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A HYDROLOGIC ANALYSIS OF THE
NORTH FORK EXPERIMENTAL WATERSHED

By

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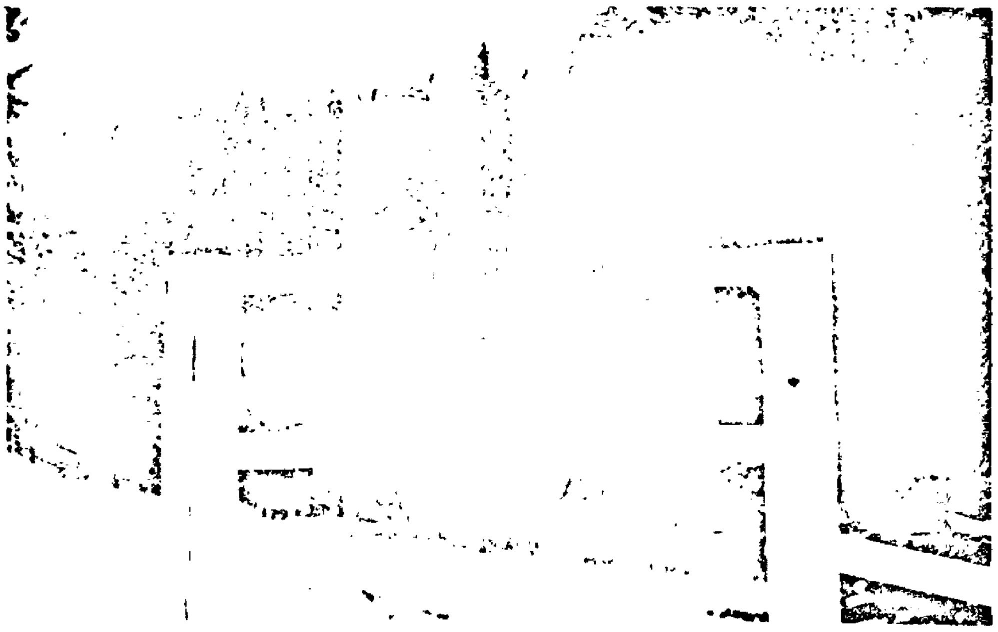
INTRODUCTION

One of the first requisites in making a hydrologic analysis of a watershed is to determine the hydrologic budget. The data collected during this study provide two essential hydrologic facts about the North Fork Experimental Watershed: (1) water recharge and (2) water discharge. In terms of the hydrologic cycle, three factors are emphasized: (a) precipitation, (b) runoff or streamflow, and (c) groundwater discharge. The data from this study form the first complete record of hydrologic information about the watershed, and will provide the basis for a continuous hydrologic study. The accumulation of hydrologic data from the watershed will also provide useful information for ecologic studies. The study is based on the single-watershed approach and will be analyzed on the basis of the factors that influence this watershed.



OBJECTIVES

The principle objective of this study is to determine the hydrologic budget of the North Fork Experimental Watershed by:

1. Determining the distribution pattern of precipitation over the watershed by:
    a. Collecting precipitation data from a large number of rain gages.
    b. Selecting a suitable method for areal averaging of the precipitation data.
    c. Making a comparison of radar precipitation estimates with the above.
2. Determining surface-water discharge from the watershed by stream gage and current meter methods.
3. Determining the amount of ground-water discharge from the watershed by discharging-well methods.
4. Estimating the total water budget including losses from evapotranspiration on the basis of 1, 2, and 3.

LITERATURE REVIEW

Small watershed studies provide a better understanding of the relationships between land management practices and water resources. Calibrating a watershed requires a thorough analysis of all phases of the hydrologic cyle; that is, a complete inventory of all forms of water recharge and water discharge. Certain phases of the hydrologic cycle are measured more easily than others. Precipitation, runoff or streamflow, and ground-water discharge measurements are primary steps in studies of small drainage areas (Johnson and Dils, 1956). However, many years of research will be required before all phases of the hydrologic budget can be accounted for accurately. The demand for long term weather data from mountainous regions far exceeds the supply, and the need to publish existing records continues to grow (Stark, 1963, p. 1).

In almost all watershed studies the major problem which confronts the investigator is determining the length of the calibration period. Reinhart (1958) has pointed out that too short a calibration period leads to inconclusive results, while too long a calibration period results in unnecessary expense. Kovner and Evans (1954) devised a simple graphic solution for approximating the length of time required to detect significant differences between treatments on experimental watersheds. This solution is a simplification of the technique developed by Wilm (1949). The methods of Wilm (1949) and Kovner and Evans (1954) proved suitable for the analysis of data and led to an apparently sound evaluation of necessary length of calibration period (Reinhart, 1958, p. 936). The techniques of Wilm (1949) and Kovner and Evans (1954) have been used successfully to detect rather small changes in streamflow resulting from watershed treatment (Reigner, 1964, p. 4). The techniques referred to above - - - have been employed with good effect in almost all of the major watershed investigations (Reigner, 1964, p. 4).

Precipitation

Precipitation is usually estimated from samples taken throughout a watershed. An effort should be made to select sample points that are representative of the area to which they apply.

Precipitation varies widely within short distances, especially where physical features differ from place to place. As a general rule, precipitation increases with altitude up to a limiting elevation.

In the literature reviewed, authors agree that accurate measurement of precipitation in mountainous regions is quite difficult. The principal factors that cause inaccurate measurements are elevation, rugged topography, variable exposures, variation of wind currents and the occurrence of a large portion of precipitation in the form of snow (Helmers, 1954). The measurement of precipitation in areas of minor relief present few problems and the use of conventional vertical rain gages yield accurate results.

> All forms of precipitation are measured on the basis of the vertical depth of water, or water equivalent, which would accumulate on a level surface if all of it remained as it fell and none flowed or soaked away or was lost by evaporation (Kadel, 1936, p. 1).

In most studies, network densities range from about one gage per 5 to 12,000 acres. Extremely dense networks are not required if the occurrence of an occasional large error is not serious (Linsley and Kohler, 1951, p. 245). In the case where reporting networks are used for river forecasting Linsley and Kohler suggest that the density should be sufficient to assure that even the largest errors which may be expected will not cause a gross error in the forecast. The uses for which precipitation data are intended should determine network density, and a network should be planned so as to yield a representative picture of the areal distribution of precipitation (Linsley, Kohler and Paulhus, 1958, p. 31). Sauer (1963) analyzed a 19 rain gage network on a 70 square mile watershed to determine whether a reduction in rain gage density would seriously reduce the accuracy of measurements of the average watershed rainfall:

> The rain gage density analysis consisted of comparing the average (arithmetic mean) storm rainfall derived for 4, 7, and 10 gages, respectively with the weighted-mean rainfall as computed by the Thiessen Polygon weighting method using all 19 rain gages. The rain gages were selected to provide the optimum areal geometric coverage for the specified number of gages (Sauer, 1963, p. 11).

Sauer concluded that the number of rain gages in his study watershed could be reduced considerably, provided that an occasional large error would not be serious for the purpose of the data.

In most studies the horizontal intervals between rain gages ranges from a few miles to a few hundred feet, and no definite vertical spacing is chosen. However, some investigators, i.e., Wilm, Nelson, and Storey (1939) did locate their rain gages at 250 foot and 300 foot contour intervals while Hamilton (1954) located his gages at 1,000 foot contour intervals.

Numerous precipitation sampling experiments have been conducted in mountainous areas and - - - the literature abounds with experiments which indicate that the most disturbing agency to a proper collection of rainfall is the wind (Kadel, 1963, p.11). Hamilton (1954), Hayes (1944), Helmers (1954), and Johnson and Dils (1956) experimented with tilted gages and stereo receivers, "sloped-orifice" gages and gages in pit exposures, stereo orifice gages and wind shields, and tilted gages respectively. In all of the above experiments the modified technique or instrument proved more accurate than conventional vertical gages.

The purpose in modifying gage installations is to take into account the fact that wind changes the angle in inclination of precipitation and, therefore, the amount passing through a gage receiver is less than if the precipitation fell vertically.

On wind-swept slopes air turbulence is produced by the gage in the moisture-bearing stream (Helmers, 1954). Wind shields minimize air turbulence over the gage orifice and increase gage catch (Alter, 1937; Hamilton, 1954; Helmers, 1954; Linsley, Kohler and Paulhus, 1958).

The Alter shield has been adopted as a standard by the U. S. Weather Bureau because of its open construction and flexible design which allows wind movement to prevent the building up of snow (Linsley, Kohler and Paulhus, 1958, p. 29).

The 8-inch nonrecording rain gage, which is standard in the United States is also used for the measurement of snow (Garstka, 1964, p. 10-11). For winter operation, the receiver and measuring tube are removed from the overflow can. The overflow can is thus used to gage the snow.

The average depth of precipitation over area can be determined by several methods. The simplest is taking the arithmetic mean of a number of stations. Other methods include:

1. Thiessen method
2. Isohyetal method
3. Percentage-of-mean-annual method
4. Abbreviated isopercentual method
5. Parsons, or Sacramento, method
6. Spreen method

The Thiessen and isohyetal are common methods. Reference to methods 3-6 can be found in Chow (1964, p. 9-29).

> The most accurate results of averaging precipitation are obtained from the isohyetal method. The average precipitation for an area is computed by weighting the average precipitation between successive isohyets (usually taken as the average of the two isohyetal values) by the area between isohyets, totaling these products, and dividing by the total area. This method permits the use and interpretation of all available data and is well adapted to display and discussion (Linsley, Kohler and Paulhus, 1958, p. 36).
>
> The criteria for preparation of an isohyetal map are:
>
> 1. The "control" of the map should be the gage records.
> 2. In drawing an isohyet from one station to another it is well to keep in mind the topography, the streamflow, and the natural and cultivated vegetation, and to weigh these conditions accordingly.

3. In areas of high mountains it is proper to carry the isohyet around rather than over the mountains.

4. Several other factors such as regions of heavy snowfall, particular valleys known to be drier than the surrounding area, climates supporting certain natural vegetation or that will permit certain types of agriculture are subordinate to gage records but help to show on which side of the area the isohyet should be drawn (Reed and Kincer, 1917, p. 233-235).

Therefore, in constructing an isohyetal map the analyst can make use of his knowledge about the above criteria. The accuracy of this method depends upon his skill, and improper estimates can lead to serious error.

Wisler and Brater (1949) also agree that the isohyetal method will yield the most accurate results depending upon the skill and good judgment of the cartographer.

Clyde (1931) used the isohyetal method to show widely varied distribution of precipitation in the Cache Valley (Utah). The U. S. Weather Bureau uses the isohyetal method for averaging precipitation over an area.

Ground Water

Many drainage basins as a whole are not impermeable due to impermeable bedrock. However, the bedrock is sometimes faulted or fissured. Precipitation falling on such a basin which eventually finds its way into the water-bearing strata can be lost to a nearby drainage basin. This is known as watershed leakage. A thorough knowledge of the geology of the basin usually provides the best evidence of such a condition. Vegetal cover also provides an indication of watershed leakage.

Studies concerning the origin, occurrence, and movement of ground water have shown that - - -

1. Ground water obeys natural laws.
2. Practically all ground water is derived ultimately from precipitation.
3. Most usable ground water is an important component of the circulatory pattern of the hydrologic cycle.
4. The complexity of occurrence of ground water is intimately associated with the geology of the area (McMurtrey, Konizeski, and Brietkrietz, 1965, p. 20).

> Ground-water hydraulics, as now defined by common practice, can be described as the process of combining observed field data on water levels, water-level fluctuations, natural or artificial discharges, etc., with suitable equations or computing methods to find the hydraulic characteristics of the aquifer; it includes the logical extension of these data and computing methods to the prediction of water levels, to the design of well fields, the determination of optimum well yields, and other hydraulic uses - all under stated conditions. The selection of equations or computing procedures to be used for analysis is governed largely by the physical conditions of the aquifer studies, insofar as they establish the hydraulic boundaries of the system (Ferris, et al, 1962, p. 70).

Perhaps the most direct method of prospecting for water is the driving of small-diameter test holes in the area of interest (Linsley, Kohler and Paulhus, 1949, p. 373). A test well which is successful in locating water can often be enlarged to a production well or left as an observation well. The cable tool (or percussion), hydraulic rotary, and reverse rotary methods are commonly used for well construction. Upon completion of a well in unconsolidated sediments the casing is either perforated or in many instances well screens of various slot sizes and lengths are inserted, to provide water entry. The well is then developed by preventing sanding and increasing the specific capacity of the well. A few common procedures for development are pumping, surging, and injection of compressed air. The final step is to determine well yield and drawdown by pumping tests.

Data determined by pumping tests:

Samples of rock fragments and other material extracted from the well during drilling provide limited information about the subsurface hydrology. The permeability and transmissibility, which determines the quantity of underflow are most reliably estimated by pumping tests (Todd, 1959).

> The field coefficient of permeability, is defined as the rate of flow, in gallons per day, under prevailing conditions, through each foot of thickness of a given aquifer in a width of one mile, for each foot per mile of hydraulic gradient (Meinzer, 1942, p. 452).
>
> The coefficient of transmissibility introduced by Theis (1935, p.520) is the field coefficient of permeability multiplied by the thickness, in feet, of the saturated part of the aquifer.

In other words the coefficient of permeability denotes a characteristic of the water-bearing material and the coefficient of transmissibility quantitatively describes the ability of the saturated part of the aquifer to transmit water.

Thus, from knowing the cross sectional area of the aquifer, the transmissibility, and the hydraulic gradient, the quantity of underflow can be determined. Todd (1959) stated that the rate of ground water movement is governed by the permeability of the aquifer and the hydraulic gradient. An example given by Todd: a slope of 100 feet per mile (0.019) and a high permeability of Ks = 5000 yields a velocity of 12.7 feet per day.

CHARACTERISTICS OF THE STUDY AREA

Location and Size

The North Fork Experimental Watershed is located in parts of Townships 13 North, Ranges 13 and 14 West of the Montana Principal Meridian. The west half of the watershed is in Missoula County and within the Lubrecht Experimental Forest, while the east half is in Powell County. The watershed covers 4410 acres or about seven square miles. The ownership within the watershed is as follows:

Lubrecht Experimental Forest	2305
Bureau of Land Management	1973
Private (2 40 acre holdings)	80
State of Montana	52
	4410 acres

Topography and Drainage

The topography is irregular; slopes range from 10 to 60 percent; and elevations range from 4,080 feet to 6,760 feet, with a maximum change in relief of 2,680 feet. Well over half of the watershed is above 5,000 feet. The watershed is oriented east-west and drains to the west by the North Fork of Elk Creek and its tributaries. The drainage pattern is dendritic, and includes ephermeral, intermittent, and perennial streams.

Elk Creek Burn - 1960

A lightning-caused fire burned 804.5 acres within the watershed in July, 1960. The burn is in the central part of the east half of the watershed (see figure 1, and plate III: insert). The following statistics were obtained from the Blackfoot Forest Protective Association.

Fire started	July 19, 1960
Brought under control	July 22, 1960
Total area burned	1,161.8 acres

Geology

The geology of the west half of the watershed was mapped by Brenner (1964). The bedrock is mostly quartz monzonite (late Cretaceous). In this area it varies somewhat in texture and composition and weathers to spheroidal, blocky outcrops. The east half of the watershed, which was not mapped by Brenner is underlain by similar rocks. The drainage divide between the North Fork and Cap Wallace Watersheds is formed on Cambrian marble overlain by Precambrian argillite (see figure 2). The valley bottom of the North Fork Watershed is formed on Quaternary alluvium. Brenner found no topographic evidence of faulting in the watershed.

Soils

The soils are formed almost entirely from weathered granite (quartz monzonite) and belong primarily to the Elk Creek series. Soil depth and profile development vary considerably. Preliminary mapping of Lubrecht Forest shows that at least four soil series occur within the watershed (Elk Creek, Garnet, Chamberlain, and Woodrock).

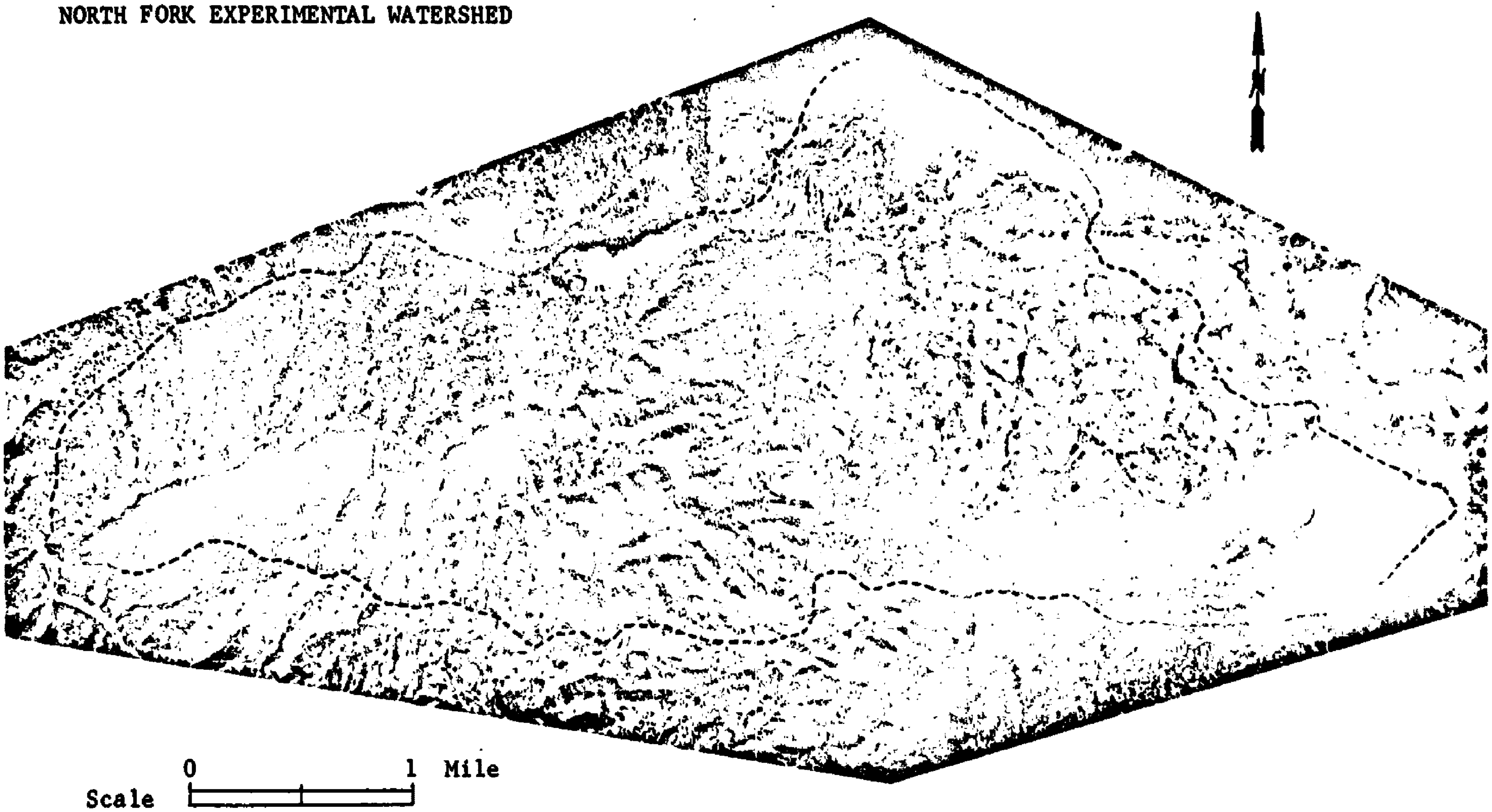
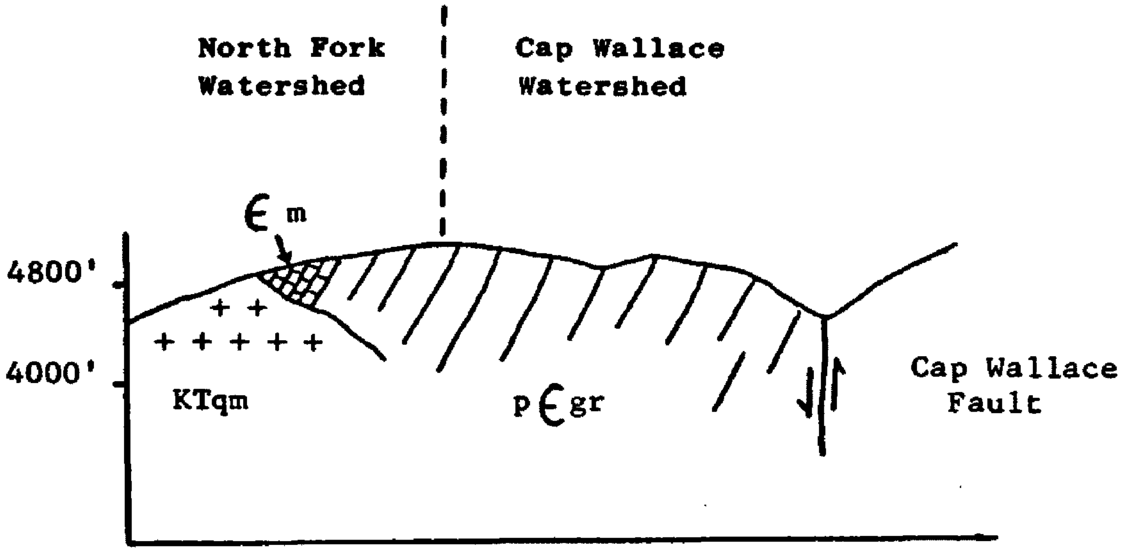


Figure 1. Uncontrolled mosaic made from 1963 aerial photos - W. H. Poliquin



Scale 1: 24,000

KTqm -- Quartz Monzonite
Єm -- Cambrian Marble
pЄgr -- Garnet Range Formation (Belt Metasediments)

Figure 2. Geologic section between the North Fork and Cap Wallace Watersheds (Brenner, 1964).

The soils in the watershed can be divided into four Great Soil Groups:

1. Degraded Chernozem soils - one series of which is associated with the quartzite and another associated with the quartz monzonite.
2. Modal Gray Wooded soils - only mantle quartz monzonite.
3. Gray-Wooded-Brown Podzolic integrades - associated primarily with quartz monzonite.
4. Brown Podzolic soils - associated only with quartz monzonite.

Vegetation

The vegetation is typical of that found in the mountain regions of western Montana. Major tree species include: lodgepole pine (*Pinus contorta* Dougl.); ponderosa pine (*Pinus ponderosa* Laws.); Douglas-fir (*Pseudotsuga menziesii* Mirb.); western larch (*Larix occidentalis* Nutt.). Engelmann spruce (*Picea engelmannii* Parry); subapline fir (*Abies lasiocarpa* (Hook.) Nutt.) also occur on some of the moist, cool sites. Lodgepole pine is most abundant, occuring primarily on north aspects, with mixtures of western larch and Douglas-fir. The composition of the south aspects is generally ponderosa pine and Douglas-fir; the Douglas-fir being predominant at higher elevations. Part of the Bureau of Land Management ownership (see figure 1; roaded area) was selectively logged in 1962. Some additional logging and clearing of brush and scattered trees was done by the Bureau of Land Management in 1965. A 40-50 acre block, at the east end of the drainage, was cleared and terraced, and planted with western larch seedlings.

Climate

The watershed is located on the west side of the Continental Divide. Here, the local topography influences the climate markedly. The region has a modified north Pacific coast climate, while east of the Continental Divide the climatic characteristics are decidedly Continental (Dightman, 1960). Most of the storm systems affecting the study area are orographic, many have an easterly component.

PREVIOUS INSTALLATIONS, CALIBRATIONS, AND DATA

Streamflow measurements were begun in the spring of 1963. The discharge was determined by use of a current meter. A record based on daily and three day collection intervals, was maintained from April 4, to June 6, 1963. A peak discharge of 13.86 cfs (cubic feet per second) occurred on the 1st of May. Discharge measurements were not resumed until the summer of 1965. The discharge during July and August varied from about one to three cubic feet per second. In September, 1965, two galvanized steel Parshall measuring flumes were installed on the main stream of the watershed.

The watershed boundary was surveyed by compass and chain in the summer of 1965.

In August, 1965, six shallow observation wells were located near the mouth of the drainage for monitoring water table fluctuations.

In late summer of 1965 three meteorological sampling stations (hydroplots) were established along an elevational gradient. Precipitation and maximum-minimum temperature were the only two measurements taken, until the spring of 1966. Hygrothermographs and wind velocity recorders were installed at each hydroplot in April. Later that summer two Class A evaporating pans were put out; one at the lower hydroplot, the other at the upper hydroplot.

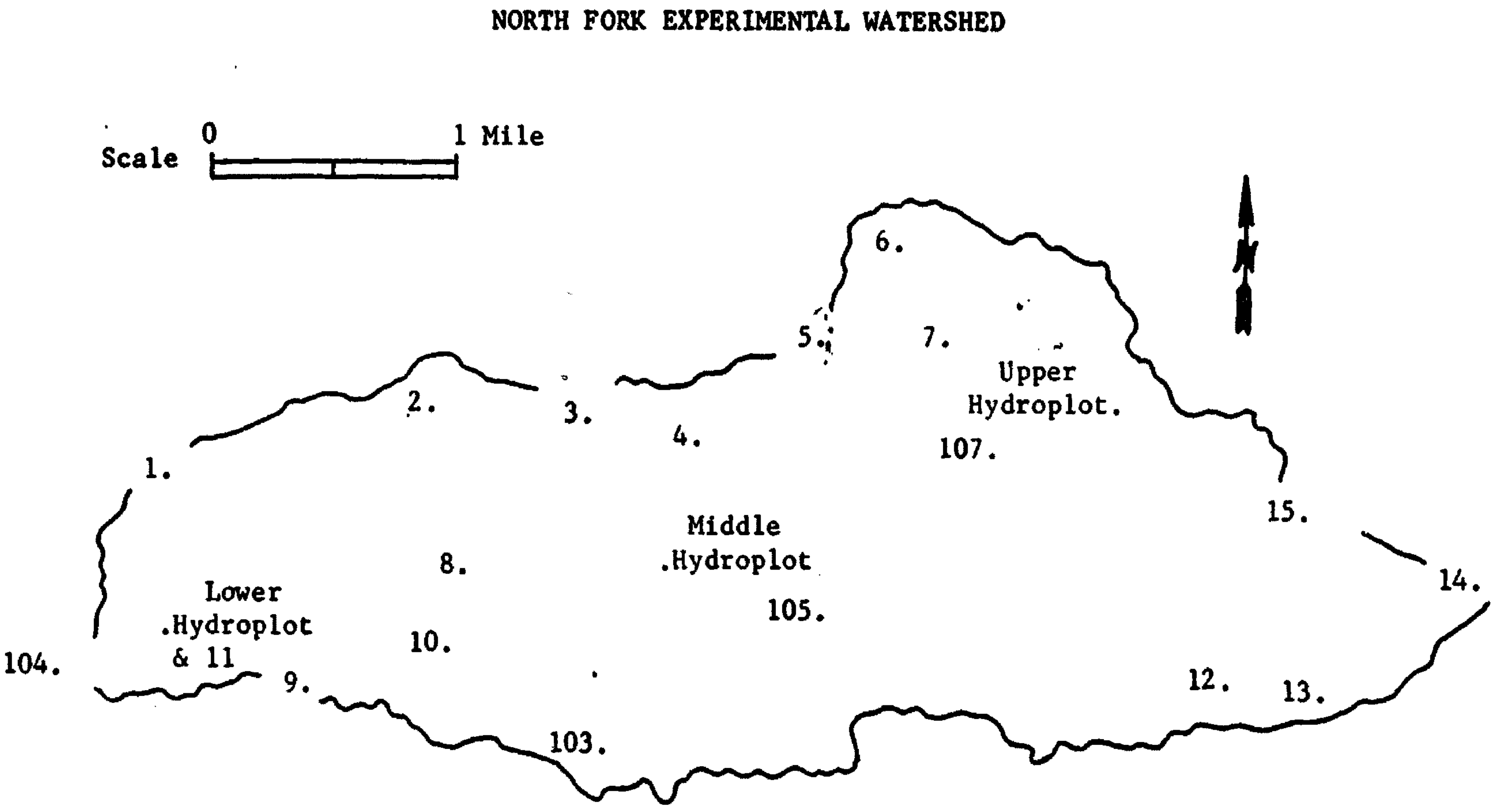
CHAPTER I PRECIPITATION ANALYSIS

INSTRUMENTATION PROCEDURE

The expansion of the original three gage network began on May 1, 1966 with the installation of ten standard rain gages. By May 21st all but four of the gages of the final network were in place. The rain gage locations were selected primarily on the basis of areal distribution and exposure. The following specifications concerning rain gage exposure and installation have been set up by the U. S. Weather Bureau (Kadel, 1936, p. 1).

> 1. It is important to select for the exposure of the gage a position in some open lot unobstructed by large trees or buildings. Low bushes, shrubbery, fences, or walls that break the force of the wind are beneficial; but in order that these protecting objects may not themselves intercept rain that would otherwise fall into the gage, they should be no nearer to the gage than their own height.
>
> 2. In general, at regular Weather Bureau stations the rain and snow gages will be installed side by side, not nearer to each other than 3½-feet, center to center. At stations where a recording rain gage is in operation, a standard 8-inch gage should also be exposed for use as a snow gage in the winter and as a check on rainfall in case of emergency.
>
> 3. Rain and snow gages are always installed with their receivers level, no matter what the slope of the ground in the vicinity may be.

Basically, the rain gages were installed according to the above standards. The density of the completed network (21 standard gages) was about one gage per every 220 acres. Figure 3 shows the rain gage network that was maintained from May 1, to December 31, 1966. Rain gages



NOTE: 5, 104, etc. - Indicate rain gage numbers and respective locations

Figure 3. The rain gage network maintained during 1966.

one through fifteen were made by a local sheet metal shop. The measuring tubes were made from 1-1/2-inch aluminum pipe and a new scale for the measuring stick had to be calculated.

A Belfort weighting-type (recording) rain gage was installed at each of the hydroplots, in addition to standard rain gages. Two were equipped with thirty-one day clocks and the other with an eight-day clock.

Two pit exposures were installed to determine any appreciable difference in rain gage catch due to inclination of falling rain caused by wind. These exposures were located at the lower and middle hydroplots. The installations were similar to those used by Hayes (1944). The installation can best be described as follows: a 2 x 2 foot wooden frame, 1-1/2-inches high; covered with 1/2-inch wire mesh; with a hole in the center to accommodate a receiver from a standard rain gage. When in place, the wooden frame is laid on the ground and the receiver rises above the wire mesh about one inch. The measuring tube is below ground level (see figure 4). Both of the pit exposures were placed on level ground. The lower hydroplot (figure 5) is one of the principal sampling stations on the watershed.

The gages were generally checked weekly and sometimes after individual storms. In the summer many of the gages were accessible only by foot, even though some of the area is roaded. During this time it generally took a full day to check the entire network. Later in the fall the road system became impassable because of mud and snow and it was impossible to check the entire network in one day. Therefore,

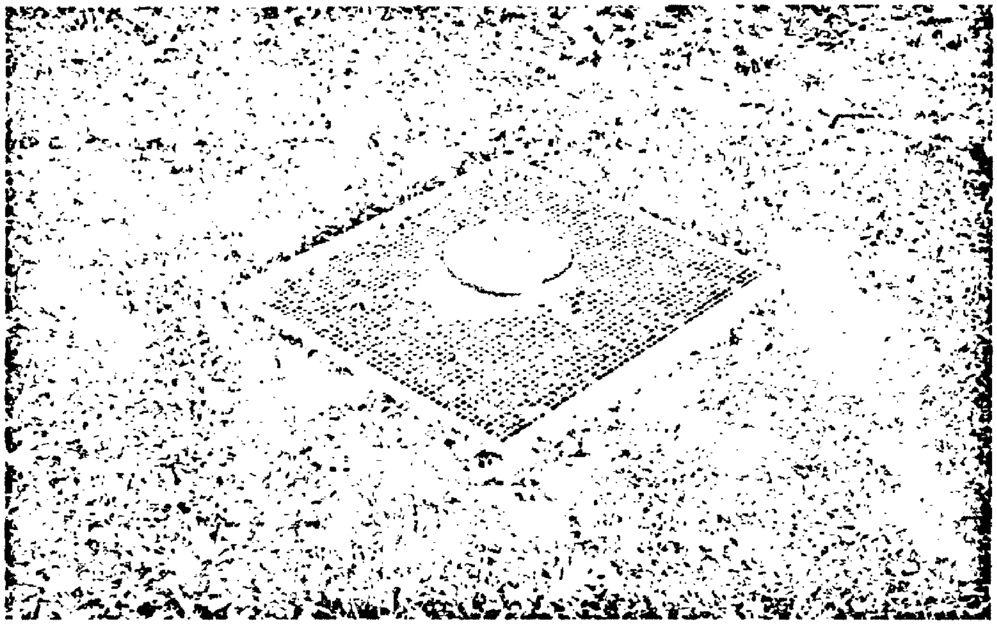


Figure 4. Standard 8-inch rain gage - pit exposure.

from October 28, to December 31, the gages were checked biweekly. That is, ten gages were checked one week and eleven the next week. In making the final measurement of the twenty-one gages on December 31, additional assistance was required. The lower reaches of the watershed were covered on snowshoes and the upper reaches by oversnow vehicle.

On the basis of the first eight months of data, it became apparent that the 21 gage network could be reduced. Analysis showed that 10 gages could be used for averaging the precipitation without serious reduction of accuracy. Because of this and because of the difficulties involved in maintaining a dense network of rain gages,

Figure 5. Lower hydroplot.

Installations and Instruments:

1. 60-inch Parshall flume
2. Weighing-type recording rain gage
3. Two standard 8-inch rain gages
4. Pit exposure (rain gage)
5. Anemometer and recorder
6. Hygrothermograph
7. Maximum and minimum thermometers
8. Instrument shelter
9. Weather Bureau Class A evaporating pan with a hook gage in a stilling well

the network was reduced to ten gages for the winter of 1967. Six of the ten gages were moved from their original locations so that the entire network could be checked in one day. The new locations were chosen on the same basis as the original network. The maximum distance of relocation was about one-quarter of a mile. Eight times during the winter the entire network was not checked weekly because of unfavorable snow conditions for travel by oversnow vehicle.

Overflow cans were used to gage snow and rainfall from mid-November, 1966 to April 30, 1967. The rain gage receivers cannot be used for winter operation because snow accumulates in the receiver and does not melt.

THE INSTRUMENTATION AND ITS PHYSIOGRAPHIC SETTING

The elevational distribution of the watershed area was determined from a U. S. Geological Survey topographic map. A planimeter was used to calculate the area between contour intervals. Table 1 shows the elevational distribution in acres and percent of total area.

Figure 6 illustrates the areal distribution by elevation and the number of rain gages at the various elevation ranges.

Figure 7 is a two dimensional view of the rain gage network.

Table 1 - Area Distribution By Elevation

Elevation	Acres	Distribution %
4080 - 4200	74	1.7
4200 - 4400	227	5.1
4400 - 4600	408	9.3
4600 - 4800	616	14.0
4800 - 5000	409	9.3
5000 - 5200	273	6.2
5200 - 5400	270	6.1
5400 - 5600	357	8.1
5600 - 5800	596	13.5
5800 - 6000	375	8.5
6000 - 6200	511	11.6
6200 - 6400	186	4.2
6400 - 6600	86	1.9
6600 - 6760	22	0.5
		100 %

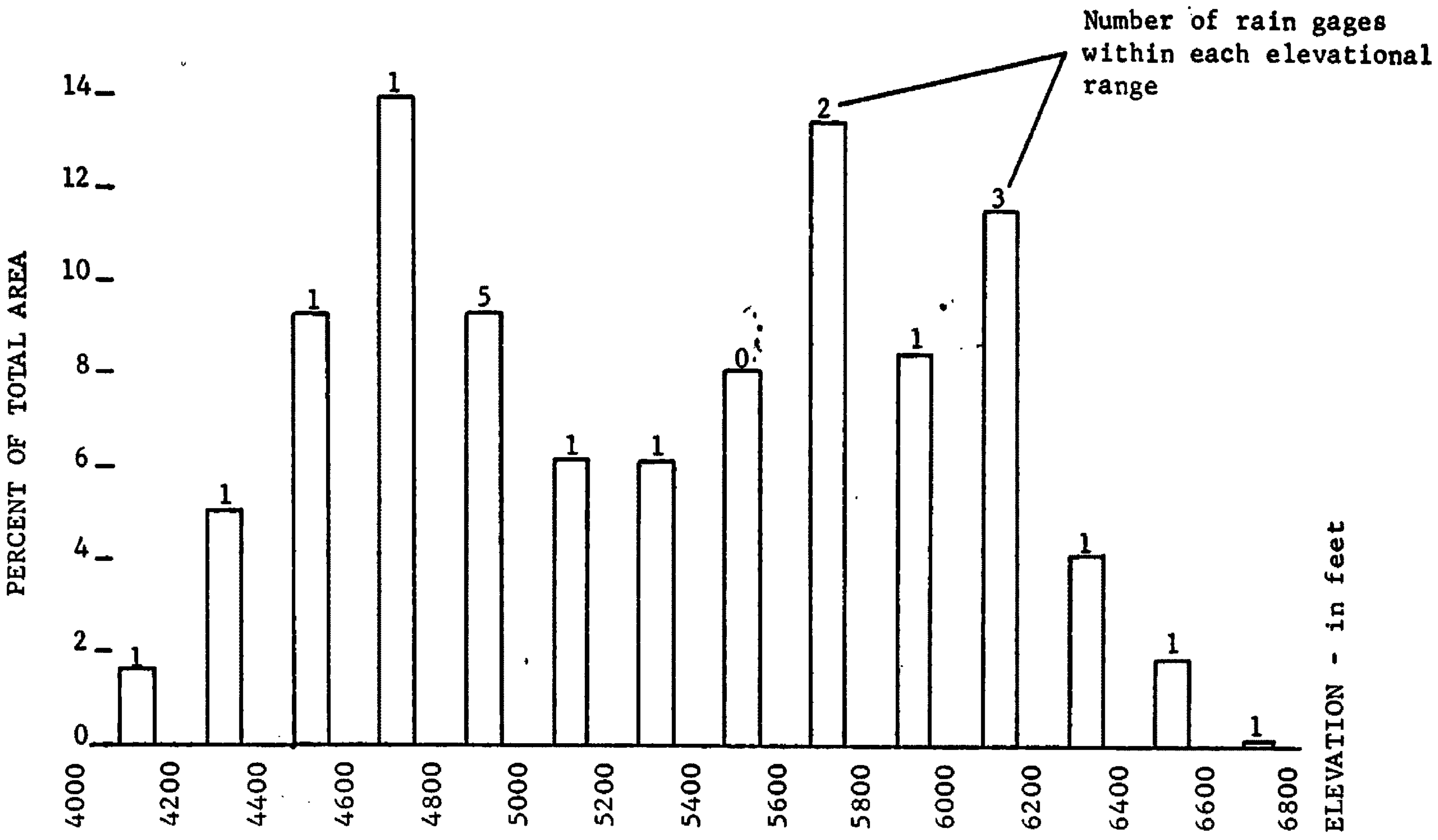


Figure 6. Areal distribution and rain gage locations by elevation.

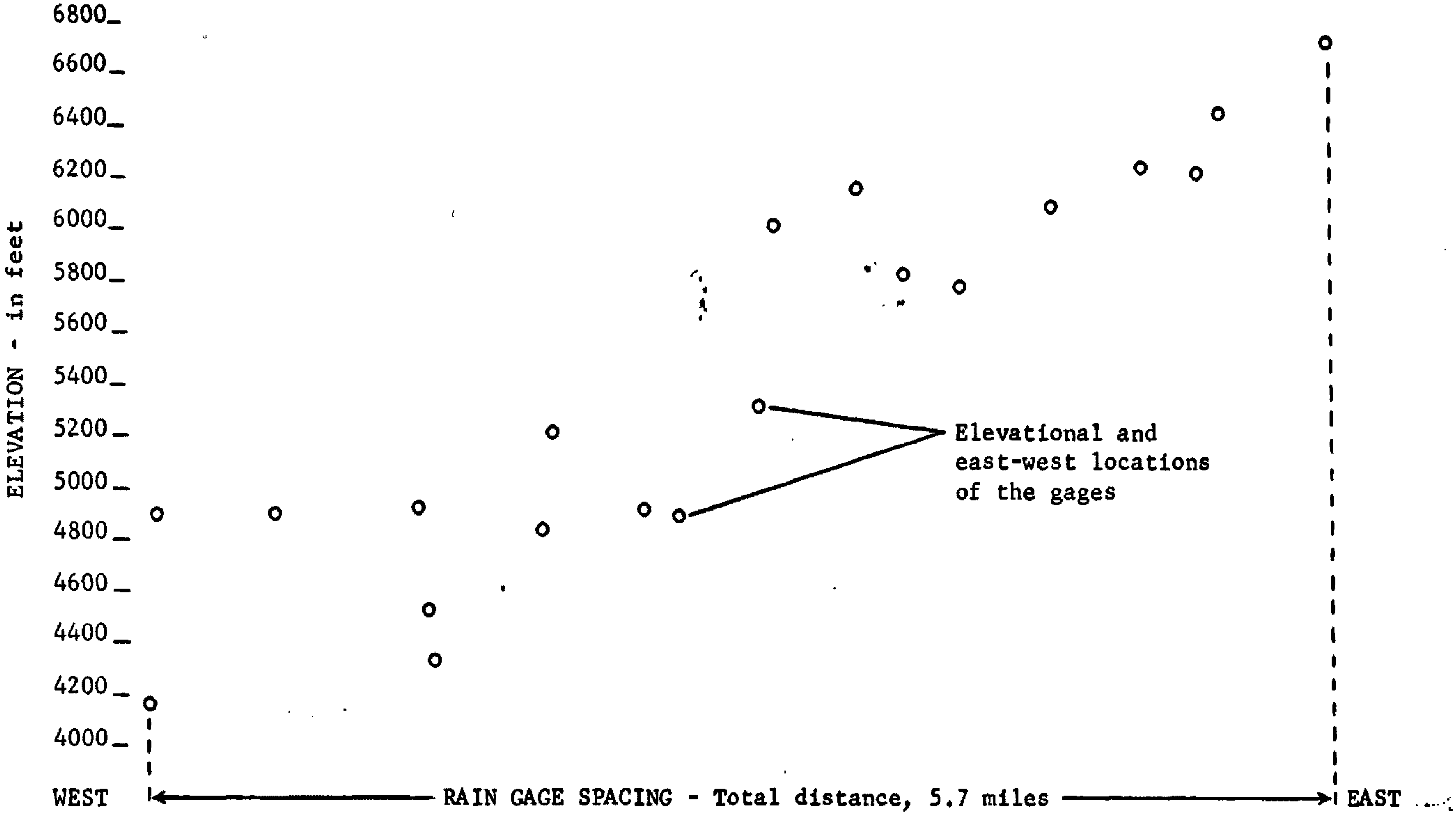


Figure 7. Two dimensional view of the 1966 rain gage network.

INTERPRETATION OF THE PRECIPITATION DATA

The interpretation can best be explained by discussing each component of the precipitation analysis.

Reliability of the Instrumentation

Rain gage number eleven, a shop made gage, was located at the lower hydroplot for the purpose of gage catch comparison with a factory made standard rain gage. The two gages were located about ten feet apart. The results of the compared analysis are as follows:

61.0% of the readings were equal.

19.5% of the readings were within + or - 0.01 of an inch; the maximum being 0.05 inches.

80.5%

In as much as less than 20 percent of the differences are more than 0.01 of an inch, it is conceivable that this much variation could occur between the two gages. Based on the above comparison the shop made gages can be used with reliability. To further substantiate this conclusion, the gage catch for No. 11 was compared with that of the factory made recording gage which was about twenty feet away. The results of the comparison are as follows:

40% of the readings were equal.

35% of the readings were within + or - 0.01 of an inch.

25% of the readings were more than + or - 0.01 of an inch; the maximum being 0.04 inches.

The precipitation measurements for the two pit exposures were compared with their respective standard rain gages and averaged. The comparison covers the period from July 1 to October 27; and indicates the following:

35.0% of the readings were equal.

40.5% of the readings were within +0.01 of an inch.

5.5% of the readings were within -0.01 of an inch.

11.0% of the readings were more than +0.01 of an inch.

8.0% of the readings were more than -0.01 of an inch.

The maximum difference was +0.04 of an inch. With such a minimum variation in gage catch between the pit and standard gages, it will be assumed that error due to angle of inclination is small.

The recording rain gages recorded the time and duration of precipitation and were very useful in making the radar comparison study. Table 2 is a comparison between the standard and recording gages at each of the hydroplots. The two gages having thirty-one day clocks were not as effective as the one with an eight-day clock. The major disadvantage of the thirty-one day clocks is the interpretation of the precipitation trace because of slow chart speed and small time intervals the readings can be in error. The clock failed at the upper hydroplot and the recording gage was discontinued.

Table 2. A Comparison of Total Precipitation as Measured by the Recording Rain Gages and the Standard Rain Gages

Lower Hydroplot	Middle Hydroplot	Upper Hydroplot
June 26-Oct. 27	May 17-Oct. 27	May 17-July 17
Recording Gage------3.81	Recording Gage------8.82	Recording Gage------6.03
Standard Gage------3.91	Standard Gage------9.13	Standard Gage------6.54
Diff. 0.10	Diff. 0.31	Diff. 0.51

Lower Hydroplot - recording rain gage equipped with an eight-day clock.

Middle and Upper Hydroplot - recording rain gages equipped with thirty-one day clocks

For a detailed comparison see Table A in the Appendix.

Big game and domestic livestock upset the rain gages several times and proved to be a problem in sampling. The data for the values in the precipitation record (Table B; Appendix) bearing an asterisk, was lost because the gages were tipped over. These values were estimated by proportioning.

Areal Average of Precipitation

The isohyetal and the arithmetic method were compared for areal averaging of precipitation. The results of the isohyetal method were nearly identical, and in some cases equal to the arithmetic mean. Tables 3 and 4 show the comparisons for 1966 and 1967 respectively. The following standard deviations were computed for these data:

1966 -- S.D. = 0.019 inches

1967 -- S.D. = 0.039 inches

The greater standard deviation for 1967 can be attributed to many factors, i.e.:

1. The standard deviation is based on three cumulative averages (see Table 4).
2. Sampling precipitation in the form of snow is difficult.
3. The 1967 data was collected from nine rain gages.

The close agreement of results as computed by these two methods indicates that the rain gage network provides a representative sample of the watershed. This is especially true of the 21 gage network. With a system of gages distributed so as to sample rainfall variation as thoroughly as possible, a simple average of their readings will agree within close limits with rainfall catch computed from isohyetal maps (Wilm, Nelson and Storey, 1937, p. 172).

The arithmetic method is much simpler and requires less time and skill than the isohyetal method. However, the isohyetal method is better adapted to display and discussion of precipitation patterns.

Table 3 - Areal Average of Precipitation - 1966

By the Arithmetical Method and the Isohyetal Method
(in inches of precipitation)

Period or Storm	Arithmetic Mean	Isohyetal Method Mean	Deviation
May 1-10	0.19		
May 10-17	0.79		
May 17-28	0.24	0.22	-0.02
28 - June 4	1.98	2.04	+0.06
June 4-11	1.69	1.68	-0.01
June 11-18	0.10	0.09	-0.01
June 18-26	1.22	1.20	-0.02
26 - July 5	0.53	0.52	-0.01
July 7	0.14	0.11	-0.03
July 9-17	0.27	0.30	+0.03
17 - Aug. 5	0.03	0.03	=
Aug. 13	0.09	0.10	+0.01
Aug. 15-23	0.11	0.10	-0.01
Aug. 23-29	0.62	0.62	=
29 - Sept. 2	0.50	0.50	=
Sept. 8	0.06	0.06	=
Sept. 11	0.02	0.02	=
Sept. 14	0.01	0.01	=
Sept. 16-23	0.16	0.16	=

Table 3 (Continued)

Period or Storm	Arithmetic Mean	Isohyetal Method Mean	Deviation
Sept. 23-29	0.30	0.31	+0.01
Oct. 2	0.56	0.54	-0.02
Oct. 6-13	0.22	0.21	-0.01
Oct. 13-20	Trace	Trace	=
Oct. 20-27	0.67	0.66	-0.01
27 - Dec. 31	2.88	2.85	-0.03
On a Seasonal Basis			
May 1-July 1	6.36	6.34	-0.02
July 1-Sept. 15	2.25	2.22	-0.03
Sept. 15-Dec. 31	4.75	4.77	-0.02
For the Eight Month Period			
May 1-Dec. 31	13.50	13.48	-0.02

NOTE: These averages based on 18 rain gages.

Table 4 - Areal Average of Precipitation - 1967

By the Arithmetical Method and the Isohyetal Method
(in inches of precipitation)

Period or Storm	Arithmetic Mean	Isohyetal Method Mean	Deviation
Jan. 1 to Feb. 9	3.87	3.90	+0.03
Feb. 9 to Mar. 30	2.79	2.73	-0.06
Mar. 30 to Apr. 30	2.00	2.01	+0.01
For the Four Month Period			
Jan. 1 to Apr. 30	8.66	8.85	+0.19

Discussion of the 1966 Isohyetal Maps

Generally, precipitation increases with altitude. However, a considerable number of storms throughout the summer yielded more precipitation at lower elevations (see Table 5). It has been noted from field observations that the watershed is definitely influenced by local and general weather systems. Storm movement with respect to winds in mountain topography is extremely complex. Every local situation must be interpreted in terms of its uniqueness in time and space (Buck, 1964, p. 24). The interaction of valley and slope winds, and convective winds combined with orientation of topography and diurnal timing are important components of local storm systems. Frontal systems and upper troughs generate considerable local activity (Granger, 1967). Local storm systems have been observed moving upslope or easterly through the study area. Systems have also been observed moving upslope or southeasterly through the main Elk Creek drainage. However, no data concerning the percentage of summer storms which are local or frontal, is available.

Figure 8 shows an extreme case of variation in precipitation per storm relative to elevation. This storm passed over the watershed in a northeasterly direction at the rate of 26 knots, between 2100 and 2200. Refer to figure 3a in Chapter II for a radar display of this storm. Figures 9-11 illustrate other periods of greater precipitation at the lower elevations.

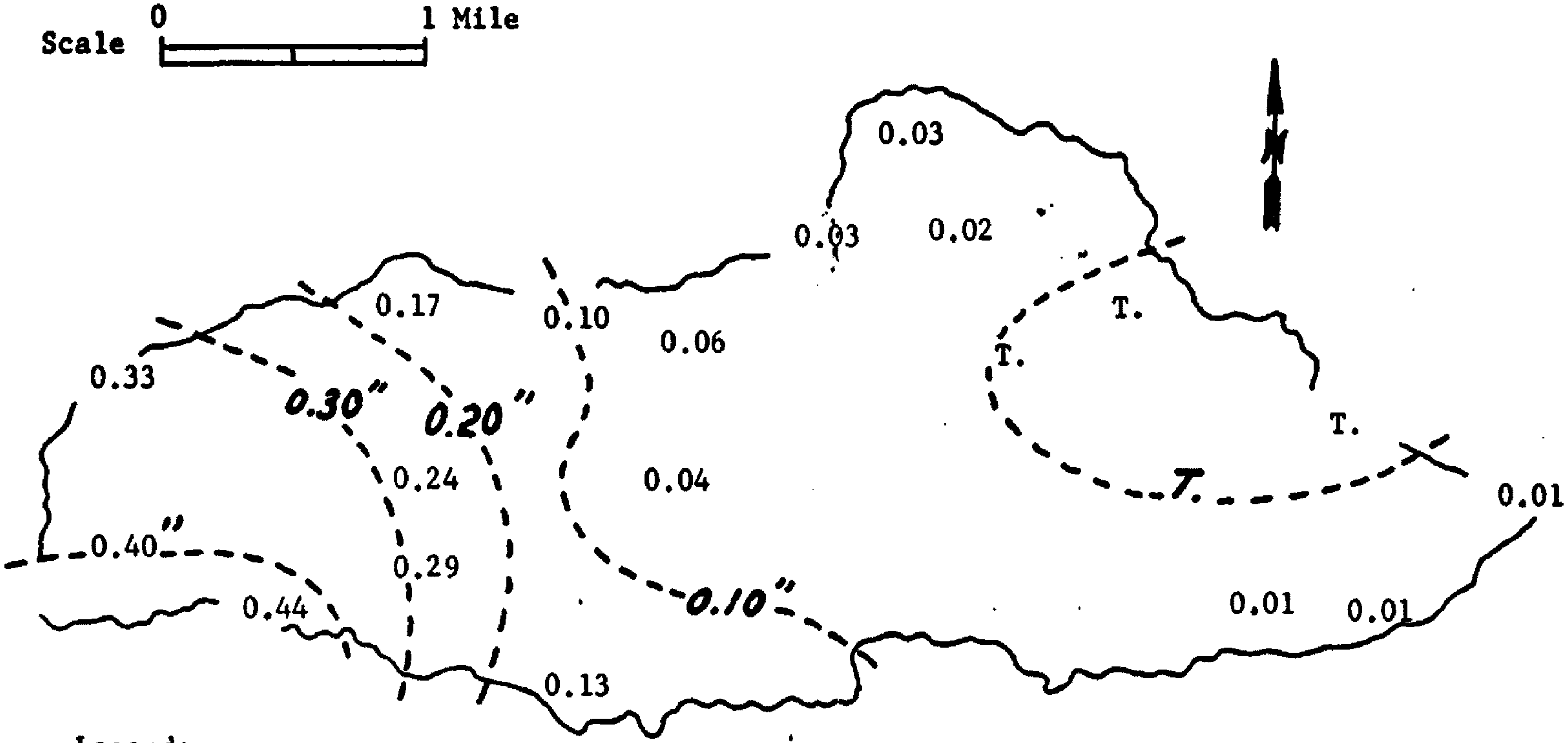
Table 5 – Periods with Heavier Precipitation at the Lower Elevations

Period	Maximum Precip.	Elevation at which it occurred	Minimum Precip.	Elevation at which it occurred	Number of Storms during that period
May 17-28	0.38	4900'	0.12	6700'	3
June 4-11	2.08	4100'	1.40	4900'	5
July 5-9	0.44	4800'	Trace	6200'	1
July 5-Aug. 5	0.67	4800'	0.25	6700'	5
Aug. 15-23	0.18	4800'	0.07	6200'	2
Sept. 9-12	0.06	4080'	0.01	6700'	1
Sept. 12-16	0.03	4800'	Trace	6100'	1
Sept. 16-23	0.20	5000'	0.12	6200'	2
Sept. 23-29	0.44	4300'	0.18	6000'	3

In reference to Table 5, the occurrence of more precipitation at the lower elevations is a result of local storm movement.

Figure 12 shows three areas of the watershed which frequently receive heavier amounts of precipitation during the summer months. These areas of concentrated precipitation are noticeable in figure 13 to 19. In addition to the actual variations in the storm rainfall the variability factor includes the effects of instrumental or observational errors and gage non-representativeness (Huff and Neill, 1957, p. 15).

NORTH FORK EXPERIMENTAL WATERSHED



Legend:
T = trace of precipitation
--- = 0.10 inch isohyet

Arithmetic average = 0.14 inches
Isohyetal " = 0.11 "

Figure 8. Isohyetal map - Storm on July 7, 1966

NORTH FORK EXPERIMENTAL WATERSHED

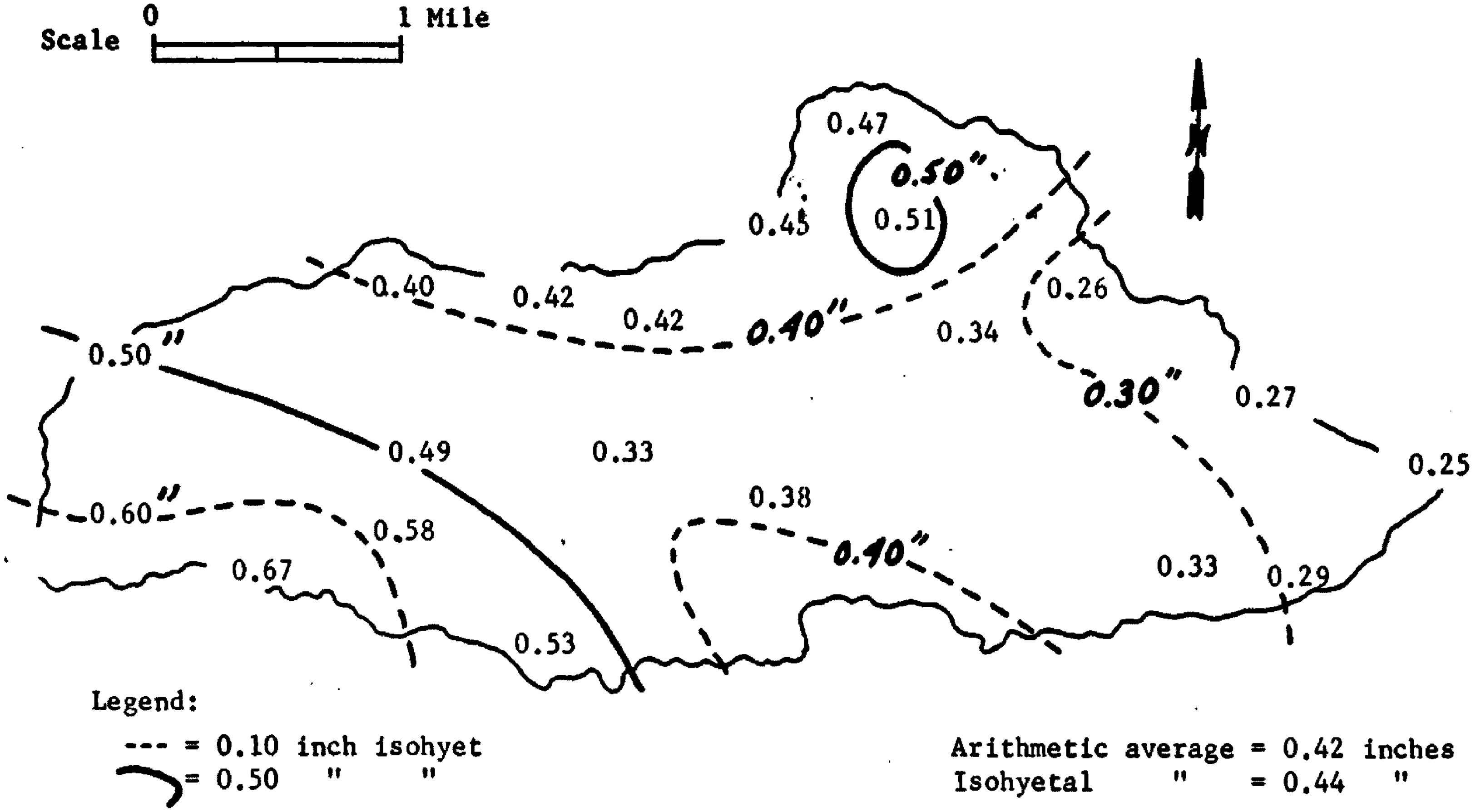
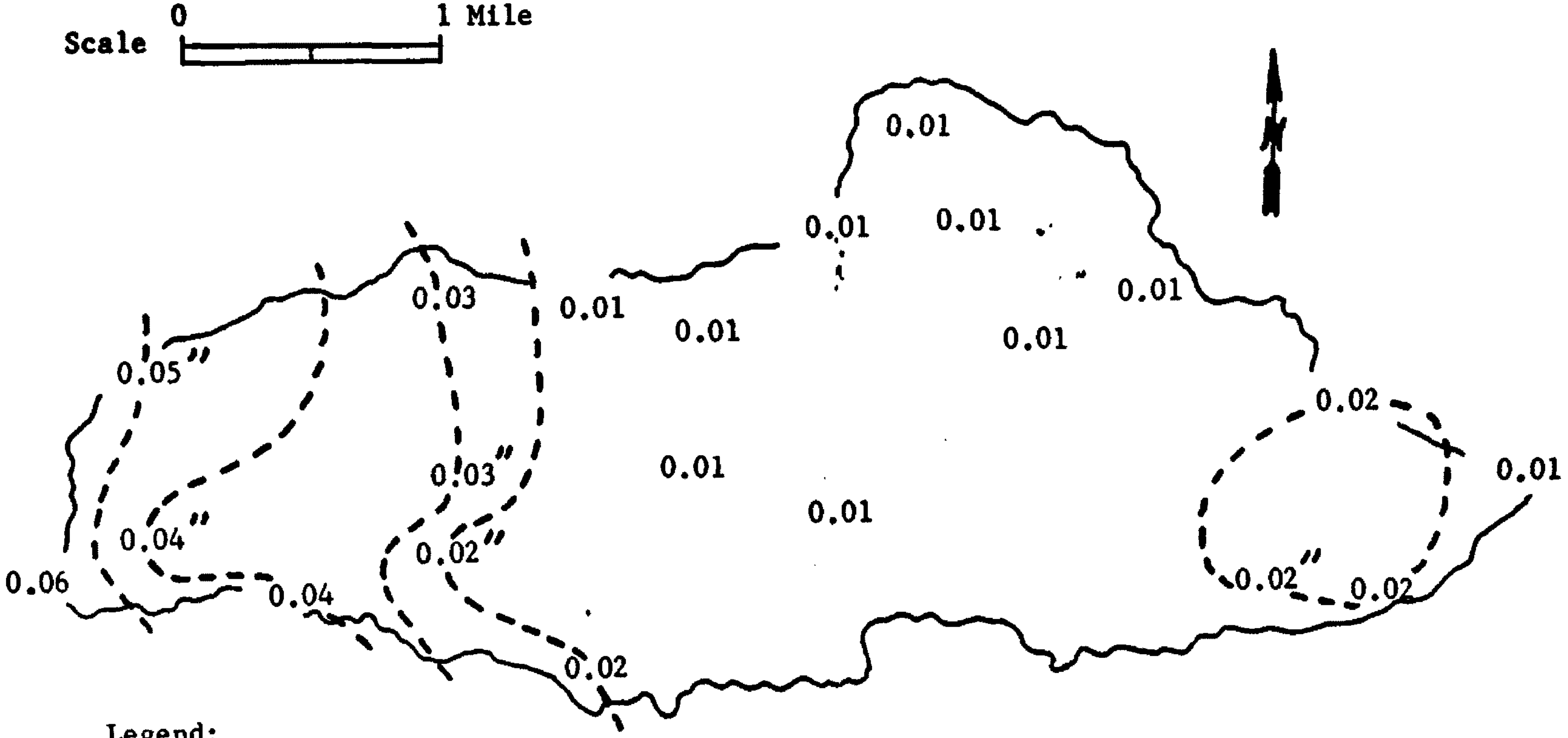


Figure 9. Isohyetal map - July 5, to August 5, 1966

NORTH FORK EXPERIMENTAL WATERSHED



Legend:
---- = 0.01 inch isohyet

Arithmetic average = 0.02 inches
Isohyetal " = 0.02 "

Figure 10. Isohyetal map - Storm on September 11, 1966

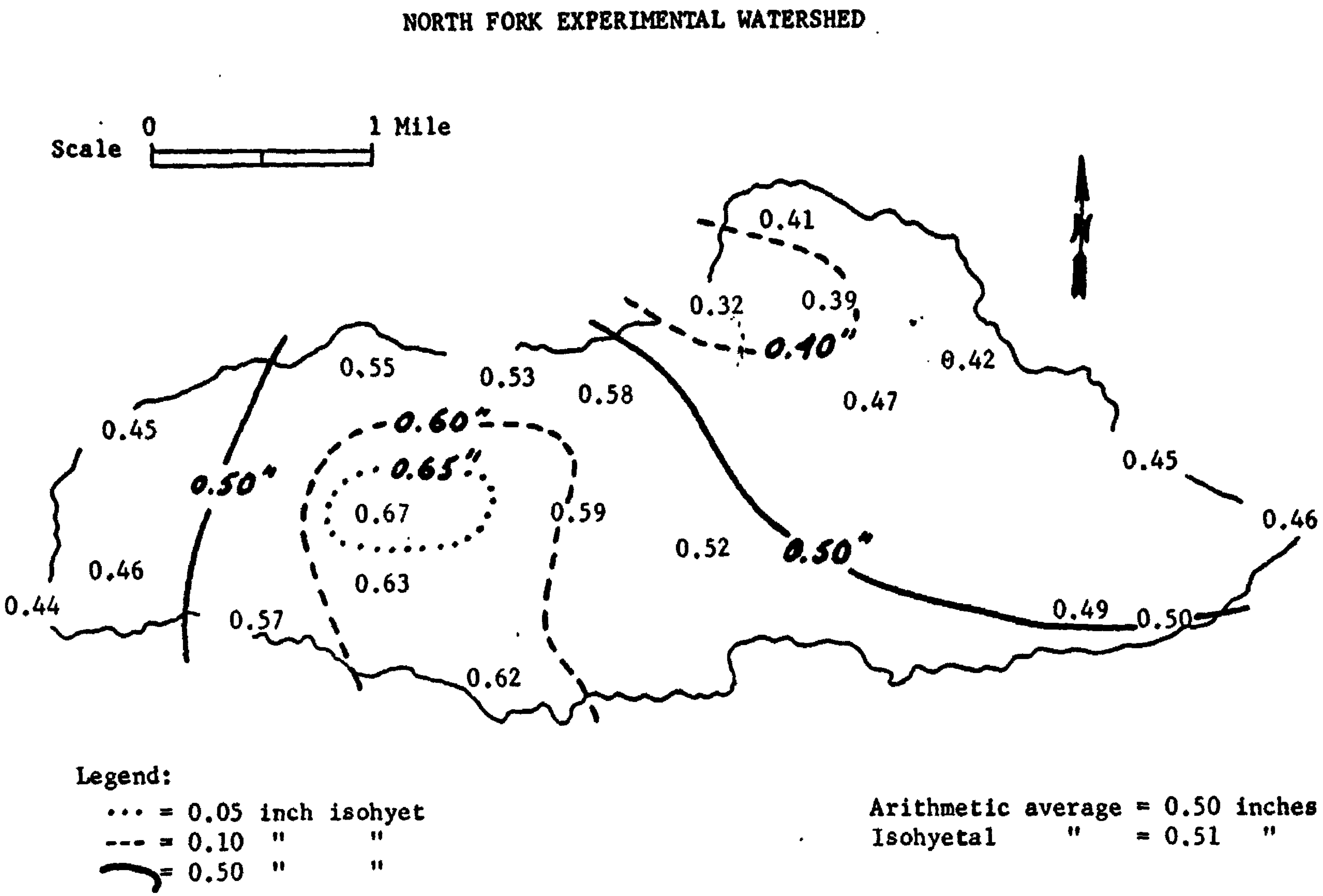
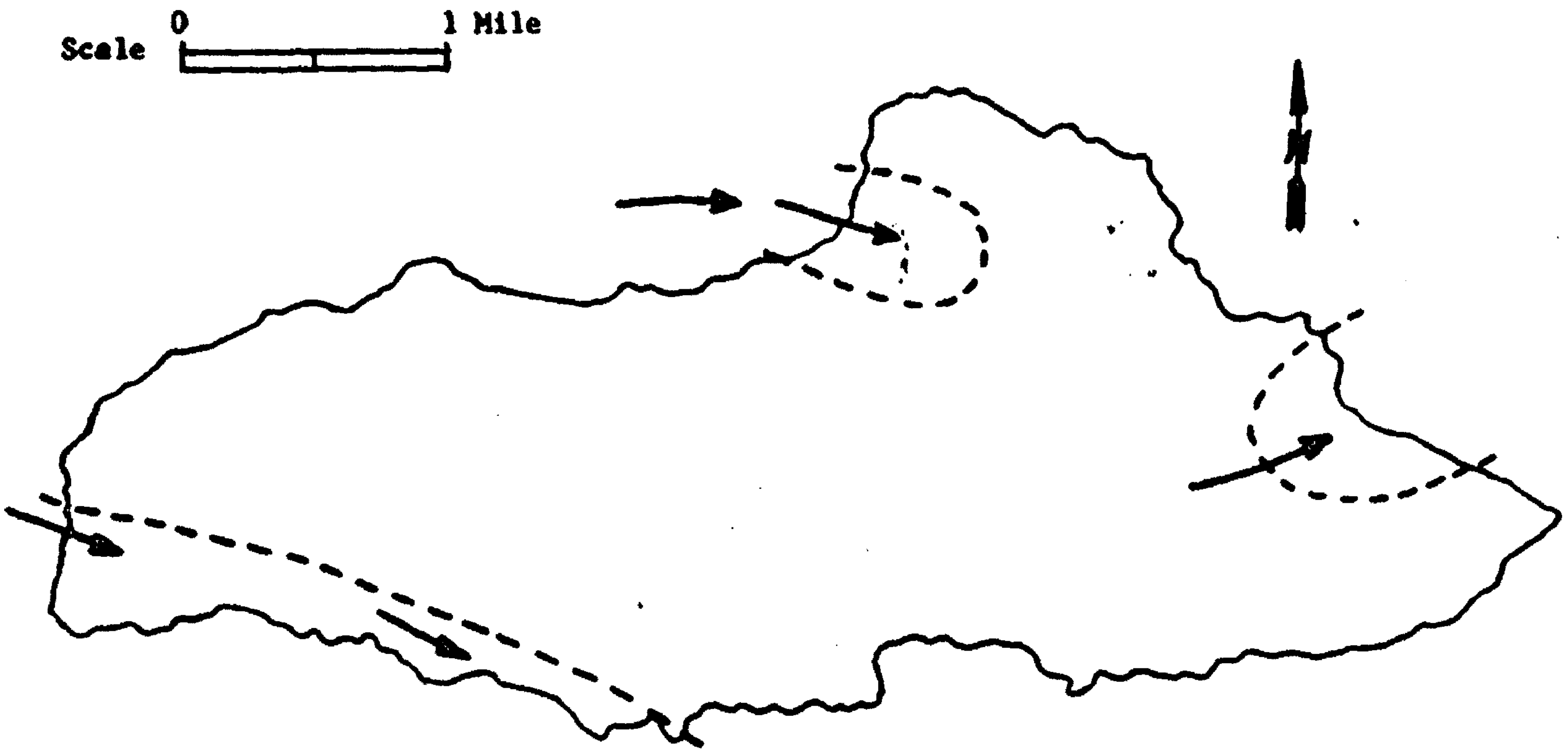


Figure 11. Isohyetal map - September 9 to September 29, 1966



NORTH FORK EXPERIMENTAL WATERSHED

The three areas shown by dashed lines are subject to upslope movement of local precipitation systems. Major storm systems from the west seem to have a greater influence on the area to the east. This area is within the burn, and subject to increased wind velocities. The elevation through this area is 6100 - 6200 feet. Storm systems leaving the east end of the watershed pass between two mountain peaks. Refer to the topographic map (insert) for familiarization of the local topography.

Figure 12. High intensity precipitation areas.

NORTH FORK EXPERIMENTAL WATERSHED

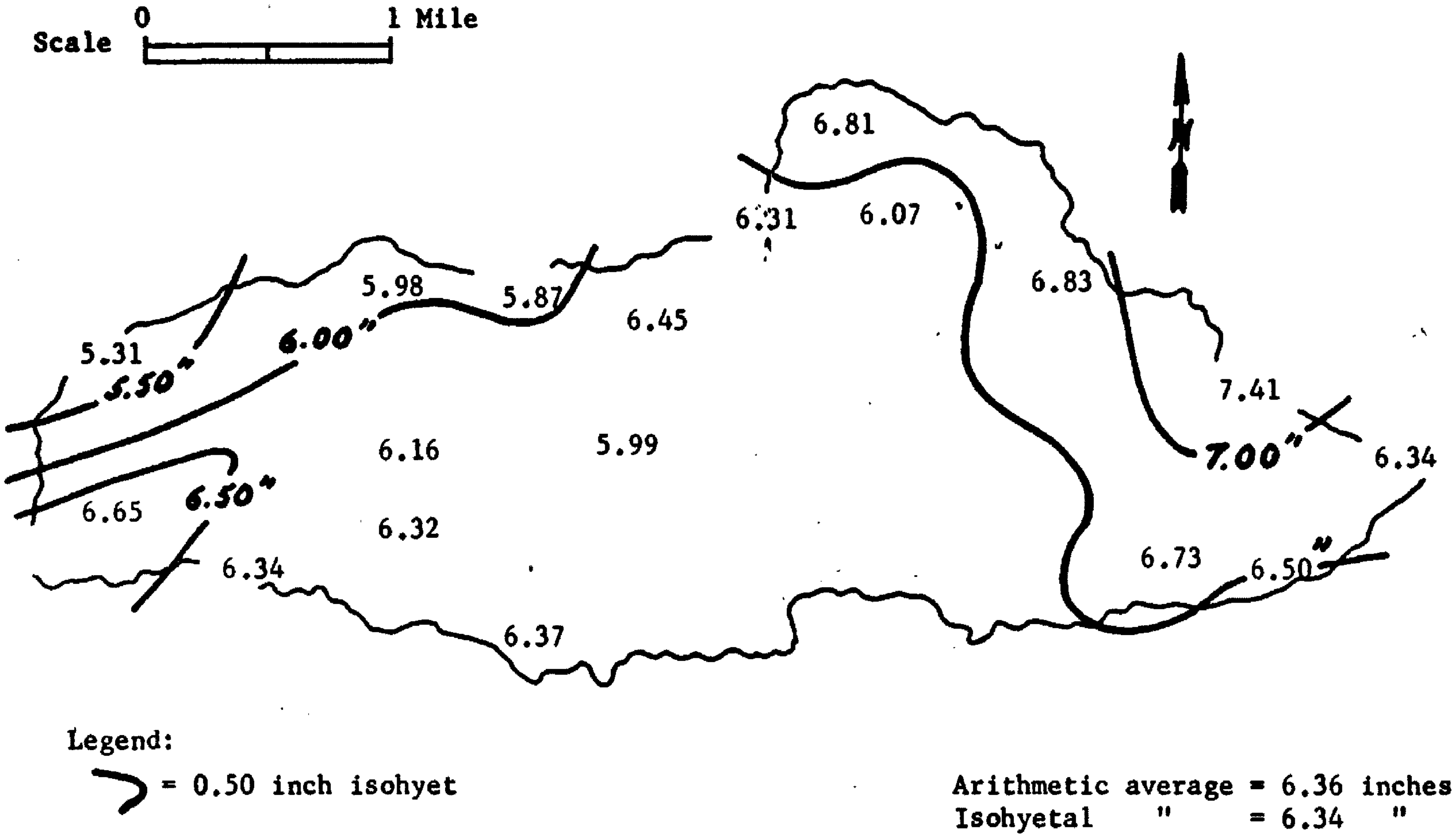


Figure 13. Isohyetal map - May 1, to July 1, 1966

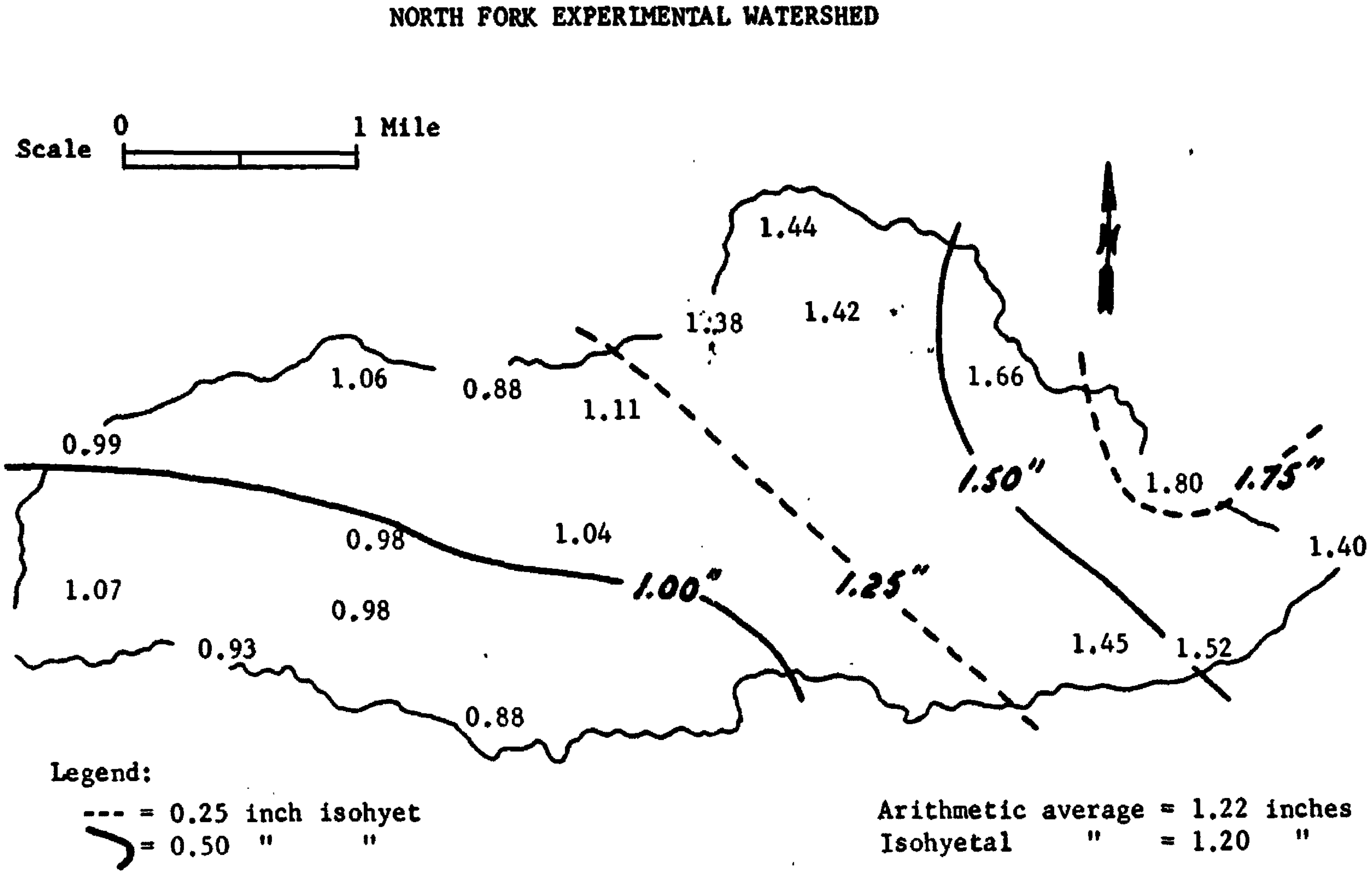
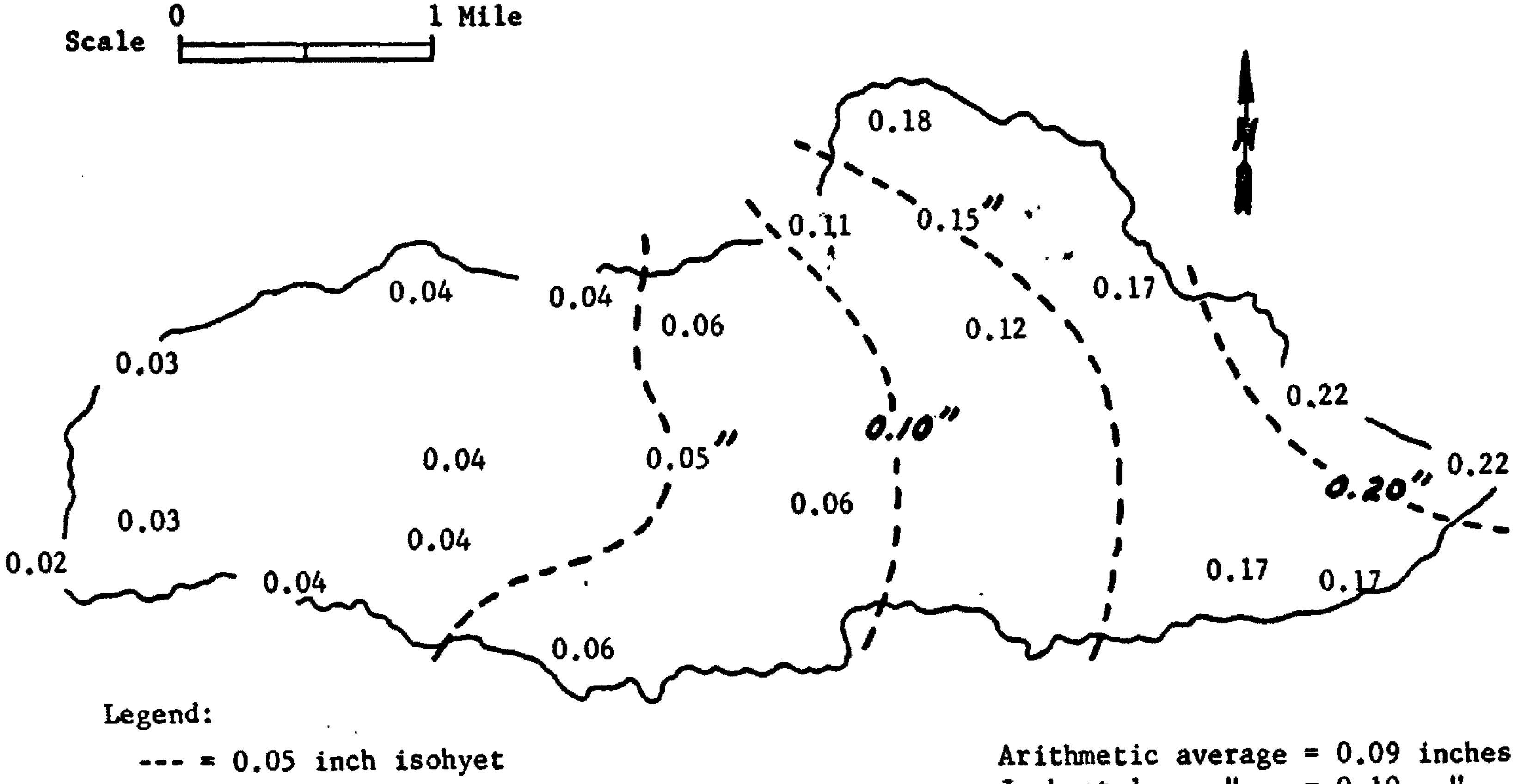


Figure 14. Isohyetal map - June 18 to June 26, 1966

NORTH FORK EXPERIMENTAL WATERSHED



Arithmetic average = 0.09 inches
Isohyetal " = 0.10 "

Figure 15. Isohyetal map - Storm on August 13, 1966

NORTH FORK EXPERIMENTAL WATERSHED

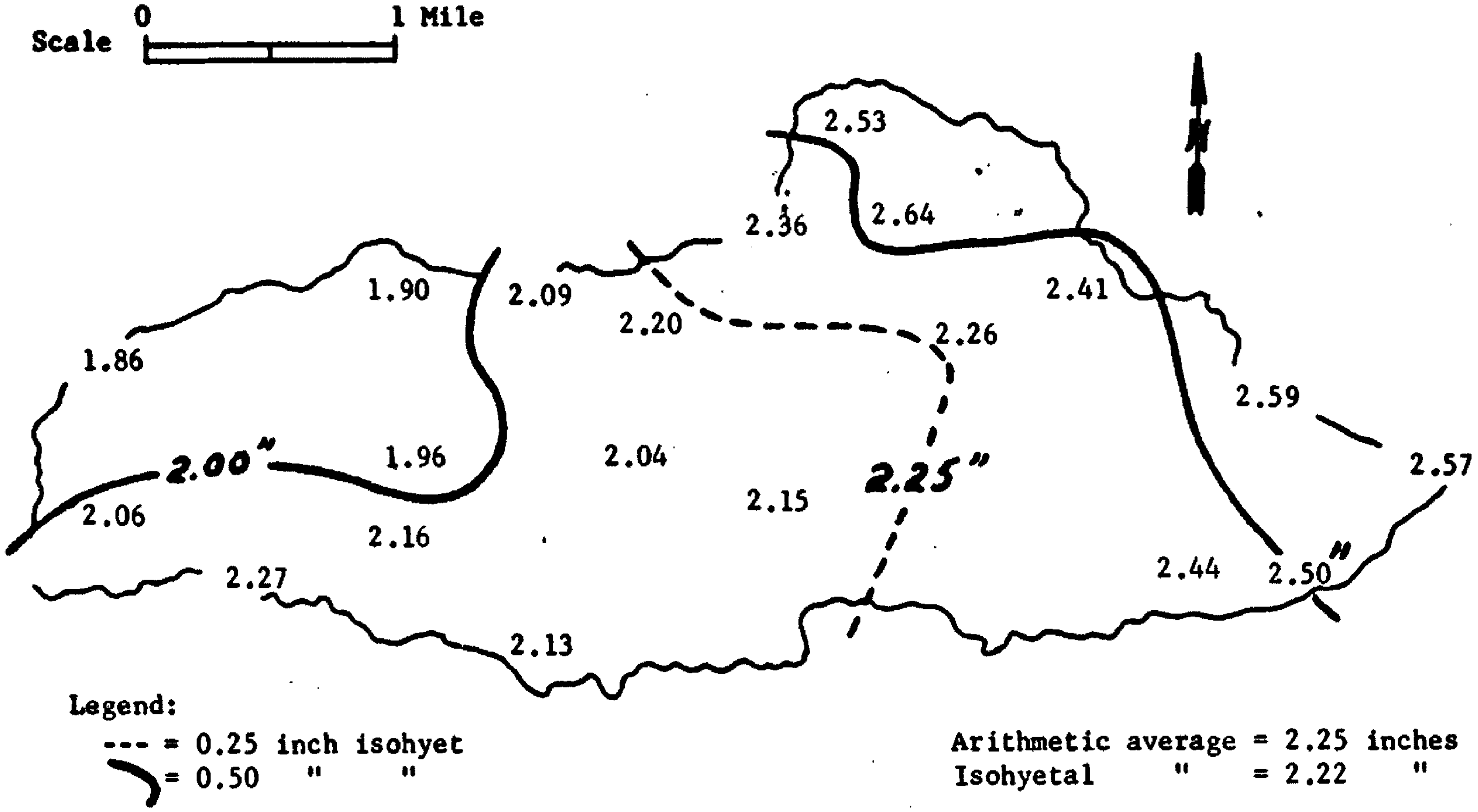
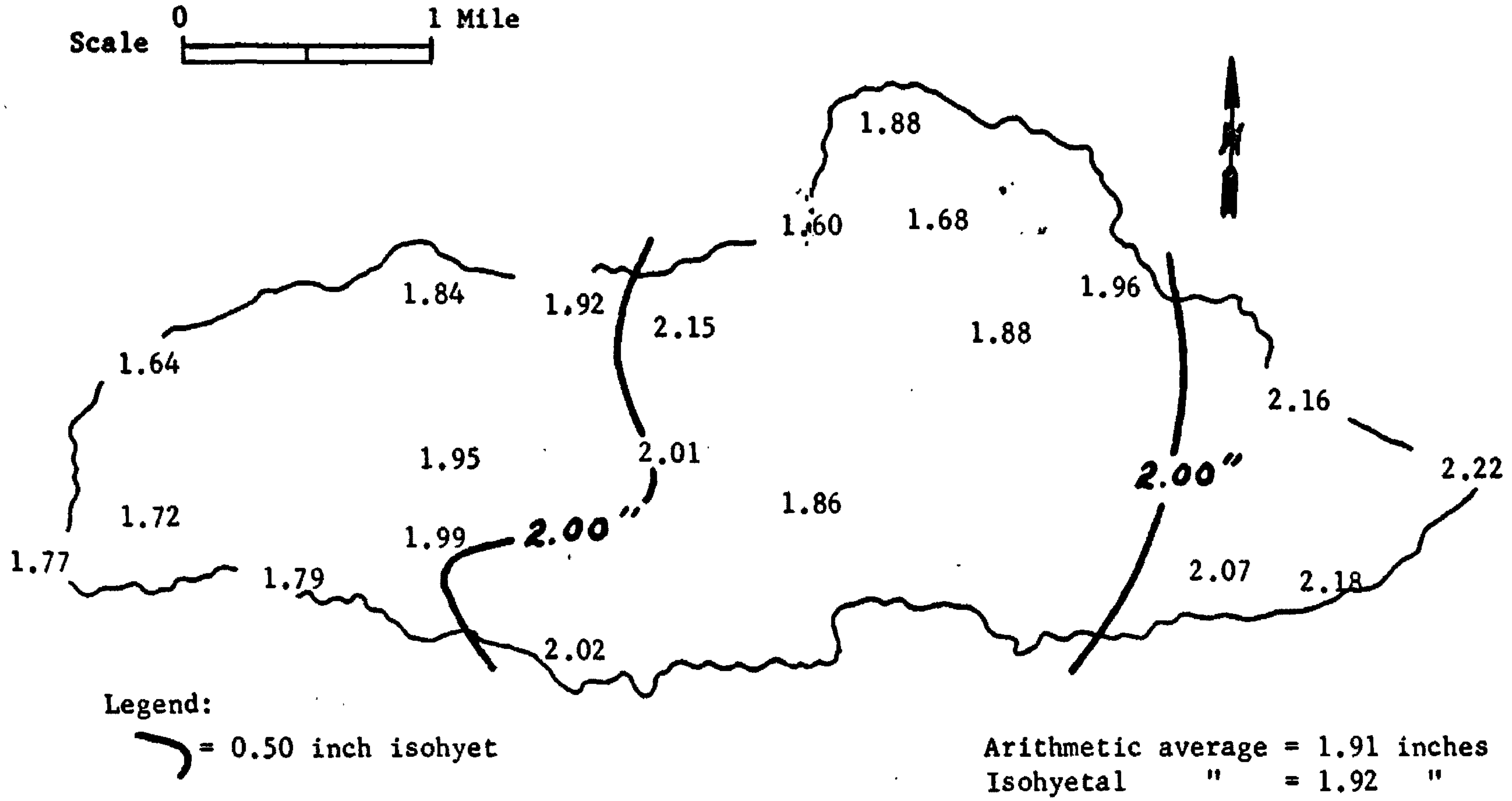


Figure 16. Isohyetal map - July 1 to September 15, 1966

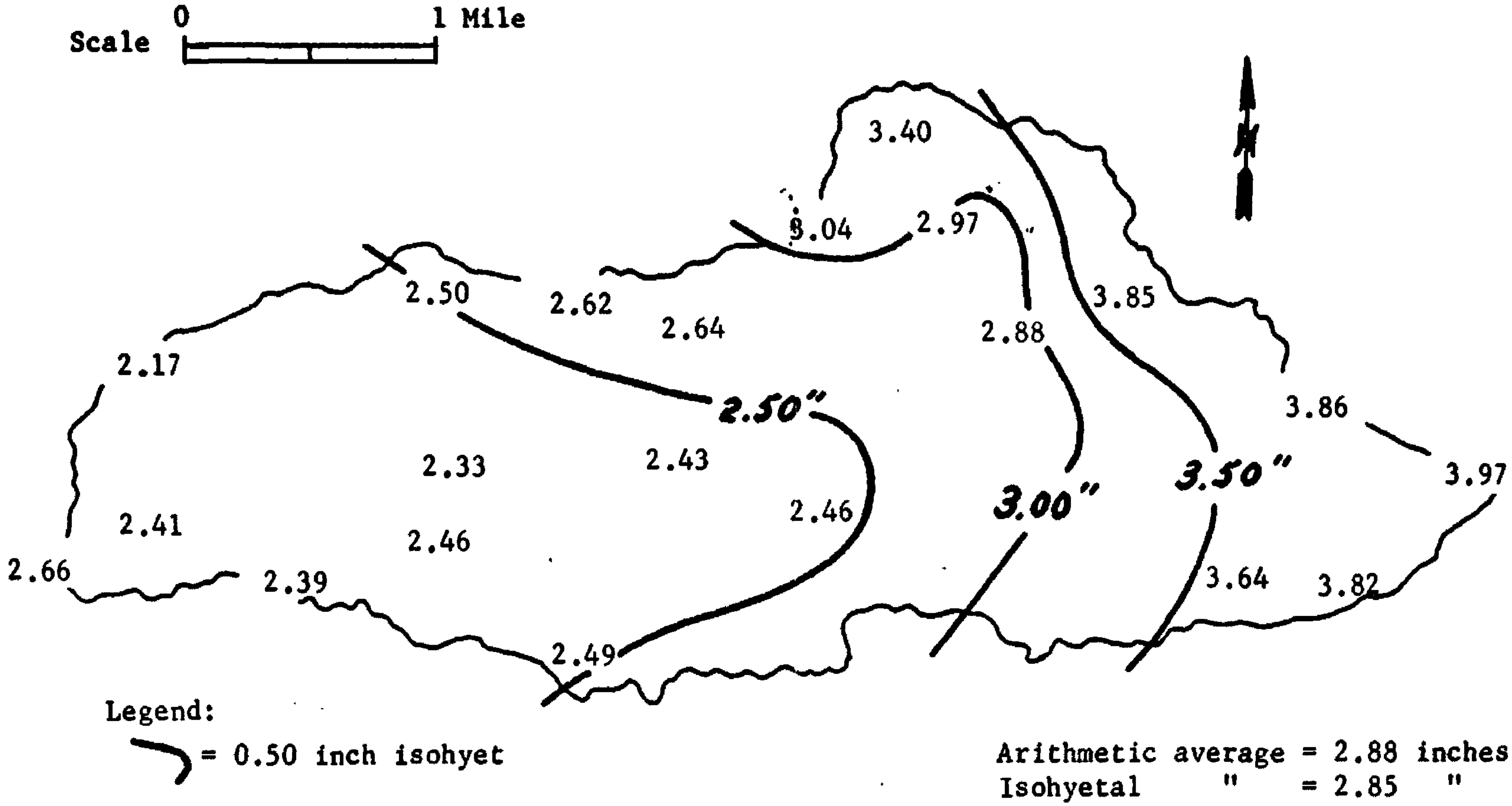
NORTH FORK EXPERIMENTAL WATERSHED



Arithmetic average = 1.91 inches
Isohyetal " = 1.92 "

Figure 17. Isohyetal map - September 15 to October 27, 1966

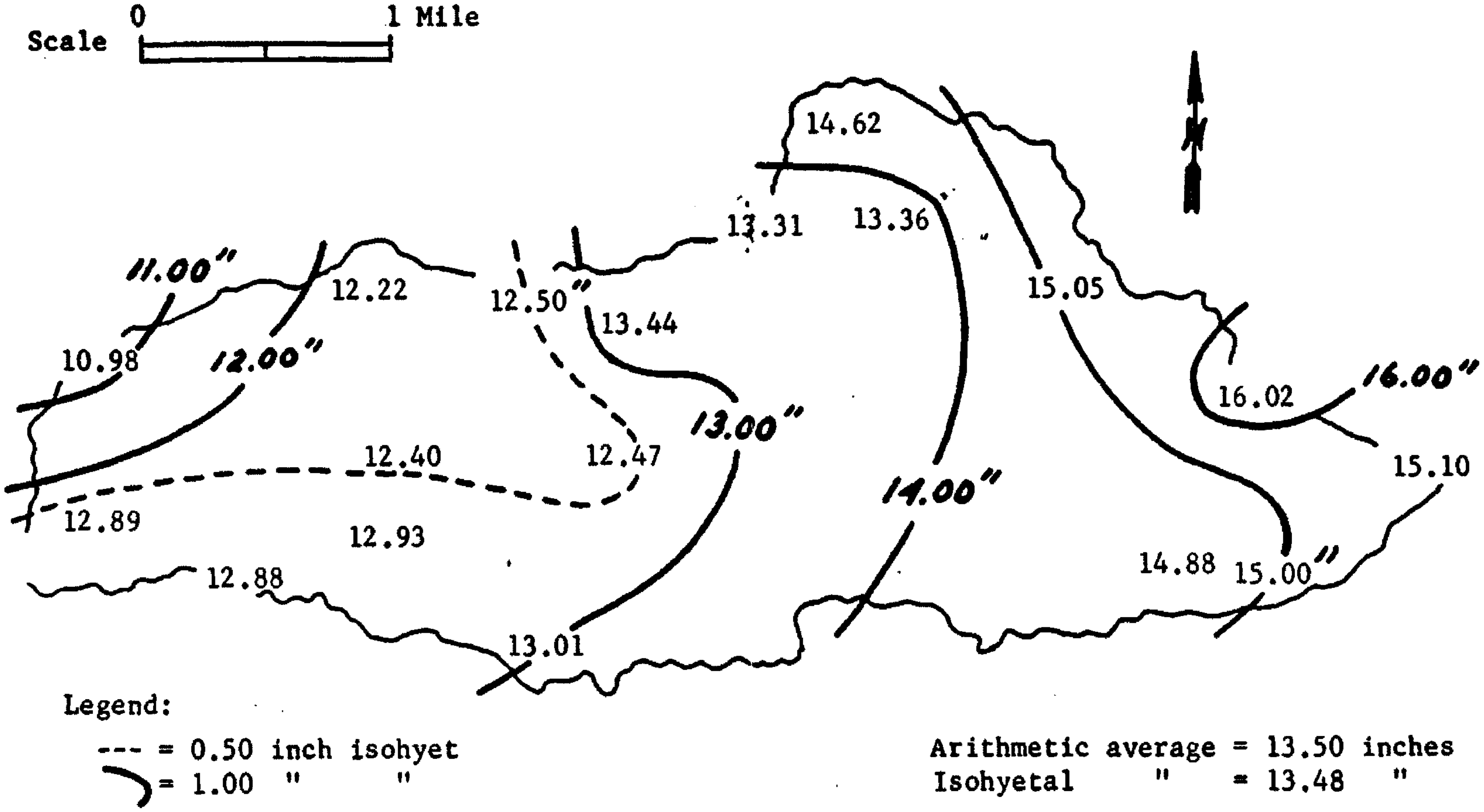
NORTH FORK EXPERIMENTAL WATERSHED



Arithmetic average = 2.88 inches
Isohyetal " = 2.85 "

Figure 18. Isohyetal map - October 27 to December 31, 1966

NORTH FORK EXPERIMENTAL WATERSHED



Arithmetic average = 13.50 inches
Isohyetal " = 13.48 "

Figure 19. Isohyetal map - May 1 to December 31, 1966

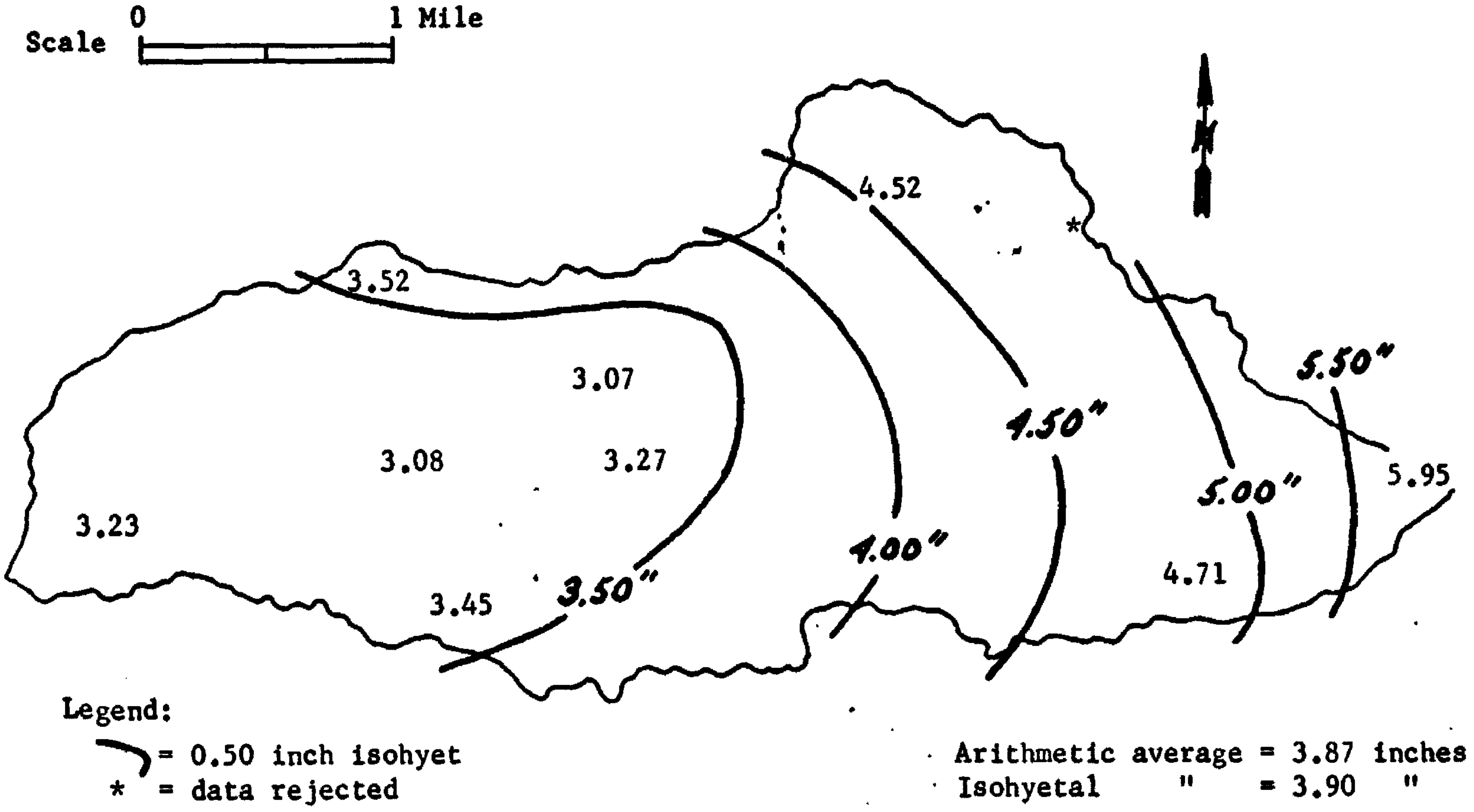
Discussion of the 1967 Isohyetal Maps

The precipitation gradient during the fall, winter, and spring months parallels the elevational gradient from west to east. A ten gage network was originally set up for the winter of 1967. However, the data from the upper hydroplot were excluded because of consistently low readings probably due to excessive wind conditions.

Figures 20 through 23 show the precipitation pattern for the winter and early spring.

Snowpack measurements were taken throughout the winter at each of the rain gage locations. These data are not being analyzed at this time but are in a depository with other watershed records.

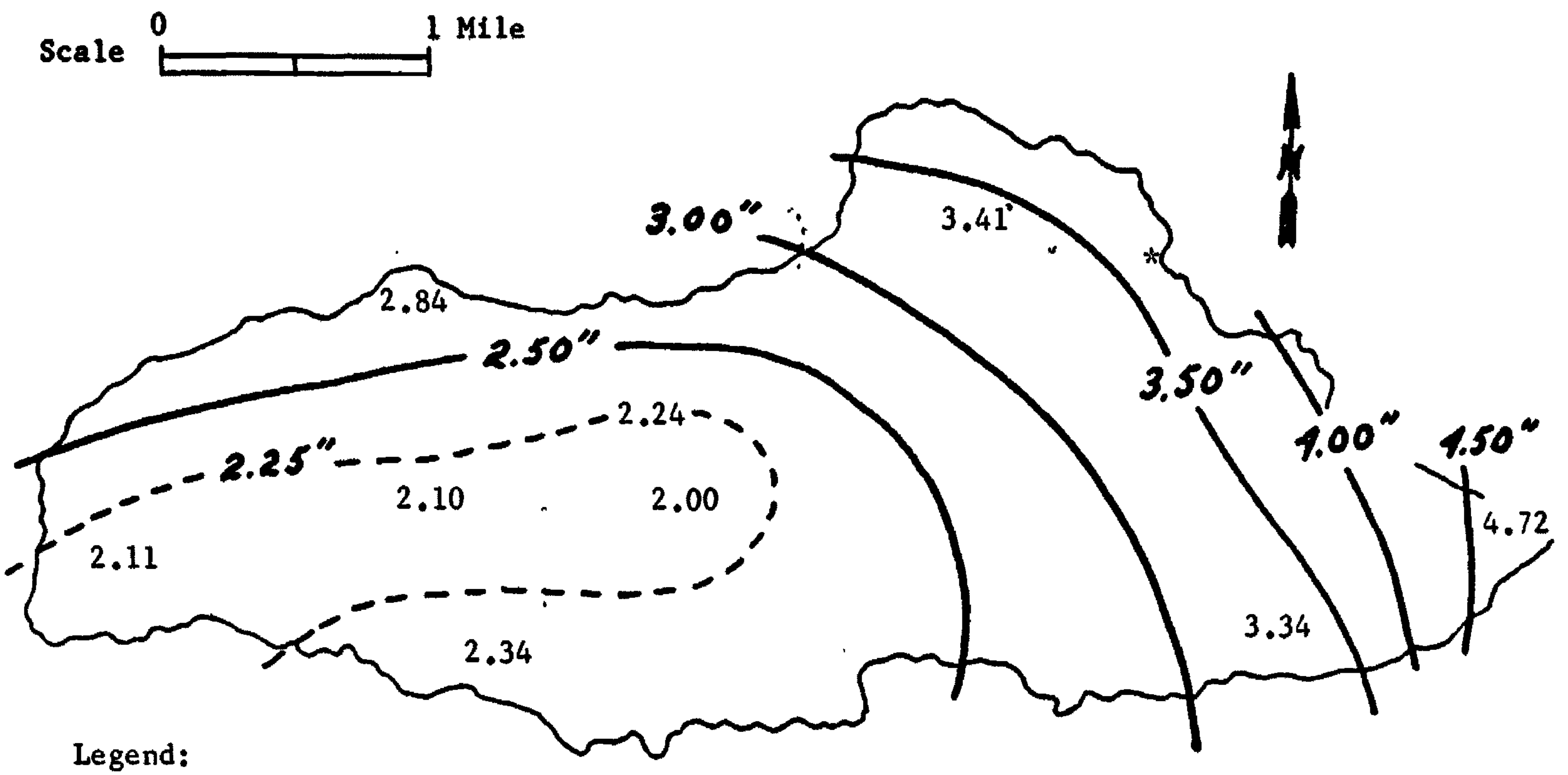
NORTH FORK EXPERIMENTAL WATERSHED



Arithmetic average = 3.87 inches
Isohyetal " = 3.90 "

Figure 20. Isohyetal map - January 1 to February 9, 1967

NORTH FORK EXPERIMENTAL WATERSHED



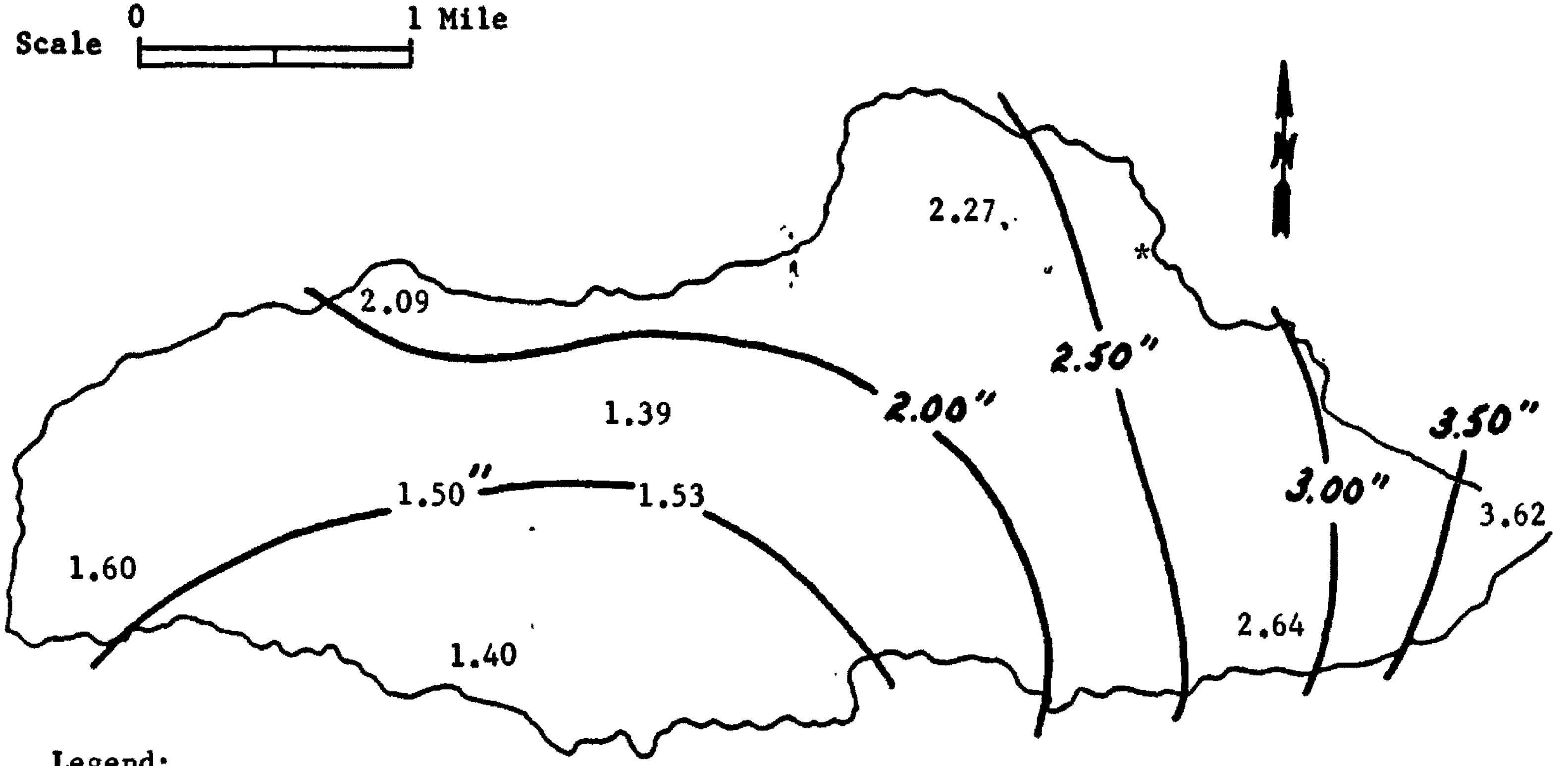
Legend:

--- = 0.25 inch isohyet
⌒ = 0.50 " "
* = data rejected

Arithmetic average = 2.79 inches
Isohyetal " = 2.73 "

Figure 21. Isohyetal map - February 9 to March 30, 1967

NORTH FORK EXPERIMENTAL WATERSHED



Legend:
= 0.50 inch isohyet
* = data rejected

Arithmetic average = 2.00 inches
Isohyetal " = 2.01 "

Figure 22. Isohyetal map - March 30 to April 30, 1967

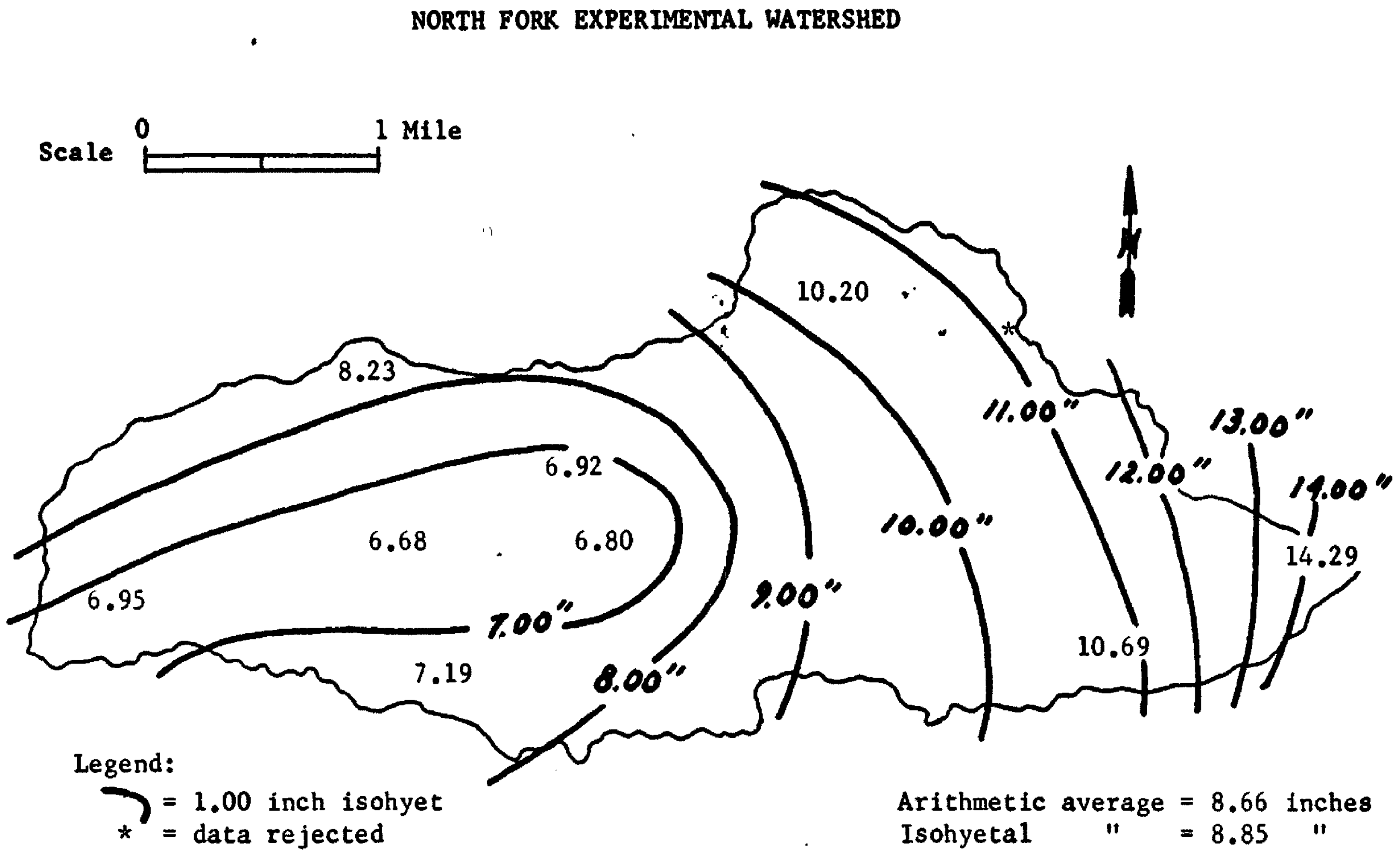


Figure 23. Isohyetal map - January 1 to April 30, 1967

Total Precipitation During the Study Period

The annual precipitation based on the arithmetic method was 22.16 inches. The isohyetal method indicated 22.33 inches, a difference of less than one percent. Approximately 40 percent of this was in the form of snow. Assuming no interception and no correction for possible evaporation from the gages, 8,143.9 acre feet of water fell on the area. Plate I (insert) shows the annual distribution of precipitation. This region has two peak periods of precipitation (May-June and Nov.-Dec.-Jan.). In the following table the watershed data for these periods is compared with two other stations.

Table 6 - Percent of Annual Precipitation
Occurring During Peak Periods

	May-June	Nov.-Dec.-Jan.
Study Area Elev. 4080-6760'	28.6%	29.5%
Greenough Station Elev. 4100'	22.1%	29.9%
U. S. Weather Bureau Msla. Elev. 3200'	24.6%	22.8%

The data for the Greenough Station is based on a seven year average, and the Missoula Station on a ten year average (Steele, 1965).

Tables C and D (Appendix) show other periodic and seasonal totals of precipitation.

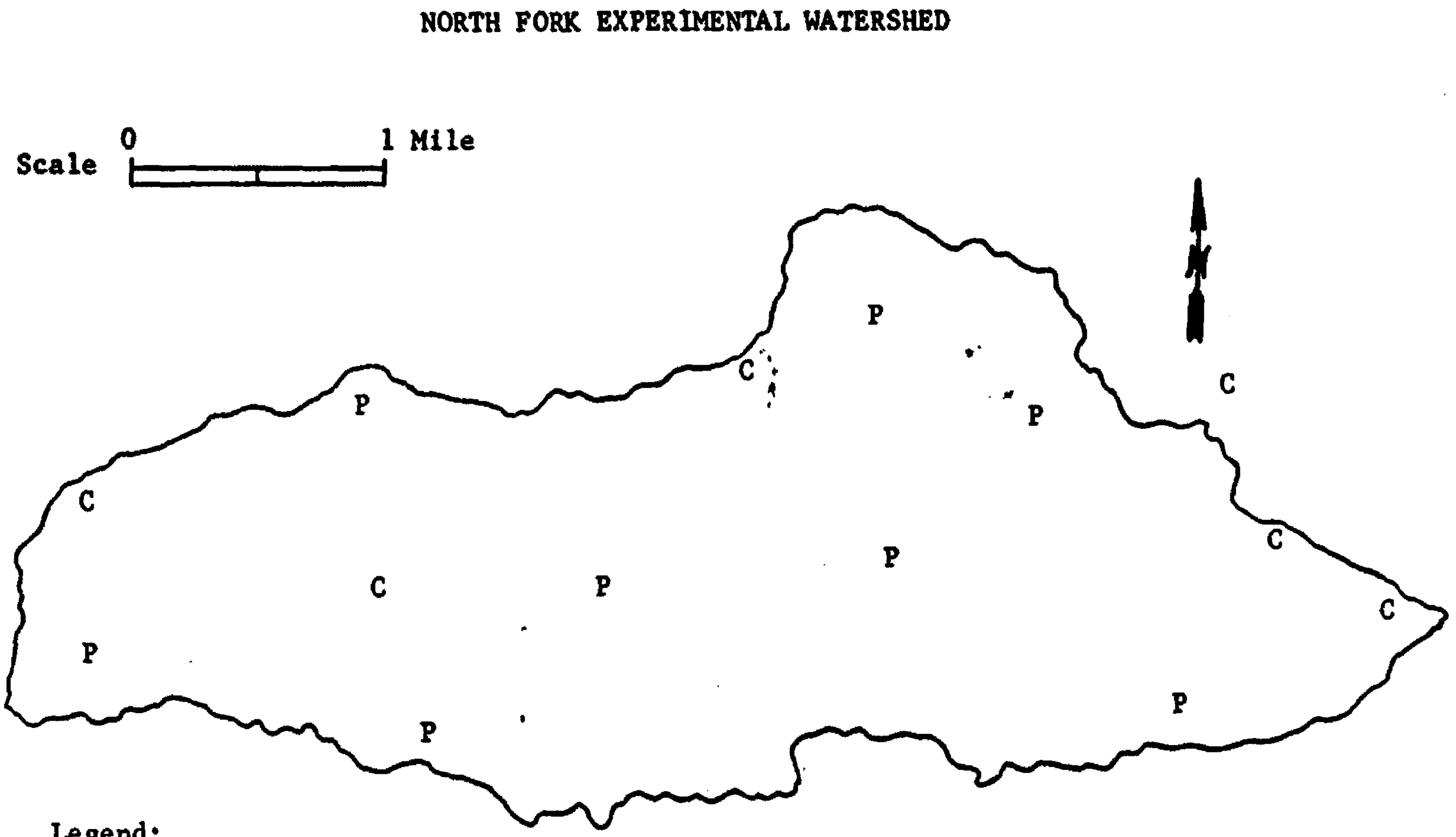
PROCEDURE FOR SELECTION OF RAIN GAGES REQUIRED TO YIELD A REPRESENTATIVE SAMPLE OF PRECIPITATION

Five combinations of 6, 7, 8, and 9 rain gages were analyzed to determine the degree of variation. These combinations were selected on the basis of being representative of the drainage. Each combination was compared over four periods between May 17, and December 31, 1966. Table E (Appendix) lists the various combinations of rain gages.

The overall average for the various combinations is as follows:

Number of Gages	Average Deviation of The Five Combinations	Maximum Deviation of any One Combination Percent
6	+ or - 0.10 inches	5%
7	+ or - 0.06 inches	1.5%
8	+ or - 0.05 inches	1%
9	+ or - 0.05 inches	1%

Even though the above deviations are small, a definite trend does exist. Thus, from the standpoint of adequate rain gage coverage, it appears that an eight gage network would suffice. Figure 24 shows the locations for the principle sample points, based on the results of the previous combinations. In addition, several check rain gages should be incorporated at other locations, especially during the summer field season. If intermediate watersheds are to be calibrated, it would be desirable to continue the 21 gage network and possibly increase the network.



Legend:

P = principle sample point
C = check gage or secondary sample point
(should be maintained at least during
the summer field season)

Figure 24. Principle locations for obtaining a representative sample of precipitation.

CHAPTER II A COMPARISON OF RADAR PRECIPITATION ESTIMATES WITH RAIN GAGE READINGS ON THE NORTH FORK EXPERIMENTAL WATERSHED

INTRODUCTION

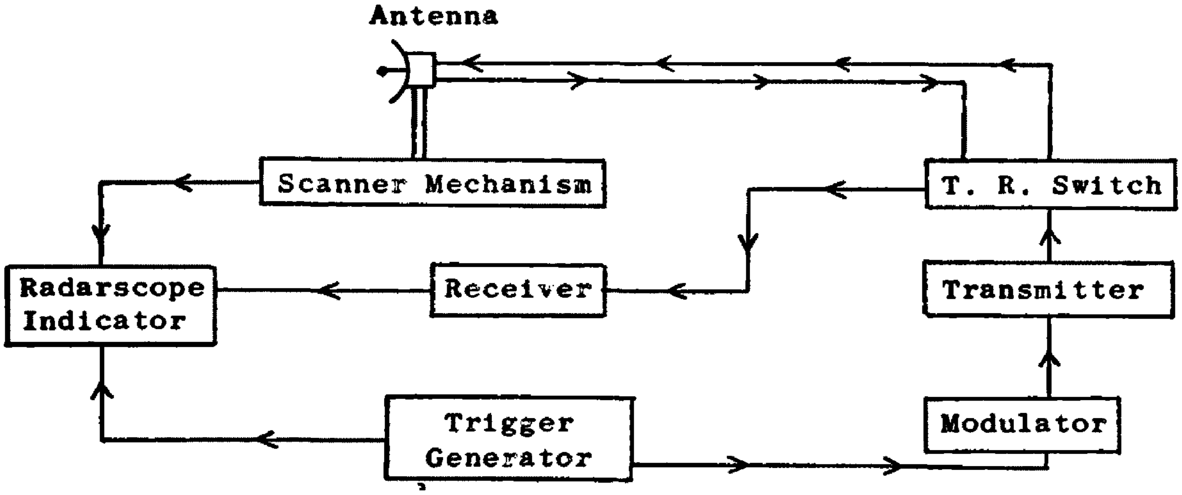
The objective of this study was to determine the effectiveness of radar precipitation estimates at close range and over a relatively small area. The estimated precipitation rates were made by the U. S. Weather Bureau in Missoula, Montana. Operation of this radar station began in November, 1961. In January, 1963 a program was developed for estimating average precipitation over 10 nautical mile squares within 100 nautical miles of the radar. The type of radar used is a Weather Surveillance Radar (WSR-57) with a wavelength of 10 cm. The WSR-57 radar is located atop an 8,000 foot peak north of Missoula, with the control center at the Missoula County Airport, just west of the city. There are 33 WSR-57 Stations throughout the United States.

There are two approaches to the problem of precipitation estimation using radar. One is the theoretical method, using equations. The second is the echo comparison method, whereby the readings from rain gages beneath weather echoes are used as a standard upon which to base precipitation estimates. The estimated intensity levels of precipitation used by this station were derived after a two year study of actual precipitation amounts throughout western Montana and parts of Idaho. Precipitation intensity is calculated on an inches per hour basis, and the resulting rates are measured at hourly intervals during periods of weather echoes. What is actually seen on the radar scope are water droplets or ice crystals. During the autumn, winter, and spring months precipitation summaries are prepared at this station for river stage forecasting. In the summer months the station primarily records thunderstorm activity.

The actual precipitation data used in this study was collected from twenty-one standard and two recording rain gages on the North Fork Experimental Watershed. These data were compared with the radar data for the period from May 1, 1966 to December 31, 1966.

THE PULSED RADAR SYSTEM

Radar has been defined as the art of detecting by means of radio echoes the presence of objects, determining their direction and range, recognizing their character and employing the data thus obtained (Battan, 1959; p. 1). The word 'Radar' was derived from the phrase RAdio Detection And Ranging (Anonymous, 1960; pp. 1-3). Radar is based on the principle of pulsed electromagnetic energy or wave propagated through space at the speed of light (186,000 miles per second). When a pulse of radar energy is intercepted by a "target" (cloud droplets, rain drops, ice particles, and snow flakes), some of the electromagnetic energy is scattered and some is absorbed. That part of the energy which is back-scattered or reflected toward the radar antenna produces an echo or "blip" on the receiver scope. Weather echoes are the result of radar energy reflections from meteorological targets or hydrometeors, such as rain, drizzle, snow or hail. The threshold of detection of the various sizes, shapes, and types of hydrometeors varies greatly with the type of radar being used (Hiser, 1959; p. 107).



The same antenna is used for both transmitted and reflected waves. One pulse goes out and a return echo is received before the next pulse leaves the set.

Figure 25. A simplified version of a radar set.

The basic function of each major part:

Trigger Generator or Timer - This initiates the number of pulses per second to be transmitted.

Modulator - This amplifies the trigger in both voltage and duration.

Transmitter - The most important unit of the transmitter is the magnetron. This produces short powerful bursts of energy at a desired frequency and at relatively high power.

Duplexer or T - R Switch - This enables the same antenna to be used for transmitting and receiving.

Antenna - This shapes the outgoing energy into a directed beam and also acts as a receiver of returned echoes.

Indicator Unit or Scope - The indicator presents radar information such as range, height, area, density, and bearing on the screen of a cathode ray tube.

Scanner - This is an auto-mechanical device used to rotate the antenna in azimuth and elevation.

SCATTERING AND ATTENUATION BY METEOROLOGICAL TARGETS

Several factors such as size, shape, temperature, phase (i.e. solid or liquid), and the number of particles per unit volume of the target, determine the degree of scattering and absorption of radar energy. Attenuation of electromagnetic waves is the reduction of intensity of the wave along its path, due to absorption and scattering. Thus, the power returned to the radar is reduced. Attenuation of microwaves by gaseous absorption is generally negligible for long wave radar. However, water vapor and oxygen are the only two atmospheric gases that need to be considered as absorbers. Water scatters and absorbs more strongly than ice. As a result of the greater absorption, the attenuation is much more pronounced for water particles than for ice particles (Hiser, 1959; p. 130). Attenuation decreases with increasing wavelength. Thus, attenuation at 10 cm. and greater wavelengths can be ignored for practical purposes (Hiser, 1959; p. 130).

TARGET DISTORTIONS

Radar distortions may be defined as a misrepresentation of a target in any of its parameters - shape, size, appearance, range, height, depth, perspective, or movement. Distortion in all of these parameters, to a greater or lesser degree, is present in all radar as a result of:

1. Beam width and shape, both horizontal and vertical
2. Pulse length
3. Scanning rate
4. Range

5. Peak pulse power
6. Curvature of the earth
7. Wind shear (meteorological targets)
8. Attenuation of signals due to precipitation
9. Fringing of meteorological targets
10. Variations in atmospheric refractive index
11. Side lobes
12. Reflected waves (Hiser, 1959; p. 148).

Although the above causes are not discussed, the reader should not be led to believe that the displays on the radarscope are unreliable. As long as proper allowances are made for the certain factors in question an intelligent interpretation can be accomplished.

RADARSCOPE INTERPRETATION

Ground pattern or ground return are echoes from targets on the ground at any range. Ground return consists of echoes from hills and mountains, trees, buildings, etc. When displayed on radarscopes these echoes are usually more dense and have sharper defined edges than precipitation echoes. Precipitation echoes generally appear as hazy or fuzzy areas with poorly defined edges. Areas of heavy precipitation show up as brighter or more intense spots. Warm fronts and other stable types of precipitation, showers and thunderstorms, cold fronts and squall lines; etc. each have characteristic precipitation patterns which the trained radar meteorologist can interpret from radar scopes.

PROCEDURE USED AT THE MISSOULA STATION TO EVALUATE INTENSITIES OF WEATHER ECHOES

The intensity of a weather echo is a measure of the precipitation rate associated with that echo. The radar energy reflected back to the radar by water droplets or ice crystals (snow) is a function of the drop size and the number of drops per unit volume. The step attenuation procedure is used by this station. The reflected signal strength is measured by introducing known amounts of attenuation, measured in decibles (db), into the signal from the radar receiver to the radarscope until the precipitation echo has been removed from the radarscope. Tables have been computed showing the comparison between precipitation rates and amounts of attenuation. Thus, for any particular echo intensity it is possible to determine a theoretical precipitation rate. See tables 7 and 8.

By using the above procedure, the weather echoes as seen on the radar scope are outlined in contours at various steps of attenuation depending upon the season of the year. During the summer the echoes are outlined in five broad ranges. During the autumn, winter, and spring echoes are contoured in eight narrowly spaced attenuation steps.

> The reflectivity of snow is much less than that of rain or hail, therefore, during periods of snow the radar is operated at a sensitivity of approximately four times greater than that needed for the detection of rain. This level of sensitivity is a calibrated -109 dbm (the deviation from a specific electronic standard). This is based on sensitivity above a zero level. The standard level for WSR-57 radars is -103 dbm. This level permits the detection of wet snow and rain and usually eliminates the detection of light snow. The strength of the received signal is further reduced by calibrated steps to measure the intensity of the stronger precipitation areas (Granger, 1967).

It has been found that the extent of filling of the radar beam by the precipitation determined the precipitation rate (Granger, 1967). At Missoula, a precipitation rate was determined for those echoes with tops less than 14,000 feet and those with tops 14,000 feet or greater (mean sea level). Table 7 is used with the charts having a 100 nautical mile radius, which are also referred to as "hydro" charts. "Hydro" charts only evaluate precipitation areas 10 nautical miles in diameter or greater. The corresponding intensities for the gridded areas in which the experimental watershed lies are given in Table 7. Additional information concerning the Grid Method for Estimating Precipitation is available in a publication by R. Granger (1966).

Table 7 - Precipitation Intensity for Autumn, Winter, and Spring "Hydro" Measurements

Color Code For Contours	db Rating	Precipitation Amount Inches/Hr. Below 14,000	Precipitation Amount Inches/Hr. 14,000 +
Black	-6 (-109 dbm)	0.02	0.00
Red	0 (-103 dbm)	0.04	0.02
Green	6	0.06	0.04
Blue	12	0.10	0.06
Black	15	0.16	0.10
Red	18	0.24	0.16
Green	21	0.34	0.24
Blue	24	0.46	0.34

During the summer months the intensity of weather echoes are not measured per se, but rated according to a theoretical graph of rainfall intensity. The theoretical graphs may work better in some areas than in others due to differences in types of rain (Anonymous, 1960). The radar may often underestimate the rainfall when the graphs are used. The rated intensities in Table 8 are for the charts having a 250 nautical mile radius. These charts attempt to show all precipitation areas regardless of size.

The precipitation amounts shown in Table 8 were determined from the Echo Intensity Chart - WSR-57 (Anonymous, 1960; p.3-43). The indicated amounts represent the theoretical rainfall rate for the mean of each db rating. There is one exception to this. The maximum theoretical rate for the 0-8 db rating is 0.006 inches/hr., but a rate of 0.01 inches/hr. was assigned. The db ratings used are all based on a range of 100 nautical miles.

Table 8 - Precipitation Intensity Rating for Summer Storms (This rating used with the 250 nm charts)

Color Code For Contours	db Rating	Precipitation Amount Inches/Hr.
Black	0-8	0.01
Green	9-23	0.03
Red	24-38	0.23
Blue	39-50	1.45
Black	51+	+1.45

PROCEDURE OR CRITERIA USED FOR COMPARING THE RADAR DATA WITH THE ACTUAL AMOUNTS OF PRECIPITATION

The estimated amounts of precipitation used for the comparison were determined by using the rated intensities of weather echoes shown in Tables 7 and 8. Initially, only those echoes covering all or part of the watershed were considered. A later comparison took into account echoes within a 5 nautical mile radius and a 10 nautical mile radius of the watershed. In using the above procedures, only the maximum intensity to appear within the given areas was considered. Figure 26 illustrates the use of a transparent overlay with the radar charts.

Actual precipitation over the watershed varies considerably. Many storms throughout the summer would yield more precipitation at lower elevations than at higher elevations. The area is influenced by local and general weather patterns. Several precipitation maps and radar charts follow (pp. 74-79), illustrating the variation of precipitation over the watershed. Table F (Appendix) provides a detailed list of both radar weather and actual precipitation over the watershed. The data compiled from this study is presented in the following tables to show the existing relationships.

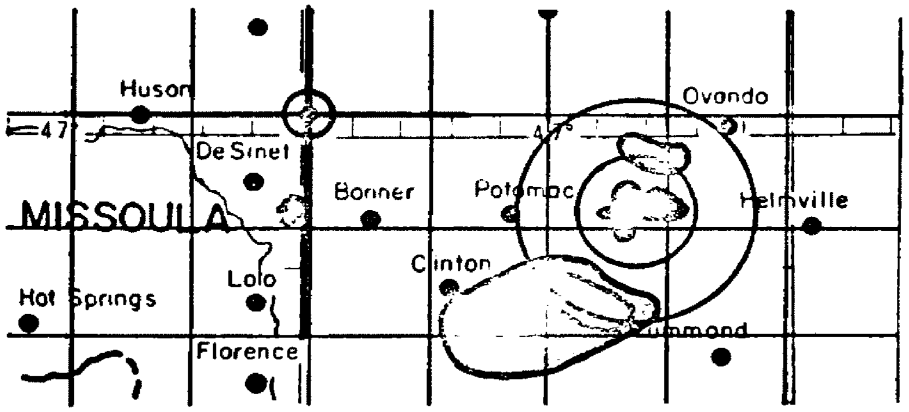


Figure 26. Use of a transparent overlay.

Table 9 - Variation in Precipitation Over the Watershed for Various Periods

Date	Arithmetic Average For Watershed	Total Radar Estimated Precipitation	Variation in Precipitation Over Watershed	
			Max.	Min.
May 1 - 10	0.19	0.04	0.22	0.14
10 - 17	0.80	0.32	0.91	0.71
17 - 28	0.24	0.05	0.38	0.12
28 - June 4	1.98	2.21	2.28	1.24
4 - 11	1.69	0.57	1.88	1.40
11 - 18	0.10	0.16	0.18	0.05
18 - 26	1.22	0.47	1.80	0.88
26 - July 1	0.09	0.11	0.11	0.08
1 - 5	0.14	0.05	0.49	0.22
5 - 9	0.14	0.06	0.44	Trace
9 - 17	0.27	0.25	0.47	0.12
17 - Aug. 5	0.03	0.02	0.06	0.01
5 - 15	0.09	0.08	0.30	0.02
15 - 23	0.12	0.06	0.18	0.06
23 - 29	0.62	0.13	0.83	0.43
29 - Sept 2	0.50	0.11	0.62	0.40
2 - 9	0.06	0.04	0.10	0.03
9 - 12	0.02	0.06	0.06	0.01
12 - 16	0.01+	0.04	0.03	Trace
16 - 23	0.16	0.02	0.19	0.12
23 - 29	0.26	0.03	0.44	0.19
29 - Oct. 6	0.56	0.11	0.80	0.39
6 - 13	0.05	No data		
13 - 20	Trace	No data		
20 - 27	0.67	0.19	0.95	0.60
27 - Dec 31	2.88	1.60	3.97	2.17
	12.89	6.78		

Percentage Ratio of Radar/Actual $\frac{6.78}{12.89} \times 100 = 53\%$

Table 10 - A Comparative Analysis of the Data from the Weather Record Table

Date	Number of Days with Precipitation and no Echoes Recorded for that Day	Number of Days Precipitation Estimated by Radar but no Actual Precipitation on Watershed	Number of Days with Precipitation but no Echoes Over Watershed. Echoes were Recorded Within 5 mi. of Watershed
May 1 to June 24	0	2	5
June 25 to Nov. 5	1	6	5

Date	Number of Times Radar Estimates Were Considerably Higher than Actual Precipitation	Number of Daily Accumulations of Actual and Radar Estimated Precipitation that are = or Nearly =	Number of Weekly or Periodic Accumulations of Actual and Radar Estimated Precipitation that are = or Nearly =
May 1 to June 24	3	4	0
June 25 to Nov. 5	0	8	5

Table 11 - Comparing the Actual Precipitation from Nine Storms with the Radar Estimates of Precipitation over the Watershed, Precipitation within 5 Nautical Miles, and Precipitation within 10 Nautical Miles

Date	Actual Precipitation (Arith. Avg.)	Weather Echoes Over Watershed	Weather Echoes Within 5 Miles	Weather Echoes Within 10 Miles
	(values below are in inches)			
May 10	0.19	0.04	0.04	0.08
July 1	0.10	0.03	0.23	0.23
July 7	0.14	0.04	0.04	0.04
Aug. 4	0.03	0.02	0.05	0.07
Aug. 13	0.09	0.08	0.08	0.10
Sept. 8	0.06	0.02	0.02	0.05
Sept. 11	0.02	0.06	0.07	0.13
Sept. 14	0.01	0.04	0.08	0.13
Oct. 2	0.56	0.10	0.13	0.16
	1.20	0.41	0.74	0.99
Percentage Ratio of Radar/Actual		34%	62%	83%

NOTE: The data in the two left hand columns were taken from the Weather Record Table in the Appendix. Only the maximum intensity echo that appeared within each radii was considered for the other two columns.

Table 12 - Comparison of Actual Precipitation with Radar Estimates of Precipitation Over the Watershed, and Within a 5 and 10 Nautical Mile Radius of the Watershed

Period	Actual Precipitation	Weather Echoes Over Watershed	Within 5 mi.	Within 10 mi.	Percentage Ratios Radar/Actual Over	5 mi.	10 mi.
May 1 - June 24	6.22	3.82	8.29	10.56	61%	133%	170%
June 25 - Oct. 27	3.79	1.36	2.48	3.74	36%	65%	99%
Oct. 28 - Dec. 31	2.88	1.60	2.63	4.04	55%	91%	140%
May 1 - Dec. 31	12.89	6.78	13.40	18.34	53%	104%	142%

Two Other Comparisons
(May 1 - June 24)

	Actual	Over	5 Mi.	10 Mi.
Using "Hydro"	6.22	3.32	4.67	6.08
Charts Only	R/A	53%	75%	98%
Using 250 nm	6.22	2.16	6.53	8.24
Charts Only	R/A	35%	105%	132%

NOTE: The above totals for the June 25 to Oct. 27 period do not include any of the data for those days when the radar was out of order. (See Weather Record Table F for dates.)

CONCLUSION

A conclusion can best be developed by discussing some of the tables presented in the text.

Table 9 shows the variation in actual precipitation over the watershed for various periods. With such variation over a relatively small area the radar measurements do provide a conservative estimate.

Due to certain limitations the Weather Surveillance Radars have a tendency to underestimate precipitation. This is supported by the fact that only three times during the period of comparison were the radar estimates higher than actual precipitation (see Table 10). There is also a tendency for increased underestimating during periods of heavy precipitation (see Table 9). The radar precipitation data from the Missoula station is now being put on IBM cards for computer programming. An improved correction factor for intensity rating of weather echoes is being sought by computerizing the data (Granger, 1967).

A complete record is available for each of the nine storms listed in Table 11. That is, the entire rain gage network was checked following each storm. The results are not as favorable as those in Table 12.

Table 12 is based primarily on the use of two boundary limits for estimating accumulative precipitation over small areas. The use of a five nautical mile radius gives the best estimate of actual precipitation. Many of the close comparisons of actual to radar determined precipitation were during the summer months, when the 250 nautical mile charts were in use. One explanation is that these charts attempt to show all precipitation areas regardless of size. Whereas the "hydro" charts only evaluate precipitation areas 10 nautical miles in diameter or greater. The comparison for the 5 mile radius at the bottom of Table 12 illustrates a more accurate estimate based on the 250 nautical mile charts. It should also be noted that very small echoes which would appear on the radarscope at the 100 nautical mile range may not appear or be so small that they would not be plotted when switched to the 250 nautical mile range.

There are several important factors that must be taken into consideration before placing too much emphasis on the results of this comparison. First of all, these data were taken from hourly charts, or once an hour readings, and it is readily seen on some of the radar charts that a considerable amount of weather may occur at one time and the next hour it may have completely dissipated or moved considerably. For example, the watershed is about six miles in length, east and west, and a small echo moving at the rate of 35 knots could pass over this area in about twelve minutes. However, the intensity rate assumed for this echo is based on a duration of one hour. Another factor not considered was echo movement, that is, rate and direction of movement. This could be determined fairly accurately from the hourly charts. A more accurate check could be made by reviewing the six-minute interval film strips of radar weather made at the station. However, this study was not intended to be that detailed.

Another major factor not to be overlooked is human error. The weather echoes are initially outlined on the face of the radar scope. Then the radar charts are placed over the scope and the echoes traced.

If the chart is not aligned properly a contour line could be off several miles. When there is considerable radar activity the larger concentrations of precipitation are considered first. Thus, many small echoes may be overlooked or not plotted because they would only appear as a dot. Another possible source of error is in reviewing the radar charts and determining the estimated amounts of precipitation.

A comparison between radar precipitation estimates and actual precipitation made by the Missoula station from December 1, 1964 to June 18, 1965 showed a correlation coefficient of 0.88. Other comparisons made by this station on a seasonal basis were rather good. In a broad sense, the data collected by the Missoula station show essentially what others have found to be true,...that point rainfall data for individual days usually correlate poorly with radar estimates (Flanders, 1964). When the data are averaged over a longer time interval and over larger areas, the correlations are improved significantly (Granger, 1966; p. 6).

Additional information concerning the operations of the Missoula Radar Station can be found by referring to Western Regional Technical Memorandum No. 19.

RECOMMENDATIONS

Before using the five mile radius as a reliable measure of actual precipitation, additional comparisons should be made on this watershed as well as comparing data for other areas. The Weather Bureau is very interested in the results of this study from the standpoint of having detailed information about convective-type precipitation on a local basis. If using a five nautical mile radius continues to yield satisfactory results, this means of estimating precipitation would be of value to meteorologists, foresters, and ecologists, especially in areas where precipitation data are lacking.

The U. S. Forest Service is attempting to make some radar precipitation comparisons on the Meadow Creek Barometer Watershed, Nezperce National Forest, Idaho. This watershed is about 80 miles from the radar site. To date no results have been formulated.

EXPLANATION OF THE PRECIPITATION MAPS AND THE RADAR CHARTS

The solid black area on the radar charts represents the watershed. The value next to the word "tops" in the upper left hand corner of the 100 nautical mile radius charts, indicates the height of the weather echoes. Example, 180 means that the top of the echo is at 18,000 feet. On the 250 nautical mile radius charts the tops are generally indicated on one or more echoes. The following maps and charts illustrate some of the variation over the watershed.

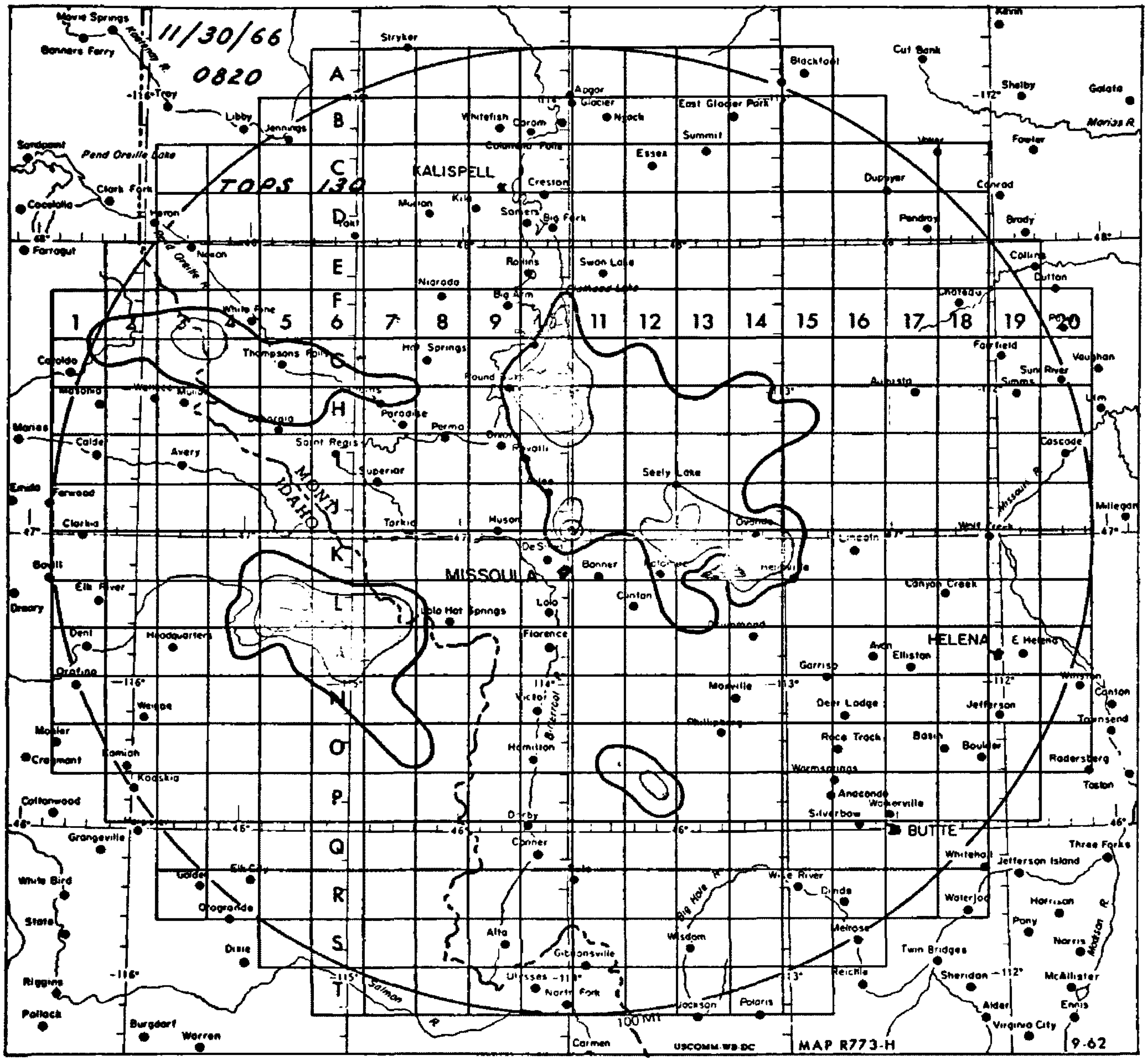


Figure 27. Variation in rainfall intensity over the watershed, as indicated by the radar echoes.

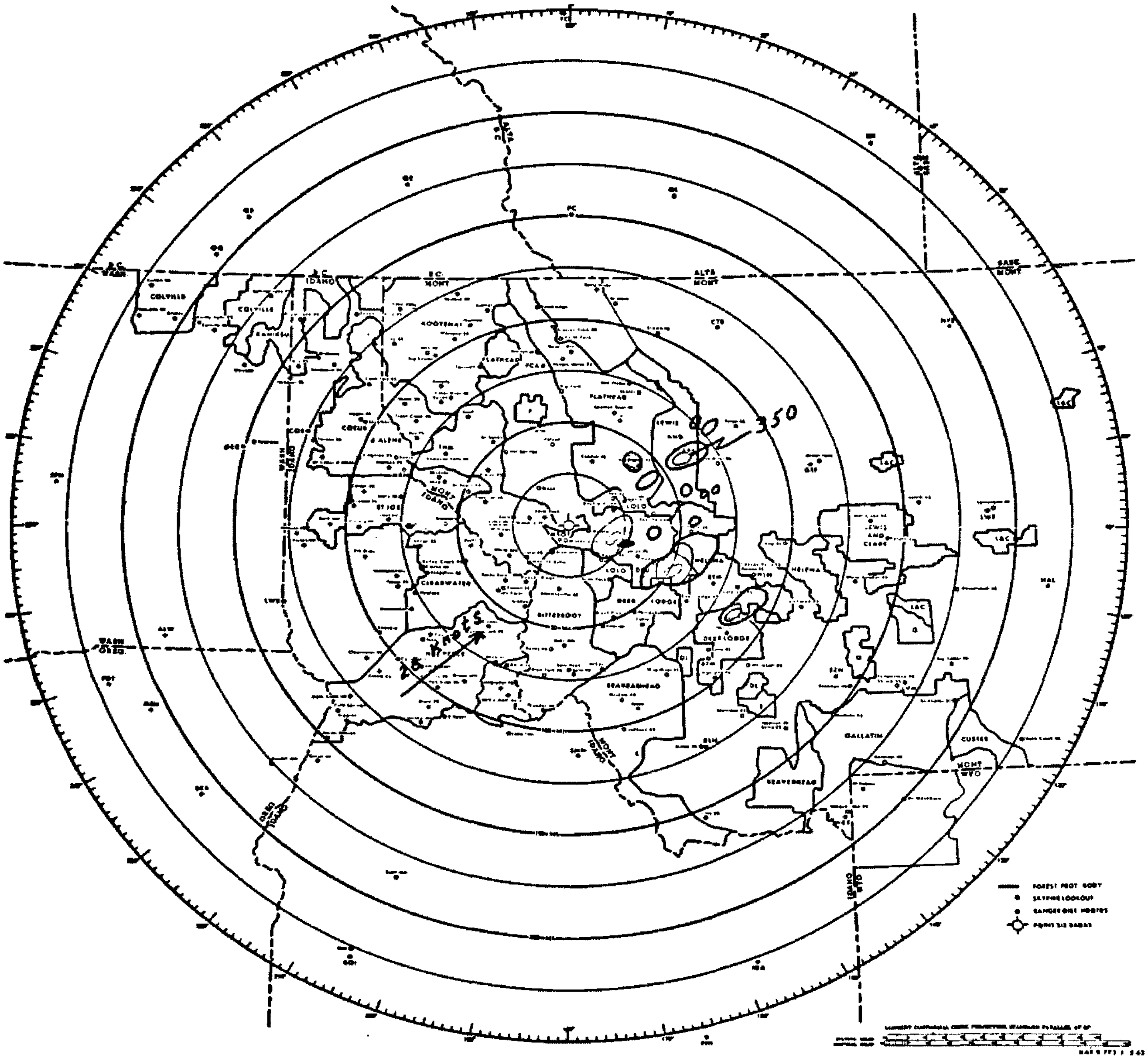
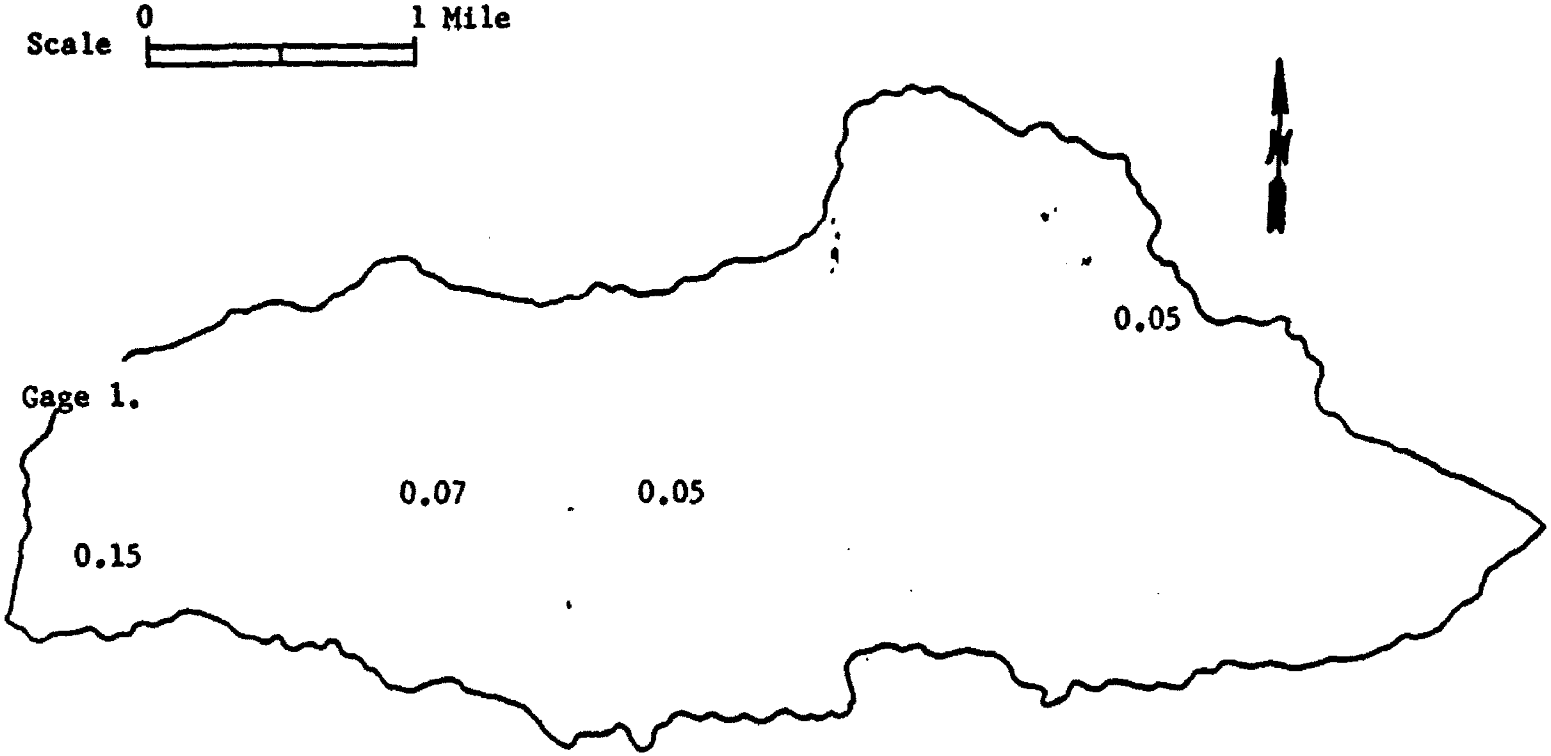


Figure 28. The rain gages were being measured when this storm occurred. The author arrived at rain gage No. 1 a few minutes after the storm began. Hail stones up to 5/8 of an inch in diameter covered the ground at this location. The storm lasted about twenty minutes. Four of the rain gages were remeasured following the storm (see precipitation map on next page).

NORTH FORK EXPERIMENTAL WATERSHED



NOTE: Four gages were remeasured following the storm

Figure 29. Precipitation map - Storm that occurred about 1500 on July 1, 1966

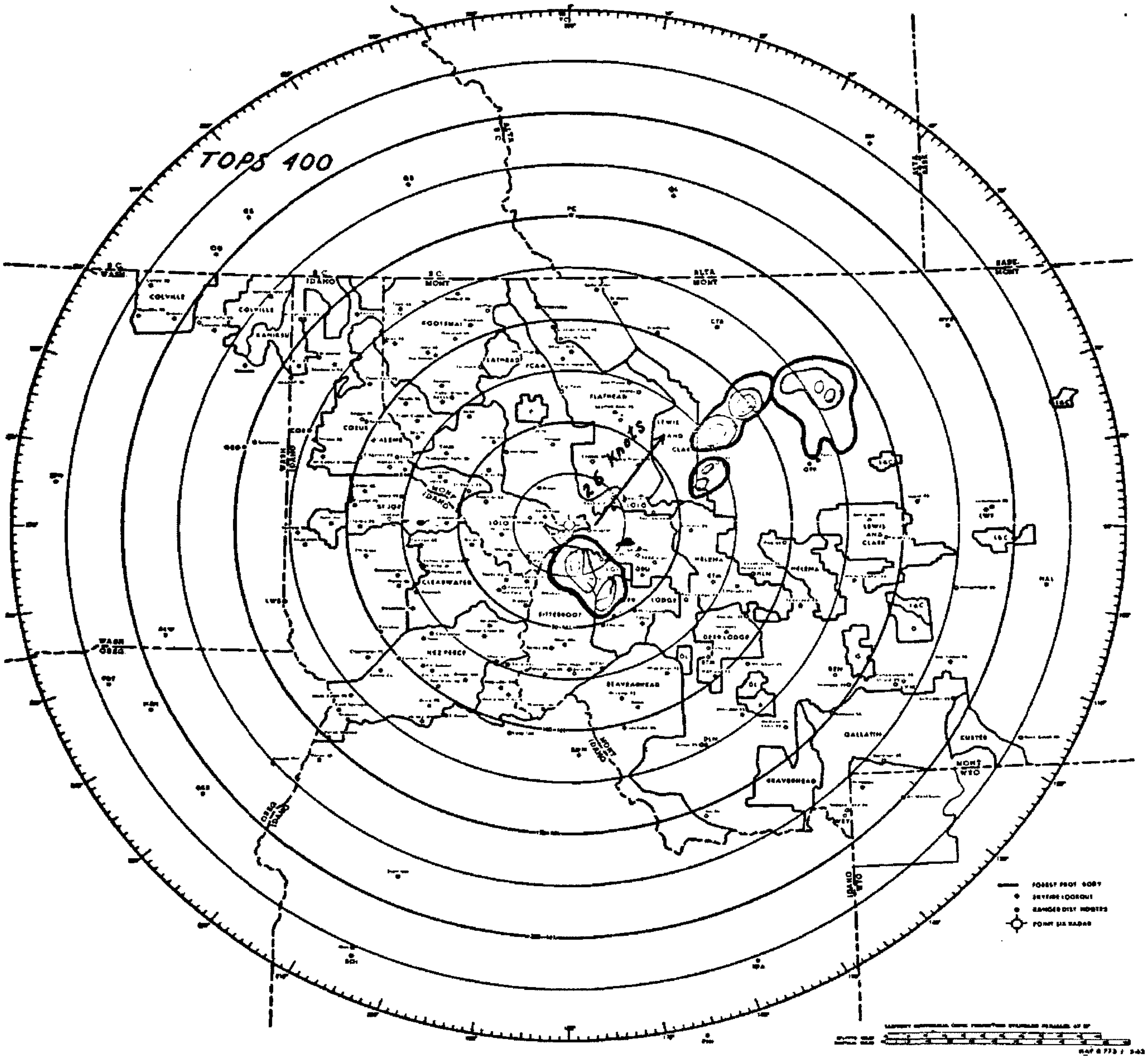
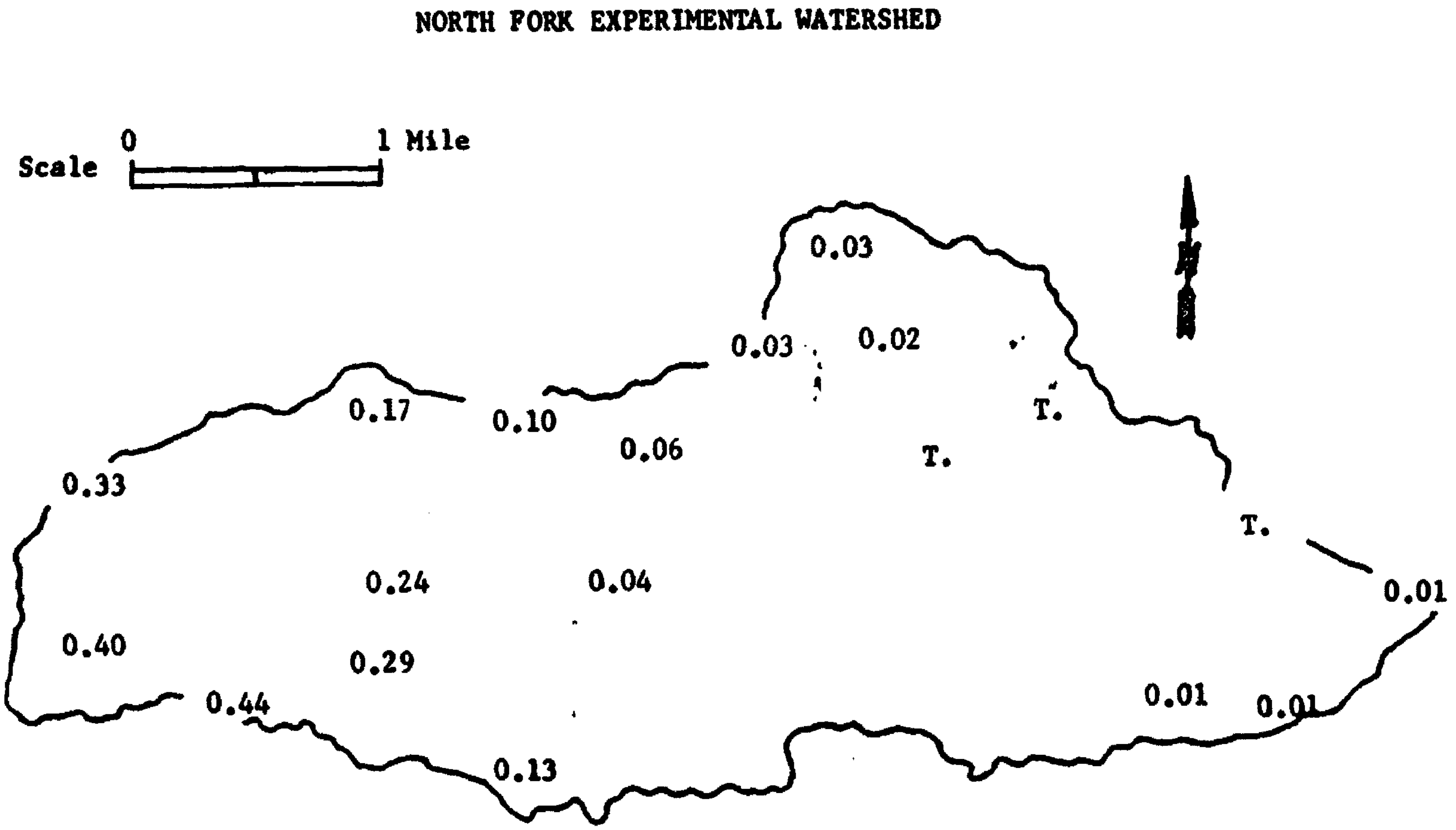


Figure 30. Precipitation was recorded over the watershed between 2100 and 0000. This chart shows a large precipitation area approaching the watershed. The echoes to the northeast have a maximum intensity of 1.45 inches per hour. The precipitation map on the next page shows the actual precipitation received from the storm.



NOTE: Extreme variation in precipitation intensity

Figure 31. Precipitation map - Storm on July 7, 1966

CHAPTER III STREAM HYDROLOGY

STREAM GAGING

A 60-inch Parshall flume (figure 32) with a rated capacity of 72.44 cfs was installed near the drainage outlet, and a 48-inch Parshall flume with a rated capacity of 57.52 cfs was installed just above the first major branch of the North Fork. In August, 1966, a 36-inch Parshall flume with a rated capacity of 28.82 cfs was installed at the mouth of intermediate watershed No. 1. Plate III (insert) shows the locations of the flumes.

Each flume is equipped with a stilling well, atop of which is a Stevens Type F water level recorder (see figure 33). The recorders are operated by 8-day spring wound clocks. Continuous records can be maintained from about April 1st to December 1st. By the beginning of December the stilling wells are generally iced over.

The Parshall flume is sufficiently accurate for gaging irrigation water (Anonymous, 1956, p. 34). Extensive tests show that it is accurate to within two percent regardless of velocity (Thompson Pipe & Steel Company, Denver, Colorado: Catalog B 31-F). However, the manufacturers discharge table for the 60-inch flume does not have computed values for flows of less than 2.22 cfs. This is because the measure of accuracy decreases at extremely low discharges. Generally, from July to March, the discharge at the 60-inch flume is less than 2.00 cfs. Thus, in order to obtain some measure of discharge the following formula, upon

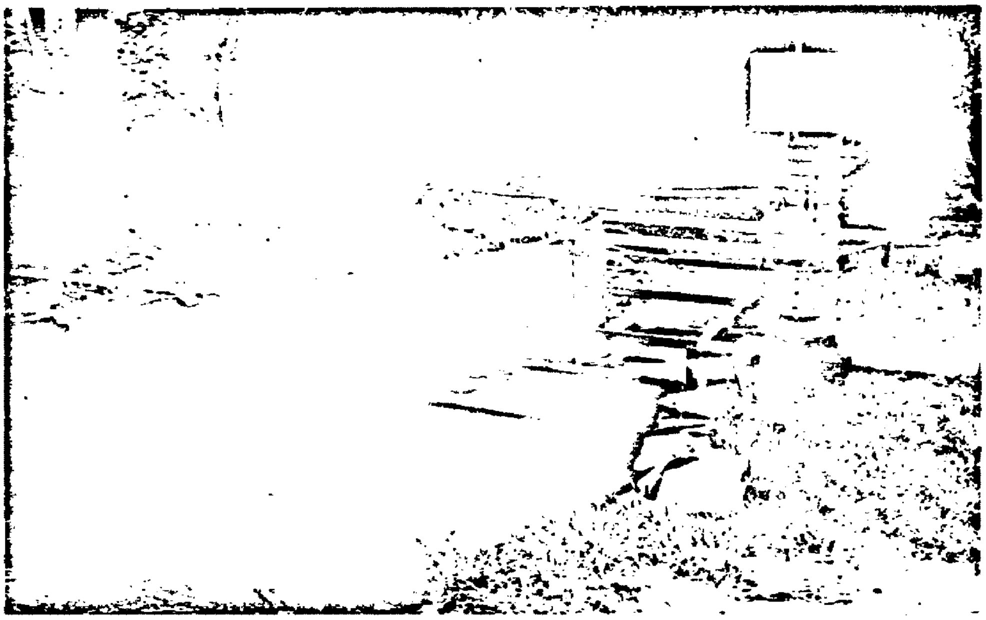


Figure 32. 60-inch Parshall flume, at the lower hydroplot.

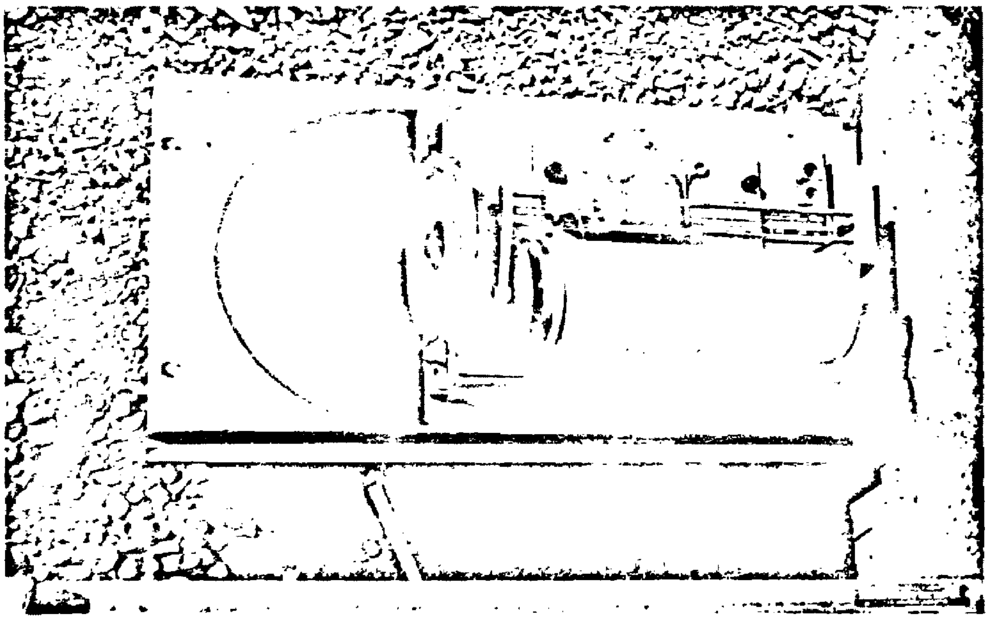


Figure 33. Water level recorder and stilling well on a Parshall flume.

which the rating table was computed, was used to obtain additional values.

$$Q = 4W\,Ha^{1.522W^{0.026}}$$

Q = discharge - cfs
W = throat width - in feet
Ha = head (staff gage) - in feet

It is possible that these low discharge measurements are in error as much as 5 to 10 percent.

STREAM DISCHARGE

A record of stream discharge covering the study period is presented in Table G (Appendix). Visual readings were taken during the winter months when the flume was free of ice. Plate I (insert) shows a hydrograph of the discharge from the 60-inch flume. About 60 percent of the annual flow occurs during April, May, and June. Table 13 shows the percentage distribution of annual discharge. These data are based on the averages from Table G. Due to extended winter conditions the discharge for April, 1967, was only 38 percent of that for the previous April. The peak period of runoff from snowmelt for 1967 did not occur until May 21st. The maximum instantaneous discharge was 28.86 cfs.

The maximum diurnal fluctuation in runoff from snowmelt generally occurs between 2000 and 2400 (see figure 34). Figure 34 also represents the daily hydrographs for two peak periods of runoff from snowmelt.

Table 13 - Total Stream Discharge
60-Inch Parshall Flume

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Acre feet per month	308.19	283.36	89.77	37.23	33.44	58.63	53.91	54.11	54.11	48.87	60.47	122.42
Percent of total	25.6%	23.5%	7.5%	3.1%	2.8%	4.9%	4.5%	4.5%	4.5%	4.1%	5.0%	10.0%

TOTAL FOR YEAR 1,204.51 acre feet

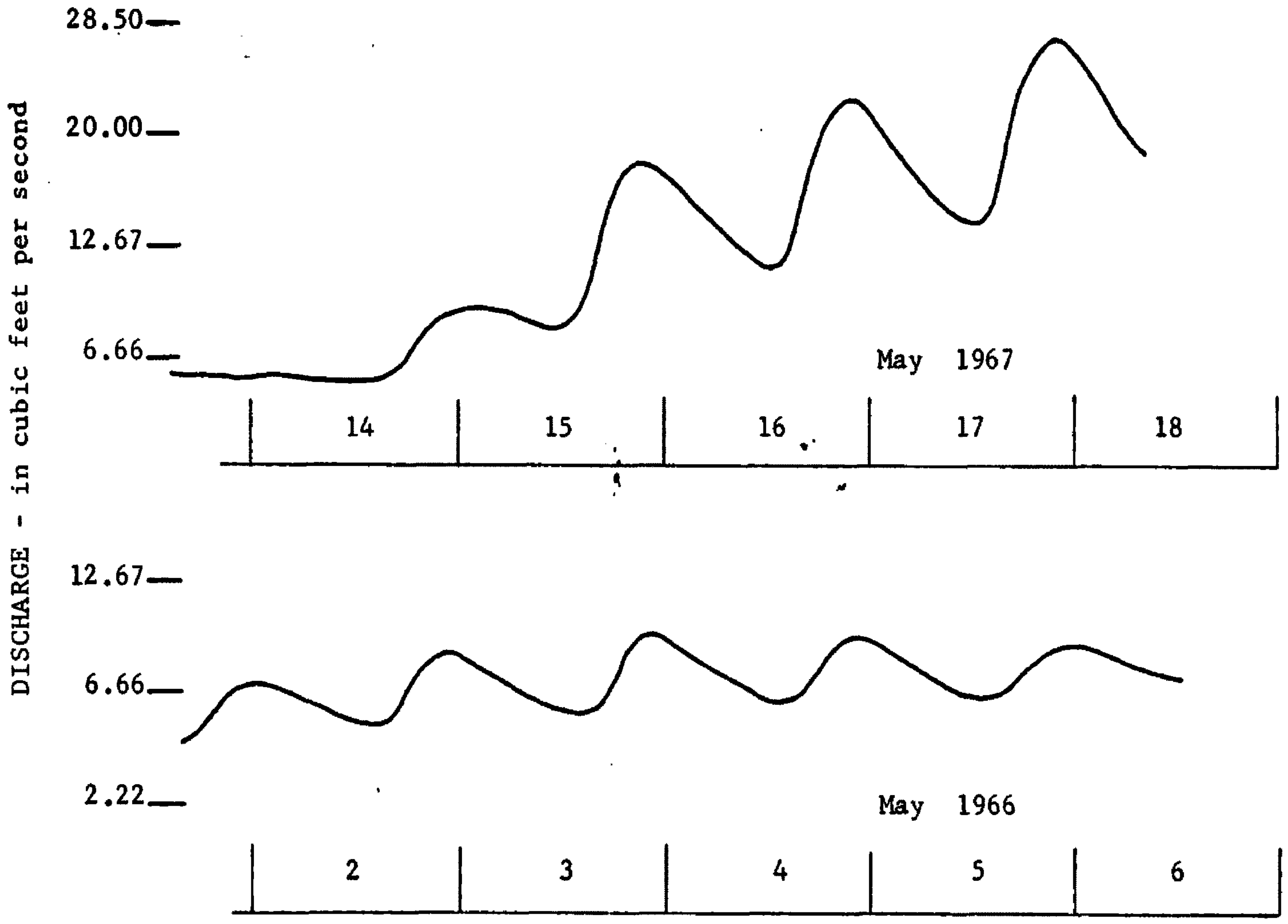


Figure 34. Daily hydrograph of snowmelt runoff.

Plate II (insert) shows the gradient for the North Fork and several perennial branch streams. The gradient of the North Fork from the mouth to the 48-inch flume is 136 feet per mile (determined by leveling). The gradient of the main stream above the 48-inch flume is about 430 feet per mile (determined from a U. S. Geological Survey topographic map). The lowest branch stream (B-B' also shown on Plate III) has its source at a mine shaft which penetrates the contact zone. This stream has a fairly constant discharge of about 0.1 cfs. Numerous springs are found throughout the drainage. The east end of the watershed is the principle area of basin storage. There are numerous swampy areas throughout this part of the drainage, most of which are within the 1960 burn. It has not been determined whether or not these are perched water tables. This part of the drainage provides the base flow for the North Fork.

CHAPTER IV GROUND WATER HYDROLOGY

GROUND WATER PROCEDURE

Well Location and Spacing

A site just inside the mouth of the drainage was selected for constructing a line of wells across the valley bottom. The site was selected primarily because of access with heavy equipment and its nearness to the drainage outlet. Five drilled wells, at fifty-foot intervals, span the drainage at the site. The spacing of the wells and the fact that each penetrates the bedrock, provides a reasonable estimate of the basement profile (see Plate IV, A-A', insert).

Well Construction

The wells were drilled during mid-July, 1966 by the standard cable tool (or percussion) method. Each well is cased with 6-inch Wall Black Steel Water Well Casing. In early October, a sixth well was drilled 257 feet downstream from well number three. The well logs and a brief discussion of each well follows.

Well No. 1

Formations Log:

0 - 4 Black Sandy overburden.
4 - 10 Quartz Monzonite. Water seepage at 9-10 feet.

Casing Log:

Well cased to 7-1/2 feet.

Water Log:

No accumulation of water.

Discussion:

This well is on the south facing slope about 17 feet above the general level of the valley floor.

Well No. 2

Formations Log:

0 - 3	Medium to coarse dark brown sandy material.
3 - 5	Sand and gravel with some clay.
5 - 6	Find sand mixed with red clay.
6 - 7-1/2	Find to medium brown sand. Some clay.
7-1/2 - 8-1/2	Medium to small sand and gravel.
8-1/2 - 9-1/2	Gravel. Some seepage.
9-1/2 - 15	Fine to course sand and gravel mixed in yellow clay.
15 - 16	Medium to course sand.
16 - 17'4"	Quartz Monzonite.

Casing Log:

Well cased from 4" below roadbed to 15' 6" with 6" casing. A forged steel drive shoe is welded to the bottom of the casing. A 5" shop perforated screen is set from 15' 6" to 17' 4". Top of screen is swaged out against the inside of the 6" casing, with a 1' 1" overlap.

Water Log:

Bailer testing indicated a yield of about 1 gpm (gallon per minute).

Well No. 3

Formations Log:

0 - 4	Black top soil.
4 - 5	Fine black silty sand.
5 - 6	Gray and red sand and gravel. Seeps of water.
6 - 7	Gray and red sand and gravel with seams of gray clay.
7 - 8	Brown and yellow sand and gravel.
8 - 10	Brown silty sand.

Formations Log Cont.

10 - 13	Very fine silty brown sand
13 - 14	Fine brown sand.
14 - 15	Coarse sand with some small gravel.
15 - 16	Medium gray cemented sand with seams of clay.
16 - 17½	Medium gray sand with black specks.
17½ - 20	Quartz Monzonite. Fine hard cuttings.
20 - 21½	Quartz Monzonite. Softer crevis. Making water.
21½ - 23	Quartz Monzonite. Soft.
23 - 27	Quartz Monzonite. Soft.
27 - 28	Quartz Monzonite. Soft.
28 - 29	Quartz Monzonite. Softer.
29 - 30	Quartz Monzonite. Harder.

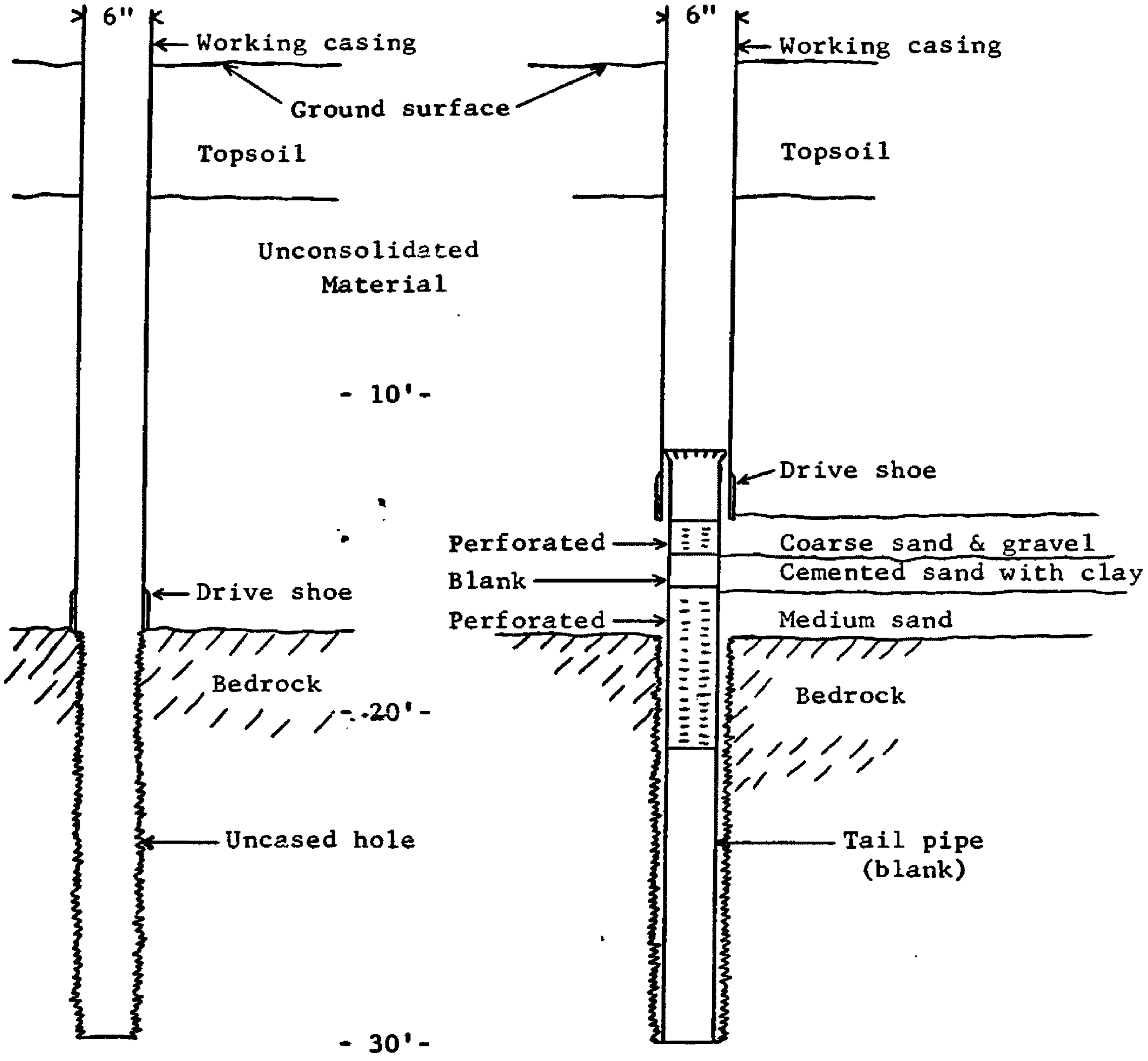
Casing Log:

Well cased from 2' 11" above surface to 14' with 6" casing. A forged steel drive shoe is welded to the bottom of the casing. A 5" shop perforated screen is set from 14' to 30'; slotted section of screen is set from 14' to 15' and from 16' to 21'; the tail pipe of the screen is blank from 21' to 30'. Top of screen is swaged out against the inside of the 6" casing, with a 2' overlap.

NOTE: Refer to figures 35 and 36 for further explanation.

Water Log:

Bailer testing indicated a yield of 2.3 gpm.



Well No. 3 was the first to be constructed. The working casing was driven to bedrock. Drilling continued into the bedrock for assurance of true bedrock and not a large boulder.

A shop perforated screen was welded together as shown in this figure and figure 36. The one-foot blank was put in to prevent silting of the well by the cemented sand with clay.

The screen was lowered into the hole, and after it was in place the 6-inch casing was pulled back to the position indicated.

Figure 35. Diagramatic presentation of the construction of well No. 3.

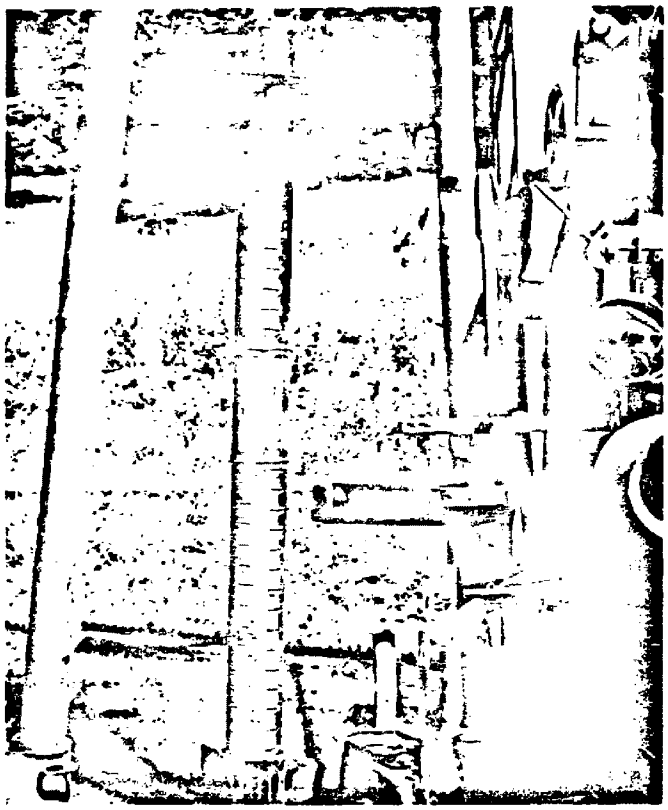


Figure 36. Perforated screen used in Well No. 3.

Well No. 4

Formations Log:

0 - 4	Top soil.
4 - 6	Boulders, gravel and clay.
6 - 8½	Coarse sand. Some clay.
8½ - 10	Medium tan sand with boulders.
10 - 14'2"	Medium to course tan sand and gravel. Water.
14'2" - 16	Quartz Monzonite.

Casing Log:

Well cased from 3' above surface with 6 5/8" casing. A forged steel drive shoe is welded to the bottom of the casing. A 5" shop perforated screen is set from 12' 2" to 16 feet. Top of screen is swaged out against the inside of the 6" casing, with a 2' 2" overlap.

Water Log:

Bailer testing indicated a yield of 1.2 gpm.

Well No. 5

Formations Log:

0 - 3	Sandy top soil. Seepage.
3 - 4	Fine silty sand and clay.
4 - 5	Silty sand. Sand a little coarser.
5 - 6	Medium sand.
6 - 6½	Coarse sand and gravel. Water.
6½ - 7	Quartz Monzonite.
7 - 8	Quartz Monzonite.
8 - 9	Quartz Monzonite.
9 - 11½	Quartz Monzonite.

Casing Log:

Well cased from 2' 2" above surface to 11-1/2' with 6" casing. A forged steel drive shoe is welded to the bottom of the casing. The bottom 1-1/2' of 6" casing is perforated.

Water Log:

Bailer testing indicated a yield of about 1 gpm.

Well No. 6

Formations Log:

0 - 6	Old railroad bed fill material.
6 - 8	Top soil.
8 - 12	Granitic sand and gravel.
12 - 15	Clean gravel and sand.
15 - 16	Decomposed granitic sand and gravel.
16 - 19	Clean granitic sand.
19 - 20½	Unweathered Quartz Monzonite.

Casing Log:

Well cased from ground level to 9' with 6" casing. A forged steel drive shoe is welded to the bottom of the casing. A 5" shop perforated screen is set from 9' to 20' 6". Top of screen is swaged out against the inside of the 6" casing, with a 2' overlap.

Water Log:

Bailer testing indicated a yield of 3 gpm.

Well Development

Each well was developed by surging with a bailer. That is, an up-and-down motion of the bailer. As the bailer rises, it draws water from the aquifer into the well, while lowering forces water back into the aquifer. During this procedure the well was periodically bailed dry to remove the inflow of sand, silt, and clay. The surging was continued until there was no appreciable amount of fine material entering the well.

Well Recorders

Wells 3 and 4 are equipped with Stevens Type F water level recorders for monitoring ground water fluctuations. The installation of these recorders is similar to those on the flumes, with two exceptions. A four inch float is used inside the well casing, and a guide pulley was necessary for positioning the float pulley counterweight. The chart speed and scale is identical to the instruments on the flumes.

Normal Pumping Test Procedure

Prior to the start of a pumping test the static water level is checked two or three times. The timing of the test starts when discharge begins. During the early part of the test, drawdown is measured at frequent intervals. The time interval of measurement becomes larger as the test progresses. Thus, after pumping for an hour or more, the interval may be as much as two hours. Water depths are generally measured by a chalked tape or an electric sounding wire (or probe).

Determining Well Yield by Pumping Tests

Initially, an attempt was made to use a small gasoline-powered pump. The tests were unsuccessful because of uncontrollable pumping rates. The wells are of very low yield and thus were pumped dry in a matter of minutes.

Successful tests were achieved by using a 3/4 horsepower electric water pump powered by a portable generator (figure 37). At first the rate of discharge was determined by recording the time required to fill a 17-gallon barrel. Maintaining uniform discharge was found to be difficult, especially during the early stages of the test. The time lapse between refillings, generally 12 to 14 minutes, was such that it did not permit immediate compensation of variations in discharge. Uniform pumping rates were eventually achieved by almost continuously timing the refilling of a one-gallon container. By using this method, any variation in discharge could be corrected almost instantaneously.

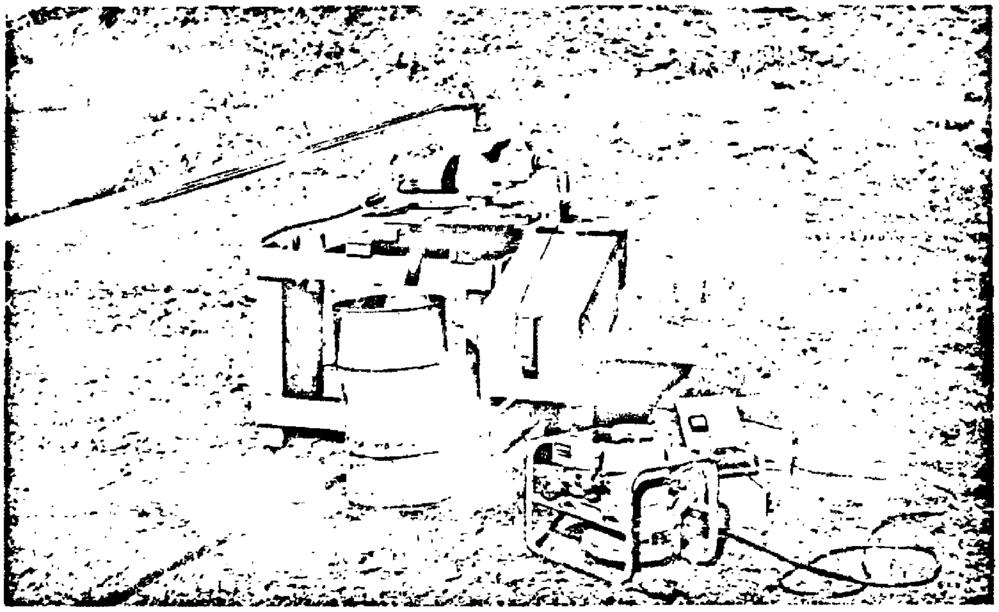


Figure 37. Pumping test.

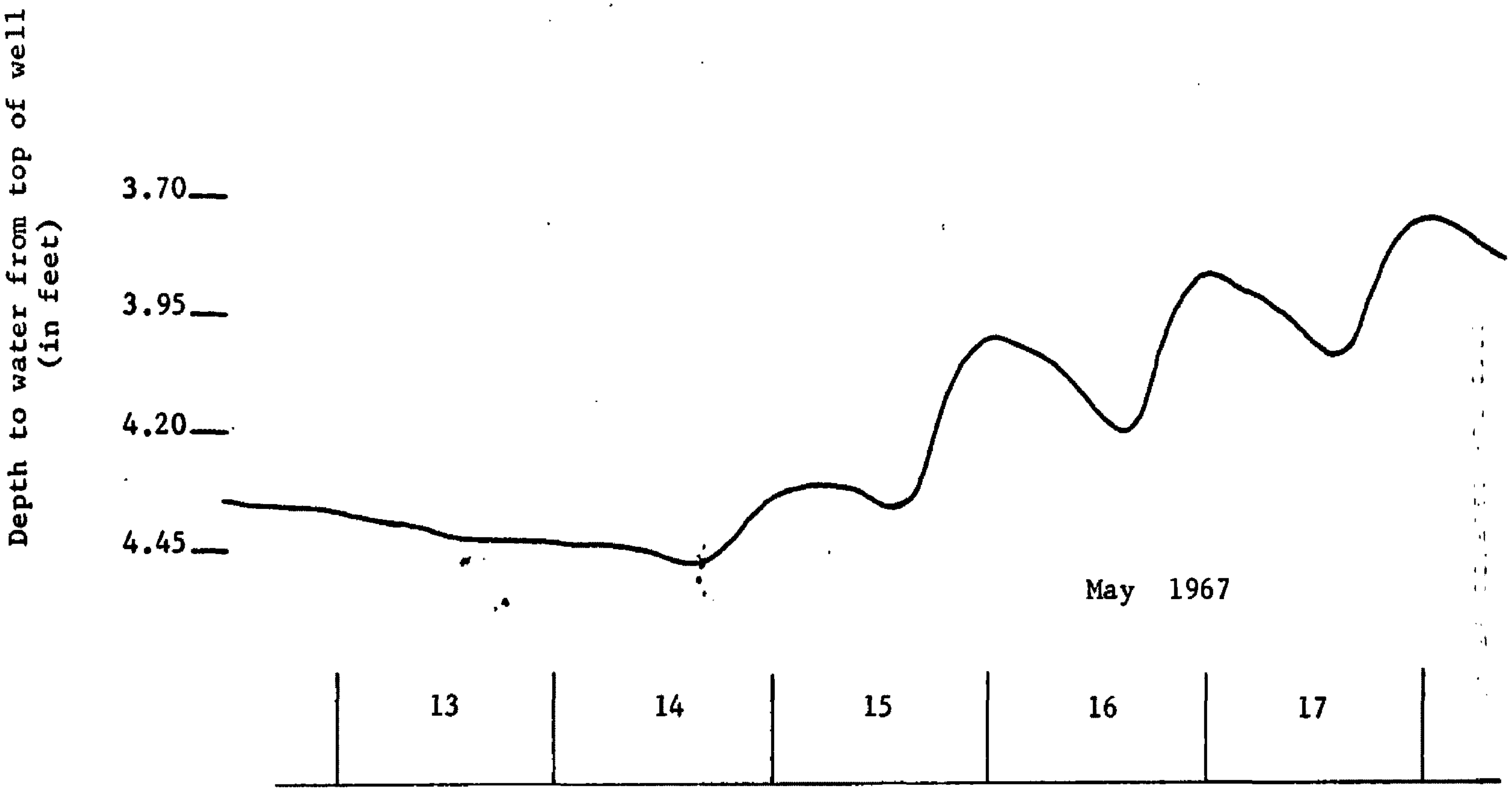
GROUND WATER INTERPRETATION

Well Hydraulics

Wells 3 and 4 were the only wells with enough yield to conduct adequate pumping tests. When pumping well 3, the drawdown in well 4 was recorded, and vice versa.

It is assumed that the wells penetrate an unconfined aquifer, although it is possible that the aquifer is partly confined due to variations in the strata (see well logs). Bank storage peaks (figure 38) succeed those of streamflow by 3 to 4 hours. This indicates a low infiltration rate to the ground water body. Diurnal fluctuations in wells 3 and 4 correspond to fluctuations in streamflow. Figure 38 shows a daily hydrograph during the spring runoff period. Table 14 shows the mean daily fluctuations of wells 3 and 4, and Plate I (insert) shows a hydrograph of the well fluctuations.

In the summer of 1965, six 2-inch pipe wells were located along the same line as the present wells. The average depth of these wells was 3 to 4 feet. During that summer it was noted that an asymmetrical influent-effluent condition existed. That is, the south side of the stream is receiving ground water discharge (effluent stream), while the north side of the stream (influent stream) is recharging the ground water aquifer. This condition also prevails with the present wells (see Plate IV, insert). It is also possible that a piezometric surface exists because of an associated aquiclude.



NOTE: The diurnal bank storage peaks succeed the streamflow peaks by 3 to 4 hours.

The mean daily fluctuations of wells 3 and 4 (Table 14) are represented in the form of a hydrograph on Plate I (insert).

Figure 38. Hydrograph of well No. 3.

TABLE 14 MEAN DAILY WATER LEVEL FLUCTUATION - WELL 3 AND 4
(in feet)

DATE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.
1		-.01	-.05	+.02	-.03	+.04	.00	-.01	+.01	+.01
2		-.01	-.04	+.15	-.03	-.02	-.01	-.01	+.01	+.03
3		.00	-.03	.00	.00	-.01	.00	.00	+.02	+.08
4		+.01	-.02	-.04	+.04	-.02	+.01	+.01	+.04	+.12
5		+.02	-.01	-.02	-.03	.00	+.01	+.01	-.04	+.05
6		-.02	-.02	-.02	+.01	-.01	-.01	-.01	-.01	+.06
7		-.01	-.01	-.03	+.02	-.01	.00	+.02	.00	+.05
8		.00	.00	-.01	-.03	-.02	.00	+.02	.00	+.06
9		.00	+.02	-.01	-.03	-.01	+.01	.00	.00	+.04
10		-.04	+.02	+.01	+.01	-.01	-.01	-.01	+.01	.00
11		+.02	.00	.00	+.03	+.01	+.01	-.01	-.01	+.07
12		-.06	+.01	+.02	-.04	+.01	+.01	.00	-.01	+.05
13		+.02	.00	+.02	.00	+.01	-.01	+.06	.00	-.01
14		+.01	.00	.00	+.01	-.01	.00	+.02	-.01	-.03
15		+.01	+.01	.00	+.02	+.01	+.10	-.02	-.01	-.04
16		-.02	-.01	-.01	+.05	.00	+.11	-.04	-.01	-.04
17		-.02	.00	-.02	+.01	-.01	-.08	-.01	+.01	-.02
18		-.02	-.01	+.01	-.01	-.01	-.04	-.02	+.03	+.03
19		-.04	+.02	+.01	+.03	+.01	-.02	-.01	.00	-.06
20		+.04	+.03	+.01	-.07	+.01	+.01	.00	+.01	-.07
21		+.03	-.02	+.01	.00	.00	-.01	.00	+.01	-.02
22		-.02	-.02	+.01	-.01	+.06	-.02	-.01	+.02	.00
23		-.03	-.01	+.06	-.01	-.03	+.02	+.01	+.06	+.05
24		-.01	-.01	+.06	-.01	-.08	-.03	-.01	+.07	+.05
25		-.02	+.02	-.02	+.01	-.03	-.01	.00	+.01	+.02
26		+.01	+.06	-.04	+.03	-.01	.00	-.01	-.01	-.02
27		+.15	.00	+.05	-.01	-.01	.00	+.01	+.01	.00
28		+.02	-.02	-.05	-.03	.00	+.01	+.01	+.03	+.04
29	0.00	-.04	-.02	-.03	-.02	+.02	+.02		+.04	-.02
30	-.02	+.13	+.01	+.03	+.01	+.02	-.02		-.01	-.06
31	-.02	-.06		-.02		.00	-.01		+.05	

Another significant hydraulic condition exists between wells 3 and 4. Observations show that four minutes after pumping commences on either well, the other well begins to drawdown. A probable explanation is, the permeability of the surface layers are low, but a good hydraulic connection exists in the lower strata (see figure 39).

Analysis of the Pumping Tests

By definition, as based upon the pumping tests, the permeability of the aquifer is about 8 gal/day/foot.

The average specific capacity of wells 3 and 4 was 0.06 gpm per foot of drawdown at the time of measurement.

Water-table fluctuations are not considered in the following analysis because of irregularities caused by local differences in the permeability of the water bearing material, and seasonal differences in discharge or recharge of the aquifer. In addition, no estimate of storage is available at this time.

The formation constant T (coefficient of transmissibility) was determined by the Theis nonequilibrium formula:

$$T = \frac{114.6\ Q}{ho-h} W(u)$$

Q = well discharge in gal/min.
$W(u)$ = exponential integral termed a "well function".
$ho-h$ = drawdown in feet

Theis devised a convenient graphical method of superposition (figure 40) that makes it possible to obtain a simple solution of the equation.

The procedure for this solution of the equation can be found in Todd (1959, p. 90-93).

> The nonequilibrium formula is based on the following assumptions: (a) the aquifer is homogeneous and isotropic; (b) the aquifer has infinite areal extent; (c) the discharge or recharge well penetrates and receives water from the entire thickness of the aquifer; (d) the well has an infinitesimal (reasonably small) diameter; and (e) water removed from storage is discharged instantaneously with decline in head (Todd, 1959, p. 90).

Despite the restrictive assumptions on which the nonequilibrium formula is based, it has been applied successfully to many problems of ground water flow.

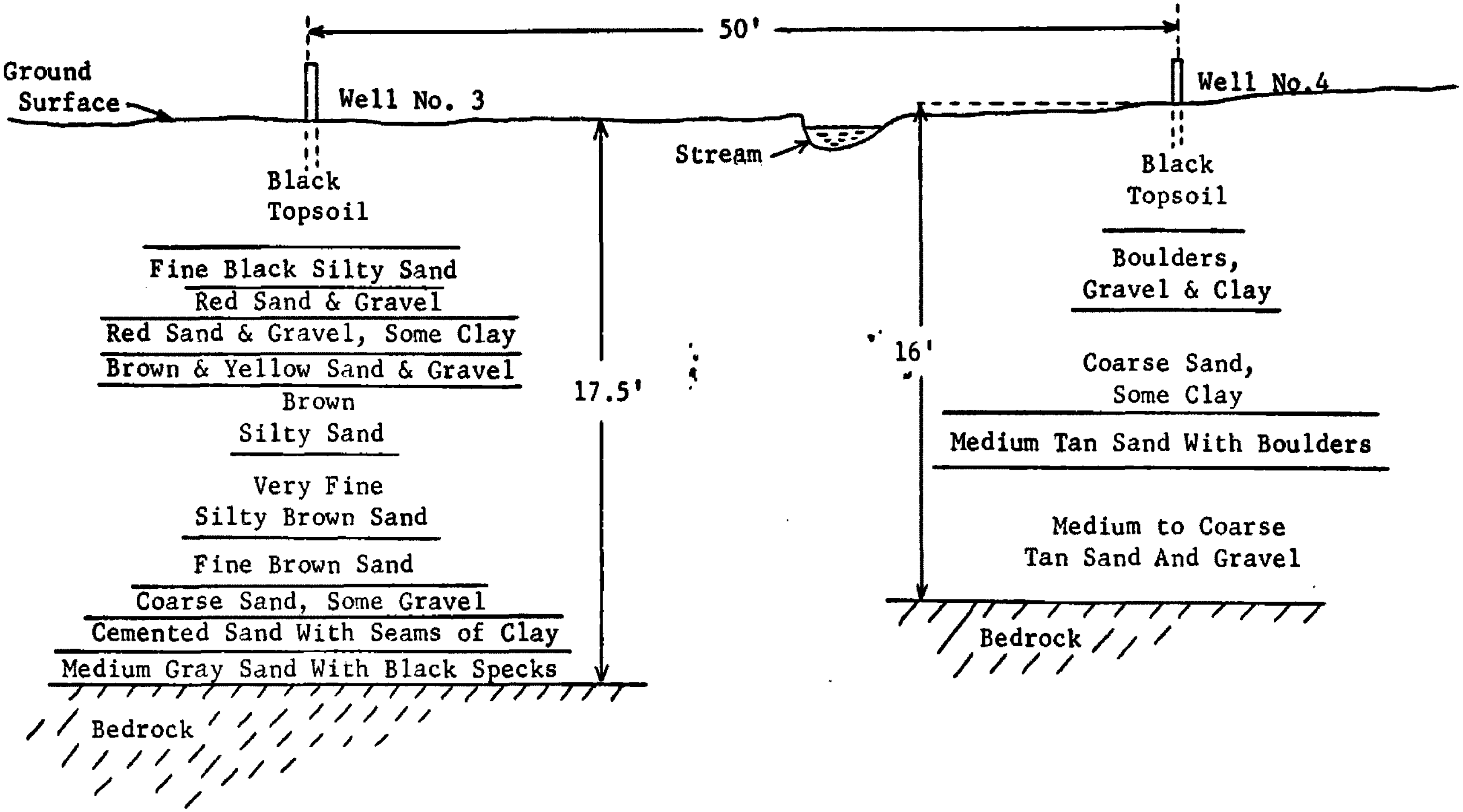


Figure 39. Formations log - Display of wells 3 and 4.

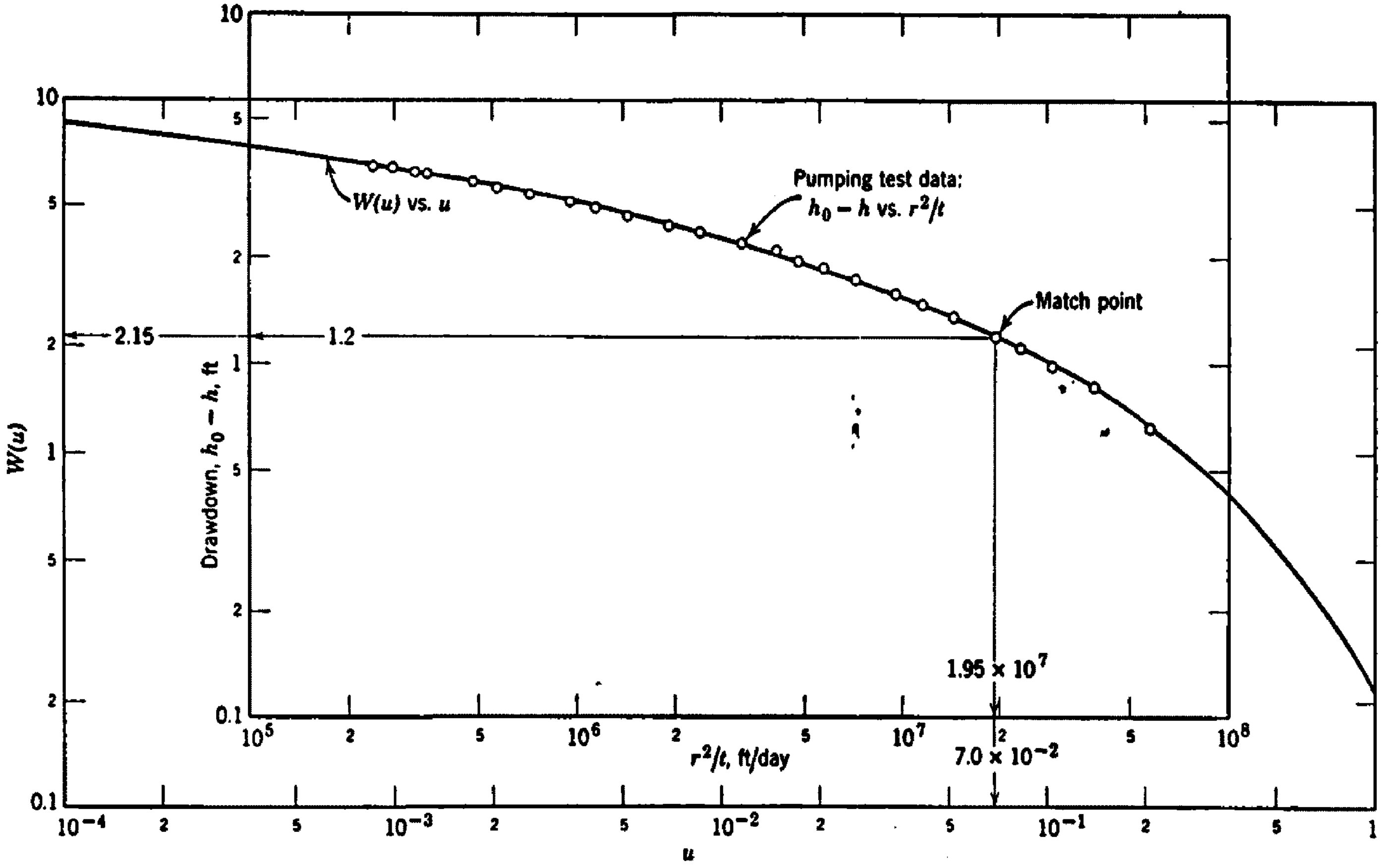


Figure 40. Theis method of superposition for the solution of the nonequilibrium equation (Todd, 1959, p. 93).

Brief discussion of procedure: The drawdown values ho-h are plotted against values of r^2/t (where r = distance in feet from discharging well to observation well; t = time in days since pumping began) on logarithmic paper of the same size as for the "type curve"; W (u) versus u (where $u = 1.87\ r^2S/Tt$). The observed data curve is superimposed on the type curve as shown. An arbitrary point (match point) is selected on the coincident segment, and the coordinates of this matching point are recorded.

The drawdown data analyzed were taken from wells 3 and 4. The recorded drawdown (as shown in figure 41) was photographed and enlarged so that small time intervals could be defined.

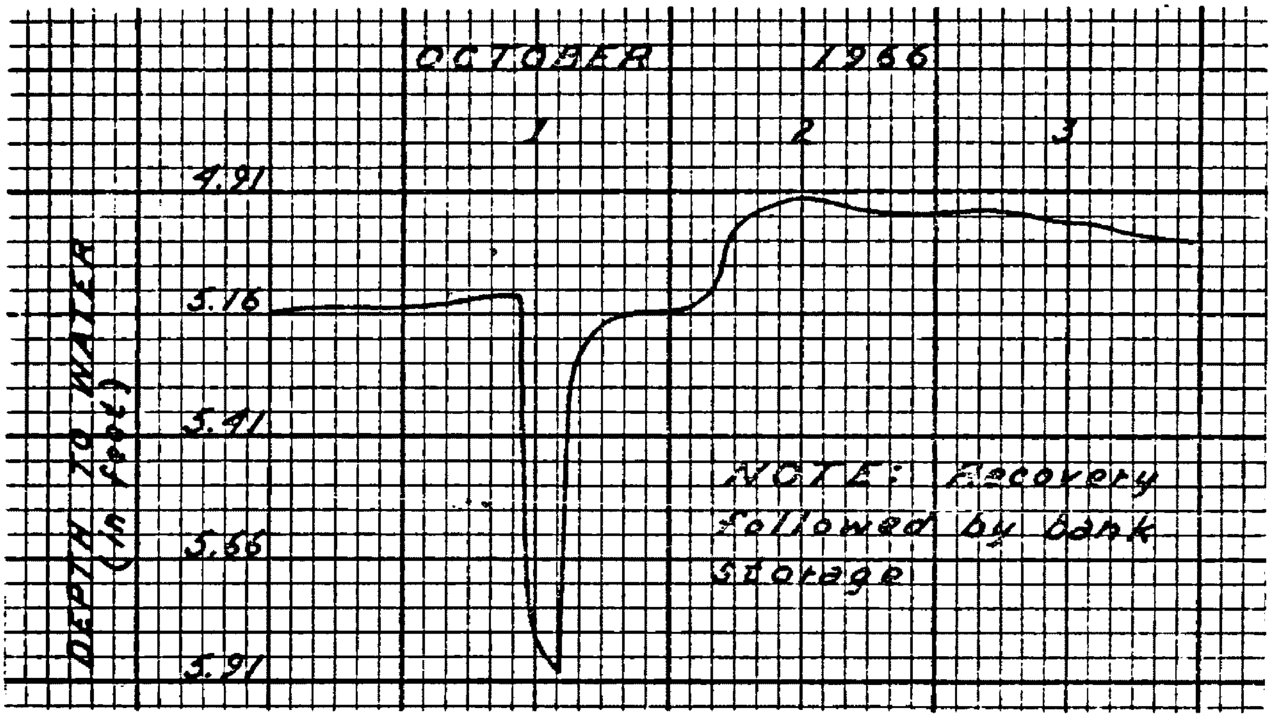


Figure 41. Recorded drawdown, well 3 during pumping test on well 4.

The pumping tests were from 180 to 315 minutes in length. Table 15 and figure 42 show the data and the plot of drawdown for a pumping test.

TABLE 15 - PUMPING TEST DATA - OBSERVATION WELL NO. 3

October 15, 1966

Q = 0.61 gal/min. r = 50 feet

Time Since Pumping Began, t Minutes	Days	r^2/t Feet^2/Day	Depth to Water From Reference Point	Drawdown in Observation well, ho-h Feet
0			5.07	0.00
5	3.48×10^{-3}	7.19×10^{5}	5.12	0.05
7	4.86×10^{-3}	5.15×10^{5}	5.17	0.10
10	6.95×10^{-3}	3.60×10^{5}	5.22	0.15
12	8.34×10^{-3}	3.00×10^{5}	5.27	0.20
15	1.04×10^{-2}	2.40×10^{5}	5.32	0.25
17	1.18×10^{-2}	2.12×10^{5}	5.37	0.30
20	1.39×10^{-2}	1.80×10^{5}	5.42	0.35
22	1.53×10^{-2}	1.63×10^{5}	5.47	0.40
25	1.74×10^{-2}	1.44×10^{5}	5.52	0.45
28	1.95×10^{-2}	1.28×10^{5}	5.57	0.50
32	2.22×10^{-2}	1.13×10^{5}	5.62	0.55
36	2.50×10^{-2}	1.00×10^{5}	5.67	0.60
40	2.78×10^{-2}	9.00×10^{4}	5.72	0.65
50	3.48×10^{-2}	7.18×10^{4}	5.77	0.70
60	4.17×10^{-2}	6.00×10^{4}	5.82	0.75
87	6.05×10^{-2}	4.13×10^{4}	5.87	0.80
180	1.25×10^{-1}	3.12×10^{4}	5.92	0.85

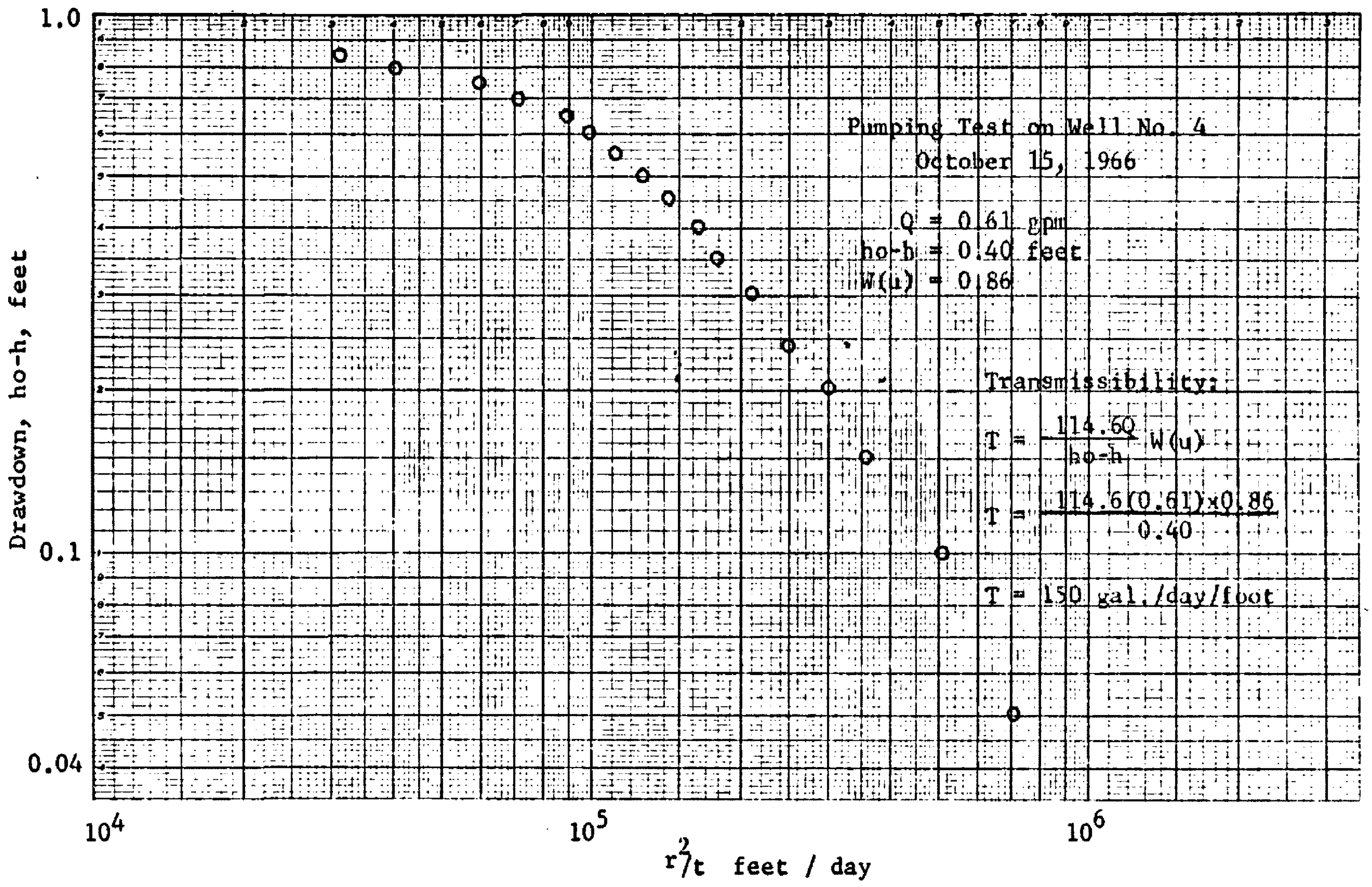


Figure 42. Drawdown curve - Observation well No. 3 (by recorder).

The results of averaging the data from three pumping tests, drawdown and recovery, indicate an average transmissibility of 130 gal/day/foot for wells 3 and 4.

The rate of ground water flow from the drainage was determined from the equation $Q = TIL$, used by (McMurtrey, et. al., 1965, p. 26).

T = transmissibility in gal/day/foot
I = slope of ground water table in feet/mile
L = length of section in miles

Substituting the following values:

T = 130 gal/day/foot
I = 80 feet/mile (determined from check wells above and below section A-A')
L = 100 feet or 0.019 miles (includes a 25 foot section on either side of the wells)

The rate of flow is:

$$Q = TIL = 130 \times 80 \times .019 = 198 \text{ gpd}$$

which is equivalent to 26.5 cubic feet/day

Because of sample error the above value may be more or less than the true coefficient of transmissibility. It is difficult to control and measure all the variables in field tests. Therefore, field conditions may only approximate those assumptions on which the formulas are based.

Expressing the rate of flow on an annual basis:

$$Q = 26.5 \text{ cf/d} \times 365 \text{ days} = 9672 \text{ cf/year}$$

or about

1/4 acre foot per year

The results of the above procedures indicate a minimal discharge or underflow from the watershed.

CHAPTER V GEOPHYSICS

INTRODUCTION

In October, 1966, Mr. S. Hughes, U.S.F.S. Geologist from the Missoula office, ran a twelve trace continuous recording seismic refraction traverse across the mouth of the drainage. This site was chosen because of the presence of numerous bedrock control points. The seismic refraction theory is based on the fact that shock waves, or more technically, seismic shock waves, will travel faster through hard-dense material than through soft or unconsolidated materials (Thompson, 1965). Shock waves initiated at the surface are refracted back to the surface by each succeeding layer of material. A sensing device called a geophone is placed at the surface, and picks up the refracted shock waves. The results of the test are shown in figure 43.

DISCUSSION

The seismic profile does not coincide very well in the center of the valley with the assumed bedrock profile determined by the drilling logs. This could be due to numerous factors, some of which are:

1. Only one traverse was run.
2. The equipment was new and possibly not in perfect adjustment.
3. The method still needs refinement.
4. Construction caps and powder were used in lieu of seismic caps and powder, for initiating the shock energy.
5. The geophone or pick-up bases were for rock and not unconsolidated material.

a. Tripod base - Rock

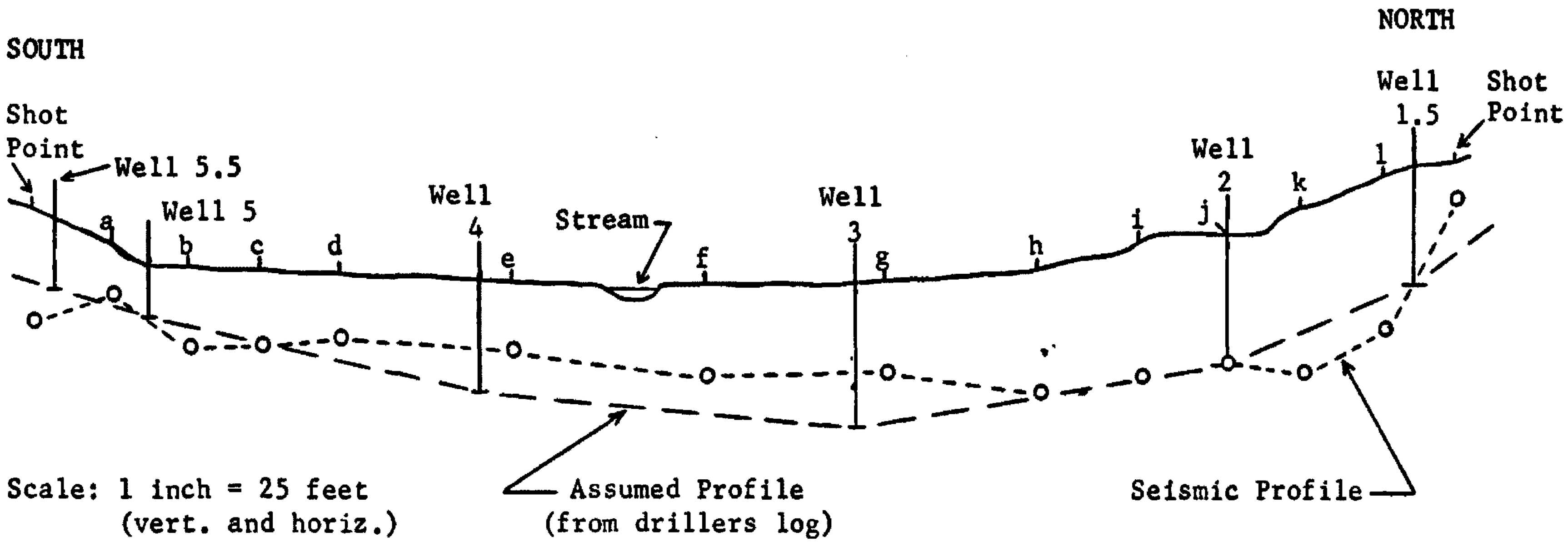
b. Spike base - Unconsolidated material

One part of the problem may be that three breaks in velocity occurred on the right side of the traverse and two on the left side. The three breaks would indicate three layers, the overburden, the weathered zone, and the dense bedrock; while the two velocities indicated overburden and bedrock.

Another possible explanation for the variation in the middle of the profile is a bench in the bedrock east of the line of wells. Seismic shock waves will be refracted from the closest contact.

Both ends of the seismic profile tie in reasonably well with the depths recorded from drilling. The depression on the right side of the seismic profile could be due to an ancient erosion channel.

Well 5.5 is merely a 3/4" pipe which is supposedly down to bedrock. This well and 1.5 were put in in order to determine the depth to bedrock. In the process of locating well 5.5, numerous boulders were encountered below the surface, between well 5 and the present location of 5.5. This then, would account for the high point between wells 5 and 5.5. Well 5.5 could also be on a boulder and not true bedrock. Also, the results of pumping tests for well 5 are not very satisfactory. The assumption being, some subsurface barrier.



<u>Depth to bedrock at wells</u>

No. 1.5 - - - 15.0 feet
2 - - - 16.0 "
3 - - - 17.5 "
4 - - - 14.0 "
5 - - - 6.5 "
5.5 - - - 9.0 "

NOTE: The letters a to l indicate the geophone or pick-up locations.

Figure 43. Bedrock profiles

RECOMMENDATIONS

Geophysical instruments show considerable promise for subsurface investigation and exploration. One prime requisite for the use of such instruments is experienced personnel for operational and interpretational procedures.

Rerunning the traverse several times would most likely yield more satisfactory results. Another possibility may be to shorten the length of spread. In such case, a double traverse would be required to span the same distance. It would also be desirable to run a traverse along the axis of the drainage.

Another instrument which could be used to determine the bedrock profile is an electrical earth resistivity meter. This method of measurement depends upon the electrolytic properties of the subsurface materials, that is, the resistivity to electrical current.

SUMMARY AND CONCLUSION

Isolation of certain components of the hydrologic budget is oftentimes difficult. The hydrologic budget of a given watershed reflects a balance between recharge, storage, and discharge. This balance is expressed by the following equation.

Surface inflow + Subsurface inflow + Precipitation + Imported water + Decrease in surface-water storage potential + Decrease in ground-water storage potential

= Surface outflow + Subsurface outflow + Consumptive use + Exported water + Increase in surface-water storage potential + Increase in ground-water storage potential

In theory the above equation must balance, but in practice it rarely does.

It is assumed that the North Fork Experimental Watershed is a closed basin. However, it is possible that some subsurface leakage from Cap Wallace Gulch does occur. Several of the north side tributary streams originate in springs along the Cap Wallace ridge. But because of their relatively small size, subsurface inflow is eliminated from the left side of the above equation. There is no surface inflow, imported water, or exported water, and these factors are also eliminated. Similarly, because of (1) the relatively small amount of Quaternary alluvium in the basin; (2) minor fluctuations of storage as indicated by a long period of minimal streamflow (see hydrograph Plate I, insert); and (3) the abrupt change in profile of the recessional limb of the streamflow hydrograph; fluctuations of surface and ground water are also disregarded.

Substitution of the study data into the revised equation, based on acre-feet per year, gives the following relationships.

Precipitation (excluding interception)	=	Surface outflow	+	Subsurface outflow	+	Consumptive use
8,143.90		1,204.51		0.25		6,939.14

On the basis of the above equation, total consumptive use (principally evapotranspiration) in the North Fork Experimental Watershed is estimated to be about 85 percent of the total annual recharge. A more detailed breakdown of the consumptive uses lies beyond the scope of this study.

Figure 44 is a graphical presentation of the previous equation.

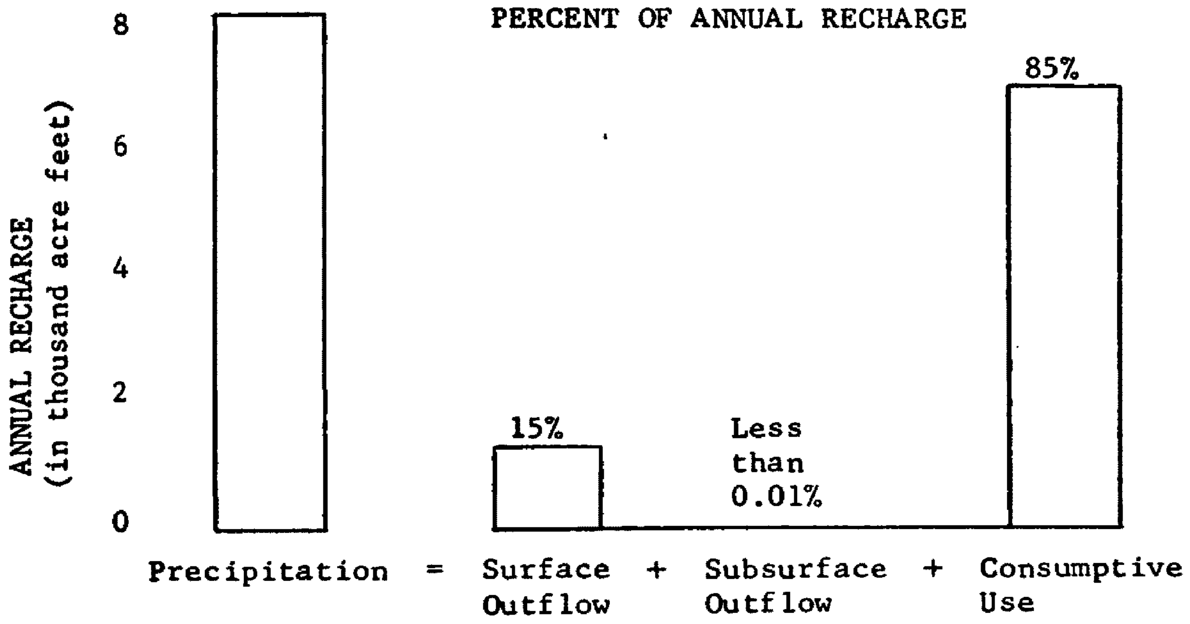


Figure 44. A Graphical Presentation of the Hydrologic Budget

RECOMMENDATIONS

The data collection should continue for another four years in order to establish a hydrologic base for subsequent correlations. A five year calibration period is somewhat of a standard for most small watershed studies. Following the calibration period, various land uses and vegetative manipulations can be assessed experimentally.

Elevated rain gage stands should be provided for winter sampling, especially at the higher elevations where snow depth exceeds five feet. Wind associated with precipitation causes inaccurate rain gage catches. Therefore, it would be desirable to use Alter shields for the permanent gages. Four months of data were rejected at one station because of a low gage catch, resulting from wind.

The major recommendation relative to stream hydrology is to relocate the 60-inch flume at the site of the wells. Permission should be sought from the landowner before relocation. If the flume was located at this site, it would provide useful information concerning stream fluctuations and bank storage relations. A second recommendation is that of installing another flume or weir on intermediate watershed No. 2 (see Plate III). During low periods of flow, the discharge from watershed No. 2 is 0.1 cfs or less. Thus, a flume or weir with a rated capacity of 3 to 5 cfs would suffice.

A stream gaging device at the site of the wells would be extremely helpful in detecting stream influence of the aquifer during pumping tests.

Further investigation of the hydraulic characteristics is necessary before an accurate estimate of underflow can be made. The prime requisite for future pumping tests is an accurate device for measuring the discharge, preferably a flowmeter.

ACKNOWLEDGEMENTS

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The author is also grateful to several graduate and undergraduate students who assisted with the data collection, and all other individuals who contrubuted in any way to the study.

Last, but not least, is my wife. Indeed, she deserves the highest degree of gratitude for her patience and understanding; for her numerous hours of typing; and her acceptance of my limited hours of homelife.

APPENDIX

TABLE A - A COMPARISON OF THE RECORDING AND STANDARD RAIN GAGE MEASUREMENTS AT THE THREE HYDROPLOTS

DATE	LOWER HYDROPLOT			MIDDLE HYDROPLOT			UPPER HYDROPLOT		
	Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.
May 9-10			.14	2100-0200	.20	.16			
10				1600-0000	.20				
11				0000-1200	.25				
12-13				2100-0400	.13				
13									
14				1200-1500	.10				
15									
16									
17			.71		.68	--- .75			
18									
19									
20									
21				1800	.05		1900-2000	.08	
22				1600-1800	.04				
23									
24									
25									
26									
27				1600-1800	.10		1600	.03	
28					.19	--- .21		.11	--- .14
28			.43	1300-0000	.20		1500-1800	.24	
29-30				1800-1200	.13		1500-0000	.10	
30							1200	.03	
31				1900-0000	.45		1800-0000	.59	

Cont.

DATE		LOWER HYDROPLOT			MIDDLE HYDROPLOT			UPPER HYDROPLOT		
		Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.
June	1				0000-0000	.18				
	2				1300-1800	.42		1400-1900	.38	
	3				1100-1600	.70		1200-2000	.72	
	4							0000-0600	.05	
	4			2.04		2.08 ---	2.15		2.11 ---	2.20
	5									
	6									
	7				1500-0000	.25		1300-0000	.38	
	8				0000-0200	.17				
	9				1200-0000	.67		0800-2200	.83	
	10				0000-0000	.12		1200-0000	.24	
	11				0000-1800	.23		0000	.06	
	11			2.08		1.44 ---	1.54		1.51 ---	1.61
	12				0600	.04		0400-0600	.08	
	13									
	14									
	15									
	16									
	17									
	18			.07		.04 ---	.06		.08 ---	.11
	19				1800-0000	.10		1600-0000	.45	
	20				0000-1200	.40		0000-0200	.10	
	21				1600-2100	.10		1200-1700	.21	
	22									
	23				1200-1500	.04		0900-1500	.30	
	24				0300-0700	.30		0000-1800	.40	
	25							1300	.02	
	26			1.07		.94 ---	1.04		1.48 ---	1.66
	27									
	28									
	29	0500	.05		0600	.04		0200	.03	
	30	0530	.07		0300-0700	.05		0000-0300	.06	

Cont.

DATE		LOWER HYDROPLOT			MIDDLE HYDROPLOT			UPPER HYDROPLOT		
		Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.
July	1		$\overline{.12}$ ---	.11		$\overline{.09}$ ---	.08		$\overline{.09}$ ---	.08
	1	1400	.15		1400-1500	.05		1400-1500	.05	
	2	1230-0000	.17		1100-0000	.30		1200-0000	.38	
	3	0000-0030	.03		0000-0100	.05				
	4									
	5		$\overline{.35}$ ---	.37		$\overline{.40}$ ---	.40		$\overline{.38}$ ---	.44
	6									
	7	2130-2200	.40		2100-0000	.04				
	8									
	9		$\overline{.40}$ ---	.40		$\overline{.04}$ ---	.04		$\overline{}$	T
	10									
	11									
	12	Pen Knocked Off			1500-1800	.15		1200	.11	
	13	1630-1900	.10		2000-2200	.04		1400-1600	.06	
	14	1900	.03		1600	.07		1000-1200	.05	
	15									
	16									
	17		$\overline{.13}$ ---	.13		$\overline{.26}$ ---	.27		$\overline{.22}$ ---	.25
	18									
	19	Recording gage discontinued because of clock failure. →								
	20									
	21									
	22									
	23									
	24									
	25									
	26									
	27									
	28									
	29									
	30									
	31									

Cont.

DATE		LOWER HYDROPLOT			MIDDLE HYDROPLOT			UPPER HYDROPLOT		
		Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.
Aug.	1									
	2									
	3									
	4	1600	.06		1600-2000	.05				
	5		.06 ---	.06		.05 ---	.02			.01
	6									
	7									
	8	Trace								
	9									
	10									
	11									
	12									
	13	2200	.04		2000	.05				
	14									
	15		.04 ---	.03		.05 ---	.05			.17
	15	1500	.04							
	16									
	17									
	18									
	19	1600	.05		1500	.10				
	20	0800	.02		0600-2000	.05				
	21									
	22									
	23		.11 ---	.07		.15 ---	.16			.11
	24									
	25									
	26	1530-1700	.15		1400-1800	.30				
	27	0430-0900	.25		0400-1000	.23				
	28	1900-2100	.02		1900-2000	.04				
	29		.42 ---	.45		.57 ---	.59			.79
	29	1400-2230	.32		1500-0000	.30				
	30	0000-0300	.13		0000-0400	.13				
	31									

Cont.

DATE		LOWER HYDROPLOT			MIDDLE HYDROPLOT			UPPER HYDROPLOT		
		Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.
Sept.	1									
	2		.45 ---	.44		.43 ---	.44			.59
	3									
	4									
	5									
	6									
	7									
	8	0600	.02		0600-0800	.05				
	9		.02 ---	.04		.05 ---	.05			.04
	10									
	11	Pen Off	.05		1700	.04				
	12		.05 ---	.04		.04 ---	.01			.01
	13									
	14	2200	.03							
	15									
	16		.03 ---	.02			.01			T
	17									
	18				1800-2200	.03				
	19	0630-1200	.16		0400-1800	.18				
	20									
	21									
	22									
	23		.16 ---	.16		.21 ---	.19			.12
	24				2200-0000	.05				
	25	0030	.02							
	25	1500-1600	.21		1400-1800	.30				
	26	1400	.02		1400-1600	.04				
	27									
	28									
	29		.25 ---	.23		.39 ---	.38			.29
	30									

Cont.

DATE		LOWER HYDROPLOT			MIDDLE HYDROPLOT			UPPER HYDROPLOT		
		Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.	Rec. Time	Gage Amt.	Std. Gage Amt.
Oct.	1									
	2	0000-0700	.48		0000-1000	.73				
	3									
	4									
	5									
	6		.48 ---	.53		.73 ---	.68			.49
	7									
	8									
	9									
	10									
	11									
	12	0100-0630	.10		0000-1800	.12				
	12	1600	.03							
	13	0930	.05		1200	.04				
	13		.18 ---	.18		.16 ---	.17			.30
	20			T			T			
	21	1130-1600	.10							
	22	1130-1500	.15		0800-0000	.25				
	23	0730-1000	.13		0000-0600	.16				
	24									
	25									
	26	2200-2330	.18		1900-2100	.10				
	27	End of record period...	.56 ---	.65		.51 ---	.59			.76

The two remaining recording gages were left in the field until November 5. However, the data from October 27, on were disregarded because some of the precipitation was in the form of snow. Unless falling snow melts upon contact, it accumulates in the receiver and melts some time later. Thus, erroneous recordings of time and duration will result.

TABLE B - EIGHT MONTH PRECIPITATION RECORD FOR THE STANDARD RAIN GAGES

May 1,-December 31, 1966

Rain Gage Numbers

(inches of precipitation)

Date:	1	2	3	4	5	6	7	8	9	10	11
5/1	Ten rain gages were put out on this date.										
10	0.19	0.19	0.19	0.18	0.20	0.22	0.21	0.19	*0.19	0.19	
17	0.72	0.76	0.81	0.85	0.82	0.87	0.91	0.71	0.87	0.73	
28	0.38	0.36	0.30	0.26	*0.15	0.17	0.15	0.34	*0.30	0.30	
6/4	1.24	*1.56	1.88	2.27	1.87	2.18	1.54	2.00	2.15	2.03	
11	1.40	1.75	1.56	1.60	1.66	1.65	1.59	1.69	1.82	1.82	
18	0.08	0.08	0.09	0.09	0.12	0.15	0.12	0.07	0.07	0.07	
26	0.99	1.06	0.88	1.11	1.38	1.44	1.42	0.98	0.93	0.98	
7/1	Before storm.			0.09				0.11	0.10		0.11
1	0.31	0.22	0.16		0.11	0.13	0.13	0.07		0.20	0.15
5	0.25	0.36	0.37	0.40	0.35	0.41	0.40	0.32	0.33	0.31	0.22
9	0.33	0.17	0.10	0.06	0.03	0.03	0.02	0.24	0.44	0.29	0.40
17	0.13	0.20	0.27	0.34	0.40	0.40	0.47	0.21	0.20	0.26	0.14
8/5	0.04	0.03	0.05	0.02	0.02	0.04	0.02	0.04	0.03	0.03	0.06
15	0.03	0.04	0.04	0.06	0.11	0.18	0.15	0.04	0.04	0.04	0.03
23	0.08	0.10	0.10	0.10	0.06	0.07	0.11	0.13	0.18	0.18	0.08
29	0.47	0.47	0.54	0.61	0.75	0.77	0.83	0.48	0.48	0.50	0.43
9/2	0.42	0.44	0.52	0.52	0.53	0.52	0.54	0.40	0.45	0.45	0.45
9	0.04	0.05	0.08	0.07	0.10	0.09	0.08	0.05	0.05	0.06	0.04
12	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.03	0.04	0.02	0.04
16	0.02	0.01	0.01	0.01	T	0.01	0.01	0.02	0.03	0.02	0.03
23	0.17	0.18	0.18	0.20	0.13	0.17	0.16	0.18	0.19	0.19	0.17
29	0.21	0.33	0.33	0.36	0.18	0.22	0.21	0.44	0.31	0.40	0.23
10/6	0.48	0.55	0.60	0.80	0.39	0.55	0.46	0.55	0.45	0.56	0.51
13	0.15	0.17	0.17	0.18	0.20	0.22	0.20	0.17	0.17	0.17	0.18
20				T				T		T	T
27	0.63	0.61	0.64	0.61	0.70	0.72	0.65	0.61	0.67	0.67	0.60
11/11				0.38				0.31	0.36	0.35	0.28
17	0.64	0.60	0.58		0.63	0.80	0.70				
23				0.55				0.50	0.47	0.51	0.62
12/1	0.51	0.88	0.91		0.94	1.02	0.93				
16				1.28				1.13	1.13	1.17	1.06
18					0.77	0.83					
19	0.61	*0.61	0.65				0.73				
31	0.41	0.41	0.48	0.43	0.70	*0.75	0.61	0.39	0.43	0.43	0.43

*Estimated values

TABLE B Cont.

Rain Gage Numbers

Date:	12	13	14	15	103	104	105	107	Lower Hydro-plot	Middle Hydro-plot	Upper Hydro-plot
5/10									0.14	0.16	
17									0.71	0.75	
28	0.25	0.14	0.12	0.14	0.23				0.43	0.21	0.14
6/4	1.95	2.07	1.89	2.35	2.28				2.04	2.15	2.20
11	1.87	1.52	1.65	1.88	1.80				2.08	1.54	1.61
18	0.11	0.15	0.18	0.13	0.05				0.07	0.06	0.11
26	1.45	1.52	1.40	1.80	0.88				1.07	1.04	1.66
7/1	Before storm.								0.11	0.08	
1	0.12	0.12	0.12	0.13	0.15				0.15		0.13
5	0.44	0.49	0.47	0.49	0.32		*0.37	*0.37	0.22	0.40	0.44
9	0.01	0.01	0.01	T	0.13		*0.03	T	0.40	0.04	T
17	0.30	0.26	0.22	0.26	0.37		0.33	*0.33	0.13	0.27	0.25
8/5	0.02	0.02	0.02	0.01	0.03	0.06	0.02	0.01	0.06	0.02	0.01
15	0.17	0.17	0.22	0.22	0.06	0.02	0.06	0.12	0.03	0.05	0.17
23	0.08	0.09	0.07	0.11	0.12	0.07	0.14	0.11	0.07	0.16	0.11
29	0.74	0.77	0.82	*0.80	0.55	0.45	0.67	0.72	0.45	0.59	0.79
9/2	0.57	0.57	0.62	0.59	0.45	0.44	0.47	0.52	0.44	0.44	0.59
9	0.08	0.09	0.10	0.08	0.06	0.03	0.04	0.07	0.04	0.05	0.04
12	0.02	0.02	0.01	0.02	0.02	0.06	0.01	0.01	0.04	0.01	0.01
16	0.01	0.01	0.01	0.01	0.02	0.02	0.01	T	0.02	0.01	T
23	0.13	0.14	0.15	0.12	0.19	0.17	0.17	0.14	0.16	0.19	0.12
29	0.33	0.33	0.29	0.30	0.39	0.19	0.33	0.32	0.23	0.38	0.29
10/6	0.37	0.59	0.68	0.71	0.65	0.56	0.58	0.59	0.53	0.68	0.49
13	0.29	0.36	0.38	0.33	0.17	0.19	0.17	0.22	0.18	0.17	0.30
20						T			T		
27	0.95	0.76	0.72	0.70	0.62	0.66	0.61	0.61	0.65	0.59	0.76
11/11					0.38	0.30	0.35		0.28	0.34	
17	*0.91	0.97	0.84	0.94				0.60			0.84
23					0.50	0.65	0.39		0.62	0.45	
12/1	1.05	1.38	1.18	1.10							1.15
16					1.16	1.22	1.24		1.11	1.21	
18	0.83	0.74	0.97	*0.94							
19								1.68			0.96
31	0.85	0.73	0.98	0.88	0.45	0.49	0.48	0.60	0.43	0.43	0.90

*Estimated values

TABLE B - FOUR MONTH PRECIPITATION RECORD FOR 11 STANDARD RAIN GAGES

January 1,-April 30, 1967

	Rain Gage Numbers										
Date	2	4	7	8	11	12	14	103	Lower Hydroplot	Middle Hydroplot	Upper Hydroplot
1/1	Started the 11 gage network										
1/12	0.82	0.62	1.12	0.68	0.68	1.21	1.54	0.71	0.68		0.75
1/19		1.15		1.11	1.23			1.30	1.23	1.96	
1/26	2.10	0.79	2.62	0.75	0.76	2.75	3.33	0.90	0.80		2.54
2/2	0.43	0.37	0.51	0.38	0.36	0.45	0.63	0.38	0.37		0.43
2/9	0.17	0.14	0.27	0.16	0.18	0.30	0.45	0.16	0.18	1.31	0.16
2/16		0.51		0.53	0.49			0.55	0.54		
2/23	1.03	0.24	1.33	0.23	0.23	1.06	1.70	0.29	0.23		0.83
3/2	0.07	0.07	0.16	0.07	0.05				0.05		0.13
3/9	0.43	0.35		0.30	0.29			0.39	0.32	1.18	
3/17	0.76	0.65	1.23	0.60	0.57	1.62	2.07	0.67	0.57		1.27
3/23	0.32	0.25	0.33	0.28	0.30			0.28	0.31	0.82	0.19
3/30	0.23	0.17	0.36	0.09	0.14	0.66	0.95	0.16	0.14		0.33
4/6	0.25	0.21	0.45	0.09	0.23	0.49	0.70	0.20	0.24		0.45
4/13	0.22			0.21	0.13				0.18	0.46	
4/17	0.28		0.36		0.60	0.88					0.49
4/20		0.25		0.18	0.16			0.28	0.16		
4/27		0.08		0.07	0.08			0.08	0.08		
4/30	1.34	0.85	1.46	0.85	0.97	1.55	2.04	0.84	0.98	1.07	1.76

TABLE C - SEASONAL AND TOTAL PRECIPITATION - 1966

Rain Gage Number	May 1 to July 1	July 1 to Sept. 15	Sept. 15 to Dec. 31	May 1 to Dec. 31
103	6.37	2.13	4.51	13.01
104			4.43	
105		2.15	4.32	
107		2.26	4.76	
1	5.31	1.86	3.81	10.98
2	5.98	1.90	4.34	12.22
3	5.87	2.09	4.54	12.50
4	6.45	2.20	4.79	13.44
5	6.31	2.36	4.64	13.31
6	6.81	2.53	5.28	14.62
7	6.07	2.64	4.65	13.36
8	6.16	1.96	4.28	12.40
9	6.43	2.27	4.18	12.88
10	6.32	2.16	4.45	12.93
11		2.07	4.08	
12	6.73	2.44	5.71	14.88
13	6.50	2.50	6.00	15.00
14	6.34	2.57	6.19	15.10
15	7.41	2.59	6.02	16.02
Lower Hydroplot	6.65	2.05	4.19	12.89
Middle Hydroplot	5.99	2.04	4.44	12.47
Upper Hydroplot	6.83	2.41	5.81	15.05

TABLE D - PERIODIC AND TOTAL PRECIPITATION - 1967

Rain Gage Number	Jan. 1 to Feb. 9	Feb. 9 to Mar. 30	Mar. 30 to Apr. 30	Jan. 1 to Apr. 30
2	3.52	2.84	2.09	8.45
4	3.07	2.24	1.39	6.70
7	4.52	3.41	2.27	10.20
8	3.08	2.10	1.50	6.68
12	4.71	3.34	2.64	10.69
14	5.95	4.72	3.62	14.29
103	3.45	2.34	1.40	7.19
Lower Hydroplot	3.23	2.11	1.60	6.94
Middle Hydroplot	3.27	2.00	1.53	6.80

NOTE: The lower hydroplot has been averaged with number 11.

The upper hydroplot has been excluded because of inaccurate measurements, probably due to wind.

TABLE E - RAIN GAGE COMBINATIONS FOR SELECTION OF MINIMUM NUMBER OF GAGES REQUIRED FOR SAMPLING
(values given in inches)

	Combination Average	Watershed Average	Difference	Average Difference
The 6 gage combination:				
L.H.P., 2, 103, 7 12, & 14	5.24	5.24	=	
	0.94	0.92	0.02	0.05
	3.41	3.35	0.06	
	3.00	2.88	0.12	
L.H.P., 2, 103, M.H.P., 107, & 12	5.26	5.24	0.02	
	0.88	0.92	0.04	0.07
	3.29	3.35	0.06	
	2.72	2.88	0.16	
1, 3, 7, 10, 12 & 105	4.92	5.24	0.68	
	0.93	0.92	0.01	0.07
	3.30	3.35	0.05	
	2.72	2.88	0.16	
L.H.P., 2, 103, 7, 12, & 15	5.42	5.24	0.28	
	0.95	0.92	0.03	0.11
	3.40	3.35	0.05	
	2.97	2.88	0.09	
L.H.P., M.H.P., 6, 107, 12, & 15	5.53	5.24	0.29	
	0.87	0.92	0.05	0.19
	3.52	3.35	0.17	
	3.13	2.88	0.25	
The 7 gage combination:				
L.H.P., 4, 10, 7, 105, 13, & U.H.P.	5.23	5.24	0.01	
	0.92	0.92	=	0.03
	3.39	3.35	0.04	
	2.94	2.88	0.06	

NOTE: L., M., and U.H.P. refers to lower, middle, and upper hydroplots.

TABLE E Cont.

	Combination Average	Watershed Average	Difference	Average Difference
L.H.P., 2, 103, M.H.P., 7, 12, & 15	5.36	5.24	0.12	0.05
	0.93	0.92	0.01	
	3.39	3.35	0.04	
	2.90	2.88	0.02	
L.H.P., 3, M.H.P., 103, 7, 12, & 15	5.34	5.24	0.10	0.06
	0.92	0.92	=	
	3.43	3.35	0.08	
	2.92	2.88	0.04	
L.H.P., 2, 103, 105, 6, 12, & 14	5.33	5.24	0.09	0.07
	0.90	0.92	0.02	
	3.42	3.35	0.07	
	2.98	2.88	0.10	
L.H.P., 10, 105, 4, 7, 12, & 15	5.44	5.24	0.20	0.09
	0.91	0.92	0.01	
	3.45	3.35	0.10	
	2.92	2.88	0.04	
The 8 gage combination:				
L.H.P., 2, 10, 6, M.H.P., 107, 12, & 14	5.29	5.24	0.04	0.04
	0.90	0.92	0.02	
	3.39	3.35	0.04	
	2.96	2.88	0.08	
L.H.P., 2, 103, 7, M.H.P., 107, 12, & 15	5.33	5.24	0.09	0.05
	0.90	0.92	0.02	
	3.40	3.35	0.05	
	2.90	2.88	0.02	
L.H.P., 2, 10, 5, M.H.P., U.H.P., 12, & 14	5.31	5.24	0.07	0.06
	0.90	0.92	0.02	
	3.37	3.35	0.02	
	3.00	2.88	0.12	

TABLE E Cont.

	Combination Average	Watershed Average	Difference	Average Difference
L.H.P., 2, 103, 6, M.H.P., 107, 12, & 15	5.33	5.24	0.09	
	0.89	0.92	0.03	0.06
	3.41	3.35	0.06	
	2.95	2.88	0.07	
L.H.P., 2, M.H.P., 103, 7, U.H.P., 12, & 14	5.27	5.24	0.03	
	0.91	0.92	0.01	0.06
	3.43	3.35	0.08	
	3.02	2.88	0.14	
The 9 gage combination:				
L.H.P., 2, 8, 103, M.H.P., 7, 107, 12, & 15	5.31	5.24	0.07	
	0.92	0.92	=	0.03
	3.37	3.35	0.02	
	2.83	2.88	0.05	
L.H.P., 3, 8, 103, 105, 107, 6, 12, & 14	5.27	5.24	0.03	
	0.88	0.92	0.04	0.04
	3.42	3.35	0.07	
	2.91	2.88	0.03	
L.H.P., 2, 10, 103, M.H.P., 6, 107, 12, & 14	5.29	5.24	0.05	
	0.90	0.92	0.02	0.04
	3.41	3.35	0.06	
	2.91	2.88	0.03	
1, 2, 10, M.H.P., 6, 107, U.H.P., 12, & 13	5.16	5.24	0.08	
	0.88	0.92	0.04	0.07
	3.40	3.35	0.05	
	3.00	2.88	0.12	
L.H.P., 2, 8, M.H.P., 6, 107, U.H.P., 12, & 14	5.33	5.24	0.09	
	0.88	0.92	0.04	0.09
	3.43	3.35	0.08	
	3.05	2.88	0.17	

TABLE F WEATHER RECORD TABLE

No echoes means that the station did not record any measurable echoes for that day.

The radar estimates in the table are for echoes that were over all or part of the watershed.

Date	Recording rain gage Lower Hydroplot Time	Amount (in.)	Recording rain gage Middle Hydroplot Time	Amount (in.)	Radar Estimate Time	Amount (in.)	Other Radar Information
May 1							No echoes
2							" "
3							" "
4							Nearest echoes, 60 mi.
5							" " 12 mi.
6							" " 15 mi.
7							" " 90 mi.
8							No echoes
9-10			2100-0200	0.20	0000-0130	0.04	
10			1600-0000	0.20	1700-0000	0.16	
11			0000-1200	0.25	0000-0200	0.04	
12-13			2100-0400	0.13	1730-0000	0.12	
13							Nearest echoes, 10 mi.
14			1200-1500	0.10			Echoes at 0415, 5 mi.
15							Echoes from 2020-2320, 10-20 mi.
16							Echoes from 0300-0630, 20 mi.
17							Nearest echoes, 20 mi.
18							" " 40 mi.
19							No echoes
20							" "
21			1800	0.05	1625-0000	0.04	The 0.04 occurred about 2120
22			1600-1800	0.04	1810	0.01	1620 - echo of 0.06 intensity about 10 mi.
23							No echoes
24							" "
25							" "

Cont.

Date	Lower		Middle		Radar		Other Information
	Time	Amount	Time	Amount	Time	Amount	
26							Nearest echoes, 40 mi.
27			1600-1800	0.10			" " 5 mi.
28			1300-0000	0.20	0210-1815	0.07	Taken from 250 mi. radius chart
29-30			1800-1200	0.13	1715-2310	0.06	" " " " "
30					1310-1410	0.24	" " " " "
31			1900-0000	0.45	1920-2325	0.32	
June 1			0000-1200	0.08			Nearest echoes, 5 mi.
			2200-0000	0.10	1820	0.02	1720-1820, echoes of 0.06 intensity within 2-5 mi.
2			1300-1800	0.42	1420-1820	0.98	1320-1820, echoes of 0.16-0.34 intensity near and over area, from 1820 on the nearest echoes were 5 mi.
3			1100-1600	0.70	1230-1620	0.46	1700-0000, nearest echoes 40 mi.
4					1020-1220	0.06	
5							Nearest echoes, 45 mi.
6							" " 25 mi.
7			1500-0000	0.25	2100-0000	0.12	2220 - echo of 0.06 intensity at E edge of watershed
8			0000-0200	0.17			Few echoes at 0120, nearby
9			1200-0000	0.67	1420-2320	0.26	Echoes of 0.10 intensity, 20 mi.
10			0000-0100	0.10			Echoes within 5 mi.
			1800-0000	0.02	1920-2320	0.16	
11			0000-0600	0.20	0010	0.03	
			1800	0.03			Echoes within 5 mi.
12			0600	0.04		0.08	0020-0220, echoes of 0.04 intensity within 5 mi.
13					1710-2010	0.08	
14							Nearest echoes, 20 mi.
15							" " 35 mi.
16							" " 70 mi.
17							" " 50 mi.
18							" " 75 mi.
19			1800-0000	0.10			1710 - nearest echoes, 5 mi.

Cont.

	Lower		Middle		Radar		
Date	**Time**	**Amount**	**Time**	**Amount**	**Time**	**Amount**	**Other Information**
20			0000-1200	0.40	0320-0520	0.10	0020-1200, echoes up to 0.06 intensity within 5 mi.
21			1600-2100	0.10		0.08	Other echoes nearby
22							Nearest echoes, 25 mi.
23			1200-1500	0.04	1310	0.01	
24			0300-0700	0.30	0220-0720	0.24	
					1820-1920	0.04	
25							Nearest echoes, 25 mi.
26							No echoes
27							" "
28							Nearest echoes, 10 mi.
29	0500	0.05	0600	0.04			RADAR OUT OF ORDER FROM 0339-0908
30	0530	0.07	0300-0700	0.05	0230-0830	0.08	
July 1	1400	0.15	1400-1500	0.05	1515	0.03	
					1810	0.03	
2	1230-0000	0.17	1100-0000	0.30	1525-0000	0.04	RADAR OUT OF ORDER FROM 1212-1525
3	0000-0030	0.03	0000-0100	0.05	1810-2010	0.02	
4							Nearest echoes, 100 mi.
5							" " 150 mi.
6					2010	0.01	
7	2130-2200	0.40	2100-0000	0.04	2210	0.04	
8					0010	0.01	
9					2210	0.01	
10					1310-1910	0.04	Echoes of 0.01 intensity
11					2110	0.04	
12	pen knocked off		1500-1800	0.15	1410-1510	0.06	
13	1630-1900	0.10	2000-2200	0.04	2010	0.04	
14	1900	0.03	1600	0.07	1410-1510	0.06	
15							Nearest echoes, 20 mi.
16							" " 100 mi.
17							" " 100 mi.
18							" " 80 mi.
19							" " 40 mi.

Cont.

	Lower		Middle		Radar		
Date	**Time**	**Amount**	**Time**	**Amount**	**Time**	**Amount**	**Other Information**
20							Nearest echoes, 80 mi.
21							" " 100 mi.
22							No echoes
23							Nearest echoes, 100 mi.
24							" " 40 mi.
25							" " 60 mi.
26							No echoes
27							" "
28							Nearest echoes, 70 mi.
29							No echoes
30							Nearest echoes, 60 mi.
31							" " 25 mi.
Aug. 1							" " 100 mi.
2							No echoes
3							Nearest echoes, 5 mi.
4	1600	0.06	1600-2000	0.05	1610-2210	0.02	
5							" " 45 mi.
6							" " 110 mi.
7							No echoes
8		Trace					Nearest echoes, 5 mi.
9							" " 40 mi.
10							" " 150 mi.
11							" " 25 mi.
12							No echoes
13	2200	0.04	2000	0.05	0910-1610	0.08	2110-2310, echoes of 0.04 intensity moving through area
14							Nearest echoes, 40 mi.
15	1500	0.04					No echoes
16							" "
17							Nearest echoes, 90 mi.
18							" " 50 mi.
19	1600	0.05	1500	0.10			1510 - few small echoes in the area

Cont.

	Lower		Middle		Radar		
Date	Time	Amount	Time	Amount	Time	Amount	Other Information
20	0800	0.02	0600-2000	0.05	0620-1620	0.06	
21							No echoes
22							" "
23							" "
24							" "
25							Nearest echoes, 20 mi.
26	1530-1700	0.15	1400-1800	0.30	1610-1910	0.05	
27	0430-0900	0.25	0400-1000	0.23	0610-0910	0.06	
					2310	0.01	
28	1900-2100	0.02	1900-2000	0.04			1810-1910, echoes of 0.01 intensity nearby
29	1400-2230	0.32	0600	0.01	0510	0.01	
			1500-0000	0.30	1610-2310	0.11	
30	0000-0300	0.13	0000-0400	0.13			0010-0310, echoes of 0.01-0.04 intensity surrounding watershed
31							No echoes
Sept. 1							" "
2							" "
3							" "
4							Nearest echoes, 130 mi.
5							" " 50 mi.
6					1710-1810	0.02	
7							1438-2010, small echoes within 5-10 mi.
8	0600	0.02	0600-0800	0.05	0700	0.02	
9							No echoes
10							Nearest echoes, 90 mi.
11	pen off	0.05	1700	0.04	1610	0.01	
					2110-2310	0.05	
12							" " 10 mi.
13							" " 50 mi.
14	2200	0.03			2200-2300	0.04	
15							" " 10 mi.

Cont.

	Lower		Middle		Radar		
Date	Time	Amount	Time	Amount	Time	Amount	Other Information
16							Nearest echoes, 30 mi.
17							No echoes
18			1800-2200	0.03			1800 - echoes at 70 mi. and by 2110, echoes within 10 mi.
19	0630-1200	0.16	0400-1800	0.18	0910-1010	0.02	
20							No echoes
21							" "
22							" "
23							Nearest echoes, 20 mi.
24			2200-0000	0.05	2210	0.01	
25	0030	0.02			0110	0.01	
	1500-1600	0.21	1500-1800	0.30	2010	0.01	
26	1400	0.02	1400-1600	0.04			1400-1500, nearest echoes 5 mi. RADAR OUT OF ORDER FROM 1535-1710
27							No echoes
28							" "
29							Nearest echoes, 50 mi.
30							No echoes
Oct. 1							Nearest echoes, 5 mi.
2	0000-0700	0.48	0000-1000	0.73	0110-0910	0.10	
					1710	0.01	
3							" " 60 mi.
4							No echoes
5							" "
6							" "
7							RADAR OUT OF ORDER FROM THIS DATE TO 1700 ON THE 16th
8							
9							
10							
11							

Cont.

	Lower		Middle		Radar		
Date	**Time**	**Amount**	**Time**	**Amount**	**Time**	**Amount**	**Other Information**
12	0100-0630	0.10	0000-1800	0.12			
	1600	0.03					
13	0930	0.05	1200	0.04			
14							
15							
16							Nearest echoes, 10 mi.
17							" " 5 mi.
18							No echoes
19							" "
20					1700-2200	0.06	
21	1130-1600	0.10			1110-1210	0.02	Small echoes in the area all day
					1910-2110	0.02	
22	1130-1500	0.15	0800-0000	0.25	1710	0.01	Numerous small echoes in the area all day
23	0730-1000	0.13	0000-0600	0.16			0010-0210 and 1710-1210 numerous small to moderate sized echoes in the area
24							No echoes
25							" "
26	2200-2330	0.18	1900-2100	0.10	1810-2310	0.05	
27					0010	0.03	
28							" "
29							Nearest echoes, 5 mi.
30	0000-0200	0.10	0000-0300	0.09	0210	0.03	
					2110-2310	0.02	
31					0010	0.01	
Nov. 1							No echoes
2							" "
3							" "
4							" "
5	1300-1800	0.05	1400-1800	0.08	1310-1610	0.06	

RECORDING RAIN GAGES DISCONTINUED AS OF THE 5th

Total precipitation over the watershed from Oct. 28 - Dec. 31, (arithmetic average).	Total precipitation over the watershed during this same period, as determined by radar echoes.
2.88"	1.60"

TABLE G - STREAM DISCHARGE RECORD

60-Inch Parshall Flume
(Mean daily flow in cubic feet per second)

DATE	MAR.		APR.		MAY		JUNE	JULY	AUG.	SEPT.
1		8.89	6.87		4.31		4.49	2.36	0.68	0.68
2			7.30		6.24		4.31	2.50	0.68	0.60
3			5.05	9.61	7.09	11.62	7.30	3.28	0.68	0.51
4			4.13	9.61	7.52		6.87	2.65	0.60	0.51
5			4.49		7.74		4.68	2.36	0.51	0.51
6			5.63		7.74		3.95	2.07	0.51	0.51
7			5.63		7.30		3.78	1.94	0.51	0.51
8		8.43	6.87		6.45		5.05	1.80	0.44	0.51
9			7.74		6.24		5.43	1.67	0.44	0.51
10			7.09		6.87	11.62	8.66	1.54	0.44	0.51
11			6.87		6.87		7.09	1.54	0.48	0.51
12			6.66		6.03		6.03	1.43	0.51	0.51
13			6.03		6.03		5.63	1.67	0.56	0.51
14			5.83		5.43		5.24	1.54	0.60	0.51
15			6.24		5.24		4.68	1.43	0.60	0.51
16			6.66		4.86		4.31	1.31	0.51	0.51
17			5.43		4.49		4.13	1.31	0.51	0.51
18			4.86		4.31		3.95	1.20	0.51	0.51
19			5.05		4.13		3.61	1.20	0.51	0.60
20			4.31		3.95		5.24	1.08	0.60	0.64
21			3.95		3.78		4.13	0.98	0.68	0.60
22			3.78		3.78		4.31	0.98	0.60	0.56
23			3.78		3.61		3.95	0.98	0.51	0.51
24			3.95		3.28		6.24	0.88	0.51	0.51
25			5.63		3.12		4.63	0.88	0.51	0.56
26			5.63		2.96		3.78	0.78	0.51	0.83
27	1.54		4.13		2.96		3.28	0.78	0.93	0.73
28	2.36		3.95		3.04		2.96	0.78	0.88	0.68
29	2.65		3.95		3.61		2.65	0.78	0.68	0.60
30	3.28		3.95		3.28		2.50	0.78	1.20	0.60
31	5.43				3.12			0.78	0.88	

NOTE: Where double entries occur, the value to the left is the maximum instantaneous discharge.

TABLE G Cont.

DATE	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.
1	0.60	0.93					1.08
2	0.98	0.93			visual	0.98	1.08
3	1.03	0.78					1.20
4	0.98	0.83					1.43
5	0.98	0.83					1.43
6	0.88	0.78					1.43
7	0.88	0.83					1.67
8	0.88	0.73					1.94
9	0.83	0.78		visual	0.88		1.94
10	0.78	0.88					1.94
11	0.83	0.88					2.21
12	0.88	0.88					2.50
13	0.88	0.88					2.80
14	0.88	0.98					2.65
15	0.88	1.03					2.50
16	0.88	1.20					2.21
17	0.88	1.14			visual	0.98	2.07
18	0.83	0.98					1.94
19	0.83	0.88					1.94
20	0.93	0.98					1.80
21	0.98	0.98					1.87
22	0.98	0.93					1.80
23	1.08	0.98			visual	0.98	1.94
24	1.43	0.88					2.36
25	1.37	0.88			visual	0.98	2.72
26	1.08	0.88				0.98	2.80
27	1.20	0.88				0.98	2.65
28	0.98	0.88				0.98	2.96
29	0.98	0.88				0.98	2.50
30	0.98	0.88				0.98	2.36
31	0.98					1.08	

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