EVALUATION OF TECHNIQUES FOR DETERMINING AVERAGE PRECIPITATION IN SEMIARID VALLEYS OF IDAHO

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ABSTRACT

The Raft River Basin in southcentral Idaho and the Reynolds Creek Experimental Watershed in southwest Idaho were studied to determine precipitation distribution in an attempt to develop better isohyetal maps for semiarid mountain valleys. Due to gage malfunctions in the Raft River network, only the data collected by the Agricultural Research Service on Reynolds Creek was analyzed.

Two methods were used to determine precipitation distribution. The computer isohyetal method worked well on Reynolds Creek but should be used only where a dense gage network is available. The Thiessen method was preferred in areas where gages are relatively spread out. The Thiessen method was also used to determine the relative accuracy of the mean precipitation estimate using less than the 45 gages available. A multiple-regression equation was developed for selecting the point precipitation measurements to be used in estimates of average precipitation on the Reynolds Creek Experimental Watershed. Results indicated that no fewer than 20 gages should be used to obtain a good estimate of average precipitation.

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CHAPTER I

INTRODUCTION

General

Records of man's first attempt to measure the precipitation component of the hydrologic cycle are lost in antiquity. As early as the fourth century B.C. containers with standard measurements were used in India for agricultural cropping purposes. Two thousand years later, in about 1650, Perreault of France provided the first crude proof of what is called the hydrologic cycle (Linsley, et al., 1958). With the last century's rapid increase in world population and with man's increased demand for water to improve his quality of life, the measurement of the hydrologic cycle has taken on new dimensions of importance.

The wise management of water resources projects depends greatly on the accurate measurement of the various parts of the hydrologic cycle, including precipitation in all its forms, evapotranspiration, ground water flow, surface runoff, and other components. This is especially true in an arid or semiarid region such as southern Idaho where the agricultural economy is inseparably linked to the water supply.

The hydrologic cycle is complex, and even if individual components could be evaluated, much would need to be learned about the interaction of these components. Of all the elements in the hydrologic cycle, perhaps the most important is precipitation; in the long run it is this factor that determines the magnitude of all other components. In view of its relative importance, it is fortunate that it is one of the easier components of the cycle to measure.

Section 43-237a paragraph g of the Idaho Code requires regulation of ground water pumping on the basis of a "reasonably anticipated average rate of future natural recharge". In view of this, the systematic measurement of precipitation and preparation of accurate isohyetal maps or other means to determine the average rate of recharge becomes very important. Over a period of several years, three studies of the water yield of the Raft River Basin showed results of 183,000, 320,000, and 140,000 acre-feet of water per year (Nace, et al., 1960; Mundorff and Sisco, 1963; Walker, et al., 1970). Each study was based on estimates of precipitation and other factors in the basin.

Objectives

In order to better understand the precipitation factor of the hydrologic cycle of a mountainous region, three objectives were pursued.

These were: (1) to study various techniques for determining the precipitation distribution and evaluate the adaptability of these techniques to drainage basins in Idaho, (2) on the basis of the techniques selected and on the data available, to prepare an isohyetal map of a selected drainage basin in Idaho, and (3) to determine the gage density requirements for estimating a basin's average annual precipitation to various degrees of accuracy.

Specific Future Value

Many of the rain gages in the West are serviced by people who are hired on a part-time basis. As a result of this the majority of gages are located in or near permanent settlements; however, the main source of water supply is the mountains where the winter snowpack melts to produce the spring runoff. As gage networks are expanded to include the mountainous areas, some method must be used to determine the best location of gages and to determine how many gages are required to produce the desired accuracy of the precipitation estimate. If a sufficient gage density cannot be obtained, data must be collected for use in a multiple-regression or similar analysis to estimate the precipitation. The results of this study may be used to make more accurate and reliable estimates of precipitation in the semiarid regions of the West.

CHAPTER II

PERTINENT LITERATURE

In order to determine what past research has been conducted on this subject, a review of the literature pertinent to precipitation-elevation relationships, rain gage performance, the preparation of isohyetal maps, and other related topics was undertaken.

Lee (1911) warned against using a linear relationship between elevation and precipitation. His study in the California Sierras indicated a cubic parabola relationship.

Donley and Mitchell (1939) used a linear relationship of the form $R' = R + K(A/100)$. R' is rainfall at an ungaged highpoint, R is the rainfall at a gaged low point, K is the inverse slope of elevation versus rainfall for the four regions used and A is the altitude difference between the two points.

Using the parameters of elevation, slope, rise, aspect, and zone of influence, Burns (1953) employed a multiple-graphical-correlation method to determine point rainfall. He then drew an isohyetal map from this.

Hamilton (1954) showed that gages placed parallel to sloped hills caught less vertically falling rain than vertical gages by a factor of the reciprocal of the cosine of the slope angle.

Probably the most promising method of developing isohyetal maps for mountainous areas was proposed by Peck and Brown (1962). They used anomalies from precipitation-elevation relationships in preparing isohyetal maps for Utah. These anomalies were shown to be closely related to physiographic features. Dyer (Walker, et al., 1970) used a similar method in preparing the isohyetal map of the Raft River Basin for use by the Idaho Department of Water Administration.

Using a network of dual gages -- one shielded and one unshielded -- Hamon (1971) derived a relationship using the ratio of catch for the two gages. This was to eliminate the error caused by wind currents around the orifice of the gage.

James (1964), Geiger (1965), Hovind (1965), and Stanz (1966) all concluded that gages on the leeward side of a hill caught more precipitation than those on the windward side because of less wind turbulence. These studies were carried out in areas in which orographic lifting was not a factor.

Using a 1130 square mile basin with approximately 175 gages in central Oklahoma, Nicks (1965) showed that as few as ten gages could estimate the annual precipitation without significant error. The reduced network was not dense enough, however, to accurately estimate precipitation on a daily or storm event basis.

Schermerhorn (1967) concluded that for western Washington, terrain elevation and barrier elevation (empirically defined) along with a latitude index explained most of the variation in precipitation.

Using precipitation and other data from the entire state of West Virginia in a multiple-regression analysis, Grafton and Dickerson (1969) determined the mean annual precipitation for that state. They found that by using three parameters in each of two zones the coefficients of multiple determination were 0.66 and 0.60.

CHAPTER III

DESCRIPTION OF STUDY AREAS

Two basins were selected for detailed study. These were the Raft River Basin in southcentral Idaho and Reynolds Creek in southwest Idaho.

Raft River Basin

Geographic Characteristics

The Raft River Basin lies in Cassia, Power, and Oneida Counties in southcentral Idaho and in Box Elder County in northwestern Utah. It includes about 1,560 square miles. The Raft River, the master stream, heads in the Goose Creek Mountains of Utah and flows generally northeast and north and joins the Snake River in the backwater of Lake Walcott, a federal reclamation reservoir on the Snake River Plain.

The climate of the Raft River Basin varies from cool semihumid in the mountains to semiarid on the floor of the Raft River Valley. The mean annual temperature of the central lowland or Lower Raft River Valley is between 45 and 48 degrees Farenheit. The average summertime humidity in the lowland is probably about 25 percent (Nace, *et al.*, 1960).

Geologic Characteristics

The geology in the Raft River Basin plays an important part in both the distribution and total amount of precipitation. Orographic lifting results in increased precipitation with elevation on the windward side of high barriers. "Rain shadows" or areas of deficient rainfall result on the lee side of the barriers.

The Raft River Basin contains all or parts of five mountain ranges: the Sublett Range to the east, the Malta or Cotterell Range in the central part, the Albion Range to the west, the Black Pine Range to the southwest, and the Raft River Mountains to the south. All have a general north-south directional trend except the Raft River Mountains which lie in an east-west direction.

The Albion Range contains two features of notable significance: (1) Cache Peak at 10,335 feet m.s.l. is the highest mountain in Idaho south of the Snake River, and (2) the Silent City of Rocks, "a small area of weirdly carved monoliths, spires, pinnacles and castellated forms in granitic rock in the heart of the Range" (Anderson, 1931). The Albion Range was covered by glaciers above 8,000 feet. It forms the western boundary of the Basin.

The Malta or Cotterell Mountains are a young tilted block formation in the central part of the Basin and attain a maximum elevation of about 8,200 feet, more than 3,000 feet above the valley floor. They have been subjected to massive landslide action which has all but erased the effects of glaciation at the higher altitudes.

The Black Pine Range in the southeastern part of the basin is isolated from the other ranges. It rises to a maximum elevation of 9,700 feet, about 3,800 feet above its base. Glaciation also occurred here, but the effects are not well preserved due to erosion.

The Sublett Range forms the eastern boundary of the Raft River Basin and is the lowest of the mountains cited. Its maximum elevaton is about 7,500 feet and because of this, the range-like aspect of its neighbors is not present and it appears more like a broad plateau. Because of its relatively low elevation, the Sublett Range appears to have escaped glaciation almost entirely.

The Raft River Range forming the southern boundary of the basin is in northern Utah. Its maximum elevation is about 9,925 feet and is the only range in the basin with an east-west orientation.

Hydrologic Characterisitics

Most of the streamflow in the Raft River Basin is a result of snowmelt in the mountains and foothills. Summer thunderstorms contribute to runoff, but runoff from thunderstorms is smaller than that from spring snowmelt because much of the thunderstorm precipitation is used to resupply soil moisture. The average precipitation for the basin has been estimated to vary from less than ten inches on the valley floor to more than 35 inches in the Raft River Mountains.

Reynolds Creek Basin

Geographic Characteristics

The Reynolds Creek Experimental Watershed is located on the north flank of the Owyhee Mountain Range, approximately 50 miles southwest of Boise, Idaho, in the northwest portion of Owyhee County. As measured from Reynolds Creek Canyon, the watershed covers 90.2 square miles (57,728 acres). Approximately 43,914 acres of the watershed are federal grazing land and 13,840 acres are private land of which nearly 2,000 acres are irrigated croplands.

Elevation within the watershed ranges from 3,600 feet at the outlet weir in Reynolds Canyon to 7,390 feet at the southwest perimeter of the watershed (Hamon, 1971). Isolated peaks in the Owyhee Mountain Range reach elevations of 8,000 feet. Local relief within the watershed is highly variable. The valley floor is of low relief, composed of dissected terrain, pediments, and local flood plains. The topography surrounding the valley floor is steep on all sides. The perimeter of the watershed varies from smooth rolling hills to rugged, high relief cliffs. North trending interior ridges and steep narrow tributary valleys open onto the valley floor.

Geologic Characteristics

The Reynolds Creek Experimental Watershed lies in an erosionally modified structural basin surrounded by structural and topographic high areas. Volcanic sedimentary rocks of the late Tertiary Age overlie a granitic "basement" of Cretaceous Age. The stratigraphy has been subdivided into five sequences separated by unconformities (McIntyre, 1972). These stratigraphic sequences are, respectively, from oldest to youngest: Granite Rocks, Salmon Creek Volcanics, Reynolds Basin Group, Rhyolitic Welded Ash Flow tuffs, and Quaternary Alluvium with pediments and landslide deposits.

Basaltic rocks cover approximately 38 percent of the total area of the watershed. The remaining rock types occur in a considerably lesser extent. Alluvium covers only 2.5 percent of the area and occurs mostly along the narrow flood plains of the valley floor.

The basaltic rocks contain the major aquifer systems within the watershed, although several flowing wells occur from local flow systems developed within sand lenses in the lake sediments. To date, no aquifer system in the watershed has been recognized as a valuable source of ground water for purposes other than domestic or stock water use.[1]

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[1] Personal correspondence, 1972, Walter J. Rawls, Hydrologist, ARS Northwest Watershed Research Center, Boise, Idaho.

Hydrologic Characteristics

About 75 percent of the annual precipitation occurs on the Reynolds Creek watershed from October to April inclusive and is mainly in the form of snow. This precipitation is a result of general frontal-type storms moving in from the west. Summer rainfall results generally from convective-type storms typical of arid and semi-arid regions. Estimates of precipitation (Neff, 1965) range from about six inches in the drier parts to more than 25 inches in the higher elevation snow accumulation zones. Of the estimated water yield of 8,000 acre-feet, approximately 75 percent is generated from 25 percent of the contributing area (Neff, 1965).

The ground water resource of the basin occurs mainly in the unconfined basaltic rocks although some wells in the lake deposits and sand lenses yield water under artesian pressure.

Vegetative Characteristics

A wide diversity of plant associations occurs on the Reynolds Creek Experimental Watershed. The diversity is accounted for by the continuum of climate along the elevation gradient. Plant communities vary from those typical of the Great Basin Desert at the lower elevations to alpine communities at the highest elevations.

Sagebrush is the dominant species in the basin. Three varieties appear in varying quantities at all elevations. Big Sagebrush (*Artemisia tridentata*) occurs mainly below 4,500 feet but is present at all elevations. Small Sagesbrush (*Artemisia arbuscula*) is dominant between 4,500 and 6,000 feet above which vaseyan sagebrush (*Artemisia vaseyana*) occurs. Interspersed among the sagebrush is a mosaic pattern of other plant communities varying according to the microclimate caused by the complex topography and relief of the basin. These communities include shadscale (*Artiplex confertifoliea*), greasewood (*Sarcobatus vermiculatus*), spiny hopsage (*Grayia spinosa*), bitterbrush (*Purshia tridentata*), mountain mahogany (*Cercocarpus ledifoluis*), bluebunch wheatgrass (*Agrophron spicatum*), currant (*Ribes* spp.), snowberry (*Symphoricarpos* spp.), bitter cherry (*Prunus emarginata*), cottonwood (*Populus tremuloides*), Douglas fir (*Pseudotsuga menziesii glauca*), and alpine fir (*Abies lasiocarpa*). Due to intensive mining activity in the area 75 to 100 years ago, there is no timber of commercial value in the basin.[2]

In addition to the 58 plant families which have been identified and mapped, the watershed has been mapped according to cover class on a scale from one to four corresponding to vegetation densities of 0-25 percent, 25-50 percent, 50-70 percent, and 75-100 percent respectively.

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[2] Personal correspondence, 1972. Walter J. Rawls, Hydrologist, ARS Northwest Watershed Research Center, Boise, Idaho.

ARS Investigational Program

In 1959 at congressional direction, the Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture,undertook studies of the hydrologic performance of Reynolds Creek. This basin was selected as representative of the 50 to 60 million acres of sagebrush-rangeland in the northwest United States. The primary purpose of this project was to study water yield as influenced by the various climatic, soil, vegetative, and topographic parameters (Neff, 1965).

When the ARS investigation was started, an initial raingage network consisting basically of one unshielded recording raingage per square mile was established. This network, which operated from 1961 to 1967, provided basic information on the seasonal and annual areal distribution of precipitation.

Because both shielded and unshielded gages have been shown to catch somewhat less than the actual amount of precipitation which falls, especially when it is in the form of snow (Warnick, 1956; Neff, 1966), investigations were initiated on the Reynolds Creek Watershed in 1964 to study methods of obtaining adequate precipitation data when the precipitation is mainly in the form of snow. These investigations led to the establishment of the dual-gage network presently used on Reynolds Creek. Each dual-gage installation is instrumented with two National Weather Service standard recording gages located 20 feet apart. Orifices are eight inches in diameter and 10 feet above ground. One gage is equipped with a modified

Alter shield with baffles individually constrained at an angle of 33 degrees from the vertical. The top of the shield is at the height of the gage orifice and the bottom of baffles extends toward the gage (Hamon, 1971). Hamon (1971) states, "The dual-gage installation -- one gage unshielded and one gage shielded -- was found to give the data required to compute 'actual' precipitation." The equation derived under Hamon's study to compute the "actual" precipitation is

$$\ln (U/A) = B \ln (U/S) \qquad \text{(Equation 1)}$$

where U = unshielded gage catch

A = "actual" precipitation

B = calibration constant, 1.80

S = shielded gage catch.

This approach to adjusting data which may have been adversely influenced by wind is promising, but because it is not yet widely accepted, only the shielded gage data were used in the analysis for this study.

CHAPTER IV

PROCEDURES

Raft River Basin Field Work

Gage Location and Network Design

In the summer and early fall of 1971 a network of gages at 24 sites was established in the Raft River Basin.

Two areas were selected for intensive study because they afforded the opportunity to locate gages in a variety of environments corresponding to increases in elevation. These areas were the north slope of the Raft River Mountains, southwest of Naf, Idaho, and the north and south slopes of Mount Harrison, southeast of Albion, Idaho. Of the 24 gage sites established for this project, 16 are in these two areas. The remaining eight sites are dispersed throughout the basin. Figure 1 shows the location of project gages in addition to gage sites established within the basin by other agencies.

Because of the cost and lack of storage volume in conventional precipitation gages, it was decided to design low-cost gages specifically for reconnaisance use. Since conventional gages mounted on towers are easy prey for vandals with firearms and since measurement of the precipitation actually reaching the ground was desired, low, ground-level gages were designed.

The gages installed for this project are of five basic types, two of which were an experimental design.

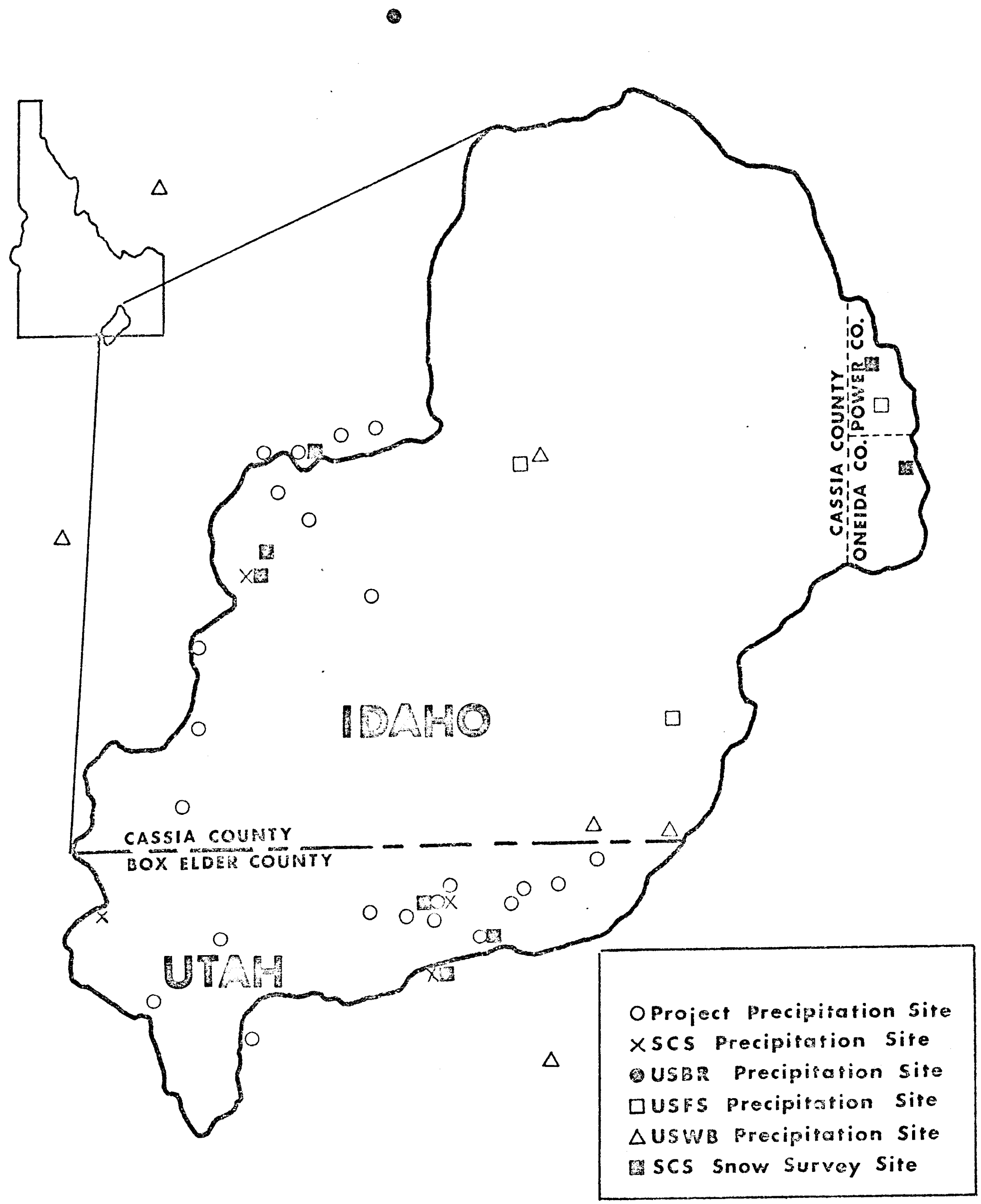

Figure 1. GAGE LOCATIONS IN RAFT RIVER BASIN

The first of the experimental gages and the most common in the network is called a "pit gage" (Figure 2). These gages are installed in ground excavations so that the top of the 5-gallon can is level with the ground surface. The orifice is approximately six inches from and parallel to the ground surface.

The second experimental gage is called a "drum gage" (Figure 3). Installation consists of burying the drum to a depth equal to approximately three-fourths of its diameter, digging a trench for the hose, and seating the catch pan on the uphill side of the drum. A problem associated with the drum gage not realized until field installation is that the lock nut inside the catch pan protrudes approximately one-half inch. Precipitation from a minor storm will be caught in the pan, but it may not fill the pan to sufficient depth to overflow the nut and become trapped in the drum. Also, the last precipitation from a major storm will not be able to run into the drum.

A problem associated with the two experimental gages, and in fact all ground-level gages used in cold climates, is that ice lenses form due to melt-freeze conditions on the snowpack. Melt water may be intercepted above these lenses and channelled away from the orifice, thus reducing the catch of the gage.

An improvised cattle guard (Figure 4) was constructed around the orifice of the experimental gages at all but a few sites which are enclosed by a barb-wire fence. After one year of service these cattle guards were judged to function adequately. The inexpensive

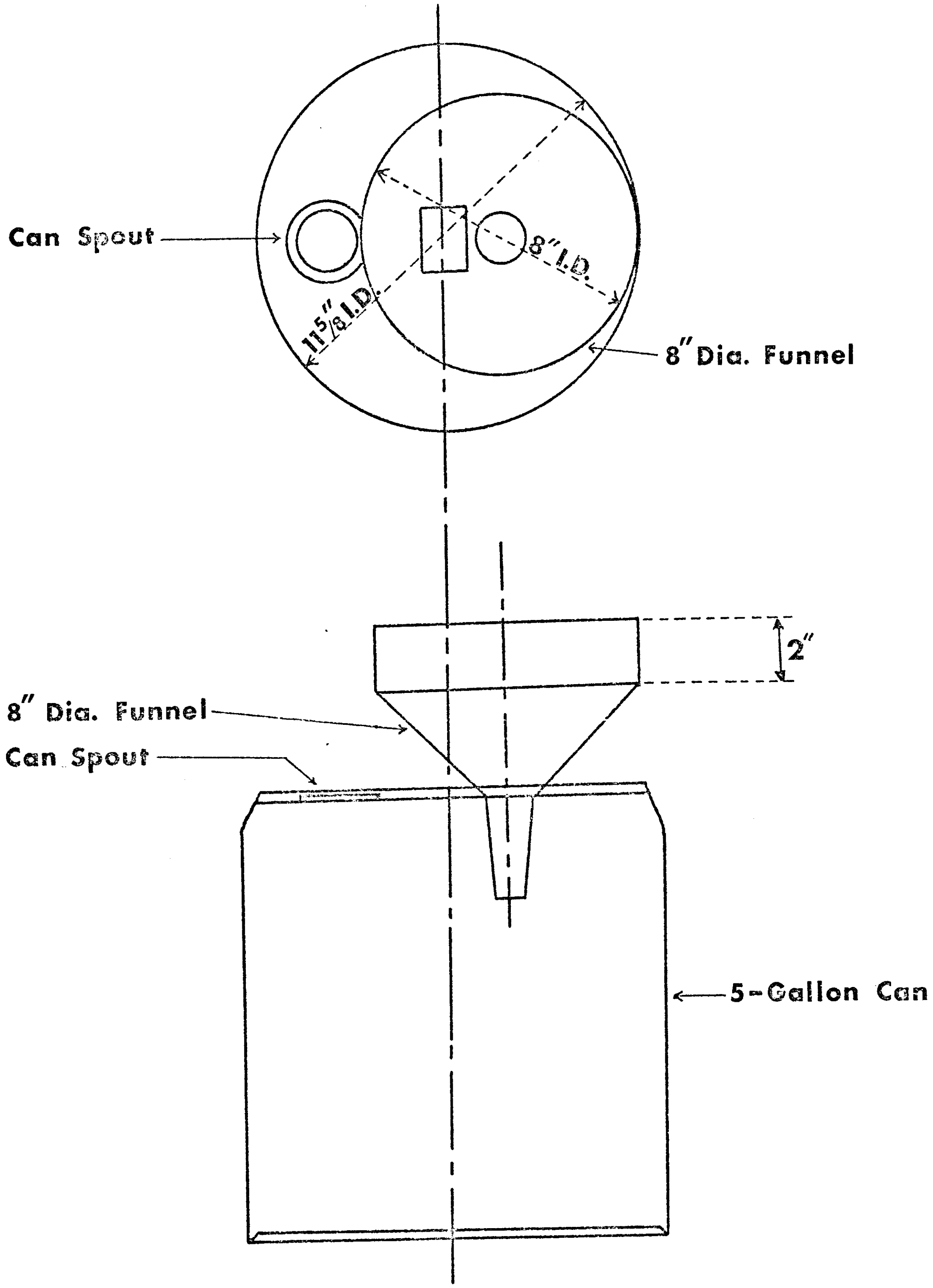

Figure 2. PIT GAGE

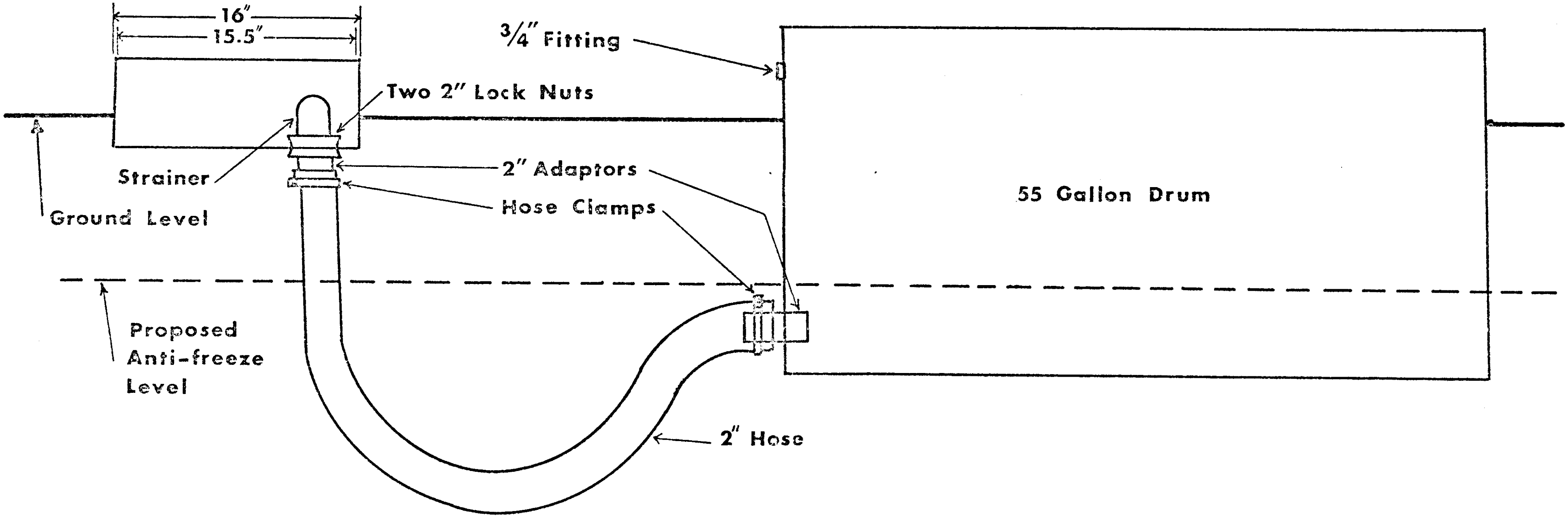

Figure 3. DRUM GAGE

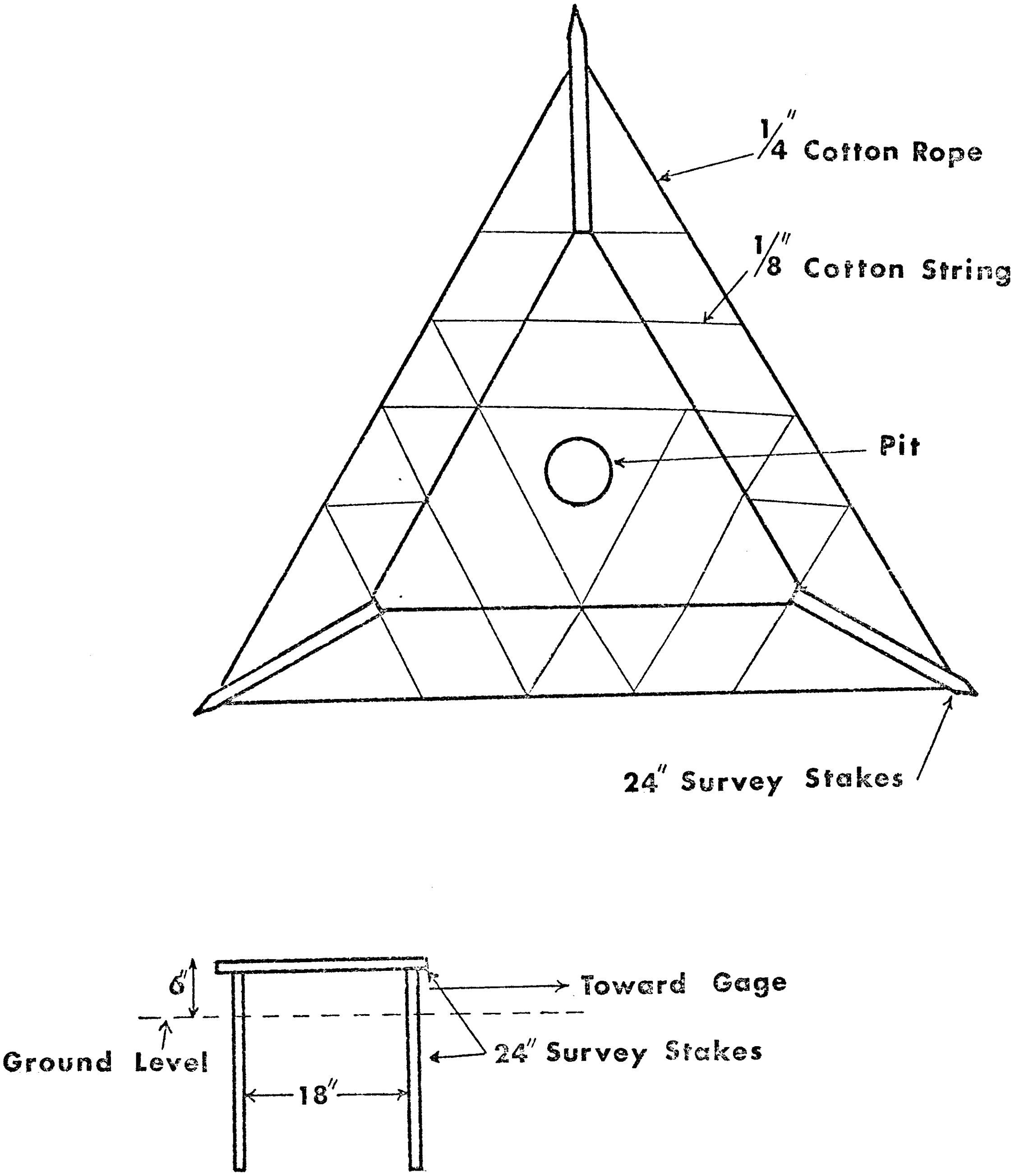

Figure 4. CATTLE GUARD

cotton rope and twine did not deteriorate as had been feared, nor was it attacked by hungry rodents. Only one of the installations was disturbed by domestic stock, and in this case the cattle guard had been destroyed by vandals. Tracks around the other sites indicated that both domestic stock and wildlife avoided the immediate area of the gage.

The third type of gage used is mounted on a tower. Two are the "Sacramento"-type with the diameter of the storage area larger than the diameter of the orifice, and four are of the straight-tube type. Four have modified Alter shields. Four are mounted on steel towers while two are mounted on wood frame structures. All tower gages are mounted so the orifice is parallel to the ground surface.

The fourth type of gage used is a standard 8-inch diameter by 24-inch high National Weather Service storage precipitation gage with the measuring tube removed. This is mounted on a 12-inch diameter timber post projecting approximately three feet above the ground so the orifice height is about five feet above the ground surface. A second use of the standard National Weather Service gage is to bury it so the orifice projects about six inches above the ground surface. In this capacity it functions like the pit gages designed for the project.

The fifth type of gage used is the Belfort Weighing Rain Gage No. 551 equipped with a battery operated 31 day chart drive mechanism. Two of these are mounted approximately 20 feet apart on 12-inch diameter timber posts projecting about seven feet above the ground so the gage orifice is approximately ten feet above the surface of the ground. These were installed and calibrated by personnel from the Northwest Watershed Research Center of the U.S. Agricultural Research Service in Boise, Idaho. These gages were to be serviced by local residents under the direction of the ARS.

The sites for locating gages in the intensive study areas of Mount Harrison and the Raft River Mountains were chosen mainly on the basis of elevation. Gages are located from 5,600 feet to 9,100 feet at elevation intervals of approximately 800-1,000 feet so that if an elevation-precipitation relationship does exist it might be revealed. The remaining eight gage sites are distributed around the basin and placed in locations that will be representative of a large surrounding area.

Nine of the 24 sites have more than one type of gage installed. The purpose of this is twofold. First, there has been no previous experience with the two experimental type gages used regarding how much precipitation they catch compared to more common types of gages such as the tower gage. By installing an experimental gage alongside a conventional gage, the two types of gages could be compared.

Second, Brown and Peck (1962) have stated, "Unless the gage is situated such that drifting snow might accumulate in the gage or blow into the gage from nearby objects, it is believed that the larger the catch, the closer it represents the amount which actually fell at the site." Thus, by having a multiple installation at the site, the investigators can choose which gage to use for precipitation data at that site. The gages that Brown and Peck experimented with were tower gages in which drifting snow could accumulate to a depth greater than that which actually fell. The two experimental gages used in this project would not normally accumulate drifts beyond the normal depth of deposition, since they are so close to the ground surface.

When the sites were established, data on slope, aspect, degree of exposure (protection), vegetation type, and vegetation height were recorded. Slope was recorded in percent, aspect was the nearest of the sixteen points on the compass measured along the slope, exposure was qualitatively rated from "well protected" (360 degree protection; angle subtended greater than 30 degrees but less than 45 degrees; e.g. an open area in a coniferous forest) to "open" (very little or no protection, gage site fully exposed; e.g., on a bare sagebrush ridge). Vegetation height included both the height in feet of the vegetation in the immediate vicinity of the gage and the height in feet of trees or brush providing protection for the gage.

Gage Maintenance

Servicing the gages installed in the Raft River Basin is done on an annual basis. The contents of the gage are pumped out with a portable D.C. pump operated by a 12-volt auto battery and are weighed on a spring scale accurate to approximately 0.1 pounds. The net precipitation is equal to the total weight of the contents minus the weight of the previous year's antifreeze-oil solution converted to inches of water for the gage orifice diameter. The antifreeze is to prevent the gages from being damaged by ice action within them and the oil is to prevent evaporation during the warmer weather. Since all the gages are installed with their orifices parallel to the ground surface, the equivalent depth of water for the orifice is divided by the cosine of the slope angle to compensate for the reduced vertical projected area of the sloped orifice (Hamilton, 1954). This assumes that incident rainfall comes in a vertical direction, but with the absence of wind records in the area, it can only be assumed that on the average rain does fall vertically.

After its contents have been pumped out, the gage is recharged with antifreeze and oil. One gallon of antifreeze will protect 30 inches of precipitation through an eight inch orifice to a temperature of 24 degrees Fahrenheit. Since ground temperature beneath a snowpack rarely goes much below 32 degrees Fahrenheit, protection to 24 degrees is considered sufficient for all buried gages. Tower gages are protected to minus four degrees Fahrenheit. Based on the premise that approximately three-fourths of the precipitation at the site would fall during the months when freezing weather would be prevalent, an amount of antifreeze sufficient to protect three-fourths of the anticipated annual precipitation is placed in the gage and the weight of that is recorded. Hamilton and Andrews (1953) stated that 0.15 inches of a light oil such as that used in dash-pots for electrical circuit breakers will stop all evaporation in gages without funnels. The oil used in the project gages was a light transformer oil and was contributed by the Raft River Electric Cooperative, Inc. An amount of oil equal to the recommended depth is placed in the gages and this weight is also recorded. Fifteen-hundredths of an inch of oil is placed in all gages regardless of whether or not they have funnels in order to insure no evaporation of water.

Gage Overflows

The gages were installed and charged with antifreeze for the first time in September, 1971. Inspection of the sites in late July, 1972, revealed that nine of the twenty 5-gallon pit gages had received precipitation in excess of their capacity due to the above average snowpack conditions during the winter of 1971-72. This excess leaked out the spout of the can into the soil and was nonretrievable. To prevent the recurrence of this loss of data in other wet years, the nine gages which overfilled and one which had been destroyed by vandals were replaced in September, 1972, with modified pit gages (Figure 5) constructed from 10-gallon milk cans. The modified pit gages have twice the storage capacity and are easier to service.

Since six of the nine gages which overflowed were not at multiple installation sites, no value for total precipitation was available at those sites. To compound the problem, the two areas of special study interest, the Raft River Mountains and Mount Harrison, are at higher elevations. Consequently, they had the greatest frequencies of overfilling. As a result of this loss of data, the investigators asked for and received permission to use data collected in the Reynolds Creek Basin by the Northwest Watershed Research Center, U.S. Agricultural Research Service, Boise, Idaho.

Reynolds Creek Basin Field Work

Gage Location and Network Design

When the ARS investigation was started, an initial raingage network consisting basically of one unshielded recording raingage per square mile was established. This network, which operated from 1961 to 1967, provided basic information on the seasonal and annual areal distribution of precipitation.

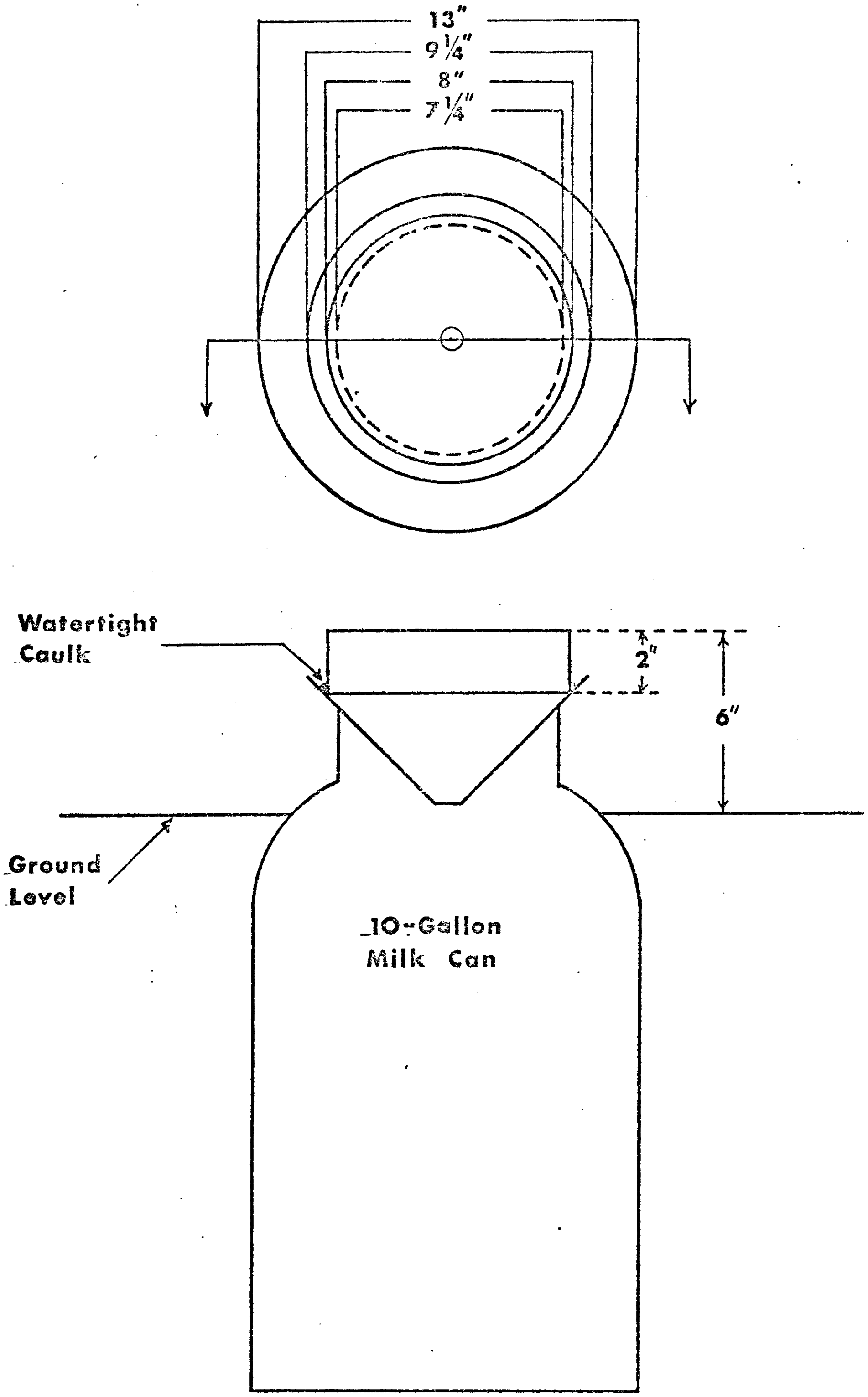

Figure 5. 10-GALLON MILK CAN GAGE
MODIFIED PIT GAGE

In the fall of 1967 the initial network of unshielded recording gages on Reynolds Creek was dismantled and the dual gage network was installed. Sites were chosen so that the distance between gage locations is approximately two miles (Figure 6). Because the main purpose of the dual-gage network is to determine the effect of wind on the catch of the gages, most of the gage sites are on exposed ridges.

Each dual-gage installation is instrumented with two National Weather Service standard recording gages located 20 feet apart. Orifices are eight inches in diameter and 10 feet above the ground. One gage is equipped with a modified Alter shield with baffles individually constrained at an angle of 33 degrees from the vertical. The top of the shield is at the height of the gage orifice and the bottom of the baffles extends toward the gage (Hamon, 1971).

Gage Maintenance

Two types of recording devices are used in the gages on Reynolds Creek. Some are equipped with 30-day strip charts to be read every two weeks, while others have eight-day drum charts to be read every week.

All gages are charged with an antifreeze-oil solution in the winter to prevent freezing and with oil in the summer to prevent evaporation.

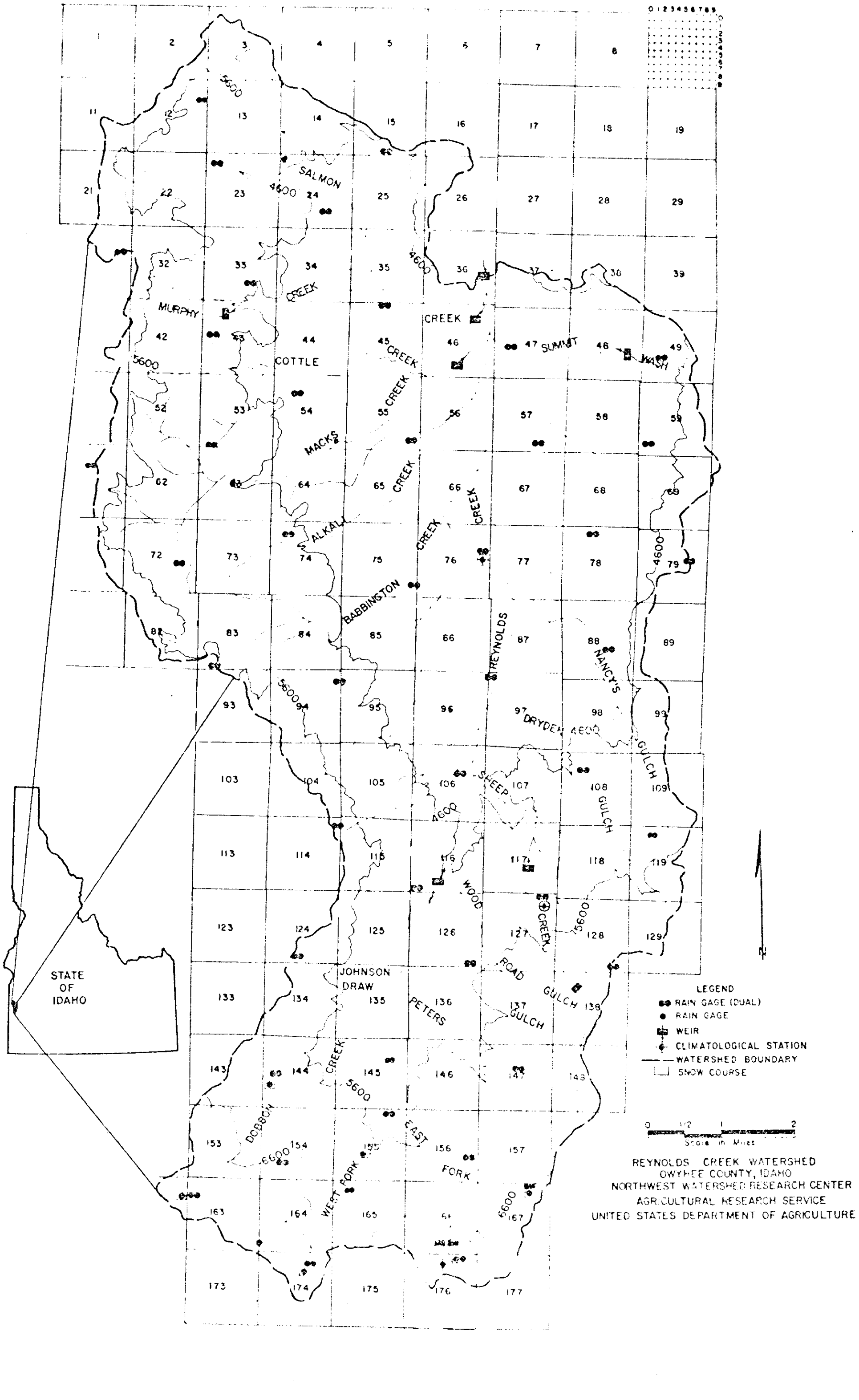

Figure 6. GAGE LOCATIONS IN REYNOLDS CREEK EXPERIMENTAL WATERSHED

Analytical Work

General

Because of the loss of data on the Raft River due to gage overlows, no analytical work was done on the existing data for that basin. All analysis was done using data obtained by the ARS on Reynolds Creek Basin. More field work and interpretive work must be done to develop a methodology for extrapolating results of this study to the Raft River Basin.

Organization of Data

The annual shielded-gage precipitation catch in Reynolds Creek Basin for the years 1969, 1970, and 1971 was used in the analysis. Of the 45 gages available, eight had missing data for one of the three years, and a method was found to determine the missing values.

Selection of Techniques

Three methods of analysis were selected to determine the distribution of annual precipitation over Reynolds Creek Basin. They are: (1) isohyetal mapping by computer, (2) a multiple-regression analysis for estimating precipitation, and (3) the Thiessen method which was used to determine relative accuracy of mean precipitation estimates using various numbers of gages.

The computer method of preparing isohyetal maps was selected rather than manual preparation because it saved time and eliminated human error in preparation.

The multiple-regression analysis was used to develop a predictive equation for estimating the annual precipitation at points in Reynolds Creek Basin. It was also used to stratify the basin into sampling zones for use in the Thiessen analysis.

The Thiessen analysis was used to determine the accuracy of five, ten, 20 and 30 gage networks relative to the 45 gage network available.

Prevailing Wind Indicator

An inexpensive device to determine prevailing wind directions in the study areas was designed by John J. Peebles and modified somewhat by the author (Figures 7 and 8). The indicator is balanced by use of the counterweight and the hardened point on the quarter-inch machine bolt scores the magnesium ring. Over the period of about a year the depth of wear in the disk can be used to determine the approximate direction of the prevailing wind. Materials softer than magnesium may be used to determine prevailing wind direction for periods of shorter duration.

This parameter of prevailing wind could logically be used as a basic measureable item for deciding on location of gages in a network. Unfortunately, no detailed data are available to make such

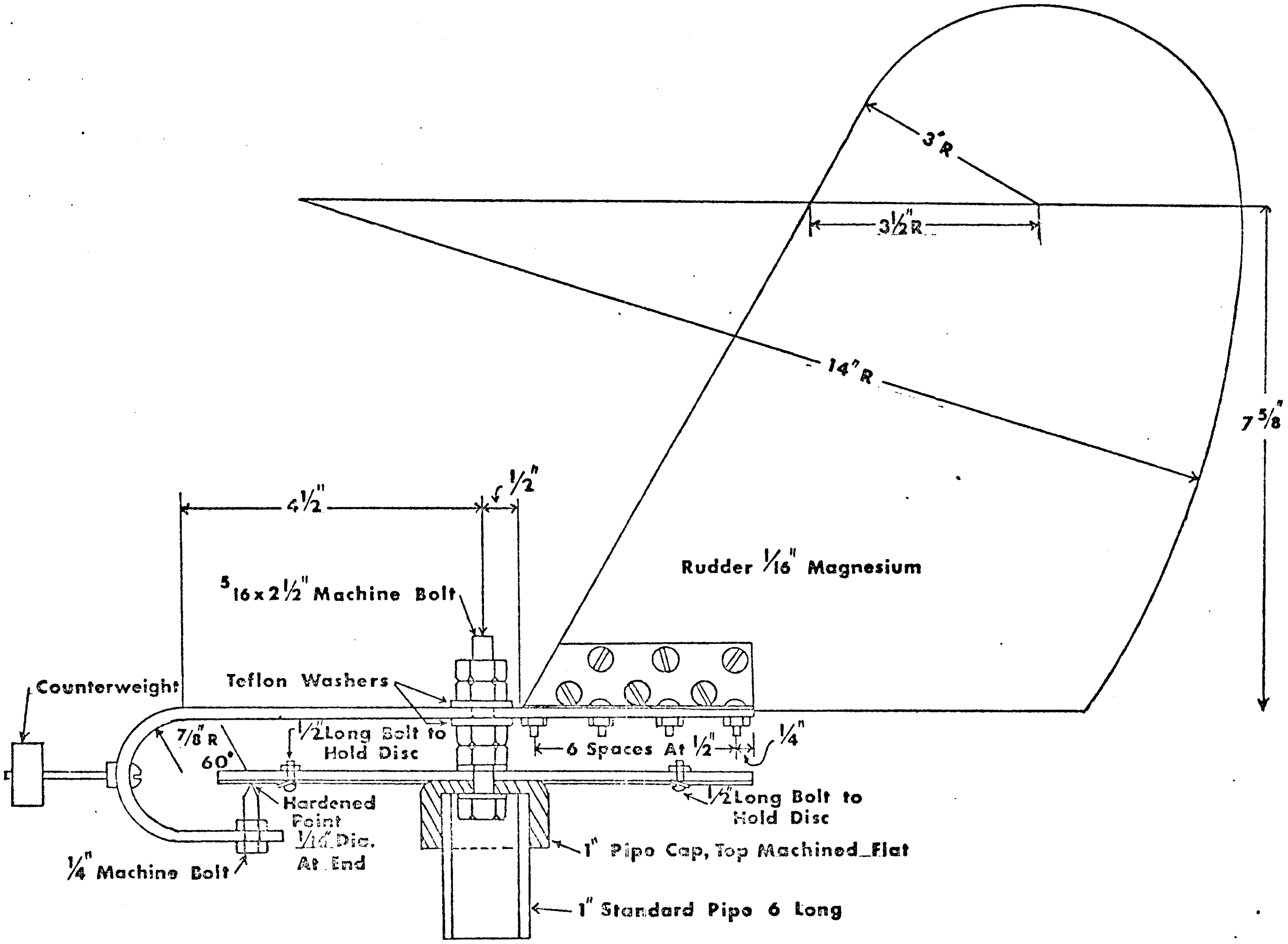

Figure 7. ELEVATION VIEW OF PROPOSED PREVAILING WIND INDICATOR

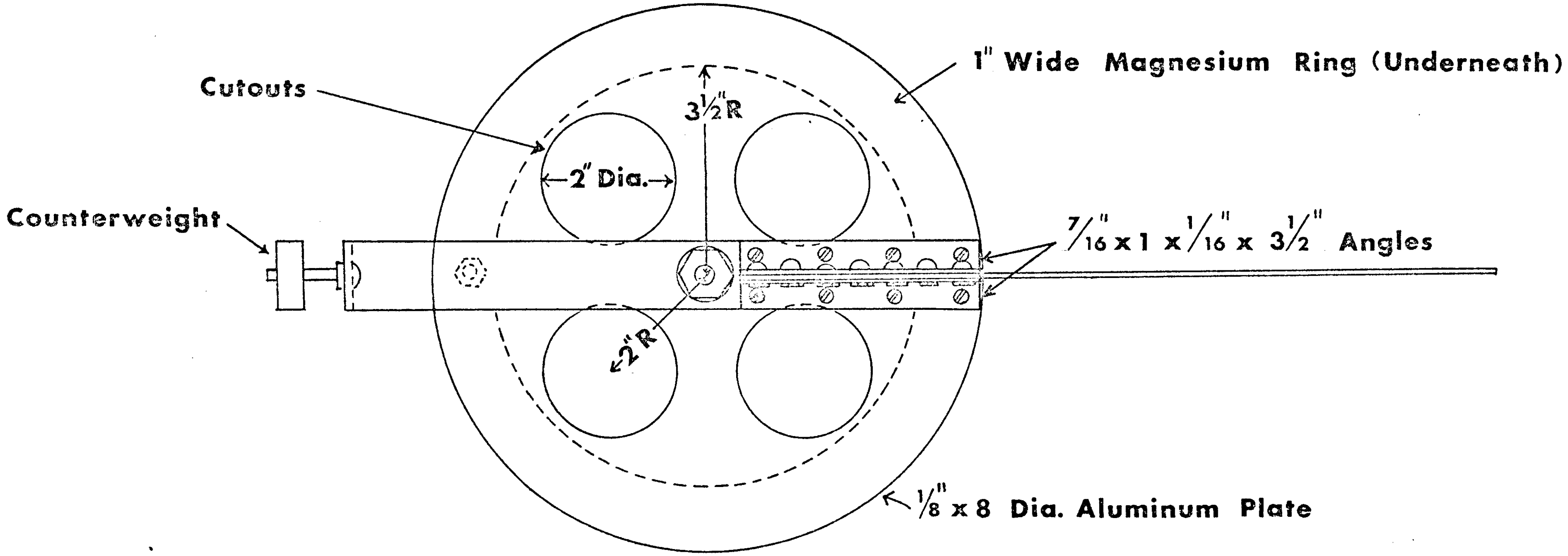

Figure 8. PLAN VIEW OF PROPOSED PREVAILING WIND INDICATOR

an analysis. This inexpensive device proposed by Peebles could be used to obtain such data.

CHAPTER V

RESULTS

Missing Data Collections

Eight of the stations had no record for one of the three years used to obtain an annual average. The National Weather Service method was used to estimate the precipitation for the missing year. In this procedure, if the normal annual precipitation at each of three nearby index stations is within 10 percent of that for the station with the missing record, a simple arithmetic average of the precipitation at the index stations provides the estimated amount. If the normal annual precipitation at any of the index stations differs from that at the station in question by more than 10 percent, the normal-ratio method is used. In this method the amounts at the index stations are weighted by the ratios of the normal-annual-precipitation values. That is, precipitation at station X, P_x is

$$P_x = 1/3 \left[N_x P_a / N_a + N_x P_b / N_b + N_x P_c / N_c \right] \quad \text{(Equation 2)}$$

where N_x, N_a, N_b, and N_c are the normal annual precipitation values and P_x, P_a, P_b, and P_c are the annual precipitation values for the year of missing data (Linsley, et al., 1958).

Isohyetal Method

An important part of the study and interpretation of precipitation records is the preparation of isohyetal maps. These maps, showing lines of equal precipitation over an area for a specified time period, are often prepared by hand. Since this is a tedious job requiring many hours of drafting and interpretation, human errors due to boredom or fatigue are often introduced. To avoid such problems, a computer program (Diskin and Davis, 1970; Appendix E) was used to develop the isohyetal maps used in this project.

The program uses an interpolation procedure similar to that which would be used by manual preparation. It is a linear interpolation along straight lines connecting adjacent stations. Thus, if the depths of rainfall at two adjacent stations are H_1 and H_2, and the distances from the stations to a point on the line are L_1 and L_2, the interpolated depth of rainfall at the point is

$$H = H_1 + \frac{L_1 (H_2 - H_1)}{L_1 + L_2} \qquad \text{(Equation 3)}$$

or

$$H = \frac{L_2 H_1 - L_1 H_2}{L_1 + L_2} \qquad \text{(Equation 4)}$$

Denoting the distance between the two stations by L, the equations may be solved for the distance along the line from Station No. 1 to a point where the interpolated depth is a given value H.

$$L_1 = \frac{H - H_1}{H_2 - H_1} L \qquad \text{(Equation 5)}$$

If the stations are specified in terms of their coordinates on a rectangular X-Y system (Figure 9), the equations may be rewritten in terms of these coordinates. The equations for the coordinates (X_p, Y_p) of the point where the depth of rainfall is H, corresponding to Equation 5, are

$$X_p - X_1 = \frac{H - H_1}{H_2 - H_1} (X_2 - X_1) \qquad \text{(Equation 6)}$$

and

$$Y_p - Y_1 = \frac{H - H_1}{H_2 - H_1} (Y_2 - Y_1) \qquad \text{(Equation 7)}$$

The first step in the application of the above procedure is the construction of a network of interpolation lines. Interpolations were performed between stations and the nearest neighboring stations. The network used for this study is shown in Figure 10. The computer-determined isohyetal map of Reynolds Creek Basin corresponding to the interpolation scheme is shown in Figure 11.

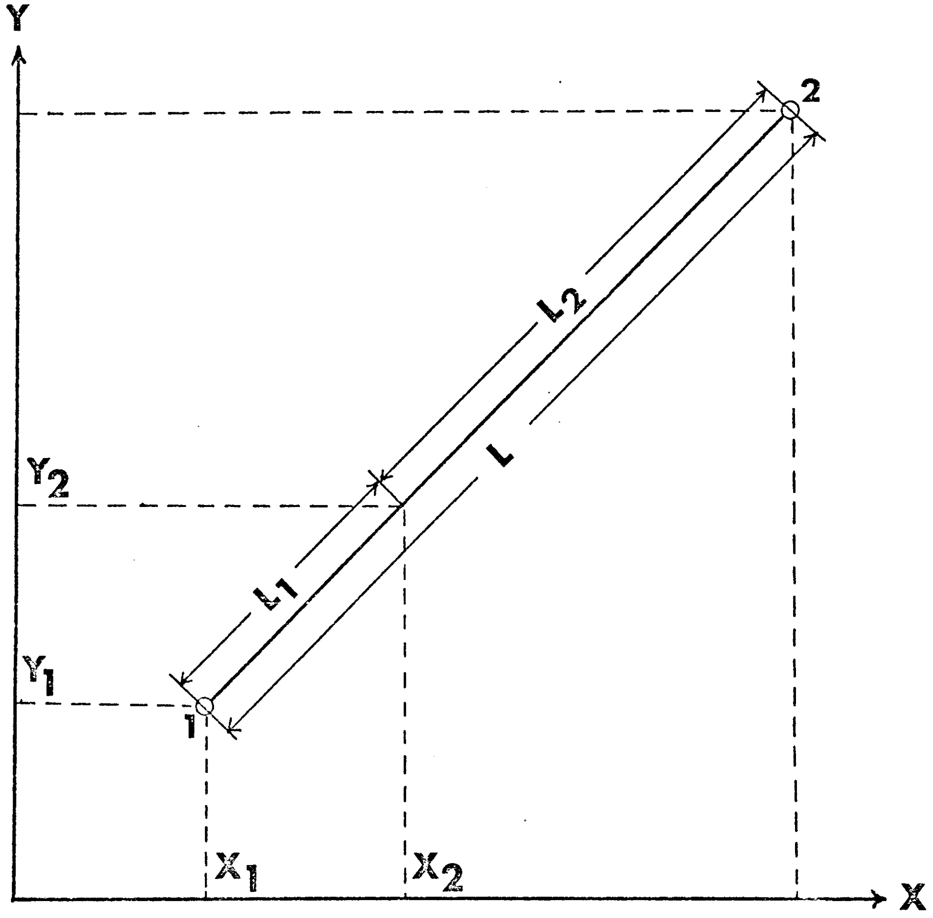

Figure 9. X-Y COORDINATE SYSTEM USED IN ISOHYETAL COMPUTER METHOD

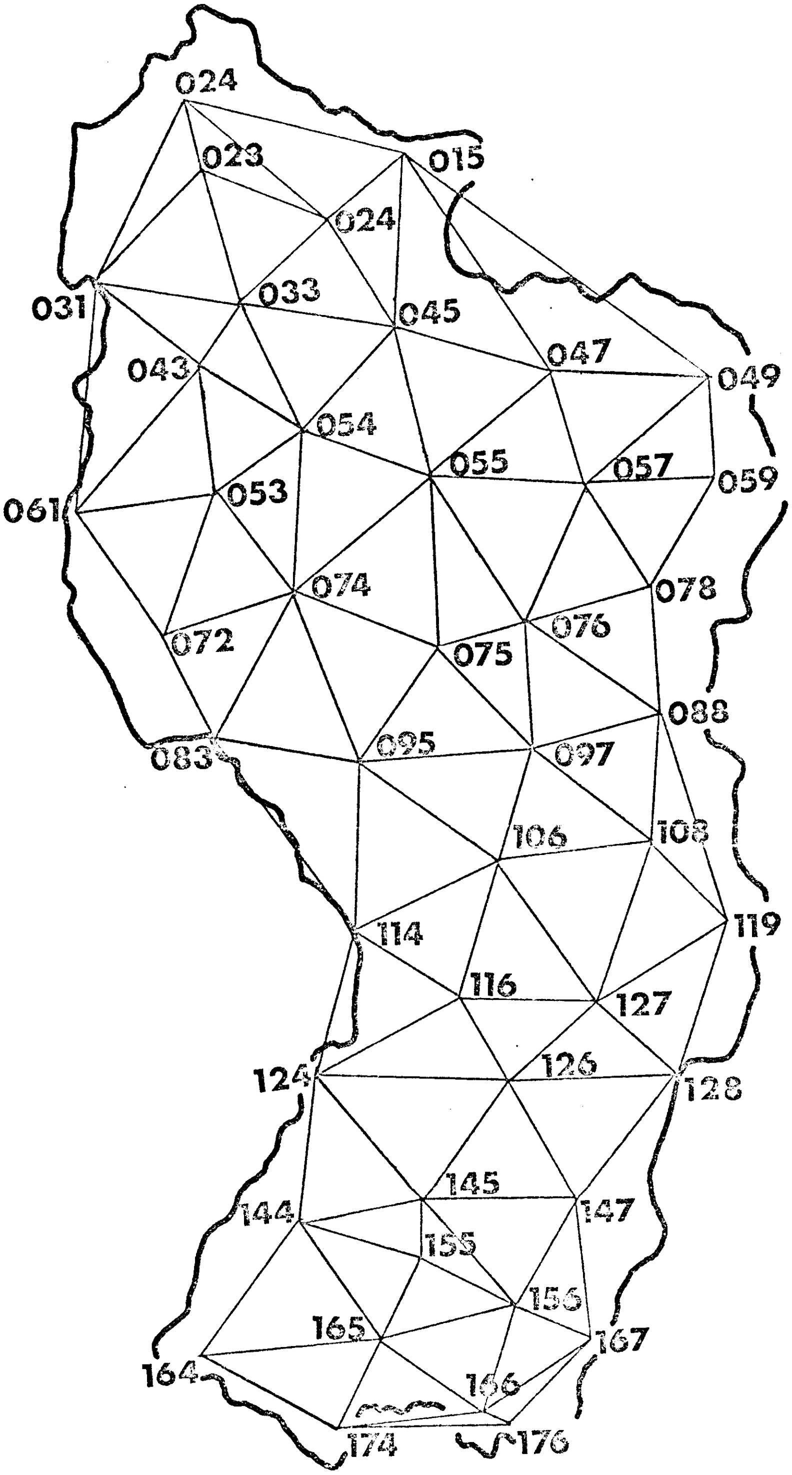

Figure 10. INTERPOLATION NETWORK USED IN ISOHYETAL COMPUTER PROGRAM

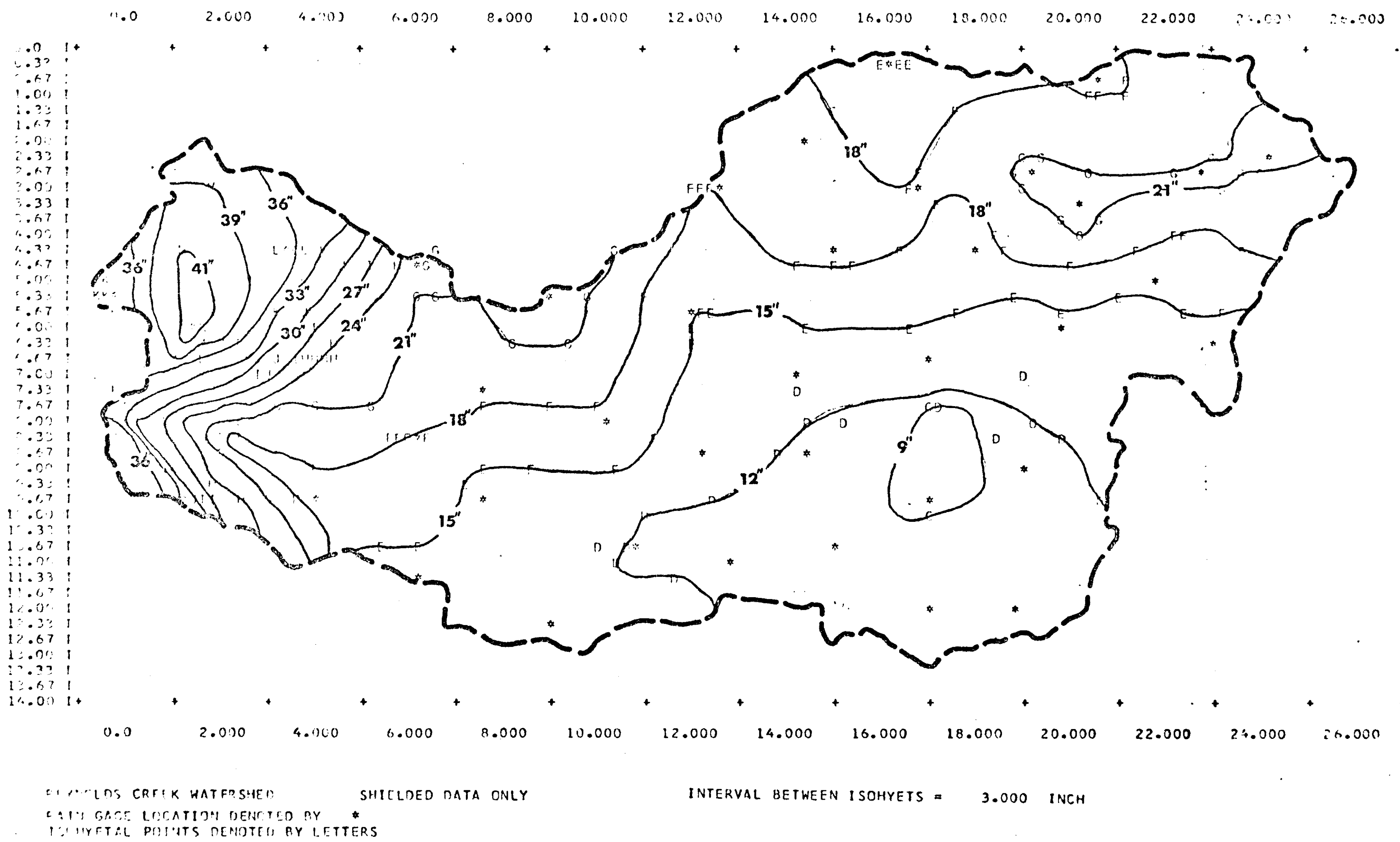

Figure 11. COMPUTER DETERMINED ISOHYETAL MAP FOR REYNOLDS CREEK WATERSHED

Multiple-Regression Method

Before investigating the confidence-interval versus gage-density relationship, some method had to be developed to determine which of the 45 gages should be used in the reduced networks. A random process of selecting gages for the reduced networks was considered but discarded because in a practical sense one would not randomly locate gages in a basin to determine the average depth of precipitation in that basin. One would carefully select sites that were not overly exposed to wind, located in snow accumulation zones, or otherwise exposed to any phenomenon which might make the data obtained from that gage unrepresentative of the surrounding area.

In order to develop a rational method of selecting gages to be used in the reduced networks, correlation and regression analyses were performed on parametric data for the gage sites. The independent parameters used in these analyses were elevation, slope, aspect, cover class, and soil type at the gage site. Elevation was height above mean sea level in thousands of feet and was obtained from previously published data (Hamon, 1971). Slope was the average slope of the area surrounding the gage site and was in percent. Aspect was the average azimuth of the slope of the surrounding area. Cover class was rated from one to four corresponding to vegetation densities of 0-25 percent, 25-50 percent, 50-75 percent, and 75-100 percent respectively. Soil type was rated from one to four corresponding to SCS hydrologic soil classifications, A, B, C, and D respectively (Appendix C). The dependent variable was a three year average of annual shielded-gage precipitation catch. The correlation matrix for the parameters used (Table 1) showed a significant interdependence between elevation and cover class at the 95 percent level ($r=0.574$). However, since the parameters in the regression analysis were to be used to predict the point precipitation rather than to explain it, the lack of independence between elevation and cover class was ignored.

Since previous investigators (Grafton and Dickerson, 1969; Donley and Mitchell, 1939; Henry, 1919; Lee, 1911; Peck and Brown, 1962) have shown that elevation has a significant effect on precipitation, elevation was included with every combination of the other four independent variables and a regression analysis was made on each of these combinations.

The multiple-regression analysis obtained the best fit for a set of observations of the dependent and independent variables in the form of

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots + b_nX_n \qquad \text{(Equation 8)}$$

In this equation Y is the dependent variable, $X_1, X_2, \dots, X_n$ are the independent variable with coefficients $b_0, b_1, b_2, \dots, b_n$.

Table 1

CORRELATION MATRIX FOR PARAMETERS USED IN REGRESSION ANALYSIS

	Elevation	Slope	Aspect	Cover Class	Soil Type	Precipitation
Elevation	1.000					
Slope	0.437	1.000				
Aspect	0.029	0.061	-1.000			
Cover Class	0.582*	0.184	-0.105	1.000		
Soil Type	0.218	0.180	0.268	-0.086	1.000	
Precipitation	0.703	0.347	-0.136	0.715	0.051	1.000

* Indicates significant correlation at 95% level (r=0.574).

Since R^2 is the fraction of the total variation in the independent variable that is accounted for by the association between the independent and dependent variables (Huntsburger, 1967), it may be used to judge whether the addition of a variable reduces the variance enough to make the inclusion of that variable in the regression equation meaningful. A variable was considered meaningful if it contributed to the explanation of more than five percent of the total variation in the independent variable.

Using elevation alone as the independent variable in the regression analysis yielded an R^2 of 0.49. The addition of cover cla as an independent variable increased R^2 to 0.64, and the addition of slope, aspect, and soil type to elevation and cover class yielded an R^2 of 0.65. Thus, the addition of slope, aspect, and soil type added only one percent to the R^2 for the equation and these last three variables were not carried forward in the later computations.

In support of eliminating the variables slope, aspect and soil type, the t-value may be used to test the significance of the regression coefficients. Here a value equal to or greater than that for the 0.05 probability of t (about 2.15 for the samples used) is construed to mean that the coefficient is not equal to zero.

Using all five independent variables, the regression equation was

$$Y = -6.47 + 3.55 X_1 + 0.14 X_2 - 0.02 X_3 + 3.50 X_4 + 0.17 X_5$$

Correlation Coefficient = 0.81 (Equation 9)
Standard Error = 5.29 inches

where Y = Estimated annual precipitation

X_1 = Elevation above m.s.l. in thousands of feet

X_2 = Slope of gage site in percent

X_3 = Compass degree reading along the slope (aspect)

X_4 = Cover Class

X_5 = Soil Type

The computed t-values for the five regression coefficients were 2.97, 0.89, -1.11, 3.78, and 0.16 respectively, Thus, only the coefficients for elevation and cover class (X_1 and X_4) were significantly different from zero at the 95 percent level.

The final regression equation using only elevation and cover class was

$$Y = -8.60 + 3.91\ X_1 + 3.54\ X_4 \qquad \text{(Equation 10)}$$

Correlation Coefficient t = 0.80
Standard Error = 5.23 inches

Where Y = Estimated annual precipitation

X_1 = Elevation above m.s.l. in thousands of feet

X_4 = Cover class

In this equation the computed t-values of the regression coefficients for elevation and cover class were 3.78 and 4.04 respectively.

Sampling Technique

Both elevation and cover class proved to be significantly associated with annual precipitation in a regression analysis. In order to insure that the hypothetically reduced networks contained a diversity of cover class and elevation sites, an attempt was made to subdivide Reynolds Creek Watershed into zones by incorporating these two parameters. However, since the cover class zones were not continuous over large areas as were elevation zones, and because no satisfactory stratification according to both elevation and cover class could be developed, the basin was divided into zones based first on the elevation parameter and then on the cover class parameter.

Since the basin was divided into zones for the purpose of deciding which gages should be used in the reduced networks, stratified sampling techniques were employed. The theory of stratified sampling is that rather than sampling the same number of items from each strata, the number of samples from each strata, n_h, should be proportional to $N_h\sigma_h/\sqrt{c_h}$, where N_h is the total number of samples, σ_h is the standard deviation, and c_h is the cost of sampling per unit in the h^{th} strata. This method of sample allocation gives the smallest standard error of the estimated mean $\bar{y}_{st}$ (Snedecor and Cochran, 1967). Assuming the cost of sampling per unit (gage) to be the same in the Reynolds Creek Basin, n_h should be proportional to $N_h\sigma_h$. Thus, more samples should be taken in a stratum with a high variance than in one with a low variance.

Three methods of stratifying the basin by elevation were tried. Method 1 had four zones each with approximately the same number of gages in them. Method 2 had four zones each containing approximately the same area. Method 3 had four zones between the lowest elevation in the basin and the highest desirable gage site such that the elevation difference in each zone was equal.

In each of the three methods, proportioning the individual stratum sample size by $N_h\sigma_h$ resulted in a need for more samples in the thirty gage networks than were present for one of the strata (Table 2). Since Method 3 required the lowest number of adjustments to correct this situation, it was adopted as the method used for stratification. When more gages were needed in a zone than were present, all the gages for that zone were used in the network and the excess number needed was distributed among the other zones proportional to $N_h \sigma_h$. In cases where the proportion of $N_h \sigma_h$ for a zone was less than one, as in the ten and five gage networks, one gage from that zone was used.

Table 2

STRATIFICATION BY ELEVATION ZONES

	Elevation Zone	N_h	σ_h	$N_h\sigma_h$	% of $\Sigma N_h\sigma_h$	Ideal Number of Gages for Reduced Networks			
Method 1	1(3600-4400 ft.)	12	2.32	27.84	11.7	4	2	1	1
	2(4400-5000 ft.)	11	3.89	42.78	17.9	5	4	2	1
	3(5000-5900 ft.)	11	5.04	55.49	23.3	7	5	2	1
	4(5900-7200 ft.)	11	10.21	112.35	47.1	14*	9	5	2
	TOTALS	45		238.46		30	20	10	5
Method 2	1(3600-4470 ft.)	14	2.46	34.42	14.7	4	3	2	1
	2(4470-5140 ft.)	9	3.62	32.61	13.9	4	3	1	1
	3(5140-5920 ft.)	11	5.04	55.49	23.6	7	5	2	1
	4(5920-7200 ft.)	11	10.21	112.35	47.8	15*	9	5	2
	TOTALS	45		234.88		30	20	10	5
Method 3	1(3600-4500 ft.)	14	2.46	34.42	13.2	4	3	1	1
	2(4500-5400 ft.)	12	3.70	44.42	17.1	5	3	2	1
	3(5400-6300 ft.)	12	9.46	113.50	43.6	13*	9	4	2
	4(6300-7200 ft.)	7	9.73	68.10	26.1	8*	5	3	1
	TOTALS	45		260.44		30	20	10	5

*Indicates more gages needed than are present in zone.

Thiessen Method

In order to establish confidence intervals for the reduced networks, of 30, 20, 10, and 5 gages, ten networks of each set were constructed. The number of gages from each zone as indicated in Table 3 was used. An attempt was made to utilize the data from each station at least once in each of the network sets unless use of that station prevented a good areal distribution of the gages.

Since the use of the isohyetal program previously cited or hand calculation of Thiessen weights would have been extremely time consuming for the 80 networks used, a computer program (Appendix F) which computes the Thiessen weights for stations in a basin was used. Based on previous experience with the program, the mean error for individual weights determined for Reynolds Creek Basin was between 1.5 and 2.0 percent with a maximum error of about 4 percent (Diskin, 1970).

Thiessen weights for all 45 of the gage sites were computed and the three year mean areal precipitation depth (18.23 inches) over the basin was used as the "true" value of average annual precipitation.

The mean and standard deviation of the annual areal precipitation for the ten networks in each set of reduced networks was calculated and confidence intervals were set about this mean (Table 5, Figure 12).

Table 3

NUMBER OF GAGES USED IN REDUCED NETWORKS BASED ON ELEVATION ZONES

Elevation Zone	Actual Number of Gages Used in Reduced Networks			
1 (3600-4500 ft)	5	3	1	1
2 (4500-5400 ft)	6	3	2	1
3 (5400-6300 ft)	12	9	4	2
4 (6300-7200 ft)	7	5	3	1
TOTAL	30	20	10	5

Table 4

STRATIFICATION BY COVER CLASS ZONES AND NUMBER OF GAGES USED IN REDUCED NETWORKS BASED ON COVER CLASS ZONES

Cover Class Zone	N_h	σ_h	$N_h\sigma_h$	% of Total	Ideal Number of Gages for Reduced Networks				Actual Number of Gages for Reduced Networks			
1	14	2.82	39.49	16.4	5	3	2	1	5	3	2	1
2	16	4.41	70.59	29.4	9	6	3	1	10	6	3	1
3	6	9.48	56.89	23.7	7*	5	2	1	6	5	2	1
4	9	8.16	73.40	30.5	9	6	3	2	9	6	3	2
TOTALS	45		240.37		30	20	10	5	30	20	10	5

* Indicates more gages needed than are present in zone.

Table 5

MEANS, STANDARD DEVIATIONS, CONFIDENCE INTERVALS, AND t-VALUES FOR REDUCED NETWORKS

		$\bar{y}$	S_y	95%CI	t_s
30 GAGES	Elevation Zones	18.33	0.065	0.15	1.54
	Cover Class Zones	18.45	0.072	0.16	3.06*
20 GAGES	Elevation Zones	18.32	0.130	0.30	0.69
	Cover Class Zones	18.59	0.113	0.26	3.18*
10 GAGES	Elevation Zones	18.70	0.338	0.76	1.39
	Cover Class Zones	18.58	0.326	0.74	1.07
5 GAGES	Elevation Zones	19.07	0.596	1.35	1.41
	Cover Class Zones	19.06	0.530	1.20	1.57

* Indicates significance at 95 percent level.

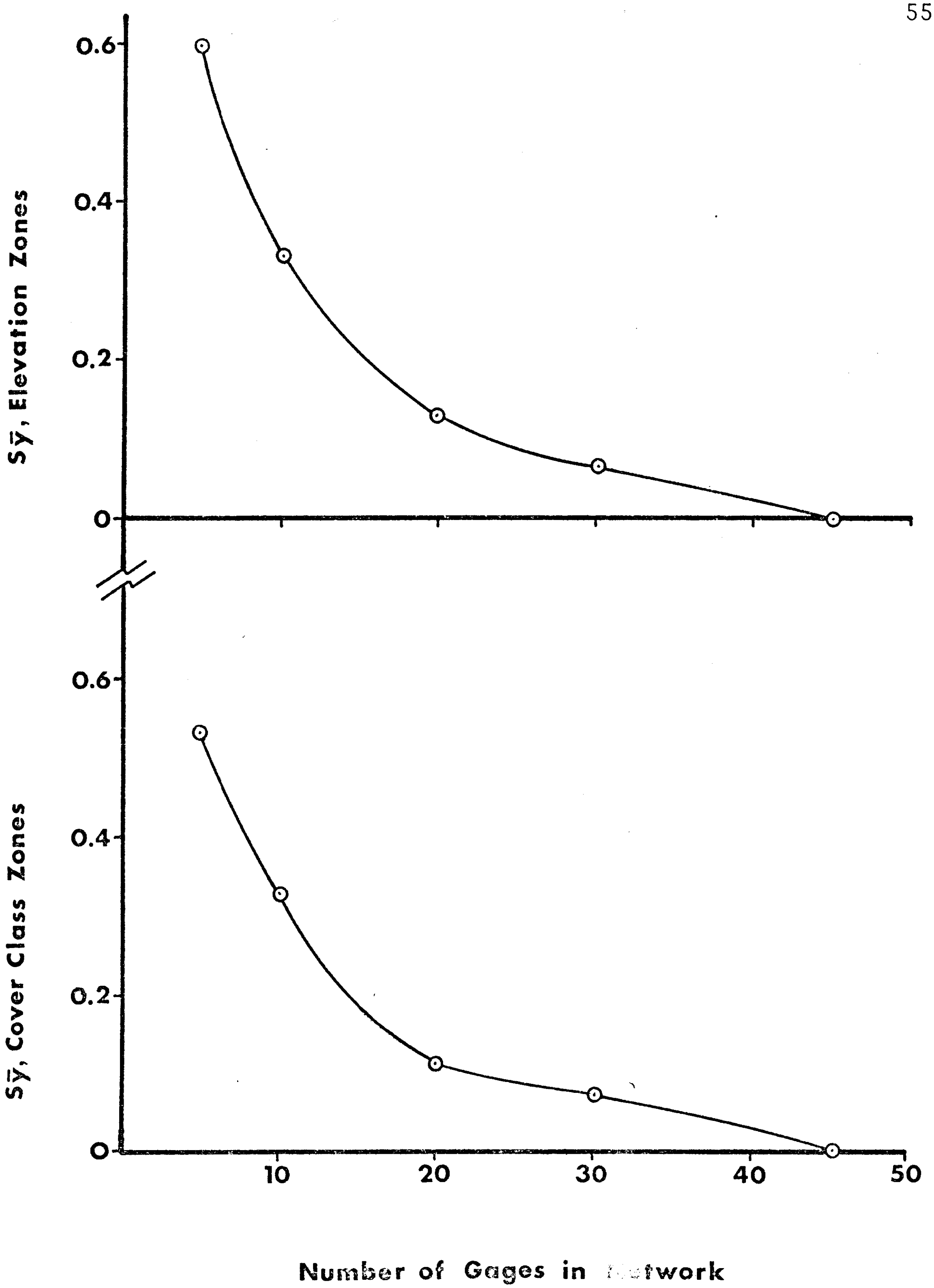

Figure 12. GRAPHS OF STANDARD DEVIATION VERSUS NUMBER OF GAGES IN NETWORK FOR ELEVATION AND COVER CLASS ZONES

It is interesting to note that in all eight sets of reduced networks based on both elevation and cover class, the mean was higher than that for the 45 gage network and significantly so in the 30 and 20 gage networks based on cover class. Significance is construed to mean a t-value equal to or greater than 2.262, the two-tailed t-value with nine degrees of freedom at the 5 percent level. This may be attributed to the fact that in the reduced networks, the gages with relatively high annual precipitation averages are less crowded and the areas weighted with their depth of precipitation are considerably larger.

Application to Network Design

The graph of standard deviation versus number of gages in the Reynolds Creek Basin (Figure 12) indicates that if fewer than 20 gages are used, the standard deviation of the estimated mean precipitation increases rapidly. When from 20 to 45 gages are used, the curve approximates a straight line.

No method was derived to determine how many gages would be required to determine to a specified degree of accuracy the mean precipitation for a given basin. The sampling technique used indicated, however, that when designing a network of raingages, more should be placed in areas where the variability of precipitation is high to reduce the standard error of estimate.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Any means employed to determine the average precipitation in a drainage basin is an estimate at best. Several methods have been studies to improve the reliability of these estimates and the following are conclusions which may be drawn as a result of this study:

1. Of the two methods studied to determine precipitation distribution the Thiessen method is preferred, mainly because of its ease of application and the lack of dense gage networks in Idaho. The isohyetal method assumes a linear distribution of precipitation between gage stations which in most cases is not true unless the stations are close together. Using the 45 gages on Reynolds Creek where the gages are close together produced a good isohyetal map.
2. Five parameters were considered in a multiple-regression analysis for Reynolds Creek Basin. Elevation and cover class were found to be significant. Slope, aspect, and soil type were found to be nonsignificant, but should not be ignored when studying other basins in Idaho where they may prove significant.

3. For the purpose of gage distribution in network design a preferred technique using elevation as a means of stratification has been proposed and used. This method reduces variance within the network to a minimum by concentrating the gages in areas where rainfall variation is highest.
4. The curves of standard deviation versus number of raingages (Figure 12) indicate that if less than 20 gages are used on Reynolds Creek Basin the variance increases rapidly and thus influences quite markedly the accuracy of average precipitation that is derived for such a basin.
5. No determination was made of how many gages are necessary to estimate to a specified accuracy the average precipitation in a basin. Gage density requirements would be associated with the total area involved and the range of values of precipitation present. A possible study approach which takes into account these two factors is recommended in the next section.

Recommendations

The following recommendations are made as suggested directions for further study of the subjects investigated in this paper:

1. Since cover class proved to be a significant parameter on Reynolds Creek Basin, obtain similar data for the Raft River Basin and see if it proves significant for that basin in a multiple-regression analysis.
2. Since Reynolds Creek Basin is only 90 square miles in area, a method should be developed for transferring the network design principles used here to a larger basin, possibly through the analysis of subbasins of the Raft River Basin.
3. If it can be shown that network design principles are transferable from Reynolds Creek Basin to the Raft River Basin, then the methods developed in this study should be applied to other basins in Idaho.
4. Study the impact of prevailing wind on the distribution of precipitation in mountainous valleys of Idaho. The prevailing wind indicator described here could be used and would require little maintenance. No present observation network has been developed. A program to study this parameter as a guide to gage distribution should be initiated.
5. As an extension of the gage density requirements portion of the research, a study might be made of analogous topographic situations having considerable variation

in elevation relief. The idea would be to study how many elevation data points would be necessary to develop a good contour map from which the average elevation of the specific areas of different size could be determined.

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APPENDICES

APPENDIX A

MISSING DATA CALCULATIONS

Table 6

MISSING DATA CALCULATIONS

Station with Missing Value	Year Missing	Index Stations Used	Estimated Precipitation
031	1971	023	17.47
		033	
		043	
054	1970	043	17.28
		045	
		074	
061	1970	043	15.20
		053	
		074	
072	1970	053	20.00
		074	
		083	
114	1971	095	26.37
		106	
		124	
126	1969	116	15.34
		128	
		145	
156	1969	155	14.88
		147	
		166	
165	1969	155	34.90
		174	
		166	

APPENDIX B

GAGE NETWORKS USED IN THIESSEN METHOD

Table 7

30 GAGE NETWORKS

	Elevation Zones Network Number										Cover Class Zones Network Number									
GAGE	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
012	X		X			X		X	X		X	X	X	X	X	X	X	X	X	X
015		X	X		X	X			X		X				X		X		X	
023		X			X		X			X					X	X		X		X
024		X		X				X					X	X		X				X
031	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
033	X		X	X	X	X			X			X				X			X	
043		X					X	X		X	X	X	X	X	X	X	X	X	X	X
045	X						X			X	X				X		X			
047	X	X	X		X				X		X	X	X	X	X			X		X
049	X			X		X				X		X		X	X	X	X		X	
053	X	X		X	X			X		X		X		X	X		X		X	X
054			X			X			X		X		X	X		X		X	X	
055		X		X	X			X	X			X		X			X			X
057						X	X			X	X	X	X	X			X		X	X
059		X	X					X			X		X		X	X	X	X		
061	X	X	X	X	X	X	X	X	X	X	X		X		X	X		X	X	
072	X	X	X		X	X			X		X	X	X	X	X	X	X	X	X	X
074		X		X			X	X		X	X		X		X		X		X	X
075				X	X	X	X	X				X		X		X		X	X	X
076	X		X								X		X				X			
078				X	X				X			X	X	X				X		
083	X	X	X	X	X	X	X	X	X	X		X		X		X	X		X	
088			X				X	X		X	X	X	X	X	X		X		X	X
095	X		X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X
097		X				X			X						X			X	X	X
106	X				X		X			X	X	X					X			
108	X		X	X		X	X			X			X	X		X				X
114	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X
116				X			X	X	X			X		X	X		X	X		X
119	X	X	X	X	X	X	X	X	X	X					X				X	
124	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X		
126	X	X	X	X	X	X	X	X	X	X					X	X		X	X	
127	X	X	X	X	X	X	X	X	X	X	X		X					X		
128	X	X	X	X	X	X	X	X	X	X		X		X		X		X		X
144	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
145								X		X	X	X	X	X	X	X	X	X	X	X
147	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X		X

Table 7 (cont.)

GAGE	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
155	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
156	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
163	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
165	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
166	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
167	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
174	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
176	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 8

20 GAGE NETWORKS

	Elevation Zones Network Number										Cover Class Zones Network Number									
GAGE	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
012			X		X				X		X		X	X	X	X		X	X	
015	X		X				X			X		X				X			X	
023		X		X								X					X			X
024						X					X			X				X		
031	X		X	X	X	X	X	X		X	X	X	X		X	X	X		X	
033					X			X											X	
043		X		X						X	X	X	X	X	X		X	X		X
045		X		X					X				X		X		X			
047	X									X			X	X		X			X	
049					X			X	X		X			X			X			X
053			X	X									X			X				
054						X	X					X					X			X
055			X		X			X			X					X				
057		X				X							X		X			X		
059			X				X					X				X			X	
061	X	X	X		X	X	X	X	X					X					X	
072						X					X	X	X		X	X	X	X	X	X
074	X	X					X	X	X		X			X				X		
075	X									X			X		X	X			X	
076			X				X					X								X
078	X			X						X										X
083	X	X	X	X			X		X	X				X			X		X	X
088					X			X			X		X		X		X	X		
095					X	X		X			X	X	X	X		X		X	X	X
097		X		X										X				X		
106									X				X		X					
108	X					X				X		X				X			X	
114	X	X	X	X		X	X	X	X	X			X	X		X			X	
116							X		X		X	X			X			X		
119		X	X	X	X	X	X	X			X						X			
124	X		X	X	X		X	X	X		X	X			X		X	X		X
126	X		X	X	X	X				X				X			X			
127		X			X		X	X	X	X			X							X
128	X	X	X	X	X		X	X	X	X					X			X		
144	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
145											X	X		X				X		X
147	X	X	X	X	X	X		X	X	X	X	X			X	X		X		X

Table 8 (cont.)

GAGE	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
155	X	X			X	X	X	X	X	X			X	X	X	X	X		X	X
156	X		X	X	X	X		X	X			X	X	X	X	X	X	X	X	
163	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
165		X	X	X		X			X	X		X	X	X		X	X	X	X	X
166		X		X			X			X	X		X		X		X		X	
167	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X	X
174	X	X			X	X	X	X	X	X	X	X		X	X		X			X
176			X			X			X			X		X		X		X		X

Table 9

10 GAGE NETWORKS

	Elevation Zones Network Number										Cover Class Zones Network Number									
GAGE	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
012	X		X									X		X		X	X		X	
015		X			X		X		X						X					X
023						X				X	X							X		
024													X							
031			X		X		X		X				X		X			X		X
033		X		X												X				
043								X				X					X		X	
045											X			X						
047			X												X				X	
049				X								X				X	X			
053	X				X	X				X						X				
054															X					X
055										X		X					X			
057	X							X					X							X
059				X		X								X						
061		X		X			X	X						X						
072									X		X		X					X		X
074			X																	
075									X		X		X							
076		X																	X	
078							X										X			
083	X				X	X				X					X		X			
088											X	X						X	X	
095					X		X					X		X	X	X				
097																X				
106												X								X
108								X							X					
114		X	X			X		X						X				X		
116													X				X		X	
119	X		X		X		X			X				X						
124	X			X			X		X	X						X				X
126	X							X	X									X		
127		X		X		X				X	X									
128			X		X				X				X						X	
144		X		X								X	X		X				X	
145											X			X			X	X		
147												X								

Table 9 (cont.)

GAGE	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
155			X			X			X										X	X
156	X						X	X					X		X					
163	X	X	X	X		X	X	X	X	X	X			X		X	X	X		
165				X						X								X		
166				X				X		X		X							X	
167		X		X		X			X		X					X				X
174	X	X			X	X	X			X	X		X		X					X
176			X		X									X			X	X		

Table 10

5 GAGE NETWORKS

	Elevation Zones Network Numbers										Cover Class Zones Network Numbers									
GAGE	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
012		X										X		X				X		
015			X							X										
023							X				X				X					
024						X														
031					X								X			X	X			
033				X															X	
043									X											X
045								X												
047	X												X							
049									X							X				
053	X																			
054												X								
055					X															
057			X															X		
059							X							X						
061			X				X			X										
072								X			X			X					X	
074						X											X			
075															X					
076		X																		
078				X																X
083		X		X					X											X
088										X									X	
095					X							X	X							
097																X				
106														X						
108											X									
114	X					X														
116										X										
119	X							X									X			
124			X				X													
126					X													X		
127		X										X								
128						X			X				X							
144				X							X							X	X	
145														X						X
147								X												

Table 10 (cont.)

GAGE	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
155									X											
156							X									X		X		
163		X						X							X		X			
165						X							X							
166					X							X								
167				X							X						X		X	
174	X															X				
176			X							X					X					X

APPENDIX C

INDEPENDENT PARAMETERS USED IN MULTIPLE-REGRESSION METHOD

Table 11

INDEPENDENT PARAMETERS USED IN MULTIPLE-REGRESSION METHOD

Gage Number	Elevation (ft)	Aspect (Degrees)	Slope (Percent)	Cover Class	Soil Type
012	5180	128.8	17.7	4	C
015	4520	172.5	11.4	1	D
023	4880	201.3	27.5	2	C
024	4435	174.8	14.7	1	D
031	5875	68.5	6.6	4	C
033	4660	137.8	10.4	1	C
043	4795	131.0	19.9	3	D
045	4000	203.8	14.2	1	D
047	3710	193.0	7.6	2	B
049	4280	275.5	8.5	2	B
053	4950	192.5	15.6	2	C
054	4430	157.5	16.1	2	B
055	3820	37.5	3.8	1	B
057	3885	267.5	2.8	2	B
059	4390	256.3	8.5	2	D
061	5880	158.5	14.2	2	D
072	5235	135.0	10.4	3	D
074	4720	73.0	13.7	2	B
075	3950	76.3	1.9	2	C
076	3915	163.8	3.3	1	B
078	4270	190.5	7.6	1	B
083	5510	175.7	6.9	2	C
088	4410	264.8	7.1	2	D
095	4880	165.0	18.5	3	B
097	4080	181.0	9.0	1	B
106	4280	123/8	8.0	1	C
108	4810	166.0	26.0	1	D
114	5885	70.3	17.0	2	B
116	4770	145.0	18.5	2	B
119	5490	177.5	14.2	1	D
124	5920	89.7	12.6	2	D
126	5460	228.8	18.5	1	D
127	5410	148.8	13.3	1	B

Table 11 (cont.)

128	6540	178.5	15.1	1	R
144	5930	155.0	5.7	4	C
145	5195	60.5	14.2	4	B
147	6140	271.8	16.1	2	C
155	5410	179.3	16.6	3	C
156	6320	235.0	15.1	3	C
163	7100	182.5	18.5	3	C
165	5950	134.3	16.1	4	C
166	6760	196.3	15.1	4	D
167	6600	113.3	17.7	4	B
174	6760	193.0	18.0	4	C
176	6800	258.8	15.2	4	D

Table 12

SCS HYDROLOGIC CLASSIFICATION OF SOILS

D	(high runoff potential) Soils have very low infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
A	None present on Reynolds Creek Watershed.
R	Rock and steep stoney land.

APPENDIX D

PRECIPITATION DATA
REYNOLDS CREEK

Table 13

PRECIPITATION DATA FOR REYNOLDS CREEK

GAGE NUMBER	Shielded-Gage Precipitation Catch			
	1969	1970	1971	Mean
012	18.93	25.65	21.45	22.01
015	13.47	14.17	14.21	13.95
023	17.55	24.35	19.44	20.45
024	14.98	17.38	16.71	16.36
031	15.67	19.00	17.47*	17.38
033	18.10	26.94	22.48	22.51
043	16.95	24.76	23.23	21.65
045	11.36	13.17	15.04	13.19
047	11.14	12.22	11.19	11.52
049	10.91	9.78	11.37	10.69
053	15.97	19.97	19.33	18.42
054	14.48	17.28*	18.16	16.64
055	10.97	13.56	15.39	13.31
057	9.07	8.16	11.35	9.53
059	9.86	8.62	12.13	10.20
061	13.43	16.05*	16.11	15.20
072	15.51	20.00*	21.98	19.16
074	17.92	19.66	19.45	19.01
075	11.00	13.07	15.03	13.03
076	9.86	11.49	13.29	11.55
078	10.51	9.46	12.27	10.75
083	16.06	19.48	18.52	18.02
088	10.07	9.90	12.70	10.89
095	16.00	20.12	22.58	15.57
097	10.50	12.73	15.65	12.96
106	13.48	17.89	19.72	17.03
108	10.09	11.99	12.75	11.61
114	18.73	25.10	26.37*	23.37
116	14.23	21.20	21.67	19.03
119	11.75	15.26	15.67	14.23
124	18.34	24.97	21.18	21.50
126	15.34*	19.15	20.07	18.19
127	11.42	14.05	15.29	13.59
128	11.90	14.37	16.34	14.20
144	30.28	44.17	32.41	35.62
145	18.50	28.37	25.99	24.29
147	14.42	17.60	16.41	16.14
155	22.87	34.85	33.74	30.49

Table 13 (cont.)

Gage No.	1969	1970	1971	Mean
156	14.88*	18.56	19.10	17.51
163	34.16	42.59	44.11	40.29
165	34.90*	50.14	45.43	43.49
166	22.62	34.60	36.18	31.13
167	21.60	34.15	31.32	29.02
174	23.80	35.67	40.54	33.34
176	27.42	41.50	42.45	37.12

---

* Indicates estimated value.

APPENDIX E

ISOHYETAL COMPUTER PROGRAM

Table 14

ISOHYETAL COMPUTER PROGRAM

```
                         A COMPUTER PROGRAM FOR
                        INTERPOLATION AND PLOTTING
                          OF ISOHYETAL POINTS

                         WRITTEN BY M.H. DISKIN
                                  AND
                               P.R. DAVIS

                         MODIFIED BY A.P. HOLMAU
                              AUGUST, 1972

                                REFERENCE
                          ARS PUBLICATION 177
                             DECEMBER, 1970




C       ALL DATA INPUT IS FREE FORM ... EACH PIECE
C       OF DATA MUST BE PRECEDED BY A BLANK OR COMMA
C
C
C
C
C   DATA CARD ORDER
C
C   1.  TITLE CARD
C   2.  PARAMETER CARD
C         A.   YMIN  = MINIMUM Y VALUE
C         B.   YMAX  = MAXIMUM Y VALUE
C         C.   XMIN  = MINIMUM X VALUE
C         D.   XMAX  = MAXIMUM X VALUE
C         E.   SCALE = DESIRED NUMBER OF INCHES PER MILE ON MAP OUTPUT
C         F.   ROT   = OPTIONAL 90 DEGREE ROTATION OF MAP, 1 IF DESIRED, 0 IF NOT
```

Table 14 (cont.)

```
C          G.   PRNT  = OPTIONAL PRINTOUT OF INTERPOLATED ISOHYETAL POINTS,
C                        1 IF DESIRED, 0 IF NOT
C    3.   INTERPOLATION CARDS
C          A.   NRG = IDENTIFYING NUMBER OF RAINGAGE
C          B.   AX  = X COORDINATE OF RAINGAGE
C          C.   AY  = Y COORDINATE OF RAINGAGE
C          D.   NA  = FIRST GAGE TO BE INTERPOLATED TO
C          E.   NB  = SECOND GAGE TO BE INTERPOLATED TO
C          F.   NC  = THIRD GAGE TO BE INTERPOLATED TO
C          G.   ND  = FOURTH GAGE TO BE INTERPOLATED TO
C    4.   CARD WITH SEVEN ZEROS PUNCHED ONE SPACE APART STARTING IN COLUMN 2
C    5.   EVENT TITLE CARD, I.E. STORM 12-7-68
C    6.   ISOHYETAL INTERVAL CARD FOR DEPTH DIFFERENTIAL BETWEEN ISOHYETS, DEL
C    7.   DEPTH OF RAINFALL CARDS
C          A.   NGA = IDENTIFYING NUMBER OF RAINGAGE
C          B.   RDP = DEPTH OF PRECIPITATION AT RAINGAGE
C    8.   CARD WITH TWO ZEROS PUNCHED ONE SPACE APART STARTING IN COLUMN 2
C
C
C
C    INPUT TO THE PROGRAM CONSISTS OF THE FOLLOWING ITEMS
C
C    1.   TITLE OF MAP
C    2.   YMIN, YMAX -- MINIMUM AND MAXIMUM Y VALUES
C    3.   XMIN,XMAX -- MINIMUM AND MAXIMUM X VALUES
C    4.   SCALE OF MAP OUTPUT
C    5.   ROT -- OPTIONAL 90 DEGREE ROTATION OF MAP
C    6.   PRNT -- OPTIONAL PRINTOUT OF INTERPOLATED ISOHYETAL POINTS
C    7.   NRG -- IDENTIFYING NUMBER OF RAINGAGE
C    8.   AX,AY -- COORDINATES OF RAINGAGE
C    9.   NA,NB,NC,ND -- GAGES TO BE INTERPOLATED TO
C   10.   EVENT TITLE
C   11.   DELH -- ISOHYETAL INTERVAL
C   12.   NGA -- IDENTIFYING NUMBER OF RAINGAGE
C   13.   RDP -- DEPTH OF PRECIPITATION AT RAINGAGE
C
C
```

Table 14 (cont.)

```
C
C    OUTPUT OF THE PROGRAM CONSISTS OF THE FOLLOWING ITEMS
C
C     1.  TITLE OF MAP
C     2.  YMIN,YMAX -- MINIMUM AND MAXIMUM Y VALUES
C     3.  XMIN,XMAX -- MINIMUM AND MAXIMUM X VALUES
C     4.  SCALE OF MAP OUTPUT
C     5.  EVENT TITLE
C     6.  NRG -- IDENTIFYING NUMBER OF RAINGAGE
C     7.  AX,AY -- COORDINATES OF RAINGAGE
C     8.  RDP -- DEPTH OF PRECIPITATION AT RAINGAGE
C     9.  DELH -- ISOHYETAL INTERVAL
C    10.  NUMBER OF RAINGAGING STATIONS
C    11.  NUMBER OF INTERPOLATED POINTS
C    12.  COORDINATES OF INTERPOLATED POINTS (OPTIONAL)
C    13.  MAP WITH BOUNDARY SHOWING RAINGAGE LOCATIONS
C         AND INTERPOLATED ISOHYETAL POINTS
C
C
C
C
C
      REAL AX(100),AY(100),HR(100),X(1500),Y(1500),SCL(12),
     1 H(1500),XS(1500).YS(1500),HS(1500),RDP(100,10)
      INTEGER NRG(100),NA(100),NB(100),NC(100),ND(100),JG(4),
     2 NGA(100),LST(1000)
      DIMENSION TITLE(30),EVENT(8,10),ALPHA(121),BETA(121)
      DIMENSION BET(26)
      DATA MINUS,PLUS.BLANK,AST/'-','+',' ','*'/
      DATA BET/'A','B','C','D','E','F','G','H','I','J','K','L','M','N',
     *'O','P','Q','R','S','T','U','V','W','X','Y','Z'/
C     FREE FORM INPUT VERSION BY MYRON MOLNAU, U OF IDAHO AUG 1972
  963 CONTINUE
      IF(TITLE(1).EQ.BLANK)STOP
      READ 115, TITLE
      CALL INPUT(X,IN)
      YMIN=X(1)
```

Table 14 (cont.)

```
      YMAX=X(2)
      XMIN=X(3)
      XMAX=X(4)
      SCALE=X(5)
      ROT=X(6)
      PRNT=X(7)
      PRINT 100
      PRINT 115, TITLE
      PRINT 117
      PRINT 114
      PRINT 116, YMIN,YMAX,XMIN,XMAX,SCALE
      PRINT 117
      DELX=SCALE/10.0
      DELY=SCALE/6.0
      DO 66 I=1,1000
      LST(I)=0
 66   CONTINUE
      DO 37 I=1,200
      HR(I)=0.0
      NRG(I)=0
      NGA(I)=0
 37   CONTINUE
      PTX=0.0
C     READ GAGE LOCATION AND INTERPOLATING POINTS
      DO 51 I=1,200
      CALL INPUT(X,IN)
      NRG(I)=X(1)
      AX(I)=X(2)
      AY(I)=X(3)
      NA(I)=X(4)
      NB(I)=X(5)
      NC(I)=X(6)
      ND(I)=X(7)
      IF(NRG(I).EQ.0) GO TO 59
      MR=I
      J=NRG(I)
      IF(LST(J).NE.0) GO TO 80
```

Table 14 (cont.)

```
      LST(J)=I
 51   CONTINUE
 59   IF(ROT.EQ.0.0) GO TO 60
      DO 75 I=1,MP
      TEMP=AX(I)
      AX(I)=AY(I)
      AY(I)=-TEMP
 75   CONTINUE
      TEMP=XMIN
      TEMA=XMAX
      XMIN=YMIN
      XMAX=YMAX
      YMIN=-TEMA
      YMAX=-TEMP
C*****  READ TITLE OF STORMS
   60 CONTINUE
      READ 115,((EVENT(I,J),J=1,10),I=1,7)
C*****  DELH = ISOHYTEAL INTERVAL
   74 CALL INPUT(X,IN)
      DELH=X(1)
      NAV=2999-MR
      DO 34 I=1,200
      LST(I)=IABS(LST(I))
 34   CONTINUE
      DO 68 I=1,200
      CALL INPUT(X,IN)
      NGA(I)=X(1)
      DO 680  II=2,IN
  680 PDP(I,II-1)=X(II)
      IF(NGA(I).EQ.0)GO TO 35
      JR=NGA(I)
      IF(LST(JR).LT.0) GO TO 81
      LST(JR)=-LST(JR)
      NGA=I
 68   CONTINUE
 35   DO 50 NFV=1,7
C--ALL *C* VALUES ON FORTRAN CODED CARDS SHOULD BE REMOVED IN ORDER FOR
```

```
C--THIS PROGRAM TO CONFORM TO THE ORIGINAL SPECIFICATIONS.
C       PRINT 100
C       PRINT 141,TITLE,(EVENT(NEV,KK),KK=1,10)
C       PRINT 117
        DO 70 I=1,NGA
        NR=NGA(I)
        RF=RDP(I,NEV)
        IF (I.EQ.1) HMX = RF
        IF(RF.GT.HMX) HMX = RF
C       IF(LST(NR).EQ.0) PRINT 118,NR
        IF(LST(NR).EQ.0) GO TO 70
        JR=-LST(NR)
        HR(JR)=RF
 70     CONTINUE
        PRINT 117
        IF(HMX.EQ.0.0) GO TO 60
        HST = HMX + 100.0*DELH
        ALM=DELH*0.001
        NP=0
        DO 54 I=1,MR
        JB=NRG(I)
C       IF(LST(JB).GE.0) PRINT 120, JB
        IF(LST(JB).GE.0) GO TO 54
        JG(1)= NA(I)
        JG(2)= NB(I)
        JG(3)= NC(I)
        JG(4)= ND(I)
        DO 55 J=1,4
        IF (JG(J).EQ.0) GO TO 55
        JM=JG(J)
C       IF(LST(JM).GE.0) PRINT 121,JB,JM
        IF(LST(JM).GE.0) GO TO 55
        JA=-LST(JM)
        DIFX=AX(JA)-AX(I)
        DIFH=HR(JA)-HR(I)
        DIFY=AY(JA)-AY(I)
        DABH=ABS(DIFH)
```

```
      IF(DASH.LT.ALM) GO TO 55
      IF(HR(I).GT.HR(JA)) GO TO 61
      XCL=HR(I)/DELH-0.2
      XCV=HR(JA)/DELH+0.2
      GO TO 62
61    XCL=HR(JA)/DELH-0.2
      XCV=HR(I)/DELH+0.2
62    NCL=XCL+1.0
      NCV=XCV
      IF(NCL.GT.NCV) GO TO 55
      DO 56 K=NCL,NCV
      NP=NP+1
      H(NP)=DELH*FLOAT(K)
      X(NP)=AX(I)+(H(NP)-HR(I))*DIFX/DIFH
      Y(NP)=AY(I)+(H(NP)-HR(I))*DIFY/DIFH
      IF (AX(I).EQ.AX(JA)) GO TO 79
      IF (X(NP).LE.AX(JA).AND.X(NP).GE.AX(I)) GO TO 49
      IF (X(NP).GE.AX(JA).AND.X(NP).LE.AX(I)) GO TO 49
      XID=ABS(X(NP)-AX(I))
      XJD=ABS(X(NP)-AX(JA))
      XDL=2.0*DELX
      XDM=ABS(0.03*DIFX)
      GO TO 67
79    IF(Y(NP).LE.AY(JA).AND.Y(NP).GE.AY(I)) GO TO 49
      IF(Y(NP).GE.AY(JA).AND.Y(NP).LE.AY(I)) GO TO 49
      XID=ABS(Y(NP)-AY(I))
      XJD=ABS(Y(NP)-AY(JA))
      XDL=2.0*DELY
      XDM=ABS(0.03*DIFY)
67    IF(XJD.LT.XID)XID=XJD
      IF(XDL.LT.XDM) XDL=XDM
      IF(XID.GT.XDL)NP=NP-1
49    CONTINUE
      IF(NP.EQ.NAV) GO TO 64
56    CONTINUE
55    CONTINUE
54    CONTINUE
```

```
 45 CONTINUE
    PRINT 141,TITLE,(EVENT(NEV,I),I=1,10)
    PRINT 117
    PRINT 128
    PRINT 126
    M=0
    DO 46 I=1,MR
    J=NRG(I)
    IF (LST(J).GE.0) GO TO 46
    NP = NP + 1
    X(NP) = AX(I)
    Y(NP) = AY(I)
    H(NP) = HST
    M=M+1
    TEMP=-AY(I)
    IF (ROT.EQ.0.0) PRINT 110, NRG(I),AX(I),AY(I),HR(I)
    IF (ROT.NE.0.0) PRINT 110, NRG(I), TEMP,AX(I),HR(I)
46  CONTINUE
    NP=NP+1
    X(NP)=XMIN+DELX*5.0
    Y(NP)=YMIN-DELY*5.0
    H(NP)=HST
    PRINT 117
    PRINT 123, DELH
    PRINT 117
    PRINT 135,M
    IF (PRNT.EQ.0) GO TO 33
    PRINT 100
    PRINT 141,TITLF,(EVENT(NEV,I),I=1,10)
    PRINT 117
    PRINT 129
    PRINT 127
33  M=0
    DO 57 J=1,NP
    YS(J)=YMIN-DELY*8.0
    DO 58 I=1,NP
    IF(Y(I).LT.YS(J)) GO TO 58
```

```
      YS(J)=Y(I)
      NS=I
58    CONTINUE
      Y(NS)=YMIN-DELY*10.0
      XS(J)=X(NS)
      HS(J)=H(NS)
      IF (HS(J).EQ.HST) GO TO 57
      M=M+1
      IF (PRNT.EQ.0.0) GO TO 57
      TEMP=-YS(J)
      IF (ROT.EQ.0) PRINT 110,M,XS(J),YS(J),HS(J)
      IF (ROT.NE.0) PRINT 110,M,TEMP,XS(J),HS(J)
57    CONTINUE
      PRINT 117
      PRINT 132,M
      DO 31 I=1,121
      BETA(I)=MINUS
31    CONTINUE
      DO 32 I=1,121,10
      BETA(I)=PLUS
32    CONTINUE
      WEST=XMIN
28    EAST=WEST+120.0*DELX
      SCL(1)=WEST
      DO 30 I=2,12
      SCL(I)=SCL(I-1)+10.0*DELX
30    CONTINUE
      PRINT 151,SCL
      PRL=YMAX-0.5*DELY
      PNL=YMAX
      IF(ROT.NE.0.0) PNL=-PNL
      PRINT 137, PNL,BETA
      L=0
33    PRL=PRL-DELY
      PNL=PRL+0.5*DELY
      IF (ROT.NE.0.0) PNL=-PNL
      DO 36 I=1,121
```

```
      ALPHA(I)=BLANK
38    CONTINUE
      IF(YMIN.GE.PRL) GO TO 48
42    L=L+1
      IF(YS(L).LT.PRL) GO TO 43
      IF(XS(L).LE.EAST.AND.XS(L).GE.WEST) GO TO 40
      GO TO 42
40    XI=(XS(L)-WEST)/DELX+0.5
      I=XI+1
      IF(ALPHA(I).NE.BLANK)I=I+1
      IF(ALPHA(I).NE.BLANK)I=I-2
      IF(I.LT.1) I=1
      IF(I.GT.121) I=121
      IF (HS(L).EQ. HST) GO TO 63
      XDIF=HS(L)/DELH
      KDIF=XDIF
      RMD=XDIF-KDIF
      IF (RMD.GT.0.5)KDIF=KDIF+1
      IF (KDIF.EQ.0)GO TO 26
      IF(KDIF.LE.26) GO TO 41
      IM=MOD(KDIF,26)
      IF(IM.NE.0) GO TO 29
      GO TO 26
29    NK=KDIF/26
      KDIF=KDIF-NK*26
41    CONTINUE
      IF(KDIF.GT.0.AND.KDIF.LE.26)GO TO 1
   63 ALPHA(I)=AST
      GO TO 42
    1 ALPHA(I)=BET(KDIF)
      GO TO 42
   26 ALPHA(I)=BET(26)
      GO TO 42
   43 PRINT 137,PNL,ALPHA
      L=L-1
      GO TO 38
48    PRINT 137, PNL, BETA
```

```
      PRINT 113, SCL
      IF (ROT.EQ.0.0) PRINT 133
      IF (ROT.NE.0.0) PRINT 134
      PRINT 141,TITLE,(EVENT(NEV,I),I=1,10)
      IF (PTX.GT.0.0) PRINT 125
      PRINT 117
      PRINT 122, SCALE,DELH
      PRINT 117
      ASTR=AST
      PRINT 130,ASTR
      PRINT 131
      IF(EAST.GE.XMAX) GO TO 50
      WEST=EAST
      GO TO 28
 50   CONTINUE
      GO TO 60
 73   PRINT 142
      GO TO 27
 64   PRINT 125
      PTX=1.0
      GO TO 45
 80   PRINT 124,J
      GO TO 82
 81   PRINT 119, NR
 82   PRINT 140
 27   GO TO 963
  100 FORMAT('1')
 101  FORMAT(8F10.0)
 102  FORMAT(I10,2F10.0,4I5)
 105  FORMAT(I10,7F10.0)
 110  FORMAT(I12,3F15.4)
 113  FORMAT(/,7X,12F10.3)
 114  FORMAT(7X,4HYMIN,8X,4HYMAX,8X,4HXMIN,8X,4HXMAX,7X,5HSCALE)
  115 FORMAT(80A1)
 116  FORMAT(6F12.4)
 117  FORMAT(//)
C118  FORMAT (5X,21HRAINFALL FOR GAGE NO.,I6,
```

Table 14 (cont.)

```
C     1 41H  NOT USED, COORDINATES OF GAGE NOT GIVEN)
 119  FORMAT(5X,50HMORE THAN ONE RAINFALL VALUE IS GIVEN FOR GAGE NO.,
     1I5)
C120  FORMAT(5X,35HNO RAINFALL DATA GIVEN FOR GAGE NO.,I5)
C121  FORMAT(5X,27HINTERPOLATION FROM GAGE NO.,I5,13H  TO GAGE NO.,I5,
C     1 23H  CANNOT BE CARRIED OUT)
 122  FORMAT(5X,14HSCALE OF MAP  ,F10.4,16H  MILES = 1 INCH,30X,
     1 27HINTERVAL BETWEEN ISOHYETS =,F9.3,6H  INCH)
 123  FORMAT(5X,27HINTERVAL BETWEEN ISOHYETS =,F9.3,6H  INCH)
 124  FORMAT(5X,20HCOORDINATES OF GAGE NO,I5,
     1 26H  ARE GIVEN MORE THAN ONCE)
 125  FORMAT(10X,46HNUMBER OF INTERPOLATED POINTS EXCEEDS CAPACITY)
  126 FORMAT(8X,'GAGE',12X,'X',14X,'Y',10X,'RAIN',/)
  127 FORMAT(7X,'POINT',12X,'X',14X,'Y',10X,'RAIN',/)
 128  FORMAT(10X,36HORIGINAL DATA USED FOR INTERPOLATION//)
  129 FORMAT(10X,17HINTERPOLATED DATA//)
 130  FORMAT(5X,32HRAIN GAGE LOCATION DENOTED BY    ,1A1 )
 131  FORMAT(5X,36HISOHYETAL POINTS DENOTED BY LETTERS )
 132  FORMAT(5X,38HTHE NUMBER OF INTERPOLATED POINTS IS   ,I6)
 133  FORMAT (/90X,13HX AXIS   MILES/)
 134  FORMAT (/90X,13HY AXIS   MILES/)
 135  FORMAT(5X,44HTHE NUMBER OF RAIN GAGING STATIONS USED IS   ,I5)
  137 FORMAT(1X,F6.2,1X,'I',121A1,'I')
 140  FORMAT(5X,32H DUPLICATE DATA, PROGRAM STOPPED)
  141 FORMAT(5X,80A1,/,5X,10A1)
 142  FORMAT(10X,11HEND OF DATA)
 145  FORMAT(1X,F8.3,3X,1HI,121A1,1HI)
 151  FORMAT(1H1,7X,12F10.3,/)
      END
```

APPENDIX F

THIESSEN COMPUTER PROGRAM

Table 15

THIESSEN COMPUTER PROGRAM

```
                A COMPUTER PROGRAM TO COMPUTE THIESSEN WEIGHTS
                             USING A UNIFORM GRID

                            WRITTEN BY M.H. DISKIN
                        ARS SOUTHWEST WATERSHED CENTER
                                TUSCON, ARIZONA

                            MODIFIED BY M.P. MOLNAU
                                FEBRUARY, 1971

                                 *REFERENCE
                      JOURNAL OF HYDROLOGY 11(1970) 59-78



C   DATA CARD ORDER
C
C   1.  IDENTIFICATION CARD (80A1)
C   2.  PARAMETER CARD
C         COLUMN 1- 5...NUMBER OF BOUNDARY POINTS (I5),M
C                6-10...NUMBER OF RAIN GAGES (I5),M
C               11-15...NUMBER OF DIVISIONS ON SMALL SIDE (I5),NDIV
C   3.  X AND Y COORDINATES OF THE STRAIGHT LINE SEGMENTS OF THE BOUNDARY
C         COLUMN 1- 5...NUMBER OF THE BOUNDARY POINT,CLOCKWISE (I5),NPT
C                6-15...X COORDINATE OF BOUNDARY POINT (F10.0)
C               16-25...Y COORDINATE OF THE BOUNDARY POINT (F10.0)
C   4.  X AND Y COORDINATES FOR RAINGAGES
C         COLUMN 2- 5...RAINGAGE IDENTIFICATION
C                6-15...X COORDINATE OF RAINGAGE (F10.0)
C               16-25...Y COORDINATE OF RAINGAGE (F10.0)
C
C   AFTER LAST DATA SET END PROGRAM WITH TWO BLANK CARDS
C
C
C
```

Table 15 (cont.)

```
C     INPUT TO THE PROGRAM CONSISTS OF THE FOLLOWING ITEMS
C
C      1.   WSID -- THE NAME OR IDENTIFICATION NUMBER OF THE WATERSHED
C      2.   N    -- THE NUMBER OF BOUNDARY POINTS
C      3.   M    -- THE NUMBER OF RAINGAGING STATIONS
C      4.   NDIV -- THE NUMBER OF DIVISIONS ON THE SMALLER SIDE OF THE
C                   ENCLOSING RECTANGLE (FOR GENERAL USE NDIV = 100)
C      5.   NPT  -- THE SERIAL NUMBER OF POINTS ALONG THE BOUNDARY
C      6.   X,Y  -- THE COORDINATES OF THE BOUNDARY POINTS LISTED IN
C                   CLOCKWISE DIRECTION
C      7.   NRG  -- THE IDENTIFYING NUMBER OF THE RAINGAGING STATION
C      8.   AX,AY-- THE COORDINATES OF THE RAINGAGING STATIONS
C
C
C
C     OUTPUT OF THE PROGRAM CONSISTS OF THE FOLLOWING ITEMS
C
C      1.   WSID -- THE NAME OR IDENTIFICATION NUMBER OF THE WATERSHED
C      2.   NSTA -- THE NUMBER OF RAINGAGING STATIONS
C      3.   NDIV -- THE NUMBER OF DIVISIONS ON THE SMALLER SIDE OF THE
C                   ENCLOSING RECTANGLE
C      4.   NPTS -- THE NUMBER OF TEST POINTS USED IN COMPUTATIONS
C      5.   SWF  -- THE FINAL SUM OF WEIGHTS FOR ALL GAGES
C      6.   AF   -- THE AREA OF THE WATERSHED RELATIVE TO THE AREA
C                   OF THE ENCLOSING RECTANGLE
C      7.   AREA OF THE ENCLOSING RECTANGLE
C      8.   AREA OF THE WATERSHED
C      9.   NRG  -- THE IDENTIFYING NUMBER OF THE RAINGAGING STATION
C     10.   AX,AY-- THE COORDINATES OF THE RAINGAGING STATIONS
C     11.   W    -- THE THIESSEN WEIGHT OF THE GAGING STATION
C     12.   AREA ASSIGNED TO THE GAGE
C
C
C
C
C
        REAL LIMW,LIMA,LIMY,X(250),Y(250),AX(100),AY(100),R(20),
```

```
     1WF(100),XL(20),XR(20),EL(100),W(100),CX(100),CY(100)
      INTEGER NS(100),NRG(100)
      DIMENSION WSID(80)
  100 FORMAT(3I5,3F10.0)
  101 FORMAT(1X,A4,2F10.0)
  103 FORMAT('0',' GAGE NO          X              Y       THIESSEN WEIGHTS
     *          AREA',//)
  104 FORMAT('0','NUMBER OF GAGES =',I4)
  105 FORMAT(80A1)
  106 FORMAT('1',80A1)
  108 FORMAT(' ',3X,A4,3X,2F10.4,2X,F10.4,9X,F15.6)
  110 FORMAT('0',' AREA OF RECTANGLE =   ',F15.8,//)
  111 FORMAT('0',' AREA OF WATERSHED =    ',F15.8,//)
  113 FORMAT(//)
  201 FORMAT('0','NUMBER OF COMPUTATION SETS =',I5,'  NDIV =',I5,
     *'  NUMBER OF TEST POINTS =',I5,//,' SUM OF GAGE WEIGHTS =',F8.4,
     2'  AREA OF WTSD/AREA RECTANGLE =',F8.5)
  204 FORMAT(' ','ERROR IN JB = JA')
C     READ INPUT PARAMETERS AND BOUNDARY POINTS
C
      LIMA = 0.0
      LIMW = 0.0
C
   51 READ 105,WSID
      READ 100,N,M,NDIV
      IF(N.LT.3)GO TO 50
      DO 1 I= 1,N
    1 READ 101,NPT,X(I),Y(I)
C
      PRINT 106,WSID
      PRINT 104,M
      X(N+1)=X(1)
      Y(N+1)=Y(1)
      XMAX=-10**7
      YMAX=-10**7
      XMIN= 10**7
      YMIN= 10**7
```

```
      DO 48 I=1,N
C
C     FIND LIMITS OF THE WATERSHED BOUNDARY
C
      IF(XMAX.LE.X(I))XMAX=X(I)
      IF(YMAX.LE.Y(I))YMAX=Y(I)
      IF(XMIN.GE.X(I))XMIN=X(I)
      IF(YMIN.GE.Y(I))YMIN=Y(I)
   48 CONTINUE
C
C     FIND THE RANGE OF X AND Y VALUES
C
      RNGY=ABS(YMAX-YMIN)
      RNGX=ABS(XMAX-XMIN)
      LIMY=RNGY*10**(-6)
      AREC=RNGX*RNGY
      AI = 0.5
      KA = 0
      DO 2 I= 1,M
C
C     READ GAGE COORDINATES
C
      READ 101,NRG(I),AX(I),AY(I)
      W(I) =1.0/FLOAT(M)
    2 CONTINUE
    3 LTS = 0
      KA = KA+1
      NA = 0
      DO 4 I=1,M
      NS(I)=0
      CX(I)=0.0
      CY(I)=0.0
    4 CONTINUE
C
      DLX = RNGX/FLOAT(NDIV)
      DLY = RNGY/FLOAT(NDIV)
C
```

```
      DLL = AMIN1(DLY,DLX)
   31 NPTS = 0
C
      NLY= YMIN/DLL - 1.0
      NUY= YMAX/DLL + 2.0
C
      DO 6 K= NLY,NUY
      JA = 1
      JB = 1
      YT = DLL*FLOAT(K) -0.5*DLL
      IF(YT.LT.YMIN.OR.YT.GT.YMAX)GO TO 6
C
      DO 5 I=1,N
      IF(Y(I).EQ.YT.AND.Y(I+1).EQ.YT)YT=YT-2.0*LIMY
    5 CONTINUE
C
      DO 7 I=1,N
      IF(Y(I).LE.YT.AND.Y(I+1).GT.YT)GO TO 35
      IF(Y(I).GT.YT.AND.Y(I+1).LE.YT)GO TO 36
      GO TO 7
   35 IF(ABS(Y(I+1)-Y(I)).GE.LIMY)GO TO 9
      XL(JA)=0.5*(X(I+1)+X(I))
      GO TO 10
    9 XL(JA)=(YT-Y(I))*(X(I+1)-X(I))/(Y(I+1)-Y(I))  +X(I)
   10 JA = JA + 1
      GO TO 7
   36 IF(ABS(Y(I+1)-Y(I)).GE.LIMY)GO TO 11
      XR(JB)=(X(I+1)+X(I))*0.5
      GO TO 12
   11 XR(JB)= X(I)  +(YT-Y(I))*(X(I+1)-X(I))/(Y(I+1)-Y(I))
   12 JB = JB + 1
    7 CONTINUE
C
      IF(JB.NE.JA)GO TO 13
      IF(JA.EQ.1)GO TO 6
      JA1 = JA -1
      IF(JA.EQ.2)GO TO 15
```

```
C
      DO 17 IB=1,JA1
      R(IB)=10**6
      DO 16 I=1,JA1
      IF(XL(I).GE.R(IB))GO TO 16
      R(IB)=XL(I)
      IM=I
   16 CONTINUE
      XL(IM)=10**7
   17 CONTINUE
C
      DO 18 I=1,JA1
   18 XL(I)=R(I)
C
      DO 19 IB=1,JA1
      R(IB)=10**6
      DO 20 I=1,JA1
      IF(XR(I).GE.R(IB))GO TO 20
      R(IB)=XR(I)
      IM=I
   20 CONTINUE
      XR(IM)=10**7
   19 CONTINUE
C
      DO 21 I=1,JA1
   21 XR(I)=R(I)
C
   15 CONTINUE
C
      DO 45 J=1,JA1
      NLX=XL(J)/DLL - 1.0
      NUX=XR(J)/DLL + 2.0
      DO 32 JX =NLX,NUX
      XT=DLL*FLOAT(JX) - 0.5*DLL
      NPTS=NPTS+1
      IF(XT.LT.XL(J).OR.XT.GT.XR(J))GO TO 32
      NA = NA + 1
```

Table 15 (cont.)

```
C
      DO 24 I=1,M
      A4=XT-AX(I)
      A5=YT-AY(I)
   24 EL(I)=A4*A4 +A5*A5
C
      ELM = EL(1)
      IS = 1
C
      DO 25 I=2,M
      IF(EL(I).GE.ELM)GO TO 25
      ELM=EL(I)
      IS = I
   25 CONTINUE
C
      NS(IS)=NS(IS) + 1
      CX(IS)=CX(IS) + 1.0
      CY(IS)=CY(IS) + 1.0
   32 CONTINUE
   45 CONTINUE
    6 CONTINUE
   41 AF=FLOAT(NA)*DLL*DLL/AREC
      IF(ABS(AF-AI).GT.LIMA)LTS=1
C
      AI=AF
      SWF=0
C
      DO 26 I=1,M
      WF(I)=FLOAT(NS(I))/FLOAT(NA)
      SWF=SWF+WF(I)
      IF(ABS(WF(I)-W(I)).GT.LIMW)LTS=1
      IF(NS(I).LT.1)GO TO 55
      CX(I)=CX(I)/FLOAT(NS(I))
      CY(I)=CY(I)/FLOAT(NS(I))
      GO TO 26
   55 CX(I)=AX(I)
      CY(I)=AY(I)
```

Table 15 (cont.)

```
   26 W(I)=WF(I)
C
      PRINT 201,KA,NDIV,NPTS,SWF,AF
      IF(LTS.EQ.0)GO TO 33
   33 AUSD =AREC*AF
      PRINT 113
      PRINT 110,AREC
      PRINT 111,AWSD
      PRINT 103
C
      DO 52 I=1,M
      ASTA =AWSD*W(I)
      PRINT 108,NRG(I),AX(I),AY(I),W(I),ASTA
   52 CONTINUE
C
   13 PRINT 204
      GO TO 51
   50 STOP
      END
```