipitation. This method was therefore not considered for use in this study.

The second method was used by Packer (21) in his report on the water problems of the Moscow area. The largest sources of error in this method are probably in determining the annual production of timber and determining the interception loss. However, the annual production of timber is a common estimation made by foresters and is reasonably accurate. The interception loss has been determined under numerous conditions of natural vegetation as a function of precipitation. It is also a function of the density of the vegetative cover and this is not easily nor accurately determined. To illustrate the difference in equations which have been developed, Packer used an equation which was derived from studies in ponderosa pine in southern Idaho in an area of 21.5 inches annual precipitation. This equation was

$$I = .02 + .13P;$$

where I is the annual interception loss in inches and P is the annual precipitation in inches. Rowe and Hendrix (28) worked with ponderosa pine in central California in an area of 47 inches precipitation and arrived at the equation

$$I = .12 + .06P.$$

The difference in these two equations is probably due to differences in the density of vegetation and the frequency and intensity of storms, with the latter being the most important, as both studies were on the same type of vegetation. The frequency and intensity of storms and the time of the year in which they occur would have a large effect, because a series of small rains in the summer may all be intercepted and evaporated while very little would be intercepted from a prolonged storm during the winter.

The third method is probably quite accurate if reasonable caution is used when transferring data and if there are data available on watersheds under comparable conditions of vegetation and climate. Regarding this, studies were carried on at Benton Creek in the Priest River Experimental Forest of northern Idaho. This watershed is at approximately the same elevation as the Gnat and Crumerine Creek watersheds, has nearly the same climate except that it is slightly colder and wetter as shown in Table 3, and is more heavily timbered. Therefore it was decided to use the data on evapotranspiration losses from Benton Creek corrected for difference in timber production and temperature. This was done by means of data on the water required to produce a board foot of timber, as given in Table 2, and by assuming a linear relationship between consumptive use and temperature above 32^0 F. as given by Lowry and Johnson (19).

The fourth method has been used quite extensively and was used by the Corps of Engineers in the Upper Columbia Snow Laboratory at Glacier Park with good results. However, at other installations the results have been inconclusive (40).

Several assumptions are made by Thornthwaite (37) which are of doubtful validity for this area.

1. That potential evapotranspiration is independent of the type of vegetation and is a function of climate only.

Table 3 Mean Monthly Temperature and Precipitation at Moscow and Priest River Experimental Forest Headquarters.

	Moscow		Priest River Experimental Forest	
	Mean Temp. (°F.)	Precipitation (inches)	Mean Temp. (° F.)	Precipitation (inches)
Jan.	28.2	2.78	23.6	3.76
Feb.	31.7	2.11	27.3	2.79
March	38.4	2.16	34.8	2.55
April	46.2	1.59	43.9	1.91
May	53.0	1.87	51.4	2.10
June	59.3	1.47	58.0	1.98
July	67.2	.56	64.4	.84
Aug.	66.1	.61	62.6	.96
Sept.	57.8	1.27	54.1	1.75
Oct.	48.9	1.68	44.4	2.64
Nov.	37.7	2.86	33.2	3.60
Dec.	30.8	2.74	26.6	4.27
Annual	47.1	21.70	43.7	29.19

2. That the potential evapotranspiration is zero when the mean monthly temperature is below freezing.

3. That snow cover is on only during the months when the mean monthly temperature is below freezing.

4. That the ground storage is brought up to capacity as soon as enough precipitation has fallen to make up the soil moisture deficit.

The last two assumptions probably have no adverse effect because the potential evapotranspiration does not exceed the precipitation until after all snow is gone and the soil water storage has been filled. However, the first assumption could result in considerable error in some areas, as it is known that the water requirements of many cultivated crops differ, as well as the requirements of natural vegetation. In this study little is known about the water use of the vegetation so it can not be shown that assumption 1 is incorrect. The second assumption is in error because there is evaporation from snow surfaces when the temperature is below freezing.

This error is somewhat compensated for in this study because the temperatures used for the calculations are those in Moscow, while the temperatures on the watersheds are probably lower due to the greater elevation, which would decrease the potential evapotranspiration. The data required to calculate evapotranspiration loss using Thornthwaite's method is the monthly precipitation, the monthly mean temperature, the latitude of the station and certain tables and charts contained in Thornthwaite's publication, <u>The Water Balance</u> (37). The total heat index "I" is first obtained by summing the heat indexes "i" for each individual month. "i" is obtained by using a chart or the equation,

$$i = \left(\frac{t}{5}\right)^{1.514} .$$

For mean monthly temperatures of less than 0^{o} C. the heat index is assumed to be zero.

To obtain a value of unadjusted potential evapotranspiration for each month "I" is used. This value is then adjusted according to the latitude of the station, because the longer days in the summer at the poleward latitudes bring about greater evapotranspiration. The monthly potential evapotranspiration is then subtracted from the monthly precipitation. The periods of water deficiency are defined as those periods when potential evapotranspiration is greater than precipitation. During this period water is being used from the root zone of the soil to satisfy partially the potential evapotranspiration. The accumulated potential water loss at each monthly interval is then calculated and used to obtain the amount of water remaining in storage in the soil. The actual evapotranspiration for any one month is then equal to the potential evapotranspiration during months of water surplus and is equal to the precipitation plus the water leaving storage during the months of water deficit. The evapotranspiration for the entire year is simply the sum of the monthly totals.

Runoff

The runoff is the most easily and accurately measured component of the water balance, as it all leaves the watershed at one point in a stream channel.

The flow in the stream is measured at a stream gaging station which consists of a stage recording device and either natural or artificial control in the channel. The control serves to maintain a constant relationship between the water elevation and the flow rate from year to year. A rating curve is then plotted relating the measured flow rate, to the recorder reading at various stages of flow. This curve is then used to obtain the flow rate at any desired recorder reading without obtaining flow measurements at that particular time.

The stream gaging station on Crumerine Creek was installed at the upper end of a culvert which serves as the control. Figure 4 shows the gage house and entrance to the culvert. The culvert slope is steep enough to produce supercritical flow through the culvert and there is a free fall of about 4 ft at the exit; thus the tailwater is never backed up enough to cause a change of control at the entrance of the culvert.

The rating curve for this station was obtained at low flows by placing a small rectangular weir at the head of the culvert and using a standard weir table to arrive at the flow rate Q. At high flows the flow rate was obtained by taking velocity measurements with a current meter at a uniform cross-section of the stream. The flow rate was then calculated by the equation

$$Q = AV,$$

where Q is the flow rate in cubic feet per second, A is the cross-sectional

Figure 4 Gagin Station on Crumerine Creek

area of the stream in square feet, and V is the average velocity in feet per second at the point where the area is measured.

The flow rate was then plotted versus the tape reading on the stage recorder on semi-logarithmic graph paper as shown in Appendix C. A smooth curve was drawn through the points. This curve was used to obtain the flow rate during certain increments of time. Daily increments were used except during periods of rapidly changing flow when smaller increments were used. The streamflow was then summarized by monthly periods as shown in Appendix C.

The gaging station on Gnat Creek is shown in Figure 5. At this installation the control was supposed to be the culvert; however, there was a higher point in the stream channel downstream which was the control at

Figure 5 Gaging Station on Gnat Creek

all but the highest flow rates. As the control was simply the earthen bottom of the stream channel, it is unlikely that the rating curve remains the same from year to year. The rating curve for this station was obtained by use of a current meter at a uniform section of channel as was done in Crumerine Creek. Considerable difficulty was experienced in keeping the entrance to the stage recorder free from sediment during the spring runoff period because at that time the stream carries a large silt load.

After the annual runoff had been calculated in cubic feet it was converted to inches depth over the entire watershed, as shown in Table 8.

Deep Percolation

There is no accurate method to determine the amount of deep percolation in this area. An indication of the total water recharging the aquifer from which the City of Moscow pumps water is gained by the fact that the recharge is apparently less than the annual pumpage as the static water level has dropped approximately 100 ft in 60 years. However, the area which contributes water to the aquifer, or the recharge area, is completely unknown. Laney (16) and Packer (21) assume that this area includes the entire southwest slope of Moscow Mountain, and the intake area extends from the bottom of the mountain nearly to Moscow. They conclude that the annual recharge exceeds the annual pumpage despite the falling water level. Recent work by the Soil Conservation Service indicates that there is a considerable area of highly impermeable soil along the base of Moscow Mountain which would reduce the extent of the intake area. This area could be accurately defined by extensive soil survey work which has not been done.

Foxworthy and Washburn (8) state that the principal intake area is in the actual stream channels. If this is the case, the intake area would be relatively small and consequently the annual increment to the ground water aquifer would be reduced. They also state that the pumping rate has exceeded the recharge rate.

In this study the deep percolation was calculated by subtracting the sum of the runoff and the evapotranspiration loss from the precipitation for each year. It is reasonably certain, (within the accuracy of the determination of the other factors), that this much water has been contributed by each watershed for that year, however, it must be emphasized that it is unknown whether there is any other area contributing to the ground water recharge.

ANALYSIS OF RESULTS

Precipitation

The method used to extend the records of the various precipitation gages involved calculating a correlation coefficient and then the regression equation relating the precipitation record of each gage, having a short period of records, to the record of the gage at Moscow, which has a long period of records. All statistical equations are from Ezekial (7).

Example: The correlation of the record of gage No. 7 with the record of the Moscow gage for the period October, 1934 to June, 1940.

X = Moscow monthly precipitation in inches.

Y = Gage No. 7 monthly precipitation in inches.

n = Number of months of records = 69

$$\sum X = (X_1 + X_2 + \cdot \cdot \cdot + X_{68} + X_{69}) = 112.76$$

$$\sum X^2 = (X_1^2 + X_2^2 + \cdot \cdot \cdot + X_{68}^2 + X_{69}^2) = 289.2612$$

$$\sum Y = (Y_1 + Y_2 + \cdot \cdot \cdot + Y_{68} + Y_{69}) = 163.06$$

$$\sum Y^2 = (Y_1^2 + Y_2^2 + \cdot \cdot \cdot + Y_{68}^2 + Y_{69}^2) = 617.0018$$

$$\sum XY = (X_1 Y_1 + X_2 Y_2 + \cdot \cdot \cdot + X_{68} Y_{68} + X_{69} Y_{69}) = 418.5563$$

$$r = \frac{\sum XY - \sum X \sum Y/n}{\sqrt{\left[\sum X^2 - (\sum X)^2/n\right]\left[\sum Y^2 - (\sum Y)^2/n\right]}}$$

$$= 0.975$$

This value is significant at the 1 per cent level, that is, less than 1 per cent of the time this high a value would be due to chance, alone. This is justification for calculating a relationship between the two gages.

The slope of the regression line was then calculated,

$$m = \frac{\sum XY - \sum X \sum Y/n}{\sum X^2 - (\sum X)^2/n}$$

$$= 1.45$$

The Y intercept, that is, the value of Y when X = 0 is given by the equation,

$$b = \frac{\sum Y \sum X^2/n - \sum X \sum XY/n}{\sum X^2 - (\sum X)^2/n}$$

$$= 0.00385$$

This value is negligible since it indicates less than .01 inch of precipitation. The equation relating the precipitation at the two gages is therefore, $P_7 = 1.45P_m$. The calculations for all gages for the period 1934 to 1940 were carried out in the same way.

The correlation between the West Twin and Moscow Mountain gages and the Moscow gage were carried out in the same way and were significant but at the 5 per cent level rather than at 1 per cent. This was undoubtedly due to having so few periods of record. The regression line was calculated by assuming that the line goes through the origin and the point $\bar{X}$, $\bar{Y}$.

Example: The slope of the regression line relating the precipitation record at Moscow and West Twin is,

$$m = \frac{\bar{Y}}{\bar{X}} = \frac{\sum Y/n}{\sum X/n} = \frac{\sum Y}{\sum X}$$

$$= 1.80$$

The equation of the regression line is therefore, $P_{wt} = 1.80P_m$. The equation relating the Moscow Mountain gage record and the record at Moscow was calculated in the same way.

Table 4 shows the relationship of all gage records to the Moscow record. There are the values which were used to construct the isohyetal map, Figure 3. When constructing this map, the value of all Y intercepts, b, was assumed to be zero, as some are negative and others are positive.

The average precipitation was calculated as shown in Table 5. On the Crumerine Creek watershed, area 1 is that below the 120 per cent isohyet, area 2 is the area between the 120 and 130 per cent isohyets, etc. Column 2 is the average value of precipitation over each area. Some of these

Table 4 Period of Record and Relationship to Moscow Precipitation For All Gages.

Gage No.	Period of Record	n	r	m	b
6	Oct. 1934 - Dec. 1939 incomp.	51	0.966	1.07	.07
7	Oct. 1934 - June 1940 complete	69	.975	1.45	.00
8	Oct. 1934 - Oct. 1938 incomp.	47	.976	1.05	.08
9	Oct. 1934 - June 1940 incomp.	67	.980	.97	-.07
10	Oct. 1934 - Sept. 1936 complete	24	.930	1.09	-.05
15	Oct. 1934 - Sept. 1935 complete	12	.949	1.30	-.03
32	Jan. 1935 - June 1940 incomp.	63	.951	1.25	.21
38	Oct. 1935 - June 1940 complete	57	.944	1.41	-.17
44	Dec. 1935 - Oct. 1937 complete	22	.960	1.02	-.04
45	Oct. 1936 - June 1940 incomp.	41	.966	.95	.06
54	Dec. 1938 - Dec. 1939 incomp.	12	.974	1.09	.12
57	Feb. 1940 - June 1940 complete	5	.989	1.14	.00
112	Dec. 1937 - June 1940 complete	31	.968	1.03	.01
7	Oct. 1957 - June 1958 complete	9	.843	1.41	.00
W.T.	Nov. 10 1956-Apr. 30 1958 incomp.	13	0.769	1.80	.00
M.M.	Nov. 5 1957-Apr. 30 1958 complete	6	0.827	2.03	.00

Table Precipitation On the Crumerine and Gnat Creek Watersheds as a Per Cent of Moscow Precipitation.

Crumerine Creek Watershed

Area	Per Cent of Moscow Precipitation	Per Cent of Total Area	Precipitation Times Area
1	119	.80	.95
2	127	7.07	8.98
3	134	9.63	12.90
4	145	7.70	11.18
5	155	6.02	9.34
6	166	7.63	12.66
7	176	10.28	18.10
8	186	22.00	40.90
9	194	22.45	43.50
10	201	6.42	12.90
		100.00	171.41 = per cent watershed precipitation is of Moscow precipitation.

(Continued)
Table 5 Precipitation on the Crumerine and Gnat Creek Watersheds as a Per Cent of Moscow Precipitation.

Gnat Creek Watershed

Area	Per Cent of Moscow Precipitation	Per Cent of Total Area	Precipitation Times Area
1	109	15.90	17.32
2	114	17.20	19.60
3	125	8.20	10.02
4	136	12.81	17.42
5	145	13.03	18.90
6	155	10.42	16.18
7	165	9.53	15.70
8	174	8.18	14.23
9	183	4.61	8.43
10	191	.30	.57
		100.00	138.37 = per cent watershed precipitation is of Moscow precipitation.

values are not the arithmetic average of the two isohyets, because the watershed was much wider at one asohyet than at the other. Column 3 is the per cent each area is of the total area of the watershed. Column 4 is the product of columns 2 and 3; the total of which gives the percentage which the average precipitation over the watershed is of the precipitation at Moscow.

Table 6 gives the average annual precipitation over the watersheds as calculated for the period of the study and for the 66-year period of the Moscow precipitation records.

The precipitation for the months of July through September, 1958 was estimated to be the 66-year mean for these months.

Evapotranspiration

The first method used to calculate the evapotranspiration loss consisted of starting with the average evapotranspiration loss at Benton Creek of 25 inches and adjusting it for the differences in productivity and

Table 6 Annual Precipitation at Moscow and on Each Watershed for the Period of Study.

Water Year	Precipitation		
	Moscow	Gnat Creek Watershed	Crumerine Creek Watershed
1955-56	24.83	34.2	42.5
1956-57	18.90	26.1	32.3 115.4 38.5"
1957-58	23.76	32.8	40.6
66-year mean	21.70	29.9	3/115.4 37.1 38.6

temperature. It was estimated by personnel of the Soil Conservation Service that the annual production of timber per acre on the Benton Creek watershed was 500 board feet per acre per year and that on the Crumerine and Gnat Creek watersheds the production was 350 board feet per acre per year. These figures then give a transpiration value, from Raber (23), of 17.07 inches of water annually at Benton Creek and 12.07 inches annually at Crumerine and Gnat Creeks. The interception loss was assumed to vary by this same ratio. As the precipitation is nearly the same, the interception calculated by the use of the equations mentioned previously would be the same and therefore the only difference in the interception loss would be due to the difference in the density of vegetation which also shows up in the difference of productivity. Therefore, the evapotranspiration loss (E. L.) each year is

$$\text{E. L.} = 25\left(\frac{12.08}{17.08}\right)\left(\frac{\text{mean annual temp. at Moscow } -32^\circ}{\text{mean annual temp. at Benton Creek } -32^\circ}\right)$$

Example: During the water year 1956-57, the average temperature at Moscow was 46.87° F.

$$\text{E. L.} = 25\left(\frac{12.08}{17.08}\right)\left(\frac{46.87-32}{43.7-32}\right) = 22.6 \text{ inches}$$

This applies to the woodland on either watershed. For the cropland, it was assumed that the transpiration would be the same as calculated by Packer (21) or 11.59 inches. The interception, however, varies as the equation

$$I = .04 + .22P_s,$$

where P_s is the May to September precipitation. The evapotranspiration loss is equal to the sum of the transpiration and interception, or

$$E.\ L. = 11.59 + .04 + .22P_s$$

$$E.\ L. = 11.63 + .22P_s$$

On the Crumerine Creek watershed (cropland) the May to September precipitation was 6.64 inches, therefore,

$$E.\ L. = 13.09 \text{ inches}$$

The average evapotranspiration loss on the entire watershed is equal to the evapotranspiration loss of the woodland times the per cent of area in woodland plus the evapotranspiration loss of the cropland times the per cent of area in cropland, or

$$\begin{aligned} E.\ L.\ \text{average} &= 22.5(.88) + 13.09(.12) \\ &= 21.37 \text{ inches} \end{aligned}$$

The same method was used on each watershed for each of the three years of the study. The temperature and precipitation for the months of July through September, 1958 were again assumed to be average. Thornthwaite's method was next used for each watershed for each year of the study. This involved calculating a heat index, I, value for the entire year. Therefore, the calendar year rather than the water year was used to obtain the evapotranspiration for each month. The evapotranspiration for the proper months was then summed to obtain the value for the water year. This method was carried out for each watershed for each year with the only difference between the watersheds being in the annual amount of precipitation. Soil storage was assumed to be 230 mm. or approximately 9 inches of water within the root zone of the vegetation. Table 7 shows all values of evapotranspiration loss for both watersheds calculated by each method.

In order to arrive at a conservative estimate of the ground water recharge it was decided to use, for the water balance, the method which gave

Table 7 Evapotranspiration Loss (Consumptive Use) on Each Watershed for the Period of Study. Evapotranspiration in inches.

	Crumerine Creek		Gnat Creek	
Water Year	Benton Creek Adjusted	Thornthwaite's Method	Benton Creek Adjusted	Thornthwaite's Method
1955-56	21.39	19.8	18.10	18.4
1956-57	21.37	17.2	18.03	16.6
1957-58	24.74	18.5	20.00	17.4

the larger value for consumptive use.

Runoff

The runoff for the two watersheds for each water year is given in Table 8, and all monthly totals are given in Appendix C. The runoff for the months of October through December, 1955 and July through September, 1958, was estimated as being the average of these months during the two years when records were obtained. It was felt that this gave a reasonable figure and as the flow is low during this time of year, a small error would have little effect on the total yearly flow.

Table 8 Runoff for the Period of Study.

4.53 mi^2

	Crumerine Creek		Gnat Creek	
Year	cubic feet	inches*	cubic feet	inches*
1955-56	68,678,000	12.10	40,226,770	4.07
1956-57	49,135,200	8.64	39,246,240	3.97
1957-58	50,778,900	8.92	72,512,550	7.35

* inches depth over entire watershed

The runoff from the Gnat Creek watershed does not seem to be consistent as the runoff during the 1957-58 water year is nearly twice that during other years. There is no indication in either the runoff in Crumerine Creek or the precipitation records that this should be the case. The most logical explanation for this is that the stream channel has changed in such a way during the past two years that the rating curve which was developed during the winter of 1957-58 by actual measurements is in error when used for the other years. This rating curve is accurate for the stream as it was at the time of measurement; however, it is not known whether the channel has silted in or eroded deeper during the previous years.

Deep Percolation

The deep percolation is the difference between the average precipitation over the watershed and the sum of runoff and evapotranspiration loss. Table 9 gives the amount of annual deep percolation from each watershed for each year. This is given both in inches depth over the watershed and total amount of water in cubic feet.

Table 9 Deep Percolation from Each Watershed for the Period of Study.

	Crumerine Creek		Gnat Creek	
Year	cubic feet	inches	cubic feet	inches
1955-56	51,300,000	9.0	119,000,000	12.0
1956-57	13,100,000	2.3	40,600,000	4.1
1957-58	39,900,000	7.0	54,500,000	5.5

Water Balance

Table 10 gives the percentage of the annual precipitation which made up each of the components of the water balance each year, and Figure 6 gives the same information in bar graph form.

Table 10 Water Balance for Each Year of Study.

Crumerine Creek

Year	1955-56		1956-57		1957-58	
	Inches	Per Cent of Precipitation	Inches	Per Cent of Precipitation	Inches	Per Cent of Precipitation
Precip.	42.5	100.0	32.3	100.0	40.6	100.0
Evapotrans.	21.4	50.3	21.4	66.3	24.7	60.8
Streamflow	12.1	28.5	8.6	26.6	8.9	21.9
Deep Percol.	9.0	21.2	2.3	7.1	7.0	17.3

Gnat Creek

Year	1955-56		1956-57		1957-58	
	Inches	Per Cent of Precipitation	Inches	Per Cent of Precipitation	Inches	Pre Cent of Precipitation
Precip.	34.2	100.0	26.1	100.0	32.8	100.0
Evapotrans.	18.1	53.0	18.0	69.0	20.0	61.0
Streamflow	4.1	12.0	4.0	15.3	7.3	22.3
Deep Percol	12.0	35.0	4.1	15.7	5.5	16.7

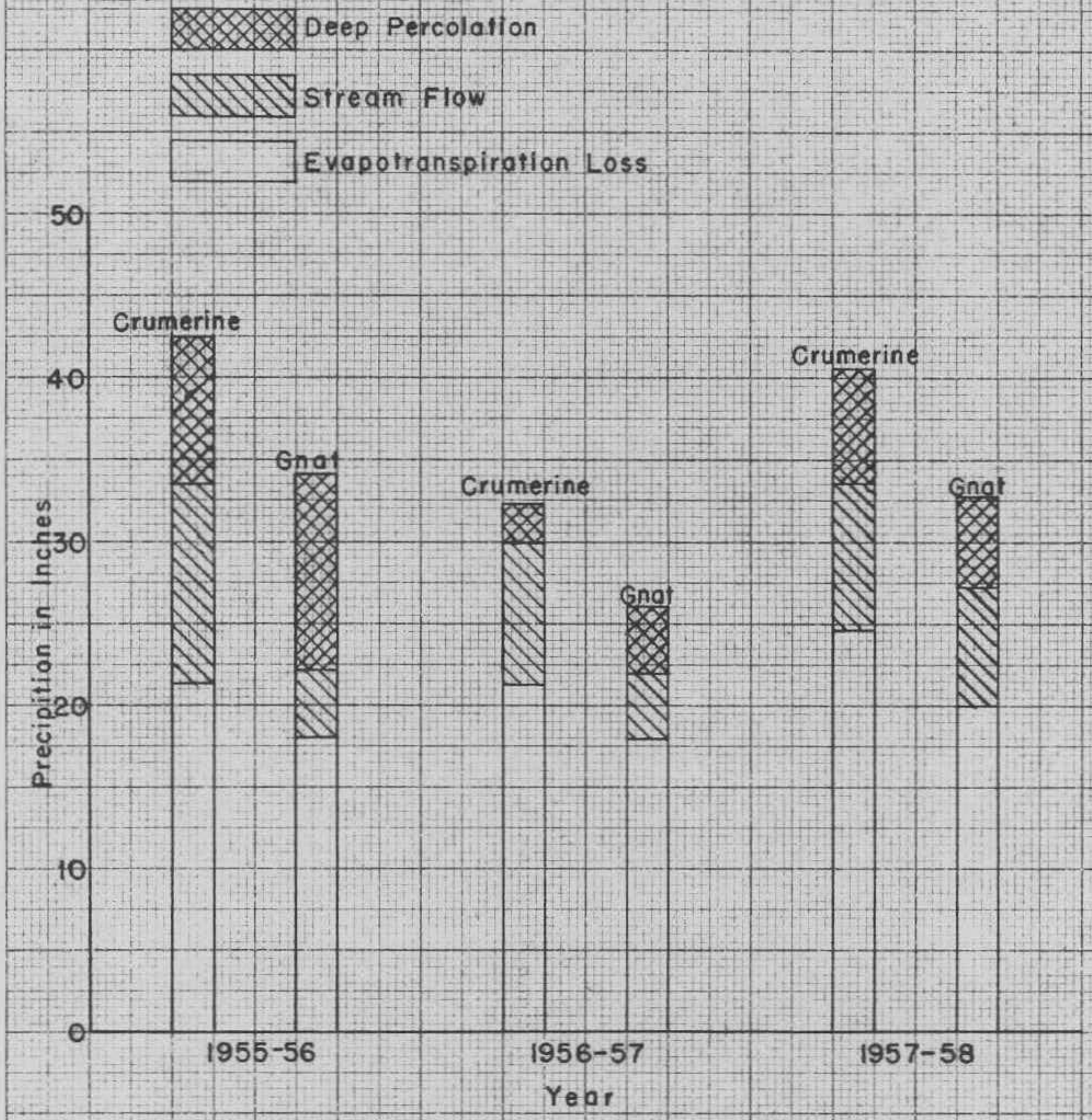

Figure 6 Disposition of Precipitation on the Crumerine and Gnat Creek Watersheds

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DISCUSSION

There is a possible source of error in the determination of the average watershed precipitation for the year 1955-56. All the records which have been collected at the gages other than at Moscow occurred during a period of relatively dry years. The relationship found between the various gages and Moscow may therefore only remain accurate for less than normal precipitation. During 1955-56 the precipitation at Moscow was 15 per cent above normal. If the increase in precipitation with altitude is less when the rainfall is above normal than when it is below normal the watershed precipitation would be less than was calculated here. However, when a study such as this is made to investigate the magnitude of the water supply it is certainly of more value to know the precipitation during dry years than during wet years.

The error of the precipitation figures as determined here is thought to be considerably less than 10 per cent, which is not too important when the precipitation is above 30 inches annually.

The fact that both of these watersheds have two distinct types of vegetation, that is, forest and field crops, complicated the determination of the evapotranspiration loss.

The evapotranspiration as calculated here remained nearly constant from year to year in the actual amount of water lost except for a slight increase during 1957-58. This increase in the calculated values was primarily brought about by high temperatures during the winter of 1957-58 when there was no month with a mean temperature below freezing. The method by which these figures were obtained does not differentiate between a temperature above average in the winter and a temperature above average in the summer, as Thornthwaite's method does. Thornthwaite's method is probably more "scientific" than the other method but would have left a larger amount of water for deep percolation which would not have been as conservative an estimation.

The per cent of the annual precipitation which is evapotranspiration varies as shown in Figure 7. As the study extended over a three-year period, there are three points on each curve for each watershed. This number of points does not completely define the curve as they extend over a relatively small range horizontally. The curves indicate that the per cent of the precipitation which goes to evapotranspiration decreases as precipitation increases. Theoretically these curves would reach 100 per cent if the precipitation was very low and would reach a small per cent if the precipitation was high. This is because there is a limit to the amount of water a plant will transpire regardless of the amount available.

The runoff is probably the most accurately determined component of the water balance, except for the years 1955-56 and 1956-57, in Gnat Creek. It is not known for sure that these figures are in error, but the annual flow in Crumerine Creek varied as the annual precipitation while that in Gnat Creek did not. Error in these runoff figures is best explained by the possible changing of the shape of the stream bottom and resulting change of the rating curve.

The amount of water going to make up the ground water recharge is inconsistent from year to year, both in inches depth and in the per cent of annual precipitation. The depth varies from 2.3 to 12 inches annually and the percentage varies from 7 to 35 per cent of the annual precipitation. If it is considered for 1955-56 that the precipitation figures are too large and the flow in Gnat Creek is too small, this variation would be reduced considerably.

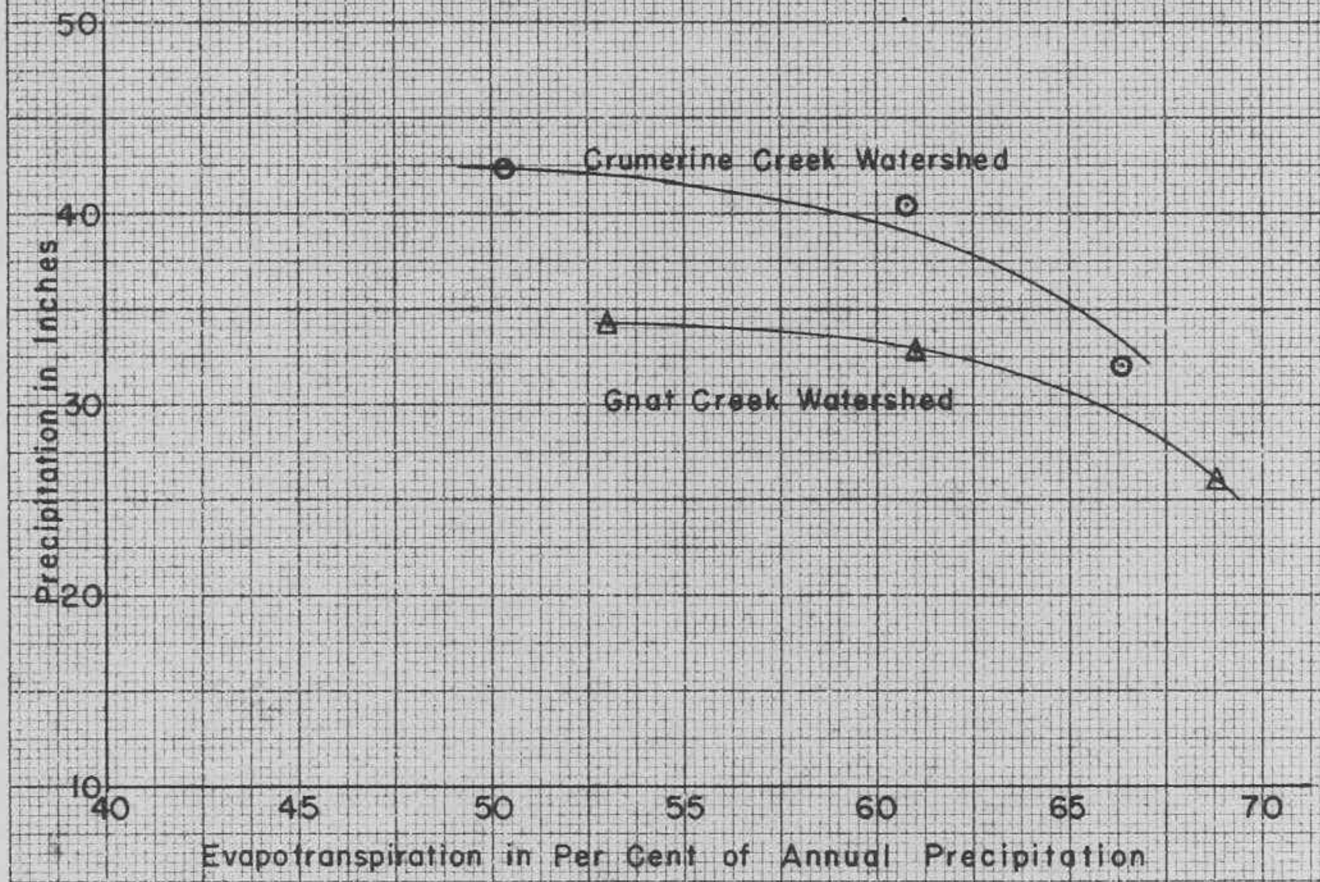

Figure 7 Evapotranspiration in Per Cent of Annual Precipitation as Affected by the Amount of Annual Precipitation

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20 X 20 to the inch, 10th lines heavy.
MADE IN U.S.A.

The City of Moscow and the University of Idaho annually pump approximately 120 million cubic feet of water. This value, when compared with the figures in Table 9, show that the deep percolation from these two watersheds is not ordinarily as much as the pumpage. There are other watersheds which probably recharge this aquifer, but, on the other hand, it is not even known for sure that the deep percolation from these watersheds recharges the aquifer from which the city and university pump.

RECOMMENDATIONS

To determine wholly new methods of hydrologic analysis with assurance of accuracy there must be enough data available to use part of it for the determination of the new method and the remaining data as a check. In this study there were certain modifications of methods to make better use of the available data but there were no completely new methods used. The following recommendations are made such that, if carried out, there would be data available which could be used to check the accuracy and perhaps modify the methods used in this report. The methods of analysis as used here could be used under other climatic and topographic conditions but the only method of checking the accuracy in any particular region is by obtaining actual data.

1. The present precipitation gages should be maintained and the possibility of installing additional gages at selected sites should be investigated. If the present gages are maintained over a long enough period of years to include extreme wet and dry years, their records will be much more reliable.

2. A small, entirely forested, experimental watershed should be established to obtain reliable data on the evapotranspiration loss from the native vegetation in this region. This watershed should preferably be smaller than 40 acres so that many of the indeterminate factors such as variations in vegetation and geological conditions which influence the watershed characteristics are minimized. The watershed should also be completely instrumented for taking precipitation, soil moisture, air temperature and runoff measurements.

3. The stream gaging station on Crumerine Creek should be maintained and several current meter measurements should be made annually to check the

accuracy of the rating curve.

4. The stream gaging station on Gnat Creek should be moved to a better location. One possibility of a better location is farther upstream on the same creek, at a point above which there is little or no agricultural land. In selecting a site, care should be taken that there is a permanent control for which a rating curve may be obtained. If a culvert is used for the control there should be free fall at the lower end of the culvert. This would eliminate the two greatest faults of this gage, that is, changing of the control and silting of the entrance to the gage. The information obtained upstream would be just as valuable, as the silt problem in the use of water from agricultural watersheds is tremendous.

5. A detailed study of the wells in this area should be made to obtain more information on the flow of ground water. If possible, an attempt should be made to obtain more information on the recharge area for the aquifers from which pumping occurs.

6. A detailed analysis of all data which are being collected should be made periodically in order to determine what phase of the experimental work should be the most intensively studied.

SUMMARY

A hydrologic study based on three years of runoff records and approximately six years precipitation records, at the best, involves considerable estimation. After consideration was given to all available data and all applicable empirical data from other hydrologic studies, the following facts were determined.

1. There is an increase in precipitation with altitude in this area. Considering an average year, there would be approximately 21.7 inches at Moscow, 37.0 inches on the Crumerine Creek watershed and 29.9 inches on the Gnat Creek watershed. During the lowest year of record (1911), there were 10.9 inches at Moscow, approximately 18.6 inches on the Crumerine Creek watershed and 15.0 inches on the Gnat Creek watershed.

2. No experimental data were obtained on the evapotranspiration losses in this area. After a review of the literature, it was decided to calculate this in two ways. One is Thornthwaite's method, assuming evapotranspiration is a function only of climatic factors, and the other is a method of adjusting data from another watershed for differences in productivity and the annual temperatures. The methods checked reasonably close and the larger figure was used in order to arrive at a conservative estimate of the available water. The evapotranspiration loss was determined to vary from 18 to 25 inches and from 53 to 69 per cent of the annual precipitation.

3. The runoff which may be expected from these watersheds was determined to be 22 to 25 per cent of the annual precipitation. During a year of normal precipitation this would be 8.7 inches over the watershed, or 49,600,000 cubic feet in Crumerine Creek and 7.0 inches or 69,000,000 cubic feet in Gnat Creek. During the year of lowest precipitation (1911)

the runoff would have been 4.4 inches or 25,000,000 cubic feet in Crumerine Creek and 3.6 inches or 35,600,000 cubic feet in Gnat Creek.

4. The ground water recharge was calculated to be between 2.3 and 12 inches, or from 7 to 35 per cent of the annual precipitation. It is thought that the average would be about 15 per cent of the annual precipitation. During an extremely dry year this component of the water balance would very likely be negligible as evapotranspiration would take nearly all the available soil water. This is the least accurately determined factor as there is no accurate method of measurement and it was therefore obtained by subtracting the annual amount of evapotranspiration and surface runoff from the annual precipitation. Any errors in the other components would therefore show up here.

APPENDIX A

Definition of Terms

DEFINITION OF TERMS

1. Aquifer - A geological formation or structure that transmits water in sufficient quantity to supply pumping wells or springs.

2. Consumptive Use - See evapotranspiration.

3. Correlation Coefficient - A number indicating how closely two variables are related. This number varies between plus one and minus one. Plus one indicates a perfect correlation, zero indicates no correlation and minus one indicates a perfect negative correlation, that is, as one variable increases the other decreases.

4. Deep Percolation (ground water recharge) - Includes all water leaving the watershed by transmission through an aquifer.

5. Evapotranspiration (consumptive use) - Includes all water losses from a given area by transpiration and by evaporation from water surfaces, soil, snow, and vegetation.

6. Interception Loss - The precipitation which is intercepted by vegetation and subsequently evaporated without reaching the ground surface.

7. Isohyets - Lines of equal precipitation on a map, either for one storm or for a definite period of time.

8. Isopercentual - Lines on a map of equal percentage of the mean annual precipitation.

9. Method of Least Squares - A method of obtaining the slope of a line which best fits a number of plotted points.

10. Orographic Precipitation - The precipitation caused by lifting of air masses over mountain barriers.

11. Precipitation - That water, in liquid or solid form which reaches the earth, including that intercepted by vegetation.

12. Rating Curve - A curve relating the depth of water at a gaging station to the flow rate at that point.

13. Regression Equation - An equation showing the relationship between a dependent and an independent variable.

14. Riparian Vegetation - Vegetation which is contiguous to a stream or other body of surface water.

15. Runoff - Includes all water leaving the watershed by way of the stream channel.

16. Soil Moisture - The water held in the soil after gravitational water has drained away.

17. Thiessen Method - A method of computing depths of precipitation over an area which gives weight to the areal distribution of stations.

18. Transpiration Loss - That water which vegetation transfers to the atmosphere as water vapor.

19. Water Balance Study - A study to determine the amount and disposition of precipitation over an area.

20. Watershed - The entire area drained by a stream or system of streams such that all streamflow originating in the area is discharged through a single outlet.

APPENDIX B

Precipitation Data Used in the Study

Table 11 PRECIPITATION RECORDS

Gage No.		6	7	8	9	10	12	15	32
Year	Month								
1934	October	3.79	4.44	3.82	3.49	3.54	3.44	3.57	
	November	3.10	3.98	3.16	2.39	3.08	2.47	3.10	
	December	3.81	4.34	3.47	2.34	3.25	2.96	4.14	
1935	January	3.17	4.93	3.13	2.82	3.11	2.73	4.59	5.07
	February	1.29	1.37	1.06	.92	1.10	1.06	1.28	1.39
	March	3.66	4.19	3.30	2.57	2.78	2.55	4.04	4.35
	April	3.07	3.44	2.93	2.63	2.69	2.93	2.96	3.23
	May	.23	.34	.21	.16	.22	.24	.26	.40
	June	.68	.77	.61	.66	.72	.61	.70	--
	July	.35	.50	.36	.41	.34	.47	.44	.33
	August	.20	.14	.15	.21	.13	.34	.35	--
	September	.29	.29	.28	.27	.20	.26	.28	--
	October	1.12	1.20	1.16	1.21	1.38	1.25		1.05
	November	.89	1.35	.82	.90	1.08	.96		1.40
	December	2.24	3.74	2.84	2.55	2.86	2.59		2.98
1936	January	5.11	6.74	5.00	5.13	5.74	5.12		6.27
	February	2.37	3.91	1.81	1.67	1.63	2.17		2.35
	March	2.02	2.41	2.22	1.67	2.10	1.92		1.78
	April	.67	.84	.95	.53	.61	.52		.69
	May	1.59	1.60	1.35	1.59	1.53	.86		1.88
	June	1.36	1.87	1.40	1.44	1.31	1.59		1.82
	July	.67	.49	.35	.36	.35	.34		.45
	August	.10	.10	.10	.05	.07	.00		.07
	September	1.12	1.18	1.02	.99	.80	1.18		1.30
	October	.28	.28	.19	.34		.30		.30
	November	.30	.38	.25	.17		.24		.34
	December	2.42	3.30	2.52	2.60		2.73		2.88
1937	January	--	6.00	--	3.66		3.60		4.57
	February	--	5.61	--	3.25		2.77		5.58
	March	2.17	2.93	2.15	2.26		2.25		2.19
	April	4.44	5.28	4.18	4.02		3.81		4.29
	May	.94	1.01	.84	.71		.69		.91
	June	2.77	3.65	3.01	2.91		2.92		2.98
	July	.37	.29	.15	.11		.23		.23
	August	.51	.66	.66	.42		.49		.63
	September	1.06	1.03	1.52	.97		.79		.91
	October	1.58	1.68	1.51	1.30		1.51		[illegible]
	November	3.83	5.31	3.42	3.21		3.60		[illegible]
	December	4.88	5.46	4.57	3.61		4.05		5.14
1938	January	2.17	3.16	2.19	1.50		1.62		2.57
	February	1.61	2.77	2.16	1.77		1.79		2.63
	March	2.28	2.80	2.38	2.16		2.30		2.80
	April	1.84	2.07	2.02	1.50		1.60		1.83
	May	--	1.87	1.66	.98		.88		1.66
	June	1.64	2.39	1.21	1.14		1.27		1 [illegible]
	July	.22	.63	.31	.30		.30		
	August	.06	.27	.08	.16		.17		

Gage No. Year	Month	6	7	8	9	10	12	15	32
1938	September	--	1.29	.86	.87		.84		.77
	October	2.00	2.41	2.04	1.61		1.80		2.1[illegible]
	November	—	3.10		2.63		2.55		2.[illegible]
	December	—	2.28		1.21		1.30		1.98
1939	January	—	2.33		1.24		1.39		1.92
	February	—	5.43		3.39		3.76		4.81
	March	—	2.51		2.07		2.35		2.50
	April	—	1.10		.43		.55		.96
	May	.93	1.21		.56		.57		1.00
	June	1.37	1.40		.80		.81		.97
	July	.85	.96		.76		.72		.87
	August	.00	.00		.00		.00		.00
	September	.57	.54		.40		.36		.47
	October	—	1.51		1.13		1.12		1.35
	November	--	.42		—		.34		.30
	December	4.51	4.78		--		3.51		4.35
1940	January		2.78		1.44		2.18		2.48
	February		7.25		4.43		4.06		6.02
	March		3.49		2.69		2.38		2.85
	April		3.76		1.75		2.60		2.85
	May		1.02		.93		.72		.95
	June		.49		.29		.36		.58
1955	October						3.65	Records are	
	November						3.99	available for	
	December						3.59	Gage No. 12	
1956	January						3.51	(Moscow) for	
	February						1.92	the period	
	March						2.12	July 1940-	
	April						.14	September 1955	
	May						1.17		
	June						1.84		
	July						1.05		
	August						1.52		
	September						.33		
	October						2.23		
	November						1.13		
	December						[illegible].76		
1957	January						1.66		
	February						[illegible]		
	March						[illegible]		
	April						[illegible]		
	May						[illegible]		
	June						[illegible]		
	July						[illegible]		
	August						[illegible]		
	September						[illegible]		
	October						2		
	November						1		
	December						2.		

#

Gage No.		6	7	8	9	10	12	15	32
Year	Month								
1958	January		4.91				2.71		
	February		3.87				2.87		
	March		1.61				1.26		
	April		4.70				4.60		
	May		1.06				.47		
	June		2.57				1.91		

Gage No.		38	44	45	50	54	57	112
Year	Month							
1935	October	1.26						
	November	1.24						
	December	3.49	2.45					
1936	January	7.99	5.04					
	February	1.91	1.76					
	March	1.04	1.65					
	April	.64	.63					
	May	1.73	1.57					
	June	1.71	1.26					
	July	.47	.40					
	August	.00	.00					
	September	1.43	1.06					
	October	.32	.25	.28				
	November	.36	.15	.16				
	December	2.98	2.44	2.44				
1937	January	5.59	5.00	—				
	February	6.37	2.14	—				
	March	2.71	1.81	1.98				
	April	5.01	4.17	3.42				
	May	1.20	.76	.67				
	June	3.06	2.86	3.00				
	July	.38	.18	.19				
	August	.66	.59	.48				
	September	.86	.80	1.37				
	October	1.52		—				
	November	4.88		3.58	3.51			
	December	6.19		4.46	3.76			3.94
1938	January	3.18		1.62	1.70			1.74
	February	2.25		1.79	2.21			1.73
	March	2.62		1.54	2.12			1.94
	April	1.92		1.95	1.61			1.59
	May	1.55		1.33	.95			1.61
	June	1.48		1.17	1.21			1.27
	July	.13		.43	.30			.12
	August	.21		.03	.21			.19
	September	.64		.88	.86			.74
	October	2.45		1.84	1.68			1.92
	November	2.40		2.11	2.65			2.41

Gage No.		38	44	45	50	54	57	112
Year	Month							
1938	December	1.84		1.42	1.52	1.73		1.30
1939	January	2.28		1.03	1.24	1.69		1.43
	February	4.67		3.40	3.46	3.99		3.71
	March	2.19		1.79	2.33	2.33		2.16
	April	.97		.77	.68	.50		.40
	May	1.09		.84	.70	.87		.88
	June	.78		1.03	.88	1.11		.87
	July	.78		.67	.63	.78		.85
	August	.00		.00	.00	.00		.00
	September	.44		.43	.43	—		.41
	October	1.08		1.17	1.12	.90		1.26
	November	.08		.36	.32	1.00		.34
	December	4.14		3.97	3.85	4.46		4.43
1940	January	3.14		1.26	2.07			1.66
	February	6.53		4.37	4.54		4.89	4.77
	March	3.10		2.51	2.58		2.61	3.02
	April	2.84		2.23	2.41		2.59	2.31
	May	.99		.94	.84		1.03	.88
	June	.44			.41		.42	.58

Period	Wes din	Moscow Mountain	Moscow
1956-57			
Nov. 10 - Nov. 30	1		.75
Dec. 1 - Dec. 29	4.[illegible]		2.64
Dec. 30 - Jan. 26	2.2		1.43
Jan. 27 - Feb. 16	3.9		1.32
Feb. 17 - Mar. 2	2.4		.92
Mar. 3 - Mar. 23	3.7		1.79
Mar. 24 - Apr. 27	2.7		2.13
Apr. 28 - June 3	6.3		3.48
1957-58			
Oct. 15 - Nov. 4	.8		1.07
Nov. 5 - Nov. 30	4.1	3.2	1.92
Dec. 1 - Jan. 4	5.4	7.0	2.92
Jan. 5 - Feb. 1	4.7	7.2	2.71
Feb. 2 - Mar. 1	5.7	5.8	2.87
Mar. 2 - Mar. 29	.9	2.4	.99
Mar. 30 - Apr. 30	5.7	7.4	4.87

APPENDIX C

Streamflow Data and Rating Curves

able 12 Summary of Flow rumerine Creek
(cubic fe er month)

Month	1955-1956	1956-1957	1957-1958
October	715,000*	800,000	631,000
November	900,600*	1,168,200	633,000
December	1,498,750*	1,609,300	1,388,200
January	2,072,000*	1,641,400	2,502,600
February	2,429,800	2,930,400	11,354,600
March	11,946,300	8,705,500	4,509,000
April	26,544,000	12,778,000	14,251,400
May	16,075,000	13,650,000	11,216,600
June	3,675,900	3,980,000	2,083,300
July	1,455,200	1,072,200	1,263,000*
August	651,300	505,100	578,200*
September	441,000	295,100	368,000*
Total (cubic feet)	68,678,000	49,135,200	50,778,900
Total (in. depth)	12.10	8.64	8.92

* Average of two other years

Table 13 Summary of Flow in Gnat Creek
(cubic feet per month)

Month	1955-1956	1956-1957	1957-1958
October	75,170*	8,640	141,700
November	170,750*	49,200	292,300
December	1,584,200*	825,600	2,342,800
January	5,464,350*	511,500	10,417,200
February	2,668,600	19,251,700	22,291,000
March	22,669,900	9,303,200	8,546,000
April	4,922,700	3,970,600	18,407,000
May	1,550,900	3,068,000	7,244,000
June	586,100	1,955,600	2,562,800
July	233,300	302,200	267,750*
August	no flow	no flow	no flow *
September	no flow	no flow	no flow *
Total (cubic feet)	40,226,770	39,246,240	72,512,550
Total (in. depth)	4.07	3.97	7.35

* Average of two other years

KEUFFEL & ESSER CO., N. Y. NO. 359-72
Semi-Logarithmic, 3 Cycles X 5 to the ½ inch.
MADE IN U.S.A.

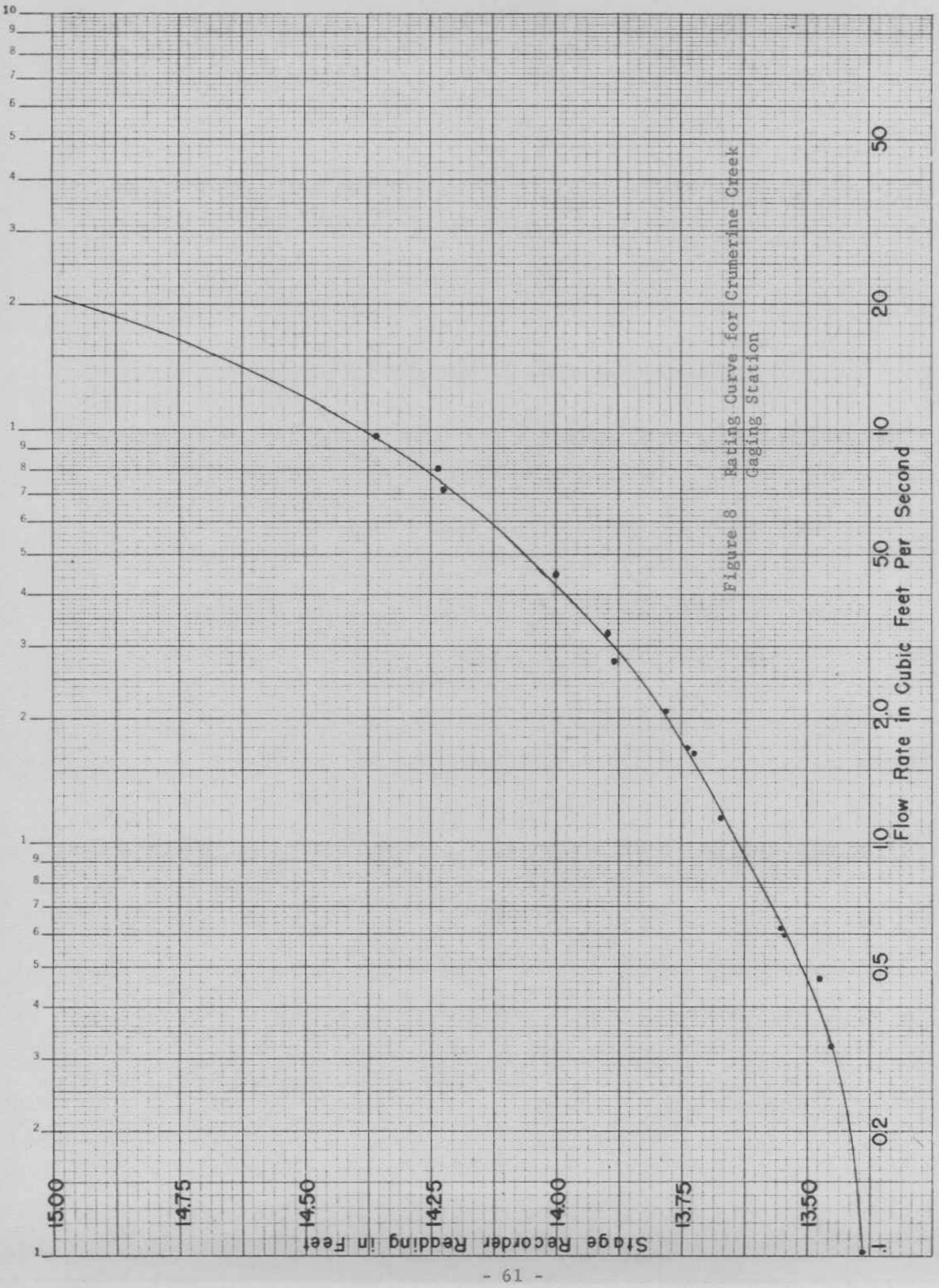

Figure 8 Rating Curve for Crumerine Creek Gaging Station

KEUFFEL & ESSER CO. N. Y. NO. 359-72
Semi-Logarithmic, 3 Cycles x 6 to the ½ inch.
MADE IN U.S.A.

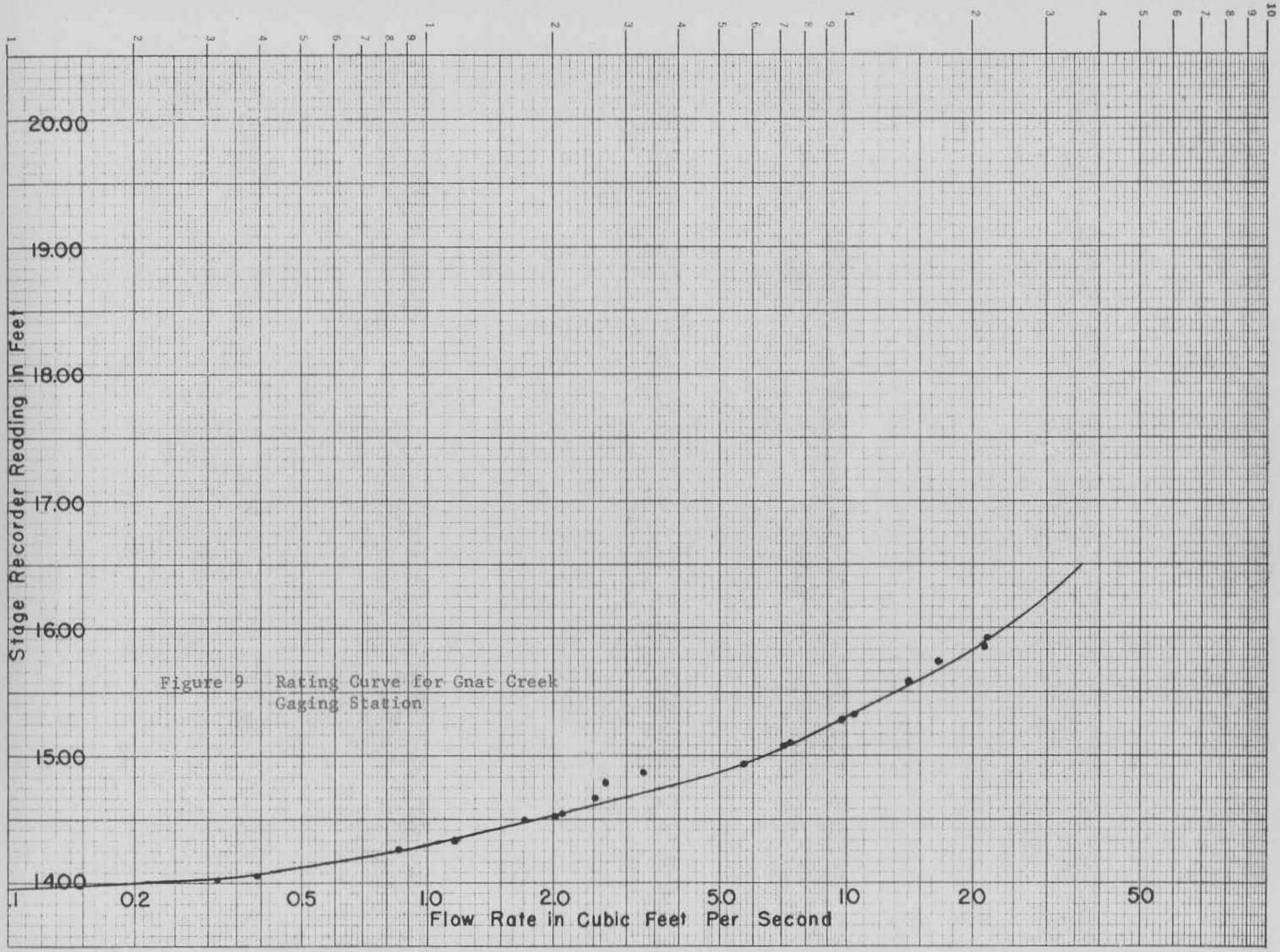

Figure 9 Rating Curve for Gnat Creek Gaging Station

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